NAVAL ARCTIC OPERATIONS HANDBOOK

V
175
.N38
1949
pt. 1-2

PART I. GENERAL INFORMATION

Prepared by the Arctic and Cold Weather Coordinating Committee of the Office of the Chief of Naval Operations

LIBRARY

NOV 23 2005

National Oceanic & Atmospheric Administration
U.S. Dept. of Commerce

U. S. COAST & GEODETIC SURVEY
LIBRARY AND ARCHIVES
NOV 10 1949

ACC. No. X1882

DEPARTMENT OF THE NAVY ★ ★ ★ ★ 1949

RESTRICTED

National Oceanic and Atmospheric Administration

International Polar Year (IPY) 2007-2008

ERRATA NOTICE

One or more conditions of the original document may affect the quality of the image, such as:

Discolored pages
Faded or light ink
Binding intrudes into the text

This has been a co-operative project between the NOAA Central Library and the Climate Database Modernization Program, National Climate Data Center (NCDC). To view the original document contact the NOAA Central Library in Silver Spring, MD at (301) 713-2607 x124 or Library.Reference@noaa.gov.

HOV Services
12200 Kiln Court
Beltsville, MD 20704-1387
February 25, 2008

GENERAL NOTE

Naval Arctic Operations Handbook is published for the information and guidance of all concerned. It is presented in two volumes, Part I being a compilation of general information, and Part II lessons learned during the conduct of operations in the polar regions and in areas where the extremes of cold weather have been encountered.

It is desired that commanders of task forces, commanding officers, and others in command of operations in the high latitudes submit data and recommendations for incorporation into subsequent editions of the handbook. Thus naval skill in these operations will develop in a continuing and orderly manner.

In time our arctic and cold weather experiences will become doctrine, to the end that polar naval operations can be planned and conducted routinely. Basic doctrines will be included in the proper USF publications at some future date.

RESTRICTED

Top—Icebreakers at Cape Sheridan, Ellesmere Island, summer of 1948, farthest north 82°34' N., 62°22' W.

Bottom—Central group of TF68 en route Bay of Whales, Antarctica, January 1947, farthest south, 78°30' S., 163°30' W.

CONTENTS

PART I

		Page
General Note		iii
Frontispiece		iv
Preface to Part I		vii
Glossary of Terms		ix
Chapter	*Title*	
1.	Introduction	1
2.	Geographic Character of Arctic and Subarctic Regions	17
3.	Climate and Weather	91
4.	The Law and Arctic Possessions	141
5.	Clothing and Personal Equipment	157
6.	Health and Survival	177
7.	Selected Bibliography	197
APPENDIX A.	Antarctic Climate and Weather	201

PART II

General Note		iii
Preface		vii
Chapter	*Title*	
1.	Planning Arctic Operations	227
2.	Ship Operations	237
3.	Communications	289
4.	Care and Operation Bureau of Ships Material	301
5.	Care and Operation of Shipboard Ordnance Material	331
6.	Aircraft Operations	351
7.	Amphibious Operations	417
8.	Base Operations	433

Appendix *Title* *Page*
A. Navigability in Arctic and Northern Seas 464
B. Notes on Ice Seamanship and Navigation Amongst Ice 467
C. Design Criteria for U. S. Naval Materiel for use in Arctic and Cold Weather Areas 483
D. Track Charts of Operations in Western Arctic, Summer of 1948, and Winter 1948–1949 484

PREFACE

Part I of *Naval Arctic Operations Handbook* is intended to be a source of general information—nature of past and probably future naval operations in the Arctic, geography, climate and weather, status of various areas in international law, clothing and personal equipment, health, survival, and a selected bibliography as a guide for further reading and study. Appendix A is a discussion of the climate of Antarctica and is included herein for reference when operations are conducted in the ocean areas around the southernmost continent.

The reader will note some repetition of data in the various chapters of Parts I and II. This is not done for emphasis. It has been found desirable in some instances in order to permit a more effective and readable presentation of the subjects of the several chapters involved. Therefore, the handbook will serve as a ready book of reference as well.

Source material for this manual is from notes derived from arctic literature—reports and books of the explorers and polar scientists, operation plans and reports, manuals hydrographic publications, pilot charts, and ice atlases.

Blank page retained for pagination

GLOSSARY OF TERMS

This selected glossary is limited to definitions helpful for an understanding of this handbook. More extensive glossaries are included in various Hydrographic Office publications. HO Study No. 103, *A Functional Glossary of Ice Terminology*, has been prepared in order to standardize ice terminology and to provide a convenient means for describing ice features and related characteristics. Refer also to Selected Bibliography, chapter 7, this handbook.

Ablation—Surface removal of ice or snow by evaporation.

Arctic Pack (Polar Pack)—The ice cover of the north polar basin or Arctic Sea, also called Arctic "Ocean."

Barrier—The cliffed edge of shelf ice. (See *Shelf Ice.*)

Bay Ice—Fast, level ice formed in an embayment.

Belt—A relatively narrow band of sea-ice of any variety.

Berg—A large mass of land ice which has broken away from its parent formation on the coast and either floats in the sea or is stranded on a shoal; a berg is tabular if derived from shelf ice, irregular if derived from glacial ice.

Bergybit—A medium-sized piece or cake of glacier ice, heavy floe, or hummocky pack ice washed clear of snow and floating in the sea.

Beset—Situation of a ship or small craft when so closely surrounded by sea-ice that control is lost. (See fig. 5.)

Big Clearing—A large area of open water, other than a lead, encompassed by fields or floes of pack ice; also polynya. (See fig. 6.)

Bit—A single piece of brash or of ice less than two feet in diameter. Note: Compare with *Glacon, Cake, Floe* and *Block.*

Blizzard—Snow storm in polar regions in which fine snow drifts so high and thick that it is impossible to tell whether sky is clear or clouded.

Block—A small piece of ice ranging in size from 6 to 30 feet across.

Brash—Small ice fragments less than 6 feet across; the wreckage of other forms of sea-ice.

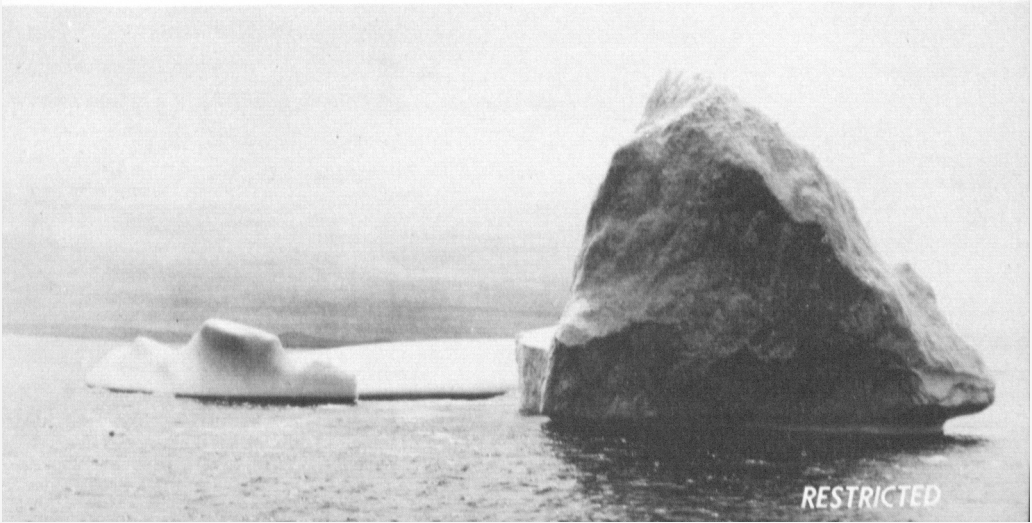
Broken Ice—Sea-ice consisting of scattered cakes and floes covering five-tenths to seven-tenths of the sea surface. (See fig. 9.)

Cake—A term of general meaning used in reference to individual pieces of pack ice. (See fig. 10.)
Calving—The breaking away of ice from its parent berg, glacier, or shelf ice formation. (See fig. 13.)
Channel—Lead (lane).
Close Ice—Ice so closely packed that it covers seven-tenths to nine-tenths of the sea surface and virtually all sea water openings are obscure.
Close Pack—Close ice or pack composed mostly of cakes in contact. (See fig. 11.)
Coast or Costal Ice (Fast Ice)—A stretch of ice, broken or unbroken, either stranded in shoal water, attached to the shore, or held fast in position of growth in embayments by glaciers or glacier systems.
Conglomerated Ice—Various forms of floating ice compacted into one mass.
Consolidated Pack—An ice area containing the heaviest forms of sea ice and entirely devoid of water spaces.
Crevasse—A rift or fissure in a glacier, shelf ice, or other land-ice formation.
Cul-de-sac—Blind lead.
Deadman—A large timber buried in the ground, snow, or ice to which a mooring line can be attached for securing a ship. (See HO 551.)
Drift Ice—Loose, very open pack where water predominates over ice; floating ice; any ice that has drifted from its place of origin. (See fig. 16.)
Erosion—Destruction of sea-ice by the action of waves and weather.
Fast Ice—See *Coast Ice*.
Field Ice—The largest connected areas of sea-ice, ranging from several to scores of miles wide; also ice field.
Floe—An area of sea-ice consisting of a single unbroken piece of ice or many large consolidated pieces; small floe, 30 to 600 feet across; medium floe, 600 to 3,000 feet across; giant floe, 3,000 feet to 5 or more miles across.
Floeberg—A mass of thick, heavily hummocked sea-ice usually detached from its parent floe.
Frost Smoke—A mist or thick fog rising from sea surface when the relatively warmer water is exposed to an air temperature much below freezing; steam fog; arctic smoke.
Giant Floe—See *Floe*.

Glacier—A massive body of land-formed ice moving slowly down a mountainside or valley. (See fig. 13.)
Glacial (Glacier) Ice—Ice which originates from glaciers.
Glacon—A piece of sea-ice ranging in size from brash to medium floe (6 to 2,000 feet across).
Grease Ice—Slush ice formed from the congelation of ice crystals in the early stages of freezing. (See fig. 14.)
Growler—A small piece of dense glacier ice usually green in color and barely showing above the water.
Growler Ice—An accumulation of growlers.
Heavy Ice—Any pack ice more than 10 feet thick.
Hummocked Ice—Ice piled haphazardly into the form of a short ridge or hillock.
Ice Barrier—See *Barrier.*
Iceberg—See *Berg.*
Ice Blink—A yellowish-white glare on the underside of extensive cloud areas created by light reflected from ice-covered surfaces.
Ice Cap—An ice sheet of vast extent covering the topographic features of a continental land mass.
Ice Field—See *Field.*
Ice Foot—A wall or belt of fast sea-ice formed along a shore not subject to rise and fall of tides.
Ice Sky—See *Ice Blink.*
Land Sky—Dark streaks, patches, or a grayness on the underside of extensive cloud areas due to the absence of reflected light from bare ground.
Lead (Lane)—A long, narrow but navigable water passage in pack ice.
Medium Floe—See *Floe.*
Nipped—As applied to a ship, caught and held tightly by sea-ice under pressure.
Nunotak—An isolated hill or mountain of bare rock rising above the surrounding ice sheet.
Open Water—Sea areas less than one-tenth covered with floating ice.
Pack Ice (The Pack)—Any large area of floating sea-ice driven closely together. (See *Arctic Pack;* also fig. 17.)
Pancake Ice—Piece of newly formed sea-ice about 1 to 6 feet in diameter.
Permafrost—Permanently frozen soil, rock or bedrock.

Polar Ice—The thickest and heaviest form of pack ice more than 1 year old.
Polynya—See *Big Clearing.*
Pool—Polynya; sometimes used to mean a depression on ice floes filled with water as result of summer thaw.
Pressure Ice—A general term for ice displaced vertically by pressure resulting from action of wind, tide, temperature change, etc.
Rafted Ice—A type of pressure ice formed by one cake over-riding another.
Ram—A horizontal extension of floe or berg below its waterline.
Rotten Ice—Old ice in an advanced stage of disintegration as result of melting.
Sastrugi—Wavelike ridges of hard snow formed on a level surface by the action of the wind with axes of the ridges at right angles to the prevailing direction of the wind.
Scattered Ice—Ice that covers less than one-half of the sea surface.
Sea Ice—A general term for all forms of ice encountered on the surface of the sea.
Seracs—Ice pinnacles on a glacier.
Shelf Ice—A thick, glacial ice formation extending from the land but attached thereto.
Shore Ice—Synonym of *Fast* or *Coastal Ice.*
Shore Lead—A lead between floating ice and the shore or between floating ice and fast ice.
Sikussaq—Very old ice trapped in fiords.
Slush—A general term for an accumulation of ice crystals which are either only slightly frozen together or separate.
Small Floe—See *Floe.*
Snow Blink—Similar to ice blink except that glare created by light reflected from snow-covered surfaces is white.
Storis—A regional term applied to large pieces of polar ice moving along the coasts of Greenland from the Arctic Sea.
Sky Map—The mirroring of land, snow, or ice in the clouds.
Tracking—Following the edge of pack ice.
Tundra—Stretch of mucky, treeless land covered with a variety of hardy plants, including grasses, lichens, and shrubs.
Water Sky—Dark stretches or patches of grayness on the underside of extensive cloud areas due to the absence of reflected light from open water areas.
Winter Ice—Sea-ice less than 1 year old.
Young Ice—Newly formed ice in the transitional stage of development from ice crust to winter ice.

(Top) Figure 1.—Field of Arctic or polar pack, Kene Basin. (Note pools of thaw water.)
(Above) Figure 2.—Ross barrier or shelf ice (background), Bay of Whales.
(Below) Figure 3.—Irregular berg, Davis Strait.



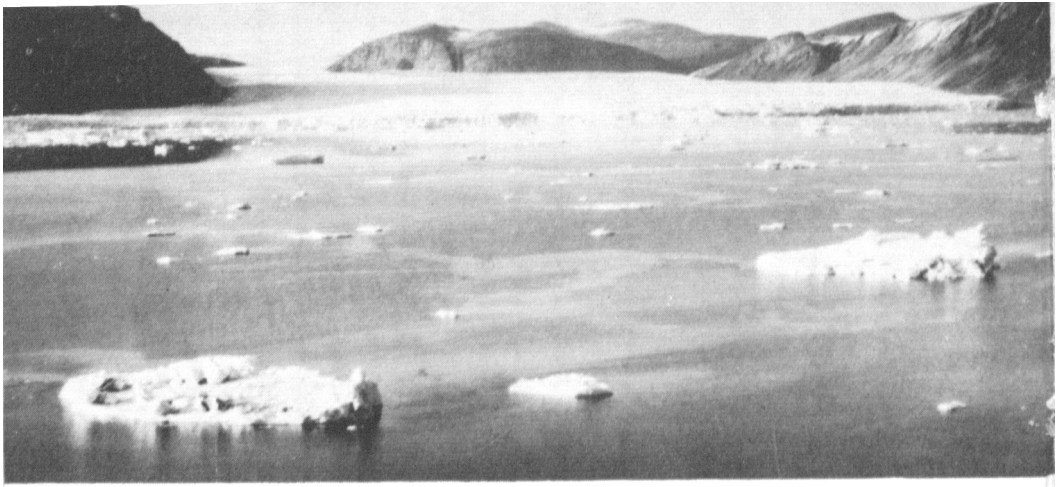
RESTRICTED

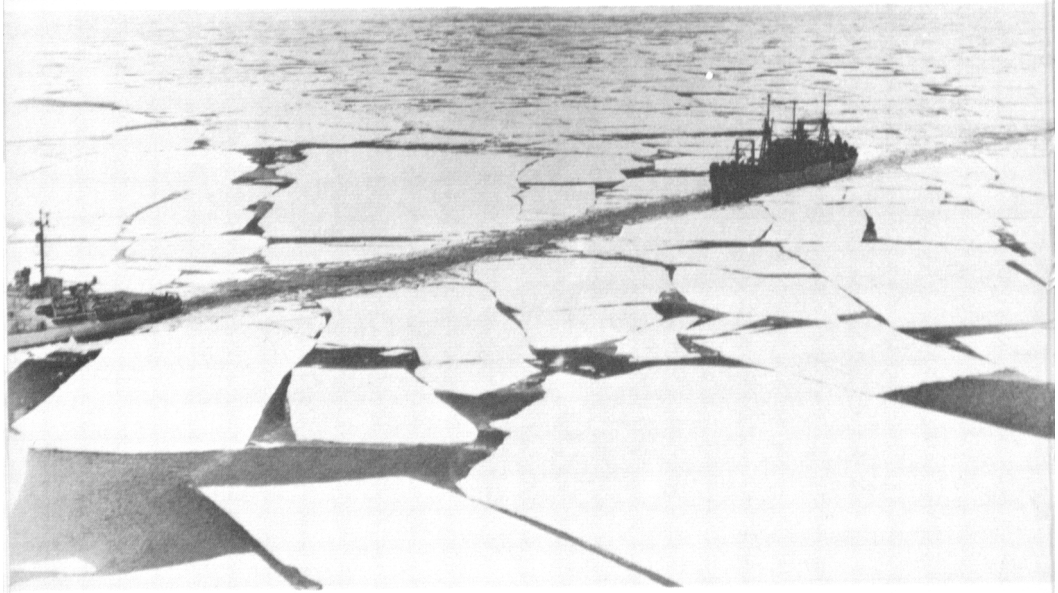
Figure 4.—Icebreaker passes Takular Berg, Antarctic pack.

Figure 5.—Part of Beaumont beset in ice, Neny Island Bay, Antarctic.

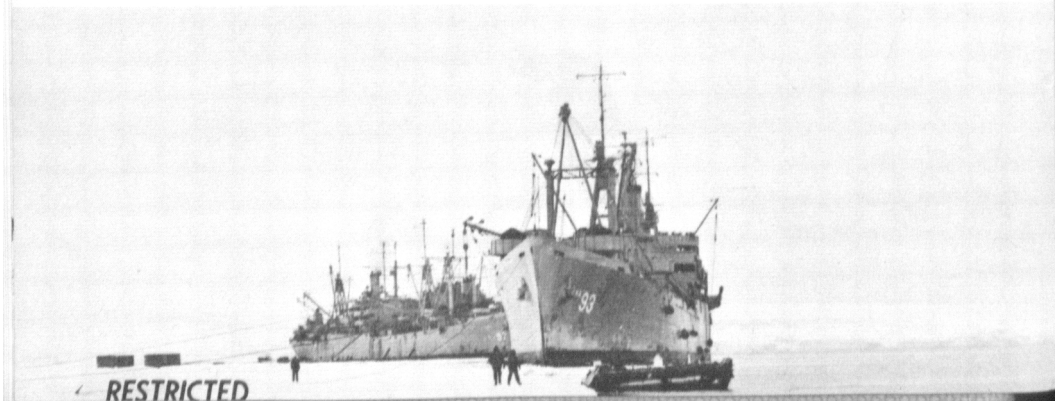
Figure 6.—Central group of TF68 in big clearing or polynya in Antarctic pack.

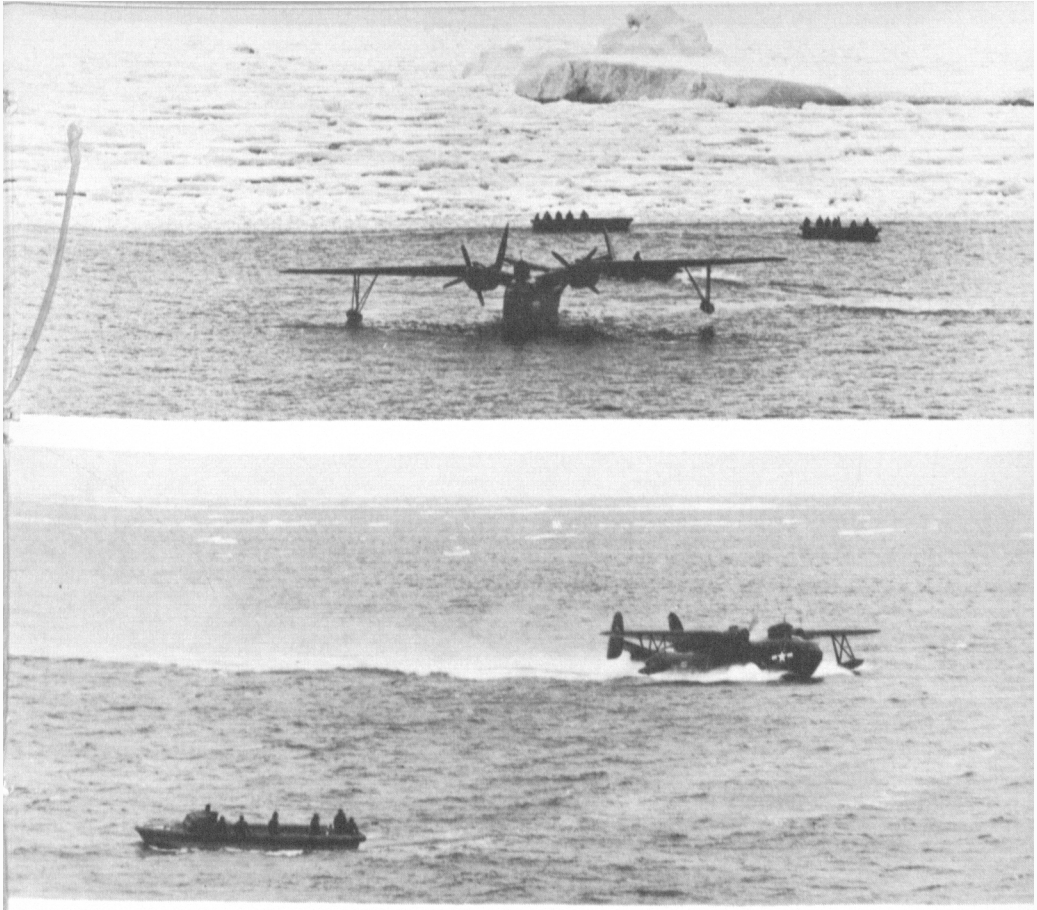
Figure 7.—An AV in broken ice.



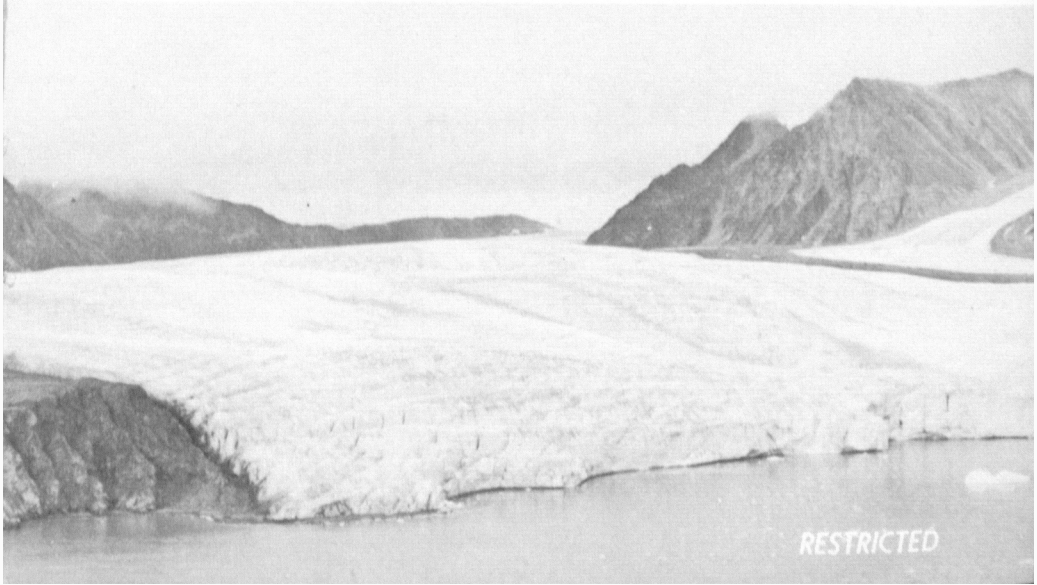


(Top) Figure 8.—Glacier calving ice. Cakes of glacial ice in foreground.
(Above) Figure 9.—Icebreaker forming lead or channel in close pack.
(Below) Figure 10.—AKA's moored to fast bay ice, Bay of Whales.





(Top) Figure 11.—An area of consolidated Antarctic pack.
(Above) Figure 12.—Drift ice.
(Below) Figure 13.—Glaciers, Devon Island.



RESTRICTED

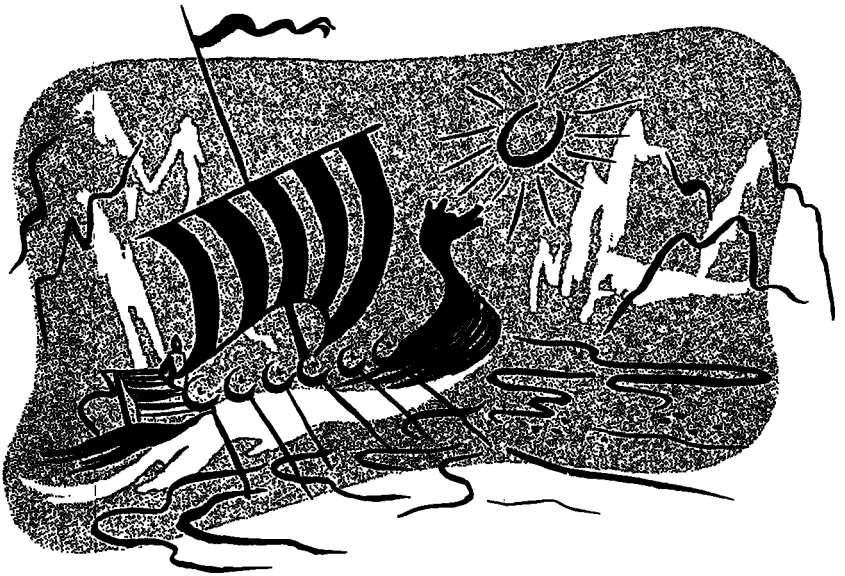
Figure 14.—Grease ice.

Figure 15.—Pancake ice.

Figure 16.—Rotten scattered ice, Norwegian Bay.

Figure 17.—Scattered ice, Baffin Bay.

RESTRICTED



CHAPTER I

INTRODUCTION

"Arctic history has suffered from prejudice as well as ignorance—the two greatest hindrances to all progress."—Hayes.

HISTORICAL BACKGROUND

The story of polar exploration and discovery is largely a naval and maritime one. The first recorded voyage to the Arctic was that of Pytheas of Massilia around 330 B. C. From the earliest time through the nineteenth century the emphasis was upon geographic exploration, chiefly the search for the northeast and northwest passages which would be shorter trade routes from Europe to the Orient. Only since the first decade of the twentieth century has the emphasis been shifted to scientific discovery, exploration and exploitation of resources, and strategic development.

The United States Navy has engaged in this work for over a hundred years—since Admiral Wilkes' long journey to East Antarctica in 1839-40. The names of Wilkes, DeLong, De Haven, Kane, Schley, Peary, Byrd—all naval officers—are prominent in the history of the polar regions. Here are listed some of the highlights of these endeavors:

1839–40 —A Naval squadron under Lieutenant (later Rear Admiral) Charles Wilkes discovered Wilkes Land of East Antarctica and determined the continentality of the south polar region.

1850–51 —Lieutenant De Haven in the *Advance*, which was fitted out at the expense of Henry Grinnell, participated in the search for Sir John Franklin in Lancaster Sound and Wellington Channel, Canadian Arctic Archipelago.

1853–55 —Dr. Elisha Kent Kane led an expedition in the *Advance* to Smith Sound between northwest Greenland and Ellesmere Island. Kane also established the first scientific station in the Arctic while wintering over. Officers and men of the U. S. Navy demonstrated that the Smith Sound route was the most promising for a dash to the North Pole. At the time, attainment of the pole appeared to be the most important motive for work in the far north.

1871–73 —An expedition to Smith Sound region under Charles Francis Hall was supported by public funds requested by the Secretary of the Navy. Hall was the first proponent of adopting Eskimo methods of living as a means to maintain one's health and operating capacity.

1879–81 —During the summer of 1879 the *Jeanette*, on an expedition in the Siberian sector of the Arctic Sea, commanded by Lieutenant George W. De Long, became beset in the polar pack near Wrangel Island and commenced a slow and uncertain drift toward Greenland. Then, on 12 June 1881, it sank near 77° 15′ N., 155° E. De Long and others lost their lives in the desolate Lena Delta when almost in reach of assistance. A second party under Lieutenant Melville was saved. The contributions to our understanding of the polar sea which these brave men made are still basic.

1884 —On 22 June, Captain W. S. Schley rescued the Greeley expedition to Ellesmere Island (First International Circum-polar Year, 1882-83).

1886 —In this year Peary (Commander Robert Edwin Peary; later Rear Admiral) began his long arctic career with a first visit to northern Greenland. His expeditions were all privately conducted and financed.

1891–92 —On 4 July 1892, Peary reached northeast Greenland across the inland ice plateau, discovering Independence Bay and Peary Land.

1893–95 —Peary made his second crossing of the ice plateau in April 1895.

1896–97 —Peary visited Greenland and brought back the famous York meteorite (50 tons), largest in the world, which he had found in 1894 in the Cape York district.

1898–1902—Peary made his first attempt to reach the North Pole in February 1902.

1905–06 —Peary, on his first Roosevelt expedition to northernmost Ellesmere Island, Cape Sheridan District, claimed to have reached latitude 87° 06 N. in this second attempt to reach the North Pole.

1908–09 —Peary's second Roosevelt expedition to Cape Sheridan was successful. By virtue of a remarkably well organized operation he reached the North Pole on 6 April 1909.

1913–17 —Donald MacMillan (Commander USNR) headed an expedition to northwest Greenland and Ellesmere

Figure 1–1.—Peary discovers North Pole April 6, 1909.

Figure 1-2.—Byrd—first to fly over the North Pole in an airplane.

Island in search of new land in the Arctic Sea to the west of Cape Columbia.

1925 —Richard E. Byrd (now Rear Admiral, Ret.) flew over Ellesmere Island and northwest Greenland in connection with MacMillan's second arctic expedition.

1926 —On 9 May, Byrd flew from Spitsbergen to the North Pole and returned in 15½ hours. He was the first to fly over the North Pole in an airplane.

1928–30 —First Byrd expedition (privately financed) to Little America, Antarctica. On 29 November 1929, Byrd flew from his base over the South Pole in a flight of 19 hours duration.

1933–35 —Second Byrd expedition (privately financed) to Antarctica.

1939–41 —Third Byrd expedition (U. S. Antarctic Service, Interior Department) to Little America and Marguerite Bay.

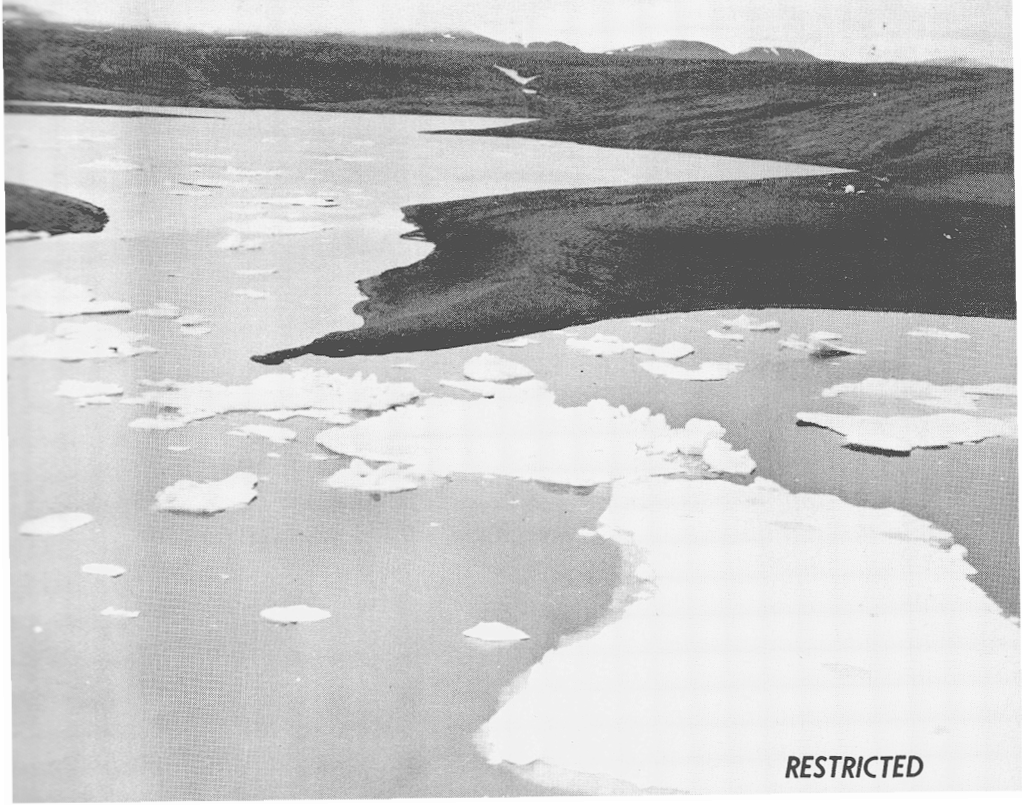
1942–45 —Various war operations in the Aleutians, Bering Sea, Greenland and Barents Seas.

1944 —First Point Barrow supply expedition (Barex) in support of Naval Petroleum Reserve No. 4. This now is an annual expedition conducted in August. In 1948 five AKA's, two LST's and one icebreaker participated, delivering close to 30,000 short tons of supplies and equipment to Point Barrow and Barter Island in the Beaufort Sea.

1946 —Cold weather cruise, *Operation Frostbite,* of a carrier task group in Davis Strait.

1946 —*Operation Nanook* to Thule, northwest Greenland and Canadian Arctic Archipelago (Melville Island, Cornwallis Island, Ellesmere Island, etc.) in support of Canadian-American weather stations. This has be-

Figure 1–3.—Summer scene. Dumbbell Bay, Ellesmere Island, 450 miles from North Pole.



come an annual summer operation. In 1948, ships of TF80 reached 82°34′ N. latitude near Cape Sheridan where Peary's cairn (1906) was found. Later an icebreaker reached Slidre Fiord on Eureka Sound.
The two icebreakers returned to Boston via Prince Regent Inlet, Fury and Hecla Strait, Hudson Bay, and Hudson Strait.

1946–47 —Fourth Byrd expedition (*Operation Highjump*, U. S. Navy) to Antarctica. Largest exploring expedition in history.

1947–48 —Two Navy icebreakers conducted a reconnaissance of East Antarctica, the Bay of Whales and Palmer Peninsula.

CHARACTER OF RECENT COLD WEATHER OPERATIONS

During the middle of the 1940's, it became evident that the course of any future war would be further northward. Implications of arctic geography on world strategy and national security

Figure 1–4.—Summer scene. The Fury & Hecla Strait first transited by ship, summer of 1948.

Figure 1–5.—Summer scene. Icebreaker in Norwegian Bay.

are evident from an examination of a polar orthographic projection made of the Northern Hemisphere. Our approaches must be guarded in the Aleutians, in Alaska, and in the complex of islands of the Greenland Sea—Iceland, Greenland and Spitsbergen. This strategic concept is not new. It was William Henry Seward, Secretary of State in President Lincoln's cabinet, who consummated the Alaska purchase and made a futile effort toward purchase of Greenland and Iceland.

In the winter of 1946 (March 10-21) *Operation Frostbite* was conducted in Davis Strait using a small carrier task group formed around the U. S. S. *Midway* (CVB41). This cruise was valuable in revealing the nature of problems associated with the operation of carrier aircraft in cold weather areas. The findings and recommendations of a special group of observers have been recorded in a Bureau of Aeronautics report. (See ch. 7.) The general opinion expressed by observers on this operation was:

"The aircraft, equipment, procedures, technical orders, technical notes, and other existing instructions are satisfactory for conditions of temperatures and winds considerably more rigorous than the conditions which can be tolerated by the deck personnel. Certain modifications are necessary to the aircraft, equipment, and technique to increase cold-weather carrier operational efficiency and to lower the limits imposed by temperature and wind conditions.

"With improvement of aircraft and equipment as indicated in the recommendation of the report, and by adherence to Bureau objectives and procedures, and what is more important, with additional training in cold weather operations at frequent and regular intervals, carrier operations can be conducted at as low temperatures as will be found in (ice-free) areas where a task group or force may be ordered to operate with only a slight reduction in efficiency and probably no decrease in aircraft complement."

During the summer of 1946 (July-September) Task Force 68, consisting of an AV, AKA, AG (icebreaker), SS and various aircraft, conducted "Operation Nanook" in waters around Greenland and among islands of the Canadian Archipelago. This operation, a resupply expedition, has been continued annually in fulfillment of the Navy's commitment for establishing and supporting of weather stations, which are maintained in the Arctic through combined American-Canadian and American-Danish efforts. New stations have been established in succeeding years. Valuable scientific observations, both afloat and ashore, are being made. During the summers of 1947 and 1948 icebreakers reached the Lincoln Sea, Slidre Fiord on Eureka Sound, and Victoria

Figure 1–6.—Summer scene. St. Patrick Bay, Ellesmere Island.

Island. In the summer of 1948 the icebreakers returned to Boston by way of Prince Regent Inlet, Fury and Hecla Strait, Foxe Basin, and Hudson Strait. Two "firsts" are credited to our forces: farthest north afloat in the Western Hemisphere, and transit of Fury and Hecla Strait. The latter resulted in the opening of a long sought route to the Canadian Arctic.

Following completion of *Operation Nanook,* the task force commander was directed to plan and prepare for *Operation Highjump* to Antarctica. The numerous ships (CV, AV, AO, AKA, AGC, SS) assigned to the force departed for their stations in December 1946. It consisted of three groups: one operating in the Palmer Peninsula—Weddell Sea sector; one in the Ross Sea sector; and one in the Wilkes Land—Queen Maud Land sector. Thus, the continent was circumnavigated in the short period of 2½ months. The valuable achievements of this exploring expedition can only be grasped and appreciated by a study of the comprehensive report submitted by the task force.

Probably the most significant lesson learned during *Operation Highjump* was that extended operations of 13 ships, 8,000 miles from their bases, were highly successful without the necessity of special preparations and special training and that our materiel and ship equipage performed satisfactorily, in most instances, to the extreme conditions encountered. These conditions were near to what might be expected in various sea-land areas in the arctic and subarctic regions during a large part of the year.

For many years the Navy has assisted in the protection of the seal fishery around the Pribilof Islands in the Bering Sea, and has participated in the logistic support of the islands.

The Point Barrow resupply expedition (Barex) is conducted annually in August in the Beaufort Sea in logistic support of

Figure 1–7.—Summer scene. Beach at Resolute Bay.

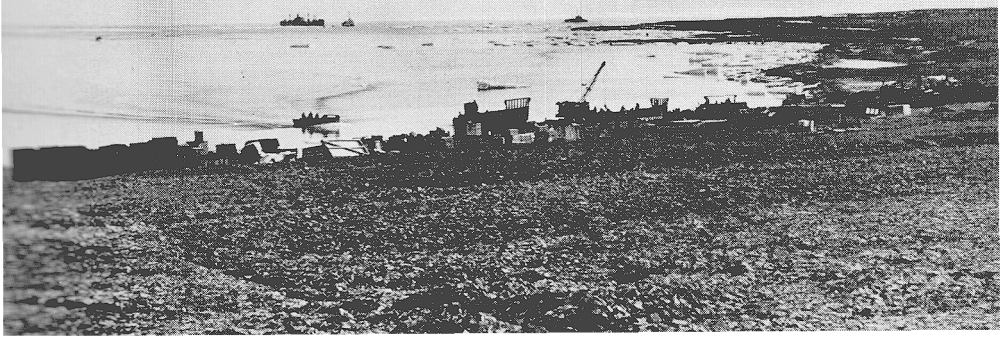


Figure 1–8.—Summer scene. Briceport Inlet, Dundas Peninsula, Melville Island.

operations at the Naval Petroleum Reserve No. 4. This is a small-scale amphibious operation growing in scope and importance each succeeding year.

In the late fall of 1948 a task fleet exercise was conducted in the North Atlantic around Newfoundland; in the late winter of 1948-49 another task fleet engaged in a similar exercise in the Gulf of Alaska around Kodiak Island. In February and March 1949 icebreakers operated in the pack ice of Davis Strait and Bering Sea. Nome, Alaska, was reached for the first time by ship during the winter.

The Navy may be called upon at any time of the year to assist in the rescue of airmen as routine arctic flights increase.

The Navy has peacetime missions which require operations on a small scale in the far north. Likewise, as a part of naval policy, the Navy is ever ready to operate any place on the surface of the globe where ships can be navigated. The frontispiece indicates that this can be done in a north-south direction through more than 163 degrees of latitude. Naval aircraft operating from ships and temporary bases, established and supported by ships, can easily extend the operations to the poles themselves. Submarines can conduct limited operations in scattered pack ice and beneath it. Amphibious ships can support activities of forces ashore in those areas which are navigable.

BASIC PRINCIPLES AND LIMITATIONS

Naval operations conducted under arctic conditions follow the same basic principles as do operations under other conditions. The differences lie in tactical and logistical limitations imposed by

the climatic conditions and weather, by variations in the application of standard emergency principles, and by the special equipment, training, techniques and procedures necessary to overcome the limitations.

The principal limitations upon sea operations are navigability, sea-ice, and extreme cold. Northern seas are navigation nightmares—high nebulosity, fog, drift ice, icebergs, pack ice, rough seas, cold water, low-surface air temperatures, sudden and long-continuing storms, and few recognizable land marks.

Civil and military flying in the Arctic have become routine. Most cold weather flight difficulties occur on the ground. Uncertain weather, formation of snow and ice on airplane surfaces, rescue and survival, and lack of adequate conventional navigational aids are the principal limitations.

In the case of military operations in the Arctic, the significant limitations are lack of transportation facilities, difficult and unfavorable terrain, and extremes of climate both in summer and winter.

MAJOR PROBLEMS

Operations of land, air, and naval forces in the polar regions, even on a limited scale, involve the solution of many problems of environmental adjustment, training, construction, ship building, logistics, research and design. The adaptation of men and machines, on a mass scale, to arctic conditions will be a long and tedious process. That some progress is being made is reassuring,

Figure 1–9.—Summer scene. Goose Fiord, Ellesmere Island.

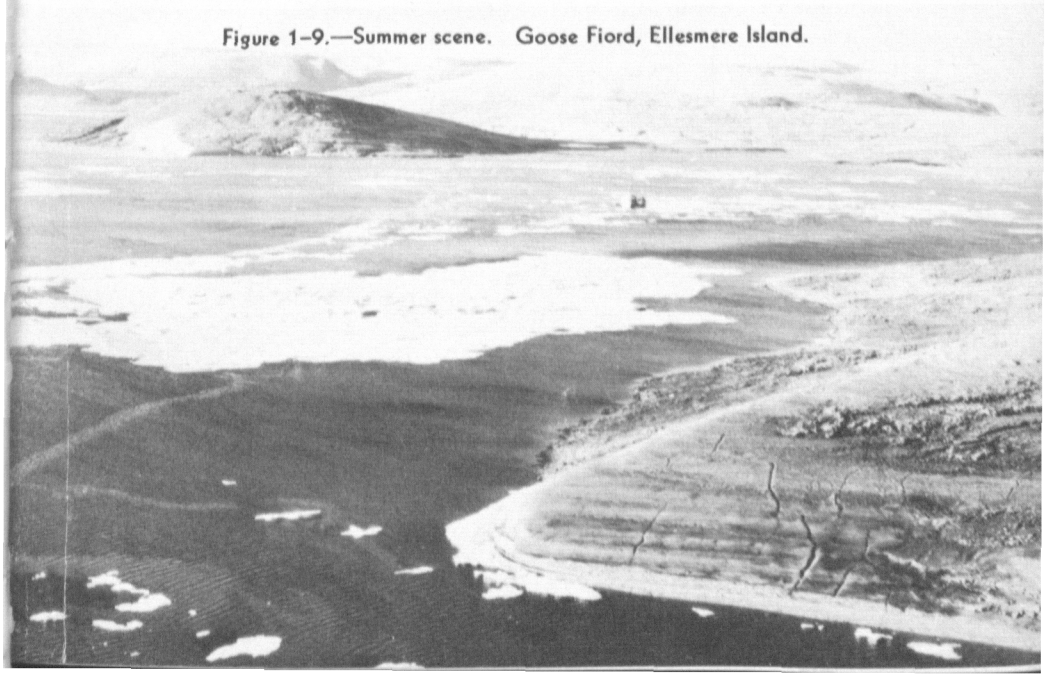


Figure 1–10.—Summer scene. Dundas Harbor, Devon Island.

but only a concerted effort of science, technology and colonization will produce lasting and significant results.

Major problems for the Navy are the adaptation of existing ships and equipment to conditions, including extreme cold, for which they were not designed initially, and the maintenance of ship readiness and personnel efficiency while in the high latitudes. New ships and equipment are being designed for extreme climatic conditions in addition to standard and other special requirements. New materials of basic industries (steel, rubber, plastics, textiles, food, petroleum products, etc.) must be developed to replace conventional materials the physical behavior of which becomes modified to the point of unreliability or uselessness at extremely low temperatures. Prevention of icing of upper works of ships and de-icing of exposed equipment are problems in need of solution.

Major problems in connection with military aviation in cold weather areas are ground maintenance of aircraft, rapid engine starting, erection of aircraft shelters, solution of manifold and complex materiel problems, prevention of ice formation on air-

craft structures, protection of personnel, rescue and survival, construction and logistic support of airfields, and bases, expense and difficulties of establishment and maintenance of adequate facilities including navigational aids and early warning radar nets, and military protection and security.

Four major problems present themselves for solution in the conduct of winter warfare on land, regardless of geographic area, under conditions of snow, ice, mud, and extreme cold, that are likely to be encountered at various times of the year above the thirty-fifth parallel in the Northern Hemisphere. These are (1) keeping men and animals warm and comfortable, (2) transportation of troops across snow and ice, (3) transportation and preservation of supplies and equipment, and (4) prevention of malfunctioning of weapons, ammunition, and equipment. Men are subject to chilling, frostbite, freezing, and at certain seasons snow blindness. When cold, they are less alert and consequently incapable of performing tasks in the usual time under conditions prevailing in temperate climates. Ordinary wheeled vehicles are

Figure 1–11.—AKA serves Pribilof Islands, Bering Sea.

useless on snow, muskeg, and the muck of the barren lands and northern Tundras. Special winterized tracked vehicles and sled trains are required. Consequently, all cross-country travel is slow and uncertain during the winter, but almost impossible during summer except on highways. Vehicle motors require special starting and maintenance techniques; lubricants stiffen; gasoline and chemicals vaporize less readily; condensation of moisture in fuel tanks and carburetors occurs and turns to ice at temperature below freezing; water jackets freeze; steel parts break more easily; storage batteries lose capacity; frost fogs lenses of optical instruments and windshields of vehicles.

Arctic clothing, equipment, and arms make 300-pound sloths of average size airborne soldiers. Sufficient cold weather exercises have been conducted to prove the feasibility of limited, small-scale military operations over snow-covered terrain. Large scale transpolar military expeditions present difficult problems. The difficulties of mass airborne and land operations in subzero weather and over rugged arctic terrain are so great that they may never be solved. Large scale attrition type combat, therefore, does not appear a reasonable possibility, but highly mobile small striking forces may play an important role in arctic warfare.

Standard construction practices employed in temperate climates must be modified for permafrost conditions in the Arctic. (See fig. 22.) The few roads, railroads, and structures built there in the past have sustained serious damage because of the destructive action of the permafrost which had been ignored or miscalculated in the original design. A thorough understanding of permafrost is, therefore, an important part of the planning of each engineering project.

Each service has an artcic and cold weather materiel program required for discharge of its respective responsibilities in war or peace. That for the Navy Department was approved by the Secretary of the Navy on 9 September 1948. It should be carefully studied by all personnel charged with research and development, materiel, and operational problems.

IMPORTANCE OF ARCTIC REGIONS

The trend of history is that successive wars become more global and more universal. No future war is likely to be restricted to a single locale. Because the Arctic is the central area of most of the earth's land masses, and since its nature is largely that of a mediterranean sea, Naval operations will be of utmost importance.

Joint and combined operations of specialized character will be certain. For national security certain of these far northern strategic areas must, if necessary, be defended. As peacetime missions, the armed services must be capable of supporting weather and other arctic stations and of assisting with the development and securing of potential economic resources of our northern territories.

Across the Arctic Sea are the shortest air routes between the United States, Europe, and Asia. Earlier "over the top" operations were very difficult in the past because of the vast expanses of relatively unexplored territory, the absence of satisfactory landing places, and the lack of weather information. Now, with the availability of powerful, long range airplanes and suitable electronic equipment and more knowledge and experience in the Arctic, the big push of polar development is emerging.

The pitchblende of arctic and subarctic Canada, the oil of arctic Alaska and Canada, the iron of Labrador, the fisheries of southern Alaska and the Grand Banks, the furs of Canada, the timber of Alaska and Canada, the cryolite and lead of Greenland, the coals of Spitsbergen, and the rich vegetation capable of supporting hordes of arctic animals are among the treasures which will serve our continent in years to come and be vital to it in any future war.

Lastly, the arctic regions are important as a source of weather and scientific data essential to the welfare of a peaceful and thrifty world.

SUMMARY

Weather is not a barrier to limited scale operations on ground and sea, or in the air, in the Arctic. Success in living and working there is predicated on knowledge and use of area conditions, plus forethought, skill, courage, and endurance. This is no different than the requirements for successful living anywhere. Fuel and shelter are prime considerations in all operations on land.

Aviation in the Arctic can now perform its functions routinely the year round if provided with the same adequate bases, installations, facilities, and logistic support essential to any type of continuing operation, large or small, anywhere. Valuable resources await further exploration and development. The Arctic regions are slowly evolving as a new crossroads of the world—possibly in time to rival in importance the Mediterranean Sea and the Panama Canal.

All personnel of the Navy require knowledge of the Arctic and training in arctic operations. Experience can only be gained by extending our peacetime training and operations northward.

Planning for such arctic operations must be more exacting and detailed than for operations in the temperate zones where the hazards are less.

CHAPTER 2

GEOGRAPHIC CHARACTER OF ARCTIC AND SUBARCTIC REGIONS

"Within the Arctic Circle lies a vast domain of prairies, lakes, forests, mountains, and pack ice."—Stefansson.

The term arctic is generally associated with ideas of cold, snow, and high latitudes. The detail and validity of the meaning of the word varies from person to person depending on knowledge, experience and specific interests in the region. There are a number of commonly used definitions, each valid in its own right and useful in a particular function.

For purposes of fleet operations, the Navy considers the Arctic to be those water areas on which ice acts either as a barrier to all navigation, or as a hindrance. The term thus defined does not relate to static global areas. It refers to conditions which may persist or exist from time to time in a number of areas in the high latitudes.

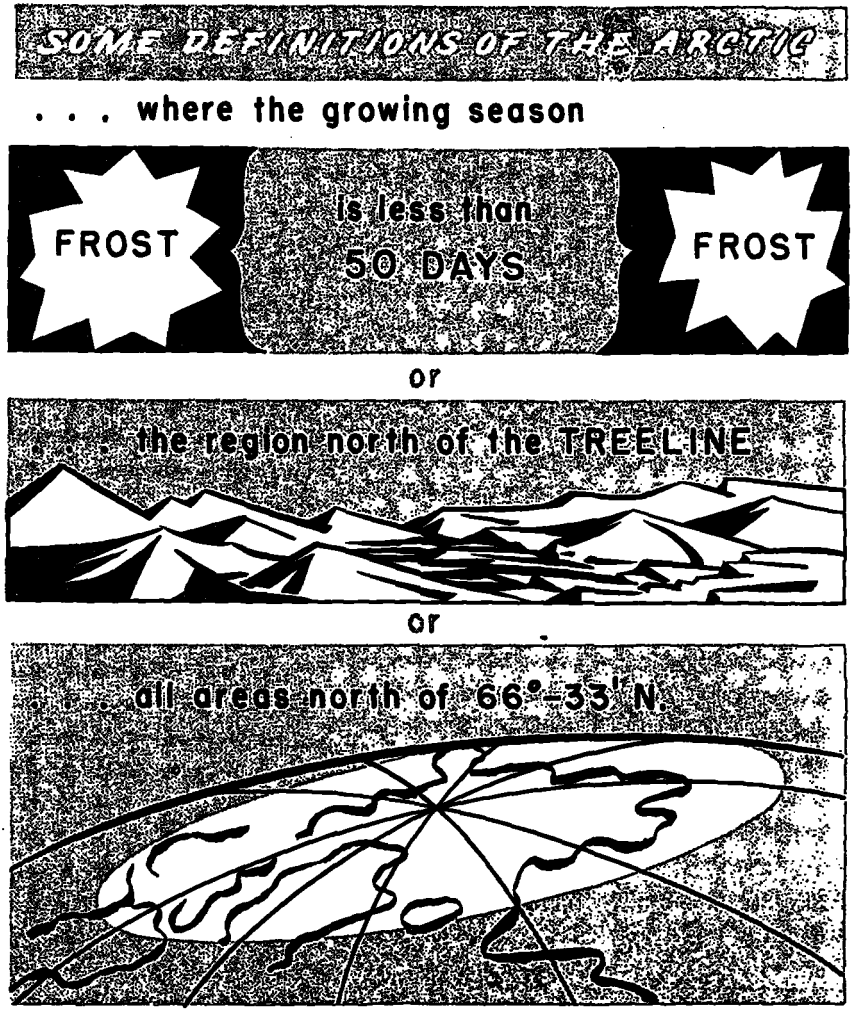


Figure 2-1.—Some definitions of the arctic region.

Many definitions use climate as a criterion to delimit the polar areas. Based on temperature, the Arctic is defined as:

1. The area lying north of the boundary fixed by the isotherm of 50° F. (10° C.) for the warmest month, or the isotherm of 14° F. (minus 10° C.) for the coldest month.
2. Areas having a mean annual temperature of 32° F. or below.
3. All areas where the sum of the average temperature in degrees centigrade of the warmest month plus one-tenth of the

temperature of the coldest month is less than 9° C. (This definition is the Nordenskjold-wall formula used by the Soviets for defining the Arctic.)

Agronomists frequently define the region on the basis of the length of growing season. Thus all areas having less than 50 days between frosts are considered Arctic.

Botanists define it as the region north of the treeline, a boundary which approximates the 50° F. summer isotherm; or as the areas in which trees will not grow because of the cold, excluding other inhibiting factors such as poor soil, lack of water, and excessive winds.

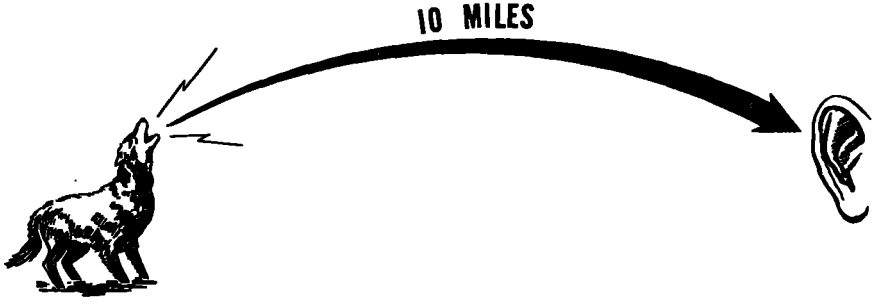


Figure 2-2.—Sharp sounds can be heard at ten miles.

The astronomical definition, used in navigation and in understanding the seasonal variations in the length of daylight and darkness, places within the Arctic all areas north of parallel 66° 33′ N.—the difference between 90° and the maximum northerly declination of the sun.

There are other definitions based on such factors as extent of permafrost and windchill.

The subarctic is defined by the temperature factor as the areas where the mean temperature for less than 4 months of the year is higher than 50° F. (10° C.) and the mean temperature of the coldest month is less than 32° F. (0° C.) It should be noted that minimum temperatures are often lower there than in areas farther to the north. This does not mean that all subarctic areas are colder than arctic areas. Some areas included in the subarctic have average winter temperatures falling so slightly below 32° F. that they are characteristically non-Arctic, such as Iceland where Reykjavik has an average temperature for the coldest month about like that of Philadelphia.

COMMON CHARACTERS

Regardless of the criteria used for the various definitions, there are certain characteristics common to the region. These are:

1. Short cool summers.
2. Long cold winters.
3. Low annual mean temperature (23° F. or minus 5° C.).
4. Long periods of semi-darkness.
5. Periods of continual daylight.
6. Absence of forests.
7. Freezing in winter of lakes, rivers, bays, and parts of the sea.
8. Scant precipitation.
9. Low absolute humidity.
10. Low evaporation rate.
11. Moist soils when thawed.
12. Presence of permanently frozen ground.
13. High windchill factor.
14. High latitude position.

Other phenomena found in the Arctic include the aurora borealis, mirage, increased visual and auditory perception, glare, fog, and the magnetic pole.

In the matter of darkness it should be noted that, although there is no direct sunshine in the winter above 74° N. latitude, there are long periods of moonlight, with the snow and ice acting as good reflectors for the light from stars, the aurora, and the moon. However, the reflected light is diffused and as there are no clear shadows it is difficult to judge size and shape of objects. Under such conditions, fliers have trouble in judging the surface of the ground.

The aurora borealis is a useful source of winter light but it is not regular and dependable. The area of maximum frequency is oval-shaped around the northern geographical and magnetic poles. Discussion of the effect of aurora upon communications is included in chapter 3, Part II.

The long summer daylight does not mean that there is good visibility. Fog is especially prevalent in the spring and summer. The fog is mainly along the coasts where the warmer continental air passes over the cold arctic waters, and is frequently concentrated in the lower levels, a few feet above the surface. Fog is also produced by communities and encampments of men, by power plants and airplanes. In the Mackenzie delta area, the *black fog* occurs, especially in March, making flying very hazardous. Some

fogs are made up of frost flakes or spicules. Another visibility problem is that of mirage. Due to the differential density of air, light cannot pass through the boundary between the layer of cold air along the surface and the warmer air above. The surface of the ground is obscured and images are inverted.

Glare is a common problem during the period when the sun is above the horizon and the sky is overcast. On sea-ice or on snow-covered land everything looks equally white. Eye strain and snow blindness come from an attempt to distinguish features in this general whiteness. Rest the eyes by viewing regularly any marked contrasts that may exist—particularly areas of open water.

In the absence of fog, the degree of visibility is very great. Normal horizontal visibility in the Arctic is 50 miles, and under special conditions visibility for 150 miles is possible. This poses a military problem of concealment.

Sound travels with great clarity in the dry, cold air. Sharp sounds can be distinctly heard at distances of 10 miles or over.

The areas having these general characteristics of the Arctic and sub-arctic include northern Alaska, the northern two-thirds of Canada and Labrador, Greenland, Iceland, the northern portions of Scandinavia in the Lapp country, the northern sections of the Soviet Union, including the lower basins of the famous north-flowing rivers (Ob, Yenisei, Lena), and all of the islands and seas north of these mainlands.

PREDOMINANCE OF THE ARCTIC SEA

Looking at the top of the world, the Arctic Sea (also referred to as Arctic Ocean) is seen to be an arm or gulf of the Atlantic Ocean, joined to it by the wide strait of the Norwegian and Greenland Seas. Unlike the impression gained from a world map on the Mercator projection, the Arctic Sea is comparatively small in area. The two great land masses of the Eastern and Western Hemispheres are separated by relatively short distances across this mediterranean. Great circle flight routes between major power centers lie over the Arctic. In economic terms, however, the uses of these routes have been *shortcuts to nowhere* up to the present time.

In general, the peoples of the two hemispheres consider the value and use of the arctic basin on quite dissimilar bases. The Soviet Union, needing an outlet for the interior of the continent, is looking north and is using the seas bordering the central basin as a seasonal supply route. Russian interest in her northern sections

has been active for many decades, emphasized by the early explorations of Bering and more lately by the establishment of an Arctic Institute in 1928. North America, on the other hand, has an abundance of temperate zone harbors, and, therefore, has felt little need to be concerned with the Arctic except in terms of exploration and exploitation on a relatively minor scale. Only in very recent times has there been any concerted effort to "know" the Arctic. In part, this effort was promoted by a realization that the polar basin is an area of junction and not separation of the two hemisphere continents.

The Arctic Sea, as the center of the north polar region, is the dominating feature. Its position gives it significance with relation to the lands bordering it. These lands are characteristically cold, desolate areas strongly influenced by the ice-covered central maritime basin.

TOPOGRAPHY

The lands in the far north are made up mainly of pre-Cambrian rocks, most of which have been metamorphosed. These ancient and resistant rocks form the great shield areas of Finland and Scandinavia, eastern Canada, and eastern Siberia. Between the shield areas are younger sedimentary deposits. In general, the lands are mainly mountain, plateau or rolling upland areas of greater or lesser height. The main highland areas are the central Siberian plateau from the Yenisei to the Lena, the Novaya Zemlya mountains, the mountains of Spitsbergen, the Greenland ranges, the mountains of the eastern Canadian arctic islands, the Yukon-Mackenzie highland, the Brooks Range of northern Alaska, and the mountains of southern Alaska. There are few extensive lowlands. Small areas of low, relatively flat ground are found in the Canadian Eastern Arctic, the Mackenzie Basin, and far northern and central Alaska. The most prominent plains are those of Eurasia in northern Siberia, and in northern Russia west of the Urals.

Most of the land of the arctic region is underlain by permanently frozen ground or permafrost. This phenomenon is a product of both past and present climatic conditions and is defined as any soil, rock or bedrock which has had a temperature below freezing throughout two or more years. Frozen ground containing little or no ice is called dry permafrost, usually associated with areas of sandy or coarse grained material which is well drained. It offers few problems in construction engineering since its proper-

ties are similar to those of unfrozen ground. Frozen ground with a high moisture content, usually in the form of ice crystals or lenses, requires special construction methods.

PERMAFROST

Permafrost is found in most of Alaska, northern Canada and the Canadian archipelago, Greenland, and as far south as northern Mongolia and Manchuria. It reaches farther south in the eastern sections of the continents than in the western parts. The thickness varies from a narrow wedge at the southern edge to depths of several hundred feet in northern Alaska and reputedly over 1,000 feet in northeast Siberia.

There are many factors that appear to be related to the formation of permafrost. A low annual mean temperature (minus 4° to minus 6° C.) can produce and maintain permafrost. Its first occurrence was probably during the excessive chilling caused by the Pleistocene ice ages, about a million years ago. Inconclusive evidence suggests that the permafrost layer is thickest in the areas which were not glaciated during the ice age. Although the relationship with the ice age is not entirely clear, permafrost is related to current climatic conditions. For example, at Port Nelson on Hudson Bay after a lake was drained, the ground froze to a depth of 8 feet the first year, to 20 feet the second year, and in the third year the permafrost reached a depth of 30 feet, the average depth for the area.

The layer above the permafrost is usually subject to thawing in the summer. This is called the active layer and its depth depends upon the annual mean temperature, the surface exposure, the heat distribution and composition of the ground, and the vegetation cover. Moss or peat act as insulators to limit the depth of the active layer. If this cover is removed or the ground is disturbed, the thawing will be increased and the active layer will become thicker. Heavy snow cover and water bodies act as insulators against the cold, and the underlying permafrost will be at a deeper level or nonexistent. Thus the bottom surface of the active layer and the top of the permafrost layer are quite irregular, frequently having little relationship to the ground topography.

Permafrost is impermeable to water. During the summer, a considerable amount of the surface water percolates through the thawed active layer. As the ground freezes in the winter from the top downward, the water continues to flow in the unfrozen layer which gradually becomes more restricted and the water

becomes subject to hydrostatic pressure. In many cases, the water under pressure is forced to the surface where it may form seepages and ice sheets, icing-mounds, blisters or bursts. Or, the water may become frozen within the active layer in large solid masses, sheets, wedges, veins, lenses or minute grains causing a swelling of the surface of the ground. In a few instances, when the water was strongly mineralized, it has remained in a fluid state although the surrounding ground was frozen. Water exists below the permafrost layer. It is always fluid, and usually is under considerable pressure.

Soil that is saturated by melt-water during a part of the summer is really half afloat, and on the slopes this soil slips slowly downward. Such solifluction causes a certain amount of sorting of the material, making a stripes take the form of small irregular terraces. On level ground the form taken by the water-soaked soil is an irregular hexagonal pattern where the centers are gravel and larger stones, and the interspaces are finer sand. These are the polygonal soils of the polar areas (fig. 22). Vegetation commonly concentrates in the perimeters of the hexagons.

The existence of permafrost has an effect on the vegetation. The excessive moisture in the active layer above the impervious frozen ground inhibits the growth of some trees. Bogs and marshes are characteristic of wet permafrost areas. Trees with shallow roots such as the larch, spruce, tamarack, balsam poplar and dwarf birch can thrive in areas, where the active layer is as shallow as 12 to 18 inches. Jack pine has a prominent tap root, and thus cannot grow in permafrost areas. Jack pine forests are a good indication that permafrost is either very far below the surface or completely absent.

DRAINAGE

Permafrost is in part the cause of the haphazard, poorly defined drainage of much of the arctic region. The inability of the surface water to seep into the frozen ground forces a considerable amount of the scant precipitation to remain on or near the surface. Glaciation, of course, is primarily responsible for the disruption of the pattern of drainage in the vast areas that were covered by the ice sheets. There has not been sufficient time since the recession of the ice for well-defined drainage to be established. Thus, much of the relatively flat land of the Arctic is studded with innumerable shallow lakes connected by sluggish streams that seem to wander aimlessly. There are, however, some prominent rivers which flow

northward into the polar basin. In Eurasia, the Ob, Yenisei and Lena are the major north-flowing rivers, the Pechora, Indigirka and Kolyma being of lesser importance. The Mackenzie river system is the largest of the North American rivers draining into the Arctic Sea. The Colville, Coppermine, Back, Thelon, Dubawnt, Kazan, Churchill, Nelson, Fort George, Great Whale, Kaksoak and George rivers are some of the smaller north-flowing rivers.

The rivers that flow from the south present problems in the spring breakup. While the lower portions of these rivers are still ice-locked, the upper reaches are being exposed to the longer days and warmer temperatures of spring. Ice in the upper sections thaws, breaks loose, and starts moving down stream. Its progress is blocked by the still frozen lower sections, and flooding and ice-damming, are common spring occurrences. Another effect of the alinement and direction of these rivers is that, although the upper portions may be ice-free early in the summer, the rivers cannot be entered until the ice at the mouths has broken up. Local river traffic can operate in the ice-free areas, but all outside traffic must wait until the summer season has progressed northward to free the river outlets.

VEGETATION

The abundance of lakes and rivers in the northern regions might give the impression that it is an area of heavy precipitation. This is not the case. The Arctic has scant precipitation, receiving only 10 to 15 inches a year. Aridity is one of the main controlling factors in the region, together with low evaporation and low temperatures. Under such circumstances soil development is at a minimum and decay is prevented. The combination of drought, inadequate soil, frozen subsoil and short growing season produces conditions inimical to tree growth. Hence, the Arctic is essentially a treeless tundra. Clumps of trees are found in areas where soil is sufficiently deep, as on terraces, raised beaches and deltas, but they are limited in size and number.

Despite the lack of forests, the tundra is luxuriant in vegetation. There are innumerable flowering plants, mostly perennials, which burst into bloom and complete a life cycle in the short season from June to August. These plants also show adaptation to the environment in other ways; for example, they have abnormally developed subterranean stems and roots spreading laterally in the shallow layer above the permafrost; they have leathery, waxy or

woolly leaves to preserve moisture like desert plants, and many are prostrate to avoid the winds and seek the protection of the snow from the extreme cold. Grass is abundant, and in many ways the meadows of the Arctic are similar to the savanna and steppe-lands. Mosses and lichens are especially numerous in the ancient shield areas. There are some 250 species of mosses.

These plants develop high osmotic pressure and, therefore, can stand low temperatures. Over 330 species of lichens have been found. Lichens are less dependent than most other plants on the type of rock or soil on which they grow because they are symbiotic, one part living on another. In the bogs and water-logged areas the sphagnum moss, peat, and sedges are the chief plants. Thus, the tundra is an area of grasses, flowering plants, heath with berry-bearing plants, mosses, and lichens, with a few stands of trees on the better soils, and patches of dwarfed prostrate willows, junipers and aspen.

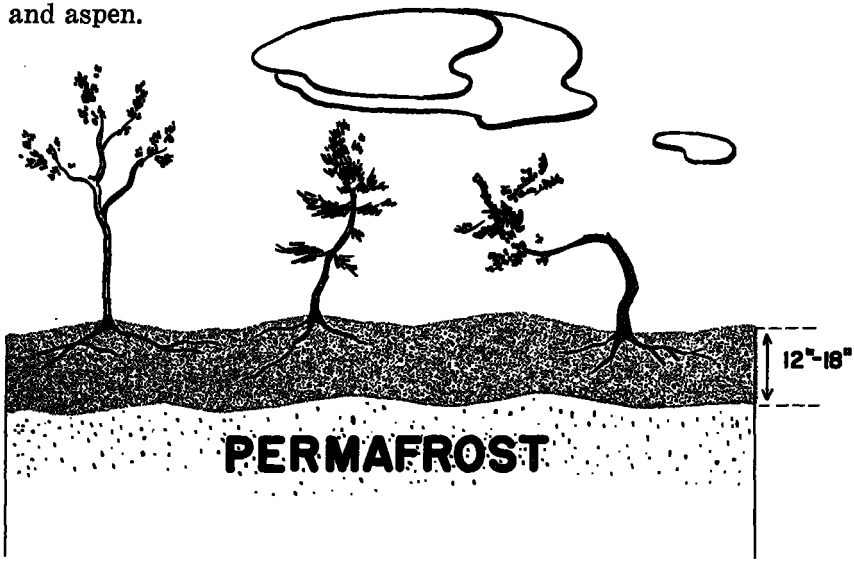


Figure 2-3.—Trees with shallow roots grow in permafrost areas.

All the plants in the tundra region have a very slow rate of growth. The size of the plants is not an indication of age, and many very small plants are 10 to 20 years old. It takes mosses 9 to 10 years to regrow after they have been grazed by migrating reindeer, becaues they grow only about ⅓ inch a year.

The treeline which roughly follows the July isotherm of 50° F. (10° C.) marks the northern edge of the vast coniferous forests. In North America the treeline lies along the foothills of the Brooks

Figure 2–4.—Muskeg and gravel in terrain around Resolute Bay.

Range, it crosses the Mackenzie River at its delta, swings southeast across the Canadian shield to Port Nelson and Fort Churchill on Hudson Bay, crosses the northern end of James Bay and the Ungava Peninsula, taking a sharp southward dip along the mountains of Labrador. In Norway, the northern limit of forests is at about the 70° N. parallel. The treeline dips southeast through the center of the Kola Peninsula, then runs almost parallel to and about 400 miles inland from the Siberian coast, trending slightly more to the south as the eastern coast is approached. The Eurasian coniferous forest is the most extensive in the world, while the Canadian forest covers more than half the Dominion.

The coniferous forest or taiga, as it is called in Siberia, is composed of several species of pines, firs, spruces, birches and larches. On the whole, the forests are not a mixture of all the species, but the trees tend to segregate into more or less solid stands of single species. The trees group themselves mainly on the basis of their ability to adapt local conditions of moisture, temperature, exposure and soil. To some extent, the different trees are indicators of particular soil, water and temperature factors.

Black spruce, for example, will grow in swampy areas and is found as far north as the treeline. It will also thrive on dry soils, but is frequently pushed out by faster growing trees. Larch is one of the hardiest of the forest trees and grows to the very northern limit of trees. This northern limit is not a clear cut line.

Toward the northern edge the trees grow farther apart, with grasses, mosses and shrubs covering the ground between the trees. The forests have a parklike appearance. Farther north there are still fewer trees. Some of the trees such as the spruce, birch, and

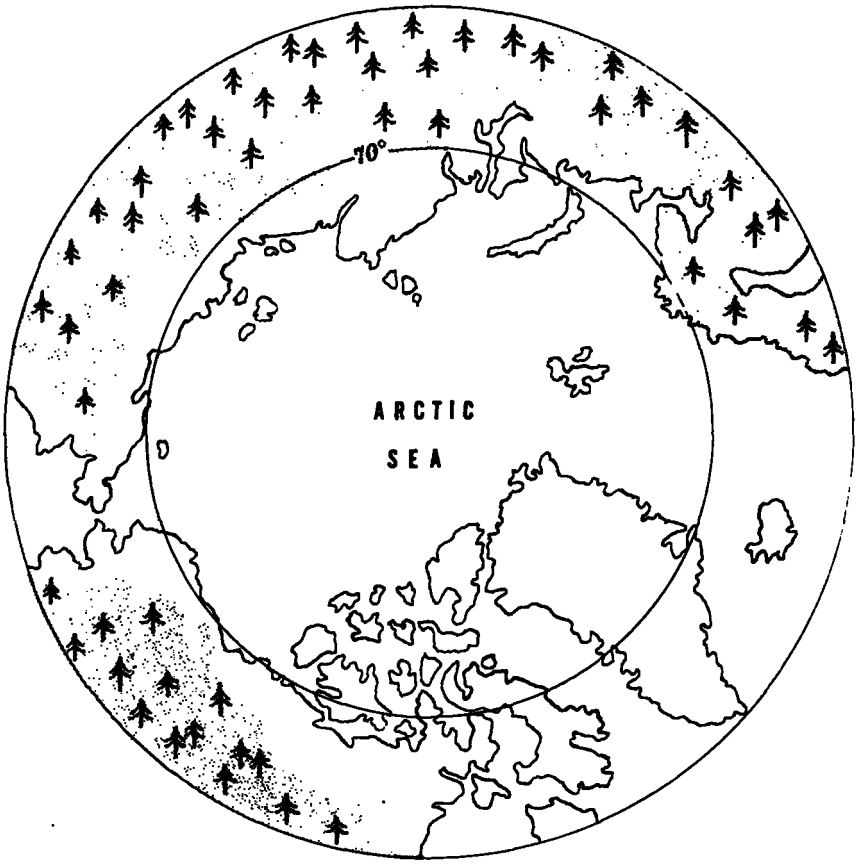


Figure 2–5.—The treeline.

fir become dwarfed and stunted. More of the area is covered by shrubs and thickets of willows and alders, especially the margins along the rivers and lakes. North of the limits of true forest growth these thickets of arctic willows and birches found in the lowlands make summer overland travel very difficult. Farther north these tangled masses of undergrowth die out, and are replaced by mosses and lichens.

To a great extent the vegetation controls the distribution of animals. The mosses, lichens, grasses, and shrubs of the tundra provide food for the migrating herds of reindeer, caribou, and musk-oxen. The lemming, ermine, and arctic hare are found in abundance. These animals, together with the flesh-eating foxes and wolves, move northward in the summer, perhaps motivated by the appearance of the infinite number of mosquitos which breed in the water-soaked lands. The white fox, one of the most valuable of northern animals for its fur, ranges along the arctic coast, living on small birds and lemmings.

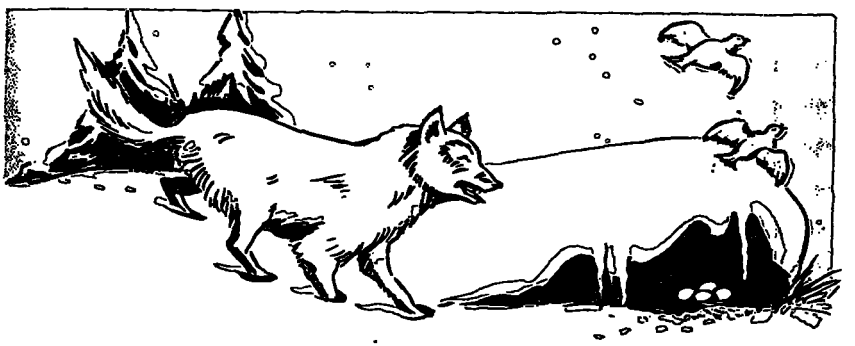


Figure 2-6.—The white fox lives on small birds and lemmings.

In winter both the arctic fox and the white fox migrate north onto the sea-ice. Here they live off partially eaten seals which the polar bear have killed and on gulls and wild duck. Wolves follow the caribou herds which are their chief source of food. The wolves range over the tundra from the tree-line to the arctic shore, rarely going out onto the sea-ice. They usually hunt alone or in pairs, and not in the much talked about multitudinous packs.

Bear are found throughout the Arctic. The polar bear, whose fur is yellowish white in color, is usually found along the coast of the continents or on the islands. They rely on seals for their food supply and therefore stay in the vicinity of the sea-ice where seals are most likely to be. Wherever the bear go, the white fox will be close behind since it depends on the polar bear to kill its food. The gulls also feed on the seal carcasses left by the bear.

The sea is particularly rich in flora and fauna, especially in protected areas. These organisms, shell fish and small fish provide food for the larger animals, such as whales, seals, walrus, and the many birds.

POPULATION

Although the Arctic has been inhabited for countless ages, it is still one of the least populated regions of the world, comparable only to the deserts. It is difficult to determine the total population, since statistics are not available for the many towns and polar stations of the Soviet Union. However, the total population is small.

The people of the North live mainly along the coasts of the mainlands and the larger islands. Most of the smaller islands are uninhabited. Native activities are as intimately connected with the sea as with the land. They depend upon the products of the sea for a substantial part of their food and clothing. Caribou furnish some of these necessities, but there are too few caribou to maintain the northern population; and the migratory habits of the land animals make them a less dependable source of supplies than the fish and mammals of the sea.

Figure 2-7.—People of the North.

The natives in their culture show remarkable adaptation to their environment. Their dress, shelter, food, and mode of transportation, as well as the implements used in their daily activities, all indicate the degree to which they have made the best use of the local materials in order to live a comfortable life. The common occupations are hunting, fishing, and trapping. There are some

areas, as Lapland, where reindeer herding is carried on. The Soviet Arctic is in contrast to the North American Arctic in the matter of farming and industry. Although most of the Hudson Bay Company posts and the missions have small garden plots of potatoes, radishes, carrots, and beets, the Soviet polar stations and industrial towns have extensive farms, reportedly able to feed their whole northern population.

As for industry, there is little comparison between the extensive development in the Soviet Arctic and the meager development in the Western Hemisphere. The mines at Great Slave Lake and Great Bear Lake are about the only industry of any scale in northern Canada, aside from the fishing, fur, and wood industries.

Despite the much talked about lure of the North not many people from temperate regions have found the Arctic an inviting place to live. The non-native population is mainly transitory, coming only to make a quick fortune, as in North American Arctic, or coming in response to Government orders and the "incentive bonuses" as in the Soviet Arctic. The severe climate requires that too much of an individual's time be devoted to keeping warm, dry, and nourished to allow for many economically remunerative activities. Attempts to transplant temperate zone habits and customs to the Arctic mean heavy expenditures for imported foods, implements, clothing, and equipment.

Whether or not the Arctic will one day be dotted with industrial developments seems to depend on more than mere exploration to discover the mineral wealth. Much must be done to conquer the environment and the isolation. However, the Arctic is still a most interesting place, offering endless opportunities for basic scientific research and experimentation. Its importance in world strategy and the scheme of twentieth century progress is growing.

TABLE I

Distance: Arctic Air vs. Normal Routes (Statute Miles)

Route	NORMAL ROUTE (Steamship and railroad)	Arctic air route
New York–Peiping via Seattle	9,340	6,850
New York–Tomsk via Seattle	10,600	5,625
New York–Tomsk via Hamburg	7,960	5,625
Edmonton–Tomsk via Vancouver	7,270	4,775
London–Tokyo via Montreal	11,550	5,940
London–Tokyo via Trans-Siberian	8,140	5,940
Seattle–Leningrad via New York and Hamburg	8,280	4,865

TABLE II

Distance Table

From	Across	To	Statute miles (approx)
Geographical Center United States	Greenland	Moscow	5,300
Do	Iceland	Berlin	4,800
Do	West of North Pole	Irkutsk	5,600
Do	Fairbanks	Nanking	6,600
Do	East of North Pole	Bombay	8,000
Washington	Greenland	Moscow	5,000
Do	Iceland	Berlin	4,200
Dutch Harbor	Kurilos	Vladivostok	3,000
San Francisco	Wrangle Island	Irkutsk	5,600
Geographical Center, Greenland	Norway	Moscow	2,300
Tokyo	Japan Sea	Vladivostok	670
Moscow	Siberia	Anadyr	5,000
East Cape, Siberia	Bering Strait	Nome	150
Dutch Harbor	Bering Sea	Petropavlousk	1,500
Fairbanks	North Pole	Moscow	4,100
Do	Canada	New York	3,260
Do	do	Chicago	2,780
Do	Alaska	Seattle	1,530
Do	Bering Sea	Yakutsk	2,375
Do	do	Tokyo	3,500
Anadyr	East Siberia	Vladivostok	2,500
Tokyo	Kurilos	Petropavlousk	1,500

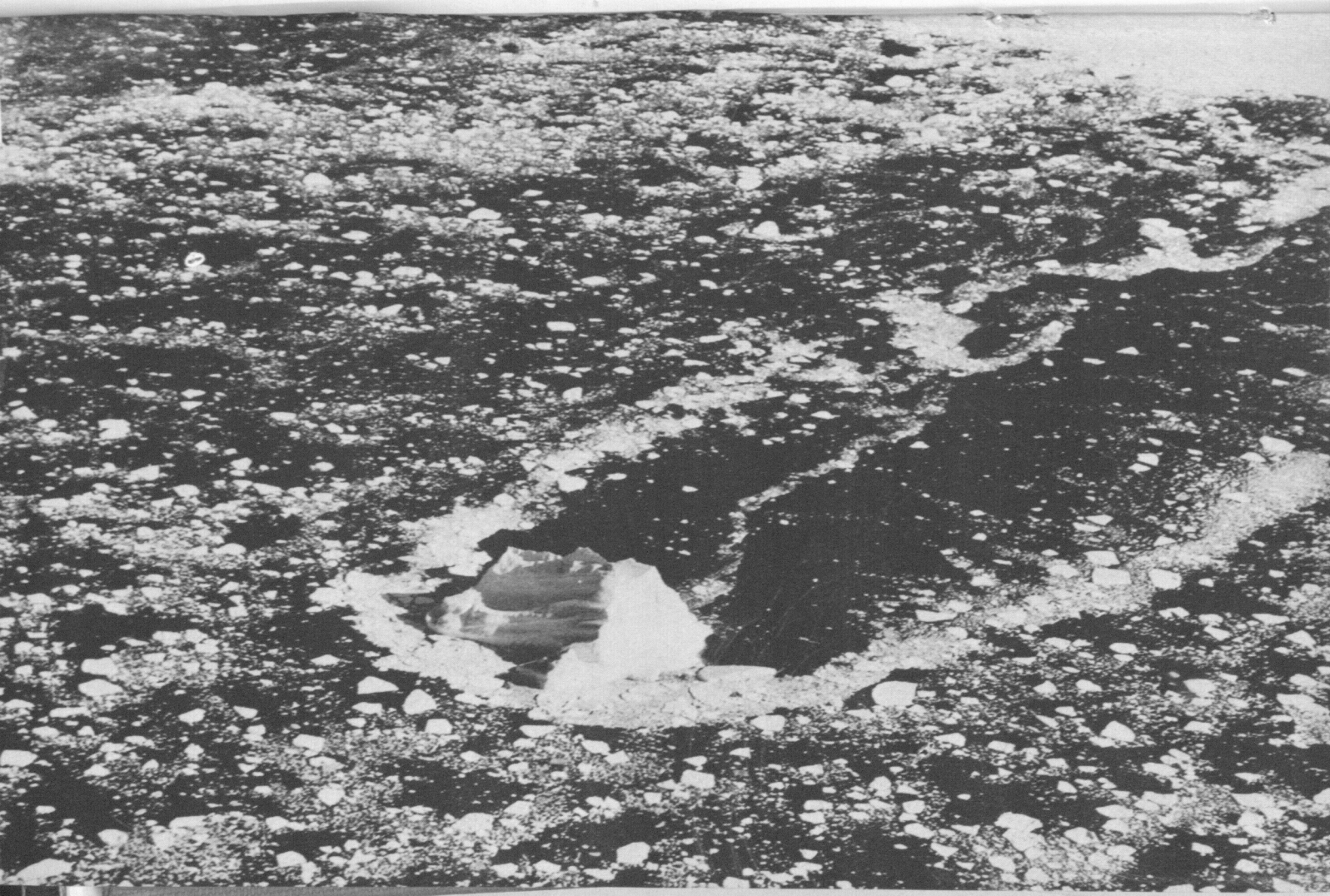
ARCTIC AND NORTHERN SEAS

The Arctic Sea fills a deep, eccentric conical basin between two great land masses, with its center toward Alaska and its long axis from Point Barrow to Rudolf Island in Franz Josef Archipelago. Although it covers about 5,000,000 square miles, it is small compared with the Pacific and Atlantic Oceans. On the surface, it appears as a gulf off the Atlantic, joined to the latter by the wide Norwegian and Greenland Seas.

However, consideration of the bottom relief shows that there are three rather distinct basins. The first and largest is the central polar basin. It extends to the rise between Spitsbergen and northeastern Greenland. The second is the Greenland Sea basin, extending from this rise to the ridge between Bear Island and Jan Mayen Island. The third, or Norwegian basin, extends southward to the Atlantic Ocean. Around the borders of the central basin local water areas have been named as separate seas, such as Barents Sea, Kara Sea, Laptev Sea, East Siberian Sea, Chukchi Sea, and Beaufort Sea.

The hydrographic survey of this sea area is not complete, but soundings which have been made indicate depths of over 15,000

Figure 2-8.—Northern seas.



feet. The deep part of the basin is egg-shaped, being nearer the Canadian and Greenland shores than the Siberian coasts. The continental shelf is well developed along the Siberian coasts from Bering Strait to the Barents Sea, having a maximum breadth of 375 miles. The shelf is very narrow along the Alaskan north coast and the Canadian archipelago. The islands of the archipelago are all on the continental shelf. However, little is known as to the water depths and submarine character of the channels and fiords in this area. The nature of the continental shelf can be seen from an examination of HoChart 2560 (Arctic Regions).

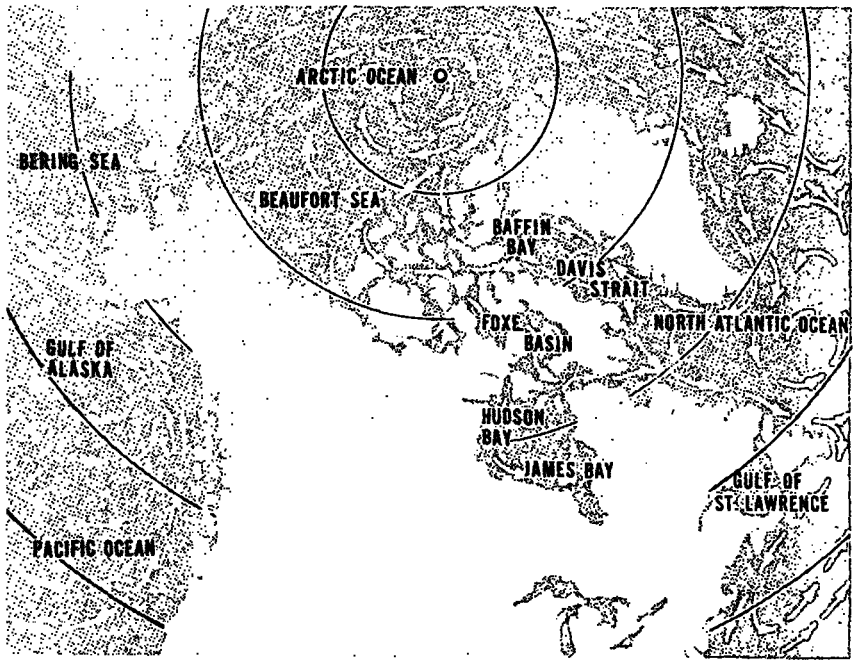


Figure 2-9.—Currents.

The Arctic Sea receives its water from two main sources, the northward flowing fresh water rivers and the highly saline current of warmer water which enters along the west coast of Spitsbergen at about middle depth, below the cold water at the surface. The water in the basin circulates in a generally clockwise direction. There are smaller currents moving eastward along the north coast of Greenland, and a large eddy some 300 miles north of the coast in the Beaufort Sea.

The principal outlet is between Spitsbergen and Greenland. The cold East Greenland current flows southward along the east coast of Greenland to Cape Farewell. Part of this current rounds the cape and flows northward along the west coast, where it is joined by a small current from the Gulf Stream. Three other outlets exist among the Canadian arctic islands. One is the narrow channel between Ellesmere Island and Greenland through Robeson Channel, Kane Basin, and Smith Sound to Baffin Bay. A second outlet is through the broad Strait, Viscount Melville Sound, and Lancaster Sound north of Baffin Island into the Bay of the same name. The third and least important outflow is through Fury and Hecla Strait to Foxe Basin and Hudson Bay.

In Baffin Bay, the northward flowing current along the west coast of Greenland curves westward in Belville Bay and merges with the outflowing polar waters which move southward along the west side of the Bay. Part of this current enters Hudson Strait and flows around the southern coast of Baffin Island, going northward along the west coast into Foxe Basin. This current joins the arctic outflow and moves counterclockwise around Foxe Basin and Hudson Bay. It flows along the south side of Hudson Strait to Davis Strait. It then merges with the southward flowing current from Baffin Bay to form the famous Labrador current. Another outlet, but one of negligible importance, is through the Bering Strait, which finally mixes with the northeastward flowing Gulf Stream to the east of Newfoundland.

Throughout much of the year, but especially during the breakup, the Labrador current and the east Greenland drift bring bergs and floes from the northern areas. It is estimated that 26 million cubic yards of ice are thus carried into the north Atlantic Ocean annually.

The circulation of the cold arctic water and the warmer Atlantic water causes considerable contrasts in the climates of the coasts along which these currents flow. Moderating influences of the relatively warm waters are also felt in northern Scandinavia. Part of the North Atlantic current flows along the coast past Murmansk and Kolguev Island, and northward along the west coast of Novaya Zemlye. The effect of this current is to keep the Barents Sea free of ice for several months, and to considerably moderate the climate of western Novaya Zemlya.

Tides in the far northern area are not high. Along the coasts the rise and fall varies from a few inches to 4 or 5 feet on an average. The tides are somewhat higher along the Kola Peninsula

and western Soviet coasts. In the channels, fiords, and inlets the tides may reach heights of 30 feet owing to the waters piling up in the restricting narrows. The spring range is frequently two to three times greater than the mean range.

ICE

The ice conditions of the Arctic Sea vary from year to year. On the average, about 90 percent of its surface is ice-covered in winter. Most of this ice is true sea-ice and not land derived. Its forms are many and diverse, depending on its age, the influence of winds, waves, currents, and the weather.

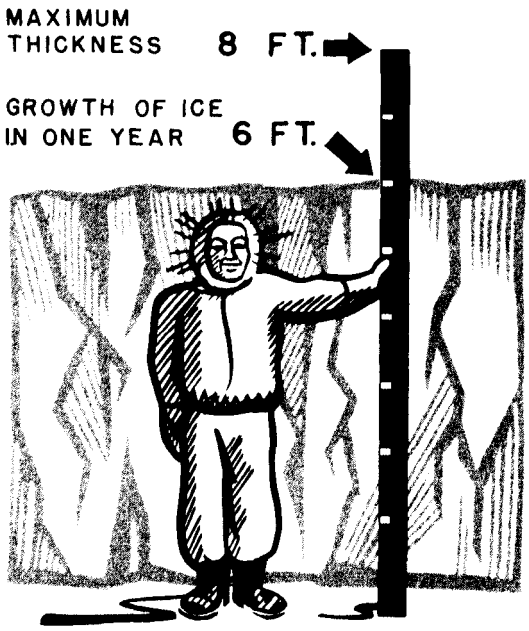


Figure 2-10.—Growth of ice.

Ice begins to form on sea water of average salinity (35°/00) when the temperature reaches about 29° F. Polar seas have lower salinity and therefore freeze at higher temperatures. The first ice formed may be salt free, but the salt becomes trapped between the crystals and new ice is very salty. During the summer the surface of the ice melts and the water percolates down through the ice, carrying with it much of the salt so that ice a year old is not especially salty to the taste. On the surface of the ice, pools of

fresh thaw water may accumulate in summer (fig. 3). The fresh water that seeps through the ice refreezes on the bottom of the ice thus causing an upward migration of debris frozen in the ice. It is not uncommon to see ice covered with rocks, shells, seaweed, and diatoms that have been brought to the surface.

Arctic ice usually grows up to 5 or 6 feet in a year. Growth continues through the summer by the addition of the new ice on the bottom of the layer. A second year may add 1 or 2 more feet to the thickness. Eight feet is about the maximum thickness of level ice, since at that point the ice acts as sufficient insulator to stop any refreezing at the bottom. Under the influences of tide, wind, current, and sea swell, the floes are pushed together or against the shores. This causes buckling, ridging, and rafting of the ice. Ice thus piled up may be 30 to 40 feet thick; and the ridges may be 100 feet high. When such pressure is released, leads and open water appear.

Ice first forms along the shore, in the bays, and at the mouths of rivers. In the fall and early winter, the polar pack which is continually in motion, coming in and moving off the shore, grinds this new ice and piles it up against the beach. When the pack moves off, a layer of new ice forms in the lead. This process continues until about the beginning of December, when the coastal ice becomes frozen fast to the bottom. This fast ice is a solid, stationary mass extending 4 to 8 miles from the shore. The fast ice is useful as a winter highway for sledges. The ice reaches a maximum thickness in April or May and then begins to crack and rot. Pools form on the surface and travel is difficult.

Between the fast ice and the pack there is a lead which intermittently opens and closes as the pack moves. Pressure ridges are formed and the grinding of the ice continues along this *flaw zone* during the winter.

Throughout the entire year approximately three-fourths of the Arctic Sea is covered by heavy pack-ice which is essentially impenetrable. During the winter, the bordering seas and bays are ice-locked and are unnavigable. The maximum extension of the heavy pack and land-fast ice is in early spring. In April and May pack-ice covers the areas along the east coast of Greenland, the Canadian archipelago, the Labrador coast, the western and northern Alaskan coasts, and the Siberian northern coast as far west as Kolguev Island. The Kara Sea, Gulf of Ob, and the Yenisei estu-

ary are entirely ice-bound. Barents Sea is mainly ice-free except in the western section along the coasts of Novaya Zemlya.

In the northern end of Baffin Bay an area of open water seems to persist throughout most of the winter. This "north water" shifts in location and extent, but usually lies between Devon Island and Thule, Greenland.

Hudson Bay appears to freeze over except for wide leads. The ice begins to move out or rot in place in mid-June. By July, the bay and strait are fairly well open, as is the west coast of Greenland as far north as Etah. The west coast of Novaya Zemlya is almost ice-free by July and the ice has moved out of the southern Kara Sea. Throughout August and September the northern coasts of Siberia and the Canadian mainland, and the northwestern coast of Alaska are ice-free. Ice persists between the far northern islands of the Canadian archipelago and remains close inshore along the coast of Alaska east of Point Barrow. Heavy pack-ice remains through the summer along the northern coast of Greenland and Ellesmere Island, and areas of unnavigable pack-ice are

Figure 2–11.—Iceberg 300 feet high.

found in western Baffin Bay and Davis Strait, eastern Foxe Basin and the southern part of the Gulf of Boothia. By November the estuaries and gulfs are again unnavigable.

The White Sea begins to freeze in mid-October. In some winters fixed ice may cover the whole Sea. There is little floe ice, and polar ice only penetrates the northern section where from November to May much floating ice makes navigation dangerous. The ice breaks up and the sea is usually navigable by June, although there have been years when ice remained during the summer.

The Gulf of Ob (Obskaya Cuba) is unnavigable after the first week in October. Both the Ob River and the Gulf are frozen over from November to the break-up, which begins on the river about the first of June and in the Gulf about the middle of June. Navigation is possible on the river in the first week of June; however, it is a month later before the Gulf is safe for ships.

In the beginning of October the Gulf of Yenisei freezes and the river freezes by mid-October. The break-up usually occurs on the river in the middle of June. The ice on the Gulf does not break up until mid-July.

The Lena River has a very short period during which navigation is possible. Ice covers the river from the first of October until the end of May, but the delta remains frozen until late June or July. Sometimes the river is ice-blocked throughout the year.

The break-up on the rivers is a rapid and violent event. The force of the waters flooding down the channels tears up the ice and drives it seaward at a rate of about 4 knots. Bends or constrictions in the channel cause temporary piling up of the ice. The water and bergs flood the valleys until the pressure breaks the ice barrier. In a week or less an entire river will rid itself of ice. River levels rise tremendously during the break-up, reaching heights of 70 feet or more over the winter levels.

WATER TEMPERATURE AND SALINITY

Much of the knowledge of temperatures and salinity come from the explorers and the men who made the famous drifts across the polar basin. From the Fram expedition of 1893–1896 it was learned that three layers of water exist. To a depth of 500 to 600 feet the water is cold with temperatures between 28.6° F. and 32° F. This upper layer has comparatively low salinity. Below this layer, to depths of 2,500 feet the water is more saline and warmer. This is probably the current from the Gulf Stream which

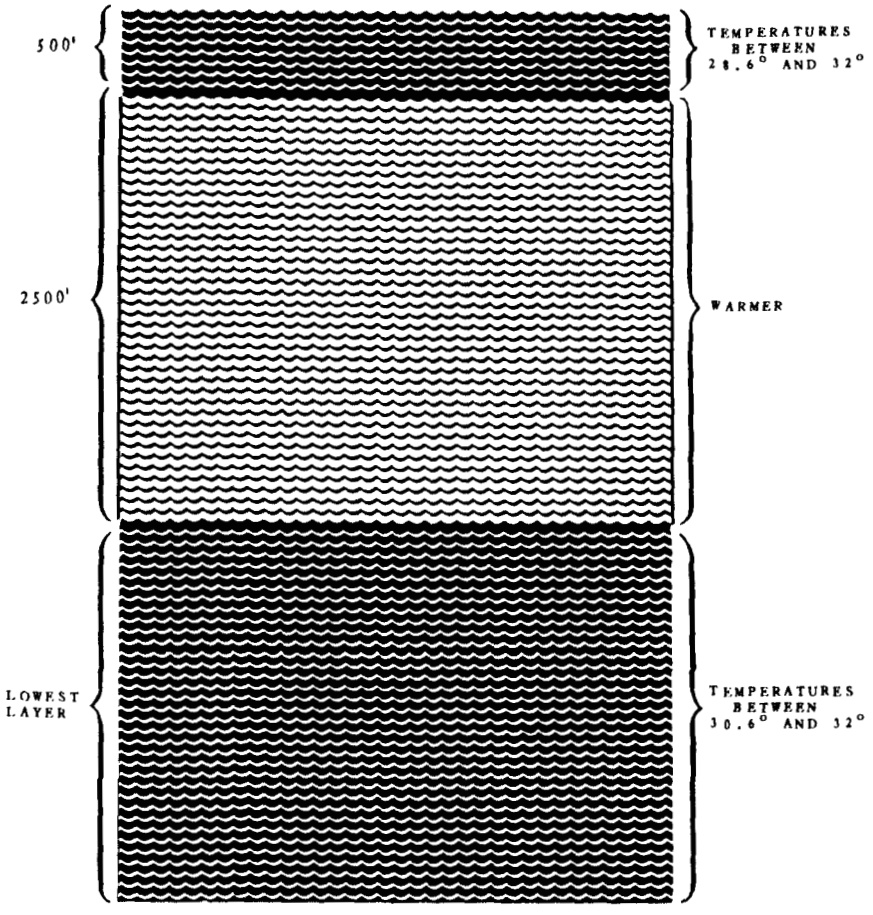


Figure 2–12.—Three layers of water.

dips under the colder arctic waters. The lowest layer is again colder water, with temperatures between 30.6° F. and 32° F.

MARINE LIFE

Although the waters are cold and are ice-covered for most of the year, they are not devoid of life. Fish are abundant in the shallow seas along the continental shelf and especially at the mouths of rivers. Seals, walrus, whales, and a few sharks are found. Several kinds of shell fish, jelly fish, and shrimp are abundant. Even at considerable depths, 3,000 feet or more, diverse mollusks, larvae, medusae and crustacea are found in large numbers. These smaller forms of marine life provide the food for the walrus and seals.

There are also several varieties of seaweed found along the shoal and bank areas.

"The world's greatest fishing grounds are on the fringes of the Arctic, with life abundant throughout polar waters," Hayes writes.

GEOGRAPHY OF CANADIAN EASTERN ARCTIC

The Canadian eastern arctic is often defined as the area north of the treeline in Canada which is served from the Atlantic Ocean and Hudson Bay. For convenience, the region is expanded to include all the islands of the Canadian archipelago. The area includes the mainland west and north of Hudson Bay in the Keewatin District, the islands of James and Hudson Bays, the islands of the Franklin District and the mainland of northern Quebec. It contains about 700,000 square miles or 19 percent of the total area of Canada. As a distinct region, the eastern arctic presents a natural environment and a combination of problems and conditions which are dissimilar from those of the western arctic and the Mackenzie valley.

COASTAL AREAS

The coastal areas of the mainland and the islands present every possible type of shoreline development ranging from the deeply indented mountainous eastern coasts of Baffin and Ellesmere Islands to the low swampy coasts of western Hudson Bay. There are very few beaches and those that do exist are limited in extent. Small islands are numerous along the coasts of the larger islands and scattered throughout the bays.

Most maps present the arctic islands as separate and distinct units. This is not everywhere the case, however, especially in winter. The open channels become ice bridges and the islands are linked together. In fact, ice persists in some of the water areas even through the summer, as in the McClintock Channel and Victoria Strait joining Victoria, King William and Prince of Wales Islands into a common unit throughout most years. The same condition prevails in the Parry and Sverdrup Islands, essentially uniting them to Axel Heiberg Island. Along the shores of the other northern islands ice begins to form about the end of September, extending outward as the temperature lowers. The wider channels either freeze over completely or become blocked with pack ice. This effectively links the islands together and provides easy surface travel from one island to another. The winter ice, especially that lying immediately offshore, is a boon to winter travel.

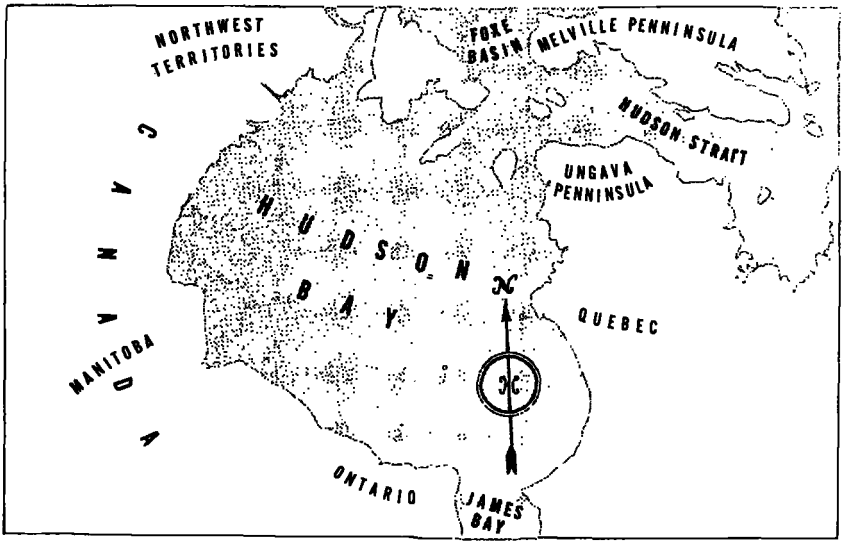


Figure 2-13.—Hudson Bay area.

Along the shores of Hudson Bay and Strait the ice begins to form about late October and builds outward to a distance of 5 to 7 miles. The thickness of the ice varies. In protected inlets the ice usually is about 5 feet thick as a winter maximum. Outside these sheltered places the ice is subject to the effects of storms which may raft the ice to thicknesses of 15 to 20 feet. By November the entrance to Hudson Strait is blocked by pack ice, and although the Strait does not freeze from shore to shore the center of the channel is filled by pack ice moving both east and west with the currents. By the end of June the ice begins to break up and drift toward Hudson Strait, thus clogging the channel during most of July. The Bay and Strait are usually open to navigation during late July, August, September, and October, depending on the direction of the prevailing winds. Early November again sees this area being cut off from outside surface communication as the sea-ice begins to form.

TOPOGRAPHY

Underlying most of this area are pre-Cambrian rocks of the Canadian shield, with a belt of sedimentary rocks extending through the central arctic islands and including most of the far northern and western islands. Erosion and weathering of the

pre-Cambrian rocks in general results in more rugged land forms while the sedimentary rocks result typically in level or low-relief forms.

Much of this area was glaciated during the most recent ice age which covered most of Canada with a sheet of ice several thousands of feet thick. There are today several areas of permanent ice caps. Glaciers and snow fields cover large sections of Ellesmere Island, Devon and Bylot Islands, and northeast Baffin Island. As a result of the decrease in load when the main ice sheet retreated, the land rose and ancient beach ridges and gravel terraces are now found as high as 500 or 600 feet above the present sea level. These terraced areas have proven to be valuable sites for settlements and airports, as well as being the most available source of loose, sorted material for road construction. In general, the lands subdued by glacial action have bare rounded hills of broken and frost-riven rocks separated by broad drift-covered coastal plain.

West of Hudson Bay the terrain of the drift-covered coastal plain is of low relief. The plain is about 50 miles wide at Churchill and broadens to the north, extending inland as far as Yathkyed and Baker Lakes. North of Chesterfield Inlet the land is more rugged, but to the west and east it slopes downward to the broad sandy valley of Back River and the low coast along Roes Welcome Sound. Melville Peninsula is a plateau with an abrupt drop to the west coast and a shelving, terraced slope along the central and northern sections of the east coast. West of the low coastal plain the interior plateau rises to an average altitude of 1,000 feet. Here the rolling surface is marked by rock ridges in a linear arrangement with narrow lakes occupying many of the intervening valleys.

There are countless lakes and streams forming a poorly integrated and undeveloped drainage system, due to the existence of permanently frozen ground which prevents underground drainage, and to the disruptive effects of glaciation. The three main rivers, Kazan, Dubawnt, and Thelon drain toward the northeast across the interior plateau in a general alinement with the bare rocky ridges and flow into Baker Lake and thence to Hudson Bay through Chesterfield Inlet. In many places along their courses they broaden out into lakes. Although these rivers are fairly well mapped as a result of being used as routes of exploration and penetration, they are difficult to identify from the air because of the abundance of unmapped rivers and lakes in the area.

North of Hudson Bay and to the South of Melville Peninsula lies

Southampton Island. It is the largest island in the bay. The southwestern two-thirds of the island is relatively low, flat limestone country with sloping terraces marking the ancient beaches, and broad belt of shoal ground fringing the coast. The northeastern portion is difficult of approach because it is frequently blocked by drift ice from Foxe Channel. The land in the northeast rises abruptly from the limestone plain into rugged mountains with altitudes of 1,000 to 1,500 feet. Southampton Island, together with Coates and Mansel Islands to the southeast, form the northern limit of Hudson Bay. The latter islands are of low relief.

The Ungava Peninsula lies to the east of Hudson Bay (fig. 38) and is mainly a rolling plateau with low, bare, rocky hills, and broad valleys containing unnumbered lakes and streams. The low areas are covered with glacial fills of boulders and gravel. The plateau rises rather abruptly from a narrow coastal plain along Hudson Bay to heights of 1,000 to 2,000 feet, and slopes gradually downward to the northeast to Ungava Bay.

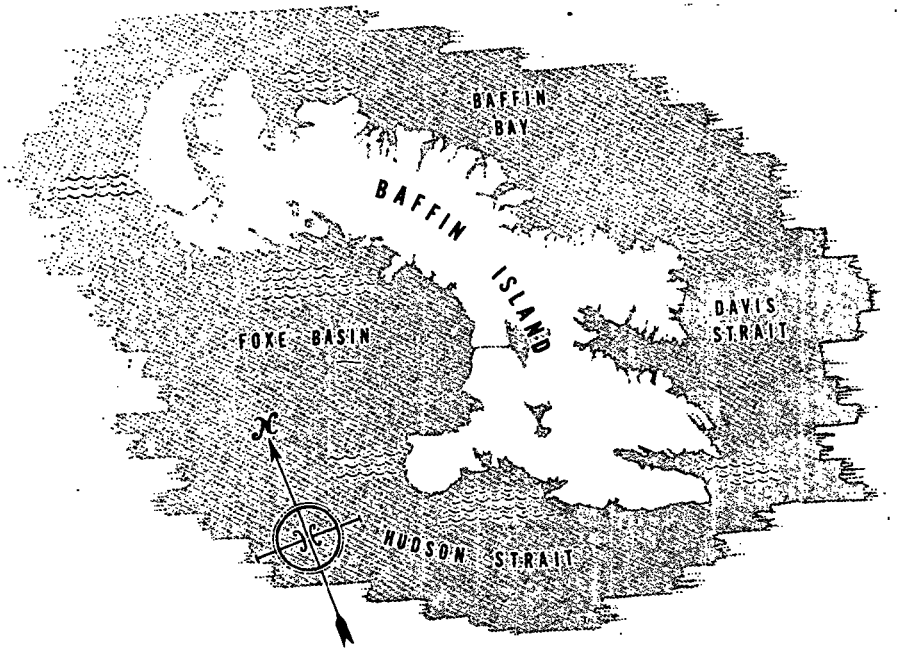


Figure 2–14.—Baffin Island, fourth largest in the world.

This plateau has been little explored and is inadequately mapped. The peninsula is fringed by many small islands. Ungava Bay indents the northeast coast. The bay is about 140 miles wide at its mouth and extends southward a similar distance. Into this bay empties the George River and the Whale River, draining the extreme eastern portion of the plateau. Between these rivers the coast is broken by three mud-filled bays. The land rises from the rocky hills of the coast to the irregular uplands. At Fort Chimo the Koksoak River enters the bay and forms banks and shoals to a distance of about 10 miles into the bay. The Koksoak is formed by the joining of the Larch and Kaniapiskau which drain the central plateau. The Leaf and Payne Rivers drain the area west of the bay. All of these rivers are characterized by extended and regular raised terraces along their courses and by numerous rapids.

Northern Labrador is mountainous with penetrating fiords, is mostly treeless, and is formed of granite and gneiss. All three coasts are hemmed in by ice the greater part of the year.

North of the Ungava Peninsula of Labrador and separated from it by Hudson Strait is Baffin Island. This is the largest of the Canadian arctic islands and has an area of 230,000 square miles making it the fourth largest island in the world. The island is long and its much indented coastline is penetrated by three sizeable bays: by Frobisher Bay and Cumberland Sound on the east coast, and by Admiralty Inlet on the northwest coast. A high, rugged mountain range of crystalline pre-Cambrian rocks rises abruptly along the eastern coast to an average height of 5,000 to 7,000 feet, with some peaks reaching heights of 10,000 feet. Permanent snowfields and icecaps in some places bury or partially cover the sharp peaks and ridges, sending long twisting glaciers down the many valleys to the sea. The east coast is deeply indented by fiords with walls rising precipitously from the water, presenting a formidable barrier. Northwestern Baffin Island, like North Somerset Island to the west, is a rolling limestone plateau surfaced by disintegrated slabs of sedimentary Paleozoic rocks. Along Admiralty Inlet and Prince Regent Inlet the plateau forms vertical walls rising 500 to 1,000 feet. Most of the interior of the southern section of the island is a rolling plateau averaging 2,000 to 3,000 feet. The southern coastal upland dips to the north and west toward the broad, lake-dotted and swampy plain west of the two large lakes, Amadjuak and Netsalik.

Devon and Ellesmere Islands are the largest of the northern group of Canadian islands lying to the north of Baffin Island. The

eastern coasts are steep and rocky rising to elevations of 3,000 to 5,000 feet in the interior tablelands. Ice caps occupy many of the elevated eastern sections and numerous glaciers fill the valleys. The western portion of the islands are made up of Paleozoic sediments. These form low plains extending several miles inland to the high cliffs of the crystalline rocks which make up the eastern ranges. The tundra-covered plains provide feeding grounds for large numbers of musk-oxen, caribou and arctic hare.

Axel Heiberg Island lies west of Ellesmere Island. Unlike the other Sverdrup Islands and the Parry Islands, it has high land in the interior with a low coastal area. The other islands have low, rolling terrain characterized by elevated beaches and terraces along the shores. Most are unglaciated.

The islands of the far northern groups which are underlain by sedimentary rock have no lakes and no established drainage patterns. The very small amount of precipitation in this area is a factor in this lack of developed systems of drainage. Victoria Island is the third largest in the archipelago. The islands are separated by only a narrow channel, and are very similar in character. Much of the shoreline and the interior of Victoria Island are unsurveyed. It can be assumed that it resembles Banks Island since it is of a like geologic structure. Banks Island is a rolling plateau with elevations up to 2,900 feet in the southern part. The coast is broken by many small bays.

TABLE III

Areas of Principal Canadian Arctic Islands

Island:	*Area square miles (approx.)*
Baffin	230,000
Ellesmere	41,000
Prince of Wales	15,000
King William	6,200
Melville	20,000
Victoria	60,000
Somerset	12,000
Banks	25,000
Devon	24,000
Bylot	4,970
Cornwallis	2,590
Bathurst	7,300
Prince Patrick	6,700
Borden	4,100
Tsachsen	1,000
Ellef	3,250
Amund Ringnes	1,800
Meighen	360
Axel Heilberg	13,200
Southampton	17,800

On the whole the climate of the Canadian eastern arctic is relatively dry and cold. The influence of the many water areas is shown in the modification of the autumn and early winter temperatures, as compared to continental areas of similar latitudes. However, temperatures average below freezing in September. The autumn days become shorter and ice is formed on small water bodies by October. Approximately half of the total snowfall occurs in autumn, which is usually the stormiest time of the year.

Winds in gale proportions may occur at any time and coupled with low temperatures they cause considerable human discomfort through increased bodily heat loss (windchill factor). The coldest month is February at most stations. The average mean temperature is between minus 20° F. and minus 30° F., with absolute minimums going to minus 50° F. to minus 60° F. The winter is long, dark, and severe. Mean temperatures below 0° F. may be expected from November to April. Only small amounts of snow fall in the winter although it is a stormy and windy period. Because the rate of evaporation is low, the snow remains on the ground all winter except where it is swept away by the wind. Snow depth is greatest in April.

Spring comes late and is evidenced more by an increase in daylight than by a marked rise in temperature. Minimum temperatures are still low and in many cases the lowest temperatures of the year are reported in March. The water areas, now frozen, tend to intensify this cold. By June the mean temperatures average above freezing. June, July, and August are cool, with July being the warmest month. Average summer maximum temperatures are in the 50's but temperatures of 84° F. have been recorded at Chesterfield and 81° F. at Lake Harbour. A secondary snowfall maximum occurs in spring and some rain may fall in summer.

The summer is short and the frost-free growing season varies from only 29 days in the northern islands to a maixmum of 67 days at Chesterfield. This short growing season and the general lack of soil minimize farming possibilities. During the summer the southern part of the eastern arctic lies under the influence of the cyclones, bringing cloudy, humid, and cool weather.

The summer is the season when fog is most prevalent, especially over the sea. It constitutes one of the greatest hazards to travel along the coastal areas. Relatively warm air from the land condenses when it contacts the cold arctic waters. Low clouds and fog may occur on as many as 15 to 25 days in any one summer

month. Hudson Strait is probably the foggiest place in the Eastern Arctic. Fog is less frequent during the winter.

VEGETATION

In the short summer when there is constant daylight plants and grasses flourish wherever soil is present. Hundreds of species of plants rush through their life cycles in the 1 or 2 months when growth is possible. Lichens and mosses grow in the less favorable areas, although many sections have no vegetation cover at all. The lichens are the chief economic plants because they are the staple food of the migrating herds of caribou. There are very few plants which are edible for humans, but the wild life depends upon the vegetation, such as it is.

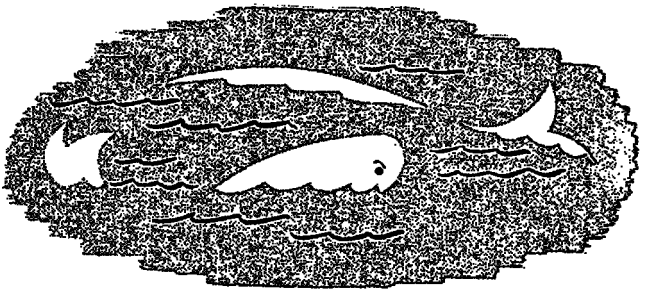


Figure 2–15.—White whales.

ANIMAL LIFE

As far as the natives are concerned, the wild life is of primary importance as a source of food, clothing, shelter, and implements. However, in the eastern arctic game is not abundant and hunting is carefully controlled for the protection of the natives. Caribou are one of the most important land animals. They range in the tundra areas west of Hudson Bay and approximately 3 million migrate between this area and the Great Slave and Great Bear Lakes. Smaller herds live on western Baffin Island in the lowlands and interior uplands. Polar caribou, a smaller species, and musk-oxen are found living on the scant vegetation of the far northern islands. The polar bear is of lesser importance, although its meat provides dog food and its fur is used for bedding and robes.

Sea mammals are a vital factor in the lives of coastal Eskimos.

Walrus are less plentiful than in earlier years, but they are the major source of dog food. The Eskimos prefer seal meat, which is their staple diet in the coastal eastern arctic. There are several species, but the ringed seal and the bearded seal are the most numerous. They feed along the coasts and in the fiords on plankton, and usually stay near the open pack ice. Whaling in the eastern arctic almost disappeared with the extinction of the larger whales. White whales and narwhal have some local importance.

Fish are not as plentiful as had at one time been supposed. Arctic char is the most common food fish and an important part of the Eskimo diet. In the spring and autumn the char are caught in the streams, but in the summer they usually go out to sea. Fish grow slowly in far northern waters and attempts to develop a fishing industry has not been successful because of the fairly rapid depletion of fish in any one area.

In the summer geese and ducks nest in the swampy areas and many birds are to be found throughout the mainland and island sections.

Fur trade is a somewhat unstable economic factor in the eastern arctic. The fur of the arctic fox is the chief export. Total fur yields, including white, blue, and red fox as well as some others, range in value from $250,000 to $700,000 annually.

RESOURCES

Detailed exploration has not been made in the Eastern Arctic to ascertain all possible mineral resources. Some deposits of nickel, copper, platinum, gold, and silver have been found along the west coast of Hudson Bay. An extensive iron ore deposit has been found recently in central Ungava, and plans are going forward for its exploitation. In the Belcher Islands iron bearing formations have been assayed as containing too much silica to make them profitable for commercial development. Some low grade coal and lignite have been a source of local fuel in northern Baffin Island but they lack commercial value. More thorough surveying and prospecting may disclose mineral wealth unknown at present to bring industry and population into this region.

HUMAN GEOGRAPHY

The present population is small, although four-fifths of the total Canadian Eskimo population live in the eastern arctic. The climate, topography, and resources have limited, and to some extent have determined, the spread and density of the population. The

white population, numbering about 150, lives in the 30 or more trading posts and missions throughout the area. There are probably 5,000 to 6,000 Eskimos scattered throughout the region north of the treeline, which forms the boundary between the Indians and the Eskimo. Owing to the relative remoteness and inaccessibility of the areas in which these Eskimos live, they have been little influenced by the white man. Usually their only contact is when the Eskimos assemble at the Hudson Bay Company trading posts and at the missions, for the arrival of the annual supply ship in summer. During the rest of the year they migrate. In the winter they divide their time between fishing through the ice, hunting seals along the coast, and tending trap-lines. Their winter homes are snow-houses. The summer is usually spent near the coast or on islands where fish, seals, and walrus provide food, clothing, and fuel. Tents of skins are used in the summer camps.

The seasons not only determine the activities of the Eskimo and white population, but they also prescribe the mode of surface transportation. Summer overland travel is almost impossible in many places because of the water-logged condition of the ground and the numerous lakes. Most transportation in this season is by water, although the navigation of ships is sometimes made difficult by the prevalent fog. In the winter, the dog-team and sled are the principal means of transportation. Coastal travel is along the "highways" of coastal or littoral ice which builds out from the shore. Overland travel by sledge usually begins about December when sufficient snow has accumulated to allow the runners to glide easily.

Spring and fall offer problems to surface transportation. The snow disappears quickly in spring and the surface of the ground begins to thaw making land travel extremely difficult. At the same time the river and sea ice begin to rot and are unsafe for sled travel. But still too thick for the small schooners and boats to penetrate. The reverse of this is true in fall before the land is snow covered and while the ice is thin and newly formed. In these seasons surface transportation is virtually stopped. Air travel would seem to offer the only all-season transportation, but even this is not without spring and fall problems. Fog, overcast, and bad weather are most common in these seasons. Although floats can be used in summer and skis in winter, the difficulties of having planes properly equipped to land during the break-up and the freeze-up are serious problems in air transportation. All northern navigations are especially acute in the eastern arctic because of the proximity of the north magnetic pole area.

It should be noted that in the areas where the Eskimos have come into closest contact with the white man they have become increasingly dependent upon the white man for food, clothing, and equipment, and have adopted many of the white man's ways. The Eskimos of the Western Canadian Arctic (between 1,500 and 1,700 in number) have become most closely identified with the white man's ways and views, while those of the central mainland area remain the most primitive. The eastern arctic native falls well in between these two positions. It is in the western arctic that the fur trade has its greatest development and plays the greatest part in the native economy. The Government's attempt to interest some of these natives in reindeer herding has not been too successful.

It is a matter of military importance to have an understanding of the culture and capabilities of the Eskimos, along with major health problems endemic to the area. The natives are susceptible to trichinosis, rabies, respiratory diseases, tuberculosis, and venereal diseases.

GEOGRAPHY OF ARCTIC ALASKA AND WESTERN CANADA

In western Canada, the treeline swings north, approaching the coast at the delta of the Mackenzie River, and continuing across Alaska along the southern foothills of the Brooks Range. Using this as a delimitation of the Arctic, it is seen that only a relatively small area in western North America can be considered true arctic, as compared with the eastern portions. Most of the Yukon and Alaska are subarctic.

ALASKAN ARCTIC

The arctic slope of Alaska widens west of the Yukon upland region. the coastal plain is flat to gently rolling, bordered on the seaward edge by beaches and lagoons separated from the ocean by bars and spits. Numerous small islands fringe the shore. The plain is drained by many small rivers and the larger Meade, Colville, and Noatak Rivers. West of the valley of the Colville, the coastal plain is dotted by many lakes. The main settlement of this area is at Point Barrow, with smaller Eskimo villages and trading posts at Wainwright, Point Hope, and Kotzebue.

Between the arctic slope and the drainage basin of the Yukon River lies the Brooks Range. This is a relatively low mountain system in comparison with other Alaskan ranges. It rises to elevations of 9,000 to 10,000 feet in only a few peaks. The range

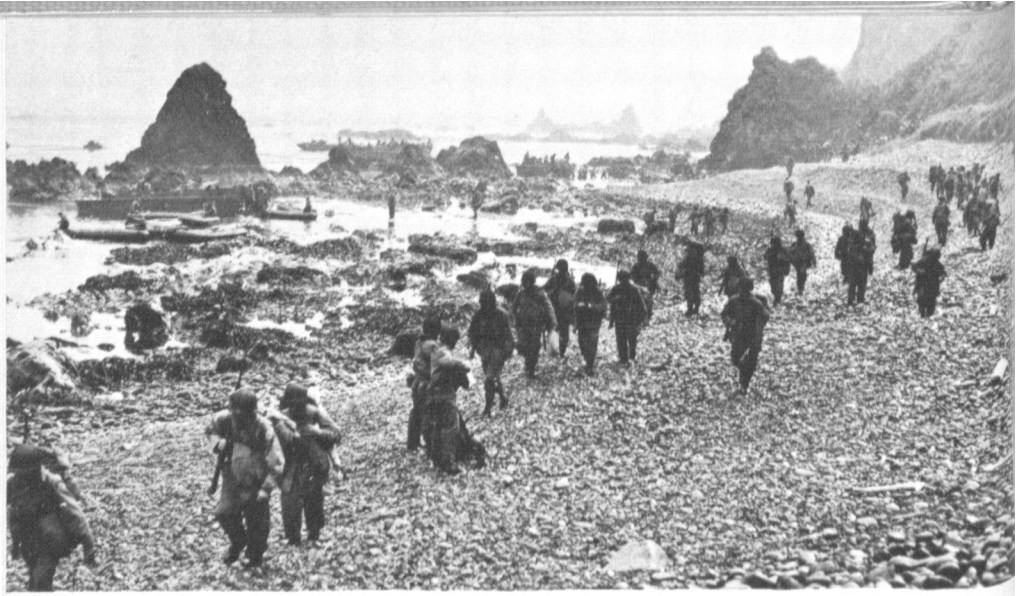


Figure 2–16.—The beach at Kiska.

is not a continuous chain but is made up of individual mountain groups including the De Long, Baird, Schwatka, Melville and Endicott mountains to the south, and the Franklin, Romanzof and Davidson mountains to the north. Between these groups there are low gaps forming passes both east-west and north-south. The mountains are treeless except for small willows growing in the canyons and ravines. Mosses, lichens and small plants cover most of the area.

WESTERN CANADIAN ARCTIC

The coastal plain is narrow or absent over most of the western Canadian arctic with the exception of the Mackenzie River valley. The delta fills an area about 125 miles long and 50 miles wide. On the east the low Caribou Hills mark the edge of the delta and on the west the plateau of the northern Yukon mountains abruptly rises from the river flats. The delta has innumerable lakes and distributaries. The main channel of the Mackenzie River keeps to the eastern side of the delta. Silt carried by the river is deposited at the mouth, thereby changing the shoreline and island detail. The banks along the channels are low and the delta is for the most part a marshy area, difficult to traverse. Separated from the delta by a narrow channel is Richards Island whose undulating, lake-dotted surface rises to 50 feet or more, considerably higher than the level of the delta. The entire area has been glaciated.

Blank page retained for pagination

GEOGRAPHY OF NORTH AMERICAN SUBARCTIC

When the Subarctic of North America is delimited in terms of climate, as already outlined, the region extends much farther south than would normally be realized. All but the southern edge of Newfoundland is within this region, as is most of the land in Quebec, Ontario, and Manitoba. The northern half of Saskatchewan and Alberta also are subarctic as is the northeastern portion of British Columbia. The Mackenzie valley, the Yukon, central and southern Alaska, and the Aleutian Islands, form the remainder of this wide belt of coniferous forests, comparable to the taiga of Siberia. Thus about 60 percent of Canada and most of Alaska have a subarctic environment.

COASTAL AREAS

The eastern edges of the North American Subarctic are the deeply indented, rugged and mountainous coasts of Labrador and northeastern Newfoundland. High, barren ranges rise abruptly from the ocean and the fiords are deep and lined by steep, rocky cliffs.

The Labrador current which flows south along those coasts brings with it floe ice and bergs during the summer. In the winter, the coasts are blocked by heavy pack ice. The combination of ice half the year and cold water the rest of the year produces a marked influence on the environment of the shore.

Fog often covers the coastal areas, particularly in Newfoundland where the mingling of water from the Gulf Stream and the Arctic make ideal conditions for fog. Inland the weather is frequently clear even when dense fog lies along the shores.

The most striking feature of the coastal area on the west side of this subarctic region is the Aleutian Island chain. Active volcanoes and cones characterize these islands that stretch from the Alaskan Peninsula to within a few degrees of longitude of the Kamchatka Peninsula. It is one of the most active volcanic areas of the world. There are hundreds of islands of varying size in this group. Their shorelines are extremely irregular, with many deep coves and inlets.

The Aleutians, especially during the summer months, are frequently shrouded in fog due in part to the contact of the arctic waters of the Bering Sea to the north, and the warmer waters of the Japanese current to the south.

TOPOGRAPHY AND DRAINAGE

Most of this subarctic region was scraped and eroded by the vast continental glaciers of the Pleistocene. The relief is thus subdued, and vast stretches of plains characterize the central portions of the region, while the remainder, except for the valleys of the Mackenzie and Yukon Rivers, is mostly rolling plateaus and dissected uplands, with rugged mountains in southern Alaska. The soil mantel is very thin and the entire area is underlain by permafrost.

The valley of the Yukon River has many areas of flatlands, some of which are thousands of square miles in extent. The river, with its many tributaries, takes a circuitous route through the rolling mountains of the Yukon plateau and the low hills in the depression between the Brooks Range and the Alaskan Range, to empty into Norton Sound, where it is building a swampy delta. The Bering Sea coasts of Alaska are generally adjoined by lowlands. Back of the shallow Bristol Bay lie a large number of lakes at low elevation. Norton Sound is likewise surrounded by low land. Kotzebee Sound is surrounded by lagoons, barrier beaches, and flat moors. Harbor conditions throughout are unfavorable because of shallow water and of insufficient protection.

Separated from the Yukon River by the northern Rocky Mountains and the Yukon plateau, the Mackenzie River drains the eastern slope of these uplands, and flows along their foothills, receiving water from the Peace and Liard Rivers and the two vast lakes of the north, Great Slave Lake and Great Bear Lake. Because the Mackenzie has such a great latitudinal extent, there is a difference of about 3 weeks in the length of the navigation period between the northern and southern sections. Delay in the navigable season is also due to the fact that although the river ice usually breaks up in middle or late May, the ice along the shores of Great Slave Lake does not break away until early June and the lake is not ice-free until mid-June. Ice begins to form again in October in the delta. Freeze-up on the upper Mackenzie comes in mid-November and on its southern tributaries by late November.

Other than these two major systems, the rest of this subarctic region is drained by ill-defined streams which wander aimlessly over the glaciated surface, where irregularities cause numberless lakes to form. In the summer, these areas are alive with hungry mosquitoes, and the soft, water-soaked ground makes transportation overland extremely difficult or impossible.

It should be noted that the absolute extremes of cold are experienced in the subarctic rather than the arctic. There is no nearby ocean area to help modify the climate. The Alaskan ranges cut the Yukon and Mackenzie valleys off from the maritime western winds. The active layer of the permafrost quickly freezes during the long nights of semi-darkness of winter, and the rivers and lakes become frozen and snow-covered. In the winter, cold air from northern Greenland and the Arctic Sea sweeps across the prairie in the Baker Lake area and, under anticyclonic control, flows into the Yukon where the clear skies and stagnant air conditions promote tremendous refrigeration. Temperatures have been recorded as low as minus 76° F. at Tanana, minus 69° F. at Whitehorse, minus 84° F. at Fat Snag, and minus 78.5° F. at Good Hope. This same area experiences high summer temperatures. The range of the temperatures is extreme, with average annual ranges about 134° F.

With all this extreme low temperature, there is relatively little snowfall. Three to ten inches a month is the general average. Over much of the area the wind keeps the snow moving about, although the forests act to break the force of the wind. The heaviest drifts of snow are just south of the treeline where snow from the open tundra accumulates. The wind which carries the snow across the open areas is slowed in velocity as it strikes the forests. With less velocity its carrying power is reduced, and snow is deposited in high drifts just inside the forest area.

VEGETATION AND ANIMAL LIFE

Over most of this region there is a heavy growth of coniferous forests. These dense forests are interspersed with peat bogs and muskegs. Like the extensive taiga of the Soviet Union, these forests have been ravaged by fires and exploited by lumbermen. In the more exposed areas and in the northern fringes of the forest, the trees are smaller and more bushy. In contrast to these forested areas, the Aleutian Islands are essentially treeless. Grass, shrubs and tundra vegetation cover most of the islands, although many barren rocky areas exist without noticeable plant life.

The largest animal in the North American subarctic is the Kodiak bear weighing from 1,200 to 1,500 pounds. However, his habitat is essentially restricted to the one island, and elsewhere the brown bear, wolves, foxes, mink, marten, beaver, and otter are common. The deer, moose, and caribou are also found in the forests.

The rivers and lakes abound with fish. The salmon fishing is of major economic importance. In the waters off the Pacific coasts there are numerous fish of commercial value such as halibut, mackerel, flounder, and Alaskan herring. Whales are somewhat less numerous since the onslaughts made upon their numbers by the early whalers. Alaska fur seals, now protected by international agreement, are fairly abundant in the Bering Sea, particularly off the Pribilof Islands. This controlled seal industry produces about 60,000 sealskins a year. In addition to the larger fish and sea animals, the ocean waters have large quantities of shrimp, crabs, clams, and small, even microscopic marine fauna.

RESOURCES

The mineral resources of this area are vast in contrast to the rather limited mineral resources of the Arctic. The gold of the Yukon is still a source of considerable yearly income. Its recovery has created much in the way of industry. It must be noted, however, that very often gold mining, especially placer mining, does not establish permanent communities because the prevailing attitude over most of the Yukon and Alaska has been to recover the gold quickly and to leave.

Another important gold mining center is at Yellowknife on the north shore of Great Slave Lake. Mining has been conducted in this location since 1934. By 1942 the yearly gold production amounted to almost 4 million dollars. During the war, however, production was almost stopped.

About 40 percent of the world's radium is produced at the Eldorado Mine on the eastern shore of Great Bear Lake. The silver-pitchblende deposits were found in 1930, but only in recent years has there been any real development. There is now a modern mining and milling plant located at this deposit. Another uranium deposit is being mined at Goldfields on Lake Athabaska.

The whole contact zone between the ancient rocks of the shield area and the recent sediments of the geosyncline appears to be rich in minerals. There are also oil fields near this contact zone.

Oil seepages in the vicinity of Fort Norman were first reported as early as 1789 by Sir Alexander Mackenzie. The first drilling was made in 1920, but not until much later was any serious effort made to develop the field. Just prior to, and during World War II, a small refinery was built at Norman Wells to serve the area. To aid in the defense of Alaska, a road and a 4-inch pipeline were

laid from Norman Wells to Whitehorse on the Yukon River, some 600 miles to the west.

Aside from the minerals and petroleum resources, the forests provide a source of natural wealth, as does the potential water-power.

HUMAN GEOGRAPHY

The coniferous forests are the home of the Indians. In scattered village communities, they subsist on their fishing, hunting, and trapping. Trading posts are their commercial centers.

Men from the more temperate zones have superimposed their culture on the native way of life in those areas where natural riches have attracted this kind of settlement. Lumbering, mining, and industry have brought many thousands of people into the subarctic.

For a more permanent colonization of these lands, the Governments of Canada and the United States have encouraged agricultural developments. The Peace River area of Canada and the Matanuska Valley of Alaska are examples of such government subsidized agricultural experiments. Farming is laborious, however, and full of risks because of the ever-present threat of frost. Wheat, barley, oats, potatoes, and hay are grown, and in a more limited extent, garden vegetables are cultivated to supply the northern settlements. Some dairying and live stock raising is carried on, utilizing the abundant grassy meadows as summer pastures, but frequently having to rely upon imported feed in the winter.

The problem of remoteness is one factor contributing to the delay in the development of this area. The means for getting into and out of these areas are very limited. Partly in an effort to make better use of the northern lands, and the shorter route to Europe by way of Hudson Bay, a railroad was built from The Pas in Manitoba to Port Churchill. This was to be a major wheat shipping route, and tremendous elevators were built at Port Churchill to store the grain during the time when Hudson Bay and Strait were closed. It has not lived up to expectations, partly due to the fact that ships plying this route must carry extra insurance because of the ice hazard, partly because in-bound trips must be made with ballast, and partly because of the very short season in which shipping is possible. However, despite these difficulties a considerable tonnage of grain is shipped over this route.

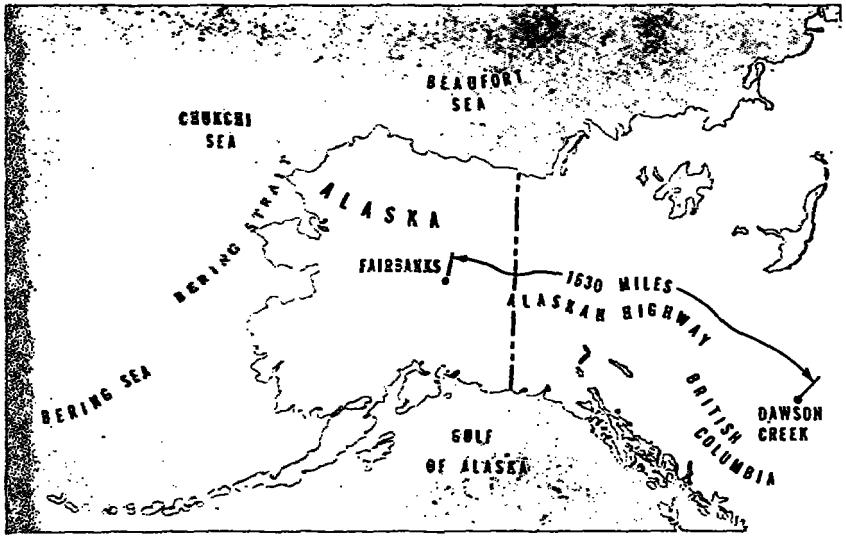


Figure 2-17.—The Alaskan Highway.

As a war measure, the Alaskan Highway was constructed by the United States to provide a safe military route into central Alaska. In 1942 the highway was built from the end of the railroad at Dawson Creek, British Columbia to Fairbanks, Alaska. The 1,630 miles of highway was rushed to completion in 8 months. Engineering problems of construction on permafrost and in areas of swamps and muskeg were given hasty consideration. The road has been put to heavy use and requires constant maintenance. Soil flow, slumping, icing, and buckling are only a few of the road troubles which clearly indicate that more study is needed in order to assure permanent and safe construction in such northern areas.

Similar problems exist along the Richardson Highway, leading from the coast into central Alaska, and along the Alaska Railroad from Anchorage to Fairbanks.

Air travel is the common means of transportation throughout most of the region. Even heavy mining and lumbering equipment is brought in by air, but the costs of such freighting make it prohibitive for all but the very large corporations. Passenger travel is probably most frequent by air since overland travel is extremely difficult in summer, due to the swampy soil conditions over much of the region.

Only by bringing life to the Arctic will the Arctic "come to life."

GEOGRAPHY OF GREENLAND, ICELAND, AND SPITSBERGEN

GREENLAND

The Danish island of Greenland is the largest island in the world, 1,650 miles long and 690 miles wide at its greatest breadth. Its interior is covered by a vast ice cap. The land surface beneath the ice is believed to be low in the center with mountain ranges along the eastern and western coasts. The eastern ranges reach heights of 11,000 feet. Ice fills the saucerlike, central basin. There are two domes on the east side of the cap, one at about 65° N. which rises to over 8,000 feet and one near 75° N. rising some 10,000 feet. From these domes the ice surface slopes gradually downward, being almost flat across the interior of the island, and becoming steep near the margins.

The ice at the edge is relatively thin with bare, rocky peaks or nunataks protruding. Glaciers flow down from the cap through the many fiords that dissect the coast. The inland ice is fed from

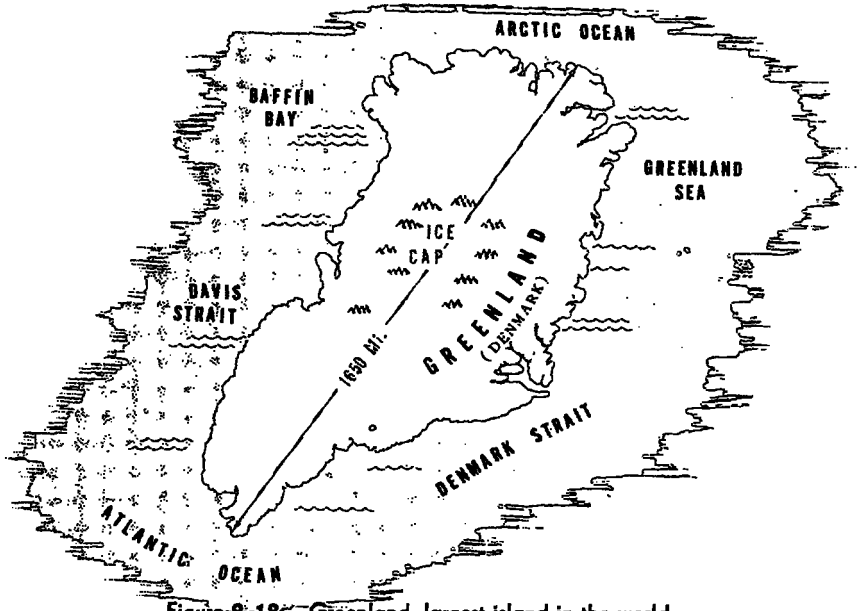


Figure 2-18.—Greenland, largest island in the world.

the east, and suffers loss mainly in the west. The glaciers are deeply crevassed in their lower courses and are difficult to ascend.

Surrounding the ice cap is an almost continuous ice-free coastal zone varying in width from 1 to over 100 miles. The most extensive ice-free land is on the western coast from latitude 65° N. to 69° N. and in the extreme north in Peary Land. The coastal area is very rugged, with numerous islands and bare skerries offshore. Deep fiords extend inland for miles, offering easy penetration into the island, but the fiords and the mountainous promontories make land travel along the coast almost impossible. The southern coast is especially rugged, and the east coast is fairly unapproachable because of the heavy off-lying polar pack ice.

In the north, the island has the form of a rectangle and in the south, a wedge. Thus, it is similar to the great continents with their broad shoulders in the north and narrow ends in the south.

The southern third of Greenland is a plateau inclined toward the interior zone. On the west side it may be considered to extend to a point south of Disko Bay and on the east side to very nearly the same latitude (68° N.). The land-forms are generally alpine in character. The mountains at the southern end rise in jagged ridges to over 6,500 feet. They are dissected by fiords and sounds, and furrowed by innumerable glaciers that arise from separate ice caps. On the east coast up to Angmagssolik, the principal settlement, the coastal belt practically maintains the same altitude and degree of dissection. However, the inland ice leaves only a narrow strip scarcely 3 miles wide free of ice in the extreme southeast. On the west coast from as far south as Julianeboob, there are rounded topographic forms with lesser height, mostly under 4,000 feet. Here, along a 500 mile stretch of coast, these sorrel forms prevail with few exceptions. At the same time, the ice-free land grows in width to as much as 100 miles as one proceeds northward.

At latitude 69° N. on the west coast the picture changes. In place of the narrow, transverse fiords, there appear broad, round bays, peninsulas, and islands. The topographic form here is, on the whole, that of an elevated peneplain rising to 7,000 feet or more. Disko Island is the largest in the area with an average altitude of 3,500 feet. There is no inland ice on any of these three prominent landmarks. The snow line in the marginal belt lies below 3,500 feet, but on the inland ice it rises to 5,000 feet. Boulder trains, boulder beds, and extensive ridges testify to the greater extension of the ice in former times in the lake-studded region.

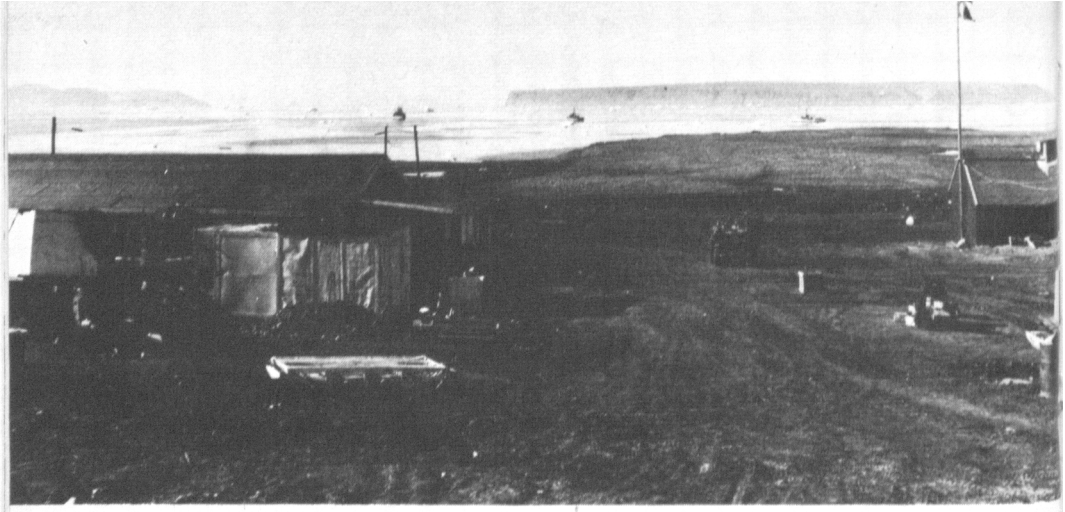


Figure 2–19.—Weather station, Thule, Greenland.

The Upernivik region from Svartenhuk to Cape York is a labyrinth of skerries. The whole strip of land, here narrowed down is broken up into a host of islands mostly of moderate height and rounded shape. Some of the sounds have depths up to 500 fathoms, whereas others are barely covered with water. A prominent feature is Melville Bay, with the inland ice reaching to the very edge of its shores at nearly every point.

A feature of the Cape York district is Smith Sound separating the large Hayes Peninsula back of Cape York from Ellesmere Island. The peninsula is a plateau 2,200 feet high divided in its central part by the deep Inglefield Gulf.

North Greenland in the west is separated from the Hayes Peninsula by the Humboldt Glacier, largest in the Arctic. The northernmost part of the island, from west to east, is divided into prominent areas not covered by inland ice, named in order: Washington Land, Nyeboe Land, Peary Land, and Prince Charles Foreland. In this area several long fiords penetrate inland, the most prominent being Sherard, Osbord Victoria, Independence, and Danmark. In general the north coast is alpine in character with peaks more than 3,500 feet in the west, rising to 6,500 in some places in Peary Land in the east. One of the interesting geographical facts is the relatively ice-free nature of this northernmost land area. Rivers and lakes develop when the snow melts in summer.

The northeast section of Greenland extends from Danmark Fiord to the seventy-fourth parallel in King Christian X Land. Here and further south to Scoresby Sound, the fiord systems introduce a new type of coastal development. In the general aspect of

the coast, long stretches of out-pouring inland ice alternate with broad, ice-free areas and large menatoks in the background.

Steep walled valleys and fiords penetrate inland. The ice cap here approaches the coast more closely than in north Greenland. At latitude 81°30′ N. the snow line or lowest limit of perpetual snow lies at sea level. Winter weather prevails the year around. This is the most forbidding area of the northern hemisphere.

Central east Greenland extends from 74° N. to 68° N. The middle section is characterized by gigantic fiords, reputedly the most beautiful in the world. The Scoresby Sound fiords system penetrates more deeply than any of the others in the whole of Greenland. It is comparable to a massive river delta.

GLACIAL MOVEMENTS

Several of the immense Greenland glaciers on the West Coast (notably Jacobstraun, Tarssuktok, and the great Karajak) produce over half of the bergs that float into the North Atlantic shipping lanes. When the glaciers flowing out from the ice cap reach the sea, large pieces of the ice calve and float away. In northern Greenland where the fiords and adjacent sea are frozen over during the winter, the icebergs can float away only during the short season when the sea-ice has melted. Off Peary Land and northwest Greenland the conglomerated polar pack ice persists throughout the summer. Consequently the icebergs are forced together against the end of the glacier and produce large masses of floating land-ice. This is similar to the shelf-ice of Antarctica, yet not quite so symmetrical in shape.

As stated above, the terrain of the coastal area varies from the hummocky topography which is most extensive to the towering, serrated mountains. The entire area is underlain by permafrost. Wherever soil exists, solifluction is common. The rock areas are undergoing rapid mechanical weathering due to the freezing and thawing of seepage water. There are no important rivers, and the short streams that do exist have steep, rocky courses.

The position of Greenland brings it under the influence of cyclones and fronts, particularly in its southwestern section. The island acts as a barrier because of its height. Only very deep disturbances cross it. However, these highs and lows determine the winds on the coasts. Usually there is a down slope sliding of the air at the surface. Cold air pours off the ice plateau and funnels through the fiords. These winds may occur in the nature of violent squalls, particularly in winter. The winds are most intense

and persistent when pressure changes provide gradients which accentuate and strengthen the catabatic winds.

There is heavy snowfall on the ice cap even in summer. Relative humidity is constantly high. Over the entire island there is an average precipitation of about 16 inches a year. A notable exception to this average is the extreme southern section near Ivigtut which receives over 45 inches of precipitation a year. The far northern areas, on the other hand, are quite arid. On the interior plateau and in the north several feet of snow is almost constantly blowing around on the surface. Under the influence of strong winds the snow may be lifted to over 100 feet above the ice.

Temperatures on the icecap in winter average minus 40° F. Local temperatures may go up to 0° F. or down to minus 70° F. By the time this air reaches the coastal area it usually is about minus 40° F. In the ice-free coastal areas temperatures differ noticeably between the sea border and the interior of the fiords. In spring and summer the inner sections are warm, even oppressively hot. In winter this area is colder than the outer coasts. Local temperatures differ markedly in the winter between north and south. Southern Greenland is under the influence of cyclones over the ice-free seas, while the northern areas receive the full climatic effect of the ice- and snow-covered land and sea.

The warmer, ice-free southern end of the island with its abundant rainfall supports a luxuriant vegetation. Willows, junipers, birch, and aspen grow in open stands in the valleys. Most of these are low and stunted but willows have been found reaching to 30 feet. Associated with these thickets is a thick growth of shrubs and herbs. In the open places, grass grows in the meadows. In general, the vegetation consists of small plants, mosses, and lichens. Vegetation is sparse along the cold, foggy, and wind-exposed headlands of the fiords. The vegetation toward the north, along the margins of the island is predominantly shrubs and mosses with an increasing number of meadows. Large areas are covered with heath and swamps. The uneven surface has many lakes, which swarm with mosquitoes during the summer. Even the far northern areas support hundreds of flowering plants. Off the western coast there is verdant growth of seaweed and algae.

Although most of the animal life is confined to the coastal margins, foxes and birds have been found on the inland ice. The numbers and varieties of animals increase toward the north. This is due to the abundance of pasture areas and the relative safety from man. Reindeer, musk-oxen, wolves, foxes, lemmings, and ermine

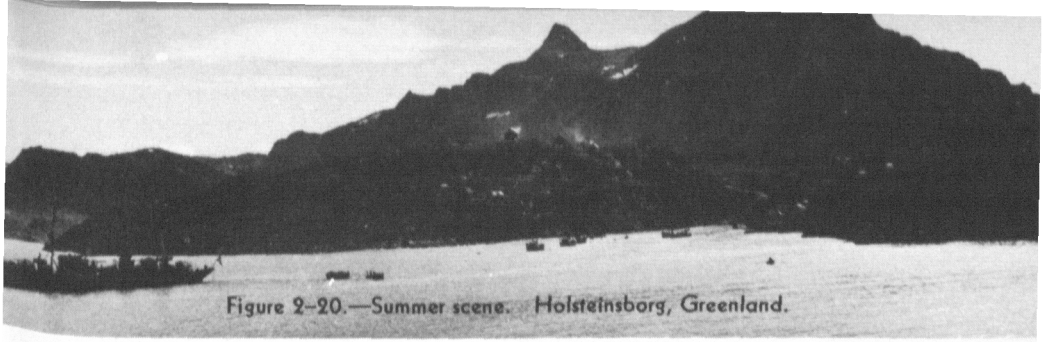


Figure 2–20.—Summer scene. Holsteinsborg, Greenland.

are among the animals found. There are many birds along the coasts. The sea animals are also varied and numerous. In the north are found the Greenland whale, narwhal, whitefish, walrus, bearded seal, and polar bear. The hooded seal, Greenland seal, humpbacked whale, bottle-nosed whale, finback whale, and swordfish are found in the south. Smaller fish are abundant along the southern coasts.

Greenland is rich in scientifically interesting mineral deposits, but these are not of particular economic interest. However, no complete surveys have been made to ascertain the full mineral wealth. Denmark has been doing some surveying. In southwestern Greenland at Ivigtut a large deposit of cryolite has been mined for many years. This is an important source of a necessary flux in the production of aluminum. Some iron has been found along the west coast occurring in basalt. Recently lead deposits have been discovered. The trade items, in addition to cryolite, are fish, fur and graphite. The trade is mainly with Copenhagen.

There are approximately 17,000 people living on Greenland, of which some 16,500 are natives and 400 are Danes. The Greenlanders spend most of their time in hunting and fishing. There is some sheep farming in the southern districts. Most of the population is in the southern and southwestern areas.

The Danish government maintains a strict control over the area through its Government Board in Copenhagen, and has a trade monopoly to keep the natives from being exploited.

Figures 27 to 37 show summer scenes in the Canadian archipelago and around Greenland.

ICELAND

Iceland lies on the southern edge of the arctic region and in many ways it resembles the more temperate regions. The name gives an improper impression. In reality, the main feature of the island is the prevalence of volcanoes and hot springs.

COASTAL AREAS

The coasts of Iceland are of two distinct types. That of the northern two-thirds of the island is rocky, deeply penetrated by fiords, and marked by high seaward-facing cliffs. Shallow deltas have been formed at the heads of the fiords and along their sides where tributary streams reach the sea. Characteristically these deltas have been altered by marine action, and bars with shallow lagoons have been formed.

The southern coast is smooth in outline and has many stretches of sand and shingle shore. Lagoons and offshore bars are common. The character of this coast is probably due to the debris-laden melt waters from nearby glaciers. There are few harbors along this coast.

Occasionally the ice-drift from the north approaches the northern Icelandic coasts. When it does it not only constitutes a hazard to navigation and the fsheries, but it has a marked effect on the weather conditions throughout the island. The irregularity with which the ice appears makes it difficult to predict its occurrence. There have been long periods that were relatively free of ice. In those years when the ice appears, it is usually in sufficient quantity by April or May to hinder navigation. The ice is first seen off the northwest peninsula in December. It is carried along the north coast by the prevailing eastward current. Ice is rare on the southeast, south, and west coasts.

The coasts of Iceland offer many good natural anchorages especially in the fiords of the west, north and east coasts. The southern coast has few indentations and no anchorages of importance. The chief port is Reykjavik which handles most of Iceland's foreign trade. It acts as the collecting and distributing center. Nearby is the port of Hafnarfjoraur. There are six other ports which can be considered of major importance: Siglufjoraur, Vestmannaeyjar, Akureyri, Neskaupstaour, Seyoisfjorour, and Isafjorour. Most of the other harbors are fishing ports and stations.

TOPOGRAPHY

The lack of harbors along the southern coast seems to be related to the heavy sedimentation from the glacial waters. About one-eighth of Iceland is covered by glaciers, of which Vatnajokull in the southeastern section of the island is the largest.

The land surface shows a marked contrast between the features developed on the older rocks of the northwestern and eastern sections and those on the younger rocks of the central part of the

island. The land forms of the older rocks are due mainly to erosion whereas the land forms of the sands, ashes and overlying lavas of the central zone are the result of earthquakes and rock accumulation. About one-quarter of the whole area of Iceland is sand and stone desert, and one-eighth is covered with lava. The central part of Iceland is built of younger accumulations of volcanic products. This process is still going on and there are several volcanoes which have been active in historic times. Volcanoes exist even under the glaciers, and in the sea off southwest Iceland.

Iceland is mainly a tableland with an average elevation of 2,500 to 3,000 feet. There are narrow borders of coastal lands and very small plains in the south and west. Very little of the island can be said to be lowlands. The highlands are considerably dissected by many valleys which cut into the tablelands from all sides. Flat-topped, steep-sided land forms characterize most of the area. Mountains rise above the general level as prominent features of the central zone. The slopes of the peaks and tablelands are covered by frost-riven, rocks, loose and angular. A common phenomenon seen in the higher areas is the arrangements of stones in ring enclosing mud. Also, stones in the pebbly flat areas may be sorted into rings with larger stones encircling smaller ones. Much of the grassland and the central desert area is covered by the hummocky surface. These features are a result of frost action and the permafrost which exists in some of the higher areas.

Over the whole of the island the soil is fairly uniform, being derived from the basic igneous rocks. On the highlands and on the desert regions near the glaciers, the soil has little organic matter. Nearer sea level the humus layer is thicker. In general, the soil is of poor quality.

DRAINAGE

The many constantly melting glaciers and the high rainfall of Iceland produce great run-off and rivers are numerous. In the rather extensive central desert, water is lacking because the water sinks into the porous and fractured lavas and volcanic deposits. Subsurface drainage from this area appears at the surface as springs along the desert borders. Both the sediment-laden glacial rivers and the clear nonglacial rivers are for the most part unnavigable because of their steep gradient, torrential currents and their shallow depths in the lowlands. In the dry summer, the clear rivers become small but the glacial rivers carry two to three

times their normal volume of water. Lakes and waterfalls are common. The potentialities of the waterfalls for power are being increasingly utilized.

CLIMATE

Iceland is characteristically cool in summer and mild in winter. The North Atlantic Drift is mainly responsible for the winter mildness of the southern and western coasts. The coldest month in the coastal areas is February, with average temperatures ranging between 25° F. and 30° F. The warmest month is July with averages of from 48° F. to 51° F. Absolute extreme low temperature has been recorded at minus 21° F., and an extreme high at 87° F. Winter is mild for the latitude. However, the interior upland has average temperatures of below freezing for the 7 months from October to April.

The relative humidity is high throughout the year, while the absolute humidity is low, especially in winter.

Fog and poor visibility along the coasts are a considerable hindrance to navigation. Sea fog is most prevalent in summer but seldom penetrates inland or up the fiords. In the fiords, radiation fog and sea smoke are most common.

In general the climate of Iceland is damp. Evaporation is slow and the wet, cold, windy winter weather is unpleasant. The total precipitation varies from over 85 inches on the southern coast to less than 12 inches in parts of the northern coast. The coastal lowlands receive frequent snow fall during the winter, especially in the northeast peninsular area. Strong winds along the coast sweep most of the snow away, leaving large patches of bare ground.

VEGETATION

Most of Iceland is without a continuous mantle of vegetation. Even in the low coastal districts there are large areas of barren rocks, stony and sand deserts, and lava flows. Over half the island has no vegetation, while the other half is covered chiefly with grasses. There are no true forests, but birch bushes and dwarf willows are found in some places.

In the interior lava and sand desert area there are only scattered plants except in the locations of springs. In these cases are found dwarf willows, grasses, and sedges.

RESOURCES

Iceland is not especially rich in commercially important minerals. Only sulphur and Iceland spar are exported. The sulphur is recovered from deposits on or near the surface as Krisuvik and in the Myvatn district. The Iceland spar, which is a transparent variety of calcite used in optical instruments to provide polarized light, is found at Helgustaoir. The greater part of the world supply comes from this deposit.

Small deposits of lignite, peat and bog iron ore are found, but these are exploited only for local consumption.

HUMAN GEOGRAPHY

Almost all of the 120,000 people in Iceland live along the coasts, while three-fifths of the island is uninhabited. About a third of the total population live in or near the capital, Reykjavik.

The chief occupation of the people is in the fishing industry. Fishing grounds extend around the entire island. The productivity of the various grounds varies with the seasons, and causes a certain amount of migration on the part of the fishermen. The fishing grounds of the southwest and west are profitable in the early months, those in the southeast and south in May and June, and those in the north are fished in late summer and autumn. The chief catch is cod, although considerable quantities of coal fish, haddock and herring are obtained.

Agriculture is of less importance in the national economy. Only limited land of suitable quality is available. The rigorous climate and the infertile soil combine to make farming a very restricted activity, confined mainly to the valley bottoms along the coastal areas. Hay production predominates, with some cultivation of sturdy root crops such as potatoes and turnips.

The main land use is in pastures. Sheep raising is widespread, and cattle and horses are raised in large numbers. Of rather unique economic importance is the eider duck farming which has developed into quite an industry in Iceland.

Because the inhabited areas of Iceland form a ring around the coasts of the island and the central portion is devoid of people, the transportation system has developed mainly along the coastal plains and coastwise along the shores. Air transportation and sea routes to Europe and England have been highly developed to overcome the general isolation of Iceland.

SPITSBERGEN (Svalbard)

The islands of the Svalbard Archipelago lie on the continental shelf (fig. 39). West Spitsbergen is the main island, 235 miles long and 130 miles wide. It is wedge-shaped with the point toward the south. The coasts are deeply indented by fiords with Bell Sound, Ice Fiord, Wijde Fiord, and Kings Bay being the largest. The other islands surround it. The long, narrow Prince Charles Foreland lies to the west; Barents and Edge Islands lie to the southeast. Northeast Land is separated from the main island by the deep, narrow Hinlopen Strait. A little farther to the east lie Hope Island and the small islands of King Karls Land.

Spitsbergen lies about 450 miles to the north of Norway on the great circle air route between the vital centers of Soviet Russia and the United States. Table IV includes distances from Longyear City on Advent Bay to various places.

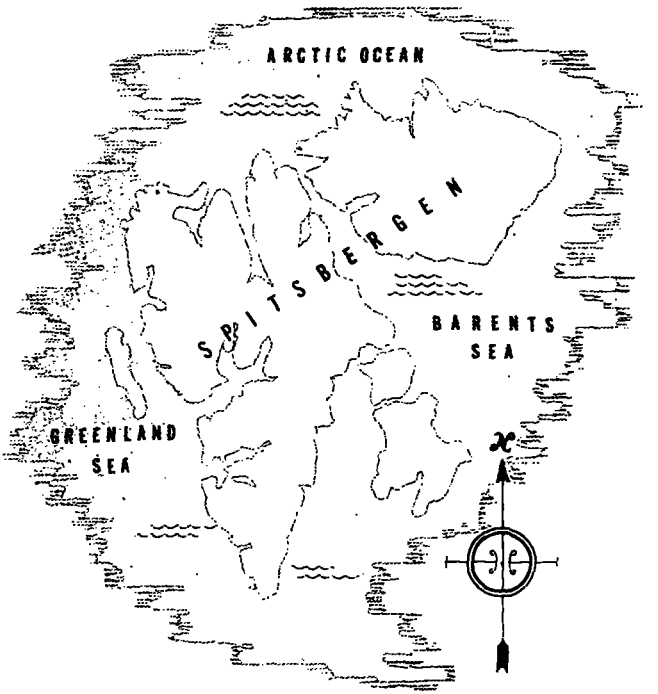


Figure 2-21.—Spitsbergen.

TABLE IV

Distance from Longyear City

To:	Distance (nautical miles)
Kola Gulf, White Sea	760
Archangel, U. S. S. R.	930
Dickson Island, Mouth of the Yenisei	930
Eyja Fiord, Iceland	930
Reykjavik, Iceland	1,100
Oslo, Norway	1,100
Helsinki, Finland	1,100
Bear Island	230
Jan Mayen Island	570
Murmansk, U. S. S. R.	625
Leningrad, U. S. S. R.	1,125
Stockholm, Sweden	1,136
Cape Farewell, Greenland	1,567
London, England	1,640
Montreal, Canada	2,745
Boston, Massachusetts	2,880
Seattle, Washington	3,095

TOPOGRAPHY

The coastal areas are a series of narrow crested mountains separated by fiords in which glaciers reach down to the sea. A notable feature of the coasts is the level plain and foreland area which lies between 70 and 100 feet above the sea. The mountains are not high, the highest being Hornsundtind of less than 5,000 feet. The interior plateaus rarely exceed 2,000 feet. The contrast between the western coastal mountains and the interior plateau is due to the geology. The west is a zone of folded rock whereas the interior is mainly horizontal strata. The slopes of the mountains and the massive tablelike land forms are covered with broken rock. The plateau is covered with ice and snow under which is a mantle of rock debris.

Within recent geologic time volcanic action has taken place. Thick diabase dikes and intrusions, and lava fields are found. In the northwest, along a prominent fault line, volcanic cones and hot springs occur.

ICE CONDITIONS

Alpine glaciers are numerous in the valleys of the western mountains. The tongues coalesce in many places to form fairly extensive ice fields. The glaciers are small and too low to create many icebergs. The interior is partially ice-covered, the ice being thicker and more continuous in the northeast sections.

Spitsbergen is underlain by permanently frozen ground and the surface is characterized by frost-broken rocks, polygonal soil, and

solifluction. The land has been little modified by water erosion. The streams are small, and they flow in the wide glaciated valleys.

The sea-ice conditions, as well as the distribution of land ice, point to the fact that Spitsbergen is a place where arctic and more temperate climate meet. The northeast groups of islands are subject to the extreme polar influences. Polar ice floes come in from the east. Stor Fiord and Hinlopen Strait are often ice-blocked and inaccessible even in summer. On the other hand, the west coast receives the benefits of the remnants of the North Atlantic Drift. This current keeps Whaler Bay open, and the harbors of the west coast are accessible for 4 months or more.

CLIMATE

The mean annual temperature of Spitsbergen is between 14° F. and 18° F. During the short summer the mean temperature is above freezing. The temperature of the warmest month is about 40° F. However, temperatures between 50° F. and 60° F. are not uncommon, particularly when warm foehn winds are blowing. At such a time the ground may thaw to depths of 2 feet.

The fiords of the west coast freeze over in late December, but January is frequently a warmer month than December. The coldest periods are in February and March, when the long dark winter is about over. The mean temperature of the coldest month is about minus 10° F. Temperatures above freezing may occur in any month, and midwinter thaws are not uncommon. The variations of winter temperatures, especially the daily ranges, are much greater than those of summer which maintains a fairly uniform warmth.

Spitsbergen feels the effects of the passing high and low pressure areas which come from the North European Sea and travel south or west of the islands. These bring winds from all directions, the velocity of which is highly variable. The mixture of warm sea air and cold land air produces frequent fog along the west coasts. This coast also receives a more abundant precipitation than the inland area. The eastern side of the islands is dry, colder and clearer, especially in winter.

ANIMAL LIFE AND VEGETATION

The low temperatures and exposed position of the outer coasts retard or prohibit plant growth. The more protected interiors of the fiords support abundant vegetation. On the flat uplands there are moors and swamps in the depressions. The slopes are covered

by a wide range of flowering and woody plants. Tundra plants and grasses cover the wide lowlands. These polar pastures are the feeding grounds for reindeer.

The bird life is divided according to whether the habitat is on the coast or inland. Sea birds are much more abundant than those of the interior. They breed in summer along the coasts and migrate southward in winter. The gulls, ducks, geese, and terns each have a definite nesting place. The inland birds, snow buntings, gulls, geese and ptarmigans nest in places inaccessible to the foxes.

Most hunting is controlled in Spitsbergen by the Norwegian government in an attempt to replenish the animal population. The eastern parts of the country are the home of many herds of reindeer, the polar bear, and the arctic fox.

Sea mammals include whales and seals, both of which have been hunted for hundreds of years. Fishing and whaling have decreased in recent years.

RESOURCES AND INDUSTRY

Coal is one of the most important natural resources of Spitsbergen. It is estimated that the fields contain 9 billion tons of coal. The deposits have been known since the early 1600's when the coal was used locally by the whalers, but systematic mining dates back only to 1905. At that time, an English company began the exploitation. Since then, Norwegian, Swedish, Soviet and Dutch mines have opened.

Although coal of several geologic ages is found, the Tertiary beds are the most abundant and accessible. These seams are nearly horizontal and run from one fiord to another. The coal is of generally good quality. Mining is not a simple matter. The severe climate, the frozen ground, and the short season in which navigation is possible all add to the difficulties.

In addition to coal, some gypsum, asbestos, iron ore, and marble are found.

The total population is about 2,700, concentrated mainly on the southwest coast of West Spitsbergen.

GEOGRAPHY OF THE FENNO-SCANNIAN ARCTIC

Characteristic arctic conditions prevail only in a narrow strip along the northern Scandinavian coast, and in the mountainous or plateau interior of Norway and northernmost Sweden and Finland. Most of this area is considered to be in Lapland. Moderating in-

fluences along the western side of the continent of Europe push the arctic boundary far to the north.

The coast of northern Norway shows a general alinement of rugged, steepsided peninsular and deep fiords oriented north and south. Innumerable mountainous islands fringe the barren headlands. Between this outer region and the interior upland lies the more sheltered region of the fiords. Here there are birch forests, meadows and some arable land. Important food crops such as potatoes, barley, rye and berries are cultivated to supply the many fishing ports. Fish are plentiful in the fiords. The main centers of the fishing industry are Vardo, Hammerfest, Tromso, and Harstad, the latter two also being the principal ports for northern shipping.

The interior region which includes northern Sweden is relatively high and rugged (elevations up to about 5,000 feet) with many lakes and marshes. East of this mountainous section, the land of northern Finland is a rolling plateau on which the extensive Lake Inari is a prominent feature. Tundra covers most of the ridges and elevated places while scrub pine, birch and spruce grow in some of the sheltered valleys. Where it exists, the soil is thin. Like the Canadian Eastern Arctic, this is a shield area of ancient crystalline rock which has been highly disturbed and fractured. The entire area was glaciated during the ice age, leaving scoured uplands and drift-filled valleys as the dominant landscape.

The upland region receives little of the moderating climatic influences felt along the coast. Winter temperatures fall well below zero, as the recorded minus 58° F. at Karasjok shows. Cold air accumulates on the plateau and flows down the fiords creating storms along the coast in winter. The long sunless winter is brightened by fine auroral displays and brilliant moonlight. In September and October full nights of Alpine glow occur. The summer is marked by about 82 days of continuous light.

The native caribou have been replaced by the domesticated reindeer which the Lapps herd. Wolves, bears, and the smaller arctic land animals are abundant. Sea mammals and fish are numerous, although whales and walrus are more scarce than in earlier times, due to excessive hunting.

The Archeozoic rock of this area is rich in iron, copper, and sulphur. Important iron mining centers are at Kirkenes near Petsamo and at Kiruna in Sweden. Iron from Kiruna is shipped from the Baltic part of Lules in the summer and from the Norwegian port of Narvik in the winter. Fish are a very important

Figure 2-22.—Lapps and their herds of domesticated reindeer.

source of national wealth, but otherwise, the northern region offers little else in the way of resources. Timber is scarce and farming is limited to the hardier crops. There is, however, considerable potential water power in the many cascading rivers and falls.

The Lapps who inhabit this region number about 10,000. They migrated to northern Scandinavia and the Kola Peninsula, probably from the area around Lake Ladoga. Their language is a combination of Finnish, Magyar, and Estonian. The majority of the Lapps have settled along the coasts, built log cabins and become quite sedentary. Only about 1,200 to 1,300 practice transhumance or the seasonal moving of livestock from or to the mountains.

These Lapps live on the plateau during the winter, allowing their herds of reindeer to feed on the moss. They live in tents of thick sacking or blankets, rarely use reindeer skin, and eat meat, cheese, frozen milk, and berries. In the summer they come down to the coasts where the herds pasture on the grassy meadows and where the Lapps can obtain the precious commodity, salt. An added attraction of the coasts in summer is the absence of the

scourge of insects that plague the uplands. Also, this change of feeding grounds enables the tundra to recover from the winter pasturing. The mountain Lapps carry on a lively summer trade in reindeer meat and skins for the Swedish markets.

Commerce and transportation are mainly by ship. The sea offers the easiest means of going from center to center since the fiords penetrate deeply into the land. Also, the land routes are forced to go over the rugged mountains or plateau areas with the fiords acting as continual breaks in the road. The sea literally unites this area, while the land divides it.

GEOGRAPHY OF THE SOVIET ARCTIC

The combined arctic and subarctic regions in the Soviet Union occupy over half of the country. Of this area, the true Arctic, treeless and cold, includes only the northernmost strip of the continent and the islands off the coast. Most of central Siberia and the northern half of European Russia lie in the subarctic zone. In many ways it is artificial to attempt to separate the two zones. The enforced development of the Arctic in the Soviet Union has made this region an integral part of the whole northern section. Although there are some definite geographic differences which mark the Soviet Arctic as a distinct region, these are insufficiently

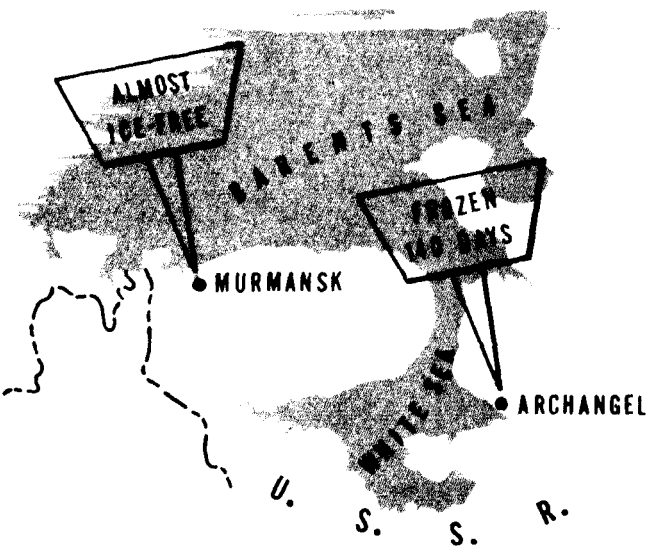


Figure 2-23.—Murmansk and Archangel.

prominent to justify a separate consideration. For convenience and accuracy the Arctic and Subarctic will be discussed together.

COASTAL AREAS

The Kola Peninsula is an extension of the Baltic shield region of northern Scandinavia. It is a glaciated barren country with abundant lakes, several sizable rivers and at least one very important harbor, Murmansk. The coast is rugged with granite cliffs rising over 500 feet above the sea with only occasional sandy beaches at the mouths of the rivers. East of the White Sea, the North Russian plains extend along the coast to the Urals, being broken only by the Timan Hills west of Pechora River. These are relatively flat plains covered with glacial deposits in the form of moraines, eskers and drumlins. Although these are minor features of low relief, they are locally important because the gentle ridges and hills rise above the marshy, lake-covered plain. On these drier sites are located the villages and fortifications.

The Timan Hills are a branch of the Urals. The glaciated northern end of the Urals can hardly be said to break the plain, since the general topography is similar on either side of this range. East of the Urals the tundra-covered plain extends thousands of miles to the Yenisei. The coast is broken by several large bays including the Cheshkaya, Pechora, Baydaratskaya, the deep gulf of Obskaya, and the Gulf of Yenisei. The lower drainage basins of the Ob and Irtysh are vast bogs and swamps, subject to flooding. They become impassable quagmires in summer.

East of the Yenisei the arctic plain extends along the coast, narrowing toward the east, to the Lena River. The Khatanga, Anabar, and Olenek drain this area. Along the north coast of Taimyr Peninsula, the Biranga plateau rises some 2,000 feet, being a rather abrupt break in the coastal plain. From the Lena eastward, the coastal area is mainly a series of ranges rising over 6,000 feet, broken only by the lowlands at the mouth of the Kolyma. It should be noted that the rivers east of the Taimyr Peninsula have deltas while those to the west have estuaries.

Off the coast there are many small islands and several large island groups, including Novaya Zemlya, Severnya Zemlya or North Land, the New Siberian Islands, and Wrangel Island. Farther to the north lie the Franz Joseph Land group of islands.

The shores of the Arctic Sea are icebound for at least 5 months and the rivers for about 8 months. On the Barents Sea the port

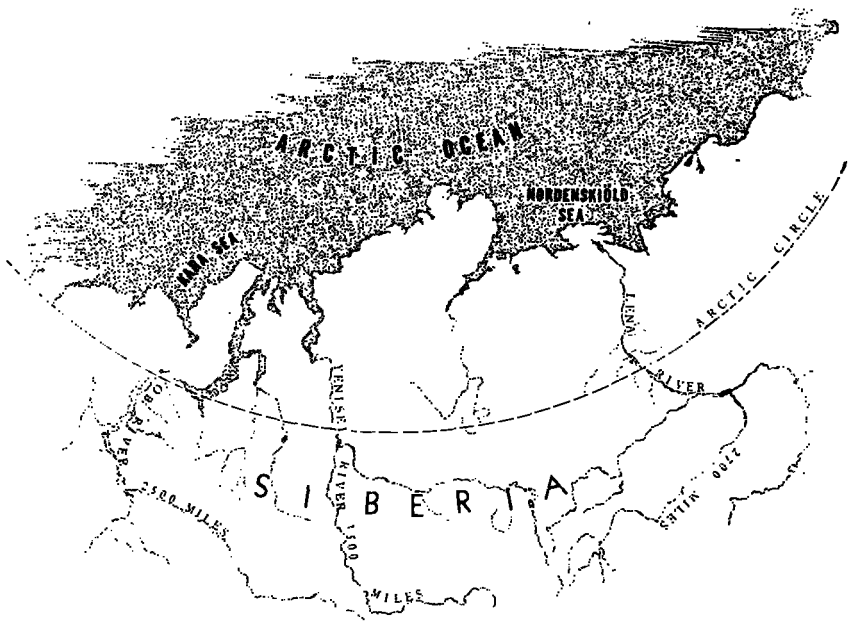


Figure 2-24.—Length of rivers in U. S. S. R.

of Murmansk is almost ice-free, while Archangel (Arkhangelsk) on the White Sea is frozen for 140 days. This is an important factor in the northern sea route.

PHYSIOGRAPHY

In general the arctic and subarctic regions of the Soviet Union can be divided into five physiographic provinces. The coastal plains described above are the tundra area. Between the Soviet or western part of these plains and the Siberian part lie the Urals and the extensive west Siberian plain, drained by the Ob and the Taz. East of the Yenisei is the central Siberian plateau. This is an area of crystalline rock extending to the Lena River. The three Tunguska rivers dissect the southern and western part of the plateau. The upland regions rise to over 3,000 feet in some places. East of the plateau is the region of the Siberian ranges, an area of rough and broken terrain, partially glaciated, and reaching to heights over 9,000 feet.

A physical map of the Soviet shows the predominance of two features: the vast plains and the long rivers. The rivers which drain the arctic and subarctic regions are very long. The Yenisei is over 3,500 miles in length, the Lena 2,700 miles, the Ob 2,500

miles. Also, most of these rivers are very broad. The Yenisei, for example, has over 3,000 miles of navigable waterway and is over 20 miles wide at the mouth. It is 4 miles across at Igarka, a port just north of the Arctic Circle, 400 miles from the mouth. Fair-sized river boats can navigate as far as Krasnoyarsk. The rivers are vital links in the transportation system although even the large rivers freeze in the winter and are icebound 6 to 8 months in the subarctic and over 8 months in the Arctic.

The Siberian rivers have been used for local traffic for as long as the area has been settled, but only recently have they figured in the transportation system of the whole Soviet Union. There are no interconnecting canals and not much has been done to develop these routes. However, the increased shipping along the northern sea route has added new importance to both the Siberian rivers and the arctic ports. Active interest in this route came with the establishment in 1932 by the Soviet government of the Northern Sea Route Administration (Glavesmorptut). It was in this year that the first vessel, the 1,400-ton Sibiriakov, made the voyage from Archangel to the Bering Strait in a little more than 2 months.

The northern sea route has become an important component of the Soviet trade pattern. The arctic fleet includes over 120 vessels and 40 icebreakers. In the 100 days of open season a considerable cargo tonnage is moved. Thousands of tons of freight now move over this route rather than using the over-loaded Trans-Siberian Railway. Timber, fur, and minerals are shipped from the ports along the Ob, Yenisei, Lena, Kolyma and Indigirka. New ports have been opened such as Dikson, Dudinka, Igarka, Nordvik, Tiksi, and Ambarchik. Dock facilities are being improved and mechanized. To assist in the planning and operation of this sea route, over 100 polar stations and more than 50 weather stations have been established, with regular flights patrolling the route to provide ice and weather information.

CLIMATE

The major handicap to the nothern sea ruote and the commerce on the Siberian and western rivers is the long period when ice makes traffic impossible. This, of course, reflects the cold winter temperatures which prevail over most of this vast area. The temperature in January almost everywhere is consistently below 32° F. The winter temperatures decrease from the southwest to the northeast. The *Cold pole* center of the Northern Hemisphere

is in the middle near Verkhoyansk. It is an arctic paradox that man finds it easier here to withstand the extremely low temperatures than some of the less extreme western temperatures, because in the east the air is dry and usually calm.

The low precipitation, low evaporation, and low temperatures are controlling factors. The short summer, even with 24-hour daylight, does not provide enough heat to thaw more than the top few inches of the ground and the subsoil remains frozen. The freezing and thawing of the surface arches it into little hillocks. There are many areas where no soil exists. On these rocky places reindeer moss is found. In some areas, as between the Pechora River and the Urals, stunted willow and birch brush grows to about 3 feet in height. The lower areas are swampy and the drainage is poor, mainly because of the underlying impervious layer of permafrost. In the short summer the many polar flowers relieve the drabness of the tundra, grasses flourish in the meadows, and the patches of heath produce abundant berries.

ANIMAL LIFE AND VEGETATION

The animal life of the tundra includes reindeer, white fox, white partridge, lemming, and arctic fox. These animals and the forest animals, which prey on the gulls and ducks, move northward in the summer.

The subarctic zone is the region of ash-gray soils or podsol, and of the coniferous forests or taiga. The upper layer of the soil consists of gray, sandy particles leached by percolating water of most of the iron hydroxides and humus. These substances and the finer clay particles form a darker layer below the surface. Leaching takes place despite the fact that the area receives relatively little rainfall; melting snow, a low evaporation rate, and cold soils account for the depletion of the top layer.

At the northern edge of the coniferous forest the birch and conifers are dwarfed and stunted. Toward the south where the snowfall is greater and the winds are less strong, firs, larches, spruces and pines flourish. Fires have burned out extensive areas and where new growth has started up, the birch is usually the first to get established.

In some areas, as around Archangel and in the central Ob basin, the sandy soil is waterlogged due to the presence of a hard pan layer below the surface, which prevents downward percolation of water. Peat-bogs take the place of forests in these areas. These

bogs, similar to the muskeg swamps of northern Canada, offer serious problems to road and railroad construction.

There is a more varied animal life in the forest than in the tundra. Berries provide food for the small animals and rodents which in turn provide food for the birds of prey and carnivorous animals. The wolf, lynx, and fox inhabit the forest, together with the marten and ermine. These animals move north in summer, following their food supply and avoiding the hordes of mosquitoes that breed in the water-soaked soil. The fur-bearing animals of the tundra and forest areas are the basis of an important occupation and source of income. Although haphazard hunting and trapping are prohibited, special breeding and trapping stations have been established.

Underlying essentially all of the tundra and taiga is a layer of frozen ground with ice filling all the spaces between the particles of soil and rock. The lower Ob, the Indigirka and Kolyma flow along beds of ice in both summer and winter. The depth of the permafrost varies, being narrower in the south and up to depths of over 1,000 feet, as at Kazhevnikov Bay in Northern Xakutia. The problems of construction, mining, and farming in permafrost areas in the development of the Soviet northland focused attention on the need for planned study. As a result, the Institute for the Study of Frozen Soil was established in 1930.

RESOURCES AND INDUSTRY

Despite the rigors of the climate and difficulties imposed by other characteristics of the arctic and subarctic environments, the Soviet Union has been active in supporting a program of exploration, exploitation and colonization of these regions. As a result, much is known of the potential wealth of these areas.

Geologic investigations of the tundra and the taiga of the Yenisei and Lena basins have shown that a large coal field exists in the area of the Tunguska River, a tributary of the Yenisei. Estimates indicate that it contains 400,000 million tons. At Norilsk, near Igarka on the Lower Tunguska, some mining is going on to provide coal for the ships using the Northern Sea route and for river steamers. There is also a deposit of nickel ore near Norilsk that is being worked. Another arctic coal field is on the Vorkuta, a tributary of the Pechora. This coal is of good quality and makes excellent coke.

On another tributary of the Pechora an oil field has been found. Here on the Ukhta in 1936 oil wells and a refinery were installed.

Near here are radio active wells, believed to be the only known possible source of uranium in the Soviet Arctic. To the east at Nordvik another rich oil field has been discovered.

In the Kola Peninsula, titanium and vanadium are being recovered from the iron-ores. Some low-grade nickel ores have been found. At Petsamo, which formerly belonged to Finland, nickel deposits have been mined for many years.

Deposits of alluvial or placer gold are found along many of the rivers of the northeast. Along the Indigirka and Kolyma these deposits are being worked. To provide an outlet for this production a road has been built to Nogaeva on the Sea of Okhotsk.

Vital to the agricultural development of the Soviet Union is a supply of phosphates. The discovery in 1926 of a huge mountain of apatite, a calcium phosphate, on the Kola Peninsula, is providing an abundant and continuing supply. A center of this production is at Kirovsk.

The coniferous forests support a vast timber industry. The forests of the northwest are the most productive, but Siberian forests are also being exploited. Together with the sawmills, wood-chemical combines have been established as at Archangel. These produce newsprint, wallpaper and wall board.

The industries that have been created in the Soviet northlands have made it necessary to develop agriculture in these areas to provide food for the thousands of people who work in the mines, quarries, mills and ports. Before the introduction of this new economy, the tundra was the home of small bands of nomadic people subsisting by hunting, fishing, and herding reindeer. They migrated south in the winter to the edge of the forests and moved north again in the summer. The Soviet government now controls the movement of these peoples and the herding of the reindeer in an attempt to prevent misuse of the grazing grounds and to convert the people to a sedentary life. With government help, settlements have been established to grow fodder crops in the river valleys. At Tiksi, Norilsk and Dudinka are grown fields of cabbage and potatoes, as well as beets, lettuce, radishes, and tobacco. Some barley, oats, and spring wheat are produced and cattle, pigs, rabbits, and poultry are kept. Hothouses are used to grow the fresh vegetables. These, and the sheds for the animals are electrically heated and lighted. Electricity is also used to heat the soil for the less hardy plants. Although production is small and the methods are complicated, supplies of fresh vegetables and milk are provided locally for each major settlement.

In the clearings of the forest area, especially in the west, agriculture has developed. Cereals, potatoes and vegetables are being grown. Meadows and pastures are being used to support dairy herds. Apple growing has been introduced in Siberia and considerable production has resulted from these orchards where the trees grow horizontally close to the ground to get protection from the cold by the snow cover and to avoid wind damage.

Agriculture is neither extensive nor a primary occupation in either the arctic or subarctic areas. However, it forms an interesting and necessary part of the economy and life of the region.

The population of the Soviet Northland is sparse. Efforts to settle the area have not resulted in a great influx of people. The settlements that now exist are of three types: the villages of the nomads whose chief occupation is hunting and fishing; the permanent settlements of the state farms and herds, the sawmills, mines, and ports; and the polar stations.

There are few roads connecting these settlements although attempts are being made to build roads from the north to tie into the system along the Trans-Siberian Railroad. The rivers are used as summer highways and the dog team and reindeer sledge are the winter modes of transportation. The airplane offers the only other means of transportation and is hindered by fog, difficulties of navigation, and lack of suitable landing areas.

ISOLATED ISLANDS OF GEOGRAPHIC SIGNIFICANCE

In this section are briefly described certain isolated arctic islands of geographical and possible strategic interest—Jan Mayen, Bear, Novaya Zemlya, Vaigach, Franz Josef Archipelago, New Siberian Island, and Wrangel.

To the east of central east Greenland lies Jan Mayen Island, almost the smallest of arctic islands. Due to the high inactive Beerenberg volcano (7,680 feet high), this island has a landscape visible from afar and serves as an unmistakable landmark in a sea area in which there are few. The generally poor, sandy, and lava soil, the high winds, and low summer temperatures permit but scanty plant life. Lying at the limit of the pack ice, it has frequent fogs.

"Jan Mayen Island is tiny, only 34 miles long, generally narrow, and so particularly narrow at its center that it nearly has a dumbbell shape. There is nothing remarkable about it except an inactive volcano that is perhaps the most remarkable in the world,

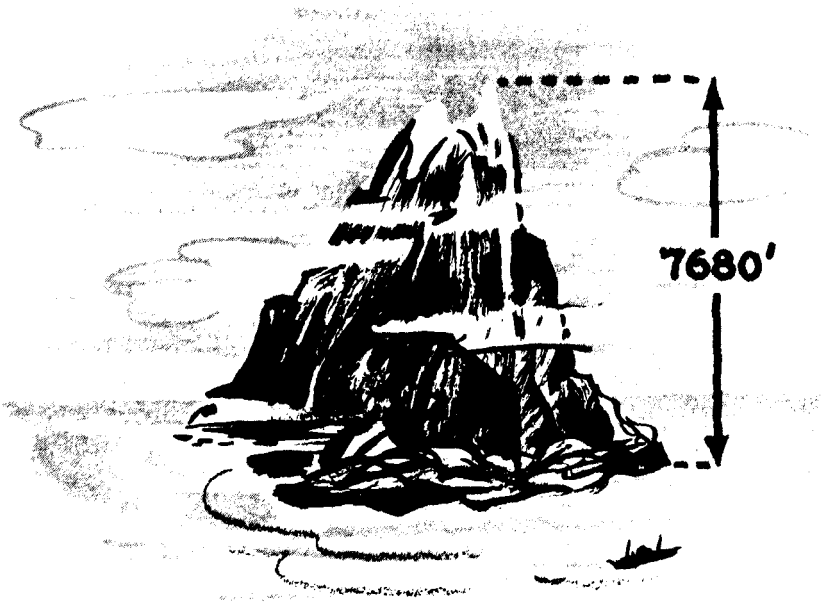


Figure 2-25.—Jan Mayen Island.

rising, as it does, from the shore steeply to greater heights than any other mountain that stands by the sea," Stefansson writes of it.

Bear Island is situated 160 miles south of Spitsbergen in latitude 74°30′ N. It has very changeable weather and is beaten by a heavy surf since it is along the storm path of the North European Sea. It is almost constantly shrouded in fog. July mean temperature is 40° F. There are no harbors. Drift ice surrounds the island about half the year. The northern two-thirds is a plain with a 100-foot high cliffed coast, gradually rising to 400 feet. Adjoining the plain is a high plateau which falls off in the South to the sea in vertical walls as much as 1,200 feet high. It has been estimated that coal deposits to the amount of 200 million tons are on the island.

Vaigach is a small rectangular island lying near 70° N., 60° E. It is separated from the Soviet mainland by the narrow Yugorshar, one of the three straits leading from the Barents Sea into the Kara Sea.

Novaya Zemlya to the northward is a long, narrow double island. It is separated at latitude 74°30′ N. by the fiordlike strait called

Matochkin Shar. At this strait the width of the island is 60 miles. Together, Vaigach Island and Novaya Zemlya are 650 miles long with an area of 37,000 square miles (fig. 40).

In view of the length and narrowness of Novaya Zemlya, the coast stands out as the most prominent element in the landscape. Along the western side there often is found a low foreland in front of the steep flanks of the mountains. The western coast of the north island is indented by deep bays. On the east side, the general outline of the coast is more uniform.

The southern island of Novaya Zemlya up to its central part is low and flat. From the somewhat higher ridges of the western coast, the land slopes off to plateaus, usually less than 700 feet high. Here are found many lakes and rivers, but no glaciers. In the northern half of the southern island and southern half of the northern island, from Gooseland to Admiralty Peninsula, the whole land rises to greater heights reaching nearly 4,000 feet in the vicinity of Matoch Kin Shar. Deep, often ravinelike transverse

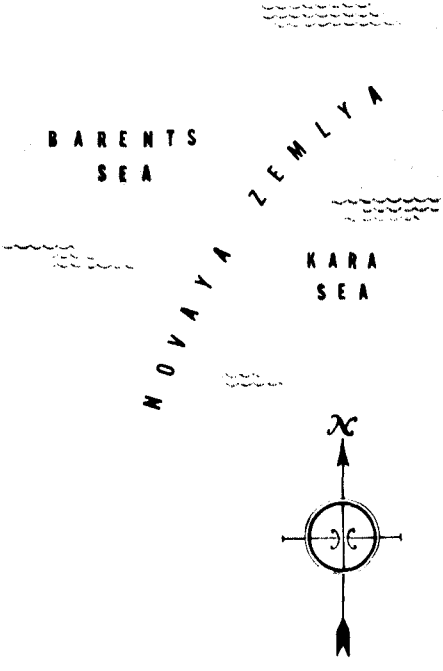


Figure 2-26.—Novaya Zemlya.

RESTRICTED

valleys and fiords cut into the land from both sides. Abreast the Admiralty Peninsula inland ice appears. This constitutes the third major subdivision of Novaya Zemlya and rises to a height of 2,000 feet with the highest parts lying in the east.

Thus, the island system of Vaigach and Novaya Zemlya rises like a wall between the Barents and Kara Seas. The Barents Sea, on the west side, has wide and open communication with the North European or Norwegian Sea from which it receives off-shoots of the North Atlantic drift. The Kara Sea, on the east side of the "wall," forms a cul-de-sac of the west Siberian coastal sea. It has been fittingly described as an ice cellar.

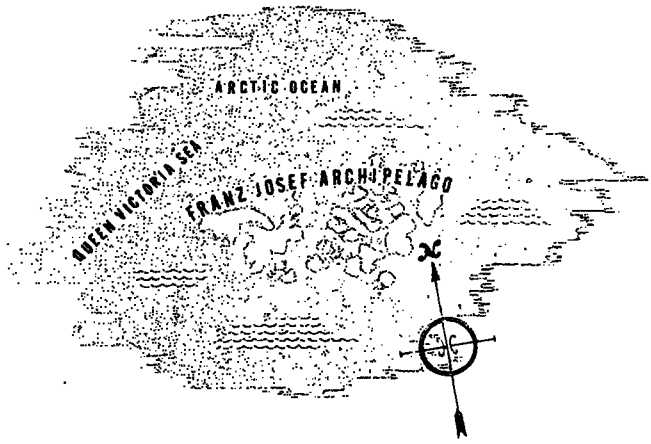


Figure 2-27.—Franz Josef Archipelago.

Anthracite coal and copper are found on Novaya Zemlya. There are immense quantities of arctic birds—guillemots, auks, petrels, gulls, geese and ducks. Both the Barents and Kara Seas abound in crabs, fishes, and sea mammals, especially seals. Among the land animals found are the arctic fox, bruinings, polar bears, and reindeer. The inland waters contain fish, including various species of salmon which are of economic importance. For several centuries, Russians have come here each season for hunting and fishing.

Franz Josef Archipelago consisting of many small islands with a total area of 65,000 square miles, lies between 79°45′ N. and 81°50′ N. It is twice as long east and west as it is north and south. Most of the islands are plateaus covered by ice caps or island ice. In the north the plateaus are about 1,000 feet high,

and in the southeast 2,500 feet high. Fogs are frequent. Mean temperature in July is 32° to 34° F. Weather is clear in winter with lowest mean in the order of minus 22° F. The absolute minimum is near minus 50° F. There is little precipitation. Animal life is sparse. Resources are nil. Sites for airfields are available. There is no question about capability of Soviets operating aircraft there.

The New Siberian Islands lie off the east Siberian coast. The archipelago consists of four major and a number of minor islands. The largest and highest is the western island, Koletroi. The eastern island, Novaya Sibir, is less than 350 feet in elevation. The strata of these islands contain the remains of various prehistoric animals which had their normal habitats in warmer climes. The vegetation is poor in species and in growth. The formation is that of dry tundra. The temperature is lower in all months than at the mouth of the Lena River.

To the northeast of the New Siberian Island, there lies a group of small islands near the edge of the continental shelf. The largest is Bennett Island in latitude 76°40′ N. It is a rocky plateau, ice-covered, with an area of only 75 square miles.

Farther to the east stands Wrangel Island, Soviet sentinel of Bering Strait and East Siberia. It is difficult to reach by ordinary ship during the normal summer season. It is 1,800 square miles in area, 80 miles long, with greatest width 30 miles. It is generally mountainous, hilly and scantily covered with tundra. The elevation of the highest mountain is 2,500 to 3,000 feet. There are sites available for airfields.

Nicholas II Land (Levin Land or North Land on some maps) is a small archipelago lying at 80° N., 100° E. to the north of Cape Chelyustin on the Tarmyr Peninsula.

SUMMARY

Geography is developing as an increasingly important science. So little is known of the geography of the Arctic, that it is covered here in some detail to give the reader a general picture of these vast areas.

The Arctic is cold, but the coldest spots in the Northern Hemisphere are not in the Arctic. It is a barren and desolate land, but in places vegetation, animals, birds, insects, and fish abound. It is windy, but chiefly in localized areas. It rains and snows heavily, but only in spots. It is not unfriendly if one knows, understands, and respects it.

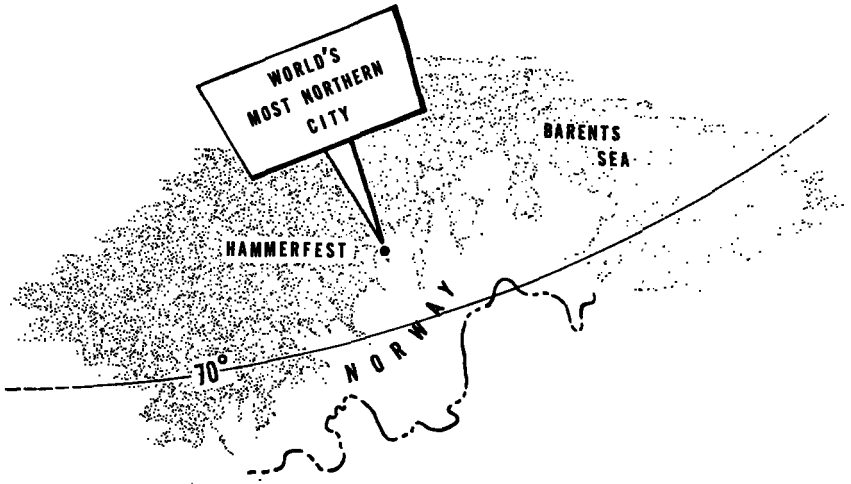


Figure 2–28.—World's northernmost city.

Table V is a summary of geographical data worth remembering.

TABLE V

Summary of Geographical Areas

Location:		*Areas (Goodis Atlas)*
Alaska	square miles	580,000
Greenland	do	837,000
Greenland Icecap	do	708,000
Hudson Bay (850 miles long by 520 miles broad)	do	472,000
Spitsbergen	do	25,000
Franz Josef Archipelago	do	65,000
U. S. S. R. Arctic	do	5,570,000
Disko Island, Greenland	do	3,006
Wrangel Island	do	1,800
Novaya Zemlya	do	35,100
Iceland	do	39,700
Land Area draining into Arctic Ocean	do	8,000,000
Alaska	do	586,000
Canadian Arctic	do	1,000,000
Northwest Territories	do	1,309,600
Lenaland, east of Yenisei	do	3,750,000
Heartland, west of Yenisei	do	4,250,000
Asiatic Portion, U. S. S. R.	do	7,346,000
Mackenzie River (total length)	miles	2,525
Lena River (total length)	do	2,700
Yenisei River (total length)	do	3,500
Yukon River (total length)	do	2,100
Arctic Sea	square miles	5,500,000
Atlantic Ocean	do	31,500,000
Pacific Ocean	do	64,000,000
Mediterranean Sea	do	1,100,000

Summary of Geographical Locations

Location:	*Situation*
Northernmost point of American continent is on Boothia Peninsula and is situated at	72° N., 95° W.
Northernmost point of Alaska is Point Barrow at	71°24′ N., 156°22′ W.
Northernmost point of land in Western Hemisphere is Cape Morris Jessup at	83°39′ N., 34° W.
Northernmost point of Eastern Hemisphere is on Rudolph Island at	81°50′ N., 60° E.
Northernmost point of Eurasian continent is Cape Chelyreskin at	78° N., 105° E.
Hourmerfest, Norway (world's northernmost city), at	70° N., 24° E.

Mileage chart of Greenland

North-south length of Greenland	miles	1,650
Greatest width in Greenland at 77° N	do	690
Nearest land to the North Pole is in Greenland	do	439

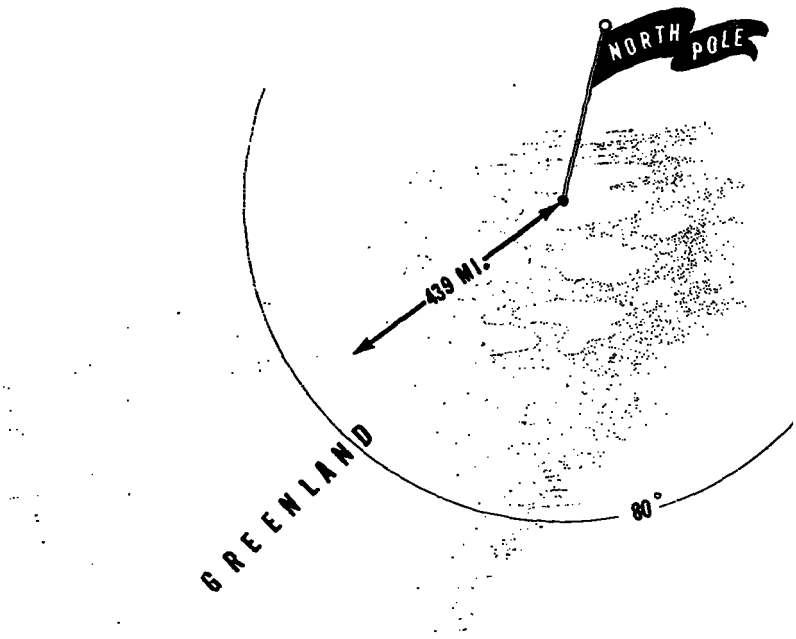


Figure 2-29.—Nearest land to the North Pole.

Blank page retained for pagination

CHAPTER 3

CLIMATE AND THE WEATHER

"Weather is now an item of major importance in planning and executing naval surface, air, and amphibious operations."—Admiral Halsey.

Weather is one of the principal factors limiting naval operations in the arctic. In view of the small amount of available data upon which to establish firm conclusions, the following may be subject to some revision, when more complete information is forthcoming. The word *season* as used in this chapter has its literal astronomical meaning.

The two prominent controls of arctic weather are (1) the Arctic Anticyclone, and (2) the extension of the semipermanent Icelandic

Figure 3–1.—Common track for low-pressure centers.

low pressure area into the Barents and Kara Seas. Separating these two pressure areas is the *Atlantic Arctic Front* along which the cyclonic disturbances in these regions are most likely to develop.

During the winter months, the center of the Arctic Anticyclone lies in the vicinity of 80° N., 165° E. The Icelandic low pressure area extends northeastward from Iceland to beyond northern Novaya Zemlya. Its central axis is marked by the mean position of the Atlantic Arctic Front, which extends intermittently along the northern Siberian coast to 170° W. longitude. At this season, an almost continuous succession of cyclones is to be noted along the Arctic Front, between Bear Island and Novaya Zemlya. East of Novaya Zemlya, the disturbances decrease in intensity and dissipate so that few storms penetrate along the east Siberian coast. Surface winds are prevalent from the westerly direction along the Siberian coast; easterly over the central arctic regions and most of Greenland; and north to northwest over the Canadian archipelago.

During the spring months, the winter pattern of mean pressure is continued with little change. The Arctic Anticyclone shifts slightly eastward to the 180th meridian and the central pressure

continues high. Pressures are slightly higher in the Icelandic high pressure cells and fewer intense cyclones develop or move along the Atlantic Arctic Front. With the eastward shift of the Arctic Anticyclone, the winds become more variable along the northern Alaskan coast.

During the summer months, the pressure gradients are weakest over the entire arctic region, and the winds are quite variable. A separate anticyclonic center occurs to the east of Greenland, while the principal Arctic Anticyclone continues its eastward movement along the eightieth parallel, to approximately the 150°-155° W. meridians, but with greatly diminished intensity. Winds are prevailingly northeasterly along the Alaskan and Siberian coasts, and north to northwest over the Canadian archipelago. While few in number, cyclonic storms may penetrate any section of the arctic at this season. The weather in the Canadian archipelago is dominated by semi-permanent cyclonic activity with centers located in Baffin Bay and northwest of Ellesmere Island.

The low pressure center which is semi-permanent over Baffin Bay is a natural result of the blocking effect of the Greenland plateau on the migratory storm centers moving in from the west and southwest. Most of these migratory centers originate as waves on the North American Polar Front. Some, however, result from the regeneration of old Pacific Ocean occluded systems, while a few are developed from various low pressure centers connected with the Aleutian Low.

The most common track of low pressure centers approaching Baffin Bay in summer is produced by migratory centers originating in southern Canada, east of the Rocky Mountains. These centers move eastward and occlude in the area immediately to the west of Hudson Bay, then gradually curve northeastward across Hudson Bay and extreme northern Quebec, and finally move across Baffin Island and over Baffin Bay. The area of major deepening of low pressure centers on the above course is in the vicinity of and just to the west of Hudson Bay. Hence, the slowest forward movement of the centers is in this area.

The speed of advance after leaving the Hudson Bay region is approximately 25 knots, gradually slowing to 5 to 15 knots over Baffin Bay, where the blocking effect of the high altitudes of the plateau of Greenland is felt. The migratory lows which develop as regenerations of old Pacific occluded systems originate in western Alberta Province, along the eastern side of the Canadian Rock-

ies. During the summer these centers move directly eastward, near 60° N., into the area west of Hudson Bay. From this position paths vary widely, some centers being forced south-southeastward across the eastern Great Lakes, some proceeding directly eastward into the Labrador-Davis Strait region, and some curving northeastward across Baffin Island and over Baffin Bay.

In the latter part of August and in early September, the trajectory of these lows across the central part of Canada shifts farther to the south, due to the gradual increase in size of the high pressure cells centered to the northwest of Canada. The northernmost track of low pressure centers moving into the Baffin Bay region is across the Canadian archipelago. These lows originate as waves on the Arctic Front or as developments off the Aleutian Low, which is separated into several small centers during the summer months. The average speed of these lows is 20 to 25 knots, except to the south of the Ellesmere Low, where they tend to intensify and thence move eastward more slowly, eventually stagnating in Baffin Bay.

By the time migratory low pressure centers arrive in the Baffin Bay area, the frontal systems connected therewith are usually in the form of well developed occlusions. When these occlusions reach the Greenland coast, they are blocked on the surface by the edge of the cold high pressure cell over the inland ice cap and are either forced aloft or dissipated.

Frontal weather affects the North American arctic more frequently in summer and early fall than in other seasons, but even in summer non-frontal processes predominate. As mentioned above, fronts encountered are generally of the occluded type, although open wave cyclones may also be observed.

During the fall months, there is an increase in cyclonic activity along the Arctic Front, which extends from southern Greenland, through Iceland, off the northern coast of Norway, over southern Novaya Zemlya and across the Taimyr Peninsula. Winds are prevailingly westerly south of the front and prevailingly easterly north of the front. The Arctic Anticyclone continues relatively weak and is centered in its easternmost position along the 80th parallel on the meridian of 140° W. longitude. The transposal of this center to near the Siberian border takes place simultaneously with the freezing over of the East Siberian and Laptev Seas in early winter.

ARCTIC AIR MASSES

Generally speaking, air masses are classified according to source and recent life history. The simplest method of designating them allows for four types, which apply to all parts of the earth. These four broad types are:

cP: continental polar.

mP: maritime polar.

cT: continental tropical.

mT: maritime tropical.

However, in a discussion of air masses over a particular region, it is desirable to use a more specialized scheme. This is because air from different geographical regions of the same general type assumes characteristics peculiar to the source region, which help materially in analysis and forecasting. For example, polar air which has lain for days over the almost unbroken pack ice north of Bering Strait, in the total darkness of winter, will show, in general, marked similarity to a mass of polar air from the subpolar plateau of Outer Mongolia. But in the arctic air, in addition to the strong inversion of temperature in the lower 5,000-foot layer, there will be found, in most cases, a characteristic 500-foot layer at the very surface, in which the temperature falls rapidly with height and the surface layer shows higher humidity. At the same time, at the top of the troposphere (at about 30,000 feet), the temperature will be somewhat lower than at the same altitude in the subpolar air. So it is customary to differentiate the two types of air by adding the following types to the above classifications:

cA: continental arctic.

mA: maritime arctic.

By adding the letter W (warm) or K (cold) to any of the above types, it can be shown whether the air is *warm* or *cold* with respect to the surface over which it is moving (*stable* or *unstable*).

Thus in the arctic and subarctic regions we have the following types, together with the general source region and the season or seasons of occurrence:

TABLE VI

Main Source Regions of Arctic Air Masses

Type	Main Source Region	Season of Occurrence
mAK	Greenland-Spitsbergen	Entire year except July and August.
cAK	Novaya Zemlya-Canadian Archipelago-Pole	Entire year except July and August.
mPK	North Atlantic	Entire Year.
cPK	Scandinavia-Siberia North	Northern Winter (September-June).
mPW	Atlantic and Pacific (around 50° lat.)	Northern winter.
cPW	Ukraine-Mongolia	Northern spring, summer, and fall.
mTW	Azores (Middle Atlantic) Anticyclone	Entire year.

In summer the distinction between polar maritime, polar continental, and arctic air almost disappears due to the nearly uniform surface conditions over the arctic and subarctic. The frozen ground over the continents thaws, at least at the surface, under the influence of continual sunshine or daylight; the snow melts from the glaciers and pack ice, the ice melts from the lake areas, and the water area in the polar basin or Arctic Sea increases markedly. Thus, the whole polar area becomes one of mild, humid, semimaritime activity. Temperatures are uniformly between freezing and 50° F. Occasionally, higher temperatures occur under the influence of strong improtation from the south, or of strong insolation in favored localities.

Diurnal ranges, horizontal differences, and inter-diurnal variabilities are slight. The latitudinal and continental influence is at a minimum. Only the effect of elevation is increased due to the greater humidity and lack of inversion, the former increasing the lapse rate and blanketing the lowlands from excessive outgoing radiation and the latter removing the anomaly, so common in the arctic winter, of having pools of cold air in the hollows while hill or mountain tops are 20°, 30°, and even 40° warmer.

If any contrast exists in the Arctic in summer, it is between the air over the pack ice at near 32° F. and the subarctic zone on the one hand, and the air over the warm Atlantic water on the other hand, where temperatures average 20° or 30° higher in July and August. This contrast is destroyed frequently when small, but sometimes intense, cyclonic storms invade the polar basin, temporarily displacing the Arctic Front. Also, at any time during the summer a mass of mAK air can build up some place in the Arctic and move down over the Canadian islands or the Norwegian and Barents Seas, giving summer snowstorms, freezing temperatures, icing and fog to those parts.

WINTER CONDITIONS

In winter, that is from September to June, the arctic air masses form over the polar basin: The continental type over the solid-pack ice north of Bering Strait, an area about half the size of the United States; and the maritime arctic air over the Atlantic side of the polar basin where a larger percentage of water exists and where the water is relatively warm with respect to the sea-ice present. The continental polar air masses come mainly from the Siberian Anticyclone, which is a northern extension of the warm central Asiatic Anticyclone, although distinctly not the warm type itself.

Unstable maritime polar air masses are formed in the North Atlantic during the entire year. The front between these masses and the continental polar or arctic air from Canada, Greenland, or Scandinavia is subject to the greatest storm activity in the Northern Hemisphere. Here is experienced the worst flying weather to be found on any of the north polar routes, if not on the whole earth.

The more stable types of both polar and maritime air come from middle latitudes (around 45°–55° N.) in North America or central Asia, the Atlantic or Pacific. Being warm-core the masses tend to stagnate in the regions where they are formed so that the invasion of these masses into the polar regions is rare. Whatever air of this type existing in the arctic or subarctic regions comes rather by a slow process of extension of the area of the warm anticyclones from southerly regions into the higher latitudes, as in the fall or "Indian Summer" in central Canada, or in Siberia.

About the only type of Pacific air that is found in the arctic, and that only rarely when a deep cyclone is centered in the Bering Sea, is mPW air from the northern extension of the Hawaiian High, which pours across the high ranges of the Alaskan coast into the interior valleys. Occasionally, the stable continental air drains down from the plateaus of the Rockies or of Mongolia, into the arctic prairies of Canada or Siberia for weeks at a time, even in December or January. This condition gives perfect cAVU weather over a vast area, with temperatures perhaps 20° to 30° above normal, thus reversing the normal condition when midwinter is a season of little flying activity.

Stable maritime air sometimes persists for long periods along the coasts. In such cases aviation is hampered by surface fogs or stratus, although such weather may be ideal for long distance

flights if fog-free terminals are available. Tropical air aloft invades the arctic only on rare occasions, and only in the Atlantic sector, coming from the Azores high in advance of an unusually deep low. Surface tropical air would be even more rare north of 60° N.

The temperature distribution in individual air masses in the arctic tends to be more uniform than in the temperate zones, but less homogeneous than the tropical air masses. In the fall and spring with rapidly moving of cold types of air masses, the coldest air may be just behind the front, so that extreme cold is coincident with the most stormy weather conditions such as strong gusty winds, rain, snow, and blizzards. The cold in such cases may preclude human activity even though the turbulence associated with the front keeps the temperature from dropping to 50° to 60° below zero, as it does in stagnant air masses. Usually if the wind is at all strong, the temperature will be above 20° below zero.

Exceptions to this rule will be noted in places like Wrangel Island, where local drainage off of the continent may give temperatures of minus 40° F. with strong winds. In the middle of the winter (December through February), on the other hand, the coldest air is to be found a day or more after the frontal passage, even in rapidly moving air masses, since turbulence in the frontal zone is about the only *warming* influence to be found in the arctic at that season.

WIND CIRCULATION OF THE POLAR REGION

From the limited data available, a generalized picture of the wind system of the north polar region can be constructed. Of primary importance is the anticyclonic circulation. As little *winds-aloft* data are available for the areas north of the eightieth parallel, conclusion about the upper-wind circulation in the Polar Anticyclone can be based, to a limited extent, on the knowledge of the circulation in anticyclones of lower latitudes.

The Polar Anticyclone, as is the case with the continental anticyclone of winter in lower latitudes, is dependent on a net loss of heat. However, in the case of the continental anticyclone of lower latitudes, sufficient insolation is received during the warmer half of the year to not only end its existence, but even to replace it with low pressure. In the summer the Polar Anticyclone is not destroyed but pressures are considerably reduced by the added insolation. During the long winter little heat is received from the sun, and there is a continual loss of heat through radiation,

with the result that there is a piling up of cold, heavy air. When a sufficient amount of air has accumulated at the North Pole so that a balance no longer exists, a gradual flow of air out of this cold air dome takes place. While the direction of this outflowing air is at first from the north, it soon assumes an easterly component, due to the rotation of the earth. Velocities associated with the central core of this arctic air mass would be small. It is believed that the vertical extent of high pressure is not great in the polar anticyclone and that above the first few kilometers the pressure field is probably reversed, with low pressure present. If the above assertion is true, the motion of the air in the Polar Anticyclone above the first few kilometers must be anticlockwise or westerly about the North Pole, with a slight component in the direction of the Pole to compensate for the loss of air at the lowest levels.

While there is a more or less steady flow of air out of this cold air dome, the process is greatly accelerated at times by the passage along its periphery of areas of low pressure which upset the balance and induce large masses of the cold air to break away from the parent mass and move out of the polar region along certain well-defined continual paths.

Those periodic mass outbreaks of cold air are not limited to the lowest levels, but embrace the entire troposphere, disrupting the shallow easterly circulation of the lower levels and also the westerly circulation above 6,000 feet. At times low pressure

Figure 3-2.—Blizzard.

centers will invade the region usually occupied by the Polar Anticyclone with attendant gales and stormy weather. Incursions such as these would be more numerous in the summer when the anticyclone is weakest, and when it has been depleted by mass outbreaks of cold air into lower latitudes.

As we mentioned earlier, areas of low pressure pass along the periphery of the cold air mass and certain areas are zones of greatest frequency. One such zone lies along the Atlantic Arctic Front. In this zone there is no well-pronounced prevailing direction and winds are strong and variable. This front marks the mean southern boundary of the arctic air mass. It extends from the vicinity of southern Greenland northeastward into the Barents Sea and beyond, changing its mean position with the progression of the seasons. Another such active region exists along the Pacific Arctic Front which extends from Alaska to eastern Siberia, passing through the Bering Sea. In addition there are two regions with winds of monsoon character, one in Siberia and the other in Alaska. Of local consequence are katabatic winds. These winds are caused by the downrush of cold air from higher elevations. The passage of a low may provide the necessary pressure gradient to set such winds into motion. These winds frequently reach gale force. If the area is snow-covered, the turbulent action of the winds will carry the snow dust aloft to such heights as to blot out the sun. Winds of this character can occur along the entire outer portion of the arctic basin, where there are elevations or mountains from which the cold air can sweep. They are known to occur along the deeply indented coast of Norway, at Wrangel Island, and in the Aleutians.

Local winds in the Alaska region are known as *williwaws*, *takas*, or *kniks*. Their strength is greatest in the months when the temperature contrast between the land areas and the open water is the largest. The critical velocity marking the beginning of sufficient turbulence to carry the snow dust aloft is about 11 m. p. h. At about 18 m. p. h. the turbulence is great enough to carry sufficient snow dust aloft to reduce the visibility to a point presenting a landing hazard to aircraft.

REGIONAL WIND SYSTEMS

The first region to be discussed is that portion of Siberia east of the Verkhoyansk Mountains. The wind system of this region is monsoonal in character. During the colder months, from September through March, a ridge of high pressure is present over

eastern Siberia and southerly winds prevail along the northern portion, blowing out from the cold land surface toward the Arctic Sea. These southerly winds are strongest along the north coastal areas, while in the interior the winds are light with long periods of calm.

For instance, at Verkhoyansk in the interior, during February to May there is practically no surface wind. Even in October and November the surface winds are light, while at Tiksi Bay, on the coast, the average wind velocity is about 12 m. p. h. except during March and April when the average drops to between 6 and 7 m. p. h. At Verkhoyansk the frequency of gales is greatest during the months of June, July, and August with an average of two or three per month. During these latter months the thermal low pressure system shows greatest development over the interior. Along the coast the frequency of gales is least during these same summer months, Tiksi Bay having an average of one per month from April through September. During the colder months when the anticyclone is well developed over the continent there are no gales in the interior at Verkhoyansk, but during these same months at Tiksi Bay the frequency is greatest. From October

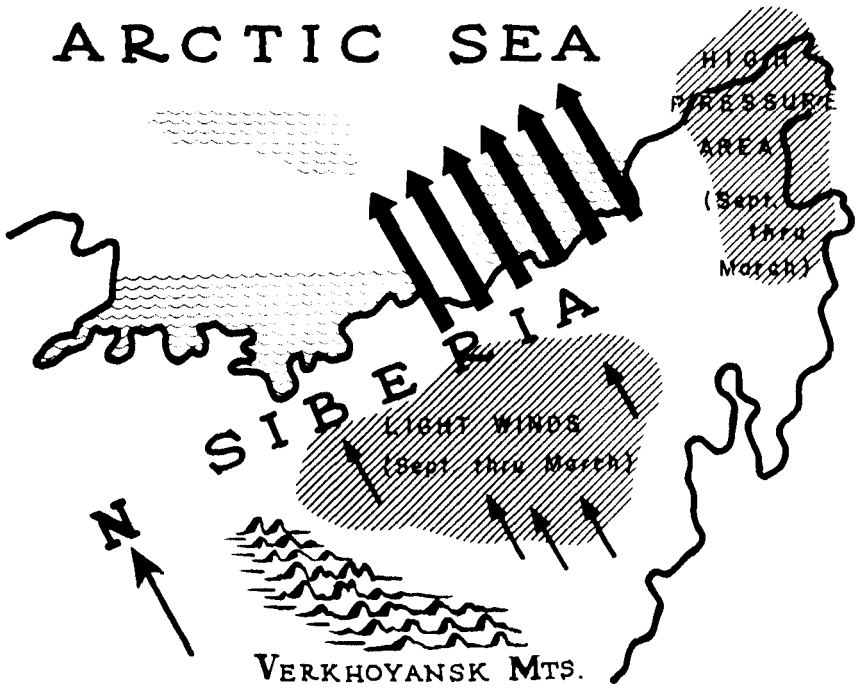


Figure 3–3.—Winter wind system of Siberia east of Verkhoyansk Mountains.

through May there is an average of about four gales each month. At Verkhoyansk the monsoonal character is also reflected in the winds aloft.

In the winter at 3,000 feet, 56 percent of the observed directions are south to southwest at about 10 m. p. h. At 10,000 feet the quadrant having the greatest percentage is to the southwest with 37 percent. Low pressure areas seldom invade this continental area of eastern Siberia because of the uninterrupted strength of the anticyclone. Any cyclonic activity is fairly well confined to the region between the Polar Anticyclone and the ridge of high pressure in eastern Siberia. The passage of cyclones in the region referred to above would affect the wind system along the northern quadrant of the Siberian anticyclone. Northwest winds follow in the wake of these cyclones and this could account for the fact that of the observed winds at 10,000 feet at Verkhoyansk 19 percent are northwest.

There is insufficient information about conditions above to draw any conclusions, but from the few available observations it appears that practically all directions are represented. At 3,000 feet southerly winds are less predominant in spring; 30 percent are south to southwest at 11 m. p. h. There is a secondary direction of greatest frequency from the northeast to north-northeast of 25 percent. At 10,000 feet, in spring, 50 percent are from that 90° quadrant from south-southwest to west-northwest, while 40 percent are from that 90° quadrant from north to east at about 12 m. p. h. At this elevation those winds having the least frequency are those with a southeasterly component. Summer brings a reversal of the wind flow, at which time the thermal low develops over the interior and winds become northerly at Verkhoyansk.

At 3,000 feet 30 percent are north-northeast to east-northeast with a secondary maximum of frequency from south-southwest to west-southwest. At 10,000 feet, however, 55 percent prevail from the northwest to northeast, and at 20,000 feet 64 percent are west to north. The great depth of the northerly current in summer is no doubt dependent upon the fact that at that time Verkhoyansk is located along the pressure gradient between the relatively high pressure of the polar region and the low pressure of the Asiatic continent. Autumn again brings southwesterly winds at 3,000 feet with 55 percent south-southwest to west. A gradual veering of the wind takes place with elevation, and at 10,000 feet 46 percent of the observed winds are from southwest to west-northwest at 14 m. p. h.

Here Bering Strait and the land areas immediately to the east and west, being low in elevation, present no obstacle to the free interchange of air between the arctic basin and the region of the Bering Sea. During the winter there is a prevailing northerly wind through this region. This northerly flow of cold air replenishes the air lost through the flow of air from the Bering Sea into the Pacific Ocean during the winter season, at which time the Aleutian low is well pronounced. The surface winds and upper winds at Nome, Alaska, confirm this. Sixty percent of the surface winds at Nome are from north to east-northeast at about 10 m. p. h. and continue from that quadrant up to 6,000 feet. At 10,000 to 13,000 feet the winds back to a northerly quadrant and about 50 percent are from that direction with an average velocity of 24 m. p. h.

Autumn winds at Nome are similar to those in winter, with 64 percent of the surface winds from the quadrant between north-northwest and east-northeast averaging 8 m. p. h. At 10,000 feet 55 percent of the winds fall in that segment between north and northeast, with an average velocity of 21 m. p. h. However, in spring and summer when the Aleutian pressure system is less pronounced and farthest south, there is no such marked prevalence in direction aloft as there is in fall and winter. It can be said that there is a noticeable absence of southerly winds at 10,000 to 13,000 feet, all other directions being represented.

The wind regime of Alaska, like that of eastern Siberia, is to some extent monsoonal in character. In the warmest months a thermal low develops over the interior of Alaska whereas in winter high pressures are present. As a result winter winds at Fairbanks are regulated by the Alaskan and polar high pressure systems and by the proximity of the Aleutian low pressure system to the south. Surface winds at Fairbanks are light as that settlement is located in a sheltered valley. The average winter surface velocity is between 4 and 5 m. p. h.

Immediately above the surface at 1,500 feet 71 percent are east-northeast to east-southeast at 13 m. p. h. But with increasing height there is a veering of the wind and at 10,000 feet 43 percent are south to west-southwest at 21 m. p. h. At 13,000 feet winds from the south to northwest at 22 m. p. h. have the greatest frequency.

Winds of spring at Fairbanks, like those of winter, veer from the

southeast at 14 m. p. h. at 3,000 feet, to southwest at 19 m. p. h. at 13,000 feet. This would indicate that, whereas the low pressure at the surface is centered to the southwest of Fairbanks, at 13,000 feet the lower pressures are found to the northwest.

In summer high pressures replace the low pressures of winter in the Gulf of Alaska and the warmed Alaskan interior produces a thermal low. The net result produces decreasing pressures across Alaska toward the north. The pressure system also does not change as much with elevation as at other seasons. Consequently, there is no great turning of the wind with increasing elevation. Prevailing winds at Fairbanks in summer, therefore, are southwesterly at about 16 m. p. h. at all levels. This is slightly less than the average at other seasons.

The progression from summer to autumn brings the greatest change at the 3,000-foot level with a shift of the prevailing wind direction from southwest to southeast and a slight increase in velocity from 14 m. p. h. in summer to 17 m. p. h. in autumn. While there is practically no change in direction in the 6,000 to 13,000-foot layer, there is a slight increase in velocity from 16 to 20 m. p. h. for the prevailing southwesterly wind. It can be said that the greatest seasonal variation in the wind at Fairbanks takes place below 6,000 feet, with little change above that level. This would indicate that mean surface pressure changes from season to season, although well pronounced, are not reflected to any height and that the relative pressure distribution above 6,000 feet is rather constant throughout the year.

WINTER WINDS AT POINT BARROW

Winter winds at Point Barrow are almost entirely dominated by the Polar Anticyclone. Northeast to east winds prevail up to at least 13,000 feet. However, the frequency percentage decreases with height from 48 percent at the surface to 30 percent at 13,000 feet. The average surface velocity is 14 m. p. h. From 3,000 to 13,000 feet the average velocity remains about 27 m. p. h. for these east to northeast winds. The change from winter to spring causes the winds aloft at Barrow to veer about 22° with little change in surface wind direction. The velocity likewise does not vary greatly from winter to spring except that, whereas in winter there is slight increase in velocity for the prevailing direction from 25 m. p. h. at 3,000 feet to 29 m. p. h. at 10,000 feet, there is a slight decrease in the velocity with elevation in the spring.

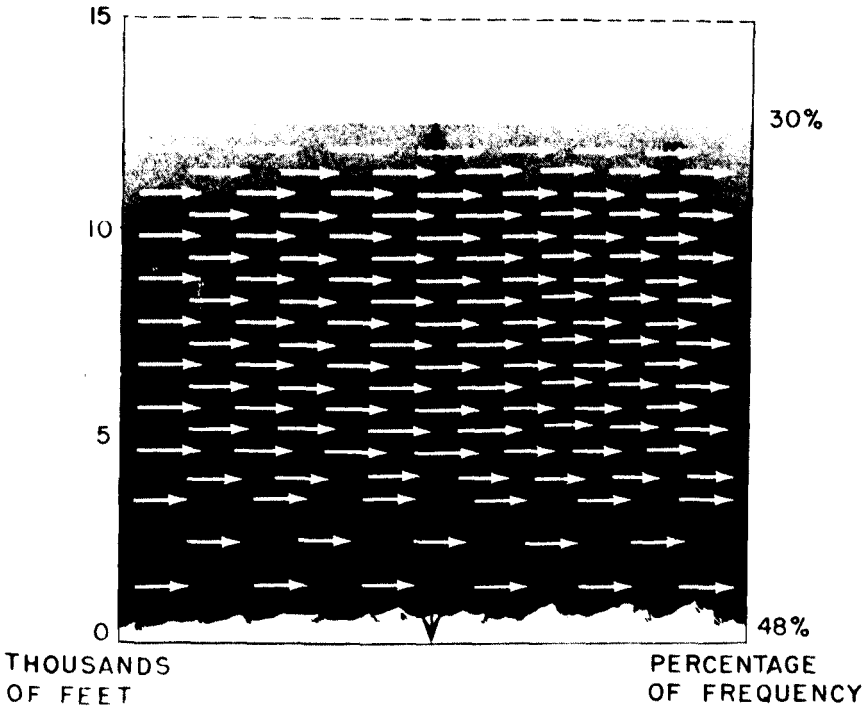


Figure 3–4.—Winter winds at Point Barrow.

Summer brings the greatest departure from the polar anticyclonic wind pattern at Point Barrow. At the surface, easterly winds still prevail but a secondary maximum of greatest frequency exists from the west to southwest. Aloft the direction of greatest frequency becomes southwest to west from 3,000 to 10,000 feet. At 13,000 feet there is no particular quadrant of greatest frequency, except that the greatest percentage of wind has a westerly component. At 13,000 feet those winds having the greatest westerly component are the strongest, reaching about 22 m. p. h. The easterly winds have the least velocity. Easterly winds are again predominant in the fall, however, with 58 percent of the surface wind coming from the east-northeast to the southeast at 16 m. p. h. At 3,000 and 6,000 feet those winds having the greatest frequency, accounting for 45 percent of the total, are from east-northeast to southeast with an average velocity of 24 m. p. h. At 10,000 feet the dominance of easterly winds is less pronounced, while at 13,000 feet there is a small weight of prevalence in favor of west to northwest winds at 21 m. p. h.

The frequency of gales in Alaska is similar to that of eastern Siberia. In the interior the season of greatest frequency is summer. Along the coast the season of greatest frequency is winter. Coastal stations have a greater annual frequency than inland stations. Point Barrow on the north coast has an average of 18.7 gales a year, while Fairbanks in the interior has an average of only 0.9. Wrangel Island has an annual average of 50.4 gales. From May through August there is an average of two each month. The season of low average at Wrangel Island is associated with the summer, at which time the Polar Anticyclone is weakest and the Aleutian Low is dissipated. During the colder months from September to April the average monthly frequency is between five and six. At this season the Polar Anticyclone is present and the Aleutian Low is well developed.

OVER NORTHERN CANADA

Little is known of the upper-wind regime of northern Canada. The elevation of the many islands of the Canadian archipelago is not great. The area is covered with ice and snow a great portion of the year. An extension of the Polar Anticyclone extends down over this region. A steady flow of air out of this high pressure area continues throughout most of the year, being greatest in winter when the anticyclone is most highly developed. As a result, winds across the Hudson Bay region are northwesterly in winter. The depth of this northwesterly current is reflected in the winds aloft at Port Harrison. Northwesterly winds are most frequent up to the limit of observational data at 13,000 feet. Progressing from winter to summer the Polar Anticyclone and its Canadian extension gradually weaken, so that the northwesterly surface winds do not penetrate as far south as Port Harrison. Aloft, however, there is still a prevalence of northwesterly wind at 6,000 to 13,000 feet, although the velocities are not as great. There are no data as to the number of gales in this region. But in the colder months of the year, during the presence of high pressure there would be few gales. In the warmer months the weakened anticyclone would allow cyclones to invade this region, with attendant gales.

The ice-covered region of Greenland, because of its high elevation and great size, exerts a considerable influence on the wind flow in its vicinity. The wind circulation in close proximity resembles that of an anticyclone. At Etah, in northwest Greenland, during the winter, the prevailing winds, from the surface to 3,000

feet, are east to northeast, flowing down from the ice cap. Between 6,000 and 13,000 feet there is a shift to south and southeast, with the circulation in relation to the island resembling that found around an anticyclone. This same circulation scheme of winds off the ice cap at low levels, with south to southeast winds above 6,000 feet, holds true for spring and summer. In autumn the prevalence of air flow from the northeast continues up to 10,000 feet, and at 13,000 feet becomes northwest to north.

The wind scheme at Mount Evans is similar to that at Etah as both are on the western side of Greenland. The lowest level of air at Mount Evans has an easterly component coming from the ice cap. Above 3,000 feet the wind assumes a southerly component at all seasons. A short summer record of winds-aloft data was obtained at a station on the ice cap in central Greenland. At this season the region of highest pressure in the arctic is located off the northwest coast of Greenland, and the region of lowest pressure is to the east, at Baffin Island. On the surface of the ice cap as a consequence, 70 percent of the wind is from the east-northeast to south-southeast. This prevalence of easterly wind continues above the ice cap to a depth of at least 17,000 feet. Too much reliability cannot be placed on the record because of its shortness. At East Station, on the east coast of Greenland, there is a high percentage of calm at the surface, a maximum in the summer of 88 percent and a minimum in the autumn of 26 percent. Light easterly winds persist for the remaining time. Immediately above the surface layer a northwesterly wind prevails, and the analogy of Greenland's wind system to that of an anticyclone is again demonstrated.

Reykjavik, off the southeast coast of Greenland, is in a region of cyclogenesis and the wind regime should be a variable one. During the winter, Reykjavik is in the central portion of the statistical low pressure system. Southeasterly winds prevail in the first 3,000 feet of atmosphere. At 6,000 feet there is no prevailing wind, and at 10,000 feet and 13,000 feet westerly winds prevail. In the spring this statistical low has moved eastward and decreased in intensity, and the prevailing wind at Reykjavik is northwesterly. Above the surface easterly winds prevail up to 10,000 feet and at 13,000 feet northerly winds prevail. In the summer the pressure in the Polar Anticyclone is highest to the northeast of Greenland and the prevalence of the deep current of northerly wind in evidence at East Station in Greenland extends eastward as far as Reykjavik. This current of north wind exists from the surface

up to at least 13,000 feet. Likewise in autumn northerly winds prevail from 3,000 to 13,000 feet.

Observations made during the Wordie expedition to northwest Greenland in 1937, and to the Canadian Arctic in 1938, confirm other observational data to the effect that the highest wind velocities are found at or immediately below the tropopause. The height of the tropopause for one observation was found at 37,750 feet, while the maximum wind velocity occurred at 32,150 feet. The maximum velocity at this elevation was 34 m. p. h. The height of the maximum wind velocity and likewise the height of the tropopause was found to vary with the surface pressure. During the presence of low pressure areas the maximum velocity occurred at lower elevations, from 26,250 feet to 31,150 feet, and in high pressure areas from 32,800 feet to 37,750 feet. In comparison with data collected at other seasons the maximum velocities are found to occur about 10,000 feet lower in the winter than in the summer.

WIDELY DIFFERENT SYSTEMS

A comparison of the winds-aloft regimes at Tikhaja in Franz Joseph Land and at Tromso, Norway, affords a good example of the widely different systems that exist on either side of the Atlantic Arctic Front. Tikhaja, near the 80th parallel, lies to the north of the front and its wind system is largely governed by the Polar Anticyclone. Tromso, on the seventieth parallel, lies south of the front and its wind circulation is governed by the Icelandic Low. However, the wind system at Tikhaja is also influenced by the latter low. Northeasterly winds are prevalent up to 13,000 feet at Tikhaja for all seasons except summer. In summer at the surface 32 percent of the time it is calm and 34 percent of the time the winds are north to east. Above the surface layer, in summer, there is no marked prevalence from any direction. The Icelandic low pressure system is practically nonexistent in the summer and the Polar Anticyclone is weak. For all seasons at Tromso, south of the front, there is a prevalence of southerly wind, shifting to southwesterly above 3,000 feet and extending up to 10,000 feet. At 13,000 feet there is no direction of greatest frequency. Velocities from 1,600 to 10,000 feet are slightly higher at Tikhaja, the average being between 12 and 18 m. p. h., while at Tromso averages are from 10 to 18 m. p. h. At 13,000 feet the average is slightly higher at Tromso.

In the winter the surface winds at Dikson Island, in the Kara

Sea, prevail from the south with a secondary maximum from the northeast. This would seem to indicate a conflict between the outflow from the continental anticyclone and the Polar Anticyclone. At no great distance above the surface the air flow is largely from the northeast and remains in that quadrant up to at least 13,000 feet. During the spring months the prevailing winds aloft are easterly. In the summer surface winds are northerly and flow into the heat low of the continent, but above 1,600 feet and continuing up to 13,000 feet the prevailing winds are southerly. During autumn there is a return of easterly winds aloft. The average wind velocities aloft are greatest in summer, blowing from 16 to 22 m. p. h., while velocities in winter range from 14 to 18 m. p. h. Surface wind velocities are greatest in winter, and the occurrence of gales is likewise highest then, averaging nine per month, against an average of three per month during the summer, for a yearly total of 80.

A summary of the winds-aloft data gathered on the Norwegian north polar expedition in the *Maud* follows. The data were gathered in the years 1918–1925, between latitudes 77°33′ N. and 70° 43′ N., and between longitudes 105°40′ E. and 175°15′ W.

For all seasons, combined surface winds showed the greatest frequency from northeast to southeast with 51 percent of all observed winds from that quadrant. The average velocity of these prevalent winds was 9 m. p. h. At 3,000 feet all wind directions are about equally represented, except for north and northwest which have about half the percentage of other directions. The velocity, as well as the prevalence, is least for these north and northwest winds, being 16 m. p. h. with southeast winds having the greatest velocity, 19 m. p. h. At 6,000 feet the situation is similar to that at 3,000 feet, except that westerly winds have a slight edge in percentage. At 13,000 feet the weight of prevalence of west and southwest wind increases but all other directions are still well represented. Velocities at this level are least for southeast winds at 17 m. p. h., and greatest for west winds at 22 m. p. h. At 20,000 feet the weight of prevalence of west and southwest winds increases to a combined total of 33 percent, southeast being the least with 5 percent, and all other directions averaging 11 percent each. Velocities at 20,000 feet are greatest for west and northwest at 25 m. p. h. and least for southeast at 19 m. p. h.

From an average surface velocity of 7.8 m. p. h. there is a sharp increase to 17.4 m. p. h. at 3,000 feet above sea level. From 3,000

to 26,000 feet the rate of increase, while at first very small, becomes progressively greater. At 26,000 feet the highest average velocity is reached, 34 m. p. h. The upper limit of the troposphere is also found at about 26,000 feet and is evidently associated with the maximum wind. Average velocities at all elevations are greater in the winter than in the summer, the average difference betweeen the two seasons being 2.5 m. p. h. At 16,000 feet the difference is greataest, 6.3 m. p. h., and at 23,000 feet the difference is least, 1.6 m. p. h.

SUMMARY OF WINDS

There are certain factors that should be considered in regard to the evaluation of the wind regime of any region. As is well known, there are shifts in the climatic scheme of the earth. As a rule these shifts are relatively small but in some years they are large and affect the climate of a region materially. These larger climatic shifts may amount to as much as several hundred miles, so that the average seasonal temperature at a given point may equal that usually experienced at a point several hundred miles to the north or south.

Naturally any climatic shift involves the wind system of a given region. The degree of change in the wind system may be so great that the wind system of one year would differ widely from that of another. Such climatic shifts do occur along the margins of the arctic basin. The desirability of long observational records is thus demonstrated, to give increasing value to a statistical study of climatological data.

Another factor affecting the representativeness of wind data is the cloudiness factor associated with wind direction. In certain areas of the Arctic, winds from one direction will bring clear skies, and as a consequence winds-aloft data gathered at such times will extend to high altitudes. Winds from other quadrants will bring low cloudiness and observations will be limited.

Some of the conclusions set forth in this discussion of the arctic wind scheme have been based on records of short duration and weighted in favor of those winds associated with clear skies. These conclusions err in proportion to the unrepresentative character of the data. However, it is believed that the data are such as to justify the statement that the conclusions set forth herein do approximate the actual conditions.

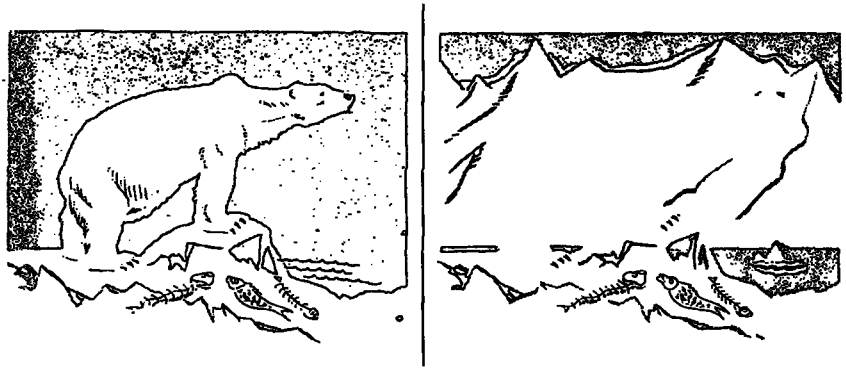


Figure 3-5.—Visibility.

VISIBILITY IN THE ARCTIC

The problem of visibility in the Arctic is extremely complex. The air is very transparent. The records of many travelers are replete with accounts of the extreme range of visibility. It is not uncommon to see dark mountains 100 miles distant. On the other hand, the lack of contrast, particularly where all surface objects are covered with new snow, results in the inability to distinguish objects close at hand. The traveler may easily fall into a crevasse which he is unable to see in midday. The black nose and claws of a polar bear may be seen clearly before it is possible to see any outline of the animal, because the yellowish white of the fur blends with snow-covered background.

The frequent well-marked temperature inversions of the arctic region explain the many accounts of mirages. Objects that are known to be below the horizon are not infrequently visible as mirages; and the periods of daytime and twilight are lengthened as the normal index of refraction is altered. The inversions may also interfere with the identification of landmarks through distortion, and the estimation of vertical distances is made much more difficult.

In winter the poorest visibility is indicated in the vicinity of Cape Chelyuskin. Improved visibility conditions are to be found to the west in the neighborhood of Murmansk, and to the east in the neighborhood of Uelen and Anadyr Visibility conditions are better in the spring, particularly over inland stations. The section with the poorest visibility continues to be the Kara Sea. Dur-

ing the summer and fall the conditions are better over the inland stations than over the coastal stations. But again, the poorest conditions are to be found in the Kara and eastern Barents Sea regions. The very short record for Franz Josef Land indicates that visibility conditions are much poorer at Tikhaja Bay in the south than at Rudolph Island in the extreme north.

Limitations to visibility in the arctic region are primarily fogs, blowing snow, and local smoke. The different types of fogs are considered in the next section. Local smoke is serious only in the vicinity of the larger towns, and often occurs with the shallow radiation fogs of winter.

Blowing snow constitutes a much more serious hazard to flying in the Arctic than in more temperate latitudes. By comparison, the snow is dry and consists of fine particles. It is easily picked up by gentle or moderate winds and is drifted into the hollows, leaving the higher elevations bare. Winds of 9 to 14 m. p. h. will raise the snow a few feet off the ground, and the blowing snow will obscure surface objects such as rocks and runway markers. Winds of 15 m. p. h. or higher will raise the snow to consider-

Figure 3-6.—Blowing snow.

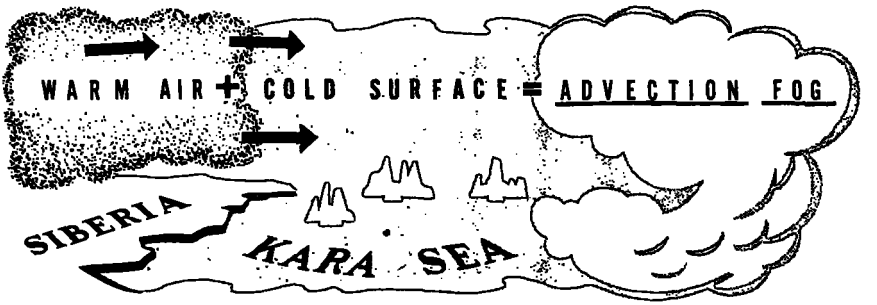


Figure 3-7.—Advection fogs.

able heights, obscuring buildings, radio masts, and other high objects. With high winds all traffic becomes impossible. The driven snow penetrates all types of buildings and equipment. The natives remain in their huts until the *urga,* as the blizzards are known, have blown over. These storms explain the poor visibility recorded at Chelyuskin in the colder months. The location of this station exposes it to frequent winds of sufficient velocity to cause almost continually blowing snow.

FOG

In many respects fog is the most important of the weather elements limiting aviation in the arctic regions. Over a large portion of the northern seas, fog may be expected to occur 90 or more days each year, and over small areas as many as 180 or more days each year. Any analysis of fog in the Arctic is rendered difficult due to the carelessness in defining and recording fog and to the lack of observational reports over large areas.

Two types of fog are frequent in the Arctic. The most common type is advection fog, formed when relatively warm air moves over a cold surface. A further condition is a fairly stable stratification of the air which would limit the increment of visible water vapor to the lowest layers of the atmosphere. Turbulence, whether convective or frontal in nature, is conducive to the formation of clouds but not of fog. The areas where conditions are most favorable for the formation of advection fog are the open waters of the Kara, Laptev, East Siberian, and Chukchi Seas during the summer. Fifteen to 20 days monthly with sea fog dur-

ing the summer are normal in these areas, and 20 to 25 days are not uncommon. In adverse years 30 days with fog may be recorded. The frequency of the summer sea fogs diminishes rapidly from the coast line inland, and diminishes less rapidly over the pack ice.

It will be noted from the data that the summer fogs are less frequent over the Barents and Norwegian Seas. This is due to the more turbulent nature of the lower atmosphere over these seas, resulting in less fog and more low clouds.

Little is known about the frequency of fogs north of the mainland of North America. It is probably that fog is only slightly less frequent over the Beaufort Sea than over the Chukchi Sea, and that fog north of the Canadian archipelago and Greenland is comparable to that over the central pack ice. In the summer the advantages of inland terminals over coastal points exposed to the sea fogs may be summed up in stating that fog is three to five times more frequent over the open water of the Arctic than over inland river ports, and many times more frequent than over interior highland stations.

Fogs are reported to occur in some localities when a sea breeze carries moist air from the sea over the land. Such a condition must be considered unusual, because the sea breezes are most frequent in summer when the land is much warmer than the ocean, and the turbulence in the cooled air passing over the warm land results in the formation of strato-cumulus clouds. However, there are days in the spring and fall when the land could be colder than the open water of the neighboring sea, and fogs result from the passage of moist air currents from the sea to land. The area

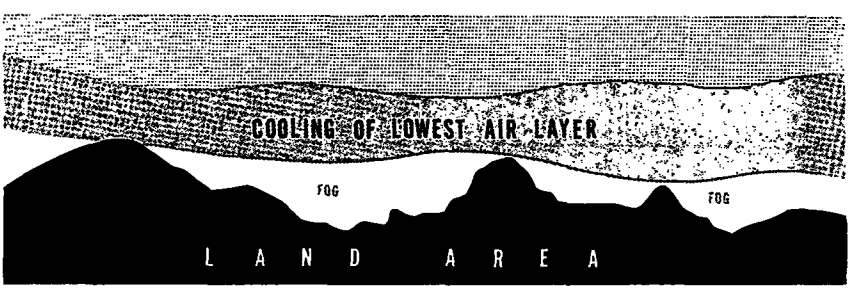


Figure 3–8.—Radiation fogs.

where this type of fog is most likely to occur is the outer islands of the Canadian archipelago, particularly Prince Patrick, Borden and Meighen Islands. Here the prevailing winds are northwest (from sea to land) at all seasons of the year. The fogs do not penetrate far inland, and localities 20 miles from the coast are relatively free of fog. Unlike other areas in the Arctic, the periods of maximum frequency of fog in the outer islands of the Canadian archipelago would be spring and fall.

The second type of fog of major importance in the Arctic are the radiation fogs of winter. These fogs form readily under inversion in very cold weather and are caused by the cooling of the lowest layer of air in contact with the ground surface. Cooling by radiation takes place most rapidly over the land areas and least rapidly over open water. The fogs that are formed are generally thin and shallow. They occur most frequently along river bottoms where the air drainage is poor and the air movement sluggish. The locale of most frequent occurrence appears to be in the lower Lena River valley in Siberia and the lower Mackenzie River valley in North America. They are also quite frequent in the Yukon valley and the valleys of the principal northward-flowing rivers of central and eastern Siberia. Radiation fogs are also common over the pack ice during very cold weather.

Over the river valleys and over the pack ice, these fogs may be expected from 8 to 12 days monthly during the winter. In more adverse years the number of days with radiation fogs may be doubled. In a few localities, such as the lower Mackenzie in the vicinity of Aklavik, early morning radiation fogs may be expected 20 to 25 days monthly during the coldest months. It should be stressed that these *frost fogs* do not present as serious an obstacle to aviation as do the *water fogs*. They are generally thin fogs, so that contrasting objects can be distinguished on the surface directly beneath the airplane. It is only in the brief interval when the airplane is passing through the thin fog layer that visibility is seriously reduced. With experience, landings and take-offs can be made with safety through the shallow frost-fogs.

Of considerable interest but of minor importance is the occurrence of *steam fogs*, also known as *arctic smoke*. They are formed by *steaming* from open water surface during extremely cold weather, occurring most frequently over rivers, unfrozen lakes, and open leads in the arctic seas. Such *steam fogs* are generally shallow and are quickly dispersed by wind. However, they may at times be sufficiently dense to obscure landing fields adjacent to

Figure 3-9.—Fog trails.

open water or to obscure landmarks along the airlines. Over the Arctic Ocean they serve the very important purpose of advising the traveler of the presence of open water. They are most noticeable when the temperature contrast between water and air is the greatest, i. e., at extremely low temperatures. In some places *steam fogs* are so frequent during cold weather as to be a natural part of the landscape. For example, Reykjavik, meaning "Smoky Bay," derives its name from the fact that steam fogs arise from the abnormally warm waters of the bay during extremely cold weather.

Of special interest is the fact that *fog trails* are left by airplanes when traveling through the very cold atmosphere of arctic regions. Canadian fliers have reported fog trails 18 miles long in the lower Mackenzie district. Various factors enter into the formation of these fog trails: the amount of condensation nuclei in the exhaust gases; the formation of water vapor in the exhaust gases; the lower pressures set up by the airfoils; and the turbulence set up by the rapidly moving airplanes. It is possible for one airplane to follow another by means of its fog trail.

The summer sea fogs occur most frequently with easterly winds over the portions of the Arctic north of the Siberian coast. The explanation may be offered that the stable condition necessary for fog formation exists with easterly winds. It was noted from the upper air observations taken on the *Maud* that the temperature inversion aloft existed most frequently with easterly winds and that warm air aloft was carried over the arctic seas in a southeasterly current. The westerly winds were generally uniformly cold at all levels. During the summer, fog occurred most frequently at all but two of the stations with winds from the north to east. The two exceptions were the stations on Great Laakhov Island and Bulun. The latter is an interior station and the former showed considerable variability due to the adjacent land masses.

During the fall and winter, the fogs appeared to occur most frequently with south or southwest winds. This would indicate that the stable conditions in which the fog occurs are associated more frequently in this portion of the arctic region with the great Asiatic Anticyclone than with the Arctic Anticyclone. However, considerable variability may be expected from year to year with the varying strength of the two anticyclonic systems.

Fogs are not to be expected in summer with offshore winds, as a rule. The offshore winds are generally dry and are not cooled sufficiently to cause the formation of fog.

Summer fogs are most frequent with light winds, but may occur with winds of high velocity under favorable conditions. Since they are advection fogs, they do not form readily in calm weather. The opposite is true of the mists or *frost fogs* of the winter season. These latter are radiation fogs and form most readily in calm weather or with very light winds. High winds are very unfavorable for the formation or continuation of fog in the colder months of the year.

Fogs in the arctic region are more frequent in the late night and early morning hours than at any other time. In discussing the fogs of the Kara Sea region, Vize has noted that the maximum frequency of fogs occurs at midnight or in the hours immediately following, and that the minimum frequency occurs at noon or in the hours immediately following. This agrees closely with experience of the *Maud* in the East Siberian Sea.

Data on the diurnal distribution of mist, or frost fogs, are not so conclusive, but indicate a similar distribution to the summer advection fogs. The data from Aklavik indicate that frost fogs are much more frequent in the early morning than at noon or in the evening. It is the common practice in these regions to limit aviation activities to the late morning or afternoon hours. It is particularly important that all flights terminating in the lower Mackenzie, the Yukon, or the Lower Lena River valleys during the winter season be so planned that they are completed at midday or in the afternoon.

CLOUDINESS

In general, cloudiness over the arctic regions is greatest in summer and fall and least in winter and spring. This statement should be modified slightly when dealing with specific locations. Those localities in the Arctic Ocean or under the immediate influence of the ocean circulation will have the maximum cloudiness

in midsummer. Those localities under the influence of the adjacent continents will have the maximum cloudiness in early autumn, with a secondary maximum in early summer.

In the warmer months of the year cloudiness shows a maximum during the daylight hours and a minimum during the night hours. In some months the trend may be reversed and the maximum cloudiness will occur at night. This may be due to the occurrence of fog at night, but further observations are necessary to verify the present data—observations taken over wide areas simultaneously. During the winter half-year the observed diurnal variation is largely due to conditions of the light, more clouds being observed in the daytime or twilight hours than are observed at night.

The character of the cloud deck is quite different over the Arctic Ocean than over more temperate latitudes. Stratus clouds are by far the most frequent type observed. They cover the sky completely and seem to merge with the snow or ice-covered landscape at the skyline. In the summer and fall the stratus clouds will constitute from 70 percent to 80 percent of all clouds observed. In the winter and spring they are not quite so frequent, making from 45 percent to 60 percent of all cloud types observed. These proportions apply only to conditions over the Arctic Ocean or adjacent seas. Along the coast lines the stratus clouds are slightly less frequent and have a tendency to be more broken up by convective currents, with an increase in the percentage of stratocumulus type of cloud being reported. In the winter, altostratus and cirrostratus clouds are frequently recorded. At this season the clouds are thin; during daylight hours the disk of the sun can frequently be observed through the clouds.

Cloudless days are uncommon in the Arctic. Days with zero- to two-tenths coverage usually occur with the greatest frequency during February and March, although the number of such days in a winter period will total no more than 3 to 10. The greater number of clear days will naturally occur over those areas where anticyclonic conditions are most likely to prevail. Thus the expectancy of clear days is greatest over the interior of the arctic basin, with the lower Mackenzie valley and the lower Lena and Yana River valleys running second. Clear days are least frequent over the Barents and Kara Seas and relatively infrequent over the Chukchi Sea. Cloudy days, those with eight- to ten-tenths coverage, are most frequent over the arctic basin in summer. From May to October they will run between 18 and 24 a month over most of the area. There are a few more cloudy days over

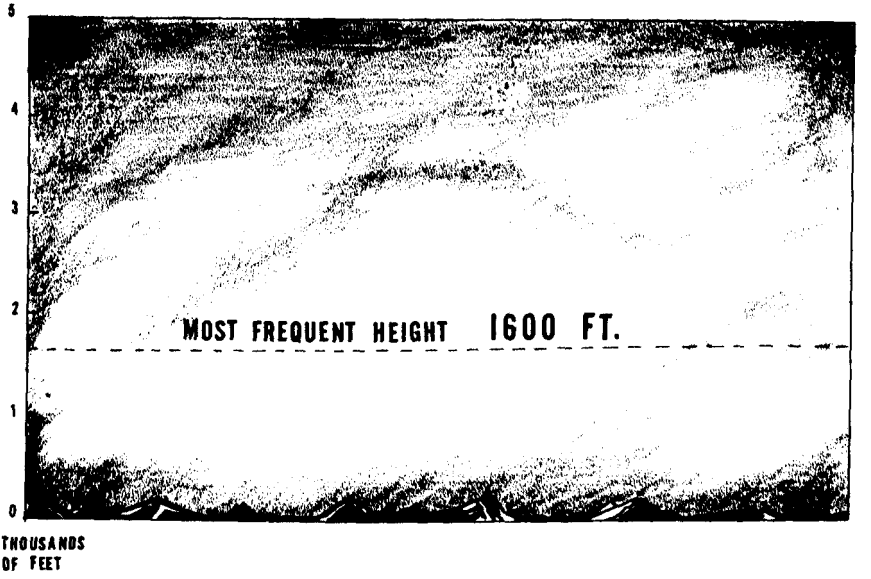


Figure 3–10.—Cloud heights are lower in the Arctic.

the pack ice than over the coastal areas. In winter the number of cloudy days will generally run between 6 and 12 a month, the greater number occurring in the same areas as the least number of clear days.

The conditions described apply only to the arctic basin and the adjacent coastal areas. In the interior of the continents within the arctic zone cloudiness is appreciably different. In particular the summer cloudiness is much less, with few cloudy or overcast days, but with a large proportion of partly cloudy days. The clouds are mostly of a cumuliform nature, as contrasted to the stratus clouds of the arctic basin. In winter the cloudiness of these interior sections is largely governed by their location with respect to the moving cyclonic disturbances. Those localities near the paths of the disturbances will have a high percentage of cloudiness with a large number of cloudy days. Other localities far removed from the paths of storms will have less cloudiness, with a larger number of clear or partly cloudy days.

Cloud heights are lower in the Arctic than in the temperate latitudes. The most frequent type of cloud, the stratus clouds, will be found anywhere between zero and 5,000 feet. The observations on the *Maud* indicated that the most frequent height is below 1,600 feet. However, the measurement of the ceilings were

made only when a kite flight or a pilot balloon observation was practicable. With very low clouds in summer, the kites became iced and were forced down so that, in general, measurements of the ceiling could not be made. From other sources it is indicated that the height of stratus clouds is frequently found between 600 and 1,000 feet. Stratocumulus may be expected most frequently at around 5,000 feet; and, as mentioned previously, they are more frequent over the coast than over the sea. Altocumulus have an average height of 10,000 feet and altostratus about 13,000 feet. The various types of cirrus clouds are encountered between 15,000 and 30,000 feet.

CEILINGS

The average height of the various types of clouds has been noted above. Data on ceilings are difficult to find and are not too reliable.

Low ceilings are most frequent over the Kara Sea area. Over

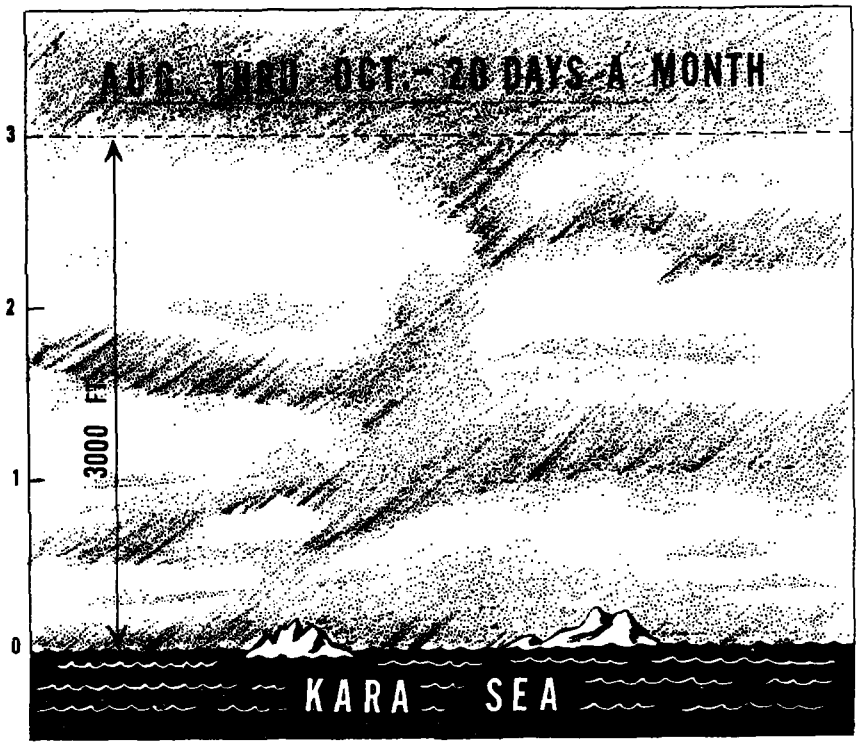


Figure 3-11.—Low ceilings over Kara Sea region.

the central polar or arctic basin they occur most frequently in the late summer and autumn. Ceilings less than 3,000 feet may be expected on 20 days a month in the Kara Sea region from August through October, and on about 15 days a month in early summer and late autumn. The best season is late winter and early spring, with approximately 10 days a month having low ceilings. In the Laptev, East Siberian, and Chukchi Sea areas the number of days with low ceilings will average about 5 less each season than over the Kara Sea area. The conditions over the Barents Sea are similar to those over the Kara Sea. Data for the American portion of the Arctic are not available. Conditions over the northern Alaskan coast and near the mouth of the Mackenzie River should be similar to conditions along the Siberian coast from the mouth of the Lena River eastward.

Slightly different conditions are shown by taking the occurrences of very low ceilings (less than 600 feet). The poorest conditions in midwinter and early spring are to be found in the Kara Sea region, but in late spring the area of most frequent very low ceilings shifts to the extreme northeast of Siberia. Uelen shows the poorest conditions in April, while in May the poor conditions extend from Wrangel Island to Cape Navarin. July and August are the poorest months of the region as a whole, taking into account the occurrence of ceilings less than 600 feet. In July the record at Cape Navarin shows more than 15 days with ceilings less than 600 feet. In the interior, the occurrence of low ceilings is not an important factor.

TEMPERATURE

The most common misconceptions of the Arctic are that the land areas are covered with eternal ice and snow; that there is everlasting winter with intense cold; and that with the everlastingness of winter there is an absence of summer and lack of vegetation. Greenland is a striking example of an ice-covered land possessing these qualities and from it the rest of the north has been pictured by analogy. The high elevation of Greenland and the rather heavy precipitation it receives are two factors which highly favor glaciation. In general, however, other arctic lands possess neither of these characteristics. Over a large portion of the Arctic the scanty snows melt rapidly with the approach of summer. Otherwise, glaciers would soon form. Most of what little snow does fall is soon swept by the wind into gullies and into the lee of

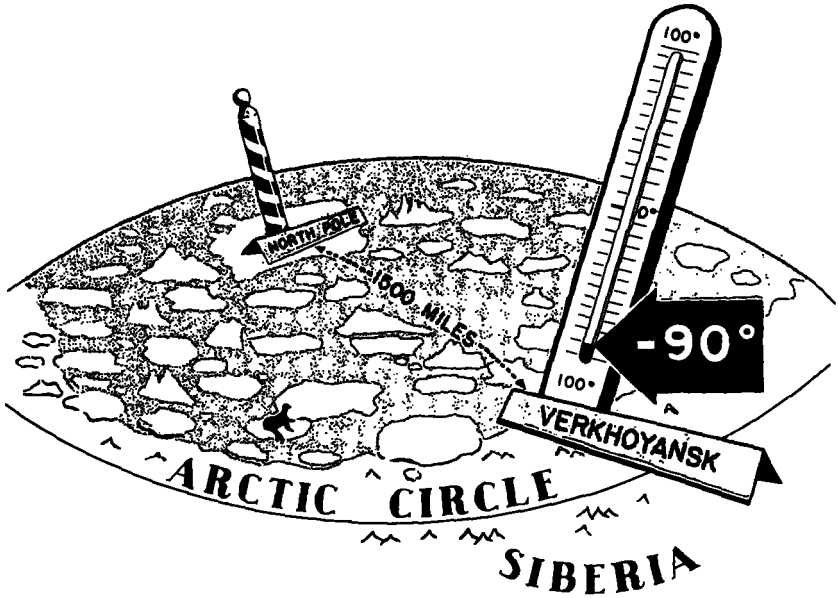


Figure 3-12.—Coldest recorded temperature.

the hills so that more than three-fourths of the arctic lands are comparatively free of snow at all seasons.

Next, considering the intense cold, it has been shown that temperatures below minus 60° F. are not possible at the North Pole, lying as it does at the center of a deep basin. At Herschel Island, off the north coast of Canada, the absolute minimum over a long period has been minus 54°. The lowest official temperature ever recorded in North America, minus 78.5° F., was registered at Fort Good Hope, several hundred miles to the south. Even at Havre, Mont., an extreme temperature of minus 68° F. or 8° F. colder than is theoretically possible at the North Pole, has been recorded. The coldest observed temperature on the surface of the earth was recorded at Verkhoyansk, near the Arctic Circle in eastern Siberia, well over 1,500 miles from the geographic pole. Until a few years ago this station enjoyed the doubtful honor of experiencing colder winter weather than any other known place in the world. Theoretically only the South Pole is colder. In 1929 a station was opened in the Oimekon River district, some 400 miles southeast of Verkhoyansk, and from the brief record available it is noted that the winter temperatures have consistently

averaged lower than those for the same time at Verkhoyansk. The lowest reading at the new station is minus 85° F., only 5° from the record of minus 90° found at Verkhoyansk. It is not at all improbable that a lower record will be established at this new station.

On the other hand, there is always a summer in the Arctic with lush vegetation in places, the presence of birds, and the hum of millions of insects. The myriads of mosquitoes can and do cause more distress than the cold. Not infrequent complaints of the summer heat are voiced. A maximum of 100° F. in the shade has been recorded above the arctic circle, and maximum 80° F. to 90° F. at stations not on the coast are the rule rather than the exception. Even with the lower maxima farther north, the high relative humidity produces oppressive conditions. Then, too, the heavy clothing necessary for protection against the insects adds to the general discomfort. Whereas native clothing is much more satisfactory in winter, the clothing of the white man is better than that of the Eskimo for summer use.

TEMPERATURE CURVE TYPES

A huge variety of climatic conditions are encountered in these regions. Areas adjacent to one another are found to have widely different climatic characteristics, determined by latitude, marine influence, and topography. A study of annual temperature curves reveals three well defined types—*maritime*, *coastal*, and *continental*:

1. In the Arctic Sea the temperature in June, July, and August deviates very slightly from the freezing point, thus producing a flat curve in summer. Likewise in winter there is a flatness to the curve, but this time the temperature stays around minus 30° F.

2. The coastal climate closely resembles the maritime, with the year consisting primarily of a long cold winter and a short cool summer similar to fall or spring as experienced on the continent. The annual curve has the same winter characteristics as that of the Arctic Sea but there is a seasonal maximum in July during summer. The mean summer temperature, however, remains under 50° F.

3. The arctic continental climate is characterized by very low winter temperatures with a pronounced winter minimum, and high summer temperatures with a highly pronounced summer maximum. Here the annual ranges of mean temperature may be as much as 80° F. to 100° F.

The winter and summer temperatures are of especial interest and will be discussed more fully.

The prominent feature of the winter temperature at arctic stations in the vicinity of the coast is that the temperatures remain nearly constant for a considerable length of time. The coldest month of the year, on the average, is not January, but February. For many stations it is March, and in some years even April has a lower mean than January. Bear Island is one case in particular which shows this tendency. The high pressure cell in the Arctic Sea has become well developed by late winter and as the mean position of the arctic front shifts southward conditions favorable to the producing of these low temperatures as late as March and April are found.

On the European continent there is no mountain barrier near the coast and the warm North Atlantic Drift has a marked influence on the temperature of central and northwestern Europe. The prevailing westerly winds carry the oceanic influence far inland. In the south, on the other hand, the prevailing northeast winds originate in the heart of the continent and consequently are quite cold. These facts account for the marked northwest to southeast trend of the winter iotherms in Russia and western and central Siberia. The temperature decreases with marked uniformity as one advances toward northeastern Siberia, until the region around Verkhoyansk, known as the *cold pole* or center of extreme cold of the northern hemisphere, is reached. Here the January average is minus 58° F., and never in this month has the temperature risen higher than 2° F. above zero. The absolute minimum of minus 90° F. is the lowest reading ever taken of the surface of the earth. With a July average of 60° F. the annual mean range of 118° F. is the greatest for any station. Also, the absolute range is the largest ever recorded, from minus 90° F. to 90° F. above, or 180° F.

That this area should have the most extreme winters known to man is readily understood from its geographical location. The heat of the North Atlantic cannot penetrate the 3,000 miles of frozen continent; the Pacific Ocean has no appreciable effect, since ranges of hills intervene and winds are prevailingly offshore; the ice-covered Arctic Ocean certainly cannot ameliorate the harsh conditions; and the lofty ranges of central Asia check any influence from the warm Indian Ocean far to the south. The characteristic *lag* of seasons, so highly pronounced on the arctic coast and conspicuous at any locality with maritime influence, is almost

totally absent. The temperature curve follows more nearly that of insolation, and April is as warm as October. In the interior of Canada the same characteristics are evident, but since the area is not comparable to the vastness of the Siberian continent, the feature is less pronounced.

The Siberian winter is by no means as unpleasant as its extreme temperatures might suggest. The air is often calm and the skies clear. Danger to man or beast occurs only when the *wild buran* or *purge* blows. These fearful blizzards also occur in the interior of Canada.

As has already been noted, average temperatures near the central polar basin are higher than in the interior. That the maritime effect of the ice-covered sea could produce the large differences observed is not logical and the explanation lies in the physical characteristics of the land. With no hills or trees of any consequence to act as frictional resistance to the wind, more freedom of movement is allowed. This produces a greater degree of mixing in the surface layers which transport warmer air to the surface.

Irregularities of the winter isotherms in the polar sea are produced by the influence of the Atlantic and Pacific Oceans. In the North Atlantic the isotherms are pushed far northward and here is found the greatest positive anomaly of temperature in the world (the greatest departure from the latitudinal average). The winter temperatures in the vicinity of Bering Strait are influenced by the open waters of the Bering Sea. North of the Strait the influence is limited to a rather small area with large local differences occurring with different wind directions. Northerly and especially northeasterly winds bring temperatures characteristic of the ice-covered sea, while southeasterly winds transport air with a much higher temperature.

The temperature inversions noted in all arctic regions are especially prominent over the pack ice in the polar sea. The diurnal variation during the dark season is, as would be expected, rather irregular. From the available data it is discovered that the maximum occurs at night hours and the minimum in the middle of the day. Again it is the wind which accounts for the irregularity. Any slight increase in wind, regardless of direction, will produce a considerable rise in temperature by the process of mixing. Since the diurnal variation of wind is largely dependent on the diurnal variation of pressure it is possible to set up definite relations which exist among temperature, wind, and pressure.

Small temperature variability in summer is a characteristic

Figure 3–13.—Breaking up pack ice.

common to all stations in the inner polar areas. The temperatures in the pack ice never deviate far from the freezing point. The diurnal ranges are smaller and the interdiurnal changes are less in summer than in any other season. Warm air from inland is often transported a considerable distance from the coast, but in passing over the icy waters it is cooled so effectively by contact with the ice that a sharp inversion is formed. Thus, the warm air current flows at some distance from the ground and has practically no influence on the surface temperature. Considerably higher temperatures are found on the coast and the transition from coastal to maritime conditions takes place within a very short distance. However, this characteristic holds for the surface layers only and is not found at higher levels. The discontinuity, therefore, represents only a quasifront and is of no consequence to the circulation of the atmosphere.

The warmest month in the Arctic over both land and sea areas is, with but few exceptions, July. However, the August temperature chart is representative of summer conditions. It is highly probable that everywhere in the Arctic Ocean the average temperature for July is within a few tenths of a degree of the freezing point, whereas in June and August the average is slightly below 30° F.

The highest temperature observed on the *Fram* expedition was 39.2° F. in June, 1896, and observers on the *Maud* found an absolute maximum of 38.3° F. in June, 1923. That both values occurred in June is probably explained by the fact that maximum cloudiness in this area occurs in July and August. At coastal sta-

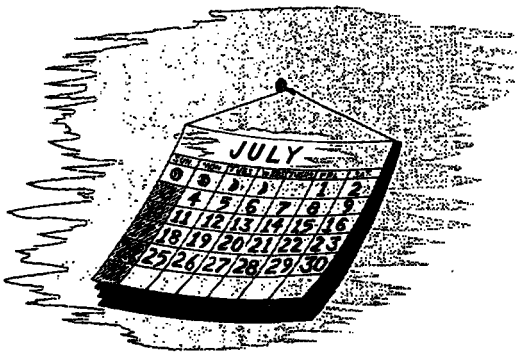


Figure 3–14.—Warmest month in the Arctic.

tions much higher readings are found and maxima near 70° F. are quite common. Still greater maxima are recorded at inland stations, and temperatures above 90° F. are the rule at stations near the arctic circle which are a considerable distance from the sea.

There are two features worthy of note which characterize the summer temperatures in the polar sea: (1) The temperature is near freezing everywhere with no variation with latitude and (2) again independent of latitude, the first day with a maximum temperature and the first day with a mean temperature of 32° F. or higher is nearly the same in all sections except those under the influence of warm winds from the south.

PRECIPITATION

There are two significant factors which make it extremely difficult to obtain satisfactory measurements of precipitation in the Arctic: (1) The fine ice needles of winter precipitation are very easily blown across the rain gage opening and (2) during snow storms it is difficult to determine whether the snow is falling or is being blown up from the surface. Another obstacle is determining the number of days with a measurable amount of precipitation. On extremely cold days the snow is very fine, and there are many days when precipitation is so slight that it cannot be measured but is present nevertheless. A striking example is found in records of the Norwegian north polar expedition. At Goose Fiord, Ellesmere Island, eleven days in April were recorded on which precipitation occurred, but the total for the month showed only 0.2 mm. or slightly less than 0.01 inch. On the North American continent the number of days with precipitation are determined from the days on which 0.01 inch or more is measured. Other stations use days with 0.1 mm. or more, while still other stations have tabulated all the days when precipitation occurred.

In the arctic and subarctic regions the inadequacy of the records permit only broad and general statements regarding yearly averages and seasonal distribution. The time of year of maximum precipitation varies with the prominence of marine or continental influence. It is a well known fact that snowfall is extremely light and stations in continental areas have maximum precipitation in late summer, indicating that a large percent of the yearly total falls as rain.

On the whole, amount of precipitation received at land stations is rather uniform, which is as might be expected in countries of monotonous relief. This is especially true in the north central portion of Siberia. Variation of the annual amounts from year to year is also slight. Snowfall varies more than rainfall, especially where it is comparatively scarce. Depth of snow for any month may exceed four times the average fall, whereas rain seldom exceeds twice the normal amount.

Although the amount of precipitation along the arctic coast is small, the ground remains soaked for a long period in summer. Underground drainage is prevented by the permanently frozen subsoil. Even though somewhat larger amounts of precipitation are received farther south at inland stations, the summer temperatures are so much higher that drought conditions become manifest.

The amount of precipitation decreases considerably toward the North Pole, especially in winter. In precipitation, as in temperature, interzonal differences are apparent. In the Canadian archipelago and on the north coast of Asia summer precipitation is greater than that of winter, but in the North Sea low pressure area, between the east coast of Greenland and Novaya Zemlya, averages are greater in winter than in summer. In the region of the foregoing low and the low pressure spur in Baffin Bay the annual amounts of precipitation are greater than in the other regions of equal geographical latitude.

Snow may fall in every month and rain falls only in June, July, August, and September. May has, on the whole, the greatest number of days with precipitation and the midwinter months the smallest. The contrast between conditions in summer and winter appear to be greater over the pack ice than at the coast.

No diurnal variation was found in winter in the pack ice but in other seasons of the year the probability of precipitation appears to be greater at night than in the daytime. The difference is especially great in spring, but apparently there is no satisfactory explanation of this feature. It was also found that the probability of precipitation was greater with northerly than with southerly winds. This is also true of the coast as the land elevations would favor precipitation with onshore winds.

The frequency of precipitation varies, in general, with the total precipitation. Koeppe suggests that at least two-thirds of the Dominion of Canada probably has fewer than 80 days per year with measurable amounts (0.01 inch or more). This area embraces

nearly all the arctic region of North America. The number of days with precipitation in the Canadian archipelago is particularly small in winter. A maximum frequency occurs in the region of the North Sea Low in October and November, while on the Asiatic Russian north coast the maximum appears in September, though the period of heaviest precipitation is more generally July and August.

FORECASTING AIDS

The following remarks relative to forecasting the weather in the Canadian archipelago were extracted from reports submitted by naval aerologists who have served with task forces operating in the area.

The rules of forecasting used in middle latitudes can be considered of consequence, but cannot be completely relied upon for forecasting in the Canadian Arctic. Single station observations, aided by a general circulation pattern, must be the basis of present forecasting in this area. First-hand experience is of prime importance as local influences are a major factor and vary widely from place to place within the area.

Forecasts covering periods of 18 to 24 hours are the maximum lengths found to have a satisfactory degree of reliability, because of the extent to which forecasts depend upon single station analysis and local observations. By use of the few synoptic reports available in the Canadian archipelago, weather can be forecast in a general way, but without experience in the area itself and without greater facilities than are now present, detailed conditions cannot be determined for longer periods in advance. The use of *persistence* forecasting, that is observing the trend of weather toward improving or deteriorating conditions, cannot be relied upon except for a period of a very few hours, and then only in a very general way.

WEATHER SCHEDULES

1. Radio Washington cannot normally be copied in most arctic areas, and the best information available comes from Dorval, Canada (VFN), or Westover Field, Mass. (WSO).

2. One or two radiomen should be assigned the primary responsibility for copying weather schedules. A radioman who is familiar with the methods of broadcast peculiar to weather schedules understands what is required of him and obtains a more complete coverage than would an unindoctrinated radioman.

WINDS

1. Wind direction and velocity are often of great aid in forecasting visibility conditions, but use of winds in forecasting must be tempered by a thorough consideration of any land mass effects in the vicinity. With a steady flow from the south, poor visibility can be expected in the Canadian archipelago in summer. This is due to cooling of the warm, humid air which moves in from the south to temperatures less than its condensation point, resulting in fog. Even with velocities in excess of 25 knots fog will not dissipate before a steady flow from the south.

2. Winds slowly veering from north to southeast or south indicate the passage of a high pressure ridge across the observing station. This gradual shift is usually accompanied by a decrease in velocity to less than 10 knots as the peak of the wedge approaches. It is an indication that a well developed occlusion is moving into the area when the wind slowly veers to the southeast, and then remains in that direction while gradually increasing in velocity as the barometric pressure decreases. If the wind-veer continues into the southwest, with or without an increase in velocity, it is an indication that a cold front is approaching from the northwest, preceding an arctic air mass outbreak from the Beaufort Sea area.

3. A wind shift into the north or northwest with a cold frontal passage is not an indication of clearing behind the front. The air masses behind cold fronts which move across the Canadian archipelago are shallow, and thus the clouds behind the fronts are more stratiform than cumuliform, having very little vertical development. Here also, when occlusions are encountered, the cessation of precipitation is not rapid, due to the fact that the occlusions moving across the archipelago are mature, and the moist air has been transported completely around the northern tip of the occlusion.

CLOUDS

1. Very often the low stratus overcast prevalent in the maritime air of the Canadian archipelago obscures all higher clouds, and only by use of radiosonde soundings can their presence be detected. However, it is very rare that there is not an occasional break in the low stratus, and through these breaks the higher clouds can be observed for short periods of time, if they are present.

2. There are two situations in which the normally prevalent low stratus can be expected to be absent. One is on the front side, near the middle of high pressure ridges, where there is marked divergent circulation. The other, less frequent, is in the relatively dry continental arctic air moving southeast from the Beaufort Sea area, prior to its picking up moisture in the maritime archipelago. This second situation is due partly to divergence, although the lack of moisture in the air mass in general is the major factor.

3. Broken layers of altocumulus clouds, usually mixed with much altostratus, are present a long distance behind fronts in the arctic areas. This is due to the usual shallowness and great homogeneity of the air masses behind the fronts in the Arctic. The broken layers of clouds are connected either with cold fronts or occlusions that are part of the systems that stagnate in the Baffin Bay area in summer. In autumn they lie to the north of the cold fronts that develop between the polar air masses of central Canada and the arctic air masses formed over the ice pack to the north and west of Canada. The distance behind fronts to which the middle clouds extend varies greatly, and no definite statement can be made without further observation.

4. Very low stratus, only a few hundred feet above sea level, forms on the sides of hills, due to the radiation effect in combination with the high moisture content of the air near the surface. Moisture is supplied during the summer months by the continuous melting of the top of the permafrost layer. Since continuous observations could not be made in any of the areas where this stratus formed, it was not possible to establish any criteria for the formation and dissipation of these clouds.

PRECIPITATION AND FOG

1. Throughout July, and until the latter part of August, drizzle type rain was the prevailing form of precipitation encountered. Commencing in the latter part of August, and from then on until completion of the operation, as the warming effect of the sun lessened and the autumn season replaced summer, temperatures decreased and snow, instead of rain, become the common form of precipitation.

2. The type of precipitation experienced was largely in the form of intermittent drizzle, and in almost all cases precipitation was

light. This was to be expected as there was little vertical development in clouds of the sort that produce precipitation of the showery type, nearly all clouds being stratiform in character.

3. In forecasting the beginning and ending of precipitation in connection with the passage of occluded fronts, it must be remembered that occlusions moving into the eastern part of the Canadian Arctic are well developed and mature by the time they reach this area; hence, rain shields extend well forward of the front and also far to the rear of the front, near the tip of the occlusion. The extension of the rain shield to the rear of the front is a result of well developed cyclonic circulation around the tip of the occlusion, to the north. Rain shields usually diminish in size after the occlusion has matured and has slowed in its forward movement. In the Canadian archipelago this does not occur until approaching Baffin Bay.

4. In forecasting the duration of precipitation after the passage of a cold front, it is important to note that the slope of the cold front is usually very gradual, since the outbreaks of arctic air from the northwest are very shallow. As a result of the gradual slope, the rain shields extend farther to the rear than in a middle latitude cold front with a steeper slope. The rain in these cases is more of a steady type, rather than showery. A rain shield extending 75 miles behind the cold front is not unusual; and beyond that, stratocumulus clouds often extend as much as 200 miles behind the front.

5. With a strong southerly flow, warm, moist air is carried north across considerable latitude and is subjected to cooling from below when it passes over the maritime Canadian archipelago. This results in the formation of fog, when the temperature of the air is lowered to the dew point or below. With strong winds, mixing occurs in the lower layer of air, and the effect of this is to intensify the fog. It has been observed that with southerly winds of from 20 to 30 knots, the fog is decidedly more dense than with winds of from 10 to 20 knots.

6. There are times, although relatively few, when precipitation is of the shower type rather than of the drizzle type. An analysis of the stability characteristics of the air mass involved will give an indication of the type of precipitation to be expected in the Arctic as elsewhere. Continental arctic air masses move into the

area from the northwest and their surface layers are warmed as they move over the Canadian archipelago. The archipelago, with its maritime characteristics in summer, in much warmer than the ice pack source region of the summer arctic air masses. The warming in the lower layer of air results in a steep lapse rate in that layer, and hence instability.

PRESSURE

1. Pressure tendency cannot be relied upon as an aid in forecasting except in very few instances in the Canadian Arctic. In the western and northern portions of the operating area, weak pressure gradients were found, and these gave little indication as to the orientation of isobars, because of the absence of reporting stations.

2. In the summer, when pressure gradients are weak, local land mass effects, rather than the general pressure field, are the major influences on wind direction. This does not apply in the cyclonic circulation of northern Baffin Bay, a large area of open water, with a normally steeper gradient than is found to the west.

3. In autumn, late August and September, the high pressure cell to the northwest of the archipelago, centered over the Beaufort Sea, becomes more pronounced. This results in a somewhat steeper pressure gradient across the archipelago. Hence, a northerly wind on the east side of the high cell prevails across the archipelago.

4. In the eastern part of the Canadian Arctic, when migratory storms move from the southwest toward Baffin Bay, the steepness of the pressure tendency provides a good indication of the intensity of the approaching lows. It follows that, in these pressure systems, the sharper the fall and subsequent rise of pressure, the greater will be the velocity of the accompanying winds.

5. During the summer months, except in the cyclonic circulation of Baffin Bay, rise and fall of barometric pressure was of practically no value in forecasting. In autumn, as the pressure field becomes more pronounced, a certain amount of reliability can be placed on pressure tendency, but not to the extent of that in middle latitudes.

SUMMARY

Our knowledge of arctic climate is based on sparse records even though collected at various places over a period of many years. More than in most other geographic areas, the success of a given operation and indeed the very safety of the unit depend on accurate and timely forecasts of weather. The data contained herein can form one of the bases for consideration in planning arctic operations. Included as appendix A is a brief description of Antarctic climate as understood at this time. It is to serve as reference matter for personnel connected with exploring expeditions to Antarctica.

TABLE VII

Place Names for Weather Tables

Place	*Area*
Archangel	U. S. S. R., White Sea.
Cape Chelyuskin	U. S. S. R., Taimyr Peninsula.
Dickson Island	U. S. S. R., Kara Sea.
Kola	U. S. S. R., Kola Peninsula.
Okhotsk	U. S. S. R., East Siberia.
Tiksi Bay	U. S. S. R., Laptev Sea.
Vaigach Island	U. S. S. R., Kara Sea.
Verkhoyansk	U. S. S. R., East Siberia.
Wrangel Island	U. S. S. R., Chukchi Sea.
Yugor Strait	U. S. S. R., Novaya Zemlya.
Anchorage	Alaska, Cook Inlet.
Dutch Harbor	Alaska, Aleutian Islands.
Fairbanks	Alaska, Central.
Juneau	Alaska, Inland Passage.
Point Barrow	Alaska, Arctic.
St. Paul Island	Alaska, Bering Sea.
Aklavik	Canada, Yukon Territory.
Barrow Strait	Canada, Northwest Passage.
Churchill	Canada, Hudson Bay.
Craig Harbour	Canada, Ellesmere Island.
Fort Resolution	Canada, Great Slave Lake.
Herschel Island	Canada, Beaufort Sea.
Lake Harbour	Canada, Hudson Strait.
Pond Inlet	Canada, Baffin Island.
Tromso	Norway.
Vardo	Do.
Bear Island	Norwegian Sea.
Jan Mayen Island	Greenland Sea.
Green Harbour	Spitsbergen.
Angmagssalik	Greenland, East Central.
Etah	Greenland, Northwest.
Godhavn	Greenland, West Central.
Ice Cap (Interior Greenland)	Greenland.
Ivigtut	Greenland, Southwest.
Godthaab	Do.
Thule (North Star Bay)	Greenland, Northwest.
Upernivik	Greenland, West Central.

RESTRICTED

TABLE VIII

Mean Monthly and Annual Temperatures (° F.) with Extremes

Place	January	March	May	July	September	November	Annual	Absolute	
								Maximum	Minimum
Archangel	8.1	17.4	41.4	59.5	45.7	21.4	32.3	94	−49
Cape Chelyuskin	−24.4	−26.4	15.0	34.9	27.9	−9.0	4.9	67	−50
Dickson Island	−13.5	−10.8	17.2	40.3	35.4	1.2	11.8	73	−55
Kola	11.3	17.4	38.1	54.5	42.6	20.5	30.7		−39
Okhotsk	−10.3	6.4	34.9	54.3	46.4	5.4	22.5	78	−50
Vaigach Island	3.1	−.6	22.5	42.2	38.1	18.9	20.7	79	−44
Verkhoyansk	−58.2	−23.8	36.3	60.3	36.1	−34.1	3.3	94	−90
Wrangel Island	−10.7	−10.1	16.7	37.0	28.5	1.4	10.8	65	−50
Yugor Strait	−1.0	−2.2	21.8	43.0	38.3	15.6	19.2	78	−47
Anchorage	11.3	22.3	44.8	57.0	47.8	22.5	34.6	84	−36
Dutch Harbor	32.1	34.1	40.7	51.3	48.5	36.4	40.4	80	5
Fairbanks	−11.2	9.5	46.9	60.1	43.6	4.1	26.1	99	−66
Juneau	27.7	33.7	47.7	56.7	50.4	35.7	42.2	89	−15
Point Barrow	−16.2	−14.8	19.6	40.0	31.6	−.3	10.2	78	−56
St. Paul Island	21.8	26.6	33.4	45.2	44.7	32.8	33.8	64	−26
Aklavik	−21.4	−7.0	30.6	55.5	37.6	−5.9	15.0	85	−56
Barrow Strait	−31.5	−21.1	15.6	37.9	21.9	−8.3	2.7		
Churchill	−18.9	−6.2	29.1	52.9	41.0	6.8	17.7	96	−57
Craig Harbour	−22.1	−14.4	15.4	40.5	28.6	−2.9	7.0	60	−49
Fort Resolution	−16.9	−1.7	40.0	60.2	45.5	8.3	23.0	90	−63
Herschel Island	−22.0	−12.1	19.2	44.1	31.3	−6.1	10.2	69	−52
Lake Harbour	−15.4	−4.9	27.7	44.0	35.0	12.4	16.4	74	−45
Pond Inlet	−29.2	−21.9	23.4	42.2	30.0	−4.2	7.2	77	−54
Tromso	26.2	26.4	38.8	51.8	44.2	30.4	36.3	82	−1
Vardo	22.1	23.5	35.1	47.7	43.2	28.2	33.3	78	−11
Bear Island	15.1	12.2	27.9	39.6	35.4	20.7	25.2		
Jan Mayen	22.8	20.7	29.7	40.5	38.1	27.0	29.8	59	−2
Green Harbour	3.2	−2.2	23.4	41.7	32.2	10.9	18.5	60	−57
Angmagssalik	17.6	18.9	33.8	44.8	37.6	23.0	29.1	77	−26
Etah	−14.2	−7.4	22.6		25.2	4.5		60	−30
Ice Cap Greenland	−33.2	−30.1	14.9	37.8	16.5	−18.9	−1.8		
Godhavn	2.1	3.7	30.6	45.5	36.5	20.7	23.0	63	−28
Godthaab	14.4	18.5	33.4	43.7	37.8	23.7	28.6	76	−20
Ivigtut	18.7	23.9	40.1	49.8	41.0	26.8	33.4	86	−20
Thule	−20.6	−15.2	23.0	40.5	28.0	−.4	9.1		
Upernivik	−7.2	−6.3	25.2	40.8	33.4	14.2	16.5	69	−44

TABLE IX

Average Number of Gales Per Month and Year

Place	January	March	May	July	September	November	Annual
Archangel	2.4	1.6	1.8	0.7	1.9	2.4	19.7
Cape Chelyuskin	5.0	1.0	2.0	3.0	0	6.0	38.0
Dickson Island	11.0	10.0	6.0	3.0	4.0	8.0	80.0
Kola	4.0	4.0	3.0	2.0	2.0	5.0	36.0
Okhotsk	0	1.0	1.0	1.0	4.0	1.0	15.0
Tiksi Bay	7.0	2.1	1.4	1.1	1.0	3.6	28.8
Vaigach	5.0	5.0	4.0	2.0	2.0	6.0	49.0
Verkhoyansk	0	0	1.0	2.0	1.0	0	10.0
Wrangel	7.9	3.0	2.3	2.6	4.8	5.0	50.4
Yugor Strait	7.0	6.0	4.0	1.0	3.0	7.0	54.0
Fairbanks	.5	.1	.1	0	0	0	.9
Nome	3.8	2.7	.6	.3	1.0	1.4	20.6
Point Barrow	2.2	.4	1.0	1.2	2.4	2.8	18.7
St. Paul Island	12.6	7.2	3.0	.2	5.6	10.5	74.0
Tromso	2.0	1.0	.2	0	.2	2.0	10.0
Vardo	6.0	6.0	2.0	.5	3.0	5.0	44.0
Jan Mayen	5.2	3.6	2.1	.2	2.0	4.5	32.9
Green Harbour	1.0	1.0	.3	0	.7	.6	8.0

TABLE X

Average Surface Wind Velocity and Direction

Place	January	March	May	July	September	November	Annual
Archangel	11.9 SE	10.6 SE	10.2 NW	8.7 NW	10.7 SW	12.4 SW	10.3
Dickson Island	19 S	17 S	15 NE	14 NE	16 S	17 S	17.0
Kola	9.8 SW	8.7 SW	9.2 SW	9.0 N	8.1 SW	9.8 SW	8.9
Okhotsk	9.8 N	8.1 N	8.9 SE	8.9 SE	8.7 N	11.9 N	9.4
Tiksi Bay	17.0 SW	6.7 SW	9.6 NE	8.9 NE	11.6 W	10.1 SW	10.1
Vaigach	18.1	16.6	15.4	14.5	15.4	20.4	16.6
Verkhoyansk	1.1 SW	1.6 SW	6.0 NE	5.4 NE	3.1 SW	1.3 SW	3.2
Wrangel	15.0 NE	9.2 N	9.2 NE	9.6 E	13.4 N	15.0 N	11.7
Yugor Strait	20 S	18 S	16 NE	13 NE	16 S	20 S	17.0
Dutch Harbor	5.4 SE	13.0 SE	10.1 SE	11.2 SE	11.6 SE	8.5 NW	9.7
Fairbanks	3.4 N	4.6 N	6.5 NE	5.9 SW	5.2 NE	3.9 N	4.9
Nome	9.8 NE	9.3 NE	7.7 NE	8.6 W	9.9 N	8.8 NE	9.1
Point Barrow	10.0 NE	11.2 NE	11.4 NE	12.5 SW	14.1 NE	11.7 NE	11.8
St. Paul Island	19.4 NE	17.4 NE	13.9 NE	10.9 S	15.8 NW	18.6 N	15.9
Tromso	12.7 SW	11.9 SW	8.2 NE	8.2 NE	8.2 W	11.2 SW	10.1
Vardo	21.6 SW	20.9 SW	15.7 NW	13.4 NW	17.1 NW	20.9 SW	18.3
Jan Mayen	20.8 NNW	18.1 NW	12.5 E	11.9 E	16.0 E	19.0 ENE	16.7

RESTRICTED

TABLE XI

Average Number of Days with Fog Per Month and Year

NOTE.—At numerous places in table below years of record are few indicating only trend of situation.

Place	January	March	May	July	September	November	Annual
Dickson Island	5.5	7.9	4.9	22.9	10.5	5.2	152.2
Kola	.7	.2	1.0	3.1	1.9	1.6	16.1
Tiksi Bay	3.7	4.4	5.3	9.0	4.6	1.0	66.1
Verkhoyansk	3.4	.6	.6	1.5	4.1	1.8	25.9
Wrangel	1.6	4.6	12.2	21.4	10.8	3.8	113.5
Yugor Strait	4.5	6.2	9.1	19.6	14.1	4.5	123.8
Aklavik	19.6	27.6	2.0	2.2	21.2	15.6	165.6
Tromso	1.0	.8	1.0	2.0	2.0	1.0	14.0
Vardo	0	0	1.0	6.0	1.0	0	18.0
Green Harbour	.1	.1	.4	4.0	1.0	0	13.0
Bear Island	1.1	2.7	6.7	18.7	12.0	3.3	82.0
Jan Mayen	1.9	3.2	3.3	12.8	5.9	1.8	58.3
Angmagssalik	1.0	1.0	7.0	9.0	4.0	2.0	48.0
Godhavn	9.0	11.0	15.0	17.0	8.0	3.0	127.0
Godthaab	1.0	1.0	7.0	13.0	7.0	1.0	61.0
Ivigtut	.2	.4	2.0	6.0	3.0	1.0	26.0
Upernivik	2.0	2.0	5.0	11.0	2.0	1.0	47.0
Churchill	1.0	*	1.0	2.0	1.0	*	13.0
Craig Harbour	*	1.0	0	2.0	1.0	*	9.0
Lake Harbour	2.0	1.0	2.0	5.0	2.0	3.0	30.0
Pond Inlet	1.0	*	*	*	*	2.0	9.0
Dutch Harbor	.9	.9	2.5	3.5	1.8	0	18.4
Fairbanks	17.2	11.6	.8	2.4	3.2	6.1	68.0
Nome	5.3	5.2	5.0	8.1	4.4	3.2	67.2
Point Barrow	5.0	2.3	7.5	15.0	5.4	2.7	82.6
St. Paul Island	1.7	2.8	6.9	7.0	2.8	1.5	52.2

* Less than 1 day.

TABLE XII

Mean Monthly and Annual Number of Days with Precipitation 0.01 Inches or More

Place	January	March	May	July	September	November	Annual
Archangel	16	13	12	12	15	17	171
Cape Chelyuskin	8	3	4	12	15	13	121
Dickson Island	8	10	10	12	17	13	142
Kola	13	12	16	15	18	17	179
Tiksi Bay	9	7	4	11	14	9	108
Vaigach	14	11	9	12	15	14	151
Verkhoyansk*	6	4	4	8	6	8	73
Wrangel	8	7	8	10	10	8	102
Yugor Strait	13	11	12	12	19	16	165
Vardo	14	16	11	9	14	16	157
Bear Island	14	14	12	7	14	14	140
Jan Mayen	19	15	11	11	15	17	174
Green Harbour	12	12	7	6	9	11	114
Anchorage	7	5	6	10	13	7	97
Dutch Harbor	22	20	19	13	18	21	219
Fairbanks	10	5	9	13	10	10	110
Juneau	18	18	18	17	20	20	221
Nome	11	9	7	13	16	9	132
Point Barrow	1	1	1	7	6	2	34
St. Paul Island	18	16	13	17	21	20	204
Aklavik	6	4	6	9	11	6	81
Churchill	4	5	7	10	12	10	101
Craig Harbour	5	5	7	6	7	8	73
Lake Harbour	5	6	8	9	8	11	91
Pond Inlet	3	2	2	6	4	4	43
Etah*	6	6	3	.....	6	14	64
Godthaab*	13	13	10	10	13	13	142
Ivigtut*	12	12	10	9	13	12	131
Thule*	1	7	3	6	10	8	.....
Upernivik*	4	6	7	7	10	10	84

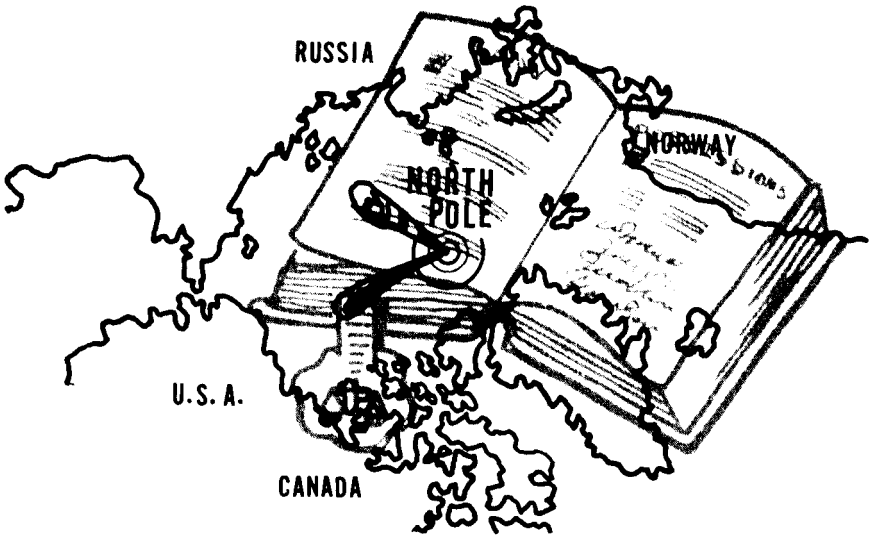
* 0.1 mm. (0.004 in.) or more.

RESTRICTED

TABLE XIII

Mean Monthly and Annual Cloudiness (Tenths)

Place	January	March	May	July	September	November	Annual
Archangel	8.1	8.1	7.0	7.1	8.1	8.6	7.7
Cape Chelyuskin	5.6	4.2	8.0	8.1	9.2	7.6	7.4
Dickson Island	6.2	6.0	8.2	7.7	8.8	7.6	7.5
Kola	7.0	6.0	7.2	7.5	7.7	7.7	7.3
Vaigach	7.2	6.4	8.1	7.3	8.3	8.3	7.6
Verkhoyansk	3.4	3.3	6.1	6.4	6.6	4.6	5.1
Wrangel	5.5	5.0	7.9	7.2	8.1	6.7	6.7
Yugor Strait	7.0	6.3	8.4	7.5	8.6	8.3	7.6
Tromso	6.5	6.0	6.8	6.6	7.6	7.0	6.6
Vardo	7.6	7.2	7.6	7.2	7.7	8.0	7.5
Bear Island	8.2	8.2	9.0	8.7	9.0	8.6	8.6
Jan Mayen	8.4	7.9	8.2	9.0	8.1	8.3	8.3
Green Harbour	6.2	5.8	6.6	7.0	7.6	6.1	6.6
Aklavik	4.1	4.3	4.5	6.0	7.0	5.8	5.4
Churchill	4.5	3.8	5.6	5.0	5.9	5.6	5.2
Craig Harbour	3.9	5.0	6.0	6.2	7.8	5.6	5.8
Lake Harbour	4.8	4.8	6.7	6.4	6.4	6.5	5.9
Pond Inlet	3.6	4.0	4.8	4.8	7.0	5.2	4.9
Dutch Harbor	7.6	7.4	8.0	7.7	8.0	7.5	7.7
Fairbanks	5.2	4.9	6.9	6.6	7.2	6.1	6.1
Nome	5.4	5.0	6.2	7.9	6.8	5.2	6.2
Point Barrow	4.2	3.1	7.1	6.2	8.2	4.7	5.6
St. Paul Island	7.8	7.4	8.8	9.4	8.4	8.1	8.3
Angmagssalik	6.7	6.1	6.3	5.6	6.3	6.7	6.2
Godhavn	6.9	6.3	6.7	6.3	6.0	7.1	6.4
Godthaab	7.3	6.8	6.8	6.6	6.8	6.6	6.9
Ivigtut	5.8	5.5	6.0	5.8	6.2	5.6	5.8
Upernivik	4.4	4.5	6.6	6.3	7.1	7.1	6.0



CHAPTER 4

THE LAW AND ARCTIC POSSESSIONS

"We cannot say that the sovereignty of all the known lands in the Arctic is definitely settled internationally. We can say, however, that the sovereignty of substantially all of these territories is not either definitely known or definitely claimed."—David William Hunter.

Unlike antarctic topography, there is no land mass of continental or subcontinental size in the north polar region. The latter area contains relatively few islands and consists chiefly of a vast ice-covered sea girdled by continental land. That portion of the ice cap resting on the sea is in motion. As a consequence, the area that may be subjected to sovereignty is very limited.

There are three general divisions in this discussion of the legal problems of the arctic region:

1. The problem of sovereignty in the region.

2. The territorial claims of the various nations.

3. United States international agreements which have been set up for activity in the region.

SOVEREIGNTY

The present high development of aircraft as a means for transporting persons, equipment, and supplies, and the capacity of modern medicine and science to sustain human life and activity in areas of climatic extremes have endowed the north polar regions with great political and military significance for the nations of the northern hemisphere. Consequently, the governments of these states are becoming increasingly concerned with the question of sovereignty in the region.

In this connection, the problem of occupation is paramount. The established law in this regard was concisely set forth in the Isle of Palms arbitration. The court held that, according to the view that has prevailed since the nineteenth century, discovery gives only an inchoate title to territory. The title of discovery must be completed within a reasonable period by the effective occupation of the region claimed to be discovered, before sovereignty is vested in the discovering state.

The problem of sovereignty in the Arctic is complicated by the fact that, in addition to land and ice areas resting on land, there is a second type of area (ice resting on the sea) on which men can build habitations and live for an indefinite period of time while carrying on activities normally pursued on land. In this sense, it could be argued that men might permanently occupy such areas, and that they are, therefore, susceptible to sovereignty. Logical as this may appear, such an argument has no legal validity. In law, an effective occupation is more than a matter of the nature of the habitations and activities in a given area. Above all, the area itself must be stationary and capable of having permanent and clearly ascertainable boundaries. The natural movement of

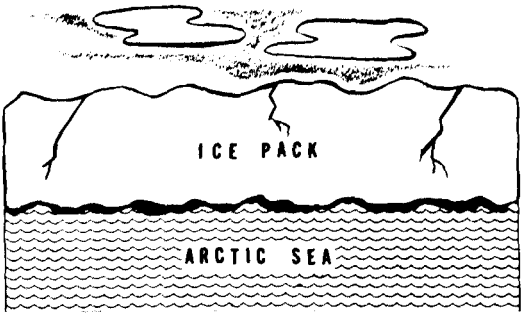


Figure 4–1.—Ice areas resting on the sea have no permanent boundaries.

ice areas resting on the sea makes any clearly defined territorial delimitation impossible. Any occupation of such areas would be too precarious and shifting to give good title. The legal rules which recognize the freedom of the high seas naturally apply also to a moving and shifting substance like the Arctic Ocean ice areas. Consequently, the most authoritative opinion is that the right of sovereignty over such ice areas is denied by international law. It was for this reason that the United States made no claim to the North Pole on the basis of Peary's discovery in 1909.

Until recently there was some doubt that occupation of ice areas resting on land was legally possible—but for a different reason. Some publicists and some governments (including the United States) held that climatic conditions prevented any occupation of these regions from being really effective. When Captain Amundsen made his arctic flight in 1926, he was authorized by the Norwegian Government to take possession of any land discovered, but was specifically denied authority to take possession of any ice areas resting on the sea. In reply to a Norwegian note concerning Amundsen's discoveries, Secretary of State Hughes said:

"Today, if an explorer is able to ascertain the existence of lands still unknown to civilization, his act of so-called discovery, coupled with a formal taking of possession, would have no significance, save as he might herald the advent of the settler; and where for climatic or other reasons actual settlement would be an impossibility, as in the case of the polar regions, such conduct on his part would afford frail support for a reasonable claim of sovereignty."

For this reason the United States would not recognize Norway's sovereignty in the polar area on the basis of the discoveries made by Amundsen.

To argue, as Secretary Hughes did over 20 years ago, that the ice cover resting on land is not susceptible to sovereignty because of the impossibility of establishing and maintaining effective establishments in such areas, is, of course, no longer a valid argument. States do now claim sovereignty to various areas of this kind and the claims are recognized as valid by the family of nations. When the rule (that climate ipso facto prevented any truly effective occupation) was formulated, the whole question of legal rights in the region was, by and large, an academic one. As a matter of actual fact, man did lack the capacity to make use of the region as an area of transit or of residence. The airplane was a vehicle of limited range and trans-polar flights were still in the future. The capacity of medicine and science, not only to sustain

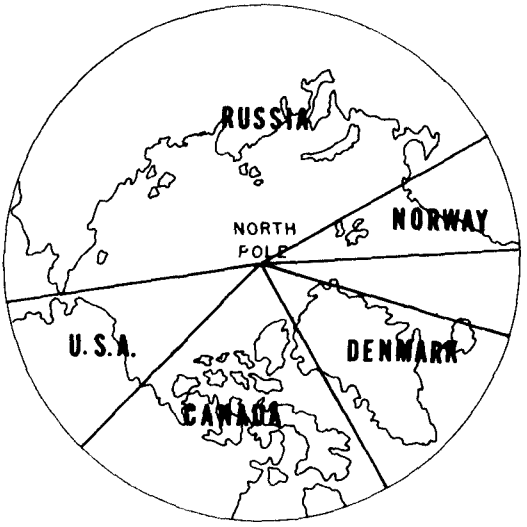


Figure 4-2.—The Sector Principle—"regions of attraction"

life under such trying conditions but to make it reasonably tolerable and practical, was still unrealized. Under such circumstances, climate did prevent any occupation from being an effective one. The recent prodigious advances in science, medicine, and aeronautics, however, now enable man to overcome the obstacle of climate and extreme cold. Claims to sovereignty can no longer be questioned solely on the ground that the occupation is ineffective because of climate.

As it became evident that in polar regions effective occupation would be difficult to realize, and claims of sovereignty over polar areas would thus remain inchoate, new theories were advanced from time to time, in an effort to circumvent the occupational requirement. One theory offered the substitute principle that sovereignty ought to attach to littoral states according to the *region of attraction* doctrine. This principle, known as the Sector Principle, has been strongly advocated as a solution to the problem in the north polar regions. According to this principle, the extreme eastern and western meridians bounding the territory of countries adjacent to the arctic circle are projected to the North Pole. These pie-shaped segments are considered as belonging to the littoral states as *regions of attraction* of such states.

The man generally credited with having called attention to this principle for the first time was P. Poirer, a Canadian Senator. In

the Canadian Senate, on 20 February 1907, he recommended that Canada should declare it had taken possession of the lands and islands lying between its northern coast and the North Pole. This proposal was not adopted by the Canadian Government, although the Canadian sector claim has been made on other occasions.

Strongest support for the Sector Principle has come from the Soviet Union. In a decree dated 15 April 1926 the Central Executive Committee expressed itself in favor of the principle and laid claim to lands and islands lying within the Soviet sector. Soviet claims are discussed below.

The United States has not accepted the Sector Principle or the wider theory of regions of attraction. Acceptance of the theory with respect to the Arctic would lend strong weight to acceptance of Chilean, Argentine, and other claims in the Antarctic, for which the United States has proposed some form of international control.

CLAIMS

Although the law governing claims to territory appears to be crystallized it is not to be assumed that all applications of it are equally well settled. There are certain areas where there is no longer any question as to which state is sovereign. There are other areas over which a state claims sovereignty but, for the time being at least, other states neither object to nor acquiesce in the claim. In other words, not enough time has yet elapsed since the crystallization of the law to allow for a definitive application of the law in all areas. Consequently, governments interested in the polar regions can, with more or less reasonable certainty, expect to become involved in complicated diplomatic negotiations and disputes, particularly with regard to areas not clearly and exclusively within the orbit of a given country. For this reason, some discussion of arctic claims should be included.

CANADA

There can be no doubt that the Canadian government considers that Canada has sovereignty over the islands lying above its northern or Arctic coast. This has been indicated by official action in various ways. In 1921, for example, Canada informed the Danish Government that any discoveries which Knud Rasmussen might make on his journey across Arctic America would not be recognized by the Canadian Government as a basis for any territorial claims by Denmark.

Figure 4–3.—Hunting and fishing in certain portions of Northwest Territories.

In June 1925 the Canadian Parliament passed a law providing that scientists and explorers wishing to work in the Northwest Territories must have a Canadian permit. The Northwest Territories, as defined in Canadian law, include the so-called District of Franklin which embraces the Canadian arctic islands.

A third example of those official actions clearly indicating Canada's claim to sovereignty over its northern islands is to be found in the Canadian game laws. In certain portions of the Northwest Territories, hunting and fishing are reserved to Eskimos, Indians, and half-breeds. One of the areas reserved to these people is the *Arctic Islands Preserve* which approximately coincides with the District of Franklin and, as stated above, includes the islands in the vast archipelago to the north of Canada. The regulations now in force with regard to hunting and fishing in the Arctic Island Preserve are found in an Order in Council of 15 May 1949.

No state has seriously questioned Canada's claim to sovereignty over these islands. Academically, one might raise the question as to whether Canada is really in effective occupation. Canada does exercise control over the area to the exclusion of all other

states, which activity is the basic test of sovereignty. Such manifestations of authority as those discussed above do effect an adequate satisfaction of the needs of the sovereign in that particular area, and seem, therefore, to constitute an effective occupation.

The following can also be offered as evidence of the strong control that Canada maintains over her Arctic:

1. The Canadian official sponsorship of the 1913–18 Arctic expedition, which made it necessary for Stefansson to return funds he had previously solicited from various sources in the United States.

2. Payment by the Canadian Government in 1930 of $67,000 to Otto Sverdrup in recognition of his discoveries, claimed by Canada.

3. The maintenance of posts throughout the inhabited area by the Royal Canadian Mounted Police and the patrols periodically made by police officers into the uninhabited areas. The enforcement of these officers of Canadian law among the resident native and white inhabitants.

4. The various services afforded by the Canadian Department of Health and Welfare in the area. These include payments in assistance of mission hospitals established in the area and payment to missions for all patients receiving treatment, and the provision of medical and dental service to all residents of the area needing such attention who are encountered in the annual arctic patrols.

5. Payment of *baby bonus*, one of the social services maintained by the Canadian Government, to Eskimos and other residents of the Canadian Arctic. The baby bonus funds are administered by the Department of Health and Welfare.

6. Command of all weather stations established jointly by the United States and Canada in the Canadian Arctic is reserved for Canadian Government employees.

UNITED STATES

It is now a certainty that there is no land mass of any significance between Alaska and the North Pole. Consequently the United States has had no occasion to make any territorial claims in the so called United States Sector. However, official pronouncements have been made indicating that, should any discoveries be made in the area, the Government would take the position that they came under our sovereignty. For example, when the Naval Com-

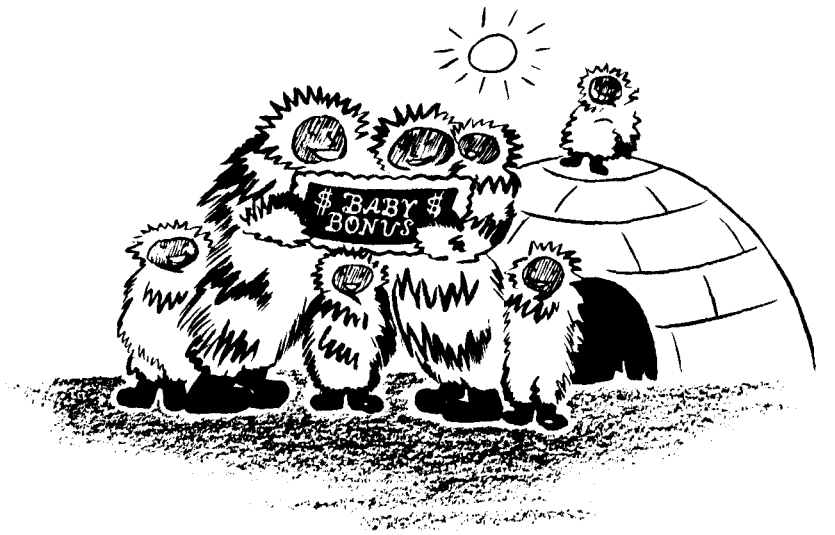


Figure 4–4.—Payment of baby bonus.

mittee of the House of Representatives was discussing the question of sending the airship *Shenandoah* to the polar regions (19 January 1924). Mr. Denby, Secretary of the Navy, said that the flight was being undertaken partly because there was an unknown area of 1,000,000 square miles north of Alaska, and that it was "highly desirable that the United States should know what is in that region." The Secretary went on to say, "If there is in that region land, either habitable or not, it should be the property of the United States." The weather flights now being made by the United States, the establishment of weather stations, and the recent trips of public vessels to the Arctic have not been made the basis for any claims by the United States to territory in the arctic regions.

SOVIET UNION

The government of the Soviet Union has categorically laid claim to all lands, known and unknown, lying north of the northern coast of Russian Siberia. A decree of 15 April 1926, mentioned previously, states that lands and islands are considered to be Soviet territory when they lie between the northern coast of the Soviet Union and the North Pole, in the region limited by the meridian 32°4′35″ E., cutting the east side of the Vaidaguba, through the

triangular mark on Cape Kekursky, and by the meridian 168°49′30″ W., cutting the middle of the sound separating the Ratmanov and the Krusenstern Islands.

Since the United States and Canada have allowed all their claims to Wrangel Island to lapse, and since the Russians are in physical possession in the Soviet Arctic Sector, Franz Josef Land merits brief mention.

The archipelago has long been the scene of Norwegian sealing and other types of hunting expeditions. Whatever settlements the Norwegians made were seasonal and of too limited a scope to have the characteristics of effective occupation. No serious claim to sovereignty could be made by Norway on the basis of these settlements.

The Soviet Union made a claim to sovereignty over the archipelago in 1928. By a decree of 7 March 1929, funds were provided for a radio station and a geo-physical station on Franz Josef Land. On 28 July 1929, the flag of the Soviet Union was hoisted on Hooker Island and other ceremonies appropriate to the taking of possession were performed. Since that time the Soviets have expanded their occupation. For all practical pur-

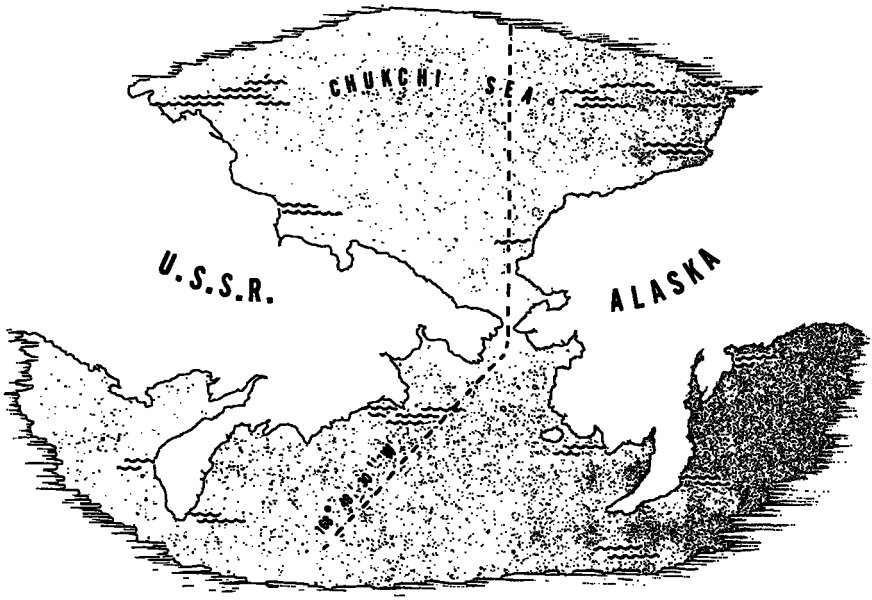


Figure 4–5.—Boundary between U. S. A. and U. S. S. R.

poses no government any longer seriously questions the sovereignty over the archipelago.

The treaty between the United States and Russia of 1867 has provided a special argument, from the Russian point of view, to the validity of the sector principle. This treaty stipulated that the boundary between the two states should be the meridian 168°49′30″ W., in the Bering Sea, and it was stated with regard to this boundary that it "continues to the north in a straight line without limitation until it disappears in the Arctic." In further support of the sector principle favoring Soviet claims is the treaty of 1825 between Russia and Great Britain relating to the boundary line between Alaska and Canada, where the expression is used that the meridian 141° W. should be the boundary line "right up to the Arctic" (*jusqu's la Mer Glacial*).

DENMARK

For some years Norway and Denmark made conflicting claims to Greenland. Denmark claimed all of the area, while Norway laid claim to Eastern Greenland on the basis of various settlements which the Norwegians had made there.

Down to 1931 no power disputed the Danish claim to all of Greenland. On 10 July of that year a royal Norwegian decree placed Eastern Greenland (territory between 71°30′ N. and 75°40′ N.) under Norwegian sovereignty. On 12 July 1932, a second decree making claim to Southeast Greenland (Territory between 60°30′ N. and 63°40′ N.) was promulgated by the Norwegian Government, while the question of Eastern Greenland was before the Permanent Court of International Justice. This second claim was also placed before the court.

On 5 April 1933, the Permanent Court handed down its decision that Denmark has a valid title to sovereignty over all of Greenland. The court said that in the East Greenland Agreement of 1925 Norway had recognized Danish sovereignty and therefore the 10 July 1931 Norwegian decree of occupation and sovereignty was void.

Although the Norwegians had established settlements in Eastern Greenland, these existed at the sufferance of Denmark, so to speak, on the basis of the Agreement of 1924. Because of this, the court concluded that the Danish claim was clearly the superior one, although the Norwegians might have been more active in the business of erecting settlements. The court went on to say

that, "It is impossible to read the records of the decisions in cases as to territorial sovereignty without observing that in many cases the tribunal has been satisfied with very little in the way of the actual exercise of sovereign rights, provided that the other state could not make out a superior claim. This is particularly true in the case of claims to sovereignty over areas in thinly populated or unsettled countries."

On 7 April 1933 (2 days after the court's decision was handed down) Norway revoked the decree of 12 July 1932 by which claim had been made to Southeast Greenland. This revocation and the court's decision in the Eastern Greenland case firmly established Denmark's claim to all of Greenland.

Denmark has made no claims under the sector principle.

NORWAY

The two Norwegian possessions in the Arctic region are Spitsbergen (Svalbard Archipelago) and Jan Mayen Island. The latter island is a desolate area of 144 square miles lying about 300 miles north of Iceland. The Norwegian Meteorological Institute established a weather station there in 1921. Otherwise Jan Mayen is uninhabited. No one disputes Norway's claim to sovereignty over the island, and they are in possession.

The Svalbard archipelago was discovered by Norsemen in 1194 and rediscovered by Barents in 1596. The islands have long been the resort of whalers of several nations. Periodically since 1261, Norway has asserted claim to the islands. From 1870 on, this claim has been asserted with increasing insistency because Norwegian explorations have discovered rich outcropping seams of coal—a mineral which Norway lacks. There are also large deposits of low-grade iron ore and gypsum. Signs of oil have been reported.

Down to 1921, the Norwegian claim was questioned by other states wishing to exploit the area. The prize was a good one and the competitors important. Possibly more to keep a rival from winning this prize than for any other reason, the interested powers relinquished all claims by a treaty signed in Paris on 9 February 1921. In this treaty, the United States, Great Britain, Denmark, France, Italy, Japan, the Netherlands, and Sweden agreed that Norway was sovereign over the archipelago. The Soviet Union, then not in a position to be a signatory, has since declared its recognition of Norwegian sovereignty.

Norway has made no claims under the Sector Principle.

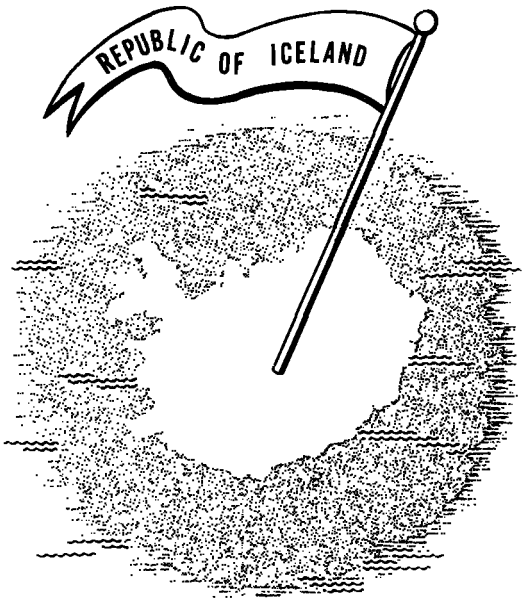


Figure 4–6.—The Republic of Iceland.

ICELAND

When Norway separated from Denmark in 1814, Iceland remained under Denmark. In 1918, the Danish Government acknowledged Iceland as a sovereign state, united with Denmark only in that the Danish king was also king of Iceland.

When Germany occupied Denmark, the Icelandic Parliament (Althing) voted in May, 1941, to terminate the union with Denmark. A regent was elected to assume the functions of the King and it was resolved that a republican constitution be adopted as soon as the union ceases. In May of 1944, the people of Iceland severed the last tenuous bond to Denmark by terminating the regency. The Icelandic Parliament formally proclaimed Iceland to be an independent republic, and the regent, Sveinn Bjoernsson, was elected President of Iceland.

Iceland claims no territory in the Arctic.

FINLAND

By the treaty of Dorpat, dated 14 October 1920, Finland was given an Arctic frontier, but this is a very short one. In the Finnish sector of the Arctic there is no land other than a small part of Svalbard (Spitsbergen) belonging to Norway.

INTERNATIONAL AGREEMENTS

As was pointed out earlier in this chapter, the United States lays claim to no territory in the arctic region other than Alaska, nor does it endorse the Sector Principle. Under modern conditions, possessions in the region are of great value, particularly to a major power, for defense as well as other reasons. The United States satisfies its defense requirements by means of agreements with other governments rather than by seeking possessions of its own to be utilized in this manner. Following is a brief discussion of the United States agreements with Denmark, Canada, and Iceland.

AGREEMENT RELATING TO THE DEFENSE OF GREENLAND

When German forces invaded and occupied Denmark in April, 1940, it opened the way for possible German occupation of Denmark's possession, Greenland, and its utilization as a base for operations against North America. Under the pressure of this threat, the local authorities in Greenland adopted a resolution (3 May 1940) expressing the hope that, for as long as Greenland remains cut off from the mother country, the United States Government would keep in mind Greenland's exposed position.

There was no question of the fact that the defense of Greenland against attack by a non-American power was essential to the preservation of the peace and security of the American continent and a matter of vital concern to our country. There was no practical way in which an agreement with the Danish home government could be made because of the German occupation. However, the 1940 resolution of the Greenland authorities did offer a practical, legal basis for negotiation. In view of this extraordinary political situation, the Danish Ambassador felt himself to be free and competent to enter into an agreement with the United States in the name of his King, although lacking specific authorization to do so. In short, it was felt that the King was no longer a free agent. The Danish Ambassador and Secretary Hull signed an agreement concerning the defense of Greenland on 9 April 1941.

In the treaty the United States Government specifically reiterated its recognition of and respect for Danish sovereignty over Greenland. Recognizing that Greenland might be "converted into a point of aggression" against this continent, we accepted the responsibility for assisting Greenland in the maintenance of its security. The agreement gives us the right to construct, maintain,

and operate such landing fields, seaplane facilities, and radio and meteorological installations as are considered necessary for the defense of the area. This grant included the right to do any and all things necessary to insure the efficient operation, maintenance, and fortifications.

Denmark retained sovereignty over all defense areas leased by the United States, but the latter has jurisdiction over such areas and the persons therein for as "long as this agreement shall remain in force." This agreement remains in force "until it is agreed that the present dangers to the peace and security of the American continent have passed." At such time, any modification or termination of the agreement is to be the subject of consultation of the two governments. After due consultation, either party may serve notice of its intention to terminate the agreement, and it shall cease to be in force "at the expiration of 12 months after such notice shall have been received" by the other party.

The treaty is still in force. A little over a year ago, the Danish Government indicated its intention to initiate consultation with the view to terminating the agreement. The discussions are currently in progress and the future of United States rights in Greenland remains unsettled.

Formal diplomatic clearance for visits of United States ships to Greenland is not required when the visit is in connection with the defense of Greenland or other related activities. It is, however, the practice of the Navy Department through the Department of State to keep the Government of Denmark informed of our activities in and around Greenland.

DEFENSE ARRANGEMENTS WITH CANADA

On the basis of the Ogdensburg Agreement (18 August 1940) the Governments of the United States and Canada established a Permanent Joint Board on Defense. This board is charged with the responsibility of making studies on sea, land, and air problems, including personnel and material. Its over-all mission is to consider, in the broad sense, the defense of the northern half of the western hemisphere.

In the interest of efficiency and economy, each Government has decided that its national defense establishment shall, to the extent authorized by law, continue to collaborate for peacetime joint security purposes. The collaboration will necessarily be limited and will be based on the following principles:

1. Interchange of selected individuals so as to increase the fa-

miliarity of each country's defense establishment with that of the other country.

2. General cooperation and exchange of observers in connection with exercises and with the development and tests of materiel of common interest.

3. Encouragement of common designs and standards in arms, equipment, organization, methods of training, and new developments. As certain United Kingdom standards have long been in use in Canada, no radical change is contemplated or practicable, and the application of this principle will be gradual.

4. Mutual and reciprocal availability of military, naval, and air facilities in each country; this principle to be applied as may be agreed in specific instances. Reciprocally each country will continue to provide with a minimum of formality for the transit through its territory and its territorial waters of military aircraft and public vessels of the other country.

5. As an underlying principle all cooperative arrangements will be without impairment of the control of either country over all activities in its territory.

While in this, as in many other matters of mutual concern, there is an identity of view and interest between the two countries, the decision of each has been taken independently, in continuation of the practice developed since the establishment of the Joint Defense Board in 1940. No treaty, executive agreement, or contractual obligations has been entered into. Each country will determine the extent of its practical collaboration in respect of each and all of the foregoing principles. Either country may at any time discontinue collaboration on any or all of them. Neither country will take any action inconsistent with the Charter of the United Nations. The Charter remains the cornerstone of the foreign policy of each.

AGREEMENT WITH ICELAND

On 11 July 1941, the United States entered into an agreement with Iceland to station American troops on the island. These troops were withdrawn after the defense agreement was terminated in October, 1946.

A new agreement was signed on 7 October 1946, under which provision was made for interim use of Keflavik airport. The agreement "shall continue in effect until the obligation of the Government of the United States to maintain control of agencies

in Germany shall have been fulfilled; provided, however, that at any time after the lapse of 5 years from the coming into force of the present agreement, the Keflavik airport will continue to be available for use by aircraft operated by or on behalf of the Government of the United States. The special character of these aircraft and their personnel will be respected as far as customs, immigration, and other formalities are concerned. No landing fees shall be charged such aircraft.

It should be noted that the agreement above does not apply to entry by United States naval ships. Formal diplomatic clearance is required for such visits to ports in Iceland.

SUMMARY

This chapter is included so that our position in the Arctic will be known, under the terms of international agreements and of accepted principles of international law. In areas over which Canada and Denmark have clearly recognized sovereignty, United States forces must be careful of their actions and statements, less infringements and misunderstandings occur.

It is recognized that these possessions are vital in the defense of the approaches to the American continent. That our position there should remain clear and indisputed is evident. Therefore, it is mandatory that personnel of the Navy respect the laws, rights, and position of the sovereign powers here as in any other part of the world.

CHAPTER 5

CLOTHING AND PERSONAL EQUIPMENT

"It is quite a mistake to suppose that one becomes hardened to the cold; however, one becomes expert in keeping oneself warm."—Scott.
"Keep dry is the first law of the North."—Carlson.

The arctic winter is not very different from the winters in northern Wyoming, Montana, or the Dakotas—except that it lasts longer. Some parts of the Arctic, of course, are much worse and every part is always subject to extremes of climate. If the few basic principles are known and applied it is possible to live and work in the Arctic without serious trouble, and still be comparatively comfortable.

CONSERVE BODY HEAT

The first problem facing men assigned to duty in the Arctic is adaptation to cold. The main objective is to keep comfortably warm. If that is not done, energy is wasted and it will be im-

possible to work or perform a duty or task assigned. The first lesson is to learn to conserve body heat which can be lost extremely fast to the cold surrounding air. There are two ways which will help to attain comfort and save body energy. One is proper wearing and use of the special clothing provided; the other is acclimatization or becoming accustomed to a colder environment than normally desirable. The success of the first depends on adaptation; the success of the second depends on how well body machinery adjusts itself to the cold.

Actually, the body is very much like a gas engine. The food eaten is the gas. When this food energy is burned by the different tissues in the body, such as the muscles or the brain, about 20 percent of the energy is used in doing work and about 80 percent is liberated as heat—just about the same ratio as that of an engine. The lungs are the carburetor, intake, and exhaust through which oxygen is drawn in, mixed with the blood, and the waste gas (carbon dioxide) eliminated. The heart and blood are the fuel pump and line; they force the absorbed food and oxygen through

Figure 5-1.—Avoid perspiration (loosen clothing or remove coat).

the body under different pressures. The surface of the body is the radiator and, like any other radiator, the bigger the surface in proportion to the thickness, the faster the loss of heat. So the arms and legs (especially the hands, feet, fingers, and toes) and other extremities such as the ears, nose, and chin are remarkably efficient radiators.

The *thermostatic control* of the body heat is more complicated than in an engine. This is roughly how it works: when exercising or working it is necessary for the body to burn more "gas" (food energy). More air is needed and the lungs simulate a supercharger; breathing is faster and deeper. More heat is generated and the "radiator" is taxed heavily. It is not possible to suddenly increase the radiating surface, but water can be poured on the outside of an overheated radiator, similar to the early practice of pouring water on the radiator of an Old Model T after climbing a hill. The body does this by means of perspiration. But perspiration in the arctic cold is liable to freeze—either on the skin or in the underclothes—and then the body may also freeze.

One of the first principles to learn is to avoid perspiration. Loosen the clothing or take some off, layer by layer, while work is in progress, replacing them layer by layer as body activity is reduced. Remember that uncontrolled perspiration may prove disastrous because it leads to freezing in low temperatures.

Remember, too, that the cold, outside air rapidly sucks heat from the body. Heat pours out like a stream running down hill. The thermostat in this case controls the amount of heat reaching the radiator by reducing the supply and slowing the rate of flow. That is, the small blood vessels near the skin shut down and the blood thickens so that it does not flow as fast. In this way, the skin temperature is lowered and the body may feel cold. The cold skin in itself is a poor conductor and less heat is lost from it than from the warm skin.

SEASONAL CLOTHING FOR THE ARCTIC

Away from the coast, summer temperatures in ice-free regions of the North are sufficiently high to make the wearing of winter clothing or even woolen uniforms decidedly uncomfortable. However, even with high temperatures complete body covering is necessary for protection against the hordes of mosquitoes and biting flies.

In the interior, if a special summer outfit is lacking, wear wind-

proofs over light underwear. An extra shirt and pair of trousers are a useful addition to the kit. As insurance against cold spells, also include a sweater or warm jacket. Coastal regions usually are colder than the interior and require warmer clothing than is normally worn inland.

Since most summer travel is over wet ground, the best foot gear is the shoepac. Wear wool socks in summer as in winter and carry spares so that the feet can be kept dry and clean.

In all coastal areas of the Arctic and sub-Arctic, fog and rain or wet snow are frequent during the summer. Here, rain suits are highly desirable. In interior areas, wet-weather clothing is less necessary. But even inland, a light rain or water-repellent jacket will come in handy.

USE AND CARE OF COLD WEATHER CLOTHING

The body's method of heat control is automatic. It helps one become accustomed to having a cold skin. It is an important way of controlling heat loss, but the most important factor in protecting the body from the cold is the manner in which protective clothing is used. Take a lesson from the arctic partridge, or ptarmigan; he knows how to keep warm. His fluffy feathers hold in many tiny pockets of dead air which slow down the escape of heat from his body. By raising or lowering his feathers, he can increase or decrease the amount of dead air around his body and thus make himself warmer or cooler. A human can be as comfortable in winter as a ptarmigan if he uses his clothing properly. On the other hand, if he underestimates the dangers of really cold weather and fails to use his clothing and other personal epuipment properly, he may lose a hand or a foot or even freeze to death.

GENERAL PRECAUTIONS

It is essential that every item of clothing fit properly. Each must be loose fitting—and remember that all items will probably shrink when washed. This is especially important around the joints—shoulders, elbows, hips, and knees—in view of the fact that pressure from the clothes will shut off the blood supply in the skin area where it occurs, and will make that area much more likely to freeze. However, if clothing is too large, air currents will be set up which carry heat away from the body. Remember that loosening the clothes is one easy way to cool off when a man becomes too hot from working, and closing them warms him as he grows cool.

The most important precaution in the use and care of cold weather clothing is to keep the clothing dry at all times. Water conducts heat faster than does air. Hence, wet clothing is cold clothing. Keep perspiration at a minimum. Do not wear more clothing than is necessary. It is better to underdress and be slightly cold than to overdress and perspire freely. Cold weather clothing is designed to be worn in several layers. When a man feels himself getting too warm, he should shed clothing to the point at which there is just enough to keep comfortably warm. On windy days, it is better to remove inner clothing than to take off the windproofs themselves. If a man perspires while traveling and fails to take off some clothing, he will grow cold quickly and will experience great discomfort on stopping at the end of the day's march. Anticipate the perspiration point. Remove some clothing before beginning to get wet with perspiration. *Train personnel to stay on the cool side!*

Though perspiration may not be noticeable, men perspire constantly. Regardless of the outside temperature, the body gives off through the skin about a pint of moisture a day. This is called *insensible perspiration*. There are, then, two degrees of perspiration to contend with: visible perspiration caused by exertion or overwarm clothing, and insensible perspiration, which occurs regardless of the circumstances. The moisture condenses and forms hoarfrost somewhere on the garments.

In cold weather the point of condensation may depend upon how much clothing is worn. If the dress is light, the frost either will form in the surrounding air and drift away as fog, or will form in the windproofs. When it forms on the garment, brush it off. On more heavily clad personnel, the frost will form somewhere within the layers of clothing. Later, in the warmth of a camp (unless precautions are taken) the frost will melt. Still later, when the resulting moisture is exposed to cold it will turn to ice. To deal with this problem, and keep perspiration at a minimum at all times, wear the smallest amount of clothing necessary to keep comfortable and adjust it to allow for ventilation. This will reduce the visible perspiration resulting from physical activity and warm clothing. Dressing lightly reduces perspiration. Thus, most of the frost forms on or near the outside of the garments rather than in them.

There are many little tricks to practice in keeping the body below the rapid perspiration point. Taking off gloves or wearing only

the leather shell may be enough to keep cool. Pull back the sleeves from the wrists or unbutton the shirt or put the parka hood down. When wearing a belt over the parka coat, remove the belt and open the parka coat forward at the neck in order to cool the body.

Melting hoarfrost makes the clothes wet. Therefore, do not let the frost melt. Before entering a warm tent or shelter, remove the outer garments and, while they are still dry, beat and brush the frost out of them. If the stay inside is long, hang the garments inside to dry. If not, leave them outside in the cold where the remaining hoarfrost will not melt.

Figure 5-2.—Shoepac.

Drying clothes is particularly difficult in crowded living quarters. To overcome this problem, hang the clothes on a rack suspended from the ceiling above the stove where the air is warmer than at stove level.

CARING FOR FOOTWEAR

Standard issue shoes with overshoes or *Arctics* are generally satisfactory for shipboard use. Footwear for shore use requires special precautions. Since it is difficult to prevent feet from perspiring, make sure the footwear does not fit tightly. Likewise, take the trouble to put on dry socks and insoles at the beginning of each day's work or march. In cold weather, moisture will condense either in the outer sock or on the inside of the boot. Frost

can be beaten out of the sock, but to get it out of the boot, use a small, stiff-bristled brush. The insole should be removed as soon as the boot is taken off; otherwise, it will freeze in the boot. Insoles keep their shape better if interchanged each day.

Change socks after returning to camp. Wash both socks and insoles and dry them over the stove by hanging them near the top of the tent. Another method is to place socks next to the body while traveling. Even though the temperature is below freezing, some drying will occur. Do not attempt to dry socks in a sleeping bag unless the temperature is above zero. Leather boots should not be greased in cold weather as grease is a poor insulator and will make the boots colder. Greased boots will freeze stiff during the night. Before sleeping, spread open the uppers of the boots so that even though they may be frozen, the feet can be slipped into them the following morning.

KEEPING CLOTHES CLEAN

Oil from the body, collecting on underwear will fill the tiny air cells (the properties that make the underwear warm) in the garment. To a lesser degree, the same is true of other clothes.

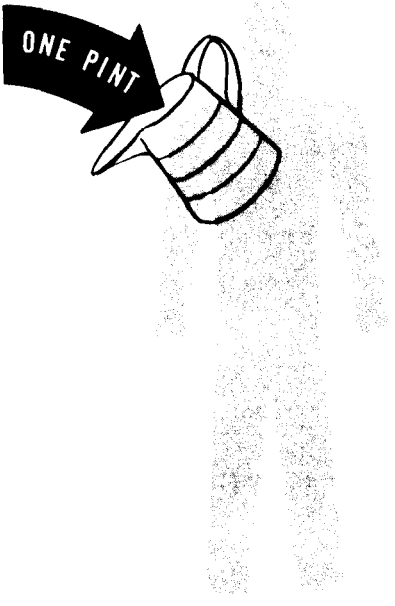


Figure 5-3. The body gives off about a pint of perspiration a day.

Figure 5-4.—Hang clothes high to dry out.

Woolens should be washed in lukewarm water with a mild soap. Issue soap is too strong and is not recommended. After washing a garment, rinse it well and squeeze it to dry (laying it flat, if possible) in a warm place. Do not put the garment where it will freeze. It is especially important to wash both socks and feet frequently.

USING A SLEEPING BAG

The best material for sleeping bags is either caribou skin with the hair on or water-repellent material filled with eiderdown. The bags now being made for military use are part down and part feathers. The outer covering should be water-repellent but not waterproof. Some bags are made with two down-filled cases, one inside the other. This type also is advantageous in warm weather, since only one case need be used. The bag can be tapered toward the feet but should have plenty of room at the shoulders to allow free arm movement. Slide fasteners (zippers) should be supple-

mented by snap fasteners or eyelets for lacing in case the slide fasteners fail to work. The bag should have a hood and scarf attachment so that the sleeper's mouth and nose are out of the bag.

Do not sleep with the head inside the sleeping bag. Moisture from the breath will ice its interior. Wear only the minimum of clothing in the bag and never wear damp underwear. If necessary, change to dry underwear before using the sleeping bag. If dry underwear is not available, it is best to bed down in the nude. In very cold temperatures, hoarfrost cannot be removed easily. Care must be taken to keep its formation down to a minimum. Because perspiration cannot be entirely prevented, open the bag immediately upon arising and pump air in and out to remove the moist air and reduce the temperature inside the bag. Arctic bags now being issued have cotton liners which can be removed and washed, thus helping to keep the bags themselves clean. Air the bag as frequently as possible. Should the fabric become torn, repair it at once to avoid loss of feathers upon which warmth depends.

Never place the sleeping bag directly on snow or any other cold surface. Generally, a mat will be provided to place under the bag. If this is not available, spruce or fir boughs and grass make handy insulators. Before getting in the bag, puff it out by shaking it so that there will be plenty of dead-air space in the down. In mosquito country in summer, netting stretched over the head of the bag is necessary for undisturbed sleep.

FUNCTION AND DESIGN OF COLD WEATHER CLOTHING

Good clothing and its proper use are more important in cold country than anywhere else in the world. If the proper technique and equipment are used, a man can work safely and comfortably even at very low temperatures. On the other hand, subzero weather is brutal to men who are poorly equipped. *The Arctic does not treat men well.* If one underestimates the dangers and fails to wear adequate clothing, or worse, fails to use adequate clothing properly, he may suffer the loss of a hand or foot, or even risk death.

FUNCTION

The primary function of clothing is to shut in body heat and keep the body warm. Heat is transferred from a warmer object to a colder one until the temperature of the two becomes nearly the same. As insulation, clothing prevents, or rather slows down,

the transfer of heat from the body to the outside air somewhat as a rubber glove prevents the jumping of electricity from a charged wire to the hand. One of the best insulators is still air. It retards the transfer of heat through it. That is why cold weather clothing is designed to hold a considerable amount of air. A soft, spongy material that holds thousands of little air cells between its fibers is better than a tightly compressed material that holds very little air. On the other hand, loose, air-holding material is not of much use as long as the air is allowed to be blown through it by the wind. For this reason an outer shell of tightly woven cotton cloth is necessary to keep the cold air out and the warm air in.

DESIGN

Not only should the material used for arctic clothing be loosely woven so it will hold plenty of air between its fibers, but it should be resilient so that it does not pack down and become compressed. Clothes must fit loosely. When they are tight, they contain little air and do not insulate effectively. Use several thin layers instead of one thick one; additional insulation will be provided by the dead air trapped between the layers, and clothing can then be removed easily to maintain comfortable body temperature. The outer layer should not only be windproof, but should also be large enough to accommodate the maximum amount of clothing that may have to be worn underneath it. Another important reason for wearing loose clothes is that tight clothes impede the circulation of blood in arms and legs. If circulation is cut off only slightly in the arms or legs, they will soon grow cold and may freeze. This point is especially important with footwear. When extra size shoes are not available, it is much better to wear but one pair of socks if a second pair means tight-fitting and uncomfortable shoes.

UNDERCLOTHING

Two-piece issue underwear is absorbent and light in weight and permits the easy escape of perspiration. Be sure that it does not bind at any point. Two-piece underwear permits the separate removal of either drawers or shirt; if a man falls through ice or wishes to strip to the waist, this is an advantage.

FOOTWEAR

Efficient footwear is probably the most important single item of winter clothing. Except for the face, feet are the parts of the body most likely to freeze. This is because shoes form a

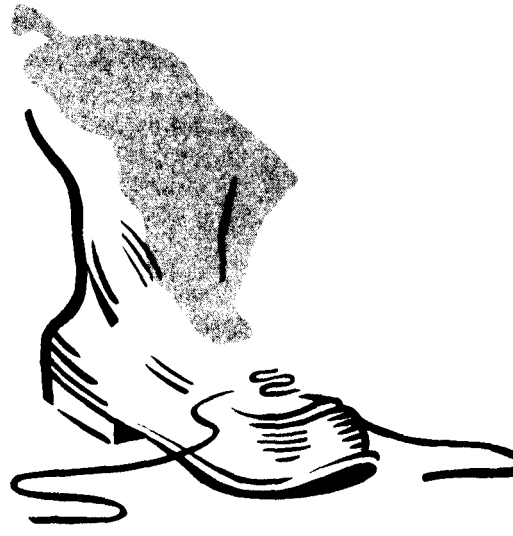


Figure 5–5.—Spread open boots.

rather tight casing and do not allow perspiration to evaporate. Hence, shoes with linings such as felt or fleece that cannot be removed for airing or washing should not be worn.

Many types of arctic footwear have been used with success. When leather boots are worn, they should be one or two sizes larger in both width and length than for ordinary wear. They should be large enough to be worn with ¼-inch insoles and two or three pairs of light wool socks without binding the feet. The need for such large shoes is hard for an inexperienced man to understand, but it is very real. Leather boots must be carefully broken in. They are not suitable for temperatures less than about 20° F.

Mukluk boots, copied from the Eskimo, have a dry-tan leather or rubber sole, and canvas uppers extending up to just below the knees. Not being waterproof, they are not adapted for use in wet and slushy snow. However, they are excellent in extreme cold. Lace them so they do not fit tightly around the calves.

Shoepacs are a serviceable type of boot for use in wet snow. They are laced boots with rubber feet and leather uppers. They are not suitable for cold weather and should not be used in temperatures below zero. Even above 0° F., socks and insoles must be thoroughly dry in order to keep the feet warm.

The best footwear for continuously exposed occupations or on the trail at extremely low temperatures is an Eskimo mukluk made of caribou skin.

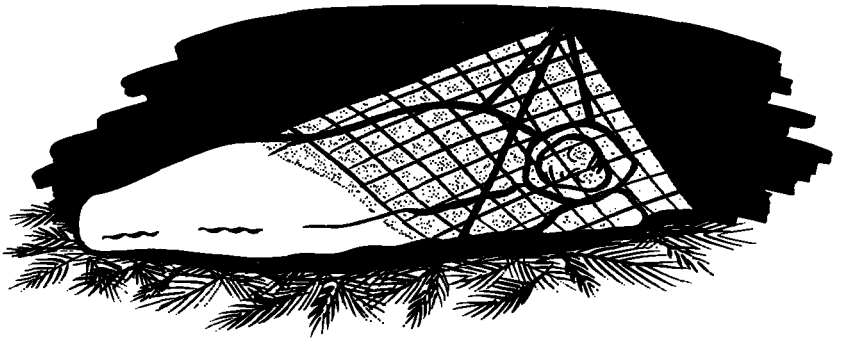


Figure 5–6.—Sleeping on fir boughs.

All arctic footwear, regardless of type, should be worn with insoles. Insoles can be made of felt, burlap, or fur. A good substitute is dry grass found throughout the Arctic. Pack the grass not only in the bottom of the boot as an insole but also around the foot for additional insulation. Insoles absorb moisture from the feet and provide additional insulation between foot and ground. This extra insulation is necessary because the socks become compressed under the weight of the body, with reduction in their ability to hold air in their fibers.

Several types of socks have been found suitable. They may be of the ordinary knitted variety or made out of blanket cloth in a design similar to that of a baby's bootee. Some men find

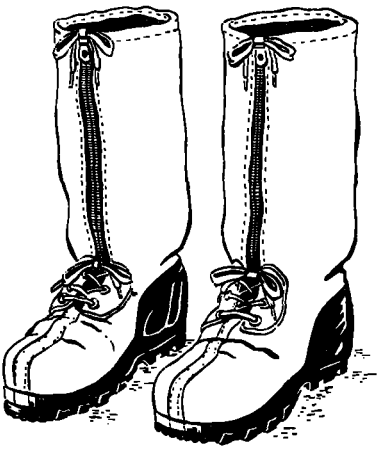


Figure 5–7.—Mukluks.

that jute or burlap socks worn outside the wool socks help to evaporate moisture from the feet. Take care that socks are large enough, so that when two or three pairs are worn, the outer socks are not unduly stretched. It is a good idea to have two sizes and wear the larger pair on the outside. Some men prefer cotton or rayon socks next to the flesh.

HANDWEAR

The best all-round type of handwear consists of a woolen insert mitten worn inside an outer shell mitten made of leather or windproof cloth. The shell mitten should be large enough to hold two insert mittens, although two may be needed only in very extreme temperatures. For troops, both shell and insert mittens have separate trigger fingers. Both mittens should be large enough so that the first finger can be withdrawn from the trigger finger and kept next to the others for warmth. Mittens of fur are good at extremely low temperatures.

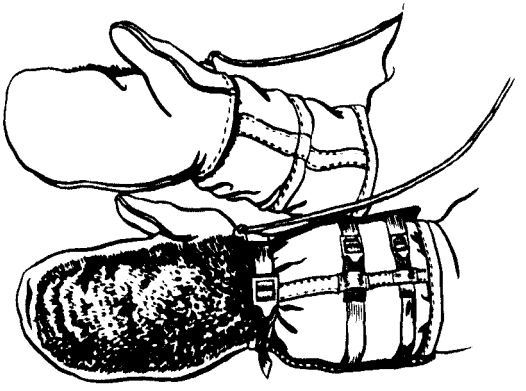


Figure 5–8.—Mittens.

For prolonged exposure without activity at very low temperatures, gauntlets made of caribou or other fur can be worn outside the woolen inserts. The chief objection to gauntlets is that snow easily collects in the gauntlet cuff.

Wristlets are recommended by some for sealing the gaps between sleeves and gloves and for work that requires the use of bare hands. In the latter case, the wristlet should cover the hand to the fingers.

Ordinarily, gloves are not suitable in temperatures below 0° F.,

but they are sometimes used when a fine sense of touch is necessary. Silk or rayon gloves are particularly good. Like the Eskimo, one can become accustomed, even in cold weather, to the use of bare hands provided they are warmed from time to time. In selecting gloves, go by the feel and fit rather than size.

HEADWEAR

A knitted wool helmet similar in design to a flying helmet is the best covering for the head. It should come well down over the forehead. Likewise, it should fit about the face and extend from the chin to the shirt collar. It must have a covering of windproof cloth, unless it is intended to be worn inside a parka hood. Whatever other headgear is devised, be sure it covers the ears since they are very easily frozen. It should not cover the mouth. It should be designed so that it does not press too heavily on the top of the head.

BODY CLOTHING

Ordinary heavy woolen trousers and shirt are very convenient for use in the Arctic, especially where troops are living in heated barracks much of the time. Many men with polar experience do not like sweaters because they are tight and are hard to put on and take off. A woolen vest worn over the shirt and buttoned up to the neck is very warm. The parka shape is best for the heavy outdoor garment. It is made of wool, woolpile, or fur, with windproof outer cover, slips on over the head, and has a permanently attached hood. It ought to be loose around the body, neck and shoulders, and should have drawstrings at the front of the hood and around the bottom or at the waist to permit adjustment for ventilation. Fur ruff on the hood is essential for protection of the face.

Windproofs are worth their weight in gold. They are made of smooth, tightly woven cotton cloth. They are water-repellent but are never waterproof because they must allow moisture from the skin to pass off into the atmosphere in the form of vapor. They must be large enough to fit over the maximum amount of clothing that will be worn. The trousers should have drawstrings at waist and ankles. Avoid a fly of the usual type. One about 2 inches long with a flap behind it is enough. The upper garment is of the parka type with drawstrings at the hood and at the bottom. It should extend below the hips.

Under conditions of high windchill such as may be experienced by men on flight decks of carriers or on lookout watch, face masks are an item of special gear that help withstand the rigors of the wind. It has been noted that at temperatures below minus 30° F. in wind a well-designed face mask added to the efficiency of the protection of the whole clothing assembly. However, when using a face mask, it is well to check the color of the face skin beneath to insure that freezing is not taking place.

UTILITY OF COLD WEATHER CLOTHING

The utility of winter clothing for shore based personnel, judged by experience at Point Barrow, Alaska, is summarized briefly as follows:

Arctics, shore N–2.—Durable and satisfactory in moderate weather—late spring, summer, and early fall.

Bag, sleeping, large.—Down-filled bag satisfactory for most purposes; for trail use it must be waterproof. In severest weather, furlined bag is necessary.

Boots, hip, rubber N–2.—Satisfactory only for summer use.

Cap, field, cotton, O. D., with visor.—Very satisfactory, particularly when fitted with ear flaps.

Coat, parka, winter N–1.—Satisfactory for moderate cold only. (Down to 0° F.)

Glasses, sun N–1.—Satisfactory (poloroids preferable).

Gloves, handmade, Eskimo type, wolf skin (fur inside).—Very satisfactory.

Gloves, work, N–1.—Suitable only for moderate cold.

Jacket, parka, rain N–2.—Very practical.

Jacket, winter N–1, alpaca lined with zipper.—Satisfactory during moderate cold.

Mittens, winter N–2.—Satisfactory for use separately in moderate cold or as a liner in leather mittens in cold weather.

Mittens, work, leather N–3.—Fairly satisfactory but short life.

Mukluks.—Eskimo types most satisfactory.

Net, head, mosquito.—A *must* where insects are present.

Pants, flying, quilled, down filled.—Very good for air travel or on the trail and during severe cold weather.

Pants, kersey-lined.—Durable and warm.

Parka, B–9, USAF.—Very good except in severe weather (minus 30° F.).

Parka, caribou.—Satisfactory during summer and winter.

Scarf, winter N–1.—Satisfactory during coldest periods (for moderate weather, rayon scarf preferable).

Shirts, army, O. D.—Very satisfactory.

Shoes, felt, Navy.—Most suitable yet found for cold, dry weather.

Shoes, field N–1.—Practical only for shipboard use or summer wear ashore.

Shoepac, Army—Satisfactory during spring, summer, early fall ashore. (Satisfactory for coldest weather on shipboard.)

Drawers, winter N–1.—Satisfactory.

Undershirt, winter N–1 with drawers, winter N–1.—Satisfactory.

CLOTHING EXPERIENCE DURING SUBMARINE OPERATION

The following items of standard cold weather clothing should be issued as a minimum to each man unless prescribed differently in operation orders:

1 woolen blanket.
1 pair, woolen trousers (Army issue).
1 woolen shirt (Army issue).
1 sweater, winter N–1.
1 jacket, winter N–1.
2 suits, winter underwear N–1.
2 pairs, woolen socks.

The following additional items are required for lookout, quartermasters, and others on watch topside:

1 helmet, winter N–1.
1 face mask, winter N–1.
1 pair goggles N–2.
1 pair sun glasses N–1.
1 pair mittens, N–1.
2 pair mittens, winter N–2.
1 scarf, winter N–1.
2 pair duffle socks.
2 pair insoles.

The following items should be furnished to the submarine to be kept in a pool system:

8 heavy winter coats, sheepskin lined.
16 parkas, winter N–1.
30 pairs, arctics N–1.
36 trousers, rain N–2.
36 jackets, rain N–2.
36 trousers, winter N–1.

CLOTHING EXPERIENCE DURING WINTER ICEBREAKER OPERATIONS

The utility of winter clothing for shipboard personnel may be judged by experience from recent icebreaker winter operations in the Bering Sea, summarized briefly as follows:

1. Standard issue cold weather clothing was found to be inadequate for watch standers when temperature was below 20° F. and for general wear when temperature was below 0° F.

2. Footwear was found to be inadequate for men whose duties require them to be exposed for extended times. Consensus showed the following:

a. Shoes ST#72–S–75560 do not keep feet warm under conditions below 0° F. while operating in pack ice.

b. Shoepacs were satisfactory down to 15° F.

c. Mukluks (L37–B–4247) were satisfactory in lowest temperatures down to minus 20° F. and were generally satisfactory when climbing rough snow or ice-covered terrain.

d. Flight boots (R37–B–4216) were excellent and were the unanimous choice as the ideal footwear by officers and men standing watches topside at lowest temperatures encountered. For beach parties these boots are too heavy and too warm except during severest cold weather below minus 30° F.

3. Hoods (R55–H–2500) with the fur face ruff were very satisfactory.

4. Winter trousers N–1 (55–T–62623) were satisfactory down to 0° F. However, trousers (55–T–350) were found to be warmer and less bulky.

5. For temperatures below 0° F., coverall (R55–C–3150) was used. This provides an over-all type of windbreaker and insulation for body warmth to be worn over the standard Navy jacket and dungaree trousers. It was found suitable for even greater protection when worn over a combination of jacket (R55–J–400) and winter trousers (R55–T–350). This coverall is an adequate article of clothing for exposed lookouts.

For similar operations, the icebreaker recommended that trousers (R55–T–350) be placed on the ship's allowance in place of trousers winter N–1 (55–T–62623); jackets (R55–J–400) be substituted in place of alpaca jacket (55–J–571); and hoods (R55–H–500) be provided for one hundred percent of complement.

It was also recommended that a quantity of mukluks (Larane Shoe Corp., Contract No. 155–QM–15830) equal to 150 percent of complement should be on board to be used for both watch standers and beach parties in subzero temperatures. It was found desirable that an allowance of 100 pneumatic sleeping bags (Air Force No. 8300–597100 SPE 3187A Order No. 45.2446–PF New York Rubber Co.) be provided for future winter operations. The purpose of the pneumatic bag is not for comfort, but to raise the sleeping bag above the snow enough to keep it from becoming wet or damp from snow melting due to body heat.

ISSUING SPECIAL CLOTHING

The procurement, issuing, and storing of special clothing both on shipboard and at shore based installations is of primary importance. Experience gained during past cold weather operations reveals that shipboard fitting and issue procedure has been complicated by the lack of adequate space. Sufficient space should be available in an issuing room to allow an inventory of sizes for immediate issue, to eliminate the requirement of issuing incorrect sizes pending the restocking of the issue room. Consideration should also be given to the provision of adequate space for the storing of special clothing from the standpoint of drying and keeping it dry.

In regard to issuing procedure, it is noted that, as a general rule, men do not accurately know their head, waist, chest, foot, and other body sizes. Therefore, the expedient of issuing garments on this basis is unsatisfactory. Further, fitting an individual satisfactorily with one garment and then issuing additional garments of the same size marking is unreliable, in view of the difference in garments by various manufacturers for the same size number.

The desirable method of issue would be a fitting stage, followed by an immediate issue of the same garment and later by an inspection of all personnel by division officers, to insure proper fittings. This method will involve large available stocks at one location and adequate space for fitting and issue. Close cooperation will be required by the ship's supply section and supply activity to satisfactorily handle the matter of properly outfitting ship personnel. Once fitted, men should be advised of correct sizes and this information noted in service records.

SUMMARY

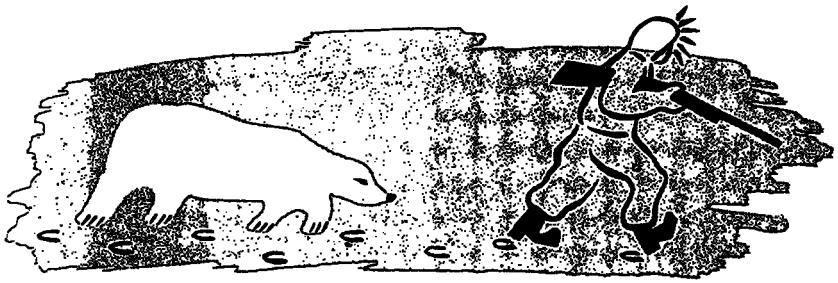
Arctic clothing made available for past polar expeditions has proven generally satisfactory for shipboard use and can be adapted satisfactorily for more severe conditions encountered ashore. Standard issue items will prove adequate for summer operations. Special issue items must be provided in addition to standard items of cold weather clothing for winter operations in arctic seas.

Problems of design and standardization must be solved in order to improve clothing and simplify stock and issue thereof. All personnel must be enjoined to take care of clothing issued for cold weather operations. Commanding officers must ensure that clothing be kept dry and clean, that facilities for laundering, drying, and stowage be provided, and that clothing is properly cleaned and refurbished before turning it in to the supply depot, following completion of the operation.

Experience has shown that men can go through a process of body conditioning to endure cold weather by reducing the amount of clothing to the minimum to keep comfortable, and by being careful to remove or put on clothing when it becomes necessary to adjust to changes in temperatures. It is preferable to resort more to exercise for warmth than to wear excess clothing. It is possible to improve the body's circulation and toughen the skin of the hands and feet by controlled and careful exposure.

For additional information refer to chapter 3 of the U. S. Army publication, *Arctic Operations* (FM31–76).

Figure 5–9.—Dressed for the Arctic. Note face mask.



CHAPTER 6

HEALTH AND SURVIVAL

But the human elements of endurance and courage are the most important of all in Polar work."—Fiala.

"To be happy in the North, one must have varied interests."—MacMillan.

Arctic medicine demands the application of principles and practices that are basically the same as those in use elsewhere throughout the north temperate zones of the world. If these known facts are kept in mind and used, there is every reason for the medical aspect of any polar operation to be successful. Indeed, Navy personnel have enjoyed as good or better health during operations in the high northern and southern latitudes as in other geographic areas with less severe climates.

Good health and low morbidity rate in cold weather areas are dependent on good caloric intake of about 4,500 calories daily, warm clothing, prevention of usual respiratory ailments, adequate protection of the extremities of the body, and adoption of means to reduce motion sickness. By all means, use the facilities available to the fullest to make living comfortable.

THE EFFECT OF INTENSE COLD

To best explain the effects of cold, the following self-explanatory quotations from the writings of explorers are offered:

"Still the biting cold would have been impossible to face by anyone not

fortified by an inflexible purpose. The bitter wind burned our faces, so that they cracked, and long after we got into camp each day they pained us so that we could hardly go to sleep. The Eskimos complained much, and at every camp fixed their fur clothing about their faces, waists, knees and wrists. They also complained about their noses, which I have never known them to do before. The air was as keen and bitter as steel."—Peary.

" . . . during which the furious wind kept us enveloped in driving snow." —Peary.

"The wind cuts through the warmest clothes."—Fiala.

"All sense of direction is lost in an arctic storm. The flying snow and drift are like a sand blast and blind anyone exposed to their fury."—Fiala.

Figure 6–1.—Hunters return with crab eater seal.

" . . . and to expose the hands to the frigid air for only a few seconds was painful."—Fiala.

" . . . and even 54 degrees below zero was not objectionable until a light breeze of 4 to 5 miles per hour altered this opinion."—Hayes.

"The greatest threat of the Arctic is not in low temperatures but in moisture turning to ice."—Carlson.

"Cold weather slows down everything except optimism."—U. S. Navy.

"Cold is depressing in its influence and soon enfeebles the powers of the will. At first it stimulates to action, but this vigor is quickly followed by torpidity; exertion is soon succeeded by the desire to rest."—Payer.

ENVIRONMENTAL SANITATION

Fortunately sufficient basic data about topography and meteorology are known to enable one to plan the sanitation for a given area in the North.

In the summer the usual precautions for assuring protection against the spoilage of food supplies, a pure potable water supply, and berthing, laundry, messing, housing and waste disposal facilities have proven satisfactory, both at sea and ashore. In areas ashore, roughly south of 70° N. latitude, insect control will tax the ingenuity of those in charge, but the methods already available —screening, head-nets, DDT spray, insect repellants—will give sufficient protection and comfort.

In winter, a difference is at once noted. At sea, the problems are similar to those faced on North Atlantic duty. All food must be kept below decks since vegetables such as potatoes, lettuce, and carrots, which are occasionally kept topside, will soon spoil because of the low temperatures 20° F. to 35° F., and the almost continual wetness from fog, rain, or snow. In addition, hot drinks and extra rations will be necessary. Waste disposal will demand that outlet pipes be warmed by an increased temperature of the affluent. The ship, as a whole, will need to be winterized and comfortably heated and ventilated. Additional space for recreation and for the stowage and drying of foul and cold weather gear must be made available. Finally, the human tolerance or work feasibility for each job will need to be carefully reassessed—usual watches topside cut proportionately, special stations manned for minimum periods, and relief gun crews trained.

Ashore, the whole sanitary concept must be built about the problems arising in winter from high winds, blizzards, extreme cold, and darkness; and in summer from constant daylight, insects, varying climatic conditions, marshy tracts, and muskeg.

In addition to what is usually built into military housing, additional lighting, heat supply, and insulation will have to be furnished. Whenever possible, buildings should be connected by closed passageways, taking into consideration proper fire protection measures.

Water supply is discussed elsewhere in this chapter.

Food that can be frozen will be easily handled, but special precautions will have to be taken to protect food that may be spoiled by freezing.

The disposal of human wastes is not a serious problem so long as only a few men are involved, units are not returning to the area, or the temperature is such that waste freezes almost immediately and stays frozen. However, under conditions of extreme cold where heated shelter is not available, a personal problem will be presented, due to the possibility of freezing exposed parts. This can be solved by the proper design of arctic clothing which will incorporate such features as long skirted parkas within which the hands may be withdrawn. In connection with waste disposal, a disposal bag or 50-gallon oil drum provided with burlap liner, which is allowed to freeze and later removed to a central dump and burned with fuel oil, is an expedient method which may be used. Wherever possible, it is recommended that heated wanigan-type heads be provided and located not too far from living quarters. Freezing prevents both the danger of contamination and unpleasant odors and the frozen waste can then be collected and burned with diesel fuel in a centrally located area.

All head, bathing, and washing facilities should be heated and located as close to living quarters as possible.

Because of the difficulties in obtaining sufficient water for laundry purposes, the question of dry-cleaning clothing should be considered.

One of the most difficult things for men to get used to is a dull, monotonous life. The solution is to keep busy and to keep the

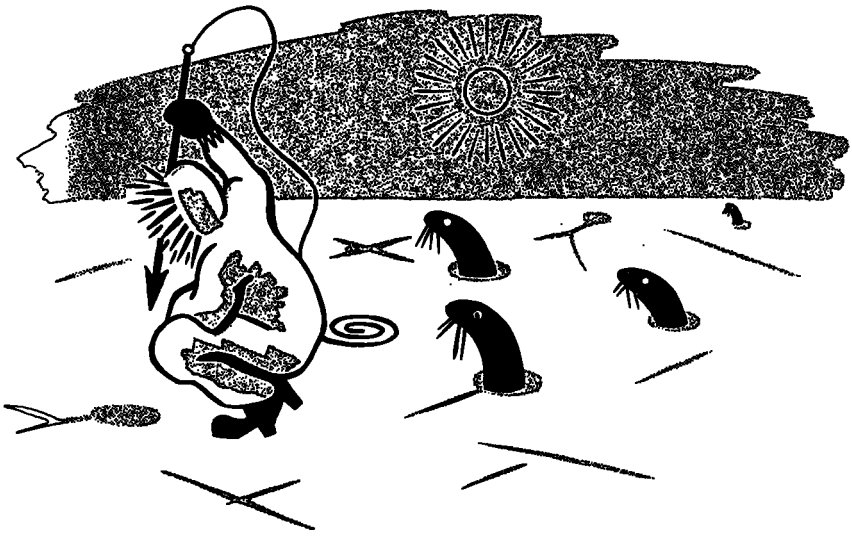


Figure 6–2.—Hunting and fishing.

mind occupied. Every form of amusement that can be provided is essential to morale and contentment. Snow sports, hunting and fishing, educational courses, hobbies, reading, movies, and various other forms of amusement should be provided at stations and outlying posts. The usual recreational facilities provided on board ship are available in the Arctic as elsewhere. At isolated posts and arctic stations, provision for amusement becomes a problem that must be met, along with others peculiar to the station. During summer cruises in the high latitudes allow as many of the personnel as possible to get ashore to satisfy their curiosity, at least.

The maintenance of a high standard of morale at arctic stations is mandatory. The principal factors are as follows: Keep men informed as to the operations at hand; provide them with a continuous estimate of the situation; maintain a good mess—men in a cold climate require a heavier caloric diet; establish a definite length of tour to be about one year, with only volunteers returning for duty; arrange for leave or rest in areas outside the Arctic.

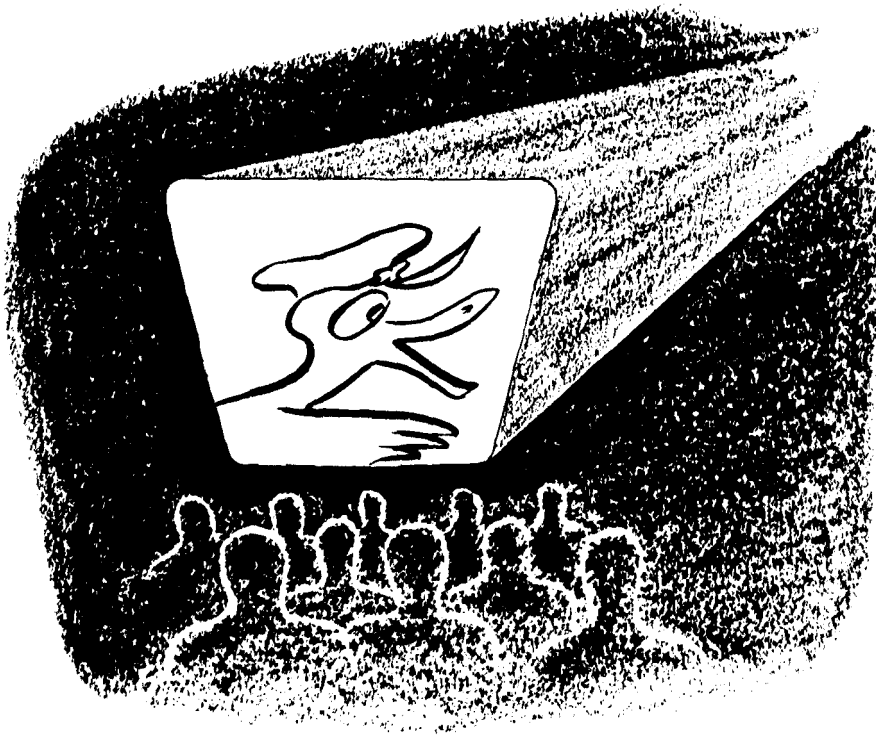


Figure 6–3—Movies.

FROSTBITE, SNOW BLINDNESS, SUNBURN

Snow blindness, frostbite, frozen extremities, trench foot, immersion foot, carbon monoxide poisoning, and insect bites are, on first sight, a rather formidable array of ailments to face. On examining each one, there is a gradual realization that each is preventable, given the proper equipment intelligently used. Large numbers of men have lived and survived in the Arctic without suffering more than minimum injury from its many hazards. At no time, however, must one relax guarding against the dangers inherent in the environment. To do so may result in a crippling illness, even death.

Snow blindness results from the action of the sun's rays in the presence of snow. Clear, bright days are not necessary, for some of the most severe cases of snowblindness have occurred on overcast days. The present goggles or sunglasses issued to service

personnel will give adequate protection, if worn continuously. If these become lost or broken, the area about the bridge of the eyes may be blackened with soot or grease to cut down glare. In an emergency, satisfactory goggles may be improvised by making a mask out of a thin piece of wood or cardboard, using narrow slits for vision. A piece of cloth thin enough to see through may be worn over the eyes if nothing else is available.

If snow blindness results, ophthalmic ointment carried in the survival kit should be freely squeezed between the lids; and if possible, the eyes should be bandaged until symptoms, such as severe pain, burning of the eyes, tearing, and inability to stand light, have passed. In addition, moist, cold compresses will relieve some of the painful swelling. If mild, the symptoms usually disapper in a few days; if severe, one may be a casualty of several weeks. Personnel who have once had snow blindness are more susceptible to a recurrence during the following weeks.

Almost anyone who has lived in the Arctic has been frostbitten at one time or another during extreme weather. The prevention of frostbite demands continual awareness of the possibility when temperatures are below freezing, particularly if there is a wind. The frozen or frostbitten area–usually the face, ears, or wrists—becomes stiff, whitish, and numb. The area will rapidly regain its normal color and sensation if treated immediately by gently warming, as by placing the warm hand over the area or placing frozen fingers inside the clothing.

Brisk rubbing with or without snow is to be condemned and must not be used. Never immerse a frostbitten foot in cold kerosene or other liquid. If damage is sustained, a condition compar-

Figure 6–4.—Emergency eye protection.

Figure 6-5.—Frostbitten face.

able to a severe sunburn results, with the formation of blisters. An ointment should be applied, and the area covered with a sterile dressing. Men should be constantly on the alert in detecting the whitish or grayish discoloration of early frostbite on their companions. As most frequently frostbitten parts are those of the face, which can not be seen by the victim, it is a wise policy to work in pairs. Thus, a man can warn his companion that his face is frostbitten and first aid measures can be applied before the condition becomes severe.

In recent winter icebreaker operations, the faces of men wearing sound powered telephones for long periods at exposed stations became frostbitten. Such casualties can be avoided by wearing phones over face masks. Face masks or circular nylon scarfs should be worn by personnel exposed to strong winds below 30° F., as on the flight deck of aircraft carriers.

Freezing of the feet or hands is one of the severest penalties that a man can pay for carelessness or accidents in the Arctic. When a man's feet are frozen, he is through. Such freezing of extremities should not normally occur if the man is careful and keeps properly dressed in service-issued clothing, gloves, and footwear. Unfortunately, it is possible for men to be placed in a situation following a crash or fire, where proper clothing is not available.

The frozen parts usually are very painful at first, with the pain

then giving way to numbness. The skin over the part may be white or little changed. If permanently damaged, the part will eventually turn black, the surrounding area swelling enormously, and the skin becoming a mass of large blood blisters. Above all else, the person should be placed in a shelter as soon as possible. The injured part is then warmed slowly and kept at room temperature (65° F. to 70° F.) with the remainder of the body made as warm as possible with blankets and stimulating hot drinks. Medical attention should be sought, if available. The pain may be controlled by further cooling and the administration of half of a morphine syrette every 4 hours, if available.

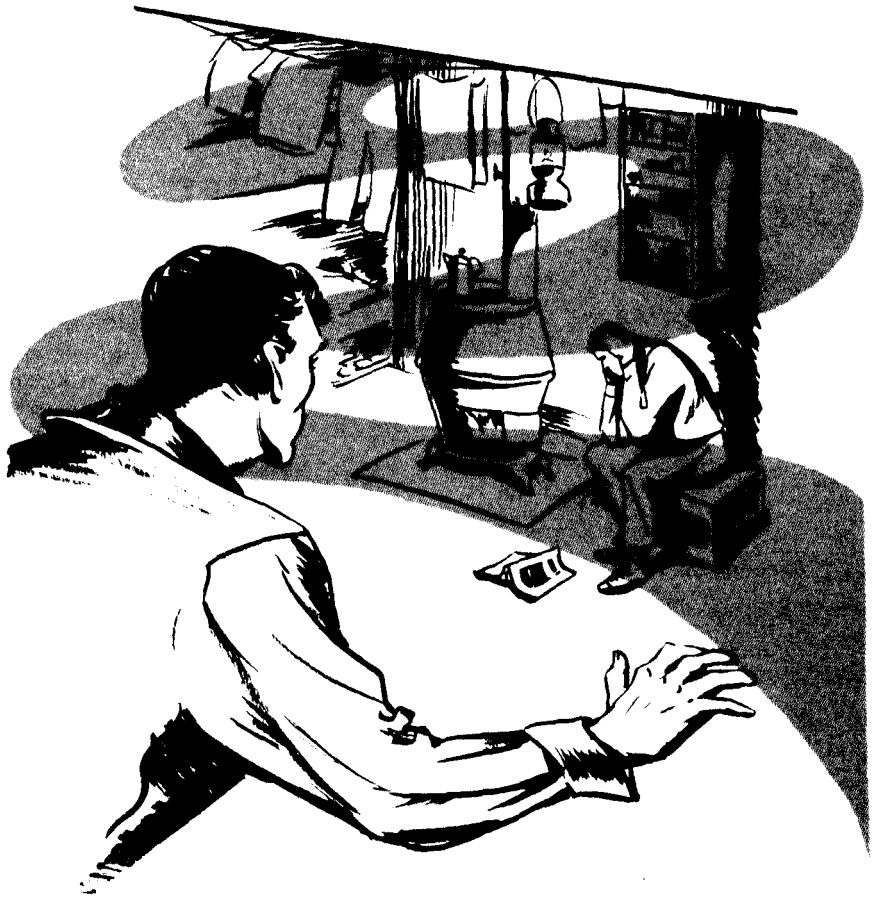


Figure 6-6.—Be alert for carbon monoxide poisoning.

This train of events, which in its severest form may lead to eventual amputation, is preventable.

Shoes, foot coverings, gloves, and body clothing must be kept dry, as explained in the previous chapter. This is best done by changing clothes or making camp and actually drying out clothing. Foot coverings should not be tight fitting. Any constriction of an extremity must be avoided. Tight fitting shoes should be replaced in an emergency by a makeshift covering made from available cloth materials such as parachute silk or blankets.

Immersion and trench foot result when temperatures at or just above freezing are associated with wet conditions. In addition, personnel are usually wearing constricting shoes or leggings. The constant wetness, cold, and constriction cause swelling of the extremity with a softness and discoloration of the skin. The prevention is a dry, well-fitting foot covering. Otherwise, massaging, elevating, and warming the feet will do much to prevent damage, if instituted early. Final treatment is similar to that for frozen extremities.

All personnel living in arctic shelters must be constantly on the alert for carbon monoxide poisoning. Under cold conditions, effort is usually made to keep warm, while ventilation is cut down. Coal or oil fires and engine exhaust are the usual sources of carbon monoxide poisoning. This colorless, odorless gas first affects a person by a slight headache, a feeling of drowsiness. The affected persons should either leave or be removed to other quarters, artificial respiration begun and oxygen given, if available.

TREATMENT AND EVACUATION OF CASUALTIES

A man who is wounded in the Arctic will be in grave peril of freezing. Suffering from shock and inactivity because of his wound, he may be an easy victim to the effects of cold. It is essential that he be provided quick warmth, shelter, and first aid treatment, followed by earliest evacuation back to base and medical treatment.

SURVIVAL AND EMERGENCY LIVING

Survival in the Arctic demands the intelligent use of all means at one's disposal. Every item of material and equipment that is available is capable of many uses and adaptations.

The Arctic covers a wide and varied environment of mountains, plains, swamps, and water areas, with temperatures ranging from

minus 70° F. in winter to 90° F. in summer. In order to survive, much general knowledge, and a basic plan of survival are necessary. The following is given as a guide, with numerous additions suggesting themselves.

Personnel should at all times be familiar with the area in which they are operating so that, if shipwrecked, forced down in a plane, or lost from a working party or group, the greatest use is made of the environment.

First aid treatment of the injured should be accomplished first. Next, take every precaution to safeguard supplies and equipment. In no event stray far from the original position until all hope for rescue has been abandoned.

Preparation should be made to signal rescuers, build a fire, erect shelter, and ration available food to last as long as possible.

See *Polar Guide* (AFTRC 50–0–23, revised 15 June 1948) chapters 17 and 18.

FIRST AID

Injuries and sickness may occur in the Arctic as well as anywhere else. Treatment will be limited by the equipment available but improvisation and common sense will do much to help.

Shock.—This results from severe injuries, bleeding, or blast. It is recognized by a sharp, thready pulse, moist, sweaty skin, and rapid breathing. Emergency treatment demands the removal of the cause, and control of bleeding. Warmth, shelter, and the giving of warm fluids is next indicated. If severe pain exists, the contents of a morphine syrette may be administered.

Bleeding.—A tourniquet is rarely necessary. Most bleeding can be controlled by the pressure of a battle dressing. Treatment for shock is then indicated.

Wounds.—A battle dressing, or any clean dressing should be placed over the wound and firmly bandaged.

Fractures.—"Splint them where they lie" is the first maxim for fracture treatment. The important fact is that a fracture must be immobilized. Pain will become much less, once proper splinting has been performed. There are means for splinting available most everywhere. The upper or lower arm may be strapped to the body; the leg splinted by the other leg. If splinting is not performed, serious damage may result to arteries and muscles or, more important, shock will certainly ensue. Splints and bandages should not be applied too tightly for fear of impairing the circulation.

Burns.—Burn cases are treated for shock, if present. The burned area is then covered with a sterile ointment, followed by sterile dressings. Morphine can be administered to relieve the patient's pain if necessary.

(By all means, in all first aid, it must be remembered that injured personnel are very susceptible to the effects of cold. Every effort must be made to keep them warm and to get them to warm, comfortable surroundings as rapidly as possible.)

Maintenance of medical supplies.—The problem of maintaining medical supplies is complicated in cold climates by the fact that liquid drugs freeze and break in their containers. In some cases certain drug products lose their potency on freezing, although some do not and may be safely used after thawing. Experience reveals two interesting facts. First, containers which are not filled to more than 90 percent of their capacity are not likely to break upon freezing; second, metal containers of drawn construction are more resistant to bursting than those with soldered edges, or glass containers.

FUEL

The oil and gasoline available are obvious sources of heat during the period of rescue. The oil should be drained into any available container before it solidifies. Stoves are fairly easily improvised from cans.

Below the tree-line, sufficient wood will be available. On going farther north, the available fuel supply becomes less and less. Driftwood, the rare coal deposits, and dwarf willows and grasses will have to serve. To kindle a fire, gun powder, birch bark, and dry leaves will serve as a tinder.

SHELTER

For making any kind of shelter, one should first utilize the materials with which one has landed. If in a plane, any of the easily removable sections, such as the cowling, will serve for shelter construction. The cabin of a large plane will provide an excellent temporary shelter. Similar use may also be made of stranded vehicles and of boats. Trees, sod, and snow furnish building material for housing once the immediate crisis is over. See *Polar Guide*, chapter 18, pages 7 to 16 inclusive, for various improvisations of livable shelters.

The food that one arrives with should be divided into portions so that the longest possible survival is planned. Roughly, this may be figured by dividing a normal daily ration into four parts. This will add up to 800 to 1,200 calories. This ration may be supplemented by shell-fish, fish, birds, mammals, and plants that can be hunted in the area. Polar bear liver and a mushroom-like plant with a yellowish red cap are the only things that are truly poisonous.

The smaller mammals, such as lemmings, rabbits, and porcupines may be taken in snares. Musk oxen, caribou, seals, and polar bear may be shot with a rifle. Ducks, ptarmigan, geese, ravens, and owls are also to be found.

Shellfish may be dug on most shorelines or in shallow water.

When using plants, it must be remembered that the roots and inner bark will supply nourishment. Except for berries, all plants should be cooked.

If an animal or bird is caught, everything should be eaten—fat, liver, kidneys, etc.—along with the flesh. (See *Polar Guide*, ch. 18, pp. 23 to 39 inclusive.)

EMERGENCY RATIONS

Emergency rations are unfortunately limited by weight restrictions. The exact ration used will depend on the weight allotted for the purpose, anticipated survival period, and activity expected.

It is known that as low as 400 calories daily will keep a man alive for 10 days, the extra caloric requirement being made up from one's tissue. One thousand calories daily are sufficient for 20 days, and 2,000 calories are adequate for an indefinite period if there is no activity.

Weight requirements per man using a concentrated ration are roughly as follows: 400 calorie diet—0.31 lb. day; 1,000 calorie diet—0.77 lb./day; 2,000 calorie diet—1.38 lb./day.

Water will have to be supplied in quantities of one to two quarts, depending on the calories ingested, and the emergency ration unit should include, if possible, both the gasoline and the stove for resupplying water.

It is easily seen that no emergency ration may be devised that will keep personnel at more than a subsistence level. Any attempt to leave the site of original emergency is probably foolish, for it takes three to five thousand calories daily to travel in the North. In addition, it is obvious that every means to supplement one's

rations off the land is of vital importance. Even though emergency rations freeze, they can be made edible by warming.

One can be heartened by the fact that both the native population and the white man have lived completely from the land in the Arctic.

CLOTHING

Clothing may be supplemented by parachute silk, blankets, cloth package material, etc. Paper may be used for insulation between layers of clothing.

If one does not have adequate foot covering, mukluks should be improvised from canvas, blankets, or parachute material. The skins of birds and mammals may also be utilized. If at all possible, loose footwear should be immediately substituted for tight shoes.

Whatever clothing is available must be carefully guarded against wetting from sweat or immersion. The clothing for each task should be planned and just enough worn to keep warm. Damp or wet clothing should be dried as soon as possible.

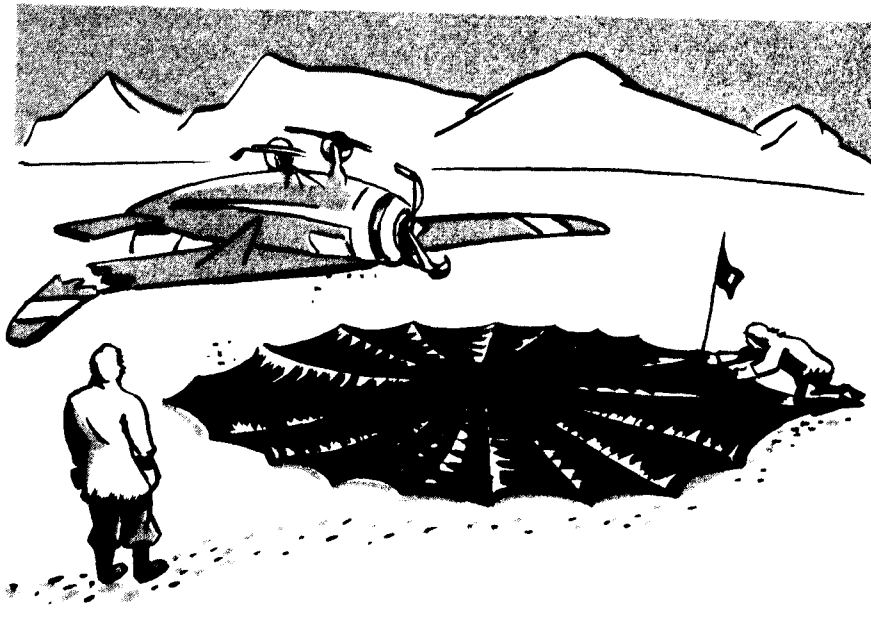


Figure 6–7.—Signal for rescuers.

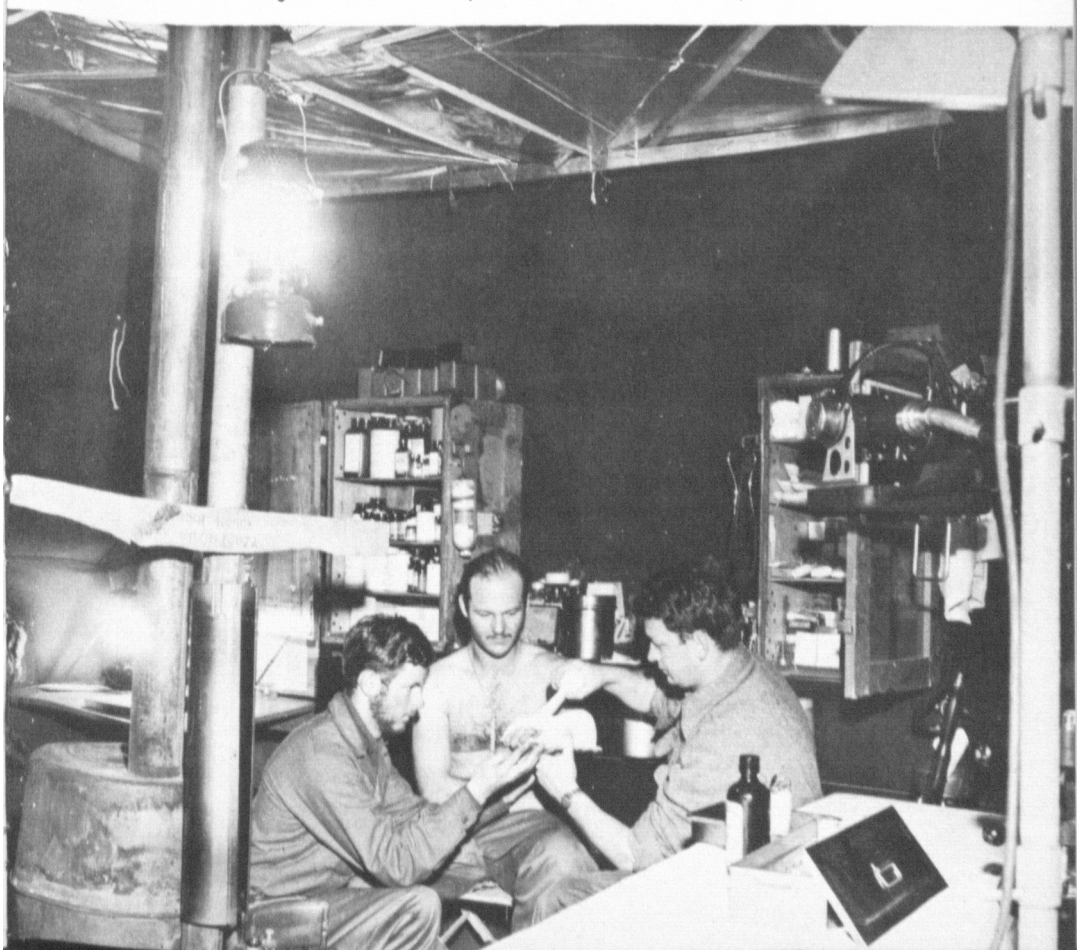
RESCUE

Rescue depends on complete cooperation between the rescuers and the persons to be rescued. The group to be rescued had best stay near the original landing point. As soon as possible, means for signalling should be ready. A well-made fire to which small quantities of water, heavy oil, grease, or rubber are added will give a thick, heavy smoke. Water gives a white smoke and the others a black smoke. Bush, boughs, or rocks may be made into 200-foot letters. Signal mirrors, the Very pistol, and smoke generator packs are additional valuable aids, but should not be used until the rescuers are in sight. (Refer to ch. 18, pp. 3 to 7 inclusive of *Polar Guide.*)

Above all, the knowledge that every effort is being made for rescue should be sufficient cause for persons in distress to continue every effort to survive.

The group planning the rescue, in addition to making adequate search plans, must be prepared to bring food, clothing, and medical

Figure 6–8.—First aid, Little America IV sick bay tent.



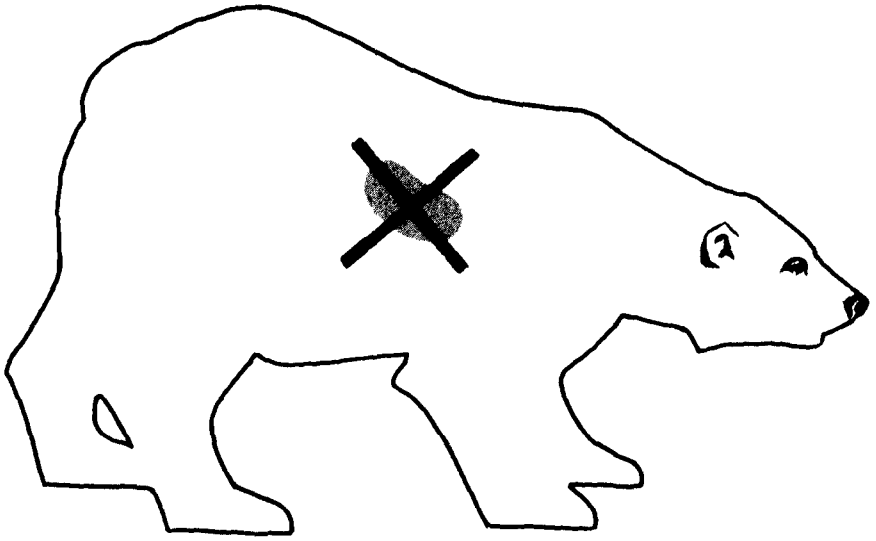


Figure 6–9.—Polar bear liver is poisonous!

aid. All of this must be droppable, if air search is contemplated. Once contact has been made, any injured or sick should be given first aid, and then evacuation performed as quickly as possible.

SOURCES OF WATER

Water in some form is universally present throughout the Arctic. There are innumerable lakes, rivers, and streams, which offer a safe potable supply for emergency use. Once these sources are frozen, the melting of snow or ice will be indicated. Volume for volume, ice is the best source, when obtainable, because of its greater specific gravity. Water may be obtained by the expedient of chopping through the ice over streams or lakes, but the difficulty involved does not ordinarily lend itself to emergency use.

When melting snow or ice, one must always remember to have a little water at the bottom of the utensil used for melting, otherwise the metal of the container may be melted through.

Eating unmelted snow is usually an unsatisfactory and unsafe method of allaying one's thirst.

At large installations, once water is obtained, the methods of purification are identical to those used elsewhere.

ABANDON SHIP

There is no experience in abandoning ship in seas of high latitudes. The real problems are survival in cold water until rescue arrives; proceeding by boat or across sea ice to shore; and living ashore, if possible, after land is reached.

Each ship operating in polar waters must evolve a plan of survival based on three conditions of open water, loose pack ice, or solid ice, and on equipment that is available.

As in abandoning ship in any area, calmness, leadership, and early rescue operations are essential to avoid catastrophe.

SUMMARY

Life ashore or on shipboard in the arctic regions is much like it is in other places. Surroundings will be different. Food will be of higher caloric content and will be served more frequently than normally. One will eat more confections. The clothing will be modified as required to meet the rigors of climate. There will

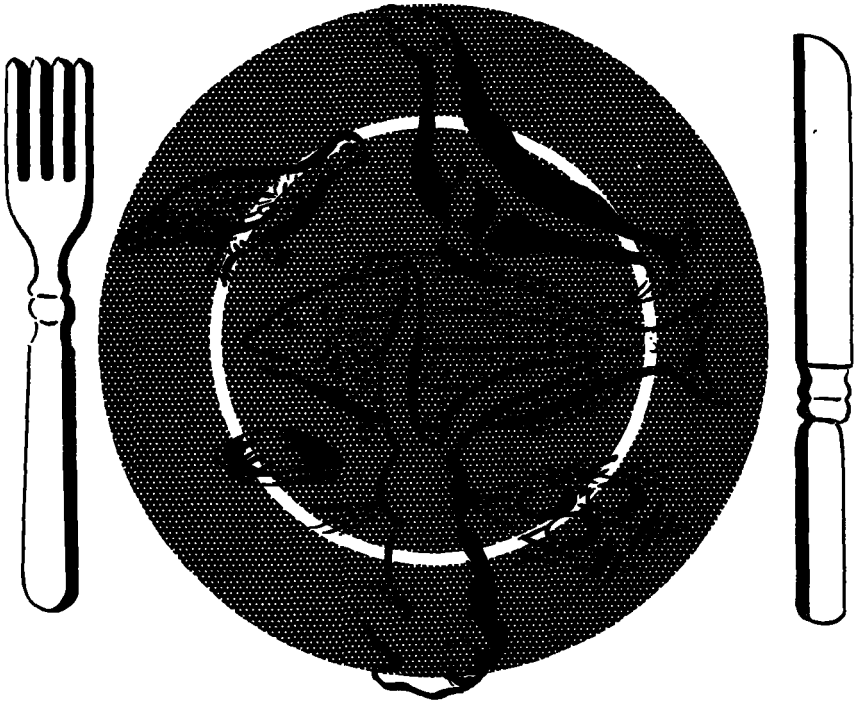


Figure 6–10.—Man can live completely from the land in the Arctic.

Figure 6–11.—Smoke signal—burning rubber.

be certain inconveniences as well as some curtailment of social and recreational activities.

It will be necessary to become adjusted to constant daylight, constant darkness, and remoteness of the areas visited. However, men in the Arctic enjoy life there and readily find ways to adapt themselves to its severe environment. Most are willing to return if the opportunity presents itself.

Men must fully understand and appreciate the fundamentals of living and survival in the polar regions. For additional information on this subject, it is suggested that the reader study chapters 6 to 9, inclusive, and chapters 17 and 18 of Air Force Publication, *Polar Guide* (AFTRC 50-0-23, revision of 15 June 1948).

Blank page retained for pagination

CHAPTER 7

SELECTED BIBLIOGRAPHY

"I had been too much in the North to be willing to plan for an expedition by studying out of books. The trouble is the Arctic isn't anything like the books, after you get there."—Bartlett.

There is a great body of literature relating to the polar regions. Many of the books and papers were written by explorers and are either not available in libraries generally or are relatively useless insofar as applying to large-scale exploratory and naval operations in the Arctic.

The essence of the above statement by Captain "Bob" Bartlett is true. Practical experience is best always. Nevertheless, few service personnel will have had that opportunity prior to visiting the Arctic in the course of conducting naval operations there.

The manuals, guides, reports, and hydrographic publications listed herein are of recent origin and more accurately describe Arctic conditions than earlier books written for popular consumption. They are factual, represent the best service thought and experience, and should be helpful and interesting to those desirous of reading further on the subject of this handbook. It is considered that these service publications represent the very best source material available.

POLAR EXPLORATION

To the Arctic	Jeanette Mirsky.
The Secrets of Polar Travel	Robert E. Peary.
Polar Exploration	Andrew J. Croft.
The Conquest of the North Pole (Modern Arctic Exploration)	J. Gordon Hayes.
Across the Top of the World	Navexos P–489.

GUIDES AND MANUALS

Arctic Manual	Vilhjalmur Stefansson.
Arctic Manual	(Army Department) TM 1–240.
Operations in Snow and Extreme Cold	(Army Department) FM 70–15.
Principles of Cold Weather Clothing and Equipment	(Army Department) TM 70–275.
Arctic Operations	(Army Department) FM 31–70.
Polar Guide	(Air Force Department). AFTRC 50–0–23.
Survival on Land and Sea	ONI Booklet.
Climate and Weather	Opnav 33–Ny–3.
Manual of Ice Seamanship	HO 551.
Cold Weather Engineering (Two parts)	Navdocks P–17.
Some Comments on Operations and Maintenance of Ordnance Equipment	Navord OD 4486.
Instructions for Cold Weather Operation of Naval Aircraft	BuAer Technical Note 84–45.
Operations in the Arctic (Thesis)	Comdr. Palmer W. Roberts, USN.
Climatology of the Arctic Regions (Study No. 52) Parts I, II, III	Air Weather Service.

REPORTS

A Report on Task Force Frigid (1946–47)	Navmed 1195.
Report on Operation Frostbite (1946)	Navy Department.
Report on Arctic Clothing Experience	Navdocks P–13.
Marine Corps Observers Report on AGF Exercise Yukon	MC 1020121.
Report on USS Midway Cold Weather Cruise	Special BuAer Report. 15 June, 1946.
Barex Annual Reports (Point Barrow Resupply Expedition)	Navy Department.
Canadian Arctic Annual Reports	Navy Department.
The Marion Expedition to Baffin Bay and Davis Strait (Three Parts)	USCG Bulletin No. 19.
Report on Equipment and Structures in the Arctic	Navdocks P–19.

HYDROGRAPHIC PUBLICATIONS

Ice Atlas of Northern Hemisphere	HO 550.
Manual of Ice Seamanship	HO 551.
Bibliography on Ice of the Northern Hemisphere	HO 240.
Eskimo Place Names and Aids to Conversation	HO 10575.
The Arctic Regions (Chart)	HO Chart 2560.
Arctic Pilot Vol. I (Eurasiatic Sector)	British Admiralty.
Arctic Pilot Vol. III (American Sector)	British Admiralty.
Newfoundland	HO 73.
East Greenland and Iceland	HO 75.
Baffin Bay and Davis Strait	HO 76.
Northern Canada	HO 77.
Nova Scotia	HO 99.
Gulf and River St. Lawrence	HO 100.
Siberia and Chosen	HO 122.

Baltic Pilots	HO 142, 143.
Atlas of Sea-Surface Temperature Charts	HO 225.
The Northwest and North Coasts of Norway	HO 136.
United States Coast Pilot Alaska Vol. I and II	USC&GS.

SEA ICE

Manual of Ice Seamanship	HO 551.
Ice Atlas of the Northern Hemisphere	HO 550.
Physical Properties of Sea-Ice	HO Pilot Chart NA. July 1946.
Ice in Arctic Ocean and Bering Sea	HO Pilot Chart NA. May 1947.
Arctic Ice	HO Pilot Chart NA. June 1947.
Seasonal Movement of Ice in Greenland Waters	HO Pilot Chart NA. August 1946.
Instructions for Use of Ice Observers Log for Aircraft	HO Study No. 99.
Instructions for Use of Ice Observers Log for Ships	HO Study No. 104.
A Functional Glossary of Ice Terminology	HO Study No. 103.

TRAINING FILMS

Operation Highjump	NN 9160.
Army and Navy Screen Magazine #85 (Operation Highjump)	NA 243-CG.
Operations in Canadian Arctic, Summer of 1947	NN 6666.
Cold Weather Technical Problems	To be published.

ANTARCTICA

Antarctica	HO 138.
Report on Operation Highjump	TF68 Navy Department.
Army Observers Report on Operation Highjump	Serial 920P34.
Antarctica	HO Chart 2562.
Characteristics of Antarctica Ice	HO Study No. 85.
Little America	Richard E. Byrd.

Blank page retained for pagination

APPENDIX A

ANTARCTIC CLIMATE AND WEATHER

The antarctic continent consists of a large elevated land mass which is almost entirely covered by ice. This condition leads to formation of the permanent Antarctic Anticyclone (high pressure area) with the center located near the South Pole. This anticyclone is modified only by the semipermanent cyclones (low pressure areas) located in the Ross, Weddell, and Bellingshausen Seas. To the north of the Antarctic Circle is a belt of low pressure circling the globe which, in general, conforms to the northernmost edge of the off lying pack ice. Cyclonic storms moving from west to east in this low pressure belt tend to move directly into the semi-permanent cyclonic regions mentioned above, reenforcing the cyclonic circulation of these areas and losing their identity in doing so. (Refer to H.O Chart No. 2562 for the geographical features of Antarctica.)

A region of high pressure, as already mentioned, lies over the high Antarctic continent. The upper air descends over the polar ice cap, becomes intensely cooled, and moves outward in anticyclonic circulation toward the bordering belt of low pressure over the oceans surrounding the continent. In flowing downward from the polar plateau, these winds become southeasterly, due to the earth's rotation. They usually attain hurricane intensity, and blow drift snow high up in the air. Millions of tons of snow at low temperatures are at such times carried into the sea and play a large part in the regime of sea ice of the southern hemisphere.

Obstacles, such as the high mountains of South Victoria Land and Palmer Peninsula, produce a concentration of moving air, resulting in the high winds recorded in the McMurdo Sound and Marguerite Bay areas. Local winds of great intensity, some of which may be a reversal of the prevailing continental winds, are found in local areas, particularly where the terrain is marked by glacier valleys transverse to the flow of the prevailing air currents. Local disturbances may be confined to a relatively small area, with calm weather existing only a few miles from the area of high winds.

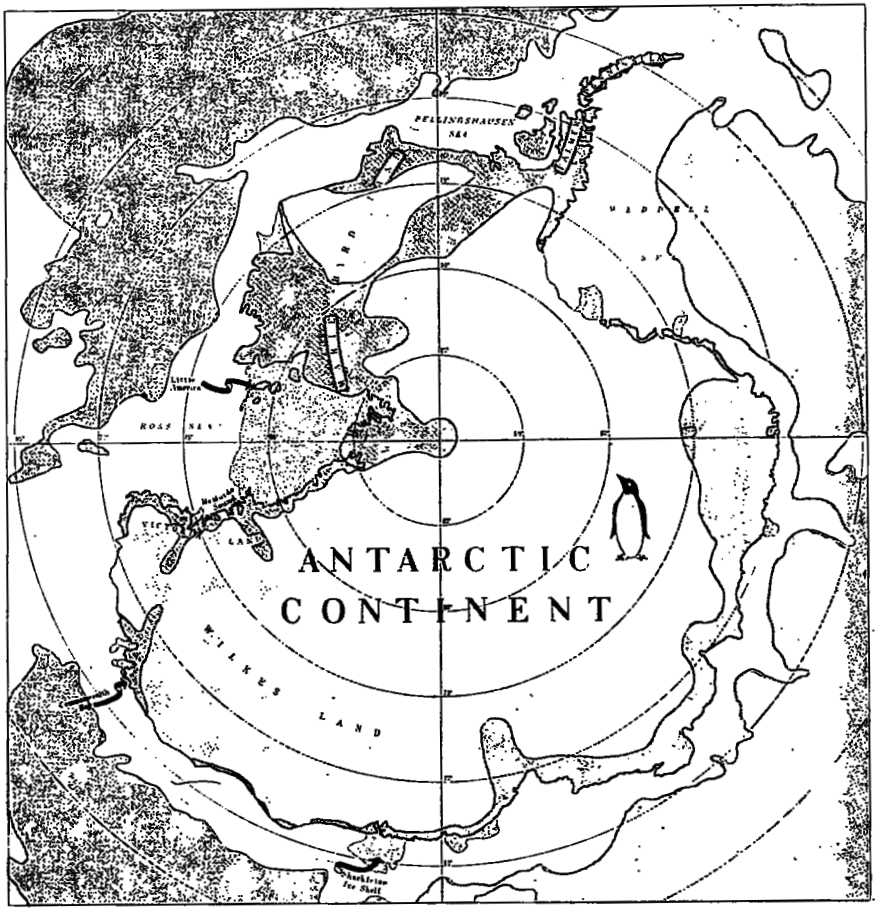


Figure A-1.—Map of Antarctica.

The Commonwealth Bay area is believed to be the windiest region in the world. The average wind speed for 22 consecutive months during 1911-14 was found to be 43 m.p.h. During July, 1913, a gale of 96 m.p.h. was experienced, during which an average speed of 89 m.p.h. was maintained for 12 hours. The mean speed for July was 55.6 m.p.h. During the month of August, 1913, an average speed of 80.6 m.p.h. was recorded during one 24-hour period, with gusts momentarily reaching over 100 m.p.h. The calmest month was February, 1912, with an average speed of 26.2 m.p.h.

Blizzards are very common in the Antarctic, but usually do not extend far out over the sea. They are rare during the *summer* period of November, December, and January, but are frequent during the *autumn* and *winter* months. The duration of a blizzard may be anything from a few hours to several days. The early indication of an approaching blizzard is the covering of the sky by light cirrus clouds which progressively become thicker, darker, and lower. Existing winds may steadily increase in force, or the blizzard may be preceded by a period of calm suddenly replaced by strong winds of 40 m.p.h. During the blizzard the wind holds steady in direction and carries large quantities of drift snow. Gusts of high velocity may be experienced, particularly towards the end of the disturbance. A period of calm usually follows a blizzard, after which the direction of the wind suddenly changes 180° and continues to blow with great force. This is characteristic of the passing of a cyclonic storm center.

Most blizzards are associated with northerly winds; that is, the blizzards are preceded by winds from that quarter. This is not always the case. Often a blizzard will commence without previous northerly winds and it is not until after the blizzard ceases that the wind shifts to that direction.

Large temperature increases have been noted with southeasterly blizzards, especially during the winter months; in the summer months the rise is not so marked owing to the less frequent temperature inversions. This phenomenon suggests foehn winds, and is due to adiabatic heating, the air descending from the plateau being compressed in striking terrestrial obstacles. The effect of this temperature rise is conspicuous at the mouth of the glaciers descending through the Queen Maud range.

The weather is extremely variable. Usually it changes in cycles, with the period of southerly winds lasting longer than northerly winds.

Fog is not infrequent in the region of icebergs and pack ice, and along the coasts of Antarctica. Frost smoke is common over open water areas during the autumn months.

Rain occurs frequently in the northern part and along the west coast of the Palmer Peninsula. It is rare in other parts of the continent. Precipitation is almost invariably in the form of snow or hoarfrost but the quantity deposited varies in different areas. Measurements have been of little value due to the great amount of drift swept by the winds.

Clouds are observed in great quantities in the Palmer Peninsula region, averaging eight-tenths. In the Ross Sea area the mean is seven-tenths, though cloudless skies over Marie Byrd Land are rare. Observations indicate a maximum cloud condition during the equinoctial months, with minima during the summer and winter months.

The low summer temperatures, particularly the maximum temperatures, are distinctive of Antarctica. The warmest month isotherm of 32° F. lies roughly along the Antarctic Circle except in the South Atlantic Ocean where it reaches the 60th parallel. On the western coast of Palmer Peninsula, due to the oceanic influence, average summer temperatures above the freezing point have been recorded. Winter temperatures vary in different areas, somewhat dependent upon latitude, but principally upon the frequency of southern blizzards and the presence of open water in the vicinity of the base.

The Bay of Whales region is believed to have the lowest annual temperatures (minus 10° F. to minus 15° F.) with minimum temperatures in the minus 70's being observed by each of the expeditions basing in that locality. The minimum temperature so far recorded there was minus 75° F. on 5 September 1940.

A winter sledge party camped on the Ross shelf ice near Cape McKay, Ross Island, recorded low temperatures. On 6 July 1911, the minimum of minus 77° F. was observed.

Very little is known of winter temperatures in the interior of the continent, but absence of the moderating effect of the sea is suggested by the winter temperatures recorded by Byrd at a station occupied from late March to mid-October 1934. This station was 94 miles south of the main base located at the Bay of Whales. A minimum temperature of minus 83° F. was recorded at the interior station on 21 July 1934, and the thermometer reached the lower 70's several times during the months of May, July, August, and September; temperatures were from 10° to 20° lower than those existent simultaneously at the main base at the Bay of Whales.

The outer boundary which separates the polar continental high lying over Antarctica from the polar maritime air masses of the prevailing westerlies is termed the Antarctic Front. This front varies from a maximum intensity where polar easterlies meet the westerlies, to non-existence in the vicinity of major low pressure areas where convergence destroys it. That this front exists has been well established in some cases of large wind sheer. Some characteristics are:

1. The front acts as a quasi-stationary frontal system bounding the polar high, sometimes advancing as a cold front or retreating as a warm front, and usually as boundaries of a wedge moving eastward. The weather along these fronts follows that of normal frontal systems, except on a less well developed scale.

2. The cold front has a line or zone of snow showers or squalls along which, if air mass showers are also present, become very dense. There is a wind shift across it varying from a few degrees when weak, to over 90° when well formed. A temperature drop of 5° to 7° F. has been observed across this front, though 2° to 3° is more common, and a definite change in air mass characteristics occurs.

3. As a warm front, the cloud shield is well defined, but omits the cirrus and cirrostratus forms of an ordinary system. When advancing, a well ordered layer of alto-cumulus at 8,000 to 10,000 feet is the leading edge of the shield, changing into an alto-stratus—alto-cumulus system as it lowers. Air mass weather, in the form of snow showers, usually begins before the snow shield is reached. Cirrus and cirro-stratus clouds can frequently be seen above this cloud shield, but they belong to the low pressure system that usually lies to the northwest in such cases.

4. As a quasi-stationary front, it may combine the characteristics of both a warm and a cold front, depending on the trajectory of the westerlies to the north. With over-running occurring, a narrow band of alto-cumulus clouds and a sparse line of weak snow showers exists.

5. The average location of this front is from 50 to 150 miles north of the ice pack, varying from 300 to 400 miles north as a maximum, and retreating to near the coastline as a minimum. It may retreat on to the continental plateau itself, under the influence of an extremely strong northerly circulation—but such cases are rare.

AIR MASSES

The following description of antarctic air masses was extracted from reports of naval units which operated in that area:

"The average depth of the polar air mass between the Antarctic Front and the continent varies inversely as the distance of the front from the continent increases. When the front is less than 150 miles from the continent this depth is about 8,000 to 10,000 feet, and when the front is 200 to 300 miles distant the depth is near 4,000 to 6,000 feet. This results from the seepage of the

polar air from the continental plateau, downwards and outwards from its edge toward the sea. Hence, the further the front from the continent the more shallow the air mass, and, therefore, the frontal surface slope is less. The result is that for a given amount of over-running of the westerlies, the precipitation and cloud shields are wider, the further the front is from the continent, and vice versa.

"It was assumed that polar continental air (cP) on the plateau region has the ideal vertical structure of that type of air, i. e., a surface inversion (shallow during summer) with an approximately isothermal layer above the surface to a depth of 3,000 to 4,000 feet and a normal lapse rate above this layer. This air was then modified by subsidence as it sank from the plateau to sea level and by heating from below as the mean temperature of the underlying surface increased downward and outward. Thus, the air had an almost neutrally stable vertical structure at the coastline. Further travel northward over solid pack ice was accompanied by heating from below, resulting in a dry adiabatic lapse in the lower levels. The depth of this layer varied from 1,000 to 2,000 feet as a minimum, to 4,000 to 5,000 feet as a maximum, depending on the width of the pack. Immediately above this layer an inversion of 2° to 5° C. existed, formed as a result of mixing and heating from below and subsidence as the air moved northward. From this inversion to the frontal surface a slightly stable lapse rate prevailed. The strength of the inversion and the character of the lapse rate above also varied, depending on convergence or divergence due to the flow pattern. With cyclonic flow, the inversion is small and nearly isothermal and a moist adiabatic lapse rate lies above. With anticyclonic flow, the inversion is larger and deeper, with a definitely stable lapse rate above.

"The cP air of the plateau was assumed to have a low moisture content throughout, which decreased with elevation. As this air flowed downward and outward, a slight amount of moisture was added in the surface layers but it was insufficient to raise the relative humidity to more than 50 or 60 percent. The dryness aloft was accentuated by subsidence so that a sharp decrease of moisture occurred at the base of the inversion. This dryness was also accentuated by divergence when the flow pattern was anticyclonic; it was decreased by convergence when the flow was cyclonic.

"The above assumptions led to the concept of two different types of cP air; that on the continental plateau and that along the coastal area and ice pack. Since each type had different struc-

tures it was decided to name them differently; cP air was the name given that on the plateau, and the air along the coastal area and ice pack was called continental antarctic (cA).

"The above discussion has been concerned with cA air along the coast and over solid pack where there are no areas of open water. If, however, this cA air does pass over water, a rapid modification takes place similar to that occurring over the Great Lakes in winter, and to the formation of polar Atlantic air. Since this process occurs continuously with the production of large areas of an air mass intermediate between cP and that normally termed mP, and the name maritime antarctic (mA) was applied to it. The term mA is used to describe cA air that has been modified by a relatively short water trajectory, usually from 50 to 100 miles minimum and up to 500 miles maximum, beyond which it assumes properties similar to fresh mP air. The Antarctic Front is the northern boundary of this cA or mA air mass.

"The production of mA air can proceed rapidly as in the case of the direct advection from solid ice to open water or slowly through the advection of the air over open water present in the ice pack. In the latter case, this water may be open water between the fast ice and the pack, rotten pack ice, openings, and small bays. The addition of moisture from this water gradually increases the moisture content below the inversion. This continues with fracto-cumulus forming first, then gradually thickening into a layer of strato-cumulus which then develops vertically. The exact stage of development depends on the total amount of previous water travel. In estimating the total water travel of the air only the trajectory of the air in the lower 500 to 1,000 feet should be considered, which involves considerable cross-isobar movement. It is emphasized that this procedure must be considered in all cases where the trajectory of the antarctic air must be estimated.

Figure A–2.—Admiral Byrd's Tent City, Little America IV.

"At first, the strato-cumulus has bases approximately 1,500 to 2,500 feet and tops at the base of the inversion, the height of which varies with the distance of travel from the continent. With average pack composition and a travel of 150 miles across it, these tops will be 3,000 to 4,000 feet high. From these average figures the approximate stage of development from cAK to mAK can be estimated by considering that longer travel and more open water increases the height of the tops and lowers the bases, while shorter travel and less open water decreases the height of the tops and raises the bases until finally no clouds result in the extreme case. Snow showers develop higher than 6,000 feet. Convergence and divergence affects respectively augment or limit the above transformation of cAK to mAK.

"After the strato-cumulus clouds have been well developed, that is, with a total water travel of at least 50 miles, the air is considered to be mA. This mA air exists primarily in wedges extending northward from the Antarctic Anticyclone, in bubble highs developing from these wedges, and in flow paralleling the continent north of the pack over the sea. The mAK air exists in the eastern and northern sectors of the wedges and bubble highs where the flow tends northward. This air then turns southward becoming mAW in the western and southern sectors. It is characterized by a stable layer from the surface to about 500 feet and a moist adiabatic lapse rate above that to 1,500 to 3,000 feet, above which is an inversion of one degree to four Centigrade. This inversion becomes progressively lower the farther the southward travel. Above the inversion the lapse rate is very stable. Stratocumulus and stratus clouds lie beneath the inversion with ragged bases from 500 to 1,000 feet. In bubble highs these clouds frequently totally dissipate near the southern limit of the air trajectory because of the lack of the vertical convection needed to maintain these clouds. Patches of fog develop after a net southward travel of about 100 miles and become denser the farther south the air travels. The transitional area from mAK to mA to mAw occurs in the north to northwest section of the wedges and bubble highs as the air begins returning southward. Here snow showers cease and the strato-cumulus tops lower to 2,500 to 3,500 feet with bases at 1,000 to 1,500 feet.

"The opposite transitional area from Aw to mA to mAK that occurs in the south to southeast section of bubble highs is one of frequent clear skies and excellent visibility. Here patchy fog is dissipated due to heating from below and the strato-cumulus cloud

deck of the mAw section frequently disappears. Maritime antarctic air flowing parallel to the continent becomes mAw upon passing over the ice pack. This change, after a distance of about 200 miles, produces dense fog which blankets the ice pack area and is frequently advected over the sea. If the fog advected over the sea has a northward trajectory, the air will be warmed from below and the fog will lift and form a stratus cloud deck after a distance of about 3 to 5 miles.

"The mP air mass that lies to the northward of the Antarctic Front is homogeneous in its east-west characteristics with a rapid north-south variation in temperature which closely corresponds to the sea surface temperature. The lapse rate is moist adiabatic to 10,000 to 15,000 feet where a small stable layer tops this moist layer. In convergence zones or where the air has an mPk classification, heavy cumulus clouds develop in the moist layer giving snow showers. These cumulus clouds frequently resemble cumulo-nimbus with flattening of tops, but on a reduced scale. They appear to be composed of super-cooled water drops through their major portion, with an ice crystal top.

"Patchy fog develops where the air becomes mPw provided there is no extremely large scale meridional flow such as is present in advance of a large low pressure area. In this latter case, the fog becomes solid advection fog and persists as long as that meridional flow exists."

WINDS

From the antarctic continent outward blowing winds prevail, and since the coast so generally trends east-west, these winds, which are always deviated to the left by the earth's rotation, generally blow from the southeasterly quadrant. Where, however, the coast trends north-south, as on the west of the Ross Sea, these winds for the same reason blow from the southwest. They are often of hurricane intensity and with gust velocities sometimes attaining to 150 or 200 miles per hour. Winds of such violence are not known elsewhere, save perhaps within a tropical cyclone. They are characterized by a noteworthy absence of humidity and an elevation of air temperature due to the adiabatic conditions.

The Antarctic Anticyclone, being due to the intense cold of the snow surface, is essentially a shallow system not more than some few thousand feet deep, and above it the general polar cyclone must exist in an intensified form. The upper winds are best shown by the movements of the clouds and by the drift of the

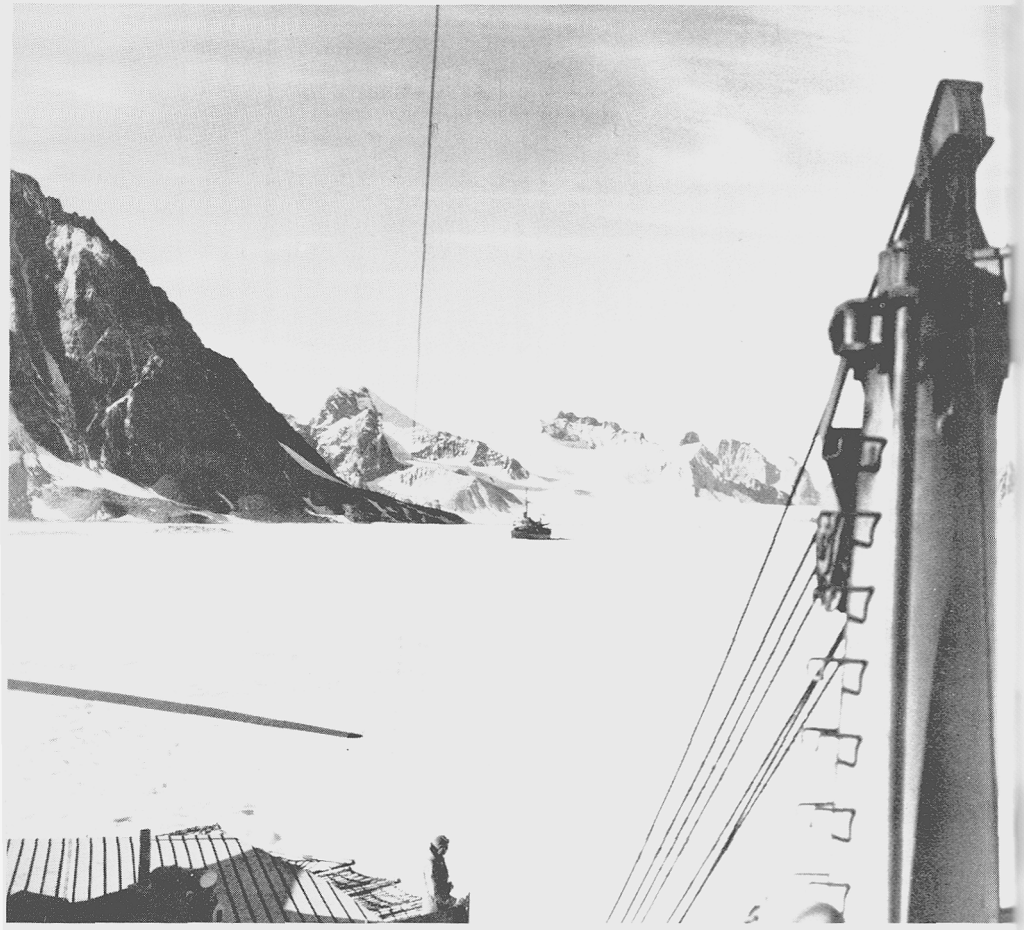


Figure A–3.—Icebreakers at Neny Island, Antarctica.

smoke from the volcanic Mount Erebus (13,000 feet). In the McMurdo Sound region the clouds between 10,000 and 13,000 feet and the smoke from Mount Erebus indicated prevailing winds between west and north, the opposite of the surface direction on the Ross Barrier, and associated presumably with the cyclonic circulation of the middle atmosphere. (See table II and III.)

VISIBILITY

Due to the absence of dust, solid particles, and the low moisture content of winds blowing off the antarctic continent, visibility is often unusually great and mirage effects are often experienced.

These latter will often lead the uninitiated into making serious errors from estimating distances. The most serious restrictions to visibility occur with blowing snow or when air from the leading edge of a low pressure system has sufficient trajectory over the ice packs to permit condensation of water vapor and the continuous formation of heavy fog. (See table IV.)

CLOUDINESS

Cloud cover is high throughout the area, amounting to 60 to 90 percent and increasing somewhat from December through March. Cloudiness increases and ceilings lower as one proceeds northward from the ice pack and approaches the antarctic front. At Little America, Cape Dennison, the Shackleton Ice Shelf, and on the *Gauss*, cloud covers are predominantly 60 to 70 percent, with only about 40 to 60 percent low cloud cover being experienced at Little America. Over the adjacent sea areas north of the Antarctic Circle, on the other hand, cloud covers are usually 80 to 90 percent, with about the same percentages of low broken or overcast being observed. Although no data is available relative to cloud conditions inland, it is expected that generally clear skies will prevail. The predominant cloud types are stratus and stratocumulus, which appear in over 50 percent of total observations taken at Little America, and more frequently over the adjacent water areas. Alto stratus and alto cumulus are also frequently observed. (See table V.)

TEMPERATURE

There is little to be added to what has previously been said concerning the temperature in the Antarctic. It is perhaps worth noting that there appears to be no month in which the mean air temperature reaches a temperature in excess of 32° F. It is realized that the open lake region discovered by a recent expedition tends to contradict the latter statement, but it is believed that this feature is normally perhaps caused by hot water springs. It is considered that the center of Antarctica has the coldest winters of the whole world, but there are no existing records to prove or disprove this theory. However, the winters of the Ross Sea region and the ocean coasts are not as cold as those of Siberia. (See table VI and VII.)

PRECIPITATION

There are few, if any, reliable statistics of the amount of precipitation, but it is known to be scanty, equivalent probably to not more than 5 to 10 inches of rain; it all falls as snow, mostly fine crystals, dry and powdery. The difficulty in measuring it is due to the strong winds which almost always accompany it, for the snow is whirled about and cannot settle in a gauge. Moreover, it is impossible to say how much of the snow is newly fallen from the clouds and how much has been swept up from the ice cap.

A perplexing problem is the cause of the precipitation in view of the anticyclonic conditions which prevail. That precipitation exceeds evaporation—and evaporation is certainly considerable—seems to be proved by the great glaciers that move down from the plateau and by the calving from the edge of the ice sheet of the numerous icebergs that beset the surrounding oceans. There must be considerable precipitation in the interior to feed this dispersal from the long periphery. The depressions of the westerlies provide considerable snowfall on the coasts that come within their influence, but their influence does not appear to extend far inland.

Antarctica enjoys very clear skies and long sunshine in the summer months, the sunshine traces being sometimes continuous for the whole 24 hours. In December, 1903, the Discovery station at McMurdo Sound recorded 490 hours, 66 percent of the possible duration, and in a year there were 1,725 hours, which is more than we have in the sunniest parts of England, though the sun in Antarctica was above the horizon for only 246 days. (See tables VIII and IX.)

FORECASTING AIDS

The Norwegian theory of air mass analysis and the forecasting rules and techniques derived therefrom may be applied in the antarctic areas by use of certain modifications based mainly on results of topographical influences. The observations of changes in certain weather elements were found to be of major aid in forecasting. Hence, the following paragraphs are headed according to these indicative elements.

WINDS

Due to the absence of any topographical interference over ocean areas to the gradient air flow, wind speed and direction were the most important factors in determining the positions and intensity

of cyclones and anti-cyclones on the synoptic chart. The following thumb rules in relation to winds were found to be of aid in antarctic forecasting:

1. Favorable weather at Little America sets in very shortly after the surface winds shift to the south. This shift is generally accompanied by a marked drop in temperature. The shift of the wind aloft to the south likewise denoted the approach of good weather in the western portion of the Bellingshausen Sea.

2. Good weather, both at Little America and in the Bellingshausen Sea, is maintained by southerly winds aloft.

3. A wind shift from south to southwest in the Bellingshausen Sea indicated the development of a weak cold front orientated east-west near the edge of the ice pack and large areas of snow showers, accompanied by low ceilings and very poor visibility in the showers.

4. A wind shift from the prevailing direction of southeast to either east or northeast indicated the approach of a migratory low pressure center from the northwest. Within the following 18 hours, heavy fog could be expected after the warm, moist air moving southward around the leading edge of the low had had a short but sufficient trajectory over the ice pack resulting in cooling and condensation.

5. An increasing pressure gradient and resultant increasing winds will not result in dissipation of fog formed on the southeast quadrant of lows moving into the Bellingshausen Sea. In winds as high as 30 knots the fog was thinned but visibility remained less than ½ mile.

6. On and near the continent, blowing snow extending to 100 feet above the surface is common when high winds (generally above 17 knots) are blowing. It is difficult to distinguish this phenomenon from an actual snowfall when observed from the ground. Aviators flying at low altitudes should be emphatically warned that blowing snow is extremely difficult to visually differentiate from terrain and that in areas where sloping hillsides might be encountered, the only safe flight is one at sufficient altitude to be well clear of any such obstacles.

7. Wind speeds were less near the center of wedges and increased toward the edges.

8. Extreme care should be exercised in keeping a check on winds aloft, particularly in the 5,000 to 10,000-foot layer. Most high pressure wedges are relatively thin and narrow and ap-

proaching storms may be noted in winds aloft in the 10,000- to 20,000-foot layer.

9. Approaching closer than 50 miles to the continent can bring the ship under the influence of drainage flow from the ice cap. This causes an abnormally high wind for the pressure gradient present. It may be due to a tight local pressure gradient, which in turn is due to the rapid increase in depth of the polar air mass between the ship and the continent. This is a large scale katabatic or foehn wind effect and may be minimized by moving further away from the continent. The total effect is largely determined by the local topography of the continent and can be predicted in advance.

10. With a southerly wind, favorable weather will exist over a coastal area, while off shore 50 to 100 miles low status will persist with resulting poor flying conditions. In general, near the coast a southerly wind will produce 0 to 2 days of good flying weather following the passage of a migratory low.

PRESSURE

The use of pressure and pressure tendency as an aid to forecasting is, at times, misleading south of 75° latitude. This is due to the fact that most of the lows and fronts in this area are dissipating. For example, filling lows and associated bad weather approaching the Bay of Whales may result in the pressure at that location remaining steady or rising slightly. There are other instances in the antarctic areas when pressure traces may be of use in forecasting, as follows:

1. Pressure tendency is an excellent indicator of weather changes in the vicinity of 65°, the location of the track of many of the circum-continental migratory lows. As elsewhere in the world, lows and fronts are preceded by falling pressure and followed by rising pressure.

2. When the barometric trace begins to fall off rapidly in the latitudes between 60° and 70°, winds 30 to 40 knots can be expected. These winds will usually continue for a period of 12 to 24 hours after pressure begins to rise. When the barometric trace begins to level off after the rise following the passage of the low center, it can safely be expected that the winds will diminish rapidly to 16 to 24 knots.

3. Good weather conditions were found along the eastern sector of wedge lines where the southeasterly flow of dry air from the continent guaranteed good visibility and negligible cloudiness locally with CAVU weather over the coast line and continent.

4. Wedge lines between the Greenwich Meridian and 110° longitude are almost always migratory in character, moving from west to east at 15 to 20 knots.

5. In moving eastward with a high pressure wedge, barometic tendency was successfully used to judge the speed necessary to keep up with the wedge's eastward movement. A speed of 15 knots would almost always maintain a steady pressure trace and indicate that exact pace was being kept with the wedge.

CLOUDS

1. Local forecasting for short periods can be handled adequately by continuous observation of cloud conditions. The sequence of clouds is similar to that experienced in midlatitudes. The clouds associated with the Antarctic Front are very similar to those associated with the Tropical or Equatorial Front. Alto-cumulus and alto-stratus shields may be followed in 1 to 2 hours with moderate to heavy precipitation and near zero conditions. Over the ocean and ice packs, low stratus, which may obscure middle and high clouds, exists for a large percentage of the time. When forecasting for flight operations near the continent the appearance of this stratus is very deceiving. Assuming a situation where the ship is moored to land-fast ice with open water to the north, the following situation often exists: southward, looking toward the continent, the stratus and snow will blend together, appearing very white; northward, the stratus appears very dark or nearly black due to the reflection of the open water. When first observed this *water sky* appears similar to an advancing roll cloud or squall line. It is very dark and ominous and pilots will question the advisability of flight operations at the time.

However, after observing this phenomena for several hours it will be found that there is very little change and everyone will soon get used to it and, in fact, be glad to see a *water sky*, because it indicates open water, which helps greatly in navigating the ice pack. Another phenomena is *ice blink*. This is the reverse of *water sky* and is light reflected from a field of ice on the low stratus clouds. The clouds appear brighter or much whiter than the surrounding clouds. When *ice blink* appears on the horizon it is a sure indication that the ice pack will soon appear. When these two situations exist it is most difficult to estimate a ceiling. In some cases the estimate was as much as 4,000 feet in error when checked by releasing a pilot balloon.

2. The tops of most cloud formations can be reached at about

10,000 feet, except in convergence zones near low pressure areas. These clouds are usually in layers which can be predicted from radiosonde soundings or air mass considerations. Aircraft icing will exist to some degree in all of these layers.

THUMB RULES FOR LITTLE AMERICA

1. Ice fogs are common when the temperature takes a sudden drop to approximately 15° F. and the wind is moderate from the southeast.

2. Antarctic sea-smoke will obscure the front of the barrier when the temperature falls suddenly and the wind is moderate.

3. Absolutely cloudless days are experienced at Little America.

4. Visibility observations are not reliable as there are no distinguishable landmarks. Exceptional visibility of over 100 miles may be expected on clear days.

THUMB RULES FOR AREAS ADJACENT TO CONTINENT

1. During the summer months, with normal southeasterly flow of air, temperatures will remain between 27° F. and 34° F. With southerly winds and modified polar continental air reaching the area, temperatures will reach a minimum of between 20° F. and 24° F.

2. Relative humidity is of little aid in practical forecasting.

3. In summer months, periods of 6 to 9 hours of favorable weather will occur at intervals of 3 to 5 days, with periods of 24 to 36 hours of favorable flying weather occurring perhaps once in 10 days. These periods depend on the progression of the migratory lows and their effect on the high pressure ridges extending from the continent.

4. Local weather depended entirely on the air trajectory. If within 150 miles of the coast line or shelf ice, evaporation into the lower layers would give nothing more than broken strato-cumulus which would decrease gradually to clear at the coast line. If operating in excess of 150 miles from the coast, considerable shower activity could be expected with occasional closed conditions, depending on the total water travel of the air. If the ice pack was more than 150 miles from the coast with 50 to 75 miles of open water between the ice pack and shelf ice, considerable fog could be expected on the leeward side of the ice pack.

5. Most favorable weather conditions were found south of the Antarctic Front.

FORECASTING FOR FLIGHT OPERATIONS

1. Forecasting for helicopter operations is difficult at the best. For ideal operations the weather should be CAVU. Since this condition seldom exists in the Antarctic and much of the operation depends on helicopters, the aerological officer will be constantly asked, "Is it safe to fly?" To answer this query necessitates constant observations of the weather elements. Every effort must be made by the forecaster to be one jump ahead of the weather and not hesitate to advise the pilot to return to the ship if the weather appears to be closing in.

2. Too much cannot be said for the need of flight instruments in helicopters. Equipped as they are now, a pilot is nearly helpless when caught in an *antarctic white-out*. This is a condition of low stratus blending into a solid ice field, producing a situation where the horizon cannot be determined, and where the pilot has no depth of perception. The aerological officer must be especially cautious on days where a low stratus deck persists at 1,500 to 2,500 feet and a flght is to be made over an unbroken ice field. From the ship, visibility will appear very good, and conditions favorable, with icebergs and dark objects showing up very well. However, soon after takeoff, as the pilot proceeds out over the ice field, he may encounter a situation where only flat ice extends ahead of him. When dark objects, such as open water leads, icebergs, or ridges in the ice do not exist, the pilot is unable to determine the horizon. The ice and clouds seem to blend together and it is impossible to distinguish the point where one begins and the other ends.

The combination of light glare in the atmosphere, uniform clouds, and uniform surface all rendering the same color, constitute the *white-out*. Task Force 39 lost one helicopter due to this phenomenon. The pilot said, "It was like flying inside a bottle full of milk. I was so confused and so lost, it was actually a relief when we hit the ground."

GENERAL

1. The Antarctic Front is subject to wave disturbances in the exact manner and under the same conditions as those of polar fronts in the northern hemisphere. Waves forming on the Antarctic Front to the westward of the Ross Sea area generally move rapidly eastward as an open wave, then slow and occlude in the vicinity of Scott Island. The wave will then veer to the south-

east and become fully occluded in the following 12 hour period.

2. Long occluded fronts orientated in the north-south line and terminating in deep depressions are very frequently found in the Ross Sea area. They form from unstable waves on a section of the polar front in the vicinity of Australia or New Zealand.

3. Not one of the cyclones investigated that formed to the west of the 180th meridian was able to work its way through the semi-permanent high, displaced along the 120th meridian, and migrate into the Bellingshausen Sea area.

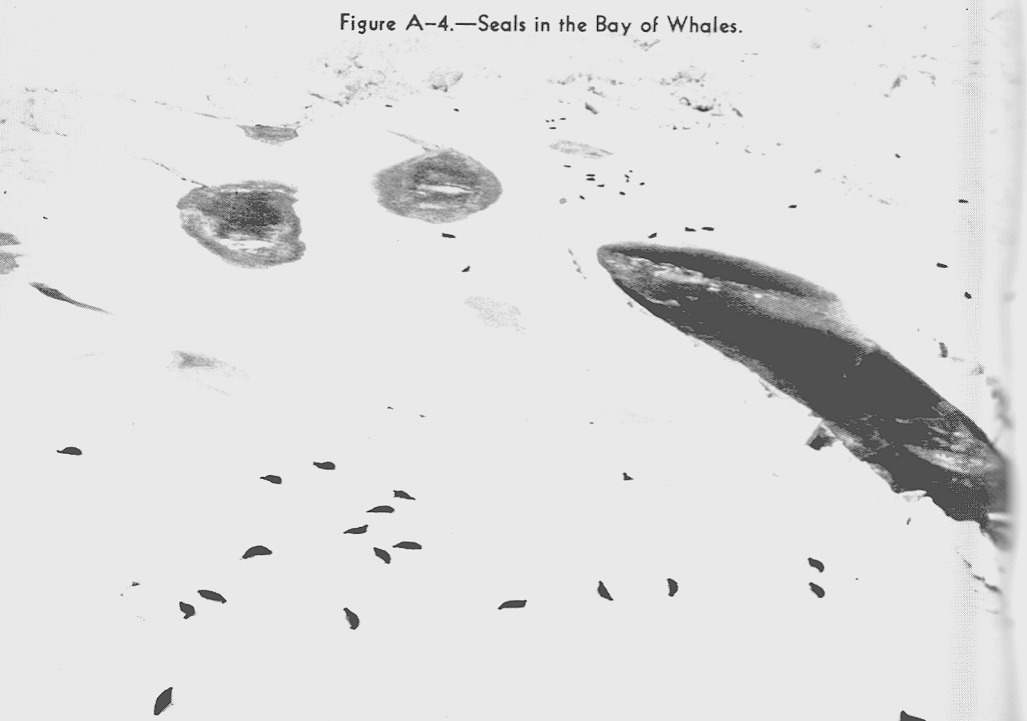
4. Low pressure centers which move into the Bellingshausen Sea are usually picked up in the vicinity of 120° and 55°.

5. When migratory low pressure centers stagnate in the Bellingshausen Sea, a new center normally develops off the northern tip of the Palmer Peninsula. The regeneration of lows north of the Palmer Peninsula cause a northward outbreak of cold continental air along the east coast of the Palmer Peninsula and behind the low as it goes into the Weddell Sea.

6. The major fronts in the Bellingshausen Sea are long occlusions, which are the remnants of waves that originate on the South Pacific polar front and develop into mature wave systems as they move southeastward. Warm and cold fronts of normal orientation extend from the occlusions.

7. Small stable waves infrequently develop on the Antarctic Front west of the Ballenys. These are found during periods in

Figure A–4.—Seals in the Bay of Whales.



which there are no other lows in the vicinity and a long quasi-stationary Antarctic Front is bounded by a large maritime polar high mass to the north. These waves normally move eastward and become absorbed by a large low of the westerlies.

TABLE I

Station Location Table

Station	Latitude ° ′	Longitude ° ′
Argentine Islands	65 15 S.	64 16 W.
Belgica Drift	69 S. to 71 30 S.	81 W. to 95 W.
Cape Adare	71 18 S.	170 09 E.
Cape Denison	67 00 S.	142 40 E.
Debenham Islands	68 08 S.	67 06 W.
Framheim	78 38 S.	163 37 W.
"Gauss"	66 02 S.	89 54 E.
Laurie Island	60 45 S.	44 43 W.
Little America	78 34 S.	163 56 W.
McMurdo Sound	77 40 S.	166 30 E.
Port Charcot	65 03 S.	64 00 W.
Port Circoncision	65 10 S.	64 12 W.
Shackleton Shelf Ice	66 18 S.	95 01 E.
Snow Hill Island	64 22 S.	57 00 W.
Water Boat Point	64 48 S.	62 43 W.

NOTE: Refer to H. O. Chart H. O. 2562 (Antarctica).

TABLE II

Prevailing Wind Direction and Mean Speed in m.p.h. (Except as Noted)

Station	January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Argentine Islands	S.		SE.	N.	N.	S.	S.	S.	S.	N.	N.	S.	1
	9		5	7	8	6	7	7	5	13	7	6	
Belgica Drift	E.	E.	W.	SE.	N.	W.	W.	W.	NE.	W.	E.	SE.	1
#	24	12	11	5	13	11	25	15	20	11	21	21	
Cape Adare			SE.	S.	SE.	S.	S.	S.	SE.	S.	S.	S.	1
			8	8	7	4	6	5	6	6	6	7	
Cape Denison	28	38	51	48	51	47	56	44	36	46	37	42	2
Debenham Islands	E.	E.	E.	E.	E.	SE.	NW.	SE.	E.	NW.	NW.	E.	1
	9	11	8	7	13	7	7	8	6	12	8	16	
Framheim	E.			E.	S.	E.	E.	E.	E.	E.	E.	E.	1
	8			10	6	9	10	9	10	14	11	11	
"Gauss"	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.	1
	10	15	10	15	21	10	15	21	10	10	10	10	
Laurie Island	NW.	NW.	NW.	NW.	NW.	NW.	NW.	NW.	NW.	NW.	NW.	SE.	9–10
	10	10	14	13	12	11	12	13	13	13	12	9	
Little America, 1934	E.	SE.	E.	E.	E.	E.	SW.	S.	E.	E.	E.	E.	1
	12	13	14	14	12	11	11	8	11	13	11	9	
McMurdo Sound	E.	SE.	SE.	SE.	SE.	SE.	SE.	SE.	E.	E.	E.	E.	1–2
	9	16	18	14	16	17	17	17	15	14	13	10	
Port Charcot	NE.	NE.	NE.	S.	S.	S.	S.	NE.	NE.	S.	NE.	S.	1
Port Circoncision	NE.	NE.	NE.	NE.	N.	N.	NE.	NE.	N.	N.	NE.		1
	3	6	10	8	8	10	16	19	15	14	11		
Shackleton Shelf Ice	ESE.	ESE.		ESE.	ESE.	SE.	ESE.	ESE.	ESE.	ESE.	ESE.	ESE.	1
	8	11		12	16	15	15	6	9	19	9	5	
Snow Hill Island	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	1–2
	11	17	31	18	20	20	22	21	18	18	19	10	
Water Boat Point	S.	SW.	SW.	NE.	S.	SE.	S.	S.	S.	SW.	SW.	S.	1
*	0	9	13	40	20	30	7	7	5	16	9	3	

* Percentage of Observations Above Force 5, Beaufort.
\# Number of Days With Less Than Force 4, Beaufort.

TABLE III

Number of Days on Which Gales (Winds Greater Than 34 m.p.h) Were Recorded (Except as Noted)

Station	January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Argentine Islands	0	.....	2	2	4	3	2	2	2	8	1	0	1
Cape Adare	11	.....	5	5	5	7	6	6	6	7	6	8	1
Cape Denison#	16	13	26	26	30	30	27	29	26	30	21	12	1
Debenham Islands	4	6	3	6	10	4	3	9	6	10	5	14	1
"Gauss"	3	6	1	5	11	6	9	12	5	6	1	4	1
Laurie Island	3	11	20	17	12	12	8	21	25	17	9	6	7
Little America, 1934	0	2	5	9	5	2	3	3	6	3	1	0	1
Port Charcot*	12	9	9	8	8	10	6	12	11	12	11	7	1
Port Circoncision	1	0	5	1	0	4	11	12	12	9	4	.....	1
Water Boat Point*	5	8	8	9	8	10	10	8	11	10	8	7	1

* Highest Wind Force (Beaufort) Recorded During Month.
\# Number of Days With Winds Greater Than 30 m.p.h. Recorded.

TABLE IV

Number of Days of Fog Per Month (Except as Indicated)

Station	January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Argentine Islands	2	.....	0	4	3	2	1	5	5	7	0	2	1
Belgica Drift	17	22	14	26	27	28	17	25	14	23	18	13	1
Debenham Islands	2	1	2	1	1	2	0	3	1	1	0	2	1
Framheim	1	.....	.....	6	.....	.....	.....	3	10	4	.....	1	1
Laurie Island*	16	12	16	13	18	18	19	20	18	17	16	13	7–8
Little America, 1934	5	1	3	6	3	2	6	5	3	6	7	11	1
Port Circoncision	5	6	10	13	20	13	23	25	25	24	20	.....	1
Shackleton Shelf Ice	8	1	.....	0	4	8	5	1	0	1	7	13	1
Snow Hill Island	16	14	4	9	11	11	8	9	7	9	8	12	1–2

* Days of Fog or Mist.

RESTRICTED

TABLE V

Mean Cloud Amount in Tenths (Except as Indicated)

Station	January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Argentine Islands	8.4		7.3	7.7	7.8	6.6	7.0	6.1	7.3	9.2	9.4	8.7	1
Cape Adare	6.9	7.7	7.7	7.6	6.7	4.5	5.7	5.2	6.5	5.8	5.7	6.7	2
Cape Denison	7.4	7.6	6.5	6.7	5.6	3.4	4.4	5.9	6.6	4.3	4.8	6.9	1
Debenham Islands	7.8	6.5	8.0	8.0	7.4	6.2	7.5	7.2	8.3	7.5	8.5	7.6	1
Framheim	5.2			7.2				4.5	5.8	7.5	4.3	6.9	1
"Gauss"	7.1	8.0	6.3	6.5	8.1	6.4	7.7	8.2	7.3	7.4	7.1	7.2	1
Laurie Island	9.2	9.1	9.1	8.9	7.8	7.7	7.5	7.8	8.1	8.7	9.3	9.2	14
Little America, 1934	7.7		6.8	7.7	5.5	5.7	4.2	4.7	5.7	7.1	6.3	5.9	1
McMurdo Sound	5.9	6.6	6.6	5.7	4.9	4.5	4.6	5.6	5.8	7.1	5.9	5.0	4
Port Charcot	9.2	8.3	7.9	6.8	5.9	6.3	5.9	8.3	7.5	7.4	8.7	8.0	1
Port Circoncision	9.5	7.8	8.5	7.0	8.5	7.7	7.8	8.0	8.7	8.7	8.0		1
Shackleton Shelf Ice	5.9	8.1			5.1	7.0	9.0	7.0	7.5	8.2	7.6	5.5	1
Snow Hill Island	8.8	7.7	8.7	6.7	6.7	6.1	6.2	5.7	7.3	7.3	8.4	7.6	1–2
Water Boat Point:													
Percentage of Overcast Sky	46	66	68	75	45	55	56	42	43	57	53	40	.....
Percentage of Sky Cover 5.0 to 9.9 tenths	36	18	13	15	29	26	24	33	40	37	42	52	.....
Percentage of Sky Cover 0.1 to 4.9 tenths	9	13	17	7	23	19	18	22	17	6	5	8	.....
Percentage of Cloudless Sky	9	3	2	3	3	0	2	3	0	0	0	0	.....

TABLE VI

Mean Temperature, F°

Station	January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Argentine Islands	35		32	26	25	24	12	−1	12	26	28	33	1
Belgica Drift	30	30	16	11	20	4	−11	12	−2	18	20	28	1
Cape Adare	32	27	19	9	−2	−15	−12	−14	−7	−1	19	29	2
Cape Denison	30	23	10	2	−2	−6	−4	−2	−2	7	19	27	1
Debenham Islands	34	31	30	25	8	0	6	6	20	28	33	35	1
Framheim	14			−18	−32	−30	−34	−49	−30	−12	4	20	1
"Gauss"	30	26	17	4	7	0	−1	−7	0	9	20	30	1
Laurie Island	32	33	31	27	19	15	13	15	20	25	28	31	21
Little America, 1934	24	0	−14	−16	−19	−14	−37	−39	−34	−14	−2	17	1
McMurdo Sound	24	16	4	−9	−11	−12	−15	−15	−12	−2	14	25	5
Port Charcot	33	31	30	23	13	12	−3	20	23	19	32	31	1
Port Circoncision	35	34	34	23	23	20	20	22	21	28	30		1
Shackleton Shelf Ice	23	20		−3	−8	−15	−2	−5	2	9	18	25	1
Snow Hill Island	30	26	13	7	−1	−4	−5	−2	4	15	17	28	1-2
Water Boat Point	36	35	31	30	21	26	15	8	21	28	28	34	1

RESTRICTED

TABLE VII

Mean Maximum and Mean Minimum Temperature (Except as Noted)

Station		January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Argentine Islands	Max.	39	.....	36	30	28	27	18	5	18	30	32	36	1
	Min.	31	.....	28	23	21	21	7	−7	5	22	23	30	
Belgica Drift	Max.	32	32	22	16	28	15	−2	22	6	23	25	32	1
	Min.	27	27	10	3	12	−6	−18	0	−11	10	11	22	
Cape Adare	Max.	37	.....	22	16	3	−5	−1	−4	−4	5	24	36	1
	Min.	30	.....	14	5	−11	−19	−18	−23	−19	−11	9	27	
Cape Denison	Max.	34	29	18	6	6	3	0	6	4	8	22	31	1
	Min.	25	21	10	−2	−2	−3	−8	−3	−6	−3	21	23	
Debenham Islands	Max.	39	36	34	30	14	10	18	17	25	.....	36	40	1
	Min.	30	27	25	20	1	−10	−6	−5	13	19	26	29	
Framheim*	Max.	27	.....	.....	12	−4	13	9	−12	15	16	23	32	1
	Min.	1	.....	.....	−54	−59	−73	−66	−74	−64	−40	−18	2	
"Gauss"	Max.	34	30	23	10	11	8	6	−3	6	16	24	33	1
	Min.	24	22	10	−3	1	−9	−9	−14	−7	0	12	24	
Laurie Island	Max.	42	43	43	40	37	35	35	37	38	41	40	41	22
	Min.	24	24	18	6	−8	−18	−21	−20	−14	−3	14	22	
Little America, 1934	Max.	31	11	21	10	17	20	18	−9	−4	7.5	18	30	1
	Min.	18	−19	−45	−49	−58	−49	−65	−62	−62	−38	−26	7	
McMurdo Sound	Max.	29	20	9	−2	−5	−5	−6	−7	−5	2	19	29	4
	Min.	17	9	−2	−15	−21	−22	−24	−24	−23	−12	7	18	
Port Charcot	Max.	35	36	37	36	29	32	23	31	32	32	34	34	1
	Min.	30	27	23	10	−3	−10	−27	−4	16	2	23	27	
Port Circoncision	Max.	38	38	38	27	27	26	25	28	27	34	38	.....	1
	Min.	33	31	30	19	19	15	14	15	16	20	23	.....	
Shackleton Shelf Ice	Max.	33	28	.....	2	−2	−7	7	2	7	16	26	33	1
	Min.	12	9	.....	−9	−14	−23	−11	−12	−4	2	7	14	
Snow Hill Island	Max.	34	30	18	15	8	7	4	9	12	23	22	33	1–2
	Min.	27	21	8	0	−9	−12	−14	−13	−4	7	13	23	
Water Boat Point*	Max.	50	49	42	47	38	38	33	39	35	36	42	48	1
	Min.	27	25	20	20	4	14	−12	−16	2	14	13	27	

* Absolute Maximum and Minimum Temperatures.

U. S. GOVERNMENT PRINTING OFFICE : O — 1949

TABLE VIII

Number of Days With Rain (Except as Noted)

Station	January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Belgica Drift	4	3			4			1		2			1
Laurie Island	16	12	20	20	20	19	22	21	19	18	19	15	8
Little America, 1934	2		1	0	0	1	1	0	0	0	0	0	1
Port Circoncision	13	19	25	20	27	18	25	24	23	25	18		1
Snow Hill Island#	23	13	11	13	11	7	9	7	11	13	24	13	1–2
Water Boat Point*	5	5	8	20	3	4	1	0	0	1	0	3	1

Sum of Days With Rain and Days With Snow.
* Percent of Observations of Rain, Sleet and Hail.

TABLE IX

Number of Days With Snow

Station	January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Belgica Drift	19	22	13	22	30	24	14	23	19	25	25	18	1
Framheim	5			8	1	5	3	3	5	10	8	11	1
Shackleton Shelf Ice	11	12		9	8	11	22	16	24	18	12	4	1

RESTRICTED

NAVAL ARCTIC OPERATIONS HANDBOOK

PART II. OPERATIONAL NOTES

Prepared by the Arctic and Cold Weather Coordinating Committee of the Office of the Chief of Naval Operations

U. S. COAST & GEODETIC SURVEY
LIBRARY AND ARCHIVES
NOV 1 0 1949
ACC. No. X-1881

DEPARTMENT OF THE NAVY ★ ★ ★ ★ 1949

RESTRICTED

G14
U.58 ONO
1949

Blank page retained for pagination

GENERAL NOTE

Naval Arctic Operations Handbook is published for the information and guidance of all concerned. It is presented in two volumes, Part I being a compilation of general information, and Part II lessons learned during the conduct of operations in the polar regions and in areas where the extremes of cold weather have been encountered.

It is desired that commanders of task forces, commanding officers, and others in command of operations in the high latitudes submit data and recommendations for incorporation into subsequent editions of the handbook. Thus naval skill in these operations will develop in a continuing and orderly manner.

In time our arctic and cold weather experiences will become doctrine, to the end that polar naval operations can be planned and conducted routinely. Basic doctrines will be included in the proper USF publications at some future date.

Blank page retained for pagination

CONTENTS

Chapter	*Title*	*Page*
1.	Planning Arctic Operations	227
2.	Ship Operations	237
3.	Communications	289
4.	Care and Operation Bureau of Ships Material	301
5.	Care and Operation of Shipboard Ordnance Material	331
6.	Aircraft Operations	351
7.	Amphibious Operations	417
8.	Base Operations	433

Appendix	*Title*	
A.	Navigability in Arctic and Northern Seas	464
B.	Notes on Ice Seamanship and Navigation Amongst Ice	467
C.	Design Criteria for United States Naval Materiel for use in Arctic and Cold Weather Areas	483
D.	Track Charts of Operations in Western Arctic, Summer of 1948, and Winter 1948–1949	484

Blank page retained for pagination

PREFACE

Part II of the *Naval Arctic Operations Handbook* is concerned with operational notes. An endeavor has been made to write down herein the problems which have arisen and experiences and lessons learned during past operations in polar and cold weather areas. Where reference is made to operations in the Antarctic, it is considered that the material is equally applicable to similar operations in the Arctic.

Blank page retained for pagination

GLOSSARY OF TERMS

This selected glossary is limited to definitions helpful for an understanding of this handbook. More extensive glossaries are included in various Hydrographic Office publications. HO Study No. 103, *A Functional Glossary of Ice Terminology*, has been prepared in order to standardize ice terminology and to provide a convenient means for describing ice features and related characteristics. Refer also to Selected Bibliography, chapter 7, this handbook.

Ablation—Surface removal of ice or snow by evaporation.

Arctic Pack (Polar Pack)—The ice cover of the north polar basin or Arctic Sea, also called Arctic "Ocean."

Barrier—The cliffed edge of shelf ice. (See *Shelf Ice.*)

Bay Ice—Fast, level ice formed in an embayment.

Belt—A relatively narrow band of sea-ice of any variety.

Berg—A large mass of land ice which has broken away from its parent formation on the coast and either floats in the sea or is stranded on a shoal; a berg is tabular if derived from shelf ice, irregular if derived from glacial ice.

Bergybit—A medium-sized piece or cake of glacier ice, heavy floe, or hummocky pack ice washed clear of snow and floating in the sea.

Beset—Situation of a ship or small craft when so closely surrounded by sea-ice that control is lost. (See fig. 5.)

Big Clearing—A large area of open water, other than a lead, encompassed by fields or floes of pack ice; also polynya. (See fig. 6.)

Bit—A single piece of brash or of ice less than two feet in diameter. Note: Compare with *Glacon, Cake, Floe* and *Block.*

Blizzard—Snow storm in polar regions in which fine snow drifts so high and thick that it is impossible to tell whether sky is clear or clouded.

Block—A small piece of ice ranging in size from 6 to 30 feet across.

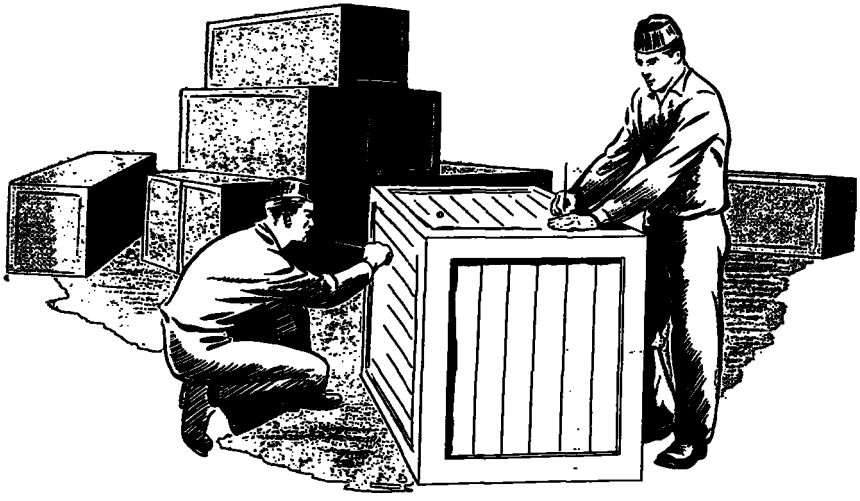
Brash—Small ice fragments less than 6 feet across; the wreckage of other forms of sea-ice.

Broken Ice—Sea-ice consisting of scattered cakes and floes covering five-tenths to seven-tenths of the sea surface. (See fig. 9.)

Cake—A term of general meaning used in reference to individual pieces of pack ice. (See fig. 10.)
Calving—The breaking away of ice from its parent berg, glacier, or shelf ice formation. (See fig. 13.)
Channel—Lead (lane).
Close Ice—Ice so closely packed that it covers seven-tenths to nine-tenths of the sea surface and virtually all sea water openings are obscure.
Close Pack—Close ice or pack composed mostly of cakes in contact. (See fig. 11.)
Coast or Costal Ice (Fast Ice)—A stretch of ice, broken or unbroken, either stranded in shoal water, attached to the shore, or held fast in position of growth in embayments by glaciers or glacier systems.
Conglomerated Ice—Various forms of floating ice compacted into one mass.
Consolidated Pack—An ice area containing the heaviest forms of sea ice and entirely devoid of water spaces.
Crevasse—A rift or fissure in a glacier, shelf ice, or other land-ice formation.
Cul-de-sac—Blind lead.
Deadman—A large timber buried in the ground, snow, or ice to which a mooring line can be attached for securing a ship. (See HO 551.)
Drift Ice—Loose, very open pack where water predominates over ice; floating ice; any ice that has drifted from its place of origin. (See fig. 16.)
Erosion—Destruction of sea-ice by the action of waves and weather.
Fast Ice—See *Coast Ice.*
Field Ice—The largest connected areas of sea-ice, ranging from several to scores of miles wide; also ice field.
Floe—An area of sea-ice consisting of a single unbroken piece of ice or many large consolidated pieces; small floe, 30 to 600 feet across; medium floe, 600 to 3,000 feet across; giant floe, 3,000 feet to 5 or more miles across.
Floeberg—A mass of thick, heavily hummocked sea-ice usually detached from its parent floe.
Frost Smoke—A mist or thick fog rising from sea surface when the relatively warmer water is exposed to an air temperature much below freezing; steam fog; arctic smoke.
Giant Floe—See *Floe.*

Glacier—A massive body of land-formed ice moving slowly down a mountainside or valley. (See fig. 13.)
Glacial (Glacier) Ice—Ice which originates from glaciers.
Glacon—A piece of sea-ice ranging in size from brash to medium floe (6 to 2,000 feet across).
Grease Ice—Slush ice formed from the congelation of ice crystals in the early stages of freezing. (See fig. 14.)
Growler—A small piece of dense glacier ice usually green in color and barely showing above the water.
Growler Ice—An accumulation of growlers.
Heavy Ice—Any pack ice more than 10 feet thick.
Hummocked Ice—Ice piled haphazardly into the form of a short ridge or hillock.
Ice Barrier—See *Barrier.*
Iceberg—See *Berg.*
Ice Blink—A yellowish-white glare on the underside of extensive cloud areas created by light reflected from ice-covered surfaces.
Ice Cap—An ice sheet of vast extent covering the topographic features of a continental land mass.
Ice Field—See *Field.*
Ice Foot—A wall or belt of fast sea-ice formed along a shore not subject to rise and fall of tides.
Ice Sky—See *Ice Blink.*
Land Sky—Dark streaks, patches, or a grayness on the underside of extensive cloud areas due to the absence of reflected light from bare ground.
Lead (Lane)—A long, narrow but navigable water passage in pack ice.
Medium Floe—See *Floe.*
Nipped—As applied to a ship, caught and held tightly by sea-ice under pressure.
Nunotak—An isolated hill or mountain of bare rock rising above the surrounding ice sheet.
Open Water—Sea areas less than one-tenth covered with floating ice.
Pack Ice (The Pack)—Any large area of floating sea-ice driven closely together. (See *Arctic Pack;* also fig. 17.)
Pancake Ice—Piece of newly formed sea-ice about 1 to 6 feet in diameter.
Permafrost—Permanently frozen soil, rock or bedrock.

Polar Ice—The thickest and heaviest form of pack ice more than 1 year old.
Polynya—See *Big Clearing.*
Pool—Polynya; sometimes used to mean a depression on ice floes filled with water as result of summer thaw.
Pressure Ice—A general term for ice displaced vertically by pressure resulting from action of wind, tide, temperature change, etc.
Rafted Ice—A type of pressure ice formed by one cake over-riding another.
Ram—A horizontal extension of floe or berg below its waterline.
Rotten Ice—Old ice in an advanced stage of disintegration as result of melting.
Sastrugi—Wavelike ridges of hard snow formed on a level surface by the action of the wind with axes of the ridges at right angles to the prevailing direction of the wind.
Scattered Ice—Ice that covers less than one-half of the sea surface.
Sea Ice—A general term for all forms of ice encountered on the surface of the sea.
Seracs—Ice pinnacles on a glacier.
Shelf Ice—A thick, glacial ice formation extending from the land but attached thereto.
Shore Ice—Synonym of *Fast* or *Coastal Ice.*
Shore Lead—A lead between floating ice and the shore or between floating ice and fast ice.
Sikussaq—Very old ice trapped in fiords.
Slush—A general term for an accumulation of ice crystals which are either only slightly frozen together or separate.
Small Floe—See *Floe.*
Snow Blink—Similar to ice blink except that glare created by light reflected from snow-covered surfaces is white.
Storis—A regional term applied to large pieces of polar ice moving along the coasts of Greenland from the Arctic Sea.
Sky Map—The mirroring of land, snow, or ice in the clouds.
Tracking—Following the edge of pack ice.
Tundra—Stretch of mucky, treeless land covered with a variety of hardy plants, including grasses, lichens, and shrubs.
Water Sky—Dark stretches or patches of grayness on the underside of extensive cloud areas due to the absence of reflected light from open water areas.
Winter Ice—Sea-ice less than 1 year old.
Young Ice—Newly formed ice in the transitional stage of development from ice crust to winter ice.



CHAPTER 1

PLANNING ARCTIC OPERATIONS

"The success of a polar expedition principally depends upon the preparations which were made before the expedition started out."—Nansen.
"Forethought for every conceivable thing."—Mikkelsen.

In planning arctic operations the same general principles apply as for any routine naval operation, except that it must be done in greater detail. The operation plan with its annexes, the pertinent directives and orders, is governed by the same policy, doctrine, and format as is applicable throughout the Military Services. As pointed out in Part I of this handbook, the arctic regions are unusual in respect to geographic character, climate, accessibility, international agreements, and population trends. These characteristics should be borne in mind throughout the planning and operational phases, and the written operation plan should take these peculiarities into account, as well as the uncertainties of weather and ice conditions, and the hazards to be encountered. The various annexes of a standard arctic operation plan are here discussed in order.

Figure 1–1.—Planning Arctic operations.

CONCEPT OF OPERATIONS

The *Concept of Operations,* as its title implies, is a broad narrative account of the operation, outlining, in sequence, the tasks of accomplishment and operational schedules. It should be written in such a fashion as to enable the novitiate to comprehend the broad objectives of the operation without detailed study of the plan. Such an annex also has been found helpful in past operations for the indoctrination of scientific and non-military observers.

INTELLIGENCE

Since sovereignty and jurisdiction in the arctic regions is a complex subject, the *Intelligence Annex* should be factual and complete. In addition, all intelligence should be evaluated and presented in a concise manner that will show the situation as it actually exists in respect to facilities, prominent personnel, and local protocol, as well as international agreements and foreign policy applicable to the area.

NAVIGATION AND AEROLOGY

The *Navigation Annex* should contain a listing of charts, hydrographic publications, and special navigational material required by all units for the safe conduct of the operation. Special navigational data and information gained from previous similar operations and expeditions should also be included, where such data have not been incorporated in standard publications or in this handbook. Provision should be made for special instruction of key personnel in polar navigation prior to commencement of the operation. Pertinent notes on navigation in sea-ice should be outlined, as well as instructions for determining and forecasting ice movements in the area of operations; for reports of ice conditions to be submitted to the Hydrographic Office; for the collection of navigational data as may appear appropriate; and for towing ships beset in the ice, or in event of damage. In the case of submarine operations, it is essential that commanding officers be furnished with digests of information from past operations relating to underice navigation and the use of sonar in ice navigation.

A comprehensive *Aerology Plan* should be formulated to ensure timely collection of meteorological data from every source avail-

Figure 1-2.—Taking hydrographic measurements in the Arctic.

able in the area of operations, to facilitate preparation of forecasts, and to keep the force advised of probable effects of weather upon operations. Full advantage must be taken of *friendly* winds in movements and changes of situations of pack ice. Watch carefully the probable effects of *unfriendly* winds.

LOGISTIC PLAN

Both planning and implementation incident to the service of supply for an arctic operation must be precise since long distances are involved and re-supply points are for the most part non-existent. The *Logistic Plan* must require strict accountability for fuel and consumable supplies in order that the task force may be self-sustaining for the duration of the operation. Additional quantities of critical spares and outfits of special portable equipment, both electronic and navigational, should be prescribed, giving sources of procurement or supply. The procedures of mail service, air lift, and emergency evacuation should be set forth in detail. Since arctic operations usually involve the establishment or re-supply of remote bases, detailed cargo loading and discharge plans, along with possible alternate discharge plans, should be included so that these evolutions may be performed quickly and efficiently without hazarding personnel and materiel. Provision should be made for all special handling equipment such as sleds, cranes, cargo nets, and slings required on board ship and on beachheads.

Figure 1–3.—Taking hydrographic measurements on Devon Island.

AIR AND COMMUNICATION PLANS

Flight operations in the Arctic are difficult because of limited directional orientation, uncertain weather, hazardous terrain, and lack of conventional air navigational aids. These factors influence and limit the *Air Plan*, in that suitable safety precautions must be taken and all flights must be conducted with ample safety margins. Facilities and plans for search and rescue are required, and proper rescue procedures must be disseminated throughout the task force and the area of operation. The plan should provide in particular for reconnaissance of pack ice by long-range aircraft and by helicopters, since such reconnaissance is essential to navigation in ice.

From an operational standpoint, efficient communications are of great significance because they are the medium by which command and control of the task force are exercised. Adequate channels and frequencies must be selected and provision made for any additional equipment required by the several units. Distant separation between isolated shore parties, boats, aircraft, ships, and the command center will of necessity exist throughout the operation. The *Communication Plan* must take into account known communication vagaries with respect to the arctic regions, and must be coordinated with all activities involved in the communications net. Provision for alternate frequencies and emergency procedure in the event of communication failure must be made. Periodic situation and position reports must be received from all units operating independently, and safety considerations dictate that these units return to base in the event of communication failure. Provision should also be made for timely reporting, and the exchange of data on meteorological and ice situations. Procedures for transmission of press releases and reception of news should be outlined. Arrangements for maximum utilization of joint facilities should be indicated. If there is need for additional communication personnel, the method of procuring such assistance should likewise be set forth in the Plan.

SCIENTIFIC AND PHOTOGRAPHIC PLANS

The conduct of various research and scientific projects and studies in the polar regions is of real importance to the National Military Establishment and the country. For this reason added emphasis is placed on a coordinated *Scientific Plan* properly cleared well in advance with the other departments of the National Military Establishment and with various interested scientific agencies

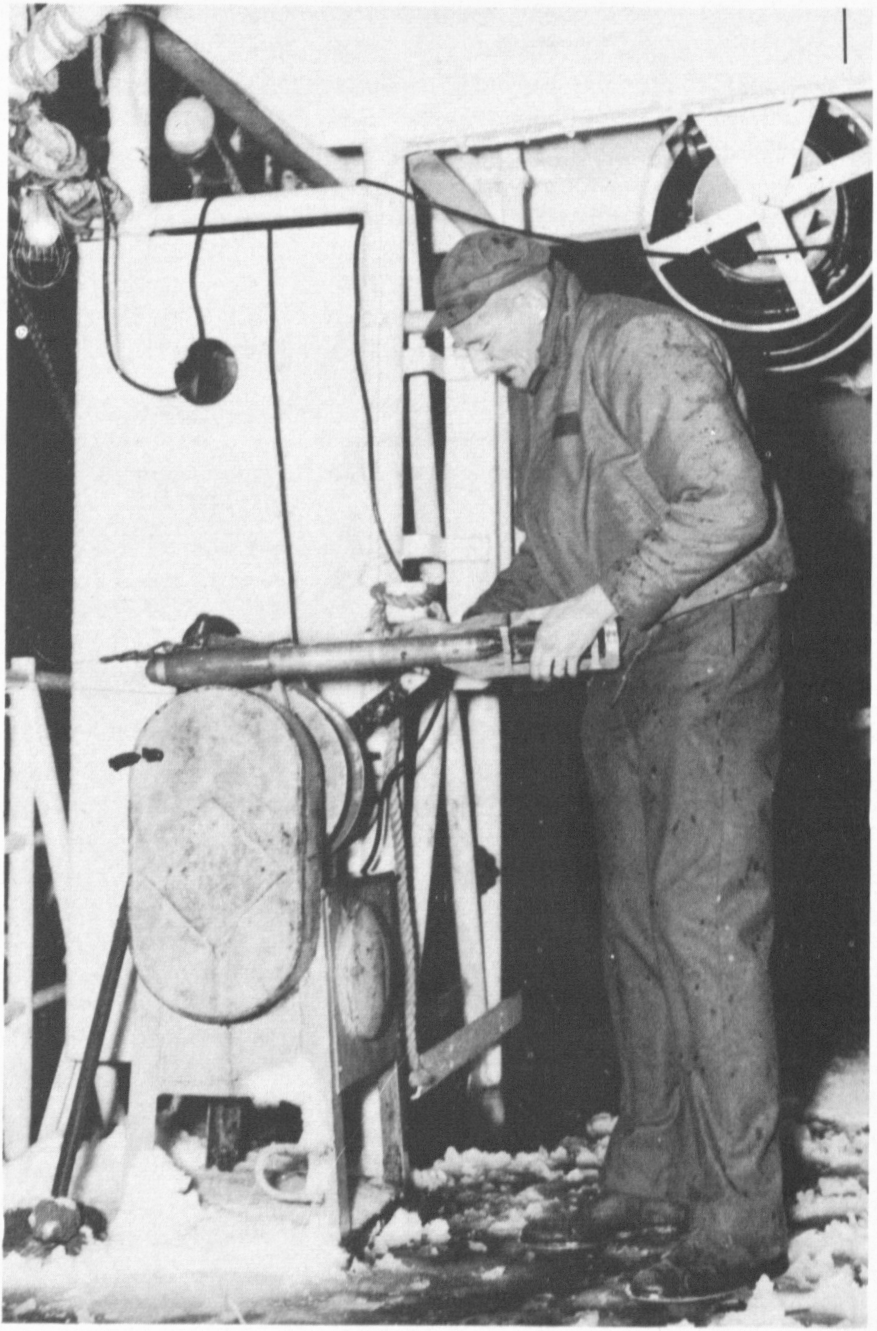


Figure 1–4.—Preparing to launch the bathythermograph.

of the Government. The Plan should provide ample opportunity for special scientific observers to take their measurements and to prosecute their studies, utilizing existing materiel, facilities, and personnel of the task force to the fullest extent. The foregoing applies particularly to oceanographic and ionospheric work. Operational and scientific aspects of an operation or expedition must be carefully integrated, taking into account important operational

Figure 1–5.—Weighing snow column for density measurement.

missions, safety precautions, and the prime desirability of obtaining as much scientific information as possible. Provision for preparation, format, submission, and distribution of reports on scientific projects should be made in this annex.

A detailed *Photographic Plan,* including provision for supply of materials and personnel, should be included when planned photography is essential to the accomplishment of either the primary or secondary purposes of the operation.

TRAINING PLAN

A secondary purpose of all operations in the high latitudes is training of personnel and test of materials and equipment under the most extreme climatic environment to be encountered. Thus, a comprehensive training plan for achieving this end uniformly and effectively throughout the force should be prepared and issued as an annex of the *Operation Plan.*

HEALTH AND SURVIVAL

Special instructions for health, first aid, and survival not included in standing instructions or in approved Navy Department publications should be set forth in a *Health and Survival* annex. General instructions for abandon ship and subsequent rescue in event of disaster should be included, to the extent deemed necessary by the task force commander.

INSTRUCTIONS FOR OBSERVERS

Consideration must always be given to the accommodations of observers in any operation to the polar regions. Because the Arctic is of strategic and scientific interest, military and civilian personnel, including foreign nationals, will usually accompany the task force. Since these personnel are not always familiar with the customs and rules of the Navy, the annex, *Instructions for Observers,* should set forth the provisions for berthing, messing, finance, mail address, and other personal details which the task force commander desires them to follow. Care must be taken to cover all contingencies despite how simple they appear, in order to avoid possible embarrassments and adverse public relations.

MISCELLANEOUS NOTES

It cannot be emphasized too strongly that early planning will contribute materially to the success of an arctic operation, from both the operational and scientific standpoints. Since careful co-

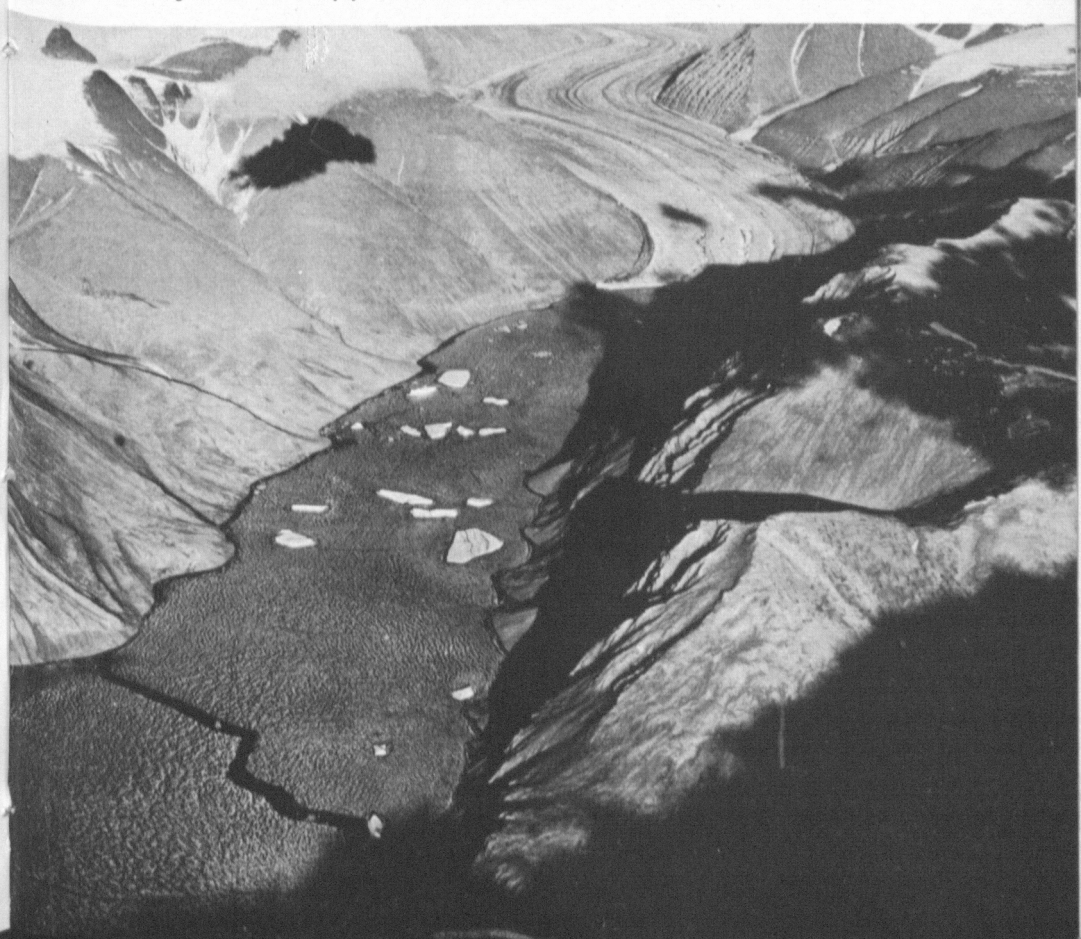
ordination with other services and various interested governmental agencies is always necessary, initial staff studies and planning should be conducted in Washington.

In the operational planning consideration should be given to stopping at one or more liberty ports, particularly if the operation is to be of long duration. Necessarily, operations in the Arctic or Antarctic do not provide opportunity for recreation, and the visiting of a liberty port on the return voyage will contribute substantially to morale.

Directives in respect to the release of public information should be formulated with, and issued as part of, the operation plan. Premature releases, the release of classified information, or undesirable publicity can be avoided by a well defined and executed public relations policy.

Pertinent directives and instructions, including those pertaining to preparation of the operation report, which have not been incorporated in the various other annexes should be included as a final annex of the operation plan.

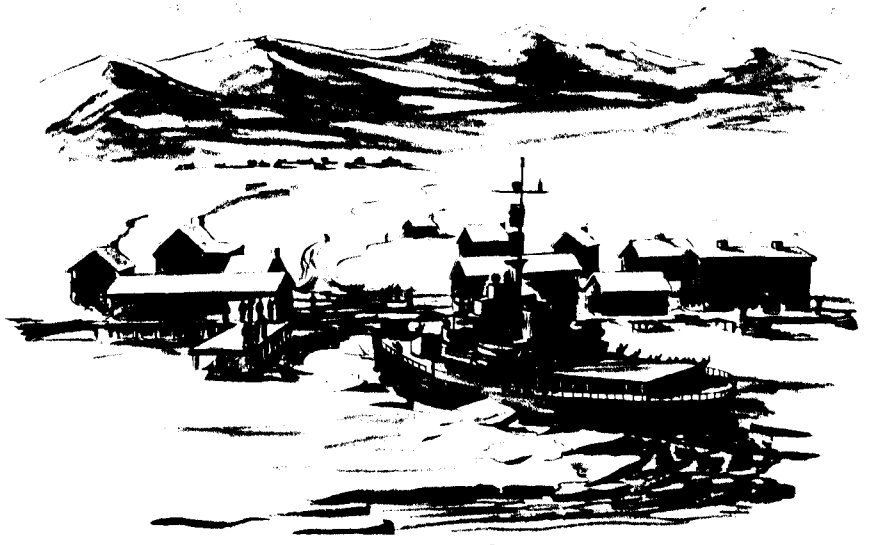
Figure 1–6.—Navy planes photo terrain within 450 miles of the North Pole.



SUMMARY

The advice of Nansen quoted at the beginning of this chapter is a fitting summary. A polar operation probably will not be successful unless studiously and carefully planned in advance, and unless executed with "forethought for every conceivable thing." Adequate time must be allowed for staff study, formulation of detailed plans, and assembly of the materials, supplies, and special equipment required, while at the same time evaluating the capabilities and limitations of materiel and personnel as they may be expected to function in the area of operations.

Figure 1–7.—Navy movie cameraman records progress of icebreaker through Antarctic ice pack.



CHAPTER 2

SHIP OPERATIONS

"The arrival of a ship at Nome, Alaska, during the winter months was hailed as the greatest thing to happen since the gold rush."—Gibson.

Ships have played a prominent and dominant role in the history of the arctic and antarctic regions since the earliest times. The accomplishment of major tasks in connection with any type of military operation—land, sea, or air—in the future in the high northern latitudes no doubt will require extensive participation by ships. Such operations might include geographic exploration, establishment of stations and facilities, logistic support of military installations, transportation, establishment and operation of temporary bases, rescue, tests of materiel, scientific observations, training, defense and military security, and offensive operations to the limit of naval weapons—naval aircraft, guided missiles, rockets, and guns.

During *Operation Highjump* in the waters around Antarctica, the significant accomplishments as to ship operations were:

1. Three large unprotected ships (2 AKA, 1 AGC) with the aid of one icebreaker traversed over 600 miles of pack ice varying from a mixture of brash and drift ice to consolidated pack ice.

All designated tasks were accomplished on time, in general, with relatively minor damage except the loss of the rudder of one AKA during a severe storm while still in the pack.

2. One wind class icebreaker, in the short period of 2 days, broke over 2 square miles of hard, dense bay ice ranging from 5 to 15 feet thick and cleared the Bay of Whales sufficiently to permit entry of the 3 heavy ships.

3. The heavy ships were successfully moored to fast bay ice while discharging cargo in the normal manner as at a pier or wharf, despite frequent interruptions due to conditions of wind, sea, and floating ice.

4. A large number of naval personnel gained invaluable experience amidst the unusual environmental conditions resulting from polar weather.

5. The endurance of the engineering plants and machinery of all the ships was tested under conditions requiring continuous steaming for extremely long periods.

6. The force of 13 ships operated without difficulty over 8,000 miles from regularly assigned bases, in unfrequented and unfamiliar waters and geographic areas, without the benefit of outside logistic support for a period of over 6 months.

7. One icebreaker successfully towed an AKA from the limits of the antarctic pack to New Zealand, a distance of over 2,000 miles, across the world's stormiest seas.

SUMMER OPERATIONS

The significant accomplishments during annual summer operations in the Canadian Arctic Archipelago and in the Beaufort Sea around Point Barrow, Alaska, have been:

1. An annual extension of limits of operations of icebreakers to a point at latitude 82°34′ N. in the Lincoln Sea, throughout Jones and Lancaster Sounds, in Prince Regent Inlet through the Fury and Hecla Strait, and in Hudson Bay.

2. The satisfactory development of amphibious techniques under the uncertain and unfavorable conditions prevailing around Point Barrow and in the Beaufort Sea.

3. The collection of valuable scientific data. During *Operation Frostbite* in Davis Strait it was shown that a carrier task group

could satisfactorily operate up to the limits of the sea ice in northern seas throughout the year. Icebreakers have operated above the Arctic Circle within Davis Strait and the Bering Sea during the winter period. These operations are typical of peacetime naval operations, and possibly may form the pattern for any operations that may be required in the Arctic in time of war.

NAVIGABILITY

The principal limitation upon ship operations in the Arctic, as elsewhere, is navigability in the assigned areas of operations. Navigation amongst ice is uncertain and hazardous at best, and is subject to considerable damage to hulls and fittings of the participating ships.

Figure 2-1.—Observation from helicopters.

The navigability of a given sea area in the Arctic can only be determined by careful study of all available charts, sailing directions, and ice atlases. It also must be remembered that the last named are based on sparse information. Only now is data on the regions becoming systematically collected and interpreted. Appendix A will serve as a guide for ready reference based on average conditions that may be expected to prevail over a period of years. Once in the area, it is quite possible that actual conditions will be different from the average. Thus the appendix can only be depended upon for general information.

Another of the limitations upon naval operations in the high latitudes is the direct effect of extreme cold on personnel and the con-current indirect effect on ship operations.

Table I which follows is a listing of approximate mean and minimum temperatures that likely would be encountered to the limits of navigability during the coldest period of the year, January and February, throughout the arctic regions. This information is essential, since it will form the basis for planning the heating of the ship and for selecting the clothing which the personnel will wear to ensure comfort, and the maintenance of personal efficiency at the highest possible degree.

TABLE I

Navigability—Sea Surface Temperatures, Coldest Month

General area	Latitude, North	Longitude, W. or E.	Average temperature ° F.	Minimum temperature ° F.
Davis Strait	66–30	59 W.	−5	−20
Davis Strait	64	61 W.	−10	−20
Godthaab, Greenland	64–11	57–43 W.	14	−20
Greenland Sea	70	15 W.	15	−15
Greenland Sea	77	0	15	−15
Vardo, Norway	70–22	31–08 E.	22	−9
Barents Sea	70	45 E.	20	
Kola Inlet near Murmansk, U. S. S. R.	68–53	33–01 E.	−22	−39
Grimsey, Iceland	66–33	18–01 W.	28	−23
Belle Island, Newfoundland	51–33	55–22 W.	17	−18
Eastport, Maine			21	−13
Archangel, U. S. S. R.	64–35	40–36 E.	−25	−49
Solovets, U. S. S. R.	65–01	35–45 E.	−7	−22
Sitka, Alaska	57–03	135–20 W.	32	−4
Kodiak, Kodiak Island	57–47	152–24 W.	30	−9
Juneau, Alaska	58–18	134–24 W.	27	−15
Nome, Alaska	64–30	165–24 W.	3	−47
Vladivostok, U. S. S. R.	[1] 42	[1] 132 E.		[1] −15

[1] Approximate.

WINDCHILL

In the language of explorers, polar winds are "bitter," "biting," "keen and bitter as frozen steel," "furious," "an active enemy," "terrific," or "violent and terrible." The intense cold associated with such winds numbs human beings, makes work killing, cuts through the warmest clothing, and slows down everything.

Windchill is the cooling effect of two variables—wind speed and average temperature. A windchill factor of 1450 and higher defines arctic conditions. Since a moving ship creates wind, arctic conditions of windchill usually prevail in northern seas during the winter. Table II below contains a listing of windchill factors under varying conditions of wind and temperature.

TABLE II

Windchill factors

Windchill factor	Body condition	Temperature ° F.	Wind speed statute m. p. h.
50	Hot	88	20
200	Pleasant	81	20
400	Cool	69	20
800	Cold	46	20
1000	Very cold	35	20
1200	Bitterly cold	23	20
1400	Exposed flesh freezes	11	20
1450	Arctic	0	10
1450	do	15	25
1800	do	−12	20

During *Operation Frostbite* near latitude 63° N. in early March of 1946, temperatures as low as 14° F. were experienced. Thus, during flight operations, it can be seen from the above table that arctic windchill conditions prevailed. It was found then that the main problem in carrier operations in cold weather areas is maintenance of efficiency of flight deck crews for the condition of high relative winds and surface air temperatures below freezing.

FORECASTING AND REPORTING SEA-ICE CONDITIONS

Reliable information about the characteristics, distribution, and movements of sea ice, including seasonal variations, is becoming increasingly important for all types of ship operations in the Arctic. In the past, this information has been largely limited to the sparse records obtained from ships which have operated near the edge of the pack ice, from ships frozen in the pack, and from

explorers traveling on foot over the ice. However, all this has contributed very little to our knowledge of seasonal variations of the ice. Increasing arctic operations offer unique opportunities to collect ice data in sea areas heretofore unexplored. These data are essential both during the conduct of an operation and for assembling the data needed for the prediction of ice conditions during the years to come. Each ship operating in a cold-weather area should make systematic observations of sea ice wherever the opportunity affords.

The principal advantage of shipboard reconnaissance of ice is that it affords the opportunity for first-hand, detailed observation of the ice itself, and its changes with time. On the other hand, there are many characteristics of ice that are better observed from the air. During the conduct of an operation a large area of the sea, long range air reconnaissance, periodic observation from helicopters, and continuous surface observation from the crow's nest are essential to safe ship navigation.

The Hydrographic Office has developed standard ice observer sheets or log forms both for ship and air observers. Certain of the information used in the two systems is interchangeable. In this way shipboard observations and air observations can be easily interpreted and rectified. Each item in the logs is there for a definite reason. Therefore, no item should be skipped because it may appear unimportant. It may be valuable in later analyses.

As occasion permits, radar photographs, ordinary still and movie photographs, sketches, and other means should be employed to obtain permanent records of the observed conditions.

The use of these ice observer log forms is explained in detail in HO Studies 99 and 104.

The task force or task group commander should make provision in his operation plan for the assistance of any available ice pilots familiar with the area of operations, for the tactical control of any air force or naval aircraft that can be made available to him for long range air reconnaissance, and for the preparation of timely ice forecasts for dissemination to all units while in the area.

ICE SEAMANSHIP AND NAVIGATION AMONGST ICE

Admiral Peary has stated that "ice navigation is the key to all polar work."

The Hydrographic Office has issued *A Manual of Ice Seamanship* (HO 551) which is a complete treatise on the subject, representing existing knowledge and the best experience to date. Each line

officer should read and study this publication prior to arrival of his ship in waters where it is expected that sea ice will be encountered.

There are summarized in appendix B some notes on experience during past polar operations relating to preparation for ice navigation, general rules of ice navigation, travel over ice, and safety. They may be applicable only in part in a given area, due to variations in climate and other geographical factors in the two polar regions. This listing is not all inclusive. A check-off list should be prepared and executed in keeping with requirements of the operation.

Navigating officers, officers of the deck, and quartermasters should receive instruction in polar navigation prior to departure from base, including:

1. Instruction in the irregularities of gyrocompasses in high latitudes as well as use of correction tables provided for latitudes above 70°.
2. Magnetic compass variations and corrections in high latitudes.
3. Navigation in fog.
4. Navigation by radar and soundings.
5. Use of bubble sextant. (Each ship should be provided with bubble sextant.)
6. Recognition of land marks or navigational aids in the area.

Remember the regulation of long standing as to the use of a hand lead when on soundings. Remember also the fact that the fathometer is not reliable when the depth is less than 10 fathoms. Take azimuths and plot line of position whenever observations of the sun permit. In the high latitudes a quick swing of the ship sets up a gyro error of considerable magnitude.

OPERATION OF BOATS AND SMALL CRAFT

There are countless tasks and missions to be accomplished by boats and small craft in any naval operation in the polar regions. They must be winterized in accordance with latest instructions of the Bureau of Ships, and placed in first class operating condition prior to arrival in the area of operation. Due to hazards that are liable to be encountered, only skilled and dependable boat crews should be used.

In table III and accompanying photographs, figures 9–1 to 9–13 inclusive, are set forth the features, characteristics, and capabili-

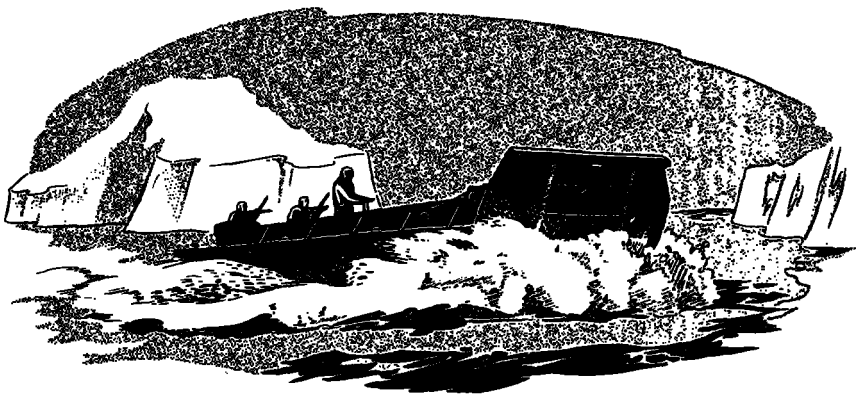


Figure 2–2.—Many tasks can be accomplished by small craft.

ties of various boats and small craft which have been used satisfactorily by the Navy and Coast Guard in the Arctic.

In operating boats in the Arctic, it is mandatory that they be equipped with efficient portable communications equipment and emergency gear. Coxswains should be completely instructed as to procedures to be followed during storms and low visibility. Remember that these boats are not suited in breaking channels through pack ice. LCVP and LCM have a tendency to ride up on the floes. All are subject to holing and damage to rudders and propellers.

The following precautions should be exercised:

1. Use caution when approaching drift ice. Proceed at slow speed. Avoid all ice possible. Avoid areas of slush and brash ice. Keep circulating water inlet free of ice.

2. Coxswains should never leave tillers unattended. Keep boat engines operating as movements of floating ice are unpredictable.

3. When approaching an area of ice for a landing alongside, proceed at dead slow speed and nose gently into it, warping alongside as necessary. Get equipment and personnel on or off the ice as rapidly as possible and back clear.

4. When operating in drift ice areas, station bow lookout to keep coxswain advised of nearby ice and submerged cakes, such as growlers, that will endanger the boat.

5. Keep circulation water to minimum just to prevent overheating of engines. Warm up engines slowly. Never race engines. Keep engine heaters in place when boat is not in use. Drain engine block when boat is hoisted or hauled out of the water for other than a temporary period.

6. Check fuel, lubricating oil, and boat equipment each time before leaving the ship. Keep fuel tanks full at all times to prevent condensation and possible subsequent freezing of the water in the fuel system. Keep storage batteries fully charged. Have portable engine starter available for use to prevent unnecessary discharge of boat batteries in event of hard starting.

7. Keep bilges of boats absolutely clean and dry. Ensure that drain plugs are kept free. Do not let them freeze. Examine carefully before placing boat in water.

8. Keep fire fighting equipment available in boats at all times when in use.

9. Test out boat radio equipment before leaving ship. Keep in communication while away from the ship.

10. First boat ashore should carry adequate survival gear for entire working party to be landed for use in event of emergency —sleeping bags, fire arms, ammunition, fuel, rations, etc.

Figure 2-3a.—LCM-3.

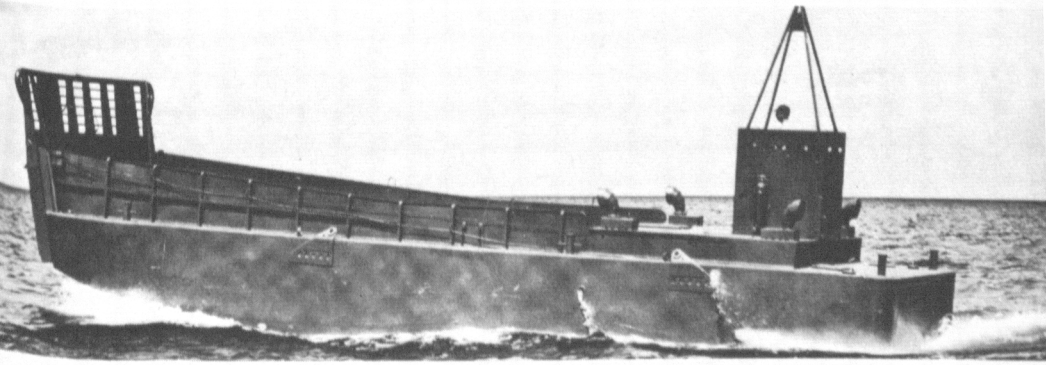


Figure 2-3b.—LCVP.

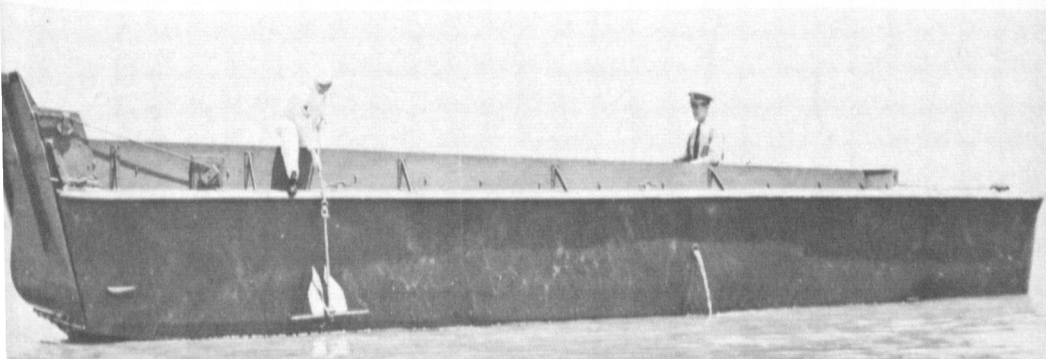
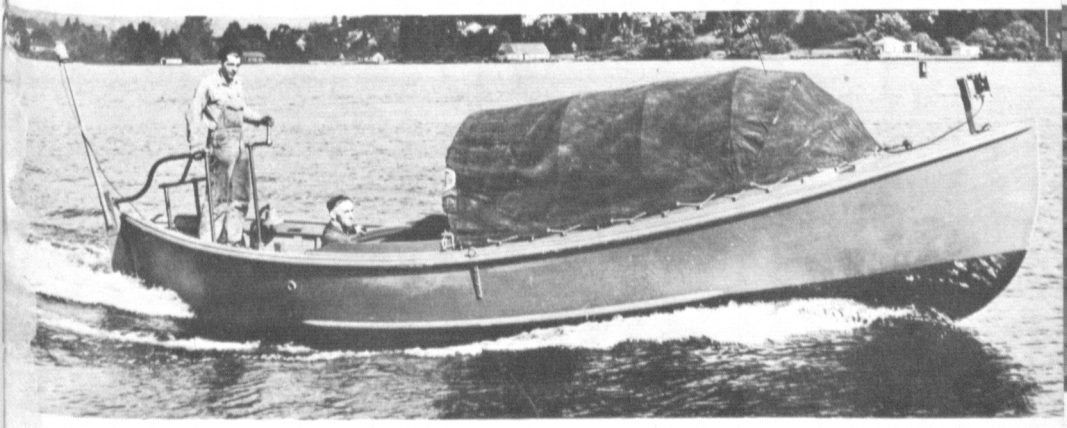


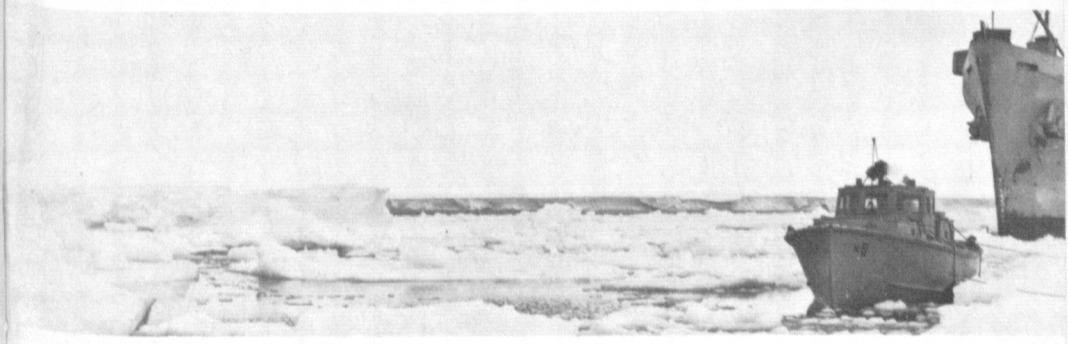
TABLE III

SMALL CRAFT DATA—POLAR OPERATIONS

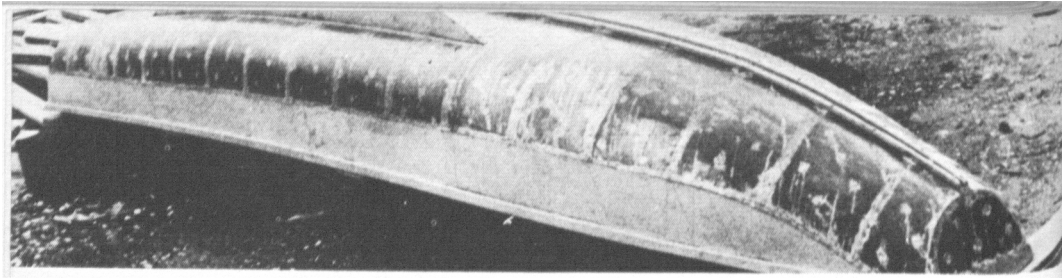
Boat	Length	Beam	Draft	Weight, empty	Usual employment	Capacity	Power plant	Speed	Type hull	Remarks
NAVY										
LCM-3	50′	14′6″	3′6″	52,000 lbs.	Cargo Passenger	50,000 lbs. 80 men	Twin diesel, 225 H.P. each	12 m.p.h.	Steel	Fig. 9–1. Dimensions of boat limit capacity to 80 men however normally boat capacities assume 10 cubic feet of internal volume per man and a weight of 165 pounds per man.
LCVP	36′	10′6″	3′4″	18,000 lbs.	Cargo Passenger	8,000 lbs. 36 men	Diesel, 225 H.P.	10 m.p.h.	....do....	Has carried 10,000 pound T-9 tractor without difficulty.
40′ motor launch	40′2″	11′4″	2′4″	16,000 lbs.	Passenger Cargo	14,850 lbs. 90 men	Diesel, 50 H.P. DB	9 m.p.h.	Wood	
26′ motor whale boat	25′11″½	7′3″$^{3}/_{8}$	.....	5,066 lbs.	Passenger Cargo	(Open) 22 men 3,600 lbs. (Hood) 20 men 3,300 lbs.	Diesel, Da	.....	....do....	
COAST GUARD										
Motor boat (cabin) "Greenland Cruiser."	36′8″	11′$1^{1}/_{4}$″	3′3″	21,255 lbs.	Passenger	25 men	Diesel 85 H.P. (Buda Lanova)	9 m.p.h.	....do....	Cruising radius 486 miles—300 gallon tank—4 berths—4 heavy chains for lifting—built on 36′ motor surf boat hull.
26′6″ motor launch (Special) GIG.	26′6″	7′10″	2′7″	7,450 lbs.	Passenger	18 men	Diesel, 35 H.P. (Buda)	9 m.p.h.	....do....	Cruising radius 95 miles.
Self-bailing motor surf boat.	25′10″	7′4″ (wood fenders) 7′11″ (cork fenders)	2′9″	6,000 lbs.	Rescue Passenger	16 men	Diesel, 30 H.P.	8 m.p.h.	Wood with Metal Sheathing	High engine hatch with Buda—low engine hatch with Kermath. (Buda has fresh water cooling tank above.) Cruising radius 75 miles.
26′ monomoy surf boat.	26′3″	7′4″	.....	2,100 lbs.	Rescue Passenger	14 men	Pulling	.....	Wood	Usually equipped with sails.
Ice skiffs	15′6″	3′8″½	.....	510 lbs.	Passenger	4 men	Pulling	.....	....do....	
AMPHIBIOUS										
M29C weasel	10′5″$^{3}/_{4}$	5′1″ (old track) 5′7″$^{1}/_{4}$ (new track)	3′5″$^{11}/_{16}$	4,771 lbs.	Passenger	4 men	Gasoline (Studebaker)	Land 32 m.p.h. Water 4 m.p.h.	Steel	Height over all—(top up) 5′10″$^{13}/_{16}$ (top down) 4′5″$^{11}/_{16}$.
LVT-3	21′6″	9′10″	.....	36,400 lbs.	Cargo Passenger	9,000 lbs. 25 men	Twin gasoline (110 H.P. Cadillac)	Land 25 m.p.h. Water 6 m.p.h.	....do....	Height 8′1″½.
DUKW	31′	8′4″	(Loaded) 42″ front wheels 51″ rear wheels	14,890 lbs.	Cargo Passenger	5,000 lbs. 25 men	Gasoline, 90 H.P.	Land 50 m.p.h. Water 6.5 m.p.h.	....do....	Height 9′2″¼.

(Above) Figure 2–3c.—Motor launch.
(Below) Figure 2–3d.—Motor whale boat.





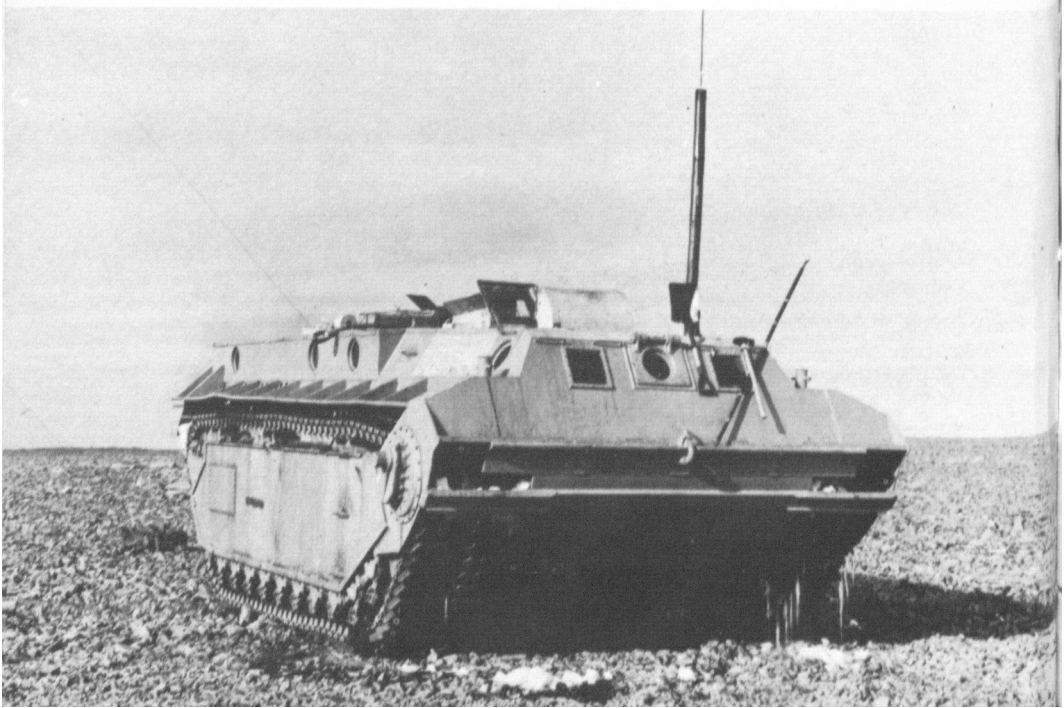
(Above) Figure 2–3e.—Greenland cruiser.
(Below) Figure 2–3f.—Special gig.



(Top) Figure 2–3g.—Ice skiff

(Above) Figure 2–3h.—M29C weasel.

(Below) Figure 2–3i.—LVT 3.



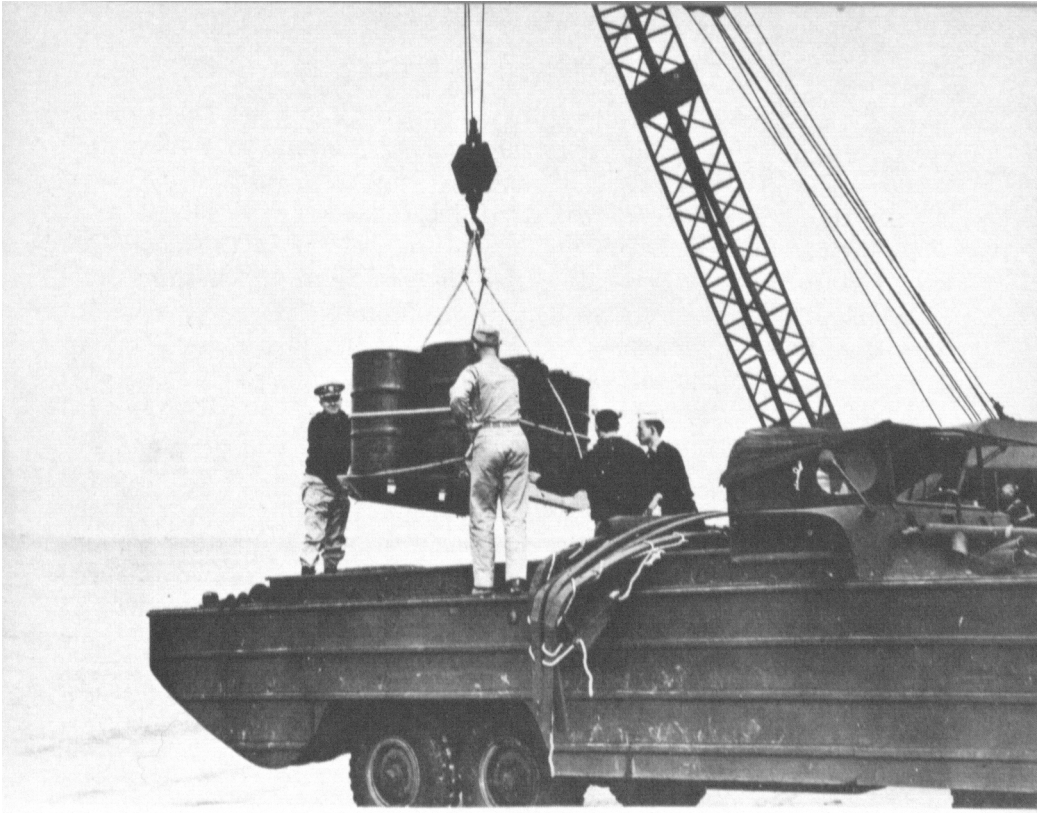


Figure 2–3j.—DUKW.

BEACHHEAD OPERATIONS

The purpose of arctic expeditions generally is the establishment or resupply of weather and other remote stations as well as continuing logistic support of existing military installations and facilities. Thus the unloading of cargo becomes one of the most important tasks to be undertaken in the area of operations. Due to the uncertainty of weather and ice conditions, unloading should be planned for accomplishment in a minimum of time consistent with safety to personnel and careful handling of materials, supplies, and equipment. Take no chances in these remote areas! *Practice safety first!!*

To introduce this subject briefly, the experience of several Point Barrow resupply expeditions will be outlined below. These expeditions have grown steadily in scope and importance to the point that they are now planned and executed as small-scale amphibious exercises. Since such operations are conducted in areas where assistance ashore is limited or not available, the crews of all participating ships must be augmented to ensure that this phase of the expedition is conducted expeditiously and in the manner required to provide the logistic support necessary. Always be prepared to do more than is planned in order to take care of contingencies. Furthermore, it is desired to build up cadres of personnel trained in cold weather exercises. This is another justification for the assignment of additional personnel to ships which participate in such special operations.

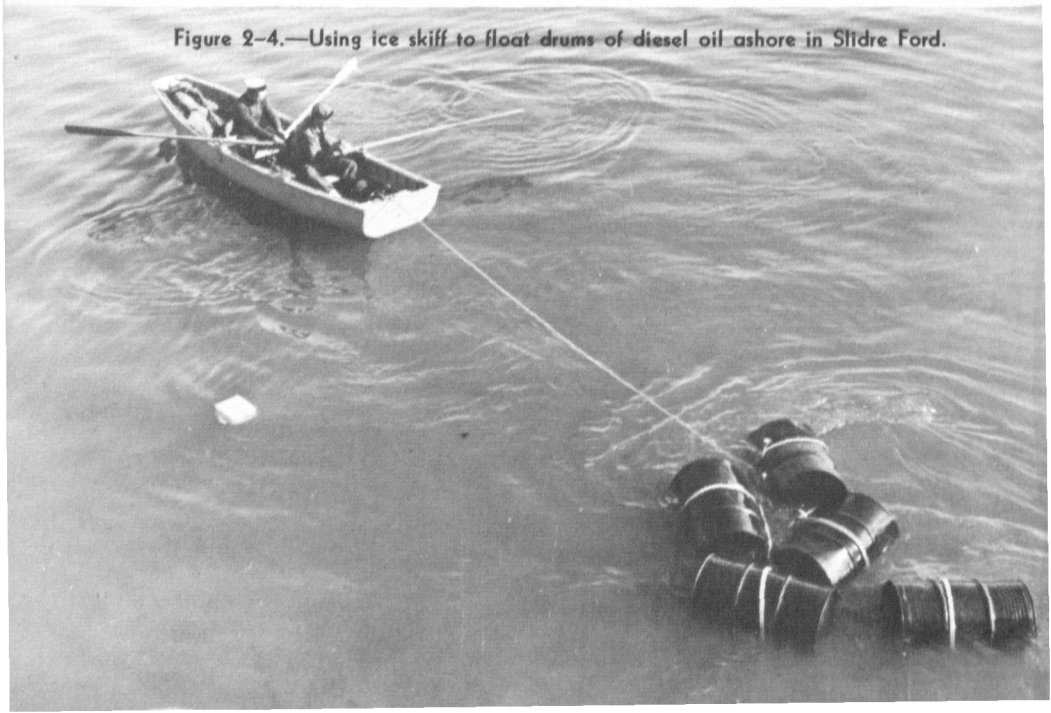


Figure 2–4.—Using ice skiff to float drums of diesel oil ashore in Sliidre Ford.

EXPERIENCE AT POINT BARROW

1. Organize an adequate beachmaster party to function on a watch-and-watch basis consisting of following totals as available:

Beachmaster.	1 motor machinist mate.
Assistant beachmaster.	1 electronic technician's mate.
Assistant beachmaster.	Seamen as required.
Communications officer.	Cdr. or LCDR.
Radiomen, signalmen.	Lt. or Lt. (jg).
Weasel drivers.	ChCarp. or ChBosn.
2 boatswain's mates as beach supervisor.	Lt. or Lt. (jg). as required.
2 hospitalmen.	as required.

2. Provide Jamesway hut, arctic tent, or similar shelter for headquarters for beachmaster party and for shelter of personnel away from ships in emergency. If practicable, subsist party ashore.

3. Organize a Seabee or engineer detachment for operating lighterage, cranes, tractors, and LVT's where quantity of cargo necessitates. This detachment is then divided into a number of units equal to the number of cargo ships with one unit assigned

Figure 2–5.—Three ice skiffs tied together as "barge" for use in shallow water.

to each for the voyage to the area of operations. An officer in charge is designated for the detachment. A unit consists of a chief petty officer and approximately 25 men.

4. The loading activity in the United States is responsible for supplying all ships with additional stevedore gear-straps, slings, and cargo nets required for their own needs on shipboard and on the beaches.

5. For the purpose of keeping cargo segregated, the beach at Point Barrow has been divided in areas as follows:

Area 1.—Lumber, hut materials, building materials, food, and commissary supplies.

Area 2.—General supplies.

Area 3.—Spare parts, heavy automotive equipment, and supplies.

Area 4.—Oil field equipment and supplies.

Area 5.—Fuel and lubricants.

Area 6.—Emergency beach.

6. An area should be selected for safely caching explosives.

7. Drummed gasoline should be segregated, with fire break and fire fighting equipment provided as a precautionary measure.

8. A beach party is organized by the station at Point Barrow

Figure 2–6.—Motor whaleboat taking ice skiff "barge" in tow.

Figure 2–7.—Ice skiff can carry four men comfortably.

to handle cargo after it has reached the beach areas, to maintain weight lifting equipment, and to assist with the maintenance and repair of small craft engaged in the unloading. This party, while maintaining close liaison with the beachmaster unit, moves the cargo from the beach to storage areas. Since weight lifting equipment is available usually in limited quantity, it must be utilized to the highest degree of its capacity and efficiency. Therefore, the unloading operations are planned to avoid any unnecessary moving of special equipment from one beach area to another. Beach areas should be kept clear to avoid congestion and slowing down shipboard and lighterage operations.

9. Unloading should begin within 1 or 2 hours after ships arrive at the anchorage and continue on a 24-hour basis, except for interruptions due to ice or weather. The unloading should be planned for rate of discharge of 45 to 50 tons per hour per ship.

10. Portable communication equipment (SCR 610, TBX, etc.) should be provided in more than adequate quantity for beach party, beachmaster unit, LCM's, LVT's, lighters, and weasels. These sets should be fully winterized and made snow and water tight.

A large scale beach operation in the arctic can be satisfactory only if the loading was expertly planned with "forethought for every conceivable thing" and taking into account conditions which, from experience, are known to prevail in the area of operations. Do not overlook the contingencies that can be caused by limitations of available weight lifting equipment or by the terrain. Remember that interruptions will occur due to the presence of heavy drift ice or by the pack unexpectedly setting down upon the anchorage.

MARKING AND PACKAGING OF CARGO

The marking and packaging of cargo is extremely important since only periodic resupply is possible. For maximum protection against loss, water damage, rough handling and pilferage, the following requirements should be fulfilled, if possible.

1. Drummed oil products need be marked only for description of contents. Gasoline should be shipped only in *new* drums. The use of reconditioned drums should be limited to lubricating oils and Diesel oil. All drums should be carefully inspected for tightness of plugs, presence of leaks, secure stowage in holds (fig. 9–14). NOTE.—*Load all drums on end with plugged end up.*

2. Cargo other than petroleum supplies should have appropriate beach marking stenciled on each container in black paint. In addition to these target symbols, additional information should be stenciled on each container about as follows:

_____ _____
Shipping Code Year
WT_____ Cube_____
Contents _____
Vendor _____

Figure 2–8.—Using ice skiff to land men on Arctic beach.

3. All cargo should be properly export-packed and, insofar as practicable, palletized to facilitate handling in the ships and on the beaches.

4. Palletized materials should be securely strapped with metal strapping using corner plates when the straps are necessary to eliminate damage to material. Loaded pallets ordinarily should not exceed a weight of 4,000 pounds (fig. 9–15).

5. Flour and sugar should be packaged in waterproof containers and boxed; metal containers are preferable, if available.

6. Commissary supplies should be packaged in waterproof containers and securely boxed.

7. Machinery and spare parts should be treated with corrosion resistant materials and preservatives and packaged in export boxing.

8. Drilling mud, sand, cement, and like materials should be packed in metal containers holding 4 sacks each. If metal containers are not available, materials should be placed in waterproof bags and export boxed or sealed in watertight barrels.

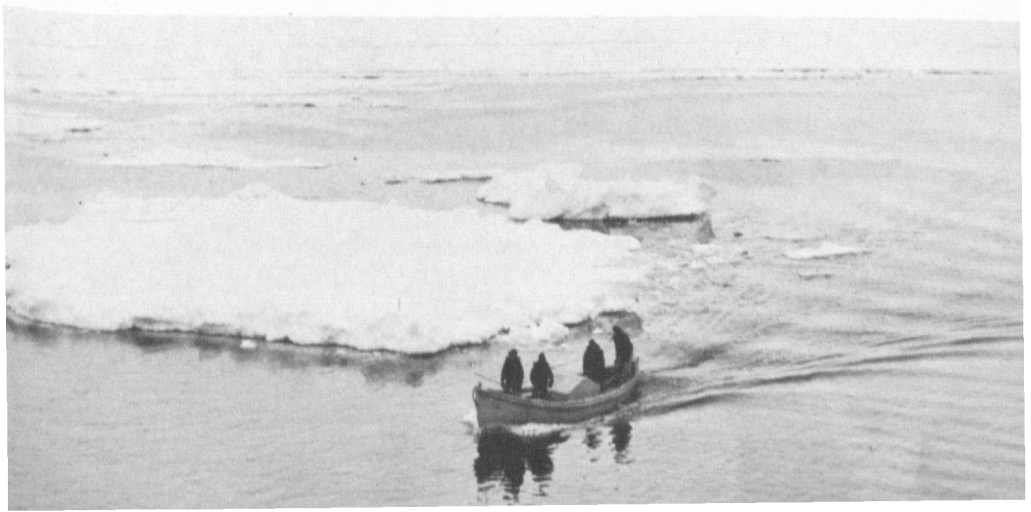
9. Lumber should be metal strapped in sling load lots not to exceed 4,000 pounds. Pieces should be of equal length.

10. Plywood, wallboard, and insulation materials should be waterproof wrapped and well crated with weight not exceeding 1,200 pounds. Figures 9–16 to 9–22 inclusive show beachhead operations in the Antarctic and figures 9–23 to 9–42 inclusive in the Arctic.

DESIGN, CAPABILITIES, AND TACTICAL EMPLOYMENT OF ICEBREAKERS

Up to the year 1949 the design of ice-breaking ships had presented perplexing problems in that very little accurate data was available on ice conditions and on the physical properties of sea

Figure 9–9.—Motor whaleboat underway in a big clearway in the pack.



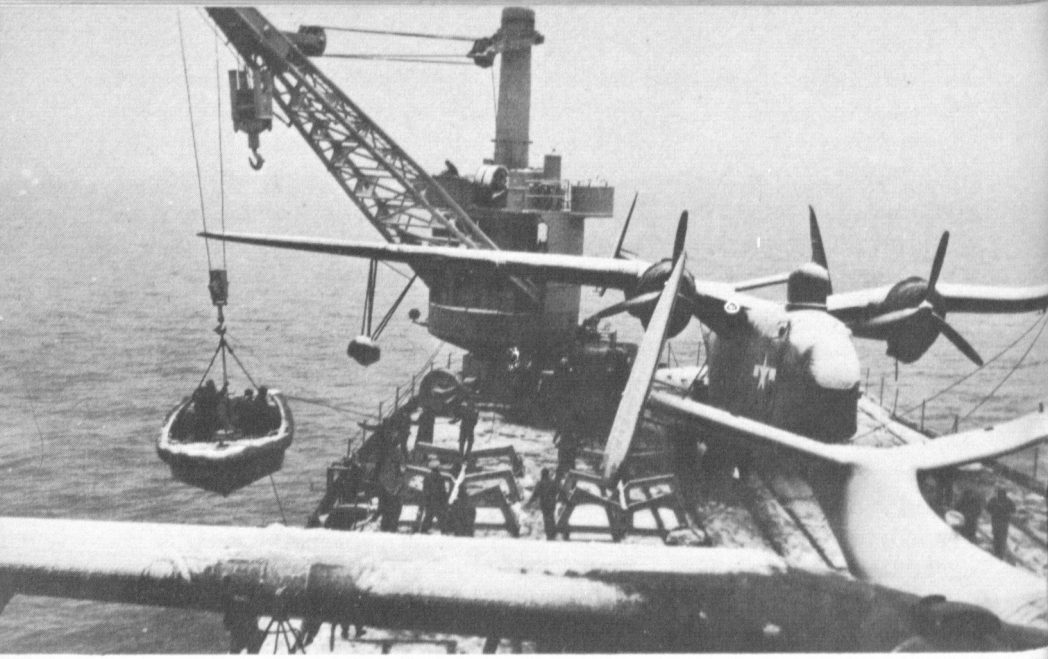


Figure 2–10.—AV lowering retriever boat.

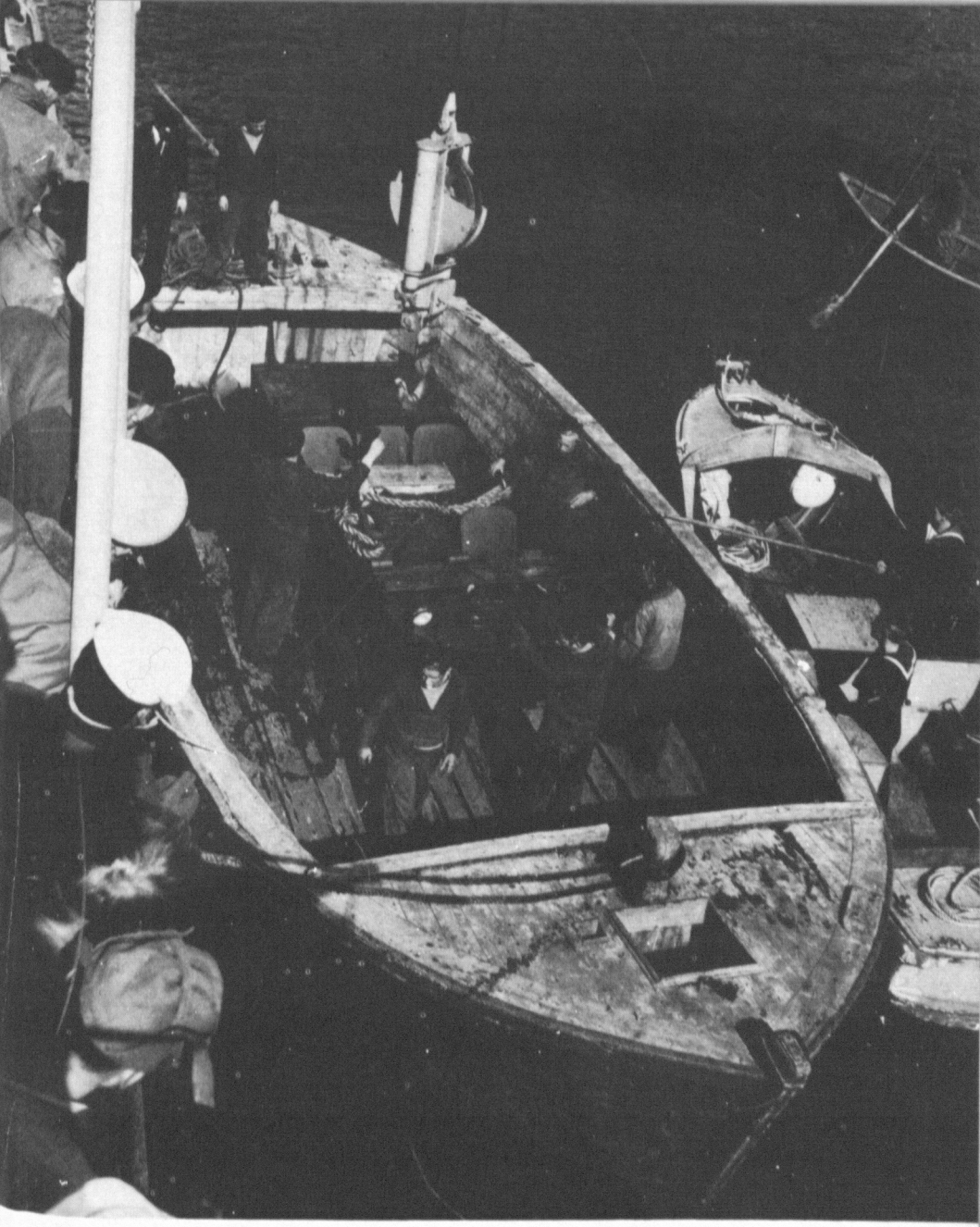
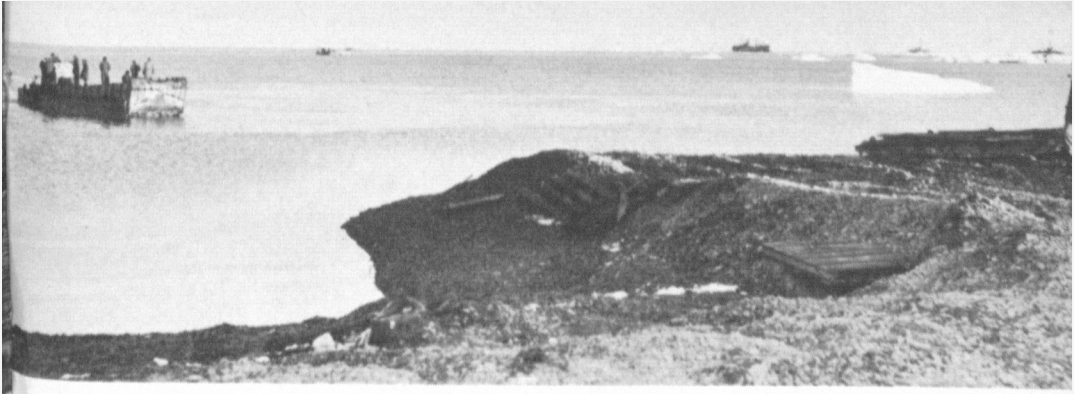


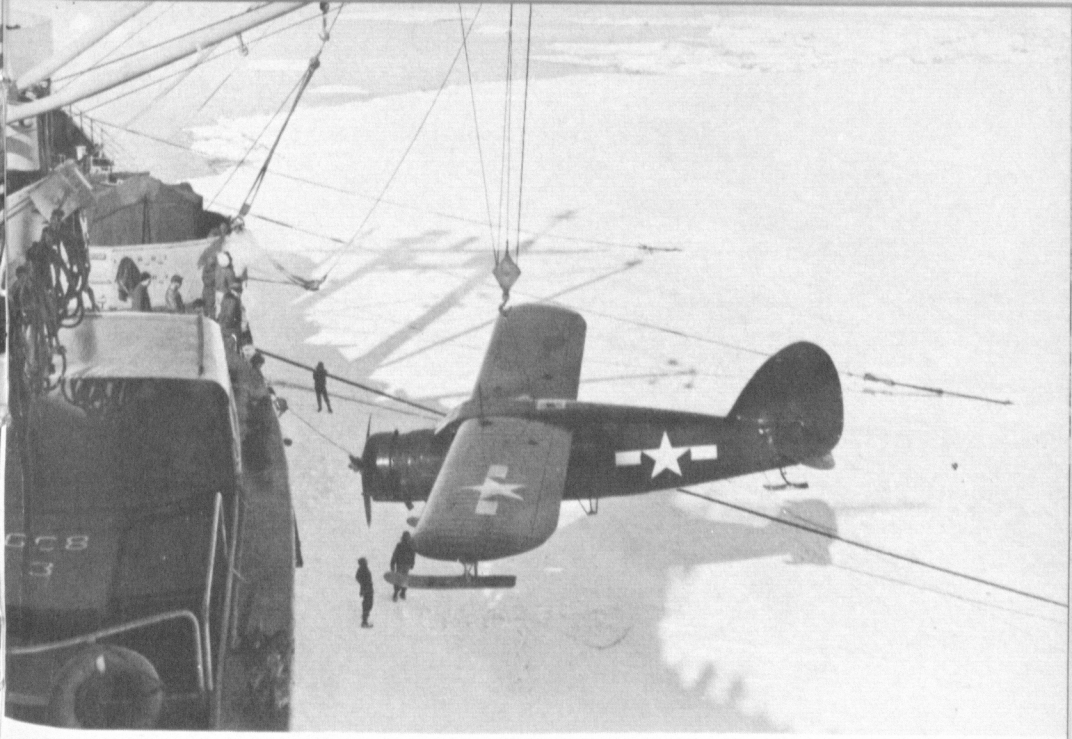
Figure 2–11.—Danish barge and small craft used in west Greenland

Figure 2–12.—LCVP moving cake of floating ice from side of ship.



(Top) Figure 2–13.—LCM–3 approaching beach at Resolute Bay.
(Above) Figure 2–14.—LVT–3 in Bay of Whales.
(Below) Figure 2–15.—LCVP caching supplies at Briceport Inlet, Melville Island.

(Above) Figure 2–16.—Loading oil drums in hold of AKA for Arctic resupply expedition.
(Below) Figure 2–17.—Palletized cargo should be securely strapped.



(Above) Figure 2–18.—Offloading on the ice.
(Below) Figure 2–19.—Beachhead scenes in the Antarctic.

RESTRICTED

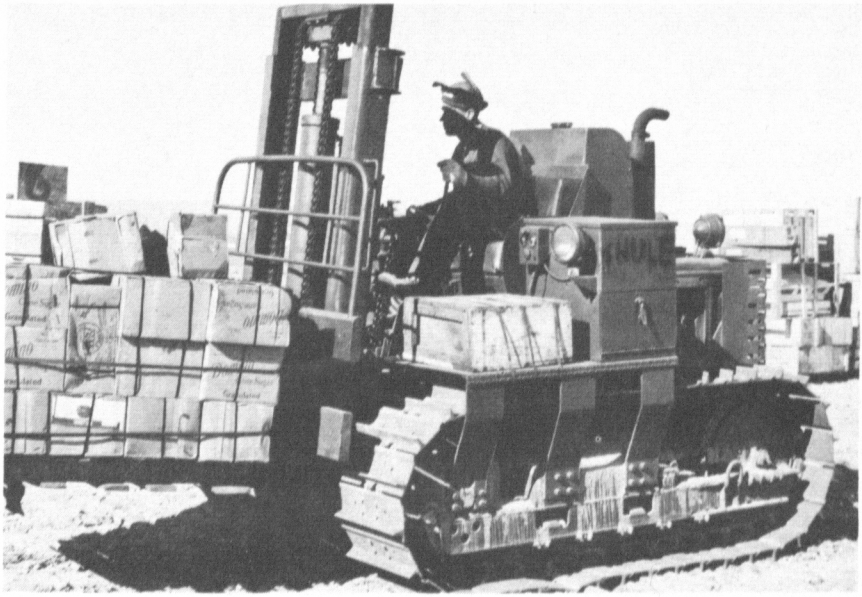
(Above) Figure 2–20.—Leaving the beachheads.
(Below) Figure 2–21.—Increased bearing surface.

RESTRICTED

(Above) Figure 2–22.—Loading an LCM.
(Below) Figure 2–23.—Tractor away.

(Above) Figure 2–24.—A cold, wet job.
(Below) Figure 2–25.—Landing aviation gasoline.

(Above) Figure 2–26.—Beachhead scenes in the Arctic.
(Below) Figure 2–27.—Transferring cargo to sleds.



(Above) Figure 2–28.—Forklifts are used frequently.
(Below) Figure 2–29.—Spotting a skid.

(Above) Figure 2–30.—Tractors are indispensable.
(Below) Figure 2–31.—General beachhead scenes.

(Above) Figure 2–32.—Strong backs are necessary too.
(Below) Figure 2–33.—Sleds are sometimes loaded aboard ship.

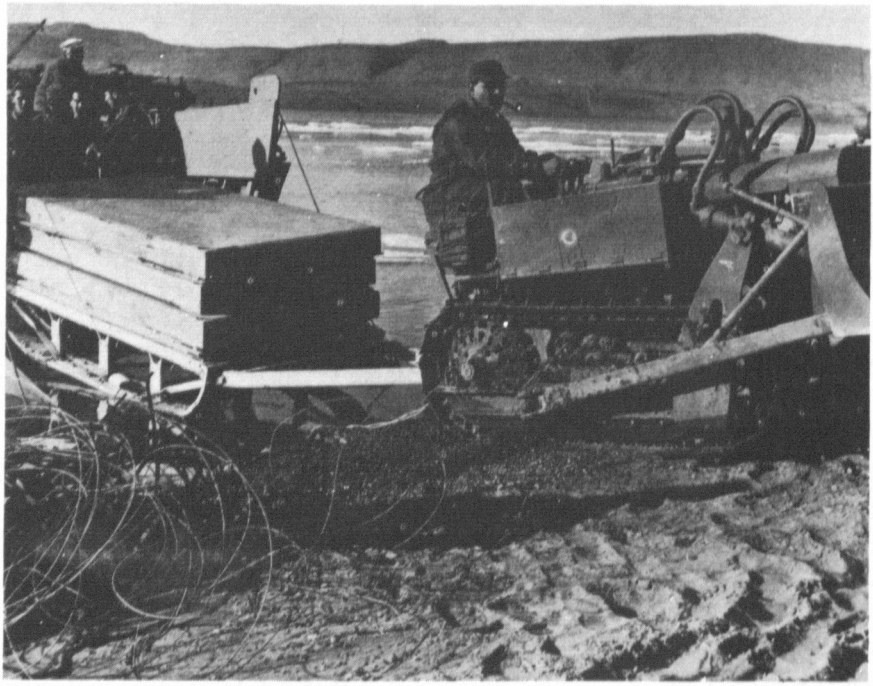


Figure 2-34.—Beachhead scenes in the Arctic.

ice. The strength, size, and form of the separate cakes of ice have a definite bearing on the design of a ship required to navigate in ice and to open lanes in frozen waters for commercial or naval ships. The strength of ice appears to vary from a possible compressive strength of 3,000 pounds per square inch and a tensile strength of 250 pounds per square inch for clear, cold solid ice, to nearly zero for slush.

Sea ice found in the waters around Greenland is probably the most heterogeneous of any found in the world. It is made up of glacial ice from the ice cap, winter ice from countless fiords, and storis from the overflow of the Arctic Sea. Glacial ice is usually of such great thickness that it cannot be broken. Similarly grounded ice fields have been reported in waters of 20 fathoms which would be beyond any possibility of breaking. Such fields must be navigated by following open leads or by forcing an opening between individual floes. However, these enormous masses of ice must be considered when they are free to move, and the strength and shape of the icebreaker must be such that the ship can survive or extricate itself if caught in a lead closing under the influence of wind or other effects.

In operating in pack ice it is necessary to take advantage of open leads where they exist along the track or by forming temporary leads by moving floes apart under thrust of a powerful and strongly constructed polar ship. All such leads are necessarily tortuous. Consequently, an icebreaker must be designed with shortest possible length and greatest maneuverability attainable. The beam of the icebreaker must be sufficiently wide to permit

large, unprotected ships to follow in convoy behind it. A machinery plant capable of remote control from conning stations is requisite. Due to remoteness of duty stations and the possibility of wintering over, the plant must be economical in fuel consumption and must have fuel capacity for long periods of full power operation and in mobilization. These requirements dictate the choice of Diesel-electric machinery.

The war emergency indicated the possible need for the construction of advance designs of icebreakers capable of operating in any and all the seas of the polar regions. The outstandingly successful Swedish icebreaker *Ymer* served as the prototype for the *Northwind* class developed in the United States. The *Ymer* was reported to be capable of breaking 5-foot solid ice at speed of 5 knots and of opening leads in heavy polar ice over 10 feet thick by backing and ramming while attaining a speed of advance of 1 to 2 knots.

The technique of breaking ice depends upon a personal factor along with design capability. The operations of our Navy and Coast Guard icebreakers of the *Northwind* type have been eminently satisfactory. Our experience has been that naval operations in the high latitudes are being annually extended to sea areas heretofore considered unnavigable by any type of ship.

Remember that these icebreakers, with all their strength and power, can suffer damage to hull, propellers, and rudder like other ships. Therefore the same general principles of safeguarding propellers and rudder apply. In particular, caution must be exercised while working heavy pack in shoal water.

To summarize, the foregoing characteristic along with many special features of ship construction combine to make the *Northwind* class of icebreakers one of the most effective types of icebreaking ships yet developed in any country. The design has been proven during operations around Antarctica, around Greenland, and in the Northwest Passage. In short, these ships can negotiate any broken pack ice with relative ease and can traverse the heaviest type of unbroken ice up to 10 feet thick. It is the general consensus and experience from various operations that the heeling system is not truly effective, due to long heeling cycle (one complete roll). This class of ship rolls heavily in the open sea and this presents a real problem. Equipment must be fixed or lashed securely. Steps must be taken to relieve motion sickness of personnel. During storms in winter months, the topside will ice rapidly.

TABLE IV

Characteristics of Comparable Ice Breakers

Characteristic	Swedish *Ymer*	U. S. S. R. *J. Stalin*	U. S. C. G. C. *Northwind*
Year built	1932	1937	1944.
Place built	Malmo	Leningrad	San Pedro.
Length overall	258	350	269.
Waterline length	246	335	250.
Waterline beam	61	74	62.
Depth, molded to weather deck	33	30	37.6.
Normal draft	21	26	26.
Maximum draft		29.7	29.
Normal displacement (tons)	3,465	9,300	5,300.
Maximum displacement (tons)	4,350	11,000	6,900.
Stem angle to waterline	25°	30°	30°.
Complement	42	142	145.
Speed, knots	15	15	16.
Propelling machinery	Diesel electric	Steam reciprocating.	Diesel electric.
Number shafts	3	3	3.
Number shafts, forward	1		1.
Number shafts, aft	2		2.
SHP after engines, normal	6,000	10,000	6,700–10,000.
RPM *normal operation*	140	125	105–145.
Thickness ice belt plating	1	1	1⅝.
Frame spacing	24″	21″	16″.
Type of steel, hull plating	Medium carbon	Medium carbon	High tensile.
Propellers	Steel	Steel	Steel-built up type.
Cruising radius			30,000 miles at 12 knots.

NOTE.—*Dimensions in Feet Unless Stated Otherwise.*

TACTICAL EMPLOYMENT

Consult HO551 for recommended practice in the tactical employment of icebreakers. Remember the versatility of these ships with the assistance of helicopters and other aircraft serving as eyes of the ship. The following paragraphs have been taken almost verbatim from the *Report of Operation Highjump* and other reports which will serve briefly to introduce the subject of this section.

At all times during the transit of the antarctic pack the escorted ships (2 AKA, 1 AGC) were deployed in column with an icebreaker at the head. When two icebreakers were available and exercised command, one selected the leads and courses while the other attempted to straighten out all the curves and bends in the leader's path. If one of the ships of the convoy got stuck, due to inability to stay in the channel or due to collision with countermingling floes or cakes, the second icebreaker (when available) would im-

mediately proceed to break it out. The remainder of the convoy would proceed at slow speed, following the leading icebreaker, provided the first escorted ship was not the one involved.

It is important to emphasize the necessity for the leading icebreaker to break as straight a path through the ice as possible. If the broken ice channel has devious curves and zigzags in it, the larger ships astern will be unable to follow such a path without a great amount of backing and filling. In time, they will suffer damage by colliding with cakes of solid ice on either side of the relatively narrow channel, cause confusion to the ships astern, and probably cause them to back down hard, thus endangering their propellers and running the risk of ramming the ship ahead. The final result will be that one or more of the ships will become stuck, it will be a hard job for the icebreaker to free them, and invariably there will be a long delay for the convoy.

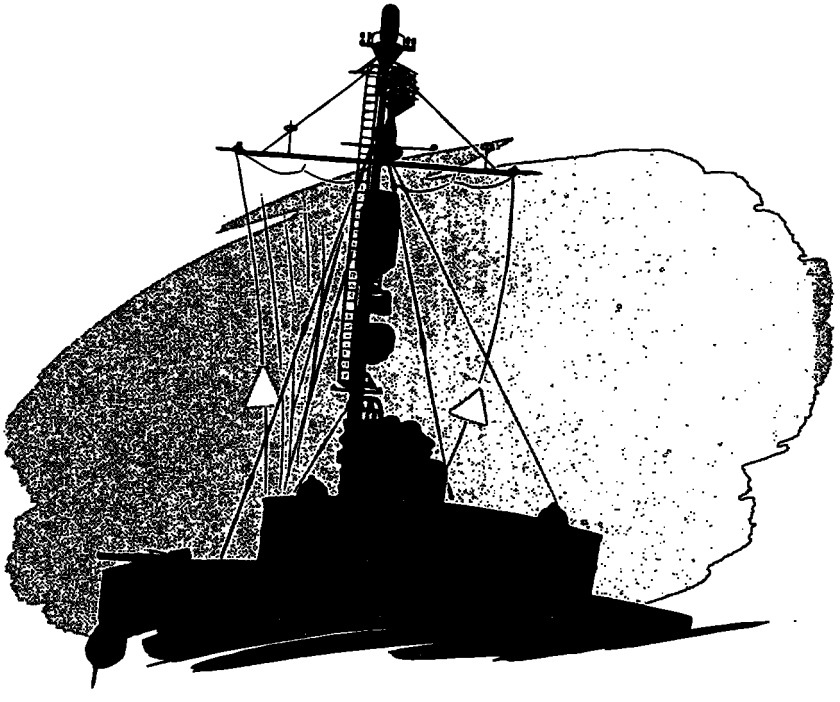


Figure 2–35.—Convoy speeds are normally controlled by speed cones aboard ice breakers.

SPEED THROUGH PACK ICE

Speed through pack ice depends on the character of the ice. It may be from dead slow in close or consolidated pack to 7 or 8 knots in drift ice or scattered rotten pack. On the average, speeds from 3 to 6 knots are employed except for periods of temporary besetment or of the necessarily slow and cautious movement in the heaviest pack. Normally the speed in an ice convoy is controlled by a speed cone from the icebreaker. The cone does not indicate the speed of the latter, but denotes the speed at which it is desired that the ships in the column steam. Speed of the convoy has to be closely controlled by the leading icebreaker, taking into account ice conditions ahead and the ability of the icebreaker to open up leads and maintain a straight—or reasonably straight—channel.

There is constant danger of collision between ships in column, particularly if ice resistance suddenly becomes heavy and following ships overrun, due to excess speed and their inability to kill their way where standard distance is small, as it must necessarily be in most cases. Under certain conditions, particularly in very heavy ice, it is sometimes more practicable for the leading unprotected ship to regulate the speed of the convoy.

It is mandatory that the ships of the convoy keep closed up. Standard distance will vary. Generally 3 or 4 ship lengths or a maximum of 400 yards will be satisfactory. When this distance is not maintained, the convoy will become unwieldy and invariably a stoppage will occur. This is true in areas of pressure ice or in event of cross winds. Remember that channels in pack ice close quickly, causing escorted ships to become scattered or stuck.

The *ice commodore* or officer in tactical command, who should be on the leading icebreaker, must carefully take into account ice conditions along the track. These are judged from reports of observations received from the crow's nest, helicopters, and long range reconnaissance aircraft. He should endeavor to select a generally straight track that will clear all heavy ice fields, hummocky pack, pressure ice, and bergs, floating in the pack. When stretches of heavy ice can not be avoided, he must maneuver the icebreaker so as to maintain course and avert glancing to one side or the other of the track. It is essential that the conner of the icebreaker station himself so that the wake of his ship is constantly in sight. Anticipation and forethought will do much to

allay difficulties. An icebreaker can charge through at high speed glancing from floe to floe without difficulty or damage, but the unprotected ships of the convoy cannot—and must not attempt to do so.

MOVEMENT OF ICE

The final point to consider is movement of the ice itself. Under the influence of wind (especially storms) and current, pack ice often has lateral movement which is most difficult to detect. Often, but not always, it takes the approximate direction of the wind. A course for the convoy should be set parallel to the axis of ice movement or as close thereto as possible. This will minimize the action of the lateral ice movement toward closing up the clear water channel in the wake of the ice breaker. During high winds it can be expected that even a consolidated pack, except in relatively narrow basins or channels, will become a mass of scattered cakes, growlers, bergs, bergy bits all countermingling violently and moving at varying speeds in the general direction toward which the wind blows. The convoy commodore, under these circumstances, must maintain such speed as will permit good maneuverability of all the ships. This may mean a much higher speed over the ground than ordinarily advisable in navigation amongst ice. However, there is no alternative except heaving to.

An icebreaker convoy must work closely as a team and promptly acknowledge and execute all orders received. Visual signalling and the TBS should be used freely to control maneuvering and operations of the group, as well as to keep adjacent ships advised of all changes in speed. Keep 24-inch searchlights ready for station keeping in event fog suddenly sets in.

Upon receiving word that one of the escorted ships is stuck, the convoy immediately stops, as a general rule. The ships not concerned attempt to stay in a maneuverable area, clear of heavy ice, and to maintain relative position in column. This procedure allows the convoy to resume speed quickly when the icebreaker and freed ship return to their positions in column. The ice breaker approaches the stuck ship from well abaft the beam, passing her close aboard. The breaker then backs down on the ship, breaking the ice in front of and to either side of the bow. Sometimes it is unnecessary to back down upon the bows, breaking the ice on one side being sufficient to free the ship. The icebreaker then goes ahead full speed, giving the ship benefit of the propeller wash to

Figure 2–36.—Taking a AKA in tow in pack ice.

clear cakes immediately ahead of it. The stuck ship now comes ahead slowly and generally should be able to follow in the wake of the icebreaker. In this operation of breaking out a ship, both the icebreaker and ship in trouble watch their counters for heavy cakes of ice being drawn under and possibly damaging propellers.

Towing is also used in breaking out ships. It was not too successful in the Antarctic with heavy ships because their bows are too high for towing with the short scope of towing cable that is required. When towing in pack ice, use a bridle; when towing in the open sea use a long scope of cable attached to the anchor chain rather than to a bridle. Figures 9–43 to 9–47, inclusive, illustrate procedure of taking in tow a heavy ship while in pack ice.

Figure 2–37.—Taking an AKA in tow in pack ice.

Figure 2–38.—Taking an AKA in tow in pack ice.

Figure 2–39.—Taking a strain.

Figure 2-40.—Taking an AKA in tow in pack ice.

While it is possible to determine to some extent favorable courses and leads by conning from the crow's nest and looking for signs of "water sky," these methods, though still useful, have been outmoded by helicopters and long-range "recco" aircraft. Accurate determination of the character, thickness, and composition of pack ice from the air well along the track is not possible except by use of helicopters. However, the situation at destination and beyond helicopter range can be determined only by long-range aircraft.

Another valuable type of ice reconnaissance is undertaken by the icebreaker. The convoy is left in a big clearing, or in a safe area of pack ice. If left in a clearing, the ships nose into the ice on the windward side of the clearing and keep their propellers turning over slowly. The icebreaker then proceeds in the most likely direction to determine first-hand the character and composition of the ice. When a lead is found, the ice-breaker returns and re-forms the convoy and proceeds in the direction found to be the most promising during its reconnaissance.

SUBMARINE OPERATIONS

In 1931, north of Spitsbergen, Sir Hubert Wilkins, in the *Nautilus*, made the first attempt to dive a submarine under pack ice. The U.S.S. *Atule* (SS403), in July 1946, succeeded in penetrating 1,000 yards under an ice field in Kane Basin, but suffered a collision between submerged pinnacles of ice and the periscope shears. The U.S.S. *Sennet* (SS408) accompanied the task force to Antarctica for *Operation Highjump* and was successful in following the convoy through heavy pack ice for a distance of over 100 miles. Rather than risk the danger of extensive damage, the submarine was escorted out of the pack and continued cold weather operations to the north. During August 1947, the U.S.S. *Boarfish* (SS327) maneuvered under the ice in shallow Chukchi Sea, northwest of Point Barrow, for a total of 10 hours in 3 dives, or a distance of about 30 miles. The U.S.S. *Carp* (SS338) successfully made vertical dives and ascents in big clearings or polynyas of the same sea during September 1948. This ship penetrated over 50 miles of scattered pack ice to the northern limit of the consolidated polar pack at latitude 72°10′ N.

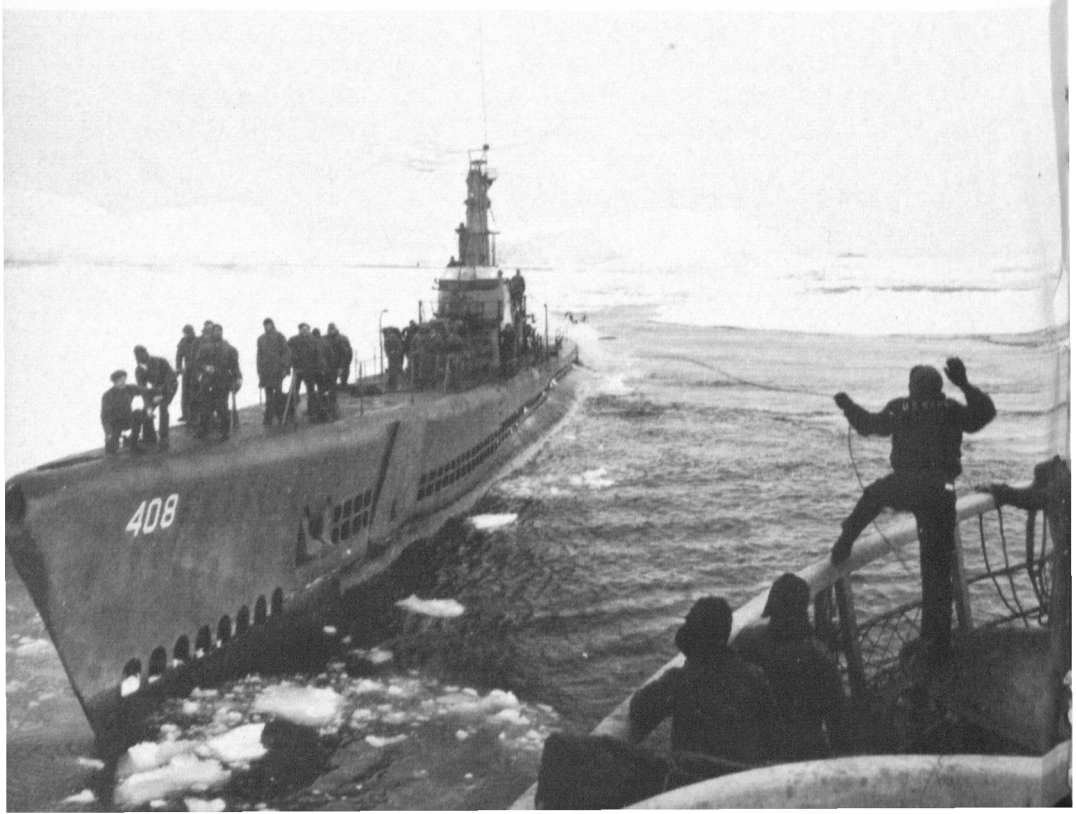
The foregoing are typical of exploratory submarine operations so far conducted in cold weather and arctic areas.

Many of the comments in other places in this handbook apply equally to submarines as to other classes of ships. Briefly set forth below are additional comments applying specifically to undersea operations. This information augments rather than supplants chapter 20 of USF 9—"Cold Weather Operations".

The Fathometer NK 7 and Scanning Sonar QLA-1 have been developed satisfactorily so that when used in conjunction they are capable of supplying information essential for short under-ice excursions and surfacings in scattered ice. The QLA-1 is capable of detecting small cakes of sea-ice from ranges of over 600 yards to its minimum performance range. It requires further improvement for extending its range.

In addition to development of improved sonar, there exist two major problems in operations of submarines in the high latitudes —namely, icing of hull and danger to rudder and propellers from collision with ice. One antidote to the former is periodic submergence to prevent building up of the ice, and to the latter, good seamanship and avoidance of areas of close or heavy pack ice.

Figure 2–41.—The sub Sennet in the Antarctic.



Conclusions that may be drawn from most recent operations of submarines in the high latitudes include:

1. Submarines can be readily adapted for polar operations and can *keep the sea* along the fringe of the polar pack as well as in areas of drift ice and scattered pack ice.
2. Extended under-ice navigation is practical with an efficient fathometer and scanning sonar.
3. Vertical dives and ascents can be made in open areas within pack ice.
4. Development of the trans-arctic submarine remains in the realm of fantasy.

DIVING AND SURFACING

A principal question in the study of under-ice navigation is the buoyancy control. Stationary dives and ascents are prerequisite for successful operations in ice areas. The study of this question was the purpose of the *Carp* patrol. The successful conclusion of the latter admits the practicability of submarine navigation in areas of the Arctic Sea. About 14 vertical dives and ascents were made by the *Carp*. The shiphandling was excellent and the diving procedure was well planned and executed. The water density

Figure 2–42.—Moving with caution.

structure, though complex, was fully recognized, and proper buoyancy changes were anticipated. The amount of sea room was small because of the ice overhead and the shallow bottom (140 feet).

Vertical dives and ascents were made by control of safety tank. Since this tank is centrally located, variations of its buoyancy did not disturb fore-and-aft trim. The venting of this tank produced a bubble screen which blanked out the sound gear. This difficulty can be prevented by inboard vents. The forward-aft trim was always very good, and it was interesting to note that second order shifts in trim were obtained by control of diving planes during ascents (e. g., forward planes thrown to extreme dive or rise to decrease surface normal to direction of motion). The procedure of stationary dives and ascents as concisely described by the commanding officer of the *Carp* is quoted below:

"Normal diving and surface procedure required revision while operating in the arctic ice-field as vertical ascents and descents were almost always mandatory. Diving procedure varied from that normally used, in that negative tank was only partially flooded (12,000 pounds) to prevent an excessive down angle. Submergence rate was controlled by the rate of blowing negative tank to its normal trim level of 6,000 pounds. In the case of the bubble, it was noticed by starting to blow safety slowly at 50 feet, the longitudinal stability was of sufficient force to prevent seesawing and the bubble could be controlled if the fore-and-aft trim was within limits of 1,000 pounds. At times a small bubble in safety tank was required to stop the descent so as to obtain a trim at the ordered depth. For ascending vertically, enough water was blown from safety tank to obtain a positive buoyancy of about 4,000 pounds. Since there was no means for blowing exact amounts from safety tank it was often necessary to reduce the rate of ascent by partially venting safety tank. The bubble was controlled by using the planes to increase or reduce the resistance to ascent on either the bow or the stern, as appropriate. The more rapid the rate of ascent, the more effective was this method of control of the bubble. The point at which safety was vented in order to stop at the desired depth depended upon the rate of ascent and depth of layer present. In ascending into layers of different density than the one in which the hovering trim had been obtained, while on the way up, enough water was pumped from or flooded into auxiliaries to give about 3,000 pounds negative buoyancy at the new depth. As soon as the rate of ascent was checked, this excess water was removed and a hovering trim was attained. The chief disadvantage in using safety tank was the necessary venting which blanked out the sonar gear. The time of venting safety and the time of needing information on the ice disposition nearly always coincided. A large inboard vent on safety tank or a small amidship tank of about 10,000 pounds located at the center of buoyancy which could be blown or vented inboard or in which the amount of water could be varied by a hydraulically operated water displacing piston would eliminate this condition by providing a more flexible means of depth control."

Procedure similar to that employed in mine fields has proven satisfactory for under-ice navigation. The commanding officer should remember the under surface of arctic pack is irregular and pinnacles of floes and ice fields may extend to depths of more than 100 feet.

The following is an almost verbatim report of the commanding officer, U.S.S. *Sennet*, made as a result of his experience in ship handling in the antarctic pack:

"Handling a submarine in an ice pack was an entirely new and different experience for everyone on board. Prior to the patrol, all available printed material on handling a ship in ice was studied. The best source of information seemed to be the translation of the Russian 'Instructions for Handling a Ship in Ice' (refer to Pilot Chart SA March, April, May 1947).

"In the following discussion it will be presupposed that a submarine will be operating in an area of growlers, brash ice, bergy bits, icebergs, and scattered pack ice without the aid of an icebreaker.

"The very first requisite of the embryonic ice pilot is to develop a healthy respect for the tremendous power of the ice. Never allow the peaceful appearance of an ice field to cause you to overestimate the safety and watertight integrity of the boat. On the other hand, do not fear the ice. A great deal of progress into ice can be made by a submarine capably handled.

"First of all, never hit a piece of ice, however small, which can be avoided—regardless of the amount of maneuvering necessary to miss it. It is necessary that well qualified men be stationed in the maneuvering room and at the helm when operating in an area in which more than brash ice and occasional growlers are encountered. The speed at which bells are answered or the rudder put over quite frequently determines whether ice is hit or avoided.

"The trim of the boat is another important consideration when operating in ice. Here the submarine has an advantage over all other types of ships. In pack, with ice extending more than 3 feet below the surface, it is recommended that the stern be trimmed down so that the propeller guards are at least a foot and a half below the surface of the water. This depth is necessary because the pack is indented at the waterline, sometimes as much as 5 feet. The purpose of the flooding down is to protect the propellers from damage by pushing the heavy pack clear of the screws. With the submarine trimmed in this manner, the top blades of the propellers are 10 feet below the surface of the water. It was found during the *Sennet* patrol that, except in close, heavy pack, 200 turns ahead and 133 turns astern could be made without damage to the propellers.

"It is presumed, of course, that a submarine which is to operate in pack ice will have propeller guards, even in wartime. It is also recommended that an additional brace be installed on the propeller guards from the forward outboard corner to a point about 10 feet forward on the hull. This additional brace is deemed necessary, not to give added strength to the present guards, which are considered sufficiently strong, but to streamline them and to prevent ice jams forward of the guards. In the latter case, it is possible that a small cake may duck under the guards and hit the propellers.

"The statement that the present guards are of sufficient strength is made in spite of the fact that the forward horizontal braces of both guards were bent considerably while the *Sennet* was being towed in heavy pack by the ice-breaker. The damage occurred when the boat's stern swung into a heavy floe at a speed that would have been inadvisable under her own power in such a pack. The present guards are considered strong enough to fend the boat off any flow with which she might collide at reasonable speeds. It is desired also to point out at this time that the present guards afforded adequate protection to the propellers while the ship was under its own power. The major damage to the propellers was done when the stern of the boat swung into heavy floes while the boat was being towed. From the above, it is evident that some of our major damage occurred while we were under tow; but, after having been nipped in the ice, it was the opinion of all hands that the most beautiful sight in the world at the time was the rear end of the Coast Guard Cutter *Northwind.*

"The propellers were nicked in several places, and their blades were bent. This damage was due, most probably, to small pieces of ice sliding below the propeller guards and hitting the "soft" bronze blades. To prevent similar damage, it is recommended that submarines designated for operations in pack ice be fitted with steel propellers, where practicable.

"Another reason for trimming the boat down by the stern was to raise the bow as high as possible, giving it more rake from the waterline to the keel. This condition made it possible to ride up on, instead of boring into, floes projecting not more than 3 feet above the water. The amount of punishment from the ice that the bow could absorb without damage was amazing. When the boat had cleared the pack, there was no damage to the bow, as far as could be determined by visual inspection from a rubber boat, from the point 18 inches above the waterline to the keel. Torpedoes were fired later without difficulty from both the forward and after tube nests.

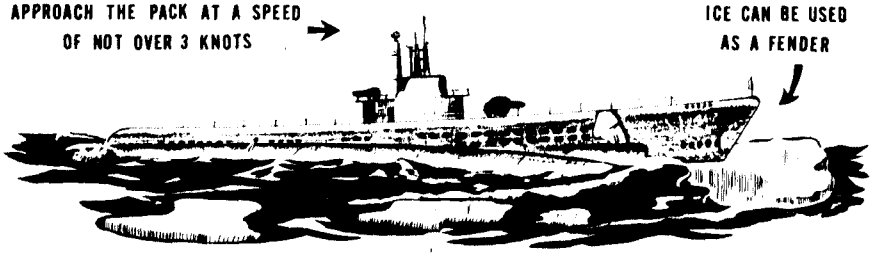


Figure 2–43.—Ice floes can be pushed ahead as a fender.

"A very minor point, but one which would undoubtedly be used to advantage many times in pack ice, is that a collection of small bits of ice around the propeller guards may be cleared very quickly by reversing the propellers.

"Always, when in a narrow lead, and especially when passing through a lead in a pressure ridge, keep way on the boat even at the expense of charging small floes. Once the boat is dead in the water, the ice will close in quickly and, before it is apparent, will nip the boat. It is particularly dangerous for a submarine to be caught in this manner in view of the fact that the ice will ride up over the tank tops, forcing the boat down. Although the *Sennet's* superstructure sustained several small casualties, such as rivets popping out, it is believed that the tanks and hull of a submarine will absorb a great deal of pressure before being damaged.

"When there is a choice of courses while proceeding through leads in relatively close pack ice, choose one as nearly as possible in the direction of the wind. This is recommended because it is believed that ice fields normally move in a direction 20 degrees to the left of the wind in the Antarctic and 20 degrees to the right of the wind in the Arctic. However, because of their small sail area, submarines do not find the problem of crosswinds as serious as do other types of ships.

"The submarine's maneuverability is also an advantage. By twisting, the submarine can easily execute the many turns required to conform to the leads in the pack.

"Should it become necessary to navigate through close pack made up of small floes, with the boat trimmed down by the stern, approach the pack at a speed of not over 3 knots. Use the rudder and engines freely to take the floes just off the stern. Stop engines after the boat has ridden up on a large floe and wait for it to break through. If the ice is too tough to be broken, go ahead slowly, pushing the floe ahead of the ship. Most of the time the floe will slide off to the side, but occasionally it will stay ahead of the ship for a considerable distance, acting as a fender for the entire ship.

"In conclusion, it is believed definitely that a submarine can operate independently without fear of damage in pack ice of less density than close, heavy pack."

MATERIEL—GENERAL NOTE

Torpedo runs in open cold water areas can be expected to be straight, hot, and normal. Gun mounts, if properly maintained, should operate satisfactorily under the extreme conditions that a submarine would encounter. Satisfactory performance of sonar and radar can be expected. In time, further improvements of the devices will enhance safety of navigation amongst scattered pack ice and under consolidated polar pack for short excursions if the tactical situation should require. Probably one of the most difficult materiel problems is control of condensation within the boat. Due to low sea water injection temperatures down to 28° F., it likely will be necessary to restrict flow of water to air conditioning heat exchangers to minimum safe extent.

COLD WEATHER BILL

The commanding officer should prepare a special cold weather bill to cover the general procedure that he desires be followed in accomplishing the mission assigned for operations in the Arctic. The following bill used by the *Carp* is suggested as a guide:

1. Sanitary tanks were blown and vented outboard once each watch.

2. All topside sonar and radar gear was worked out once each hour.

3. The low pressure blower was run at 2-hour intervals. During the blow-up, the main vents were cracked in succession.

4. Periscopes were stowed in a slightly raised position with their bearing surfaces just extending above the tops of the shears.

5. Both air conditioning plants were run continuously.

6. When possible, the main induction system was tested at 2-hour intervals.

7. Engines were drained when it was expected that they would be idle for more than 24 hours.

8. All engines were run for at least 15 minutes out of each 4-hour watch.

9. Before starting an engine, it was rolled for a full 3 minutes (with standby flushing oil).

10. A constant flow of compensating water was maintained at all times.

11. The conning tower hatch was checked and worked out once each hour.

TRAINING

Prior to departure from base for a polar expedition, training essential to successful accomplishment of the mission and the various assigned tasks should be planned and conducted.

The training should ensure smooth, continuous, and controlled rate of discharge of cargo at destination. Dangers inherent in cargo handling on shipboard and on the beaches should be stressed. All hands should be instructed in safety precautions and should be trained not to strive for speed or record breaking. Stress close supervision, precision, and careful handling of all materials and equipment. A rehearsal using dummy cargo should be conducted if time permits.

Personnel should be trained in the operation, winterization and handling of small craft, LVT's, weasels, weight lifting equipment and ship's cargo handling equipment.

A short refresher course in polar navigation for quartermasters and navigating officers should be scheduled during the loading phase or while en route to the area of operations. Officers of the deck, boat coxswains, and others should be instructed in ice seamanship and as many as possible should read and study *Manual of Ice Seamanship*, (HO 551). Boat crews, beachmaster unit, beach party, Seabee, and engineer detachments should be schooled in voice procedure and in the operation and care of portable radio equipments.

Personnel of the force who will be expected to assist with scientific projects or ice observations should be completely briefed as to their duties prior to arrival in the area.

En route to the area, all hands should be briefed on the operation and exercised in damage control, rescue operations, and emergency drills. Conduct flight operations with helicopters at every favorable opportunity.

Commandants of nearby naval districts should be advised well in advance as to available space for assignment of naval reservists desirous of cold weather and arctic training.

In case of submarine operations, the following training while en route to the area is recommended: 3 section dives daily with 1 deep submergence to obtain bathythermograph data; 1 surface and 1 submerged emergency drill daily; casualty and steering drills at unannounced times each watch; school-of-the-boat training program for indoctrination of all personnel in the particular operation. After arrival in the area, several vertical ascents should be conducted and a satisfactory procedure for diving and surfacing in restricted areas evolved. Training of operators in use of QLS sonar in scattered ice areas should be undertaken prior to attempting under-ice navigation.

MISCELLANEOUS AIDS

Mechanical and electronic navigational aids in the arctic regions are sparse. Radar techniques in ice navigation are not sufficiently developed to be absolutely dependable. It must be fully appreciated that older methods in navigation—direct observation of ice conditions, use of hand lead, caution during fog—are still the rule.

Data on work feasibility should be collected for areas of extreme

climate, both ashore and afloat, for guidance and for planning war operations in the high latitudes. From these data, work feasibility charts such as the one shown in chapter 8 of Part II can be prepared. A work feasibility chart is a plot for each month of the year, of data such as daylight hours, average ceiling, visibility, mean and extreme temperatures, average wind speed, and prevailing direction, range of wind chill factors, precipitation, ice situation, transportation, construction, water supply, and other factors that limit or influence the performance of work.

SUMMARY

Ship operations employing all types of naval craft can be conducted in various sea areas in the arctic and subarctic regions throughout the year.

By the use of modern, powerful icebreakers, the navigable season at many places can be extended.

Careful preparation and cautious seamanship are requisite to successful navigation amongst ice. Follow the rule of *safety first!*

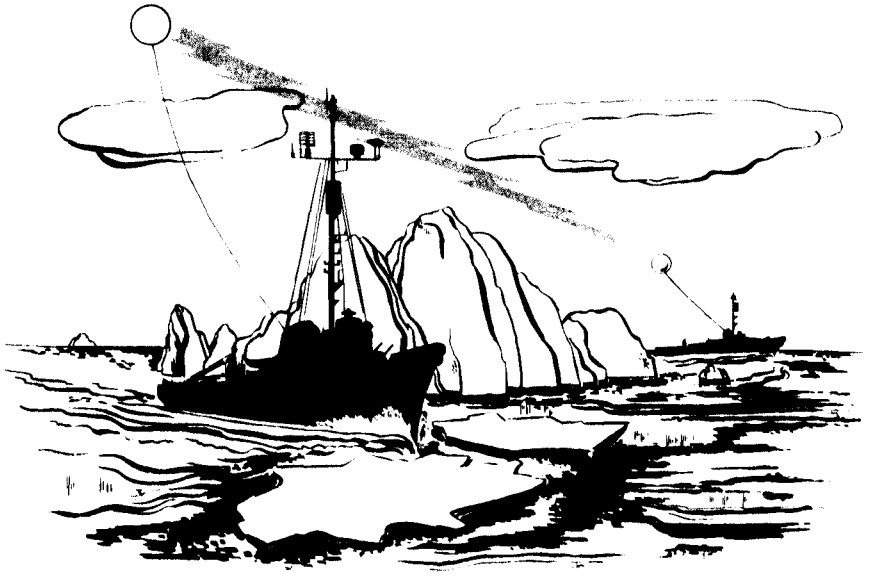
Accurate forecasts of weather are essential to the conduct of special operations in areas where strong winds are required for dispersal of pack ice to permit navigation even by icebreakers.

There are few differences between comparable operations conducted in the Arctic and in more temperate areas. Those that exist must be well known and steps taken to reduce the degree of the limitations imposed by them. The major problems are:

Protection of personnel against windchill.—Clothing must be warm, light, easy to put on and remove. It must permit freedom of movement. An efficient face mask to permit personnel to endure high winds at low temperatures is essential. Foot gear, hand gear and head gear must afford adequate protection to the extremities. An immersion suit which will ensure survival in event of abandon ship awaits development.

Prevention of formation of ice on flight deck, aircraft, ordnance, and other exposed equipment vital to the fighting efficiency.—There are two phases to the problem—retardation of formation and removal. The development of anti-icing and de-icing agents is required. The technique of using ice removal equipments is to be evolved during operations in the high latitudes.

Protection of hulls and fittings of ships against damage from ice as practicable.—"Remember, one has to be tireless to move a ship through ice."—Bartlett.



CHAPTER 3

COMMUNICATIONS

A large amount of the material published on high latitude communications is still controversial. Many anomalies exist and are not yet thoroughly understood. It should be realized, therefore, that the theories and practices outlined in this chapter should be considered only as an effort to acquaint the communication officer with some of the abnormal conditions which he may expect in the Arctic. Also included are some practices which have aided in overcoming these conditions and in maintaining rapid communications in these remote regions.

COMMUNICATION VAGARIES PECULIAR TO ARCTIC REGIONS

Abnormal conditions affecting radio communication in the Arctic likewise are encountered in the Antarctic. In general, the description of those conditions and suggested measures for maintaining reliable communications outlined in this chapter apply also to areas in the high southern latitudes.

Communication plans for operations in the Arctic will normally be the same as those used in temperate regions to cover similar

operations over equivalent distances. In the actual establishment and maintenance of communication circuits in some areas, however, arrangements must be made to provide for prevailing and possible rapid changing wave propagation characteristics not normally experienced in lower latitudes.

Much data on high latitude communication are incomplete and inconclusive. Some observations and conclusions are contradictory. From arctic research projects and past expeditions to the Arctic and Antarctic, it is certain that in some high northern and southern areas absorption of medium and high frequencies exceeding that at lower latitudes is present both day and night. Fadeouts on medium and high frequencies due to ionospheric disturbances are more frequent and remain for longer periods of time. High frequency propagation over long distances, even when normal conditions prevail, is, at times, extremely erratic, and usual practices for selection of optimum working frequencies are not always valid.

The shielding effects of mountains is particularly noticeable on all frequencies, and, in fiords or enclosed harbors, communication may be lost completely.

Transmission following the earth's magnetic field have greater range than those at right angles to it.

For example, in the Baffin Bay area and through the Northwest Passage to Melville Island, where the earth's magnetic field is heavily concentrated around the north magnetic polar area, one expedition found that in transmitting on a frequency of 4 MCS it was possible to work a distance of 1,200 miles while transmitting in the direction of the magnetic field. Using the same equipment and power, it was possible to work a distance of only 300 to 400 miles when the transmission path was at right angles to the field.

THE AURORAL ZONES

The northern auroral zone, so called because auroras are most frequently seen there, is a belt about 10° of latitude in width, located about 1,200 miles radially from a center near Etah, Greenland, at approximately 78°50′ N. 69° W. The belt passes very close to the whole north coast of Europe and Asia, dips down through Iceland and Alaska, and comes furthest south across Canada, through Iceland and Alaska, and comes furthest south across Canada, through Churchill on the Hudson Bay, at latitude 59° N. It should be noted that the auroral zone is about 24° further north in Siberia than it is in Canada.

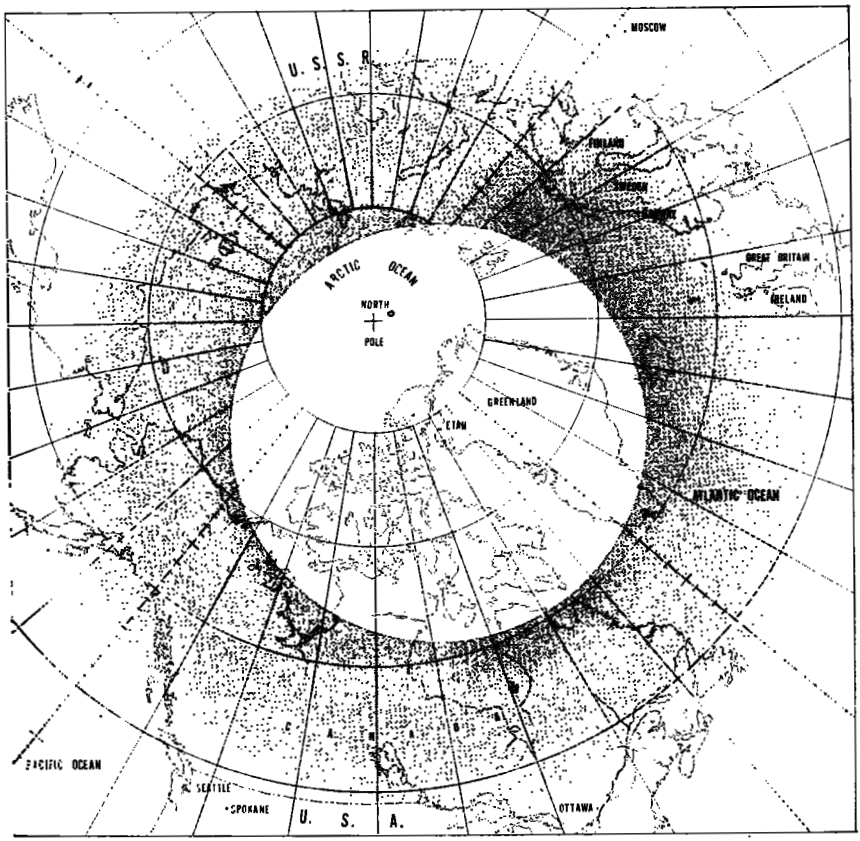


Figure 3–1.—The northern auroral zone.

A similar zone exists in the Antarctic, with its radial center around point 78°30′ S. and 111° E. but it passes south of uninhabited islands, extending furthest north to the south coast of Australia.

The earth's magnetic field, at distances well removed above the surface, is roughly that of a magnet at the earth's center oriented along the axis of the two auroral zones.

These zones are believed to be due to charged particles, possibly electrons, ejected from the sun. These particles, entering the earth's field, are deflected so that they tend to spiral down and around the lines of force, striking the ionosphere both night and day.

The visible effect of the particles striking the ionosphere is the

aurora, called Aurora Borealis in the northern hemisphere and Aurora Australis in the southern, and is seen directly overhead in the auroral zones. The frequency is such that auroras are seen nearly 100 percent of all clear, dark nights, and are maximum across the lower three-quarters of the belts. As one moves from the auroral zones toward either the geo-magnetic pole or toward the equator, auroras are seen less frequently.

During intense magnetic storms the auroras shift to lower latitudes, and with them shift the characteristic magnetic disturbances.

IONOSPHERIC DISTURBANCES

The most striking of anomalous ionospheric phenomena are ionospheric storms that are in no way associated with the meteorological storms of the Troposphere, but derive their names from the similar erratic character of both. They are one aspect of the electro-magnetic disturbance to which the earth is subjected which have been known a long time as *magnetic storms.*

When active solar areas develop into solar storms, there is an extra heavy bombardment of the ionosphere which produces great auroral displays accompanied by extreme instability of the ionospheric layers.

These storms result in disturbances of the earth's magnetic field which last from several hours to several days, during which the magnetic field fluctuates over much wider limits than normally. These fluctuations are not only marked by their magnitude, but also by their irregularity. Many storms begin with a sudden start which is within a few seconds of being simultaneous all over the earth. During the next few hours the horizontal component of the earth's magnetism remains above normal. This is called the *initial* or *positive* phase of the storm. Then the horizontal force drops rapidly to well below a normal value. This is called the *main* or *negative* phase. Recovery continues for the next few days in what is known as the post-perturbation periods. The most violent and erratic changes occur in shifting from the positive to the negative phase. The field changes are such as might be compared roughly to a ring current circling the earth at a distance of several thousand kilometres above the surface, flowing first in one direction (*positive*) and then in the other (*negative*).

While the effects of severe storms on communications are felt in all latitudes, the most erratic changes take place, and last longer, in the auroral zones.

Figure 3-2.—Magnetic storm warnings are broadcast by Station WWV and by major United States Navy radio stations.

The close relationship between magnetic storms and sunspots has been very well established. A tendency of the storms to recur at about 27-day intervals has also been established, as has the fact that magnetic storms occur in about 50 percent of the cases within a day or two of the time when an active sunspot group passes the center meridian of the sun.

These principles furnish the basis for prediction of ionospheric storms, and because during the early phases of some storms communications are not greatly affected, it is sometimes possible to warn radio operators several hours in advance as to when the disturbances are likely to occur, although the intensity and duration of the storms cannot be predicted.

Warnings are broadcast by Station WWV, Bureau of Standards, Washington D. C. in connection with time signal broadcasts and by major U. S. Navy radio stations. Arrangements should be made to copy these broadcasts or receive the information otherwise while operating in the Arctic.

EFFECTS OF IONOSPHERIC DISTURBANCES ON COMMUNICATIONS

The effects of an ionospheric storm on high frequency communication is manifest somewhat as follows:

First, flutter fading becomes extreme and the maximum usable frequency decreases. The turbulence produces erratic propaga-

tion deviation from the normal great circle paths, which may cause wide diversion in direction finder bearings. In a few minutes, as the disturbance penetrates the lower ionospheric levels, absorption increases sharply, blacking out higher and higher frequencies. As the maximum usable frequency drops, the lower useful high frequency rises, with the result that the entire band of useful frequencies may disappear. This condition of black-out may last a few minutes, a day, or several days, and may seriously disturb world communication systems, both wire and radio.

Instances have been recorded in the auroral zone of loss of communication on the higher frequencies for a period of 2 weeks, during which time the only signals heard were local, and low and very low frequency transmissions from Washington, San Francisco, Honolulu, and Halifax. Recovery to normal conditions may be fastest on the lower high frequencies, but black-outs on medium frequencies below 2 MCS may last for several days. At times, however, frequencies much higher than customarily useful may be useful during initial recovery.

Propagation on frequencies below 200 KCS may actually improve during black-outs. This is attributed to the fact that during the auroral storms the density of the lowest ionospheric layer is greatly increased. While this layer acts as an absorbant for the higher frequencies, it becomes a very good reflector for the lower frequencies, so that in effect, a wave guide is formed between the layer and the earth which aids in extending the range of low frequency transmissions.

As an ionospheric storm develops, there is an actual shift of the entire auroral belt toward the equator. Consequently, in a severe storm communications may actually improve over paths on the polar side of the zone while they may be seriously interrupted as much as 20° from the latitude of maximum auroral activity. For this reason, transmission between North America and Europe, which follows great circle paths and is reflected by the ionosphere in high latitudes, is frequently disrupted by electro-magnetic storms. Frequently, communications can be maintained at such times by relaying traffic through low latitude stations which are less subject to disturbances.

MAINTAINING COMMUNICATIONS IN HIGH LATITUDES

Hard and fast rules for maintaining communications cannot be laid down: As in any latitude, thorough preparation, indoctrination, and ingenuity are the important factors. From ex-

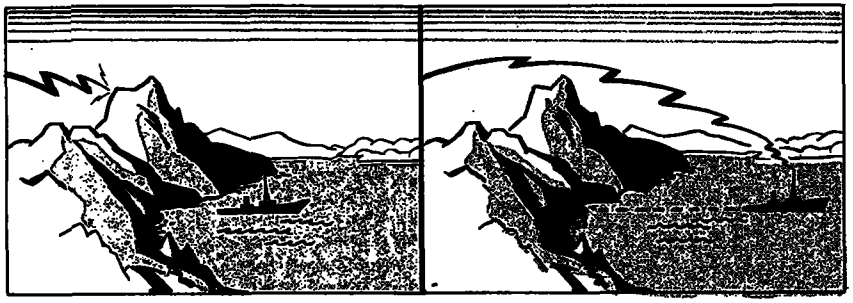


Figure 3–3.—Mountains, fiords, interfere with signal strength.

perience gained on several expeditions some observations, perhaps inconclusive, contained in communication reports herein collated should serve as a guide for assuring optimum continuity of communication.

Communication planning for high latitude operations should be based on consideration of the following known factors:

1. In the auroral zones, absorption of radio waves is normally high at night as well as in day, especially on the lower high frequencies, resulting in high lowest useful frequencies.

2. The zones are characterized by extreme variability, due to the frequency of ionospheric disturbances.

3. Any communication circuit which lies within the zone, or touches it at any point, is affected by the abnormal absorption and is susceptible to disruption during ionospheric storms.

4. During periods of these disturbances high frequency circuits, except for those within a few hundred miles radius, may, with little warning, blackout completely and remain so for periods of from a few minutes to several weeks, or be characterized by extreme instability during such periods.

5. Very low frequency transmissions (10–30 KCS) originating outside auroral zones are not appreciably affected at receiving points across or within the auroral zones.

6. Low frequency transmission on frequencies lower than 200 KCS appear to offer the best means of maintaining communication during black-out periods.

7. Long range high frequency circuits (1,500 to 3,000 miles) to points outside, even in *quiet* periods in the auroral zones, are at times very erratic, due to a rapidly varying effective frequency for the distance and direction involved.

8. The shielding effect of mountain ranges are particularly noticeable, and, in fiords or enclosed harbors, signal strength may decrease to such an extent as to necessitate the ship proceeding to open water in order to reestablish communication.

9. Some evidence exists that VHF/UHF ranges are extended in the auroral zones, both normally and during periods of disturbance, although reports of several naval expeditions do not support that contention.

PREPARATIONS

Before departure for high latitude operations, radio equipment in excess of normal type allowances, if required, should be installed, and all radio equipment thoroughly checked. Spare parts should be carefully inventoried and an additional stock of the most vital items obtained. Communication facilities for high latitude operation should certainly include a transmitter with a high frequency operating range of at least 26 MCS and another that will operate on frequencies as low as 175 or 195 KCS. Both transmitters should have substantial power capabilities.

ROB *Registered Publications* should be carried in sufficient supply to last for the length of possible stay in the Arctic.

Combined crypto systems for communication with friendly foreign governments should be included in the *Registered Publication* allowance on board.

Publications relating to high latitude communications not normally carried aboard United States naval ships should be obtained. (Some recommended publications are listed later in this chapter.)

All transmitters and receivers should be calibrated on the various frequencies which might be used in order to afford the most flexible operation possible.

To capitalize on the advantages of low frequency operation and very low frequency reception during black-out periods, antenna systems in addition to those installed probably will be required.

The standard shipboard low frequency transmitter required for high latitude operations usually covers down to 175 or 195 KCS, depending on the model. At the lower end of the range, the radiated power obtained may be very small, being somewhat in the order of 0.6 percent to 1.5 percent of the rated output power. This is caused by inability to properly load the antenna because of its small physical size. Radiation is further decreased by the necessarily short vertical section of the antenna, upon which radiation depends. Optimum radiation with current shipboard an-

tennas is usually realized at around 500 KCS, and effective radiation decreases as the operating frequency is decreased.

It has been found, too, in operating the low frequency transmitter at frequencies in its lower range at substantial power (1–2 KW), using standard shipboard antennas, that severe arc-overs and large losses in antenna trunks will be experienced.

That these important lower frequencies may be utilized during periods of ionospheric disturbances, procedures should be worked out for installing temporary transmitting antennas of the greatest length and height practicable. The possibility of paralleling or placing existing antennas in series should not be overlooked, nor should provisions for emergency use of a balloon suspension of long wire to obtain more effective antenna.

The Kytoon, which is a helium filled kite-balloon, has been evaluated by the Operational Development Force and recommended as a practical emergency system for suspending sufficient wire to permit greatly improved communications on low frequencies. Communication has been established between ships using the Kytoon, on 195 KCS, over distances across which it was impossible to communicate when using conventional shipboard antennas.

Sound communication planning, therefore, should include procurement of and familiarization with the technique of using Kytoon or comparable suspended antenna systems. Such alterations to antennas, trunks, and coupling devices as approved or recommended by the Bureau of Ships should be effected before sailing. Standard aeronautical balloons have been used for suspending antennas with some success where Kytoons were not available.

Operating personnel should be thoroughly familiarized with any emergency antenna system to be employed, and the capabilities and limitations of the system should be established by experimentation before its use is mandatory.

A list of all fixed radio stations in the general operating area, with their position, call signs, and working frequencies indicated, should be prepared and made available to operating personnel by posting in radio rooms and communication offices. Mobile stations in the area should be similarly listed and kept up to date. In the event of disruption of normal communications, relaying through such stations might provide the only means for clearing traffic.

Several alternate working frequencies with considerable spread in the spectrum should be designated, and definite arrangements made with working stations as soon as communication is established, to shift to various alternates at pre-arranged times, should

communication be lost on one frequency. During magnetic or ionospheric storms, frequent shifting of frequencies will be necessary. Therefore, operators should be thoroughly drilled in rapid tuning of transmitters and receivers, as well as in anticipating shifts by means of stand-by equipment.

In arctic operations, a considerable portion of communications may be with U. S. Air Force, U. S. Army, British, and Canadian stations, including aircraft of these services. Operating personnel should be thoroughly familiar with joint, combined, and commercial operating procedures.

In operations in and around mountainous regions VHF/UHF circuits with aircraft should be paralleled with higher medium frequency circuits, even on local flights.

On long distance circuits the practice of keying two or more transmitters simultaneously on widely divergent frequencies has been found to facilitate communications, and procedures should be worked out in advance for so doing.

Because of erratic propagation, it may be necessary for a flagship to operate two separate circuits to task group commanders, each on a different frequency with separate operators, whereas ordinarily in other regions a single circuit would suffice. This point should be taken into consideration when setting up personnel and equipment allowances.

PUBLICATIONS

In addition to the normal allowance of registered and non-registered publications carried, the publications listed below are considered indispensable for the efficient conduct of communications in high latitudes. They should be included in the library of ships operating in those areas. They are:

1. Berne List (corrected).
2. HO 205—U. S. Hydrographic Office—*Radio Aids to Navigation.*
3. Ionospheric Radio Propagation Circular 462—National Bureau of Standards, Washington, D. C.
4. Basic Radio Propagation—U. S. Navy—DNC 13-1 ( ).
5. Equi-distant Chart of the World centered on the U. S. No. ZD-10 with bearing and distance.
6. Nomagram No. ZD10-N—U. S. Coast and Geodetic Survey, Washington, D. C.
7. U. S. Air Force Radio Facility Charts, North Pacific Area.
8. U. S. Air Force Radio Facility Chart, North Atlantic Area.

(These charts are published monthly and may be obtained directly from Commanding Officer, 1917th AACS Squadron, Westover Air Force Base, Mass.)

9. *AACS Communication Planning Chart No. 3, North Pacific Area.

10. *AACS Communication Planning Chart No. 6, North Atlantic Area.

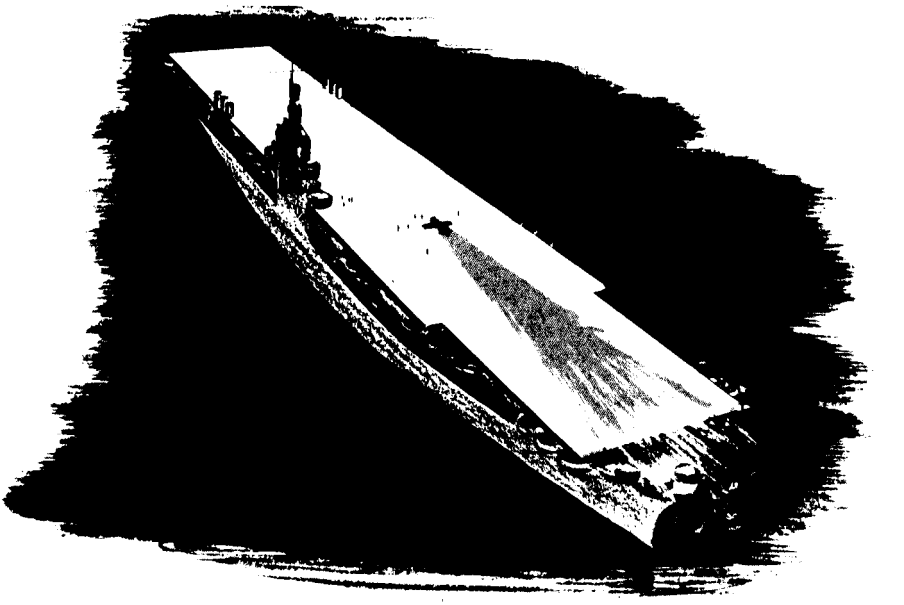
11. *(May be obtained from Commander Military Air Transport Service, Andrews Air Base, Md.)

SUMMARY

High frequency transmissions are often completely blacked out in the polar regions. Very low frequency and low frequency circuits offer the best means of maintaining communication during periods of ionospheric disturbances. By development of a flexible communication plan and by provision of radio equipment covering the usable portions of the frequency spectrum, rapid communications can be maintained with a fair degree of reliability.

Reports of previous expeditions should be carefully studied by personnel charged with the various phases of communications prior to departure for a polar region. Every effort should be made to anticipate operational and material problems that most assuredly will arise.

Blank page retained for pagination



CHAPTER 4

CARE AND OPERATION BUREAU OF SHIPS MATERIAL

"Know every inch of the ship inside and out."—Peary.

Special climatic and other environmental conditions which will affect shipboard material and equipment during arctic and cold-weather operations may be broadly stated as follows:

1. Low surface air temperatures.
2. Sudden changes in air temperature.
3. High winds.
4. Low sea-water injection temperatures.
5. Low humidity.
6. Ice conditions varying from a mixture of slush and drift ice to solid pack.
7. Snow, sleet, or freezing rain.
8. Heavy seas with attendant spray.
9. Abnormal magnetic conditions.

Except that low humidity is a deterrent to corrosion, the general effect of the above conditions on the care and operation of ship-

board material and equipment is adverse. Operations under these conditions require careful planning, preparation, and the institution of suitable precautionary measures prior to and during the time spent in arctic and cold-weather areas.

The necessity for thorough preparation for such operations must be emphasized. Careful attention to all details, complete familiarity with the ship and her equipment, and painstaking inspection to ensure proper material condition prior to departure are essential. For satisfactory performance of the ship and ship's equipage, such material preparation must be coupled with good seamanship and expert ship handling, with due recognition of the limitations of the particular ship or ships involved, with due respect for the conditions of sea, ice, and weather to be encountered, and with the exercise of good judgment and sound engineering and maintenance practices at all times.

SHIPS EQUIPAGE AND MACHINERY

TOPSIDE OR EXPOSED MACHINERY AND EQUIPMENT

Deck machinery and topside or exposed electric motors or motors in unheated compartments along with their driven auxiliaries should be lubricated with suitable low-temperature lubricants in accordance with existing instructions for the particular equipment involved. In general, Navy Department Specification 14G10 grease is suitable for grease lubricated bearings and Universal Gear Lubricant, A2-105, Grade 80 oil should be used in gear casings. For other lubrication, where an oil is required, Navy Symbol (NS) 2135 is suitable for general use.

BuOrd specification 51F21 hydraulic fluid should be used in hydraulic power transmissions (variable delivery pumps and motors). Correct lubrication of the driven auxiliary is of the utmost importance, particularly when electrically driven, for no matter how well the motor itself is lubricated, the motor will be slow in coming up to speed if the driven auxiliary is stiff. The current taken by the motor will be large until the motor comes up to speed. Thus the conductors will be very rapidly heated by the current, which may be detrimental to the motor insulation.

Canvas covers provided for deck winches and similar appliances should be kept securely in place except when the equipment is in use or undergoing inspection, warm-up, or test. Under freezing or icing conditions, covers on essential equipment should be in-

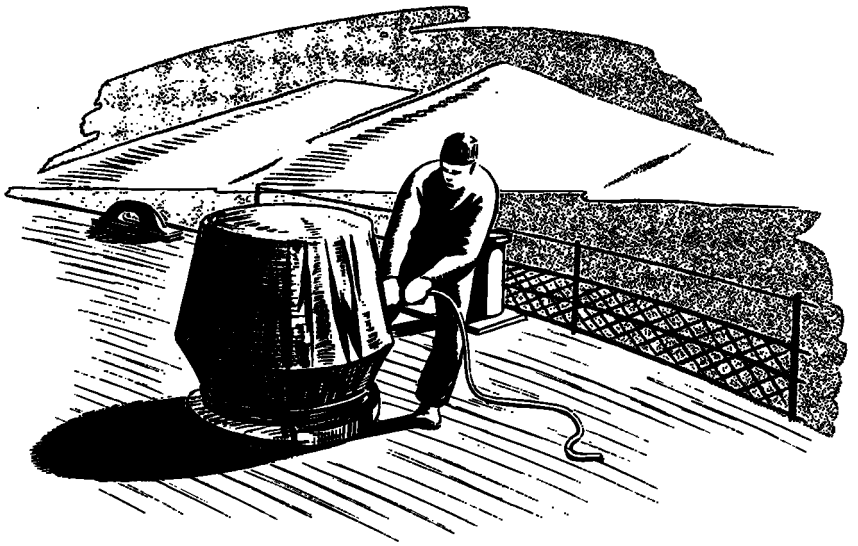


Figure 4–1.—Keep winch covers securely in place.

spected frequently, any accumulated ice removed, and lashings or other securing devices freed-up to ensure that the equipment may be put into operation in the minimum time when needed.

Exposed machinery should be inspected daily, and more frequently under severe icing conditions. Other vital equipment not otherwise protected should be kept freed of accumulated ice insofar as practicable. Care should be taken to avoid damage to the equipment when removing ice. Prior to operation, a check should be made to ensure that there are no lumps of ice which may foul moving parts. When practicable, the equipment should be turned over by hand or jacked prior to operation by power.

It is also necessary to see that any ice formation is removed from certain structural or rigging parts prior to operation of the auxiliary. This applies especially to wire-rope sheaves and guides, trackway rollers and rotating portions of cranes. Steam deck machinery should be operated daily in extremely cold weather and, when conditions necessitate, essential steam capstans and winches may be kept ready for instant use by warming up and turning over at slow speed, taking care that they are not permitted to stop. Steam deck machinery should be given careful attention to prevent clogging with ice, and all condensed water should be drained out immediately after use.

For electric driven apparatus it is not considered advisable to start the motor and run the equipment simply for purposes of warming up or testing. The effect of a warm-up will soon disappear unless the warm-up is continued for a considerable period of time and repeated at frequent intervals. Unnecessary starting of the motor imposes a strain upon the insulation because of the expansion and contraction resulting from heating and cooling. Under emergency conditions, however, electric motors may be warmed-up and kept in operation as necessary and dictated by the circumstances prevailing at the time. A number of motor controllers in exposed locations, such as controllers for unit winches and boat davits, are provided with a heater inside the controller enclosure. Such controllers should be inspected daily to make sure that the heaters are operating.

Where the arrangements permit, space or unit heaters can be used to advantage in warming up hydraulic fluids and lubricants prior to operation. Hydraulic transmissions should be operated with pumps on zero stroke until the hydraulic oil has been at least partially warmed. Should freezing of the hydraulic fluid occur at low temperatures, the equipment will not run and attempts to operate the equipment may seriously damage the electric motor. If the starter button is pushed and the motor does not start to turn over, power should be turned off immediately and the condition of the fluid checked.

Figure 4–2.—Caution will prevent breath freezing telephone transmitters.

Some types of equipment, such as directors and anti-aircraft guns, receive electric power through flexible electric cables which may be exposed to low temperatures. Such equipment should be used to the minimum extent practicable when the temperature is below minus 10° F. When it must be used, every effort should be made to use the equipment in such a way as to twist or flex the cables to the minimum extent practicable.

In using telephones or microphones in exposed locations care should be exercised to prevent the talker's breath from freezing up the transmitter. Certain microphones in shipboard announcing system transmitter stations are or have been converted to the close talking or anti-feed back type. These microphones have smaller holes in the disc than do those not having this feature. If proper operation is prevented by ice formation in these small holes, the disc containing these holes should be removed and the amplifier gain reduced slightly to compensate. In general, the use of portable microphones supplied with the transmitter station in protected spaces is preferred to the use of the microphones in the exposed transmitter station.

Magnetic-minesweeping gear should be kept free of ice. Magnetic-minesweeping cable should be warmed by the best available means before being streamed. Magnetic-minesweeping operations in drift ice areas should be kept to the essential minimum and such care as practicable should be exercised to prevent the ice from cutting the magnetic cable. Motor driven acoustic-minesweeping gear when not in use should be given heated, inside stowage, if available. If such stowage is not available, deck stowage under canvas cover, heated by portable heater, is satisfactory. After streaming, the gear should remain in the water for 2 hours for temperature adjustment prior to operation.

PIPING SYSTEMS, TANKS AND RELATED EQUIPMENT

Main drainage pumps, electric submersible pumps and auxiliary pumps should be maintained in the optimum operating condition and should be tested at least weekly. Hose, and suction hose in particular, should be inspected periodically and maintained in good condition. Bilge well suctions should be inspected as practicable to ensure against clogging, fouling with debris, or freezing. Frequent instruction and drill should be held in the operation of the main drainage system. All overboard drainage and relief valve discharge lines that terminate above the water line should

be inspected daily, and more frequently as practicable and necessary, to insure that they are ice-free.

Fresh-water tanks should not be filled to over 90 percent capacity, to allow for expansion in the event of possible freezing. Potable water should be taken from forward tanks, such as peak tanks, first, due to the greater probability of leaks developing in these tanks from subsequent contacts with ice.

Any occasion for transferring fuel oil from one tank to another should be anticipated by an interval sufficient to permit adequate heating of the oil prior to such transfer. Fuel oil tanks should be kept warmed-up when operating under conditions or circumstances which may require fueling at sea on short notice. Oil filling and fuel oil transfer at sea should follow the standard practice outlined in USF 83. The average temperature requirement will be about 90° F. Steps should be taken to prevent formation of ice in transfer hoses.

FIRE FIGHTING EQUIPMENT

Special and detailed measures to be taken in connection with the firemain system in below-freezing temperatures will depend upon the arrangement of this system, and its relative complexity or simplicity, on the particular ship involved. Such measures as are taken should be carefully studied, and the modified procedures which are thereby required for the emergency use of the system should be rehearsed in fire fighting drills. In general, sections of the firemain which are exposed to the weather or run through unheated compartments should be completely drained and maintained in a dry condition when temperatures are below freezing. For ships on which the arrangements permit and warrant, secure firemain cut-out valves on firemain risers to weather decks and drain plugs at lowest point between riser and plug; leave weather-deck fire plugs in the open position when their risers have been drained and secured from below decks.

For ships having a more complex system, as aircraft carriers, the extent to which the above or other suitable measures can be taken will depend upon the detailed arrangements in any particular case. Fire hose and the locations in which they can be taken and nozzles should be stowed on racks and fittings provided and should be completely dry prior to such stowage. Nozzles should be stowed with shut-off gates in the open position. Cans of foam, proportioners, and P–500 and handy billy pumps should be stowed

in heated compartments with access as close as practicable to weather-deck location of probable use. Oxygen breathing apparatus, together with spare canisters, should likewise be stowed in heated compartments.

Fire hoses and nozzles will perform satisfactorily at freezing temperatures, and below, provided the water is kept flowing and a good pressure is maintained. If the pressure is reduced or the hose is secured the nozzle and plug may become frozen. If a long lead of hose is to be secured at temperatures below 10° F., stop and flow only for the time necessary to disconnect each length of hose. After securing, hoses and nozzles should be taken below decks and completely dried prior to returning to topside stowages. Duplex proportioners should be drained after use, dismantled, dried, oiled, and the chamber change-over valves reassembled. Foam, P–500 and handy billy pumps, and oxygen breathing apparatus and spare canisters for same should be returned to below decks stowage as soon as no longer needed.

Portable gasoline engine driven fire pumps should be lubricated with cold weather lubricants, and should be given test runs of approximately one-half hour's duration at least twice weekly. When operating in below-freezing temperatures, a tarpaulin should be thrown over the pump to retain sufficient engine heat to prevent freezing of water in pressure gages and control piping.

RIGGING AND ANCHOR GEAR

The provisions of the *Bureau of Ships Manual*, chapter 17, sections 23 to 27, inclusive, and chapter 18, in regard to booms and rigging, are particularly pertinent in connection with the preparation for and conduct of cold weather operations. Due to the abnormal conditions, rough weather, and possible icing conditions under which rigging, boat-handling gear, and burtoning gear may be required to operate, these items should be placed and maintained in the best possible condition. Mooring lines should be kept dry by stowing below decks or under canvas. Rigging should be protected with a light grease coating and running rigging that can reasonably be covered should be provided with canvas covers. Essential rigging or rigging that may be required for emergency use should be kept as ice-free as practicable at all times with particular care to remove lumps or collection of ice that would foul or damage blocks or sheaves.

Should circumstances indicate a possible need for ground tackle, the anchor detail should be stationed well in advance, with time

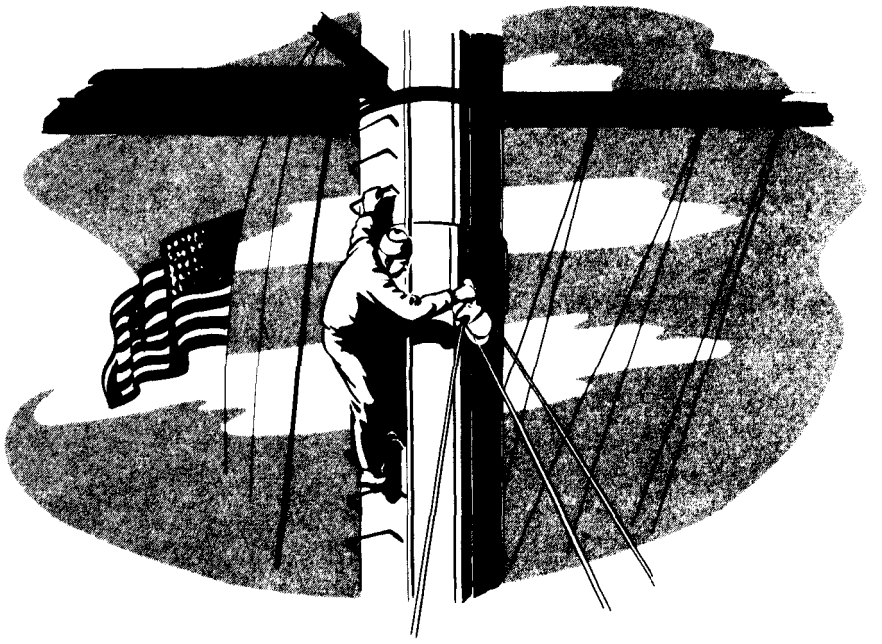


Figure 4–3.—A light grease covering will prevent icing.

to free the chain, stoppers, and wildcats of ice with mallets, scrapers, or other suitable tools. The anchor engine should be warmed up well in advance, and the chain worked back and forth to free the chain and hawse of ice and ensure that the anchor will let go upon release. When on soundings under icing or freezing conditions, a watch should be set and the anchor kept ready for instant use by such of the above measures as may be necessary.

BOATS

Boats should be hauled out and drained when not in use, and boat interiors, particularly bilges and engine compartment, kept as dry as practicable. Boat covers, where available, should be kept in place. Lacking better protection, the engine box should be covered with a small paulin under icing conditions.

Fresh water cooling systems should have antifreeze compound (glycol type, Navy Department Specification 51C39a) added to give protection against the lowest expected temperature. Salt water systems should be checked and, if necessary, petcocks installed at the low points to permit complete drainage of the sys-

tem. If the boat is equipped with a sand strainer, the strainer basket should be removed from one section and water taken through this section when temperatures are freezing or below. For prolonged operations in the Arctic, it may be advisable to remove the entire sandtrap and install as straight a run of pipe as practicable instead.

For ease in starting, artificial means of heating the engine should be used when temperatures fall below 20° F. Glow plugs, flame primers, and associated equipment must be kept in the best condition. Starters and generators should be checked and brushes renewed if worn. Batteries should be kept fully charged and specific gravity raised to 1.280 to increase output (refer *Bureau of Ships Manual*, chapter 62, section II, paragraph 267(4)). Engine and transmission oils in grades specified for arctic service should be used. Care must be taken to avoid grounds in the battery cables when the boat is not in use. If the boat is to be out of service for some time, it is advisable to disconnect the cables at the battery terminals and recharge the battery periodically to maintain it at peak capacity.

MACHINERY PLANT

Regulation of the cooling water temperatures requires special attention during cold weather operations. Since cooling water inlet temperatures may be greatly reduced, special care should be taken to provide cooling water at reduced rates or, if the ship is so equipped, to recirculate the hot discharge water to the inlet chest. Careful observation should be made for any incipient slush formation, and strainers should be cleared as practicable in order to keep the system in operating condition and prevent the cooling water lines from becoming sluggish and clogged with ice. If icing of condenser tube sheets occurs and restricts cooling water to an extent where operation is impaired, the steaming out connection on the inlet scoop should be used. Reducing the flow of inlet water and mixing steam may free the tube sheets of ice. However, caution should be observed against the excessive consumption of fresh water which continuous use of this process may entail.

Prior to starting up, lubricating oil in sump tanks should be heated to the recommended starting temperature or as near thereto as possible. Means are provided for heating this oil by the purifier heater, by steam connections on lubricating oil coolers, and by other means. When lubricating oil system is in operation, the

flow of water through the cooler should be controlled to keep the oil temperature within specified limits.

Normally machinery spaces will be manned and kept above freezing temperatures. If for any reason a space in which machinery or equipment is installed is secured and temperatures allowed to drop below freezing, water coolers and similar equipment should be completely drained or antifreeze solutions used.

VENTILATION AND HEATING

Ventilation heater controls should be adjusted to maintain space temperatures of 66°–69° F. in lieu of 72°–80° F. This will minimize the drying effect in living compartments since the relative humidity of the compartment air will be greater at the lower space temperatures than at the higher. It will also reduce the temperature differential for personnel going to and from topside or exposed locations. To avoid freezing of ventilation heaters, it is essential that condensate lines are kept open and that traps are at all times in proper operating condition. Machinery space ventilation fans should be operated to give a slight positive pressure within the area. This will avoid creating drafts through the ship proper and will conserve the heat in the interior of the ship. All living space ventilation supply fans should be operated on low speed to reduce the amount of outside air taken into the ship. Systems have been designed to give optimum conditions at low speed. Exhaust fans for washrooms and water closets, galleys, sculleries, and similar spaces should be kept running at all times for the proper removal of odors, fumes, and water vapor.

To ensure that blowers are operated at low speed, that thermostats are not tampered with, and that thermostatic traps or preheaters are operative, it is suggested that a heating patrol be established as a part of each watch. This procedure is particularly recommended for large ships engaged in low temperature operations.

BATTERIES

Dry batteries to be used in equipment subjected to exposure to temperatures below 0° F. should be of the low temperature types designated in Specification JAN–B–18A under battery type numbers 2000 through 2999. Thus ordinary BA–38 batteries should be replaced by BA–2038 batteries. As the low temperature batteries are more expensive and do not have as good shelf life as the ordinary batteries, they should not be used except in the cir-

cumstances specified in the first sentence of this section. Present stocks are not large and orders should be placed through ESO Great Lakes as much in advance of need as possible. The low temperature batteries should be stored in a refrigerated space aboard ship.

Particular care must be exercised to keep all lead-acid storage batteries fully charged when operating under cold weather conditions. Articles 62–262(2), 62–267(4), 62–267(5), 62–269(1), 62–269(2) and 62–269(3) of the *Bureau of Ships Manual* pertain particularly to the handling, storage, and maintenance of storage batteries under cold weather conditions. Although article 62–269 deals specifically with carboys of acid, the pertinent information therein is equally applicable to the acid contained in the storage batteries.

LAUNDRY

In arctic and cold-weather operations, the laundry may handle a considerable amount of woolen and part-woolen clothing, such as underwear. Emphasis is placed on the following important points in laundering woolen. These points are applicable with either low-titerbuilt soap or saltwater soap. Wool should be washed at constant tapwater temperature in 5 minute suds and 3-minute rinses, at high water levels. The wheel must be stopped when draining or filling. A heavy suds should be built up in the wheel before adding the clothes on the first bath. No bleach or additional alkali is needed with woolens.

In no case should live steam be introduced into the wheel. A short formula is necessary to reduce the possibility of shrinkage from too much mechanical action. Woolens are never extracted over 5 minutes. It is customary to allow the extractor to reach top speed, let it run for a minute, then stop it and unload. Too much extraction may damage the fabric. If woolens are to be tumbled dry, they should be separated from any cotton load, and the heat in the tumbler should be reduced by adjusting the dampers. Woolens should be tumbled only for as long as is necessary to dry them. For additional information, see chapter 35 of the *Bureau of Ships Manual.*

GYROCOMPASS EQUIPMENT

When operating in latitudes higher than 70 degrees, special attention should be given to the provisions of the gyrocompass instruction books regarding the manual operation of the speed corrector.

WIND DIRECTION AND INTENSITY EQUIPMENT

In utilizing this equipment allowance should be made for the fact that accuracy will be impaired by ice collecting on the aloft transmitter vanes. Where such equipment is not provided, ships should be provided with hand-held anemometers.

WINDOW WIPERS

The pendulum-type window-wiper mechanisms are designed to operate satisfactorily in cold weather. The following instructions should be followed for optimum results under arctic conditions:

1. To prevent ice formation, saturate felt blade with a solution of 50 percent glycerin and 50 percent alcohol, and fill the reservoir on the back of the blade with the solution (one filling of the reservoir should be satisfactory for several hours operation).
2. Start the wiper as soon as icing conditions are suspected or anticipated—once ice has formed on the glass, the wiper may not be able to remove it.
3. Be sure that the blade is not frozen to the glass before starting the wiper.
4. Ensure that an adequate supply of both rubber and felt blades, which are standard Navy stock, are on hand.

Figure 4–4.—Start window wipers as soon as icing is suspected.

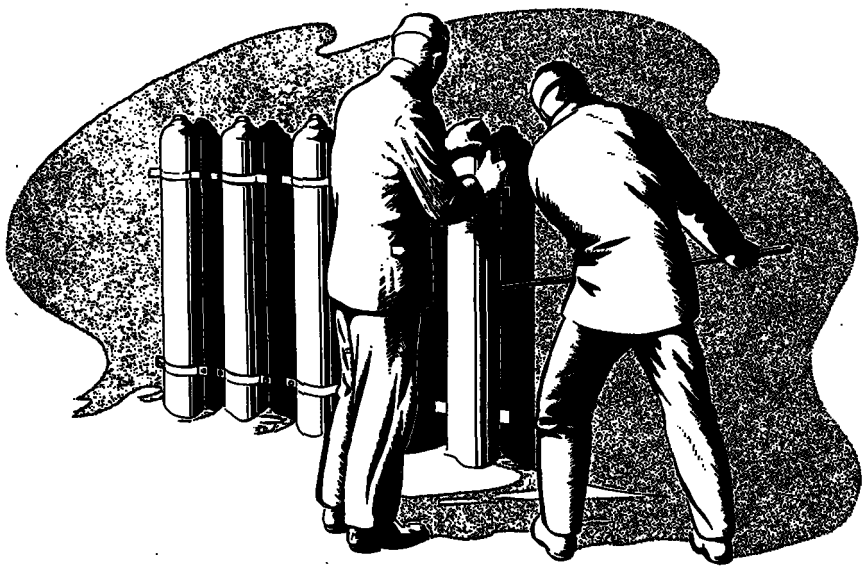


Figure 4–5.—When loosening cylinders do not bear on caps or valves.

COMPRESSED GAS CYLINDERS

Pressure in compressed gas cylinders subjected to cold will drop considerably and may be insufficient for practical use. If such is the case the cylinder may have to be warmed, but extreme caution is necessary if artificial means are used. Care must also be observed in using steam or other heat for de-icing to ensure that cylinders stowed on deck are not overheated (see article 92–273 (6), *Bureau of Ships Manual*). When loosening cylinders for use do not allow crowbars or similar tools to bear on cylinder valves or caps (see article 92–280 (1), *Bureau of Ships Manual*).

ELECTRONICS

Operation of electronics equipment exposed to the weather conditions encountered in arctic and cold weather areas presents the same general problems encountered in operation of all machinery under similar conditions: such as icing of elements, lubrication problems, breakage due to low temperatures, installation and maintenance difficulties, electrical instability.

Generally speaking, all equipment should be winterized. A check should be made to ensure the installation of all winterization kits available and the execution of applicable winterizing

techniques such as renewal of original grease and oil, use of low temperature lubricants, preheating of equipments. Preheaters should be used wherever possible and are considered mandatory below minus 35° F. Preheating shall be accomplished by separately fired devices. A long warm-up period is good practice whenever possible with equipment under no-load or light-load condition.

In the case of transmitters or radars operating in low temperatures, a preheating period is desirable before application of plate voltages. Equipment not regularly in use should be fired up periodically to drive out moisture from units. Condensation of moisture when bringing equipment from cold temperature outdoors into a warm room will often cause corrosion and many times this accumulated moisture may freeze and cause other failures when the equipment is again exposed to low temperatures. In this case, the use of canvas covers and baking of equipment to drive out moisture is suggested. The cover should be placed on the equipment and zippers pulled while the equipment is still exposed to low temperature and then brought indoors. When canvas covers are not available, it is imperative that equipment be kept dry by wiping off the moisture. It is important to protect all exposed equipment with some sort of shelter.

Much trouble has been encountered in the past due to dry, finely powdered snow sifting into equipment. It is recommended that snowproof covers be provided for all equipment to be used ashore and that a whisk broom be placed in every tool kit. Regarding mobility ashore, skid-mounted equipment is most valuable. Long sleds are also recommended to reduce damage of equipment due to shock and vibration. For outdoor installation and maintenance of equipment, *personnel should always wear gloves to prevent the skin from sticking to metal parts.*

Electronics maintenance in exposed positions will be very difficult at best. However, reasonable comfort can be maintained by providing suitable canopies, where possible, for men to work under and also providing small, safe heaters to heat the space under the canopies.

ELECTRONICS COMPONENTS

Prior to departure from the United States, all ships and units should draw an adequate supply of fresh batteries for all portable equipment. Dry batteries can be stored for long periods at very

low temperatures without appreciable depreciation. Upon removal from stowage at low temperatures, the batteries should be warmed to a temperature of approximately 70° F. very slowly. It is suggested that the cold batteries be placed in a temperature of approximately 5° below freezing temperature for about 1 hour and then moved into a 70° F. temperature for another hour. If cold batteries are exposed to elevated temperatures, frosting will occur and the battery cases may be damaged by ice.

Regarding storage batteries, maximum usable life can be insured by preventing damage due to freezing of the electrolyte. Therefore, the specific gravity should be checked at frequent intervals. Batteries with electrolyte specific gravity of 1.140 will freeze at 10° F. whereas at 1.300 freezing does not occur until minus 90° F. Freezing may cause permanent damage to cells and case. Do not add water to a cold battery, even if fully charged. Always add warm distilled water when the battery is warm and is being charged. To prevent excessive discharge of battery in starting gasoline engines in cold weather, the use of a slave battery is highly recommended.

The use of shelters, and preferably drift-proof shelters, is highly recommended for gasoline engine generators installed in exposed locations. Special cold weather fuels and lubricants should be used whenever possible. It is to be noted that prestone in concentrated form will freeze at 19° F. whereas, by proper dilution, the freezing point may be lowered to approximately minus 65° F.

Microphones fail when left in snow because the snow accumulates, melts, and freezes, or because of breath moisture freezing. This can be prevented by using suitable thin microphone covers of nylon, polyethylene, or vinylite. Supply sufficient spares with each type. Headsets must be kept warm and dry to prevent disabling of diaphragms due to moisture freezing at the edges and to prevent breaking of plastic seats.

All rotating joints, rotary machines, rotating shafts as in switches or potentiometers should be winterized by cleaning with fluids and by replacing existing lubricant with cold weather lubricants or graphite. Also, these units must be kept dry to prevent moisture from freezing and jamming rotating parts.

Ordinarily condensers, resistors, and inductors are not likely to fail at low temperatures. However, their characteristics may change, requiring frequent readjustment of critical circuits. Electrolyte condensers are subject to considerable variation in capacity and in effective series resistance, especially at tempera-

tures lower than 0° F. Capacity decreases with temperature while resistance increases.

The formation of ice on antennas can cause wires to break and may reduce operating range. Check antenna installation frequently. Knock off icicles with a light bamboo pole. Remove all ice from strain insulators to prevent excessive transmission losses.

Ice on connecting points of telescoping or sectional antennas causes damage. As a remedy, a film of light-grade oil is recommended for their protection. Frequent inspection, cleaning, and replacement of the film will be necessary.

Cables and cords should be handled with care to prevent cracking or breaking. Learn the flexing capabilities of the particular cord and handle accordingly. Do not bend at sharp angles. At temperatures approaching minus 40° F., it is necessary that cable be placed in a warm shelter and unreeled in this temperature before attempting installation.

SHORE ELECTRONICS

COMMUNICATIONS EQUIPMENT

Radio interference noise levels may be exceedingly high in standard communications receivers operated on high barrier ice or snow where electrical grounding is impossible and counterpoises become pickup antennas suspended in space. Individual antenna-counterpoise systems are recommended. All transmitters, vehicles, power units, and particularly d.c. generators should be isolated as far as possible from receiving positions.

Nonmobile noise generators should be equipped with filters for isolating noise voltages from radiating power lines and/or bonded to a central connection other than those used for propagation or reception. Additionally, all battery charging near receiving positions should be accomplished with a.c. rectifiers instead of d.c. generators. It is imperative that the number of rotating electrical machines using commutators be held to a minimum. There is no noise trouble with alternating current equipment.

In connection with the above, ice drilling machinery or deep well equipment should be included in all operations involving the installation of radio communication stations on an ice shelf. This machinery could be used to drill through the ice at a number of points on the perimeter of a circle or quadrangle surrounding the buildings housing radio communications equipment. Wires should

Figure 4–6.—Drag wire antennas on snow for good results.

extend from the center radially to the holes drilled and the surface horizontal wires tied together as a counterpoise system. The radius of the counterpoise system should be a minimum of a quarter wave length at the lowest frequency to be employed and the length of the vertical wires down into the ice should be as long as necessary to provide contact with the salt water or ground. Noise elimination and good antenna design cannot be over-emphasized inasmuch as they are prime factors in improving communications.

All MHF portable or vehicular equipment covering long distances should have their whip antennas supplemented by wire dipole antennas, antiprecipitation and corona proof, which can quickly be flung out on the snow one-quarter wave length either side of vehicle when not in motion.

Vehicles, when not too closely accompanied by others, on remote assignments can drag along wire antennas behind them (on thick snow) with excellent results. Whip antennas are especially desirable due to their adaptability to use in igloos or shelters. However, antennas pushed through drift-tight holes in tent roofs that are covered with melting snow are not conducive to optimum operation. (Shunt across antenna.)

The following comments as applied to early warning radar equipment are applicable to radar navigational aids such as GCA, GCI, IFF or any other equipment similar in construction or in operational features.

Since early warning radars may be either fixed or mobile, they represent two separate and distinct problems in arctic regions. On the one hand, the fixed type is a problem chiefly because of its mass, whereas the mobile type may be difficult to locate. All the usual troubles experienced with motor transport facilities are to be expected and personal comfort may have to be sacrificed to obtain mobility.

The antenna is a very vital part of the radar and must receive special maintenance care. All facilities available to prevent icing must be utilized, such as pedestal space heaters and wave guide stimulated by a warm air blast from below. Only low temperature oils and greases should be used in pedestals. When rotating the antenna after a period of idleness, it should be rotated at slow speed for a short period in one direction only. Sudden changes of speed or changes in direction should not be imposed on the system until it has had a chance to work in. Where high winds prevail the antenna should always be stowed so that its least frontal area will be presented to the prevailing wind direction.

Cable runs from the antenna to the radar should be protected throughout their length, say inside the tower leg if possible, in order to permit whatever servicing required. Stuffing boxes and cable terminals must be well protected. In the case of wave guide runs all points must be regularly inspected to ensure that no moisture is allowed to enter. Well protected drainage holes should be provided at the base of all long wave guide runs and these holes must be constantly checked to assure that they do not become stopped. Condensation and freezing inside a wave guide may cause very considerable power loss and consequent loss of range.

Assuming that the enclosures housing the radar equipment on the ground are kept reasonably comfortable for personnel during periods of operation, it may be that full heat is not maintained during nonoperating periods. Such on-off operation is very hard on the equipment due to condensation, freezing, and strain on mechanical parts incident to extreme temperature changes. About the best means of combating this condition is to keep all tube filaments burning and space heaters on during periods of nonoperation. This will also make the equipment available for oper-

ation almost immediately in emergency, by merely applying the plate voltages.

Secondary power is recommended for all fixed installations. The capacity should be sufficient to supply power for lights, space heaters, low voltage radar filament supplies, etc. This requirement is based on the premise that the radar will be called on to operate only part of each day. Standby power is also highly recommended both for emergency and for use while maintenance is being carried out on the primary radar power supply equipment. The main fuel storage for the motor generators should be located not closer than about 100 feet from any r-f element. As a safety measure all gasoline drums should be adequately grounded when located in the general area of a radar set.

All rotating machinery and gear trains should be checked regularly for proper lubrication. A sufficient quantity of oil or grease is not enough, it must flow or adhere to the moving parts in order to provide satisfactory lubrication. All blower motors should be carefully checked for operation since failure of a blower often is followed by a major breakdown due to overheating in the space served by the blower. Just because it is cold outside it does not follow that the blowers may be dispensed with. Intakes must be kept snow-free and clear. Wick-type bearings are especially susceptible to binding at low temperatures.

As in the case of an automobile the gasoline or Diesel engines which drive the power generators may be expected to start hard in cold weather. Also, it may take as much as 15 minutes before they have reached operating temperature and deliver a constant torque thereby enabling the generator to supply a constant voltage. It is, therefore, recommended that after a period of idleness the radar not be turned on until at least 15 minutes after the generators have been started. This is good tube, transformer, and capacitor insurance.

In cold climates special care must be taken to service adequately the hidden, though vulnerable, portions of the system such as the wet cell batteries and the cooling systems of the engines. The specific gravity of all wet cell batteries should be kept up to prevent freezing and it must be borne in mind that the Navy standard battery has a lower specific gravity than the commercial standard. This means that the former will freeze at a higher temperature than the latter. All water cooled systems must be adequately protected by a suitable antifreeze. Some of the early radar sets

employed circulating distilled water for cooling the plates of the transmitter tubes. Although this is no longer common practice it serves to illustrate how important it is to know your equipment before you try to operate it at subfreezing temperatures.

Mobile early warning radar equipment may be expected to present all the low temperature difficulties experienced with the fixed type of installation plus a few additional ones. As in the case of the fixed installation, the mobile type must also have its antenna located at a high point to obtain an unobstructed view in all directions. This means that the antenna van or trailer, and, most likely, the operations van or trailer, must be driven or hauled into place. It is recommended that at least two trucks in the expedition be provided with high capacity winches for pulling the radar vans into position. Tractors are very desirable for such work. It is also suggested that each van be fitted before the start of the expedition with special skis or steel runners which may be clamped to the wheels. Rubber-tired wheels have virtually no traction on ice or packed snow. Their use should not even be attempted.

Each van, housing operating personnel, must not only be adequately heated, preferably with a gasoline heater, but must also be adequately ventilated with the doors closed. All doors must be tight and vents to the outside must be protected so that powdered snow may not enter.

Since the average van presents a considerable area to the wind and since winds in the Arctic reach a high velocity, it is best to anchor all vans in place by means of suitable guy wires to prevent overturning. If outriggers are furnished as part of the equipment they should be employed instead of guys. If not already

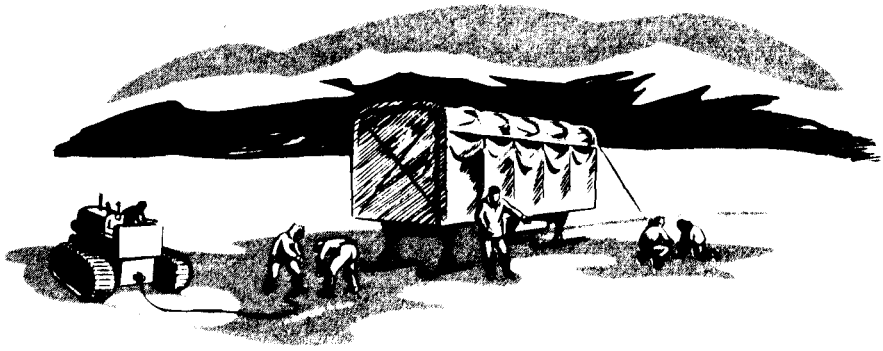


Figure 4–7.—When in place vans are anchored with steel guy wires.

furnished with the equipment, provision should be made for securing the antenna against high winds. Unless absolutely necessary, it is not advisable to drive the antenna in a high wind. Under such conditions the strain on the antenna drive system is great, sudden gusts often reaching higher velocities than economical design may be able to withstand. Also special precautions should be taken to prevent excessive icing on the antenna.

All recommendations concerning the use of low temperature oils and greases and constant maintenance surveillance over all moving parts apply equally well to the mobile installations and to the fixed ones discussed previously. It should also be remembered that there are a greater number of mechanical parts subjected to temperature extremes in the case of mobile installations than in the average fixed installation. The mechanical strains are therefore greater and maintenance must be expanded accordingly.

Comments above concerning early warning radar shall be considered applicable to radar navigational aids.

SHIPBOARD ELECTRONICS

RADIO COMMUNICATIONS EQUIPMENT

LF transmitting equipment is most valuable in arctic and cold weather areas and should be maintained at highest efficiency, particularly if operating with aircraft. Especially large receiving antennas for use on the NSS low-frequency Fox transmissions are recommended for these long distance polar operations. Immense improvement can be effected in the reception of Fox transmissions by rigging from the topmost radar mount a T receiving antenna up to 200 feet long and 90 to 100 feet high. In this connection, it has been found that the *Boston trunk* for bringing LF antennas down to the receiving room proved superior in performance to the solid dielectric flexible coaxial lines.

RADAR EQUIPMENT

Shipboard radar problems are similar to those discussed in section III above for shore radar equipment—in particular, all comments on antenna care, lubrication, icing, and preheating of pedestal, applying.

SONAR EQUIPMENT

For submarine installations, precautions shall be taken to prevent excessive icing of topside sonar transducers and periodic inspections shall be made for any breakage due to the icing. Re-

tractable topside hydrophones shall be in a retracted position when the submarine is surfaced. After submerging, sufficient time shall be allowed for ice to melt before transducer training systems are energized.

In marginal ice areas, retractable domes on surfaced submarines or surface ships should be retracted, tactical situation permitting.

Low temperature lubricants shall be used in cold weather operations and extreme care shall be taken with training systems which present rotating difficulties due to freezing.

NAVIGATIONAL AIDS

The importance of direction finders in polar operations cannot be over-emphasized. All D/F equipment should be calibrated prior to departure for the operational area, and rechecked after arrival therein, where practicable.

Homing beacons are most valuable. Care should be taken to prevent heavy icing of the antenna which will cause failure of the rotating mechanism. The difficulty has been corrected in some installations (of Model YG) by building a radome (shelter) over the antenna pedestal. Despite heavy icing of the radome, operations remained satisfactory.

OTHER SPECIAL ELECTRONICS EQUIPMENT

Regarding the operation of infrared equipment, there is very little special care required other than a check of the lubrication and particular care regarding batteries in portable receivers as stated above. Equipment covers shall be used at all times especially to keep the window of the infrared receiver equipment free from ice. Warm-up period will melt ice from beacons; at least a 10 minute warm-up period will be required in operating the Type Easy (AN/SAC–1) infrared communications equipment.

TOPSIDE DE-ICING AND SNOW REMOVAL ON SHIPS

The most serious effect of topside icing, particularly if ice continues to accumulate, is the increased topside weight. This may result in dangerous loss of stability, reduction in reserve buoyancy, and critical impairment of the ship's ability to withstand damage. Other adverse effects of such icing are: the increased load on decks, masts and other structures; interference with the handling and operation of topside equipment; and the slippery effect on decks and other exposed walking and working areas endangering personnel.

There are several methods of ice removal which have been used with varying degrees of success. These are:

1. *Manual*—Ice broken away and chipped off by use of mallets, clubs, scrapers and similar tools. This method must be used with caution to avoid or minimize damage to metal surfaces, equipment, electric cables, gun mounts, and other machines or mechanisms.

2. *Steam jet.*—This method may be of limited usefulness in small or restricted areas when a steam lance can be employed to undercut layered ice as, for example, in freeing an anchor which has become frozen in the hawse pipe. Disproportionate consumption of steam, with consequent loss of feed water, restricts this method to only very limited application.

3. *Anti-icing and de-icing coatings.*—While not thoroughly tried, this method is applicable to the protection of comparatively small areas or items with grease, usually of special formulation. The grease or anti-icing compound retards the formation of ice and contributes to the ease of removal of any superimposed ice coating or accumulation.

4. *Heated salt water under pressure.*—Sea water at temperature of at least 45° F. (and higher if readily obtainable) is used in high pressure streams to slot, undercut, and break up accumulated ice. No attempt is made to melt the ice directly; but to break it up and weaken it to facilitate mechanical removal.

Figure 4–8.—Use mallets and clubs with care.

Figure 4–9.—Undercutting with salt water spray.

In general, a combination of methods (1) and (4) above is considered to be the most effective for any extensive ice removal. Certain ships are equipped with special means for supplying heated salt water through the fire-mains, but at this time these installations are still on an experimental basis. However, ships not so fitted can effectively employ fire and wash deck hoses under most conditions so long as solid streams of water at a pressure exceeding 40 p. s. i. are available. The latter method should be used with caution under conditions of extreme cold. Any tendency of the water to freeze and add to the ice accumulation should be noted and the method discontinued immediately if such conditions occur. It is also essential in using this method that overboard deck drains be kept clear.

When removing ice, care must be exercised not to damage electric cables, including topside degaussing cables installed on some ships. In certain tankers the degaussing cables run over the tank tops only a few inches above the deck and can easily be damaged if an attempt is made to clear the deck of ice by shoving the ice overboard through the space between the deck and the cable.

When conditions of severe topside icing exist and ice continues to accumulate dangerously in spite of all attempts to remove it, it

may be necessary to alter course, lie to, or even head for a warmer area or area of more moderate weather. This may occur when heading into heavy winds or seas with attendant spray under conditions of low air and sea-water temperatures, and is particularly applicable to smaller ships having low freeboard and reserve stability.

The primary consideration in keeping decks clear of snow and ice is to remove the snow before it has an opportunity to form a crust or become trampled and hardened. This may be done by means of rattan hand sweepers, shovels, and similar equipment. On aircraft carrier decks, tractor powered rattan sweepers and rotary brushes have been used with success. Care must be exercised not to damage deck cleats or other deck coverings when using scrapers and rotary brushes. Light snow does not accumulate on steel decks, due to the heat transfer through the deck. In some cases advantage may be taken of high winds to blow the snow clear.

Hand brooms and turning up of aircraft engines are the most effective means of removing snow around closely parked airplanes. Rock salt may be used as a final resort in removing ice and packed snow, but this method should be kept to the minimum due to the corrosive effect of the salt and the hazard to personnel and equipment from the flying salt particles, particularly on carrier flight decks.

HULL DAMAGE

The type of hull damage which may be encountered in sea areas where ice may be encountered is not appreciably different from that which may result in any area of operation. Generally speaking, normal damage control procedures and practices are applicable. However, the possibility of hull damage is considerably increased when operating in close pack ice, and extra preparatory and precautionary measures should be taken. When cargo is loaded it should be distributed to permit access to side plating, bulkheads, and bilge suction drain wells and strainer plates. It should also permit normal drainage in event of hull damage. A full allowance of damage control equipage, including shores, wedges, and plugs, should be on board prior to departure, and should be stowed in various underwater spaces for ready availability in case of damage. As indicated previously the drainage system, portable pumps, and hose should be maintained in the best condition and personnel should be thoroughly instructed and drilled in operation of this equipment. Upon entering ice, con-

dition *Yoke* or *Baker* should be set and an adequate hull repair party kept on watch at all times.

Damage may consist of rupture of shell or distortion and weakening of structure due to ice pressure or contact with ice, or loss or damage to rudder, propellers, shafts, or other appendages. In case of shell rupture, normal damage control procedures are applicable, i. e. contain the flooding, plug, and shore as necessary and feasible, and get the loose water out of the ship. Distorted or weakened structure should be shored as necessary for temporary reinforcement. Voyage repairs for loss of, or serious damage to, underwater appendages are seldom feasible, and such damage may require that the ship be taken in tow. Depending on the nature and extent of the loss or damage, the possibility of a temporary or jury rig should be thoroughly considered, and all possible steps taken to salvage or prevent complete loss of the appendage.

In case any welding is to be done, chapter 92, *Bureau of Ships Manual*, should be consulted, particularly article 92–6(3). As indicated therein, welds made without preheat on very cold metal may not be satisfactory, and may even do further damage.

WINTERIZATION

This section indicates the principal items that should be considered in preparing an ordinary naval ship for operation in the Arctic. The extent to which the various items are applicable will depend upon the type of ship, mission, duration of voyage, and probable area of operations, and upon the time available for preparation.

There are certain items in the nature of temporary modifications or alterations which should be considered. Unless the ship is being readied for extended operations under known severe conditions these changes, in view of their temporary nature, should be accomplished by ship's force with materials at hand and jury rigs insofar as possible. Among them are:

1. Designation or reassignment of certain spaces for drying of heavy weather clothing. On many ships the uptake spaces will be suitable for this purpose. Jack stays or other means of hanging heavy weather clothing should be installed.

2. Rearrangement or designation of certain spaces to provide for stowage of additional heavy weather and bulk clothing to be taken aboard for cold weather operations.

3. Rearrangement or reassignment of certain storerooms, refrigerated spaces, or other spaces to provide for increased capacity of food supplies. In some cases consideration of the temporary topside installation of portable reefer boxes may be warranted.

4. Installation of temporary shelters or wind screens for exposed personnel and topside watch-standers. Locations to be considered are bow station and crow's nest station for ice lookouts and other lookout stations; exposed conning station or pilot house if not enclosed; deck, cargo winch, and crane operators' stations.

5. Suitable lighting for leadsman's platform, particularly for high-latitude winter operations.

6. Installation of special propellers for ice operation, if available, and if docking of the ship is directed prior to departure. Preferable materials for such propellers are stainless steel, copper nickel-silicon (Silicon Monel), or special high strength bronze alloys.

7. Replacement of alcohol-water filled magnetic compasses with oil filled type.

8. Temporary timber bracing of the bow in the forepeak may be advisable, particularly if ship is of light construction, such as LST's. Additional bracing to the forepeak after bulkhead may also be desirable.

9. Installation of thermal insulation on shell or bulkheads behind and above main switchboards if such bulkhead or shell areas have a tendency to show condensation.

10. Replacement of any fluorescent lighting installed in spaces where the ambient temperature may be expected to fall below 50° F. Presently available fluorescent lamps do not operate satisfactorily in spaces below 50° F., and are practically impossible to operate in ambient temperatures below 32° F.

11. Provision of additional insulation for exposed steam and water piping which will not be completely drained at all times except when in use. Lagging should be common to both the steam supply and drain line wherever possible.

12. Provision of a brow which can be easily rigged to shelf ice.

13. Provision, on overboard discharges or drains above the water line, of a temporary heating coil around the piping directly inboard of the shell. Steam supply should be taken from the steam heating system and drainage returned to the heating system drains.

In addition to temporary alterations, provisions, and modifications such as those outlined above, there are certain preparatory measures for installed systems and equipment, and certain tests

and inspections which should be carefully observed as a matter of voyage preparations:

1. Accomplish topside painting maintenance and bring ship to the highest possible standard in this respect to arrest corrosion during a long period of operations in cold climate when routine maintenance can not be accomplished. Little opportunity for further painting may be afforded under cold weather conditions.

2. Clean ventilation and heating systems to ensure that they are in the best operating condition. All heaters, temperature controls, and condensate traps should be checked for installation. Heaters removed in warm climates should be reinstalled and placed in operation.

3. Check towing gear and overhaul or replace items as necessary.

4. Refill water breakers to 75 percent capacity.

5. Check the operating condition of main drainage pumps and portable pumps, inspect and test associated piping and hose, correct all leaks and renew hose as necessary. Clean all bilge well suctions.

6. Overhaul cargo falls. Remove excess grease.

7. Test heating coils for fuel oil tanks.

8. Test main damage control bulkheads and tanks, as practicable, by hydrostatic pressure.

In connection with the stocking and outfitting of the ship, the following items are particularly pertinent:

1. Provide spare batteries for boats, in addition to those installed. Upon request, the Bureau of Ships will approve up to 100 per cent spares in excess of allowance, depending on the nature and expected duration of the operation.

2. Ensure that full allowances of maintenance and repair spare parts are on board. Requisitions should be submitted as far in advance as practicable, and should clearly indicate the special purpose or operation for which required. Particular attention should be given to checking spares for all pumps, both installed and portable, and for electronics equipment, particularly navigation radars.

3. Provide full allowance of damage control and repair materials, such as shores, plates, clamps, wedges, etc.

4. Provide full allowance of mooring gear, and obtain adequate supply of materials needed for any special mooring, such as mooring to shelf ice, if such operations are anticipated.

5. Provide adequate supply of special lubricants, antifreeze solutions, hydraulic fluids.

6. Carry a good supply of wooden mallets, scrapers, and similar tools for ice removal or for working in ice. Provide long ice poles for clearing or fending ice, and special ice fenders (sections of telegraph poles 10 to 15 feet long are suitable for this purpose).

7. Provide supply of special dry batteries as needed for use only below 0° F.

8. Provide extra supply of vacuum-type bottles and jugs for serving hot liquids to watch standers. These are carried as standard stock items:

1-quart size—standard stock No. 63-B-500

1-gallon size—standard stock No. 63-J-600

9. Provide extra space and unit heaters as needed. Requisitions in excess of allowance for these and for item (8) above will be given favorable consideration, depending upon the nature and expected duration of the operation.

10. Provide good supply of window-wiper blades, and glycerin and alcohol for filling. Wiper blades and de-icing liquids are available in standard stock as indicated below.

Blade Length:	*Standard Stock No.*
7 inches	12-B-1616-150
8 inches	12-B-1616-160
9 inches	12-B-1616-170
10 inches	12-B-1616-180

Material and Unit:	*Standard Stock No.*
Denatured alcohol, 5 gallons	51-A-1935
Glycerine, 5 gallons	51-G-356
Ethylene Glycol, 1 gallon	51-C-1554-15

SUMMARY

In general it can be expected that equipment will perform satisfactorily or can readily be adapted to do so. Extreme care and good seamanship must be practiced while operating in pack ice or ice areas to avoid holing and damage to fittings of the ship. In event of holing or other hull damage, "plug the holes, man the pumps, practice damage control, and keep going."

Blank page retained for pagination

CHAPTER 5

CARE AND OPERATION OF SHIPBOARD ORDNANCE MATERIAL

Ships operating in cold weather areas have, at surface or weather air temperatures below freezing, experienced difficulties with ordnance equipment due principally to the congealing of non-cold-weather lubricants and to the formation of ice on exposed equipment. As a result, equipment may become inoperative, or extremely sluggish and difficult to operate at required speeds.

Low temperatures also have a detrimental effect on most propellants. Propellant grains become brittle at low temperatures and may crack. Gun propellants are satisfactory for firing at propellant temperatures down to 0° F. Rockets should not be fired at rocket motor temperatures below those stencilled on the rocket motors.

According to partially completed tests at the Naval Proving Ground, it is indicated that armor and inert components of ammunition are not affected adversely by low temperatures.

GENERAL PRECAUTIONS

LUBRICATION AND MAINTENANCE

1. Under cold weather conditions certain lubricants, prescribed for normal operating conditions, tend to congeal and cause unsatisfactory operation. In general, the approved lubricants for ordnance service use must meet specification requirements for satisfactory performance down to 0° F. (with the exception of certain lubricants for specific applications). Changes in lubrication required for lower temperatures include dilution of high viscosity oils and heavy greases with low viscosity oils, or by replacing with a suitable cold weather lubricant. Excessive amounts of lubrication must be avoided in all cases. In arriving at these substitutions, consideration has been given to adequate low temperature starting and operation as well as maintenance of satisfactory lubrication at the final operating temperature (which may be nearly as high as under normal temperature conditions). Cold weather relubrication of ordnance equipment should be accomplished prior to entering low temperature areas (0° F. and below). However, if cold weather is encountered before relubrication of the equipment is accomplished, special methods for removing the congealed lubricant must be utilized.

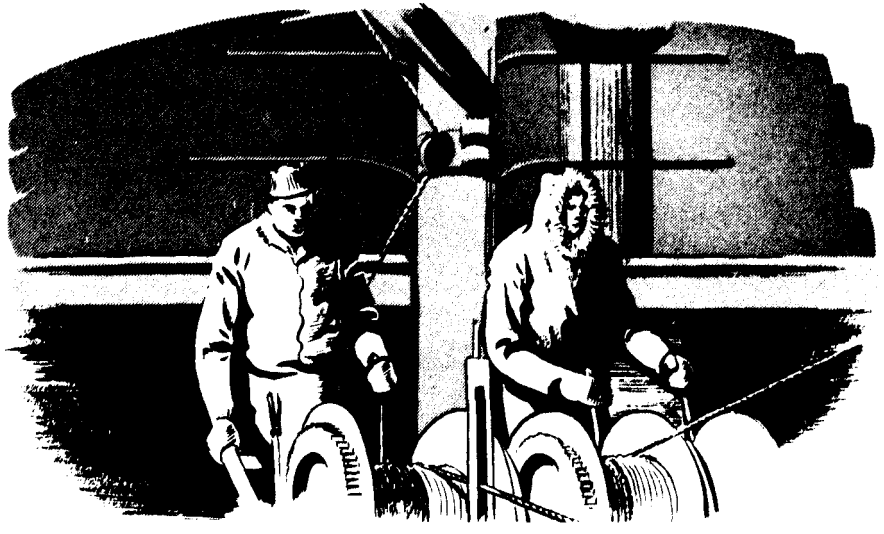


Figure 5–1.—Icing makes equipment difficult to operate at required speeds.

2. Lubrication precautions prior to entering cold weather areas: When relubrication is required, accessible grease lubricated parts should be cleaned prior to applying the cold weather lubricant. Where the parts are not accessible, it is recommended that the units be exercised while lubricating, care being taken to remove any excess grease.

When replacing oil, it may be necessary to raise the temperature of the oil to be removed (to reduce its tenacity) in order to assure as complete a removal as possible. This may require exercising the equipment for a period of time, then draining the oil and refilling with the cold weather lubricant. Oil trapped in pockets should be removed with a hand suction pump. For oil lubricated parts which do not have a pump and are lubricated by direct application, large quantities of the cold weather lubricant should be injected, in order to flush out the original lubricant.

3. Relubrication for cold weather operation under emergency low temperature conditions:

a. *For relubrication of inaccessible parts* during an emergency, such as lack of time to permit cleaning out the lubricant, or where the lubricant has already thickened or congealed under cold weather conditions, a light mineral oil JAN–L–644 (formerly O.S. 1361) (first choice) or VV-O-401 (second choice) should be injected in moderate amounts at intervals, and accompanied by exercising until the equipment operates freely. The use of JAN–L–644 as a diluent is desirable due to its corrosion prevention properties. The proper cold weather lubricant should be applied to the surfaces which have been treated as above.

b. *For relubrication of accessible parts* where the grease has congealed, the cover plates should be removed and the parts wiped off with a kerosene (VV–K–211) soaked cloth and moderately exercised while cleaning whenever possible. Care should be taken to apply the cold weather lubricant immediately after cleaning. If it is apparent that this cleaning procedure does not remove a major portion of the original lubricant, moderate amounts of VV–K–211 should be applied until the parts are freed. Follow up with a generous quantity of JAN–L–644 while exercising the equipment, in order to provide a measure of lubrication until it is possible to relubricate completely for anticipated temperature conditions. When VV–K–211 (kerosene) is used, extreme care must be taken to prevent its running on to adjacent lubricated bearing surfaces or electrical insulation. As kerosene is some-

what volatile, care should also be exercised in its use in areas where an open flame or electric arc may be encountered.

4. Where a lighter oil or diluted lubricant is used as the cold weather lubricant, more frequent applications of the lubricant are required than are prescribed for the normal lubricant.

5. General considerations relating to selection of proper lubricants:

The approved and required lubricants for all ordnance applications appear on the applicable lubrication chart or ordnance publication, or may be contained in other instructions such as NavOrd OD 3000. The lubrication chart drawing numbers are normally found on the assembly sketch list for all mounts, directors, torpedo tubes, and similar equipments, and on the list of drawings for the particular component such as the slide or projectile hoist for all turret equipment. In the case of torpedoes and fire control equipment such as computers, rangekeepers and indicators, lubrication charts are not necessarily issued, and the general lubrication instructions are contained in the applicable ordnance publication which describes the particular equipment.

It is extremely important that the applicable lubrication charts of the latest revision and the latest lubrication instructions issued be used at all times for the lubrication and maintenance of ordnance equipment.

6. The recommended lubricants for normal and cold weather operation for various applications in ordnance equipment are listed in NavOrd OD 3000, section X. Lubrication charts contained in the ordnance pamphlets (other than for torpedoes and fire control equipment) are those of original issue and may have been revised. A cental lubricating chart file and office is being established at the Naval Gun Factory, Washington, D. C., to which application may be made for information concerning specified types of equipment. The lubricants specified on the lubrication charts and in the ordnance pamphlets of current issue are usually adequate to cover operation down to 0° F. In general, cold weather lubricants provide adequate lubrication down to minus 35° F. It will not be necessary to change the lubricants other than normal winter practices in enclosed (heated) locations to cover low temperature limits from 0° to minus 35° F. However, it will be necessary to change to different lubricants or to resort to diluted lubricants for most exposed locations.

NOTE.—*Enclosed locations* are considered to be those in which the equipments involved are inside of a completely enclosed shield

or structure or are in locations normally heated for personnel. *Exposed locations* are those in which the equipments are not shielded and are subjected to weather air temperatures.

GUNS, MOUNTS, AND LAUNCHES

The following factors influence the firing of guns at low temperatures:

1. Increased tendency of metals to fracture at low temperatures.
2. Propellants.
3. Lubricants.
4. Fluids (recoil, cooling system, and power transmission).

Items, 2, 3 and 4 are discussed in the succeeding paragraphs below. The effect of low temperature on the strength of materials varies with the chemical composition and heat treatment of the material as well as with the presence of sharp corners and cracks under stress in the material.

The safe lowest ambient temperature for firing of shipboard guns is not definitely known. However, the following temperature limits are suggested (refer to appropriate lubrication charts for instructions on lubricants and fluids for low temperature operation):

Gun:	*Lowest ambient temperature for firing*
20 mm	minus 35° F.
40 mm	minus 35° F.
3"/50	minus 35° F.
5"/38	0° F.
6"/47	0° F.
8"/55	0° F.
12"/50	0° F.
16"/50	0° F.

Recoil mechanisms and buffers.—Recoil mechanisms containing glycerine-water mixtures should function satisfactorily in cold weather, except that sluggish action (or perhaps short recoil) may become increasingly apparent at temperatures below the freezing point at which ice crystals begin to form in the mixture, although the solution does not freeze solid until temperatures below the pour point are reached. Heat should be provided if unsatisfactory recoil action is experienced. There is no authorized substitute for either mixture inasmuch as the orifices are designed specifically for each mixture. Freezing points and pour points are given below.

Mixture	Freezing point	Pour point (by test)
OS 1324 (60 40 mixture)	Minus 32° F.	Minus 60° F.
OS 1914 Type A (80 20 mixture)	Minus 5° F.	Minus 55° F.

Buffer fluids under cold weather conditions will slow the action of the buffers as the pour point of the fluid concerned is approached. With the exception of NS (Navy Symbol) oil 2075, having a pour point of approximately minus 10° F., all buffer fluids used in ordnance applications have pour points below minus 35° F. Therefore, no cold weather substitutes are recommended. OS 1362 is the recommended cold weather substitute for NS 2075.

Cooling systems.—In areas where it is certain that freezing temperatures will not be encountered, the normal coolant for gun cooling systems (except .50-caliber machine guns) is fresh water treated with a corrosion inhibitor consisting of 5 grams of neutral (chemically pure) sodium chromate crystals per gallon of fresh water used.

When temperatures below 35° F. are anticipated, a solution of antifreeze compound, 51C39-Type A, and fresh water should be used. Directions for preparing this solution appear on the container or shipping case of the compound and in OD 3000. This compound contains inhibitors to prevent corrosion of metals. It is of extreme importance that the proportions of antifreeze compound and water be maintained at all times.

Hydraulic power transmission systems.—When it is anticipated that the ambient temperature will reach 35° F. or below, 51F23 (Ord) (formerly OS 1113) should be drained from the exposed systems and replaced with 51F21 (Ord). It is emphasized that the change should be made well in advance of entering cold weather areas of operation. While changing the fluid, the greatest care must be taken to avoid contamination. Filling should be accomplished by using a Luber-Finer filter, or, if a filter is not available, a filling funnel, BuOrd Dwg. 8–Z–801, pc. 14, or by some other means of straining the fluid through a 200-mesh or finer screen. For power transmission system containing 51F21 (Ord) (formerly OS 2943) no replacement of fluid is to be made for cold weather operation. Where very low temperatures are encountered, sluggish operation may be anticipated and frequent exercising of the equipment will be required. The temperature at which the equipment will perform satisfactorily and frequencies of exercising re-

quired are dependent upon the effectiveness of the cold weather lubrication measures taken and the type of hydraulic equipment involved. For instance, hydraulic drives and regulators to operate satisfactorily at minus 10° F. may require exercising 15 minutes per hour.

FIRE CONTROL EQUIPMENT

LUBRICATION AND MAINTENANCE

Hydraulic fluid.—In fire control systems containing hydraulic units, change the fluid from 51F23(Ord) to 51F21(Ord), similar to change described in paragraph (4) above under gun mounts.

Damping devices.—At low air temperatures, handle-bar directors may possibly become difficult to move in train and elevation due to congealing of the damping fluid. In this case, it may be necessary to disconnect the gearing which drives the damping device.

Optics.—Provisions for defrosting and de-icing are described in the applicable ordnance pamphlets and in NavOrd OD 4486.

UNDERWATER ORDNANCE

Steam torpedoes (Mks 13, 14, 15).—Malfunctions, with consequent erratic runs or failures to run, are to be expected in steam torpedoes whenever completely chilled to any temperature below about 30° F., at the instant of starting. Data as to the percentage of erratic runs or failures to run which are to be expected at various temperatures lower than this is lacking, but the percentage can be expected to increase rapidly with decrease of temperature.

Obvious immediate effects of chilling which in turn may lead to erratic runs or failures are:

1. Freezing of the water carried by a steam torpedo (such as Mk 13, 14, and 15).

2. Freezing or frosting of moisture entrained in the high-pressure air charge as pressure is reduced or as air is released from a nozzle or orifice.

3. Thickening of lubricants, causing ineffective lubrication, binding or sluggish controls.

4. In extreme cases, differential contraction of dissimilar metals (such as a steel shaft in a bronze bearing) causing binding, or possibly even causing permanent set or rupture.

5. Formation of adherent ice upon a chilled torpedo (or, more important, within chambers and passages such as the exploder impeller duct or the tube to the immersion chamber) as it enters the water.

Certain of these effects may be palliated by measures not involving the actual physical preheating of a torpedo. For instance, the water carried by a torpedo may have alcohol added as an antifreeze, in accordance with standard tables, and the pour point of a torpedo lubricant may be reduced by the addition of fluid supplied for the purpose by the bureau. However, since equally simple methods for curing some of the other effects (e. g. 2 and 5 of the preceding paragraph) are not available, the following general precautions are stated:

In destroyers, when the ambient air temperature has been below 30° F. for more than an hour or so, reliance must be placed upon the torpedo tube barrel heaters (steam) to keep torpedoes in tubes ready for action. They require a great deal of care and maintenance in order to prevent breakage, leakage, freezing of condensate in return lines when steam has been turned off, etc. However, in actual experiment, temperatures well above freezing have been maintained in the afterbodies and water compartments of torpedoes in an ambient temperature of 0 ° F., with considerable wind.

Muzzle covers, specially made with weak seams which tear open to permit the exit of torpedoes, are to be used in conjunction with the barrel heaters. These covers decrease heat loss and keep off water which might otherwise freeze solid between the heads of torpedoes and torpedo tube spoons or spoon extensions. During the experiments attendant upon the development of this type of cover, it appeared from high-speed photographs that the weak seams were ruptured by gas pressure rather than by actual contact with torpedoes, and that the covers therefore did not interfere with propellers and rudders of the torpedoes. Nothing in the foregoing should be interpreted to interfere with current instructions for using alcohol as an antifreeze in the water carried in destroyer steam torpedoes (such as Mk 15), or for using pour-point depressants in torpedo lubricants, since the reliability of the torpedo tube steam heaters is not such that they can be operated continuously without breakdown, and freezing of the water in the water compartment of a torpedo (for example) would be expected to damage the torpedo enough to render it unserviceable.

In PT boats the torpedo launching racks customarily installed offer no protection to torpedoes against either chilling or icing. Electrically warmed tarpaulins (although not standard Bureau of Ordnance equipment) can be used where power is available, as from dockside installations, but are beyond the present capacity of the boats themselves to supply with electric power. Lightweight torpedo tubes with air-circulating carbureted gasoline heaters of the commercial *Southwind*-type can be installed, but at a cost of approximately 700 pounds additional weight per torpedo. "Tearable" muzzle covers, similar in principle to those supplied for destroyer torpedo tubes can be supplied. The efficiency of the gasoline-burning heaters for PT boat torpedo tubes has not been established with the same degree of reliability as that of the steam heaters on destroyer tubes, but they are considered effective down to 10° F. or possibly a little lower. As in destroyers, torpedoes in PT boats should receive whatever antifreeze and lubricant-pour-point depressant treatment is prescribed by current instructions.

In submarines temperatures in torpedo rooms less than 30° F. are not expected under ordinary conditions, and no special cold weather procedures are therefore prescribed for steam torpedoes.

In aircraft the water carried by torpedoes Mk 13 should be replaced by alcohol in proportions required to prevent freezing and approved pourpoint depressants should be added to the oil. For aircraft drops when a Mk 13 torpedo will be chilled during flight, provision can be made for heating during its drop by throwing the water trip at the time the torpedo is loaded into the aircraft. This will result in the torpedo starting to run "hot" as soon as it is released from the aircraft (instead of starting to run "cold" at that time and lighting off only when it strikes the water, as when the water trip is operative). This procedure involves the risk of destroying the torpedo by disintegration of the turbine due to overspeeding while in the air (the prevention of which is the function of the water trip mechanism). It is suggested, however, that the acceptance of this risk may, under certain circumstances, be preferable to declining an opportunity to attack. The time required to accelerate a Mk 13 torpedo turbine by a hot run in air to a speed which will cause it to fly apart will vary among individual torpedoes and is not closely predictable, but generally speaking may be taken as 6 to 10 seconds. Dropping heights should be chosen accordingly.

In stowage and transit steam torpedoes are supposed to contain neither water nor high pressure air. Consequently no permanent injury to properly drained steam torpedoes is to be expected from exposure to cold while stored or in transit except by the very remote possibility of mechanical injury of closely associated parts of dissimilar metals due to differential contraction. Although this possibility exists theretically in various torpedo mechanisms, no actual case of damage definitely due to such cause has as yet been reported.

Electrical torpedoes (Mk 18 and 28).—These torpedoes are used only by submarines and, therefore, are not expected to be exposed, while reliable running is required, to temperatures below about 30° F. The best data now available on effects of various electrolyte and seawater temperatures down to 30° F. upon the range and speed of Mk 18 torpedoes is shown by figure 5-1. Similar data is not yet available for torpedoes Mk 28, but, for an approximation, the following may be applied:

Starting with an assumed average speed of 20.92 knots to 1,000 yards run at an original battery electrolyte temperature of 82° F., reduce average speed by 0.20 knots per each additional 1,000 yards run and also by 0.03 for each degree Fahrenheit which the original electrolyte temperature is less than 82° F. These figures are based upon average sea water temperatures, and take no account of further speed reduction to be expected at lower sea water temperatures, for which data are not yet available. Electrical torpedoes introduce only one factor affecting cold sensitivity which is not also present in the steam torpedoes, previously discussed, i. e., wet-plate storage batteries. These batteries, in torpedoes Mk 18 and 28, are lead-acid types, quite conventional except in minor particulars, and offering no exception (as regards cold weather hazards and treatments) to instructions of the Bureau of Ships for similar types under the cognizance of that bureau.

Electrical dry-cell batteries.—The dry-cell batteries which are used in torpedoes, mines and depth charges generally lose potency, or capacity, at low temperatures. Few will operate at all as low as 0° F. Others will become impotent as high as 30° F., depending apparently upon their "shelf life." Shelf life appears to depend upon other factors than lapse of time alone, notably upon the degree of chemical action allowed to occur before placing the battery in use. Fortunately, chilling of a dry cell to the point of loss of potency (or even to much more extreme temperatures,

e. g., minus 65° F.) does not prevent recovery of potency when the cell is rewarmed, except in the unusual cases where mechanical damage is done by freezing of the electrolyte. Where it is necessary that batteries of this type operate within the range 30° to 0° F., they should be selected from those of shortest shelf life available and from those which have been most continuously stowed under refrigeration (40° F.), since such refrigeration slows chemical action and thereby lengthens shelf life. Unfortunately, no practical, nondestructive test is available from the results of which the remaining power-life of any dry cell at any instant can be predicted.

Mines.—The only known points of vulnerability of mines (as such) to chilling are mechanical impairments due to frosting or icing and loss of potency of dry cells. Since naval mines are not called upon to function in ambient temperatures less than about 30°, since a mine will eventually assume the temperature of the water in which it is laid, and since neither icing nor loss of battery power due to cold are apt to cause *permanent* disablement of a mine, special cold weather procedures applicable to mines are not prescribed. There are still circumstances under which a mine may fail to be properly laid on account of effects of cold. For instance, heavy icing of the flight gear of an aircraft-carried mine could prevent the opening of the parachute. No practical means for preventing such a casualty are provided at this time. On the other hand, no report of the actual occurrence of such a casualty has as yet been received.

Depth charges.—The mechanical or hydraulic features of depth charge arming and firing devices are rendered inoperative by icing, such as may occur either prior to firing from a projector or launching from a release track (by the freezing of rain or spray), or after water entry (due to chilled metal parts). Current instructions as to filling chambers with authorized antifreeze solutions should be followed when cold weather is expected. Depth charges having influence fuzes depend upon electrical dry cell batteries and are subject to the limitations discussed under that heading in subparagraph (3) above.

Torpedo tubes.—Special care required under cold weather conditions includes the following:

In destroyers multi-barrel, deck-mounted, trainable tubes (which covers all in general service use at the present time) are supplied with steam radiators of a "saddle-bag" type for heating torpedoes carried in the torpedo tube barrels. (See under "Steam

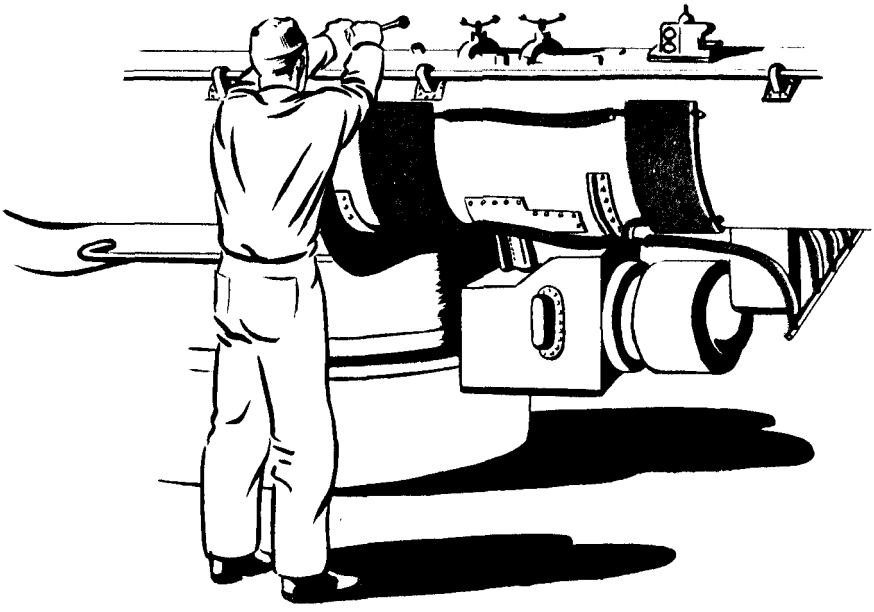


Figure 5–2.—Saddle-bag type heaters are used on torpedoes.

Torpedoes.") It is presumed that these heaters also have some small effect upon the temperature of torpedo tube mechanisms which are in immediate contact with torpedo tube barrels (such as tripping latches, gyro and depth setting gear boxes, etc.). However, this effect has not been determined experimentally and must not be counted on to afford protection against icing at any freezing temperature. Also, these same torpedo tube heaters have a single steam coil running around the lower edge of the training circle cover.

The purpose of this coil is to lessen the probability of ice closing the gap between fixed and trainable parts. Although this purpose is undoubtedly served to some degree, again no experimental data exists on the exact extent of protection afforded (although due to the relatively low heat capacity of the single steam coil, and to the low reliability of the present heater as a whole, the extent of such protection must be presumed small). Electric-hydraulic training gear drives on these tubes are powered by an electric motor of nominal 3 horsepower rating which can deliver 6 horsepower at peak load for at least 5 minutes. If current instructions as to use of hydraulic fluid suitable for cold weather operation are followed, 5 minutes operation of this motor (which is direct-

connected to the hydraulic pump or "A" end), before attempting to train the tube, should churn and warm the hydraulic fluid sufficiently so that full training torque can be developed.

If current instructions for replacing ordinary lubricants by cold weather lubricants in the training gear drive have been properly followed, the tube should then train properly at minimum open deck temperatures unless obstructed by solid ice. All shafting between units of gyro and depth-setting mechanisms are protected from the weather by gasketed housings and therefore will not normally be fouled by ice. It should therefore be practicable to set torpedo gyro and depth at minimum open deck temperatures if current lubricating instructions have been properly followed, and the operating handwheels or cranks and the setting spindle extensions are not fouled or obstructed by solid ice. Firing mechanisms on the tubes, and particularly the manual firing gear, are especially susceptible to becoming inoperative from cold weather effects. Impulse chamber doors, firing hammer rods, firing handles, and other exposed mechanical parts must be kept free of ice where it would impede their necessary motions. The manual firing cables, being housed in flexible tubing, will not be interfered with physically by ice, but current instructions for the disassembly and cleaning of these cables, for the flushing of their housing tubes, and for the subsequent filling of these tubes with

Figure 5–3.—Depth charge racks are highly vulnerable to icing.

lubricant suitable for cold weather, *must* be followed if these mechanisms are to remain operative at minimum open deck temperatures.

In addition to the precautions suggested by the foregoing, and to painstaking observance of all current instructions for cold weather lubrication and the use of generally applicable procedures for the removal of ice from deck installations, it is recommended that covers be left in place until the last practicable moment before action. The reason is that ice may usually be loosened more readily from a substance which is inherently pliable than from a rigid object; also because, as a last resort, covers may be forcibly ripped off "ice and all" more readily than ice can be removed from a cold metallic surface.

Make sure that torpedoes can be fired during an expected period of heavy icing, by training the tubes, before heavy icing immobilizes them, to a bearing where they can be safely fired and where the muzzle will be best protected from heavy icing. It is true that when tubes are so trained, torpedo stop tension links may be more apt to break than when the tubes are trained fore-and-aft. But, on the other hand, these links are designed to be at least twice as strong as necessary to withstand the accelerations for normal rolling up to 45° from vertical.

In PT boats torpedo tubes may be either fixed or trainable, depending upon hull arrangements. None of the tube mechanisms are expected to become inoperable from chilling alone. However, these tubes are fired by compressed air, and the impulse tank air pressure should be kept under observation and boosted if it drops below the proper firing pressure due to cold. If trainable, the training gear, due to its lack of housing, exposed location, and features of construction (threaded training nut moving along a threaded training rod) is the most vulnerable to icing of the tube mechanisms.

Other features (common to both trainable and fixed tubes) likely to be rendered inoperative by icing are:

1. The system of levers and connecting rod by which the torpedo starting mechanism is operated from the torpedo stop housing.
2. The local firing handle and the pilot-valve stem extension with which it engages (located at the main firing-valve).
3. The firing valve air vent holes (located in the stop mechanism housing).

Where tubes cannot be fired unless trained out, it is suggested that they be so trained before this is prevented by actual icing,

when action is anticipated under icing conditions. It is obvious that with the tubes trained out caution must be exercised in coming alongside a wharf or another craft. Although the difficulty is realized, it is considered probable that the other features vulnerable to icing (besides the training gear) can be kept operable as long as personnel can safely stay on deck.

In submarines, while at sea, no special cold weather procedures are indicated for torpedo tubes except the observance of current instructions for lubrication. However, if under any conditions a submarine is to be moored upon the surface, with no heat supplied to torpedo rooms during freezing weather, a small appropriate quantity of alcohol should be added to the fresh water which is carried in the firing valves as a hydraulic buffing fluid.

Torpedo launching racks.—It is not considered practicable to keep torpedo launching racks of present design reliably operable under icing conditions.

Torpedo release gear in aircraft.—This material is under the cognizance of the Bureau of Aeronautics.

Mine launching gear.—In submarines, mines are launched from torpedo tubes, the operation of which in cold weather is covered in a preceding paragraph. In surface craft, mine launching gear is under the cognizance of the Bureau of Ships. In aircraft, such gear is under the cognizance of the Bureau of Aeronautics.

Depth charge release tracks.—Depth charge release tracks and associated mechanisms are not apt to be rendered inoperative by chilling alone, but are highly vulnerable to icing, due to exposed location and large surface extent. With present designs and locations, no practicable means exists for keeping them reliably free from ice in freezing weather when they are continuously wetted by rain or spray. Even with wide distribution of electrical spot heating it has been found impractical to keep all parts operably clear of ice without heating other parts to a degree which is dangerous due to the explosive contents of the depth charges themselves. Use of warm sea water as in freeing decks of ice is one possibility.

Depth charge projectors.—This material is classified with gun mounts.

Depth bombs (aircraft).—Depth bombs are classified as ammunition.

AMMUNITION

Ammunition should be kept in protected storage, at temperatures not below the safe values where specified. Gun propellants should be maintained above 0° F. Navy service rocket motors are

subject to the same regulations as smokeless powder as far as storage temperature limits are concerned. Rocket and jato safe firing temperatures are stencilled on the rocket motor or jato unit. These temperatures are the actual temperature of the rocket motor or jato unit, and not necessarily the weather air temperature. If the temperature of the jato unit has been permitted to fall below the safe temperature, it is no longer safe for firing at any temperature. All aircraft gun ammunition is satisfactory for firing at round temperatures down to minus 65° F. (See OP 1480 for instructions on operational use of VT fuzes.)

DEMOLITION EQUIPMENT

The following precautions should be observed in the use of demolition equipment under cold weather conditions:

1. The safety fuse must be handled with care to prevent cracking. If practicable, it should be carried under a coat so that it will be warmed by body heat. It should not be carried uncoiled, since a fuse uncoiled in cold weather cracks readily and becomes unusable.

2. Friction tape loses adhesion in temperatures below 35° F. Taping caps to primacord becomes difficult and could result in misfires. For this reason, detonating cord initiators Mk 2 should be used exclusively during cold weather for securing caps to primacord. Equal quantities of caps and initiators should be carried to avoid the use of tape.

3. Detonating cord, reinforced (primacord) has been found to be deficient in cold weather in that its gummy property is lost and knots cannot be drawn tight. A good tight knot will spring open the instant hand pressure is released. This can be avoided to some extent by substituting the clove hitch for the girth hitch. The former binds on itself and does not depend upon the primacord's cohesion to keep the knot tight. Square knots are not dependable and the clove hitch should be substituted whenever possible.

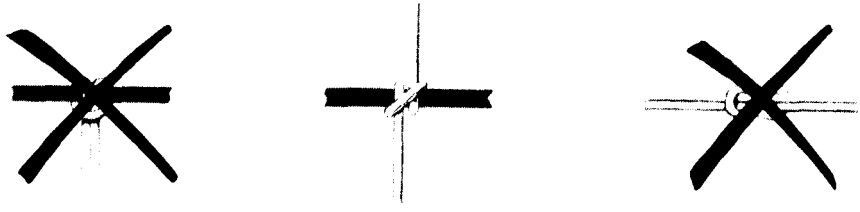


Figure 5-4.—Substitute clove hitch in primacord.

4. Electric firing cable is easily cut by rock fragments and difficult to mend in the cold. In addition, the wire loses some of its flexibility.

5. The galvanometer should be carried under outer clothing since its cell is affected by low temperatures.

6. In the use of the fuselighter, waterproof, M2, care should be taken to avoid failure due to faulty pin pulling. When hands are covered with gloves, there is a tendency not to pull the pin perpendicularly to the fuselighter, thereby breaking off the tip end of the pin leaving the striker locked in position.

7. Tests indicate that the demolition firing device Mk 13 Mod O may tend to fire early when exposed to low temperatures.

8. The Mk 135 Mod O charge composition C–3 loses much of its plasticity at 30° F. after a period of 10 minutes. It can be hand molded at that temperature only after working it for several minutes by bending the Mk 20 charge across the knee. Even after this treatment, the explosive is lumpy and difficult to mold in cracks.

GOING HOME PRECAUTIONS

Lubrication.—Cold weather lubricants or diluted lubricants should be replaced with the specified service lubricant as soon as conditions permit. Where a lubricant classed for extreme emergency cold weather use has been applied (in accordance with section X of NavOrd OD 3000), the emergency lubricant should be removed and relubrication should be accomplished with the specified lubricant immediately after leaving the cold weather area. Substitute lubricants listed for extreme emergency use generally provide less protection against corrosion and are easily removed by water spray or wash and, having lower viscosities, are deficient in desired lubrication properties as normal temperatures are approached.

Cooling systems.—Normal coolants may be substituted for the antifreeze solutions when convenient after returning to normal temperatures.

Hydraulic power transmission systems.—In general, it will not be necessary to replace the power transmission fluid 51F21(Ord) when returning to normal temperature areas. However, if greater leakage is experienced at higher temperatures, 51F23(Ord) may be substituted for the 51F21(Ord) fluid. A flushing is not required when changing unless the fluid to be drained, or the operation of the system indicate that dirt, sludge, or other impurities are

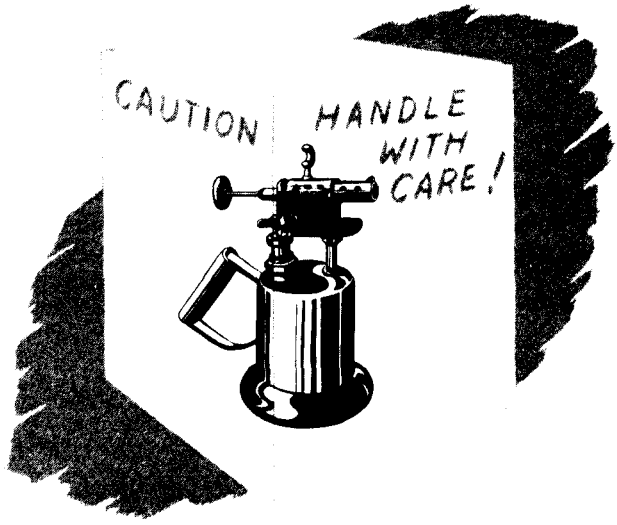


Figure 5–5.—Torches should be used with extreme care.

present. See NavOrd OD 3000 for instructions on power transmission fluids.

DE-ICING AND ANTI-ICING METHODS

1. Instructions for ordnance optical equipment are contained in the applicable ordnance pamphlets.

2. Information on anti-icing for underwater ordnance equipment is included earlier in this chapter.

3. No special methods have been developed to date for de-icing and anti-icing of other ordnance material. For topside equipment, protective covers should remain on the equipment as long as practicable. For removing accumulations of ice from metal shields or from protective covers, when special de-icing and anti-icing means have not been provided, washing with warm water is the preferred method. Chipping or use of torches should be done with considerable care to avoid damage to equipment. Never do this work in the presence of ammunition. Use of unauthorized chemicals to remove or prevent formation of ice on ordnance equipment is prohibited. The quickest way to remove ice is by applying heat. As experience is gained in cold weather operations, means for solving this problem either by adaptation or provision of heaters and improved coverings will be evolved.

SUMMARY

Major sources of difficulty in cold weather operations are due to:

1. Congealing of non-cold-weather lubricants.
2. Formation of ice on exposed equipment. When practicable, accomplish cold weather relubrication prior to entering low temperature areas (0° F. and below, in general).

Avoid an excessive amount of lubrication.—On return to normal temperature, cold weather lubricants or diluted lubricants should be replaced by the specified service lubricant as soon as conditions permit. Where a lubricant classed for extreme emergency cold weather use has been applied, the emergency lubricant should be removed, and relubrication should be accomplished with the specified lubricant immediately after leaving the cold weather area.

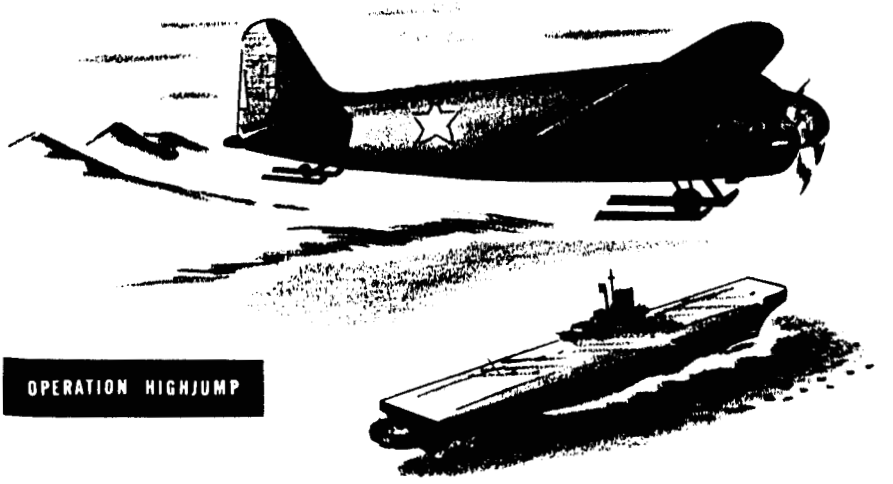
Protective covers should remain on exposed equipment as long as practicable. For removing accumulations of ice from equipment or covers, when special de-icing and anti-icing means have not been provided, washing with warm water is the preferred method. Periodic exercising of equipment may be necessary to insure ability to function satisfactorily.

Condensation, which sometimes forms inside of shields, should be wiped off as frequently as practicable, and should not be permitted to drop or seep into electrical equipment.

It may not be found practicable, particularly for some types of present service equipment, to provide automatic means for elimi-

Figure 5–6.—Avoid excessive lubrication.

nating all difficulties arising during cold weather operations. It will be expected that ships' crews will adapt themselves to such conditions and take any steps necessary and practicable to keep ordnance equipment operating satisfactorily.



CHAPTER 6

AIRCRAFT OPERATIONS

"The great circle route from any point in North America to any point in Asia which combines (1) shortest flying time (2) maximum flight over land (3) minimum flight over water is a great circle route through the Arctic."—Owen Lattimore.

The possibility of exploring polar areas by air occurred to aviators as a natural result of their experience with aircraft. The advantages of this most modern mode of travel early became quite apparent to others in polar work. It remained to be seen whether aircraft could be operated under the extreme weather conditions found in polar regions. In 1923, the Bureau of Aeronautics, in official recognition of this fact, requested and received Presidential approval to send the new rigid airship *Shenandoah* to the Arctic. It was planned to base the airship on tenders at Nome, Alaska, and from that point carry out mapping and reconnaissance flights. If it seemed feasible, these flights would be followed by one over the top of the world to Spitsbergen where another tender would be ready to receive the airship. Torn from her mooring mast in a heavy gale at Lakehurst in January 1924, some doubt of the ability of the airship to withstand the arctic storms arose, and, although advance units were already on the way to Alaska, the entire plan was cancelled.

In that same year of 1924, the Bureau of Aeronautics gave Lieutenant Davidson leave to act as aviator for Amundsen, who then was organizing a polar expedition. Because funds could not be raised to finance the exploration, it was cancelled and Davidson, who had already left the bureau, lost his chance to be the first to demonstrate the usefulness of aircraft in polar exploration.

In September of the same year, the U.S.S. *Richmond* took her UO–1's up to Greenland where the pilots made reconnaissance flights in search of suitable landing areas for Army pilots when making an around the world flight. In the next year, one of the *Richmond* pilots, Floyd Bennett, was in the aviation party, under command of the then Lieutenant Commander Richard E. Byrd, attached to the MacMillan expedition bound for exploration of the north Greenland coast. This expedition sailed from Boston on 17 June aboard the *Peary* and was joined by the *Bowdoin* at Wiscasset, Me. After a voyage of 3,000 miles, the expedition on 1 August reached its base at Etah.

The three Loening amphibians (OL–2) were removed from their crates on deck and floated ashore. They were beached without mishap and by the 4th were assembled and ready to fly. Between that date and 20 August, when the end of the arctic summer made it necessary to withdraw from the area, a total of 76 hours of flying time had been logged. Extensive flights over Ellesmere Island and Grinnell Land covered altogether about 30,000 square

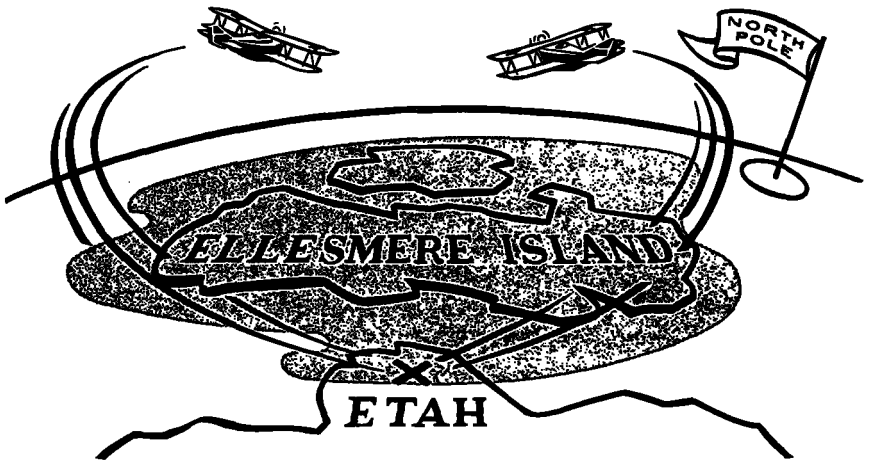


Figure 6–1.—Loening amphibians over Ellesmere Island.

miles of territory, much of which was previously unexplored. During this time only one forced landing occurred and that in open water only a short distance from base.

AIR STRATUM

Several peculiarities of arctic flying were observed. Over the Greenland ice cap a comparatively warm stratum of air was encountered at 7,000 feet and a bitterly cold one at 11,000. As was expected, the navigation problem was different from any before experienced. With the magnetic pole to the south, and the magnetic forces weak, such strange things happened to the magnetic compass that it was practically useless. At times it indicated east for all headings of the plane, and on one occasion Byrd made good a course of 254 true by setting a compass course of 012. The induction compass was found to oscillate slowly after take-off, but a steady course was flown and it soon settled down and gave fairly accurate indications. Byrd was more enthusiastic about the sun compass, devised for the expedition by A. H. Bumstead of the National Geographic Society which, although useful only in clear weather, was extremely accurate.

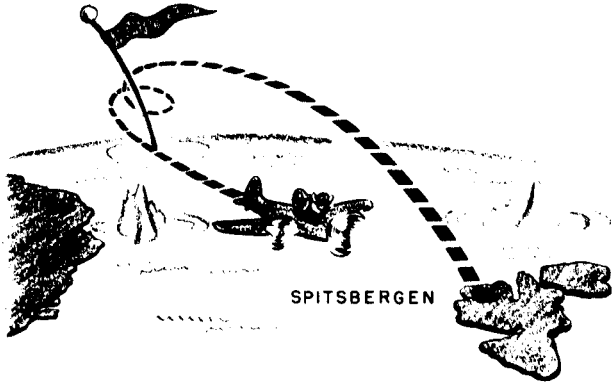


Figure 6-2.—Bennett & Byrd fly over the North Pole.

These experiences proved to Byrd the advantages of aircraft in polar exploration. Not long afterward he and Floyd Bennett, while on leave from the Bureau of Aeronautics, flew the *Josephine Ford*, a three-motored Fokker monoplane, from Spitsbergen to the North Pole. In this historic flight, most of the navigating was

done with the instruments tried out the year before at Etah. On 9 May 1926, they flew over and around the Pole, the first to reach it by air, and on the return flight hit Spitsbergen "on the nose."

In the same month, the Italian aviator Umberto Nobile accomplished what the Bureau of Aeronautics had planned in 1923 when he piloted the airship *Norge* across the Arctic Ocean to Alaska. Amundsen and Lincoln Ellsworth were passengers on this flight. Two years later, Byrd was off on the first of his expeditions to the Antarctic. Here again, he demonstrated the usefulness of aircraft in polar exploration.

All of the foregoing were expeditions intended to reach or explore geographic areas. While much was learned of the aviation requirements, the primary purpose was exploration rather than experimentation. They demonstrated clearly the feasibility of operating aircraft under extreme conditions, and the Navy became interested in a further study of the requirements. For one thing, the aerial mapping of the territory of Alaska was on the agenda and because much of it lies above the Arctic Circle, polar weather conditions would be encountered. For another, aircraft carriers would be more effective if they could operate in any kind of weather, and to increase their effectiveness it was necessary to learn the nature of the special equipment and operating techniques which would be required to meet conditions.

The first carrier to conduct such tests was also the Navy's first carrier, the U.S.S. *Langley* (CV–1). For the first 10 days of December 1931, she operated in the area between Cape Cod and Bar Harbor, encountering temperatures below freezing on 6 of the 10 days. Flight operations with O3U's and F3B's were conducted on 4 days, but tests of flight deck gear operation, engine starting apparatus, and cold weather clothing for pilots and deck hands were made every day. This test brought out clearly how little was known about cold weather requirements and emphasized the need of much preliminary work before another practical test could be made advantageously.

It was not until the winters of 1935 and 1936 that a carrier was again used, this time the *Ranger* (CV–4). Even before she was commissioned, plans were being made but in December 1934 when the shake-down trials revealed the need for additional work on her gasoline tanks, the plans were called off and the *Ranger* went into the yard instead.

This left her air group free to conduct some of the tests ashore which were carried out during January and early February 1935.

Several flights were made from Norfolk to Hartford and Buffalo. During these flights various types of starting equipment were tested under the operating conditions of cross-country flight in temperatures reaching as low as 2° F. and most of the time below the freezing point. In these temperatures it was found that pyralin cockpit enclosures and celluloid computer discs cracked; that enamel tended to crack and peel, while factory finishes and aluminum paint did not; and that radio receivers lost some of their sensitivity. Various types of flight clothing were again tested and recommendations for reducing its bulk and improving its design to meet practical requirements were made. Covers for protecting the aircraft from cold and frost were also tested and improved. Perhaps, the greatest effort went into testing starters and heaters because once the engine was started it was really not much more difficult to fly in low temperatures than in higher ones.

CARRIER TESTS

New information was applied in the laboratory tests which followed and in the preparations which began immediately for another carrier test the next winter. On the basis of meteorological data, Cook Inlet in Alaska was selected as the spot most likely to produce the temperatures and weather required and on 22 January 1936 the *Ranger* arrived in that area with 23 planes aboard. Tests of arresting gear, clothing, and engine starting were to be continued, and in addition the general operating efficiency of the carrier was to be measured.

For over a week the weather was mild and did not drop below freezing until 3 February. From that day until the 12th, the average temperature was 17° F., and the lowest of 10° F. was recorded on the 10th. During that time starting and warm-up operations were conducted daily and 5 test flights were made. The lowest average air strut temperature for these flights was 1.4° F. and the lowest recorded was minus 7.6° F., at 16,000 feet. One blizzard was encountered which lasted 32 hours, and, although there was a 40-knot wind across the deck, the snow covered it in drifts to about 2 feet.

Tests of engine starters showed that much progress had been made. The commanding officer of the *Ranger* reported that this problem could be considered solved down to temperatures of 10° F. Launching and recovery of aircraft was affected only by the condition of the deck. Deck gear worked well under all conditions, but clearing the deck of snow and ice took time. The out-

standing problem encountered was icing and frosting on the wings and the packing of snow and freezing ice over external fittings of the plane. Because planes could not be launched in these conditions, they had to be cleaned and only by taking them back to the heated hangar where they could be dried before being again exposed to cold air, could they be put in condition for safe flight. Once they were in the air following a normal takeoff, no unusual cold weather effect was noted.

Tests of carrier operating efficiency were felt inconclusive because a full complement of planes was not aboard. The difficulties of removing ice and frost, although time consuming, were quite simple with only a few planes because there was always space to move them about, but to do this with a full complement of aircraft would be a different matter. Generally this test showed that cold weather in itself was no hazard to flying or to carrier operations. It was apparent that the cold, bad weather experienced in the area along with its snow, ice, and frost, made operations a difficult and serious problem and that additional study of the problem was required.

Before other tests could be made, the Navy became fully occupied with the duties of neutrality patrol. The next time carriers operated in cold weather areas, it was not on an experimental basis but under the conditions approaching war. After completing shakedown trials in 1940, the *Wasp* (CV–7) was assigned to the Atlantic Squadron and became responsible for patrol of coastal waters from Nova Scotia to the Lesser Antilles. During the winter of 1941, this ship operated in the North Atlantic encountering severe weather in which difficulty resulting from the formation of ice crystals in the gasoline system caused delays in refueling planes. The *Long Island* (CVE–1) operated off Argentia during the month of January 1942. Both experienced difficulty with ice and frost on the wings and caked snow and ice on the control surfaces of the aircraft. It could be removed only by sending the planes down to the hangar deck. No difficulty was experienced with the deck and arresting gear.

COLD WEATHER OPERATION

From April through July 1943, the *Ranger* came in for some more cold weather while operating in the Argentia area. In October of that year she appeared on the other side of the Atlantic, launching strikes on German shipping at Bodo, Norway, just above the Arctic Circle.

Figure 6–3.—Ranger attacks German shipping—1943.

In May of the same year, the *Nassau* (CVE–16) provided support for the landings on Attu in the Aleutians. This was not cold weather flying, but it was bad weather, perhaps worse than any encountered in the Atlantic. After the initial bombardment, the *Nassau* provided the only air support for the landings and operated as close in as 10 miles from shore to take full advantage of any break in the heavy fogs characteristic of the area. Even then, only 179 sorties were flown and weather was responsible for the loss of 8 planes and 6 pilots.

These were the only instances during the war in which our carriers operated under what can be considered cold weather conditions. Through most of the war period patrol planes operated from bases in the Aleutians, Argentia, Greenland, and Iceland. The war was barely over when the Bureau of Aeronautics issued its technical note on "Instructions for Cold Weather Operations of Naval Aircraft." These instructions informed naval aviators that most of the difficulties of cold weather operations were those encountered on the ground, aboard ship, and on the water before and after each flight. Once the plane was in the air the problems were almost identical to those encountered in warmer climates.

OPERATION FROSTBITE

Early in the next year (1946) carrier tests were resumed during a cold weather cruise designated *Operation Frostbite*. The U. S. S. *Midway* (CVB–41) and three destroyers made up the task group.

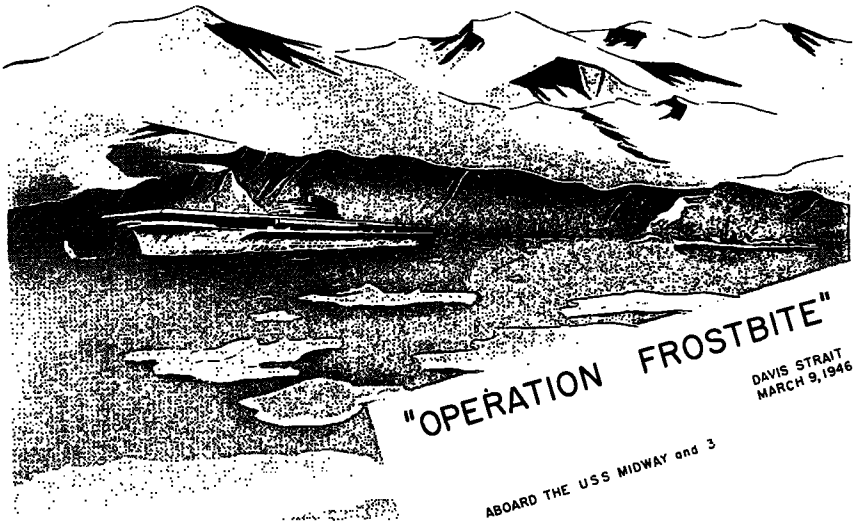


Figure 6–4.—Operation Frostbite.

The task group attained highest north at the 63rd parallel in Davis Strait on 9 March. Later the ships hauled to the south to find the low temperatures required and operated at about the fifty-eighth parallel until 21 March. Temperatures between 14° and 41° F were encountered. The lowest mean temperature for a given operating period was 17°. The following planes were aboard the *Midway*: 27 F4U–4, 25 SB2C–5, 2 F6F–5N, 2 F6F–5P, 2 TBM–3, 1 F8F–1, 1 FR–1, and 1 helicopter (HNS–1). Air operations during the period were limited by snow, rain squalls, and high seas. However, flights were conducted whenever weather permitted. As a matter of precaution against delay in rescue, all flights were contact, with aircraft kept within gliding range of the carrier. Training and exercises in rendezvous, glide bombing, break-up, and strafing were carried out.

As a result of the cruise it was concluded that normal carrier operations can be conducted at temperatures above 25° F. with a relatively untrained crew and air group, and that, as training and experience accumulated, operations at lower temperatures would be possible. Snow removal equipment, including tractors equipped with snow plows, was adequate to clear the deck within two hours, only half the time required by the *Ranger* 10 years before. In all respects, the operation showed that much had been learned and

that it was bad weather, rather than cold, that interfered with flight operations. Much was learned of the problems of predicting weather in the higher altitudes and of the effects of nearby sea, land, and ice areas, and cold and warm water currents on the weather in the Davis Strait, in particular.

The importance of the arctic regions in future strategy was becoming more apparent. In cooperation with the Army Air Forces and the Royal Canadian Air Force, other expeditions were outfitted and sent to learn more about meeting the operating requirements of these areas. Toward the end of 1945, a chain of Loran stations was established in northern Canada for experimental purposes and to aid the units participating in *Operation Musk Ox*. This operation covered a series of expeditions during 1945 and 1946 in which Canadian and United States military services participated. Although it was primarily a ground force experiment, naval observers were along to study how naval survival gear stood the test of a long overland trek.

Operation Nanook, a joint United States-Canadian project, took place from July to September 1946 for the purpose of adding to the knowledge of weather and navigational conditions, the collection of scientific data, and to provide training for personnel. In Task Force 68 was included the tender U. S. S. *Norton Sound* (AV–11) with PBM's aboard. These planes were used to spot breaks and leads through the ice and made long reconnaissance flights over Greenland, the Canadian Arctic, and contiguous sea areas. Flying along and beyond the coast of the northernmost land areas, the navigators found the electric gyrocompass a reliable instrument.

Late in the same year, the Navy launched *Operation Highjump*, the largest expedition ever to undertake polar exploration. It was in effect a continuation of *Operation Nanook* and carried the same task designation, Task Force 68. Preliminary planning was done during Nanook by the men in command, many of whom were transferred to the new operation. Objectives for Highjump included: training of personnel and testing equipment, testing the feasibility and developing the techniques for establishing, maintaining, and utilizing air bases in the high latitudes; adding to existing knowledge of the geography of the Antarctic.

Forces finally assigned consisted of 13 ships including the U. S. S. *Philippine Sea* (CV–47), U. S. S. *Currituck* (AV–7) and U. S. S. *Pine Island* (AV–12). Aircraft assigned were: 6 R4D's carried on the deck of the carrier, 6 PBM's aboard the tenders, 2 J2F, 2

SOC, 1 JA, and 2 OY–1, and 6 helicopters, HO3S and HOS. Naval and Marine personnel totalled over 4,700 officers and men, and others included Army and civilian observers and representatives of the press and radio. This force was absent from the country from December 1946 to June 1947. During this time about 1 month, from 19 January to 23 February, was devoted to support and operation of a temporary airbase ashore on the continent of Antarctic at Little America.

Equipped with a combination sheel and ski landing gear, and with jato, the R4D's took off from the carrier deck without difficulty. Once ashore, and with the wheels removed, no serious problem was encountered in operating from atop the Ross Barrier. The planes of the force rolled up a total of 650 hours of flight time much of which was spent in mapping and photo-reconnaissance. With the R4D's concentrating on flights over the continent and the PBM's over the coastline, over 70,000 photographs were taken of 1,500,000 square miles of territory and 5,500 miles of coastline. The area covered was equal to about half that of the United States and the coastline distance almost equal to the combined Atlantic, Pacific, and Gulf coasts of our country.

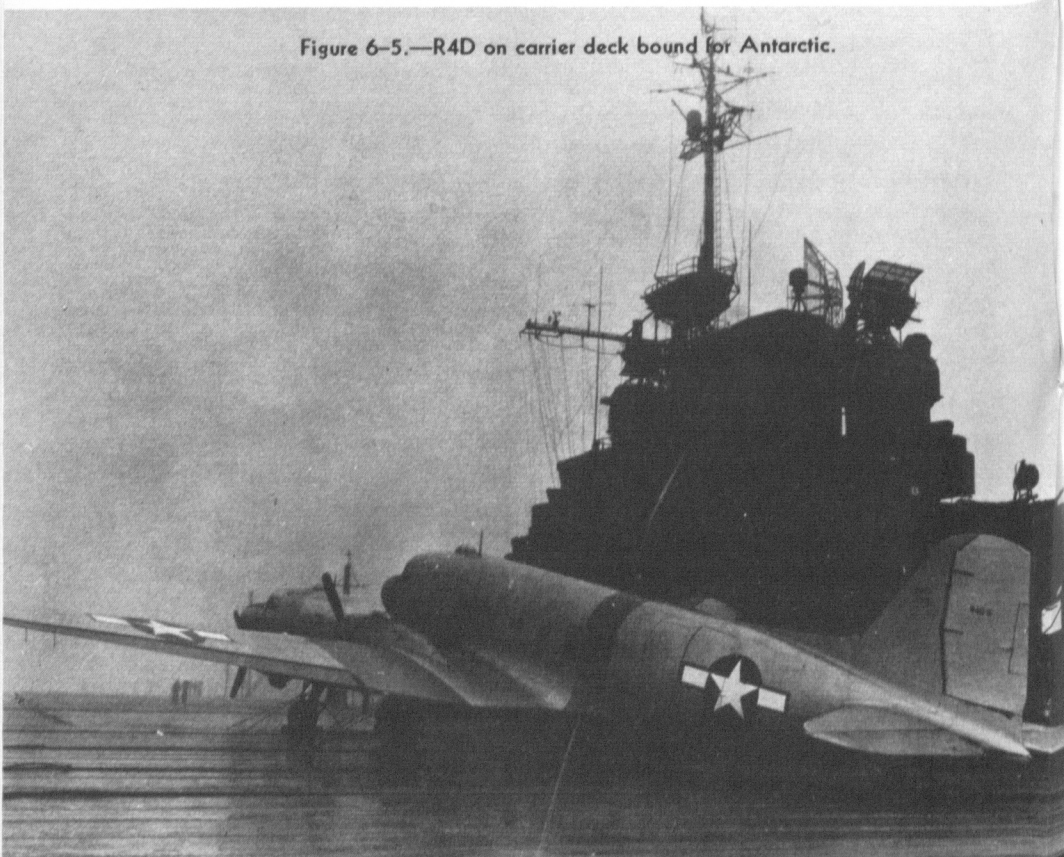


Figure 6–5.—R4D on carrier deck bound for Antarctic.

In an early reconnaissance flight, a PBM was caught in bad weather and crashed, killing three of the nine passengers and crewmen aboard. Two helicopters were lost in water landings without injury to personnel, and one PBM was swept overboard in heavy weather. One R4D had an engine failure and one PBM developed a gas leak requiring feathering of the propeller, both shortly after take-off. In each case normal landings were made. Except for these two minor incidents, there were during the entire period no accidents caused by engine or materiel failures.

These operations provided further proof that polar flying is feasible and possible. Experience once more bore out the fact that the problems of operating aircraft are not basically different from those encountered during the winter months in northern United States, although lack of adequate facilities for service and repair make the problem more difficult. Greatest hazards to flight were low visibility, ice, and frost. Ice was generally present in the clouds particularly at their base. With de-icing equipment only partially effective, the only safe solution was to avoid the clouds. High winds drifted the surface snow and made visibility poor, blending the terrain with the sky and wiping out the horizon so that the general effect was like *flying in a bowl of milk.* The absence of radio aids and lack of well charted landmarks added to the navigators problem, already complicated by weak magnetic forces.

During the same year two much smaller expeditions were sent to the opposite ends of the earth. From July to September 1947, Task Force 68 composed of three small ships operated in the Arctic in cooperation with the United States Weather Bureau, to train personnel, obtain scientific data, and specifically to supply weather stations established in the Canadian Arctic area. Task Force 39, composed of two ice breakers with helicopters aboard, was sent to the Antarctic in December 1947. For about 2 months of the period from December 1947 to March 1948 it operated in and about the Antarctic ice pack, gathering scientific data and adding to our knowledge of pack conditions.

The following summer another expedition was sent to the Arctic. From July to September 1948 Task Force 80, composed of the cargo ship *Wyandot* with the icebreakers *Edisto* and *Eastwind*, operated between the islands to the north of Canada. With the cooperation of the Canadian Government and the United States Air Force, this naval task force made further surveys of the area and conducted studies of arctic conditions. The main purpose

of the expedition was to re-supply the jointly operated weather stations in the area and to locate sites for others to be established later. The four helicopters (HTL) operating from the ice breakers logged over 200 hours in reconnaissance and utility flights and the two RB-17G's of the Air Force conducted 25 flights, the longer ones averaging from 8 to 9 hours. As an indication of how much past experience has helped in solving the problem of the Arctic, two of the three ships of this force penetrated beyond the eighty-second parallel, farther north in the Western Hemisphere than any ship up to that time.

Interest in polar areas continues. Experience through the years has resulted in the accumulation of much useful knowledge of the requirements of air operations in cold weather. Through all the tests we find the greatest difficulties being encountered on the ground, although developments of better equipment have done much to simplify them. Cold weather flying cannot even yet be looked upon as a routine matter, but as in all flying, once the dangers and difficulties are known, proper precautions can be taken to overcome them. The continuing program of investigation and testing is directed toward this end.

MATERIAL ASPECTS OF NAVAL AIRCRAFT OPERATIONS

Since its first aviation expedition with 3 Loening amphibians in 1925, the Navy's experience with aircraft operations in polar and other cold weather areas had broadened to include all of the heavier-than-air types—carrier aircraft, seaplanes, land planes, and helicopters. Each type of aircraft has had its peculiar prob-

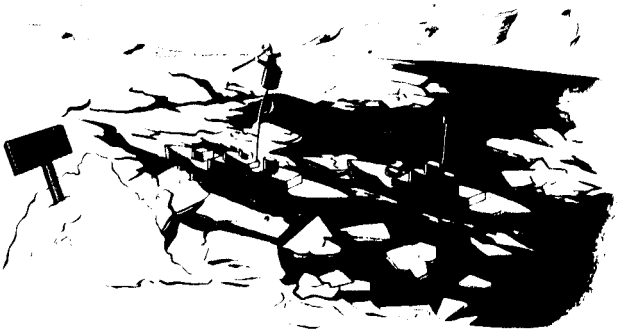


Figure 6–6.—Task Force 80.

lems arising from differences in operating base; yet many problems of flight have been found common to all types. Experience throughout these operations has shown that, while none of the problems was simple, the most serious occurred between flights while the aircraft were on the ground, water, or carrier deck.

Another of the lessons learned, is that the problems encountered on the more recent operations are not essentially different from those met during the earliest ones. The changing character of operations has developed new aspects of old problems. New problems arise only as the field of operations is extended, new techniques are tried, or as new equipment is introduced. Generally, the development of new techniques and improved equipment has changed past problems rather than eliminated them. They remain factors to be considered and guarded against.

Navigation has been outstanding among the problems common to the operation of all types of aircraft. Although enough has been accomplished in this field to make accurate navigation possible, there is still much to be done before it can become as relatively simple as over well charted and marked areas. Polar navigation is still no field for the novice. In the 1925 expedition to Greenland the unreliability of the magnetic compass for aerial navigation was well demonstrated. A compass of the induction type—that is, one which depends on the current generated in a coil revolving in the earth's magnetic field—was found much superior to the types of aircraft compasses, and entirely satisfactory for local flights. For longer flights it was necessary to navigate by the celestial method. Later Byrd found the sun compass accurate and adaptable to the problem. Since this type of navigation required clear weather to take observations, it was necessary to rely on dead reckoning most of the time. The problem had been simplified with the development of the gyrocompass, its adaptation to the peculiarities of the polar regions, and the development of the grid method of plotting courses in the higher latitudes. Radar has been used with success, but is not reliable under certain conditions. Such radio stations and loran networks as have been established have made the air navigator's work easier. There remains a lack of well marked charts. Although this deficiency will be corrected as exploration and air mapping increase knowledge of the various areas, the scarcity of prominent terrain features will make it impossible to provide detailed charts for only the more important and strategic areas.

ADVERSE WEATHER CONDITIONS

Adverse weather restricts flying in any area. In polar areas it is especially necessary to be familiar with conditions which may affect flight operations. Storms are violent and likely to come up with little warning. Icing conditions almost always exist and as long as de-icing equipment remains only partially effective, icing can be overcome best by avoiding those altitudes and areas in which it is most likely to occur. Extensive fogs and low overcast are natural products of polar areas. At times, dry surface snow raised by violently high winds tends to obscure the ground and the horizon, making visibility poor and obliterating all references to surface and sky. Any of these conditions make flying dangerous, but a thorough knowledge of the hazards involved coupled with observance of proper cautions will help to reduce much of the mystery of arctic flying.

Cold weather operations require more careful inspection of aircraft, closer adherence to prescribed procedures, and more frequent servicing than comparable operations under more moderate climate conditions. Closer attention to detail is necessary not only because of the greater strain placed on the aircraft by low temperatures, but also because of the fatal consequences likely to follow mechanical or material failure in flight. Low temperatures increase the difficulty of performing these tasks and also increase the time required to do them. The amount depends largely on the protection afforded personnel and the kind of facilities furnished them.

The use of external power units, engine heating and starting apparatus, wing and engine covers, ice retardents, and other materials and gear used to protect aircraft for flight. For R4D's used in Operation Highjump this time averaged 3 hours per large plane. This factor combined with the rapidity with which weather can change often results in the loss of flight time when the weather clears unexpectedly and in additional work for the ground crews when the weather closes in. Due to short periods when flying weather can be considered good, there is a major problem in maintaining operational readiness of aircraft to quickly take advantage of all such opportunities.

OTHER COLD WEATHER PROBLEMS

Other problems of cold weather operations for all types of aircraft require provisions for the comfort of flight personnel with adequate cabin heat and proper flight clothing, selection of sur-

vival and emergency gear along with instruction in its proper use, and the provision of rescue services.

One of the most difficult and persistent of all the cold weather problems is starting the engine. Discussion of the merits and efficiency of equipment designed to simplify and facilitate engine starting fills the reports of cold weather operations. Practically everything has been tried. More effort has been expended on this one phase of cold weather operations than on any other. As the result of past efforts, equipment has been developed which is considered reliable for use in temperatures as low as 0° F. Below this temperature a real problem exists, particularly in the case of carrier aircraft and helicopters on icebreakers.

Two phases of the engine starting operation are normally required. First, prior to each shut-down of the engine, dilution of the entire lubrication system must be accomplished. This is done by introducing raw gasoline into the system and diluting the oil to the extent required. By reducing the viscosity the oil will not congeal after the engine has been allowed to cool. Then, to simplify and ensure starting, the engine must first be warmed to a temperature where it can be turned over easily. Ordinarily this is done by the application of heat from some external source and by heating the oil either in the crankcase or before it is poured into the engine. With the help of additional power the engine is then turned over and primed to start combustion. Once started, the engine is warmed up slowly under its own power. Although the general types of equipment and methods used have remained the same, the specific items have changed considerably.

HEATING DIFFICULTIES

In tests aboard the U.S.S. *Langley* in 1931, difficulty was encountered with all methods of heating the engine known at that time. Live steam was unsuccessful. The oil immersion heaters then provided required 2½ hours at full heat and 3 hours at half-heat to bring cold lubricating oil up to operating temperature. Inertia starters performed satisfactorily only at temperatures above freezing. Below freezing external types were required although their performance was somewhat deficient. Some of these difficulties came about because much of the equipment was provided without proper fittings and in some cases was incompletely assembled or of poor quality, but others undoubtedly came from lack of previous experience and adequate preparation. Tests

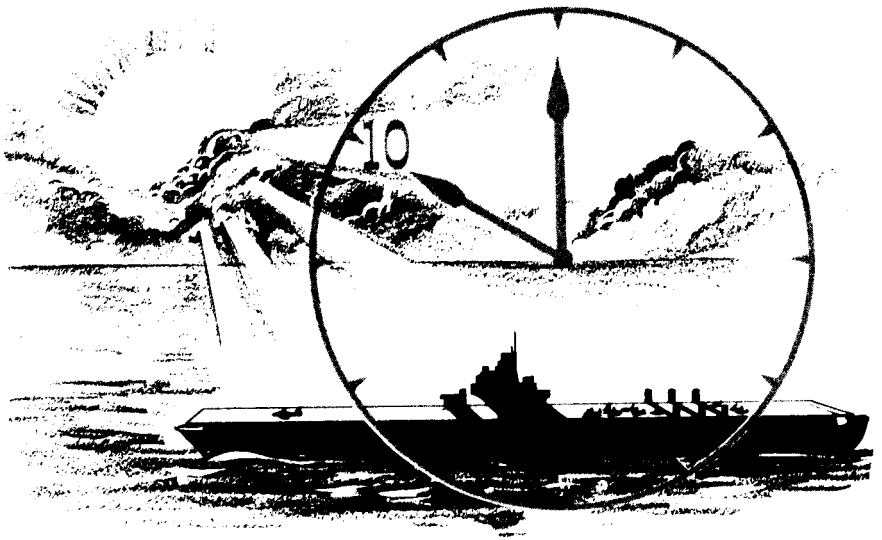


Figure 6–7.—Ranger waits for 1000.

conducted by U. S. S. *Ranger* squadrons ashore in 1935 and aboard ship in 1936 were more promising in this respect and when completed were the most extensive carried out before the war.

In tests ashore and aboard ship, the equipment used seemed reliable for temperatures down to 10° F. Even in the short interval between these tests, however, there was some change and improvement in equipment. In cross country and other tests ashore during cold weather, propane heaters installed in the aircraft were used for preheating. These proved to be unsatisfactory because their location inside the fuselage did not permit adequate air circulation and added what was felt to be unnecessary weight to the aircraft. In the shipboard tests detachable heaters were used with success but some question arose as to the need for preheating in carrier operations.

The use of propane as a primer was discarded in 1936 in favor of a gasoline priming system developed in the cold test room at the Naval Aircraft Factory. This system, using spray nozzle jets to each cylinder, was controlled from the cockpit. It was entirely satisfactory and considered to be one of the most significant developments of the early tests.

Oil immersion heaters were found in both tests to reduce the period of warm-up and a new special oil proved an excellent cold

weather engine lubricant. This was too early to know the results of contemporaneous Army experiments with oil dilution, but it was recommended that further work in the development of cold weather oils be postponed until more about oil dilution was known.

ENGINE COVERS

Engine covers, serving the dual purpose of protecting the engine from the cold and of retaining heat during preheating, were considered unsatisfactory in both tests. They were poorly fitted and, with the electrical heating inserts used aboard ship, were bulky and hard to handle.

Starters of the cartridge and inertia types were used. A large number of mechanical failures made the cartridge type unsatisfactory in the shore tests. However, experience aboard ship was the opposite. Inertia starters lacked power and external units were required to turn over the engine. In both tests it was agreed that external units were essential for cold weather starting.

With this experience, laboratory tests continued the development of equipment and when carriers operated in cold weather areas during the war they were equipped with types quite similar to those in use today. Herman Nelson preheaters were used on board the *Ranger* and the *Wasp* and found superior to the Colvinex electric type. The York nacelle type was under procurement at the time and later this also proved to be reliable. A Waukesha generator powered by a gasoline engine gave satisfactory performance as an auxiliary power unit for engine starting.

Cold weather operating experience was summarized shortly after the war in BuAer Technical Note 84–45. This note contained instructions for handling aircraft aboard ship, aircraft operations, maintenance of aircraft and equipment, and protection of personnel. The following paragraphs summarize briefly its information on engine starting equipment.

EXTERNAL HEATING

The time required to preheat an engine depends on several factors—air temperature, size of engine, output of heater, force of wind over engine, efficiency of engine cover, and amount of oil dilution—but it will usually require ½ to 1 hour's time.

The application of external heat is unnecessary in temperatures down to zero if the engine oil has been properly diluted.

ENGINE HEATERS

The York heater has an electric motor operating a fan which furnishes the air for combustion and circulates the heated air. This unit has an output of about 75,000 B. t. u. per hour. It has an integral fuel tank and can be mounted either on deck, on the ground, or on the engine nacelle.

The Herman Nelson heater has a single cylinder 4-cycle gasoline engine operating the fan and has a rated output of about 250,000 B. t. u. per hour. It is rather large and bulky but is the most satisfactory, completely self-sustained heater in use by the Navy. Because it supplies uncontaminated air it is also suitable for heating spaces occupied by personnel, provided the exhausts have an outside duct.

EXTERNAL AUXILIARY POWER

Some such unit is a "must" for cold weather operations, and should be an auxiliary power plant rather than a battery cart. Suitable types are: Homelite C–10 unit (a combination power plant and battery cart), the Waukesha, Onan, and Homelite (unit without the battery cart).

After the war a series of tests showed the general reliability of Technical Note 84–45 for maintenance and operation of aircraft under cold weather conditions. In March 1946, tests of engine heaters were conducted aboard the U. S. S. *Midway*. They were found unnecessary in the temperatures encountered in that operation—a low of 14° F. The Herman Nelson heater was found reliable but too large for use on a carrier deck. In this respect the York type was more useful but not sufficiently rugged for heavy duty. Three types of auxiliary power units were tested. Of these the Homelite C–10A was considered best for flight deck use because of its ease of handling. The Waukesha and the Hartmann gave satisfactory performance but were too heavy and unwieldy to maneuver easily on the flight deck. Insulated engine covers were heavy, bulky, and hard to handle. This condition was made worse when the covers absorbed the moisture resulting from melting ice and snow. A plywood cover designed to fit over the cowling entrance was equally efficient and much easier to handle. Oil dilution systems proved satisfactory. Inertia starters proved unreliable but direct cranking starters were adequate in all respects.

Experience on Operation Highjump furnished further proof of the above. Herman Nelson heaters operated perfectly under

all conditions ashore and aboard the seaplane tenders. Auxiliary power units of the Lawrence type were satisfactory for use aboard the tenders, but the Homelite failed to provide enough power to start the R4D engines. Engine covers of the insulated type were unsatisfactory because of their bulk, and again plywood covers proved to be a simpler and more useful design. The standard Navy-issue lube oil 1100 series gave good performance under all conditions, and made oil dilution, for the PBM's, unnecessary.

Later operations confirmed the above findings. As more types of aircraft were used certain problems occurred in the operation of one type that did not occur in others. These will be discussed briefly by aircraft types in the following paragraphs.

CARRIER AIRCRAFT

From the first carrier cold weather test with the *Langley* in 1931 through the year 1948, only 3 scheduled carrier tests have been made. Together these covered a total of 35 days but only 15 days on which air operations were conducted. The year 1949 began with carrier tests in each of the first 2 months. In the Atlantic, the U. S. S. *Palau* conducted operations off the coast of Maine, the area used by the *Langley* in 1931. In the Pacific the first test in which more than one carrier participated took place. This was *Operation Micowex*, an amphibious operation in the Aleutians in which carrier aircraft from one CV and two CVE's provided support for the attackers and were opposed by shore-based air from naval and air force bases.

The first tests emphasized the performance of equipment rather than the capabilities of the carrier and its air group. Later tests included the objectives of training pilots, squadrons, and personnel, and the determination of carrier efficiency. No tests were conducted with a full complement of aircraft on board the carriers. Although the wartime operations of two CV's and one CVE in the North Atlantic were carried out with normal complements, experience brought out the fact that the additional demands placed upon handling and servicing personnel made a reduction of aircraft complement desirable if air operations were to be efficient. This was also the conclusion of the British during wartime. There is good reason to believe that it will be some time before cold weather operating techniques will develop to the point where a full aircraft complement can be used under prolonged bad weather conditions coupled with temperatures below 15° F.

Carrier flight operations can be divided into three phases:

1. Preparation of planes for flight.
2. Launching and recovery.
3. The operation of planes in the air.

The effect of cold weather on the first phase depends upon several factors already discussed, but basically it depends upon the severity of the weather conditions. The second phase is affected principally by the condition of the flight deck and the extent to which snow and ice impair operations particularly in the recovery phase. If the problems of the first two phases are adequately met, few difficulties will occur in the third phase.

PREPARATION OF PLANES FOR FLIGHT

The problem of starting engines is the same, whether aboard a carrier or ashore. The outstanding problem initially encountered by the *Ranger* in 1936—the removal of ice, snow, and frost from the wings and control surfaces—was still only partially solved 10 years later. Aboard the ship, no means were found to clear ice from the surface of a plane quickly and effectively or to prevent its formation. Cockpit covers did not keep snow out of the cockpit and away from the interior controls. Wing covers were not used and snow, ice, and frost stuck to the wings and became packed into the fittings. The solution adopted was to send the planes to the comparatively warm hanger deck where they could be thoroughly dried before being again exposed to the cold. Unless planes were absolutely dry, frosting took place when they were returned to the flight deck.

Early war experience confirmed the conclusions of the *Ranger* tests. Freeing the propeller, wings, and control surfaces was particularly difficult with a full complement of aircraft because free use of the hangar deck and easy movement of aircraft was impossible. When the *Ranger* operated in the North Atlantic during the April-July period, take-off was usually delayed until about 1000, by which time the sun's rays had raised the temperature enough to assist in ice and snow removal.

On Operation Frostbite, the first cold weather carrier test after the war, enough difficulty was encountered with wing covers to lead to the conclusion that they were impractical for carrier use. It took 15 men 20 minutes to install a cover on one wing in a relative wind of 30 knots. Covers were dangerous to personnel in high winds and caused some damage to antennae bases and wires during installation. Discarding them was considered de-

sirable because Kilfrost, a standard stock de-icing fluid, applied with a spray gun and wiped off with rags, was found satisfactory for removing light ice.

The increased importance of the hangar deck in cold weather was brought out in these tests. It was also realized that in order to maintain its heat it was necessary to exercise constant care in the use of elevators and in the number of times curtains and doors were opened. On the *Midway* cruise, high seas caused additional difficulty. Water, shipped in during heavy weather, made the hangar deck so slippery that at times plane handling was impossible. More time was spent keeping it in condition than was spent removing ice and snow from the flight deck.

It was also on the *Midway* that the problems resulting from condensation first gave concern. The moisture in the air of the warm hangar deck condensed on the cold metal of planes brought down from the flight deck, froze hard when the planes again returned to the flight deck. Such moisture could be removed from the exterior or exposed parts but on inner parts such as the aircraft machine guns, it could be removed only by complete dismantling. The freezing of this moisture inside the weapon produced many stoppages and when the weapon did function its action was noticeably slow. In view of these difficulties, tests were conducted aboard the *Palau* in January 1949. However, no problems were encountered despite the fact that aircraft were purposely left on deck at all times except for about one-half hour when they were taken to the hangar for condensation purposes.

There were numerous examples of the unexpected troubles which arise in cold weather. Aboard the U.S.S. *Long Island* gasoline tanks, fueled to capacity on the flight deck, overflowed when the planes were sent to the hangar deck—a natural result of the expansion of a fluid in a warmer environment. The U.S.S. *Wasp* was troubled with serious delays resulting from the presence of ice crystals in the ship's gasoline system which blocked the lines during refueling. It was believed that heavy moisture-laden air, drawn into the system during the pumping down process, condensed in the piping and when the fuel was pumped out was carried up to the exposed parts of the system, collecting and freezing in the strainers and meters. On one occasion on the *Ranger* test in 1936, steam from the ship's whistle condensed and froze on the cold metal aircraft wings. On another, spray thrown up by a turn in heavy seas coated the ship's radio insulators causing fail-

ure of the transmitting system and making it impossible to communicate with the aircraft.

All of these increased the time required to prepare the aircraft for flight and caused delays in launching. The extent to which they may be expected to affect air operations is unpredictable. From experience to date it is only possible to state that it will be less on clear, cold days than on days when the cold is combined with inclement weather.

LAUNCHING AND RECOVERY

The safe and efficient operation of aircraft is impossible until the flight deck is skid proof and free of ice and snow. Plane handling is slowed down by an icy deck. Keeping the carrier deck clear and ready for air operations is not particularly difficult but it requires a ready crew, the use of foresight, and a knowledge of climatic conditions combined with accurate weather reporting and forecasting.

Keeping snow off the flight deck is one of the problems. The *Ranger* ran into a blizzard which lasted 32 hours. Although there was a 40-knot wind across the deck, snow covered it in drifts to about 2 feet. Using brooms, shovels, scrapers, and hot blowers and torches, 40 men cleared the deck in 4 hours. Because the time required to clear the deck delayed launching time, and the residue of ice and snow slowed the movement of servicing and handling personnel, it was suggested that the possibility of installing heating units under the flight deck be given some thought.

Experience with delays of this sort was repeated during the early war period in operations in the North Atlantic. It was shown, however, that the extent of delay could be reduced by foresight and particularly by maintaining work parties to keep the deck clear during a storm rather than clearing it after the snow had fallen or ice had formed following its compaction. Rain at temperatures around freezing turned to ice as it hit the cold deck and was much easier to clear before its thickness was built up.

Time required to remove snow from the deck during this period was still more than air operations in wartime could allow. The *Wasp* made use of a plow attached to the tractor to push loose snow over the side but the *Long Island* did it all by hand. Its equipment was 20 each of snow shovels, ice scrapers and heavy bristle brooms, and 12 wooden snow pushers. These, with the help of hot blowers and torches from the shop, were considered sufficient to handle the job.

Figure 6–8.—Cleaning snow off carrier deck.

The validity of the earlier proposal for heating the flight deck was shown on the *Midway* operation in 1946. Although no heating units were installed, the relatively high coefficient of heat transfer of her metal flight deck was of material help in preventing the formation of ice and in melting snow, in temperatures as low as 20° F. The *Midway's* snow removal equipment included rattan and wire rotary brooms and plows attached to tractors, and the usual hand implements. Attaching the rotary brooms to tractors required from 3 to 4 hours. With this equipment, the deck was cleared of 3 inches of snow in 2 hours, using 2 tractor sweepers, 2 tractor plows, and crews for 50 hand brooms and 50 shovels. Wire brooms were more effective than rattan for removing light ice from the deck but were destructive to the skid-proof covering on the flight deck. Rock salt, although satisfactory for removing ice and melting snow, was picked up by propeller blast and blown about over the deck endangering personnel and lodging on aircraft where it caused excessive corrosion. Four hundred pounds scat-

tered on the snow from the barriers aft was enough to keep it soft and slushy for 12 hours in subfreezing temperatures. Grease was superior to Kilfrost or rock salt in removing ice from sunken tie-down pad eyes.

In January 1949, the *Palau* had no difficulty in clearing the decks of 2 inches of snow in 1½ hours using the Hough sweeper and scrapers, shovels, chippers, and brooms. The task was made simple by keeping all unnecessary personnel off the flight deck after a snow because the hard ice which formed in footprints could not be removed by the sweeper and had to be chipped by hand. Excessive wear on the sweeper indicated the advisability of adding a spare to the section "W" allowance for CVE's.

Deck gear has operated well under all conditions. This was true in the *Ranger* tests when flight deck equipment such as wires, sheaves, yielding elements, barriers, and elevators functioned properly and were easily cleared in spite of the fact that ice was intentionally formed on much of the gear by pouring water over it. It was also true during the war period when experience showed that this gear could be kept in operating condition more easily than the flight deck could be kept clear. Catapult tracks were kept covered when not in use. Canvas covers protected the barriers and conventional plate covers the yielding elements when flight operations were not being conducted. Because working units were under the flight deck, arresting gear and barriers functioned satisfactorily even when the exposed parts were heavily iced. Fluid in the unprotected arresting gear units was changed to 70 percent Prestone and 30 percent distilled water. The catapult also operated satisfactorily but it was necessary to increase the opening of the catapult pump regulator orifice valve one-quarter turn to insure automatic action.

Experience aboard the *Midway* was similar. There was no difficulty with the operation of catapults and arresting gear. Canvas covers over the barrier sheaves were satisfactory and metal track covers without rubber gaskets provided adequate protection for the catapult. Steam and salt water from the fire hose cleared the ice from the tracks.

The *Palau* test resulted in similar findings. The amount of ice forming in the catapult tracks offered a problem only when it became so thick that the retraction of the shuttle would not break it up. On this test such ice was cleared by hand or with rock salt, a method which delayed flight operations from 3 to 4 hours.

Yielding elements were kept clear of ice by leaving them in a raised position during nonoperating periods.

Plane handling was slowed down by icy deck conditions and the effect of extreme cold on personnel. Aboard the *Palau* it was found that the comfort of the personnel was helped by proceeding downwind during most of the time the crew was at flight quarters. On another ship it was found advisable to double handling crews when slippery deck conditions combined with high winds to make the task difficult. During the war turnbuckles and sister hooks were found a stronger and faster means of securing planes than the conventional manila lines. This was also considered the best method aboard the *Midway* but the task group commander considered the time required for installation and removal excessive.

On the basis of the *Midway* test it was concluded that normal deck procedures were applicable to cold weather but that more time had to be allowed to carry them out. Time was necessary because pilots needed about 15 minutes to don cold weather clothing, planes took longer to warm up, and plane handling was slower. Condition Thirteen could be maintained satisfactorily in the weather and temperatures encountered. With heat maintenance on the forward half of the deck load, heaters, engine covers, and heater boards could still be removed from the remaining planes in time to launch them on schedule. To maintain Condition Eleven, planes on the catapult required periodic turn-ups, and pilots had to depend on electric boots and gloves for warmth. It was found that spotting two planes on the catapult and the remainder on the hangar deck was the best method. This reduced the number of pilots exposed to the discomfort of sitting in a cold cockpit on the flight deck and planes on the hangar deck would be warm enough for immediate launching when brought up to the flight deck.

OPERATION OF PLANES IN THE AIR

No cold weather effect was noted in air operations conducted from the *Ranger* in 1936 tests nor were any particular difficulties met during wartime operations. Operation Frostbite was the first of the carrier tests in which training was given as a specific objective. With a complement of one bomber and one fighter-bomber squadron, about half the normal complement, flight operations were conducted whenever weather permitted. Although all flights were restricted to within gliding distance of task group units, practice in rendezvous, break-up, glide bombing, rocket attack, and strafing followed normal procedures.

Difficulties in the air were also minor in the tests carried out by the *Palau* in 1949, and in Pacific tests, experience was no different. Strikes in support of the amphibious landings were made on schedule whenever it was possible to take off from the deck. Although there was some difficulty with the functioning of rockets, there were no difficulties with operating aircraft attributable directly to the effects of cold weather.

SEAPLANES

Tests of seaplane operations in cold weather areas have been limited and on each test fewer difficulties were encountered than might be expected. The feasibility of operating from the water was shown on the first naval aviation expedition to the Arctic in 1925. This expedition, equipped with three amphibians, found that landing sites would require an excessive amount of labor to build runways smooth enough to be safe for use. Operations from the water on the other hand required only the location of open spots adjacent to a beach suitable for the erection of temporary maintenance and servicing facilities. Because these were readily found, all operations during this expedition were conducted from the water. When only minor difficulties were encountered, and these mainly a concern over damage likely to occur while the planes were moored at their buoys, the possibilities of the seaplane for operations in the higher altitudes appear to be good.

This promise was not fulfilled, however, by wartime experience. The operations of patrol planes in Iceland during the winter months were hampered by ice. It became necessary to exchange the seaplanes for land types. As a result of this experience it was standard practice during the remainder of the war to assign either land planes or amphibians to all patrol squadrons sent to high northern latitudes.

The first test of the seaplane in cold weather after the war was with PBM's aboard the tender *Norton Sound* in Operation Nanook in the summer of 1946. It was entirely successful and proved the feasibility of operating from the water in northern areas during the summer months, but the most extensive test took place on Operation Highjump during the antarctic summer 1946–47. This was more than a test of engineering equipment. It was a test of the operating capabilities of the aircraft and the ability of the tender to support them during extensive photographic reconnaissance. Heavy seas and bad weather hampered flight operations, but in 20 of the 68 days on which conditions permitted flights, the

6 PBM's aboard the two tenders demonstrated the value of seaplanes for exploration by completing a photographic survey of almost the entire coastline of Antarctica.

All operations were conducted in the open sea, and as might be expected it was this factor that accounted for most of the problems. This was particularly true of hoisting operations and handling the plane alongside during fueling. The design of the PBM allows a weight not exceeding 46,000 pounds on the hoisting sling limiting the gasoline load to about 700 gallons. Since an additional 2,700 gallons was required on each mission, this amount had to be loaded aboard during the hoisting in process and it was often necessary to defuel. This was done either by bowser boat or by jettisoning. For fueling, the plane was hoisted over the side with the gasoline hose messenger attached to the hull and the plane was held in position with the aid of three rearming boats, one secured to each side of the hull at the bow and the third holding lines to the stern. In calm weather, only the stern boat and bow and wing lines from the tender were required. That caution was necessary in bringing the bow boats alongside while the hoisting sling was attached, was shown on one occasion when the roll of the ship lifted the plane from the water while the boats were still secured to the hull, resulting in minor damage to the plane and to the boats. It was standard practice aboard the *Currituck* to release the hoisting hook before the boats came alongside.

Take-offs and landings were made parallel to the swell with a cross wind of less than 15 knots. Little trouble developed from the ice freezing on the windshield during the run. Although a boat swept the landing and takeoff area clear of ice, some adroit maneuvering was necessary to avoid the growlers. Visibility was generally good enough so that only once did a plane strike ice on a take-off or landing, and that resulted in only minor damage. At the end of the operating period when the temperature fell to 14° F., some ice was picked up on the plane during take-off and occasionally ice froze over the static openings of the pressure instruments at times rendering them useless for as long as 3 hours.

Landings, normal in all respects, were made into the wind, full stall. For glassy surfaces a standard power landing was made using the radio altimeter for levelling off, and on some occasions the pilot was talked down from the ship. No instrument landings were made, but let downs through the overcast followed the instrument pattern and were always controlled to give practice to the pilots and crew. In this procedure the plane was controlled

by SK radar until within 5 miles of the ship after which SG radar took over. Controlled landings required care in selecting a safe orbit and let down path particularly in areas where icebergs were present.

Ice picked up on take-off was not particularly troublesome but frost on the windshield formed soon after the plane cleared the water and continued throughout the flight. It was cleared by opening the windows—to the discomfort of the crew. Heated flight suits were adequate to the situation, but being inadequate in case of a forced landing and therefore impractical for operations over barren areas, the need for an efficient defroster was apparent. Cabin and fuselage heat was inadequate. The Selas system was a continuous fire hazard and the Stewart Warner did not give a good distribution of heat.

Maintenance aboard the tenders was normal, although deck space was at a premium and required careful spotting of aircraft. No special techniques were required by cold weather but the need for having planes ready immediately after the weather cleared for flight made it necessary at times to work maintenance crews around the clock. Engine checks were made at frequent intervals; inspection of fuel and oil systems to prevent accumulation of water and ice was made daily, and paralketone was sprayed over the engines to prevent moisture getting into them and their accessories. One adjustment of control cable tension after arrival in the area was sufficient for the entire period. One engine change was accomplished in 75 hours. The outer wing panels were assembled on one PBM and major damage to wing tips, de-icers, boats, and ailerons were repaired with only minor difficulty.

To date, no other tests of seaplanes in cold weather operations have been made. The conclusions from Operation Highjump indicate that a good training program and detailed planning will ensure satisfactory solution of the maintenance and repair problems that are likely to arise in operations around Antarctica. Thus, they should also be applicable to operations in any cold weather area in the Northern Hemisphere where open water exists.

LANDPLANES

The first extensive test of operations on land was carried out in 1935 by carrier aircraft and was primarily a means of determining the value of cold weather equipment designed for use aboard a carrier. Aside from difficulties accompanying starting

the engines as previously discussed, pilots found that low temperatures introduced few new problems for the operation of aircraft in flight. This conclusion was reached in spite of the fact that one flight encountered a low temperature of minus 22° F., which was lower than any encountered on the carrier tests and only 1 degree higher than the lowest encountered at Little America in February 1947 during Operation Highjump.

Planes normally used by the Navy for operations from shore bases are multiengine patrol planes and transports. Except for experiences during the war, only three tests of such plane types have been made. All of these were conducted on an operational basis with emphasis on the effectiveness with which the aircraft could carry out an assigned mission rather than on how well certain types of equipment functioned in cold weather.

The first such test came in Operation Highjump with R4D's. Transported to the Antarctic on the deck of the U.S.S. *Philippine Sea*, take-off from the carrier was the first of many problems. It was solved by equipping the aircraft with a combination wheel and ski landing gear designed so that the wheels protruded through the skis and carried the plane on hard surfaces such as the carrier deck. On softer surfaces such as snow the skis would carry the weight. Jet assisted take-offs from the carrier and landings on the snow were normal in every respect, but for operations at Little America, the wheels were removed to reduce the excessive drag which they created in flight and in take-offs.

LANDING ON SNOW

At first skis gave the pilots some trouble because of the different handling characteristics on the ground. With skis, a landplane handled on the snow much like a seaplane on the water. Having no brakes the plane was difficult to control particularly during landing, but by landing in the sastrugi alongside the runway, enough resistance was provided to slow the plane and at the same time allow better control. Taxiing was something of a problem because of the tendency for the skis to freeze to the snow whenever the speed was slow or any brief stop was made such as for a turn.

With the aid of four jato bottles, the R4D's could take off from the soft and drifted snow with a gross weight up to 33,000 pounds; however, the preparation of a smooth hard snow runway was necessary to avoid delays. Three flight strips were constructed by using a snow drag to level the sastrugi, compacting it with tractors, and giving it a final smoothing with a flat bottom drag

constructed of pontoons. After completion, the strips were kept in operable condition with drags and bulldozers to level the snow and remove the drifts.

Planes equipped with skis and weighing up to 32,000 pounds did not break through the surface. Take-offs were made regularly with two jato bottles and several flights took off without assistance. An R4D on wheels weighing about 23,000 pounds was taxied on the runway but broke through in the spots not properly compacted. Although the method of construction provided a runway satisfactory for this operation, certain climatic conditions and greater density of traffic would be expected to require a stronger surface, perhaps a superimposed one which would distribute the load over a larger area and reduce wear.

TEST STRIPS

Test strips of this type were constructed with pierced planks. In some sections of these strips, the plank was placed directly on the snow, in others over burlap, and in still others over compacted snow. There was a tendency for snow cylinders to build up through the holes as the planks settled, more apparent on undisturbed than on compacted snow, but it did not appear at all through the burlap. Load tests which included taxiing an R4D with wheels over the various sections, gave varying results but led to the general conclusion that a satisfactory surface was possible only when the supporting power of the snow was increased by compaction or by the action of melted water in hardening the surface.

Several problems appeared in servicing and maintenance. Planes were parked on plank platforms to prevent freezing to the

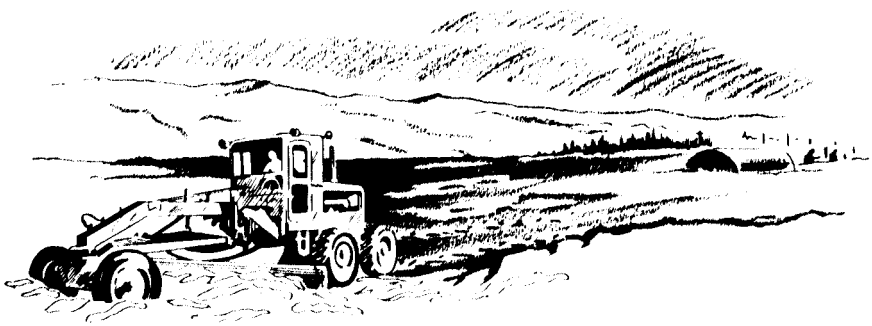


Figure 6–9.—Dragging flight strips.

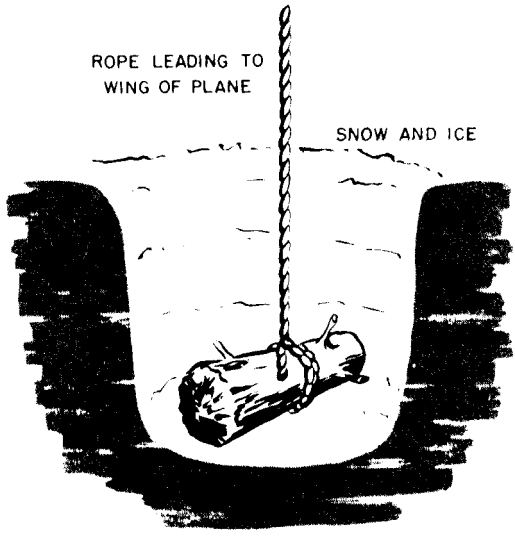


Figure 6–10.—"Deadmen".

snow. The possibility of strong winds made it necessary to keep them tied down at all times. This was done by securing the wing and tail lines to "deadmen" (see Glossary) buried in the snow and anchored by pouring water over them. Fueling a plane with a 1,600-gallon capacity from an 800-gallon truck proved too slow. By installing auxiliary pumps on the forward end of two go-devil sleds, each loaded with 24 drums of gasoline, the process was speeded up. To make use of the separators on the truck, fuel was transferred from the drums to the truck while it was pumping its fuel into the aircraft. The use of two sleds made it possible for one to refill while the other was pumping, thus keeping a continuous supply flowing into the truck. The method of dispensing oil was also changed. The heating system installed on the 500-gallon truck was too slow and the capacity of the truck more than was required. Five-gallon cans with a flexible spout were used instead and proved quite satisfactory.

Maintenance presented no unusual problems principally because the R4D lived up to its reputation for being an easy plane to maintain. It was noted, however, that with low temperature and exposure more men were required to complete a job than would be required in more temperate zones. The progress of work was also noticeably slower. The large wood shelter for working on engines

could not be used. It was too heavy, was equipped with wheels rather than skis making it difficult to move, and it presented too large a frontal area to the wind. A light weight fabric hood was improvised and used instead. It was so constructed that it covered the engine and nacelle being supported in front by the propeller blades, leading back over the trailing edge of the wings, and the lower portion tying to the landing gear strut. After it was erected in place, the duct of a Herman Nelson heater was led inside at the bottom and the heat kept it expanded and warm. This proved a good solution but it was suggested that further improvement, particularly for an engine change, would be possible by the use of a folding framework.

AIR OPERATIONS

Difficulties in air operations were few, the most important occurring in connection with landings. Surface winds over 17 knots picked up the dry snow and made it difficult to judge altitude when coming in for a landing. A GPN unit (ground pulse navigation) was set up and proved a good substitute for GCA. It worked well within 25 miles of the base, but pilots had to use their radio altimeter in a power stall approach for landings. Glare incidence was very high and even when the sun was obscured it was necessary to wear dark glasses or goggles to prevent snow blindness. On good flight days visibility was generally excellent, high mountains sometimes being visible for 150 miles. A most unusual condition, in that it has been noted only in the Antarctic, but a dangerous one, occurred on the so-called "white days" on which snow and clouds blended into one, obliterating all horizontal references and all shadows.

A second test of landplanes was made during an aerial photographic survey of Alaska, but it can hardly be called a cold weather test. It was conducted during the summer of 1948 and covered the southeast portion of Alaska where the temperatures compare favorably with those in the northwest section of the United States. One feature of this operation, was the use of seaplanes tenders to support a shore-based squadron. Although not unique, because it was also used in that area during the war, it was sufficiently effective for it to be repeated in an exercise during 1949.

That was *Operation Micowex* (minor cold weather exercise), an amphibious exercise in which 2,000 Marines were landed in the Kodiak area under cover of carrier aircraft against the opposition of Navy and Air Force land-based planes. Navy aircraft—P2V

and PB4Y—operated from the airstrip at Yakutat and were supported by the tender *Salisbury Sound*.

The tender arrived in the area on 30 January with a deck load of assorted automotive and snow removal equipment and two helicopters. The dock was under about 4 feet of hard packed snow and it took almost nine hours to clear it enough for the ship to moor alongside. Because the "snow-go" had not arrived at Seattle before the departure of the *Salisbury Sound*, only D–6 bulldozers were available for use in clearing the runway for the arrival of the aircraft. When these arrived on 3 February a taxiway from the hangar to the runway with revetments for the aircraft had been cleared of 7 feet of snow but progress had been slow until the arrival of the snow-go on the 2nd. A small rotary snow plow belonging to the CAA had been used to improve the runway and it was noted that this machine required 4 hours to make one trip down the runway.

EMERGENCY LANDING

First aircraft to arrive practiced an emergency GCA landing procedure worked out by the CIC team aboard the tender. The dock at which the ship was moored was nearly in line with the runway at a distance of about 3½ miles. The aircraft were vectored into a long final approach by means of air search radar and when they reached a point approximately 4 miles from the ship, fire control radar was used to make the final corrections in course. Magnetic heading and time to the runway was given to the pilot as the plane passed over the ship. Although the aircraft disappeared from the screen after passing over, the procedure worked well enough to show its possibilities for use in an emergency.

Operations began on 5 February with seven planes flying search sectors. Contact with the attacking force was made on the initial search and in spite of opposition from carrier aircraft, which was reported as being only minor, the surface force was tracked and under constant surveillance for the remainder of that day and the next when the operation was concluded.

An average temperature for the 2 days of 22° F. introduced no difficulty in engine starting and in some cases no preheat or oil dilution was used. Flights were carried out on schedule. Fueling time averaged 2 hours per plane. The support of the tender for operations ashore was entirely satisfactory and the possibilities for using this method for supporting future operations from advanced bases was indicated.

HELICOPTERS

The use of this type of aircraft by the Navy is of fairly recent origin, but few cold weather tests since the war have been conducted without their use. Helicopters have participated in every test since Operation Frostbite. In each they have demonstrated their usefulness. As a mean of close reconnaissance of ice fields they are extremely effective and because of their adaptability to small take-off and landing areas they are without equal for operations from small ships such as icebreakers. In short, they are indispensable for arctic operations.

The helicopter (HNS–1) taken on Operation Frostbite was a U. S. Coast Guard plane intended primarily for use in air-sea rescue. Its operations were satisfactory but several minor difficulties arose which led to the conclusion that this type was too light for carrier use. Its power after engine warm up was not enough to engage the rotor blades on deck when it was exposed to winds of any velocity. This was overcome by placing the plane on the elevator at the hangar deck level and after the rotors were engaged bringing it up to the flight deck. Because the rotor blades were of the nonfolding type it required more stowage space than an SB2C. In addition radio equipment was inadequate.

Seven helicopters of the HO3S, HOS and HNS types were taken along on Operation Highjump. They were used for ice recon-

Figure 6–11.—Helicopter operations.

naissance from the ice breakers and for auxiliary purposes and air-sea rescue from the seaplane tenders and the carrier. Those aboard the seaplane tenders were stowed in the hangar and used very little. None were considered to have proper instruments or radio equipment for antarctic use. Only one, the HNS, was equipped with floats. Personnel assigned had little experience in the care of the aircraft or its engines, and the HO3S's were new and relatively untried. The weight and balance of this type was critical and may have contributed to the loss of the one assigned to the *Philippine Sea.*

Navigation equipment in the helicopters was meager consisting only of a magnetic compass and airspeed meter. Instrument flight was therefore impossible and the weather had to be watched closely. To make this possible radio equipment was installed in all of the craft. An ARC–1 VHF was installed in three of the larger types, an ARR–2 navigational radio was installed in the nose of one, and an ABK-type IFF set was placed in the baggage compartment of another. HOS and HNS types were equipped with SCR 274N radio.

In addition to limited equipment, other drawbacks included the limited range of the craft, which on this operation was 50 miles. Lack of rotor anti-icing equipment was another. Icing of the rotor blades made it impossible for an HO3S to reach the flight deck of the *Pine Island* and it crashed into the water near the ship. Cabin heat was also inadequate and on occasion ice formed on the nose.

Except for these difficulties the aircraft gave satisfactory performance. Starting was accomplished without incident with the aid of the York heater and oil immersion heaters. Maintenance was normal. Constant possibility of carburetor ice was a danger on all flights but careful use of carburetor heat was the answer.

HELICOPTERS ABOARD

Helicopters aboard the ice breakers were parked in position with the brakes locked and were secured to the deck by 3 or 4 turns of 1½-inch manila line or steel tie down cables run from the main landing gear to a deck cleat about 3 feet aft of the wheels. The nose wheel was secured in the same manner, but a small amount of slack was left in the line to permit the wheel to give with the motion of the ship. Under normal wind conditions, rotors were left on with brakes locked and tie down boots over

the tips. When winds of over 25 knots were expected, both main and tail rotors were removed. Aboard the *Currituck* a wind screen was erected which protected the helicopters from damage in winds of over 70 knots.

Four men were enough to handle the planes on deck. With the ship lying to, the direction of the wind was unimportant, but with the ship underway, the big helicopters needed a 10 knot wind within about 30° of the bow to provide a reasonable safety factor. The same wind was best for landing with the ship under way, but sliding in over the deck from a course parallel to the ship was not good practice because of the loss of cushion during the slide. The best procedure was to fly over the deck as fast as possible, then hover for the final approach and landing.

Helicopters were also used by Task Force 68 in the Arctic during the summer of 1947 and by Task Force 39 in the Antarctic during the winter of 1947–48. During the summer of 1948, Task Force 80 took over the task of supplying the weather stations in the Arctic and its experience with helicopters are the most recent on which information is available.

The four aircraft (HTL) operating from two icebreakers, logged 229 flights totalling 213.2 hours. No particular difficulty was encountered until the end of the cruise when the temperatures dropped from a range of 28° to 38° F., to 16° to 24° F. with the dew point consistently within 1 degree of the temperature. These low temperatures were accompanied by fog and high moisture content in the air. Under these conditions ice formed on the canopy, sometimes thick enough to impair visibility. It also formed on the rotor blades but because planes were not kept in the air for long periods under these conditions, no change in flight characteristics was noted. Only one case of carburetor icing was noted, and although it required several adjustments of carburetor heat, it was corrected.

Unless planes on deck were to be launched in a short time, the canopy, engine, and main and tail rotors were kept covered to keep rain and snow from freezing on the parts. When ice formed on the rotor blades, a gust from the Herman Nelson heater, slipped over the blades, melted it immediately and moisture was cleared by wiping the blade with an oiled rag.

ENGINE STARTING

Engine starting was no problem. Auxiliary power units were used occasionally for starting, but generally battery power alone

was enough. From a cold start an engine could be brought to operating temperature in from 6 to 10 minutes.

Navigation was all contact and the planes seldom operated out of sight of the ships. On the few occasions when fog moved in between the planes and the ship, contact was maintained by radio and the plane directed either to the nearest land or back to the ship, being tracked by ship's radar.

Take-off and landing procedure followed normal practice. Helicopters were launched from either side of the deck but the length of the rotor blades permitted only one aircraft to warm up at a time. After being airborne and clear of the ship the aircraft swung into the wind until speed was gained. Landing approaches were made into the wind until over the flight deck at which point the helicopter turned and landed along the fore-and-aft line of the ship. Landing spots ashore were almost always covered with rock and sharp edge shale. On this rough surface the floats gave excellent service. Although several punctures resulted, loss of air did not endanger the landings.

One difficulty with handling trucks was overcome by a substitution of equipment. The trucks were the type used for handling VO-VS aircraft modified to fit into the space between the floats. Screw jacks on the truck, used to raise the floats from the deck, were the seat of all the difficulty. The two jacks on each bar had to be raised or lowered at exactly the same rate or one of them would freeze. When this happened it was extremely difficult to release them and bring them into proper alinement. On one occasion 2 hours was required to mount and secure two helicopters.

The solution was simple. The support bars on the trucks were left in a raised position and four hydraulic jacks of the automotive type were used to raise the helicopter enough to permit the truck to be moved into position. Adjustments of holding clamps and the substitution of wing nuts increased the speed with which the aircraft could be secured and released.

NOTES ON PREFLIGHT PRECAUTIONS

This section deals with the general problems of maintenance and preflight preparation. It does not endeavor to explain in detail the maintenance procedures for each type of airplane. That information is found in technical notes and elsewhere. The effort is made here, however, to briefly list some of the ideas, rules, and precautions which have been found to apply over a period of years.

1. *The airplane.*—At temperatures of minus 15° F. and lower, elevator trim may not operate for as long as 5 minutes after take-off because of the freezing of the drive shaft. Moreover, the trim tabs may not be at zero when the indicator is at zero, and at the high speeds of jet flights, they may cause the pilot to over control. Preheating is therefore essential—the engine, canopy, cockpit, oil system, and elevator trim tabs, in particular.

2. *The engine.*—Cold weather starting is a major problem. Experiments are being conducted with special fuels and high pressure priming to ensure ease of starting. At the present preheating by the application of external heat or by stowage in a warm hangar is necessary. If the proper oil dilution procedure was used at shut-down, apply external heat when outside air temperature is below 0° F. If oil dilution was not used, preheating will be required at temperatures lower than freezing. The use of insulated engine covers or engine closures will facilitate preheating. If the whole engine cannot be heated, concentrate first on the rear accessory section and next on the nose gearing and propeller hub. Jet power plants do not require preheating. Preheating is considered satisfactory only after fluid oil will flow from the Y drain and the propellers can be pulled through with comparative ease. Always use an external source for starting and for running the engine and operating electrical equipment of the airplane on the ground.

3. *Snow, ice and frost.*—Never take off with snow, ice, or frost on the wings, or empennage. A thin layer of ice—or snow which rapidly compacts into ice—will cause loss of lift and a treacherous stalling characteristic. Sweep hoarfrost and snow from surfaces with a stiff broom. Remove all accumulations of snow in the wings and fuselage. To remove ice, apply sufficient heat to loosen the ice particles and remove them with a brush. It is best not to melt the ice completely as water is likely to get into control surface bearings and freeze. Landing gear, bomb-bay doors, flap operating gear must be freed of ice and snow. Remove snow packed in carburetor intake. Clean off antennas using a light bamboo pole before take-off. Operate all ailerons, elevators, rudders, and trim tabs through several complete cycles. If resistance is excessive, a careful investigation must be made.

4. *Tires.*—If tires become frozen to the ground or flight deck, free them by the use of external heat from ground heaters. In an emergency, they can be freed by over-inflation up to 1½ of normal

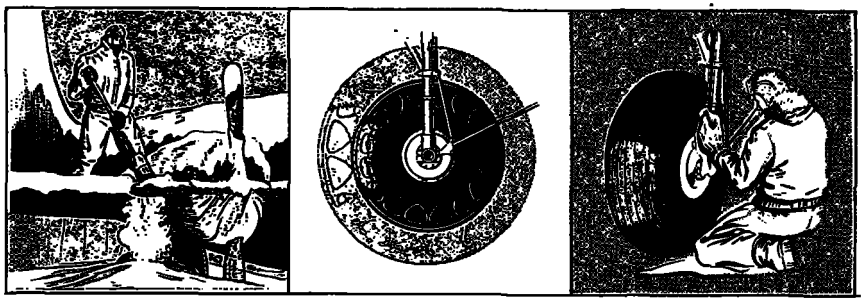


Figure 6-12.—A—Sweeping snow from plane with stiff broom. B—Freeing frozen tires by overinflation. C—Cleaning shock struts.

pressure. Take adequate precautions not to burst tires or endanger personnel.

5. *Shock struts.*—Wipe the shock strut piston tubes clear of all snow, ice, or dirt with a rag soaked in the fluid used in the strut oleo. Use kerosene to clean if necessary. Follow by lubrication with hydraulic fluid. Repeat this procedure on landing. Clean piston rods of actuating cylinders in same manner. Examine shock struts carefully for hydraulic leaks and proper inflation. Check for the proper distance from the lower end of the cylinder to the inflation mark on the piston.

6. *Drains and vents.*—Check the Y drain and oil tank sump for fluid oil immediately before starting the engines. Do not attempt to start without free oil flow. Take steps to prevent condensation and subsequent formation of ice in the sump.

7. *Engine starting.*—Remove engine covers, ground heaters, and immersion heaters. Pull the propeller through 4 or 5 complete turns before engaging the heater. If this cannot be done with ease, more preheating will be required. Prime the engine in accordance with existing instructions. Be cautious when priming as overpriming will result in fires and engine failures. Start in the usual manner. Use auxiliary power starting. After engine starts, watch the oil pressure. If there is no oil pressure after 30 seconds of operation, shut down immediately and investigate. Keep the carburetor heat control in full cold position while starting in order to avoid heater valve damage due to backfire. Use carburetor heat as soon as the engine is firing regularly to increase the full air ratio and improve vaporization and combustion. After the engine oil temperature and pressure are up to normal, operate the propeller control for full pitch control. When this is observed, allow the rpm to return to normal. Repeat the procedure three times.

8. *Preflight planning.*—Before take-off, get a briefing on the geographical and aerological information relating to the particular area of operations. Learn the distress, bail-out, ditching, and crash landing procedures that have been prescribed. Be sure you know, do not guess. Carefully plan and schedule preflight ground activities. Arrange the periods of preheating so that all equipment will be inspected, warmed, ready, and operating at the time of starting engines or take-off. While preheating is taking place, ice and snow should be removed, inspections and operational checks made, electronic equipment warmed up, and other necessary activities conducted. In short, maintenance crews must know the over-all time required for preparing the airplane for flight at various low temperatures.

9. *Personal care.*—Be sure proper clothing is made available to keep pilots and air crew warm in the air and on the water or ground in event of crash landing. Load in survival equipment and food dictated by the nature of the flight. Dress for the worst possible conditions, not the best. Remember the effect of cold metal on the skin. Wear gloves. Keep out of prop wash. The blast can cause severe frostbite.

10. *Weather.*—Obtain latest weather information. Know limits of airplane and instruments in weather conditions.

11. *Warm-up.*—Warm up engines thoroughly. Do not turn on electrically heated suits or other electrical equipment not absolutely needed until generator shows output.

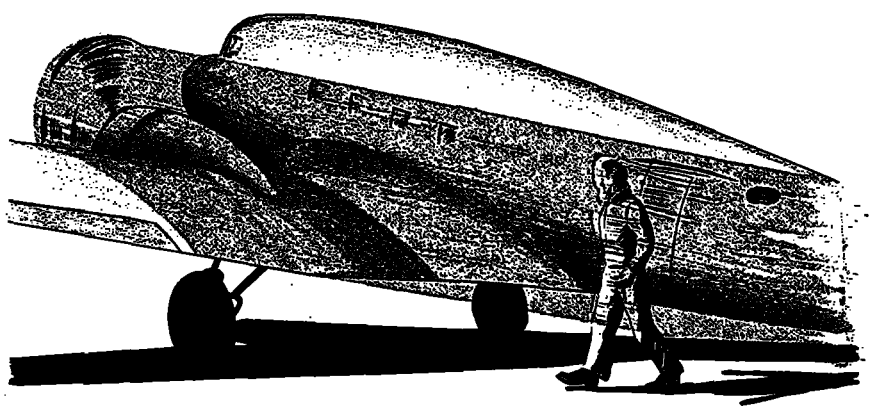


Figure 6–13.—Prop wash can cause severe frostbite.

Present specifications require equipment capable of performing satisfactorily at temperatures ranging from 130° to minus 65° F. Also prescribed are conditions of high humidity, dust, fungus, actual precipitation, and spray. In most cases special precautions must be taken to ensure satisfactory operation at temperatures lower than minus 10° F. Special lubricants must be used on rotating equipment. Storage batteries are affected seriously by cold weather as capacity is reduced by 50 percent at temperature of minus 15° F. Condensation inside the airplane will require more frequent inspection and cleaning of electrical devices.

ELECTRICAL EQUIPMENT

Condensation is a problem in cold weather operations. Watch for corrosion of electrical equipment caused by condensation—particularly relay contacts and switches. Spark plugs, magnetos, ignition harnesses, and electrical leads are all susceptible to the ill-effects of condensation. Interiors of aircraft and exterior surfaces of electrical equipment should be wiped periodically to reduce presence of moisture as interior temperature of the airplane changes.

The capacity of storage batteries falls off rapidly with drop in temperature. The standard-type AN 3150 battery has capacity of 54 amperes for 26 minutes at a temperature of 102° F., while at minus 20° F. the same current can be supplied for only 5 minutes. A cold battery cannot be charged as rapidly as one at normal ambient temperature. The charging rate at minus 20° F. is one-sixth that under ordinary conditions. For these reasons battery power must be conserved. Auxiliary power units are essential for cold weather engine starting and preflight line checks. Do not operate electrically heated flying suits, turrets, or other electrical devices unless a suitable generator is kept in operation.

Late model aircraft are equipped with quick disconnects to facilitate removal and reinstallation of storage batteries. These disconnects should be installed locally on aircraft not so equipped when required for polar operations. When feasible, it might be desirable to remove batteries from aircraft to warmed spaces to prevent freezing and loss of capacity. A battery with specific gravity of 1.100 will freeze at 19° F.; one of 1.200 at minus 16° F.; and one in fully charged condition with specific gravity of 1.250 at minus 62° F. A frozen battery is likely to burst. The evapora-

tion of the electrolyte within the battery is greatly accelerated at low temperatures and may result under some circumstances in sufficient loss in only a few hours to cause complete battery failure.

Battery maintenance is important. Check the battery at least weekly. Use portable generator at every opportunity to build it up. Remove it and recharge if the specific gravity falls below 1.240. Keep the battery in charged condition.

Rotating electrical equipment, motors, dynamotors, inverters, and generators will require special maintenance and low temperature lubricants under conditions of extreme cold. Even then slow starting and heavy loads on equipment may be expected. Electrical radiating heaters or hot air blasts from a hand heater should be used where practicable for preheating prior to operation.

ELECTRONIC EQUIPMENT

Airborne electronic equipment has been designed to operate in most cases at temperatures below minus 40° F. However, failure to operate may result from a variety of reasons. Dry cell batteries and electrolytic condensers will not work at the very low temperatures, but will probably resume normal operation when warmed. Condensation here again is a problem at it always occurs when cold equipment is brought into a warm enclosure. A higher degree of maintenance will be required to prevent corrosion of parts resulting from moisture formed by rapid changes of temperature of equipment. Wipe off visible moisture carefully from exterior surfaces and use warm air to dry out the interior. Changes in electrical characteristics of components may be so great as to necessitate frequent readjustment of critical circuits. On the AN/ART 13 transmitter, for example, the power amplifier output circuit becomes detuned with a temperature drop of 10° below 0° F.

When temperature falls below 0° F., apply heat to electronic equipment if it must be ready for immediate use. Batteries and electrolytic condensers in particular may require the application of heat to operate normally. Long warm-up periods by tube filament heating is good practice because it helps to bring equipment up to proper operating temperatures before application of plate voltage. Follow handbooks of maintenance for instructions on warm-up time. Increase warm-up time for extreme low temperature.

The operation of slow-moving mechanical parts such as shafts and bearing surfaces will operate more satisfactorily if surfaces

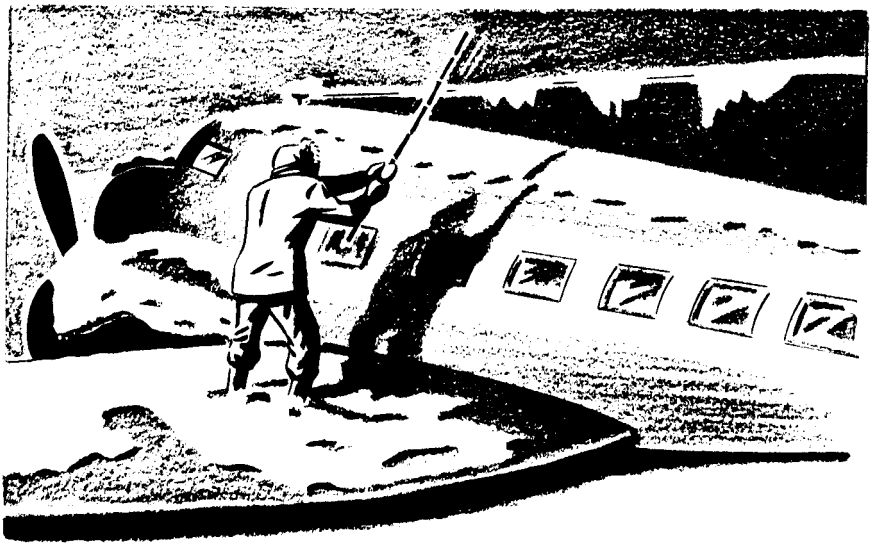


Figure 6–14.—Knock icicles off antenna.

are buffed and polished. Do not lubricate at all unless required and then lubricate sparingly.

Ice formation will be a hazard on all types of external antennas due either to excessive stress causing breakage or to changing antenna characteristics thus reducing the operating range. Knock off icicles with a thin bamboo pole. Remove ice and snow from strain insulators to prevent excessive transmission losses. Keep the antennas a little loose as a slight whip will break the ice.

Rubber-covered flexible cables become stiff at temperatures lower than minus 10° F. Insulation becomes brittle when cold and is liable to crack and shatter rather than bend. Therefore, avoid sharp bends in cables.

To avoid difficulties in selecting channels on push-button type equipment, it is good practice to set it on the desired channel before starting on the mission.

As stated above, electrical and electronic equipments provided in aircraft have undergone operational tests at temperatures as low as minus 65° F. To ensure operational readiness and to operate for long periods at low temperature, more frequent preventive maintenance and adherence to the special precautions outlined herein and in technical maintenance notes will be necessary.

Refer also to chapter 11 of *Polar Guide* (AFTRC 50-0-23), or BuAer Technical Note 84-45.

To ensure satisfactory gun operation at low temperatures and under all weather conditions proper maintenance cannot be overstressed. Preventive maintenance instructions and the safety precautions set forth in applicable technical manuals and publications pertaining to specific equipments must be strictly adhered to. For satisfactory low temperature operation guns must be clean and properly lubricated. When firing in subzero temperatures, gun heaters are required and should always be turned on just before takeoff.

Prior to firing, guns should be completely disassembled, cleaned, inspected for defects that may cause malfunction and parts breakage, and lubricated. When the gun is disassembled and is in the process of being cleaned, ensure that all traces of hard drying preservatives have been removed from the bolt assembly and other working parts of the gun.

It is very important that driving springs and all other springs are within the allowable limits of free length specified in the applicable technical manual. When preparing the gun for firing, refer to current ordnance modification instructions. All applicable and authorized ordnance modifications should be incorporated as soon as possible.

Dry cleaning solvent Specification P–S–661 is recommended for cleaning the gun mechanism. For removal of corrosive primer salts from the bore, bolt and receiver, use rifle bore cleaner Specification JAN–C–372. This solvent contains water and all traces must be removed with a dry cloth. Incomplete removal of the bore cleaning solvent may result in malfunctioning of the gun at low temperatures. Immediately after cleaning apply lubricating oil if guns are being readied for firing, or, if being temporarily stored, apply a preservative. Lubricating oil is required for operation at all temperatures. Oil Specification OS–1361 is the best gun lubricant presently available.

Apply the oil sparingly. This oil *shall not* be diluted with kerosene. Cold temperature tests have proven that gun operation at extremely low temperatures is not improved by lubrication with mixtures of kerosene and oil. At temperatures above minus 20° F. this mixture is not a satisfactory lubricant. For additional information concerning lubrication, cleaning, and preservation of ordnance equipment it is recommended that reference be made to ordnance publication OD–3000.

Guns are subject to rapid rusting from condensation following exposure to low temperatures and introduction into a warm building or space. After the guns have reached room temperature disassemble, wipe the parts dry, thoroughly clean, and reoil immediately. This procedure must be repeated each time the guns are brought from a cold temperature to a warm temperature.

After guns have been installed in aircraft and prior to flight a careful preflight inspection is recommended. When making this inspection bear in mind the following points:

1. Prior to working on the guns remove the feed mechanism and the ammunition belt from the feed way, making sure no live rounds are in the chamber or in the gun mechanism.

2. Do not operate charging mechanism or perform any work on hydraulic system while the feed mechanism and ammunition belt are connected to the gun. After these components have been removed examine chamber to ensure that gun is not loaded.

3. Do not operate gun switches or make gun electrical tests without first removing the feed mechanism and the ammunition belt from the gun and inspecting the chamber to ensure that the gun is not loaded.

4. Prior to arming the plane check the following:

a. Operation of gun heaters.

b. Bore and gun mechanism free of ice, snow, and dirt and freshly lubricated.

c. Bolt assembly free to operate in the receiver body.

d. Gun solenoids and gun charges operating properly and all connections secure.

e. On aircraft having the 20-mm. M3 gun, check the gas cylinder for freedom of movement.

f. Link and ammunition ejection chutes clear and not bent or damaged.

5. Before loading ammunition ensure that the master armament and individual gun switches are *off* and the gun charger is on safe.

6. When handling ammunition exercise care to keep the rounds in calibration with the links. Lightly lubricate 20-mm. ammunition and links as prescribed in TM 9–229 to prevent extraction malfunctions.

7. When loading the 20-mm. feed mechanism AN–M2 follow the instructions outlined in TM 9–229; however, wind the main drive shaft until the drive spring slips. This may require as much as 35 foot pounds of torque applied to the winding nut. Overwinding will not damage the mechanism.

GUN SIGHTS AND AIRCRAFT FIRE CONTROL EQUIPMENT

All gun sights and aircraft fire control systems are capable of being operated in temperatures as low as minus 55° F. provided lubricants prescribed in the applicable ordnance pamphlets are used.

BOMBSIGHTS AND BOMB DIRECTORS

The bomb director Mark 3 Mod 3 and the Gyro Mark 18 are capable of being operated at minus 65° F., when using prescribed lubricants. Bombsight Mark 15 and stabilizer Mark 15 and SBAE Mark 2 Mod 1 (C-1 Auto-pilot), when covered with a heating blanket and preheated, will operate under conditions minus 55° F. The bombsight Mark 23 is not capable of being operated below minus 40° F. However, lower temperatures will not damage the equipment.

AMMUNITION AND MISCELLANEOUS ORDNANCE

Refer to chapter 5, Part II for information on ammunition, torpedoes, mines and miscellaneous ordnance items.

HEATING

Heating of aircraft is primarily for personnel comfort. It may be used for preheating equipment or for defogging windshields. There are two types of heaters in use—combustion heaters and exhaust gas heat exchangers.

Combustion heater type heating—A cumbustion heater is a complete source of heat in itself although it is dependent upon other aircraft components for fuel, air, and electrical power. The fuel is usually supplied by the engine fuel pump. However, in some installations a special pump is used for the heater alone. The separate pump is small, compact, and light in weight and can pump as much as 25 to 30 gallons of fuel per hour. The fuel is introduced to the heater combustion chamber by either a fuel nozzle or a wick-type evaporating surface. The nozzle is the most common application being used on the majority of heaters. Ram air caused by the forward motion of the airplane is picked up by a scoop and ducted to the heater. Usually two scoops are used, one for combustion air and one for ventilating air. The combustion air is introduced into the combustion chamber of the heater in such a manner that it produces a turbulence, thus mixing

with the fuel and producing a fuel-air mixture that is satisfactory for combustion.

To ignite this mixture use one or the other of these systems:

1. A glow plug or hot wire ignitor similar to the bread toaster principle.

2. A spark plug similar to that used in the aircraft engine.

Of these two systems the spark plug type is the most positive and fastest and will also ignite the mixture at higher altitude than the glow plug type ignitor. The electrical potential for the ignition system is basically supplied by the aircraft power system. Thus, after the fuel-air mixture is ignited, the flame and gases travel through the passages of the combustion side of the heater and exhaust overboard. The heat of the flame and gases is transferred to the combustion chamber during this passing where it is absorbed by the ventilating air passing by on the opposite side of the wall. The ventilating air is scooped from the outside of the aircraft as previously stated and is therefore fresh air. It is directed to the desired locations throughout the airplane by ducts. This type unit has been thoroughly tested for defects in the original design and is perfectly safe in regard to personnel and the aircraft.

Exhaust gas exchanger type heating.—The exhaust gas heat exchanger requires nothing from the airplane other than that the aircraft engines be operated and the airplane be in motion. A single scoop is used to pick up the ram air which is directed to a muff around the exhaust stacks of the engine where it absorbs the heat of the gases in a manner similar to that of the combustion type heater. The warmed air is then directed to the required positions throughout the aircraft.

ANTI-ICING

The formation of ice on the wings, tails surfaces, and propellers of aircraft creates a dangerous situation because of the added weight and change in the shape of the airfoil section which alter the lift or thrust characteristic. Anti-icing equipment is used to prevent the formation of ice on these critical surfaces. This may be accomplished either thermally or chemically.

Thermal anti-icing.—Thermal anti-icing prevents the formation of ice on the critical surfaces of the aircraft by passing hot gases through the leading edges of the desired surfaces and raising the temperature sufficiently to preclude the formation of ice. This is accomplished by the use of exhaust heat exchangers or

combustion heaters that raise the temperature of the gas approximately 350° F. This hot gas may be air or a mixture of air and exhaust gases.

For small items of equipment such as pitot tubes and radio masts, electrically heated pads or blankets are used. Large surfaces are not heated electrically because of the great load imposed on the electrical power system.

Anti-icing compounds.—There have been a few compounds developed to delay or prevent icing of the airplane surfaces. To date these compounds have not proven to be too successful because the surfaces of the aircraft must be resprayed or repainted after a few flights and in some instances after each flight. The problem of recovering the surfaces is impractical for large aircraft, but seems fairly reasonable for some fighter, attack, and utility types which are low to the ground and easily accessible. In general, however, this method must be considered experimental—possibly impracticable—for the present.

DE-ICING

De-icing equipment is for use after ice has formed on the critical surfaces of the aircraft.

Thermal de-icing.—Thermal de-icing is primarily the same as thermal anti-icing except that units producing more heat in B. t. u. per hour are used. Here again either of the heating systems noted previously may be used.

Boot de-icing.—De-icing boots are prepared of rubber or a rubber-type material and installed upon the leading edges of the critical aircraft surfaces. Air pockets or cells in the boot along the logitudinal plane of the surface are inflated and deflated, alternately producing a flexing condition. Thus, the ice is broken from the surface leading edge. Air is supplied to the pockets at approximately 7 pounds per square inch pressure during inflation although the pressure might fluctuate during this period.

Chemical de-icing.—Chemical de-icing methods depend on the use of materials which are soluble in water and which lower the temperature at which the ice melts. A familiar example of this is the use of rock salt to remove ice. Salt, however, may not be used extensively on aircraft surfaces as it may cause serious corrosion difficulties. In some instances such materials have been used in lacquers to provide a thin film of liquid adjacent to the surface. Mechanical action such as the forces exerted by rotating

propellers will throw the ice from the surfaces until the soluble material is exhausted. Those materials are not useful for extensive de-icing of surfaces such as wings, and fuselage, as mechanical forces are required to rupture the ice film.

General de-icing may be performed by concentrated water solutions of salt. It is necessary, however, to provide corrosion inhibition even in thin films. The most effective material used which does not have adverse effects on metal surfaces, paints, and dopes, is a concentrated solution of sodium nitrate, to which molasses and alcohol have been added to provide a slightly thicker film and to provide wetting properties. This material will function at temperatures above 10° F., but becomes relatively ineffective below that temperature. Alcohols, glycols, and glycerine are effective at slightly lower temperatures, but may have serious corrosive and other adverse effects on aircraft materials.

In general, icing conditions occur within a range of 32° F. and 20° F. At lower temperatures the ice is usually not adherent and may be removed mechanically. In some instances the use of de-icing fluids at temperatures below 0° F. may cause adherent ice to form which would not have occurred if the fluid had not been used. This is an inherent difficulty which will occur in any material which depends on the lowering of the melting point of ice to provide removal.

GROUND OPERATION

Ground operation of thermal anti-icing or de-icing equipment is accomplished by blower fans within the conventional installation. This is also applicable to the heating system. The fans supply air for the heating and combustion units. Auxiliary power units supply the electrical power required to drive the blowers.

PRE-FLIGHT PLANNING

In order to navigate a flight in the polar regions, detailed preflight planning is mandatory because of the large amount of work which is necessary during the flight. There are few navigational aids and landmarks. The pilotage charts available are generally inaccurate. In addition to this, the nature of the terrain renders pilotage difficult, to say the least. In summer it is characterized by numerous lakes, islands, and rivers, extremely hard to identify or differentiate; in winter it is covered with ice and snow which obscures the demarcation between the water and land, making identification almost impossible. The variation of seasons further

complicates the situation by limiting the aids offered by celestial navigation.

In summer, continuous months of constant daylight restrict observation of celestial bodies to sights of the sun and periodically, the moon, and then only when they are not obscured by clouds or haze. In spring and fall long twilight periods may prevent any observation at all. The proximity of the north magnetic polar area to the geographic pole prevents the use of the magnetic compass for determining directions in a large part of the Western Arctic and adds to the difficulties and hazards of polar flying. Because of the number of navigational uncertainties, it is recommended that the following pre-flight procedure be followed:

TIME

Because of the difficulties introduced by the seasonal variations and the twilight period, the time schedule for a flight must be planned in advance and as closely adhered to in flight as possible. It is necessary to know:

1. At what time important celestial shots are to be taken.
2. At what time changes in course will occur.
3. At what time gyro precession is to be determined.
4. At what point in the flight the twilight period will occur.
5. What celestial bodies will be available during the flight.

The master watch should be set with a time tick and then carried in an inside pocket because most precision watches are unreliable at low temperatures. This watch should only be used to check the hack wrist watch which should give no difficulty as long as it is worn. The master watch should never be worn on outside clothing or attached to a sextant for more than 15 minutes.

CHARTS

A large variety of maps and charts have been used in an attempt to determine which are most suitable for arctic flying. On these the lack of physical features is evident and in many instances the location of these physical features are inaccurate or conflicting. The following is a list of charts which have been selected for reference and plotting:

U. S. Aeronautical Charts 1:1,000,000.	Map Reading.
National Topographic Series, Aeronautical Edition, 8 mile to 1 in.—Department of Mines and Resources, Canada.	Map Reading.
USAF Aeronautical Planning Charts.	Map Reading.

USAF Long Range Navigation Charts.	Reference.
Emergency reproduction of British Admiralty charts for North Coast of Canada and Arctic Archipelago—original engraving, January 20, 1855, Amended to 1939.	Reference.
Northwest Territories and Yukon 1:5,068,800—Department of Mines and Resources, Canada.	Reference.
Modified Lambert Confermal Projection of Canadian Arctic Regions—Department of Mines and Resources, Canada.	Plotting.
VP Plotting Sheets 1:1,000,000—U. S. Navy Hydrographic Office.	Plotting.

PLOTTING AND DEAD RECKONING

In areas around the magnetic poles, dead reckoning is the foundation of navigation as it is in other areas. The task of maintaining a continuous track is very involved and requires coordination of all navigational procedures to determine ground speed, drift, and position. Keep DR navigation accurate by continual use of radar and celestial observations, where possible.

The standard computers, plotters, dividers, and log forms are used as in lower latitudes. Several revisions to log forms have been suggested to facilitate checking gyro precession rate and heading, but as yet these forms are only suggestions from operational navigators and have not been standardized. It is anticipated that a revised log form for use in polar areas will be adopted within the not too distant future.

The B–3 driftmeter has been winterized to operate in temperatures as low as 65° F. The power and functioning should be checked, and the lenses cleaned before uncaging it. The gyro should warm up 30 minutes after starting before uncaging it. It is impossible to turn the rheostats on these driftmeters at very low temperatures, so the reticle light should be adjusted to the proper intensity before the airplane is exposed to low temperatures.

The most valuable aid for dead reckoning information in these regions is radar. In spite of undercasts the ground can be "seen" and the scope information used in a manner similar to the use of a pilotage chart. Wind runs, drift determination, and fixes from landmarks are obtained in this way similar to the procedure used when the ground is observed. There are some few radar beacons available and their locations are listed on the standard Racon List.

CELESTIAL

Celestial navigation is the most important method of fixing position in polar regions. The procedure is similar to procedures used elsewhere but refraction and ceriolis corrections must be applied. Computed altitudes and azimuth can be determined by use of tables in H. O. 249, H. O. 214,—volumes VIII and X, and H. O. 230. The tables in H. O. 249 are the easiest to use, but this volume includes only certain stars and a similar volume is needed for the sun, moon, and planets. Another valuable aid is the Weems Star Altitude Curves, but again these are restricted to the selection of particular stars. By use of these tables it is advisable to plan which stars are to be used and prepare in advance the altitudes and azimuths. In addition meridional altitude shots should be precomputed to save time and effort in flight.

The astrocompass is used for checking gyro precession and heading. This instrument should be properly alined before take-off.

The Mark V sextant will give excellent results, providing it is handled with care. The flashlight batteries should be kept warm by carrying them inside the flying suit because low temperatures affect their generating power. Breathing directly on the index prism of the sextant will cause ice or frost to form and should be avoided. In the event ice does form, the surface should be warmed with the hand until the ice melts and then the prism should be cleaned carefully with a soft clean cloth or lens tissue.

LORAN

Loran stations are gradually being installed in the Arctic. The low frequency loran stations are in the test stage and are not considered to be reliable aids as yet. Three such stations have been established near Point Barrow, on Victoria Island, and at the mouth of the Mackenzie River. Except along the base line extension, they have a fairly reliable coverage up to 1,000 miles of the more distant station of the pair being received. There is a chain of standard-frequency stations centered about the Aleutians with a range of about 700 miles in the day time and 1,400 miles at night. More stations will be installed as time goes on. Information should be obtained from loran charts issued by Hydrographic Office and the Aeronautical Chart Service.

GRID NAVIGATION

Measuring courses in midlatitudes is fairly simple, but in high latitudes the convergence of the meridians at the geographical pole causes the course to change rapidly. To simplify determining course and direction, the grid system is used. This system substitutes a grid for meridians and parallels of the aeronautical chart and grid direction for geographic direction. On any chart, the grid is made by drawing a line parallel to the 0 to one-hundred and eightieth meridian. The direction away from the North Pole along the one-hundred and eightieth meridian is "grid" north. Then, in north polar regions: True Direction plus W. Long equals Grid Direction, and True Direction minus E. Long equals Grid Direction. A series of lines parallel to this grid north-south line are considered as grid meridians and a series of lines perpendicular to these lines are grid parallels. With this new system of coordinates the heading and wind direction remain constant and the determination of the course is greatly simplified.

IN-FLIGHT PROCEDURE

After detailed pre-flight planning, the in-flight procedure is a detailed job. No new principles of navigation are necessary, but constant checking and employing of a combination of all procedures is necessary.

The directional gyro is the instrument used to maintain heading. It is not affected by magnetism and with corrections for precession will maintain a true line in space. The most important procedure with reference to the gyro compass, therefore, is correction for precession. A constant checking of the gyro information by astro-compass is necessary. This information must be logged accurately to determine the precession rate. As previously stated the log form for recording gyro precession and astro-compass information has not been standardized, but the procedure now employed by operational navigators provides a record of gyro precession with enough reliability to use the instrument if an overcast prevents astro-compass checks of heading.

Radar is the chief source of dead reckoning information in the polar regions. The procedure for using radar in pilotage, wind runs, and fixes is the same as the procedure used with a pilotage chart. However, pilotage is not too reliable either visually or from the scope because maps are constructed from sketchy data, and the terrain features are hard to distinguish as discussed above.

Celestial navigation in arctic regions is like celestial anywhere else. The availability of celestial bodies for observation is somewhat limited, however, depending upon the season of the year. Corrections are about the same as anywhere else but refraction and coriolis force corrections are quantitatively larger and they must be applied correctly. During the periods of continuous twilight, celestial navigation is practically impossible, since stars are not visible. An instrument for determining direction by the use of polarized light (the Pfund Sky compass) is being flight tested to prove its value.

Polar navigation is still an arduous task requiring the full time of several well-qualified men. Celestial is the primary method for maintaining direction and determining position, with constant logging of all available information. All phases of the trip must be carefully planned because the success of the undertaking depends entirely upon the accuracy of the navigation.

SEARCH AND RESCUE OPERATIONS

Successful search and rescue—and rescue operations—in the Arctic will require a well organized plan, executed by personnel having an understanding of the problems involved, utilizing efficient communications.

For initial indoctrination; personnel should study the *Air Sea Rescue Manual,* JANP–300, from which much of the following material has been taken.

The primary mission of search and rescue is to render emergency assistance to aircraft and ships in distress and to rescue survivors. It includes assistance and rescue operations, distress communication procedures and distress flight control, survival methods and equipment, and the indoctrination of personnel in these matters.

COLD WEATHER CONDITIONS

The problems connected with search and rescue under cold weather conditions are complex and deviate from those problems occurring in more temperate zones because of the following factors:

1. Cold air temperatures.
2. Low water temperatures.
3. High winds.
4. Vast expanse of waste lands.
5. Low ceilings and icing conditions in clouds.

6. Unreliable communications.

7. Absence of navigational aids and unreliability of magnetic compasses.

Search and rescue for the distressed can be considered to be divided into two operational phases—the first is the search, and the second is the rescue of survivors.

Those concerned with search and rescue in the Arctic should be familiar with all of the various types of special clothing which is available and should be certain that adequate outfits are in their possession before embarking on any mission. The problem of maintaining adequate warmth inside the airplane should be considered. All devices in use, such as cabin heaters, should be checked to ensure that they are in good operating condition. Information concerning survival after an accident has occurred is available. It must be read and understood. Pilots, air crews, and passengers should be appropriately briefed in the various aspects of survival. It should be especially borne in mind that immersion in cold water will cause death in a matter of minutes unless the victim wears an appropriate immersion suit.

The high winds encountered frequently in arctic regions are a concern to those engaged in search as well as the downed personnel. When engaged in the search, the air crew should make every effort to determine the force and direction of the wind and to maintain a constant check thereon. The air crew should obtain all the local aerological and geographical data that has been compiled in the past in order to get a general idea of what may be ahead. The survivor is also concerned with this problem since adequate shelter must be devised to protect him against the wind as well as the cold.

It must be borne in mind that it is difficult to live off the land in the major part of the arctic wasteland. Provision must be made for adequate survival by carrying clothing, food, and other supplies in the airplane. The survivor should also keep firmly in mind that he can hasten his rescue by the accepted use of smoke signals and other signalling devices. Therefore, he must understand their use before take-off.

Low ceilings and icing conditions often hamper search and rescue operations. Here again, a knowledge of local weather conditions can be of the utmost importance to a search plane. At times it may be comparatively safe to fly when there is a 300- or 400-foot ceiling in certain areas. The survivor should understand the obstacles which must be overcome when poor flying conditions prevail.

ERRATIC COMMUNICATIONS

Communications in the Arctic generally will be erratic and unreliable. On some occasions phenomenal ranges and clarity of signals are obtained. At other times results are extremely poor. Hope for the best, but prepare for the worst. The air crew must be alert to these conditions and know how to cope with them, for instance by changing the frequency. It is absolutely essential that all communications equipment be kept in a state of readiness. The network of search and rescue facilities which may be available in local areas by the various government agencies should be known to all those operating in the Arctic. The means of alerting these activities should be understood. The joint frequencies available for communications should be studied.

It is, of course, well known that the magnetic compass becomes unreliable in the high latitudes. For those who conduct extensive flights in the Arctic, the grid system of navigation should be understood and used. Navigational aids, such as radio ranges, beacons, and loran, are meager. However, the location of navigational aids as well as their peculiarities must be understood. If the plane is to be ditched every effort should be made to broadcast its position by use of an urgent message with the proper emergency heading. Prompt action can save the lives of all.

In a search and rescue organization there must be certain key personnel who are trained and designated for operations duty. Rescue operations in the Arctic require even closer understanding and cooperation in operating procedure among separate commands and agencies. Efficient rescue requires the use of all available facilities, prompt delivery of information, competent evaluation of that information and positive immediate action.

RESCUE OPERATIONS

Rescue operational plans and facilities must be consistent with their relative importance to normal or tactical operations. Efficient coordination of such facilities depends upon a well-conceived search and rescue plan for each area. Each such plan should clearly define responsibility of each participant and should provide for precise communications and operations procedure for all parties to the plan.

Basic principles of successful rescue operations require planned methods for:

1. Anticipating distress incidents when operations permit.

2. Promptly reporting and relaying distress information.
3. Promptly dispatching adequate assistance.
4. Following through rescue operations to completion.

When distress reports are received at the operating base, the duty officer or officer in charge of rescue operations must obtain all information available on the situation as rapidly as possible in order to determine the course of action to be followed. If a search is indicated, the following factors will influence search plannings:

1. Best known, or most probable, position of the accident.
2. Whether personnel parachuted or ditched.
3. Time elapsed since parachuting or ditching.
4. Whether personnel are in life rafts.
5. Force and direction of wind.
6. Force and direction of ocean current.
7. Whether personnel (if in rafts) are sailing or drifting.
8. General weather conditions.

When a search aircraft is dispatched on an emergency rescue mission, it should immediately establish and maintain communication with Rescue Operations Center.

During the search all possible observation points for lookouts should be manned by aircrew members. The lookout who makes a sighting should report immediately to the pilot on the interphone, giving the relative bearing.

RESCUE REPORT

The plane or ship effecting rescue should report the following information to rescue operations center as promptly as possible:

1. Total number of personnel rescued.
2. Total number of personnel injured. (If seriously ill or injured give name, condition, treatment administered, and effect.)
3. Total number of personnel dead or missing. (Give names if available.)
4. Destination to which proceeding and ETA.

In combat areas and remote frontiers such as most arctic areas, special directives will be necessary in connection with the various rescue organization systems and procedures. In many cases facilities will differ and methods will vary, but the principles will remain the same. All persons connected directly or indirectly with rescue operations must be familiar with command directives and local orders on the subject.

No airplane available today has been designed especially for rescue purposes, and no existing airplane possesses all the necessary requirements. However, several types of military aircraft are being used for rescue operations, and these are satisfactory if their limitations are borne in mind by operating personnel.

The helicopter is in use in certain areas for limited operations. Difficulties experienced in present operational models are being overcome as rapidly as possible. Improved models are in design, and at such time as they are placed in large scale production, will figure prominently in rescue operations.

Types and quantities of equipment required will vary with different operating localities. With every airplane, weight is a major consideration and discretion must be used to prevent overloading, particularly when aircraft are carrying a regular operational load as well as rescue equipment.

SURVIVAL EQUIPMENT

The air plan should prescribe the essential survival equipment to be carried by the several types of aircraft engaged in the operation. Operational experience indicates the following as a guide:

Figure 6–15.—The continental Arctic above the treeline.

Food for 10 men for 60 days:

1 Case of butter.
1 Sack of Navy beans.
1 Case powdered sugar (easier carried in this form).
1 Case raisins.
3 Six-pound cans dehydrated pea soup.
1 Case powdered eggs.
1 Case dehydrated cabbage.
4 Three and one-half pound boxes dehydrated sweet potatoes.
1 Case dehydrated carrots.
2 Cases canned chicken.
12 Cans of canned ham.
10 Pounds tea.
10 Pounds bouillon cubes.
10 Bottles vitamins.
4 Five-pound cans cocoa.
9 Five-pound cans powdered whole milk.
1 Case chocolate bars (Hershey).
360 Life raft rations.
6 42-pound cases of pemmican.
10 2-pound cans of bacon.
10 2-pound cans peanut butter.
10 6½-pound cans of biscuits.
10 2-pound cans oatmeal.
300 ½-ounce pkgs. of salt.
150 4-ounce pkgs. of cheese.
Cigarettes (carried by each man).

NOTE.—The above will provide approximately 3,600 calories per day per man for 60 days.

The following equipment has been carried by various units. Some of it is nonessential. Items not having a quantity should be provided on a basis of one for each expected crew member and passenger.

Sleeping bags (arctic type and pads).
Two-man tents (at least 6).
2 Five-gallon gas cans of safety type.
1 Arctic type two-man sled and harness.
1 Set of sails.

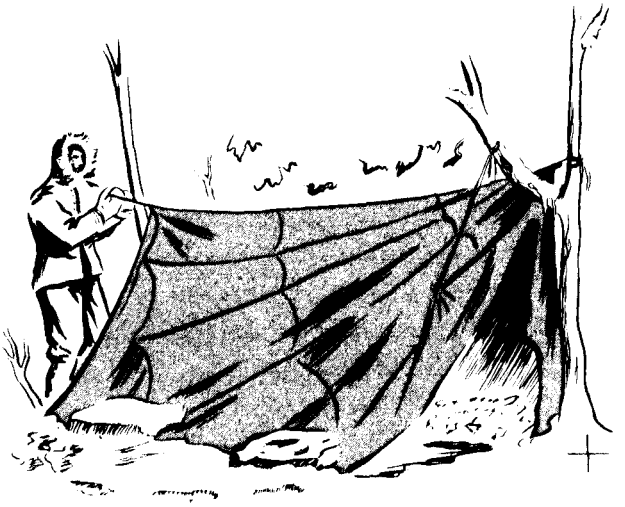


Figure 6–16.—Emergency shelter.

Life rafts with capacity for all intended personnel.
1 Gibson girl.
2 Ice picks.
1 Shovel (Trench type).
1 Machete.
1 Snow saw.
Parachutes and harnesses.
Life jackets.
1 Set cooking equipment.
1 Set plates and eating equipment.
1 Gallon orange paint and brush.
1 Box matches.
Skis and poles.
Crampons.
Snowshoes.
Immersion suits (quick donning).
Byrd cloth wind-proof ski units or equipment.
1 Stocker stretcher.
Flares, smoke, orange, hand held.
2 Stoves, Coleman, single.
1 Set splints.
8 Blankets.
4 First aid kits.

If loading plan will permit, extra gloves, mukluks, parkas, face masks, and other items of outer clothing should be carried in case torn or damaged clothing is caused by the emergency. Each pilot should carry a standard aviator's medicine kit.

The following items should be carried by regular crew members and passengers on extended hops:

1 Tube lip chap.
1 Water proof flashlight with lanyard for securing around the neck.
1 Boy Scout knife.
1 Extra pair sun goggles (preferably N2 type).
1 Small waterproof match container with matches.
Several safety pins.

VA TYPE

The equipment will be greatly reduced over that for VR–VP type; and should include as much of the following as possible:

Food for 5 men for 12 days or 1 man for 60 days:

30 8-ounce pkgs. pemmican.
32 Bags tea.
7½ Pounds powdered milk.
2 Pounds bacon.
2 Pounds peanut butter.
6½ Pounds biscuits.
1 Pound cocoa.
4 Lbs. butter.
2 Lbs. oatmeal.
30 ½-ounce pkgs. salt.
30 20 oz. pkgs. cereal blocks.
30 1½ oz. pkgs. chocolate blocks.
2 Bottles vitamins.
36 Life raft rations.
30 2-ounce cocoa blocks.
60 2¾ oz. sugar blocks.
2 Lbs. sugar.
15 4 oz. pkgs. cheese.
30 Pkgs. breakfast "C" rations if available.
30 Pkgs. dinner "C" rations if available.
30 Pkgs. supper "C" rations if available.
Cigarettes, toilet paper, and wooden spoons packed as necessary.

Figure 6–17.—Raft and wind break.

Due to space limitations the following equipment may not all be carried but should be given consideration over other items:

1 Two-men tent.
1 Ice pick.
1 Shovel (trench type).
1 Snow saw (any large tooth hand saw).
1 Single Coleman stove.
1 Gallon fuel for stove.
28 Immersion suits (constant wear).
2 Blankets.
2 Sleeping bags and pads.
1 Gibson girl.
Flares, orange, smoke, hand
snowshoes (if room permits).
2 Byrd cloth windproof ski suits.
1 Box matches.
Life raft.
Life jackets.
Parachutes and harness.

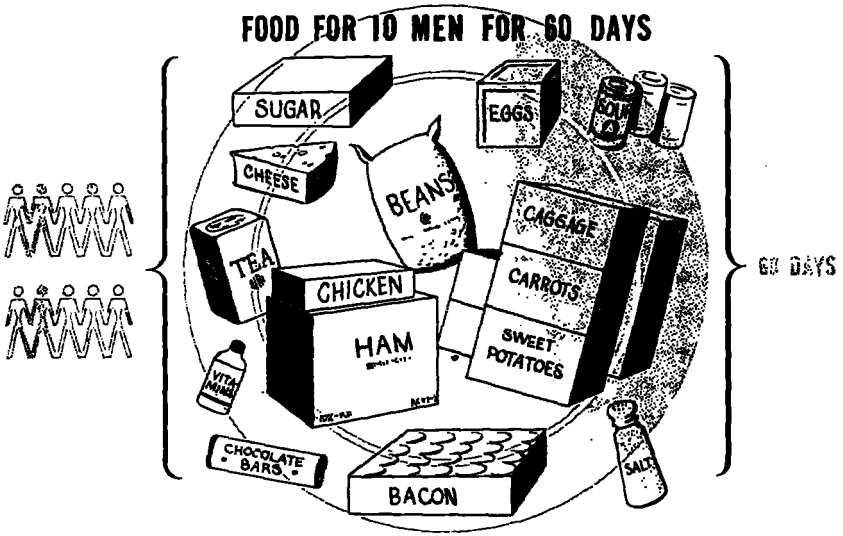


Figure 6–18.—Food for 10 men for 60 days.

VF TYPE

Survival equipment carried in this type of aircraft must be selected with order of precedence. The pilot must be more completely briefed than pilots of other types of aircraft since he will have less equipment on which to depend for survival following a forced landing. The VA type food allowance listed above should be carried, but space and weight should not be taken by food at the expense of the following items:

1 Sleeping bag and pad.
  Flares, orange, smoke hand.
1 Tent (the difference in weight of one man and two is insignificant and should use the two-man).
1 Shovel (trench type).
1 Snow saw.
1 Immersion suit.
  Life raft.
  Life jacket.
  Parachute and harness.
1 Gibson girl.
1 First aid kit.
1 Pair snowshoes (if space permits).
1 Byrd cloth windproof ski suit.

Figure 6–19.—Survivor.

DISTRESS SIGNALS

Visual signalling devices such as signalling paulins, smoke signals, Mark 13, and mirrors are effective for great distances under CAVU conditions in the North. Proper use of the signalling paulin can effect transfer of intelligence to search aircraft when the grounded party has been sighted. Messages may be spelled out with sticks, rocks, or in the snow with dye or lamp black, if available.

SURVIVAL PRECAUTIONS

Survival in the polar regions will always be a struggle against time. Time is of the essence. Select proper fitting clothing and understand the proper use of the immersion suit. Insure that survival equipment and supplies are properly packaged and placed in the airplane before take-off. Rehearse ditching procedure and the plan to be followed in event of forced landing. Do not bail out unless absolutely necessary either over land or water. If a forced landing is made on the water, remain with life raft. Even

if wet, put on immersion suit and cover the hands. Use the same procedure in life raft as in tropical waters. Flex the muscles and try to rig a wind break of some sort. If canned heat is available, try to make a hot drink even if it is dirty water (not sea water, of course). It will help, in event of forced landing, to stay in the vicinity of the aircraft and *keep it visible*.

To facilitate search, a detailed flight plan should always be filed before take-off and adhered to in flight as closely as possible. All changes in flight plan should be reported.

Be prepared for cross-country travelling. Therefore, knowledge of skis, snowshoes, and crampons is important. The cross country ski is the best type for emergency use as it is lighter and is better suited for flat or rolling country.

Refer also to chapters 5 and 6 (part I) and to *Polar Guide* (AFTRC 50-0-23).

SUMMARY

Successful aircraft operations in the Arctic depend on many things—excellent maintenance and preflight preparation, careful and detailed flight planning, mastery of all-weather flying, understanding of polar air navigation, knowledge of survival equipment and techniques, and good communications. Above all else, good judgment is required.

This chapter of the handbook is merely an introduction to the nature of past operations and to the problems and techniques of flying the Arctic with military aircraft. It is based on past experiences under arctic and antarctic conditions and should prove useful to nonflying personnel, as well as flyers.

Naval operations in the polar regions require considerably more preparation than operations anywhere else in the world. This applies particularly to aircraft and airborne equipment. Most cold weather operating difficulties in the case of aircraft will occur on the ground or flight deck. What is done before take-off determines to a large extent whether the mission will be a success or a failure. Failures in the Arctic are likely to be fatal. Check methodically for every source of trouble before take-off.

Since this chapter can touch only the highlights, the attention of the reader is directed to the following publications dealing specifically with the subject of this chapter:

Aircraft Carrier Bulletin No. 1, Aer–E–342–TJW, CV/A4, serial 163080, 23 October 1943. Restricted.

Bureau of Aeronautics Technical Note No. 84-45, instructions for cold weather operations of naval aircraft, Aer–E–43–JED, F24–5(1), 10 September 1945. Restricted.

USAF Polar Guide (AFTRC 50–0–23 of 15 June 1948).

Report on U.S.S. Midway Cold Weather Cruise, 15 June 1946. Restricted. (This is the report of Bureau of Aeronautics' observers to the Chief of the Bureau.)

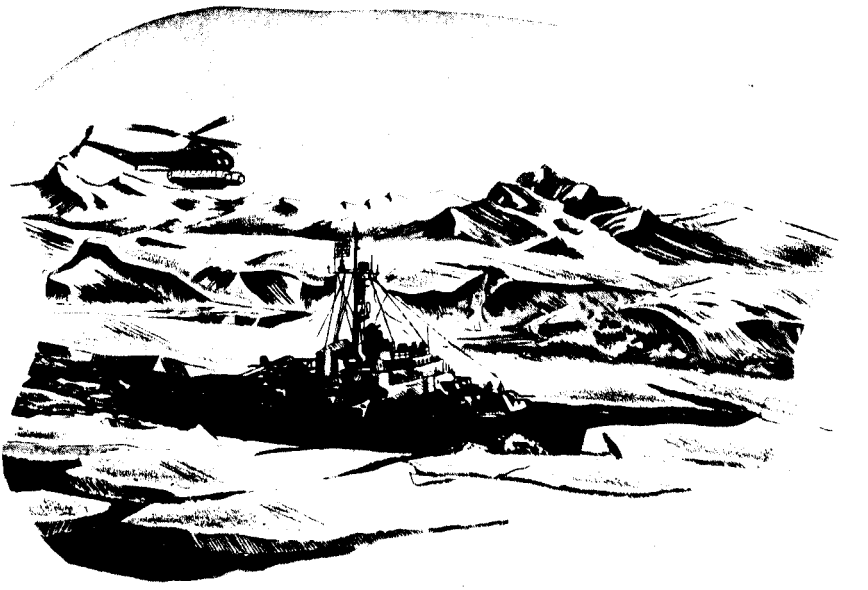
Cold and Heavy Weather Operations, March 1946 (Frostbite), CTG 21.11 conf. ltr to CinCLant, FB 2–1/A4–3, serial 02, 13 April 1946.

Report of U.S. Navy Antarctic Developments Project, 1947 (Operation High Jump), forwarded by CTF 68 conf. ltr. to CNO, CTF68/A9/rdk, serial 0184, 10 June 1947.

A Treatise on the Preparation of Aircraft for Extremely Cold Weather Operations, enclosure (A) to NAS Quonset Point ltr. to BuAer, NA43/L2(53–HK:alr), serial 53 239, 21 June 1948. (A detailed discussion of the winterization of six R4D and one J2F aircraft for Operation Highjump.)

An Aerial Reconnaissance of Arctic North America by K. R. Greenway, Flt. Lt., RCAF, and S. E. Colthorpe, 1st Lt., USAFR, May 1948. Confidential.

Report of Arctic Summer Operation, 1948. CTF 80 conf. ltr. to CNO, CTF80/A4–3/A9/rd, serial 025, 12 November 1948.



CHAPTER 7

AMPHIBIOUS OPERATIONS

In analyzing the global aspects of modern warfare, particularly with reference to warfare among the major powers of the Northern Hemisphere, the arctic regions raise problems of primary military importance by virtue of their possible strategic location and because of the limited number of previous military operations conducted there. In the vast areas included within these regions, no fully continuous or systematic scientific studies as to geographical and environmental conditions have been conducted nor has there been the necessary accumulation of knowledge adequate for planning military campaigns. Since it may become necessary to seize advance bases for the prosecution of a naval campaign or to destroy enemy bases that may have been established within the arctic and subarctic regions, it is of primary importance that the adaptation of established doctrine and techniques to the characteristics peculiar to these regions be investigated and promulgated within the limitations of the existing data.

Figure 7–1.—Troops about to land at Attu, Aleutian Islands.

The mode of warfare in any theater is characterized by the geographical nature of the theater and by the distribution, frequency, intensity, and duration of environmental factors. In perhaps no other possible military theater of the world do these factors result in such pronounced extremes. The factors of the arctic environment have combined in such a way as to limit the economic development of the area and to influence effectively the sociological characteristics of the inhabitants. Thorough understanding of these factors as they apply to a specific objective area is required in the successful planning and execution of any military operation conducted there, regardless of its size or nature.

The vast regions included within the Arctic are composed of many kinds of country under many combinations of environmental conditions. The difficulties imposed by these conditions, particularly as to limitations upon transportation and communications, have, to a large extent, resulted in curtailment of activity except in areas accessible by water. This general characteristic dictates that amphibious operations will be a major military factor in the control of these regions.

The amphibious planner must determine the arctic characteristics of the target area, and then estimate the effect of these characteristics upon operational planning and execution of the assault phase. The effect of these conditions on subsequent operations ashore, construction and engineering, and the establishment of a base is found in other chapters of this handbook.

EFFECTS OF ARCTIC OCEANOGRAPHIC CONDITIONS

SEA ICE

Within the Arctic, major ocean currents prevent the formation of sea ice within a considerable area in which amphibious operations may be required. Because of this ice-free condition, these areas have progressed economically to a greater degree than the remaining areas of the arctic and are thus of greater military significance. Within ice-free areas, no departure from standard techniques of amphibious operations is required except as those operations may be influenced by climatic conditions, and operating conditions ashore.

Sea ice is the greatest single factor affecting amphibious techniques in their adaptation to arctic requirements. In any amphibious operation within sea-ice areas, the attack force commander should be given great latitude in determining whether or not he will attack, and the manner of attack, including time and location of the landing, since these factors are influenced by ice conditions.

There always will exist an element of danger to any task force of amphibious ships that must enter an area of pack ice. The force must be accompanied by ice breakers, and even with these, progress will be slow. Probably little evasive action can be undertaken. Positive air protection must be provided against any possible enemy air action. Amphibious operations wherein amphibious ships are required to enter a pack may well be beyond the level of a calculated risk.

UNNAVIGABLE ICE AREAS

Unnavigable ice consists of pack ice on land fast ice fields that are either impenetrable, or penetrable only by the largest and most powerful ice breakers. Should it become necessary to effect a landing against an area protected by unnavigable ice fields, the helicopter appears to afford the best method for the ship-to-shore movement. The manner in which the operation will be conducted

will, therefore, be limited both tactically and logistically in accordance with the limitations of the helicopter. It must be noted that a full investigation of the capabilities and limitations of the helicopter has not yet been completed.

In the event that helicopters cannot be used and amphibious operations must be conducted by surface craft against the edge of an unnavigable pack for subsequent movement against an objective, the operation must be limited in nature. Operations of this type will normally be conducted against undefended or lightly held enemy positions, such as weather stations, for the purpose of destruction, followed by withdrawal from the area. Only small, lightly armed, swiftly moving, highly trained units can be employed. Should flying conditions permit, the unit may be logistically supported by aircraft. Aircraft may also be used, particularly during the withdrawal, to drop trail markers in order to simplify the problem of land navigation. Evacuation of the wounded will constitute a serious problem.

MARGINAL ICE AREAS

Marginal ice areas include these areas that are negotiable by light ice breakers or specially reinforced ships, and areas free of pack ice but subject to drift ice and scattered ice flows. Pack ice within the marginal areas is continuously moving under the influence of winds and currents.

If at all possible, amphibious landings should be undertaken, because of the unpredictable nature of the pack, below the pack area and the units should move overland against the objective. If the landing must be made within the pack area the attack force commander must determine when to attack basing his decision on local ice conditions. Once the attack is initiated, speed in landing troops and conducting logistical support is of critical importance.

Within marginal ice areas, there is always the possibility that land-fast ice may exist on the shore line even though the sea surface may be clear for several miles. When this condition exists, it will impose considerable difficulties upon the landing of heavy equipment and the operation of amphibious craft over the "beachline." Extensive quantities of explosives may be required and considerable time involved in clearing the landing area. This condition may dictate the use primarily of infantry organizations unsupported by heavier weapons or equipment.

The landing in and movement over the solidly frozen pack in marginal ice areas is considered inadvisable by rapidly moving units for more than relatively short distances. Because of the unpredictable nature of the pack even the movement of small, light, and swiftly moving elements will be hazardous.

Within marginal areas, including those subject to small floes, the logistic support of the operations is far more hazardous than the tactical venture. Frequent changes of wind or the current may fill relatively wide open areas with pack ice of such density as to require suspension of operations and the movement of the supporting ships. It is mandatory that an adequate supply be built up ashore as rapidly as possible.

The logistic plan for an operation either within a pack or a marginal floe area should provide for an alternate method of emergency supply. Flying conditions permitting, consideration should be given to the use of aircraft in providing emergency drops. The overland distance to the objective, and the conditions of trafficability may determine the location of dropping areas and the logistic support organization required. In order to facilitate ship-to-shore communications, the shore party may be given full responsibility for logistic support and provided with adequate units and local communication facilities to operate inland dropping areas. In this event, the shore party should be provided with additional communication facilities to communicate directly with the carriers or bases providing the emergency support aircraft.

Marginal ice may restrict the movement of naval gunfire ships, thus limiting the effectiveness of this type support.

The use of helicopters in marginal ice areas may obviate the difficulties involved in the ship-to-shore movement by conventional surface craft.

MARGINAL ICE OPERATIONS

As a general rule, the following points bear consideration in the conduct of amphibious operations in marginal ice areas.

1. A beach assault, within marginal ice areas, may well be beyond the level of a calculated risk. Landings should be made below the marginal ice area if at all practicable, or beyond the limits of enemy interference, and the movement conducted overland to the objective.

2. The attack force commander must be given wide latitude in the conduct of amphibious operations within marginal ice areas

since the success of operations depends to a great degree upon local ice conditions.

3. The operations frequently will be in the nature of a raid of short duration, and with a limited number of troops participating.

4. Speed of landing troops and of the conduct of logistic support is mandatory.

5. The logistic support plan should include provisions for emergency support.

6. If practicable, the operation should be conducted by helicopter and supporting ships should not enter the pack.

7. Submarine reconnaissance will be extremely hazardous or may be entirely precluded. Operation of amphibious reconnaissance units, if not entirely impracticable will be restricted and retarded.

8. Within marginal ice areas, reconnaissance reports of sea-ice conditions are not of long standing value, since conditions may frequently and rapidly change.

TIDES AND CURRENTS

In general, tidal ranges in the Arctic are slight, particularly in areas of straight coastline. In bays, deeply indented coastlines and other restricted areas, the tidal range may be considerable, in some regions varying as much as 20 feet. Tidal conditions in the Arctic have not been completely and progressively studied. Furthermore, since wind and ice conditions exercise such a pronounced influence, predictions are not as reliable as they are in other regions of the world.

As a general rule, the slight tidal changes permit more latitude in the selection of the time of landing than do such changes permit in other areas. However, in areas where the tidal range is great, more caution must be exercised than is required in other regions where regularity exists. Local wind or ice conditions may result in unpredictable tides.

In areas of tidal variation, the beach may be covered with ice floes left as a result of a preceding tide. This condition should normally be expected in any ice area.

In marginal ice areas, it is highly desirable that data on currents be collected so that the movement of ice may be evaluated. The confluence of warm and cold currents gives rise to a vapor condition. The effect of this on amphibious operations is presented later.

The sea temperatures normally encountered in cold weather areas are such as to require that troops be landed dry. Immersion for a prolonged period is usually fatal. Both aboard ship and ashore with the shore party, provisions must be provided for the treatment of immersion cases.

Operations of the shore party will be restricted by the temperature of the water. Drying stations must be established wherein clothing may be exchanged and personnel warmed. The efficiency of shore party personnel will be considerably reduced since prolonged individual operations are impossible. To every degree possible, personnel must be protected by adequate replacement clothing. Warm stimulants and food must be available early in the operation and may be expected to be consumed at a high rate.

In shore-to-ship evacuation, casualties must be protected from sea water.

Operations of amphibious reconnaissance units and UDT's will be restricted by low water temperatures. Special individual swim clothing and equipment will be required.

Surf and swell are negligible in marginal and unnavigable ice areas since ice exerts a quieting influence upon the sea. As a consequence, amphibious operations will not normally be affected by surf and swell to any significant degree within ice areas. In ice free areas, surf and swell will require the same consideration as in other areas of the world.

EFFECTS OF TERRAIN UPON AMPHIBIOUS ASSAULT

The Arctic contains coastal land forms varying from extensive coastal plains to rugged mountains, cut by long, deep fjords. The advance and retreat of the great ice shields have left the marks of glaciation. Existing glaciers usually enter or approach very near to the sea.

FROZEN GROUND

Frozen ground is a phenomenon common to the Arctic as a whole. The term frozen ground as used in this chapter includes permafrost, the active layer of permafrost, dry frozen ground, and other variations. Frozen ground is influenced not only by constant factors including geographic position and temperature but also by variable factors including such features as snow cover, vegetation, hydrology, and ground heat conductivity. As a result of the wide variations of local conditions within the Arc-

Figure 7–2.—Glaciers make good approaches to inland objectives.

tic that influence the active layer of permafrost, no detailed discussion as to the effects of frozen ground on the amphibious operation is possible.

Permafrost, and particularly the fluctuations of the active layer, will seriously influence the amphibious operation in regions where these conditions exist. The problems of trafficability, field fortifications, effects of projectiles, excavation, including that necessary for road and airfield construction and for the burial of the dead, water supply, and innumerable other activities must be viewed under conditions entirely different from those normal to the temperate and equatorial areas. Analysis of these problems can only be accomplished through understanding of the phenomenon of frozen ground in specific objective areas.

GLACIERS

Glaciers which approach the sea may in some instances provide the best approaches to inland objectives. For this reason the landing force may have to operate over glaciers. However, such operations will very probably be in the form of small raids.

In over-glacier operations, units should be lightly equipped so as to allow maximum mobility. Infantry should be provided with special foot gear. Sledges and tracked vehicles should be used exclusively. Thorough and continuous route reconnaissance must be made in advance of the main body, regardless of the proximity of the enemy. Alternate plans for supply and evacuation by air should be laid.

GLACIAL EFFECTS

In many flat coastal plains and more poorly drained areas, innumerable lakes and ponds have been left as a result of glacial action. In summer, when not frozen, they will constitute a serious obstacle to movement inland and will hinder maintenance of direction and control. In winter, the lakes will be frozen so that the landing force may use the ice surfaces as ready-made airstrips ashore.

The recession of the ice shields may have led to emergence of coastal areas from the sea in some parts of the Arctic. At any rate a phenomenon known as the "raised beach" exists. Raised beaches may be characterized by series of beach ridges some of which have water or ice filled marshes behind them. These beaches may extend several hundred yards inland, increasing the requirements for beach matting during periods when the surface is unfrozen.

Glacial action has left many coastal areas with large numbers of rocks and boulders on the beach and hinterland surface. These will constitute a minor obstacle, and may result in difficulties in crossing the beach with land or amphibian vehicles.

Figure 7-3.—Beach strewn with ice hinders landing operations.

VEGETATION AND CULTURE

Characteristic of the Arctic is a general lack of vegetation and man-made culture. Vegetation is low, for the most part, and provides no appreciable concealment. Man-made culture exists in isolated localities, but in the greater portion of the Arctic there are few roads, airfields, or port facilities which are of any significance.

The lack of significant vegetation and culture will require:

1. Increased emphasis upon camouflage discipline and utilization of minor terrain features for cover.

2. Increase in quantity of camouflage material carried by the landing force.

3. Provision by the landing force of all buildings, facilites, and materials required for operations ashore.

EFFECTS OF CLIMATE AND WEATHER

The wide variations in temperature ranges, wind force and direction, type and amount of precipitation, and climatic factors affecting visibility which occur throughout the Arctic, and the sudden unpredictable changes of these factors in many areas, will exert certain major effects on the conduct of the amphibious assault. Their nature, vagaries, and complexities will have the following major effects:

1. Broad, flexible operation plans which allow latitude in time of landing and selection of specific landing areas often will be required.

2. A greater number of alternate plans for operations in certain areas may be necessary, particularly in those areas where the weather factor is subject to sudden and severe change.

3. Alternate means of logistic support and employment of supporting arms should be included in administrative and operation plans and rehearsed prior to an operation in order to precisely determine the time-distance factors and difficulties involved, mainly due to low visibility and heavy snow.

4. Greater flexibility of organization, primarily because of the necessity for the above, will be required.

5. It will often be necessary to delegate more authority to subordinate commanders in determining actual time and place of landing due to differences in local weather conditions.

6. In many areas, due to precipitation in various forms and

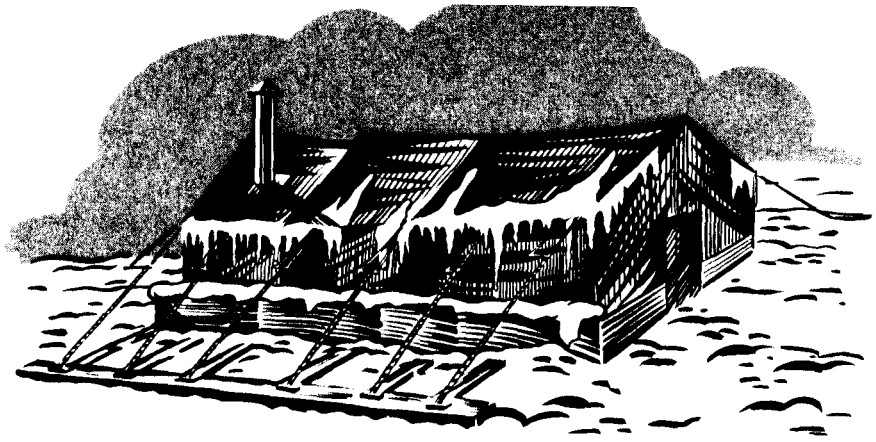


Figure 7–4.—Shelter.

combinations, there will be an increased dependence on manhandling and manhauling of landing in severe cold.

8. Weather alone, particularly low temperatures, will require inclusion of a far greater proportion of special clothing, equipment, rations, fuels and lubricants, and other special items.

9. Amphibious forces operating in the Arctic over a period which includes more than one season will be required to include equipment and supplies appropriate for each season.

TEMPERATURE AND WIND

The severe cold of arctic winters will affect both the materiel and personnel of the amphibious force. Extreme low temperatures in themselves have a very strong effect on such materials as glass, rubber, copper wiring, steel, and explosives. They also effect the functioning of such elements of equipment as motors and storage batteries. The effects of extreme low temperature on personnel, in itself is severe, but when combined with wind, oftimes produces situations that are humanly unbearable. The combination of these factors is known as windchill. Windchill alone may be the factor that prevents successful completion of a landing operation.

Shelter is one of the important factors in successful arctic operations, especially during the winter months. Adequate shelter must be provided the landing force, and it is likewise desirable that the landing force destroy enemy shelter. Winter conditions may require a considerable increase in number of troops needed because of the frequent reliefs required. Likewise, it may

be necessary to reduce the number of boat spaces allocated as standard in temperate zones because more room is needed per person for clothing and equipment.

The chill which may result from getting wet is an even more important factor in the winter and must be guarded against at all costs. This may require enclosed landing craft and certainly will require special arctic suits for use by amphibious reconnaissance units and underwater demolitions teams. The extreme cold may require special storage facilities for explosive ordnance. Naval gunfire support ships should not, however, encounter the same problems in using VT fuze projectiles as will field artillery units ashore. Temperatures of freezing and below along with other conditions will tend to cause duds and premature bursts.

Water supply by conventional means ashore will be difficult. It will be impossible, for example, to utilize the standard 5-gallon can as a means of water supply and resupply. Obtaining water ashore from natural sources will be difficult in view of the fact that the vast majority of the sources will be completely frozen. Water may have to be obtained from ships and carried ashore in heated containers. Recoil of artillery will be slow under conditions of extreme cold. This will reduce the rate of fire of the larger artillery pieces and may indicate increased need for naval gunfire support and an increased use of the smaller weapons which do not require a lengthy period to return to battery. The reduced performance of aircraft and aviation ordnance may restrict operations of air support units and may require a considerable increase in the number of aircraft allotted to the landing force because of the slowing down effects of the extreme cold combined with the wind. The time involved in any operation may be increased considerably.

PRECIPITATION

Precipitation in the form of snow will cause difficulties which may effectively reduce the ability of the landing force to operate ashore. Movement over snow covered areas which are not tightly packed, and through areas of heavy drift, may be restricted to foot troops and special over-snow vehicles. Even the movement of foot troops will often be slowed down considerably. The usual time factors utilized in movement of supplies, troops, and vehicles may have to be increased considerably. Air and naval gunfire support may be presented with difficulties in spotting and target designation. The snow will cover landmarks ordinarily visible

and will so change the surface feature of any particular area as to make it very difficult to operate from a map.

Likewise, the presence of snow on beaches and coastal terrain may make it hard to conduct suitable aerial photographic surveys and to provide the landing force with aerial photographic interpretation in sufficient detail. The difficulties of map-reading and orientation from maps in snow covered areas may be so extreme that the landing force will have to operate entirely from information obtained after landing in the area and relayed to higher echelons and supporting arms. Cold rains and sudden freezes may require that the shore party and other units establish drying stations or shelters in which wet clothing may be exchanged for dry.

VISIBILITY

Intense low lying coastal fogs, heavy low cloud cover in coastal areas, intense rainfall, snow driven by high winds, and periods of long winter darkness, all of which occur in various areas of the Arctic, may restrict observation to the extent that landing operations, particularly those involving combined arms, may have to be postponed or executed with great difficulty. Utilization of support aviation, naval gunfire, and artillery will be extremely limited in such situations. Air and ground reconnaissance, control and coordination of the ship-to-shore movement, and direction of the landing force ashore may be seriously affected. Conversely, periods in which decreased visibility prevails may often provide the landing force with much needed concealment for grouping and movement. In general, the operations of large units employing combined arms and vehicular equipment will be severely restricted by decreased visibility while the operations of small, lightly equipped landing forces may be facilitated by the same factor.

OTHER SPECIAL CONSIDERATIONS

DAYLIGHT AND DARKNESS

The characteristic long summer day and the long winter night of the Arctic will provide difficulties for the landing force. In the summer, daylight lasts 24 hours, and although the sun may not necessarily be above the horizon, it is present sufficiently to provide continuous illumination. The lack of darkness in the summer will make it difficult for individuals to adjust themselves to a schedule normally followed in the temperate areas.

Tactical movements involving regroupment of forces and movement of supporting units to positions in readiness for attack cannot be accomplished under cover of darkness. This again may require extensive use of smoke. Obviously the need for illuminating shells by naval gunfire and artillery will be reduced to a very minimum in summer operations. In the winter, however, when there is little light it may be necessary to increase the quantity of illuminating shells tremendously. It should be borne in mind, however, that except where reflection is poor, the arctic night is not totally dark; for example, when half the moon is visible, it is possible to see a mountain as far away as it can be seen in full daylight. Operation of supporting arms, such as naval gunfire support ships, and air support will be hampered during the winter by darkness. Considerable reliance may have to be placed on radar beacons for directing gunfire support. The arctic night, despite the hindrance it imposes upon operations in general, will provide ideal conditions in which to conduct small raids which are dependent almost entirely upon surprise for success.

Morale of troops may be adversely affected by the continuous darkness during the winter. Conversely, in the summer, as a result of lack of darkness, morale may be considerably higher as long as enforced rest is carried out. During arctic winter operations, some consideration should be given to providing artificial lighting for operations conducted behind the lines, particularly those involving the shore party operations and cargo unloading.

Figure 7–5.—Moonlight in the Arctic.

Terrestrial magnetism, particularly that in the vicinity of the north magnetic pole, will provide difficulties in the use of the compass. The hand compass, however, in most areas in the Arctic can be relied upon for local beachhead operations.

SUMMARY

The very nature of winter warfare, especially in arctic regions, is so complex as to require the highest caliber of planning, training, and logistic support. However, the strategic situation may force upon us the need to conduct these difficult operations in order to counter operations or prospective operations by enemy forces in such areas.

Blank page retained for pagination

CHAPTER 8

BASE OPERATIONS

"Can it be done? Is it worth while? What will it cost?"—Peary.

Advanced base construction in the Arctic resolves itself into the fundamentals of A B C, "Achievement Bespeaks Commonsense."

Sir Hubert Wilkins, noted arctic explorer, once said, "A misadventure in the Arctic is due to one of three reasons: Ignorance, incompetency, or inexperience." This is another way of saying that operations such as the establishment and maintenance of advanced bases in the arctic and sub-arctic regions can be successfully accomplished when a full understanding of the conditions to be met are known. Realizing the conditions of terrain and climate, and working in accordance with the limitations imposed by them, personnel can successfully complete an assigned task provided they are properly equipped and provided they follow the established techniques. The Bureau of Yards and Docks along

with other units of the Navy has been conducting successful operations above the Arctic Circle since 1944. A brief review of material from part I will facilitate understanding of this chapter and is therefore included.

The arctic region in the Western Hemisphere includes the northern coasts of Alaska and Canada, the Canadian Arctic Archipelago, much of Labrador, and the greater portion of Greenland. The sub-arctic region, a belt of variable width south of the arctic region, includes Newfoundland, southwestern Labrador, most of Alaska, and most of interior Canada. In the Arctic and the subarctic areas there is a great contrast in climate between the coast and the interior. For this reason the coastal and interior areas of the subarctic are usually considered separately. The greater part is, with the exception of a few spots here and there, heavily forested.

The arctic region, on the other hand, has no forests whatever. Aside from the shrub willows which are more or less common there, it is characterized chiefly by vast stretches of mucky, treeless land covered with a variety of hardy plants, including grasses, lichens, and shrubs. This type of country is called tundra. Unlike prairie country which it generally resembles, tundra is, to a

Figure 8–1.—Arctic station at Point Barrow, Alaska.

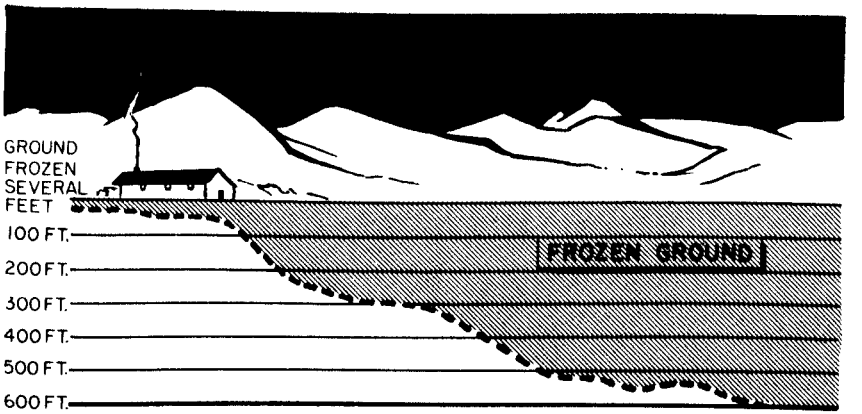


Figure 8–2.—Permanently frozen ground varies from several feet to 600 ft.

large extent, poorly drained and marshy. Hummocks of vegetation abound in the marshy areas, but the soil is poor.

Most of the tundra and parts of the forested subarctic region are permanently frozen a few feet below the surface. The thickness of this permanently frozen ground varies from several feet in the southern fringes of the subarctic area to depths reaching reportedly as great as 600 feet in the coastal plains of Alaska and East Siberia. During the summer the ground thaws to a depth of two feet or more, but, because of the underlying frozen ground, water can neither sink below the thawed layer nor run off. This results in the marshy character of the tundra and the notoriously poor drainage of large parts of the Far North. It is also partly responsible for the many lakes scattered over the region (fig. 8-1).

Temperatures vary considerably throughout these areas. In general, the subarctic interior area has the coldest winters and warmest summers. The arctic coastal area has warmer winters and cooler summers because the large bodies of contiguous water tend to stabilize the temperatures.

LIGHT, FINE SNOW

It is a popular fallacy that there is a great deal of snowfall in these regions. The idea arises from the fact that the snow, being light and fine, is easily stirred about by the wind after it has fallen. So, as long as the wind blows, it appears to be snowing.

Although it is true that many places are windy, at most places the winds are moderate. Winds are usually stronger on or near

Figure 8–3.—The williwaw.

land than out at sea. The most intense storms occur on high land facing the sea. An outstanding example of a windy region is western Greenland. Gusts of over 100 m. p. h. have been measured frequently in southwestern Greenland.

A peculiar Alaskan wind is the williwaw. It is caused by winds piling up on the windward side of a mountain and boiling over on the leeward side. The turbulence is similar to a thunderstorm and is nearly as violent. These types of winds are common to the Aleutian chain of Alaska.

One of the peculiar effects of cold temperatures (minus 30° F. to minus 60° F.) in the sub-arctic interior regions is to dry the air, because colder air loses its ability to hold moisture. This inability to hold moisture causes condensation of the exhaust of engines, resulting in an ice or steam fog sometimes great enough to suspend operations. Such a situation often arises in the areas of still wind and extreme cold of the interior regions of the subarctic.

Factors such as the above—tundra, muskeg, lakes, snow, ice, wind, extreme cold—must be taken into account in any construction project in the Arctic.

WORK FEASIBILITY

Temperature, wind, visibility, amount of daylight, rain and snow greatly influence construction operations. Figure 8-2, Work Feasibility Chart, graphically illustrates the recommended times in which to conduct various operations with reasonable effective-

ness in a given area such as around Point Barrow or Fairbanks in northern Alaska. To meet these climatic conditions, as well as to cope with permanently frozen ground and remoteness, construction methods and techniques must be adapted accordingly.

The movement of equipment, personnel and supplies and the establishment of bases in the Arctic may be likened to the techniques of an amphibious operation. All supplies for use in arctic regions except sand, gravel, and water must be brought in either by ship or aircraft and then delivered to the construction site by tractor or bush plane. Native workers may sometimes be utilized to a limited degree, but skilled personnel must be moved to the site and properly trained to resist the rigors of the environment.

Although the mission or function of a base in an arctic or subarctic area is an important factor in the lay-out and plot plan of an installation, due consideration when selecting a site must be given to the features of terrain and minimizing permafrost problems, providing adequate water supply, and insuring adequate waste and sewage disposal.

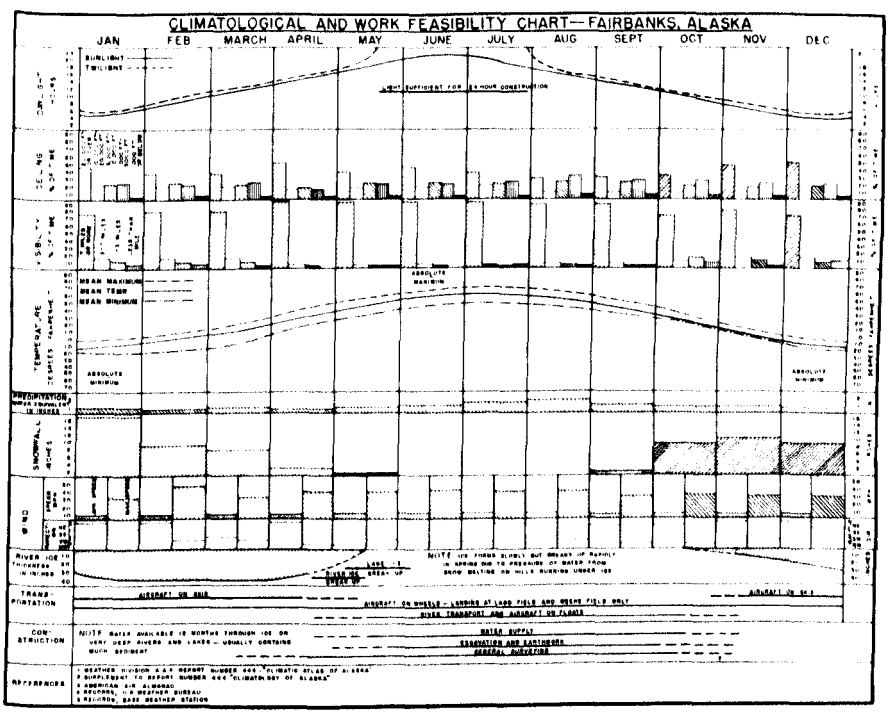


Figure 8-4.—Work Feasibility Chart.

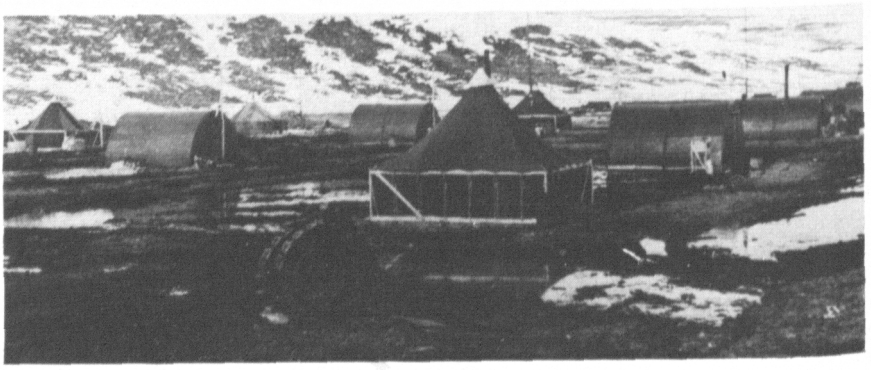


Figure 8–5.—Drainage problem in a permafrost area.

On the arctic plain and plateau regions, ridges and old river terraces located inland, and former beaches along the coast are likely sites for facilities. The site should be in an area that is well drained in order to permit the most efficient construction with the least possibility of permafrost problems. Areas having natural drainage and composed of soil made up of coarse, well-drained material are the most suitable. Figure 8-3 is an illustration of the drainage problem in a permafrost area.

Lay-outs should consider the effects of drifting snow, and buildings should be located with their long axes parallel to the direction of the prevailing winter winds.

FIRE PREVENTION

Due to the presence of many gasoline heaters, fire is an ever present menace. The difficulties of combating fires at extremely low temperatures and in high winds require that established fire

Figure 8–6.—Buildings should be located with long axis parallel to prevailing winterwind.

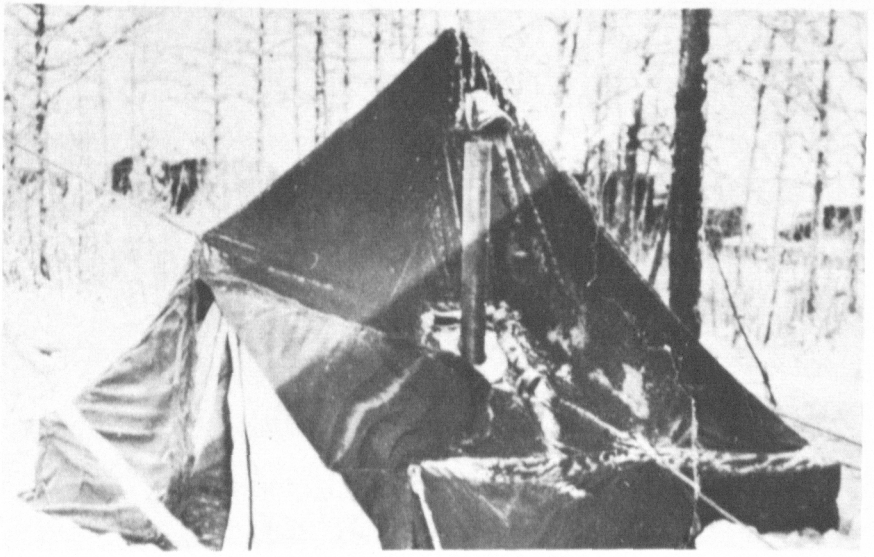


Figure 8–7.—5-man pyramidal tent, with inner liner.

prevention discipline be rigidly observed. Precautionary measures are the best fire-fighters in the Arctic, as elsewhere. For this reason, buildings should not be grouped or interconnected unless fire resistant and fire prevention techniques are used. Caches of fuel, gasoline, and explosives should be located remote from any buildings.

SHELTERS AND BUILDINGS

Since presently designed arctic clothing does not provide adequate insulation for extended periods of time in extremely low temperatures and wind, shelter is essential for the survival of personnel as well as for the maintenance of equipment. The types of shelters and structures that may be used are varied, but all must be capable of providing adequate heating and insulation, ventilation, maximum usable space, and ease of erection. Temporary shelters may include double-walled nylon tents (fig. 8–4), wanigans, Jamesway huts, improvised shelters made from tarpaulins, or snow houses with heaters or stoves. The 16 by 16 or 16 by 24 Jamesway hut and the 20 by 48 Arctic hut (fig. 8–5) may be utilized for temporary bases while the northern-type, insulated 20 by 48 quonset hut (fig. 8–6) is satisfactory when climatic conditions are not too severe to prevent erection. The Navy arctic hut can be erected at minus 65° F. by 12 men in less than 4 hours.

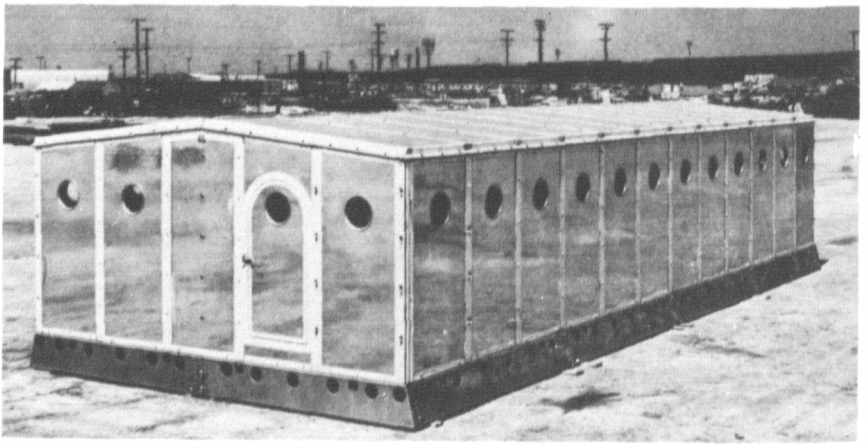


Figure 8–8.—Navy arctic hut.

CONSTRUCTION IN PERMAFROST

Construction in permafrost areas again emphasizes the importance of site selection and the proper scheduling of the various phases of construction in relation to terrain and seasons of the year.

In connection with operations, the selection of a suitable site for a facility is of prime importance. It should be in an area that will permit the most efficient construction with the least possibility of permafrost problems. Areas of natural drainage are most suitable. If natural drainage is not available, the area should be capable of being easily drained by artificial means. Carefully located ditches provide artificial drainage when natural drainage is inadequate. In permafrost areas, ditches should be lined with gravel to prevent erosion and to provide adequate insulation against the possibility of lowering the permafrost table, with resulting sluffing and possible damage to any road or facility.

Most earth work is accomplished during the period from mid-June to the first of September. During this time all types of gravel, sand or silt can be moved with conventional earth-moving equipment. During the winter season, river bed gravel may be obtained through the ice. All coarse sands and gravel located above the water table may be loosened by blasting or shocking with a dozer grader. Permafrost may be moved during the winter by blasting, or a limited amount of frozen earth may be thawed by steam produced by a small Alaska protectors-type low pressure boiler. Such earth moving is slow and not very efficient, and is feasible only in emergency.

The characteristics of the active layer on the permanently frozen ground makes foundation construction a serious problem. A structure of subgrade built on the active layer may change the frost table. After a thaw, settling may occur; and after a freeze, if moisture has been trapped, heaving is probable. To take care of such a possibility, heavy foundations are placed on piles which extend well down into permafrost. Prevention of the lowering of the permafrost table or the maintenance of thermal equilibrium is maintained by wide spacing of piles, and, in case of buildings, by providing adequate ventilation between the floor and ground and by insulating the floor. The heavy force of the active layer is counteracted by the ad-freezing force of permafrost to the piling. In some cases the silt and organic material of the active layer is removed and replaced by coarse or drained material. Figure 8–7 is a typical view of permafrost terrain in the Arctic.

ROAD CONSTRUCTION

Road construction is usually limited to camp areas and immediate surroundings. The active layer is removed if it contains moisture-holding material such as silt, fine sand, or organic material. Such material is replaced by coarse gravel, or material suitable for good drainage is provided. Air strips have been similarly constructed except for final surfacing.

The Point Barrow strip has a gravel foundation and a pierced-plank surface. The runway has been able to take care of large two and four engine aircraft. The only maintenance involves the replacement of pieces of mat. The Umiat strip is on an old river

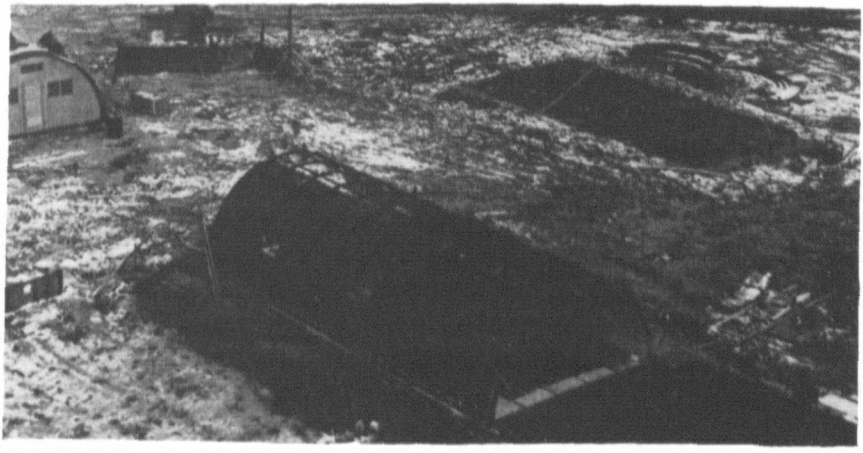


Figure 8–9.—Northern type quonset hut.

terrace. Coarse silt and gravel replace the silt and organic material in the active layer, and ditches have been provided to effect a fast run-off of water. The Barter Island runway was constructed on a gravel bar in a river delta, and in this case the active layer consisted of well-drained gravel and silt. This material was sufficiently coarse so that only grading was necessary.

Various types of buildings have been constructed, most being of the temporary advanced base type. The 40 by 100 quonset hut is usually erected on piling extending into permafrost, or in areas of coarse, well-drained materials. Sills are placed on short wooden blocks. For heavier foundations where piles are not desired, flat footings or slabs placed well within the permafrost and fastened to the base of a concrete or timber pillar may be used.

Old river terraces and gravel beach bars provide the most suitable landing areas. The use of frozen fresh water lakes for airstrips for planes on wheels has been successfully used from November to early June. Landings can be made on frozen terrains on skis.

Snow runways have been successfully used by R4Ds equipped with skis (fig. 8–8). To compact the snow, a pontoon drag is used in conjunction with bolted wooden track extensions to the tractor's track-plates, utilizing the weight and vibration of the machine.

An important property of snow which must be considered in compaction is that it automatically continues to harden if left undisturbed after having been compacted by mechanical means. This curing interval must be recognized because attempting to work hard, dry snow continuously without allowing this interval will only result in churning the snow mass with no increase in compaction.

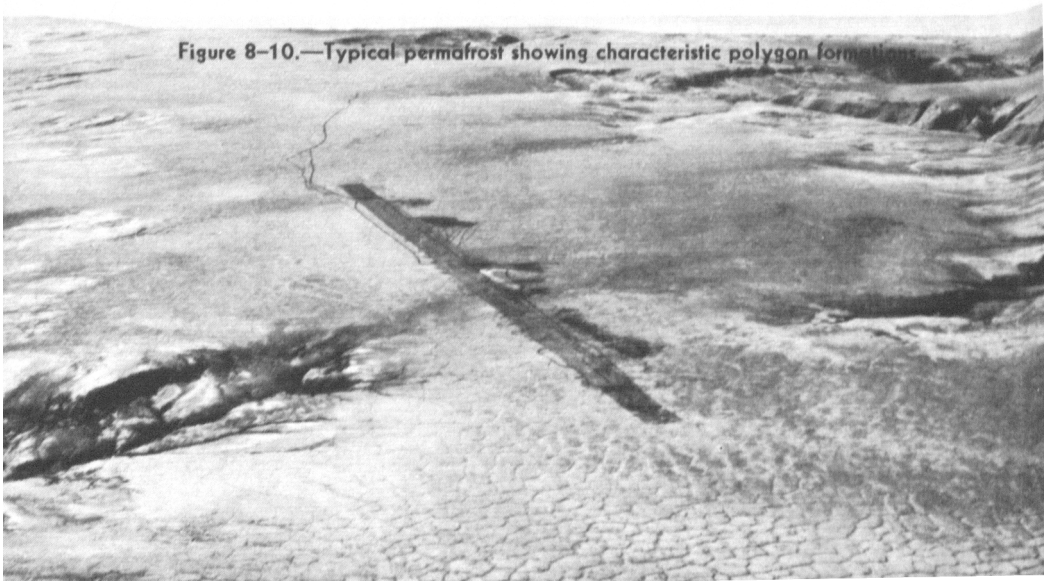


Figure 8–10.—Typical permafrost showing characteristic polygon formations.

Figure 8–11.—Runway in an arctic area.

UTILITIES

For temporary and mobile bases, a source of water can usually be obtained from lakes or rivers which have not frozen to the bottom, or from the melting of snow or fresh water ice. All water used for drinking or cooking should be given primary treatment, such as chlorination. Heated latrines are essential since answering "nature's call" is rather inconvenient, to say the least, unless a heated shelter is provided. Waste material may be collected in oil drums lined with burlap, allowed to freeze, and then periodically burned. In some cases, it may be dumped on ocean ice, should the location be so situated. For temporary bases, electrical distribution can be handled in the conventional manner. Permanent installations should provide heated "utilidors" for carrying of utility lines as well as fire lines.

FOOD AND DIET

The problem of food and diet in base operations in the Arctic resolves itself into the careful preparation of tasty and highly nutritious food. The morale of personnel can be considerably increased by the provision of the widest and most divergent diet possible. However, there is no essential difference between nutrition in the Arctic and nutrition in other parts of the world. Base

operations will require personnel to be exposed to cold weather for extended periods of time, warranting increased rations and the improved level of preparation made necessary by the climatic conditions and the environment.

The amount of food required by individuals will vary, with average requirements approximating 4,500 calories per day. Under some circumstances as many as 6,000 calories may be required. A greater than normal amount of body heat energy must be generated to balance the loss of heat due to the extreme low temperatures and inadequacies of clothing.

Special precaution must be taken in the packaging and shipping of food to prevent the freezing of liquids and the possible breakage of glass containers.

Advantage can be taken of natural refrigeration by utilizing underground storage in permanently frozen ground. This can be accomplished by sinking a shaft into the permafrost and widening the bottom horizontally for storage area. This practice has been followed by the Eskimo for centuries.

TRAINING OF CONSTRUCTION PERSONNEL

The tendency of travelers in relating their experiences in the Arctic, or for that matter, in other parts of the world, is to recount those that are most vivid in their minds. It is only human nature to remember the most startling or severe experiences encountered.

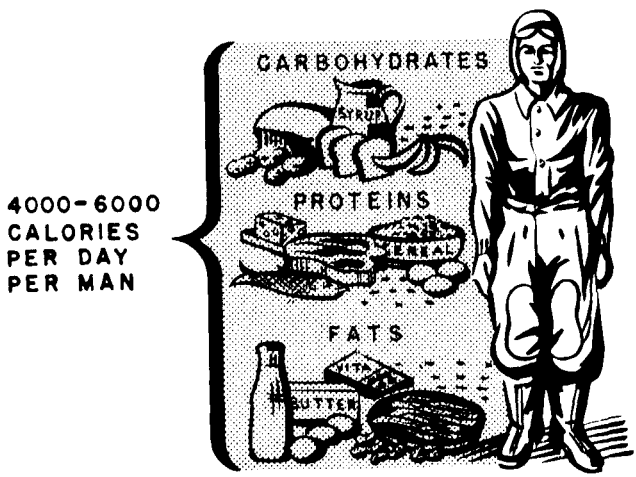


Figure 8-12.—4500–6000 calories per day, per man.

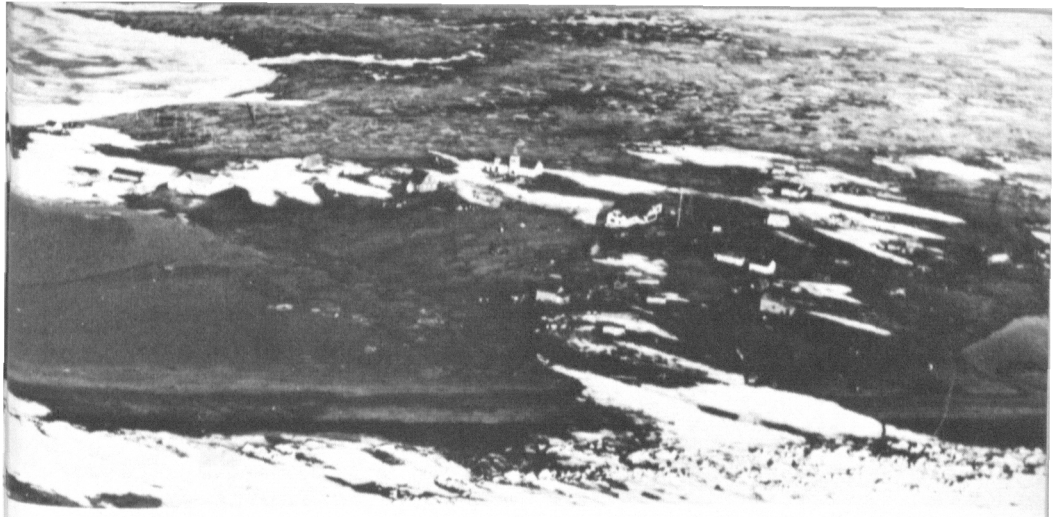


Figure 8–13.—Typical arctic terrain in Point Barrow, Alaska, area.

As a result, the tales of people who have been in the Arctic will gloss over the many normal conditions of life there and stress only the most severe and exciting conditions. This breeds in their hearers a psychological fear of the cold.

Experience has proven that this psychological fear can best be overcome by natural exposure to the arctic environment, rather than by lectures and movies. The techniques of survival will be based on the experiences of the men moving into the uninhabited area to establish an advance base. It is essential that these people have special training to enable them to adapt themselves to the rigors of the North and how to best use their personal equipment. The fact should also be emphasized that, as the temperature drops, personal efficiency will also be lowered. Obviously then, personnel for arctic duty should be carefully selected and highly trained.

TRAFFICABILITY

Due to the terrain features of the Arctic (fig. 8–9) and the absence of roads, wheeled vehicles are unsatisfactory except in an immediate camp area where a few roads may have been constructed. Track-type equipment has been most successful. The presence of many streams and lakes during the summer season requires that personnel and light utility vehicles be amphibious in order to provide year-round service.

At the present time, the M29C cargo carrier or weasel (fig. 8–14), with proper modification and winterization is the most

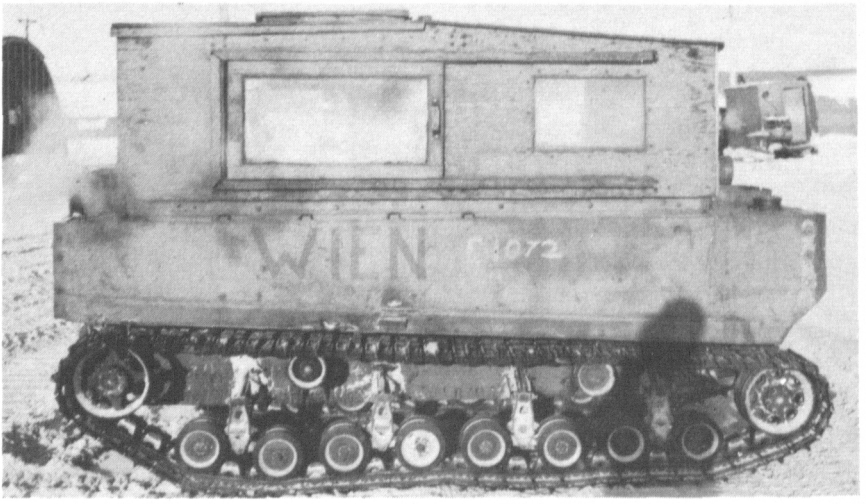


Figure 8–14.—Winterized weasel with permanent type cab.

satisfactory vehicle yet developed for small personnel carriers. The basic weaknesses in the weasel are general fragile construction, weak track suspension assemblies, weak transmission and a very high-speed motor. These limitations must be taken into account in the use of the equipment.

Advantage is taken of the frozen terrain to transport heavy equipment during the winter months. It has been the practice of Seabees engaged in construction work in northern Alaska to move their large quantities of supplies and equipment over the ice and frozen terrain by means of tractor trains between January and June. The trains are made up of five D–8 tractors, cook house wanigan, one 8-bunk sleeping wanigan, one emergency ship, and 12 to 16 sleds or go-devils. The lead tractor is provided with a V-type plow or dozer blade for breaking trail. The trail is scouted by a single-engined aircraft which drops weighted trail flags. This trail is then reconnoitered by a weasel scout vehicle which checks ice and route conditions.

OPERATION AND MAINTENANCE OF CONSTRUCTION EQUIPMENT

In general, most of the construction equipment designed for temperate climates can, with some modifications, be successfully used in construction projects in the arctic regions. However, this equipment must be fortified to meet the conditions of severe cold by the use of proper winterization kits, proper lubricants, coolants,

and cold starting aid kits. The general points of consideration in winterizing equipment will consist in protection for personnel, insulation of the engine compartment, insulation of hydraulic sytsems, heat of the batteries, and in some cases, modification of the track system.

Construction equipment used in the Arctic must be powerful and rugged to withstand the rough usage over the frozen terrain. However, it must be realized that during the summer season the trafficability of heavy construction equipment is limited, due to the marshy tundra.

Diesel power equipment is preferred because it has proven more dependable than other types and is usually more rugged. Wheeled vehicles are of little use until such time as graded roads are built.

PRIME MOVERS

The D–8 caterpillar tractor, equipped with a hydraulic bulldozer and a single drum winch equipped with ice grousers for winter and standard grousers for summer, has proven to be the most satisfactory of the prime movers. The D–6 tractor has proven satisfactory for operations during the summer months over the tundra and for pulling loads up to 5 tons.

Due to the many possibilities of failure on equipment operating at the low temperatures and over the rough terrain, all mechanical equipment used must be kept in the best condition possible. Equipment scheduled for arrival in the Arctic during the winter months should be completely overhauled and winterized prior to shipment. If equipment arrives during the warm season, schedules of operation must provide for winterization overhaul prior to the beginning of the cold weather.

Only first echelon maintenance can be accomplished in exposed areas at extremely low temperatures. Mechanics cannot handle tools while wearing heavy mittens. Exposure of bare hands will cause almost immediate freezing, and handling of cold metal can be very uncomfortable. In fact, bare hands stick all too easily to cold metal surfaces. It is therefore necessary to provide a greater area of heated shop space in any camp layout than would normally be provided in temperate climates.

LUBRICATION

Lubrication is, by and large, one of the most serious problems encountered in the operation of internal combustion engines. The effect of cold on greases and oils is one of the principal causes of

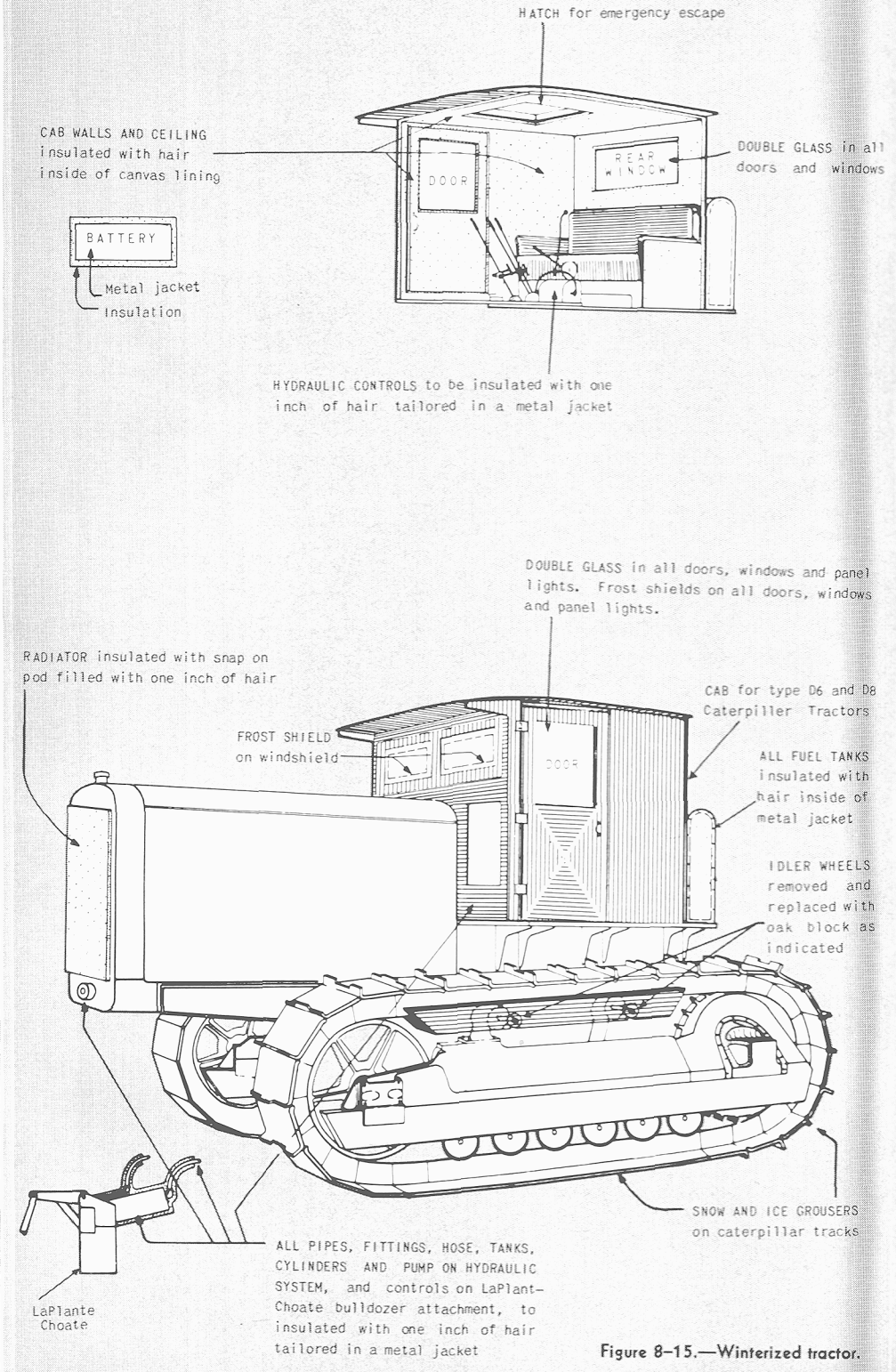


Figure 8–15.—Winterized tractor.

engine starting trouble. Lubrication ties in very closely with the problem of cold engine starting. Ten-weight engine oil in an engine cold-soaked for more than 3 or 4 hours can become so stiff that a fully charged battery with a specific gravity of 1.3 cannot turn over the engine. The problem of cold weather starting is further aggravated by the tendency for lead-acid storage batteries to lose much of their available capacity at lower temperatures. At 0° F. a storage battery can be expected to produce about 50 percent of its rated capacity, while at minus 30° F. its output is only 20 percent of its rated capacity.

While dilution aids starting by lowering the pour point of lubricants, it may also contribute to failures due to lack of lubrication. Engine oil OE–10 has a pour point of minus 10° F., while OE–30 has a pour point of 0° F., but with maximum dilution both of these oils are solid at minus 60° F. As a result, preheat is essential below minus 35° F. At minus 40° F., it may require about 2 hours of operation of a 250,000 B. t. u./hr. heater to start a gasoline engine, and about twice that time, or about 4 hours, to start a cold-soaked Diesel engine. Theoretically, the diluent should burn off at normal operating temperatures leaving the original grade lubricant, but often normal operating temperature is not reached and the diluent remains in the oil unless precautions are taken to check the operating temperature of the engine.

It is essential to analyze the type of operation to be undertaken when considering methods of cold engine starting. Military requirements will call for shutdown periods and quick start periods depending upon the tactical situation or the availability of fuel supply. In this situation, a light or low pour point lubricant, dilution, or reliable sources of preheat are required. On the other hand, construction in the limited time available will often require continuous operation of equipment, eliminating for the most part the problem of cold engine starting.

Heavy duty operation of construction equipment entails long hours of continuous operation, requiring a heavy-bodied oil despite the ambient temperature, so that when the engine has warmed up we will have an oil that is heavy enough to provide the necessary lubrication. For heavy equipment, such as a D-8 tractor, a heavy lubricant must be used to withstand the workload, and present methods make preheat almost mandatory for starting when the equipment has been cold-soaked.

STARTING THE ENGINE

Starting a gasoline engine at extremely low temperatures requires an engine that is free to rotate, a source of power to turn the engine, a fuel that will vaporize and burn at these temperatures, and ignition systems which will provide the necessary spark under these conditions. Free rotation may be prevented by the solidification of oil and the stiffness of fan belts and other accessories which turn with the engine. At minus 50° F., fan belts may become so stiff that they shatter like glass when twisted. Rubber tires may freeze solid and often develop frozen flat spots when left standing for a short period. Congealed or frozen gear lubricants may result in wheels skidding on ice-covered terrain and from starting. It is necessary therefore to start vehicles by heating each individual vehicle with such preheaters as the slave kit or 250,000 B. t. u. Herman Nelson heater.

Two methods of applying preheat are commonly used. First, by stand-by heaters which are run continuously during the shutdown period of the engine, and then by quick heaters which are operated just prior to attempting to start the engine. To date, the most dependable of the stand-by heaters is the Superfex 460 coolant-type heater. The best of the quick heaters is the Herman Nelson 250,000 B. t. u./hr. gasoline heater. The biggest objection to the Herman Nelson is its high rate of fuel consumption. Until low pour point lubricants have been developed, we shall have to depend on external heat for starting at temperatures as low as minus 40° F.

SCRAPERS, GRADERS AND ROOTERS

Scrapers under 16-cubic yard capacity have been used successfully in the Arctic. They should, however, be equipped with offset frost blades with protruding chisel-bit teeth. The center section of the blade should be slightly lower than the sides for very rough or frozen ground.

Figure 8–16.—View of motorized graders clearing snow off runway.

Motorized patrol graders with 12-foot blades have proven more effective than the towed type. It is essential that the grader operator be protected by a heated cab.

The standard 3-tooth rooter or scarifier has been used with some success when only 1 or 2 of the teeth were utilized.

CRANES AND POWER SHOVELS

As in all motorized equipment, the operators of cranes and power shovels must be protected from the weather with an insulated enclosure. Truck-mounted cranes are more mobile, but frequently bog down in the marshy tundra.

FORK LIFTS

Crawler mounted fork lifts with winterized cabs are very efficient on snow, ice, or marshy tundra. Use of the wheeled model, however, is generally confined to the interior of warehouses (fig. 8–17).

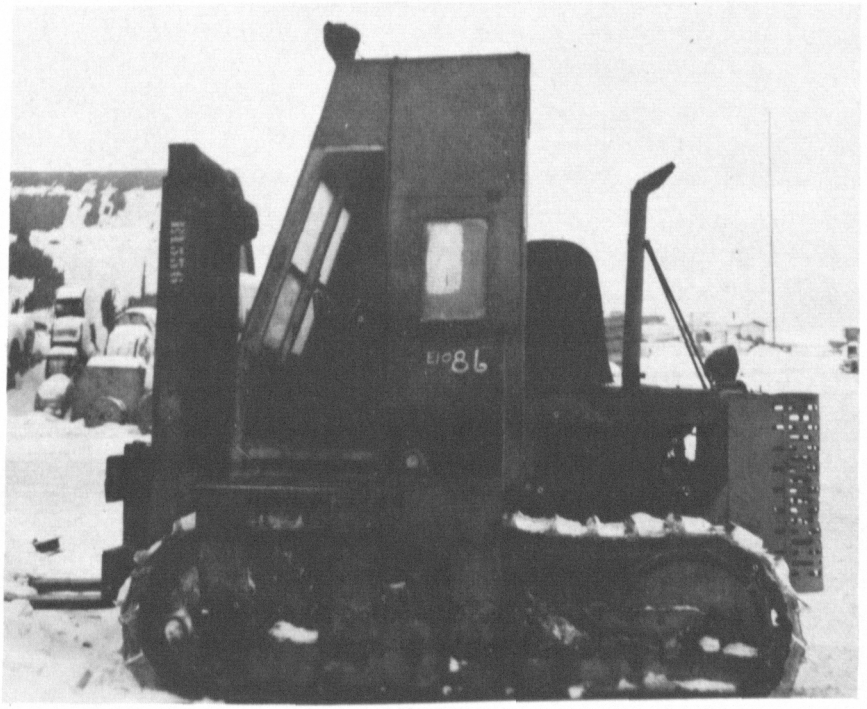
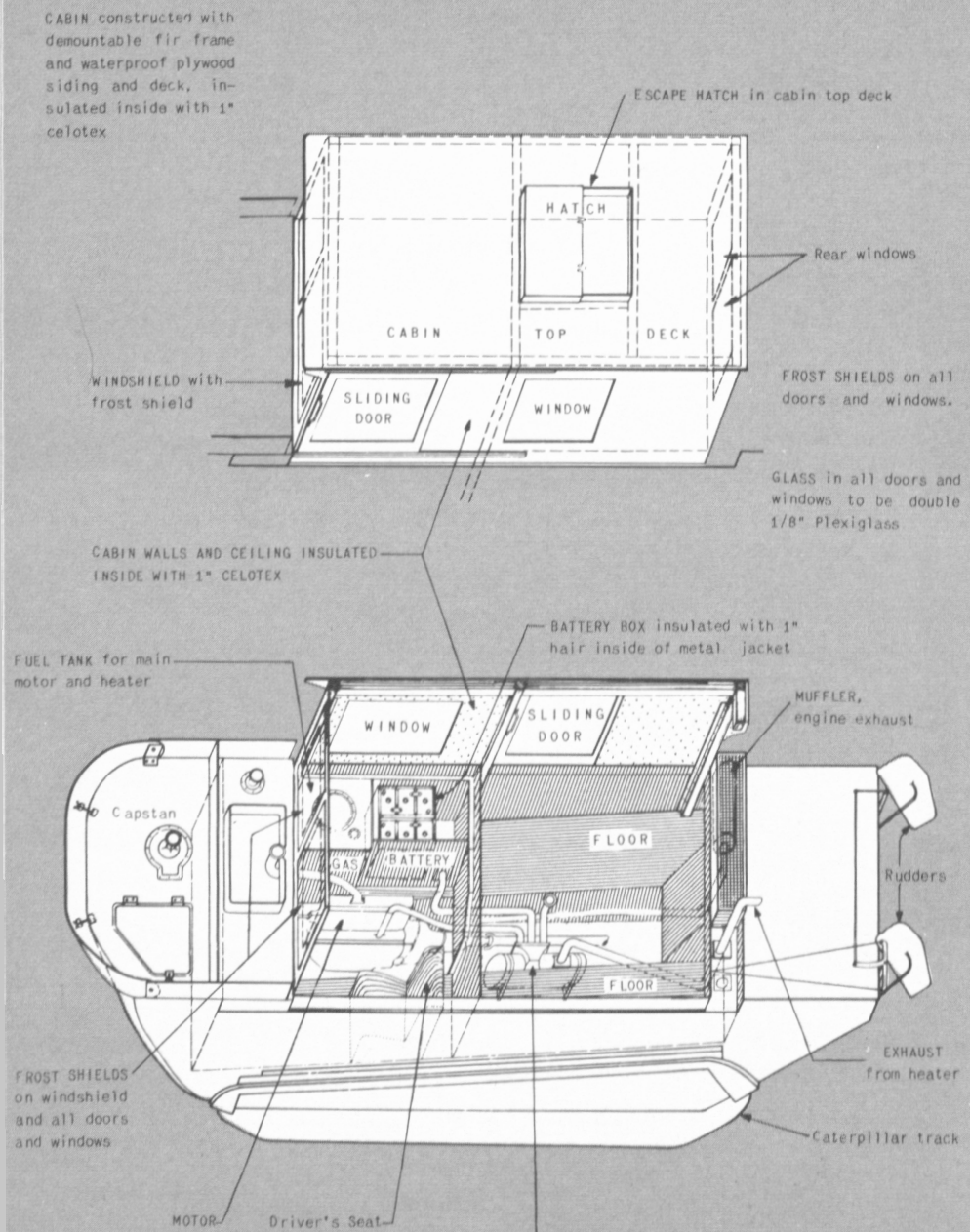


Figure 8–17.—Winterized fork lift crawler tractor.



HOT AIR HEATER, capacity 20,000 BTU, operating on gasoline, made by Herman Nelson Corp., Moline, Ill. Install in driveshaft well with 3 flexible pipe hot air outlets to (1) main motor crankcase, (2) battery compartment, and (3) cabin. Floor plate over heater removed to show installation.

HEATER CONTROL button on instrument panel. Hood over machinery compartment removed to show heater pipes to motor crankcase and battery box.

Figure 8-18.—Winterized weasel.

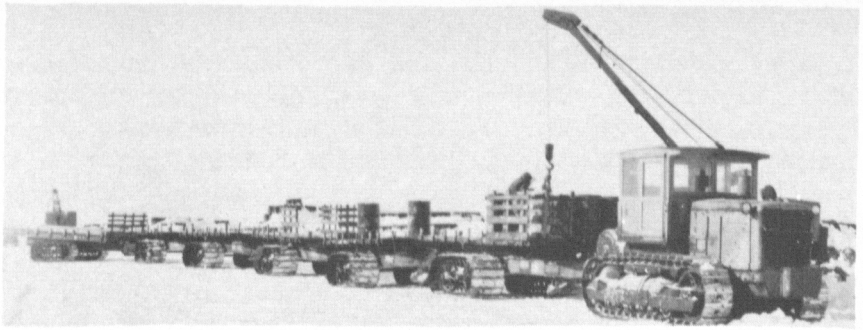


Figure 8–19.—A train of athey wagons.

PERSONNEL AND CARGO CARRIERS

The usefulness of jeeps and trucks is generally limited to improved roads and camp areas and, to some extent, to surfaces of ice or hard packed snow (fig. 8–14, winterized weasel).

The standard Army winterization kit for ¼-ton jeep on Task Force Frigid included the following items:

Primer pump.
Side curtains.
Superfex engine heater.
Fuel tanks.
Hood curtains.
Radiator cover.
Engine blanket.
Cab heater.
Hose, connections, and thermostat.
Slave kit connector.

ATHEY WAGONS

These nonmotorized vehicles are tracked cargo carriers of 15 and 25-ton capacity, used as a cargo carrying trailer. They give excellent service at low speeds but will not stand up well at towing speeds exceeding 15 miles per hour.

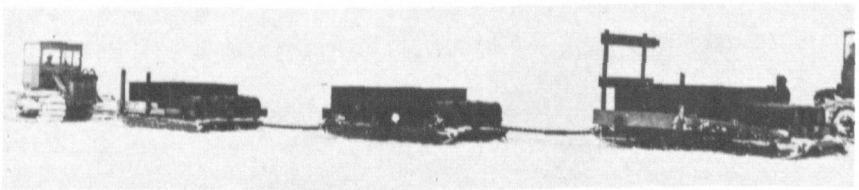


Figure 8–20.—View of go-devil sleds.

GO-DEVIL SLEDS

These sleds are the simplest and most easily constructed type of trailer unit used. They consist essentially of a pair of runners carrying a low platform. They can be built by a team of blacksmiths and carpenters in 50- to 150-man-hours. The center of gravity is low, eliminating tipping, and the load capacity is limited by bulk rather than weight. The load should not be higher than the width of the sled and no longer than 24 feet to assure satisfactory handling on the trail. The bed of a go-devil drags over a greater area of snow than do the runners of a bob-sled, hence more power is required to tow a go-devil than a bob-sled (fig. 8–20, view of go-devil type sled).

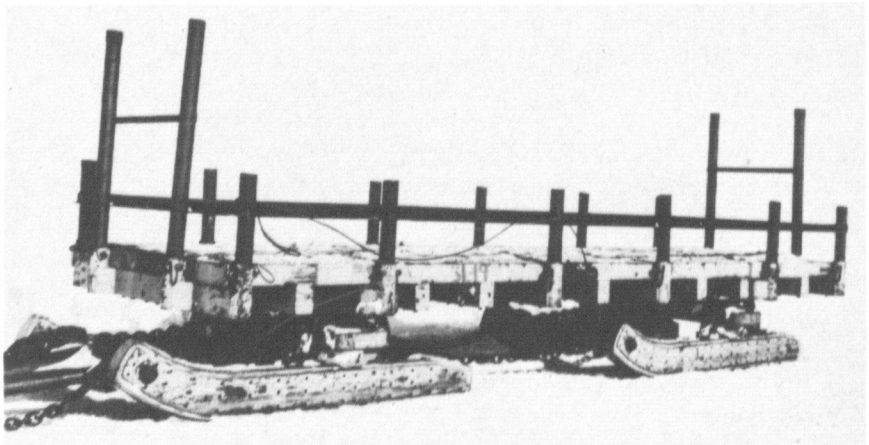


Figure 8–21a.—View of bob-sleds.

BOB-SLEDS

These sleds (fig. 8–21a) are of various sizes and design. Essentially, they consist of two sets of runners joined by cross-chains which make the rear set of runners track with those in front when negotiating a curve. Each set of runners is connected by a low or stationary bunker. An upper or movable bunker pivots on the stationary bunker, about a king pin. In this manner the runners can swing without interfering with the load. The bob-sled is attached to the tractor by a tongue. All parts are extremely rugged and reinforced with steel. Depending on the size, bob-sleds have a capacity of 10 to 75 tons.

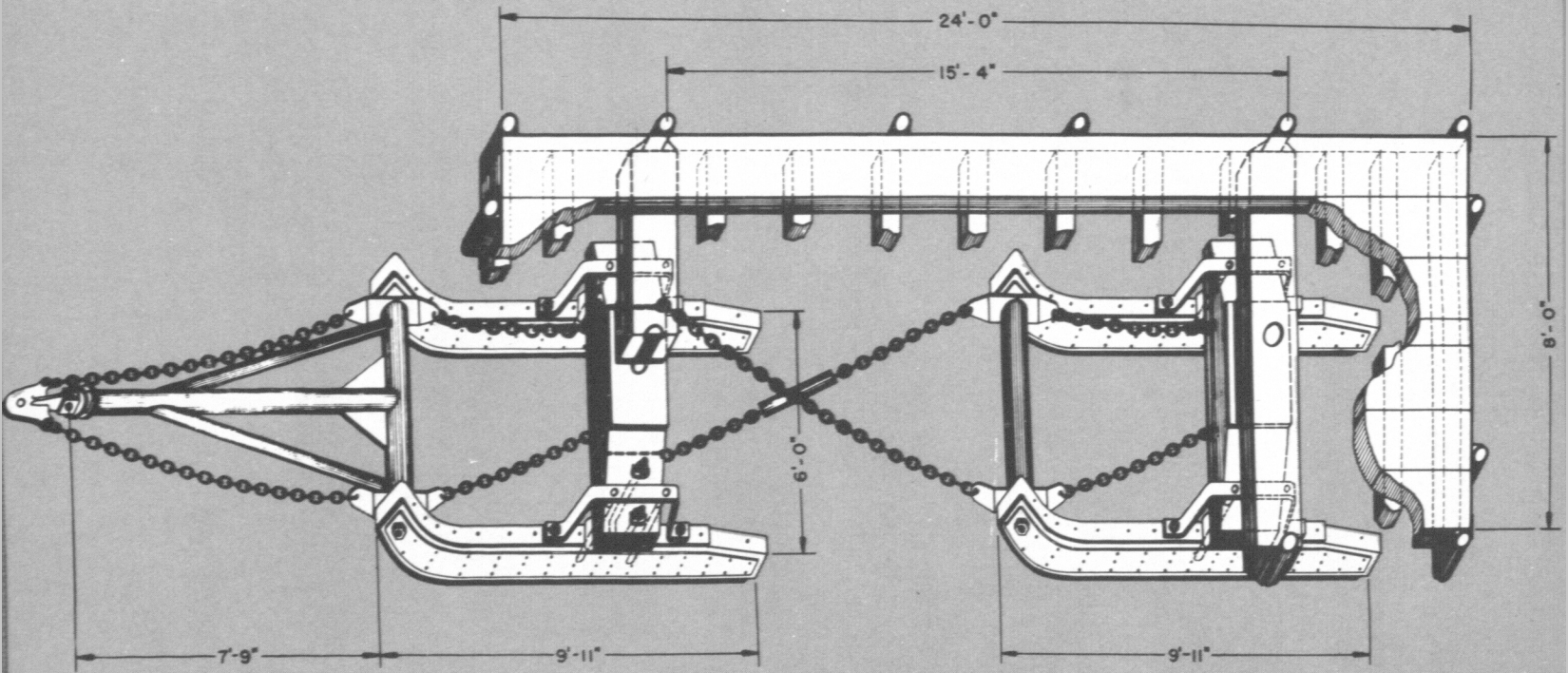


Figure 8–21b.—Drawing of Modified Micheler No. 9 sled.

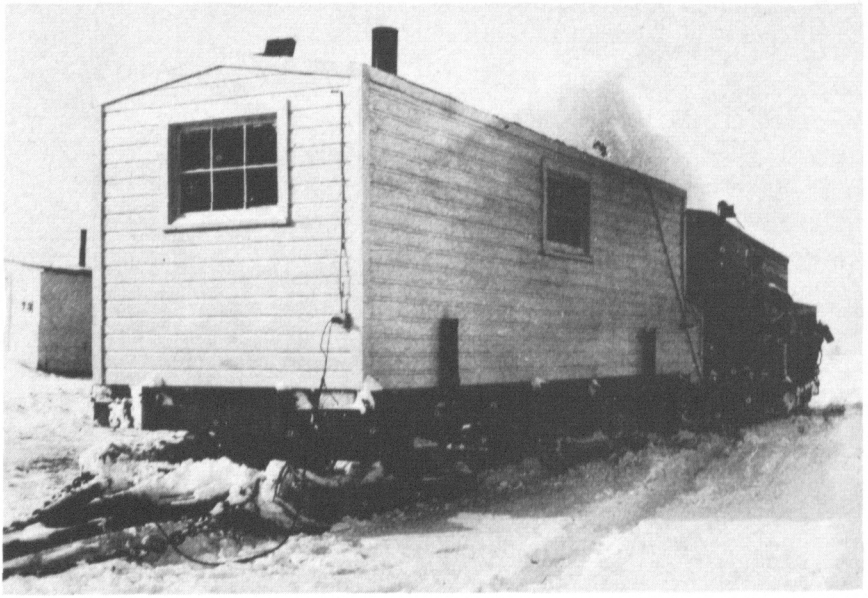


Figure 8–22.—A typical wanigan.

WANIGANS

Wanigans (fig. 8–22) are small buildings for use on the trail or in temporary camps. They can be mounted on sleds or go-devils. They provide quarters, messing, and shop facilities. Wanigans are usually constructed of 5/8″ plywood or sheet metal on a heavily braced frame to withstand the strains imposed by tractor train operations. The roof is curved in a flat arch and is of the same material as the walls with a sub-layer of roofing paper. Windows require heavy protective screens to prevent damage by branches. The interior is insulated with celotex or similar material. The height should be a minimum of 7 feet, the width about 8 feet, but no greater than the width of the dozer blade and the length variable. Longer wanigans ride more smoothly on sleds than shorter ones.

STEAM BOILERS

Skid-mounted steam boilers (fig. 8–23) are very essential pieces of equipment in the Arctic. Steam is required to thaw holes in the permafrost for piling and explosive charges. It is also used to thaw ice-filled culverts and to remove ice and frozen mud from equipment and tools. For small operations, a 15-h.p. boiler

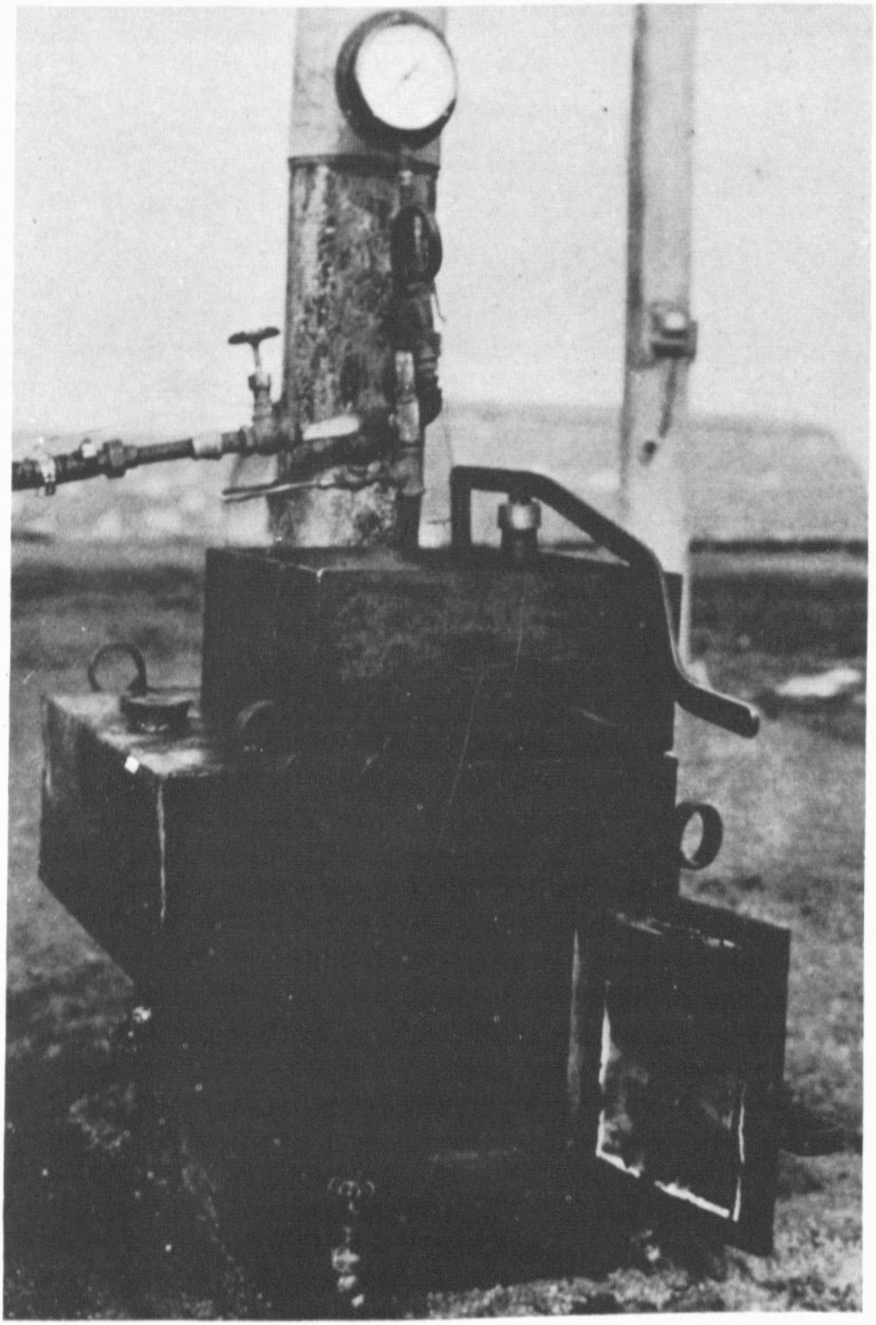


Figure 8–23.—A low pressure miners steam boiler for thawing frozen ground.

will suffice but for larger jobs a 45-h.p. to 60-h.p. size will be necessary. Pipes of various sizes and lengths for headers, steam hose, and steam jet pipes should be included as required accessories.

SUB-ZERO EFFECT ON MATERIALS

An understanding of the effect of extreme cold on the elasticity, durability, strength, and other physical characteristics of materials is important. A study of the mechanics of various materials at Point Barrow indicated the following:

Rubber.—New rubber resists cold rather well while synthetic and old rubber are not reliable. In any case, rubber should be handled carefully in low temperatures.

Neoprene.—Unsatisfactory at temperatures below minus 20° F.

Fabrics.—Untreated and water-repellent fabrics give no trouble down to minus 40° F.

Nylon.—Extreme cold, below minus 40° F. has no apparent effect on nylon. This material does not crack and remains soft and pliable at that temperature.

Canvas.—Freezes and loses its pliability; this is sometimes mistaken for shrinkage.

Leather.—Becomes stiff and tears easily. Wet leather is usually ruined if frozen. Protective coating of good shoe oil on rough side will increase life.

Glass.—Glass is susceptible to sudden change in temperature. A warm blast of air on a thin pane or lens of frozen glass may cause it to shatter.

Ceramics.—Glazed ceramics are not affected unless subjected to sudden changes of temperature.

Copper Wiring.—Wiring becomes very brittle—failing under tension.

Steel.—Contracts and becomes brittle. Care should be taken to avoid rough handling.

While it is true that the physical properties of many materials undergo a change in extremely low temperatures, particularly an increase in brittleness, it is also true that failure, as in the case of iron or steel, might also be caused by a jolting contact with permanently frozen ground. It is important that a preventive maintenance program be constantly employed.

COOLANTS

An antifreeze mixture containing 60 percent Prestone (ethylene glycol) and 40 percent water should give protcetion down to minus 64° F. Pure water or pure antifreeze should never be

Figure 8–24.—A Herman Nelson heater in operation.

added directly to the radiator. Only a thoroughly mixed solution should be added.

PREHEATERS

At the present time, the cold weather starting of all motorized equipment is accomplished by preheating. There are three main types of preheaters.

The most satisfactory of these units is the Herman Nelson heater (fig. 8–24) that generates 250,000 B. t. u./hr. It is a self-powered unit designed to produce a steady flow of hot air. It consists of a vaporizing-type gasoline burner, a combustion chamber, a pressure-type propeller fan, a blower fan, a gasoline engine, and a system of ducts. The heater was originally designed for use in heating large spaces, such as portable hangars and garages. However, it is used by both the Army and the Navy in heating vehicle engines and battery compartments and planes. One difficulty with it is that its gasoline engine generally has to be preheated at temperatures below minus 10° F. If a source of power is available, the Herman Nelson heater can be converted to an electric motor drive which would eliminate its own cold

weather starting problem. Anyway, its efficiency is greatly reduced at temperatures below minus 35° F. It has a high rate of fuel consumption, averaging about 4 gallons of gasoline per hour; but at present it is considered indispensable in cold weather starting of all equipment. The heat is applied to intake manifold, crankcase, oil pan, and carburetor.

Another type of heater is known as the Stewart Warner self-powered heater. This portable unit, weighing 200 pounds, is designed to produce a steady flow of hot air through a system of collapsible ducts. The heat output is 100,000 B. t. u./hr. with a gas consumption of 1½ gallons per hour. Like the Herman Nelson heater, its efficiency is greatly reduced at temperatures below minus 35° F.

A smaller type of preheating unit is the Stewart Warner hand crank model 796–A heater. This small portable unit, weighing only 5½ pounds, is capable of delivering 40,000 B. t. u. at 120 r. p. m. through a flexible metal hot air duct. This unit is satisfactory for heating small engines such as the one on the Herman Nelson heater. It is unsatisfactory at temperatures below minus 30° F.

Plumbers-type firepots and ordinary blow torches have been found acceptable for limited use. However, due to the fire hazard, they are not recommended.

Another type of portable heater is the Superflex heater model 460 which is a component part of the Army's vehicle winterization kit. It is a forced draft heater and is used as a stand-by heater to maintain starting temperatures in both gasoline and Diesel engines. At minus 30° F. the unit will supply sufficient heat to start engines after 30 or 40 minutes. It has also worked at minus 62° F.

INSECT PESTS

Swarms of mosquitos and other insects are prevalent in the Arctic following a spring thaw. Among these are the horse fly, bot fly, and blue fly, which are a nuisance and troublesome but present no serious problem. However, the arrival of mosquitos coincides with the mildest weather and the season of greatest human activity. To eliminate this nuisance, control measures may be required in the vicinity of bases and permanent camps. An effective control program which has been used in the arctic region of Alaska consists of 5 percent and 10 percent solutions

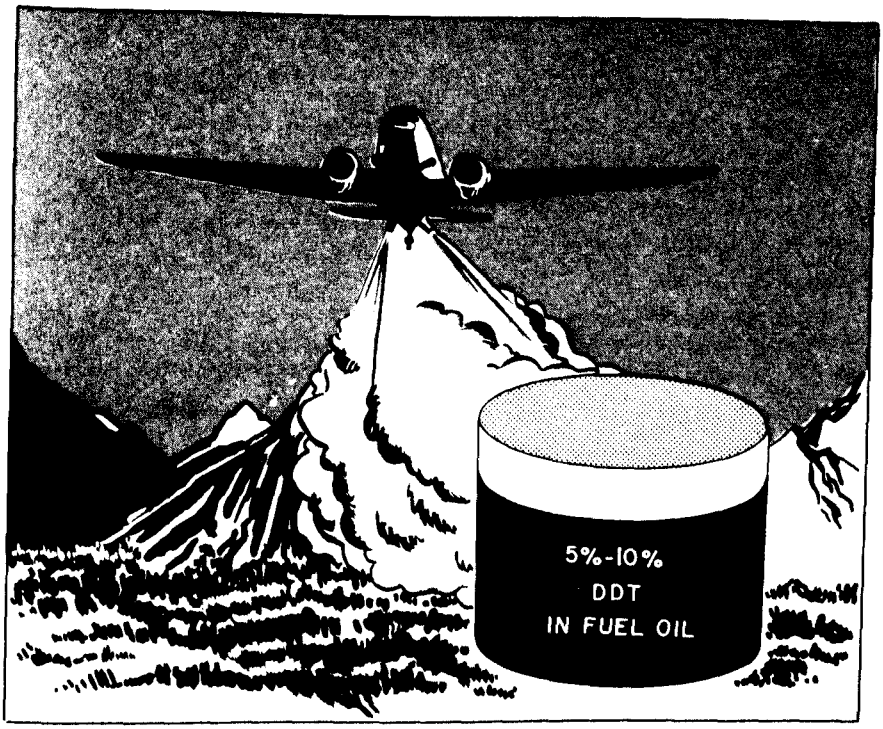


Figure 8-25.—Spraying with DDT.

of DDT in fuel oil applied aerially in dosage of 0.2 to 0.4 pounds of DDT per acre, sprayed at approximately 5-day intervals. Personnel in the field should be provided with repellents, head nets, and aerosol bombs.

SUMMARY

Only the highlights of problems encountered in the establishment of stations and in construction projects in the Arctic are described herein. For greater detail the following publications should be consulted:

NavDocks P–17, *Cold Weather Engineering.*

NavDocks, P–19, *Report on Equipment and Structures in the Arctic.*

NavDocks P–13, *Report on Arctic Clothing Experience.*

In arctic operations, time is precious. Advanced, detailed planning for a construction project is essential to success. All materials and equipment must be delivered to site in good condi-

tion, in secure packages, and with an inventory ensuring that everything ordered was, in fact, shipped and received. There is no time for reordering. Shortages can prevent meeting deadline dates and can well delay completion of the task until the following season.

In the case of establishment of special stations and facilities, the over-all project must be planned in phases about as follows:

Phase I.—Determination, procurement, and assembly of material requirements.

Phase II.—Selection of site—preferably by actual sighting during the preceding season—and preparation of a lay-out of site along with preliminary study of soil conditions.

Phase III.—Development of complete, detailed working drawings and plans for the entire installation.

Phase IV.—Let contracts to private contractors if required.

Phase V.—Shipment of materials and equipment to site.

Phase VI.—Selection of personnel. Important factors are: high skill, dependability, willingness to see project through, ability to adjust to a harsh and uncomfortable environment, and ability to get along well with others.

Phase VII.—Construction and installation plan worked up in detail.

Phase VIII.—Plan for evacuation of personnel, as required.

Figure 8-26.—Head nets.

Blank page retained for pagination

APPENDIX A

NAVIGABILITY IN ARCTIC AND NORTHERN SEAS

Area	Navigable season	Remarks
Eurasiatic Sector of Arctic Sea from Wrangel Island to Spitsbergen.	Not navigable, but penetrable by specially constructed polar ship or icebreaker.	In the autumn of 1893, Nansen in the *Fram* deliberately entered one of the leads in the arctic pack to the northward of the New Siberian Islands and became beset. The *Fram* remained closely beset for three winters and was finally liberated from the pack north of Spitsbergen. The drift was to the north of all the islands on the continental shelf.
American Sector Arctic Sea from Greenland to Bering Straight.	Not navigable; generally impenetrable.	The ice is impenetrable with the exception of the arctic coast of Alaska and occasionally the southern part of the Lincoln Sea and the west side of Banks Island. For a short period most years, the ice recedes 20 or 30 miles from the Alaskan coast permitting limited navigation of small ships from Point Barrow to the Delta of the Mackenzie River. There is little level ice in the sector. The Pole of Relative Inaccessibility of the Arctic Sea lies north of Alaska near 84° N., 160° W.
Barents Sea; Novaya Zemlya.	Navigable generally during all seasons in southernmost part to entrance of White Sea; southeastern part from White Sea to Kara Strait icebound from November to June.	Access to the bays and gulfs along the Murman coast of the Kola Peninsula is possible all year. Occasionally Kola Inlet and the harbor at Murmansk are covered with ice for a short period in winter.
Franz Josef Archipelago....	July and August with icebreaker assistance.	Some years navigation is possible in late June.
White Sea.....	Navigation possible throughout the year in a considerable part of this sea from its entrance to Archangel.	The normal season is May to December. It is possible that powerful icebreakers can keep Archangel and other ports open during the period from December through April when heavy ice in inlets and along the shores exists. The central part of sea is usually open to navigation. Due to its shallowness and narrowness the entrance is frequently clogged with ice during the winter period.
Kara Sea.....	August to October with icebreaker assistance. This is a main link in the Soviet Northern Sea Route — Northeast Passage.	Navigation in southern part is generally favorable, while in northern part it is usually uncertain due to intrusion of heavy polar ices breaking away from the arctic pack. Matochkin Shar and Kara Strait are usually open latter part of July.
Laptev Sea, East Siberian Sea, Chukchi Sea.	August to September with icebreaker assistance.	Considerable floebergs, tabular bergs, and grounded ice are encountered in these waters. Navigation is generally uncertain, difficult, and hazardous.

Davis Strait, Godthaab to Cape Farewell.	June to December. Some places could probably be reached all year with icebreakers.	At Cape Farewell, southernmost point of Greenland, storis usually arrives in January extending sometimes 150 miles seaward. By April this belt averages 70 miles and by August 30 miles wide on an average. The bay at Julianehaab may have drift ice all year and is usually closed during February. At Arsuk Fiord, storis appears in March rendering access difficult or impossible up to June. There is little ice along the coast and in the fiords from June to December.
Davis Strait, Godthaab to Disko Bay.	June to December. This period can be extended by use of icebreakers. Icebreakers probably can operate in winter up to arctic circle.	"West ice," or Baffin Bay polar ice, appears along the coast to latitude 66° N. in January. Winter ice forms far out to sea during period February to April, and west ice from the North appears in the districts of Sukkertoppen and Holsteinsborg. In May, coast is usually free of ice; often west ice is not far off. In June and July coast is clear of ice with the west ice appearing 70 to 80 miles off the coast. From August to November there is little ice. In December ice appears in the vicinity of Egedesmunde.
Baffin Bay, Disko Bay to Upernivik.	June to November; period may be extended with ice-breakers.	In November west ice begins to appear and winter ice to form. In December the two ices freeze together. In June the ice begins to break up. Coasts are generally clear of ice from July to December. There are many bergs calved during the latter period.
Baffin Bay, Melville Bay. Upernivik to Cape York.	July to October; icebreaker assistance required.	Due to grounding of bergs in the shallow waters of Melville Bay, ice forms in thick, consolidated sheets during the winter months. There is usually a congestion of ice until late in the navigation season.
Cape York to Smith Sound.	July to September; icebreaker assistance desirable.	Waters and coasts are generally clear of ice except for bergs and drift ice during this period.
Smith Sound to Lincoln Sea; Hall Basin, Kane Basin, and Robeson Channel.	August to September; icebreaker assistance required.	Navigation is uncertain due to narrowness of channels and fact that this is an overflow of heavy polar pack from Lincoln Sea.
Davis Strait, West Side	July to October	Entrance to Frobisher Bay generally closed from October to July. Cumberland Sound is navigable from July to September.
Hudson Strait, Hudson Bay.	July to November; period can be extended with icebreaker assistance.	Ice forms in late November and breaks up in late June. However, neither the bay or strait is entirely frozen over in winter. Fury and Hecla Strait and Prince Regent Inlet leading into Lancaster Sound possibly may be navigable by icebreakers during some summers.
Lancaster Sound, Barrow Strait, Viscount Melville Sound, Prince of Wales Strait, Amundsen Gulf.	August to September for icebreakers or icebreaking type ships only.	This is the Northwest Passage from Baffin Bay to the Bering Sea. Ice conditions vary considerably from year to year. Heavy amphibious ships cannot operate safely west of Cornwallis Island (95° to 97° W.).

RESTRICTED

Area	Navigable season	Remarks
Southwest Spitsbergen	Probably most of the year except March to May—with assistance of icebreakers.	April and May are worst months for ice. In late summer the pack has receded northward leaving little ice along west coast of the archipelago. Late May to November is normal period of navigation for Advent Bay.
Spitsbergen, North and East Coasts.	August; icebreaker assistance required.	Navigation is uncertain except along north coast which is usually open for a short period during August.
Iceland	All year	Drift ice reaches north coast occasionally.
Baltic Sea	All year except Gulfs of Bothnia and Finland.	There is ice in Gulf of Bothnia and gulfs in eastern part of the Baltic Sea during period January through March. The Gulf of Finland to Leningrad can be navigated in winter with assistance of icebreakers.
Black Sea	All year	This sea is a cold weather area with shore ice forming along north coast in winter and with drift ice in harbors and over northern part of the Sea.
Bering Sea, South of Pribilof Islands.	All year	Drift ice seldom appears south of the latitude of the Pribilof Islands except along east coast of the Kamchatka Peninsula.
Bering Sea, North; Beaufort Sea, Chukchi Sea to Wrangel Island.	July to September with icebreaker assistance; powerful icebreakers of wind class can possibly reach Bering Strait all year and under favorable circumstances might even reach Point Barrow in winter.	By July, Bering Strait and southern part of Chukchi Sea to latitude of 70° N. are usually free of ice. Ships should be able to reach Icy Cape without the assistance of icebreakers. In August the southern limit of arctic pack lies near the 72nd parallel and in some places may recede as far as 73° N. Ships are seldom able to reach Point Barrow prior to 1 August. Beyond Icy Cape navigation is uncertain and extremely hazardous. The arctic pack starts its annual southward motion toward Alaskan coast around the middle of September. It is safest to be clear of the Beaufort and Chukchi Seas by the middle of September at the latest. Let it be remembered that north winds will drive the arctic pack to the coast of Alaska from Point Barrow to Barter Island at anytime during the navigable period. Wrangel Island can be reached by icebreakers during the season. Bering Strait is usually covered with polar ice by the end of October. Submarines have reached latitude of 72° 10′ N. in the Chukchi Sea during navigable period. Western side is probably more favorable than eastern side of Bering Sea for navigation during winter months.

APPENDIX B

NOTES ON ICE SEAMANSHIP AND NAVIGATION AMONGST ICE

Thorough preparation and painstaking inspection of the ship before departing for operations in polar seas are essential to success. The following "arctic measures," written from the point of view of a large amphibious ship, should be taken in full or in part, as appropriate:

1. Inspect ship in most painstaking manner.

2. Check the operating condition of main drainage pumps, electric submersible pumps, and auxiliary pumps such as gasoline *handy-billies* and P–500 pumps. Check spare parts and ensure that there is on board a full allowance of parts for these pumps. Inspect suction hose and discharge hose to see that both are in good condition. All pumps should be in as near perfect operating condition as possible. After departure, test pumps regularly —at least weekly—for operability.

3. Thoroughly clean out bilge well suctions in holds, wash down with fresh water, and take suction on each for an over-all operating test. While loading cargo, station men in holds to prevent debris from fouling bilge wells. Do not permit use of sand, sawdust, or like materials used frequently by stevedores for traction for *fork lifts* while loading a ship.

4. Enroute to area of operations instruct personnel as to operation of main drainage system and all types of portable pumps.

5. Provide some form of jury rudder rig for emergency use.

6. If available and authorized, fit steel propellers to shaft(s); carry spare propeller(s) if operation is remote from bases. Ensure that prints of docking plans are on board ship in event docking in commercial dockyard might be required to repair rudder or propeller following damage in ice.

7. Draw good supply of hull damage repair materials—shores, timbers, sand, cement, steel hull plate, angle iron, and channels. Distribute throughout the ship in vital spaces for ready use for strengthening bent frames and backing up sections of the ship's side that might become dented by collisions with ice floes.

8. Distribute plugs, mattresses, shores, etc. in various underwater spaces to have them handy in event of holing. Instruct personnel in the repair of underwater damage resulting from holing.

9. Pay close attention to loading of cargo. Ensure that it is properly shored and distributed in such manner as will permit access to side plating, bulkheads, and bilge suction drain wells and strainer plates. If possible, load for a drag of 3 to 4 feet. Ensure that cargo stowage plans are accurate and that all cargo is adequately marked for ease of identification. Cargo must also be inspected for packaging and packing to ensure that damage from water, rough handling, and pilferage will not be possible.

10. If required, install "ice beams" or heavy timbers extending from one side of the ship to the other at loaded waterline in forward part of the ship. This would not apply in the case of ships whose hulls have been strengthened for navigation in ice.

11. Rig towing bridle forward for immediate use in event of damage to rudder or propeller and for being towed in traversing areas of consolidated pack. Ensure that bridle is made up to permit ease of connection to towing cable of icebreaker. Consult ice breaker on this point before departure. In pack ice it is best to use bridle, while for ocean towing in the open sea, it is preferable to connect towing cable to anchor chain of towed ship. Conduct of towing exercise while en route to area of operations is desirable when time and conditions permit.

12. Break out towing cable after arrival in the area of operations and secure in position so that it will be ready for emergency use in event of receipt of orders to tow another ship.

13. Safeguard exposed fresh and salt water piping by appropriate means. Deck risers for fire mains freeze at 15° F. or lower temperature. To keep operative, it may be necessary to keep a trickle of water running through the lines.

14. Install air or preferably steam blow lines on salt water injection piping in order to prevent choking of strainer plates by slush ice.

15. Draw additional quantities of electronic spares as may be required to service radar and radio equipments during the operation. Check over TBS, other radio equipments permanently installed, and all portable equipment received for use in boats, LVT's, and weasels. Ensure that radars are in perfect operating condition.

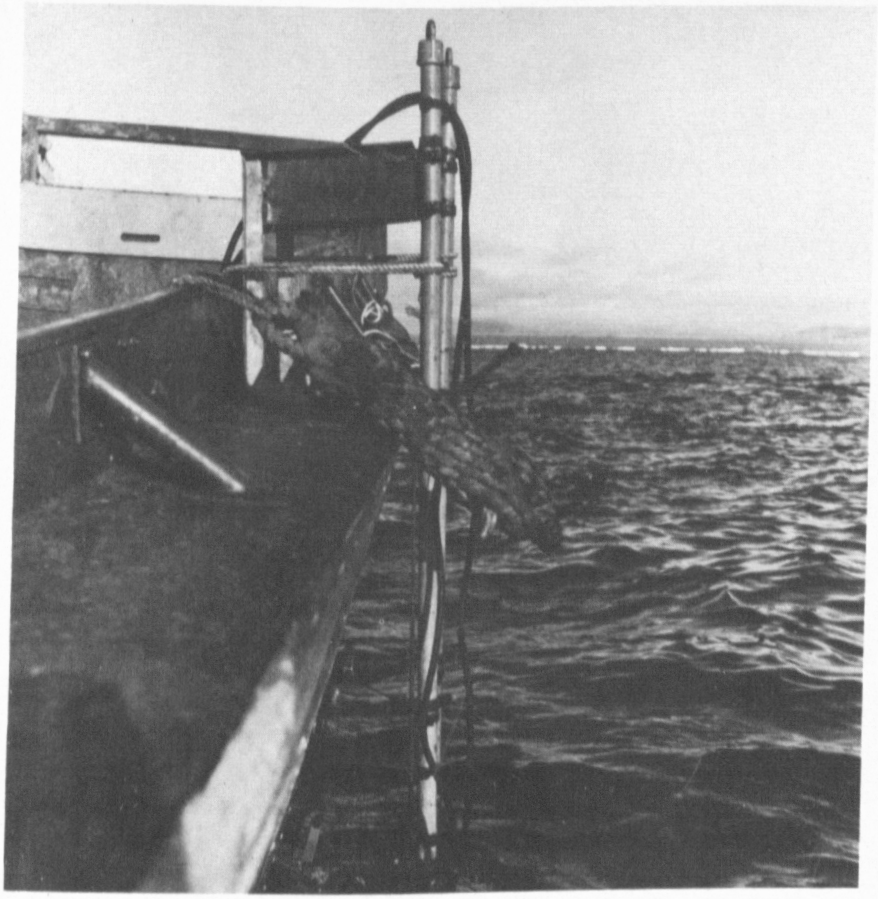


Figure B–1.—LCVP equipped with portable fathometer.

16. Rig up shelter on open deck over pilot house for conning detail.

17. Winterize forward crow's nest. Fit it out as an emergency conning station, if practicable.

18. Build shelter in eyes of the ship for ice lookouts.

19. Winterize pilot house and bridge deck as practicable.

20. Overhaul falls for all booms. Remove excess grease.

21. Winterize all deck machinery. Keep covered with tarpaulins or canvas covers when not in use.

22. Equip one boat with portable fathometer for use in sounding ahead of the ship when entering poorly charted or doubtful harbors (fig. B–1).

Figure B–2.—Stern line attached to "dead man" buried in fast bay ice.

23. Do not fill fresh water tanks in excess of 90 percent of capacity while in cold climates.

24. Winterize searchlights, both signalling and 24″, and place in best operating condition.

25. Refill waterbreakers to 75 percent of capacity to prevent breakage in event of freezing.

26. Carry good supply of antifreeze materials (Prestone) for cooling systems of boat engines, emergency Diesel pump engines, transportation equipment.

27. Where mooring to shelf ice will be required, provide good supply of pickaxes, shovels, crowbars, 7/8″ wire straps, 8″ manila straps, "deadmen," commanders, etc. for use in mooring (fig. B–2).

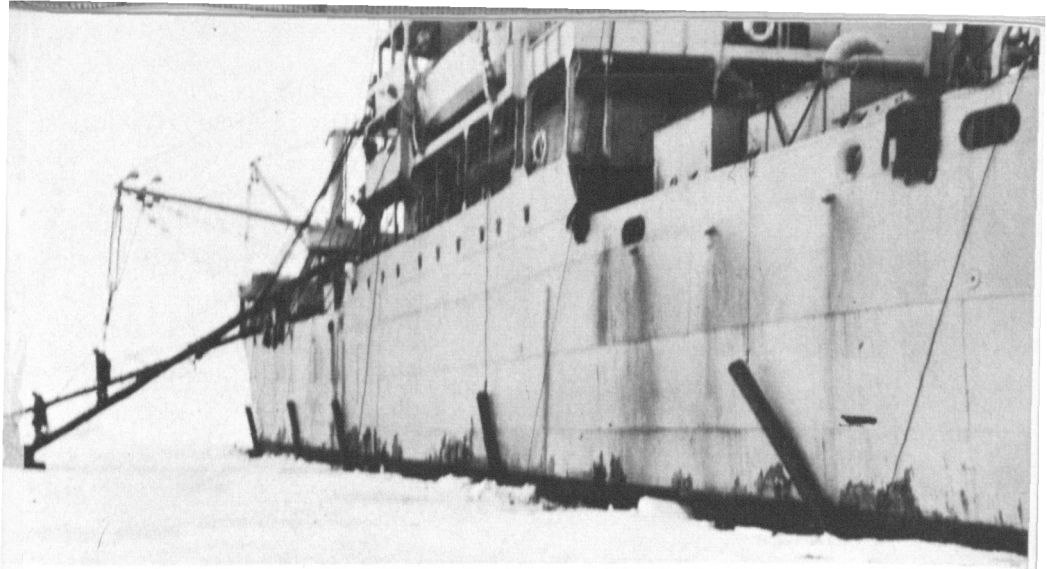


Figure B–3.—Ice fenders.

28. Provide supply of wooden mallets, shovels, heavy wire or rattan brooms and scrapers for removing ice and snow from exposed decks.

29. Provide supply of ice fenders (sections of telegraph poles 10 to 15 feet long) for use when mooring to ice. Lay out ball and cylindrical cone fenders about main deck for handy use while navigating in ice. Provide a number of long ice poles for fending ice from around counter (fig. B–3).

30. Provide several pairs of wading boots for use in event of holing—also immersion or constant wear exposure suits, if available. Provide equipment using the principle of the boom and basket method of survivor recovery.

31. Provide supply of latest abandon ship equipment suitable for cold water.

32. If no anemometer is installed, draw two portable or handheld ones.

33. Rig canvas screens for windbreaks at stations for control of boom winches.

34. Carry breeches buoy rig and parbuckling gear for transfer of personnel and supplies while under way.

35. Prior to departure from base test out heating coils for fuel tanks.

36. Clean and overhaul ventilation and heating systems to ensure that they are in best operating condition.

37. Have leadsman's platform fitted with lights. Provide adequate number of hand leads. Train leadsmen before arrival in the area.

38. Carry at least two movie projectors with full supply of spare parts. Provide additional books, magazines, hobby crafts, and other recreational supplies. Set aside space for recreation rooms for the crew.

39. Have medical and dental examinations conducted on all personnel prior to departure from base. Transfer bad medical risks.

40. Exercise care in fitting cold weather clothing to all hands.

41. Enroute to the area of operations brief all hands on subjects: handling and stowage of cargo, geography and climate, ice seamanship, polar navigation, operation of boats in ice, safety precautions, over-ice or over-snow travel instructions.

GENERAL RULES OF ICE NAVIGATION

Admiral Peary on ice navigation.—"The chief work of a polar ship is to push and pry and wedge its way in and out among cakes and floes ranging from three to twenty or fifty and even up to one hundred and twenty feet thick."

Captain Bob Barlett on ice navigation.—"The man in the crow's nest has to look out for the best lead ahead. To be a good conner, one must not let his mind stray from the job in hand. He must always look for the best leads and high up as he is and often with a heavy ship, deeply laden with supplies, he has to look out for corners of ice. He also has to watch her stern for the swinging of the quarter onto a hard point of ice. A tongue (ram) underneath the water may carry away propeller blade, shaft, and propeller. Then, if she is deeply laden, she may carom from the corner of a heavy piece of ice to a hard opposite corner, hitting her on the turn of the bow, which is liable to cripple her. In going astern the rudder should always be amidships. One has to exercise great caution in going astern (and in backing). The officers on the bridge must be trained and skilled to watch every movement. One has to be tireless to move a ship through ice. The ice movements themselves may be very quick and a few minutes lost may put one a long way astern. Patience, again, is a great virtue. The first thing is to keep your ship free. When she is free, you can go where the breaks occur; if caught in the ice you are powerless and have to go where the ice brings you, but free you can take the first favorable opportunity or leads that open in the direction you want to go."—(Not an exact quotation.)

42. The rule of precaution, caution, and good seamanship applies. Allow only officers fully qualified in ship handling to conn the ship in pack ice (fig. B–4).

43. On approach to drift ice or iceberg waters reduce speed, set radar watch, station ice lookouts aloft and in the eyes of the ship.

44. On entry into pack ice station stern lookouts to keep the conning station advised of ice conditions around the propeller. The forecastle ice lookouts keep the conner advised as to dangerous floes or cakes ahead which can be missed. *Water sky* helps in choosing a general direction in which ice conditions may be favorable. *Ice blink* indicates areas to avoid.

45. Avoid the weather edge of pack ice; avoid areas of pack ice having the appearance of pressuring and churning; avoid grounded and hummocky ice in the pack.

46. Before entering pack ice make a complete reconnaissance by all means available—radar, aloft lookouts, helicopter observations, ice breaker scouting, long range aircraft observations and photographic records. Always enter pack ice at the most favorable point and proceed in general toward weakest areas of the pack (fig. B–5).

47. Avoid the leeward shore on which ice is usually dense and hummocky. Favor the windward shore where there should be a free channel. Remember that strong currents set out from inlets,

Figure B–4.—The rule of precaution, caution, and good seamanship applies.

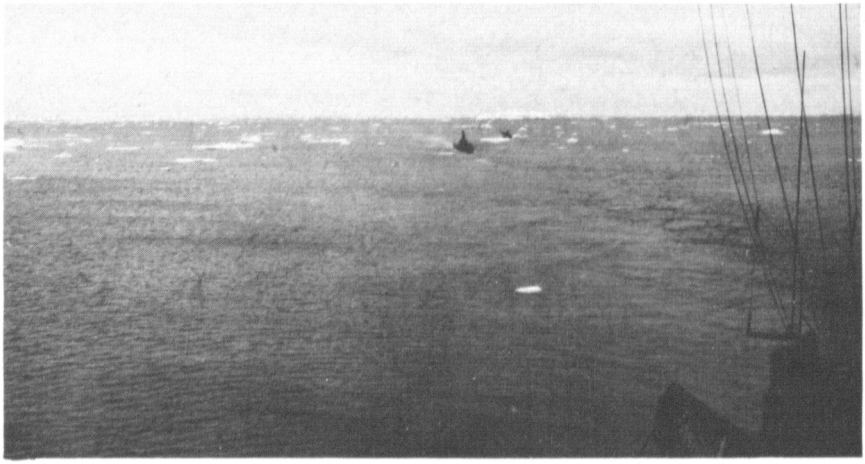


Figure B–5.—Enter the pack at the most favorable point.

fiords, and bays into channels and basins. Therefore, do not operate so closely to points of land that a combination of heavy ice and strong, unknown currents can drive a ship aground.

48. Give all icebergs—in the open sea and in the pack—as wide a berth as possible.

49. Follow the general rule of avoiding all ice possible—no matter how small or rotten. If necessary to collide with floes or cakes, try to take them on the stem with the ship decelerating rapidly by backing full speed. Do not collide with growlers in drift ice areas. *Watch your propellers!*

50. Go around large accumulations of ice on the windward side.

51. Avoid dead spaces where currents or wind have little effect on the condition of the ice.

52. Do not navigate in pack ice during dark nights, dense fogs, or at the time of heavy compression of the ice.

53. Avoid dropping anchor in a place where there is considerable floating ice or the liability of the pack setting down upon the ship and driving the ship aground (fig. B–6).

54. Keep accurate dead reckoning since celestial observations are rare and unreliable, especially in summer.

55. Ice breakers should break the ice from ships which they are clearing on the windward side.

56. Remember cardinal principles of working in pack ice are (a) keep moving (b) work with—not against—the ice (c) do not rush the work—be patient.

57. Keep closed up; standard distance 3 to 4 ship lengths.

58. First ship after icebreaker is convoy guide and regulates the speed of advance depending on ability of the leading icebreaker to keep moving. Icebreaker displays speed cone to indicate desired speed of guide or first ship in column of escorted ships.

59. Be alert to prevent collision with ship ahead in event of temporary besetment. In case the ship ahead stops engines, becomes jammed against a floe in the channel or is forced out of the lead, all ships in column astern should immediately back engines to kill headway and avoid piling up. In cases of this kind each ship should endeavor to maintain relative position in column.

60. Each ship of the convoy should use its TBS or signal searchlights for keeping ship immediately astern advised of all engine changes.

61. Convoy commodore in the icebreaker selects a generally straight track, if possible, that will clear heavy ice, pressurized ice, hummocks, bergs, and grounded ice (fig. B–7).

62. Avoid groups of bergs and shelf ice or areas of consolidated pack; 2 to 4 knots in close pack; 5 to 7 knots in drift ice and open pack.

63. Speed—dead slow in close, heavy or consolidated pack; 2 to 4 knots in close pack; 5 to 7 knots in drift ice and open pack.

Figure B–6.—Pack ice setting down upon AKA in Resolute Bay.

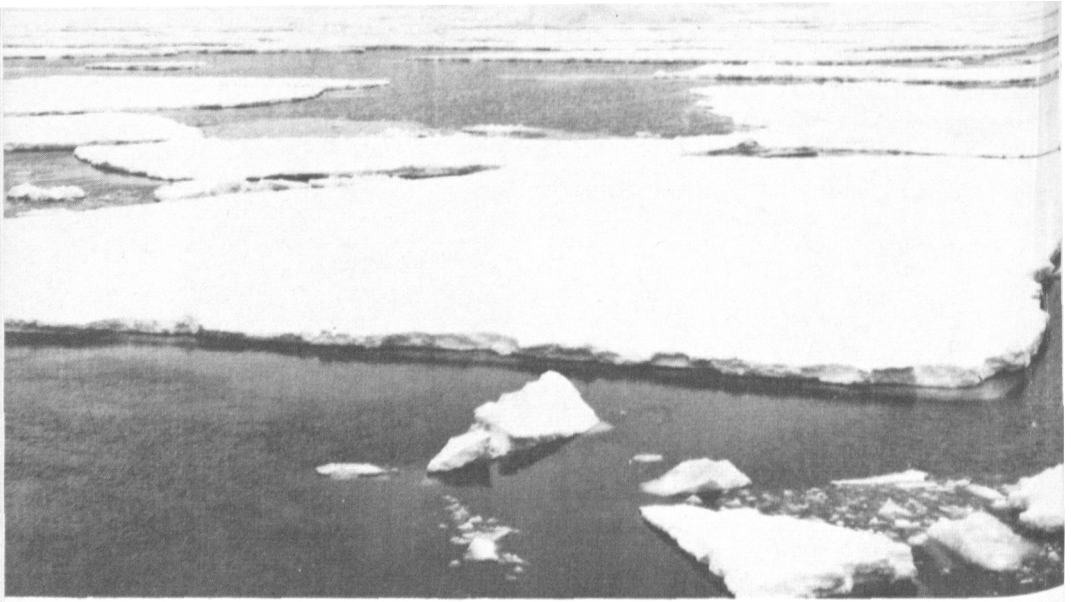


Figure B–7.—Select a track that will clear heavy ice, hummocks, and bergs.

OPERATIONAL EXPERIENCE—NOTES

OPERATION HIGHJUMP

Operate helicopters only in contact weather (fig. B–8). Be prepared to tow seaplanes (PBM).

Keep planes warmed up to take early advantage of good weather when it comes.

Keep fuel tanks warmed in order to be able to fuel other ships on short notice.

Use adequate number of ice lookouts. In no case accept radar as 100 percent perfect. Be prepared for periods when radar is not available at all. Visual lookouts should be primary means for detecting and reporting sea ice.

Keep a hull repair party on watch while in pack ice. Keep living spaces, heads, and washrooms well heated and comfortable.

Provide storeroom for stowage of special clothing when not in use.

Provide recreation rooms for enlisted men.

Be prepared to serve 4 meals daily as workday is 24 hours.

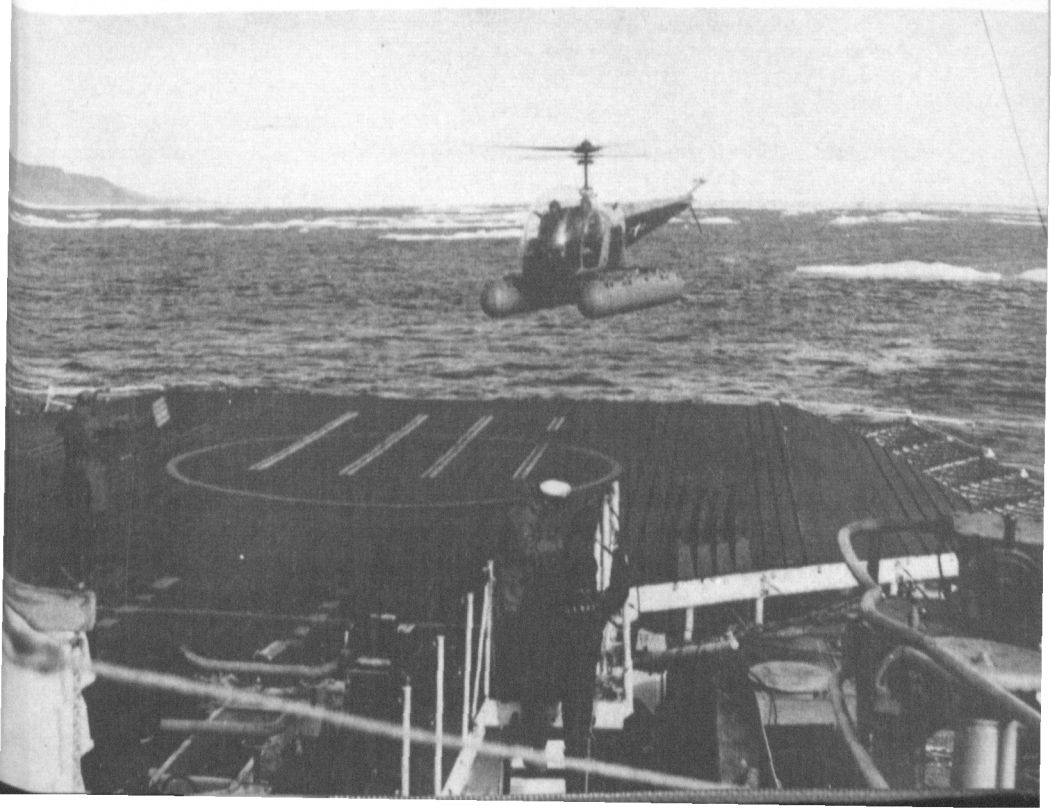
Ice forms rapidly on ships under conditions of injection temperature 34° F. or lower, continuous spray, and surface air temperature 25° F. or lower. It has been estimated that 1 inch of

ice forming on topside (main deck and upper works) of a large destroyer will weigh 80 tons approximately. A building up of such an ice cover would soon place the ship in a critical and unsafe condition. Warm water from fire main is most effective combatant of topside ice.

In flying large seaplanes in polar seas remember that:

1. Wind over 17 knots is hazardous due to wind getting under the wings while hoisting.
2. Swell causes the tender to roll and pitch with the natural tendency of the plane to swing while hoisting.
3. Chop or wind swell puts a heavy strain on the hoisting sling and makes boating alongside planes hazardous.
4. Bad combinations of swell and low wind make take-offs hazardous for a heavily loaded plane.
5. Brash, drift ice, growlers in the line of take-off and landing are a constant danger.
6. Heavy wind, low ceiling, undercast, and other unfavorable weather phenomena are limiting factors in polar flying.
7. Icebergs do not provide much of a lee for seaplane operations.
8. Straight off-pack winds give best weather and calmest sea conditions (fig. B–9).

Figure B–8.—Operate helicopters only in contact weather.



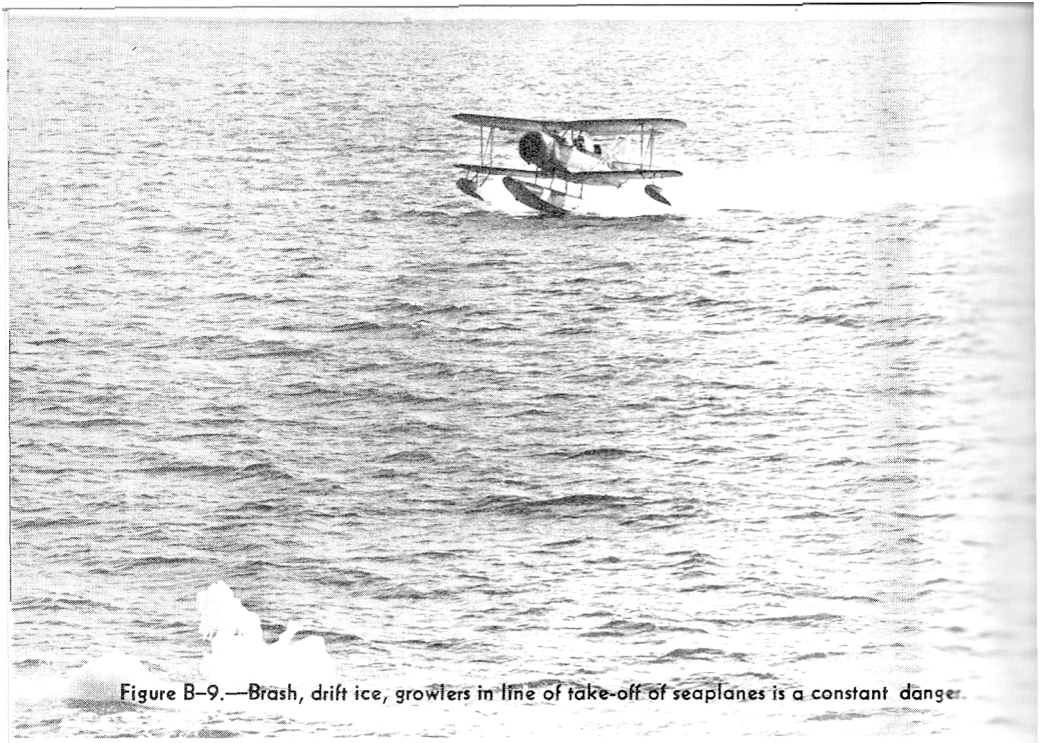


Figure B–9.—Brash, drift ice, growlers in line of take-off of seaplanes is a constant danger.

OPERATION FROSTBITE

In Davis Strait during the winter, icing of ships is most likely to occur on the Labrador side. To free them of ice use warm water from fire mains or proceed toward point south of Cape Farewell on the Greenland side where higher air temperatures will be found.

Large rattan rotary sweepers pushed by tractors will handle up to 6 inches of snow on flight deck. Do not tramp down the snow as it will freeze and be harder to remove. Use rattan or wire hand brooms, large or street size, in the areas around parked planes. Clear windward side of flight deck first. To free catwalks of snow and ice use warm water from the fire main.

Rotary wire sweepers will remove up to ½ inch of ice on flight deck. Use rock salt only as last resort.

Use canvas covers over barrier sheaves of arresting gear to keep out snow and ice.

Use metal cover over catapult tracks to keep out snow and ice.

Winterize all mobile machinery and handling equipment for flight deck use. Stow below at night for ease of starting during early morning flight operations following day.

The installation of covers over wings and tails of aircraft is hazardous; use of killfrost and other chemicals is preferable when such can be obtained.

Planes must be secured with heavy weather tie-downs due to prevalence of storms (winds over 70 knots) and rough seas in the North Atlantic. Take extra precaution to prevent loss of personnel over side due to combination of slippery decks and rough seas.

Familiarize all personnel with cold weather operating procedures prior to arrival in the area.

Safety first! Make no effort to attain small or average launching and landing intervals, at the expense of safety.

During air operations all rescue facilities shall be completely manned and alerted.

Provision should be made to rotate exposed personnel at hourly intervals for hot drinks and warming.

Flight deck personnel should wear face masks when wind velocity is in excess of 30 m. p. h. over flight deck.

ICEBREAKER OPERATIONS BERING SEA IN WINTER

A wind-class ice breaker can penetrate north of Bering Strait and might even reach Point Barrow if advantage taken of *friendly* winds.

Snow cover and hummocks on ice fields are limiting factor of breaking through. Level ice is 2 to 3 feet thick and can be broken readily.

Flying conditions are generally good. Helicopters operated satisfactorily at minus 10° F. Principal limitation was controls becoming sluggish or inoperative.

M29C cargo carrier or weasel performed satisfactorily without special winterization down to minus 20° F.

Heavy swell was encountered in open pack during storms.

During the early part of a 5-day storm when the temperature was below freezing, a hard ice cover built up over the ship to a thickness of almost 2 inches.

An arctic adapted cargo ship could follow an icebreaker to Nome and discharge cargo over the shelf ice without difficulty.

Star sights were possible. Loran was satisfactory up to the latitude of St. Lawrence Island. Radar was valuable north of that island.

Snow squalls and blizzards spring up suddenly. Thus helicopters should stay within 20 or 30 miles of the icebreaker.

The western side of Bering Sea was found to be more open than the eastern side.

SAFETY PRECAUTIONS

Below is set forth a listing of safety precautions applicable to naval personnel working away from their ships in the polar regions.

TRAVEL

1. Remain in vicinity of your ship or your temporary camp unless accompanied by other members of your party.

2. When away from camp be equipped with safety lines, emergency rations, and sufficient wearing apparel to protect yourself in event of a sudden blizzard. *Never take chances!*

3. While traversing an unknown area of sea or land ice, walk in single file, lead man continously testing the surface of the ice. If possible, stay on marked trail or on solid surface unless soundings and tests are made to determine the condition of the surface of the ice. Use trail markers freely.

4. Do not take the risk of falling into an unmarked crevasse. Give a wide berth to areas where cracks, disturbed or pressure ice, and crevasses are found.

5. Stay away from the edges of bay ice, shelf ice, icefoots, shore ice.

6. In event of a sudden or unexpected blizzard while away from camp or ship, dig in for shelter. Do not wander aimlessly about and get lost.

7. Do not molest wild life in the area. In the Arctic there are laws against it. Walruses, seals, penguins, and skuas can be vicious. Do not hunt animals unless a license has been granted and unless accompanied by experienced Arctic huntsman. Do not kill an animal unless necessary in self-defense.

8. Do not eat snow except in an emergency and then very slowly. Try to melt it first. Always carry a canister of water.

OPERATION OF SHIP'S MECHANIZED EQUIPMENT ASHORE

1. If preheating of engines is necessary for starting, be sure not to play the flames of heating torches directly onto cast-iron pipes.

2. Keep fuel tanks as full as possible by frequent refueling to reduce condensation in the tank. Ice in fuel and carburetors is a considerable hazard.

3. Do not pump fuel drums completely dry as to do so increases the chances of picking up water which has developed due to condensation. Before removing the plug of a fuel drum, brush all snow, ice, or water from off the top of the drum. Keep plugs of all drums tight. Caches of gasoline should be kept distant from other supplies with fire guard stationed around the cache as a precautionary measure.

4. When possible, filter all fuel before filling fuel tanks.

5. Do not start a tracked vehicle in motion too quickly. Rock it back and forth for a short period to loosen up track bands.

6. Do not permit men to ride on tracked vehicles, weight handling equipment and other vehicles used on beach heads, except where their duties so require.

7. By careful inspection ensure that all mechanized equipment to be used away from the ship is properly winterized prior to departure from base.

8. While working with hand tools around equipment, men should tie light lashings to them keeping other end secured to their wrists to prevent loss of tools when dropped.

9. When off-loading cargo directly from ship to shelf ice for sledging to caches, restrict amount placed on ice to small quantities to reduce loss to minimum in event of calving or breaking away of a section of the shelf ice. It is preferable to load cargo directly on sleds and to haul them away by a tractor as soon as sleds are loaded (figs. B–10 and B–11).

GENERAL

1. Keep constant watch for evidences of frostbite on the persons of your shipmates or companions. Skin becomes milk-white when frozen. Do not rub or apply snow to frozen flesh. *Thaw by warmth!*

2. Mark the locations of temporary caches of food, clothing, and supplies with trail markers as drifting snow will cover everything once a storm sets in. Never remove trail markers from a trail unless placed there by yourself. A suitable trail marker can be made by attaching a square of red or blue bunting, 1½- to 2-feet on a side, to a bamboo pole 5 or 6 feet in length.

3. When a ship is moored to shelf ice, use trail markers freely in marking cracks or areas of the ice which are likely to break away suddenly. Place cautionary signs nearby.

4. When finished using skis and skipoles, stand them upright in the snow to prevent loss (fig. B–12).

5. Do not set up a cache or place any large object in such position that snow drifting from the object will cover nearby articles of equipment.

6. When cooking or sleeping in an arctic tent ensure that there is adequate ventilation to permit escape of fumes and to protect the occupants against carbon monoxide poisoning.

7. Remain active when outside the shelter.

8. Remove snow from clothing before entering camp shelter or quarters on board ship.

9. For defecations use heads on board ship or in camp area. Carry supply of toilet paper in your pockets. You may urinate off trails or beaten tracks.

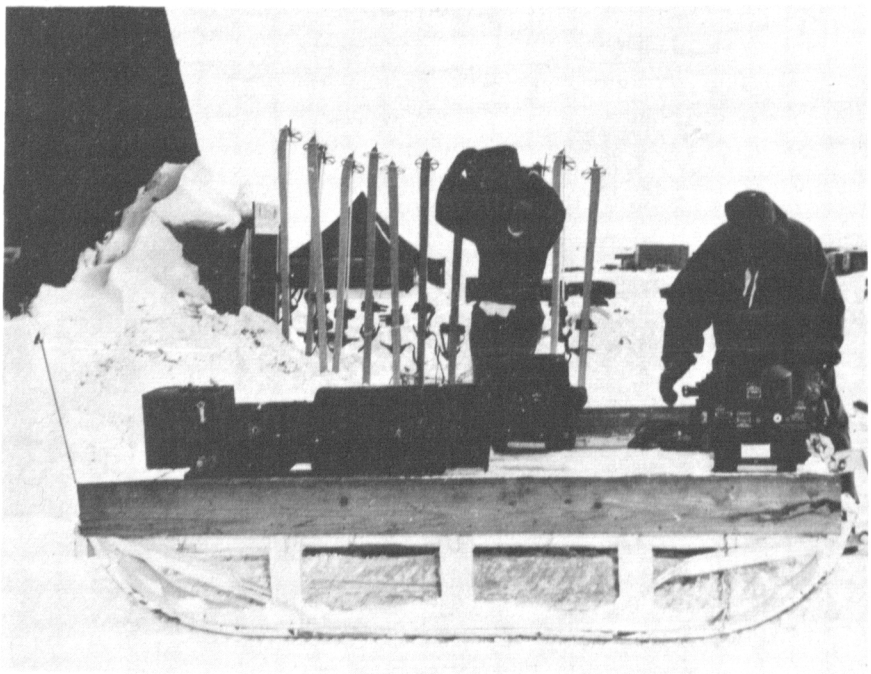
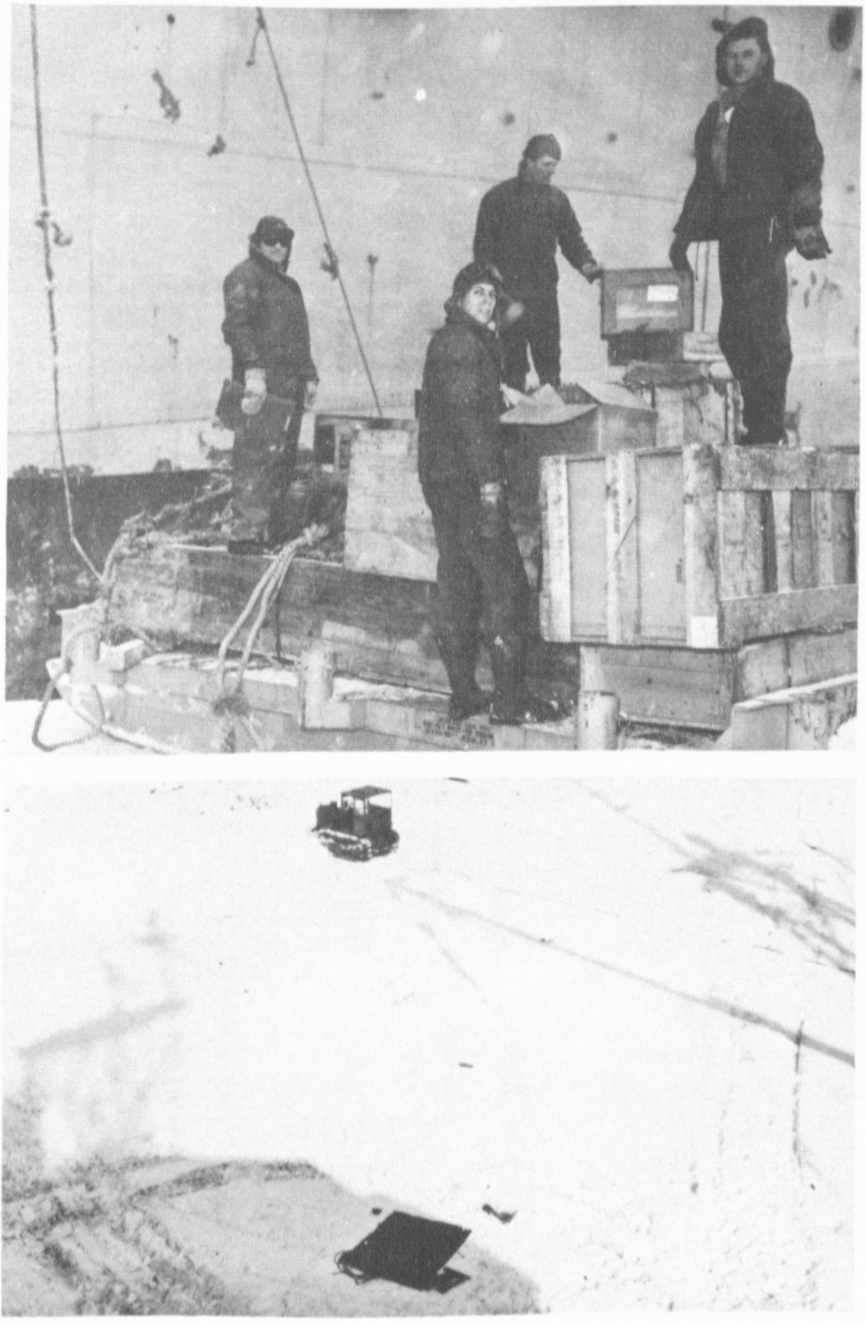


Figure B–10 —When finished with skiis and ski poles, stand them upright in the snow to prevent loss.



Figures B–11, B–12.—Load cargo directly onto sleds drawing latter away from side of ship by tractor.

RESTRICTED

APPENDIX C

DESIGN CRITERIA FOR U. S. NAVAL MATERIEL FOR USE IN ARCTIC AND COLD WEATHER AREAS

	Unnavigable ice areas and ashore	Marginal ice areas
Minimum *sustained* temperature/knots*	Minus 65° F./10	Minus 20° F./40.
Maximum *sustained* temperature/knots*	80° F./100	80° F./100.
Mean minimum temperature (coldest month)	Minus 25° F.	10° F.
Mean maximum temperature (warmest month)	40° F.	50° F.
Minimum sea water temperature	28° F.	28° F.
Maximum solar radiation temperature	160° F.	160° F.

*Maximum wind speed to be expected at the temperature indicated.

FOOTNOTES

NOTE 1.—Ambient air temperatures specified, in degrees Fahrenheit.

NOTE 2.—Maximum wind velocity for any area is considered as 100 knots from any quadrant, and may reverse itself in direction in a few minutes.

NOTE 3.—Relative humidity may vary from 10 to 100 percent, and can change 50 percent in 4 hours or 80 percent in 7 hours.

NOTE 4.—Temperatures may change as much as 50° F. in 1 hour.

NOTE 5.—Wind velocities may increase from a dead calm to 70 knots within a few minutes and subside to calm just as rapidly.

NOTE 6.—Heavy ice may accumulate on board ships due to wind and temperature combination in otherwise ice-free area.

NOTE 7.—By "sustained" is meant "for period of 24 hours or longer."

APPENDIX D

TRACK CHARTS OF OPERATIONS IN WESTERN ARCTIC, SUMMER OF 1948, AND WINTER 1948-1949

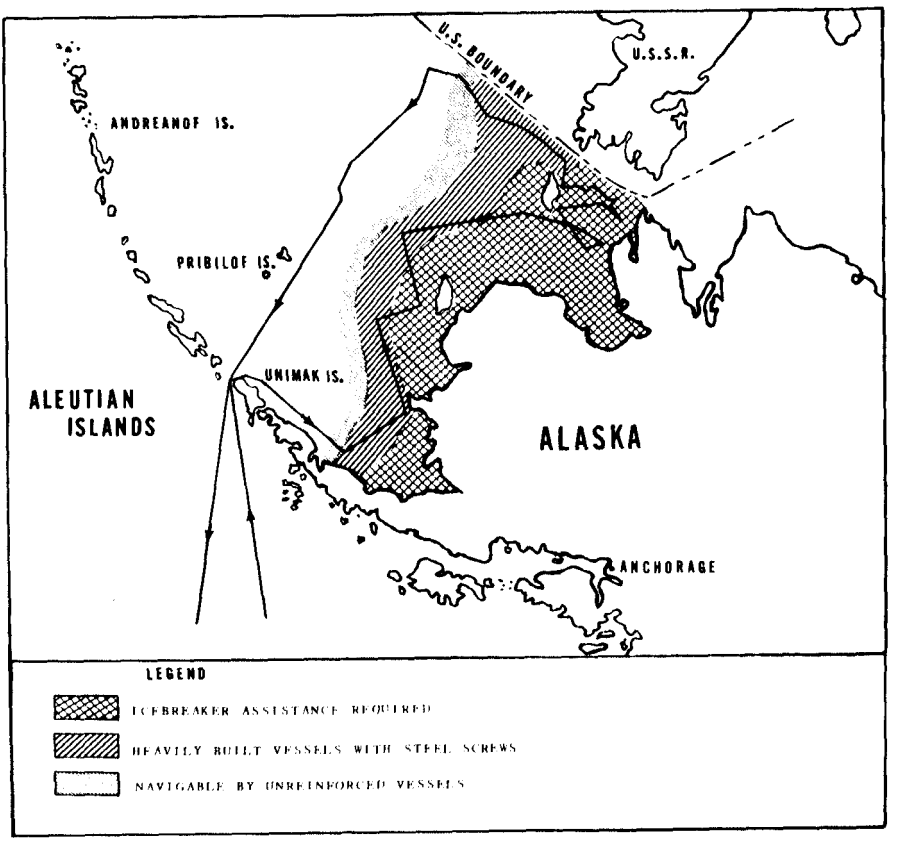


Figure D–1.—Track chart—Arctic operations—Summer 1948.

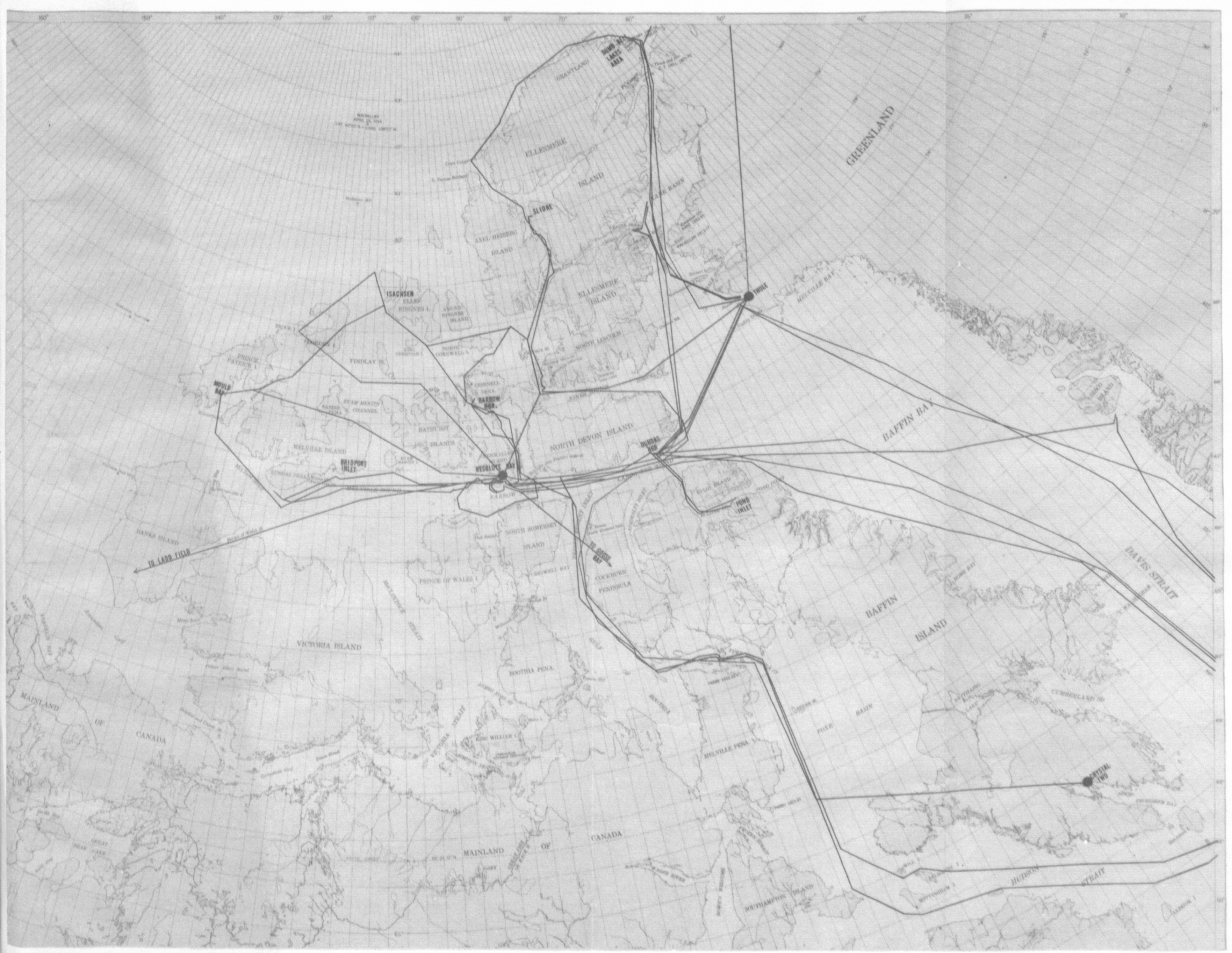


Figure D–2.—Track chart—Task Force 80—1948.

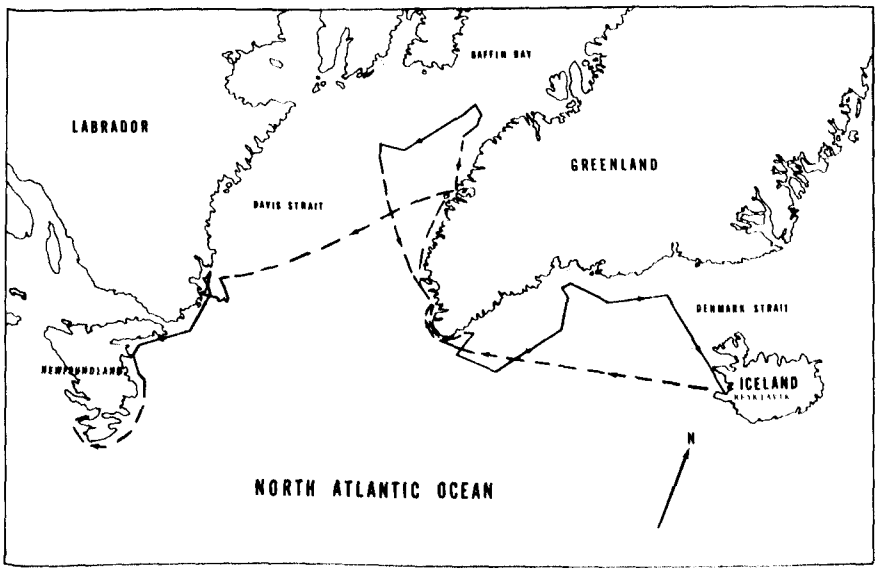


Figure D–3.—Track chart—Winter icebreaker operations—1949.

U. S. GOVERNMENT PRINTING OFFICE: 0 — 1949