WEATHER OBSERVING PROGRAM

A Descriptive and Suggestive Summary

compiled by

RONNE ANTARCTIC RESEARCH EXPEDITION

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PREFACE

Technical Report Number 4 in this series on certain technical investigations carried out by members of the Ronne Antarctic Research Expedition presents a descriptive and subgestive summary of the conduct of the Expedition's weather observational program. A statistical summary of the weather elements has been given in Technical Report Number 1 and general remarks on meteorology will be presented in Technical Report Number 5.

This report was prepared by H.-C. Peterson, Expedition physicist.

Commander Finn Ronne
USNR (Inactive)
Expedition Leader

CONTENTS

SCOPE OF OBSERVATIONS

Weather observations were made on board ship during the voyages to and from Antarctica, from the base established in Antarctica during the stay of the Expedition, and from outposts and trail parties for periods of several months.

Marine Observations

Twice daily synoptic observations were taken and radioed to the Central Office of the U. S. Weather Bureau, Washington, D. C. from the Expedition ship in international marine weather code from the Equator to the Antarctic Base and return to New York. No observations were made from the ship while it was at anchor outside the Antarctic Circle.

Base Observations

Initially twice and later thrice daily synoptic weather observations were taken and radioed to the U. S. Weather Bureau from the Antarctic Base on Stonington Island, Marguerite Bay, Palmer Peninsula, Antarctica (68.2° S. -67.0° W.) from March 1947 to February 1948. Over 200 pilot balloon ascents attaining an average height over 17,000 ft. were also radioed in.

Plateau Observations

Thrice daily synoptic weather observations were taken and radioed to the U. S. Weather Bureau from an outpost established atop 5,800 foot high Palmer Peninsula, approximately 25 miles east of base, from September 1947 through November 1947. Approximately 20 pilot balloon ascents were also radioed.

Cape Keeler

Thrice daily synoptic weather observations were taken and radioed to the U. S. Weather Bureau from an outpost established on Cape Keeler, Palmer Peninsula, Weddell Sea Coast, approximately 125 miles southeast of base, from September 1947 through November 1947. Several pilot balloon runs were made.

Weddell Sea Coast Sledge Party

Once daily weather observations were taken from a dog sled party operating on the Palmer Peninsula, Weddell Sea Coast as far as 500 miles south of base to latitude 75° S. during December and January of 1947 and 1948.

Marguerite Bay Sledge Party

Once daily weather observations were taken from a dog sled party operating in the vicinity of Marguerite Bay as far as 125 miles southwest of base during months of November and December 1947.

NARRATIVE OF THE EXPEDITION'S WEATHER PROGRAM

From the start of the Expedition's planning, it was recognized that meteorology would be an important element of the scientific program. Early in December 1946, a cooperative agreement was signed with the U. S. Weather Bureau providing the Expedition with two complete sets of standard airways weather station equipment and some finances in return for which the Expedition agreed to radio to the Bureau twice daily synoptic weather observations from shipboard to and from Antarctica and from the Antarctic Base when it became established. Some additional aerological equipment was secured from the U. S. Navy and private sources. C. O. Fiske and H.-C. Peterson were assigned to the execution of the meteorological program.

The program began upon entry into the southern hemisphere with twice daily synoptic shipboard observations taken at 05h and 17h GMT. These observations were radioed by the Expedition radio operator, L. D. Kelsey, to the central office of the U. S. Weather Bureau by prior arrangement through the Civil Aeronautics Administration's overseas station, WEK, New Orleans, La. The Base Site-Stonington Island, Marguerite Bay, Palmer Peninsula, Antarctica, 68°12'S-67°00'W--was reached on 13 March 1947. Twice daily synoptic observations continued to be taken from the ship until June 1947 when all weather observations were taken from the main base meteorological station at 00h and 12h GMT and coded in the land station code. However, thermographs and barographs were put into operation upon arrival at the base site.

Pilot balloon equipment was set-up in June and the first upper air sounding made on 22 June. Thrice daily synoptic observations were begun on 1 September 1947 and were regularly taken at 12h, 18h, and 23h GMT.

During mid-winter it was decided to establish a meteorological outpost station on top of the nearby mile-high Palmer Peninsula plateau in order to obtain:

(a) Additional data for analysis of down glacier glass.
(b) Data for 6,000-ft. level analysis of westerly air streams.
(c) Better view of region to report weather for flying because of elevation and suspected absence of fog.

This last desire was not achieved since the plateau had a much higher percentage of cloudiness than the coastline, and fogginess on the coastline was infrequent and limited. Initial deposits of supplies were brought up near the outpost site on 8 July by dog team; however, it was not until 28 August that the station was established and finally manned. With only five percent of observations reporting less than 50 percent cloudiness, life at the plateau station was carried on mostly inside the tents which, after some 20 days, were completely snowed over. Equipment of special interest at the plateau station included a 25-watt radio transmitter, two radio receivers, a wind charger, a storage battery, electric lights, and two sleeping cots. These luxury items were possible only through air transport and contributed substantially to the morale and efficiency of plateau station personnel. From 28 August, all supplies were brought in by airplane. Operation of the station was a joint British-American operation. Our principal observer was E. A. Wood.

On 30 September C. O. Fiske established by air transport a meteorological outpost approximately 125 miles southeast of the base at Cape Keeler, Palmer Peninsula, Weddell Sea Coast, Antarctica, 69°42'S-62°48'W. Correlation between Stonington Island, the plateau station, and a Weddell Sea Coast station would have been better if all three stations were located on the same latitude. However, Cape Keeler, approximately 125 miles southeast of the main base, was selected as the site of the Weddell Sea Coast outpost to better view the weather to the south where geographical operations would be conducted, and because a nearer location would have been wasteful of the flying altitude necessary to cross the plateau.

The Cape Keeler Station, together with the Plateau station and Stonington Island station, furnished a good series of observations on how the mile-high Palmer Peninsula affected west-east storms passing over it.

As summer approached, two trail parties were being organized which would spend several months in meteorologically uninvestigated areas. Every effort was made to have meteorological observations taken as part of the trail program. Special light weather equipment, simple code procedures and suitable observer training were given to members of trail parties in preparation for this work. The first party, a geological mission, dog-sledded over Marguerite Bay to the northern extremity of Alexander I Island with return made off the west coast of Palmer Peninsula. The principal observer was Robert Dodson.

In the Expedition's geographical investigation of the southwestern coastline of the Weddell Sea, ground and air parties were to mutually supplement each other: the air transport providing supplies for the dog sled parties; the dog sled parties providing ground control points for the aerial photographic mapping, weather data, and rescue facilities. Arthur Owen volunteered to take on the responsibilities of principal observer on the Weddell Sea Coast sledge party and brought back a good collection of weather data about this previously uninvestigated region. Thus, for several months around the summer solstice, weather data of five stations straddling the southern half of Palmer Peninsula were linked by radio and contributed substantially to the efficient prosecution of the aviation program.

By mid-January all remote operations had been secured, and weather data was carefully organized preparatory to departure for the United States. Conferences and numerous discussions were carried on by the nine weather observers[1] who were then at Stonington Island. Many valuable ideas on the problems of Antarctic weather observing were exchanged and originated.

The Expedition departed from Stonington Island on 20 February 1948, arriving at New York, 15 April 1948. Except while at anchor outside the Antarctic circle, twice daily synoptics were carried out from shipboard throughout the return voyage.

DISCUSSION OF EQUIPMENT

In this section the following equipment is discussed:

(1) aerograph, (2) anemometers, (3) aneroids, (4) balloons, (5) ballon-borne equipment, (6) barographs, (7) barometers, (8) binoculars, (9) cameras, (10) gage for height of snow cover, (11) gage for precipitation, (12) hygrometers, (13) library, (14) nephoscope, (15) plotting device for winds aloft, (16) shelter for instruments, (17) snow flake replicas, (18) sunshine recorders, (19) theodolites, (20) thermographs, (21) thermometers, and (22) wind direction indicator.

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[1]Robert Dodson, RARE, principal observer Marguerite Bay Sledge Party,
George de Georgio, RARE, Asst. Plateau Station observer,
C. O. Fiske, RARE, Climatologist, and principal observer at Cape Keeler,
Michael A. McChoice, FIDS, Base D meteorologist,
Kenneth McLeod, FIDS, Base E, Asst. meteorologist,
Arthur Owen, RARE, Principal observer Weddell Sea Coast Sledge Party.
Harries-Clichy Peterson, RARE, Principal observer Stonington Island,
Bernard Stonehouse, FIDS, Base E. meteorologist,
E. A. Wood, RARE, Principal observer Plateau Station.
FIDS = Falkland Islands Dependencies Survey.

1. Aerographs

The Expedition was supplied with two Navy aerographs, one of which was lost on the opening day of our spring flying season when the British aircraft, GAIBI, crashed during a forced landing about 100 miles south of the base. The second aerograph was used late in the flying season and rather seldom. Factors restricting the use of the aerograph on the Expedition's airplanes were the pilot's aversion to its added drag and weight (absolutely peak loads were carried on nearly all flights) and the unavailability of time to improvise installation of the aerographs on the airplane in a safe and acceptable manner. The recording ink was found to freeze during the summertime at elevations above 8,000 ft; otherwise the instruments performed very well. If available, two speed drums are recommended in order to make the aerograph more suitable for both long and short duration flights. No aerograph records were interpreted in the Antarctic due to lack of time.

2. Anemometers

A standard three-cup ("S" type) anemometer supported by a 12-ft. mast and giving remote readings in 1 mph/pulse/min electrical impulses were used by the Expedition at Stonington Island. The miles-of-wind dial on the anemometer was never read, although both observers knew how to read it and such readings would have given good average wind data.

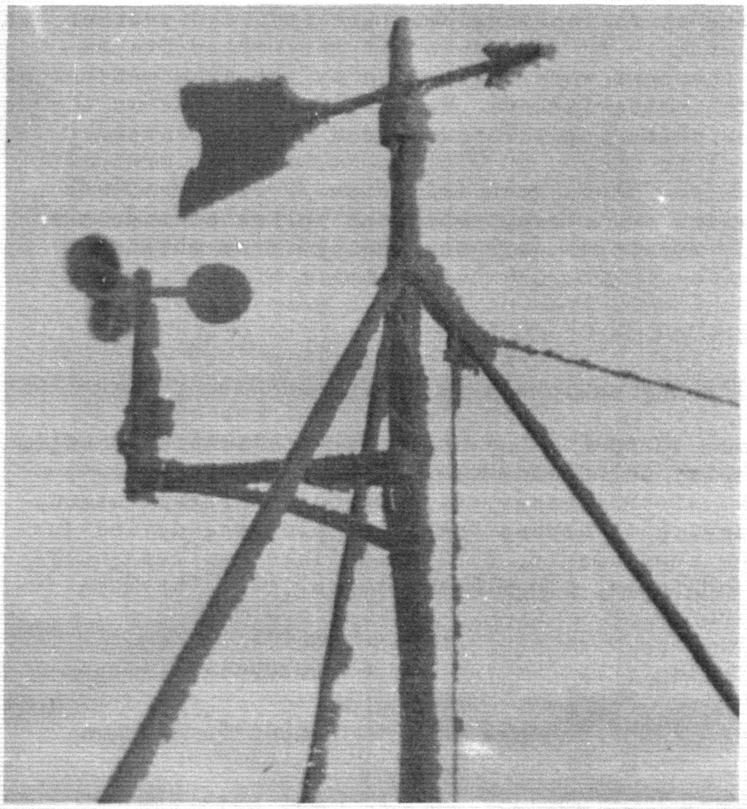
Fig. 1. Heavy radiation frost on anemometer.

The anemometer was never lubricated with oil as the type provided by the Weather Bureau was considered too thick at near zero (F) temperatures. Kerosene was on several occasions applied to the anemometer. In view of the fact that no time was readily available for maintenance care of this anemometer and the frequent gales experienced, the anemometer stood up remarkably well during the year of exposure.

Snow or frost accumulation in anemometer cups was an occasional nuisance. (See Fig. 1). Dry snow could be removed by shaking the anemometer mast. Frost required a patient scraping. When burdened with enough snow or frost to look like round balls of cotton, the anemometer would read approximately 1/3 of the correct velocity.

A 1936-pattern, USN hand-held instantaneous reading anemometer was also available and proved useful in accurately observing gustiness. Its size and weight made it unsuitable for trail or outpost use.

An instantaneous-indicating station anemometer using the selsyn system would be preferred at stations with aviation activity in order to more definitely observe gustiness.

3. Aneroids

Eight Taylor-built shiny brass-cased aneroid barometers of varying pressure ranges were supplied the Expedition by the U. S. Weather Bureau. The constancy of calibration was very poor and results obtained were far from satisfactory.

The Weather Bureau also provided two Friez-built precision marine aneroids of a special pattern, which were moderately rugged and free from noticeable calibration drift. (Accuracy 1/2 mb). However, the calibration correction varied considerably for different scale readings.

The U. S. Navy provided two Friez-built, millibar scale, aneroids in leather carrying cases with shoulder straps. These aneroids appeared to be quite accurate but, although of portable design, were extremely delicate and broke early in the program.

The best aneroids on the Expedition for simplicity, lightness, ruggedness, and precision were aviation dashboard altimeters (Kollsman-built) and Wallace and Tiernan-built U. S. Corps of Engineer's Surveying altimeters.[2] The latter type were available in sufficient excess to be issued to trail parties and outposts and as a base station accessory. Constancy of Calibration was excellent in spite of rough usage and readings could be made with 0.2 mb over a range of 0-6,000 ft. The only handicap of the W. and T.-built altimeters was that conversion from altitude to pressure was not automatic as in the aviation dashboard altimeter, but required the use of a chart which was fastened on the instrument.

A W. and T.-built altimeter, used as an accessory barometer at the main base, was never found to differ from the station mercury barometer more than the usual error with which the observer read the station barometer (0.3 mb). This particular W. and T. altimeter was used with satisfaction for the determination of pressure at sea during the northbound voyage.

4. Balloons

Pilot balloon observations at Stonington Island were a joint American-British operation, and a variety of sizes of balloons were used:

(a) Standard British 70-inch (inflated circumference) of approximately 23g weight
(b) Standard U S 30g
(c) Standard U S 100g (Since these old balloons did not always take a spherical shape when inflated, some error may have been introduced because of abnormal air resistance during ascent.)
(d) Standard U S 350g (of the kind used to bear aloft instruments).

A variety of balloon sizes allows short or leisurely runs to be made with 70-inch or 30g balloons giving a finer degree of winds aloft

[2]See Fig. 8.

interpolation. For rush jobs, such as aviation requests for winds aloft, or in inclemental weather, a fast-ascending 100 or 350g balloon could be launched.

The British 70-inch balloon, made of natural rubber which did not require preheating, suffered no bursting failures up to the highest ascent observed—30,000 ft. The 30g balloons were furnished the Expedition in 1946 by the U. S. Navy and Weather Bureau and were made of neoprene. They required preheating which, it was found, could best be accomplished by barbecuing a partially inflated balloon over a hot stove to as hot a temperature as one's hand could stand. No bursting failures were observed at the highest ascent followed—35,000 ft. The 100 and the 350g balloons were procured from stock abandoned in 1941 by the U. S. Antarctic Service Expedition and were made of natural rubber. Only slight deterioration had taken place during the 7 years in which these balloons were lying in Antarctica. Although these balloons were given a pre-inflation heating, frequent failures due to bursting were observed to take place at about 50,000 ft. for the 100g size and about 75,000 ft. for the 350g size. After these balloons were inflated and before released, they were inspected for potential weak spots, over which was applied a coating of rubber cement. This large variety of balloon sizes was considered extremely helpful in most efficiently utilizing the supply of balloon inflation gas.

A choice of white, black, and red—orange color was available in the 70-inch and 30g balloons. The 100g and 350 g sizes were available only in the white and red color. White was used only on clear days. Black was acceptable on bright overcast days, but was not used otherwise. Red was found to be as good as white on clear days and considerably better than white on partly cloudy days. Red balloons would get through dusk in which white and black balloons became quickly lost. It was decided by all observers that the red color was as good, or better, than any other color for any and all conditions.

Inflation

Both helium and hydrogen were available for inflating balloons. Hydrogen was more effective as a balloon inflating gas, but possessed the disadvantage of explosibility. For example, twenty-five 70-inch balloons could be inflated from a hydrogen tank while only seventeen could be inflated from a helium tank. Twenty tanks of helium were provided the Expedition by the U. S. Navy and the U. S. Weather Bureau and about twenty-five hydrogen tanks were found in good condition abandoned by the U. S. Antarctic Service. However, some trouble was experienced with the valves on these old tanks. Good valves, found on a few bottles, had to be transferred. The British possessed equipment for the chemical generation of hydrogen, but this was seldom used since the additional time it required to prepare gas could not be tolerated in a heavily overworked expedition. In supplying the Plateau meteorological station, weight figures were drawn up comparing the British chemical generator with a tank of hydrogen. On a basis of twenth-five 70-inch ballons, the hydrogen tank weighed less. Methods used to determine correct balloon inflation differed in British and American practices. U. S. practice inflated balloons to a certain weight, while British practice inflated balloons to a certain mean circumference. These differences were not considered on theoretical grounds. On practical grounds, the weight inflation method is much more convenient. Balloons were inflated in a sparkfree, covered, and sheltered space between buildings.

Lanterns

Balloons sent up at night were made visible by suspending an electric light or candle underneath the balloon. The candle light was placed inside a paper lantern and was a very clumsy affair to manipulate in cold weather. The electric light was brighter, easier to see, and very convenient to attach. Its useful life was limited to about 15 to 20 minutes at near 0° F temperatures.

Ascension Rates

Pilot balloon ascension rates are given in the following table:

TABLE NO. 1

Size of Balloon	Approximate Ascension Rate ft/min
70-inch (British)	500
30g (U. S.)	600
100g (U. S.)	1,000
350g (U. S.)	1,500

5. Balloon-borne equipment

No balloon-borne equipment was used by the Expedition. It was considered possible to improvise various temperature devices which could be sent up a few thousand feet and then recovered, but this was not done due to the lack of time. It was felt that an aerograph was more suitable.

6. Barographs

A standard microbarograph was furnished the Expedition and was found quite satisfactory. During wind storms, when the building would shake, a small erratic trace would result which was partially corrected by filling the dampening cylinders with kerosene.

7. Barometers

Two Fortin-pattern barometers were supplied the Expedition. One was broken in transit while the other, upon opening in Antarctica, was found to have an air inclusion with resulting low readings. Fortunately, a Fortin barometer, abandoned by the U. S. Antarctic Service, was in good condition. This was used as the Stonington Island station barometer. Now returned to the U. S. Weather Bureau for calibration, it was compared with the British Kew-pattern barometer at FIDS Base E and the ship's mercury barometer on board the USS BURTON ISLAND with calibration discrepancies less than 0.3 of a millibar. The Stonington Island barometer was mounted inside a copper box for the purpose of stabilizing temperatures. Such an accessory is considered highly desirable for cold climate stations where room temperatures frequently undergo extreme fluctuation. The Fortin-pattern barometer, which is the standard U. S. Weather Bureau issue, was considered a very inconvenient type of apparatus to work with. The Kew-pattern barometer, the standard British Air Ministry issue, read in millibars directly, was suitable for marine operation, and was considered because of its built-in reduction-to-sea-level device to be a much more pleasing apparatus from the standpoint of time, error, and strain for a busy observer to work with daily. The Kew-pattern barometer was supplied with provision for packing, while the Fortin barometer was not.

Height of the Stonington Island station barometer above mean sea level was 29 ft.

8. Binoculars

It is considered desirable that all Antarctic stations in which there is an extensive reach of visibility be provided with a good set of binoculars, preferably with anti-reflection coated lenses. Such binoculars would be important in determining the cloud characteristics of fronts advancing from a distance of 50 to 100 miles away, the inspection of distant mountains for the presence of katabatic gales, and also to study nearby cloud formations with virga to determine the degree and type of precipitation underneath in event a flight is contemplated in that region.

9. Cameras

It is suggested that weather stations located in such unique areas as the Antarctic be provided with a simple but high quality camera to encourage the photographing of both typical and unusual weather phenomena. The careful photography of significant stages in the profile of local weather could do much to supply local experience to replacement meteorologists. Reliance on an Expedition camera is often unsatisfactory.

10. Gage for height of snow cover

To investigate factors affecting snow accumulation and snow ablation, it is necessary to keep an accurate record of the changes in snow cover. Some sort of linear measuring stick should be erected upon the snow surface. No such instrument was provided as part of standard Weather Bureau station equipment. A suitable 8-ft. wooden stick was found among expedition stores, and it was painted with bright orange and red inch-graduations. In mounting the stick, precautions had to be made to avoid undesirable sinking of the stick in the snow when the stick became heated by the sun. A wooden stick causes less melting than a metal stick because it does not conduct the heat as well. In determining a suitable location for this stick, many problems are encountered. Accessibility must be convenient enough to allow daily readings. Also, it would be advisable to mount the stick in a relatively wind-swept area removed from the lee of any drift producing obstacles. The Stonington Island snow cover gage was mounted on a relatively flat glacier surface on the northwestern side of the island, free from excessive drift accumulation and the effect of heat radiation from rock exposures.

11. Gage for precipitation

The accurate measurement of snow precipitation in the Antarctic region has always been a serious problem for the weather observer. The principal fault with conventional gages is that they trap drifting snow in addition to the desired precipitation. In the selection of the mounting site for a precipitation gage, a high wind-swept location was chosen. This minimized the depth of snow through which the observer had to trod to obtain measurements and generally kept the precipitation gage above the level of drifting snow. A 1937 Mount Washington[3] pattern wind-shield for a standard eight-inch snow gage was salvaged from equipment abandoned by the U. S. Antarctic

[3] C. F. Brooks. "Windshields for precipitation gages," Trans. Am. Geophysical Union, (1938). "Need for Universal Standards for Measuring Precipitation, Snowfall, and Snow-cover," Trans. International Comm. of Snow and Glaciers. Edinburgh, (Sept 1936). See Fig. 13.

Service Expedition of 1940. A picture of this gage in use in shown in Fig. 2. The top of the gage was mounted approximately six ft. above the surface level. This made it relatively free from drifts. In determining the water equivalent of precipitation in winter, the collector can was brought inside and the frozen precipitation melted by the addition of a tare amount of room temperature water. On summer days even though the air temperature would be substantially below freezing, the dark color of the precipitation gage would absorb much solar radiation and during nearly all the summer months would melt any snow that fell into it. This was unexpectedly convenient but probably introduced evaporation errors. A number of smaller precipitation gages were made for outpost stations on the 1937 Mount Washington idea.

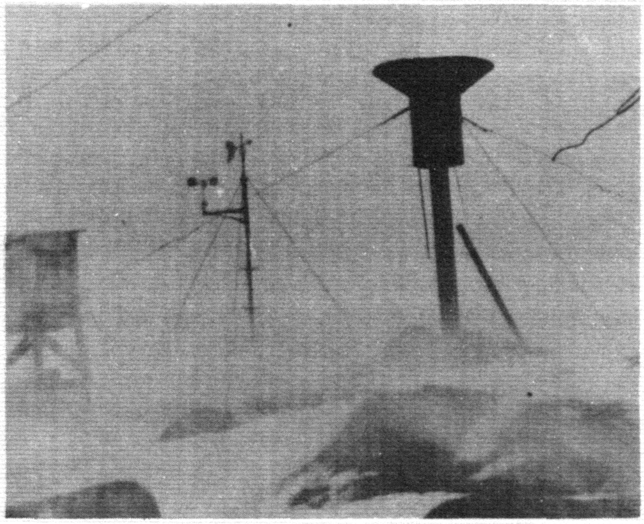

Fig. 2. Left to right: instrument shelter, wind instrument, precipitation gage with anti-drift windshield. Note that the drift level is below the top of the gage.

Perhaps the most natural of precipitation gages would be a snow colored mat of known dimensions from which precipitation could be dumped and measured. This would seem to give the truest indication of how much snowfall actually accumulated on the island; although it would by no means indicate only the snow which fell from the clouds, but would be considerably affected both additively and subtractively by winds blowing over the snow cover.

12. Hygrometers

The Expedition was not provided with any type of recording hygrometer, and spot measurements of dewpoint and humidity were made only with a sling psychrometer and a precision dewpoint indicator lent by the University of Chicago. The latter operated by determining with an electrical thermocouple the temperature of a mirror cooled by a carbon dioxide and heated by electrical induction and kept at the dewpoint by a sensitive photoelectric cell which controlled the induction heating device through an electronic circuit.

The instrument, while very precise, was difficult to operate and required a supply of electricity and carbon dioxide. Accordingly, use of the University of Chicago dewpoint indicator was limited to periods of subzero temperature when the sling psychrometer was unacceptably accurate and during unusual weather when it was desirable to know the dewpoint accurately. (See Fig. 3). A Serdex-built hygrometer was given the Expedition by Serdex, Inc. It operated on the principle of dilation of material, called goldbeater's skin, being a function of relative humidity. Readings were observed to deviate as much as 25% from sling psychrometer measurements at sub-freezing temperatures and were not seriously used.

Investigation of the field for the latest in hygrometer design is presented in the following tabular form:

TABLE NO. 2

Type of Hygrometers Currently Available			
Manufacturer	Principle	Advantages	Disadvantages
(1) Greene (Brooklyn)	Sling psychrometer	Simplicity	Not direct reading, not precise at low temperatures
(2) Friez (Towson, Md.)	Dilation of human hair as a function of relative humidity	Simplicity, direct indicating	Hysterisis of humidity sensitive material
(3) Serdex (Boston)	Dilation of gold-beater's skin as a function of relative humidity	Simplicity, direct indicating	Hysterisis of humidity sensitive material
(4) Friez (Towson, Md.)	Resistance as a function of humidity on a thin film of a salt solution of lithium chloride in a binder[4]	Simplicity, can be read electrically	Element resistance also a function of temperature; has aging errors
(5) American Instrument Co. (Silver Spring, Md.)	" "	Simplicity, can be read electrically; improved aging effects	Element resistance also a function of temperature
(6) Foxboro (Foxboro, Mass.)	Heats up coating of lithium chloride to crystallization point, temperature of which is a hygrometric function	Direct indicating	Requires extensive components
(7) Elnor (Illinois Testing Labs.)	Measures dewpoint temperature at condensation point of suddenly expanded air	Cools air by expansion; (rather than by use of coolant)	At present, indirect indicating; requires extensive pneumatic components
(8) University of Chicago	Mirror, cooled below frost point by carbon dioxide, intercepts beam of light aimed at photocell which electronically controls induction heating device to keep mirror at threshold of defrosting.	Precision (.1° C.), direct indicating of dewpoint temperature.	Requires coolant, extensive electrical components.

[4]The use of lithium chloride as a humidity determinant is described in "An improved electric hygrometer," Francis W. Dunmore, J. of Research, Bureau of Standards 23, (December 1939).

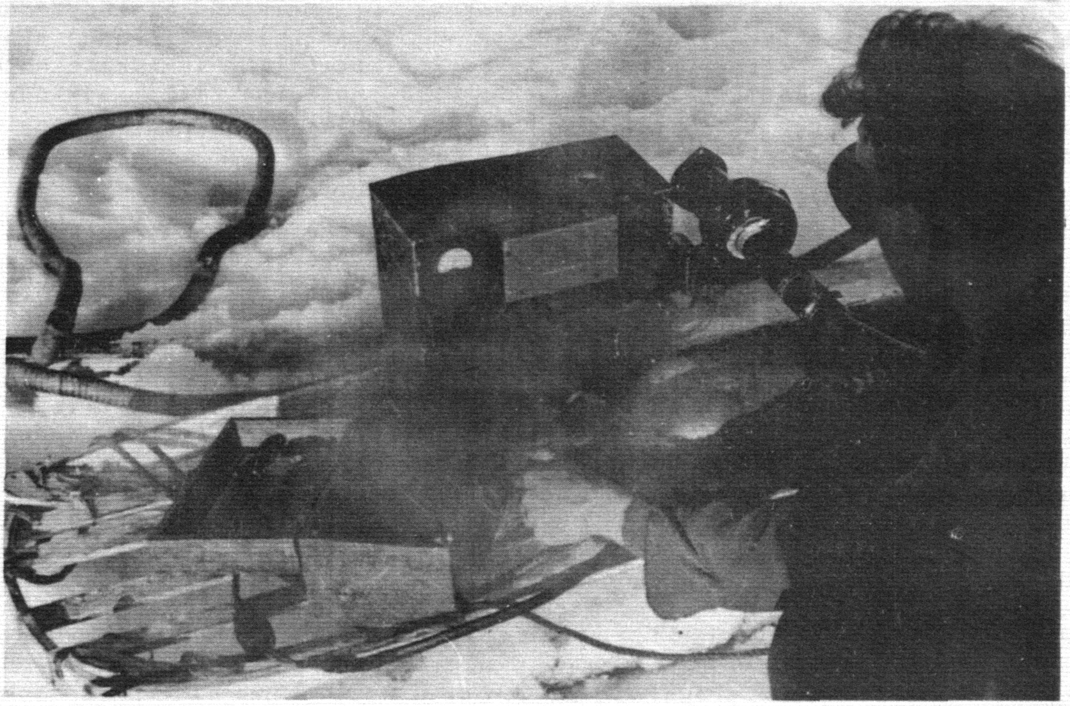

Fig. 3. The University of Chicago Dewpoint Indicator used in measuring surface humidity gradients.

13. Library

No library of meteorological literature was provided the Expedition. It is strongly advised that, in addition to the usual Weather Bureau circulars, a standard line of meteorological books be provided and be accompanied by a bibliography of polar meteorological literature.

A good, all-inclusive, weather handbook for station personnel is needed. Such a single handbook, while issued by many foreign nations, is lacking in the United States Service.

14. Nephoscopes

The Expedition was not provided with a nephoscope. After a short period of observing, the observers at Stonington Island decided to build a nephoscope in order to more accurately and easily report cloud direction. The Stonington Island-built nephoscope was used for all synoptic observations whenever there were any clouds in the sky. The advantages of using a nephoscope are:

(a) It provides a convenient azimuth circle to indicate directions.
(b) It provides a wider span of reference in which to track clouds.
(c) The observer avoids straining his neck.
(d) By holding onto the nephoscope in a kneeling position, the observer is in a more rigid position and hence cloud movements can be more sensitively detected.

The use of the nephoscope occasionally replaced a pilot balloon observation and on many occasions enabled the determination of winds aloft to be made when only a short-time interval of low-cloud clearing occurred during which a balloon could not have reached middle or upper-cloud levels.

In the use of a nephoscope, caution should be exercised in the determination of direction by oblique movements of distant clouds. Winds aloft determined by the nephoscope are useful for indicating the immediate motion of cloud decks, but should not be considered to represent climatic winds aloft as Grimminger cautions that cloud decks usually move in altitudes of minimum wind stability.[5]

15. Winds aloft plotting devices

The standard U. S. Weather Bureau pilot balloon plotting board was furnished the Expedition and its performance was considered satisfactory until a variety of pilot balloons were used. When the British 70-inch balloons and the United States 100g and 350g ballons were used and no tables for computing horizontal distance were available, slide rule computations had to be resorted to. This was an extremely tedious job for an already overworked staff, so a new type of winds aloft plotting device was made in the Antarctic. (See Fig. 4). Its over-all dimensions were approximately 17 in. by 17 in., and this unusually small size made it possible for a plotting board to be carried to outposts where pilot balloons observations were made. While it was admittedly not as accurate as the larger plotting board, results were considered consistent with our knowledge of balloon ascension rates in the Antarctic, mechanical play of the regular plotting boards, and coding approximations. The Antarctic-made plotting board was similar to the standard plotting board, except that a radius arm was added which enabled the quick, graphical solution of horizontal distances from the balloons' vertical angle and elapsed ascent time. Operation of the Antarctic-made plotting board ran as follows:

(a) Letting the degree divisions around the periphery of the plotting circle represent the balloon's horizontal azimuth, rotate the plotting circle until the balloon's horizontal azimuth is aligned with the index of the plotting board.
(b) Set the radius arm on the balloon's vertical azimuth, using the proper scale for the size of balloon involved.
(c) Sight the intersection of the radius arm and the minute line corresponding to the number of minutes that the balloon has been in the air. Run a visual line from this point across horizontally to the center line of the plotting board. (This operation is assisted by parallel background lines.) The point of intersection locates the balloon at that minute on a horizontal projection.

The curve so plotted is then read off as in a standard plotting board to give wind direction and velocity for each altitude corresponding to a minute of elapsed ascent time.

Aviation personnel demanded frequent winds aloft which had to be available very shortly after the ascent was terminated. In view of the shortage of man power common to all Expeditions, the most efficient and straight forward winds aloft computation technique had to be adopted. No graphs were made of vertical wind gradients. Conversion of winds at heights corresponding to minute intervals of balloon ascent were converted into winds at 1,000 and 5,000-ft. increments of altitude by mental interpolation from a table compiled showing the many minutes it took a balloon to get up to the standard 1,000 and 5,000-ft. levels.

[5] R. A. J. English. "Sailing Directions for Antarctica," H. O. 138, 39, (1943).

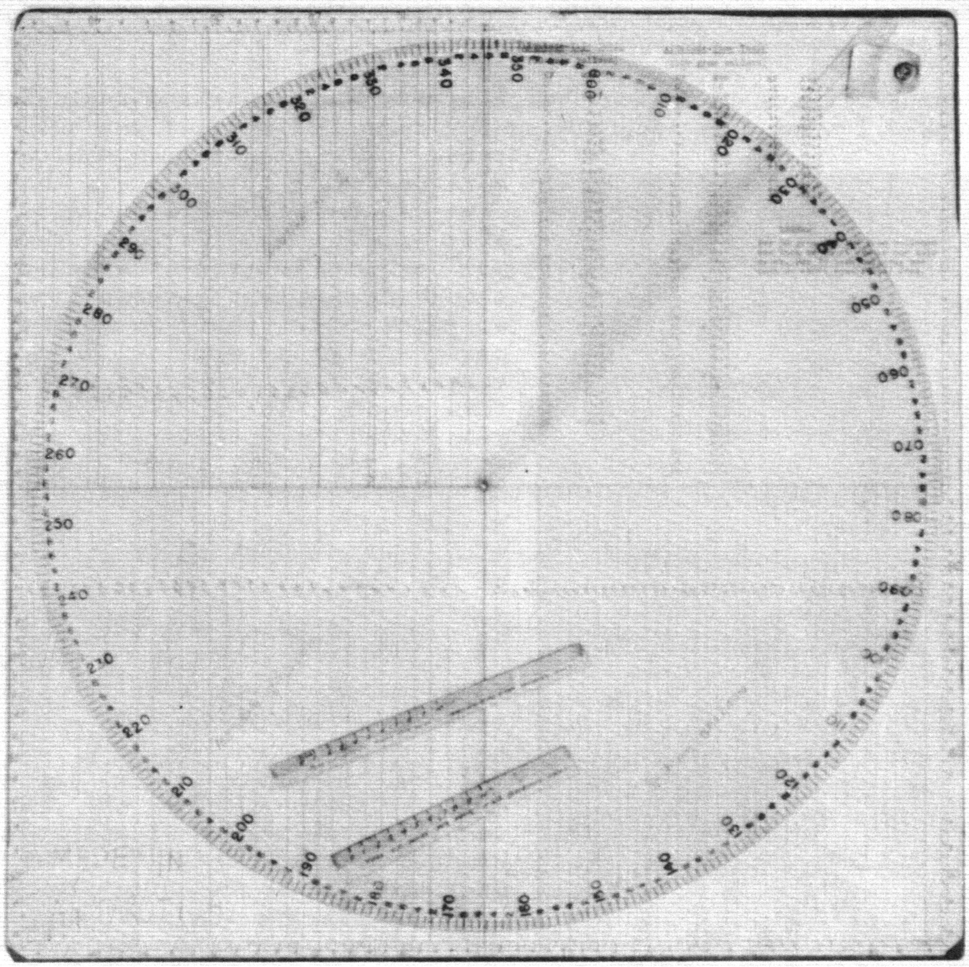

Fig. 4. Antarctic-made winds aloft plotting board.

16. <u>Instrument shelters</u>

Free air instruments at Stonington Island were housed in a cotton-region shelter located on top of a wind-swept rock exposure about 50 ft. above mean sea level, and approximately 250 ft. southwest of the meteorological office in a spot seldom disturbed by men engaged in activity about camp. To withstand occasional gusts of hurricane force, the shelter had to be strongly held down by wires to rock-impounded pitons.

This location was primarily selected for its elevation above other regions of the Island. Unlike almost every other shelter used by Antarctic weather observers who complained about drift accumulation, the interior of the Stonington Island shelter was seriously clogged with snow on only one or two occasions in nearly twelve months of use. Location on high terrain, if available, is the primary factor in minimizing drift produced snow clogging of instrument shelters.

Knocking out the bottom deck of the shelter was considered in order to further avoid snow accumulation in the shelter. With such a modification, thermographs and other instruments would have to be suspended inside the shelter. However, the execution of the idea brought up new problems of error from underneath of the shelter. If the underneath of the shelter were white, sunlight would be reflected up into the shelter. If black, heat produced under the shelter on sunny days would have unimpeded entry into the shelter. Thus, the bottom of the shelter would have to serve as a reflecting surface and could not be removed.

Because of its convenient height above the ground and inclusion of a handcranked fan to give accurate spot readings of dry and wet bulb temperatures, the cotton-region shelter was more desirable to observers than a comparison item: the British Air Ministry Stevenson screen. On calm, sunny, summer days the instrument shelter, even though it had been given a fresh coat of white paint, would pocket hot air parcels and give erratic, high temperatures. A small fan would have solved this problem, but a simpler solution seems to be in convection ventilation.[6]

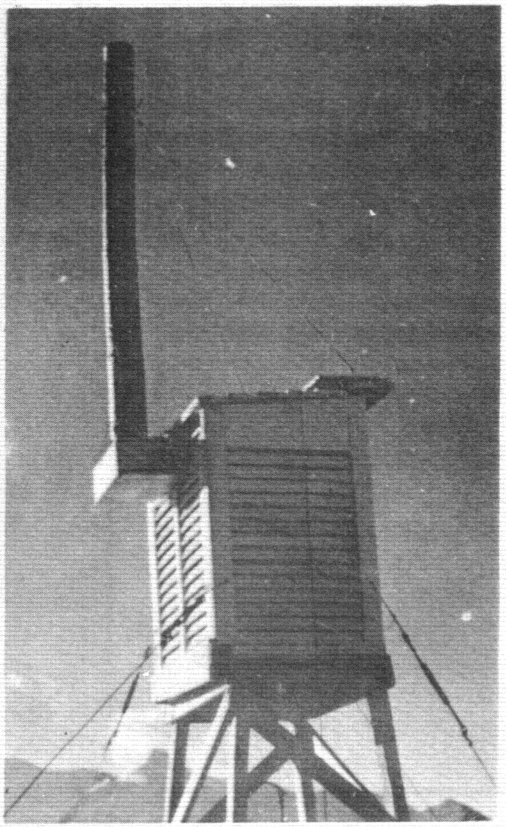

Fig. 5. Antarctic-improvised convection-ventilator installed on instrument shelter.

A 6-ft. stove pipe painted black was installed in the top of the shelter with a flue connected to the interior of the shelter. (See Fig. 5). Thereby a draft would shoot up the sun-warmed stack and draw fresh air inside. Cigarette smoke observed on a sunny day to travel rather fast up the stack tested the convection. On one occasion when the stack was temporarily muffled, the stack temperature was observed to rise. When the stack was unmuffled the shelter temperature dropped approximately 4°F. For winter operation, it might be advisable to have the black stack rotatable downward so that radiation cooling would similarly ventilate the shelter.

17. Snow-flake replicas

To obtain an accurate record of various types of frozen precipitation encountered at Stonington Island, several replicas of snow flakes were made using the technique introduced by Vincent J. Shaeffer, of General Electric's Research Laboratories, using solutions of Ethyalene Dichloride. (A number of excellent publications have appeared showing the almost infinite forms of snow-flake replicas, prominent among which is Snow Crystals by W. A. Bently and W. J. Humphries, New York, 1931.) It was intended on this expedition to use the snow-flake replica technique to provide an accurate profile of the types of precipitation that occur through a snow storm; however, shortage of man power did not make this aim completely possible.

18. Sunshine Recorders

The number of hours of daily sunshine is a common element to be recorded by weather stations. Eppley-patter pyrheliometers and a constantly recording microammeter were used at Stonington Island by the RARE to record

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[6] S. P. Fergusson. "On the Improvement of Certain Meteorological Instruments, Exposures, and Techniques," Blue Hill Observatory, Harvard University, Milton, Mass., Reprint No. 5, 1944, page 3.

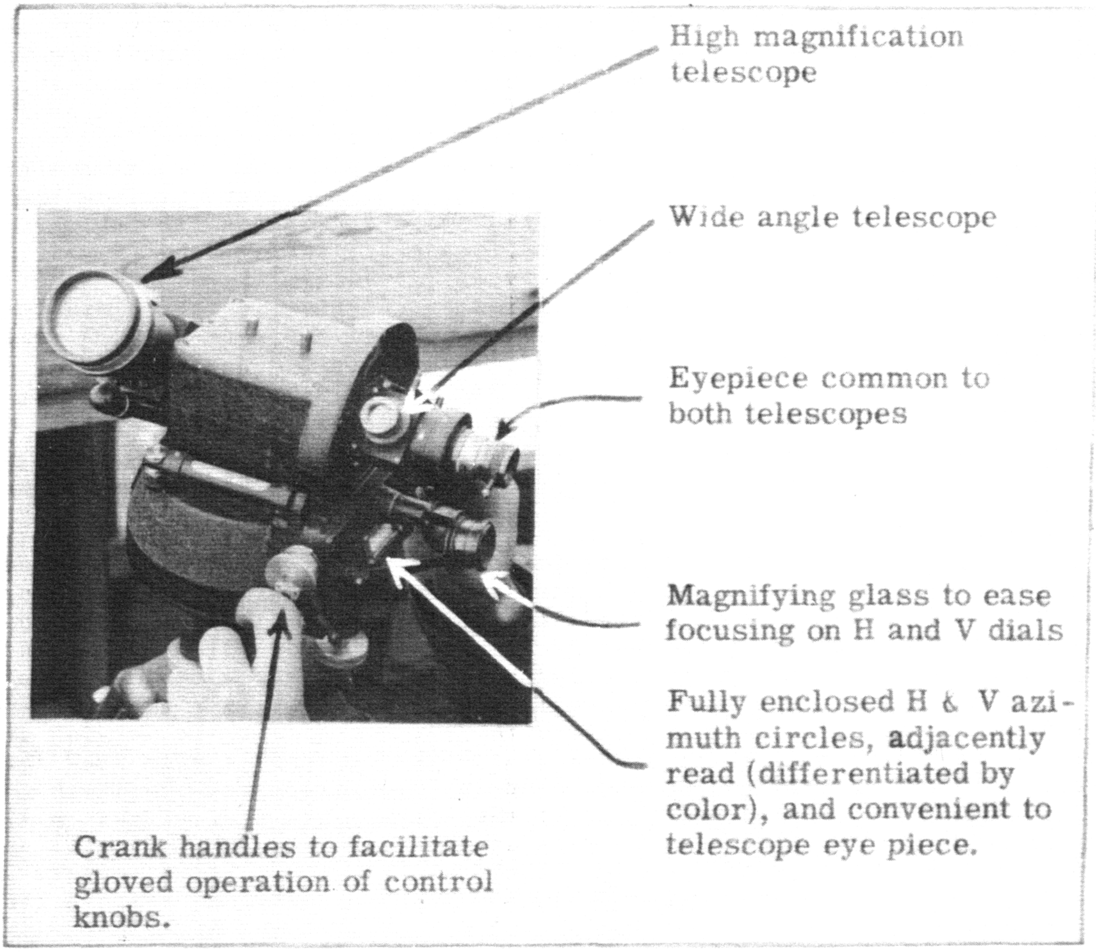

Fig. 6. Equipment comparison item: British balloon theodolite

insolation. Records were made from 6 October 1947 to 20 February 1948, and results presented in Technical Report No. 3 of this series.

19. Theodolites

While completely reliable in its operation, the David White-built theodolite furnished the Expedition by the Weather Bureau was considered by the author to be inferior in several points to the standard British land-station theodolite. The controls on the British theodolite (See Fig. 6) all came equipped with crank handles which were of considerable value when inclemental weather demanded the use of heavy gloves and twisting an ordinary knob is awkward. On the British theodolite both horizontal and vertical azimuths were read through a single window a few inches underneath the eyepiece and, as the azimuth circles were enclosed, the numbers printed on them retained their original high degree of legibility. Another advantage of the British theodolite was the provision of two optical fields: One, a wide angle field to follow the balloon during its initial few minutes of ascent; the other, a narrow field with higher magnification, to observe the balloon at more remote distances. During the summertime, when pilot balloon observing procedure was not difficult, dual fields could be dispensed with; however, the addition of wide angle fields in the wintertime, when very heavy clothing and cold temperatures made manipulation of the theodolite awkward, would have greatly minimized the frequent loss of balloons at low altitudes.

Frosting of theodolite lenses was an extremely serious problem in winter. Often the theodolite would be removed from its permanently-mounted tripod and heated up over a stove before carrying outside. Until the theodolite approached the atmospheric temperature, which took about 10 minutes, there would, of course, be no frosting. However, after a period of about 10 minutes, frosting would occur and no remedies, such as face masks or glycerine coating of the lenses, were successful. This problem was finally solved by inserting an electrically-heated wire between the outermost brass cover of the eye lens and the eye lens itself. It was felt that this hot wire might crack the lens, but this did not materialize. The only theodolite defrosting device likely to be successful must involve electrical heating wires; and that failing this, it could not be expected that a preheated theodolite would remain unfrosted for more than 10 minutes at sub-zero temperatures.

20. Thermographs

Standard thermographs were provided the Expedition by the United States Weather Bureau and came with a chart range of -50° to +70°F. They were considered in all important respects to be completely satisfactory for our use at Stonington Island. It is worthy to note that the clock mechanism had a reasonably constant rate and never stalled even at the lowest temperatures of -30°F. Previous complaints against these thermographs for use in cold climates was focused on their openness to drifting snow. The instruments were seldom clogged by snow at Stonington Island because they were located on a high point on the Island and generally above the level of drift. (See Instrument Shelters.) The only suggestion that this observer has for improving the thermograph is to dispense with the detachable clip used for holding the chart paper to the drum, and instead incorporate built-in clips, one at the top and the other at the bottom of the drum, that will snap down on the paper at the two ends of the chart paper. This will exclude the possibilities of loosing the chart clip when changing papers and, in the event that the chart is not changed on time, will not obscure the overtime record.

21. Thermometers

Both mercury and alcohol filled thermometers were supplied the Expedition.

Alcohol Thermometers filled with red spirit are more legible than the ordinary mercury thermometers. However, the new red mercury thermometer made by Precision Thermometer and Instrument Company of Philadelphia is the most legible of all. It was not available to the expedition in 1946.

Mercury separates more easily than alcohol and pure mercury is inoperate below -39°F., its freezing point. Temperatures below the freezing point of pure mercury were not experienced by the expedition. (However, a special thallium-mercury alloy suitable for thermometry down to -60°F. is made by the Taylor Instrument Companies, Rochester, N. Y.)

In general, the mercury thermometer was preferred, as most alcohol thermometers used by the Expedition gave erroneously low indications caused by some alcohol remaining on the walls of the thermometer bore.

However, one alcohol thermometer which was mounted vertically in the shelter was accurate to .2°F. for eight months until it was broken.

22. Wind direction indicators

A standard U. S. Weather Bureau wind vane, remotely indicating to 16 points of the compass, was used. When the base was first established and the bay open, strong down-glacier gales would drive considerable salt moisture into the head of the wind vane and cause corrosion. A coating of Vaseline helped, but after 14 May, when the bay finally froze over, salt moisture practically disappeared. For reliable use in regions exposed to salt moisture, the bottom of the indicating head should be sealed.

With the exception of its susceptibility to wind-driven moisture, the wind vane proved a reliable and sensitive instrument.

A selsyn indication system would have provided a finer degree of accuracy in indicating wind directions, which - for stations with aviation activity - would be helpful in observing variability in wind gusts. Another advantage of the selsyn system is the requirement of fewer lead wires.

DISCUSSION ON OBSERVATIONS AND REPORTING

In this section the author takes opportunity to describe the more important observational techniques used at Stonington Island and to explain certain man-hour saving expedients adopted. In addition, some inadequacies in present reporting codes are pointed out.

The following elements are discussed: (1) pressure, (2) temperature, (3) hygrometry, (4) precipitation, (5) visibility, (6) winds, (7) past weather, (8) ceiling height, and (9) clouds.

DISCUSSION ON OBSERVATIONS

1. Pressure

Weather observing personnel of the RARE regarded carefully maintained barographs as precision instruments and accordingly took synoptic pressures directly from barogram traces. This procedure was permissible on the basis of accuracy and was adopted to save observer time during synoptic observations as well as for frequent aviation altimeter settings. Once a day, however, the station mercury barometer was read and barograph compared.

2. Temperature

Attention commonly paid to accuracy of the thermometer readings is inconsistent with the general errors likely to result in obtaining representative air mass temperatures at Stonington Island. Factors introducing error in determining free air temperature are: instrumental, exposure, and natural environment.

Discrepancies of 1-5° F. were commonly found between minmax thermometer readings and thermograms. The old practice of assuming the thermograph to be generally in error appears faulty; carefully maintained thermographs are precision instruments capable of indications accurate to .3° F.[7] Discrepancies between thermometer and thermograph when not due to

[7] S. P. Fergusson. "On the Improvement of Certain Meteorological Instruments, Exposures, and Techniques," Blue Hill Observatory, Harvard University, Milton, Mass., Reprint No. 5, 1944.

maladjustment of the thermograph were caused by differences in response of the thermometer and thermograph. For example, short duration temperature extremes in thermally patchy air would not fully actuate a thermograph and as a result cause discrepancy between minimax and thermograph indications.

It is suggested that only periods of steady temperature be used to adjust a thermograph in the Antarctic. It was found that a carefully adjusted thermograph would repeat agreement with alcohol or mercury thermometers on all steady temperature periods for several weeks duration.

Natural factors at Stonington Island which affected the determination of free air temperature were:

(1) Warming of air parcels by buildings.
(2) Narrow currents of cool down-glacier winds.
(3) Parcels of hot air drifting in from sun-baked rock exposures.
(4) Parcels of air drifting in from ocean exposures.

These natural factors, in addition to the errors of the instrument shelter described in the section on Equipment Performance, would often considerably confuse the determination of the general air mass temperature at Stonington Island and made the reading of thermometers to a precision of .1°F. seem unjustified.

During winter, good observation technique requires a careful guard against the thermometer rises due to body-heat, breath, and even flashlight rays. With breath held, the observer should quickly approach and open the shelter, aim the flashlight on the top of the thermometer column and read the indication, tenths and/or units first, (before the heat brought in by the observer has influenced the thermometer) and then the tens digit of temperature.

3. Hygrometry

Hygrometry at Stonington Island was carried out using the University of Chicago electronic dewpoint indicator and ordinary psychrometers.

Complexity of operation, infrequency of electrical supply, and shortage of carbon dioxide coolant limited use of the dewpoint indicator.

The psychrometric principle was used at temperatures down to 0°F., although the technique involved in order to get reliable measurements was quite critical. In subfreezing psychrometry the observer would first dip the "wet" bulb in water, hang it outside to cool, and then whirl the psychrometer until a minimum "wet" bulb was finally reached. When hung out to quietly cool, the "wet" bulb would often cool below 32°F. without actually freezing; then, when jarred by whirling, would jump up to 32°F. as the freezing proceeds. Energy for the freezing process and the subsequent cooling to a "wet" bulb temperature comes from evaporation of water vapor from both water and ice. The cooling effects of these two evaporations are different and thus psychrometric tables require two separate bases depending whether the "wet" bulb was impregnated with super-cooled water or coated with ice. This offers a nice problem when air is super-saturated with respect to ice, but not saturated with respect to super-cooled water. The ice-coated "wet" bulb will then read higher than the dry bulb! If hygrometry continues to use the psychrometer, then the psychrometric tables might well list the values of hygrometric arguments with reference to super-cooled water. An investigation of relative humidity, dewpoint, condensation, and transition from water to ice should be made with a view towards clarification.

During cold stagnant air masses with occurrences of frost, the dewpoint would occasionally be arrived at by assuming it to be equal to the minimum temperature. This, in practice, worked out quite well. During the sun's equinoctial phases--when both day and night occurred in a 24-hour period--the evening frost or fog would commence when the free air temperature fell to the dewpoint assumed on the basis of the previous early morning's minimum. This procedure had to be adopted on several observations when the dewpoint indicator was inoperative and the psychrometric method was too critical to accurately determine dewpoint.

4. Precipitation

Precipitation at Stonington Island was measured with a standard eight-inch precipitation gage provided with a 1937 Mt. Washington pattern anti-snow drift shield.[8]

In the winter, the water equivalent of precipitated snow was obtained by melting the collected snow with the addition of a tare amount of room temperature water.

During the months near the summer solstice, solar radiation was on nearly all precipitation days sufficiently strong to keep the sunshine absorbing precipitation gage above freezing, even though the free air temperature might be substantially below freezing.

In reporting types of frozen precipitation occurring at Stonington Island, frequent use was made of the code derived by GE Research Laboratory's Vincent J. Schaefer. This code classified frozen precipitation into nine kinds: (1) stellar crystals, (2) graupel, (3) hexagonal plates, (4) hexagonal columns, (5) capped hexagonal columns, (6) ice needles, (7) asymmetrical crystals, (8) powder snow, and (9) sleet, and gives exactness to a weather element usually reported in only the most general terms.

Extensive use of this code in cold climates and study of the new data obtained should make substantial contributions to our knowledge of the profile of snow storms.

5. Visibility

Situated on the mountainous coastline of Palmer Peninsula, Stonington Island visibility was severely restricted by terrain in the major portion of the horizontal azimuth and far reaches were possible only in limited corridors to the western half of the horizon. The irregular terrain did, however, provide many landmarks useful for estimating visibility. (See Fig. 7.)

Standard Weather Bureau coding systems pertaining to visibility were insufficiently comprehensive to present a good picture of visibility for Antarctic aviation interests and should be improved in the following particulars:

(a) Maximum and minimum reaches of visibility.
(b) Specification as to reason for uneven visibility:

1. Direction of reduced visibility
2. Direction of optimum visibility

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[8] See "Gage for precipitation."

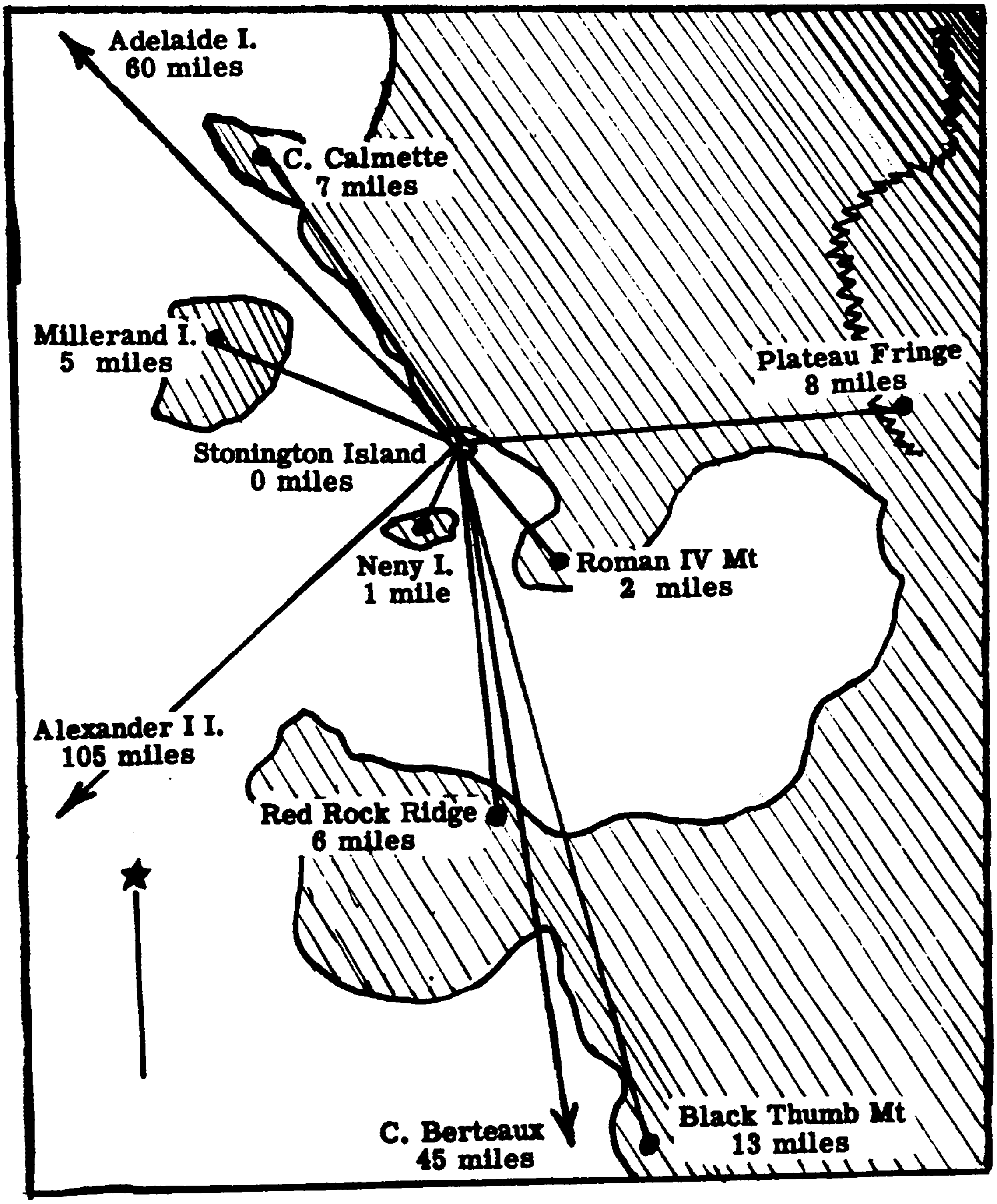

Fig. 7. Visibilities at Stonington Island

3. Cause of temporal fluctuations, if any, in visibility (e. g. visibility from one mile under shower to 10 miles between showers)

(c) Trend in visibility
(Diffuse stratiform mist gradually reducing, or sharp edge advancing front exposing excellent visibility, etc.)

(d) Certainty
(Due to lack of light certain terrain features may be unrecognizable, even though the air may be quite transparent).

In connection with particular (d) two concepts are applicable in reporting visibility:

(a) Transparency of the atmosphere, which--

1. Indicates the distance at which prominent objects could be seen, and which--
2. In a meteorologically useful manner often indicates the amount of precipitable moisture in the air.

(b) Reach of actual vision, which depends on--

1. Transparency of the atmosphere and,
2. The existence of a currently prominent object in the line of vision.

For example, on a dark night a prominent 100-mile distant snow-clad island may not be visible until the moonlight strikes it, while a profile of a one-mile distant rock mountain may be visible against starlight. The observer is likely to be conservative in his report of visibility, until the moon rises. The meteorologist or pilot receiving such a report would have no way of discriminating between a conservative dark night report of visibility and a definite reduction in the transparency of the atmosphere due to an increase in incipiently precipitable moisture.

Visibilities in excess of 100 miles were occasionally reported even though geometric calculation showed this to be impossible for the altitudes involved due to the curvature of the earth. Such visibility was actual and possible only because of a pronounced atmospheric refraction.

6. Winds

Since the wind instrument at Stonington Island was non-recording:

(a) Statistics of average winds were obtained from synoptic records
(b) Notice of exact time of wind shift was subject to observer laxity
(c) Measurement of peak wind was subject to observer laxity in detecting peak wind
(d) Duration of gales or calms could only be approximated.

Short time variations in wind direction and velocity were difficult to observe with station non-recording, indirect-indicating, wind equipment. However, often a hand-held instantaneous-indicating anemometer was brought outside to investigate gustiness for aviation interests. Gustiness is of aviation interest in describing landing conditions and of meteorological interest to often indicate the cause of the wind. For example, down-glacier katabatic winds were quite gusty, but winds from the same direction due to an extensive pressure system were quite uniform. Gustiness was reported by adding 33 to the coded wind direction.

The many scales of wind velocity such as knots, MPH, MPS, KM/HR, Beaufort, variously used were an occasional source of inefficiency.

7. Past Weather

Since only 3 observations were made each day at 12h, 18h, and 23h, GMT, the cooperation of all members of the expedition was sought in obtaining observations on interim conditions. It was particularly fortunate that of the 23 members of the expedition, nine possessed airman licenses and four others were navigational officers. Such backgrounds greatly assisted the accurate reporting of weather phenomena as time precipitation began, wind shifts, character of night's weather (observed by night watchman), trend in cloud movement, etc. Thus, with recording pressure and temperature equipment and numerous reasonably good interim weather notes, it was felt that our three daily coded observations offered a good climatic record and by not having more frequent observations freed our limited man-hours for more pilot-balloon work, analysis, and research.

8. Ceiling Height

Ceiling heights up to 5,000 ft. were easily reported with good accuracy due to the presence of mountains to act as reference scales of altitude. Ceilings in excess of 5,000 ft. could be estimated from their distances above mountain peaks or from recent pilot balloon soundings. On only one occasion was it felt necessary to specially launch a balloon for checking ceiling estimation, and this was for an aviation interest. Occasionally vertical visibility would be so good through a cloud deck that the observer hesitated to establish a ceiling. The indescernible point of a pilot-balloon ascent was often used for ceiling height, and when higher clouds could be recognized through any low overcast, the low overcast was not considered as constituting a ceiling.

Here, as in other ambiguous weather elements, the aviation viewpoint was held.

9. Clouds

While many of the clouds observed at Stonington Island readily fell into standard international code types, these elements of the cloud description were not given due recognition in the code:

Where formed:

(a) Generally
(b) Over mountain tops primarily
(c) Over nearby water areas
(d) Over nearby land areas

Density:

(a) Heavy (obscures sun)
(b) Moderate (permits faint shadows)
(c) Thin (fair vertical visibility)

Grouping:

(a) Scattered
(b) Congested
(c) Solid layer

Trend:

(a) Not undergoing apparent change
(b) Diurnal variation only
(c) Increasing
(d) Decreasing

The tabulation is intended to be suggestive rather than comprehensive. It is desirable to report after an observation every possible significant weather element.

For example, an extensive carpet of dense maritime stratus may be approaching the station and at the time covering 1/4 of the sky. Using the 1942 US Land Station Code. the observer would report only 0.2 stratus moving from a certain direction. Although some additional details could be provided by an extensive use of the special phenomena groups, the recipient of the report could not be expected to grasp the idea of an impending blanket of stratus.

TRAIL WEATHER OBSERVATIONS

Desirability

In midwinter while expedition members competing for positions on sled journeys were training dog teams and preparing trail gear, plans were being made by the meteorological department to have daily weather observations included in the trail routine. As the dogsled parties would be operating as far as 500 miles south of the main base, any data that they could gather would be important for climatic surveys, air mass correlation with the base, and for specific aid to aviation. Trail parties of many previous antarctic expeditions neglected to record even the most basic of meteorological data; thus any post-expedition weather picture of the area which they explored is at the mercy of an aged and distorted memory.

Difficulties

The inclusion of weather observations in the trail routine was not a simple task. Exploration, distance covered, surveying, or geology--seldom meteorology--have been the primary aims of Antarctic trail parties. Eager trail members will spend their daily efforts to the point of heavy fatigue on accomplishing primary aims. Before and after the day's run, there is much routine work on dogs, tents, food, and clothing. It is usually out of this time that meteorological observations have to be taken, recorded, and from time to time radioed to base. The "met" man will have a minimum of time and effort to devote to this task. Furthermore severe cold makes the temptation of his sleeping bag inside the tent very great. Meteorological procedure must be simple.

Importance of weight

Weight on a trail party is of primary importance. The food ration per dog is one pound. If a ten-dog team can carry rations for 40 days, then the addition of 10 pounds of dead weight cuts the duration of the trip by one day. In addition to simplicity of operation, meteorological equipment must be light.

Personnel

Two lectures on weather observing were presented to expedition members aspiring to trail journeys. They covered obstructions to visibility, clouds, weather for flying, and use of instruments. The two meteorological men selected were given a short additional discussion on coding and Antarctic weather phenomena of special interest. In addition, books were borrowed from the station library to supply background. It was fortunate that both trail men possessed a fair meteorological background from Naval training.

Instruments

No meteorological instruments really designed for field use were provided the Expedition, and such equipment had to be improvised at the Antarctic base. (See Fig. 8). Instruments initially furnished trail parties were: thermometer, barometer, minimax thermometers, and anemometer. The minimax thermometers and anemometer were later discarded because of weight. In the design of a thermometer mount, the factors of unbreakability, convenience of reading, and true exposure to free air were considered. It was decided to flexibly mount one alcohol and one mercury thermometer in the recesses of an E cross section white-painted-wood frame which could be fastened onto one of the upright handlebar posts at the stern of the sled. The extra alcohol thermometer was provided for very cold temperatures, as a check on the mercury, and as a convenient and integral spare. Sled mounting minimized the risk of instrument loss and permitted the temperature to be read while underway without the use of hands. This, it was felt, encouraged the observer to trap a maximum or minimum and reliably observe sudden temperature changes. The E cross section permitted easy access to the thermometers to rub off frost or snow when necessary, yet excluded most objects from striking the thermometers. The E frame could withstand a crushing

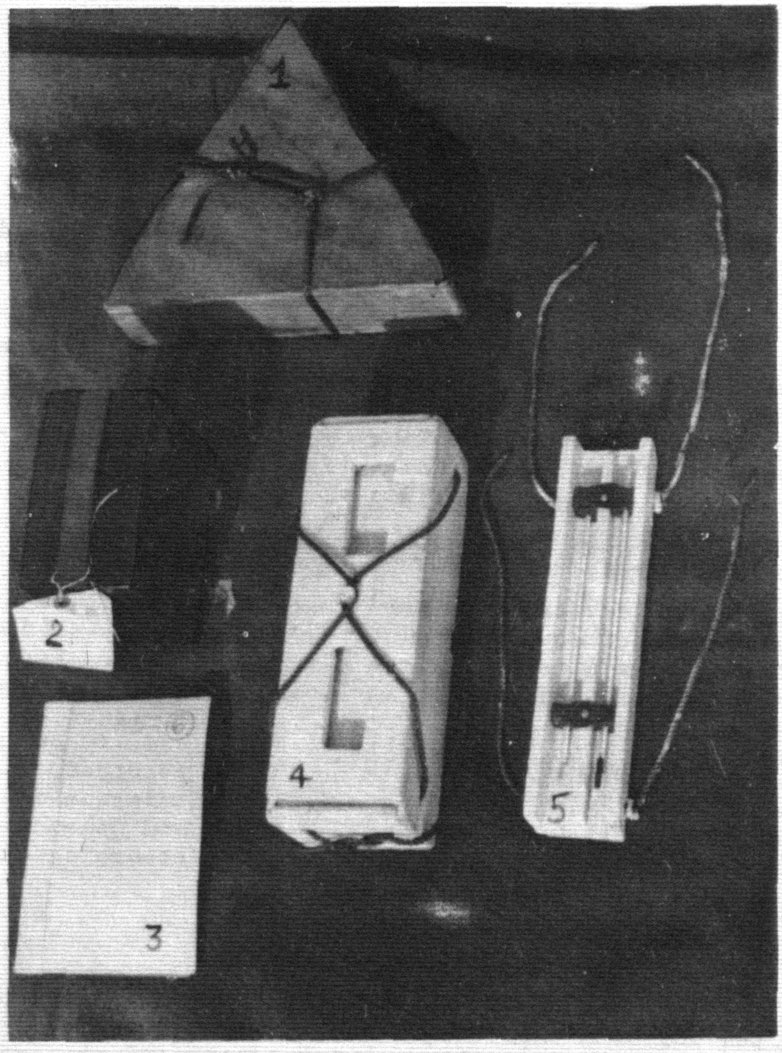

Fig. 8. Complete meteorological equipment carried by sledge parties: (1) anemometer in case, (2) aneroid, (3) met code book, (4) minimax thermometers, (5) free-air thermometers.

force of 300 pounds. This mounting device was fastened onto a box at the base and tested by kicking the box around the base for about five minutes. The thermometers could not be broken, although the columns became separated and had to be reunited. Some compromise with free air temperature must have resulted on sunny days, but a shade screen would introduce unacceptable weight and the whirling of thermometers was an undesirable complication. Total weight of the thermometers and mount was 1.1 pounds.

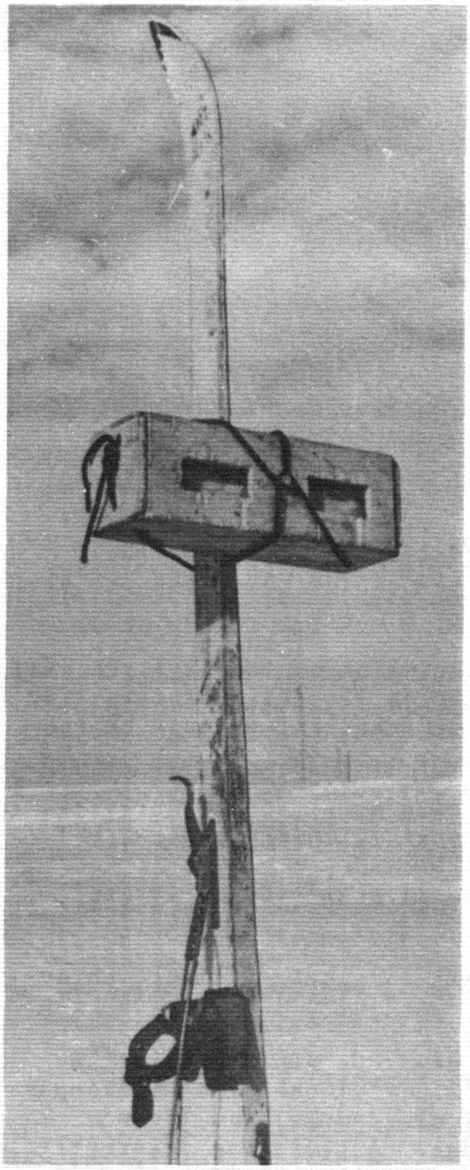

Fig. 9. Antarctic-made minimax thermometer box mounted on ski while sledge party sleeps.

The Taylor-built aneroids supplied the Expedition for trail and outpost use, having been grossly unsatisfactory (See <u>Aneroids</u>, p. 5), Wallace and Tiernan-built, Corps of Engineers, altimeters were supplied the trail parties. (See Fig. 8). They weighed two pounds with wooden case and were considered practically perfectly reliable. Only an aviation dashboard altimeter could have been better for weight, legibility, and ease of conversion from altitude to pressure.

Initially, it was thought that maximum and minimum thermometers could be carried, and so a small (15" x 5" x 5") shade shelter was constructed. It was designed to be mounted on top of the sled while underway, and to be fastened broadside to the wind on a ski struck vertically in the snow during sleeping periods. (See Fig. 9). Reset of the maximum thermometer was accomplished by whirling the whole box with thermometers inside; while reset of the minimum was done by gravity. Total weight of the minimax thermometer box was 2.1 pounds. Trueness of exposure was considered fair.

In order to accurately measure peak velocities encountered in the numerous down-glacier gales common to the Antarctic, an anemometer was provided for trail parties. A standard Weather Bureau "SA" three-cup anemometer was modified to make cups readily detachable from the bearing box, and the bearing box was fitted with an additional gear train which rotated an external pointer. (See Fig. 10). Wind velocities were measured by timing the number of revolutions made by the pointer. Total weight with case was 2.3 pounds. A factory-built, instantaneous reading, light weight anemometer designed for field use is needed.

A B

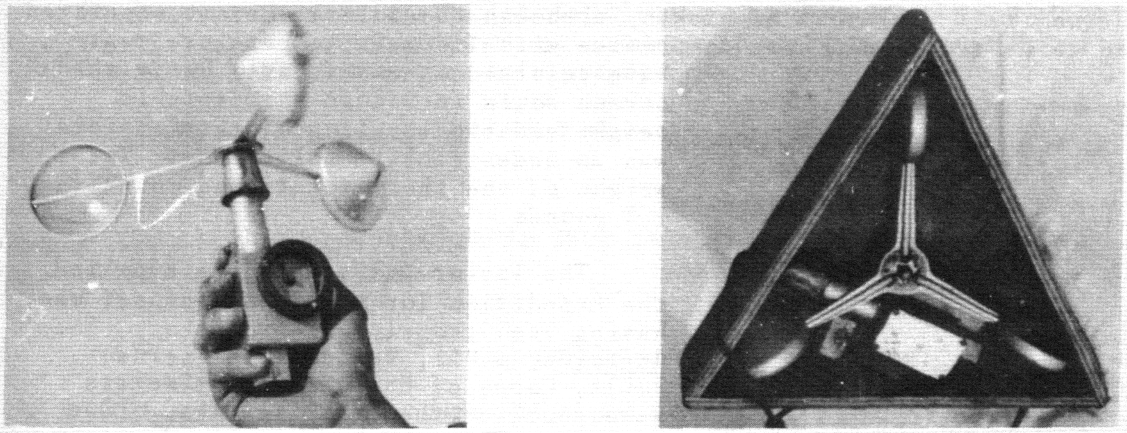

Fig. 10. Anemometer modified for trail, A) in use with dial facing out, B) packed in box with cups detached from bearing box.

Observations

In view of the strenuous effort put out by trail parties for their primary aims, it was not considered desirable to ask for more than one observation a day.

Observations were usually taken at the conclusion of the days run just before supper. This was about 8 A.M. local time or 12h GMT. At this time weather would be coded, and often a few plain language notes would be entered in the log book.

When several of the major aerial flights were made, thrice daily reports were taken by the trail parties generally at 12h, 18h, and 23h GMT.

Observations in general consisted of state of sky, wind, pressure, temperature, surface, and terrain.

Clouds, wind direction, and wind force were somewhat difficult to observe with accuracy in the field.

Cloud cover observations were based on a new code explained in the following section. Wind direction required a study of the magnetic compass with associated mental burdens and possibility of error. Wind force in the absence of anemometers, was hard to judge. A tentative descriptive index of wind forces applicable to Antarctic conditions was incorporated in the code book. (See pages 33 and 34).

Coding

Coding was an important element in the success of trail weather observing. It shortened radio transmission and reduced the mass of weather records; but more importantly, it provided a comprehensive pattern for the observer to follow when making his observations. The relief of mental burden on trail party is fully as needed as the physical. The fatigued observer, when he had completed his coded report, could rest satisfied that all significant elements had been covered and none omitted.

After much discussion it was decided that no standard code existed which would be suitable for our needs. We wanted a code easily taught personnel with no further meteorological background than that given naval or aviation officers. Yet this code must comprehensively report weather from an aviation operational standpoint.

Here is a typical weather message transmitted from a trail party in the RARE Trail Code:

KHSD WKUH JNCN 937480 703845

Which when decoded, states:

K-Past weather: sky continuously covered, base of clouds mainly under 2,000 ft.
H-Present weather: layer of clouds receding.
S-The direction of low clouds (reported in preference to the direction of surface wind in this message is NW.
D-Surface wind is force 3, not gusty.

W-Visibility: minimum 20 miles, maximum over 80 miles.
K-Middle clouds direction (to 4 points) is E, High cloud direction is stationary.
U-The sky cover consists of low clouds covering more than 3/10ths of sky, some scattered middle clouds, and some scattered high clouds.
H-The least terrain clearance of clouds is found to the North where it is between 1,000 and 2,000 ft.

J-The barometric tendency is rising slowly, less than 7 mb/12hrs. The period of observation on this occasion has been the last 12 hours.
N-The surface is sastrugi, with snow cover, under 6" high.
C-The weather for flying is classified as suitable because the edge of clouds is retreating from the observer and exposing a clear sky.
N-The terrain is flat snow covered land.

93-The temperature is -7°F.
74-The barometer is 974 mb.
80-The elevation is 800 ft.

703-The latitude is 77°03' S.
845-The longitude is 58°45' W.

The following features are of note:

The use of letters rather than numbers more than doubles the useful meaning of each character.

The first literal group contains only the most basic weather information and is especially applicable when stormy weather confines the members of the trail party to their tents.

When the weather clears somewhat and more details are noticeable, the second and third literal groups can be coded.

A surface description is provided to, among other purposes, check by sastrugi the presence of windswept areas.

A terrain description is provided to assist the meteorologist in his interpretation of the observation.

Visibility reports both maximum and minimum reaches.

Terrain clearance of clouds is reported in past weather and in present weather. Often the direction of least clearance can be specified.

A tentative descriptive index of wind forces applicable to Antarctic conditions is provided in the code book. (See pages 33 and 34.)

Gustiness can be reported under wind force.

In reporting barometric tendency, provision is made for several different intervals of observing the tendency.

The cloud cover is classified more according to the composition and distribution of the clouded area rather than the complicated forms of middle and high stratus and cumulus. While the cloud tables need considerable improvement, it is felt that this line of thought in classifying clouds is easier to teach and often more useful in practical forecasting on a 3-6 hourly basis.

A copy of the trail weather code appears in the appendix.

GENERAL REMARKS

To be completely successful, the meteorological program of any Antarctic expedition should achieve these four aims:

1. The prompt radioing of current weather data to central offices of countries influenced by antarctic weather for their analysis and dissemination.

<u>Requirements</u>:

(a) Maintenance of a first order weather station with upper air soundings
(b) Location in a meteorologically strategic area
(c) Maintenance of a regular schedule of synoptic observations
(d) The availability of a reliable high-powered beamed radio transmitter competently operated and adequately supplied with electricity
(e) Contacts with countries to reach mutual agreements about codes, units, and radio schedules.

<u>Benefits</u>:

(a) First hand experience with polar/temperate zone weather correlation
(b) The philanthropic use of scientific knowledge ("good neighbor")

2. The compilation and reduction of several years of weather data of a south polar region.

<u>Requirements</u>:

(a) Maintenance of several first order weather stations in meteorologically strategic locations

(b) Maintenance of several adequately trained and equipped supplementary weather observation sources such as outposts, sledge parties, and airmen's reports
(c) An efficient organization for transforming the mass of collected weather data into useful statistics
(d) A competent service for analysing the weather data into general pictures of air masses, pressure patterns, and storm paths
(e) Means of publishing and disseminating data to elevate the start of all subsequent investigations to the level of knowledge achieved by the expedition.

<u>Benefits</u>:

(a) Picture of regional navigational difficulties caused by weather
(b) Picture of weather factors for local living conditions
(c) Picture of local weather for possible economic or military activities.

3. The close observation of regional weather to assist the expedition's aviation program and other outside activities.

<u>Requirements</u>:

(a) Maintenance of several first and secondary order weather sources in meteorologically significant locations
(b) A fast communications network employing an effective meteorological code to gather all observational data into the hands of, . . .
(c) An analyst and forcaster skilled in cold climate weather and operating on an ample time budget.

<u>Benefits</u>:

(a) Minimize vain flight anticipatory action
(b) Minimize incompleted missions
(c) Promptly furnish weather data on alternative areas to flights in progress
(d) Offer optimum times and altitudes for utilization of fuel
(e) Provide warning of hazardous weather
(f) Assist the leader in deciding plans of outside activity

4. The careful study of weather phenomena peculiar to the antarctic continent for contributions to the fields of physical meteorology.

<u>Requirements</u>:

(a) At least one first order station
(b) Provision for numerous portable supplementary stations, preferrably with automatic recording equipment
(c) Upper air sounding equipment
(d) Access of meteorological personnel to transportation, photographic services, and a high man-hours budget
(e) A suitable stock of special instruments as needed
(f) Scientifically competent personnel:

   1. keen in observation
   2. rich in knowledge of the history of investigation of Antarctic meteorological problems

(g) Professional interest and means of pursuing antarctic investigations to conclusion upon return to the U S.

Benefits:

(a) Knowledge about problems advancing the science of meteorology.

APPENDIX

Copy of Trail Meteorological Code of RARE

The first two groups can be observed without instruments. The first group describes weather and wind; the second, visibility and clouds. When the sky is obscured and visibility is under 0.1 mile the second group need not be sent. The third group will be needed when a flight is planned. To avoid ambiguity the third group should never be sent if the second group is omitted. The fourth group reports temperature, pressure, and elevation. It is hoped that these important elements can be reported daily. The fifth group reports position. Dead reckoning positions are acceptable. Estimated positions are better than none. The following asumptions will hold at the base:

If only one literal group is received, it is the first.
If only two literal groups are received, they are the first and second.
If only one numerical group is received, it is the position.

All literal groups must be four letters long and all numerical groups must be six numerals long. If a particular element is not observed or is unknown, then the letter Z will be put in its place. If several descriptions apply to a particular weather element, the one nearest the end of the alphabet, or the higher numeral will be coded. Check the final coded report for ambiguity or errors.

CODE SYMBOLS

The complete code used for transmitting weather observations from trail parties and temporary outposts is represented symbolically by three literal groups (each of four letters) and two numerical groups (each of six numbers):

WwDF VD_cCh aSW_fE_s TTPPEE   LLLlll

W Past weather
w Present weather
D Wind direction
F Wind velocity

V Visibility
D_c Cloud direction
C Description of cloud cover
h Terrain clearance of clouds

a Barometric tendency
S Description of surface
W_f Weather for flying
E_s Supplementary elevation or terrain description

TT Temperature
PP Pressure
EE Elevation

LLL Latitude
lll Longitude

W PAST WEATHER

A Clear skies.
B Sky completely covered but no precipitation.
C Precipitation.

(A–C: In last twelve hours.)

D Clear skies.
E Partly cloudy skies, or variable skies.
F High clouds only
G Sky completely covered with middle type clouds.
H Sky completely covered with low type clouds, but with occassional breaks.
I Sky continuously covered, base of clouds mainly over 5,000 ft.
J Sky continuously covered, base of clouds mainly between 2,000 and 5,000 ft.
K Sky continuously covered, base of clouds mainly under 2,000 ft.
L Cumulonimbus, visible within 20 miles.
M Cumulonimbus, visible beyond 20 miles.
N Drifting snow, sky visible.
O Drifting snow, sky invisible.
P Fog, sky visible.
Q Fog, sky invisible.
R Light snowfall.
S Moderate or heavy snowfall.
T Light rain, or drizzle; or light rain and snow.
U Moderate or heavy rain, or rain and snow.
V Snow flurries, blue sky occasionally visible.
W Snow flurries, no blue sky seen between flurries.
X Showers.
Y Hail in any form or amount.

(D–Y: In Preceding Six hours.)

W PRESENT WEATHER

A Clear skies.
B Partly cloudy skies.
C Sky covered with clouds.
D Rapid rise in temperature (10° F/hr.) within last hour.
E Rapid fall in temperature (10 F/hr.) within last hour.
F Frost deposits in preceding three hours.
G Glaze deposits in preceding three hours.
H Layer of clouds receding.
I Layer of clouds advancing.
J Visibility falling rapidly
K Fog in patches.
L Light continuous fog.
M Moderate or thick fog, sky visible.
N Moderate or thick fog, sky invisible.
O Light storm of drifting snow.
P Moderate or heavy storm of drifting snow, sky visible.
Q Moderate or heavy storm of drifting snow, sky invisible.
R Light snowfall.
S Moderate or heavy snowfall.
T Drizzle, or drizzle and fog.
U Light rain, or rain and snow mixed.
V Moderate or heavy rain, or rain and snow mixed.
W Intermittent flurries of snow.
X Intermittent showers of rain, or rain and snow mixed.

Y Hail, large or small, accompanied or not accompanied by other forms of precipitation.

Z

D WIND DIRECTION

When the direction from which low clouds move is unknown, the direction from which the surface wind flows will be sent.

A Calm
B Variable
C N
D NE
E E
F SE
G S
H SW
I W
J NW

When the direction of low clouds is known, it is preferable to send the direction from which the low clouds move:

K Stationary
L N
M NE
N E
O SE
P S
Q SW
R W
S NW

Direction: For 20°E variation, the magnetic compass points true North when it reads 340°.

F WIND VELOCITY

For steady winds code under the left hand column. For Gusty winds, when the minimum velocity is less than half the maximum, use the right hand column.

Force:		M.P.H.	Knots:	Description:	
A	0	0	0	Calm. Powder snow falls plumb.	
B	1	1-3	1-3	Light. Falling powder snow slightly deflected.	N
C	2	4-7	4-6	Light. Trail flags begin to flap gently.	O
D	3	8-12	7-10	Light. Light string deflected 30° from plumb.	P
E	4	13-18	11-16	Moderate. Raises loose paper. Tent begins to flap.	Q
F	5	19-24	17-21	Fresh. Light string extended nearly horizontal. Drifts of light snow shoot off in streams from obstacles.	R
G	6	25-31	22-27	Strong. Air whistles past wires. Tip of ski pole deflected one foot from plumb.	S
H	7	32-38	28-33	Strong. Dangling ski pole deflected 45°.	T

Force:		M.P.H.	Knots:	Description:*	
I	8	39-46	34-40	Gale. Small sastrugi formed. Impossible to stand erect with feet together.	U
J	9	47-54	41-47	Gale. Impossible to stand erect with feet braced.	V
K	10	55-63	48-55	Strong Gale. Large sastrugi formed.	W
L	11	64-75	56-65	Strong Gale.	X
M	12	75-	65-	Hurricane. Large chunks of windpacked snow broken loose and flying in air. Wind roar and rumble very loud.	Y

*Tentative.

V VISIBILITY

A	Between 0 and 0.1 mile	In all directions.
B	Between 0.1 and 0.5 mile	
C	Between 0.5 and 1.0 mile	
D	Between 1 and 5 miles	
E	Between 5 and 10 miles	
F	Between 10 and 20 miles	
G	Between 20 and 40 miles	
H	Between 40 and 80 miles	
I	Between 80 and 100 miles	

	Minimum:	Maximum:
K	0.5 mile	1 mile
L	0.5 mile	5 miles
M	0.5 mile	10 miles
N	0.5 mile	20 miles
O	0.5 mile	Over 20 miles
P	5 miles	10 miles
Q	5 miles	20 miles
R	5 miles	40 miles
S	5 miles	80 miles
T	5 miles	Over 80 miles
U	20 miles	40 miles
V	20 miles	80 miles
W	20 miles	Over 80 miles
X	40 miles	80 miles
Y	40 miles	Over 80 miles
Z		

D_c CLOUD DIRECTION

	Middle Clouds: (Moving from)	High Clouds:
A	O*	O
B	O	N
C	O	E
D	O	S
E	O	W
F	N	O
G	N	N
H	N	E
I	N	S
J	N	W

*No clouds, or clouds apparently stationary.

	Middle Clouds: (Moving from)	High Clouds:
K	E	O
L	E	N
M	E	E
N	E	S
O	E	W
P	S	O
Q	S	N
R	S	E
S	S	S
T	S	W

	Middle Clouds: (Moving from)	High Clouds:
U	W	O
V	W	N
W	W	E
X	W	S
Y	W	W
Z	No observation, or sky obscured.	

C

DESCRIPTION OF CLOUD COVER

Note: T stands for tenths of sky covered by cloud.

	Low Clouds:	Middle Clouds:	High Clouds:	
A	None	No middle or high clouds.		
B	Patches or stratus, 1T-3T	No middle or high clouds.		
C	Scattered cumulus, 1T-3T	No middle or high clouds.		
D	Congested cloud, 4T-9T	No middle or high clouds.		
E	Overcast, 10T	No middle or high clouds.		
F	No low clouds, or low clouds covering less than 3T.	None	Scattered, 1T-3T	F
G	No low clouds, or low clouds covering less than 3T.	None	Closely packed, or layer, 1T-3T	G
H	No low clouds, or low clouds covering less than 3T.	None	Closely packed, or layer, 4T-10T	H
I	No low clouds, or low clouds covering less than 3T.	Scattered, or layer, any amount.	Scattered, 1T-3T	I
J	No low clouds, or low clouds covering less than 3T.	Scattered, or layer, any amount.	Closely packed, or layer, 1T-3T	J
K	No low clouds, or low clouds covering less than 3T.	Scattered, or layer, any amount.	Closely packed, or layer, 4T-10T	K
L	No low clouds, or low clouds covering less than 3T.	Scattered, 1T-3T	No high clouds, or high clouds occupying less than 1T.	L
M	No low clouds, or low clouds covering less than 3T.	Scattered, 4T-6T	No high clouds, or high clouds occupying less than 1T.	M
N	No low clouds, or low clouds covering less than 3T.	Sheet, or layer, 1T-3T	No high clouds, or high clouds occupying less than 1T.	N
O	No low clouds, or low clouds covering less than 3T.	Sheet, or layer, 4T-6T	No high clouds, or high clouds occupying less than 1T.	O
P	No low clouds, or low clouds covering less than 3T.	Thin layer, 7T-10T	No high clouds, or high clouds occupying less than 1T.	P
Q	No low clouds, or low clouds covering less than 3T.	Thick layer, 7T-10T	No high clouds, or high clouds occupying less than 1T.	Q

	Low Clouds:	Middle Clouds:	High Clouds:	
R	Low clouds covering more than 3T.	None	Scattered	R
S		None	Closely packed, or layer	S
T		Scattered	None	T
U		Scattered	Scattered	U
V		Scattered	Closely packed, or layer	V
W		Layer, or closely packed	None	W
X		Layer, or closely packed	Scattered, or layer	X
Y	Cumulonimbus	Cumulonimbus	Cumulonimbus	Y
Z	No observation, sky obscured, in cloud, (or in tent).			

h TERRAIN CLEARANCE of lowest cloud occupying more than 1/10th of sky.

A No clouds.

	Height of cloud base:	Direction from observer to cloud:
B	Under 1,000 feet	Overhead*
C		N *
D		E *
E		S *
F		W *
G	Between 1,000 and 2,000 feet	Overhead
H		N
I		E
J		S
K		W
L	Between 2,000 and 5,000 feet	Overhead
M		N
N		E
O		S
P		W
Q	Over 5,000 feet	Overhead
R		N
S		E
T		S
U		W

*If distant fog is reported and there are no clouds in the sky, then code letters B through F may be used to indicate the direction where the fog bank exists.

a BAROMETRIC TENDENCY

A Steady
B Rising rapidly, more than 1/2mb (.02")
C Falling rapidly, more than 1/2mb (.02")
} In preceding hour.

D	Steady	In preceding six hours.
E	Rising slowly, less than 3-1/2mb(.1")	
F	Rising rapidly, more than 3-1/2mb(.1")	
G	Falling slowly, less than 3-1/2mb(.1")	
H	Falling rapidly, more than 3-1/2mb(.1")	
I	Steady	In preceding twelve hours.
J	Rising slowly, less than 7mb(.2")	
K	Rising rapidly, more than 7mb(.2")	
L	Falling slowly, less than 7mb(.2")	
M	Falling rapidly, more than 7mb(.2")	

S DESCRIPTION OF SURFACE
(or subsurface reached by boot)

A	Bare glacier ice	
B	Extensive rock outcrop	
C	Rock beach	
D	Powder snow, dry, 1-6 inches deep	
E	Powder snow, dry, 6-12 inches deep	
F	Powder snow, dry, over 12 inches deep	
G	Sticky snow, damp, 1-6 inches deep	
H	Sticky snow, damp, over 6 inches deep	
I	Slushy snow, wet, 1-6 inches deep	
J	Slushy snow, wet, over 6 inches deep	
K	Crusty, or windpacked snow, breakable by boots	
L	Crusty, or windpacked snow, unbreakable by boots	
M	Sastrugi, windswept, under 6 inches high	
N	Sastrugi, with snow cover, under 6 inches high	
O	Sastrugi, 6-10 inches high, easily breakable by boots	
P	Brash ice, irregularities under 6 inches high	
Q	Sastrugi, over 6 inches high, unbreakable by boots	Unsuitable for takeoff and landing
R	Sastrugi, over 10 inches high	
S	High drifts	
T	Highly irregular brash ice	
U	Crevasses, or open leads	
V	Irregular terrain, or icebergs prevalent	
W	Exposed rocks	

W_f WEATHER FOR FLYING

A Excellent: No clouds.
B Excellent: Less than 0.1 cloud visible

C Suitable: Edge of clouds retreating from observer and exposing clear sky.
D Suitable: Scattered cirrus, not increasing.
E Suitable: Scattered middle clouds, not increasing.
F Suitable: Scattered low type clouds apparently of diurnal duration, not likely to cover over 0.3 of sky.

G Unfavorable: Increasing visibility and ceilings, improvement likely, but recession possible.
H Unfavorable: Rapidly advancing upper clouds.
I Unfavorable: Bank of fog in distance, apparently stationary but development possible.

J Hazardous: Horizon obscured
K Hazardous: Strong winds, turbulence, or gusts
L Hazardous: Drifting snow
M Hazardous: Fog
N Hazardous: Precipitation
O Hazardous: Advancing cloud cover
P Hazardous: Reduced visibility
Q Hazardous: Low ceilings

E_S SUPPLEMENTARY ELEVATION OR TERRAIN DESCRIPTION

When known with accuracy the tens digit of the elevation in feet will be sent:

A	0	F	5
B	1	G	6
C	2	H	7
D	3	I	8
E	4	J	9

When the tens digit of the elevation is not sent, the following terrain description will be sent:

K In shallow valley or trough
L In valley or trough surrounded by mountains
M In amphitheater or cirque
N On flat snow covered land
O On bare glacier ice
P On or within 100 feet of rock outcrop or beach
Q On side of mountain or open slope
R On sloping glacier
S On peak, ridge, crest, or knoll
T Beyond one mile from sea and open water visible
U Within one mile from sea and no open water visible
V On shelf ice
W On sea ice
X Within one mile from sea and open water visible.

TEMPERATURE **TT**

PRESSURE **PP**

ELEVATION **EE**

LATITUDE **LLL**

LONGITUDE **lll**

TT <u>Temperature</u>: The tens and units digits of the temperature in degrees Fahrenheit will be sent. When temperature is negative, 100 will be algebraically added and the tens and units digits of the sum sent.

PP <u>Pressure</u>: The tens and units digits of the pressure in millibars will be sent.

EE <u>Elevation</u>: When under 1,000 feet, the hundreds and tens digits will be sent. When over 1,000 feet, the thousands and hundreds digits will be sent. When known with accuracy, the tens digit of elevation when over 1,000 feet may be sent under the supplementary elevation, E_s.

LLL Latitude: The first L represents the units digit of the degrees. The second L represents the tens digit of minutes. The third L represents the units digit of the minutes.

lll Longitude: The first l represents the units digit of the degrees. The second l represents the tens digit of the minutes. The third l represents the units digit of the minutes.

EXAMPLES

On plateau near Mobile Oil Bay at 68°31'S-65°53'W. Continuing very heavy storm of drifting snow with steady ESE winds at 50 knots.

OQFK 831553.

In unknown territory south of Mt. Tricorn at 77°03'S-58°45'W, crossing a small peninsula at elevation 800 feet. Camping on flat land covered with dry powder snow about 5" deep with low sastrugi underneath. Temperature has fallen rapidly to minus 7 F as a steady 10 mph surface wind blew in from the south exposing clear skies and unlimited visibility to the south. During the past six hours the sky was mostly covered with very low stratus cloud. The following clouds remain in the sky but are gradually receding: stratus, 4T, moving from the south, about 1,500 feet above the ocean; altocumulus, 2T, moving from the SE; cirrus, 2T, apparently stationary. Visibility to the North is about 15 miles. Barometer is now 974 mb. It was 970 mb about 12 hours ago.

KHSD WKUH JNCN 937480 703845

Examining rocks on the Northern tip of Alexander Island at 68°59'S-70°26'W, elevation 15 feet. Intermittent snow flurries fall from broken cumulus clouds at 2,000 feet moving from NNE under a clear sky. The past weather was light snowfall and a low ceiling of less than 1,000 feet. Very gusty 20 mph surface winds are blowing from the ENE. Visibility varies from 1/2 to 20 miles. Barometer reads 28.83 inches and has fallen 0.3" during the preceding twelve hours. Temperature is 24 F.

RWLR NADL 247602 859026

PRESSURE CONVERSION TABLE

Inches:	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
				Millibars:						
20	677	681	684.	687	691	694	698	701.	704	707
21	711	714	718	721	723	728	731	735	738	742
22	745.	748	752	755	759	762	765	769	772	775
23	779	782	786	789.	792	796	799	803	806.	809
24	813	816	819	823	826	830	833.	836	840	843
25	847	850.	853	857	860	864	867	870	874	877
26	880	884	887	891	894.	897	901	904	908	911
27	914	918	921	924	928	931	935	938.	941	945
28	948	952	955.	958	962	965	969	972	975	979
29	982.	985	989	992	996	999.	002	006	009	013
30	1016	019	023	026	029	033	036	040	043.	046
31	1050	053	057	060.	063	067	070	073	077	080