NOAA TECHNICAL MEMORANDUM NWS AR-23

A FORECAST PROCEDURE FOR COASTAL FLOODS IN ALASKA

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UNITED STATES DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Richard A. Frank, Administrator

National Weather Service
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A FORECAST PROCEDURE FOR COASTAL FLOODS IN ALASKA

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ABSTRACT. Coastal floods are caused by a combination of wind-driven transport of sea water, tide levels and atmospheric pressure. Wind-driven transport of sea water is the most important factor. Tide levels are important only when tidal variation is large. Atmospheric pressure is a minor factor in Alaska coastal floods. By reviewing recent Alaska coastal floods, an empirical forecast procedure has been constructed. The factors in this procedure are: wind direction and speed; length and duration of the fetch of the wind; ice cover over the fetch; tidal variation and time of maximum monthly tides; boundary-layer stability in the fetch; lowest sea-level pressure over the vulnerable area during the storm; time of frontal passage; time of daily high tides. The procedure will provide an estimate of the severity of a coastal flood and a forecast of the time of high water.

INTRODUCTION TO THE PROBLEM

Coastal floods occur when the sea is driven above high tide level on to normally dry land. Coastal floods are caused by a combination of factors: wind-driven transport of sea water, tide levels and atmospheric pressure.

The high water level that exists during coastal floods is not of primary concern. What makes coastal floods one of the leading causes of property damage in Alaska is the powerful and destructive surf that occurs in conjunction with the high water.

Many Alaskan coastal communities, particularly on the Bering and Arctic coasts, are situated on low-lying land. Especially vulnerable to coastal floods are villages built on sand spits, barrier islands and river deltas. Such land has the advantage of being level and close to the sea. It has the disadvantages of (1) topographic instability -- that is, it can easily be modified by erosion -- and (2) low elevation, which means that as water level rises, flood and surf damage increase very rapidly.

Erosion and change are part of the life cycle of such landforms. Normal wave action and currents cause gradual and continous change in the shape and location of sand spits, barrier islands and river deltas. In a sense, any structure placed on such land has a limited life expectancy.

During major coastal floods, the rate of topographic change is increased enormously. A sand spit may undergo more change during one day in a major coastal flood than it would normally undergo in several years.

Damage during large coastal floods in Alaska is not limited to the effects of high water and surf. If sea ice is present, as it was during the 1963 Barrow storm, the moving blocks of ice, carried by high water and driven by waves and wind, can have considerable destructive effect on structures. In addition, Alaskan coastal floods are normally accompanied by high wind, rough seas, extensive precipitation and poor aviation weather. All of these factors contribute to making these storms a subject of vital interest to weather forecasters.

CAUSES OF COASTAL FLOODS

Coastal floods in Alaska are caused by a combination of wind-driven transport of sea water, tide levels and atmospheric pressure.

1. Wind-driven transport of sea water is the most important factor of the three. For example, during the 1974 Nome flood, the total static water level rise was about 12 feet. Tide levels and atmospheric pressure accounted for about 2 feet of this; the other 10 feet were due to wind-driven transport of the sea.

There is friction at the air-sea interface. Thus, wind blowing over water pushes water along the surface. Due to the Coriolis force, moving objects in the Northern Hemisphere are pushed to the right of their direction of motion. Thus, surface ocean currents driven by the wind are at about a 20 degree angle to the right of the wind (Williams, 1962).

Each successive layer of the ocean acts on the next lower layer as the wind acts on the surface of the sea. That is, the direction of wind-driven currents turns steadily to the right with increasing depth. This effect is commonly known as the Ekman Spiral. The Ekman Spiral was developed to explain the movement of icebergs in the Arctic noted by Fridtjof Nansen during the historic voyage of the *Fram* in 1893-96. The movement of icebergs is a net result of surface and subsurface ocean currents. Nansen observed icebergs in the Arctic moving in a direction about 30 degrees to the right of the wind (Neumann and Pierson, 1966).

The result is that, in the deep ocean, net mass transport of water is at a 90 degree angle to the right of the wind. In the shallow depths of the Bering Sea and Alaska's Arctic coastal waters, one may assume a net transport of roughly 45 degrees to the right of the wind.

What is important is not the exact direction of water transport, but that wind flow need not be directly onshore to cause shoreward movement of sea water. The most favorable wind direction for flooding is west at Barrow (where the shoreline is SW-NE), southeast at Nome (where the shoreline is ESE-WNW), and southwest at Unalakleet (where the shoreline is N-S).

The amount of wind-driven transport increases as the wind speed and duration of wind increase. So do the wave heights and surf. Thus, potential coastal flood damage increases with increasing wind speed and duration of wind.

Wind-driven water transport and seas also increase as the length of the fetch of the wind increases. A factor to consider here is the extent of ice cover, which tends to negate the effects of fetch by reducing friction at the air-sea interface. This, in turn, reduces the amount of wind-driven transport of water. Sea ice also dampens water wave action by inertia. In summary, its effect is the same as reducing the fetch.

Friction at the air-sea interface increases as the air becomes colder than the sea surface. When the air is colder than the sea surface, the first few meters of air develop an unstable vertical temperature profile, which is associated with convective overturning of the air. This overturning increases the transfer of momentum and energy from the wind to the sea. Thus, as this boundary-layer instability increases, wind-driven water transport and wave heights increase. When the air is warmer than the sea, the low-level temperature profile is stable, and there is less transfer of momentum from the wind to the sea.

2. Tide levels can be computed for many coastal locations in Alaska using the Tide Tables, published annually by the National Ocean Survey. The typical ranges between high and low tides vary considerably, as can be seen in figure 1. Tidal variation is greatest in V-shaped bays and inlets, such as Cook Inlet and Bristol Bay. In these locations, tides are a major contributor to water levels during coastal flood situations. At locations where tidal variation is small, as on the Arctic coast, wind, ice cover and sea-level pressure are the only major contributors to water levels.

During the 29-1/2 day lunar month, the difference between high and low tides reaches a minimum when the moon is on the opposite side of the earth than the sun. The difference reaches a maximum, and monthly high tides occur, when the moon is directly between the sun and the earth. In this situation, the gravity of the sun and the gravity of the moon work together to produce maximum tides on earth.

In locations where tidal variation is large, such as in eastern Bristol Bay, the occurrence of maximum monthly tides in a coastal flood situation can increase the peak water level by several feet, and thus considerably increase the severity of the flood.

Use of the Tide Tables can help one to estimate the timing of high water in a coastal flood situation. In locations with large tidal variation, the highest water level in a coastal flood will usually occur at the time of high tide. This is useful information for coastal flood warnings.

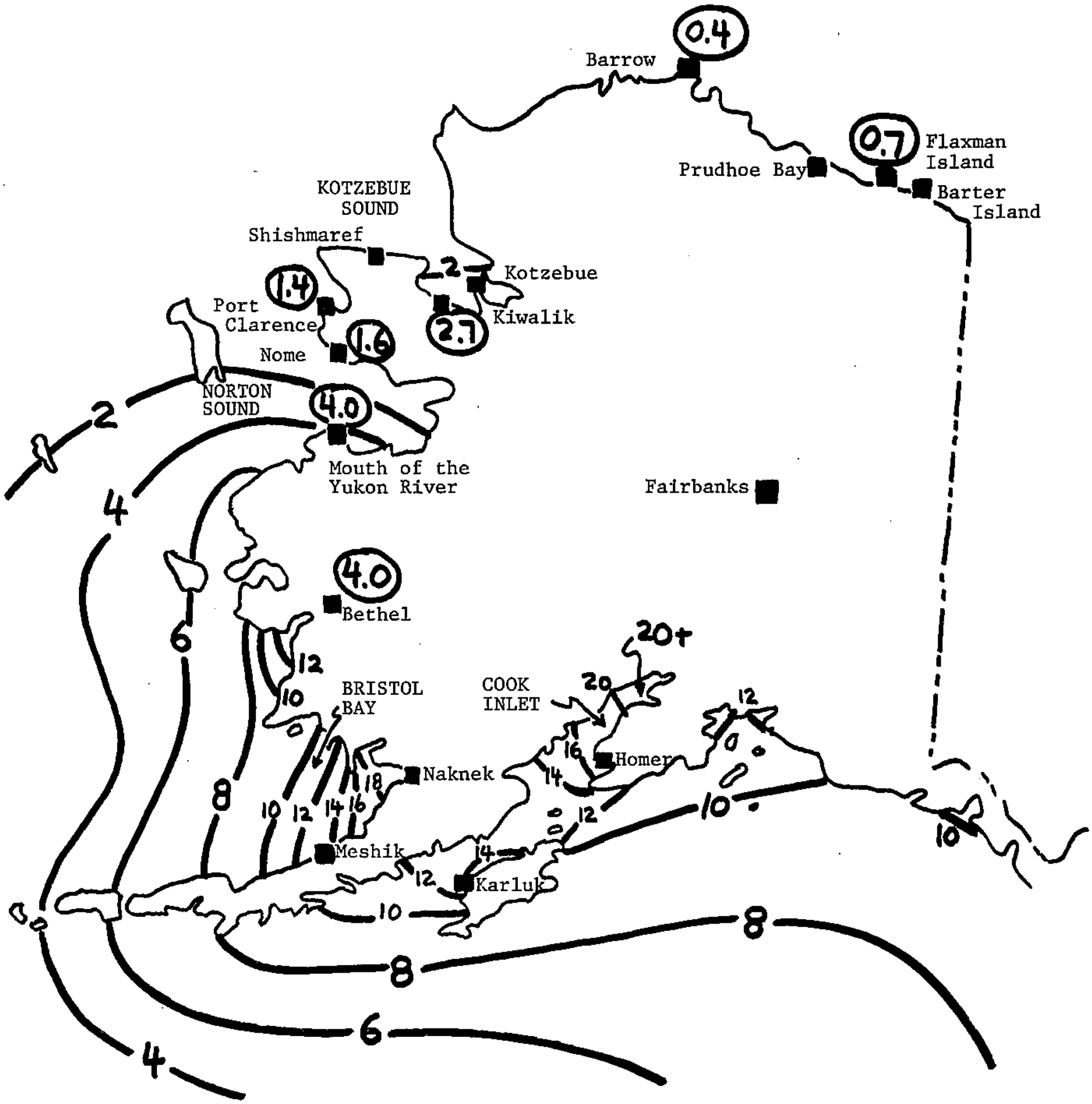


Figure 1. Corange lines -- showing mean maximum semi-monthly tide ranges in feet. Numbers in circles are diurnal tide ranges in feet for selected stations. (Adapted from U. S. Navy, 1961 and National Ocean Survey, 1977.)

3. Atmospheric pressure has an effect on water levels. As atmospheric pressure is lowered, water levels can rise. We can use the following common equivalents of pressure to derive a relationship:

$$33.87 \text{ mb} = 1'' \text{ of mercury}$$
$$13.6'' \text{ water} = 1'' \text{ of mercury}$$

thus:

$$10 \text{ mb} \cong 4.0'' \text{ sea water}$$

Thus, for every 10 mb that atmospheric pressure is below normal, one can add 4" to sea level. Figure 2 shows average atmospheric pressure at sea level for Alaska for September, October and November, the months in which most coastal floods occur in Alaska.

GENERAL APPROACH TO THE FORECAST PROCEDURE

In studying Alaska coastal floods, there are only a limited number of storms to examine. Each storm is different, though there are similarities in storms that affect the same geographic area. Also, detailed tide and water level data for Alaskan coastal floods is very limited or non-existent, particularly for the Northwest coastal waters and for the Arctic.

Thus, with the small number of cases available, procedures based on statistics are not feasible. Instead, each storm in the recent past will be examined. Following the examination of these individual cases, some generalizations will be made. Based on these generalizations, a forecast procedure will be recommended.

ALASKA COASTAL FLOODS SINCE 1960

Unalakleet Storm, Oct. 3, 1960. *See figure 3.* A storm developed off the eastern Kamchatka coast and moved northeast along the Siberian coast. Landfall was near Port Clarence on Oct. 3. The storm weakened northeast of Kotzebue on Oct. 3. Peak winds were 50 to 75 knots. There was an ice-free fetch of about 1000 miles over the Bering Sea for about 36 hours. Lowest sea-level pressure over Unalakleet during the storm was about 975 mb. Combined seas in Norton Sound were estimated at 20 feet at the height of the storm. Major flooding and about $100,000 damage occurred at Unalakleet; a 55 year resident said it was the worst flood in memory. Wave action was described as violent. Minor damage occurred at Nome.

Barrow Storm, Oct. 3, 1963. A storm moved northeast out of Siberia across the Arctic Ocean, then turned east on a track about 400 miles north of Barrow. The central pressure of the low was estimated at 975 mb at 1800 GMT Oct. 3. There were strong post-frontal westerly winds at Barrow (45 to 65 knots). The fetch was essentially ice-free, and extended 800 to 1000 miles to the west. The sea was driven about 400 feet inland at Barrow. Large chunks of ice, up to 12 feet thick, were carried about 15 feet inland. Several houses were lifted by flood waters and destroyed. This was the most severe coastal flood at Barrow in recent years.

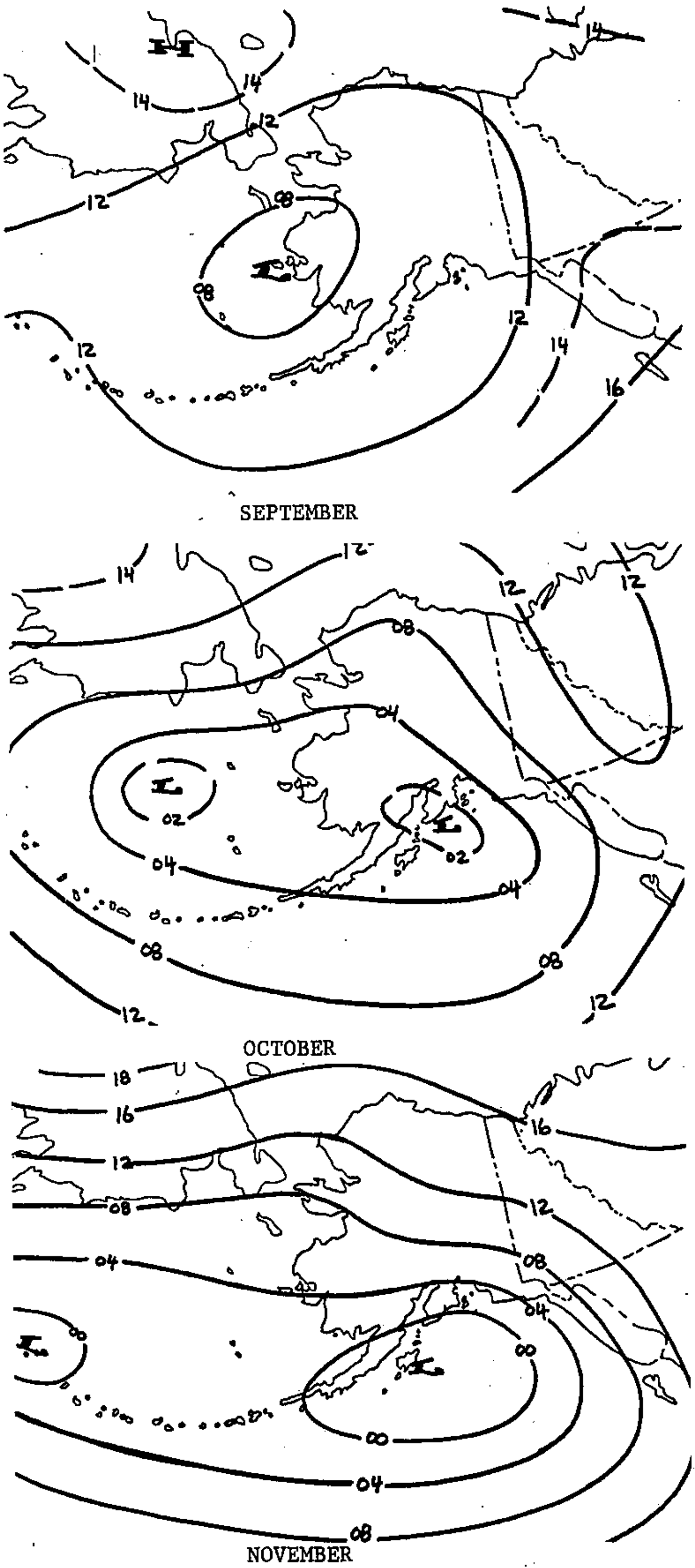


Figure 2. Mean sea-level pressure maps for Alaska during the fall and early winter. (Adapted from Crutcher and Meserve, 1970.)

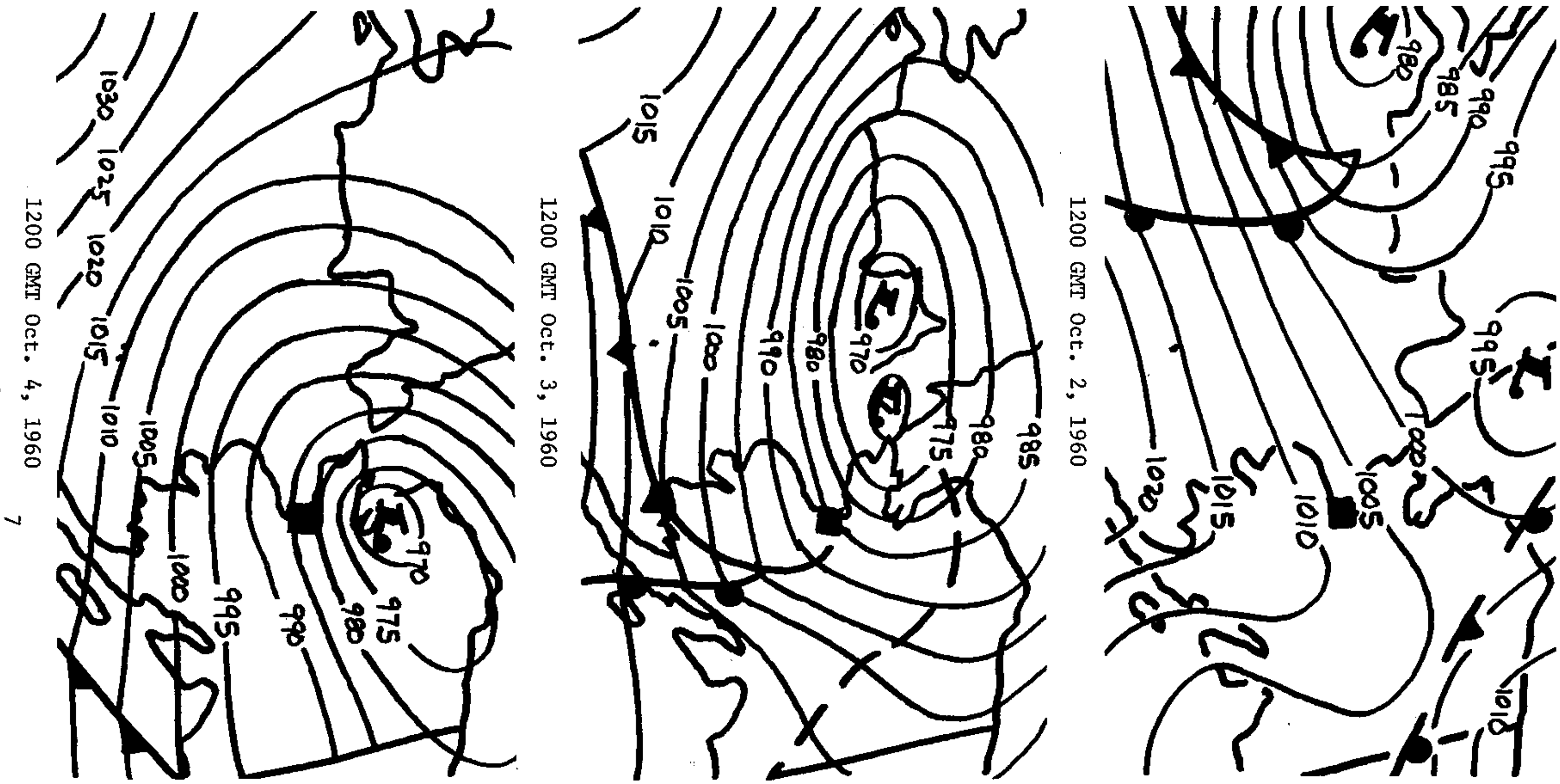


Figure 3. Sea-level pressure analyses for the Unalakleet coastal flood of Oct. 3, 1960. Isobar interval is 5 mb. Unalakleet is marked with a square (■).

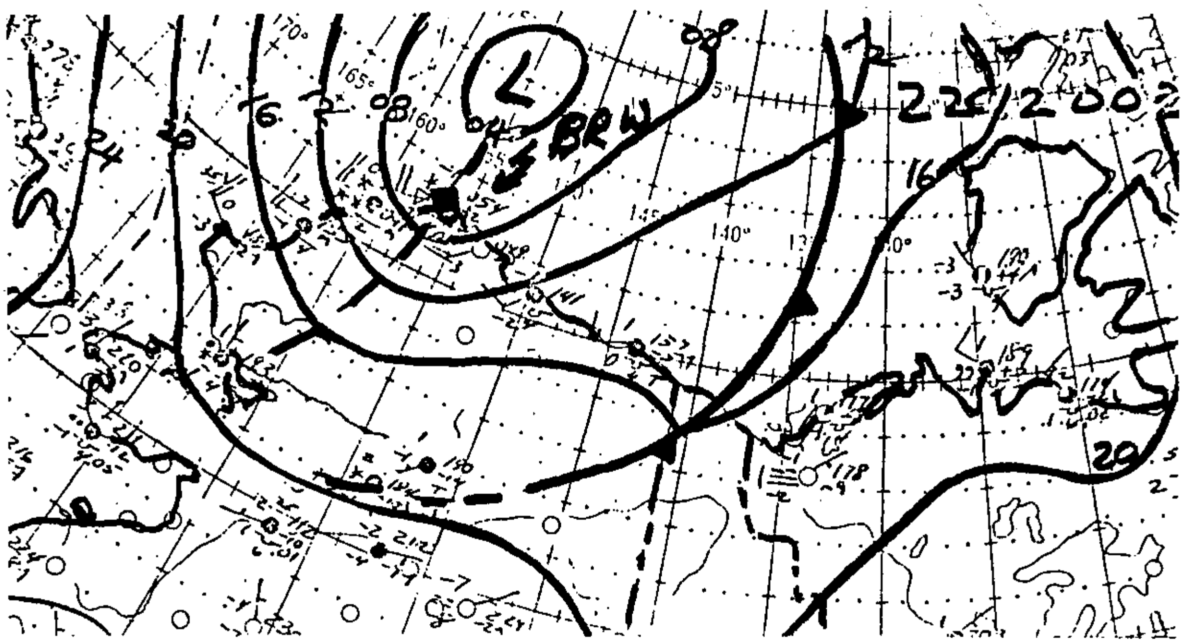
Barrow Storm, Nov. 16, 1966. After moving northeast over the Chukotsk Peninsula, a storm turned eastward well offshore from Barrow. Peak winds were post-frontal westerlies of 50 to 70 knots. There was minor flood damage and moderate wind damage.

Barrow Storm, Sept. 22, 1968. *See figure 4.* Moving eastward on a track about 200 miles north of Barrow, a storm caused westerly post-frontal winds of 30 to 45 knots. The ice edge was unusually far to the north of Barrow -- about 160 miles -- giving a total length of ice-free fetch of about 250 miles to the northwest of Barrow. The lowest sea-level pressure in Barrow during the storm was about 1004 mb. Seas just offshore were as much as 15 feet. Damage caused by the storm was minor: the road that runs from the village of Barrow to Point Barrow was washed out.

Shishmaref Storm, Sept. 10, 1973. A storm in the Chukchi Sea washed out about 30 feet of beach and caused minor flood damage at Shishmaref. Peak winds were 45 knots or more. The storm occurred about 2 days before maximum monthly tides.

Shishmaref Storm, Nov. 10, 1973. *See figure 5.* A rapidly moving Bering Sea storm moved northeast just off the Siberian coast as a second center moved into the Chukchi Sea out of Siberia. Post-frontal northwest winds were 40 to 70 knots. The southerly fetch ahead of the front was about 500 miles. The northwest fetch behind the front was about 250 miles in Norton Sound and over 500 miles in the Chukchi Sea. The duration in each case was 12 to 24 hours. Norton Sound was ice-free. Most of the Chukchi Sea, including Kotzebue Sound, was ice-covered. Maximum monthly tides occurred at the time of the storm. Lowest sea-level pressure over the western Seward Peninsula was about 978 mb. The water rose 6 to 8 feet above fast ice at Kotzebue. There were seas up to 15 feet in Norton Sound and in Bering Strait. There was minor flood damage in Norton Sound and moderate damage in Kotzebue Sound, principally at Shishmaref.

The Great Bering Sea Storm of Nov. 12, 1974. *See figure 6.* An intense storm moved north-northeast from the central Aleutians up through Bering Strait. Winds of 50 to 75 knots occurred within 12 hours of frontal passage. The southerly fetch in the Bering was about 1000 miles long, and persisted for about 36 hours. Aside from some new ice in eastern Norton Sound, the Bering was ice-free. Kotzebue Sound and most of the Chukchi Sea were ice-covered. Maximum monthly tides occurred at the time of the storm. The lowest sea-level pressure at Nome during the storm was about 970 mb. Rises in water level ranged from 12 feet at Nome to 6 feet at Kotzebue and 5 feet at Naknek. The rise in water level at Nome was the greatest on record. Combined seas in the Bering were as much as 20 feet. Moderate to major flood damage occurred all the way from Bristol Bay to Kotzebue Sound. As far north as Barrow, the ice was lifted a foot or two by rising water. The most severe damage was at Nome, where an estimated $12 million of property damage was sustained. The storm was the most severe in the recorded history of Nome, which goes back to 1898. The area was declared a Federal disaster area by President Ford. Floating blocks of sea ice aggravated the flood damage to communities in eastern Norton Sound.



1200 GMT Sept. 22, 1968

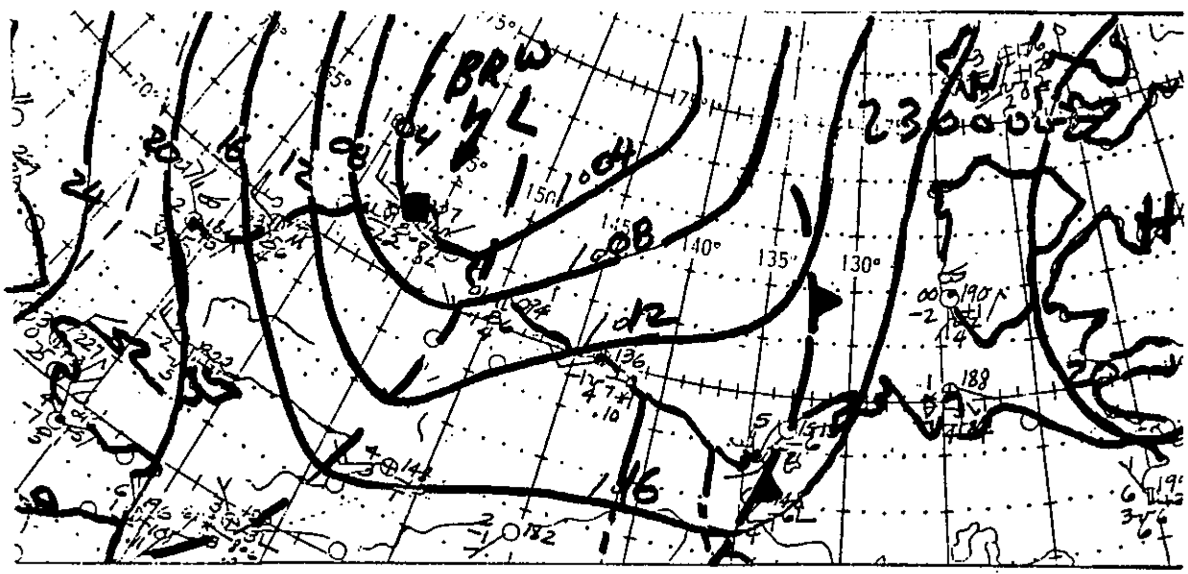


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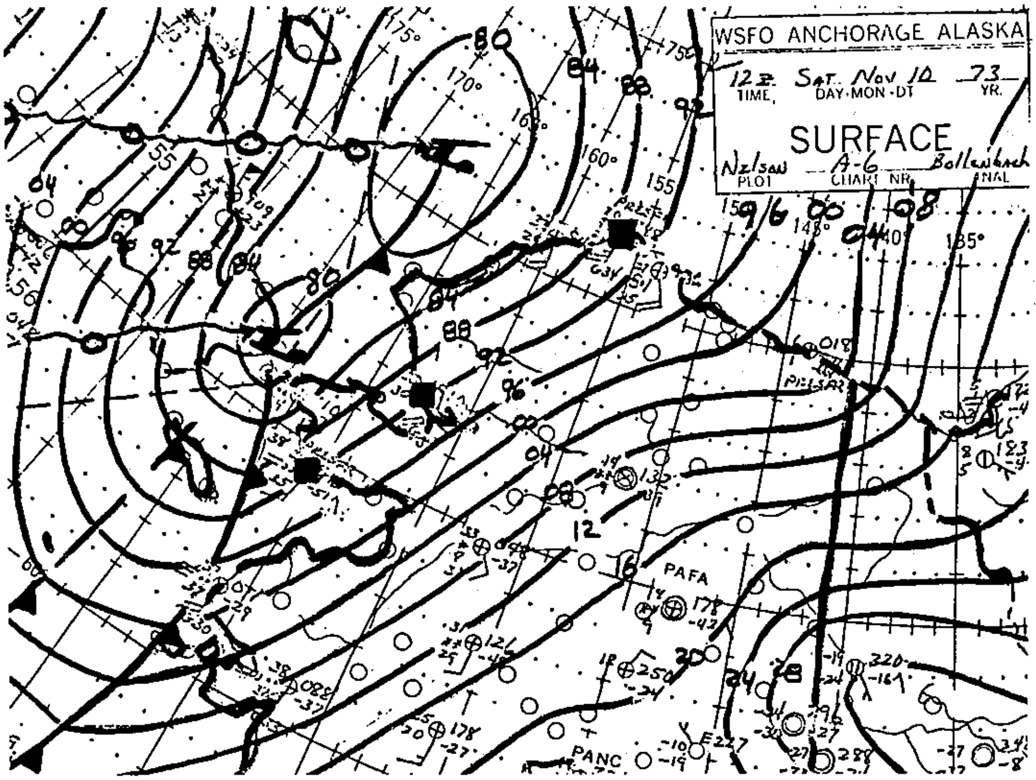
Figure 4. Sea-level pressure analyses for the minor coastal flood in Barrow on Sept. 22, 1968. Barrow is marked with a square (■).



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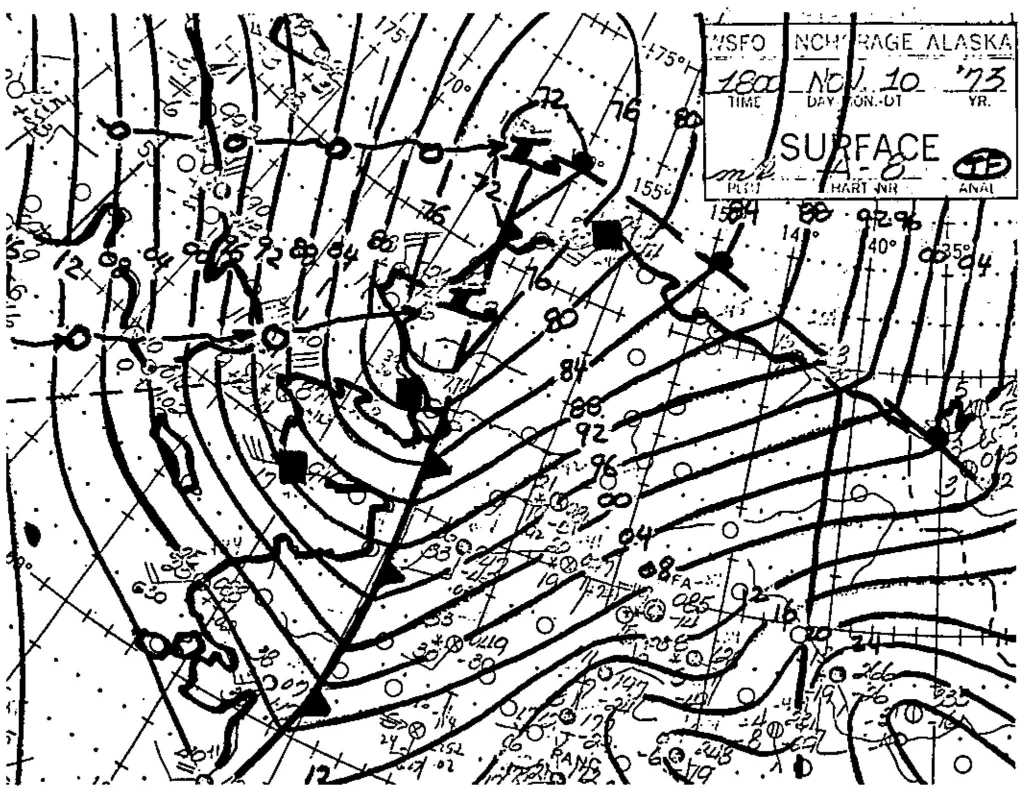
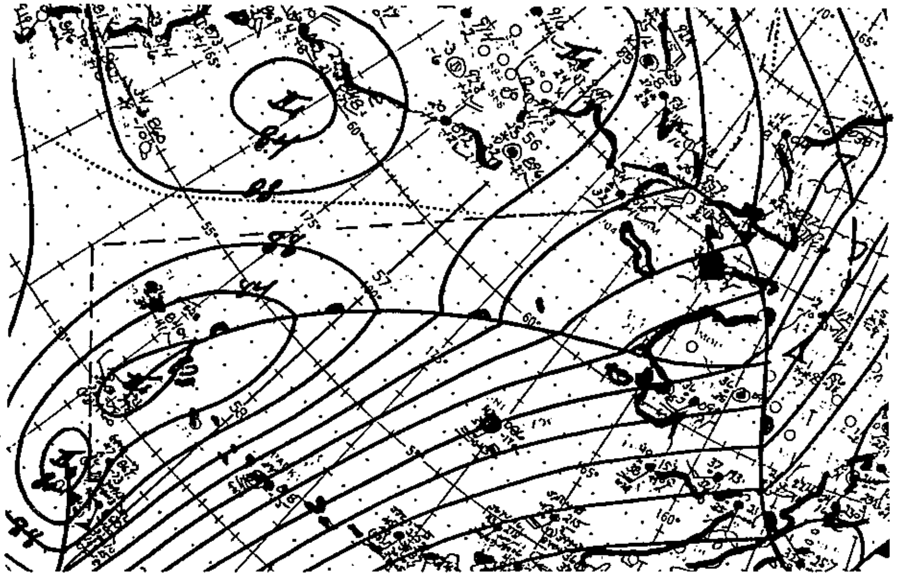
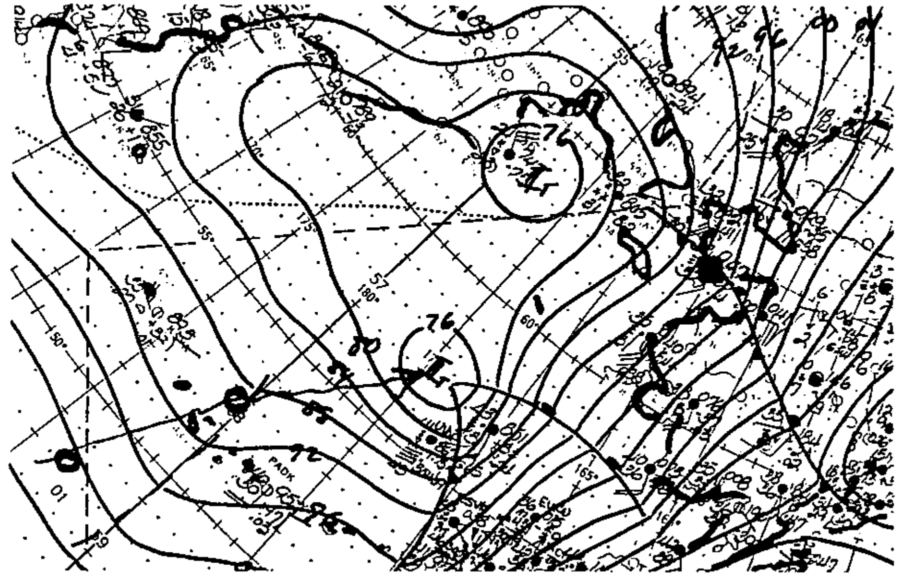


1800 GMT Nov. 10, 1973

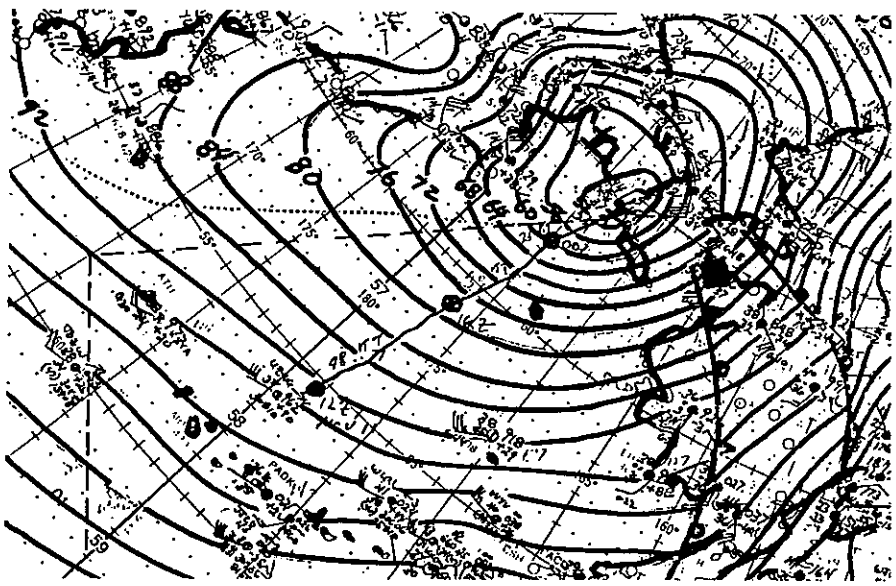
<u>Figure 5.</u> Sea-level pressure analyses for the coastal flood of Nov. 10, 1973 in Norton Sound and Kotzebue Sound. Nome, Kotzebue and Barrow are marked with a square (■).



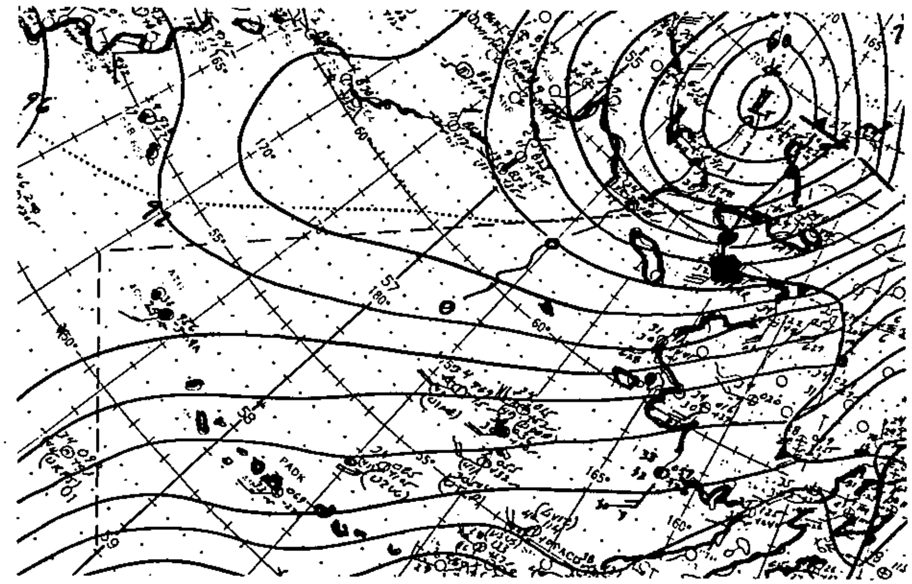
0600 GMT Nov. 11, 1974



1800 GMT Nov. 11, 1974



0600 GMT Nov. 12, 1974



1800 GMT Nov. 12, 1974

Figure 6. Sea-level pressure analyses for the Great Bering Sea Storm and coastal flood of Nov. 12, 1974. Nome is marked with a square (■).

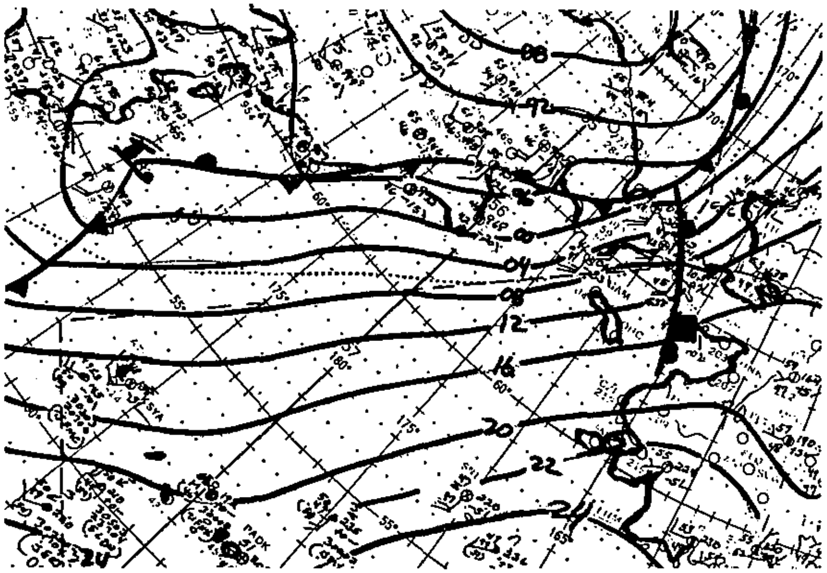
Western Seward Peninsula Flood, Aug. 25, 1975. *See figure 7.* The remains of Tropical Storm "Rita" moved northeast along the eastern Kamchatka coast and strengthened in the central Bering. The storm crossed the Chukotsk Peninsula and moved into the Chukchi Sea. Peak winds were 35 to 50 knots. The southwesterly fetch over the Bering was about 1000 miles long and persisted for about 30 hours. The Bering and southern Chukchi Seas were ice-free. The Arctic coast from near Wainwright on east was iced in. The storm occurred near the time of minimum monthly tides. Lowest sea-level pressure over the western Seward Peninsula during the storm was 988 mb. Wave heights in the Bering and Chukchi Seas were up to 15 feet. The 1975 Prudhoe Bay sealift fleet was stopped for several days by the storm about halfway from Point Hope to Barrow. One barge in the fleet went aground in the strong westerly winds that followed the frontal passage. Minor flooding occurred at Teller, near Port Clarence.

Meshik Storm, Oct. 27-28, 1976. *See figure 8.* A low pressure center moved southeast from Nunivak Island to Kodiak. Moderate northwesterly flow of cold, unstable air brought heavy surf into the village of Meshik, situated on low-lying land on the east shore of Port Heiden. Peak winds were 30 to 45 knots over a 300 mile fetch that was ice-free. The duration of the northwesterly fetch was about 36 hours. Maximum monthly tides occurred Oct. 26-27, about a day before the storm. The lowest sea-level pressure at Meshik during the storm was about 990 mb. Moderate damage was sustained in Meshik.

Seward Peninsula Storm, Sept. 13, 1977. *See figure 9.* The remains of Typhoon "Babe" moved northeast along the eastern Kamchatka coast and then strengthened in the northwest Bering Sea. Peak winds over the eastern Bering were 35 to 55 knots. A southerly fetch of about 800 miles persisted over the Bering for about 30 hours. The Bering and Chukchi Seas were free of ice. Maximum monthly tides occurred about 4 days after the storm. The lowest sea-level pressure on the Seward Peninsula during the storm was about 997 mb. There was minor wind damage with the storm, and the runway was flooded at Golovin, about 60 miles east of Nome.

Karluk Storm, Jan. 8, 1978. *See figures 10 and 11.* Strong low pressure moved northwest from the southern Gulf of Alaska to Kodiak Island. By the early morning hours of Jan. 8, the occluded front associated with the low was approaching Kodiak Island from the southeast. Northerly gales over Shelikof Strait preceded the front. As one can see from figure 11, a north wind is directly onshore at Karluk. The wind switched to light southeasterly after the front moved over the area. Peak winds were 35 to 50 knots over an ice-free fetch of 150 miles that persisted for about 24 hours. Maximum monthly tides occurred on the day after the storm. The lowest sea-level pressure at Karluk during the storm was approximately 974 mb. Heavy surf caused considerable damage and shore erosion at Karluk.

Homer Storm, Feb. 5-7, 1978. *See figures 12 and 13.* Deep low pressure moved north through the Gulf of Alaska toward Seward on the evening of Feb. 5. A strong pressure gradient and strong west winds persisted over the Alaska Range and western Cook Inlet. The gradient and the wind decreased some on Feb. 6, but increased again on Feb. 7.



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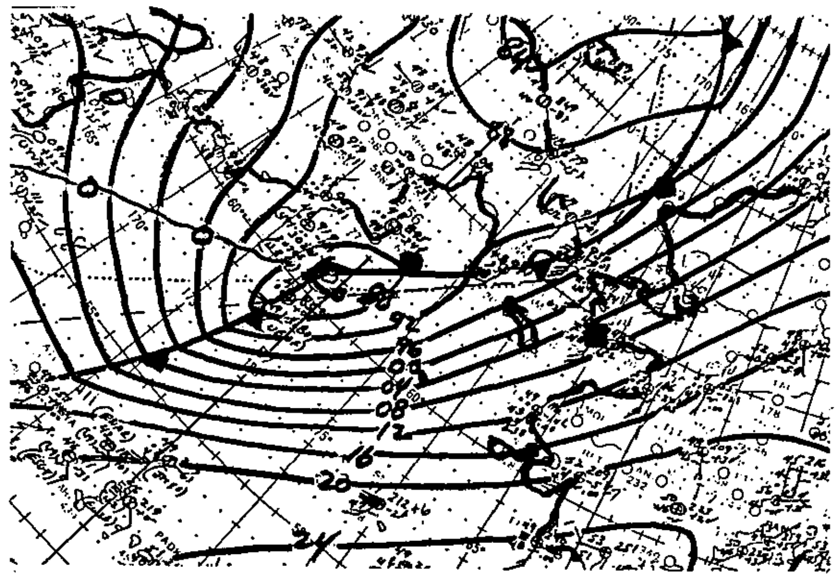

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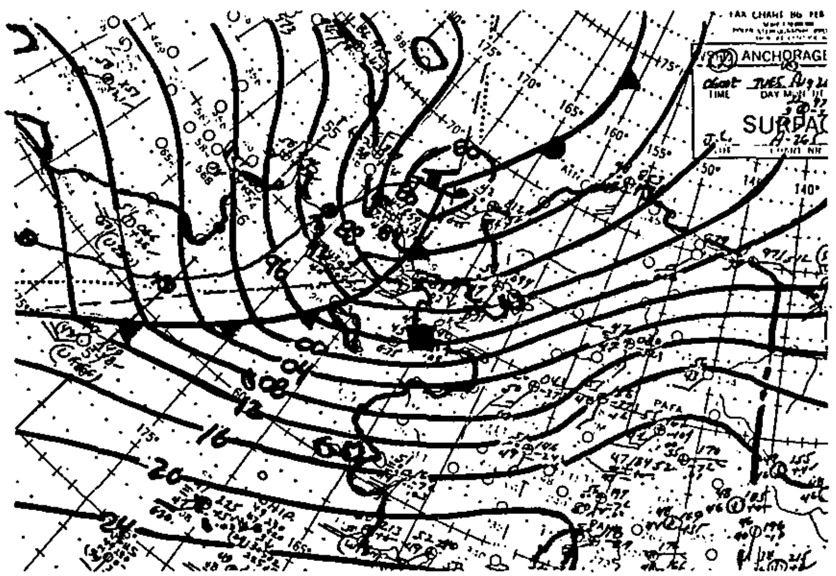

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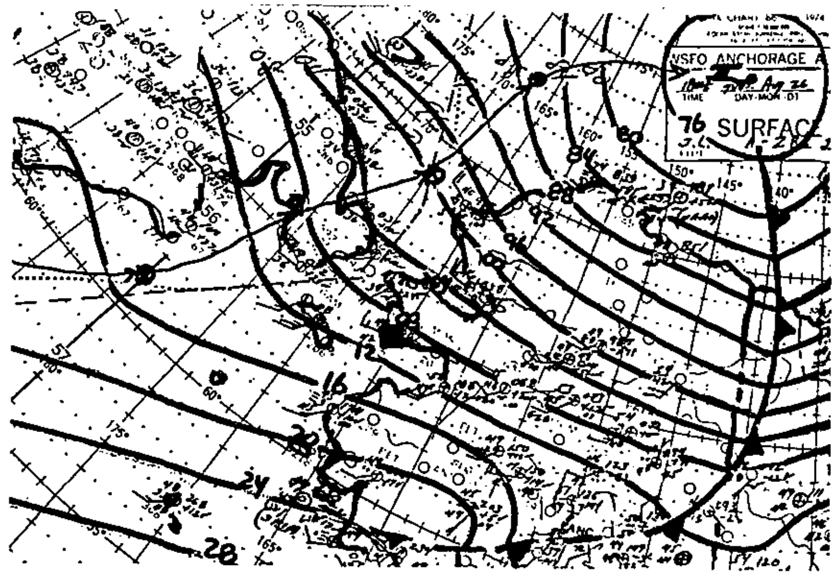
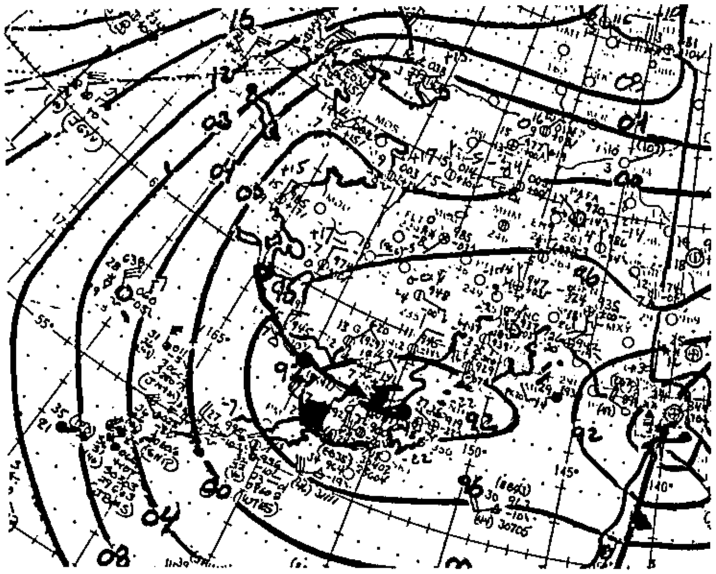


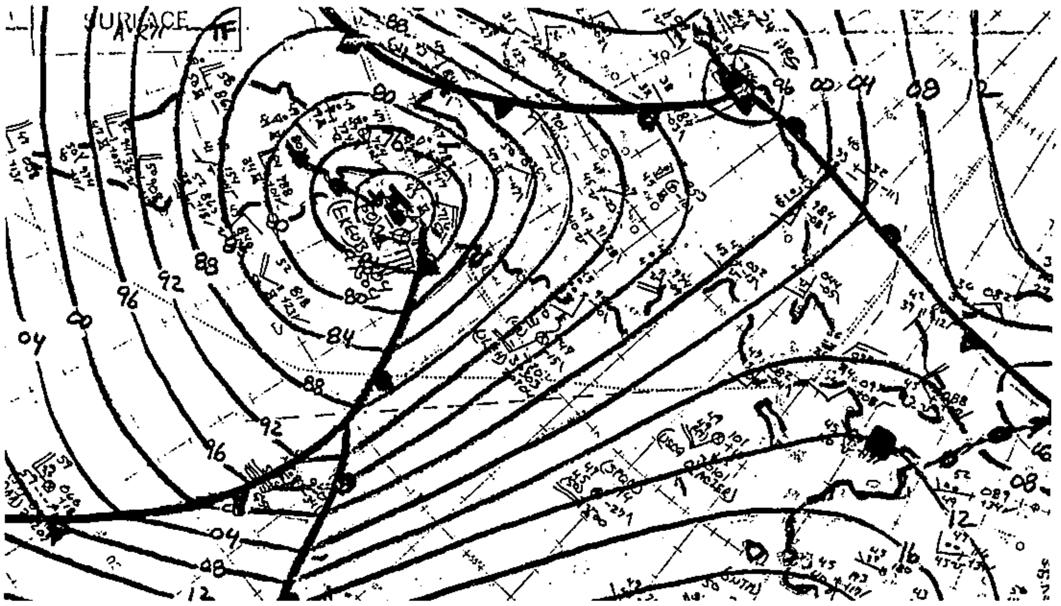
1800 GMT Aug. 26, 1975

Figure 7. Sea-level pressure analyses for the Western Seward Peninsula coastal flood of Aug. 25, 1975. Nome is marked with a square (■).



0000 GMT Oct. 28, 1976

Figure 8. Sea-level pressure analysis for the period of high surf at Meshik (near Port Heiden) of Oct. 27-28, 1976. Meshik is marked with a square (■).



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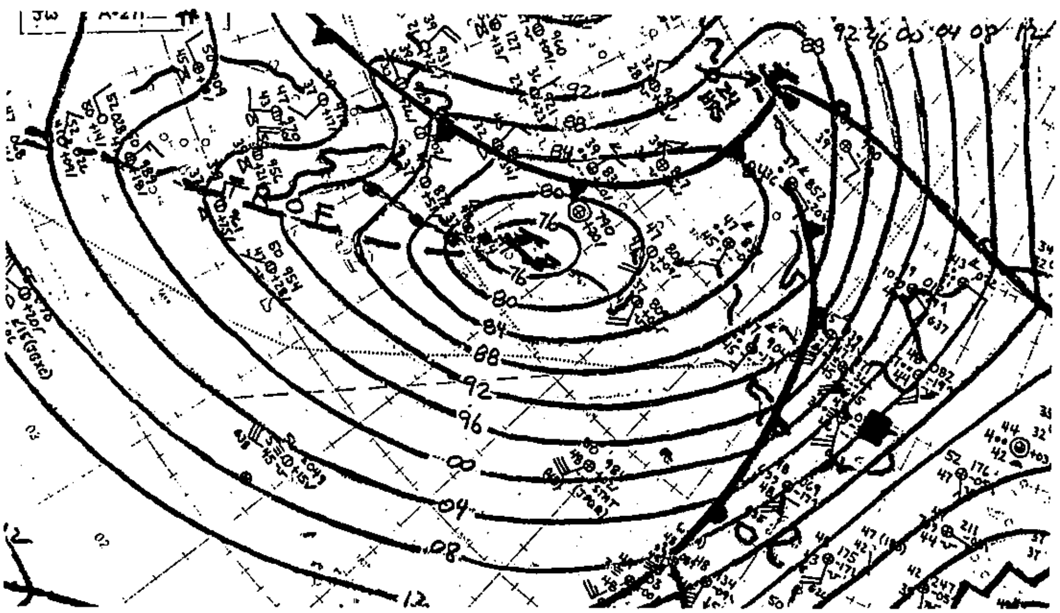
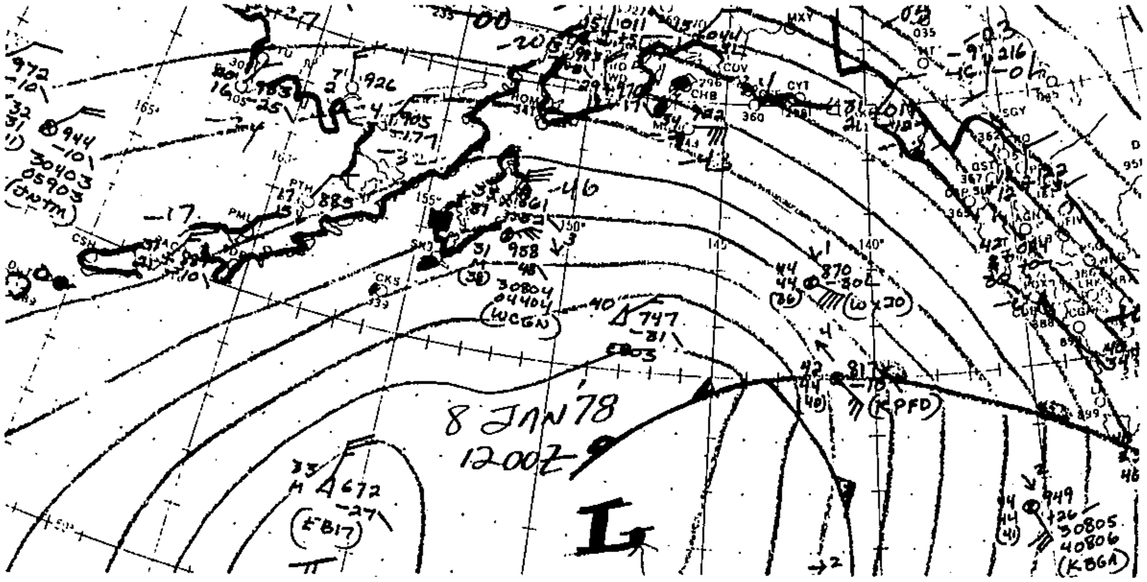


1200 GMT Sept. 13, 1977

Figure 9. Sea-level pressure analyses for the Seward Peninsula coastal flood of Sept. 13, 1977. Golovin is marked with a square (■).



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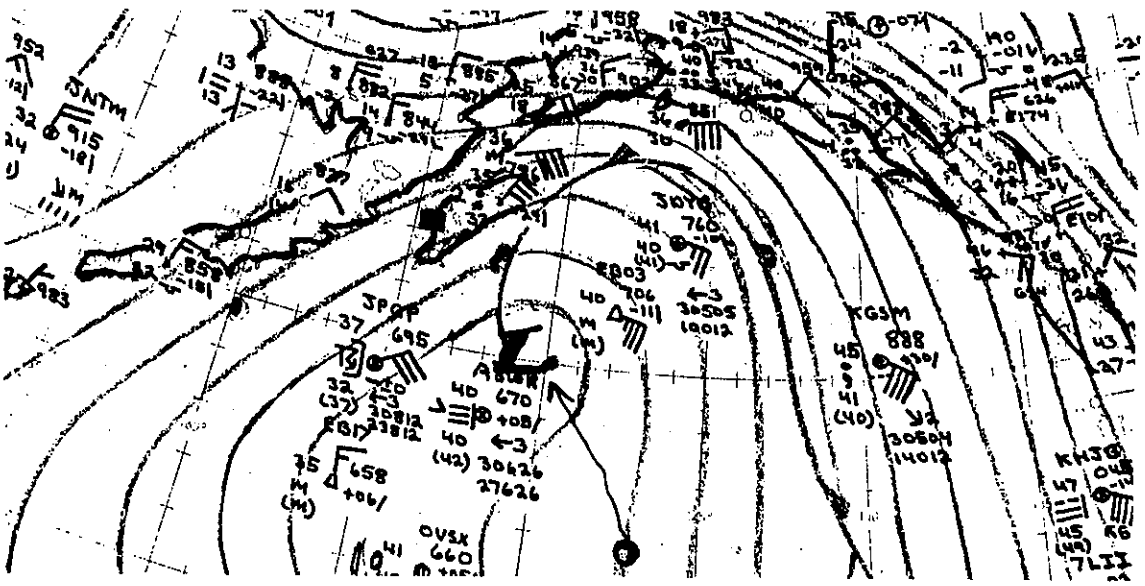

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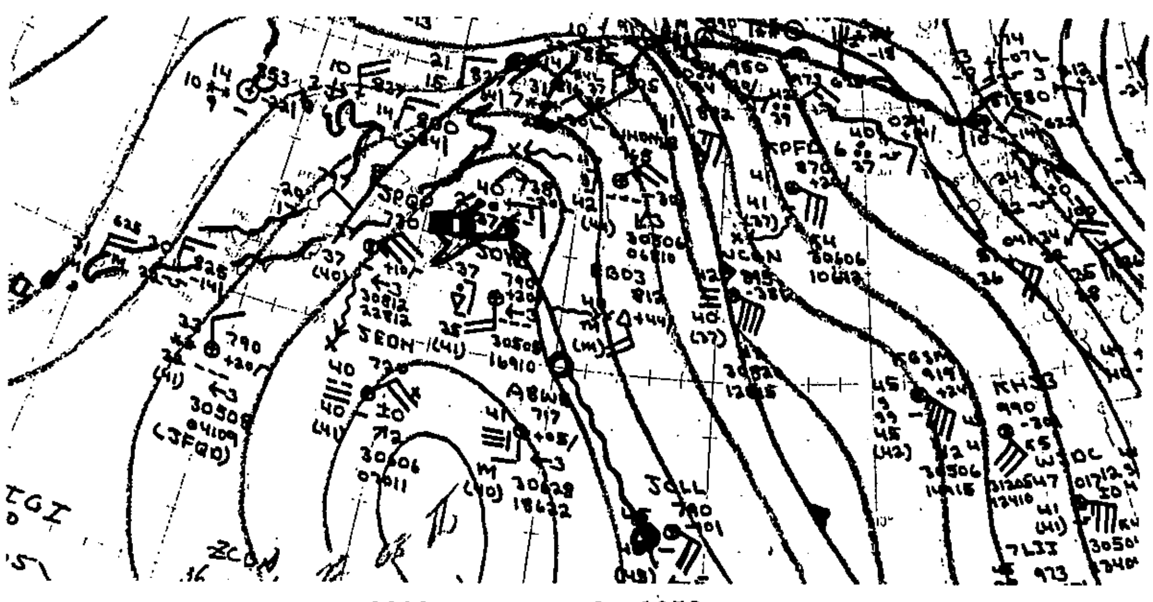


0000 GMT Jan. 9, 1978

Figure 10. Sea-level pressure analyses for the period of high tides and heavy surf at Karluk on January 8, 1978. Karluk is marked with a square (■).

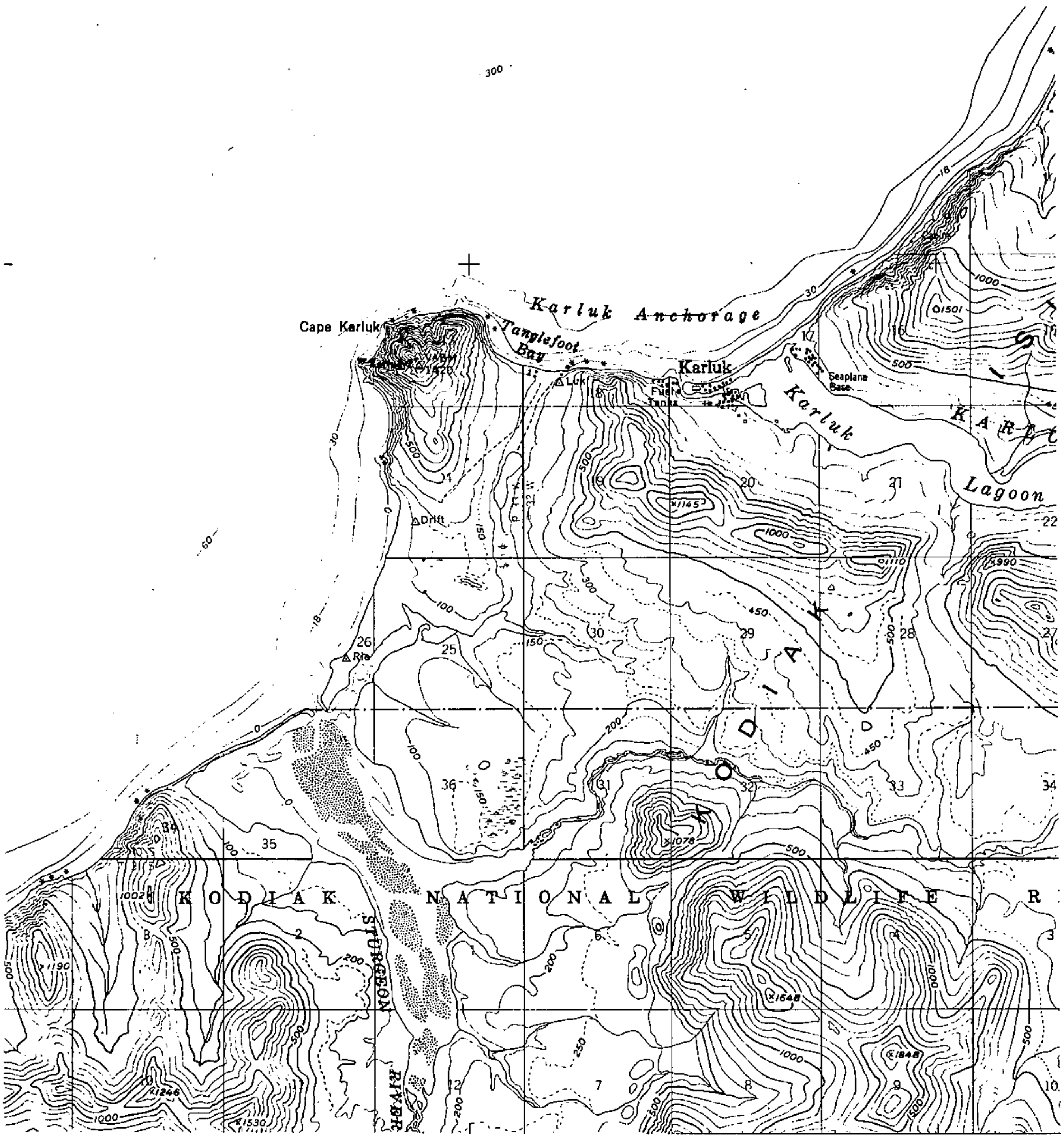


Figure 11. Map of the Karluk area. Note that Karluk is situated half on the mainland and half on a sandspit. The shoreline faces north. [From USGS quadrangle map, 1952. Scale: 1" = 1 mile.]

Pressure rose steadily, starting late on the evening of Feb. 5, and moderate southwest winds blew at Homer from late in the evening of Feb. 5 until late on the evening of Feb. 7. While the wind at Homer was only 20 to 35 knots, winds farther west over Cook Inlet were stronger. Winds in the Barren Islands were estimated at northwest to 120 knots on the night of Feb. 7-8. The ice-free fetch over water extended about 70 miles to the west of Homer and persisted over 2 days. Maximum monthly tides occurred on Feb. 8, a day after the storm. The lowest sea-level pressure at Homer during the storm was 953 mb. There was heavy surf and moderate shoreline erosion on the southwest side of Homer Spit. Damage was minor and occurred mainly on the road on Homer Spit. During this episode, Anchorage had one of its heaviest snowstorms on record.

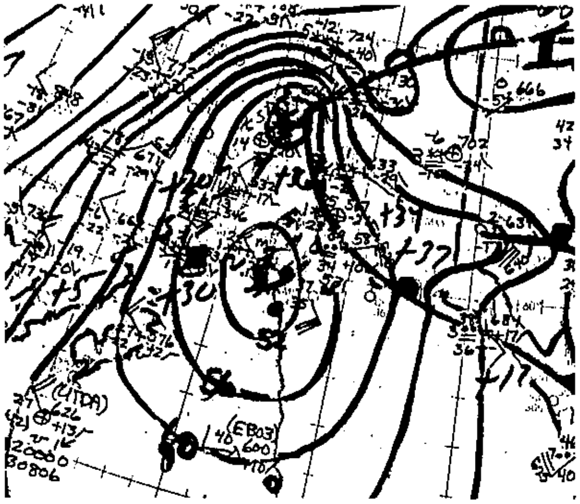
Heavy ice cover does not rule out the possibility of water-level rises and ice damage. During the winter, people traveling across Kotzebue Sound have been surprised to find water overflow on top of fast ice on some occasions. It is likely that these instances follow a period of strong south to southeast winds over the Bering Sea. The following storm is an example of ice damage during mid-winter:

<u>Barrow Storm, Dec. 29-30, 1977</u>. *See figure 14.* A storm moved north at 40 to 50 knots from the Central Aleutians to Bering Strait and continued into the Chukchi Sea. The storm was just northwest of Barrow on the morning of Dec. 30, and turned east and weakened rapidly thereafter. South winds of 50 to 65 knots were common along the west coast of Alaska from Nunivak Island to Barrow as the low passed. The south to southwest fetch over the western Arctic coast of Alaska was 300 miles long and persisted about 12 hours. The Arctic Ocean and the northern Bering Sea were ice-covered. At the time of the storm, tides were near the monthly minimum; however, this factor has little effect in the Arctic. The lowest sea-level pressure over Barrow during the storm was about 985 mb. Early on the morning of Dec. 30, rising water lifted the pack ice at Barrow and the wind drove it up to 30 yards inland. Minor ice damage was sustained at Barrow. There was considerable wind damage at Nome on the evening of Dec. 29.

It is interesting to see the oppsite effect of coastal flooding: low water levels. Though there are very few documented instances of this, here is an example:

<u>Low Water in Prudhoe Bay, Sept. 25-26, 1974</u>. *See figures 15 and 16.* High pressure held over the Beaufort Sea while low pressure prevailed over the Interior of Alaska. A moderate pressure gradient developed over the Arctic coast of Alaska on Sept. 23. At Prudhoe Bay, east winds increased to 40 knots by the end of Sept. 23. Easterly winds of 25 to 45 knots blew all day on Sept. 24 and 25. The wind decreased on the afternoon and evening of Sept. 26. Air temperatures were in the mid-20s on the Arctic coast throughout the period.

Blowing sand began at Prudhoe Bay around noon on Sept. 24 and lasted until the end of Sept. 25. It resumed for several hours on Sept. 26. Blowing sand is unusual at Prudhoe Bay; its presence in this example suggests that the boundary-layer of the atmosphere was unstable along the Arctic coast.



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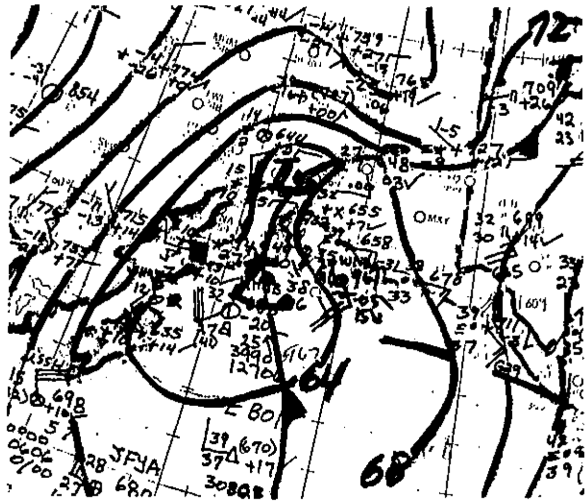

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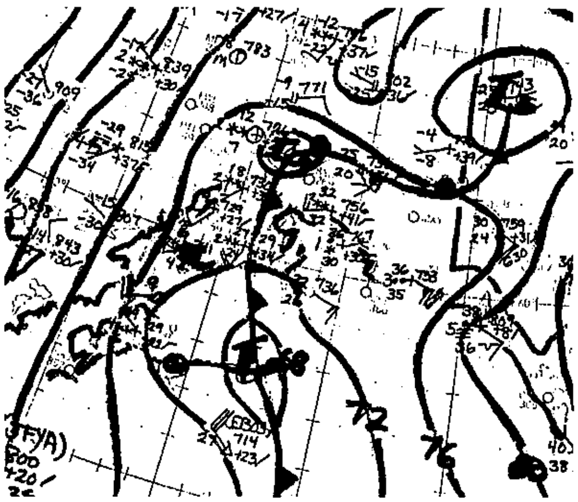

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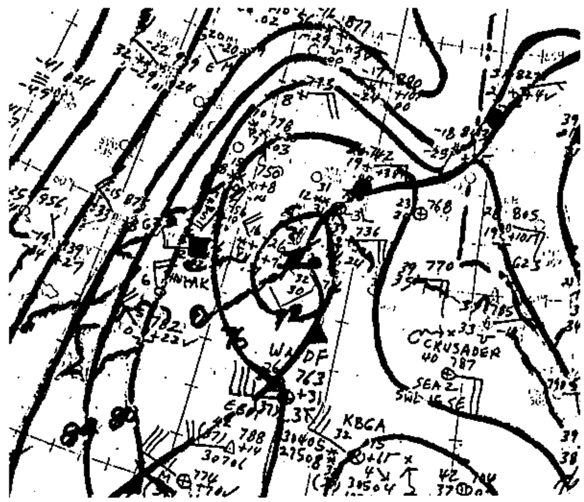

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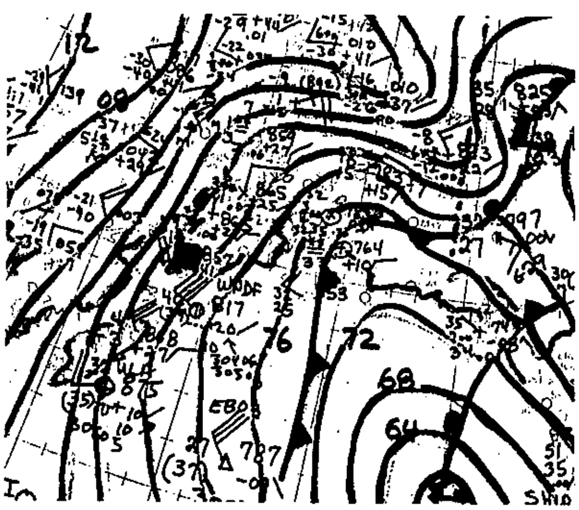

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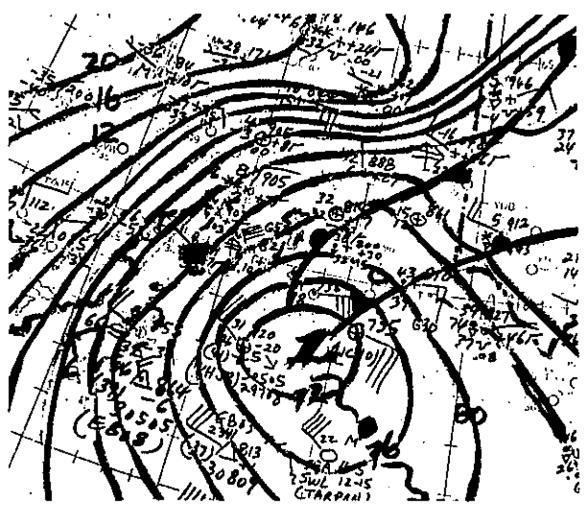
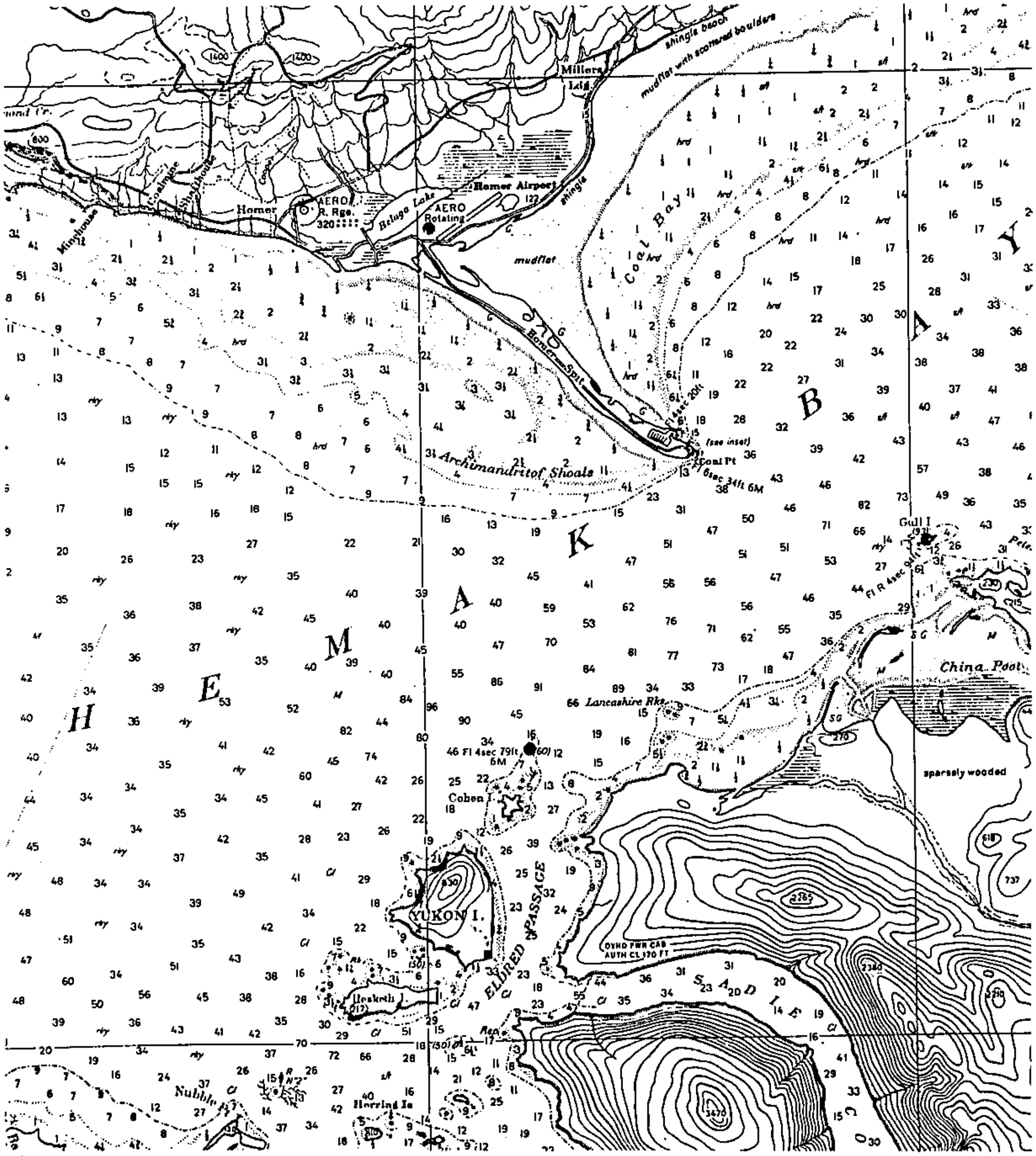
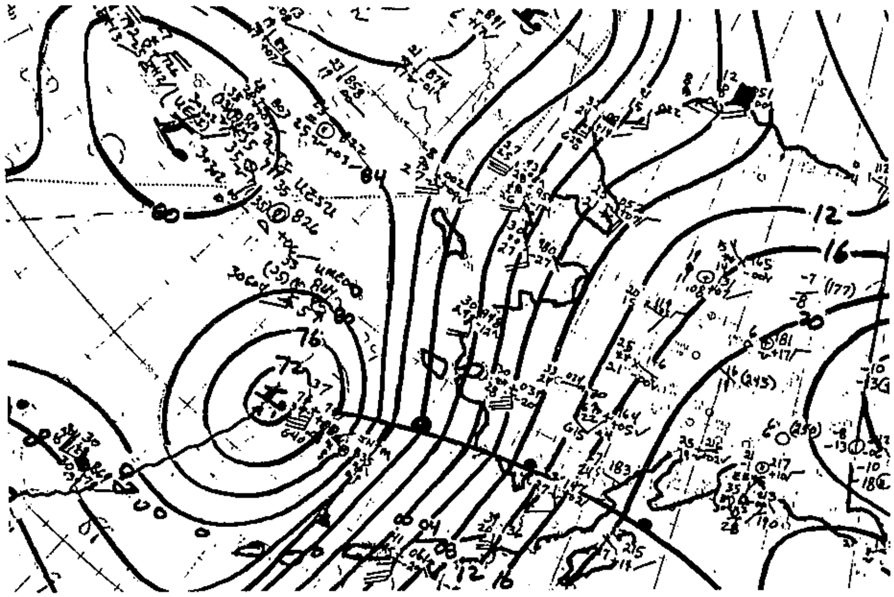


1800 GMT Feb. 8, 1978

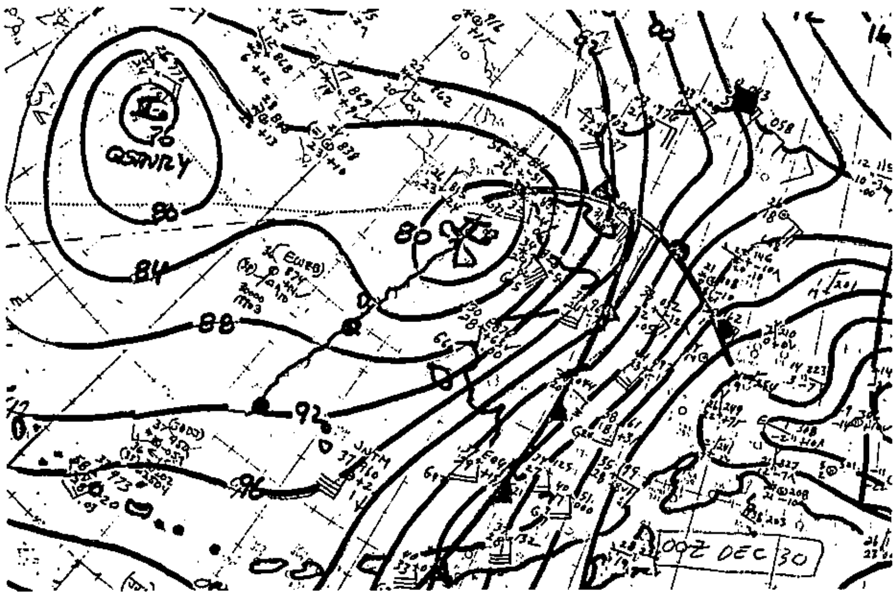
Figure 12. Sea-level pressure analyses for the period of heavy surf on Homer Spit, Feb. 5-7, 1978. Homer is marked with a square (■).



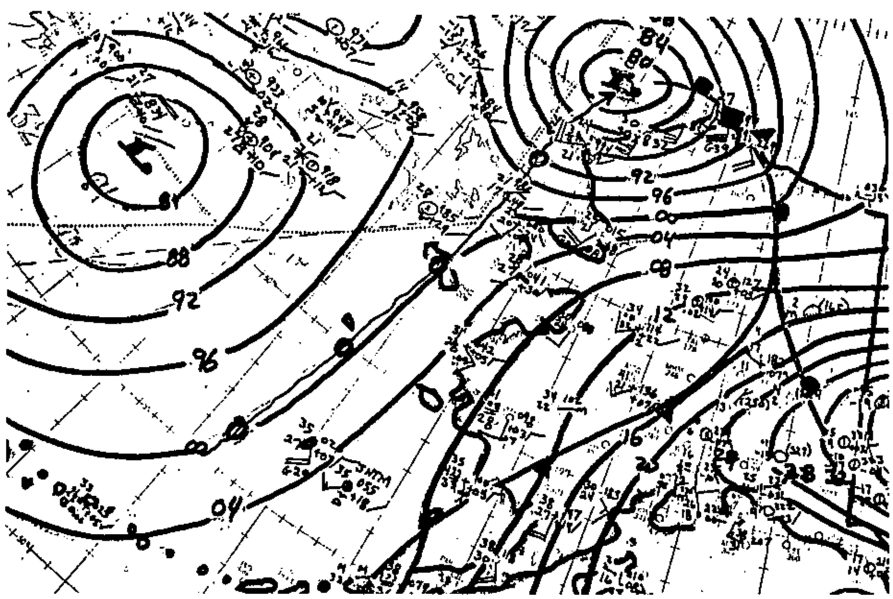
<u>Figure 13</u>. Nautical chart of the Homer area. [From NOS chart Number 8531, 1970. Soundings in fathoms.]



1200 GMT Dec. 29, 1977



0000 GMT Dec. 30, 1977



1200 GMT Dec. 30, 1977

Figure 14. Sea-level pressure analyses during the Barrow storm of Dec. 29-30, 1977. Barrow is marked with a square (■).

During the summer of 1974, the ice was unusually far north of the Arctic coast of Alaska. For several weeks it was about 100 miles offshore. During the September storm, it was more than 20 miles north of Prudhoe Bay.

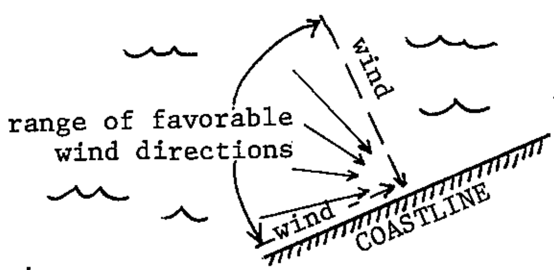
The unusually strong east winds persisted for almost 3 days along the 400 mile coast from the northern Yukon to Barrow. The wind, combined with the instability of the boundary-layer and the abnormal northern extent of open water, caused considerable seaward transport of water. Sea-level pressure at Prudhoe Bay increased from about 1010 mb on Sept. 24 to 1018 mb on Sept. 27. This is slightly above normal for September.

The water level in Prudhoe Bay was several feet below normal on Sept. 25-26. Extensive marine operations and offloading of barges in Prudhoe Bay were underway before this episode. During Sept. 25-26, this activity was brought to a halt by the low water level. As one can see from Figure 16, Prudhoe Bay is very shallow.

GENERALIZATIONS

Based on the cases presented above, one can draw some general conclusions:

1. For onshore transport of sea water, a wind direction that makes a 0 to 90 degree angle with the coast (looking downwind to the right) is favorable. Any other wind direction is unfavorable for coastal flooding.

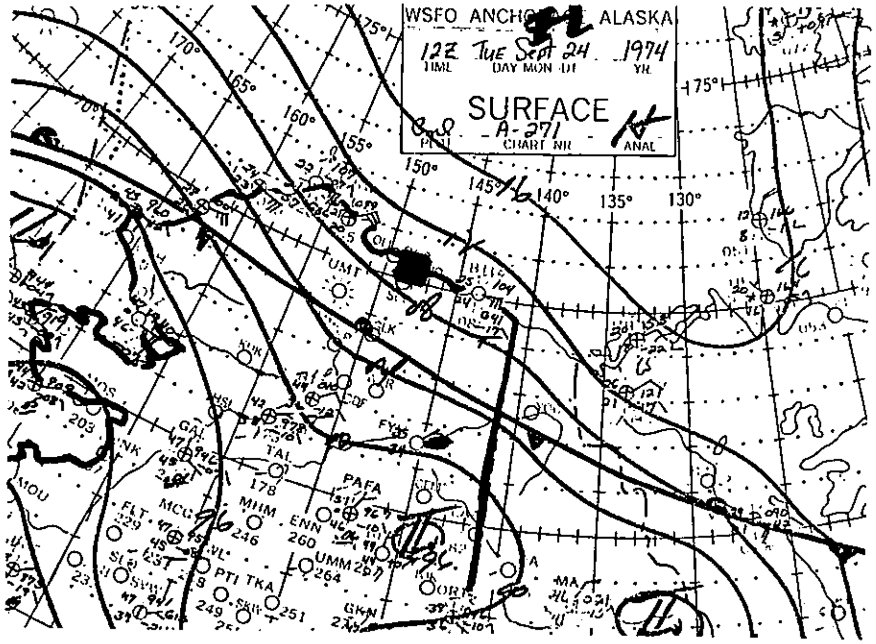


2. Although it is a minor factor, abnormally low sea-level pressure is related to higher water levels. One may add 4" to water level for every 10 mb that sea-level pressure is below normal.

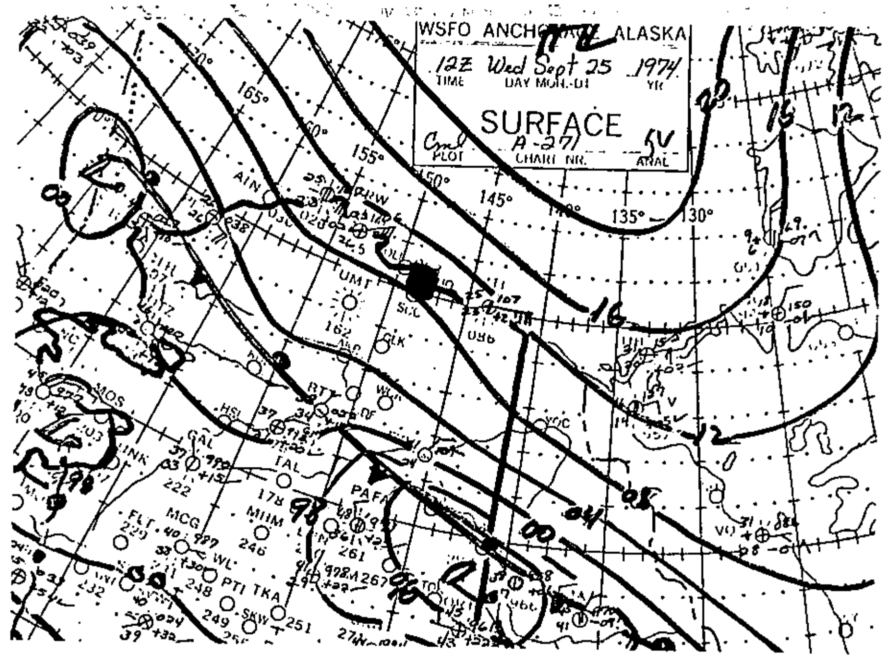
3. There is about a 12- to 24-hour time lag between the development of favorable wind and sea-level pressure conditions and high water level. This enables a forecaster to have several hours of lead time on a coastal flood warning.

4. The highest water level in a coastal flood generally comes within 12 hours of a frontal passage. If tidal variation is large, high water may come at the time of high tide.

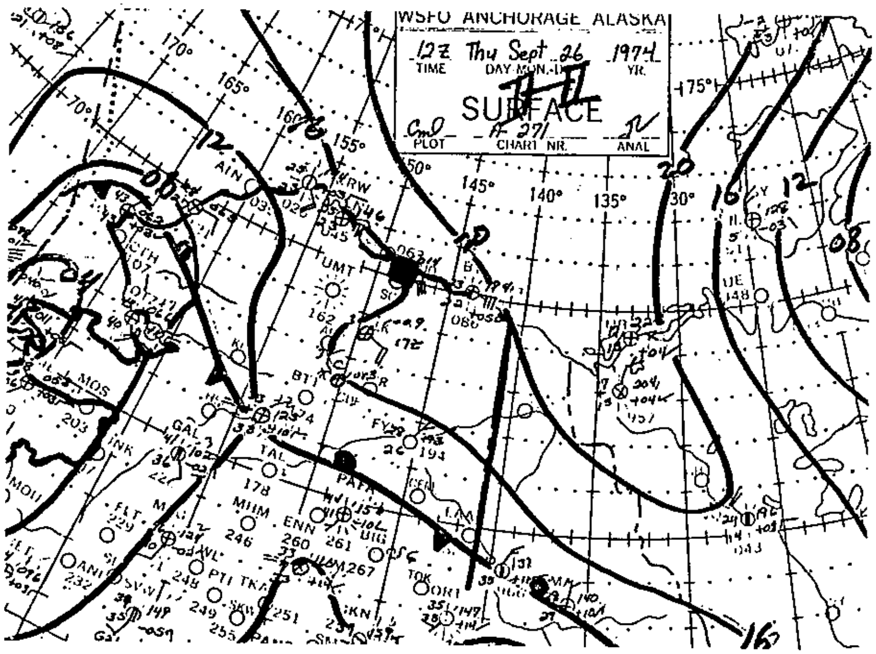
5. Major coastal flooding is coastal flooding that is likely to cause significant damage to vulnerable communities. Water level rises are typically 6 feet or more in these cases.



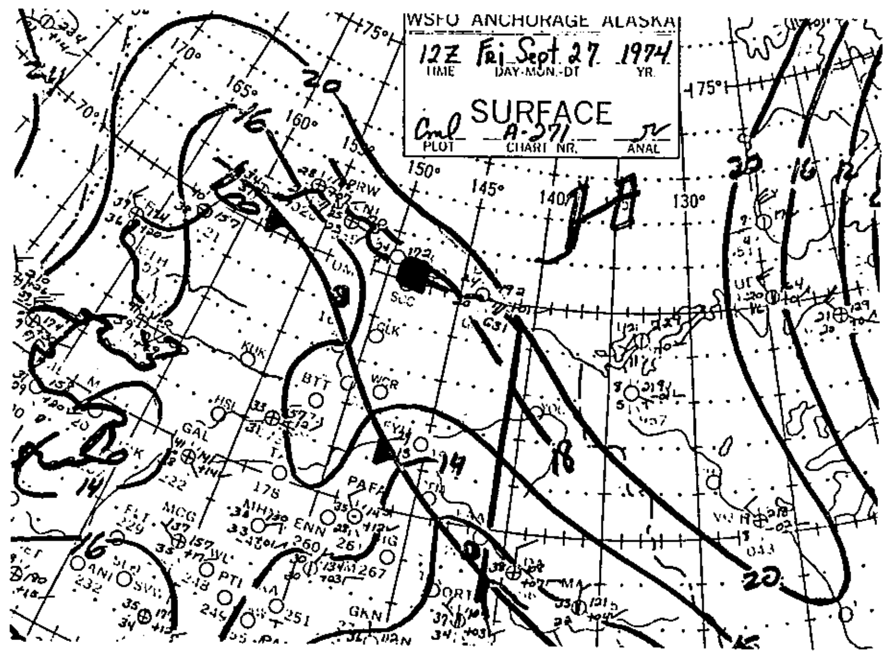
1200 GMT Sept. 24, 1974



1200 GMT Sept. 25, 1974



1200 GMT Sept. 26, 1974



1200 GMT Sept. 27, 1974

Figure 15. Sea-level pressure analyses for the period of low water levels in Prudhoe Bay, Sept. 25-26, 1974. Prudhoe Bay is marked with a square (■).

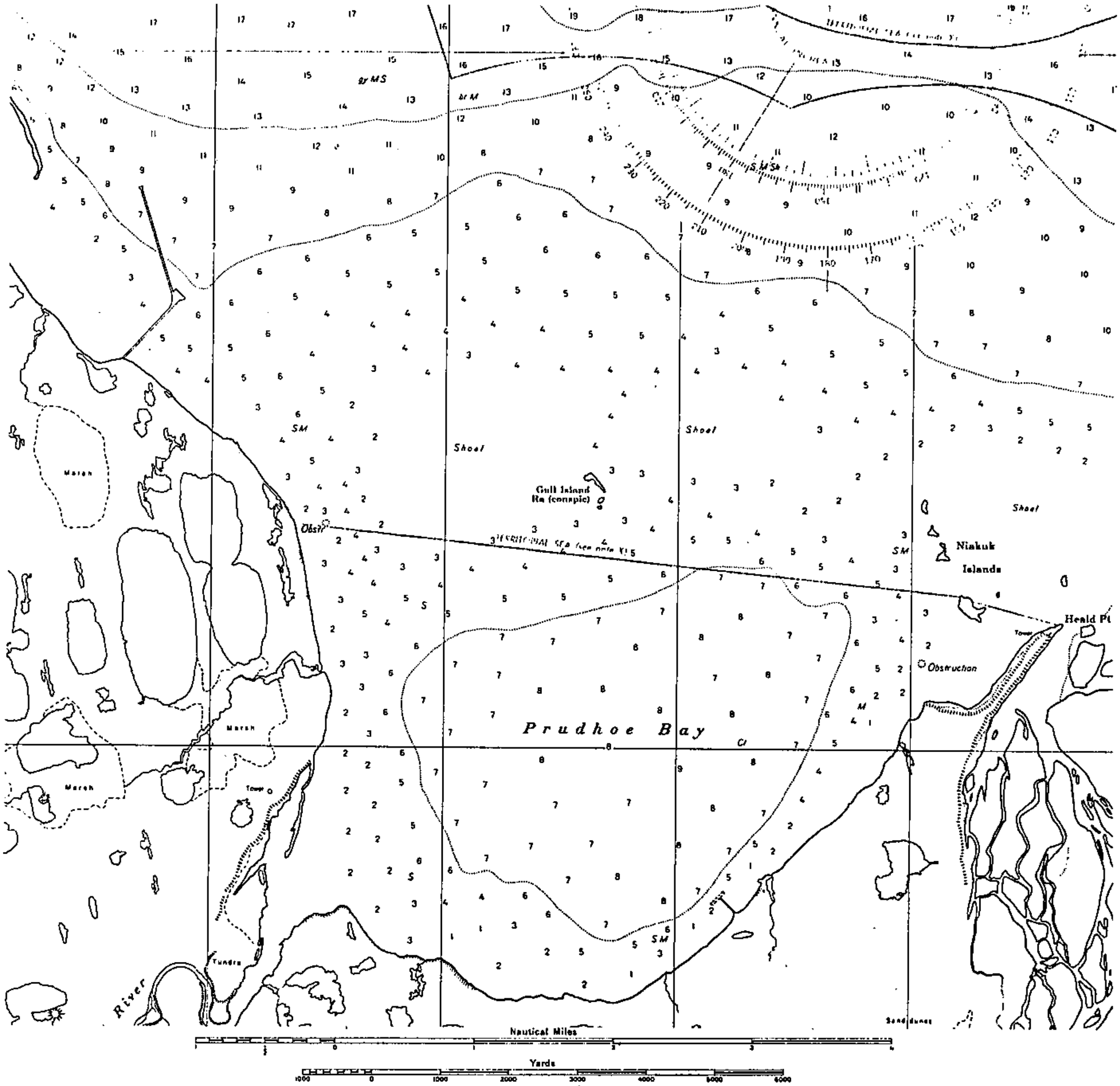


Figure 16. Nautical chart of Prudhoe Bay. Soundings in feet. [From National Ocean Survey chart number 16061, July, 1977.]

Major coastal floods require peak winds in the fetch of 50 to 75 knots or more. The fetch must be 500 miles or more and mostly ice-free. The duration of the fetch for a major flood should be at least 12 hours and flooding is more likely with a 24-hour duration.

Due to the strong winds required, nearly all major Alaska coastal floods can be expected in the stormy months of early winter, namely October and November. Conditions are more favorable for coastal flooding when air temperatures drop below sea surface temperatures. Favorable conditions for major coastal floods end with the formation of significant sea ice. In summary, the prime coastal flood "season" in Alaska begins in autumn and ends in the first part of winter.

In areas where tidal variation is large, major coastal floods are more likely to take place at the time of monthly maximum tides. Roughly, this is at new moon. Monthly minimum high tides occur around full moon. The tide factor is not important in the Arctic coastal waters of Alaska.

6. Minor coastal floods typically cause slight to moderate damage to the lowest-lying terrain in vulnerable communities. Rises in water level are generally from 2 to 6 feet.

Minor coastal floods require peak winds of 35 to 50 knots and a mostly open water fetch of 50 to 500 miles. Minor coastal floods can occur before or after the prime season described above.

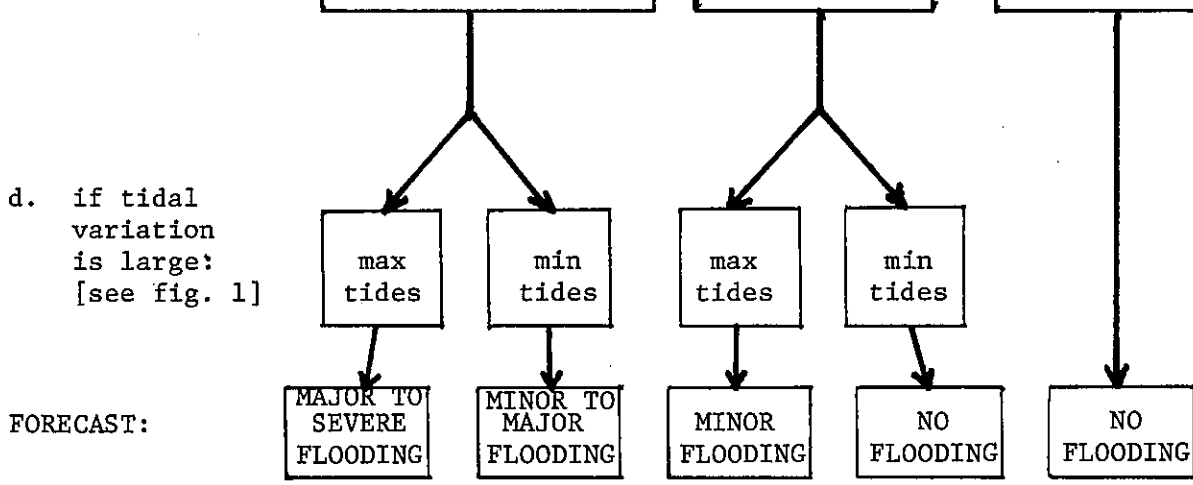
FORECAST PROCEDURE

The above generalizations can be incorporated by the following forecast procedure:

1. Determine the following:
    a. wind direction and range of peak wind speed in the fetch
    b. length and duration of the fetch of the wind
    c. sea ice coverage in the fetch
    d. tidal variation [see figure 1.]; if variation is large, time of maximum monthly tides [from Tide Tables]
    e. boundary-layer stability (air temp - sea surface temp)
    f. lowest sea-level pressure over vulnerable area during the storm
    g. time of frontal passage
    h. time of daily high tides [from Tide Tables].

2. Follow the flow chart on the next page from the top down. If an unfavorable factor comes up in the process, move to the right (toward a forecast of less flooding). If all factors are favorable, a record storm is possible, and a forecast of SEVERE flooding may be issued.

	MAJOR FLOODING	MINOR FLOODING	NO FLOODING
a. wind direction:	favorable	favorable	unfavorable
peak wind speed in the fetch:	50-75 knots or more	35-50 knots	$<$ 35 knots
b. fetch length over water:	500 miles or more	50-500 miles	$<$ 50 miles
duration of fetch:	12-24 hours or more	12-24 hours	$<$ 12 hours
c. ice coverage over fetch: (minimum expected during storm)	$<$ 1/10	$<$ 1/10	$>$ 1/10
typical rises in water level:	6 feet or more	2 to 6 feet	$<$ 2 feet



ADJUSTMENTS:

1. Boundary-layer stability: Forecast more flooding if the boundary layer of the fetch is unstable. Forecast less severe flooding if the boundary layer of the fetch is stable.

2. Lowest sea-level pressure: Add 4" to water level for each 10 mb below normal sea-level pressure. Obtain normal sea-level pressure from Figure 2.

3. Timing of high water level:
   a. Within 12 hours of the frontal passage.
   b. If tidal variation is large [see figure 1]: at the time of high tide, which may be obtained from the Tide Tables for the year.

EXAMPLE. After analysing the weather situation, we have made the following determinations for a forecast storm:

a. wind direction southwest over the southern Bering Sea; peak wind speed in the fetch 40-60 knots. [favorable direction for a coastal flood in southwest Alaska]
b. fetch 700 miles long, duration 30 hours
c. ice-free over fetch
d. tidal variation: [from figure 1, it is large for the southwest Alaska coast]; monthly max tides 3 days from now
e. boundary-layer stability: neutral to slightly stable
f. lowest sea-level pressure during storm [over southwest Alaska]: 984 mb [given a time of year of November, this is about 20 mb below normal...equivalent to an 8" rise in water level]
g. time of frontal passage: noon tomorrow
h. time of daily high tides [from Tide Tables]: 6AM and 6PM tomorrow.

Factors (a) through (c) are mostly in the major flooding category. Since factors (d) through (f) are favorable for more severe flooding, we subjectively adjust the forecast to major flooding. Since we do not have 50-75 knots or more of wind (just 40-60 knots in this case), a forecast of SEVERE flooding is not justified. For the timing of high water, anytime from noon to midnight tomorrow is the first guess. Since high tide is at 6PM, and since there is considerable tidal variation, the best guess would be 6PM tomorrow. To summarize this example: one would forecast major coastal flooding in southwest Alaska tomorrow afternoon and evening.

Obviously, the weakness of this forecast procedure is the requirement that the meteorologist make subjective adjustments correctly. This is the weakness commonly found in most forecast procedures that are used on a real-time basis. For the time being, we have to live with this.

RECOMMENDATIONS

As in other branches of weather forecasting, coastal flood forecasting is an inexact science. Thus, coastal flood warnings should be worded in general language. For example, one should not include specifics on water level rise to the nearest half foot if we can't forecast consistently with that degree of accuracy.

To accurately determine what effect a storm will have in a particular location, one must have detailed local knowledge of the area. WSFO meteorologists rarely have this knowledge. There are many flood-prone communities on Alaska's coasts. Civil defense officials and local residents are most likely to have this knowledge. Forecasters can gain some knowledge of local conditions by consulting the <u>Tide Tables</u>, the <u>Coast Pilot</u> and Nautical Charts published by the National Ocean Survey and U. S. Geological Survey topographic maps.

It is not advisable for a meteorologist in a WSFO to predict the extent of damage of a storm to a particular community. For example, two major coastal floods could erode away 60 feet of beach, but not flood a community. The next storm might need to erode only 10 feet inland to reach the town and do major damage. Local residents will be aware of this, but the forecaster will probably not.

Prompt and frequent exchange of information between WSFO forecasters, WSO personnel and civil defense officials is essential. Unofficial weather observations and local reports from vulnerable communities are of great benefit in updating and refining coastal flood warnings. Weather warnings should be passed to local residents and to civil defense officials as promptly as possible to give time for protective measures to be taken. Arrangements should be made with weather stations that normally close at night to remain open during the storm.

Official National Weather Service policy on coastal flood warnings is contained in WSOM Chapter C-43.

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