Alaska Sea Grant Program

RECENT FLUCTUATIONS IN METEORLOGICAL AND OCEANOGRAPHIC PARAMETERS IN ALASKA WATERS

by
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Alaska Sea Grant Report 79-12
IMS Report 79-2

February 1980

UNIVERSITY OF ALASKA

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ACKNOWLEDGEMENTS

I wish to thank J. Niebauer and T. Paluszkiewicz, who helped process data and D. Nebert and T. Weingartner who helped with the manuscript.

This work is the result of research sponsored by the Alaska Sea Grant Program, cooperatively supported by NOAA, National Sea Grant College Program, Department of Commerce, under grant number 04-8-M01-187, by the National Science Foundation, Division of Polar Program Grant DPP 76-23340 A02 (PROBES), and by the University of Alaska with funds appropriated by the State of Alaska.

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INTRODUCTION AND MOTIVATION

Many investigators (e.g., Dow 1972) have attempted to relate spatial and temporal fluctuations in biomass and fisheries to spatial and temporal fluctuations in oceanographic conditions. More recently investigators are looking into the world oceans and atmosphere for the link among weather/climate and oceanographic and biological fluctuations (Cushing and Dickson 1976). Alaskan waters are no exception.

In the last few years, especially since 1970, there have been extraordinary variations in the short-term climate over the North Pacific that are hypothesized to cause variations in oceanographic conditions such as sea temperature and ice coverage in Alaskan waters. This report outlines some of the relatively large-scale fluctuations in sea surface temperature, surface and 700 mb (3000 m) winds and ice coverage and their interrelationships. The study areas are the shelf regions of the Gulf of Alaska from Sitka to Kodiak and the southeastern Bering Sea. The time span considered is approximately the early 1960s to the present.

BACKGROUND

GULF OF ALASKA

The Gulf of Alaska is a large, deep, open gulf in the northeastern Pacific Ocean (Figure 1). Its bathymetry is characterized by a relatively broad (75 to 150 km), relatively deep (150 to 350 m) shelf with numerous troughs and ridges and a steep continental slope. The mean depth of the Gulf of Alaska is about 2.4 km, with a maximum depth of about 5.6 km. The coastline is characterized by high mountains (~1 km) with peaks reaching to 3 km.

The circulation of the Gulf of Alaska is dominated by the cyclonic (CCW) Alaska Gyre centered generally south of Kodiak (Favorite, Dodimead and Nasu 1976). The gyre is bounded on the east and northeast by the Alaska Current, and on the northwest and west by the Alaska Stream, a western boundary current. The circulation of the Alaska Stream has been treated theoretically by Thompson (1972) and Veronis (1973).

The seasonal weather variations over the Gulf of Alaska are extreme. In winter, the intense Aleutian Low centered in the western gulf generates winter storms that migrate eastward (see Dodimead, Favorite and Hirano 1963). The mean winter winds are strong and generally westward along the south coast, causing surface coastal Ekman convergence and downwelling in the northern gulf. In summer, the North Pacific High moves northward, displacing the weakened Aleutian Low. The winds along the south coast become weaker and are often northeasterly, leading to a relaxation of the coastal downwelling. Both Bakun (1973) and Royer (1975) have considered these seasonal variations.

A second major driving force is the influx of freshwater from precipitation and coastal runoff around the Gulf of Alaska, especially in late

Figure 1. Alaskan continental shelf region (Brower et al. 1977).

summer and early fall. In addition, the surplus of precipitation over evaporation exceeds 90 cm/year off the coast of southeastern Alaska (Jacobs 1951). Royer (1979) shows evidence that this large seasonal input of freshwater may be the dominant forcing function in the surface layers of the coastal waters.

For more details on the physical oceanography of the Gulf of Alaska, see Ingraham, Bakun and Favorite (1976) and Favorite, Dodimead and Nasu (1976), which also contains a rather complete bibliography for the gulf region as does Weingartner et al. (1979).

BERING SEA

The southeast Bering Sea shelf (Figure 1) is an extraordinarily broad (~500 km) but shallow (shelf break ~150 m) region. In considering the overall circulation of this region, it has been suggested that there are three fronts on this shelf, all approximately parallel to the bathymetry. (A front here is defined as a strong horizontal gradient of a parameter.) Schumacher et al. (1978) illustrate a structural front at about 50 m depth while Coachman and Charnell (1979) consider a double front system with an inner front at 100 m depth and an outer front at the shelf break (about 150 m). Schumacher et al. suggest that the 50 m front is a narrow transition zone that separates a well-mixed coastal domain from a two-layered central shelf region. This front does not separate two distinct water masses. Rather, it separates a seasonally varying balance between buoyant energy input (insolation and runoff) and tidal stirring that allows the formation of seasonally differing water masses. In addition, Schumacher et al. find that ice cover influence and salinity distribution is important in the front structure and that mean flow is small (<2 cm/sec).

Coachman and Charnell (1979) provide a rather complete summary of the oceanographic regime of outer Bristol Bay. The shorter time scale circulation of this section of the southeast Bering Sea shelf is dominated by tides and the extremely rough weather from the wintertime Aleutian Low. They find that the longer time scale means flow is weak, on the order of 1 to 2 cm/ sec^{-1}, moving from the southeast to the northwest parallel to the shelf bathymetry. This has the effect of decoupling the transport of mass characteristics ($S°/_{oo}$, T°C) from the mean advection (see Csanady 1976) and makes their movement a function of diffusion.

The diffusive transport of salt and heat in the case of this broad shallow shelf is perpendicular to the shelf bathymetry between a fresher, colder shelf water and a warmer, more saline Alaska Stream/Bering Sea source water off the shelf. The interaction of these water masses occurs between the 100 m isobath and the shelf break. As previously mentioned, this zone contains two fronts, one over the 100 m isobath and the other over the shelf break, separated by a 50 to 100 km wide transition zone with no frontal characteristics. The Bering Sea/Alaska Stream water intrudes as a bottom layer beneath this transition zone shoreward to the inner front at 100 m. Above this intrusion, but beneath 30 m, the shelf water moves seaward. Coachman and Charnell (1979) conclude that this 50 to 100 km transition zone is an area in which the two water masses actually meet and mix by layering. This layering is expressed as fine structure (1 to 10 m) instabilities in a layer beneath the surface wind mixed layer and above a bottom tidally mixed layer.

Reed (1978) considered changes in heat content in two 1° X 1° areas in the region of the "inner front" of Coachman and Charnell. Due to the low net flow in the region, advection of heat was neglected. His data also suggested that heat gain through horizontal diffusion had little effect on the heat budget and that net radiation is typically the dominant heat flux in the southeast Bering Sea in summer. During the early fall, evaporation and heat conduction fluxes become significant due to increased wind speed and rapid cooling of the overlying atmosphere. In winter, because of the high latitude and extensive ice cover, the net heating is relatively low in comparison to other open ocean areas. The conclusion drawn is that net heat gain or loss here is primarily through air-sea interaction.

Relatively little work has been done on relationships between the ice cover and weather in the Bering Sea. Konishi and Saito (1974), using 12 years of data, state that stagnant weak weather fronts and lows frequently exist along the ice edge. They suggest that low pressure systems flowing northward over the Aleutians in the Bering Sea become stationary in the vicinity of drift ice and dissipate. Conversely, low pressure systems and accompanying fronts that move southward over the Bering Sea gain force over the warm sea surface in the vicinity of the ice edge. Konishi and Saito (1974) conclude that a stagnant frontal zone is always found at the southern edge of the sea ice, and lows are seen to move along the frontal zone. Moreover, the occluding low pressure will at times move westward and, in this way, the sea ice may have the effect of blocking low pressure system migration.

Muench and Ahlnäs (1976) observed ice movement and distribution in the Bering Sea using satellite imagery from March to June 1974. They found ice movement was southward in response to northerly winds until late April, after which variable ice motion reflected variable winds.

DATA

Weekly mean southern ice limit data for the Bering Sea were obtained from the naval fleet facilities in Suitland, Maryland. The weekly percentage of ice coverage (PIC) was calculated as the ratio of ice coverage to total area considered (ice plus open water east of 175° west longitude). This gives a quantitative estimate of ice coverage but does not take into account ice thickness or concentration. For example, 1/8 concentration is weighted equally with 8/8 concentration.

Northern hemisphere 700 mb pressure charts were obtained from Monthly Weather Review.

Monthly mean sea surface temperatures (SST) and air temperatures were obtained from the Naval Fleet Numerical Weather Central, Monterey, California through D. R. McLain of National Marine Fisheries Services in Monterey. He also provided the SST autocorrelation analysis. Bottom temperatures were obtained from Coachman and Charnell (1979).

Storm track maps were obtained from the U.S. Weather Bureau Climatological Data National Summary.

RESULTS

SEA SURFACE TEMPERATURES

Deviation from mean sea surface temperatures (SST), annual cycles and autocorrelation analysis for five locations in the Gulf of Alaska and Bering Sea are shown in Figure 2.

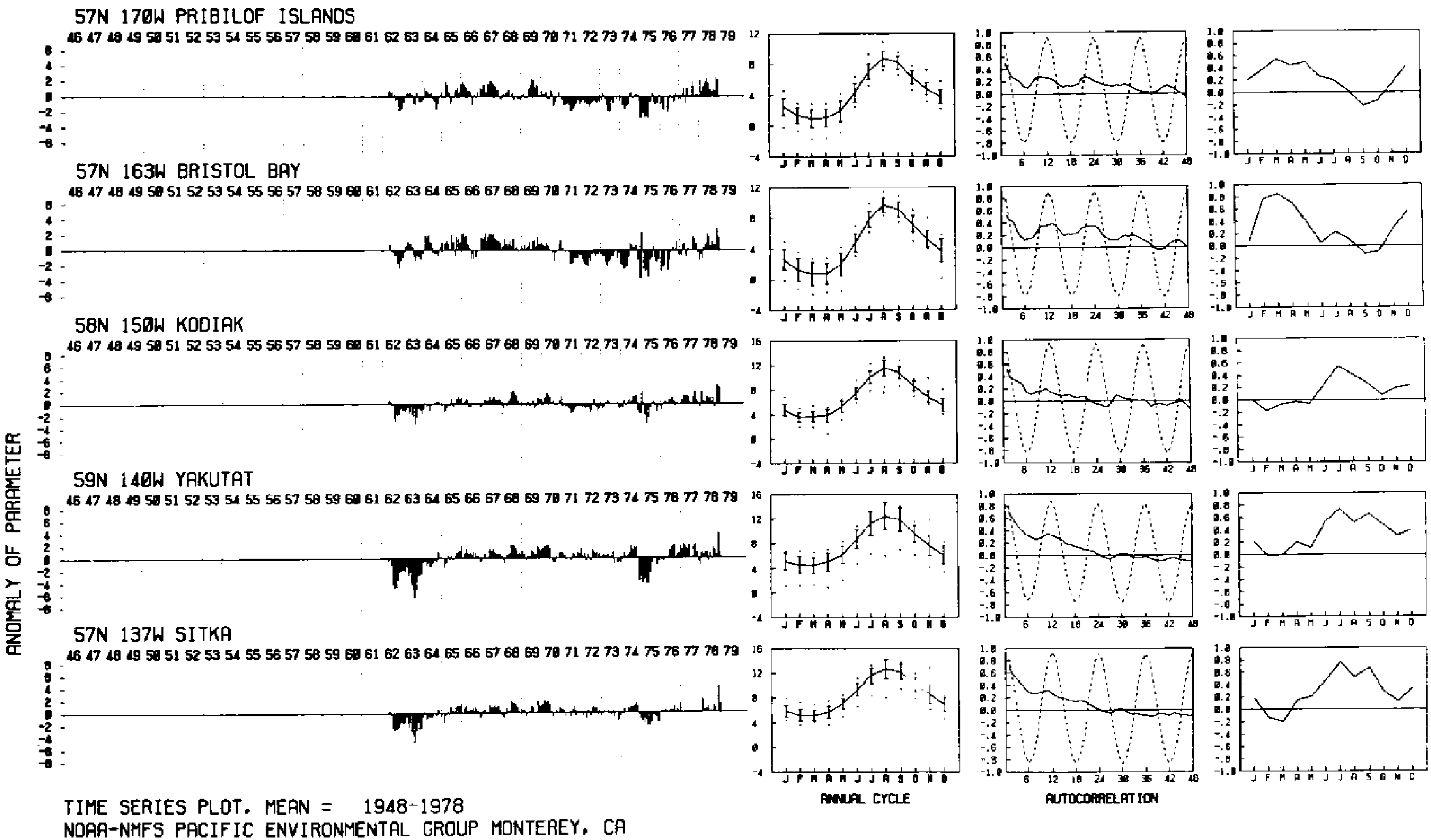


Figure 2. Monthly mean sea surface temperature (^{o}C) data for the Gulf of Alaska and the Bering Sea. Bars on annual cycle are standard deviations, dots are extremes. Solid line in autocorrelation is the anomaly series, dashed line is the annual cycle.

The five SST annual cycle curves have the same general shape, such as the seasonal cycle, with maxima in August in all cases. The maxima averages about 12°C in the Gulf while the Bering Sea averages 8 to 10°C. Minima occur about March and April in the Bering Sea (~1°C). Minima in the gulf occur about a month earlier (February to March) with magnitudes of 3 to 5°C.

Five air temperature annual cycle curves (Figure 3) also have similar general shapes but somewhat different from the SST. The maxima occurs in July in Juneau but slowly shifts to August as one progresses around the gulf to Cold Bay. Maxima generally average between 10 to 15°C. Minima in air temperature are generally reached much earlier than SST (January for Juneau and Yakutat; December and January for Homer; and December, January and February for Kodiak). Minimum air temperatures range from about -1 to -6°C.

The positive correlation coefficients in the SST autocorrelation analysis at approximately 12 and 24 months suggest the sea surface temperatures in the Bering Sea "remember" the temperature regime for at least two years: cold years follow cold years and vice versa. This is probably due to the rather sluggish circulation of the eastern Bering Sea shelf. The analysis for the Kodiak, Yakutat and Sitka series suggests that the SST "remembers" what the SST was one year earlier but by two years has completely "forgotten". This is probably indicative of the much more advective nature of the shelf circulation in the Gulf of Alaska.

The dramatic year-to-year fluctuations in sea surface temperature (SST) over the past 16 years on the southeast Bering Sea shelf are illustrated in Figures 2 and 4. The mean annual SST was 4.1°C in 1963, rising to 5.4°C in 1967 before falling to 2.8°C in 1975. Since 1975, there has been a rapid

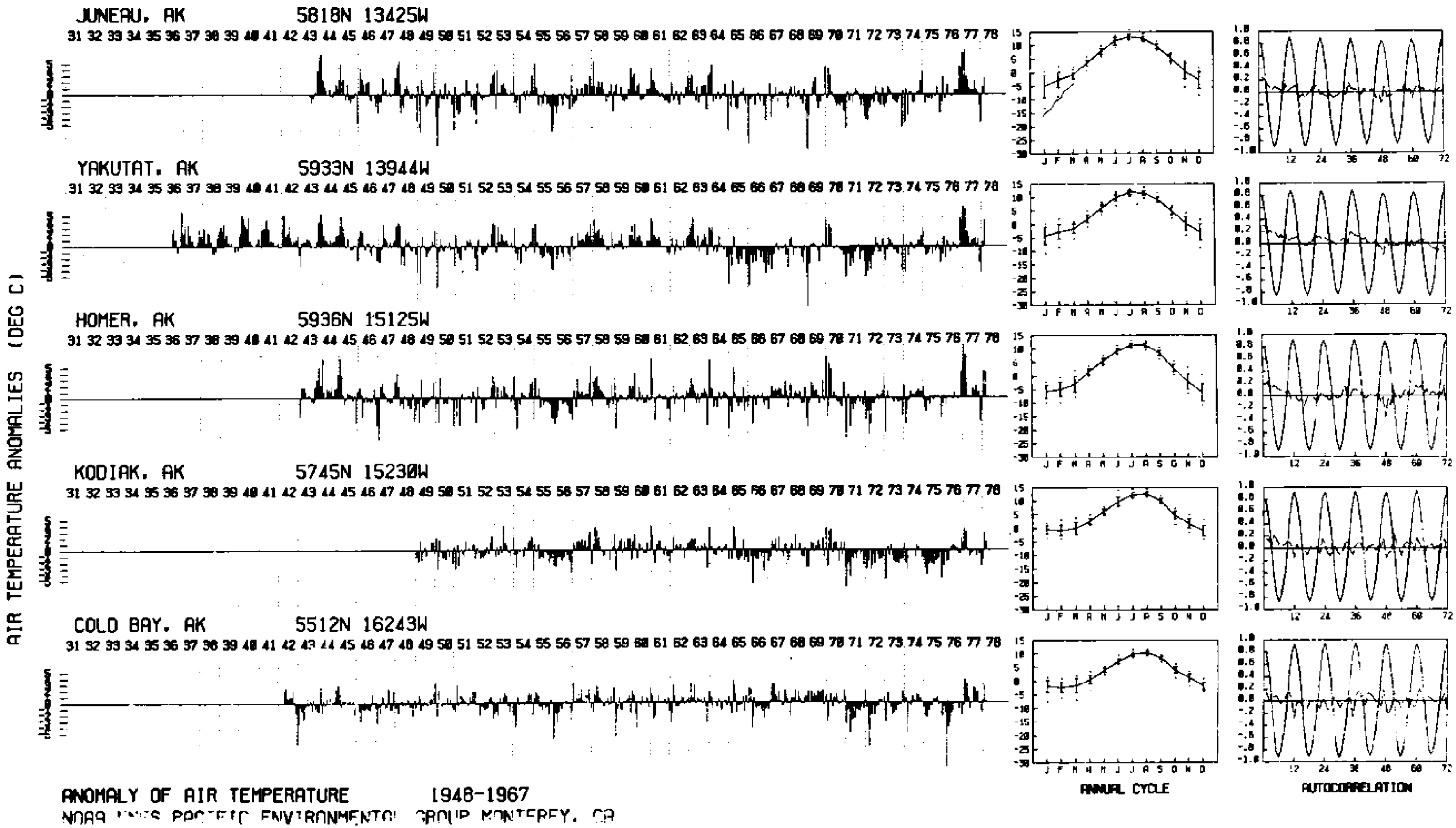


Figure 3. Monthly mean air temperature (^{o}C) data for the Gulf of Alaska and the Bering Sea. Bars on annual cycle are standard deviations, dots are extremes. Solid line in autocorrelation is the anomaly series, dashed line is the annual cycle.

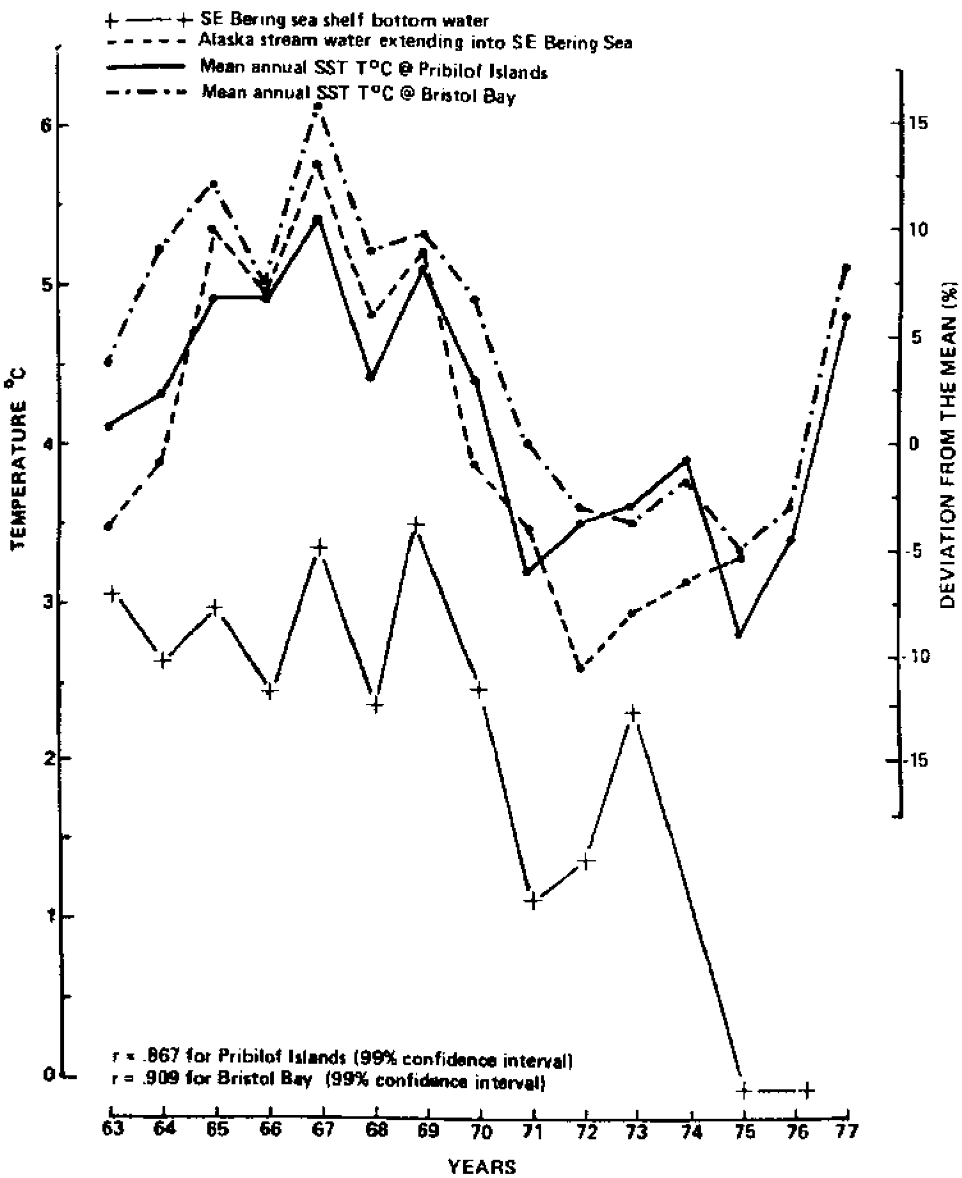


Figure 4. Mean annual sea surface and sea bottom temperatures for the southeastern Bering Sea.

rise reaching 4.8°C in 1977. Figure 5 shows these trends in the monthly mean SST. Note that the June record is significantly warmer than the February to May data. January (not plotted) is of the same approximate level as June suggesting February to May is the oceanographic winter on the shelf.

Figure 4 also illustrates the bottom temperatures on the shelf which generally follow the trend of the SST and are significantly correlated with the SST. This suggests that the process that causes fluctuations in SST also causes fluctuations throughout the water column. Reed's (1978) work, along with the strong correlation between June shelf bottom water temperature and the previous winter's degree-day data (Coachman and Charnell 1979), suggests that the cause may be found in the climate (or fluctuations in climate) of the region.

To outline this theory, Figure 6 illustrates upper air flow from the south over the Bering Sea, bringing warmer air from the Pacific Ocean. This correlates with, and is probably a cause of, the warm SST in the mid-1960s.

Figure 7 illustrates the monthly mean 700 mb pressure chart in the winter of 1974-1975, showing essentially meridional flow from the arctic south into the Bering Sea. Some of the flow then turns east and flows into the southeast Bering Sea. This cold arctic air appears to cool the underlying Bering Sea. The onset in the decline of SST coincides with anomalous southward penetration of the ice pack (Kukla and Kukla 1974) or perhaps vice versa. Johnson and Sackel (1976) have pointed out that this climatic shift had a drastic effect on some Alaska fisheries. The low salmon catches in 1973-1974 are attributed to the effects of the unusually cold winters of 1971-1972 in the Bering Sea. McLain and Favorite (1976) related the cold

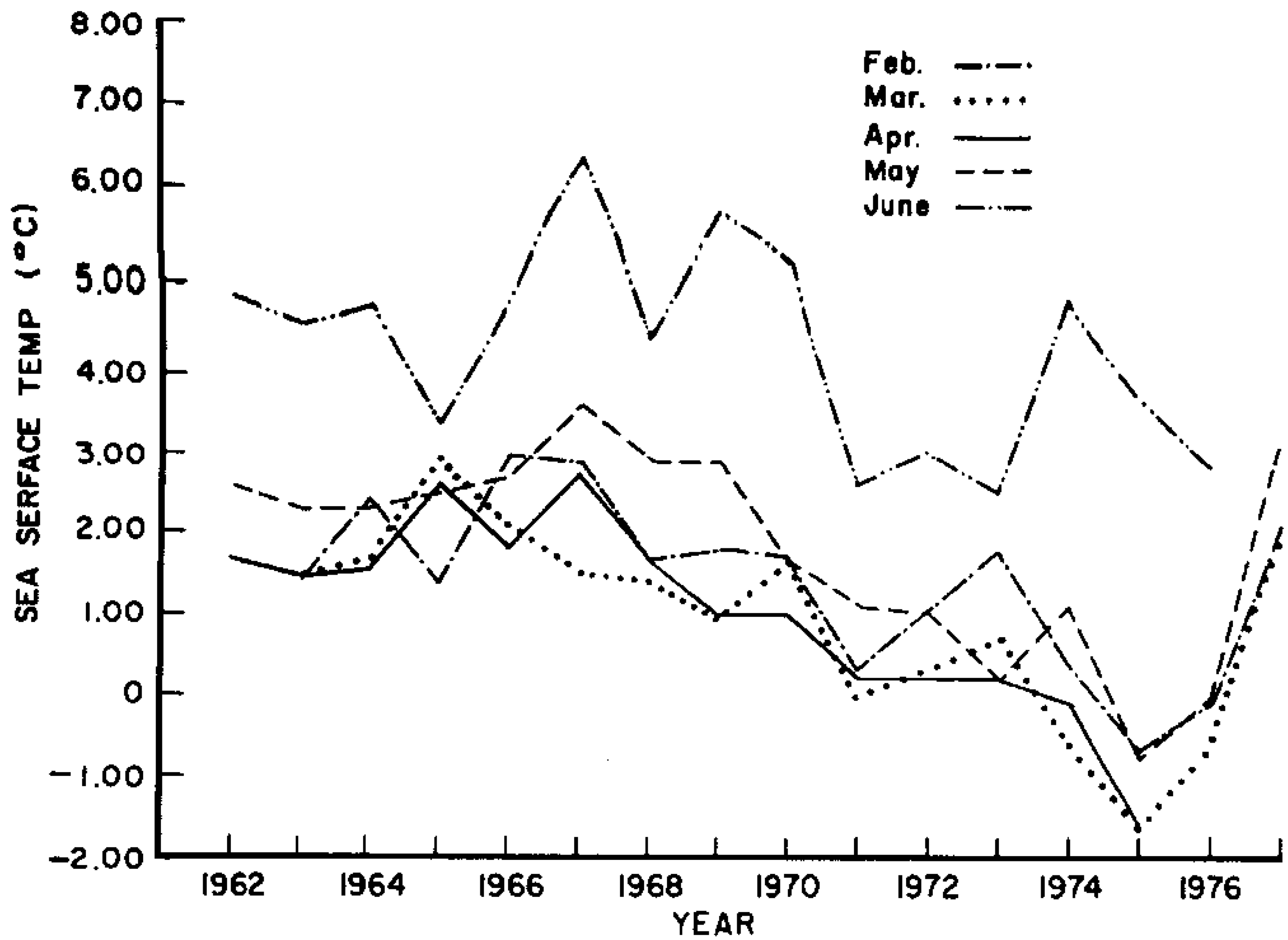


Figure 5. Mean monthly sea surface temperatures for the southeast Bering Sea.

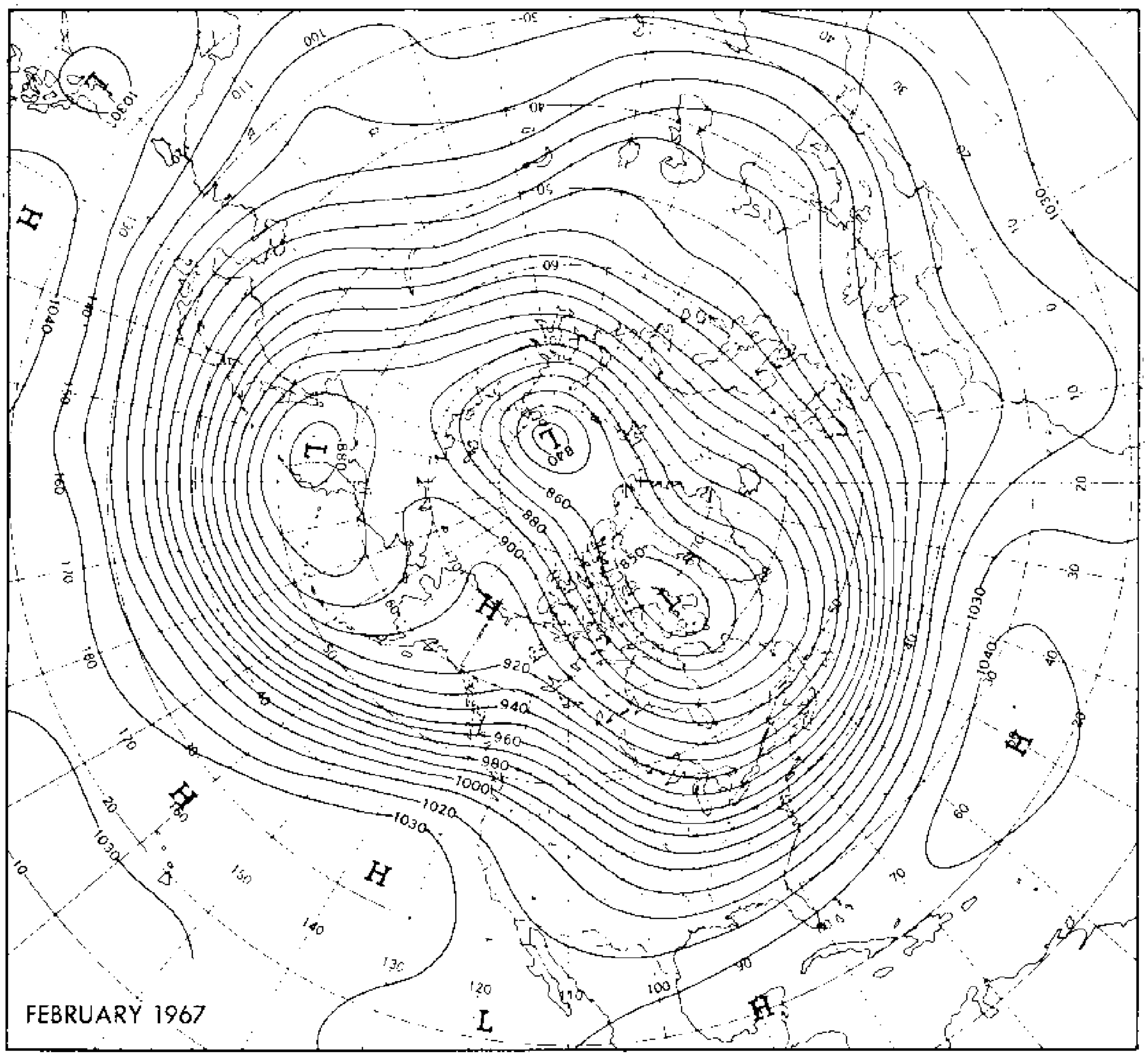


Figure 6. Mean 700 mb coutours (tens of feet), February, 1967 (Posey 1967). Flow is generally parallel to the isobars counterclockwise around low pressure areas.

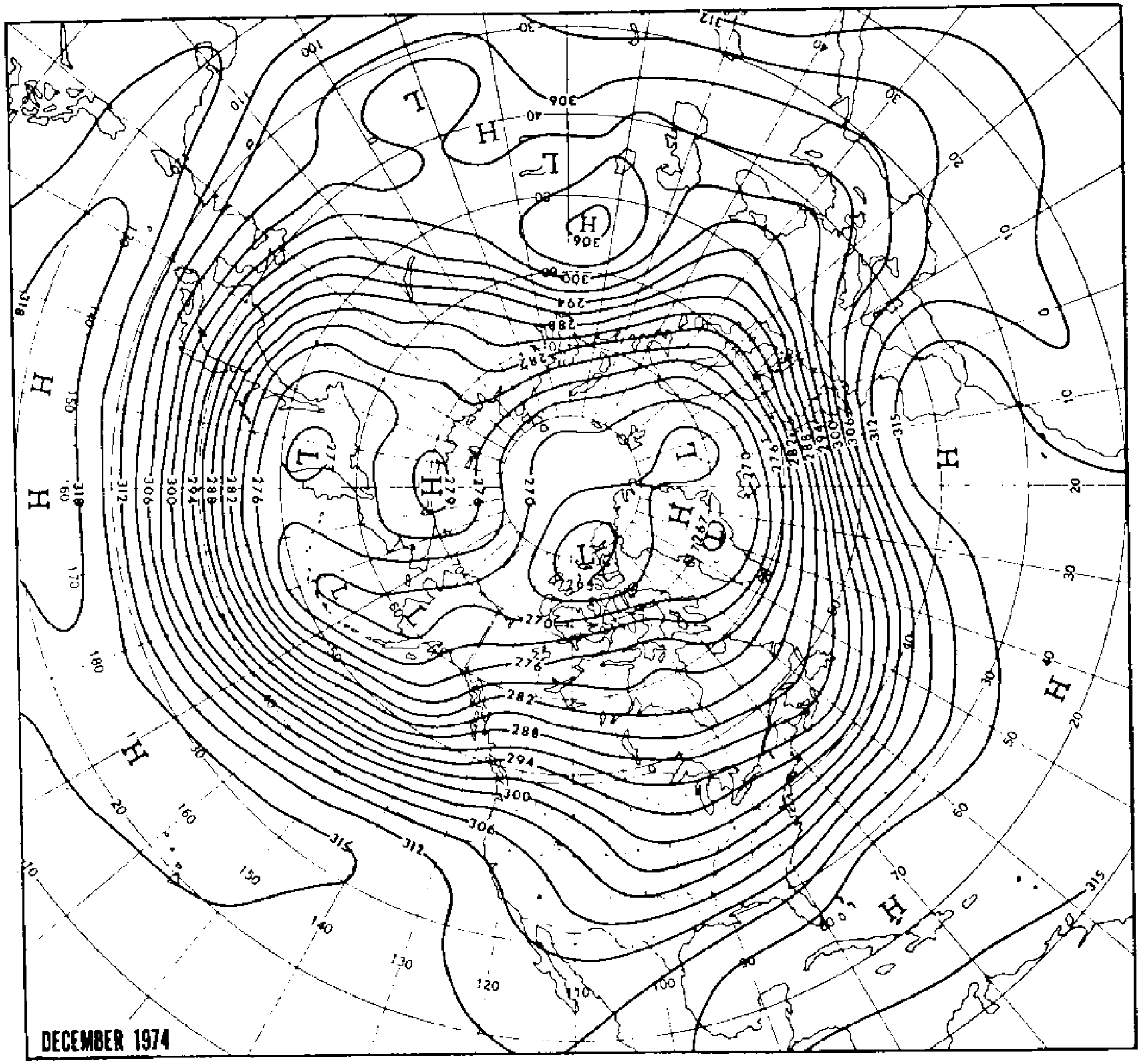


Figure 7. Monthly mean mb pressure chart (Taubensee 1975).

SST to large-scale changes in the atmospheric circulation which caused northerly wind over the Bering Sea.

Niebauer (1978) has related a subsequent rise in sea surface temperature in the Bering Sea to, again, large-scale changes in the atmospheric circulation which caused southerly flow over the Bering Sea. Figure 8 illustrates the mean 700 mb contours for February 1977 which shows the Aleutian Low over the western Aleutians and strong meridional flow into the southeast Bering Sea from the North Pacific. Namias (1978) has suggested that SST patterns in the North Pacific in November 1976 foretold the strong and persistent air flow from the south over the Bering Sea during the winter of 1976-1977. These air flow patterns can explain, to a large measure, the high SST in the Bering Sea.

Intensity of Alaskan Stream extension water (which has mass characteristics similar to Bering Sea source water near Unimak Pass) on the Bering Sea shelf north of Unimak Pass and east of the Pribilof Islands, expressed as the ratio of mixing of Alaska Stream, Bering boreal cold water and Alaskan coastal water (Kihara and Uda 1969, Kihara 1971) has been calculated by Kihara (1977). The intensity of Alaska Stream extension water into the Bering Sea is plotted against, and correlated with, southeast Bering Sea SST (Figure 4). The significant positive correlations (r = .867 for Pribilof Islands SST, r = .909 for Bristol Bay SST, both at the 99 percent confidence level) suggest that during periods of southerly upper air flow which result in warm SST in the Bering Sea, Alaska Stream water may be pushed northward through, among others, Unimak Pass onto the outer reaches of the Bering Sea shelf. The converse may also be true; flow from the north keeps Alaska Stream water out of the Bering Sea. Kihara (1971) has reported that the strength of the Alaskan Stream extension water in the summer season

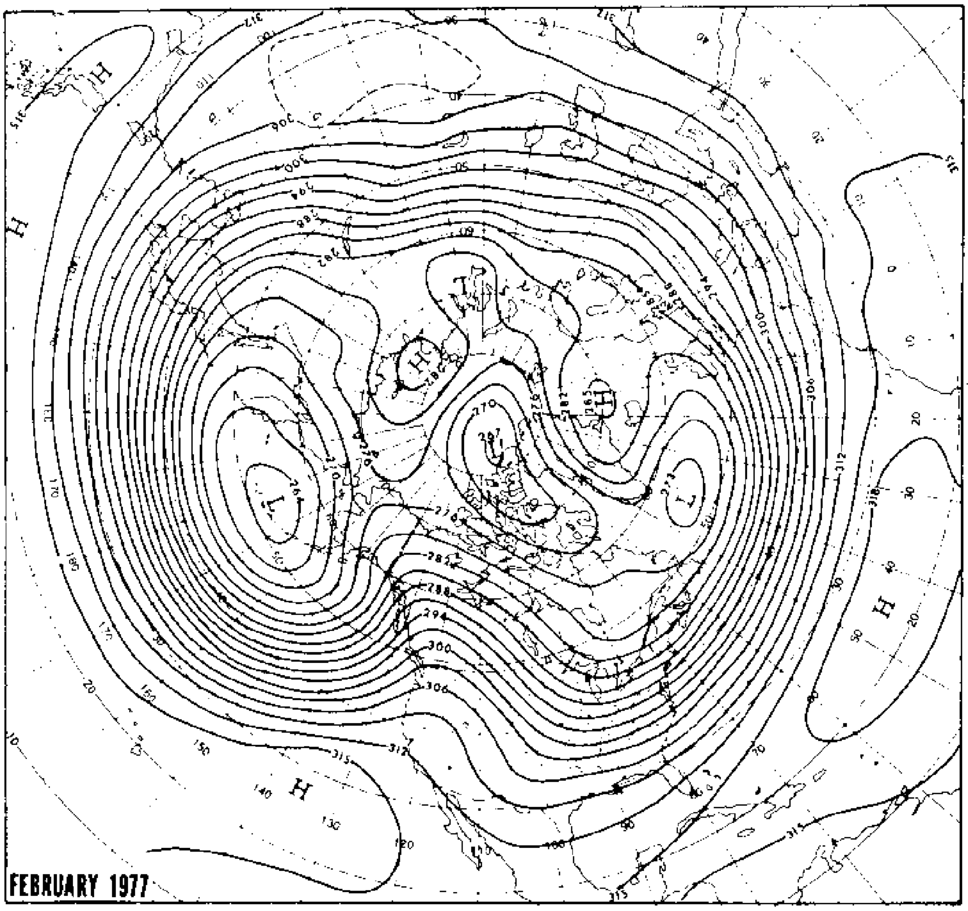


Figure 8. Mean 700 mb (dam) for February 1977 (Dickson 1977).

is clearly related to the February-to-July mean surface wind at Unimak Island.

A question arises, though. Is the rise in SST on the Bering Sea shelf due to air-sea interaction with warmer southerly wind or to advection of warm Alaska Stream water, and vice versa? The water mass analysis of Kihara and Uda (1969) and Kihara (1971) was done with data between 60 m and the bottom of the Bering Sea, suggesting little direct relation to SST. In addition, Coachman and Charnell (1979) suggest that advection is less important in the transport of heat on the shelf. They also define Alaska Stream water as $3.0 \leq T°C \leq 4.0$. Figure 4 shows SST often greater than 4.0°C. Reed (1978) suggests that, at least in the summer-fall, heat gain and loss on the southeast shelf is primarily through the air-sea interface. A speculation is that the amount of Alaska Stream water mixed onto the outer reaches of the shelf and fluctuations in SST are related through the mean weather, but that SST does not depend directly on Alaska Stream water. More data and analysis are needed to resolve this question. The Alaska Stream water of Kihara (1971) is probably the same as the Alaska Stream/Bering Sea water of Coachman and Charnell (1979) and thus slowly intrudes as a bottom layer only up to the front at the 100 m contour.

ICE

The ice cover on the eastern Bering Sea shelf varies over 1000 km in north-south extent from summer to winter. During the winter this relatively shallow (~100 m), but extremely wide shelf (~500 km), becomes covered with pack ice reaching south, at times, to the shelf break (Figure 1). The ice is on the order of 1 to 2 m thick in unstressed flows that can become 10 m or thicker in pressure ridges. The shelf is ice-free in summer.

Figure 9 illustrates the seasonal mean percent of ice cover. The ice generally begins its seasonal southward formation at the Bering Strait in November. Most of the ice is formed and melted within the Bering Sea with very little being carried onto the shelf through the Bering Strait. Ice formation progresses at a mean rate of 12 to 13 percent per month reaching 60 to 65 percent coverage in late March. The ice advance actually consists of a rapid advance (~24 percent per month) in November and December before slowing (~6 to 7 percent per month) from December to March. The ice appears to dissipate faster than it forms, at a mean rate of 18 to 20 percent per month from late March to early July. Superimposed on this seasonal ice cycle are large deviations from the mean driven by short term climatic fluctuations (~year). For example, consider January southern ice limits in Figure 10 for 1975 to 1979. Late January ice conditions for 1975 are illustrated showing ice extending 10 to 45 nautical miles south of the Pribilofs on the western edge of the shelf and covering part of Bristol Bay to the east. Figure 4 illustrates the cold SST of this time period. The extremely low SST in 1975 may be due both to southward movement of the ice around the Pribilofs and to the air flow shown in Figure 7.

Figure 10 illustrates the ice conditions for 1977, showing the position of the ice to be much farther north than the colder year of 1975. Specifically the ice edge is on the order of 2° or 120 nautical miles north of the Pribilofs on the western shelf and is almost excluded from Bristol Bay to the east. This is again related to the air flow as illustrated in Figure 8.

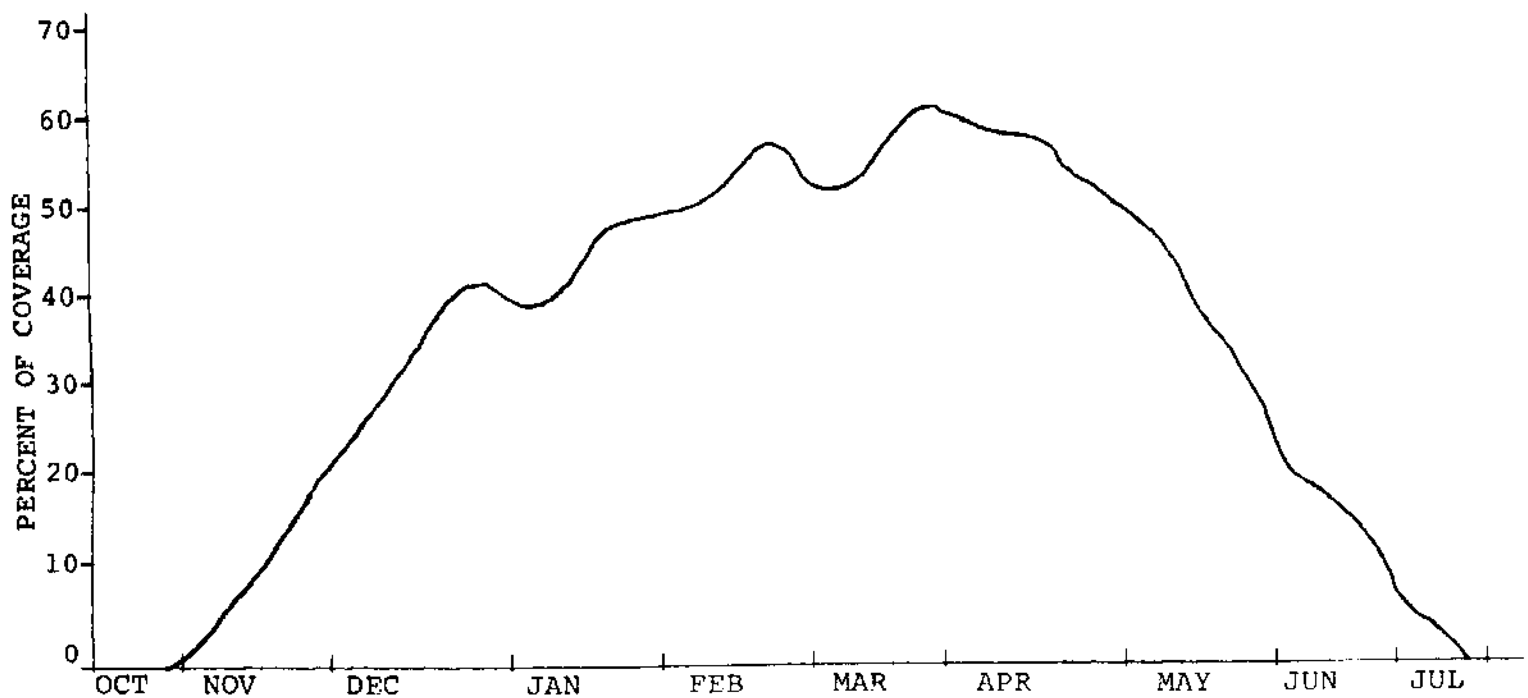


Figure 9. Mean (1973 to 1978) percent ice cover for the eastern Bering Sea (east of 175°W).

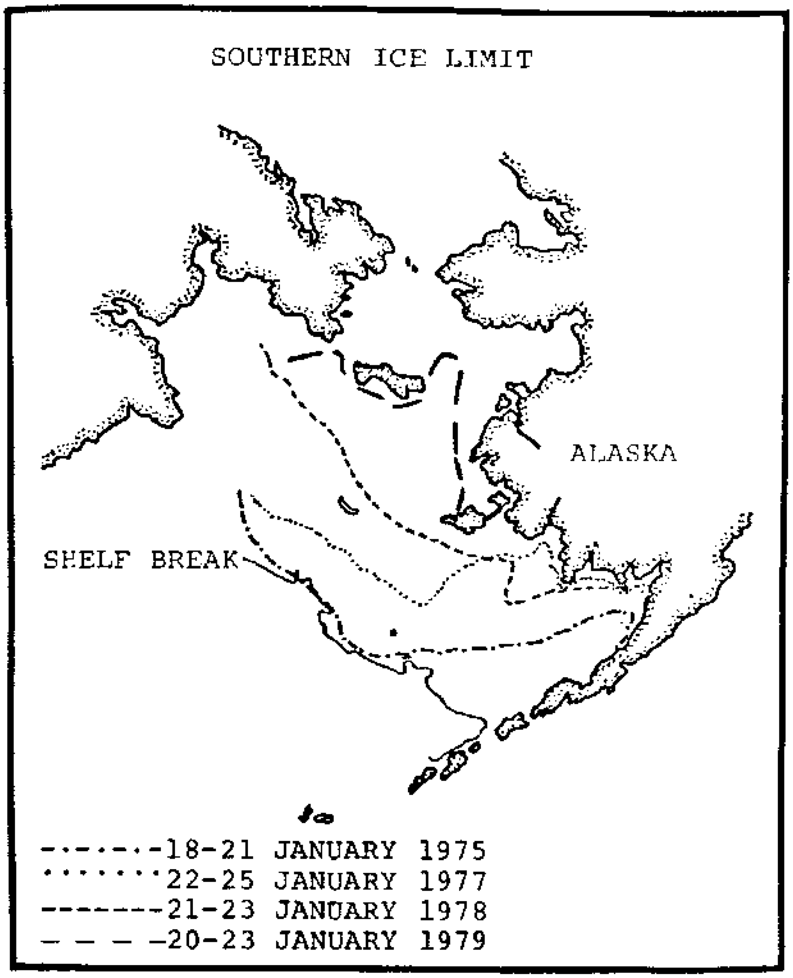


Figure 10. Southern ice limit for 1975, 1977 1978 and 1979.

Figure 11 shows the 700 mb situation for 1978 which is similar in some respects to 1977. The SST (Figure 4) and ice edge position (Figure 10) for 1977 and 1978 are similar. Note that the ice edge is nearly 3° or 180 nautical miles north of the Pribilofs in 1978. This pattern of southerly air flow has persisted into the winter of 1978-1979 with the result that the ice edge position in January 1979 (Figure 10) is even farther north than in 1978.

It is interesting to note (and to place the most recent [1975 to present short term climatic fluctuation in perspective) that for the three-year period from 1975 to 1978, there has been nearly a 3°C rise in mean annual SST of the southeastern Bering Sea shelf water. Further, winter SST departures from monthly means are even more dramatic than yearly means (Figure 4). In March and April 1975, the SST was about 2.7°C below normal while by April 1978, the SST was 2.2°C above normal giving a rise in SST or nearly 5°C over three years. This coincides with the strong northward retreat of the ice edge in the Bering Sea.

Figure 12 shows the preferred primary and secondary storm tracks for the Gulf of Alaska-Bering Sea region for March. Generally, storms are the norm for these two regions. However, the deviations from these mean conditions can be quite dramatic and are probably related in some way to fluctuation in sea temperatures and ice conditions. For example, compare the 700 mb flow for March 1977 and 1978 and the associated surface storm tracks. Figure 13 shows the well-developed Aleutian Low located over the eastern Bering Sea with little ridging over Alaska. This allows the storms (Figure 14) to migrate about equally over the Gulf of Alaska and Bering Sea.

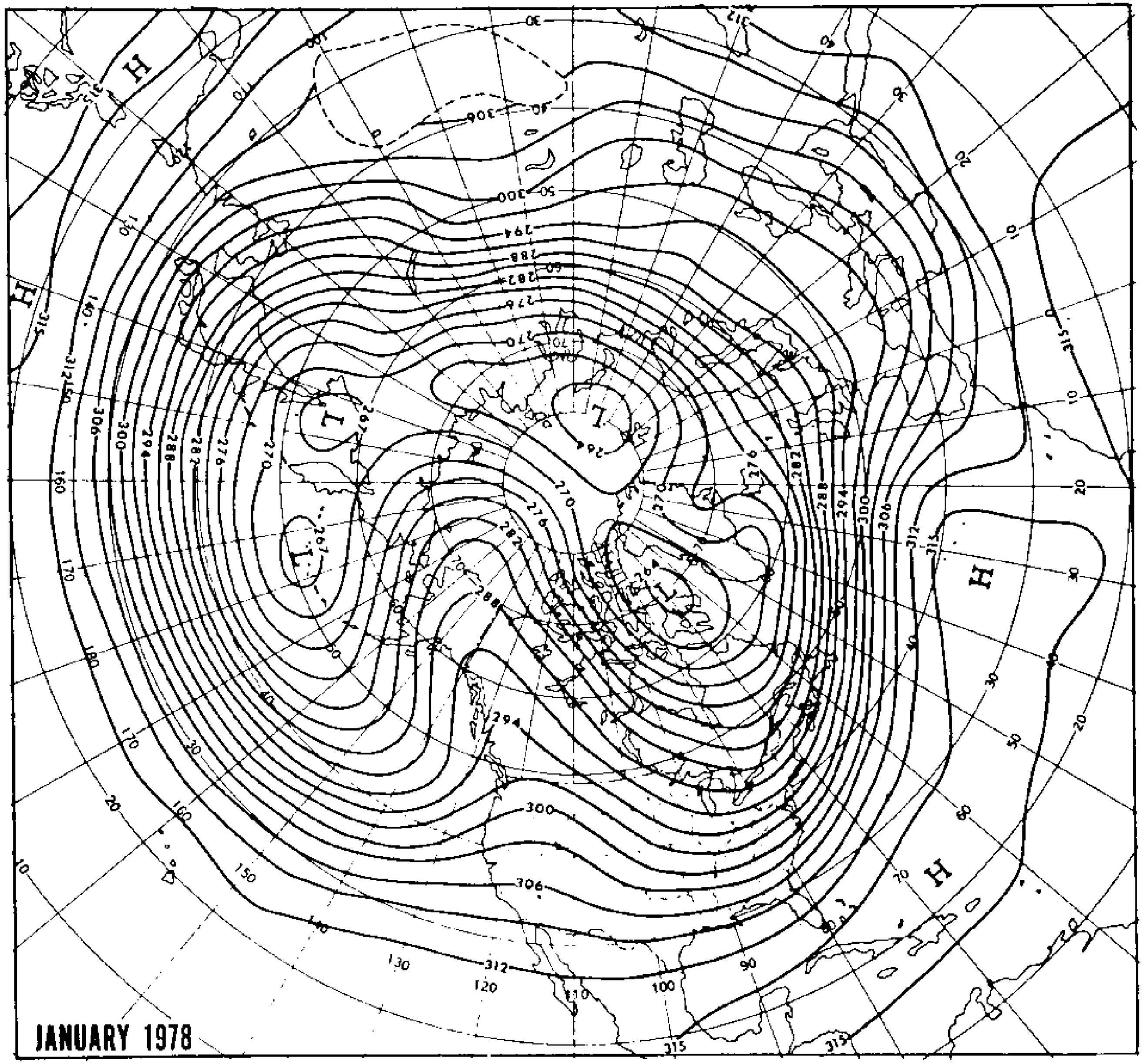
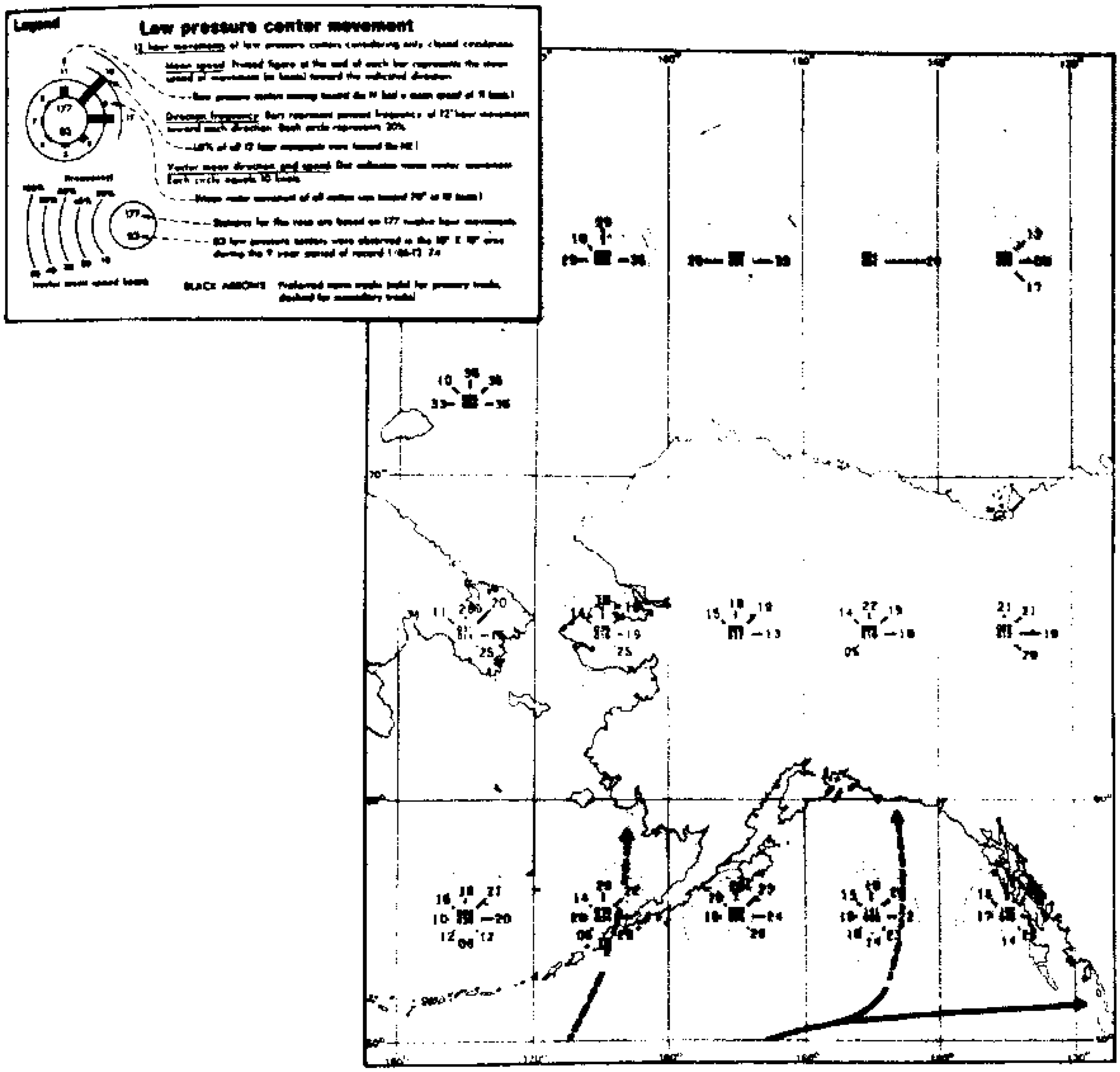


Figure 11. Monthly mean 700 mb pressure chart (Wagner 1978).



March

18 Low pressure center movement

Figure 12. March mean storm tracks for the Gulf of Alaska and Bering Sea (Brower et al. 1977).

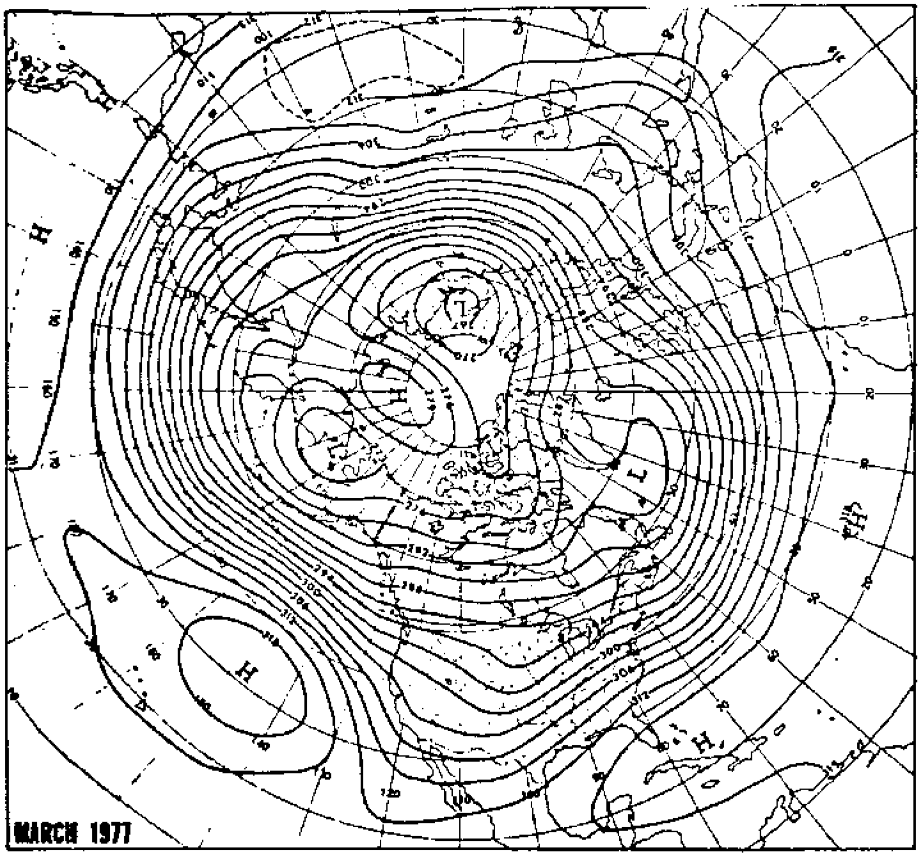


Figure 13. Mean 700 mb height contours (dam) for March 1977 (Taubensee 1977).

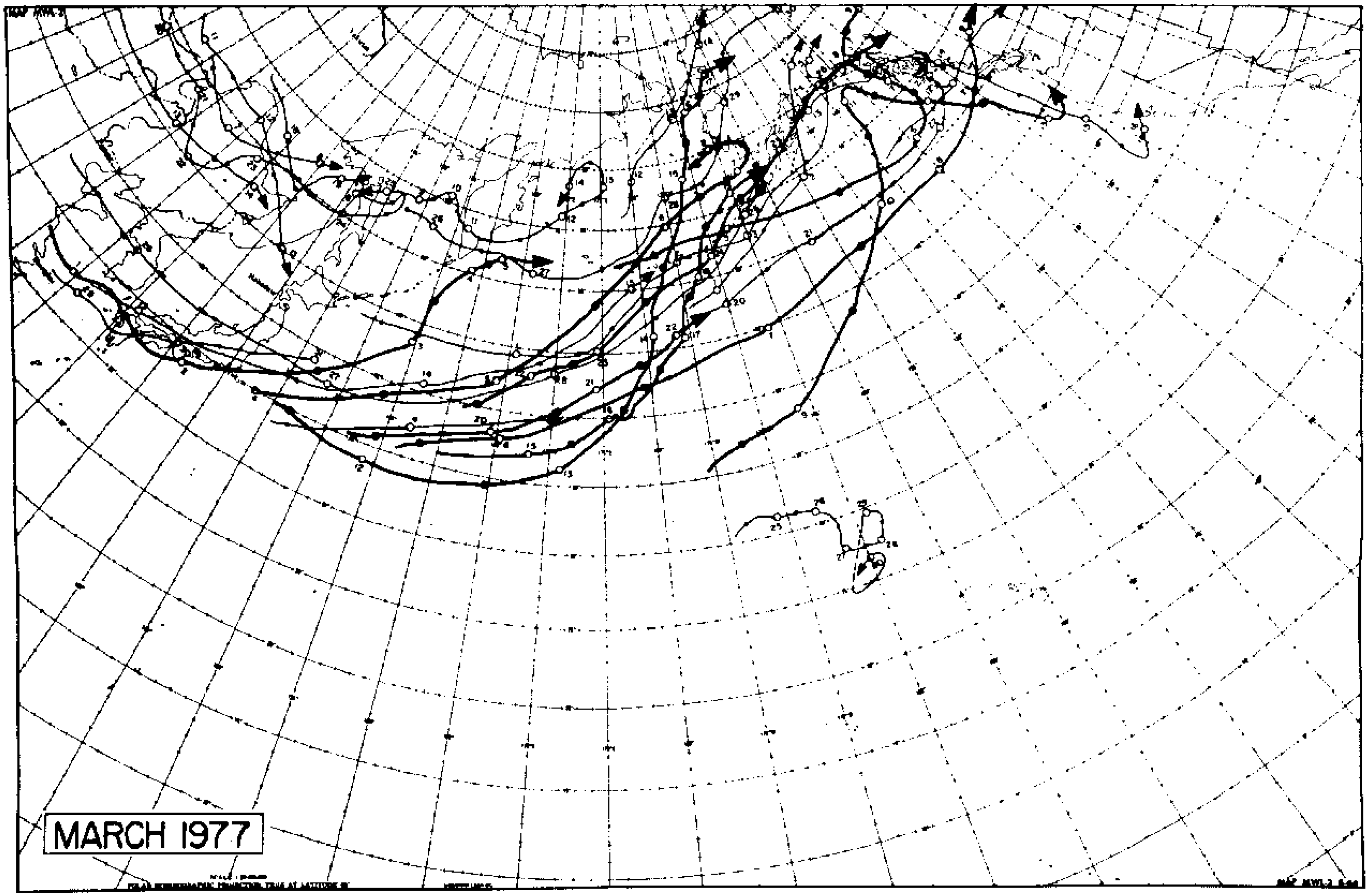


Figure 14. Principle tracks of centers of cyclones at sea level, North Pacific, March 1977. Figure next to open circle indicates date. Solid circle indicates intervening 12-hourly positions. Only those centers which could be identified for 24-hours or more are included.

Figure 15 shows the Aleutian Low over the North Pacific and Aleutian Chain with an enormous ridge/high over Alaska, the northern Bering Sea and Siberia. Figure 16 shows that this 700 mb pattern forced the storm tracks south into the Gulf of Alaska and almost eliminated them from the Bering Sea. Inspection of 12 hourly weather charts from February to May in both years showed that in 1977 only one high pressure system (mostly fair, clear and perhaps calm) actually passed over the Bering Sea. In 1978, the Bering Sea was under the influence of high pressure approximately seven times.

SUMMARY REMARKS

This report has outlined some of the relatively large-scale (and in general not very subtle) fluctuations in SST, surface and 700 mb winds and ice coverage, and their interrelationships over the last 15 years. The study areas are the shelf regions of the Gulf of Alaska from Sitka to Kodiak and the southeastern Bering Sea. The time considered is approximately the early 1960s to the present.

The mid-1960s were a period of southerly air flow and higher SST in these shelf regions. The early 1970s were a period of northerly air flow resulting in lower SST and extensive ice coverage in the Bering Sea. Suddenly in the mid-1970s, the air flow reversed, SST rose and the seasonal ice coverage in the Bering Sea retreated.

Autocorrelation of SST time series suggests that the Bering Sea "remembers" what the SST was at least two years past, whereas the Gulf of Alaska seems to "remember" less than two years. This is probably related to the low current flow on the Bering Sea shelf as opposed to the stronger flow on the Gulf of Alaska shelf. In addition, fluctuations in SST and

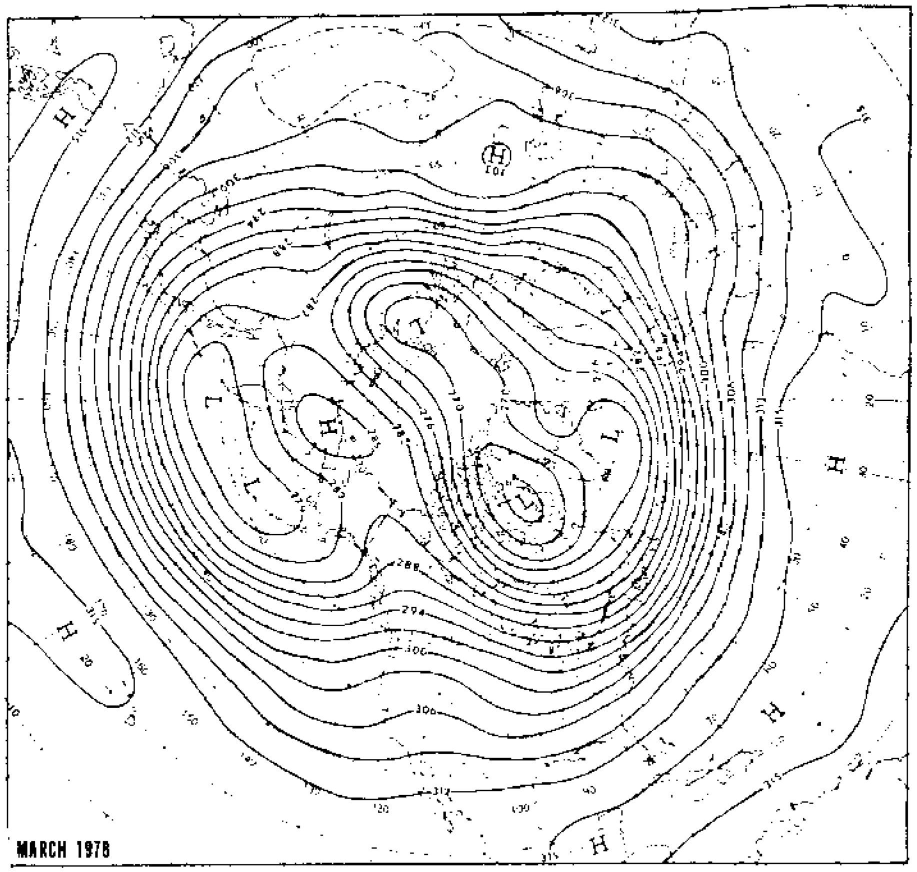


Figure 15. Mean 700 mb contours (dam) for March 1978 (Taubensee 1978).

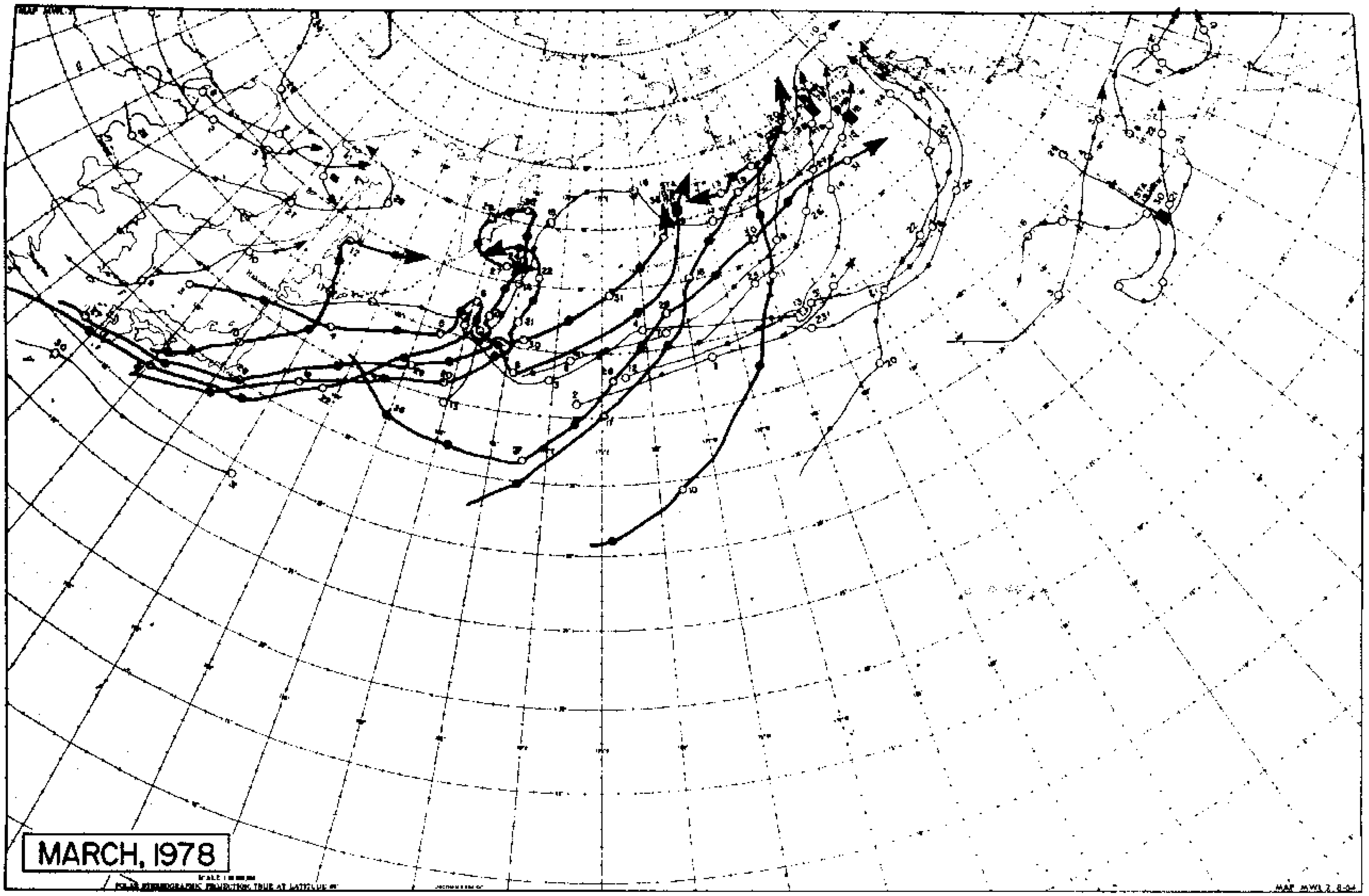


Figure 16. Principle tracks of cyclones at sea level, North Pacific, March 1978. Figure next to open circle indicates date. Solid circle indicates intervening 12-hourly positions. Only those centers which could be identified for 24 hours or more are included.

ice coverage in the Bering Sea seem to follow or reflect the weather. Fluctuations on the Gulf of Alaska shelf probably also reflect, to some extent, the weather/climate. Namias (1978) has suggested that SST patterns in the North Pacific in November 1976 foretold the strong and persistent air flow from the south over the Bering Sea during the winter of 1976-1977. More work is needed on this problem.

Finally, it is worth pointing out that all the data presented and analyzed in this report were obtained at little cost from various (mostly U.S. Government) sources. Thus, the data are available to fishermen, fishery managers, research scientists, etc. for use in studying trends in oceanographic and meteorological climates without the need for large research projects.

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