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National Weather
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ABSTRACT

The ice coverage on Cook Inlet was extensive during the 1978-1979 ice season with the maximum approaching the record 1970-1971 season; however, the ice was much thinner and softer than in the 1970-1971 season. The peak extent was reached in the late part of February when ice covered nearly all the inlet north of Anchor Point and Cape Douglas. The southward extent of the ice at its maximum reached Cape Douglas on the west side but only to Anchor Point on the east side. This is attributed to a greater northward heat flux in the eastern than on the western lower inlet due to the Kenai Current.

The maximum observed ice thickness of 30 cm was reached in January and February. This was also the thickness estimated using accumulated frost degree-day data.

Ice drifted south of Cook Inlet into Shelikof Strait on February 27 and 28, then slowly disintegrated. The last day the ice was in evidence in Shelikof Strait was March 7.

Some heat transport considerations which may delay the onset of ice by several weeks are discussed and an attempt is made to explain the mechanisms involved.

DATA SOURCES

Ice observations for the Cook Inlet ice forecasting program and for this report come mainly from TIROS-N satellite imagery. TIROS-N is in a polar orbit approximately 840 km above the earth

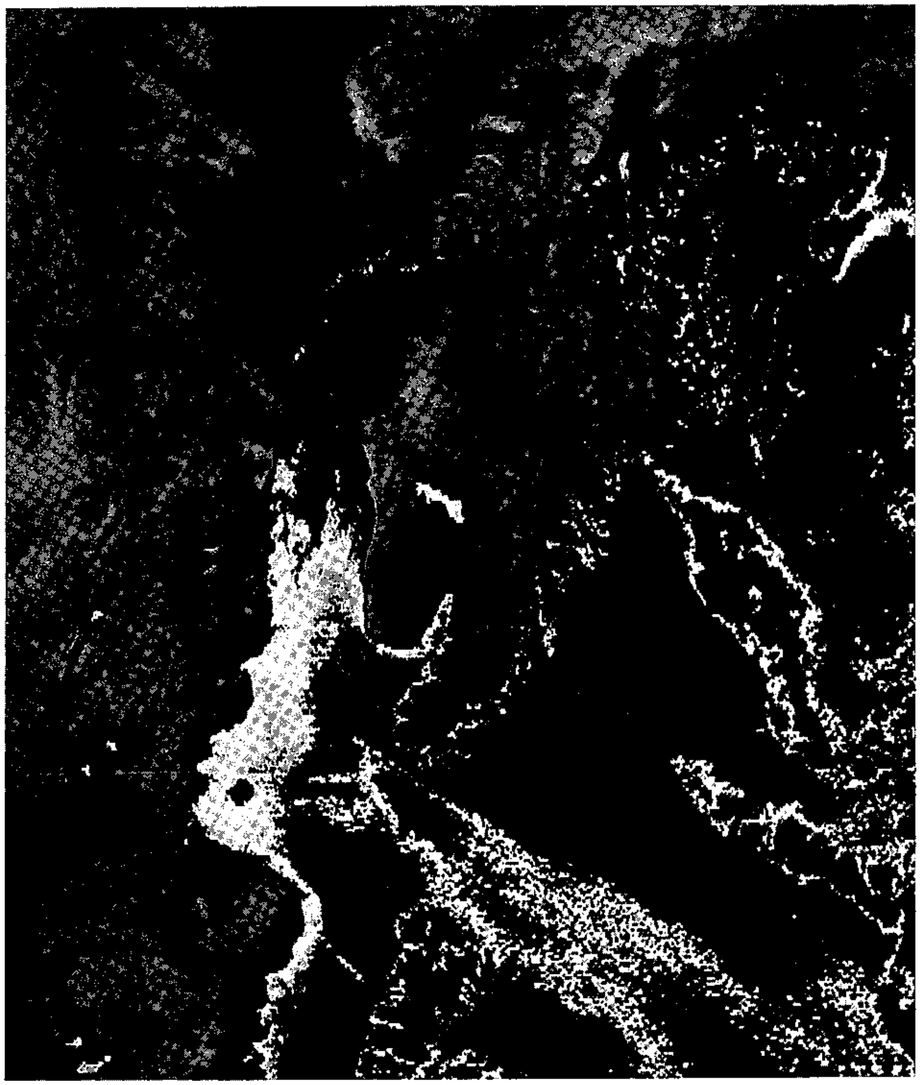

Figure 1. Double enhanced satellite imagery from 0954 AST, February 6, 1979. (In this example, the black shading over the northern inlet waters is ice, while the white to the south is water at $0^{o}C$.)

and furnishes two good observations (1 km resolution) of Cook Inlet each day; these observations may be in either the visual (0.55-0.68μm) or infrared (10.5-11.5μm) spectrums. The infrared images can be enhanced to more easily define sea surface temperatures; an example of enhanced infrared imagery is shown in figure 1. Images in the visual spectrum are not very useful during the ice season due to the lack of daylight. Ice observations are also obtained from oil platforms (See figure 2), from the Union Chemical dock at Nikiski, and from occasional ship reports. Sea water temperatures are received from the Phillips, Dolly Varden and Dillon Platforms. At all three platforms, the sea water intake is located approximately 5 m below sea level and the temperature is measured as it enters a heat exchanger. These thermometers are periodically checked by National Weather Service representatives.

PRE-ICE CONDITIONS

Air temperatures during the month of October in Anchorage averaged 2.5°C above the long-term normal temperatures shown in figure 3. Cook Inlet water temperatures at the Phillips and Dolly Varden platforms, as shown in figure 4, were above 10°C through the middle of October then began to fall quite rapidly. Air temperatures at Anchorage in November were a little above normal during the first part of the month, then climbed well above the normal on the 19th, as southerly flow was established over Cook Inlet, and remained well above normal through December 13.

Water temperatures at the Phillips and Dolly Varden platforms cooled rapidly through late October 1978, at a rate of about 0.4°C/day and 0.3°C/day, respectively (figure 4). However, these rates were reduced dramatically--by a factor of 1/3 and 1/2, respectively--during the first 15 days of November. A second period of rapid cooling--about 0.6°C/day--ensued over November 18-20. This phenomenon, i.e., a several weeks-long period of reduced heat loss, has been observed in water temperature data from these platforms in previous years (1974-1977).

Mechanisms which affect the heat content of northern Cook Inlet waters include air-sea exchange, fresh water drainage, and heat flux from adjacent waters (southern Cook Inlet). If the only mechanism was heat loss to the atmosphere, then one would expect a rather uniform cooling of waters through November 15, followed by a period of uniform but reduced cooling. While the latter inferred cooling is consistent with water temperature observation, uniform cooling is not observed during early November. The discharge rate of freshwater entering northern Cook Inlet, north of the Forelands, rapidly decreased during October 1978 (figure 5). The effect of reduced drainage may be to weaken estuarine circulation while lower discharge temperatures (not available in 1978) would reduce ambient water

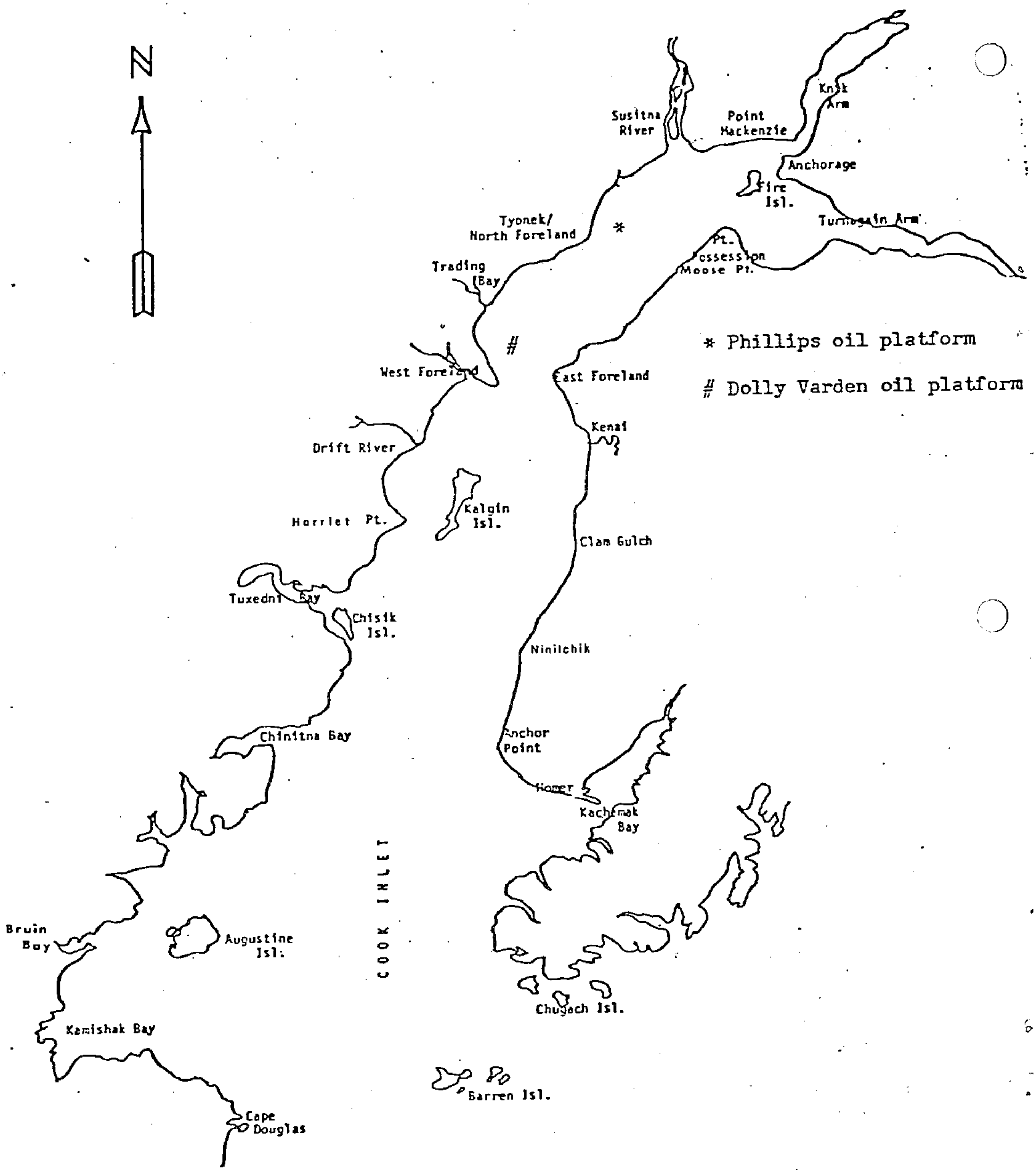

Figure 2. Map of Cook Inlet, Alaska.

temperatures. There is no obvious relation between this mechanism and the observed water temperature signal. Instead, an explanation in terms of increased heat flux from southern Cook Inlet is proposed.

Recent observations (Schumacher et al., 1978, 1979; Reed and Schumacher, 1979) indicate that coastal flow in the northwest Gulf of Alaska is dominated by the Kenai Current. This current flows along the Alaska coast, primarily through Kennedy Entrance and southwest through Shelikof Strait. While the bulk of the transport bypasses Cook Inlet, the Kenai Current does furnish a source of warm water. Furthermore, its peak transport occurs during the fall, over a 2 to 3 week period. During October 1977, temperatures in the upper 100 m were greater than 8°C. Such waters could be either advected or tidally diffused into northern Cook Inlet. A net circulation scheme (Burbank, 1977) suggests that waters from Kennedy Entrance flow northward along the eastern side of southern Cook Inlet and into northern Cook Inlet. The hypothesis that the Kenai Current waters are a source of heat related to the water temperature observation in northern Cook Inlet is also supported by satellite imagery. A warm tongue of water was observed along eastern Cook Inlet as far north as the East Forelands in the fall 1979 imagery. The 1979 satellite imagery suggests two pulses of the warm Kenai Current water occurred in the fall between October 5-18 and October 30-November 6 at the oil platforms. There is some suggestion that the same thing may have occurred in 1978 at Dolly Varden Platform. However, it seems that the warm Kenai Current water is absent at the platforms after about mid-November, consistent with the reduction in transport of the Kenai Current near Kennedy Entrance by the end of October (Reed and Schumacher, 1979). This suggests a lag time of about 2-3 weeks at the platforms for the reduction of warm water flow compared to Kennedy Entrance.

The decrease in the cooling rate described probably delays the onset of significant ice in Cook Inlet by a minimum of 2 to 3 weeks and is persistent enough to be considered a yearly event. Serious consideration of the phenomenon must be incorporated in oil spill and hazardous substances-pollution contingency plans because supporting models do not consider heat flux into northern Cook Inlet. Full investigation--a major undertaking more appropriate to the field of oceanography than meteorology--is required for a formal hypothesis and a better understanding of the mechanisms involved in the observed water temperature signal.

DESCRIPTION OF ICE CONDITIONS

The sea water temperature continued to fall from mid-November until mid-December when it reached 0°C. The first ice of the season was reported in Knik Arm on November 16; this was freshwater ice from the Matanuska River. Some sea ice was

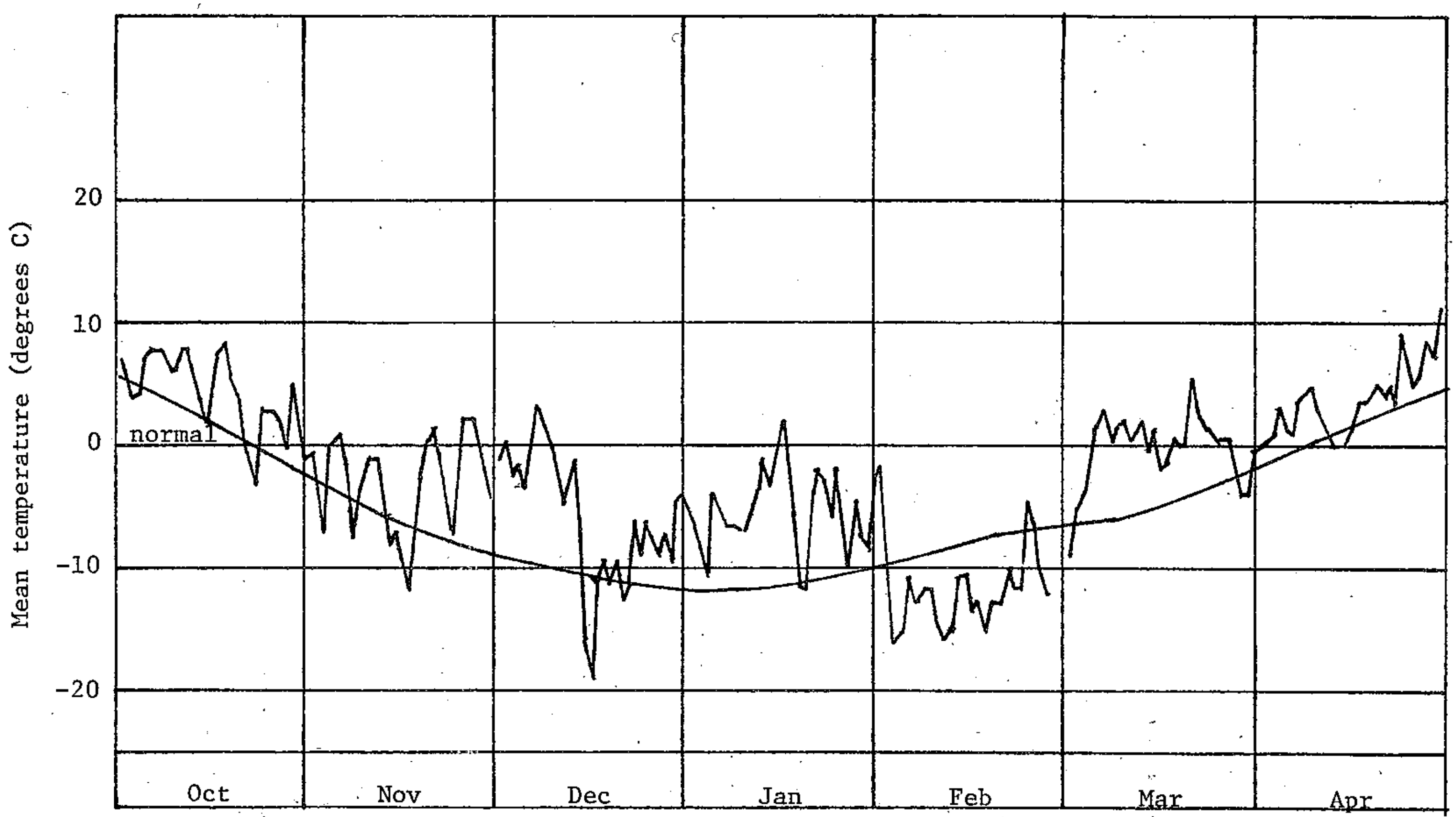

Figure 3. Mean daily temperatures at Anchorage, Alaska, 1978-1979.

observed east of Fire Island on November 21; on November 24, a 5% concentration of ice was reported at the Phillips Platform. Significant ice (see glossary), however, was not observed at Phillips platform until December 16 which was also the coldest day of the season at Anchorage (-24°C). A shift from southwest flow of air aloft to a cold zonal flow had occurred on December 14 and brought much colder air over the Cook Inlet area. Southwest flow was again established by December 18 and temperatures rose above normal and continued there, with two minor interruptions, until January 12. During this time there was a slow but rather steady increase in the cumulative frost degree-day[1] total (figure 6) and ice; by December 25, an open pack of new and young ice of medium floes and brash (see glossary) existed north of a line from the West Forelands to Boulder Point.

By January 12, a close pack of new to young ice covered the inlet north of the Forelands. North of a line from the East Forelands to Kalgin Island to Chisik Island there was an open pack of thin and young ice consisting of small floes and brash; a very open pack extended south along the east side of the inlet to Ninilchik. The pack was very stable from January 13 through February 5 with little growth or disintegration.

A large surface and upper-atmosphere high pressure system developed over the Chukchi Sea on February 1 and formed a block in the migratory storm track for most of Alaska. This block continued with only minor changes through the end of the month. Temperatures over Cook Inlet dropped below normal on February 2 and remained there, with the exception of one day, through March 2.

Ice growth resumed on February 2 and continued at a steady rate until maximum coverage was reached on February 27 when a very close pack of brash to medium floes extended north of a line from Anchor Point to 10 km east of Chinitna Bay then south to Cape Douglas. A close pack of ice extended north of a line from Anchor Point to Cape Douglas.

On February 27, with relatively high pressure over southwest Alaska, a moderate low pressure center moved south of the Alaska Peninsula and just south of Kodiak Island, and continued into the

1 - Frost Degree-Days are defined as the difference between 0°C and the mean daily temperature. When the temperature is less than 0°C the correlation is one to one and positive. When the temperature is above freezing, the correlation is 3.33 to one and negative because the rate of decay of sea ice is approximately 3-1/3 times the rate of growth.

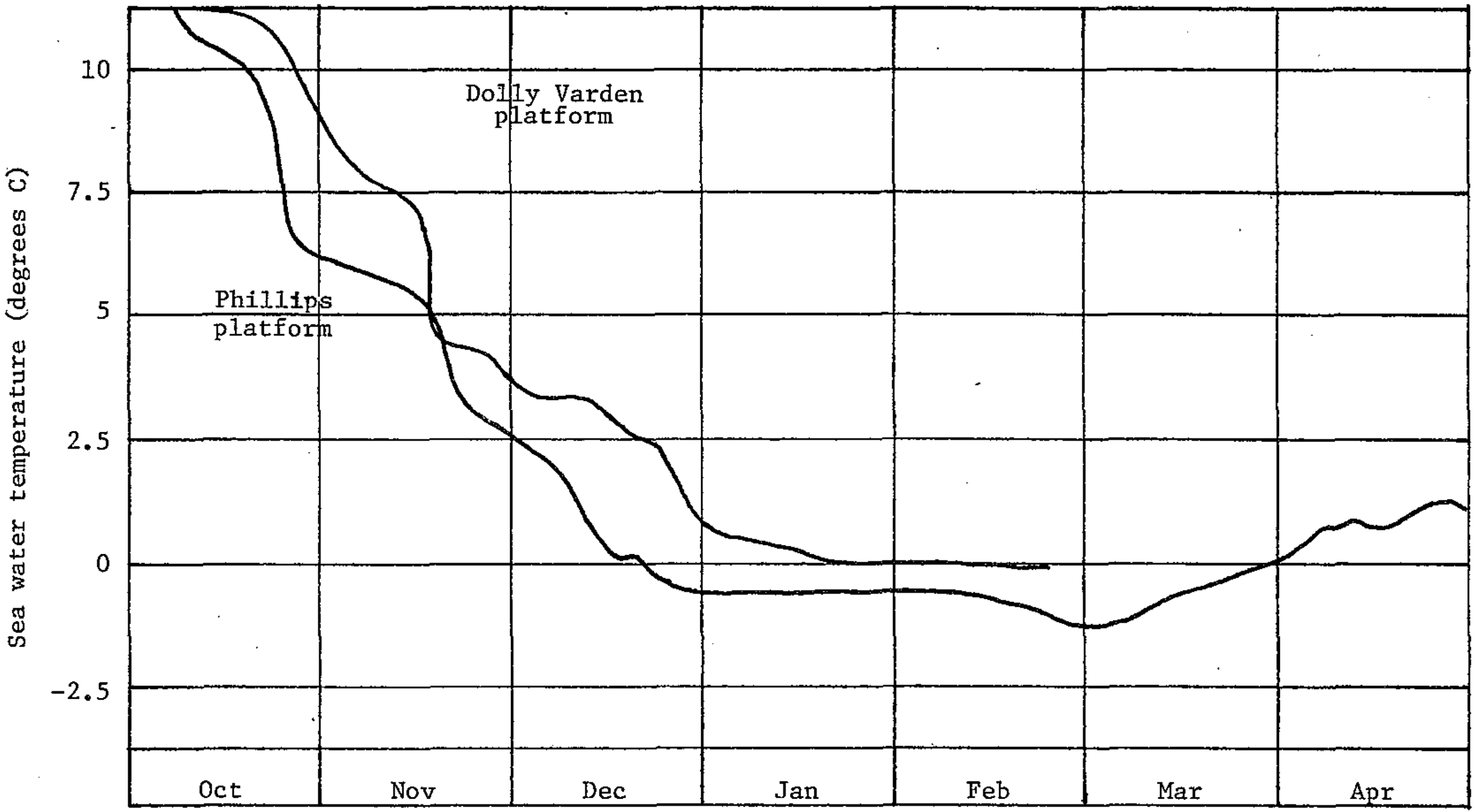

Figure 4. Sea water temperature in Cook Inlet, Alaska, 1978-79.

eastern Gulf of Alaska. After a long cold spell, southwest Alaska and Kamishak Bay warmed to near 0°C on the 27th, then cooled again on the 28th. As the low passed south of Cook Inlet, strong west to northwest winds were established across Kamishak Bay and the extreme southern inlet. On February 28, a ship reported that "ice dangerous to navigation" had moved out of Cook Inlet into Shelikof Strait. The ice was observed as far south as Halo Bay (approximately 50 km southwest of Cape Douglas) and extended to 20 km offshore from the Alaska Peninsula-side of Shelikof Strait. Pans up to 20 m long were reported in ice that ranged up to close pack. By March 8, the ice in Shelikof Strait had disintegrated.

The high pressure block that dominated mainland Alaska through February broke down on March 1 and warming began over Cook Inlet. By March 5, the main close-pack concentration extended across the inlet in the vicinity of the Forelands, while open-pack covered the remainder of the northern inlet and only a few strips and patches of ice existed south of the Forelands. Shore-fast ice remained in Kamishak Bay out to about 3 km. Ice continued to rot and disintegrate so that by March 28 only a few strips and patches of ice were located in mid-channel from north of Kalgin Island to west of Fire Island. The morning of March 31 was the last time the Phillips Platform reported significant ice.

SUMMARY

In the 1978-1979 ice season, ice coverage in Cook Inlet probably approached the limit to which it can extend. Growth farther south would have put the ice in an area of the inlet where warmer waters flow from the Gulf of Alaska in the Kenai Current which enters Kennedy Entrance and exits into Shelikof Strait (Reed and Schumacher, 1979). It is further noted that the observed limit of ice cover on southern Cook Inlet indicates open water on the eastern side north to Anchor Point. This is consistent with the suggestion that warmer Kenai Current waters significantly affect southern Cook Inlet water temperatures. The observation of open waters is also consistent with the circulation scheme presented by Muench et al. (1978). A conservative estimate of the amount of calories available to melt sea ice at Kennedy Entrance, using

$$\frac{dQ}{dT} = \rho C_p \; K_H \frac{dT}{dy} \; + K_V \frac{dT}{dZ}$$

(where Q is heat, T is temperature, ρ is density, C_p is specific heat, K_H is the horizontal eddy coefficient of heat, and K_V is the vertical eddy coefficient of heat)

is about 30 cm/day (approximately 80 cal/cm^3 of ice). Recognizing some uncertainties in the calculations because of short

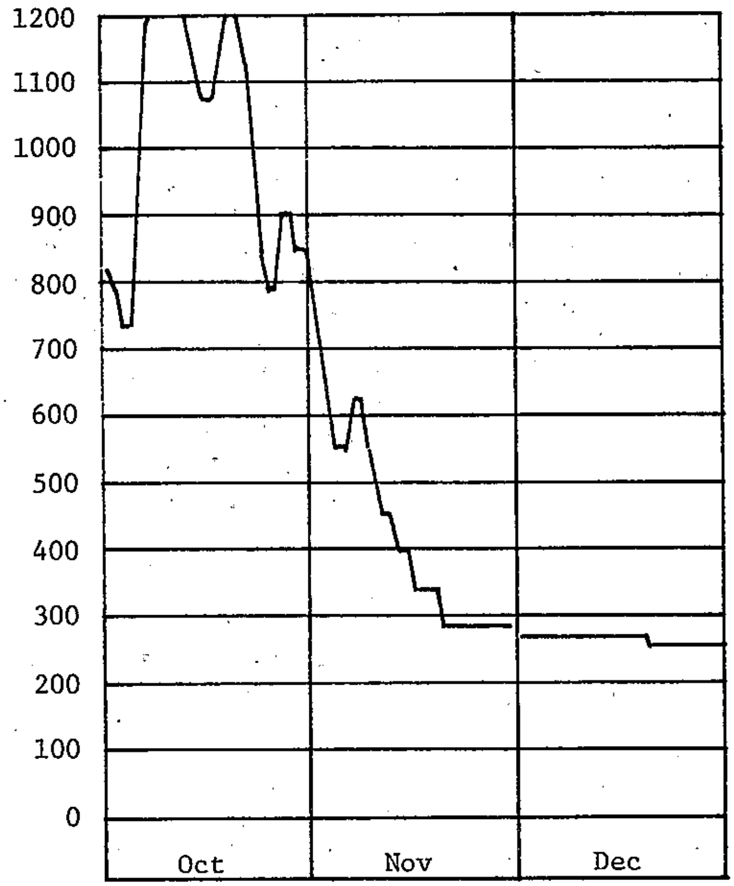

Figure 5. River discharge in cubic meters per second at Susitna station, Alaska, 1978.

period variabilities in the system, it still appears that the Kenai Current water near Anchor Point is capable of melting 12 cm of ice/day in January and February.

The 1978-1979 coverage was greater than in many years and approached that of the 1970-1971 season when the most extensive coverage was reported since observations began. The waters of Cook Inlet had fully cooled before the main February cold period set in which is an important consideration and, once the cold period began, there was no interlude of substantial warming to soften the ice. These conditions also occurred in the ice season of 1973-1974 but in that season there was a maximum of 1405 cumulative frost degree-days (see table 1) while the peak in the 1978-1979 season reached only 735. In the 1973-1974 season the maximum coverage reached only to the south end of Kalgin Island.

It seems reasonable to assume that in some years there is a process at work which inhibits the growth of ice which was not at work in the 1978-1979 season. During the first quarter of 1974, a much stronger-than-normal onshore flow was observed along the western North Gulf Coast as reported by Ingraham et al. (1976). This could increase the Kenai Current flow through Kennedy Entrance and increase the heat exchange through the southern part of Cook Inlet. If the Kenai Current has this substantial effect on the formation of ice in Cook Inlet, then it appears that a real-time current monitor during the winter should be part of any comprehensive ice forecast program.

While the measure of cumulative frost degree-days does not provide a reliable tool in estimating areal extent of ice, it does provide a good estimate of thickness. Ice thickness was observed in the northern inlet at a maximum of 30 cm, which was also the thickness calculated from the Zubov ice growth curve with 5 cm of snow cover[2] (Zubov, 1938).

The cumulative frost degree-day total for the 1978-1979 season was less than the long-time average covering the years from 1923-1968 and the 9 year average of 1969-1978 which coincides with ice records for Cook Inlet.

The average date of the first significant ice (see table 2) in Cook Inlet, using the past 10 years, is November 15; the first significant ice of the 1978-1979 season was December 16. Also

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2 - We have found, through experience, that the 5 cm curve gives the best estimate of ice thickness and we use this curve in all but the most extreme snow cover cases.

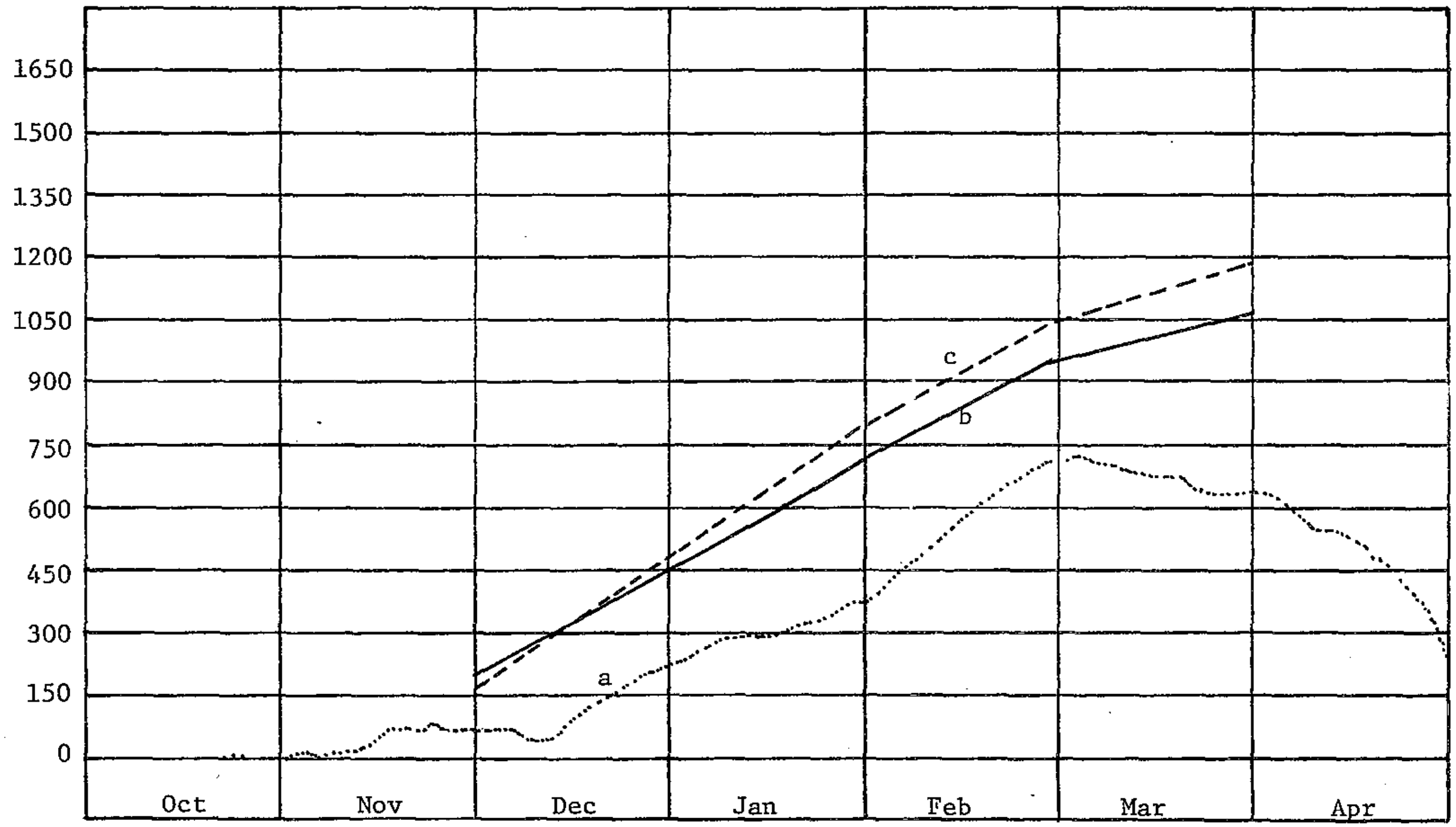

Figure 6. Cumulative frost degree-days (based on $0^{o}C$) for Anchorage, Alaska, (a) 1978-79, (b) 10 year average, 1969-1979, (c) 42 year average, 1923-1968, (1925-27 and 1928-29 missing).

using the past 10 years of data, and assuming a normal distribution, there is an 80% probability of significant ice in Cook Inlet after November 24. The average date that Cook Inlet is ice-free is April 4; in 1979 the inlet was ice-free on March 31. Finally, assuming a normal distribution, and with 10 years of data, there is an 80% probability that Cook Inlet will be ice-free by April 16.

Acknowledgements

My thanks to my colleague, Gary L. Hufford, for his technical help, to J.D. Schumacher for his ideas and review, to Richard Crisci for editing, and Mary Jo Rugwell for typing this memorandum.

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Table 1

Cumulative Frost Degree-Days (Base 0^oC) at Anchorage, Alaska, Since Ice Records Began in 1969.

	Period Ending				
Winter of	Nov 30	Dec 31	Jan 31	Feb 28*	Mar 31
1969-70	147	205	599	643	581
1970-71	201	497	1008	1196	1500
1971-72	227	498	938	1236	1514
1972-73	181	528	1014	1306	1450
1973-74	300	512	931	1229	1297#
1974-75	151	358	682	957	1111
1975-76	339	686	929	1217	1321
1976-77	0	149	56	12	123
1977-78	276	628	803	836	832
Average	202	451	773	959	1081
1978-79	6	227	387	716	650

*February 29 for leap-years
#Maximum value was 1405 on March 18

Table 2

First Significant Ice and Ice Free Dates for Cook Inlet for the Winters 1969 Through 1979

	First Ice	Ice Free
1969-70	Nov 18	May 23
1970-71	Oct 17	May 7
1971-72	Nov 23	May 15*
1972-73	Nov 13	Apr 10
1973-74	Nov 18	Apr 6
1974-75	Nov 24	Apr 9
1975-76	Nov 12	Apr 10
1976-77	Dec 17*	Apr 9
1977-78	Nov 20	Mar 18
1978-79	Dec 16	Mar 31
Average	Nov 15	Apr 4

*Latest Occurrences

APPENDIX - ICE GLOSSARY

Term	Usual Age	Usual Thickness
New ice	Hours to days	Less than 10 cm
Young ice	Days to weeks	10-30 cm
Thin (first year) ice	Weeks to months	30-60 cm
Medium (first year) ice	Months	60-120 cm
Thick (first year) ice	Months	Greater than 120 cm
Multi-year ice	More than one year	3 m or more

Categorical Term	Coverage (in tenths)
Ice free	0
Very open pack ice	1-3
Open pack ice	4-6
Close pack ice	7-9
Very close pack ice	10

Term	Size (diameter)
Brash (disintegration of other ice)	Less than 1.5 m
Cakes	1.5-20 m
Small floe	20-90 m
Medium floe	90-450 m
Big floe	450 m - 1.5 km
Vase floe	1.5-10 km
Giant floe	Greater than 10 km

Other Terms Used

Fast ice: attached to the shore, beached, stranded in shoal water, or attached to the bottom of shoal areas.

Slush: an accumulation of ice crystals which may or may not be slightly frozen together; sometimes found as a viscous, floating mass in water after heavy snowfall.

Stamukha: (plural: stamukhi)...results when a piece of beach ice has been deposited on the mud flats by the tides and is frozen to the underlying mud. Ice floes floating toward the beach are caught on top of the piece of ice and, as the tide recedes, the overhanging edges break off leaving a stack of layered ice with nearly straight sides. This process may be repeated many times, limited only by the height of the tides and strength with which the original beach ice was frozen to the mud.

Significant ice: in Cook Inlet, ice is considered significant when the concentration of ice at the Phillips Oil platform is 10% or more.