TR-23

TECHNICAL REPORT

LOCAL ENVIRONMENTAL FACTORS AFFECTING ICE FORMATION IN NORTH STAR BUGT, GREENLAND

RAYMOND J. McGOUGH
Applied Oceanography Branch
Division of Oceanography

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U. S. NAVY HYDROGRAPHIC OFFICE
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ABSTRACT

Environmental factors influencing the formation and growth of sea ice in the area of North Star Bugt and Wolstenholme Fjord indicate that the peculiar characteristics of the harbor are the free water exchange with the fjord at all levels, the relatively small importance of fresh-water runoff, and the small annual change in surface water temperatures during the open season. Because of these characteristics, the harbor is well situated for the use of long-range ice prediction techniques based on the thermohaline structure.

The formation and growth of sea ice in 1953 was studied in detail. Data indicated that the observed and computed ice thicknesses were nearly identical, both for the original ice and for the newer ice which formed after the first ice was broken up by wind action. It is shown that in order to determine the weather conditions over the ice, observations from a ship anchored in the harbor are more accurate than those at a land station because of the greater wind velocity and warmer air temperature over the ice. Accumulation of degree days of frost corresponded closely to the ice growth in two different years, but the total number of degree days of frost varied widely from season to season. It is concluded that this area is suitable for the use of long-range ice prediction techniques.

FOREWORD

Successful arctic operations require a considerable amount of preparation and planning. To aid such planning, the Hydrographic Office has been engaged in the development of various techniques for the forecasting of growth, movement, and disintegration of sea ice, especially in the harbor areas since each arctic and subarctic harbor constitutes a special environmental problem.

This report presents a study of the environmental factors that are peculiar to North Star Bugt and Wolstenholme Fjord, and evaluates their effect on the formation and growth of sea ice in the harbor area. The ice growth in the autumn of 1953 was studied in detail.

The conclusions expressed in this report are tentative and may require revision as more data become available. All additional information which might amplify or modify this report will be welcomed by the Hydrographic Office.

H. H. MARABLE
Captain, U.S. Navy
Hydrographer

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I. INTRODUCTION

During the past 3 years, the U. S. Navy Hydrographic Office has been providing ice forecasts in support of military operations in the Arctic. These forecasts include information on the distribution, growth, and disintegration of sea ice, and other predictable factors which serve as aids to such operations. The forecasts are divided into two classes (a) short-range (48-hour) forecasts designed to provide detailed ice information for the field units while operating in the ice and (b) long-range (5-day to 6-month) forecasts designed for operational planning.

Forecasts of ice conditions in open-water areas present problems which involve oceanographic and meteorological factors that simultaneously influence major areas. Conditions in the open water are sufficiently homogeneous so that forecasts can cover large areas. However, the local topography influences the various oceanographic and meteorological factors for each harbor site. Separate ice studies are contemplated for the various harbors in which military shipping is conducted. These reports will describe the special local factors which affect ice forecasting in each harbor, so that the local sequence of freezeup and ice growth can be delineated and a study of the particular harbor will be available for future operations. The present report discusses the local conditions of North Star Bugt and Wolstenholme Fjord, Greenland.

North Star Bugt, which is approximately three square miles in area, is situated in a protected cove opening to the west. A narrow peninsula to the north separates this bay from Wolstenholme Fjord, into which large glaciers discharge from the inland icecap. The peninsula terminates with the spectacular landmark, Mount Dundas, which is over 700 feet high. Hills about 1,000 feet high lie close to the south and east of the bay. Between these hills, Pitufik Valley (local name) extends to the east-southeast with a relatively gentle slope. Geographic features of the area are shown in figure 1.

The bay is normally open to shipping for three months annually (5 July to the first week of October). These dates vary somewhat from year to year, depending on the influencing factors. During the first half of July, shipping is almost entirely dependent on icebreaker escort. Obstructions to shipping are caused largely by the presence of sea ice, since ice of land origin is not of sufficient concentration to present a navigational problem.

II. CLIMATOLOGY

The warmest air temperatures at Thule occur during July with a mean temperature of 42° F. The coldest air temperatures occur during February with a mean temperature of -15° F. The total precipitation throughout the year averages about 2.5 inches, nearly half of this amount occurring during July and August. January and February are the driest months, averaging less than 0.1 inch per month. An interesting feature, in contrast to the low amount of precipitation, is that nearly half of the days throughout each month record a trace or more of precipitation. The amount of cloudiness somewhat parallels the precipitation pattern, the greatest mean total cloud amount being observed during the summer and the least during winter. July observations show a mean total cloud amount of four-tenths or more about 78 percent of the time, whereas in December, the percentage drops to 45. Mean total cloud amounts of eight tenths or more were observed 68 percent of the time in July and 39 percent of the time in December.

Surface winds are comparatively weak throughout the year, averaging 10 knots or less approximately 80 percent of the time, with considerable monthly variation. Almost all of the stronger winds are from an easterly direction.

III. OCEANOGRAPHY

The most important oceanographic factors in the formation and growth of ice are surface water temperatures, which indicate the heat loss and gain at the sea surface, and physical properties, which show how the heat loss and gain will be distributed throughout the water mass. Figure 1 shows the location of the oceanographic stations (sites A and B) occupied in the area.

Surface water temperatures in North Star Bugt vary little from year to year. Figure 2 shows the relationship between air and sea surface temperatures and indicates that the air temperature is higher than the water temperature until approximately 21 August. Air temperatures reach a peak near the end of July and decrease rapidly thereafter. Surface water temperatures lag behind the air temperatures by about 3 weeks, reaching a maximum near 16 August and decreasing slowly to the freezing temperature by the first week in October. At this time, however, the air temperature is more than 10° F. colder than the water temperature. The reversal of the heat budget (the date when the water temperature begins to fall) can be placed at about 16 August. After that date it may be assumed that the water is losing heat continuously.

The oceanographic structure was studied for four stations made at site A (fig. 1) on 29 September and 6, 12, and 21 October 1953. Observations at site B, in shallow water, showed that the ice thickness was largely independent of depth. Changes in the oceanographic structure are shown by the four station plots for site A (figs. 3, 4, 5, and 6). Surface water temperatures and salinities are listed in table I. The gradual disappearance of the layer of warm water produced by the summer heating is illustrated by the oceanographic plots. Only the upper 100 meters were affected by this seasonal warming, while the water below 100 meters was nearly isothermal and isohaline, water temperature being about -0.8° C. and salinity ranging between 33.70 and 33.90 ‰. Cooling of the upper layer was steady and had evidently been proceeding from the time of the reversal of the heat budget. In the station profile of September 29 (fig. 3), 45 days after the heat budget reversal, the surface water temperature was −1.3° C. and the warmest temperature at 50 meters was −0.36° C. The salinity curve shows the beginning of convection in the first 10 meters. The seasonal thermocline lies between 75 and 100 meters and is still fairly sharp.

In the second station profile (fig. 4) taken a week later, the shallow layer has cooled further, so that the warmest water now has a temperature of −0.5° C. The surface convection extends to 15 meters. At this time, the ice was 1.6 inches thick. The seasonal thermocline had weakened during the week.

In the third station profile (fig. 5) taken 6 days later on 12 October, cooling has reduced the temperature of the upper layer so that it is less than that of the lower layer, thus eliminating the seasonal thermocline. The nearly isothermal lower layer now is the warmer of the two layers. Convection has produced an isohaline layer in the upper 20 meters, while the continuing surface cooling has brought the temperature to the freezing point. At this time, a 6-inch covering of ice at site A was the result of thermohaline convection.

Finally, 9 days later on 21 October, the station profile (fig. 6) shows that the surface cooling has extended below 75 meters. Little change in the salinity and in the depth of the mixed layer has occurred. Since the ice thickness was nearly 12 inches, it is evident that the loss of a moderate amount of heat through the ice produced a relatively large amount of ice with little added change in the convection of the water. At this point, the winter oceanographic structure is well established. The precipitation of salt and the process of convection during the formation of ice are shown clearly in the four profiles. The surface salinity increased from 31.20 ‰ on 29 September to 31.64 ‰ on 6 October, to 32.00 ‰ on 12 October, and to 32.21 ‰ on 21 October.

IV. ICE FORMATION AND GROWTH IN 1953

Fringe ice was first noticed on 25 September along the eastern edge of North Star Bugt where fresh water empties from Pitufik Valley. By 1 October, grease ice was forming over North Star Bugt in the area northeast of Delong Pier; a considerable amount of slush ice formed along the eastern shore. By 3 October, the first new ice was formed over this area of the bay. Temporary patches of grease ice were forming in the area of sites A and B. The first sheet of young ice formed at site B during the morning of 4 October and at A during the morning of 5 October. This new ice attained a thickness of about 2 inches by 6 October, the thicknesses being 1.6 and 2.2 inches at sites A and B, respectively. The areal distribution of ice at this time is illustrated in figure 7. A polynya with some grease ice existed slightly north of site A, and a few smaller open-water areas were present. Some rafting had occurred. Ice continued to grow with little change in areal distribution, attaining a thickness of 4.8 inches at site B by 9 October (1000 IST). The snow cover amounted to one-half inch. Figure 8 shows the synoptic ice picture at this time. The polynya north of site A had decreased in size; a small polynya had developed a short distance southwest of Delong Pier; and a small area in the immediate vicinity of the pier had become ice free. A point of interest here is that within 2 hours after this ice was observed at 1000 LST by helicopter the areal distribution changed very rapidly to that indicated in figure 9. This change occurred with the approach of high tide and 10-knot surface winds from the east and southeast. Average tide range during this period (9 to 10 October) was about 6 feet.

On 10 October, westward movement of the ice was noticed at approximately 1000 LST. Easterly winds at this time had increased to 19 knots with gusts to 25 knots. At 1100 LST, aerial reconnaissance made possible a detailed synoptic analysis of the ice as shown in figure 10. Numerous cracks, leads, and polynyas had developed. Considerable amounts of slush ice had formed in the newly developed water areas. Ice thickness on this date measured 5.0 inches. By 1300 LST, the wind speed was 32 knots with gusts to 40 knots. By 1600 LST, the ice picture was radically different. The ice had moved out of the local harbor area, except along the east shore, as shown in figure 11. Comparatively strong easterly winds continued throughout the next day.

During the period from 1 to 12 October, the USS ATKA (AGB-3) was anchored in North Star Bugt. Weather observations were taken regularly aboard the ship during the time and can be compared directly with the observations taken at Thule Air Force Base. These observations are given in table II. On 10 October, when the ice changed radically as shown in figures 10 and 11, winds recorded on the ATKA were considerably stronger than those recorded at the Air Force station. In checking the winds for 1030, 1330, and 1630 LST, it was found that the wind speeds at the land station were only 54 percent of those at the ship. Similar conditions also existed on nearly every day. This wind speed differential plays an important role in forecasting ice distribution during breakup as well as during the period of freezeup. Since nearly all of the wind information used by the Hydrographic Office in making ice forecasts in harbors is derived or inferred from observations at neighboring land stations, it is evident that local harbor studies are necessary to determine the relative applicability of each land-station record to the forecasting of sea ice conditions in the surrounding areas.

Grease ice developed on the newly formed water area during the morning of 12 October, at which time there was about five-tenths grease ice coverage. The distribution of the ice between the harbor and Wolstenholme Ø on this date is shown in figure 12. Ice that formed on this newly exposed water area will be known as "new" ice hereafter, whereas the ice that formed the first part of the month will be known as "old" ice. On this date (October 12), the old ice was 6.0 inches thick. Much rafting had occurred in this ice southeast of Saunder Ø to the mainland coast. By 21 October, the new ice attained a thickness of 8.5 inches and the old ice 11.2 inches. No polynyas, cracks, or leads were present from Kap Athol to the dock area. On 23 October (fig. 13), the old ice was 12.0 inches thick with 1.5 inches of snow cover. No snow cover was evident on the new ice, even though some very light snow had fallen between 20 and 23 October. However, there was a brine covering of three-sixteenths of an inch, which appeared to cover the entire area of new ice. A sample of this brine, taken 50 feet south of the dock on 23 October, had a salinity value of 62.3 ‰. Evidently, this salinity value is the result of rapid ice formation on and after 12 October. The ice was able to form with comparatively low air temperatures, averaging about 7° F. between 12 and 14 October. Over a large area 300 feet south of the dock, walking was found to be very difficult owing to the slippery brine covering.

Three ice temperature and salinity profiles, as illustrated in figures 14, 15, and 16, were taken from ice in the immediate dock area. The salinity values were taken at 2-inch intervals vertically; i.e., 0-2, 2-4 inches, etc. Temperature readings were taken at 2-inch intervals, starting at the surface. It will be seen that the temperature gradients are nearly linear, while salinity decreases irregularly with depth.

Several ice thickness measurements were made from time of formation until the ice had attained a thickness of approximately 13 inches. Only one measurement was made after this time, and that was on 18 November 1953. The new ice thickness at that time was 28 inches with 2 inches of snow cover. Ice growth as a function of degree days of frost (° F.) and the accumulation of degree days of frost with time for the new and old ice are shown in figures 17 and 18. Degree days of frost are based on the normal freezing point of the water at each location and may be expressed either in ° F. or ° C. To illustrate the use of degree days of frost, a day with an average temperature of 25° F. would accumulate 4 degree days of frost when the base temperature of 29° F. is used. It is the practice in the Hydrographic Office to use a base of 29° F. or -1.8° C. at sites with salinity between 25 ‰ and 35 ‰ while a base of 32° or 31° F. for fresh or brackish water is used.

In figure 19, the ice growth as a function of degree days of frost is shown for two ice seasons, 1948-49 and 1953-54. The curves are nearly identical for the overlapping portion. Physically, this identity expresses the fact already noted that the water of North Star Bugt is well mixed because of the free exchange to depths. Since the composition of the sea water does not change greatly from year to year, the relationship between ice growth and the heat loss expressed in degree days of frost is also the same. There is, however, a wide variation in the accumulation of degree days of frost. Figure 20 shows the available historical data on degree days of frost and reveals that the extreme values ranged from the total of 7,950 degree days of frost on 31 May 1954, to the total of 5,650 on 31 May 1947. This variation would be expected to cause considerable differences in ice thickness, assuming the other parameters were unchanged.

V. ICE GROWTH COMPUTATIONS

In computing the ice growth a formula developed in the Hydrographic Office (Lee and Simpson, 1954) is used, which takes into account the influencing oceanographic and meteorological parameters.

$$\int_{t_o}^{t} (T_F - T)\,dt = \frac{1}{k_i} \left[\frac{\rho_i K}{2} l_i^2 + \left\{ \frac{K k_i l_s}{k_s} + \frac{Q_T}{2} \right\} l_i + \frac{k_i\, l_s}{k_s} Q_T \right],$$

where T_F = temperature of freezing in $^\circ$ C.,
T = temperature of the water in $^\circ$ C.,
k_i = heat conductivity of sea ice,
k_s = heat conductivity of snow,
ρ_i = density of sea ice,
K = latent heat of fusion,
l_i = thickness of the ice in cm.,
l_s = thickness of the snow in cm., and
Q_T = amount of sensible heat loss in kg. cal.

Using this method, ice-growth curves, figures 21 and 22, are plotted against degree days of frost ($^\circ$ F.) for various snow depths that may be covering the ice. The growth curves are based on oceanographic data taken at site A on 29 September and 12 October. Ice grows more rapidly during the early stages and/or with no snow cover. Greater ice thickness and/or snow cover offer more insulation therefore resulting in a slower rate of ice growth as compared to degree days. It will be noted here that these degree days are based on 28.8° F. compared to the previous 29.0° F. However, differences are very small, less than 1 percent. The computed ice growth curve (in inches) versus degree days of frost ($^\circ$ F.), using the actual measured snow depths, is shown in figures 23 and 24. Figure 23 and figure 24 are for the new and old ice, respectively. For comparison purposes, the actual growth curves are plotted. In the case of the new ice, these curves parallel very closely. The old ice curve does not verify as well. Nevertheless, after 450 degree days ($^\circ$ F.) with 13 inches of ice, the computed thickness of the old ice is only 1.5 inches less than the actual depth. It is possible that this discrepancy may be the result of measuring the ice thickness in a comparatively shallow area, whereas the oceanographic data is based on information from site A, in deeper water. The same was not true in the case of the new ice. In this latter case the ice growth was the same over the entire area; i.e., from the pier to site A, which is approximately 6 nautical miles to the southwest. Nevertheless, the actual growth curves parallel the computed values very closely, especially in the case of the new ice, thus reflecting the accuracy of the method in predicting ice growth.

Naturally, if one were to predict the air temperature and snow depth values, a forecast of this nature probably would not be so accurate as in the case pointed out here is figures 23 and 24, where the observed values for snow cover and temperatures are used. Difficulty in making accurate long-range predictions of snow depths and temperatures will vary for different areas. In general, the larger the monthly variation of these particular parameters, the more difficult the forecast will be. Comparatively the variation for these two parameters is small in the area of Thule.

For instance, table III indicates that the snowfall varies very little. Therefore, accurate predictions for this element are relatively easy. Temperature forecasting, however, is not so easy, as is evidenced in figure 20, which shows considerable variation. For example, on 15 November 1947 there was an accumulation of about 650 (° F.) degree days of frost as compared to 1,200 (° F.) degree days of frost on the same date in 1953. In referring to figure 23 this difference would mean approximately 10 inches more ice (19 versus 29 inches). Of course, the comparison assumes all other influencing factors to be the same. This is clearly an extreme case. In other years the temperature values are more nearly equal.

VI. CONCLUSIONS

The area of North Star Bugt and Wolstenholme Fjord constitutes an open bay with free water exchange at all depths from surface to the bottom. The special characteristics of this area from an oceanographic standpoint are 1) the presence of continual water exchange and hence temporal continuity in thermohaline structure, 2) the relatively small importance of runoff water, and 3) the small annual change in surface water temperatures during the open season.

North Star Bugt, although a harbor suitable for shipping operations, is not a closed water system but, instead, is an arm of Wolstenholme Fjord and open at all levels. Since the water of the bay is continually mixed with that of the fjord, the thermohaline structure remains relatively constant from week to week. This continuity, in turn, is an essential prerequisite for long-range ice forecasting, in which the thermohaline structure must be studied in early autumn and the heat budget utilized on the basis of the early sampling. It also makes possible the use of an oceanographic sampling in deep water to predict ice growth in the bay.

There is relatively little runoff into North Star Bugt, coming mostly from the Pitufik River. This runoff stops by the first week in September, so that there is essentially no runoff problem thereafter; the water salinity remains nearly constant, increasing slightly due to evaporation.

The combination of the above characteristics makes North Star Bugt a suitable harbor for the use of the techniques of long-range ice prediction even though these techniques were developed for use in open-water areas. The 1953 long-range ice prediction verified satisfactorily, as shown by figures 23 and 24.

In one aspect North Star Bugt presents obstacles to long-range ice prediction methods. The techniques assume that the ice remains in situ once it is formed. In North Star Bugt, however, it is normal for the ice to break up in the area of the pier as often as three times during the freezeup period, sometimes not permanently until the first part of November. Similar movement of the ice will generally apply to the greater part of Baffin Bay north of 70° N.

Table I

SURFACE WATER TEMPERATURE AND SALINITY

Location	Site A		Site B		South Edge of Pier		50 ft. South of Pier		300 ft. South of Pier		West Edge of Pier		30 ft. North of Causeway	
Date	T °F	S o/oo	T °F	S o/oo	T °F	S o/oo	T °F	S o/oo	T °F	S o/oo	T °F	S o/oo	T °F	S o/oo
Sept. 29	29.8	31.20	30.0	31.60										
Oct. 6	28.9	31.64	28.9	31.76										
7					28.8	31.94								
8					28.9	31.47					28.9	31.85		
9			28.9	31.31	28.9	31.62					28.9	31.62		
10			29.0	32.00	28.9	31.94								
11					28.9	31.85							29.0	30.17
12	28.8	32.00	28.8	32.23	28.8	31.91								
21	28.8	32.21	28.8	32.27										
23									28.9	31.24				
24							28.8	38.38						

TABLE II SYNOPTIC WEATHER OBSERVATIONS AT THULE AIR FORCE BASE AND ON THE USS ATKA

		THULE - AIR FORCE BASE						USS ATKA - IN NORTH STAR BAY				
		Temperature (°F.)				Wind		Temperature (°F.)			Wind	
Time / Weather		Dry bulb	Wet bulb	Relative humidity Percent	Present weather**	Direction	Speed (kn.)	Dry bulb	Wet bulb	Relative humidity Percent	Direction	Speed (kn.)
Oct. 1953	LST*											
1	0130	17.5	17.0	85	LS	SW	6	23.0	22.5	89	ESE	10
	0430	18.8	18.0	81	LS		c	25.0	24.5	91	E	6
	0730	18.0	17.5	85	LS	E	4	21.9	21.0	81	E	8
	1030	19.8	18.0	67		E	5	22.5	21.0	75	E	6
	1330	20.0	19.0	80		E	4	22.9	21.0	69	E	5
	1630	20.0	18.5	73		E	4	25.0	24.0	84	E	4
	1930	20.0	18.9	78	LS		c	24.2	22.9	77		c
	2230	18.9	18.1	81	LS	E	4	23.0	22.0	82		c
2	0130	20.0	18.8	77	LS	SE	9	23.0	22.1	82	E	8
	0430	20.0	18.2	68		ESE	5	24.1	22.7	77	E	7
	0730	18.2	17.6	84		E	4	24.3	22.8	76	E	7
	1030	17.0	15.5	69		E	5	23.1	21.5	75	ESE	5
	1330	14.8	13.7	73		E	5	21.6	20.0	74	E	5
	1630	11.2	10.5	76		SE	11	19.2	17.2	65	E	10
	1930	10.9	10.0	72		SE	5	15.4	14.0	75	E	7
	2230	9.3	8.3	68		E	7	13.5	12.2	76	E	9
3	0130	5.8	5.0	69		E	8	14.8	13.6	78	E	8
	0430	6.8	6.2	71		ESE	7	16.2	15.0	79	E	5
	0730	8.9	8.2	74		E	7	17.2	16.0	80	ESE	8
	1030	13.3	12.8	82		ESE	5	19.0	17.5	77	E	6
	1330	16.1	15.2	77	LS	SE	8	21.5	19.2	68	E	7
	1630	16.5	16.0	84	LS	SE	5	20.0	18.7	74	E	6

TABLE II SYNOPTIC WEATHER OBSERVATIONS AT THULE AIR FORCE BASE AND ON THE USS ATKA (Cont'd)

		THULE - AIR FORCE BASE						USS ATKA - IN NORTH STAR BAY				
		Temperature (°F.)				Wind		Temperature (°F.)			Wind	
Time	Weather	Dry bulb	Wet bulb	Relative humidity Percent	Present weather**	Direction	Speed (kn.)	Dry bulb	Wet bulb	Relative humidity Percent	Direction	Speed (kn.)
Oct. 1953	LST*											
3	1930	17.3	17.0	88	LS		c	20.4	18.7	72	E	5
	2230	15.1	14.9	88	LS	S	19	21.0	19.0	66	SE	19
4	0130	14.1	13.9	87	LS	SSE	22	19.0	17.7	80	SSE	24
	0430	18.1	12.3	88	LS	WSW	10	20.1	18.9	77	SW	12
	0730	17.3	16.8	85	LS	SW	4	20.9	19.0	81	W	11
	1030	16.6	15.8	79		SW	7	21.7	20.6	80	SSW	10
	1330	10.2	10.0	86		E	8	20.0	17.5	58	SSE	9
	1630	5.8	5.4	77		ESE	11	13.2	10.8	61	E	13
	1930	2.6	1.9	68		ESE	6	12.8	11.6	67	E	8
	2230	10.0	9.0	70		ESE	10	14.2	11.8	50	E	10
	0130	6.1	5.9	82		SE	7	11.0	10.0	70	ESE	4
	0430	7.9	7.6	82		E	5	11.8	10.6	72	SE	5
	0730	5.3	5.0	80			c	11.1	9.9	71	E	10
	1030	6.8	5.8	70		SE	9	11.2	9.8	63	ESE	6
	1330	6.9	6.3	76		ESE	5	14.0	12.4	50	E	10
	1630	1.4	1.2	79		E	9	9.6	7.6	50	E	6
	1930	-0.2	-0.4	78		E	5	5.0	3.6	55	E	9
	2230	-2.4	-2.2	78		SE	9	4.0	3.0	61	E	8

* Weather observations were taken on the half hour, at AWS, whereas the ATKA observations were taken on the hour, for example, 0100 LST in place of 0130 LST.

** S - Snow
LS - Light Snow

TABLE II SYNOPTIC WEATHER OBSERVATIONS AT THULE AIR FORCE BASE AND ON THE USS ATKA (Cont'd)

Time \ Weather		THULE - AIR FORCE BASE: Temperature (°F.) Dry bulb	Wet bulb	Relative humidity Percent	Present weather**	Wind Direction	Speed (kn.)	USS ATKA - IN NORTH STAR BAY: Temperature (°F.) Dry bulb	Wet bulb	Relative humidity Percent	Wind Direction	Speed (kn.)
Oct. 1953	LST*											
6	0130	0.0	-0.2	78		E	10	3.2	2.3	61	E	12
	0430	-4.8	-5.2	69		E	8	2.7	1.9	63	E	10
	0730	-2.0	-2.2	64		E	7	4.2	3.2	63	E	14
	1030	1.9	1.4	72		E	7	15.6	13.8	64	NE	6
	1330	2.8	2.4	76		ESE	5	12.9	9.9	39	E	6
	1630	1.8	1.2	70		E	4	7.6	6.0	55	E	9
	1930	6.0	5.2	69			c	13.0	11.8	69	E	2
	2230	-1.5	-1.9	72		SE	7	8.0	6.8	63	E	9
7	0130	-1.8	-2.2	72		ESE	13	7.0	6.0	66	E	6
	0430	2.0	1.0	59		SE	15	10.8	9.5	65	E	7
	0730	10.8	10.0	74		SE	7	16.2	15.0	72	E	10
	1030	15.1	14.8	87		ESE	4	19.8	18.0	69	ENE	9
	1330	17.8	16.7	76		S	7	21.8	20.0	67	ENE	4
	1630	18.4	17.1	74		SE	8	21.5	19.8	74	NNE	3
	1930	17.4	16.0	72			c	22.0	19.8	67	E	6
	2230	17.8	17.2	84	LS	SSE	5	22.0	20.4	73	SE	2
8	0130	18.0	17.2	81	LS		c	21.2	20.0	79		c
	0430	15.4	15.1	87	LS		c	22.0	21.0	81		c
	0730	15.1	14.8	87	LS		c	22.0	20.0	67	WNW	12
	1030	17.7	16.9	83	LS	NW	9	22.3	20.8	74	WNW	14

TABLE II SYNOPTIC WEATHER OBSERVATIONS AT THULE AIR FORCE BASE AND ON THE USS ATKA (Cont'd)

		THULE - AIR FORCE BASE						USS ATKA - IN NORTH STAR BAY				
		Temperature (°F.)				Wind		Temperature (°F.)			Wind	
Time	Weather	Dry bulb	Wet bulb	Relative humidity Percent	Present weather**	Direction	Speed (kn.)	Dry bulb	Wet bulb	Relative humidity Percent	Direction	Speed (kn.)
Oct. 1953	LST*											
8	1330	17.3	17.1	90	LS	NW	8	20.2	18.8	73	W	10
	1630	16.5	16.0	84	LS	SW	10	18.0	16.8	74	SW	12
	1930	15.4	15.0	85	LS	ESE	4	20.3	18.8	72	W	4
	2230	15.5	15.2	87	LS		c	18.8	17.4	73	WSE	9
9	0130	15.0	14.5	83	LS	S	4	18.8	17.6	74	WSW	5
	0430	14.6	14.0	82	S		c	16.5	15.9	83	WSW	2
	0730	12.2	11.8	83	LS	E	5	15.2	14.2	74	ENE	6
	1030	12.2	11.8	83	LS	SE	10	16.5	15.3	77	E	9
	1330	13.2	12.8	84	LS	E	8	18.2	17.8	87	ENE	7
	1630	15.0	14.6	85	LS	ENE	4	18.6	18.0	84	ESE	3
	1930	14.6	14.3	85	LS	NE	11	20.0	18.8	80	ESE	4
	2230	13.6	13.1	82		E	4	20.0	18.8	80	ESE	4
10	0130	12.9	11.8	71		SSE	9	16.0	14.6	70		c
	0430	6.9	6.1	70		E	5	13.0	11.8	69		c
	0730	13.5	13.5	90	LS	W	6	17.0	16.0	77	SSW	2
	1030	21.0	20.0	81		E	12	24.0	22.0	70	ENE	18
	1330	22.5	21.2	78		E	14	25.0	22.9	71	NE	32
	1630	23.0	21.0	70		E	17	25.0	23.0	71	NE	28
	1930	22.1	20.3	77		E	13	25.1	23.2	71	NE	29
	2230	21.9	20.8	86		E	22	25.0	22.8	70	ENE	28

TABLE II SYNOPTIC WEATHER OBSERVATIONS AT THULE AIR FORCE BASE AND ON THE USS ATKA (Cont'd)

		THULE - AIR FORCE BASE						USS ATKA - IN NORTH STAR BAY				
	Weather	Temperature (°F.)				Wind		Temperature (°F.)			Wind	
Time		Dry bulb	Wet bulb	Relative humidity Percent	Present weather**	Direction	Speed (kn.)	Dry bulb	Wet bulb	Relative humidity Percent	Direction	Speed (kn.)
Oct. 1953	LST*											
11	0130	22.9	21.2	73		E	23	25.0	23.1	71	ENE	26
	0430	21.3	19.7	73		E	17	25.1	23.1	71	ENE	20
	0730	20.4	19.2	77		E	13	24.5	22.5	71	ENE	20
	1030	22.0	20.3	72		E	14	27.0	24.0	62	ENE	20
	1330	23.6	22.4	80		E	15	26.2	24.0	72	ENE	28
	1630	25.0	22.8	69		ESE	16	25.5	23.5	73	NE	22
	1930	23.8	22.1	74			c	25.2	23.0	70	NE	4
	2230	19.6	18.9	83		ENE	7	26.0	24.5	73	E	2
12	0130	14.2	13.7	89		ESE	10	22.0	18.5	48	E	4
	0430	13.8	12.1	62		E	9	19.2	17.1	64	E	8
	0730	6.8	5.9	63		E	10	12.0	10.0	53	E	12
	1030	6.6	5.8	69		ESE	6	16.4	13.2	41	E	12
	1330	9.0	7.9	66		E	6	15.0	13.1	58	ESE	8
	1630	9.9	8.5	62		E	5	20.2	18.2	66	ENE	10
	1930	5.8	5.0	68		E	6					
	2230	0.9	0.2	65		SE	10					
13	0130	9.1	8.5	76		SE	8					
	0730	5.9	5.6	80		SE	7					
	1330	12.4	10.9	63		E	7					
	1930	6.5	5.5	66		E	7					

TABLE II SYNOPTIC WEATHER OBSERVATIONS AT THULE AIR FORCE BASE AND ON THE USS ATKA (Cont'd)

		THULE - AIR FORCE BASE						USS ATKA - IN NORTH STAR BAY				
		Temperature (°F.)				Wind		Temperature (°F.)			Wind	
Time / Weather		Dry bulb	Wet bulb	Relative humidity Percent	Present weather**	Direction	Speed (kn.)	Dry bulb	Wet bulb	Relative humidity Percent	Direction	Speed (kn.)
October 1953	LST*											
14	0130	4.5	3.6	65		SE	5					
	0730	3.7	3.4	78		E	8					
	1330	6.7	6.2	76		ESE	5					
	1930	11.2	9.8	66		E	4					
15	0130	13.0	12.5	81		ESE	4					
	0730	20.0	19.0	82			c					
	1330	13.5	13.1	84		ESE	[illegible]					
	1930	6.8	6.5	82		ESE	8					
16	0130	2.2	1.8	75		SE	7					
	0730	3.8	3.6	81		ESE	6					
	1330	7.9	7.2	73		ESE	6					
	1930	2.8	2.5	78		ESE	7					
17	0130	0.2	0.0	79		ESE	6					
	0730	1.2	0.9	76		ESE	7					
	1330	5.9	5.2	72		E	4					
	1930	3.3	3.0	78		E	5					
18	0130	8.6	7.0	56		ESE	6					

TABLE II SYNOPTIC WEATHER OBSERVATIONS AT THULE AIR FORCE BASE AND ON THE USS ATKA (Cont'd)

Time \ Weather		THULE - AIR FORCE BASE: Temperature (°F.) Dry bulb	Wet bulb	Relative humidity Percent	Present weather**	Wind Direction	Wind Speed (kn.)	USS ATKA - IN NORTH STAR BAY: Temperature (°F.) Dry bulb	Wet bulb	Relative humidity Percent	Wind Direction	Wind Speed (kn.)
Oct. 1953	LST*											
18	0730	7.4	6.4	67		ESE	5					
	1330	9.7	8.8	71		E	4					
	1930	6.7	6.0	73		ESE	6					
19	0130	4.8	3.9	66		E	6					
	0730	5.0	4.2	63		ENE	6					
	1330	10.1	9.0	68		ESE	5					
	1930	6.9	6.2	72		ESE	8					
20	0130	13.7	12.8	76	LS	S	17					
	0730	15.4	14.7	80	LS	S	5					
	1330	11.4	11.2	86	LS		c					
	1930	10.4	10.2	85	LS	SE	6					
21	0130	11.2	10.5	77	LS	S	4					
	0430	10.8	10.5	84	LS		c					
	0730	9.8	9.6	85	LS	ESE	5					
	1030	7.8	7.7	86	LS	ESE	4					
	1330	10.8	10.8	89	LS		c	20.4	19.0	73	N	10
	1630	10.8	10.5	84	LS	ESE	4	17.0	16.2	79	E	8
	1930	11.5	11.0	81		ENE	5	14.8	14.0	69	ESE	1
	2230	9.1	8.9	85		ESE	6	16.0	15.0	75	E	7
22	0130	10.1	9.9	85		SE	4	14.5	13.5	75	E	7
	0430	-1.3	-1.4	81		SE	6	9.0	7.6	60	E	7

TABLE II SYNOPTIC WEATHER OBSERVATIONS AT THULE AIR FORCE BASE AND ON THE USS ATKA (Cont'd)

		THULE - AIR FORCE BASE						USS ATKA - IN NORTH STAR BAY				
		Temperature (°F.)				Wind		Temperature (°F.)			Wind	
Time \ Weather		Dry bulb	Wet bulb	Relative humidity Percent	Present weather**	Direction	Speed (kn.)	Dry bulb	Wet bulb	Relative humidity Percent	Direction	Speed (kn.)
Oct. 1953	LST*											
22	0730	-2.3	-2.3	83		SE	5	5.9	4.9	64	ESE	8
	1030	-2.2	-2.3	80		SE	6	7.9	7.1	71	E	5
	1330	-1.8	-2.2	72		SE	7	1.6	0.8	66	E	8
	1630	-1.0	-1.0	84		SE	6	2.8	1.8	60	E	7
	1930	6.2	6.2	87	LS	SE	6	1.0	0.4	60	E	9
	2230	3.8	3.8	86	LS	SE	8	10.7	9.9	74	E	4
23	0130	2.0	2.0	85	LS	SE	12	9.1	8.3	75	E	7
	0430	4.1	4.0	83	LS	SE	14	11.0	10.4	77	E	13
	0730	6.2	5.8	79		SE	13	13.7	12.7	74	E	13
	1030	6.4	6.1	81	LS	SE	7	12.9	11.9	72	ENE	12
	1330	8.2	7.9	82	LS	SE	12	14.0	12.4	68	ENE	3
	1630	8.7	8.2	78	LS	SE	8	12.8	11.8	72	ESE	9
	1930	10.0	9.4	77	LS	SE	5	12.0	11.0	67	E	7
	2230	9.3	8.8	79		SE	7	14.0	13.0	73	SSE	8
24	0130	6.9	6.2	73		SE	6	13.1	12.3	76	SSE	4
	0430	6.8	6.5	81	LS	SE	5	12.0	10.8	67	ESE	6
	0730	6.9	6.7	83	LS	SE	6	11.2	10.2	71	E	8
	1030	7.8	6.3	57		SE	9	13.0	12.0	72	ESE	9
	1330	5.0	4.5	75		SE	8	10.0	8.6	61	ESE	10

TABLE II SYNOPTIC WEATHER OBSERVATIONS AT THULE AIR FORCE BASE AND ON THE USS ATKA (Cont'd)

		THULE - AIR FORCE BASE						USS ATKA - IN NORTH STAR BAY				
		Temperature (°F.)				Wind		Temperature (°F.)			Wind	
Time / Weather		Dry bulb	Wet bulb	Relative humidity Percent	Present weather**	Direction	Speed (kn.)	Dry bulb	Wet bulb	Relative humidity Percent	Direction	Speed (kn.)
Oct. 1953	LST*											
24	1630	3.9	3.3	72		SE	8	8.8	7.8	69	E	6
	1930	2.8	2.6	80		SE	11					
	2230	3.1	2.9	81		SE	8					
25	0130	2.9	2.7	81		SE	8					
	0730	2.4	2.1	78		SE	13					
	1330	-4.0	-4.3	73		SE	10					
	1930	3.9	3.5	76		SE	8					
26	0130	0.0	-0.2	79		ESE	7					
	0730	10.0	8.8	65	LS	SE	10					
	1330	3.9	3.2	69			c					
	1930	-1.3	-1.8	69		E	5					
27	0130	0.0	-1.1	54		E	7					
	0730	-0.4	-0.9	70		ESE	9					
	1330	-1.0	-1.5	69		ESE	6					

Table III

MONTHLY SNOWFALL IN INCHES

	1946	1947	1948	1949	Average
January		1.0	0.4	0.4	0.6
February		0.9	0.6	0.1	0.5
March		1.1	0.4	0.4	0.6
April		6.1	0.5	T	2.2
May		2.1	1.2	T	1.1
June		2.5	T	0.0	0.8
July		0.0	T	T	T
August		T	T	T	T
September		3.5	3.2	T	2.2
October	1.1	T	4.5	0.2	1.5
November	1.8	4.9	1.1	2.0	2.4
December	2.4	4.3	0.5	0.3	1.9
				Annual	13.7

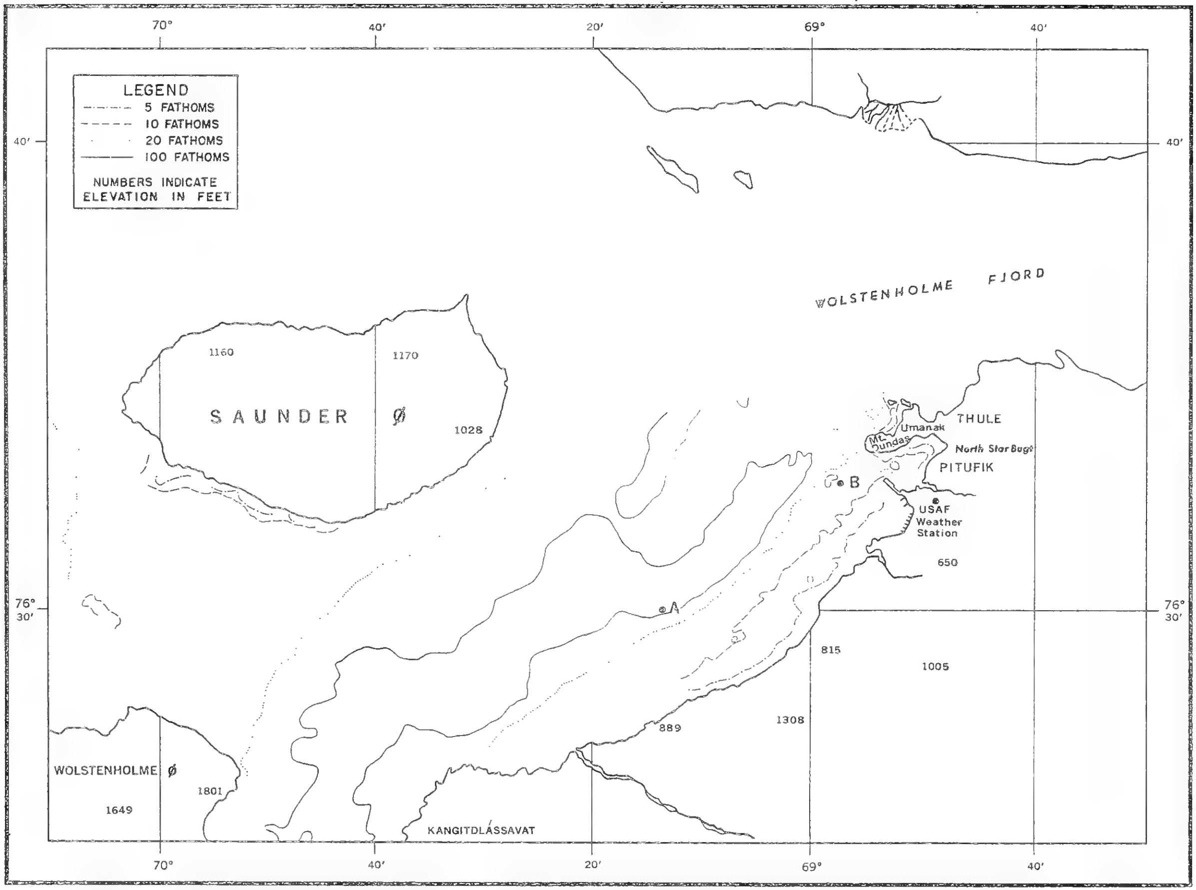

FIGURE I. LOCATION AND BATHYMETRIC CHART — NORTH STAR BUGT AND WOLSTENHOLME FJORD

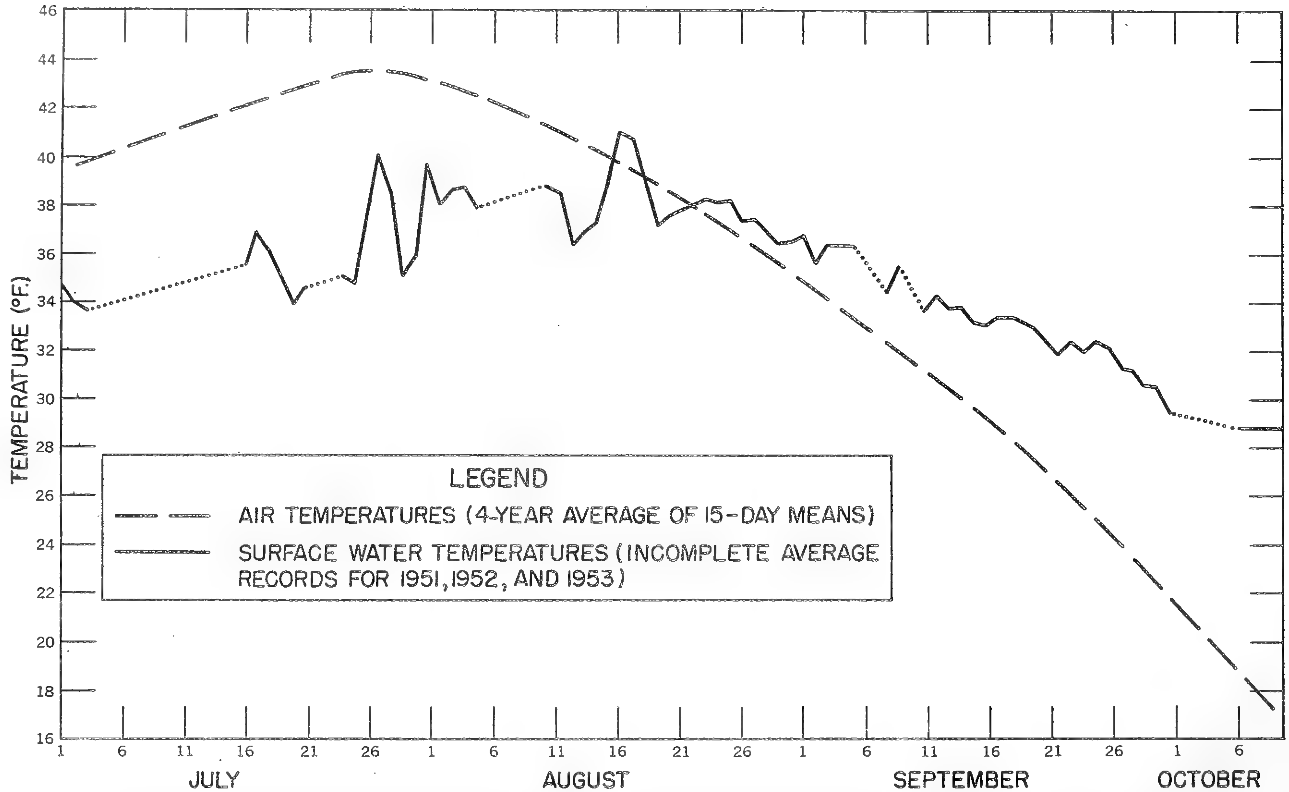

FIGURE 2. MEAN AIR AND SURFACE WATER TEMPERATURES IN NORTH STAR BUGT

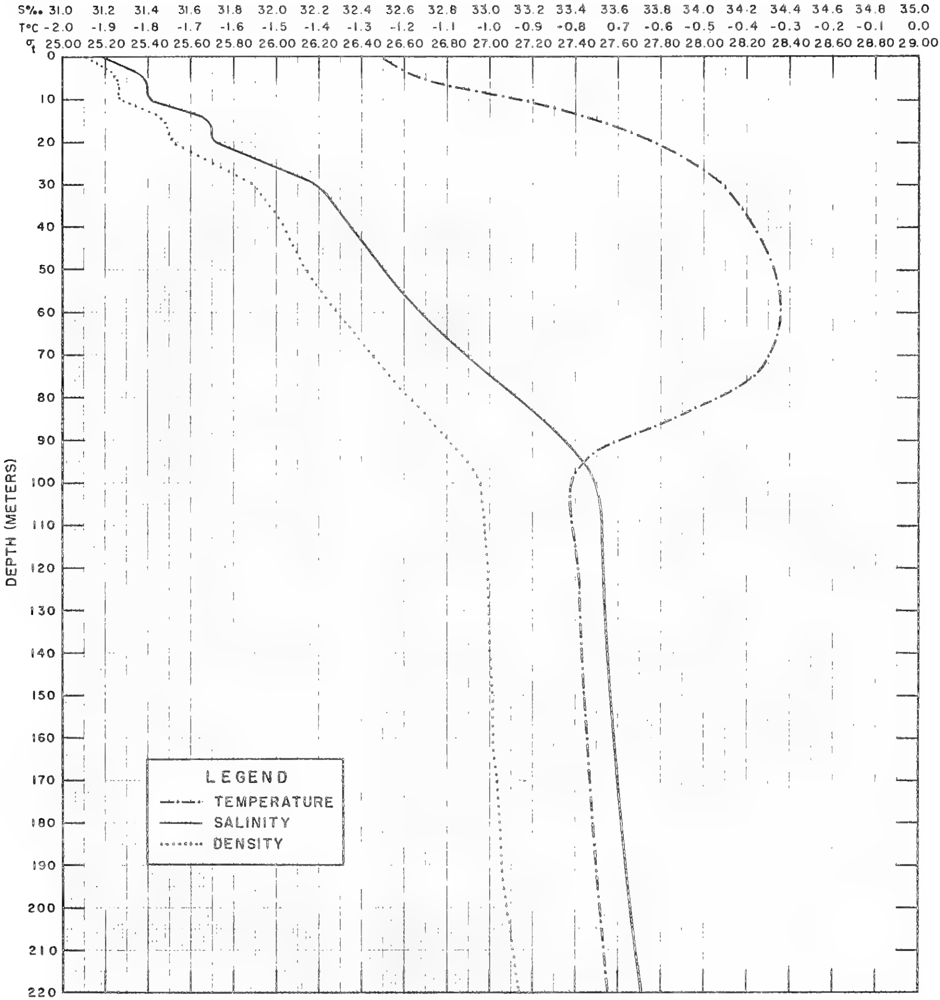

FIGURE 3. TEMPERATURE, SALINITY, AND DENSITY PROFILES FOR SITE A, 29 SEPTEMBER 1953

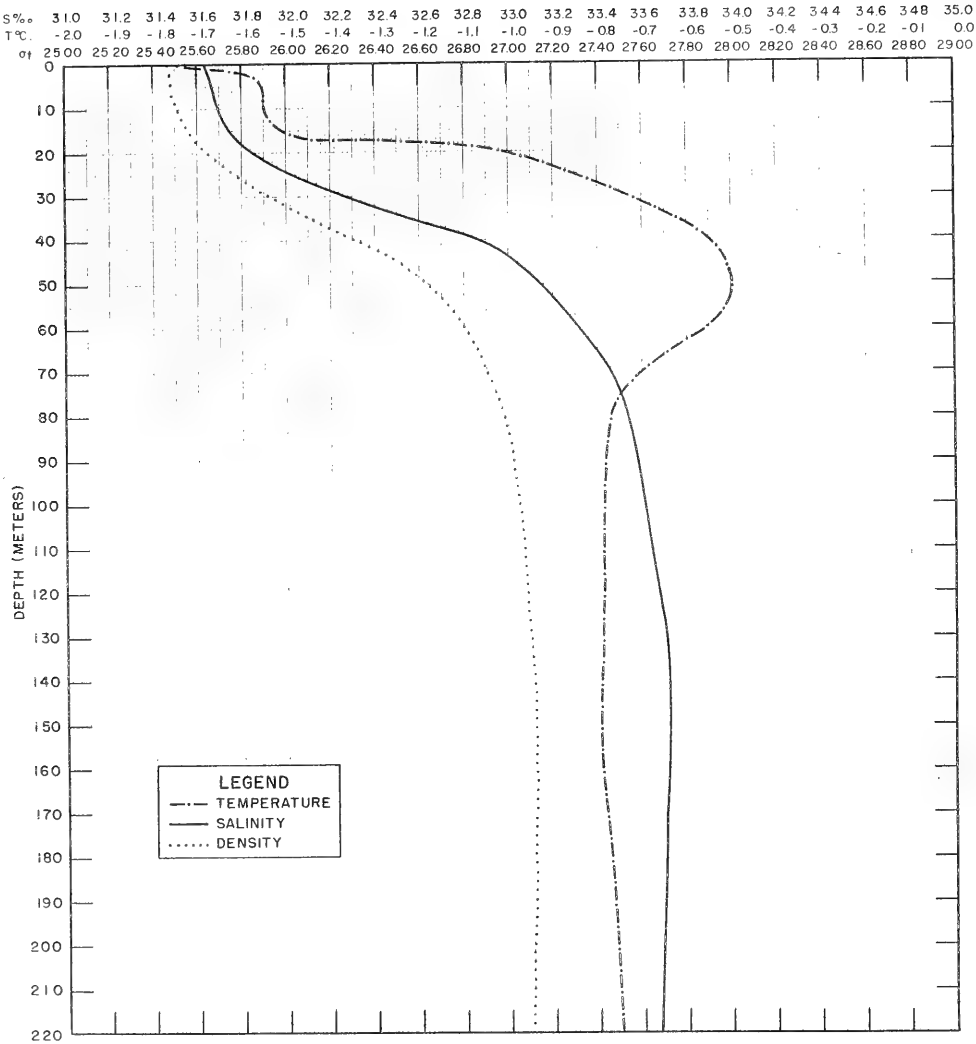

FIGURE 4. TEMPERATURE, SALINITY, AND DENSITY PROFILES FOR SITE A, 6 OCTOBER 1953

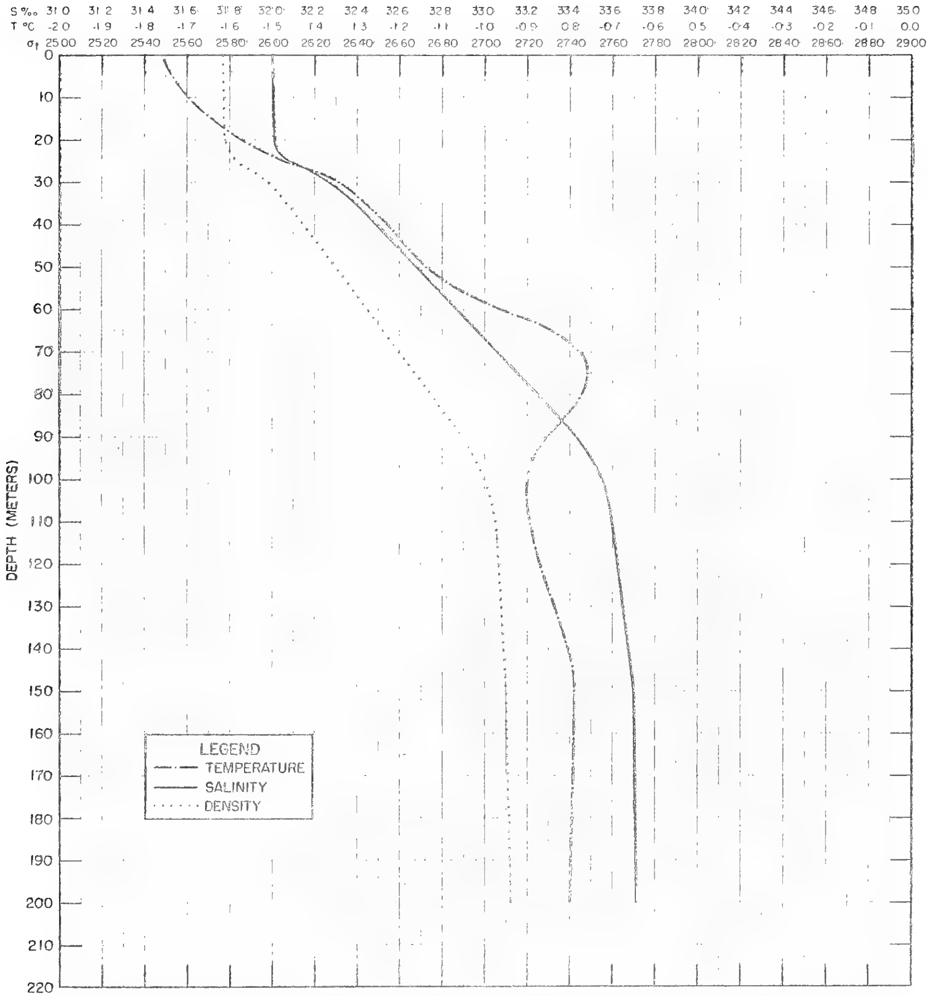

FIGURE 5. TEMPERATURE, SALINITY, AND DENSITY PROFILES FOR SITE A, 12 OCTOBER 1953

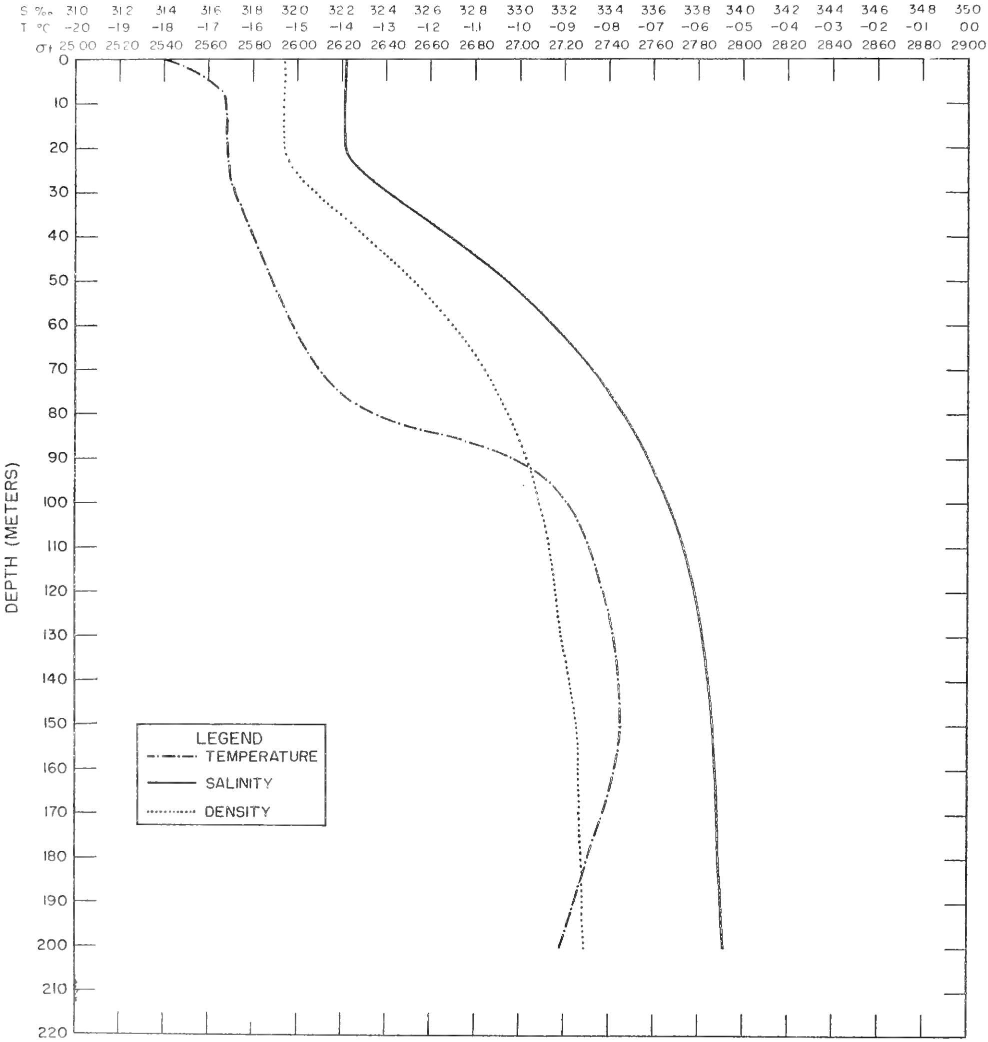

FIGURE 6. TEMPERATURE, SALINITY, AND DENSITY PROFILES FOR SITE A, 21 OCTOBER 1953

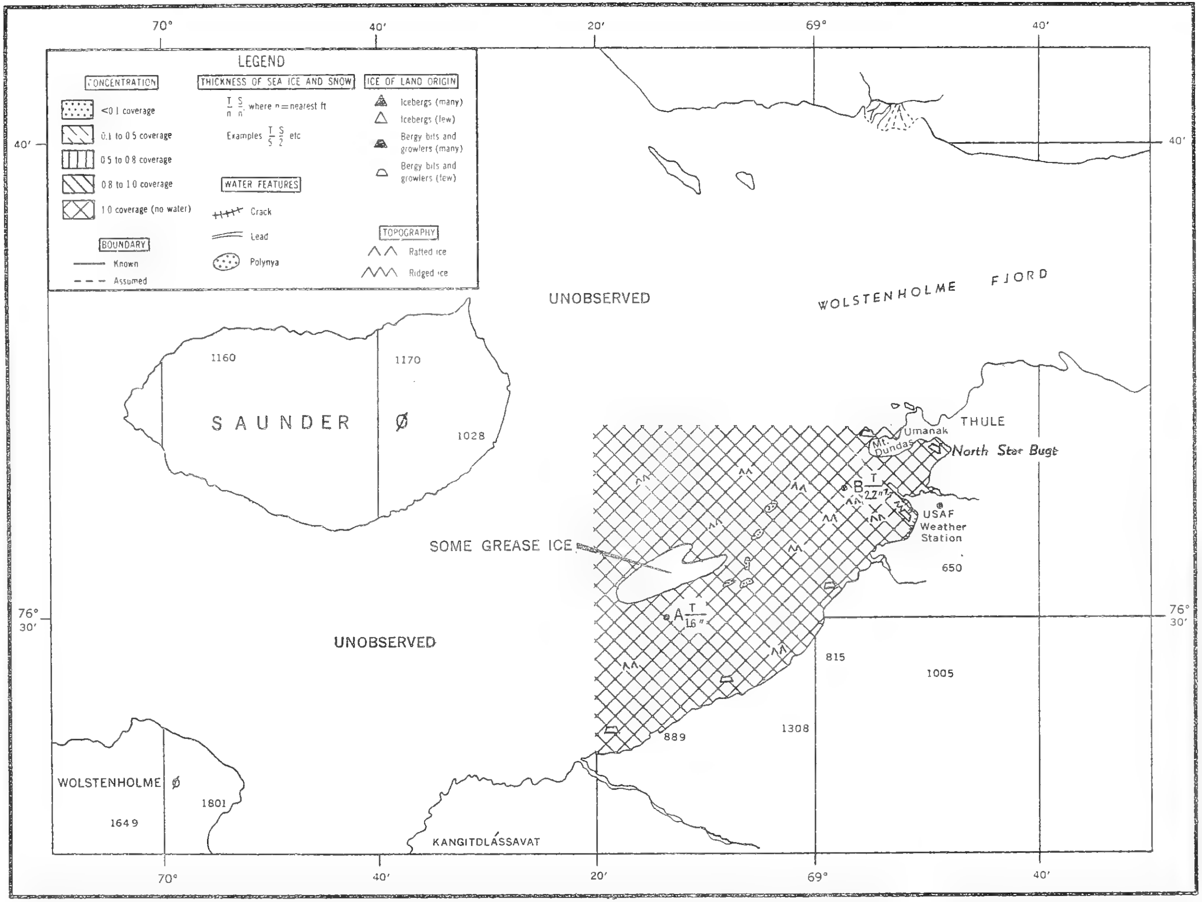

FIGURE 7. SYNOPTIC ICE CONDITIONS, 6 OCTOBER 1953 (1000 LST)

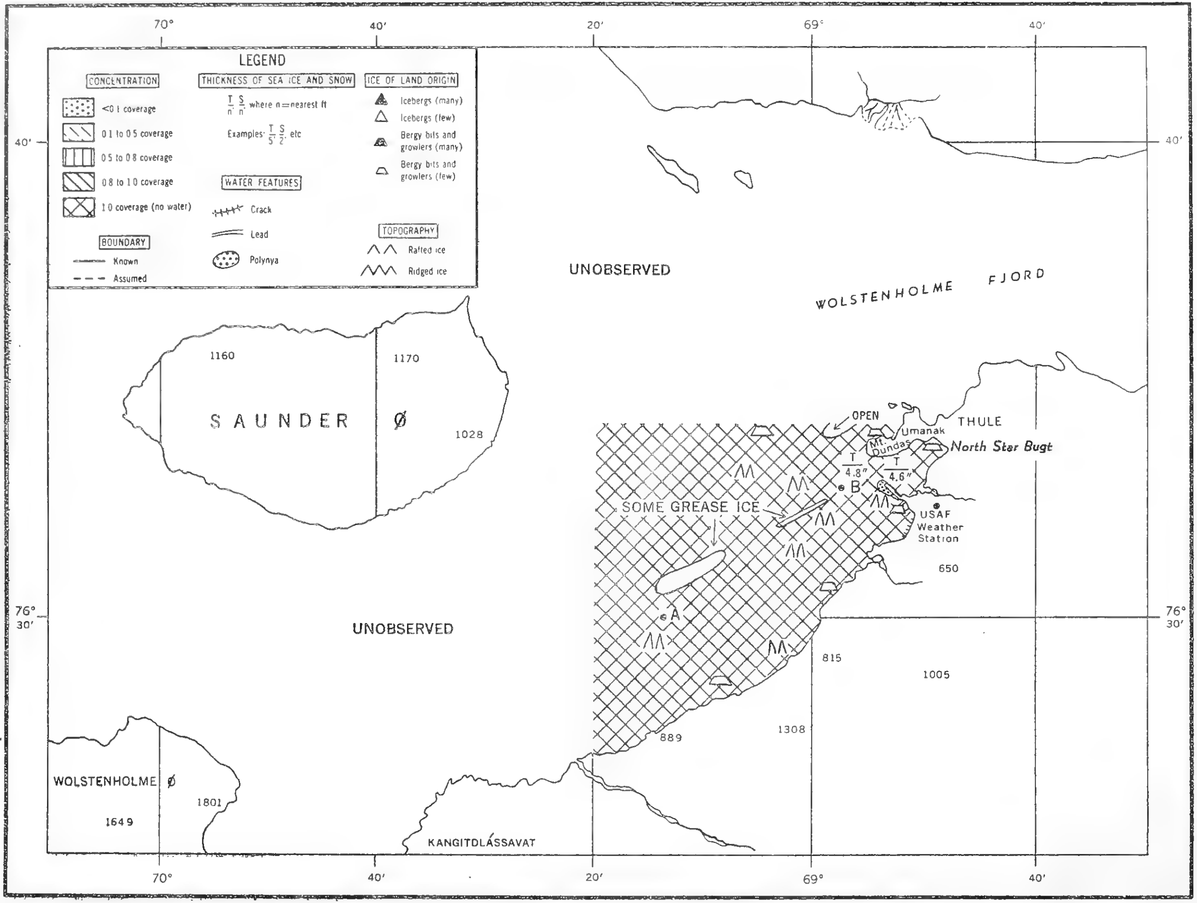

FIGURE 8. SYNOPTIC ICE CONDITIONS, 9 OCTOBER 1953 (1000 LST)

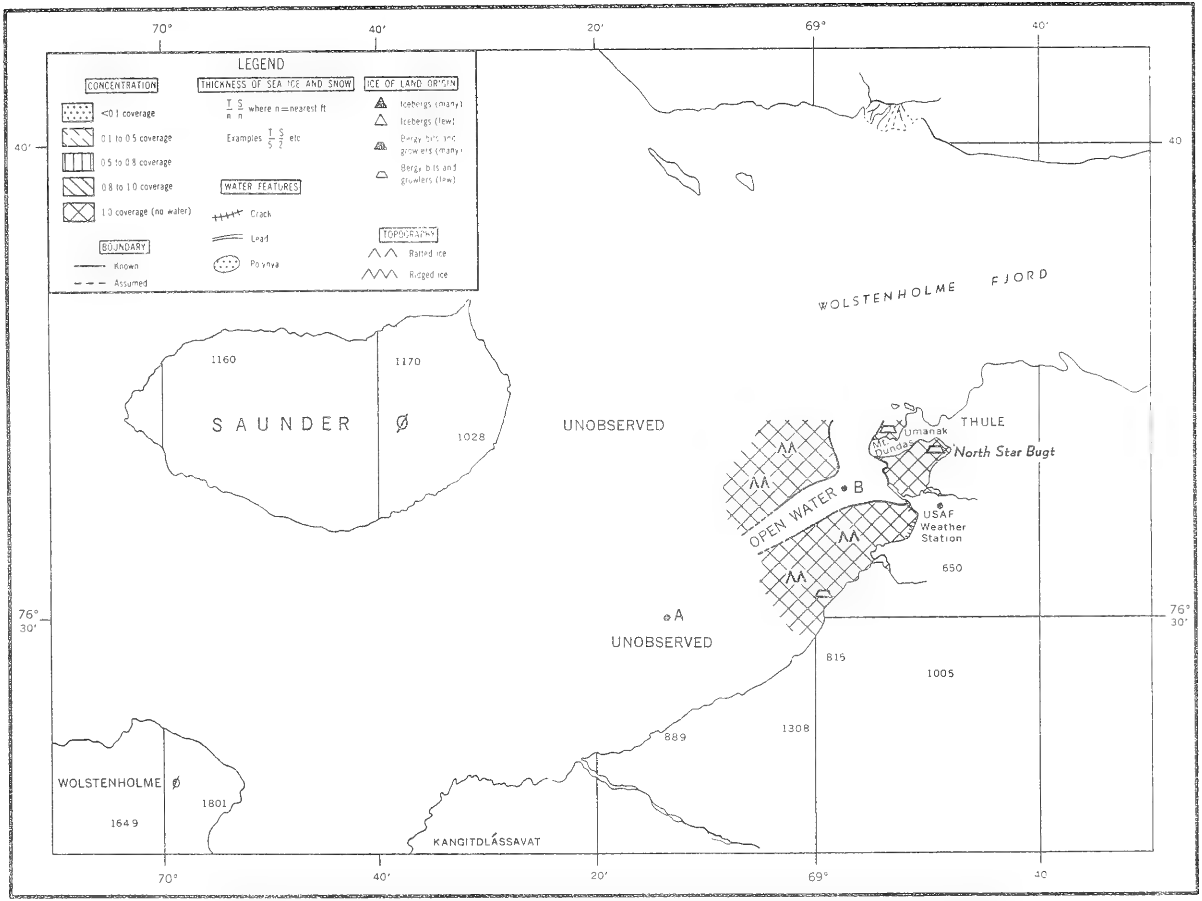

FIGURE 9. SYNOPTIC ICE CONDITIONS, 9 OCTOBER 1953 (1200 LST)

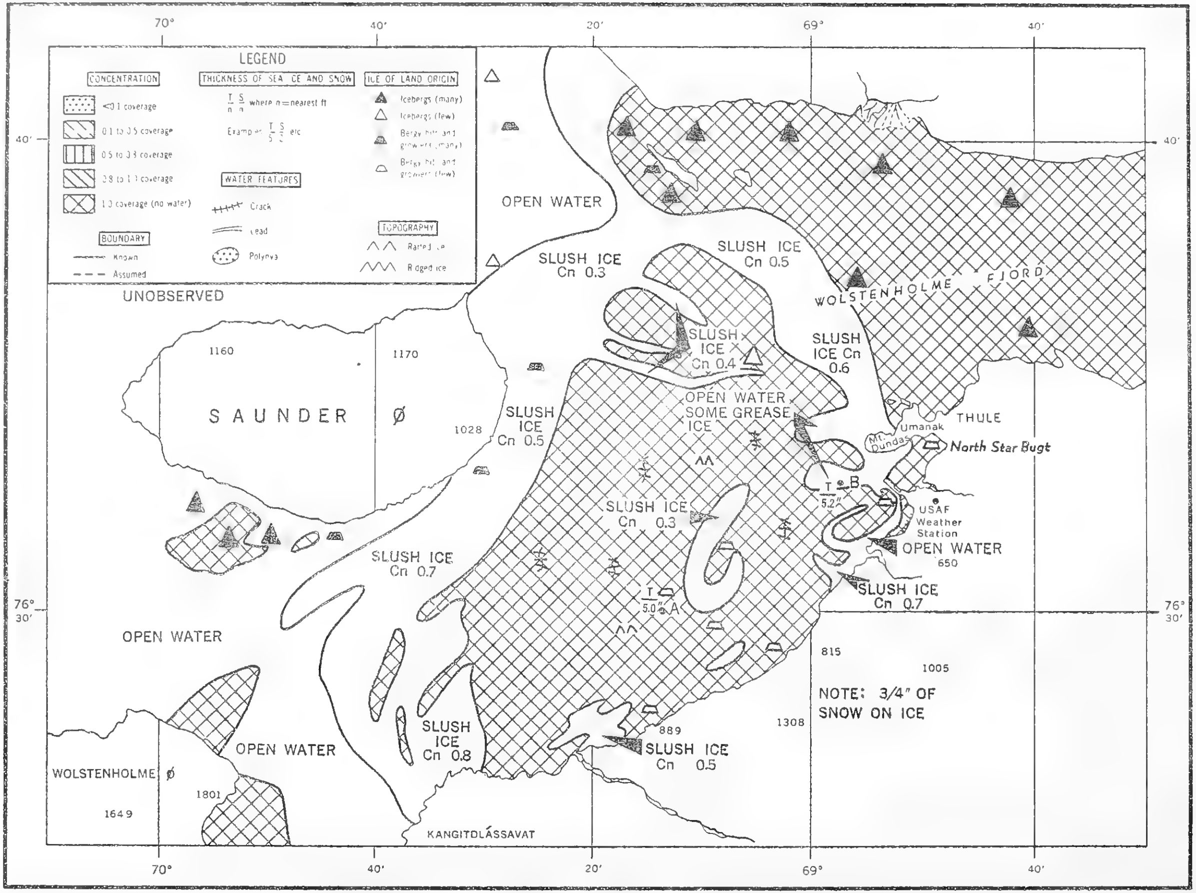

FIGURE 10. SYNOPTIC ICE CONDITIONS, 10 OCTOBER 1953 (1100 LST)

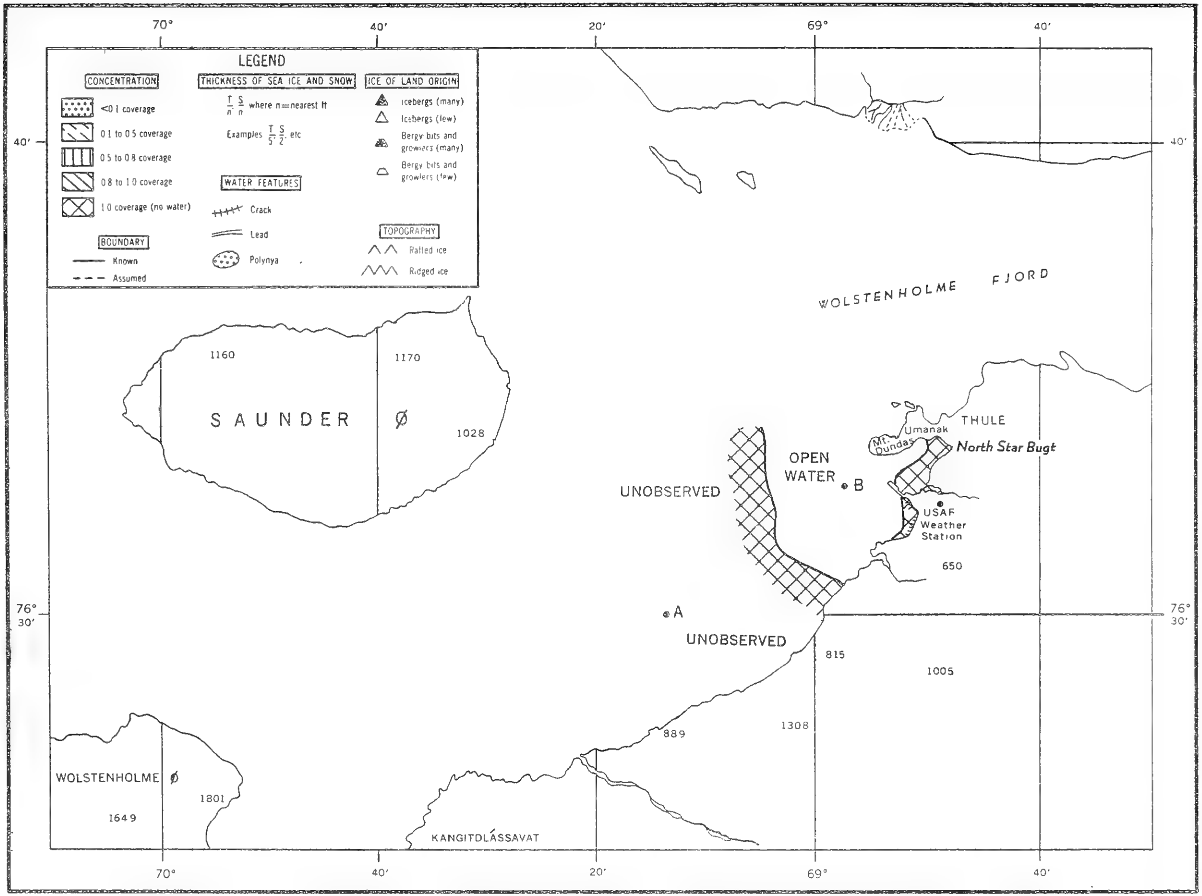

FIGURE 11. SYNOPTIC ICE CONDITIONS, 10 OCTOBER 1953 (1600 LST)

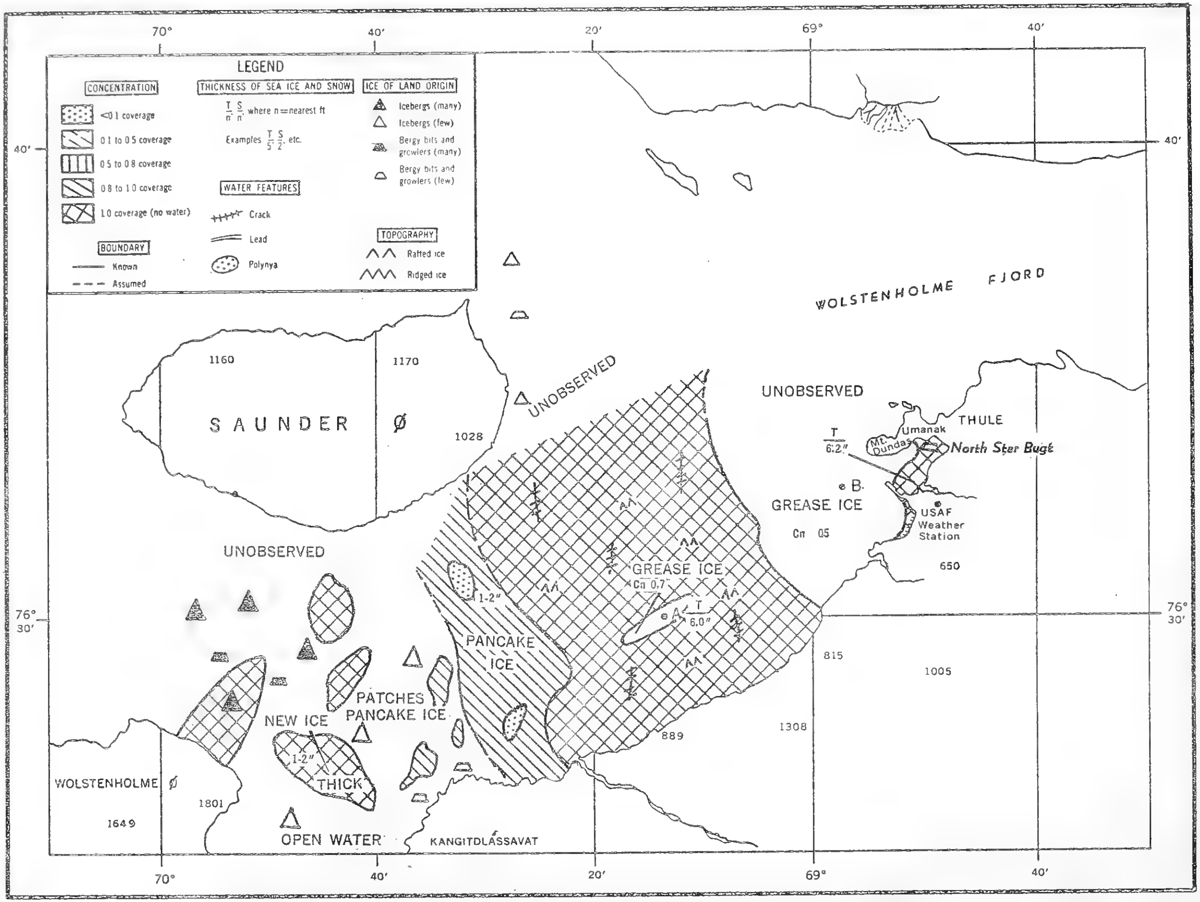

FIGURE 12. ICE CONDITIONS, 12 OCTOBER 1953

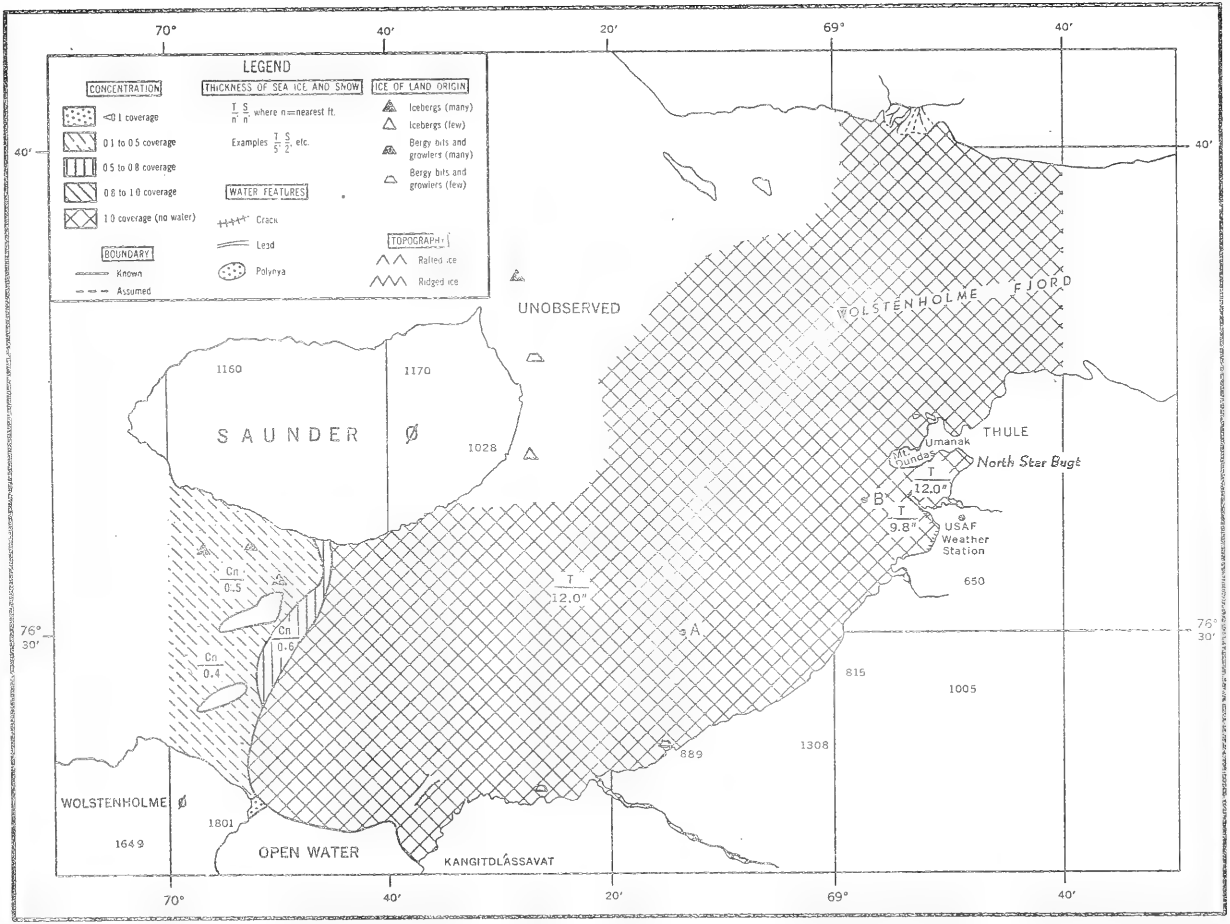

FIGURE 13. ICE CONDITIONS, 23 OCTOBER 1953

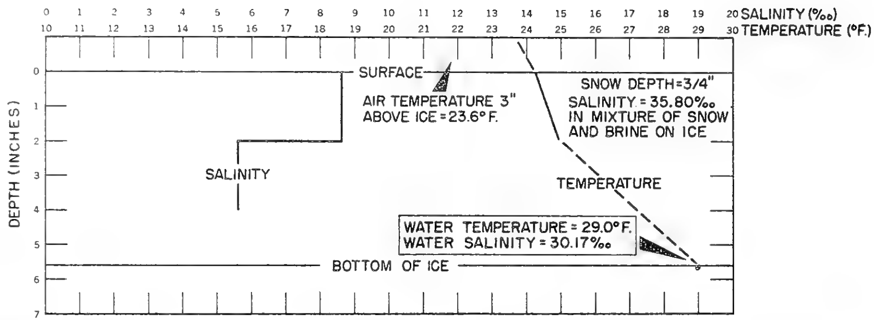

FIGURE 14. TEMPERATURE AND SALINITY GRADIENTS IN ICE, 11 OCTOBER 1953 (1030 LST- OLD ICE)

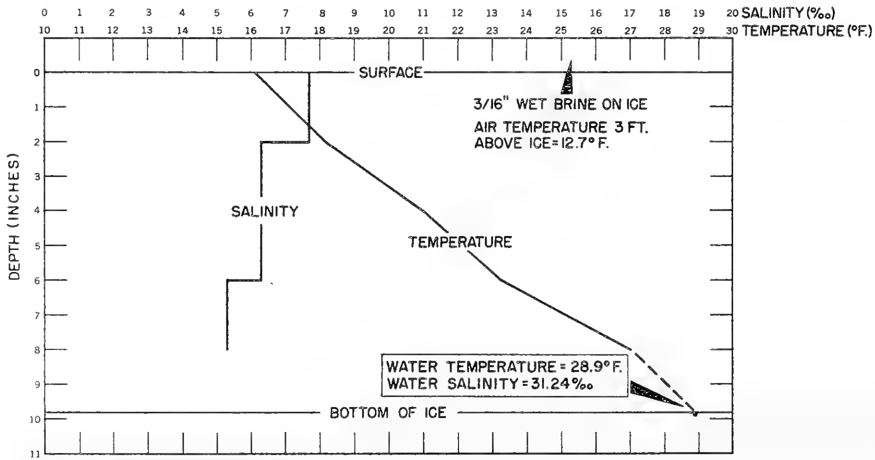

FIGURE 15. TEMPERATURE AND SALINITY GRADIENTS IN ICE, 23 OCTOBER 1953 (1600-1900 LST-NEW ICE)

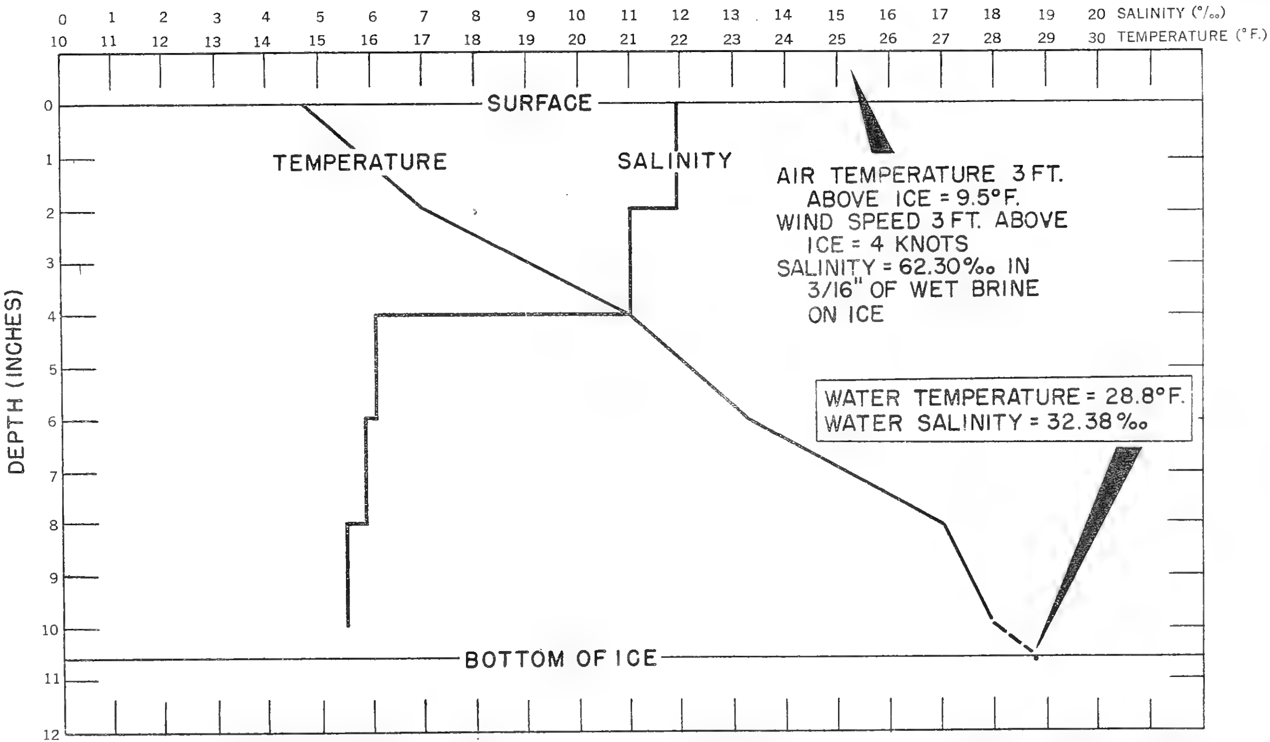

FIGURE 16. TEMPERATURE AND SALINITY GRADIENTS IN ICE, 24 OCTOBER 1953 (1000 LST-NEW ICE)

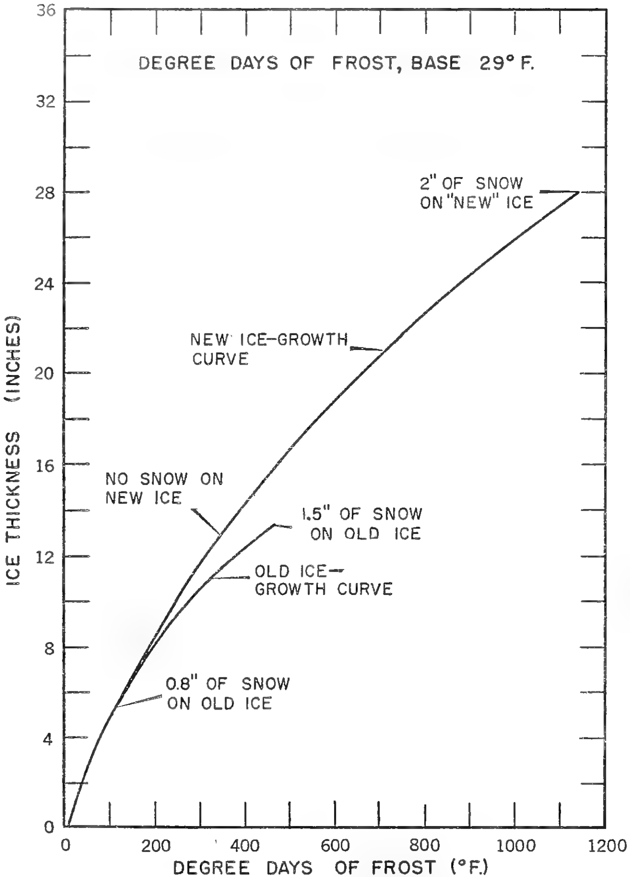

FIGURE 17. ICE GROWTH AS A FUNCTION OF DEGREE DAYS OF FROST

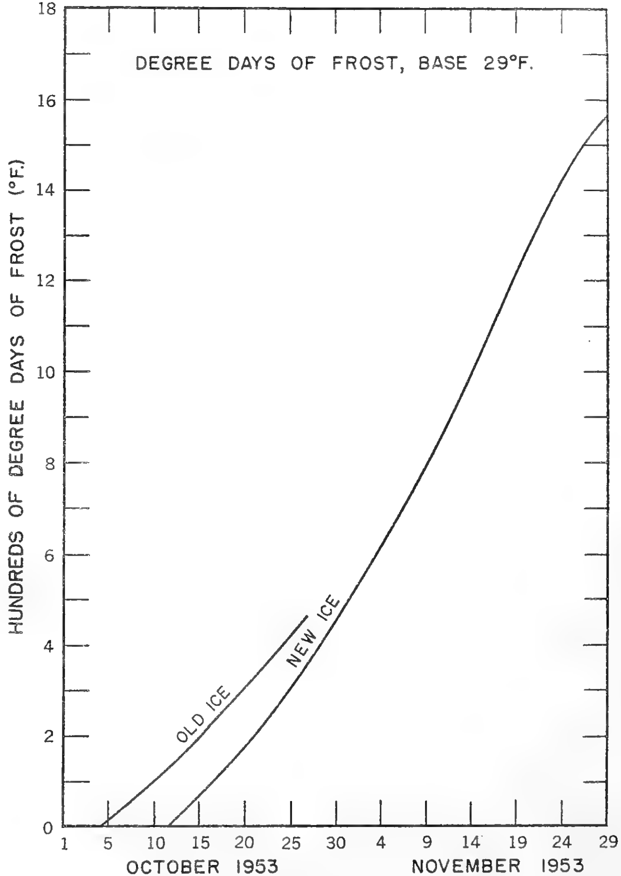

FIGURE 18. ACCUMULATION OF DEGREE DAYS OF FROST

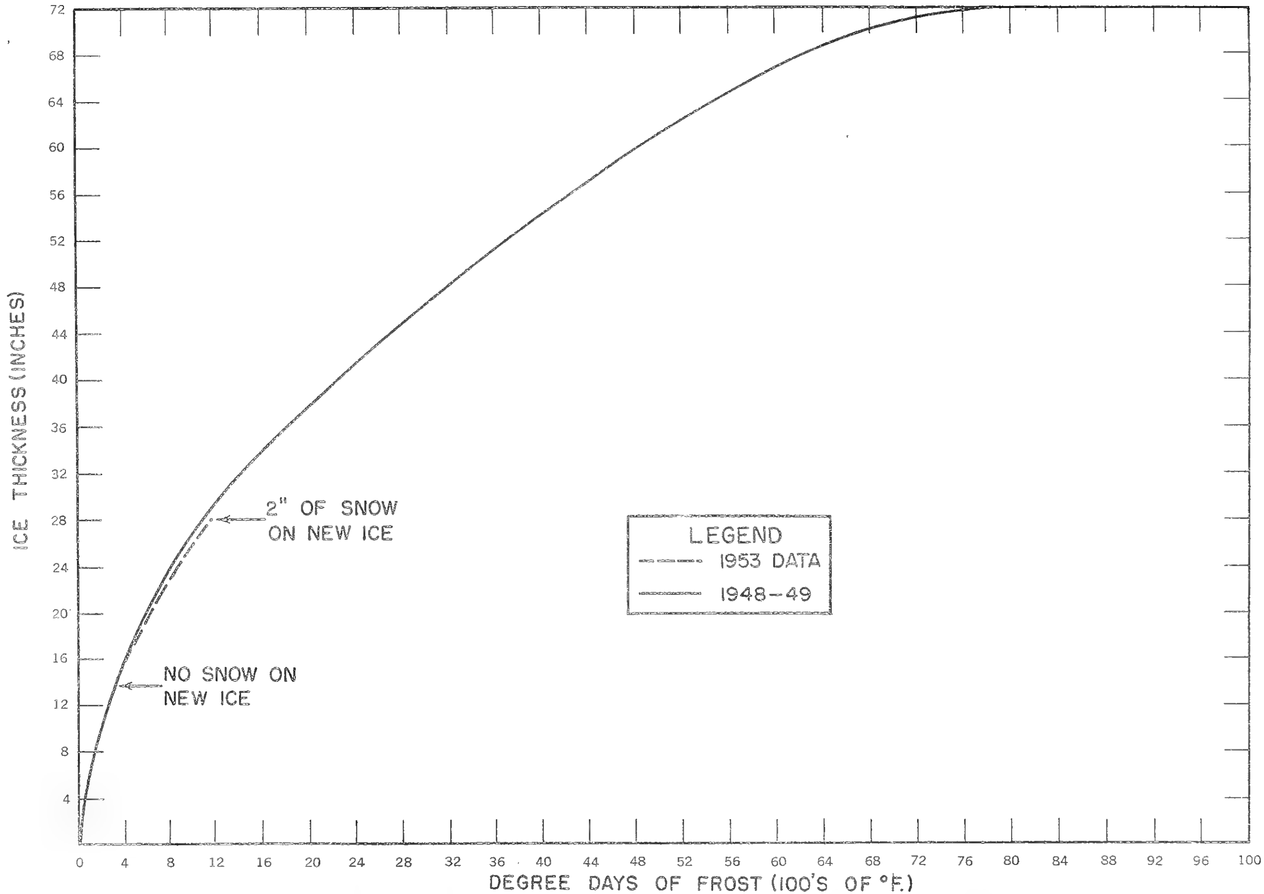

FIGURE 19. ICE GROWTH AS A FUNCTION OF DEGREE DAYS OF FROST IN 1948-49 AND 1953

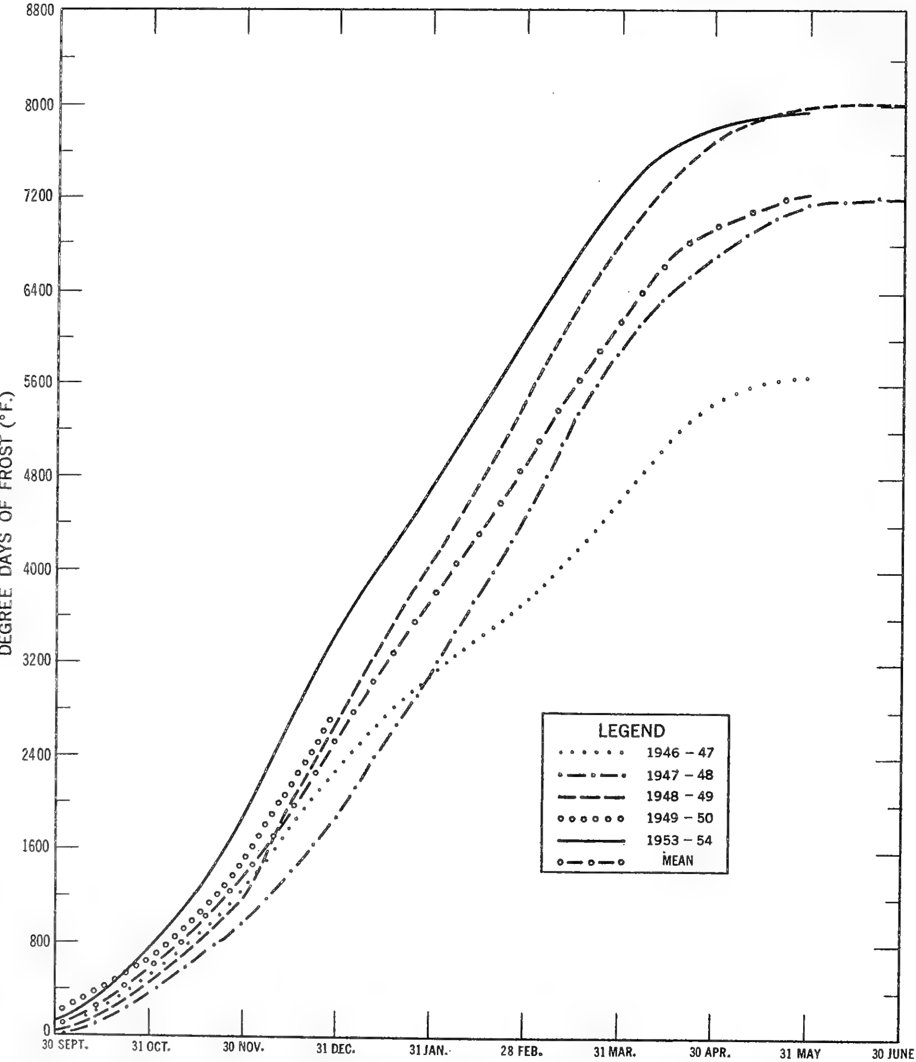

FIGURE 20. HISTORICAL DEGREE DAYS OF FROST CURVES

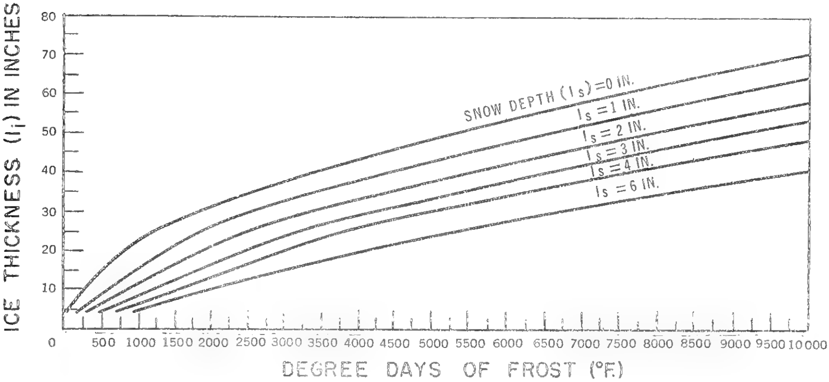

FIGURE 21. COMPUTED ICE-GROWTH CURVES FOR SELECTED SNOW COVERS. COMPUTATION BASED ON DATA FROM SITE A, 29 SEPTEMBER 1953.

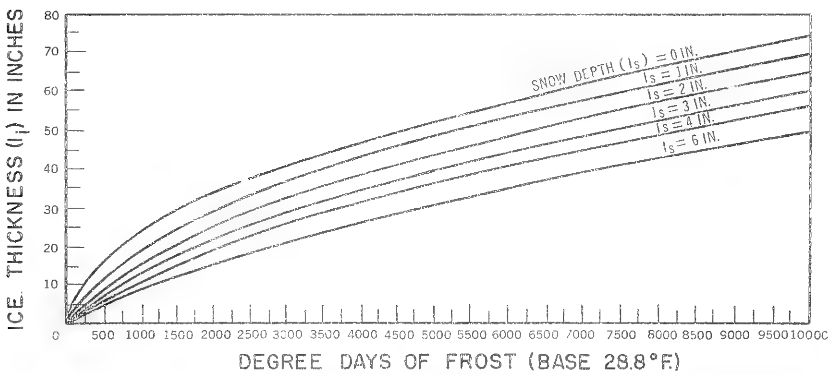

FIGURE 22. COMPUTED ICE-GROWTH CURVES FOR SELECTED SNOW COVERS. COMPUTATION BASED ON DATA FROM SITE A, 12 OCTOBER 1953.

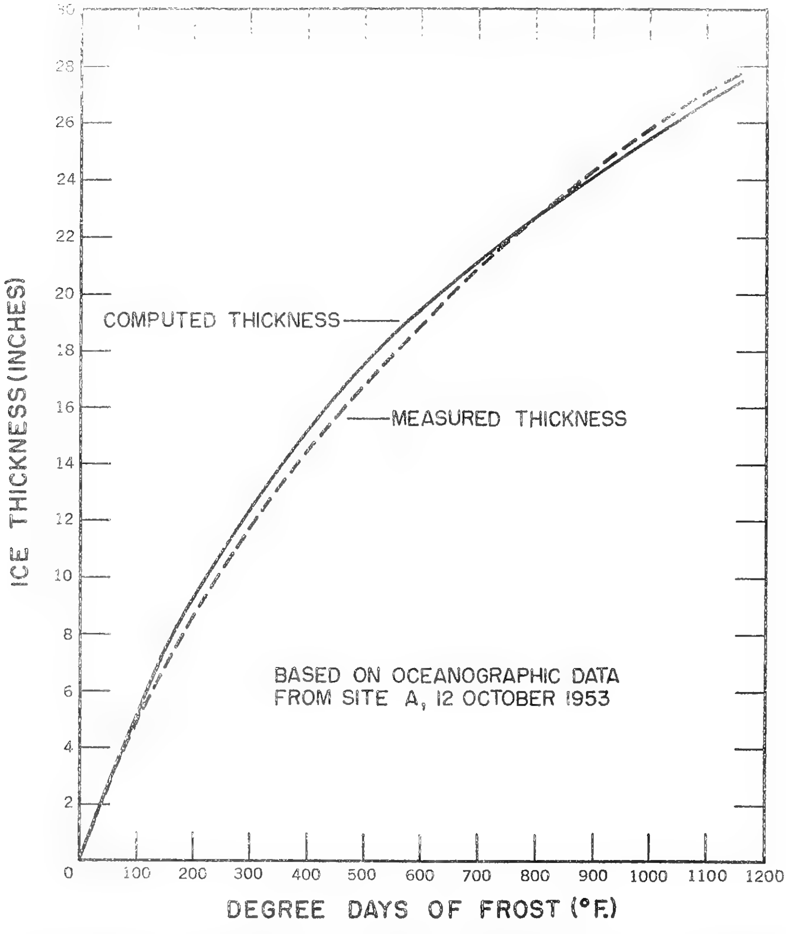

FIGURE 23. COMPUTED AND OBSERVED ICE-GROWTH CURVES FOR NEW ICE

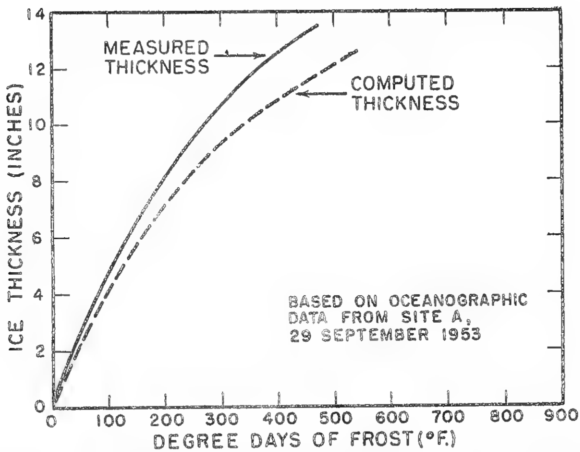

FIGURE 24. COMPUTED AND OBSERVED ICE-GROWTH CURVES FOR OLD ICE

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U. S. Navy Hydrographic Office
LOCAL ENVIRONMENTAL FACTORS AFFECTING ICE FORMATION IN NORTH STAR BUGT, GREENLAND, by Raymond J. McGough. January 1956. 7 p., 24 figures, 3 tables. (H. O. TR-23).

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