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Technical Report

POINT BARROW TRIALS – FY 1962; ABLATION AND CRYSTAL STUDIES OF SEA ICE

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U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

POINT BARROW TRIALS — FY 1962; ABLATION AND CRYSTAL STUDIES OF SEA ICE

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by

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ABSTRACT

During the spring of 1962, the U. S. Naval Civil Engineering Laboratory, Port Hueneme, California conducted trials at Point Barrow, Alaska on the deterioration, ablation and some physical characteristics of natural and constructed sea ice. Although deterioration occurred throughout the ice sheet, ablation occurred only at the surface. Observations on temperature, salinity, density and crystal orientation of these two ice types showed that the average ice temperature for the total ice thickness was about the same for an undisturbed natural ice area as for a constructed ice area. It was found that the high salinity of constructed ice did not greatly affect the salinity of the underlying natural ice and that with time the salinity and density of the constructed ice approached that of natural ice. Also it was observed that the preferred C-axis orientation of sea ice is towards the horizontal, although snow and wind influence a random orientation and crystal size.

It was concluded from these trials that prevention and reduction of ablation during thaw should improve the characteristics of sea ice, but further knowledge is needed to determine the influence and effect of the size and C-axis orientation of the ice crystals. Improved field sampling and testing techniques are needed to obtain more accurate knowledge of the properties of ice.

INTRODUCTION

Since man first began to travel, sea ice has been a deterrent to exploration, travel and occupancy of the polar regions, for much of the polar ocean area has a perennial ice cover. In recent years, sea ice has been used for floating scientific stations and aircraft operations. Both uses have been limited in scope and time because of the structural limitations and unstable nature of the ice.

The feasibility of producing stable sea ice platforms was first investigated by the Navy in 1951. Since then the effort has been directed toward achieving this objective by accelerating the growth of sea ice and protecting the ice surface during melt and by developing fundamental knowledge on both natural and constructed sea ice.

This report covers an investigation by NCEL of natural and constructed sea ice under rising temperatures at Point Barrow, Alaska from 14 May to 23 June 1962 (late spring to early summer). The observations made on ice-crystal orientation, ice lost due to ablation, and general behavior of the constructed and natural ice showed that, with time, both types approached similarity.

The Arctic Research Laboratory, Point Barrow, Alaska under authority of the Office of Naval Research, supported this program by quartering the NCEL test personnel and providing some technical and logistical assistance. During May and June, investigators from Onondaga Associates, Syracuse, New York under contract to the Laboratory, conducted aqueous foam studies on the protection of the ice from deterioration due to solar radiation and high temperatures.[1]

Historical Background

During the winters of 1950-51 and 1951-52, experimental work sponsored by the Bureau of Yards and Docks was conducted near Point Barrow, Alaska to determine the feasibility of thickening natural sea ice at a faster rate than occurs naturally. This work, which showed much promise toward improving sea ice by surface flooding, resulted in the issuance by the Bureau of Yards and Docks in 1955 of a manual on the construction of sea ice bases.[2] However, a major problem associated with this technique was found to be the high salinity of the flood-produced ice, which resulted in a lower strength and greater heterogeneity of the ice mass. Therefore, small-scale studies of the distribution and migration of brine in flood-produced sea ice were conducted in the NCEL cold chamber in 1955 and at Thule, Greenland in 1958.[3]

Trials were again conducted on the sea ice at Point Barrow in the winters of 1958-59 and 1959-60 to further explore methods for strengthening a natural ice sheet by surface flooding. Test plots in 1958-59 were constructed by confined flooding, free flooding, sprinkling and spraying.[4] In 1959-60, a model ice platform was constructed by free flooding and small test plots were constructed using chipped natural sea ice aggregate and fractured young sea ice aggregate.[5] It was concluded that free flooding offered the most advantageous method of thickening sea ice by surface flooding because it either eliminated or minimized many of the problems associated with the other methods investigated.

In conjunction with the Air Force Cambridge Research Laboratories, a practical application of the free flooding method was made in the winter of 1960-61, during Project ICE WAY[6] at North Star Bay, Thule, Greenland. In this project, a runway was made by clearing the natural sea ice of snow, and three separate parking aprons were constructed — one by free flooding, one by fiberglas-reinforced free flooding, and one by fiberglas-reinforced ice-aggregate fill. These aprons had total thicknesses at the center of 94, 85 and 71 inches, respectively, as compared to the natural ice thickness on the runway of 52 inches. A test load of 200,000 pounds for one hour deformed the free flooded and reinforced free flooded aprons 0.07 foot as compared to 0.29 foot on the natural ice. During 100 hours of observation and progressive loading up to 235,000 pounds, the natural sea ice showed elastic deformation followed by elastic or transient creep and permanent creep. Only elastic deformation and elastic or transient creep were observed on the reinforced free flooded apron during a similar period of observation and progressive loading up to 272,000 pounds.

Test Site

The test site for the FY-1962 Point Barrow trials was located on the Arctic Ocean pack ice (Figure 1). The natural ice in this area, which formed sometime during the preceding November, had broken up and refrozen early in the season, and suitable level areas for the test plots were at least 1000 feet apart. This wide spacing reduced the influence of one test area on other adjacent areas. Between 30 March and 9 April, four areas were thickened by confined flooding and one by free flooding. These five areas and three natural ice areas were selected for the trials.

The confined flooded plots (plots 1 through 4) were 100 feet in diameter with a total flood lift of 12 inches built in 3-inch increments as measured at the edge. Plastic diking, 12 inches in diameter, was used to confine the flood water (Figure 2). Except on plot 1, the snow cover was prepacked with a tractor before flooding. On plot 1 the snow was removed. The free flooded plot (plot 5) was about 100 feet in diameter and 12 inches thick at the center of the flooded area. It was built in four lifts of 3 inches each as measured at the point of discharge (Figure 3).

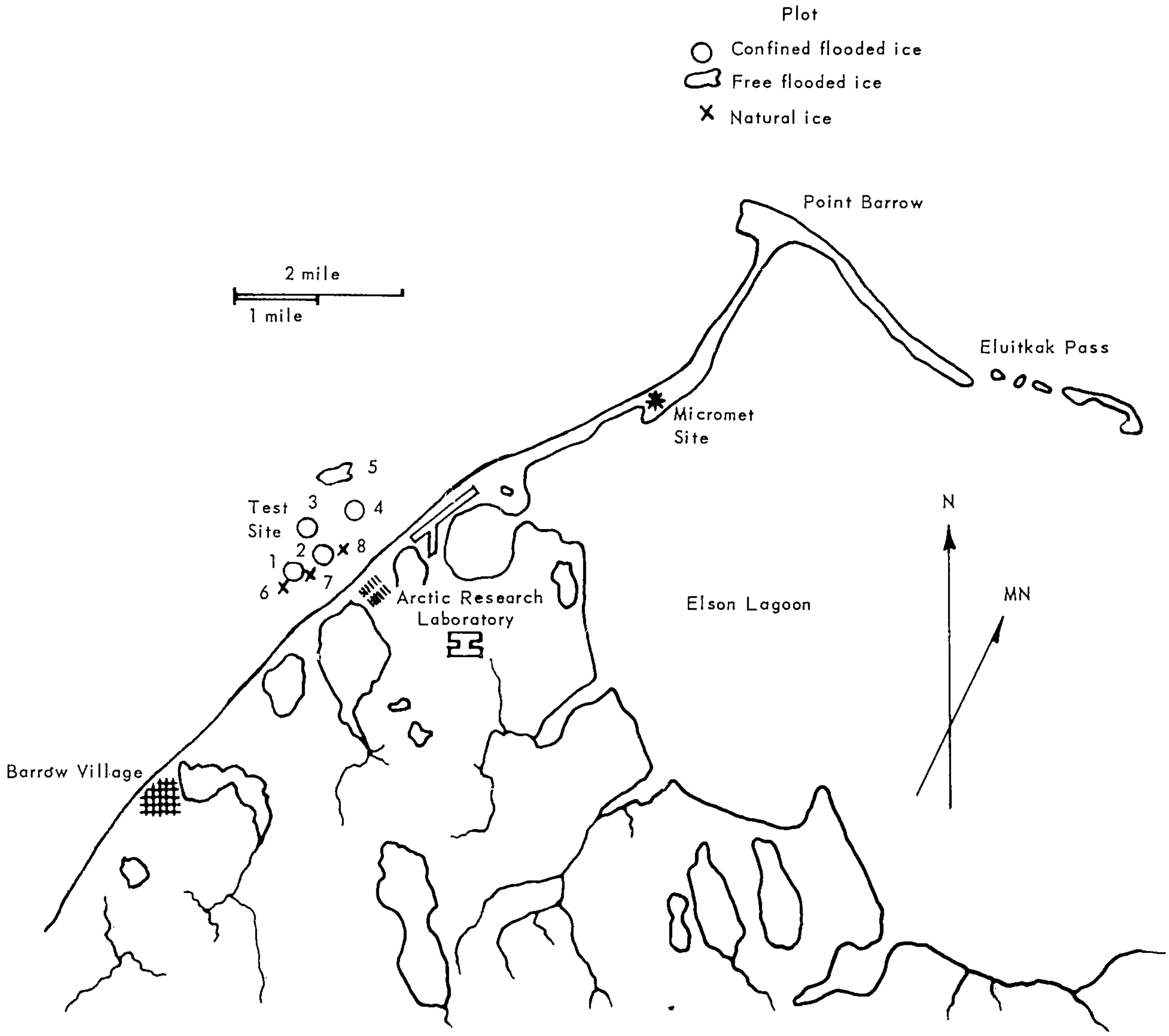


Figure 1. Map of Point Barrow coastline showing location of FY-1962 test site.

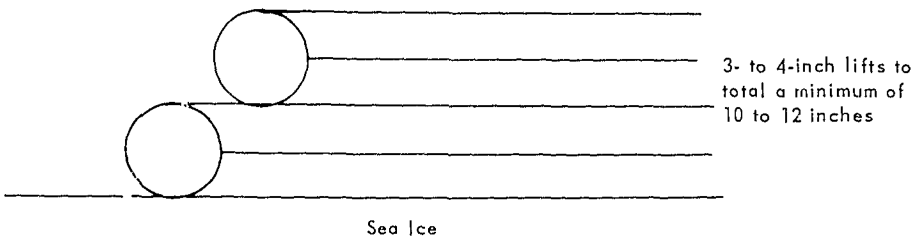


Figure 2. Construction diagram of diking.

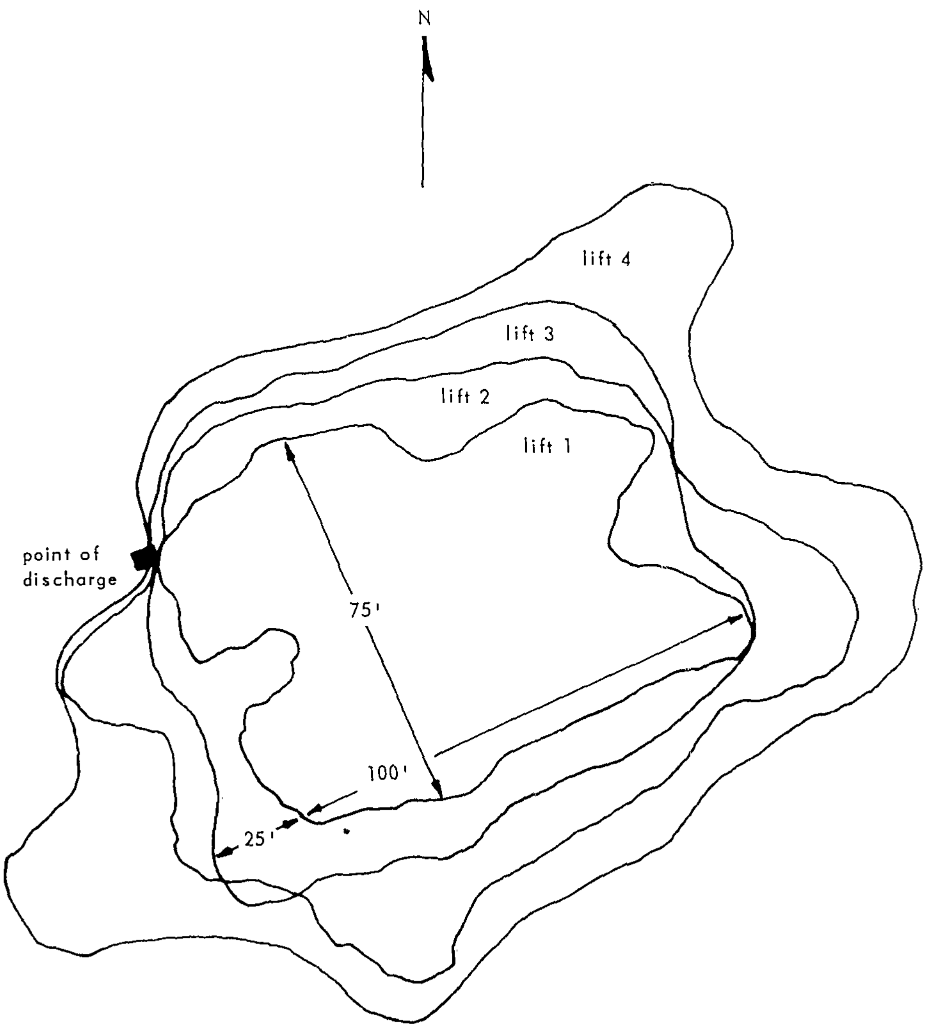


Figure 3. Free-flooded plot 5 showing extent of flood lifts.

After construction, thermocouples, made with blue thermocouple wire, were placed through the ice in three of the confined flooded plots (plots 1, 2 and 3), the free flooded plot (plot 5), and the three natural ice areas (plots 6, 7 and 8). Ablation stakes made of 3/16-inch doweling painted white were also installed in these plots. These were arranged in a triangle with the tops of the stakes about 12 inches above the ice surface.

Weather

Air temperature and wind at the test site were observed twice daily during the trials (14 May to 23 June 1962). Maximum and minimum air temperatures were obtained with a two-leg thermometer installed 4 feet above the ice surface in a shaded, ventilated box next to plot 2; these temperatures were averaged for the mean. Net solar radiation measurements over the ice were obtained from the University of Washington Micrometeorology Station which was located on the coast several miles north of the test site (Figure 1). Temperature, wind and radiation are shown in Figure 4. The beginning of thaw is evidenced by the increase in air temperature to above 29 F on 9 June; thaw continued at this above-freezing temperature.

ICE GROWTH AND DETERIORATION

During the period of rising temperatures, thickness measurements were made on the natural and confined flooded ice; ablation and deterioration were observed on all plots. The natural ice growth was measured every three to four days. Surface ablation was measured weekly until strong evidence of thaw was obtained. At this time, measurements were made every other day until the stakes melted out of the ice. The general deterioration of the ice sheet, including brine drainage, surface water and crystal separation, was observed nearly every day for several days before thaw until the end of the test period. When measurements began, the natural ice was about six months old and the constructed ice about one and one-half months old.

Natural Growth and Surface Ablation

Growth was determined from ice thickness measurements made with a SIPRE ice thickness kit when the natural or confined flooded ice was completely cored. Ablation measurements on each test plot were made halfway between adjacent ablation stakes, (Figure 5). The tops of these stakes were used as a line of reference, and the differences between the initial measurement between this reference line and the ice surface and the new measurements were recorded as the total ablation at the time of observation.

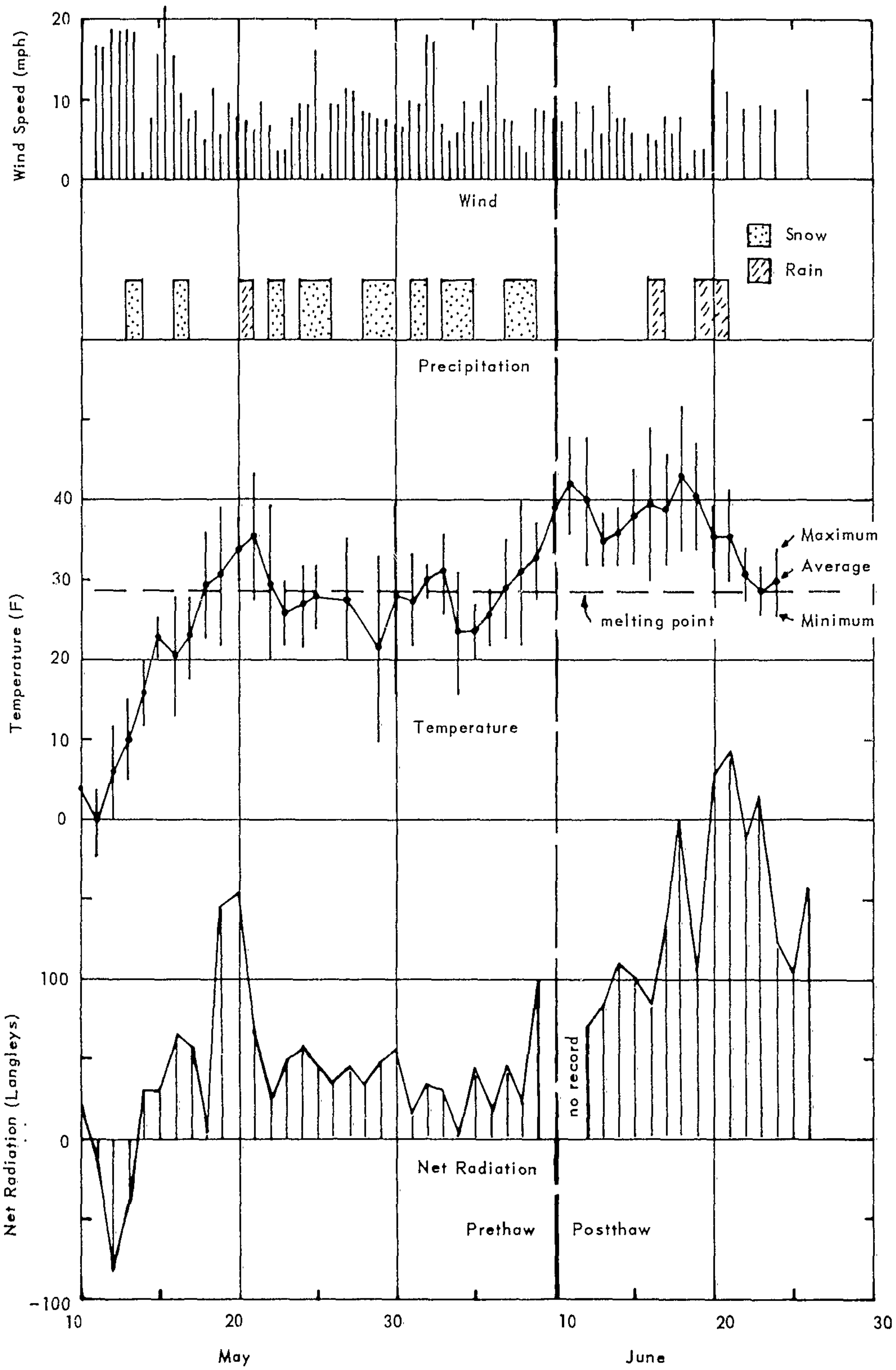
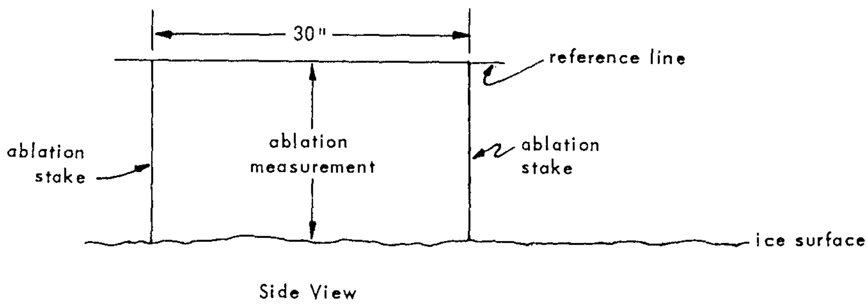
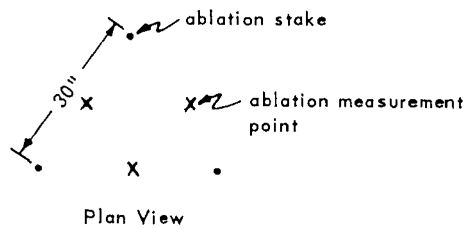


Figure 4. Daily weather during FY-1962 trials at Point Barrow, Alaska.



Method of Ablation Measurement



Ablation Stake Arrangement

Figure 5. Location and method of measurement with ablation stakes.

The average thickness of the ice and the ablation during the trials are shown in Figure 6. About 6 inches of ice growth is noticeable, all during the first month of observation. There was no ablation of the ice until after thaw; however, the original 1- to 2-inch-thick snow cover completely disappeared about two days before thaw. Figure 6 shows that the amount of ice lost by ablation on the confined flooded ice was about the same as that lost on the natural ice. The total loss of surface ice was about 19 inches by 25 June (a period of 16 days). From this observation it appears that the flood-constructed ice was as susceptible to ablation as the natural ice.

The reduction of ice thickness during thaw is directly attributable to the loss of ice at the surface. In Figure 6, if the ablation loss is added to the total ice thickness at any given time, the result is equal to or greater than the thickness before thaw, indicating that the ice loss was from the surface. This implies that if ablation could be reduced or prevented, the thickness of an ice sheet could more easily be maintained during thaw.

Deterioration

The end of the prethaw period is marked by the pronounced increase in air temperature, net solar radiation, and ablation which indicates the commencement of the postthaw period (that time after thaw had begun).

Prethaw. Until shortly before thaw, evidence of deterioration was limited to brine channels and pockets within the ice. The channels were made noticeable by the presence of air in the ice cores (Figure 7). Brine pockets were not as prevalent, and usually occurred only within the bottom foot of the ice sheet (Figure 8). The ice surface was protected by a light snow cover until shortly before thaw, and consequently showed little evidence of deterioration.

With the continued rise in air temperature, brine drainage increased. Ten days before thaw, brine draining from within the ice sheet into 30-inch-deep core holes in constructed ice increased so that brine water with an average salinity of 48 parts per thousand (ppt) filled a core hole (680 cubic inches) in less than one minute, at least 3 gallons per minute (gpm). However, the cores from these holes lost only enough brine to wet their surfaces. At this same time, the water draining from the natural ice was so slight, the amount could not be estimated and no salinity samples could be obtained.

Postthaw. The beginning of thaw was marked by a noticeable change in the ice itself. Brine pockets and channels increased, particularly in the top and bottom of the ice sheet. A week after thaw there were channels all the way through the ice sheet, and the top and bottom 1 to 2 feet were much more porous.

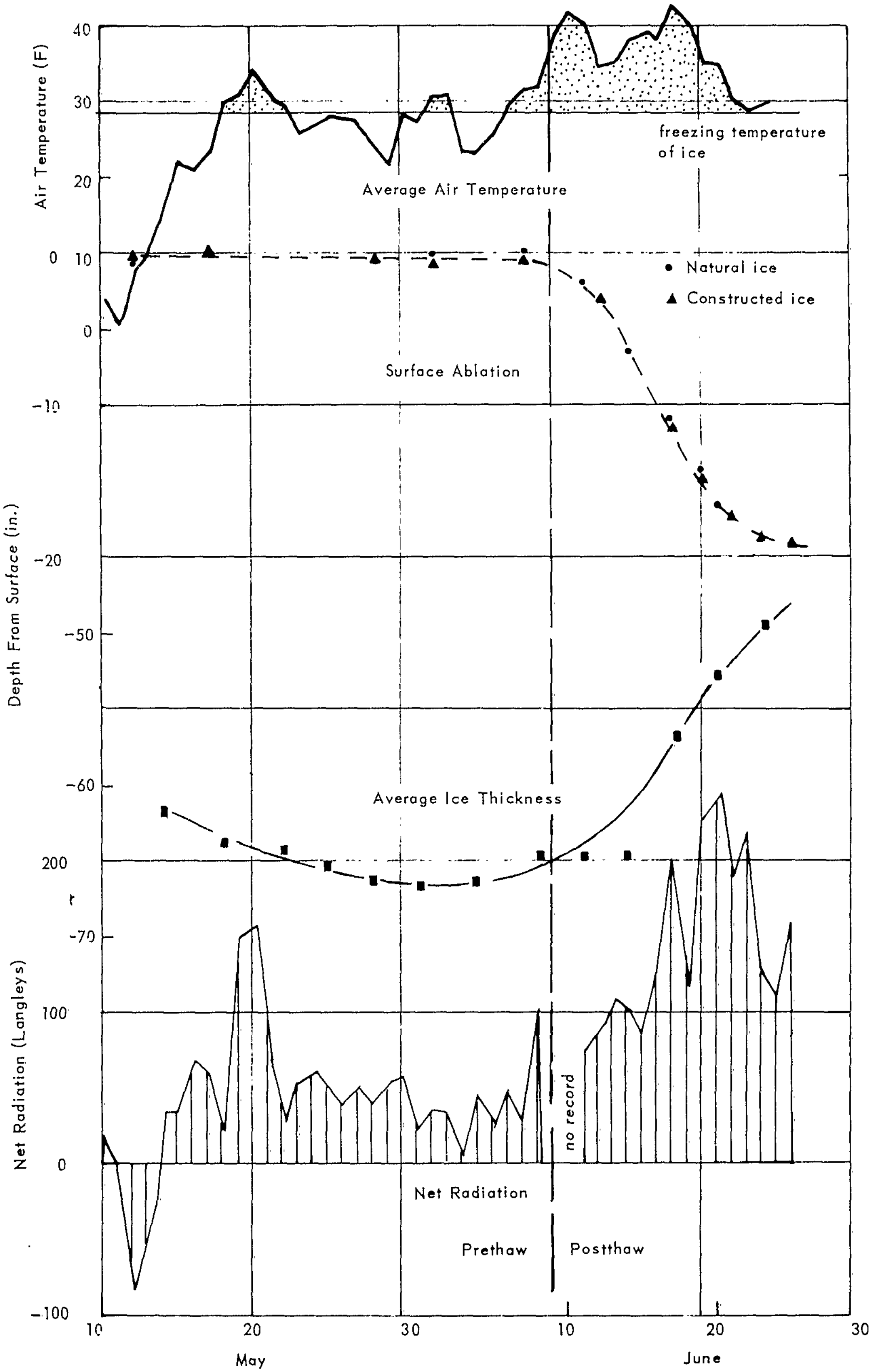


Figure 6. Average ice thickness and ablation during trials.

Figure 7. Ice core from natural ice showing prethaw brine channels.

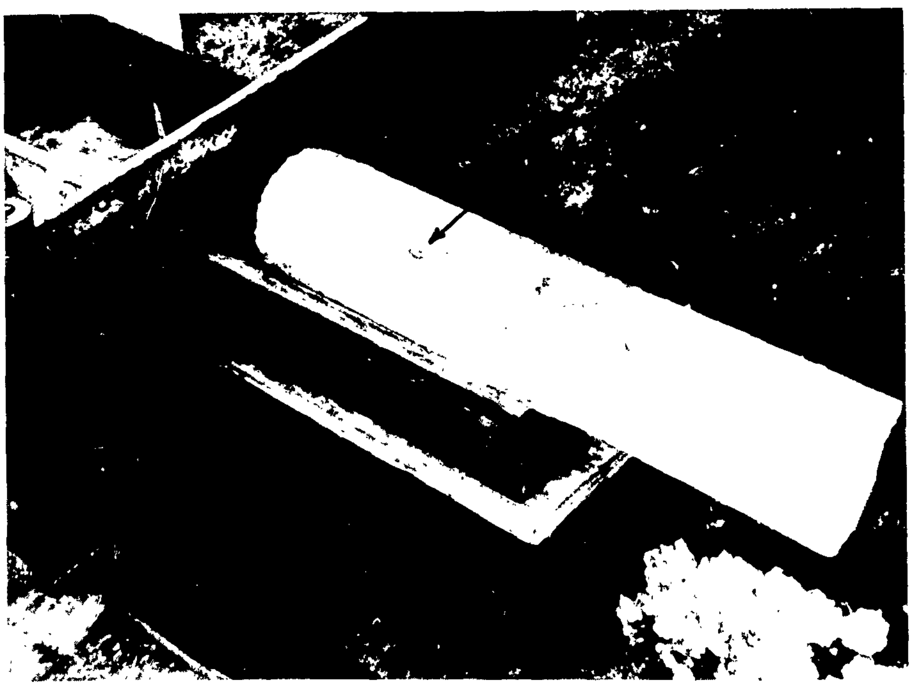


Figure 8. Prethaw brine pocket in natural ice from confined plot.

Within three days after thaw, the natural ice began to drain considerably, and core holes in this ice also filled with drain water, with a salinity of 11 ppt. This drainage water came from within the ice sheet at the same rate as that in the constructed ice before thaw. At this time there was considerable surface water (Figure 9), but within one week this water had drained off through holes in the ice sheet (Figure 10). Following this, the drainage into core holes in both the natural or flooded ice was reduced by about one-half. As thaw progressed, there was even less drainage from within the ice sheet into the core holes. Also, the salinity of the drainage in the natural and constructed ice decreased to about 8 ppt or 6 times less than the salinity of drainage ten days before thaw. However, the salinity of the drainage was still about 2-1/2 times greater than the average salinity of the natural ice (3 ppt).

Because the constructed ice plots were raised above the natural ice surface, melt water from the constructed ice tended to flow onto the natural ice. This left the constructed ice relatively dry, while the natural ice became flooded. Although wet spots developed within a few days after thaw on the constructed ice plots, it was nearly a week later before much water accumulated on their surfaces. At that time about 60 percent of each plot was covered with water approximately 4 inches deep (Figure 11). Gradually the depth of water and the area of coverage increased. By the end of the trials, 75 percent of each plot was covered with 6 to 8 inches of water, and the dry areas consisted of slush and corn ice (granular, snow-like ice resulting from crystal separation). The condition of the natural ice at this time was similar.

Figure 9. Water on the natural ice three days after thaw.

Figure 10. Two drain holes through the natural ice after thaw.

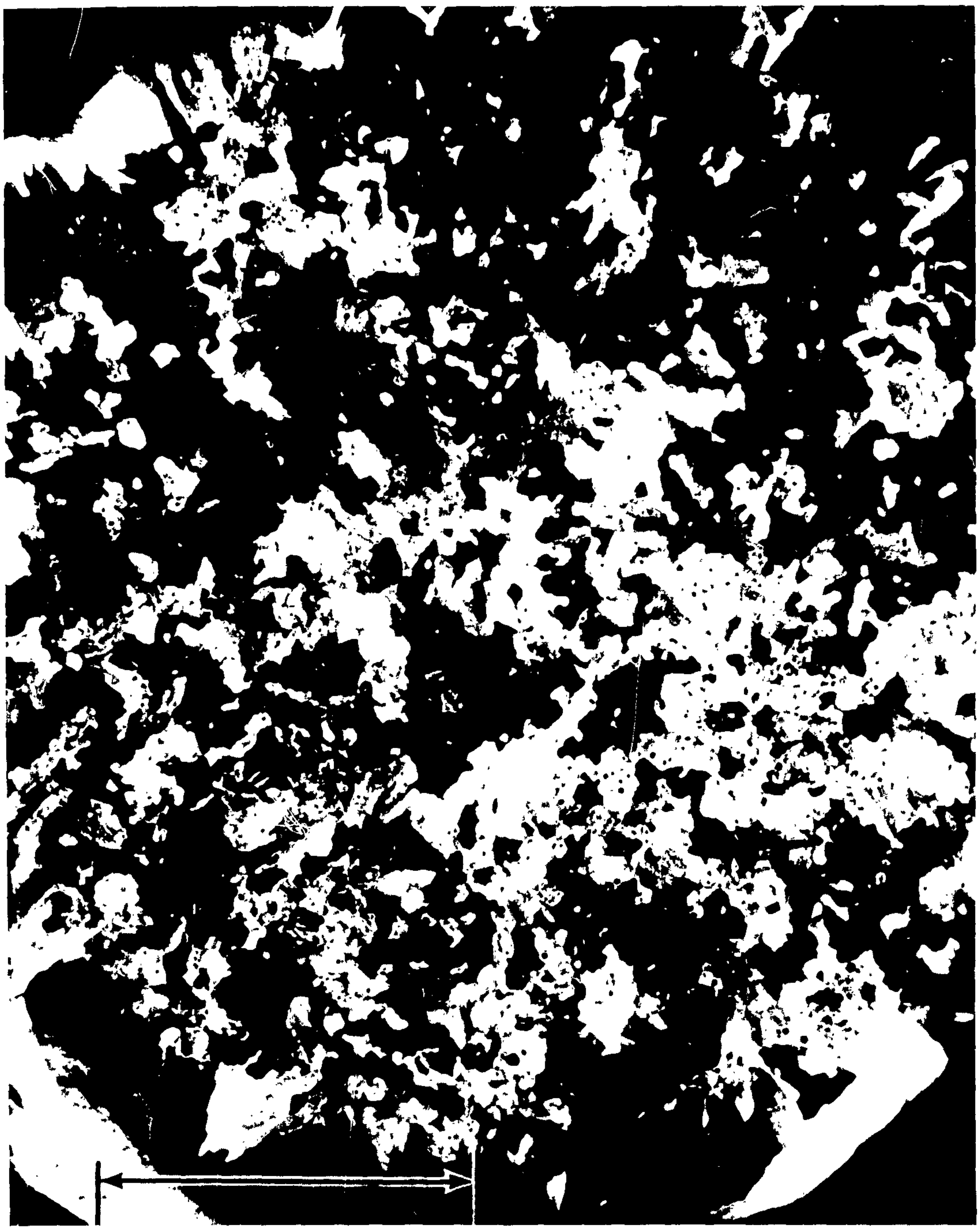
Figure 11. Surface water on a confined flooded plot after thaw.

ICE-CRYSTAL ORIENTATION AND SIZE

Recent research has shown that there is a relationship between the orientation of sea ice crystals to stress and ice strength; in fresh water ice on the Ellesmere Ice Shelf, Well[7] noted a relationship between the ice-crystal orientation and the resistance of ice to deterioration. Because of these relationships and the lack of information on natural- and flooded-sea-ice-crystal orientation and size, studies of these properties were conducted during the prethaw period of the trials.

Because ice consists of optically uniaxial, birefringent crystals, the optic axis, or C-axis, orienration of sea ice crystals can be determined with a universal stage with four axes of rotation. In this study, thin sections were cut parallel with the ice surface at 3-inch intervals from the first two cores of each plot. This included cores through the natural ice, through the total thickness of ice on a confined flooded plot (plot 1), and 30 inches into the other confined flooded plots (plots 2, 3 and 4) and the free flooded plot (plot 5). The thin sections were prepared and examined for crystal orientation in the manner described by Langway.[8]

No attempt was made to measure the C-axis angle of orientation except to determine if the C-axes were dominantly horizontal, vertical or random. Since a detailed log was kept of the weather conditions during flooding it was possible to correlate roughly these conditions with the C-axis orientation of the crystals produced on the flooded ice. The ice crystals produced by flooding were in all cases small (Figure 12), being less than 0.2 inch across and 0.4 inch long. The only natural-ice crystals in this same size range were found in the top 6 inches of the natural ice sheet. Figure 13 illustrates generalized cross sections of two ice cores, one through a confined flooded plot (plot 1) and one through the natural ice, showing the predominant grain size and C-axis orientation in each 3-inch segment. There is a similarity in the natural ice of both cores, but the flooded ice is noticeably different from any of the natural ice. Either random or predominantly horizontal C-axes appeared to be preferred by the flood-produced ice; out of 40 thin sections, only one had a predominantly vertical C-axis orientation. Random crystal orientation and small-sized crystals appear to have been encouraged by snow on the plot during flooding and by wind speeds greater than 10 mph, especially when accompanied by blowing snow. Lyons and Stoiber[9] noted that wind velocities of 6.2 mph on fresh water created a predominantly horizontal orientation of the C-axis. This was also noted by Well[7] in field studies of flood-produced fresh water ice on the Ellesmere Ice Shelf.



1 inch

Figure 12. Flood-produced ice crystals as seen under polarized light.

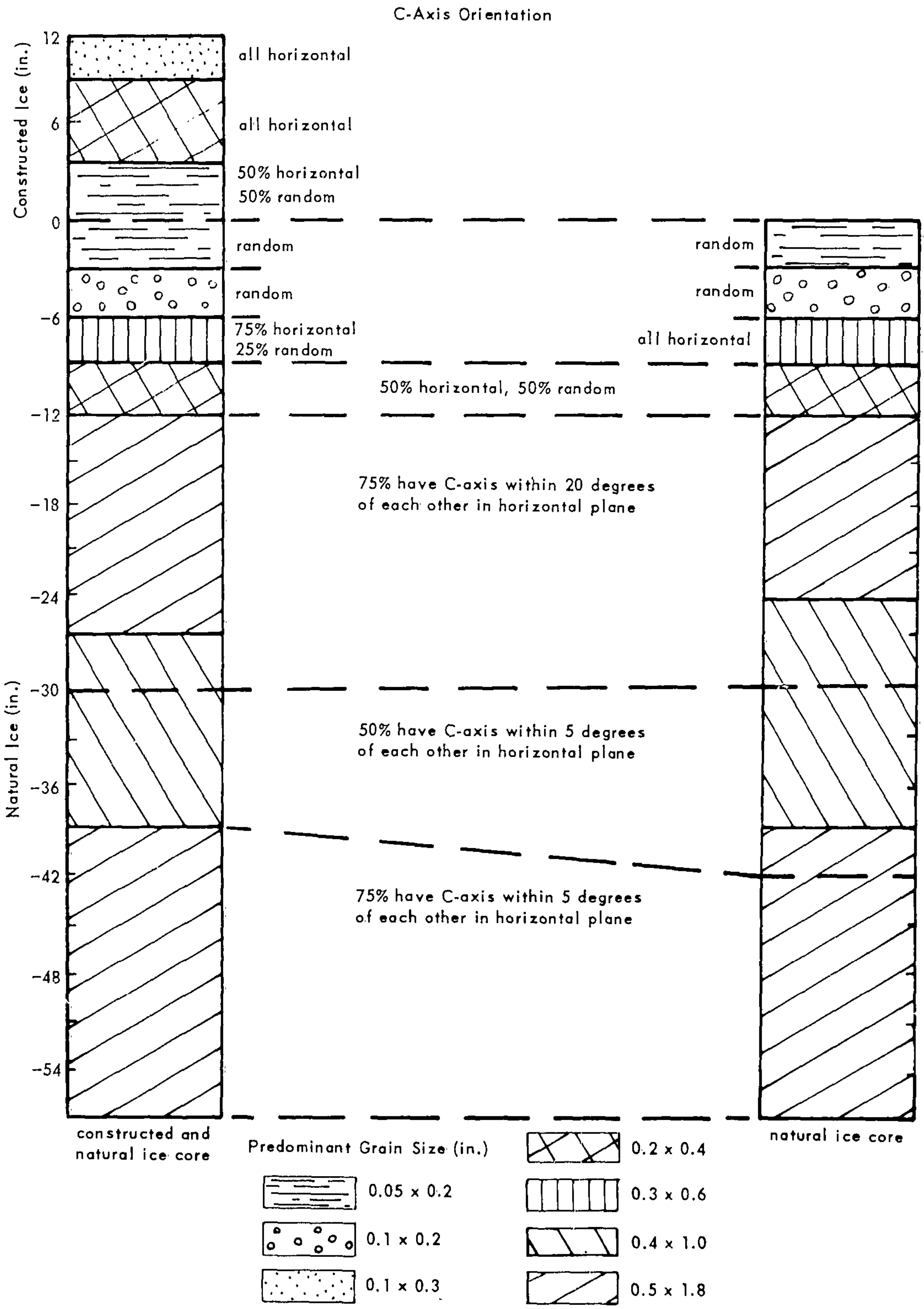


Figure 13. Cross sections of natural and constructed ice showing crystal orientation and size.

The predominance of a horizontal over a vertical orientation, where there is a dominant orientation, appears to be characteristic of sea ice. Sections made through the ice sheet indicated that the C-axes of the crystals became predominantly horizontal within 9 to 12 inches below the surface and remained that way throughout the rest of the ice thickness (Figure 13). With depth, the crystals became larger and attained a preferred C-axis orientation within the horizontal; near the bottom of the ice sheet (42 inches) the orientation of 75 percent of the crystals had a C-axis within 5 degrees of each other. This preference of sea ice for a horizontal C-axis has been noted by Mr. H. R. Peyton, University of Alaska, in several ice areas of the arctic.

TEMPERATURE, SALINITY AND DENSITY

Temperature, salinity and density were determined for the total ice thickness in a constructed ice plot (plot 1) and in the natural ice near this plot. These properties were also determined for the top 2.5 feet on the other constructed ice plots.

Each plot was sampled every three or four days between 14 May and 23 June. Two cores within several feet of each other were taken from each plot being sampled. Immediately on removal from the ice sheet, the core was cut into 3-inch segments, measured and weighed for density, and placed in a covered plastic canister for subsequent measurement of salinity.

Temperature

After construction, copper-constantan thermocouples made up of blue-coated thermocouple wire were frozen into all test plots except plot 4. They were arranged so that the bottom thermocouple projected 6 to 12 inches into the sea water under the ice sheet. The thermocouples in the natural ice sheet were spaced 12 inches apart, beginning 12 inches below the ice surface. Those in the constructed ice were located 3 inches apart beginning at the interface of the natural and constructed ice. Temperatures were read to the nearest 0.5 F with a portable potentiometer equipped with an automatic, reference junction, temperature compensator and a scale calibrated to read directly over the range from minus 100 to plus 100 F.

The average daily temperatures for the total ice thickness of natural ice (plot 7) and confined flooded ice (plot 3) are shown in Figure 14. For comparison, the average daily air temperature and the net daily radiation over ice are also shown.

In general, the temperatures for the two plots were closer, with less variation, before thaw. During prethaw the average temperature of the confined flooded plot was slightly less than that of the natural ice. However, after thaw, the average temperatures of both plots fluctuated widely with neither having a predominantly higher or lower temperature. The temperatures of both plots responded to the variation and general increase in the air temperature and net solar radiation. In some cases the average temperature is above the melting point of ice, although ice was present. This is attributed to the melting out of some thermocouples and to the absorption of radiation by the thermocouple wire.

Salinity

The salinity was determined with salinity hydrometers graduated to 0.2 ppt, and the water temperature was measured with a mercury thermometer to the nearest 0.5 C. Then, for correlation, the readings were converted to salinity at 15 C.

The average salinities during the test period are shown for the total ice thickness in a confined flooded ice plot (plot 1) and a natural ice area in Figure 15. The average salinity in the confined flooded ice plot was continually higher than that in the natural ice area. Before thaw it was a maximum of 2.5 ppt higher; after thaw it was a maximum of 1 ppt higher. The widest range in salinity was found in the top foot of ice in each area; in the lower layers the salinities were very close, with less than 1 ppt difference. However, by the end of the sampling period, the salinity of the 1 foot of constructed ice decreased to that of the top foot of the natural ice as shown in Figure 16.

In an attempt to determine if the brine draining into the core holes, as described in ICE GROWTH AND DETERIORATION, affected the final salinity of the specimen, a test was made on ten cores just before thaw. Two 3-inch specimens were taken from each core at the same depth from the surface (21 and 24 inches), in the natural ice where there was very little drainage into the core holes.

In order to duplicate the normal test procedure as closely as possible, density measurements were made before the specimen was stored in a canister. The first five cores were immediately measured for density and put in canisters. The last five cores, while still in the coring auger, were immersed in a fresh, brine-filled, core hole on a nearby confined flooded plot as soon as they were cored. Immersion continued approximately 30 seconds (the length of time it took to core) before the samples were measured for density and stored in canisters. All cores were wet, and they drained a little while being measured and weighed.

As shown in Table I, the salinity of the brine-soaked cores was slightly lower although there was little difference between the two methods. This is attributed to the extra time required for soaking the cores which allowed them longer to drain. Consequently, the length of time a core drains before being cut and placed in a canister appears to be more critical in salinity determination than the fact that it passes through a brine of higher salinity during coring.

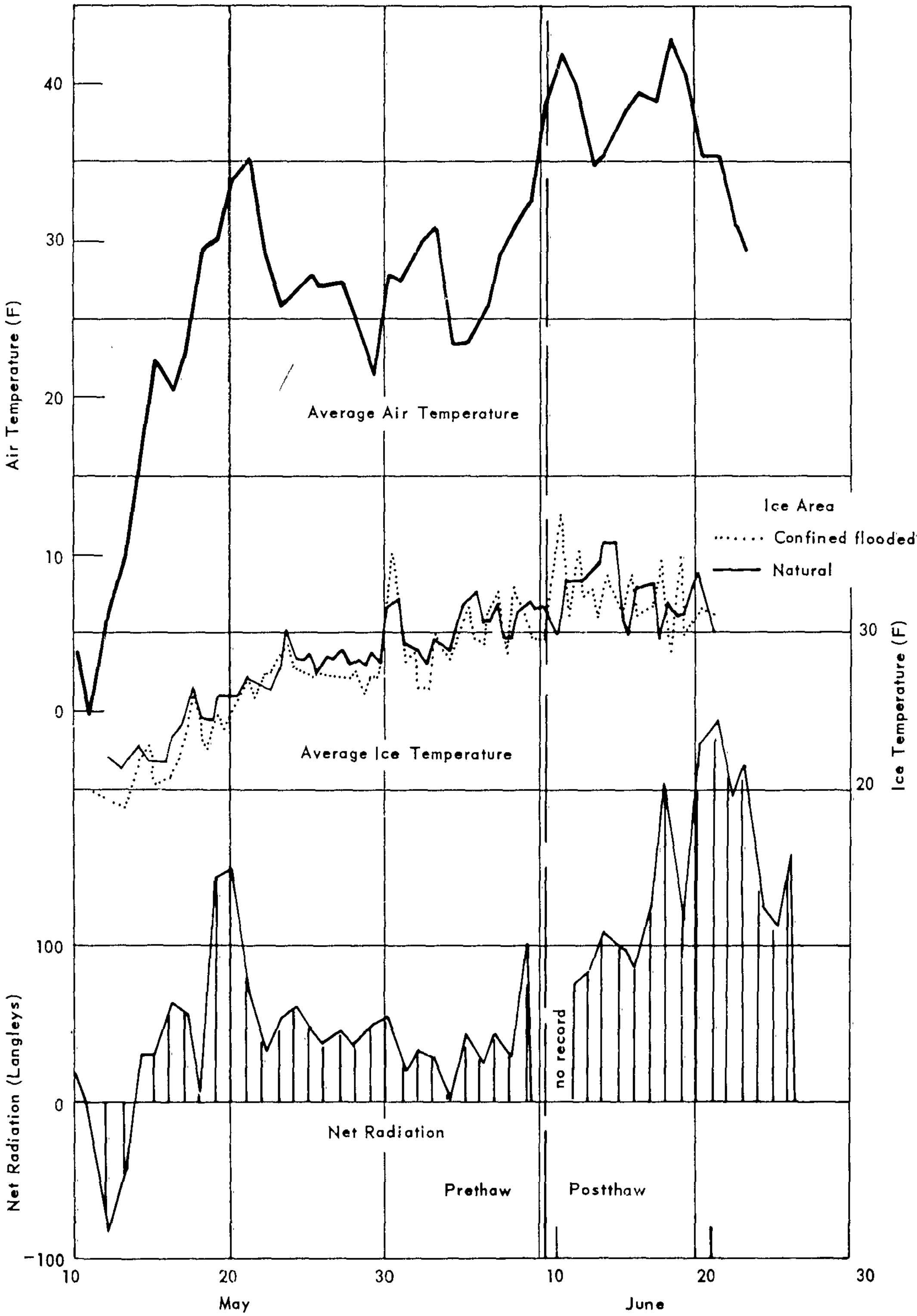


Figure 14. Average ice temperatures for the total ice thickness in the natural and confined flooded ice.

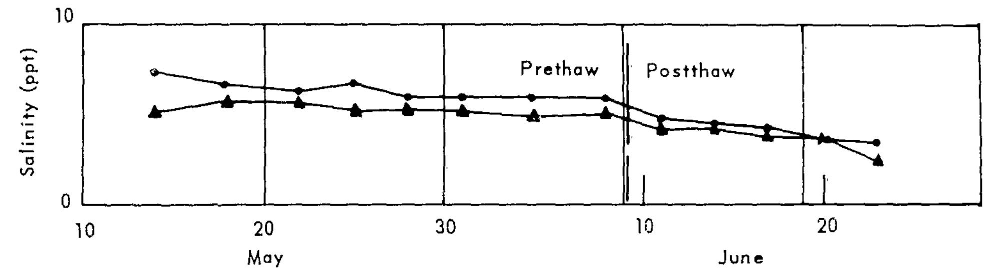


Figure 15. Average salinity for the total ice thickness in the natural and confined flooded plots.

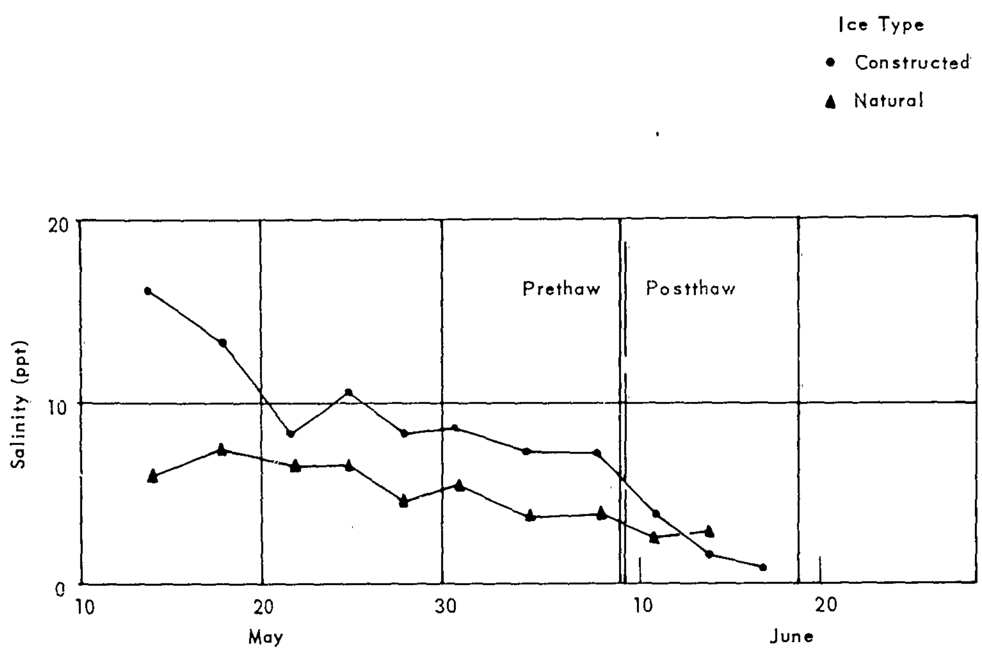


Figure 16. Salinity of 1-foot-thick constructed ice compared with the top foot of natural ice.

Table I. Average Salinity of Fresh and Brine-Soaked Cores

Core	Depth (in.)	Avg. Salinity (ppt)	Salinity Range (ppt)
Fresh	21-24	5.3	4.6-5.7
Fresh	24-27	5.3	5.1-5.5
Brine-soaked	21-24	5.1	4.8-5.4
Brine-soaked	24-27	5.0	4.6-5.2

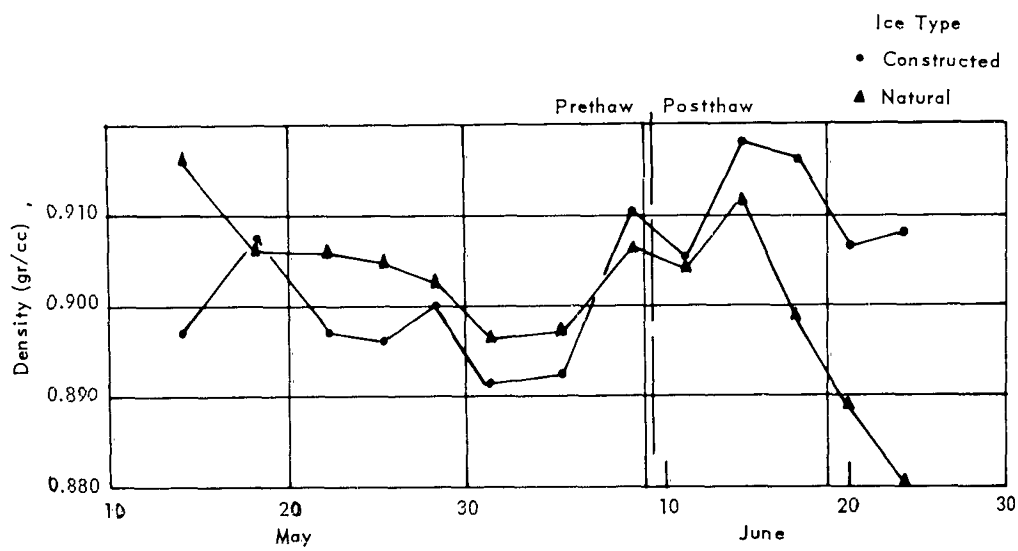


Figure 17. Average density for the total ice thickness in the natural and confined flooded plots.

Density

The density was computed from the specimen weight as measured to the nearest 0.1 gram on a double beam balance and from the average of three diameter and three length measurements of the specimen. These dimensions were measured to the nearest 0.01 cm with dial calipers.

The average densities for the total ice thickness of the natural ice and confined flooded ice (plot 1) are shown in Figure 17. In general, the density for both areas decreased slowly until the beginning of thaw when it rose to its highest value for the test period and then declined abruptly. During prethaw, the density of the confined flooded plot was lower than that of the natural ice; however, during postthaw the density of the confined flooded plot was higher.

The greatest difference in density was found in the top foot of ice in each area (Figure 18). However, during the postthaw period, these densities converged; the density of the top foot of the natural ice decreased while the density of the 1 foot of the constructed ice returned to its original value. This change is attributed to a replacement of the brine drainage with melt water. In the lower layers the densities were very close before thaw. About ten days after thaw the density of the 2-foot layer decreased considerably in both areas; whereas in the other layers the densities diverged after thaw.

FINDINGS

Growth and Deterioration

1. The natural ice and constructed ice ablated at the same rate.

2. The total reduction in ice thickness occurred at the surface.

3. Because it was elevated, the constructed ice resisted surface deterioration about two weeks longer than the natural ice.

4. Internal deterioration of the ice was about the same in both the constructed and natural ice areas.

5. Brine drainage and salinity in the constructed ice reached a maximum shortly after thaw but within a week decreased to less than before thaw.

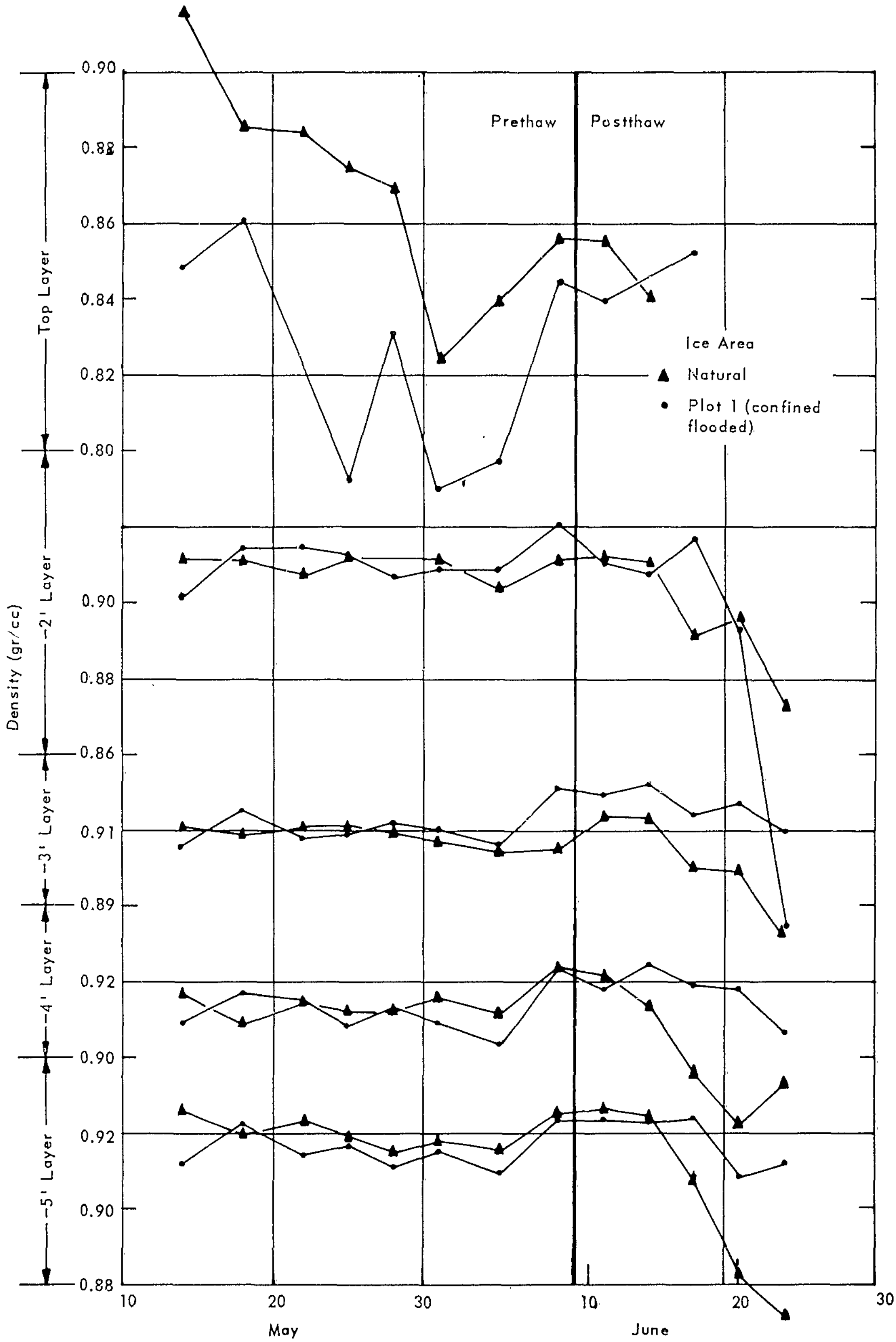


Figure 18. Density of 1-foot-thick constructed ice and the underlying disturbed natural ice compared with the top foot of natural ice and the underlying undisturbed natural ice.

Ice-Crystal Orientation and Size

1. The size and C-axis orientation of crystals in the constructed ice appeared to have been largely influenced by the presence of snow on the flooding surface and by wind, especially when carrying snow.

2. When the crystals in the flooded ice had a preferred C-axis orientation, it was predominantly horizontal.

3. Except for a random C-axis orientation in the top 6 inches, the natural ice had a horizontal C-axis orientation throughout the ice sheet.

4. The only natural-ice crystals as small as those in constructed ice were found in the top 6 inches of the ice sheet.

Temperature, Salinity and Density

1. The average temperatures for the total ice thickness in the natural and confined plots were nearly the same during the test period.

2. These average temperatures were influenced by the fluctuations and general increase in air temperature and net solar radiation.

3. Erroneous readings may have occurred after thaw due to radiation absorption by the thermocouple wire.

4. The higher salinity of the constructed ice did not greatly affect the salinity of the underlying natural ice.

5. The salinity of the constructed ice decreased with time until it was approximately equal to that of the natural ice after thaw.

6. The salinity of an ice sample was influenced more by drainage during processing than by coring in holes into which brine was draining.

7. The replacement of brine drainage with melt water had a greater effect on the density of the constructed ice than on the natural ice.

CONCLUSIONS

1. Prevention or reduction of ablation of an ice sheet during thaw will preserve its thickness and should permit reduction of salinity and increase of density in constructed ice.

2. Further knowledge is needed on the influence of snow and wind on the size and C-axis orientation of ice crystals produced by flooding.

3. The influence of size and C-axis orientation of ice crystals on strength and resistance to deterioration should be investigated.

4. Improved field sampling and testing techniques, especially for temperature and salinity, are necessary in order to obtain more accurate information on the properties of ice.

ACKNOWLEDGMENTS

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Technical Report R-238
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