CHAPTER 32

ICE NAVIGATION

INTRODUCTION

3200. Ice and the Navigator

Sea ice has posed a problem to the navigator since antiquity. During a voyage from the Mediterranean to England and Norway sometime between 350 B.C. and 300 B.C., Pytheas of Massalia sighted a strange substance which he described as “neither land nor air nor water” floating upon and covering the northern sea over which the summer sun barely set. Pytheas named this lonely region Thule, hence Ultima Thule (farthest north or land’s end). Thus began over 20 centuries of polar exploration.

Ice is of direct concern to the navigator because it restricts and sometimes controls vessel movements; it affects dead reckoning by forcing frequent changes of course and speed; it affects piloting by altering the appearance or obliterating the features of landmarks; it hinders the establishment and maintenance of aids to navigation; it affects the use of electronic equipment by affecting propagation of radio waves; it produces changes in surface features and in radar returns from these features; it affects celestial navigation by altering the refraction and obscuring the horizon and celestial bodies either directly or by the weather it influences, and it affects charts by introducing several plotting problems.

Because of this direct concern with ice, the prospective polar navigators must acquaint themselves with its nature and extent in the area they expects to navigate. In addition to this volume, books, articles, and reports of previous polar operations and expeditions will help acquaint the polar navigator with the unique conditions at the ends of the Earth.

3201. Formation of Sea Ice

As it cools, water contracts until the temperature of maximum density is reached. Further cooling results in expansion. The maximum density of fresh water occurs at a temperature of 4.0°C, and freezing takes place at 0°C. The inclusion of salt lowers both the temperature of maximum density and, to a lesser extent, that of freezing. These relationships are shown in Figure 3201. The two lines meet at a salinity of 24.7 parts per thousand, at which maximum density occurs at the freezing temperature of –1.3°C. At this and greater salinities, the temperature of maximum density of sea water is coincident with the freezing point temperature, i.e., the density increases as the temperature gets colder. At a salinity of 35 parts per thousand, the approximate average for the oceans, the freezing point is –1.88°C.

As the density of surface seawater increases with decreasing temperature, convective density-driven currents are induced bringing warmer, less dense water to the surface. If the polar seas consisted of water with constant salinity, the entire water column would have to be cooled to the freezing point in this manner before ice would begin to form. This is not the case, however, in the polar regions where the vertical salinity distribution is such that the surface waters are underlain at shallow depth by waters of higher salinity. In this instance density currents form a shallow mixed layer which subsequently cannot mix with the deep layer of warmer but saltier water. Ice will then begin forming at the water surface when density currents cease and the surface water reaches its freezing point. In shoal water, however, the mixing process can be sufficient to extend the freezing temperature from the surface to the bottom. Ice crystals can, therefore, form at any depth in this case. Because of their lower density, they tend to rise to the surface, unless they form at the bottom and attach themselves there. This ice, called anchor ice, may continue to grow as additional ice freezes to that already formed.

3202. Land or Glacial Ice

Ice of land origin is formed on land by the freezing of freshwater or the compacting of snow as layer upon layer adds to the pressure on that beneath.Under great pressure, ice becomes slightly plastic, and is forced downward along an inclined surface. If a large area is relatively flat, as on the Antarctic plateau, or if the outward flow is obstructed, as on Greenland, an **ice cap** forms and remains essentially permanent. The thickness of these ice caps ranges from nearly 1 kilometer on Greenland to as much as 4.5 kilometers on the Antarctic Continent. Where ravines or mountain passes permit flow of the ice, a **glacier** is formed. This is a mass of snow and ice which continuously flows to lower levels, exhibiting many of the characteristics of rivers of water. The flow may be more than 30 meters per day, but is generally much less. When a glacier reaches a comparatively level area, it spreads out. When a glacier flows into the sea, sections will break off an float away as **icebergs**. Icebergs may be described as tabular or non-tabular. Non-tabular icebergs can be further described as domed, pinnacled, tabular (Figure 3202a) and (Figure 3202b), wedged, drydocked, or as an ice island. A floating iceberg seldom

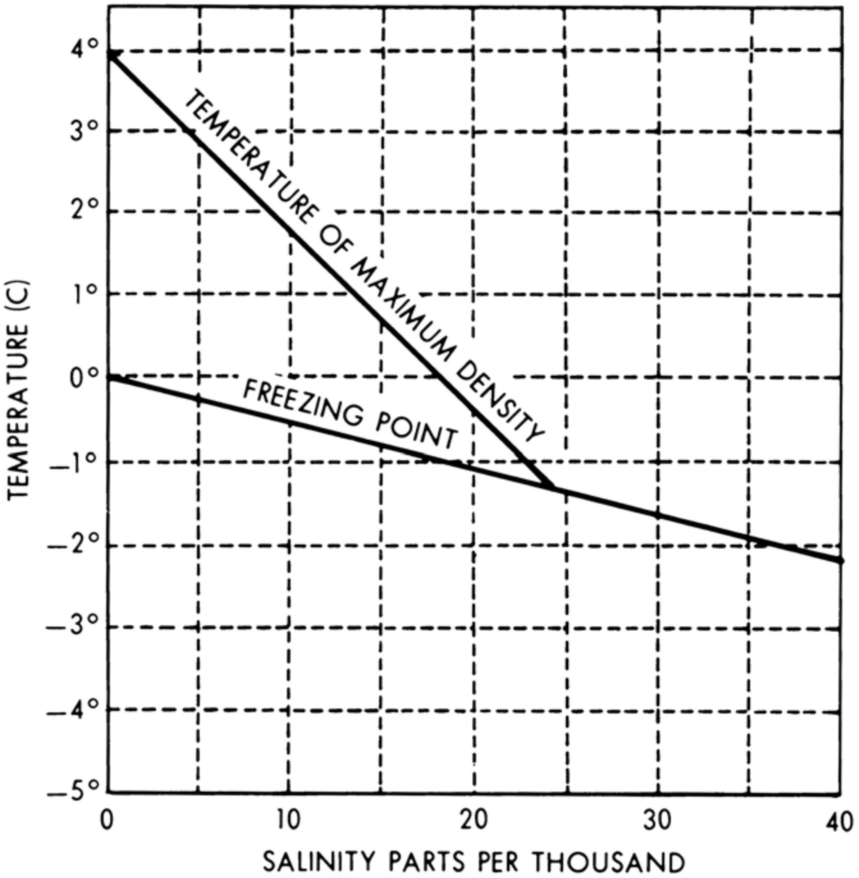

Figure 3201. Relationship between temperature of maximum density and freezing point for water of varying salinity.

Figure 3202a. A tabular iceberg. Photographer: Lieutenant Elizabeth Crapo, NOAA Corp.

melts uniformly because of lack of uniformity in the ice itself, differences in the temperature above and below the waterline, exposure of one side to the sun, strains, cracks, mechanical erosion, etc. The inclusion of rocks, silt, and other foreign matter further accentuates the differences. As a result, changes in equilibrium take place, which may cause the berg to tilt or capsize. Parts of it may break off or **calve**, forming separate smaller bergs. A relatively large piece of floating ice, generally extending 1 to 5 meters above the sea surface and 5 to 15 meters length at the waterline, is called a **bergy bit**. A smaller piece of ice large enough to inflict serious damage to a vessel is called a **growler** because of the noise it sometimes makes as it bobs up and down in the sea. Growlers extend less than 1 meter above the sea surface and about a length or about 5 to 15 meters. Growlers can be greenish or have semi-transparent blue tones that blend into the seawater and make them particularly difficult to detect visually. Bergy bits and growlers are usually pieces calved from icebergs, but they may be the remains of a mostly melted iceberg. The population of Antarctic icebergs includes many icebergs in the larger size classes compared to the Arctic population. Tabular icebergs can have linear dimensions of many kilometers, and for the very largest, up to in excess of a hundred kilometers.

Figure 3202b. Pinnacled iceberg. Photographer: Lieutenant Philip Hall, NOAA Corp.

One danger from icebergs is their tendency to break or capsize. Soon after a berg is calved, while remaining in high latitude waters, 60-80% of its bulk is submerged. But as the berg drifts into warmer waters the underside begins to melt, and as the berg becomes unstable, it can sometimes roll over. Eroded icebergs that have not yet capsized have a jagged and possibly dirty appearance. A recently capsized berg will usually be smooth, clean, and curved in appearance. Previous waterlines at odd angles can sometimes be seen after progressive tilting or one or more capsizings.

The stability of a berg can sometimes be noted by its reaction to ocean swells. The livelier the berg, the more unstable it is. It is extremely dangerous for a vessel to approach an iceberg closely, even one which appears stable, because in addition to the danger from capsizing, unseen cracks can cause icebergs to split in two or calve off large chunks. These sections can be many times the size of a vessel and displace huge volumes of water as they break away or turn over, inducing an immense swell.

Another danger is from underwater extensions, called **rams**, which are usually formed due to melting or erosion above the waterline at a faster rate than below. Rams may also extend from a vertical ice cliff, also known as an **ice front**, which forms the seaward face of a massive ice sheet or floating glacier; or from an **ice wall**, which is the ice cliff forming the seaward margin of a glacier which is aground. In addition to rams, large portions of an iceberg may extend well beyond the waterline at greater depths.

Strangely, icebergs may be helpful to the mariner in some ways. The melt water found on the surface of icebergs is a source of freshwater, and in the past some daring seamen have made their vessels fast to icebergs which, because they are affected more by currents than the wind, have proceeded to tow them out of the ice pack.

Icebergs can be used as a navigational aid in extreme latitudes where charted depths may be in doubt or non-existent. Since an iceberg (except a large tabular berg) must be at least as deep in the water as it is high to remain upright, a grounded berg can provide an estimate of the minimum water depth at its location. Water depth will be at least equal to the exposed height of the grounded iceberg. Grounded bergs remain stationary while current and wind move sea ice past them. Drifting ice may pile up against the up current side of a grounded berg.

3203. Iceberg Drift

Icebergs extend a considerable distance below the surface and have relatively small "sail areas" compared to their underwater body. Therefore, the near-surface current is primarily responsible for drift; however, observations have shown that wind can govern iceberg drift at a particular location or time.

The relative influence of currents and winds on the drift of an iceberg varies according to the direction and magnitude of the forces acting on its sail area and subsurface cross-sectional area. The resultant force therefore involves the proportions of the iceberg above and below the sea surface in relation to the velocity and depth of the current, and the velocity and duration of the wind. Studies tend to show that, generally, where strong currents prevail, the current is dominant. In regions of weak currents, however, winds that blow for a number of hours in a steady direction materially affect the drift of icebergs.

As icebergs deteriorate through melting, erosion, and calving, observations indicate the height to draft ratio may approach 1:1 during their final stage of decay, when they are referred to as a dry dock, winged, horned, or pinnacle iceberg. The height to draft ratios found for icebergs in their various stages are presented in Table 3203a. Since wind tends to have a greater effect on shallow than on deep-draft icebergs, the wind can be expected to exert increasing influence on iceberg drift as the iceberg deteriorates.

Iceberg type	*Height to draft ratio*
Blocky or tabular	1:5
Rounded or domed	1:4
Picturesque or Greenland (sloping)	1:3
Pinnacled or ridged	1:2
Horned, winged, dry dock, or spired (weathered)	1:1

Table 3203a. Height to draft ratios for various types of icebergs.

Simple equations that approximate iceberg drift have been formulated. However, there is uncertainty in the water and air drag coefficients associated with iceberg motion. Values for these parameters not only vary from iceberg to iceberg, but they probably change for the same iceberg over its period of deterioration. Further, the change in the iceberg shape that results from deterioration over time is not well known.

Present investigations utilize an analytical approach, facilitated by computer modeling, in which the air and water drag coefficients are varied within reasonable limits. Combinations of these drag values are then used in several increasingly complex water models that try to duplicate observed iceberg trajectories. The results indicate that with a wind-generated current, Coriolis force, and a uniform wind, but without a gradient current, small and medium icebergs will drift with the percentages of the wind as given in Table 3203b. The drift will be to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

Wind Speed (knots)	*Ice Speed/Wind Speed (percent)*		*Drift Angle (degrees)*	
	Small Berg	*Med. Berg*	*Small Berg*	*Med. Berg*
10	3.6	2.2	12°	69°
20	3.8	3.1	14°	55°
30	4.1	3.4	17°	36°
40	4.4	3.5	19°	33°
50	4.5	3.6	23°	32°
60	4.9	3.7	24°	31°

Table 3203b. Drift of iceberg as percentage of wind speed.

The movement of icebergs can be counter-intuitive. In the Antarctic an example is provided by the massive iceberg B15A (length 150 km) when it was located adjacent to Ross Island in the Southern Ross Sea. Its presence had a huge impact on wild life in the area and on access to McMurdo Sound and the McMurdo station. The prevailing wind in its locality is typically offshore from the ice shelf. When the winds are light the berg can be observed to drift slowly away from the edge of the shelf. But when the wind strengthened, the berg suddenly moved quickly south (i.e. upwind) to collide with the sea floor. A possible explanation of such behavior can be found in likely changes in the sub-surface ocean currents. While the wind was strong, surface water was advected away from the shelf, to be replaced by water drawn in from the north at greater depths. The iceberg would then be driven south by the increased velocity of the sub-surface current which would have acted on its sides for a large fraction of its depth and on the basal surface of the berg.

It is important to note that iceberg drift is frequently influenced by the presence of eddies and meanders of mean ocean currents. These oceanic features make iceberg trajectory predictions challenging. For example, eddies and meanders are frequently found in the North Atlantic where the Labrador Current meets the North Atlantic Current near the tail of the Grand Banks. In the Southern Hemisphere, predicting iceberg and sea ice drift is affected by the Southern Orkney islands. Careful attention to near real time observations from satellite imagery and drifting buoys can help improve the understanding of iceberg drift in these complex oceanographic environments.

3204. Icebergs in the North Atlantic

Sea level glaciers exist on a number of landmasses bordering the northern seas, including Alaska, Greenland, Svalbard (Spitsbergen), Zemlya Frantsa-Iosifa (Franz Josef Land), Novaya Zemlya, and Severnaya Zemlya (Nicholas II Land). Except in Greenland and Franz Josef Land, the rate of calving is relatively slow, and the few icebergs produced melt near their points of formation. Many of those produced along the western coast of Greenland, however, are eventually carried into the shipping lanes of the North Atlantic, where they constitute a major menace to ships. Those calved from Franz Josef Land glaciers drift southwest in the Barents Sea to the vicinity of Bear Island.

Generally the majority of icebergs produced along the east coast of Greenland remain near their source. However, a small number of bergy bits, growlers, and small icebergs are transported south from this region by the East Greenland Current around Kap Farvel at the southern tip of Greenland and then northward by the West Greenland Current into Davis Strait to the vicinity of 67°N. Relatively few of these icebergs menace shipping, but some are carried to the south and southeast of Kap Farvel by a counterclockwise current gyre centered near 57°N and 43°W.

The main source of the icebergs encountered in the North Atlantic is the west coast of Greenland between 67°N and 76°N, where approximately 10,000–15,000 icebergs are calved each year. In this area there are about 100 low-lying coastal glaciers, 20 of them being the principal producers of icebergs. Of these 20 major glaciers, 2 located in Disko Bugt between 69°N and 70°N are estimated to contribute 28 percent of all icebergs appearing in Baffin Bay and the Labrador Sea. The West Greenland Current carries icebergs from this area northward and then westward until they encounter the south flowing Labrador Current. West Greenland icebergs generally spend their first winter locked in the Baffin Bay pack ice; however, a large number can also be found within the sea ice extending along the entire Labrador coast by late winter.

During the next spring and summer they are transported farther southward by the Labrador Current. The general drift patterns of icebergs that are prevalent in the eastern portion of the North American Arctic are shown in Figure 3204a. Observations over a 117-year period (1900-2016) show that an average of 486 icebergs per year reach latitudes south of 48 N; approximately 10 percent of this total will be carried south of the Grand Banks (43 N) before they melt. Icebergs may be encountered during any part of the year, but in the Grand Banks area they are most numerous during spring. The maximum monthly average of iceberg sightings below 48 N occurs during April, May and June, with May having the highest average of 151. The distribution of the Davis Strait-Labrador Sea pack ice appears to influence the melt rate of the icebergs as they drift south. Sea ice decreases iceberg erosion by damping waves and holds surface water temperatures below 0 C, so as the extent of the sea ice increases the icebergs will tend to survive longer. Stronger than average northerly or northeasterly winds during late winter and spring will accelerate sea ice drift to the south, which also may prolong an iceberg's survival. The large inter-annual variations in the number of icebergs calved from Greenland's glaciers, makes forecasting the length and severity of an iceberg season very challenging.

The variation from average conditions is considerable. More than 2,202 icebergs have been sighted south of latitude 48 N in a single year (1984), while in 1966 and 2006 not a single iceberg was encountered in this area. In 1940, 1958, and 2010, only one iceberg was observed south of 48 N. More recently, within the two-year period from 2013-2014, the number of icebergs south of latitude 48 N varied from 13 in 2013 to 1546 in 2014. The variability of the iceberg population in the transatlantic shipping lanes is related to environmental conditions. Average iceberg and pack ice limits in this area during May are shown in Figure 3204b. Beyond these average limits, icebergs have been reported in the vicinity of Bermuda, the Azores, and within 500 kilometers of Great Britain.

Pack ice may also be found in the North Atlantic, some having been brought south by the Labrador Current and some coming through Cabot Strait after having formed in the Gulf of St. Lawrence.

3205. Sea Ice

Sea ice forms by the freezing of seawater and accounts for 95 percent by area of all ice encountered. The first indication of the formation of new sea ice (up to 10 centimeters in thickness) is the development of small individual, needle-like crystals of ice, called **spicules**, which become suspended in the top few centimeters of seawater. These spicules, also known as **frazil ice**, give the sea surface an oily appearance. **Grease ice** is formed when the spicules coagulate to form a soupy layer on the surface, giving the sea a matte appearance. Calm wind conditions are favorable for initial sea ice growth but sea ice can form in most wind conditions given sufficiently cold water temperatures. The next stage in sea ice formation occurs when **shuga**, an accumulation of spongy white ice lumps a few centimeters across, develops from grease ice. Upon further freezing, and depending upon wind exposure, sea state, and salinity, shuga and grease ice develop into **nilas**, an elastic crust of high salinity, up to 10 centimeters in thickness, with a matte surface, or into **ice rind**, a brittle, shiny crust of low salinity with a thickness up to approximately 5 centimeters. A layer of 5 centimeters of freshwater ice is brittle but strong enough to support the weight of a heavy man. In contrast, the same thickness of newly formed sea ice will not support more than about 10 percent of this weight, although its strength varies with the temperatures at which it is formed; very cold ice supports a greater weight than warmer ice. As it ages, sea ice becomes harder and more brittle.

New ice may also develop from slush which is formed when snow falls into seawater which is near its freezing point, but colder than the melting point of snow. The snow does not melt, but floats on the surface, drifting with the wind into beds. If the temperature then drops below the freezing point of the seawater, the slush freezes quickly into a soft ice similar to shuga.

Sea ice is exposed to several forces, including currents, waves, tides, wind, and temperature variations. In its early stages, its plasticity permits it to conform readily to virtually any shape required by the forces acting upon it. As it becomes older, thicker, more brittle, and exposed to the influence of wind and wave action, new ice usually separates into circular pieces from 30 centimeters to 3 meters in diameter and up to approximately 10 centimeters in thickness with raised edges due to individual pieces striking against each other. These circular pieces of ice are called **pancake ice** (Figure 3205) and may break into smaller pieces with

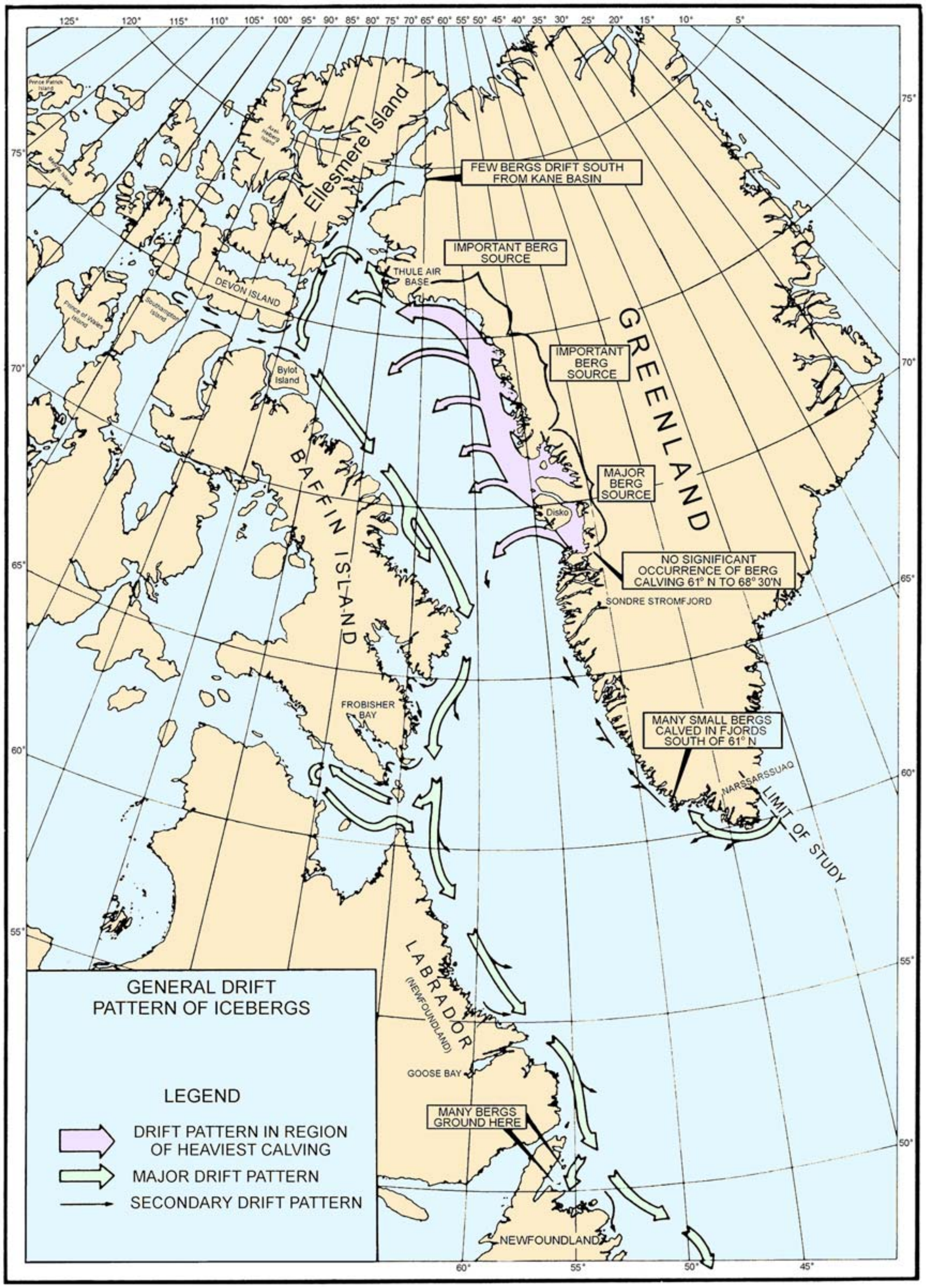

Figure 3204a. General drift patterns of icebergs in Baffin Bay, Davis Strait, and Labrador Sea.

strong wave motion. Any single piece of relatively flat sea ice less than 20 meters across is called an **ice cake**. With continued low temperatures, individual ice cakes and pancake ice will, depending on wind or wave motion, either freeze together to form a continuous sheet or unite into pieces of ice 20 meters or more across. These larger pieces

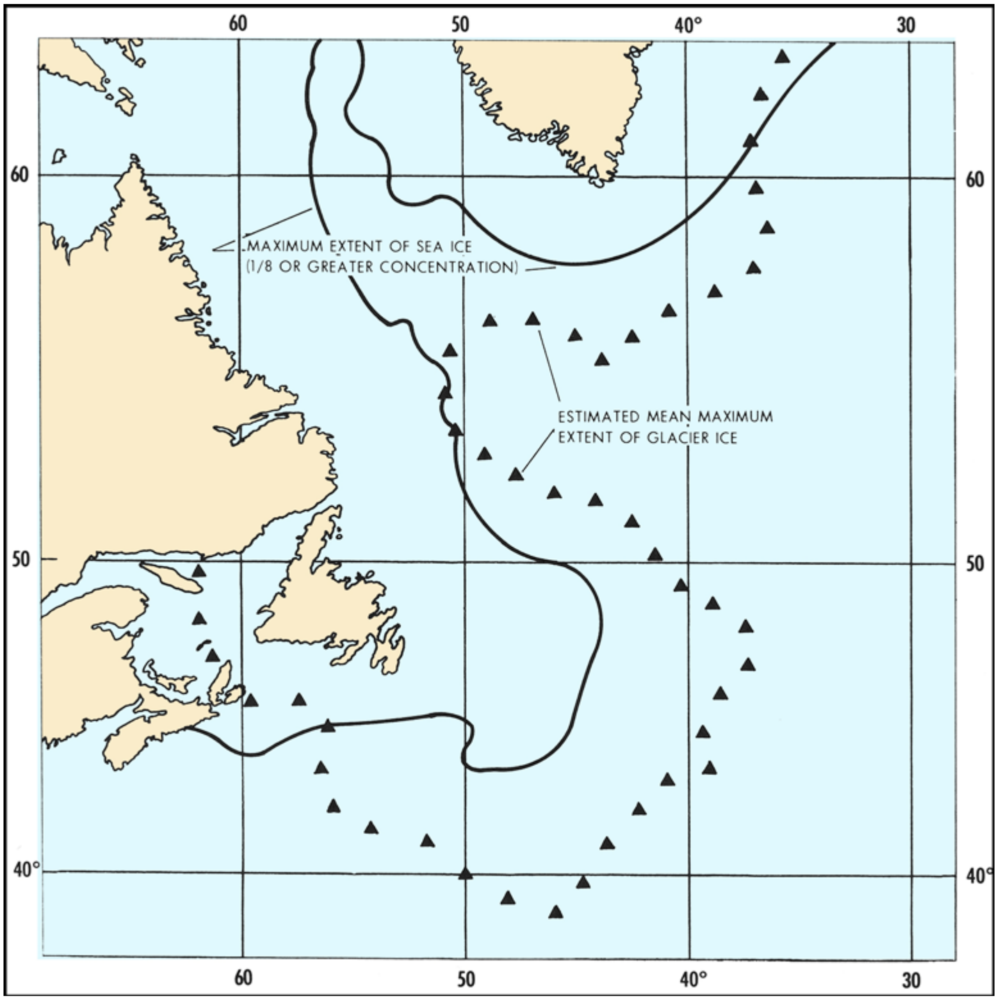

Figure 3204b. Average iceberg and pack ice limits during the month of May.

Figure 3205. Pancake ice. Image courtesy of John Farrell, U.S. Arctic Commission, Healy 1202.

are then called **ice floes**, which may further freeze together to form an ice covered area greater than 10 kilometers across known as an **ice field**. In wind sheltered areas thickening ice usually forms a continuous sheet before it can develop into the characteristic ice cake form. When sea ice reaches a thickness of between 10 to 30 centimeters it is referred to as **gray** and **gray-white ice**, or collectively as **young ice**, and is the transition stage between nilas and **first-year ice**. Sea ice may grow to a thickness of 10 to 13 centimeters within 48 hours, after which it acts as an insulator between the ocean and the atmosphere progressively slowing its further growth. Sea ice may grow to a thickness of between 2 to 3 meters in its first winter. Ice which has survived at least one summer's melt is classified as **old ice**. If it has survived only one summer's melt it may be referred to as **second-year ice**, but this term is seldom used today. Old ice which has survived at least two summers' melt is known as **multiyear ice** and is almost salt free. This term is increasingly used to refer to any ice more than one season old. Old ice can be recognized by a bluish tone to its surface color in contrast to the greenish tint of first-year ice; both first year and multiyear ice is often covered with snow. Another sign of old ice is a smoother, more rounded appearance due to melting/refreezing and weathering by wind-driven snow and spray

Greater thicknesses in both first and multiyear ice are attained through the deformation of the ice resulting from the movement and interaction of individual floes. Deformation processes occur after the development of new and young ice and are the direct consequence of the effects of winds, tides, and currents. These processes transform a relatively flat sheet of ice into pressure ice which has a rough surface. **Bending**, which is the first stage in the formation of pressure ice, is the upward or downward motion of thin and very plastic ice. Rarely, **tenting** occurs when bending produces an upward displacement of ice forming a flat sided arch with a cavity beneath. More frequently, however, **rafting** takes place as one piece of ice overrides another. When pieces of first-year ice are piled haphazardly over one another forming a wall or line of broken ice, referred to as a **ridge**, the process is known as **ridging**. Ridges on sea ice are generally about 1 meter high and 5 meters deep, but under considerable pressure may attain heights of 20 meters and depths of 50 meters in extreme cases. Pressure ice with topography consisting of numerous mounds or hillocks is called hummocked ice, each mound being called a hummock. The corresponding underwater feature is known as a bummock. In the Antarctic **Seasonal Sea Ice Zone (SSIZ),** rafting makes an important contribution to the growth of the thickness of the ice. One immediate danger of rafting occurs when the thickness of the rafted ice is double that of its constituent pieces. This process shifts the distribution of ice thickness classes to thicker ice. Another major contributor to the growth in thickness of Antarctic ice is accumulation of snow on the upper surface. In addition the added weight of snow can depress the surface of the underlying ice to below the level of the sea water. Sea water can then infiltrate the snow to form snow-ice. Sea water will find a path into the snow from the outer edges of floes and from underneath the floe via cracks in the ice.

The motion of an individual floe is driven by its interaction with the ocean current and wind, as well as with adjacent floes or obstacles such as a coastline, or icebergs. Momentum is transferred from the wind and current to the floe through their interaction with the roughness of the upper and lower surfaces at various scales, and the "sail" effect of the upper ridges, sub-surface keels, and the outer edges of a floe. The motion of adjacent floes is seldom equal. Some ice floes are in rotary motion as they tend to trim themselves into the wind. Since ridges extend below as well as above the surface, the deeper ones are influenced more by currents at those depths. When a strong wind blows in the same direction for a considerable period so that there is a net convergence in the motion of a field of sea ice floes, each floe exerts pressure on the next one, and as the effect accumulates over time, the pressure becomes tremendous.

The alternate melting and growth of sea ice, combined with the continual motion of various floes that results in separation as well as consolidation, causes widely varying conditions within the ice cover itself. The mean areal density, or concentration, of pack ice in any given area is expressed in tenths. Concentrations range from:

Open water (total concentration of all ice is < one tenth)
Very open pack (1-3 tenths concentration)
Open pack (4-6 tenths concentration)
Close pack (7-8 tenths concentration)
Very close pack (9-10 to <10-10 concentration)
Compact or consolidated pack (100% coverage)

The extent to which an ice cover of varying concentrations can be penetrated by a vessel varies from place to place and with changing weather conditions. With a concentration of 1 to 3 tenths in a given area, an unreinforced vessel can generally navigate safely, but the danger of receiving heavy damage is always present. When the concentration increases to between 3 and 5 tenths, the area becomes only occasionally accessible to an unreinforced vessel, depending upon the wind and current. With concentrations of 5 to 7 tenths, the area becomes accessible only to ice strengthened vessels, which on occasion will require icebreaker assistance. Navigation in areas with concentrations of 7 tenths or more should only be attempted by icebreakers.

Sea ice which is formed in situ from seawater or by the freezing of pack ice, of any age, to the shore and which remains attached to the coast, to an ice wall, to an ice front, or between shoals is called **fast ice**. The width of this fast ice varies considerably and may extend for a few meters or several hundred kilometers in bays and other sheltered areas. Fast ice, often augmented by annual snow accumulations, may attain a thickness of over 2 meters above the sea surface.

An **ice shelf** forms where land ice flows across the coastline and becomes afloat. Ice shelves are comprised primarily of meteoric ice, ice formed from densification of precipitated snow. These shelves are typically formed by the coalescence of ice flow from multiple ice streams. Where a main ice stream / glacier contributes to the shelf, they may be called glacier tongues. Some sections of some Antarctic ice shelves may also have a considerable fraction of the thickness comprised of marine ice which has accreted to the base of the meteoric ice either by direct freezing of sea water or by accumulation of frazil ice formed in the water column beneath the ice shelf. There may also be a net input to the thickness by accumulation of snow on the upper surface. Massive ice shelves, where the ice thickness reaches several hundred meters, are found in both the Arctic and Antarctic.

Within the ice cover, openings may develop resulting from a number of deformation processes. Long, jagged cracks may appear first in the ice cover or through a single floe. When these cracks open and reach lengths of a few meters to many kilometers, they are referred to as **fractures**. If they widen further to permit passage of a ship, they are called **leads**. In winter, a thin coating of new ice may cover the water within a lead, but in summer the water usually remains ice-free until a shift in the movement forces the two sides together again. A lead ending in a pressure ridge or other impenetrable barrier is a **blind lead**.

A lead between pack ice and shore is a **shore lead**, and one between pack and fast ice is a **flaw lead**. Navigation in these two types of leads is dangerous, because if the pack ice closes, the ship can be caught between the two, and driven aground or caught in the shear zone in between.

A **polynya** is an area within pack ice where there is: open water; or ice concentration lower than in the surrounding pack. There are two types of polynya: **sensible-heat polynya**, and **latent-heat polynya**. "Sensible-heat" polynyas occur where there is an upwelling of relatively warmer water that melts the sea ice or prevents it forming in that area. "Latent-heat" polynyas are caused by motion of the pack ice relative to something. Thus they may result from motion of the ice away from an obstacle, such as a coastline or grounded iceberg which acts as a barrier against incursion of pack ice into the area from elsewhere, or even by divergence of the pack ice. The name comes from the process whereby latent heat released by the freezing of water is lost to the atmosphere. **Recurring polynyas** are located where the required conditions regularly occur.

In the Arctic, sensible-heat polynyas are often the site of historical native settlements, where the open water of the polynya allows fishing and hunting at times before the regular seasonal ice breakup. Thule, Greenland is an example. The presence of a sensible heat polynya can also ameliorate the local climate.

In both polar regions, latent-heat polynyas occur at various locations around the coast, where prevailing off-shore wind sweeps the area clear of newly formed ice. They can be very large in area and typically produce very large amounts of sea ice. This happens through the loss of heat from the water surface to the atmosphere and rapid freezing of the surface water. The freezing of the water and export of the relatively fresh ice also leaves excess salt in the water column which increases the salinity and thus density of the water. This cold dense water sinks to the bottom and may eventually contribute to the generation of "bottom-water" and to the deep overturning circulation of the world's oceans.

The majority of icebergs found in the Antarctic originated from the massive ice shelves and glacier tongues that fringe the continental ice sheet. Most of the ice discharged from the Antarctic ice sheet passes through those regions of floating ice, which together comprise about 40% of the coastline. The icebergs have either calved directly from those ice margins or from the resultant icebergs. Icebergs formed in this manner are called **tabular icebergs,** having a box like shape with horizontal dimensions measured in kilometers. The thickness of icebergs can range up to several hundred meters. In the Antarctic, the thickness is typically 200-300 m, and in extreme cases can be 500 m or more, with heights above the sea surface of 25-40 meters and approaching 60 meters. See Figure 3202a. The largest Antarctic ice shelves are the Ross Ice Shelf at the southern boundary of the Ross Sea and the Filchner-Ronne Ice Shelf in the Weddell Sea.

The expression "tabular iceberg" is generally not applied to icebergs which break off from Arctic ice shelves; similar formations there are called **ice islands.** These originate when shelf ice, such as that found on the northern coast of Greenland and in the bays of Ellesmere Island, breaks up. As a rule, Arctic ice islands are not as large as the tabular icebergs found in the Antarctic. They attain a thickness of up to 55 meters and on the average extend 5 to 7 meters above the sea surface. Both tabular icebergs and ice islands possess a gently rolling surface. Because of their deep draft, they are influenced much more by current than wind.

3206. Thickness of Sea Ice

Sea ice has been observed to grow to a thickness of almost 3 meters during its first year. However, the thickness of first-year ice that has not undergone deformation does not generally exceed 2 meters. In coastal areas where the melting rate is less than the freezing rate, the thickness may increase during succeeding winters, being augmented by compacted and frozen snow, until a maximum thickness of about 3.5 to 4.5 meters may eventually be reached. Old sea ice may also attain a thickness of over 4 meters in this manner, or when summer melt water from its surface or from snow cover runs off into the sea and refreezes under the ice where the seawater temperature is below the freezing point of the fresher melt water.

The growth of sea ice is dependent upon a number of meteorological and oceanographic parameters. Such parameters include air temperature, initial ice thickness, snow depth, wind speed, seawater salinity and density, and the specific heats of sea ice and seawater. Investigations, however, have shown that the most influential parameters affecting sea ice growth are air temperature, wind speed, snow depth and initial ice thickness. Many complex equations have been formulated to predict ice growth using these four parameters. However, except for air temperature and wind speed, these parameters are not easily observed for remote polar locations.

Field measurements suggest that reasonable growth estimates can be obtained from air temperature data alone. Various empirical formulae have been developed based on this premise. All appear to perform better under thin ice conditions when the temperature gradient through the ice is linear, generally true for ice less than 100 centimeters thick. Differences in predicted thicknesses between models generally reflect differences in environmental parameters (snowfall, heat content of the underlying water column, etc.) at the measurement site. As a result, such equations must be considered partially site specific and their general use approached with caution. For example, applying an equation derived from central Arctic data to coastal conditions or to

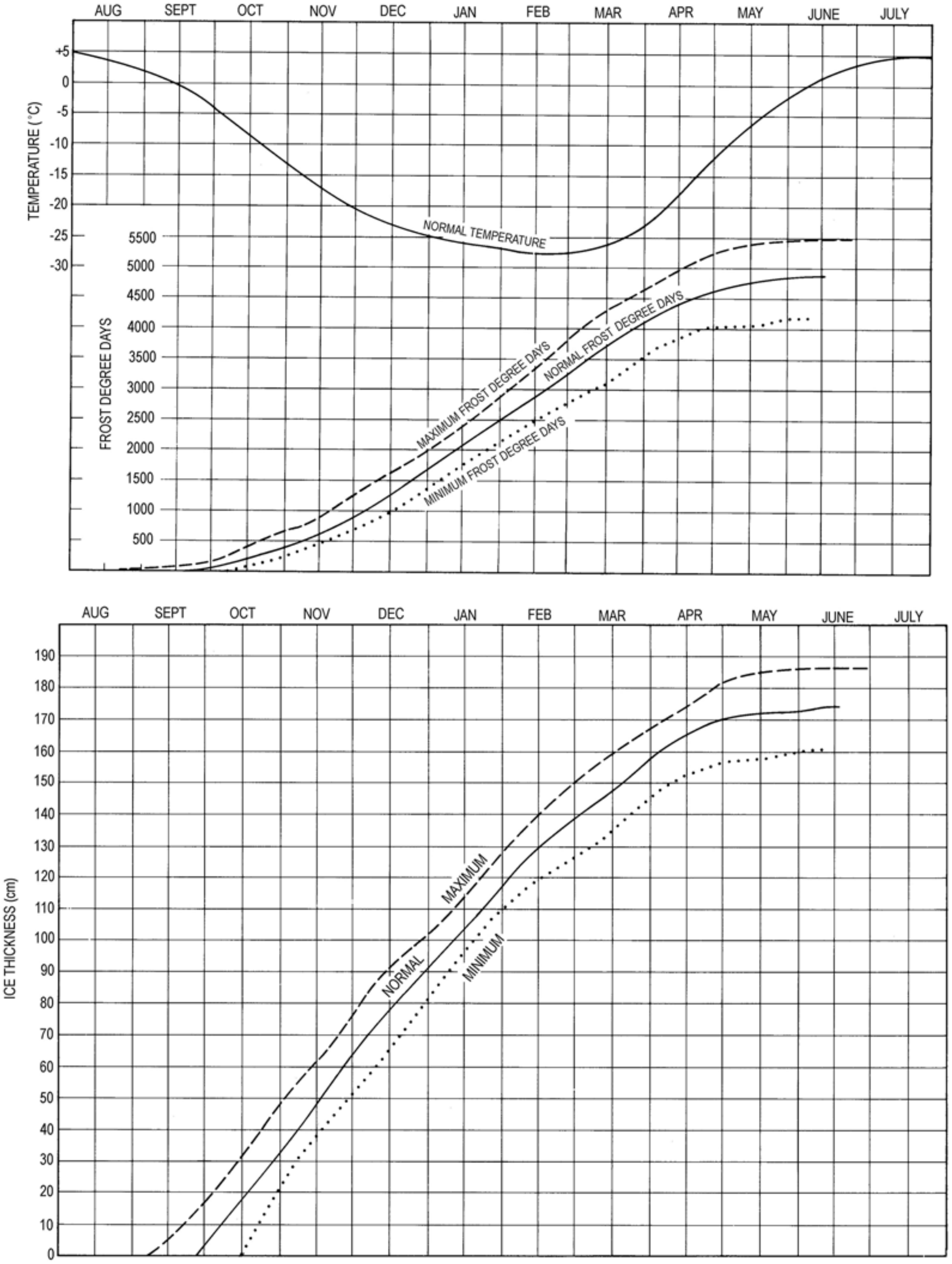

Figure 3206a. Relationship between accumulated frost degree days and theoretical ice thickness at Point Barrow, Alaska.

Antarctic conditions could lead to substantial errors. For this reason Zubov's formula is widely cited as it represents an average of many years of observations from the Russian Arctic:

$$h^2 + 50h = 8\phi$$

where h is the ice thickness in centimeters for a given day and ϕ is the cumulative number of frost degree days in degrees Celsius since the beginning of the freezing season.

A **frost degree day** (or **freezing degree day**) is defined as a day with a mean temperature of 1 below freezing. The base most commonly used is the freezing point of freshwater (0° C). If, for example, the mean temperature on a given day is 5 below freezing, then five frost degree days are noted for that day. These frost degree days are then added to those noted the next day to obtain an accumulated value, which is then added to those noted the following day. This process is repeated daily throughout the ice growing season.

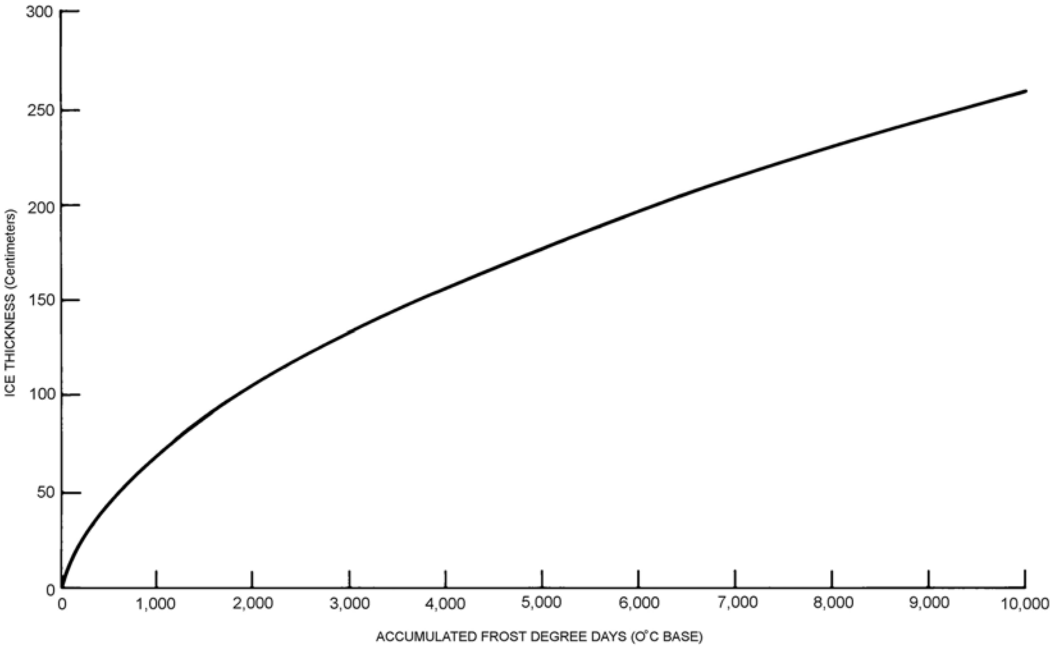

Figure 3206b. Relationship between accumulated frost degree days (°C) and ice thickness (cm).

Temperatures usually fluctuate above and below freezing for several days before remaining below freezing. Therefore, frost degree day accumulations are initiated on the first day of the period when temperatures remain below freezing. The relationship between frost degree day accumulations and theoretical ice growth curves at Point Barrow, Alaska is shown in Figure 3206a. Figure 3206b graphically depicts the relationship between accumulated frost degree days (°C) and ice thickness in centimeters.

During winter, the ice usually becomes covered with snow, which insulates the ice beneath and tends to slow down its rate of growth. This thickness of snow cover varies considerably from region to region as a result of differing climatic conditions. Its depth may also vary widely within very short distances in response to variable winds and ice topography. While this snow cover persists, up to 90% of the incoming radiation is reflected back to space. Eventually, however, the snow begins to melt, as the air temperature rises above 0 C in early summer and resulting freshwater forms puddles on the surface. These puddles absorb the incoming radiation and rapidly enlarge as they melt the surrounding snow or ice. Eventually the puddles penetrate to the bottom surface of the floes forming **thawholes**. This slow process is characteristic of ice in the Arctic Ocean and seas where movement is restricted by the coastline or islands. Where ice is free to drift into warmer waters (e.g., the Antarctic, East Greenland, and the Labrador Sea), decay is accelerated in response to wave erosion as well as warmer air and sea temperatures.

3207. Salinity of Sea Ice

When sea ice crystals first form, the salt collects into brine droplets. The brine is normally expelled back into the ocean water. Some of the droplets can be trapped in the pockets between ice crystals and, because it would take much colder temperatures to freeze, the liquid brine droplets remain trapped in the pockets between the ice crystals. As the freezing process continues, some brine drains out of the ice, decreasing the salinity of the sea ice. At lower temperatures, freezing takes place faster, trapping a greater amount of salt in the ice.

Depending upon the temperature, the trapped brine may either freeze or remain liquid, but because its density is greater than that of the pure ice, it tends to settle down through the pure ice, leaching into the sea. As it does so, the ice gradually freshens, becoming clearer, stronger, and more brittle. By the time sea ice survives multiple melt seasons, much of the brine has been expelled, and may be suitable to replenish the freshwater supply of a ship. Even though the brine has been expelled, other contaminants may be present that would prevent the meltwater from being consumable. Icebergs, having formed from precipitation, contain no salt, and uncontaminated melt water obtained from them is fresh.

The settling out of the brine gives sea ice a honeycomb structure which greatly hastens its disintegration when the temperature rises above freezing. In this state, when it is called **rotten ice**, much more surface is exposed to warm air and water, and the rate of melting is increased. In a day's time, a floe of apparently solid ice several inches thick may disappear completely.

3208. Density of Ice

The density of freshwater ice at its freezing point is 0.917gm/cm^3. Newly formed sea ice, due to its salt content, is more dense.The density decreases as the ice freshens. By the time it has shed most of its salt, sea ice is less dense than freshwater ice, because ice formed in the sea contains voids left by brine leaching. Ice having no salt but containing air to the extent of 8 percent by volume (an approximately maximum value for sea ice) has a density of 0.845 gm/cm^3.

The density of land ice varies over even wider limits. Most land ice is formed by compacting of snow. This results in the entrapping of relatively large quantities of air. **Névé**, a snow which has become coarse grained and compact through temperature change, forming the transition stage to glacier ice, may have an air content of as much as 50 percent by volume. By the time the ice of a glacier reaches the sea, its density approaches that of freshwater ice. A sample taken from an iceberg on the Grand Banks had a density of 0.899gm/cm^3.

When ice floats, part of it is above water and part is below the surface. The percentage of the mass below the surface can be found by dividing the average density of the ice by the density of the water in which it floats. Thus, if an iceberg of density 0.920 floats in water of density 1.028 (corresponding to a salinity of 35 parts per thousand and a temperature of -1 C), 89.5 percent of its mass will be below the surface.

3209. Drift of Sea Ice

In 1893, Fridtjof Nansen, a 32-year old Norwegian explorer aboard the vessel Fram noted that floes of sea ice did not drift directly downwind. He documented this phenomenon and shared the observations with his colleague Vagn Walfrid Ekman. In his 1902 doctoral thesis, Ekman mathematically described the wind forcing on surface waters. The result is described as **Ekman Transport**, and was further refined a various depths as the **Ekman Sprial**.

Although in some cases, surface currents have some effect upon the drift of pack ice, the principal factor is wind. As described above, the earth's rotation imparts an apparent force (Coriolis force) such that ice does not drift directly downwind, but varies from this direction, depending upon the force of the surface wind and the ice thickness. The force is a consequence of physics related to the rotation of the earth about its axis. The force is zero at the equator and increases with increasing latitude. In the Northern Hemisphere, this drift is to the right of the direction toward which the wind blows, and in the Southern Hemisphere it is to the left. The relationship between surface wind speed, ice thickness, and drift angle was derived theoretically for the drift of consolidated pack under equilibrium (a balance of forces acting on the ice) conditions, and shows that the drift angle increases with increasing ice thickness and decreasing surface wind speed. See Figure 3209. A slight increase also occurs with higher latitude.

In the Antarctic, these effects on the movement of pack ice about the continent contribute to the pattern of spatial distribution of the ice and the direction of the drift of the ice. Near to the coast the drift is from east to west, and further out the drift is from the west to the east. The effect of the Coriolis force is to keep the pack ice in the near coastal drift belt close to the coast. The passage of storms modifies this overall movement pattern. In very general terms, when a low pressure system passes north of an area, the easterly component of the wind strengthens which can lead to ice being moved south towards the coast compacting into a belt locked against the coast.

In the Arctic, a comparable situation with a storm passing to the south of an area, would result in pack ice at the outer margins of the Arctic Ocean moving away from the coast and compacting seawards.

Since the cross-isobar deflection of the surface wind over the oceans is approximately 20°, the deflection of the ice varies as much as 70° to the right of the isobars, with low pressure on the left and high pressure on the right in the Northern Hemisphere. The positions of the low and high pressure areas are, of course, reversed in the Southern Hemisphere.

The rate of drift depends upon the roughness of the surface and the concentration of the ice. Percentages vary from approximately 0.25 percent to almost 8 percent of the surface wind speed as measured approximately 6 meters above the ice surface. Low concentrations of heavily ridged or hummocked floes drift faster than high concentrations of lightly ridged or hummocked floes with the same wind speed. Sea ice of 8 to 9 tenths concentrations and six tenths hummocking or close multiyear ice will drift at approximately 2 percent of the surface wind speed. Additionally, the response factors of 1/10th and 5/10ths ice concentrations, respectively, are approximately three times and twice the magnitude of the response factor for 9 tenths ice concentrations with the same extent of surface roughness. Isolated ice floes have been observed to drift as fast as 10 percent to 12 percent of strong surface winds.

The rates at which sea ice drifts have been quantified through empirical observation. The drift angle, however, has been determined theoretically for 10 tenths ice concentration. This relationship presently is extended to the drift of all ice concentrations, due to the lack of basic knowledge of the dynamic forces that act upon, and result in redistribution of sea ice, in the polar regions.

3210. Extent of Ice in the Sea

When an area of sea ice, no matter what form it takes or how it is disposed, is described, it is referred to as **pack** ice. In both polar regions the pack ice is a very dynamic feature, with wide deviations in its extent dependent upon changing oceanographic and meteorological phenomena. In winter the Arctic pack extends over the entire Arctic Ocean, and for a varying distance outward from it; the lim-

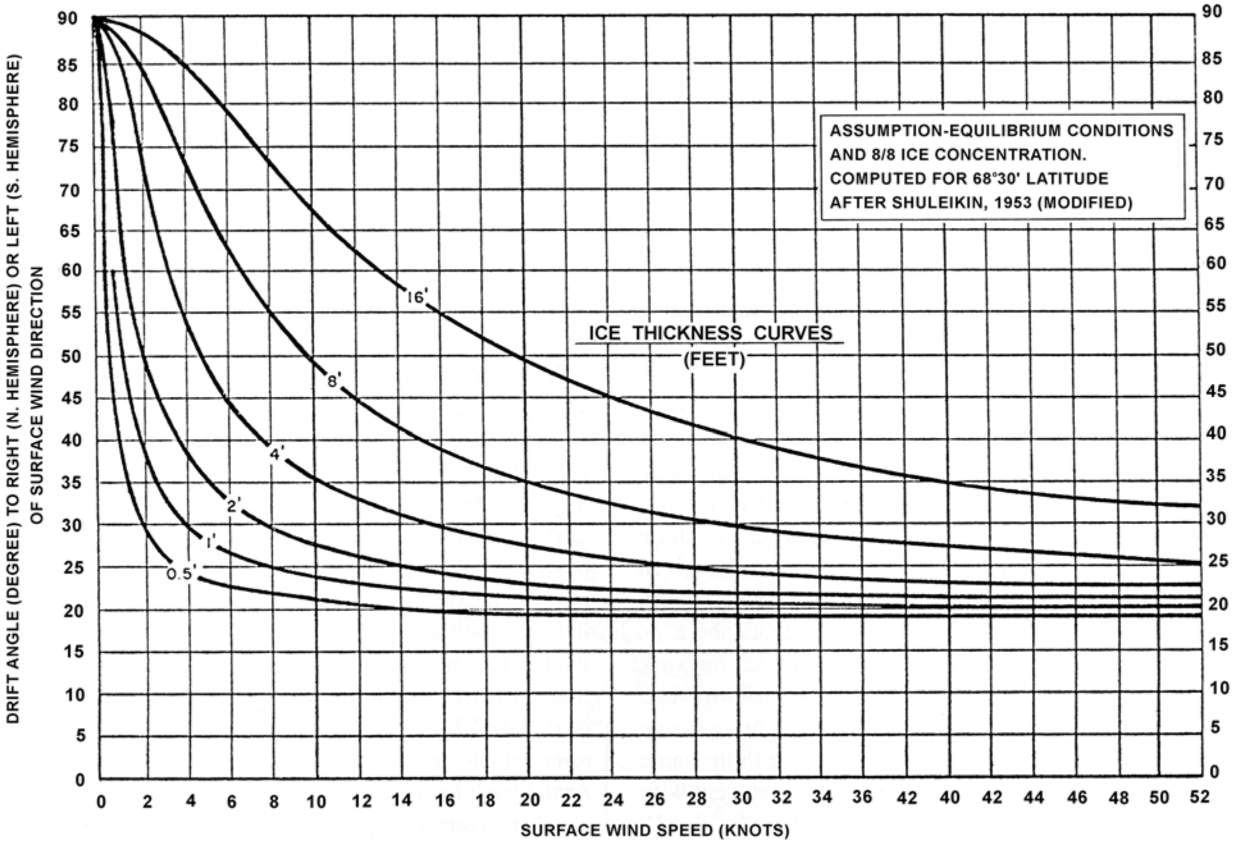

Figure 3209. Ice drift direction for varying wind speed and ice thickness.

its recede considerably during the warmer summer months. The average positions of the seasonal absolute and mean maximum and minimum extents of sea ice in the Arctic region are plotted in Figure 3210a. Each year a large portion of the ice from the Arctic Ocean moves outward between Greenland and Spitsbergen (Fram Strait) into the North Atlantic Ocean and is replaced by new ice. Because of this constant annual removal and replacement of sea ice, relatively little of the Arctic pack ice is more than 10 years old.

The average monthly Arctic sea ice extent for August has been decreasing dramatically over the last several decades as reflected in Figure 3210b. The phenomenon is discussed in more detail in Chapter 33.

Ice covers a large portion of the Antarctic waters and is probably the greatest single factor contributing to the isolation of the Antarctic Continent. The total area of sea ice varies between about 3 million square kilometers at its minimum and 19-20 million square kilometers at its maximum extent. The seasonal absolute and mean maximum and minimum positions of the Antarctic ice limit are shown in Figure 3210c. The overall minimum extent occurs in approximately February and maximum extent usually occurs in late September / early October. The extent progressively expands from its minimum with the onset of the colder months and waning sun-light. The distribution results from the increase in area where freezing is occurring together with a net advection north of the sea ice. The northern limit in particular regions is influenced by wind and its variability. The extent can also be influenced by the total area and distribution of ice remaining from the previous winter. The pack ice completely surrounds the continent, forming an almost impassable barrier that extends northward on the average to about 54°S in the Atlantic and to about 62°S in the Pacific. As the ice retreats in the warmer months, opening up and disintegration of the pack ice allows navigation access to some coastal areas of the Antarctic. The date at which a particular area can be accessed depends on the local ice conditions. In some areas access to the fast ice edge can be attained early in the season, such as November, but access to the coast may not occur until January or February. In other areas, access to a region may not occur until later in the season. Access also depends very much on the capability of the vessel. In some seasons the coastal fast ice in front of some coastal stations has not broken out for one or more seasons preventing ship-access to those stations.

The **National Snow and Ice Data Center (NSIDC)**, located at the University of Colorado in Boulder, maintains data sets comprised of Arctic sea ice concentration climatology derived from the **U.S. National Ice Center's (USNIC)** weekly or biweekly operational ice-chart time series. The charts used in the climatology are from 1972 through 2007; and the monthly climatology products are

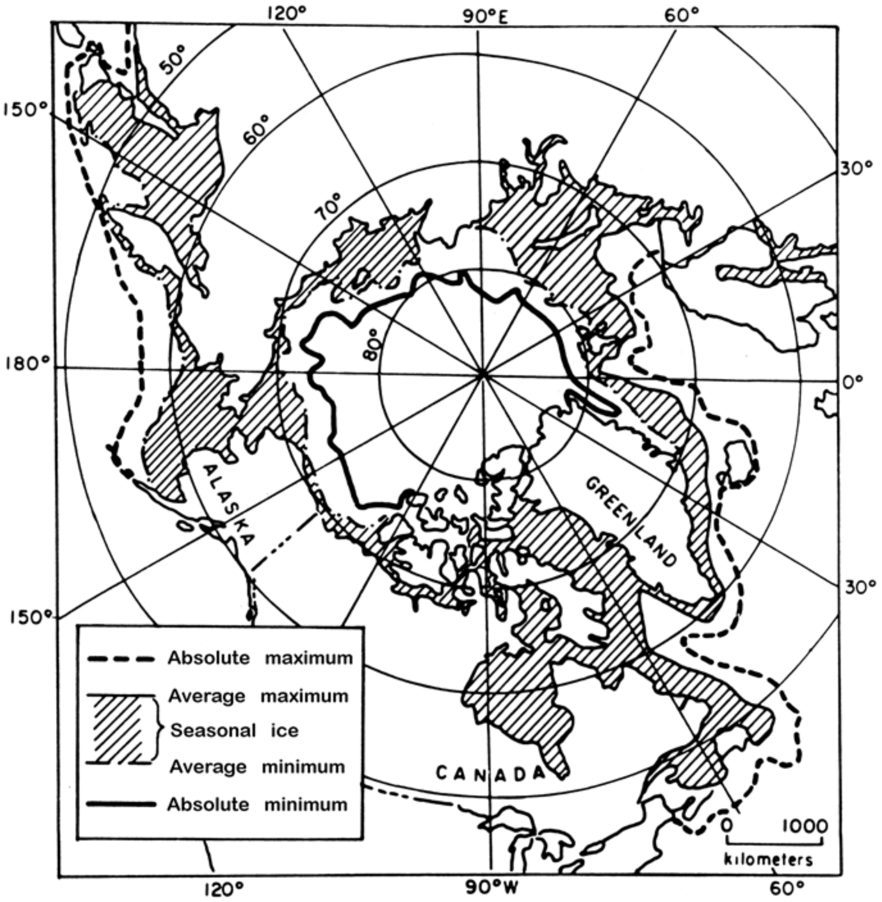

Figure 3210a. Average maximum and minimum extent of Arctic sea ice.

median, maximum, minimum, first quartile, and third quartile concentrations, as well as frequency of occurrence of ice at any concentration for the entire period of record as well as for 10-year and 5-year periods. These climatologies and the charts from which they are derived are provided in the 25-km Equal-Area Scalable Earth Grid (EASE-Grid) binary (.bin) format. The USNIC climatologies are also available in ArcGIS geodatabases (.mdb), and GIF format browse files (.gif) are also provided.

USNIC charts are produced through the analyses of available in situ, remote sensing, and model data sources. They are generated primarily for mission planning and safety of navigation. USNIC charts generally show more ice than do passive microwave derived sea ice concentrations, particularly in the summer when passive microwave algorithms tend to underestimate ice concentration. The record of sea ice concentration from the USNIC series is believed to be more accurate than that from passive microwave sensors, especially from the mid-1990s on, but it does not maintain the consistency of some passive microwave time series. NSIDC hosts numerous passive microwave and other sea ice data information useful to mariners planning voyages in or near areas affected by sea ice. These data sets are available through the link provided in Figure 3210d. Daily sea ice edge analysis is available online via the link provided in Figure 3210e.

Additionally, the National Geospatial Agency's (NGA) **Arctic GEOINT Services portal** that includes nautical charts, sailing directions, shape files and infographics for the Arctic that allow the user to focus on specific data layers. The link is provided in Figure 3210f.

3211. Ice Detection

Safe navigation in ice infested waters depends on a number of factors, not the least of which is accurate knowledge of the location and amount of sea ice that lies between the mariner and his destination. Sophisticated electronic equipment, such as radar, sonar, and the visible, infrared, and microwave radiation sensors on board satellites, have added to our ability to detect and avoid ice.

Depending on the geographic location, as a ship proceeds into higher latitudes, the first ice encountered is likely to be in the form of icebergs, because such large pieces require a longer time to break up and melt. Icebergs can be avoided if detected early. The distance at which an iceberg can be seen visually depends upon meteorological visibility, height of the iceberg, source and condition of lighting, and

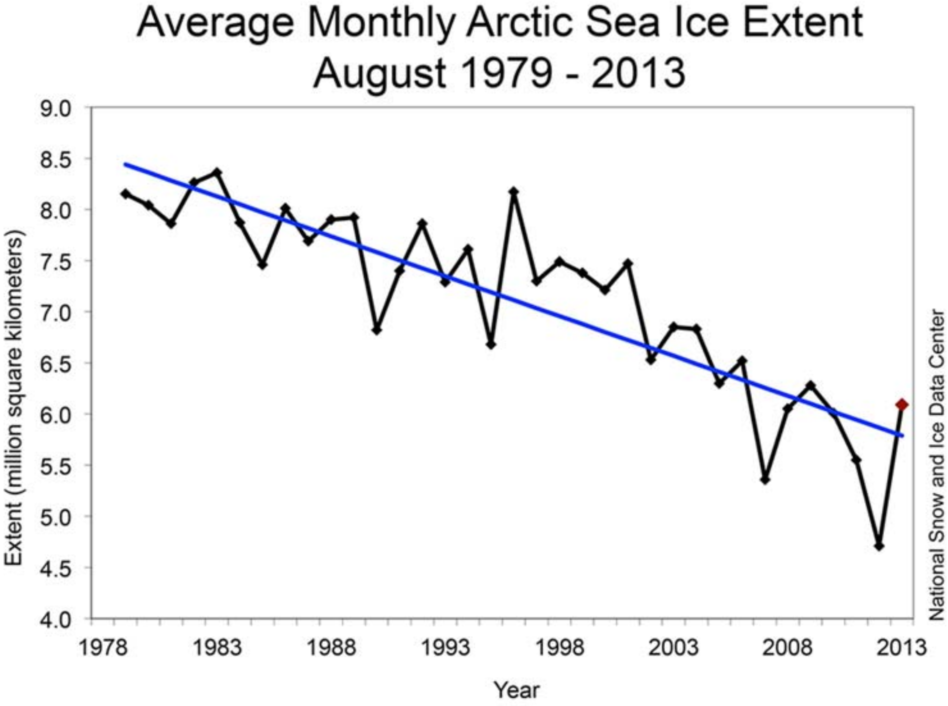

Figure 3210b. Average monthly Arctic sea ice extent August 1979 - 2013.

the observer. On a clear day with excellent visibility, a large iceberg might be sighted at a distance of 20 miles. With a low-lying haze around the horizon, this distance will be reduced. In light fog or drizzle this distance is further reduced, down to near zero in heavy fog.

In a dense fog an iceberg may not be perceptible until it is close aboard where it will appear in the form of a luminous, white object if the sun is shining; or as a dark, somber mass with a narrow streak of blackness at the waterline if the sun is not shining. If the layer of fog is not too thick, an iceberg may be sighted from aloft sooner than from a point lower on the vessel, but this does not justify omitting a bow lookout. The diffusion of light in a fog will produce a **blink**, or area of whiteness, above and at the sides of an iceberg which will appear to increase the apparent size of its mass.

On dark, clear nights icebergs may be seen at a distance of from 1 to 3 miles, appearing either as white or black objects with occasional light spots where waves break against it. Under such conditions of visibility, smaller growlers are more difficult to detect and pose a greater danger to vessels. The vessel's speed should be reduced and a sharp lookout maintained.

The moon may either help or hinder, depending upon its phase and position relative to ship and iceberg. A full moon in the direction of the iceberg interferes with its detection, while moonlight from behind the observer may produce a blink which renders the iceberg visible for a greater distance, as much as 3 or more miles. A clouded sky at night, through which the moonlight is intermittent, also renders ice detection difficult. A night sky with heavy passing clouds may also dim or obscure any object which has been sighted, and fleecy cumulus and cumulonimbus clouds often may give the appearance of blink from icebergs.

If an iceberg is in the process of disintegration, its presence may be detected by a cracking sound as a piece breaks off, or by a thunderous roar as a large piece falls into the water. These sounds are unlikely to be heard due to shipboard noise. The appearance of small pieces of ice in the water often indicates the presence of an iceberg nearby. In calm weather these pieces may form a curved line with the parent iceberg on the concave side. Some of the pieces broken from an iceberg are themselves large enough to be a threat to shipping.

As the ship moves closer towards areas known to contain sea ice, one of the most reliable signs that pack ice is being approached is the absence of swell or wave motion in a fresh breeze or a sudden flattening of the sea, especially from leeward. The observation of icebergs is not a good indication that pack ice will be encountered soon, since icebergs may be found at great distances from pack ice. If the sea ice is approached from windward, it is usually compacted and the edge will be sharply defined. However, if it is approached from leeward, the ice is likely to be loose and somewhat scattered, often in long narrow arms.

Another reliable sign of the approach of pack ice not yet in sight is the appearance of a pattern, or **sky map**, on the horizon or on the underside of distant, extensive cloud areas, created by the varying amounts of light reflected

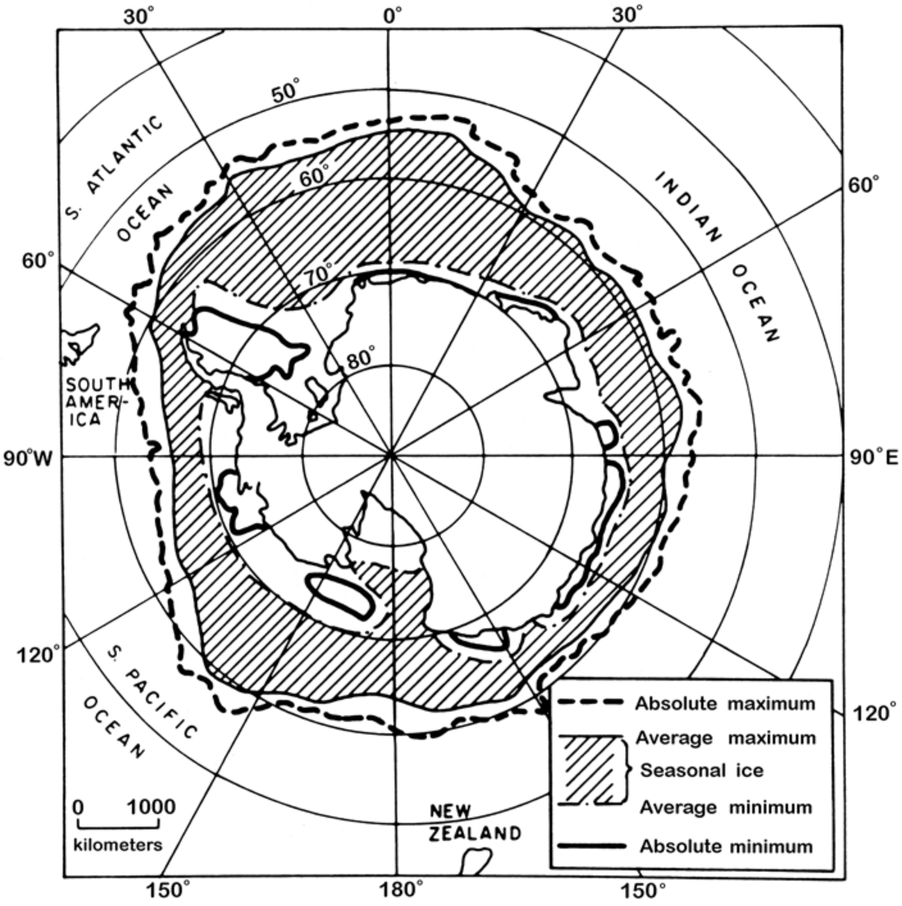

Figure 3210c. Average maximum and minimum extent of Antarctic sea ice.

Figure 3210d. U.S. National Snow and Ice Data Center.
http://www.nsidc.org

Figure 3210e. U.S. National Ice Center.
http://www.natice.noaa.gov

from different materials on the sea or Earth's surface. A bright white glare, or **snow blink**, will be observed above a snow covered surface. When the reflection on the underside of clouds is caused by an accumulation of distant ice, the glare is a little less bright and is referred to as an **ice blink**. A relatively dark pattern is reflected on the underside of clouds when it is over land that is not snow covered. This is known as a land sky. The darkest pattern will occur when the clouds are above an open water area, and is called a **water sky**. A mariner experienced in recognizing these sky maps will find them useful in avoiding ice or searching out openings which may permit the vessel to make progress through an ice field.

Figure 3210f. NGA Arctic Support.
http://nga.maps.arcgis.com/apps/MapSeries/index.html?appid=cf2fba21df7540fb981f8836f2a97e25

Another indication of the presence of sea ice is the formation of thick bands of fog over the ice edge, as moisture condenses from warm air when passing over the colder ice. An abrupt change in air or sea temperature or seawater salinity is *not* a reliable sign of the approach of icebergs or pack ice.

The presence of certain species of animals and birds can also indicate that pack ice is in close proximity. The sighting of walruses, seals, or polar bears in the Arctic should warn the mariner that pack ice is close at hand. In the Antarctic, the usual precursors of sea ice are penguins, terns, fulmars, petrels, and skuas.

Due to the low profile and poor reflectivity, ice presents only about 1/60th of the radar return of a vessel of the same cross sectional area. It has a reflection coefficient of 0.33. Despite these limitations, a properly tuned radar can prove to be a valuable tool. Although many icebergs will be observed visually on clear days before there is a return on the radarscope, radar will detect the average iceberg at a range of about 8 to 10 miles.

The intensity of the return is a function of the nature of the ice's exposed surface (slope, surface roughness); however, it is unusual to find an iceberg which will not produce a detectable echo. Ice is not frequency-sensitive; both S- and X-band radars provide similar detectability. However, there is an advantage in using S-band radar in heavy precipitation since signal attenuation is less than X-band allowing better detection in these conditions.

While large icebergs will almost always be detected by radar in time to be avoided, a growler large enough to pose a serious danger to a vessel may be lost in the sea return and escape detection. Growlers cannot usually be detected at ranges greater than four miles, and are usually lost in seas greater than four feet. If an iceberg or growler is detected by radar, careful tracking is necessary to distinguish it from a rock, islet, or another ship.

Radar can be of great assistance to experienced radar observers. Smooth sea ice, like smooth water, returns little or no echo, but small floes of rough, hummocky sea ice capable of inflicting damage to a ship can be detected in a smooth sea at a range of about 2 to 4 miles. The return may be similar to sea return, but the same echoes appear at each sweep. A lead in smooth ice is clearly visible on a radarscope, even though a thin coating of new ice may have formed in the opening. A light covering of snow obliterating many of the features to the eye will have little effect on radar return.

Experience in interpretation is gained through comparing various radar returns with actual observations. The most effective use of radar in ice detection and navigation is constant surveillance by trained and experienced operators.

Experience in interpretation is gained through comparing various radar returns with actual observations. The most effective use of radar in ice detection and navigation is constant surveillance by trained and experienced operators.

In lieu of other means of detections, echoes from the ship's whistle or horn may sometimes indicate the presence of icebergs and indicate direction. If the time interval between the sound and its echo is measured, the distance in meters can be determined by multiplying the number of seconds by 168. However, echoes are unreliable because only ice with a large vertical area facing the ship returns enough echo to be heard. Once an echo is heard, a distinct pattern of horn blasts (not a Navigational Rules signal) should be made to confirm that the echo is not another vessel.

Ice in the polar regions is best detected and observed from high above, either from aircraft or by satellite. Fixed-winged aircraft have been utilized extensively for obtaining detailed aerial ice reconnaissance information since the early 1930's. Some ships, particularly icebreakers, proceeding into high latitudes carry helicopters, which are invaluable in locating leads and determining the relative navigability of different portions of the ice pack. Unmanned aerial systems are also used for ice reconnaissance. Ice reports from personnel at Arctic and Antarctic coastal shore stations can also prove valuable to the polar mariner.

The enormous ice reconnaissance capabilities of meteorological satellites were confirmed within hours of the launch by the **National Aeronautics and Space Administration (NASA)** of the first experimental meteorological satellite, TIROS I, on April 1, 1960. With the advent of the polar-orbiting meteorological satellites during the mid and late 1960's, the U.S. Navy initiated an operational satellite ice reconnaissance program which could observe ice and its movement in any region of the globe on a daily basis, depending upon solar illumination. Since then, improvements in satellite sensor technology have provided a capability to make detailed global observations of ice properties under all weather and lighting conditions. The current suite of airborne and satellite sensors employed by the USNIC and the International Ice Patrol include: aerial reconnaissance using a real aperture maritime search radar with visual observations, visual and infrared satellite sensors, and all-weather passive microwave. In addition, **synthetic aperture radar (SAR)** on various commercial and government satellite platforms provide all-weather, day/night ice information for both sea ice and iceberg detection. Commercial SAR systems in use today include the Canadian Radarsat-2, the

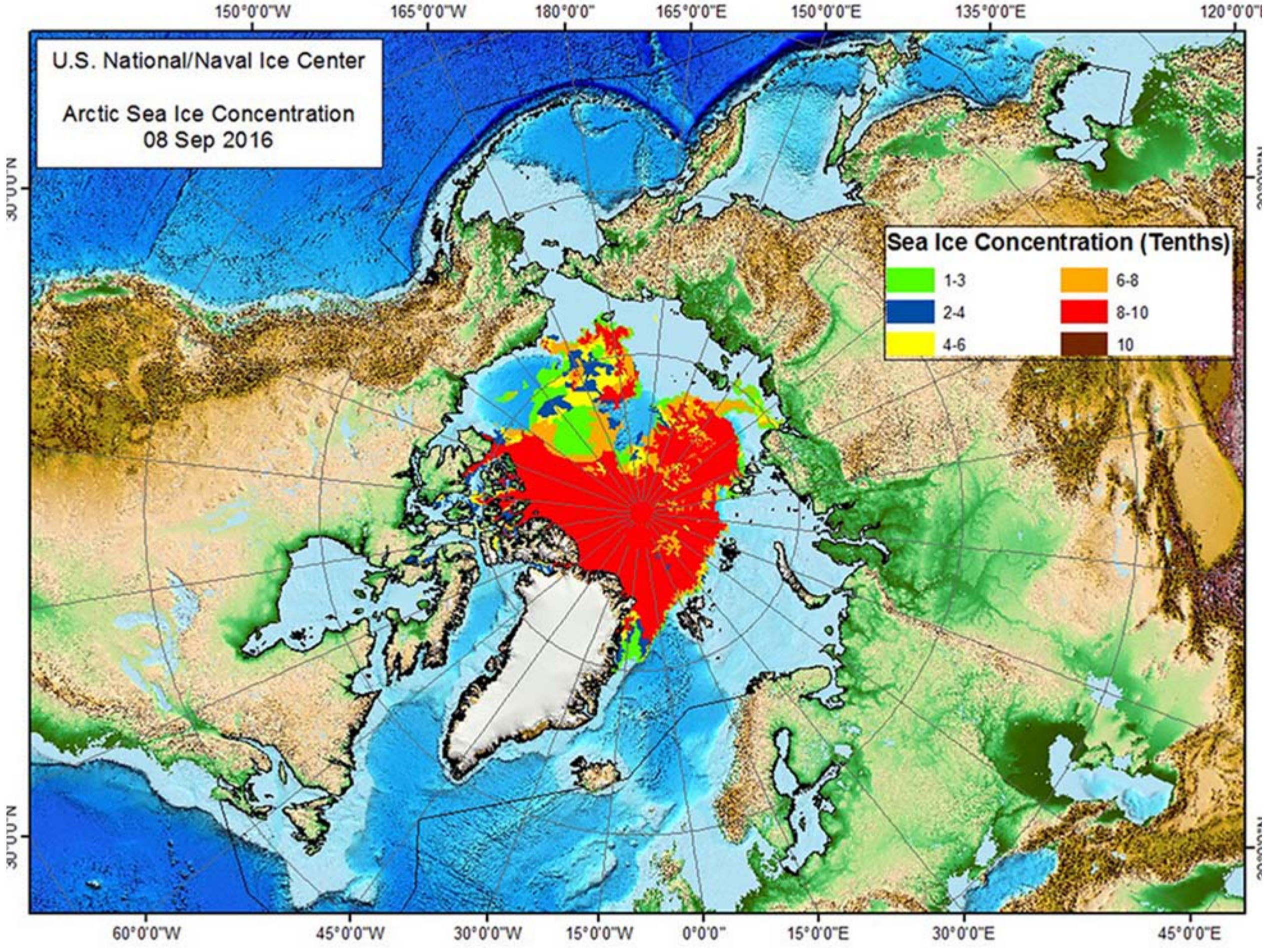

Figure 3211. Example of a USNIC Sea Ice Concentration Product derived from satellite imagery.

German TerraSAR-X, Italian COSMO-SkyMed, and the European Space Agency Sentinel-1 satellites. Operational ice services around the world have come to rely on SAR technology for ice monitoring and charting. A satellite-derived Sea Ice Concentration Product produced by the USNIC for 08 September 2016 is shown in Figure 3211.

3212. Operations in Ice

Operations in ice-prone regions necessarily require considerable advanced planning and many more precautionary measures than those taken prior to a typical open ocean voyage. The crew of a polar-bound vessel should be thoroughly indoctrinated in the fundamentals of polar operations, utilizing the best information sources available. The subjects covered should include training in ship handling in ice, polar navigation, effects of low temperatures on materials and equipment, damage control procedures, communications problems inherent in polar regions, polar meteorology, sea ice terminology, ice observing and reporting procedures (including classification and codes) and polar survival. Training materials should consist of reports on previous Arctic and Antarctic voyages, sailing directions, ice atlases, training films on polar operations, and U.S. Navy service manuals detailing the recommended procedures to follow during high latitude missions.

The preparation of a vessel for polar operations is of extreme importance and the considerable experience gained from previous operations should be drawn upon to bring the ship to optimum operating condition. At the very least, operations conducted in ice-infested waters require that the vessel's hull and propulsion system undergo certain modifications.

The bow and waterline of the forward part of the vessel should be heavily reinforced. Similar reinforcement should also be considered for the propulsion spaces of the vessel. Cast iron propellers and those made of a bronze alloy do not possess the strength necessary to operate safely in ice. Therefore, it is strongly recommended that propellers made of these materials be replaced by steel. Other desirable features are the absence of vertical sides, deep placement of the propellers, a blunt bow, metal guards to protect propellers from ice damage, and lifeboats for 150 percent of personnel aboard. The complete list of desirable features depends upon the area of operations, types of ice to be encountered, length of stay in the vicinity of ice, anticipated assistance by icebreakers, and possibly other factors. Strength requirements and the minimum thicknesses deemed necessary for the vessel's frames and additional plating to be used as reinforcement, as well as other procedures needed to outfit a vessel for ice operations, can be obtained from the American Bureau of Shipping. For a more definitive and complete guide to the ice strengthening of ships, the mariner may desire to consult the procedures outlined in Rules for Ice Strengthening of Ships, from the Board of Navigation, Helsinki, Finland. Further specifications have been published by the International Association of Classification Societies (IACS). These requirements are collectively known as **Polar Class**, and assess vessels from PC1 to PC5.

Equipment necessary to meet the basic needs of the crew and to insure the successful and safe completion of the polar voyage should not be overlooked. A minimum list of essential items should consist of polar clothing and footwear, 100% UV protective sunglasses, food, vitamins, medical supplies, fuel, storage batteries, antifreeze, explosives, detonators, fuses, meteorological supplies, and survival kits containing sleeping bags, trail rations, firearms, ammunition, fishing gear, emergency medical supplies, and a repair kit.

The vessel’s safety depends largely upon the thoroughness of advance preparations, the alertness and skill of its crew, and their ability to make repairs if damage is incurred. Spare propellers, rudder assemblies, and patch materials, together with the equipment necessary to effect emergency repairs of structural damage should be carried. Examples of repair materials needed include quick setting cement, oakum, canvas, timbers, planks, pieces of steel of varying shapes, welding equipment, clamps, and an assortment of nuts, bolts, washers, screws, and nails.

Ice and snow accumulation on the vessel poses a definite capsize hazard. Mallets, baseball bats, ax handles, and scrapers to aid in the removal of heavy accumulations of ice, together with snow shovels and stiff brooms for snow removal should be provided. A live steam line may be useful in removing ice from superstructures.

Navigation in polar waters is at best difficult and, during poor conditions, impossible, except using satellite or inertial systems. Environmental conditions encountered in high latitudes such as fog, storms, compass anomalies, atmospheric effects, and, of course, ice, hinder polar operations. Also, deficiencies in the reliability and detail of hydrographic and geographical information presented on polar navigation charts, coupled with a distinct lack of reliable bathymetry, current, and tidal data, add to the problems of polar navigation. Much work is being carried out in polar regions to improve the geodetic control, triangulation, and quality of hydrographic and topographic information necessary for accurate polar charts. However, until this massive task is completed, the only resource open to the polar navigator, especially during periods of poor environmental conditions, is to rely upon the basic principles of navigation and adapt them to unconventional methods when abnormal situations arise.

Upon the approach to pack ice, a careful decision is needed to determine the best action. If it is possible to go around the ice, rather than through it, do so. Unless the pack is quite loose, this action usually gains rather than loses time. When skirting an ice field or an iceberg, do so to windward, if a choice is available, to avoid projecting tongues of ice or individual pieces that have been blown away from the main body of ice.

When it becomes necessary to enter pack ice, a thorough examination of the distribution and extent of the ice conditions should be made beforehand from the highest possible location. Aircraft (particularly helicopters) and direct satellite readouts are of great value in determining the nature of the ice to be encountered. The most important features to be noted include the location of open water, such as leads and polynyas, which may be manifested by water sky; icebergs; and the presence or absence of both ice under pressure and rotten ice. Some protection may be offered the propeller and rudder assemblies by trimming the vessel down by the stern slightly (not more than 2–3 feet) prior to entering the ice; however, this precaution usually impairs the maneuvering characteristics of most vessels not specifically built for ice breaking.

Selecting the point of entry into the pack should be done with great care; and if the ice boundary consists of closely packed ice or ice under pressure, it is advisable to skirt the edge until a more desirable point of entry is located. Seek areas with low ice concentrations, areas of rotten ice or those containing navigable leads, and if possible enter from leeward on a course perpendicular to the ice edge. It is also advisable to take into consideration the direction and force of the wind, and the set and drift of the prevailing currents when determining the point of entry and the course followed thereafter. Due to wind induced wave action, ice floes close to the periphery of the ice pack will take on a bouncing motion which can be quite hazardous to the hull of thin-skinned vessels. In addition, note that pack ice will drift slightly to the right of the true wind in the Northern Hemisphere and to the left in the Southern Hemisphere, and that leads opened by the force of the wind will appear perpendicular to the wind direction. If a suitable entry point cannot be located due to less than favorable conditions, patience may be called for. Unfavorable conditions generally improve over a short period of time by a change in the wind, tide, or sea state.

Once in the pack, always try to work with the ice, not against it, and keep moving, but do not rush. Respect the ice but do not fear it. Proceed at slow speed at first, staying in open water or in areas of weak ice if possible. The vessel's speed may be safely increased after it has been ascertained how well it handles under the varying ice conditions encountered. It is better to make good progress in the general direction desired than to fight large thick floes in the exact direction to be made good. However, avoid the temptation to proceed far to one side of the intended track; it is almost always better to back out and seek a more penetrable area. During those situations when it becomes necessary to back, always do so with extreme caution and *with the rudder amidships*. If the ship is stopped by ice, the first command should be "rudder amidships," given while the screw is still turning. This will help protect the propeller when backing and prevent ice jamming between rudder and hull. If the rudder becomes ice-jammed, man after steering, establish communications, and *do not* give any helm commands until the rudder is clear. A quick full-ahead burst may clear it. If it does not, try going to "hard rudder" *in the same direction slowly* while turning full or flank speed ahead.

Ice conditions may change rapidly while a vessel is working in pack ice, necessitating quick maneuvering. Conventional vessels, even if ice strengthened, are not built for icebreaking. The vessel should be conned to first attempt to place it in leads or polynyas, giving due consideration to wind conditions. The age, thickness, and size of ice which can be navigated depends upon the type, size, hull strength, and horsepower of the vessel employed. If contact with an ice floe is unavoidable, never strike it a glancing blow. This maneuver engages the ice with weaker parts of the hull, and may cause the ship to veer off in a direction which will swing the stern into the ice. If possible, seek weak spots in the floe and engage it head-on at slow speed. Unless the ice is rotten or very young, do not attempt to break through the floe, but rather make an attempt to swing it aside as speed is slowly increased. Keep clear of corners and projecting points of ice, but do so without making sharp turns which may throw the stern against the ice, resulting in a damaged propeller, propeller shaft, or rudder. The use of full rudder in non-emergency situations is not recommended because it may swing either the stern or mid-section of the vessel into the ice. This does not preclude use of alternating full rudder (**sallying** the rudder) aboard icebreakers as a technique for penetrating heavy ice.

Offshore winds may open relatively ice free navigable coastal leads, but such leads should not be entered without benefit of icebreaker escort. If it becomes necessary to enter coastal leads, narrow straits, or bays, an alert watch should be maintained since a shift in the wind may force drifting ice down upon the vessel. An increase in wind on the windward side of a prominent point, grounded iceberg, or land ice tongue extending into the sea will also endanger a vessel. It is wiser to seek out leads toward the windward side of the main body of the ice pack. In the event that the vessel is under imminent danger of being trapped close to shore by pack ice, immediately attempt to orient the vessel's bow seaward. This will help to take advantage of the little maneuvering room available in the open water areas found between ice floes. Work carefully through these areas, easing the ice floes aside while maintaining a close watch on the general movement of the ice pack.

If the vessel is completely halted by pack ice, it is best to keep the rudder amidships, and the propellers turning at slow speed. The wash of the propellers will help to clear ice away from the stern, making it possible to back down safely. When the vessel is stuck fast, an attempt first should be made to free the vessel by going full speed astern. If this maneuver proves ineffective, it may be possible to get the vessel's stern to move slightly, thereby causing the bow to shift, by quickly shifting the rudder from one side to the other while going full speed ahead. Another attempt at going astern might then free the vessel. The vessel may also be freed by either transferring water from ballast tanks, causing the vessel to list, or by alternately flooding and emptying the fore and aft tanks. A heavy weight swung out on the cargo boom might give the vessel enough list to break free. If all these methods fail, the utilization of deadmen (2- to 4-meter lengths of timber buried in holes out in the ice and to which a vessel is moored) and ice anchors (a stockless, single fluked hook embedded in the ice) may be helpful. With a deadman or ice anchors attached to the ice astern, the vessel may be warped off the ice by winching while the engines are going full astern. If all the foregoing methods fail, explosives placed in holes cut nearly to the bottom of the ice approximately 10 to 12 meters off the beam of the vessel and detonated while the engines are working full astern might succeed in freeing the vessel. A vessel may also be sawed out of the ice if the air temperature is above the freezing point of seawater.

When a vessel becomes so closely surrounded by ice that all steering control is lost and it is unable to move, it is **beset**. It may then be carried by the drifting pack into shallow water or areas containing thicker ice or icebergs with their accompanying dangerous underwater projections. If ice forcibly presses itself against the hull, the vessel is said to be **nipped**, whether or not damage is sustained. When this occurs, the gradually increasing pressure may be capable of holing the vessel's bottom or crushing the sides. When a vessel is beset or nipped, freedom may be achieved through the careful maneuvering procedures, the physical efforts of the crew, or by the use of explosives similar to those previously detailed. Under severe conditions the mariner's best ally may be patience since there will be many times when nothing can be done to improve the vessel's plight until there is a change in meteorological conditions. It may be well to preserve fuel and perform any needed repairs to the vessel and its engines. Damage to the vessel while it is beset is usually attributable to collisions or pressure exerted between the vessel's hull, propellers, or rudder assembly, and the sharp corners of ice floes. These collisions can be minimized greatly by attempting to align the vessel in such a manner as to insure that the pressure from the surrounding pack ice is distributed as evenly as possible over the hull. This is best accomplished when medium or large ice floes encircle the vessel.

In the vicinity of icebergs, either in or outside of the pack ice, a sharp lookout should be kept and all icebergs given a wide berth. The commanding officers and masters of all vessels, irrespective of their size, should treat all icebergs with great respect. The best locations for lookouts are generally in a crow's nest, rigged in the foremast or housed in a shelter built specifically for a bow lookout in the eyes of a vessel. Telephone communications between these sites and the navigation bridge on larger vessels will prove invaluable. It is dangerous to approach close to an iceberg of any size because of the possibility of encountering underwater extensions, and because icebergs that are disintegrating may suddenly capsize or readjust their masses to new positions of equilibrium. In periods of low visibility the utmost caution is needed at all times. Vessel speed should be reduced and the watch prepared for quick maneuvering. Radar becomes an effective but not infallible tool, and does not negate the need for trained lookouts.

Since icebergs may have from eight to nine-tenths of their masses below the water surface, their drift is generally influenced more by currents than winds, particularly under light wind conditions. The drift of pack ice, on the other hand, is usually dependent upon the wind. Under these conditions, icebergs within the pack may be found moving at a different rate and in a different direction from that of the pack ice. In regions of strong currents, icebergs should always be given a wide berth because they may travel upwind under the influence of contrary currents, breaking heavy pack in their paths and endangering vessels unable to work clear. In these situations, open water will generally be found to leeward of the iceberg, with piled up pack ice to windward. Where currents are weak and a strong wind predominates, similar conditions will be observed as the wind driven ice pack overtakes an iceberg and piles up to windward with an open water area lying to leeward.

Under ice, submarine operations require knowledge of prevailing and expected sea ice conditions to ensure maximum operational efficiency and safety. The most important ice features are the frequency and extent of downward projections (bummocks and ice keels) from the underside of the ice canopy (pack ice and enclosed water areas from the point of view of the submariner), the distribution of thin ice areas through which submarines can attempt to surface, and the probable location of the outer pack edge where submarines can remain surfaced during emergencies to rendezvous with surface ship or helicopter units.

Bummocks are the subsurface counterpart of hummocks, and **ice keels** are similarly related to ridges. When the physical nature of these ice features is considered, it is apparent that ice keels may have considerable horizontal extent, whereas individual bummocks can be expected to have little horizontal extent. In shallow water lanes to the Arctic Basin, such as the Bering Strait and the adjoining portions of the Bering Sea and Chukchi Sea, deep bummocks and ice keels may leave little vertical room for submarine passage. Widely separated bummocks may be circumnavigated but make for a hazardous passage. Extensive ice areas, with numerous bummocks or ice keels which cross the lane may effectively block both surface and submarine passage into the Arctic Basin.

Bummocks and ice keels may extend downward approximately five times their vertical extent above the ice surface. Therefore, observed ridges of approximately 10 meters may extend as much as 50 meters below sea level. Because of the direct relation of the frequency and vertical extent between these surface features and their subsurface counterparts, aircraft ice reconnaissance should be conducted over a planned submarine cruise track before under ice operations commence.

Skylights are thin places (usually less than 1 meter thick) in the ice canopy, and appear from below as relatively light translucent patches in dark surroundings. The undersurface of a skylight is usually flat; not having been subjected to great pressure. Skylights are called large if big enough for a submarine to attempt to surface through them; that is, have a linear extent of at least 120 meters. Skylights smaller than 120 meters are referred to as small. An ice canopy along a submarine's track that contains a number of large skylights or other features such as leads and polynyas, which permit a submarine to surface more frequently than 10 times in 30 miles, is called **friendly ice**. An ice canopy containing no large skylights or other features which permit a submarine to surface is called **hostile ice**.

3213. Great Lakes Ice

Large vessels have been navigating the Great Lakes since the early 1760's. This large expanse of navigable water has since become one of the world's busiest waterways. Due to the northern geographical location of the Great Lakes Basin and its susceptibility to Arctic outbreaks of polar air during winter, the formation of ice plays a major disruptive role in the region's economically vital marine industry. Because of the relatively large size of the five Great Lakes, the ice cover which forms on them is affected by the wind and currents to a greater degree than on smaller lakes. The Great Lakes' northern location results in a long ice growth season, which in combination with the effect of wind and current, imparts to their ice covers some of the characteristics and behavior of an Arctic ice pack.

Since the five Great Lakes extend over a distance of approximately 800 kilometers in a north-south direction, each lake is influenced differently by various meteorological phenomena. These, in combination with the fact that each lake also possesses different geographical characteristics, affect the extent and distribution of their ice covers.

The largest, deepest, and most northern of the Great Lakes is **Lake Superior**. Initial ice formation normally begins at the end of November or early December in harbors and bays along the north shore, in the western portion of the

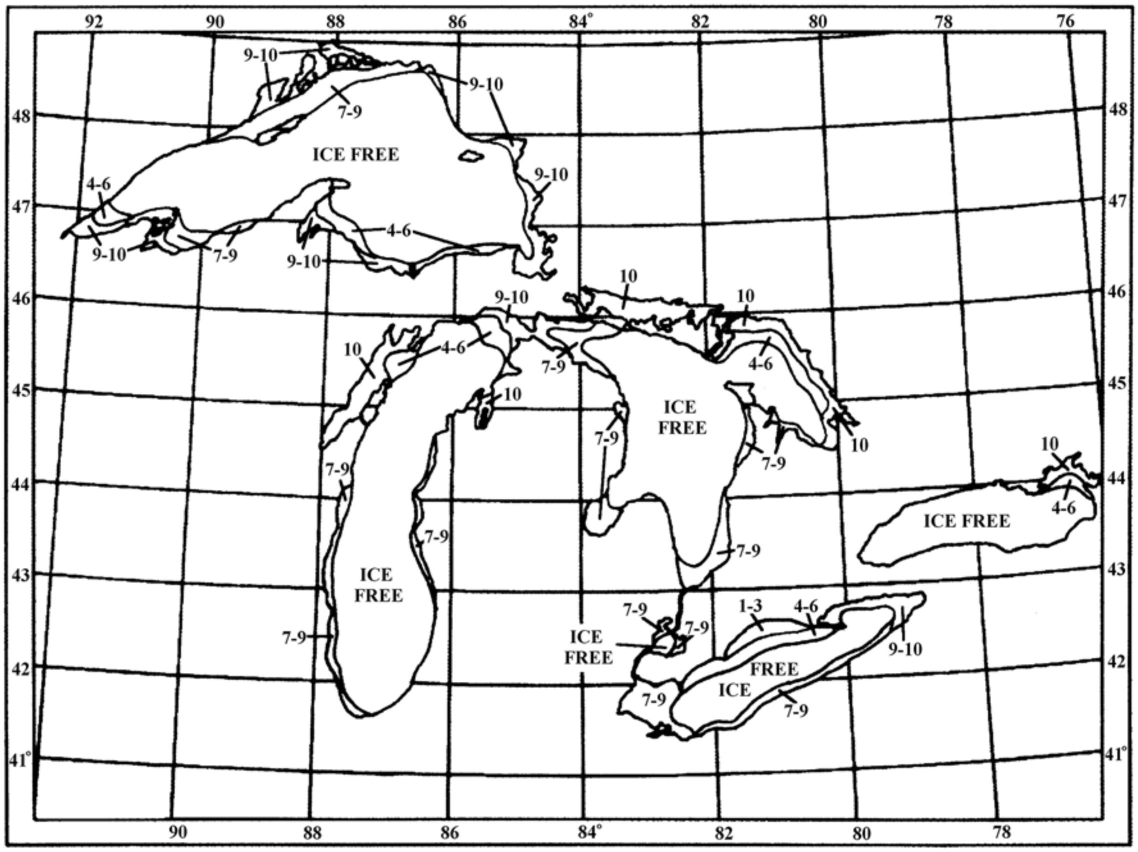

Figure 3213a. Great Lakes ice cover during a mild winter.

Figure 3213b. USCG cutters KATMAI BAY and MORRO BAY hold position as ice breaker MACKINAW works to find open water leads out of Whitefish Bay, Lake Superior, March 21-23, 2014. Credit: USCG Soo.

lake and over the shallow waters of Whitefish Bay (see Figure 3213b). As the season progresses, ice forms and thickens in all coastal areas of the lake perimeter prior to extending offshore. This formation pattern can be attributed to a maximum depth in excess of 400 meters and an associated large heat storage capacity that hinders early ice formation in the center of the lake. During a normal winter, ice not under pressure ranges in thickness from 45–85 centimeters. During severe winters, maximum thicknesses are reported to approach 100 centimeters. Winds and currents acting upon the ice have been known to cause ridging with heights approaching 10 meters. During normal years, maximum ice cover extends over approximately 75% of the lake surface with heaviest ice conditions occurring by early March. This value increases to 95% coverage during severe winters and decreases to less than 20% coverage during a mild winter. Winter navigation is most difficult in the southeastern portion of the lake due to heavy ridging and compression of the ice under the influence of prevailing westerly winds. Breakup normally starts near the end of March with ice in a state of advanced deterioration by the middle of April. Under normal conditions, most of the lake is ice-free by the first week of May.

Lake Michigan extends in a north-south direction over 490 kilometers and possesses the third largest surface area of the five Great Lakes. Depths range from 280 meters in the center of the lake to 40 meters in the shipping lanes through the Straits of Mackinac, and less in passages between island groups. During average years, ice formation first occurs in the shallows of Green Bay and extends eastward along the northern coastal areas into the Straits of Mackinac during the second half of December and early January. Ice formation and accumulation proceeds southward with coastal ice found throughout the southern perimeter of the lake by late January. Normal ice thicknesses range from 10–20 centimeters in the south to 40–60 centimeters in the north. During normal years, maximum ice cover extends over approximately 40% of the lake surface with heaviest conditions occurring in late February and early March. Ice coverage increases to 85–90% during a severe winter and decreases to only 10–15% during a mild year. Coverage of 100% occurs, but rarely. Throughout the winter, ice formed in mid-lake areas tends to drift eastward because of prevailing westerly winds. This movement of ice causes an area in the southern central portion of the lake to remain ice-free throughout a normal winter. Extensive ridging of ice around the island areas adjacent to the Straits of Mackinac presents the greatest hazard to year-round navigation on this lake. Due to an extensive length and north-south orientation, ice formation and deterioration often oc-

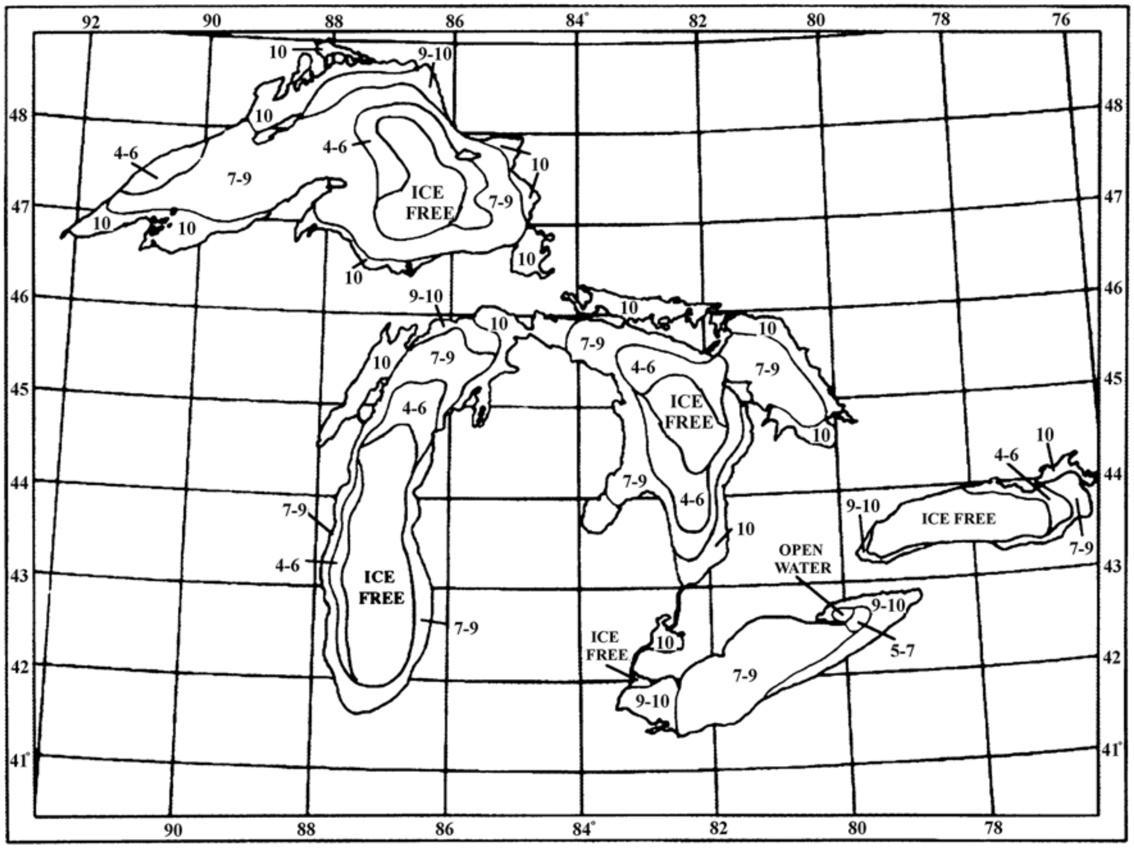

Figure 3213c. Great Lakes ice cover during a normal winter.

cur simultaneously in separate regions of this lake. Ice break-up normally begins by early March in southern areas and progresses to the north by early April. Under normal conditions, only 5–10% of the lake surface is ice covered by mid-April with lingering ice in Green Bay and the Straits of Mackinac completely melting by the end of April.

Lake Huron, the second largest of the Great Lakes, has maximum depths of 230 meters in the central basin west of the Bruce peninsula and 170 meters in Georgian Bay. The pattern of ice formation in Lake Huron is similar to the north-south progression described in Lake Michigan. Initial ice formation normally begins in the North Channel and along the eastern coast of Saginaw and Georgian Bays by mid-December. Ice rapidly expands into the western and southern coastal areas before extending out into the deeper portions of the lake by late January. Normal ice thicknesses are 45–75 centimeters. During severe winters, maximum ice thicknesses often exceed 100 centimeters with windrows of ridged ice achieving thicknesses of up to 10 meters. During normal years, maximum ice cover occurs in late February with 60% coverage in Lake Huron and nearly 95% coverage in Georgian Bay. These values increase to 85–90% in Lake Huron and nearly 100% in Georgian Bay during severe winters. The percent of lake surface area covered by ice decreases to 20–25% for both bodies of water during mild years. During the winter, ice as a hazard to navigation is of greatest concern in the St. Mary's River/North Channel area and the Straits of Mackinac. Ice break-up normally begins in mid-March in southern coastal areas with melting conditions rapidly spreading northward by early April. A recurring threat to navigation is the southward drift and accumulation of melting ice at the entrance of the St. Clair river. Under normal conditions, the lake becomes ice free by the first week of May.

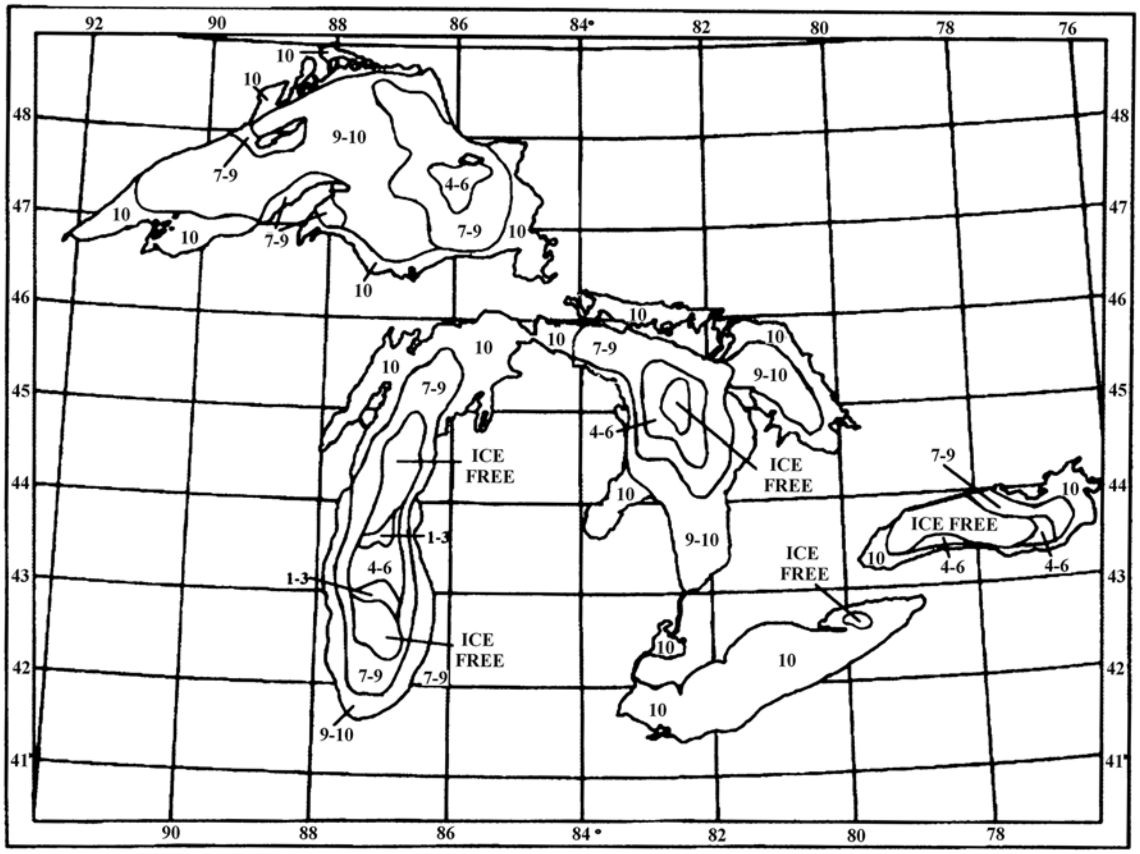

Figure 3213d. Great Lakes ice cover during a severe winter.

The shallowest and most southern of the Great Lakes is **Lake Erie**. Although the maximum depth nears 65 meters in the eastern portion of the lake, an overall mean depth of only 20 meters results in the rapid accumulation of ice over a short period of time with the onset of winter. Initial ice formation begins in the very shallow western portion of the lake in mid-December with ice rapidly extending eastward by early January. The eastern portion of the lake does not normally become ice covered until late January. During a normal winter, ice thicknesses range from 25–45 centimeters in Lake Erie. During the period of rapid ice growth, prevailing winds and currents routinely move existing ice to the northeastern end of the lake. This accumulation of ice under pressure is often characterized by ridging with maximum heights of 8–10 meters. During a severe winter, initial ice formation may begin in late November with maximum seasonal ice thicknesses exceeding 70 centimeters. Since this lake reacts rapidly to changes in air temperature, the variability of percent ice cover is the greatest of the five Great Lakes. During normal years, ice cover extends over approximately 90–95% of the lake surface by mid to late February. This value increases to nearly 100% during a severe winter and decreases to 30% ice coverage during a mild year. Lake St. Clair, on the connecting waterway to Lake Huron, is normally consolidated from the middle of January until early March. Ice break-up normally begins in the western portion of Lake Erie in early March with the lake becoming mostly ice-free by the middle of the month. The exception to this rapid deterioration is the extreme eastern end of the lake where ice often lingers until early May.

Lake Ontario has the smallest surface area and second greatest mean depth of the Great Lakes. Depths range from 245 meters in the southeastern portion of the lake to 55 meters in the approaches to the St. Lawrence River. Like Lake Superior, a large mean depth gives Lake Ontario a large heat storage capacity which, in combination with a small surface area, causes Lake Ontario to respond slowly to changing meteorological conditions. As a result, this lake produces the smallest amount of ice cover found on any of the Great Lakes. Initial ice formation normally begins from the middle to late December in the Bay of Quinte and extends to the western coastal shallows near the mouth of the St. Lawrence River by early January. By the first half of February, Lake Ontario is almost 20% ice covered with shore ice lining the perimeter of the lake. During normal years, ice cover extends over approximately 25% of the lake's surface by the second half of February. During this period of maximum ice coverage, ice is typically concentrated in the northeastern portion of the lake by prevailing westerly winds and currents. Ice coverage can extend over 50–60% of the lake surface during a severe winter and less than 10% during a mild year. Level lake ice thicknesses normally fall within the 20–60 centimeter range with occasional reports exceeding 70 centimeters during severe years. Ice break-up normally begins in early March with the lake generally becoming ice-free by mid-April.

The maximum ice cover distribution attained by each of the Great lakes for mild, normal and severe winters is shown in Figure 3213a, Figure 3213c and Figure 3213d. It should be noted that although the average maximum ice cover for each lake appears on the same chart, the actual occurrence of each distribution takes place during the time periods described within the preceding narratives.

Analysis of the Great Lakes ice is done at the USNIC in conjunction with the Canadian Ice Service. This partnership - the North American Ice Service provides daily analysis of the Great Lakes ice throughout the season. Near real time lake ice products are publicly available at www.natice.noaa.gov. Additional information is available to the mariner from NOAA's **Great Lakes Environmental Research Laboratory (GLERL)** via the link provided in Figure 3213e.

GLERL
NOAA - Great Lakes Environmental Research Laboratory

Figure 3213e. NOAA - Great Lakes Environmental Research Laboratory. https://www.glerl.noaa.gov/

ICE INFORMATION SERVICES

3214. Importance of Ice Information

Advance knowledge of ice conditions to be encountered and how these conditions will change over specified time periods are invaluable for both the planning and operational phases of a voyage to the polar regions. Branches of the United States Federal Government responsible for providing operational ice products and services for safety of navigation include the Departments of Defense (U.S. Navy), Commerce (NOAA), and Homeland Security (U.S. Coast Guard). All of these agencies are part of the joint **U.S. National Ice Center (USNIC)**. The USNIC provides ice products and services to U.S. Government and maintains a public website for general ice conditions in the Arctic, Antarctic and Great Lakes. USNIC charts are produced through the analyses of available, near real time remote sensing, and model data sources. They are generated primarily for maritime domain awareness, and for U.S. government mission planning and safety of navigation. The content of sea ice analyses is directly dependent upon the planned use of the product, the required level of detail, and the availability of on-site ice observations and/or remotely-sensed data. Ice analyses are produced primarily from satellite remote sensing data. Information from ship observations, aircraft reconnaissance, and buoy data are used when available.

The accurate interpretation of these data is critical to producing the USNIC's daily sea ice edge and the weekly Arctic and Antarctic hemispheric sea ice charts. Great Lakes ice analysis are done through the ice season; December through May.

3215. Ice Forecasts and Observations

Ice forecasting services are provided to U.S. Government agencies upon request for ongoing polar operations and operational planning. For government entities, optimum track ship routing (OTSR) recommendations via the USN's Fleet Weather Center in Norfolk, VA will include sea ice edge information as applicable. Government units can request support via the USNIC website or by contacting the Command Duty Officer. Commercial operations interested in ice products may obtain routinely produced ice products from the public USNIC website and, in U.S. Alaska waters, from the **Alaska Sea Ice Program (ASIP)** sea ice desk in Anchorage, Alaska. They provide support to government and public users. Their products are available via the link provided in Figure 3215a.

The U.S. Coast Guard has an additional responsibility, separate from the USNIC, for providing icebreaker support for polar operations and the administration and operations of the **International Ice Patrol (IIP)**.

NWS Alaska Sea Ice Program (ASIP)

Weather.gov > Anchorage, AK > NWS Alaska Sea Ice Program (ASIP)

Figure 3215a Alaska Sea Ice Program.
https://www.weather.gov/afc/ice

Ice observation codes make use of special nomenclature which is precisely defined in several languages by the WMO publication *Sea Ice Nomenclature - WMO No. 259, TP 145*. This publication, available from the Secretariat of the WMO, contains descriptive definitions along with photography of most ice features. This publication is very useful for vessels planning to submit ice observations. The publication is available online via the link provided in Figure 3215b.

Figure 3215b. WMO Sea-Ice Nomenclature.
http://www.jcomm.info/index.php?option=com_oe&task=viewDocumentRecord&docID=14598

3216. The North Atlantic Ice Patrol

The North Atlantic Ice Patrol was established in 1914 by the International Convention for the Safety of Life at Sea (SOLAS), held in 1913 as a result of the sinking of the RMS TITANIC in 1912. The TITANIC struck an iceberg on its maiden voyage and sank with the loss of 1,513 lives. In accordance with the agreement reached at the SOLAS conventions of 1960 and 1974, the U.S. Coast Guard International Ice Patrol monitors the iceberg danger in the North Atlantic Ocean and to provide relevant iceberg warning products to the maritime community. Information on ice conditions for the Gulf of St. Lawrence and the coastal waters of Newfoundland and Labrador, including the Strait of Belle Isle, is provided by **ECAREG Canada** (Eastern Canada Traffic System), through any Coast Guard Radio Station, from the month of December through late June. Sea ice data for these areas can also be obtained from the Ice Operations Officer, located at St. Johns, Newfoundland, via Sydney, Halifax, or St. John's marine radio. The ice operations desk can be contacted at: iceatl.cggc@dfo-mpo.cg.ca

During the war years of 1916-18 and 1941-45, the Ice Patrol was suspended. Aircraft were added to the patrol force following World War II, and today perform the majority of the reconnaissance work. During each ice season, aerial reconnaissance surveys are made in the vicinity of the Grand Banks of Newfoundland and along the coast of Labrador to determine the southern, eastern, and western limit of the seaward extent of icebergs. The U.S. Coast Guard aircraft use the 360-degree ELTA radar to help detect and identify icebergs in this notoriously fog-ridden area. Reports of ice sightings are also requested and collected from ships transiting the Ice Patrol's operational area. Vessels are encouraged to report sightings of icebergs or stationary radar targets that may likely be icebergs to the nearest **Canadian Coast Guard Marine Communications and Traffic Services (MCTS)** station or the International Ice Patrol at: iipcomms@uscg.mil. Ice reports may also be sent at no charge using INMARSAT Code 42. The IIP implements a voluntary ice observation reporting system called the **Vessel of Opportunity Observation Program (VOOP)**. More information on the VOOP can be found at: http://www.navcen.uscg.gov/pdf/iip/VOOP.pdf.

International Ice Patrol activities are directed from an Operations Center in New London, Connecticut. The Ice Patrol gathers iceberg reports from all sources, including its own reconnaissance flights, commercial reconnaissance flights, and ships at sea and incorporates them into a computer database. An iceberg drift and deterioration model is then used to analyze and predict the movement and melt of the icebergs. Due to the large size of the Ice Patrol's operating area, some icebergs are seen only once. Model predictions are used to create iceberg warning products.

The results from the iceberg drift and deterioration model are used to compile bulletins that are issued once daily at

0000Z by radio communications. Bulletins are available over INMARSAT as a NAVAREA IV navigational warning. A bulletin and iceberg chart can also be found on the USCG Navigation Center webs portal via the link provided in Figure 3216.

Figure 3216. Products produced by the North American Ice Service (an international partnership between the International Ice Patrol, Canadian Ice Service and the National Ice Center) can be found via the following link: http://www.navcen.uscg.gov/?pageName=iipProducts

When icebergs are sighted outside the Iceberg Limit, **Notices to Shipping (NOTSHIP)** are issued by MCTS St. John's in between the regularly scheduled bulletins. Iceberg positions in the ice bulletins are updated for drift and deterioration at 12- hour intervals. A radio-facsimile chart is also broadcast once a day throughout the ice season.

A summary of broadcast times and frequencies can be found in Pub. 117, Radio Navigational Aids, and on the International Ice Patrol web site at: http://www.navcen.uscg.gov/?pageName=IIPHome.

Ice Patrol formed a partnership with the **Canadian Ice Service (CIS)** and the USNIC as the **North American Ice Service (NAIS)** with a goal to be the leading authority in ice information and services for the maritime interests of the Canadian and United States Governments in North America. IIP and CIS share a joint database of icebergs in the North Atlantic. Each organization produces the NAIS Iceberg Warning products at different times of the year. IIP is responsible for the products from January through September when icebergs typically threaten the transatlantic shipping lanes while CIS is responsible for the products during the remainder of the year when icebergs normally only threaten Canadian coastal waters. Both an English and a French version of the NAIS iceberg chart can be found on the CIS website at http://iceweb1.cis.ec.gc.ca/Prod/page2.xhtml?CanID=11091&lang=en&title=East+Coast.

3217. Ice Navigation in Canadian Waters

Ice Navigation in Canadian Waters is published by the Canadian Coast Guard and is intended to assist ships operating in ice in all Canadian waters, including the Arctic. This outstanding publication is available for free online through the link provided in Figure 3217 and provides vessels transiting Canadian ice-covered waters with the necessary understanding of the regulations, shipping support services, hazards and navigation techniques in ice.

Ice Navigation in Canadian Waters

Figure 3217 Ice Navigation in Canadian Waters. http://www.ccg-gcc.gc.ca/folios/00913/docs/ice-navigation-dans-les-galces-eng.pdf

3218. International Ice Information

The International Ice Charting Working Group (IICWG) was formed in October 1999 to promote cooperation between the world's ice centers on all matters concerning sea ice and icebergs. Members of this group are the world's experts in observing ice from satellites and aircraft, modeling ice, and preparing ice warning products for mariners to promote safe navigation. The group is dedicated to staying on top of emerging technologies in sea ice and iceberg detection by all means. Members share information on these technologies to benefit the ice services and mariners worldwide.

Contacting the ice services of the IICWG for accurate ice information will directly contribute to the protection of the marine environment by assisting with planning response efforts in the vicinity of the ice. The contact information, working hours, and internet addresses for each of the ice services, both in the Northern and Southern Hemispheres, are provided below.

International Ice Service Emergency Response Numbers

Argentina: http://www.hidro.gov.ar
Meteorology Department
Naval Hydrographic Service
Address: Av. Montes de Oca 2124 - Ciudad Autónoma de Buenos Aires. República Argentina. P.O. Box C1270AVB
Phone: (+54) 11 4317 2534 Spanish-speaking only

Hours: 24/7
E-mail: hydroshn@gov.ar

Australia: http://www.bom.gov.au/ant
Bureau of Meteorology Tasmania/Antarctica Region
Address: AACECRC Privatebag 80, HOBART Australia 7001
Phone: +61-3-62323642
Alternate Phone: +61-3-62323113
Hours: 24/7, Leave a message if no one answers, and response will be made within the hour
E-mail: season.ops@aad.gov.au, jan.lieser@acecrc.org.au
Neal.young@acecrc.org.au

Brazil:
https://www.mar.mil.br/dhn/chm/meteo/indexing.htm
Navy Hydrography Center-Marine Meteorological Service
Address: Rua Barão de Jaceguay, s/n Ponta da Armação Niterói, RJ CEP. 24048-900
Phone: (+55) 21 2189-3275
Hours: 0830L-1630L, Monday thru Friday
Best Contact Number: (+55) 21 893-270, Available 24/7
E-mail: meteorologia-oceanografia@chm.mar.mil.br

Canada: http://ice-glaces.ec.gc.ca
Canadian Ice Service - Environment Canada
Address: 373 Sussex Drive, Block E, Ottawa, Ontario, Canada K1A 0H3
Phone: +1-800-668-6767
Hours: 0830L-1630L
E-mail: cis-scg.client@ec.gc.ca / enviroinfo@ec.gc.ca

Chile: http://www.shoa.cl/index.html
Chilean Navy Weather Service
Address: Errazuriz Echaurren 254 Playa Ancha, Valparaiso, Chile
Phone: +61 220 1161, Punta Arenas Duty Number
Hours: 24/7
E-mail: meteomag@directemar.cl

China: http://english.nmefc.gov.cn
National Marine Environment Forecast Centre
Address: 8, Dahuisi Rd., Haidian District, Beijing, 100081
Phone: Phone not available.
Hours: 0800L-1700L
E-mail: webmaster@nmefc.gov.cn

Denmark:
http://www.dmi.dk/en/groenland/hav/ice-charts
Danmark Meteorologiske Institut
Address: Lyngbyvej 100, DK-2100 Copenhagen
Phone: +45 39 15 72 45
Hours: 0800L-1700L
E-mail: iskort@dmi.dk

Estonia: http://www.emhi.ee
Estonian Meteorological and Hydrological Institute (EMHI)
Address: Rävala 8,EE-0001 Tallin, Estonia
Phone: TBD
Hours: 0800L-1700L
E-mail: mere@emhi.ee

Finland: http://en.ilmatieteenlaitos.fi/ice-conditions
Finnish Meteorological Institute, Ice Service
Address: P.O. Box 503, FIN-00101 Helsinki, Finland
Phone: +358 29 539 3464
Hours: 0800L-1700L
E-mail: iceservices@fmi.fi

Germany:
http://www.bsh.de/en/Marine_data/Observations/Ice/index.jsp
BSH-Eisdienst
Address: Neptunallee 5, 18069 Rostock, Germany
Phone: +49 381-4563780
Emergency Phone: +49 381-4563781 (with voice mail and contact information for off-office hours)
Hours: 0800L-1700L
E-mail: ice@bsh.de

Greenland: http://www.dmi.dk/vejr
Danish Meteorological Institute (DMI)
Ice Patrol Narsarsuaq
Address: PO Box 505, 3923 Narsarsuaq, Greenland
Phone: + 299 66 52 44 24/7 Emergency Representative
Hours: 0800L-1600L Monday thru Friday; 24/7 # always available
E-mail: icepatrol@dmi.dk

Iceland: http://www.vedur.is
Icelandic Meteorological Office
Address: Bustadavegur 9, IS-150 Reykjavik
Phone: + 354 522 6000 ** English recording, Can press 5 to access 24/7 Emergency Representative
Hours: 0830L-1600L Monday thru Friday; 24/7 response available
E-Mail: fyrirspurnir(at)vedur.is

Japan: http://www.jma.go.jp/jma/indexe.html
Japan Meteorological Agency
Address: 1-3-4 Otemachi Chiyoda-ku,Tokyo, 100-8122,Japan
Phone: Not Available
Hours: 0800L-1700L
E-Mail: seaice@climar.kishou.go.jp

Latvia: http://www.meteo.lv
Latvian Environment, Geology and Meteorology Centre
Address: 165 Maskavas Str, LV1019, Riga, Latvia
Phone: +371 67 032 609
Hours: 0800L-1700L (outside working hours - forecaster

on duty)
E-Mail: marine@meteo.lv

Lithuania: http://www.meteo.lt/english
Lithuanian Hydrometeorological Service
Address: Rudnios str 6, 09300 Vilnus, Lietuva
Phone: +3706 252247 voicemail not monitored
Hours: 0800L-1700L
E-Mail: lhmet@meteo.lt

Netherlands:
http://www.infocentrum_binnenwateren.nl.ijskaart
Rijkswaterstaat/Riza Centre for Water Management
Information and Warning Centre
Address: Infocentrum Binnenwateren, Postbox 17, 8200 AA Lelystad
Phone: +31-320 298 888
Hours: 24/7
E-mail: infocentrum@riza.rws.nl

Norway: http://polarview.met.no/
MET Norway
Norwegian Ice Service
Address: Vevarslinga for Nord-Norge, Postboks 6314 Langnes, NO-9293 Tromsoe
Phone: +47 7762 1300
Hours: 24/7
Norwegian Coastal Administration: +47 33 034800 (pollution cases), 24/7
Search and Rescue Coordination Center: +47 51 517000 (SAR cases), 24/7
E-Mail: istjenesten@met.no

Poland:
http://www.baltyk.pogodynka.pl//index.php?page=2&sub-page=64
Instytut Meteorologii i Gospodarki Wodnej - PIB (IMGW-PIB) - Oddzial Morski
Ice Service
Address: Waszyngtona 42, PL 81-342 Gdynia
Phone: +48-58 62 88 146 (Ice Team)
Hours: 0730L-1500L, Monday-Friday
Fax: +48 58 620 16 41
Emergency: +48-58 62 88 151, 24/7
E-mail: hydrologia.gdynia@imgw.pl

Russian Federation: http://www.aari.ru
Arctic and Antarctic Research Institute (AARI)
Address: 38, Bering Str., St.Petersburg, Russia 199397
Phone: +7 812 337-3168 (hours: 0900-1900UTC+0300)
Phone: +7 921 865-4056 (hours: 1900-0900UTC+0300)
Fax: +7 812 337-3241 (24/7)
E-mail: sat_info@aari.ru, service@aari.ru

Sweden: www.smhi.se
Swedish Meteorological and Hydrological Institute (SMHI)
Ice Service
Address: S-601 76 Norrkoping
Phone: +46-11 495 8533 ** Recorded message in Swedish and English
Hours: 0800L-1600L
E-mail: ice@smhi.se

United Kingdom: http://www.metoffice.gov.uk
Meteorological Office
Address: FitzRoy Road, Exeter, Devon EX1 3PB, United Kingdom
Phone: +44 1392 885680
Hours: 0800L-1700L
E-mail: enquiries@metoffice.gov.uk

United States

U.S. National Ice Center: http://www.natice.noaa.gov
Address: 4251 Suitland Road, NSOF, Washington, DC 20395
Phone: +301-943-6977
Hours: 0730L-1600L, Duty Officer - 24/7
E-mail: nic.cdo@noaa.gov

International Ice Patrol: http://www.navcen.uscg.gov/iip
Address: 1 Chelsea St., New London, CT 06320
Phone: +1-860 271 2626, Operations Center (forwarded to Watch Cell after hours)
Watch Cell Phone: 1 860 235 8171
Hours: 0730-1600 EST (Minimum); Watch phone - 24/7
E-Mail: iipcomms@uscg.mil

U.S._National_Weather_Service:
http://pafc.arh.noaa.gov/ice.php
Ice Desk-NWS Anchorage
Address: 6930 Sand Lake Road, Anchorage, AK 99502
Phone: (907) 266-5138
Emergency: (907) 271-6540, press 0 after hours for emergency
Hours: 0630L-1530L
E-Mail: nws.ar.ice@noaa.gov