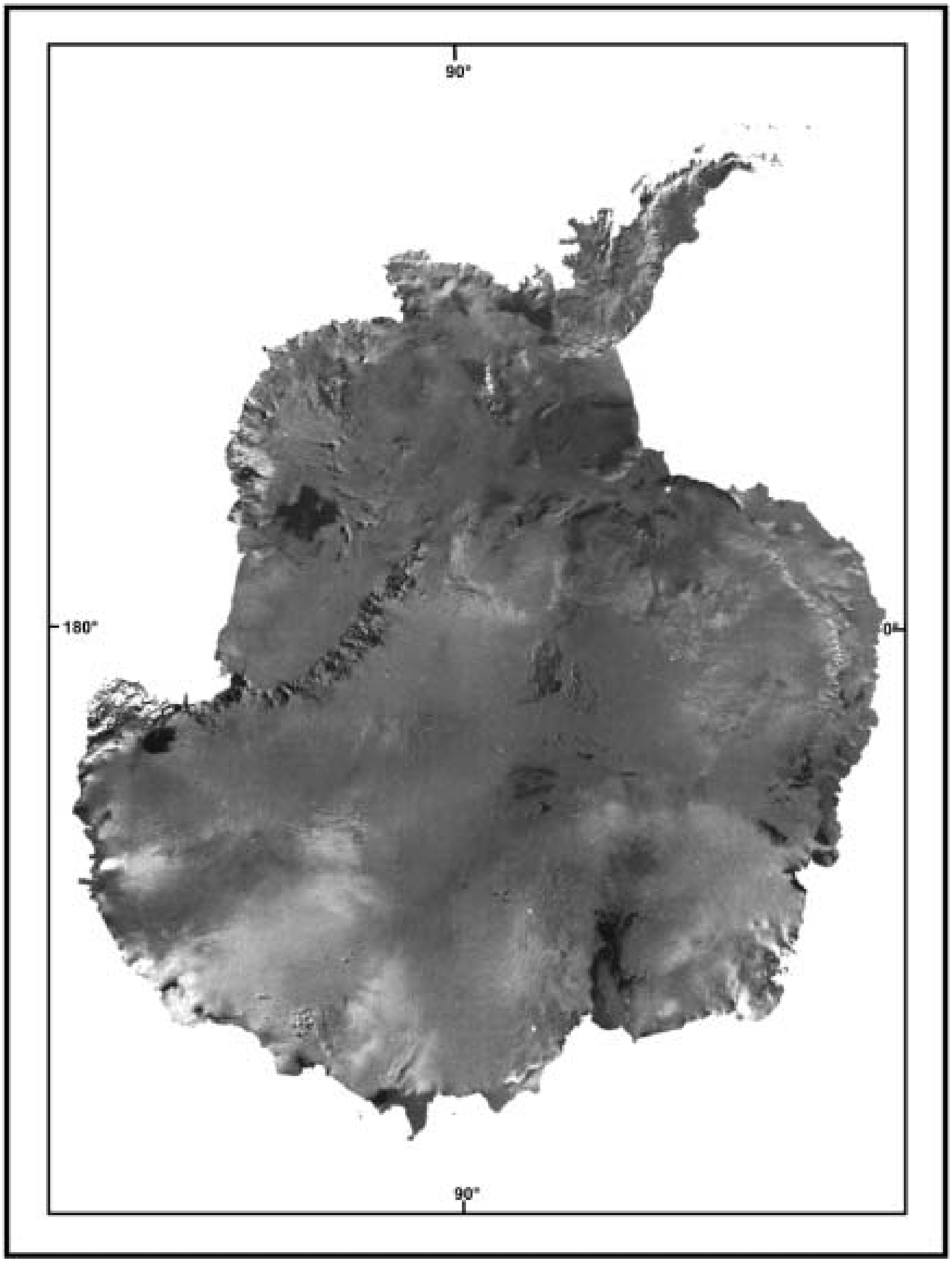
PART I

SATELLITE IMAGE MAP OF ANTARCTICA



Prepared by the United States Geological Survey in cooperation with the National Oceanic and Atmospheric Administration and the National Remote Sensing Center, England with support from the National Science Foundation.

Table of Contents

THE ANTARCTIC

General

The Antarctic is defined by the Antarctic Treaty as the area lying S of 60˚S. Antarctica is defined as the Antarctic continent and the off-lying islands within its general proximity. The area covered by this publication extends N from the shores of Antarctica to 60˚S, or approximately to the limits of the drift ice.

Pub. 200, Sailing Directions (Planning Guide and Enroute) Antarctica, unlike the series of publications which cover the world in separate Enroute and Planning Guide formats, is a combination of both volumes and contains in one publication information normally found in both of the above. This combination of volumes was initiated due to the rather unique aspect of the Antarctic continent.

Part I, Sailing Directions (Planning Guide) Antarctica includes information concerning physical geography, meteorology, exploration, treaties and legal agreements, regulations, history, and navigation.

Part II, Sailing Directions (Enroute) Antarctica is comprised of four sectors and includes basic coastal and navigational information.

Polar Regions.—Various criteria have been used to define the polar regions and many have been based upon meteorological considerations, mean temperatures, the length of the frost-free growing season, the amount of ice, or the tree line.

Astronomically, the limits of the Arctic Circle and the Antarctic Circle may be considered to lie at approximately 66˚30'N and S, respectively, or at the point where the sun becomes circumpolar (90˚ minus the maximum declination of the sun).

Below the S polar region, the transitional subpolar region is often defined as the winter limits of the drift ice (about 60˚S). However, this subpolar region is sometimes considered as extending another 10˚ of latitude and well into the stormy seas surrounding Antarctica.

Geographic Names.—The lack of international agreement on the use of geographic names is a world problem. However, the problem of geographic names in Antarctica differs from that of any other land mass of comparable size because this area has unresolved questions of sovereignty.

As a result of the Antarctic Treaty, there is now a degree of agreement to handle this problem. Although some duplication and substitution of names occurs, most participating countries have now established nomenclature committees responsible for names in this region.

All proposed new names, together with the supporting arguments for their recognition, are considered by national committees. Subsequently, these names are brought forth for international agreement and are ultimately proclaimed by the initiating country. Some geographic features have not achieved international agreement on nomenclature, and different names may be found on charts produced by different countries.

In the United States, a gazetteer, Geographic Names of the Antarctic-1995, has been published with approval by the United States Board on Geographic Names and the Secretary of the Interior. This gazetteer contains names for features in Antarctica and the area extending N to the Antarctic Convergence.

For the names of submarine features, reference should be made to Undersea Features-1990, which is also published by the U.S. Board on Geographic Names. These names have been approved for use by U.S. Government agencies.

Climatology

The following information concerning weather along the shipping routes was prepared by the National Environmental Satellite Data and Information Service, National Oceanic and Atmospheric Administration (NOAA).

Antarctic Climate.—The Antarctic is one of the coldest regions in the world with a recorded minimum temperature of -86.9˚C. The continental influence of Antarctica is enhanced by its size and altitude. Along with minimum sunlight and maximum radiational cooling, the continental influence produces extremely cold winters. These severe conditions are tempered on the coast and at sea by a vast expanse of relatively warm ocean surrounding the continent.

Most of the ice-free ocean area is located in a belt of strong, persistent W winds. The boundaries between the polar continental and polar maritime air masses (Antarctic front) and between the polar maritime and tropical maritime air masses (polar front) represent areas of frequent and intense storm activity throughout the year. Most of these storms form to the N of 70˚S and circle the continent from W to E. Lows forming along the polar front tend to move SE toward the continent. Some penetrate the interior, while others end up in the Ross Sea and the Weddell Sea, where they dissipate. Some tend to stagnate in the Bellingshausen Sea where the resultant NE winds provide a milder climate than on the E side of the Antarctic Peninsula.

The storms of this region resemble those of the N hemisphere except that the winds blow clockwise toward the center. The contrast in air mass temperatures and the uncomplicated land and sea distribution makes fronts and weather changes more distinct than in the N latitudes. This is especially true of cold fronts. In addition, the storm movement is more constant, more rapid, and less erratic than in the N. The average speed of these systems ranges from about 20 knots in summer to more than 30 knots in winter. The regularity of movement enables vessels proceeding E to remain in an area of good or bad weather if its speed matches the speed of these troughs and ridges (good weather). Vessels proceeding W usually encounter a series of disturbances. These storms have a tendency to occur every 3 to 5 days. The first indications of their approach is often a cirrus or altocumulus cloud deck observed some 100 to 200 miles away on the W horizon. Several hours later, the barometer begins to fall and mist gradually fills the air reducing visibility to a few miles. About 8 hours after the first cirrus, a stratus deck forms, becoming overcast within a few hours. The passage of the low is indicated by rising pressure and winds from a W quadrant.

In addition to the intense low pressure systems and their associated fronts, frequent cold frontal troughs occur which extend for hundreds of miles to the N and NW. The sudden and often violent changes occurring during the E passage of these troughs can create problems for vessels.

Summer (October-March).—Since nearly 85 per cent of the sea ice melts during the summer, navigation is much less restricted, particularly from December through March. However, the weather remains hazardous. During September and October when the ice cover reaches its N position and the temperature difference between the air masses is the greatest, storms are most frequent and intense. To the S of 60˚S, two to six storms per month are common. By the middle of summer this frequency is usually cut in half. The effects of these storms are greatest along the N portions of the routes.

Through the Drake Passage, where extratropical storm activity is frequent in early summer, gales are encountered up to 20 per cent of the time. The frequency slackens to 15 per cent and less by the middle of summer as storm activity decreases. The worst conditions are found on the W side of the passage where SW through NW winds blow at an average of about 20 knots throughout the season. These winds are responsible for wave heights of 3m or more, which are reported 20 to 35 per cent of the time even in the middle of summer. They are reported more than 50 per cent of the time during the rough October period. Under mostly cloudy skies visibility remains good except in precipitation, which occurs about 30 to 40 per cent of the time. Snow and frontal fogs can decrease visibility to less than 0.5 mile, but this is uncommon. Snow is most likely early in the season and to the S. Temperatures hover around freezing in these waters while near Cape Horn they range from about 4.4˚ to 8.9˚C; the warmest readings occur in January and February.

The routes that approach Antarctica from the Atlantic Ocean usually encounter the roughest conditions. Winds from SW through NW are responsible for the gales that blow 10 to 20 per cent of the time even in the middle of summer. Gale frequencies, in general, decrease with increasing latitude. Gales are most likely to occur to the N of 55˚S from around South Georgia Island and E into the W part of the Indian Ocean area. Near 60˚S, NE gales become common by the middle of summer.

Fog is most likely during the middle of summer when visibility decreases to less than 5 miles about 40 to 60 per cent of the time and less than 0.5 mile about 10 to 20 per cent of the time.

Precipitation as well as fog restricts visibility. Precipitation is most likely along the N portions of the routes where it is encountered about 30 to 40 per cent of the time. It falls as snow on about one-half of the precipitation observations. Snow is most likely to occur to the S of 60˚S where temperatures average about -2.2˚ to 0˚C.

Routes from the Indian Ocean usually face less hostile conditions than those in the Atlantic region. To the S of the Cape of Good Hope, gales blow 20 to 30 per cent of the time, as storm activity remains frequent, but to the E of 60˚E in the middle of summer, the frequency drops to 5 per cent or less. Winds from SW through NW are common everywhere near 60˚S. To the S, winds from E are frequent, but strong winds are not. Fog and precipitation decrease the visibility in summer to less than 5 miles about 40 per cent of the time. Along the 60th parallel, isolated areas exist where the visibility falls to below 0.5 mile up to 20 per cent of the time. Precipitation is encountered about 30 to 40 per cent of the time. Snow accounts for 15 to 20 per cent of the precipitation observations. This is reflected in the temperatures which drop below freezing at about 60˚S.

Winds from SW through NW also prevail when entering the adjacent waters from the Pacific where extratropical activity is at a minimum in summer. Gales are encountered about 5 to 10 per cent of the time. To the S of 60˚S, winds are lighter and more variable. The visibility decreases to less than 5 miles about 20 to 40 per cent of the time. Temperatures close N of the region, which range from 7.8˚ to 11.1˚C on the average, decrease to an average of 1.7˚C to the S of 60˚S. This is reflected in the snowfall frequency which accounts for about one-half of all observations at these higher latitudes. Precipitation is generally encountered about 30 to 40 per cent of the time.

Along circumpolar routes near 60˚S there is some climatic variation in conditions. While W winds predominate, these routes are close to the transition area and velocities are generally slower than those farther N. Winds from E are also present on occasion. Gales are encountered only about 5 per cent of the time. The frequency of the visibility being less than 5 miles ranges from 20 per cent on the Pacific Ocean side to 40 per cent elsewhere. The visibility decreases to less than 0.5 mile about 5 to 10 per cent of the time with some isolated 20 per cent occurrences existing to the N of Queen Maud Land during the middle of summer. Temperatures range from 5˚ to 7˚C on the Pacific side and from -2˚ to 0.5˚C on the Atlantic side. This accounts for the variation in snow frequency which ranges from one-half of all precipitation to the S of the Atlantic as compared to less than 10 per cent to the S of the Pacific. In general, precipitation occurs 30 to 40 per cent of the time along these routes.

Winter (April-September).—Most winter navigation is restricted to the seas around and N of 60˚S because of ice. Along the routes that circle the continent at about 55˚S, winds blow mainly out of the SW through NW. They are strongest early and late in the season when gales are encountered 20 to 30 per cent of the time in the Drake Passage and in the waters to the S of the Atlantic. Elsewhere along these routes, gales can be expected 10 to 20 per cent of the time. During the middle of winter, gales are less frequent, but may still be expected about 20 per cent of the time in the Drake Passage.

The visibility is usually good, except during precipitation. It is best along the portions of the routes to the S of the Pacific and Indian Oceans and worst to the S of the Atlantic Ocean and Drake Passage, off the Cape of Good Hope. In general, the visibility decreases to less than 5 miles about 20 to 40 per cent of the time. Sometimes fog or snow may reduce the visibility to less than 0.5 mile. This is most likely to the S of the Atlantic Ocean where the frequency is about 10 per cent.

On the average, temperatures are coldest and least variable in the middle of winter when they are near freezing everywhere along these routes except in the Pacific area where the average is a few degrees warmer. Early and late in the season, temperatures remain around freezing, or even a little below, to the S of the Atlantic. However, they are more likely to be a few degrees warmer elsewhere. This temperature spread is indicative of the snowfall distribution as well. In general, precipitation occurs about 40 to 50 per cent of the time along these routes with little seasonal variation. However, in the Drake Passage, the precipitation occurs as snow about one-quarter of the time. To the S of the Atlantic during the middle of winter and late season, snow occurs on about 30 per cent of all precipitation observations. To the S of the Indian and Pacific Oceans, this frequency decreases to about 10 per cent.

Antarctic Peninsula.—The rugged peninsula and the nearby islands project out into the adjacent waters, interrupting the general E flow around the continent and extending into the W winds of the lower latitudes. The climate benefits from the relatively warm waters that flow into the area for a good portion of the year. Its maritime nature is most apparent in summer when diurnal temperature variations are small, rain is prevalent, and winds are weakest. Weather producers include extratropical storms, from the oceans to the N, and cold continental outbreaks, from the S. Both are modified somewhat by local topography.

Storms, high pressure systems, and local topography produce variable, and often strong, winds throughout the region. Wind speeds are usually highest from June through October when averages range from 10 to 20 knots, depending upon exposure. Gales are most likely during this period. From November through May, wind speed averages range from 5 to 15 knots while gales blow on about 1 to 8 days per month. January and February are usually the quietest months.

Coastal and island locations are subject to foehn winds, which develop on the lee side of the mountains. Their descent causes a sharp increase in wind speed along with a drop in humidity and a rise in temperature. For example, the wind increased from calm to WSW at 44 knots at Hope Bay during an observation in July. The humidity dropped from 86 to 20 per cent and the temperature increased from -10˚ to 6.1˚C.

In the Bellingshausen Sea, dissipating storms generate a preponderance of NE winds over its E shores. However, a strongly curved arc of mountains protects this area from the gales that blow along the flank of the Graham Land range. Hence, the leeward side of the Antarctic Peninsula has a noticeably high percentage of calms and light winds. For example, calms are reported at Port Lockroy on about 20 per cent of the observations from February through August.

Along the Argentine Islands, winds are variable and gales are infrequent. In Marguerite Bay during the summer, winds from NW through N have been observed to blow for weeks at a time. These winds produce a densely packed area of drift ice off the W coast of Adelaide Island, which clogs the S part of the bay. At times, winds from the N and NE reach gale force in this bay.

In Crystal Sound, the predominant winds blow from the SW, but the effects of the central plateau and coastal topography cause strong E gales close to the coast in some areas. Lows often bring N gales, which cause a rise in temperature and heavy snow. Darbel Bay is affected by winds blowing down the glaciers, particularly in the SE corner. Lallemand Fjord forms a natural funnel to strong winds blowing off the plateau, which turn to the N when moving up the fjord. The S part of Hanusse Bay is influenced by winds funneling through The Gullet.

Among the South Shetland Islands and South Orkney Islands, winds are variable and often strong. Winds from E and W are both frequent as lows pass to the N and S of these islands. The stations at Admiralty Bay and Deception Island are sheltered from the worst effects of the high winds. At Deception Island, gales blow on an average of 35 days annually as compared to 60 days at Scotia Bay on Laurie Island. In the South Orkney Islands, winds are frequently from the NW and W. Winds from the SE and SW are also common. The stations on the South Shetland Islands have reported a slight preponderance of NE winds, but only SE and S winds are infrequent. Throughout the islands, winds are usually strongest from about July through October with average speeds ranging from 12 to 18 knots.

The visibility is often exceptional in this region, which is free of pollution and dust particles. Fog is reported less than 5 per cent of the time while the visibility is more likely to be reduced by rain, mist, drizzle, snow, blowing snow, and sea spray. On rare occasions, radiation fog forms in protected areas. This is usually composed of supercooled water droplets, but observations of ice fog have been reported at Marguerite Bay with temperatures below -31.7˚C. Occasionally steam fog or sea smoke, usually 15 to 30m thick, will form when very cold air off the continent blows out over warmer water.

Snowstorms and blowing snow can obscure the coast and adjacent waters. A 20-knot wind blowing over a recent dry snowfall can raise snow a few meters while a 40-knot gale can raise it as high as 15m and reduce the visibility to less than 100m.

In the South Shetland Islands, blowing snow is the major restriction to visibility. At Deception Island, poor visibility is reported on an average of 84 days annually as compared to Scotia Bay, in the South Orkney Islands, where 41 days are reported. The visibility is worst in winter throughout these islands.

The annual average number of days with fog or reduced visibility ranges from less than 20 in the Argentine Islands to more than 100 at Hope Bay. Winter is the worst period when 5 to 10 fog days per month occur on the average. December, January, and February are generally the months with the best visibility.

Most precipitation in this region falls as snow or other frozen forms. Rain frequency generally increases with decreasing latitude. Frequent precipitation does not necessarily coincide with large amounts, as much of it falls as light, dry, powdery snow. Blowing and drifting snow make measurements difficult while the topography and ice shelves complicate precipitation patterns. Another form of precipitation observed on the Antarctic Peninsula is rime or hoarfrost from supercooled fogs. Rime deposits on the windward sides of obstructions may build up to a thicknesses of a few meters.

Precipitation is usually generated by the frequent extratropical storms and their associated fronts. Many of these systems, moving E from W of Cape Horn, are channeled through the Drake Passage and deflected S across the Antarctic Peninsula and into the Weddell Sea.

Precipitation is frequent throughout the year along the Antarctic Peninsula and over the islands. In the Bellingshausen Sea, it is observed on about 15 to 25 days per month on the average. September through October and March through April seem to be the peak periods along the coasts. Snow is usually most frequent, but rain reaches a peak during the latter period. From December through April, rain occurs on up to 12 days per month over the off-lying islands. At Signy Island during March, rain falls on an average of 12 days while snow occurs on 16.

Gray overcast conditions blanket the area for days at a time. Dense masses of frontal clouds can cover large areas of the open sea, restricting daylight and reducing visibility. Near Deception Island, cloudy conditions prevail on an average of 240 days annually while clear days are only observed about 4 times per year at some island locations. Near the coast, the onset of offshore winds sometimes improves conditions. The least cloudy conditions generally occur from May through September. In coastal waters on both sides of the peninsula, clear skies are estimated to occur about 10 per cent of the time. Summer is usually the cloudiest period in many locations, but local variations occur. For example, on Stonington Island, in Marguerite Bay, the least cloudy months of December and January coincide with the period of least frequent precipitation. In the South Orkney Islands, the cloudiest period is from October through April.

While an extreme of -89.6˚C was recorded in the interior at Vostok (78˚27'S., 106˚52'E.), temperatures along the coast are much warmer. On the peninsula, extremes range from -26.1˚ to 45.5˚C. Extreme maximums range from 7˚C near the base of the peninsula to 15.5˚C in the South Shetland Islands. The extent of the cold continental air reaches a minimum in February when the warmer maritime air advances beyond the latitude of the South Orkney Islands.

In general, temperatures are warmer on the W side of the peninsula than on the Weddell Sea side. The distribution of ice and water may also account for temperature differences between nearby locations. For example, Port Lockroy is usually 1.7˚ to 3.3˚C warmer than the Argentine Islands, which are only about 40 miles distant. Diurnal temperature changes are smallest in summer (2.8˚ to 5.6˚C) due to the small change in the angle of elevation of the sun between day and night. However, day to day differences are large. Changes of 11.1˚ to 16.7˚C can occur in a few hours by a change in the air mass. In Graham Land, high temperatures are often associated with foehn winds. At Hope Bay, maritime air crossing the mountains may reach a temperature of 10˚C, even in winter.

Maximum temperatures climb above freezing consistently from November through March. January and February are usually the warmest months when average maximums are about 2˚C and minimums range from -2.2˚ to -1.1˚C. Latitudinal influences are small in summer in this region. The coldest temperatures usually occur in July when maximums average -7.8˚ to -5.3˚C and minimums range from -17.8˚ to -9.4˚C.

The average relative humidity across this region ranges from 78 to 85 per cent with a small daily change. The annual range is also small, but lowest values usually occur on summer afternoons. Although humidities are high, the relatively low temperatures mean that absolute moisture is small. When a foehn wind blows, humidities can drop below 30 per cent, particularly on the islands. Highest readings occur when relatively warm air from the N flows across the colder water.

Areas of fog may occur when the saturation point is reached. The highest recorded readings in this region occur in the islands. At Scotia Bay, in the South Orkney Islands, the average relative humidity ranges from 86 per cent in January to 92 per cent during June and August.

East Antarctica.—The circumpolar trough that flanks this region throughout the year reflects the large number of storms that affect the area. Winds are mostly from the E quadrant while gales are frequently generated by the storms and interior winds. Precipitation, under mostly cloudy skies, is usually snow as temperatures do not often climb above freezing.

The prevailing winds blow from NE to SE throughout the year, although S winds are also somewhat common. In general, winds are strongest in winter, blowing from the prevailing directions at averages of 20 to 35 knots at many locations. At Sanae in May, NE winds average a speed of 39 knots. In summer, the averages decrease to 10 to 25 knots. Gales blow on about 100 days annually and are most likely from March through September. In many locations, katabatic or drainage winds boost the averages. Novolazarevskaya, Roi Baudouin, Mawson, and Mirnyy are particularly susceptible along this coast. The winds usually extend out only into the near coastal waters and are local. For example, at Gauss, winds are lighter and gales much less frequent than at nearby Mirnyy Station. Mawson is exposed to SE winds which blow, at an average of 20 to 25 knots, for 60 to 85 per cent of the time all year-round, and 80 to 85 per cent from February through May and again from August through September.

Maximum wind gusts throughout the year range from 80 to 120 knots and usually blow from the SE or ESE. By contrast, the second most common wind conditions are calms which occur 5 to 15 per cent of the time at Mawson. Sanae also has a relatively high percentage of calms. Strong wind gusts are common throughout the region and many locations have recorded speeds of 100 knots or more. While they can occur in any season, strong gusts are most likely from April through October. Snow prevails and is recorded on 150 to 200 days annually along these coasts. Precipitation amounts are often not reported because of the difficulty in obtaining accurate measurements. At the few stations where records are available, the averages range from 150 to 630m annually. At Novolazarevskaya, the peak period for snow is from July through October. Mirnyy Station records about 600mm of precipitation each year with 50 to 100mm of snow per month from May through September.

The coast is usually less cloudy than the open sea. Sheltered locations on the lee side of high ground often have frequent periods of broken clouds. May through September is usually the least cloudy period. Showa, one of the few locations measuring clear days, records 69 days annually when skies are clear. This reaches a peak during the period from May through September when 6 to 8 clear days per month occur on the average. Summer is usually the cloudiest time.

Good visibility prevails and exceptional visibility is common. Coastal stations are usually not affected by sea fog or radiation fog and most report true fog less than 2 per cent of the time. At Sanae, fog or poor visibility has been reported on 25 days annually. Snow, rain, and drizzle are common restrictions and can cause the visibility to decrease below fog limits. Strong winds can reduce visibility with sea spray on the water and blowing snow along the coast. This blowing snow can obscure both the coastline and adjacent waters.

In general, fog is most likely in summer when relatively warm air is cooled by the water or ice. In coastal waters, the visibility can decrease to less than 0.5 mile on up to 10 days per month. In winter, the visibility is more wind and precipitation related. At Halley Bay, blowing snow has been recorded on average on 188 days annually and on 16 to 19 days per month from March through November.

Along this coast there is a temperature swing of about -1.1˚C from winter to summer. Maximums in the middle of summer average 0˚ to 1.7˚C with the minimums being 4.4˚ to 8.3˚C colder. Extreme maximum temperatures may reach up to 5˚C. Temperatures generally decrease rapidly as the sun moves to the N. By April, the maximum temperatures average less than -6.7˚C. July, August, and September are the coldest months. Average maximums range from -16.1˚ to -13.9˚C at lower elevations to -25˚C at Halley Bay (30m above Mean Sea Level) in August. Minimums usually decrease to -17.8˚C. Extreme minimums range from -34.4˚ to -51.1˚C.

The average relative humidity along this coast ranges from 55 to 85 per cent. The determining factors seem to be exposure to winds off the water and temperature. Foehn winds can drop the humidity to less than 30 per cent. The highest humidity often occurs in winter, when temperatures are lowest, although the moisture content of the air may be very small.

West Antarctica.—Storms in this area are frequent and often move past Cape Adare into the Ross Sea. The area extending from the Adelie Coast to George V Land is known as the windiest region in the world and the "home of the blizzards." Stormy conditions are almost continuous for 9 months of the year and frequently reach hurricane force. Cyclogenesis is pronounced W of the Ross Sea where frequent outbreaks of cold continental air steepen the horizontal temperature gradients. The resulting differences between cold, dry, continental air and relatively warm, moist, maritime air are also pronounced in the Ross Sea with its sharply indented coastline. These differences, and therefore cyclonic activity, are most pronounced during September and October.

In this region, particularly around the Ross Sea, the frequency of extratropical cyclones and continental air mass outbreaks increases the frequencies of winds from W to S. At Little America, winds are mostly from the E, except from July through September when S and SW winds are more common. At Cape Hallett, S winds are frequent all year-round while SW winds are common from April through August. Winds from SE and S make up most of the observations at Cape Denison while E winds prevail at Oasis.

The extreme wind speeds experienced along these coasts are the result of extratropical cyclones and local katabatic winds off the interior highlands and ice plateaus. However, these winds seldom extend more than 3 miles to seaward.

In Commonwealth Bay, violent SE gales are common. Along the coast between the Adelie Coast and George V Land, strong land winds can develop at night even in the relatively quiet summer season. At Cape Denison, the annual average wind speed is 38 knots and this is probably the windiest region in the world. The average wind speed for July is 47 knots with gales blowing on 29 days on the average. For the year, gales occur on an average of 284 days and blizzards are almost continuous for 9 months.

Other locations are less windy and some are well sheltered from strong winds. At Cape Hallett, when strong winds aren't blowing from the S, there is a good chance that conditions are calm. Extreme winds at most locations approach or exceed 100 knots. At Wilkes, a maximum gust of 120 knots was reported blowing from the ESE during October.

Reduced visibility is often associated with storms. In the frontal zone, precipitation may be accompanied by fog while blowing snow is often a problem in coastal waters. In this region the winds are the rule rather than the exception. At Dumont d'Urville, near Cape Denison, 132 days annually are reported with blowing snow and 346 days with wind speeds of 28 knots or more. This station records 30 days per year with fog as compared to 50 days at McMurdo. The fog is most likely to occur from April through October. At Little America, the visibility decreases to less than 0.5 mile on 40 days per year.

Most of the precipitation in this region falls as snow. Although a large number of snow days are recorded each year, in many places, amounts are not large since many snows are light. At Oasis, 200mm of precipitation was recorded as compared to 300mm at Wilkes, where snow falls on an average of 104 days annually. At Cape Hallett, snow, measuring about 200mm, falls on an average of 181 days annually, with the maximum occurring during February and March. Mist is observed sometimes during the summer months.

Cloud amounts are often difficult to assess due to persistent blowing snow. Cumulus clouds are uncommon, but cirrus is widespread and forms at lower levels than in temperate regions. While extratropical storms and their associated fronts bring an abundance of cloudiness to this region, the downslope flow from the interior often dissipates clouds and this is reflected in cloud cover minimums over the Ross Ice Shelf and on the Wilkes Land coast. Cloudiness reaches a seasonal minimum in winter when the long nights and expansion of the ice field further intensify the polar anticyclones. At Little America, clear skies have been reported on as many as 17 days in July. Minimum cloud coverage usually occurs from May through September and a maximum occurs in summer.

Along these coasts, the average maximum temperatures range from above freezing in summer to -12.2˚C and less in winter. Minimums are usually 2.8˚ to 5.6˚C cooler in summer and 5.6˚ to 11.1˚C cooler in winter. As a result of foehn winds descending from the interior, extreme high temperatures have reached from 4.4˚ to 10˚C. These are most likely to occur in January although they have occurred in November and December at some locations. The coldest temperatures are recorded from July through September and range from -34.4˚ to -51.1˚C.

Diurnal temperature variations are similar to those in temperate latitudes except in winter. When the sun is continuously below the horizon (May, June, and July), the temperatures remain above the daily average from 0900 to 1900, but they fall below during the remaining hours.

During December and January, the average maximum temperatures range from -1.1˚C at McMurdo to 4.4˚C at Oasis. The minimums average below freezing everywhere. By March, temperatures everywhere usually remain below freezing even during the day. The coldest temperatures occur from June through August when average maximums range from -12.2˚ to -23.3˚C and average minimums range from -17.8˚ to -34.4˚C. The warmest region is along the S coast of Wilkes Land while the coldest is along the Ross Sea shore.

Because of the pronounced continental influence and the extensive ice fields, the relative humidity is low along these coasts and ranges from 45 to 85 per cent on average. The higher readings are often due to the low temperatures and not any large moisture content. The highest readings occur at Cape Denison from March through May when averages range from 80 to 87 per cent. This is due to a combination of minimum ice cover and falling temperatures. At Oasis, with its frequent land winds and relatively warm temperatures, the usual humidity in summer is about 45 per cent.

Geophysical Features

Physical Geography.—Antarctica is a geographically isolated land mass centered approximately at the South Pole and surrounded by water. South America, the nearest continent to Antarctica, lies about 380 miles away. The land area of Antarctica is approximately 5.4 million square miles, or slightly larger than the size of the continental United States and Mexico. The continental shelves of Antarctica, although relatively narrow, have an area of about 1.5 million square miles.

The weather conditions of Antarctica are extremely cold and harsh, and about 98 per cent of this continent is permanently covered with an ice sheet that averages 2,000m in thickness. Only areas along the coast, the Transantarctic Mountains, and the Ellsworth Mountains have extensive snow and ice-free areas.

East Antarctica (Greater Antarctica), the area lying between approximately 30˚ W and 165˚ E, is characterized by a vast dome-shaped cover of ice that is generally over 3,000m thick and locally exceeds 4,000m in thickness. Beneath the ice sheet in East Antarctica, the bedrock surface is made up of large lowland plains bounded by several large interior and coastal mountainous regions. The Transantarctic Mountains separate East Antarctica from West Antarctica, and extend from the Oates Coast to Coats Land. They range in elevation from 2,000 to 4,530m.

West Antarctica (Lesser Antarctica) includes Marie Byrd Land, Ellsworth Land, and the Antarctic Peninsula. This area would be a mountainous island archipelago if the ice cover were removed. The mountains of the Antarctic Peninsula are considered to be a continuation of the South American Andes to which they are linked by a sub-marine arc, the Scotia Ridge, that curves out to enclose the Scotia Sea. The South Orkney Islands, the South Sandwich Islands, and South Georgia are but above-water peaks of this undersea chain.

Vinson Massif, the highest peak, attains a height of 5,140m and rises in the Ellsworth Mountains.

Two great indentations in the continent, the Ross Sea and the Weddell Sea, reduce Antarctica to its narrowest width of about 1,200 miles.

East Antarctica (Greater Antarctica) is twice as large as West Antarctica (Lesser Antarctica) and geologically much older,

Return to page: 18 52

having been inactive since Precambrian time. This area is what geologists call a "shield," a term used to describe a very old and stable part of the earth's crust. It is similar to the continental shields of Africa, Australia, and Canada. In East Antarctica, the shield forms a high plateau which on average is one of the world's highest continents. If the ice were removed from this area, much of the under-lying land would remain above sea level.

The base of East Antarctica is composed of high-grade metamorphic and intrusive igneous rocks such as basalts. Flat-lying sedimentary and volcanic rocks, such as sand and siltstones, overlie the base. These strata are exposed extensively in the Transantarctic Mountains but rarely in other sections of this area.

West Antarctica (Lesser Antarctica) is geologically very different. This area is composed of a series of mountain ranges whose rocks are much younger, but its geologic structure is less well known. The base is believed to be of Paleozoic age and mostly composed of igneous intrusives and metamorphic rocks. Strongly folded and metamorphosed sedimentary and volcanic sequences of Paleozoic and Mesozoic age mantle this base level.

The relatively few lakes that are located in Antarctica have few associated streams. These lakes rarely receive sediments and are rarely thermally stratified in the summer. Most of the lakes are highly saline and have low species diversity. They may or may not be permanently covered by ice.

Ice-free oases, or "dry valleys," occur in some portions of East Antarctica. They are the result of evaporation and sublimation of water and ice, and the restricted flow of glaciers into the valleys. The soils, ponds, or lakes within the valleys are usually saline because there is no external drainage. The best known dry valleys are those located in the S part of Victoria Land and the Bunger Oasis region.

Permafrost.—Knowledge of the permafrost conditions in Antarctica is limited. Dry permafrost, a condition in which the soil or rock contains no ice or contains very little ice, prevails over most of the continent, but ice-rich permafrost has been identified at some locations. When dry permafrost materials thaw, there is little or no reduction in volume and consequently no expansion upon refreezing. However, the melting of ice-rich permafrost produces large volumes of water. This almost spontaneous liquefaction can cause the mass movement of sediment and water even on slight inclines. The base of the permafrost in the McMurdo-Dry Valley area is irregular, ranging from 440 to 550m in depth at McMurdo Station to 970m near Lake Vanda. This irregularity is explained by steep geothermal gradients, the high salinity of groundwater, and possible solar heating beneath the lake ice. Ice-rich permafrost is more prevalent in the Antarctic Peninsula, especially in depressions and on slopes facing S.

Volcanism.—Evidence of volcanic activity (past and present) has been found along the Transantarctic Mountains between McMurdo Sound and Cape Adare, and in the Queen Maud Range. It has also been found in Marie Byrd Land, the Antarctic Peninsula, and the South Shetland Islands.

The largest volcano, Mount Erebus, rises on Ross Island and attains a height of 3,743m. The crater of this volcano consists of a pool of molten lava.

Fumarole activity (a hole or vent from which vapors rise) has been reported at Mount Erebus; at Mount Terror, on Ross Island; at Mount Morning, which rises 140 kilometers SW of Mt. Erebus; on Deception Island, in the South Shetland Islands; and on Thule Island, in the South Sandwich Islands.

Seismic studies were conducted in the McMurdo Sound and Mount Erebus areas and the data collected showed that one small earthquake occurred every two days. Other tectonically active areas are the Antarctic Peninsula, with its surrounding islands, and the Scotia Arc region. Prominent tectonic features include active volcanoes in the South Sandwich Islands and South Shetland Islands.

Extensive seismic studies are needed to determine the stability of the entire continent. However, it can be reasonably assumed that East Antarctica is a more stable area in comparison to West Antarctica.

Terrestrial Biota.—The terrestrial ecosystems of the Antarctic are simple and lack diversity because they exist under extreme conditions for life support. In addition, in many cases, they represent the early stages of colonization following deglaciation. Even so, interrelationships between organisms are poorly understood. Due to energy pathways or food webs being simple, the ecosystems are vulnerable to disruption and are slow in recovering from disturbances.

The ecosystems of Antarctica comprise mainly non-vascular plants and small invertebrates. The vegetation on the continent consists mostly of scattered patches of crptogams such as mosses, lichens, algae, and fungi. The invertebrates include bacteria, protozoa, and certain arthropods such as springtails and mites.

The maritime areas of the continent have less snow, higher temperatures, and more precipitation. Therefore, these areas have additional developed vegetation such as ferns, fruiticose, crustose lichens, and some flowering plants. Invertebrates and other low life forms are more abundant and small wingless insects, annelids, spiders, and molds exist. (See Regulations—Special Protective Areas on page 66.)

Ice Sheet.—The enormous ice sheet that covers Antarctica accounts for about 65 to 70 per cent of the world's freshwater. The average thickness of this ice sheet is approximately 2,000m, but it attains a thickness of over 4,500m in places.

From the high elevations in the interior, the ice slowly flows outward to the edge of the continent. At the coast, the flows combine to form ice shelves in many places. These ice shelves comprise more than 10 per cent of the area of Antarctica. The largest are the Ross (700,000 square kilometers), Filchner, Ronne, and Amery ice shelves. An ice shelf may range in thickness from 200 to 600m and may be either floating or grounded.

Icebergs.—Eventually, as the ice shelves grow, icebergs calve off the leading edges and move N into the adjacent waters. These icebergs can be of enormous size, some measuring larger than 60 kilometers by 100 kilometers horizontally. They can also rise up to 100m above sea level and extend up to 400m below sea level, causing deep scouring of the continental shelf.

In 1987, it was reported that a massive iceberg (Designated B9) was calved from the Ross Ice Shelf. This berg was the largest piece of floating ice on record, being approximately 208 km long, 53 km wide, and 250m thick. (Three times the size of Long Island, NY.)

The icebergs move in a N direction in response to the ocean currents and can generally be found as far N as 45˚S in the Pacific Ocean and 35˚S in the Atlantic and Indian Oceans.

The ice cap of Antarctica represents a potential resource to those areas of the world deficient in freshwater resources. The annual yield of icebergs that break off the ice cap is approximately 1,000 cubic kilometers. If 10 per cent of this annual iceberg production could be transported economically, the water demands of an urban population of 500 million could be satisfied. (See Ice—Icebergs on page 17.)

Sea Ice.—Whereas icebergs calve off the front of ice shelves, sea ice (drift ice) forms from the freezing of seawater and covers enormous areas around Antarctica, with significant physical and biological implications. The area of the sea ice varies several fold between the summer and the winter. In March, sea ice covers approximately 3 million square kilometers; in August or September, it covers approximately 20 million square kilometers, hence, in effect, doubling the ice area of Antarctica. In winter, this ice cover completely encloses Antarctica and can extend as far N as 55˚S. Individual ice floes extend 10 to 100m across and can be about 3m thick, but most of the drift ice is "first-year ice," which averages 1.5m in thickness. As the summer progresses, the ice moves N and melts. Consequently, open water can be found in coastal areas while a zone of drift ice occurs farther offshore. Sea ice moves in response to the winds and can travel up to 65 kilometers in a day.

The widely varying extent of the ice is believed to have an important influence on worldwide climatic conditions. However, the relationship is complex and only partially understood. Two factors that play a role are the thermal insulating properties of ice and its high albedo. Sea ice acts as a thermal insulator that restricts the exchange of heat between the atmosphere and the ocean. Because of its high albedo relative to water, it affects the amount of radiant energy that is absorbed regionally. These properties along with the wide seasonal fluctuations in the extent of the sea ice cover will affect the heat transfer in Antarctica and, hence, the global climate.

The sea ice provides habitat for many seals and penguins. While these animals feed on organisms in the ocean, the sea ice offers a refuge from predators. Therefore, these animals are frequently found at the edge of the sea ice near open water. (See Ice—Sea Ice on page 18.)

History of Exploration

History.—The concept of a southern continent intrigued even the ancient Greeks, who believed that such a continent was needed to balance the land masses of the North Hemisphere. In 1772-1775, Captain James Cook circumnavigated Antarctica, but saw no continent. However, the 1800s brought many adventurers to this region.

The first person to sight the continent, as reported by the Americans, was Nathaniel Palmer in November, 1820; Captain Edward Bransfield, as reported by the English, in January, 1820; and Captain Fabian Von Bellingshausen, as reported by the Russians, 1820-1821. Between the years of 1838 and 1843, three expeditions, led by d'Urville, Wilkes, and Ross, were made to Antarctica in order to find the S magnetic pole. Although the goal of these expeditions was not realized, other significant scientific contributions were made. A number of "firsts" in the history of the continent include achievements by Bull, Gerlache, Borchgrevink, Bruce, Mawson, and Amundsen. Subsequently, scientific research programs began in the early 1900s and have continued to the present.

Early geologic exploration of Antarctica began in the late 19th century with the collection of rock fragments from the sea bottom. Extensive programs were carried out by teams of scientists who accompanied voyages to Antarctica from the 1890s to the 1920s. Progress was made in mapping and in understanding Antarctica's geology, glaciology, and geography. After World War I, advances in transportation and communications allowed even greater exploration.

The International Geophysical Year (IGY) conducted in 1957-58 was the beginning of Antarctica's role as an international science laboratory. Base stations were maintained by twelve countries during this period. New data was obtained on meteorology, upper atmosphere physics, geomagnetism, seismology, glaciology, and geography.

EXPLORATION AND RESEARCH HISTORY OF THE ANTARCTIC CONTINENT

Expedition	Expedition	Remarks
James Cook	1772-1775	Circumnavigated Antarctica but did not sight the continent.
Fabian von Bellingshausen	1820	Circumnavigated Antarctica but did not sight the continent.
Nathaniel Palmer	1820-1831	Discovered the Antarctic Peninsula in 1820.
Edward Bransfield	1820	Discovered the Antarctic Peninsula (According to British reports).
James Weddell	1822-1824	Discovered the Weddell Sea in 1823.
James Clark Ross	1839-1843	Discovered the Ross Sea and the Ross Ice Shelf.
Charles Wilkes	1838-1842	Discovered Wilkes Land.
Dumont d'Urville	1837-1840	Discovered the Adelie Coast

EXPLORATION AND RESEARCH HISTORY OF THE ANTARCTIC CONTINENT

Expedition	Expedition	Remarks
Adrien de Gerlache	1897-1899	First to winter aboard ship in the area.
C. E. Borchgrevink	1898-1900	First to winter on the continent.
William S. Bruce	1902-1904	First to set up a permanent station in the region.
Douglas Mawson, T. David, and A. Mackay	1911-1914	First to reach the South Magnetic Pole.
Roald Amundsen	December 14, 1911	First to reach the geographic South Pole.
Robert Scott	1901-1913	Various expeditions. Reached the geographic South Pole on January 17, 1912, but perished in blizzard with four others on return journey.
Ernest Shackleton	1907-1922	Various expeditions.
United Kingdom	1923-1939	First continuing scientific research program.
Hubert Wilkins	1928	First flight across the Antarctic Peninsula.
Richard E. Byrd	1828-1941	Various expeditions. First to fly over the geographic South Pole in 1929.
Lincoln Ellsworth	1933-1939	Demonstrated feasibility of aircraft landings and takeoffs.
United States	1946-1947	Operation Highjump. The largest expedition in Antarctica.
United States	1947-1948	Operation Windmill.
International effort— • Argentina • Australia • Belgium • Chile • France • Japan • New Zealand • Norway • Russia • South Africa • United Kingdom • United States	1957-1958	International Geophysical Year (IGY). First major international scientific effort.

The record of investigations begins in the 1830s with observations made by James Eights and the Charles Wilkes expedition. Robert Cushman Murphy made important contributions concerning subantarctic birds and terrestrial flora and fauna in the early 1900s.

Between 1920 and 1955, four expedition teams from the United States developed a sizable data base on Antarctic terrestrial features, including that of the interior. The Second Byrd Antarctic Expedition (1935-37) explored the inland mountains and nunataks, and made extensive discoveries. The United States Service Expedition of 1939-1941 investigated the natural resources of Antarctica; studied botany, zoology, and oceanography; and made physiological observations of expeditionary personnel. Two United States Navy projects, "Operation Highjump" (1946-1947) and "Operation Windmill" (1947-1948), made extensive observations on the Antarctic.

In the late 1950s, the United States established a permanent expedition, the United States Antarctic Research Program (USARP).

In 1968, the first drill hole to penetrate rock through the ice, which was 2,164m thick, was made at Byrd Station (elevation 1,530m).

ANTARCTIC RESEARCH STATIONS

Country	Station	Location	Comments
Argentina	Orcadas (LOK)	Laurie Island.	Permanently manned.
	Esperanza (LTS)	Trinity Peninsula	Permanently manned.
	Vice Comodoro Marambio (LUU)	Seymour Island	Permanently manned. Landing strips.

ANTARCTIC RESEARCH STATIONS

Country	Station	Location	Comments
Argentina	General Belgrano II (LTS4)	Coats Land	Permanently manned.
	General San Martin (LTS2)	Debenham Island	Permanently manned.
	Jubany (J25)	King George Island	Permanently manned.
	Almirante Brown (LOY)	Danco Coast	Summer occupation only.
	Primavera (LTR88)	Danco Coast	Summer occupation only.
	Teniente Camara	South Shetland Islands	Temporary occupations.
	Decepcion	Deception Island	Temporary occupations.
	Melchior	Palmer Archipelago	Temporary occupations.
	General Belgrano (LTA)	Filchner Ice Shelf	Temporary occupations.
	Teniente Matienzo (LUM)	East Coast-Graham Land	Temporary occupations. Landing strips.
	Alferez de Navio Sobral	Filchner Ice Shelf	Temporary occupations.
	Petrel	Joinville Island Group	Temporary occupations. Landing strips.
Australia	Macquarie	Macquarie Island	Permanently manned.
	Mawson	MacRobertson Land	Permanently manned. Landing strips.
	Davis	Ingrid Christensen Coast	Permanently manned. Winter landings on sea ice.
	Casey	Budd Coast. Wilkes Land	Permanently manned. Landing strips.
	Heard Island	Atlas Cove	Summer only occupation.
	Law Base	Larsemann Hills	Summer only occupation.
	Law Dome	110 km from Casey	Summer only occupation.
Brazil	Commandante Ferraz (ZXOECF)	Keller Peninsula	Permanently manned.
Bulgaria	Ochridski	Livingston Island.	Periodically manned.
Chile	Capitan Prat (CCZ)	South Shetland Islands	Permanently manned.
	General Bernardo O'Higgins (CATU2)	Trinity Peninsula	Permanently manned. Landing strips.
	Julio Escudero	South Shetland Islands	Permanently manned. Landing strips.
	Eduardo Frei Montalva	King George Island	Permannetly manned. Landing strips.
	Teniente Luis Carvajal	Adelaide Island	Summer occupation only. Landing strips.
	Presidente Gonzalez Vidiez	Danco Coast	Summer occupation only.
	Yelcho	Palmer Archipelago	Summer occupation only.
	Ripamonti	King George Island	Summer occupation only.
	Risopatron	Robert Island	Summer occupation only.
China	Great Wall	South Shetland Islands	Permanently manned.
	Zhongshan	69˚22'S, 76˚23'E	Permanently manned.
Ecuador	Vicente	Antarctic peninsula	Occassionally manned.
Finland	Aboa	Dronning Maud Land	Summer occupation only.
France	Alfred Faure		Permanently manned.
	Port aux Francais	Iles Kerguelen	Permanently manned.
	Dumont d'Urville	Terre Adelie	Permanently manned. Landing strips.

ANTARCTIC RESEARCH STATIONS

Country	Station	Location	Comments
France	Martin-de-Vivies		Permanently manned.
	Dome C (Concordia)	Antarctic plateau	Summer use only.
Germany	Dallmann	King George Island	Summer station only.
	Georg von Neumayer (DLA21) (DB9020)	Eckstrom Ice Shelf	Permanently manned. Landing strips.
	Kohnen	Dronning Maud Land	Summer use only. Landing strips.
India	Maitri	70˚45'S, 11˚44'E	Permanently manned. Helipad.
Italy	Baia Terra Nova	Victoria Land	Summer use only. Landing strips.
	Dome C (Concordia)	Antarctic plateau	Summer use only.
Japan	Syowa (JGX)	East Ongul Island	Permanently manned. Landing strips.
	Miznho	East Antarctica	Summer occupation only.
	Asuka (JGY)	Queen Maud Land	Summer occupation only.
	Dome Fuji	Valkyrjedomen peak	Summer occupation only.
Korea	King Sejong (6NA20)	King George Island	Permanently manned.
New Zealand	Scott (ZLQ)	McMurdo Sound	Permanently manned. Landing strips.
Norway	Troll	Dronning Maud Land	Summer occupation.
	Tor	Dronning Maud Land	Summer occupation.
Peru	Macchu Picchu		Summer occupation only.
Poland	Henryk Arctowski (3ZL301)	King George Island	Permanent occupation. Scientific base.
Russia	Bellingshausen (UGE2)	King George Island.	Permanently manned.
	Molodezhnaya (RUZU)	Enderby Land	Permanently manned. Landing strips. Airfield. Main Russian research base.
	Mirny (UBA) (UFE)	Queen Mary Land	Permanently manned.
	Vostok (RKIS)	East Antarctica	Permanently manned. Landing strips.
	Novolazarevskaya	Dronning Maud Land	Permanently manned.
	Progress	Princess Elizabeth Land	Permanently manned.
	Druzhnaya 4 (ULO1)	Ingrid Christensen Coast	Summer occupation only.
	Soyuz (RUNI)	McRobertson Land	Summer occupation only.
South Africa	Marion Island	Prince Edward Islands	Permanently manned.
	Sanae IV (ZRP)	Queen Maud Land	Permanently manned.
	Gough Island	Tristan de Cunha group	Permanently manned.
	E-base	Queen Maud Land	Summer occupation only.
Spain	Juan Carlos I (3ZL34)	Livingston Island	Summer occupation only.
	Gabriel de Castilla	Deception Island	Summer occupation only.
Sweden	Wasa (SLUI)	Dronning Maud Land	Summer use only.
Ukraine	Vernadsky	Galindez Island	Permanently manned.
United Kingdom	King Edward Point (ZBH)	South Georgia	Permanently manned.
	Bird Island	W end of South Georgia	Permanently manned.
	Signy (ZHF33)	South Orkney Islands	Summer use only.

ANTARCTIC RESEARCH STATIONS

Country	Station	Location	Comments
United Kingdom	Adelaide Island (Rothera) (ZHF45)	West Coast-Graham Land	Permanently manned. Landing strips.
	Halley (VSD)	Coats Land	Permannently manned. Landing strips.
United States	Palmer (NGH)	Anvers Island	Permanently manned. Heliport.
	McMurdo (NGD)	Ross Sea	Permanently manned. Airfield. Largest station in Antarctica.
	Amundsen-Scott (NPX)	South Pole	Permanently manned. Landing strips.
Uruguay	Artigas (C2C)	South Shetland Islands	Permanently manned. Landing strips.

Note.—In addition to the above research bases and stations, numerous small refuges, most with provisions and fuel, are situated on the continent and off-lying islands. Vessels should contact McMurdo Station for the latest information concerning the locations and conditions of these refuges.

Currently, work is being done in all aspects of Antarctic research with funding, management, and guidance provided by the National Science Foundation (NSF).

Additional information concerning stations and bases is available from the Council of Managers of National Antarctic Programs (COMNAP) at their website www.comnap.aq.

Significant international interest in the continent developed during the International Geophysical Year (IGY) 1957-1958. This marked the beginning of major scientific activities that have continued to the present. Although earlier expeditions conducted some scientific activities, the efforts of international working agreements reached during the IGY period were recognized as unique by all nations involved. Twelve nations established over sixty research stations in Antarctica during the IGY period. This became the basis for the Scientific Committee on Antarctic Research (SCAR) and the formulation of the Antarctic Treaty. The nations included Argentina, Australia, Belgium, Chile, France, Japan, New Zealand, Norway, South Africa, Russia, the United Kingdom, and the United States.

In 1958, the SCAR, as a committee of the International Council of Scientific Unions, was tasked to continue the scientific and logistic cooperation which began during the IGY period. The SCAR seeks to identify scientific problems of Antarctica, their scope and significance. The member nations work independently or jointly to bring available logistics support and scientific personnel to seek solutions to these problems, maintaining multinational efforts as the common objective.

Following the IGY period, with the claims issue made by seven nations to portions of Antarctica unsettled since 1945, the United States called a conference in 1959. The Washington Conference convened on October 1 and was attended by those twelve nations which had conducted substantial activities in Antarctica including the following seven claimant states (The United Kingdom, France, Australia, New Zealand, Norway, Argentina, and Chile). The final act of the Washington Conference on the Antarctic was the Antarctic Treaty, signed at Washington on December 1, 1959. Subsequently, this treaty was ratified by all the signatories by June 23, 1961, with the continued spirit of cooperation achieved during the IGY period. By April 1991, thirty nine nations were signatories.

An agreement reached in Madrid in April of 1991, signed by all 39 parties, imposes a ban on all mineral exploitation in Antarctica for 50 years. The agreement demilitarizes the continent, establishes the right to scientific research for all countries, and creates a procedure for monitoring the environment.

Sovereignty.—Seven of the original 12 signatories to the 1959 Antarctic Treaty have claimed sovereignty over parts of Antarctica. These countries are Argentina, Australia, Chile, France, New Zealand, Norway, and the United Kingdom. Some areas of Antarctica are claimed by more than one of these countries, while other areas remain unclaimed. The remainder of the original signatories (Belgium, Japan, South Africa, Russia, and the United States) have neither made claims nor recognized claims made by other countries. In the Antarctic Treaty, the disagreement over the issue of territorial sovereignty is dealt with in a manner that allows the parties to cooperate in the conduct of the specific activities addressed by the treaty. (See Regulations—Legal Information and Regulations on page 65.)

Historical Impact.—To date, the major impacts on the terrestrial environment from the present occupation of Antarctica are localized and are mostly associated with support facilities such as fuel handling and storage; waste disposal; and construction, operation, and maintenance of stations and field camps. Those environmental features that have been affected include rocks, soils, lakes, ponds, terrestrial biota, and glacial snow and ice. The degree to which they have been affected, in some cases, is unknown, but is generally only local in extent.

During 1980 and again in 1991, the National Science Foundation performed comprehensive environmental impact assessments of U.S. activities in Antarctica. The assessments concluded that continuation of these activities would have no significant continental impacts on Antarctica.

Only a few localized impacts of any significance could be identified. Most of these impacts are significant only in instances where research being carried out requires an undisturbed environment for its success.

The protection of the Antarctic environment is of prime concern to personnel working in Antarctica, and this concern is reflected in directives issued under the Antarctic Treaty.

Current scientific activities and tourism in Antarctica have little impact on the marine environment. Those impacts that have been noted are only local in extent. A small number of birds and seals are lost to scientific collecting. Activities near rookeries, such as helicopter overflights and foot expeditions, are restricted.

Impact on the marine environment has been limited in the past except for the harvesting of mammals. The disposal of garbage, sanitary waste, and solid waste in coastal waters degrades water quality on a local scale. Vessel traffic and the handling of petroleum products have resulted in small oil spills or oil discharges which may harm local animal populations. During 1989, a vessel ran aground to the SW of Palmer Station, spilling 170,000 gallons of fuel into the sea.

Commercial harvesting of whales and seals has had significant impacts in the past. Twentieth century whaling greatly reduced the populations of baleen whales. The International Whaling Commission now regulates whaling. The fin, blue, humpback, and southern right whales are protected from harvesting, and harvest quotas have been set for other species. The reduction of the number of whales in this century from approximately 975,000 to approximately 338,000 means that less krill are consumed by whales. Whereas baleen whales used to consume an estimated 180 million tons of krill, they now only consume an estimated 33 million tons, increasing the availability of krill for other predators. Subsequently, the population of crabeater seals increased and the populations of other predators may also have increased. Hence, whaling may have altered the populations of many species besides the whales themselves.

Fur seals and elephant seals were captured for their fur and blubber, respectively, during the eighteenth and nineteenth centuries, and the number of fur seals was severely reduced. Both of these seals are now protected by the Convention for Conservation of Antarctic Seals.

In the early twentieth century, a whaling station was established in King Edward Cove, on South Georgia Island, to support whaling operations. The activities in this harbor grossly polluted the water with organic effluents and fuel oil, impacting the local marine communities. However, contamination has stopped and evidence indicates that the benthic fauna has recovered.

The Antarctic environment has been contaminated at extremely low levels with organochlorides as a result of human activities outside of Antarctica. The entire impact of these contaminants is not known. However, DDT and other chlorinated hydrocarbons have been found in Antarctic birds. In addition, DDT, PCBs, and other organochlorides have also been found in krill, although at concentrations that do not pose a human health hazard.

Marine traffic is considerable in the Drake Passage, which is used by vessels too large to pass through the Panama Canal. Commercial shipping, which includes oil tankers, pass through this area, usually to the N of the Antarctic Convergence. Recently, several cruise vessels have transited Antarctic waters.

Bases.—McMurdo Station is the main United States base and also the largest multipurpose research and logistics center in Antarctica. The population of bases on the continent may reach 2,000 people during the summer and 800 people during the winter. The U.S. bases rely heavily on aircraft, rather than on ships, for transport of personnel and priority cargo. However, when fuel or bulk cargo is transported (some 90% of the total), it is shipped to McMurdo. Icebreakers are used to open an approach channel, enabling cargo vessels and tankers to off-load directly at this station. McMurdo has one of the few airfields on the continent that are suitable for use, at times, by wheeled aircraft. (See Part II—paragraph 4.7.)

Ice

Formation and Growth of Sea Ice in Polar Regions.—An understanding of the formation, growth, and decay of sea ice is desirable for comprehension of many of the problems in ice seamanship. The climatic factors bearing on the formation of ice naturally vary from place to place and from season to season. However, a knowledge of the basic physics involved should be of great assistance and enable mariners to recognize certain salient features of ice and take advantage of its properties.

Freezing.—In temperate and tropical latitudes, the ocean acts as a storehouse of radiant heat from the sun, the visible and infra-red wave lengths being largely absorbed in the surface layers. The heat that is stored by this action is then given off to the air at night and at other periods when the air is colder than the sea surface. However, in higher latitudes, insufficient heat is stored in the short daylight periods to compensate for the losses at night and the temperature of the surface water is lowered. As the altitude of the sun becomes lower, less radiation is received and more is reflected from the sea surface due to the low angle of incidence of the rays. Finally, the water reaches freezing point and further loss of heat results in the formation of ice.

Conditions then become even less favorable for the retention of radiant heat from the sun; since, ice reflects much more of the visible radiation than does water. The cooling of the air that is in contact with the ice becomes accelerated and even more ice is formed as this cold air spreads.

Salinity.—Fresh water freezes at 0˚C, but sea water remains liquid until a lower temperature is reached due to the presence of salt. The greater the amount of salt (salinity), the lower the freezing point. Ordinary sea water, with a salinity of 35 parts per thousand, does not begin to freeze until it has been cooled to -1.88˚C.

Salinity may also affect the rate of freezing through its influence on the density of the water. Fresh water contracts on cooling and sinks below the surface until a temperature of 4˚C is reached. On further cooling, fresh water expands and its density decreases. If the cooling takes place at the surface with no other process of mixing at work, the coldest water will stay in a layer at that position. It is then necessary for only the layer at the surface to be cooled to the freezing point for ice to form.

The temperature of maximum density decreases faster than the freezing point with increasing salinity. These two temperatures coincide at a salinity of 24.7 parts per thousand. This means that with a salinity of 24.7 parts per thousand or greater, density currents operate until the freezing point is reached and theoretically the entire body must be cooled to this temperature before ice can form on the surface.

However, in nature, rapid cooling of still water often occurs under conditions where heat is removed from the surface layers faster than it can be supplied from the deeper layers through convection currents. In such a case, ice will form on the surface of the water before the deeper layers have approached the freezing point.

A practical outcome of the foregoing is that if a body of water originally of uniform density is losing heat at the surface, ice will be formed most readily in fresh water, less readily in sea water of low salinity, and least readily in sea water of high salinity. The greater heat removal required to freeze sea water is due not only to its relatively low freezing point, but also to the increased tendency of the cooled surface water to sink as the temperature of maximum density decreases.

Ice Propagation.—Ice forms first in shallow water, near the coast or over shoals and banks; in bays, inlets, and straits in which there is no current; and in regions with reduced salinity, such as those near the mouths of rivers. It then spreads from these areas.

The first sign of freezing is an oily or opaque appearance of the water. This is due to the formation of needle-like spicules and thin plates of ice, about 1 centimeter wide, which are known as frazil crystals. These crystals of fresh ice, which are free of salt, increase in number until the sea is covered by a thick and soupy slush, known as grease ice.

Snow, falling into water, aids the freezing process by cooling and by providing nuclei for the ice crystals. In such conditions, the slush forms into new ice. Except in sheltered waters, an even sheet of ice seldom forms immediately. The slush, as it thickens, breaks up into separate masses and frequently into the characteristic pancake form, the rounded shape and raised rim of which are due to the fragments colliding with each other. The formation of slush dampens down the sea and swell, and if the low temperature continues, the pancakes of ice adhere to each other, forming a continuous sheet or floe.

An accumulation of spongy ice lumps, known as shuga, is the next normal stage of formation from grease ice. On further freezing and depending upon the salinity and wind exposure, shuga develops into nilas, an elastic crust of high salinity and up to 10 centimeters thick, or into ice rind, a brittle and shiny crust of low salinity up to 5 centimeters thick. When the ice reaches a thickness of from 10 to 30 centimeters, it is collectively referred to as young ice which is the transition stage between nilas and first-year ice. First-year ice is usually between 30 centimeters and 2 meters thick. Ice up to 3m or more in thickness that has survived at least one summer melt is known as old ice. Multi-year ice is the term now used to describe old ice which has survived more than two summers melts. Old ice has a bluish-green tone on its surface in contrast to the greenish-white tone of first-year ice. Multi-year ice usually develops an intense blue tone with age.

Melting.—The melting of ice takes place mostly at the expense of the heat of the surrounding water. This heat may have been absorbed from solar radiation in the vicinity or provided by currents originating in warmer latitudes. Melting also results from direct absorption of radiation by the ice and from contact with warm air. Ice will condense dew from warm, moist air on its surface, and each increment of moisture so condensed will melt several times its weight of ice in the ratio of the latent heat of evaporation to the heat of fusion.

Another factor tending to accelerate the rate of ice melting from solar radiation, once it has commenced, is the increased stability of the surface layers of the sea brought about by the freshening effect of the melt water. Mixing between the surface and deeper layers, already diminished by the wave-damping action of floating ice, is further decreased by the formation of a surface stratum of relatively low density. The normal transfer to greater depths of heat received as infra-red radiation in the top layers is retarded, and the melting of the ice is thereby speeded up.

The phenomenon of "dead water" is sometimes encountered by vessels in areas where a layer of nearly fresh water that has derived from melting ice extends to about keel depth. Under such conditions, the propulsive power of a vessel may be largely dissipated in generating internal waves in the boundary between the fresher water and the more saline water. Consequently, the vessel slows down, begins to steer sluggishly, and appears to be "stuck" in the water. Fortunately, this state of affairs occurs only when the speed of the vessel is below the speed of propagation of such waves, which is not more than 2 or 3 knots. Therefore, "dead water" will usually affect only sailing vessels, in light winds, small craft, or tugs with very heavy tows.

In regions where the spring melting of ice is brought about chiefly by atmospheric transfer of heat from lower latitudes and where local fogs restrict the solar radiation reaching the ice and sea surface, the fresh surface layers of sea water may become greatly chilled and the rate of melting reduced.

In places where the vertical exchange of water caused by wind, sea, currents, and tides occurs, melting of the ice is expedited by heat being brought to the upper layers.

Disintegration.—In spring, as the duration of daylight begins to increase and the mean air temperature at the sea surface rises, the snow cover of the sea ice and the top layers of the ice itself begin to thaw. Under conditions of low humidity, most loss on the upper surface of the ice will take place through evaporation imperceptible to the ordinary observer. When the relative humidity is high, pools of dew and melt water will form on the surface. This fresh water, running down through cracks and holes in the ice, will freeze again on contact with the cold sea water; hence, sealing the openings. In addition, cracks extending only part way through the ice will be widened by the expansion of the water freezing in them. On further rising of the air temperature and melting of the surface, these cracks open up again and fresh water in a layer, as much as 1m thick, flows under the ice.

Sea ice less than 1 year old melts more readily than older ice because of its higher salt content. Fast ice usually melts first near the shore, forming the so-called "offshore water." As melting progresses, the ice farther out from the shore becomes honeycombed with cracks due to tides, air temperature changes, temperature gradients in the ice, and ice pressure.

Under the influence of wind and current, this ice now commences to disintegrate and an increased number of channels and polynyas (open areas) are produced. With the first strong wind, the ice breaks into smaller pieces and finally all the fast ice disintegrates into drift ice.

Decay of the ice is expedited by mechanical attrition from the swell. The physical erosion of the floes produces scaling, resulting in the formation of a quantity of small blocks and brash. The scaling process enables the sea to reach more extensive areas of ice where the cycle continues.

The final stages of melting vary with the type of ice. Ice of one winter's growth melts readily in low latitudes, if brine is still present. The internal melting due to variations in the salt content produces a honeycombed appearance with a much greater surface area. Since the rate of heat absorption through conduction is proportional to the area exposed, the ice so formed quickly disappears. Fresher and firmer hummocky ice is longer lived. The old floes are heavily undercut at the water line, but honeycombing is rare, due to the absence of salt. Underwater rams are produced by the melting back of the uppermost meters of ice. The years-old hummocks, having a homogeneous structure of nearly salt-free ice and a minimum of exposed surface in proportion to their bulk, survive the longest in warmer waters.

Break-up on rivers usually occurs three or four weeks after the mean air temperature has risen above 0˚C. Ice on lakes breaks up two or three weeks later, and sea ice may break up about this same time.

Comparison of Arctic and Antarctic Ice.—The warmth of the Arctic summer has no parallel in the Antarctic and, mainly because of this thermal difference, the ice sheets of the N polar region are unlike those of the S. The edge of the Antarctic cap, overflowing its land support, is free to spread over the sea until it fractures and large strips become detached. Hence, such large strips that form tabular or box-shaped bergs are generally a characteristic of only the S polar region.

In Greenland, by contrast, the edge of the inland ice ends on land and usually icebergs that are irregular in shape are formed. Hence, the pinnacled and picturesque berg is generally a characteristic of only the N polar region.

The Antarctic sea ice surrounds the continent while the Arctic sea ice forms a central mass surrounded by land. The ice moves around and outward from Antarctica and it is unusual for sea ice to be more than 1 or 2 years old. The drifts in both the Weddell Sea and the Ross Sea carry the ice out into the open oceans in a period of just over 1 year.

However, in the Arctic, floes of great age are frequent. Ice formed off the Siberian coast may take from 3 to 5 years to drift across the polar basin and down the E side of Greenland. Subsequently, ice of this age becomes pressed and hummocked to a degree unknown in lower latitudes. During the Arctic summer, melting on the surface is considerable and pools of fresh water are formed on the floes. In the Antarctic, surface pools on floes in the ice such as these are almost unknown.

The outstanding difference between Arctic and Antarctic ice, which becomes soon apparent to the navigator, is the softer texture of the latter.

While Arctic sea ice appears to be formed primarily through surface freezing of sea water, Antarctic sea ice apparently includes substantial amounts of infiltrated snow ice and underwater ice. Infiltrated snow ice is formed by the flooding and refreezing of extensive fields of snow lying on existing floes. Underwater ice results from the growth and consolidation of a cloud of ice crystals in the cold water column beneath existing ice.

Classification.—Ice met at sea consists for the most part either of icebergs, originating from glacier and continental ice sheets, or of sea ice, formed by the freezing of the top layers of the sea itself. Sea ice proper accounts for probably 95 per cent of the area of ice encountered, but bergs are important because of the manner in which they drift far from their place of origin and constitute a grave menace to navigation. A certain amount of ice may also originate in rivers or estuaries as freshwater ice, but it is already in a state of decay by the time it reaches the open sea and its importance is no more than local.

Icebergs.—Icebergs are large masses of floating (or stranded) ice derived from the fronts of glaciers, from glacier ice tongues, or from the shelf ice of the Antarctic. They are products of the land and not of the sea. Their structure and, to some extent, their appearance depend upon the source from which they are derived.

Antarctic ice islands, commonly called tabular icebergs, are significantly larger and more numerous than their Arctic counterparts. Some, with observed horizontal dimensions of more than 200 kilometers by 50 kilometers, have calved away from the Ross, Ronne, and other ice shelves. These huge tabular floes, which may tower as high as 200 meters above the sea surface, have been observed grounded at depths of about 500m. However, Antarctic icebergs rarely find their way into the main shipping lanes. They move in a N direction in response to the ocean currents and can generally be found as far N as 45˚S in the Pacific Ocean and 35˚S in the Atlantic and Indian Oceans.

Bergs are usually an opaque, flat, and white color with soft iridescent hues of blue or green. Many bergs show veins of soil or rock debris and others may have yellowish or brownish stains, probably due to diatom (minute algae) films. Under certain conditions of illumination, an iceberg may appear dark in color in contrast with the sky or with other bergs under direct sunlight. This phenomenon has often led mariners to report islands where none exist.

The ratio of the mass of the submerged portion of a berg to its total mass is equal to the ratio of the specific gravity of the berg to that of the water in which it is floating. On account of the origin of glacial ice in compacted snow, berg ice contains up to perhaps 10 per cent of trapped air and is somewhat less dense than ordinary ice. Measurements of the specific gravity of icebergs have given values close to 0.9, while the cold sea water in which they float has a specific gravity of about 1.027. Consequently, about seven-eights of the mass of a berg is submerged.

It is often erroneously assumed that an iceberg floats with a draft seven times its height above the water, but these ratios hold good for only mass and not for linear dimensions. Actual reported measurements of bergs indicate that the draft is seldom more than five times the exposed height for the blockiest bergs, and may be as low as one or two times the exposed height for the pinnacled and irregular types.

On a clear day, an iceberg can be seen at a great distance due to its brilliant luster. However, an iceberg may not be perceptible until dangerously close during foggy weather. When the fog is dense and the sun is shining, the first appearance of an iceberg is in the form of a luminous, white object. If the sun is not shining, the first appearance is in the form of a dark, somber mass with a narrow streak of black at the water line. The diffusion of light in the fog will produce a blink around the berg that augments the apparent size of the ice mass.

Icebergs may, at any time, calve off large sections of sheet ice or glaciers, relieving stresses set up by temperature changes or responding to vibrations from sound or wave action. After falling into the water, they may travel up to the surface again with great force and often at a considerable distance away. Icebergs are often so balanced that this calving causes a shift in their center of gravity with consequent capsizing and readjustment of their mass to a new state of equilibrium. Therefore, vessels and boats should keep well clear of icebergs that give any evidence of disintegrating or overturning. In addition, icebergs may also possess underwater spurs and ledges which extend considerable distances from the visible portions.

In good weather, icebergs can be of great assistance to navigation in floating ice as they may mark shoals, break up a consolidated mass of ice, and provide reference points. Having a relatively small sail area in proportion to their bulk, icebergs are not affected by wind to the same extent as drift ice. With the wind blowing drift ice past a berg, an optical illusion often occurs and the berg seems to be moving to windward and cutting a channel through the ice. Illusion or not, such a lee may be a desirable place for a vessel to lie in order to avoid heavy ice. Under such circumstances, vessels have reported laying out an ice anchor to a berg, but a careful watch must be kept for growlers which have calved off. Vessels are frequently alarmed by the presence of icebergs in an anchorage area. However, it is usually safe unless the bergs are of mammoth size or disintegrating.

When navigating in fog, the presence of a large number of growlers, bunched together, may be a good indication of an iceberg to windward. In calm weather, growlers may sometimes be found distributed in a curved line, with the iceberg located on the concave side of the curve. (See Geophyical Features—Physical Geography on page 8 and Navigational Information on page 48.)

Sea Ice.—Sea ice can be divided into fast ice and drift ice, according to mobility.

Fast ice forms in sheltered bays, gulfs, and fjords, as well as among floating lumps of old ice. Developing along the shore and spreading into the sea, fast ice joins the new ice formed around islands, grounded floebergs, and floating masses of old ice. Although subjected to repeated fracturing with the fall in temperature of the air, it then spreads farther and farther into the sea, increasing in thickness and offering more and more resistance to breaking up. Finally in the first months of the winter, the fast ice extends up to its maximum distance offshore, beyond which the region of drift ice is found. The width of a belt of the fast ice depends upon the configuration of the shore, since the more rugged the coastline and the greater the number of islands in its vicinity, the greater is the width of the fast ice. Hummocks stranded in shoal water also assist fast ice to develop. Fast ice can extend a few meters or several miles from the shore. Generally, fast ice that projects more than 2m above sea level is known as an ice shelf.

Along open coasts, the fast ice is liable at all times to break up and drift away. However, this break-up may not occur in regions where the configuration of the land is such as to shelter the ice from the prevailing winds. In addition, stranded bergs sometimes act as anchors for fast ice and prevent it from breaking out and drifting into the open sea.

Drift ice is the term widely used to include any area of sea ice, other than fast ice, no matter what form it takes. When drift ice is highly concentrated, over seven-tenths of the surface, it is then described as pack ice. Flat pieces of sea ice that are 20m or more wide are called floes. An ice-covered area over 10 kilometers wide that is formed by floes freezing together is called an ice field.

The age of floes may often be judged by the presence of colored bands at their edges. During the summer, minute algae, known as diatoms, adhere to the underside of pieces of floating ice, which may be slowly growing through the freezing of fresh water derived from melting of their upper side. In the winter, the ice grows more rapidly and diatoms are absent due to the lack of sunlight. Consequently, the intervals between two winter freezings are marked by yellow strata of frozen diatoms and may indicate the age of the floe.

A piece of sea ice that rises less than 1m above the sea level, covers an area of about 20 square meters, and often appears transparent, green, or almost black in color is known as a growler.

A large piece of sea ice that rises between 1 and 5m above the sea level and covers an area of about 100 to 300 square meters is known as a bergy bit.

A massive piece of sea ice that is composed of a hummock or several hummocks, rises up to 5m above sea level, and is separated from any ice surroundings is known as a floeburg.

Pack Ice.—Pack ice may be composed of high concentrations of drift ice, detached fragments of fast ice, and, to a lesser extent, disintegrated particles of land ice.

Pack ice is classified according to the thickness of its arrangement and may be described as compact pack, consolidated pack, close pack, and open pack. The ice masses themselves are described according to size and may be icefields, floes, or pancakes. Depending on their surface, they may be described as level or hummocked.

The belts of pack ice usually lie perpendicular to the prevailing wind. Projections, called tongues, are sometimes formed by the wind or currents and extend considerable distances from the ice edge. Bays or bights may also be formed by the wind or current in a belt of pack ice. The degree of openness and the physical character of the ice forming the belt greatly determine the resistance offered against such actions. When the wind produces this effect, the indentation is usually small. However, indentations formed in the pack ice by the influence of a current sometimes are of huge dimensions.

Often consolidated pack ice, the heaviest form, will drift away from the shore or will separate, forming cracks, fractures, and leads through the ice area. When the separation is wide enough to permit the passage of a ship, it is called a lead. A lead between pack ice and the shore is known as a shore lead and one between pack ice and fast ice is known as a flaw lead. A lead ending in an impenetrable barrier is known as a blind lead.

Navigation in shore leads and flaw leads is dangerous because the pack ice can close against the fast ice or the shore. Before leads refreeze, lateral motion generally occurs between the floes. Hence, unless the pressure is extreme, numerous large patches of open water remain. These nonlinear shaped open patches, which are called polynyas, may contain small fragments of ice. In summer, the leads do not generally refreeze.

Pressure Ice.—The deformation of ice results in greater thickness and is caused by the movement and interaction of floes. This process is usually caused by winds, tides, and currents. It transforms a relatively flat sheet of ice into pressure ice which has a rough surface.

Pressure set up in the floes produces bending, tenting, and rafting. Bending, the first stage, is an upward or downward motion and occurs in thin and very plastic ice. In heavier floes, which are less resilient, tenting occurs. Here, the ice bends up until a crack is formed perpendicular to the direction of pressure. This results in the formation of a flat-sided arch with a cavity beneath that resembles a tent-like structure. Rafting, the most frequent movement, is the overriding of one floe on top of another.

When pieces of ice pile up haphazardly over one another and form a wall or line of broken ice, the process is known as ridging and the wall is referred to as a ridge. When this action results in the pressure ice having a surface consisting of numerous mounds, the process is known as hummocking. The surface is referred to as hummocked ice and each mound is referred to as a hummock. When weathered, hummocked ice has the appearance of smooth hillocks.

The ridges in pressure ice may be as high as 15m where grounded against a coast, but in deep water and away from the land they are usually no more than 10m high.

Massive detachments of ice resulting from hummocking are called floebergs. These should not be confused with icebergs, or growlers, which are of glacial origin.

Movement.—Any wind will tend to regroup ice that is more or less scattered over a considerable area. As the wind rises, the separate floes form lines at right angles to the wind direction. These lines break up when the wind changes and, after a time, realign themselves at right angles to the new wind direction. When the wind blows out from the coast, a channel of open water usually forms between the shore and the ice or any such existing channel increases in width. When the wind blows toward the coast, the fast ice tends to move closer to shore and reduce the width of any existing channel. If the wind is strong enough, hummocks may be produced along a line lying approximately at right angles to the wind direction.

The rate at which the different floes travel is not so much dependent upon the size and depth of the floe as upon the nature of its surface. Since pack ice is made up of a conglomeration of young ice, old floes, and icebergs, it varies radically in resistance to wind and current. Surface irregularities, such as hummocks and pressure ridges, act as sail areas. Hence, the rate of movement of a floe depends to a certain extent on the amount of hummocking in proportion to the area and weight of the floe. As a result of previous pressure, hummocked floes in turn become the cause of still further pressure. When two floes are moving at different rates, either the distance between them is increased and an open lane is produced or the distance between them is decreased and they are brought into physical contact. In gaining momentum, larger floes will accelerate more slowly. However, once underway, they will retain their motion long after smaller floes have stopped. Therefore, in the early stages, the large and heavy floes will be charged and overtaken by smaller floes. In the later stages, the smaller floes will be disrupted by the larger ones and their surface appearance will be changed. This process will then create new and further differences in the speed of their movement.

The swinging or turning of floes is due to the tendency of each cake of ice to trim itself to the wind when the cover is sufficiently open to permit this freedom of movement. In close pack ice, this tendency may be produced by pressure from another floe. Since floes continually hinder each other and the wind may not be constant in direction, even greater forces may result. Hence, the wind can also produce a rotating motion in the floe. This shearing or rotating effect results in excessive pressure at the projecting corners of floes and usually forms a hummock of loose ice blocks. The process of rotating is referred to as screwing and this action is extremely dangerous to vessels.

During its motion, ice opens up and closes like an accordion. There are always a certain number of lanes or leads present, otherwise the ice could not move. In summer, these lanes usually remain open, except in very high latitudes. However, in winter they are soon frozen over with young ice. In addition, the swell tends to break up the ice. Consequently, as a result of all these actions, the ice is alternately being broken up, even throughout the winter, and subjected to pressure.

Signs of Ice.—There are two reliable signs of drift ice, ice blink and abrupt smoothing. Ice blink, the reflection of ice on the lower clouds, is the indication that has been most used by experienced polar navigators. It is rarely, if ever, produced by bergs, but is nearly always distinct over consolidated and extensive pack ice. On clear days with a mostly blue sky, ice blink is reported to appear as a luminous yellow haze on the horizon in the direction of the ice. On days with an overcast sky or low clouds, it is reported to appear as a whitish glare on the clouds, the yellow color being absent. Under certain conditions, ice blink has appeared as brilliant, scintillating strips on the horizon.

Abrupt smoothing of the sea and the gradual decrease of the normal sea swell is a sign that drift ice lies to windward.

Other likely signs of ice include fog and the presence of birds.

In late spring and summer, a thick band of fog often lies over the edge of the drift ice. In fog, white patches indicate the presence of ice at a short distance.

In the Antarctic, the presence of the Antarctic Petrel or the Snow Petrel indicates the proximity of ice. The former bird is normally seen only within about 400 miles of the ice edge and the latter considerably closer.

The lowering of the sea surface temperature is reported to give little or no indication of the proximity of ice. However, if the surface temperature falls to 1˚C and the vessel is not in one of the main cold currents, the ice edge may be considered to lie between 100 and 150 miles distant. If the temperature falls to -0.5˚C, the nearest ice should generally be considered to lie not more than 50 miles distant.

Signs of Open Water.—Dark patches or steaks on the underside of low clouds, sometimes almost black in comparison with the clouds in general, usually indicate the presence of open water below them. This phenomena is known as water sky.

Like ice blink, water sky depends upon the greater absorption of sunlight by water than by ice or snow and the subsequent diffusion of the reflected light in the lower atmosphere.

Dark spots in fog give a similar indication, but are only visible at a short distance. A dark bank on the underside of a cloud at a high altitude indicates the existence of small patches of open water below which may connect with a larger distant area of open water.

The sound of a surge in the ice indicates the presence of large expanses of open water in the immediate vicinity.

When approaching ice, a darkness appearing on the low horizon indicates that there is probably open water beyond the ice, in some cases up to 40 miles or more beyond the visible horizon.

With a cloudless sky, no iceblink is possible although a yellow or white haze or glare on the horizon may indicate the presence of ice. However, abnormal refraction may occur. This effect raises the horizon and enables the observer to see the ice or patches of open water at greater distances than would normally be possible. The ice or area of open water, or a mixture of the two, may be seen as an erect or inverted image, or both images may be seen at once, one above the other. In the latter case, the erect image is the higher of the two. Allowance must also be made for the fact that refraction causes the apparent dimensions of ice to increase. Hence, sometimes bergy bits appear to be icebergs. Areas of open water often appear dark relative to the ice. (See Optical Phenomena on page 63.)

Drift.—While the general direction of the drift of icebergs over a long period of time is known, it may not be possible to predict the drift of an individual berg at a given place and time because bergs lying close together have been observed to move in opposite directions. Bergs usually move under the influence of the prevailing current at the depth to which they are submerged. Such currents may often be in opposition to the existing wind and current at the surface.

Drift ice moves with the wind and tide, usually to the left of the true wind in the S hemisphere and to the right in the N hemisphere. The speed of drift may not depend entirely upon the strength of the wind, since it is influenced greatly by the presence or absence of open water in the direction of the drift, even though the open water may be somewhat distant.

Neglecting the resistance of the ice, Ekman's theory of wind drift calls for the ice to drift 45˚ from the wind direction. Observations show that the actual drift is about 30˚ from the wind direction on the average, or very nearly parallel to the isobars on a weather map. In winter, when the ice is more closely packed and offers more resistance, its drift deviates less from the wind direction than in summer, and tidal influences become more important. Therefore, the speed of drift ice (pack ice) can be fairly closely determined from the wind speed.

Note.—The National Ice Center (NIC) operates MetFax which is a dial-up service. In order to receive MetFax, ships must have a facsimile (fax) machine with polling function capability. The products available include sea ice analysis and forecasts for the Antarctic.

To receive weather data charts from MetFax and access the autopolling system, receivers should dial (301) 763-3190 or 3191. When connected, receivers should follow the menu and select the data required. To access the system, a Personal Identification Number (PIN) is required which allows the NIC to identify users and requests in order to maximize services. PIN access is provided at no cost. For a PIN or further information concerning MetFax, send requests to the NIC at the following address:

National Ice Center
Federal Building No. 4
4251 Suitland Road
Washington D.C. 20395
(Fax) (301) 457-5305

The National Climatic Data Center (NCDC) provides weekly Antarctic sea ice analysis charts on a mail subscription basis. For further information contact NCDC at the following address:

National Climatic Data Center (NCDC)
151 Patton Ave
Asheville NC 28801-5001
(Tel) (828) 271-4800
(Fax) (828) 271-4876

For further information concerning ice, see Pub. No. 9, The American Practical Navigator (Bowditch-1995 Edition); or contact the National Science Foundation (NSF) at the following address:

National Science Foundation (NSF)
Office of Polar Programs (OPP)
4201 Wilson Boulevard
Arlington VA 22230
(Tel) (703) 292-8030
(Fax) (703) 292-9081

Ice Terms

The following glossary provides definitions in general use for the many kinds of ice encountered at sea. The terms are based on the nomenclature established by the World Meteorological Organization (WMO).

Aged ridge: A ridge which has undergone considerable weathering. These ridges are best described as undulations.

Anchor ice: Submerged ice attached or anchored to the bottom, irrespective of its formation.

Area of weakness: A satellite-observed area in which either the ice concentration or the ice thickness is significantly less than that in the surrounding areas. Because the condition is satellite observed, a precise quantitative analysis is not always possible, but navigation conditions are significantly easier than in surrounding areas.

Bare ice: Ice without snow cover.

Belt: A large feature of ice arrangement; longer than it is wide; from 1 km to more than 100 km in width.

Bergy bit: A large piece of floating ice generally showing between 1 and 5m above sea-level and normally about 100 to 300 square meters in area.

Bergy water: An area of freely navigable water in which ice of land origin is present in concentrations of less than one-tenth. There may be sea ice present, although the total concentration of all ice should not exceed one-tenth.

Beset: Situation of a vessel surrounded by ice and unable to move.

Big floe: See Floe.

Bight: Extensive crescent-shaped indentation in the ice edge formed by either wind or current.

Brash ice: Accumulations of floating ice made up of fragments not more than 2m wide.

Bummock: From the point of view of the submariner, a downward projection from the underside of the ice canopy, the counterpart of a hummock.

Calving: The breaking away of a mass of ice from an ice wall, ice front, glacier, or iceberg.

Close pack ice: Pack ice in which the concentration is seven-tenths to eight-tenths, composed of floes mostly in contact.

Compacted ice edge: Close, clear-cut ice edge compacted by wind or current, usually on the windward side of an area of pack ice.

Compacting: Pieces of floating ice are said to be compacting when they are subjected to a converging motion, which increases ice concentration and/or produces stresses that may result in ice deformation.

Compact pack ice: Pack ice in which the concentration is ten-tenths and no water is visible.

Concentration: The ratio expressed in tenths describing the amount of the sea surface covered by floating ice as a fraction of the whole area being considered. Total concentration includes all stages of development that are present. Partial concentration may refer to the amount of a particular stage or of a particular form of ice and represents only a part of the total.

Concentration boundary: A line approximating to the transition between two areas of pack ice with distinctly different concentrations.

Consolidated pack ice: Pack ice in which the concentration is ten-tenths and the floes are frozen together.

Consolidated ridge: A ridge in which the base has frozen together.

Crack: Any fracture of fast ice, consolidated ice, or a single floe which has been followed by a separation ranging from a few centimeters to 1m.

Dark nilas: Nilas which is under 5 centimeters in thickness and is very dark in color.

Deformed ice: A general term for ice which has been squeezed together and in places forced upwards (and downwards). Subdivisions are rafted ice, ridged ice, and hummocked ice.

Difficult area: A general qualitative expression to indicate, in a relative manner, that the severity of ice conditions prevailing in an area is such that navigation in it is difficult.

Diffused ice edge: Poorly defined ice edge limiting an area of dispersed ice; usually on the leeward side of ice.

Diverging: Ice fields or floes in an area are subjected to diverging or dispersive motion; hence, reducing ice concentration and/or relieving stresses in the ice.

Dried ice: Sea ice from the surface of which melt water has disappeared after the formation of cracks and thaw holes. During the period of drying, the surface whitens.

Drift ice: Term used in a wide sense to include any area of sea ice other than fast ice no matter what form it takes or how it is dispersed. When concentrations are high, i.e. seven-tenths or more, drift ice may be replaced by the term pack ice.

Easy area: A general qualitative expression to indicate, in a relative manner, that ice conditions prevailing in an area are such that navigation is not difficult.

Fast ice: Sea ice which forms and remains fast along the coast, where it is attached to the shore, to an ice wall, to an ice front, between shoals or grounded icebergs. Vertical fluctuations may be observed during changes of sea level. Fast ice may be formed in situ (in its original place) from sea water or by the freezing of drift ice of any stage to the shore. It may extend a few meters or several hundred kilometers from the coast. Fast ice may be more than one year old and may then be prefixed with the appropriate age category (second-year or multi-year). If it is thicker than about 2m above sea-level, it is called an ice shelf.

Fast ice boundary: The ice boundary at any given time between fast ice and drift ice.

Fast ice edge: The demarcation at any given time between fast ice and open water.

Finger rafted ice: Type of rafted ice in which floes thrust "fingers" alternately over and under the other.

Finger rafting: Type of rafting whereby interlocking thrusts are formed, each floe thrusting "fingers" alternately over and under the other. Common in nilas and gray ice.

Firn: Old snow which has recrystallized into a dense material. Unlike snow, the particles are to some extent joined together. However, unlike ice, the air spaces in it still connect with each other.

First-year ice: Sea ice of not more than one winter's growth developing from young ice. It has a thickness of from 30 centimeters to 2m and may be subdivided into thin first-year ice/white ice, medium first-year ice, or thick first-year ice.

Flaw: A narrow separation zone between pack ice and fast ice, where the pieces of ice are in a chaotic state; it forms when pack ice shears under the effect of a strong wind or current along the fast ice boundary.

Flaw lead: A passage-way between (pack) drift ice and fast ice which is navigable by surface vessels.

Flaw polynya: A polynya between pack ice and fast ice.

Floating ice: Any form of ice found floating in water. The principal kinds of floating ice are lake ice, river ice, and sea ice, which form by the freezing of water at the surface, and glacier ice (ice of land origin), which is formed on land or in an ice shelf. The concept includes ice that is stranded or grounded.

Floe: Any relatively flat piece of sea ice 20m or more wide. Floes are subdivided according to horizontal extent. Giant, over 10 km wide; Vast, 2 to 10 km wide; Big, 500 to 2,000m wide; Medium, 100 to 500m wide; and Small, 20 to 100m wide.

Floeberg: A massive piece of sea ice composed of a hummock, or a group of hummocks, frozen together and separated from any ice surroundings. It may protrude up to 5m above sea level.

Flooded ice: Sea ice which has been flooded by melt-water or river water and is heavily loaded by water and wet snow.

Fracture: Any break or rupture through very close ice, compact ice, consolidated ice, fast ice, or a single floe resulting from deformation processes. Fractures may contain brash ice and/or be covered with nilas and/or young ice. Their length may vary from a few meters to many kilometers.

Fracture zone: An area which has a great number of fractures.

Fracturing: Pressure process whereby ice is permanently deformed and rupture occurs. Most commonly used to describe breaking across very close ice, compact ice, or consolidated ice.

Frazil ice: Fine spicules or plates of ice suspended in water.

Friendly ice: From the point of view of the submariner, an ice canopy containing many large skylights or other features which permit a submarine to surface. There must be more than ten such features per 30 nautical miles (56 km) along the submarine's track.

Frost smoke: Fog-like clouds due to the contact of cold air with relatively warm water, which can appear over openings in the ice, or to leeward of the ice edge, and which may persist while ice is forming.

Giant floe: See Floe.

Glacier: A mass of snow and ice continuously moving from higher to lower ground or, if afloat, continuously spreading. The principle forms of glacier are inland ice sheets, ice shelves, ice streams, ice caps, ice piedmonts, cirque glaciers, and various types of mountain (valley) glaciers.

Glacier berg: An irregularly-shaped iceberg.

Glacier ice: Ice in, or originating from, a glacier, whether on land or floating in the sea as icebergs, bergy bits, or growlers.

Glacier tongue: Projecting seaward extension of a glacier, usually afloat. In the Antarctic, glacier tongues may extend for over many tens of kilometers.

Grease ice: A later stage of freezing than frazil ice when the crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the sea a matte appearance.

Grey (gray) ice: Young ice 10 to 15 centimeters thick. Less elastic than nilas and breaks on swell. Usually rafts under pressure.

Grey (gray)-white ice: Young ice 15 to 30 centimeters thick. Under pressure more likely to ridge than to raft.

Grounded hummock: Hummocked grounded ice formation. There are single grounded hummocks and lines (or chains) of grounded hummocks.

Grounded ice: Floating ice which is aground in shoal water (See Stranded ice).

Growler: Smaller piece of ice than a bergy bit or floeberg, often transparent but appearing green or almost black in color, extending less than 1m above the sea surface and normally occupying an area of about 20 square meters.

Hostile ice: From the point of view of the submariner, an ice canopy containing no large skylights or other features which permit a submarine to surface.

Hummock: A hillock of broken ice which has been forced upwards by pressure. May be fresh or weathered. The submerged volume of broken ice under the hummock, forced downwards by pressure, is termed a bummock.

Hummocked ice: Sea ice piled haphazardly one piece over another to form an uneven surface. When weathered, it has the appearance of smooth hillocks.

Hummocking: The pressure process by which sea ice is forced into hummocks. When the floes rotate in the process it is termed screwing.

Iceberg: A massive piece of ice of greatly varying shape, protruding more than 5m above sea level, which has broken away from a glacier. May be afloat or aground. Icebergs may be described as tabular, dome-shaped, sloping, pinnacled, weathered, or glacier bergs.

Iceberg tongue: A major accumulation of icebergs projecting from the coast, held in place by grounding and joined together by fast ice.

Ice blink: A whitish glare on low clouds above an accumulation of distant ice.

Ice bound: A harbor, inlet, etc. is said to be ice bound when navigation by ships is prevented on account of ice, except possibly with the assistance of an icebreaker.

Ice boundary: The demarcation at any given time between fast ice and drift ice or between areas of drift ice of different concentrations (See Ice edge).

Ice breccia: Ice of different stages of development frozen together.

Ice cake: Any relatively flat piece of sea ice less than 20m wide.

Ice canopy: Drift ice from the point of view of the submariner.

Ice cover: The ratio of an area of ice of any concentration to the total area of sea surface within some large geographic locale; this locale may be global, hemispheric, or prescribed by a specific oceanographic entity such as Baffin Bay or the Barents Sea.

Ice edge: The demarcation at any given time between the open sea and sea ice of any kind, whether fast or drifting. It may be termed compacted or diffuse (See Ice boundary).

Ice field: Area of floating ice consisting of any size of floes, which is greater than 10 km wide (See Ice patch).

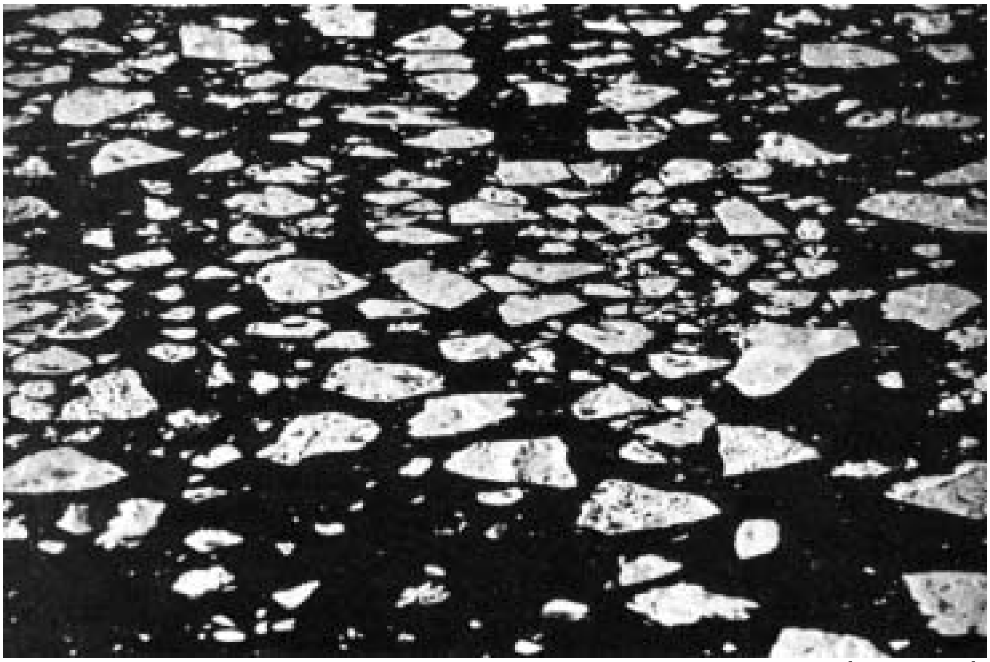
Ice foot: A narrow fringe of ice attached to the coast, unmoved by tides and remaining after the fast ice has moved away.

Ice-free: No sea ice present. There may be some ice of land origin present (See Open water).

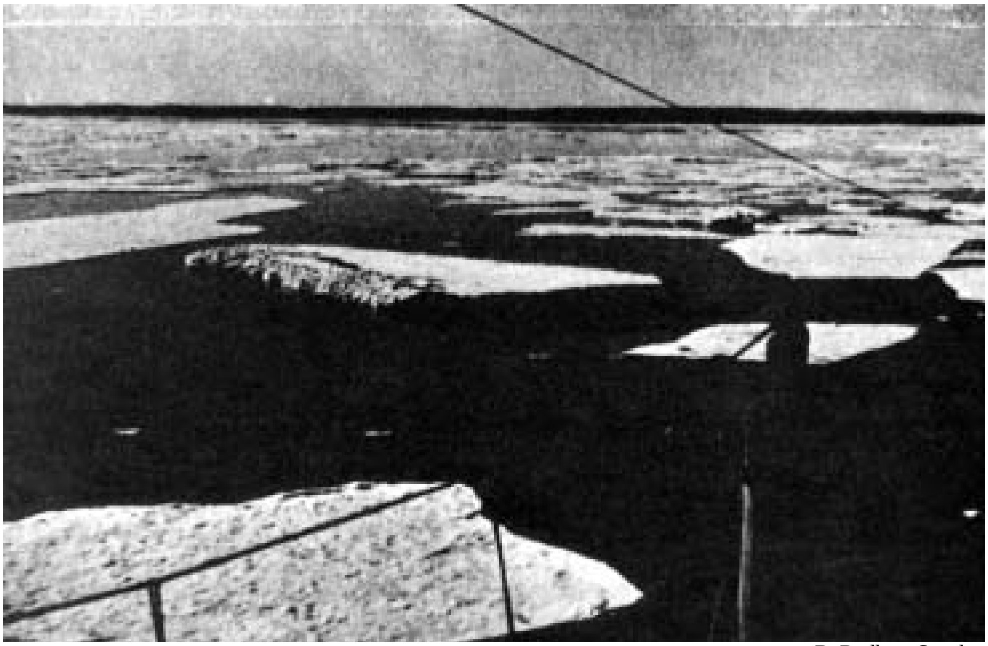
H.H. Valeur—Denmark

F.Krugler—Germany (Fed. Rep.)

VERY OPEN PACK ICE



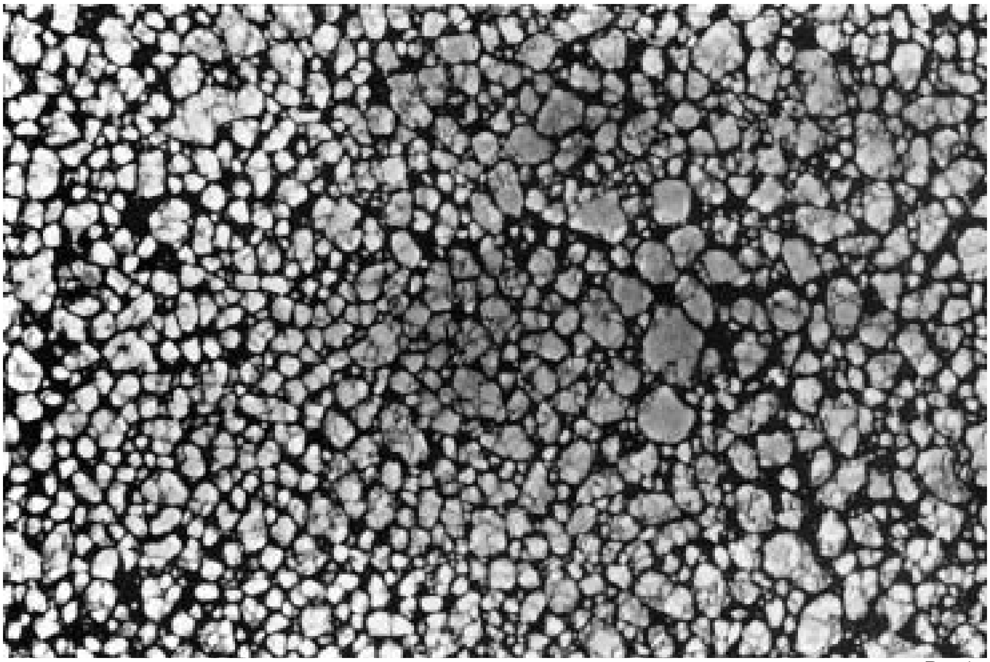
H.H. Valeur—Denmark



B. Rodhe—Sweden

OPEN PACK ICE

Return to page: 41

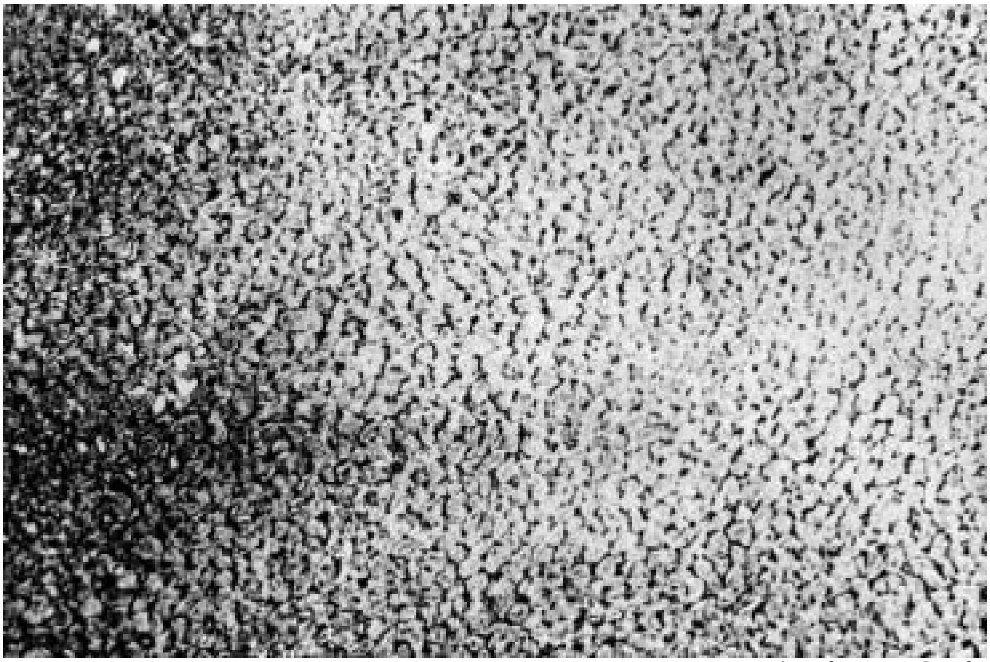


Russia

R. Van Humbeck—Canada

CLOSE PACK ICE

Return to page: 21



Armed Forces—Canada

Hamburg-Germany (Fed. Rep.)

VERY CLOSE PACK ICE

Return to page: 42

Armed Forces—Canada

Meteorological Agency—Japan

COMPACT PACK ICE

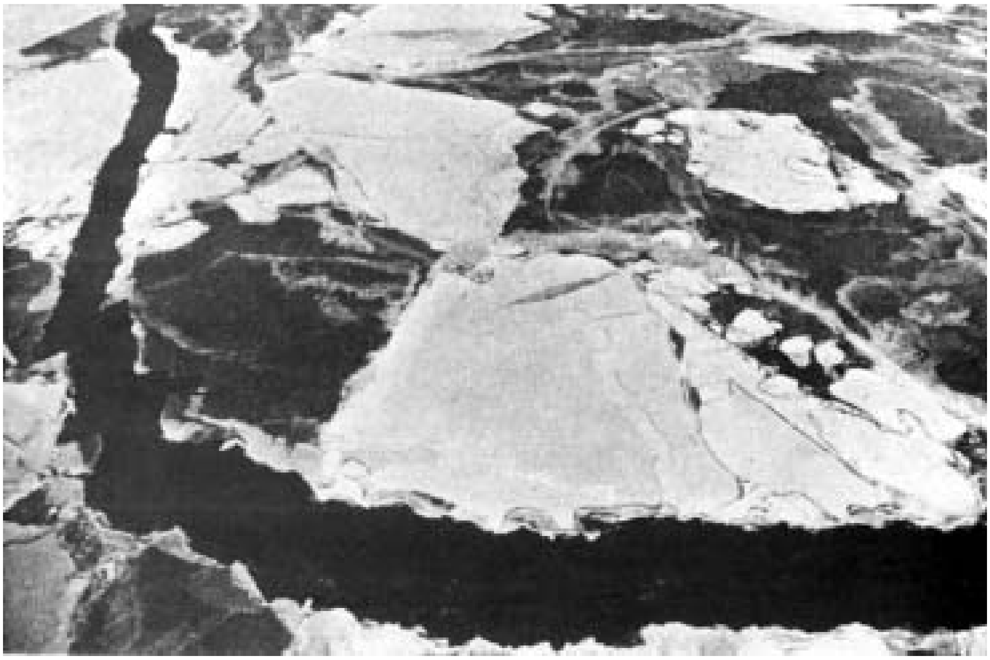
Armed Forces—Canada

J.F. Hurley—Great Britain

CONSOLIDATED PACK ICE


Meteorological Agency—Japan

FRACTURE ZONE



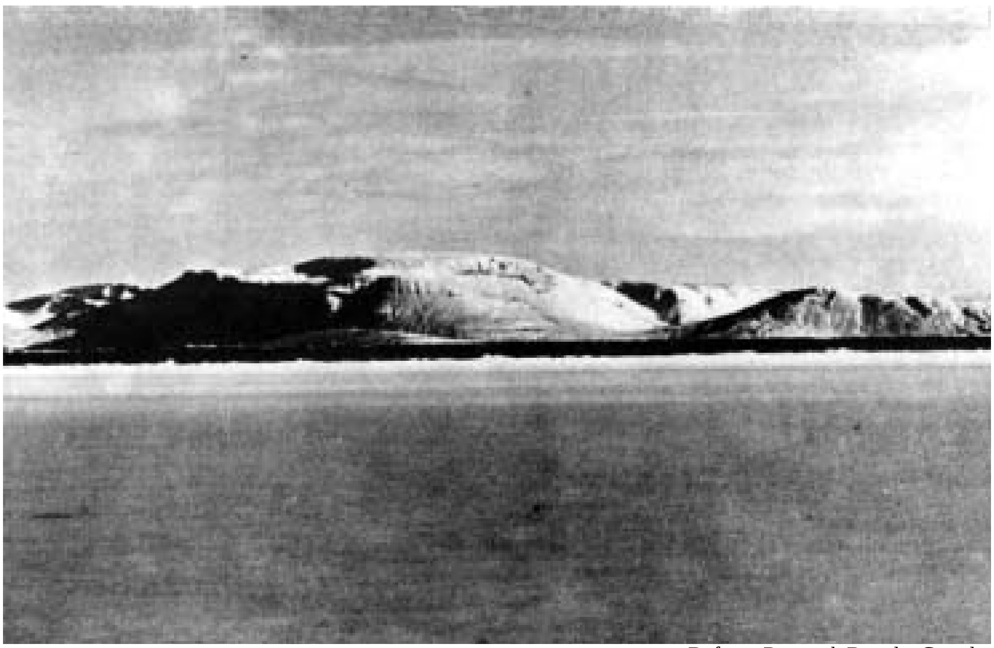
Armed Forces—Canada

N.M. Shakirov—Russia

LEAD

Table of Contents

Trans-Antarctic Expedition—Great Britain



Defense Research Board—Canada

SHORE LEAD

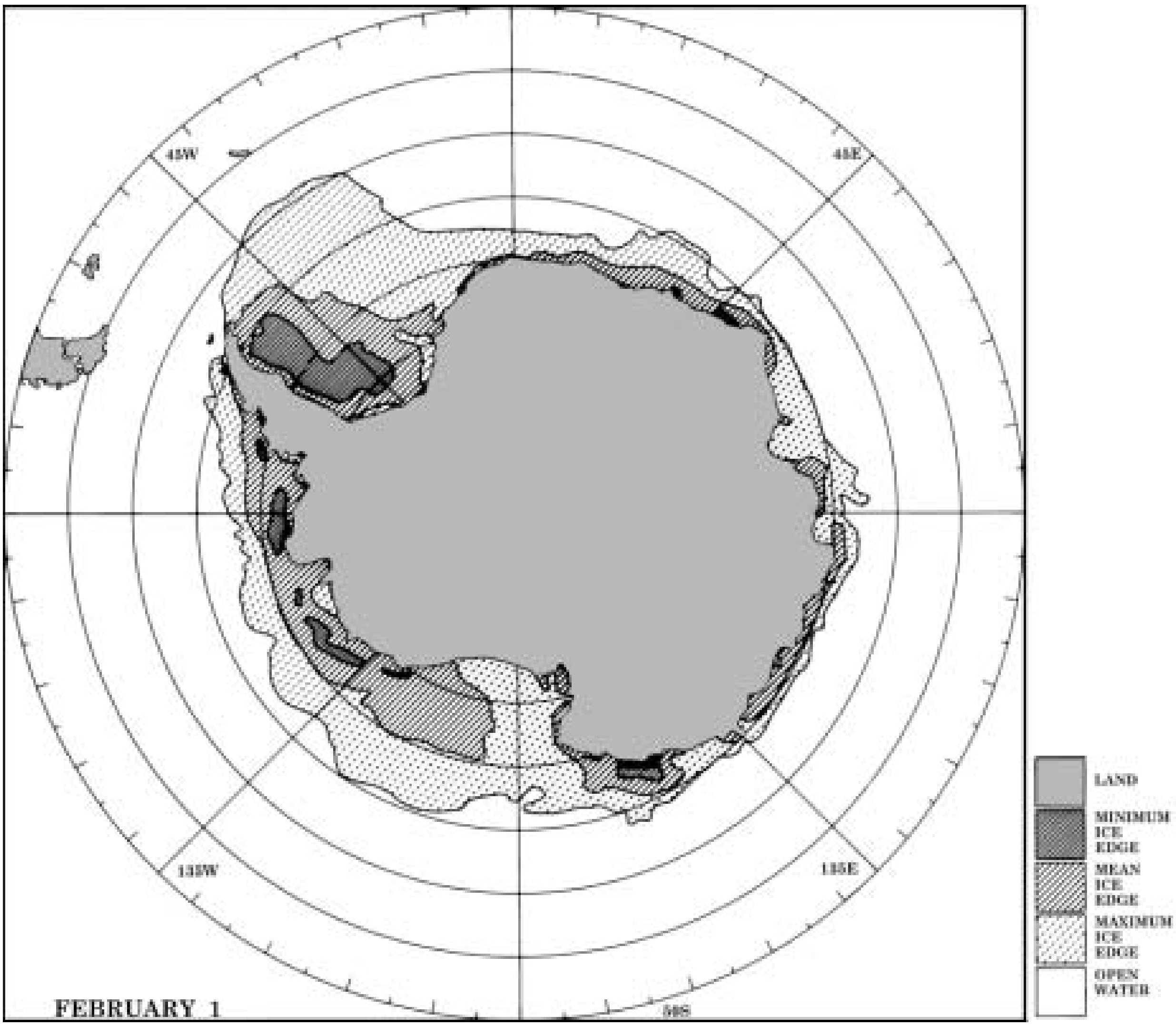
Return to page: 42

Armed Forces—Canada

V.A. Voevodin—U.S.S.R.

FLAW LEAD

MAXIMUM — MEAN — MINIMUM ICE EDGES



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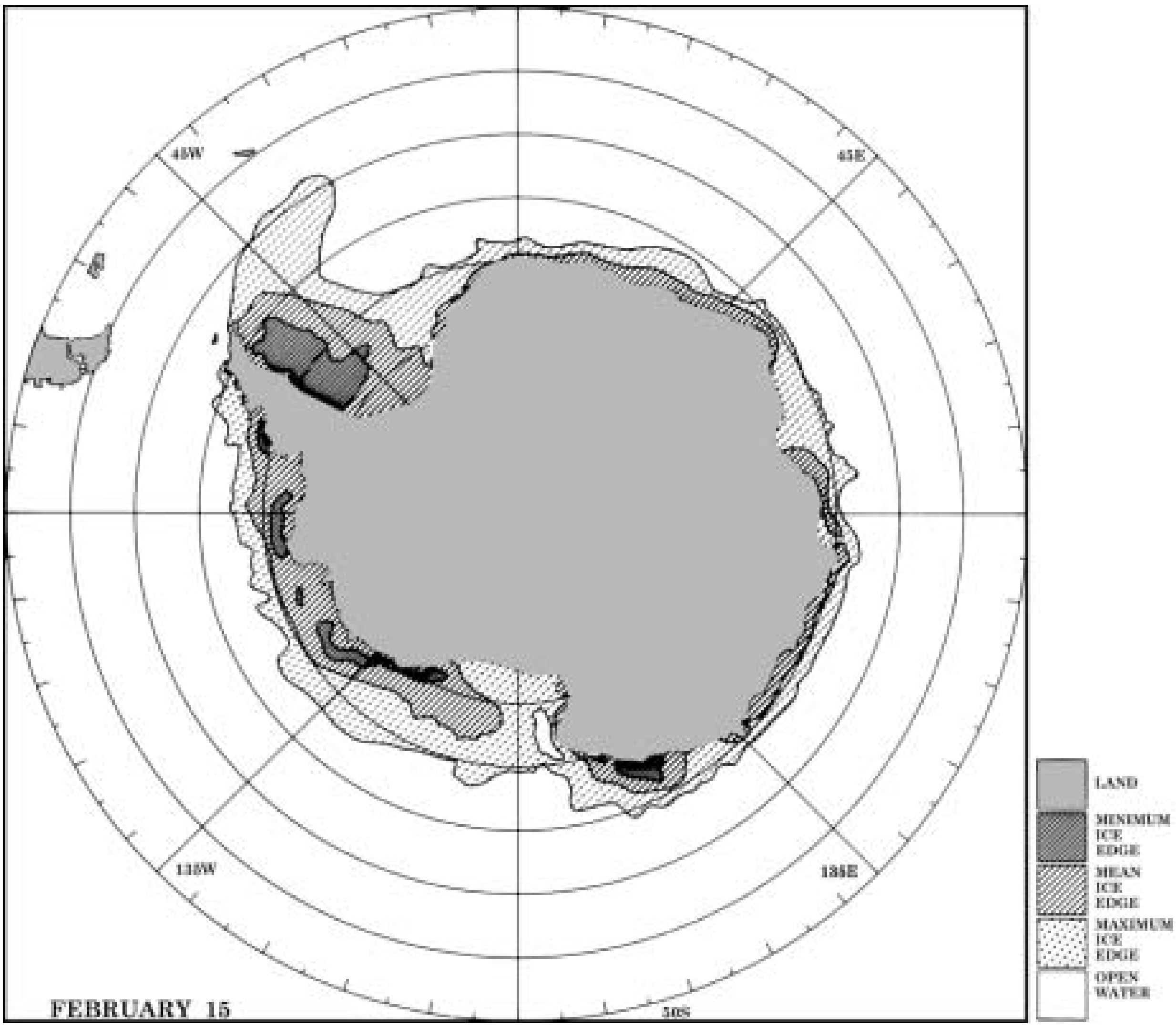

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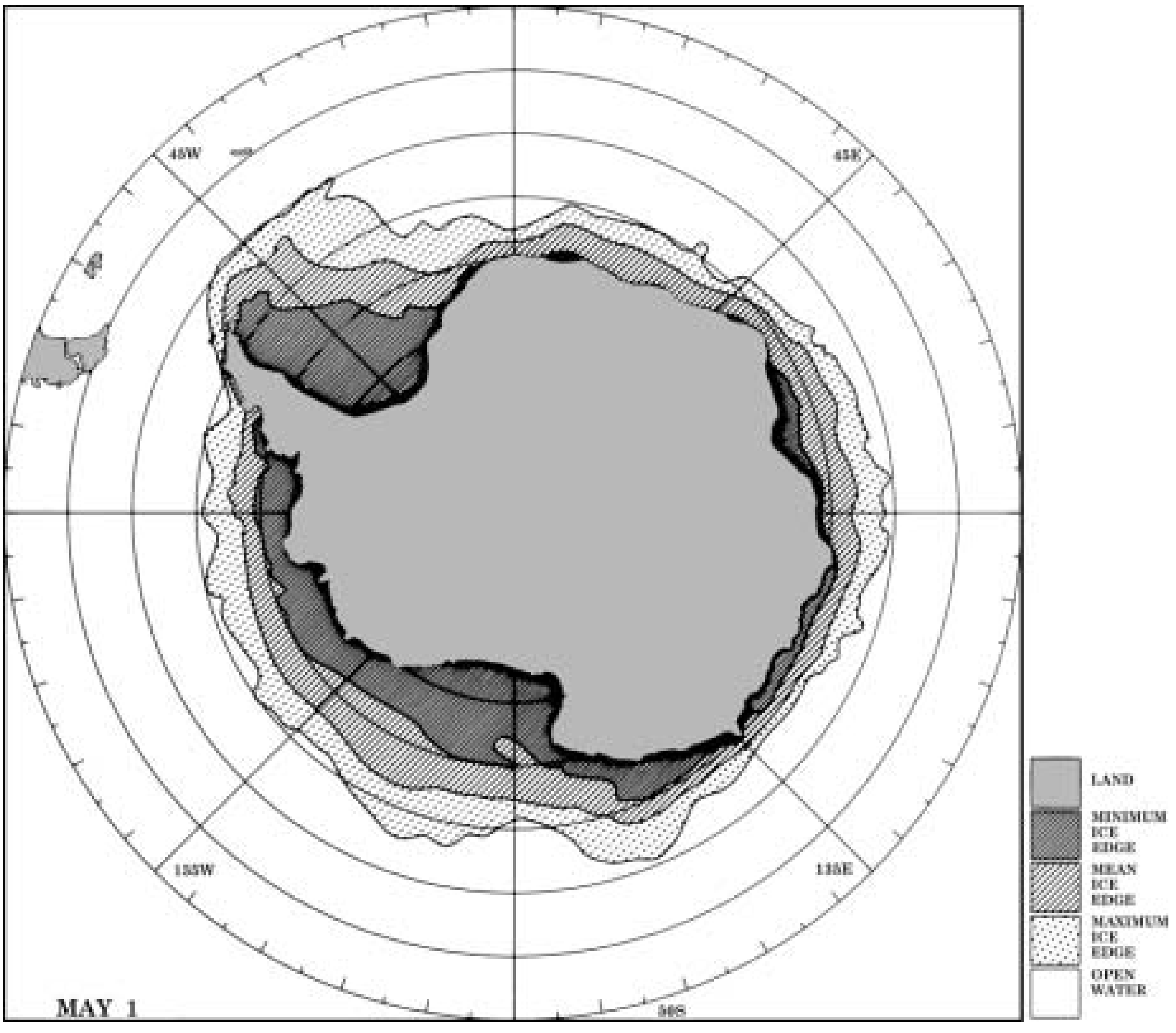

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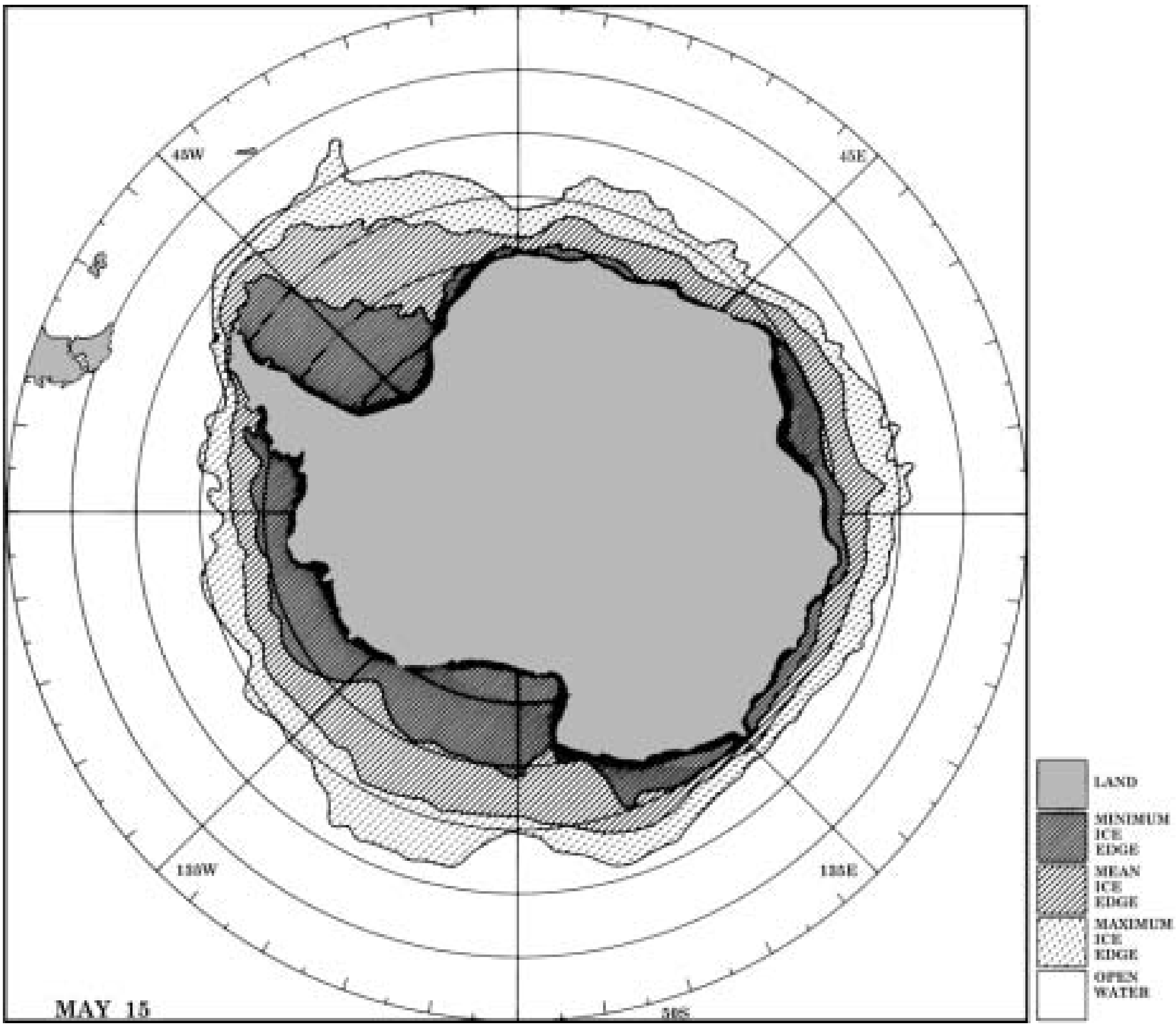

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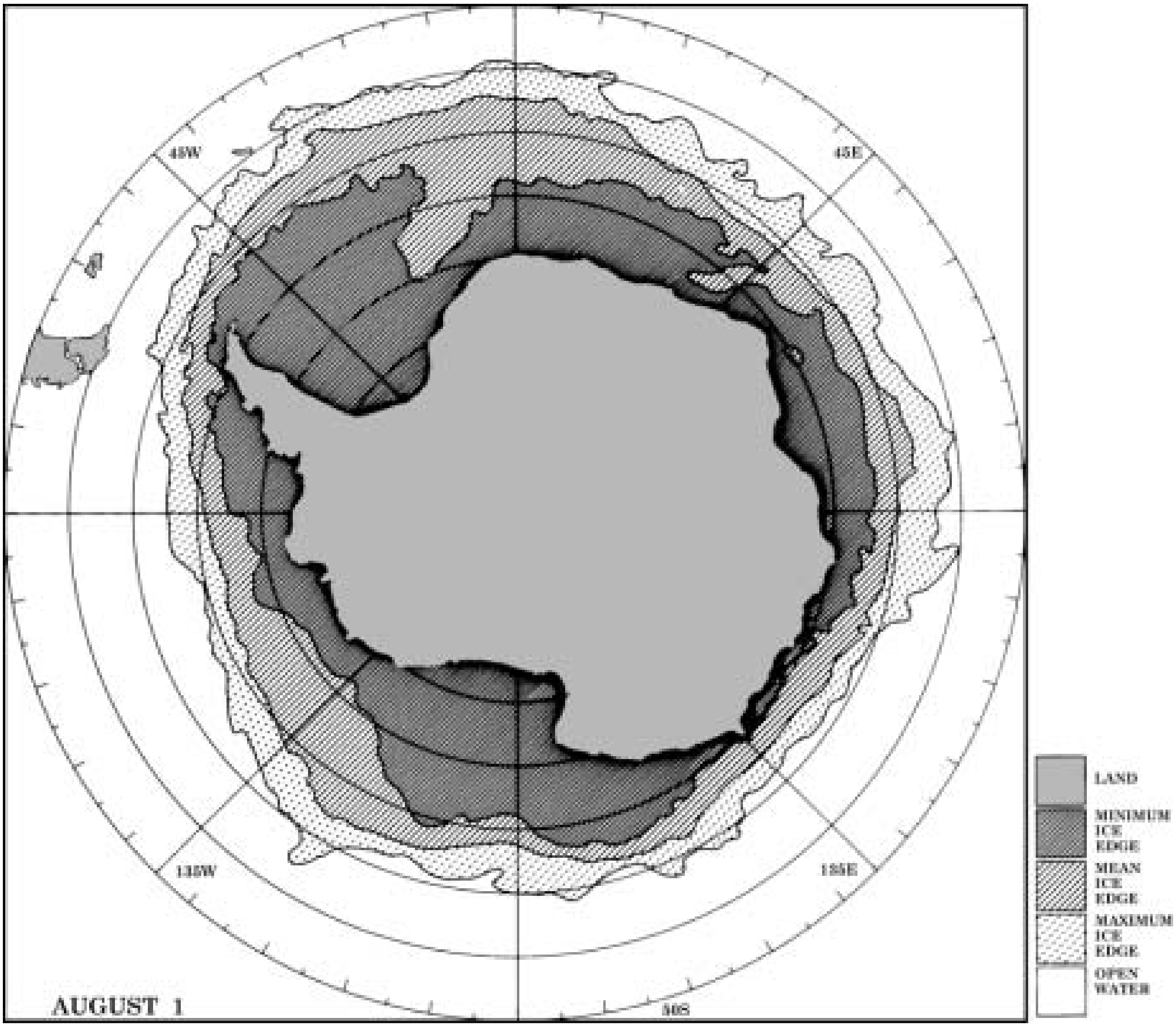

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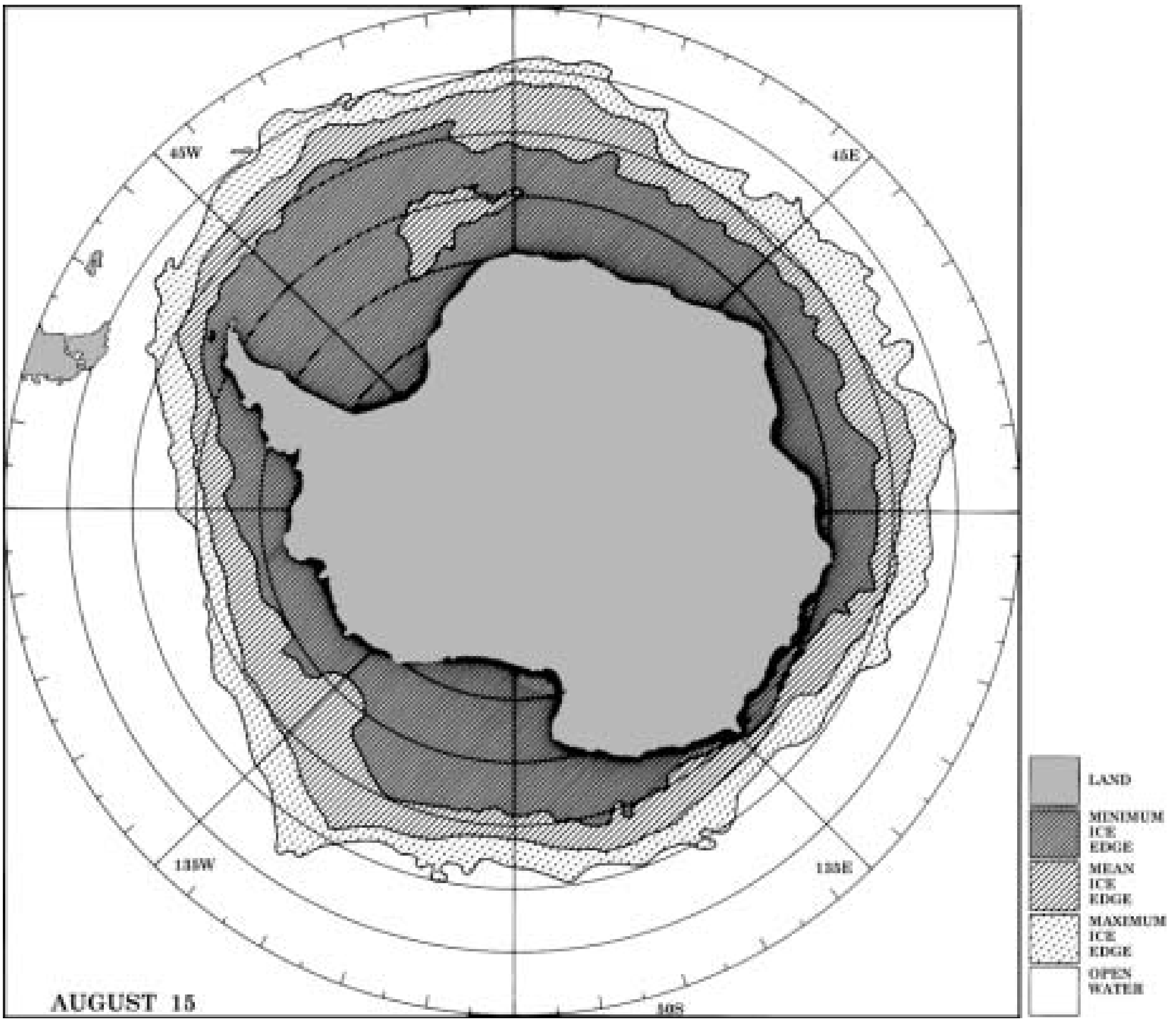

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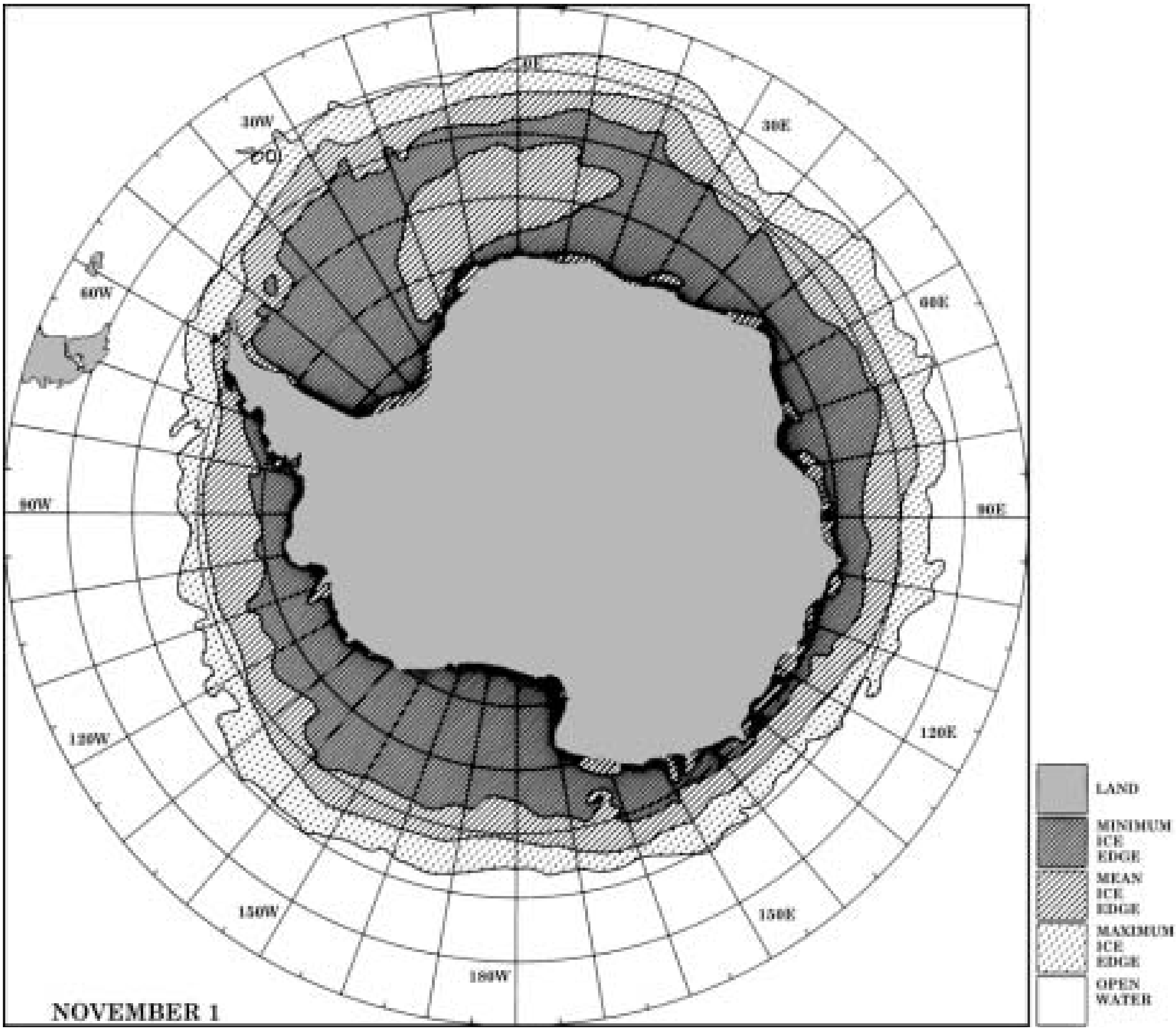
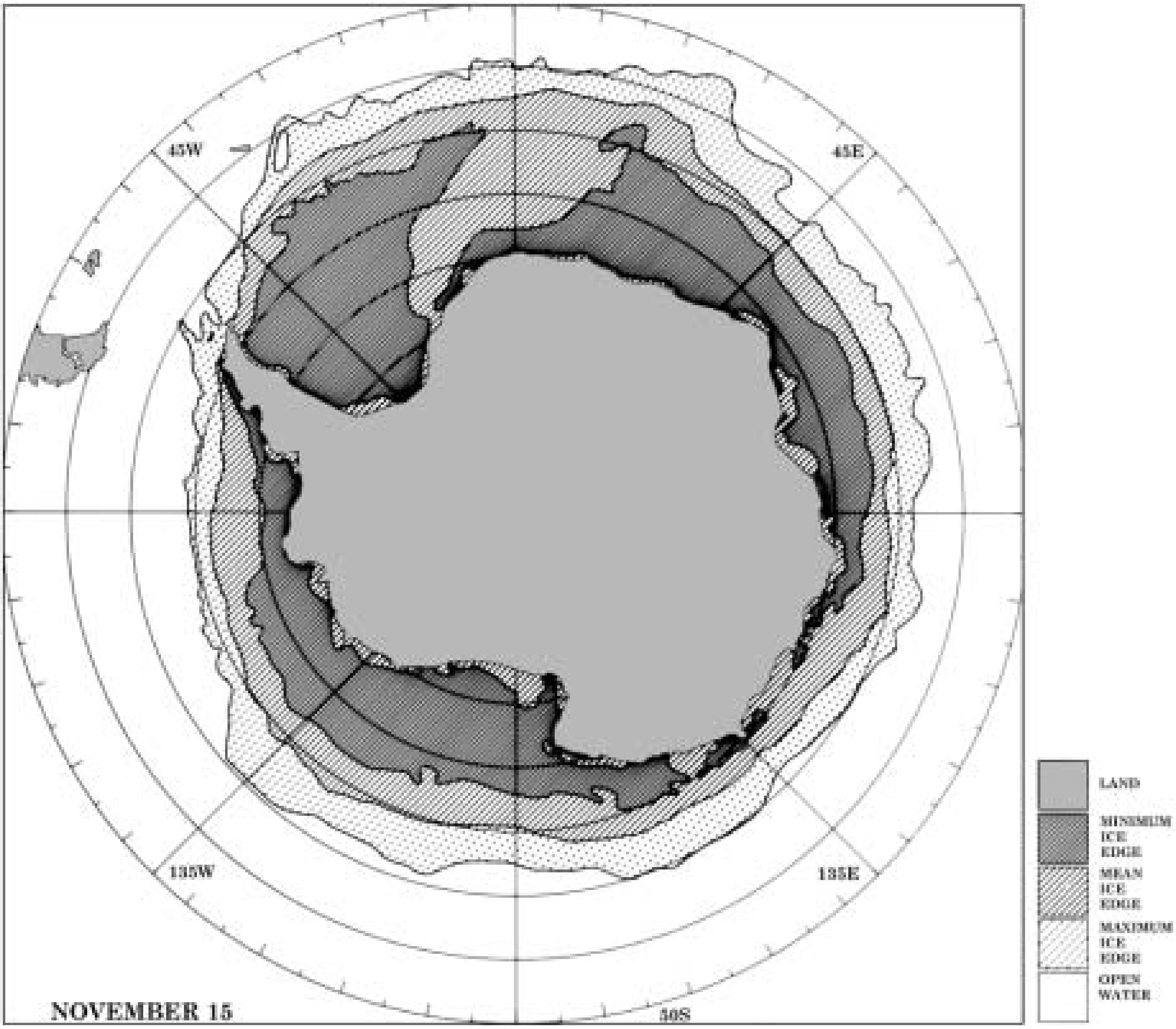


MAXIMUM — MEAN — MINIMUM ICE EDGES



Ice front: The vertical cliff forming the seaward face of an ice shelf or other floating glacier varying in height from 2 to 50m or more above sea-level (See Ice wall).

Ice island: A large piece of floating ice protruding about 5m above the sea level which has broken away from an Antarctic ice shelf, having a thickness of from 30 to 50m, and an area of from a few thousand square meters to 500 square kilometers or more. Usually characterized by a regularly undulating surface which gives it a ribbed appearance from the air.

Ice jam: An accumulation of broken river ice or sea ice caught in a narrow channel.

Ice keel: From the point of view of the submariner, a downward-projecting ridge on the underside of the ice canopy; the counterpart of a ridge. Ice keels may extend as much as 50m below the sea level.

Ice limit: Climatological term referring to the extreme minimum or maximum extent of the ice edge in any given month or period based on observations over a number of years. Term should be preceded by minimum and maximum (See Mean ice edge).

Ice massif: A variable accumulation of close or very close drift ice (pack ice) covering hundreds of square kilometers which is found in the same regions every summer.

Ice of land origin: Ice formed on land or in an ice shelf, found floating in water. The concept includes ice that is stranded or grounded.

Ice patch: An area of pack ice less than 10 kilometers wide.

Ice port: An embayment (indentation) in an ice front, often of a temporary nature, where ships can moor alongside and unload directly onto the ice shelf.

Ice rind: A brittle shiny crust of ice formed on a quiet surface by direct freezing or formation of grease ice, usually in water of low salinity. Thickness to about 5cm. Easily broken by wind or swell, commonly breaking in rectangular pieces.

Ice shelf: A floating ice sheet of considerable thickness showing 2 to 50m or more above sea level, attached to the coast. Usually of great horizontal extent and with a level or gently undulating surface. Nourished by annual snow accumulation and often also by the seaward extension of land glaciers. Limited areas may be aground. The seaward edge is termed an ice front.

Ice stream: Part of an inland ice sheet in which the ice flows more rapidly and not necessarily in the same direction as the surrounding ice. The margins are sometimes clearly marked by a change in the direction of the surface slope, but may be indistinct.

Ice under pressure: Ice in which deformation processes are actively occurring and therefore a potential impediment or danger to shipping.

Ice wall: An ice cliff forming the seaward margin of a glacier which is not afloat. An ice wall is aground, the rock basement being at or below sea level (See Ice front).

Jammed brash barrier: A strip or narrow belt of new, young, or brash ice (usually 100 to 5,000m wide), formed at the edge of either drift or fast ice or at the shore. It is heavily compacted mostly due to wind action and may extend from 2 to 20m below the surface but does not normally have appreciable topography. Jammed brash barriers may disperse with changing winds but can also consolidate to form a strip of unusually thick ice as compared to the surrounding drift ice.

Lake ice: Ice formed on a lake, regardless of observed location.

Large fracture: Fracture more than 500m wide.

Large ice field: An ice field over 20 kilometers wide.

Lead: Any fracture or passage-way through sea ice which is navigable by surface vessels.

Level ice: Sea ice which is unaffected by deformation.

Light nilas: Nilas which is more than 5 centimeters in thickness and rather lighter in color than a dark nilas.

Mean ice edge: Average position of the ice edge in any given month or period based on observations over a number of years. Other terms which may be used are mean maximum ice edge and mean minimum ice edge (See Ice limit).

Medium first-year ice: First-year ice 70 to 120 centimeters thick.

Medium floe: See Floe.

Medium fracture: Fracture 200 to 500m wide.

Medium ice field: An ice field 15 to 20 kilometers wide.

Multi-year ice: Old ice up to 3m or more thick which has survived at least two summers' melt. Hummocks even smoother than in second-year ice, and the ice is almost salt-free. Color, where bare, is usually blue. Melt pattern consists of large interconnecting irregular puddles and a well-developed drainage system.

New ice: A general term for recently formed ice which includes frazil ice, grease ice, slush, and shuga. These types of ice are composed of ice crystals which are only weakly frozen together (if at all) and have a definite form only while they are afloat.

New ridge: Ridge newly formed with sharp peaks and slope of sides usually 40˚. Fragments are visible from the air at low altitude.

Nilas: A thin elastic crust of ice, easily bending on waves and swell under pressure, thrusting in a pattern of interlocking "fingers" (finger rafting). Has a matte surface and is up to 10 centimeters in thickness. May be subdivided into dark nilas and light nilas.

Nip: Ice is said to nip when it forcibly presses against a ship. A ship so caught, though undamaged, is said to have been nipped.

Old ice: Sea ice which has survived at least one summer's melt, thickness up to 3m or more. Most topographic features are smoother than on first-year ice. May be subdivided into second-year ice and multi-year ice.

Open ice: Floating ice in which the concentration is four-tenths to six-tenths with many leads and polynyas, and the floes are generally not in contact with one another.

Open water: A large area of freely navigable water in which sea ice is present in concentrations less than one-tenth. When there is no sea ice present, the area should be termed ice free.

Pack ice: Concentration of seven-tenths or more of drift ice (See Drift ice). (The term was formally used for all ranges of concentration.)

Pancake ice: Predominantly circular pieces of ice from 30 centimeters to 3m in diameter. Up to about 10 m in thickness with raised rims due to the pieces striking up against one another. It may be formed on a slight swell from grease ice, shuga, or slush or as a result of the breaking of ice rind, nilas, or under severe conditions of swell or waves, of gray ice. It also sometimes forms at some depth, at an interface between water bodies of different physical characteristics, from where it floats to the surface. Its appearance may rapidly cover wide areas of water.

Polynya: Any non-linear shaped opening enclosed in ice. Polynyas may contain brash ice and/or be covered with new ice, nilas, or young ice. Submariners refer to these as skylights. Sometimes the polynya is limited on one side by the coast and is called a shore polynya or by fast ice and is called a flaw polynya. If it recurs in the same position every year, it is called a recurring polynya.

Puddle: An accumulation of melt-water on ice, mainly due to the melting of snow, but in the more advanced stages also to the melting of the ice. Initial stage consists of patches of melted snow.

Rafted ice: Type of deformed ice formed by one piece of ice overriding another (See Finger rafting).

Rafting: Pressure processes whereby one piece of ice overrides another. Most common in the new and young ice (See Finger rafting).

Ram: An underwater ice projection extending from an ice wall, ice front, iceberg, or floe. Its formation is usually due to a more intensive melting and erosion of the unsubmerged part.

Recurring polynya: A polynya which recurs in the same position every year.

Ridge: A line or wall of broken ice forced up by pressure. May be fresh or weathered. The submerged volume of broken ice under a ridge, forced downwards by pressure, is termed an ice keel.

Ridged ice: Ice piled haphazardly one piece over another in the form of ridges or walls. Usually found in first-year ice (See Ridging).

Ridged ice zone: An area in which much ridged ice with similar characteristics has formed.

Ridging: The pressure process by which sea ice is forced into ridges.

River ice: Ice formed on a river, regardless of observed location.

Rotten ice: Sea ice which has become honeycombed and which is in an advanced state of disintegration.

Sastrugi: Sharp, irregular ridges formed on a snow surface by wind erosion and deposition. On mobile floating ice, the ridges are parallel to the direction of the prevailing wind at the time they were formed.

Sea ice: Any form of ice found at sea which has originated from the freezing sea water.

Second-year ice: Old ice which has survived only one summer's melt. Thickness up to 2.5m and sometimes more. Because it is thicker than first-year ice, it stands higher out of the water. In contrast to multi-year ice, summer melting produces a regular pattern of numerous small puddles. Bare patches and puddles are usually greenish-blue.

Shearing: An area of ice is subject to shear when the ice motion varies significantly in the direction normal to the motion, subjecting the ice to rotational forces. These forces may result in phenomena similar to flaw.

Shear ridge: An ice ridge formation which develops when one ice feature is grinding past another. This type of ridge is more linear than those caused by pressure alone.

Shear ridge field: Many shear ridges side by side.

Shore lead: A lead between drift ice and the shore, or between drift ice and an ice front.

Shore melt: Open water between the shore and the fast ice, formed by melting and/or due to river discharge.

Shore polynya: A polynya between drift ice and the coast, or between drift ice and an ice front.

Shore ice ride-up: A process by which ice is pushed ashore as a slab.

Shuga: An accumulation of spongy white ice lumps, a few centimeters wide; they are formed from grease ice or slush and sometimes from anchor ice rising to the surface.

Skylight: From the point of view of the submariner, thin places in the ice canopy, usually less than 1m thick and appearing from below as relatively light, translucent patches in dark surroundings. The undersurface of a skylight is normally flat. Skylights are called large if big enough for a submarine to attempt to surface through them (120m), or small if not.

Slush: Snow that is saturated and mixed with water on land or ice surfaces, or as a viscous floating mass in water after a heavy snowfall.

Small floe: See Floe.

Small fracture: Fracture 50 to 200m wide.

Small ice cake: An ice cake less than 2m wide.

Small ice field: An ice field 10 to 15 kilometers wide.

Snow-covered ice: Ice covered with snow.

Snowdrift: An accumulation of wind-blown snow deposited in the lee of obstructions or heaped by wind eddies. A crescent-shaped snowdrift, with ends pointing downwind, is known as snow barchan.

Standing floe: A separate floe standing vertically or inclined and enclosed by rather smooth ice.

Stranded ice: Ice which has been floating and has been deposited on the shore by retreating high water.

Strip: Long and narrow area of pack ice, about 1 kilometer or less wide. Usually composed of small fragments detached from the main mass of ice which have run together under the influence of wind, swell, or current.

Tabular berg: A flat-topped iceberg. Most tabular bergs form by calving from an ice shelf and show horizontal banding (See Ice island).

Thaw holes: Vertical holes in sea ice formed when surface puddles melt through to the underlying water.

Thin first-year ice/white ice: First-year ice 30 to 70cm thick. May sometimes be subdivided into first stage, 30 to 50cm thick, and second stage, 50 to 70cm thick.

Tide crack: Crack at the line of junction between an immovable ice foot or ice wall and fast ice, the latter subject to rise and fall of the tide.

Tongue: A projection of the ice edge up to several kilometers in length, caused by wind or current.

Vast floe: See Floe.

Very close pack ice: Pack ice in which the concentration is nine-tenths to less than ten-tenths.

Very open pack ice: Pack ice in which the concentration is one-tenth to three-tenths and water preponderates over ice.

Very small fracture: Fracture 1 to 50m wide.

Very weathered ridge: Ridge with peaks very rounded, slope of sides usually 20˚ to 30˚.

Water sky: Dark streaks on the underside of low clouds, indicating the presence of water features in the vicinity of sea ice.

Weathered ridge: Ridge with peaks slightly rounded and slope of sides usually 30˚ to 40˚. Individual fragments are not discernible.

Weathering: Processes of ablation and accumulation which gradually eliminate irregularities in an ice surface.

White ice: (See Thin first-year ice/white ice).

Young coastal ice: The initial stage of fast ice formation consisting of nilas or young ice. Its width varies from a few meters up to 200m from the shoreline.

Young ice: Ice in the transition stage between nilas and first-year ice, 10 to 30 centimeters thick. May be subdivided into gray ice and gray-white ice.

Magnetic Field

(The following information was prepared by the U.S. Naval Oceanographic Office.)

Antarctic Magnetic Field.—The dip poles, commonly referred to as the magnetic poles, are the points on the earth's surface at which the horizontal component (H) of the total magnetic field decreases to a minimum (approaches zero) and where the magnetic field is most nearly all vertical. At such a point, a dip needle will stand straight up and down.

The magnetic poles should not be confused with the geomagnetic poles. Although the term geomagnetic pole does not have a rigorous definition and usage varies among different textbooks, the most common definition is a theoretical point at which the axis of a central dipole field intersects the earth's surface. However, the earth's magnetic field is not a pure dipole as it contains approximately 5 per cent quadrupole and external magnetic field components. Therefore, the two principal magnetic dipoles (North and South) do not correspond with the geomagnetic poles.

There is a misconception that the needle of a magnetic compass points to the magnetic pole. Actually, the direction indicated by such a needle is the local horizontal direction of the earth's magnetic lines of force. These lines eventually converge at the magnetic poles but wander considerably. A compass cannot be used in regions near the magnetic pole to find direction as it will remain in any direction in which it happens to be placed. In reality, a rather large area, in which a compass cannot be used, surrounds the magnetic pole because of the low magnitude of H. Where H is approximately 6,000 nanoteslas (nT) or less, the compass is frequently erratic. The magnetic compass is not reliable for underway navigation where H is 3,000 nT or less. An illustration of horizontal magnetic intensity contours shows the areas bounded by the 3000 and 6,000 nT contours. In comparison with the North Magnetic Pole, the region surrounding the South Magnetic Pole, where the compass is unreliable, is much smaller.

Magnetic Poles.—The Department of Defense (DoD) computed the location of the North Magnetic Pole on January 1, 1995, to be 79˚00'N, 105˚06'W and the location of the South Magnetic Pole to be 64˚44'S, 138˚38'E. These locations were computed using the 1995 Epoch World Magnetic Model, WMM-95, which was used in the compilation of charts published by NIMA from January 1995 to January 2000. A 2000 version of the Epoch World Magnetic Model is now available for use, replacing the 1995 model.

WMM-95 is the product of a cooperative effort between the United States Naval Oceanographic Office (NAVOCEANO) and the United Kingdom's British Geological Survey (BGS). It is the official model for both the U.S. and U.K. defense establishments.

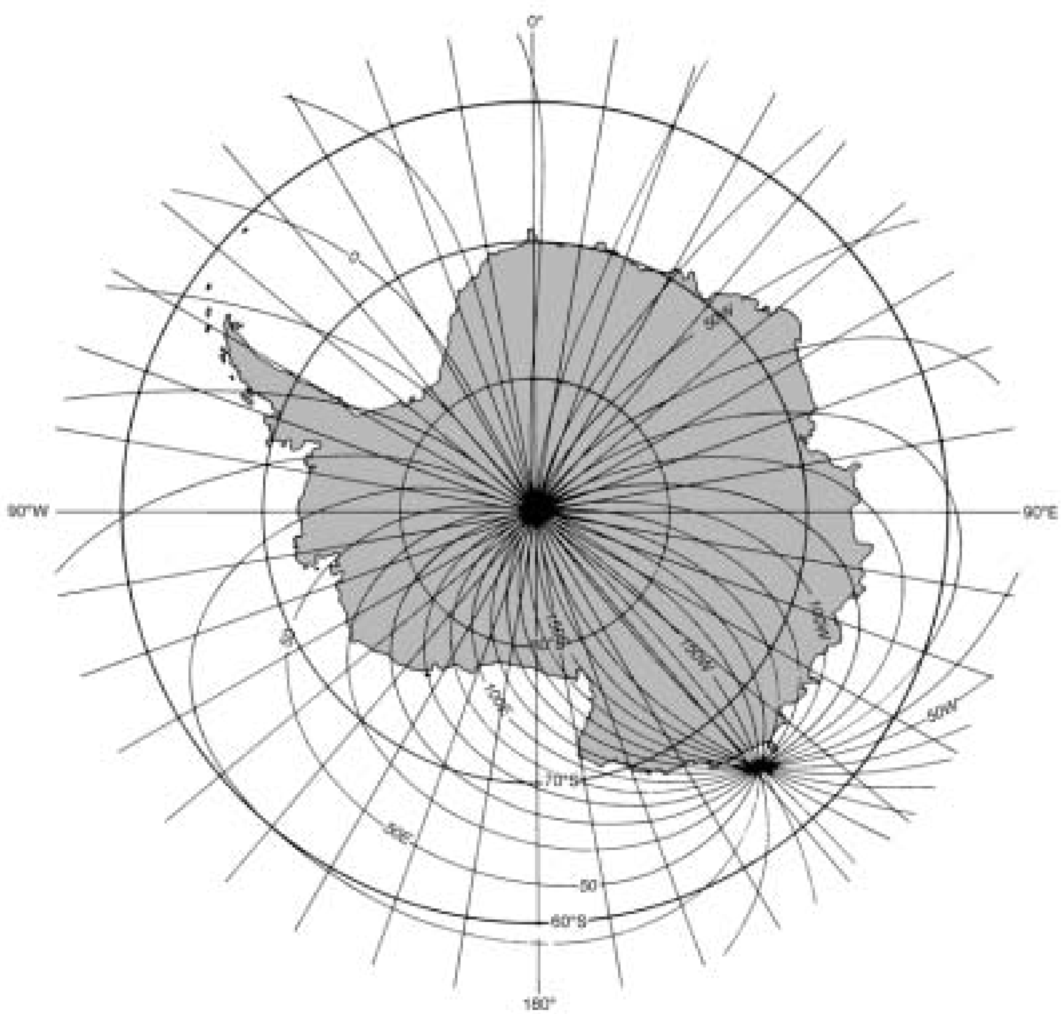
Magnetic Variation.—Magnetic variation information printed on topographic maps and navigation charts is derived from a model, which must be redefined at least every five years. The principal reason is that the earth's magnetic field changes appreciably in that period of time, and it has not been possible to predict the secular change with confidence more than a few years into the future.

Variation, also known as magnetic declination, is measured in angular units and named East or West to indicate the side of True North on which the N part of the magnetic meridian lies. East variation is positive and West variation is negative. The DoD publishes grid variation charts which illustrate the angle between the grid and magnetic meridians at any place.

Anomalies.—Significant magnetic anomalies may exist due to local magnetization in the earth's crust. These geologically produced magnetic fields cannot be modeled on a world-wide basis. Individual detailed geomagnetic surveys are required. Local conductivity anomalies will affect the way external magnetic fields generate currents in the crust, which in turn generate induced magnetic fields. These induction fields will also be local in character. Observations of erratic compass behavior should be reported with details of the particular circumstances at the time. Any disturbances to the geomagnetic field can also interfere with magnetic navigation. The flow of the solar wind (which contains electrons and protons) past the earth creates magnetic disturbances at the earth's surface. Some of these disturbances are known to be highly localized while others occur over wide areas. Auroras are the visible result of a significant magnetic storm.

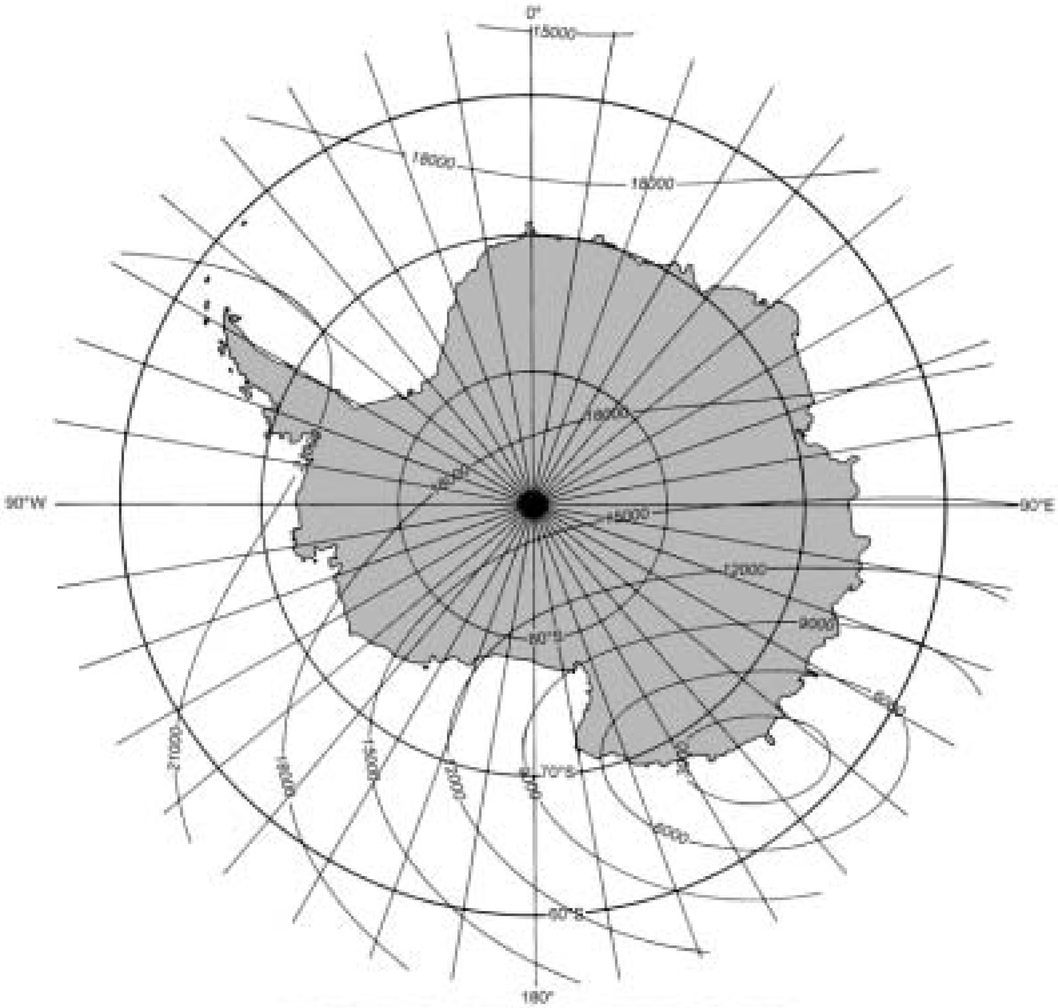
There are four different periodicities of magnetic disturbances. Although magnetic storms can occur at any time, they are most numerous during the period of maximum activity in the 11-year sunspot cycle. There is a weak semi-annual periodicity where the level of disturbance is at a maximum in October and April. More prominently, magnetic storms tend to have a 27-day repetition period due to the synodic rotation period of the sun, that is, the apparent rotation period as seen from the earth. Magnetic storms typically last 2 to 3 days. The substorms which accompany them only last from 1 to 3 hours and tend to occur more frequently and more strongly at local midnight.

During a particularly intense magnetic storm, such as occurred in March 1989, electrical currents are generated in the magnetosphere and the ionosphere. The magnetic fields of these currents also induce fluctuating voltages in the earth and cause additional current. The total current can significantly alter the geomagnetic field observed at the earth's surface and change its direction as much as several degrees and its magnitude as much as 10 per cent.



MAGNETIC VARIATION

Contour interval = 10 Degrees



HORIZONTAL INTENSITY

Contour interval = 3000 Nanoteslas

Navigation.—Navigation by magnetic compass in polar regions is much less reliable than in equatorial and mid-latitudes. Low directive force on the compass card, the enhanced effects of magnetic storms near the magnetic poles, the relatively sparse knowledge of local anomalies in regions outside commercial traffic areas, and the slow drift of the actual magnetic pole positions all contribute. As a minimum, the most current magnetic information and charts should be carried. Any chart older than the current model should be replaced.

Charts of the geomagnetic field are available from the Department of Defense (DoD). Magnetic variation charts are published every five years. Charts of the total intensity, vertical intensity, horizontal intensity, and inclination (magnetic dip) are published every ten years.

Meteorology

The meteorological conditions encountered on the Antarctic continent and adjacent seas are the world's most adverse. The frequent passage of intense cyclonic offshore storms (60˚ to 70˚S), the strong outflow of relatively cold air from the continent (katabatic winds), extremely low temperatures, and precipitation in excess of evaporation are the major features that contribute to the rigorous climatic conditions. Not only are the average conditions harsh, but the weather can be extremely variable. This high degree of variability and the relatively sparse number of weather stations makes meteorological forecasting somewhat unreliable.

In coastal areas, the mean temperatures range from about 0˚C in summer to -30˚C or lower in winter. The Antarctic Peninsula, particularly its NW coast and the islands of the Scotia Arc, have a milder winter, with mean temperatures of approximately 10˚C. The mean temperatures on the continental plateau are much colder, ranging from -40˚C in summer to -70˚C or lower in winter. These extremely low temperatures result from the loss of heat by radiation from the snow covered ground. The temperature is actually much higher at a height of only a few meters above the ground.

Coastal areas can be stormy. Storm conditions are associated with cyclonic centers or depressions which are frequently generated around Antarctica between 60˚S and 70˚S. The S extent of these storms can penetrate the coastal areas, causing windy conditions and heavy snowfalls.

Katabatic winds or gravity winds occur when cold, dense air flows down the slopes from the high continental interior. These winds can be extremely strong. With the passage of cyclonic storms, conditions are enhanced for katabatic outflow from the continent, particularly along the E coast of the Antarctic Peninsula and along most of the coast of East Antarctica. These katabatic winds often last for the entire period, one to several days, between cyclonic storm passages. They are more frequent in winter and may continuously exhibit wind speeds in excess of 70 knots for several hours. During the summer, the frequency of windstorms (both katabatic and cyclonic) is significantly reduced, but by no means nonexistent.

The primary role of the polar regions in relation to global climate is that they provide a major heat sink to counterbalance the heat source of the tropics. Atmospheric motions are initiated and maintained by patterns of heating and cooling. Changes in these thermal patterns, if persistent, can change atmospheric circulation patterns which, in turn, feed back to alter the thermal patterns.

Thermal patterns are influenced by the composition of the atmosphere and by radiative and reflective properties of the earth's surface. Constituents of the atmosphere, both natural and anthropogenic, which can significantly affect radiative properties of the air and hence the climate, include carbon monoxide, water vapor, and ozone. Chlorofluoromethane, nitrous oxide, methane, and carbon tetrachloride also affect the radiative properties, but to a less certain degree.

Radiative properties of the earth's surface also have a strong influence on the patterns of heating and cooling and, thereby, atmospheric motions. Seasonal fluctuations in the extent of the ice around Antarctica strongly influence the heat exchange between the air and sea surface. This interaction affects air temperature and the degree to which Antarctica acts as a global heat sink. For example, the strength, frequency, and track of cyclonic storms near 65˚S varies seasonally in response to the seasonal fluctuations of the drift ice boundaries. In the summer when the ice has receded, the intensity and frequency of cyclonic storms is reduced and they tend to pass to the S of their mean winter tracks.

The reflective properties or albedo of the surface of Antarctica strongly influence the heat budget of the polar region and hence the climate. Snow and ice can reflect up to 98 per cent of incoming solar radiation but they average about 80 per cent, while moderately rough ocean water will reflect only 10 to 15 per cent. This characteristic of the Antarctic ice cap provides a powerful positive feedback mechanism, affecting climate. For example, a decrease in the average Antarctic temperature will lead to an increase in sea ice cover, which, in turn, increases the albedo of the S pole and leads to further cooling. While the importance of Antarctica in influencing the global climate is clear, the interactions and feedback mechanisms of the atmosphere-hydrosphere-cryosphere system are far too complex and polar observations far too meager to provide a complete understanding of its role.

Weather-Related Phenomena

Superstructure Icing.—In certain weather conditions, ice accumulating on hulls and superstructures can be a serious danger to vessels. Ice accumulation may occur because of fog with freezing conditions; freezing rain or drizzle; and sea spray or salt water breaking over vessels when the air temperature is below freezing (about -1.9˚C).

The most dangerous form of icing is caused by sea spray, sometimes known as "Glaze Ice," which has high density and great powers of adhesion.

In evaluating the potential for superstructure icing, two categories were subjectively selected. Moderate ice accumulation seems to occur when the air temperature is less than or equal to -2˚C and the wind is stronger than or equal to 13 knots. If the air temperature decreases to -9˚C or below and the wind reaches 30 knots or more, ice accumulation takes place at an accelerated rate. This category is termed severe. For example, on a small fishing vessel of 300 to 500 tons displacement, ice accumulation in the severe category would exceed about 4 tons per hour.

Radio and radar failures due to ice accumulating on aerials and insulators may be experienced soon after superstructure icing begins. The ice tends to form high up on vessels and a large amount of accumulation may result in a loss of freeboard and stability.

The probability of forecasting gales with freezing air temperatures is made difficult by the sparseness of meteorological and oceanographic information in the Antarctic region. For this reason, superstructure icing represents a serious hazard to navigation anywhere S of the Antarctic Circle.

Immersion Hypothermia.—Immersion hypothermia is the loss of heat when a body is immersed in water. With few exceptions, humans die if their normal rectal temperature of approximately 37.6˚C drops below 25.9˚C. Cardiac arrest is the most common direct cause of death. Except in tropical waters warmer than 20˚ to 25˚C, the main threat to life during prolonged immersion is cold or cold and drowning combined.

Cold lowers the body temperature, which in turn slows the heart beat and lowers the rate of metabolism. This increases the amount of carbon dioxide in the blood and results in an impaired mental capacity which is a major factor in death by hypothermia. Numerous reports from wrecks and accidents in cold water indicate that people can become confused and even delirious, further decreasing their chances of survival.

The length of time that a human can survive in water depends on the water surface temperature and, to a lesser extent, on a person's behavior. The table following shows the approximate human survival time in the sea. Body type can cause deviations, since thin people become hypothermic more rapidly than fat people. Extremely fat people may survive almost indefinitely in water near 0˚C if they are warmly clothed.

The cooling rate can be slowed by the person's behavior and insulated gear. Studies have shown that if the critical heat loss areas can be protected, survival times will increase. The Heat Escape Lessening Posture (HELP) was developed for those persons in the water alone and The Huddle for small groups of people, but both methods require life preservers.

HELP involves holding the upper arm firmly against the sides of the chest, keeping the thighs together, and raising the knees to protect the groin area. In The Huddle, people face each other and keep their bodies as close together as possible. These positions improve survival time in water with a temperature of 8.9˚C to 4 hours, or approximately double that of a swimmer and one and one-half times that of a person in the passive position.

Table of Survival Time versus Water Temperature

Water temperature	Exhaustion or unconsciousness	Expected time of survival
0˚C	15 minutes	15 to 45 minutes
0˚ to 5˚C	15 to 30 minutes	30 to 90 minutes
5˚ to 10˚C	30 to 60 minutes	1 to 3 hours
10˚ to 15˚C	1 to 2 hours	1 to 6 hours
15˚ to 20˚C	2 to 7 hours	2 to 40 hours
20˚ to 25˚C	3 to 12 hours	3 hours to indefinite
25˚C	Indefinite	Indefinite

Near-drowning victims in cold water (temperature less than 21.1˚C) show much longer periods of revivability than usual. The keys to a successful revival are immediate cardio-pulmonary resuscitation (CPR) and administration of pure oxygen. The whole revival process may take hours and require medical help.

Windchill—Frostbite.—A body begins to lose heat when it is warmer than the surroundings. The rate of loss depends on the barriers to heat loss such as clothing and insulation in addition to the speed of air movement and the air temperature. Heat loss increases dramatically in moving air that is colder than skin temperature (33˚C). In the Antarctic, windchill results from the intense cold and strong winds. This combination affects not only comfort, but the morale and safety of personnel.

The equivalent windchill temperature relates a particular wind and temperature combination to whatever temperature would produce the same heat loss at about 3 knots, the normal speed of a person walking. At extremely cold temperatures, wind and temperature effect may account for only two-thirds of the heat loss from the body. For example, at a temperature of -40˚C, about one-third of the heat loss from the body occurs through the lungs in the process of breathing. Conversely, heat loss is not as great in bright sunlight.

When the skin temperature drops below 10˚C, a marked constriction of the blood vessels occurs, leading to vascular stagnation, oxygen want, and some cellular damage. The first indication that something is wrong is a painful tingling. Swelling of varying extent follows, provided freezing has not occurred. Excruciating pain may then be felt if the skin temperature is lowered rapidly, but freezing of localized portions of the skin may be painless when the rate of change is slow.

Cold allergy is a term applied to the welts which may occur. Chilblains usually affect the fingers and toes and are manifested as reddened, warm, and itching swollen patches. Trench foot and immersion foot present essentially the same picture. Both result from exposure to cold and a lack of circulation. Wetness can add to the problem as water and wind soften the tissues and accelerate heat loss. The feet swell, discolor, and frequently blister. Secondary infection is common and gangrene may result.

Injuries from the cold may, to a large extent, be prevented by maintaining natural warmth through the use of proper footgear and adequate, dry clothing. Personnel should avoid being in cramped positions or wearing constricting clothing. They should also carry out active exercises of the hands, legs, and feet.

Frostbite usually begins when the skin temperature falls within the range of -10˚ to -15.5˚C. Ice crystals form in the tissues and small blood vessels. Once started, freezing proceeds rapidly and may penetrate deeply. The rate of heat loss determines the rate of freezing, which is accelerated by wind, wetness, extreme cold, and poor blood circulation. Parts of the body most susceptible to freezing are those with surfaces large in relation to their volume, such as toes, fingers, ears, nose, chin, and cheeks.

Navigational Information

Pilotage.—Pilotage is not available at any place within the area covered by this publication. However, vessels approaching a manned base or harbor are advised to seek information concerning navigational conditions by radio.

Navigational Aids.—Lights, ranges, buoys, and beacons etc., are virtually non-existent in the Antarctic region. Such aids are subject to damage and failure by ice or storm, or may disappear altogether and remain unreported for long periods of time.

Polar Charts.—Even in high latitudes, mariners have exhibited an understandable partiality for Mercator charts, on which a rhumb line appears as a straight line, and these have been used virtually everywhere ships have sailed. However, as the latitude increases, the superiority of the Mercator projection decreases, primarily because the value of the rhumb line becomes progressively less. At latitudes greater than 60˚, the decrease in utility begins to be noticeable, and beyond 70˚, it becomes troublesome. In the clear polar atmosphere, visual bearings are observed at great distances, sometimes 50 miles or more. The use of a rhumb line to represent such a bearing and distance at high latitudes introduces excessive errors. Another problem with the use of Mercator charts at high latitudes is the increasing rate of change of scale over a single chart. This aspect results in the shape of the land mass being distorted and subsequent errors in measuring distances.

At some latitudes, the disadvantages of the Mercator projection outweigh its advantages. The latitude at which this occurs depends upon the physical features of the area, the configuration and orientation of land and water areas, the nature of the operation, and mostly, upon the previous experience and personal preference of the mariner. Because of differences of opinion in this matter, a transitional zone exists in which several projections may be useful. Under all circumstances, a wise navigator should be prepared to use any of them, because coverage of the operating area may not be adequate on the preferred projection.

Charts of polar areas are generally inferior to those of other regions because of lack of detail, inaccuracy, and poor coverage.

Relatively few soundings are available in polar areas and many of the coastal features are only shown on the chart by their general outlines. Large areas are perennially covered by ice which presents a changing appearance as the amount, position, and the character of the ice changes. Heavy covers of ice and snow also prevent the accurate determination of the surface features beneath.

Polar charts, of which relatively few are available, may be inaccurate because they are based upon limited information and reports from those who have been in the areas. These reports are usually less reliable than in other areas as icebergs are sometimes mistaken for islands, especially those having morainic deposits; and ice-covered islands are occasionally mistaken for grounded icebergs. In addition, shorelines are not easy to detect and inlets and sounds may be completely obscured by ice and snow.

The three chart projections most commonly used near the poles are the transverse Mercator, the modified Lambert conformal, and the polar stereographic. When a gyro is used as a directional reference, the track of the craft is approximately a great circle. A desirable chart is one on which a great circle is represented as a straight line with a constant scale and with angles correctly represented. These requirements are not met entirely by any single projection, but they are approximated by both the modified Lambert conformal and the polar stereographic.

Polar Navigation.—Navigation in polar regions does not differ materially from that in lower latitudes. However, unique conditions, such as high latitude and meteorological factors, require the use of special techniques. Much of the thinking of the marine navigator is in the terms of the "rectangular" world of the Mercator projection, on which the meridians are equally spaced with vertical lines perpendicular to the horizontal parallels of latitude. On such a projection, direction is measured relative to the meridians a straight line on a chart represents a rhumb line.

In polar regions, conditions are somewhat different as the meridians rapidly converge at the poles, which are centers of a series of concentric circles constituting the parallels of latitude. The rapid convergence of the meridians renders the usual convention of direction inadequate for some purposes and even visual bearings cannot be adequately represented as rhumb lines. At the pole, all directions are toward the opposite pole and lines of position, in the usual sense, are replaced by longitude.

Stars circle the sky without noticeable change in altitude and planets rise and set once each sidereal period (12 years for Jupiter, 30 years for Saturn). At the S pole, the sun rises about September 23; slowly spirals to a maximum altitude of approximately 23˚27' about December 21; slowly spirals downward to the horizon about March 21; and then disappears for another 6 months.

It requires about 32 hours for the sun to cross the horizon, during which time it circles the sky one and one-third times. The twilight periods, following sunset and preceding sunrise, last for several weeks. The moon rises and sets about once each month and only celestial bodies with S declination are visible at the pole.

The long polar night is not wholly dark as the full moon at this time rises relatively high in the sky. In addition, light from the aurora australis is often quite bright, occasionally exceeding that of the full moon. Even the planets and stars contribute an appreciable amount of light in this area where the snow cover provides an excellent reflecting surface.

All time zones, like all meridians, meet at the pole. Local time does not have its usual significance, because the hours of the day bear no relation to periods of light and darkness or to the altitude of celestial bodies.

Return to page: 18

Operations in polar regions are attended by hazards and problems not encountered elsewhere. Lack of knowledge, sometimes accompanied by fear of the unknown, has prevented navigation in these areas from being conducted with the same confidence with which it is pursued in more familiar areas. As experience in high latitudes has increased, much of the mystery surrounding these areas has been dispelled and operations there have become more predictable.

Before entering polar regions, navigators should acquaint themselves with the experience of those who have preceded them into these areas. This information can be found in accounts of explorers, reports of previous voyages in high latitudes, and articles in professional journals concerning operations in polar regions. The search for knowledge should not be confined to just navigation and such subjects as survival, geography, ice, climate, and weather should be studied.

Planning, important in any operation, is vital to the success of polar navigation. Vessels should be provided with all the needed charts, publications, and special navigational material. All available data and information from previous operations in the area should be available. Key personnel should be adequately instructed in polar navigation prior to departure or while enroute to the region. Forecasts on anticipated ice and weather conditions should be obtained before departure and on approach to the continent.

Radar.—In polar regions, where fog and long periods of continuous daylight or darkness reduce the effectiveness of both celestial navigation and visual piloting, radar is particularly valuable. Its value is further enhanced by the fact that polar seas are generally smooth, resulting in relatively little oscillation of the shipborne antenna. In addition, when ice is not present, relatively little sea return is encountered from the calm sea.

However, certain limitations exist with the use of radar in polar regions. Similarity of detail along the polar shore is even more apparent by radar than by visual observation. Lack of accurate detail on charts adds to the difficulty of coastal identification. Identification is even more of a problem when the shoreline is beyond the radar horizon and accurate contours are not shown on the chart. When an extensive mass of ice extends out from shore, accurate location of the shoreline is also extremely difficult.

Experience is required to interpret accurately the radar returns in polar regions where ice may cover both land and sea. A number of icebergs lying near the coast may be located too close together to be resolved, giving an altered appearance to a shoreline, or they may be mistaken for off-lying islands. The shadow of an iceberg or pressure ridge and the lack of return from an open lead in the ice may easily be confused. Smooth ice may look like open water.

As with visual bearings, radar bearings require correction for convergence unless the objects observed are quite close to the vessel.

As the state of the sea increases, so does the minimum size of berg that can be detected. On very rough seas, bergs as high as 15m cannot always be detected in the sea return. Only in exceptionally smooth seas can radar be depended upon to pick up growlers.

Meteorological conditions in certain areas affect radar propagation in a manner that may, under certain conditions, reduce the range in fog when radar is most needed.

Caution is essential during periods when vessels are navigating in consolidated ice during low visibility. Generally, large icebergs can be distinguished from adjacent drift ice returns at ranges of 3,500m or more, but they may be obscured at lesser ranges. Therefore, in no case should the radar be accepted as 100 per cent accurate, resulting in the relaxation of normal safety precautions.

Radio Direction Finder.—The Radio Direction Finder (RDF) is useful when the few transmitting stations in the polar region are within range. One of the principal uses of RDF in polar regions is to assist in locating other vessels, for rendezvous or other purposes. This is particularly true in an area of many icebergs, where radar may not distinguish between ships and bergs.

Magnetic Compass.—The magnetic compass depends for its directive force upon the horizontal intensity of the magnetic field of the earth. As the magnetic poles are approached, this force becomes progressively weaker until at some point the magnetic compass becomes useless as a direction-measuring device. In a marginal area, the magnetic compass must be kept under almost constant scrutiny as it may become somewhat erratic in dependability and its error may change rapidly. Compass observation logs are always useful to keep as a reference. Magnetic storms may also cause additional magnetic compass errors.

The magnetic poles themselves are somewhat elusive, because they participate in the normal diurnal, annual, and secular changes in the earth's field, as well as more erratic changes caused by magnetic storms.

Measurements indicate that the magnetic poles move within an elongated area of perhaps 100 miles in a generally N/S direction, and somewhat less in an E/W direction. Normally, they are at the S end of the area of movement at local noon and at the N end 12 hours later. However, during severe magnetic storms, this motion is upset and becomes highly erratic. Due to the motions of the poles, they are sometimes regarded as areas rather than points. Some evidence exists to support the belief that several secondary poles exist, although such alleged poles may be anomalies, possibly of intermittent or temporary existence. Various severe anomalies have been found to occur in the polar areas and others may exist.

The continual motion of the poles may account, at least in part, for the large diurnal changes in the variation encountered in high latitudes. Changes as large as 10˚ have been reported.

Measurements of the earth's magnetic field in polar regions are neither numerous nor frequent. The isogonic lines in these areas are close together, resulting in rapid changes within short distances in some directions. As a result, charted variation in polar regions is not at the same order of accuracy as elsewhere.

The decrease in horizontal intensity encountered near the magnetic poles, as well as magnetic storms, also affects the deviation of vessels. Any deviating magnetic influence remaining after adjustment, which is seldom perfect, exerts a greater influence as the directive force of horizontal intensity decreases. It is not uncommon for residual deviation determined in moderate latitudes to increase 10 or 20 fold in marginal areas. Interactions between correctors and compass magnets exert a deviating influence that may increase to a troublesome degree in high latitudes.

The heeling magnet, correcting for both permanent and induced magnetism, is accurately situated only for one magnetic latitude. Near the magnetic pole, its position might be changed, but this may induce sufficient magnetism in the Flinders Bar to more than offset the change in deviation due to the change in the position. In addition, the relatively strong vertical intensity may render the Flinders Bar a stronger influence than the horizontal field of the earth. When this occurs, the magnetic compass reading remains nearly the same on all headings.

Another effect of the decrease in the directive force of the compass is a greater influence of frictional error. This, combined with an increase in the period of the compass, results in greatly increased sluggishness in its return to the correct reading after being disturbed. For this reason, the magnetic compass may be frequently inaccurate for quite a long period after an impact by the vessel against ice.

Magnetic storms can also affect the magnetism of vessels as well as that of the earth. Changes in deviation of as much as 45˚ have been reported during severe magnetic storms, although it is possible that such large changes may be a combination of deviation and variation changes.

The area in which the magnetic compass reduces its value cannot be determined in specific terms. However, a magnetic compass in an exposed position generally performs better than one in an enclosed position. However, there is a danger of the compass liquid freezing when it is subjected to extremely low temperatures. Sufficient heat to prevent the liquid from freezing can normally be obtained from the compass light, which should not be turned off during severe weather.

Despite the various limitations, the magnetic compass is a valuable instrument in much of the polar regions, where the gyrocompass is also of reduced reliability. Careful compass adjustment, frequent checks, and review of the records of previous behavior are advised.

Gyro Compass.—The gyro compass is generally reliable up to about 70˚. At higher latitudes, the disturbing effect of imperfections in the compass or the adjustment is magnified. The latitude adjustment becomes critical and the speed error increases as the speed of the vessel approaches the rotational speed of the earth. In addition, the ballistic deflection error increases and the compass becomes slow to respond to correcting forces. Subsequently, frequent changes of course and speed, which are often necessary when proceeding through ice, introduce errors that are slow to settle out. When the gyro compass is deflected by the impact of the vessel against the ice, it does not return or stabilize quickly to the correct heading.

These errors increase and become more erratic as the vessel proceeds to higher latitudes. Extreme errors as large as 27˚ have been reported at latitudes greater than 82˚. The gyro compass probably becomes useless at about latitude 85˚. At latitude 70˚, the gyro error should be determined frequently and the gyro compass should be compared frequently with the magnetic compass. Instructions for use at high latitudes are sometimes provided by the manufacturer of the gyro compass.

Bearings.—Natural landmarks are plentiful in some areas, but their usefulness is restricted by the difficulty in identifying them, or locating them on the chart. Along many of the coasts in the Antarctic, the various points and inlets bear a marked resemblance to each other. In addition, the appearance of the coast is often very different when many of its features are masked by a heavy covering of snow or ice.

Bearings of landmarks are useful, but they have limitations. When bearings of more than two objects are taken, they may fail to intersect at a point because the objects may not be charted in their correct relation to each other. Even a two-point fix may be considerably in error since the objects used may be charted in correct relationship to one another, but in the wrong position geographically. However, in restricted waters, it is usually more important to know the position of the vessel relative to the nearby land and shoals than to know the accurate latitude and longitude. The bearings and distances of uncharted, locally known objects then become valuable.

When a position is established relative to nearby landmarks, it is good practice to use this to help establish the identity and location of some prominent feature a considerable distance ahead. Through this practice, unidentifiable or uncharted features can be used to establish future positions.

In high latitudes, it is not unusual to make use of bearings of objects which are located a considerable distance from the vessel. Because of the rapid convergence of the meridians in these areas, such bearings are not accurately represented by straight lines on a Mercator chart. Therefore, if this projection is used, the bearings should be corrected in the same manner as radio bearings because both can be considered to be great circles. (See Conversion Angle Table on page 51.) Neither visual nor radio bearings require a correction when plotting on a Lambert conformal or a polar stereographic chart.

Soundings.—Soundings are so important in polar regions that echo sounders are customarily operated continuously while underway. A good practice is to have two such instruments, preferably those of the recording type with a wide flexibility in range. Enough soundings have been obtained to produce an accurate portrayal of the bottom configuration in only a few parts of the polar regions. Hence, caution should be maintained at all times in order to avoid unobserved shoaling.

The polar regions have relatively few shoals, but a number of pinnacles and ledges may rise abruptly from the bottom in some areas. Such dangers constitute a threat to vessels because they exist in areas generally not surrounded by any apparent shoaling. Therefore, in unknown areas, vessels are advised to send one or more small craft ahead with portable sounding gear. It should be noted that echo sounders will not give a reading when ice is under the vessels or when the water beneath the ship is disturbed by turbulence by ice floes being shoved around. A vessel proceeding in uncharted coastal waters may minimize the risk of grounding by having a boat equipped with a portable echo sounder scout ahead.

In very deep water, 2,000m or more, the echo return from the bottom is sometimes masked by the sound of ice coming in contact with the hull of the vessel. This is generally not a problem when the bottom is close enough to be menacing. Ice generally prevents the effective use of a hand lead unless the vessel is stopped.

CONVERSION ANGLE TABLE FOR VISUAL BEARINGS IN POLAR WATERS

Difference of Longitude

Mid Latitude	0˚	0.5˚	1˚	1.5˚	2˚	2.5˚	3˚	3.5˚	4˚	4.5˚	Mid Latitude
61	0.0	0.2	0.4	0.7	0.9	1.1	1.3	1.5	1.7	2.0	61
62	0.0	0.2	0.4	0.7	0.9	1.1	1.3	1.5	1.8	2.0	62
63	0.0	0.2	0.4	0.7	0.9	1.1	1.3	1.6	1.8	2.0	63
64	0.0	0.2	0.4	0.7	0.9	1.1	1.3	1.6	1.8	2.0	64
65	0.0	0.2	0.5	0.7	0.9	1.1	1.4	1.6	1.8	2.0	65
66	0.0	0.2	0.5	0.7	0.9	1.1	1.4	1.6	1.8	2.1	66
67	0.0	0.2	0.5	0.7	0.9	1.2	1.4	1.6	1.8	2.1	67
68	0.0	0.2	0.5	0.7	0.9	1.2	1.4	1.6	1.9	2.1	68
69	0.0	0.2	0.5	0.7	0.9	1.2	1.4	1.6	1.9	2.1	69
70	0.0	0.2	0.5	0.7	0.9	1.2	1.4	1.6	1.9	2.1	70
71	0.0	0.2	0.5	0.7	0.9	1.2	1.4	1.7	1.9	2.1	71
72	0.0	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	2.1	72
73	0.0	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	2.2	73
74	0.0	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	2.2	74
75	0.0	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	2.2	75
76	0.0	0.2	0.5	0.7	1.0	1.2	1.5	1.7	1.9	2.2	76
77	0.0	0.2	0.5	0.7	1.0	1.2	1.5	1.7	1.9	2.2	77
78	0.0	0.2	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	78
79	0.0	0.2	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	79
80	0.0	0.2	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	80
81	0.0	0.2	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	81
82	0.0	0.2	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	82
83	0.0	0.2	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	83
84	0.0	0.2	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	84
85	0.0	0.2	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	85

The table should be entered with the middle latitude and the difference in longitude (between the object and the vessel). The angles listed in the table (corrections) represent the difference between the great circle bearing and the rhumb line direction (Mercator). The sign of the correction to be applied is, as follows:

Latitude of Vessel	Object/Landmark (direction from vessel)	Correction Sign
South	East	-
South	West	+
North	East	+
North	West	-

When vessels become beset by ice, they may lose steerage way and drift with the ice. Such vessels may be in danger of grounding as the ice moves over a shoal area. Therefore, it is important that soundings be continued to be taken even when a vessel is beset. If necessary, a hole should be made in the adjacent ice and a hand lead used. A vessel with limited means for freeing itself may prudently save such means for use only when there is danger of grounding.

Return to page: 50

Useful information concerning the depth of water in the vicinity of a vessel can sometimes be obtained by watching the ice. A stream of ice moving faster than surrounding ice or a stretch of open water located in loose drift ice often marks a channel leading through shoal water. A patch of stationary ice located in the midst of moving ice often may mark a shoal.

Some knowledge of earth formations may also prove helpful. The slope of the land is often an indication of the underwater gradient. Shoal water is often found off low islands and spits, etc., but seldom near a steep shore. Where glaciation has occurred, moraine deposits are likely to have formed an offshore bar. Submerged rocks and pinnacles are more likely to be encountered off a rugged shore than near a low, sandy beach.

Icebergs.—Radar can easily pick up large icebergs in ample time to avoid collision. However, small bergs or growlers, which are capable of inflicting serious damage to vessels, may go undetected even with moderate conditions of wind and sea. Only in exceptionally smooth seas can radar be depended upon to pick up growlers. Therefore, it is unsafe for any vessel, because of radar, to assume immunity to ice hazards.

Air temperatures are not a reliable guide to the presence of icebergs, nor can sea temperatures be depended upon to give warning of their approach. It is true that a small increase in water surface temperature can usually be detected within about 1 mile of an iceberg. This increase is due to the freshening of the surface layer of the sea by the melting ice. However, variations of surface temperature of the same order of magnitude are frequently encountered in the total absence of icebergs.

In fog, the use of the steam whistle or foghorn for detecting small bergs or growlers by echo is of little value. The sound waves will only be reflected by a high, vertical wall of ice and they are not always discernible. Hence, the absence of an echo does not mean that no bergs are close.

Care should be exercised when approaching icebergs and soundings should be taken continuously as submerged projections caused by overcutting may extend a considerable distance to seaward.

Vessels hove-to in drift ice during heavy weather are advised to place their bow against a floe and use their engines to hold themselves up into the wind. If vessels are allowed to drift in such circumstances, serious damage may be sustained from grinding and surging floes. Often in the mass of ice, old ice is integrated by a film of young ice. Under such conditions, it is prudent to remain amongst the young ice since its soft texture will buffer the vessel against encroachment by old ice.

When approaching snow-covered land from ice-free waters, a yellowish landblink is usually observed before the land is seen above the horizon. Many of the coasts of Antarctica are fronted by a belt of ice which extends between 20 and 60 miles offshore. Hence, a strip of ice-free water lies adjacent to the shore. When transiting in this strip of water, vessels should maintain observations of any movement of the belt of drift ice. With onshore winds, the belt of drift ice may be driven in quickly and such vessels placed in danger of being set on to the land.

An accumulation of icebergs offshore invariably marks a shoal. An area of water lying offshore from which a line of icebergs extends is almost certain to be foul. Islands with nearly continuous lines of icebergs extending between them and the shore are usually connected to the coast by shallow water or by a submerged shoal ridge. However, if the icebergs are concentrated around the islands, leaving wide spaces free of ice, such spaces are probably clear of shoals. A coast that is fringed by glaciers or studded with inshore bergs, but is free of ice to seaward, is usually considered to be safe up to about 1 mile from the shore.

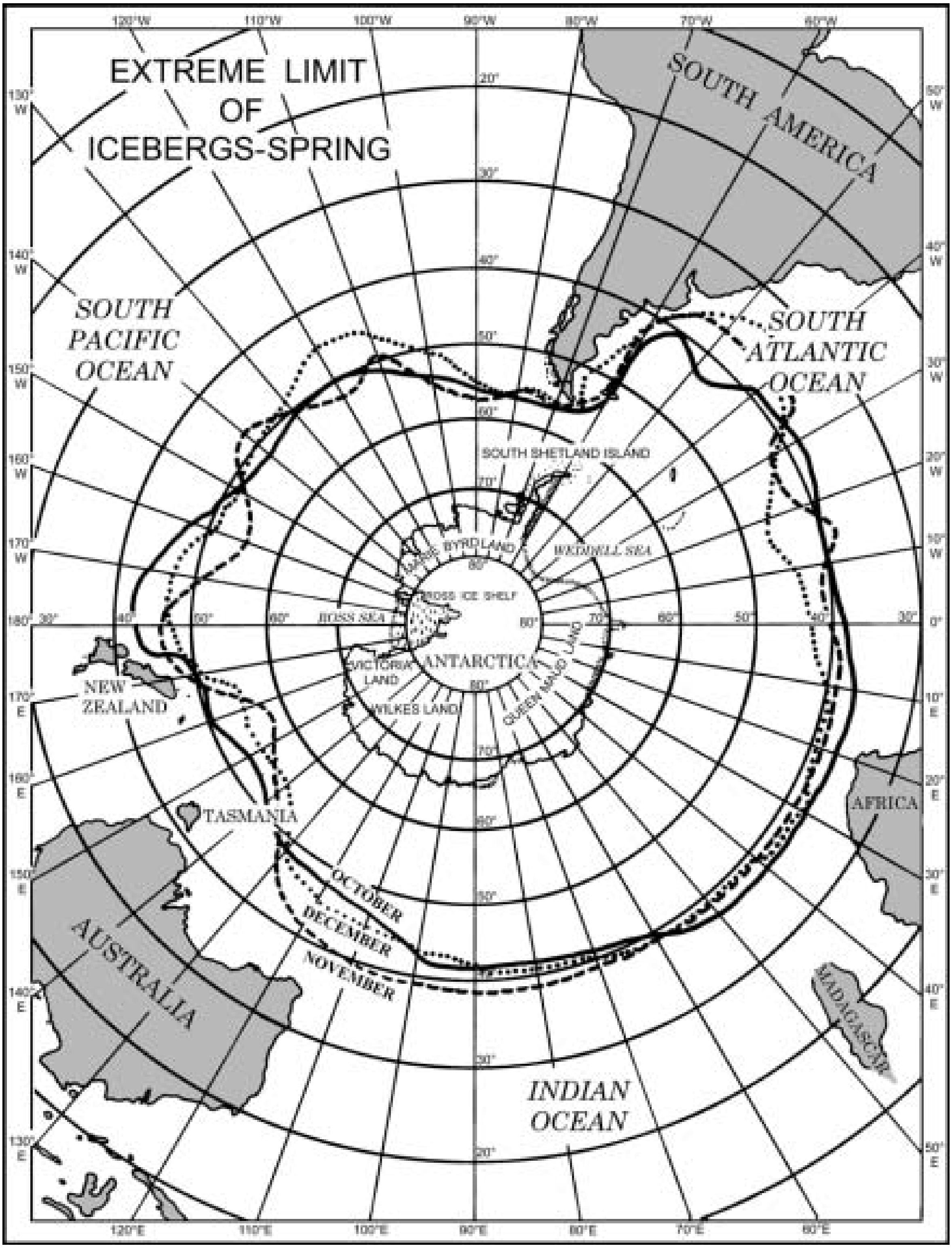
Bays in which icebergs are found generally have a channel leading into them. Channels, the sides of which are bordered with bergs, may invariably be considered safe if their centers are clear of ice. Open water will usually be found during the summer adjacent to coasts where offshore winds prevail. (See Geophysical Features—Physical Geography on page 8 and Ice on page 15.)

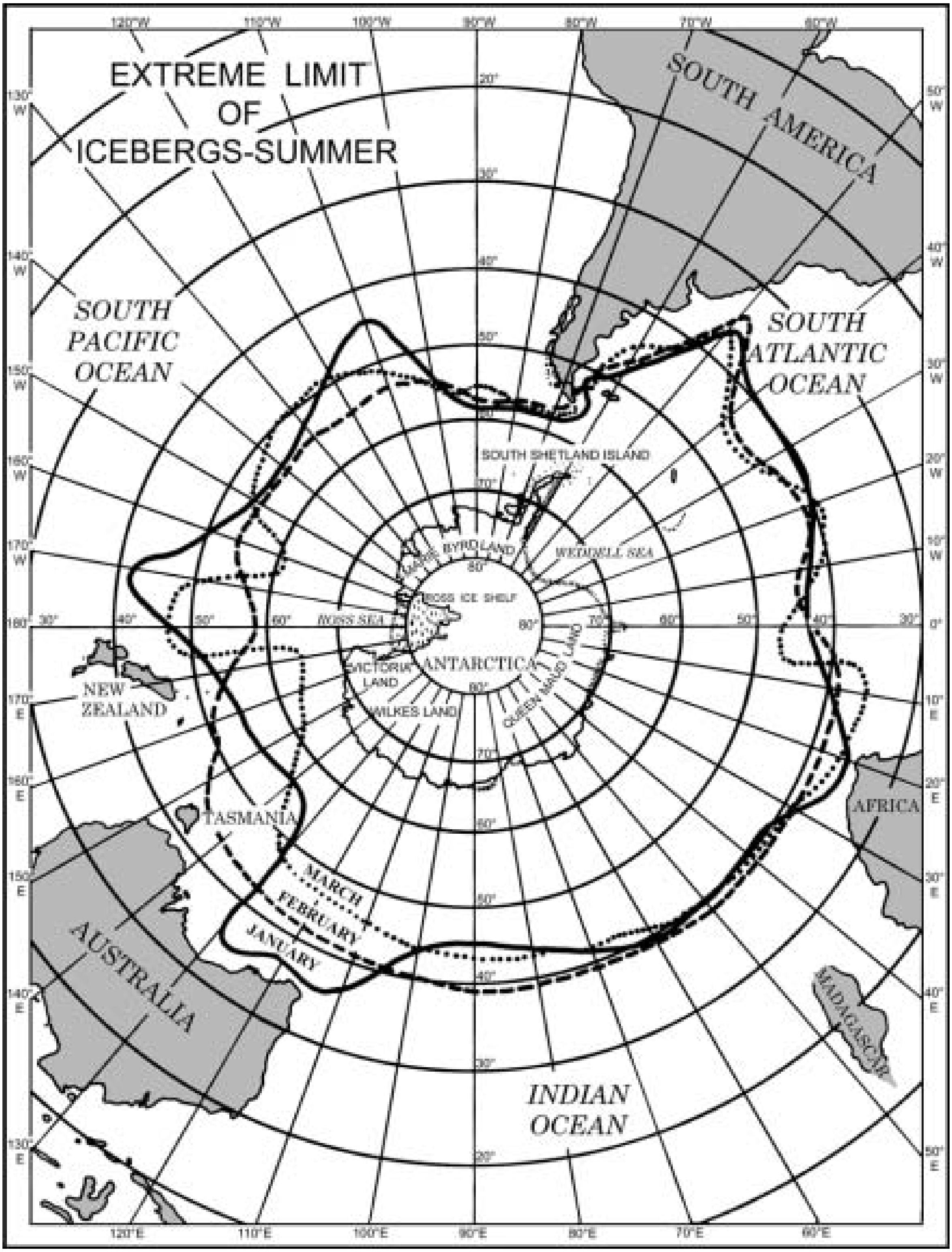
Duration Of Sunlight.—Rising, setting, and twilight data are tabulated in the Nautical Almanac to latitude 72˚N and 60˚S. Within these limits, the times of these phenomena can be determined. Graphs are used in the higher latitudes instead of tables because they give a clearer picture of conditions, which may change radically with relatively little change in position or date. Under these conditions, interpolation is simpler by graph than by table. In those parts of the graph which are difficult to read, the times of the phenomena's occurrence are themselves uncertain, being altered considerably by relatively small changes in refraction or height of eye. The graphs for high latitudes may be found in the Air Almanac which is published each year by the U.S. Naval Observatory.

The graph displaying the semiduration of sunlight may be used for latitudes higher than 60˚ and shows the number of hours from sunrise to meridian passage or from meridian passage to sunset. There is continuous daylight in the area marked "sun above horizon." The figures near the top of the graph indicate, for several convenient dates, the LMT of meridian passage. With the aid of the intermediate dots, the LMT for any given day may be obtained to the nearest minute. Using the latitude and the LMT of meridian passage, the semiduration can be extracted. The time of sunrise may be found by subtracting the semiduration from the time of meridian passage. The time of sunset can be found by adding the semiduration to the time of meridian passage. Similar graphs for twilight and semiduration of moonlight in high latitudes are also displayed.

ODAS.—The term Ocean Data Acquisition System (ODAS) covers a wide range of devices for collecting weather and oceanographic data. However, the devices of most concern to vessels consist of buoy systems which support instruments. These buoy systems may be expected to become more numerous each year and may be found in polar waters.

The buoy systems vary considerably in size and are either moored or free-floating. As far as possible, positions of the former will always be widely promulgated, and, if considered to be of a permanent enough nature, will be charted. In both types, the instruments may be either in the float or attached at any depth beneath it.


EXTREME LIMIT
OF
ICEBERGS-SPRING
SOUTH AMERICA
SOUTH PACIFIC OCEAN
SOUTH ATLANTIC OCEAN
SOUTH SHETLAND ISLAND
BYRD LAND
WEDDELL SEA
ROSS ICE SHELF
ROSS SEA
ANTARCTICA
VICTORIA LAND
WILKES LAND
QUEEN MAUD LAND
NEW ZEALAND
TASMANIA
AUSTRALIA
AFRICA
MADAGASCAR
OCTOBER
DECEMBER
NOVEMBER
INDIAN OCEAN


EXTREME LIMIT
OF
ICEBERGS-SUMMER
SOUTH AMERICA
SOUTH PACIFIC OCEAN
SOUTH ATLANTIC OCEAN
SOUTH SHETLAND ISLAND
BYRD LAND
WEDDELL SEA
ROSS ICE SHELF
ROSS SEA
ANTARCTICA
VICTORIA LAND
WILKES LAND
QUEEN MAUD LAND
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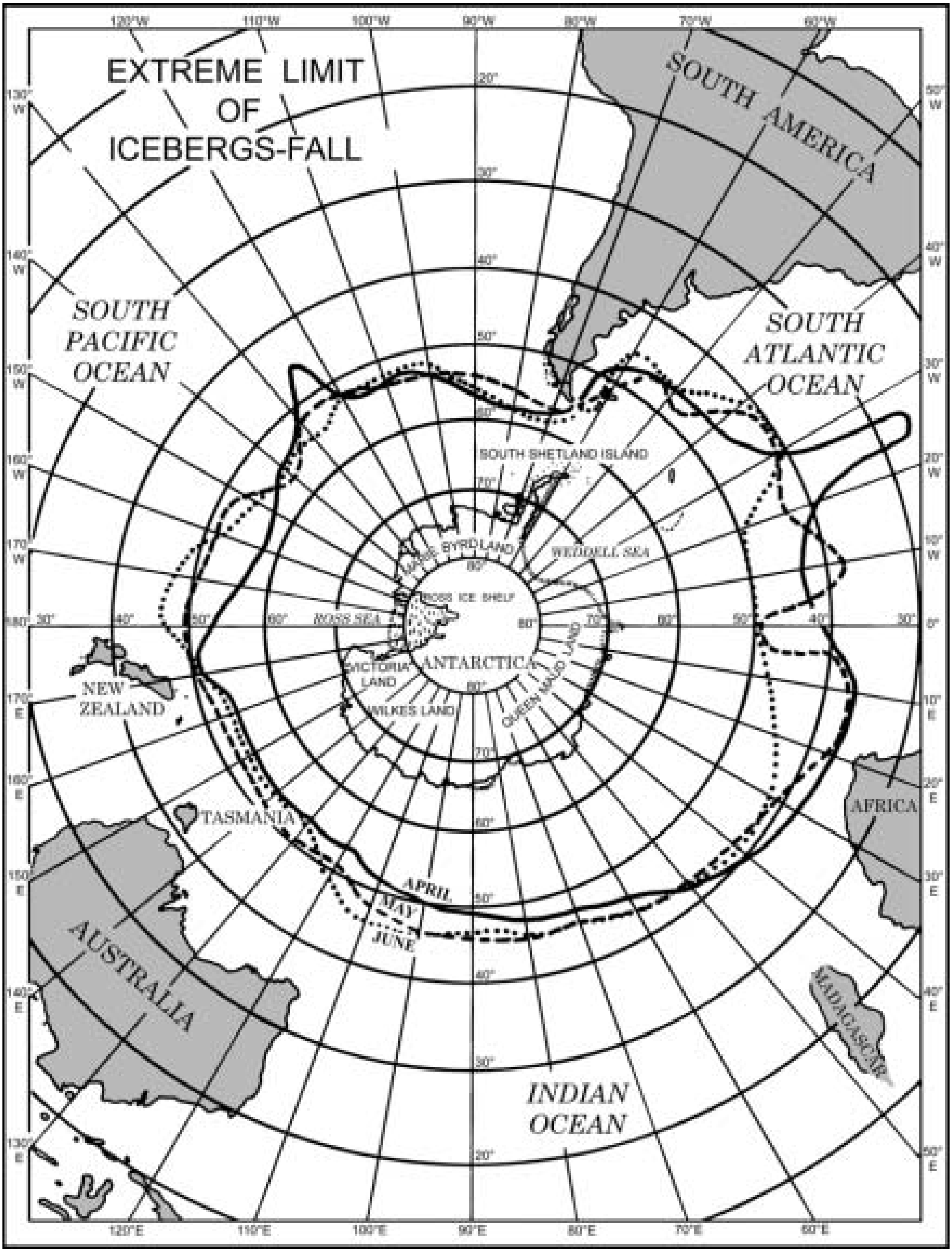
AFRICA
MARCH
FEBRUARY
JANUARY
AUSTRALIA
MADAGASCAR
INDIAN OCEAN


EXTREME LIMIT OF ICEBERGS-FALL
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SOUTH PACIFIC OCEAN
SOUTH ATLANTIC OCEAN
SOUTH SHETLAND ISLAND
BYRD LAND
WEDDELL SEA
ROSS ICE SHELF
ROSS SEA
ANTARCTICA
VICTORIA LAND
WILKES LAND
QUEEN MAUD LAND
NEW ZEALAND
TASMANIA
AUSTRALIA
AFRICA
MADAGASCAR
INDIAN OCEAN
APRIL
MAY
JUNE
120°W
110°W
100°W
90°W
80°W
70°W
60°W
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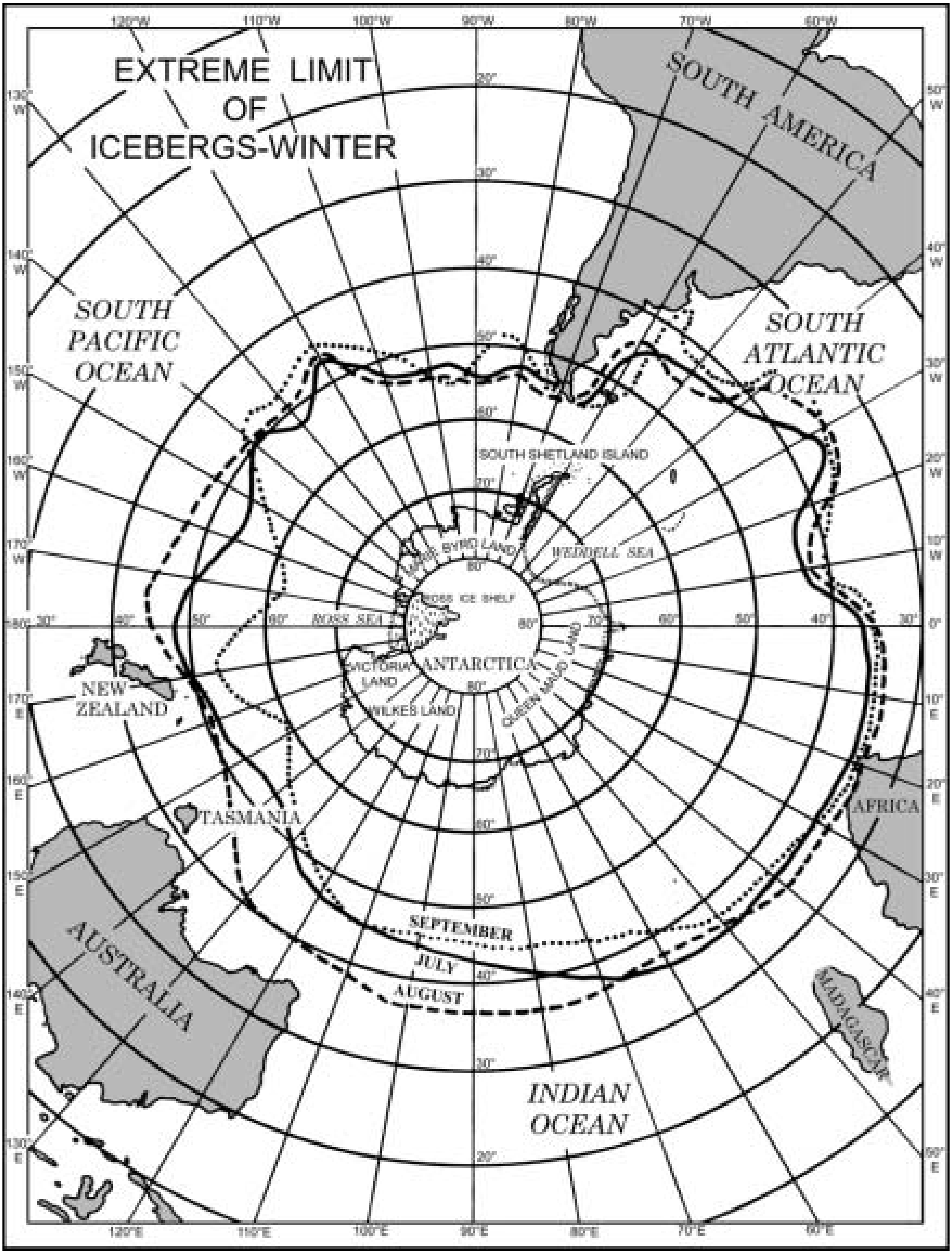
80°E
70°E
60°E


EXTREME LIMIT
OF
ICEBERGS-WINTER
SOUTH AMERICA
SOUTH PACIFIC OCEAN
SOUTH ATLANTIC OCEAN
SOUTH SHETLAND ISLAND
BYRD LAND
WEDDELL SEA
ROSS ICE SHELF
ROSS SEA
ANTARCTICA
VICTORIA LAND
WILKES LAND
QUEEN MAUD LAND
NEW ZEALAND
TASMANIA
AFRICA
SEPTEMBER
JULY
AUGUST
AUSTRALIA
MADAGASCAR
INDIAN OCEAN
120°W
110°W
100°W
90°W
80°W
70°W
60°W
120°E
110°E
100°E
90°E
80°E
70°E
60°E

The buoys are colored yellow and marked ODAS with an identification number. The moored buoys usually display a yellow light, showing a group of 5 flashes every 20 seconds.

ODAS may be encountered in unexpected areas and often in deep water where navigational buoys would not be found. It should be noted that valuable instruments are often suspended beneath these systems or attached to the mooring lines. In some cases, the moorings have been cut loose beneath the buoy by unauthorized salvors, with the consequent loss of the most valuable part of the system.

The moored buoys may be up to 7.5m in diameter and 2 to 3m in height. The free-floating buoys are usually much smaller, 2m wide, and do not display a light.

Caution.—Vessels should use extreme care when navigating in the regions covered by this publication as very few of the bays, inlets, and harbors have been carefully surveyed. Information contained herein was compiled from numerous sources, much of which appears to be contradictory. Charts of the region lack details and should be utilized only as a guide.

Reliance should not be placed upon sketchy reports by observers as the unusual phenomena and atmospheric conditions in the S pole region often lead the inexperienced observer to optical errors. Navigation in this area becomes further complicated with sea ice, sudden and violent changes in the weather, dangerous shoals, compass instability, and the absence of navigation aids.

The most serious danger is that caused by the pressure of ice on a vessel, which may result in the crushing of the hull or damage to underwater hull fittings. The risk is greatest when a vessel is navigating in pack ice. Apart from this hazard, vessels beset in ice, and hence drifting with it, may be forced into waters that are dangerous for navigation.

Distances.—The following navigable surface distances (nautical miles) between points combine the use of great circles and rhumb lines:

From:	Anvers Island—Antarctic Peninsula (64˚00'S., 64˚00'W.)	
To:	Boston, United States	7,235
	Buenos Aires, Argentina	1,856
	Cape Town, South Africa	3,811
	Fremantle, Australia	6,839
	Montevideo, Uruguay	1,762
	Panama	4,489
	Port Stanley, Falkland Islands	885
	Rio de Janeiro, Brazil	2,604
	Ushuaia, Argentina	606
	Valparaiso, Chile	1,987

From:	Cape Adare—Ross Sea (71˚00'S., 172˚00'E.)	
To:	Auckland, New Zealand	2,287
	Dunedin, New Zealand	1,532
	Fremantle, Australia	3,504
	Hobart, Tasmania	1,843
	McMurdo Sound, Antarctica	380
	Melbourne, Australia	2,208
	Pearl Harbor, Oahu	5,662
	Sydney, Australia	2,338
	Wellington, New Zealand	1,800

Note.—Due to changing ice conditions in the Antarctic region, the above distances may differ from those actually steamed.

Electronic Navigation and Communication

In general, radio wave propagation in high latitudes follows the same principles that apply elsewhere. However, certain anomalies occur, and although these are but imperfectly understood and experience to date has not always been consistent, there is much that has been ascertained. An understanding of these conditions is important if maximum effective use is to be made of electronics in high latitudes.

Communication between the scientific stations in Antarctica and the rest of the world, including vessels at sea, is vital. However, radio communications in high latitudes presents special problems. The permanent stations on the various parts of Antarctica are widely separated within an area of four million square miles. Hence, these stations are isolated by great distances and by ice caps. Most radio communications depend on the high frequency band, using the ionosphere as a reflector. A network of high frequency radio systems connects other parts of the world to Antarctica, including summer bases, field parties, ships, and aircraft. Generally, this high frequency network of communications is effective over great distances, but the system may become ineffective at times due to atmospheric disturbances, high ionospheric absorption flutter, drift static, and local man-made interference.

Disturbances.—The ionosphere is irregular and unstable in the auroral zone and the intensity of absorption is high nearly all of the time, especially during the daylight hours.

Man-made interference is caused by locally produced noise such as generators, transmitters, mobiles, switchgear, power lines, scientific equipment, etc. Because the Antarctic atmosphere is not restrictive to noise interference, a receiver unit becomes unusually sensitive to locally produced noise. In addition, the noise from other electrical equipment is accentuated by low ground conductivity.

Drift static and/or precipitation static are caused by electrically charged particles and are a common phenomena in this region. Static discharges are a serious problem frequented by severe blizzards, particularly when the drifts are dry and powdery, driven over a long distance by a gradient wind, and steep fronted. This phenomena usually builds up an electrical charge of several thousand volts before it discharges and can strongly distort high frequency radio systems. It is reported that measures to reduce smaller forms of static shocks have been successful to some degree by filterization and special grounding.

Flutter, which is a rapid succession of reflected pulses resulting from ionospheric storms, is common in polar regions. Its effect is particularly noticeable on voice circuits and in severe cases, radio teletype reception is impacted. Since flutter is usually associated with fading signal strength, high powered transmitters are sometimes suggested, but they should not exceed signal to noise ratios required for good reception.

It is important that the signal to noise ratio at the receiver should be at as high a level as is necessary to give intelligible communication. However, it is equally important that the power used to transmit the signal should not be greater than necessary. Hence, it should not be so great as to cause radio frequency interference with scientific programs and other radio reception, nor is it desirable for logistics reasons to use more power than is necessary.

The specification of signal to noise ratio for the mode of signal to be employed presents no problems. Nor is there any problem in measuring the noise level on which to base this specification. As previously stated, the ionosphere in the auroral zone is unstable. Therefore, the theory of measuring noise level in this case becomes highly speculative.

Disturbances on the sun may cause interference with radio communication. At the time of an intense solar flare or eruption, a flash of ultraviolet light and a stream of charged particles are emitted from the sun. The flash of ultraviolet light takes only eight minutes to reach the earth, where it produces great ionization (electrification) at abnormally low layers of the upper atmosphere. Short radio waves, which travel round the earth by being reflected from a higher layer of the upper atmosphere, cannot penetrate this barrier of ionization and a radio "fadeout" is experienced. However, long radio waves may be reflected more strongly from the base of the lower layer of ionization. Since these short wave radio fadeouts and long wave enhancements are caused by the effects of ultraviolet light from the sun, they are confined to the sunlit side of the earth and are almost simultaneous with the flare, lasting on the average for about 20 minutes.

The stream of charged particles, traveling much more slowly than light, arrives at the earth, if it is suitably directed, in about one to three days. The stream visibly signals its arrival at the earth by producing a bright and active aurora. It also causes great ionization in the upper atmosphere, which is much more prolonged than that caused by the ultraviolet light. There is again deterioration in short wave radio communications, which may be a complete "blackout" in higher latitudes. At this time, currents of up to a million amperes may circulate in the upper atmosphere. The resulting magnetic field may extend to the surface of the earth and may deflect a compass needle noticeably from its normal position. The effects of these magnetic and ionospheric storms, which may persist with varying intensity for several days, are usually greatest in higher latitudes. Radio "blackouts" and simultaneous deflections of magnetic compasses are not uncommon in and near the auroral zones. When a great aurora is seen in abnormally low latitudes, it is invariably accompanied by a magnetic and ionospheric storm. Unlike the fadeouts which occur only on the sunlit side of the earth, the interference with radio communications that accompanies an aurora and a magnetic storm may occur by day or at night. All these effects occur most frequently and in most intense forms at the time of sunspot maximum.

Polar Cap Disturbance (PCD) is an ionospheric disturbance which is in no way dependent on the ice cap in the polar region. It is the result of the focusing effect the earth's magnetic field has on particles released from the sun during a solar proton event. The effect concentrates high energy particles in the region of the magnetic pole with the result that normal very low frequency propagation is disrupted. The effect on radio waves is known as Polar Cap Absorption (PCA).

Historically PCDs produced large or total absorption of high frequency radio waves crossing the polar region. A transmission path that is entirely outside the polar region is unaffected by PCDs. The PCDs, often called PCA Events (PCAs), may persist for a week or more, but commonly the duration lasts only a few days. The frequency of this phenomenon increases during those years of peak solar activity.

Sudden Ionospheric Disturbance (SID) is a sudden increase in the ionization density in the lower part of the ionosphere. It is caused by very sudden and large increases in X-ray flux which is emitted from the sun, usually during a solar flare. These disturbances (SIDs) also occur during flares called X-ray flares that produce large X-ray flux, but which have no components in the visible light spectrum. The effect, which is restricted to sunlit propagation paths, causes a phase advance and is known as a Sudden Phase Anomaly (SPA). The SID effects are related to solar zenith angle and consequently occur mostly in lower latitude regions. Usually, a phase advance over a period of 5 to 10 minutes occurs which is followed by a recovery over a period of 30 to 60 minutes.

International Maritime Satellite Organization (INMARSAT).—Around the world satellite communication systems have now become synonymous with reliable and quality transfer of information. The International Maritime Satellite Organization (INMARSAT) is an international consortium comprising over seventy-five partners who provide maritime safety management and maritime communications services.

The INMARSAT system consists of a number of satellites, which maintain geosynchronous orbits, and provides quality communications coverage between about 77˚N and about 77˚S, including locations with less than a 5˚ angle of elevation.

INMARSAT-A, the original system, provides telephone, telex, and fax services. However, this system is being replaced by INMARSAT-B, which, by the use of digital technology, is providing the services with improved quality and higher data transmission rates. INMARSAT-C provides a store and forward data messaging capability, but no voice communication.

To qualify for access into the system, the National Science Foundation (NSF) applied through COMSAT, the United States representative to INMARSAT. Because McMurdo Station, the main United States base in Antarctica, qualifies as a search and rescue coordination center for that region, the application was approved and the base now operates within the network as a ship/earth station. Since 1983, a permanent communication link between McMurdo Station and the United States has been provided via INMARSAT.

Global Maritime Distress and Safety System (GMDSS).—The Global Maritime Distress and Safety System (GMDSS) provides a great advancement in safety over the previous usage of short range and high seas radio transmissions. This system, fully implemented since 1 February 1999, consists of satellite as well as advanced terrestrial communications operations.

The GMDSS has been adopted by the International Convention for the Safety of Life at Sea (SOLAS) 1974. It applies to cargo vessels of 300 grt and over and all vessels carrying more than twelve passengers on international voyages. Unlike previous regulations, the GMDSS requires vessels to carry specified equipment according to the area in which they are operating. Such vessels navigating in polar regions must carry VHF, MF, and HF equipment and a satellite Emergency Position Indicating Radiobeacon (EPIRB).

It should be noted that after 1999, compliant vessels are no longer required to maintain a voice listening watch on VHF channel 16 or 2182kHz and considerable difficulty may be experienced in establishing communications between a GMDSS and a non-GMDSS equipped vessel.

SafetyNET.—NAVTEX is an international automated direct printing service for providing coastal navigational information, distress warnings, and meteorological warnings, including ice reports. It is an element of GMDSS and has replaced the broadcasts of safety information over MF morse frequencies.

The SafetyNET broadcast system provides the same information as NAVTEX to vessels on the high seas and is delivered by the INMARSAT-C system.

Global Positioning System (GPS).—The NAVSTAR Global Positioning System (GPS) is a satellite-based system, operated by the U.S. Air Force, which provides very accurate positioning, time, and velocity information to multiple users. It is an all-weather system with world wide and continuous usage which will replace OMEGA and other such hyperbolic radio navigation systems. The space component of GPS consists of twenty-four satellites, of which a minimum of six are observable from any place on earth. GPS receivers convert data from the satellites to produce three-dimensional positions (latitude, longitude, and altitude). They compute information for fixes in terms of the World Geodetic System (1984) reference ellipsoid; hence, a datum shift correction may be required before a position can be plotted on a chart.

GPS provides two services for navigation positioning, but accuracy of a fix also depends upon the capability of user equipment.

Standard Positioning Service (SPS) is the standard level of positioning and timing accuracy. It is available without restrictions to any user on a continuous world-wide basis and provides horizontal accuracy to approximately 100m.

Precise Positioning Service (PPS) is limited to authorized users and provides horizontal accuracy to approximately 30m.

Note.—For further information concerning the International Maritime Satellite Organization (INMARSAT), the Global Maritime Distress and Safety System (GMDSS), the SafetyNET system, and the Global Positioning System (GPS), see Pub. No. 9, The American Practical Navigator (Bowditch-1995 Edition); Pub. 117, Radio Navigation Aids; and Annual Notice to Mariners No. 1.

Oceanography

The Antarctic continent is surrounded by waters forming a confluence of the S portions of the Pacific Ocean, the Atlantic Ocean, and the Indian Ocean. Adjacent to the continent lie the Weddell Sea, the Bellingshausen Sea, the Amundsen Sea, and the Ross Sea. The water surrounding Antarctica is unique among the world's oceans because the configuration of land and water in the southern hemisphere permits a circumpolar oceanic flow comprising about 10 per cent of the world's sea water. The only major physical boundary that constricts the zonal flow is Drake Passage which lies in the Scotia Sea region between the southernmost part of the South American continent and the Antarctic Peninsula. Great depths within this passage permit an unhindered flow of water. However, this area can become exceptionally stormy because there is no barrier to reduce the persistent and strong W winds.

Antarctica provides the S boundary of the adjacent waters whereas the N boundary is defined by the cold water lying S of the Antarctic Convergence or Polar Front Zone.

The continental shelves surrounding Antarctica are relatively narrow and deep. Although they have an average width of 30 kilometers, they comprise an area of approximately 4 million square kilometers and reach depths of 500 to 900m at the shelf edge. This is two to four times greater than the world average shelf depth, and may be caused by isostatic subsidence in response to the weight of the ice cap. At the edge of the shelf, the gradient steepens to define the continental slope. The water depth increases rapidly to approximately 3,000m over a distance of less than 100 kilometers. Seaward of the continental slope, the continental rise and deep ocean bottom lie at depths greater than 3,000 and 4,500m, respectively. These areas are underlain by thick sediments.

The Antarctic Convergence.—The Antarctic Convergence occurs where the cold Antarctic water merges with warmer tropical waters and downwells or dives underneath the warmer surface of the South Atlantic, Pacific, and Indian Oceans. This phenomenon occurs in a remarkably discernible climatic and oceanic boundary which extends to the 50th parallel. In many locations this line is easily and precisely distinguished by a quick alteration in surface temperature; hence, producing a physical boundary between the waters lying adjacent to Antarctica and those of the sub-polar region or Polar Front Zone.

The Antarctic Convergence may form the extreme N limit of drift ice, but such ice is rarely found so far to the N. The waters to the S of the Antarctic Convergence are ice laden and abound with sub-polar aquatic life, forming a feeding ground for pelagic birds and the world's largest population of seals and whales.

The Antarctic Divergence.—In the zone of Antarctic upper water, between the continent and the Antarctic Convergence, there is an area of divergence of surface waters and consequent upwelling, which coincides with the boundary between the E and W wind belts. The position of this Antarctic Divergence and the occurrence and strength of divergent motion are both variable and depend on the prevailing meteorological conditions. Influenced by the wind and the rotation of the earth, the ocean surface water on each side of the Divergence moves in a direction to the left of the wind direction. The Divergence lies N of the drift ice and between 5˚ and 10˚ of latitude S of the Antarctic Convergence.

Tides—Currents.—The Antarctic Circumpolar Current, known as the West Wind Drift, is the world's greatest current. Strong W winds between about 40˚S and 60˚S (Roaring Forties) drive this current in an E direction at approximately 0.5 meter per second. This current completely encircles Antarctica and is so deep that it can reach the ocean bottom. Closer to Antarctica, E or SE winds prevail that cause a W current which is known as the East Wind Drift. The flow of this current is complicated by the irregular coastline and gyres (eddies) can form in bays such as the the Weddell Sea, the Ross Sea, and Bellingshausen Sea.

Relatively warm, saline, and nutrient-rich water, which has flowed at depth to high latitudes from lower latitudes, upwells to the surface in a zone. This zone of general upwelling, known as the Antarctic Divergence, separates the Circumpolar Current from the East Wind Drift. This divergence, located 150 to 200 miles from the coast, is not entirely continuous, but disappears to the E of Drake Passage.

More than half of the bottom waters of the world's oceans are formed around Antarctica. Cold winter temperatures and ice formation produce dense seawater which sinks to the ocean bottom, where it spreads to the N. The continual production of this Antarctic Bottom Water plays an important role in renewing the bottom waters of the oceans; without this renewal, the respiration of animals in the deep ocean would deplete the oxygen content of the bottom waters. In the Weddell Sea, which is believed to be the major source, bottom water formation appears to occur year-round, particularly on the S and W continental shelf. Estimates of bottom water formation in the Weddell Sea vary from 2 to 5 million cubic meters per second.

Tides are long-period forced waves whose speed is determined by the balance between the attraction of the sun and moon and the frictional effects of the ocean bottom. Tidal movement around Antarctica is unique in the world's ocean basins in that there are no significant land masses to impede the E/W (counterclockwise) sweep of the tides around the continent. The tidal movement is therefore principally a progressive wave, and the tide is predominantly diurnal. Diurnal tides are characterized by one high water and one low water each tidal day (a lunar day of 24 hours and 50 minutes).

Wind-generated waves are greatest around 50˚S to 60˚S because of predominant W winds and the long fetch. The tip of the Antarctic Peninsula extends into this region and rough seas can be encountered along its ice-free coastline. Higher latitudes and ice cover account for smoother seas along the rest of the Antarctic coast.

Surface Temperature.—The Antarctic Convergence is a boundary surface which separates the heavier, colder Antarctic water to the S from the lighter but more saline water to the N. The mean position of this circumpolar boundary is fairly constant, lying at about 50˚S in the Atlantic sector and between 50˚S and 60˚S in the Pacific sector. Its position is marked by steep horizontal temperature and salinity gradients at the surface. Across the convergence, the temperature ranges in the summer from 3.9˚ to 6.7˚C and in the winter from 1.1˚ to 2.8˚C. Surface waters immediately S of the convergence have an average temperature of about 1.1˚ to 2.2˚C in the winter and 2.8˚ to 5˚C in the summer, while further S near the continent temperatures vary only from about -1.7˚ to -0.5˚C.

Salinity in the region to the N of the Antarctic Convergence changes only little throughout the year. However, to the S of the convergence, the melting of ice during spring and summer results in a highly variable distribution of surface salinity. Partially melted fields of drift ice produce extensive local areas of relatively low salinity.

Tsunamis.—Earthquakes, volcanic eruptions, and submarine land slides frequently produce an unusual wave called a seismic sea wave or a tsunami. Tsunamis have long wave lengths and travel across the open ocean at high speeds. As they approach the shore, the wave length decreases and the wave height increases, so that they can be a formidable agent of destruction. In the open ocean, the wave height is only 0.3 to 0.6m and may pass unnoticed. However, near the shore, the wave may build rapidly to heights of more than 15m.

Approximately 6 tsunamis occur in the Pacific Basin per year and only one of these is likely to cause local damage. There is little chance that a tsunami will form that is large enough to affect the entire Pacific Basin, including the Antarctic. Such a tsunami may occur only once every 7 to 10 years, but even then stations in the Antarctic would probably not experience any damage.

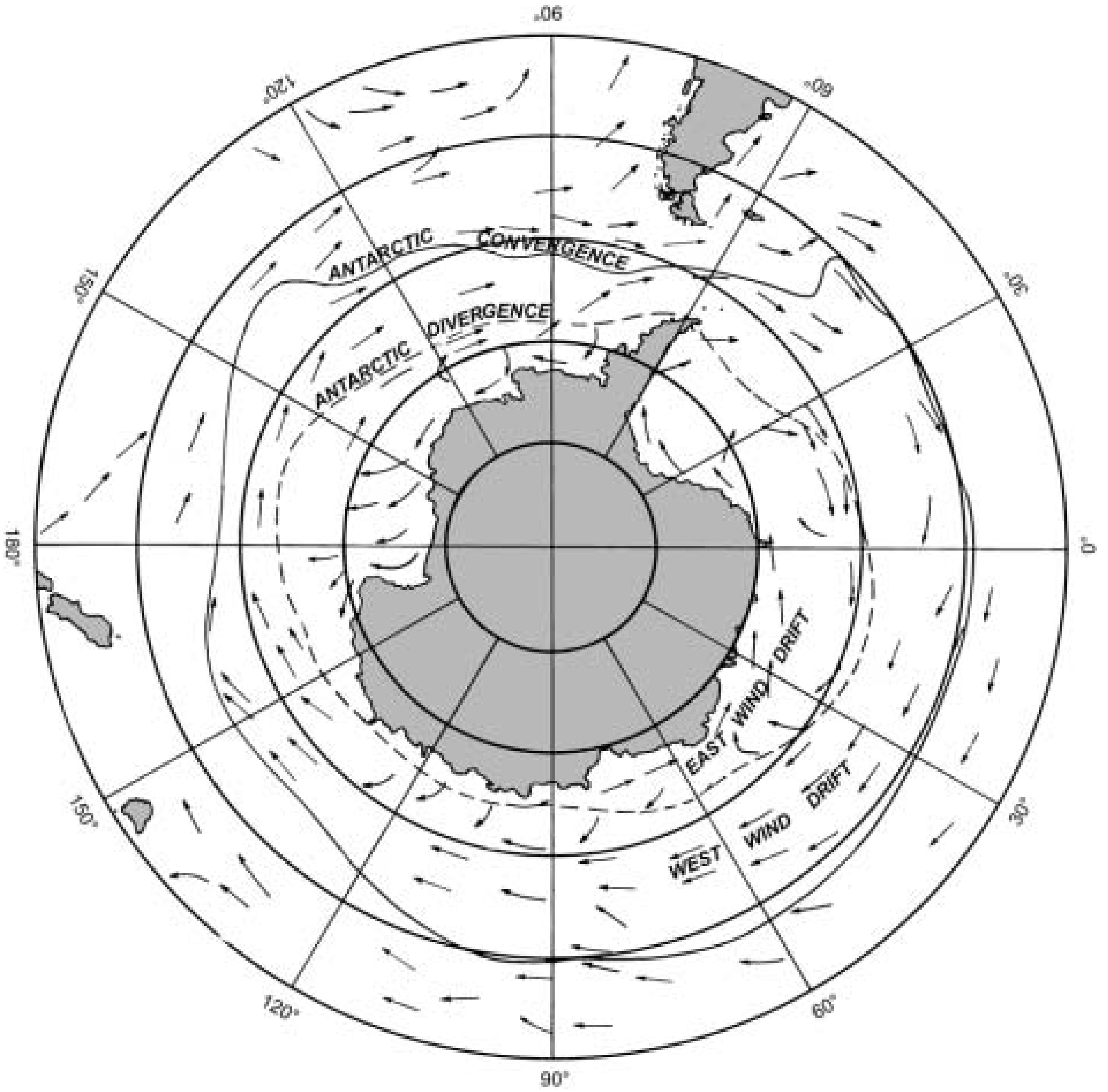
Marine Biota.—The food web of the Antarctic is short, allowing unusually large populations of top carnivores to develop. The key element is krill which are the dominant zooplankton. Krill serve as an important link between the primary production and the marine mammals and birds. Krill, which grow to several centimeters in length, are large marine herbivores (shrimp-like crustaceans) and are found in swarms, several to hundreds of meters wide. They serve as the prime food source for seals, squid, penguins, whales, and several other animals.

Squid are the predominant cephalopod in the adjacent seas to the continent. They live in open waters and may be concentrated near the Antarctic Convergence.

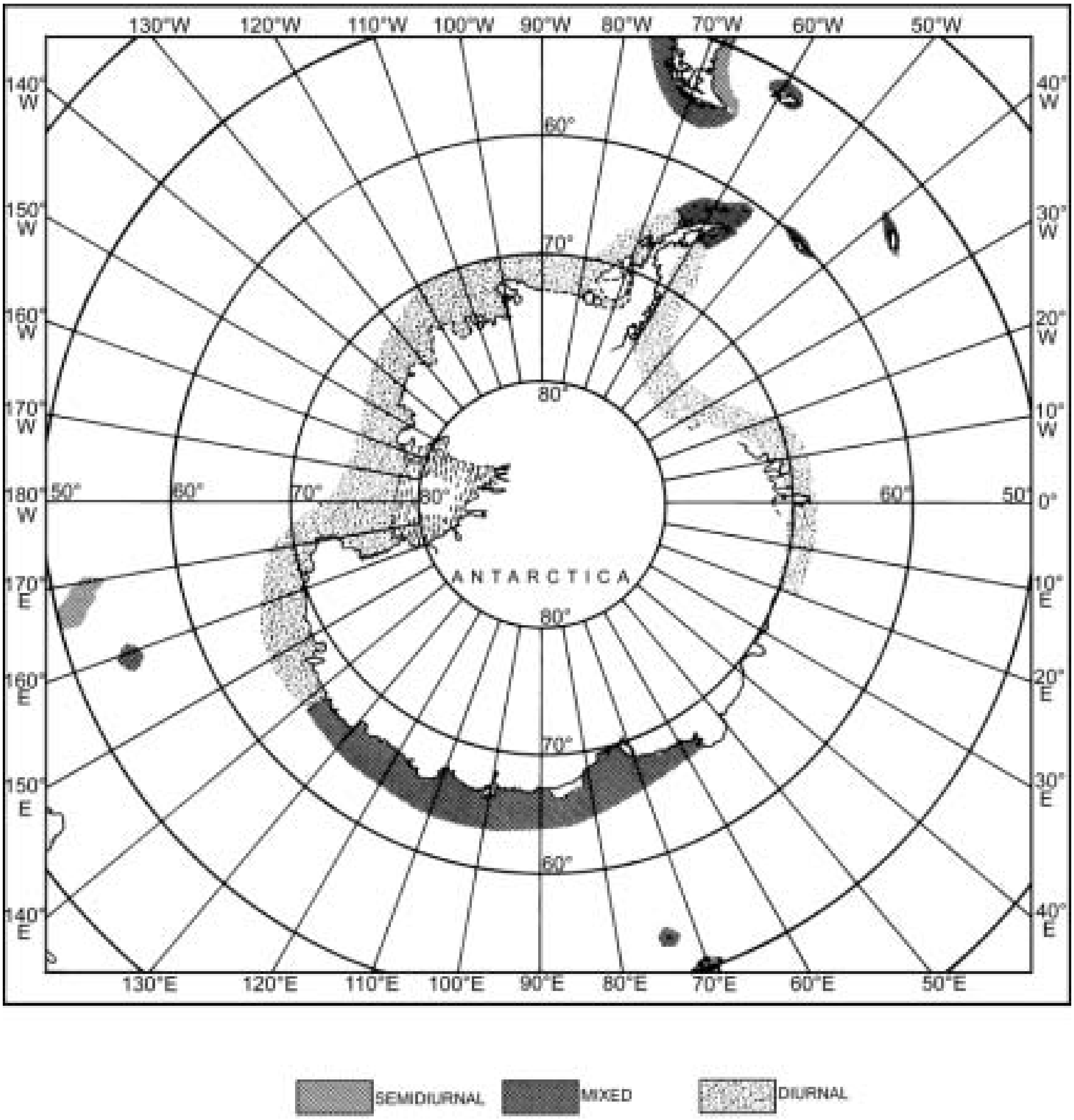
Fish stocks include Antarctic cod, icefish, whiting, toothfish, and silverfish. However, these stocks are believed to be less abundant and fewer in number of species relative to other oceans.

Crabeater seals are the most abundant of the continent and leopard seals are the largest of such species. Weddell seals are the most well known because of their proximity to the existing land bases. Ross seals are the rarest of the Antarctic breeds.

Southern fur seals and elephant seals are found N and S of the Antarctic Convergence. To the S of the convergence, these seals only inhabit the islands N of and along the Antarctic Peninsula.



GENERAL SURFACE CIRCULATION



TYPES OF TIDES

Several species of penguins inhabit the continent, including adelie, which are the most abundant; emperor; chinstrap; macaroni, which breed mostly near the subantarctic islands; and gentoo.

Several spieces of whale migrate to the adjacent seas during the austral summer and have a circumpolar distribution. Baleen whales, which feed intensively on krill and other zooplankton, include fin, blue, sei, humpback, and minke. Southern right whales are occasionally found off the continent, but generally inhabit more temperate waters. Sperm whales and killer whales (related to dolphins) are found in the adjoining waters throughout the entire year.

Bioluminescence.—Bioluminescence is the emission of light by biological organisms. In the ocean environment, organisms may be stimulated to glow around the hulls and in the wake of vessels, submerged vessels, small boats, and divers. This phenomenon is generally infrequent in the Antarctic region, but luminescence can occur in all waters at any time. Some strong luminescence activity has been reported in ice as it is broken by icebreakers. It has also been reported along the Antarctic Convergence, in the Scotia Sea, and around the South Sandwich Islands, South Georgia Island, the South Orkney Islands, and the South Shetland Islands.

Krill have been reported to give off a luminescence in the form of a greenish light. When vessels pass through extensive areas (swarms) of krill, flashes from the individual crustaceans have been observed within 100m of the hull against the background color of the water.

Optical Phenomena

Optical phenomena are common in the region to the S of 50˚S and their frequency reaches a maximum in Antarctica. These phenomena, whose appearance range from intricate geometric patterns to colorful electrical displays, are associated with the refraction, reflection, or diffraction of light, and electromagnetic activity.

There is almost no dust or solid particles in the Antarctic air and the prevailing winds blowing off the continent have small moisture content. Consequently, the visibility is usually very good and often exceptional, a fact which, if not appreciated, may lead the observer into serious error when judging distances. An object which may be thought to be but 5 miles distant could well be 30 miles away, and mountains have been sighted at 300 miles.

Mirages—Abnormal Refraction.—An unusual lapse rate of temperature (and therefore density as well) with height immediately above the sea (or land) surface produces a distortion in the appearance of objects near the horizon; such a phenomenon is known as mirage.

When the surface is relatively cold (and the wind very light) so that the density of the air decreases rapidly for a short distance above the surface, light rays from objects near the horizon are bent down, the same way in fact as are usually the rays of the sun when entering the earth's atmosphere at a low altitude. These objects then appear to have been lifted above their true positions and hence, seem much closer to an observer. Objects below the horizon may actually become visible and this effect is known as looming. If the images are also stretched vertically, this refraction phenomenon is known as towering.

A further occasional effect produced when the air is appreciably warmer than the sea, is a superior mirage in which an inverted image is seen over the real object. Sometimes an erect image is seen immediately above and touching the inverted one. The object and its images in this instance are usually well defined in contrast with the shimmering object and image of the inferior mirage. Superior mirage is most often experienced in high latitudes and wherever the sea surface temperature is abnormally low. The impression of a greatly expanded ice field can be created, particularly when great numbers of otherwise invisible bergs are lifted into view as the stretched upper image of a superior mirage.

An inferior mirage, the effect of which is to decrease the distance at which objects are visible in a horizontal direction, is due to a rapid increase of density with height close to the surface. This may occur when air of comparatively low temperature blows over a warmer sea, or over a tarred road or desert when a hot sun is beating down on it. In such cases, the light rays are bent up and away from the surface. This occurs because light rays travel faster through the warm, less dense air at the surface than through the more dense air above. Coastlines, vessels, and islands may appear at times to be floating in the air above a shimmering horizon. Sometimes the hulls of vessels are either invisible or appear with an inverted image underneath. Inferior mirage is comparatively uncommon at sea and is more likely to be observed near a coast. This effect may cause an observer to overestimate the distance to the shore or nearby objects.

A case known as stooping causes the visual image of a distant object to be foreshortened in the vertical and is the opposite of towering. This flattening may be so slight that it is not noticeable, yet it will seriously affect the determination of distances.

Generally, mirage effects are mostly observed when the sun is low in altitude.

On clear days shortly after sunset or before sunrise, green light is sometimes refracted from the sun's spectrum. When refractive conditions are suitable, red, orange, and yellow waves of sunlight are not refracted sufficiently to reach the eye, but green waves are. The visual result is a green flash in the surrounding sky. In well-developed cases, if the atmosphere is both abnormally refractive and clear, a fully developed blue coloration or blue flash can be seen.

Fata Morguna is a complex mirage that is characterized by multiple distortions of images, generally in the vertical, so that such objects as houses are distorted and magnified into fantastic, tall castles. An unusual density stratification is required to produce this mirage, namely the joint occurrence, in vertically adjacent layers, of density gradients that would give an inferior mirage and a superior mirage.

Parhelia, mock suns, and Parselenae, mock moons, are quite common. These images appear as refraction of the sun or moon, respectively, and take forms such as symmetrically arranged rings or arcs, usually of many colors. Prismatic sunrise and sunset both appear as a high arch, with the colors of the spectrum extending from the top of the arch to the horizon, in the sky opposite the sun.

Return to page: 20

Solar Haloes and Lunar Haloes are produced by refraction and reflection through and from ice crystals. They appear as rings, mock images, contra images, and other shapes.

Solar and Lunar Coronas consist of a series of rainbow-colored rings around the sun or moon. They resemble halos, but have a reverse sequence of the spectrum colors, red being the color of the outer ring. This reversal sequence is due to the diffraction. They are observed through high cloudiness and their radius varies inversely with that of the cloud particles.

The multicolored rainbow and whitish fogbow are due to refraction through water droplets, the colors varying with the size of the drops. The smaller the drops the lighter the colors and the nearer the violet end of the spectrum. Hence, the white rainbows sometimes seen over the Ross Ice Shelf.

Diffractional phenomena are often similar to those caused by refraction except for a reversal in the spectrum colors, red being away from the source of light. Several widely observed phenomena in the Antarctic are due to diffraction. These include the broken bow or glory, which consists of colored rings around shadows projected against fog banks or clouds.

Iridescent clouds are brighter than other forms of phenomena and usually appear as a deep, blue, central tract with banded margins of vivid purple, orange, green, and other colors.

Earth shadows, or aerial shadows, are believed to be produced by mountain peaks and take the form of dark blue bands projected into the sky as straight or curved shadows.

Other reflection phenomena observed in the Antarctic include iceblink, landblink, water sky, and land sky. Iceblink is a white or yellowish-white glare cast on the underside of clouds by considerable amounts of sea ice while landblink is its land ice counterpart. Water sky and land sky are observed as dark reflections of open water or land on the underside of an overcast. The pattern formed is known as a sky map. The sharply contrasting water sky and iceblink may sometimes be observed side by side from a great distance, strikingly outlining adjacent surface water and ice.

Whiteout is a condition in which daylight is diffused by multiple reflection between a snow surface and an overcast sky. Contrasts vanish and the observer is unable to distinguish the horizon or any snow surface feature. In addition, depth perception is greatly reduced. As falling snow, drift, fog, and mist are not involved, a dark object can be seen at any distance. This condition is a special hazard to low-flying aircraft.

Auroral Forms.—Aurorae are among the most beautiful of all natural phenomena. Their cause, which has attracted study since the 17th century, is still not fully understood by scientists.

The generally accepted thesis at the present time is that streams of electrically charged particles, possibly electrons and protons, are shot from the flaming surface of the sun with a velocity of a little less than that of light. These particles are believed to be pulled toward the N and S magnetic poles of the earth, striking the alternated outer atmosphere which may extend up to 800 miles above the earth's surface. There, the streams collide with atoms and molecules of the atmosphere, stripping off outer electrons and causing light-producing states. There are indications that the greatest auroral activity is associated with sunspots and magnetic disturbances, but this has not been proven. Aurorae are not visible when the sky is overcast, during daylight, or when brilliant moonlight obscures the effects.

The light of the aurora is emitted by the atmospheric gases when they are bombarded by a stream of electrically charged particles originating in the sun. As this stream of particles approaches the earth, it is directed towards the two magnetic poles by the earth's magnetic field and so it normally enters the upper atmosphere in high latitudes in each hemisphere. Therefore, the aurora occurs most frequently in two zones girdling the earth about 20˚ to 25˚ from the N and S magnetic poles. The aurora of the N hemisphere is called Aurora Borealis and that of the S hemisphere Aurora Australis.

The emission of the light that is seen as aurora, takes place at heights above 60 miles. Consequently, the aurora may be seen at distances of up to 600 miles from the place where it is overhead.

Auroral rays are always aligned along the direction of the lines of force of the earth's magnetic field so that when they cover a large part of the overhead sky, they appear to radiate from a point to form a crown or corona. The point from which they radiate lies in the direction in which the S pole of a freely suspended magnetic needle (a dip needle) points. The luminance of the normal aurora is below the threshold of color perception of the eye, so the forms appear gray-white in color. However, a brilliant display may be strongly colored, greens and reds being predominant. When the aurora is brilliant, with colors, and the rays have rapid movement, the phenomenon produces a very magnificent display, beyond description.

Much of the S auroral zone lies within the continent of Antarctica. This zone extends N into the adjacent oceans, passing near Macquarie Island, and reaching its lowest latitude, 53˚S, at approximately 140˚E. Hence, the Aurora Australis is seen more frequently over the SE parts of the Indian Ocean and in Australian waters than at the same latitudes in the South Atlantic. It is believed to be centered over Wilkes Land and is usually associated with the moonless Antarctic night.

While the overhead aurora is mainly confined to the two auroral zones, where it may be seen at some time on every clear and dark night, there are times when it moves towards the equator from each zone. On rare occasions, it has even been visible in the tropics. Departures of aurora far from its usual geographical position occur at times of great solar activity, when large sunspots appear on the sun's disk. The aurora that is seen widely over the earth usually follows about a day after a great flare or eruption has occurred in the central part of the sun's disk and is known as the Great Aurora. It is at this time that observers in lower latitudes may see the aurora, not as the familiar unspectacular glow on the horizon, but in the many striking forms that it may assume when it is situated nearly overhead.

Solar Activity.—Being closely associated with solar activity, the intensity and frequency of auroral displays are greatest at the time of the maximum of the 11-year sunspot cycle and least at the time of sunspot minimum. Especially at the time of sunspot minimum, the aurora shows a tendency to recur at intervals of 27 days, which is the period of rotation of the sun as observed from the earth. This suggests that a particular local area of the sun is the source of a continuous stream of particles, which is sprayed out, rather like water from the rotating nozzle of a hose. This stream sweeps across the earth at intervals of 27 days. Marked disturbances in the earth's magnetic field, which are called magnetic storms when they are of exceptional severity, are associated with the aurora.

Saint Elmo's fire is less frequent than the aurora, but may occur anywhere. It is more likely in summer than in winter and is best observed at night or under stormy conditions because of its faintness. Saint Elmo's fire occurs when static electricity collects in sufficiently large charges around the tips of pointed objects. These charges ionize the air in the vicinity and leak off in faintly luminescent discharges. Eerie flickers of blue light are observed on the masts of vessels and on airplane wings, often in the vicinity of storms. Sometimes, these discharges are described as weird greenish glows or as thousands of tiny, air-like electrical sparks flickering along the sharp edges of the surfaces.

Regulations

Legal Information and Regulations

Antarctic Treaty.—Below is a summary of the Antarctic Treaty which was signed by 12 nations at Washington D.C. on December 1, 1959 and ratified in 1961. For further information, see Exploration-History/Sovereignty.

In the treaty, the seven territorial claimant nations agreed for a period of 30 years to set aside their claims. However, the treaty is non-expiring and signatory nations must adhere to the agreements and conventions unless they give a 12-month advance notice that they intend to withdraw.

Article I states that Antarctica shall only be used for peaceful purposes and no military action or testing of weapons can be carried out.

Article II gives scientists the freedom of investigation.

Article III states that all scientific information, observations, and results shall be accessible.

Article IV states that the treaty shall not renunciate any previously made territorial claims. It also says that no new claims or enlargement of existing claims are allowed.

Article V prohibits nuclear explosions, nuclear waste, and radio active waste.

Article VI states that the treaty applies to the area located to the S of 60˚S. It also says that the treaty should not affect the rights of any nations under international law regarding the high seas within this area.

Articles VII and VIII give any of the contracting nations the right to observe, inspect, and examine any other nation's work in order to ensure compliance with the treaty. In addition, nations shall give advance notice of their expeditions and voyages to the Antarctic.

Article IX states that regular meetings shall be held and nations may make recommendations concerning the Antarctic. However, these recommendations must be unanimously agreed.

Article X prohibits any activity that is not allowed by the treaty.

Article XI states that any disputes between the signatory nations will be peacefully resolved.

Article XII states that the treaty will be in effect for a minimum of thirty years, but can be amended or modified.

Articles XIII and XIV state that the treaty shall be subject to ratification, shall be deposited in the United States archives, and shall be written in English, French, Russian, and Spanish.

The following two items that are included in the treaty are of particular operational importance to mariners:

1. Article VII.3 gives any of the contracting nations the right to inspect any other nation's work in order to ensure compliance with the treaty. This includes the inspection of all ships discharging, or loading, cargoes or personnel.
2. Article VII.5 requires each contracting party to inform the other contracting parties of expeditions to Antarctica by its ships or "organized in or proceeding from its territory."

   Planned U.S. government expeditions are reported through the Department of State by the National Science Foundation, which funds and manages the United States Antarctic Research Program.

Nongovernmental U.S. vessels or nongovernmental expeditions, organized in or proceeding from the U.S.A., should report their plans directly to the Office of Ocean Affairs, Room 5801, Department of State, Washington, D.C. 20520.

Subsequent agreements since 1959 include the following:

1. The Agreed Measures for the Conservation of Antarctic Fauna and Flora were recommended at the Third Antarctic Treaty Consultative Meeting held at Brussels in 1964 and were subsequently ratified by the treaty nations.

In the analyses of comparison between Antarctic fauna and flora with other parts of the world, the relationship to their environment has sustained little hindrance by man, except in the case of whales. In addition, it was established that Antarctica offers outstanding research opportunities, due to its present state of untempered ecology. In parallel, it was also established that the Antarctic fauna, seals and penguins in particular, are peculiarly vulnerable and susceptible to extermination, willfully or by accidental introduction of disease.

The Antarctic Conservation Act of 1978 (Public Law 95-541), enacted by the 95th Congress, is the United States basis for the ratification of The Agreed Measures.

Regulations pursuant to U.S. Public Law 95-541 (the Antarctic Conservation Act of 1978) establish Specially Protected Areas (SPA), into which entry is restricted, and make it unlawful, unless authorized by permit, to carry out the following:

(a) kill, handle, or import Antarctic animals or birds.

(b) introduce species into Antarctica not already native to the continent.

(c) discharge pollutants.

An Annex to The Antarctic Conservation Act of 1978 concerns pollution control. The Director of the National Science Foundation has determined that those provisions of the act regarding pollution control shall be implemented by an administrative directive in lieu of formal regulations. This directive (United States Antarctic Program Directive No. 84-1) directs that U.S. Antarctic Program participants will comply with the Code of Conduct for Antarctic Expeditions and Station Activities.

2. The Convention on the Conservation of Antarctic Marine Living Resources 1980 (CCAMLR).

U.S. Public Law 98-623 (Title 3: Antarctic Marine Living Resources Convention) provides the legislative authority necessary to implement the convention. This law makes it unlawful to harvest marine species in Antarctica and in violation of the convention. The law also directs the Secretary of Commerce to promulgate regulations pursuant to the convention.

The area to which the new convention applies extends farther N than the area to which the Antarctic Treaty applies. The treaty covers the area to the S of 60˚S, whereas the convention extends N to the Antarctic Convergence, defined in the convention as being as far N as 45˚S. Antarctic marine living resources are defined as all species of living organisms found S of the Antarctic Convergence.

By designating all populations, not just harvested ones, as resources, the convention recognizes the interdependence of all components of an ecosystem. This broad concept of resources is a significant advance for conservation in international agreements concerning renewable marine resources.

3. Guidelines for visitors to the Antarctic were discussed in 1979 at the 10th Antarctic Treaty consultative meeting. Subsequently, the treaty nations adopted a recommendation (X-8) which is primarily intended to inform tourists and nongovernment expeditions of suitable actions and behavior. The recommendations included subjects such as disturbing wildlife, retaining litter, use of sporting guns, introduction of plants or animals, collecting eggs or fossils, taking care of historic monuments, and entering restricted areas.

4. In 1988, the signatory nations tried to pass a Mineral Resources Agreement, commonly referred to as CRAMRA, which banned mineral and oil exploration. However, this agreement was never ratified.

Subsequently, in 1991 at Madrid, representatives of the treaty nations signed a Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol 1991) that significantly modified environmental standards in Antarctica and superseded CRAMRA.

The protocol applies to the area, as defined in the treaty, as that located to the S of 60˚S. It prohibits any activity relating to mineral resources, other than scientific research; it requires an environmental impact assessment of any proposed activity; and it obliges member nations to devise rules and procedures relating to liability for damages.

The protocol has four annexes which describe the procedures for environmental impact assessment, the elaborate measures for conservation of fauna and flora, the procedures for waste disposal and management, and the rules concerning disposal of waste at sea and the prevention of marine pollution.

Law of the Sea.—In 1982, the Law of the Sea was established which conflicted with the rules and regulations of the Antarctic Treaty.

In regard to the Law of the Sea and the Madrid Protocol, it should be noted that Article VI of the Antarctic Treaty states "nothing in the present Treaty shall prejudice or in any way affect the rights, or the exercise of the rights, of any State under international law with regard to the high seas within that area." Hence, open access to the territorial waters of the high seas around Antarctica has been allowed.

Specially Protected Areas.—The regulations pursuant to the Antarctic Conservation Act of 1978 (U.S. Public Law 95-541) established several Specially Protected Areas (SPA), into which entry is restricted. Collecting of native plants and driving of vehicles in these areas are prohibited.

Permits authorizing entry into SPAs may be issued only if there is a compelling scientific purpose for entry and only if the actions allowed under the permit will not jeopardize the natural ecological system of the area.

Specially Protected Areas are listed in the accompanying table.

SPECIALLY PROTECTED AREAS

Special Area No.	Location
1	Taylor Rookery, MacRobertson Land (67˚26'S., 60˚50'E.)
2	Rookery Islands, Holme Bay (67˚37'S., 62˚33'E.).
3	Ardery Island (66˚22'S., 110˚28'E) and Odbert Island (66˚22'S, 110˚33'E.), Budd Coast
4	Sabrina Island, Balleny Islands (66˚54'S., 163˚20'E.)
5	Beaufort Island, Ross Sea (76˚58'S., 167˚03'E.)
7	Cape Hallett, Victoria Land (72˚18'S., 170˚19'E.)
8	Dion Islands, Marguerite Bay (67˚52'S., 68˚43'W.)
9	Green Island, Berthelot Islands (65˚19'S., 64˚10'W.)
13	Moe Island, South Orkney Islands (60˚45'S., 45˚41'W.)
14	Lynch Island, South Orkney Islands (60˚40'S., 45˚38'W.)

Return to page: 9

SPECIALLY PROTECTED AREAS	
Special Area No.	Location
15	Powell Island, South Orkney Islands (60˚45'S., 45˚02'W.)
16	Coppermine Peninsula, Robert Island (63˚23'S., 59˚24'W.)
17	Litchfield Island, Palmer Archipelago (64˚46'S., 64˚06'W.)
18	Coronation Island, South Orkney Islands (60˚33'S., 45˚36'W.)
19	Lagotellerie Island, Marguerite Bay (67˚53'S., 67˚24'W.)
20	New College Valley, Caughley Beach,Cape Bird, Ross Island (77˚14'S., 166˚23'E.)
21	Avian Island, Marguerite Bay (67˚46'S., 68˚54'W.)
22	Mount Melbourne, Victoria Land (74˚21'S., 164˚42'E.)
23	Dufek Massif, Davis Valley Pond and Forlidas Pond (82˚27'S., 51˚21'W.)
24	Terre Adelie (66˚40'S., 140˚02'W.)
25	Cape Evans, Ross Island (77˚38'S., 166˚25'E.)
26	Lewis Bay, Mount Erebus, Ross Island (77˚25'S., 167˚28'E.)
27	Cape Royds, Ross Island (77˚33'S., 166˚10'E.)
28	Hut Point, Ross Island (77˚51'S., 166˚38'E.)
29	Cape Adare, Victoria Land (71˚19'S., 170˚09'E.)

For additional information and applications concerning permits, contact the National Science Foundation (NSF), Office of Polar Programs (OPP), 4201 Wilson Boulevard, Arlington, VA 22230.

Sites of Special Scientific Interest.—At the Eighth Antarctic Treaty Consultative Meeting, in 1975, the representatives of the nations recognized the need to protect scientific investigations which might suffer from willful or accidental interference. Subsequently, in order to avoid any interference and to protect sites, which could not be designated as Specially Protected Areas (SPA), certain locations have been identified as Sites of Special Scientific Interest. Different rules apply to each site, but in general, they should only be entered by persons engaged in scientific research. In addition, vehicles should not be used in the sites and helicopters and low-flying aircraft should avoid them.

The Sites of Special Scientific Interest likely to affect marinersare listed in the accompanying table.

SITES OF SPECIAL SCIENTIFIC INTEREST	
Site No.	Location
1	Cape Royds, Ross Island (77˚33'S., 166˚08'E.)
2	Hut Point Peninsula, Ross Island (77˚49'S., 166˚39'E.)
3	Barwick Valley, Victoria Land (77˚18'S.,161˚00'E.)
4	Cape Crozier, Ross Island (77˚30'S., 169˚25'E.)
5	Fildes Peninsula, King George Island, South Shetland Islands (62˚12'S., 58˚56'W.)
6	Byers Peninsula, Livingston Island, South Shetland Islands (62˚38'S., 61˚05'W.)
7	Haswell Island, Queen Mary Land (66˚31'S., 93˚00'E.)
8	Admiralty Bay, King George Island, South Shetland Islands (62˚12'S., 58˚27'W.)
9	Rothera Point, Adelaide Island (67˚35'S., 68˚08'W.)
10	Caughley Beach, Cape Bird, Ross Island (77˚15'S., 166˚23'E.)
11	Mount Erebus, Ross Island (77˚31'S., 167˚07'E)
12	Canada Glacier, Victoria Land (77˚37'S.,163˚03'E.)
13	Potter Peninsula, King George Island South Shetland Islands (62˚15'S., 58˚41'W.)

SITES OF SPECIAL SCIENTIFIC INTEREST	
Site No.	**Location**
14	Harmony Point, Nelson Island, South Shetland Islands (62˚18'S., 59˚14'W.)
15	Cierva Point, Danco Coast (64˚10'S., 60˚57'W.)
16	Bailey Peninsula, Budd Coast, Wilkes Land (66˚17'S., 110˚32'E.)
17	Clark Peninsula, Budd Coast, Wilkes Land (66˚15'S., 110˚36'E.)
18	White Island, McMurdo Sound (78˚10'S., 167˚25'E.)
19	Asgard Range, Victoria Land (77˚35'S., 161˚05'E.)
20	Biscoe Point, Anvers Island, Palmer Archipelago (64˚49'S., 63˚48'W.)
21	Port Foster, Deception Island, South Shetland Islands (62˚55'S., 60˚39'W.)
22	Prins Harald Kyst, Lutzow-Holmbukta (69˚15'S., 39˚45'E.)
23	Svarthamaren, Dronning Maud Land (71˚54'S., 5˚10'E.)
24	Mount Melborne, Victoria Land (74˚21'S., 164˚41'E.)
25	Marine Plain, Vestfold Hills (68˚36'S., 78˚07'E.)
26	Greenwich Island, Discovery Bay, South Shetland Islands (62˚29'S., 59˚41'W.)
27	Port Foster, Deception Island, South Shetland Islands (62˚58'S., 60˚38'W.)
28	South Bay, Doumer Island, Palmer Archipelago (64˚52'S., 63˚36'W.)
29	Alexander Island, Graham Land (70˚50'S., 68˚30'W.)
31	Mount Flora, Hope Bay, Trinity Peninsula,(63˚25'S., 57˚01'W.)
32	Cape Shirreff, Livingston Island, South Shetland Islands (62˚28'S., 60˚47'W.)
33	Ardley Island, Maxwell Bay, King George Island (62˚08'S., 59˚08'W.)
34	Lions Rump, King George Island, South Shetland Islands (62˚08'S., 58˚08'W.)
35	Low Island, Western Bransfield Strait (63˚20'S. to 63˚35'S. and 61˚45'W. to 62˚30'W.)
36	East Dallman Bay, Brabant Island (64˚00'S. to 64˚20'S. and 62˚50'W. to intertidal zone)
37	Botany Bay, Cape Geology, Victoria Land (77˚00'S., 162˚32'E.)

Operations Support.—Antarctic research is a remote expeditionary activity requiring a support system capable of providing virtually all necessities for living and working in Antarctica. Such necessities include special cold weather clothing, food and housing, transportation, utilities, communications, tools, equipment, research instruments and laboratories, and all supplies, particularly fuel, essential for life support in the Antarctic.

The National Science Foundation (NSF) funds and manages the entire United States Antarctic Program, obtaining operations support, under contracts, from private sector firms and, on a reimbursable basis, from the Department of Defense (DoD) and the Department of Transportation (DoT).

Major logistic elements currently provided include the operation and maintenance of McMurdo Station and an advance staging facility in Christchurch, New Zealand; aviation support on the Antarctic continent; intercontinental air and sealift support between the U.S.A. and Antarctica; and communications support. The DoT, through the U.S. Coast Guard, provides icebreaker services to support surface resupply and research activities.

Note.—For information concerning operations and logistics in the Antarctic; the Antarctic Treaty, including any modifications or amendments; U.S. laws and regulations pursuant to the Antarctic Treaty; Specially Protected Areas; Sites of Special Scientific Interest; historic monuments; and research bases, questions and correspondence should be directed to:

The National Science Foundation (NSF)
Office of Polar Programs (OPP)
4201 Wilson Boulevard
Arlington, VA (22230)
Telephone: (703) 306-1031
Facsimile: (703) 306-0139

Pollution.—The International Convention for the Prevention of Pollution from Ships, as modified by the Protocol of 1978 (MARPOL 73/78) is implemented into United States law by The Act to Prevent Pollution from Ships (33 U.S.C. 1901). The International Convention includes five annexes. Annexes I, II, and V are mandatory and the remainder optional.

Annex I contains regulations concerning the prevention of pollution by oil.

Annex II contains regulations concerning the control of pollution by noxious liquid substances carried in bulk.

Annex III contains regulations concerning the prevention of pollution by harmful substances carried in packaged forms, containers, or tanks.

Annex IV contains regulations concerning sewage from ships.

Annex V contains regulations concerning the disposal of garbage from ships and the management of ballast.

Special Areas and Particularly Sensitive Sea Areas are designated in the Annexes. In these areas more stringent restrictions are applied to avoid the effects of harmful substances. A Particularly Sensitive Sea Area may lie within a Special Area.

The Antarctic Area, which is the sea area S of 60˚S, has been designated in the Annexes as a Special Area (1992).

For further information, see Annual Notice to Mariners No. 1, MARPOL 73/78, and The Act to Prevent Pollution from Ships (33 U.S.C. 1901).

Search and Rescue

Ship Reporting Systems

AMVER.—The Automated Mutual-assistance Vessel Rescue (AMVER) System is operated by the U.S. Coast Guard to promote safety of life and property at sea. It is a maritime mutual assistance organization which provides important aid to the development and coordination of search and rescue (SAR) efforts in many offshore areas of the world.

Merchant vessels of all nations making offshore voyages are encouraged to send movement reports and periodic position reports to the AMVER center in New York via selected radio stations or via INMARSAT.

Information from these reports is entered into a computer which generates and maintains dead reckoning positions for such vessels. Characteristics of vessels that are valuable for determining SAR capability are also entered from available sources. Appropriate data concerning the predicted location and SAR characteristics of each vessel is then made available upon request to recognized SAR agencies of any nation, or persons in distress, for use during an emergency. Such information is kept strictly confidential and only disclosed for reasons connected with maritime safety.

Generally, participation in AMVER is voluntary. However, requirements exist for certain U.S. flag or U.S. interest vessels.

The U.S. Maritime Administration (MARAD) regulations state that United States flag merchant vessels of 1,000 grt or more, operating in foreign commerce, and foreign flag vessels of 1,000 grt or more, for which an Interim War Risk Insurance Binder has been issued under the provisions of Title XII, Merchant Marine Act (1936), must report to the AMVER center.

Title 47 of the Code of Federal Regulations (CFR CH. 1, Sec. 80.905) states that United States vessels, which transport more than six passengers for hire, operated more than 200 nautical miles from the nearest land must participate in AMVER while engaged on a voyage where the vessels is navigated in the open sea for more than 24 hours.

Participating vessels must send a Sailing Plan Report, a Position Report, a Deviation Report, and an Arrival Report.

Departure Reports have been eliminated in favor of the more common practice of filing a combined Sailing/Departure Report. However, Departure Reports will continue to be accepted indefinitely.

A world-wide radio station network of coastal facilities supports AMVER. To ensure that no charge is applied, all AMVER reports should be passed through the specified stations.

In cases of emergency, all distress messages must be sent to the nearest radio communications station, not the AMVER center.

Note.—For further details of the system, see Pub. 117, Radio Navigational Aids; and the AMVER Bulletin, which is available from U.S. Coast Guard District Offices, Marine Inspection Offices, and Captain of the Port Offices.

Detailed instructions in English and several other languages are contained in the AMVER Users Manual which may be obtained free of charge from the following address:

AMVER Maritime Relations Office
U.S. Coast Guard
Battery Park Building
New York, NY (10004)
USA

The Australian Ship Reporting System (AUSREP)

The Australian Ship Reporting System (AUSREP) is compulsory for Australian-registered commercial vessels and for foreign vessels on voyages between Australian ports. All other vessels are encouraged to participate when within the AUSREP area.

The objective of the AUSREP system is to contribute to the safety of life at sea by:

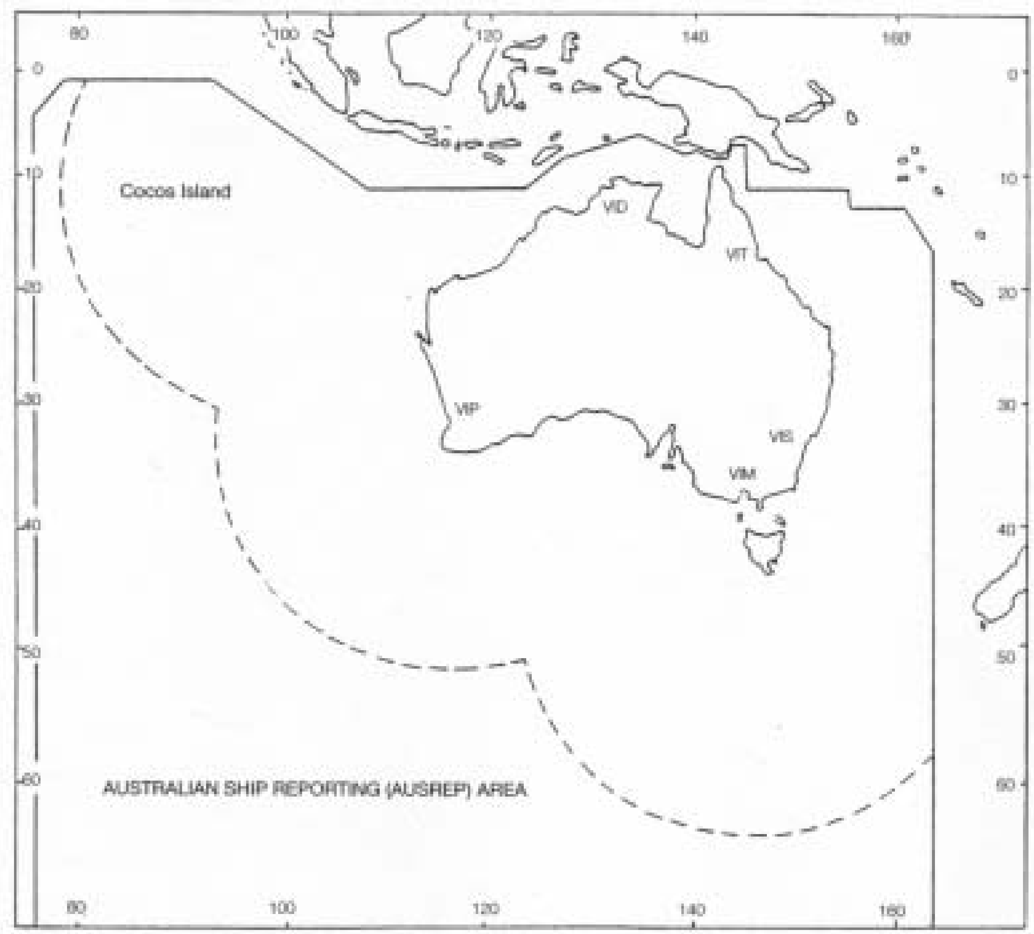
1. Limiting the time between the loss of a vessel and the initiation of SAR action, in cases where no distress signal is sent out.
2. Limiting the search area for a SAR action.
3. Providing up-to-date information on all shipping resources available in the area, in the event of SAR action.

The AUSREP area, and Australian SAR region, covers the coast of Australia, as well as the coast of Antarctica between 75˚E and 163˚E, and extends N to approximately 6˚S at its W limit and to 12˚S at its E limit. The limits are best seen in the accompanying graphic.

The system is operated by the Australian Maritime Safety Authority (AMSA) through AusSAR, specifically the Rescue Coordination Center Australia (RCC Australia).

Telephone:	AusSAR AUSREP
	+61(0)2 6230 6880
	AusSAR Maritime
	+61(0)2 6230 6811
Facsimile:	+61(0)2 6230 6868
Address:	P.O. Box 2181
	Canberra ACT 2601
	Australia
Internet:	http://www.amsa.gov.au/amsa/sar.htm

The AUSREP/REEFREP Interface, a two-way automatic data exchange interface, has been implemented between the



— — Depicts approximate radius of action for Australian based long range search aircraft

REEFREP Ship Reporting System and the existing AUSREP system. This will avoid the need for dual reporting by vessels when participating in the AUSREP and REEFREP systems and will enhance the information available in each system. Further information about REEFREP can be found in Pub. 127, Sailing Directions (Enroute) East Coast of Australia and New Zealand.

On departure from an Australian port or on entering the AUSREP area, the following procedures are applicable:

1. Masters are to send a Sailing Plan (SP) to RCC Australia.
2. A computerized plot is maintained of the vessel's estimated position.
3. Position updates can be done by either of the following methods:
   a. Position Reports (PR) are sent to RCC Australia each day at the time that has been nominated by the vessel's master so that a report is received at least every 24 hours. Dates and times shall be in Coordinated Universal Time (UTC).
   b. Masters may agree to their vessels being queried via INMARSAT-C which, when requested, will automatically send a PR.
4. On arrival at the destination or on final departure from the AUSREP area, a Final Report (FR) should be sent to RCC Australia.
5. Should a vessel at any time be in a position more than 2 hours steaming from the position that would be predicted from the last SP or PR, a Deviation Report (DR) should be sent to the MRCC.
6. All dates and times used in AUSREP reports are to be in Coordinated Universal Time (UTC).

Sailing Plan (SP).—The SP is sent up to 24 hours prior to joining the AUSREP system, with the following exceptions:

1. At ports within the REEFREP area, the SP must be sent prior to departure.
2. At other Australian ports, the SP may be sent up to 2 hours after departure.
3. When entering the system from sea at an ocean boundary, the SP may be sent 24 hours prior to entering the area or up to 2 hours after crossing the boundary.

The SP contains information necessary to initiate a plot and give an outline of the intended passage. If a vessel does not sail within 2 hours of the time stated in the SP, then that SP must be canceled and a new one sent.

In the case of a foreign vessel departing on an overseas voyage from an Australian port, if the Master does not intend to send AUSREP Position Reports, this fact must be indicated in the SP by the inclusion of the word NOREP in place of the nominated daily reporting time in Field N; amplifying remarks may be included in Field X. Under this option, RCC Australia will not undertake SAR action unless specific information is received which indicates an air search is warranted. However, a NOREP vessel must still comply with the mandatory REEF-REP reporting requirements when the vessel enters the REEF-REP area.

The AUSREP report format for an SP is given in the accompanying table.

Position Report (PR).—The PR is sent at the Date/Time of Next Report as listed in Field N of the Sailing Plan. These reports must be sent at the nominated daily reporting time until and including the day of arrival in, or departure from, the AUSREP area. The interval between PRs should not exceed 24 hours.

The information contained in the PR will be used by RCC Australia to update the plot. The PR must reflect the position and course of the vessel at the designated reporting time. However, the speed should be the anticipated speed until the next report time.

The ETA at port of destination or AUSREP area boundary should always be confirmed in the last PR of a passage. It may also be amended in any PR whenever the Master is aware of a revised ETA.

The AMSA has introduced the use of INMARSAT-C polling as an option to replace the submission of PRs. Vessels can request RCC Australia to poll the vessel using INMARSAT-C by inserting the word POLL in Field N of the SP instead of nominating a Date/Time of Next Report. Polling involves RCC Australia sending a signal to the vessel's INMARSAT-C terminal to prompt an automatic position report, which includes the vessel's position, course, and speed. INMARSAT-C polling eliminates the need for a manual submission of the PR. Sailing Plans, Deviation Reports, and Final Reports must still be submitted as normal.

The AUSREP report format for a PR is given in the accompanying table.

Deviation Report (DR).—A DR must be sent to RCC Australia if a vessel, at any time, is in a position more than 2 hours steaming from that which would be predicted from the last SP or PR. A DR can also be sent when any other voyage details are altered.

Failure to send an appropriate DR may have a negative effect on SAR operations. If the vessel is in distress and has not sent out a distress message, the AUSREP procedures may result in RCC Australia initiating an air search to locate the vessel. The search aircraft will start looking in the area related to the vessel's route and speed as indicated in the SP and subsequent PRs. If the vessel has not submitted a DR when there is a change in route and speed, the search aircraft may be unable to find any survivors. It is in the vessel's best interest to keep RCC Australia up-to-date on all voyage details.

The AUSREP report format for a DR is given in the accompanying table.

Final Report (FR).—An FR is sent, as follows:

1. For vessels enroute overseas and departing the AUSREP area, the FR should be send at the AUSREP boundary.
2. For vessels ending a voyage at an Australian port within the REEFREP SRS area, the FR must be sent at the last REEFREP reporting point
3. For vessels ending a voyage at any other Australian port, the FR can be sent within 2 hour's steaming of the port or pilot station. Under no circumstances should the FR be sent more than 2 hours prior to arrival.

As an alternative, the FR may be telephoned to RCC Australia immediately after berthing, but not more than 2 hours after arrival. If it is known that the vessel is to anchor or berth where telephone facilities are not available, the FR should be sent via the appropriate coast radio station or INMARSAT-C.

The AUSREP report format for an FR is given in the accompanying table.

Overdue AUSREP Reports.—AUSREP is a positive reporting system. If a PR or an FR is not received by RCC Australia within 2 hours of the expected time, action is taken to determine the vessel's location and confirm the safety of the crew.

To avoid unnecessary search action it is most important that vessels report at the nominated reporting time each day and send their FR when leaving the AUSREP area. If a vessel is unable to pass a PR or an FR, all attempts must be made to pass a message to this effect through another vessel, a harbor, or other shore authority either by VHF, signaling lantern, or emergency transmitter.

The action taken by RCC Australia if a report is not received as expected will depend on the prevailing circumstances, but will generally include the following:

1. Internal checks to establish if the vessel's report has been received by RCC Australia.
2. For INMARSAT-equipped vessels, an attempt to contact the vessel directly.
3. Attempts to contact the vessel via HF DSC.
4. The listing of overdue vessels will be listed on CRS traffic lists to alert vessels to submit the overdue report.
5. When 6 hours overdue, a broadcast of the vessel's call sign, with REPORT IMMEDIATE preceding traffic lists, indicating concern due to non-receipt of the PR or FR.
6. Extensive communication checks with Australian and overseas CRS, owners, agents, and other ships are carried out to trace the last sighting or contact with the vessel.
7. When 21 hours overdue, the upgrading of the REPORT IMMEDIATE broadcast to the Urgency Signal PAN PAN indicator.

By the time 21 hours have elapsed, search planning will be in progress and details included in NAVAREA X and facsimile weather broadcasts. By the time the report is 24 hours overdue, positive SAR action will have been initiated to locate the vessel. It should be noted that resources available for an air search decrease with the distance from an Australian base and that the times may differ if the vessel is participating in INMARSAT-C polling.

Sending an AUSREP report.—AUSREP reports can be sent, as follows:

1. In an Australian port.—All reports should be made from the vessel directly to RCC Australia, in order to avoid delays that may be associated with using intermediate agencies. Collect telephone calls, facsimile messages, or INMARSAT-C may be used to make an AUSREP report.
2. Via INMARSAT.—Reports must be addressed RCC Australia and sent via the Pacific Ocean Region (POR) or Indian Ocean Region (IOR) satellites to Perth Land Earth Station (Perth LES). These procedures apply only to AUSREP messages. Calls are free of charge when submitted within the AUSREP area.

INMARSAT-C fitted vessels will not be charged for messages sent via INMARSAT-C if these procedures are followed: Select Special Access Code (SAC) 43 through Perth LES only; Pacific Ocean (222) or Indian Ocean (322).

INMARSAT-A, B, or M fitted Ship Earth Stations will be charged for messages sent via INMARSAT-A, B, or M to RCC Australia.

While participating in AUSREP, vessels should ensure that their INMARSAT equipment remains active in the LOGIN mode at all times.

3. Via Coast Radio Stations.—Until 30 June 2002, AUSREP reports may be sent free of charge through any Australian Coast Radio Station operated by Telstra. All reports must be addressed to RCC Australia.After 30 June 2002, all Telstra CRS are expected to cease operations

From 1 July 2002, the preferred method of submitting an AUSREP report is via INMARSAT-C.

AUSREP Reporting Format

Field	Meaning	Type of Report			
		SP	PR	DR	FR
A	Vessel name, call sign and IMO number.	X	X	X	X
B	Date/time of position.		X	X	
C	Position (latitude and longitude).		X	X	
E	Course.	R	X	A	
F	Speed (vessel's anticipated average speed, in knots and tenths of knots, until next report).	X/R	X	A	
G	Name of last non-Australian port of call.	A			
H	Date/time and point of entry into AUSREP area (point is either the Australian port of departure or the latitude/longitude of crossing the AUSREP area boundary).	X			
I	Next foreign (non-Australian) destination and ETA.	A		A	
J	Coastal pilotage details: 1. Yes/no. 2. Last name of pilot. 3. License number of pilot.	R		A	
K	Date/time and point of exit from the AUSREP area (the point is either the latitude/longitude of crossing the area boundary or the Australian port at which the vessel is to arrive).	X		A	X
L	Route (vessel's intended track—state rhumb line or coastal, great circle, or composite with limiting latitude).	X/R		A	
M	Coast radio maritime communication stations monitored (include INMARSAT A and C numbers, if fitted).	X		A	
N	Date and time (UTC) of next report. (See **Note 1** below.)	X	X	X	
O	Draft, fore and aft, in meters and tenths of meters.	R			
P	Cargo.	R		A	
Q	Defects or other limitations.	A		A	
R	Pollution (or reports of any seen).	A		A	
U	Vessel type, length (in meters), and gross tonnage.	R			
V	Medical personnel carried.	X			

AUSREP Reporting Format					
Field	**Meaning**	**Type of Report**			
		SP	**PR**	**DR**	**FR**
X	Remarks.	A	A	A	X
Y	Request to relay a report to AMVER. (See **Note 2** below.)	A			

Key:

1. X—Required field
2. R—Vessels transiting the REEFREP Ship Reporting System should also include these fields.
3. A—Include if appropriate.

Notes:

1. See text under Sailing Plan for vessels electing not to participate in the AUSREP system.
2. Place the word AMVER in Field Y; do not separate the letters in the word AMVER by spaces, as this may disrupt the computer processing. Masters should note that an AMVER report will only be forwarded if a vessel is in the AUSREP area and is currently participating in the AUSREP system.

Seas

Marginal Seas

(The following information was prepared by the U.S. Naval Oceanographic Office.)

The marginal seas are divided geographically into the Ross Sea sector (160˚E to 120˚W); the Amundsen-Bellingshausen Sea sector (120˚ to 60˚W); the Weddell Sea sector (70˚W to 0˚); and the Continental Coast sector (0˚ to 160˚E).

The Ross Sea Sector.—Drift ice concentration along the Ross Ice Shelf to the E of Ross Island begins to diminish in late October and reduces to open water (less than one-tenth ice concentration) by late November. An open-water flaw polynya, centered at 75˚S, 165˚E, forms by late November. The ice-free area off the shelf expands to the N and eventually meets the retreating outer edge of the ice during the second half of January. Drift ice in the S portion of the Ross Sea drifts NW against Victoria Land where it persists throughout the austral summer. Thick ice floes are also advected into the central and easternmost portions of the Ross Sea by prevailing W winds and currents. Sea ice coverage becomes minimal in the middle of February.

Reinforced vessels can normally reach the NE end of Ross Island by the end of December, and all shipping by the third week of January. The route becomes closed to nonreinforced vessels in the first week of March and closed to all vessels in the middle of March. The Ross Sea becomes covered with very close or compact ice in April.

In McMurdo Sound, the maximum extent of fast ice in the approaches to McMurdo Station, on Hut Point Peninsula, is normally 30 miles and occurs in the middle of October. However, fast ice continues to thicken until the first part of December when the average winter's maximum thicknesses are 0.9 to 1.2m at the fast ice edge, 1.2 to 1.8m at several nautical miles inside the edge, 1.8 to 2.1m off Hut Point, and 2.7 to 3m along the Ross Ice Shelf. The thickest section of fast ice ever recorded in the sound was 6.4m thick.

A channel leading through the fast ice to Hut Point is kept open by icebreakers from the middle of December to early January, depending upon the severity of the winter. Vessels will normally need icebreaker assistance for a period following the channel completion. The channel is usually open to all vessels in late January although, it was open one year as early as 10 December.

Fast ice begins to deteriorate in late December and to dislodge in late January. By the first week of March, all fast ice is usually gone except for a narrow strip attached to the shelf. Soon thereafter, new ice rapidly forms and the sound is frozen over by late March.

Sea ice in the Ross Sea area reaches its maximum extent during late September. The heaviest ice is encountered between 67˚30'S and 72˚30'S. Multi-year floes, 2.4 to 3.6m thick, drift into the N central area from the E. Sea ice in the W part of the Ross Sea is principally first-year ice, 0.6 to 1.2m thick. The movement of ice during the austral winter is in a N direction away from the ice shelf, and as a consequence, relatively thin ice, up to only 0.3m thick, prevails off the shelf front.

Numerous icebergs occur throughout the Ross Sea. The S half of the sea is covered by the Ross Ice Shelf, the front of which varies in height above sea level from 30 to 55m. Tabular icebergs are periodically calved off the shelf front. Most of these bergs are between 300 and 3,048m long with an estimated freeboard-to-draft ratio of 1:5. However, icebergs of 16 to 22 miles in length are occasionally formed. The largest berg observed in the Ross Sea was 100 miles long. The icebergs drift to the W off the Ross Ice Shelf and then to the N along Victoria Land. Icebergs may enter McMurdo Sound, but normally they do not drift farther than 77˚30'S.

The W flow of the East Wind Drift is strongly influenced by the deep indentation of the Ross Sea. One branch of this current passes outside the entrance of the Ross Sea, while another branch sets S along the sea's E boundary. The S branch continues W along the Ross Ice Shelf at a rate of 1 to 3 knots and is then deflected N along the coast of Victoria Land. This outflow from the Ross Sea rejoins a branch of the East Wind Drift near Cape Adare. The combined flow then passes between the Balleny Islands and the continent.

Satellite imagery was used to make observations of sea-ice drift motion near the Ross Sea along the Getz Ice Shelf, between Cape Colbeck and Mount Siple. The sea ice studied displayed a highly variable motion when observed over two-day time intervals with typical speeds ranging from nearly zero to 0.6 knot. In agreement with the circulation pattern, a general W flow was observed near shore.

In the S part of the Ross Sea, the ocean tide beneath the Ross Ice Shelf is dominated by diurnal, harmonic constituents, with small semidiurnal tidal constituents. Along the N margin of the ice shelf, near 78˚S, the tropic (diurnal spring) tide ranges from 0.9m to more than 2m near the Siple Coast. The amplitudes of the diurnal tide constituents are larger in the Ross Sea than in the adjacent S part of the Pacific Ocean, indicating a diurnal resonance related to the shape of the embayment and the depth of the sea.

The main inflow into McMurdo Sound is the Cape Bird Current which reaches Cape Bird as a W flow and turns into the sound with velocities of up to 3 knots. Direct current measurements (1967) made at a depth of 55m, between Cape Bird and Beaufort Island, indicate a W current with an average speed of 1 knot and a maximum speed of 2.7 knots. The Cape Bird Current continues along the W coast of Ross Island until it approaches Cape Royds where it joins a strong NW flow from under the Ross Ice Shelf, near Cape Armitage. However, direct current measurements made more than 1 mile from the coast near Cape Armitage indicate a flow towards the Ross Ice Shelf. The flow along the W side of McMurdo Sound, near the Dailey Islands, is towards the NW at an average speed of 0.2 knot. This flow is part of the outflow from the Cape Bird Current with some addition from the N flow near Cape Armitage. The surface flow in the center of McMurdo Sound is directed towards the Ross Ice Shelf. It is uniformly slow, usually having a mean speed of less than 0.1 knot.

Since a large portion of the Ross Sea is generally covered with ice, the sea surface temperatures in summer are almost at the freezing point, ranging from -1.7˚ to 0.3˚C.

Salinity in the Ross Sea area is strongly influenced by the amount of melting and freezing that occurs at the sea surface and beneath the ice shelves. The Ross Sea Shelf water, which forms primarily from freezing at the sea surface in the W part, has the highest salinity and density of any sea water in the Antarctic region. The horizontal surface salinity distribution is also influenced by the clockwise circulation pattern in the Ross Sea, the highest salinity values being concentrated in the W part.

The density field is determined primarily by the salinity distribution, hence, only minor horizontal variations in density are present in the Ross Sea.

The Amundsen-Bellingshausen Sea Sector.—Ice conditions in the Amundsen Sea and the Bellingshausen Sea are highly variable from year to year and the N movement of the outer edge of the drift ice fluctuates. This outer edge normally reaches its lowest latitude in the Bellingshausen Sea and the Amundsen Sea during late August and the middle of September, respectively.

Usually by early November, polynyas develop to the SW of Alexander Island, to the W of Smyley Island, to the W of King Peninsula, and to the N of Bear Peninsula. These polynyas expand N and can join with the open water in mild summers. Sea ice coverage in both of the seas is minimal during early March.

Palmer Station (64˚46'S., 64˚03'W.) is normally open to reinforced vessels from the middle of December to the middle of May and to all vessels from the middle of January to the middle of April. The opening and closing of the approach to Palmer Station varied greatly during the navigation seasons from 1974/75 through 1982/83. The approach opened to reinforced vessels as early as late October and as late as early February. It closed to reinforced vessels as early as the middle of April and as late as the end of June.

Rothera Station (67˚34'S., 68˚08'W.) is normally open to reinforced vessels from early February through the middle of April.

The current pattern within the Amundsen Sea and the Bellingshausen Sea is typical of the general adjacent seas circulation. The W current follows the coast with an outward cyclonic flow which eventually merges with the E current near the Antarctic Convergence.

The surface temperatures in the Amundsen Sea and the Bellingshausen Sea range from -1.7˚C, near the coast, to greater than 1.7˚C, near the Antarctic Convergence (62˚ to 64˚S). The surface shows an expected warming trend to the N of the Antarctic Convergence. The horizontal variations of surface salinities are small.

The Weddell Sea Sector.—The Weddell Sea contains throughout the year a large portion of the Antarctic ice cover. During the austral winter, the ice cover for all of Antarctica reaches its northernmost extent to the N of the Weddell Sea. During the austral summer, most of the W part of this sea is covered by heavy drift ice. Summer sea ice is normally discharged from the perennial ice regime in an ice tongue extending out to the NE.

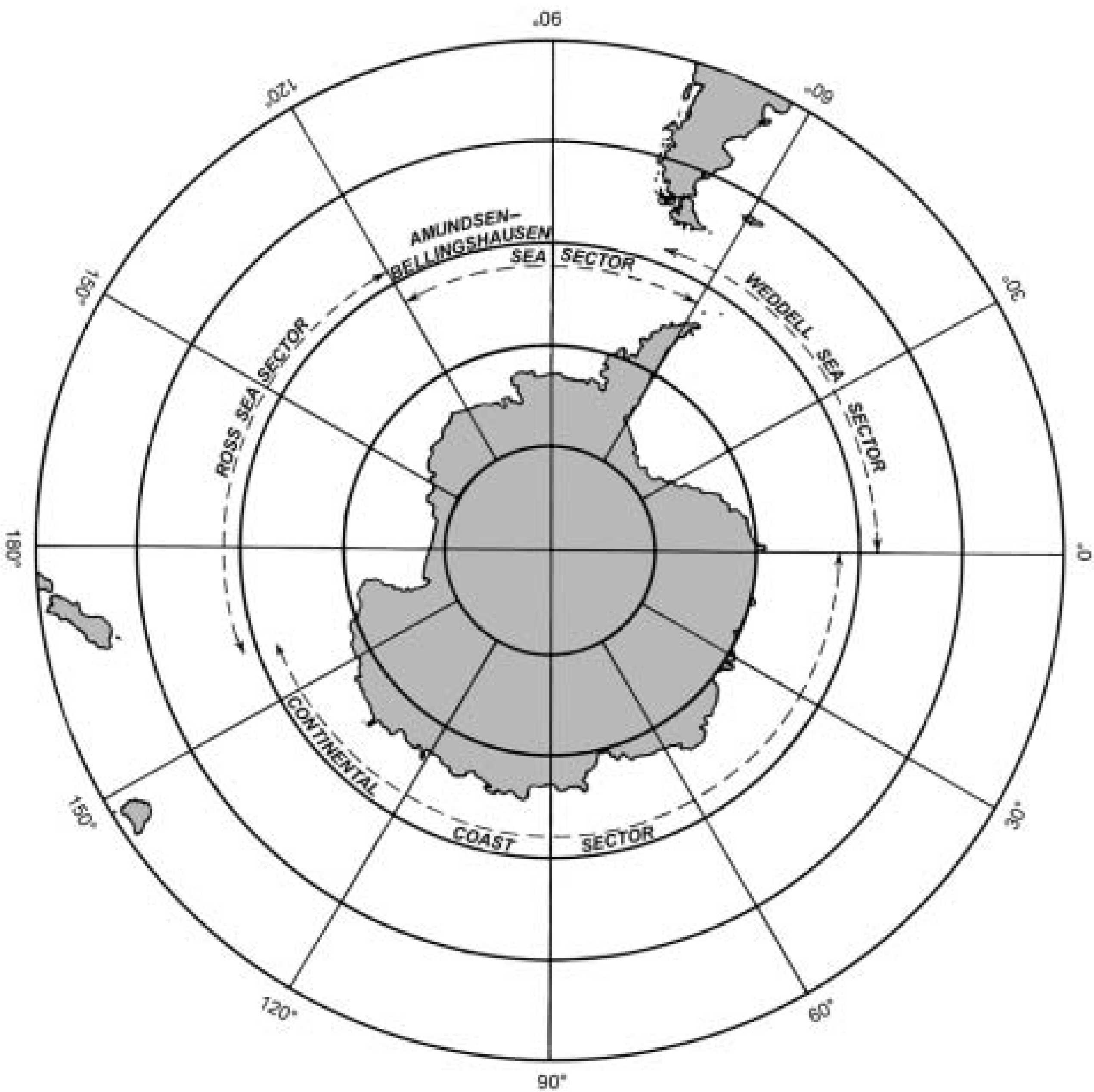
The maximum ice cover is attained during the first week of September in the Weddell Sea region to the W of 40˚W. It is attained during the last week of September in that part to the E of 40˚W.

During the winter period of the mid-1970s, an extensive open-water polynya formed generally from 5˚W to 25˚W and from 63˚S to 70˚S. Scientists have hypothesized that this recurring polynya was the result of wind divergence and a large vertical ocean heat flux.

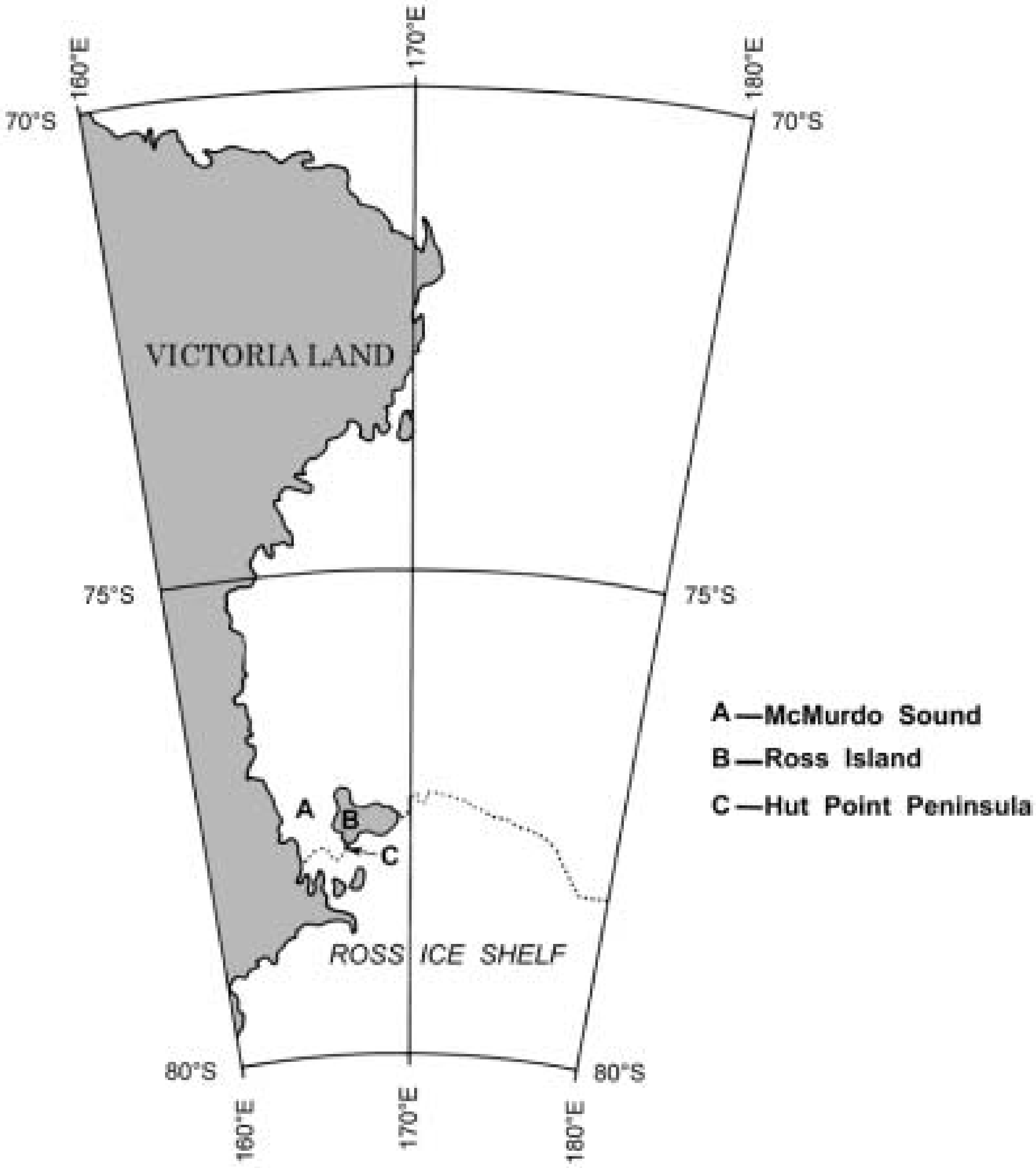
Flaw leads usually appear during the first half of November. During most summers, the Weddell Sea is clear of ice to the coast, between the Greenwich meridian and 20˚W. Sea ice becomes minimal in the last week of February.

Halley Station (75˚31'S., 26˚56'W.) is usually open to reinforced vessels from early January to the middle of March. During most years, this year-round station can be reached by all vessels from the middle of January through late February. Further S, Berkner Island can normally be reached by reinforced vessels from the middle of January to the middle of February. Only during relatively light ice years can all vessels reach Berkner Island and then only for a period lasting from late January through the middle of February.

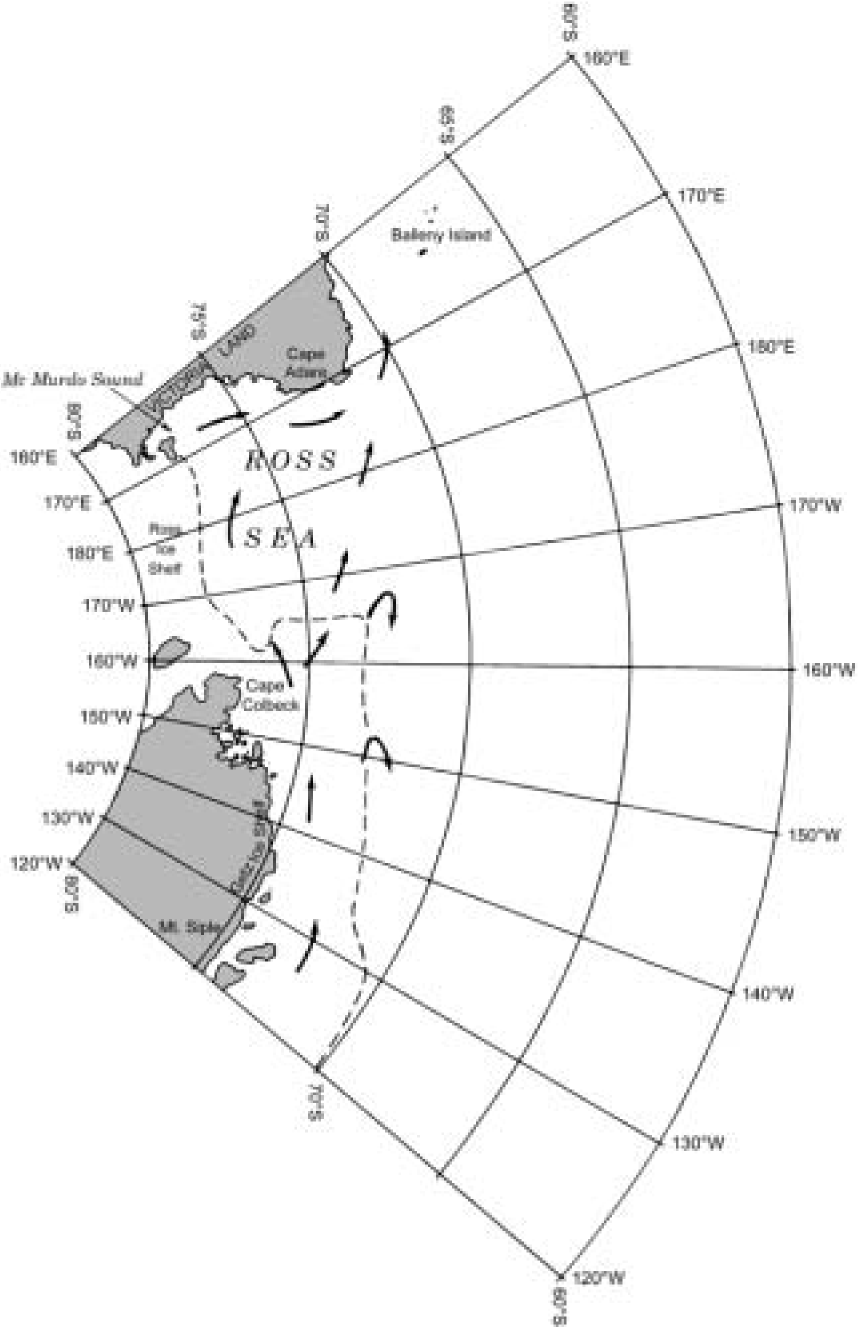
Level and rafted ice up to 4.9 and 11.9m thick, respectively, have been encountered in the E part of the Weddell Sea during the navigation season. A special hazard exists in the lowermost W part of the Weddell Sea which is sometimes navigable. Ice floes, consisting of many decades old ice and fast ice, may be



MARGINAL SEAS

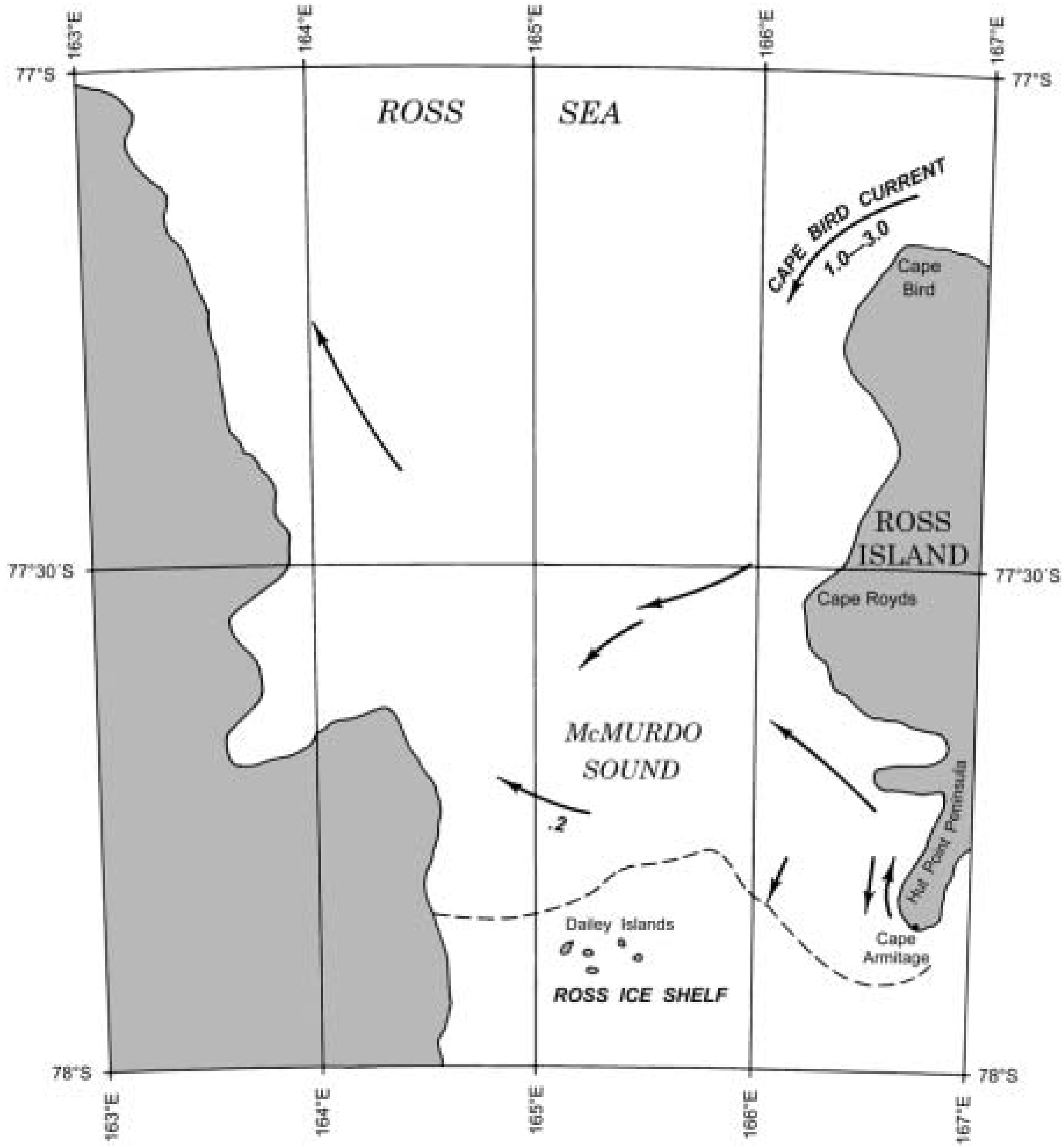


ROSS SEA LOCATOR CHART



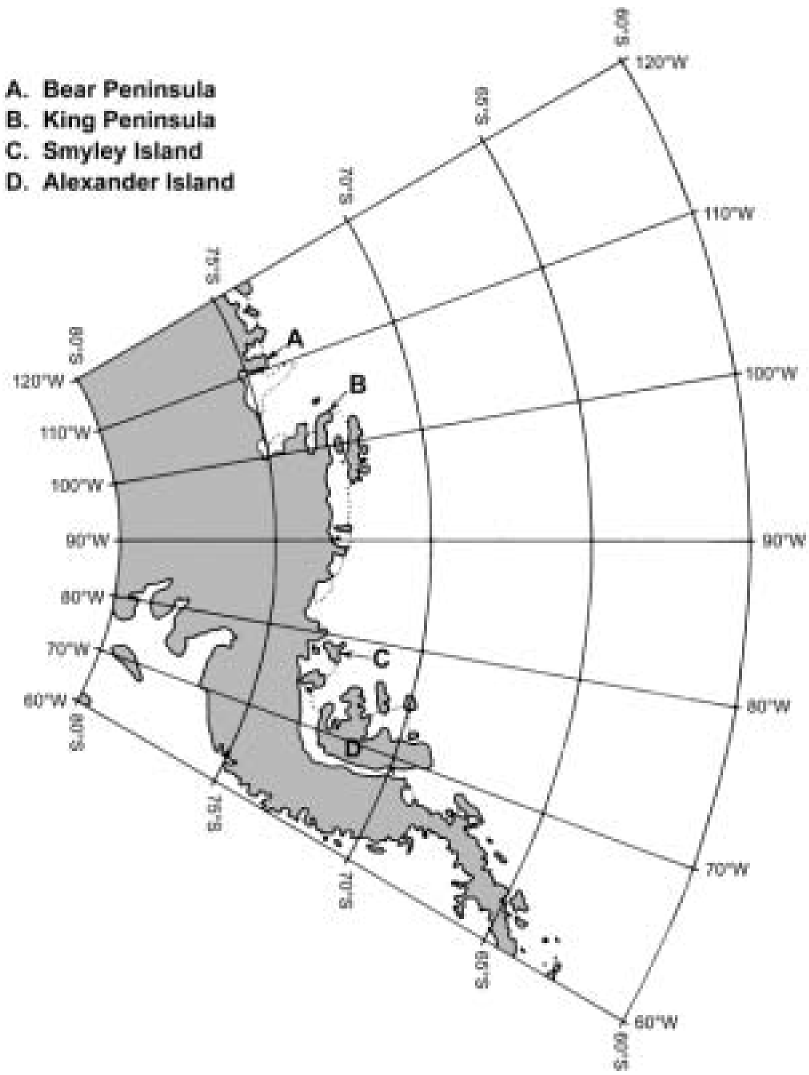
GENERAL SURFACE CIRCULATION
----Typical Mid-Summer 7/10 Ice Concentration Limit

ROSS SEA GENERAL SURFACE CIRCULATION

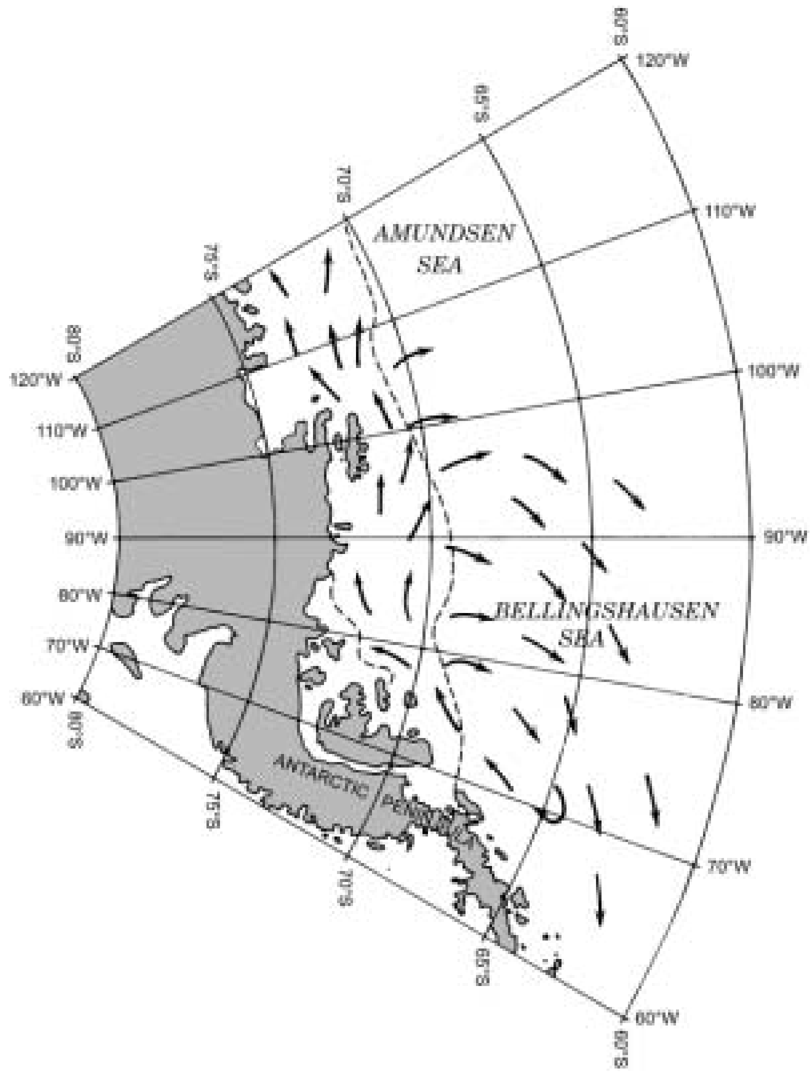


GENERAL SURFACE CIRCULATION
Speed in knots

McMURDO SOUND GENERAL SURFACE CIRCULATION



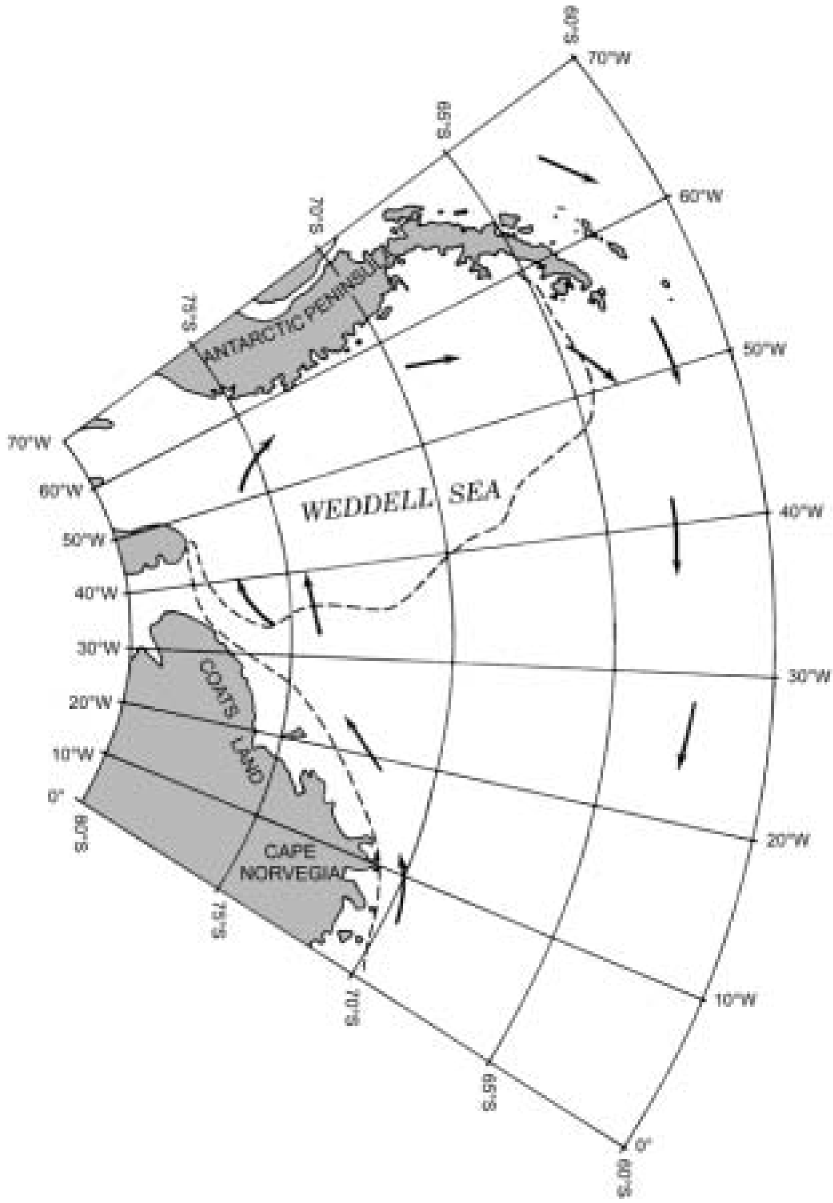
AMUNDSEN—BELLINGSHAUSEN SEA LOCATOR CHART



GENERAL SURFACE CIRCULATION
----Typical Mid-Summer 7/10 Ice Concentration Limit

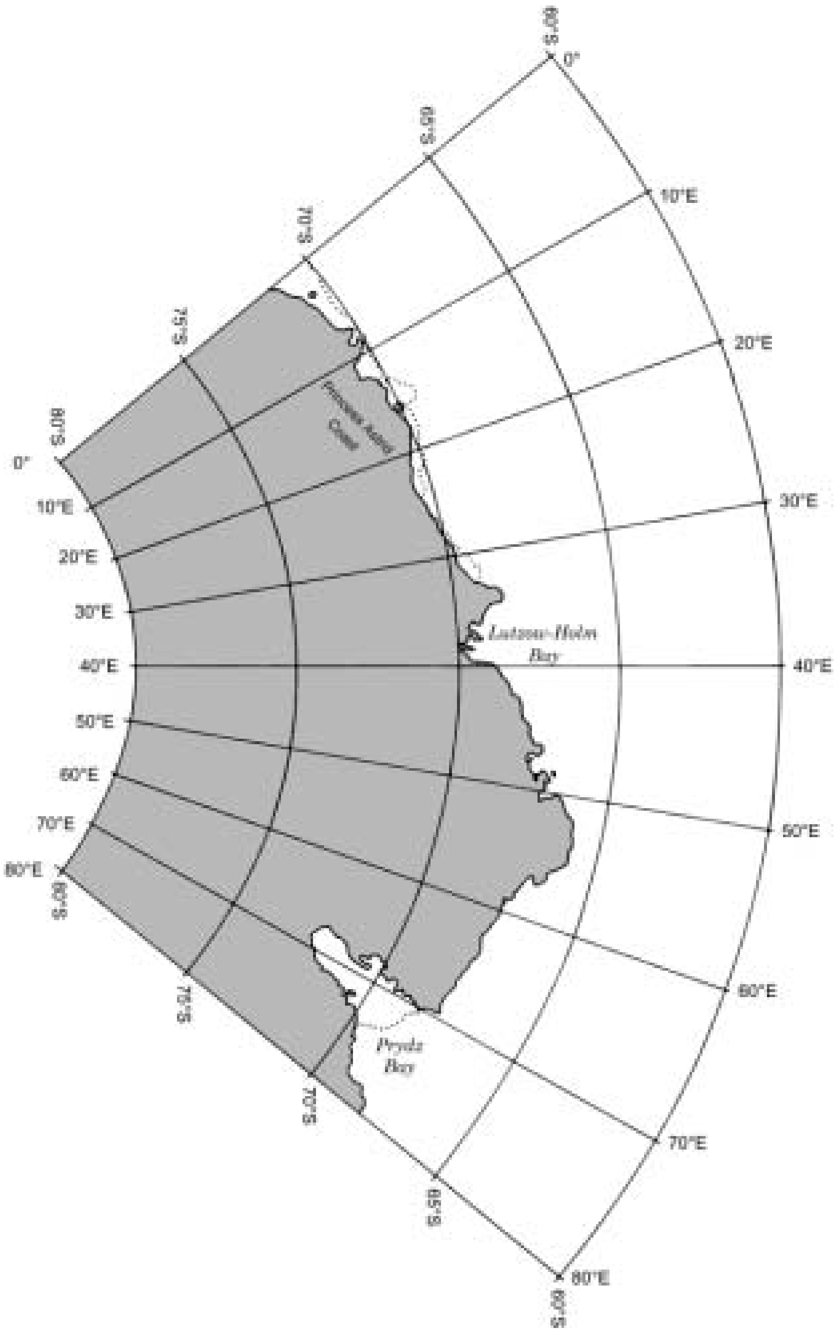
AMUNDSEN—BELLINGSHAUSEN SEA GENERAL SURFACE CIRCULATION

WEDDELL SEA LOCATOR CHART

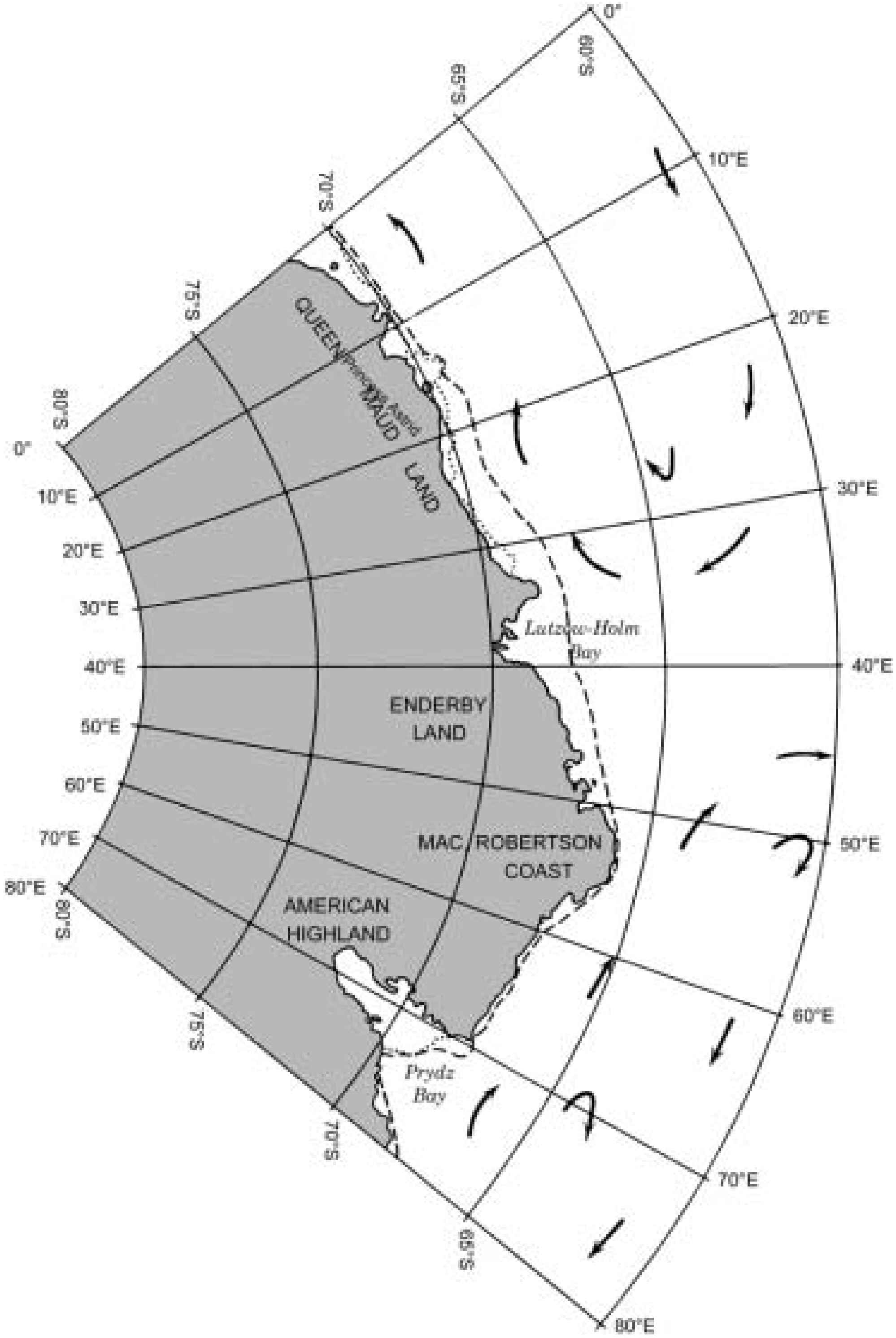


GENERAL SURFACE CIRCULATION
----Typical Mid-Summer 7/10 Ice Concentration Limit

WEDDELL SEA GENERAL SURFACE CIRCULATION

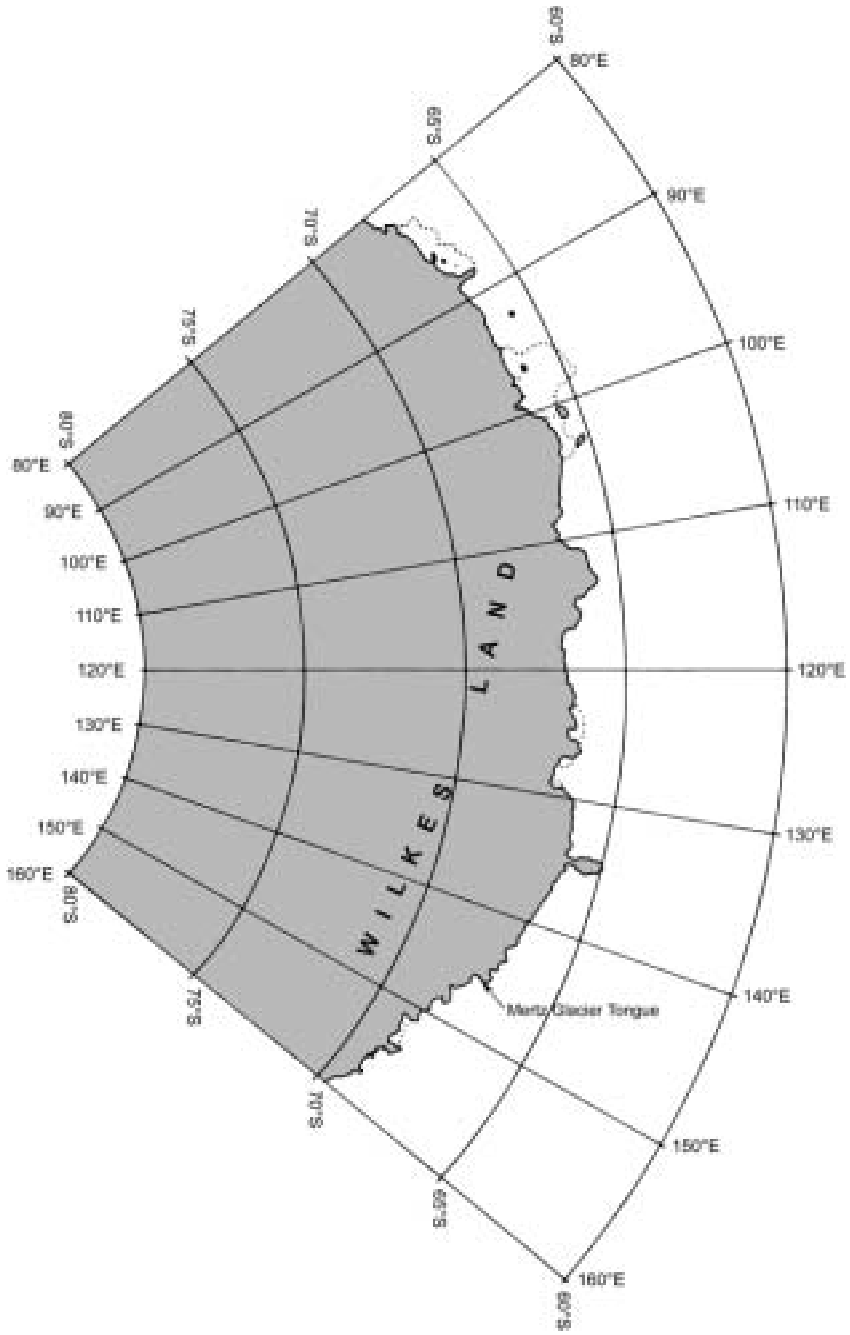


CONTINENTAL COAST SECTOR FROM 0˚ TO 80˚E LOCATOR CHART

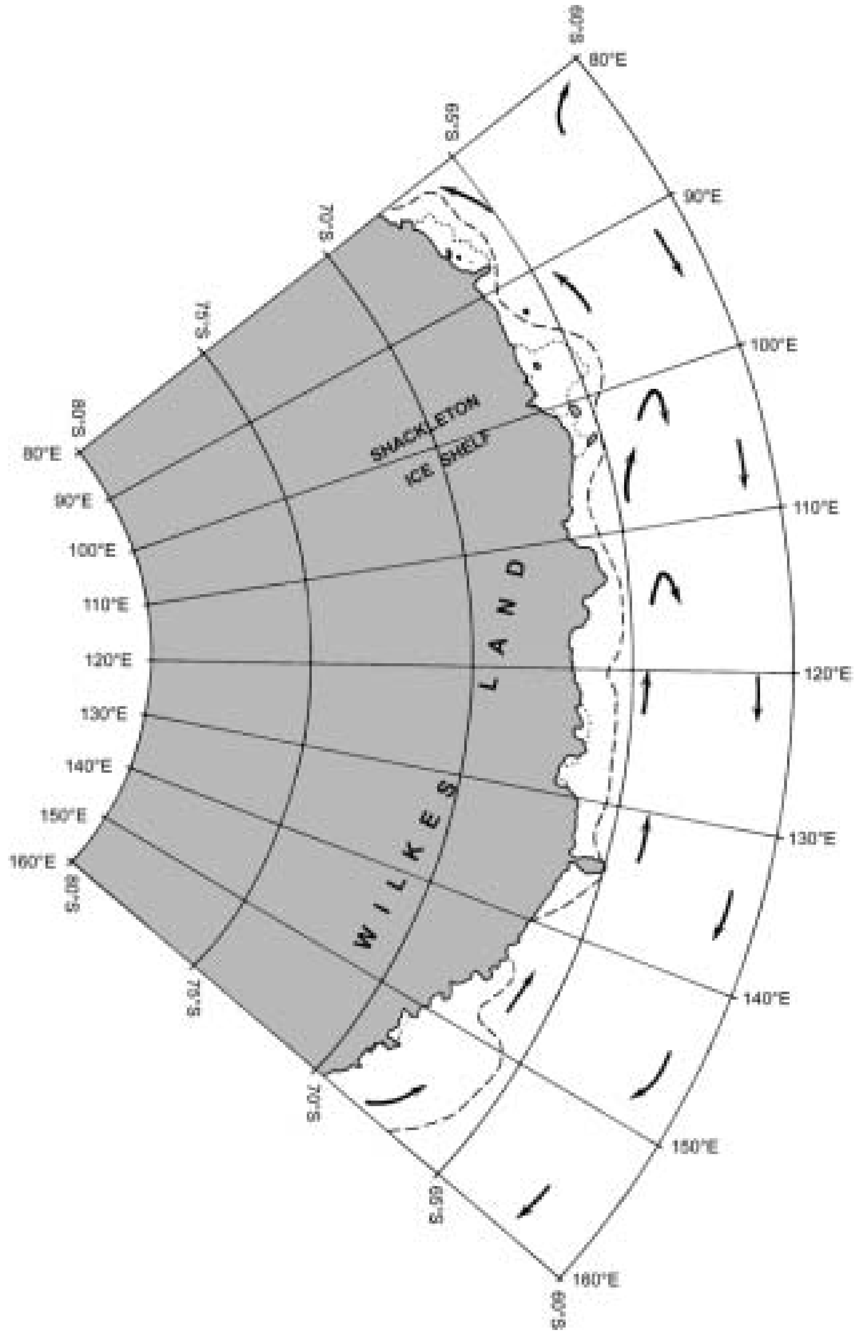


GENERAL SURFACE CIRCULATION
---Typical Mid-Summer 7/10 Ice Concentration Limit

CONTINENTAL COAST SECTOR FROM 0˚ TO 80˚ E



CONTINENTAL COAST SECTOR FROM 80˚E TO 160˚E LOCATOR CHART



GENERAL SURFACE CIRCULATION
----Typical Mid-Summer 7/10 Ice Concentration Limit

CONTINENTAL COAST SECTOR FROM 80˚E TO 160˚E GENERAL SURFACE CIRCULATION

layered with snow, frozen slush, and solid ice up to a thickness of 24.4m.

Sea ice and glacier ice (icebergs) drift in a clockwise pattern about the Weddell gyre (eddy). Sea ice presents the greatest obstruction to navigation in the W part the sea where it compresses against the Antarctic Peninsula and is forced upward into pressure ridges. Glacier ice is mostly concentrated within a zone, 100 miles wide, extending along the continental coast, the W part of the sea, and the latitude of 60˚S.

The Weddell Sea acts as a collection area for numerous icebergs, some having mammoth dimensions. Giant tabular icebergs are formed when floating glacier tongues, which project tens of nautical miles into the sea, are broken off, possibly from the impact of another giant iceberg. An iceberg, 60 miles long and 40 miles wide, calved from the Amery Ice Shelf in late 1963 and is believed to have impacted the Trolltunga Ice Shelf. This shelf then broke off in September 1967 to form a berg, 57 miles long and 29 miles wide, which in turn impacted the Larsen Ice Front in March 1968 and supposedly caused the detachment of another berg, 50 miles long and 20 miles wide.

The oceanography of the Weddell Sea is strongly influenced by the presence of the Antarctic Peninsula and the ice shelves. The mountain barrier, 1,200 to 1,981m high, standing on the peninsula has a strong effect on the climate and on the wind driven water and ice circulation in the W part of the Weddell Sea. Barrier winds blowing along the W side of the sea, winds blowing from the E along the E side of the sea, and winds reacting to the presence of the Weddell Sea low-pressure atmospheric system, cause a cyclonic circulation of the surface waters. The result is a well-defined cyclonic gyre (eddy) within the Weddell Sea. Surface currents near the Scotia Ridge have been determined to set E at a rate of 0.2 knot. A weak flow, with a rate of less than 0.1 knot, has been determined to set W in the central portion of the gyre.

At the E entrance to the Weddell Sea, a narrow current, with a rate of generally less than 1 knot, flows approximately parallel to Coats Land. The core of this current has a characteristic width of about 60 miles and is strongest near the edge of the continental shelf. The current sweeps into the S boundary of the sea at 77˚S before turning N and flowing parallel to the coast of the Antarctic Peninsula. This current has a broad outflow from the NW corner of the sea that sets in a NE direction and passes close S of the Scotia Ridge where it merges with water from the Bellingshausen Sea.

The tides in the Weddell Sea are mainly diurnal, but mixed tides can be found at the N extremity of the Antarctic Peninsula.

The sea surface temperatures near the Ronne and Filchner Ice Shelves and along the E part of the Antarctic Peninsula are very near the freezing point in summer due to the coverage of ice. The temperatures increase toward the E as the E borders of the Weddell Sea tend to be free of ice.

Higher surface salinity values in the Weddell Sea are found near the ice shelves and along the E part of the Antarctic Peninsula. Only minor horizontal variations in density are present in the Weddell Sea.

The Continental Coast Sector.—The sea ice reaches its northernmost extent in late September in this area. Aided by very strong winds that blow seaward off the continental ice plateau, areas of open water develop in late October off the coast of Wilkes Land (80˚E to 150˚E). Polynyas also form to leeward (W side) of glacier tongues, giant grounded icebergs, and fields consisting of large grounded bergs or consolidated sea ice. A large polynya usually forms early in Prydz Bay. The N ice edge rapidly retreats to the S in November and December. Minimum sea ice coverage occurs during the third week of February.

The most accessible area of the Antarctic coastline lies between Mertz Glacier Tongue and **Dumont d'Urville Station** (66˚40'S., 140˚01'E.). The navigation season for this station normally ranges from the middle of December to late March for reinforced vessels and from early January to early March for all vessels.

Reinforced vessels may normally reach **Mirnyy Station** (66˚33'S., 93˚01'E.) from early January to the middle of March and all vessels from late January to early March. **Davis Station** (68˚35'S., 77˚58'E.) is normally open to reinforced vessels from late December to mid-March and to all vessels from mid-January to mid-February.

At **Mawson Station** (67˚36'S., 62˚52'E.), the navigation season occurs after the fast ice breakout. It lasts from the middle of January to late March for reinforced vessels and from late January to early March for all vessels.

Permanent ice conditions exist in Lutzow-Holm Bay and along the coast from 150˚E to 140˚E. It is normal for fast ice to remain attached to ice shelves and ice tongues throughout the year. Fast ice attains a mean maximum thickness of 1.8m at Mawson Station and Mirnyy Station, and 2.1m along the Princess Astrid Coast (20˚E to 5˚E). In the vicinity of **Molodezhnaya Station** (67˚40'S., 45˚51'E.), a floe, of fast ice origin, was reported to be 4m thick. In comparison, a hummocked floe, of drift ice origin, was reported to have a depth in excess of 8m.

Glacier ice, such as an iceberg, occurs throughout the area, but is much more concentrated in the coastal region. Glacier ice generally drifts from E to W except between 90˚E and 80˚E where it drifts N and then E to the vicinity of 60˚S. This coastal area is known to calve giant icebergs, some up to 300m thick and 60 miles long.

The current system along the E continental coast is typified by a weaker W current near the coast and a stronger E current near the convergence zone. The main exception to this general current structure occurs between approximately 20˚E and 40˚E. This region represents the E portion of the Weddell Sea gyre (eddy) where the clockwise current flows toward the continent. It joins water from the West Wind Drift at the convergence zone and from the East Wind Drift near the coast. Other small projections jutting from the continent, such as Enderby Land and the Shackleton Ice Shelf, lead to the formation of much smaller clockwise gyres (eddies). These gyres (eddies) block the coastal current and usually join the two drift systems. A strong N flow is generally present near 80˚ E.

As with other regions which surround the Antarctic continent, sea temperatures are close to the freezing point near the icebound coast and increase toward the convergence zone' larger gradients occur leading to temperatures from 1.1˚ to 2.2˚C. Horizontal variations of salinity and density are small..