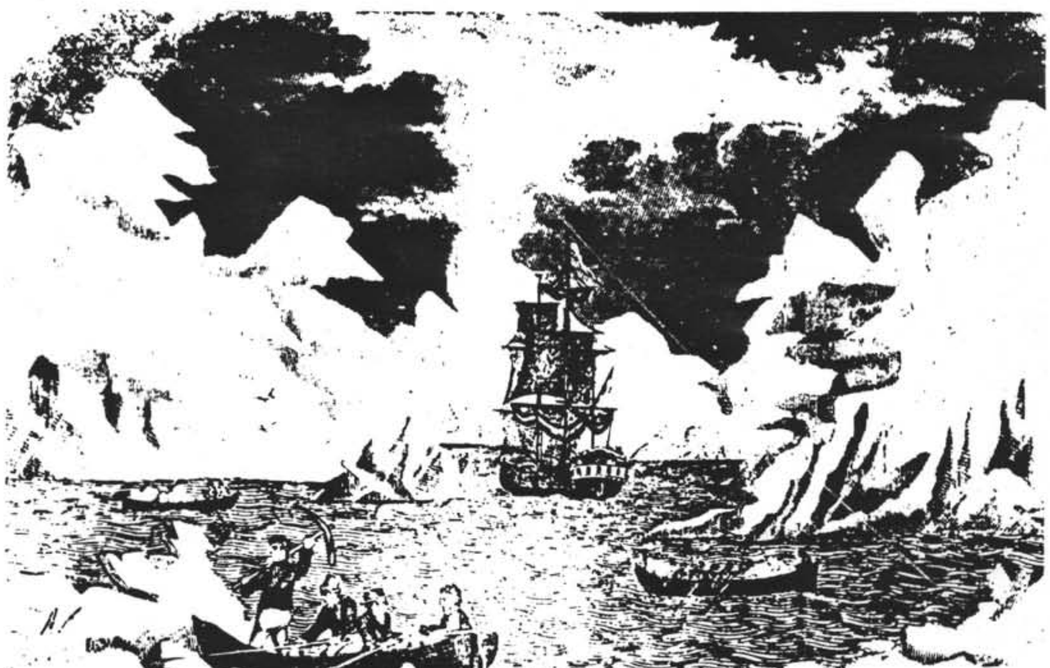
Environmental Conditions for Ocean Drilling Program Operations in the Weddell Sea and Sub-Antarctic South Atlantic



Cover: engraving from *Voyages Round the World Performed by Captain Cook,* showing the *Resolution* among the ice islands during the first recorded visit to Antartica.
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ENVIRONMENTAL CONDITIONS
FOR OCEAN DRILLING PROGRAM
LEG 113 (WEDDELL SEA) AND LEG 114 (SUBANTARCTIC SOUTH ATLANTIC)

PROPOSED DRILLING SCHEDULE: JANUARY-APRIL, 1987

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TABLE OF CONTENTS

I. INTRODUCTION

This report summarizes available meterological and oceanographic data as a guide to the planning of drilling operations for Ocean Drilling Program Legs 113 and 114 (Weddell Sea and subantarctic South Atlantic, respectively). Leg 113 is currently scheduled to depart Punta Arenas, Chile, on 1 January 1987 and arrive in Port Stanley, Falklands, on 3 March 1987. Leg 114 will leave Port Stanley approximately 6 March and arrive in Mauritius 1 May 1987. Proposed drillsites for these legs are listed in Table 1 and located on Figure 1.

Operational Problems Encountered During Previous Drilling Legs in the South Atlantic/Southern Ocean

High winds, heavy seas and/or ice led to operational problems and delays during the several previous Deep Sea Drilling Project (DSDP) legs in the South Atlantic/Southern Ocean region. The following information on these legs is summarized from the Operations Resumes prepared by the Deep Sea Drilling Project's shipboard Cruise Operations managers (DSDP Operations report, 1974, 1976 and 1984).

Leg 36

(Drake Passage, Falkland Plateau, Falkland Outer Basin, and Argentine Basin; 30 March - 22 May, 1974)

Leg 36 had a number of weather-related problems, causing a total loss of 5.55 days (9%) because of weather. Problems started on the transit to the first site (Site 326) during which the ship experienced rolls of 20-25° and pitches of 5-8°. Conditions improved temporarily upon arrival on site, but soon worsened. As the ship attempted to position while experiencing 40 knot winds, 15-20 foot swells and a current of 3-4 knots, the drill string parted.

Weather interfered at Site 327, where operations were terminated when vessel roll exceeded 9°. Departing Site 327, the ship headed toward a proposed site in the central Scotia Sea. An iceberg was sighted at 55° 37.3'S, 41°

21.9'W, and seas began building. Winds soon were gusting to 80 mph, with the ship rolling 25° and pitching 5-10°. Unable to hold heading into the wind and seas, the Challenger was forced to reverse course, abandoning efforts to drill the proposed site; the decision was made to head for a second proposed site (outer wall of South Sandwich Trench). Numerous icebergs were sighted on this transit at 54° 49.6'S, 33° 15'W, causing a decision to abandon efforts to drill at the site.

The ship then headed toward a third proposed site in the Falkland Outer Basin, passing hundreds of icebergs along the course. Approach of an iceberg later delayed spud-in at Hole 328, and an iceberg passing within 0.4 mile of the site caused loss of Hole 328B. Plans to drill Hole 328C were cancelled because of a bad weather forecast.

As the ship headed back toward the Falkland Plateau for Site 329, a course change and speed reduction were necessary to avoid icebergs. Shortly after the last iceberg of the cruise had been sighted, the bad weather previously forecast arrived. Hurricane force winds and 40-50' swells hit the ship. Conditions improved, however, for operations at Site 329 and 330, and for the transit to Site 331. At Site 331, however, hurricane force winds struck again, although reasonably good weather had initially been forecast. Weather conditions ultimately deteriorated to the point of being too hazardous to continue pulling pipe out of the hole, and 2187 m of drill pipe were left hanging below the ship as winds reached 90 mph, swells 30-40'; the ship was blown 5-6 miles off course by the time the storm subsided. Efforts to continue drilling at the site were abandoned. Weather conditions improved for the remainder of the leg, although equipment problems continued to plague the cruise.

Leg 71

(Falkland Plateau and southeast Argentine Basin; 28 December - 21 February, 1979)

Leg 71 drilled on the Falkland Plateau and the extreme southeast Argentine Basin. Adverse weather conditions cost a total of 5.4 operating days (10% down time) during the cruise. The transit to the first site (Site 511) was slowed by head winds and fog, which caused reduced visibility. While logging was in progress at the site, a heavy swell developed and the maximum operating limits for vessel roll were reached, and pipe was pulled; conditions improved shortly.

Weather began deteriorating during the transit to Site 512. While the vessel hove to and rode out the gale, the barometer went off scale at 965 mbar, and wind speed reached 55 knots; the ship drifted 40 miles off site during this time. Later, during operations at Site 512, it was necessary to interrupt the pipe trip several times to find the optimum heading to reduce roll, as a strong current aligned at a high angle with wind and swell. After drilling Hole 512, while preparing for Hole 512A, it was necessary to shut down several times to reposition the vessel and minimize roll. Time ran out for operations at Site 512 during such a 5-hour repositioning effort.

On the transit from Site 512 to 513 on Leg 71, several icebergs were detected by radar, and it became necessary to detour about 50 miles to the north and take a parallel track to avoid the bergs. At the original position proposed for Site 513 (target site AB-3: 49° 41.27'S, 21° 17.98'W) the pipe trip had to be halted as gusts reached 35 knots and heavy seas affected vessel motion. As the pipe was retrieved in gale force winds a number of icebergs approached the ship, moving at speeds up to 3 knots under the combined forces of wind and currents. Two hours were required to maneuver clear of the ice field before the vessel could be stopped and the hydrophones recovered. The ship then relocated to "new" Site 513, 180 miles to the northwest. Operations were abandoned at 104 m sub-bottom penetration as strong gale conditions developed and vessel pitch reached 12°; after a 9-hour wait, conditions improved to the point that operations were resumed and drilling completed.

During the transit to Site 514, two icebergs were passed at a safe distance. After successful HPC operations at the site, however, conditions deteriorated before spud-in could be achieved for rotary coring operations. Wind gusts exceeded 35 knots during the 11-hour wait. At that time the wind decreased, only to change direction nearly 180°, regaining its former strength. The resulting confused sea state and swell condition resulted in rolling of the ship and interfered with positioning. After a 4-hour wait, operations at the site were terminated. The transit back to port was completed in relatively calm seas.

Operational Problems on DSDP Antarctic Legs

The experiences of DSDP Antarctic Legs 28 and 35 provide additional background on high-latitude drilling for use in planning ODP Legs 113 and 114.

Leg 28

(Wilkes Land and Ross Sea, Antarctica; 20 December - 27 February, 1972)

Leg 28 drilled in the Ross Sea, Antarctica. Although only a total of 0.37 days were lost waiting on icebergs and/or weather, this leg offers insights into Antarctic drilling operations.

During the transit to the first site (Site 265), high winds blowing steadily at 40 mph and gusting to 60 mph produced 12-16' swells and a roll of 10-20°. These conditions persisted for several days, although the weather abated during drilling at the site.

While enroute to Site 267, icebergs were first encountered. The site had to be relocated 8 miles to the southwest to minimize ice. Movement of icebergs and large growlers within 10 miles of the ship was tracked using radar, with a three-mile approach to the ship being the point at which operations would be suspended. A current meter was lowered into the water for use in tracking the icebergs, as currents appear to influence their speed and direction. Actually, most bergs were found to follow a zigzag course, caused by their attitude, size and configuration relative to the current. One iceberg actually crossed the site, necessitating offset of the ship.

While departing Site 267, 49 icebergs were observed on the radar screen to lie within 10 miles of the ship. Dense fog in the area reduced visibility to 50 yards and all available personnel were recruited as ice lookouts. Site 268 proved difficult to locate because thermal layers in the water apparently caused reflections of the air gun signal above bottom.

The freezing temperatures at this site caused clogging of water and air lines and air valves. Thawing the water lines and de-icing the air lines wasted precious on-site site, limited already by the possible approach of icebergs. Fog occasionally reduced visibility to almost zero, yet 15-40 icebergs were usually present on the radar screen. However, radar would sometimes fail to locate oval or round-topped icebergs. Temperatures remained below freezing, and dipped into the lower 20's during the 1-2 hours of darkness each day; the wind-chill factor sent these well below zero. In addition, all forms of communications with the outside world were very poor.

Departing Site 269, at which operations were uneventful, a rendezvous was held with the USCG Icebreaker North Wind, the escort vessel for the Ross Sea. Large patches of pack ice were observed, although no more than 1/8 to 3/8 (Percentage of ice in octals used by NAVY-NOAA JOINT ICE CENTER) coverage was encountered. On three occasions the Challenger stopped while the North Wind explored ahead to find the best route (free of blue or bluish-green "hard" ice; snow white or brownish pack ice posed less of a threat). Of the 20 mile transit, the last 2 miles was the most hazardous, and "close escort" procedures were used (600-1000 yards between the drillship and icebreaker with constant radio communication). As a result of these precautions, no dangerous situations arose throughout the pack ice encounter.

Icebergs posed a problem while drilling Site 273. When an iceberg penetrated the 3-mile safety zone around the drillship, the Icebreaker Burton Island, which had replaced the North Wind, pushed the berg 1/2 mile to the port side. However, changes in current directed the berg back toward the drillship several times, to be deflected again by the Burton Island. Although the exposed ice was less than half the size of the icebreaker, 80% of its mass was submerged. The icebreaker sustained damage when the iceberg rolled while being pushed, but the drillsite was saved. A second, larger, iceberg was later pushed completely out of the way.

The final area to be drilled in the Ross Sea Program was the Iselin Plateau. Ice reports had indicated that the proposed site remained ice-covered, but the decision was made to attempt to reach the site, assuming that the ice reports could be in error, or that winds would clear the ice from the site. However, after a 36-hour transit with wind gusts up to 60 mph, swells to 26' and the ship rolling 10-20°, the pack ice was found to be as reported. Several alternate approaches were attempted before the area was abandoned.

During Ross Sea operations (Sites 271, 272, 273), the temperature with the wind chill factor reached -15°. Various non-weather related operations problems were also encountered, such as poor positioning in shallow water, poor recovery of glacio-marine sediments, and hydrocarbon traces. Throughout the leg icy decks and rig floor also presented hazards.

While underway to the last site on the Belleny Plateau, the wind remained at gale force. The "Burton Island" had rolls of 45° and reported that she was taking some water though her damaged bow. Fortunately, basement objectives at Site 274 had just been reached when rough seas forced termination of operations.

An invaluable resource during Leg 28 was a shipboard ice observer from Lauritzen Lines of Denmark, hired by Global Marine. This observer updated and evaluated ice information received three times a week from the Navy/NOAA Joint Ice Center in Suitland, Maryland. Weather information was also obtained from Canberra, Australia (four facsimile maps per day) for the first two sites; the Russian station Molodezdnaya also provided many good facsimile maps. Difficulties in reception resulted in only ten good maps being received from McMurdo Station. ESSA 8 reception was good throughout the cruise, with four to nine pictures received per day (coverage only as far south as 70°S). Nimbus 4 pictures were also useful for south of 50°S.

Leg 35

(Pacific Antarctic Basin and Drake Passage; 13 February - 30 March, 1974)

Leg 35 was the second Antarctic DSDP leg, drilling in the Pacific Antarctic Basin and the Drake Passage. During the cruise, only a total of 0.8 days were lost because of bad weather, although some severe conditions were encountered.

Enroute to the first site (Site 322) winds speeds reached 75 mph, and the ship took rolls up to 35°. On site, the NSF R/V Hero rendezvoused with the drillship. Departing Site 322, and for the remainder of the ship's operations south of 60°S, the Hero scouted for ice 5-15 miles ahead of the Challenger. Transit speed was reduced to 5 knots during snow squalls, nighttime, and other periods of poor visibility. Only two icebergs were observed, both on the same day. One of these was a bergy bit not visible on radar, but first spotted by the bow lookout.

Positioning at Site 325 was made difficult by 60 mph winds and sea swells of 16-18 feet. When the site was abandoned, swells had reached 22 feet, causing the ship to pitch 10°.

Throughout the remainder of the leg, the ship was "constantly rolling $10-20^{\circ}$ or pitching $5-10^{\circ}$."

High-Latitude Drilling Experience with the JOIDES Resolution

The experiences documented above regarding GLOMAR Challenger drilling in high latitudes identify situations which may be encountered by the JOIDES Resolution during Legs 113 and 114. However, high-latitude operations during ODP Legs 104 and 105 indicate that the Resolution will respond more favorably to severe weather conditions than did the Challenger.

Leg 104

(Norwegian Sea; 19 June - 23 August, 1985)

Despite some severe weather during the cruise, no weather downtime was experienced. Sustained winds of 30-40 knots, with gusts to 50 knots, were recorded at Site 642, with swells up to 10 feet.

Leg 105

(Baffin Bay and Labrador Sea; 23 August - 27 October, 1985)

During the Resolution's operations above the Arctic Circle, only 0.13 days were lost waiting on icebergs, and no days were lost waiting on weather throughout the cruise. Accompanied by the ice picket M/V Chester, the Resolution passed numerous icebergs on the transit to Baffin Bay (Site 645). While on site, the ship was forced to offset several times to avoid approaching icebergs, one of which passed directly over the site.

Upon completion of operations at Site 645, the Resolution again sighted numerous icebergs on the transit out of Baffin Bay. Speed was adjusted to the speed of the ice picket (10-11 knots) during the day, and reduced to 5 knots at night. As the ship entered the Labrador Sea, the effects of Hurricane Gloria were experienced. Two days out from Site 646, 70 mph winds were encountered, and seas built to 12-16', later increasing to 20-25'. An innovative piston coring procedure that used the heave compensator resulted in minimal weather-related operations problems for the duration of drilling at the site. As Hole 646B was being logged, another front moved in, causing 14-16' swells; the ship's heading was changed to eliminate the 9-12° roll.

The ship moved to Site 647 in moderately heavy seas, which soon built to 25-30' swells, and rolls and pitches of 6°; the heave compensator was stroking 16-18' at this time. During the storm, however, no loss of beacon signal was experienced, and coring operations continued without interruption. Recovery was adversely affected, though, as the heave compensator was not designed to stroke 18' fast enough to eliminate vessel motion.

Conclusions Regarding Challenger and Resolution High Latitude Experiences

The combined experiences of the DSDP and ODP legs discussed above indicate that some weather-related problems are certainly in store for Legs 113 and 114; however, the Resolution's excellent performance to date may minimize the adverse effects of weather conditions on drilling operations.

Previous drilling near the Antarctic continent (Legs 28 and 35) indicates that both pack ice and ice bergs may pose problems for Leg 113. This may be compounded by limited visibility in fog and during nighttime hours, and the difficulty in identifying flat, tabular Antarctic ice by means of radar. Freezing temperatures may disrupt operation of air and water lines, and may create icy conditions on the rig floor and decks. Storms may also prove severe enough to cause delays.

Based on the experiences of Leg 36 and 71, it appears that severe storms are likely to be the most troublesome weather factor on Leg 114, and may tax the Resolution's operating limits. Icebergs are another potential hazard, particularly when fog, storms or night reduces visibility.

II. GENERAL ANTARCTIC WATER MASSES AND CIRCULATION

The Southern Ocean is divided into three zones surrounding the Antarctic continent: the Antarctic Zone, south of the Antarctic Polar Front; the Polar Frontal Zone, up to 50°S, and the Subantarctic zone, 50°S-40°S, north of the Polar Front. A westward-flowing coastal current (East Wind Drift; Figures 2 and 3), attributed to the prevailing easterly wind, enters the Weddell Sea from the east and leaves the coast near Halley Bay (75.5°S, 27.5°W). This current flows along the edge of the continental shelf as a ribbon of cold, fresh water between cold, salty water on the shelf and relatively warm salty water characteristic of the circumpolar region (Gill, 1973); velocities range from 5 to 10 cm/s (0.1-0.2 knots) with little seasonal variation. The East Wind Drift is deflected to the north by the Palmer Peninsula, which projects north from the Antarctic continent.

Farther to the north, the Southern Ocean is dominated by a strong, deep, eastward-flowing current, the Antarctic Circumpolar Current or West Wind Drift. The surface flow of this current is driven primarily by frictional stress of the westerly wind. In general, the West Wind Drift is not a very fast current, with a surface speed of only 4 cm/s (0.1 knot) in the Antarctic zone, increasing to 20 cm/s (0.4 knots) north of the Polar Front (50°S). However, the current is very deep and its volume transport near the Palmer Peninsula is estimated to be 110-290 Sv (1 Sv = 10^6 m^3/s) by Nowlin et al. (1977) and Bryden et al. (1977). Many of the variations of volume transport are associated with the deflected East Wind Drift, the narrow Drake Passage, and especially with strong zonal jets at the major fronts. In these jets, current speeds of 50-100 cm/s (1-2 knots) have been observed.

The water masses of the Southern Ocean have typical high latitude characteristics. South of the Antarctic Polar Front, the Antarctic Surface Layer (Figure 2) has properties which are determined by ice melting in summer and freezing in winter. This 100-250 m thick layer has a low temperature ranging down to the freezing point (about -1.9°C). South of the Polar Front, the surface temperature is between -1.9°C and 1°C in austral winter and between -1°C and 4°C in austral summer.

Below the 100-250 m surface layer, and extending to the sea floor at 4000 m, is the Circumpolar Deep Water (Figure 2). Its temperature south of the Polar Front rises to a maximum of 1.5°C at 300-600 m and then decreases to between 0 and 0.5°C near the sea floor.

A very important water mass, the Antarctic Bottom Water (AABW), is formed in the Weddell Sea near the Antarctic continent (Seabrooke et al., 1971; Figure 2). This water mass is a mixture of the Antarctic Circumpolar Water and shelf water, and has a temperature of about -0.26°C; this mixture flows into the Weddell Sea from the east near the Coast Land and is entrained into the AABW which exits the Weddell Sea between 50° and 15° W and 60° and 65° S.

III. AIR TEMPERATURE

In Antarctica, there are only two months of summer (December and January), but six months of winter (April through September). The mean annual surface air temperatures for the Antarctic region are shown in Figure 4; Tables 2 and 3 show the monthly mean, maximum and minimum temperatures for January through April, extrapolated from Weyant (1967), U.S. Navy (1970) and Gorshkov (1978). These tables reflect values from observation stations nearest the proposed drillsites.

Generally, the air temperatures are considerably lower than those of the sea surface in the Weddell Sea. The high frequency of cold air over relatively warm water indicates that unstable conditions are common. However, the subantarctic South Atlantic Ocean has a typical maritime temperature, i.e., air temperatures are slightly higher than those of the sea surface. According to Weyant (1967), temperatures show no marked relation to wind direction, and small seasonal variations.

IV. SEA TEMPERATURE

The proposed Leg 113 drillsites are mostly south of the Polar Front, where there is a thin surface water layer. Beneath this is a large mass of relatively warm Circumpolar Deep Water. The cold Antarctic Bottom Water formed at the continental edge flows to the north and east. The sea surface temperature usually ranges between -1°C and 4°C in the austral summer. The temperatures are lowest in the south and increase toward the north due to the absorption of heat during the austral summer. South of the Polar Front, sea-ice limits the range of temperature variation between the austral winter and summer. The freezing point of sea water is no lower than 1.9°C and limits the reduction of temperature in the austral winter. During the austral summer, the melting of ice absorbs a considerable proportion of the heat inflow, because of the large latent heat of melting of ice, leaving only a small part to raise the temperature of the water. The subsurface temperature of the Circumpolar Deep Water in the Weddell Sea rises to a maximum of 1.5°C at 300-600 m below sea level, and decreases to 0-0.5°C at the sea floor.

The proposed Leg 114 drillsites lie within to slightly north of the Antarctic Polar Front. In this region, the Subantarctic Surface Water (Figure 2) occupies the upper 500 m, and has a temperature of 4-10°C in the austral winter and up to 14°C in the austral summer.

Figure 5 shows the temperature profiles at the proposed drillsites during austral summer, and Figure 6 shows the typical temperature profiles along the 17°E and 25°W longitudes (Gordon, 1970 and Gorshkov, 1978).

V. WIND AND CYCLONE TRACK

The polar belt of lowest pressure (mean atmospheric pressure = 985 mbar within this belt) lies near latitude 65°S. However, at most locations south of 40-50°S in the South Atlantic Ocean, the pressure falls about 1 mbar per degree of latitude, which is reflected in the strong mean westerly winds. The ocean area from about 40°S to near the Antarctic Circle has the strongest sustained westerly winds. This clockwise circulation, found around low pressure centers in the Southern Hemisphere, is at its strongest around Antarctica because of the steep pressure gradient between the mean low pressure belt off the Antarctic coast and the high pressure zone at 30-35°S. Generally, winds in the South Atlantic Ocean are strong in austral winter and more moderate in austral summer.

Above 60°S there are relatively strong westerlies all through the year. The westerlies often attain gale force; they are accompanied by very rough seas, and are the driving force for the west to east wind drift of the surface waters of the ocean. Wind speeds are usually highest from June through October, when the averages range from 10-20 knots; gales (>34 knots) are most likely during this period. From November through May, wind speed averages range from 5-15 knots, with gales on 2-8 days per month. January and February are usually the quietist months, with gales only 1-4 days per month.

Data on wind conditions appear in Tables 4 and 5, based on Weyant (1967), U.S. Navy (1970) and Gorshkov (1978). Normally, it is not the vector mean wind velocity that is of interest, but the scalar mean wind speed, which is computed without considering wind direction, and is therefore the larger of the two; scalar wind speeds appear in the tables. The average wind speed, expected prevailing wind direction, and the percentage frequencies of gale-force winds (>34 knots) are shown.

Interaction between the frigid air coming from Antarctica and the relatively warm, moist air from the low latitude ocean areas creates the cyclonic storms which make the region from 40-60^{o}S one of the stormiest areas of the world. During September and October, storms are frequent and intense (2-6 storms per month). By mid austral summer these frequencies are decreased by half (Defense Mapping Agency, 1985). The main course of these cyclones is from west to east around the periphery of Antarctica, as shown in Figures 7 and 8. These circumferential cyclones are responsible for the belt of low pressure surrounding the continent, and for the strong westerly surface winds over most of the circumpolar ocean. Cyclones occasionally penetrate the Antarctic interior. While many cyclones are generated and deepen in high latitude ocean areas, some form farther north and move in southeasterly arcs to the latitude of most frequent cyclonic activity. One of the favored areas for such meridional movement of cyclones appear to be the west and central portions of the South Atlantic Ocean, where Leg 114 will be drilling.

An additional problematic wind-related factor is windchill. Windchill temperatures relate a particular wind and temperature combination to a temperature which would produce the same heat loss at about 3 knots (Defense Mapping Agency, 1985). Windchill poses an increased frostbite danger because body heat loss increases greatly in moving air that is colder than skin temperature. Personnel aboard the drillship must maintain natural warmth through use of appropriate clothing and active exercise of the limbs; particularly vulnerable are toes, fingers, ears, nose, chin and cheeks (Defense Mapping Agency, 1985).

VI. FOG AND VISIBILITY

Although fog is most likely in austral summer in the Weddell Sea, the lack of dust or solid particles in the Antarctic air and the small moisture content of the prevailing winds blowing off the continent lead to low frequencies of fog. As a consequence, visibility is usually very good. January and February are generally the months with the best visibility and the austral winter is the worst period. In the Weddell Sea, true fog in austral summer is reported less than 5% of the observed time, while visibility is more likely to be reduced in rain, mist, drizzle, snow and sea spray. Occasionally steam fog or sea smoke will form when very cold air off the continent blows out over warmer water; it is usually 50-100 ft thick. According to the observed data in South Orkney Island (near sites W-6,-7,-8 and -9), there are 8 fog days in January, 7 in February and 8 in March. Near South Georgia Island (sites SA-5 and -6), there are 4 fog days in January, 5 in February and 4 in March.

Table 6 shows the percentages of all visibility observations which result in less than 2-5 nautical miles of visibility. For example, during January at sites W-1 and -2, 33% of all observations recorded <5 n mi visibility, 24% recorded <2 n mi visibility, 14% were accompanied by precipitation, and 10% were without precipitation.

Table 7 shows percentages of precipitation in the Weddell Sea. Most precipitation in the region is frozen, as a result of the low air temperature.

VII. ICE COVERAGE/ICEBERGS/SUPERSTRUCTURE ICING

Ice covers a large portion of the Antarctic waters and is probably the greatest single factor contributing to the isolation of the Antarctic continent. During the austral winter, ice completely surrounds the continent, forming an almost impassable barrier; the largest continental ice shelves are found in the Weddell Sea. A major source area of Weddell Sea/South Atlantic icebergs, the Filchner Ice Shelf (Figure 9a) has an area of 0.40×10^6 km^2 (Robe, 1980); this and other Antarctic ice shelves are approximately 200 m thick. As some sites proposed for drilling on Leg 113 are located near the Antarctic margin, potential problems with pack ice may arise; both Legs 113 and 114 may encounter icebergs.

A. Pack Ice

The Antarctic pack is composed of ice formed in the open sea, fast ice formed along the coast, and the land ice derived from the continent and islands. Ice shelves form partly in place from ice and firn accumulation, and consequently have lower density than glacier ice. The ice of the Antarctic, both pack ice and icebergs, differs radically from that of the Arctic. Probably the most important characteristic distinguishing Antarctic ice is the extreme heterogeneity of the pack. In any one locality the ice may range from huge bergs many miles long and wide, to ice crystals produced by supercooling of sea water.

According to this 12-year record, the austral summer 1977 was warmer than average (unusually low sea ice coverage) and 1978 was colder than average (unusually high sea ice coverage). Thus these years may be used as "best case" and "worst case" projections for the amount of sea ice which Leg 113 may encounter. The "best case" projections suggest that all sites, including W-4 (Caird Coast), will be ice free from late January through early March; the "worst case" indicates that site W-4 may remain inaccessible, although pack ice should present no problem at other Leg 113 sites. Although pack ice coverage is highly variable, Site W4 is statistically due to be occupied during an unfavorable time and would be better drilled later in the season. Site W5 has approximately the same ice conditions and therefore drilling W5 before W4 should not make little difference and in addition, it will add transit time to the program.

The U.S. Navy/NOAA Joint Ice Center in Suitland, Maryland, has been utilizing satellite imagery to estimate sea ice coverage of the Southern Ocean since 1973. This facility produces weekly Ice Analysis Charts, which summarize pack ice coverage. Recently, the U.S. National Weather Service has digitized these weekly gridded sea ice data for the years 1973-1984, allowing regional summaries to be produced. Mean pack ice concentrations and the maximum and minimum limits of the Antarctic sea pack ice for the warmest months, January and February, are shown in Figure 10A through 10E (Naval Oceanography Command, 1985). These maps show average conditions; the yearly variation, not shown here, is considerable.

Using the weekly satellite ice maps, the pack ice coverage by year has been estimated for each of the Leg 113 site locations. This data, with the approximate time of occupation, as estimated from the scheduled clockwise drilling program is given for each site or each group of sites in Tables 8A to 8E. Pack ice coverage is described as ice covered, clear and borderline(s).

B. Icebergs

Icebergs are found practically everywhere in Antarctic waters, both within the ice pack and in the open water north and south of the pack. Antarctic bergs may be as much as 100 miles (160 km) in length and as high as 200 ft (60 m) above the waterline, and frequently have a boxlike or tabular form. In 1969 two giant icebergs, 25 by 55 miles and 38 by 62 miles respectively, were reported in the Weddell Sea (Defense Mapping Agency, 1985). A more typical size, as measured using Landsat imagery by Weeks and Mellor (1978) is 0.65-0.75 km in length. Bergs appear to drift at speeds up to 2 knots.

Figure 9b shows the drift of Antarctic icebergs. In general, these bergs tend to move more zonally than meridionally, except on the eastern side of the Antarctic Peninsula where drift is northward, following the cyclonic Weddell Gyre (through the Leg 113 and 114 drilling areas; Robe, 1980). Iceberg drift tracks recorded from the Deep Freeze 85 Cruise Report (1985) indicate a surface drift toward the northeast at approximately 2 km/hour (25-30 cm/s) near site W-9 (Drake Passage).

The northern limit of iceberg drift (Figure 11) is the boundary between the Antarctic Surface Water (-1 to $4^{\circ}C$) and the Subantarctic Surface Water ($6-14^{\circ}C$), which is located at the Polar Front. Although an occasional iceberg may drift into the Atlantic Ocean as far as $40^{\circ}S$, and can reach $26^{\circ}S$ off the Atlantic Coast of South America during April (Figure 11). It is unlikely that icebergs would survive for more than a week north of the Polar Front (Robe, 1980). However, the northern drift limit in the subantarctic South Atlantic varies as much as 300 miles in different years; this variation is greater than in other Antarctic areas and fluctuates as much as 30 miles daily (Defense Mapping Agency, 1985).

C. Ice Operations

During Leg 113 the JOIDES Resolution will be accompanied by an ice picket boat.

ODP plans to check ice coverage from satellite data immediately preceding Leg 113 as well as during the cruise, providing weekly updates. Any ships transiting near the area or aircraft flying over the area will be asked to relay information about the ice conditions.

According to data presented here, Leg 114 should experience little problems from ice apart from the possibility of icebergs; these may be particularly troublesome at the western sites. Figures 12A through 12C show drift buoy trajectories from the First GARP Global Experiment (FGGE; Patterson, 1985). From the analysis of the FGGE data, the drift speed of icebergs in the Leg 114 operating area are in the range of 0.4-1.0 miles per hour.

D. Superstructure Icing

Superstructure icing is an additional ice-related phenomenon which may pose a problem for Antarctic drilling operations. Ice may accumulate on hulls and other superstructures as a result of any of three factors: a) fog with freezing conditions; 2) freezing rain or drizzle; and 3) sea spray or saltwater breaking over the ship when the air temperature is below the seawater freezing point (-1.9°C) (Defense Mapping Agency, 1985). The major danger posed by this icing, apart from hazardous icy deck surfaces, is that the weight of the ice above the waterline could cause the ship to capsize in extreme conditions (i.e. gale force winds). Conditions under which this situation might arise can be detected by falling barometric pressure at the onset of strengthening winds from a cold quarter, and depressed air and sea temperatures (Defense Mapping Agency, 1985). Moderate ice accumulation occurs when air temperatures are -2°C or less, and winds are 13 knots or more; accelerated accumulation occurs at -9°C and below, and 30 knot winds.

VIII. CURRENTS

The general surface and cross-sectional circulation patterns in the Weddell Sea are shown in Figures 2 and 3. The East Wind Drift, dominated by easterly and southeasterly winds which prevail around the periphery of Antarctica, is circumpolar except for areas on either side of Palmer Peninsula. It is separated from the east going West Wind Drift on the north by a zone of general upwelling, the Antarctic Divergence. The mean velocity of surface current speed of the West Wind Drift is the range of 10 to 20 cm/s (0.2-0.4 knots). The configuration of the both continent and sea-floor topography produce eddies and countercurrents which force water from the East Wind Drift across the divergence into the West Wind Drift. The most prominent deflection is caused by the Palmer Peninsula, where the current is turned north and diverted directly into the West Wind Drift. In the vicinity of South Orkney Island (near drillsites W-6, -7, -8, -9, -10 and -11) the dominant current is toward the northeast. The currents appear to flow west along the north coast of the South Shetland Island and east along the south coasts. Strong currents (2-6 knots) run within and across the straits which separate the islands (Defense Mapping Agency, 1985).

North of the Antarctic Divergence, the West Wind Drift transports large volumes of surface water east and northeast around Antarctica. A zone of convergence (Antarctic Convergence) exists within the West Wind Drift. It separates easterly and slightly southeasterly currents to the north from slightly northeasterly currents to the south. The movement of subsurface water in the Antarctic is generally in the same direction as the surface currents; however, with increasing depth and changing bottom configuration, the subsurface current directions may deviate considerably from the surface current directions.

Figure 13 illustrates bottom currents in the western parts of the Leg 113 and 114 operations areas. Foldvik and Kvinge (1985) report currents with speeds of 6.2-7.2 cm/s in the Weddell Sea, 23 m above the sea floor. The maximum tidal (bottom) current speeds measured were 10 cm/s (0.2 knots). Variations in the mean current speed have no apparent relationship to the mean current directions, which are remarkably stable. Monthly winter averages are twice the values for the austral summer season. The most conspicuous feature of current velocity records is the diurnal oscillation associated with tidal fluctuations.

Sites W-1 and W-2 (Maude Rise) are within an area of deep vertical convection (Gordon, 1978). The surface result of this convection is a cyclonic eddy with a maximum surface velocity of 75 cm/s (1.5 knots), decreasing with depth. These eddies extend to at least 4000 m depth. During the austral summer of 1977, the number of eddies was approximated to be 100 (Gordon, 1978). The youngest ages obtained from piston cores near W-1 and W-2 are upper Pliocene (Ledbetter and Ciesielski, 1982); these sites are located in the "Weddell Basin Scour Zone," through which Antarctic Bottom Water flows northeast toward the Atlantic-Indian Ridge.

Surface and bottom current velocities at sites W-3 (Astrid Ridge) and W-4 (Caird Coast) are primarily influenced by the Antarctic Coastal Current. This current flows westward into the Weddell Sea, following the bathymetric contours of the Antarctic shelf (Hollister and Elder, 1969). The maximum velocity of this current is 30 cm/s (0.6 knots); there is also a low-velocity northward component of flow at sites W-3 and -4, resulting from flow off the shelf (Gill, 1973).

The flow of water across the Weddell Basin (site W-5) is northeastward at an average of 3 cm/s (Carmack and Foster, 1975), although the velocity will increase where constrained by topography.

Part of the eastward-flowing Weddell gyre (Deacon, 1979) goes north through the gap between the Scotia Ridge and the South Orkney Islands (39°W). Sites W-6, -7 and -8 are located on the South Orkney Plateau. Bottom currents at these sites are expected to be moderate because most of the flow travels to the east until turning north at the South Sandwich Trench (Gordon, 1966 not all of it). An <u>Eltanin</u> station reported a north-northeast sea direction near these sites.

Surface flow at Site W-9 (Powell Basin) is to the northwest at approximately 25-30 cm/s (0.5-0.6 knots), based on iceberg drift tracks recorded from the Deep Freeze 85 Cruise. Two cores from this cruise indicate recent current erosion, probably caused by a tongue of Scotia Sea Bottom Water which flows west at moderate speeds (Gordon, 1966).

Site W-10 (Bransfield Strait) lies at the boundary of the Weddell Sea/Scotia Sea confluence. This boundary is relatively homogenous as a result of vertical mixing, and extends from the surface to deep waters (Patterson and Sievers, 1980). The site is located in the Central Basin of the Bransfield

Trough, separated by sills less than 1500 m deep, so bottom water is not in contact with ocean water. Convection processes mix low salinity bottom water with surface water (Gordon and Nowlin, 1978). Currents measured near the site were 15 cm/s (0.3 knots) toward the southeast (Capurro, 1971).

Site W-11 (Southeast Drake Passage) lies south and east of the Antarctic Convergence, where maximum surface velocities of 100 cm/s have been measured (Goodell, 1973). Mid-depth current measurements near W-11 through the Drake Passage average 15 cm/s (0.3 knots) towards the north or northwest. The maximum bottom current velocity measured in the Drake Passage is 50 cm/s (1 knot). Current rings have been observed forming at the Polar Front boundary zones that extend to the bottom, thus affecting current velocity and direction. Cyclonic rings are the most common, originating from the continental water boundary (Pillsbury and Bottero, 1984). A cyclonic ring with a radius of 50 km, observed west of the site W-11 location, exhibited a geostrophic velocity of 90 cm/s (Peterson et al., 1982).

The general bottom currents in the area of the South Sandwich Trench are contour currents, flowing north towards the Antarctic Convergence. Signs of bottom scour, rock outcrops, and ripple marks indicate strong currents (Heezen and Johnson, 1965). Topographic constraints should decrease velocities from sites SA-4 to SA-2 to SA-1. Site SA-3 is located within the westward-flowing Antarctic Circumpolar Current, south of the maximum velocity Antarctic Convergence. There is no indication of any topographic restrictions that would increase the flow, so a relatively slow velocity is predicted. The Antarctic Circumpolar Current is potentially the strongest bottom scouring current in the Southern Ocean (Goodell, 1973). The current extends from the sea surface to the sea floor. The strongest currents are recorded at the Antarctic Convergence, especially through the Drake Passage and the basin west of Scotia Ridge. Sites SA-5 and -6 are located along the Antarctic Convergence past the gap in Scotia Ridge, and therefore a relatively strong westward current is predicted.

Sites SA-7, -8 and -9 are also located in the Antarctic Circumpolar Current, near the Antarctic Convergence. In this frontal area surface velocities may be as high as 50 cm/s to 100 (2 to 4 knots) decreasing to 1 to 2 cm/s near the seafloor. Thus currents here are analogous to those observed in the Drake Passage. The location of these strong currents is variable on the scale of weeks (Whitworth, pers. comm., 1986).

Maximum Current Profiles

Currents are composed of two large components: the local wind-driven current, and the normal current which includes geostrophic flow and tidal current. For the maximum geostrophic current, we used 30 cm/s (0.6 knots) as a surface current speed (Nowlin et al., 1977) and applied the Bretschneider's Type A profile in our calculation (Bretschneider, 1977). A maximum tidal current of 10 cm/s (0.2 knots) was estimated from analysis of tidal ranges measured by the U.S. Navy (1965, 1970). We then used Ekman's formula to calculate the wind-driven component using the expected extreme wind speed of 43 m/s. To get the maximum resultant current, we added the maximum tidal current to the normal current and assumed that the normal current and waves are in the same direction (Bretschneider, 1979). This calculation method was adopted from Merrell (1984). The calculated maximum profiles are shown in Figures 13 and 14. These calculated maximum profiles should be considered as extreme cases. As the wind speed increases, the wind-driven component of current speed will increase. However, strong winds will transport more floating icebergs, retarding both the wind-driven and tidal currents. Our calculation does not consider this complex interaction, given its time-dependant unpredictability.

IX. WAVES

Observed wave data for the Southern Ocean is very scarce. Data on wave height, period and direction were compiled by the U.S. Navy (1970) and the Defense Mapping Agency (1985). Table 9, extrapolated from these sources, shown the mean and maximum significant wave height and expected maximum wave height. Generally, wave heights are not high in the zone of partial ice cover, since an ice field acts as a filter. However, high swell may occur in the zone of partial ice cover since swell will penetrate the boundary of the ice pack. The extent of penetration depends on the concentration and thickness of ice and period of the swell.

The proposed Leg 113 and Leg 114 sites are within the extreme drift limit of the icebergs, but whether and when the sea ice will clear cannot be determined far in advance. The volume of floating icebergs and the wave heights are controlled primarily by the strength of the wind. The increased floating icebergs resulting from the strong wind retard the development of wave height and current speed. However, we do not expect this effect to be too great because of the sparse ice concentration, especially in the subantarctic South Atlantic Ocean. The extreme wave heights in the subantarctic South Atlantic are high because the proposed Leg 114 drillsites are in the strong West Wind Drift zone, while high waves are not expected for Leg 113 in the Weddell Sea. We can summarize the U.S. Navy (1970) wave data as follows:

1) Wave heights in the subantarctic South Atlantic Ocean are high compared to those in the Weddell Sea.
2) Wave heights are lowest in the south and increase toward the north.
3) The periods of most waves are in the range of 7-9 seconds in the subantarctic South Atlantic, and 6-8 seconds in the Weddell Sea.
4) Wave directions are toward the east and southeast in the subantarctic South Atlantic Ocean, but there is no particular direction in the Weddell Sea.

X. RECOMMENDATIONS

1. Delay Leg 113 up to 2 weeks to maximize favorable ice conditions.

2. Include reasonable estimates of weather-related down-time in site transits and occupation/drilling schedules for both legs.

3. Winterize ship to prevent structural freezing problems encountered on Leg 28. Leg 113 conditions will be more severe than those encountered during Leg 105 and therefore more stringent winterization will be required. The hazard of superstructure icing should be considered as well.

4. Obtain as much ice data as possible before departing Punta Arenas for Leg 113.

5. Request fixed wing reconaissance survey of W4 and W5 area before departing Maud Rise during Leg 113.

6. With respect to the severe weather conditions possible on Legs 113 and 114 (particularly Leg 114) operational limits of pitch and roll, etc., with regard to drill string safety should be reviewed for the Resolution in comparison to procedures used aboard the Challenger; the performance of the heave compensator for hydraulic piston coring in heavy seas should also be considered.

7. Provide current meter to determine surface flow conditions to aid in monitoring iceberg drift patterns.

8. Ice picket ship should accompany JOIDES Resolution while drilling the SA-1 through SA-5 sites on Leg 114.

9. Shipboard participants should be made aware of procedures necessary to avoid frostbite, particularly the need for adequate clothing.

10. Films on Antarctic (polar) marine safety/survival should be obtained, if not already available on brand.

FIGURE CAPTIONS

Figure 1. Weddell Sea/Subantarctic South Atlantic operations areas. Tentative ship track for ODP Legs 113 and 114 are indicated.

Figure 2. Schematic cross sectional view of Antarctic oceanic water masses and meridional Plow. (From Kennett, 1982).

Figure 3. Plan view of general Antarctic surface circulation (Perry and Walker, 1977).

Figure 4. Mean annual surface temperatures in ^{o}C (Gordon et al., 1970).

Figure 5. Temperature profiles at the proposed drillsites during the austral summer (compiled from Gordon et al., 1970 and Gorshkov, 1978).

Figure 6. Typical meridonal temperature profile at 17^{o}E and 25^{o}W (Gordon et al., 1970).

Figure 7. Mean monthly cyclone tracks for January and February. Solid lines represent most frequently followed tracks; dashed lines are tracks occasionally followed (Weyant, 1967).

Figure 8. Mean monthly cyclone tracks for March and April. Solid lines represent most frequently followed tracks; dashed lines are tracks occasionally followed (Weyant, 1967).

Figure 9. A. The major ice shelves. B. Typical April iceberg drift patterns (Robe, 1980).

Figure 10. Maximum, mean and minimum pack ice edges from satellite imagery averaged from years 1973-84. Defense Mapping Agency, 1985 A) January 1; B) January 15; C) February 1; D) February 15; E) March 1).

Figure 11. Extreme limit of iceberg drift, austral summer (from U.S. Navy, 1970 and Naval Oceanography Command Detachment, 1985).

Figure 12. FGGE drift buoy trajectories (numbers indicate the beginning of each month:

A) #17606 (10 December 1978-3 December 1979; average drift speed = 0.23 mi/hr for January-April); #17608 (12 December 1978-3 December 1979; average drift speed = 0.48 mi/hr for February-April);

B) #17610 (22 November 1978-24 February 1979; average drift speed = 0.20 mi/hr for February-April); #17621 (26 January-21 July 1979; average drift speed = 0.20 mi/hr for February-April);

C) #17625 (9 December 1978-14 July 1979; average drift speed = 0.16 mi/hr for January-April); #54601 (12 December 1978-3 December 1979; average drift speed = 0.23 mi/hr for January-February).

Figure 13. Maximum current profiles in the Weddell Sea (calculated following the method of Merrell, 1984).

Figure 14. Maximum current profiles in the subantarctic South Atlantic (calculated following the method of Merrell, 1984).

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TABLE CAPTIONS

Table 1. Location of the proposed drillsites.

Table 2. Surface air temperatures (^{o}C) in the Weddell Sea (compiled from U.S. Navy, 1970 and Gorshkov, 1978).

Table 3. Surface air temperatures (^{o}C) in the subantarctic South Atlantic (compiled from U.S. Navy, 1970 and Gorshkov, 1978).

Table 4. Wind conditions in the Weddell Sea (compiled from Weyant, 1967 and Gorshkov, 1978).

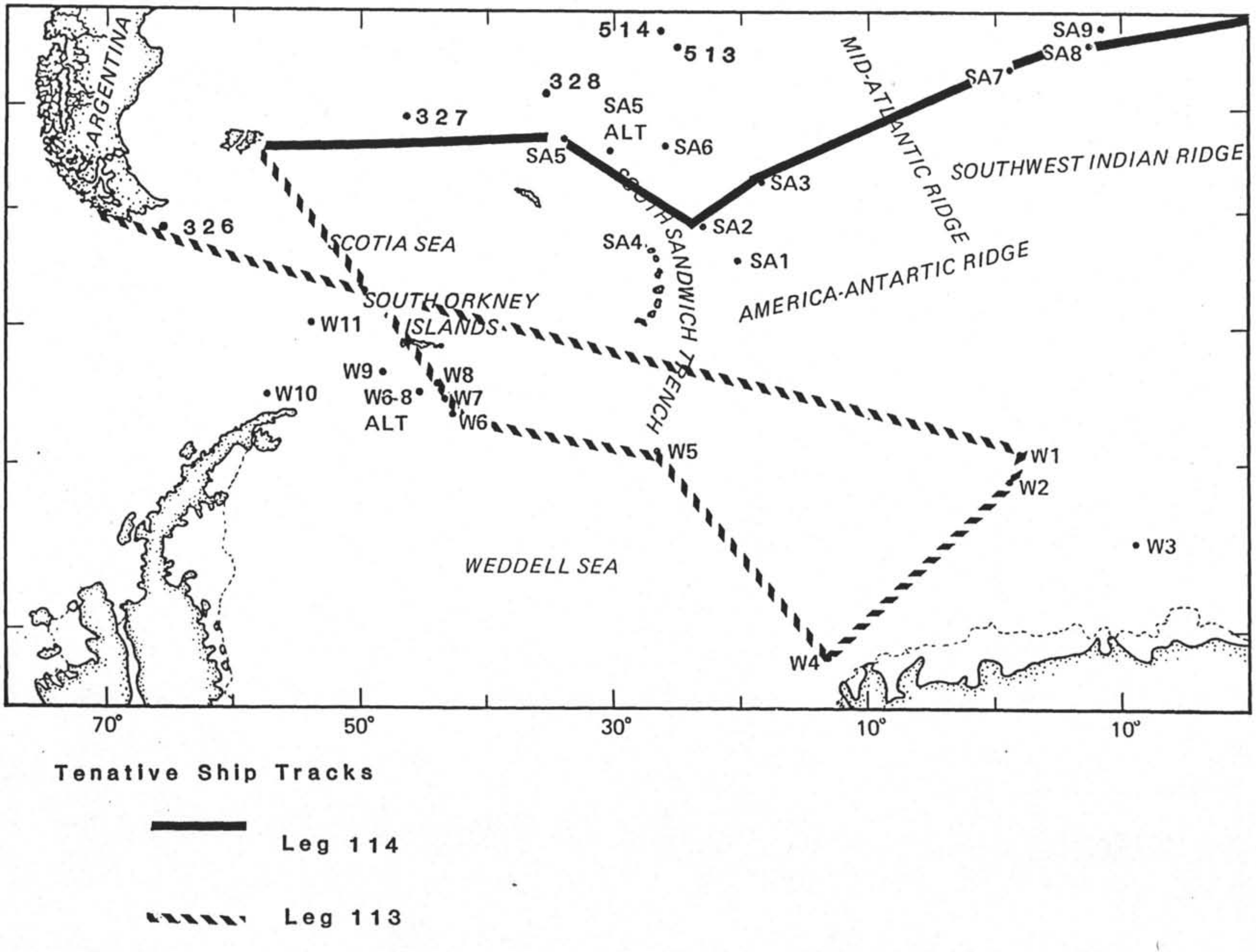
Table 5. Wind conditions in the subantarctic South Atlantic (compiled from Weyant, 1967 and Gorshkov, 1978).

Table 6. Percentage frequencies of visibility in the Weddell Sea and subantarctic South Atlantic (U.S. Navy, 1965).

Table 7. Percentage frequency of precipitation in the Weddell Sea (compiled from U.S. Navy, 1970 and Gorshkov, 1978).

Table 8. Pack Ice conditions at Weddell Sea sites for year 1974-1986 from U.S. satellite data: A, W_1 and W_2; B, W_4; C, W_5; D, W_6-W_8; E, W_{10}.

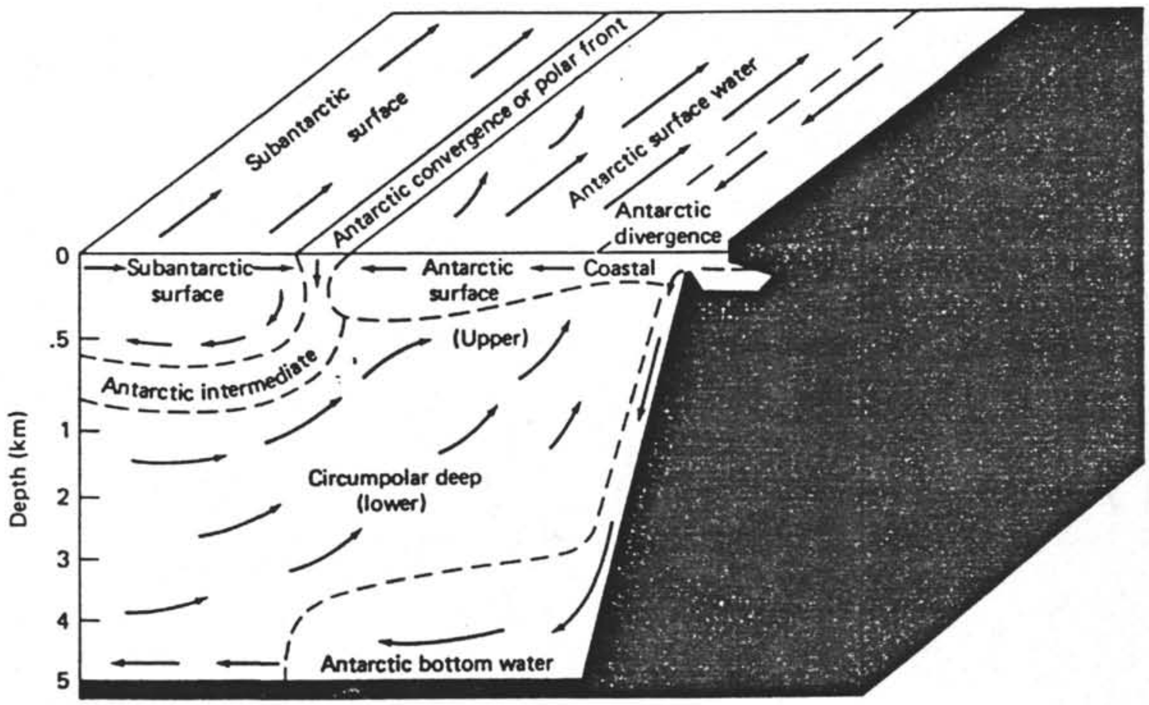
Table 9. Summary of wave data in the Weddell Sea and subantarctic South Atlantic (compiled from U.S. Navy, 1970 and Defense Mapping Agency, 1985).



ARGENTINA
514
513
328
327
SA5
ALT
SA6
SA5
SA3
SA2
SA1
SA4
SA7
SA8
SA9
MID-ATLANTIC RIDGE
SOUTHWEST INDIAN RIDGE
AMERICA-ANTARTIC RIDGE
SOUTH SANDWICH TRENCH
SCOTIA SEA
326
SOUTH ORKNEY
ISLANDS
W11
W9
W8
W10
W6-8
ALT
W7
W6
W5
W1
W2
W3
W4
WEDDELL SEA
50°
60°
70°
70°
50°
30°
10°
10°
Tenative Ship Tracks
Leg 114
Leg 113

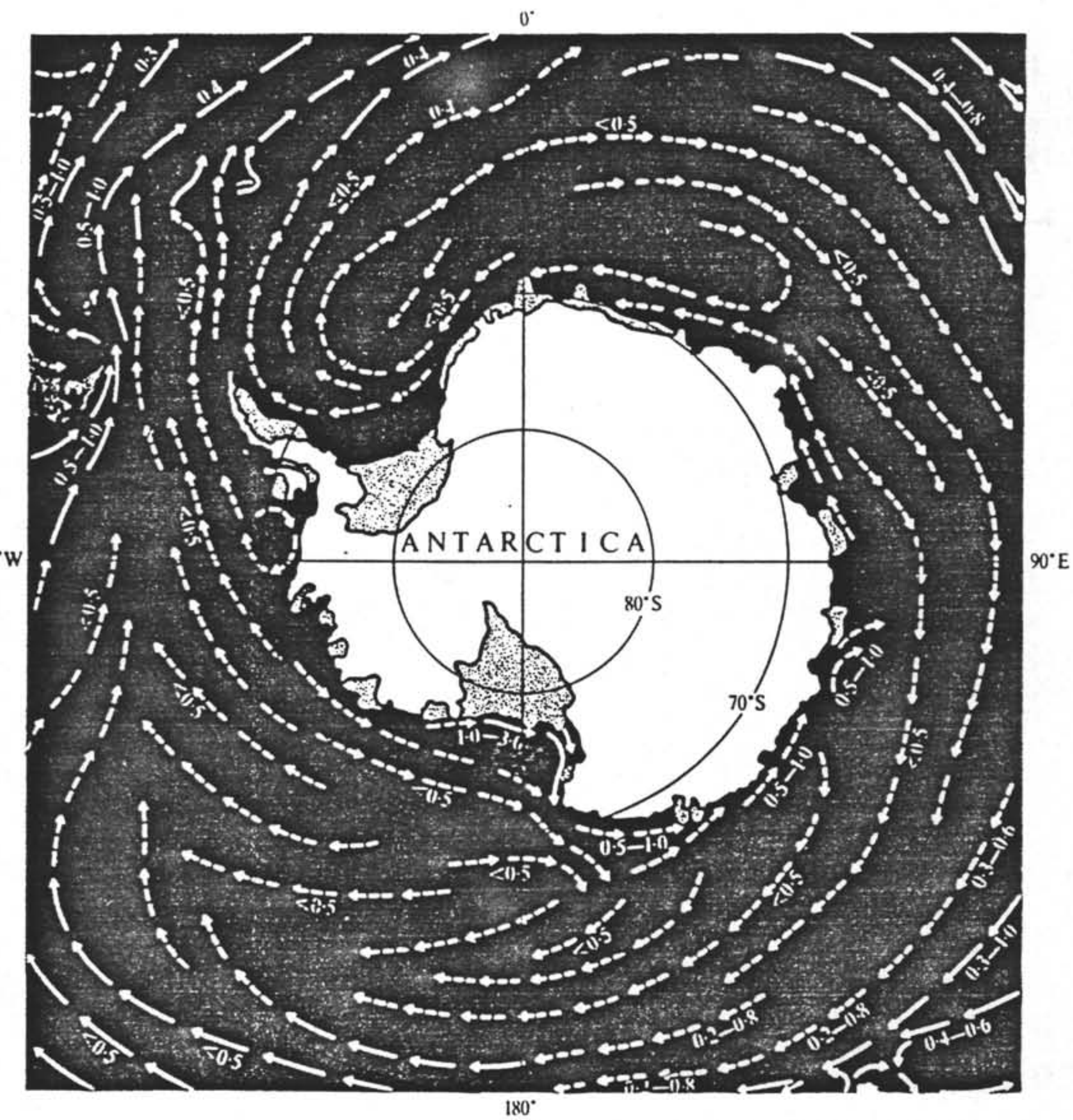
Figure -1-

Figure -2-



Subantarctic
surface
Antarctic convergence or polar front
Antarctic surface water
Antarctic
divergence
0
Subantarctic
surface
Antarctic
surface
Coastal
.5
(Upper)
Antarctic intermediate
1
Depth (km)
2
Circumpolar deep
(lower)
3
4
5
Antarctic bottom water

Figure -3-

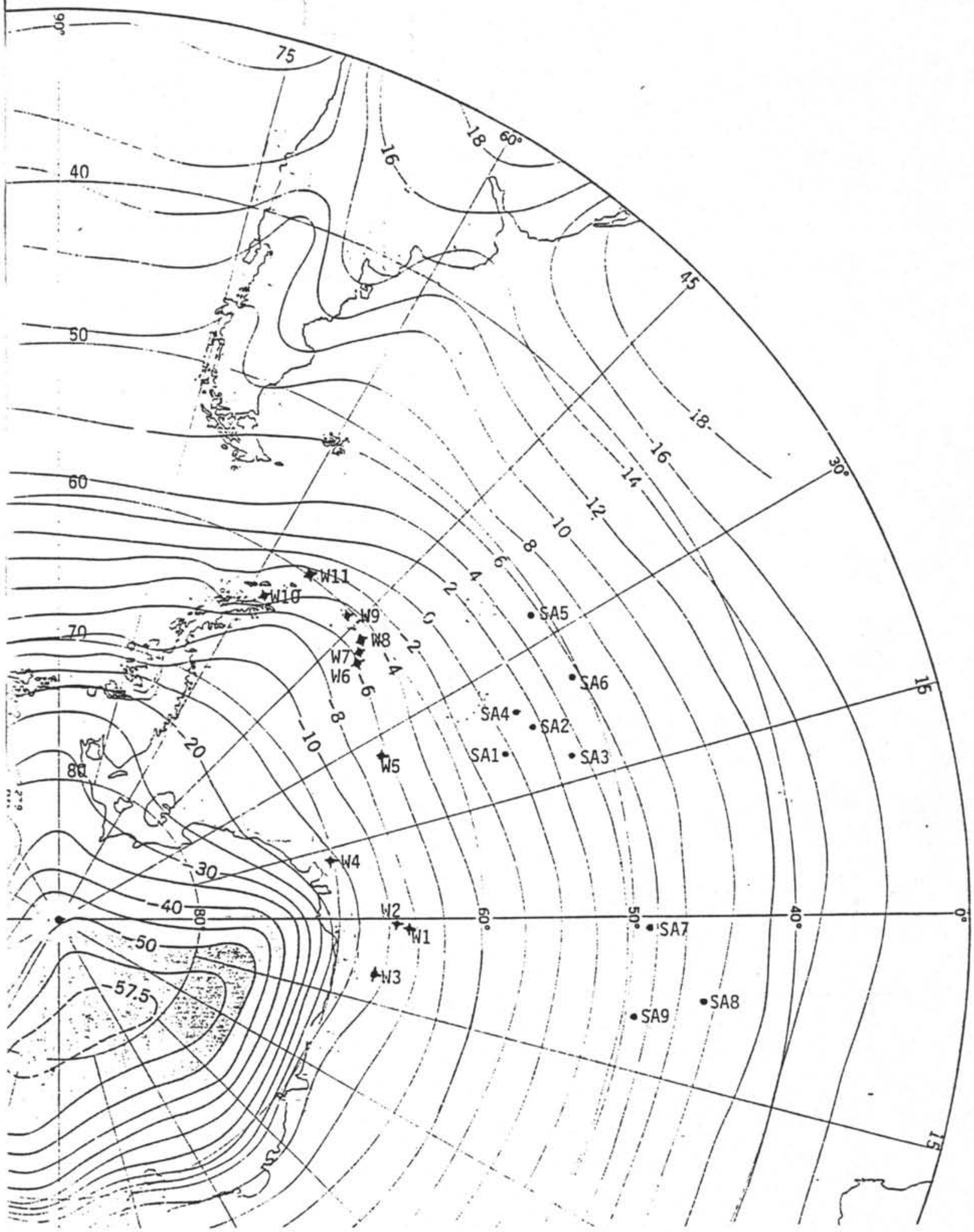


Numbers indicate current speed in knots

Data adequate

Data sparse-direction inferred

Figure -4-



90°
75
60°
45
30°
15
0°
15
40
50
60
70
80
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-20
-30
-40
-50
-57.5
80
60°
50°
40°
W1
W2
W3
W4
W5
W6
W7
W8
W9
W10
W11
SA1
SA2
SA3
SA4
SA5
SA6
SA7
SA8
SA9

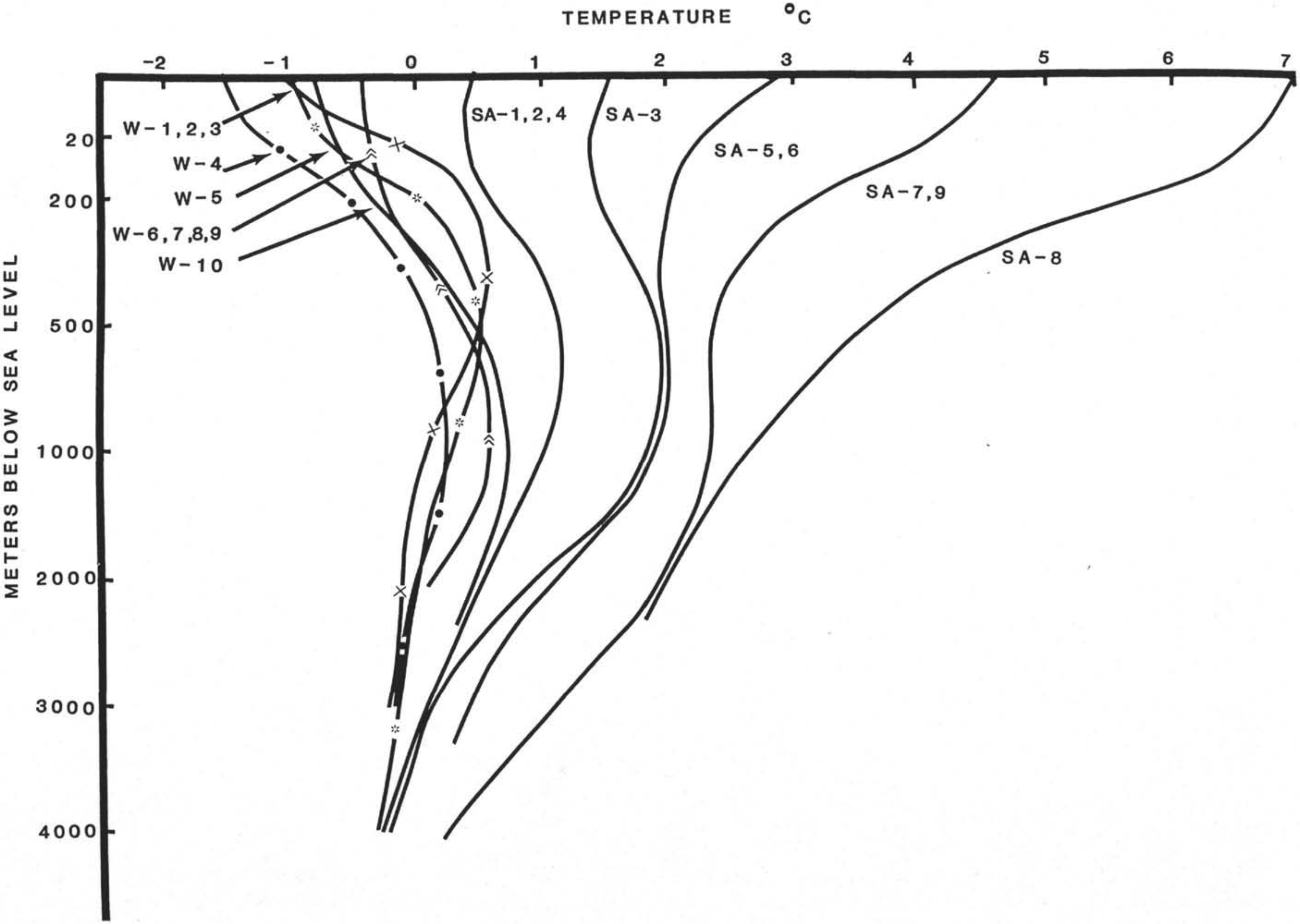

TEMPERATURE °C
-2
-1
0
1
2
3
4
5
6
7
METERS BELOW SEA LEVEL
20
200
500
1000
2000
3000
4000
W-1,2,3
W-4
W-5
W-6,7,8,9
W-10
SA-1,2,4
SA-3
SA-5,6
SA-7,9
SA-8

Figure -5-

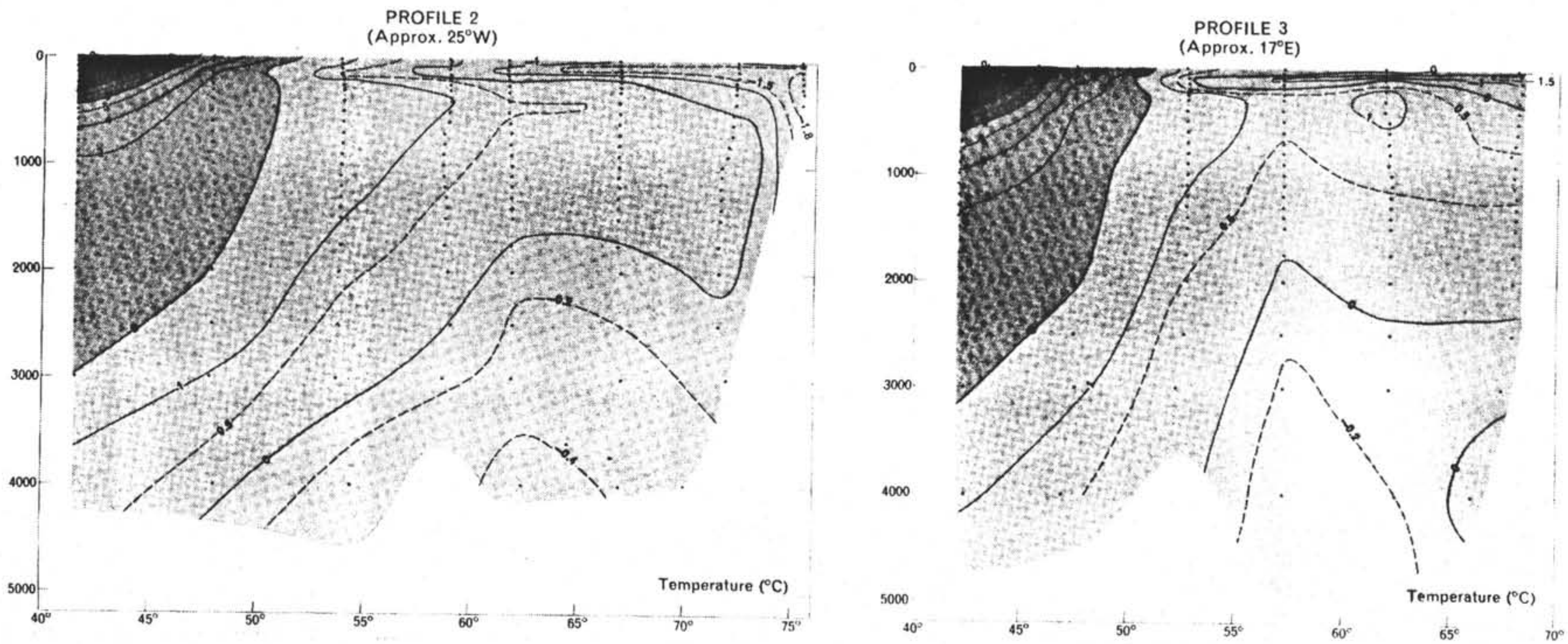
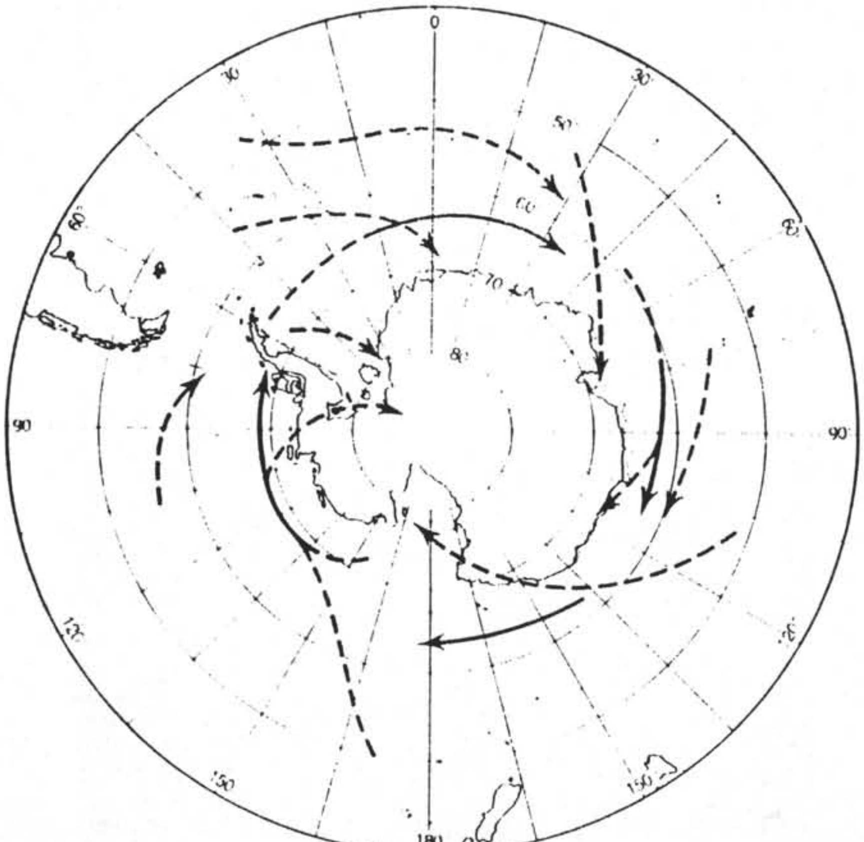
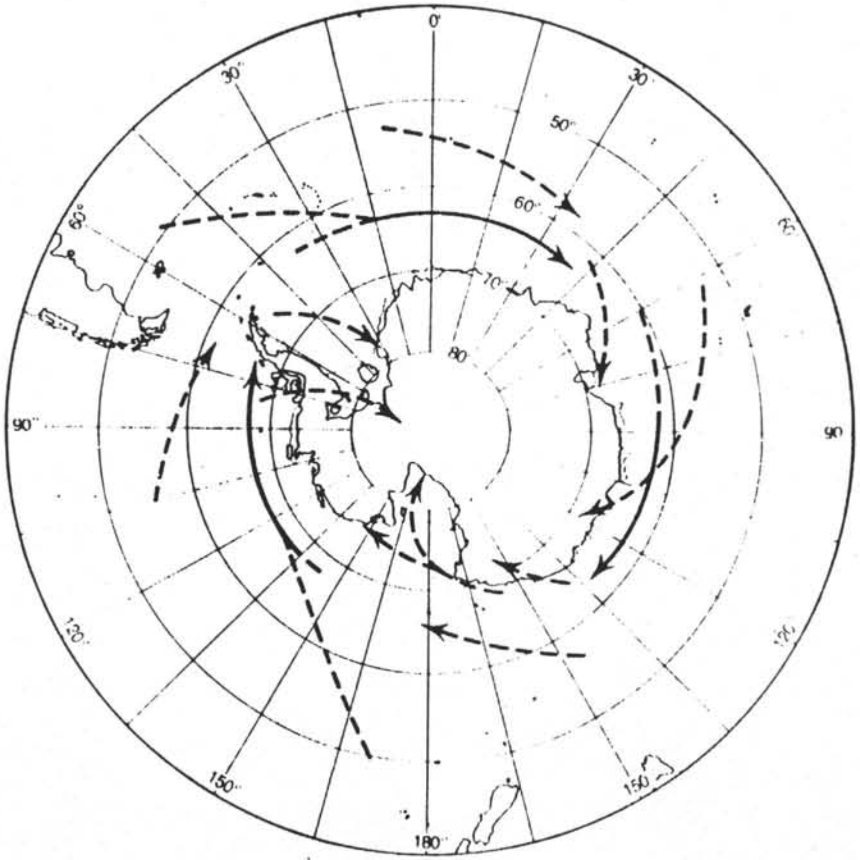

PROFILE 2
(Approx. 25°W)
0
1000
2000
3000
4000
5000
40°
45°
50°
55°
60°
65°
70°
75°
Temperature (°C)
PROFILE 3
(Approx. 17°E)
0
1000
2000
3000
4000
5000
40°
45°
50°
55°
60°
65°
70°
Temperature (°C)

Figure -6-

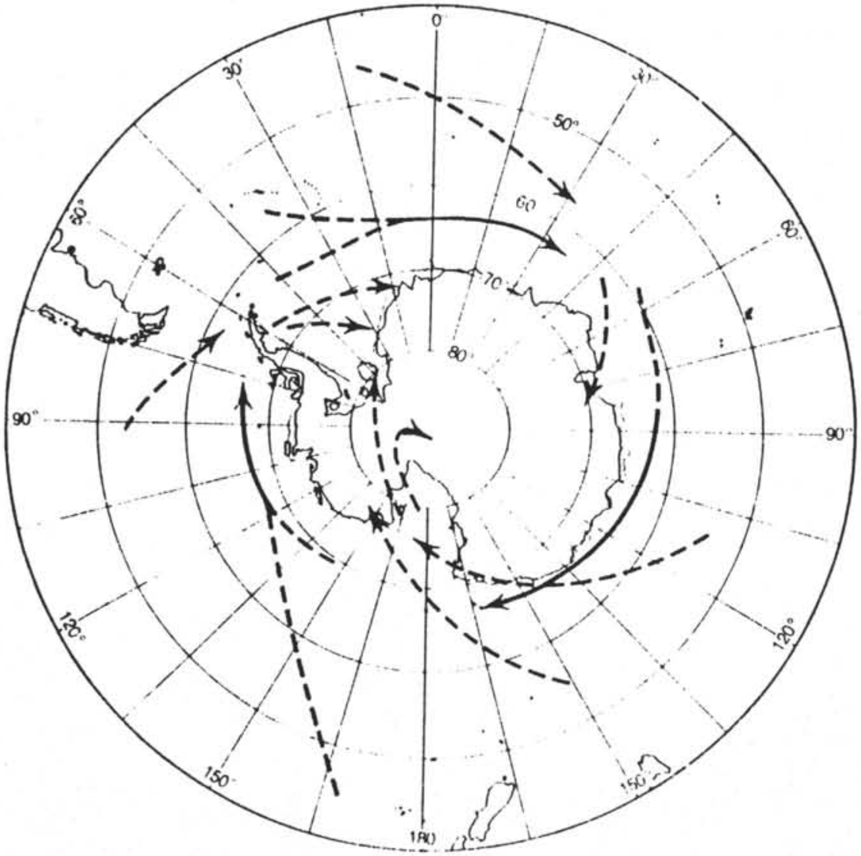


JANUARY

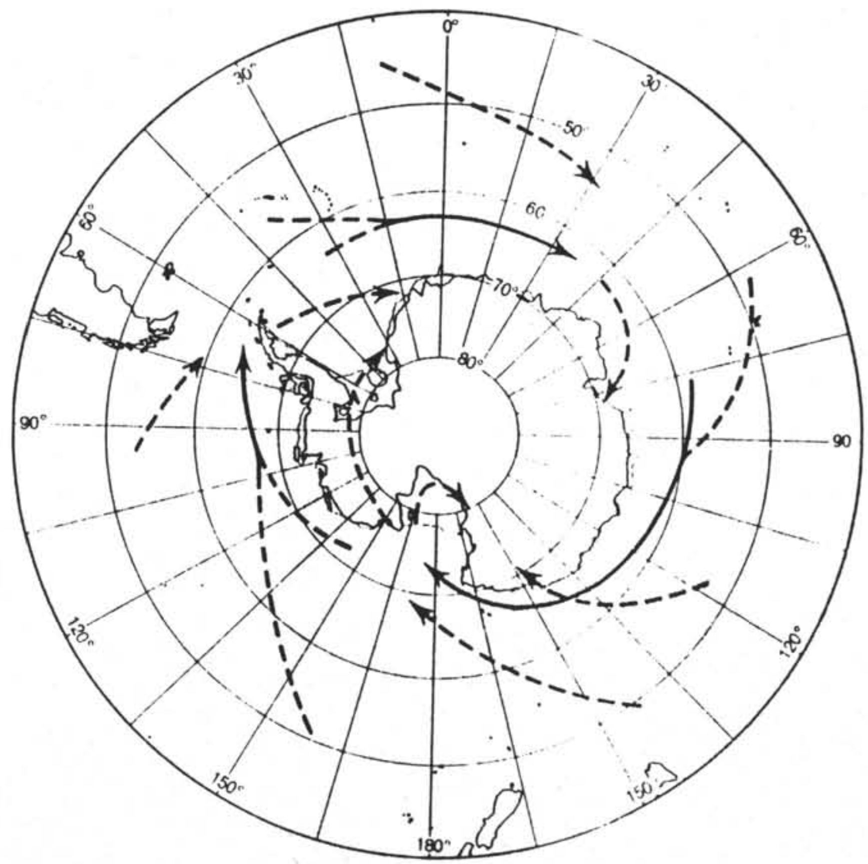


FEBRUARY

Figure -7-



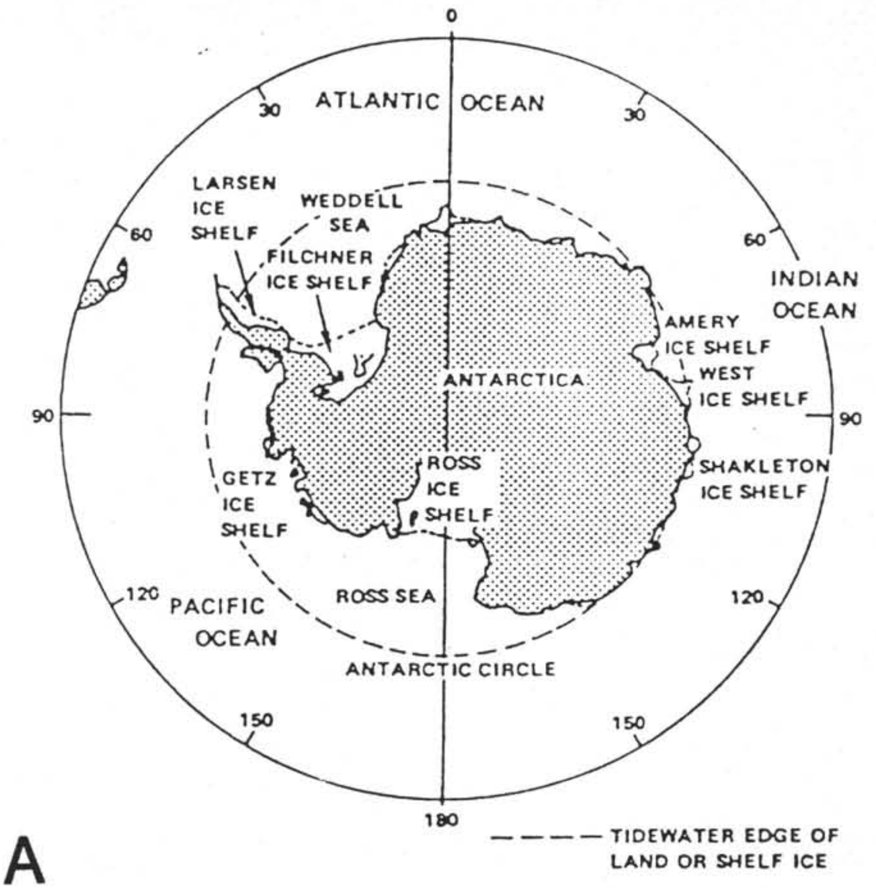
MARCH



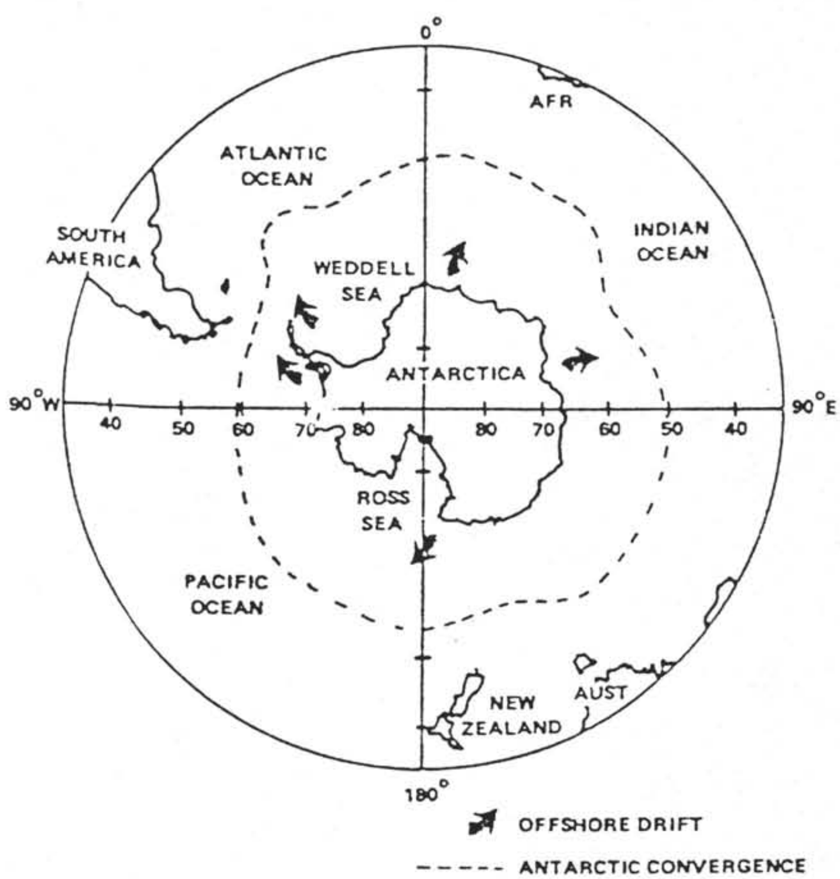
APRIL

Figure -8-

Figure -9-


0
30
ATLANTIC OCEAN
30
LARSEN ICE SHELF
WEDDELL SEA
60
FILCHNER ICE SHELF
60
INDIAN OCEAN
AMERY ICE SHELF
WEST ICE SHELF
ANTARCTICA
90
90
ROSS ICE SHELF
SHAKLETON ICE SHELF
GETZ ICE SHELF
120
PACIFIC OCEAN
ROSS SEA
120
ANTARCTIC CIRCLE
150
150
180
TIDEWATER EDGE OF LAND OR SHELF ICE

A


0°
AFR
ATLANTIC OCEAN
SOUTH AMERICA
INDIAN OCEAN
WEDDELL SEA
ANTARCTICA
90°W
40
50
60
70
80
80
70
60
50
40
90°E
ROSS SEA
PACIFIC OCEAN
NEW ZEALAND
AUST
180°
OFFSHORE DRIFT
ANTARCTIC CONVERGENCE

B

Figure -10A-

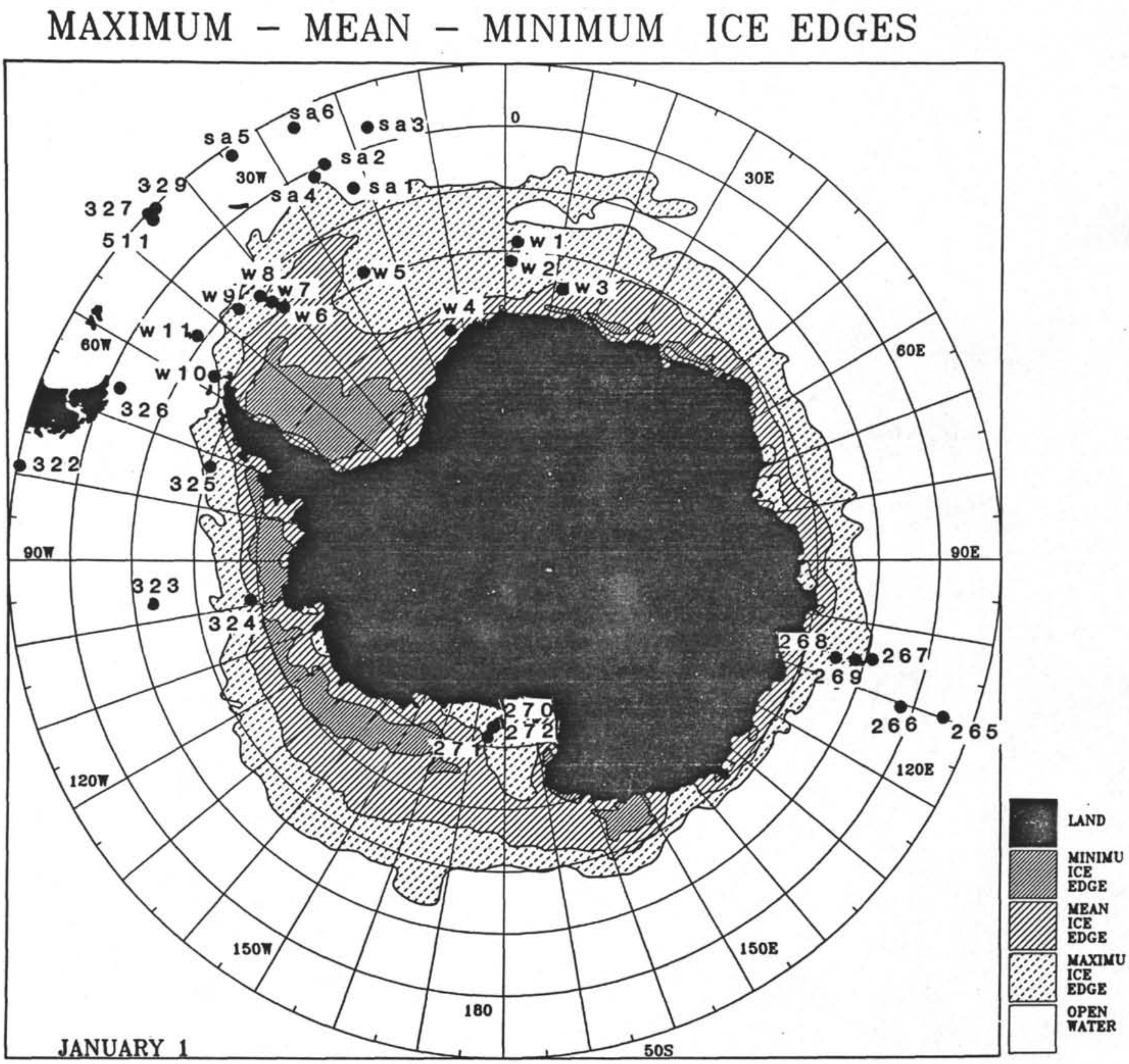

MAXIMUM - MEAN - MINIMUM ICE EDGES
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
50S
sa6
sa3
sa5
sa2
sa4
sa1
329
327
511
w1
w2
w3
w4
w5
w6
w7
w8
w9
w10
w11
326
322
325
323
324
268
267
269
266
265
270
272
271
JANUARY 1
LAND
MINIMU ICE EDGE
MEAN ICE EDGE
MAXIMU ICE EDGE
OPEN WATER

Figure -10B-

MAXIMUM - MEAN - MINIMUM ICE EDGES

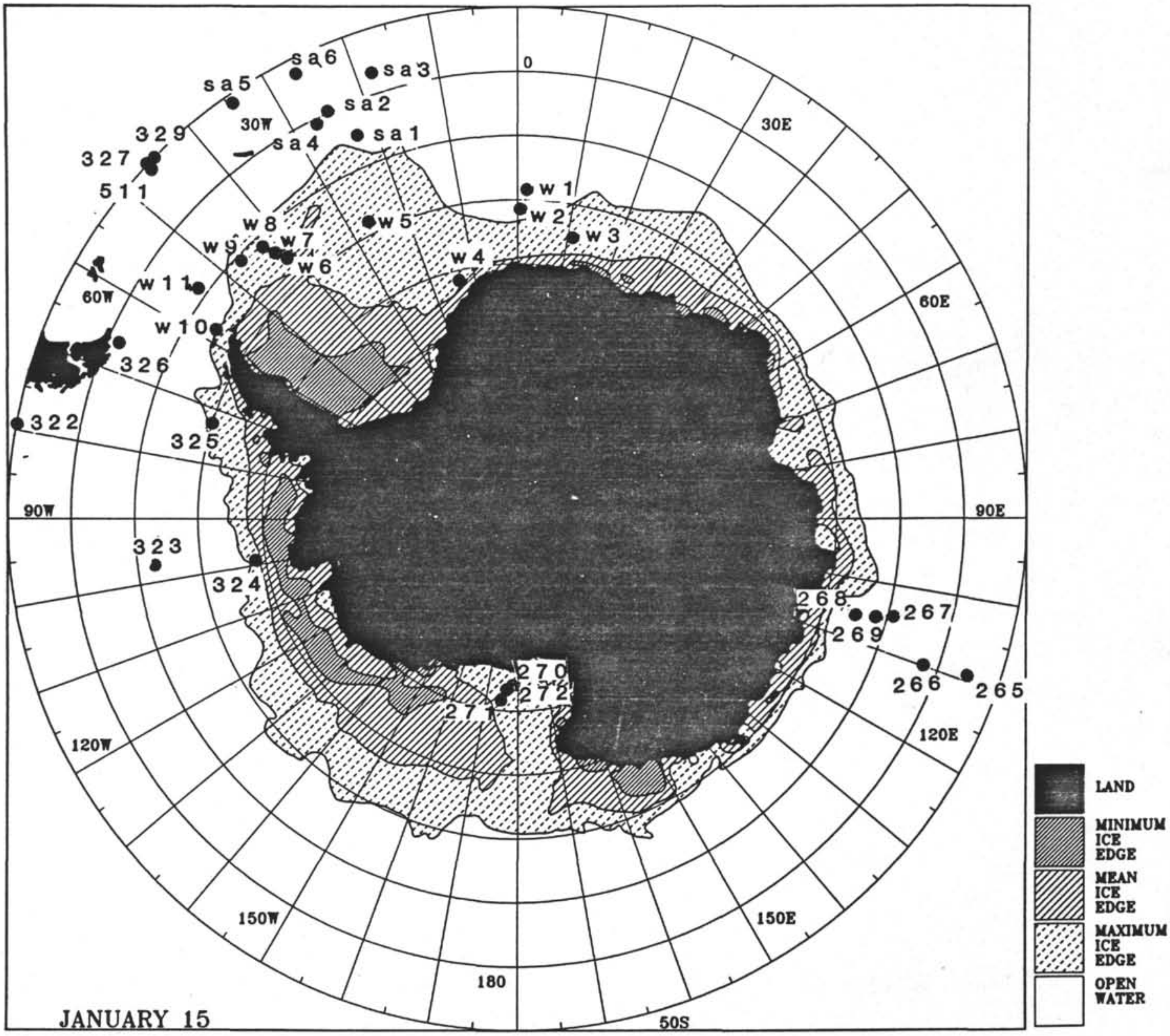


Figure -10C-

MAXIMUM - MEAN - MINIMUM ICE EDGES

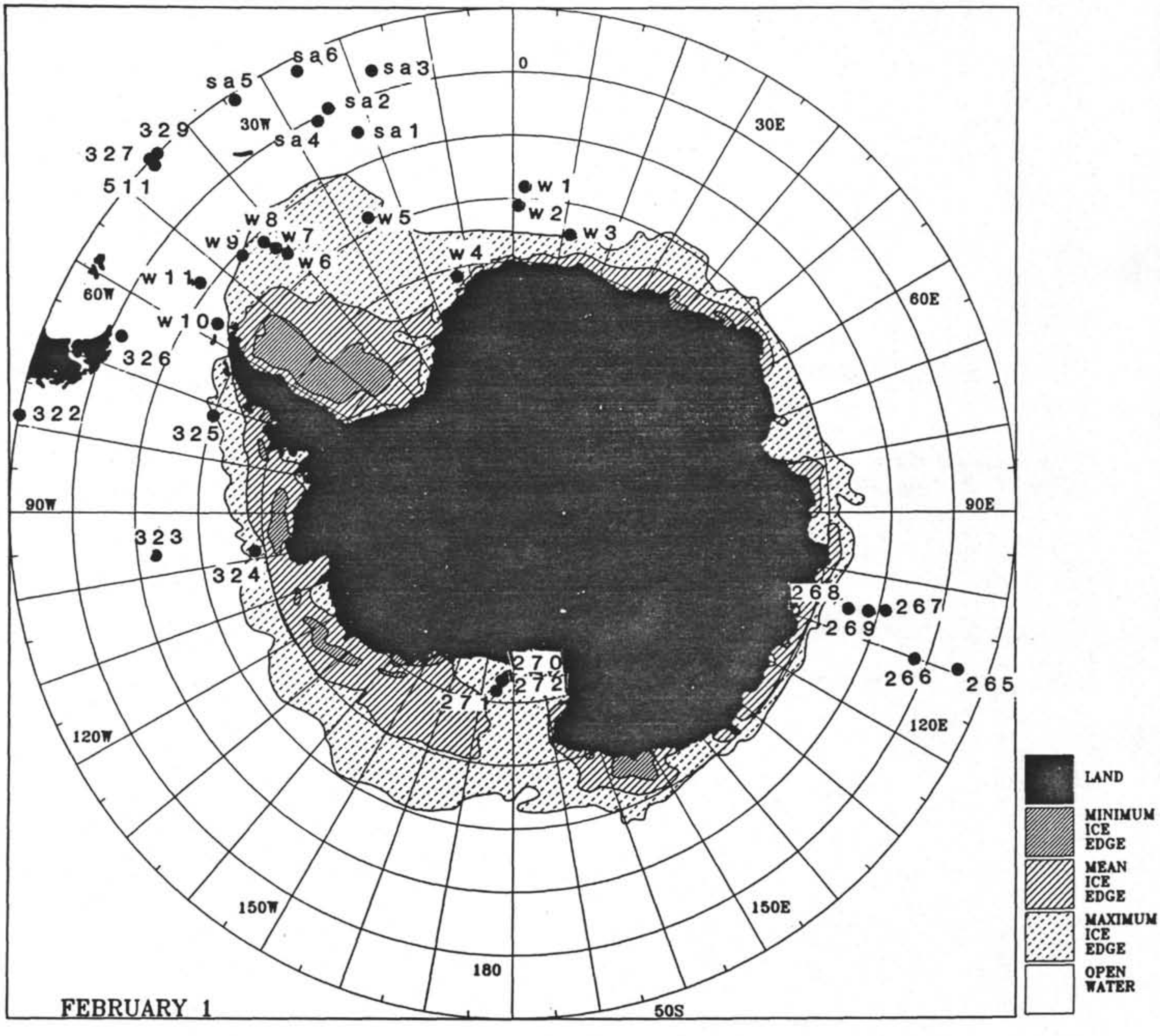


Figure -10D-

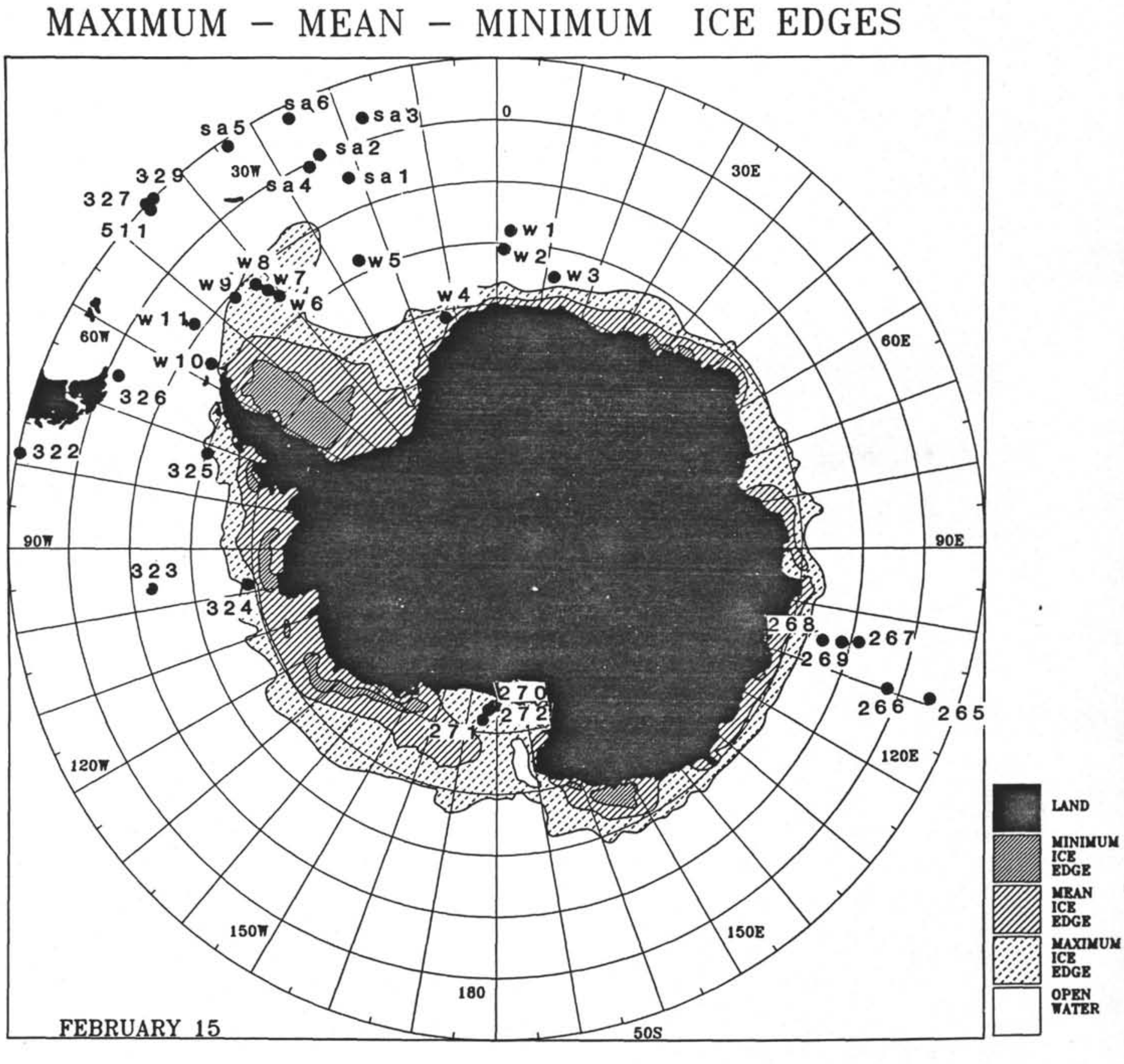

MAXIMUM - MEAN - MINIMUM ICE EDGES
sa6
sa3
sa5
sa2
329
30W
sa4
sa1
327
511
w1
w2
w5
w8
w3
w9
w7
w6
w4
w11
60W
w10
326
322
325
90W
323
324
268
267
269
270
266
265
272
271
120W
120E
150W
150E
180
FEBRUARY 15
50S
0
30E
60E
90E
LAND
MINIMUM ICE EDGE
MEAN ICE EDGE
MAXIMUM ICE EDGE
OPEN WATER

Figure -10E-

MAXIMUM - MEAN - MINIMUM ICE EDGES

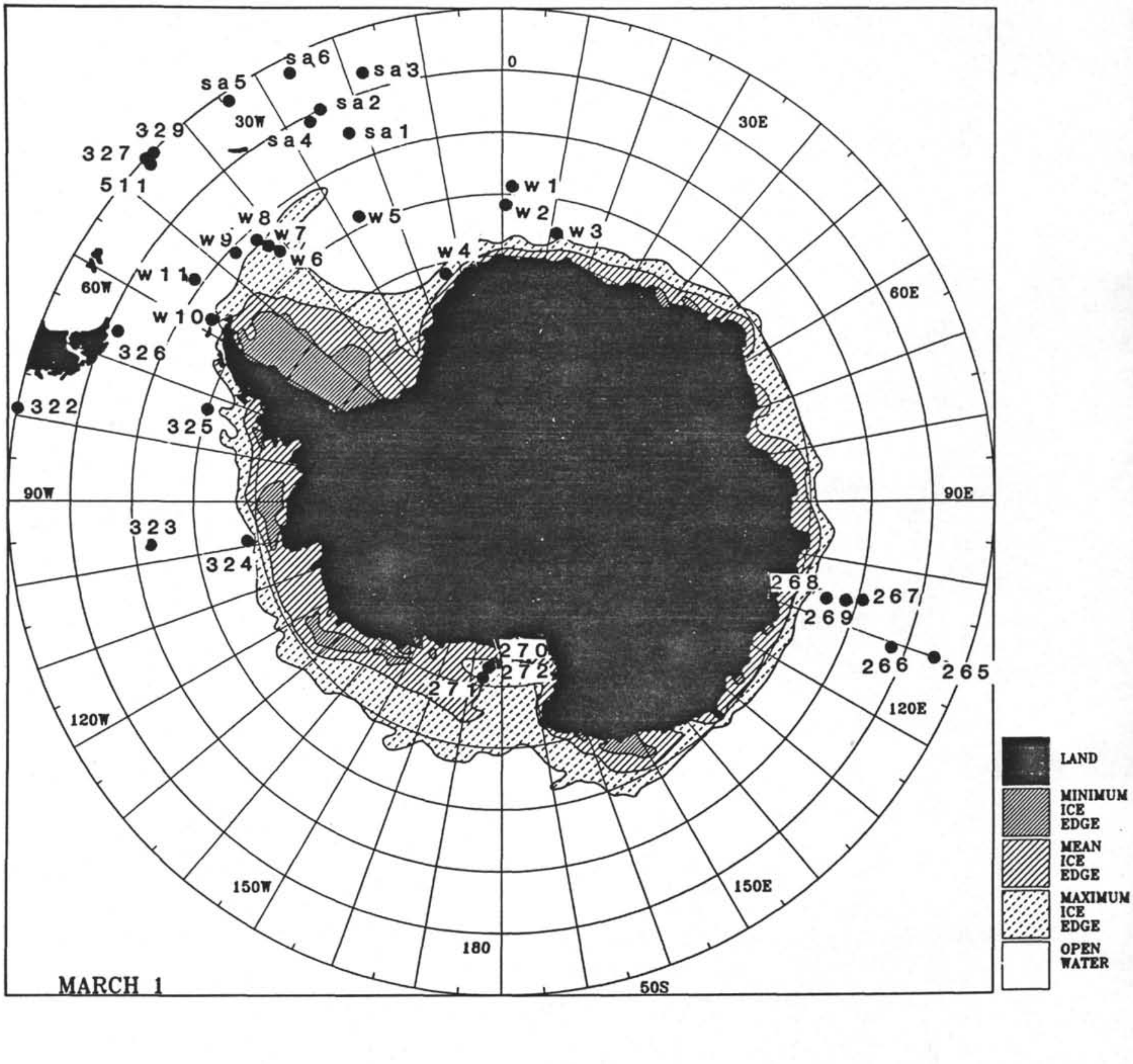


Figure -11-

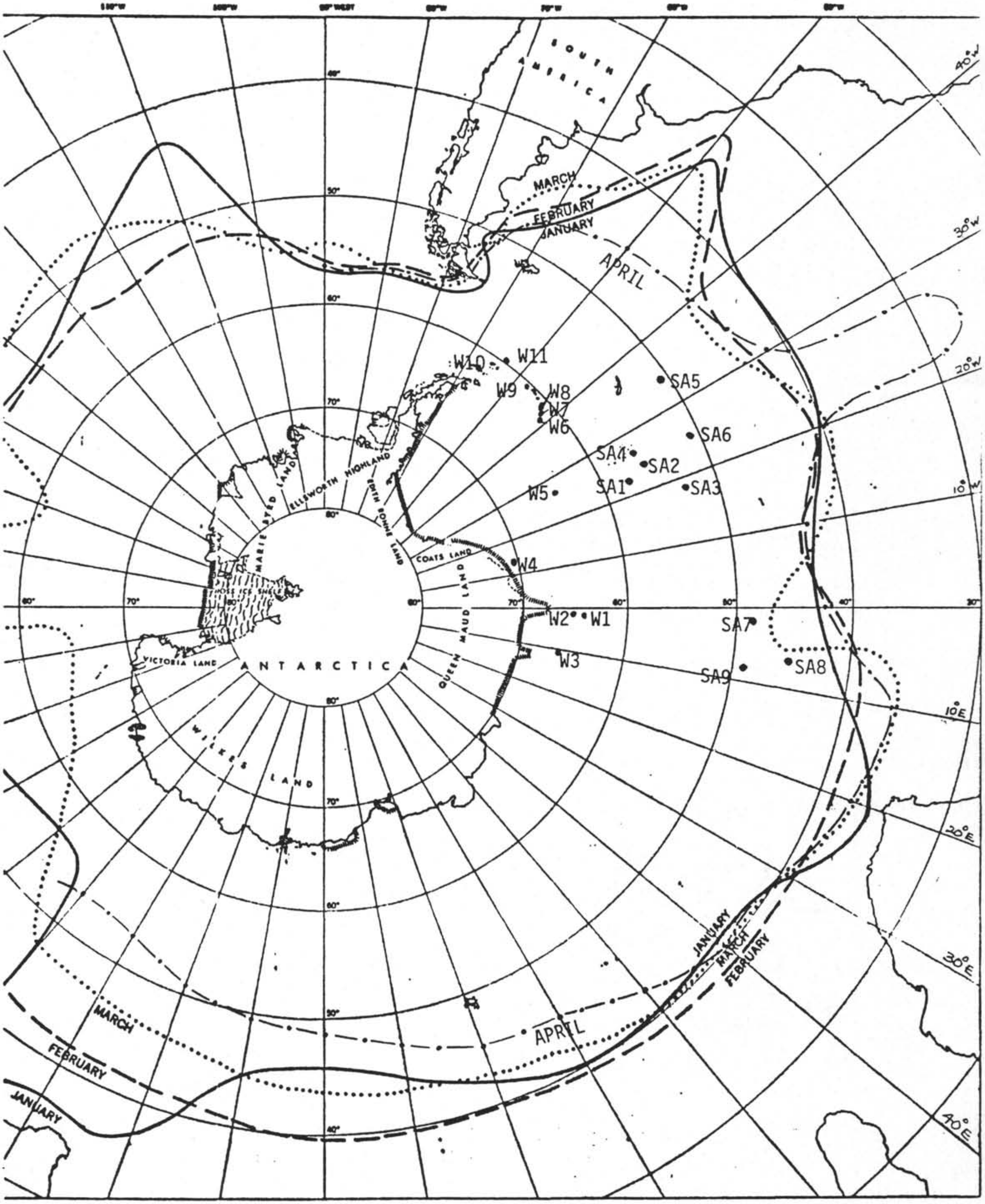
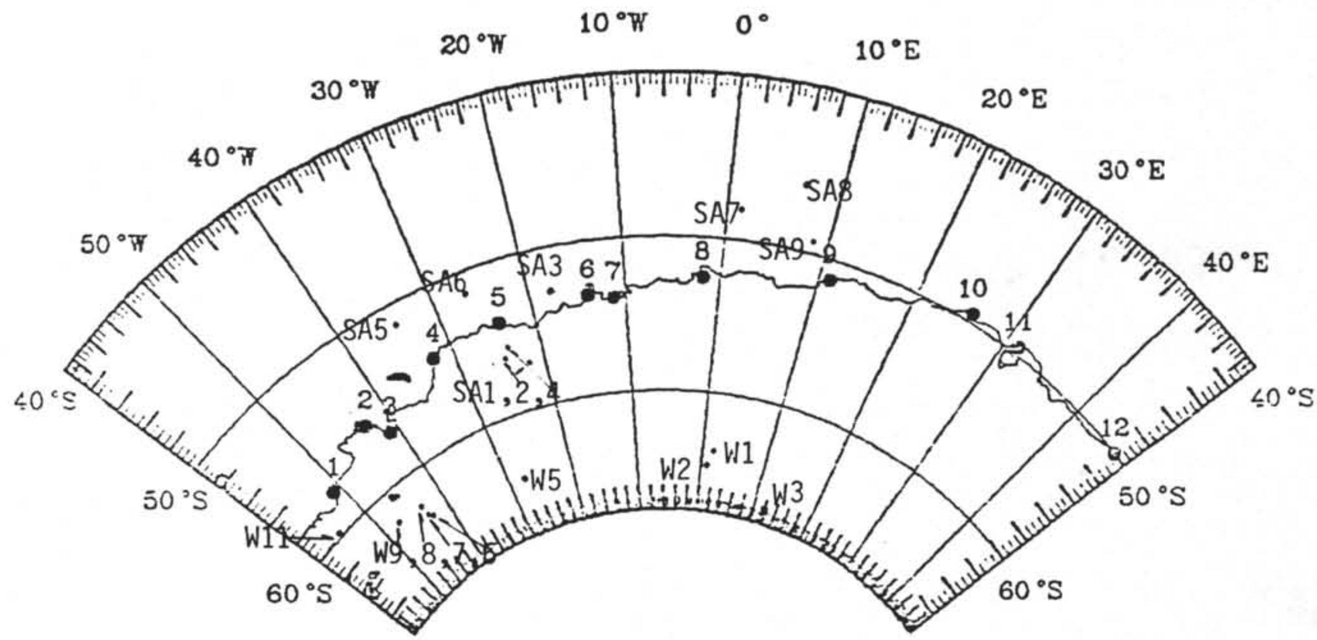
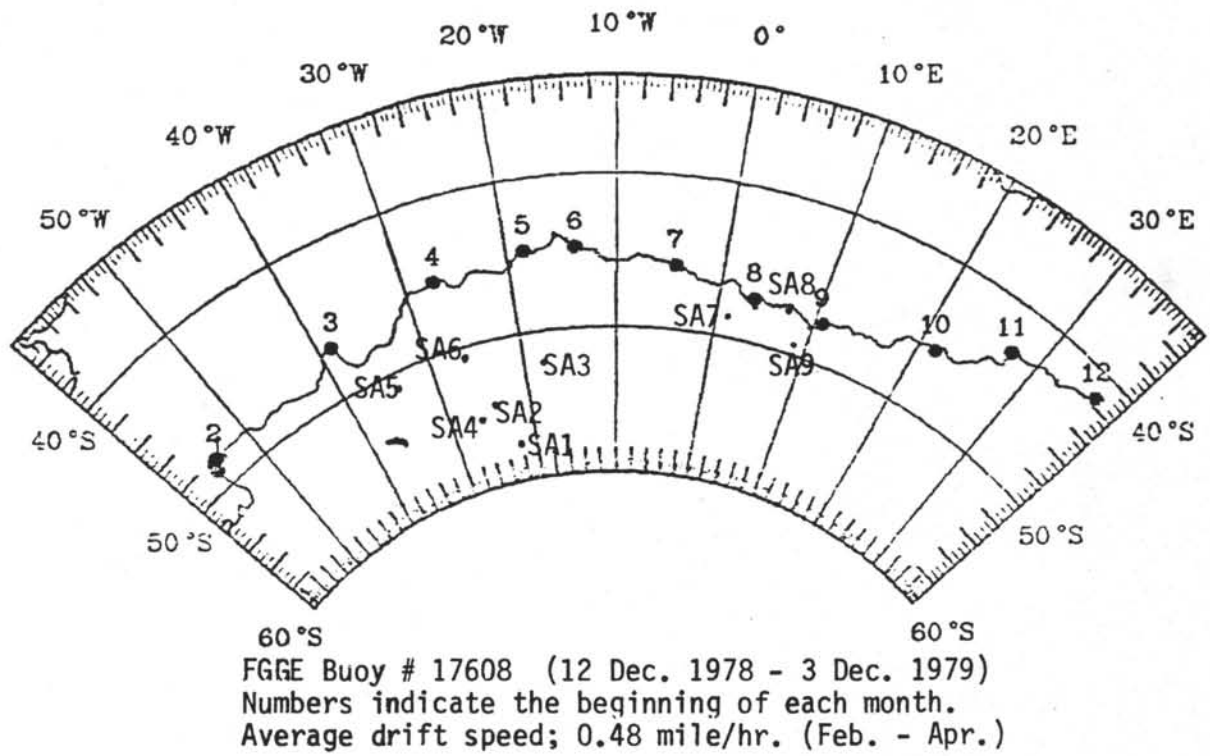

SOUTH AMERICA
MARCH
FEBRUARY
JANUARY
APRIL
W10
W11
W9
W8
W7
W6
SA5
SA6
SA4
SA2
SA1
SA3
W5
W4
W2
W1
W3
SA7
SA8
SA9
ELLSWORTH HIGHLAND
MARIE BYRD LAND
EDITH RONNE LAND
COATS LAND
QUEEN MAUD LAND
ROSS ICE SHELF
VICTORIA LAND
ANTARCTICA
WILKES LAND
JANUARY
MARCH
FEBRUARY
APRIL
MARCH
FEBRUARY
JANUARY
40°W
30°W
20°W
10°W
10°E
20°E
30°E
40°E

Figure -12A-

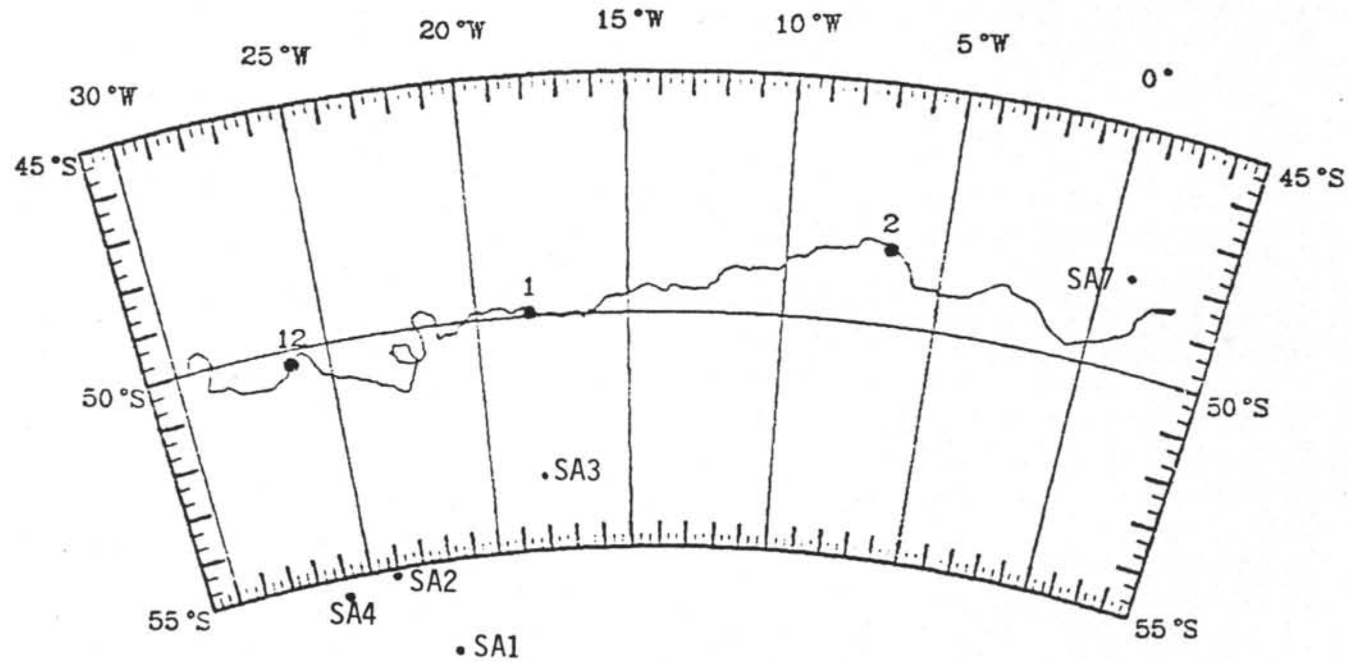


FGGE Buoy # 17606 (10 Dec. 1978 - 3 Dec. 1979)
Numbers indicate the beginning of each month.
Average drift speed; 0.23 mile/hr.(Jan. - Apr.)

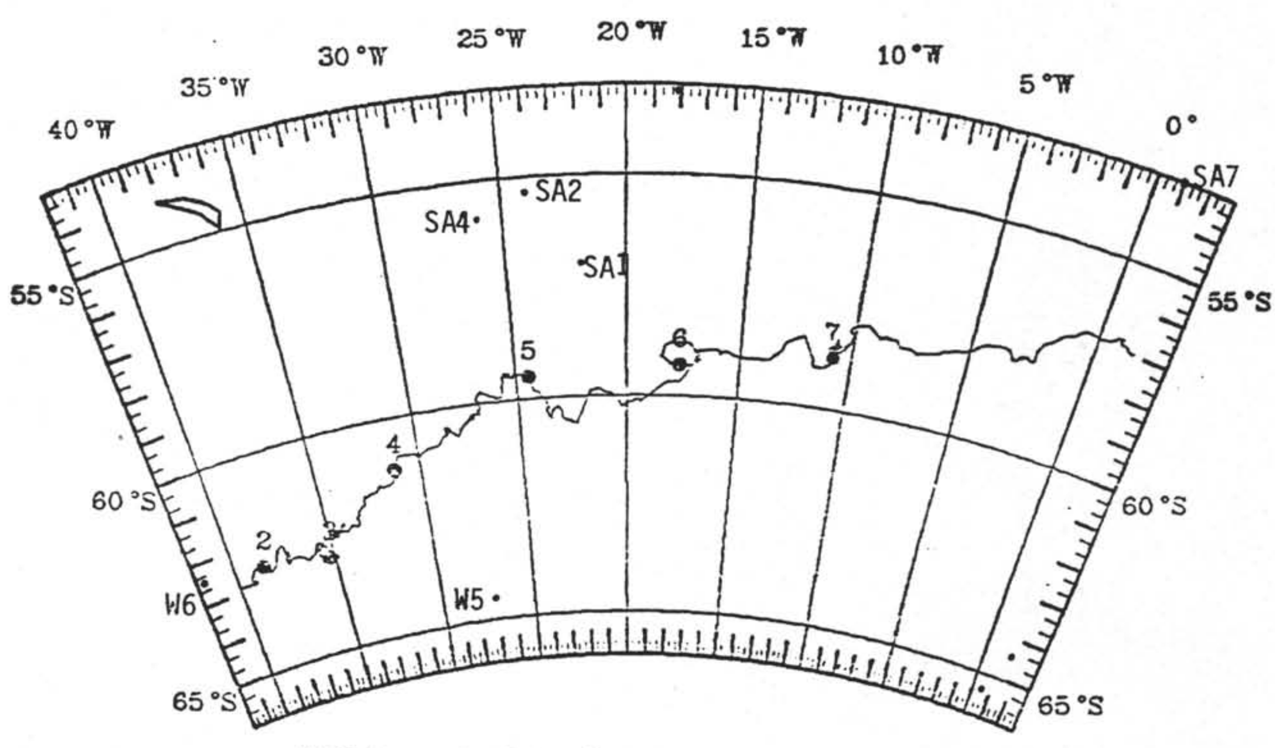


FGGE Buoy # 17608 (12 Dec. 1978 - 3 Dec. 1979)
Numbers indicate the beginning of each month.
Average drift speed; 0.48 mile/hr. (Feb. - Apr.)

Figure -12B-

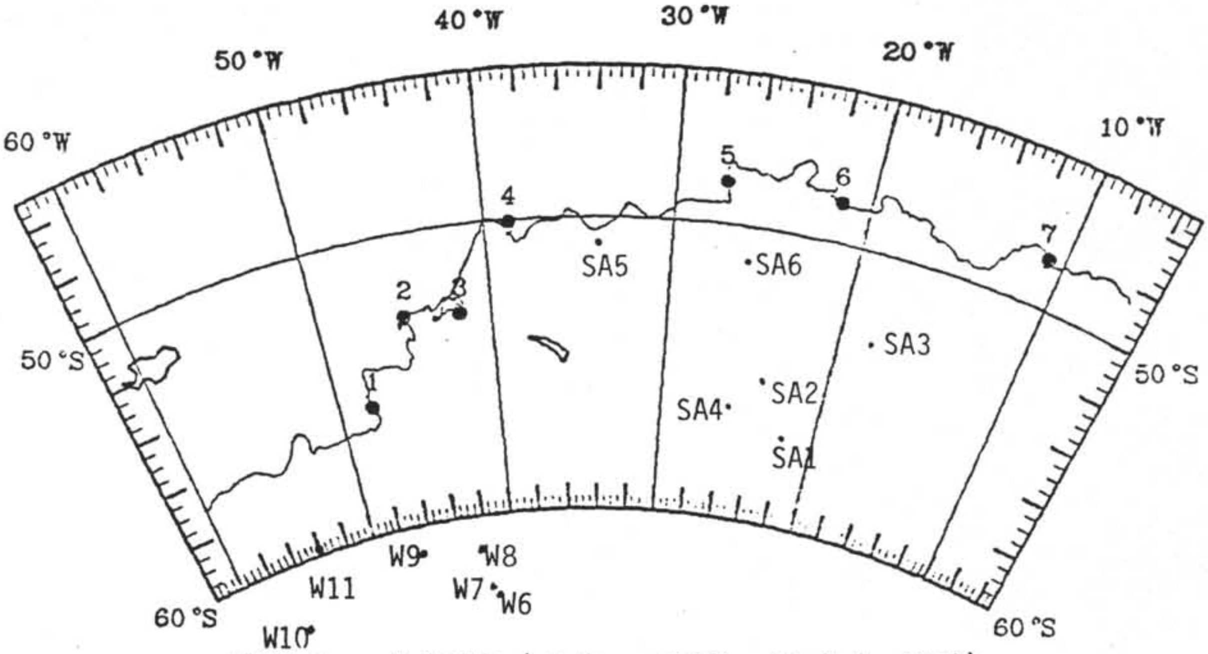


FGGE Buoy # 17610 (22 Nov. 1978 - 24 Feb. 1979)
Numbers indicate the beginning of each month.
Average drift speed; 0.62 mile/hr. (Jan. - Feb.)

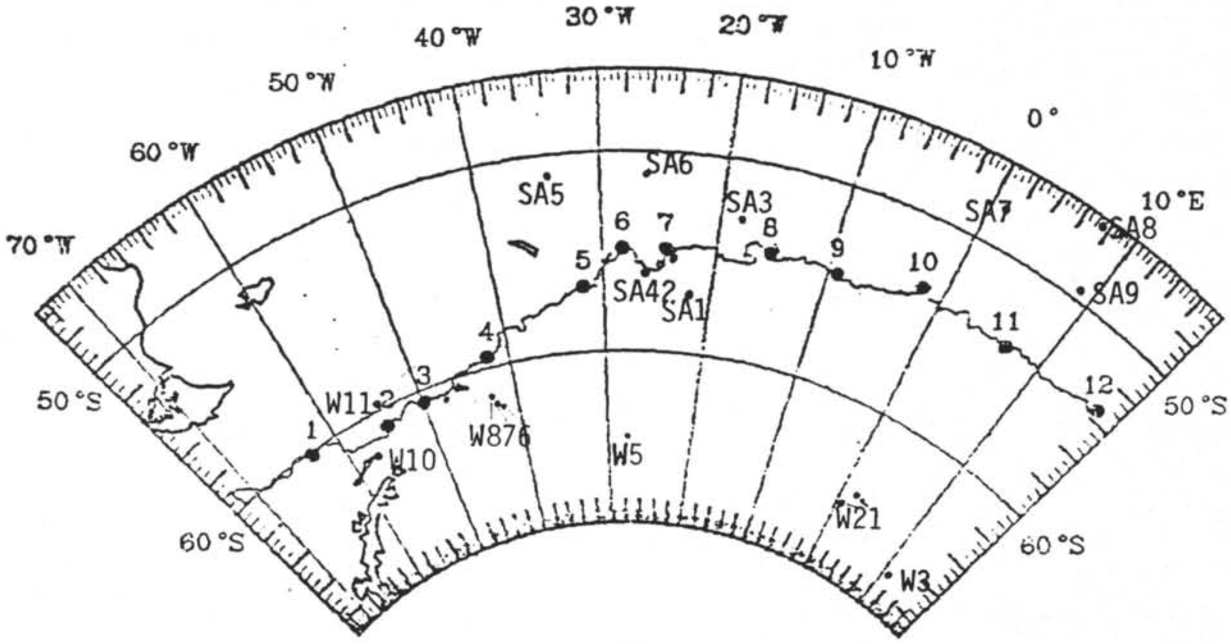


FGGE Buoy # 17621 (26 Jan. 1979 - 21 July 1979)
Numbers indicate the beginning of each month.
Average drift speed; 0.20 mile/hr. (Feb. - Apr.)

Figure -12C-



FGGE Buoy # 17625 (9 Dec. 1978 - 14 July 1979)
Numbers indicate the beginning of each month.
Average drift speed; 0.16 mile/hr. (Jan. - Apr.)



FGGE Buoy # 54601 (12 Dec. 1978 - 3 Dec. 1979)
Numbers indicate the beginning of each month.
Average drift speed; 0.23 mile/hr. (Jan. - Feb.)

Figure -13-

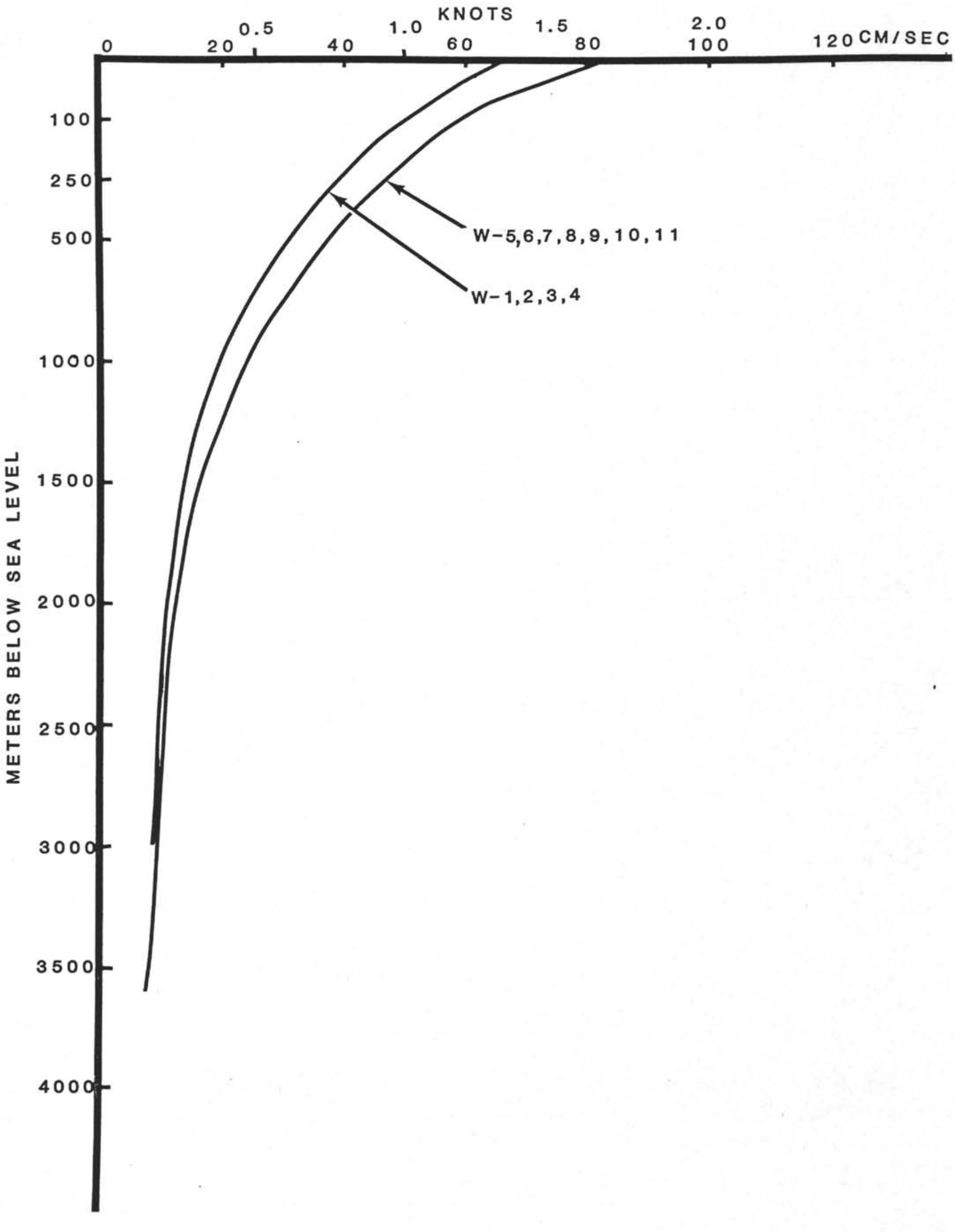

KNOTS
0.5
1.0
1.5
2.0
0
20
40
60
80
100
120 CM/SEC
100
250
500
1000
1500
2000
2500
3000
3500
4000
METERS BELOW SEA LEVEL
W-5,6,7,8,9,10,11
W-1,2,3,4

Figure -14-

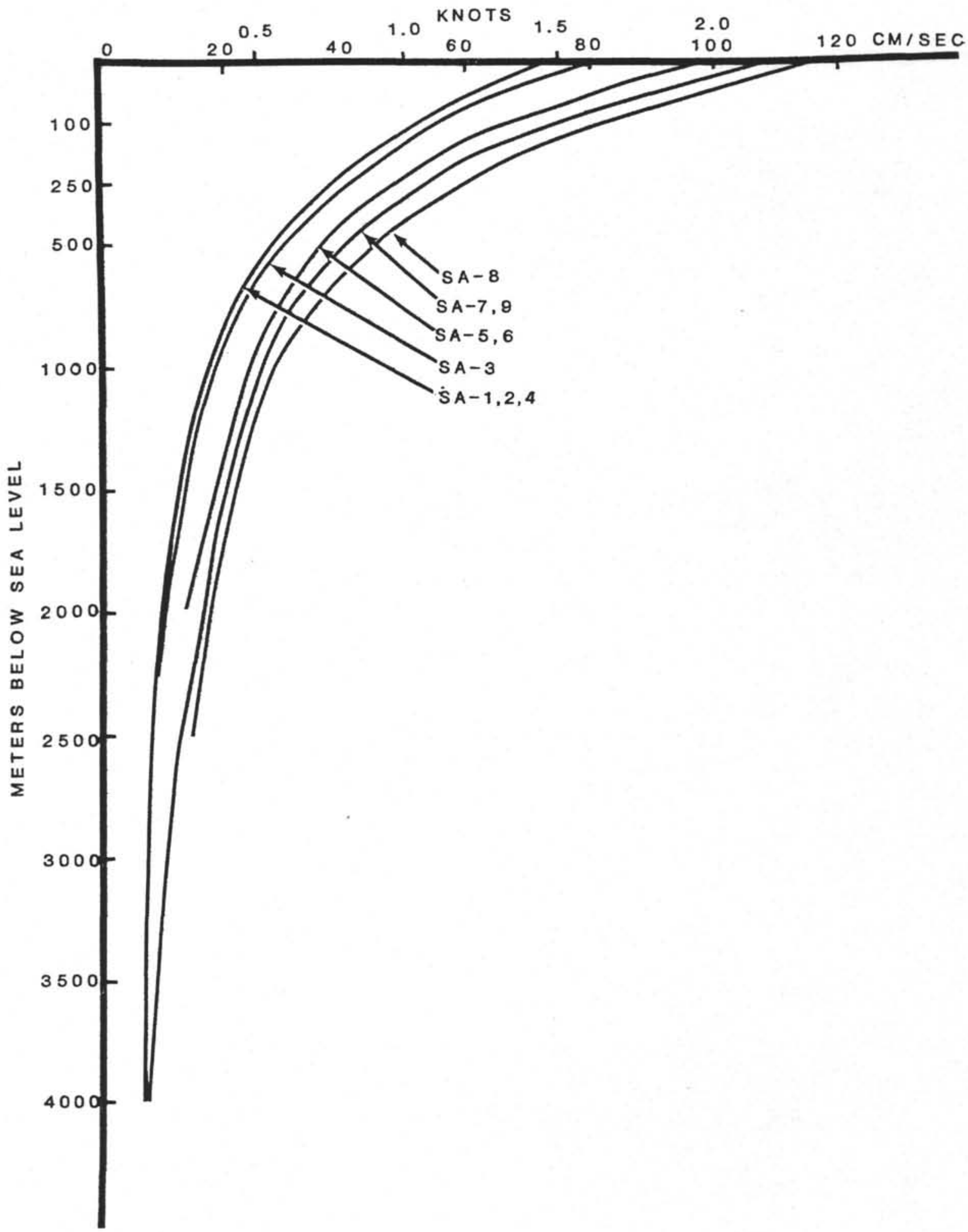

KNOTS
0.5
1.0
1.5
2.0
0
20
40
60
80
100
120 CM/SEC
100
250
500
1000
1500
2000
2500
3000
3500
4000
METERS BELOW SEA LEVEL
SA-8
SA-7,9
SA-5,6
SA-3
SA-1,2,4

TABLE CAPTIONS

Table 1. Location of the proposed drillsites.

Table 2. Surface air temperatures ($^{\circ}C$) in the Weddell Sea (compiled from U.S. Navy, 1970 and Gorshkov, 1978).

Table 3. Surface air temperatures ($^{\circ}C$) in the subantarctic South Atlantic (compiled from U.S. Navy, 1970 and Gorshkov, 1978).

Table 4. Wind conditions in the Weddell Sea (compiled from Weyant, 1967 and Gorshkov, 1978).

Table 5. Wind conditions in the subantarctic South Atlantic (compiled from Weyant, 1967 and Gorshkov, 1978).

Table 6. Percentage frequencies of visibility in the Weddell Sea and subantarctic South Atlantic (U.S. Navy, 1965).

Table 7. Percentage frequency of precipitation in the Weddell Sea (compiled from U.S. Navy, 1970 and Gorshkov, 1978).

Table 8. Pack Ice conditions at Weddell Sea sites for year 1974-1986 from U.S. satellite data: A, W_1 and W_2; B, W_4; C, W_5; D, W_6-W_8; E, W_{10}.

Table 9. Summary of wave data in the Weddell Sea and subantarctic South Atlantic (compiled from U.S. Navy, 1970 and Defense Mapping Agency, 1985).

TABLE 1. LOCATION OF THE PROPOSED LEG 113 AND 114 DRILLSITES

SITE	LOCATION	LATITUDE	LONGITUDE	DEPTH (m)	PENETRATION (m)
W1		64°30'S	1°45'E	2800	800
W2		65°30'S	0°30'E	3000	500
W3		67°20'S	11°E	2000	1000
W4		71°S	13°W	3040	1000
W4A		71°S	13°W	3000	500
W5		64°30'S	27°W	4950	1000
W6		62°30'S	41°30'W	3500	500
W7		62°S	41°45'W	1700-2500	500
W8		61°30'S	42°W	700	500
W9		61°S	47°W	3200	500
W10		62°30'S	57°W	1980	600
SA1		57°S	22°W	4700	500
SA2		55°19'S	24°W	4000	700
SA3		53°20'S	18°10'W	4300	500
SA4		55°50'S	26°W	2700	600
SA5		51°S	34°W	2000	800
SA6		51°30'S	26°W	3000	500
SA7		48°S	1°E	4300	500
SA8		46°37'S	7°33'E	2480	500
SA9		49°36'S	8°41'E	4386	500

Table 2 Surface air temperatures(^{o}C) in Weddell Sea(compiled from US Navy,1970 and Gorshkov,1978)

sites	mean annual surf. temp.	January			February			March		
		1)	2)	3)	1)	2)	3)	1)	2)	3)
W-1,2,3	-9.0	-5.0	0.2	-12.1	-8.2	-2.1	-21.9	-15.5	-1.9	-29.8
W-4	-15.0	-6.0	0.1	-13.2	-8.4	-2.5	-19.4	-17.0	-6.0	-31.6
W-5	-6.5	1.0	3.1	-3.3	0.3	2.4	-2.2	0.2	2.3	-3.8
W-6,7,8,9	-4.0	1.9	5.8	-4.1	1.7	5.7	-4.5	0.9	4.8	-6.3
W-10,11	-2.0	2.2	6.2	-2.7	1.1	6.0	-3.5	0.8	4.7	-4.5

1) mean temperature 2) max. of the mean temperature 3) min. of the mean temperature

Table 3 Surface air temperatures(^{o}C) in Subantarctic South Atlantic Ocean (compiled from US Navy, 1970 and Gorshkov, 1978)

sites	mean annual surf. temp.	February			March			April		
		1)	2)	3)	1)	2)	3)	1)	2)	3)
SA-1,2,4	0.5	3.3	8.3	-1.1	2.8	6.7	-1.7	2.6	6.6	-2.0
SA-3	3.0	4.4	11.7	0.1	3.9	9.4	0.2	3.1	9.0	-1.0
SA-5,6	5.5	7.2	17.9	1.1	6.7	15.1	0.6	6.3	12.7	-0.5
SA-7,9	6.5	7.8	18.4	1.7	7.2	17.3	-1.1	6.6	14.4	-2.5
SA-8	8.0	9.4	20.1	2.8	8.9	19.6	0.0	7.0	17.0	-1.4

1) mean temperature 2) max. of the mean temperature 3) min. of the mean temperature

Table 4 Wind conditions in Weddell Sea (compiled from Weyant,1967 and Gorshkov,1978)

sites	January				February			
	1)	2)	3)	4)	1)	2)	3)	4)
W-1,2,3	13.9 (7.2)	23.0 (11.9)	E	5	13.5 (7.0)	29.5 (15.2)	E	2
W-4	15.6 (8.0)	28.1 (14.4)	E,SE	7	15.8 (8.1)	30.0 (15.5)	E	13
W-5	12.2 (6.2)	27.5 (14.2)	S	5	13.5 (7.0)	29.8 (15.4)	W	3
W-6,7,8,9	12.8 (6.6)	29.3 (15.1)	W	4	17.0 (8.8)	33.9 (17.5)	NW	10
W-10,11	14.5 (7.5)	35.0 (18.0)	NW	5	17.0 (8.8)	33.7 (17.4)	NW	10

1) mean wind speed in knots (m/sec) 2) max. of the mean wind speed in knots (m/sec) 3) prevailing direction

4) percentages of wind speed greater than 34 knots(18m/sec)

Table 5. Wind conditions in subantarctic South Atlantic (compiled from Weyant, 1967 and Gorshkov, 1978).

sites	March				April			
	1)	2)	3)	4)	1)	2)	3)	4)
SA-1,2,4	14.7 (7.6)	27.2 (14.0)	W	8	17.0 (8.8)	31.0 (16.0)	W,SW	15
SA-3	15.1 (7.8)	33.9 (17.5)	W	13	18.0 (9.3)	34.5 (17.8)	W	16
SA-5,6	22.7 (11.7)	40.7 (21.0)	W	15	22.9 (11.8)	40.5 (20.8)	W	19
SA-7,9	17.5 (9.0)	39.8 (20.5)	NW	17	23.0 (11.8)	39.9 (20.6)	W	21
SA-8	22.3 (11.5)	40.7 (21.0)	W	21	23.5 (12.1)	40.0 (20.7)	W	23

1) mean wind speed in knots(m/s) 2) max. of the mean wind speed in knots(m/s) 3) prevailing direction

4) percentages of wind speed greater than 34 knots(18m/sec)

Table 6 Percentage frequencies of visibility
(from US Navy Atlas, 1965)

drillsites	January 1)	2)	3)	4)	February 1)	2)	3)	4)
W-1,2	24	14	10	33	15	12	3	30
W-3	3	3	0	18	14	10	4	28
W-4	18	16	2	25	24	23	1	30
W-5	20	13	7	40	28	19	11	36
W-6,7,8,9	9	6	3	27	8	6	2	31
W-10	8	7	1	20	12	9	3	22
W-11	7	6	1	25	3	3	0	24
	March 1)	2)	3)	4)	April 1)	2)	3)	4)
SA-1,2,3,4,5,6	4	2	2	20	7	4	3	28
SA-7,8,9	6	3	3	25	no data			20

1) Total percentage of observations recorded visibility less than 2 miles.
2) Percentage with precipitation (2 miles)
3) Percentage without precipitation (2 miles)
4) Total percentage of observations recorded visibility less than 5 miles.

Table 7 Percentage frequencies of precipitation in Weddell Sea (compiled from US Navy, 1970 and Gorshkov, 1978)

observed station	nearest drillsites	October 1) 2) 3)	November 1) 2) 3)	December 1) 2) 3)	January 1) 2) 3)	February 1) 2) 3)	March 1) 2) 3)
69°S 0°E	1,2,3	22, 21, 1	18,18, 0	14,13, 1	14,13, 1	10, 9, 1	24,22, 2
71°S 11°W	4	23,3, 0	25,25, 0	25,25, 0	21,20, 1	24,23, 1	18,18, 0
63°S 28°W	5		36,34, 2	36,34, 2	28,27, 1	33,21,12	32,26, 6
61°S 45°W	6,7,8,9	36,31, 5	40,32, 8	37,32, 5	35,22,13	37,20,17	40,24,16
63°S 59°W	10	34,31, 3	24,20, 4	21,16, 5	26,16 10	31,15,16	36,23,13
56°S 58°W	11		17,	36,	24,	11,	15,

1) total percentage of precipitation 2) frozen precipitation 3) liquid precipitation

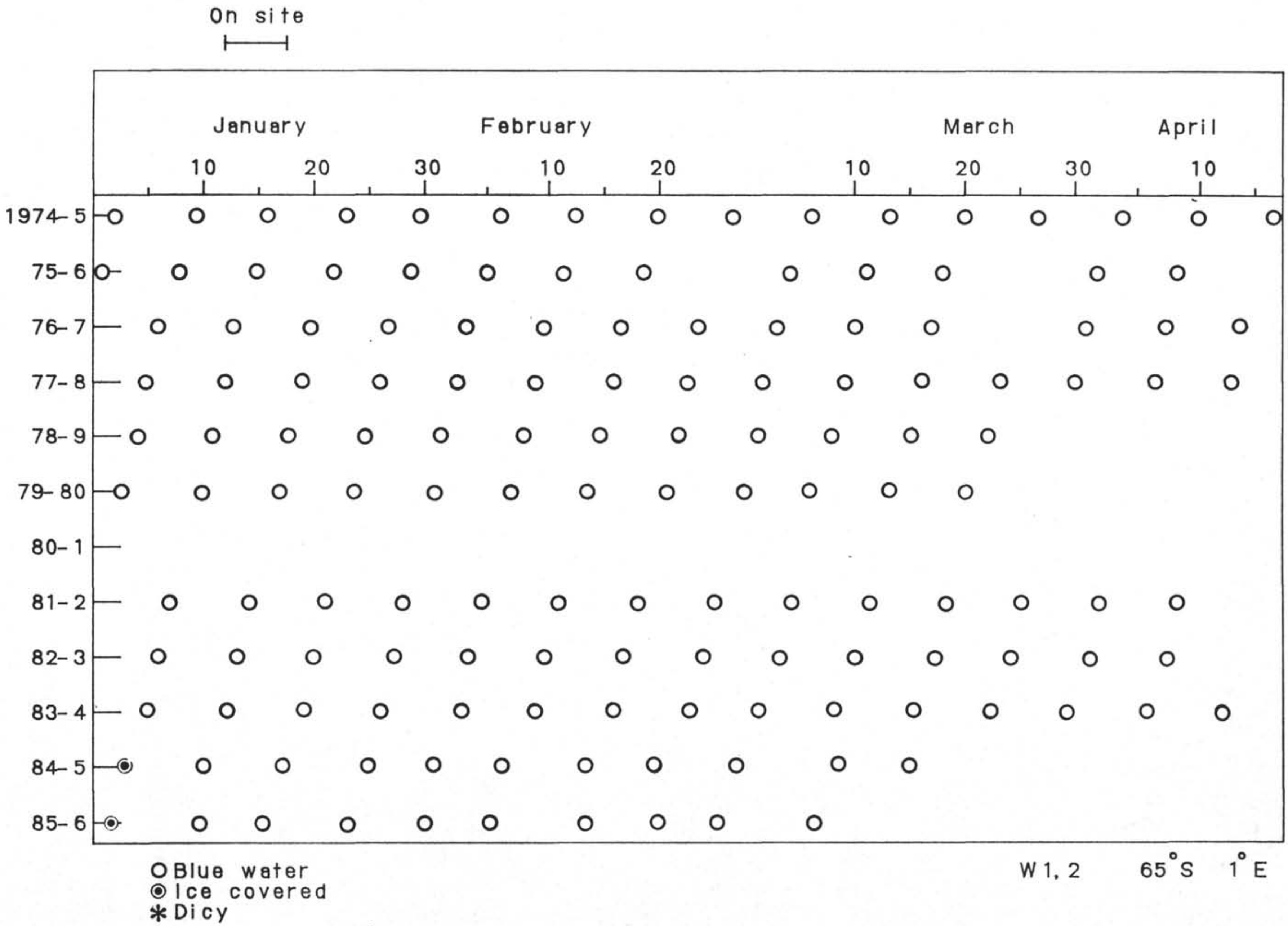

On site
January
February
March
April
10 20 30 10 20 10 20 30 10
1974-5
75-6
76-7
77-8
78-9
79-80
80-1
81-2
82-3
83-4
84-5
85-6
Blue water
Ice covered
Dicy
W1,2 65°S 1°E

Table -8A-

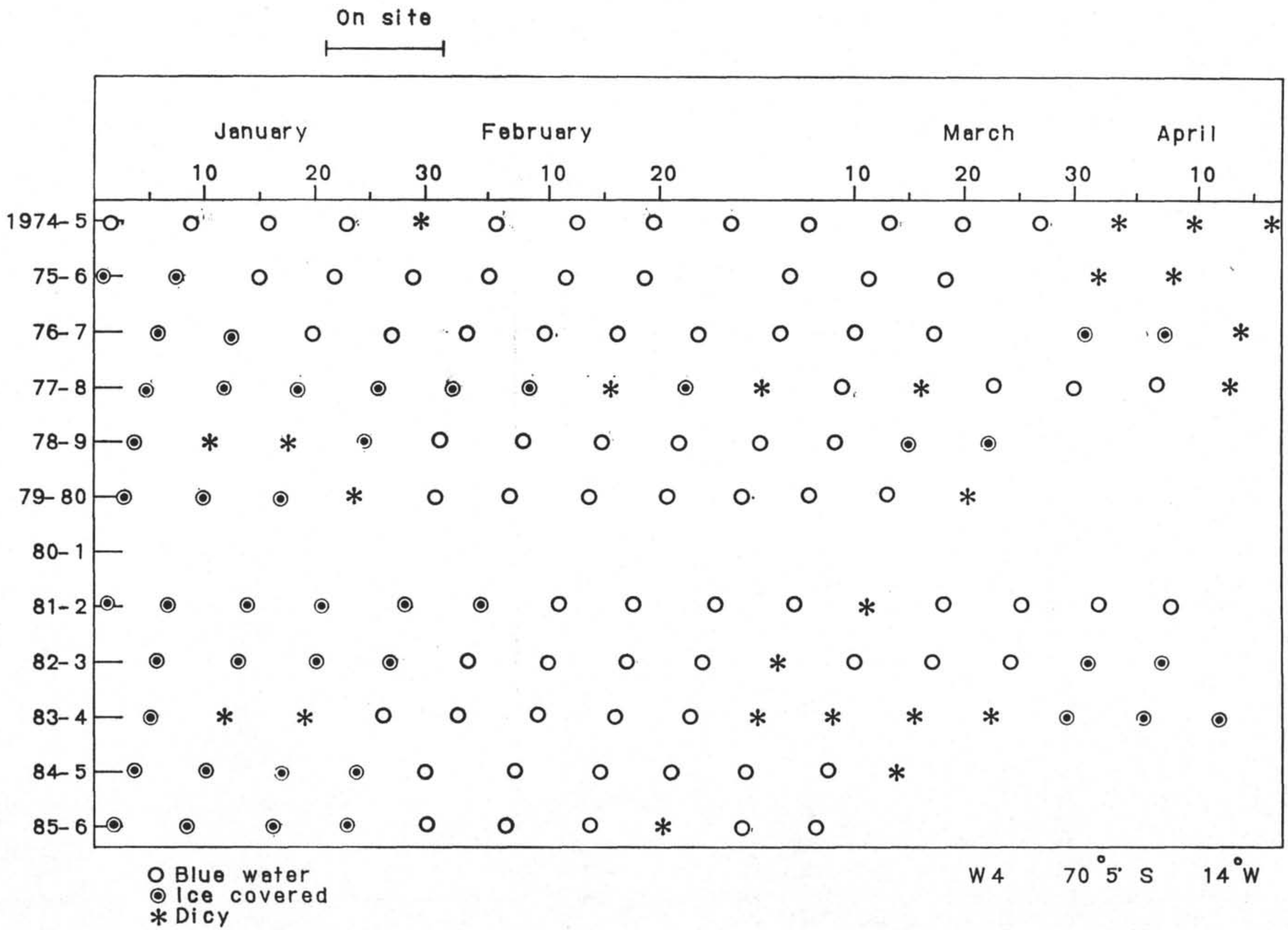

On site
January
February
March
April
10
20
30
10
20
10
20
30
10
1974-5
75-6
76-7
77-8
78-9
79-80
80-1
81-2
82-3
83-4
84-5
85-6
O Blue water
◉ Ice covered
* Dicy
W4
70°5' S
14°W

Table-8B-

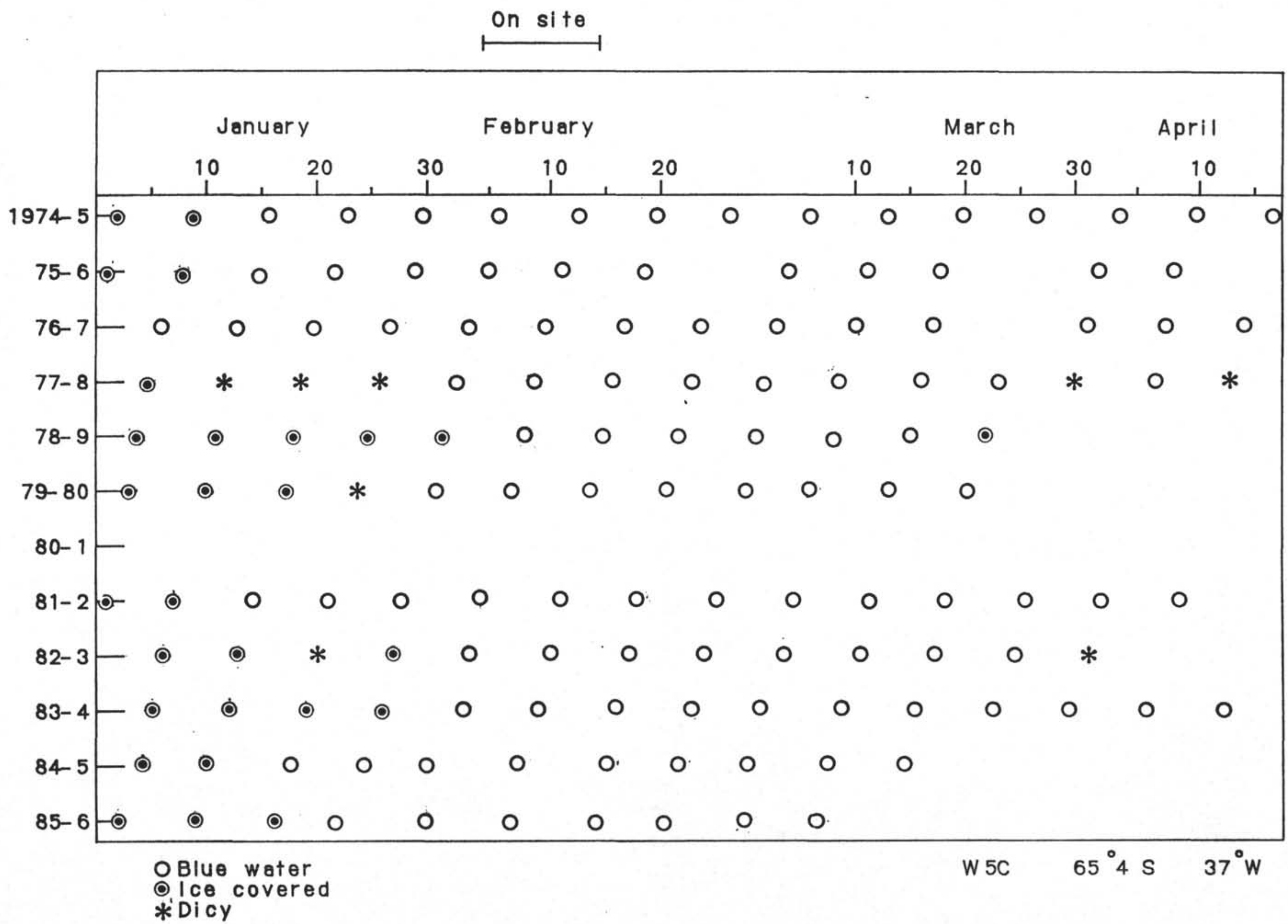

On site
January
February
March
April
10
20
30
10
20
10
20
30
10
1974-5
75-6
76-7
77-8
78-9
79-80
80-1
81-2
82-3
83-4
84-5
85-6
Blue water
Ice covered
Dicy
W 5C
65°4 S
37°W

Table -8C-

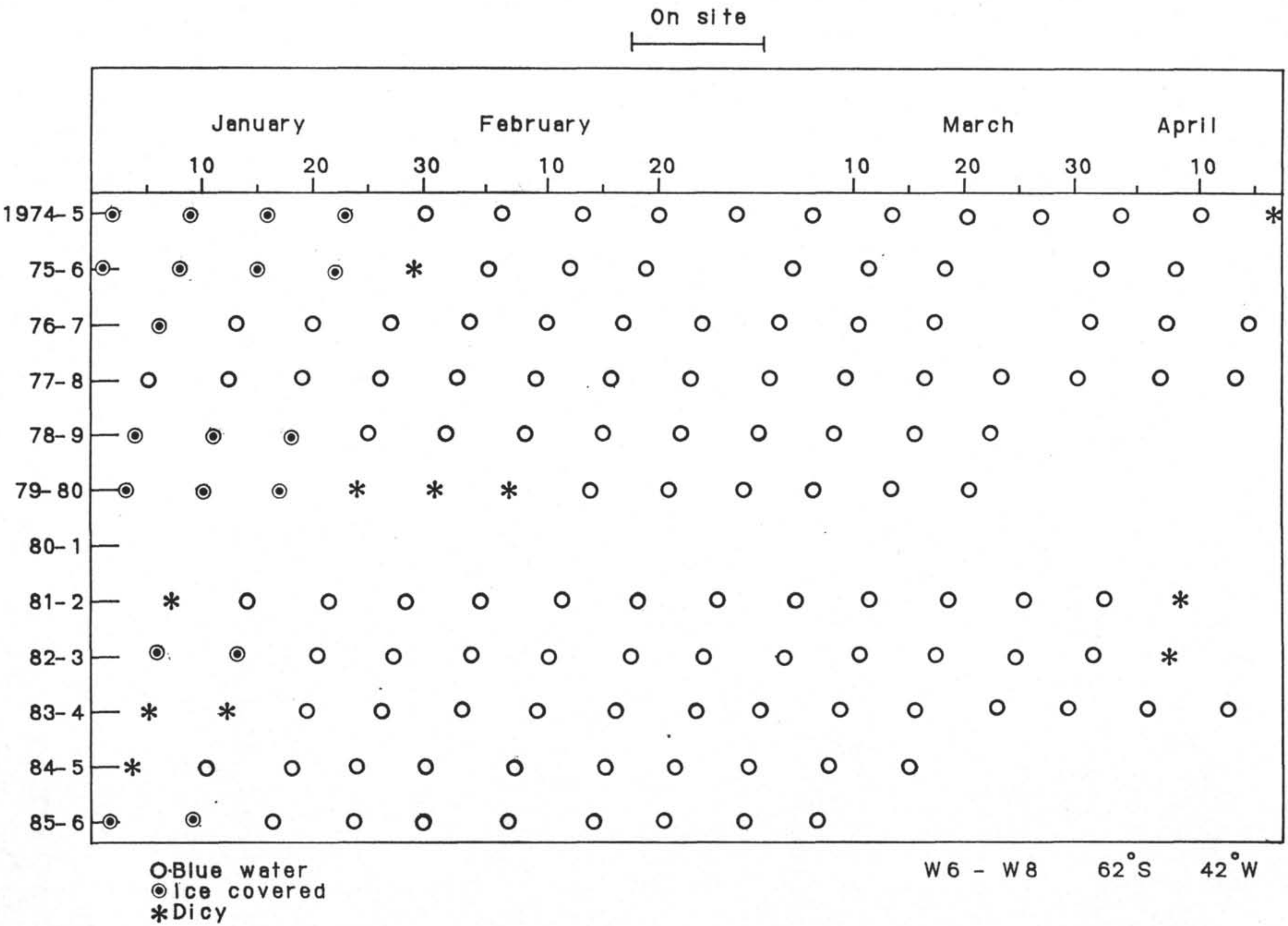
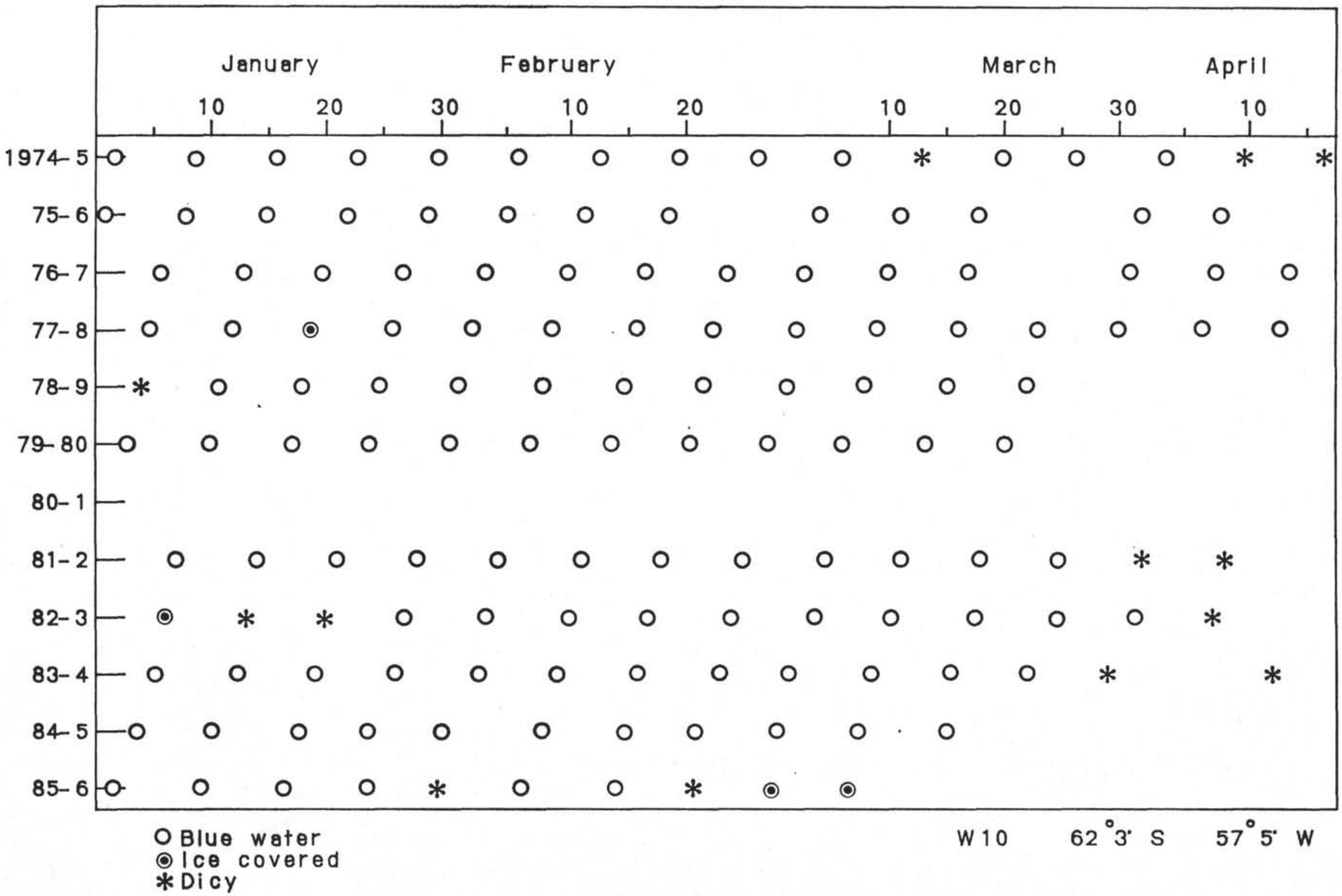

On site
January
February
March
April
10
20
30
10
20
10
20
30
10
1974-5
75-6
76-7
77-8
78-9
79-80
80-1
81-2
82-3
83-4
84-5
85-6
O Blue water
⊙ Ice covered
* Dicy
W6 - W8
62°S
42°W

Table -8D-



January
February
March
April
10
20
30
1974-5
75-6
76-7
77-8
78-9
79-80
80-1
81-2
82-3
83-4
84-5
85-6
O Blue water
◉ Ice covered
* Dicy
W10
62°3' S
57°5' W

Table -8E-

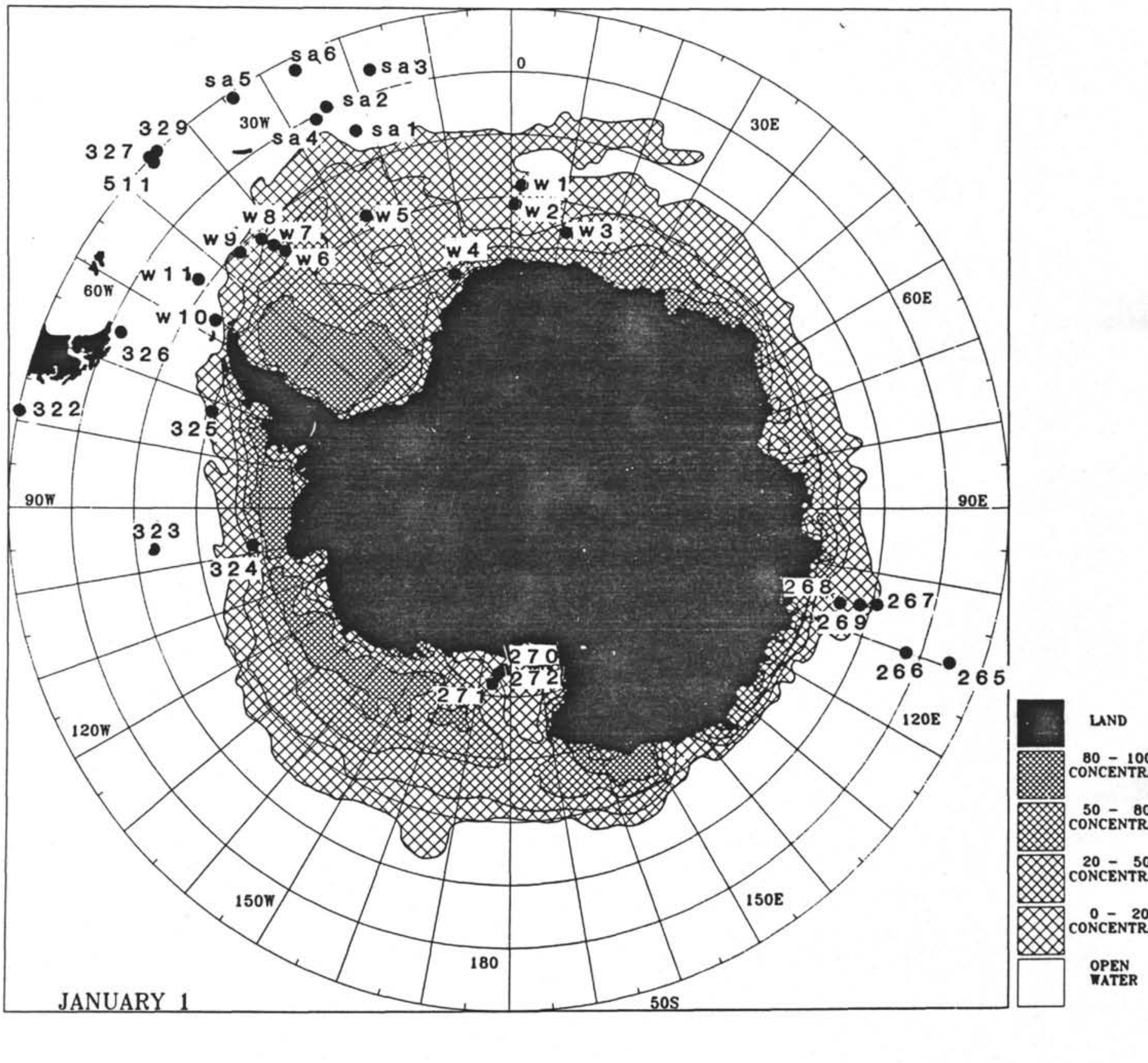
Table 9. Summary of the wave data in Antarctic Sea (compiled from U.S. Navy, 1970 and Defense Mapping Agency, 1985).

proposed drillsites	mean Hs 1) (m)	maximum Hs (m)	expected max. wave (m)	freq 1.5m 2) (%)	freq 3.6m 3) (%)
W-1,2,3	1.50	3.64	6.5	31	14
W-4	0.65	1.10	2.0	11	5
W-5	1.15	2.90	5.2	21	9
W-6,7,8,9	1.25	2.98	5.4	28	13
W-10,11	1.35	3.24	5.8	29	13
SA-1,2,4	1.37	4.24	7.6	31	20
SA-3	1.46	4.55	8.2	32	24
SA-5,6	1.52	4.85	8.7	44	27
SA-7,8,9	1.96	5.45	9.9	47	29

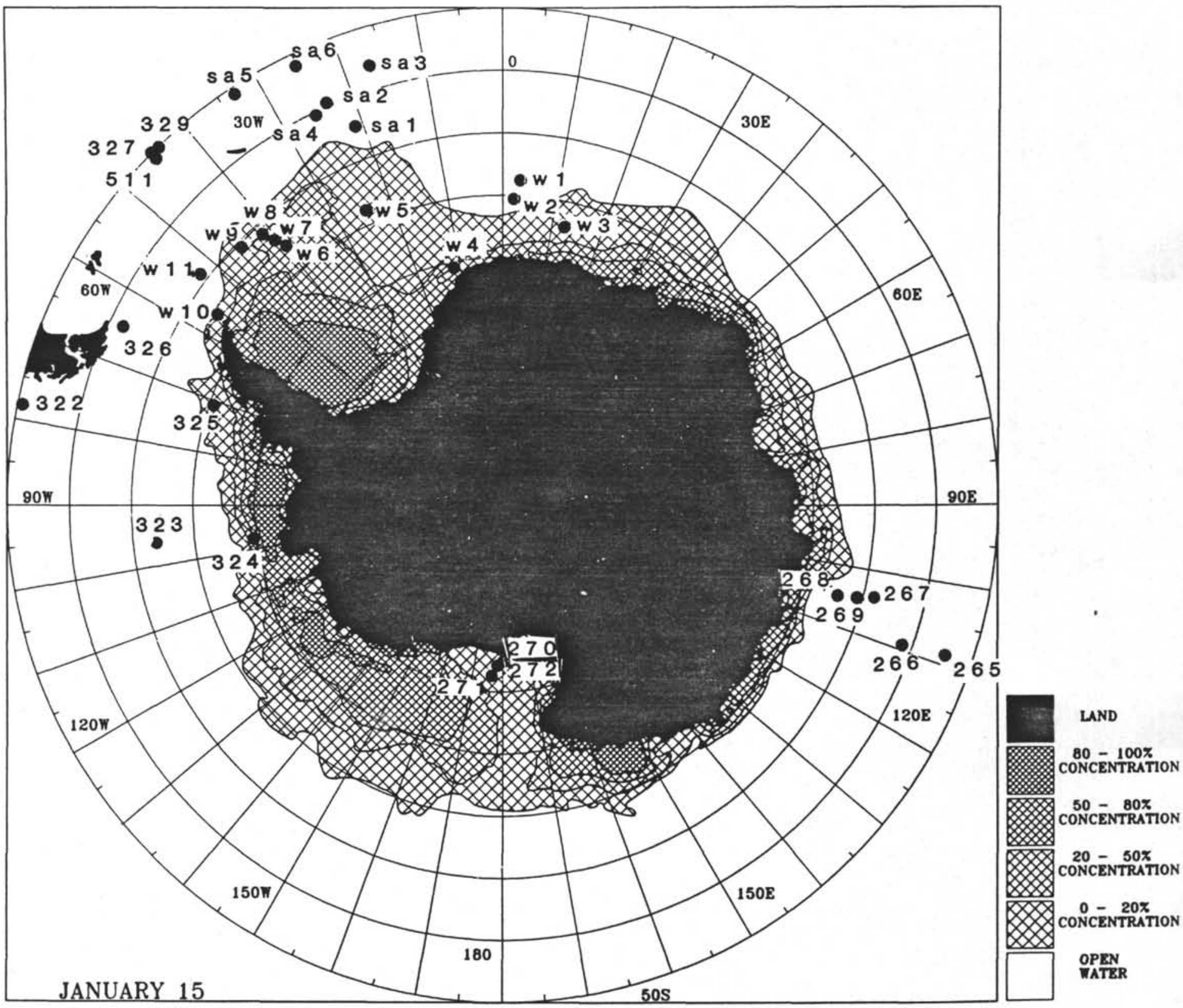
1) Hs; significant wave height, the average height of the highest third of all observed sea or swell waves.
2) Percentage frequency of wave height greater than 1.5 m.
3) Percentage frequency of wave height greater than 3.6 m.

APPENDIX FIGURES

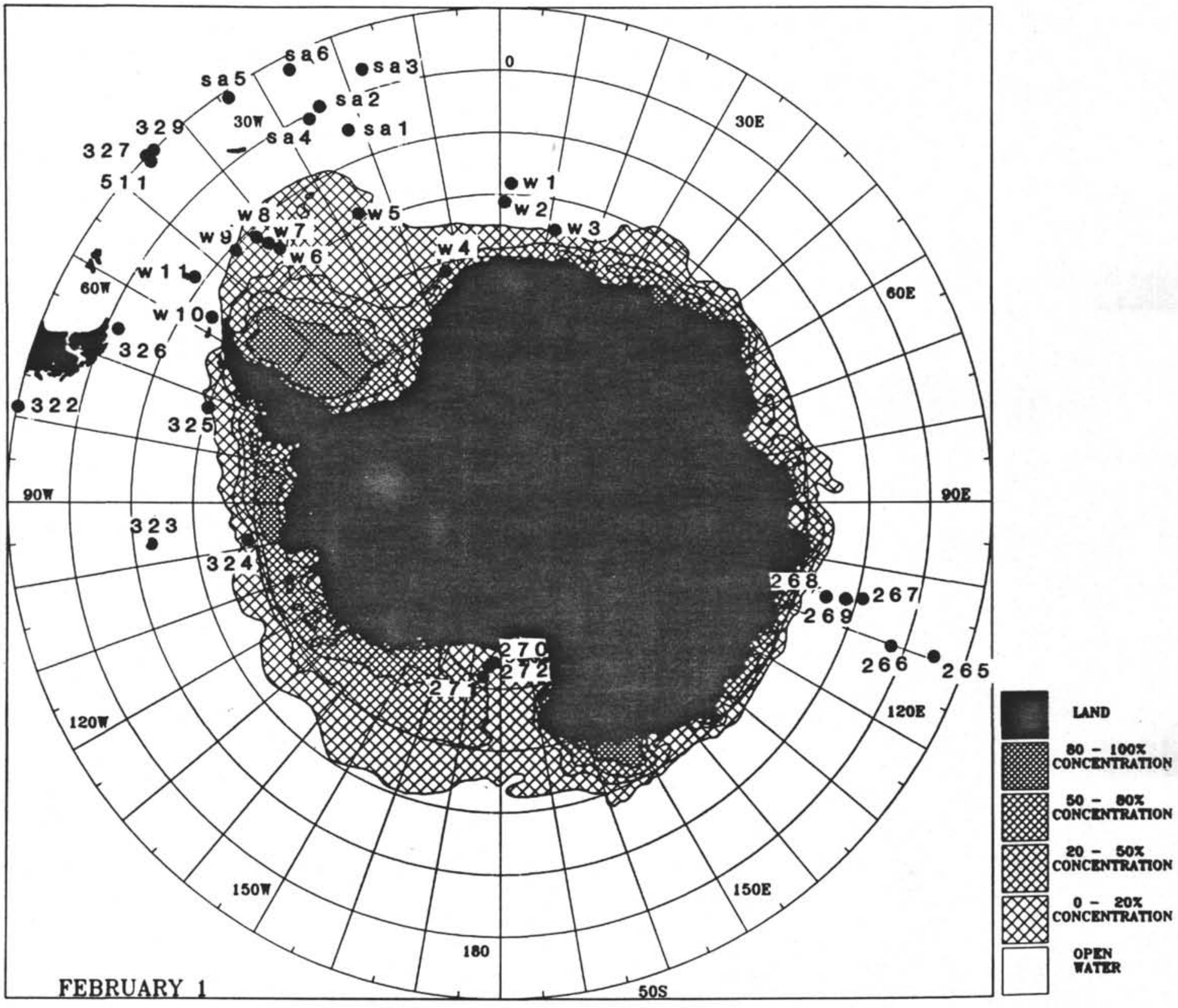
MEAN ICE CONCENTRATION



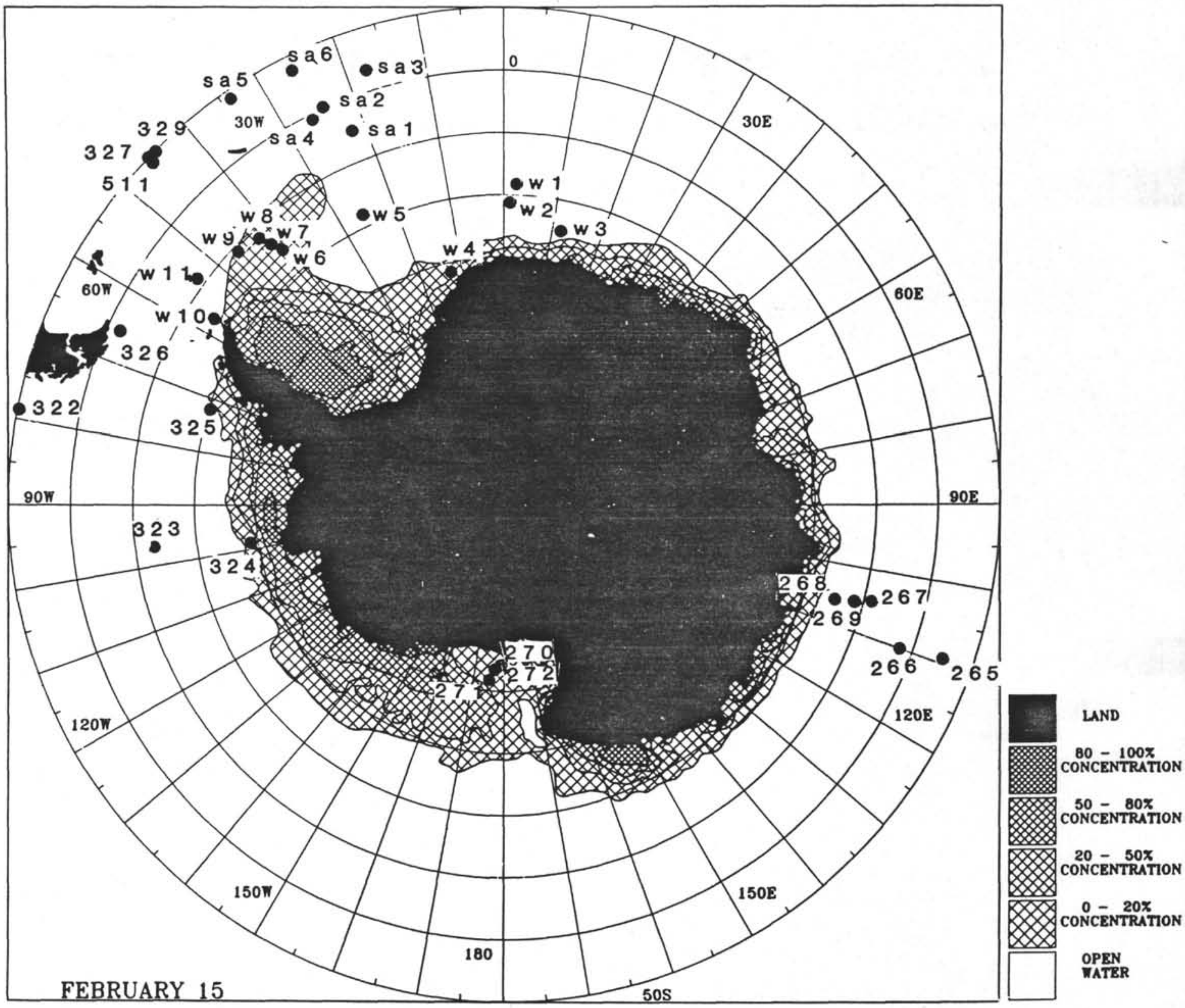
MEAN ICE CONCENTRATION



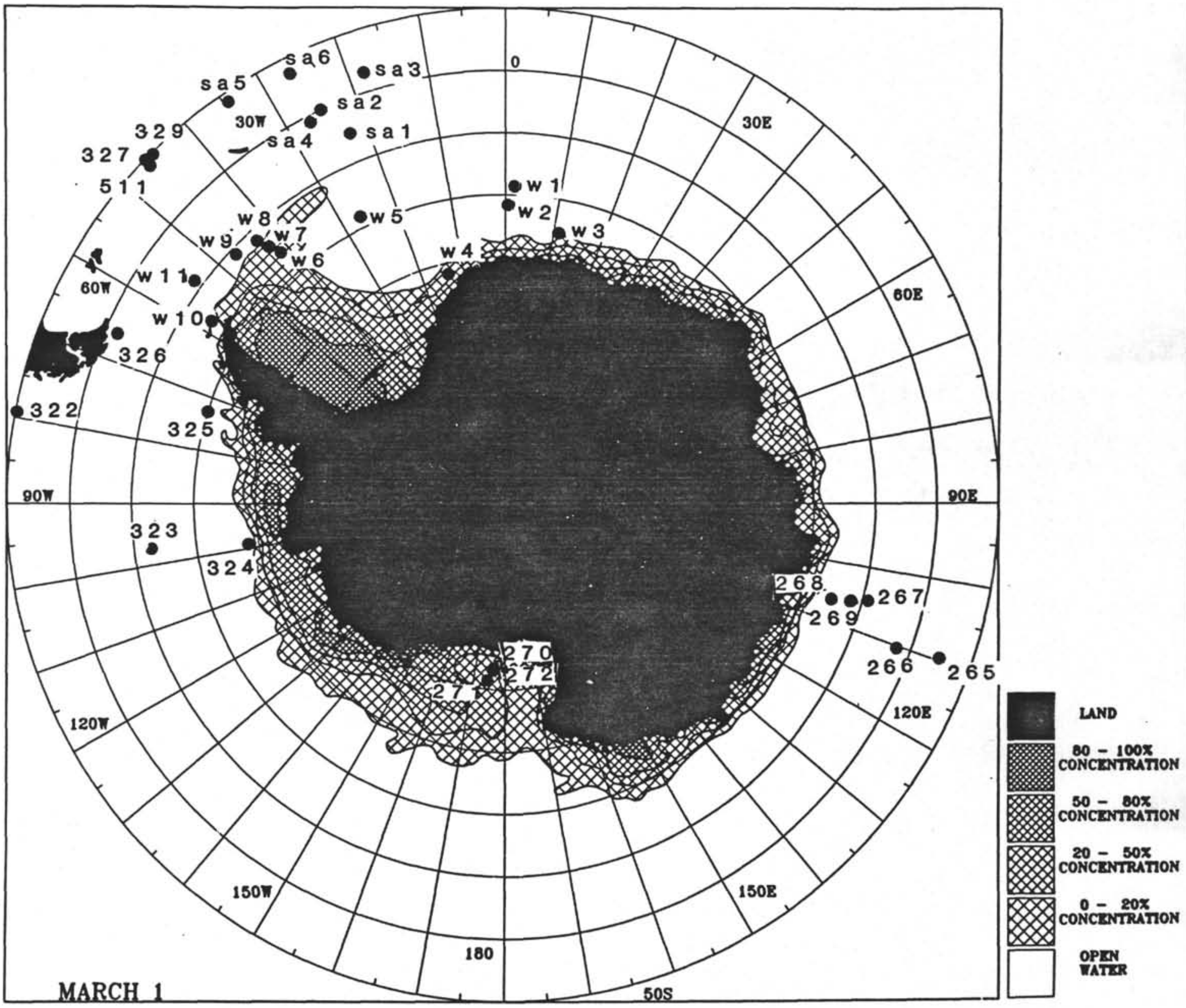
MEAN ICE CONCENTRATION



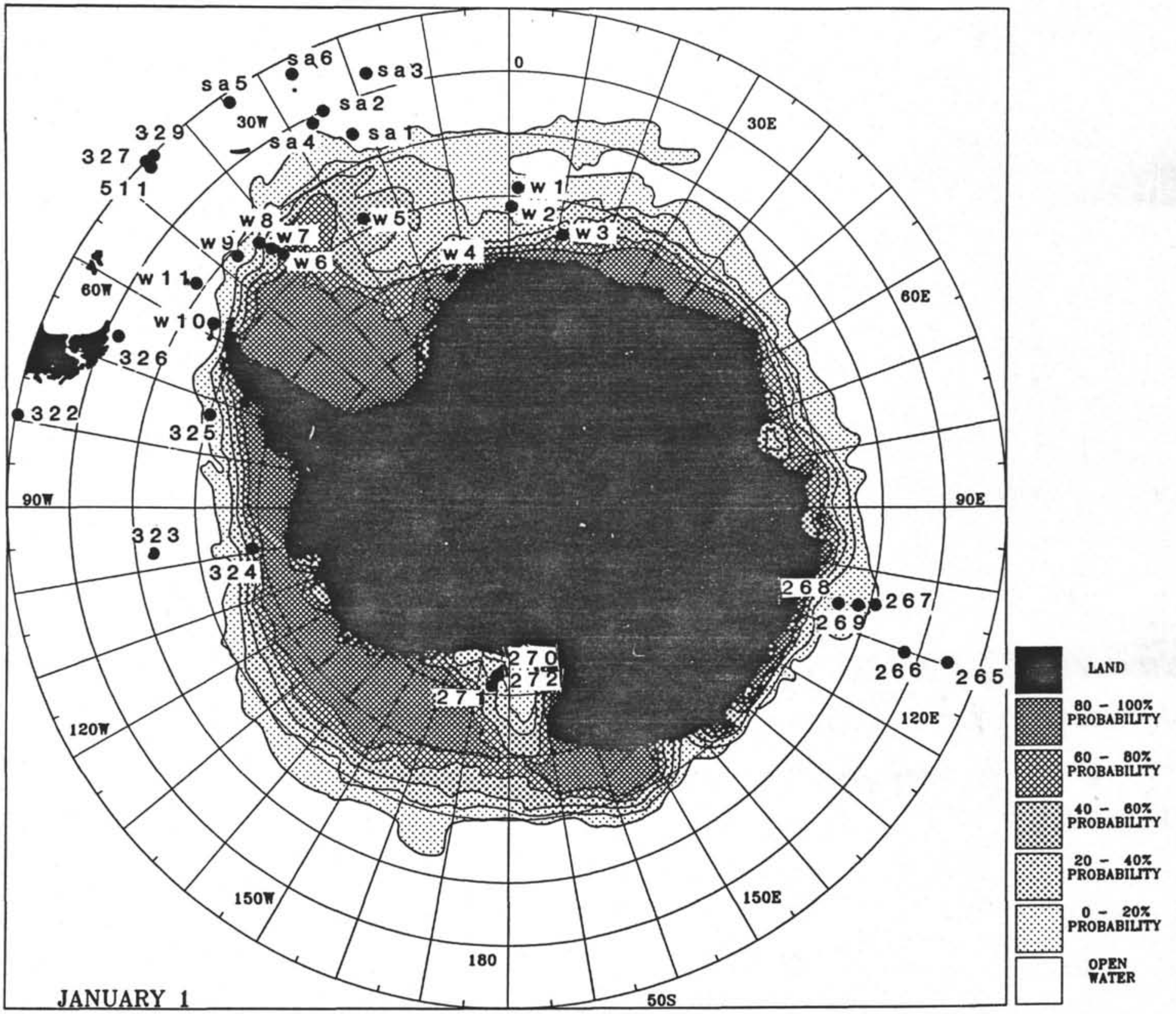
MEAN ICE CONCENTRATION



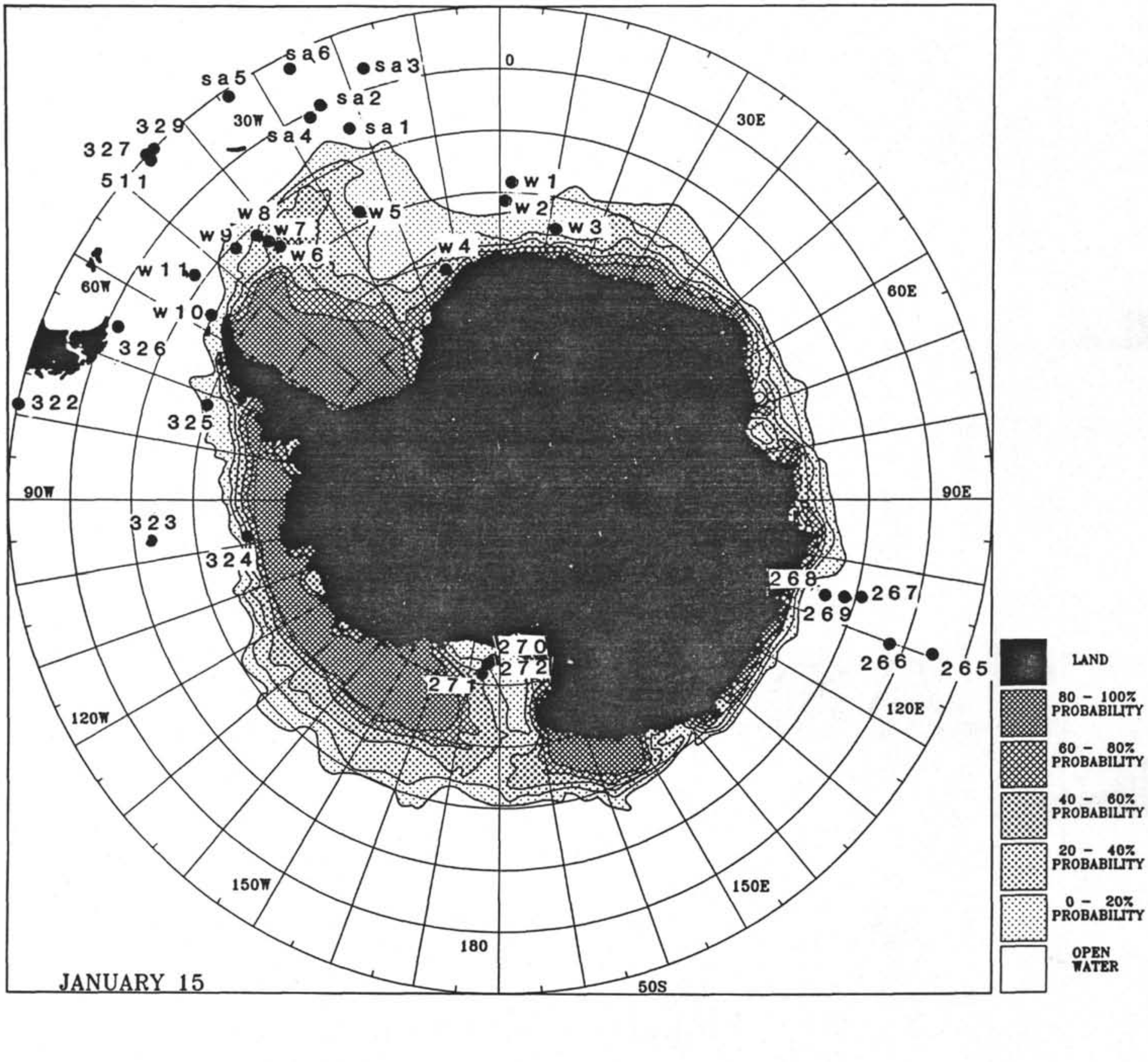
MEAN ICE CONCENTRATION



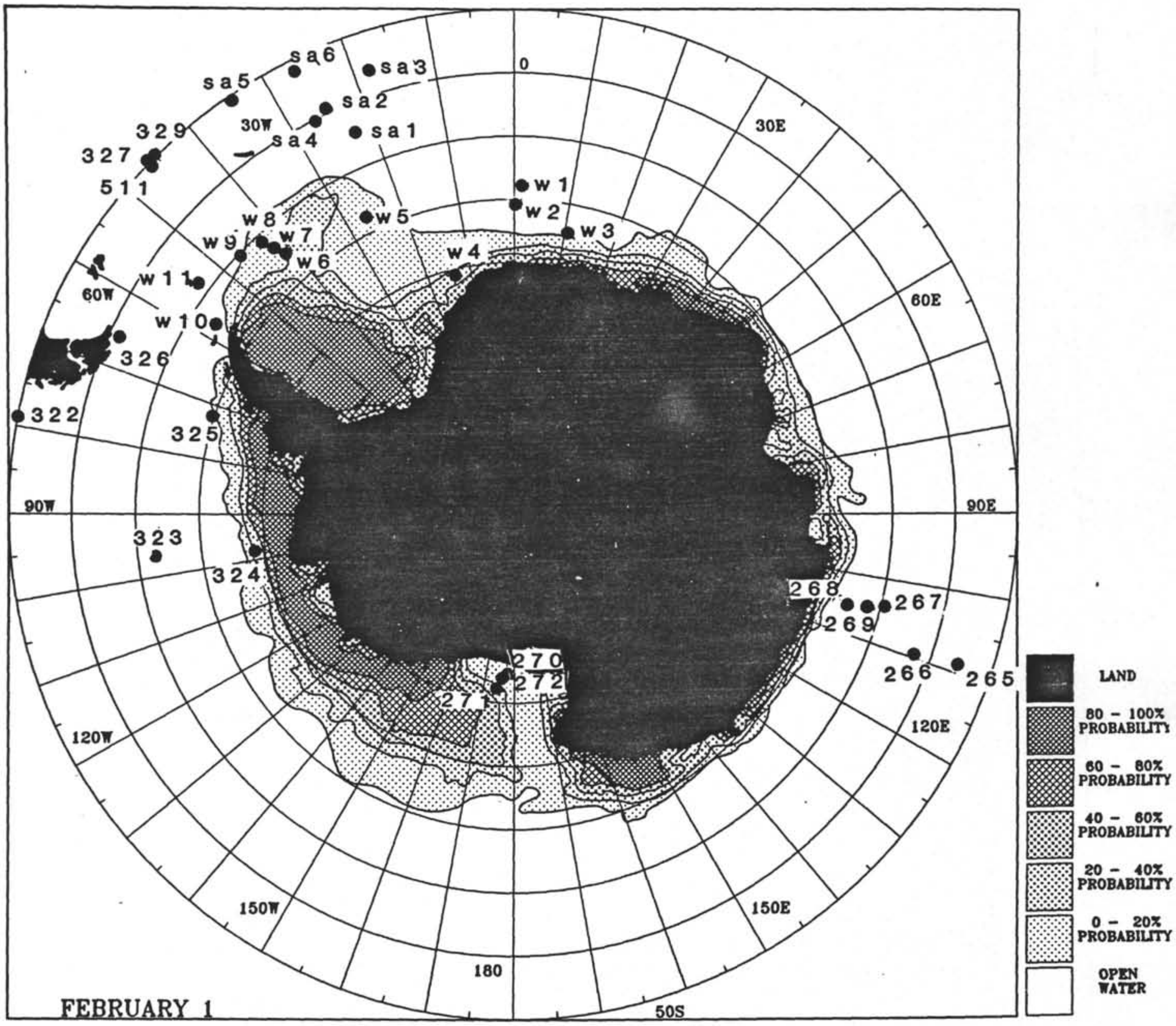
PERCENT PROBABILITY OF OCCURRENCE OF ANY ICE



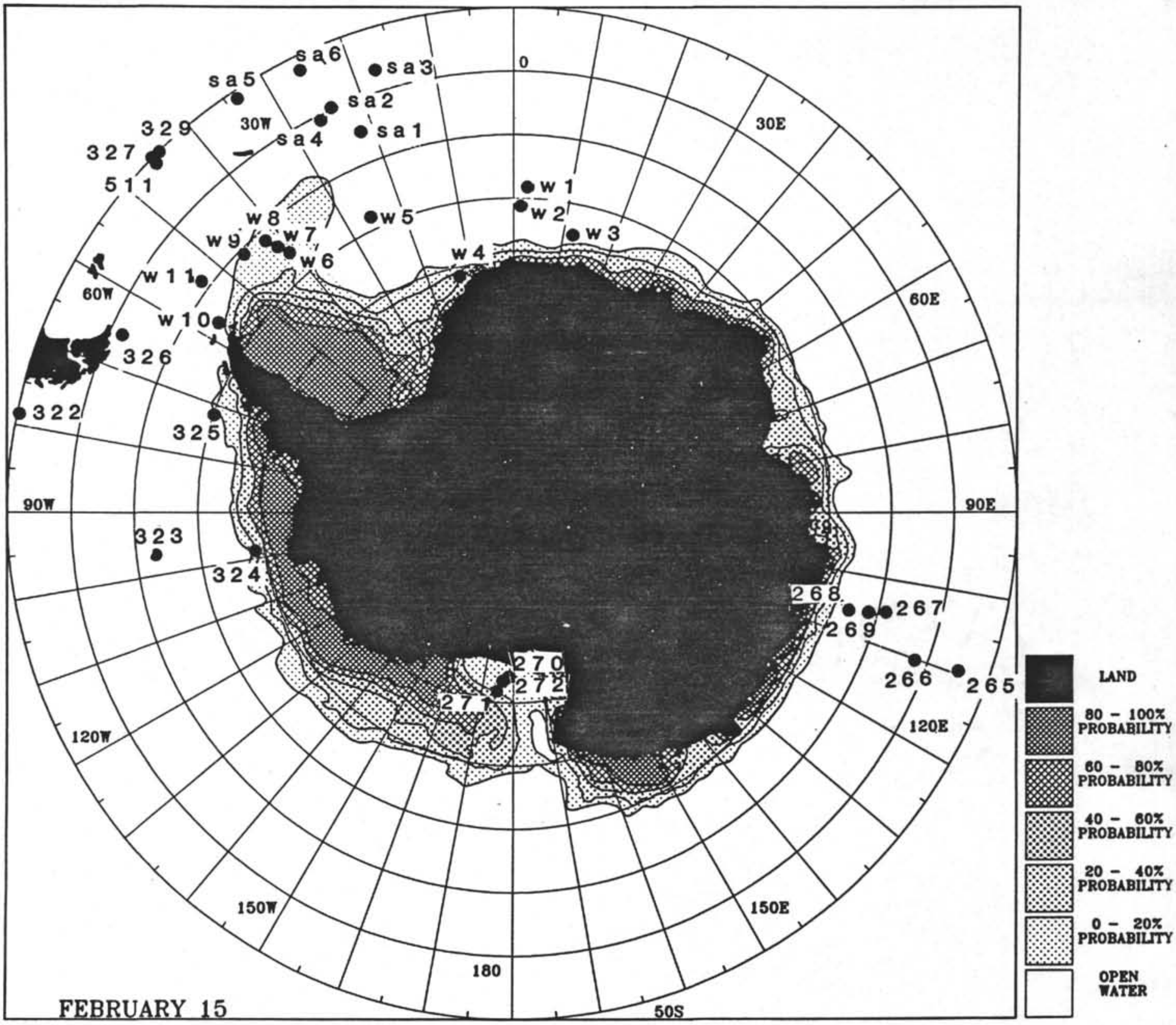
PERCENT PROBABILITY OF OCCURRENCE OF ANY ICE



PERCENT PROBABILITY OF OCCURRENCE OF ANY ICE



PERCENT PROBABILITY OF OCCURRENCE OF ANY ICE



PERCENT PROBABILITY OF OCCURRENCE OF ANY ICE