JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 93, NO. C4, PAGES 3583–3590, APRIL 15, 1988

Winter Observations of Iceberg Frequencies and Sizes in the South Atlantic Ocean

PETER WADHAMS

Scott Polar Research Institute, University of Cambridge, Cambridge, England

The numbers and apparent sizes of icebergs in the South Atlantic Ocean in midwinter were measured by radar and visually from F. S. *Polarstern* during the 1986 Winter Weddell Sea Project cruise. Results show that in a heavy sea (sea state 7–8), icebergs have to be at least 115 m in diameter to be detected at all and that detectability falls off severely for all bergs at ranges exceeding 8 n. mi. (15 km); that most bergs had diameters of less than 1 km with a preferred size of 400–500 m; and that a high density of icebergs in the latitude band 53°–56°S at longitude 19°–30°W contrasted with a virtual absence of bergs in the same latitude band at longitude 1°–9°E. The latter effect is ascribed to melt and wave-induced deterioration causing the disappearance of this iceberg population between the two sets of longitudes.

INTRODUCTION

Since 1981 a large data set of ship reports on iceberg frequencies and sizes in the Antarctic has been collected by the Norsk Polarinstitutt, Oslo [*Orheim*, 1985]. The data come almost entirely from summer voyages. Similarly, attempts which have been made to derive functional forms for the iceberg size distribution in the Antarctic [e.g., *Neshyba*, 1980] are also dependent on summer data. An opportunity to obtain midwinter data from part of the Antarctic arose during the 1986 Winter Weddell Sea Project cruise of F. S. *Polarstern*, organized by the *Alfred-Wegener-Institut für Polar- und Meeresforschung* [1986*a*, *b*] Bremerhaven (AWI). The measurements were made by *X* band radar and visually.

In this paper we report on the results of a transect made by the ship through the South Atlantic during July 1986, which brought her into iceberg-infested waters within the region 53°–56°S, 30°–19°W. The transect was terminated prematurely by the need for the ship to put into Cape Town to disembark a sick scientist. The ship then sailed south and crossed the same range of latitudes at the more easterly longitude of 1°–3°E, returning northward through longitudes 7°–9°E in September. We describe the observed geographical and size distributions of the icebergs and contrast their plentiful occurrence in the west with their virtual absence in the east. The data set also allows the problem of radar detectability to be addressed.

EQUIPMENT AND TECHNIQUE

The radar used was a Krupp Atlas 8500 *X* band (3 cm) radar, with a scanner mounted at an elevation of 42 m above sea level. According to *Burger* [1978] the range *R* km at which a target of elevation h_1 m may be detected by an *X* band radar with a scanner at elevation h_2 m is given by

$$R = 4.096\ [(h_1)^{1/2} + (h_2)^{1/2}] \quad (1)$$

This implies that high icebergs can be detected at a greater range than low icebergs. At extreme ranges, only the upper part of the iceberg freeboard is above the radar horizon so that the berg may have too low a radar cross section to be detected, especially if it is other than tabular in shape. The whole target can be detected out to a range given by $h_1 = 0$, i.e., $R = 14.33$ n. mi. (26.54 km) (we shall express ranges in nautical miles (with metric equivalent) henceforth since these were the units used on the radar). A target with an elevation of 30 m (a typical iceberg height) is detectable, in principle, out to a maximum distance of 26.4 n. mi. (48.9 km). At ranges between 14 n. mi. (26 km) and about 26 n. mi. (48 km) therefore we expect a progressive decline toward zero in the proportion of icebergs which are detected by the radar due to a progressive reduction in the cross section of the berg which lies above the radar horizon. In addition, the detectability will decline with increasing range due to weakening of the received echo.

At intervals of approximately 2 hours the radar screen was examined, and the range, bearing, and angular spread of every iceberg were noted; in the Atlas 8500 the range and bearing of targets selected by the operator are presented digitally to accuracies of 0.01 n. mi. (0.02 km) and 0.1°. Icebergs which seemed likely to pass close to the ship's track were then examined visually at their time of closest approach, and their subtended angle was measured at the waterline with a horizontal circle. Comparison with the radar range then gave an independent estimate of visual diameter.

ICEBERG DETECTABILITY

The validity of the radar technique depends on the effectiveness of the radar in detecting iceberg numbers and sizes. We identified the following factors as important.

First, icebergs very close to the ship tended to be lost in the sea clutter. A very heavy sea was running during the first transect, generated by winds of 20–30 m s^{-1} (Beaufort Force 9–11; sea state 7–8). This gave strong radar sea clutter at ranges out to 6–8 n. mi. (11–15 km), within which it was difficult to identify bergs. The technique adopted was to expand the range ring marker on the radar slowly from zero, stopping at every strong return and watching it to see if it persisted. Since the ship was also rolling and pitching in the sea, even a true iceberg tended to suffer from fading as the scanner orientation varied, but usually the image returned after a few scans, whereas a sea clutter spot did not return after fading. Such a procedure was necessarily slow (involving 30–40 min for a complete scan of the screen) and imperfect, so a number of icebergs may have escaped detection; 6–8 n. mi. (11–15 km) is normally within visual range, so one might hope that icebergs lost in radar sea clutter could be spotted by eye,

Paper number 8C0114.
0148-0227/88/008C-0114$05.00

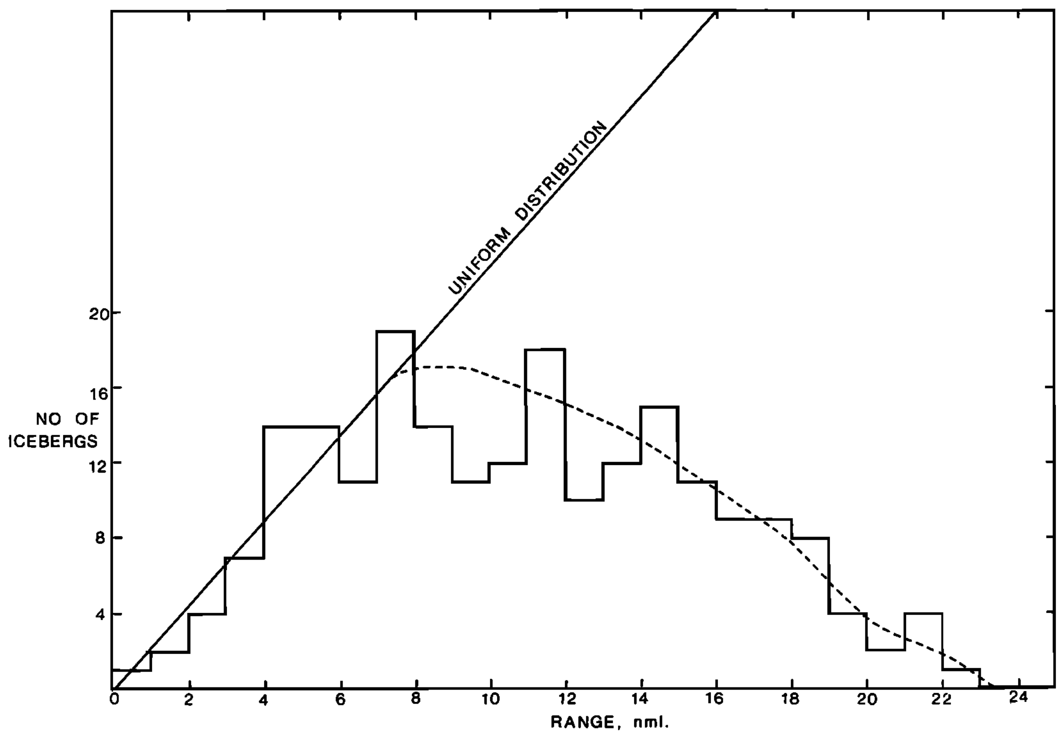

Fig. 1. Numbers of icebergs observed on radar as a function of range, in 1 n. mi. (1.85 km) increments. Dashed line is smoothed representation of the deviation from a linear trend.

but frequent snow squalls reduced visibility to a few meters for considerable lengths of time. We did find that in clear conditions an iceberg that was visible on radar at extreme ranges would often disappear into the clutter as it passed the ship within 1–2 n. mi. (2–4 km); further, a number of smaller bergy bits which were seen visually were not seen on radar at all. The use of radar in a heavy sea therefore sets a lower limit to the size of iceberg that may be detected. The smallest berg measured on radar during this experiment had an apparent diameter of 115 m, which is thus a measure of the smallest size that can be detected in sea state 7–8.

This result is in general agreement with conclusions from other direct measurements. There have been, however, only two serious studies, both carried out in more moderate seas: a 1945–1946 U.S. Coast Guard study in sea states up to 5 reviewed by *Williams* [1979], and a Decca study from 1966 discussed by *Williams* [1973].

Second, icebergs at extreme ranges, close to the radar horizon, were detected only if they gave unusually strong echoes. We tested this effect by plotting the distribution of ranges at which bergs were observed on the radar. Assuming a uniform spatial distribution of bergs, we would expect the number of bergs per unit range increment to increase linearly with range, out to a sharp cutoff at the horizon. In fact, the results (Figure 1) show that the efficiency of detection falls off with increasing range.

The data used to generate Figure 1 consisted of the 212 radar observations from the first transect, plotted in increments of 1 n. mi. (2 km). We see that out to a range of 7–8 n. mi. (13–15 km) the numbers per bin increase approximately linearly as expected, showing that within this range the detection rate is constant. It is not necessarily 100% because of the possibility of a low diameter cutoff which is independent of range. Beyond 8 n. mi. (15 km) the iceberg numbers fall off progressively from this linear trend, until beyond 23 n. mi. (43 km) no further icebergs are detected. The falloff is represented in a smoothed way by the dashed line in Figure 1, and the ratio of smoothed observed numbers to the numbers expected on a linear trend is plotted in Figure 2. This is then the percentage success in iceberg detection at a given range, assuming 100% success in the detection of nearby icebergs. The success rate begins to drop from 100% at 7 n. mi. (13 km); it drops below 50% at 12.6 n. mi. (23.3 km) and it reaches zero beyond 23 n. mi. (43 km). By weighting the curve of Figure 2 by area we obtain an overall detectability rate. If 24 n. mi. (44 km) is taken as the outer limit of observation (a typical range setting for radars), then the weighted detection rate is 35%; that is, only 35% of all icebergs present within 24 n. mi. (44 km) radius will be seen on the radar. If 12 n. mi. (22 km) is the limit, the weighted detection rate rises to 85%.

These results are of importance for the estimation of true

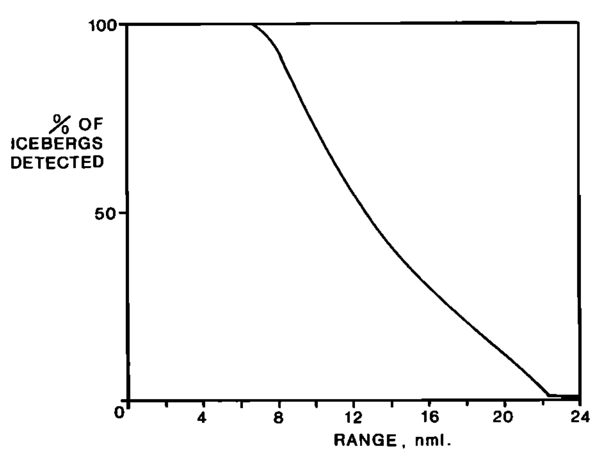

Fig. 2. Percentage success in iceberg detection by the radar, estimated from the results of Figure 1.

iceberg concentrations. An ambiguity exists in the instructions issued by the Norsk Polarinstitutt to ships contributing iceberg observations to them. The instructions ask the observer to make either a visual or a radar count. The radar range to be used is not specified, although the instructions include a guide for determining iceberg dimensions based on range and subtended angle out to a maximum range of 12 n. mi. (22 km). *Orheim* [1985], in his interpretation of the data, assumes that the radar horizon was used by all observers as their outer limit, and he takes this to be 21 n. mi. (39 km). Our results show that within this range, only 45% of icebergs present will be detected, so that estimates of concentration will be much too low. We recommend that 8 n. mi. (15 km) be taken as the outer limit for iceberg counts in order to give reliable concentration estimates.

Recently, *Musil* [1988] has shown that the results of Figure 2, as well as a similar distribution obtained in summer by *Nella Dan*, can be fitted quite well by a simple model based on the assumption that the iceberg surface diffusely scatters the radar signal, i.e., that roughness elements are large compared to the radar wavelength. This implies that the received echo power P is proportional to the exposed cross-sectional area of the iceberg (S^2, say, where S is a linear dimension) and to R^{-3}, i.e.,

$$P = K\, S^2/R^3 \qquad (2)$$

The use of observed threshold values for S (a minimum diameter S_0) and R (a range at which detectability begins to fall off) permits the shape of the detectability curve to be inferred.

As well as iceberg numbers being in error, the size estimates made from radar may also be inaccurate. Every target, even a point target, appears to have a finite width on radar due to the width of the radar beam. This gives a "zero error" to the measured iceberg width, which increases linearly with range. To offset this, we found that if an iceberg happened to have a tabular shape but with some low-freeboard structure near the waterline (e.g., an eroded terrace only a few meters above sea level), then only the tabular part was detected by the radar, giving an erroneously low diameter. In one instance, a berg of this type appeared to have a diameter of 169 m on radar but when observed visually had a waterline diameter of 501 m. Changes in apparent diameter due to change of aspect as the ship passes the berg can also be expected. In general, however, there was reasonable agreement between radar and visual diameters, which gives grounds for hope that the errors in size estimation are not too extreme. We found that of five bergs in which both radar and visual diameters could be measured (10 independent radar and six visual measurements) the mean diameter from radar was 479 m and visually 420 m, indicating only a modest size exaggeration by the radar.

Finally, we found that compact snow squalls in the distance often gave echoes which looked remarkably like those of large icebergs. Such squalls advect approximately with the wind speed and direction, so by examining the screen for several minutes and making repeated range measurements we were usually able to resolve any uncertainty in identification.

GEOGRAPHICAL DISTRIBUTION OF ICEBERGS

Figure 3 shows the track of *Polarstern* on her first transect of the South Atlantic. She sailed from Bahia Blanca, Argentina, on June 27, 1986, and crossed the Antarctic Polar Front at approximately 49°S, 40°W. Southward of this latitude she was continuously in Antarctic surface water with the temperature of the uppermost 200 m lying within the range −1.9° to +0.5°C, except for the single case of an eddy of 100 km diameter, some 200 km beyond the Polar Front, in which the surface water temperature rose above 4°C. The temperature structure was measured by XBT casts every 50 km and continuous monitoring of sea surface temperature by the ship. *Polarstern* had to change course after reaching a latitude of 55°40′S at 23°30′W and then sailed NE toward Cape Town, crossing the Antarctic Polar Front again at about 48°S, 7°W.

The radar screen was monitored from the day after our departure, but no iceberg was observed until 0700 UT on July 4 at 53°21′S, 30°22′W, when four icebergs appeared on the radar screen at the same time. From this point onward, icebergs were continuously on the radar, in increasing numbers up to our maximum latitude and then in decreasing numbers until the last iceberg disappeared from the screen at 0345 UT on July 6 at 53°34′S, 18°57′W. Thus the first remarkable observation was that there were no "stray" icebergs seen at low latitudes; the icebergs had a well-defined northern limit, south of which they were seen at moderate to high densities. This northern limit is not directly related to ocean temperature structure, since it lies some way south of the Antarctic Polar Front.

The two northern limits shown on Figure 3 differ in latitude by only 13 n. mi. (24 km), the easterly limit being farther south than the westerly, although the two points are separated zonally by 410 n. mi. (759 km). We conclude that the iceberg limit in this region runs approximately E-W, which suggests that the individual icebergs are also moving eastward, with some northerly component to account for losses at the lowest latitude. Such motion conforms roughly to the streamlines of near-surface water in the Weddell Gyre. This water emerges from the western Weddell Sea and moves ENE and then E across the South Atlantic [*Gordon et al.*, 1981], running parallel to, and southward of, the water of the Antarctic Circumpolar Current proper which has passed through Drake Passage. The motion also corresponds to the preferred trajectories of satellite-tracked icebergs at more southerly latitudes analyzed by *Tchernia and Jeannin* [1983, 1984] and to the inferred motion of the giant iceberg "Trolltunga" across the South Atlantic [*Vinje*, 1979]. A. Gordon (personal communication, 1987) has commented that some of the bergs seen by him in this region may have originated from the west side of the Antarctic Peninsula, so the Weddell Sea is not necessarily the sole source of the berg population.

After leaving Cape Town, *Polarstern* proceeded southward at a more easterly longitude but did not encounter any icebergs until a single large tabular berg of 1564 m diameter (mean of eight radar and two visual measurements) was observed less than 10 n. mi. (19 km) from Bouvet Island at 54°15′S, 3°24′E, on July 16. Three small 50-m bergs were also observed less than 1 km from the island but were assumed to have calved from the island's ice cap. No more bergs were observed north of 56°; the next sighting was of a berg of 935 m diameter (mean of two measurements) at 56°13′S, 0°52′E, and a berg of 416 m diameter (mean of two measurements) at 56°24′S, 1°00′E. Again there was a gap until 58°20′S, 0°50′W, where two more bergs were seen, and from this point onward, icebergs were continuously visible on radar; the ice edge was crossed soon afterward at 58°46′S. Iceberg observations from the pack ice zone will be discussed in a later paper. Summarizing, we found on this transect that only a single berg was seen in the latitude range in which bergs were continuously

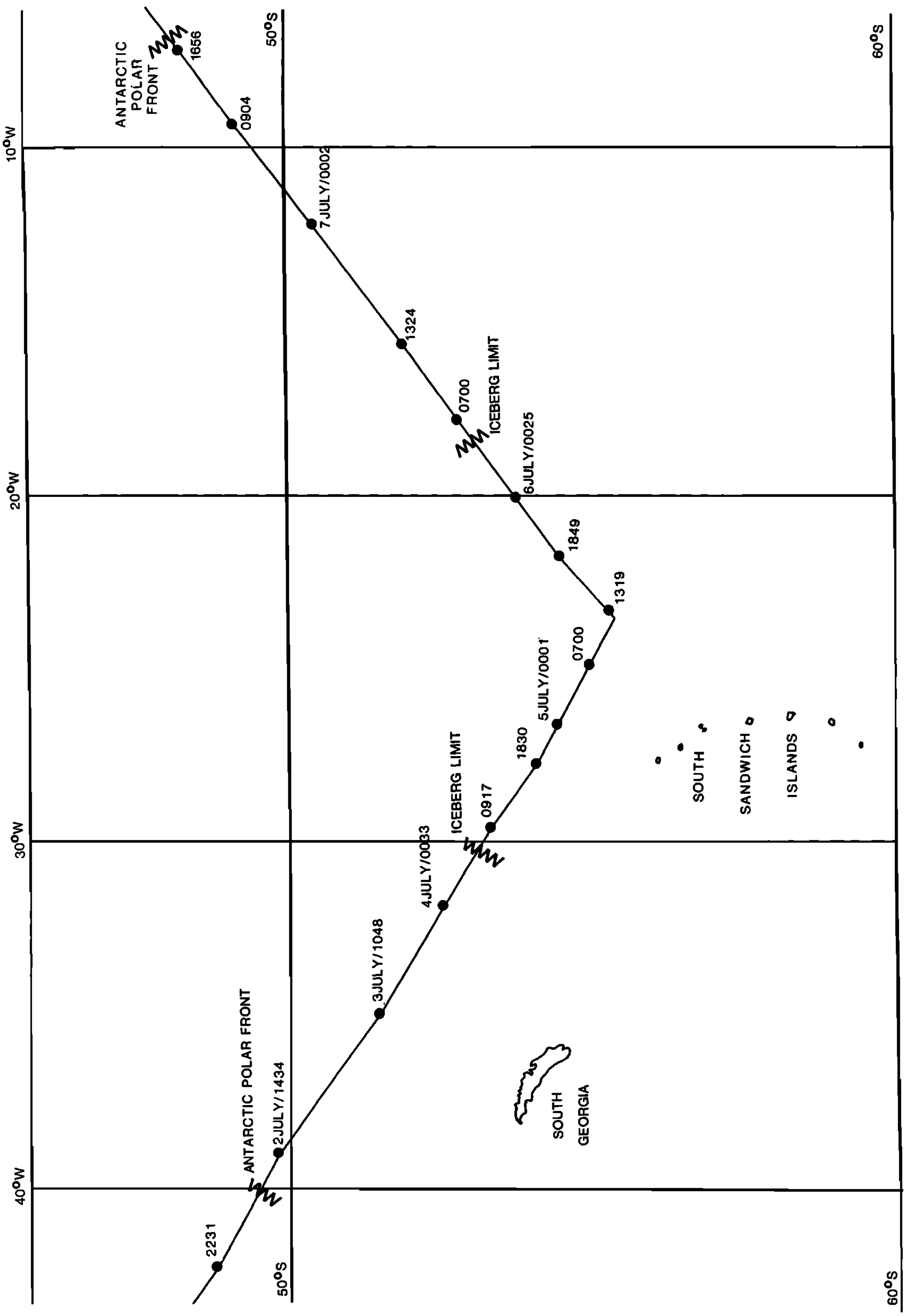

Fig. 3. Track of *Polarstern* on first transect through South Atlantic, showing region in which icebergs were observed.

TABLE 1. Iceberg Observations During First Transect With Bergs Assigned to Size Categories

			Number of All Icebergs at Diameter of						Number of Bergs < 8 n. mi. Away at Diameter of					
Time, UT	Latitude S	Longitude W	Total	0–50 m	50–200 m	200–500 m	500–1000 m	1000 + m	Total	0–50 m	50–200 m	200–500 m	500–1000 m	1000 + m
							July 4, 1986							
1020*	53°39′3	29°37′3	4	0	0	1	3	0	0	0	0	0	0	0
1046	53°41′5	29°31′1	3	0	0	1	1	1	1	0	0	0	0	1
1102	53°42′8	29°26′7	3	0	0	1	2	0	2	0	0	1	1	0
1156	53°47′2	29°13′2	4	0	0	1	3	0	3	0	0	1	2	0
1308*	53°52′9	28°55′6	5	0	0	2	3	0	3	0	0	1	2	0
1404	53°58′4	28°42′8	6	0	1	3	2	0	2	0	1	1	0	0
1434	54°01′4	28°36′0	5	0	0	4	1	0	3	0	0	3	0	0
1552*	54°07′7	28°17′8	7	0	0	5	2	0	1	0	0	0	1	0
1556	54°08′0	28°17′0	9	0	0	8	1	0	2	0	0	2	0	0
1649	54°13′3	28°05′4	7	0	1	6	0	0	1	0	0	1	0	0
1805	54°19′9	27°50′4	10	0	1	5	4	0	2	1	0	1	1	0
1830*	54°21′6	27°46′3	18	0	0	4	13	1	3	0	0	2	1	0
2130*	54°33′0	27°03′3	22	0	1	12	8	1	8	0	1	6	1	0
							July 5, 1986							
0001*	54°44′1	26°36′3	16	0	3	9	3	1	3	0	2	1	0	0
0312*	54°56′9	25′49′5	21	0	0	15	6	0	8	0	0	7	1	0
0700*	55°13′3	24°53′3	17	0	2	11	4	0	5	0	2	2	1	0
1007*	55′27′7	24°09′9	22	0	3	15	4	0	13	0	3	9	1	0
1319*	55°34′9	23°22′4	13	1	1	7	4	0	5	1	1	2	1	0
							Turn							
1455*	55°18′7	22°59′0	11	0	1	7	2	1	5	0	1	4	0	0
1649*	55°05′2	22°27′6	6	0	0	5	1	9	3	0	0	3	0	0
1849*	54°48′0	21°48′8	4	0	0	3	1	0	3	0	0	2	1	0
2221*	54°19′9	20°44′7	5	0	0	5	0	0	3	0	0	3	0	0
							July 6, 1986							
0025*	54°02′8	20°01′6	2	0	0	0	1	1	0	0	0	0	0	0

Eight nautical miles equal 14.8 km.
*Independent observations chosen for the estimation of concentration.

visible farther to the west and that a significant density of icebergs was not encountered until a latitude of 58°20′S was reached, no less than 300 n. mi. (556 km) farther south than the limit in the 19°–30°W longitude band.

The third and final transect through this range of latitudes was carried out on September 7–10 during *Polarstern*'s return northward. The most northerly icebergs encountered were a pair of diameter 182 m (means of four radar and two visual fixes) and 668 m, seen at 56°30′S, 7°15′E and 56°24′S, 7°12′E, respectively. These were south of the sea ice limit (which had advanced to 55°55′S) in a zone of pancake ice. The next most northerly bergs were at 57°30′S, 7°16′E. It is tempting to identify the northernmost pair with the two bergs seen just south of 56° on the second transect. To have reached their September position, they would have to have traveled 210 n. mi. (389 km) on a course very slightly south of due east. By comparison, an Argos Waverider satellite-tracked buoy (built by the Institute of Oceanographic Sciences) was launched by the Scott Polar Research Institute (SPRI) group at 57°00′S, 0°15′E on July 17 in open water and was recovered at 55°50′S, 7°9′E on September 7, a journey of 228 n. mi. (422 km) eastward (with a 70 n. mi. (130 km) northward component) in approximately the same time interval. The SPRI buoy was drogued at a depth of 100 m and so was likely to move mainly with the near-surface currents in much the same way as an iceberg (except for the last few days, when the drogue broke off and most of the northward movement occurred). It therefore seems feasible that these two icebergs were the bergs seen at about 56°20′S in July.

Thus the two icebergs, the drogued Argos buoy, and a farther berg tracked by *Vinje* [1979] from Bouvet Island, all appear to move almost due eastward in the longitude range 0°–10°E. In addition, we have seen that the northern limit of frequent icebergs in these longitudes, while lying about 50 n. mi. (93 km) farther north in September than in July, is still more than 250 n. mi. (463 km) farther south than in the longitude range 20°–30°W. There are two possible hypotheses to account for this. First, the population of bergs seen at 20°–30°W may have completely disappeared by 1°E through melt and weathering. Second, the icebergs may have turned southward between 20°W and 1°E and moved about 300 n. mi. (556 km) southward while drifting less than 700 n. mi. (1296 km) eastward. The latter hypothesis appears unlikely in view of the fact that no iceberg has ever been observed following this sort of drift pattern. *Gordon et al.* [1978] showed that the geostrophic current at the sea surface relative to the 1000-dbar level does turn sharply southward in this region, but the southward component is all accomplished in the 30°–20°W zone and is followed by a NE trend, restoring the streamlines to the same latitude by 0°E. Further, the iceberg motion is likely to be also a function of the wind-driven circulation, and *Gordon et al.* [1981, Figure 3] show the Sverdrup transport to be almost perfectly zonal within the region 53°–56°S, 30°W–10°E. We conclude that the population of bergs seen in the west in such a deteriorated state did actually disappear between the longitudes of 20°W and 1°E. The voyage of 690 n. mi. (1278 km) between these longitudes would take a berg approximately 5–6 months if it drifted at the same speed as

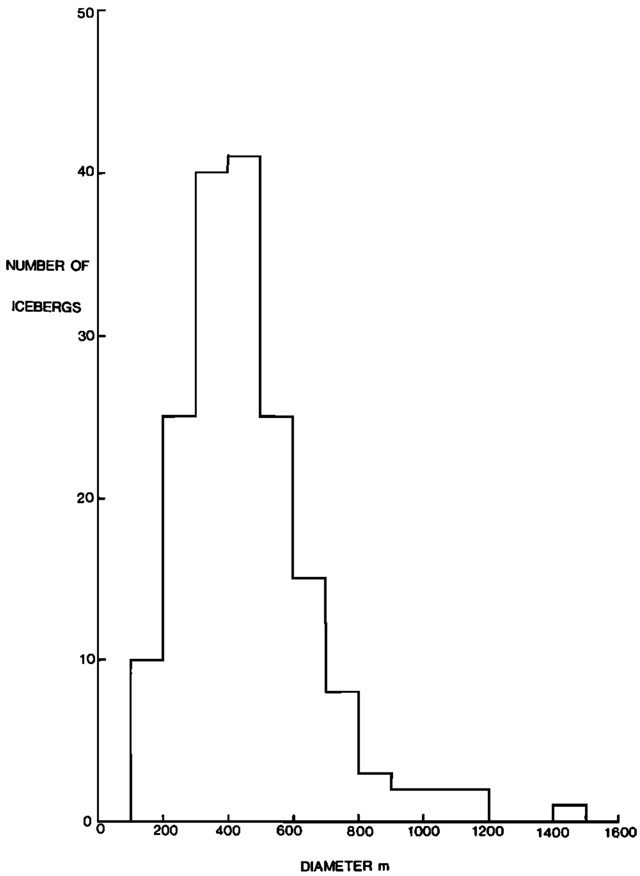

Fig. 4. Distribution of iceberg diameters, in 100-m increments.

the SPRI buoy. This period is thus an upper limit for the survival time of weathered bergs of initial diameter less than 1 km (see below) in the open South Atlantic south of the Convergence in midwinter.

A survival time of 6 months or less for bergs of typical diameter 400 m suggests a sidewall attenuation rate of more than 1 m d^{-1} if melt is assumed to be the main decay process. This is much greater than the expected melt rate in such cold waters; for example, *Weeks and Mellor* [1978] estimated a melt rate of 0.12 m d^{-1}/°C of mean water temperature, for a berg undergoing a relative drift of 1 knot (1.85 km/h). The implication is that the decay rate is greatly enhanced by fracturing; each calving event exposes two new sidewalls to melt.

ICEBERG CONCENTRATION

Table 1 shows all the observations made during the first transect, using the standard Norsk Polarinstitutt format to ascribe them to various size ranges. Table 1 also shows the numbers seen at less than 8 n. mi. (15 km) range, and we use this second part of the table to estimate iceberg concentrations. A set of independent observations was chosen for the estimation (shown by asterisks in Table 1), "independent" implying that the ship sailed more than 16 n. mi. (30 km) between observations. During the first part of the experiment the observations were very closely spaced because an attempt was made to identify and track every iceberg in the swathe traced out by the ship, so that not all observations were independent. The ship's speed was 8–9 knots (15–17 km/h) before her turn and 14–15 knots (26–28 km/h) after the turn when she was sailing toward Cape Town.

The selected observations give a total of 63 icebergs at less than 8 n. mi. (15 km) range in 15 independent observations. This implies a mean density of one iceberg per 47.9 (n. mi.)^2, i.e., one iceberg per 164 km^2. This figure is in good agreement with estimates of density in other iceberg-rich regions of the open southern ocean made by examination of Norsk Polarinstitutt maps. Table 1 suggests that there is a gradation of concentration, with the density increasing from north to south, but the data are too sparse to make numerical estimates other than a single overall average.

ICEBERG SIZES

A total of 174 separate icebergs had their apparent diameters measured during the first transect. Figure 4 shows the distribution of measured diameters, in 100-m increments. Where a berg had multiple measurements made of its size by radar and/or visually, a mean value is used. It can be seen that the modal diameter lies in the range 400–500 m; the mean diameter is 459 m and the median diameter 418 m.

Neshyba [1980] suggested that the distribution of iceberg diameters in a given region can be fitted by a Rayleigh distribution. The shape of the distribution in Figure 4 is not a good fit to a Rayleigh. It does, however, provide a good fit to a two-parameter lognormal distribution through much of its range. A random variable X is said to have a lognormal distribution if the random variable $Z = \ln X$ is normally distributed [*Aitchison and Brown*, 1957]. If the mean and standard deviation of Z are μ and σ, then the probability density function of X is

$$f(x) = \frac{1}{x\sigma(2\pi)^{1/2}} \exp\left[-(\ln x - \mu)^2/2\sigma^2\right] \tag{3}$$

The slightly more complex three-parameter lognormal involves replacing X by $(X - \theta)$, where θ is a threshold value. Figure 5 shows a graphical test of the fit of the iceberg diameters to a lognormal. Here logarithmic probability paper is used, in which the cumulative probability

$$L(x) = \int_0^x f(x)\, dx \tag{4}$$

is plotted as its equivalent normal deviate against $\ln x$ (x is the diameter in meters). The data provide a good fit in the range of probabilities 8–99.5%, that is, most of the range of the distribution excluding only the smallest diameters. The best values are $\mu = 6.04$, $\sigma = 0.413$.

The lognormal distribution is commonly encountered in nature, fitting such diverse variables as incomes, age at first marriage, particle sizes in a soil, and numbers of words in sentences by a given author. In glaciology it has been applied to the spacings between pressure ridges in sea ice fields [*Wadhams and Davy*, 1986]. Physically, the variables which fit a lognormal exhibit a central tendency which is rather weak in relation to the randomising factors present; the variable is also constrained to take positive values (or values above the threshold) always, thus preventing the distribution from being purely normal.

A notable feature of this distribution is the rarity of icebergs with diameters exceeding 1000 m, despite the fact that many very large icebergs occur near calving sites and within the pack. Icebergs in the open sea lose mass through melt, mechanical wave erosion, and sidewall fracture leading to the

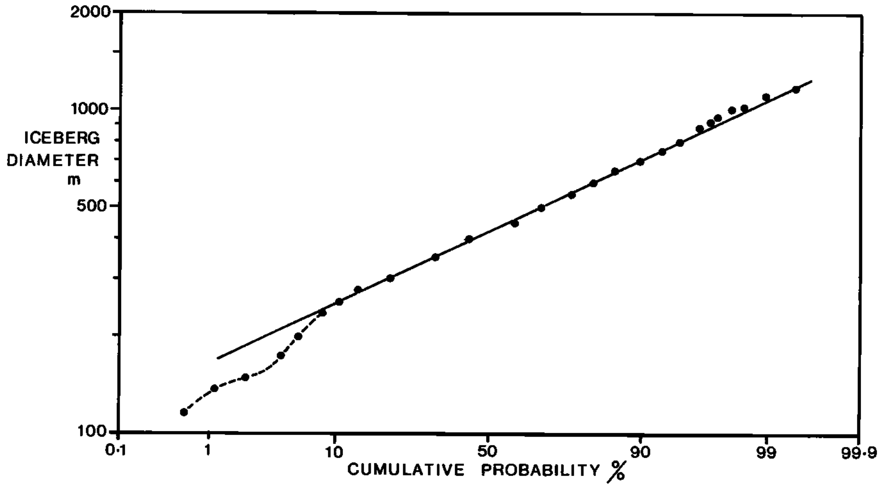

Fig. 5. Fit of iceberg diameter data to a lognormal distribution, using logarithmic probability paper.

calving of growlers, but a major mechanism which radically reduces the size of large tabular bergs is wave-induced flexural failure. It was predicted by *Goodman et al.*[1980] that icebergs flexing under swell action should fracture in a heavy sea if their lateral dimension exceeds about 1–2 km, and wave-induced flexure in tabular icebergs has since been observed in direct experiments [*Kristensen et al.*, 1982; *Wadhams et al.*, 1983]. We can assume that in the extremely heavy seas of the southern ocean at this time of year any large tabular bergs will have fractured into fragments each of which is less than about 1 km in diameter. Further deterioration was clearly in progress in the bergs that were observed visually (e.g., Figure 6): waves were breaking against their sides, often flinging spray over the top surface of the berg; the smaller bergs were visibly wallowing in the sea, with waves riding up over the entire height of their windward faces which were eroded to reveal translucent blue ice riven by drainage channels; and when bergs passed within 1–2 n. mi. (2–4 km), small growlers (typically 2–5 m in diameter and of random shape) were sometimes observed in the vicinity of the ship. These more mundane erosion mechanisms are probably the ones which finally cause the iceberg to disappear.

Fig. 6. A typical iceberg observed during first transect, being swept by waves.

Thus it is reasonable to expect the distribution of sizes to resemble a lognormal, in that the central tendency is the preferred diameter which results from wave-induced flexural failure, while the threshold is the diameter at which the iceberg finally decomposes into a few rotted bergy bits as a prelude to complete disapperance. The sparseness of the data set and the fact that these are apparent (radar) diameters rather than real maximum diameters imply that the application of the lognormal distribution should be treated with caution. We note also that the data discussed by *Neshyba* [1980] include observations made close to the Antarctic continent where the icebergs are young and wave-induced fracture has had little opportunity to occur; this may explain the difference between his distribution and our own.

CONCLUSIONS

The population of icebergs in the open South Atlantic Ocean in midwinter conforms, by the sizes and state of deterioration of the bergs, to the hypothesis that it comprises bergs which are moving eastward from the general source area of the western Weddell Sea and Peninsula, and which have experienced a long sojourn in the open sea. The population in the 53°–56° latitude band appears to vanish completely between the longitudes of about 20°W and 1°E, probably due to melt and wave-induced decay.

The population presented a unique opportunity to study radar detectability of icebergs in high sea states, with the conclusion that 8 n. mi. (15 km) appears to be the range limit for the unfailing detection of bergs larger than 115 m in diameter, while smaller bergs are not detected at any range. The falloff in detectability with increasing range enables us to estimate the reliability of iceberg counts made by ships' radar.

The larger numbers of icebergs seen during this cruise within the pack ice zone will be reported on in a future paper.

Acknowledgments. I am grateful for the assistance of Vernon Squire and other members of the scientific staff of F. S. *Polarstern* in carrying out these observations. I acknowledge with thanks the invitation by Alfred-Wegener-Institut für Polar- und Meeresforschung to take part in the cruise and the financial support of the Natural Environment Research Council of Great Britain.

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P. Wadhams, Scott Polar Research Institute, University of Cambridge, Lensfield Road, Cambridge CB2 1ER, England.

(Received March 27, 1987;
accepted April 14, 1987.)