SCIENCE AND RESEARCH INTERNAL REPORT 9

IMMEDIATE SCIENTIFIC REPORT OF THE ROSS SEA ICEBERG PROJECT 1987-88

by

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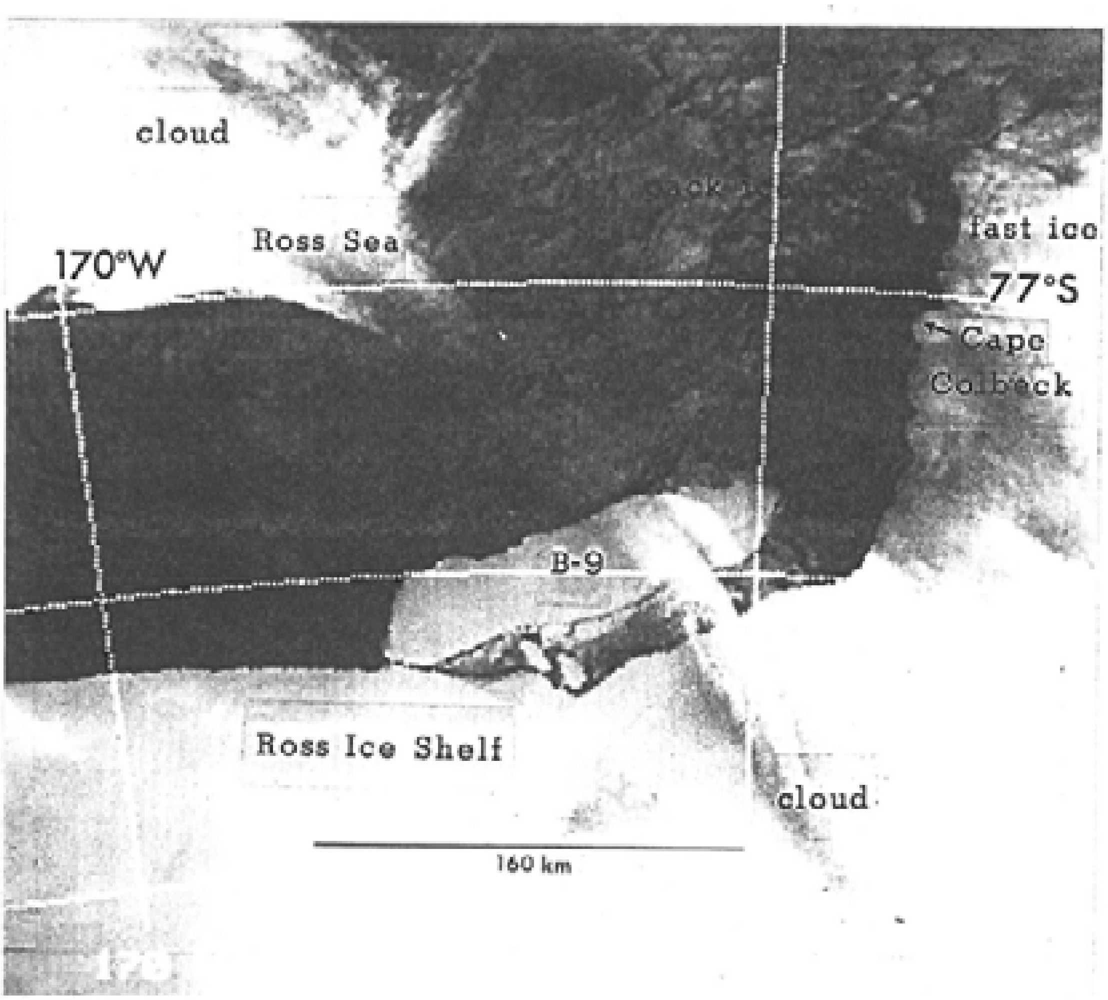
Frontispiece. NOAA 9 infrared satellite image of the 160 km long mega-giant iceberg B-9 on 9 November, four weeks after separating from the eastern front of Ross Ice Shelf. The image was digitized by US Navy scientists at McMurdo Station, paid for by the US National Science Foundation and supplied by the Antarctic Research Center at Scripps Institute. Several other bergs up to 20 km long that calved at the same time can be seen between B-9 and the ice shelf. These bergs have since drifted as far west as Ross Island (approx 600 km) whereas B-9 has moved only 215 km by 13 April, generally in a west-north-west direction.



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1. SUMMARY

Increased logistic support and the fortuitous appearance of a giant iceberg greatly benefited the project this A RNZAF C-130 enabled us to make the first accurate and complete of icebergs in fast ice along the entire coast of Victoria Land and survey bergs in the pack ice zone as well. A record 1841 icebergs in fast ice were detected in this way, including bergs in fast ice or the ice foot at Franklin and Islands and Lewis Bay, but not counting in the closely monitored area south of Nordenskjold Ice Tongue. An almost four-fold increase in the count was due to our ability to cover the large of ice in Lady Newnes and Moubray Bays (which contained 60% of the bergs) as well as a significant increase in the numbers of bergs present north of Drygalski Ice Tongue. Almost five times as many berga than usual were present in northern Terra Nova Bay. In addition, 325 bergs were detected in the pack ice zone north of the Drygalski but only 7 between there and Cape Bird via Franklin and Beaufort Islands, suggesting accumulation in north-west Ross Sea. Also, a small unreported iceberg tongue, containing about 40 bergs discovered between Turks Head and Erebus Glacier Tongue.

261 bergs were detected south of the Nordenskjold, a similar number to last year. Purchase of a SPOT satellite image greatly improved the ease of counting and precise fixing of bergs in the image target area centred on Bay of Sails. Berg movements from year to year and berg sizes were more easily measured than from oblique aerial photos. Icebergs down to 20 m wide were detected satisfactorily but the smallest bergs, 10 m wide (the resolution of SPOT monochrome imagery) were visible only on clean snow-covered ice. Thus, of the 143 bergs detected in the target area, 94X were covered in vertical aerial photography and were visible on SPOT although 100% of berga wider than 30 m were detected on SPOT. In total, about 2700 icebergs were seen this season, far more than previously.

The calving of the mega-giant iceberg B-9 from eastern Ross Ice Shelf in September-October has given us an excellent opportunity to learn more about current patterns and iceberg behaviour. By 13 April the 154 km long berg was 215 km west-north-west of its source and moving at 2 km/day. It is still intact after colliding with the ice shelf and rotating 45 degrees anticlockwise, although bergs that calved with B-9 have fragmented into 10 or so bergs up to 20 km long. These are drifting west along the ice front at up to 10 km/day and the westernmost was only 80 km west of Cape Crozier on 23 February. The mega-giant draws up to 300 m and may ground on Ross Bank before it reaches western Ross Sea.

2. INTRODUCTION

The Ross Sea Iceberg Project aims to determine the distribution, sources, movement and sizes of icebergs in the Ross Sea, Antarctica. These characteristics are not well known but such information is useful because icebergs are a significant part of both the Antarctic marine environment and the balance of the Antarctic ice sheet. The Antarctic has an important effect on the global environment (eg the ozone layer, climate, sea level) but the rates at which the ice sheet loses mass are poorly known. Iceberg production is probably the most important mechanism of mass-loss, and one which is likely to be susceptible to the substantial climatic warming expected in the near future. The project is establishing a continuous set of validated data to document any change in the iceberg population that may occur. This goal is similar and may prove relevant to the International Geosphere-Biosphere Programme launched by the International Council of Scientific Unions in 1986 to provide the information needed to assess the future of Earth in the next 100 years.

Another major reason for the study is that icebergs are a major natural hazard. They pose a threat to shipping and to science projects such as the scientific drilling programme being proposed for the western Ross Sea in the next few years. Icebergs are also one of the reasons why the prospect of offshore oil activities in Antarctica causes so much concern. Collisions between icebergs and ships, for example, tankers supplying scientific bases in Sound, could cause large oil slicks to come ashore. These might have tragic affects on penguin colonies, coastal ice-free terrain and on other environmental, scientific and aesthetic values there. Knowledge about icebergs will aid international planning and management of the Antarctic and so help reduce the chance of accidents there.

The field work for the project is now essentially monitoring, after a pilot study in 1983-84 and a major ground-based study in 1984-85. We now have 5 seasons data for parts of the Victoria Land coast, a valuable base-line for what is numerically a quite variable iceberg population. We have determined the best means of detecting icebergs, identified the reasons why icebergs are trapped along the coast (Keys, 1985), determined and classified their shapes to give source information (Keys, 1986) and also delineated the most hazardous areas prone to the largest numbers of bergs near shore. This delineation has been able to be extended to the rest of Ross Sea by deducing the main drift paths and sources of bergs in Ross (Keys and Fowler, in press). This could provide the basis for a system of predicting some months in advance the iceberg hazard in western Ross Sea.

3. PROPOSED PROGRAMME

There were two parts to the programme planned for this season.

(1) Oblique photography of icebergs in fast ice along the entire Ross Sea coast of Victoria Land (ca 800 km) from a special Royal New Air Force C-130 aircraft, with additional photography on an opportunity basis in the pack ice zone between Ross, Beaufort, and Franklin Islands, Drygalski Ice Tongue and north towards Cape Adare (Fig 1); and

(2) vertical photography from a US Navy helicopter of icebergs in fast ice between Cape Roberts and New Harbour in an area of a concurrent SPOT satellite image.

The scientific objectives of this programme were to:

(1) monitor the number and distribution of icebergs in known locations and elsewhere in fast ice along the entire Victoria Land coast of the Ross Sea;

(2) determine the movement patterns of these bergs by comparison with previous years' photography and identification of iceberg sources or other characteristics;

(3) monitor the number and distribution of bergs in the pack ice zone, particularly across the main iceberg drift paths and up-current of McMurdo Sound, to examine how detectable they are and if possible determine berg types and concentration for comparison with the fast ice zone (eg to verify previous reports and deductions of generally much lower concentrations of icebergs there);

(4) quantify the detectability of icebergs by visual remote sensing methods using concurrent satellite (SPOT) imagery, vertical aerial photographs (helo) and oblique aerial photographs (C-130);

(5) determine the types, general sources and horizontal above-water sizes of bergs in fast ice in the satellite image area.

In addition we hoped to extend our photographic coverage of iceberg producing glaciers in western Ross Sea to help identify berg sources.

The calving of one of the world's longest icebergs (B-9), between 25 September and 13 October 1987, presented us with an excellent opportunity to learn more about Ross Sea bergs. Discussions were held with the chairer of the Ross Dependency Research Committee, Antarctic Division and the Leader of Scott Base about the possibility of over-flying the berg (eg to measure its size precisely, examine its height and crevassing etc).

This big request proved too difficult and expensive to arrange. A visit to the Weather Division at MAC Center was planned however to obtain satellite images of B-9, position data and other information.

4. ITINERARY

2 December;	Keys and Fowler to Scott Base.
3 December;	Event briefing and preparations.
4 December;	Examination of surface and ice front of McMurdo Ice Shelf between Scott Base and dirty ice.
5 December;	Iceberg monitoring flight postponed due to broken windscreen.
6 December;	Examine icebergs and iceberg sources in Erebus Bay.
7 December;	Report writing. Visit to Mac Center Weather Office to get data on mega-giant iceberg B-9. Briefing for C-130 flight and standby for helo in evening.
8 December:	0210-0310 hours: photograph icebergs in area covered by SPOT satellite image (Debenham Glacier to New Harbour) from US Navy helicopter: 1020-1715 hours: iceberg monitoring in western Ross Sea and along the Ross Sea coast of Victoria Land from an RNZAF C-130.
9 December:	Return to New Zealand. Some monitoring en route.

5. SCIENTIFIC ACHIEVEMENTS

5.1 RNZAF C-130 iceberg monitoring flight.

The scientific highlights of this flight were;

-the first accurate and complete survey of icebergs in fast ice along the western coast of Ross Sea. Flights in previous years had been constrained by Operation Icecube operational requirements and to some extent by cloud so that coverage of the fast ice had been far from complete. Only a single season's data had been obtained in places (eg Moubray Bay which is an area of major accumulation, see Table 1).

-a record 1841 bergs detected north of Drygaleki Ice Tongue. Previously we had detected an average of only about 350 bergs (Table 1) due in part to the logistic difficulty.

-reliable documentation of a significant increase in iceberg quantities north of the Drygalski (Fig. 2). The one area here, Cape Washington to Campbell Glacier, where we have good records for four years now, had about five times more bergs this year (152) than the previous average (38, standard deviation 5). There were more bergs seen in Terra Nova Bay polynya this year as well (Table 1).

This increase is not matched by a corresponding increase south of the Drygalski (Table 2, Fig. 2) suggesting some "partitioning" between the two areas leading to differences in iceberg accumulation. "Partitioning" could be caused by the separation of current systems in western Ross Sea, due for example to the presence of Ross, and Franklin 'Islands and Drygalski Ice Tongue. It is unlikely that temporal variations in iceberg quantities of the type noted by Keys (1983) could explain the different quantities of icebergs on this scale.

- significant spacial variation in iceberg quantities detected in pack ice, with 325 bergs counted north of the Drygalski but only 7 bergs seen between there and Ross Island (Table 3). While this variation is consistent with "partitioning", caution required on two counts:

1. the detection of bergs in pack ice is difficult, especially on black and white photos, because of leads and pressure ridge shadows. We used visual counts supplemented by slides and photos but even so many small, medium and some large sized bergs would have been missed;
2. iceberg concentrations in pack ice in western Ross Sea vary considerably with time (Keys, 1983).

-our first opportunity to examine icebergs between Cape Bird, Beaufort Island and Franklin Islands. We believe these places lie either side of the main paths along which icebergs drift into south-west Rose Sea (Keys and Fowler, in press). The small quantities of icebergs detected here are the equivalent of a concentration of less than 1 berg per 1000 square This low value is a minimum estimate only but is consistent with previous reports and evidence of low average concentrations in pack ice (eg Romanov, 1984; Keys and others, 1987) and with our conclusion (Keys and Fowler, in press) that only a small percentage of bergs produced by the western Ross Ice Shelf find their way into the fast ice of south-west Ross Sea. A single traverse however is not enough to verify this becauee of the possibility of a low rate of detection and the variable nature of iceberg distribution. Of the seven bergs detected, one tabular, three others probably tabular, two were irregular and one's shape was too far off to be differentiated.

- determination of some iceberg drifts north of Drygalski Ice Tongue. Data have been insufficient to do this before. While details have not been worked out yet, at least two drifts were identified from "sourceable" bergs in Lady Newnes Bay, and various bergs near Moubray Bay and in Terra Nova Bay polynya were recorded in different positions on 8 and 9 December.

-"discovery" of “Icecube Iceberg Tongue" immediately north of Erebus Glacier Tongue and eouth of Turke Head. This tongue was about 3 km wide and 1 km long and contained at least 40 uneven tabular bergs and many other smaller bergs of various shapes. As in iceberg tongues elsewhere, most of the bergs will be grounded as the sea is less than 100-200 m deep here (from Pyne and others, 198). To our knowledge it has not been reported in the literature. This may be because it had not been recognised or that it is not a permanent feature. The fast ice in its vicinity was at least two winters old so the bergs may have just accumulated below a fast flowing ice stream discharging into the bay. Nevertheless the glacier/tongue is probably the main producer of icebergs in eastern McMurdo Sound and is likely to be the source of berg 87EB-01 aground off Cape Evans since at least 1984-85 (see below) as well as many other bergs in the closely monitored area. In addition it is the only iceberg tongue we know of in Ross Sea.

We propose to call it the Iceberg Tongue in recognition of the valuable role that the RNZAF Operation has played in the New Zealand and United States Antarctic Programmes.

5.2 SPOT satellite image and concurrent aerial photography.

The scientific highlights of this part of the Event were;

-near-vertical aerial photos of fast ice bergs obtained from 2400m over the SPOT image area within a of image acquisition. The SPOT image we accepted was taken on 11 November 1987 being close enough to our ordered area and cloud-free. The vertical photos were taken from 0210 to 0310 hours on 8 December 1987 out the port-side rear door of a US Navy helicopter. This was done primarily to determine the utility of SPOT for such iceberg work, in particular to quantify the detectability of icebergs using SPOT. The photos and image were concurrent because as expected the fast ice containing the bergs had not broken out or otherwise changed for the purposes of this study over the one month period.

-icebergs down to 20m long are able to be neaeured using SPOT and some 10 m bergs were detected (refer Fig. 4). Preliminary measurements suggest that all 30 m long bergs in fast ice can be detected reliably. Icebergs as small as 10 m long can be seen if they are surrounded by clean snow-covered ice. Previous satellite imagery has not been able to detect icebergs smaller than the median width ie 50-100 m.

- 80±7% of bergs in target area were visible on SPOT compared to 94% on aerial photos. These values give a quantitative indication of the overall detectability of icebergs using these methods. We have known since 1984 that helo-based aerial photography is reliable but it is time-consuming and limited in range. More bergs can be detected using SPOT than some C-130-based oblique aerial photography.

-icebergs are easier to count, previous years' bergs are easier to identify and yearly movements are more accurately determined using SPOT. A SPOT scene is a vertical view covering 60x60 km, much greater than vertical aerial photos and easier to extract information from than oblique aerial photos. This makes counting, berg identification and locating, and movement plotting more straight forward, quicker and more accurate.

-for specific target in fast ice SPOT imagery is more convenient logistically and scientifically than aerial photography. For an area less than 60x60 km (eg Bay of Sails, Cape Washington bay) a SPOT scene would be very convenient and useful for monitoring. It took much less time to organize the imagery than the helicopter time. The SPOT scene cost NZ$3700 including GST but helicopter time in Antarctica will be cheaper for as long as it is not organized on a commercial basis.

5.3 Ground-based fieldwork

Fieldwork was carried out from Scott Base on an opportunity while waiting for the photographic flights. This work gave useful information on iceberg sources and movement.

The surface of McMurdo Ice Shelf between Scott Base and the dirty ice was examined to see if it could be matched with that of certain icebergs visited during previous seasons. The ice shelf was traversed by skidoo on lines between:

1. Scott Base, the crashed Constellation aircraft and about 1 km towards Bratina Island; then
2. north towards Tent Island to the ice front; then
3. west towards Dailey Islands to rough ice: then
4. north-northwest and north towards the tip of the dirty ice; and finally
5. a zig-zag course generally southwest back to Scott Base.

On traverse (1) the snow-covered accumulation zone was followed onto the vicinity of the Equilibrium Line where snow-free patches of glacial ice and frozen ponds began to be exposed about 7 km southwest of Scott Base. By 1 km west of the Constellation only patches of snow were present. A few hundred metres further on (10-15 km from Scott Base) the ice surface became too rough for casual skidoo travel, having small ponds and 0.5 m of relief.

Significant amounts of moraine and some algae were present in this area which is a few kilometres east of the first main bands of dirty ice derived from the tide cracks along the northeast coast of Black Island. Traverses (2) and (5) covered bare or thinly snow-covered smooth ice shelf with frozen lakes and ponds that are quite extensive in area and in places domed up to about 0.5 m by expansion on freezing.

Traverses (3) and (4) covered ablated ice shelf with relief up to 0.3 m, increasing towards the dirty ice in the west with its fossiliferous moraine, ponds and streams. The ice front was always less than 0.5 m above the sea ice and often seemed to merge virtually imperceptibly with it. Presumably this was due to both the multi-year nature of the fast ice and to thinning of the ice shelf at the ice front.

Iceberg 84GI - 09 was derived probably from the ice shelf in the vicinity of traverses (3) and (4) as indicated by the surface and low height (< 4m) of this berg. It may have calved and drifted north to Gregory Island during the open water season of 1983-84. Similar characteristics suggest that other low tabular bergs in Bay of Sails probably also came from this part of McMurdo Ice Shelf.

Locally derived bergs seem to predominate in the Erebus Bay - Dellbridge Islands area. Three small irregular shaped firn bergs within 100 m of the coast 5 km south-southwest of Hutton Cliffs were adjacent to their calving sites on the ice wall of the ice mantling Hut Point Peninsula. A small uneven tabular berg had almost severed from the tip of one of the "teeth" on the southern side of the Glacier Tongue about 3 km from the snout. A large tabular berg between Cape Evans and Inaccessible Island was present in a similar position in December 1984 but has since rotated horizontally through approximately 180 degrees. Its uneven tabular shape, surface features including melt-water ponds, composition and position suggest that it was derived from “Icecube Iceberg Tongue” between Turks Head and the Erebus Glacier Tongue. In 1984 several small “McMurdo Ice Shelf” bergs were present near Turks Head.

Iceberg distribution appears to be uneven in McMurdo Sound itself as well as in the fast ice zone there. Observation of southern McMurdo Sound from Tent Island on 7 December revealed no icebergs in an extensive polynya there. Only one small irregular berg was observed on 8 December (from the helo and C-130) floating near the fast ice edge in the western sound. Observations during previous years have also shown that the average concentration of icebergs outside the fast ice is very low, normally less than 1 berg per 1000 square km. Large numbers of bergs were photographed in open water in northern McMurdo Sound by Keys in late January 1975 and bergs are not infrequently seen drifting past Cape Bird Station. Apparently, however, only small numbers of icebergs drift south in tidal currents into southern McMurdo Sound.

Observations made by Greenpeace during the winter are consistent with this distribution. Greenpeace saw only one tabular iceberg drift south past Cape Evans and it drifted back north shortly thereafter presumably with the tide (C. van Dorp, personal communication). Probably few non-local bergs ever enter or ground in Erebus Bay.

Probably the regional mean current that rounds Cape Bird then sets south in eastern McMurdo Sound before turning west near Cape Royds (Heath, 1977) tends to take most non-local bergs in this general path. This hypothesis will be tested by determining whether the concentration of "Ross Ice Shelf" type bergs newly trapped along the Victoria Land increases significantly with distance north of the Blue Glacier.

5.4 The mega-giant iceberg B-9.

The calving of B-9 iceberg will provide a lot of information about Ross Sea over the next 1 to 10 years. Position data and images from United States weather satellites, the US Navy-NOAA Joint Ice Centre in Maryland, and the new Antarctic Research Center at Scripps University in San Deigo are being used to track and examine the progress of iceberg B-9. This is being done to verify or (otherwise) the predicted paths of icebergs in southern and western Ross Sea, measure iceberg drift rates and residence times within Ross Sea, and examine the behaviour of such large icebergs. The data will also give valuable information on currents which will be useful because of their affect on sea ice formation, drift and decay, as well as their affect on the marine ecosystem including krill, penguins and whales.

The calving and movement of B-9 have already produced relevant information. The berg calved from an area of the ice shelf that is up to 350 metres thick, which indicates a maximum draft of up to 300 m -probably the deepest modern iceberg in the Ross Sea. So far the total drift of B-9 has been more complex than expected but it has moved on average west-north-west, consistent with what is thought (Keys and Fowler, in press) to be the main drift zone of icebergs (westwards parallel to the ice shelf front) in Ross Sea (Fig 5.). B-9 seems to have been caught, from 6 January until about 17 March, in an eddy or area of sluggish water movement. Another possibility is that the berg was grounded on the sea floor, although the water depth here (77 35 S, 166 W) is mapped as being about 450 m, probably more than 140 m deeper than the maximum draft of the berg. A third possibility is that the sea floor is shallower than thought.

Bergs that calved with B-9 have drifted more rapidly westwards at up to 10 km/day and the westernmost was only 80 km east of Cape Crozier on 23 February. This has verified our deductions shown in Fig. 5. There is a significant probability that B-9 will ground on Ross Bank (water depth of 178 metres at 76.6 deg. South, 178 deg. East) where the sea shallows to leas than 300 m within 90 km of the Ross Ice Shelf, or elsewhere in western Ross Sea.

Much of a prominent northerly component of drift during December appears to have been due to the western end of the berg colliding with the ice shelf, causing the berg to rotate anticlockwise. It may also have been pushed by a current flowing north from under the ice shelf in this area.

There have been suggestions made that B-9 is breaking up. Some confusion has arisen because, as it spawned B-9, the ice shelf developed two parallel fracture systems about 10 km apart and about 40 km south of the former ice shelf coastline. The southern-most fracture became the new front of the ice shelf, while the northern-most fracture became the southern side of B-9. The ice between the fractures broke up into several icebergs, some of which are still near B-9 and have continued to break-up. In addition, B-9 had areas of sea ice frozen to it when it calved and these have also been drifting away.

As with all icebergs, small amounts of B-9 have cracked off around the sides. The dimensions of B-9 were given by the Joint Ice

Centre as 86 x 22 nautical miles (160 x 40 km) until 21 January when it was measured more precisely and then listed as 83 x 19 nautical miles (154 x 35 km). The accuracy of these measurements is about ±4 km, so while there may have been some loss of ice from the edges, the area of B-9 has not decreased sufficiently to be able to say it is breaking up. The most precise measurements of B-9 are 154 x 30 km derived by Jay of NASA from images early in 1988 and they are accurate to within a kilometre. B-9 will eventually fracture into two or more large bergs, probably across a narrow portion about 40 km one end, but significant fracturing has not occurred yet.

6. CONCLUSION

This was in some ways the most productive season since the project started and field work lasted only a week! With improved logistic support we have been able demonstrate that it possible to monitor the fast ice zone along the whole west Ross Sea coast. This monitoring is now extending across several years and is to produce excellent results. It is interesting that an increase in the quantity of icebergs north of Drygalski Ice Tongue recorded in December 1987 occurred in the open water season preceding the calving of B-9, probably the largest calving of the Rose Ice Shelf this century. One could speculate that this was due to some strong regional metoerological or oceanographic would be unlikely to be due to global climatic warming as the glacial response time is too long.

7. FUTURE RESEARCH

It is worth continuing the monitoring for at least one more year. This will allow assessment of the observed increase north of the Drygalski and give a better time perspective. This monitoring would be best done by a repeat of the dedicated RNZAF C-130 flight. We will continue to examine the possibility that iceberg quantities in Bay of Sails and Cape Washington bay can provide indices of quantities elsewhere on the coast, particularly in terms of volume.

We know too little about icebergs and currents in most of Ross Sea where pack ice requires logistics that New Zealand can not readily obtain. The fortuitous appearance of B-9 is helping and it will continue to be tracked to give fundamental information. It or its "cohorts" will give us information about the pack ice zone in western Ross Sea that has been difficult to obtain from aircraft. Our proposal for using the forthcoming Earth Resources Satellite-1 and its synthetic aperture radar sensor appears to have been turned down by the French authorities. Therefore a ship is still the most feasible and proven platform for iceberg observations in the pack.

8. PUBLICATIONS

Three to five publications are in press at this time. These are two chapters in books (editors Hatherton, Glasby), the sources and movement paper (Annals of Glaciology) and possibly two notes about B-9 (Annals and the NZ Antarctic Society's 'Antarctic' bulletin). Other publications are listed in previous immediate reports and the references. An article about the iceberg project appeared in the February/March 1988 edition of 'Nga Kaitiaki' the bulletin of the Department of Conservation. A manuscript on for 'Iceberg Research' is partly completed and one on B-9 iceberg sizes and volumes is planned for after that.

9. ACKNOWLEDGEMENTS

The Department of Conservation and the Division of Information Technology (DSIR) sponsored this project and it was supported by the Ross Dependency Research Committee. We are particularly grateful to the Antarctic Division of the Department of Scientific and Industrial Research for providing the dedicated C-130 flight and to the pilot (Dave McIsaacs), navigator (Edward Poot), and crew of RNZAF 03. We also thank Antarctic Division staff, Graham Ayres and other Scott Base staff, Ian Speden and Lloyd Homer (NZ Geological Survey) and collegues at DIT for their support. We acknowledge the cooperation of Dr Peter Wilson and members of his penguin census Event throughout the planning and execution of the C-130 flight.

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Figure 1. Map of western Ross Sea showing the C-130 routes flown on 8.12.87 (lines shown dotted and solid) and north of Moubray Bay en route to New Zealand on 9.12.87. The Iceberg Project's work was concentrated flying southwards over the fast ice zone (solid line), although worthwhile information was obtained over the pack ice between Ross, and Franklin Islands and Drygalski Ice Tongue.

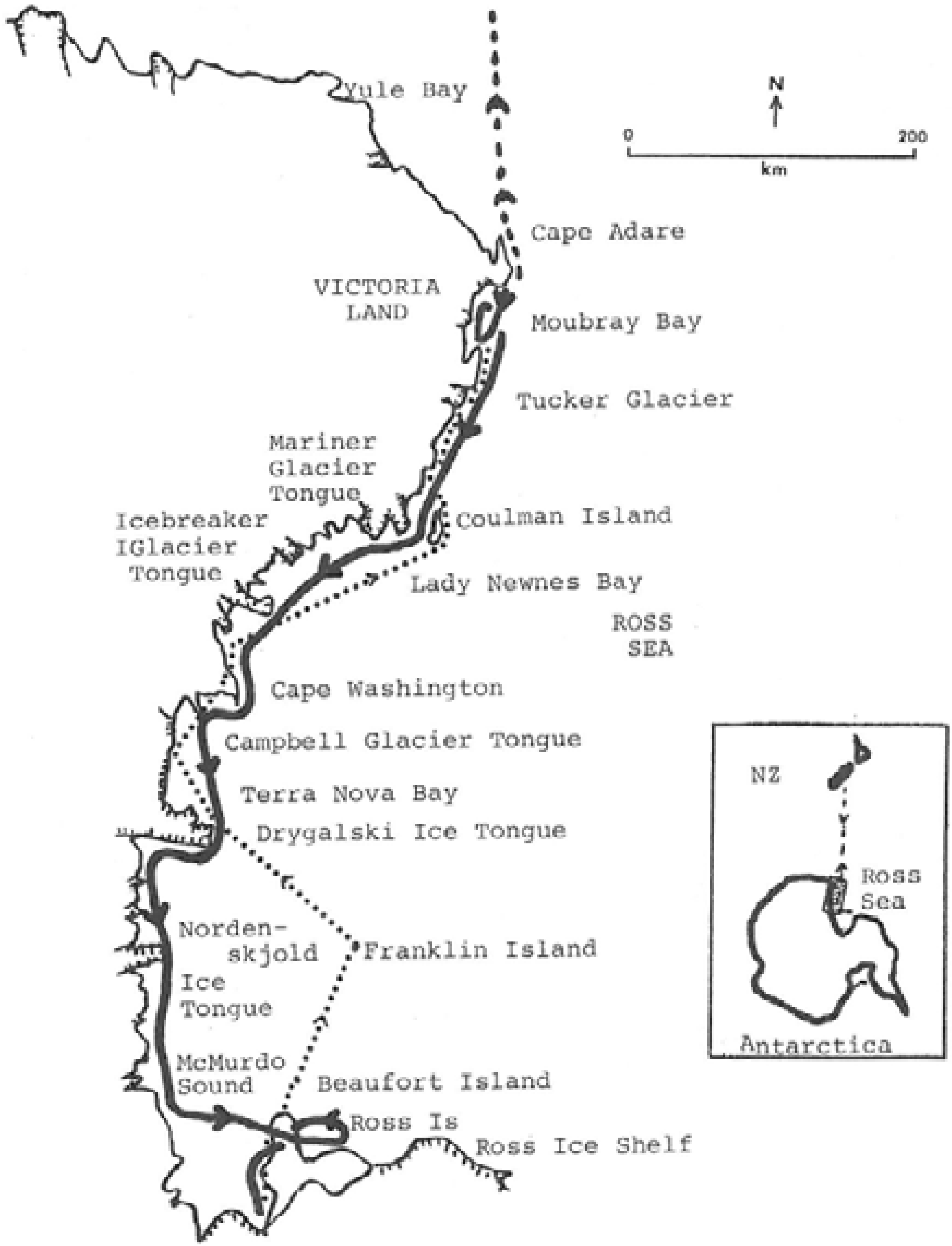


Figure 2. Summary of iceberg monitoring from 1983-84. The increased number of icebergs detected in the north this year is greater than one standard deviation for the Cape Washington area, which up to this year has had a fairly constant quantity of bergs (standard deviation = for the three years to 1986-87). The curves for the area south of Nordenskjold Ice Tongue and Bay of Sails appear to be quite well correlated suggesting that the latter may be a good index for the former. These data do not correlate with the data for the Cape Washington area 300 km north of Bay of Sails.

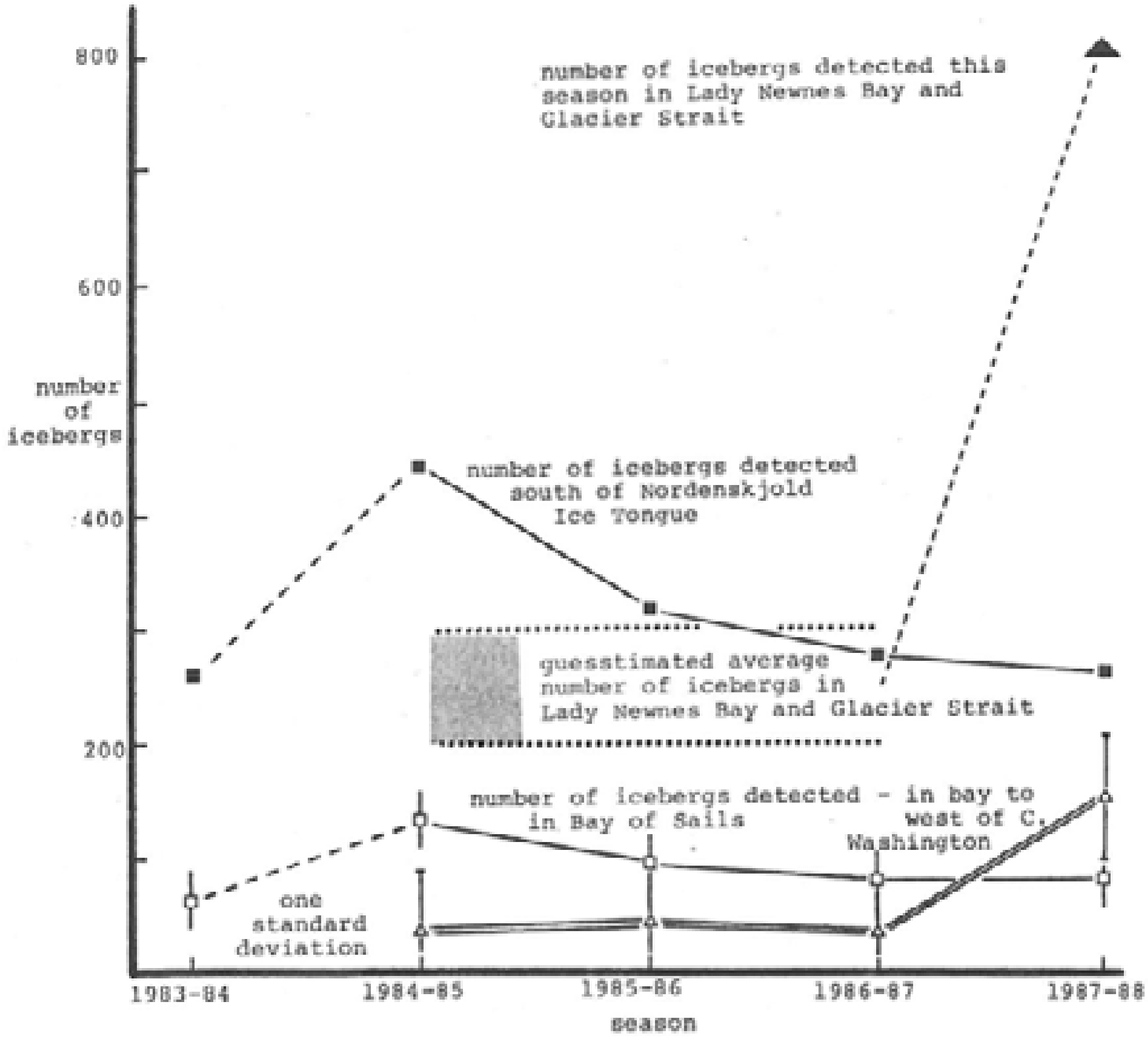
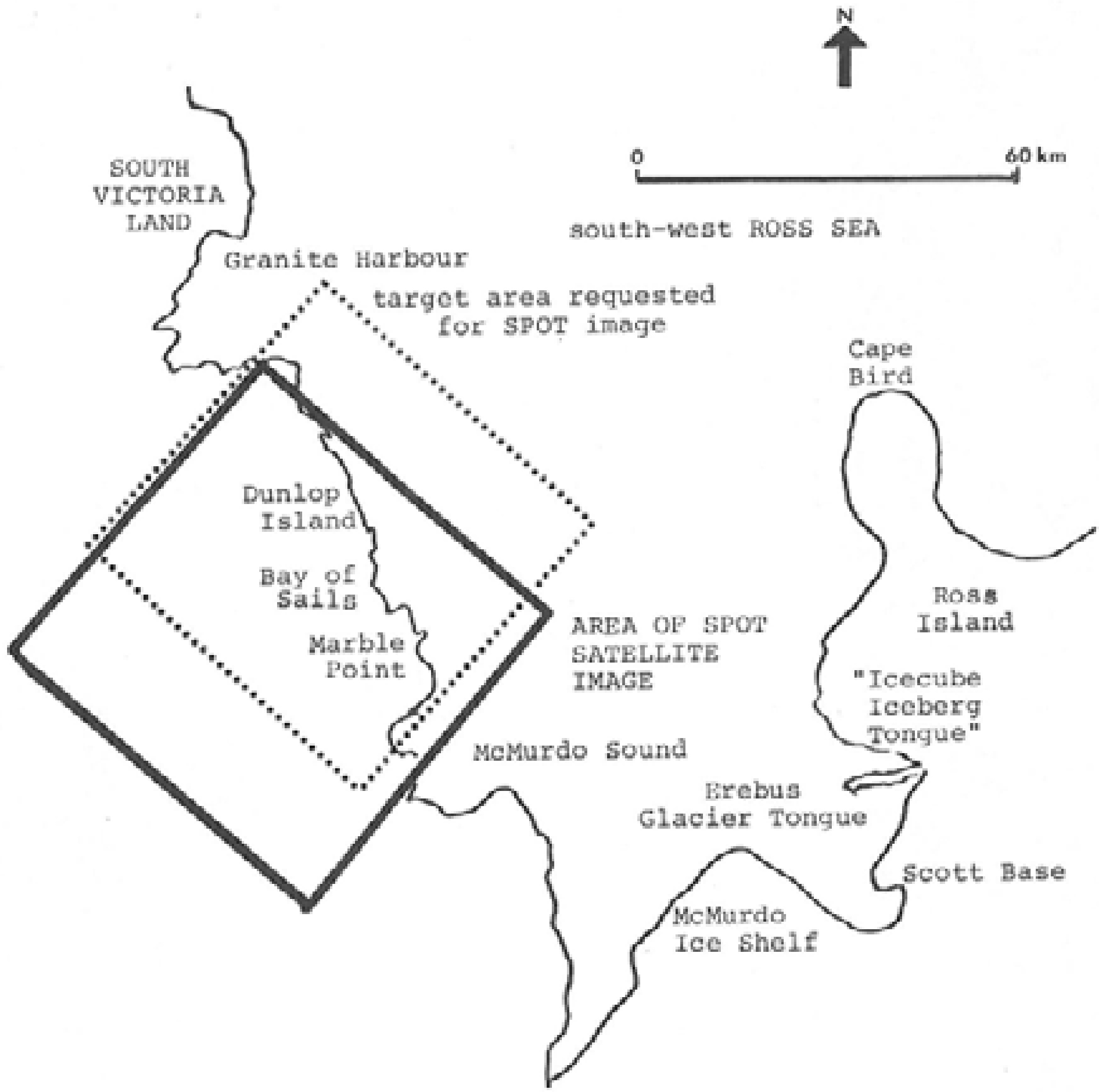


Figure 3. Area of the SPOT satellite image purchased compared to the area actually ordered. The 60x60 km cloud-free scene over western McMurdo Sound and South Victoria Land was imaged on 11.11.87 from 820 km using a push broom scanner in the panchromatic band (0.51-0.73 microns) with a 10x10 m ground sampling interval.



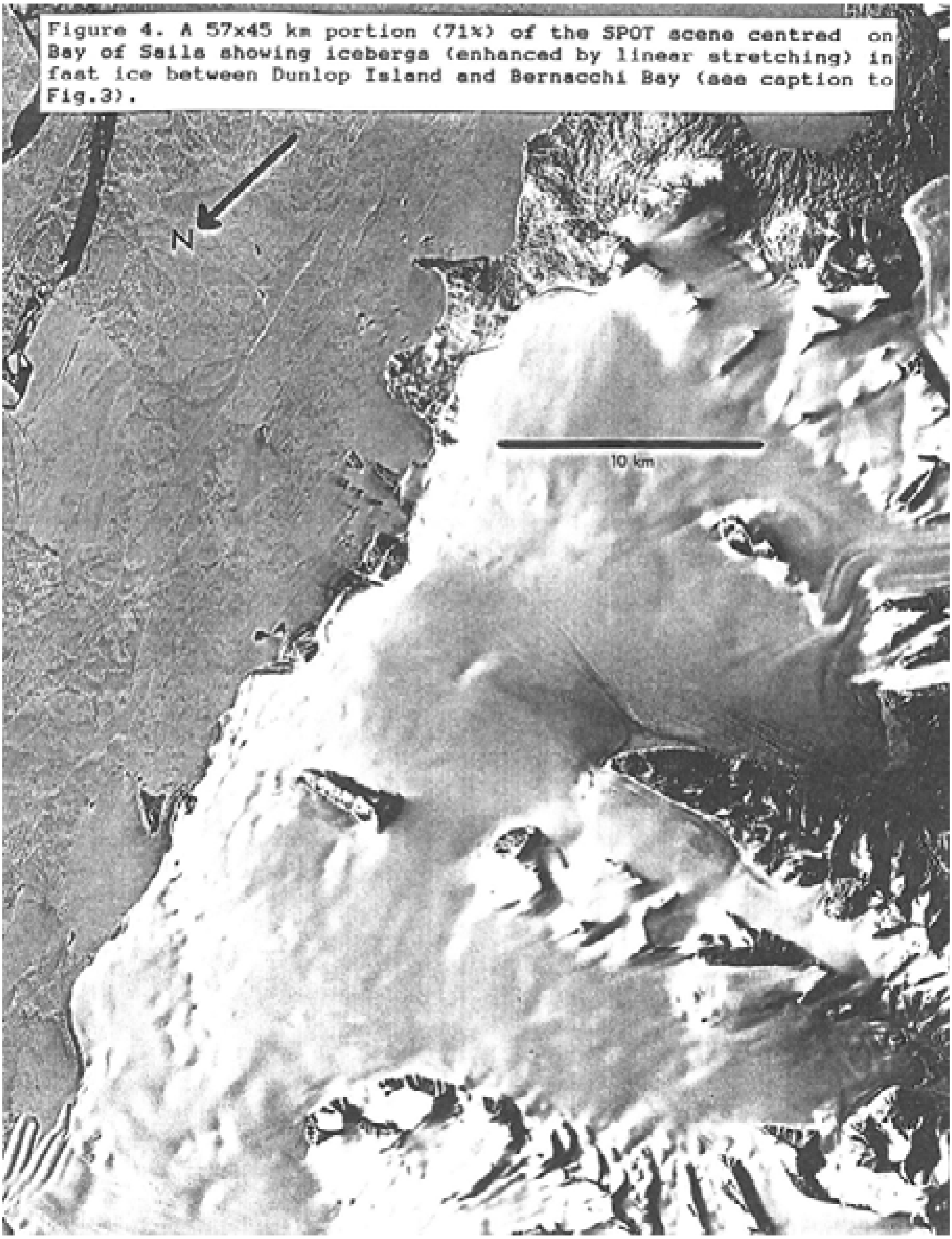


Figure 4. A 57x45 km portion (71%) of the SPOT scene centred on Bay of Saila showing icebergs (enhanced by linear stretching) in fast ice between Dunlop Island and Bernacchi Bay (see caption to Fig.3).

Figure 5. The Roes Sea sector showing the main drift zones of icebergs in the region (after Keys and Fowler, in press).

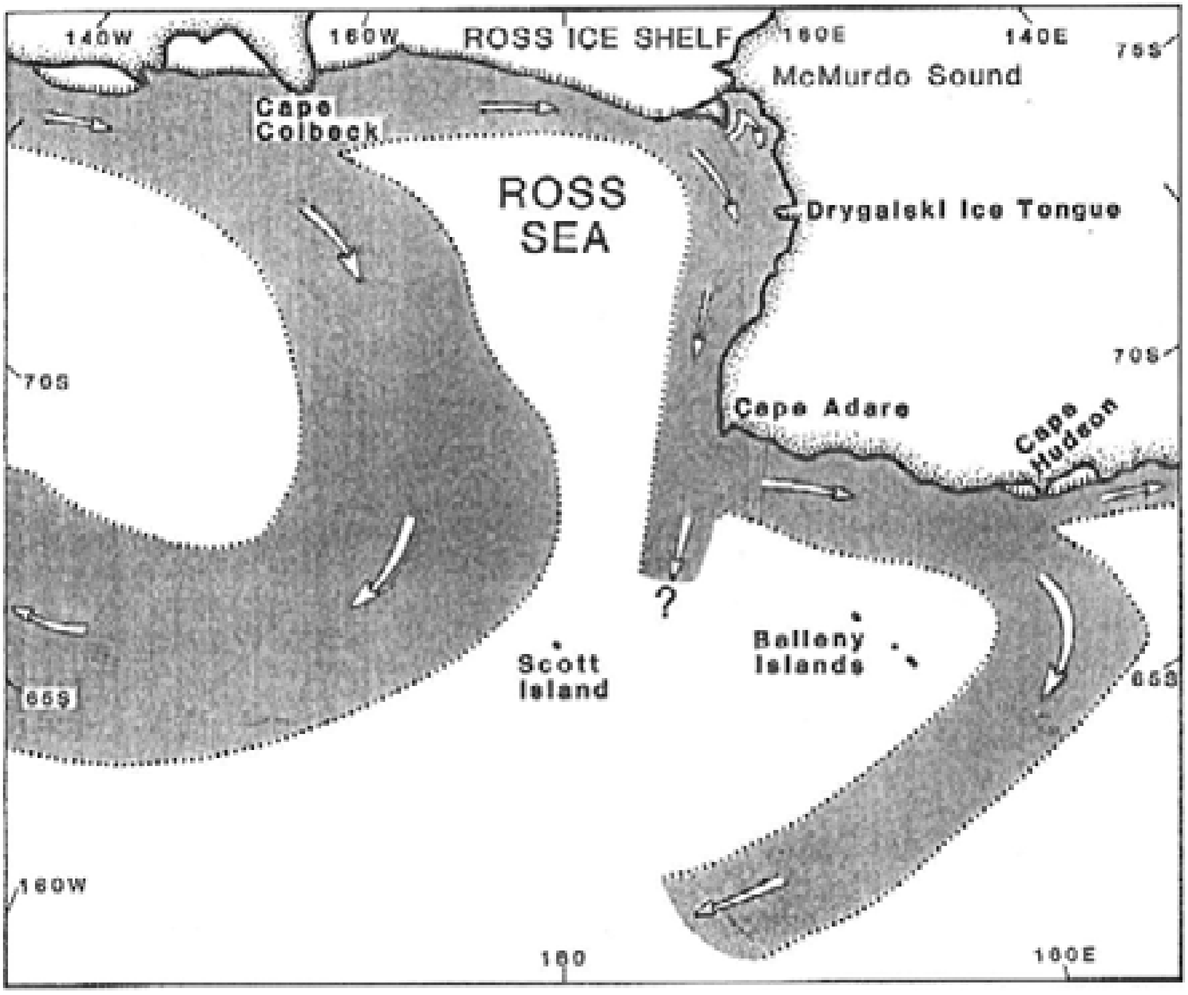


Table 1. Census of icebergs in fast ice along the Victoria Land coast north of Drygalski Ice Tongue, from RNZAF C-130 flight, 8 December 1987. (+ shows some distant bergs not resolved).
C = Cape, G.T. = Glacier Tongue

Locations of icebergs	Number of icebergs detected	Sublocations	
Cape Adare to saddle south of Hansen Peak	ca. 100		
Cape Roget to C. Hallett	399+		399+
		NE Moubray Bay	25
C. Hallett to C. Wheatstone	226	NW Moubray Bay	53+
C. Wheatstone to Tucker Gl.	13+	Central Moubray-Burnette Gl. Tongue	135
C. Daniel to Tucker Gl. area	5	Hedgehog Is-C. Hallett	158
C. Daniel to Mandible Cirque	13	Edisto Inlet	8
		NE of C. Hallett	10
Glacier Strait	48		48
		SW Cape Coulman Is.	17
		Gl Strait-Borchgrevink G.T.	31+
Lady Newnes Bay	688 plus ca. 85+ inshore		688 plus ca. 85+
		Mariner G.T.-Icebreaker G.T.	280+
		Ditto : inshore	ca. 15+
		Icebreaker-Aviator G.T.	480+
		Ditto : inshore	ca. 70+
Wood Bay	127+		127+
		Aviator-Tinker G.T.	60+
		Tinker-C. Washington	67+
C. Washington to Campbell Glacier Tongue	167+		167+
		E of Markham Is-Oscar Pt	82+
		W of " "	70
		Near Campbell G.T.	15
Eastern Gerlache Inlet	10+		
TOTAL	1796+		
	plus ca. 85+ discernable nearshore in distance		

Note. Approximately 100 bergs were counted in the fast ice immediately north of Yule Bay on Oates Coast, but Yule Bay itself was covered by undercast cloud.

Table 2. Census of icebergs in fast ice in south-west Ross Sea (south of Drygalski Ice Tongue) including main monitoring area south of Nordenskjold Ice Tongue, from RNZAF C-130, and USN helicopter on 8 Dec 1987, plus a ground visit in Erebus Bay.

Locations of icebergs	Number of icebergs detected	Sublocations	
Drygalski Ice Tongue to Nordenskjold I.T.	17		17
Nordenskjold I.T. to "Cape Iceberg"	7+	Geike Inlet-Lamplugh Is	3+
		L. Is-Cheetham Gl	2
"Iceberg bank" area - north and central parts	15	Cheetham-Harbord Gl	1
- southern edge	11	Bay south of Harbord Gl	7
- bay north of Fry G.T.	10	C. Hickey-Nord. I.T.	4
East and SE of Fry G.T.	3		
Tripp Is to Depot Is	6		
Depot Is to Cape Ross	0		
Cape Ross to Gregory Is	3		
Gregory Is to Cape Archer	8		
Granite Harbour	10		
"VUWAE bank"	0		
Cape Roberts	20		
Debenham Glacier to Dunlop Is	9		
Dunlop Is and Strait	9+		
Spike Cape bay	0		
Bay of Sails	80+		
Gneiss to Marble Points	13+		
Bernacchi Bay	13+		
Cape Bernacchi	14		
"Drillhole submarine spur"	2		
New Harbour	9+		
Butter Point to Strand Moraines	ca 7		
Blue Glacier	ca 10		
South of Blue Glacier	-		
Others	2		
Main monitoring area, total	ca 261+		
South Victoria Land coast, total	ca 278+		
Beaufort Island icefoot etc	6		
Franklin Island icefoot etc	4		
Lewis Bay (fast ice only)	18+		
C Evans to Erebus G.T.	3+		
"Icecube Iceberg Tongue"	ca 40+	(not counting small ones)	
Erebus G.T. to Hut Point	4+	(EGT hinge zone not visited)	
TOTAL	ca 353+		

Table 3. Icebergs detected in pack ice or open water, including bergs grounded near shore. Observations mainly from RNZAF C-130 on 8, 9 Dec 1987 but also from USN helicopters on 7 Dec (I. Speden) and 8 Dec. Numbers are approximate only.

Locations of Icebergs	Number of icebergs detected	
Shoal area bearing 330° True from Cape Adare	23	(including some in rotting fast ice)
C. Adare to C. McCormack	50	
C. McCormack to C. Roget	7	
Possession Islands	10+	
Outer Moubray Bay	33+	
Daniel Peninsula	6	
Coulman Is to C. Washington (mainly Lady Newnes Bay)		
- trapped in giant floes	132+	
(7 floes contained 24+, 15+ 23, 32+, 16+, 5+, 17 respectively)		
- in pack and smaller floes	56+	
Terra Nova Bay polynya	8	
North of Drygalski Ice Tongue, total	325	
Between Drygalski I.T. and Franklin Is	1	(T?)
Between Franklin and Beaufort Islands	5	(2xtT, 1xT?, 2xI?)
Between Beaufort Is and C. Bird	1	(rI)
Lewis Bay (pack ice only)	7	See Keys, 1986 for explanatin of these shape symbols: most bergs were too distant to classify for shape.
Off C. Bird penguin colonies (probably aground)	8	
Nearshore in Wolschlag Bay (probably aground)	5	
Near C. Royds (aground in Horseshoe, Backdoor Bays)	2	
McMurdo Sound polynya	1	
South of Drygalski Ice Tongue, total	30	
TOTAL	355	