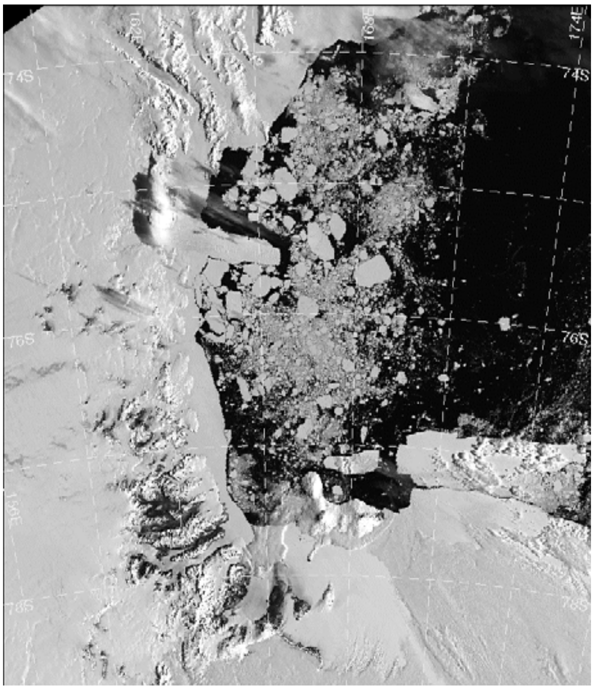
ISSN 0375 8192

March 2004

Antarctic Data Series No 27

ICE BREAKOUT HISTORY IN SOUTHERN MCMURDO SOUND, ANTARCTICA (1988-2002)

T.R. Falconer and A.R. Pyne



ANTARCTIC RESEARCH CENTRE
in association with the

SCHOOL OF EARTH SCIENCES
Te Kura Tātai Aro Whenua

VICTORIA UNIVERSITY OF WELLINGTON
Te Whare Wananga o te Upoko o te Ika a Maui

Antarctic Data Series No. 27
A Publication of the Antarctic Research Centre:
Victoria University of Wellington
PO Box 600, Wellington, New Zealand

This publication is available in pdf format at our ftp site.
ftp://ftp.geo.vuw.ac.nz/ARC/

Contents

List of Figures

List of Tables

List of Appendices

SUMMARY

Proposed drilling in Southern McMurdo Sound will use seasonal sea ice as the drill platform. Sea ice in the area generally breaks up and reforms annually. The timing of breakout and ice formation is variable, and analysis is required to determine the viability of sea ice drilling at the proposed sites. We have been able to build up an historical picture of the variability and viability of the sea ice at the proposed sites, using satellite imagery for the last fifteen years, local temperature data and ice thickness measurements.

Sea ice at the drilling sites needs to be 1.75m thick by day 250 to ensure safe operations, and this requires ice to have formed by day 125 and remain stable without breakout. The site needs to have 5km seaward buffer zone of stable ice, and stable ice routes for supply and demobilisation.

There appear to be two typical patterns of ice breakout, related to calm or stormy weather patterns. The stormy pattern is associated with warmer temperatures and later breakouts (through to late July), giving insufficient time for ice of a sufficient thickness to grow before the drilling season commences. The calm pattern is associated with cold temperatures and fewer breakout events. Ice growth commences by early May (day 125), which means that the ice will have reached sufficient thickness (1.75m) by day 250 to begin establishing the drill site. Further required growth of the ice, can be expected to continue to day 275.

Drilling at sites SMS and SMS-X would have only been possible once in the last fifteen years. Sites SMS-1, SMS-2 and SMS-s (an alternative, more southerly site) would have been viable six to eight times in the last fifteen years. Even though drilling might have been possible for about 50% of the time, it should be noted that this does not indicate it would be possible in alternate years. There were as many as three consecutive years where drilling would not have been possible.

1. Project Description

The ANDRILL project has identified drill targets that may be assessable from the fast sea ice platform, which forms annually in McMurdo Sound. An analysis process for weather satellite imagery (DMSP) has been developed by Alex Pyne (ARC) to evaluate the winter sea ice growth and breakout history in McMurdo Sound. The analysis process was specifically developed and used to predict the viability of the fast sea ice platform at Cape Roberts Project drill sites, successfully drilled offshore of Cape Roberts in 1997-1999 (Pyne 2001).

An evaluation of the sea ice history is required for proposed ANDRILL sea ice targets in the southern part of McMurdo Sound. Some of these sites are up to 17km offshore and were originally programmed for drilling in the spring and early summer of 2005 or 2006. In addition ship based seismic operations are planned and the summer sea ice break out history is required for ship program planning.

2. Explanation of the Data and Methodology

2.1 Satellite imagery

Weather satellite imagery has been used to interpret fast ice formation and breakout in Southern McMurdo Sound for 1988 through to 2002.

DMSP and some AVHRR imagery for 1988 to 2002 was processed by staff from archived data at the Antarctic and Arctic Research Centre (AARC), Scripps Institute of Oceanography, San Diego. Images were processed to find cloud free images, ideally looking for a good image about once a week. In several months this was not possible and the number of images available for these periods varied. In the years when fewer images were available the error in interpreting the timing of breakout events and start of ice re-growth may be in error by a week or two but for the other years the error should be less than a week.

DMSP images processed by staff of Antarctic Support Associates (ASA) in Denver were available from 1996 to 1999 on a more regular basis. These images have a better spatial resolution and several good images are often available each week. The timing of breakout events can usually be determined within 1-3 days. DMSP imagery has a pixel resolution equivalent to 0.5km over most of the image and this combined with geographical positioning uncertainties probably limits the position accuracy of this methodology to no better than 1-2km.

There are gaps in the satellite data, especially in the February through April period. These gaps have been indicated in the figures.

2.2 Temperature data

Air temperature data was derived from the Marble Point Automatic Weather Station (AWS) courtesy of Prof. C R Stearns "Antarctic Automatic Weather Station Program, NSF-OPP9726040". The data comprises monthly mean temperatures and deviation from the mean, over the period Jan 1988 - Apr 2000.

Scott Base weather data is raw data from Scott Base meteorological observations over the period 1988 to 1999.

2.3 Ice thickness

Measurements of sea ice thickness have been taken at several drill sites between 1975 and 1999 (Pyne pers. comm.) in the McMurdo Sound region.

2.4 Methodology

This study built on similar analysis done in preparation for the Cape Roberts Project, which looked at characterising fast ice formation and activity by identifying breakout events during the winters of 1988 to 1999 (Pyne 2001). Past evaluation of the McMurdo Sound sea ice history has covered the winter and spring periods for the years of 1988 (when DMSP imagery first became available) to 1999. The current project comprised:

- Analysis of the subsequent years 2000 –2002 winter-spring growth.
- Analysis of the summer breakout history for the entire period 1988-2002.

The first stage was to determine the location, magnitude, and timing of sea ice breakouts, using the satellite images, with Figure 1 as a template. The magnitude and location were tabulated with reference to the locations on Figure 1. In Figure 1 the five breakout patterns are identified and the magnitude of each pattern is determined on a scale of 1 to 3.

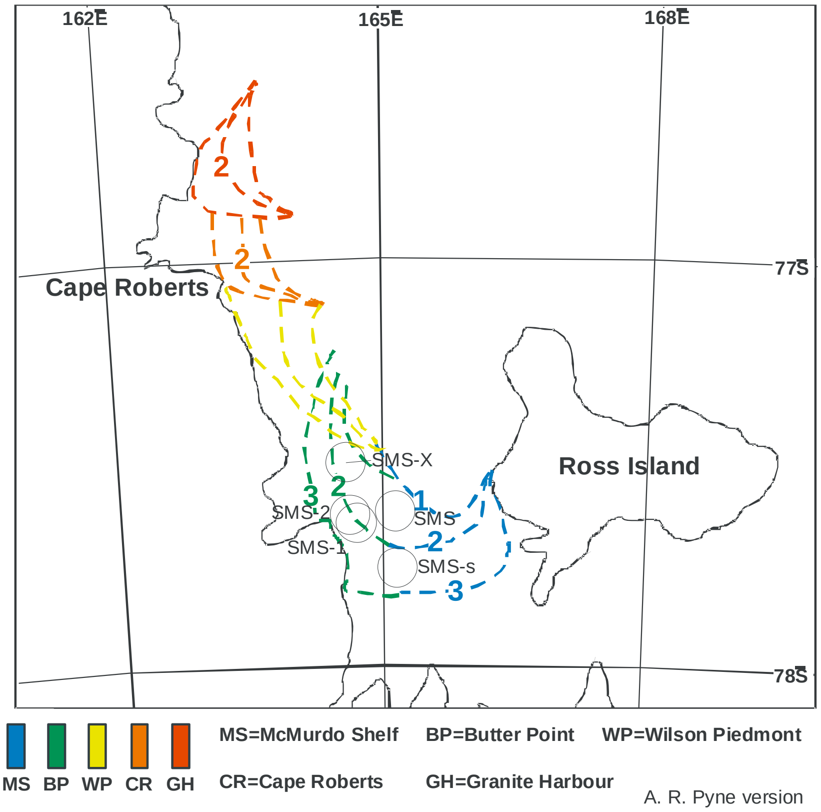


Figure 1. Map showing breakout zones and proposed SMS drill sites

The breakout magnitudes are displayed with previously analysed data in Figures 2a-c, which shows individual breakout events in each of the 15 years analysed. Mean temperature information from the Marble Point AWS is also included on Figure 2.

The satellite images were analysed to determine breakout events for Granite Harbour and New Harbour (Appendix 1).

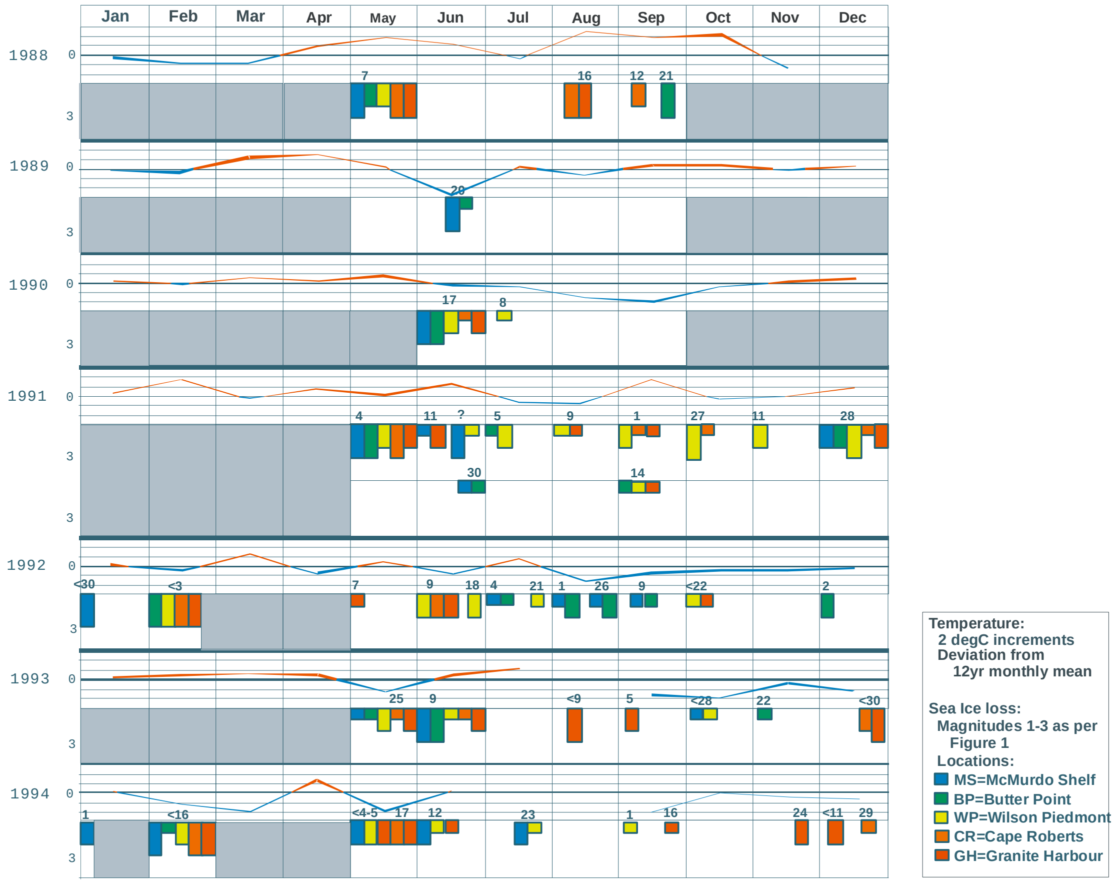


Figure 2a. Breakout events and temperature 1988-94

Figure 2b. Breakout events and temperature 1995-1998

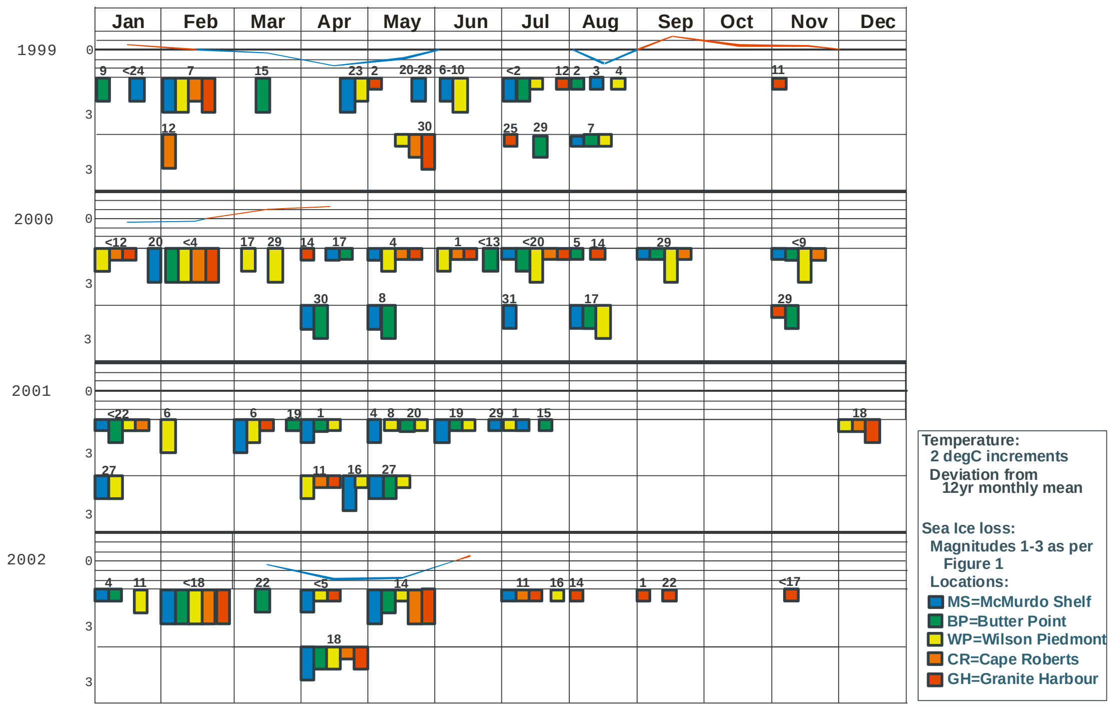


Figure 2c. Breakout events and temperature 1999-2002

The analysis developed in this stage was used as a starting point to examine breakouts at the specific sites proposed for ANDRILL drilling (Table 1).

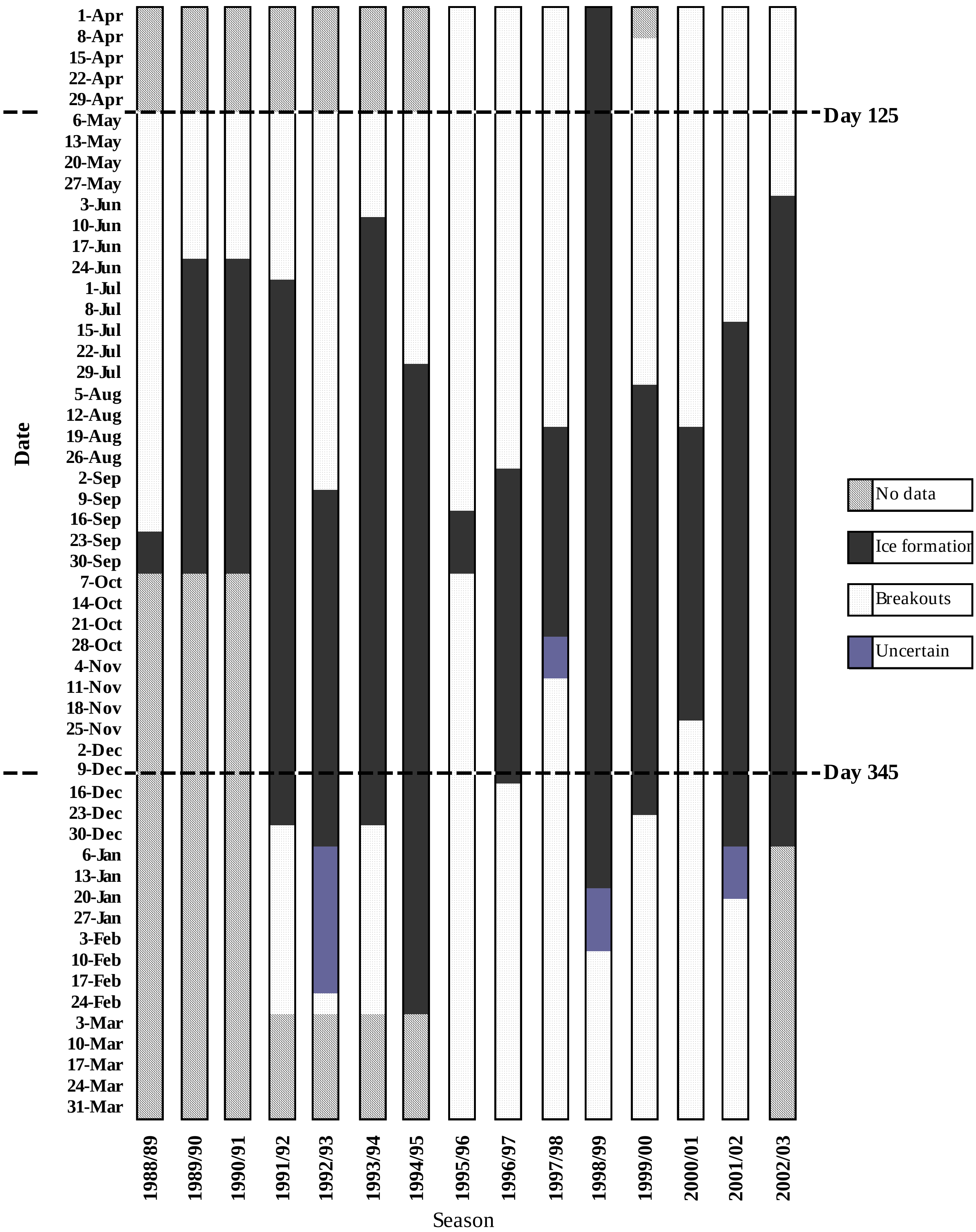
Table 1: Proposed Southern McMurdo Sound Drill sites:

Site name	Shot point	Latitude	Longitude
SMS	(SP 3252 IT90A-70)	**77.63°S**	**165.115°E**
SMS-1	SP 241 PD90-01/02)	**77.65°S**	**164.706°E**
SMS-2	(SP 361 PD90-01/02)	**77.625°S**	**164.623°E**
SMS-X	(SP 621 PD90-15)	**77.494°S**	**164.567°E**
SMS-s	n/a	**~77.76°S**	**165.115°E**

The next stage was to determine two key dates: the last breakout of the autumn and the first breakout of the summer. Breakouts within a 5km radius of each proposed site were considered. This allowed us to determine the length of time in which the sea ice platform could form (Figures 3a-d).

A simple model derived from historical measurements of sea ice thickness over the period of ice formation was used to determine whether ice would have developed the thickness required for drilling.

Figure 3a. Sea ice formation period for SMS



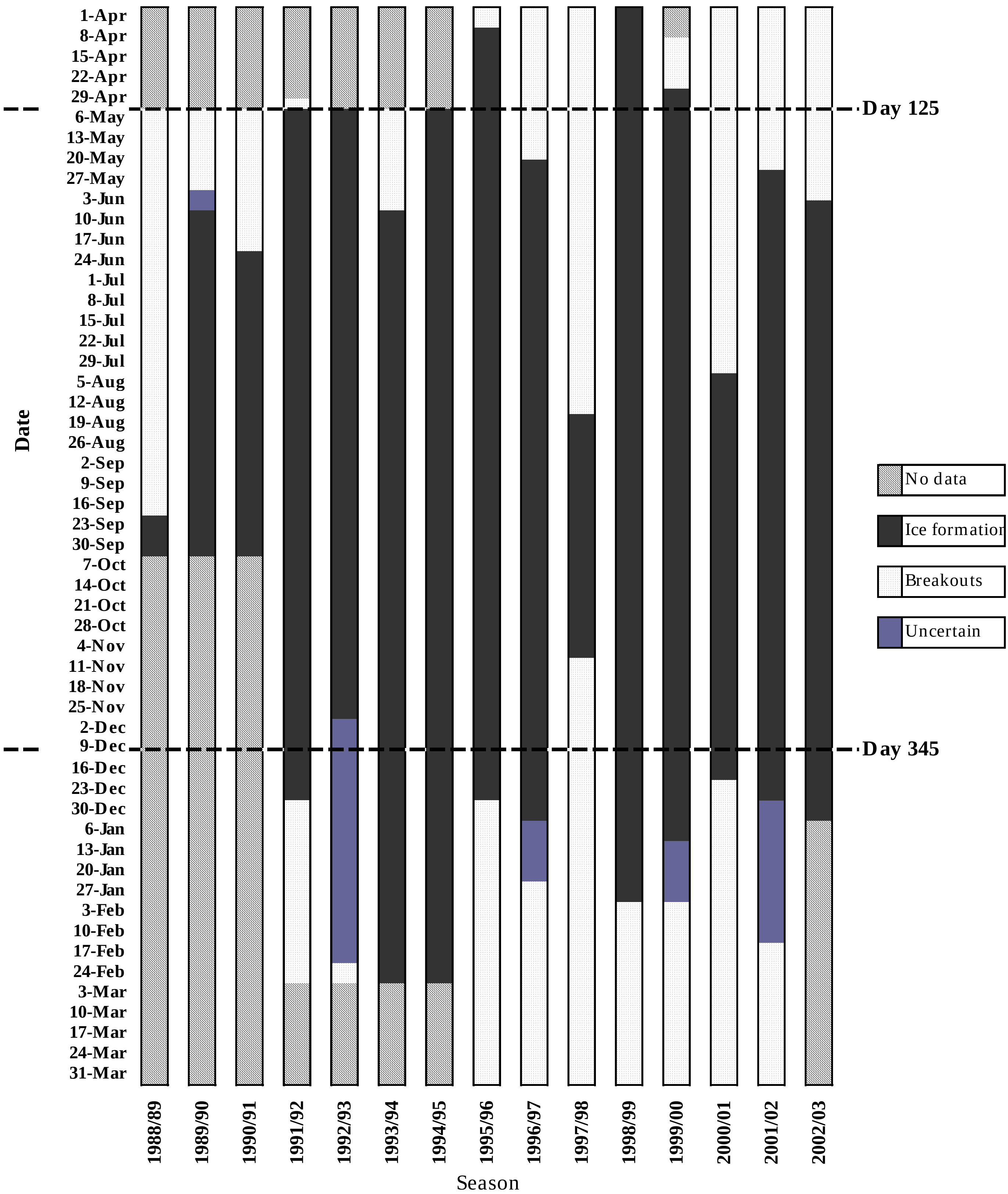


Figure 3b. Sea ice formation period for SMS1 & SMS-2

Figure 3c. Sea ice formation period for SMS-X

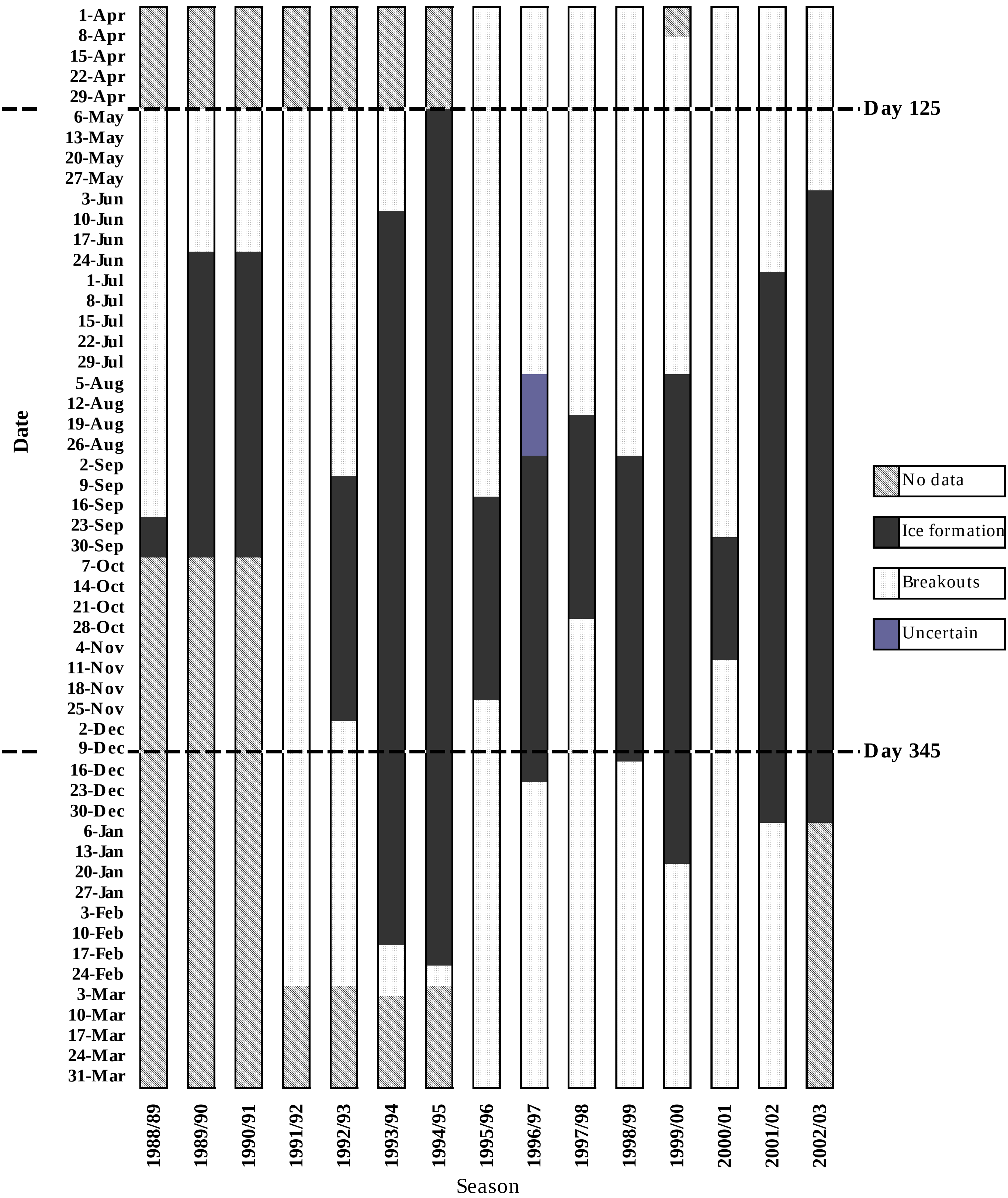
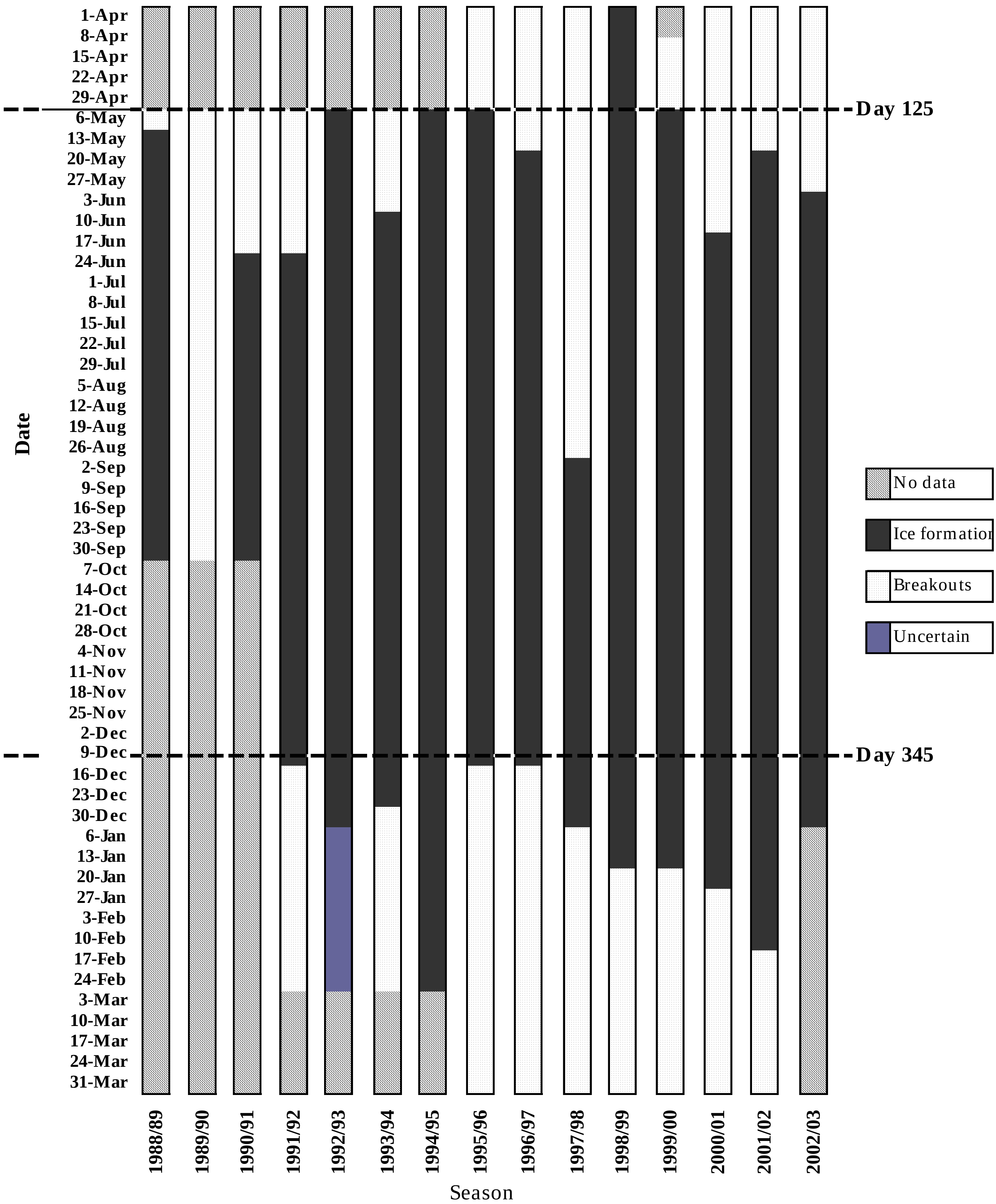


Figure 3d. Sea ice formation period for SMS-s



2.5 Constraints

Massive icebergs C-16 and B-15 became jammed and grounded against Ross Island in July 2001, and anecdotal evidence, especially relating to shipping access to McMurdo Station indicated that they could be retaining more sea ice longer in the southeastern part of McMurdo Sound. The analysis reported here for McMurdo Sound winter growth/breakout and SMS specific sites does not show a significant reduction in winter breakout in the years when the iceberg is present. Neither does there seem to be a significant change to the timing of summer ice breakout for the SMS sites. The iceberg is now breaking into smaller bergs and most are moving away from the McMurdo area.

It seems unlikely that other large bergs will calve from the same area in the next five years, but circulation patterns may mean that bergs calved elsewhere end up in the McMurdo Sound area.

3. Criteria for ANDRILL sea-ice drilling

3.1 Drilling Platform

Past experience, especially the recent Cape Roberts Project (CRP) has improved our understanding and estimates of the ice thickness required for a suitable drilling platform. CRP used a minimum ice thickness of 1.5m (by approximately day 260). In 1997 CRP-1 was started in a minimum thickness situation and the ice thickness was considered marginal. The minimum ice thickness in combination with an unusually stormy and warm spring period resulted in ice breakout events that required abandoning the drilling operation prior to target completion. The 1997 ice thickness at the CRP-1 site corresponds to the thin ice population (Figure 4).

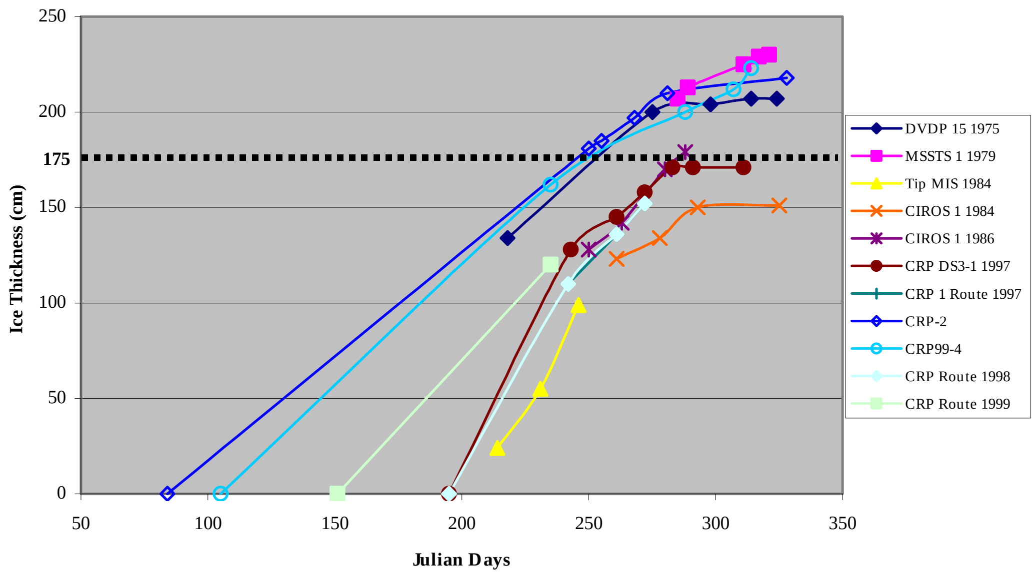


Figure 4. Measured sea ice growth

In subsequent years 1998 and 1999 CRP drilling was carried out successfully without significant sea ice thickness problems at the drill site. These two years are in the "thick" ice population (Figure 4). This experience has shown that the 1.5m minimum thickness was probably inadequate for CRP drilling.

The ANDRILL drilling system will be significantly larger and heavier than that used by CRP. Some of the greater ice loadings from this new equipment will be compensated by submerged air bags installed beneath the sea ice platform. **However the minimum ice thickness required for the drilling platform is now estimated to be 1.75m at day 250 for the SMS sites. This requires drilling platform ice stabilisation by day 100 to 125.** Further ice growth after day 250 to day 275 would normally be expected and is required to ensure safe demobilisation at the end of the drill period.

3.2 Vehicle Routes

The ice thickness for vehicle routes can be less than for the drilling platform because the ice along the route is only subjected to short loading by moving vehicles. Minimum thickness is still required and CRP experience suggests that a **minimum ice thickness of 1.25m is required by day 250 with an expectation of continued growth to day 275. This requires an ice route stabilisation date of day 200.**

3.3 End of sea ice drilling season

The end date for the sea ice drilling season will be controlled by the condition of the sea ice. The ice conditions are affected by ice and atmosphere warming, surface melting of ice and snow and the condition of any route transitions from sea ice to permanent ice or land. The ice condition will vary from season to season but past experience indicates that about 10 December (day 344-345) is probably a reasonable end date for planning purposes. The breakout analysis also indicates that in some years early summer breakout in mid December can also occur and this possibility will also will have to take into account in planning an acceptable drilling window for specific sites.

4. Results

4.1 Breakouts

4.1.1 General breakout pattern

Analysis of the satellite imagery in previous work showed that similar patterns in the breakout events occur from year to year. Five standardised breakout patterns have been identified when storm events cause the loss of fast ice from a nominal October fast ice area. The nominal October fast ice distribution is not a rigorous average for the last 15 years. It can be approximated by a fast ice edge that curves west and north westwards from Cape Royds to about 15-20km off-shore of Marble Pt then parallels the western coastline of South Victoria Land resulting in a fast ice strip 20–22km wide.

The nominal ice edge for the McMurdo Ice Shelf (MS) breakout pattern is about 30km north of the ice shelf, so a magnitude one event would cause about a 10km loss of fast ice and a magnitude three event would be a breakout to within a kilometre of the ice shelf edge. The nominal ice edge for the Butter Point breakout region (BP) is approximately 22kms offshore, and this is also the case for Wilson Piedmont area (WP). The typical breakout patterns in these areas are not symmetrical in geography or magnitude. The patterns overlap because variations occur from year to year. It is unusual that only one breakout area will be affected during a single storm event unless the magnitude of the breakout is low; more commonly breakouts overlap the standardised areas.

Figures 2a-c show fast ice breakout events as groups of coloured bars of magnitudes 1 to 3 "hung" from a horizontal line with the date of the event above the bar group. Some breakout events such as those on July 14 1997 and May 30 1999 have occurred when a breakout event is initiated, mobilising the ice but the ice then becomes "frozen" before the mobile ice is completely lost from the area. The ice is then reincorporated into the fast ice zone with new ice growth started inshore. These events are shown in the same way as completed breakout events but a diagonal line is incorporated into the bar. From an operational viewpoint the new ice growth becomes the limit to ice surface transport in the area and these breakout events are significant.

4.1.2 General analysis conclusions

- The "winter" climate that affects sea ice breakout and growth in McMurdo Sound appears to have two states. The "calm" state with cold temperatures enables ice growth to initiate and stabilize early in the winter March-May, allowing ice to grow thick so that any subsequent breakout events are generally small. The "stormy" state and probably warmer temperatures does not allow ice stabilisation in the March–May period so large more regular breakouts of winter ice continue to occur through June-July and often into August.
- The earliest time that an indication of which state is current for a particular season can be made is probably not possible until late May-June. However confirmation of state and an estimate of early September ice thickness are only realistic until late July or early August.
- In the calm state winter breakout events are small and seem to be regularly distributed between the south and western areas of McMurdo Sound. In the stormy state large breakouts can occur in any of the area and there is little indication that the south and south-western area is any more "protected" than areas further north, in fact in some stormy seasons the area off-shore of Cape Roberts can be more stable than further south.

4.1.3 Granite Harbour/New Harbour

The analysis of late summer breakouts of Granite Harbour and New Harbour is relatively simple and results are tabulated in Appendix 1. These breakouts commonly occur in two phases, with the outer harbour breaking out approximately a week before the complete breakout. However, the harbours do not clear of ice every year. For the years in which images are available, breakouts occur during February and March. The harbours tend to clear of ice after the whole western McMurdo Sound coastline breaks free of ice, and this also does not occur every year.

4.2 Temperature

Figure 5 compares the mean temperature records for Scott Base and Marble Point. Scott Base temperatures are generally about 3-5°C cooler during the primary winter sea ice growth period and this probably reflects the general south east airflow off the McMurdo and Ross Ice shelves. Sites SMS-1/2 and SMS-s are closer to the McMurdo Ice Shelf so might be expected to also be influenced by cooler ice shelf airflows like Scott Base. The northerly and offshore sites SMS and SMS-X are more likely to see temperatures closer to those of Marble Point. It is likely that an intermediate value between the two records is appropriate to southerly SMS sites for ice growth calculations.

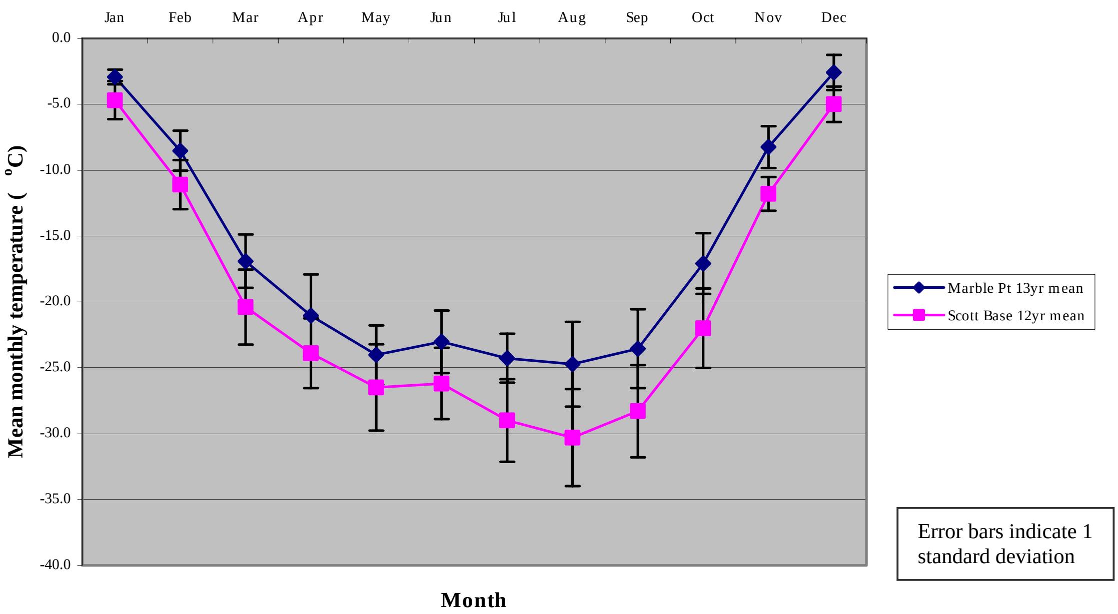


Figure 5. Mean monthly temperature – Marble Point AWS & Scott Base

Figure 2(a-c) also incorporates air temperature data from the Marble Point Automatic Weather Station (AWS). This figure shows the monthly mean temperatures as a deviation from the mean of 13 years of data (1988-2000). The temperature deviation for each year is displayed above the breakout event bars and is coloured red for temperatures warmer than the 13 year mean and blue for temperatures cooler than the 13 year mean.

4.3 Ice formation

The growth rate of fast sea ice is dependent on air temperature. The ice thickness that is attained is related to the time over which the sea ice remains stable without breakout. The breakout analysis reported in this study primarily determines the time period for ice growth. We have used historical ice thickness measurements from the western side of McMurdo Sound to determine a semi quantitative model of ice growth rates (Figure 4).

The determination of more rigorous ice growth rates from mathematical ice growth models would require site-specific temperature and snow accumulation measurements. Snow accumulation has a significant effect on growth rate. Because most of the sea ice that we are interested in for drill site platforms and vehicle routes forms annually it is unlikely that a site could be instrumented, meaning that remote sensing techniques (satellite imagery) would be required to determine temperature and snow accumulation.

The historical measurements of ice thickness indicate two populations of ice growth (Figure 4). For five of the ice growth curves the date that ice started growing can be estimated based on the satellite imagery analysis methodology used in this study. It is not possible to determine the start date for the other six curves, as there is no matching satellite data. The "thick" ice population requires ice stabilisation around day 100, (early season) and ice should be expected to reach a thickness of 2.0m by day 265. The "thin" ice population has an initiation date around day 200 and is only likely to reach a thickness of about 1.7m by day 265 when growth rate slows significantly. The two ice thickness populations are probably related to the two seasonal climate states we have identified in the sea ice breakout analysis.

5. Analysis of proposed SMS drill sites

The satellite imagery was re-examined specifically for five areas in southwestern McMurdo Sound. Four of these areas correspond to the proposed SMS sites and a fifth area (SMS-s), 15km due south of SMS, which may be considered in the future for drilling. The four areas were each defined as the area within a circle 5km radius centred on the target point, to incorporate a 5km ice buffer zone seaward of the drill site (Figure 1). The areas for sites SMS-1 and SMS-2 overlap, are parallel to the coast and experience the same breakout pattern so were analysed as a single area.

Evaluation of each area was carried out by checking the breakout history against individual imagery for the 15 years of data as shown in Figure 3 a, b, c and d. A latest ice stabilisation date of day 125 is used to determine which years would have provided a sufficiently thick drilling platform, as displayed in Table 2.

Table 2: SMS site evaluation by years – would drilling have been viable?

	SMS	SMS-1&SMS-2	SMS-X	SMS-s
1988	No	No	No	Yes
1989	Yes	No	No	No
1990	No	No	No	No
1991	No	Yes	No	No
1992	No	Yes	No	Yes
1993	No	No	No	No
1994	No	Yes	Yes	Yes
1995	No	Yes	No	Yes
1996	No	Maybe	No	Maybe
1997	No	No	No	No
1998	No	Yes	No	Yes
1999	No	Yes	No	Yes
2000	No	No	No	No
2001	No	No	No	Maybe
2002	No	No	No	No
Total	**1 year**	**6 to 7 years**	**1 year**	**6 to 8 years**

The evaluation shows:

- For SMS and SMS-X sites only 1 year in 15 (6.7%) would have provided a sea ice platform 1.75 m thick (@day 250) suitable for drilling.
- For SMS1/2 and SMS-s 6-8 years of 15 (40% - 53%) would have provided a sea ice platform 1.75 m thick (@day 250) suitable for drilling.
- For the SMS 1/2 area. Of the 6-7 years considered suitable for drilling, 2-3 years (33-42%) had early summer breakout within the month of December.
- For the SMS-s area. Of the 6-8 years considered suitable for drilling 3 years (38–50% had early summer breakout within the month of December.
- For SMS-1/2 and SMS-s, where drilling is possible for about 50% of the time, it should be noted that this does not indicate drilling in alternate years. There were as many as three consecutive years where drilling would not have been possible.

References

Pyne A. R. 2001. Sea Ice – Chapter 6. In Cape Roberts Project Final Report 1995-2001, Cowie J. (Ed.). Antarctica Miscellaneous Series No.8, ISBN: 0-478-10962-8

Appendix 1: Granite Harbour and New Harbour breakout history 1987-2002

Season	Missing data	Granite Harbour	New Harbour
Summer 87/88	Missing data Sep, Oct, Jan, Feb, Mar, Apr		
Summer 88/89	Missing data Oct-Apr		
Summer 89/90	No data		
Summer 90/91	Missing data Oct-Apr (except 9/2/91)	Breakout some time before 9th Feb, possibly open at west 9th May	Possibly full of drift ice on 9th Feb. Probably clear prior to 4th May
Summer 91/92	Not many images. Missing data mid-Feb to Apr	Clear at south 3rd Feb, completely clear 10th Feb	Clear 3rd & 10th Feb (missing later data)
Summer 92/93	No images for most of Oct, most of Dec, all of Jan, most of Feb, most of Mar, all of Apr		
Summer 93/94	Missing data late Feb-Apr		
Summer 94/95	Missing data Mar	Clear 23rd Feb	Obscured for late Feb & missing later data
Summer 95/96		Breakout between 15th Feb and 15th Mar	Possible partial breakout/weak ice 10th Apr
Summer 96/97		Part breakout at Cape Roberts 4th Feb, complete breakout during Feb.	Clear at east 30th Jan (previous image 1st Jan), further clearance 4th Feb, but ice remains at west
Summer 97/98		Breakout at south 19th Feb	Not cleared
Summer 98/99		Slightly free of ice 21st Feb, totally clear before 15th Mar	Not cleared

Season	Missing data	Granite Harbour	New Harbour
Full year 1999		Slightly free of ice 21st Feb, totally clear before 15th Mar	Not cleared
2000		Broken out completely between 4th and 25th Feb. Clear until 11th March. Half broken back out between 17th and 29th March, stays out until 7th Apr, possibly as late as 13th Apr.	Weak on 7th, clear on 11th, refrozen by 17th.
2001		No breakouts	No breakouts
2002		Broken out at south 2nd Mar, further clearing by 12th but ice still remains at north until 20th. Open water in western Granite Harbour on 31st March (ice to east)	No breakouts

NB Grey indicates insufficient data available