DATA LIBRARY
Woods Hole Oceanographic Institution

U.S. Department
of Transportation

**United States
Coast Guard**

Report of the International Ice Patrol in the North Atlantic

**1998 Season
Bulletin No.84**
CG-188-53

shelve : bulletin of the United States Coast Guard

GB
2427
.N5
U5
no.84

DATA LIBRARY
Woods Hole Oceanographic Institution

U.S. Department
of Transportation

**United States
Coast Guard**

Report of the International Ice Patrol in the North Atlantic

1998 Season
Bulletin No.84
CG-188-53

shelve : bulletin of the United States Coast Guard

GB
2427
.N5
U5
no.84

Bulletin No. 84

REPORT OF THE INTERNATIONAL ICE PATROL IN THE NORTH ATLANTIC

Season of 1998

CG-188-53

Forwarded herewith is Bulletin No. 84 of the International Ice Patrol, describing the Patrol's services, ice observations and conditions during the 1998 season.

R. L. DESH
Commander, U. S. Coast Guard
Commander, International Ice Patrol

MBL/WHOI
0 0301 0040707 8

International Ice Patrol
1998 Annual Report

Contents

Introduction 3
Summary of Operations 5
Iceberg Reconnaissance & Oceanographic Operations 11
Ice and Environmental Conditions 17
Monthly Sea Ice Charts 23
Biweekly Iceberg Charts 33
Acknowledgements 47
Appendix A: Nations Currently Supporting International Ice Patrol 49
Appendix B: Ship Reports 51
Appendix C: Qualitative Assessment of the Iceberg Detection and Identification Capabilities of RADARSAT 55

LIST OF ACRONYMS AND ABBREVIATIONS

ADRO	RADARSAT Application Development and Research Opportunity
AXBT	Air-deployable eXpendable BathyThermograph
BAPS	iceBerg Analysis and Prediction System
CAMSLANT	Communications Area Master Station Atlantic
C-CORE	Centre for Cold Ocean Research and Engineering
CCRS	Canadian Centre for Remote Sensing
CFR	Canadian Ice Service reconnaissance aircraft
CIIP	Commander, International Ice Patrol
CIS	Canadian Ice Service
DFO	Canadian Department of Fisheries and Oceans
DN	digital number (RADARSAT backscatter values)
EGAREG	Eastern Canada Vessel Traffic Services Zone
FLAR	Forward-Looking Airborne RADAR
FNMOC	USN Fleet Numerical Meteorology and Oceanography Center
IRD	Ice Reconnaissance Detachment
IGOSS	Integrated Global Ocean Services System
IIP	International Ice Patrol
ISAR	Inverse Synthetic Aperture RADAR
km	kilometer
LAKI	Limit of All Known Ice
m	meter
METOC	Canadian Forces Meteorological and Oceanographic Center
NIC	National Ice Center
NMF	CAMSLANT's international call-sign
NOAA	National Oceanic and Atmospheric Administration
OMW	Ocean Monitoring Workstation
RT	RADAR Target
SAR	Synthetic Aperture RADAR
SOLAS	Safety Of Life At Sea
SST	Sea Surface Temperature
SLAR	Side-Looking Airborne RADAR
USCG	United States Coast Guard
UTC	coordinated universal time
WOCE	World Ocean Circulation Experiment

Introduction

This is the 84th annual report of the International Ice Patrol (IIP). It contains information on Ice Patrol operations, environmental conditions, and iceberg conditions for the 1998 IIP season. The U. S. Coast Guard conducts the Ice Patrol in the North Atlantic under the provisions of the U. S. Code, Title 46, Sections 738, 738a through 738d, and the International Convention for the Safety of Life at Sea (SOLAS), 1974. The IIP is supported by 17 member nations (Appendix A). It was initiated shortly after the sinking of the RMS TITANIC on April 15, 1912 and has been conducted yearly since that time.

Commander, International Ice Patrol (CIIP) is under the operational control of Commander, Coast Guard Atlantic Area. CIIP directs the Ice Patrol from its Operations Center in Groton, Connecticut. IIP receives iceberg location reports from ships and planes transiting its patrol area and conducts aerial iceberg reconnaissance detachments (IRDs) to survey the southeastern, southern, and southwestern regions of the Grand Banks of Newfoundland for icebergs. IIP analyzes ice and environmental data and employs an iceberg drift and deterioration model to produce twice-daily iceberg warnings, which are broadcast to mariners as ice bulletins and radio-facsimile charts. IIP also responds to requests for iceberg information. Ice Patrol's IRDs were based in St. John's, Newfoundland, Canada during the 1998 season.

The cover is a picture of a U. S. Coast Guard Air Station Elizabeth City HC-130 flying over an iceberg near the Grand Banks of Newfoundland while conducting Ice Patrol reconnaissance. Photo by PA1 Brandon Brewer.

Vice Admiral Kent H. Williams was Commander, Atlantic Area. CDR Stephen L. Sielbeck was Commander, International Ice Patrol.

For more information concerning the U. S. Coast Guard International Ice Patrol, including daily iceberg bulletins and facsimiles, see IIP's website at http://www.uscg.mil/lantarea/iip/home.html.

Summary of Operations

The 1998 ice year (1 October 1997 to 30 September 1998) marked the 84th anniversary of the International Ice Patrol, which was established 7 February 1914. IIP's operating area is enclosed by lines along 40°N, 52°N, 39°W and 57°W (See Figure 1).

IIP's first preseason ice reconnaissance detachment (IRD) of the year departed on 11 February 1998. The 1998 IIP season opened on 13 February, and from this date until 31 July 1998, an IRD operated from Newfoundland approximately every other week. The season officially closed on 31 July 1998.

IIP's Operations Center in Groton, Connecticut analyzed the iceberg sighting information from the IRDs, ships, Canadian Ice Service (CIS) sea ice/iceberg reconnaissance flights, and other sources. IIP received 1,283 reports (Figure 2) and merged 4,644 targets (Figure 3) into the iceBerg Analysis and Prediction System (BAPS) model, the computer program IIP uses to track icebergs. Air reconnaissance, consisting of U.S. Coast Guard (IIP) and other air reconnaissance (which includes CIS), was the major source of iceberg sighting reports this season, accounting for 80% of the icebergs detected.

Although ships provided only 7% of the iceberg sightings received by IIP in 1998, they accounted for 76% of the total number of reports submitted to IIP in 1998. Their continued active participation indicates the value they place on IIP's

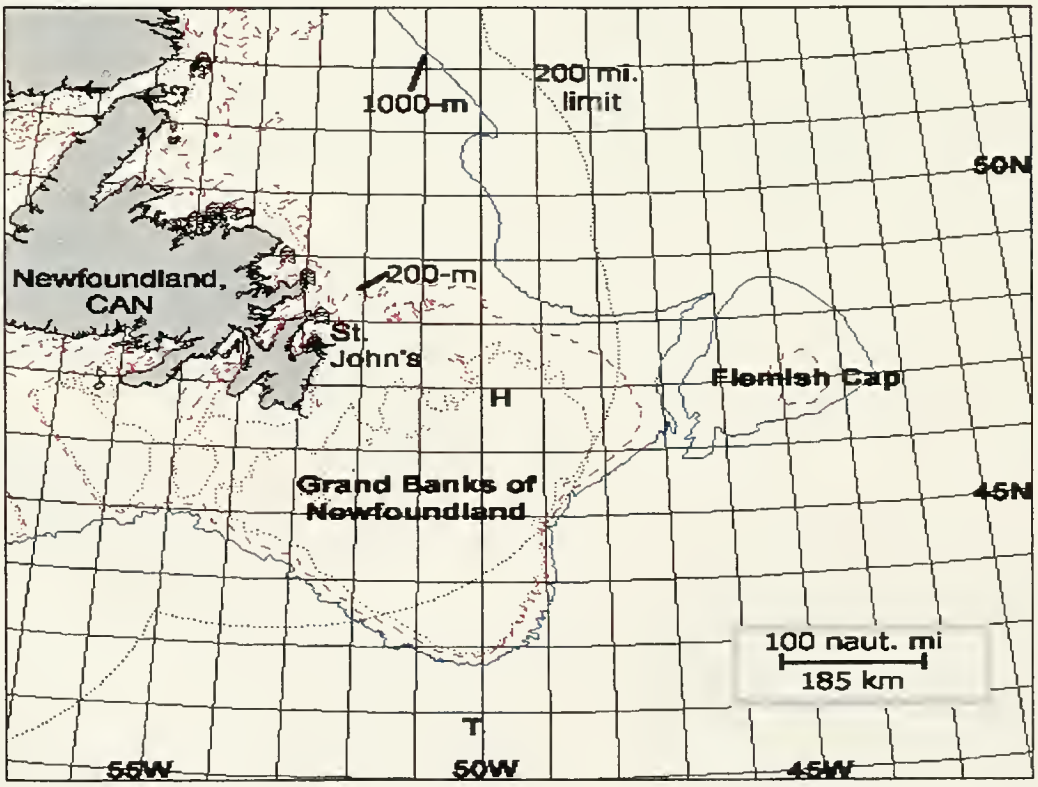

Figure 1. IIP Operations Area on Grand Banks. Location of Hibernia GBS shown by "H", location of TITANIC sinking shown by "T".

service. In 1998, 251 ships of 40 different nations provided ice information to IIP. This demonstrates that the number of nations using IIP services far exceeds the 17 member nations underwriting IIP under SOLAS 1974. Appendix B lists the ships that provided iceberg sighting reports, including reports of stationary radar targets. In Appendix B, a single report may contain multiple targets. Also note that the term "ice report" may include a ship's "report of no ice", which may also contain a report of sea surface temperature (SST) as measured by the ship. The most active ship reporting ice was the M/V MAERSK TORONTO, which sent 32% of all ship reports. Also, aircraft reconnaissance usually reports multiple targets within the same report, while ships report fewer targets per report. Thus, IIP, which accounted for only 5% of the total ice reports in 1998, provided 21% of all targets entered into the BAPS model, and ships, which accounted for 76% of all reports, provided 7% of all merged targets. Regardless of numbers and percentages, the continued success and viability of IIP depends heavily upon all contributors of ice reports.

The largest contributor of air reconnaissance reports was the CIS reconnaissance aircraft, which is used primarily for sea ice mapping. In 1998, it located 2302 targets which IIP merged into BAPS (over 83% of the targets provided by aircraft). The other contributor in this category is Provincial Airlines, Limited, a private company that provides aerial reconnaissance services for Canada's Department of Fisheries and Oceans (DFO) throughout the year, and for CIS from June through December. Although DFO flights are intended to monitor the activities of fishing vessels, they frequently cover areas with high iceberg concentrations. CIS-contracted flights are usually flown closer inshore, along the Newfoundland and Labrador coasts, and map both icebergs and sea ice concentrations.

IIP flew 55 sorties, locating 960 targets that were entered into the BAPS model. This reconnaissance was conducted using RADAR-equipped U.S. Coast Guard HC-130 aircraft, provided by Air Station Elizabeth City, North Carolina. IIP focuses its reconnaissance effort on the boundary of the iceberg danger area, which is called the Limits of All Known Ice (LAKI). This region is generally far

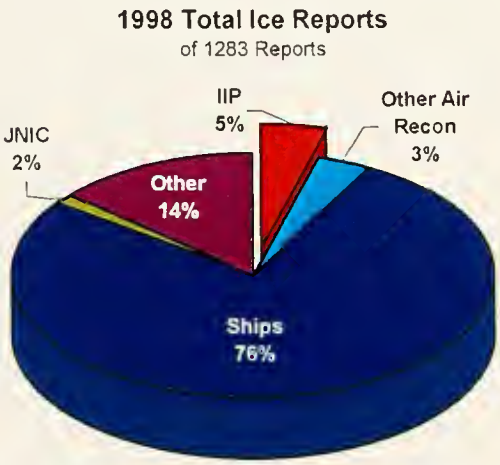

Figure 2. Total ice reports for 1998, including ice, "no-ice" and SST reports..

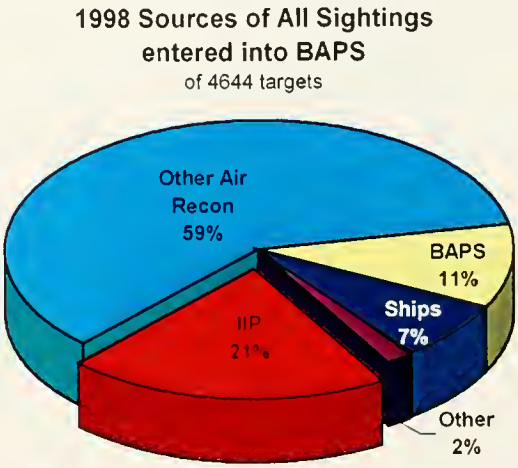

Figure 3. Reporting sources for IIP Ice reports during 1998.

offshore in international waters near the 1000-m depth contour (Figure 1). As a result of this emphasis, IIP detects approximately 50% of the icebergs that define LAKI (Figure 4).

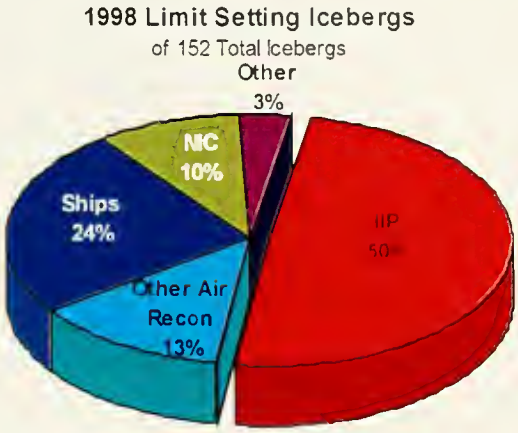

Figure 4. Sources of Limit Setting Icebergs

The differences in the area covered and the operations among the Canadian and IIP flights results in a complementary reconnaissance system which achieves excellent aerial coverage over the entire Grand Banks area. This combined system allows for better coverage than either organization could achieve separately and prevents duplication of effort. Information is shared freely among all organizations.

Although ships of opportunity account for 7% of the total number of targets entered into BAPS, they find 24% of the icebergs that define LAKI. In 1998, the National Ice Center (NIC) detected 10% of the icebergs that defined the iceberg limits.

The "Other" category, which accounted for 3% of the icebergs that defined LAKI, contains reports from less-frequent or less-regular ice reporting sources. IIP receives several ice reports per year from operators of lighthouses along the Newfoundland coast, from commercial transatlantic airlines and from service providers for the Jeanne d'Arc Oil and Gas consortium, which operates several offshore petroleum platforms in the IIP operations area. Finally, the BAPS category contains targets that are originally detected north of the demarcation between IIP and CIS operations areas (52°N latitude) and that drift south across the line with the Labrador Current.

To compare with previous years' ice seasons, 1998 was approximately average in terms of season length and was the second lowest in terms of merged targets (Figure 5). In previous years, IIP has used

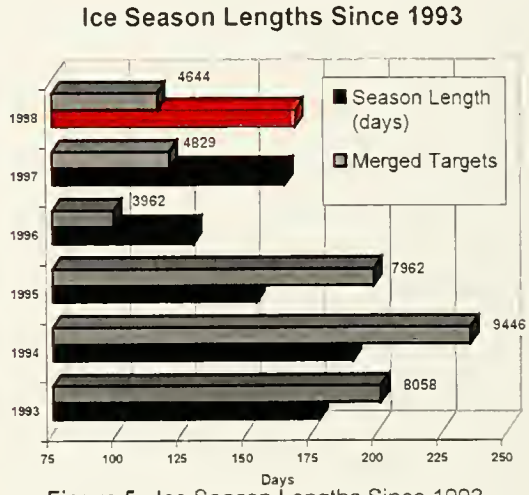

Figure 5. Ice Season Lengths Since 1993.

the number of icebergs south of 48°N as a metric for ice-season severity (Figures 6 and 7). This metric includes both icebergs detected south of 48°N and those that are predicted to drift south of 48°N. The icebergs south of 48°N measurement is generally preferred by IIP because it places the emphasis on icebergs that represent a significant hazard to transatlantic shipping. In addition, IIP may not necessarily merge all reported targets into its database: sightings of targets outside IIP's area of responsibility and coastal icebergs are usually not merged as they represent little threat to transatlantic shipping. Thus, total merged targets is not

necessarily an objective and unbiased measurement from year to year.

Admittedly, season length is related to icebergs south of 48°N, as Commander, International Ice Patrol considers this

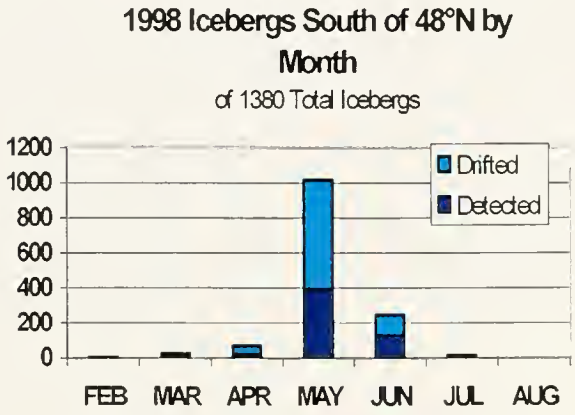

Figure 6. Icebergs South of 48°N for 1998, excluding growlers, bergy bits and radar targets.

measurement in his decision on when to open and close the season. Various authors have discussed the appropriate metric for ice season severity (Alfultis, 1987; Trivers, 1994; Marko, *et al.*, 1994). Comparing 1998 to the past five years and measuring the statistics against historical standards in various papers, 1998 was moderate in terms of length and extreme in terms of icebergs south of 48°N. Moderate for season length is defined as a season between 105 and 180 days. Extreme for icebergs is defined as greater than 600 icebergs south of 48°N (Trivers, 1994, Marko, *et al.*, 1994).

Each day during the ice season IIP prepared and distributed ice bulletins at 0000Z and 1200Z to warn mariners of the southwestern, southern, and southeastern limits of ice. U. S. Coast Guard Communications Area Master Station, Atlantic (CAMSLANT)/NMF in Chesapeake, VA and Canadian Coast Guard Marine Communications and Traffic Service St. John's, Newfoundland/VON were the primary radio stations responsible for the dissemination of the ice bulletins. In addition, ice bulletins and safety broadcasts were delivered over the INMARSAT-C SafetyNET via the AOR-W satellite. Other transmitting stations for the bulletins included Canadian Forces METOC (Meteorology and Oceanography) Centre Halifax, Nova Scotia/CFH, Marine Communications and Traffic Services in St. Anthony, Newfoundland/VCM, and Radio Station Bracknell, UK/GFA.

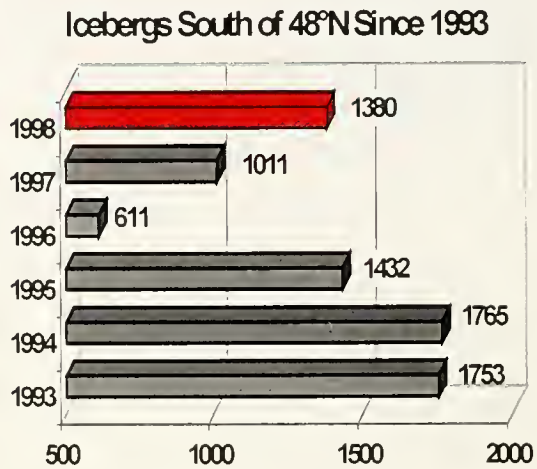

Figure 7. Icebergs South of 48°N since 1993, excluding growlers, bergy bits and radar targets.

IIP sent 338 text bulletins in 1998. IIP measures the quality and timeliness of the bulletins it delivers to the mariner via the SafetyNET service, as this is the primary product for IIP's largest customer base. Of 338 total bulletins sent, 330 (93%) arrived on the system on time, or by 0000Z or 1200Z, respectively. Of the 338 bulletins, 330 (98%) were error-free when delivered. The late deliveries mainly resulted from communications system failures, and the erroneous bulletins were primarily a function of human error. IIP also sent seven safety broadcasts. IIP sends these special broadcasts whenever late-breaking ice information, received

between the release of the 0000Z products and the 1200Z products, results in a change to the IIP limits.

IIP also prepared a daily facsimile chart, depicting the limits of all known ice, for broadcast at 1600Z and 1810Z daily. In addition, the facsimile chart was placed on the World Wide Web on IIP's web site. U. S. Coast Guard Communications Area Master Station, Atlantic/NMF and the NOAA/National Weather Service assisted with the transmission of these charts. Canadian Coast Guard Marine Communications and Traffic Service St John's, Newfoundland/VON and U. S. Coast Guard Communications Area Master Station, Atlantic/NMF also provided special broadcasts as required.

In 1998, IIP sent 338 ice facsimile charts. Of these, 314 (93%) were delivered on time and 334 (99%) were sent without errors. Late ice facsimile charts are defined as those for which the radio-frequency start tone starts greater than one minute later than 1600Z or 1810Z, respectively. The primary cause of late ice facsimile charts was communications-system errors. The primary cause of erroneous ice facsimile charts was computer or operator error.

As in previous years, International Ice Patrol requested that all ships crossing through the area of the Grand Banks report ice sightings, weather, and sea surface temperatures (SST) via Canadian Coast Guard Radio Station St John's/VON, U.S. Coast Guard Communications Area Master Station Atlantic/NMF or INMARSAT-C or INMARSAT-A using code 42. Ships are encouraged to make ice reports even if "no ice" is sighted (Reports with "no ice sighted" are included in IIP's statistics as ice reports). Knowledge of where ice is not found is also very important to IIP. IIP has tabulated the number of reports received and the start/end date of the 1998 Ice Season (See Table 1). Appendix B lists all contributors. IIP received relayed information from the following sources during the 1998 ice year: Canadian Coast Guard Marine Communications and Traffic Service St. John's/VON; Canadian Coast Guard Vessel Traffic Center/Ice Operations St. John's; Ice Center Ottawa; Canadian Coast Guard Marine Communication and Traffic Services Halifax, Nova Scotia/VCS; ECAREG Halifax, Nova Scotia; U.S. Coast Guard Atlantic Area Command Center; and U.S. Coast Guard Automated Merchant Vessel Emergency Response/ Operations Systems Center, Martinsburg, WV. Commander, International Ice Patrol extends a sincere thank you to all stations and ships that contributed reports during

Table 1. Iceberg and Sea Surface Temperature (SST) Reports

Type/Source	Number or Date
Ships Furnishing Reports	249
Total Reports Received	987
Ships Furnishing Reports with SST	110
Reports Received with SST	682
First Ice Bulletin	13FEB98
Last Ice Bulletin	31JUL98
Length of Season	169

Table 2. Newfoundland Lighthouse Iceberg Reports

Lighthouse	Number of Reports
Bacalhao	79
Bell Island	57
Twillingate	23
Cape Race	11
Belle Isle Southwest	3
Belle Isle Northeast	1
Total	**174**

the 1998 ice year. The vessel providing the most reports was the MAERSK TORONTO, a Cyprus flag vessel.

In addition, Ice Patrol receives land-based lighthouse reports from stations along the coast of Newfoundland (See Table 2), reports from commercial airlines, and reports from the Joint National Ice Center in Suitland, MD.

References

Alfultis, M.A., 1987. Iceberg Populations South of 48° N since 1900, Appendix B in *Report of the International Ice Patrol in the North Atlantic*, Bulletin No. 73, 1987 Season, CG-188-42, 63-67.

Marko, J. R., D. B. Fissel, P. Wadhams, P. M. Kelly and R. D. Brown, 1994. Iceberg Severity off Eastern North America: Its relationship to Sea-ice Variability and Climate Change. *Journal of. Climate*, **7**, 1335-1351.

Trivers, G., 1994. International Ice Patrol's Season Severity, Appendix C in *Report of the International Ice Patrol in the North Atlantic*, Bulletin No. 80, 1994 Season, CG-188-49, 49-59.

Iceberg Reconnaissance & Oceanographic Operations

Reconnaissance Operations

The U. S. Coast Guard International Ice Patrol (IIP) formally begins its seasonal ice observation and Ice Patrol service whenever icebergs threaten primary shipping routes between Europe and North America. This usually occurs in the month of February and the threat usually extends through July, but the Ice Patrol is flexible and commences operations when iceberg conditions dictate. The 1992 season, the longest on record, ran from March 7th through September 26th, 203 days. Except during unusually heavy ice years, the Grand Banks are normally iceberg free from August through January. The activities of the International Ice Patrol are delineated by treaty and U.S. law to encompass only those ice regions of the North Atlantic Ocean that affect transatlantic shipping routes. Fixed wing Coast Guard aircraft conduct the primary reconnaissance work for the Ice Patrol. Ice reconnaissance flights are made on the average of five days every other week during the ice season. The mainstay of the Ice Patrol flights for the past 20 years has been the Hercules HC-130H aircraft.

USCG HC-130H long-range surveillance aircraft equipped with Side-Looking Airborne RADAR (SLAR) and Forward-Looking Airborne RADAR (FLAR) systems are used to conduct iceberg reconnaissance and monitor the location of iceberg threats to the transatlantic mariner. U. S. Coast Guard aircraft are the primary means of detecting icebergs, which form the limit of all known ice (LAKI). When iceberg reconnaissance is not being conducted, IIP relies on computer modeling of the iceberg drift and deterioration to determine iceberg position and size updates. The computer model ingests ice reconnaissance data, environmental data, and historical ocean current data to predict iceberg drift and deterioration. The LAKI is based on the model output.

The Ice Reconnaissance Detachment (IRD) is a sub-unit under Commander, International Ice Patrol with Commanding Officer, Air Station Elizabeth City providing the aircraft platform. The IRD is deployed to observe and report the ice and oceanographic conditions in the vicinity of the Grand Banks of Newfoundland. Commander, International Ice Patrol (CIIP), disseminates this ice information to shipping as per Title 46, USC Section 738a and the Convention on the Safety of Life at Sea (SOLAS). Oceanographic observations are used for operational and research purposes at IIP.

Environmental conditions are favorable for visual reconnaissance in and around the vicinity of the Grand Banks approximately 20-30% of the time during ice reconnaissance operations. Therefore, Ice Patrol relies heavily on the combination of Side-Looking Airborne RADAR and Forward-Looking Airborne RADAR to detect and identify icebergs through fog and/or cloudy conditions. A more detailed description of IIP reconnaissance procedures is provided on Ice Patrol's web page:

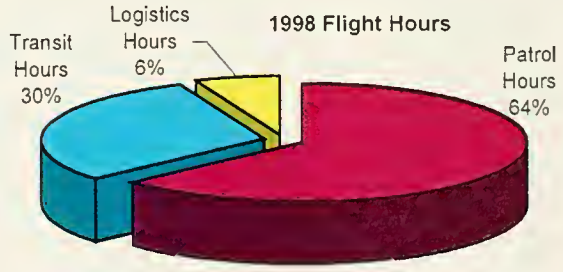

Figure 8. 1998 Flight Hour Usage

http://www.uscg.mil/lantarea/iip/home.html.

During 1998, 116 aircraft sorties were flown in support of IIP. Of these, 55 were transit flights to St. John's, Newfoundland, IIP's base of operations. There were 55 ice observation or patrol sorties conducted to locate the south-western, southern and southeastern limits of icebergs. Six logistics flights were required to support and maintain the patrol aircraft operational status. Figure 8 shows IIP's flight hour usage for 1998. As indicated in Table 3, Ice Patrol schedules aerial reconnaissance every other week rather than every week. This is due, in part, to the ability of the FLAR and SLAR RADAR combination on the HC-130 to detect and differentiate

Table 3. 1998 IIP Ice Reconnaissance Detachment Summary.

IRD #	DATE DEPART	DATE RETURN	RESOURCE DAYS	FLIGHT HOURS	TOTAL SORTIES
PRE	26-Jan-98	31-Jan-98	6	35.2	9
1	11-Feb-98	18-Feb-98	8	31.3	7
2	25-Feb-98	06-Mar-98	10	30.1	7
3	11-Mar-98	19-Mar-98	9	37.4	8
4	26-Mar-98	02-Apr-98	8	42.5	9
5	8-Apr-98	15-Apr-98	8	33.7	8
6	22-Apr-98	29-Apr-98	8	31.4	9
7	7-May-98	15-May-98	9	50.3	11
8	22-May-98	30-May-98	9	42.6	9
9	3-Jun-98	12-Jun-98	10	37.8	8
10	17-Jun-98	26-Jun-98	10	47.6	11
11	1-Jul-98	08-Jul-98	8	44.5	9
12	15-Jul-98	23-Jul-98	9	26.3	6
POST	28-Jul-98	31-Jul-98	4	11.7	5
1998 TOTAL			**116**	**502.4**	**116**

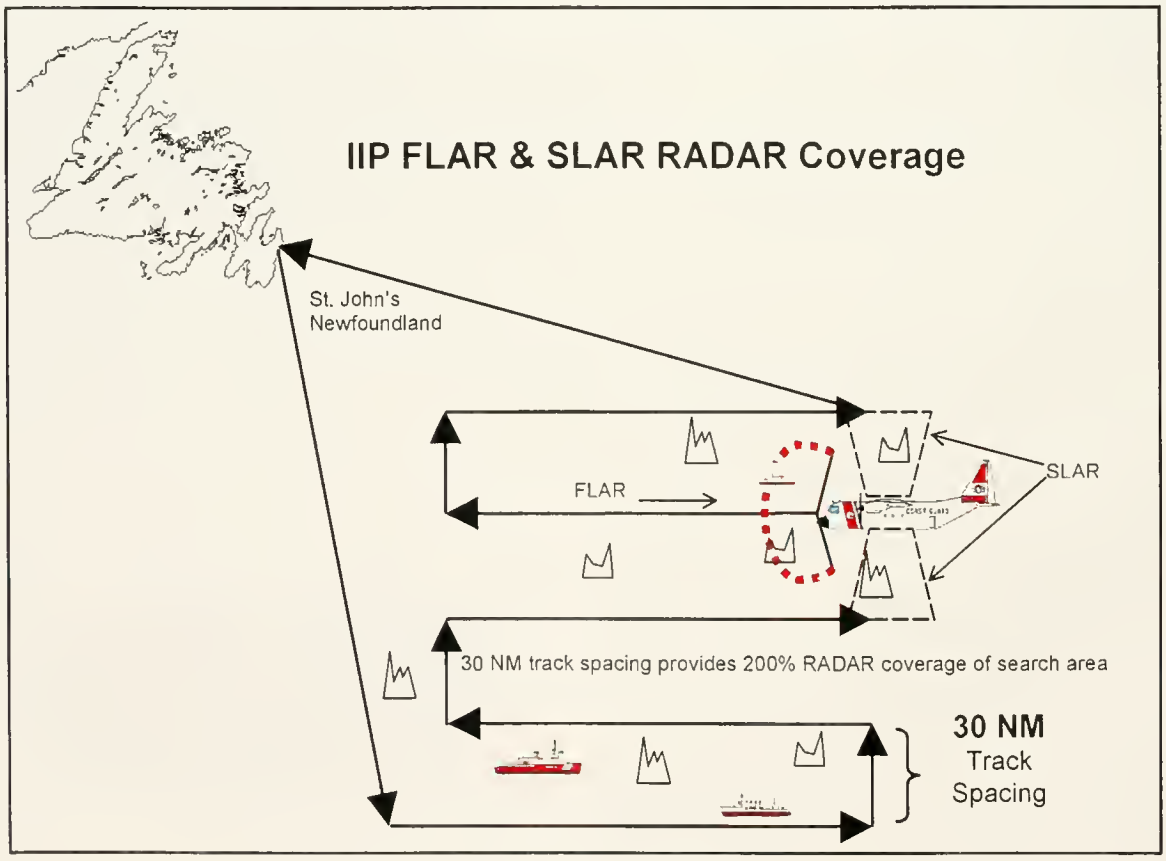

Figure 9. IIP Radar Reconnaissance Plan.

icebergs in the pervasive low visibility reconnaissance conditions. SLAR has been used by IIP since 1982, and FLAR since 1993. This RADAR combination also allows IIP to use a 30 nautical mile (nm) track spacing as compared to a 10 (nm) track spacing which was used prior to 1983. Figure 9 shows how the HC-130H with SLAR and FLAR are able to cover a larger geographic area of ocean and still provide 200% RADAR coverage and 30 nm track spacing. The 30 nm track spacing allows IIP to cover approximately 100,000 nm^2 of ocean in good or poor visibility conditions as opposed to approximately 20,000 nm^2 with a 10 nm track spacing in only good visibility conditions.

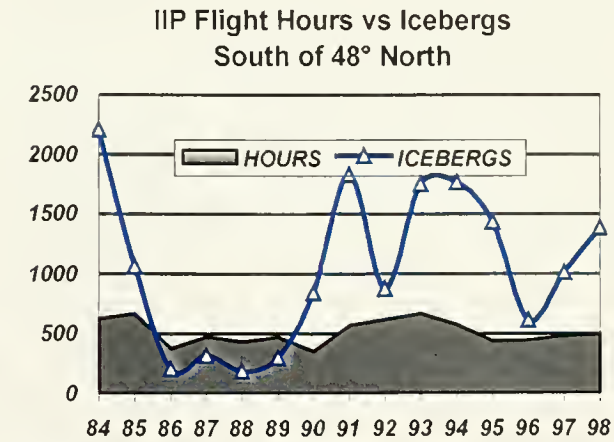

Figure 10. 1994 to 1998 comparison of the number of icebergs south of 48° North to IIP's total flight hours.

Figures 10 & 11 show the comparison of flight hours versus the number of icebergs south of 48° North latitude since 1983. This graphic shows that although the threat to the transatlantic mariner may vary, Ice Patrol still must ensure that the Grand Banks region of the North Atlantic ocean is safe for navigation. Thus, the flight hour usage over time. In addition, a few icebergs may greatly

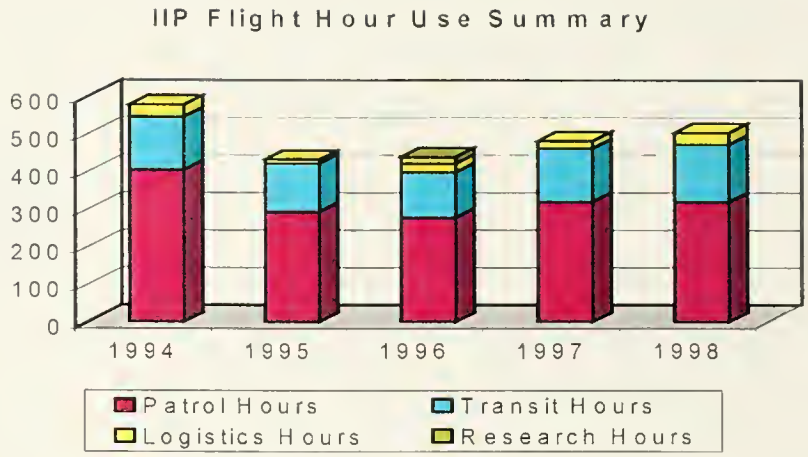

Figure 11. 1994 to 1998 flight hour use summary.

extend LAKI even though there may not be a large number of icebergs posing a threat to the mariner. Therefore, Ice Patrol often is in the position to patrol a large area of ocean with sparsely spaced iceberg targets.

Figure 12 provides a breakdown of numbers and types of targets detected during 1998 IIP reconnaissance patrols. The three general categories are icebergs, vessels and RADAR targets. When flying reconnaissance in low visibility conditions it is difficult to determine whether a target is an iceberg or a vessel. Occasionally, Ice Patrol will detect and confirm other types of targets such as marine life, fishing markers, etc. The Grand Banks region is a

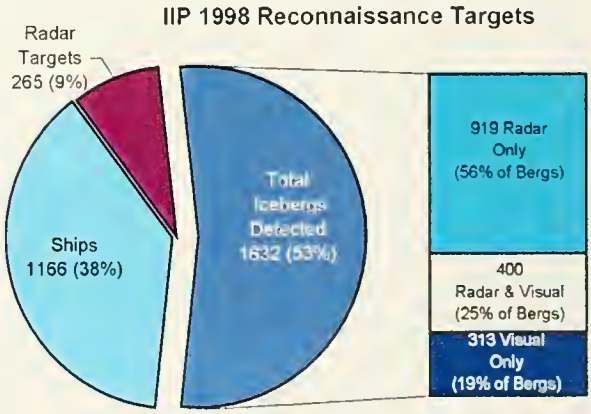

Figure 12. A breakdown of the 1998 IIP reconnaissance targets

major fishing area, frequented by fishing vessels ranging in size from 60 ft to over 200 ft. Since 1997, the Grand Banks region has rapidly been developed for its oil reserves. In November of 1997, the gravity-based oil platform "Hibernia" was set in position approximately 150 nm offshore on the north eastern portion of the Grand Banks. Each year, there have been several other mobile drilling rigs in the White Rose and Terra Nova oil fields. This increased development of the Grand Banks has increased air and surface traffic in IIP's search area further complicating Ice Patrol's reconnaissance efforts in distinguishing icebergs from other types of targets. As previously mentioned, the addition of FLAR in 1993 has provided IIP with a reliable method of discriminating targets without actually visually confirming the target. This method works well for larger targets but is very difficult with small fishing vessels and smaller icebergs. Often, both present similar RADAR returns and may not be able to be differentiated. The unknown RADAR targets in Figure 13 represent 9% of all targets in the search area. Of the 1632 icebergs detected, 56% were detected and identified with RADAR only. This further emphasizes the need for FLAR and the continuing need to pursue technological innovations in reconnaissance equipment.

Figure 13 and Table 4 illustrate IIP's efforts to determine iceberg size. Of the 1430 "larger" icebergs, many are determined to be icebergs by FLAR but size determinations are not made. Accurate size measurements are not available while operating with FLAR; therefore all "RADAR" icebergs are given a medium size classification for the IIP drift and deterioration model. Intuitively, one could assume there is a greater distribution of different sized icebergs throughout the IIP operating area.

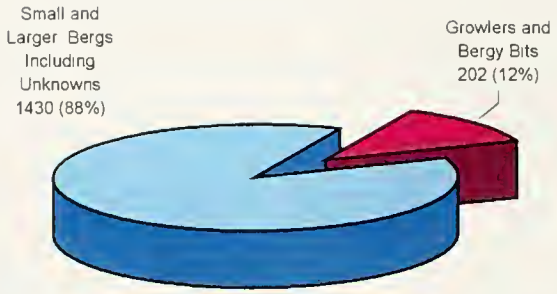

Figure 13. 1998 IIP detected icebergs by size.

Oceanographic Operations

During the 86-year history of IIP, extensive oceanographic tests were conducted in the Grand Banks and Greenland regions. These oceanographic operations peaked in the 1960s when the U. S. Coast Guard devoted vessel assets solely for collecting oceanographic data. Currently, the Ice Patrol uses only air assets during operational patrols. Oceanographic data are collected using air-deployed satellite-tracked drifting buoys and air expendable bathythermograph (AXBT) probes. Figure 14 summarizes the drift of 13 drifters deployed in 1998. For specific drifter information, request IIP's 1998 Buoy Atlas. In addition, Ice Patrol drifter data are archived and available from the National Oceanographic Data Center.

Table 4. Iceberg Size Categories.

Size Category	Height		Length	
	Feet	Meters	Feet	Meters
Growler	<17	<5	<50	<15
Small	17-50	5-15	50-200	15-6-
Medium	51-150	16-45	201-400	61-122
Large	151-240	46-75	401-670	123-213
Very Large	>240	>75	>670	>213

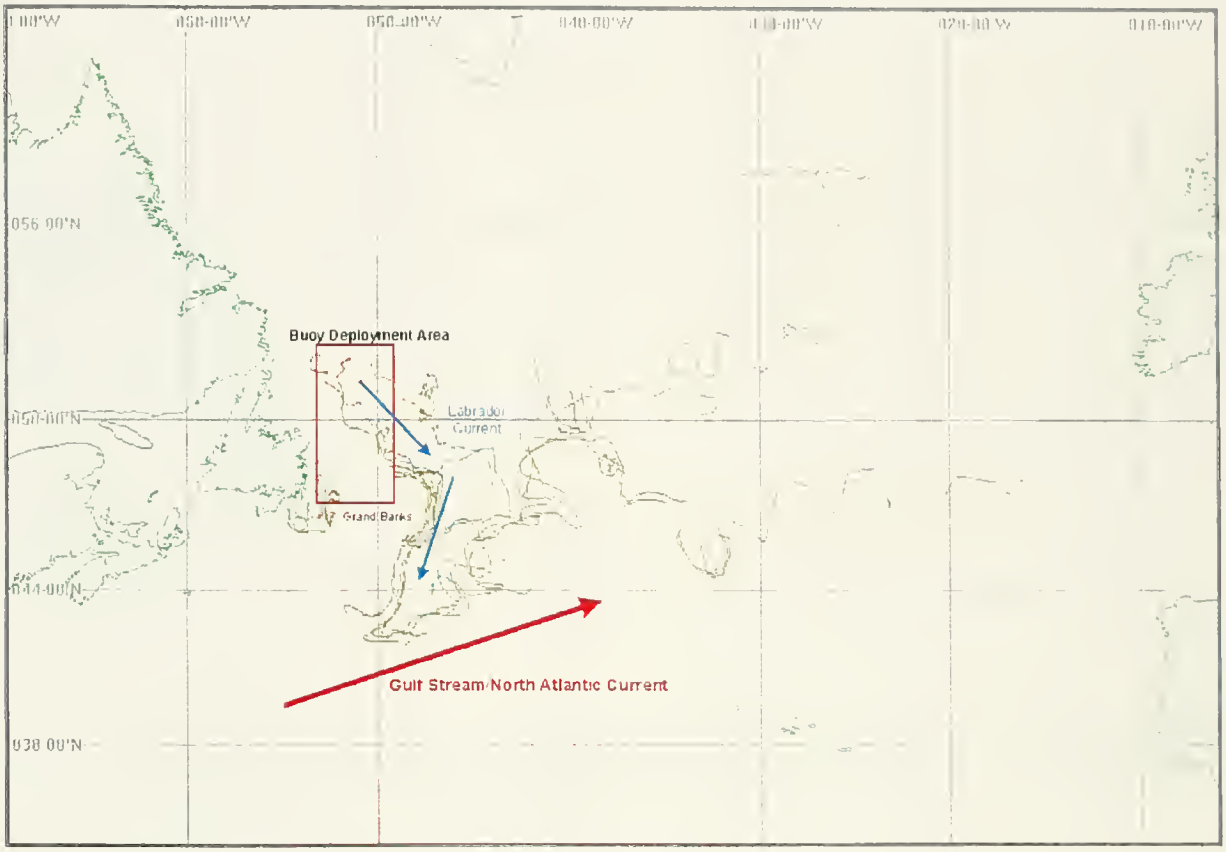

Figure 14. Spaghetti plot of 1998 satellite-tracked drifters.

IIP also drops AXBT probes to determine the water temperature profile down to approximately 300 meters. This information is coded into the standard JJYY format and sent to METOC Halifax Canada, the U. S. Navy's Fleet Numerical Oceanographic and Meteorological Center (FNMOC) and the Naval Oceanographic Center. At FNMOC, the data are processed, quality controlled and redistributed via FNMOC's oceanographic model products. For more information on FNMOC, see their web site at http://www.fnmoc.navy.mil/.

Figure 15 shows how IIP's AXBT program has developed since 1994. The failures in 1998 were from flaws in IIP's AXBT receiver system. In 1999, IIP awarded a contract to replace the AXBT receiver with a rugged, reliable system to reduce AXBT failures.

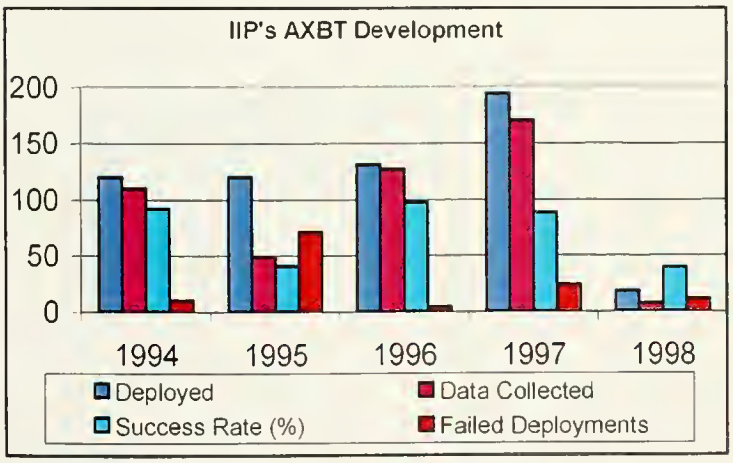

Figure 15. IIP AXBT program statistics for 1994 through 1998.

Ice and Environmental Conditions During the 1998 Iceberg Season

1998 Iceberg Season

Many factors combine to shape the severity of an iceberg season in the western North Atlantic Ocean. They may be divided into three main categories. First are those factors affecting the supply of icebergs to the southern Labrador coast, including calf ice production at the various glaciers and deterioration processes in Baffin Bay that might destroy the icebergs before they reach the shipping lanes. The second category includes factors relating to the mechanisms that destroy icebergs in east Newfoundland waters, such as the duration and areal extent of the sea-ice cover, air and sea surface temperature (SST), and storm tracks. The final category includes those factors relating to the movement of icebergs once they reach the vicinity of the Grand Banks of Newfoundland, primarily the ocean currents in the region, and to a lesser extent, winds.

Since there is no routine monitoring of calf ice production or iceberg destruction in Baffin Bay, the following discussion focuses on the second and third categories. This discussion draws from several sources, including the Seasonal Summary for Eastern Canadian Waters, Winter 1997-1998 (Canadian Ice Service, 1998); sea-ice analyses provided by Canadian Ice Service (CIS) and the United States National Ice Center (NIC); and the Integrated Global Ocean Services System Products (IGOSS) SST Anomaly (Climate Data Library, International Research Institute for climate prediction at Lamont-Doherty Earth Observatory of Columbia University); and, finally, summaries of the iceberg data collected by Ice Patrol. It is useful to compare the 1997-1998 sea-ice and iceberg observations to the historical record to emphasize departures from normal. For sea ice, Cote (1989) provides maximum, median and minimum extent of sea-ice cover along the eastern Canadian seaboard at weekly intervals from mid-November through the end of July. The maps are based on a 25-year record beginning in 1962. Viekman and Baumer (1995) present an iceberg limits climatology from mid-March to 30 July based on 21 years of Ice Patrol observations from 1975 through 1995. They provide the extreme, median, and minimum extent of the limits of all known ice (LAKI) for the period, as well as two intermediate extents, the 25th and 75th percentiles. The 75th percentile means that, for the 21-year period, 75% of the limits for a particular date extended beyond the 75th percentile limit.

December 1997 through February 1998

Sea-ice development along the Labrador coast was near normal in December 1997 and January 1998, but warmer-than-normal air temperatures in the second half of February resulted in southern and eastern ice edges that were less extensive than normal at the end of month. The SST along the southern Labrador and northeast Newfoundland coasts was near normal, except near the Strait of Belle Isle where it was about 1° C colder than normal. In east Newfoundland waters, the January southern and eastern ice extents were near normal. The Strait of Belle Isle was closed for navigation in mid-January. A series of storms during the last two weeks of February caused a reduction in the eastward extent of the ice edge in east Newfoundland waters. The 1998 iceberg season began on February 13,

1998, which is about two to three weeks earlier than normal. However, this early start to the season was not indicative of a widespread iceberg threat south of 48° N in mid-February. Rather, a single very large iceberg (Fig. 25) had passed through Flemish Pass in early February and moved rapidly southward in the offshore branch of the Labrador Current. As it broke apart near 45° N it created several smaller icebergs and many growlers (Fig. 26), creating a hazardous environment for mariners, some of whom expressed alarm at the situation. During the month of February eight icebergs passed south of 48° N latitude.

March

During March, the SST on the Grand Banks and in the offshore branch of Labrador Current was within a degree of normal. A series of strong storms and above-normal air temperatures resulted in southern and eastern sea-ice limits that were less extensive than normal at mid-month. The southern limit was about 120 nm north of its normal position. By month's end the sea-ice distribution returned to normal. After the few isolated southern icebergs melted, the limits of all known ice (LAKI) retreated substantially (Fig. 27). The mid-March LAKI was at the 75th percentile. By the end of March (Fig. 28) the iceberg distribution was about normal. Ice Patrol estimated 26 icebergs passed south of 48° N in March.

April

In April, the SST on the Grand Banks and offshore branch of the Labrador Current was again near normal. The southern part of the Ice Patrol operations area, south of 44° N, was more than a degree warmer than normal. The sea-ice distribution at mid-month was slightly greater than normal, but some ice destruction began to occur along the edge during the second half of the month. The LAKI during April (Fig. 29) were again at the 75th percentile. However, by mid-month, IIP started to receive reports of extraordinary numbers of icebergs between 48° N and the Strait of Belle Isle. In fact, on 21 APR, CIS detected over 1000 icebergs during a single reconnaissance flight. By the end of April (Fig. 30) there were over 1600 icebergs between 48° N and the Strait of Belle Isle. By the end of April large numbers of icebergs that had been seen within the sea ice were emerging into open water; thus they became exposed to the accelerated deterioration processes, wave attack and warmer ocean temperatures. Ice Patrol estimated that during April 70, icebergs passed south of 48° N.

May

The sea-ice edge began a rapid retreat, most notably the eastern limit. By mid-month most of the continental shelf northeast of Newfoundland was sea-ice free, with only the area within 90 nm of the northern peninsula having significant sea ice. At the end of May the sea ice retreated north of the Strait of Belle Isle, although the dense population of icebergs in and east of the Strait continued to discourage mariners from using this passage. From mid-April to mid-May there had also been a dramatic reduction in the offshore extent of the sea ice along the southern Labrador coast, thus exposing the upstream icebergs to deterioration. In the second half of May there was a moderate-to-strong easterly wind pattern and coincident 2-3° C higher-than-normal air temperatures along the southern Labrador coast, which accelerated ice destruction. In fact, by the end of May, there was very little sea ice south of

Hamilton Inlet. This occurrence was about two weeks earlier than usual. During May, the SST on the Grand Banks was 1-2° C above normal, while at the Tail of the Bank it was 2-3° C above normal (Fig. 16). More than 1000 icebergs were estimated to have passed south of 48° N in May, the largest number of icebergs for any one month in IIP's history. By the end of the month, there were over 500 icebergs south of 48° N. In mid-month (Fig. 31), the LAKI were at the median. By the end of the month (Fig. 32), LAKI expanded to approximately the 25th percentile, with the exception of the eastern limits, which were being held at an extreme position by a small number of isolated icebergs.

June

In most areas east of Newfoundland, the SST was 1-2° degrees warmer than normal. The mean air temperature for June was also 1-2° C above normal for both Newfoundland and southern Labrador. During the entire month, the LAKI were near the median (Figs. 33 and 34), but it was clear that the iceberg season was waning. By mid-month the number of icebergs south of 48° N diminished dramatically from the previous month (379 to 171), indicating rapid deterioration was taking place. The number of icebergs between 48° N and the Strait of Belle Isle also shows a substantial reduction during the same period. Part of

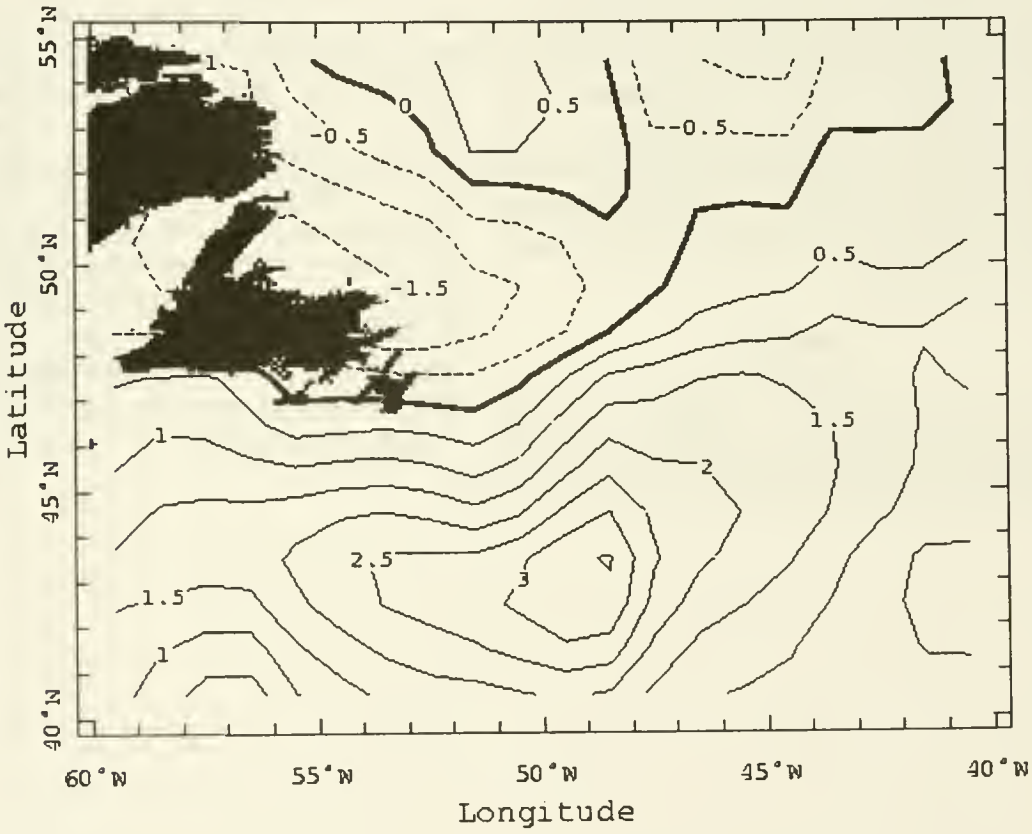

Figure 16. Sea Surface Temperature Anomaly on the Grand Banks of Newfoundland during May 1998.

the reason for this decline might be the fact that IIP aerial reconnaissance was focusing on the areas near the LAKI: thus, there were fewer opportunities to detect icebergs north of 48° N. The number of icebergs estimated to have passed south of 48° N during June was 247, a substantial reduction from May's 1017.

July

The trend of warmer-than-normal SST continued in July, with most east Newfoundland areas experiencing temperatures 1-2° C above normal. In Newfoundland and southern Labrador, the air temperature was 1-2° C above normal for July. The number of icebergs south of 52° N continued to decline precipitously. By mid-July it was evident that the iceberg season was nearing its end. In mid-month (Fig. 35), the LAKI were at the median, and by month's end they declined to the minimum extent, with only 3 icebergs south of 48° N. During July, 15 icebergs passed south of 48° N. The iceberg season closed on 31 July 1998.

Summary

Two primary indicators of the severity of an iceberg season are the number of icebergs passing south of 48 N and season length. In 1998, Ice Patrol estimated that 1384 icebergs passed south of 48° N, which by all scales (Trivers,1994) classifies the 1998 season as severe. This places the 1998 season in the top 10 of the most severe seasons on record (8th), but well below the successive severe seasons in the early 1990s. On the other hand, the 169-day season length classifies the season as average (Trivers,1994), despite the season's early start. It is likely that the warmer-than-normal SST in east Newfoundland waters hastened the season's end in July and prevented the season from exceeding 180 days in length, which would place it in the severe classification.

Much publicity was given to the fact that the 1997-1998 El Nino was one of the strongest in the recent record, exceeded only by the 1982-1983 event since 1950 (Wolter and Timlin, 1998). There was some apprehension about the 1998 season because, on some occasions, severe El Nino events have been followed by severe iceberg seasons, although the link is by no means well established. While the 1998 iceberg season was well above average and maybe even severe, it falls far short of being a record-setter, even for the decade of the 1990s.

References

Cote, P. W., 1989. *Ice Limits Eastern Canadian Seaboard*. Unpublished Manuscript, Canadian Ice Service, 373 Sussex Drive, Ottawa, Ontario, Canada K1A 0H3, 39 pp.

Viekman, B. E. and K. D. Baumer, 1995. *International Ice Patrol Iceberg Limits Climatology (1975-1995)*, Technical Report 95-03, International Ice Patrol, 1082 Shennecossett Road, Groton, CT 06340-6096, 20 pp.

Canadian Ice Service, 1998. *Seasonal Summary for Eastern Canadian Waters, Winter 1997-1998*. Unpublished Manuscript, Canadian Ice Service, 373 Sussex Drive, Ottawa, Ontario, Canada K1A 0H3, 11 pp.

IRI/LDEO Climate Data Library . IGOSS monthly SST Anomaly data
URL: http://ingrid.ldgo.columbia.edu/SOURCES/.IGOSS/.nmc/.monthly/.ssta/ (8 May 2000)

Trivers, G., 1994. International Ice Patrol's Iceberg Season Severity. App. C in: *Report of the International Ice Patrol in the North Atlantic*, Bulletin No. 80, 1994 Season, CG-188-49, 49-59

Wolter, K, and M. S. Timlin, 1998. Measuring the strength of ENSO – how does 1997/98 rank? *Weather*, **53**, 315-324.

1998 Monthly Sea Ice Charts

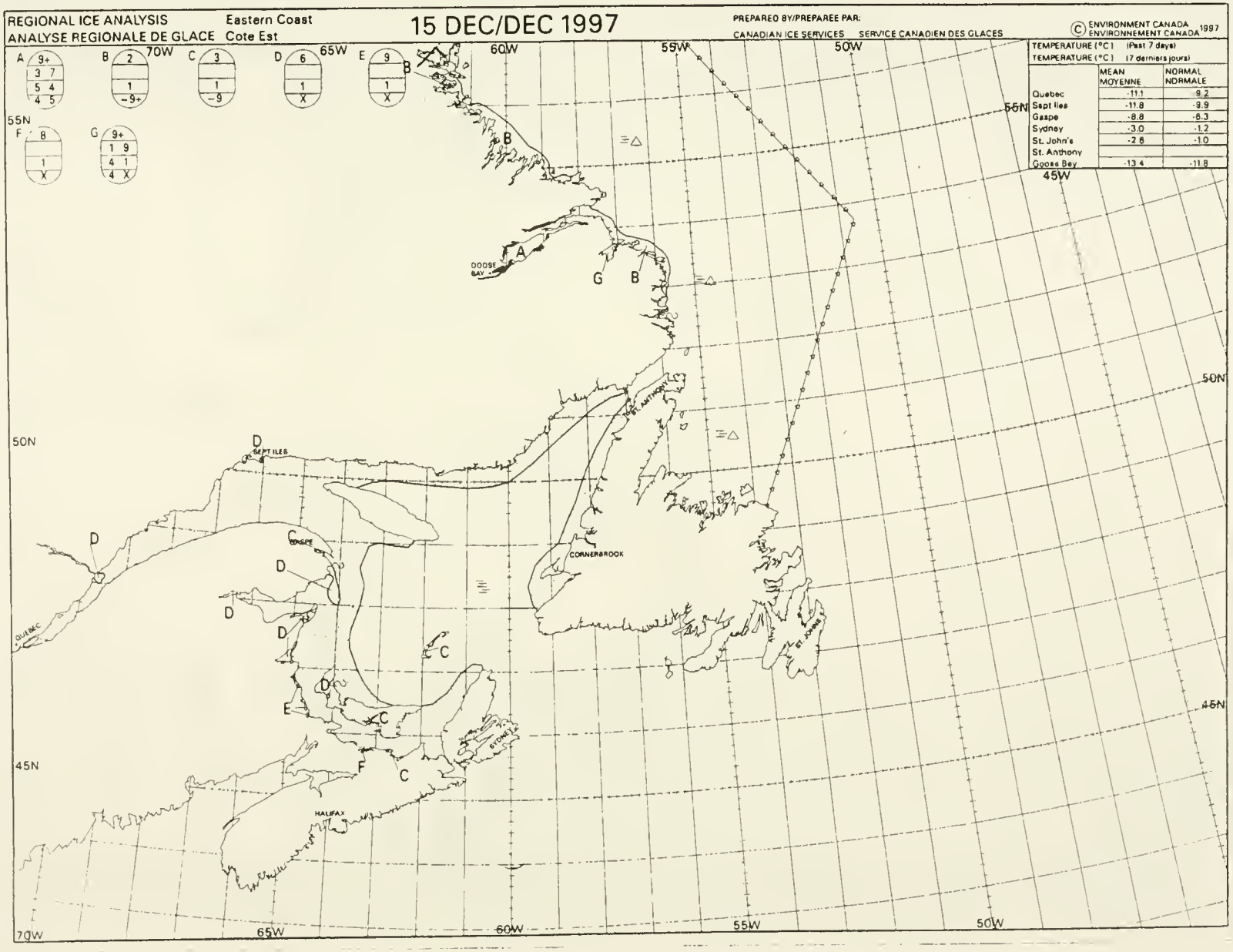
REGIONAL ICE ANALYSIS
ANALYSE REGIONALE DE GLACE
Eastern Coast
Cote Est
15 DEC/DEC 1997
PREPARED BY/PREPAREE PAR:
CANADIAN ICE SERVICES SERVICE CANADIEN DES GLACES
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 1997
TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec -11.1 -9.2
Sept Iles -11.8 -9.9
Gaspe -8.8 -6.3
Sydney -3.0 -1.2
St. John's -2.6 -1.0
St. Anthony
Goose Bay -13.4 -11.8
GOOSE BAY
ST. ANTHONY
SEPT ILES
GASPE
CORNERBROOK
QUEBEC
ST. JOHNS
STONEY
HALIFAX
70W
65W
60W
55W
50W
45W
55N
50N
45N

Figure 17.

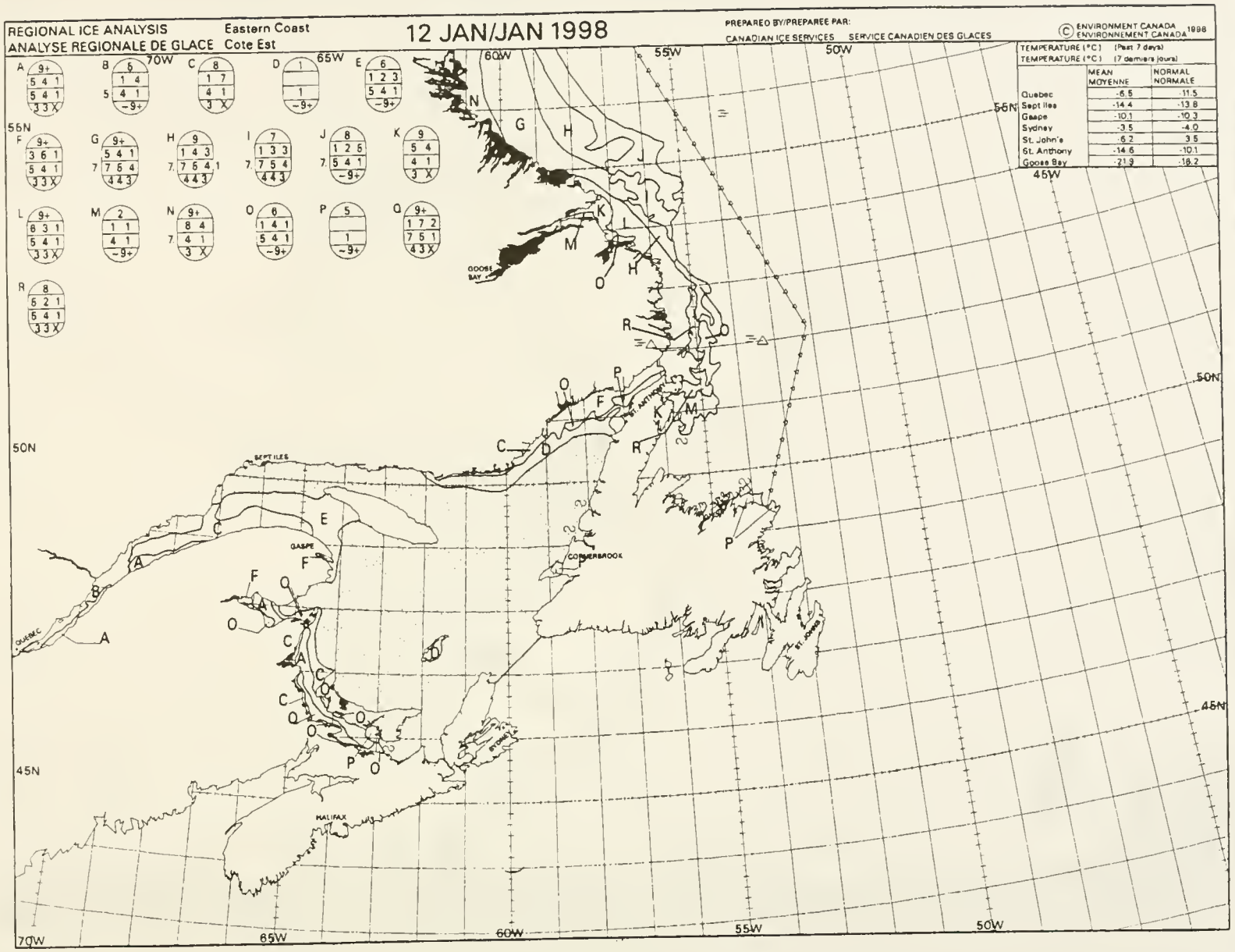
REGIONAL ICE ANALYSIS
ANALYSE REGIONALE DE GLACE
Eastern Coast
Cote Est
12 JAN/JAN 1998
PREPARED BY/PREPARÉE PAR:
CANADIAN ICE SERVICES SERVICE CANADIEN DES GLACES
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 1998
TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec -6.5 -11.5
Sept Iles -14.4 -13.8
Gaspe -10.1 -10.3
Sydney -3.5 -4.0
St. John's -6.2 3.5
St. Anthony -14.6 -10.1
Goose Bay -21.9 -18.2
GOOSE BAY
SEPT ILES
GASPE
CORNERBROOK
ST. ANTHONY
ST. JOHN'S
HALIFAX
QUEBEC
70W
65W
60W
55W
50W
45W
56N
50N
45N

Figure 18.

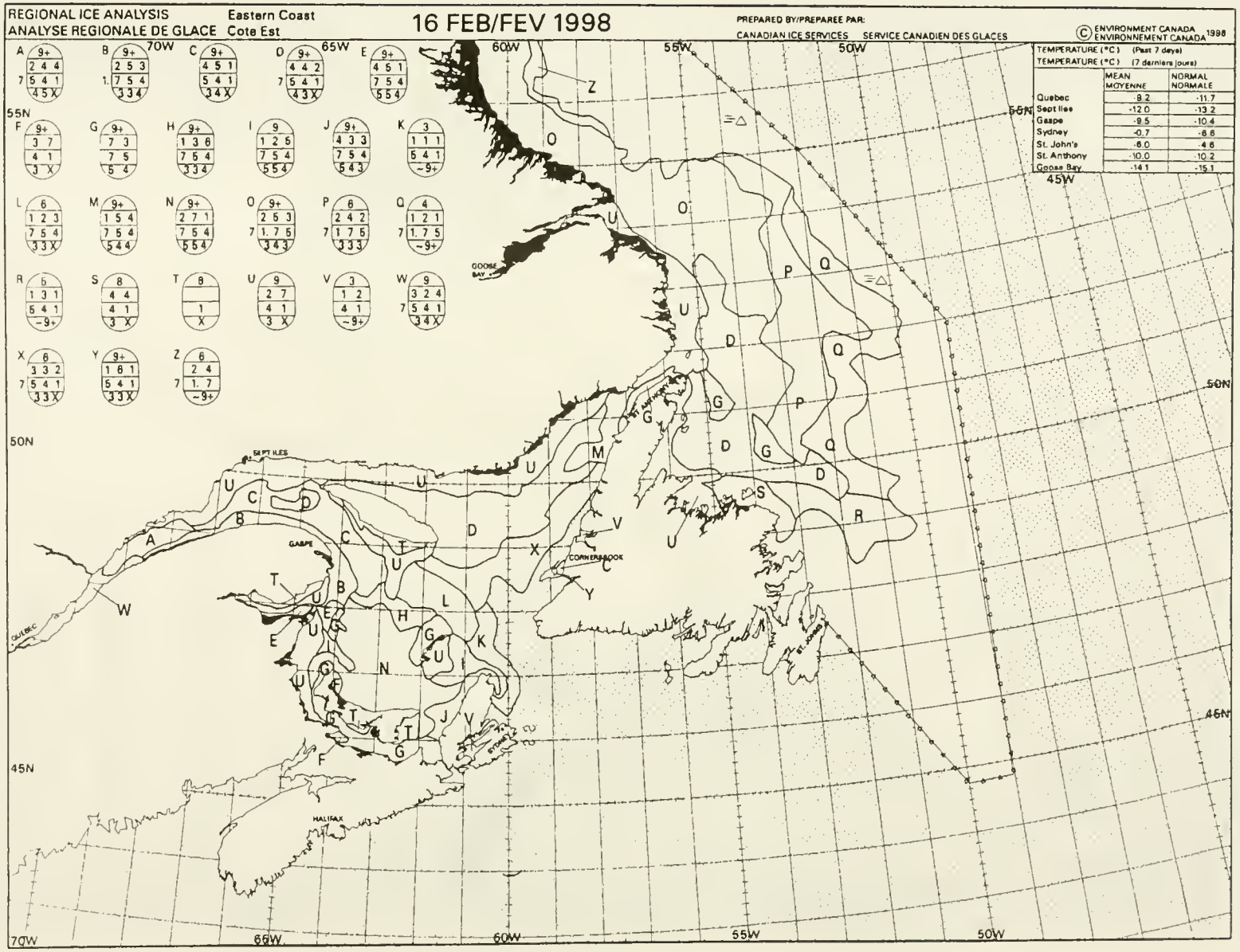
REGIONAL ICE ANALYSIS
ANALYSE REGIONALE DE GLACE
Eastern Coast
Cote Est
16 FEB/FEV 1998
PREPARED BY/PREPARÉE PAR:
CANADIAN ICE SERVICES SERVICE CANADIEN DES GLACES
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 1998
TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec -9.2 -11.7
Sept Iles -12.0 -13.2
Gaspe -9.5 -10.4
Sydney -0.7 -6.6
St. John's -6.0 -4.6
St. Anthony -10.0 -10.2
Goose Bay -14.1 -15.1
70W
65W
60W
55W
50W
45W
55N
50N
45N
SEPT ILES
GASPE
CORNERBROOK
GOOSE BAY
HALIFAX
QUEBEC

Figure 19.

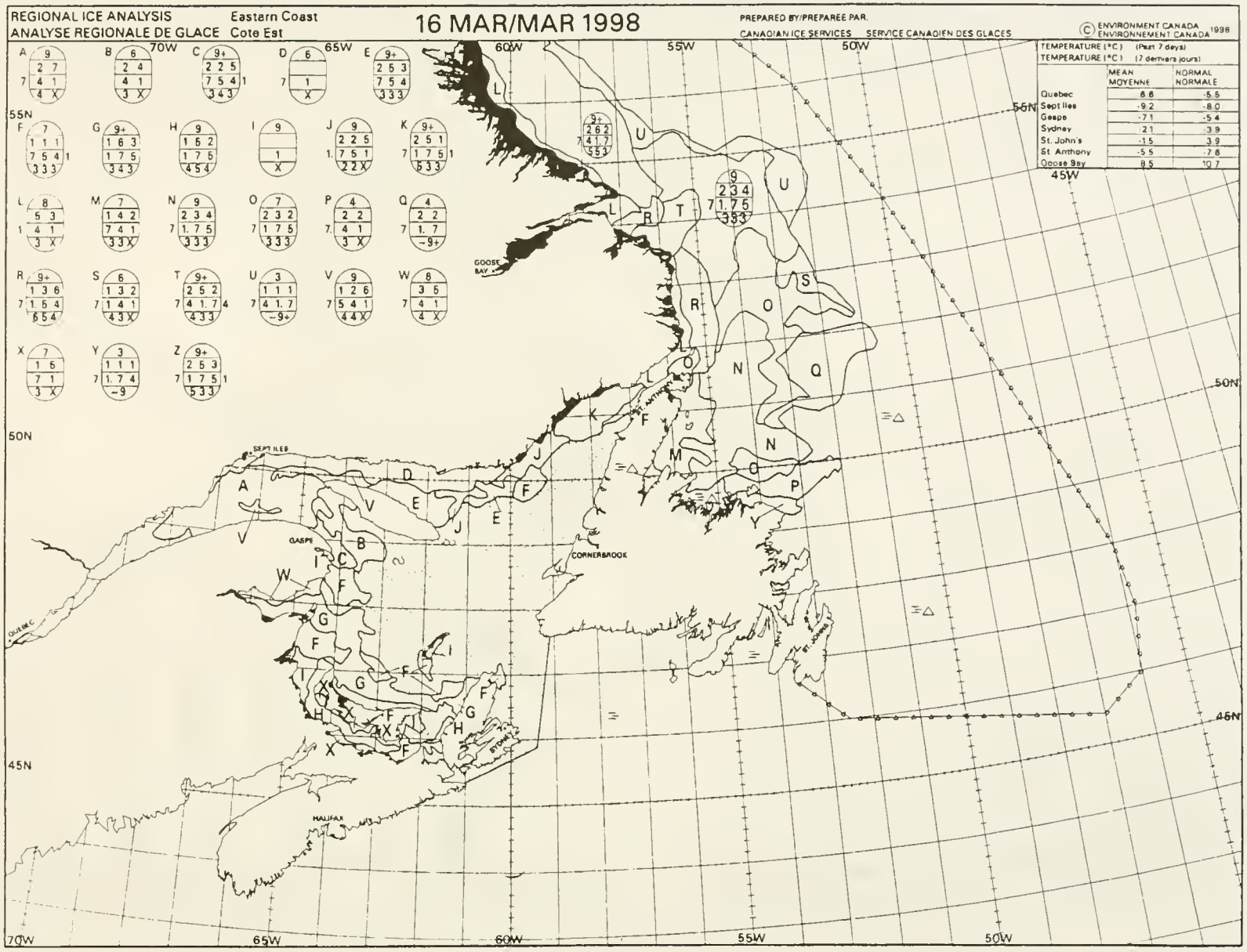
REGIONAL ICE ANALYSIS
ANALYSE REGIONALE DE GLACE
Eastern Coast
Cote Est
16 MAR/MAR 1998
PREPARED BY/PREPARÉE PAR.
CANADIAN ICE SERVICES SERVICE CANADIEN DES GLACES
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 1998
TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec 8.6 -5.5
Sept Iles -9.2 -8.0
Gaspe -7.1 -5.4
Sydney 2.1 -3.9
St. John's -1.5 3.9
St. Anthony -5.5 -7.6
Goose Bay 8.5 10.7
70W
65W
60W
55W
50W
45W
55N
50N
45N
GOOSE BAY
SEPT ILES
GASPE
QUEBEC
CORNERBROOK
ST. ANTHONY
ST. JOHNS
BYDUNES
HALIFAX

Figure 20.

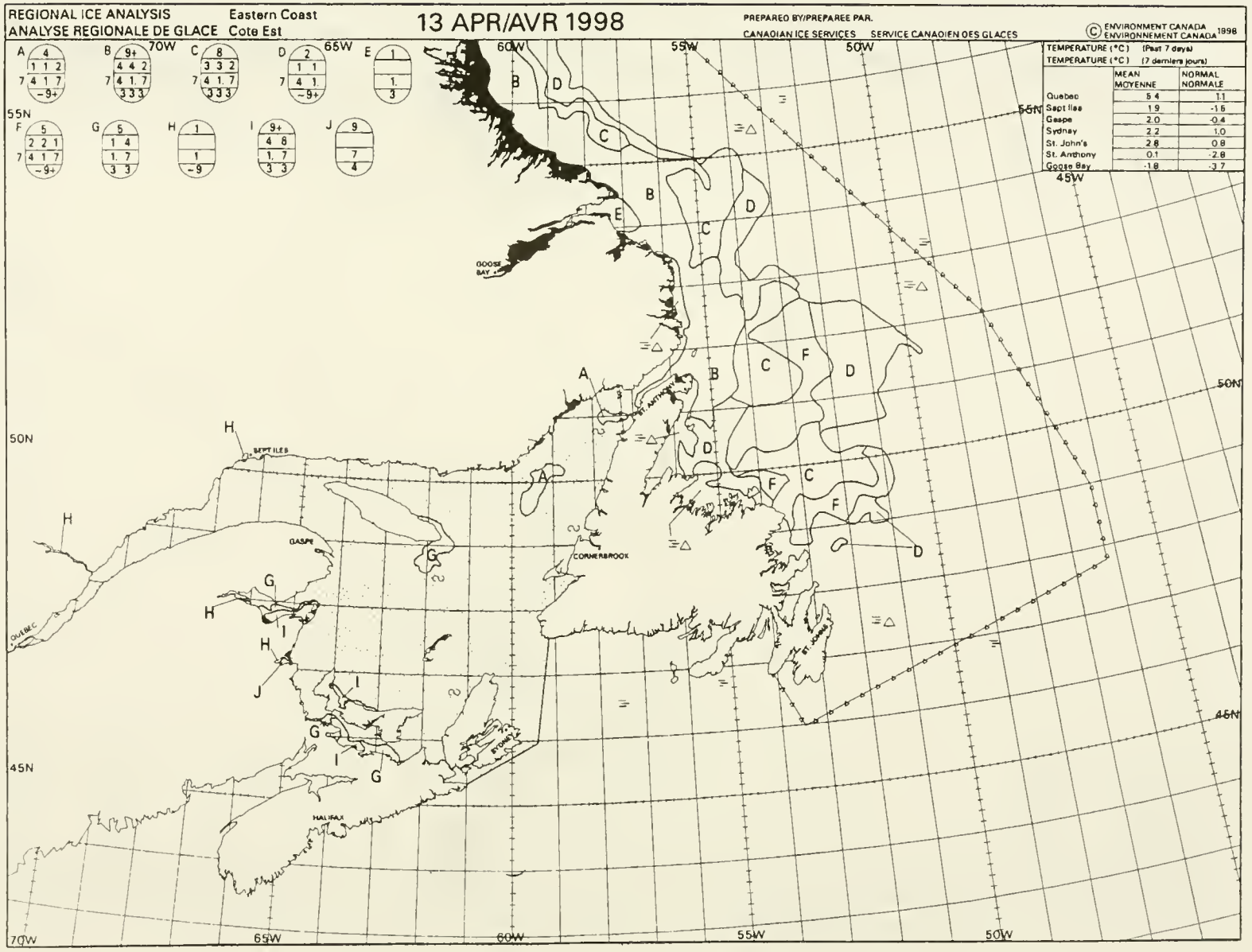
REGIONAL ICE ANALYSIS Eastern Coast
ANALYSE REGIONALE DE GLACE Cote Est
13 APR/AVR 1998
PREPARED BY/PREPAREE PAR.
CANADIAN ICE SERVICES SERVICE CANADIEN DES GLACES
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 1998
TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec 5.4 1.1
Sept Iles 1.9 -1.5
Gaspe 2.0 -0.4
Sydney 2.2 1.0
St. John's 2.8 0.8
St. Anthony 0.1 -2.8
Goose Bay -1.8 -3.7
GOOSE BAY
ST. ANTHONY
SEPT ILES
GASPE
CORNERBROOK
QUEBEC
HALIFAX
ST. JOHN'S
70W
65W
60W
55W
50W
45W
55N
50N
45N

Figure 21.

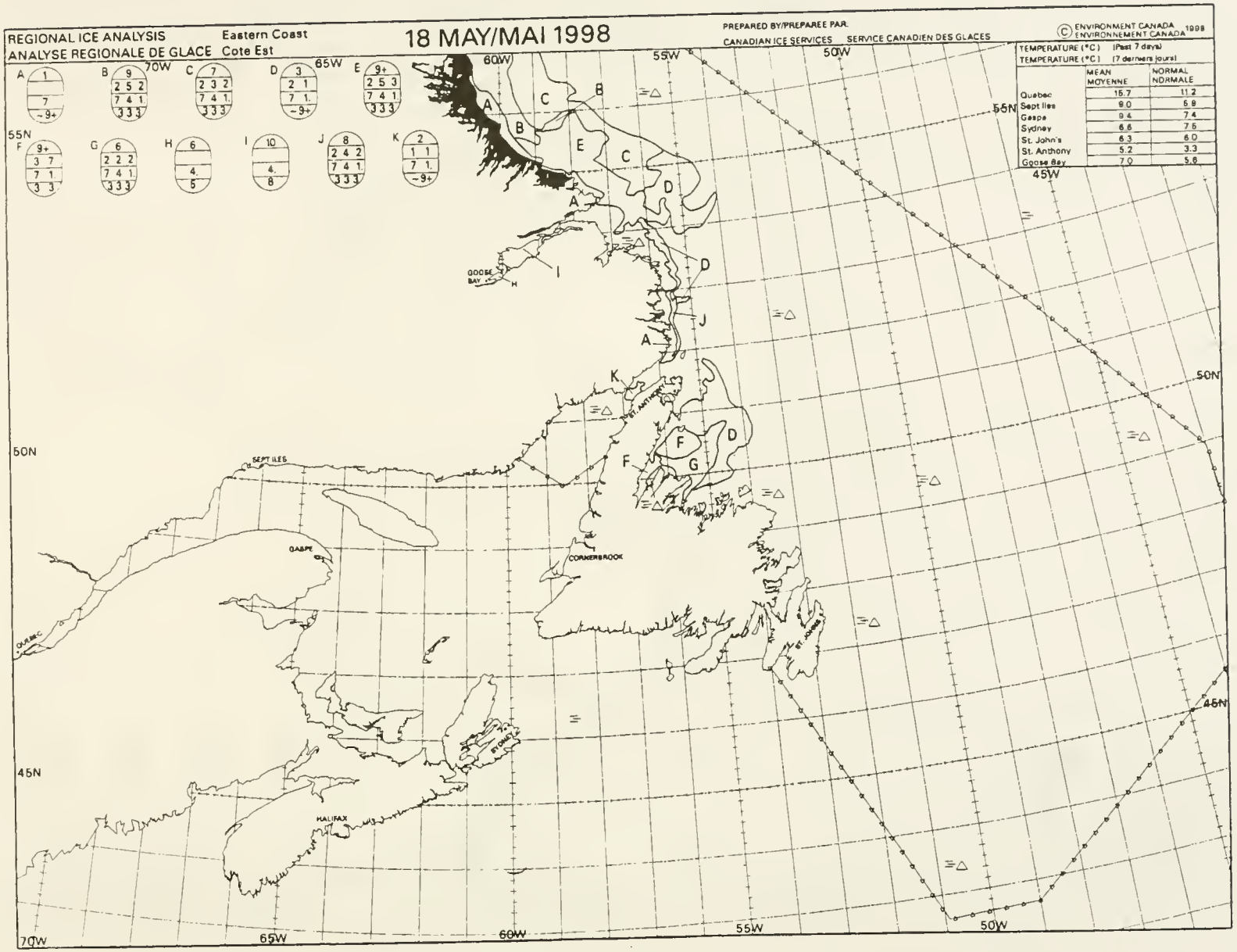
REGIONAL ICE ANALYSIS
ANALYSE REGIONALE DE GLACE
Eastern Coast
Cote Est
18 MAY/MAI 1998
PREPARED BY/PREPARÉE PAR:
CANADIAN ICE SERVICES SERVICE CANADIEN DES GLACES
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 1998
TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec 15.7 11.2
Sept Iles 8.0 5.8
Gaspe 9.4 7.4
Sydney 6.6 7.5
St. John's 6.3 6.0
St. Anthony 5.2 3.3
Goose Bay 7.0 5.8
70W
65W
60W
55W
50W
45W
55N
50N
45N
GOOSE BAY
SEPT ILES
GASPE
QUEBEC
CORNERBROOK
ST. ANTHONY
ST. JOHN'S
HALIFAX

Figure 22.

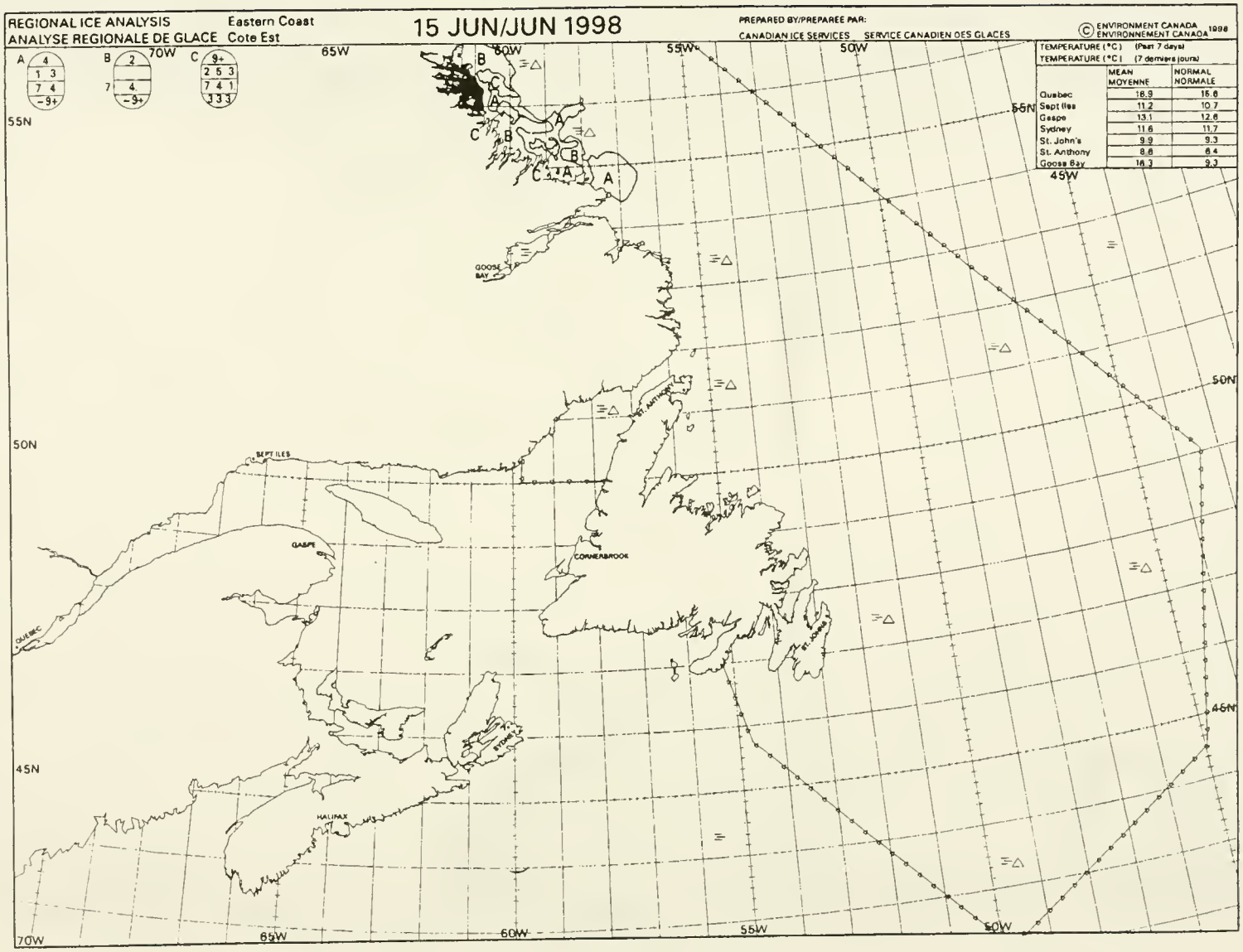
REGIONAL ICE ANALYSIS
ANALYSE REGIONALE DE GLACE
Eastern Coast
Cote Est
15 JUN/JUN 1998
PREPARED BY/PREPAREE PAR:
CANADIAN ICE SERVICES SERVICE CANADIEN DES GLACES
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 1998
TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec 16.9 15.6
Sept Iles 11.2 10.7
Gaspe 13.1 12.6
Sydney 11.6 11.7
St. John's 9.9 9.3
St. Anthony 8.8 8.4
Goose Bay 16.3 9.3
70W
65W
60W
55W
50W
45W
55N
50N
45N
GOOSE BAY
ST. ANTHONY
SEPT ILES
GASPE
CORNERBROOK
QUEBEC
ST. JOHN'S
HALIFAX

Figure 23.

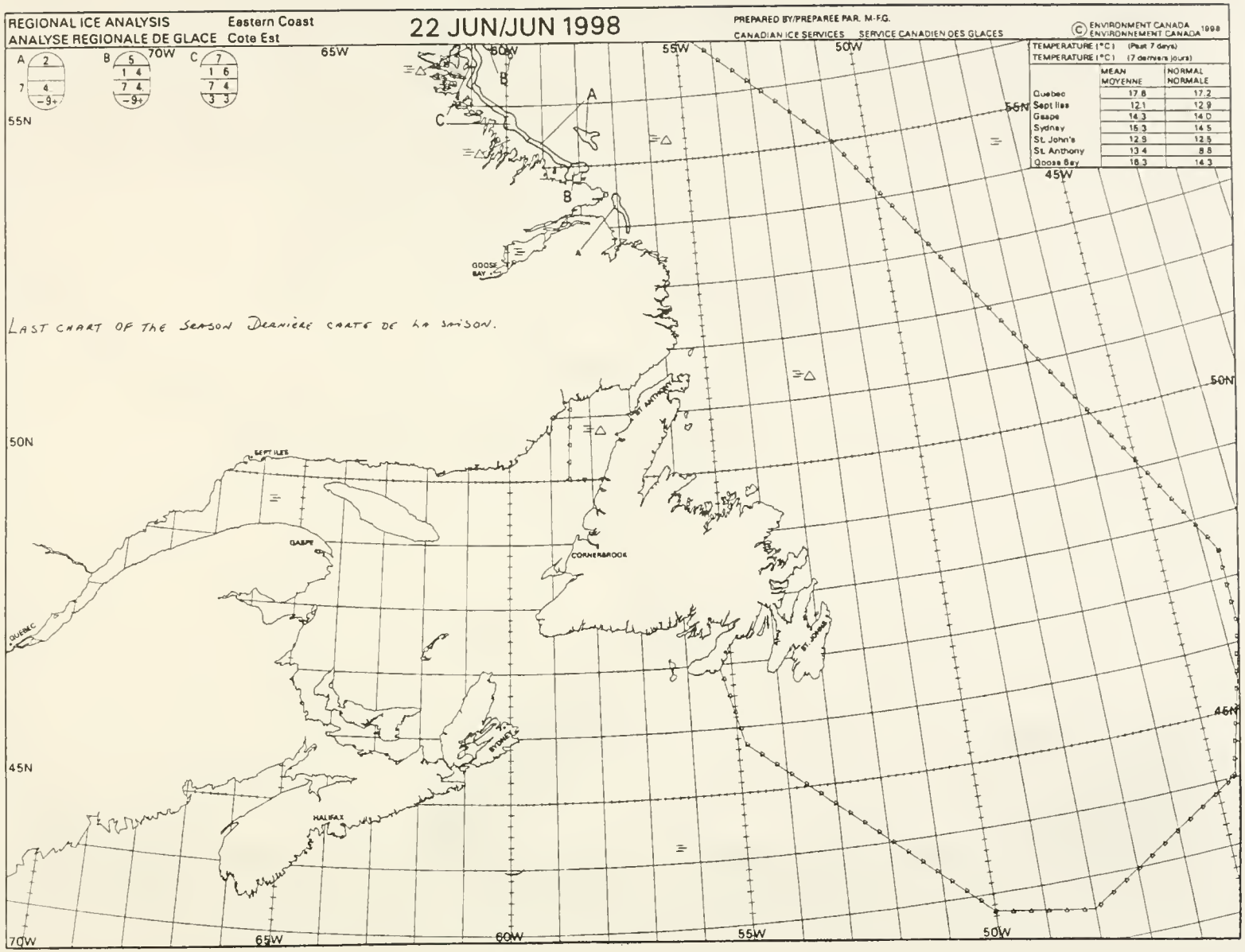
REGIONAL ICE ANALYSIS
ANALYSE REGIONALE DE GLACE
Eastern Coast
Cote Est
22 JUN/JUN 1998
PREPARED BY/PREPAREE PAR. M-F.G.
CANADIAN ICE SERVICES SERVICE CANADIEN DES GLACES
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 1998
TEMPERATURE (°C) (Past 7 days)
TEMPERATURE (°C) (7 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Quebec 17.8 17.2
Sept Iles 12.1 12.9
Gaspe 14.3 14.0
Sydney 15.3 14.5
St. John's 12.9 12.5
St. Anthony 13.4 8.8
Goose Bay 18.3 14.3
LAST CHART OF THE SEASON DERNIERE CARTE DE LA SAISON.
GOOSE BAY
ST. ANTHONY
SEPT ILES
GASPE
CORNERBROOK
QUEBEC
SYDNEY
HALIFAX
ST. JOHN'S
55N
50N
45N
70W
65W
60W
55W
50W
45W

Figure 24.

1998 Biweekly Iceberg Charts

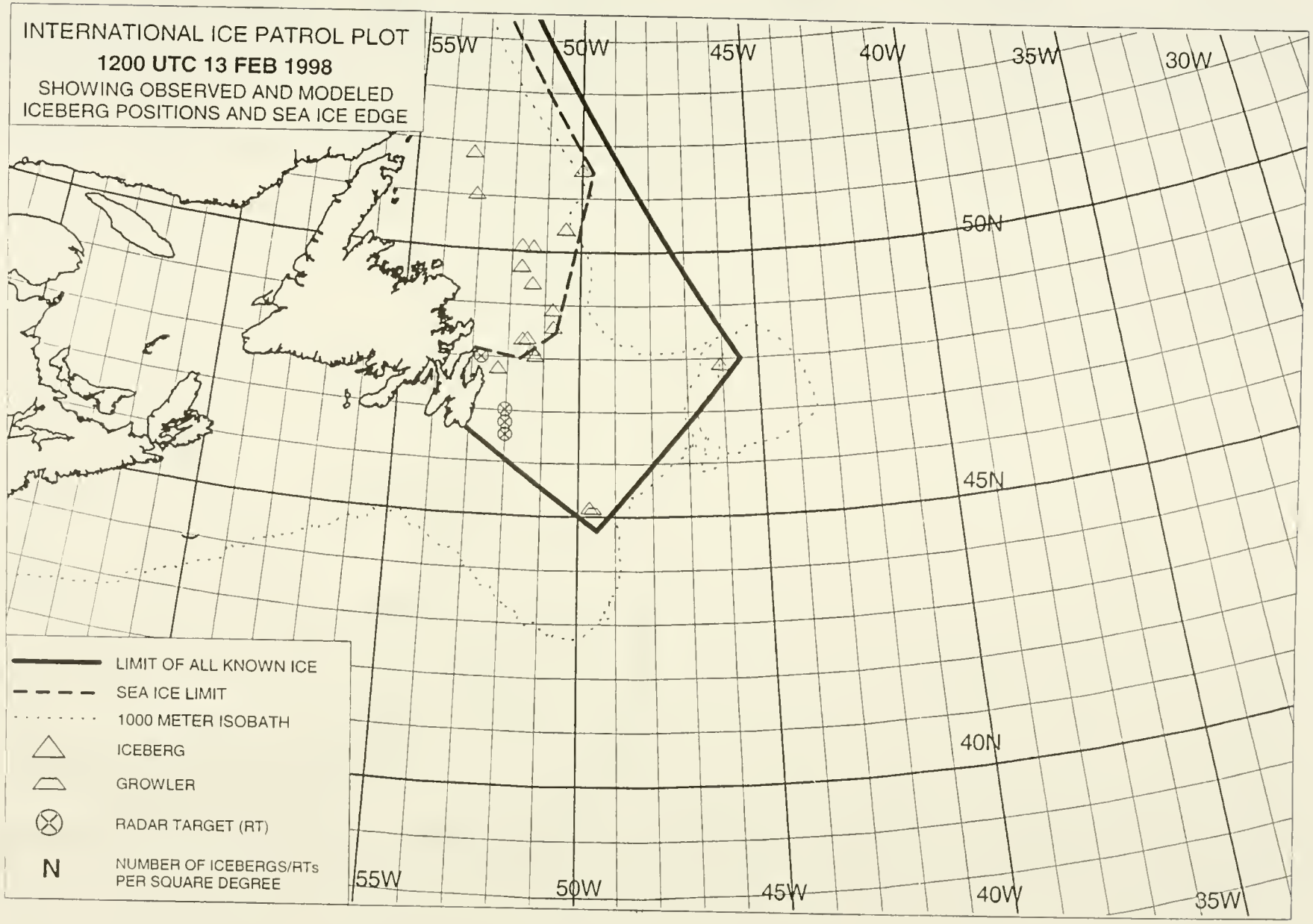
INTERNATIONAL ICE PATROL PLOT
1200 UTC 13 FEB 1998
SHOWING OBSERVED AND MODELED
ICEBERG POSITIONS AND SEA ICE EDGE
55W
50W
45W
40W
35W
30W
50N
45N
40N
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/RTs
PER SQUARE DEGREE

Figure 25.

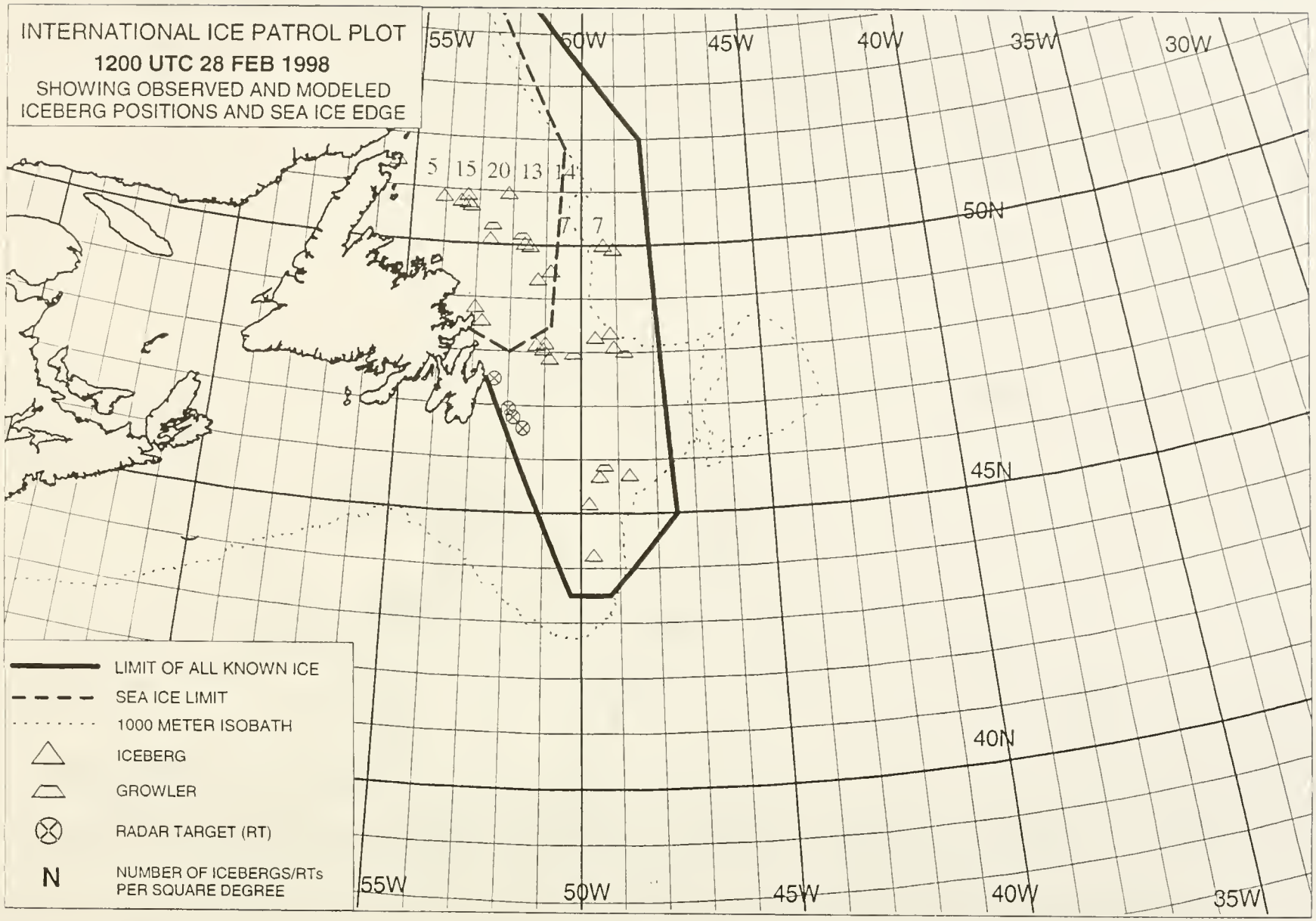
INTERNATIONAL ICE PATROL PLOT
1200 UTC 28 FEB 1998
SHOWING OBSERVED AND MODELED
ICEBERG POSITIONS AND SEA ICE EDGE
55W
50W
45W
40W
35W
30W
50N
45N
40N
5
15
20
13
14
7
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/RTs
PER SQUARE DEGREE

Figure 26.

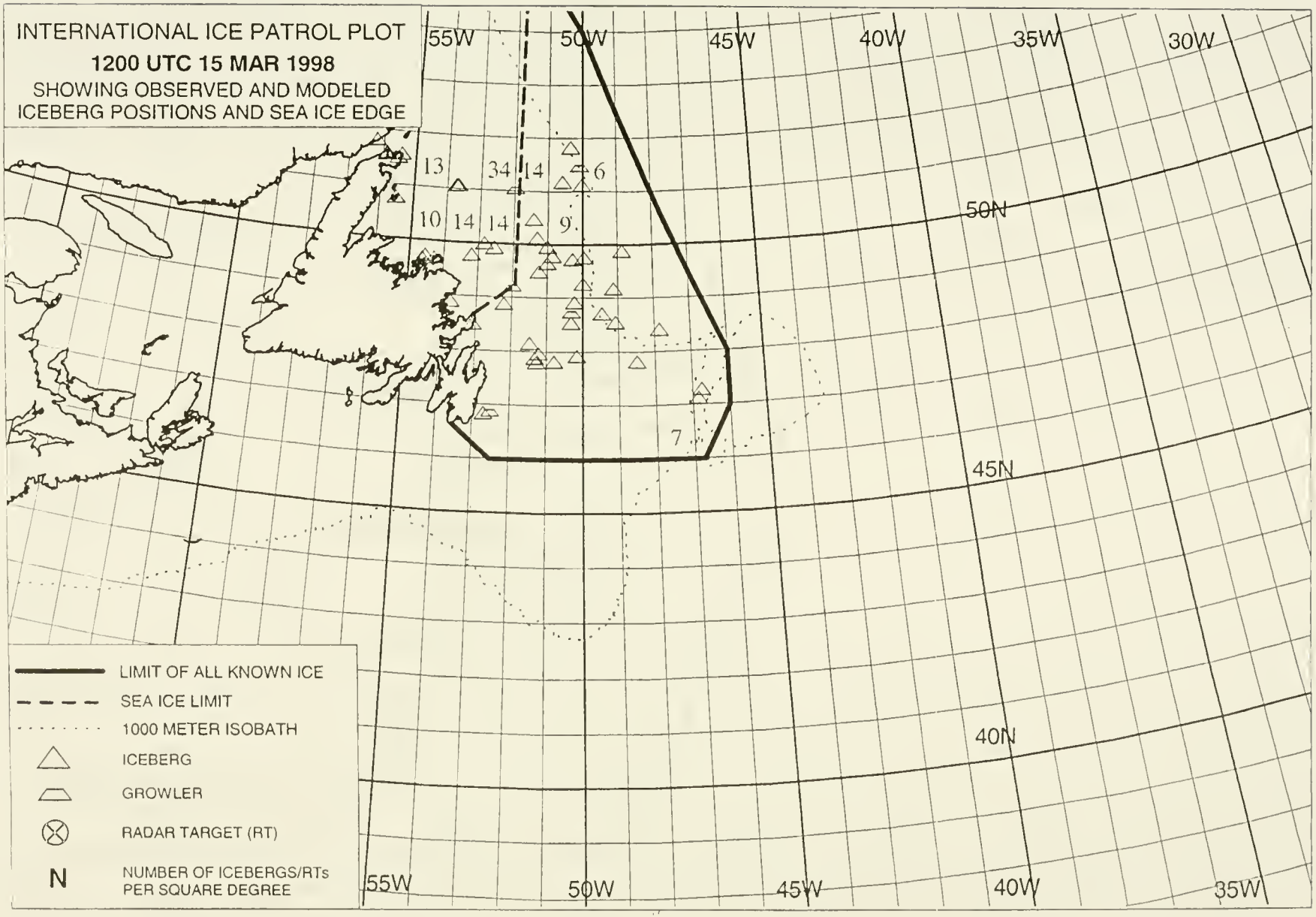
INTERNATIONAL ICE PATROL PLOT
1200 UTC 15 MAR 1998
SHOWING OBSERVED AND MODELED
ICEBERG POSITIONS AND SEA ICE EDGE
55W
50W
45W
40W
35W
30W
50N
45N
40N
13
34
14
6
10
14
14
9
7
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/RTs
PER SQUARE DEGREE

Figure 27.

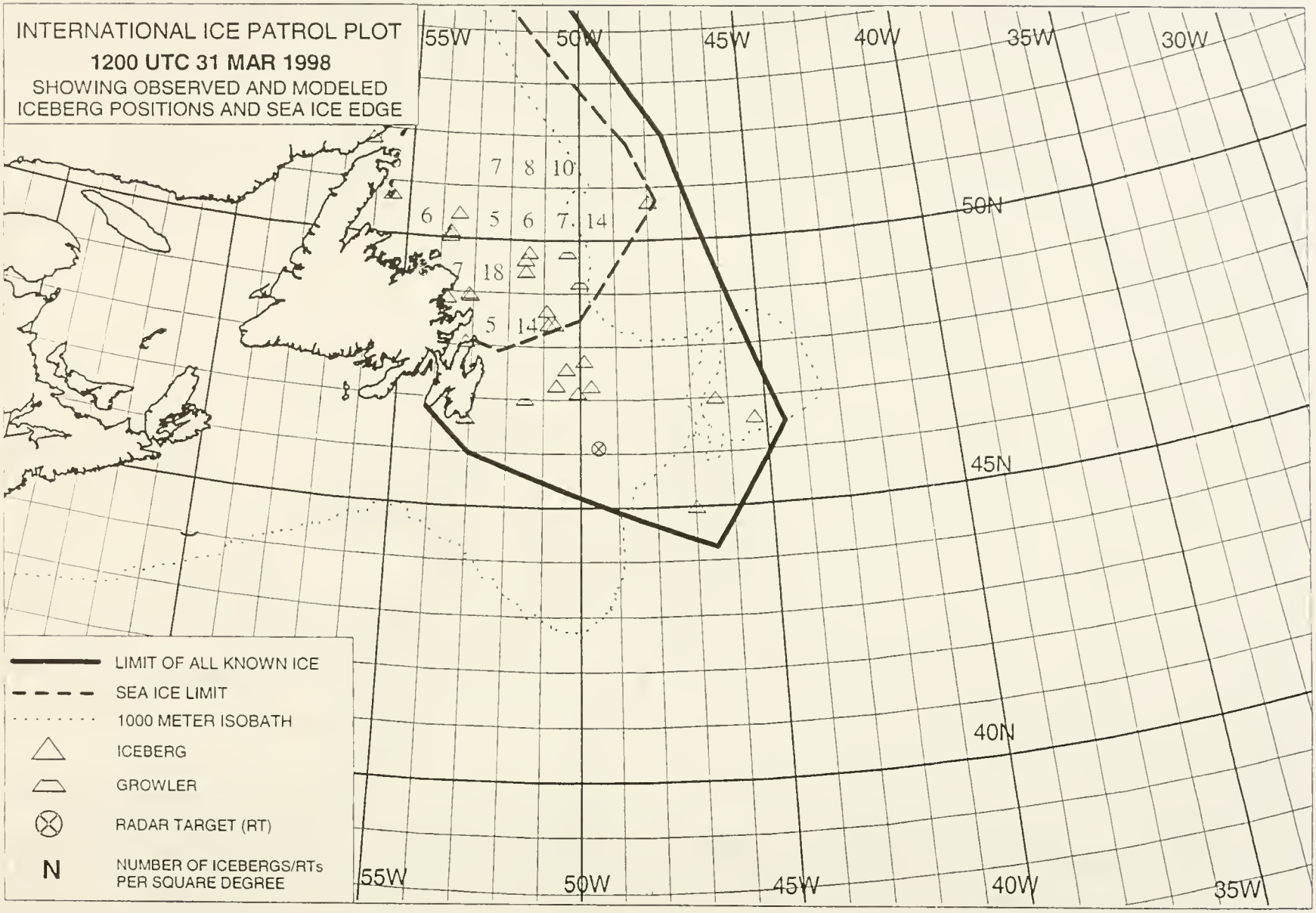
INTERNATIONAL ICE PATROL PLOT
1200 UTC 31 MAR 1998
SHOWING OBSERVED AND MODELED
ICEBERG POSITIONS AND SEA ICE EDGE
55W
50W
45W
40W
35W
30W
50N
45N
40N
7 8 10
6 5 6 7 14
7 18
5 14
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/RTs
PER SQUARE DEGREE

Figure 28.

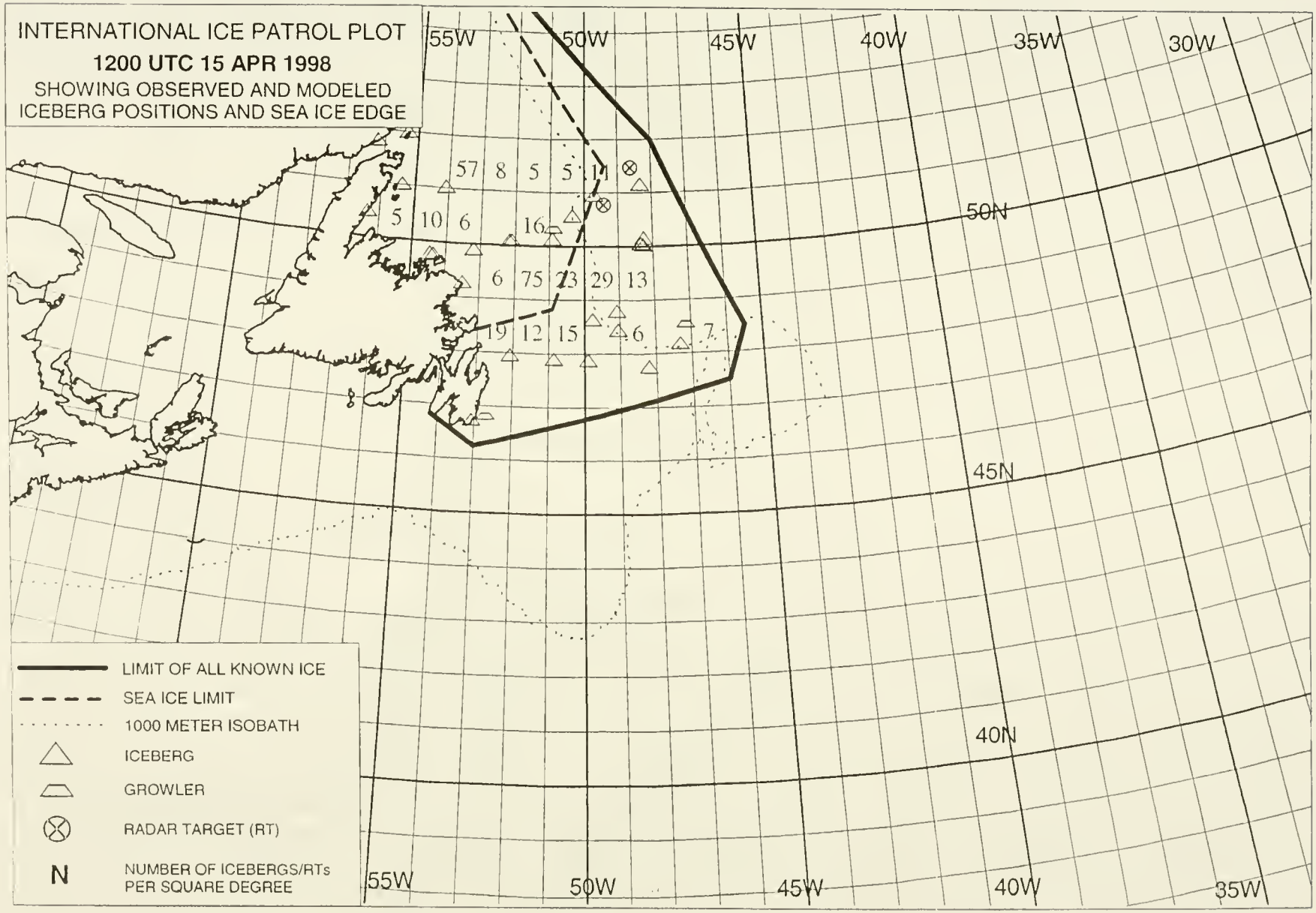
INTERNATIONAL ICE PATROL PLOT
1200 UTC 15 APR 1998
SHOWING OBSERVED AND MODELED
ICEBERG POSITIONS AND SEA ICE EDGE
55W
50W
45W
40W
35W
30W
50N
45N
40N
57
8
5
5
11
5
10
6
16
6
75
23
29
13
19
12
15
6
7
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/RTs
PER SQUARE DEGREE

Figure 29.

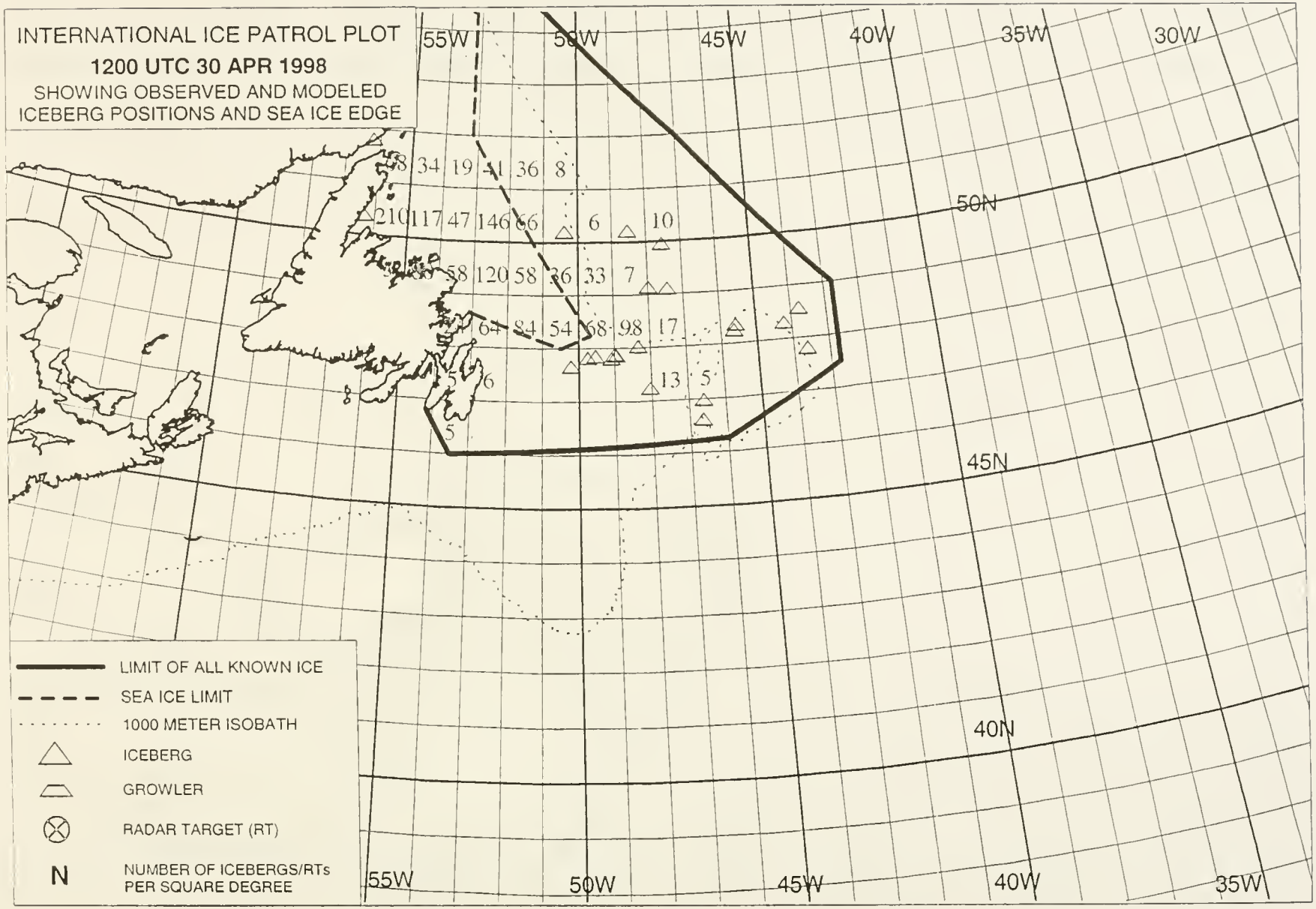
INTERNATIONAL ICE PATROL PLOT
1200 UTC 30 APR 1998
SHOWING OBSERVED AND MODELED
ICEBERG POSITIONS AND SEA ICE EDGE
55W
50W
45W
40W
35W
30W
50N
45N
40N
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/RTs
PER SQUARE DEGREE

Figure 30.

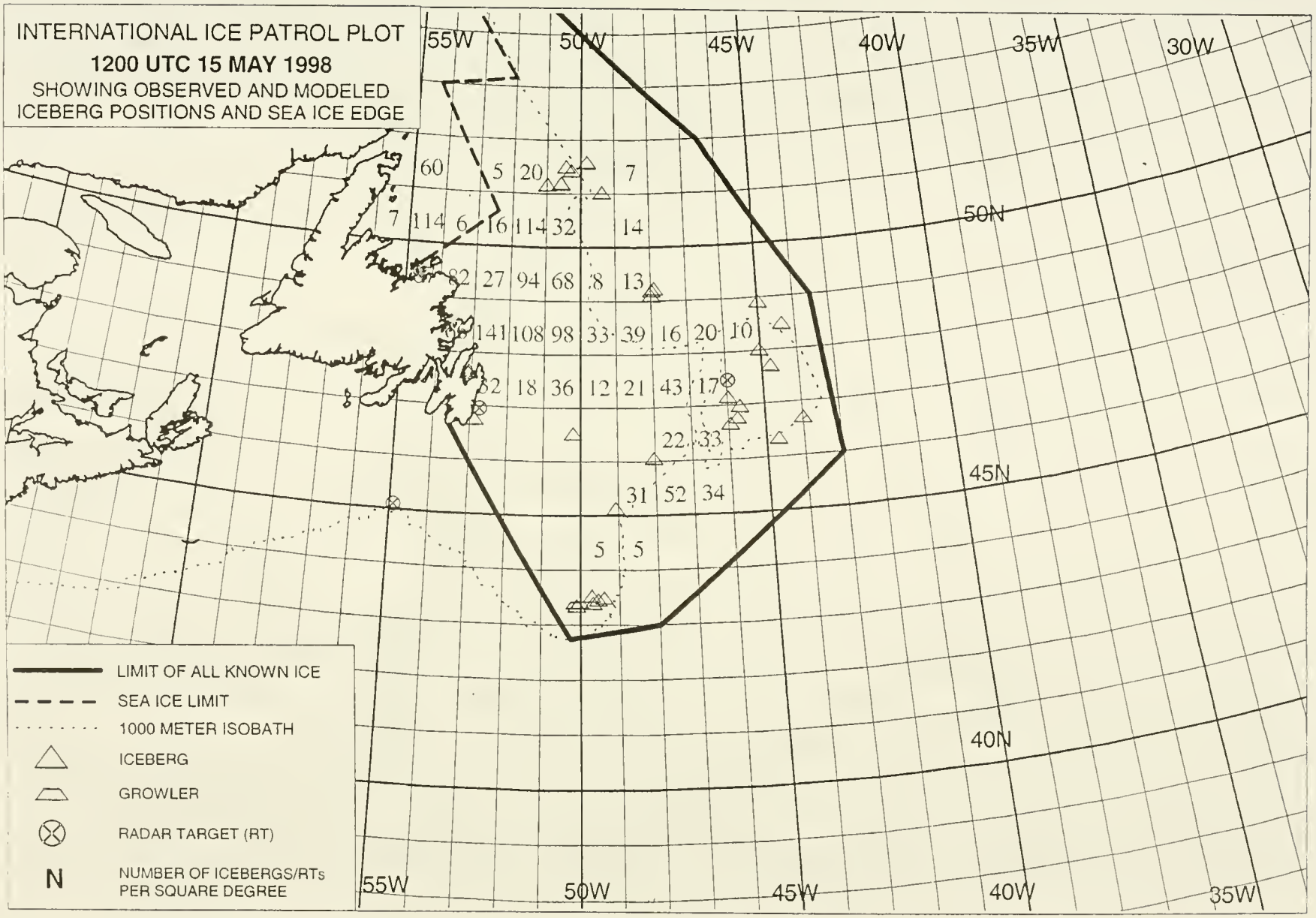
INTERNATIONAL ICE PATROL PLOT
1200 UTC 15 MAY 1998
SHOWING OBSERVED AND MODELED
ICEBERG POSITIONS AND SEA ICE EDGE
55W
50W
45W
40W
35W
30W
50N
45N
40N
60
5
20
7
7
114
6
16
114
32
14
82
27
94
68
8
13
141
108
98
33
39
16
20
10
82
18
36
12
21
43
17
22
33
31
52
34
5
5
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/RTs
PER SQUARE DEGREE

Figure 31.

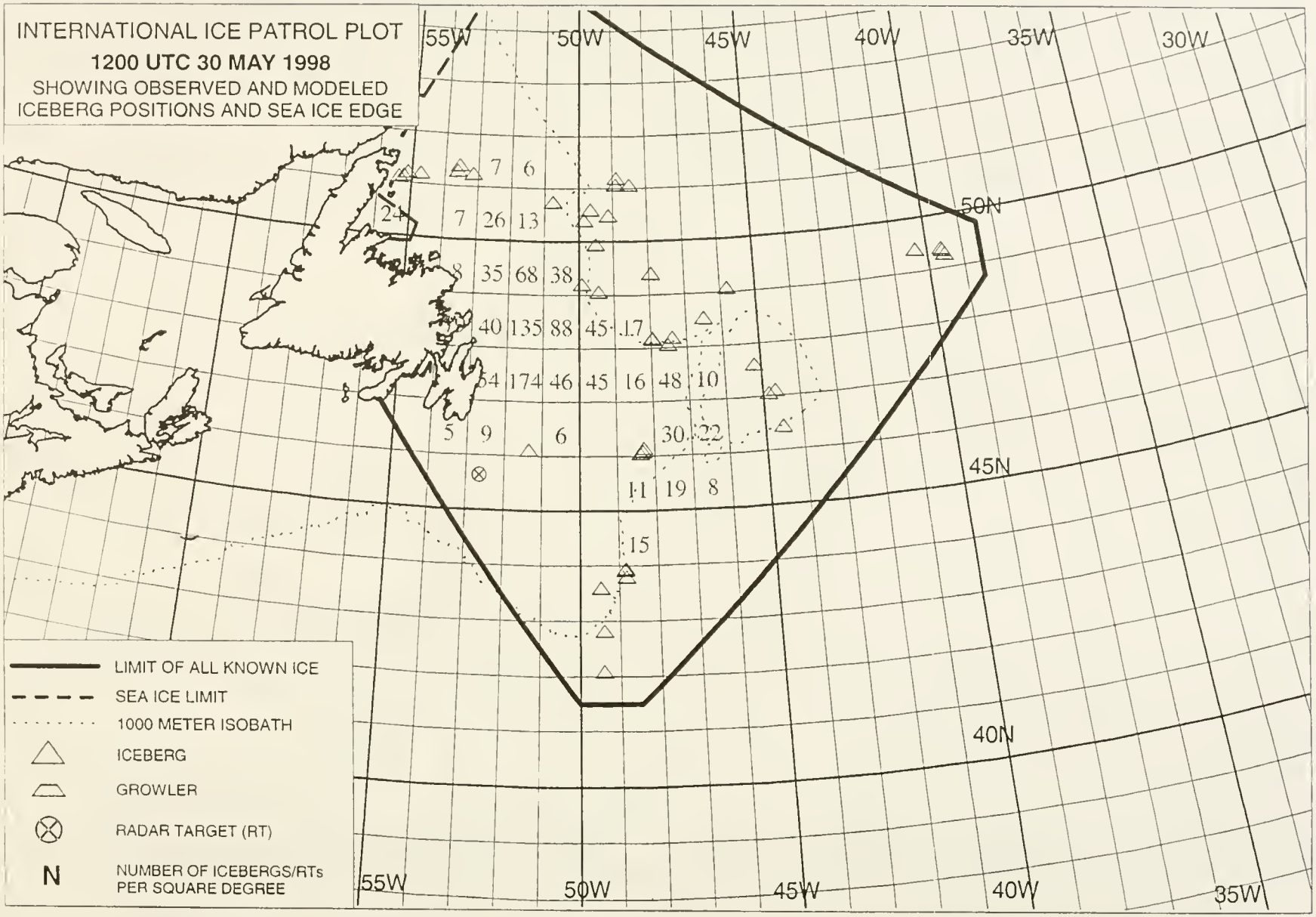
INTERNATIONAL ICE PATROL PLOT
1200 UTC 30 MAY 1998
SHOWING OBSERVED AND MODELED
ICEBERG POSITIONS AND SEA ICE EDGE
55W
50W
45W
40W
35W
30W
50N
45N
40N
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/RTs
PER SQUARE DEGREE

Figure 32.

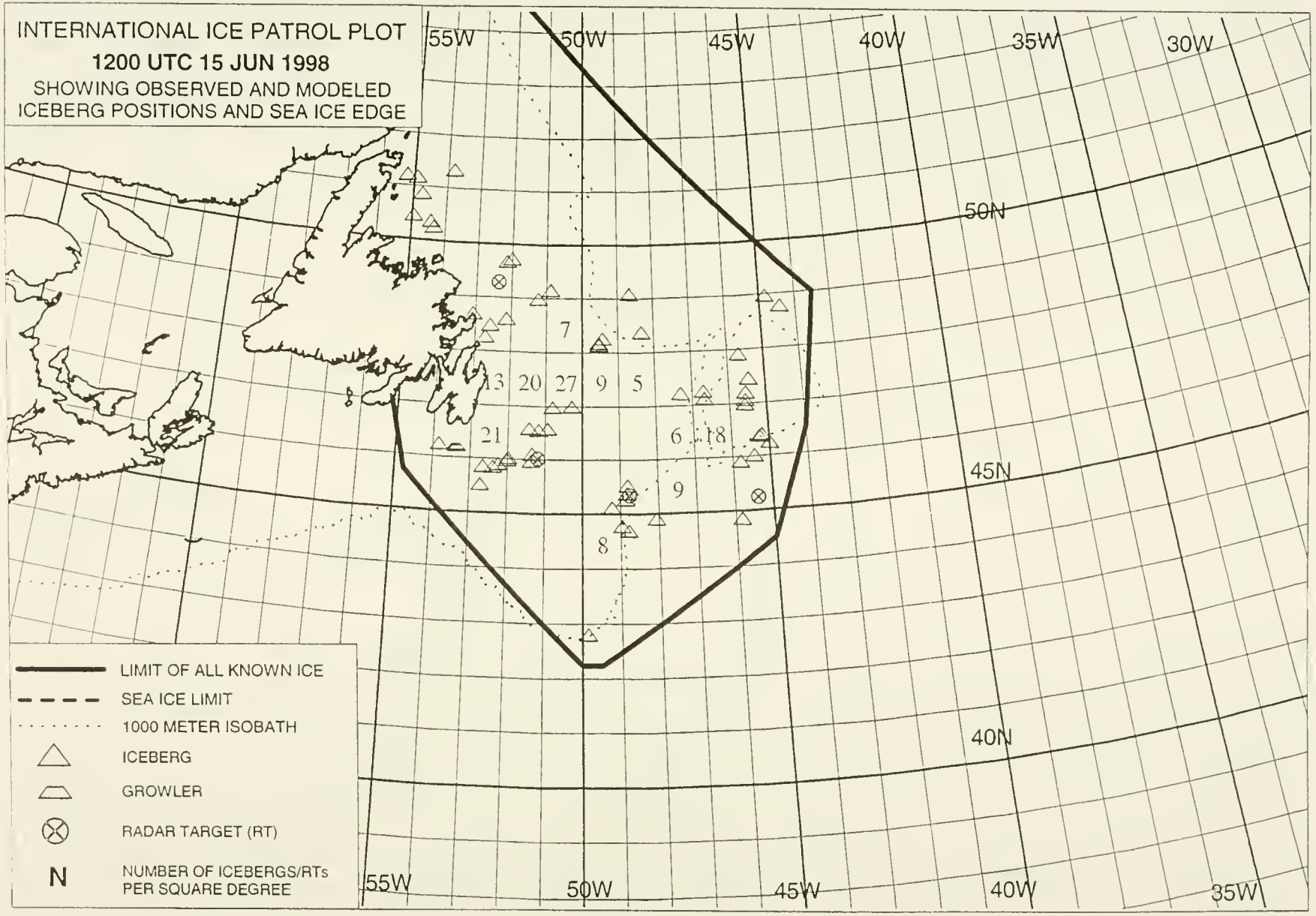
INTERNATIONAL ICE PATROL PLOT
1200 UTC 15 JUN 1998
SHOWING OBSERVED AND MODELED
ICEBERG POSITIONS AND SEA ICE EDGE
55W
50W
45W
40W
35W
30W
50N
45N
40N
7
13
20
27
9
5
21
6
18
9
8
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/RTs
PER SQUARE DEGREE

Figure 33.

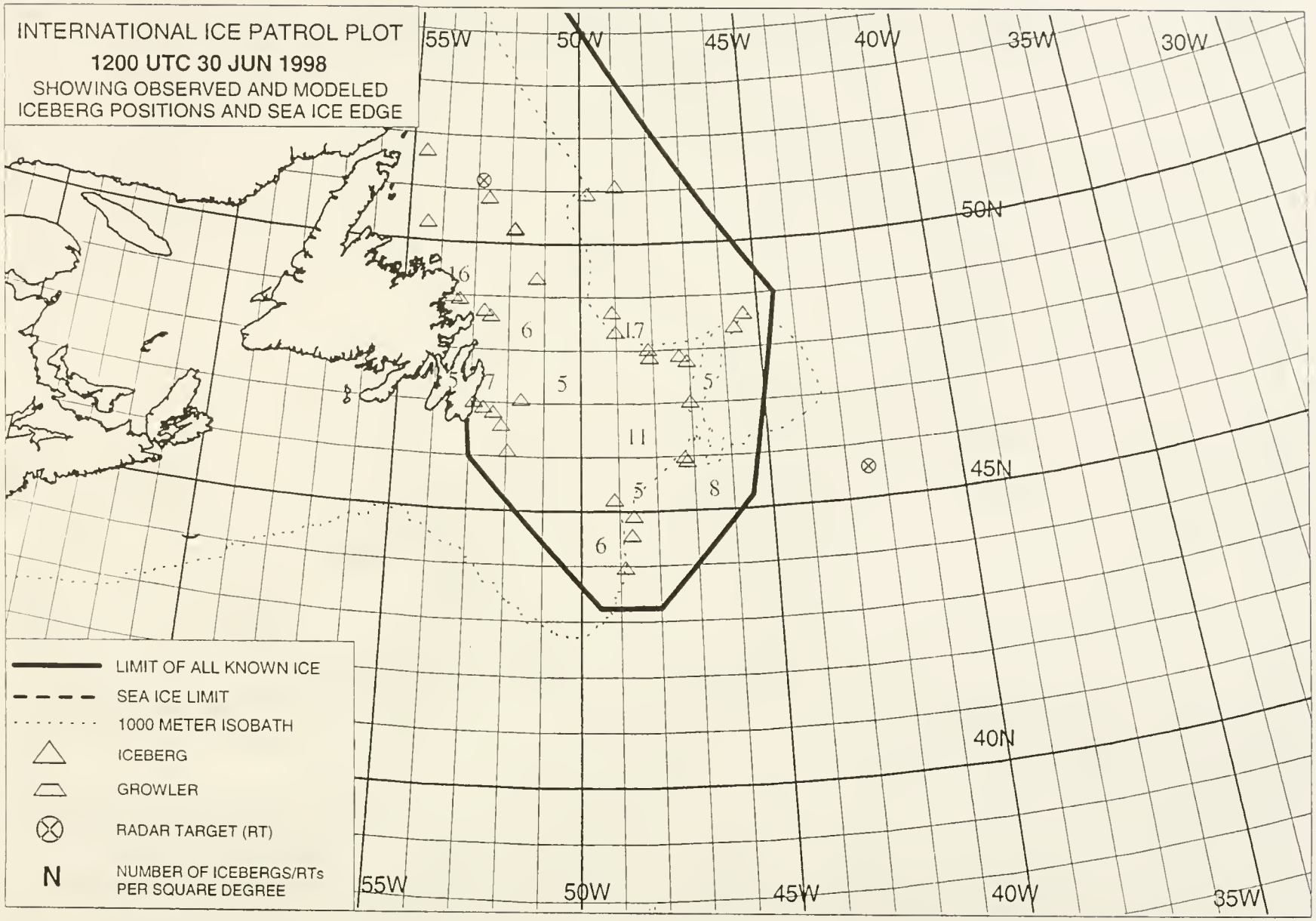
INTERNATIONAL ICE PATROL PLOT
1200 UTC 30 JUN 1998
SHOWING OBSERVED AND MODELED
ICEBERG POSITIONS AND SEA ICE EDGE
55W
50W
45W
40W
35W
30W
50N
45N
40N
16
6
17
5
7
8
5
11
5
8
6
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/RTs
PER SQUARE DEGREE

Figure 34.

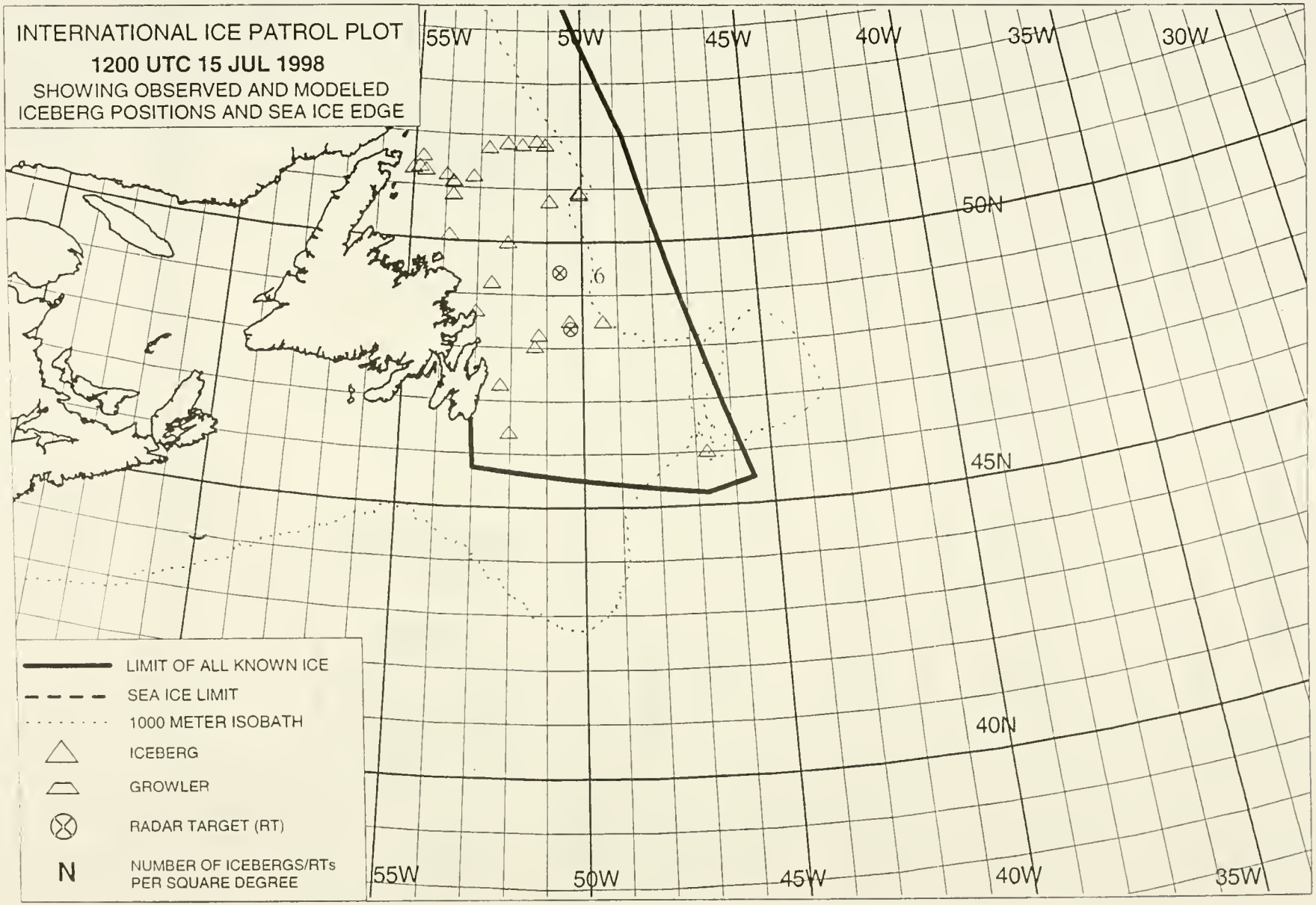
INTERNATIONAL ICE PATROL PLOT
1200 UTC 15 JUL 1998
SHOWING OBSERVED AND MODELED
ICEBERG POSITIONS AND SEA ICE EDGE
55W
50W
45W
40W
35W
30W
50N
45N
40N
6
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/RTs
PER SQUARE DEGREE

Figure 35.

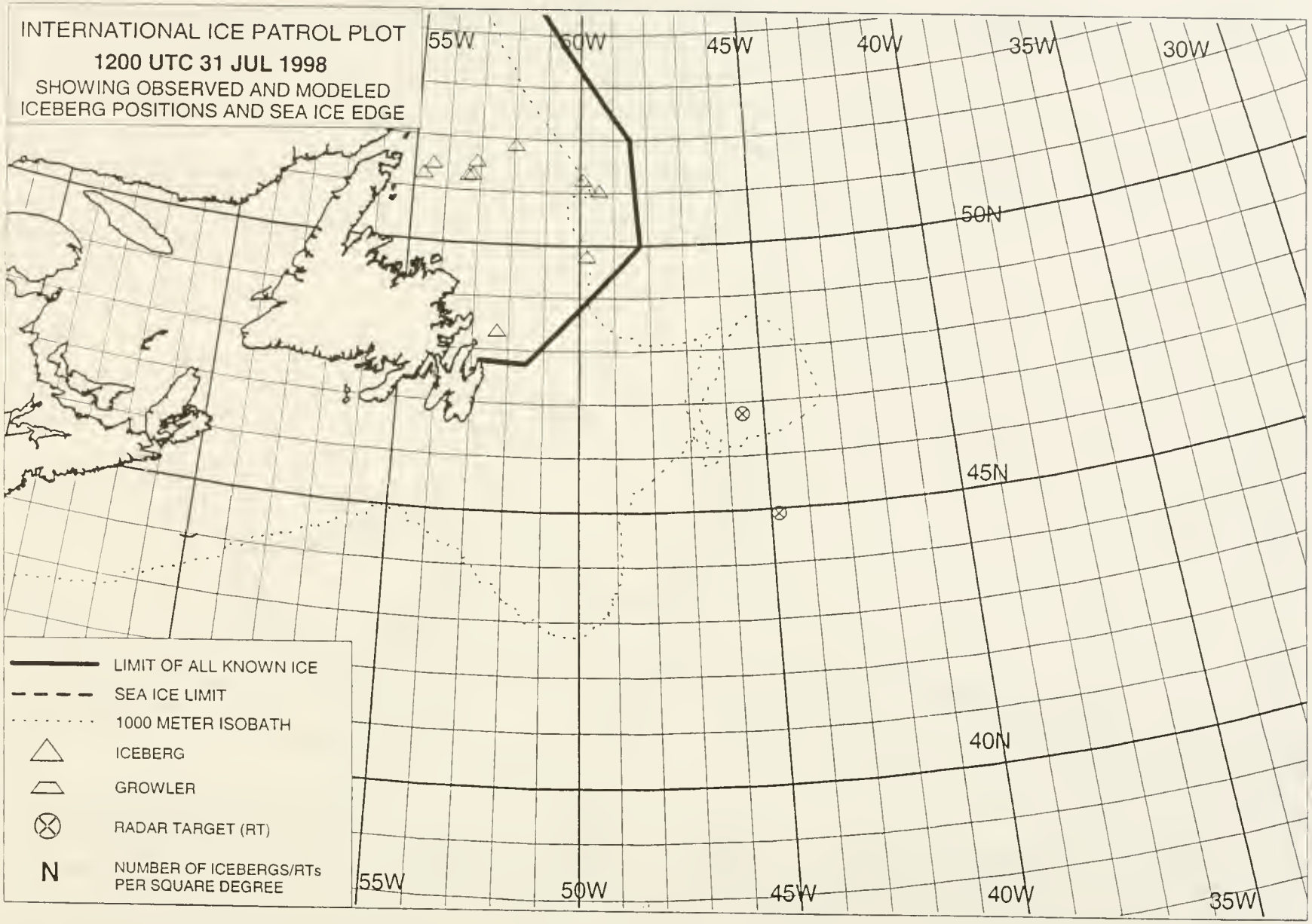
INTERNATIONAL ICE PATROL PLOT
1200 UTC 31 JUL 1998
SHOWING OBSERVED AND MODELED
ICEBERG POSITIONS AND SEA ICE EDGE
55W
50W
45W
40W
35W
30W
50N
45N
40N
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/RTs
PER SQUARE DEGREE

Figure 36.

Acknowledgements

Commander, International Ice Patrol acknowledges the assistance and information provided by:

Canadian Ice Service
Canadian Coast Guard
Navy / NOAA / USCG National Ice Center
U. S. Naval Fleet Numerical Meteorology and Oceanography Center
U. S. Naval Atlantic Meteorology and Oceanography Center
U. S. Coast Guard Research and Development Center
U. S. Coast Guard Atlantic Area Staff
U. S. Coast Guard Atlantic Area Command Center
U. S. Coast Guard Atlantic Area Master Communications Center

We extend our sincere appreciation to the staffs of these organizations for their excellent support during the 1998 International Ice Patrol season:

Canadian Coast Guard Radio Station St. John's, Newfoundland/VON
Ice Operations St. John's, Newfoundland
Air Traffic Control Gander, Newfoundland
Canadian Forces Gander and St. John's, Newfoundland
St. John's Flight Services Office
U. S. Coast Guard Air Station Elizabeth City, North Carolina
National Weather Service, Maryland

It is important to recognize the outstanding efforts of the personnel at the International Ice Patrol:

CDR S. L. Sielbeck
LCDR M. R. Hicks
Dr. D. L. Murphy
Mr. G. F. Wright
LT T. P. Wojahn
LT J. E. Andrews
MSTCM S. B. Bell
YN1 S. J. Hoss
MST1 R. A. McKnight
MST1 L. L. Valliere
MST1 L. S. Howell
MST2 E. M. Fusco
MST2 J. C. Luzader
MST2 H. R. Harbuck
MST2 T. T. Krein
MST2 P. J. Jenicek

This report was produced using Microsoft® Word 97 and Excel 97 by MST1 John C. Luzader.

Appendix A

Nations Currently Supporting International Ice Patrol

Belgium

Greece

Poland

Canada

Italy

Spain

Denmark

Japan

Sweden

Finland

Netherlands

United Kingdom

France

Norway

United States of America

Germany

Panama

Appendix B

Ship Reports

Ships Reporting By Flag	Ice Reports
ANTIGUA/BARBUDA	
ADRIANA	8
GODAFOSS	5
HANSEWELL	5
SKOGAFOSS	7
BAHAMAS	
ATLANTIC CARTIER	1
BAUCHI	6
BERGEN ARROW	12
CHICAGO EXPRESS	1
DAGEID	2
EASTERN BRIDGE	1
ENGLISH STAR	2
GENIE	8
GREEN VIOLET	1
GRIGOROUSSA	6
HERON ARROW	9
INVIKEN	1
LACKENBY	2
MAPLE	1
MAXIM GORKIY	1
MED NAPLES	1
OAK	5
ORDANES	12
UTVIKEN	1
BARBADOS	
CHERYL C	1
FEDERAL CALUMET	1
FEDERAL RHINE	4
CANMAR CONQUEST	1
CANMAR GLORY	3
CANMAR SUCCESS	2
MALYOVITZA	4
CANADA	
ANN HARVEY	3
ARCTIC	3
ARGO SCOTIA	2
CAPE AARON	1
CAPE AILLIK	1
CAPE ROGER	5
CHEBUCTO SEA	1
EASTERN MARINER	1
FRANKLIN	2

Ships Reporting By Flag	Ice Reports
CANADA (continued)	
GREEN WATERS	1
GRENFELL	1
GRIFFON	8
HENRY LARSON	17
HMCS ANTICOSTI	4
HMCS CHARLOTTETOWN	5
HMCS HALIFAX	10
HMCS MONCTON	1
HMCS NIPIGON	5
HMCS SHAWINGIGAN	3
HMCS ST JOHN'S	6
HMCS TRITON	1
J.E. BERNIER	1
JACQUES DESGAGNES	1
LADY KENDA	3
LEONARD J. COWLEY	1
LISTEVEN	1
LOUIS ST. LAURENT	1
LUCIEN PAQUIN	1
MAERSK NASCOPIE	1
MAERSK PLACENTIA	1
MAJESTIC MARINER	2
MATTEA	8
MCCARTHY BROTHERS	1
NORTHERN EAGLE	1
PIERRE RADISSON	3
SIR HUMPREY GILBERT	5
SIR ROBERT BOND	2
TELEOST	8
TERRT FOX	1
VICKI LYNN	1
WELLINGTON KENT	3
WILFRED TEMPLEMAN	1
CAYMAN ISLANDS	
ABBEY	8
BRITISH STEEL	3
FETISH	1
IRONBRIDGE	16
CHINA	
HUA TONG HAI	6
CROATIA	
MLJET	1

Ships Reporting By Flag	Ice Reports
CYPRUS	
BLUEBELL	2
CHARLOTTE SCHULTE	4
DIANA	1
EDDA	4
FINNSNES	5
HARALAMBOS	10
LUCKYMAN	1
*MAERSK TORONTO	80
MARILIST	1
NORDSTRAND	3
SEALAND CANADA	1
STRANGE ATTRACTOR	7
DENMARK	
ICE BIRD	2
LION	1
LIS WEBER	1
NATHALIE SIF	1
VAEDDEREN	1
ESTONIA	
GUSTAV SULE	2
NORDANA ADVISOR	1
FRANCE	
ODET	1
FRENCH ANT TERR	
HOUSTON	1
GERMANY	
ABITIBI CLAIBORNE	1
ABITIBI ORINOCO	1
CONTAINERSHIPS III	3
GAUSS	20
LEBASEE	3
GREAT BRITIAN	
HMS RICHMOND	7
GREECE	
FEDERAL DORA	12
HONG KONG	
OOCL BRAVERY	2
OOCL CANADA	2
INDIA	
HOLK LARSEN	5
MARATHA MISSION	3
INDONESIA	
LT ARGOSY	1
ISLE OF MAN	
ALSTERSTERN	3

Ships Reporting By Flag	Ice Reports
ISLE OF MAN (continued)	
CHESHIRE	3
KOMMANDOR AMALIE	3
MAERSK STAFFORD	1
THORKIL MAERSK	10
ITALY	
UMBERTO D'AMATO	3
LATVIA	
PAVELS STERNBERGS	3
LIBERIA	
ADIMON	1
AFRICAN BEGONIA	12
ANNA OLDENDORFF	7
CHANDA	1
CHEMBULK TRADER	1
DSR SENATOR	4
ISPAT UMANG	1
LIELUPE	3
LOUISE	4
NARRAGANSETT	8
OLMECA	1
OSCO STAR	1
SCF SPIRIT	2
ST LUCY	1
ST PETERSBURG SENATOR	5
STAR GRINDANGER	1
STAR OHIO	32
STOLT ASPIRATION	1
STOLT PRIDE	1
STOLT PROTECTOR	1
TUNDRA QUEEN	2
UNITED STELLA	7
LITHUANIA	
KAPITONAS ANDZEJAUSKAS	1
KAPITONAS DOMEIKA	2
KAPITONAS MARCINKUS	2
KAPITONAS SEVCENKO	4
KAPITONAS STULPINAS	1
MALAYSIA	
BUNGA SAGA DUA	1
BUNGA SAGA EMPAT	2
MALTA	
DAPHNE	3
GREEN ESKIMO	1
GREEN TUNDRA	1
HERO	5

Ships Reporting By Flag	Ice Reports
MALTA (continued)	
HOPE I	1
LITA	17
SVITAVA	5
TROGIR	2
MARSHALL ISLANDS	
LAKE CHAMPLAIN	3
LAKE CHARLES	1
LAKE ERIE	8
LAKE ONEIDA	1
LAKE ONTARIO	3
LAKE SUPERIOR	3
SEA-LAND FREEDOM	2
MYANMAR	
GREAT LAKER	5
NETHERLANDS	
AMSTELGRACHT	1
AMSTELWAL	1
EGELANTIERSGRACHT	2
JO EIK	1
KIELGRACHT	1
MAINEBORG	1
MARKBORG	3
MERWEBORG	1
NORWAY	
ALOUETTE ARROW	2
BAUTA	6
BELTRADER	1
BERGE NORD	11
BERGE STADT	8
BOW PIONEER	1
CONSENSUS MANITOU	1
FEDERAL VIBEKE	8
MARINETTE	1
MENOMINEE	2
NOMADIC POLLUX	4
NOMADIC PRINCESS	1
NORDIC LAURITA	50
NORNEWS SUPPLIER	7
SAGA RIVER	2
SKS TRENT	10
SOLVEIG	25
STAR SKARVEN	1
TORID KNUTSEN	1
PANAMA	
BRILLIANT CORNERS	5
CAPE HAWK	9
CLIPPER FAME	1

Ships Reporting By Flag	Ice Reports
PANAMA (continued)	
DONAU ORE	2
FEDERAL FRASER	1
FRONTIER	1
GECO RHO	8
GOLDEN YANG	9
GREAT FORTRESS	1
HAMLET	3
HAPPINESS II	2
HNOMS VIDAR	2
INNOVATION KVAERMER	1
JEAN CHARCOT	10
LOWLANDS JADE	7
LUOBAHE	6
PHILIPS VAN ALMONDE	1
TOKYO HIGHWAY	4
PHILIPPINES	
DIAMOND BULKER	2
VISAYAS VICTORY	2
POLAND	
GENERAL JASINSKI	1
POMORZE ZACHODNIE	1
ZIEMIA GNIEZNIENSKA	8
ZIEMIA SUWALSKA	2
RUSSIA	
ALEKSANDR NEVSKIY	1
GAMAL ABDEL NASER	2
MIKHAIL KUTUZOV	1
SERGEY LEMESHEV	1
USSURIYSKIY ZALIV	1
SINGAPORE	
CAST ELK	3
CAST WOLF	2
ROTTERDAM EXPRESS	1
SOVIET UNION	
DMITRIY DONSKOY	1
BHARTI	1
CAPE ZENITH	6
CONCORDE	5
SWEDEN	
ADA CORINTH	1
ADA GORTHON	1
ATLANTIC COMPANION	2
ATLANTIC COMPASS	2
ATLANTIC CONCERT	2
CORNER BROOK	4
DON PASQUALE	1

Ships Reporting By Flag	Ice Reports
SWEDEN (continued)	
JON GORTHON	1
MARIA GORTHON	1
MUNKSAND	1
RIGOLETTO	1
TOFTON	1
WESTON	1
THAILAND	
KISO MARU	8
TURKEY	
MINI CEBI	1
UKRAINE	
KRAMATORSK	2
USA	
KNORR	1
MEDALLION	1
STRONG ICELANDER	1
USCGC GALLATIN	7
USCGC WILLOW	14

* DENOTES THE VESSEL PARTICIPATION AWARD WINNER.

Appendix C

A Qualitative Assessment of the Iceberg Detection and Identification Capabilities of RADARSAT

LT James E. Andrews
U.S. Coast Guard International Ice Patrol

ABSTRACT

A test was conducted as part of the RADARSAT Application, Development and Research Opportunity (ADRO) program to determine the ability of RADARSAT, in Wide 2 beam mode (W-2), to detect icebergs. Testing the ability of RADARSAT to detect icebergs, determining the finest expectable resolution for point targets, and assessing our ability to differentiate between icebergs and vessels are necessary prerequisites for IIP in eventually employing RADARSAT operationally for remotely sensed iceberg reconnaissance.

On 28 July 1997, a visual reconnaissance by Ice Patrol personnel on board a Coast Guard Hercules C-130 was conducted over the footprint area of a previously arranged RADARSAT overpass. Photographs were taken by the aircrew of all icebergs sighted within the footprint area, as well as of several boats observed during the flight. The flight commenced at 10:00 UTC, and the last target within the footprint was detected at 13:23 UTC. IIP received a RADARSAT scene from 09:43:40 UTC, 28 July 1997, centered on 50°49'N, 52°10'W with a 150 km swath width and 12.5 m pixel spacing. This scene contained 11 certain targets and exhibited a nearly equal mix of observed icebergs and vessels from the underflight. We then conducted qualitative comparisons between the photographed icebergs and the RADARSAT detected targets in approximately similar locations. Iceberg size, image target size, "brightness" values and shapes were compared between observed objects and detected targets. Of the eleven targets, six were associated with icebergs and five were associated with vessels. In addition, a visually observed growler (waterline length between 7 and 15 m) was undetected by RADARSAT.

We compared the cost of replacing IIP's aerial reconnaissance methods with coverage by RADARSAT W-2 imagery. We determined that the cost of an ice season-length program of repeated scene coverage of the Grand Banks area would cost approximately $1.4 million, compared to aircraft costs alone of approximately $1.7 million. Despite the cost savings, IIP must await further development in detecting icebergs, especially growlers, in image delivery and in cost savings. It appears that an ice season length program would be very beneficial in augmenting aerial reconnaissance and in providing flexibility and repeat coverage; however, funding sources and a more in-depth cost-benefit analysis would need to be performed.

Introduction

Following the RMS TITANIC's disastrous collision with an iceberg off the Tail of the Grand Banks of Newfoundland in 1912, the U.S. Coast Guard has been charged with the conduct and administration of the North Atlantic Ice Patrol. The ongoing exploitation of remote sensing techniques, starting with shipboard radar and progressing to airborne radar, has enabled the International Ice Patrol to safely discharge its duties for over 85 years. The International Ice Patrol (IIP) currently uses a suite of airborne radars, visual reconnaissance, data from Canadian government sources and observations by transatlantic ships to record, track and report the locations of icebergs in the vicinity of the Grand Banks of Newfoundland (Figure 1). IIP performs aerial remote sensing reconnaissance on board a Coast Guard Hercules (HC-130), a four engine turboprop aircraft, equipped with a Motorola AN/APS-135 Side Looking Airborne Radar (SLAR) and a Texas Instruments AN/APS-137 Forward Looking Airborne Radar (FLAR). Though both are X-band radars, SLAR is a real aperture radar which provides a thermal film analog output. The newer FLAR displays on a seven-inch digital screen and features an Inverse Synthetic Aperture (ISAR) mode, allowing the user to identify targets based on doppler characteristics. IIP has operated using this dual-sensor mode effectively since 1991. (CIIP, 1994)

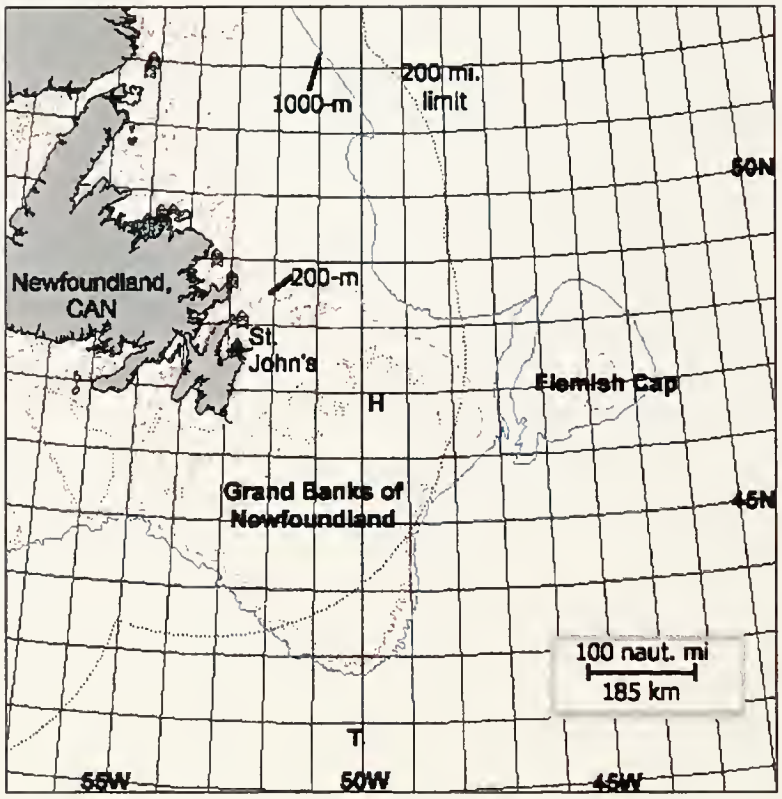

Figure 1. IIP Operations Area on Grand Banks. Location of Hibernia GBS shown by "H", location of TITANIC sinking shown by "T".

In November 1995, a Mission Analysis was conducted to investigate IIP operations and to identify its major costs and opportunities for future improvements (Pritchett and Armacost, 1995). This report stated that as satellite Synthetic Aperture Radar (SAR) assets become more prevalent and tested, IIP should investigate SAR products as additional means of conducting ice reconnaissance. It is speculated that as SAR costs decrease, satellite remote sensing products may alleviate the major cost to IIP of aircraft operation and help obviate the accelerating obsolescence of the AN/APS-135 SLAR (Sielbeck *et al.*, 1998). Over the past five years, much work has been done to assess the abilities of satellite SAR with respect to point target detection (Vachon *et al.*, 1997; Olsen *et al.*, 1995), though admittedly and understandably, most of this work has been devoted to the detection and identification of surface vessels or natural oceanic phenomena. Some researchers, however, have focused

on the iceberg detection/identification problem (Desjardins and McRuer, 1996; Willis *et al.*, 1996). These studies illustrated some of the difficulties inherent in the iceberg detection/identification problem. The lack of predictability of iceberg distribution and lifespans over the timescales required for satellite SAR data acquisition, unpredictability of weather and visibility for photographic ground truth collection, and the relatively low dielectric constant of glacial ice, which inhibits microwave radar detection, are among these challenges.

Study Development

In early 1996, International Ice Patrol began conducting a test of RADARSAT's ability to detect icebergs, as part of the Applications Development and Research Opportunities (ADRO) Program. The RADARSAT SAR, a Canadian satellite operation, was launched in 1995. A C-band HH polarization microwave radar instrument, it is capable of gathering terrestrial and ocean surface data day or night and is virtually unaffected by fog or weather. In addition, its greater flexibility in terms of user-selected beam modes, incidence angles and resolutions presents a great advantage in specifying the operating requirements for detecting point targets (Raney *et al.*, 1991). Vachon *et al.*, (1997) advocate image mode ScanSAR Narrow (SCN)-Far as a good compromise between swath size and resolution or smallest-detectable target when pursuing vessel detection. After some consideration, however, the need to detect growlers and small icebergs at dimensions smaller than those expected for vessels places a heavier emphasis on more fine-scale resolutions, requiring a sacrifice in swath size. For iceberg detection, we eventually assumed that beam-mode W2 would be more useful, given the finer resolution, moderately high incidence angle, and reasonably large swath width, though growlers would certainly not be detected by this beam-mode. We planned to compare the targets detected in the RadarSat images with those detected by IIP's visual and airborne radar observations. Operational constraints required that the study be conducted without allocation of additional funding or personnel. In addition, any ground-truthing had to be done without significantly impacting IIP's primary responsibility of performing iceberg

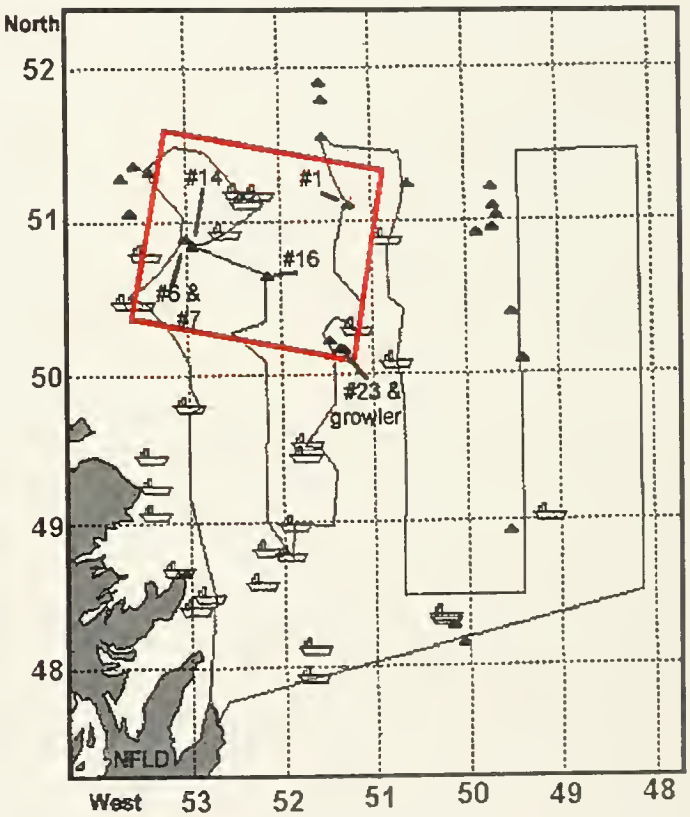

Figure 2. The box marks the bounds of the RADARSAT scene taken at approximately 09:40 UTC. The aircraft, CG-1503, departed St. John's airport at approximately 10:10 UTC and proceeded northward to the operation area, detecting the final contact within the footprint area at 13:23 UTC. The locations of icebergs are marked by triangles, with the corresponding index number shown. Ship icons indicate vessel positions at the time of aerial detection. The island of Newfoundland is shown in gray in the lower left area of the figure.

reconnaissance and ice report dissemination. Finally, the environmental and logistical challenges estimating where appropriate iceberg targets might be on a particular day, extremely variable and frequently inhospitable weather and sea conditions, as well as airframe serviceability and aircraft radar operation imposed nearly insurmountable obstacles in this study. We requested RADARSAT scenes on 25 July 97 (SCN), 28 July 97 (W-2), 25 April 98 (W-2) and 28 April 98 (W-2). All scenes were affected by either aircraft or weather logistics or by unfavorable iceberg distribution, except for one of the 28 July 97 W-2 images. This image was obtained at approximately 09:44 UTC, descending pass, centered on 50°49'N 52°10'W, with a pixel spacing of 12.5 meters.

Image Processing and Visual Reconnaissance

This image was processed using a range equalization function and a speckle suppression routine consisting of two consecutive Lee-Sigma filters with 3x3 windows. These processing functions were found in the ERDAS Imagine (a commercially available image processing program) v8.3 interface. Though not cutting-edge techniques, these corrections allowed us to easily eliminate much of the speckle and range variation found in the image. Fortunately, the image was completely over ocean and contained no terrestrial illumination. The processing produced an array of 16 bit pixels yielding digital numbers (DN) in the range 0 to 65536. By individual comparison of the point targets in the scene, as indicated by "bright splotches", we were able to characterize targets as grouped pixels collectively brighter than approximately 5500. The areas of interest containing brightness values for identified targets were extracted from RADARSAT scenes as ASCII text arrays and imported into Microsoft Excel worksheets for graphing and manipulation. As a secondary measure, the scene was run through the Canadian Centre for Remote Sensing's (CCRS) Ocean Monitoring Workstation (OMW). Initial arguments used were: minimum targets size of 3 pixels, target separation of 500m, maximum target size of 550m and a land mask of 1500m. Ten certain targets resulted with target sizes ranging from 64 pixels to 3 pixels (Table 1).

A typical International Ice Patrol reconnaissance flight track was flown over the area of the 28 JUL 98 RADARSAT scene, consisting of a "ladder search" with 150-nautical mile (275km), north-south oriented legs and cross legs of 30 nautical miles (55 km) (Figure 2). These flights are usually flown at an altitude of 8000 ft (2.4 km) but for visual reconnaissance and pictures, the icebergs were observed at 400 ft (730 m). The airplane, CG-1503, departed St. John's Airport at 10:00 UTC and the crew detected the final contact within the footprint area at 13:23 UTC. The weather conditions were excellent: 20

Table 1. Target results for Ocean Monitoring Workstation (OMW) analysis of 28 JUL 98 RADARSAT Scene.

ID	Target Latitude	Target Longitude	Size: Pixels	Scene Row	Scene Column
A	50-39-20°N	52-12-16°W	64	7563	6540
B	50-56-07°N	53-06-04°W	15	6014	1114
C	50-16-06°N	51-31-40°W	15	10200	10984
D	50-29-41°N	53-11-53°W	14	9978	1265
E	50-52-59°N	52-44-10°W	12	6106	3220
F	50-53-28°N	52-46-17°W	7	6071	3011
G	50-54-14°N	53-05-05°W	7	6273	1254
H	50-53-35°N	52-39-44°W	4	5944	3612
I	50-55-13°N	52-34-06°W	3	5611	4088
J	50-53-58°N	53-03-14°W	3	6281	1432

Table 2. Surface contacts detected though routine IIP aerial reconnaissance. Index number was assigned based on photographic frame number from film roll: size and shape are according to IIP classification scheme (CIIP, 1994), and position is based on CG-1503's Inertial Navigation System (INS).

Index #	IIP Size	Waterline	Shape	Latitude	Longitude	Time UTC
1	Large	121-200m	Drydock	51-08°N	51-19°W	13:23
6	Medium	61-120m	Drydock	50-55°N	53-05°W	10:59
7	Medium	61-120m	Wedge	50-55°N	53-06°W	10:59
14	Small	15-60m	Wedge	50-52°N	53-00°W	11:38
16	Medium	61-120m	Drydock	50-40°N	52-12°W	11:48
23	Medium	61-120m	Drydock	50-15°N	51-32°W	13:00
24	Growler	7-15m	No Shape	50-11°N	51-23°W	13:00
Ship		46m	Stern Trawl	50-40°N	53-18°W	10:45
Ship		20m	Long Line	51-12°N	52-25°W	11:18
Ship		18m	Long Line	51-08°N	52-20°W	11:22
Ship		15m	Long Line	51-11°N	52-13°W	11:19
Ship		18m	Long Line	50-56°N	52-35°W	11:27

nautical mile visibility (37.5 km) and calm seas. The icebergs observed in the reconnaissance effort (Table 2) were numbered based upon the frame number of the film from which the photographs were developed. Although our primary effort was to correlate observed icebergs with their corresponding RADARSAT-detected targets, a number of vessels were observed in and around the footprint area at the time of the reconnaissance. Despite having photographs of many of the vessels during our reconnaissance, correlating them to RADARSAT targets was difficult because of the approximately one- to five-hour time differential between SAR detection and aerial detection, and the lack of access to their positions/tracks during the intervening period.

Results

the OMW data with the visual underflight data yielded the results in Table 3. The observed positions of icebergs and detected target positions were within 2 nautical miles (3.7 km) except for Iceberg 14/Target J, which was over twice that distance. Expected error for the Inertial Navigation System (INS) on CG-1503 is on the order of 2-3 nautical miles (approximately 4 km), but can be as high as 10 nautical miles (18 km). It should also be noted that the position of each visually observed iceberg is based on a subjective determination of distance from the aircraft track. This estimation can vary from observer to observer.

Observed Iceberg #1 and the growler(s) at 50°11'N, 51°23'W were

Table 3. Ocean Monitoring Workstation (OMW) and visual ground-truth correlation.

OMW Target	Iceberg Visual ID #	Visual Target Size	OMW Size (pixels)	Distance
A	16	61-120 m	64	1400m
B	7	61-120 m	15	2100m
C	23	61-120 m	15	2200m
D	SHIP	46 m	14	-
E	SHIP	15-20 m	12	-
F	SHIP	15-20 m	7	-
G	6	61-120 m	7	1300m
H	SHIP	15-20 m	4	-
I	SHIP	15-20 m	3	-
J	14	16-60 m	3	5400m

undetected by the OMW. We did not expect to observe the growler(s), however. The Wide-2 beam characteristics, while beneficial for iceberg reconnaissance in terms of areal coverage and high incidence angles, are not conducive to detecting contacts 15m or smaller. We observed one additional contact in the OMW output than was observed visually. It is thought that this may have been a ship that was observed in the RADARSAT scene, but had moved out of the bounds of the scene area by the time the aircraft arrived. There were five ships that were observed at the edge of the RADARSAT footprint area, which could have been within the area 1.5 to 4.5 hours earlier. Though unlikely on account of the outstanding visibility, this result does present the possibility that an iceberg may have been detected by RADARSAT that was undetected by visible means.

We extracted the pixel values from the RADARSAT scene and plotted them for each iceberg as mesh wire plots, to demonstrate the diffuse scattering characteristic of icebergs (Figure 3). We did the same with the ship targets from the scene (Figure 4) to show the qualitative differences between the ship's radar return and those from the icebergs. With each iceberg plot, we included a photograph of the iceberg that correlated to the particular RADARSAT target. One can observe that some of the morphological features of the icebergs are captured in the RADARSAT return. More work is required to discuss this more quantitatively.

Discussion

Despite the difficulty in arranging the logistics, the one successful underflight demonstrates that RADARSAT beam-mode W-2 is appropriate for determining the locations of point targets in the IIP Operations Area. Further study is needed to develop the expertise to quickly and accurately classify targets as ice/non-ice. Work is currently underway by a number of agencies, including the Canadian Ice Service, the Danish Meteorological Institute, and the Canadian Centre for Cold Ocean Research and Engineering (C-CORE), as well as some private companies such as Satlantic, Inc. and Space Imaging, Inc., to develop algorithms to quickly and accurately filter targets based on their radar return.

There was no clear relationship between iceberg size and DN, or "brightness". In fact, there should be no strong relationship, as the radar backscatter from a point target is more dependent upon the shape of the object than upon the size (Raney, 1994). This could be observed in the comparison between the mesh plots of the RADARSAT targets and the photograph of the corresponding iceberg. The brightest target was iceberg #16/Target A, with a maximum DN of 54970. This iceberg, a drydock shape with several pinnacles surrounding a melt pool, likely presented a highly efficient discrete reflector that caused a high return of the incident radiation in this part of the iceberg. However, it is possible that this extremely high brightness value is an artifact of the speckle suppression procedures. In pursuing a qualitative target decision as either iceberg or ship, however, this artifact is not of great consequence.

The RADARSAT signature for Iceberg #1 had a maximum brightness of 7285, relatively weak compared to the other targets. This contact remained undetected by the OMW and was very difficult to discern, even with a priori knowledge of its location. This may be due to its peculiar shape (three small pinnacles connected to a large underwater mass) or to its increased incidence angle (as a result

of its near-range location. As noted previously, we did not detect the growlers in 50-11°N, 51-23°W. Though beam mode W-2 is not suited to detection of contacts of this size, these "small" ice masses can equal a ton or more (900 kg) and pose a significant hazard to shipping (CIIP, 1994). However, beam-modes that are more appropriate for growler detection, Fine or Extended High, would require a much greater number of images to cover the same illuminated area as would be needed using Wide-2 images. Finally, we made no mention of the degradation in detection capabilities with increasing wind speed and/or wave height. However, it is well documented that these factors directly affect the detection capabilities of radar systems (Vachon, *et al.*, 1997; CIIP, 1994; Willis, *et al.*, 1996)

Given the present state of RADARSAT point target capabilities, is it feasible for Ice Patrol to conduct its mission using RADARSAT data in place of aerial reconnaissance? Clearly, IIP has the requirement to detect the small masses of ice that may drift to extreme locations along with the frigid and southward-moving Labrador Current. Its mission is to "determine and broadcast the southeastern, southern and southwestern limit of all known ice (LAKI)", a subtle, but significant difference from detecting all or even most of the icebergs in the operational area. The advantages of spaceborne reconnaissance are broad areal and instantaneous coverage and good repeat coverage of a specified area. The user derives additional benefit from RADARSAT's offering of several beam-mode settings. In addition, it is not weather or visibility dependent and is not manpower intensive for the end user. However, the cost per processed and near-real-time delivered image can be substantial. The advantages of aerial reconnaissance are increased flexibility and much greater user control. Also, we have the ability, at least under some conditions, to visually corroborate our radar data. These data do not require as much processing and, therefore, can be delivered and incorporated into our ice reporting products extremely rapidly. Finally, with both FLAR and SLAR operating, IIP receives integrated data from these complementary systems, allowing IIP to perform reconnaissance more effectively and less expensively than with either system alone. Airborne disadvantages are that it is extremely labor intensive and can be expensive, both in the operation of the aircraft and radar sensors, as well as in personnel support for lodging and logistics for a 15-person crew for 9-day detachments to St. John's. Also, the repeat coverage of a particular region of our operational area is lower.

Presently ignoring the detection capabilities, the question becomes: is it more economical to perform International Ice Patrol's mission using airborne or spaceborne radar remote sensing techniques? Traditional airborne reconnaissance, via Coast Guard Hercules C-130 using SLAR and FLAR, covers, on average, a 300km x 300km area per sortie. The most critical region of IIP's patrol responsibility is between 41°N and 49°N, and between 44°W and 55°W, or an area of about 750,000 km^2. To patrol this area, IIP requires about 8 days of reconnaissance, each day covering approximately 90,000 km^2. This patrolled area is actually covered at 200% since each leg of reconnaissance benefits from "double coverage" or overlap from the preceding leg. Also, this considers the optimal condition of fully functional SLAR and FLAR. Although the area numbers are not precise (there may be areas of overlap, decreased emphasis, or less than 200% coverage), they are submitted for discussion. Averaged over the past three

years, a C-130 cost IIP $3,600 per hour, considering personnel, fuel, maintenance and operational support and depreciation (Commandant, 1991). The cost per sortie is approximately $15,350 for an average sortie of slightly over 4 hours. In reality, average reconnaissance sorties usually approach seven hours, while the two transit sorties between St. John's and Providence, RI are about 3.7 hours each. Considering this, a full reconnaissance sortie can cost about $25,000. On a per Ice Reconnaissance Detachment (IRD) basis, with approximately seven sorties per trip, the aircraft costs can amount to over $100,000, for a full Ice Season support cost approaching $1.7 million.

However, to adequately cover the same area using RADARSAT the following data are offered, per discussion with Mr. David Hisdal, Marketing manager, SPACE IMAGING, Inc. A single W-2 image costs $3500; however, for bulk orders, the effective price drops to $1500 for a 600-image delivery plan. Due to IIP's specific needs we would require "Near-Real-Time Delivery" services, at $800 per image; however, this price may decrease with a bulk order, as well. IIP's needs would be a full coverage of the area described above, which could occur once every 24 days, considering only one orbit mode (descending). Descending orbit acquisition is actually more economical given the geometry and orientation of the Grand Banks bathymetry. For an average of 65 images (to fully cover the area) which provides a very satisfactory level of overlap, this would result in the acquisition of 574 images, which we would round up to 600. The total cost for the entire year would be almost $1.4 million, considering Near-Real-Time fees but some arrangement would have to be made for file transfer.

On the basis of these estimated, and admittedly roughhewn, figures, RADARSAT appears to be an economical alternative to airborne reconnaissance operations. However, the need to identify the limit-setting ice, which would presumably be quite weathered depending on timing and location, requires more close and considered scrutiny than could be achieved with spaceborne remote sensing techniques, at least presently. In fact, IIP standing orders are to visually confirm, if possible, all limit setting icebergs (CIIP, 1994). Thus, though RADARSAT may not be appropriate for a complete replacement of IIP's airborne operations, it could perhaps be used in tandem, to corroborate and increase the flexibility of the C-130's patrols. In addition, it could make a very powerful planning tool. Finally, if used in this mode, there exists the potential of reducing the number of flights needed per sortie, and potentially shortening both the length of some flights and the length of a particular IRD. All of these contributions could help reduce costs to the Ice Patrol, and ultimately to SOLAS signatory nations. Assuming that a data acquisition plan similar to the one described previously, were used it could reduce by half IIP's aircraft costs per season AND reduce the IRD costs by half as well. As an average figure over the past three years, this sum would amount to over $900,000, and could reduce the ultimate cost of a RADARSAT plan to $500,000. Clearly, for a Coast Guard unit of only 16 personnel, automating tasks and reducing workload is an important goal. However, an acquisition plan, whether at an absolute cost of $1.4 million or a realized cost of $500,000, would require serious consideration and program support, especially for a unit whose operating budget is only about $200,000.

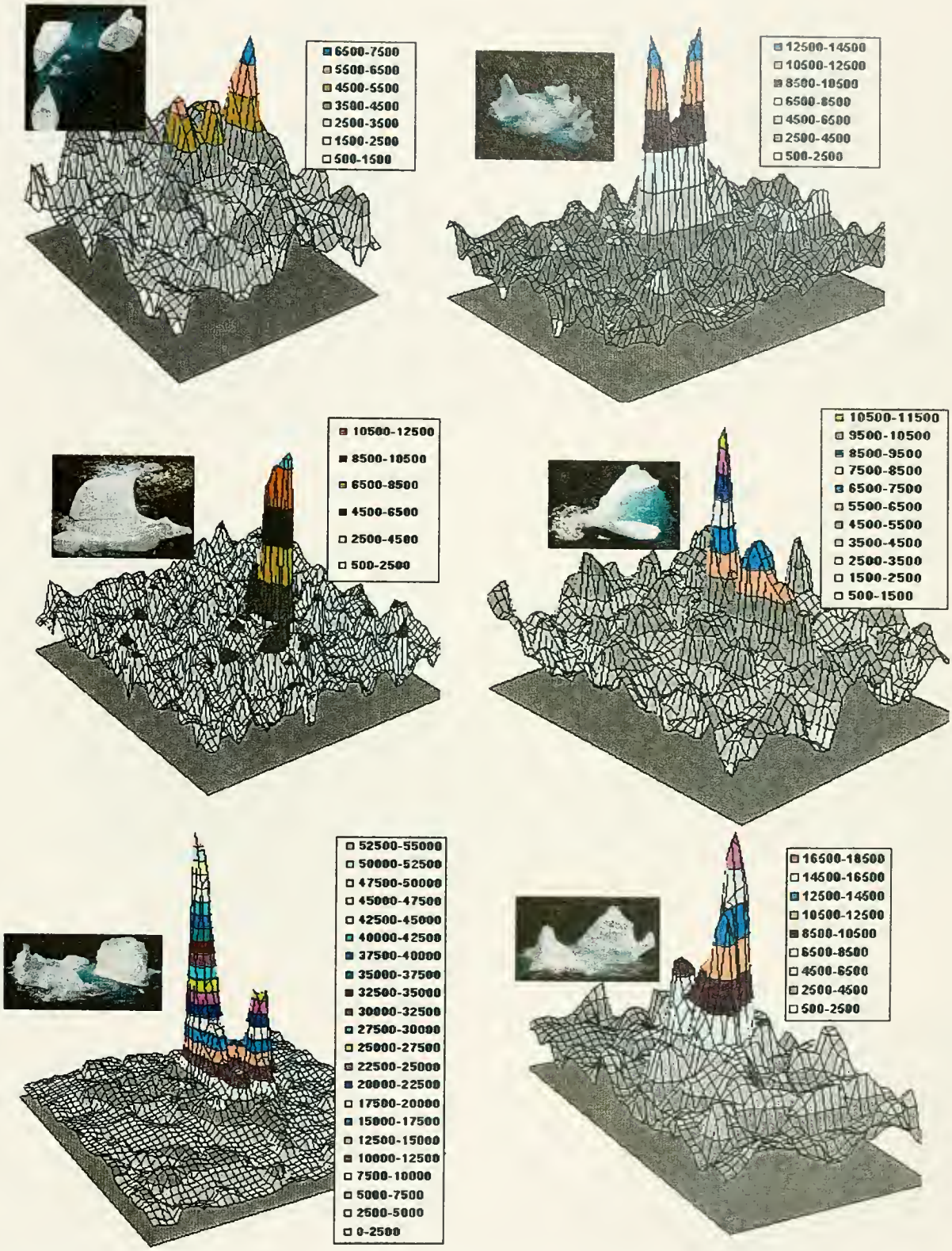

Figure 3. Wire mesh plots of RADARSAT return for Icebergs 1 (top left), 6 (top right), 7 (center left), 14 (center right), 16 (bottom left), and 23 (bottom right). Photographs of the icebergs are inset with each plot.

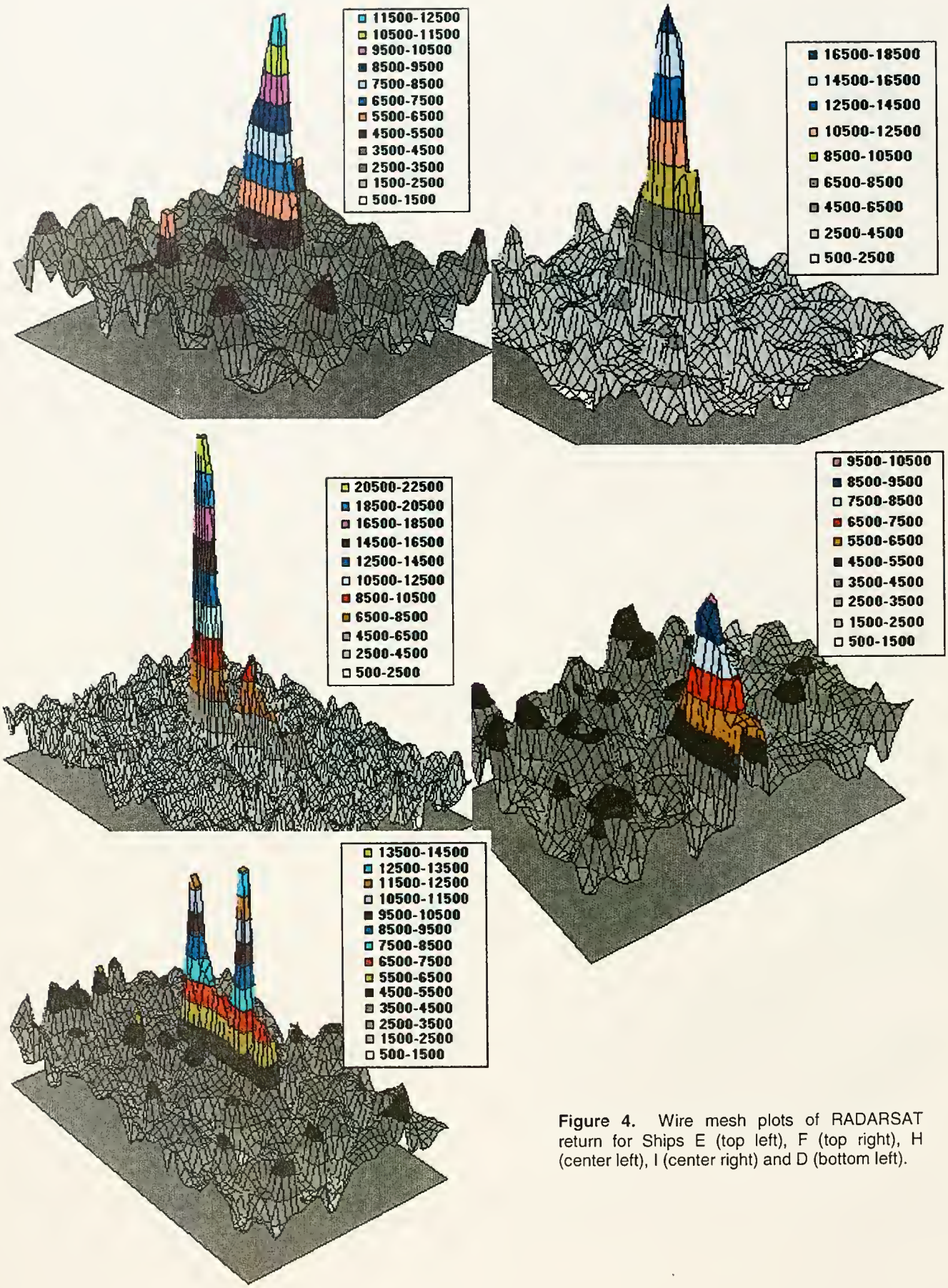

Figure 4. Wire mesh plots of RADARSAT return for Ships E (top left), F (top right), H (center left), I (center right) and D (bottom left).

Acknowledgements

We greatly appreciated the assistance of Cathryn Bjerkelund and others at CCRS, as well as the personnel at International Ice Patrol and Air Station Elizabeth City, NC. We gratefully acknowledge the support of the RADARSAT Application Development and Research Opportunity (ADRO). This research was performed under ADRO program number 579.

References

Commandant, U.S. Coast Guard, 1991. *Standard Rates. COMDTINST 7310.1(Series),* 2100 2nd Street S.W., Washington, DC, 20593, 21 pp.

Commander, International Ice Patrol (CIIP), 1994. *Ice Reconnaissance Detachment (IRD) Standard Operating Procedures (SOP).* CIIPINST M3100.2B, 1082 Shennecossett Rd., Groton, CT, 06340.

Desjardins, L. and H. McRuer, 1996. *Berg Search '95: Evaluation of ERS-1 and Ground Wave Over-The-Horizon Radar Target Detection and Identification.* Canadian Ice Service, 373 Sussex Drive, Block E, 3rd Floor, Ottawa, Ontario K1A0H3 Canada.

Olsen, R.B., P Bugden, Y. Andrade, P. Hoyt, M. Lewis, H. Edel, and C. Bjerkelund, 1995. Operational use of RADARSAT SAR for marine monitoring and surveillance. *Proceedings of 1995 International Geoscience and Remote Sensing Symposium (IGARSS'95)*, 10-14 July, Firenze, Italy 95CH35770, 224-226.

Pritchett, C. W. and R. L. Armacost, 1995. *Mission Analysis Support for USCG International Ice Patrol.* Report CG-D-01-96, U. S. Coast Guard Research and Development Center, 1082 Shennecossett Road, Groton, CT 063240-6096, 11 pp.

Raney, R.K, 1994. Active Microwave Systems. In*: Remote Sensing of Sea Ice and Icebergs.* Haykin, S., E.O. Lewis, R. K. Raney and J. R. Rossiter, eds. John Wiley and Sons, Inc, New York, 259-297.

Raney, R.K, A.P Luscombe, E.J. Langham and S. Ahmed, 1991. RADARSAT. *Proceedings of IEEE.* **79**(6), pp. 839-849.

Sielbeck, S.L., M.R. Hicks, and D.L. Murphy. International Ice Patrol: Using Technology to Promote Maritime Safety. In*: Proceedings of the Marine Technology Society Annual Conference*, 1998. Vol. 2, 628-632.

Vachon, P.W., J.W.M. Campbell, C.A. Bjerkelund, F.W. Dobson, and M.T. Rey, 1997. Ship Detection by the RADARSAT SAR: Validation of Detection Model Predictions. *Canadian Journal of Remote Sensing,* **23**(1), 48-59.

Willis, C.J., K.A. Teleki, J.T. Macklin, K.C. Partington, R.G. Williams, and W.G. Rees, 1996. Iceberg Detection Using ERS-1 Synthetic Aperture Radar. *International Journal of Remote Sensing,* **17**(9), 1777-1790.