Homeland Security

United States Coast Guard

Report of the International Ice Patrol in the North Atlantic

2004 Season
Bulletin No. 90
CG-188-59

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REPORT OF THE INTERNATIONAL ICE PATROL IN THE NORTH ATLANTIC

Season of 2004

CG-188-59

Forwarded herewith is Bulletin No. 90 of the International Ice Patrol, describing Ice Patrol's services and ice observations and conditions during the 2004 season. Opening on 27 April, the 2004 season marked the latest opening date on record. Warmer-than-normal winter temperatures off the Labrador coast coupled with a series of powerful low-pressure systems during January resulted in limited sea-ice growth and the destruction of icebergs that would normally reach the shipping lanes during February and March.

Though a light season, the following Core Values governed Ice Patrol activity, ensuring continued operational excellence:

Partnerships Built on the Spirit of International Cooperation
Continuous Improvement through the Use of Technology
Individual Commitment to the IIP Mission

Nowhere is the spirit of international cooperation better demonstrated than in the collaborative work of the North American Ice Service, in which IIP became one of three component services in 2004, joining the U.S. National Ice Center and the Canadian Ice Service. Ice Patrol's participation in this group sparked continuous process improvement, particularly in upgrading the iceberg drift and deterioration model (outlined in Appendix E). IIP continued to validate the use of satellites for detecting and identifying icebergs (Appendix D). While much work is still needed, this technology holds hope for the future of iceberg reconnaissance. In addition, IIP looks to its history to inspire commitment to the mission. The cover of this year's report depicts one of several iceberg-destruction experiments. Appendix C is a fascinating article documenting the history of these experiments. Although we have been unsuccessful in our attempts to destroy icebergs, the crew of IIP continues to diligently monitor iceberg danger and reduce the risk of iceberg collision by providing accurate, timely warnings to transatlantic shipping.

I hope you enjoy reading this report of the 2004 season.

M.R. Hicks

M. R. Hicks
Commander, U. S. Coast Guard
Commander, International Ice Patrol

International Ice Patrol
2004 Annual Report

Contents

Cover photograph: Iceberg destruction using thermite. June 1960.

List of Abbreviations and Acronyms

AOR	Area of Responsibility
ASAR	Advanced Synthetic-Aperture Radar
AXBT	Air-deployed eXpendable BathyThermograph
BAPS	iceBerg Analysis and Prediction System
CAMSLANT	Communications Area Master Station atLANTic
CCG	Canadian Coast Guard
CIS	Canadian Ice Service
DFO	Department of Fisheries and Oceans
ENVISAT	ENVIronmental SATellite
FLAR	Forward-Looking Airborne Radar
FTP	File Transfer Protocol
GMES	Global Monitoring for Environment and Security
HF	High Frequency
HH	Horizontal transmit Horizontal receive
HMCS	Her Majesty's Canadian Ship
HV	Horizontal transmit Vertical receive
IDS	Iceberg Detection Software
IIP	International Ice Patrol
INMARSAT	INternational MARitime SATellite (also Inmarsat)
IRD	Ice Reconnaissance Detachment
IS	Incident Swath
LAKI	Limit of All Known Ice
MANICE	MANual of standard procedures for observing and reporting ICE conditions
M	Meter
M/V	Motor Vessel
NIC	National Ice Center
NTIS	National Technical Information Service
NM	Nautical Mile
PAL	Provincial Aerospace Limited
POC	Probability Of Classification
POD	Probability Of Detection
RADAR	Radio Detection And Ranging (also radar)
RMS	Royal Mail Steamer
SOLAS	Safety Of Life At Sea
SLAR	Side-Looking Airborne Radar
SST	Sea Surface Temperature
WIM	What-If Model
WOCE	World Ocean Circulation Experiment

Introduction

This is the 90th annual report of the International Ice Patrol, which is under the operational control of Commander, U.S. Coast Guard Atlantic Area. The report contains information on IIP operations, environmental conditions, and iceberg conditions in the North Atlantic during the 2004 season. Funded by 17 member nations and conducted by the U.S. Coast Guard, Ice Patrol was formed soon after the RMS *Titanic* sank on 15 April 1912. Since 1913, except for periods of the World Wars, Ice Patrol has been monitoring iceberg danger near the Grand Banks of Newfoundland and broadcasting the Limit of All Known Ice to mariners. The activities and responsibilities of IIP are delineated in U.S. Code, Title 46, Sections 738, 738a-738d and the International Convention for the Safety of Life at Sea, 1974.

The International Ice Patrol conducted aerial reconnaissance from St. John's, Newfoundland to search for icebergs in the southeastern, southern, and southwestern regions of the Grand Banks. In addition to IIP reconnaissance data, Ice Patrol received iceberg reports from other aircraft and mariners in the North Atlantic. (Ice Patrol salutes M/V *Berge Nord* for providing the most ship reports during the 2004 season.) At the Operations Center in Groton, Connecticut, personnel analyzed iceberg and environmental data and used a computer model to predict iceberg drift and deterioration. Based on the model's prediction, IIP produced iceberg warnings that were broadcast twice a day to mariners as text bulletins and charts. In addition to these routine broadcasts, IIP responded to individual requests for iceberg information.

Vice Admiral James D. Hull was Commander, U. S. Coast Guard Atlantic Area through 16 July 2004, when he was relieved by Vice Admiral Vivien S. Crea. CDR Michael R. Hicks was Commander, International Ice Patrol.

For more information about the International Ice Patrol, including iceberg bulletins and charts, visit our website at http://www.uscg.mil/lantarea/iip/home.html.

INTERNATIONAL ICE PATROL

Summary of Operations

International Ice Patrol actively monitors the iceberg danger to transatlantic shipping in the region bounded by 40°N, 52°N, 39°W, and 57°W (**Figure 1**). Ice Patrol formally begins ice reconnaissance and product dissemination when icebergs threaten the primary shipping lanes between Europe and North America. This threat usually begins in February and extends through July, but IIP commences operations when iceberg conditions dictate. Except during unusually heavy ice years, the Grand Banks of Newfoundland are normally free of icebergs from August to January.

Ice Patrol began issuing weekly products on 13 February 2004. Commander, International Ice Patrol opened the season on 27 April 2004, and IIP distributed products daily until the season's close on 27 July 2004. The opening on 27 April marked the latest start to a season on record. Note: All information-report statistics presented in this summary refer to the period of 13 February to 27 July.

International Ice Patrol's Operations Center in Groton, Connecticut analyzed 1,642 information reports from IRDs, merchant ships, Canadian Ice Service reconnaissance flights, the National Ice Center, and other sources (**Figure 2**). Two-hundred seventy-two of these reports contained ice information (**Figure 3**), ranging from single or multiple iceberg sightings to stationary radar targets and sea ice. From these reports, IIP merged 2,862 individual targets into BAPS (**Figure 4**), the drift and deterioration model that Ice Patrol and CIS operate jointly.

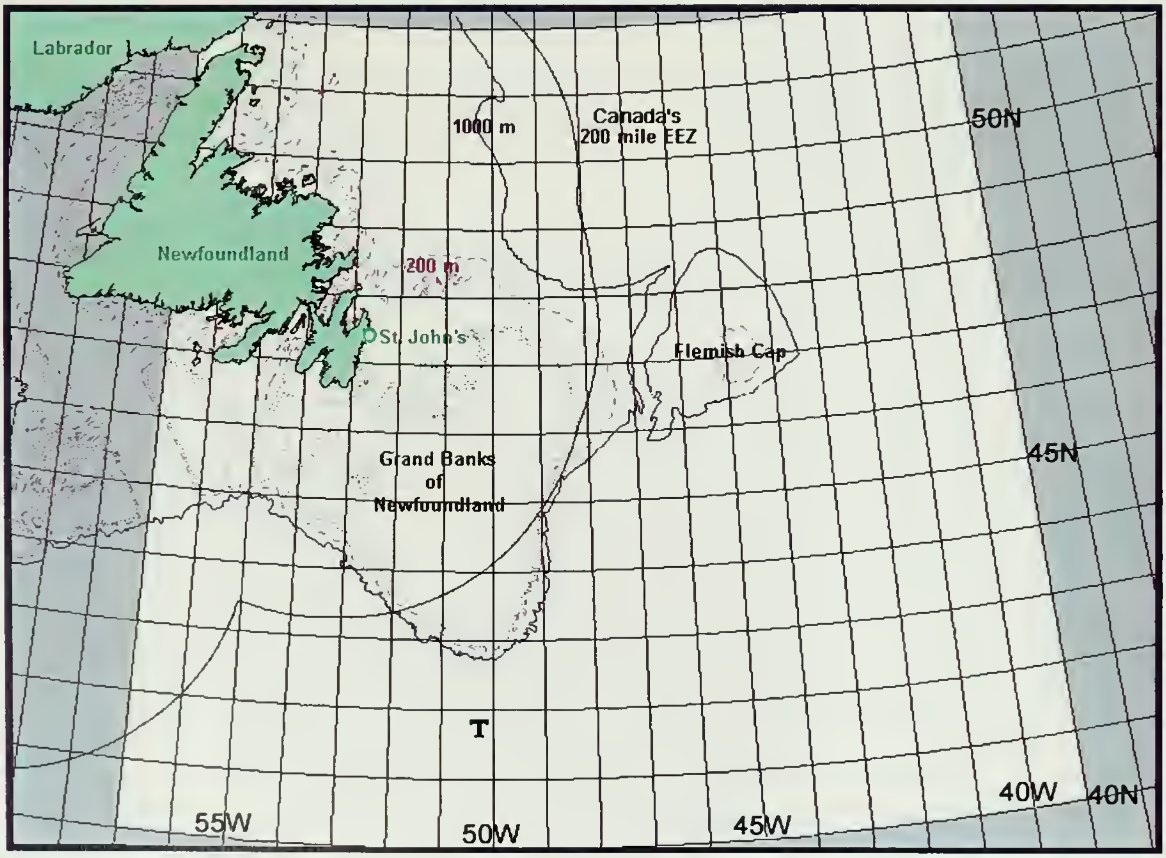

Figure 1. IIP's operating area. **T** indicates location of *Titanic* sinking.

Information Reports

As in previous years, IIP requested voluntary information reports from all ships transiting the Grand Banks region. Ice Patrol requested that ships report ice sightings, radar targets, weather, and sea surface temperatures via Canadian Coast Guard Radio Station St. John's/VON, U. S. Coast Guard CAMSLANT, or—using code 42—Inmarsat-C and Inmarsat-A. Ice Patrol encouraged ships to make ice reports even if no ice was sighted because knowledge of the absence of ice is also fundamental to accurate product generation. The continued success and viability of the International Ice Patrol depends heavily upon all who contribute information reports.

Merchant shipping provided the majority of reports. In 2004, 139 ships from 34 different countries provided IIP with 1,379 reports—84% of total reports—demonstrating that the number of nations using Ice Patrol services exceeds the 17 member nations that support IIP under SOLAS. Furthermore, the international merchant fleet's high level of participation in 2004 indicates the value of Ice Patrol products and services. For the second year in a row, the merchant vessel *Berge Nord* (Norway) made the most reports to IIP, submitting a total of 99. Appendix B lists the ships and all other sources that made information reports during the 2004 season.

While the majority of information reports came from merchant shipping, Ice Patrol also received valuable information from many Canadian Government sources. These sources include the Canadian Ice Service's aircraft, contract reconnaissance flights by Provincial Aerospace Limited, HMCS and CCG vessels, and coastal lighthouses, all of which combined provided 129 reports, or 8% of the year's total. Finally, other sources (e.g., fishing vessels, commercial aircraft, recreation boats)—some for which the platform is unknown—provided the remaining 5% of reports. **Figure 2** provides a breakdown of the sources of all information reports received in 2004.

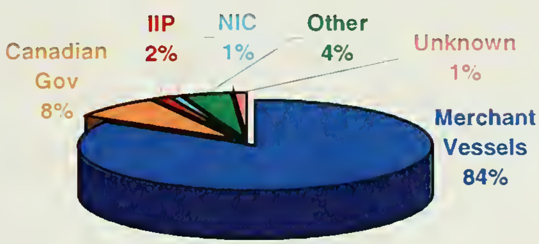

Figure 2. Reporting sources of the 1,642 information reports received by IIP in 2004. Information reports include ice, sea-surface temperature, and weather.

Ice Reports

Only 272 of the 1,642 reports sent to Ice Patrol contained ice information. The Canadian Government provided 43% of ice reports and the international merchant fleet 33%. The remaining 24% came from IIP reconnaissance, the National Ice Center, and other sources, some for which the platform is unknown. **Figure 3** displays a breakdown of ice report sources.

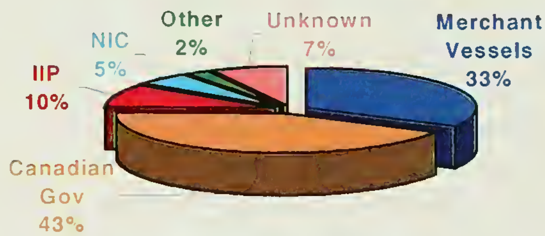

Figure 3. Reporting sources of the 272 ice reports received during 2004. Ice reports include icebergs and stationary radar targets.

Merged Targets

The 272 ice reports received by IIP contained 2,862 targets that were merged into BAPS. The Canadian Government reported 65% of merged targets while IIP, the National Ice Center, and merchant shipping reported 22%. Targets transferred via BAPS (Ice Patrol's iceberg drift and deterioration model) made up the remaining 13%. These latter targets were originally sighted north of Ice

Patrol's AOR and entered into the CIS model, which forwarded them to IIP once they drifted south of 52°N. This BAPS configuration makes it extremely difficult to determine the original reporting source of a target transferred from the CIS model and thus explains why Figures 2 and 3 do not account for targets transferred via BAPS. **Figure 4** provides a breakdown of merged-target reporting sources.

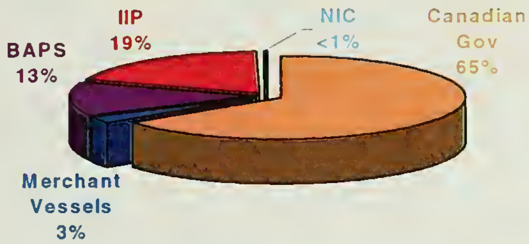

Figure 4. Reporting sources of the 2,862 individual targets merged into BAPS in 2004.

LAKI Iceberg Sightings

SOLAS mandates Ice Patrol to guard the southeastern, southern, and southwestern regions of the Grand Banks. In addition to monitoring the icebergs that set the Limit of All Known Ice, IIP uses most of its resources to search for the most seaward icebergs. This year IIP detected 53% of LAKI icebergs; but, fortunately, Ice Patrol is not alone in the search for limit-setting icebergs. Merchant ships reported 25% of LAKI icebergs, and NIC reported another 3%. Finally, BAPS model transfers between IIP and CIS accounted for 18%, and other sources accounted for 1% of LAKI icebergs (**Figure 5**).

IIP Broadcasts/Products

Throughout the iceberg season, IIP produced two LAKIs a day (0000Z and 1200Z) and distributed them by various means. United States Coast Guard Communications Area Master Station Atlantic/NMF and Canadian Coast Guard Marine Communications and Traffic Service St. John's/VON were the primary radio stations that transmitted ice bulletins. Marine Communications and Traffic Services St. Anthony/VCM transmitted bulletins as well. In addition, ice bulletins and safety broadcasts were delivered over the Inmarsat-C SafetyNET via the Atlantic East and West satellites. Moreover, IIP produced an ice chart that depicted the 1200Z LAKI and broadcast it daily at 1600Z and 1810Z. United States Coast Guard Communications Area Master Station Atlantic/NMF and the National Weather Service assisted with the transmission of the ice chart. On the eastern side of the Atlantic, the German Federal Maritime and Hydrographic Agency stations Hamburg/DDH and Pinneberg/DDK transmitted IIP's ice chart, which was also available via plain paper facsimile and email on demand. Finally, both the bulletin and chart were available on Ice Patrol's website.

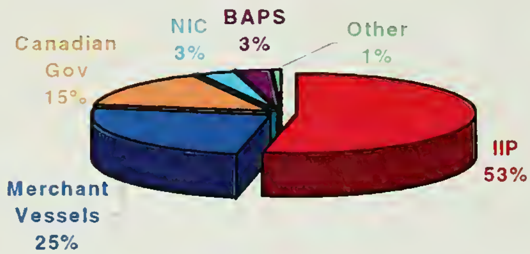

Figure 5. Initial reporting sources of LAKI-setting icebergs during 2004.

In 2004, Ice Patrol transmitted 184 scheduled ice bulletins via SafetyNET, all of which reached the SafetyNET on time. The timeliness, however, of ice-chart transmissions was not quite as high as that of bulletins. Ice Patrol produced 92 ice charts that were transmitted twice a day (184 total transmissions) via HF radio facsimile, made available via email on demand, and posted on the web. Of these 184 transmissions, 172 (93%) were delivered on time. Ice Patrol considers an ice chart transmission late when the radio frequency start tone begins more than one minute later than the scheduled transmission time (1600Z or 1810Z). This year one ice-chart transmission was late, and 11 were not transmitted at all. A problem in the line between CAMSLANT and the transmitter antenna in Boston was the primary cause for late and missed ice-chart transmissions.

Safety Broadcasts

During the 2004 season, Ice Patrol sent six unscheduled safety broadcasts for icebergs and stationary radar targets near or outside the LAKI. These six safeties reported eight targets: one iceberg inside but near the LAKI, four stationary radar targets outside the LAKI, and three icebergs outside the LAKI.

Because of two untimely reports of icebergs outside the LAKI—which resulted in two of the season's six safeties—the Limit was inaccurate in four of 184 bulletins. The icebergs in these two reports—made on separate days—were sighted before IIP had created the 0000Z LAKI, but the reports did not arrive at IIP until after personnel had already released both the 0000Z and 1200Z bulletins. Therefore, on two days, Ice Patrol unwittingly broadcast inaccurate 0000Z and 1200Z LAKIs. In both cases, however, personnel immediately sent a safety upon receipt of the ice report. The end result was 98% LAKI accuracy in 2004 (**Figure 6**).

Historical Perspective

To compare ice seasons, IIP uses two measurements developed by various authors (Alfultis, 1987; Trivers, 1994; Marko et al., 1994). Ice Patrol determines season severity based on season length (**Figure 7**) and the number of icebergs south of 48°N (**Figure 8**). This second measurement includes both icebergs sighted south of 48°N and those that were sighted north of 48°N but that BAPS eventually drifted south of 48°N. Of the two measurements, IIP focuses more on the number of icebergs south of 48°N because it

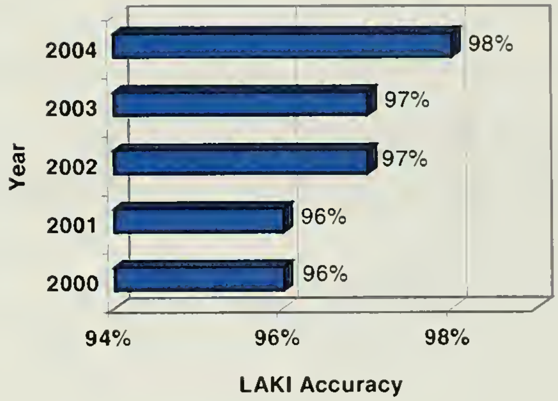

Figure 6. LAKI accuracy.

emphasizes the degree of a season's iceberg danger to transatlantic shipping.

The 2004 season lasted 92 days and saw 262 individual icebergs south of 48°N. Compared to the past four years, 2004 was light both in terms of season length and number of icebergs south of 48°N. Furthermore, the 2004 statistics accord with Trivers's (1994) definition of a light season, which he determined lasts less than 105 days and has fewer than 300 icebergs south of 48°N.

Canadian Support

As they do every year, the Canadian Government generously supported IIP during the 2004 season. The Canadian Ice Service conducted ice reconnaissance using a SLAR-equipped Dash-7 airplane and shared its

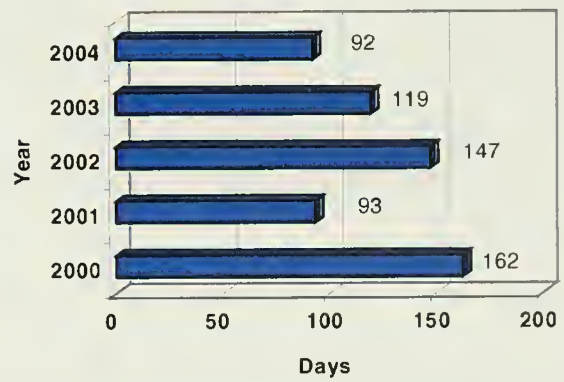

Figure 7. Length of ice season since 2000. The 20-year (1985-2004) mean is 142.

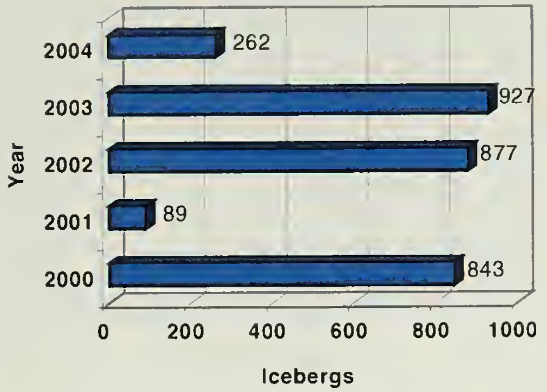

Figure 8. Number of individual icebergs (sighted and drifted) south of 48°N since 2000. The 20 year (1985-2004) mean is 900.

reconnaissance data with IIP. In addition, CIS provided Ice Patrol with critical support of BAPS. Finally, Provincial Aerospace Limited supplied IIP with invaluable ice data.

Customer Relations

According to surveys from customers, mariners use all of Ice Patrol's products; therefore, IIP will continue generating the same products next season, along with a new ice chart valid for 0000Z. Moreover, because feedback from customers was not as comprehensive as planners had hoped, Ice Patrol will continue sending surveys to mariners in 2005.

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Marko, S. R., Fissel, D. B., Wadhams, P., Kelly, P. M., & Brown, R. D. (1994). Iceberg Severity off Eastern North America: Its Relationship to Sea Ice Variability and Climate Change. *Journal of Climate*, *7*(9), 1335-1351.

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Iceberg Reconnaissance & Oceanographic Operations

Iceberg Reconnaissance

The Ice Reconnaissance Detachment is a sub-unit under Commander, International Ice Patrol partnered with Coast Guard Air Station Elizabeth City, which provided the aircraft platform. Ice Reconnaissance Detachments deployed to observe and report sea ice, icebergs, and oceanographic conditions on the Grand Banks of Newfoundland. Oceanographic observations were used for operational support and research purposes.

Ice Patrol's pre-season IRD departed on 29 January 2004 to determine the early season iceberg distribution. The iceberg distribution noted during the pre-season IRD did not warrant regular (every other week) deployments to Newfoundland. Consequently, only one IRD deployed during the six weeks between the end of the pre-season and 24 March, which marked the beginning of regular deployments. Because of the limited severity of ice conditions, IRD deployments were shortened from nine to seven days. These abbreviated IRDs, averaging two reconnaissance flights per deployment, operated from St. John's, Newfoundland until 3 July 2004. Iceberg reconnaissance operations concluded on 30 July 2004 with the return of the post-season IRD.

Ice Reconnaissance Detachments were deployed to IIP's base of operations in St. John's, Newfoundland for 70 days during the 2004 season (**Table 1**). Ice Patrol flew 51 sorties, 24 of which were transit flights to and from St. John's. The 27 remaining sorties were iceberg reconnaissance patrols to determine the LAKI. Ice Patrol dedicated a portion of two patrols to ground-truth data collection for use in conjunction with the GMES project, a program sponsored by the European Space Agency. This data will be used to evaluate a computer-based target identification algorithm that may be used in future IIP operations. Ice Patrol participated as an end user through the Northern View element of the project. Appendix E further describes IIP's involvement in the GMES project. In addition to the 51 sorties, there were four logistics flights from Coast Guard Air Station Elizabeth City to maintain and repair the aircraft. **Figure 9** details IIP's flight hours for 2004.

IRD	Deployed Days	Iceberg Patrols	Flight Hours
Pre	8	2	23.9
1	Cancelled		
2	12	2	41.2
3	Cancelled		
4	5	3	24.9
5	4	2	26.9
6	6	2	23.5
7	6	3	30.2
8	6	3	30.4
9	6	2	24.2
10	6	3	31.8
11	6	4	35.0
Post	5	1	16.8
Total	**70**	**27**	**308.8**

Table 1: 2004 IRD Summary.
Note: Flight hours include patrol and transit hours. IRD #2 includes 18.2 logistics hours.

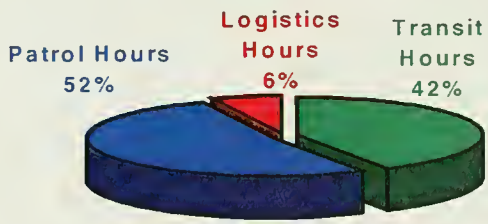

Figure 9. 2004 flight hours.

Ice Patrol used 308.8 flight hours in 2004, a 20% decrease from 2003 (**Figure 10**). **Figure 11** compares flight hours with the number of icebergs south of 48°N since 1995. This figure demonstrates that IIP annually

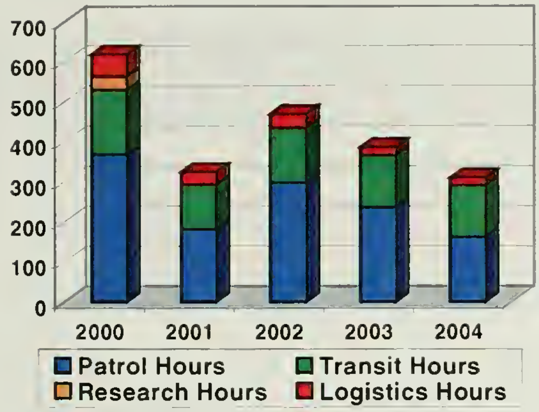

Figure 10. Breakdown of flight hours (2000-2004).

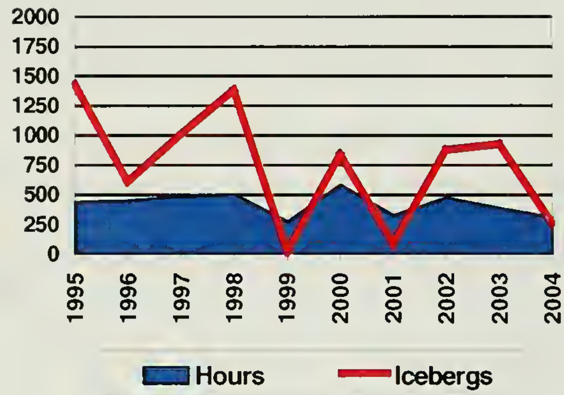

Figure 11. Flight hours versus icebergs south of 48°N (1995-2004).

expends a fairly consistent number of flight hours even though the number of icebergs varies significantly from year to year. Ice Patrol maintains this consistency because even a small number of icebergs passing south of 48°N can dramatically extend the geographic distribution of the LAKI, thus requiring coverage of a large area of ocean despite a sparse iceberg population.

Coast Guard aircraft provided the primary means of detecting the icebergs that set the Limit of All Known Ice. To conduct iceberg reconnaissance, IIP used a Coast Guard HC-130H long-range aircraft equipped with the Motorola AN/APS-135 Side-Looking Airborne Radar and the Texas Instruments AN/APS-137 Forward-Looking Airborne Radar. Ice Patrol began using SLAR in 1983, FLAR in 1993, and incorporated the Maritime Surveillance System 5000 with SLAR in 2000.

Environmental conditions on the Grand Banks permitted adequate visibility (≥10 NM) only 36% of the time during iceberg reconnaissance. Consequently, Ice Patrol relied heavily on its two airborne radar systems to detect and identify icebergs in cloud cover and fog. The combination of SLAR and FLAR enabled detection and identification of icebergs in pervasive low-visibility conditions, minimizing the flight hours necessary to accurately determine the LAKI. This radar combination allowed IIP to use 30 NM track spacing and provide 200% radar coverage of approximately 40,000 NM^2 of ocean each patrol despite poor visibility (**Figure 12**). A detailed description of IIP's reconnaissance strategy is provided at http://www.uscg.mil/lantarea/iip/FAQ/ReconnOp_10.shtml.

Identifying the various types of targets on the Grand Banks is a continual challenge for IIP reconnaissance. Frequently, visibility is poor and targets are often identified based solely on their radar image. Both SLAR and FLAR provide valuable clues to target identity, but in most cases FLAR's superior imaging allows definitive target identification. **Figure 13** displays the number and types of targets that

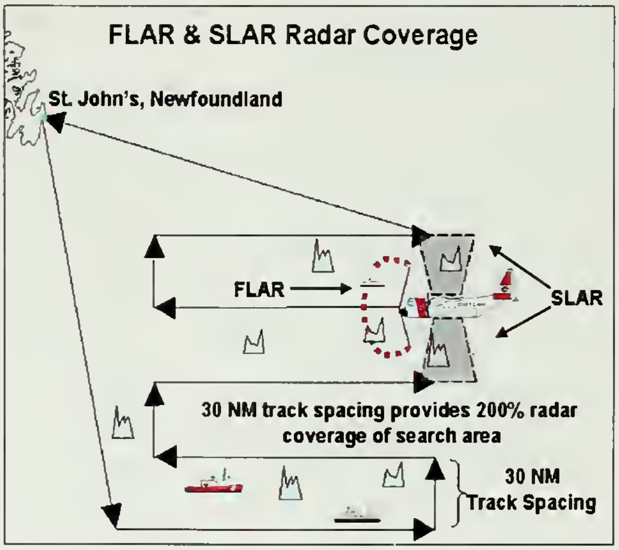

Figure 12. Radar reconnaissance plan.

reconnaissance patrols detected during the 2004 season. Reconnaissance detachments detected a total of 1,127 icebergs; 35% (389) were identified with radar alone (not seen visually) while the remaining 65% (738) were identified using a combination of visual and radar information or by visual means alone. This data demonstrates Ice Patrol's reliance on radar information.

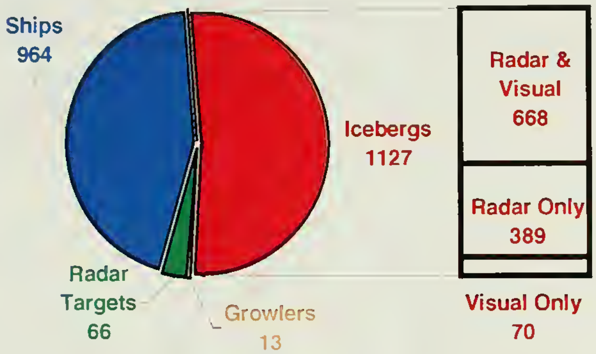

Figure 13. Breakdown of targets detected by IRDs in 2004.

The Grand Banks are a major fishing area frequented by fishing vessels ranging in size from 60 to over 200 feet. Determining whether a radar contact is an iceberg or a vessel is difficult with small vessels and small icebergs. These small contacts sometimes create similar radar returns and cannot be differentiated. Therefore, when a radar image does not present clear, distinguishing features, Ice Patrol classifies the contact as a radar target.

The Grand Banks region has been rapidly developed for its oil reserves since 1997. In November 1997, Hibernia, a gravity-based oil production platform, was set in position approximately 150 NM offshore on the northeastern portion of the Grand Banks. In addition to Hibernia, other drilling facilities—including Glomar Grand Banks, Terra Nova, and Henry Goodrich—are routinely on the Grand Banks. Consequently, this escalated drilling has increased air and surface traffic in IIP's area of responsibility, further complicating iceberg reconnaissance.

Oceanographic Operations

Ice Patrol's oceanographic operations peaked in the 1960s when the U.S. Coast Guard dedicated substantial surface ship resources to collecting oceanographic data. Since that time, however, IIP's involvement in oceanographic surveys on the Grand Banks has declined. The decline is a result of numerous factors, three of which are the most significant. First, increased competition among various U.S. Coast Guard missions made it increasingly difficult for IIP to obtain the ship resources necessary to continue extensive oceanographic surveys. Second, because the capability and reliability of air-deployable oceanographic instruments has improved vastly, Ice Patrol can collect oceanographic data without the aid of surface ships. Finally, the wide availability of oceanographic information now on the internet enables personnel to focus more narrowly on Ice Patrol's primary mission of iceberg reconnaissance.

In 2004, IIP collected oceanographic data using air- and ship-deployed satellite-tracked drifting buoys and AXBTs. The AXBT probes measured the water temperature profile, which helped Ice Patrol determine the location of the Labrador Current, validate temperatures from satellite-tracked drifting buoys, and obtain precise SSTs for numerical models. **Figure 14** describes the development of IIP's AXBT

Figure 14. AXBT drops and failure rates (2000-2004).

program since 2000. The marked reduction in AXBT drops over the last two years is the result of a change in AXBT drop policy that followed the 2002 ice season. The new policy states that AXBT drops are not to interfere with reconnaissance.

After coding AXBT data into a standard format, Ice Patrol shared it with the Canadian Maritime Atlantic Command Meteorological and Oceanographic Center—IIP's supplier of AXBT probes—and the U. S. Naval Fleet Numerical Meteorological and Oceanographic Center, where it was quality controlled and redistributed via oceanographic products.

Satellite-tracked drifting WOCE buoys, drogued at a depth of fifteen or fifty meters, provided near real-time ocean current information. Ice Patrol deployed WOCE buoys primarily in the offshore and inshore branches of the Labrador Current and used data from these buoys to modify the historical current database within IIP's computer model. Because of the sparse distribution of icebergs during the 2004 ice season, IIP was able to choose drop locations near individual icebergs or small clusters. This precise targeting enabled accurate modelling of such a sparsely distributed iceberg population and therefore demonstrates the value of WOCE buoy data to the Ice Patrol mission.

During the 2004 season, IIP deployed nine satellite-tracked drifting buoys, five from reconnaissance aircraft and four from volunteer ships (**Figure 15**). **Figure 16** displays AXBT drop locations and composite drift tracks for the buoys deployed in 2004. Detailed drifter information is provided in IIP's 2004 WOCE Buoy Drift Track Atlas which is available upon request.

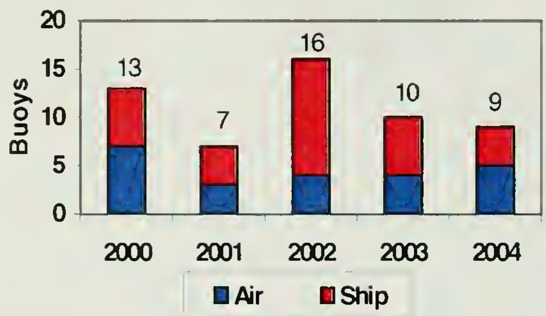

Figure 15. WOCE buoy deployments (2000-2004).

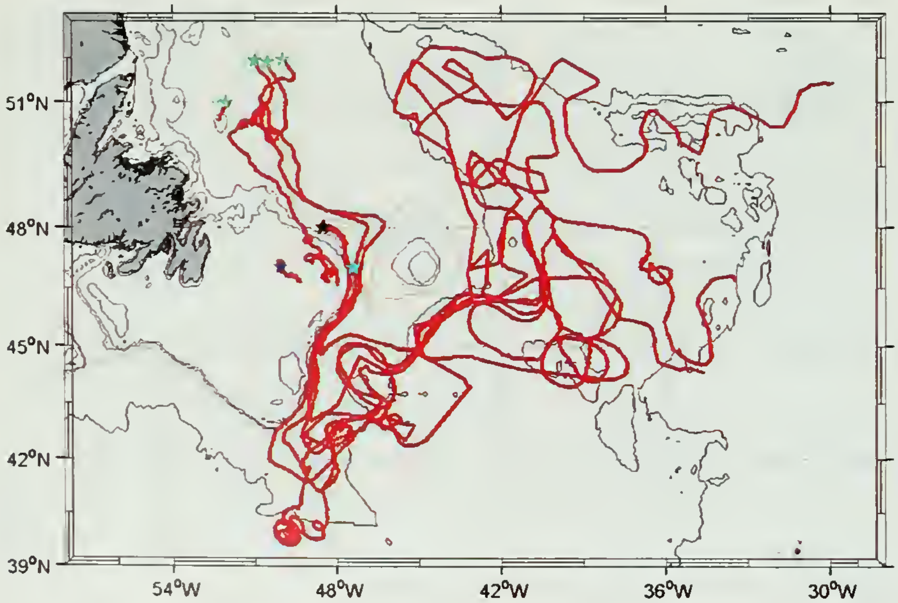

Figure 16. Composite buoy tracks. Green stars represent drop locations of air-deployed buoys and AXBTs. Light blue star represents 1 air-deployed buoy with AXBT and 1 ship-deployed buoy. Dark blue star represents 1 ship-deployed buoy, and black star represents 2 ship-deployed buoys.

Ice and Environmental Conditions

Introduction

After two consecutive active iceberg seasons in 2002 and 2003, 2004 was a dramatic change. It had the latest season opening date, 27 April, in Ice Patrol history. By the traditional measures of season severity, season length (92 days) and iceberg count (262), 2004 was a light and short iceberg season. This section describes its progression and the accompanying environmental conditions.

The IIP ice year extends from October through September. The following month-by-month narrative begins as sea ice began forming along the Labrador coast (**Figure 17**) in late December 2003 and concludes in late July with the closing of IIP's iceberg season. The narrative draws from the following sources: *Seasonal Summary for Eastern Canadian Waters, Winter 2003-2004* (Canadian Ice Service, 2004); sea-ice analyses provided by the Canadian Ice Service and the U. S. National Ice Center; sea-surface temperature anomaly plots provided by the U. S. National Weather Service's Climate Prediction Center (Climate Prediction Center, 2004); and summaries of the iceberg data collected by Ice Patrol and CIS. The plots on pages 30 to 37 document the Limits of All Known Ice on the 15th and last day of each month for the duration of the ice season. In addition, the LAKI for the opening (27 April) and closing

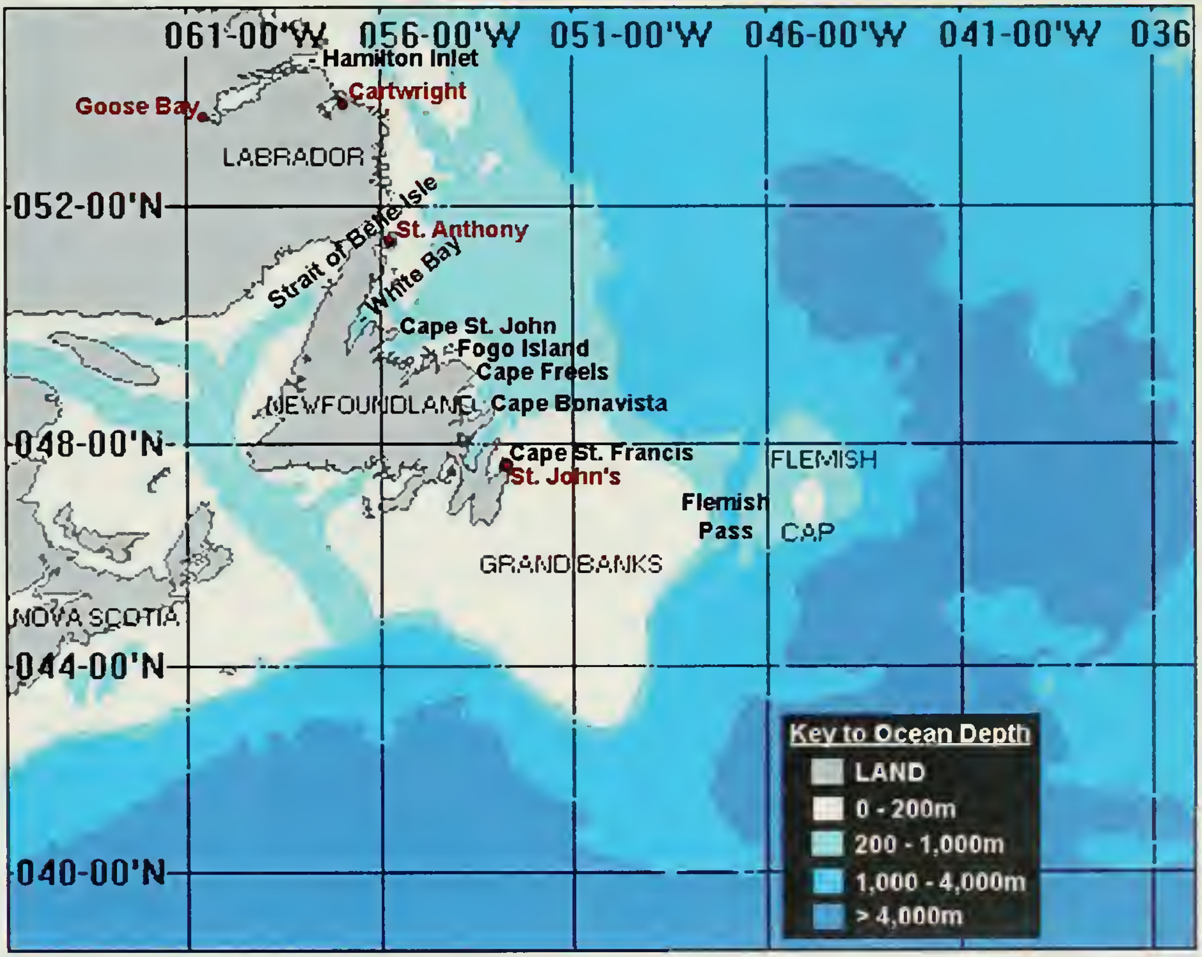

Figure 17. Grand Banks of Newfoundland.

(27 July) days of the season are presented.

The progress of the 2003-2004 season is compared to sea-ice and iceberg observations from the historical record. The sea-ice historical data are derived from the *Sea Ice Climatic Atlas, East Coast of Canada, 1971-2000* (Canadian Ice Service, 2001), which provides a 30-year median of ice concentration at seven-day intervals for the period from 26 November through 16 July. Historical iceberg information is derived from Viekman and Baumer (1995), who present iceberg-limit climatology from mid March to 30 July based on 21 years of Ice Patrol observations from 1975 to 1995. They provide the extreme, median, and minimum extent of the LAKI for the period. Finally, the average number of icebergs estimated to have drifted south of 48°N for each month was calculated using 104 years (1900-2003) of Ice Patrol records (IIP, 2004).

The pre-season sea-ice forecast (Canadian Ice Service, 2003), which was issued in early December, predicted:

- movement of the southern ice edge into the Strait of Belle Isle during the third week of January 2004,
- that sea ice would reach Cape Bonavista during the second week of February,
- that the sea ice would attain its maximum extent during the third week of March, with the ice edge approximately at the latitude of Cape St. Francis for most of the month,
- and that sea-ice would begin to retreat during the last week of the month and proceed at a normal rate.

A series of five CIS reconnaissance flights conducted in late October 2003 documented a population of 461 icebergs and radar targets from 59°N to 70°N, with the greatest number near shore or in the bays of Baffin Island. This was the smallest number of icebergs seen during the CIS fall survey flights in the last four years (Desjardins, 2003). Because of the lack of a significant number of icebergs in the southward-moving offshore waters, Desjardins (2003) predicted a late start to the 2004 iceberg season.

December 2003

Much warmer-than-normal November and December air temperatures in Labrador delayed the arrival of the southern edge of the main ice pack by three to four weeks. At the end of December, it reached Cape Chidley, the northernmost point of Labrador. Meanwhile, sea ice began forming in the bays and near-shore regions along the southern Labrador coast during the third week of December, although the warm conditions slowed this ice growth as well. Mean December sea-surface temperatures were within 1°C of normal off the southern Labrador coast and on the northeast Newfoundland shelf. At month's end, the Strait of Belle Isle was free of sea ice. No icebergs passed south of 48°N during December.

January 2004

January's warm and stormy weather conditions, particularly along the Labrador coast, had a dramatic affect on sea-ice growth and the iceberg season that followed. Much warmer-than-normal air temperatures prevailed in Labrador during the entire month (**Figure 18**), with a monthly average in Goose Bay that was nearly 5°C above normal.

This led to slow sea-ice growth along the Labrador coast. During the third week of January, as predicted by Canadian Ice Service (2003), sea ice reached the northern part of the Strait of Belle Isle, but not in sufficient quantity to block the strait to marine traffic. The arrival in the strait of the sea ice was about three weeks later than normal. The eastward extent of the sea ice along the southern Labrador coast was a small fraction of normal. At Cartwright, the ice edge was approximately 20 nm offshore in mid January, while in a normal year it extends seaward over 100 nm.

In January, several powerful low-pressure systems brought strong onshore winds to the Labrador coast. By far, the most significant storm occurred from 15 to 21 January, when a storm explosively intensified near Newfoundland. By the 16th, the central pressure deepened to 948 hPa (**Figure 19**) while the storm was over northern Newfoundland (Bancroft, 2004). It brought gale-force onshore winds to the Labrador coast (**Figure 20**). Strong onshore winds persisted until the storm moved out on 22 January. Another intense low-pressure system struck the region later in the month (26-29 January), following a similar track (Bancroft, 2004). Again, vigorous and persistent onshore winds battered the Labrador coast for several days. The impact of the two major storm systems on sea-ice growth was twofold. First, the onshore winds brought relatively warm maritime air into the region, as seen by the strong positive temperature anomalies (**Figure 18**) for the two storm periods, thus creating unfavorable ice-growth conditions. Second, the onshore winds caused widespread ice destruction and compressed what ice remained along the coast. In addition, it is likely that any icebergs in the vicinity were also driven toward shore, out of the core of the Labrador Current.

The combination of much warmer-than-normal air temperatures and strong onshore winds led to sea-ice conditions at the end of January that were far less than normal. In a normal year, the southern sea ice edge reaches Cape Freels by the end of January (**Figure 21**). In 2004, the southern-ice edge (**Figure 22**) was barely into the Strait of Belle Isle.

Ice Patrol deployed its pre-season Ice Reconnaissance Detachment to Newfoundland on 27 January 2004. The intent of the IRD was to monitor the progress of the icebergs toward the Grand Banks and help determine the start date for the 2004 season.

During January, no icebergs passed south of 48°N; the average for the month was three.

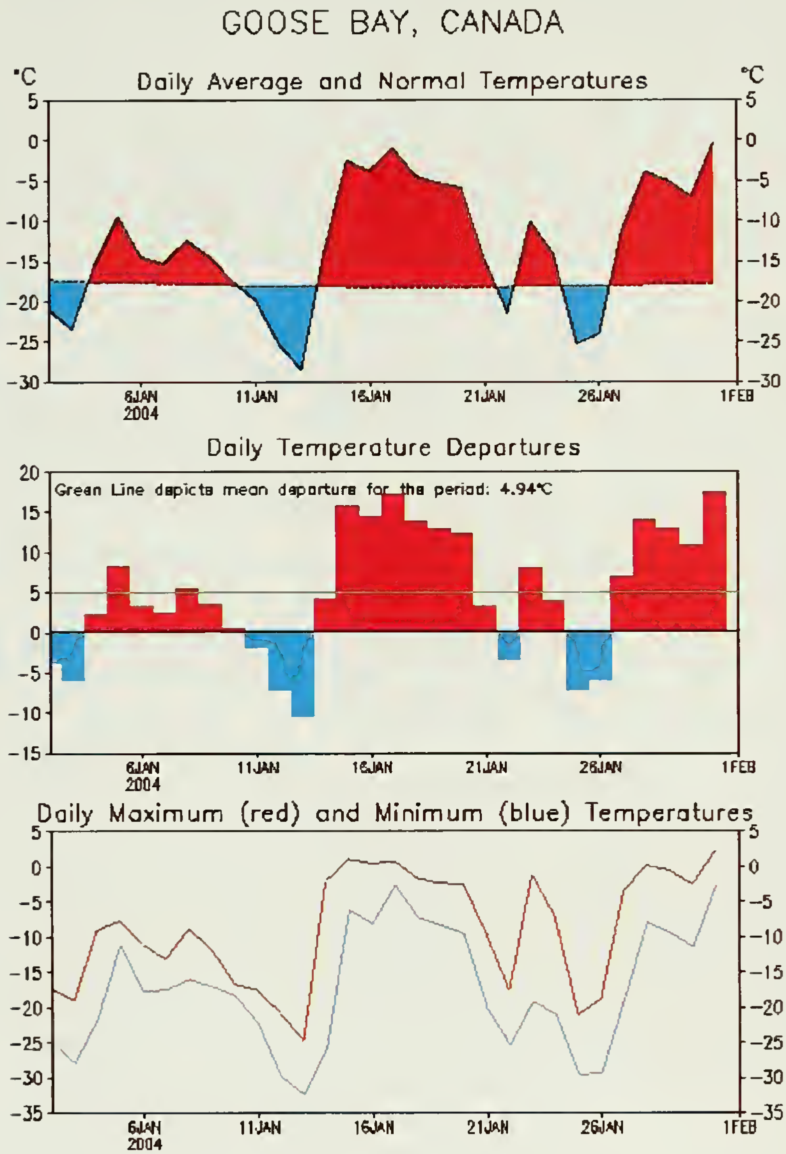

Figure 18. January 2004 air-temperature record for Goose Bay.

February

Much warmer-than-normal conditions persisted in Labrador and northern Newfoundland throughout February, substantially slowing the advance of the ice edge. By mid month, sea ice clogged the Strait of Belle Isle, prompting the Canadian Coast Guard to advise mariners against using it for transatlantic voyages, effective February 13, 2004. Due to the extraordinarily light sea-ice conditions in 2004, this warning was issued about 6 weeks later than normal.

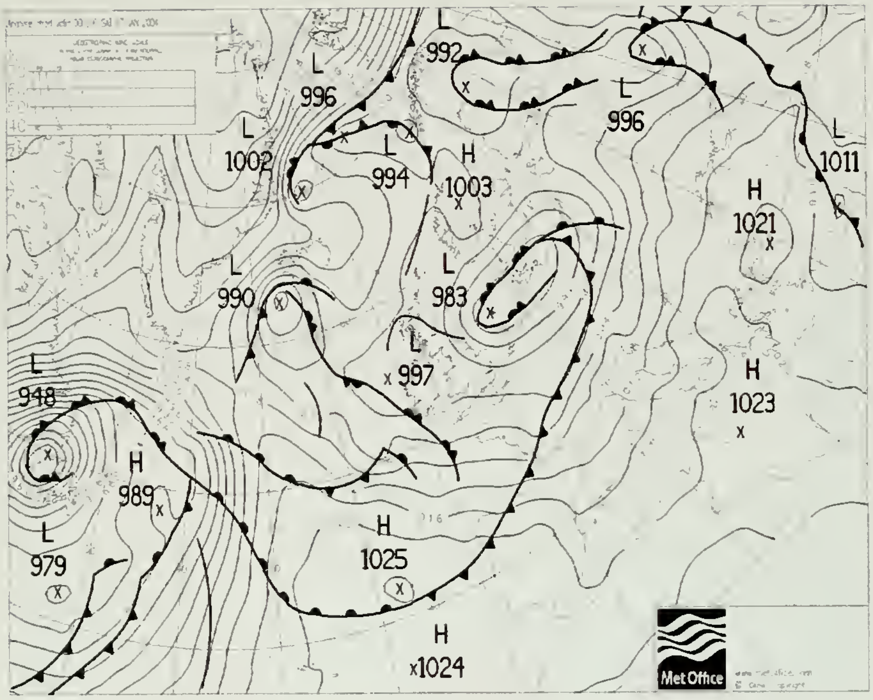

Figure 19. Sea-level pressure for 00Z 17 January 2004 (Met. Office, Bracknell).

The second half of February witnessed a slow but persistent southward sea-ice growth, with the southern edge extending into White Bay by month's end. The eastern ice edge was much closer to shore than normal. For example, at St. Anthony the eastern ice edge was about 60 nm off shore versus the normal distance of about 200 nm.

An early February series of aerial reconnaissance patrols, two by Ice Patrol's pre-season IRD and one by the CIS airplane, found a sparse iceberg population near Newfoundland and Labrador. On 2 and 3 February, the IIP airplane conducted two reconnaissance flights, one over the sea-ice-free waters of the offshore branch of the Labrador Current between 48°N and 52°N and the other a survey flight northward along the sea-ice edge off the Labrador coast from 55°N to 59°N. On 3 February, the Canadian Ice Service's reconnaissance airplane conducted iceberg reconnaissance in the Strait of Belle Isle and along the Labrador coast from 52°N to 55°N. The coordinated IIP and CIS patrols detected 16 icebergs, all north of 55°N. The results of these early February flights suggested that the prediction of a late start to the iceberg season (Desjardins, 2003) was correct. The unusually warm

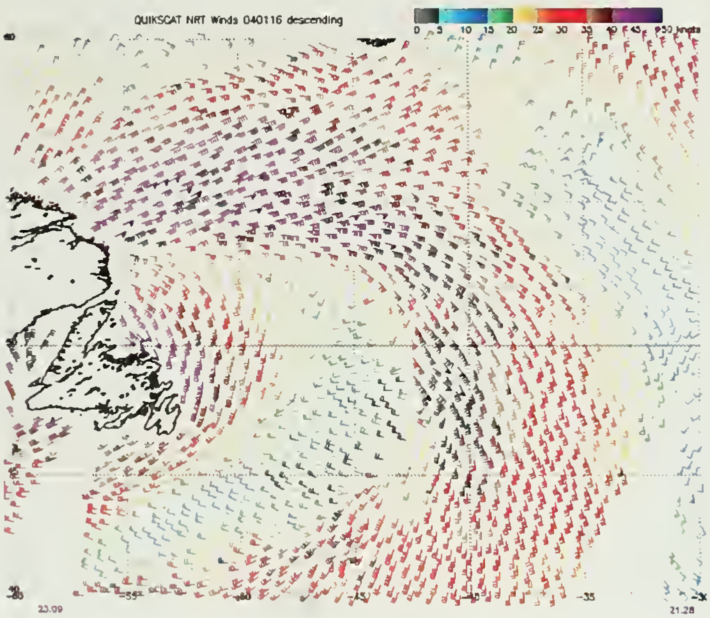

Figure 20. Surface winds for 16 January 2004 at 2309 UTC.

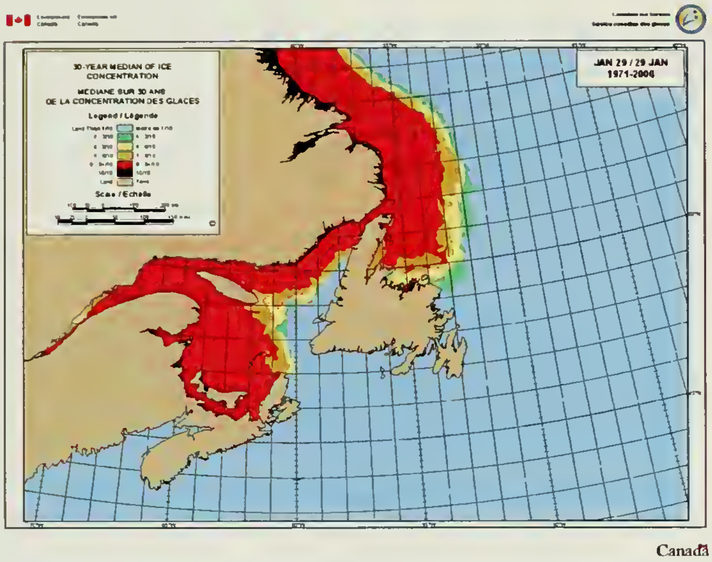

Figure 21. Median ice concentrations for 29 January. (Map courtesy of CIS.)

conditions from December through February and the stormy January caused the 2004 progression of the sea ice to be far from the predictions of the seasonal forecast. (CIS, 2003)

No icebergs passed south of 48°N during February; the average for the month is 15.

March

Normal air temperatures returned to the region in March. On 2 March, the southern ice edge reached Fogo Island, where it remained until the last week of the month. The passage of two potent low-pressure systems, one on 7–8 March and the other on 13 March, brought strong onshore winds to northeast Newfoundland waters. This pushed the sea ice westward and compressed it along Newfoundland's Northern Arm. During the last week of March, west and north winds loosened the ice pack, created a wide shore lead along the Northern Arm, and drove the southern ice edge to its southernmost 2004 position, approximately the latitude of Cape Bonavista. In a normal year, the southern ice edge spends most of March near the latitude of St John's, which is over 75 nm farther south. At month's end, the eastern ice edge was much closer to shore than normal. It extended approximately 80 nm offshore of Cape Freels. The normal position of the eastern ice edge at the end of March is about 80 nm farther east.

In early March, aerial and surface iceberg reconnaissance markedly changed the iceberg-population picture. Up to this point, the reconnaissance had been sporadic and had found very few icebergs. From 4 to 7 March, four reconnaissance flights (three by CIS and one by IIP) and a series of surface reports from the Canadian icebreaker CCGS *Henry Larsen* documented the iceberg population from 48°N to 60°N. The CIS flights found 358 icebergs from 51°N to 60°N and CCGS *Henry Larsen* found 21 icebergs within

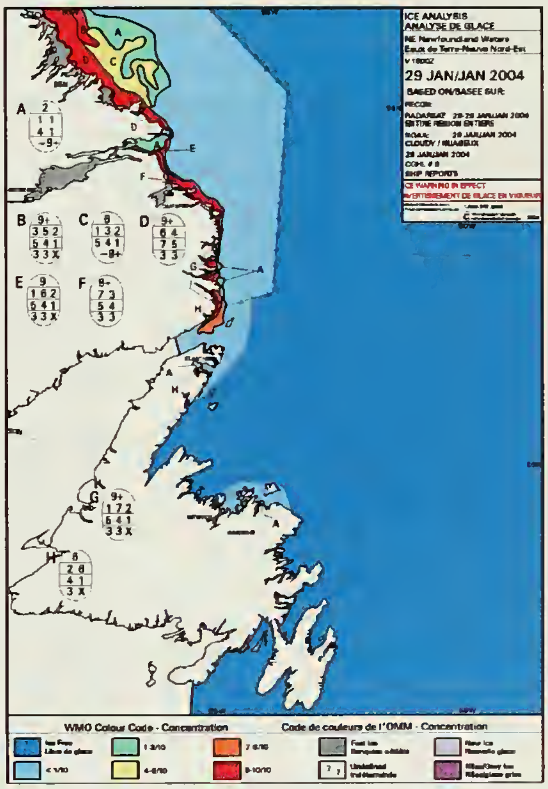

Figure 22. Sea-ice distribution in east-Newfoundland waters on 29 January 2004. (Map courtesy of CIS.)

the sea ice while transiting from Cape St. John to St. Anthony. Ice Patrol's flight on 4 March focused on the ice-free waters of the offshore branch of the Labrador Current, which is the primary conduit of icebergs into the shipping lanes. The flight found only one iceberg between 48°N and 53°N. It was clear that the season opening would be delayed, but there was a significant population not far to the north.

During a five-day period from 25 to 29 March, CIS and IIP conducted six reconnaissance flights, with IIP focusing its efforts on the offshore branch of the Labrador Current from 48°N to 55°N and CIS searching near and within the sea ice closer to the Newfoundland and Labrador coasts. In all, the flights found 781 icebergs, most due to CIS's search within the sea ice (**Figure 23**).

During March, no icebergs drifted south of 48°N, while the month's average is 62. This was the first March since 1970 that no icebergs passed south of 48°N.

April

The first part of April was characterized by much warmer-than-normal air temperature in Goose Bay and warmer-than-normal conditions in Newfoundland. During the first week of April, the southern and eastern ice edge moved very little. However, the next ten days (6-15 April) witnessed a dramatic change in the character of the ice pack. Moderate to strong south winds dominated the period, with particularly strong south winds associated with the passage of a low pressure system on 11 to 12 April. By mid April the pack ice had loosened considerably, and the southern ice edge retreated to 50°N, which was about two to three weeks earlier than normal.

Colder-than-normal air temperatures persisted in the region for the remainder of April. In addition, there were several periods of moderate north and northeast winds over east Newfoundland waters, the strongest of which were associated with the passage of a low-pressure system on 26 to 27 April. These

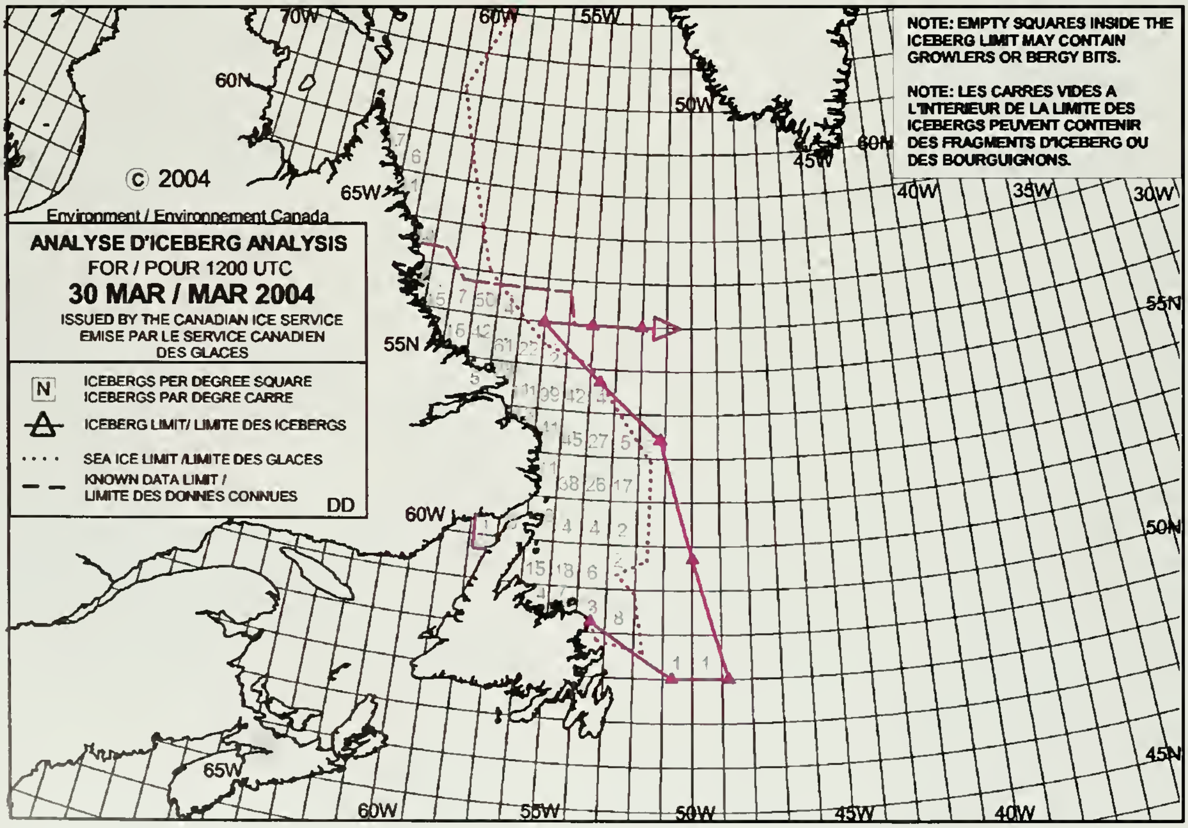

Figure 23. Iceberg distribution on 30 March 2004. There are 856 icebergs and radar targets, most in sea ice. (Chart courtesy of CIS.)

winds caused a brief re-advance of the southern ice edge. By month's end, the southern ice edge was near Cape St. John at the entrance of Notre Dame Bay. At this time, the sea ice retreat was one to two weeks ahead of normal.

On 19 April, CCGS *Henry Larson* reported a 600 m ice-island fragment at 51° 23'N and 54°54'W, about 25 nm east of St. Anthony, Newfoundland.

Ice Patrol aerial reconnaissance on 22 and 24 April found a small iceberg population immediately north of 48°N and a very large population between 50°N and 52°N. It was clear that icebergs were starting to move southward into the transatlantic shipping lanes. Ice Patrol opened the iceberg season on 27 April (see p. 30), the latest opening date on record. The southern LAKI at month's end was at the 75th percentile. In April, 24 icebergs passed south of 48°N, well below the monthly average of 123 icebergs.

May

Monthly averaged air temperatures in Goose Bay and St. John's were normal during May. During the month, sea ice retreated from east Newfoundland waters at a pace that was two to three weeks faster than normal. The disappearance of sea ice from the Strait of Belle Isle led the Canadian Coast Guard to recommend its use for transatlantic voyages on 11 May 2004, nearly three weeks earlier than last year. By mid month the southern ice edge had moved to the vicinity of Belle Isle, and by month's end the southern ice edge retreated north of Cartwright.

A moderate number of icebergs moved onto the Grand Banks in May, with 114 icebergs passing south of 48°N. The monthly mean for May is 151. A Provincial Aerospace Limited reconnaissance flight on 25 May documented a substantial iceberg population on the northeast Newfoundland shelf between 48°30'N and 52°N. The flight found over a 1000 icebergs west of 51°W. In May, the southern LAKI remained near 46°N, while the eastern LAKI never extended east of 45°W (see pp. 32-33). These limits are at the 75th percentile according to the iceberg climatology of Viekman and Baumer (1995)

June

Sea ice continued a rapid retreat northward along the coast of Labrador in June, aided by above-normal air and sea-surface temperatures along the northern coast. By the end of the month, ice departed Labrador's coast about three weeks earlier than the norm.

The number of icebergs on the Grand Banks peaked in early to mid June and by 15 June (see p. 34) Ice Patrol was tracking 55 icebergs south of 48°N. The southern LAKI was at 45°N, and the eastern LAKI was near 45°W. Both values were at the 75th percentile for mid June.

On 8 June, an ice-island fragment (**Figure 24**) was found at 47°17.7'N, 47° 56.5'W. It measured 422 m by 314 m with an estimated mass

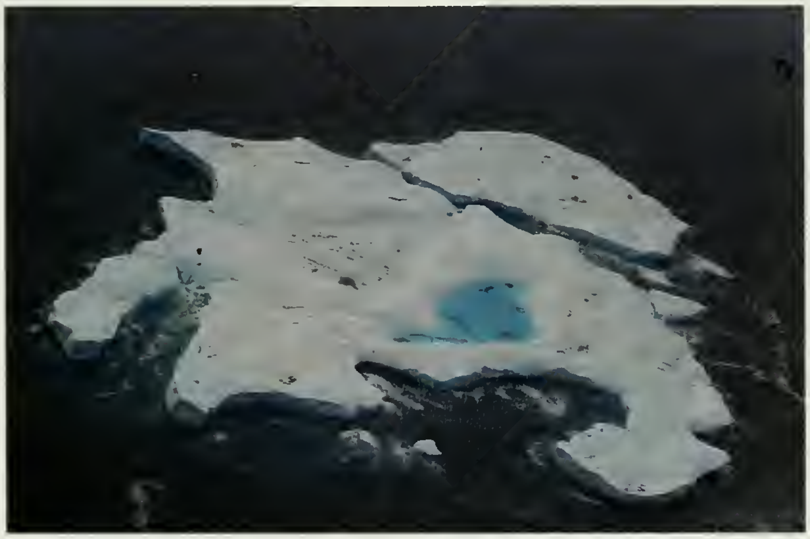

Figure 24. Ice-island fragment (422 m by 314 m) found on the Grand Banks of 8 June 2004. (Photo courtesy of Pip Rudkin, PAL.)

of 4.1 million tons (Pip Rudkin, personal communication). Ice Patrol, in cooperation with Provincial Aerospace Limited, attempted to place a satellite-tracked beacon on the iceberg, but persistent poor visibility prevented the deployment.

Between the middle and end of June, there was a significant reduction in the iceberg population south of 48°N, as seasonal warming began to take its toll. On 30 June (see p. 35), there were ten icebergs and growlers south of 48°N. Despite the small number of icebergs, the southern and eastern LAKI expanded during the second half of June. Two isolated growlers set the southern LAKI at 44°N, which is between the 75th percentile and the median for the date. A single, isolated iceberg set the eastern LAKI at 41° W, which was at the 25th percentile. June was the only month of the 2004 iceberg season during which the number of icebergs that passed south of 48°N (117) exceeded the monthly average (85). On 19 June, a ship found the eastern-most iceberg (46°N, 45.60W) detected during the season.

July

July brought Ice Patrol's 2004 ice season to a close. By 15 July (see p. 36), the iceberg population south of 48°N had been reduced to two widely separated icebergs. The southern LAKI was at the median for the date, while the eastern LAKI was at the 75th percentile. The iceberg season closed on 27 July. Seven icebergs passed south of 48°N during July; the average for the month is 31. Ice Patrol's last 2004 Ice Reconnaissance Detachment returned from Newfoundland on 3 July. On 2 July, the Ice Patrol reconnaissance airplane found the southern-most iceberg detected during the season at 43°22.3'N, 49°16.2'W. Both the eastern-most and southern-most estimated (drifted by the model) iceberg positions for the season occurred in July: the eastern-most (46°46.8'N, 41°21.6'W) on 1 July and the southern-most (42°30.6'N, 49°54.6'W) on 11 July.

Summary

By all measures, 2004 was a mild iceberg season. Icebergs arrived at 48°N in late April, about two months later than normal; indeed, the 27 April season opening was the latest in Ice Patrol's history. With 262 icebergs estimated to have passed south of 48°N, the 2004 season falls into the light category (<300 icebergs), as defined by Trivers (1994) and the 92-day season length places 2004 in the short-season category (<105 days).

Sea-ice coverage in east-Newfoundland

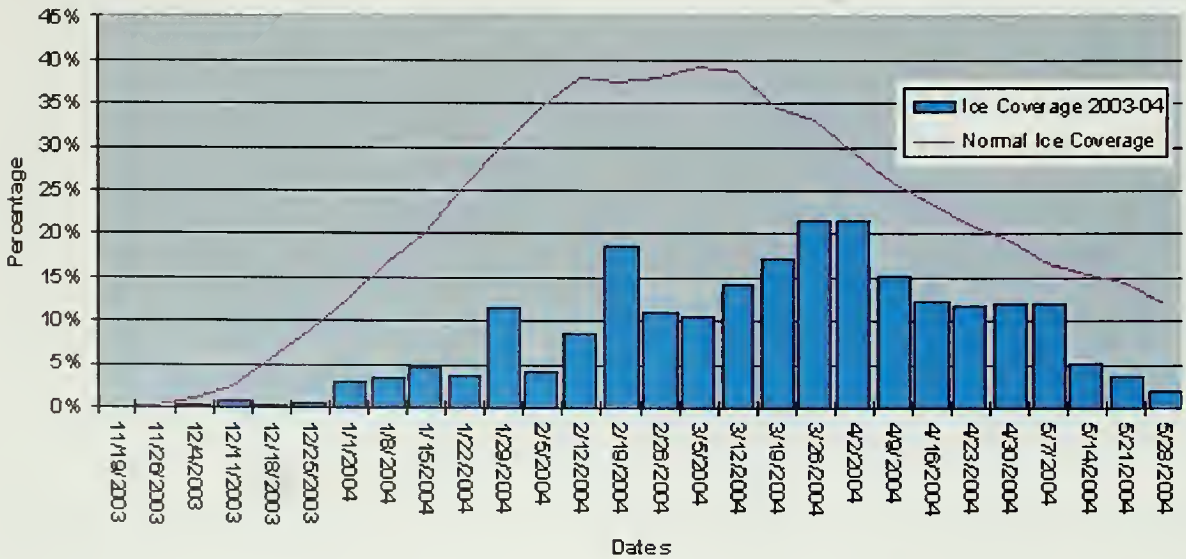

Figure 25. Normalized ice coverage in east-Newfoundland waters in 2004. (Courtesy of CIS.)

waters was significantly less extensive than normal (**Figure 25**) for all weeks during the season. It attained its maximum extent in late March and early April, with the southern ice edge approximately at the latitude of Cape Bonavista.

The winter 2004 (December 2003 through March 2004) North Atlantic Oscillation Index was weakly negative (-0.07), while the previous two years were weakly positive (Hurrell, 2004).

It is likely that the late arrival of icebergs on the Grand Banks was due to the anomalously warm and stormy conditions along the Labrador coast in January. As a rule of thumb, it takes three to four months for icebergs to move from Cape Chidley, the northernmost point of Labrador, to 48°N, a distance of about 720 nm. It takes an additional month to move from Davis Strait to 48°N. In 2004, the February through April supply of icebergs to the Ice Patrol operations area was strung out along the Labrador coast during January. During the intense storm in mid month, it is likely those went ashore or were destroyed. As a result, 24 icebergs passed south of 48°N during February through April (**Figure 26**), while the average over the 104-year Ice Patrol record for the period is 200 icebergs. On the other hand, the icebergs near Davis Strait were not subjected to this storm system. The icebergs from that region and farther to the north began arriving at 48°N from May to June. Over this period 238, icebergs moved south of 48°N, while the average for the period is 267.

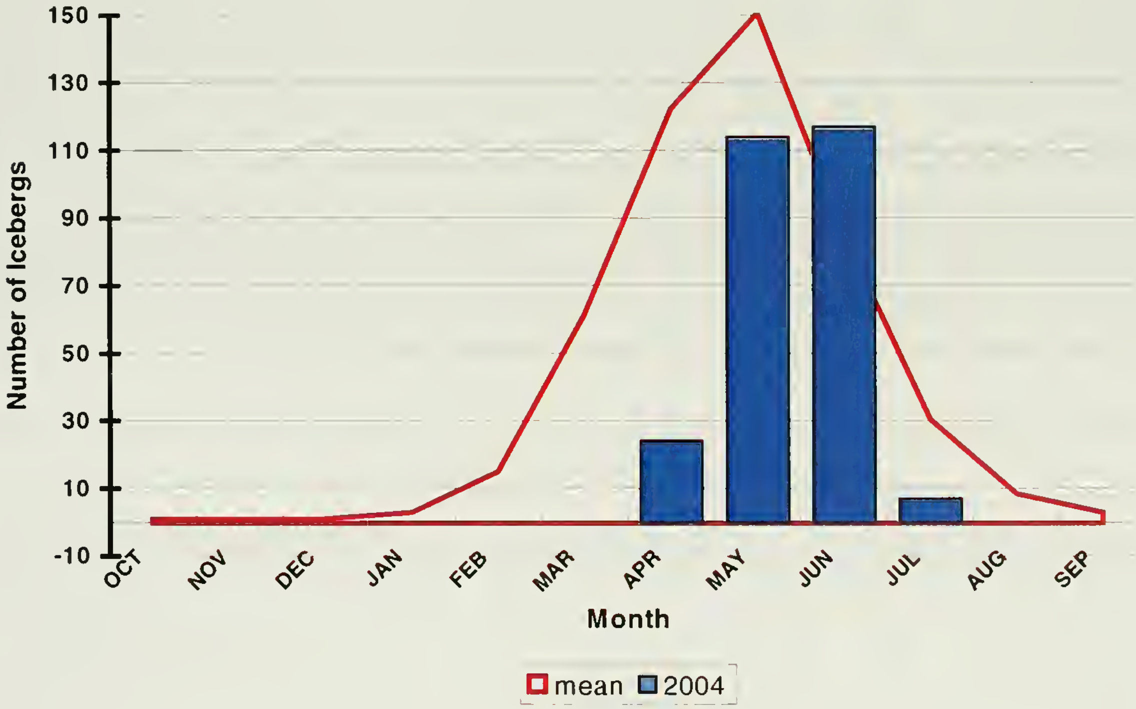

Figure 26. Estimated number of icebergs that passed south of 48°N each month of 2004.

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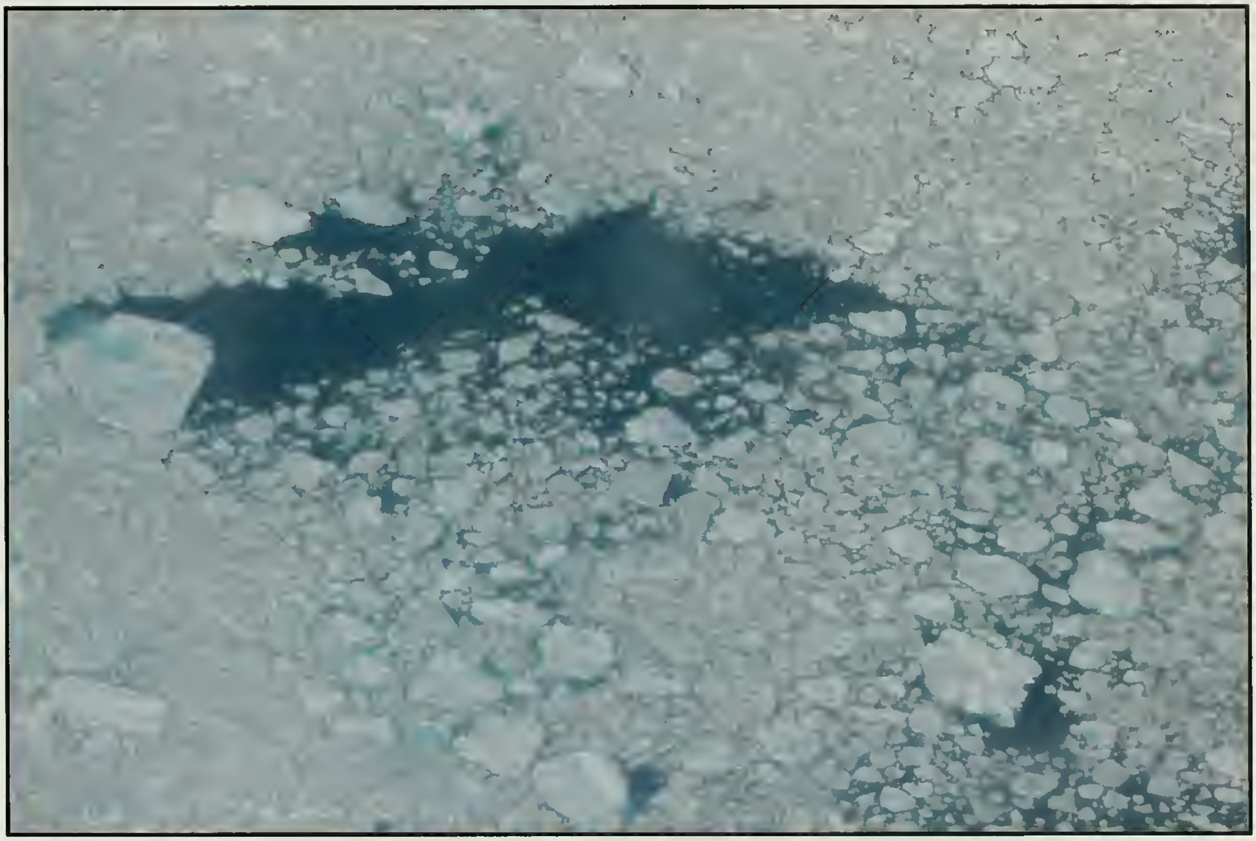
Monthly Sea-Ice Charts



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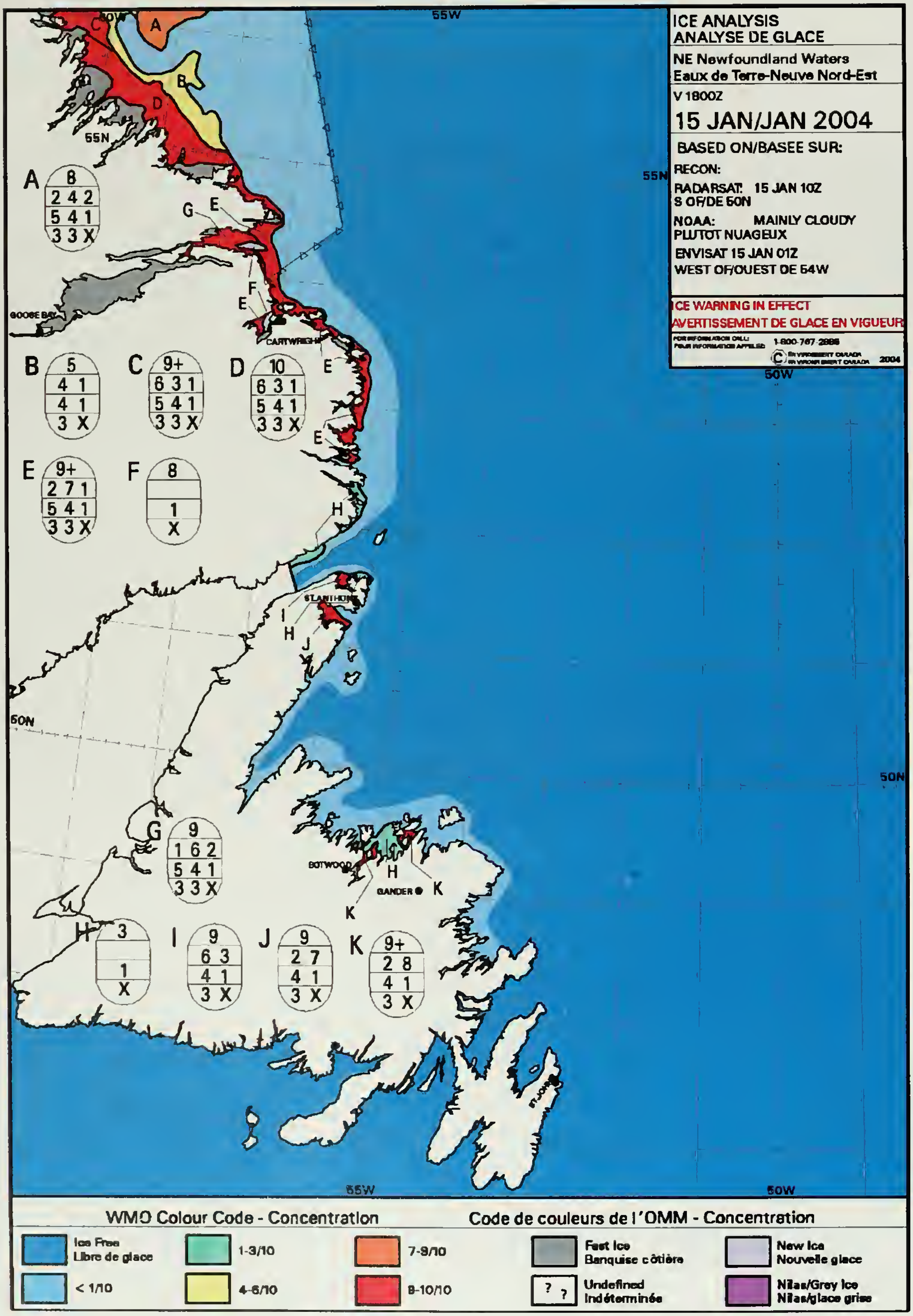
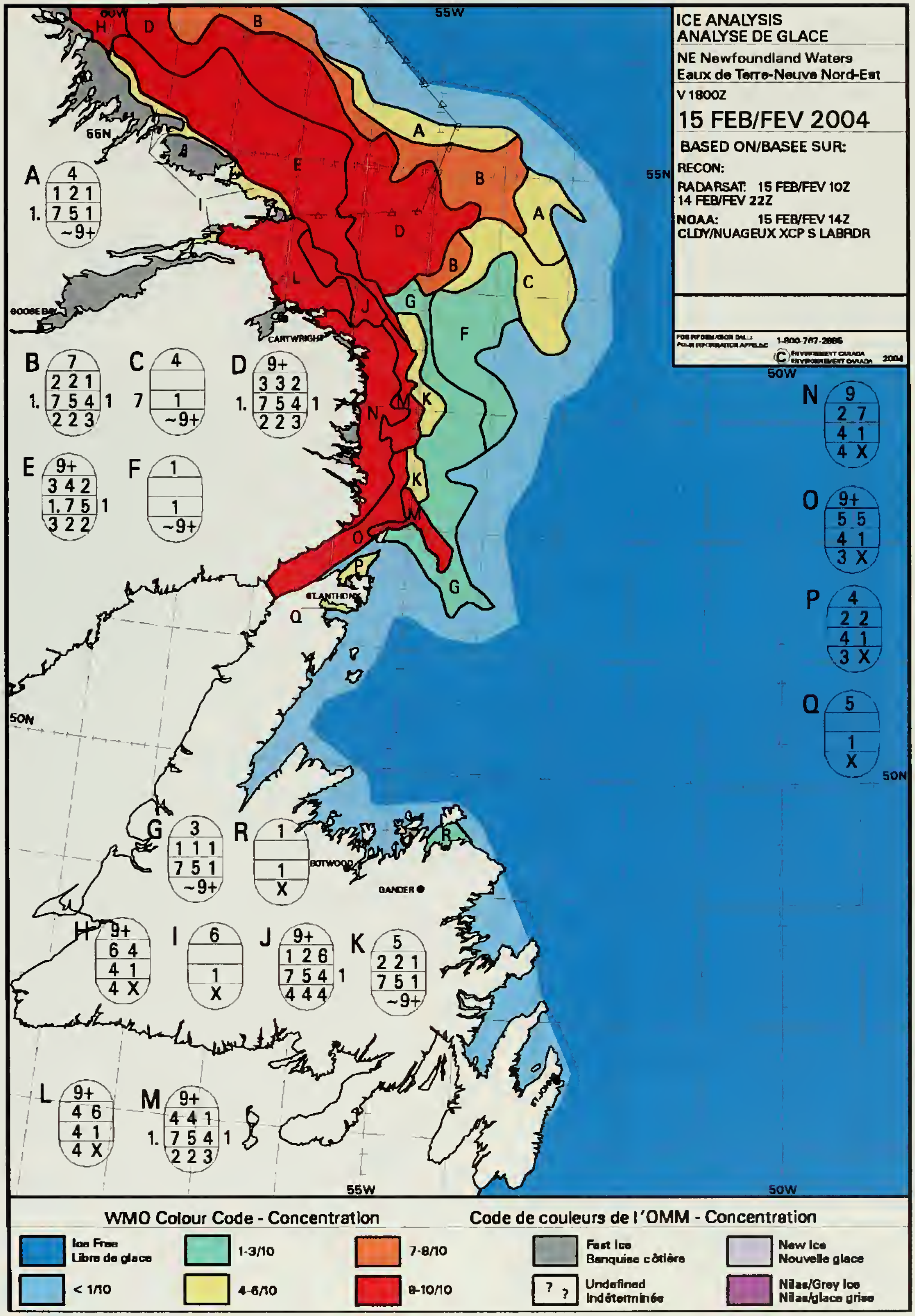
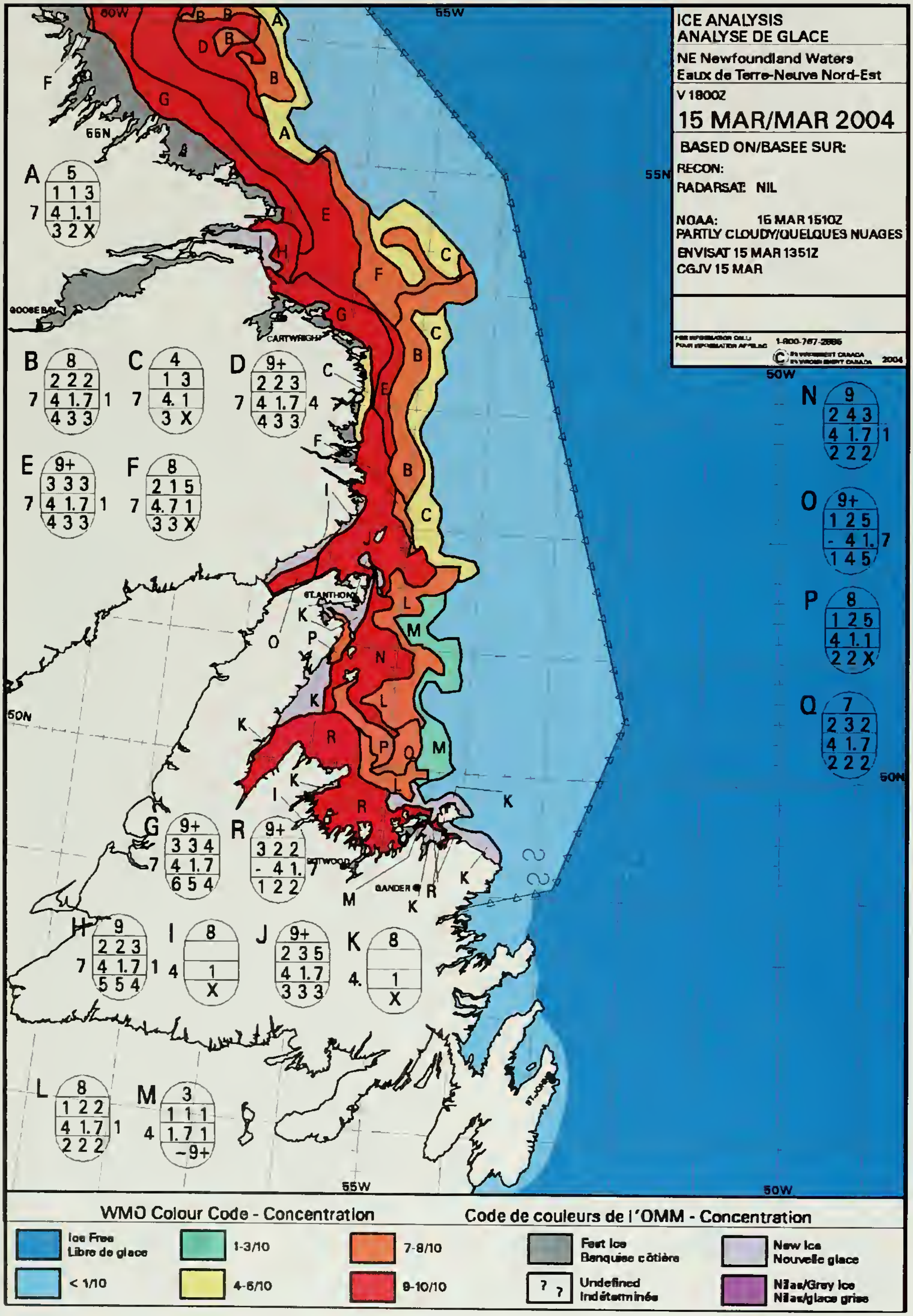

ICE ANALYSIS
ANALYSE DE GLACE
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 JAN/JAN 2004
BASED ON/BASEE SUR:
RECON:
RADARSAT 15 JAN 10Z
S OF/DE 50N
NOAA: MAINLY CLOUDY
PLUTOT NUAGEUX
ENVISAT 15 JAN 01Z
WEST OF/OUEST DE 54W
ICE WARNING IN EFFECT
AVERTISSEMENT DE GLACE EN VIGUEUR
1-800-767-2885
2004
55W
50W
55N
50N
GOOSE BAY
CARTWRIGHT
ST. ANTHONY
BOTWOOD
GANDER
WMO Colour Code - Concentration
Code de couleurs de l'OMM - Concentration
Ice Free
Libre de glace
< 1/10
1-3/10
4-6/10
7-9/10
9-10/10
Fast Ice
Banquise côtière
Undefined
Indéterminée
New Ice
Nouvelle glace
Nilas/Grey Ice
Nilas/glace grise



ICE ANALYSIS
ANALYSE DE GLACE
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 FEB/FEV 2004
BASED ON/BASEE SUR:
RECON:
RADARSAT: 15 FEB/FEV 10Z
14 FEB/FEV 22Z
NOAA: 15 FEB/FEV 14Z
CLDY/NUAGEUX XCP S LABRDR
1-800-767-2885
2004
60W
55W
50W
55N
50N
GOOSE BAY
CARTWRIGHT
ST ANTHONY
BOTWOOD
GANDER
ST JOHNS
WMO Colour Code - Concentration
Code de couleurs de l'OMM - Concentration
Ice Free
Libre de glace
1-3/10
7-8/10
Fast Ice
Banquise côtière
New Ice
Nouvelle glace
< 1/10
4-6/10
9-10/10
Undefined
Indéterminée
Nilas/Grey Ice
Nilas/glace grise


ICE ANALYSIS
ANALYSE DE GLACE
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 MAR/MAR 2004
BASED ON/BASEE SUR:
RECON:
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NOAA: 15 MAR 1510Z
PARTLY CLOUDY/QUELQUES NUAGES
ENVISAT 15 MAR 1351Z
CGJV 15 MAR
1-800-767-2885
2004
60W
55W
50W
55N
50N
GOOSE BAY
CARTWRIGHT
ST.ANTHONY
GANDER
WMO Colour Code - Concentration
Code de couleurs de l'OMM - Concentration
Ice Free
Libre de glace
< 1/10
1-3/10
4-6/10
7-8/10
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Fast Ice
Banquise côtière
Undefined
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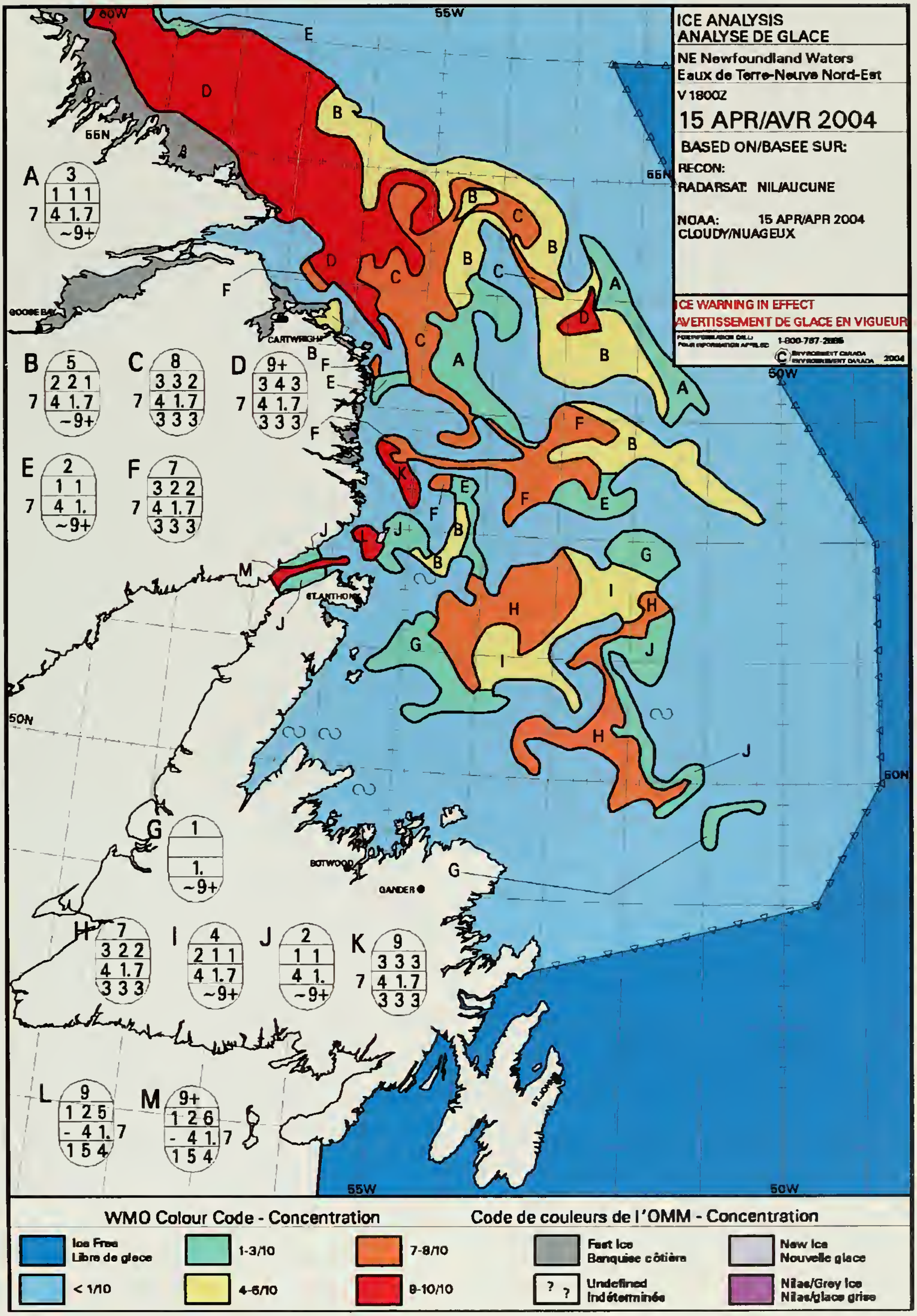
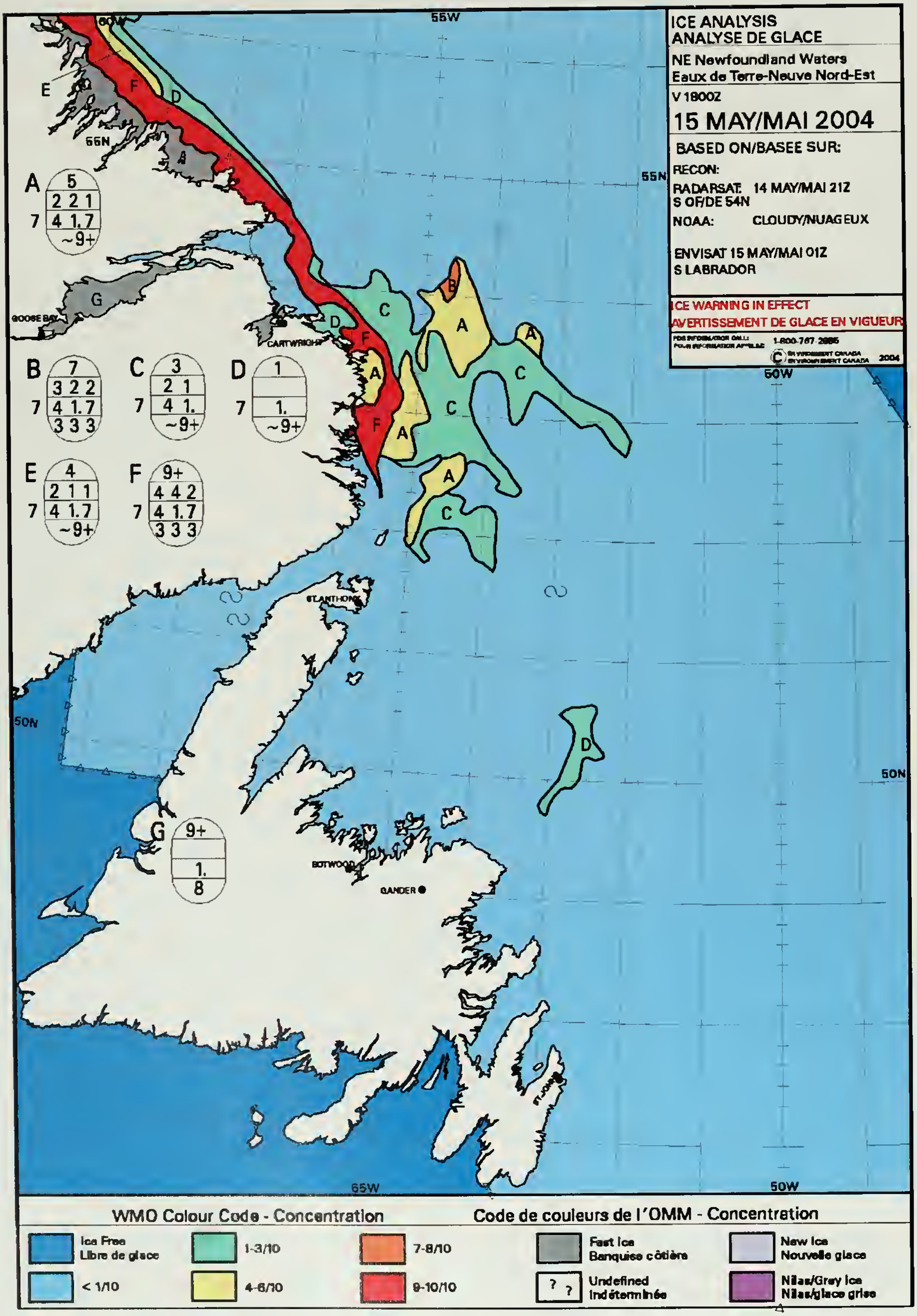
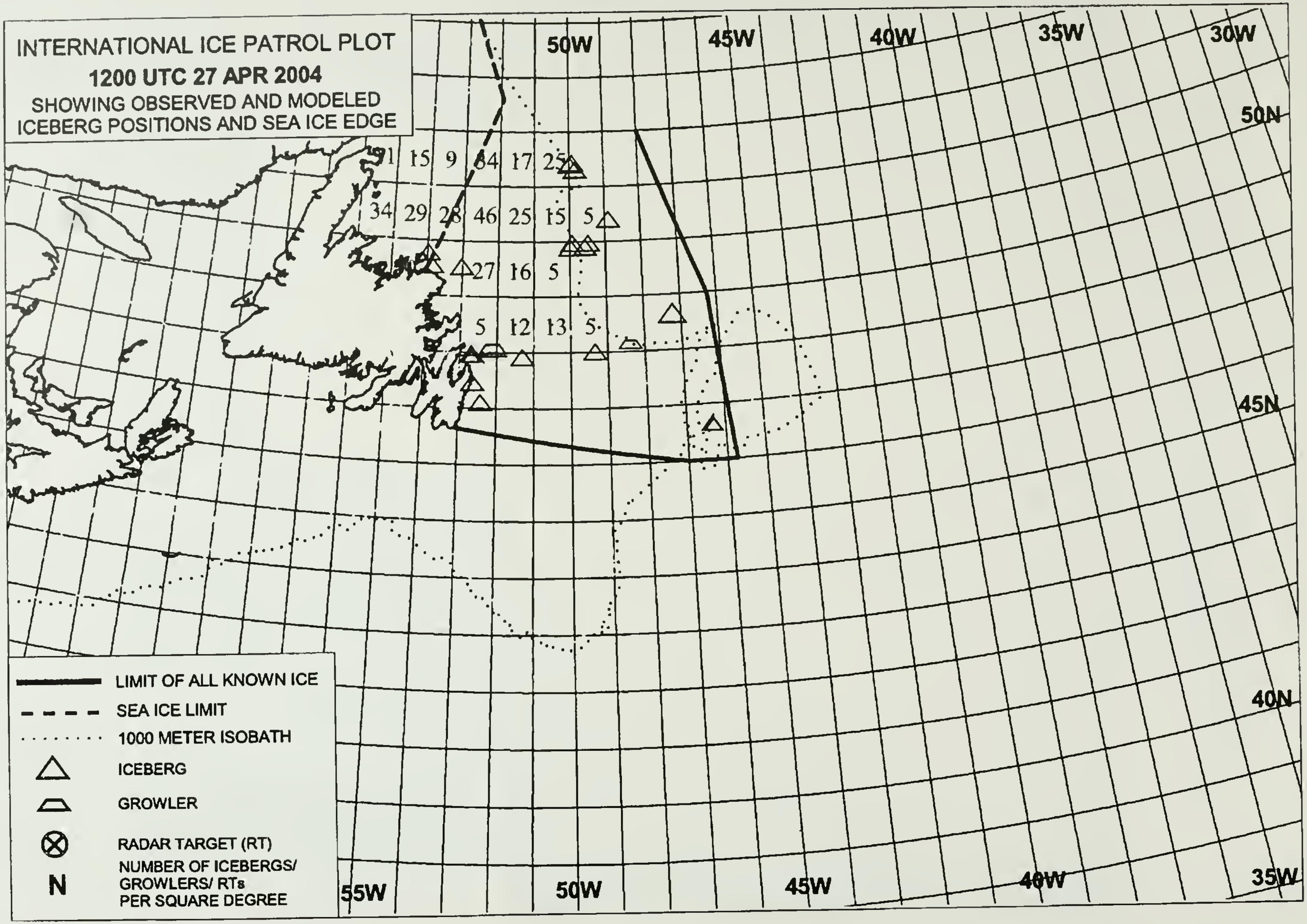
New Ice
Nouvelle glace
Nilas/Grey Ice
Nilas/glace grise

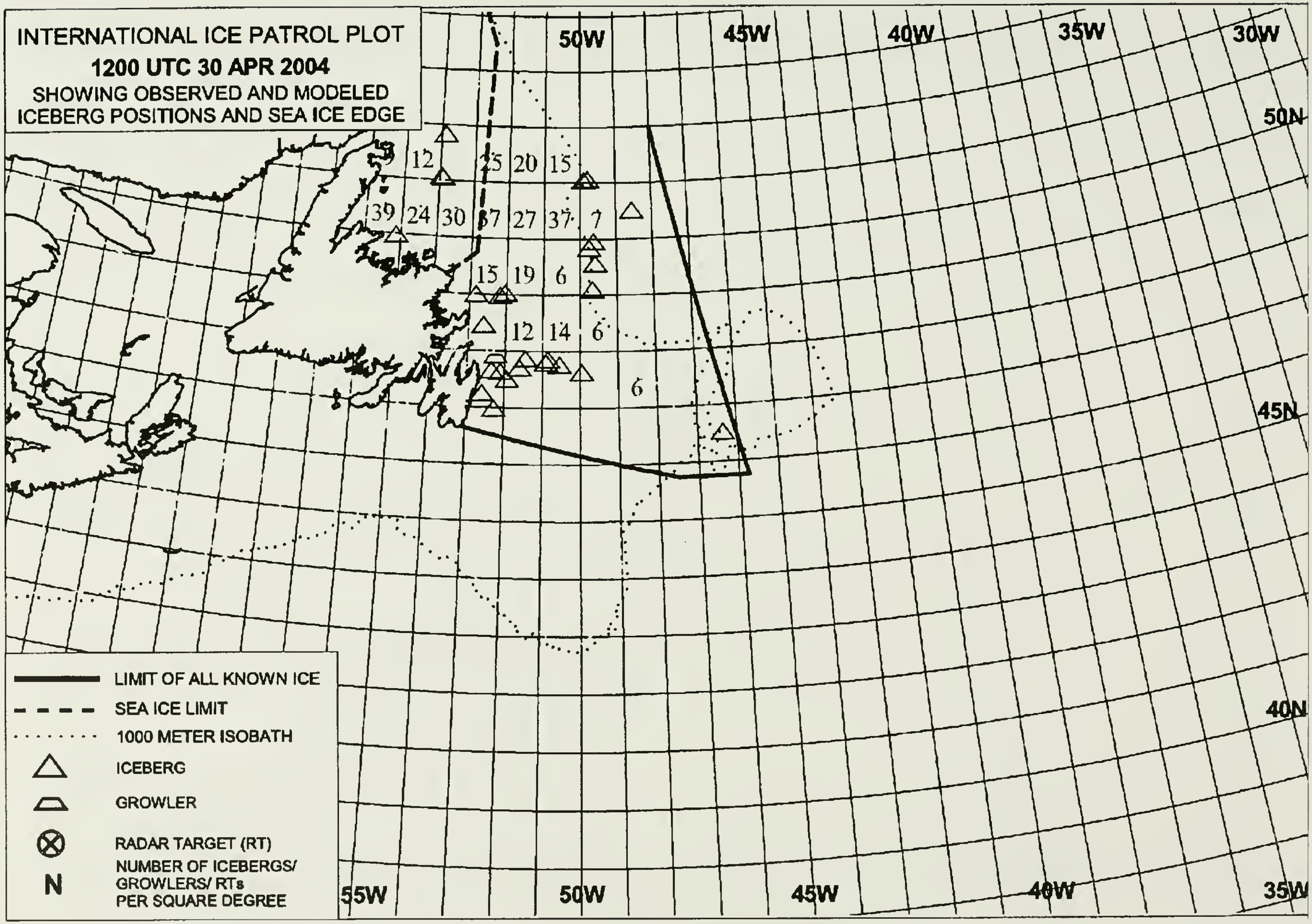

ICE ANALYSIS
ANALYSE DE GLACE
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 APR/AVR 2004
BASED ON/BASEE SUR:
RECON:
RADARSAT: NIL/AUCUNE
NOAA: 15 APR/APR 2004
CLOUDY/NUAGEUX
ICE WARNING IN EFFECT
AVERTISSEMENT DE GLACE EN VIGUEUR
1-800-767-2885
2004
60W
55W
50W
55N
50N
GOOSE BAY
CARTWRIGHT
ST.ANTHONY
BOTWOOD
GANDER
WMO Colour Code - Concentration
Code de couleurs de l'OMM - Concentration
Ice Free
Libre de glace
< 1/10
1-3/10
4-6/10
7-8/10
9-10/10
Fast Ice
Banquise côtière
Undefined
Indéterminée
New Ice
Nouvelle glace
Nilas/Grey Ice
Nilas/glace grise



ICE ANALYSIS
ANALYSE DE GLACE
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 MAY/MAI 2004
BASED ON/BASEE SUR:
RECON:
RADARSAT 14 MAY/MAI 21Z
S OF/DE 54N
NOAA: CLOUDY/NUAGEUX
ENVISAT 15 MAY/MAI 01Z
S LABRADOR
ICE WARNING IN EFFECT
AVERTISSEMENT DE GLACE EN VIGUEUR
55W
60W
50W
55N
50N
GOOSE BAY
CARTWRIGHT
ST.ANTHONY
BOTWOOD
GANDER
WMO Colour Code - Concentration
Code de couleurs de l'OMM - Concentration
Ice Free
Libre de glace
< 1/10
1-3/10
4-6/10
7-8/10
9-10/10
Fast Ice
Banquise côtière
Undefined
Indéterminée
New Ice
Nouvelle glace
Nilas/Grey Ice
Nilas/glace grise

Biweekly Iceberg Charts


INTERNATIONAL ICE PATROL PLOT
1200 UTC 27 APR 2004
SHOWING OBSERVED AND MODELED ICEBERG POSITIONS AND SEA ICE EDGE
50W
45W
40W
35W
30W
50N
45N
40N
55W
50W
45W
40W
35W
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/ GROWLERS/ RTs PER SQUARE DEGREE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35W
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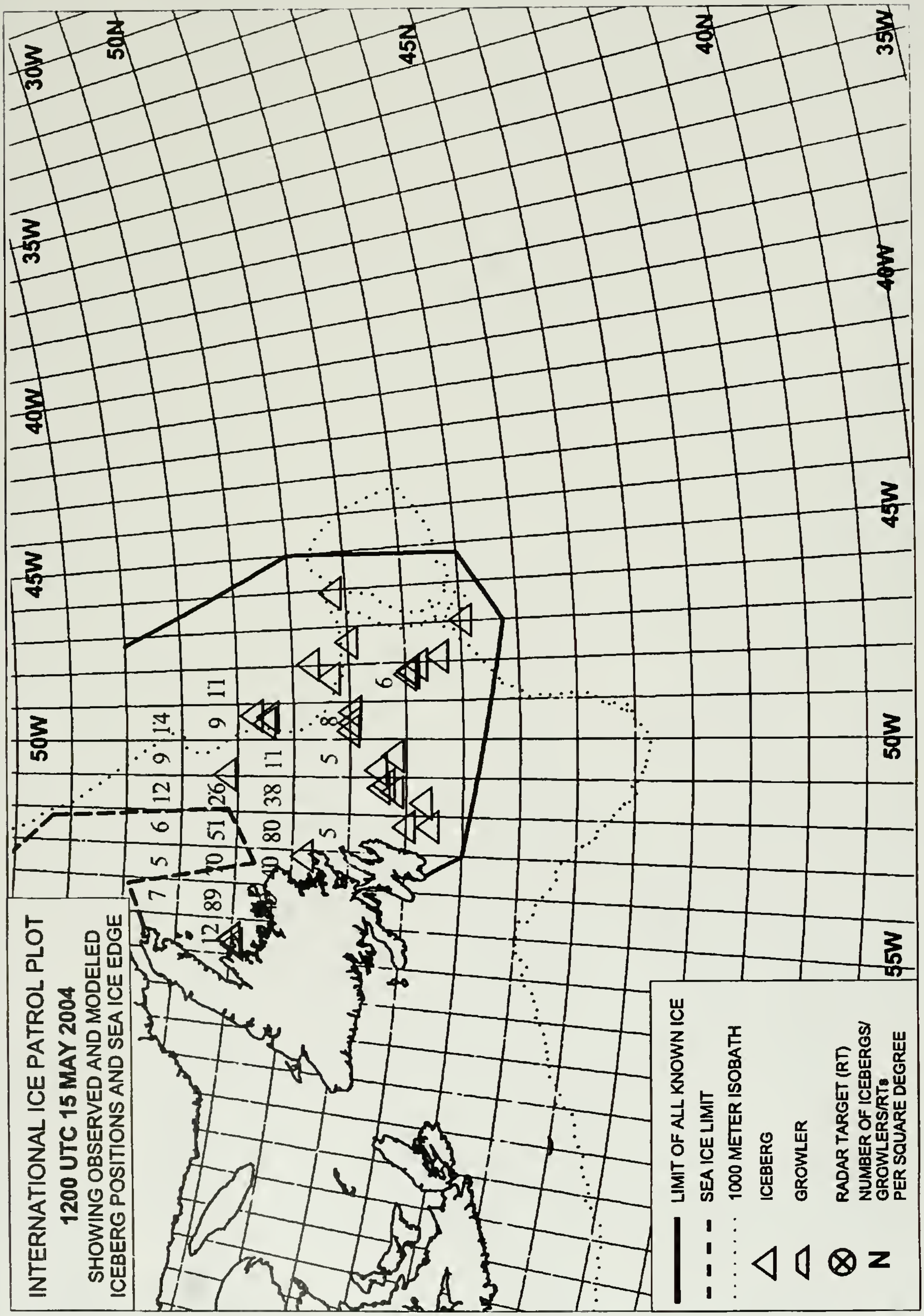
6
6
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/
GROWLERS/ RTs
PER SQUARE DEGREE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SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N NUMBER OF ICEBERGS/GROWLERS/RTs PER SQUARE DEGREE
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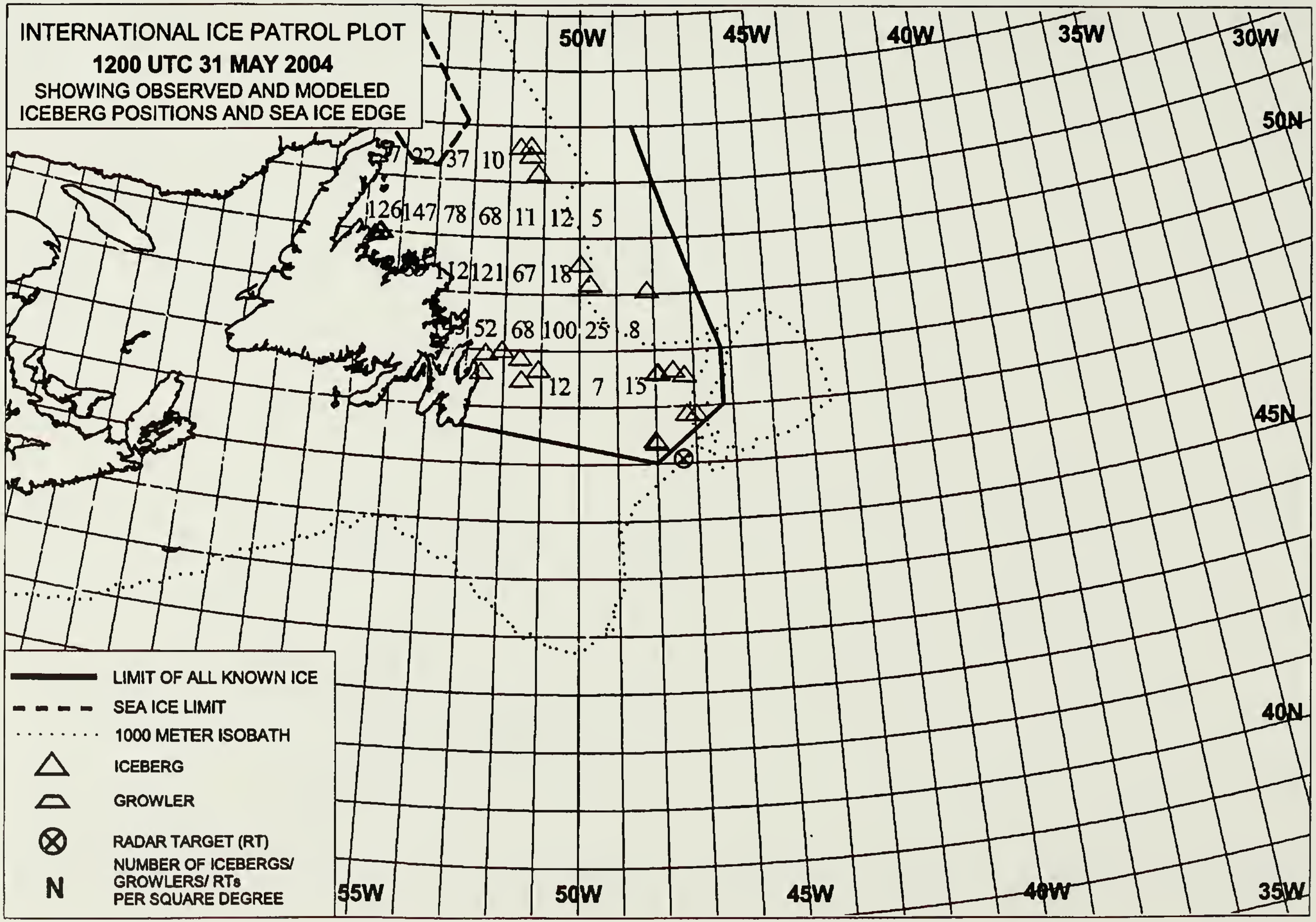
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LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
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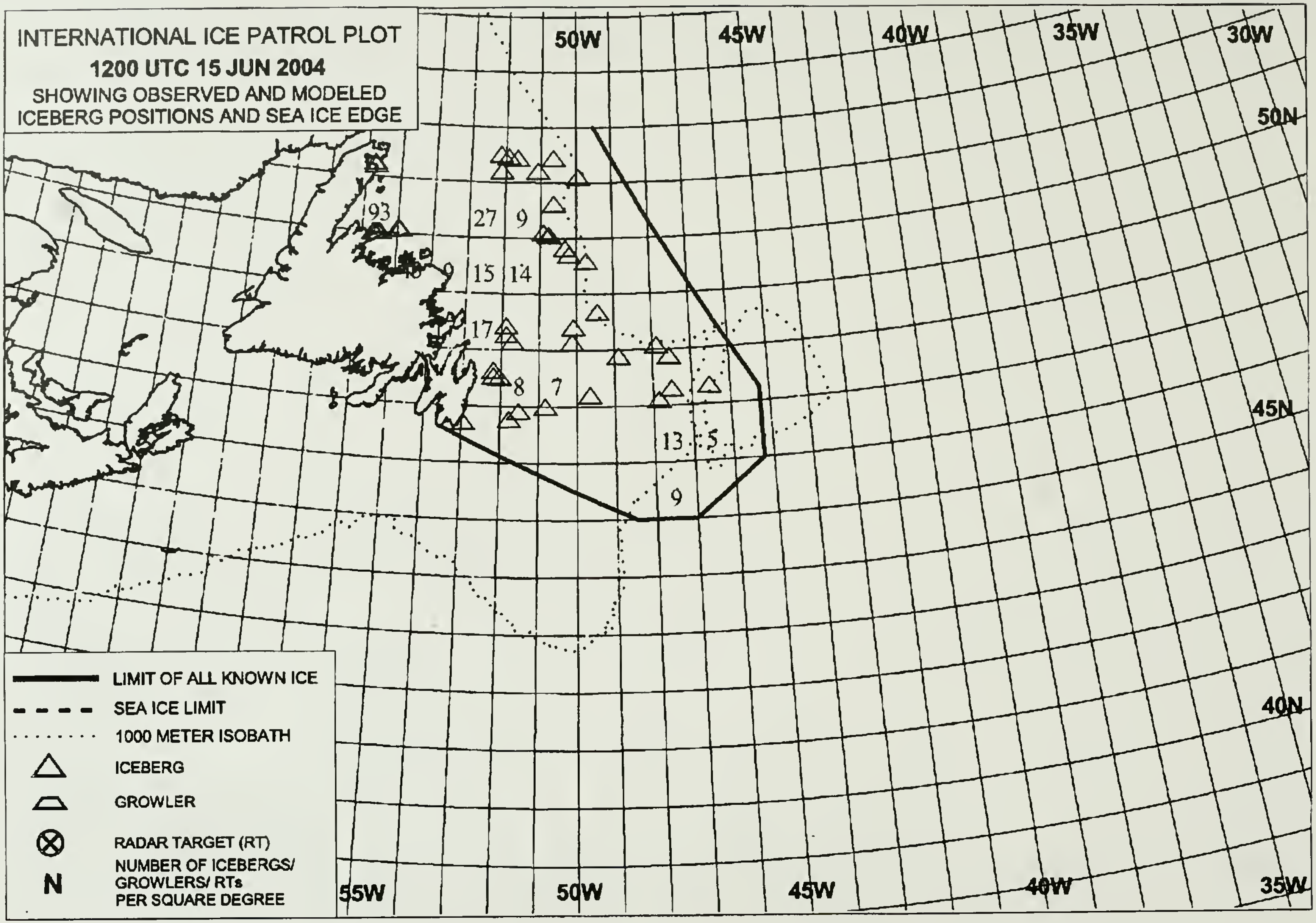
ICEBERG
GROWLER
RADAR TARGET (RT)
NUMBER OF ICEBERGS/
GROWLERS/ RTs
PER SQUARE DEGREE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45N
40N
55W
50W
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35W
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13
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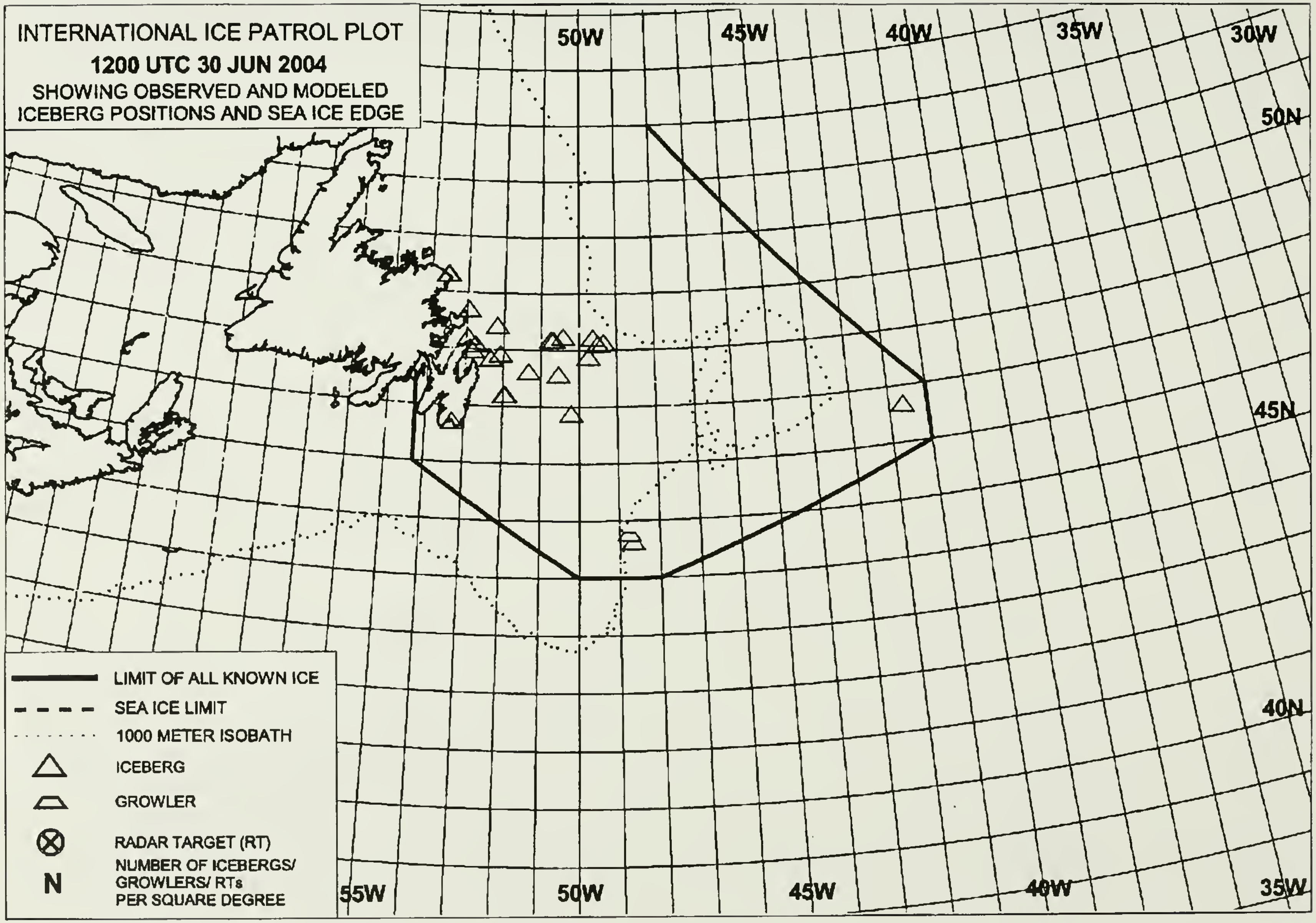
9
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/
GROWLERS/ RTs
PER SQUARE DEGREE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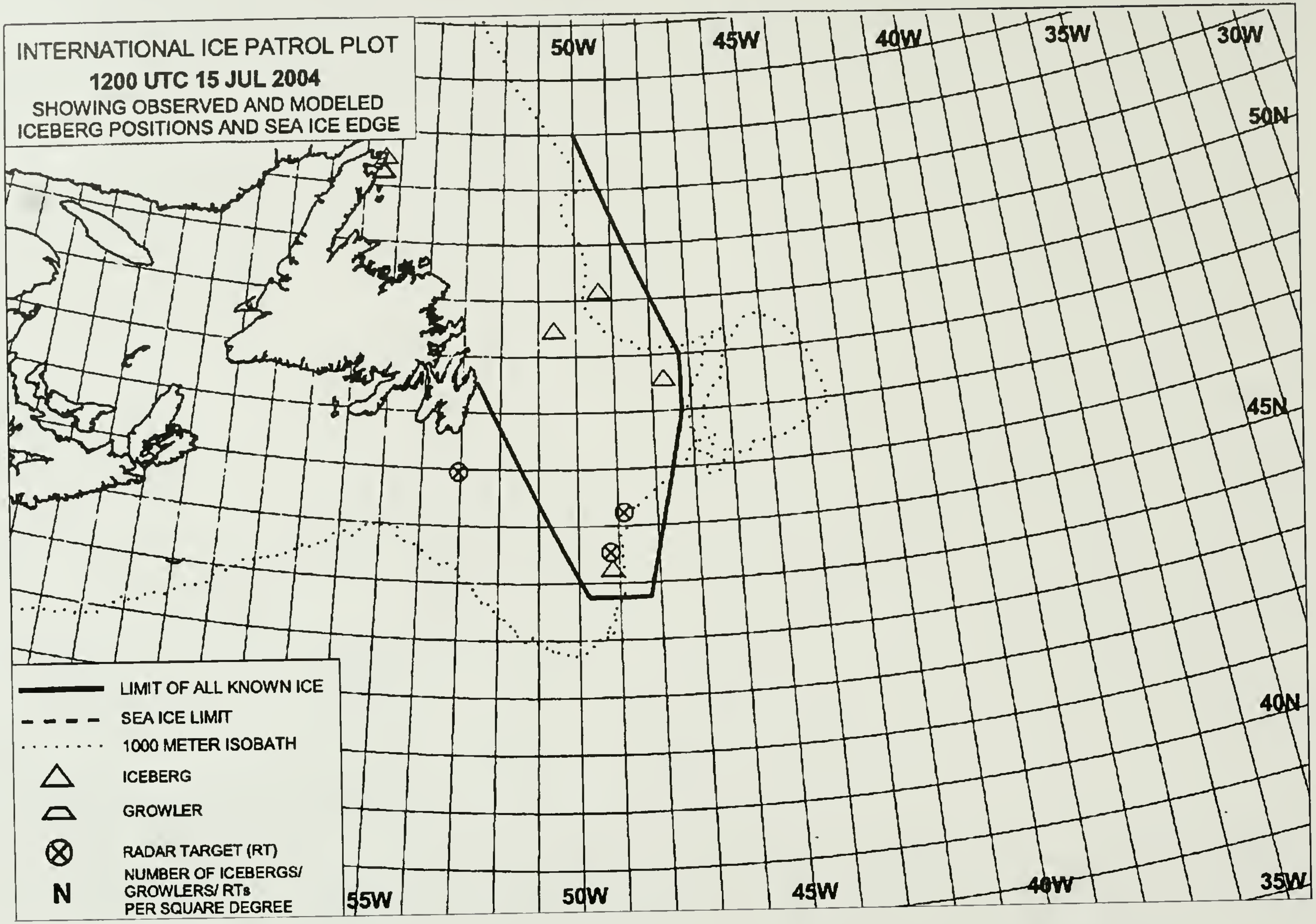
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/
GROWLERS/ RTs
PER SQUARE DEGREE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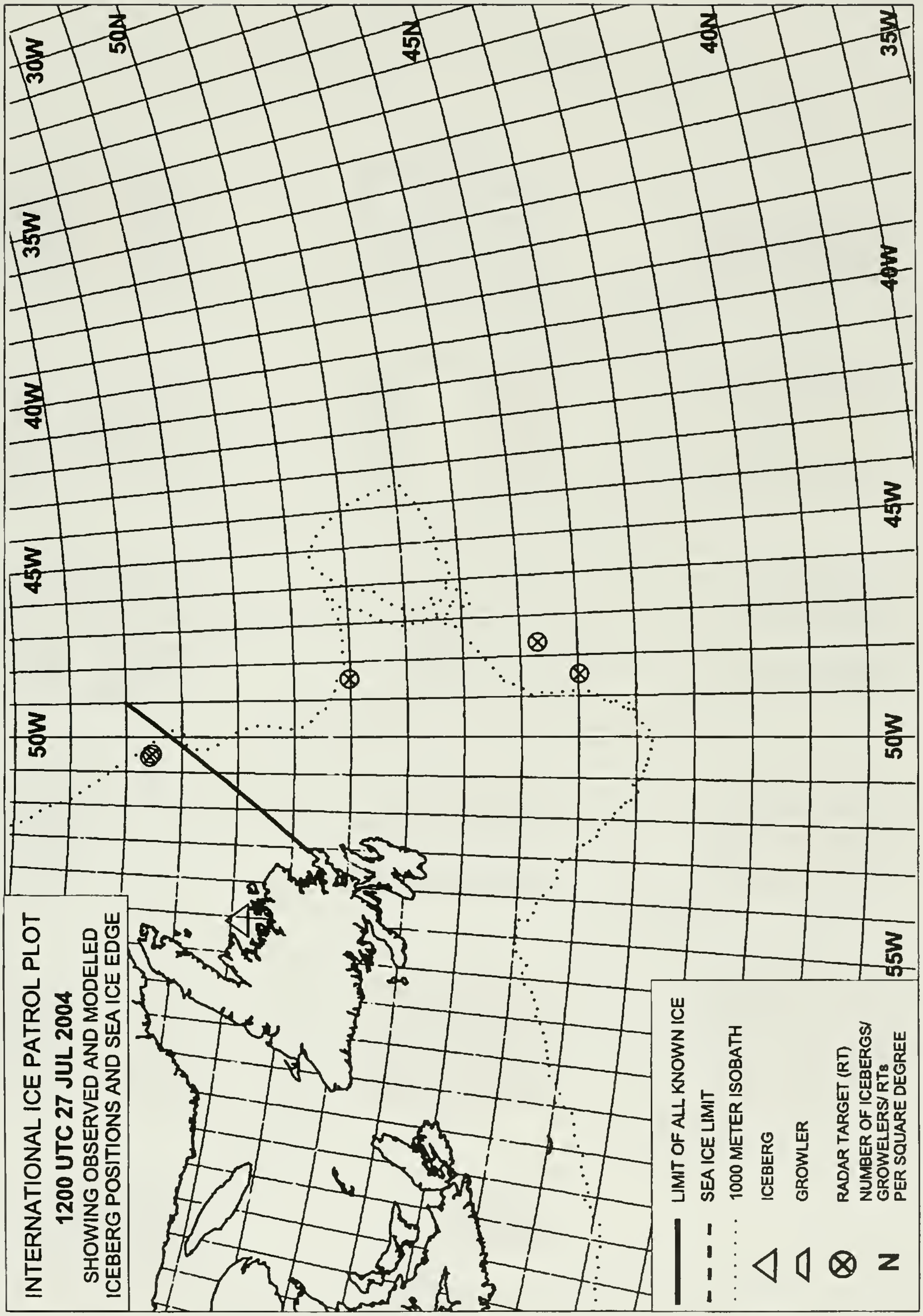
40N
55W
50W
45W
40W
35W
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
N
NUMBER OF ICEBERGS/ GROWLERS/ RTs PER SQUARE DEGREE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ICEBERG POSITIONS AND SEA ICE EDGE
LIMIT OF ALL KNOWN ICE
SEA ICE LIMIT
1000 METER ISOBATH
ICEBERG
GROWLER
RADAR TARGET (RT)
NUMBER OF ICEBERGS/
GROWELERS/ RTs
PER SQUARE DEGREE
N
30W
35W
40W
45W
50W
55W
50N
45N
40N

Acknowledgements

Commander, International Ice Patrol acknowledges the following for providing information and assistance:

C-CORE
Canadian Coast Guard
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Canadian Ice Service
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National Ice Center
National Weather Service
Nav Canada Flight Services
Provincial Aerospace Limited
U. S. Coast Guard Air Station Elizabeth City
U. S. Coast Guard Atlantic Area Command Center
U. S. Coast Guard Atlantic Area Staff
U. S. Coast Guard Automated Merchant Vessel Emergency Response System
U. S. Coast Guard Communications Area Master Station Atlantic
U. S. Coast Guard Operations Systems Center
U. S. Coast Guard Research and Development Center
U. S. Naval Atlantic Meteorology and Oceanography Center
U. S. Naval Fleet Numerical Meteorology and Oceanography Center

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

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LCDR B. D. Willeford
Dr. D. L. Murphy
Mr. G. F. Wright
LT S. A. Stoermer
LTJG N. A. Jarboe
MSTCS V. L. Fogt
MSTCS J. M. Stengel
MST1 D. L. Alexander
YN1 T. J. DeVall
MST1 S. R. Houle
MST1 E. W. Thompson
MST1 T. T. Krein
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MST3 D. N. Brown
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MST3 J. E. Hutcherson
MST3 J. P. Buehner
MST3 W. P. Tootle

International Ice Patrol staff produced this report using Microsoft® Word 2000 and Excel 2000.

Appendix A

Nations Currently Supporting International Ice Patrol

Belgium

Canada

Denmark

Finland

France

Germany

Greece

Italy

Japan

Netherlands

Norway

Panama

Poland

Spain

Sweden

United Kingdom

United States of America

Appendix B

Information Reports

Reporting Source by Flag	Reports
ANTIGUA & BARBUDA	
BBC SPAIN	1
BRUARFOSS	1
BAHAMAS	
AEGEN SPIRIT	45
AFRICAN SPIRIT	65
ATLANTIC CARTIER	33
DAVIKEN	1
HAMANE SPIRIT	8
JAEGER ARROW	3
JOH GORTHON	1
KYEEMA SPIRIT	17
MAYON SPIRIT	43
NIRINT PRIDE	5
SA ALTIUS	17
STENA CONFIDENCE	11
BARBADOS	
FEDERAL SCHELDE	22
BERMUDA	
CANMAR GLORY	11
CAST PRIVILEGE	1
CANADA	
14TH AIRWING OPERATIONS	1
ALEX GORGON	1
ALGOSAR	7
ANGLIAN LADY	1
ANN HARVEY	3
ARCTIC	1
ATLANTIC EAGLE	1
ATLANTIC ENTERPRISE	1

Reporting Source by Flag	Reports
CANADA cont.	
ATLANTIC HAWK	1
CAPE RACE LIGHTHOUSE	1
CAPE ROGER	4
C-CORE	51
CIS	24
DES GROSEILLIERS	2
FREDERICTON	11
GREEN ISLAND LIGHTHOUSE	3
HENRY LARSON	11
HMCS ST JOHNS	1
LEONARD J. COWLEY	1
MAERSK CHIGNECTO	1
MAJESTIC MARINER F/V	1
MATTEA	78
MERSEY PHOENIX	1
NEWFOUNDLAND OTTER F/V	1
OCEAN PRAWNS	1
PIERRE RADISSON	2
PROVINCIAL AEROSPACE	23
RADARSAT PASSES	2
TERRY FOX	1
TWILLINGATE LIGHTHOUSE	46
YANKCANUCK	5
CAYMAN ISLANDS	
ICE CRYSTAL	13
CYPRUS	
ATLANTIC PATROLLER	15
GARGANTUA	13
INDEPENDENT ACTION	1
ISADORA	3
KAMARI	6
KAPITAN NAZAREV	1

Reporting Source by Flag	Reports
CYPRUS cont.	
PINTAIL	2
EGYPT	
EDCO STAR	1
FINLAND	
BIRKA FOREST	8
PURHA	1
FRANCE	
PIERRE LD	17
FRENCH ANTARCTIC TERRITORY	
NEW WISDOM	9
GERMANY	
BRISTA	1
ROTTERDAM EXPRESS	1
GIBRALTAR	
KENT NAVIGATOR	25
MALAYSIA	
TOFTON	19
GREECE	
ANANGEL EAGLE	1
BOW CHEETAH	1
IRNES HORIZON	1
PROSKY	15
CAP GEORGES	1
CAP JEAN	4
CAP PIERRE	1
CAP ROMUALD	16
CAP GEORGES	1
HONG KONG	
DARYA CHAND	6
INDOTRANS CELEBES	1
SAGA JANDAIA	1

Reporting Source by Flag	Reports
ITALY	
CRYSTAL RUBINO	3
GRON FALK	28
KOREA (SOUTH)	
OCEAN HOST	1
LIBERIA	
DZINTARI	9
INDEPENDENT TRADER	1
INDEPENDENT VENTURE	1
KAPITAN KOZIAR	12
KAPITAN ZHURAVLYOV	18
KUBAN	1
MSC BOSTON	37
RAZNA	1
SHANGHAI SENATOR	1
STOLT ASPIRATION	4
ZIEMIA SUWALSKA	1
ZIM FLORIDA	13
LITHUANIA	
KAPITONAS A. LUCKA	1
SVILAS	4
BUNGA ORKID EMPAT	1
MALTA	
SUN LIGHT	14
TROGIR	7
VINDEMIA	1
MARSHALL ISLANDS	
LAKE ONTARIO	21
SKS SENNE	26
VALIANT	1
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NETHERLANDS	
JO SPRUCE	5

Reporting Source by Flag	Reports
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ROTTERDAM	4
VICTORIAB0RG	4
NETHERLANDS ANTILLES	
BBC ICELAND	3
SCHIPPERSGRACHT	1
SNOEKGRACHT	1
NORWAY	
BERGE ARCTIC	4
BERGE ATLANTIC	29
BERGE NORD*	99
CHRISTINA	15
HAVFROST	6
HELICE	2
HELIOS	2
ICE LOUISE	5
MENOMINEE	21
NAVION SCANDIA	4
SAUNDSTRAUM	1
SIBOHELLE	8
SPAR RUBY	1
NORWEGIAN INT. REGISTER	
ALOUETTE ARROW	5
BOW CLIPPER	2
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ANELLA	3
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MOSEL ACE	3

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DONA LIBRA	1
STAR SAVANNAH	32
RUSSIA	
DMITRIY DONSKOY	1
TYNDA	1
SINGAPORE	
STAR IKEBANA	6
STAR SIRANGER	36
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ATLANTIC COMPANION	6
SWITZERLAND	
GENERAL GUISAN	14
UNITED KINGDOM	
ANVIL POINT	2
BRITISH ENDURANCE	1
BRITISH MERLIN	13
CAPE OSPREY	8
CHARLES DARWIN	1
EDDYSTONE	9
GREEN AUSTEVOLLO	3
GREEN SPRING	6
QUEEN MARY 2	14
RFA OAKLEAF	10
TMM CAMPECHE	11
UNITED STATES OF AMERICA	
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IIP	26

Reporting Source by Flag	Reports
UNITED STATES OF AMERICA cont.	
KNORR	28
MAERSK GEORGIA	4
NATIONAL ICE CENTER	15
SEALAND FLORIDA	10
UNKNOWN	**?**
ANY SHIP	85
APPOLO	4
BCC SEALAND	2
BORC	9
CHINOOK	1
WEISBADEN	1
VANUATU	
POLSKA WALCZACA	19

*DENOTES VESSEL PARTICIPATION AWARD WINNER

Appendix C

Iceberg Demolition Experiments

Donald L. Murphy and MST1 Duyane Alexander, USCG (ret.)

Introduction

> *All ice is brittle, especially that in bergs, and it is wonderful how little it takes to accomplish their destruction. A blow of an ax will at times split them, and the report of a gun, by concussion, will accomplish the same end.* Ensign Hugh Rodman, USN in 1890[1]

The shocking sinking of the *Titanic* made the menace that icebergs pose to shipping horribly evident. Icebergs are a clear and present danger to mariners traversing the North Atlantic Ocean in springtime. They are the enemy. Why not just destroy them? In the early 20th century it is unlikely that very many people shared Ensign Rodman's optimism on how easy this would be, especially in light of *Titanic's* fateful collision, but destroying threatening icebergs seemed to be a reasonable thing to try. For nearly half a century, the Coast Guard International Ice Patrol did just that. The following sections describe Ice Patrol's iceberg-destruction attempts, which were sometimes spur-of-the-moment and other times involved extensive planning.

Gunfire

In April 1913, U. S. Revenue Cutters *Seneca* and *Miami* began taking turns conducting iceberg-scouting patrols in the vicinity of the Grand Banks. On 26 April, less than three weeks after beginning these regular patrols, *Miami* fired a shot from her 6-pounder gun against the vertical wall of an iceberg. The result was far less dramatic than Ensign Rodman would have predicted since the shot "had no other effect than to shake down a barrelful of snowlike dust."[2] While this was hardly a concerted or even mildly promising effort at iceberg demolition, it marks the beginning of the International Ice Patrol's experimentation with iceberg destruction.

Figure 1. *Seneca*'s crew conducts target practice with the type of gun used in iceberg demolition attempts.

In the years that followed, *Miami* and *Seneca* fired their 6-pounder guns at icebergs sporadically, partly for diversion and partly for experimentation. *Miami*'s efforts on 26 May 1914 involved firing twelve 6-pounder shots at an iceberg southeast of the Tail of the Banks. The results were "just as effective as if we had stormed the Rock of Gibraltar."[3] It had become evident that the small guns on the early patrol vessels were no match for the icebergs they were charged with tracking. The practice of shooting at icebergs with the various weapons on the patrol vessels has continued throughout Ice Patrol's history, but these efforts were undertaken in the name of gunnery practice rather than serious attempts at iceberg demolition.

Mines

One of the little-known responsibilities of the Revenue Cutter Service in the early 1900s was the destruction of derelict vessels drifting in the ocean.[4] Abandoned wooden vessels could drift for many years, circumnavigating the North Atlantic Ocean several times and creating a great hazard to navigation. Their destruction was usually accomplished using standard Navy-type wrecking mines, which had guncotton as the explosive agent and were detonated using an electrical charge from a battery. The Ice Patrol vessels conducted this important Coast Guard mission and carried the wrecking mines, so it was natural to see if they would fare any better than the gunshots against the icebergs.

In May 1923, USCGC *Tampa* tracked a particularly fast-moving iceberg in the warm (>15° C) Gulf Stream waters south of the Tail of the Banks. Since this iceberg was well into the busy steamer lanes and considered particularly menacing, they decided to use wrecking mines to hasten its demise. The effort was done mostly in the name of experimentation, but the iceberg's location imparted an operational urgency to the destruction of this iceberg.

From 20 to 24 May, *Tampa* exploded four charges at depths ranging from 6 to 30 feet along the underwater portion of the iceberg. The first attempt consisted of suspending the mine from a float and allowing it to drift toward the iceberg with the hope of detonating it as it came up against the side of the iceberg. However, the flow of the water carried the mine past the iceberg. The mine was retrieved, placed over a subsurface ledge of the iceberg, and exploded. The remainder of the attempts, conducted in very calm sea conditions, involved attaching the mines to the iceberg using lines with grapnels. This allowed the mines to explode right alongside the iceberg at various depths. The explosions produced much loose ice and calved many growlers. Overall, *Tampa* considered the experiment a success, the crew believing that they had shortened the iceberg's life by one to two days—an important achievement considering the dangerous location of the iceberg. Before it completely melted on 25 May, this iceberg reached 39°08'N, which at that time was the lowest latitude attained by an iceberg since the establishment of the International Ice Patrol. It was clear that the effective use of wrecking mines, while successful in this case, could be undertaken only in conditions calm enough for small boat operations and in warm water, so natural deterioration processes and the explosives could work in concert to destroy the iceberg.[5]

The experimental use of wrecking mines to demolish icebergs continued in 1924, with three separate attempts, two by *Tampa* and one by *Modoc*.[6] The experiments met with, at best, fair success.

On 28 May 1926, *Tampa* undertook the final effort to destroy icebergs using wrecking mines. *Tampa* came upon a small to medium iceberg in the steamer lanes, again in the warm Gulf Stream waters. Although natural deterioration processes were taking their toll on this dangerous iceberg, *Tampa* used its 6-pounder gun and 238-pound wrecking mines to speed the decay. They concluded: "Considerable ice was shaken down but it is questionable whether the expenditure would be justifiable in continuing the practice on a greater scale." That evening *Tampa* remained close to the iceberg, "warning all approaching ships of its location." [7]

Heat (Thermite)

Howard T. Barnes, a professor of physics and an ice expert from McGill University in Montreal, was one of the earliest proponents of using thermite to destroy ice. He was a self-described ice fighter who regarded ice "as an enemy to mankind." As an observer on *Modoc* in June 1924, he had seen Ice Patrol's use of wrecking mines. He realized that it would be better to create an intense thermal shock by igniting thermite inside an iceberg. Thermite is a mixture of aluminum and iron oxide. When ignited, it creates a violent reaction that burns at very high temperatures, as hot as 3,500° C, which is enough to melt steel.

In the summer of 1926 in Notre Dame Bay, Newfoundland, Prof. Barnes conducted several iceberg destruction experiments using thermite and bermite, a high explosive. In one of the tests, 500 pounds of thermite was placed about four feet into the iceberg and

> *fired at sundown in order to allow the people of Twillingate an opportunity to see the spectacle of the burning and disrupting ice. The whole thing was a most wonderful sight when the mighty charge fired and roared, lighting up the iceberg and surrounding hills like Vesuvius in eruption. Flames and molten thermite and ice were shot upwards 100 feet or more by the explosion which followed. Much of this berg was disrupted but the full effect of the big charge was lost into the air.*[8]

He concluded that the charge would be much more effective if it could be placed 50 to 100 feet into the iceberg using a rock drill, a process, he declared, that could be accomplished from a boat without boarding the iceberg.

After the results of Prof. Barnes's 1926 experiments became widely known, the following optimistic assessment appeared in the March 1927 issue of *Nautical Magazine*:

> *[I]t would appear that as soon as an iceberg is reported approaching the trans-Atlantic steamer routes all that is necessary is for a handful of men to approach the berg and with the judicious use of thermite completely destroy it in a few hours.*[9]

Bombs, Carbon Black, and More Thermite

While Ice Patrol recognized the promise of Prof. Barnes's thermite experiments, the prospect of taking explosive charges and boarding or even closely approaching an iceberg tossing in the sea conditions typical of the North Atlantic seemed foolhardy. They sought a better way to deliver the required thermal shock to an iceberg at sea.

Using an aircraft to deliver modern ordnance seemed like a safe and promising tactic. During and after World War II, there were tremendous advances in the manufacture of "shaped" charges and special bomb and rocket designs. In 1959, Ice Patrol obtained 20 aircraft incendiary bomb clusters and conducted a series of bombing experiments against several icebergs near Newfoundland.[10] Two types of incendiary bombs were tested, each consisting of many bomblets containing material, including thermite, that burned at very high temperatures. The airplane delivering the bombs was the USCG UF2G *Albatross*, a twin-engine amphibious airplane. The first several bombing attempts met with poor results, primarily because the *Albatross* had no bombsight. After the installation of a makeshift bombsight, 11 of 12 bombing runs resulted in the bomblets striking the iceberg. Unfortunately, many of the bomblets of both types failed to detonate on impact. The bomblets that contained the thermite mix created spectacular, brilliant balls of white flame that left deep and wide burn holes. While there was some modest evidence of success against one of the icebergs that had been struck eight times, the bomb clusters were not able to deliver the concentrated heat source required by Prof. Barnes's thermal stress theory of ice demolition.

The following year, 1960, brought three separate demolition tests: bombing with explosive charges, igniting thermite inside an iceberg, and coating an iceberg with carbon black to accelerate natural solar deterioration.

The bombing tests were a direct follow-up to those conducted in 1959,

Figure 2. Photo taken minutes after a strike by a 1000-lb bomb during the 1960 tests. The bomb caused a spray of ice fragments, but no significant change in the iceberg's shape.

Figure 3. Drilling a hole in the iceberg with a power auger was a 45-minute procedure

except that high explosive bombs were used. Ice Patrol obtained 20 1000-pound bombs from the U.S. Navy, 10 general-purpose bombs and 10 semi-armor-piercing bombs.[11] Over an eight-day period (23 to 30 May), an *Albatross* dropped all 20 bombs on a single large iceberg using the same bombsight design from the previous year with similar accuracy. Of the 20 bombs dropped, 18 struck the iceberg: three were underwater bursts and three failed to detonate. Some of the bomb strikes resulted in a spray of ice fragments that rose to over 500 ft. Others caused minor changes to the iceberg's waterline orientation due to a loss of ice mass. At the conclusion of the bombing, Ice Patrol estimated that the iceberg's size had been reduced by a quarter to a third, but could not say for certain how much of the disintegration was due to bombing and how much was due to natural deterioration.

The second phase of the 1960 tests was essentially a repeat of Prof. Barnes's thermal shock experiments using thermite. Led by project officer LCDR Bob Dinsmore, an Ice Patrol field party on 8 June conducted three thermite detonations on two icebergs in the protected waters of Bonavista Bay. Because the test was conducted in Canadian territorial waters, Ice Patrol obtained the full support of Canadian authorities, including personal approval from Newfoundland's Premier.

For each detonation, a team boarded the iceberg from a rubber raft, drilled holes in the iceberg with a power auger, and planted the charges. Drilling each hole took about 45 minutes, during which time loud cracking noises could be heard from within the ice. After planting the charges, the party ran a detonation cable to USCGC *Evergreen*, which ignited the thermite. The first detonation, consisting of 196 pounds of thermite, scattered a shower of molten iron over a radius of 100 yards but, other than producing a few growlers, had no significant impact on the size of the iceberg. The second detonation, on a different iceberg, used 364 pounds of thermite with the same results as the first. A third detonation, a 560-pound thermite charge planted near the base of the iceberg's pinnacle, had the following result:

Figure 4. Shortly after the detonation of 560 lbs of thermite a large plume of smoke and steam rose

> [A] magnificent display took place as smoke and molten iron was hurled hundreds of feet into the air, but the berg remained virtually unchanged. This concluded the thermite tests"[12]

These tests showed that thermite detonations would not necessarily cause the disintegration seen by Prof. Barnes's experiments in 1926.

The intent of the final phase of the 1960 tests was to cover an iceberg with carbon black and other dark substances to speed its solar-induced deterioration. Ice Patrol first tried to drop the material on the iceberg from an airplane (USCG's R5D, which is a military version of the Douglas DC-4). Regardless of the material used, it was not possible to achieve adequate coverage of the iceberg using the aircraft delivery method. Again, Ice Patrol resorted to boarding the iceberg, in fact the same Bonavista Bay iceberg that was the subject of the first thermite detonation. Three persons with fiber brooms spread 25 pounds of carbon black in 30 minutes. They covered 6,500 square feet, approximately half the iceberg's surface. Five hours after the carbon black was placed on the iceberg, it broke apart, and by the next day it was reduced to less than a third of its pervious size. As with the bombing and wrecking mine tests, it is not possible to say how much of the observed breakup was due to natural causes and how much to Ice Patrol's intervention.

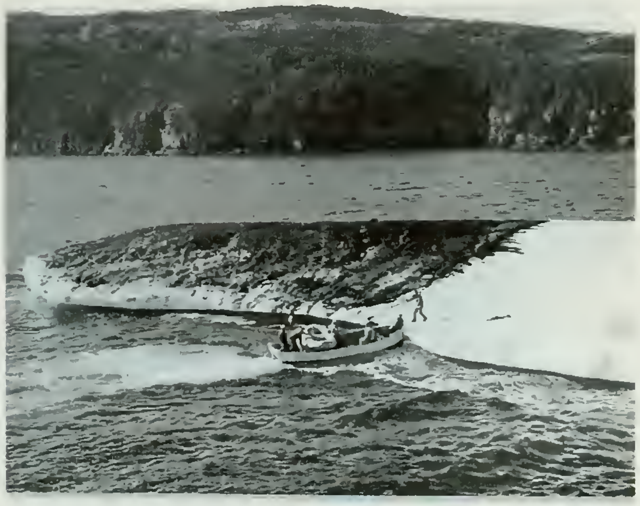

Figure 3. It took three men using fiber brooms about 30 minutes to cover half the iceberg's surface with carbon black.

The tests in 1959 and 1960 can be best be summarized as follows:

Although some damage to the bergs resulted, it must be admitted that all of the means tried were unsuccessful in destroying the icebergs.[13]

Conclusion

Ice Patrol's attempts at iceberg demolition ended with the 1960 tests. Rather than destroying icebergs, Ice Patrol adopted *Tampa*'s May 1926 approach of monitoring dangerous icebergs and warning mariners of their locations.

This practice makes good sense for several reasons. The demolition process is expensive and dangerous. Even if an iceberg could be broken into smaller pieces, the result would be more icebergs. They would be smaller than the parent iceberg and thus harder for mariners to detect visually or with surface radars.

Since the conclusion of Ice Patrol's 1960 tests, there have been two periods of renewed interest in iceberg destruction: the late-1970s and the mid-1980s. In the late-1970s, researchers studied the feasibility of towing icebergs to the Middle East as a freshwater source. If the long-distance towing process succeeded, the icebergs would have to be processed at their destination, which would mean cutting them apart and melting them. Fragmentation by blasting, electrochemical cutting, mechanical sawing, etc., were all considered.[14] The problem that couldn't be solved was preserving the iceberg during transport to the Middle East, so the processing step became moot.

On a smaller scale, iceberg processing for fresh water has been routinely practiced in Newfoundland for the last several years. A company that produces vodka from iceberg water has a permit from the provincial government to harvest icebergs for their water. Harvesters prefer working with icebergs grounded in sheltered coves. They use a variety of methods to harvest iceberg ice, the most sophisticated of which is a barge equipped with a crane that uses a grapple to chip pieces off the iceberg. The pieces are then crushed and melted in storage tanks. Chain saws, rifles, and cargo nets are some of the less sophisticated tools for harvesting iceberg ice on a small scale.

In the 1980s, plans for oil development on the Grand Banks spurred renewed interest in iceberg destruction. This time the problem was protecting the drilling platforms and the sub-bottom pipelines from being struck by icebergs. Breaking up an iceberg approaching a drill rig or pipeline would reduce the mass and draft of the iceberg. Using a hot-wire system to cut the iceberg was the most promising method of accomplishing this.[15] A field test conducted in 1985 demonstrated modest success, but the process has not become operational. For many years the oil industry has used a common practice popularly known as "iceberg wrangling," which involves placing a line around the iceberg and towing it out of the rig's way.[16]

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Appendix D

Iceberg Reconnaissance Using ENVISAT

LTJG Nicolas A. Jarboe

Introduction

Using satellite-borne sensors to locate icebergs has interested the International Ice Patrol (IIP) since the first weather satellite was put in orbit in 1960. The first satellites could detect large cloud systems, but it was not until the 1972 launch of the Earth Resources Technology Satellite that IIP started to consider satellite imagery for iceberg detection. With a spatial resolution of approximately 80 meters, this visual sensor could detect sea ice as well as medium and large icebergs, but could not see through fog and clouds. Consequently, IIP did not use this system for iceberg reconnaissance. In 1975, an internal assessment was conducted on remote sensing as it applied to IIP. That report (Super & Osmer, 1975) expressed IIP's interest in using satellites to perform its mission; thus, IIP eagerly awaited the projected 1978 launch of the ocean monitoring satellite SEASAT-A, which had an L-band synthetic-aperture radar with 25-meter resolution. However, SEASAT's three-and-a-half-month lifetime prevented the sensor from realizing its promise.

In early 1996, IIP began considering satellites for operational iceberg reconnaissance by testing the target detection capability of the Canadian satellite RADARSAT. RADARSAT has a synthetic-aperture radar with a C-band horizontal-polarization microwave radar instrument that can gather ocean-surface data day or night and is virtually unaffected by fog or weather. In July of 1997, IIP conducted a validation flight of RADARSAT data to determine the satellite's ability to detect icebergs. This study concluded that RADARSAT could detect targets 15 meters or greater, but it could not classify targets or distinguish between an iceberg and a ship; furthermore, the satellite imagery was very costly (Andrews, 1997). Fortunately, however, the European Space Agency's satellite, ENVISAT—an advanced synthetic aperture radar (ASAR) capable of dual polarization—was launched in 2002 and has the potential to distinguish between icebergs and ships.

During the 2003 and 2004 ice seasons, IIP participated in the Global Monitoring for Environment and Security program, which was sponsored by the European Space Agency and European Commission. Ice Patrol was an end user of ice products from the Northern View team, which was led by the Newfoundland-based organization C-CORE. Ice Patrol cooperated with C-CORE to evaluate ENVISAT's ability to detect and classify targets on the ocean's surface. ENVISAT ASAR is a C-band active-microwave radar that possesses dual alternating polarization in both HH and HV modes. ENVISAT ASAR has various incident-swath (IS) modes ranging from IS1 through IS7. Table 1 shows the incidence angle and swath width for each IS mode. IS4 through IS7 modes at 30-meter resolution are suitable for iceberg detection; however, the probability of target detection increases in IS6 and IS7 modes, which are recommended for iceberg detection (Lane, Randell, Youden, & Power, 2003).

ENVISAT's dual-polarization capability helps satellite-image analysts distinguish between icebergs and ships (Lane et al., 2003). Icebergs tend to show up in the imagery only in HH mode, whereas ships show up in both HH and HV. By looking at a target in both modes, one can determine whether it is an iceberg or a ship. Figure 1 shows, in both HH and HV modes, an example of a ship, which was confirmed by Provincial Aerospace Limited (PAL), an aerial reconnaissance firm based in St. John's, Newfoundland. Figure 2 shows an example of an iceberg in both HH and HV modes that was confirmed by C-CORE. Notice the ship appears in both HH and HV modes, while the iceberg shows up only in the HH mode.

In addition to visually comparing HH and HV imagery, C-CORE developed an iceberg-detection-software (IDS) algorithm that classified both icebergs and ships from ENVISAT imagery. The data was sent to IIP in MANICE code but—because it needed further validation—not merged into IIP's BAPS database. However, IIP used the data for flight planning and decision making.

Methods

During the 2004 ice season, a cooperative experiment involving IIP, C-CORE, the Canadian Ice Service (CIS), and PAL was conducted to validate the algorithm's ability to distinguish between icebergs and ships. Ice Patrol and PAL conducted five under flights in April and May of 2004 and identified 101 icebergs and 41 ships. These results were compared to the MANICE output generated by C-CORE. The MANICE output reported iceberg and ship positions from the ENVISAT imagery based on the confidence of C-CORE's algorithm and imagery review. Modeled environmental conditions from the U.S. Navy Fleet Numerical Meteorology and Oceanography Center were used to compare on-scene wind speed and wave height during the validation efforts.

Because C-CORE needed a minimum of two weeks to order ENVISAT frames from the European Space Agency, C-CORE requested that IIP indicate a satellite-reconnaissance area 14 days before the acquisition date. Images were obtained by C-CORE near real time, processed through the IDS, quality controlled using the dual polarization modes, and sent to IIP in MANICE code approximately three to four hours after satellite acquisition. Combined with few southern icebergs and a late season opening, the required two-week lead time made planning satellite acquisitions very difficult. Therefore, without regard to the IS mode, IIP acquired ENVISAT frames in areas of the ocean where icebergs were predicted to be. Consequently, four of the five validation flights were conducted over areas where the sensor was in the IS modes (4 and 5) not optimal for iceberg detection (Table 2).

Provincial Aerospace Limited and IIP conducted validation flights to compare targets reported in the C-CORE MANICE messages with confirmed target data. Ice Patrol conducted its flight at patrol altitude to detect targets via radar and then descended to identify each target in the satellite-acquisition swath. C-CORE, IIP, PAL, and CIS evaluated the data to determine the probability of detection (POD) and probability of classification (POC) of the MANICE message produced by C-CORE. Table 2 represents the data from the five validation flights correlated by C-CORE.

Results

Probability of detection is defined as the probability of C-CORE to report a target in MANICE that was detected by aerial reconnaissance. Probability of classification is defined as the probability of C-CORE to correctly classify a target as an iceberg or ship in MANICE. The ENVISAT targets not confirmed by reconnaissance represent false targets reported in MAINCE.

Based on this small data set, the overall POD was 50%, and the overall POC was 72% (Table 2). The POD in IS7 was 100%; however, only one ship was seen in this IS mode, and it was incorrectly classified as an iceberg. The IS5 acquisition on 15 May compared to the IS4 acquisition on 21 May shows that both were consistent with the overall 50% POD, but the IS4 acquisition had a much higher POC (Table 2). Environmental conditions on both days were relatively the same, with winds at 5-10 knots and seas at 2-3 meters on 15 May and winds at 10-15 knots and seas at 1-2 meters on 21 May. Therefore, environmental conditions would have had little effect on the POC numbers between the different IS modes. A conclusion could be drawn that IS4 has a better POC than IS5 since the number of icebergs confirmed in both data sets was relatively the same; however, the number of ships in the area must be considered. The acquisition on 21 May was in an iceberg-dense region of the ocean where there was little vessel traffic, thus likely affecting the POC number on that day.

Regardless of the target density, each acquisition had an average of 13 false targets, with no more than 14 and no less than 11 for any given day during the validation efforts (Table 2). False targets are of a concern to IIP, especially if they are limit setters. Ice Patrol does not set limits around radar targets, which are targets that cannot be positively identified. Although a false target could potentially provide a safer Limit of All Known Ice (LAKI), it may unnecessarily cost the mariners who heed IIP's LAKI valuable time on their transits.

Conclusion

The POD and POC results from the validation effort did not meet IIP's thresholds for operational use. However, IIP plans to continue validation efforts during the 2005 ice season, focusing primarily on IS6 and IS7 acquisitions. In addition, C-CORE has recently completed changes to the classification algorithms, which will be implemented in the IDS prior to the 2005 ice season. This is expected to improve overall probability of classification.

Insufficient data was collected and confirmed in the 2004 ice season to make a determination on the POD and POC in the recommended IS6 and IS7 modes. Moreover, POC decreases in areas of mixed target density, as seen when comparing the results of 15 May with those of 21 May. Because IIP's area of most concern is in the transatlantic shipping lanes, where both icebergs and ships are prevalent and it is necessary to distinguish between them, Ice Patrol does not intend to use ENVISAT imagery to determine the LAKI. However, IIP could potentially use this data to assess the iceberg-feeder population in an area with less shipping traffic if POD numbers increase with the IS6 and IS7 acquisitions and improvements are made to the algorithm to increase the POC. Probability of detection and POC numbers must increase before IIP considers using this information to update the IIP iceberg database in BAPS. If POD and POC numbers increased to 75% and 90%, respectively, IIP would consider strategic use of this data. An example of strategic use for this service would be to target a specific location, such as the Flemish Pass, by obtaining repeated looks in the same area to determine the population of potential limit-setting icebergs.

The required lead time necessary to direct ENVISAT acquisitions proved very difficult to work with because predicting iceberg location two weeks into the future in the dynamic North Atlantic is extremely challenging. This two-week lead time cannot be used tactically to determine limit-setting icebergs because of the day-to-day changes in the LAKI. However, the near real-time capability of receiving the MANICE messages from C-CORE was comparable to the current method of data delivery from aircraft reconnaissance and voluntary ship reports and would be operationally beneficial.

Analysis of this service is ongoing and will continue during the 2005 ice season. C-CORE has made improvements to the IDS, which will be validated in 2005 with more under flights. A greater understanding of how environmental conditions affect POD and POC is necessary. Eventually, a cost analysis will be necessary to compare the detection capability and coverage area of the C-CORE output versus HC-130 reconnaissance.

Currently, it is unlikely that satellites will replace the HC-130 aircraft as IIP's primary means for iceberg reconnaissance. The flexibility of directing the aircraft and the ability to visually identify ambiguous radar targets give the airplane a great advantage over satellite reconnaissance. Satellites, however, do have the potential to augment aircraft reconnaissance in the near future, potentially allowing some HC-130 hours to be reallocated to other U.S. Coast Guard missions.

Ice Patrol will continue to seek technological advances to improve its ability to find the icebergs that pose a threat to transatlantic mariners. In addition to working with C-CORE, IIP is also considering various technological innovations for iceberg reconnaissance, such as the use of unmanned aerial vehicles (UAV). Theoretically, UAVs combined with satellite coverage over Ice Patrol's operations area could eventually eliminate the need to deploy aerial ice observers to the North Atlantic. The International Ice Patrol of the future could be two people sitting in a command center, while directing a UAV and receiving satellite iceberg data to create and issue iceberg warnings; yet much work is still necessary to determine the feasibility of operationally incorporating these technologies.

Image Swath	Swath Width(km)	Incidence Angle Range
IS1	105	15.0 - 22.9
IS2	105	19.2 - 26.7
IS3	82	26.0 - 31.4
IS4	88	31.0 - 36.3
IS5	64	35.8 - 39.4
IS6	70	39.1 - 42.8
IS7	56	42.5 - 45.2

Table 1. Image Swath Modes for ENVISAT.

Date	Beam Position	Recon Flights	Confirmed Icebergs	Confirmed Ships	Overall POD	Overall POC	ENVISAT Targets Not Identified
26-Apr-04	IS5	PAL	7	0	0	N/A	14
6-May-04	IS7	PAL	0	1	100	0	13
15-May-04	IS5	PAL	43	22	49.23	68.75	14
19-May-04	IS5	PAL	7	16	65.22	46.67	11
21-May-04	IS4	IIP	44	2	50.00	95.65	12
Overall			101	41	50.00	72.00	64

Table 2. IDS validation results for the 2004 ice season. Data compiled by C-CORE.

Figure 1. 19 May 2003 ENVISAT image in HH and HV polarization confirmed to be a ship by PAL.

Figure 2. 02 May 2003 ENVISAT image in HH and HV polarization confirmed to be an iceberg by C-CORE.

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Appendix E

Iceberg Deterioration Estimates: A Model Comparison

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Introduction

To minimize the risk of iceberg collision, the U.S. Coast Guard International Ice Patrol began routine patrols in 1913 after the sinking of the RMS *Titanic* in 1912. Ice Patrol was tasked with observing and studying the ice and oceanographic conditions in the vicinity of the Grand Banks and providing warnings to mariners of existing iceberg hazards. In order to create iceberg warnings and accurately predict iceberg positions, IIP needs information about an iceberg's characteristics (i.e., position, size, and shape), as well as environmental data, such as sea surface temperature, wave height and wave period. Iceberg data is gathered from Coast Guard surveillance flights, other aircraft, and ships operating in the area, while the U.S. Navy's Fleet Numerical Meteorology and Oceanography Center provides environmental data.

Personnel at the IIP Operations Center in Groton, CT use a computer model to predict the drift and deterioration of icebergs based on assimilated iceberg information. Ice Patrol then broadcasts the Limit of All Known Ice (LAKI) south of 52° North in message bulletins and graphical charts. These messages are sent out twice per day during the iceberg season, which usually extends from March to July. Ice Patrol bulletins contain the estimated LAKI and other pertinent ice information.

Iceberg modeling, including drift and deterioration estimates, is of premier importance to the Ice Patrol. Since most icebergs are visually observed only once, IIP relies on the information provided by computer models so that information about iceberg location can be continuously provided to the mariner. In general, the iceberg model fills the gap between reconnaissance sorties—which provide real-time iceberg data to update the model—with estimations of iceberg locations and melt. In recent Ice Patrol history, a succession of computer models has been applied to the problem of drift and deterioration estimates. The analysis presented in this paper compares the melt modules of two Ice Patrol models, one presently operational and the other being considered for use as its replacement.

Background

Attempts at modeling icebergs began in the 1960s, when IIP maintained hand plots of predicted motion using vector addition of the effects of winds and ocean current. The hand-plotting technique was made possible by research that IIP conducted on the effects of wind and

* This project was conducted as a 3-credit directed-study course in coordination with the Marine and Environmental Sciences Department of the U.S. Coast Guard Academy.

current on iceberg drift. Hand plots suffered from a number of problems, including the fact that wind and currents were the only parameters considered. In addition, gathering and plotting collected information was time-consuming (IIP, 2004). In 1971, IIP began using a computerized model that employed the vector-addition routine described in Morgan (1971). The model area selected for this routine covered the area from 40° to 52° North and from 39° to 57° West. This model helped eliminate cumulative errors associated with hand plotting and improved the ability to model all icebergs accurately (IIP, 2004).

In 1980, the Coast Guard Research and Development Center released a report that discussed the physics involved with iceberg deterioration. *Theoretical Estimate of the Various Mechanisms Involved in Iceberg Deterioration in the Open Ocean* (White, Spaulding, & Gominho, 1980) supplied equations and figures for the erosion of icebergs due to buoyant convection, wind-forced convection, insolation, and wave erosion. This report gave rise to the ICEPLOT computer program, which was used to predict iceberg drift and to predict the melt of an iceberg over time.

In 1992, IIP implemented the precursor to BAPSNT, a system that the Canadian Ice Service (CIS) had been using since 1986. This system permitted estimation of iceberg-melt rates based on real-time sea-surface temperature (SST), significant wave height, and significant wave period. The BAPSNT deterioration algorithm uses the parameters of stability, water velocities, drag, surface melt due to insolation, air convection surface melt, buoyant vertical convection, forced convection, calving, and wave erosion to compute estimated iceberg melt. The combination of wave erosion and convection based on SST is responsible for over 90% of the deterioration of icebergs (El-Tahan, El-Tahan, & Venkateshl, 1987). Any assumptions that are made by the model are conservative, meaning that the model will calculate an iceberg to melt more slowly than it would in the ocean (Anderson, 1983).

The most recent advance in the modeling of iceberg deterioration from the Ice Patrol perspective is the Canadian Ice Service's implementation of BAPSNT 1.7 in January of 2004. This model is based on the same prediction routines as BAPSNT 1.4, but results have not been tested to ensure that re-coding did not alter the algorithms or induce sensitivity differences. Sensitivity differences in the two models would result in the programs generating slightly different prediction results, which have yet to be compared or understood. It should be noted that although newer versions were implemented in Canada, IIP continued to use version 1.4 operationally.

In this study, we used iceberg size, wave erosion, and SST to review iceberg-deterioration results computed by the What-If Model (WIM) of BAPSNT 1.4 and compared them to the WIM of BAPSNT 1.7. The WIM provides the ability to deteriorate selected icebergs, while applying pre-selected environmental data to gain estimates of percent melt versus time. Estimates of percent melt versus time were used to compare the algorithms/melt routines used by BAPSNT 1.4 and BAPSNT 1.7. Additionally, the sensitivity of melt estimates to each of the environmental parameters were briefly analyzed. One of the main goals of this work was to ensure that version 1.7 is an operationally acceptable replacement for version 1.4. The drift comparisons will be completed in another project.

Methods

In order to complete a successful evaluation of the models, an appropriate study area had to be chosen. A location off the northern Grand Banks was chosen based on the large number of icebergs that flow through the region, giving the area the nickname "iceberg alley." The specific area of 1° by 1° around the center point of 48° North and 048° West was designated as the study region, which falls within IIP's AOR.

In an effort to model iceberg deterioration using reasonable environmental-forcing values, we selected climatological data from the *Wind and Wave Climate Atlas* (MacLaren Plansearch Limited, 1991). Parameter ranges were selected so that the mean values, as well as minimum and maximum values found during a complete ice season, were modeled. Other variables such as wind and current, which do not have a direct modeled effect on melt, were not taken into account for these runs. The waterline lengths modeled for growler, small, medium, and large icebergs had starting lengths of 7.5m, 35m, 90m, and 170m, respectively. These lengths were determined by selecting the middle of each iceberg-size classification group given by International Ice Patrol (2004).

A parametric study was constructed in an effort to model the effect of environmental variables on deterioration. The study held constant (or did not consider) any variables that did not impact melt. The same environmental conditions were used in both models to allow for direct comparison of the outputs. The environmental values used for the 33 runs done on growler, small, medium, and large icebergs are shown in Table 1. Since the WIMs can run multiple iceberg melts at one time, all four were put in the same parameter file, each being one-half degree to the north, south, east, and west of the center of the study area.

The WIM-limits model runs to a maximum of ten days with values computed at six-hour intervals. This ten-day limitation forced operator intervention, so that resultant percent melt and remaining lengths from one run could be made the starting values of the next run. All parameter files and model-run outputs were saved.

Run #	SST (deg. C)	Wave Ht (ft)	Wave Pd (s)	Run #	SST (deg. C)	Wave Ht (ft)	Wave Pd (s)
1	0	4	5	***18***	16	4	8
2	2	4	5	***19***	0	4	11
3	4	4	5	***20***	2	4	11
4	6	4	5	***21***	4	4	11
5	8	4	5	***22***	6	4	11
6	10	4	5	***23***	8	4	11
7	12	4	5	***24***	10	4	11
8	14	4	5	***25***	12	4	11
9	16	4	5	***26***	14	4	11
10	0	4	8	***27***	16	4	11
11	2	4	8	***28***	2	1	8
12	4	4	8	***29***	2	4	8
13	6	4	8	***30***	2	7	8
14	8	4	8	***31***	12	1	8
15	10	4	8	***32***	12	4	8
16	12	4	8	***33***	12	7	8
17	14	4	8				

Table 1: The environmental parameters used on growler, small, medium, and large icebergs.

Analysis

By using pre-selected environmental data, a parametric study was conducted to compare the melt estimates of the WIM of BAPSNT 1.4 with the estimates of the WIM of BAPSNT 1.7. Environmental parameters (SST, wave height, and wave period) were used to test the algorithm of these models. Three modeling series were conducted, each consisting of two constant and one varied parameter (Table 1). This approach not only allowed simple comparison of melt rates but also parameter sensitivity. The selection of metric and non-metric units is a function of the parameter files. For the purpose of BAPS calculations, SST is given in Celsius, wave height in feet, and wave period in seconds.

The first series of runs modeled the effect of SST on deterioration, while holding wave height and wave period constant. It was found that 1.4 and 1.7 melt linearly and at the same rate. This result is depicted in Figure 1. The 1.4 and 1.7 results for the growler melt were not exactly the same due to an unaccounted-for variation in starting-length parameter between the models, which is discussed below.

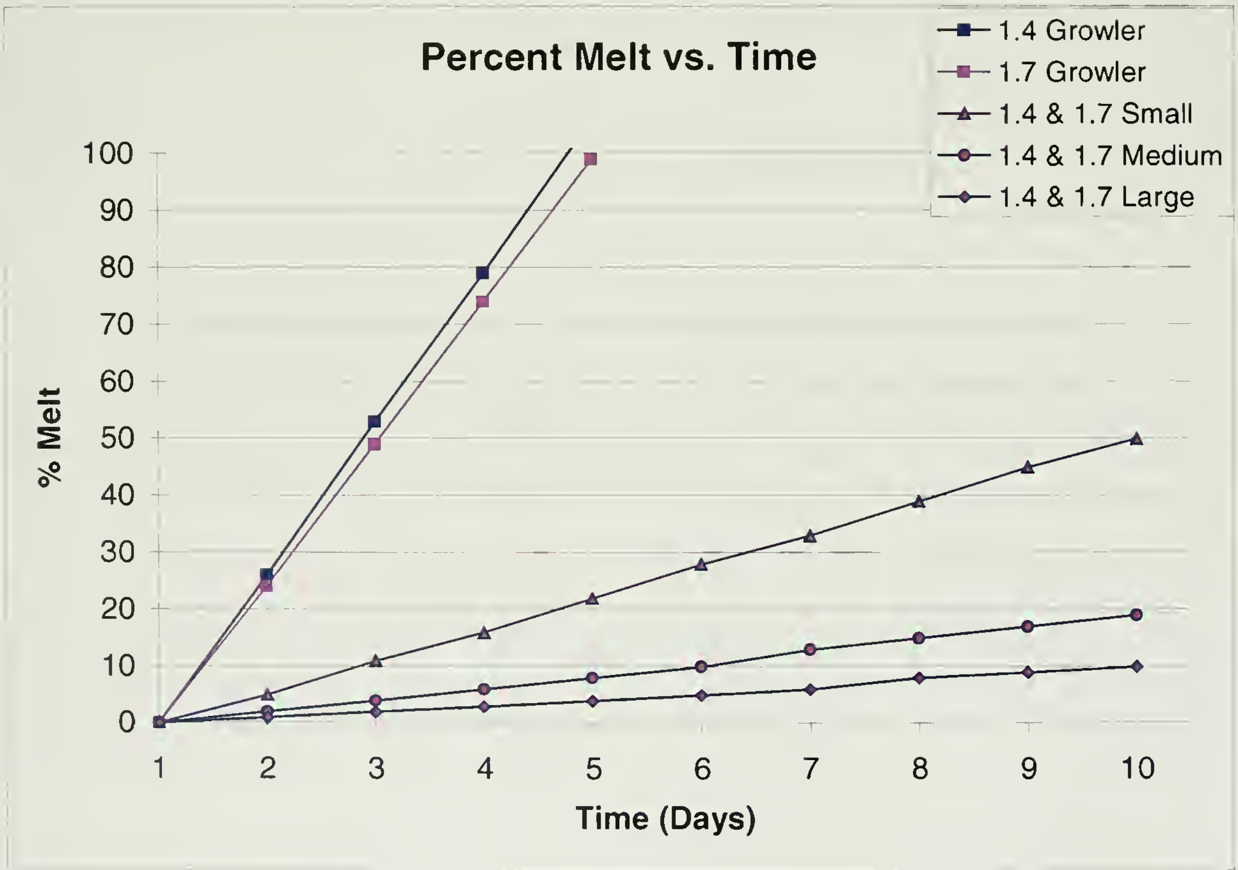

Figure 1: The percent melt for each iceberg for both WIM's during the first 10 days of the run. This run was conducted at an SST of 12°C, wave height of 4ft, and wave period of 8 seconds. The small, medium, and large icebergs produced similar results.

The second series of runs modeled the effect of wave period on deterioration, while holding SST and wave height constant. The 1.4 and 1.7 WIMs melted linearly and at the same rate, much the same as the previous series. These runs also allowed the evaluation of the algorithm's sensitivity to changes in wave period. When comparing sensitivity within the model, there was around a 36% increase in the melt rate when the wave period was decreased from the mean of 8 seconds to 5 seconds. There was a 20-30% decrease in melt rate when the wave period was increased to 11 seconds. An example of the results due to decreasing wave period can be observed through comparison of the slope of all the lines in Figure 1 and 2. In both models, it appears that a larger change in deterioration occurs when the period is increased by 3 seconds rather than when decreased by 3 seconds. This result is intuitive since an increase in the frequency that an iceberg is bathed by relatively warm water and impacted by wave energy would increase deterioration and vice versa for a decrease in the frequency.

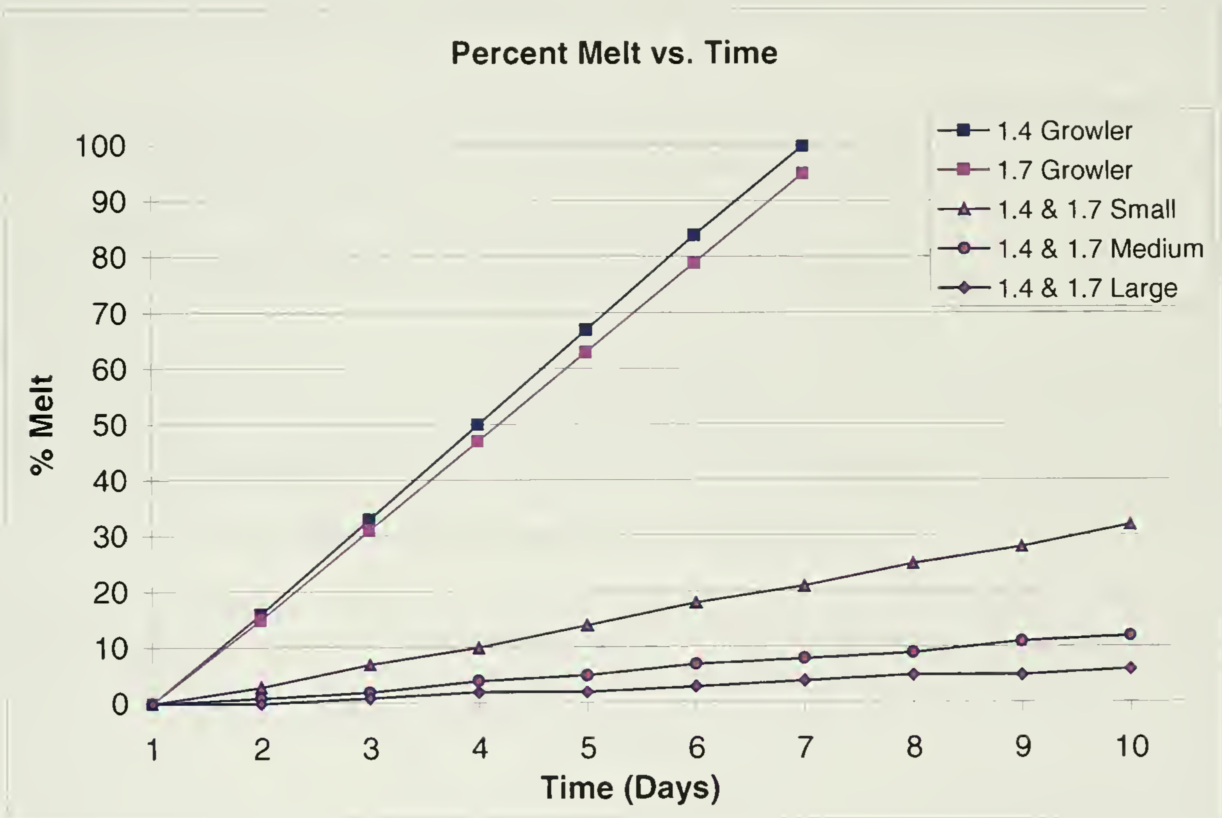

Figure 2: The percent melt for each iceberg for both WIM's during the first 10 days of the run. This run was conducted at an SST of 12°C, wave height of 4ft, and wave period of 11 seconds. The small, medium, and large icebergs produced similar results.

The last series of runs modeled the effect of wave height on deterioration while holding SST and wave period constant. As with the previous runs, the 1.4 and 1.7 models melted linearly and at the same rate. Sensitivity to changes in wave height were observed by a 33-36% increase in melt rate when the wave height was increased to 7 ft and a 63-70% decrease when wave height was decreased to 1 ft, by noting the increased slope. The effect of increasing wave height can be observed in Figure 3. It appears that when varying wave period, a much larger change is seen than when wave height is increased.

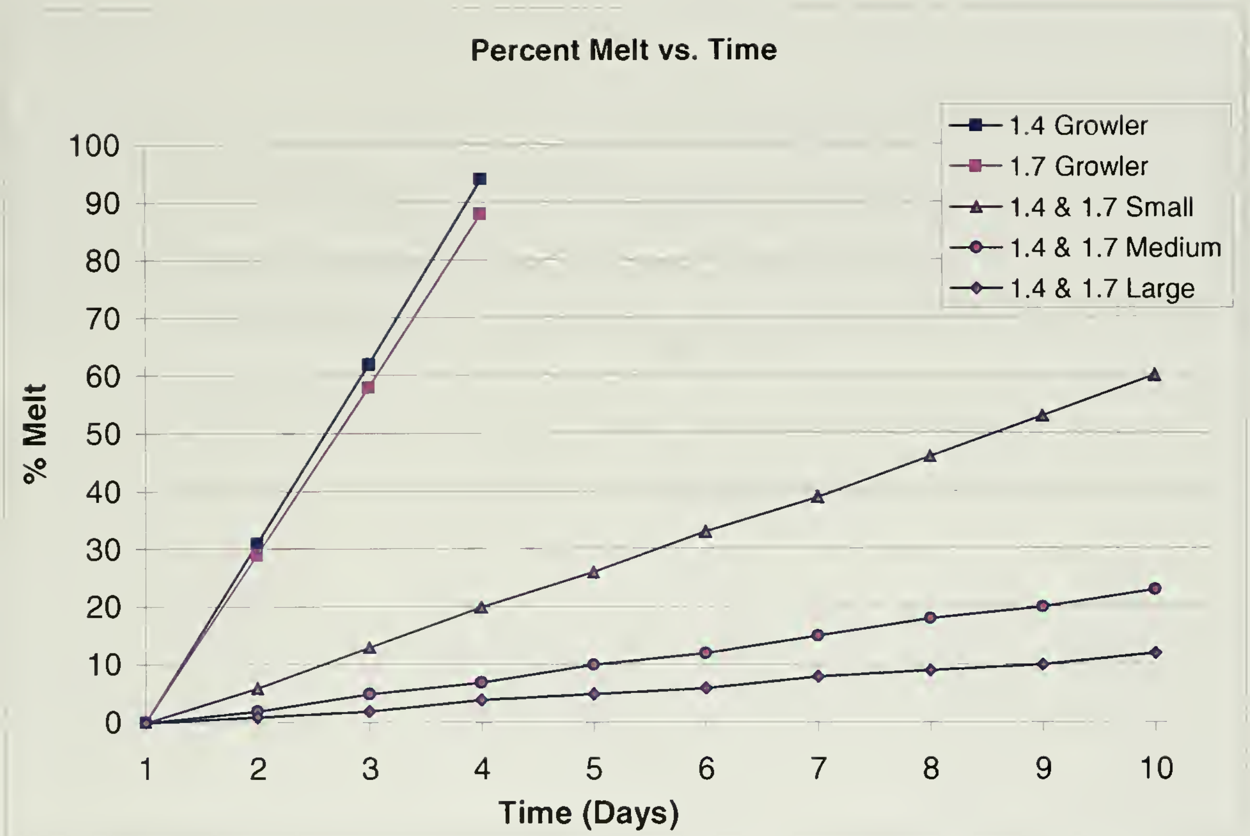

Figure 3: The percent melt for each iceberg for both WIM's during the first 10 days of the run. This run was conducted at an SST of 12°C, wave height of 7ft, and wave period of 8 seconds. The small, medium, and large icebergs produced similar results.

A comparison of computations, using the original algorithm set forth in Anderson (1983) and comparing it with the WIM 1.7 outputs, was made to examine how closely the models are running with the original algorithms. The tabulated numbers from Anderson (1983) were used to make this comparison. Also, another comparison was done using the parameters of this study and calculating the results with the original algorithms. In both comparisons, it was found that the models are running in accordance with the algorithm, since both methods produced the same results within rounding error.

Conclusion

In conclusion, this study shows that the WIM of BAPSNT 1.4 and the WIM of BAPSNT 1.7 compute identical melt estimates. Some differences between the models were found that have not been documented. The documentation for the WIM of BAPSNT 1.7 states that the input files are the same as 1.4, when in fact they are not. BAPSNT 1.4 requires a new length and percent melt to be included in the input file to continue melting an iceberg after ten days. The parameter file for 1.7 is different and treats the remaining length field as original length and calculates a new starting length using percent melt and original length. It is recommended that this change be noted in the documentation of BAPSNT 1.7. Another slight variation that should be noted is that while we tried to use 7.5m as the original length for growler, BAPSNT 1.7 rounded this length up to 8m, which had an effect on the output files. BAPSNT 1.4 did not do this, and so it is recommended that this change also be noted in the documentation for BAPSNT 1.7. Finally, with these differences noted, it is recommended that a switch to BAPSNT 1.7 be made for operational use.

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