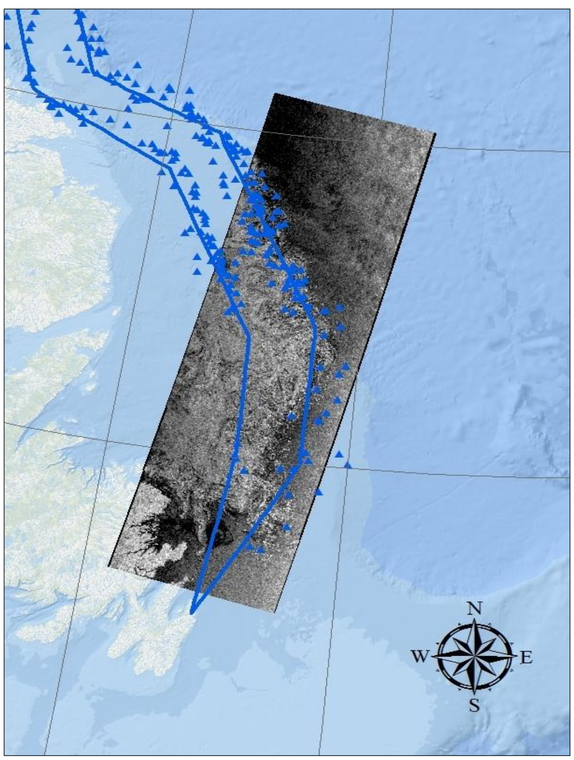
Homeland Security

United States Coast Guard

Report of the International Ice Patrol in the North Atlantic



2016 Season
Bulletin No. 102
CG-188-70

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Report of the International Ice Patrol in the North Atlantic
Season of 2016
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Forwarded herewith is Bulletin No. 102 of the International Ice Patrol (IIP) describing the Patrol's services and ice conditions during the 2016 season. With 687 icebergs drifting into the transatlantic shipping lanes, 2016 was the 36th most severe Ice Season on record dating back to 1900. For the third year in a row, ice conditions in the North Atlantic resulted in an extreme Ice Year. Although the number of icebergs in the shipping lanes was considerably less this year than in 2014 and 2015, the iceberg distribution was similar to the distribution in 2015 with expansive limits to the south and east. The Ice and Environmental Conditions section presents a discussion of the meteorological and oceanographic conditions that created this extreme season.

In October 2015, IIP shifted its organizational structure within the Coast Guard from the First Coast Guard District to the Coast Guard Marine Transportation Systems (CG-5PW) at Coast Guard Headquarters. CG-5PW was historically IIP's Program Office. This shift aligned IIP's chain of command with this office.

IIP made significant improvements to its iceberg warning products this season. These changes provided mariners with information on the most recent reconnaissance conducted and added an estimated Iceberg Limit around the southern and southeastern coast of Greenland. The Operations Center Summary of this report provides a complete description of these improvements.

In 2016, IIP completed an operational evaluation of the North American Ice Service (NAIS) iceberg drift and deterioration model. IIP currently uses the IIP iceberg drift and deterioration model operationally. The goal of this evaluation was to determine which model more accurately predicts iceberg melt and movement. Described in detail in Appendix B, this evaluation recommended key areas for NAIS model improvements and concluded that both should be used to maximize each model's strengths in order to improve the accuracy of IIP's iceberg warning products.

IIP began its transition to operational implementation of commercial synthetic aperture radar satellite reconnaissance for iceberg detection and identification. IIP published its Satellite Reconnaissance Concept of Operations (CONOPS) in February of 2016. Planned for full implementation in 2017, this plan uses a tiered, risk-based approach for the inclusion of satellite data in IIP products. In the fall of 2016, IIP procured, installed, and received training on Iceberg Detection Software, a computer algorithm that is used to analyze satellite imagery for iceberg detections. Included as Appendix C, the CONOPS describes how IIP will acquire satellite imagery data at no cost and how the results of the imagery analysis will be used operationally. IIP also prepared a Report to Congress on the state of satellite reconnaissance technology signed by the Commandant of the U.S. Coast Guard. The cover of this year's report represents IIP's transition to satellite reconnaissance.

In recognition of our Public Affairs initiatives highlighted in the 2015 Annual Report, IIP was selected as the winner of the 2015 CDR Jim Simpson Award for Outstanding Unit Achievement in Coast Guard Public Affairs. IIP continued this commitment to telling the Ice Patrol Story in 2016 by hosting several international and national production companies and media outlets, including Along Mekong Productions of Germany, Monocle Magazine of the United Kingdom, and the Travel Channel's Mysteries at the Museum from the U.S.

IIP continued its pursuit to become a world leader in ice hazard monitoring, modeling, and charting in 2016. IIP led an Iceberg Subcommittee of the International Ice Charting Working Group (IICWG) to share best practices on monitoring, modeling, and charting and to standardize iceberg terminology and symbology globally. IIP also directed efforts to prepare the national ice services within IICWG for how ice information would be used in the event of an emergency response in ice-infested waters. IIP prepared an International Ice Services Contact List and verified this list with an unannounced notification exercise in February 2016. This event was followed by an Emergency Response Tabletop Exercise conducted at the seventeenth meeting of the IICWG in Ottawa in October 2016. Both of these initiatives significantly improved the preparedness of the national ice services for an emergency response. In December 2016, on behalf of the IICWG Co-Chairs, I briefed the Emergency Prevention, Preparedness, and Response Working Group of the Arctic Council on these efforts and coordinated collaboration between the two groups.

On behalf of the dedicated men and women of IIP, I hope that you enjoy reading this report on the 2016 season.

Gabrielle G. McGrath CDR

G. G. McGrath
Commander, U. S. Coast Guard
Commander, International Ice Patrol

International Ice Patrol

2016 Annual Report

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Previous IIP Annual Reports may be obtained from the following sources:

- IIP website: http://www.navcen.uscg.gov/?pageName=IIPAnnualReports
- Printed and bound Annual Reports (1963 – 2015) can be ordered from the National Technical Information Service (NTIS) website at http://www.ntis.gov.

Cover art: Collage representing International Ice Patrol's 2016 Satellite Integration

Abbreviations and Acronyms

AIS	Automatic Identification System
AMS	Aviation Mission Specialist
AOI	Areas of Interest
APN-241	HC-130J Tactical Transport Weather Radar
Argos	A worldwide satellite-based system used to collect Doppler-based position data from a special transmitter built into drifting buoys.
ASEC	U. S. Coast Guard Air Station Elizabeth City
AVHRR	Advanced Very High Resolution Radiometer
BAPS	iceBerg Analysis and Prediction System
cm	centimeter
CG-5PW	U. S. Coast Guard Director of Marine Transportation Systems
CCG	Canadian Coast Guard
C-CORE	Center for Cold Ocean Resources Engineering, St. John’s, Newfoundland
CIIP	Commander, International Ice Patrol
CIS	Canadian Ice Service, an operational unit of the Meteorological Service of Canada
COMSAR	Commercial Synthetic Aperture Radar
CONOPS	Concept of Operations
DHS	Department of Homeland Security
DMI	Danish Meteorological Institute
DND	Department of National Defense, Canada
DWO	Duty Watch Officer
DWS	Duty Watch Stander
ELTA	ELTA Systems Ltd., a group and a wholly-owned subsidiary of IAI (Israel Aerospace Industries) specifically referring to the ELM-2022A Airborne Maritime Surveillance Radar aboard the HC-130J
EMOC	Canadian Enhanced Marine Ordering Coordination
EOIR	Electro-Optic Infrared
ERMA	Environmental Response Management Application, NOAA
ESA	European Space Agency, owner of the Sentinel-1a satellite
ESRL	Earth Systems Research Laboratory, Boulder, Colorado
FNMOC	U.S. Navy Fleet Numerical Meteorology and Oceanographic Center
FTP	File Transfer Protocol

GHz	Gigahertz
HC-130J	U. S. Coast Guard Long Range Surveillance Maritime Patrol Aircraft
ICC	U. S. Coast Guard Intelligence Coordination Center
ICC GEOINT	U. S. Coast Guard Intelligence Coordination Center Geospatial Intelligence
IDS	Iceberg Detection Software
IICWG	International Ice Charting Working Group
IIP	U. S. Coast Guard International Ice Patrol
IRD	Ice Reconnaissance Detachment
ISAR	Inverse Synthetic Aperture Radar
IWS	Interferometric Wide Swath
KML	Keyhole Markup Language
KIAS	Knots Indicated Airspeed
kts	knots
M/V	Motor Vessel
MANICE	Manual of Standard Procedures for Observing and Reporting Ice Conditions
m	meter
mb	millibar
MCTS	Marine Communications and Traffic Service, Canadian Coast Guard
MDA	MacDonald, Dettwiler and Associates, owner of the RADARSAT-2 satellite
MIFC LANT	U. S. Coast Guard Maritime Intelligence Fusion Center Atlantic Area
MPA	Maritime Patrol Aircraft
NAIS	North American Ice Service
NAO	North Atlantic Oscillation
NAOI	North Atlantic Oscillation Index
NAVAREA	Navigational Area
NAVTEX	Navigational Telex
NGA	U. S. National Geospatial-Intelligence Agency
NIC	U. S. National/Naval Ice Center
NL	Newfoundland and Labrador, Canada
NM	Nautical Mile
NOAA	National Oceanographic and Atmospheric Administration
NOTSHIP	Notice to Shipping
NS	Nova Scotia, Canada

NTIS	National Technical Information Service
NWS	National Weather Service
OFA	U.S. Naval Oceanographic Office Ocean Features Analysis
ONI	Oceanic Niño Index
OPAREA	Operational Area
OPCEN	Operations Center
P/V	Passenger Vessel
PAL Aerospace	Commercial aerial reconnaissance provider based in St. John’s, Newfoundland.
POD	Probability of Detection
RADARSAT-2	Canadian C-Band SAR satellite system, owned and operated by MacDonald, Dettwiler, and Associates.
RCM	RADARSAT Constellation Mission
RMS	Royal Mail Steamer
R/T	Radar Target
SafetyNET	Inmarsat-C Safety Net, automated satellite system for promulgating marine navigational warnings, weather, and other safety information.
SAIC	Science Application International Corporation
SAR	Synthetic Aperture Radar
Sentinel-1a	ESA C-Band SAR satellite system
SLAR	Side Looking Airborne Radar
SITOR	Simplex Teletype Over Radio
SOLAS	Safety of Life at Sea
SOP	Standard Operating Procedures
SST	Sea Surface Temperature
SVP	Surface Velocity Program
TCPED	Tasking, Collection, Exploitation, and Dissemination
TerraSAR-X	German X-Band SAR satellite system
USCG	U. S. Coast Guard

Introduction

This is the 102nd annual report of the International Ice Patrol (IIP) describing the 2016 Ice Season, currently the thirty-sixth most severe ice season on record since 1900. It contains information on IIP operations and environmental and iceberg conditions in the North Atlantic for the 2016 season. The IIP deployed Ice Reconnaissance Detachments (IRD) to conduct aerial reconnaissance in search of icebergs in the North Atlantic and Labrador Sea, primarily operating from St. John's, Newfoundland using HC-130J aircraft from U.S. Coast Guard (USCG) Air Station Elizabeth City (ASEC). In addition to this reconnaissance data, IIP received iceberg reports from other sources, including aircraft and mariners in the North Atlantic. The IIP personnel analyzed iceberg and environmental data using the iceberg drift and deterioration model within the iceBerg Analysis and Prediction System (BAPS) at the IIP Operations Center (OPCEN) in New London, Connecticut. In accordance with the North American Ice Service (NAIS) Collaborative Arrangement, IIP used BAPS to produce an iceberg chart and a text bulletin created from the predicted drift and deterioration model output. These iceberg warning products were then distributed by multiple means to the maritime community. The IIP responded to individual requests for iceberg information in addition to these routine broadcasts.

The IIP was formed after the Royal Mail Steamer (RMS) TITANIC sank on 15 April 1912. Ever since 1913, with the exception of periods of World War, IIP monitored the iceberg danger in the North Atlantic and broadcast iceberg warnings to the maritime community. The IIP activities and responsibilities are delineated in U.S. Code, Title 46, Section 80302 and the International Convention for the Safety of Life at Sea (SOLAS), 1974.

For the 2016 Ice Year, IIP was under the operational control of the USCG Director of Marine Transportation Systems (CG-5PW). Mr. Gary C. Rasicot was Director until 12 February. Captain David C. Barata was Acting Director of CG-5PW from 12 February until 03 September, and Mr. Michael D. Emerson was Director from 04-30 September. Commander Gabrielle G. McGrath was Commander, IIP (CIIP).

For more information about IIP, including historical and current iceberg bulletins and charts, visit our website at www.navcen.uscg.gov/IIP.

Ice and Environmental Conditions

Ice Year Summary

The 2016 Ice Year was classified as 'extreme' based on the number of icebergs crossing south of 48°N, considered the northern boundary of the transatlantic shipping lanes. (IIP, 1994) The 2016 Ice Year is currently ranked as the 36th most severe season on record dating back to 1900 based on this measurement. By definition, the "Ice Year" spans the time period between 01 October of the previous year and 30 September of the current year.

Season Severity: Icebergs South of 48°N

The number of icebergs south of 48°N provides a count of icebergs initially sighted or detected south of 48°N as well as those originally sighted or detected further north and drifted south, as modeled by BAPS. IIP uses this latitude because the great circle route between the English Channel and New York intersects Flemish Pass at 48°N. The main branch of the Labrador Current flows southward through Flemish Pass and is responsible for transporting icebergs into the transatlantic shipping lanes.

During the 2016 Ice Year, 687 icebergs (not including bergy bits or growlers) crossed south of 48°N. By the convention defined in the IIP 1994 Annual Report, an Ice Year is classified as 'extreme' if the number of icebergs south of 48°N exceeds 600. (IIP, 1994) The number of icebergs south of 48°N has been highly variable throughout history. The average number of icebergs south of 48°N from 1900-2015 is 486.

IIP began using this latitude as a season severity measure in 1926 following a study by IIP's oceanographer, Rear Admiral Edward "Iceberg" Smith. Smith recorded this measure for the years from 1900 through 1926 in the IIP 1926 Annual Report. (IIP, 1926) **Figure 1** shows the historical variability for this measurement from 1900 to 2016 (blue columns) along with the five-year running average (red line). Variations arise both due to actual changes in season severity and as a result of modifications to sighting methods. For example, in 1983, IIP began using Side-Looking Airborne Radar (SLAR) for the first time on the USCG HC-130H aircraft. The introduction of this new sensor likely resulted in an increase in the total number of icebergs sighted during this and subsequent years.

For this reason, IIP considers 1983 as the beginning of the modern aerial reconnaissance era when the use of aircraft equipped with sophisticated radar systems like SLAR and today's ELTA radar became standard. During the modern aerial reconnaissance era, the average number of icebergs south of 48°N is 787. Though still classified as 'extreme', the 2016 Ice Year had 100 fewer icebergs than the average for the modern aerial reconnaissance era.

Season Severity: Ice Season Length

Another factor tracked by IIP that contributes to the iceberg hazard posed to shipping is the Ice Season length. Ice Season length is defined as the number of days icebergs were present south of 48°N. Icebergs south of this latitude represent a particularly hazardous situation for transatlantic shipping. In 2016, icebergs were present south of 48°N from 09 January through 07 August for a total of 212 days.

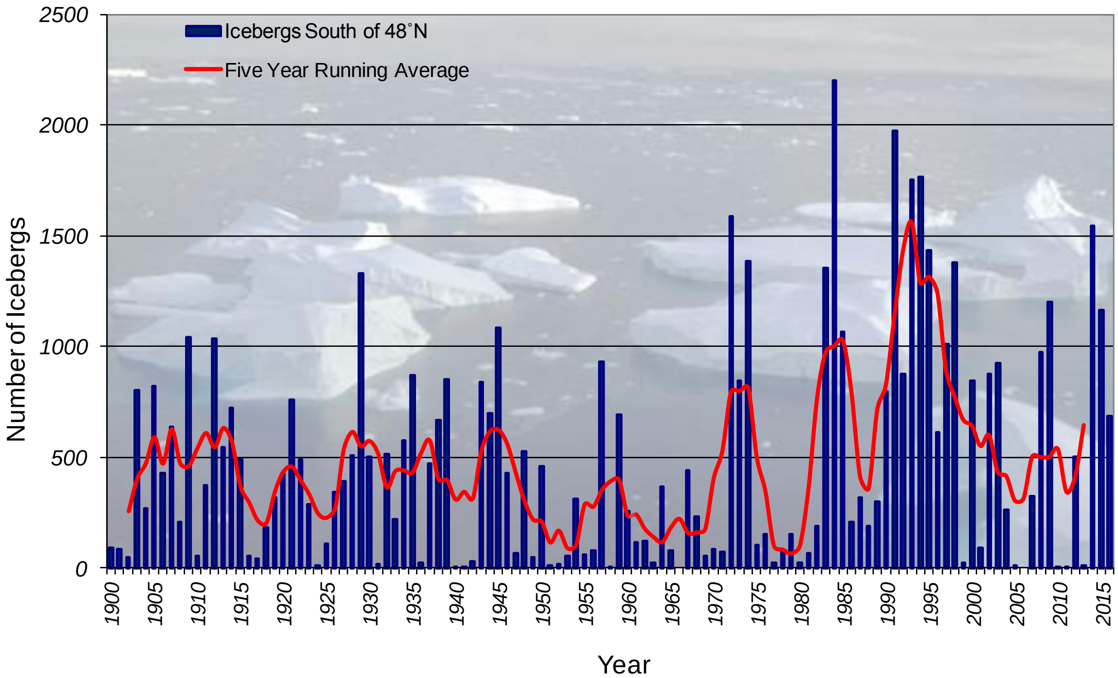


Figure 1. Icebergs Crossing South of 48°N and Five-Year Running Average (1900-2016).

IIP adopted this definition for Ice Season length in 2011 to coincide with the first year that IIP and the Canadian Ice Service (CIS) began issuing daily iceberg warning products 365 days per year. An earlier definition, used prior to 2010, tracked the number of days that IIP issued daily products at the discretion of CIIP.

Figure 2 compares the Ice Season length for two periods during the modern aerial reconnaissance era corresponding to the years that IIP used these two definitions. The blue columns represent the number of days that IIP created and disseminated daily products from 1983-2010. The average for 1983-2010 is 126 days. It is important to note that, while loosely tied to the number of iceberg hazards south of 48°N, this metric was subject to the philosophy of the CIIP leading IIP at the time. The red columns reflect the number of days that icebergs were present south of 48°N from 2011 to present. The average during this time period was 133 days. While only collected for a short, six-year time period, Ice Season length, as defined by the number of days icebergs were south of 48°N, was the highest on record in 2016 and far surpassed the average for both time periods. IIP will continue to track this objective measurement for future Ice Years. In short, icebergs began threatening the shipping lanes in early January and remained a hazard through the beginning of August. Dangerous iceberg conditions that persist for long periods of time both increase the risk for commercial shipping and demand extended reconnaissance efforts for IIP and the CIS.

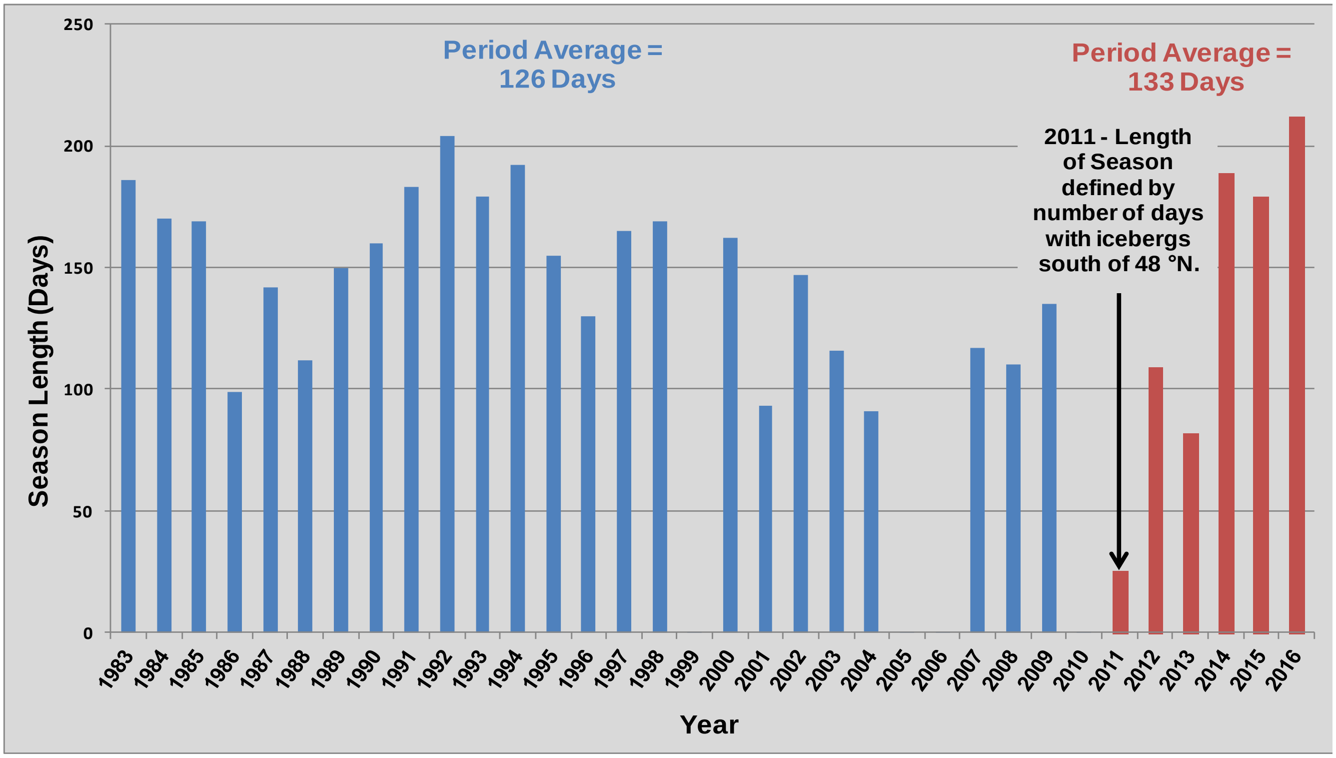


Figure 2. Length of Ice Season in Days from 1983-2016 Showing the Change in Season Length Definition in 2011. Blue columns are the number of days that daily iceberg warning products were released at CIIP discretion. Red columns are number of days when icebergs were south of 48°N.

Season Severity: Iceberg Distribution

The final factor contributing to the risk of iceberg collision in a given Ice Year is the iceberg distribution. Iceberg distribution in 2016 was similar to 2014 and 2015. In 2016, icebergs sighted over the northern part of Flemish Cap drifted eastward toward the North Atlantic Current. This situation both increased the hazard to transatlantic shipping and challenged IIP reconnaissance. Iceberg distribution, as defined by the area encompassed by the Iceberg Limit, will be discussed in greater detail in the Operations Center Summary section of this report.

The remainder of this section describes the environmental conditions in the waters off of Newfoundland and Labrador that led to the extreme iceberg conditions observed by IIP during the 2016 Ice Year. The inset map in **Figure 3** illustrates the IIP Operational Area (OPAREA) for aerial reconnaissance and iceberg warnings. The OPAREA pictured in **Figure 3** shows both the region in which IIP normally conducts its aerial reconnaissance (within the dashed line) and the area for which NAIS Iceberg Limit Warnings are issued (shaded in green). The region in green, outside of the IIP reconnaissance area, reflects the 2016 chart improvement for including an Estimated Iceberg Limit around Greenland. The 2016 Product Improvements will be further discussed in the next section, Operations Center Summary. The final section of this report will be a discussion on Ice Reconnaissance and Oceanographic Operations.

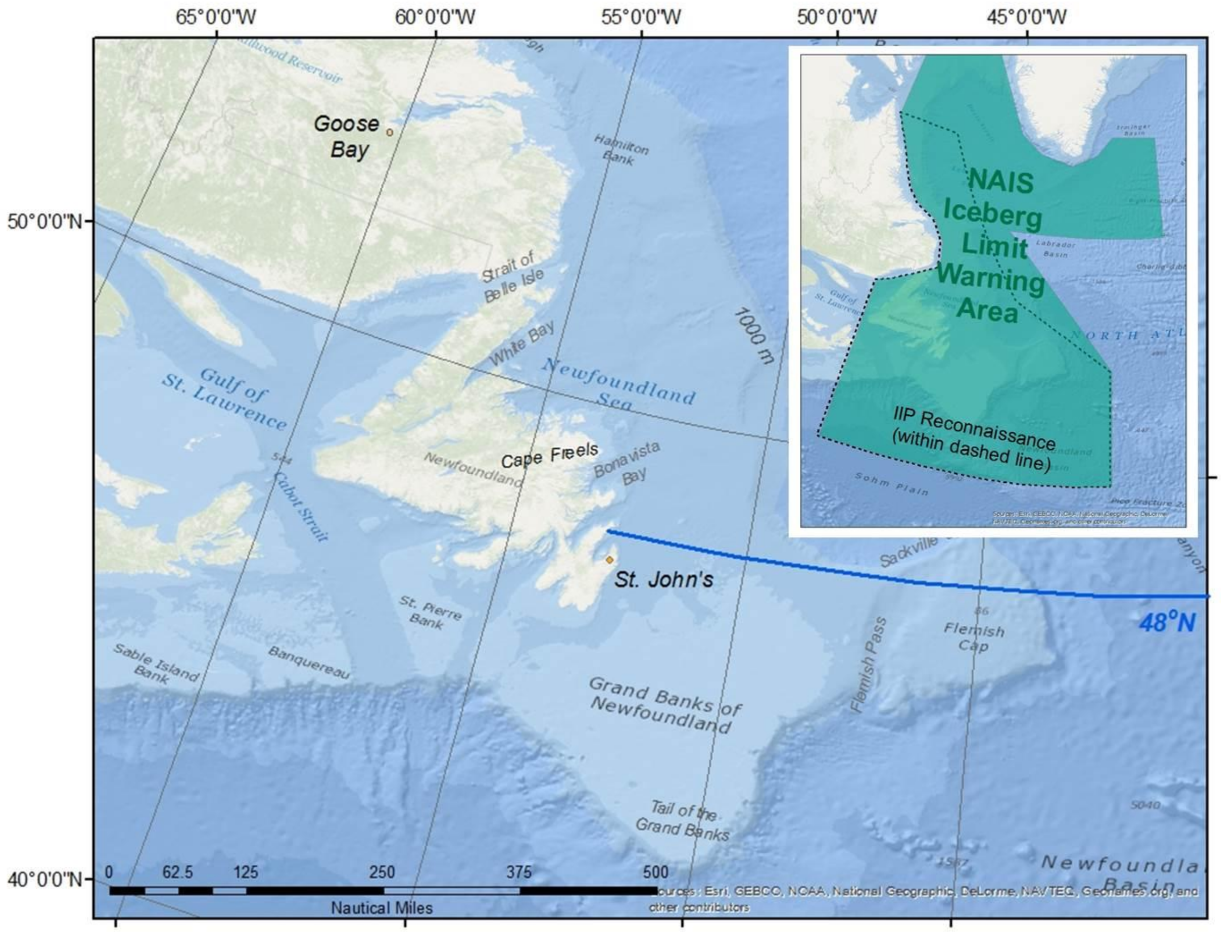


Figure 3. International Ice Patrol Operational Area (OPAREA). The region shaded in green represents the NAIS Iceberg Limit Warning Area. The region within the dashed line is the IIP iceberg reconnaissance area. The latitude of 48°N is typically considered the northern boundary of the transatlantic shipping lanes. IIP measures season severity based on this line.

Pre–Season Predictions

CIS issued a Seasonal Outlook for Winter 2015-2016 on 01 December 2015 based on analog years with similar atmospheric and sea surface temperature conditions. (CIS, 2015a) Of note, CIS incorporated the fact that the 2016 Ice Year was an El Niño year and provided expected sea-ice coverage for December through March for the Gulf of St. Lawrence, East Newfoundland Waters, and the Labrador Coast based on similar El Niño years dating back to 1968. El Niño impacts Canadian weather by promoting milder temperatures, particularly in western Canada, due to a northward shift of the jet stream as compared to non-El Niño years. (Environment and Climate Change Canada, 2016) The impact of the El Niño event on the Ice Season will be discussed in more detail in the Atmospheric and Oceanographic Discussion section below.

Based on these analog years, average air temperatures were expected to be above normal over the East Newfoundland Waters and southern Labrador Coast and near normal along the northern Labrador Coast. Correspondingly, sea-ice coverage was expected to be below normal for southern Labrador and off the eastern shores of Newfoundland and near normal along the northern Labrador Coast. (CIS, 2015a)

Figure 4 shows the expected median sea-ice concentration for 19 February 2016 based on the analog El Niño years. The dashed line shows the approximate observed sea ice edge for that date. (CIS, 2016a) The southernmost and northernmost sea ice edge projections were remarkably close to the actual observation. The central portion of the sea ice edge (between 50°N and 55°N) was observed at approximately 45 Nautical Miles (NM) farther east from the forecast. This departure from expected conditions persisted throughout late March and is discussed further below.

Since sea-ice concentration is closely correlated to iceberg season severity, projecting these conditions during the late fall provided IIP with an early indicator for iceberg reconnaissance planning. At IIP's Annual Meeting in December 2015, a CIS analyst presented expected median sea-ice concentrations for

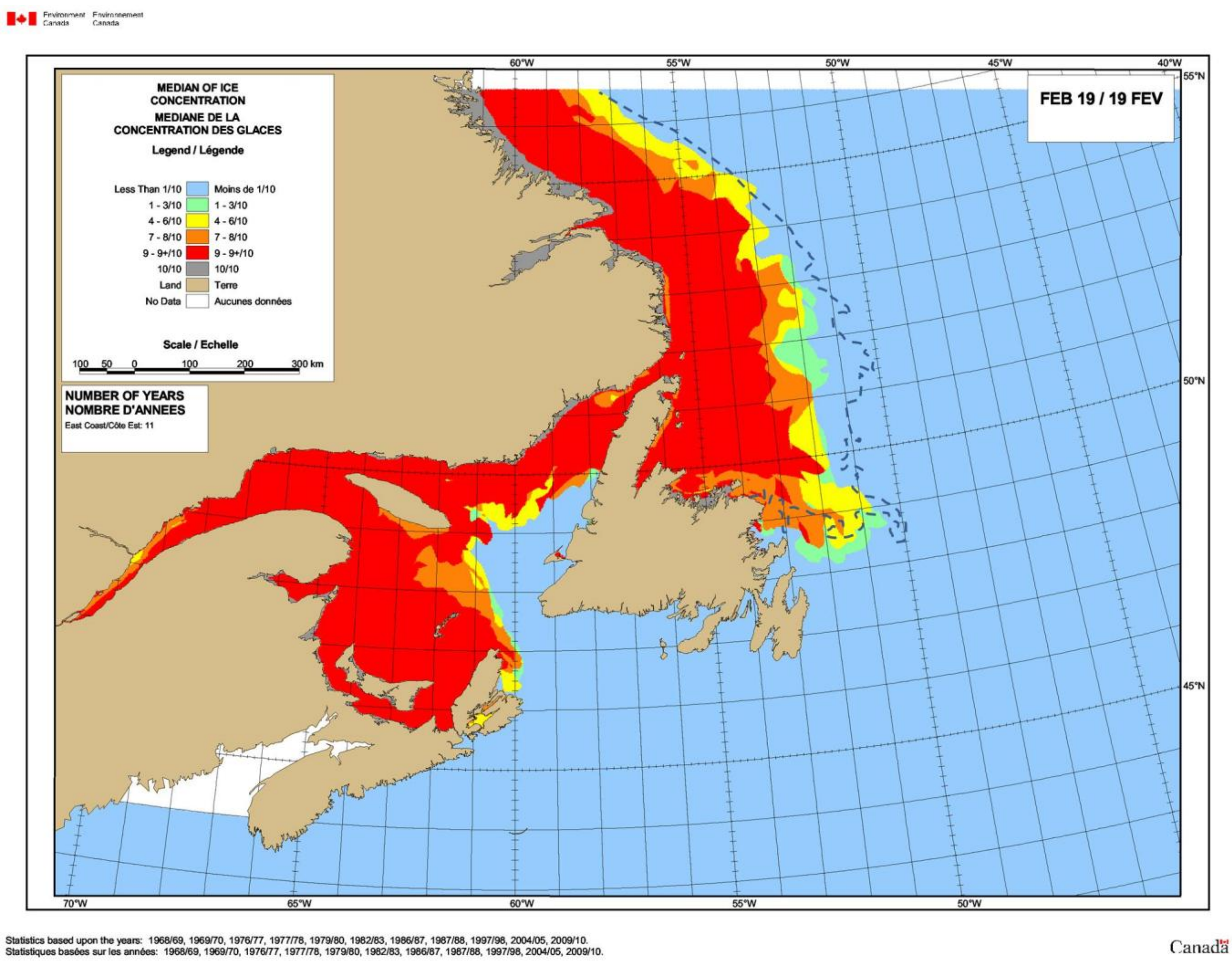


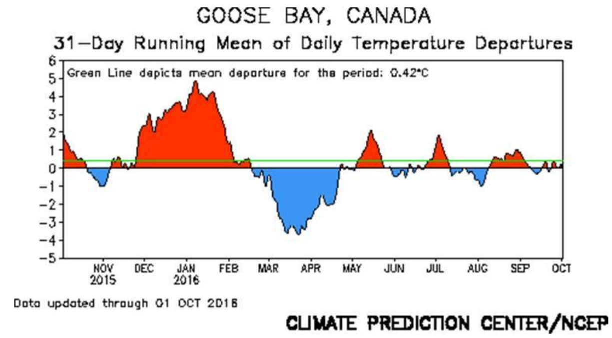
Figure 4. Median Sea-Ice Concentration for 19 February Based on Ten Analog El Niño Years: (69/70, 76/77, 77/78, 79/80, 82/83, 86/87, 87/88, 97/98, 04/05, 09/10). Dashed blue line depicts actual approximate location of the 1-3/10 ice edge on 19 February 2016. (CIS, 2016a)

mid-December through mid-March. (CIS, 2015b) The CIS analyst also provided an iceberg outlook for 2016 using monthly sea-ice outlooks along with the most recently observed iceberg conditions and mean sea-level pressure during analog years. (CIS, 2015b)

While sea-ice forecasts were normal to below normal, the CIS analyst noted that sea-ice conditions in Davis Strait were 1-2 weeks ahead of normal by late November. These conditions prompted a forecast for the sea ice edge and thus, the majority of icebergs, to arrive at 48°N by early March. At the time of the forecast, only seven icebergs were known to be present along the Labrador Coast up to 60°N. Expected prevailing wind patterns, based on sea-level pressure composites, favored sea-ice expansion and iceberg drift toward the offshore branch of the Labrador Current during December and January. However, expected conditions were opposite for February and March. It is instrumental to understand how the factors considered in the CIS projections impacted the 2016 Ice Year.

Quarterly Environmental Summaries

Observed conditions affecting sea-ice growth and iceberg distribution along with key reconnaissance results are summarized by quarter below. Variations of mean air temperatures, wind speeds, and wind directions over Newfoundland and Labrador during the months of December through March help to explain sea-ice development and expansion as the year progressed. **Figure 5** shows the daily air temperature departures from mean throughout the Ice Year at two key locations along the east coast of Canada: Goose Bay, Labrador (top panel) and St. John's, Newfoundland (bottom panel). (NOAA /NWS, 2016a)



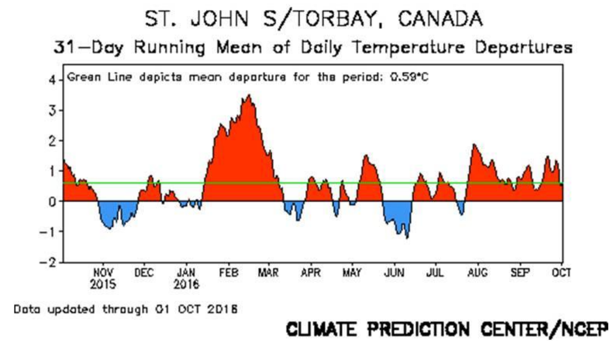


Figure 5. 31-Day Running Mean of Daily Temperature Departures for Goose Bay (top) and St. John's Newfoundland (bottom). (NOAA/NWS, 2016a)

As indicated by the horizontal green line in each graph in **Figure 5**, temperatures at these two locations were slightly above normal for the entire year with two significant warming periods for both locations during the end of 2015 and the first months of 2016. Goose Bay experienced a short-lived cold outbreak from mid-February through late-April. Air temperature fluctuations and their impact on sea ice and iceberg conditions are summarized by quarter below.

October – December 2015

For the start of the Ice Year (01 October 2015), CIS held the responsibility for creating and disseminating the daily NAIS iceberg products. At that time, the southern Iceberg Limit was just south of the Strait of Belle Isle and approximately 60 NM offshore. Two icebergs were in the Strait of Belle Isle with an additional 19 scattered within 100 NM of the Labrador coast up to 60°N. A single radar target, reported outside of the Iceberg Limit by M/V BALTIC FOX in September 2015, remained on the chart and well outside of the published Iceberg Limit to open the Ice Year. (IIP, 2015)

Sea ice began forming in Lake Melville in mid-November. Ice continued to grow across Lake Melville and along the southern coast of Labrador throughout the remainder of November. In early December, sea ice appeared in the bays in the northern part of Newfoundland. By the end of December, sea ice advanced to 60 NM off of the southern Labrador coast and into the Strait of Belle Isle. (CIS, 2016a)

From October through December, PAL Aerospace reported iceberg observations from 10 sorties in support of CIS and other Canadian Government interests. These flights were generally focused south of 54°N and near the Newfoundland and Labrador coasts. PAL Aerospace reported a total of 11 icebergs during this period. Notably, on two occasions in November, PAL Aerospace observed icebergs outside of the published Iceberg Limit. Further details on these sightings are provided in the Operations Center Summary.

To complement PAL Aerospace reconnaissance, CIS collected RADARSAT-2 imagery on 11 different dates during this quarter that were all north of the PAL Aerospace sortie areas along the Labrador coast. CIS acquired these images using ScanSAR Narrow mode (40 m resolution, 300 km swath size) and Wide mode (25 m resolution, 150 km swath size). Through CIS satellite imagery analysis, a total of 26 targets were incorporated into the daily Iceberg Limit Warning product. In addition, IIP acquired RADARSAT-2 Extra Fine imagery (8 m resolution, 125 km swath size) on 26 December that was analyzed through the use of a MacDonald, Dettwiler and Associates (MDA) ship detection algorithm. From this process, IIP identified three radar targets for inclusion into the Iceberg Limit product. The use of satellite imagery in this region is consistent with IIP's commercial synthetic aperture radar (SAR) satellite reconnaissance concept of operations (CONOPS) that is included as **Appendix C** to this report.

During this period, two vessels reported icebergs outside of the published Iceberg Limit. One was reported less than 10 NM south of the southern limit at 51°53′N near the approach to the Strait of Belle Isle in November, and a second was reported approximately 250 NM south of Cape Farewell, Greenland and nearly 500 NM east of the published Iceberg Limit in December. These reports are discussed in greater detail in the Operations Center Summary of this report.

By the end of December, the Iceberg Limit expanded southward to 50°N due to the drift of a single iceberg. Eight additional icebergs were scattered along the Labrador coast up to 59°N.

January – March 2016

The warm air temperature anomaly observed in Goose Bay throughout December reached a peak of nearly 5°C above normal in early January (**Figure 5**). Throughout the remainder of January and into February, mean air temperatures steadily declined to near normal as the axis of the jet stream shifted southward. A similar warm air temperature anomaly appeared in St. John's from mid-January through mid-March. As seen in **Figure 5**, a dramatic air temperature reversal over Goose Bay occurred in mid-February. Mean air temperatures fell to almost 4°C below normal and remained below normal until late-April. This cold outbreak did not occur over St. John's since the main axis of the jet stream (and storm track) remained over Newfoundland throughout the period. The Ice Reconnaissance and Oceanographic Operations section discusses how this atmospheric pattern impacted IIP operations.

The cold outbreak in southern Labrador, coupled with persistent offshore winds in February, promoted near-normal sea-ice growth throughout the period in southern Labrador. Sea-ice development off of Newfoundland proceeded more slowly but exceeded median coverage during the last three weeks of March. Sea ice reached its southernmost extent of the year on 29 March when a small patch of first-year ice (thickness greater than 30 cm) drifted to near 46°30′N. While sea-ice growth was near-normal in terms of coverage, the warm anomalies experienced during January and February affected ice thickness, particularly south of 50°N. **Figure 6** compares sea-ice coverage and stage of development for 29 March (left) with the same date in 2015 (right). Although sea-ice extent was similar in both years, slow ice development in 2016 left the sea ice thinner and more vulnerable to severe storms, ultimately hastening its retreat at the end of March. **Figure 6** shows that the sea-ice stage of development for 2016 was dominated by grey and grey-white ice (thickness less than 30 cm), shown as shades of purple. In

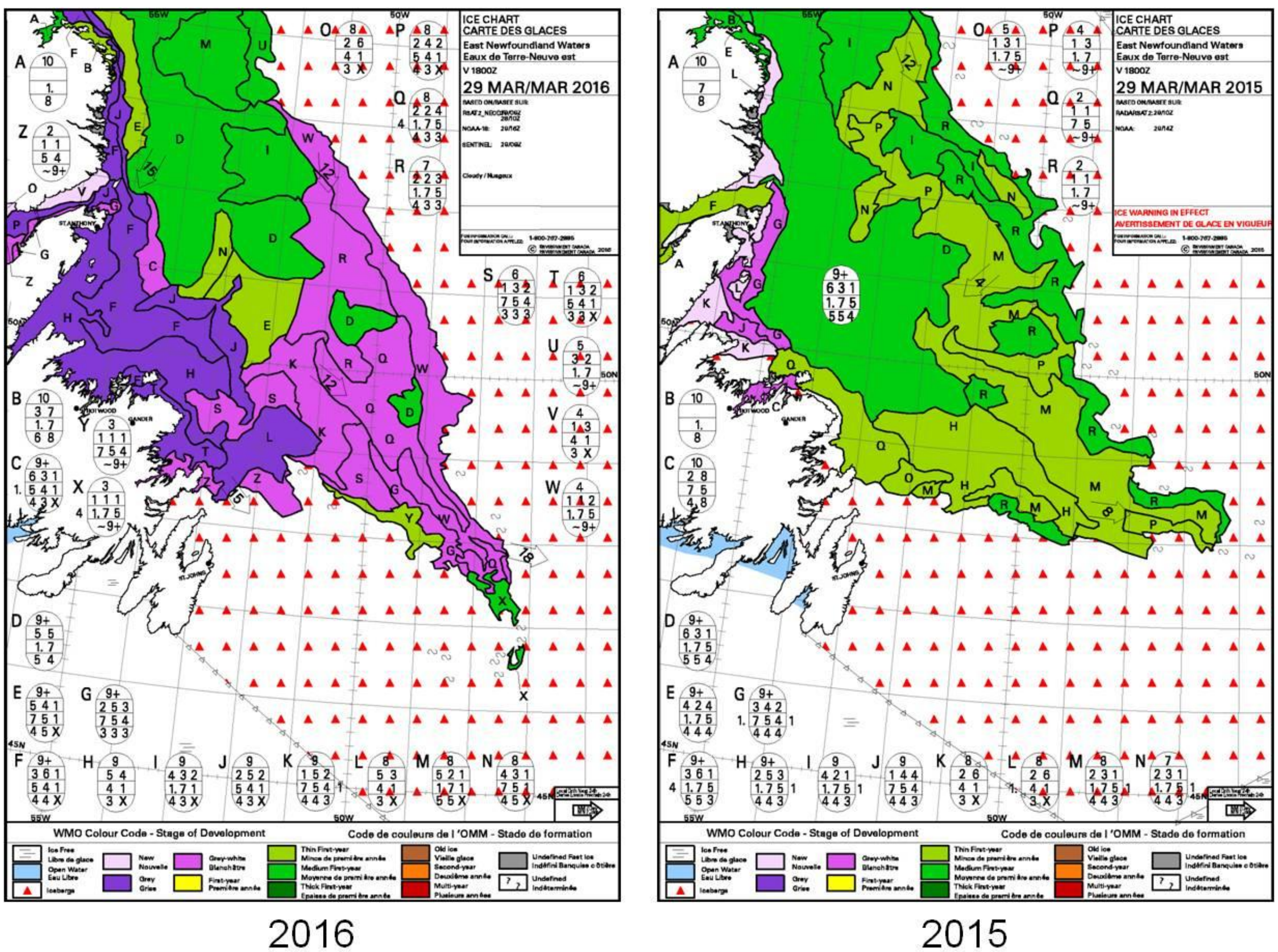


Figure 6. CIS Stage of Development for 29 March 2016 (left) and 29 March 2015 (right). (CIS, 2016b)

contrast, in 2015, thin and medium first-year ice (thickness greater than 30 cm) was most prevalent over a similar area and is shown as shades of green. The predominance of grey and grey-white ice in 2016 resulted in a rapid decline in sea-ice coverage, particularly south of 50°N by the end of March.

After eight flights in support of the Canadian government that located a few icebergs off of the Newfoundland coast, PAL Aerospace conducted their first two 1000 m depth contour ice flights in support of industry and CIS on 09 and 11 January, respectively. These flights patrolled through Flemish Pass and over the oil facilities on the Grand Banks. The patrols located a single iceberg approximately 60 NM southeast of St. John’s on the Grand Banks. Additional flights later in the month detected small groupings of icebergs (approximately 20) along the southern Labrador coast and near the entrance of the Strait of Belle Isle. In January, a total of four icebergs were sighted or drifted south of 48°N.

On 17 January, an offshore supply vessel, M/V ATLANTIC KESTREL, reported an iceberg approximately 125 NM southeast of St. John’s that established the Southern and Eastern Iceberg Limit into early February. Warm air temperatures and onshore winds during the second two weeks in January slowed sea-ice growth. With a forecast for these conditions to continue through early February, CIIP decided to cancel the first IRD scheduled to deploy during the first week of February. Through coordination of NAIS reconnaissance between CIIP and the CIS Director, PAL Aerospace flew additional patrols for CIS during the first half of February to assess the iceberg threat on the Grand Banks and in Flemish Pass. These flights revealed that there was not a significant popluation of icebergs south of 48°N. Gaining reconnaissance coverage from CIS allowed IIP to save flight hours for use later in the season when icebergs extended outside of PAL Aerospace aircraft range.

IIP’s IRD 1 arrived in St. John’s on 19 February and conducted its first patrol the following day. The first flight passed through the Newfoundland Sea and along the Labrador coast up to 57°N, detecting 525 icebergs, many within sea ice. Additional flights during this IRD located 13 icebergs near 48°N and also verified that no icebergs had drifted southward through the Flemish Pass. Though, the main population of icebergs was still well north of the transatlantic shipping lanes, results from the first IRD provided the first indicator of another extreme Ice Year.

IRD 2 returned to St. John’s on 02 March after a short patrol of the eastern part of the Gulf of St. Lawrence and the Strait of Belle Isle to assess the Western Iceberg Limit. An intense, 980 mb low pressure system passed directly over St. John’s on three separate dates causing cancellation of operations due to poor weather conditions at the airport and in the planned OPAREA.

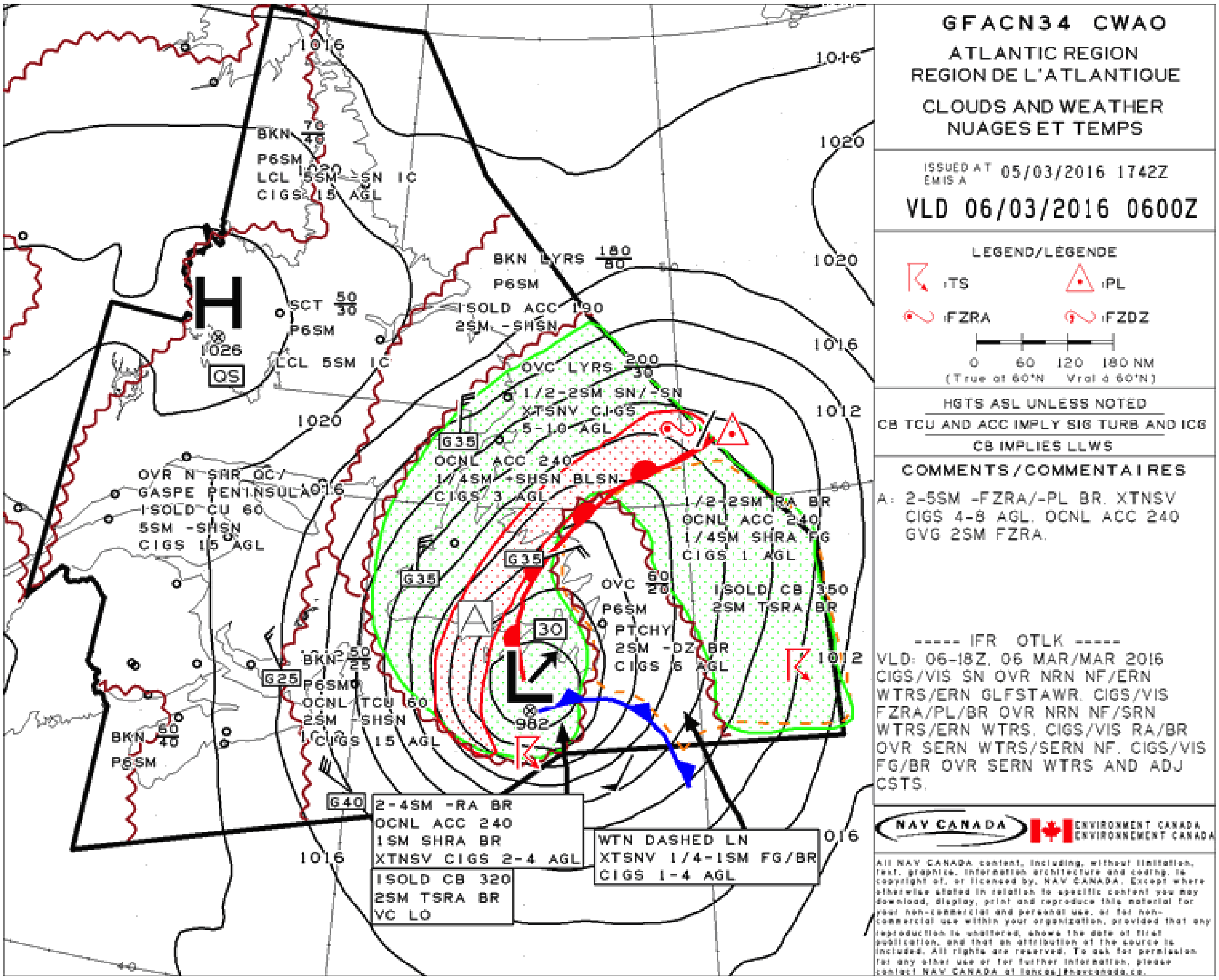


Figure 7. NAV CANADA Atlantic Region Graphical Forecast Area Clouds and Weather Product Valid for 0600 UTC, 06 March 2016. (NAV CANADA, 2016)

Figure 7 shows this system just prior to reaching Newfoundland. The IRD overcame this storm system to complete four additional patrols that located a total of 162 icebergs, all north of 48°N.

Of note, on 09 March, as part of an operational evaluation of the NAIS iceberg drift and deterioration model, IIP flew one leg of its flight plan through an area well to the east of the 1000 m depth contour to verify the presence of a large iceberg population predicted by this model. IIP's operational iceberg model did not indicate that icebergs would be present here. This portion of the patrol located four icebergs well to the east of the 1000 m contour, including one outside of the Iceberg Limit. This situation is described in detail in the Operations Center Summary, and additional details on the NAIS Model evaluation can be found in **Appendix B**.

During the second half of March, IRD 3 conducted five patrols and detected 320 icebergs. These flights focused on the 1000 m contour, the northern entrance to Flemish Pass, and the region over Sackville Spur (refer to **Figure 3**). The IRD also conducted a search along the eastern contour of the Grand Banks down to 44°N latitude to verify that no icebergs drifted southward in the Labrador Current. Again, this Southern Iceberg Limit flight did not locate any icebergs. For the second deployment in a row, a powerful, 948 mb low pressure system that tracked along the western edge of Newfoundland required the IRD to cancel three reconnaissance flight days.

PAL Aerospace continued to actively patrol, conducting 21 ice reconnaissance flights – 17 for the oil and gas industry and four for CIS. These four flights were focused on the 1000 m contour and the icebergs positioned to drift into the transatlantic shipping lanes. An additional 22 flights for other Canadian Government interests reported icebergs as well.

By the end of the month, a sizable population of icebergs accumulated around Sackville Spur. Numerous icebergs began drifting over the north side of Flemish Cap. However, very few icebergs drifted southward in the offshore branch of the Labrador Current.

April – June 2016

The cold air temperature anomaly that began in mid-February in Goose Bay continued through the first three weeks in April (see **Figure 5**). From late April through the remainder of the Ice Year, mean air temperatures for Goose Bay

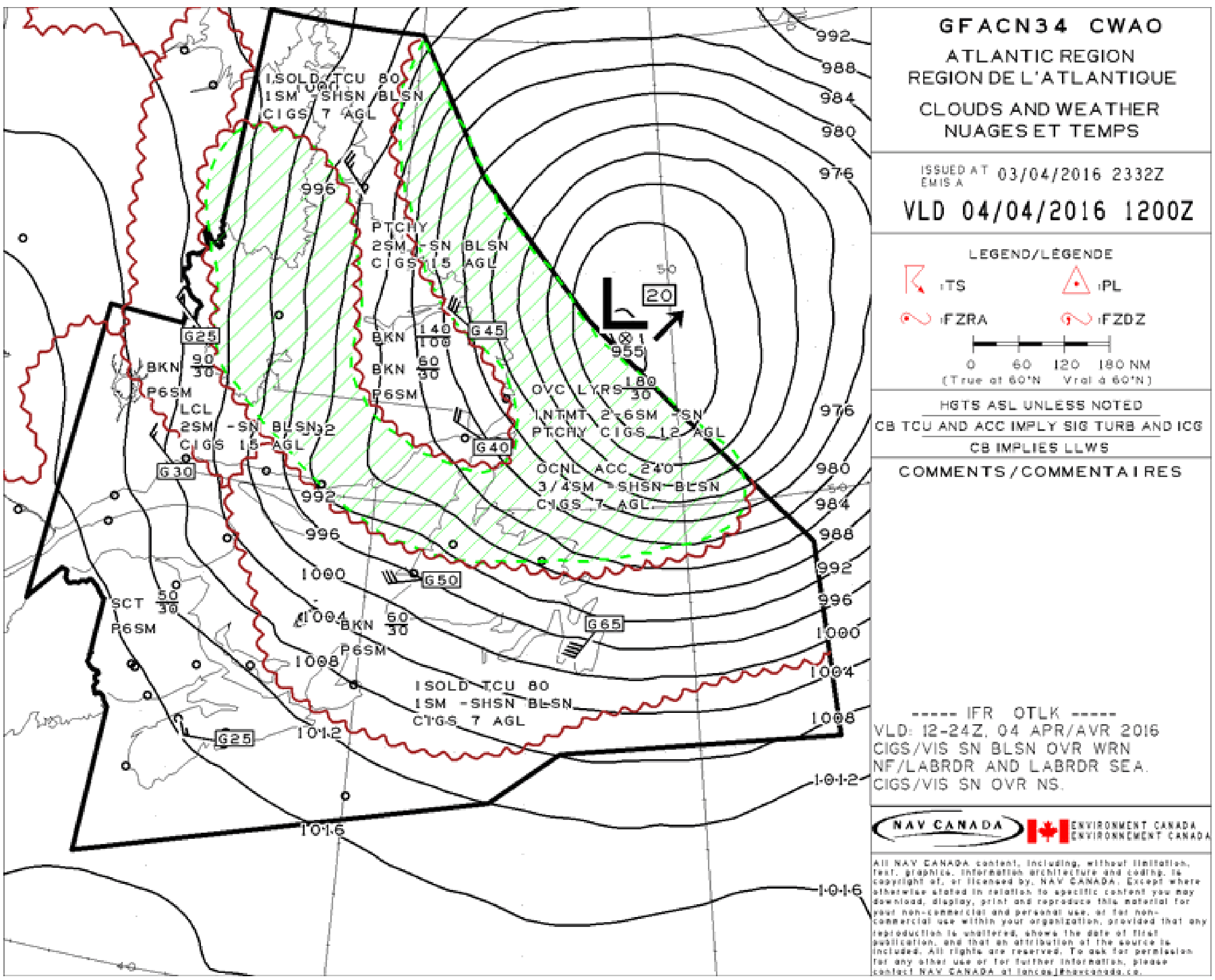


Figure 8. NAV CANADA Atlantic Region Graphical Forecast Area Clouds and Weather Product Valid for 1200 UTC, 04 April 2016. (NAV CANADA, 2016)

fluctuated within 2°C of normal. St. John's experienced a similar temperature pattern until late July when temperatures remained above normal through the end of September.

The absence of prolonged cold air temperatures along the Canadian east coast allowed a rapid decline in the sea-ice coverage by early April. On 04 April, yet another intense storm system passed over Newfoundland causing dramatic sea-ice destruction (**Figure 8**). In a single day, the sea ice edge collapsed from 48°N to 50°N. After the first week in April, the sea ice edge retreated north of 50°N and remained there for the rest of the Ice Year. Although the southern ice edge retreated rapidly, the sea ice edge north of 50°N extended further offshore than normal. The CIS weekly sea-ice departure from normal graphic for 11 April illustrates this situation in **Figure 9**. (CIS, 2016b) The blue-shaded regions represent sea-ice concentrations that are greater than normal conditions (1981-2010). Red shades are less than normal concentrations. **Figure 9** shows a strong tendency for sea-ice growth well to the east of normal conditions. As observed during the 09 March flight described above, icebergs located during IIP reconnaissance in April through June reflected a similar eastward drift tendency.

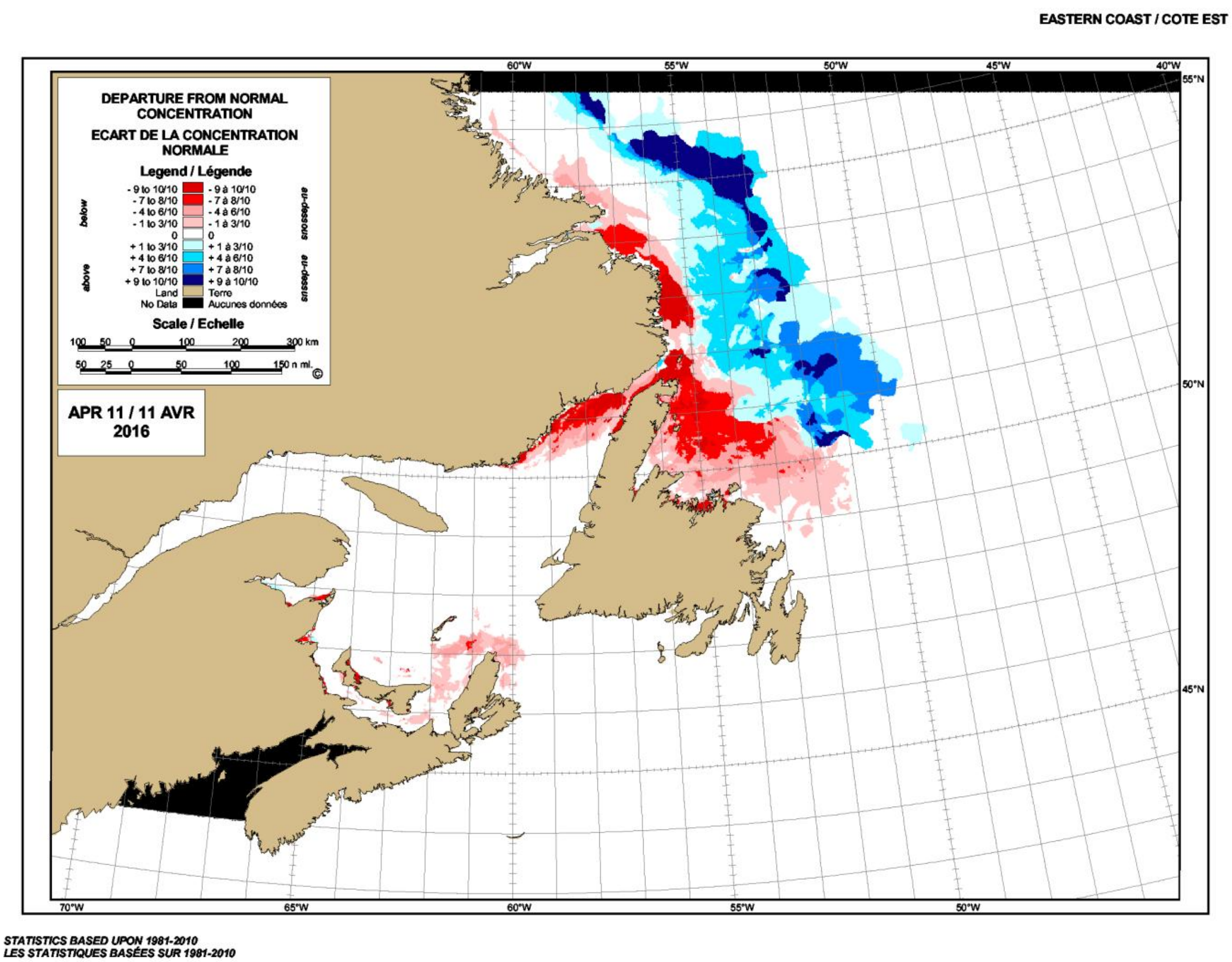


Figure 9. Departure from Normal Sea-Ice Concentration for 11 April 2016. (CIS, 2016c)

During IIP's first IRD of this quarter, the 04 April storm system combined with multiple aircraft equipment casualties hindered the completion of IRD 4 objectives. The IRD completed only two patrols: one of the Southwestern and another of the Eastern Iceberg Limit. Consistent with the observed sea-ice departure from normal described above, IIP's eastern patrol on 01 April located a grouping of 257 icebergs between Sackville Spur and east to 43°W. All of these icebergs were north of Flemish Cap. The southwestern patrol verified that no icebergs were present in the inshore branch of the Labrador Current, adjacent to the Newfoundland coast. The IRD was unable to search the offshore branch of the Labrador Current south of the oil facilities on the Grand Banks due to the storm and aircraft maintenance issues.

During the third week of April, IRD 5 experienced much better weather conditions and successfully completed five patrols of the Southwestern, Southern, Eastern, and Northeastern Iceberg Limit. Though significantly fewer in number than the 01 April flight on IRD 4, the majority of icebergs (58 of 75 total) were detected on a single flight on 15 April. These icebergs were concentrated in a similar area between Sackville Spur and the northern half of Flemish Cap. This patrol also observed the easternmost iceberg for the year in position 47°14′N, 43°11′W. The reduction of the quantity of icebergs sighted between flights on 01 April and 15 April is noteworthy. Both patrols experienced favorable conditions that allowed visual confirmation of detections. This difference in quantity likely resulted from rapid iceberg deterioration due to increased sea state caused by the 04 April storm and increased sea temperature as icebergs entered the warm North Atlantic Current on the northeast side of Flemish Cap.

PAL Aerospace flights during the first half of April primarily focused on monitoring the icebergs in the same region as IIP's Eastern Iceberg Limit flights since they posed the greatest threat to the oil facilities. Prior to 14 April, no reconnaissance was completed in the southern OPAREA. Due to the fact that the previous IRD was unable to complete a Southern Iceberg Limit flight, the IRD conducted a search well to the south of the published Iceberg Limit to investigate the southern extent of the Labrador Current along with a clockwise-circulation eddy that was entraining cold water eastward just south of Flemish Cap. This situation will be described in greater detail in the Atmospheric and Oceanographic Discussion.

PAL Aerospace conducted 10 additional flights focused on the oil facilities and one for CIS through the Newfoundland Sea and Strait of Belle Isle throughout the remainder of April. On 21 April, PAL Aerospace reported a small grouping of four icebergs drifting south of the oil rigs in the offshore branch of the Labrador Current. IIP returned to St. John's as previously scheduled and conducted a flight in this region on 29 April that located 14 icebergs drifting south in the Flemish Pass. On IRDs 6, 7, and 8 between late April and early June, IIP conducted 11 patrols that detected 578 icebergs. The majority of these icebergs were observed north of 50°N.

The first icebergs entering the Strait of Belle Isle appeared on 03 May. These icebergs began drifting into the Gulf of St. Lawrence throughout May causing the Western Iceberg Limit to expand to near 60°W. On 02 June, IRD 8 detected 33 icebergs in the Strait of Belle Isle west of 56°W. On 23 June, IRD 10 found 67 icebergs present in this area including the westernmost sighted iceberg for the year in position 50°50′N, 58°58′W. Icebergs located in this area posed a significant hazard to ships transiting to and from Montreal, Canada and remained a key focus for both IIP and PAL Aerospace reconnaissance throughout July and August.

Small groupings of icebergs began moving southward in the Labrador Current throughout the first part of June. On 04 June, the M/V PACIFIC PRINCESS reported a growler in position 41°38′N, 50°17′W near the Tail of the Bank. This iceberg became the southernmost sighted and modeled iceberg for the 2016 Ice Year.

IIP completed seven patrols on two separate IRDs that detected a total of 650 icebergs in June, IRDs 9 and 10. While most of these sightings were north of 50°N, a flight on 16 June located a grouping of 19 icebergs that were all south of 43°N but still within the published Iceberg Limit. As sea-surface temperature (SST) increased, these icebergs began to melt rapidly. Based on an IIP Southern Iceberg Limit flight with good visibility and calm seas on 27 June, IIP deleted numerous icebergs from its database and raised the Southern Iceberg Limit from 41°N to 44°N on 28 June. The next day, an unidentified vessel reported a stationary radar target with 11 smaller radar targets nearby just outside of the new Iceberg Limit. For safety, CIIP reported these as icebergs, made notifications, and revised the daily Iceberg Warning products. Further details on this sighting are summarized in the Operations Center Summary section of this report.

PAL Aerospace remained active throughout May and June conducting 31 flights in support of industry and seven flights for CIS. With few exceptions, most PAL Aerospace flights for industry followed a similar flight track that searched eastbound along 47°30′N out to Sackville Spur and then in the vicinity of the oil facilities. The iceberg population in this region remained steady for May and through mid-June but began to decline during the second half of June. Flights in support of CIS were focused more in the Newfoundland Sea and the Strait of Belle Isle areas. An excellent example of the value of the NAIS partnership, CIS continued to use weekly input from IIP for development of PAL Aerospace flight tasking to fill gaps in IIP reconnaissance.

July – September 2016

Air temperatures in Goose Bay stayed near normal while temperatures in St. John’s remained above normal for the remainder of the Ice Year. During the first week of July, remnants of sea ice were observed north of 55°N. Water temperatures on the Grand Banks continued to warm as the summer progressed, accelerating the destruction of icebergs in the transatlantic shipping lanes.

IIP conducted its final IRD of the 2016 Ice Year from 06-14 July. This detachment conducted five patrols that verified there were no icebergs south of 48°N or east of 46°W. This IRD also confirmed that the iceberg population in the Strait of Belle Isle declined but would still need to be monitored. IIP continued to provide input to CIS for PAL Aerospace tasking, and PAL Aerospace conducted periodic flights in the Strait of Belle Isle throughout September reporting isolated icebergs inside the eastern edge of the Gulf of St. Lawrence.

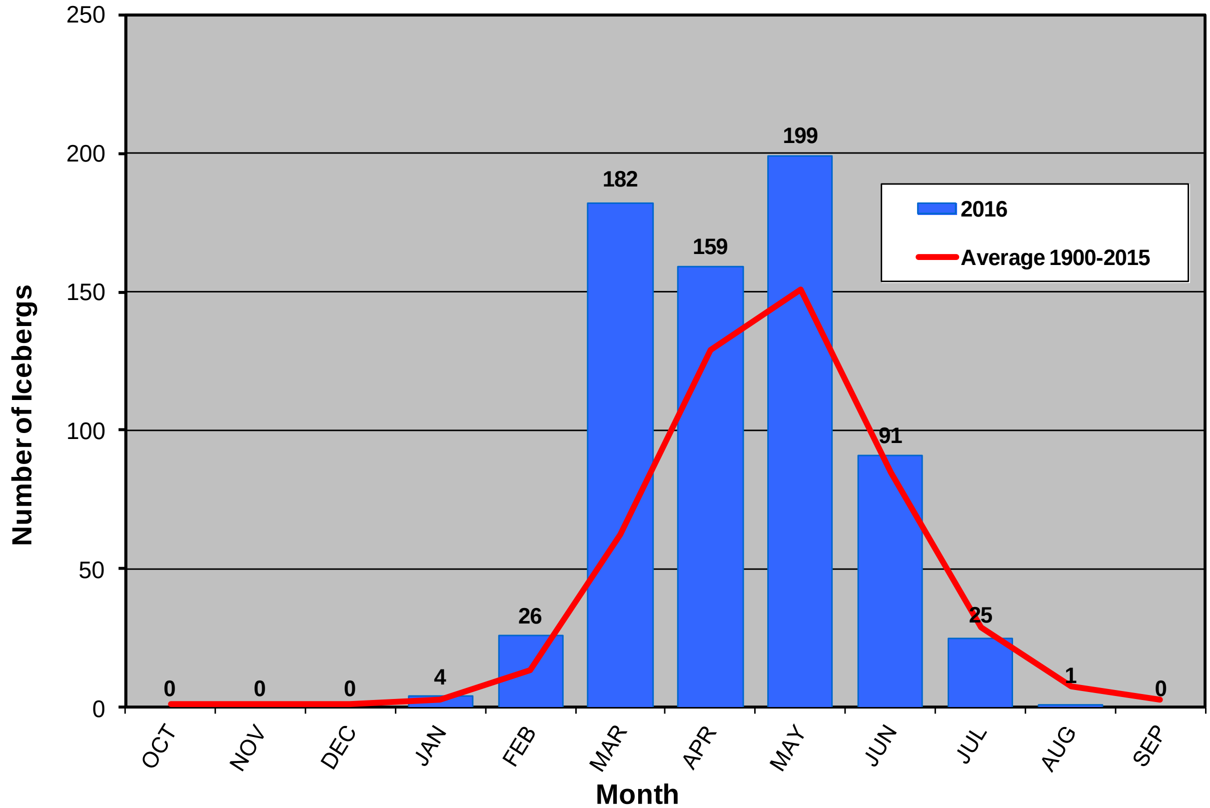


Figure 10. Estimated Number of Icebergs Passing South of 48°N by Month (687 total for 2016).

Ice Reconnaissance Detachment 11 flew a patrol on 13 July to 60°N along the Labrador Coast searching 41,614 NM^2 and locating 1,152 icebergs. The reconnaissance crew was able to visually confirm 67% of these icebergs and reported a significant proportion (438) of icebergs with lengths greater than 60 m (medium icebergs and larger). These icebergs remained on the daily Iceberg Limit chart, based on the iceberg drift and deterioration model, through the month of July but steadily deteriorated with warmer air and sea temperatures. With the exception of a few isolated icebergs along the Newfoundland coast, these icebergs did not survive to the transatlantic shipping lanes. After 30 August, the Iceberg Limit shifted north of 48°N and remained so for the remainder of the Ice Year. IIP transferred the responsibility for creating and disseminating the daily Iceberg Limit products to CIS on 01 September.

In summary, **Figure 10** graphically shows the number of icebergs estimated to have drifted south of 48°N by month for the 2016 Ice Year. The monthly average was calculated using 116 years (1900 through 2015) of IIP records and is plotted as a solid red line for comparison. A summary of the 2016 extreme iceberg positions, both sighted and drifted by modeling, along with the sighting source is presented in **Table 1**.

Atmospheric and Oceanographic Discussion

Atmospheric Discussion

The strong El Niño of 2015-16 provided an opportunity to examine the connection, if any, that this global atmospheric /oceanographic event has on iceberg season severity. El Niño is a tropical Pacific Ocean phenomenon that occurs every 3-7 years and is marked by an increase in SST in the eastern part of the equatorial Pacific. Changes in SST here

Extreme Icebergs	Sighted				Drifted			
	Source	Date	Latitude	Longitude	Source	Date	Latitude	Longitude
Southern	Vessel	04-Jun-16	41-37.7N	50-17.3W	Vessel	13-Jun-16	41-17.0N	47-46.3W
Eastern	IIP HC-130J	15-Apr-16	47-14.0N	43-11.0W	IIP HC-130J	01-Jun-16	46-28.9N	38-41.4W
Western	IIP HC-130J	23-Jun-16	50-50.5N	58-58.1W	IIP HC-130J	23-Jun-16	50-51.6N	58-55.1W

Table 1. 2016 Extreme Sighted and Drifted (Modeled) Iceberg Positions by Original Sighting Source and Date. Note: Western icebergs listed were those used to set the iceberg limit in the Gulf of St. Lawrence.

can influence atmospheric conditions globally. In general, Canada typically experiences relatively milder and drier than normal weather, particularly in the western part of the country. (Environment and Climate Change Canada, 2016)

The strength of an El Niño event is measured by the SST anomaly in the Pacific Ocean in the region between 5°S and 5°N and between 120°W and 170°W. (El Niño Region 3.4),(NOAA/NWS, 2016b) This measure, known as the Oceanic Niño Index (ONI), tracks a three-month running average compared to the 30-year average for the time period between 1986 and 2015. During the modern aerial reconnaissance era (1983 through the present), the three strongest El Niño events as measured by the ONI occurred in 2015-16, 1997-98, and 1982-83 (**Figure 11**). (NOAA/NWS, 2016b) Notably, the number of icebergs drifting south of 48°N in these three years was 687, 1,380, and 1,352, respectively. All three years were classified as ‘extreme’ in accordance with IIP (1994), suggesting a possible link between ONI and the number of icebergs drifting south of 48°N. However, statistically, the correlation coefficient comparing the number of icebergs south of 48°N and the ONI between 1983 and 2016 showed no correlation (correlation coefficient = 0.25). In fact, only the 1982-83 and 1997-98 events were in the top ten most extreme iceberg seasons in terms of icebergs drifting south of 48°N. Further, the number of icebergs drifting south of 48°N during two moderately strong El Niño events in 1987-88 and 2009-10 were among the lowest on record. In short, the relationship between iceberg season severity and El Niño is not clear, even during strong events. Local changes in weather patterns as a result of the North Atlantic Oscillation (NAO) likely dominate over the influence of El Niño when considering the formation of sea ice and iceberg drift.

As described in prior IIP Annual Reports (e.g., IIP, 2015), the NAO Index (NAOI) represents the dominant pattern of winter-time atmospheric variability in the North Atlantic, fluctuating between positive and negative phases. Generally, speaking, a positive phase of the NAOI is associated with offshore winds that supply cold air from Newfoundland and Labrador promoting seaward sea-ice growth. Onshore winds, associated with a negative phase of the NAOI, inhibit seaward sea-ice growth, leaving icebergs exposed to open waters and causing grounding events which limit iceberg movement toward the offshore branch of the Labrador Current.

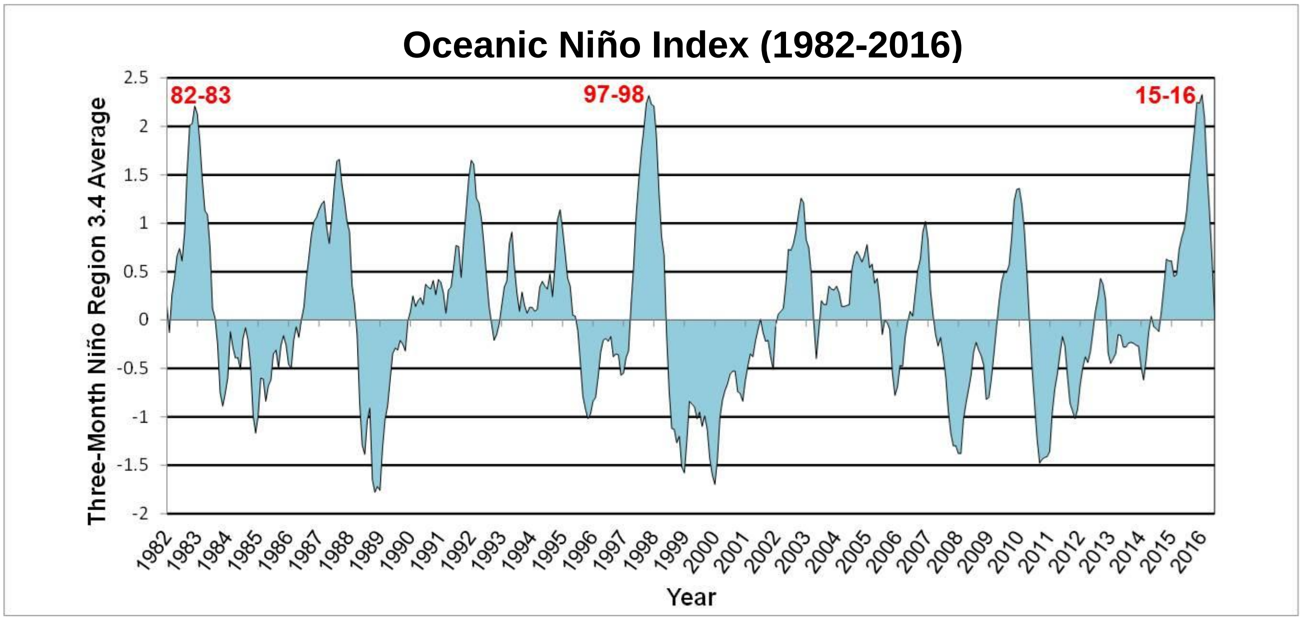


Figure 11. Three-Month Region 3.4 Average of the Oceanic Nino Index for 1950-2016. (NOAA/NWS, 2016b)

The station-based version of the NAOI is calculated using the difference in normalized sea-level atmospheric pressure between Lisbon, Portugal and Stykkisholmu/Reykjavik, Iceland. (Hurrell, 1995) The winter-time, station-based NAOI for December 2015 through March 2016 was only slightly positive at +0.98. By comparison, the NAOI for the same months during the extreme Ice Years of 2014 and 2015 was +3.56 and +3.10, respectively.

Figure 12 shows the daily 500 mb-based NAOI calculated from 01 December 2015 through 29 March. (NOAA/NWS, 2016c) This index yields similar physical significance as the single, winter-time station-based index described earlier, i.e., positive values indicate offshore winds with favorable sea-ice growth conditions and the opposite for negative values. Although the NAOI remained positive throughout the month of December, warmer than normal air temperatures along the east coast of Canada kept sea-ice growth close to the median. As shown in **Figure 12,** on 07 January, the NAOI reversed and remained negative for two weeks until it shifted back to positive for the entire month of February and first two weeks of March. Composite Sea Level Pressure Means during time periods with a negative NAOI in the left panel (07-23 January) and positive NAOI in the right panel (23 January – 05 February) are depicted in **Figure 13**. (NOAA/ESRL, 2016) Red arrows indicate the approximate average wind direction along the central Labrador coast during these two time periods.

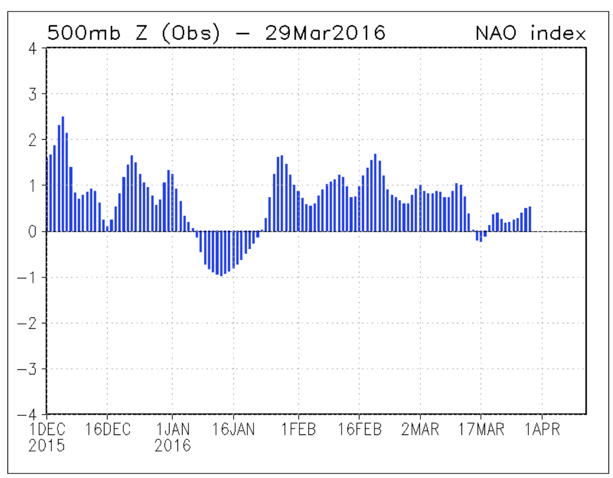


Figure 12. 500 mb North Atlantic Oscillation Index (NAOI) for 01 December 2015 through 29 March 2016. (NOAA/NWS, 20156c)

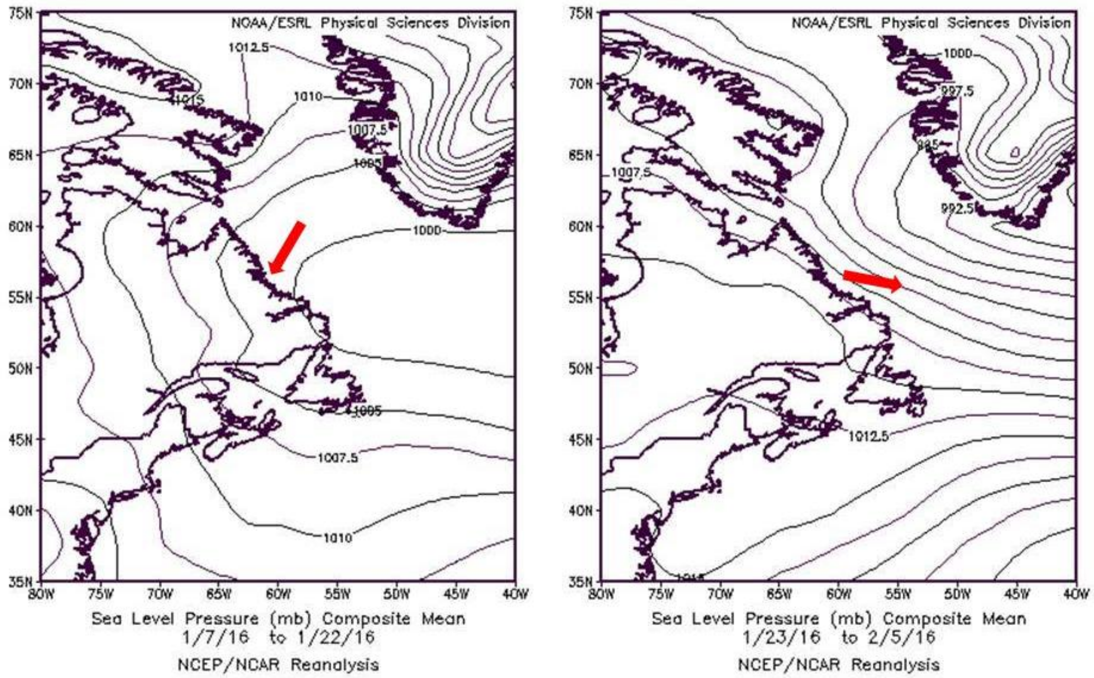


Figure 13. Sea Level Pressure (mb) Composite Mean during Negative NAOI from 7-22 January (left) and Positive NAOI 23 January – 05 February (right) 2016. Red arrows indicate approximate mean wind directions during each period. Image provided by the NOAA-ESRL Physical Sciences Division, Boulder Colorado. (NOAA/ESRL, 2016)

Changes in mean wind direction as indicated by the NAOI at these same time periods can be seen in the Weekly Regional East Coast Ice Coverage graphical product created by IIP by combining ice coverage data from the CIS Ice Graph 2.0 program for the Southern Labrador Sea and East Newfoundland Waters program (**Figure 14**). (CIS, 2016d) This chart shows combined sea-ice coverage for the southern Labrador Sea and East Newfoundland Waters. Sea-ice coverage in the Gulf of St. Lawrence was significantly below normal throughout the year and is not represented in **Figure 14**. Sea-ice coverage during periods of positive NAOI through the first week in January was above the median. Following the period of negative NAOI from 07 through 23 January, sea-ice coverage fell to just below median levels. After the week of 12 February, sea-ice coverage remained well above the median for six weeks until the rapid decline in early April. Sea-ice coverage in this region remained at or above median throughout the remainder of the Ice Year

Oceanographic Discussion

The retreat of sea ice in late March typically marks the beginning of the most active months for iceberg drift south of 48°N. Iceberg drift during this period is governed by the dynamics of the cold southward-flowing Labrador Current and its interaction with the North Atlantic Current.

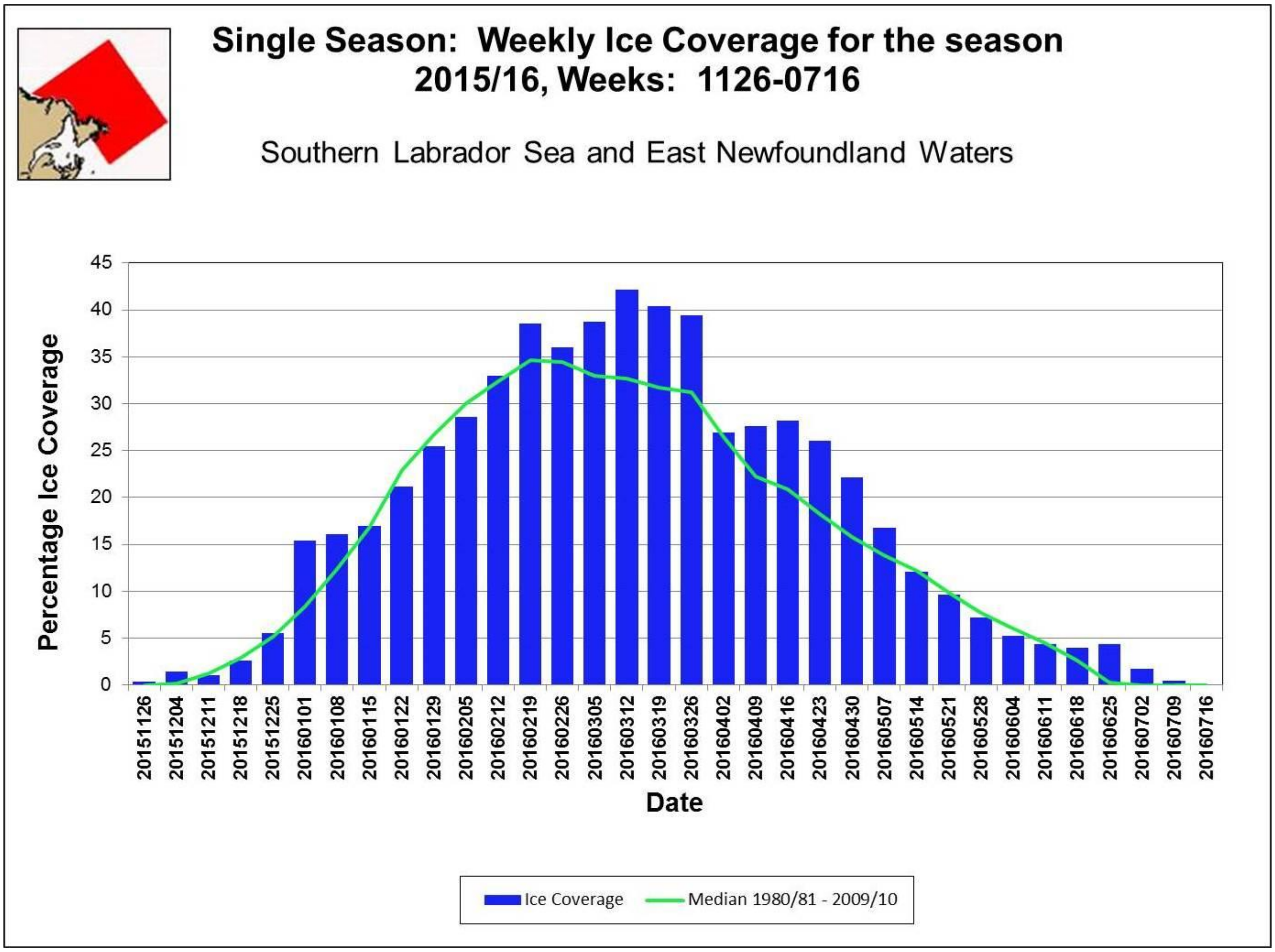


Figure 14. Weekly Regional East Coast Ice Coverage for 2015-2016 for Southern Labrador Sea and East Newfoundland Waters. The percent coverage is relative to the area shaded in red in the upper left map of this figure. (CIS, 2016d)

In 2016, several key oceanographic features influenced iceberg drift and drove IIP's reconnaissance flight planning decisions. For example, as stated in the quarterly summary above, a clockwise-circulating, warm core eddy caused cold water to flow eastward just to the south of Flemish Cap. A Surface Velocity Program (SVP) drifting buoy deployed by IIP in early March became caught in this feature making a sharp left-hand turn toward the east away from the southward flow of the Labrador Current.

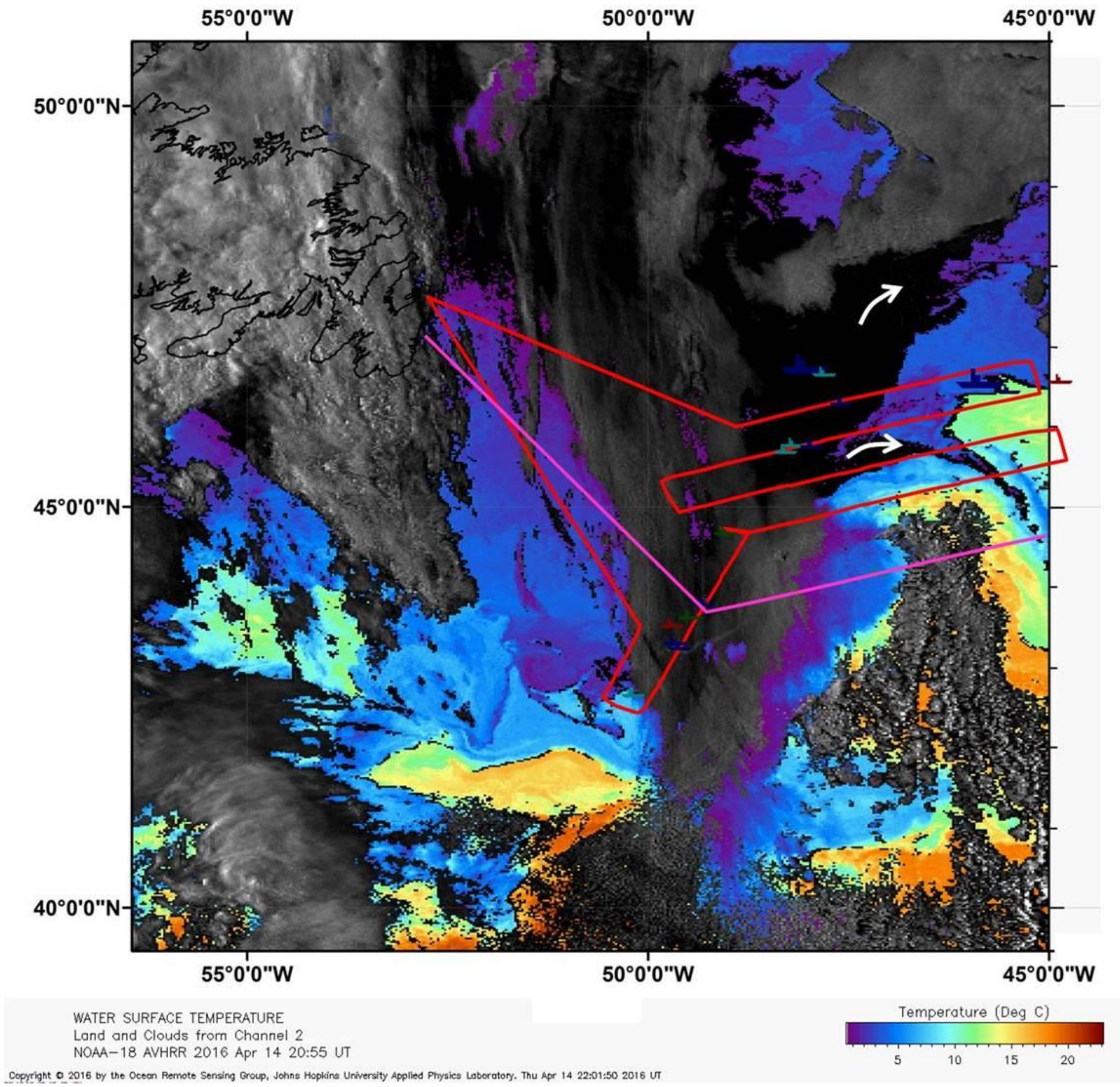


Figure 15. Advanced Very High Resolution Radiometer (AVHRR) Sea Surface Temperature (SST) Image from 14 April 2016. IIP flight track for 14 April flight is shown in red. IIP Iceberg Limit for 14 April is shown in ginger-pink. White arrows show eastward cold water flows. Image provided by the Ocean Remote Sensing Group, Johns Hopkins University Applied Physics.

Figure 15 shows IIP's flight track (red) and the published Iceberg Limit for 14 April (ginger-pink) overlaid on an SST satellite image from the Advanced Very High Resolution Radiometer (AVHRR) (**Figure 15**). (Johns Hopkins University, 2016) The top half of the warm-core eddy can be observed in the right part of the image. The bottom white arrow in **Figure 15** shows the eastward flow of cold water represented in black being entrained by this eddy. The IIP OPCEN planned the flight to search this cold feature along with the main branch of the Labrador Current to the

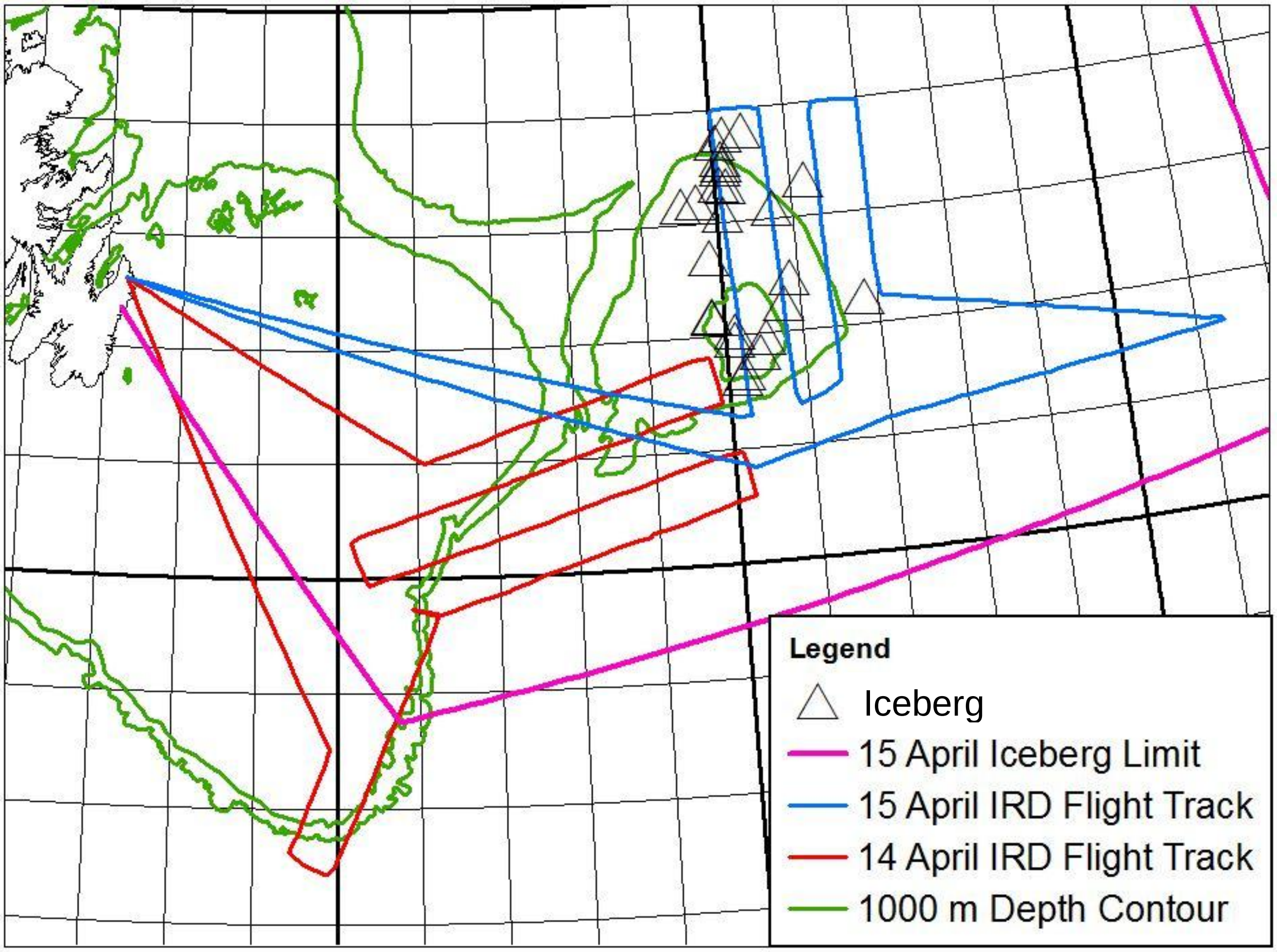


Figure 16. IIP IRD Flight Results for 14 and 15 April 2016.

southwest. On 15 April, IIP searched an area north of Flemish Cap to focus on the broad, cold water flow depicted by the top white arrow in **Figure 15**. Results from these two flights are graphically shown in **Figure 16**, illustrating that iceberg drift during April favored a path north of the Flemish Cap. The fact that no icebergs were sighted during the southern search on 14 April provided invaluable information for CIIP to confidently declare this dangerous region free of iceberg hazards.

This tendency for icebergs to follow a more eastward (vice southward) track persisted throughout May. **Figure 17** shows the U.S. Naval Oceanographic Office Ocean Features Analysis (OFA) for 21 May with tracks from five IIP drifting buoys in red. White arrows provide approximate flow directions for these buoys. As in the earlier example, buoy drift clearly showed the eastward current flow north of Flemish Cap that continued to divert many icebergs away from Flemish Pass towards the warmer North Atlantic Current. The North Atlantic Current can clearly be seen in the OFA as shades of light blue north of 47°N and east of 43°W. The North Atlantic Current begins at 50°W and is an extension of the Gulf Stream. This current offers a warm-water boundary that deteriorates icebergs drifting north and over Flemish Cap to the east. The fact that reconnaissance flights in April and May

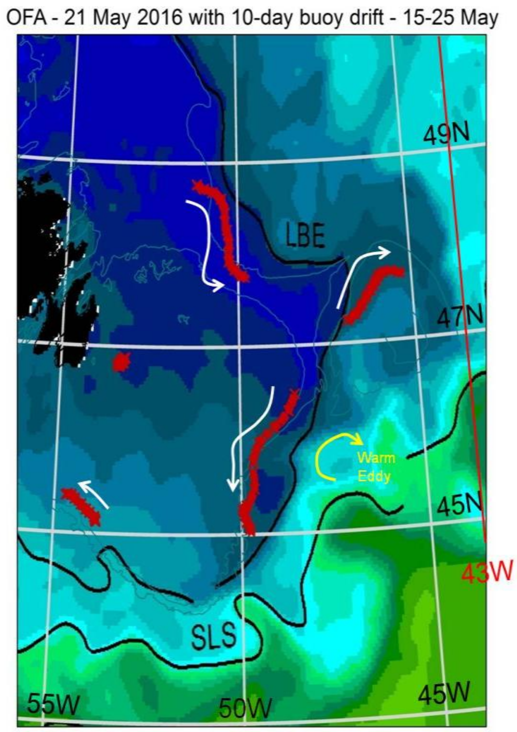


Figure 17. US Naval Oceanographic Office, Sea Surface Temperature Ocean Features Analysis for 21 May 2016. Buoy tracks for 15-25 May are shown in red. White arrows indicate flow direction. (Naval Oceanographic Office, 2016)

located only nine icebergs south of 45°N provides further evidence of the presence of this eastward flow both north and south of Flemish Cap that likely reduced the number of icebergs entering the main branch of the Labrador Current. As described above, very few icebergs were reported in the southern part of IIP's OPAREA (south of 45°N) until mid-June.

In summary, the 2016 Ice Year was classified as 'extreme' based on the number of icebergs drifting south of 48°N. In addition, the number of days that icebergs were observed south of 48°N was the highest on record and increased the risk for transatlantic vessels to encounter an iceberg in the North Atlantic. Fortunately, the oceanographic conditions present for the year tempered the impact that these hazards imposed on the transatlantic shipping lanes.

Operations Center Summary

The IIP OPCEN is manned seven days a week by a Duty Watch Officer (DWO) and a Duty Watch Stander (DWS) from 1200Z until 2000Z during daylight savings time and 1100Z until 1900Z during standard time. While supporting IRDs, the OPCEN is manned throughout the duration of every reconnaissance flight. When the OPCEN is not manned, the DWO monitors a cell phone, allowing him or her to take action as necessary at any time. The watch is responsible for receiving iceberg reports from a wide variety of sources, including IRD flights, PAL Aerospace flights, and merchant vessels. The watch processes the iceberg reports and enters them into BAPS. Once the relevant information is entered into BAPS, the watch produces iceberg warnings for the North Atlantic, utilizing the iceberg drift and deterioration computer model, and distributes the products to the maritime community.

To accomplish the mission, IIP works in concert with CIS and the U. S. National/Naval Ice Center (NIC) in a formal partnership known as NAIS. In 2016, the Danish Meteorological Institute (DMI) joined NAIS as an "observer," providing valuable iceberg and climatological data in the vicinity of Greenland and the waters of Navigational Area (NAVAREA) I (see **Figure 18.**). NAIS partners collaborate to create and distribute iceberg warning products to provide the maritime community with accurate information regarding icebergs that threaten navigational safety in the North Atlantic Ocean. Because the NAIS Iceberg Warning products are international products, IIP creates and distributes the warnings in English only. During the 2016 Ice Year, CIS distributed a bilingual version of the same product in English and French in order to meet their domestic requirements.

CIS and IIP also serve as continuity-of-operations locations for one another. If one entity is unable to create the iceberg warning products, the other can seamlessly assume responsibility for product generation until capabilities are restored. In 2016, there was only one instance in which CIS generated products on behalf of IIP. On 08 February, IIP members could not safely travel to work to create and distribute iceberg warning products due to a severe snowstorm. The IIP DWS briefed CIIP and coordinated with the CIS watchstander to ensure the daily iceberg warning products were created and distributed on time. By formalizing the information-sharing and collaborative product generation and distribution, NAIS ensures the maritime community consistently receives the most timely and accurate iceberg information available. During the 2016 Ice Year, 100% of the iceberg warning products were released on time, meeting all required broadcast schedules.

Products and Broadcasts

IIP creates two forecast products for the maritime community each day, the NAIS-10 iceberg bulletin (text form) and the NAIS-65 iceberg chart (graphical representation). They are released at 1830Z and are valid for 0000Z the following day. The iceberg chart is broadcast over radio facsimile (Radiofax) and the internet. The iceberg bulletin is broadcast over SafetyNET, NAVTEX, Simplex Teletype Over Radio (SITOR), and the internet. Both products are posted on the IIP and the National Weather Service (NWS) websites at: http://www.navcen.uscg.gov/?pageName=iipProducts. and http://tgftp.nws.noaa.gov/fax/marsh.shtml, respectively. In addition, IIP posts a KML version of the daily Iceberg Limit on the IIP website for customers to use with web-based mapping software. The daily Iceberg Limit is also available in shapefile format on NOAA's Arctic Environmental Response Management Application (ERMA) website http://response.restoration.noaa.gov/maps-and-spatial-data/environmental-response-management-application-erma/arctic-erma.html.

Product Changes for 2016

On 09 December 2015, the IIP hosted a Product Improvement Workshop with NAIS members from CIS and DMI to discuss product improvements and to brainstorm possible changes that could be made to iceberg warning products to provide better ice information to NAIS customers. The group determined that iceberg warning products could be produced in English only because they are "international" products. To meet Canadian domestic requirements, CIS continued to create a bilingual version in English and French.

At the end of the 2015 Ice Season, P/V QUEEN MARY II returned a customer survey providing feedback on NAIS products. One element of the master's feedback was the benefit mariners would gain by knowing where and when the most recent reconnaissance was conducted. The Product Improvement Workshop decided to include this information on the products in order to inform customers of the location, source, and date of the latest iceberg observations. IIP collaborated with NAIS partners and prioritized iceberg reconnaissance sources based on mission, frequency, and training. Iceberg reconnaissance conduct by IIP was determined to be the most reliable due to IIP's specific training and consideration for setting the Iceberg Limit to warn transatlantic shipping of iceberg danger. Following IIP's flights, PAL Aerospace flights funded by CIS were second because they are contracted specifically for iceberg reconnaissance. PAL Aerospace flights funded by sources other than CIS were third because the focus of these flights is typically on other missions. Satellites were last in the order of precedence because the accuracy of reports are still being validated to determine the reliability of the information they provide.

The final change made in 2016 was the addition of an Estimated Iceberg Limit on the NAIS Iceberg Bulletin and Iceberg Chart. The Estimated Iceberg Limit includes the area north of 53°N and was represented by a dotted ginger-pink line on the NAIS-65 Iceberg Chart. Reconnaissance south of 53°N generates an exact limit, whereas reconnaissance north of 53°N is geared towards assessing general conditions and the region of iceberg danger. If reconnaissance was conducted near the Estimated Iceberg Limit north of 53°N, it was adjusted to a solid line as part of the traditional Iceberg Limit at the discretion of CIIP. In the north, the Estimated Iceberg Limit extends east to

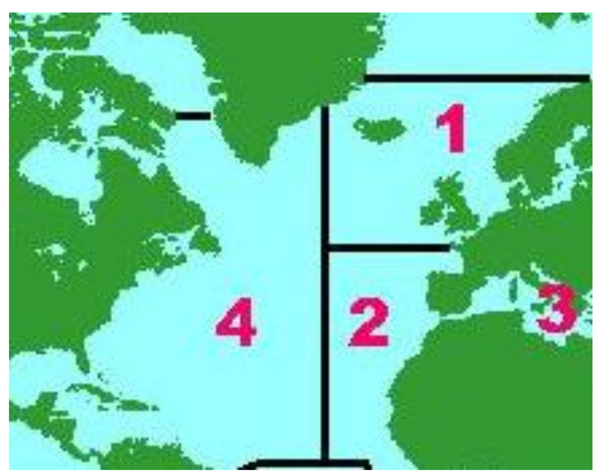


Figure 18. NAVAREA Boundaries. Previous to DMI joining NAIS as an "observer," IIP's products only covered NAVAREA IV. Now, DMI shares iceberg and climatological data with NAIS, expanding coverage into NAVAREA I.

30°W, into NAVAREA I (see **Figure 18**), serving to advise customers of iceberg danger south and east of Greenland. The points of the Estimated Iceberg Limit are based on monthly climatological iceberg observation data collected at DMI. If the Estimated Limit significantly changed, it was noted in the NAIS-10 Iceberg Bulletin and NAIS-65 Iceberg Chart. A significant change in the Iceberg Limit was determined to be an expansion or reduction of 60 NM. Currently, NAIS includes the number of icebergs per square degree of latitude and longitude within the Iceberg Limit on the daily Iceberg Chart. The goal for the 2017 Ice Season will be to use DMI satellite reconnaissance to include the number of icebergs per square degree of latitude and longitude for the region north of 53°N and around Greenland.

In addition to the improvements to the NAIS Iceberg Warning products, IIP added iceberg forecast information to the CIS 30-day Ice Outlook for East Newfoundland waters and the Labrador coast in 2016. The IIP Chief Scientist conducted this forecast every 15 days. IIP will continue to work with CIS to provide these iceberg forecasts to the maritime community in 2017.

IIP Protocol for Icebergs Reported Outside of the Iceberg Limit

Occasionally, an iceberg or a stationary radar target was reported to the IIP outside of the published daily Iceberg Limit, prompting short-term and long-term actions. Short-term actions included issuing an immediate warning to mariners and releasing a revised Iceberg Limit bulletin and chart. Long-term actions included examining the reconnaissance schedule and running the iceberg drift and deterioration model to identify adjustments to improve product accuracy.

Any report of an iceberg or radar target outside the published limit is passed to the Canadian Coast Guard's Marine Communications and Traffic Service (MCTS) center at Port Aux Basques, NL. MCTS Port Aux Basques uses this information to broadcast a Notice to Shipping (NOTSHIP), which is automatically forwarded to the U. S. National Geospatial-Intelligence Agency (NGA). The NGA then generates and broadcasts a NAVAREA IV Warning to all vessels operating within NAVAREA IV, shown in **Figure 18**. NAVAREA IV is defined as the North Atlantic Ocean extending eastwards of the North American coast to 35°W, from 7°N to 67°N, including the Gulf of Mexico and Caribbean Sea. Comparing **Figure 3** and **Figure 18**, it is clear that the IIP reconnaissance area falls entirely within NAVAREA IV. If a target was reported outside of the published limit prior to 1400Z, the IIP watch revised and redistributed the NAIS-10 and NAIS-65 products valid for 1200Z, before the next scheduled 0000Z release.

In-Season Icebergs and Radar Targets Outside the Iceberg Limit

During the 2016 Ice Year, there were three occasions when icebergs or radar targets were reported outside of the published Iceberg Limit while IIP was responsible for product generation (25 January through 31 August 2016). When put into context, these three events represented less than 0.4% of the 687 icebergs reported south of 48°N in 2016. Notwithstanding, these three cases also represented potentially dangerous situations for vessels heeding the Iceberg Limit. It was critical for IIP to document and learn from these instances to improve the future execution of the IIP mission. Below are the three aforementioned cases:

1. On 09 March, an IRD reported an iceberg outside of the Estimated Iceberg Limit in position 53°48′N, 47°55′W. IIP was conducting an operational evaluation of the iceberg drift and deterioration model created by the National Research Council of Canada and CIS. This model is referred to as the “NAIS Model,” and a full description of the model evaluation is included as **Appendix B**. As shown in **Figure 19**, the NAIS Model predicted iceberg movement much further to the east when compared to the IIP operational iceberg drift and deterioration model. Because IIP was already planning to conduct a Northern Survey flight on that day, CIIP elected to fly through this predicted region of icebergs to validate the accuracy of the NAIS Model predictions. Although flight conditions were very poor, the IRD detected an iceberg outside of the published limit, verifying the eastward movement predicted by the NAIS Model. Three other icebergs were detected near and within the Iceberg Limit, but many more could have been present and not detected due to the poor flight conditions. A NOTSHIP was released, and IIP distributed the revised iceberg products at 2240Z the same day.

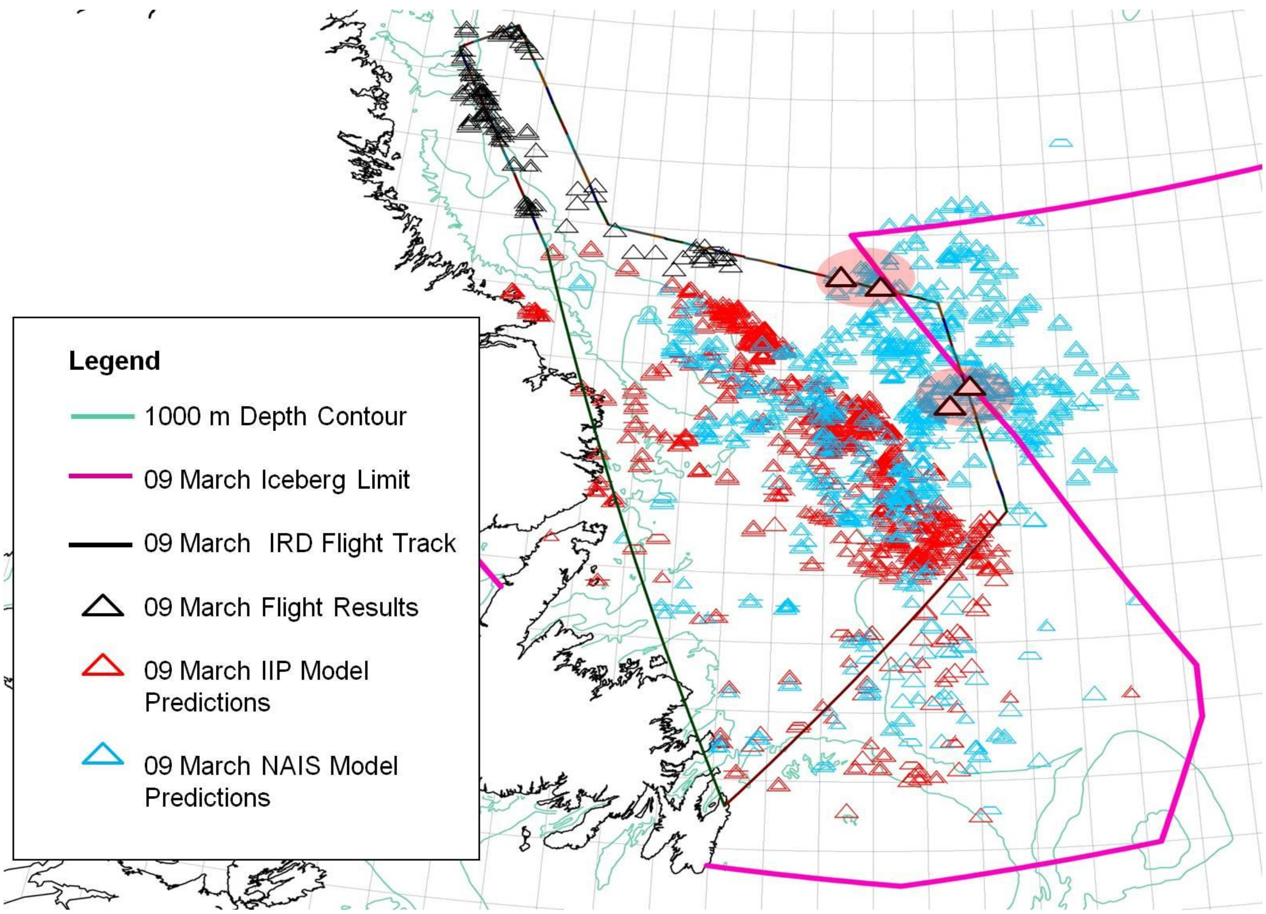


Figure 19. IIP Operational Evaluation of the Predictions from the NAIS Model (blue icebergs) Compared to the IIP Model Predictions (red icebergs). The black polygon represents the flight track of the IRD, and the black triangles are the icebergs the IRD discovered. Those four icebergs highlight in red were either close to or outside the Iceberg Limit (ginger-pink line).

Prior to this evaluation of the NAIS Model, IIP would not have surveyed this region because the IIP Model did not predict icebergs drifting this far east.

2. On 29 June, an unidentified commercial vessel reported 12 stationary radar targets outside the published Iceberg Limit at 44°00′N, 49°11′W. Two days prior, on 27 June, IRD 10 conducted a 9.2 hour Southern Limit (**Figure 20**) patrol just south of this iceberg report. Because no icebergs were found on this flight, the icebergs within the database were deleted, and the Iceberg Limit was moved 30 NM to the north. Upon close analysis of the iceberg movement and the environmental conditions, CIIP determined that the reported icebergs could have drifted into the area since the Southern Limit patrol was conducted. With this information, IIP erred on the side of caution and charted the radar targets as icebergs. The limit was adjusted accordingly to ensure the safety of vessels transiting close to the limit. A NOTSHIP was sent, and revised products were distributed at 1635Z the same day.

3. On 11 July, the M/V FEDERAL DANUBE reported a stationary radar target outside of the published limit at 46°05′N, 46°32′W. In accordance with IIP OPCEN Standard Operating Procedures, the DWO established

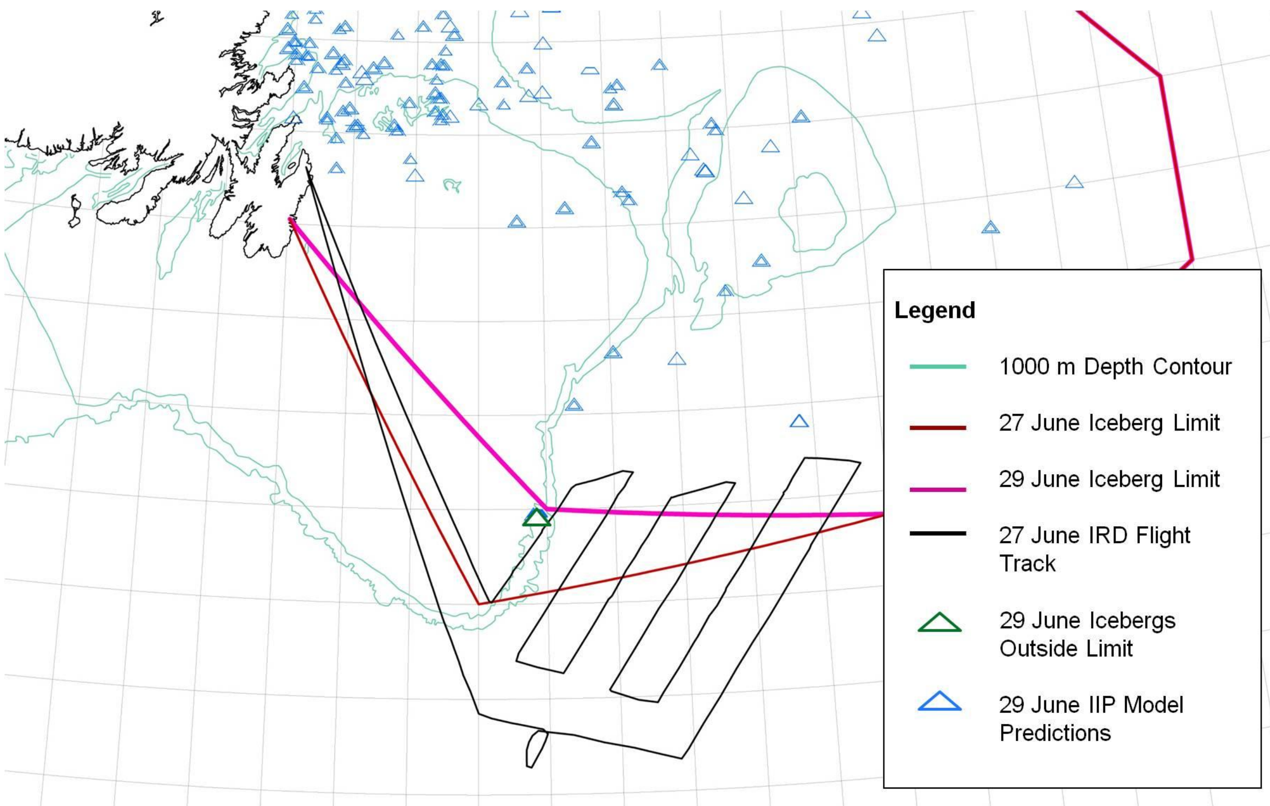


Figure 20. 27 June 2016 IRD Patrol. The track line depicted in the figure above and did not detect any icebergs. IIP adjusted the Iceberg Limit from the 27 June line (red) to the 29 June line (ginger-pink) based on this reconnaissance. On 29 June 2016, a commercial vessel reported 12 stationary radar targets (represented by the black triangle) outside of the Limit.

contact with the vessel to gather more information about the report. The master of the vessel conveyed that he detected the target only via radar, and no visual confirmation could be made. The IIP had conducted Southern Limit and Eastern Limit patrols on 08 and 09 July, respectively, and did not detect any icebergs that correlated with the M/V FEDERAL DANUBE's report. After analyzing recent aerial reconnaissance and SSTs in the area, it was determined the object should be represented as a radar target, and the limit was not adjusted. Due to the quick release of the revised product, a NOTSHIP was not released. The target was added to the chart as a radar target, and products were revised at 1254Z the same day (see **Figure 21**).

The DWO must use his or her judgment when determining whether a target reported solely via radar detection requires Iceberg Limit adjustment. The IIP watch utilizes all available resources to determine whether or not a reported target will be charted as an iceberg or a radar target. Upon receiving an iceberg report, the watchstander compares the location of the report with the most recent reconnaissance, in addition to evaluating the on-scene environmental conditions, most importantly, the SST. This year, there were two occasions when the published limit was inaccurate, yielding an Iceberg Limit accuracy over 99% for the Ice Season.

Out of Season Icebergs and Radar Targets Outside the Iceberg Limit

Outside of the 2016 Ice Season, but during the 2016 Ice Year, there were eight additional incidents involving iceberg reports outside the published limit. There were seven reports during the period of 01 October 2015 to 24 January 2016 and one report during the period of 01 to 30 September 2016.

1. On 03 November 2015, PAL Aerospace reported an iceberg at position 52°20.5′N, 53°51.9′W. This iceberg was not reported to CIS until 04 November 2015, after products were released. CIS issued a NOTSHIP, and revised products were prepared for release. Prior to releasing revised products, CIS received another report of an iceberg outside of the limit from the M/V OTTOWA EXPRESS, detailed below.
2. On 04 November 2015, M/V OTTAWA EXPRESS reported an iceberg 300-400 m long and 30-40 m tall at position 51°53′N, 54°04′W after products were made and released. CIS issued revised products valid for 05 November 2015, and a NOTSHIP was issued.
3. On 16 November 2015, PAL Aerospace reported an iceberg, detected both visually and with radar, outside the published limit at 49°14′N, 52°42′W. CIS received the report close to the next day's scheduled broadcast window and was able to include the iceberg information into the product prior to release.

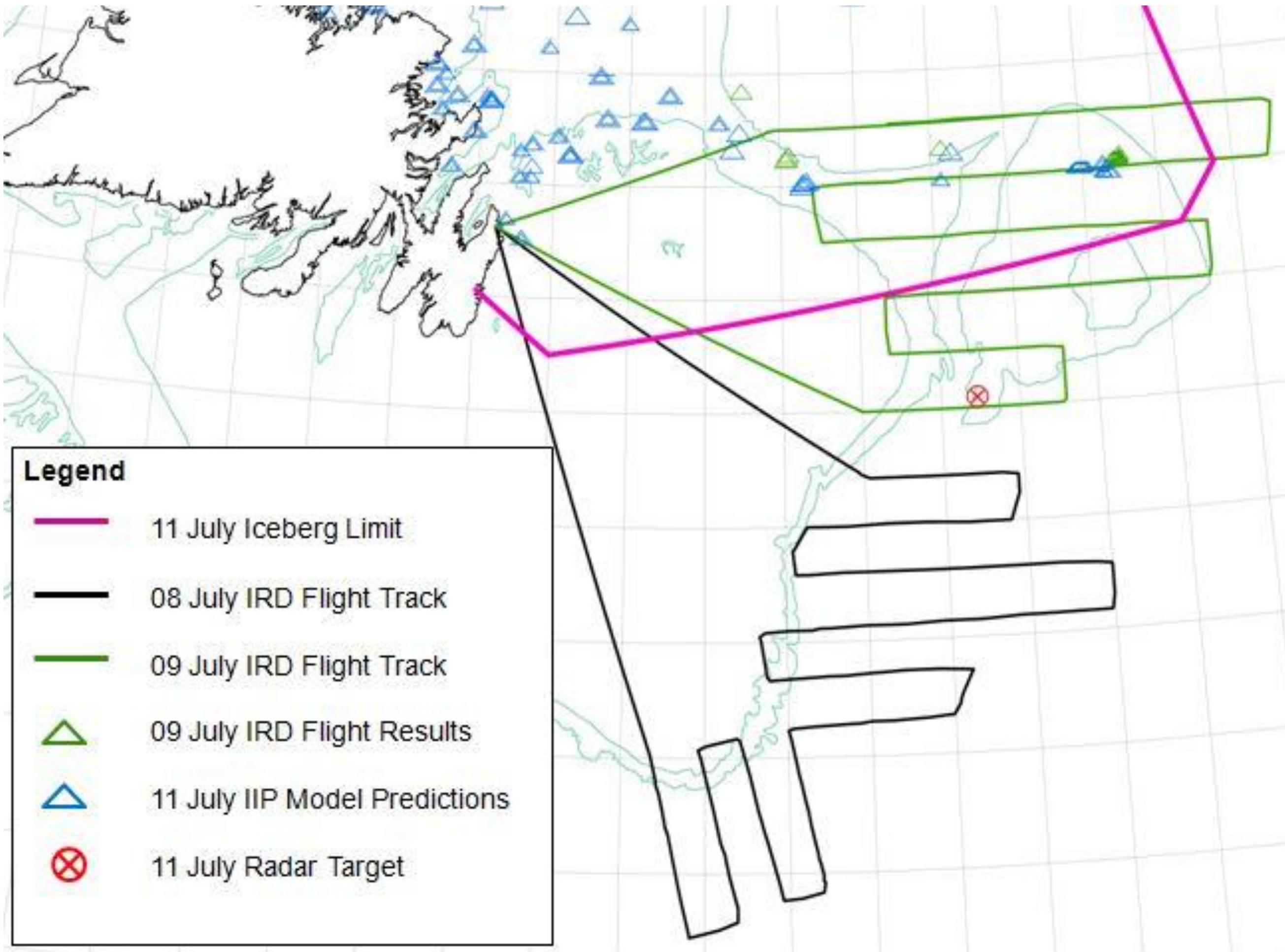


Figure 21. 08 and 09 July IRD Patrol. IIP patrolled the track lines depicted by the black and green lines on 08 and 09 July respectively, and set the Iceberg Limit (ginger-pink line) based on this reconnaissance. The M/V FEDERAL DANUBE reported a stationary radar target outside of the Limit on 11 July. Because the IRD flights saturated this area and did not detect any icebergs, and the SST in the area was 12-15°C, IIP did not adjust the Limit. The report was added to the chart as a radar target.

4. On 22 December 2015, M/V FEDERAL WESER reported a radar target outside the published limit at position 56°07′N, 42°29′W. No product revision was necessary as the information was included in the regular product dissemination window.

5. On 29 December 2015, IIP received notification from CIS that analysis of RADARSAT-2 satellite imagery detected radar targets outside the published limit. The satellite pass occurred on 26 December 2015. Following analysis, CIS entered the targets into BAPS on 28 December 2015. The radar target positions were: (1) 53°21′N, 52°56′W, (2) 50°36′N 52°07′W, and (3) 50°20′N, 53°25′W. The CIS watchstander categorized the targets as low confidence and added them to the chart as radar targets. Due to the fact that the targets were considered as low confidence and recent PAL iceberg reconnaissance did not detect these targets, the CIS watchstander determined the Iceberg Limit did not need to be adjusted.

6. On 05 January, PAL Aerospace reported an iceberg at position 49°12′N, 51°55′W. CIS revised products prior to distribution, and a NOTSHIP was issued.
7. On 10 January, PAL Aerospace and M/V FEDERAL BEAUFORT reported an iceberg at position 46°44′N, 51°38′W, outside the published limit. CIS released revised products, and a NOTSHIP was issued.
8. On 21 September, M/V OOCL BELGIUM reported an iceberg at position 51°55′N, 54°20′W, outside the published limit. No product revision was necessary as the information was incorporated prior to product release.

The two in-season incidents and seven out-of-season incidents when the Iceberg Limit needed to be revised, make a total of nine occasions during the Ice Year when the published Iceberg Limit was inaccurate. The Iceberg Limit accuracy would be expected to be higher in-season when compared to the Ice Year. During the Ice Season, the IIP OPAREA is saturated with aerial reconnaissance. In 2016, there were 342 flights conducted during the season, and only 51 flights conducted outside of the Ice Season.

Iceberg Distribution

As discussed in the Ice and Environmental Conditions section of this report, 2016 was categorized as an 'extreme' season. Although fewer icebergs were reported this year, the expanse of the Iceberg Limit was nearly one degree further south in 2016 than in 2015. Relatively few icebergs were responsible for the southward expanse of the Iceberg Limit. The 2016 Season was the longest on record, totaling 212 days when icebergs were present south of 48°N. On 09 January 2016, the Iceberg Limit moved south of 48°N, 21 days earlier than in 2015. By 25 June 2016, the limit reached its southernmost extent, stretching to 40°N, 45 NM further south of its southernmost extent in 2015. On 08 August 2016, the limit finally receded north of 48°N, close to the monthly climatological mean and slightly earlier than it did in 2015.

Iceberg Reports

The IIP Vessel of Opportunity Observation Program is an essential element of IIP's successful safety record. Individual vessels' voluntary contribution to this program is captured in **Appendix A**. In 2016, 40 vessels from 15 flag states provided 59 information reports regarding icebergs and oceanographic conditions. These reports covered the heavily-travelled transatlantic shipping routes, critical to navigational safety in the North Atlantic Ocean. The IIP OPCEN typically received iceberg reports from vessels via email or from CIS. Midway through the season, IIP discovered that INMARSAT Code 42 (Navigation Hazards and Warnings) transmissions were not being received at the IIP OPCEN. The OPCEN coordinated with MCTS Halifax and MCTS Port Aux Basques to ensure all Code 42 messages pertaining to icebergs were forwarded to IIP. During the remainder of the season, IIP received and processed 33 Code 42 messages. It is unknown how many Code 42 messages were not received by IIP prior to the issue being resolved.

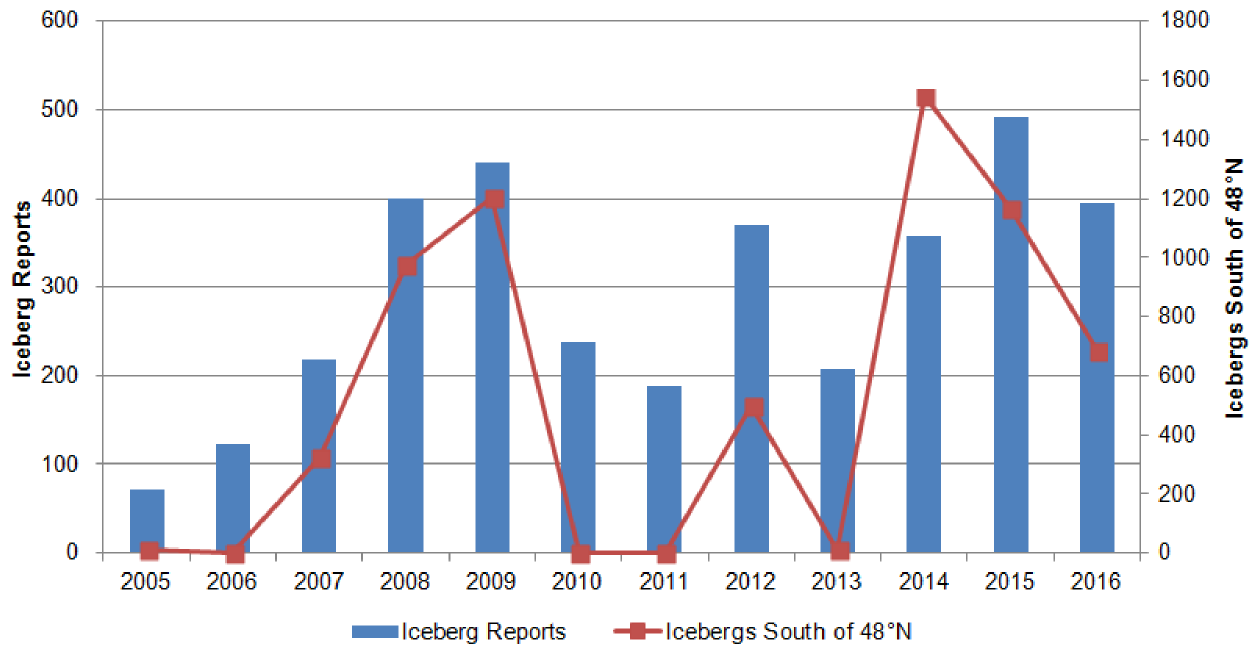


Figure 22. Total Iceberg Reports Received by IIP Each Year Relative to Ice Season Severity Represented by Number of Icebergs Crossing South of 48°N (2005-2016).

During the 2016 Ice Season, IIP's OPCEN received, analyzed, and processed 395 iceberg messages, approximately 20% fewer messages than 2015. **Figure 22** shows the number of iceberg sighting reports received by IIP compared to the number of icebergs reported or drifted south of 48°N for each of the last ten seasons. The first bar of **Figure 23** shows the distribution of these reports by source in 2016, and **Table 2** captures the numerical breakdown of these reports. The number of icebergs reported south of 48°N was 201 more than that of the 115-year average. As discussed in the Ice and Environmental Conditions section, many of these icebergs followed an eastward path, north of the Flemish Cap.

Before entering data from each message into the model, the contents are evaluated for accuracy and validity by the IIP watch. Atmospheric and oceanographic conditions, recent reconnaissance in the same area, and method of detection are all

Reporting Source	Iceberg Sighting Messages	Icebergs Incorporated into Model	Limit-Setting Icebergs
Other	3	3	8
Satellite Recon	2	36	19
Canadian Government	1	1	0
IIP Recon	43	3571	389
Merchant Ships	59	151	76
Commercial Recon	287	6233	404
Total	395	9995	896

Table 2. Numbers of Iceberg Sighting Mmessages, Icebergs Incorporated into the Model, and Limit-Setting Icebergs Broken down by Reporting Source in 2016.

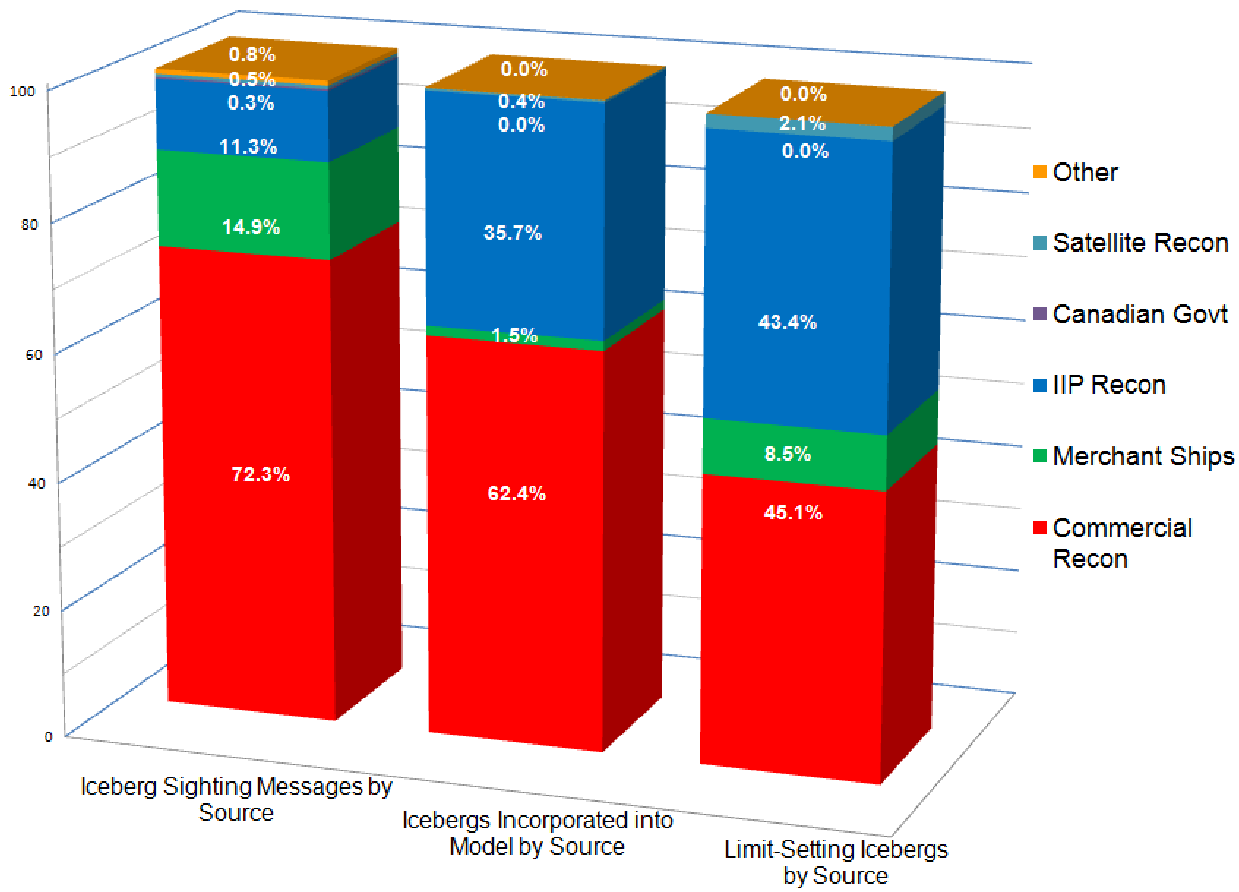


Figure 23. Percentage of Iceberg Sighting Messages, Icebergs Incorporated into the Iceberg Database, and Limit-Setting Icebergs by Reporting Source in 2016.

considered in this process. To ensure the best quality product, IIP's own iceberg sighting messages are given the same level of scrutiny as those from outside sources. After this process, 9,995 individual icebergs were incorporated into BAPS in 2016. The second bar of **Figure 23** shows distribution of these incorporated icebergs by source, and **Table 2, Column 1** captures the numerical breakdown.

Generally, each individual report from merchant ships contained a small number of icebergs, while IIP flight messages typically reported the greatest number of icebergs per flight entered into the IIP database. This season, IIP conducted 43 reconnaissance flights and accounted for 3,571 icebergs incorporated into the model, for an average of 83 icebergs per flight. In comparison, commercial reconnaissance conducted 287 flights and accounted for 6,233 icebergs incorporated into the model, for an average of 22 icebergs per patrol. **Table 2** also captures the reporting source of all iceberg messages received in 2016.

It is important to note that PAL Aerospace was contracted by a variety of clients including the Canadian Government and the oil and gas industry. Regardless of the client, PAL Aerospace shared its iceberg information with IIP. **Figure 24** shows the breakdown of PAL Aerospace aerial reconnaissance. The majority of the flights were flown for Canadian Government organizations other than CIS. The second largest portion of flights were flown for the oil and gas industry concerned with icebergs in the immediate vicinity of offshore oil rigs. Only a small portion of the flights were flown explicitly for CIS to fill iceberg reconnaissance gaps. This year, IIP received 298 iceberg reports from PAL Aerospace compared to the 320 received last year. Of the reports received this year, 84 were for industry versus 127 last year.

Of all icebergs modeled by IIP, the most important are those that define the Iceberg Limit. On any given day, three to seven icebergs defined the Iceberg Limit. With the limit stretching 644 NM east to 37°W and 467 NM south of St. John's, to nearly 40°N in 2016, the distances exceeded the range of PAL Aerospace aircraft. Inherently, PAL Aerospace flights typically focus on interior reconnaissance and provide IIP with valuable iceberg reports throughout the year. However, in 2016, PAL Aerospace reports accounted for 45.1% of icebergs setting the limit, an increase compared to the previous two seasons, and just slightly higher than IIP's own reconnaissance at 43.4%. The increase in limit-setting icebergs identified by PAL Aerospace is due to a multitude of factors. Nineteen percent of IIP IRDs were conducted without the use of the ELTA radar, limiting the crew to visual reconnaissance only. Due to maintenance issues and inclement weather experienced in the IIP OPAREA, described in the Iceberg Reconnaissance and Oceanographic Operations Section, IIP took a more conservative approach to iceberg deletion parameters and left icebergs in the model beyond standard procedures. Drifting icebergs in the model for an extended time period allowed icebergs detected on interior reconnaissance flights, which would normally be removed from the model, to become limit-setting icebergs. The HC-130J's endurance was instrumental to validating model predictions and enabled IIP to adjust the Iceberg Limit with confidence. As stated, HC-130J reconnaissance resulted in detection of 43.4% of limit-setting icebergs. This resource is key to the validation of iceberg drift and deterioration model predictions in regions far to the south and east.

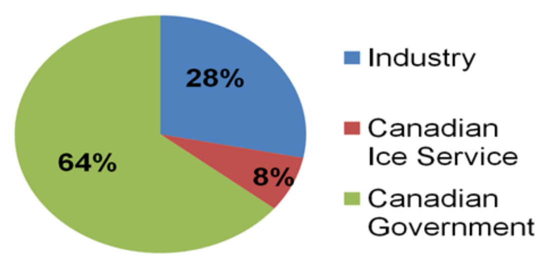


Figure 24. Breakdown of PAL Aerospace Aerial Reconnaissance.

Iceberg Reconnaissance and Oceanographic Operations

Ice Reconnaissance Detachment

The IRD is a sub-unit under Commander, IIP, which is partnered with ASEC. During the 2016 Ice Season, 11 IRDs deployed to observe and report icebergs, sea ice, and oceanographic conditions in the North Atlantic Ocean. All observations were transmitted to the IIP OPCEN in New London, CT where they were entered into BAPS and processed. The IIP OPCEN then created and distributed the NAIS iceberg warning products to the maritime community.

Throughout the 2016 Ice Season, IRDs operated for a total of 102 days and conducted 43 ice reconnaissance patrols. Two days prior to the first IRD, ASEC flew an HC-130J to Groton, CT to provide required Aviation Mission Specialist (AMS) training for IIP personnel. Five IIP personnel returned to ASEC with the aircraft and provided pre-season training for ASEC personnel the following day. The first IRD departed Elizabeth City, NC for St. John's, NL on 19 February, and the last IRD returned to Groton, CT on 14 July.

From a historical perspective, this year is considered an extreme iceberg season based on the number of icebergs crossing south of 48°N. The wide distribution of icebergs within the IIP OPAREA and persistent presence of icebergs south of 48°N required significant aircraft resources to accomplish necessary reconnaissance. This season, icebergs were present south of 48°N for a total of 212 days, the longest period on record. A summary of IRD operations is provided in **Table 3.**

IRD	Deployed Days	Iceberg Patrols	Transit Flights	Patrol en Route	Logistics Flights	Flight Hours
1	10	3	3	0	0	28.2
2	9	4	1	1	0	44.8
3	11	5	2	0	0	44.4
4	10	2	2	0	1	23.2
5	7	4	1	1	0	45.0
6	9	4	2	0	0	38.3
7	9	3	2	0	0	36.1
8	9	3	1	1	0	34.2
9	10	2	1	1	1	40.5
10	9	4	2	0	0	42.2
11	9	4	1	1	0	45.0
Total	**102**	**38**	**18**	**5**	**2**	**421.9**

Table 3. Summary of IRD Operations.

Aerial Iceberg Reconnaissance

Aerial iceberg reconnaissance operations were conducted using the U.S. Coast Guard's HC-130J, a long-range surveillance maritime patrol aircraft. The aircraft is equipped with two radars and an Automatic Identification System (AIS) integrated into the mission system suite. The ELTA-2022 360° X-Band radar is capable of detecting and discriminating surface targets. The APN-241 Weather Radar is capable of detecting surface targets but not identifying them. The AIS receives information transmitted by equipped ships for positive identification and is used to differentiate vessels from icebergs on the radar.

The 360° coverage provided by the ELTA radar supports the use of 25 NM track spacing for patrol planning in order to achieve a 95% probability of detection (POD) of small icebergs (15-60 m). This level of POD is long-established by IIP's Reconnaissance Requirements. Under calm conditions (less than 10 kts of wind, calm seas), IIP expands track spacing to 30 NM while maintaining a 95% POD. Calm environmental conditions warranted the use of 30 NM track spacing during six patrols this season which allowed IIP to cover 20% more patrol area in the same amount of time.

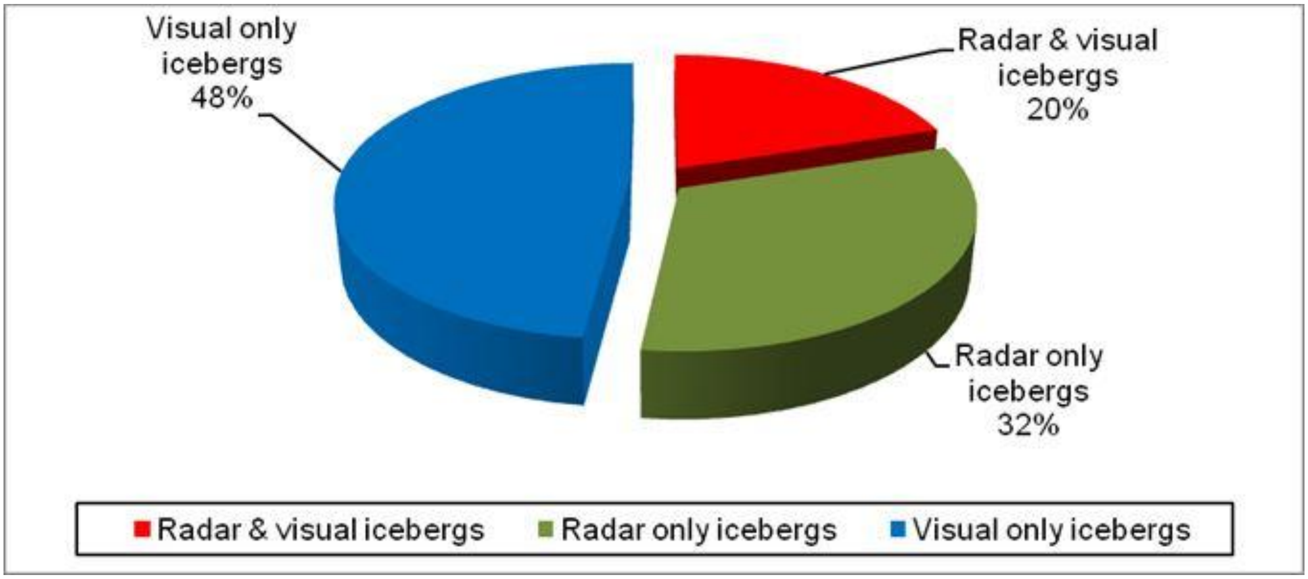


Figure 25. Iceberg Detections by Method.

IRD personnel detected 3,571 icebergs which accounted for 35.7% of the total icebergs added to the IIP database in 2016. Icebergs are detected in one of three ways: (1) combination of radar and visual, (2) radar only, or (3) visual only. This year, 20% of the icebergs were detected by both radar observations and visual sightings. The remaining icebergs were either detected only by radar (32%) or only by visual detection (48%) (**Figure 25**). The percentage of visual-only icebergs nearly doubled the percentage of icebergs detected visually in 2015 (26%) (**Table 4**).

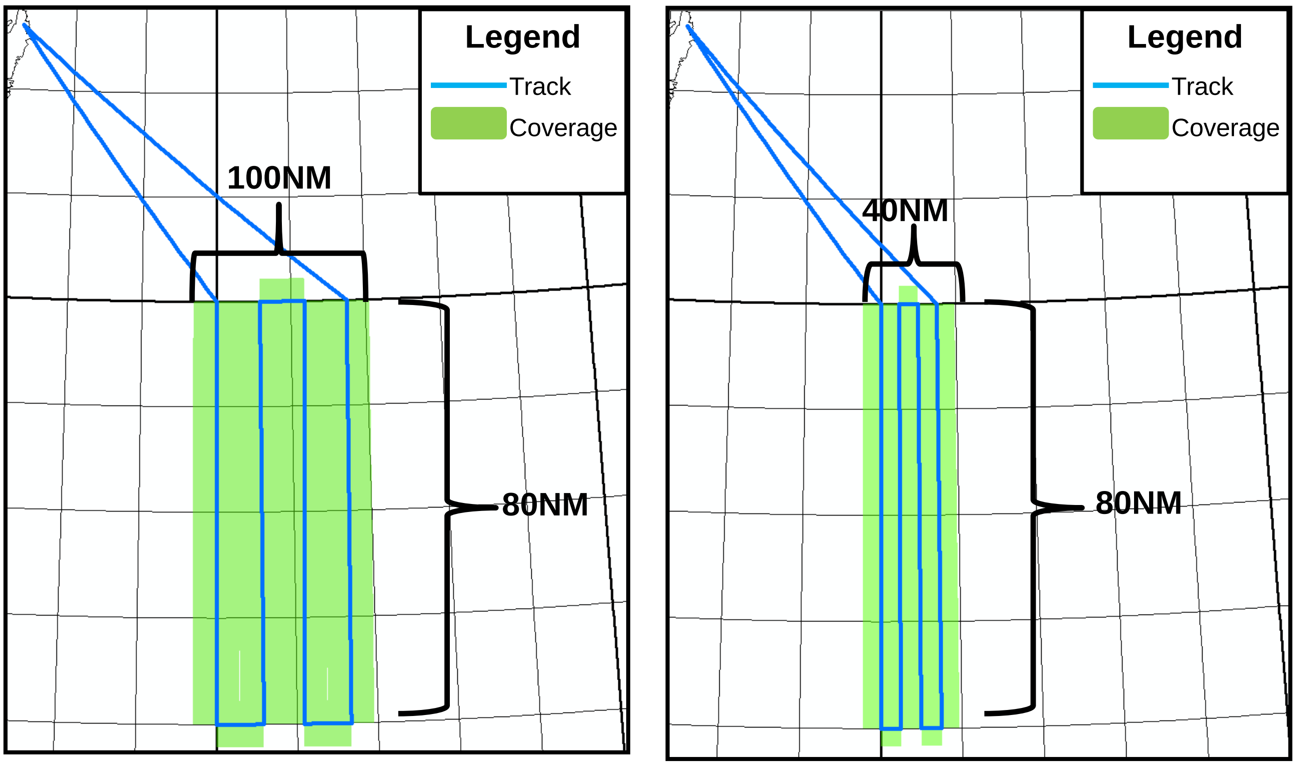
Poor performance of the ELTA radar greatly impacted aerial iceberg reconnaissance this season. As shown in **Figure 25**, IIP detected only 32% of all icebergs using the ELTA radar alone during the 2016 Ice Season. On three separate IRDs, the ELTA radar experienced a casualty that rendered it inoperable. The remote location of IIP's base of operations in St. John's, NL made receiving replacement parts and enacting repairs on the ELTA radar challenging. In all three cases, the ELTA radar could not be repaired during the scheduled IRD.

Year	Radar and Visual	Radar Only	Visual Only
2012	47%	10%	43%
2013	46%	17%	37%
2014	43%	5%	52%
2015	29%	45%	26%
2016	20%	32%	48%

Table 4. Historical Iceberg Detections by Method.

Radar vs. Visual Patrol Efficiency

Radar Patrol – 25 NM Track Spacing | **Visual Patrol – 10 NM Track Spacing**



7hrs, 36 minutes, 1,483 NM track length, 8,000 NM² covered

7hrs, 13 minutes, 1,409 NM track length, 3,200 NM² covered

Figure 26. Radar and Visual Patrol Comparisons for an Example IIP Reconnaissance Flight.

Eight patrols were flown without the ELTA radar capability this season. When the ELTA radar is inoperable, the IRD is forced to fly patrols under "visual-only" specifications (10 NM track spacing instead of normal 25 NM track spacing). The ELTA radar casualties not only reduced the number of radar-detected icebergs, but also resulted in longer and less-efficient patrols. As shown in **Figure 26**, visual-only patrols with reduced track spacing cover 40% less area in a given time period compared to IIP's normal radar-based patrols. IIP must complete two patrols to cover the same area as one patrol when the ELTA radar is operational. Further, patrols are limited to areas with pristine environmental conditions. Clear skies and visibility to the surface are requirements for visual-only patrols. These conditions rarely occur in IIP's meteorologically-active OPAREA. Two patrols were canceled, and two patrols were aborted due to prohibitive on-scene weather that would have otherwise been acceptable with a working ELTA radar.

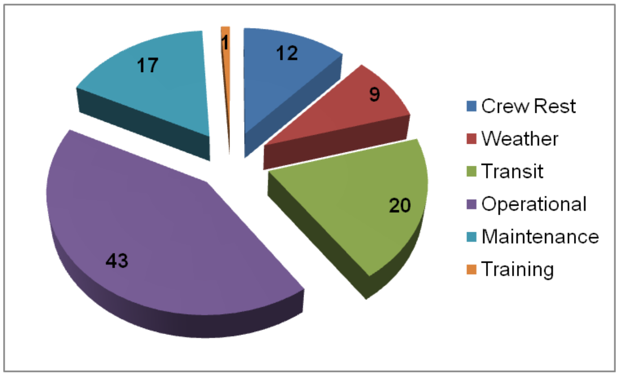


Figure 27. Summary of 2016 IIP Deployment Days.

Figure 27 shows a summary of IIP's deployment days during the 2016 season. Operational days include all patrols, including those conducted during transits. The IRD normally takes one crew rest day during each deployment in accordance with the USCG Aviation Safety Regulations. On IRD 7, two crew rests were taken due to the illness of two critical aircrew members. Crew rest days were typically scheduled to coincide with poor weather days.

Each season, the prevailing OPAREA weather contributes

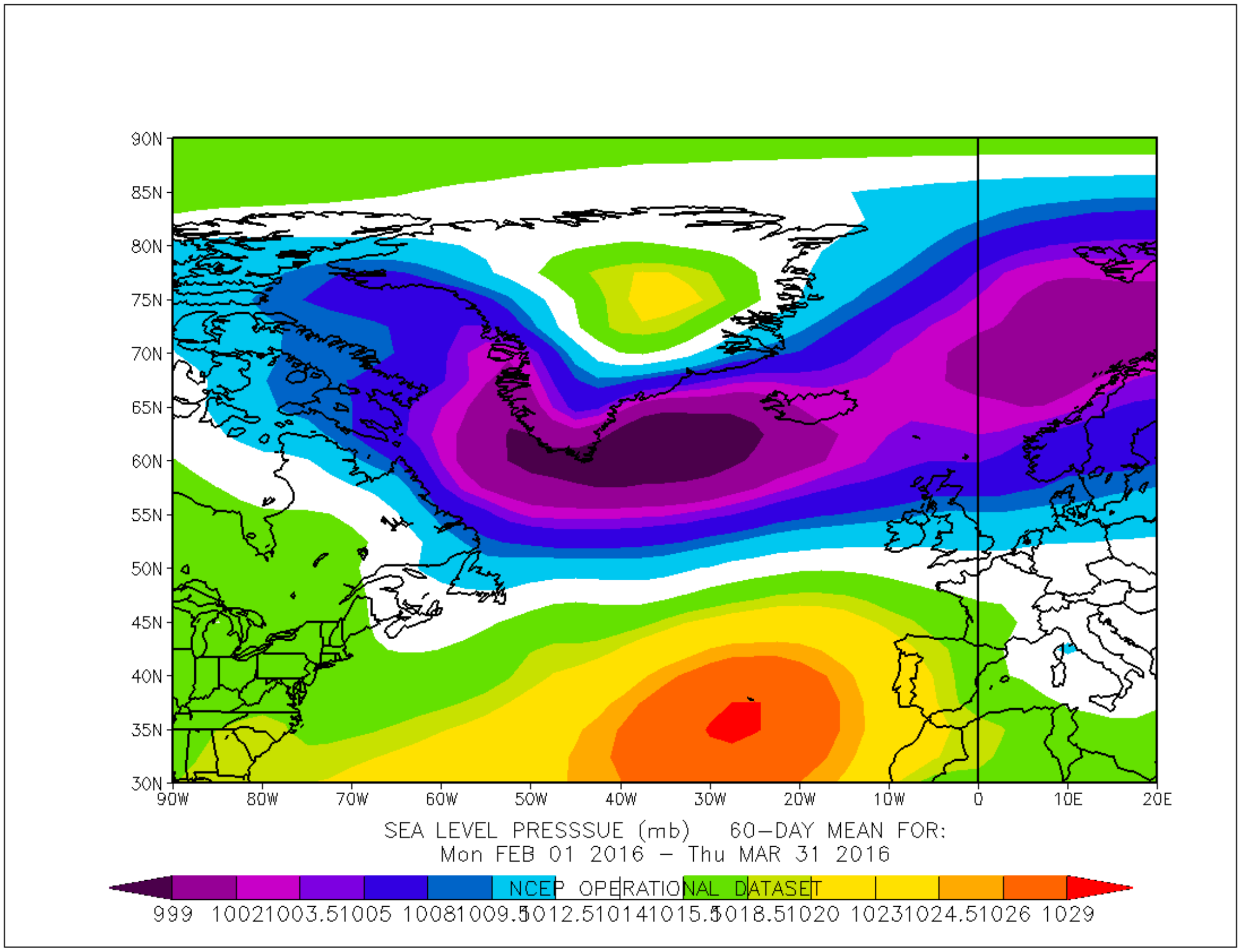


Figure 28. Mean Sea Level Pressure (mb) for February and March 2016. (NOAA/ESRL, 2016)

significantly to the number and effectiveness of reconnaissance patrols. On nine occasions, flights were canceled due to poor weather (**Figure 27**). As previously described, the effect of weather is magnified when the ELTA radar is inoperable. As detailed in the Ice and Environmental Conditions section, the Icelandic Low Pressure System developed west of its climatological position and created a low pressure anomaly over the Labrador Sea in mid-February. This Icelandic Low directed the Northern Hemisphere Storm Track south of its normal path, towards St. John's, NL, resulting in above average significant weather events in the region (**Figure 28**).

2016 Flight Hours

Figure 29 shows the breakdown of the 421.9 flight hours used during the 2016 Ice Season for IIP operations. The flight hours are categorized as transit hours, patrol hours, or logistics hours. Transit hours are hours the aircraft transited to and from specific locations in support of the IIP mission. There were 126.2 hours used this season for transits. These flights are generally to or from St. John's, NL. However, in 2016, transit hours also included a transit to Halifax, NS for planned IIP partner meetings during IRD 4, an unscheduled divert to Atlantic City, NJ due to poor weather in Groton, CT inhibiting the IIP crew from disembarking concluding IRD 3, and an unscheduled divert to Gander, NL due to poor weather in St. John's, NL during the transit to NL on IRD 9.

Patrol hours are the hours associated with iceberg reconnaissance including flight time to and from the reconnaissance area. IIP flew 286.2 patrol hours this season. On five occasions, patrols were conducted during transits to or from St. John's, NL. Only the portions of these flights when the IRD is actively searching for icebergs are counted towards patrol hours. Further, these patrols tend to require additional time due to reconnaissance starting or ending positions north or east of St. John's, NL. Patrols during transit remain a valuable strategy for IIP to mitigate the impact of poor weather or aircraft maintenance and increase IRD reconnaissance effectiveness.

In 2015, the USCG placed restrictions

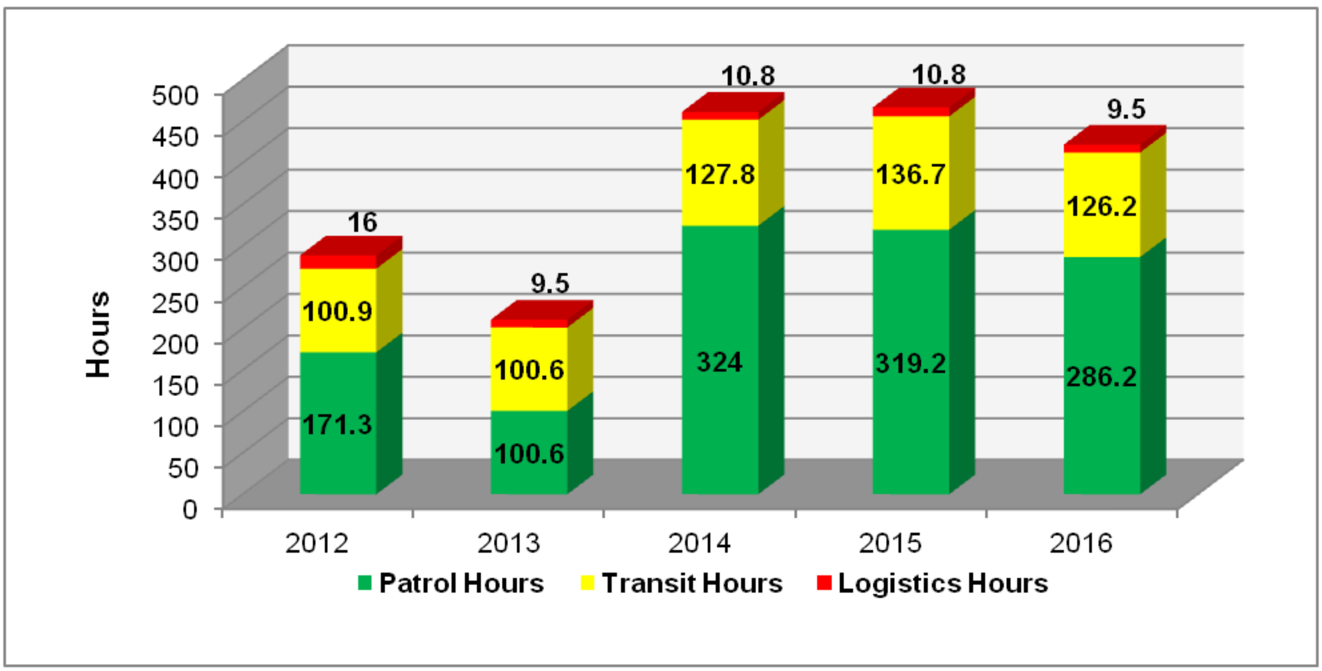


Figure 29. Summary of Flight Hours (2012-2016).

on aircraft speed at patrol altitudes below 2,000 feet. Patrol speeds were restricted to 190 KIAS below 2,000 feet. The restrictions were established to preserve HC-130J airframes. However, this requirement limited how much area the aircraft could cover at patrols flown below this altitude, significantly increasing patrol time when conditions and iceberg density necessitated flying at lower altitudes. Due to persistent presence of low-level stratus clouds in IIP's OPAREA, these restrictions impacted nearly every patrol this season. Depending upon the height of the cloud deck and target density, the IRD was required to fly at low altitudes and slow speeds to maintain visibility of the ocean surface. Conversely, the IRD could choose to fly at higher speeds and altitudes while relying solely upon the ELTA radar. IRDs often used a combination of both methods as on-scene conditions warranted.

Logistics hours are the hours used to support the IIP mission, but do not fall into the previous two categories. Logistics hours accrue when a Coast Guard aircraft is used to transport parts for an aircraft deployed on an IIP mission. In 2016, 9.5 logistics hours were used. The majority of these hours (9.1) were used for a round trip flight from Elizabeth City, NC to St. John's, NL during IRD 9 to deliver parts. This parts delivery was necessary because the required replacement parts were too large to ship via courier and were mandatory for the movement of the aircraft. The remaining 0.4 hours occurred during IRD 4 when a short test flight was required after repairs to the aircraft were conducted.

The number of flight hours needed for IIP to monitor the iceberg danger to transatlantic mariners is closely linked to the number of icebergs observed or modeled south of 48°N. **Figure 30** shows a comparison of flight hours to the number of icebergs drifted south of 48°N from 2006 to 2016. The red line indicates IIP's total flight hours. The blue bars indicate the number of icebergs observed or drifted south of 48°N. As in previous seasons, IIP was allotted 500 Maritime Patrol Aircraft flight hours from Coast Guard Atlantic Area for its operations in 2016. IIP used 429.1 hours compared to 466.7 in 2015. While the iceberg population was smaller this season, the distribution of icebergs was nearly the same as in 2015 requiring similar reconnaissance coverage. In addition, the ELTA radar casualties required additional flight time to cover IIP's OPAREA.

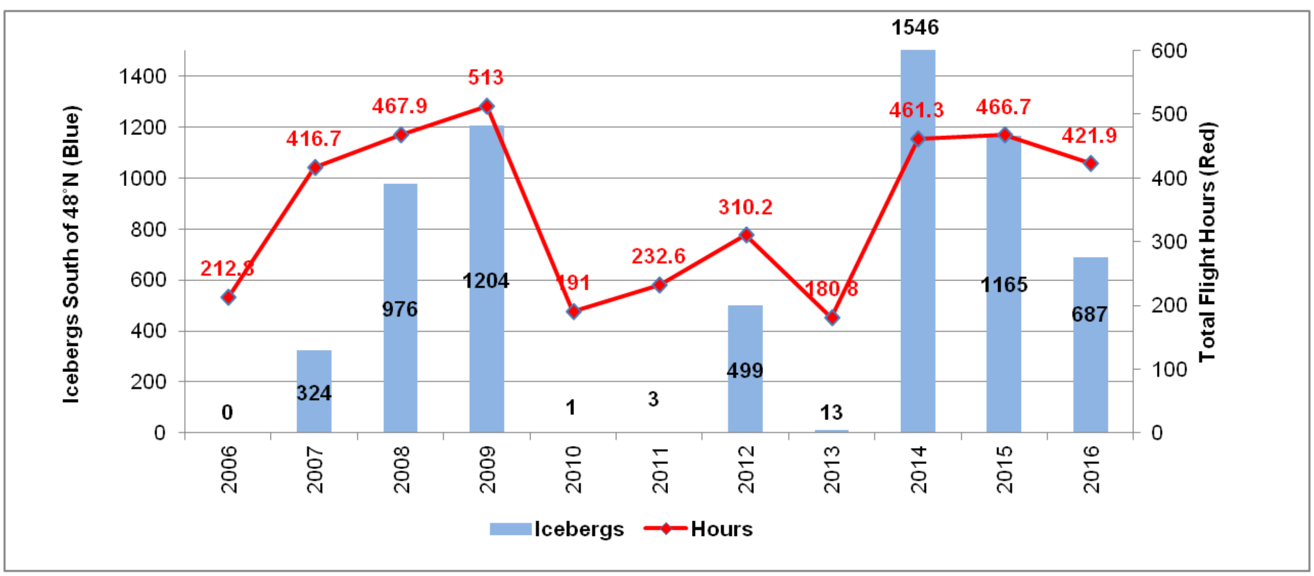


Figure 30. Flight Hours Versus Icebergs South of 48°N (2006-2016).

On two occasions, IIP personnel were required to return to New London, CT via commercial means. At the end of IRD 3, poor weather conditions and disabled airport navigational aids prevented landing in Groton, CT, and the aircraft diverted to Atlantic City, NJ. On the second occasion during IRD 9, ASEC required the returning aircraft to proceed directly to Elizabeth City due to an aircraft maintenance issue. The IIP flew back to New London, CT via commercial carrier. These days were counted as additional transit days in **Figure 27.**

NAIS Reconnaissance Results

IIP continued to leverage its NAIS partnership with CIS to maximize efficient use of aerial reconnaissance resources. IIP coordinated flight plans with CIS to minimize overlap and maximize efficiency. **Figure 31** depicts the NAIS flight hours for 2016. Data provided includes hours flown by each service. CIS contracted PAL Aerospace for a total of 113.1 hours resulting in a total of 399.3 patrol hours in support of NAIS reconnaissance.

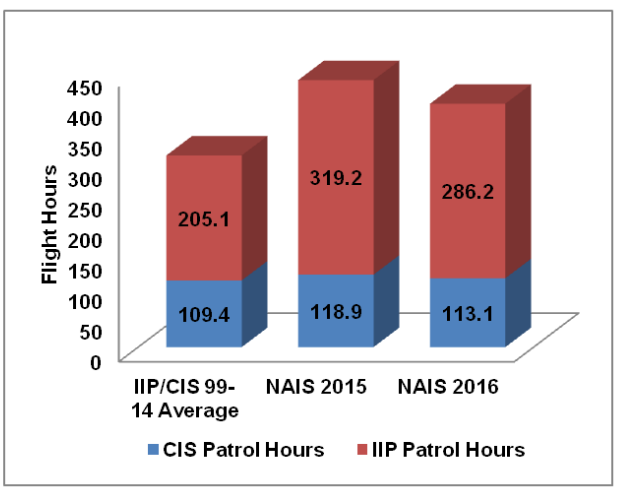


Figure 31. NAIS Flight Hours (February - August 2016).

The NAIS region is divided into five areas based on the risk of iceberg collision for vessels in the transatlantic shipping lanes. Areas "A" and "B" are monitored to determine the overall iceberg population early in the season and to predict the continued threat of icebergs drifting south in the Labrador Current. Once the Iceberg Limit extends into areas "C", "D", and "E", iceberg reconnaissance flights are mainly focused in these regions. Similar to the 2015 Ice Season, significant expansion occurred to the south and east during 2016, and once again area D was further divided into four quadrants to more clearly show coverage of the expansive limit. **Figure 32** shows a one-day snapshot of recent NAIS reconnaissance coverage on 30 June 2016.

Vessel Interactions

Most of the HC-130J's on-scene patrol time is focused on locating and classifying icebergs using visual and radar reconnaissance methods. During patrols, the IRD also communicated directly with the maritime community to request recent iceberg sighting information. This communication took two forms: a SECURITE` broadcast to all vessels in vicinity of the aircraft and direct calls to vessels identified by AIS. The information coming from the individual vessels proved especially useful during periods of reduced visibility or when numerous small vessels not equipped with AIS were present in the reconnaissance area. The IRD did not rely on vessel reports to identify or classify icebergs. However, vessel information was an insightful confirmation of data provided by the aircraft's radar. During the 2016 season, IRDs made 106 general SECURITE` broadcasts and 79 direct vessel callouts. IRD 7 also provided one urgent iceberg warning broadcast to report an iceberg sighted near the Iceberg Limit.

Oceanographic Operations

IIP employed nine drifting buoys on and near the Grand Banks of Newfoundland to collect near real-time ocean current information. The data were used to refine the historical ocean currents database within

BAPS in order to improve the accuracy of the model-calculated drift for each iceberg.

IIP drifting buoys are based on the SVP design. The buoys deployed in 2016 were drogued at 15 m and 50 m. The buoys with drogues centered at 50 m were deployed in deep waters of the North Atlantic, most frequently in the offshore branch of the Labrador Current. This current brings icebergs southward along the edge of the continental shelf and into the shipping lanes, a primary threat. The drifting buoys with drogues centered at 15 m were used to measure the currents in the shallower coastal waters on the Grand Banks and the inshore branch of the Labrador Current, another southerly route for icebergs to travel.

IIP used reconnaissance aircraft and Canadian Coast Guard (CCG) ships to deploy the drifting buoys. Air deployments were conducted during regular reconnaissance patrols using an air-drop package prepared by IIP and ASEC personnel. Air deployments were conducted offshore in regions outside of the normal range of the CCG ships. Ship deployments were conducted on or near the Grand Banks through a cooperative arrangement with CCG ships operating out of St. John's, NL.

In 2016, IIP air-deployed seven 50 m SVP drifting buoys (**Figure 33**). One air-deployed 50 m buoy failed to transmit any data, and another failed within 15 days of deployment. CCG ships deployed one 15 m

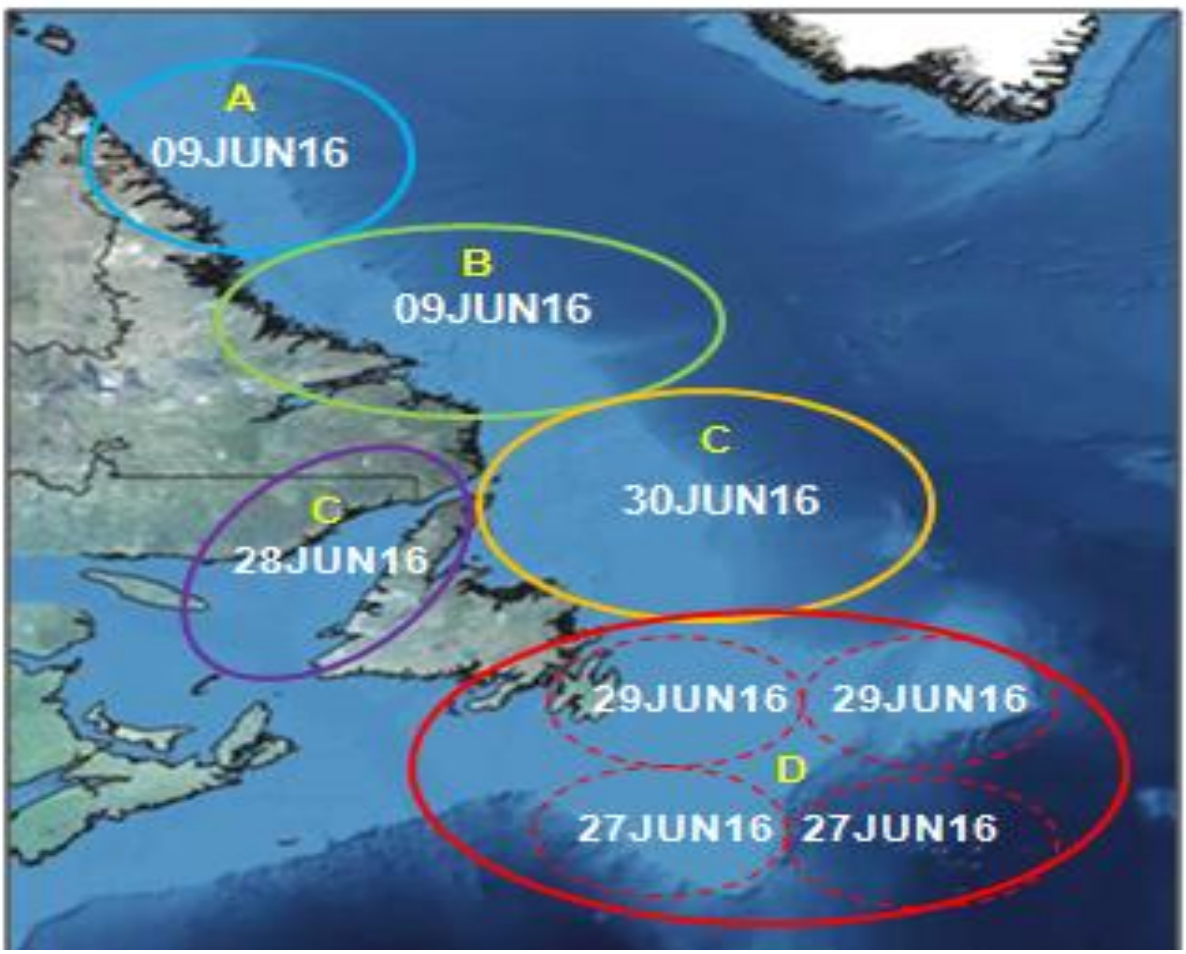


Figure 32. NAIS Coverage Status on 30 June 2016.

buoy and one 50 m buoy. All were successfully deployed without incident. **Figure 34** shows each of the buoy deployment locations and tracks for the 2016 season. The green stars represent the deployment location for each buoy.

As described in the 2015 Annual Report, IIP prototyped the use of SVP buoys using a new tracking system. Traditionally, IIP deployed buoys tracked by the Argos satellite system but began a transition to Iridium buoys in 2016 after a successful operational evaluation in 2015. All remaining Argos buoys were deployed in 2016. IIP will employ Iridium buoys exclusively in 2017.

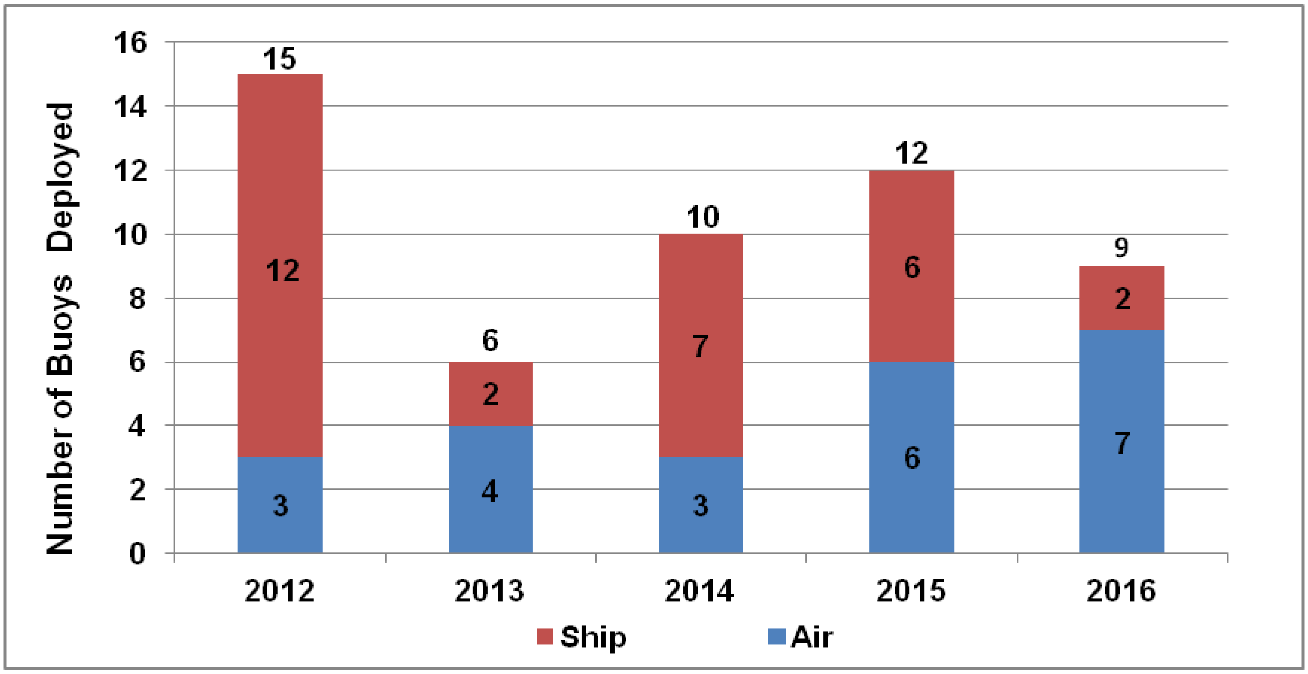


Figure 33. IIP SVP Drifting Buoy Deployments by Year (2012-2016).

Commemorative Wreath Drops

Each year, IIP deploys commemorative wreaths in conjunction with reconnaissance operations to remember the lives lost at sea in the North Atlantic Ocean. This year, IIP held two memorial services to commemorate the 104th anniversary of the sinking of the RMS TITANIC. The first ceremony was held at the IIP offices in New London, CT on the morning of 30 March. The second ceremony was held later that day at Fairview Lawn Cemetery in Halifax, Nova Scotia (NS), the final resting place for 120 victims of the RMS TITANIC tragedy. IRD 4 conducted a visit to Halifax for partner meetings and held the ceremony at sunset following these meetings. All four wreaths dedicated during the ceremonies were deployed from an HC-130J aircraft on 08 April 2016. The wreaths were donated by the TITANIC International Society, the TITANIC Historical Society, TITANIC Heroes, and Fisher's Florist of New London, CT.

On 06 June, IIP held a memorial ceremony at City Pier in New London, CT commemorating the sacrifices of those serving as part of the Greenland Patrol during World War II. The Chief Executive Officer of the National Coast Guard Museum invited IIP to hold the ceremony at New London City Pier, which is the future site of the Museum. The wreath dedicated at the memorial service was deployed in the North Atlantic from an HC-130J aircraft on 23 June. This wreath was donated by the Coast Guard Foundation.

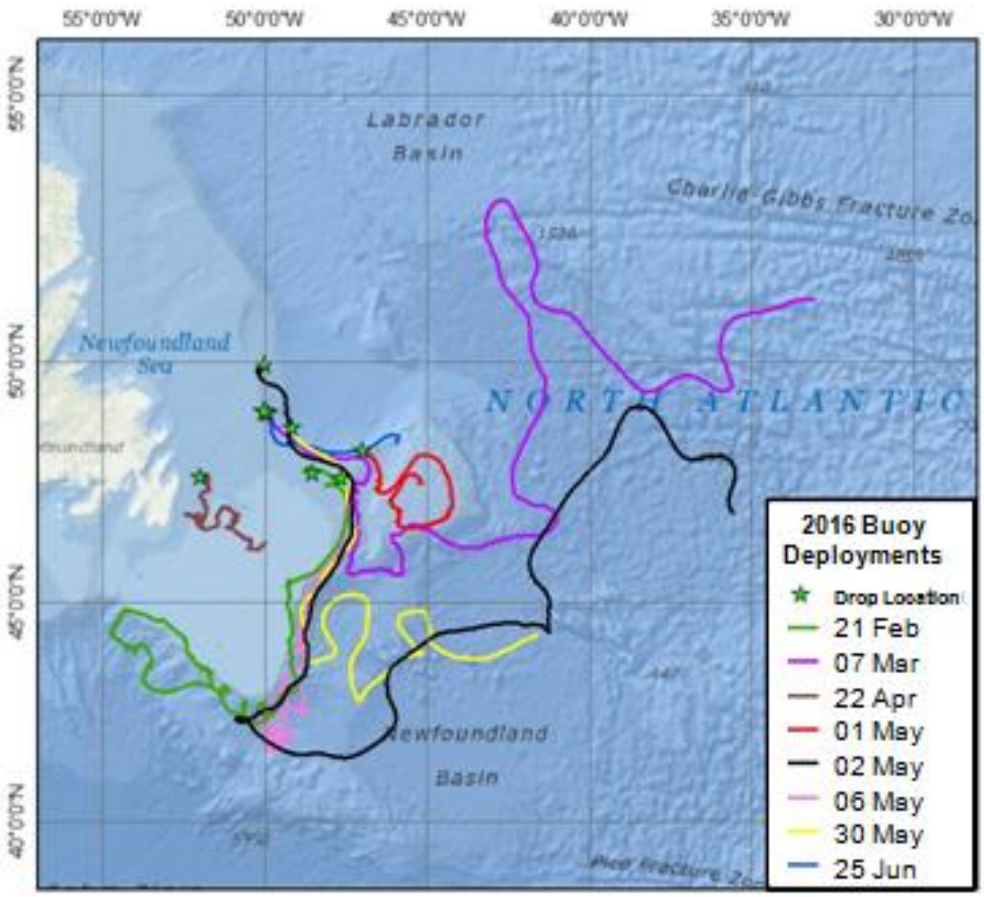


Figure 34. Figure 33. SVP Drifting Buoy Composite Tracks.

Satellite Reconnaissance

IIP began implementation of its commercial SAR satellite CONOPS in 2016 (**Figure 35**). The CONOPS includes a three-tiered geographic approach for IIP's use of satellite data. Most notably, data collected south of 50°N was not incorporated into the IIP iceberg database. Instead, this information will be used for research projects to determine satellite iceberg detection accuracy and viability. As IIP gains confidence in satellite data, IIP will also use satellite collections south of 50°N to prompt aerial reconnaissance. A summary of this CONOPS is included in this report as **Appendix C**. The net result of this change in policy was an overall reduction in the number of satellite-derived iceberg information reports ingested into the IIP iceberg database. While the amount of satellite data used operationally decreased, this measure ensured that unreliable and unproven data did not impact the location of the Iceberg Limit.

During the 2016 season, IIP successfully acquired 43 RADARSAT-2 images through its partnership with the NIC. NIC accesses this data under the Northern View Program. Northern View is an arrangement between NGA and Canada's

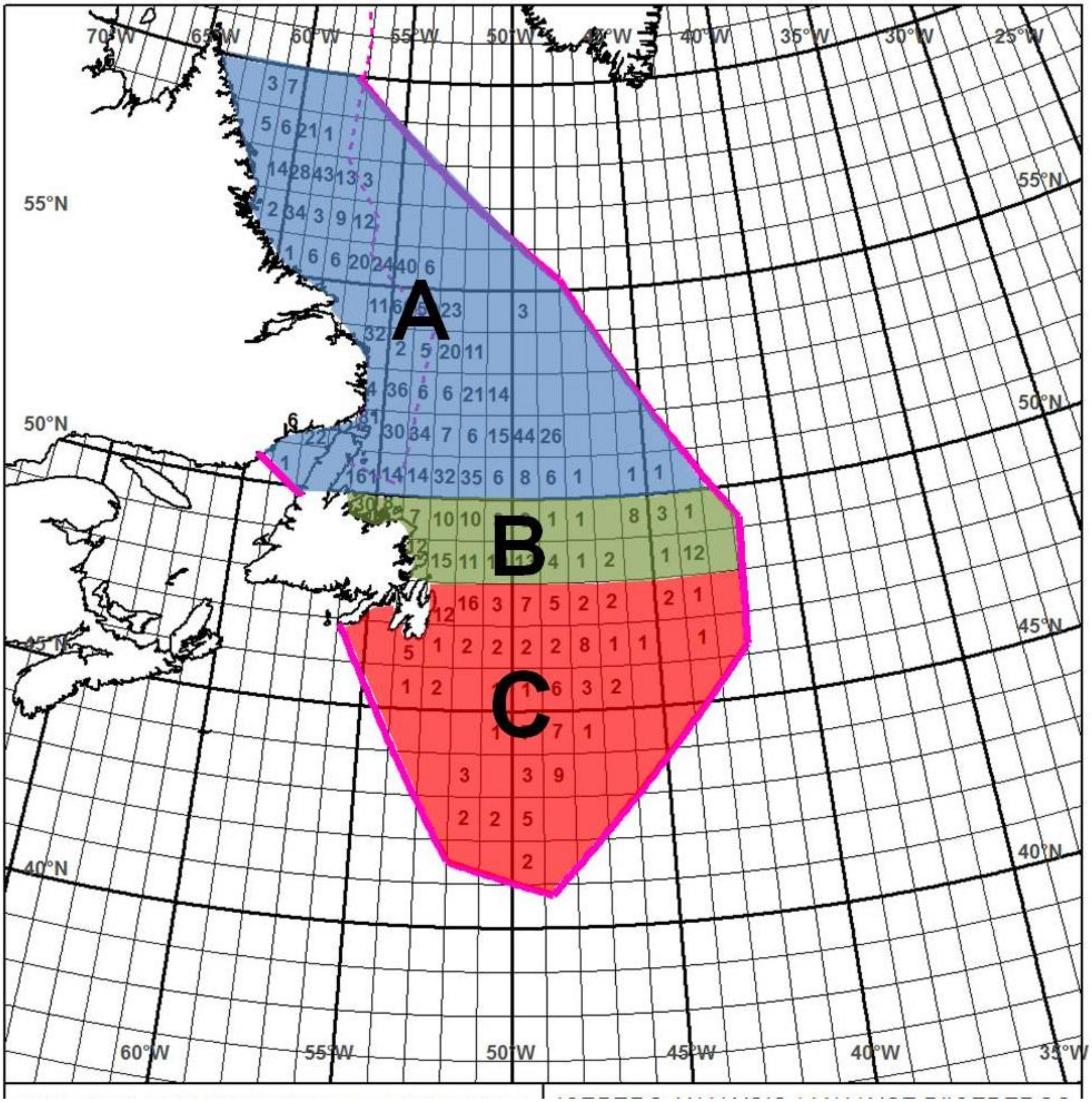


Figure 35. IIP Satellite Reconnaissance Strategy Regions from Satellite CONOPS. Iceberg Limit shown is typical for late May and early June.

Department of National Defense (DND) to share RADARSAT-2 imagery between the U.S. and Canada. An improved ordering process with earlier data request submission deadlines than used in previous years greatly eased IIP's ability to acquire data in desired areas and collection modes. In addition, IIP continued to collect open-source Sentinel-1a data provided by the European Space Agency (ESA).

During the 2016 season, IIP focused on satellite collections south of 50°N, the area currently designated for research. Data collected from this region are particularly valuable when compared with coincident aerial observation. Coincident data provides

RADARSAT-2 Extra Fine Mode – 12 May 2016 0824Z

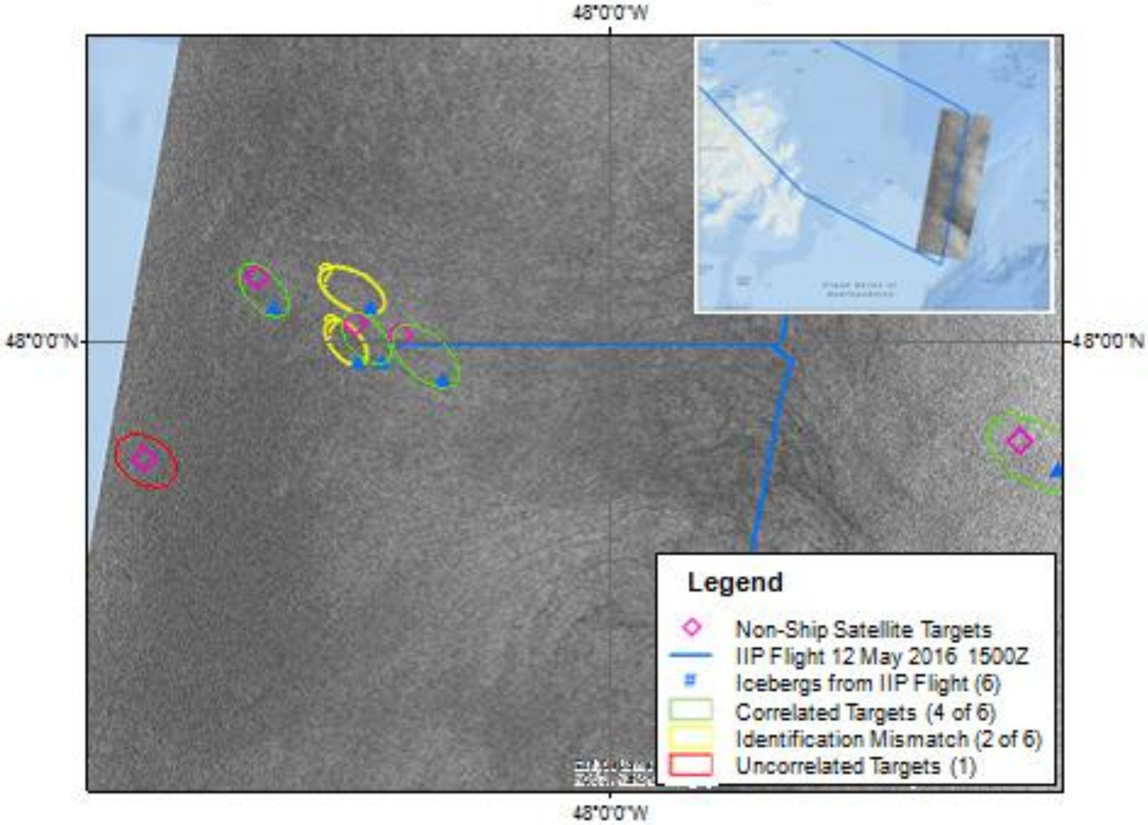


Figure 36. IIP Flight Results Compared with RADARSAT-2 Extra-Fine Mode Collection from 12 May 2016.

IIP with the ability to evaluate the accuracy and reliability of satellite data. However, the previously-mentioned weather challenges and ELTA radar casualties made coincident observations by the IRD challenging. Only four coincident satellite/IRD collections were made this season. Each of these flights were completed in conjunction with routine reconnaissance. IIP is conducting an analysis and evaluation of these collections and intends to complete them prior to the start of the 2017 Ice Season.

IIP collected RADARSAT-2 Extra-Fine mode images for the first time this season. Extra-Fine mode was first introduced in 2014 and offers a unique combination of high resolution (5 m) and wide area coverage (125 x 125 km). This combination of resolution and coverage makes Extra-Fine mode an attractive option for iceberg reconnaissance. IIP was able to conduct a coincident IRD flight with an Extra-Fine collection on 12 May (**Figure 36**). Due to cloud cover, IIP was only able to detect icebergs using the ELTA radar. The satellite pass was analyzed by a ship detection algorithm at MDA, the company that owns the RADARSAT-2 satellite. The IIP flight detected six radar icebergs. The satellite image analysis detected all of these targets. It classified four of them as non-ship targets (likely icebergs) and the other two as ships. The satellite pass only detected one uncorrelated target. Due to the lack of visibility, the IIP flight was unable to make 100% confirmation of targets as ships or icebergs. Further under-flights are required for more conclusive results. This initial analysis suggests that Extra-Fine mode may be feasible for use in IIP operations, and IIP will continue to investigate its use in 2017.

In the Coast Guard Authorization Act of 2015, Congress directed the USCG to submit a report on IIP's current operations and alternatives to carrying out the IIP mission, including satellite surveillance technology. The report was to specifically include the ability for each surveillance technology to: 1) provide timely data on ice conditions with the highest possible resolution and accuracy; (2) operate in all weather conditions or any time of day; and 3) be more cost-effective than the cost of current operations. The report was submitted to Congress in November 2016. IIP concluded, after evaluating the most promising alternatives for carrying out the IIP mission (satellite reconnaissance, commercial aerial reconnaissance, and unmanned aircraft systems reconnaissance) that none can currently meet mission needs. The evaluated alternatives fail to provide a cost-effective means that achieves the all-weather capability and high probability of detection required for the mission in comparison to the current combination of Coast Guard aircraft and no-cost commercial satellite reconnaissance operations.

In May 2016, IIP was approved and received funding to acquire a license for iceberg detection software. Once installed in the fall of 2016, this software will provide IIP with the capability to ingest and analyze satellite data within its own OPCEN. IIP intends to fully implement this new capability in 2017. This added capacity will allow IIP to analyze and ingest satellite data in near real-time without reliance on third party analysts. Further, IIP personnel will begin to develop the imagery analysis skills necessary for further expansion of the IIP satellite mission.

References

Canadian Ice Service. (2015a). Seasonal Outlook, Gulf of St. Lawrence, East Newfoundland Waters and Labrador Coast, Winter 2015-2016. Issued by Canadian Ice Service of Environment Canada, 01 December 2015.

Canadian Ice Service. (2015b). Sea Ice and Iceberg Seasonal Outlook 2015-2016. Presented at IIP Annual Conference on 10 December 2015.

Canadian Ice Service. (2016a). Seasonal Summary for Eastern Canada – Winter 2015-2016, Retrieved 07 August 2016 from: http://www.ec.gc.ca/glaces-ice/default.asp?lang=En&n=E4444163-1.

Canadian Ice Service. (2016b). CIS Ice Charts of East Newfoundland Waters. Retrieved 07 November 2016 from: http://iceweb1.cis.ec.gc.ca/Archive/?lang=en.

Canadian Ice Service. (2016c). Departure from Normal Concentration Chart for 11 April 2016. Retrieved 15 April 2016 from: http://www.ec.gc.ca/glaces-ice/default.asp .

Canadian Ice Service. (2016d). Single Season: Weekly Ice Coverage for the season 2014/2016. Created with CIS IceGraph program on 26 November 2016: http://iceweb1.cis.ec.gc.ca/Prod20/page2.xhtml?CanID=11091&lang=en.

Environment and Climate Change Canada (2016). Climate and Historical Weather, El Niño Retrieved 07 November 2016 from: http://www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=1C524B98-1.

Hurrell, James. (1995). NAO Index Data provided by the Climate Analysis Section, NCAR, Boulder, USA, Hurrell. Updated regularly. Retrieved 07 October 2016 from: https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based.

IIP. (1994). Report of the International Ice Patrol in the North Atlantic (1994 Season), Bulletin No. 80, Appendix C.

Johns Hopkins University. (2016). Applied Physics Laboratory Ocean Remote Sensing Group, Water Surface Temperature, Land and Clouds from Channel 2 NOAA-18 AVHRR 14 April. Retrieved from: http://fermi.jhuapl.edu/avhrr/SW/.

National Oceanic and Atmospheric Administration/Earth Systems Research Laboratory. (NOAA/ESRL) (2016). Physical Science Division. Sea Level Pressure, Monthly Mean Composite. Interactive Plotting and Analysis Pages. Retrieved 23 November from: http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/plot20thc.v2.pl.

National Oceanic and Atmospheric Administration/National Weather Service. (2016a). National Centers for Environmental Prediction, Climate Prediction Center. Retrieved 03 October 2016 from: http://www.cpc.ncep.noaa.gov/products/global_monitoring/temperature/ecanada_1yrtemp.shtml.

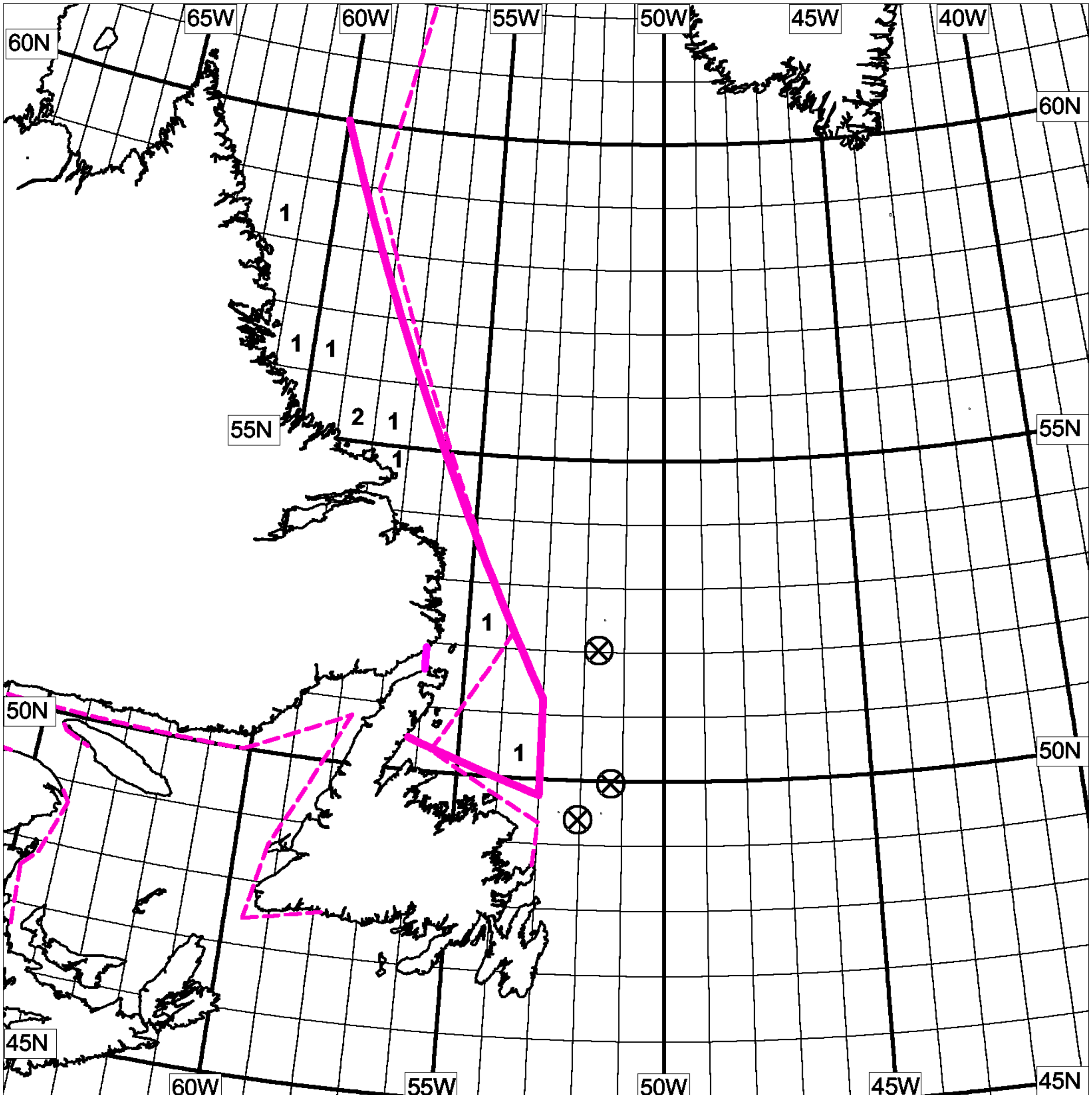
National Oceanic and Atmospheric Administration/National Weather Service. (2016b). National Centers for Environmental Prediction, Climate Prediction Center. Retrieved 07 November 2016 from: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_change.shtml.

National Oceanic and Atmospheric Administration/National Weather Service (2016b). NOAA Climate Prediction Center, Daily NAO Index. Retrieved 24 September 2016 from: http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao_index.html

Naval Oceanographic Office (2016). Ocean Features Analysis, Coast Guard North Atlantic Color, 21 May 2016. Retrieved on 25 May 2016 from: https://oceanography.navy.mil/legacy/web/cgi-bin/graphic.pl/metoc/337/19/0-0-5/1

Nav Canada (2016). Aviation Weather Web Site. Forecasts and Observations / Graphical Forecast Area. Retrieved on 05 March and 04 April 2016 from: https://flightplanning.navcanada.ca/cgi-bin/GenerProduit.pl?Produit=GFA&Region=33&Langue=anglais

Semi-Monthly Iceberg Charts



NORTH AMERICAN ICE SERVICE
SERVICE DES GLACES
DE L'AMERIQUE DU NORD

ICEBERG ANALYSIS / ANALYSE D'ICEBERGS
FOR / POUR 0000 UTC

01 JAN / JAN 2016

ICEBERG LIMIT / LIMITE DES ICEBERGS

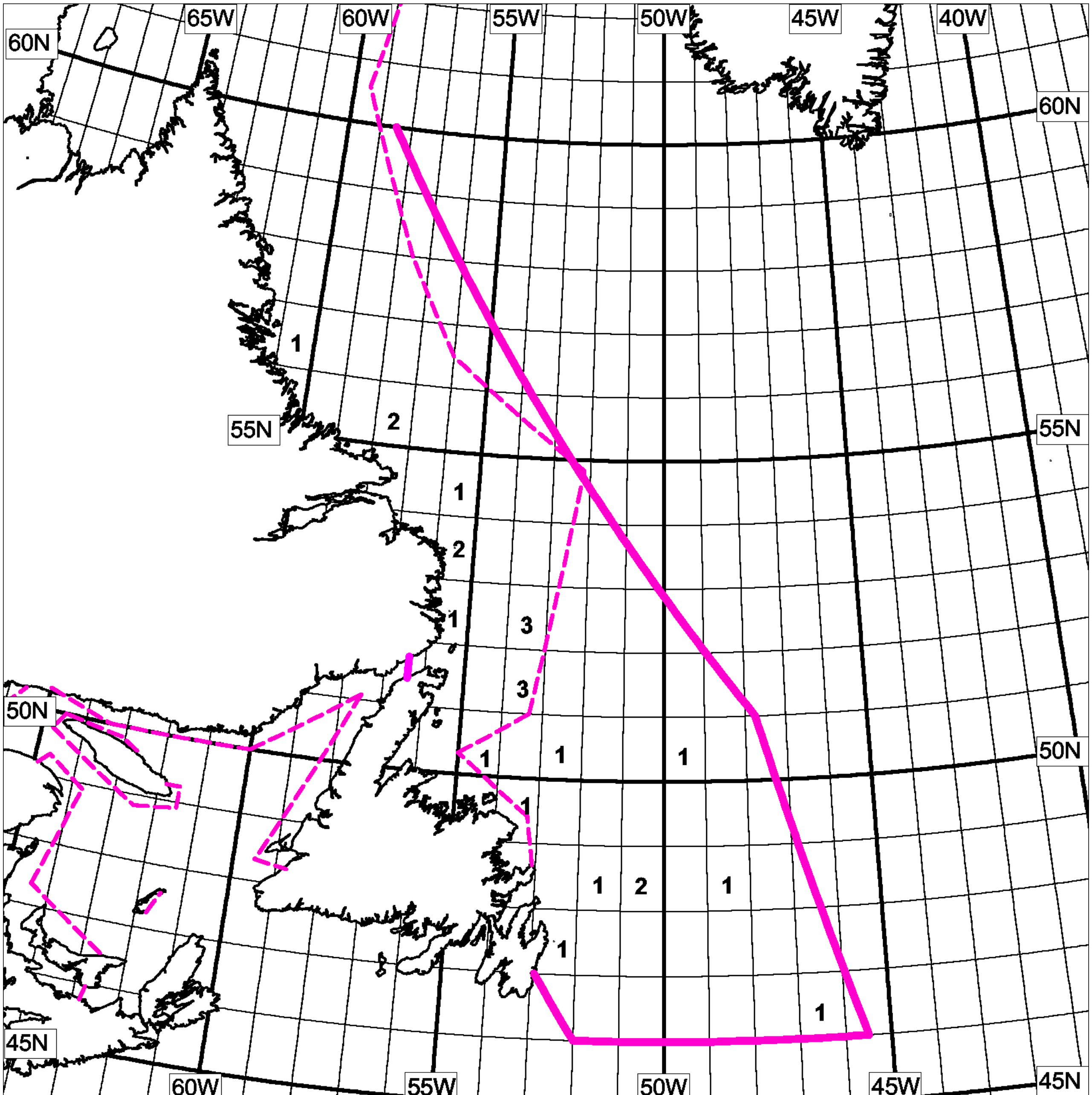
SEA ICE LIMIT / LIMITE DES GLACES

— ICEBERGS PER DEGREE SQUARE / ICEBERGS PAR DEGRE CARRE

⊗ — RADAR TARGET OUTSIDE ICEBERG LIMIT / CIBLE RADAR A L'EXTERIEUR DE LA LIMITE DES ICEBERGS

NOTE / NOTER:

For more information:
Pour plus de renseignement:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca



NORTH AMERICAN ICE SERVICE
SERVICE DES GLACES
DE L'AMERIQUE DU NORD

ICEBERG ANALYSIS / ANALYSE D'ICEBERGS
FOR / POUR 0000 UTC

15 JAN / JAN 2016

ICEBERG LIMIT / LIMITE DES ICEBERGS

SEA ICE LIMIT / LIMITE DES GLACES

\# ICEBERGS PER DEGREE SQUARE
ICEBERGS PAR DEGRE CARRE

⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT
CIBLE RADAR A L'EXTERIEUR DE LA
LIMITE DES ICEBERGS

NOTE / NOTER:

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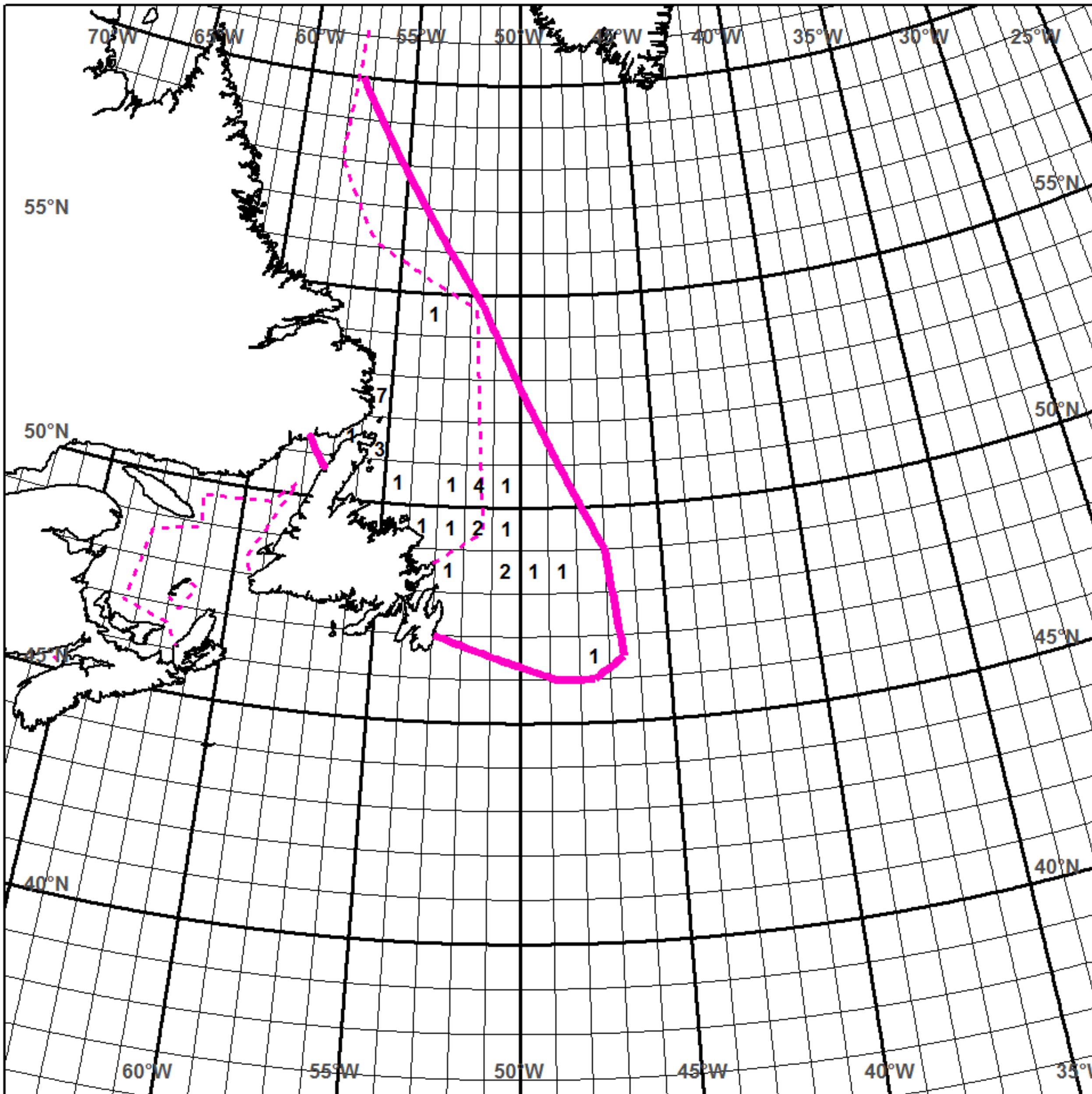
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca



NORTH AMERICAN ICE SERVICE
SERVICE DES GLACES
DE L'AMERIQUE DU NORD

ICEBERG ANALYSIS / ANALYSE D'ICEBERGS
FOR / POUR 0000 UTC

01 FEB / FEV 2016

ICEBERG LIMIT / LIMITE DES ICEBERGS

SEA ICE LIMIT / LIMITE DES GLACES

— ICEBERGS PER DEGREE SQUARE / ICEBERGS PAR DEGRE CARRE

⊗ — RADAR TARGET OUTSIDE ICEBERG LIMIT / CIBLE RADAR A L'EXTERIEUR DE LA LIMITE DES ICEBERGS

NOTE / NOTER:

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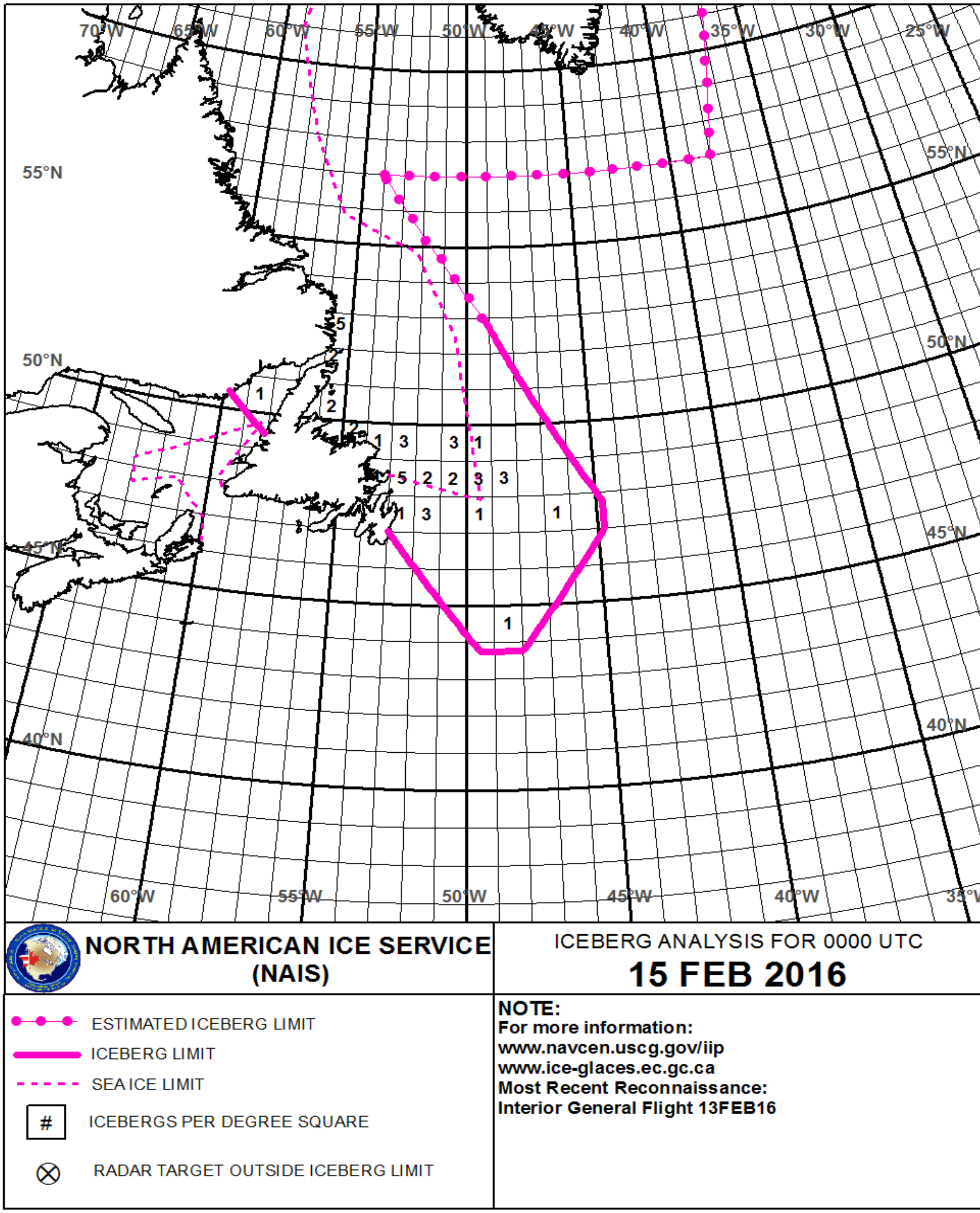
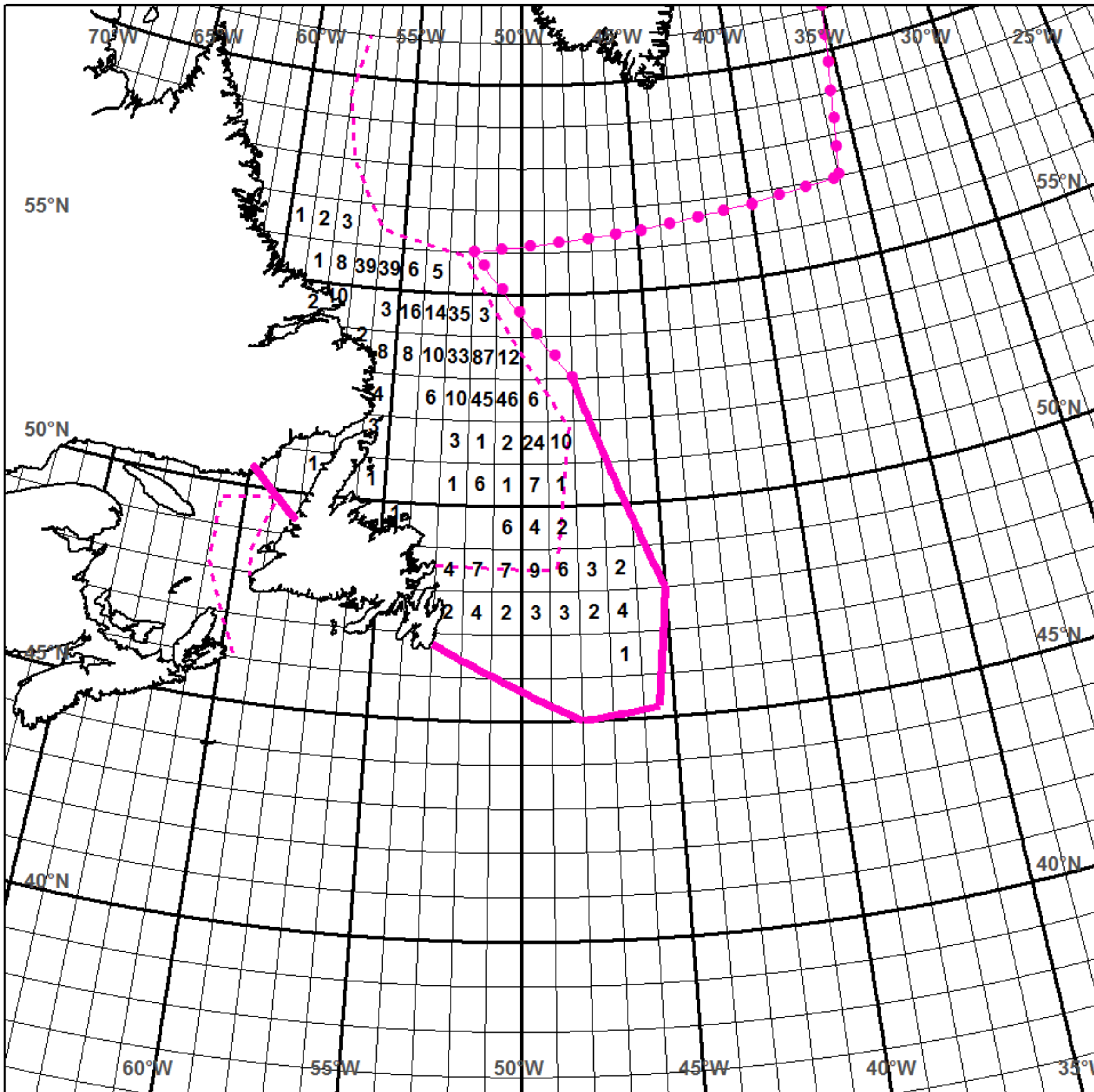
www.ice-glaces.ec.gc.ca



This Chart is the First of the New NAIS Products. Significant improvements include an Estimated Iceberg Limit north of 53°N represented by a dotted ginger-pink line. It is a result of the 09 December 2015 NAIS product improvement workshop.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 MAR 2016

ESTIMATED ICEBERG LIMIT

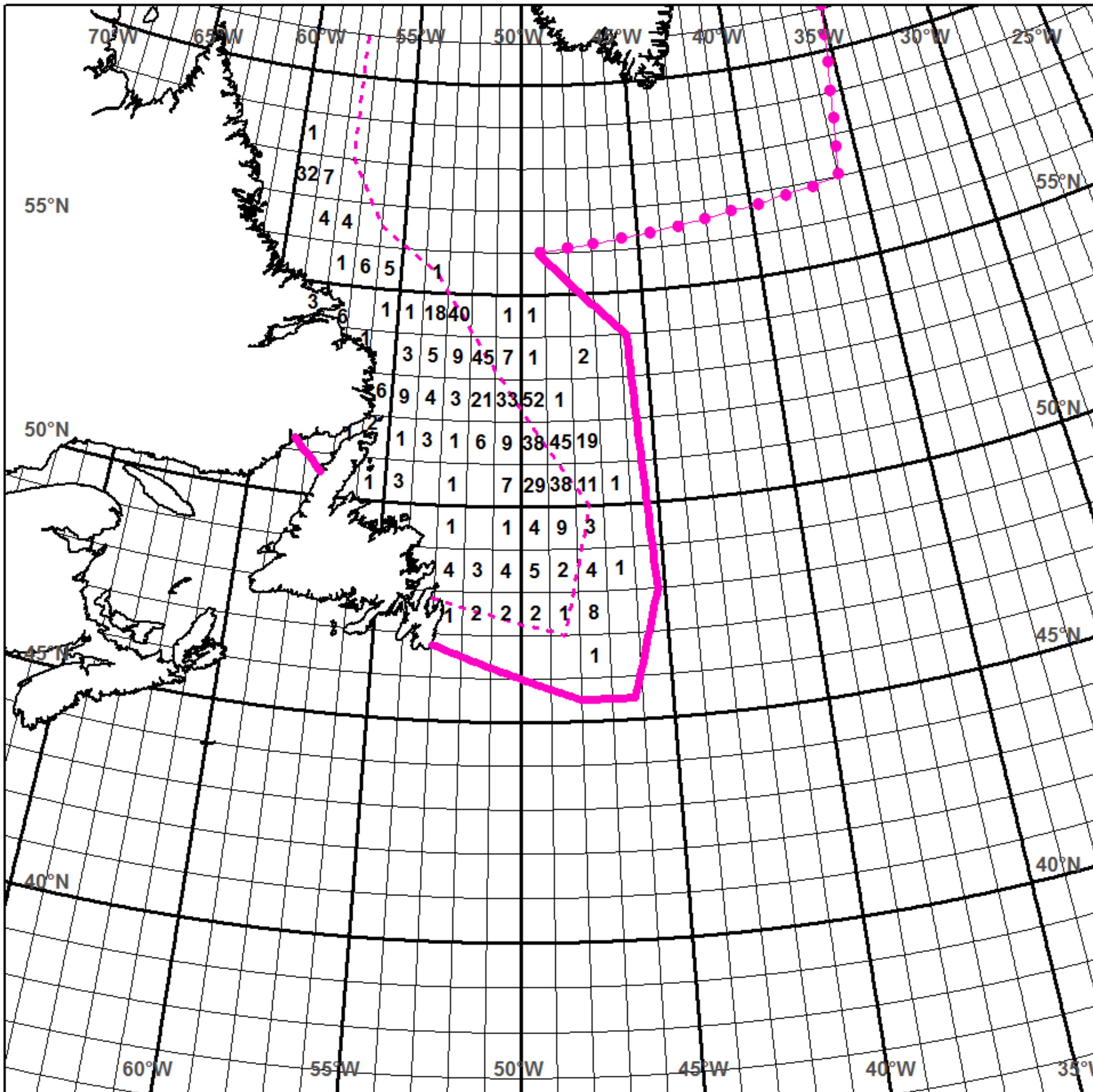
ICEBERG LIMIT

SEA ICE LIMIT

ICEBERGS PER DEGREE SQUARE

⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Southern Limit Iceberg Flight 24FEB16



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 MAR 2016

ESTIMATED ICEBERG LIMIT

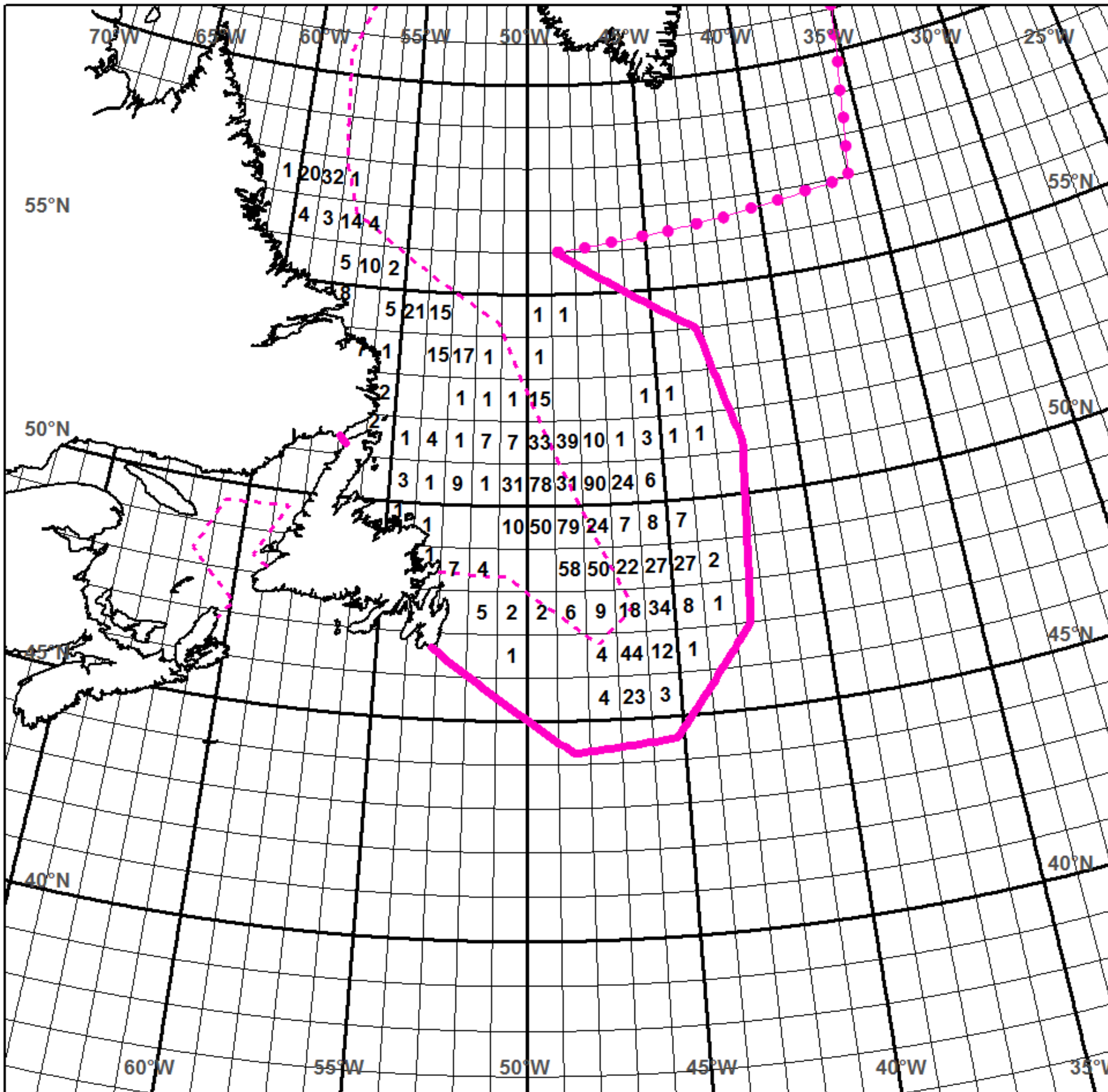
ICEBERG LIMIT

SEA ICE LIMIT

\# ICEBERGS PER DEGREE SQUARE

⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Northern survey iceberg flight 09MAR16

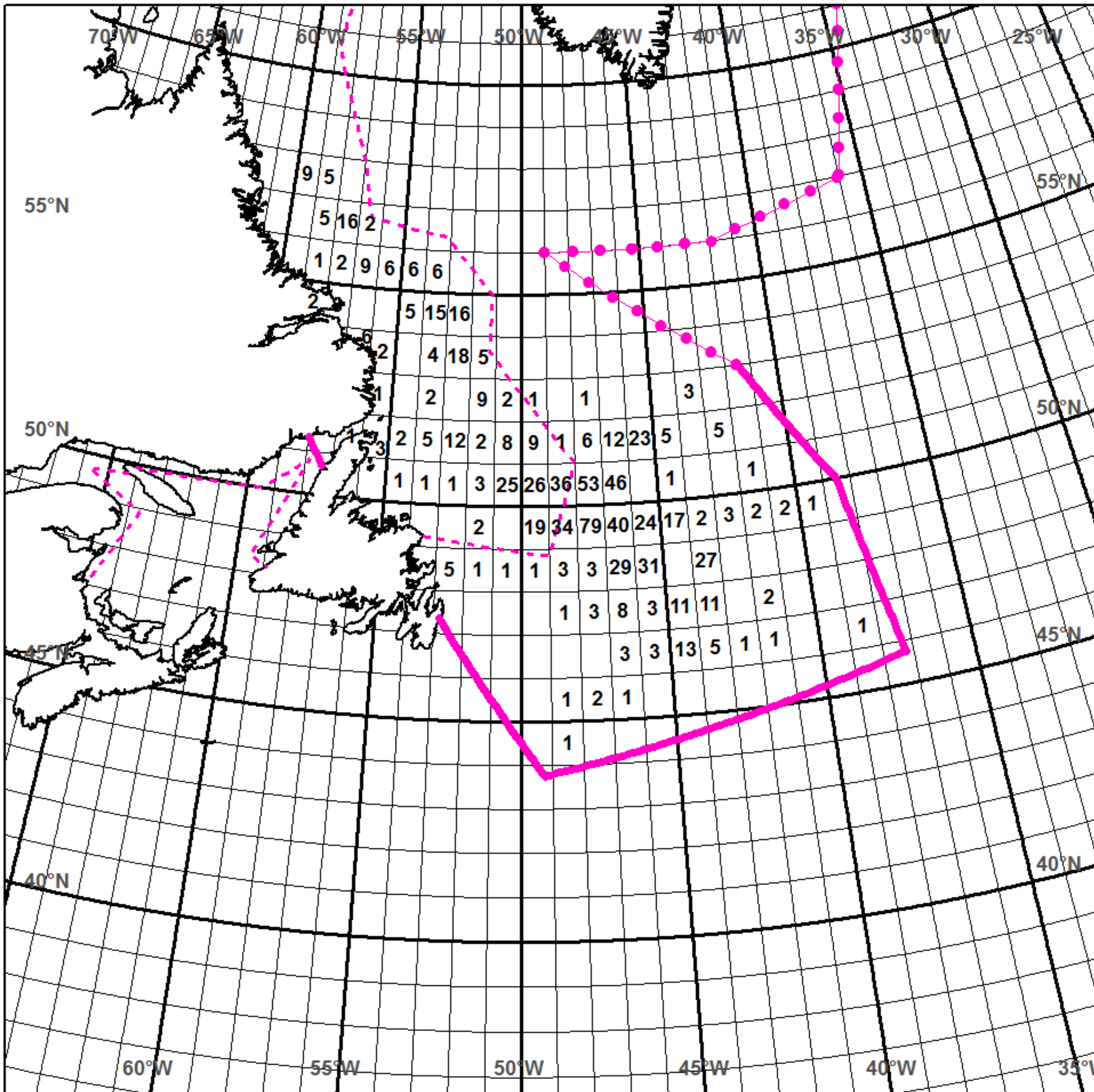


NORTH AMERICAN ICE SERVICE
(NAIS)

ICEBERG ANALYSIS FOR 0000 UTC
01 APR 2016

ESTIMATED ICEBERG LIMIT
ICEBERG LIMIT
SEA ICE LIMIT
ICEBERGS PER DEGREE SQUARE
RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Interior General Flight 30MAR16



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 APR 2016

ESTIMATED ICEBERG LIMIT

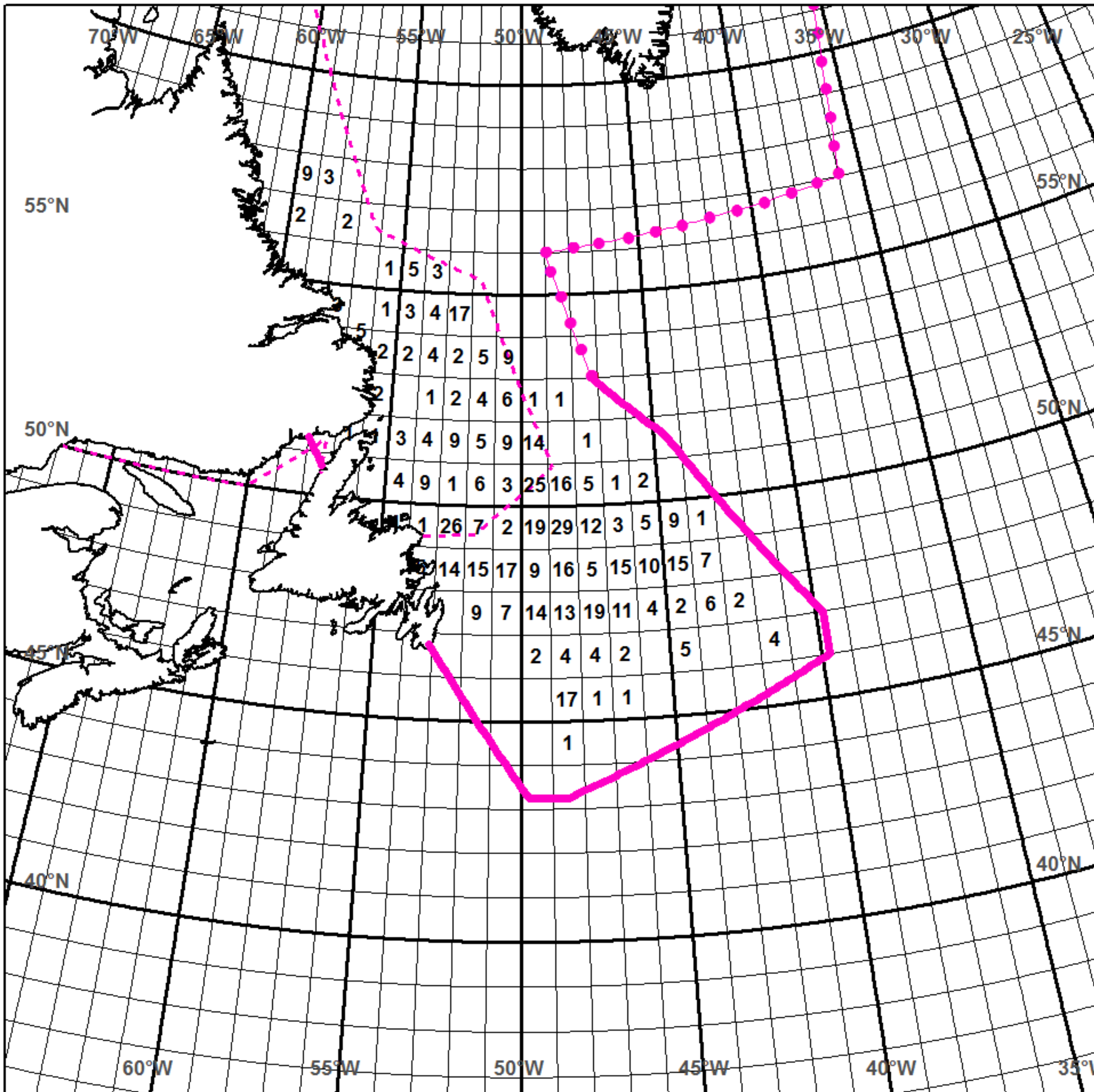
ICEBERG LIMIT

SEA ICE LIMIT

\# ICEBERGS PER DEGREE SQUARE

⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:
Today we commemorate the 104th anniversary of the sinking of the RMS Titanic.
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Southwestern Limit Iceberg Flight 13APR16



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 MAY 2016

ESTIMATED ICEBERG LIMIT

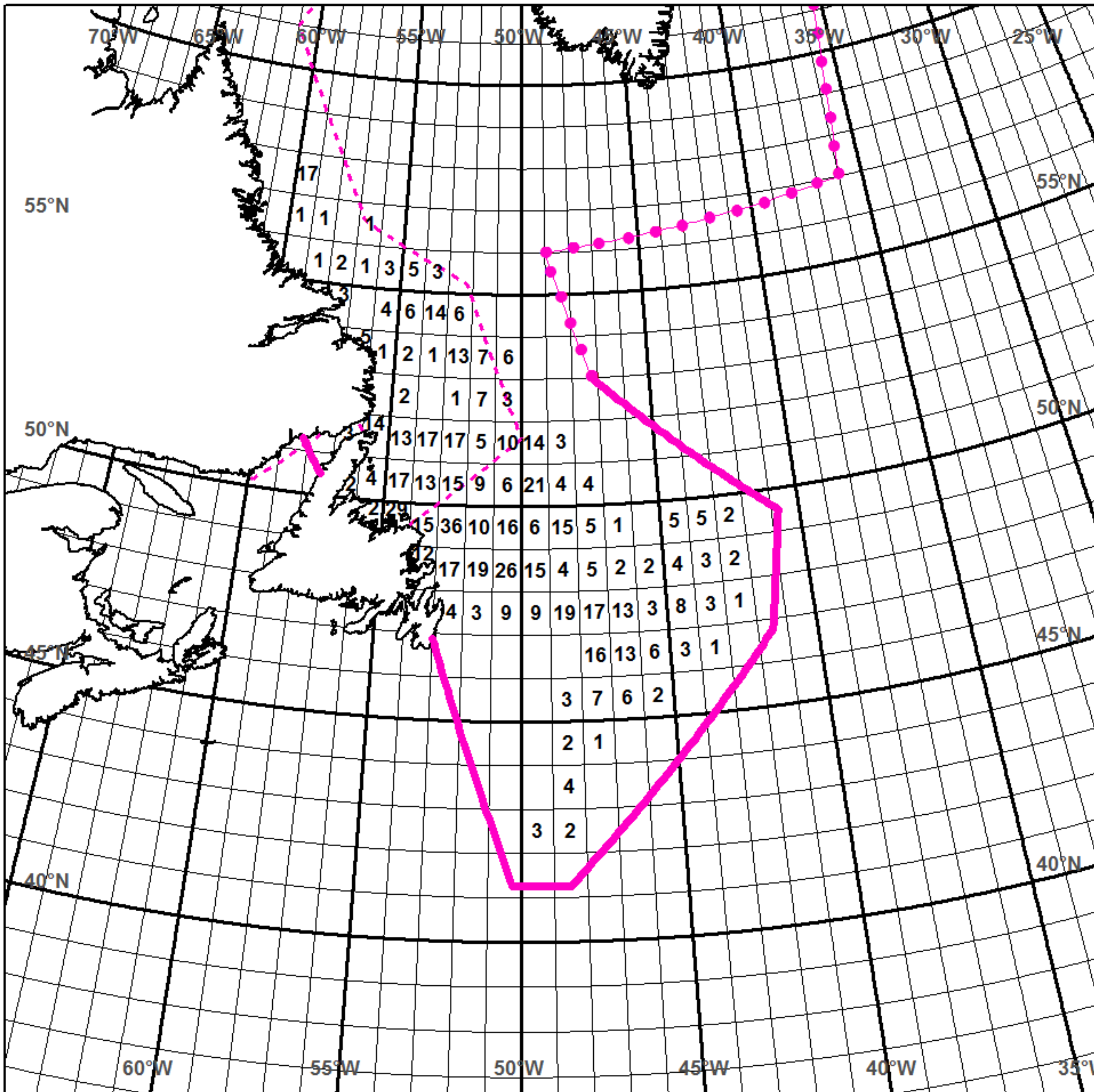
ICEBERG LIMIT

SEA ICE LIMIT

\# ICEBERGS PER DEGREE SQUARE

RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Southern Limit Iceberg Flight 29APR16



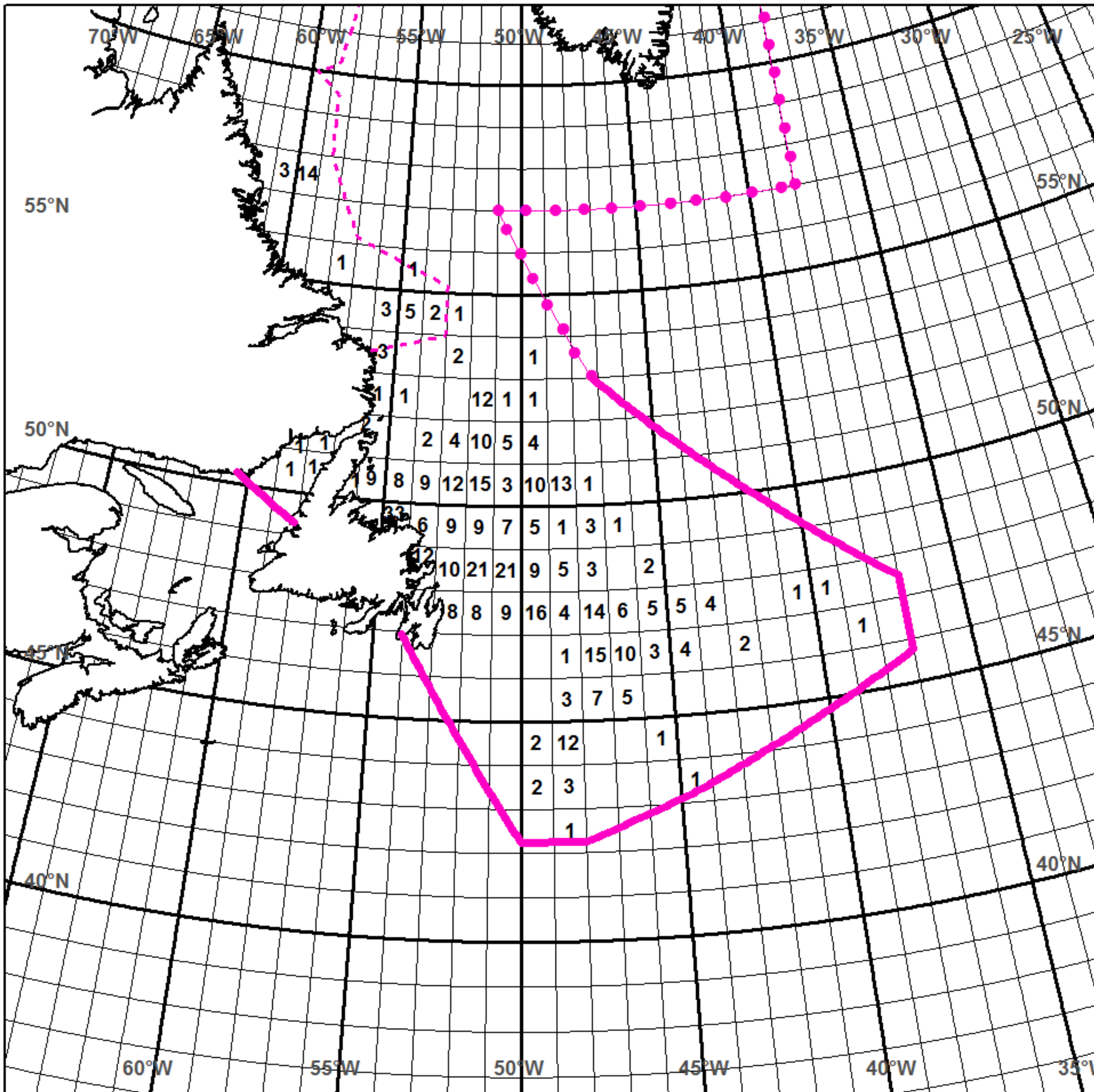
NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 MAY 2016

- ESTIMATED ICEBERG LIMIT
- ICEBERG LIMIT
- SEA ICE LIMIT
- # ICEBERGS PER DEGREE SQUARE
- ⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Western Limit Iceberg Flight 12MAY16



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 JUN 2016

ESTIMATED ICEBERG LIMIT

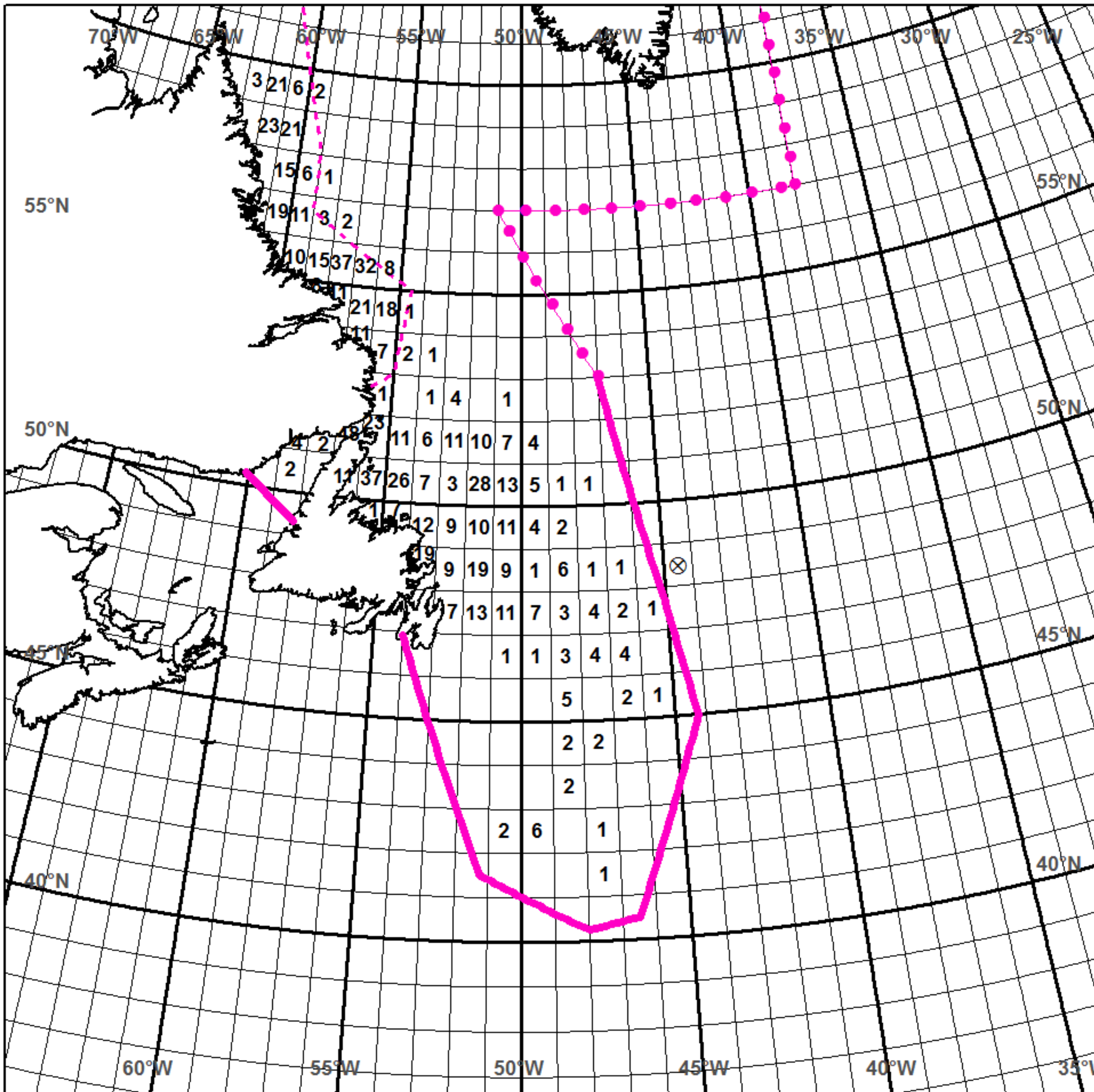
ICEBERG LIMIT

SEA ICE LIMIT

ICEBERGS PER DEGREE SQUARE

⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Eastern Limit Iceberg Flight 30MAY16



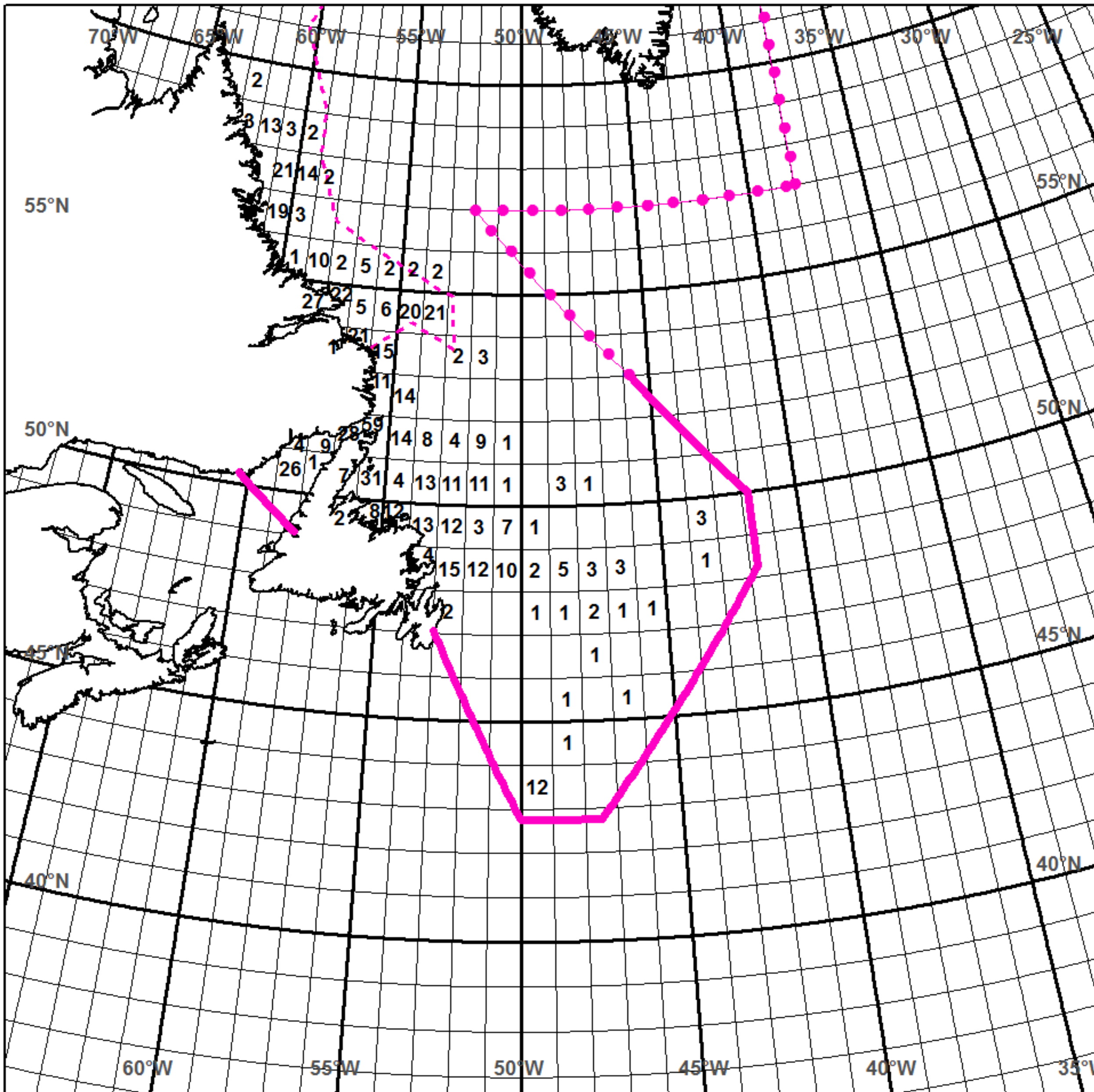
NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 JUN 2016

- ESTIMATED ICEBERG LIMIT
- ICEBERG LIMIT
- SEA ICE LIMIT
- # ICEBERGS PER DEGREE SQUARE
- ⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Eastern Limit Iceberg Flight 10JUN16



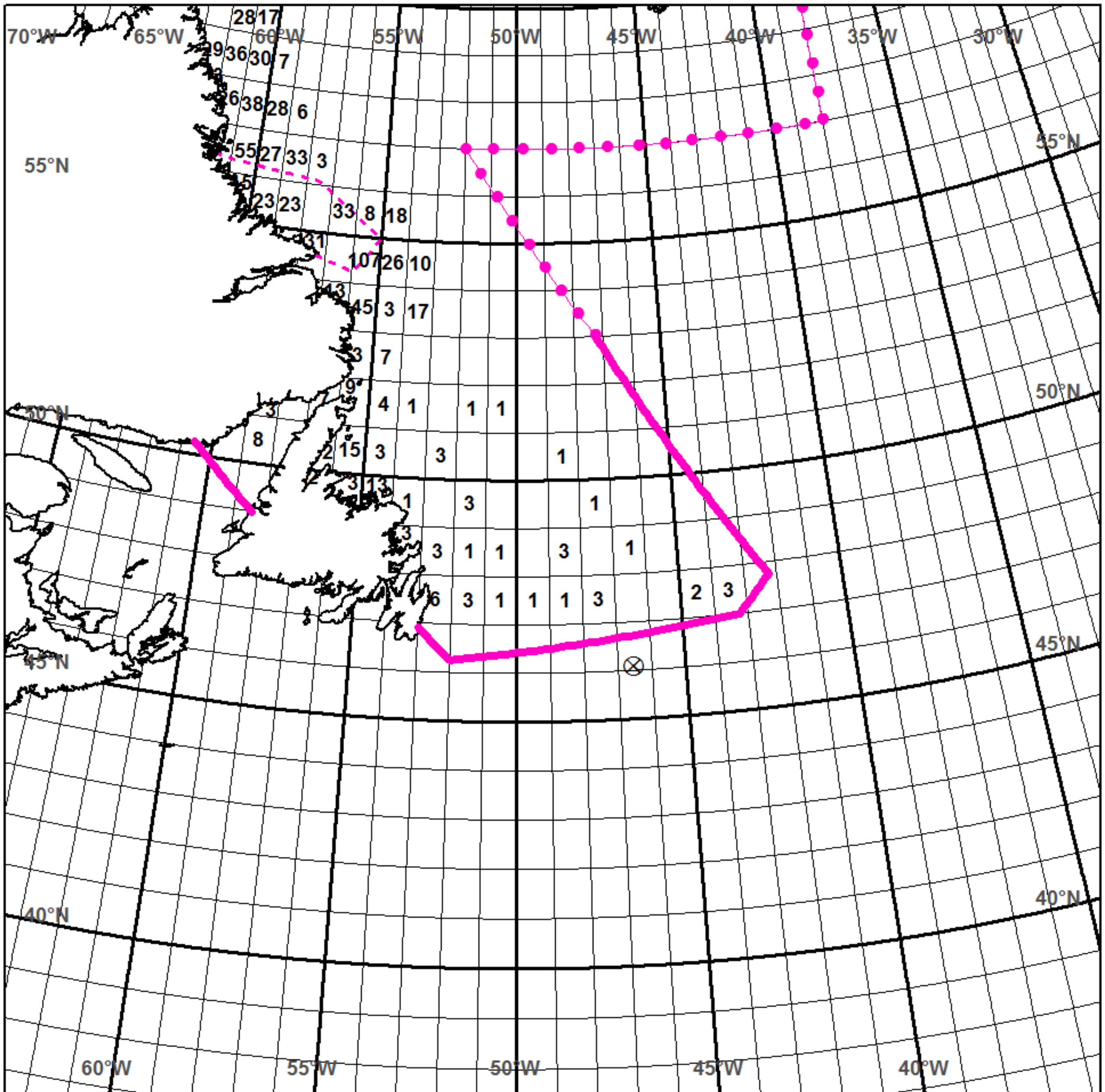
NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 JUL 2016

- ESTIMATED ICEBERG LIMIT
- ICEBERG LIMIT
- SEA ICE LIMIT
- \# ICEBERGS PER DEGREE SQUARE
- ⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:
Significant reduction of iceberg limit due to recent reconnaissance .
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Eastern Limit Iceberg Flight 29JUN16



NORTH AMERICAN ICE SERVICE (NAIS)	ICEBERG ANALYSIS FOR 0000 UTC **15 JUL 2016**

ESTIMATED ICEBERG LIMIT

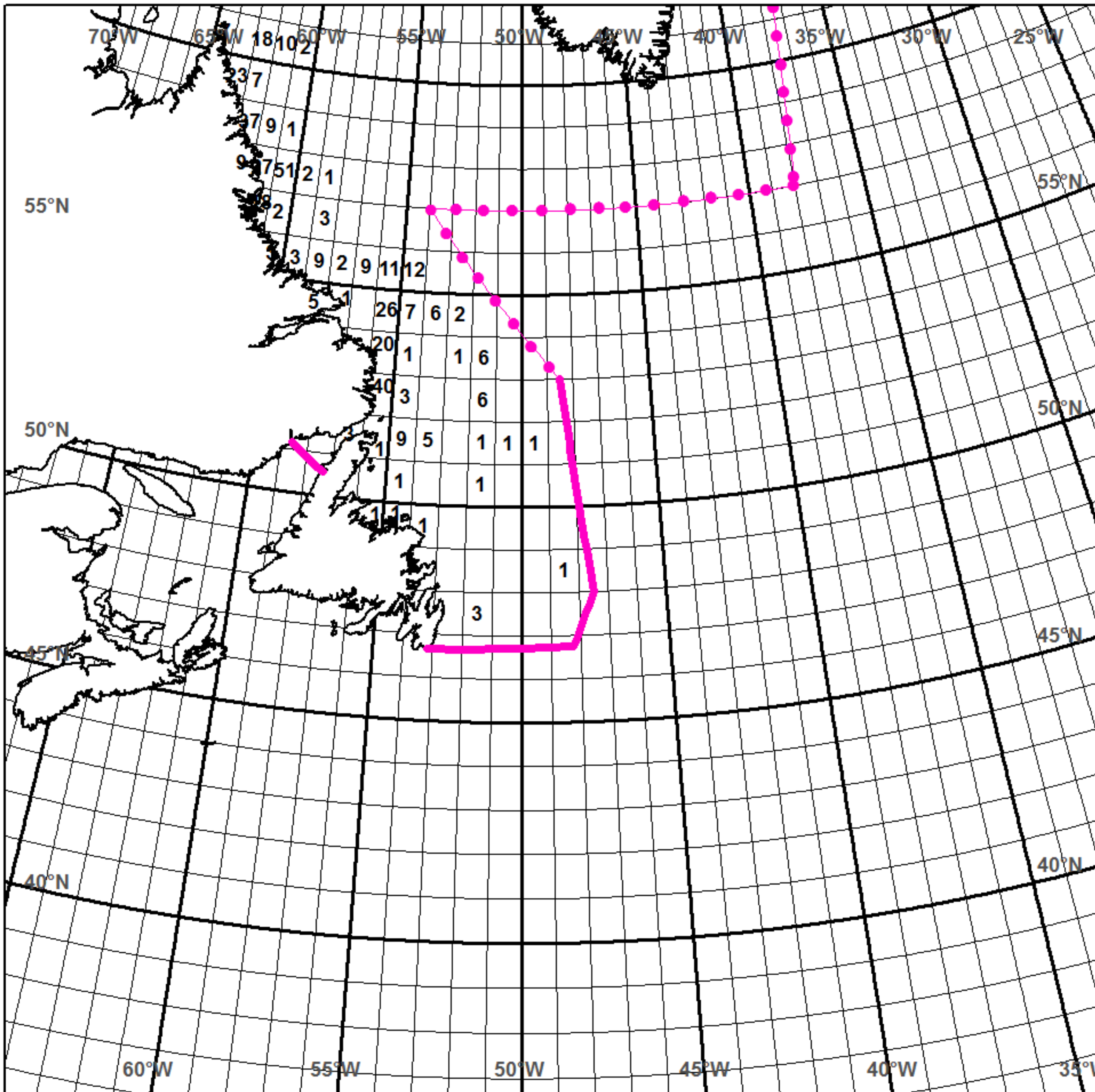
ICEBERG LIMIT

SEA ICE LIMIT

ICEBERGS PER DEGREE SQUARE

RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Northern Survey Iceberg Flight 13JUL16.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 AUG 2016

ESTIMATED ICEBERG LIMIT

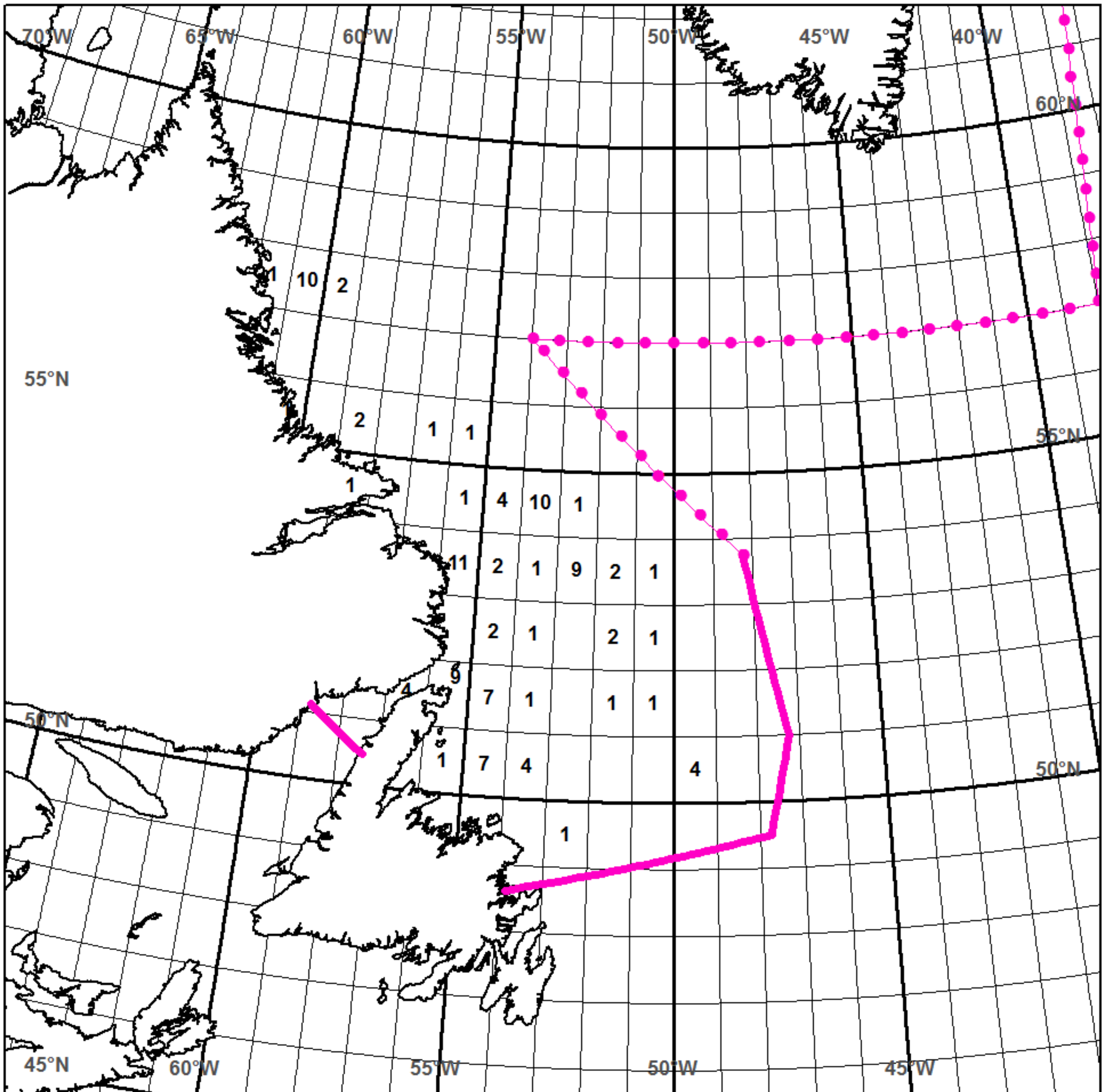
ICEBERG LIMIT

SEA ICE LIMIT

ICEBERGS PER DEGREE SQUARE

RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Interior General Flight 25JUL16



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 AUG 2016

ESTIMATED ICEBERG LIMIT

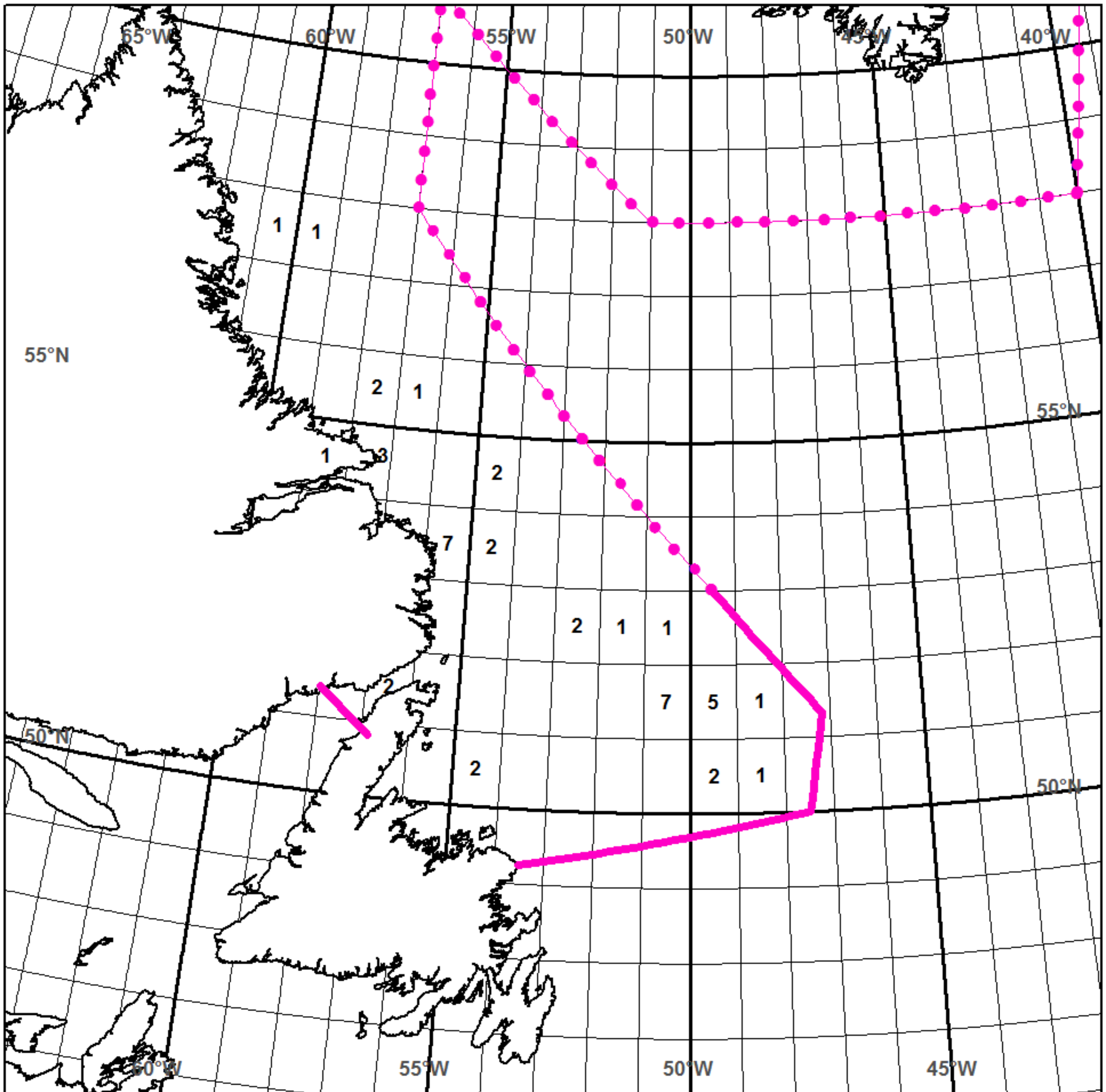
ICEBERG LIMIT

SEA ICE LIMIT

ICEBERGS PER DEGREE SQUARE

⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Southern Limit General Flight 12AUG16.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 SEP 2016

ESTIMATED ICEBERG LIMIT

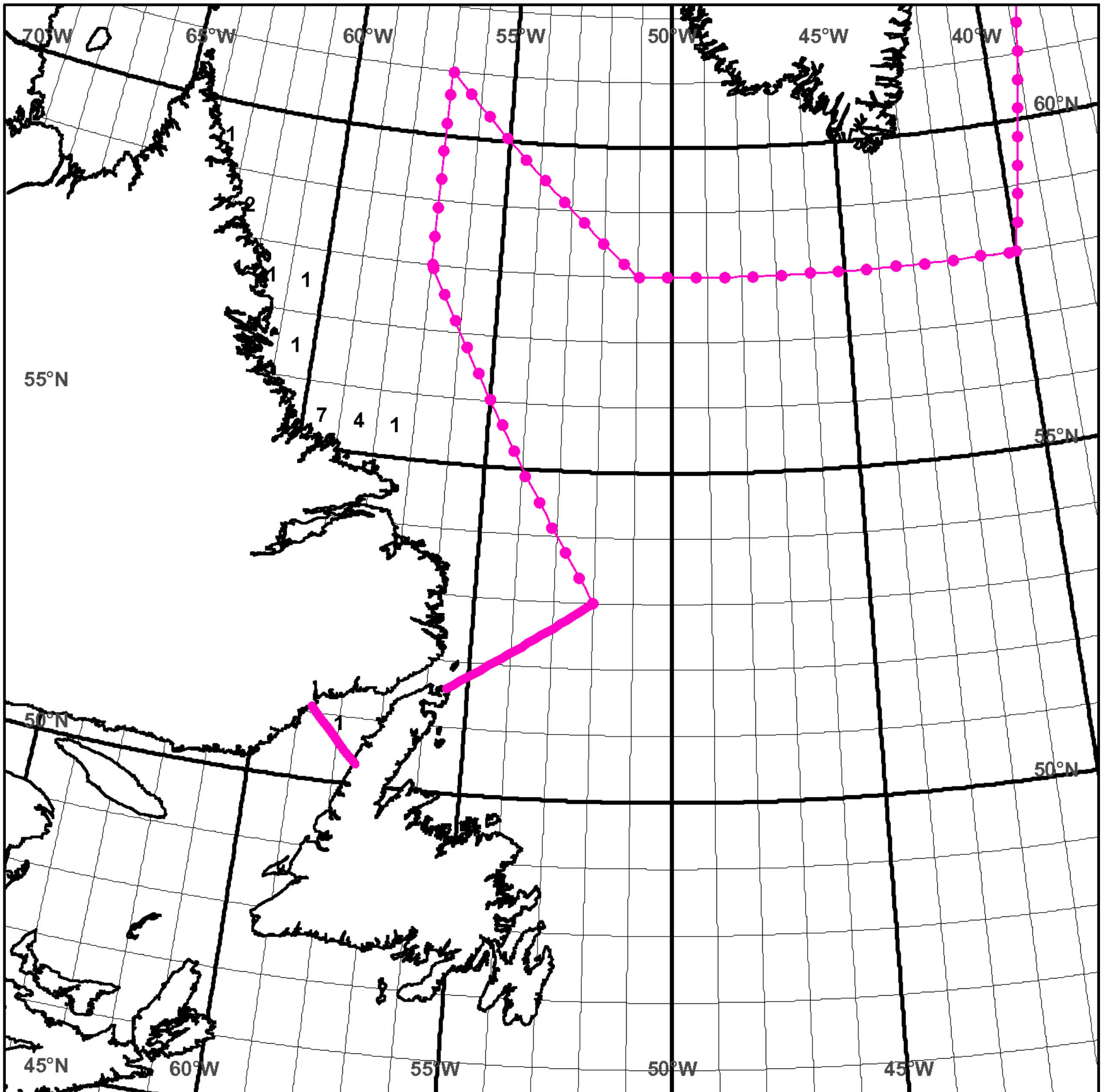
ICEBERG LIMIT

SEA ICE LIMIT

\# ICEBERGS PER DEGREE SQUARE

⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Western Limit General Flight 29AUG16.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 SEP 2016

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

SEA ICE LIMIT

\# ICEBERGS PER DEGREE SQUARE

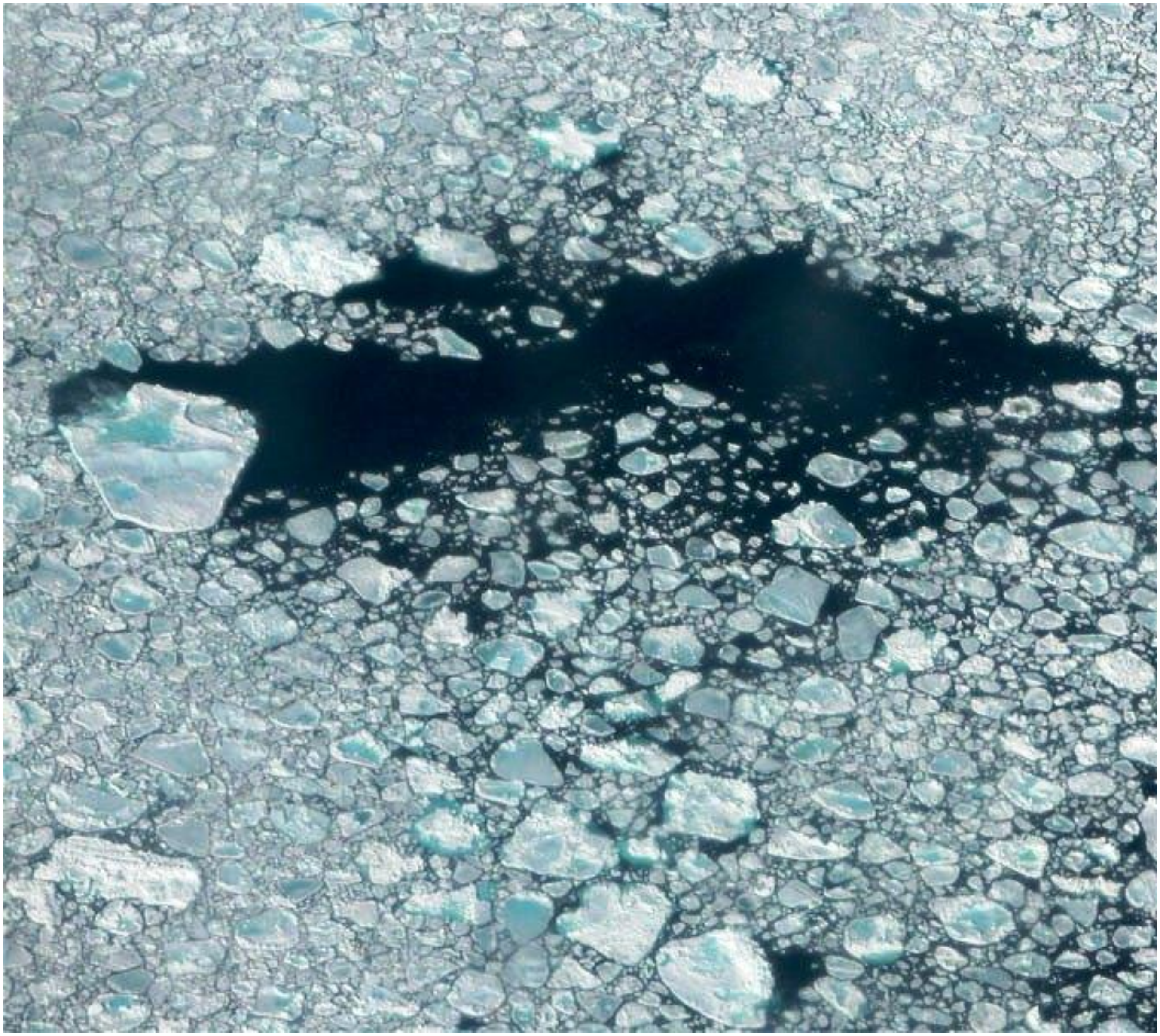
⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:

Significant reduction of iceberg limit due to recent reconnaissance (predicted deterioration).

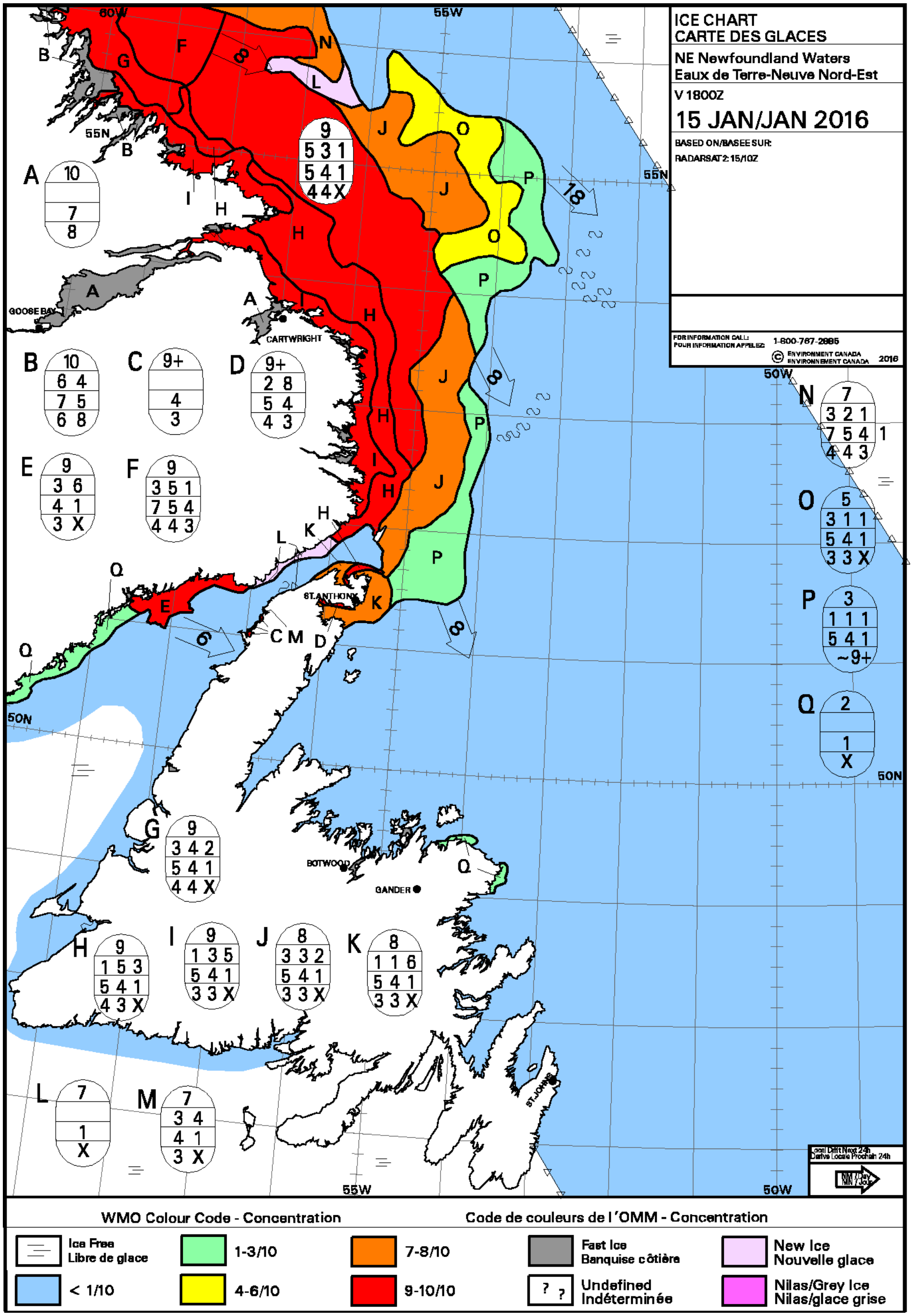
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Interior Iceberg Flight 13SEP16.

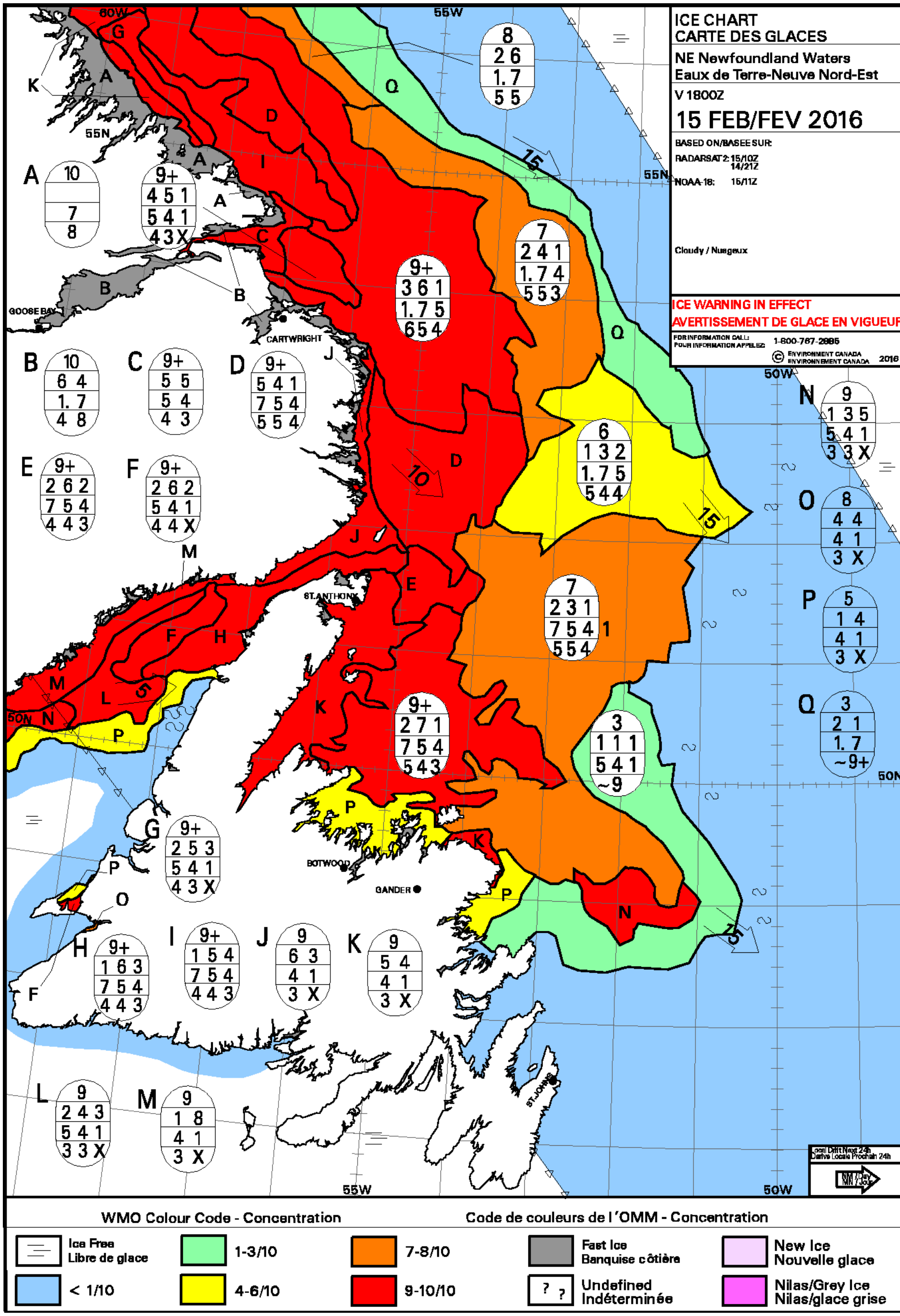
Monthly Sea-Ice Charts

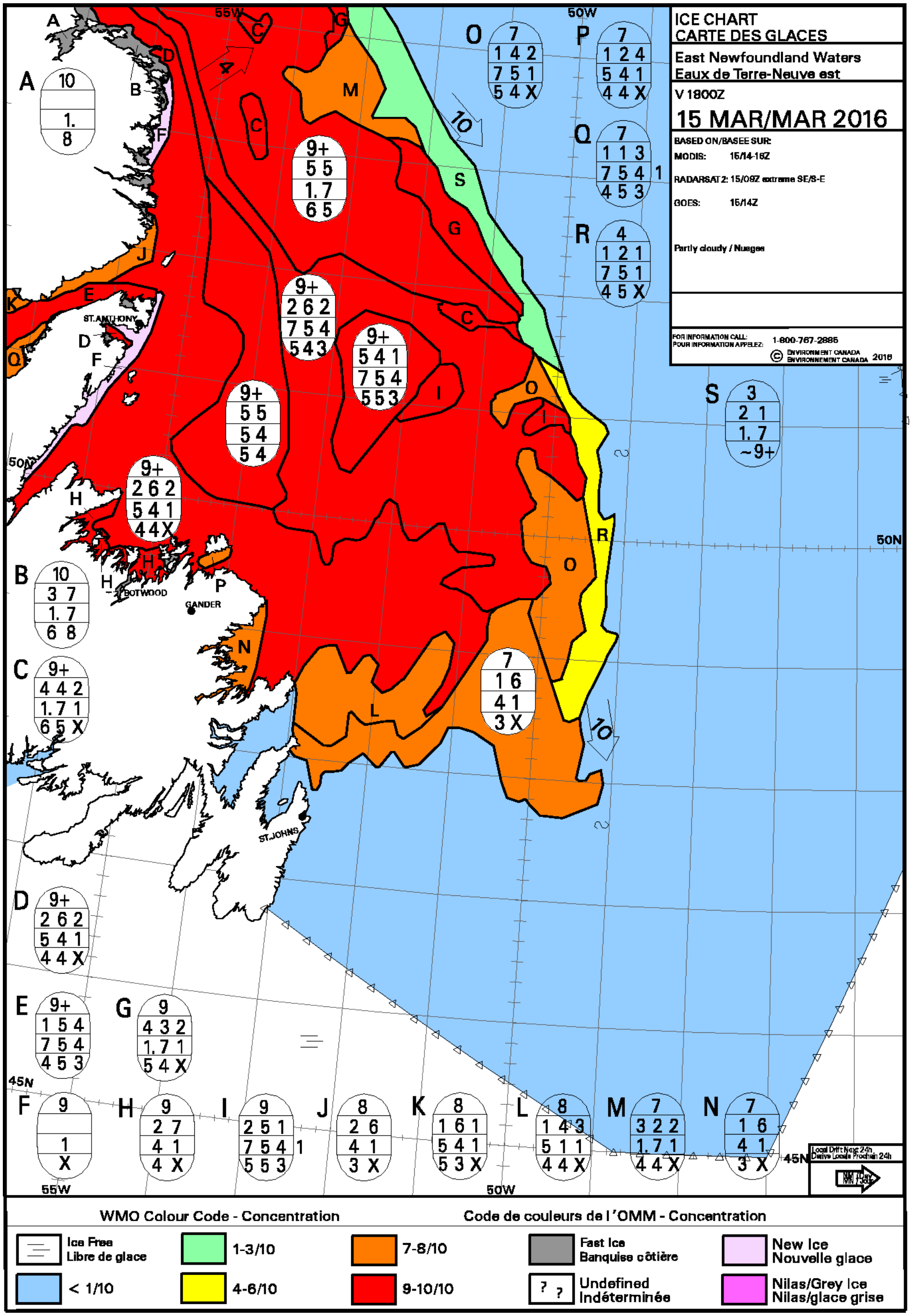


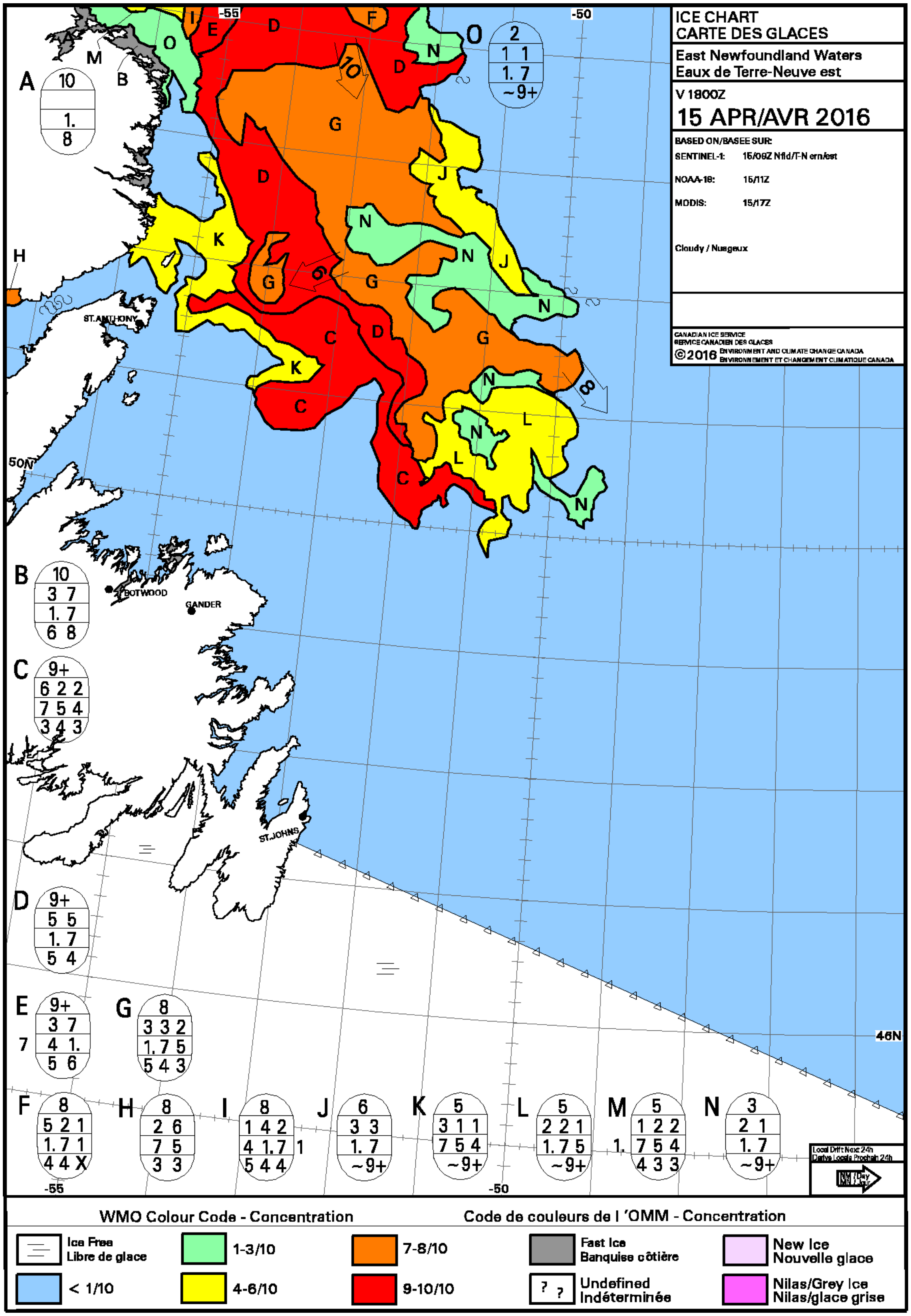
Sea-ice charts are reprinted with permission of the Canadian Ice Service.

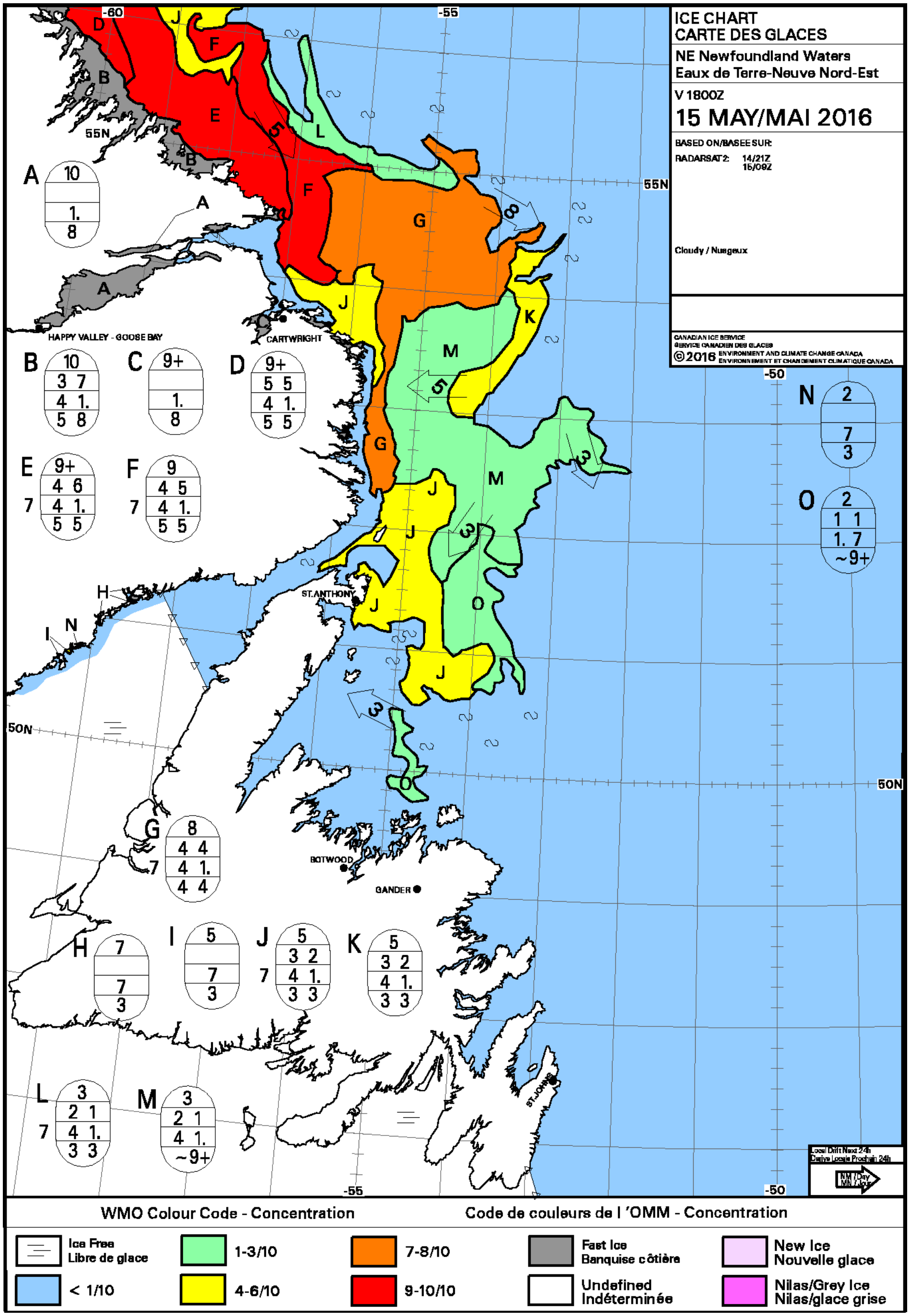
Sea-ice symbols are in accordance with the World Meteorological Organization.


ICE CHART
CARTE DES GLACES
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 JAN/JAN 2016
BASED ON/BASEE SUR:
RADARSAT2 15/10Z
FOR INFORMATION CALL: POUR INFORMATION APPELEZ: 1-800-767-2885
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 2016
GOOSE BAY
CARTWRIGHT
ST.ANTHONY
BOTWOOD
GANDER
ST.JOHNS
60W
55W
50W
55N
50N
Local Drift Next 24h
Dérive Locale Prochain 24h
NM / Day
NM / Jour
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

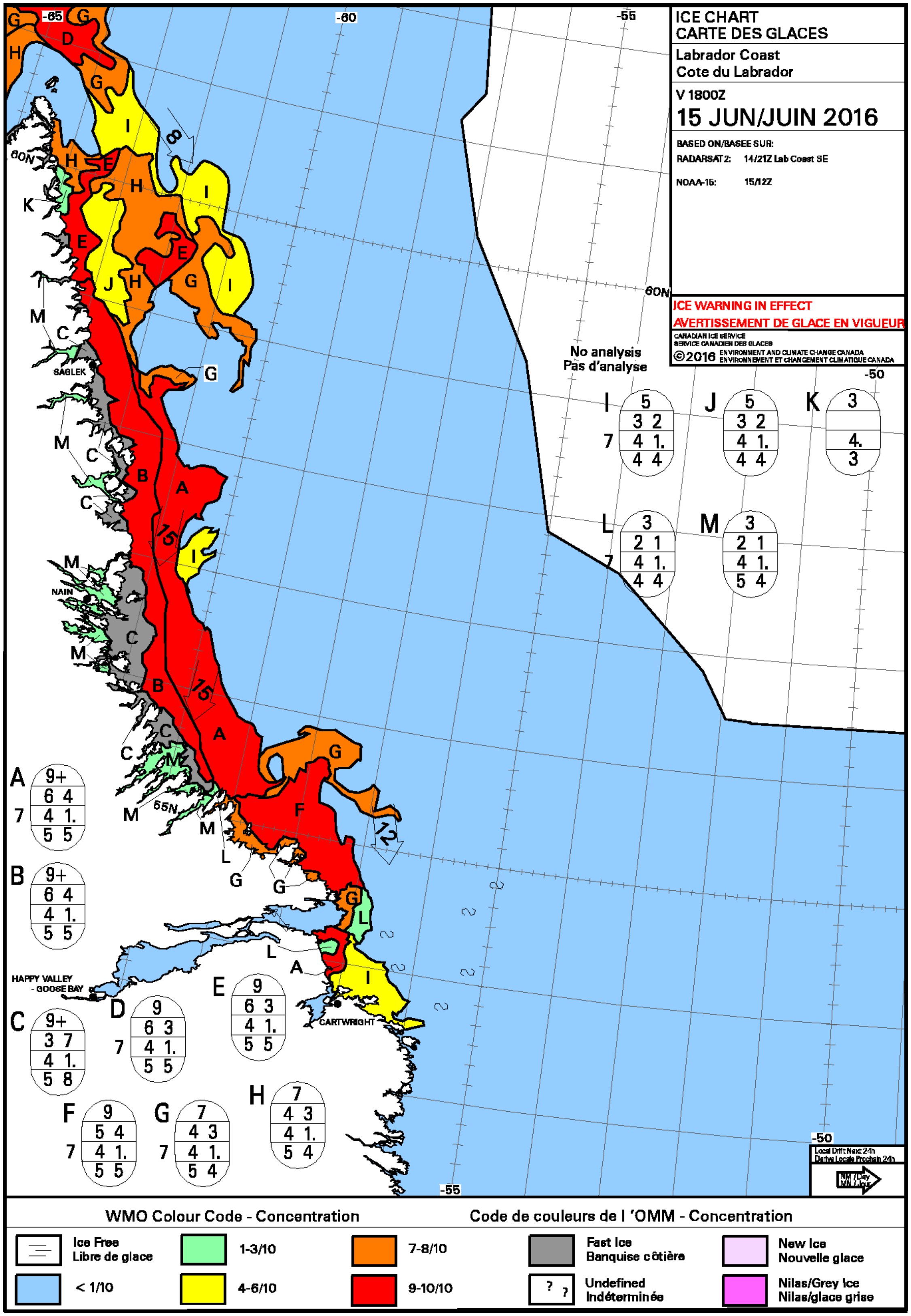

ICE CHART
CARTE DES GLACES
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 FEB/FEV 2016
BASED ON/BASEE SUR:
RADARSAT-2: 15/10Z 14/21Z
NOAA-18: 15/11Z
Cloudy / Nuageux
ICE WARNING IN EFFECT
AVERTISSEMENT DE GLACE EN VIGUEUR
FOR INFORMATION CALL: POUR INFORMATION APPELEZ: 1-800-767-2885
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 2016
60W
55W
50W
55N
50N
GOOSE BAY
CARTWRIGHT
ST. ANTHONY
BOTWOOD
GANDER
ST. JOHN'S
Local Drift Next 24h
Dérive Locale Prochain 24h
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

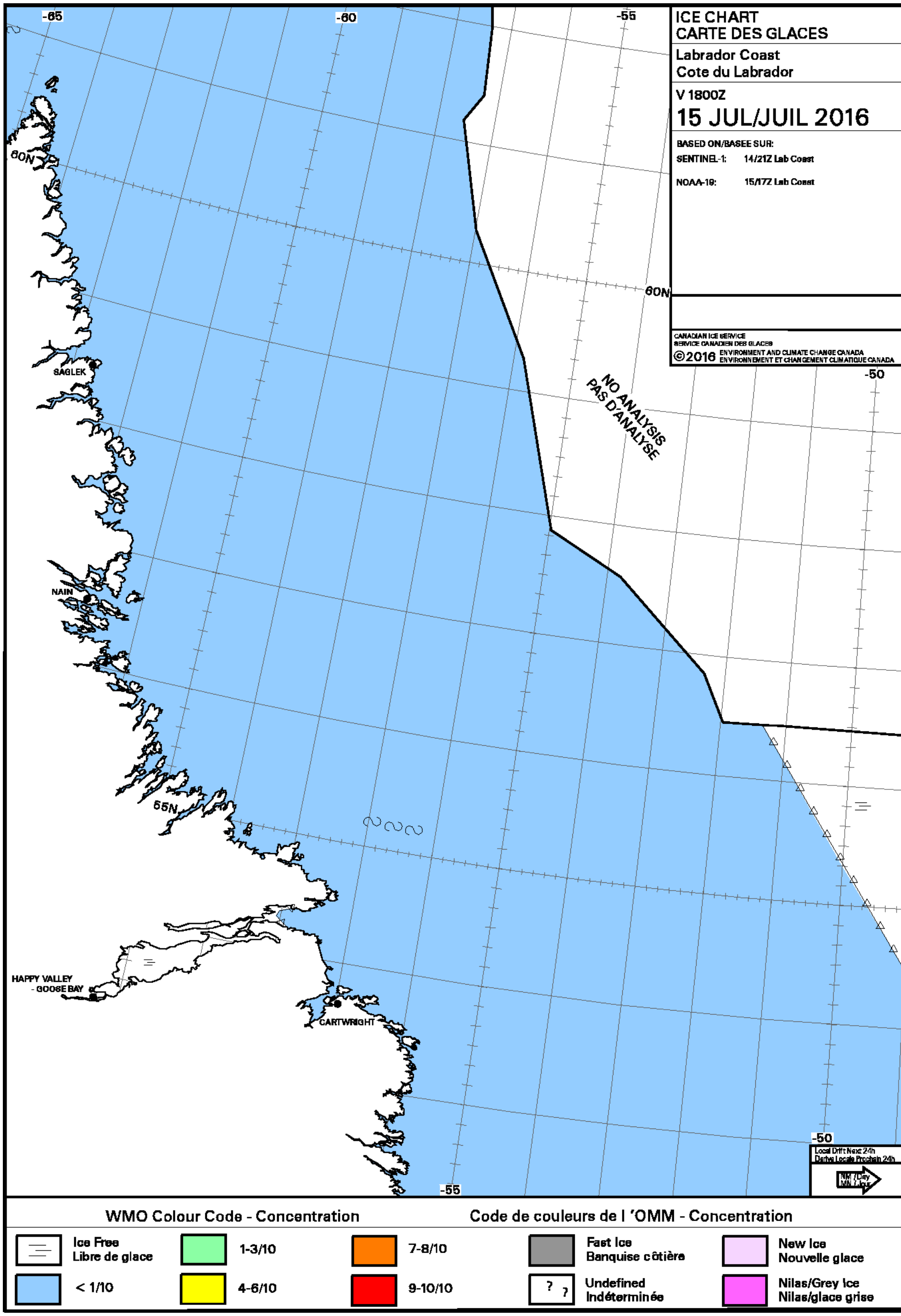

ICE CHART
CARTE DES GLACES
East Newfoundland Waters
Eaux de Terre-Neuve est
V 1800Z
15 MAR/MAR 2016
BASED ON/BASEE SUR:
MODIS: 15/14-16Z
RADARSAT2: 15/09Z extreme SE/S-E
GOES: 15/14Z
Partly cloudy / Nuages
1-800-767-2885
ST.ANTHONY
BOTWOOD
GANDER
ST.JOHNS
55W
50W
50N
45N
WMO Colour Code - Concentration
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 CHART
CARTE DES GLACES
East Newfoundland Waters
Eaux de Terre-Neuve est
V 1800Z
15 APR/AVR 2016
BASED ON/BASEE SUR:
SENTINEL-1: 15/09Z Nfld/T-N ern/est
NOAA-18: 15/11Z
MODIS: 15/17Z
Cloudy / Nuageux
CANADIAN ICE SERVICE
SERVICE CANADIEN DES GLACES
©2016 ENVIRONMENT AND CLIMATE CHANGE CANADA
ENVIRONNEMENT ET CHANGEMENT CLIMATIQUE CANADA
ST.ANTHONY
BOTWOOD
GANDER
ST.JOHNS
50N
46N
-55
-50
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 CHART
CARTE DES GLACES
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 MAY/MAI 2016
BASED ON/BASEE SUR:
RADARSAT2: 14/21Z 15/09Z
Cloudy / Nuageux
CANADIAN ICE SERVICE
SERVICE CANADIEN DES GLACES
©2016 ENVIRONMENT AND CLIMATE CHANGE CANADA
ENVIRONNEMENT ET CHANGEMENT CLIMATIQUE CANADA
HAPPY VALLEY - GOOSE BAY
CARTWRIGHT
ST.ANTHONY
BOTWOOD
GANDER
ST.JOHNS
55N
50N
-60
-55
-50
Local Drift Next 24h
Dérive Locale Prochain 24h
NM/Day
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 CHART
CARTE DES GLACES
Labrador Coast
Cote du Labrador
V 1800Z
15 JUN/JUIN 2016
BASED ON/BASEE SUR:
RADARSAT 2: 14/21Z Lab Coast SE
NOAA-15: 15/12Z
ICE WARNING IN EFFECT
AVERTISSEMENT DE GLACE EN VIGUEUR
CANADIAN ICE SERVICE
SERVICE CANADIEN DES GLACES
©2016 ENVIRONMENT AND CLIMATE CHANGE CANADA
ENVIRONNEMENT ET CHANGEMENT CLIMATIQUE CANADA
No analysis
Pas d'analyse
SAGLEK
NAIN
HAPPY VALLEY - GOOSE BAY
CARTWRIGHT
60N
55N
-65
-60
-55
-50
Local Drift Next 24h
Dérive Locale Prochain 24h
NM / Day
MN / Jour
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 CHART
CARTE DES GLACES
Labrador Coast
Cote du Labrador
V 1800Z
15 JUL/JUIL 2016
BASED ON/BASEE SUR:
SENTINEL-1: 14/21Z Lab Coast
NOAA-19: 15/17Z Lab Coast
CANADIAN ICE SERVICE
SERVICE CANADIEN DES GLACES
©2016 ENVIRONMENT AND CLIMATE CHANGE CANADA
ENVIRONNEMENT ET CHANGEMENT CLIMATIQUE CANADA
-65
-60
-55
-50
60N
55N
SAGLEK
NAIN
HAPPY VALLEY - GOOSE BAY
CARTWRIGHT
NO ANALYSIS
PAS D'ANALYSE
Local Drift Next 24h
NM /Day
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

Acknowledgements

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

Canadian Coast Guard

Canadian Forces

Canadian Ice Service

Canadian Maritime Atlantic Command Meteorological and Oceanographic Centre

Canadian Meteorological Centre

Centre for Cold Ocean Resources Engineering

Department of Fisheries and Oceans Canada

Danish Meteorological Institute

European Space Agency

German Federal Maritime and Hydrographic Agency

MacDonald, Dettwiler and Associates

National Geospatial-Intelligence Agency

Nav Canada Flight Information Center

NOAA National Weather Service

PAL Aerospace

Shell Torbay Aero Services

Transport Canada

USCG Air Station Elizabeth City

USCG Air Station Cape Cod

USCG Atlantic Area

USCG Aviation Training Center Mobile

USCG Director of Marine Transportation Systems

USCG Director of Intelligence and Criminal Investigations

USCG First District

USCG Maritime Fusion Intelligence Center Atlantic

USCG Navigation Center

USCG Research and Development Center

U.S. National/Naval Ice Center

U.S. Naval Fleet Numerical Meteorology and Oceanography Center

It is important to recognize the outstanding efforts of the personnel assigned to the International Ice Patrol during the 2016 Ice Year:

CDR G. G. McGrath
LCDR B. P. Morgan
LCDR J. C. Gatz
Mr. M. R. Hicks
Mrs. B. J. Lis
LT R. H. Clark
LT S. M. Elliott
LT B. P. Dougherty
MSTCM V. L. Cates
MSTCS K. E. Brockhouse
YNC J. J. Zwearcan
YN1 J. I. Vega
MST1 S. A. Baumgartner
MST1 W. M. Savage
MST1 S. L. Skeen
MST2 M. J. Harrell
MST2 J. J. Menard
MST2 D. M. Morrisey
MST2 B. M. Reel
MST3 J. L. Crocker
MST3 Z. P. Kniskern
MST3 J. J. Paulk

Appendix A

Ship Reports for Ice Year 2016

Ships Reporting by Flag	Reports
BAHAMAS	
BOUDICCA	1
AJAX	1
BERMUDA	
PACIFIC PRINCESS	1
CANADA	
POLAR PRINCE	5
MAERSK NEXUS	1
CHINA	
DETROIT EXPRESS	1
CYPRUS	
ISOLDA	2
DENMARK	
THUNDERBIRD	1
GERMANY	
QUEBEC EXPRESS	4
GIBRALTAR	
SANCO SPIRIT	1
HONG KONG	
*OOCL MONTREAL	6
OOCL BELGIUM	2
LIVORNO EXPRESS	2
LIBERIA	
CHEM SINGAPORE	1
LADY M	1
MALTA	
INTREPID	1
TYSLA	1

MARSHALL ISLANDS	
FEDERAL DANUBE	3
FEDERAL WESER	1
FEDERAL YUKON	1
INSIGNIA	1
PANTAGRUEL	1
FEDERAL BISCAY	1
FEDERAL BALTIC	1
NETHERLANDS	
STELLA POLARIS	2
SCHOKLAND	2
SOUMIGRACHT	1
VIKINGBANK	1
FIVELBORG	1
MAASGRACHT	1
FLORETGRACHT	1
AMORBORG	1
MAERSK PEMBROKE	1
PANAMA	
BULK ASIA	1
NEW BREEZE	1
UNITED STATES OF AMERICA	
INDEPENDENCE II	1

*Denotes the CARPATHIA award winner.

IIP awards the vessel that submits the most iceberg reports each year. The award is named after the CARPATHIA, the vessel credited with rescuing 705 survivors from the TITANIC disaster.

Appendix B

North American Ice Service Iceberg (NAIS) Drift and Deterioration Model Operational Evaluation

LT Stephen M. Elliott
Mr. Michael R. Hicks
December 2016

Background

The objective of this evaluation was to assess the operational use of the North American Ice Service (NAIS) iceberg drift and deterioration model. Initially, IIP approached this evaluation as a decision point to make a complete shift from the currently-used International Ice Patrol (IIP) model to the NAIS Model for use in creating daily NAIS iceberg warning products. Lessons learned from this evaluation show that each model has its benefits, and both should be considered to maximize the accuracy of IIP's iceberg warning products. This evaluation identified several differences between the two models in terms of impact on the operational product.

The IIP Model was used by IIP and the Canadian Ice Service (CIS) since it was fully developed in 1983. Although changes were made, the model was not updated for many years. The NAIS Model was fully developed in 2007 and includes numerous improvements over the current IIP Model, including the ability to accept current inputs from a wider variety of sources, the ability to account for wave-induced iceberg drift, and the ability to include an improved description of iceberg geometry. Murphy and Carrieres (2010) conducted a comprehensive inter-comparison between the NAIS and IIP Models. This study found the performance of the two models to be essentially the same when run with identical environmental inputs and found that, when the NAIS Model was forced by Canadian East Coast Ocean Model (CECOM) currents, it produced more accurate results than the IIP Model with IIP currents. It is important to note that Murphy and Carrieres (2010) used historical IIP currents and did not incorporate updates from near real-time drifting buoy data.

To verify performance of the NAIS deterioration model, Murphy and Carrieres (2010) also conducted a series of computer-based tests that compared results from both models. Without validated ground truth data, these tests simply compared results from each model using varying sea-surface temperatures (SST), wave heights, and wave periods as inputs. The deterioration comparison showed that, in the NAIS Model, deterioration increased as wave period increased and for the IIP Model, deterioration increased as wave period decreased. This appendix provides examples of how varying deterioration rates impact IIP'S Iceberg Limit product.

In short, Murphy and Carrieres (2010) provided detailed results from both drift and deterioration tests and included an excellent summary of the improvements of the NAIS Model over the IIP Model. The report recommended that IIP perform an operational evaluation of the NAIS Model to assess its suitability for use in establishing the Iceberg Limit and creating IIP's daily iceberg warning product.

During the 2015 Ice Season, IIP compared IIP's results from the IIP Model with those from the NAIS Model. For this comparison, the IIP Watch Officer ran both the IIP and NAIS Models in parallel. Results from the two models were compared and several differences were noted. However, modifications to the active iceberg database such as iceberg deletions, additions, and re-sightings were performed using the IIP Model analysis only. Subsequent NAIS Model runs were then based on iceberg positions and deterioration statuses that were updated by using the IIP Model. These procedures resulted in unusual iceberg drift behavior for NAIS Model results and numerous examples of NAIS Model icebergs drifting outside of the daily Iceberg Limit, also established using the IIP Model only. Further, all flight planning and decisions to maintain icebergs on plot after 150% melt were made exclusively based on predictions from the IIP Model. Operator decisions accounted for a large portion of the observed differences between analyses and prognoses in the 2015 trial. It became clear that the approach used in 2015 did not provide the insight IIP needed to make meaningful conclusions on the use of the NAIS Model for operations. Lessons learned from the 2015 efforts highlighted key requirements that allowed IIP to design and conduct a more meaningful operational evaluation. These requirements included:

- Creation of a separate active iceberg database populated with NAIS Model results only;
- Establishment of a separate watch to apply Standard Operating Procedure (SOP) guidance for additions, deletions, and re-sightings of NAIS Model icebergs separately;
- Establishment of a daily Iceberg Limit based solely on NAIS Model results and separate from IIP's normal watch;
- Comparison of key metrics to reveal bulk characteristics and systematic biases in IIP's daily Iceberg Limit product

In 2016, IIP conducted tests meeting these requirements during two key evaluation time periods: (1) 17 February to 04 March (17 days) and (2) 08 to 18 June (11 days). These evaluation periods were selected to investigate the impact of NAIS Model implementation during the early season, while the Iceberg Limit was expanding and during the late season, when the Iceberg Limit was contracting. Both evaluation periods included one iceberg reconnaissance detachment (IRD). The remainder of this appendix documents the methods, results, conclusions, and recommendations of the 2016 NAIS Model operational evaluation.

Methods

To create a separate active iceberg database, IIP's Information Technology (IT) Specialist established an independent computer workstation with version 1.12 of the iceBerg Analysis and Prediction System (BAPS) installed. All tests were conducted using BAPS as the user interface to run the NAIS Model. The IT Specialist replicated the active iceberg database on the Test BAPS station and then cut the network connection for updates to all operational databases. This action ensured that the active iceberg database, Iceberg Limits, and iceberg charts could be different on the Test BAPS when compared to the Operational BAPS system running the IIP Model. All other connections were maintained to ensure that the Test BAPS system could access the most recent environmental forcing data as well as all of the Standard Iceberg Messages (SIMs) that resulted from iceberg reconnaissance and vessel reports.

Reconnaissance inputs were identical for both the IIP and NAIS Model runs. This evaluation used the Test BAPS computer to make daily products based on the NAIS Model and the operational BAPS computer to create daily products based on the IIP Model for normal operational distribution. The Test BAPS workstation was located within IIP's Operations Center (OPCEN) to best simulate the daily routine of IIP's operational watch. This arrangement remained identical for both the February-March and June evaluation periods

SIM Processing and Model Runs

For each day during the evaluation periods, the Test BAPS Operator followed an identical routine as IIP's operational watch. The following tasks were performed by the Test BAPS Operator daily:

- Initiated NAIS analysis model runs valid for 0000Z and 1200Z. An analysis run performs both drift and deterioration and is the basis for incorporating iceberg reports into the iceberg database. In accordance with IIP SOP, the BAPS operator used the analysis run closest in time to the iceberg sighting.
- Processed SIMs. This procedure involved adding new iceberg sightings and updating (or re-sighting) iceberg positions using IIP SOP criteria. By SOP, icebergs may be deleted from the database based on high-quality IIP reconnaissance (low sea-state, excellent visibility, and/or properly functioning maritime search radar).
- Initiated a NAIS prognosis model run valid for 1200Z to confirm that no icebergs drifted outside of the published Iceberg Limit. A prognosis run invokes only the drift portion of the model.
- Documented when an iceberg or its error circle crossed the Iceberg Limit. When this situation occurs, the IIP daily warning products are revised and redistributed.
- Using the NAIS analysis model run valid for 1200Z, deleted icebergs whose predicted deterioration exceeded 125% for icebergs more than 60 NM inside the Iceberg Limit and 150% for icebergs closer to the Iceberg Limit. Limit-setting icebergs were only deleted after consulting with Commander, IIP (CIIP).
- Initiated NAIS prognosis model run valid for 0000Z, established daily Iceberg Limit based on these results, and created a daily Iceberg Limit chart. NOTE: No NAIS Model-based products were actually distributed outside of IIP during this evaluation.
- Briefed CIIP in accordance with criteria established in the IIP SOP. This step was essential to more realistically simulate actual operations as CIIP frequently provides guidance and direction in addressing ambiguous situations.

Daily Measurements

The data collected during this evaluation reflect key statistics that impact IIP's daily Iceberg Limit product. By design, these measurements are closely related to season severity and attempt to illustrate how the use of each model would affect IIP's operations – both with respect to the aerial reconnaissance and OPCEN functions of the IIP mission. At the end of each day, the following statistics, valid for 0000Z on the next day, were captured for the IIP

Model-based chart and iceberg database as well as the NAIS Model-based chart and iceberg database:

- Iceberg Counts
    - The total number of icebergs in each active iceberg database.
    - The total number of icebergs south of 48°N.
    - The total number of icebergs east of 48°W.
    - The total number of icebergs west of 56°W and south of 52°N (describing the region west of the Strait of Belle Isle and into the Gulf of St. Lawrence).
- Key Iceberg Limit Areas
    - Area, in square nautical miles, inside the Iceberg Limit and south of 48°N.
    - Area, in square nautical miles, inside the Iceberg Limit, south of the horizontal Estimated Limit south of Greenland, and east of 48°W.
    - Area, in square nautical miles, inside the Iceberg Limit, south of 52°N.
- Watch process statistics
    - Icebergs added to the database since the last product release.
    - Icebergs deleted from the database since the last product release.
- Daily “heat” maps color-coded according to the quantity of icebergs that drifted into a 0.25° by 0.25° latitude-longitude grid cell for each 0000Z model prognosis.
- Daily difference “heat” maps created by subtracting the IIP iceberg database map from the NAIS iceberg database map. These maps provided a color-coded, daily comparison that showed the areas where icebergs drifted for each model.
- Cumulative difference “heat” map showing the sum of all daily difference maps for each evaluation period.
- Anecdotal cases of iceberg drift illustrating key findings from the evaluation.

These measurements were created based on the subjective decisions of a human operator in response to standard criteria. IIP Model-based results were generated by the normal IIP OPCEN Watch Officer and were the result of a rotating staff of qualified Watch Officers. Two different qualified individuals, removed from the normal watch rotation, functioned as the Test BAPS Operators for each evaluation period.

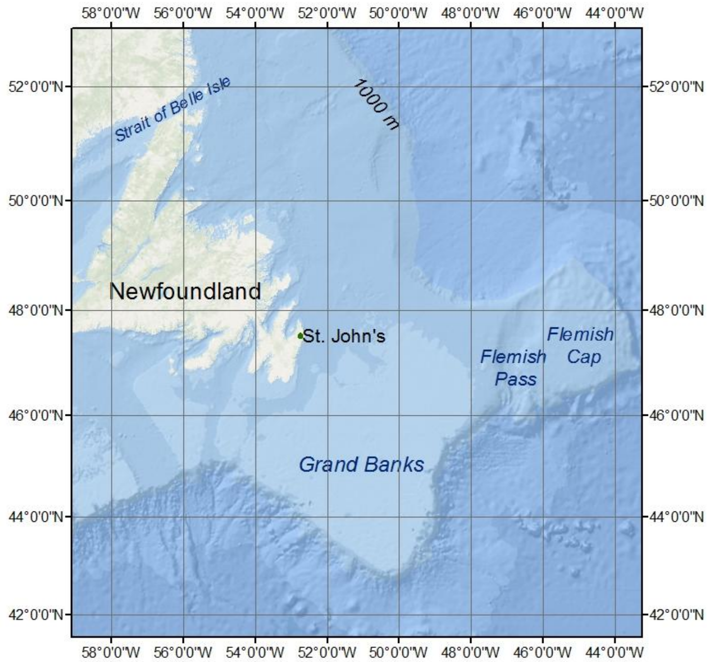


Figure B-1. Area Locator Map.

Results

Key results of the operational evaluation are presented below. The first key result was that BAPS never experienced any problems in completing all tasks required to produce NAIS Model daily products on time. Environmental forcing data appeared reasonable and arrived on time every day of the test. From a functional perspective, there is no issue with IIP switching to use the NAIS Model for product creation immediately. Concerns regarding the information content of the output from the NAIS Model will be addressed below. This section covers the differences in the bulk properties of iceberg distributions predicted by the two different models. **Figure B-1** provides a locator map for key geographic features referred to throughout this appendix.

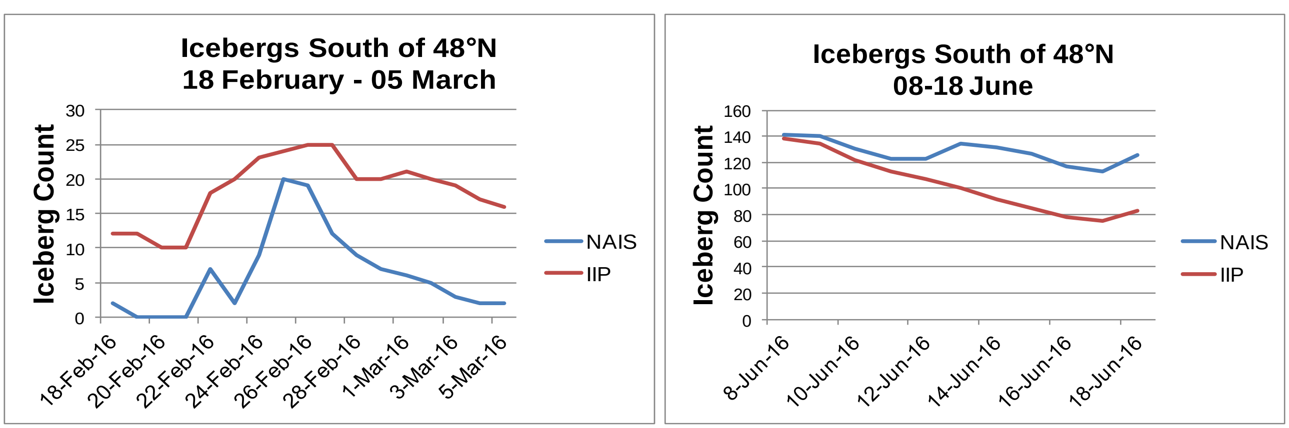


Figure B-2. Iceberg Counts South of 48°N in the NAIS (blue) and IIP (red) Databases During Each Test Period.

Iceberg Counts and Iceberg Limit Area – South of 48°N Latitude

As described in the main body of the annual report, the number of icebergs south of 48°N provides an indicator of season severity. Since this latitude represents the northern limit of the transatlantic shipping lanes, it reflects the current danger to shipping from iceberg hazards. **Figure B-2** shows the iceberg count south of 48°N during the two test periods. Throughout the entire first evaluation period (left panel of **Figure B-2**), the number of icebergs south of 48°N in the IIP Model exceeded the count in the NAIS Model, but both models produced similar patterns. After a slight drop in both models, the iceberg count built to a maximum from 25-27 February before declining through the end of the evaluation. This did not appear to be a product of the NAIS Model melting the icebergs in the south faster than the IIP Model. Instead, the NAIS Model appeared to be much more sensitive to strong westerly and southerly winds which moved icebergs north of the Flemish Cap instead of allowing them to drift through Flemish Pass in the core of the Labrador Current.

The second evaluation period shown in the right panel of **Figure B-2**, was marked by a general decline in the number of icebergs south of 48°N in both IIP and NAIS Models, with two exceptions. First, the number of icebergs in the NAIS Model showed a slight increase on 13 June while the count in the IIP Model steadily declined until 17 June. This reflected the fact that icebergs appeared to melt more slowly in the NAIS Model than in the IIP Model allowing icebergs to linger for a longer time period in the NAIS Model and drift south of 48°N. The second exception where the iceberg count increased in both models resulted from an IIP reconnaissance flight on 16 June that detected 20 icebergs near 42°N.

The Iceberg Limit area south of 48°N (**Figure B-3**) represents the region of the North Atlantic Ocean that IIP recommends transatlantic shipping avoid. Throughout the first evaluation period (left panel), **Figure B-3** shows that the IIP Iceberg Limit area south of 48°N exceeded the NAIS Iceberg Limit Area. The trend shown in this is mainly due to the fact that the area in the IIP Model was determined exclusively by a single iceberg prior to 26 February. Since an IIP IRD was scheduled to conduct a reconnaissance flight as early as 20 February, CIIP elected to retain this iceberg in the IIP Model database, even with an estimated melt exceeding 500%. If this iceberg had been removed when it melted beyond 150%, the Iceberg Limit area south of 48°N early in the test would have been much lower for IIP and more consistent with Iceberg Limit area created by the NAIS Model. Prior to the start of the

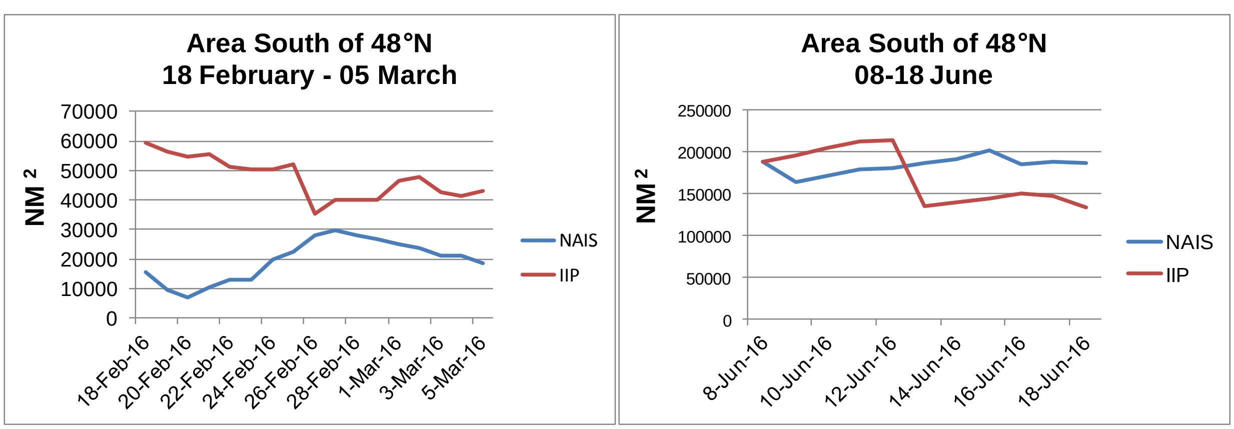


Figure B-3. Iceberg Limit Area South of 48°N for NAIS (blue) and IIP (red) Databases for Each Test Period.

evaluation period, the NAIS Model drifted the same iceberg well outside of the IIP OPAREA, and it was removed from the database.

The second evaluation period shown in the right panel of **Figure B-3,** depicts a significant decrease in area for IIP Model results on 13 June. This result reflects decisions by the IIP Watch Officer to delete 53 icebergs from the IIP database from 11-13 June. These decisions were based on an IIP flight on 10 June and iceberg deterioration on 12 and 13 June. The Iceberg Limit area south of 48°N for the NAIS Model continued to increase throughout the remainder of the evaluation period.

This result highlights three important points in this operational evaluation. (1) During both evaluation periods, with exception of a flight on 09 March as described below, the IIP OPCEN used results from the IIP Model to plan all flights. This resulted in the deletion of a key iceberg from the IIP database on 10 June that was not deleted from the NAIS database because it did not meet IIP's deletion criteria for radar (or visual) reconnaissance coverage. Consequently, this iceberg remained in the NAIS database throughout the evaluation period and eventually established the Eastern Iceberg Limit for the NAIS Model. This decision alone does not offer meaningful insight into the performance of either model being evaluated but reflects limited resource availability for NAIS Model validation. (2) As detailed above, the NAIS Model generally deteriorated icebergs more slowly than those in the IIP Model. In addition to this iceberg that remained in the NAIS database after a reconnaissance flight, a second iceberg

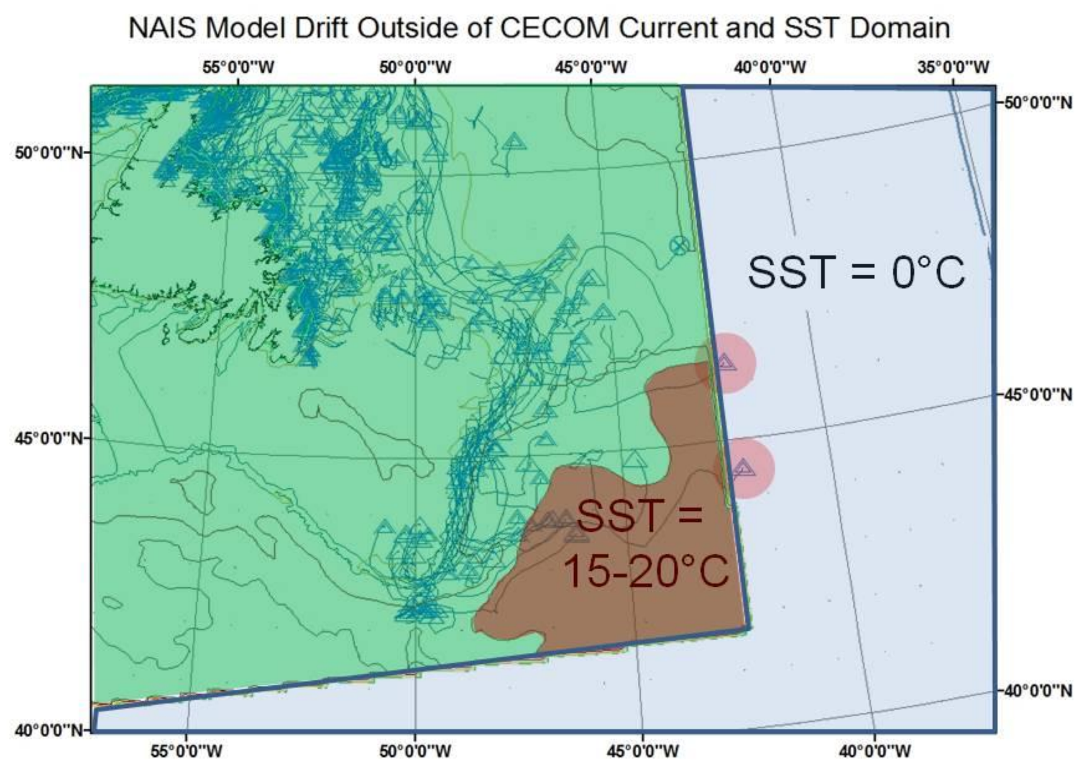


Figure B-4. NAIS Model Icebergs Adrift Outside of CECOM Current (red highlight) and SST Domain on 18 June. CECOM domain is shown in green with the 15-20°C contour highlighted in brown.

that was deleted from the IIP database in accordance with IIP SOP (deterioration >150%) remained in the NAIS database because it did not meet this criteria. This iceberg continued to drift eastward, and the Test BAPS Operator used this iceberg to establish the NAIS Iceberg Limit. (3) Both of these icebergs eventually drifted outside of the CECOM domain for currents and SSTs that are used by the NAIS Model. **Figure B-4** shows the location of these two icebergs on 18 June, with respect to the CECOM current and SST domain shown in green. As these icebergs drifted outside of the CECOM domain, the SST, as interpreted within BAPS, became zero effectively halting normal deterioration. In addition, absent any current vectors, the NAIS Model reverted to wind forcing alone. The availability of suitable currents and SST data over the entire IIP OPAREA is essential for continued operational use of the NAIS Model.

Iceberg Counts and Iceberg Limit Area – East of 48°W Longitude

South of Davis Strait, icebergs coming from the north are fairly well-constrained to the west by land, so it is instructive to look at the number of icebergs moving east in the different models. This evaluation used 48°W longitude as a boundary to measure the eastward progression of icebergs. IIP used this longitude for this evaluation because it closely represents the western edge of the Flemish Pass. Icebergs drifting east of 48°W generally follow two paths – one southward, through the Flemish Pass, and a second, eastward to the north of the Flemish Cap. Both situations represent a potentially hazardous condition for transatlantic vessels.

Figure B-5 shows iceberg counts during the two evaluation periods. For the first period (left panel), the IIP database initially had more icebergs east of 48°W primarily because there were more icebergs in the IIP database. On 20 February, an IIP IRD conducted a survey patrol along the Labrador coast north to 57°N detecting 525 icebergs. The number of icebergs in both models remained very close until 28 February when icebergs in the NAIS Model began to drift eastward as a result of persistent westerly and southwesterly winds. The fact that both models showed general movement eastward after 28 February is interesting and consistent with IIP observations throughout the year that showed relatively few icebergs drifting southward through the Flemish Pass. The number of icebergs in the NAIS Model was consistently higher after that date suggesting greater sensitivity to wind events when compared to the IIP Model which favors drift along the 1000 m bathymetric contour within the Labrador current. Careful examination of the plots during the first evaluation period shows that the rate

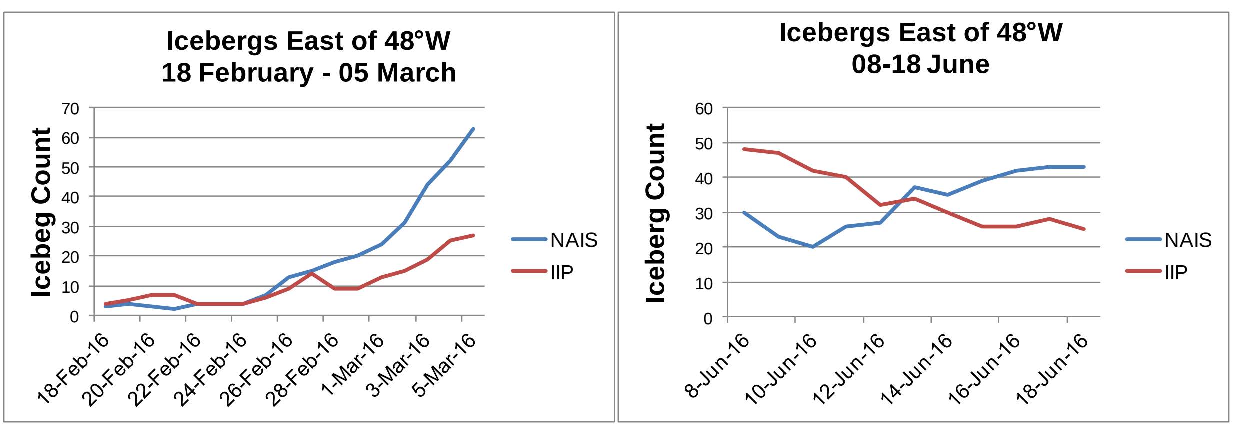


Figure B-5. Total Icebergs East of 48°W in the NAIS (blue) and IIP (red) Databases for Each Test Period.

of increase in NAIS icebergs drifting east of 48°W increased after 01 March.

For the first two days of the second evaluation period (right panel of **Figure B-5**), the number of icebergs in both models declined. This trend continued for the IIP database but reversed for the NAIS database. This result is likely due to the slow NAIS iceberg deterioration described in the previous section.

Notably, the NAIS Model results showed this eastward drift trend well to the north of 52°N and roughly 150 NM seaward of the 1000 m depth contour. Since this area is well to the east of the main branch of the Labrador Current, IIP typically does not focus reconnaissance here. On 09 March, in an effort to validate NAIS Model projections, IIP modified its normal northern survey search pattern to investigate this region where the NAIS Model predicted that a large population of icebergs was present. **Figure B-6** shows IIP's flight track and reconnaissance results in black with IIP and NAIS Model prognosis files for 09 March. Icebergs in the IIP Model are red, and icebergs in the NAIS Model are blue. Although flight conditions were poor, the IRD detected an iceberg slightly outside of the Estimated Iceberg Limit in position 53°48'N, 47°55'W. Three other icebergs were detected near and within the Iceberg Limit. These icebergs are highlighted by red ovals in **Figure B-6**. The IRD noted that additional icebergs could have been present but simply not detected due to the poor flight conditions.

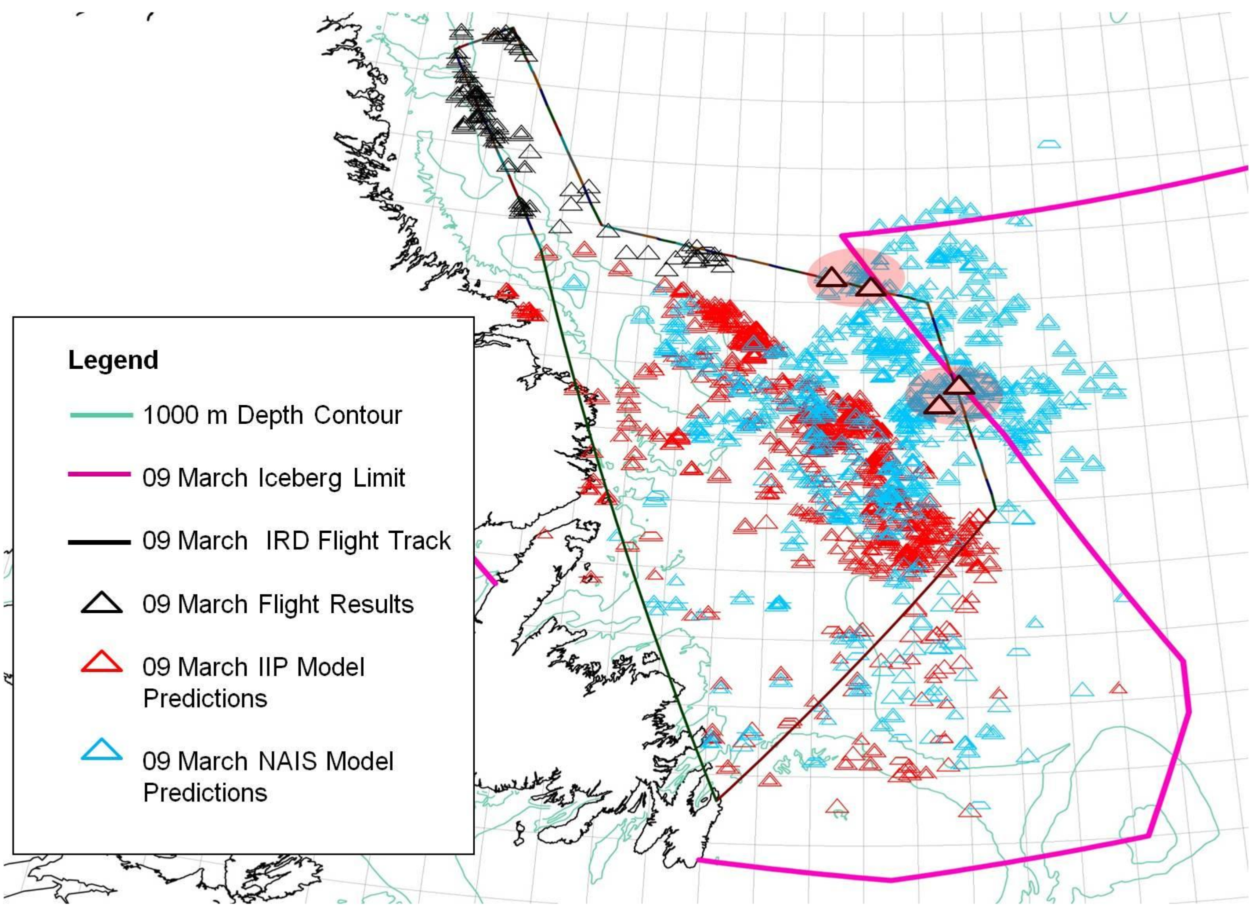


Figure B-6. IIP Flight Track Overlaid on IIP and NAIS Iceberg Databases on 09 March. The four icebergs highlighted in red ovals were either close to or outside the Iceberg Limit.

Figure B-7 shows changes in the Iceberg Limit area east of 48°W for both evaluation periods. The Iceberg Limit area east of 48°W also impacts the great circle routes followed by transatlantic mariners. In addition, the impact to IIP's aerial reconnaissance can be substantial. An eastward expansion of the Iceberg Limit can result in significant aircraft transit time (up to two hours) prior to any actual searching. During the first evaluation period (left panel) the two distinct peaks in the NAIS area were caused by single fast-moving growlers.

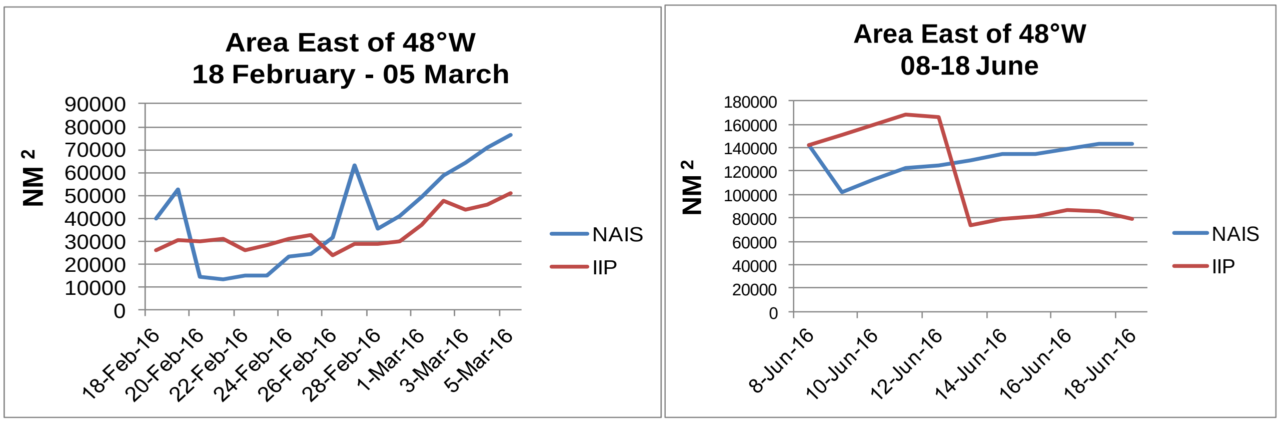


Figure B-7. Iceberg Limit Area East of 48°W for NAIS (blue) and IIP (red) Databases for Each Test Period.

The increase in area after 27 February was driven both by the increase in the number of icebergs and the tendency for eastward drift, particularly in the NAIS Model as shown in **Figure B-5**. Prior to this, the area was driven by a small number of icebergs. The fact that the Iceberg Limit area for both models seems to be showing the same trend suggests that the models are responding to a real trend in the environmental forcing. This observation is consistent with the positive phase of the North Atlantic Oscillation Index (NAOI) as described in the main body of this report.

The rapid drift of growlers should be a future focus of NAIS Model improvements and is worthy of a more detailed example. **Figure B-8**, centered near 48°N, 46°W shows the 1200Z prognosis valid on 24 February with positions of a growler over the previous 24 hours. At 000Z on 24 February, the winds were out of the northwest at 25 kts. This growler moved a total of 85 NM over a 24-hour time period making its average speed 3.5 kts. This situation caused the growler's error circle to drift outside of the established NAIS Iceberg Limit which would require a daily Iceberg Limit product revision in accordance with IIP's SOP criteria.

Iceberg Counts and Iceberg Limit Area – West of 56°W Longitude (South of 52°N Latitude)

During the first evaluation period, only two icebergs were present west of 56°W and south of 52°N. Consequently, IIP could not make any meaningful conclusions about the iceberg count and Iceberg Limit area in this region and no results are presented for the first evaluation period. A significant population of icebergs entered the Strait of Belle Isle and drifted west of 56°W in early May. **Figure B-9** shows the iceberg count west of 56°W during the second evaluation period from 08-18 June. The number of icebergs present in the NAIS database remained higher than that in the IIP database. The patterns in both the NAIS and IIP databases are consistent. Most of the icebergs shown in **Figure B-8** were originally sighted by an IIP IRD on 02 June that flew through the Strait of Belle Isle and into the Gulf of St.

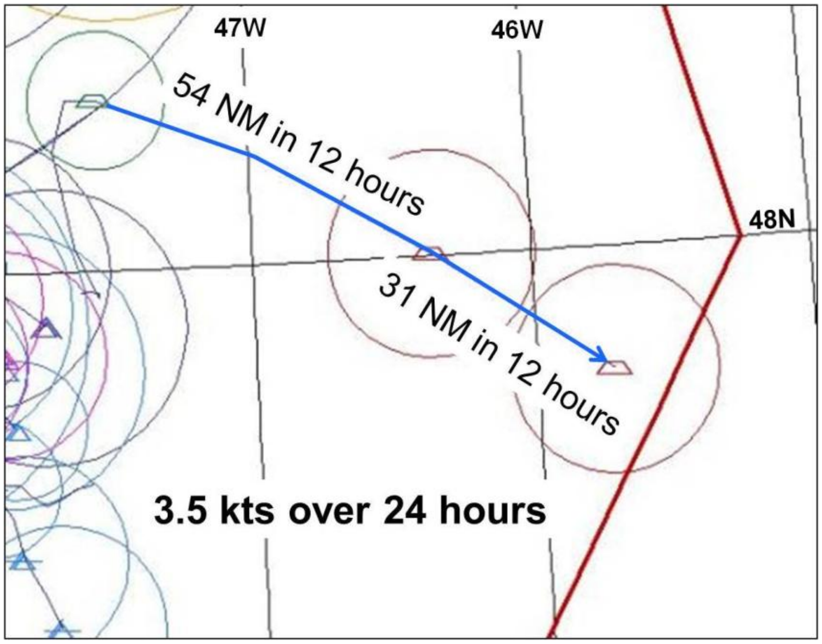


Figure B-8. NAIS Model Growler Drift Over 24-Hour Period from 23-24 February.

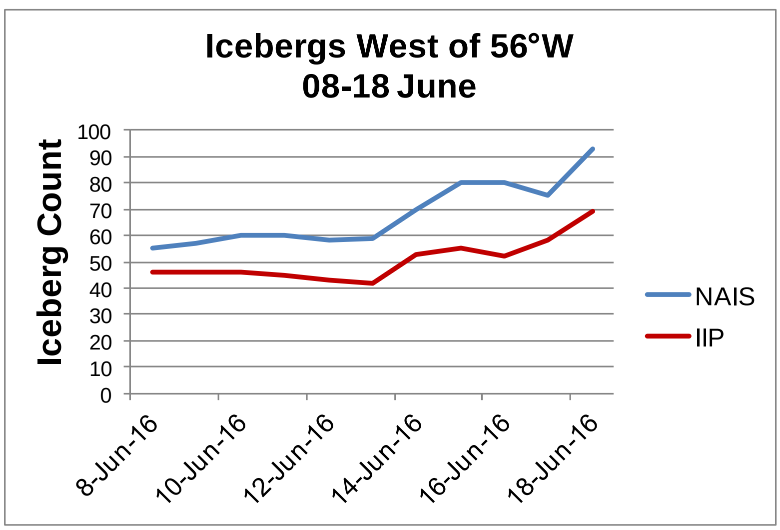


Figure B-9. Total Icebergs West of 56°W and South of 52°N for NAIS (blue) and IIP (red) Databases for the Second Evaluation Period.

Lawrence. Of note, the higher quantity and rate of increase in the NAIS database after 13 June reflects a tendency for slower melt and stronger westward drift due to the NAIS Model.

This result is more clearly represented in **Figure B-10**, when looking at the Iceberg Limit area west of 56°W. **Figure B-10** shows a constant area based on iceberg drift in the IIP Model. In fact, the position of the IIP Model Western Iceberg Limit did not change at all during the evaluation period and remained nearly constant throughout the entire month of June. The

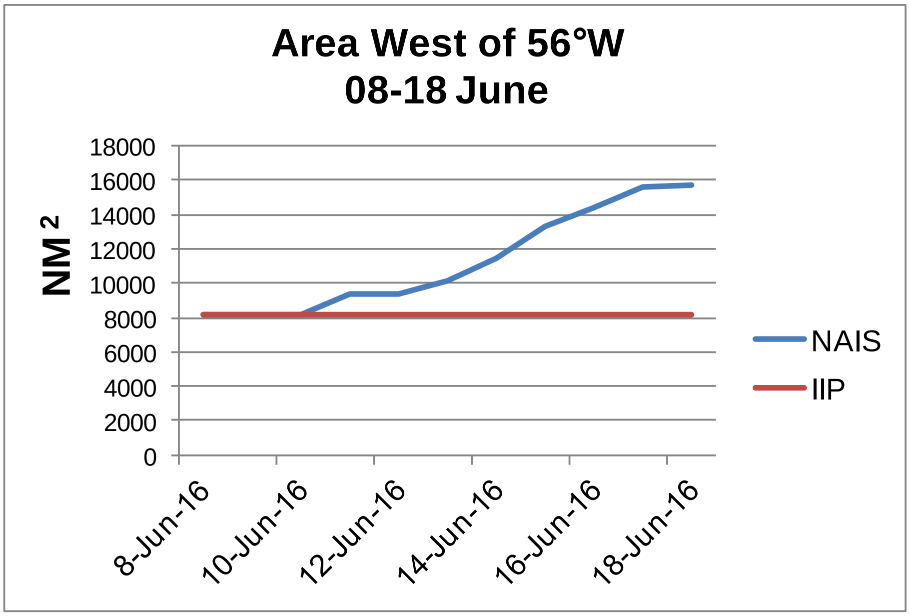


Figure B-10 Iceberg Limit Area West of 56°W for NAIS (blue) and IIP (red) Databases for the Second Evaluation Period.

NAIS Iceberg Limit, however, continued to expand westward throughout the period, predicting individual iceberg drift west of 59°W. While there were no validation flights in the area during the evaluation period, an IIP flight on 23 June, five days after the evaluation period, IIP located 67 icebergs west of 56°W with a significant number (22) located west of 58°W. In fact, this flight sighted the westernmost iceberg for the entire year. While the NAIS Model appears to have drifted icebergs too aggressively toward the west in the eastern Gulf of St. Lawrence it appears that it represented a realistic situation since IIP located icebergs further west than predicted.

NOTE: On several occasions, icebergs were sighted in shallow water, repeatedly in the same location. Both models ignored the fact that they were potentially grounded. Without this capability, a risk of "growing" icebergs on the Grand Banks exists if the model drifts the iceberg outside of the criteria necessary to re-sight the iceberg.

Cumulative Difference "Heat" Maps

After each day in both evaluation periods, the Test BAPS Operator created a color-coded "heat" map for the iceberg databases created by each model. These maps showed the number of icebergs that drifted into a 0.25° by 0.25° latitude/longitude grid cell for each model. Daily difference maps were then created by subtracting the IIP iceberg database map from the NAIS iceberg database map to provide a visual indication of iceberg drift trends for each model. At the end of each period, the number of icebergs in the daily difference map was summed to provide a graphic representation of large-scale iceberg drift tendencies for each model.

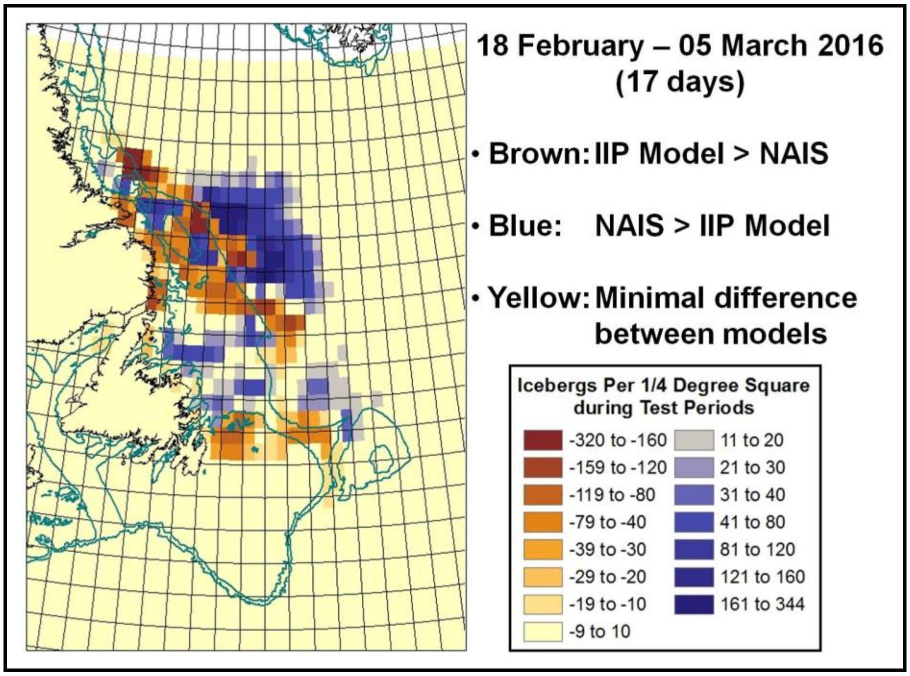


Figure B-11. The Summary of All Daily Difference "Heat" Maps Between the IIP and NAIS Databases During the First Evaluation Period. Brown areas represent areas where IIP had more icebergs, and blue areas represent areas where NAIS had more icebergs. Yellow areas indicate minimal difference between the models.

For the first evaluation period, **Figure B-11** visually captures bulk trends discussed above in a single image. In this figure, brown shades represent areas where the number of icebergs in the IIP database exceeded those in the NAIS database. Blue shades indicate the opposite. **Figure B-11** clearly shows how the northern portion of the distribution moved much further east in the NAIS Model while the northern portion of the distribution in the IIP Model stayed much closer to the 1000 m contour as expected. The southern portion of the NAIS distribution shows a clear bias towards the region to the northwest of Flemish Cap, while the IIP Model shows a bias for more southward drift in the main branch of the Labrador Current. This map shows a clear tendency for the IIP Model to favor the flow of the Labrador Current along the 1000 m depth contour as the primary driver for iceberg drift in this region and suggests that the NAIS Model places a greater emphasis on wind-driven forces for iceberg drift than the IIP Model.

Figure B-12 reinforces the difference between the IIP and NAIS Models for wind sensitivity. In this case, with predominantly on-shore winds during the evaluation period, NAIS icebergs, again shown by blue shading, accumulated closer to the coast than IIP icebergs. In both **Figures B-11** and **B-12**, the IIP Model icebergs were consistently located near the 1000 m depth contour which generally defines the main branch of the Labrador Current. The applicability of one approach over another is likely linked to the geographic area of iceberg drift. For example, while in the Flemish Pass, use of the IIP Model may be more appropriate than use of the NAIS Model since the IIP Model emphasizes ocean currents over air drag produced by the wind. The use of near real-time drifting buoy data to update currents, or at least assess the accuracy of modeled current data such as CECOM, may also improve model

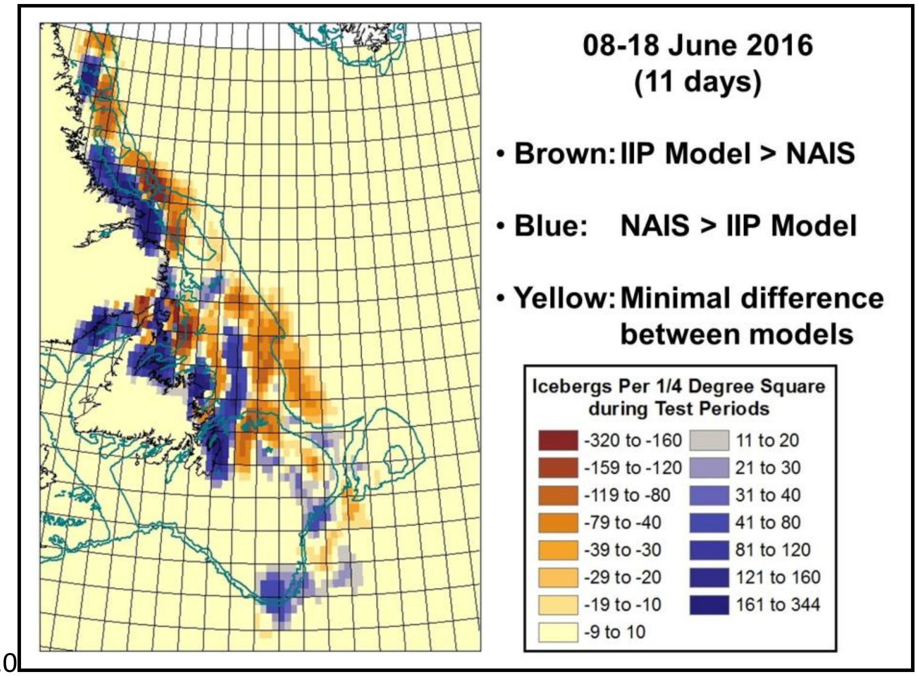


Figure B-12. The Summary of All Daily Difference "Heat" Maps Between the IIP and NAIS Databases During the First Evaluation Period. Brown areas represent areas where IIP had more icebergs, and blue areas represent areas where NAIS had more icebergs. Yellow areas indicate minimal difference between the models.

accuracy. This result supports the need for a more detailed sensitivity study focused on the most appropriate application of wind and current forcing for each model. Again, robust ground truth validation is critical for such a study.

Summary - Final Iceberg Limit Products

Examining the Iceberg Limit product on the final day of each test period summarizes the metrics presented above and provides insight on the impact of each model on IIP's daily product. **Figure B-13** presents the actual Iceberg Limit product that the IIP OPCEN distributed on the final day of each evaluation period. The distribution numbers and Iceberg Limit (in ginger-pink) were based on the IIP Model database. A similar product was also created using the NAIS Model but not distributed outside of IIP. To facilitate a visual comparison, the NAIS Iceberg Limit is overlaid onto the IIP product and depicted in blue. The first period (left panel of **Figure B-13**) clearly shows the eastward bias for iceberg drift in the region north of 48°N for the NAIS Model. While this difference in the northern area appears significant, its impact on transatlantic shipping would have been negligible since it occurred well north of the primary great circle route across the North Atlantic Ocean. In the southern part of the product, the IIP Model Iceberg Limit extended approximately 1.5° of latitude (90 NM) further south than the NAIS Model Iceberg Limit. The IIP Iceberg Limit did extend into the great circle route and would have caused a mariner, heeding IIP's daily product, to divert further south than by following a product created by the NAIS Model Iceberg Limit. Approximate great circle routes are indicated in **Figure B-13.** This observation supports the need for further investigation on the most accurate way to represent wind and current in the NAIS iceberg drift model.

At the end of the second evaluation period (right panel of **Figure B-13**) the Southern Iceberg Limit produced by both models is very consistent. This consistency is due to the fact that IIP sighted numerous icebergs that were used to establish the Iceberg Limit on 16 June, just two days prior to the creation of this product. However, the effect on the Eastern Iceberg Limit is dramatic and resulted from the two icebergs that drifted outside of the CECOM domain (refer to **Figure B-4**). The NAIS Iceberg Limit in this case was approximately 3° of longitude (120 NM). This difference underscores the need to validate iceberg deterioration and to modify the CECOM domain or identify a new source of current information.

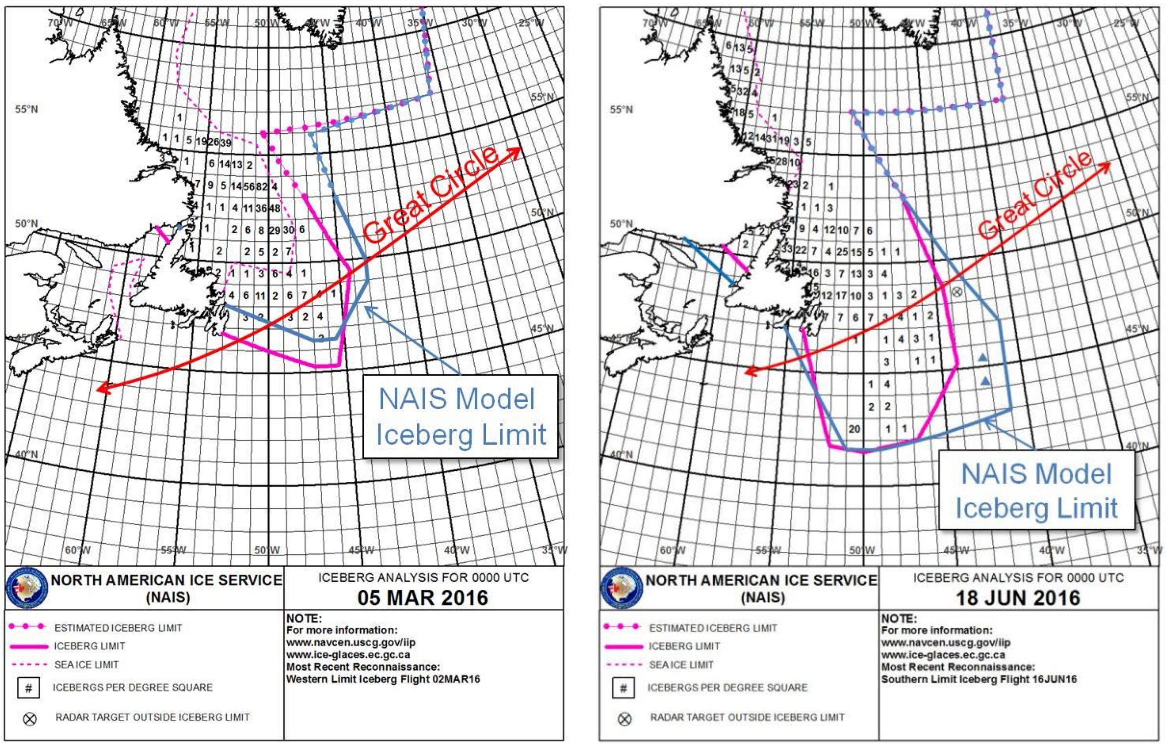


Figure B-13. IIP Product for the Last Day in Each Evaluation Period. NAIS Model Iceberg Limit for each date is overlaid in blue. Approximate great circle routes are shown in red. Locations for two icebergs that established the Eastern Iceberg Limit for 18 June are shown with solid blue triangles.

Conclusions

- Functionally, IIP could begin using the NAIS Model immediately. At a minimum, resolution of the CECOM current forcing must be resolved prior to wholesale operational use of the NAIS Model.
- During the first evaluation period, the NAIS Model moved icebergs further east than expected in response to predominantly offshore winds. During the second evaluation period, the NAIS Model moved icebergs towards the coast in response to predominantly onshore winds. During both periods, the majority of icebergs in the IIP Model remained close to the 1000 m contour in the main branch of the Labrador Current.
- The NAIS Model is presently driven by CECOM currents and SSTs. As observed during the second evaluation period, the CECOM domain for currents and SSTs does not adequately cover IIP's entire OPAREA.

- On several instances, NAIS Model product revisions were required due to fast-melting, fast-moving growlers and bergy bits. This movement was unrealistic and could be addressed by a combination of model improvements (longer term) and/or IIP policy changes (short term).

Recommendations

- IIP should work through NAIS committees to propose a business case to allocate appropriate human and/or financial resources to make improvements to the NAIS Model. This effort should consider:
    - Collecting additional ground truth data for model validation.
    - Conducting an analysis to support the best application of wind and current forcing for iceberg drift using robust ground truth information.
    - Modifying the manner in which the NAIS Model drifts growlers.
    - Determining a more appropriate source for ocean current information – either by modifying the CECOM domain or testing other possibilities such as Mercator or the Hybrid Coordinate Ocean Model (HYCOM).
    - Investigating the use of near real-time drifter data for current updates or to assess the accuracy of modeled current input.
    - Investigating the value of an ensemble approach that uses outputs from both IIP and NAIS Models to improve overall product accuracy.
    - The addition of a new module that checks the modeled iceberg keel depth against the bathymetry of the modeled position to prohibit movement until the iceberg melts enough to reduce the draft to less than the bathymetry.
- IIP recently initiated and facilitated an effort between CIS, the Canadian National Research Council (NRC), the Danish Meteorological Institute (DMI) and Argentina's Naval Hydrographic Service to share the NAIS Model with Denmark and Argentina. Both DMI and Argentina have installed the model locally and will begin testing during the remainder of 2016 and into 2017. In addition, the Norwegian Ice Service has recently received the NAIS model and will begin using it as well.
- In the near term, IIP should investigate ways to use the NAIS Model in a more operational manner – particularly in areas where IIP current information is weak such as the regions north of 52°N and in the Gulf of St. Lawrence. If the NAIS Model is to be used operationally, IIP should modify its policy to change deletion criteria for NAIS growlers. For example, IIP should consider deleting at 75% deterioration for icebergs that are greater than 60 NM within the Iceberg Limit and deleting at 100% deterioration for icebergs less than 60 NM.
- Incorporate lessons learned from testing in different parts of the world to gain insight on possible model improvements. Both NAIS and the International Ice Charting Working Group Iceberg Sub-committee provide suitable forums for this collaboration.

- **Reference:**

Murphy, D.L., and T. Carrieres, 2010. CIS-IIP Model Intercomparison. A report to the North American Ice Service, June 2010.

Appendix C

International Ice Patrol Satellite Commercial Synthetic Aperture Radar Iceberg Reconnaissance Concept of Operations

CDR Gabrielle G. McGrath
Mr. Michael R. Hicks
LT Ryan H. Clark

Background

Introduction

As mandated by SOLAS, the U.S. guards the southeastern, southern, and southwestern limits of the region of icebergs in the vicinity of the Grand Banks of Newfoundland for the purpose of informing passing ships of the extent of this dangerous region. Title 46, Section 738 of the U.S. Code directs the USCG to administer this service. The IIP, operating under CG-5PW, currently oversees this mission. IIP executes this mission primarily with USCG HC-130J aerial reconnaissance flights that begin in February and continue as long as icebergs pose a hazard to transatlantic shipping, generally through the end of July.

In 2016, IIP began a transition from purely aerial reconnaissance to a mix of both aerial and satellite reconnaissance to fulfill its international treaty obligations. While satellite technology is not yet capable to be used exclusively to conduct the mission, satellite-derived SAR iceberg data can be used to augment HC-130J reconnaissance. Incorporating satellite reconnaissance routinely will reduce IIP's complete reliance on USCG aircraft to execute the mission. Appendix B in IIP's 2015 Annual Report provides a comprehensive discussion on the basis for IIP's position on satellite reconnaissance.

This CONOPS describes IIP's plan to incorporate commercial SAR (COMSAR) data into its operations. While there are numerous external entities involved, for simplicity, this CONOPS only addresses IIP's role with its immediate partners in the COMSAR tasking, collection, exploitation, and dissemination (TCPED) process: the USCG Intelligence Coordination Center Geospatial Intelligence (ICC GEOINT), the USCG Maritime Intelligence Fusion Center, Atlantic, Collections division (MIFC LANT), and NAIS. NAIS comprises IIP, the NIC, and CIS. As new SAR satellite systems are launched, and IIP personnel become more proficient at interpreting SAR results, IIP expects to become more fully integrated into each phase of TCPED.

IIP Mission

IIP's mission is to monitor the iceberg danger in the North Atlantic Ocean and provide relevant iceberg warning products to the maritime community. During times when icebergs threaten the transatlantic shipping lanes, IIP creates and maintains a database that is populated with iceberg reports from IIP's reconnaissance, from other commercial and

Canadian government aerial reconnaissance, and from ships at sea. Each day, the IIP OPCEN runs a computer model that predicts the drift and deterioration of all icebergs in its database based on key environmental parameters. The DWO establishes the Iceberg Limit and broadcasts its location both graphically and textually. The graphical version of the Iceberg Limit product also includes IIP's estimate on the number of icebergs within a 1° by 1° latitude/longitude grid cell.

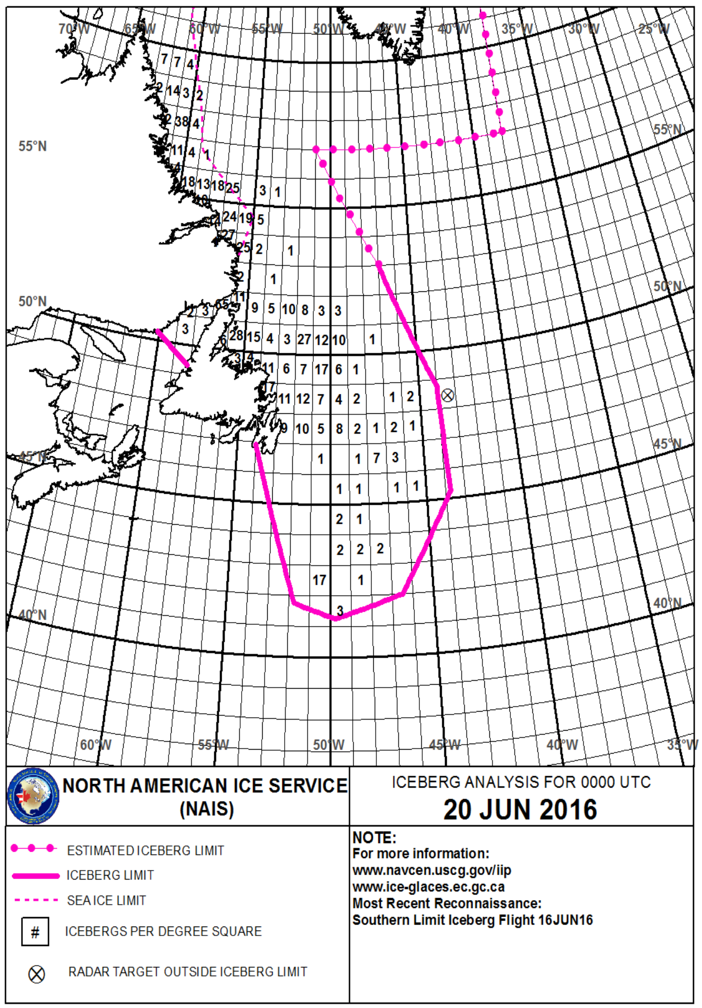


Figure C-1. NAIS Daily Iceberg Limit Chart on 20 June 2016.

Figure C-1 is an example Iceberg Limit product for 20 June 2016, when the Iceberg Limit was near its southernmost extent for 2016. The solid ginger-pink line represents the Iceberg Limit on that date. While conceptually, determining the Iceberg Limit is a straightforward task, implications of its proper placement on transatlantic shipping are significant and carefully considered by IIP when creating this daily product. An Iceberg Limit that is too conservative (too far south or east) unnecessarily encumbers vessel traffic and erodes IIP's credibility. Not extending the Iceberg Limit far enough to encompass all ice hazards increases the risk that a vessel will encounter and, in a worst case, collide with an iceberg endangering both lives and property.

The IIP's reconnaissance focuses on detecting small icebergs (15-60 m in length) at the extreme iceberg positions where oceanographic features such as the cold, southward-flowing Labrador Current and/or cold-core eddies support the presence of hazardous icebergs. The IIP estimates that aerial reconnaissance currently achieves a 95% probability of detecting small icebergs. Full transition to satellite reconnaissance demands a similar accuracy, so that the CIIP can confidently declare the areas outside of the Iceberg Limit free of iceberg danger. A study, conducted by Science Applications International Corporation (SAIC) in 2011, estimated that accomplishing coverage of a typical Iceberg Limit for 15 May would require 31 frames over a two-week time period using the Canadian RADARSAT-2 satellite with Wide-Fine Beam mode as shown in **Figure C-2**. The probability of detecting small icebergs has not been determined with this satellite mode, however validation efforts to date indicate that this mode has achieved only marginal correlation with aerial reconnaissance flights as discussed below.

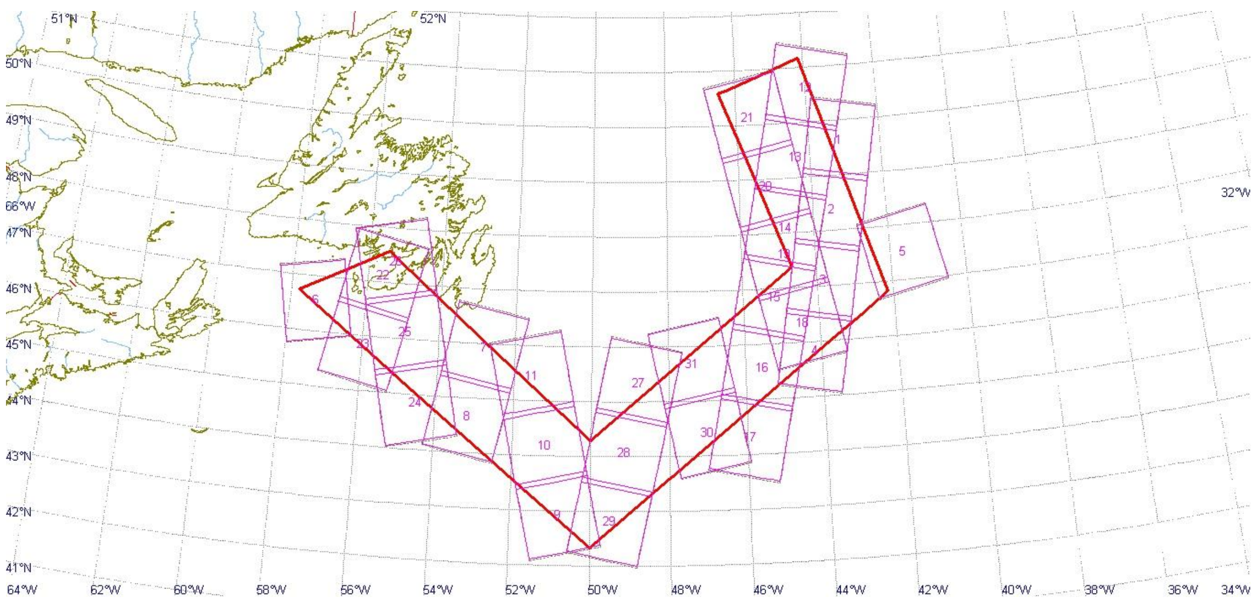


Figure C-2. RADARSAT-2 Wide Fine Beam Mode Coverage of Typical 15 May Iceberg Limit Providing Coverage with 31 Frames. Probability of detection estimates are undetermined. (SAIC, 2011)

COMSAR Validation Efforts

Since 1997, IIP investigated the use of COMSAR from various polar-orbiting satellite platforms. The distinct advantages of COMSAR over sensors that operate in other bands of the electro-magnetic spectrum, such as electro-optic infrared (EOIR), are that it is not limited by cloud cover and can also be operated night and day. The IIP's OPAREA) is frequently obscured by clouds making COMSAR the only viable option for satellite iceberg detection. However, iceberg data derived from SAR satellites must be validated, so that it can be used to support IIP's mission to determine the Iceberg Limit with confidence.

Recent validation efforts are described in detail in Appendix B of IIP's 2015 Annual Report and are summarized below. Comparative analyses between satellite and aerial reconnaissance to date, show only marginal correlation for operationally-relevant satellite modes. **Figure C-3** illustrates both coverage area and resolution along with IIP's correlation percentages between aerial and satellite detections associated with each mode tested. The best correlation rates were achieved with RADARSAT-2 Fine mode (green frame), but this mode covers only a very narrow swath roughly equivalent to a single HC-130J aerial search leg and is not operationally or economically viable. RADARSAT-2 Wide-Fine (blue box) or TerraSAR-X ScanSAR (red box) modes offer the best compromise between coverage and resolution. However, the correlation of these modes with aerial reconnaissance under-flight is only 42-49%. In 2015, IIP began evaluating the ESA Sentinel-1a satellite that was launched in 2014. The Sentinel-1a Interferometric Wide Swath (IWS) mode provides excellent coverage (250 km) with 20 m resolution. Unlike other COMSAR sources tested, Sentinel-1a imagery reflects ESA's open data-sharing policy and is available at no cost, representing a major breakthrough in satellite data acquisition. Preliminary correlations of Sentinel-1a data show similar marginal results as the other COMSAR systems.

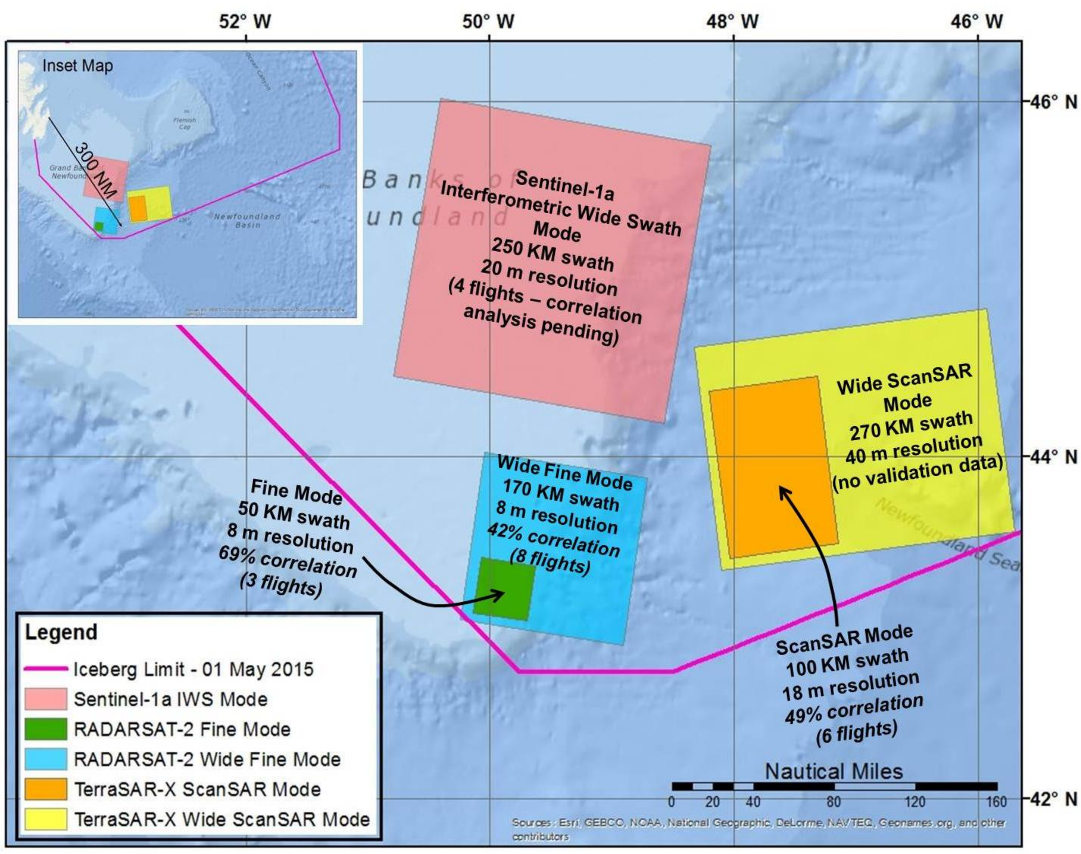


Figure C-3. Satellite Mode Coverage vs. Resolution Comparison. Correlation percentages between satellite-derived data and aerial reconnaissance are noted for each mode.

Satellite Reconnaissance Strategy

Validation results to date formed the basis for a conceptual two-pronged satellite collection strategy, based geographically on the location of the transatlantic shipping lanes. As discussed earlier, IIP strives to provide transatlantic mariners with a daily Iceberg Limit that is as accurate as possible. IIP's daily warning product represents a declaration that vessels traveling outside of the published Iceberg Limit will not encounter an iceberg. Reconnaissance data to support this high standard must be commensurate with this goal. This conceptual strategy is based on:

- IIP's level of confidence to routinely exploit data from COMSAR imagery in an operationally-relevant time frame (within 12 hours of satellite acquisition).
- The assumption that IIP will be able to routinely receive imagery in the OPCEN.

To illustrate this strategy, **Figure C-4** depicts three satellite regions overlaid on a typical early-June NAIS Iceberg Chart.

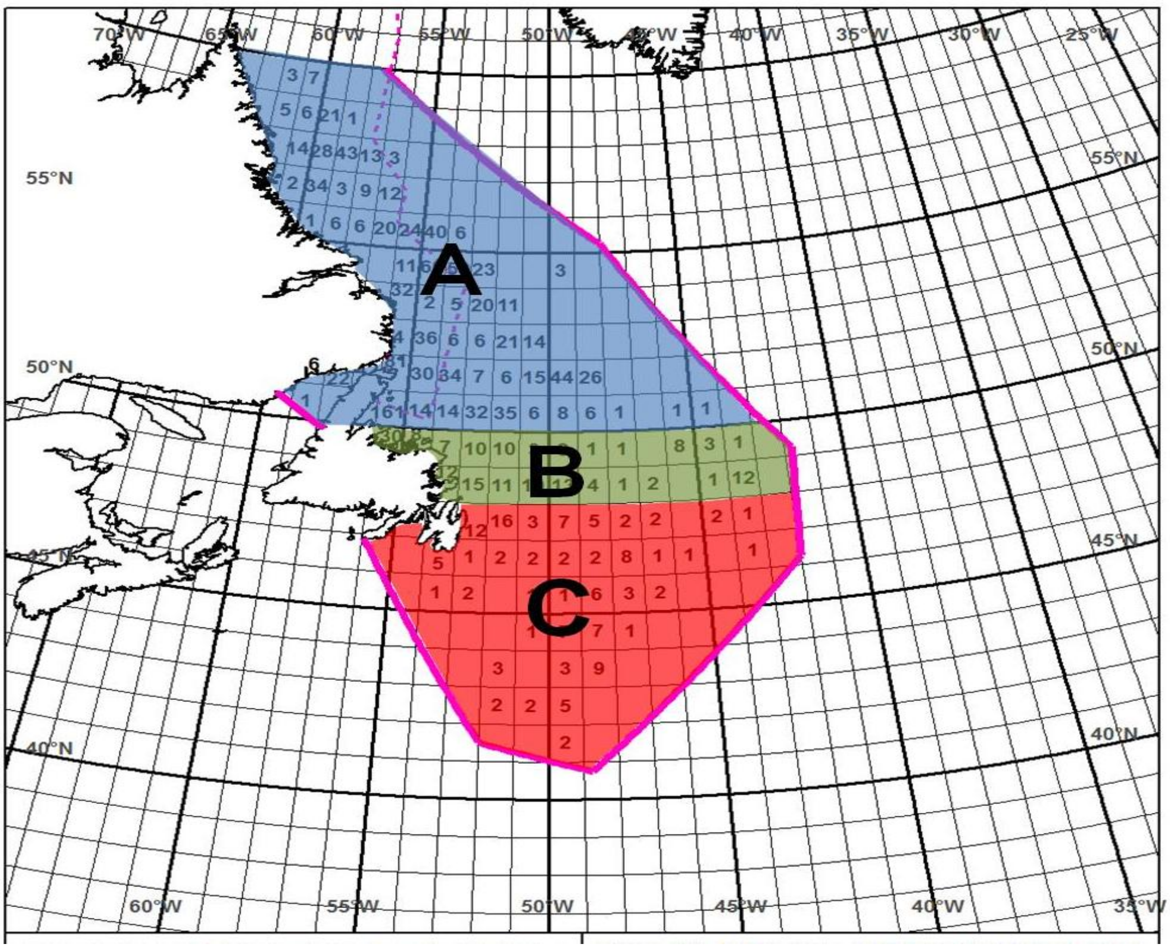


Figure C-4. IIP Satellite Reconnaissance Strategy.

The first part of IIP's strategy focuses on the region of the IIP OPAREA north of 50°N (Satellite Region A in **Figure C-4**). Satellite data collected in this area are intended to be used to augment IIP's iceberg database directly. Satellite modes that sacrifice image resolution for larger spatial coverage, such as RADARSAT-2 ScanSAR Narrow or TerraSAR-X Wide ScanSAR, provide sufficient resolution to identify larger icebergs while covering a greater area.

Satellite	Preferred Acquisition Mode	Resolution	Scene size	Polarization	Incidence Angle
RADARSAT-2	ScanSAR Narrow	50 m	300 km x 300 km	Dual	> 35°
TerraSar-X	Wide ScanSar	40 m	270 km	HH	
Sentinel-1a	Interferometric Wide-Swath	40 m	400 km	HH/HV	
COSMO-SkyMed	ScanSAR - Wide	30 m	100 km x 100 km	HH	

Table C-1. Preferred Commercial Satellite Modes for Iceberg Detection in Satellite Region A.

This region typically contains the "feeder" population of icebergs which have the potential to eventually drift into the higher traffic shipping lanes. Generally, in Satellite Region A, the presence of larger icebergs and fewer ships, makes discrimination of ship/iceberg targets less challenging than in areas further south. Preferred modes of operation for this region are outlined in **Table C-1**. This approach is used routinely by CIS between September and January. During these months, the Iceberg Limit generally does not intersect the transatlantic shipping lanes, and icebergs are primarily a Canadian domestic problem. It should be noted that this region is frequently covered by sea ice through early-April. Detecting icebergs embedded in sea ice remains a challenging problem with both aerial and satellite reconnaissance.

The second part of IIP's satellite strategy focuses on the OPAREA south of 50°N where icebergs pose a greater hazard to transatlantic shipping (Regions B and C in **Figure C-4**). Region B in **Figure C-4** (between 48°N and 50°N) is separately identified from Region C because IIP will use this area to conduct concurrent aerial observations for continued satellite validation which requires higher resolution images as specified in **Table C-2**. This area was selected due to its proximity to IIP's base of operations in St. John's, Newfoundland and associated ease of coordination. IIP will consider adding targets identified as icebergs that are detected in Region B depending on the target's proximity to the Iceberg Limit and the presence of existing icebergs within criteria defined in IIP's OPCEN Standard Operating Procedures (SOP) at the time of detection. The presence of cold-water oceanographic features such as the Labrador Current, the availability of AIS or other vessel identification systems, and the timing of the next planned aerial reconnaissance flight will also be considered in making this decision.

Satellite Region C (south of 48°N) carries the highest risk of iceberg collision with transatlantic vessels and requires HC-130J aerial reconnaissance for primary detection. Icebergs detected by satellite in Region C will generally not be incorporated into the IIP database without other corroborating evidence as to the targets' identity. Data for Region C must be of the same quality as Region B as shown in **Table C-2**.

Satellite	Preferred Acquisition Mode	Resolution	Scene size	Polarization	Incidence Angle
RADARSAT-2	Extra Fine	8 m	125 km x 125km	HH or HV	> 35°
RADARSAT-2	Wide Fine	8 m	150 km x 170 km	Dual	
TerraSar-X	ScanSAR	18 m	150 km x 100 km	HH	
Sentinel-1a	Interferometric Wide-Swath	20 m	250 km	HH/HV	
COSMO-SkyMed	ScanSAR - Wide	30 m	100 km x 100 km	HH	

Table C-2. Preferred Commercial Satellite Modes for Iceberg Detection in Satellite Regions B and C.

COMSAR Data Acquisition (Tasking and Collection)

The IIP works with the NIC to take advantage of their unique capability to acquire RADARSAT-2 SAR imagery directly from the RADARSAT-2 operator, MDA. Collaboration between NIC and IIP has greatly benefitted the NAIS partnership. The NIC has allotted approximately 120 images (equivalent of $300k if purchased from MDA) from their RSAT imagery totals to provide data to the IIP.

The IIP will continue to request RADARSAT-2 imagery through the NIC, leveraging NGA's and Canada's Northern View arrangement until 2018. Renewal of this arrangement beyond March 2018 is under consideration by the Canadian government and NGA.

To obtain desired imagery, IIP identifies areas of interest (AOI) two to three months in advance based on iceberg climatology and the most recent environmental conditions. Sufficient lead time improves the likelihood that IIP's request receives favorable consideration through the Canadian Enhanced Marine Ordering Coordination (EMOC) process. Communication on potential conflicting interests such as CIS or DND is key to successfully obtaining RADARSAT-2 data.

The IIP works with the NIC to take advantage of their unique capability to acquire RADARSAT-2 SAR imagery funded by the NGA directly from the RADARSAT-2 operator, MDA, under an arrangement between NGA and the DND to share RADARSAT-2 imagery between the U.S. and Canada called Northern View.

The IIP will continue to request RADARSAT-2 imagery through the NIC under the Northern View arrangement for until 2018. The IIP will identify AOI between two to three months in advance based on iceberg climatology and the most recent environmental conditions. Sufficient lead time will improve the likelihood that IIP's request receives favorable consideration through the EMOC process. Communication with potential conflicting interests such as CIS or the DND is key to successfully obtaining RADARSAT-2 data.

COMSAR Data Analysis (Processing, Exploitation, and Dissemination)

Unlike other USCG missions that rely on aerial reconnaissance, IIP is unique in the fact that trained IIP iceberg observers deploy as a detachment with the HC-130J air crew from USCG Air Station Elizabeth City. Detachments travel to St. John's, Newfoundland and operate as a team for nine-day periods during February through July. IIP personnel undergo a rigorous training program that builds expertise in iceberg reconnaissance by air. This same proficiency must be developed and maintained to successfully interpret satellite data for incorporation into IIP operations. Unlike EOIR, analyzing SAR imagery is not intuitive and requires a trained analyst to properly interpret results. While SAR offers distinct advantages over EOIR such as day/night operation and the ability to penetrate cloud cover, SAR data analysis demands a sophisticated approach with an appropriate blend of an automated computer algorithm and manual human interpretation for success.

Data processing involves the receipt of raw SAR image files that frequently exceed 1 GB in size. For RADARSAT-2 data, downloading this file is accomplished through MDA's file transfer protocol (FTP) site by either NIC or IIP. Sentinel-1a data can be downloaded directly from an ESA web site for further analysis. Once the image data arrives at the analysis site, an automated detection algorithm can be applied to identify candidate iceberg targets. Image data must be geo-registered prior to using the automated detection algorithm. Automated detection algorithms incorporate a routine that compares the brightness of pixels associated with a possible target to those of the ocean background. These targets must then be evaluated by a human to decide the nature of the target: vessel, iceberg, or noise. The human analyst must identify prospective targets while considering factors such as satellite beam mode, resolution, incidence angle, image polarization, environmental conditions, and prior experience with analogous targets. This semi-automated approach to satellite SAR data analysis provides the best opportunity for timely, operationally-relevant results. To ensure that only actual targets are considered for inclusion into the iceberg database, the analyst can modify the sensitivity of the output from the automated algorithm by adjusting the constant false alarm rate.

In 2016, IIP procured Iceberg Detection Software to be used to analyze all collected satellite imagery directly. Initial training was conducted in November of 2016, and IIP will fully implement this process into the OPCEN watch during the 2017 Ice Season. Staff will need to become proficient in the use of this tool. **Figure C-5** is a RADARDAT-2 Extra Fine Mode image provided by MDA which clearly shows the difficulty in visually detecting icebergs using COMSAR imagery. The red circles show targets that could not be identified as vessels by MDA's detection algorithm.

Desired Output

The output of the exploitation process will consist of:

- A listing that contains latitude and longitude positions for targets detected by the automated algorithm and screened by human analysts. Targets will be identified as an iceberg or a vessel. An estimate on target length will be provided.
- A Manual of Standard Procedures for Observing and Reporting Ice Conditions (MANICE) formatted file, allowing IIP watch standers to quickly input this data into IIP's BAPS.

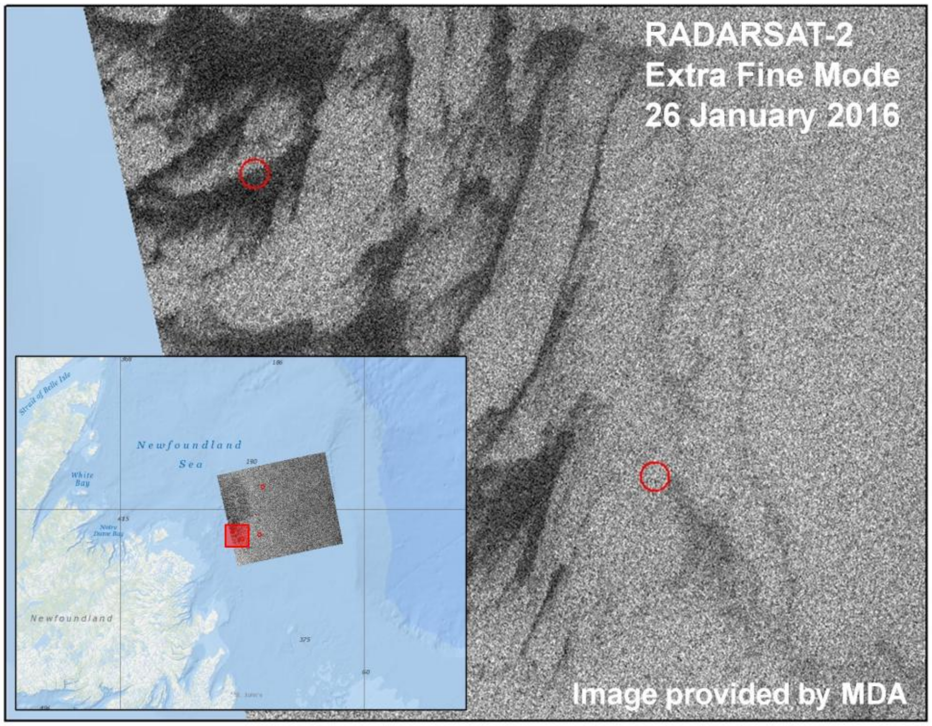


Figure C-5. RADARSAT-2 Extra Fine Mode Image Collected on 26 January 2016. Red circles indicate targets that could not be identified as vessels.

- A geo-located shape file that can be opened by ArcGIS 10.1 which serves as the user interface for BAPS.

Timeliness

To be operationally relevant, IIP must receive and analyze imagery in a timely manner. Timeliness pertains both to frequency of iceberg sighting data within a geographical area and the latency in receiving data in the IIP OPCEN after a detection. IIP's current reconnaissance strategy seeks to acquire iceberg position reports every 4-5 days. Icebergs drift with ocean currents and can move up to 25 NM in a day. The iceberg drift model used by the IIP OPCEN is not a perfect representation of actual conditions. The error may be as large as 30 NM by the fifth day after a sighting report, unless positions are regularly validated using recent siting data. Because of this error, the IIP endeavors to acquire iceberg information from all available sources and updates iceberg positions as frequently as possible.

It is important to minimize the time between data collection and incorporation into the iceberg model, and subsequently, incorporation into the daily warning products. Optimally, IIP expects to receive iceberg sighting data in the IIP OPCEN within 12 hours of collection in order to maximize operational relevance. Data can be incorporated beyond this time period, but generally becomes operationally irrelevant after 36 hours due to inherent errors caused by iceberg drift and excessive model run times for data older than 36 hours.

COMSAR Data Integration into the IIP Product

The final step described in this CONOPS is the disposition of the data once it is derived through the TCPED process. As described previously, correlation percentages for COMSAR iceberg data using operationally-realistic satellite modes remains at 42-49%. This correlation is not adequate for direct inclusion into IIP's iceberg database, particularly for targets detected near or outside of the Iceberg Limit.

One of the goals of the exploitation phase described above is to eliminate false positives as they create a particularly challenging scenario for CIIP when reported near or outside of the Iceberg Limit. For targets reported in these critical areas, CIIP is faced with the dilemma of using an unverified, satellite-derived report to set the Iceberg Limit or choose not to include this data on the daily Iceberg Warning product and risk allowing a possible hazard to remain unreported to shipping. This decision must be made while considering the following:

- Time of the year: Is the Iceberg Limit expanding or contracting?
- Report location: Is the target near or outside of the Iceberg Limit?
- Ocean current: Is there a plausible path for an iceberg to be in the position of the report?
- Sea surface temperature: While water temperature alone does not determine the possible presence of an iceberg, it should be considered in the context of other factors.
- Recent aerial reconnaissance in the area.

Ship versus iceberg identification remains a significant challenge. Although IIP's automated iceberg detection algorithm attempts to discriminate an iceberg from a vessel, recent validation efforts show that targets are frequently mis-identified. The use of a vessel AIS or other auxiliary tools can improve target identification considerably and ultimately increase IIP's confidence in integrating COMSAR data into its product. IIP will employ real-time AIS data provided by the USCG E-GIS application to aid in classifying satellite detections.

Summary

IIP recognized the potential for conducting iceberg reconnaissance by satellite for decades. Validation efforts with available COMSAR assets, to date, show only marginal correlation between satellite and aerial observations, both from USCG HC-130J and commercial flights. However, ESA's free and open data sharing policy with its recently launched Sentinel-1a and the promise of a similar philosophy for the planned launch of the RADARSAT-2 replacement, the RADARSAT Constellation Mission (RCM), access to no-cost COMSAR data for IIP will continue to improve access to COMSAR data dramatically. COMSAR image access at no-cost, coupled with the availability of automated iceberg detection software to exploit SAR imagery opens the door for IIP to bring this source of iceberg data into its operations routinely and may ultimately allow a phase-out of aerial reconnaissance once sufficient confidence and proficiency is attained by IIP staff.

The two-pronged reconnaissance strategy outlined in this CONOPS mitigates the risk of using a new, unproven technology while providing the opportunity for IIP personnel to become proficient at each phase of the TCPED process. Building this proficiency in satellite iceberg reconnaissance will involve IIP personnel gaining skills in the use of the iceberg detection software combined with human analysis to routinely incorporate satellite data into the daily IIP iceberg warning products.

IIP views the transition to the use of satellite technology for iceberg reconnaissance as an on-going process. Only through continued validation, adjustment of the automated detection algorithm and improved proficiency by IIP staff in every phase of the TCPED process will this transition become a reality. Ultimately, CIIP must carefully evaluate iceberg data from any source – surface, aerial, or space-borne to guard transatlantic mariners from the continued threat posed by drifting icebergs.