Homeland Security

United States Coast Guard

Report of the International Ice Patrol in the North Atlantic

2015 Season
Bulletin No. 101
CG-188-70

Bulletin No. 101
Report of the International Ice Patrol in the North Atlantic
Season of 2015
CG-188-70

Forwarded herewith is Bulletin No. 101 of the International Ice Patrol (IIP) describing the Patrol's services and ice conditions during the 2015 season. With 1,165 icebergs drifting into the transatlantic shipping lanes, 2015 was the 13th most severe Ice Season on record dating back to 1900. While the southern Iceberg Limit extended to 40°45'N, approximately the latitude of New York City in the United States, the eastern Iceberg Limit expanded to 36°00'W due to an unusual flow of cold water east over Flemish Cap. The Ice and Environmental Conditions section presents a discussion of the meteorological and oceanographic conditions that created this extreme season.

In 2015, IIP improved the efficiency of iceberg reconnaissance. IIP maximized its use of HC-130J aircraft hours by fully implementing 30 nautical mile track spacing in calm conditions based on the 2013 radar study and testing completed in 2014. IIP used this capability during six patrols, covering the same amount of area in 20% less time. IIP also continued efforts to integrate synthetic aperture radar (SAR) satellite data into regular operations. Correlation flights were conducted for images from the Canadian RADARSAT-2, the German TerraSAR-X, and the European Space Agency's recently-launched Sentinel-1a satellites. Sentinel-1a imagery holds great promise for the future as a publicly-accessible resource acquired at no cost to the user. Appendix B captures IIP's historical satellite reconnaissance efforts and documents its correlation efforts to date.

Throughout the season, IIP received significant interest from domestic and international media. The Discovery Channel Canada show "Daily Planet", Canada's The Weather Network show "Angry Planet," the Canadian Broadcasting Corporation (CBC), and 60 Minutes Australia produced features on IIP that were broadcast internationally. Not limited to television, IIP was highlighted in many national-level written publications, including Combat Aircraft Monthly, Bloomberg News, Boating Magazine, Seapower Magazine, and Harper's Magazine. For a five-day period in May 2015, IIP assumed responsibility for the Coast Guard's account on Instagram, a valuable social media tool with over 40,000 followers used to highlight unique and diverse Coast Guard missions to the general public. While IIP hosted the account, the Coast Guard amassed more than 30,835 individual points of engagement with the American public. The cover of this year's report represents the 2015 IIP Media Campaign. The two pictures to the left are from the Canadian National broadcast of the CBC News feature, and the picture on the right is a screen capture from IIP's Instagram posts.

On behalf of the dedicated men and women of IIP, I hope that you enjoy reading this report on the 2015 season.

Gabrielle G. McGrath, CDR

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

International Ice Patrol
2015 Annual Report

Contents

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

- ☑ Electronic copies of the 1913 – 2015 Annual Reports can be accessed on the IIP website: http://www.navcen.uscg.gov/?pageName=IIPAnnualReports
- ☑ Printed and bound Annual Reports (1963 – 2012) can be ordered from the National Technical Information Service (NTIS) website at http://www.ntis.gov.

Cover art: Collage representing International Ice Patrol's 2015 Media Campaign.

Abbreviations and Acronyms

AIS	Automatic Identification System
ALC	Aviation Logistics Center
APN-241	HC-130J Tactical Transport Weather Radar
Argos	A worldwide satellite-based system used to collect Doppler-based position data from special transmitter built into drifting buoys.
ASEC	Air Station Elizabeth City
AVHRR	Advanced Very High Resolution Radiometer
BAPS	iceBerg Analysis and Prediction System
CCG	Canadian Coast Guard
CCGS	Canadian Coast Guard Ship
CG-257	U. S. Coast Guard Office of Intelligence
C-CORE	Centre for Cold Ocean Resources Engineering
CIIP	Commander, International Ice Patrol
CIS	Canadian Ice Service
CECOM	Canadian East Coast Ocean Model
D1	U. S. Coast Guard First District
DMI	Danish Meteorological Institute
DND	Canadian Department of National Defense
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	Enhanced Marine Ordering Coordination
EO	Electro-Optical
ESA	European Space Agency
FNMOC	U.S. Navy Fleet Numerical Meteorology and Oceanographic Center
FTP	File Transfer Protocol
GEOINT	the Geographic Intelligence Branch of the Coast Guard Intelligence Coordination Center
HC-130J	Long-Range Surveillance Maritime Patrol Aircraft
ICC	Intelligence Coordination Center
IDS	Iceberg Detection Software
IIP	U. S. Coast Guard International Ice Patrol
IRD	Iceberg Reconnaissance Detachment

ISAR	Inverse Synthetic Aperture Radar
IWS	Interferometric Wide Swath
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
MDA	MacDonald, Dettwiler and Associates Ltd.
MIFC LANT	Maritime Intelligence Fusion Center Atlantic Area
MST	Marine Science Technician
NAIS	North American Ice Service
NAO	North Atlantic Oscillation
NAOI	North Atlantic Oscillation Index
NAVAREA	Navigation Area
NGA	National Geospatial-Intelligence Agency
NIC	U. S. National Ice Center
NL	Newfoundland and Labrador, Canada
NM	Nautical Mile
NOAA	National Oceanographic and Atmospheric Administration
NOTSHIP	Notice to Shipping
NTIS	National Technical Information Service
NTM	National Technical Means
NWS	National Weather Service
OPAREA	Operational Area
OPCEN	Operations Center
PAL	Provincial Aerospace Limited
POD	Probability of Detection
RDC	Research and Development Center
RMS	Royal Mail Steamer
SAIC	Science Applications International Corp.
SAR	Synthetic Aperture Radar
SITOR	Simplex Teletype Over Radio
SOLAS	Safety of Life at Sea

SST	Sea Surface Temperature
SVP	Surface Velocity Program
TENCAP	Tactical Exploitation of National Capabilities
USCG	United States Coast Guard
UTC	Universal Time Coordinated

Introduction

This is the 101st annual report of the International Ice Patrol (IIP) describing the 2015 Ice Season, currently the thirteenth most extreme ice season on record since 1900. It contains information on IIP operations and environmental and iceberg conditions in the North Atlantic in 2015. 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 aircraft and mariners in the North Atlantic. 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 using the model output. These iceberg warning products were then distributed by multiple means to the maritime community. IIP also responded to individual requests for iceberg information in addition to these routine broadcasts.

IIP was formed after the 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 activities and responsibilities of IIP 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 2015 Ice Season, IIP was under the operational control of Commander, U.S. Coast Guard First District (D1). RDML Linda L. Fagan was Commander, D1. CDR 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 2015 Ice Year was marked by expansive sea-ice growth and a large number of icebergs drifting south of 48°N. It was the thirteenth most extreme year on record since 1900. By definition, the "Ice Year" spans the time period from 01 October of one year to 30 September of the following year. IIP uses two measurements to classify the severity of an Ice Year: (1) icebergs crossing south of 48°N, considered the northern boundary of the transatlantic shipping lanes and (2) Ice Season length. The first measurement includes 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. During the 2015 Ice Year, 1,165 icebergs (not including bergy bits or growlers) crossed south of 48°N. The number of icebergs in the shipping lanes has been highly variable over time. **Figure 1** shows the historical variability of the number of icebergs south of 48°N (blue columns) from 1900 to 2015 along with the five-year running average (red line). The second measurement, 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. By design, IIP generally deploys IRDs during the Ice Season, defined by SOLAS as the period from 15 February until 15 July. During the time after IIP began deploying IRDs in early February 2015, there were icebergs south of 48°N from 02 March through 15 August (167 days). Additionally, early in the 2015 Ice Year, four icebergs drifted south of 48°N, creating a 12-day time period from 31 October to 11 November 2014 when icebergs were south of this latitude. Therefore, the total Ice Season length for the 2015 Ice Year

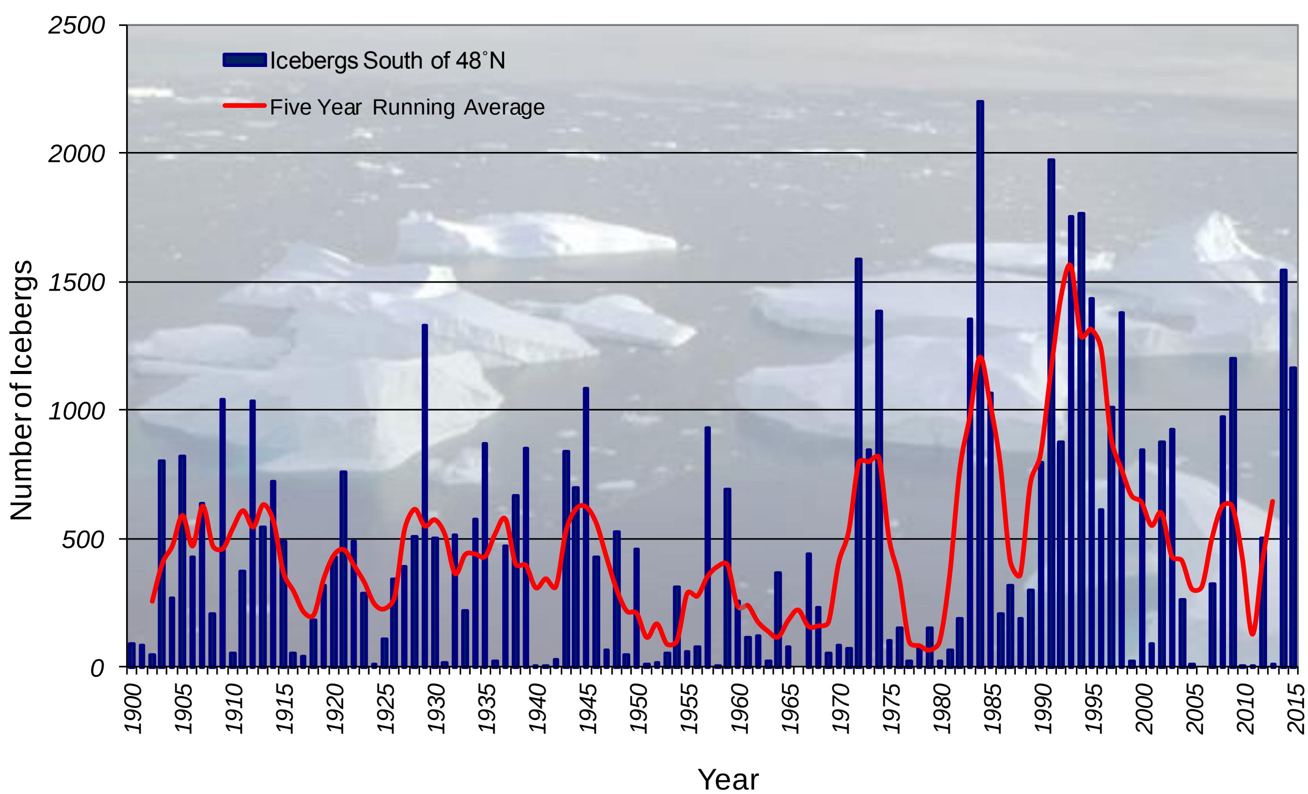


Figure 1. Icebergs crossing south of 48°N and five-year running average (1900-2015).

was 179 days.

For perspective, it is useful to compare these metrics during the modern aerial reconnaissance era (1983 through the present) when the use of aircraft equipped with radar became standard. During this time period, the average number of icebergs sighted or modeled south of 48°N is 787, and the average Ice Season length is 124 days. These measurements classified the 2015 Ice Year as 'extreme' in accordance with IIP's iceberg population severity classes detailed in IIP's 1994 Annual Report (IIP, 1994).

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 2015 Ice Year. The inset map in **Figure 2** illustrates the IIP Operational Area (OPAREA) for aerial reconnaissance and iceberg warnings. This section will be followed by an Operations Center Summary and a discussion on Ice Reconnaissance and Oceanographic Operations.

Pre-season Predictions

The Canadian Ice Service (CIS) issued a Seasonal Outlook for winter 2014-2015 on 03 December 2014. The CIS outlook provided expected sea-ice coverage for December through February for the Gulf of St. Lawrence, East Newfoundland Waters, and

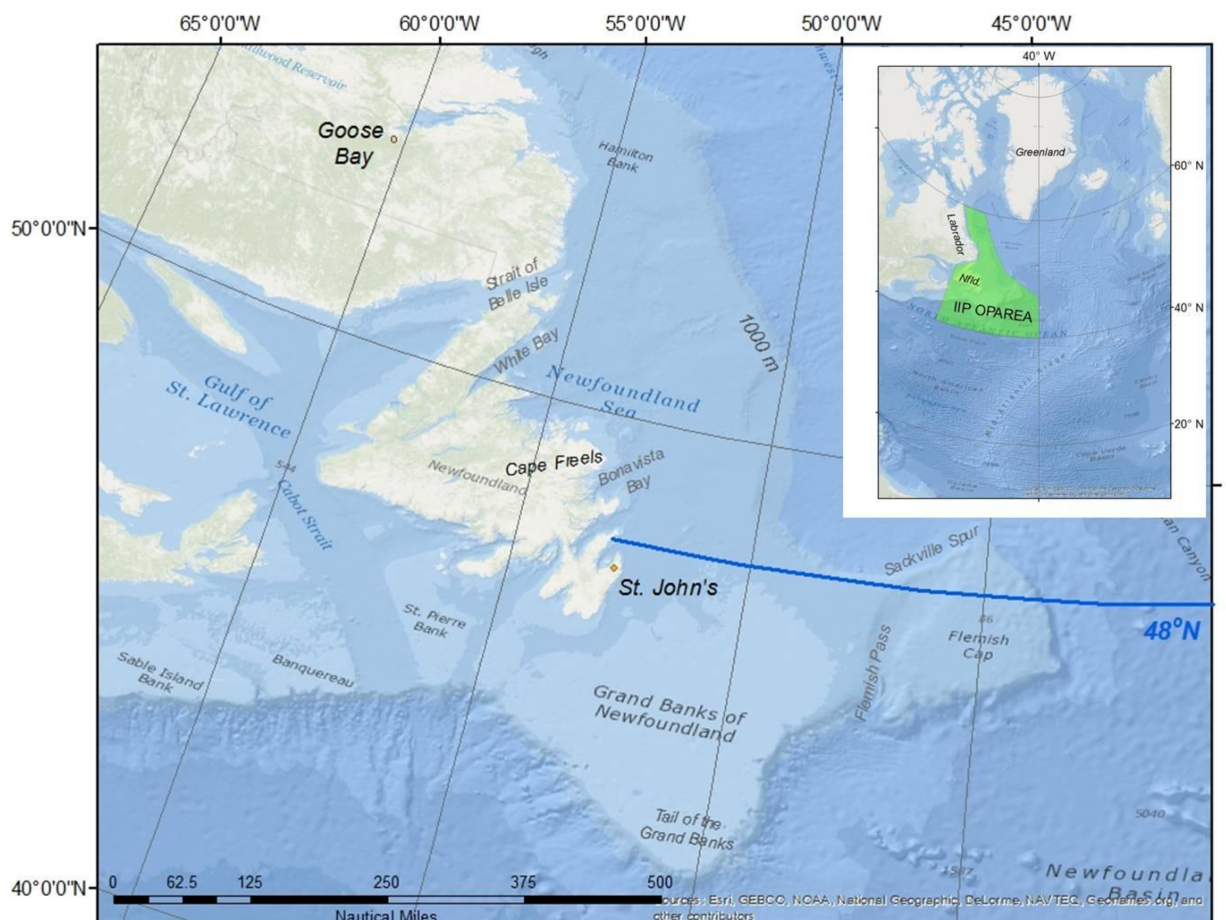


Figure 2. International Ice Patrol Operational Area (OPAREA) in green. The latitude of 48°N is typically considered the northern boundary of the transatlantic shipping lanes. IIP measures season severity based on this line.

the Labrador Coast. With predicted average air temperatures ‘near to above normal’ for December, January, and February, the 2015 Ice Year was expected to have near to slightly below normal sea-ice conditions in all three locations (CIS, 2014a).

IIP relies on sea-ice growth predictions as an early indicator for the iceberg severity for the upcoming months. **Figure 3** shows the expected median sea-ice concentration for 26 February 2015 based on three years with similar environmental characteristics: 1979/80, 1993/94, and 2003/04 (CIS, 2014a). The dashed blue line in **Figure 3** depicts the approximate sea-ice edge observed on 26 February 2015 (CIS, 2014a). The projected outlook for the southern ice edge on this date was approximately 40-60 NM further south than the actual observed sea-ice edge. On the other hand, the observed eastern sea-ice edge along the Newfoundland and Labrador coasts was 40-80 NM further offshore than the projected outlook. These departures from expected sea-ice conditions suggested a delay in the advance of icebergs toward 48°N based on the southern sea-ice location. However, the offshore extent of the sea-ice edge suggested the potential for a large number of icebergs to access the offshore branch of the Labrador Current supporting robust iceberg activity for 2015.

At IIP’s Annual Meeting on 11

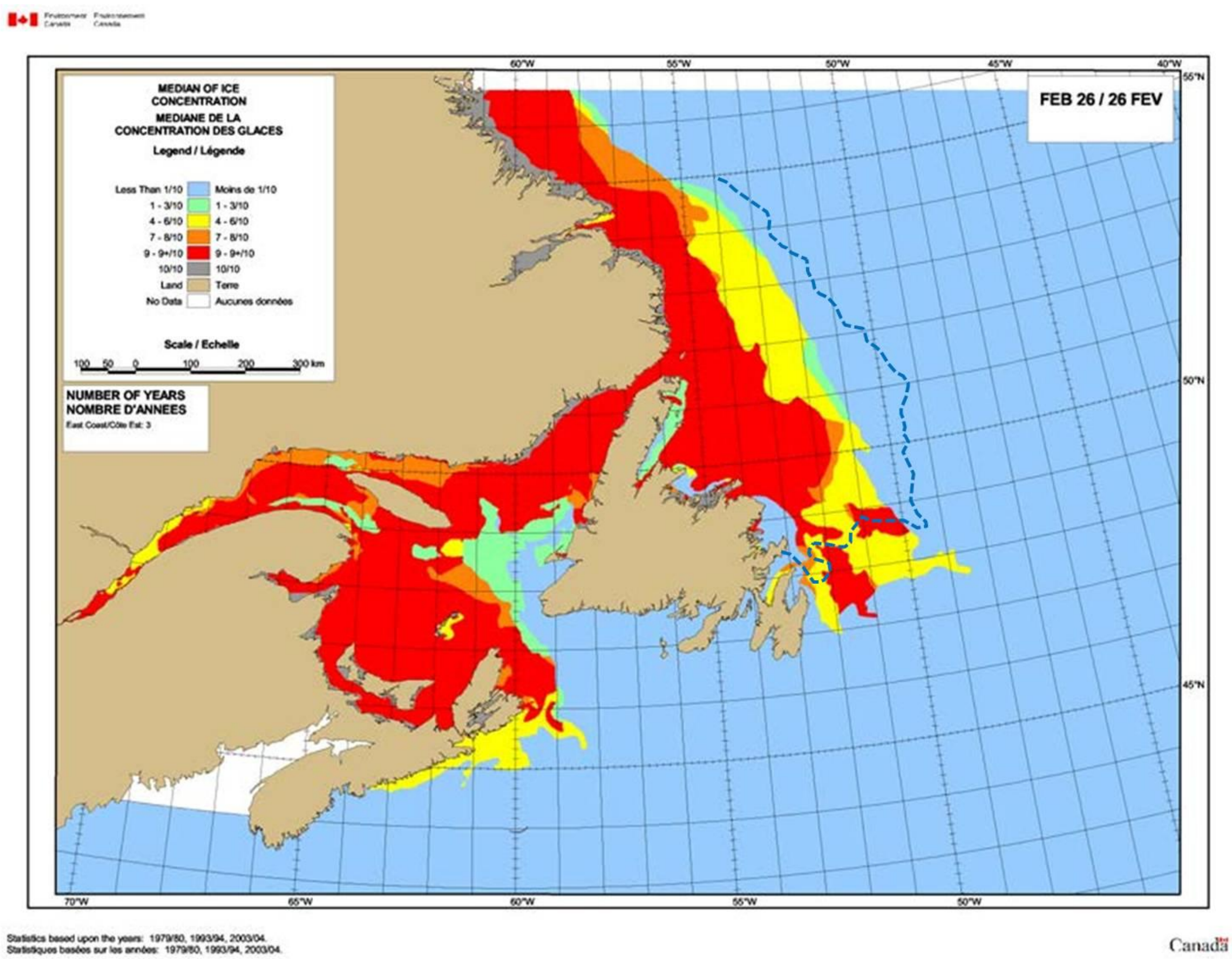


Figure 3. Expected sea-ice concentration for 26 February 2015 (CIS, 2014a). Dashed blue line depicts approximate location of the 1-3/10 ice edge on 26 February 2015.

December 2014, a CIS Senior Ice Forecaster provided additional insight into the expected iceberg conditions for the upcoming season (CIS, 2014b). The outlook presented at this meeting predicted moderate iceberg conditions (~600 icebergs south of 48°N) based on the following: (1) Davis Strait sea ice was 1-2 weeks behind normal, (2) expected onshore winds off of Labrador through January would impede the growth of sea ice along the Labrador coast and thus limit the number of icebergs entering the offshore branch of the Labrador Current, and (3) Provincial Aerospace Limited (PAL) reconnaissance flights in October and November detected a relatively small number of icebergs (239) off of Baffin Island.

The CIS forecast also suggested the possibility of a shift in the prevailing winds from onshore to offshore for February. Such a transition would support sea-ice growth and a larger number of icebergs drifting into the shipping lanes above the expected outlook. This transition did occur and contributed to the iceberg severity observed later in the year.

Quarterly Environmental Summaries

Sea-ice growth was influenced by mean air temperatures along with changes of the mean wind speed and direction in central and southern Labrador early in the year and over Newfoundland as the year progressed. **Figure 4** 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, 2015a). With the exception of November in Goose Bay, air temperatures at both locations remained above normal until late December. Beginning in late December, air temperatures in Goose Bay dropped below normal and remained so until late April. St. John’s experienced similar cold temperatures from mid-February through May. This temperature pattern, coupled with a shift to offshore winds by mid-February, set the stage for expansive sea-ice growth with above normal sea-ice concentration for Newfoundland and Labrador from mid-February through the end of May.

Conditions affecting sea-ice growth and iceberg distribution along with key reconnaissance results are summarized by quarter below.

October – December 2014

At the beginning of the Ice Year, CIS had responsibility for creating and disseminating the daily NAIS iceberg warning products. At that time, CIS was only monitoring six icebergs. All of these were north of 48°N, and two icebergs were located offshore near the 1000 meter (m) contour. Aerial iceberg reconnaissance was relatively active from October to November compared to recent years. PAL conducted 12

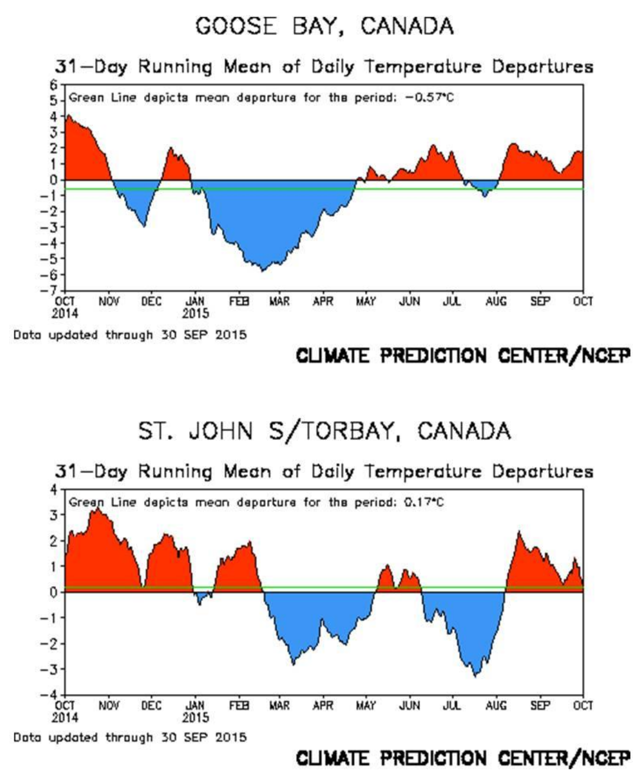


Figure 4. 31-day running mean of daily temperature departures for Goose Bay, Labrador (top) and St. John’s, Newfoundland (bottom) (NOAA/NWS, 2015a).

reconnaissance sorties in October and November. In October, these flights focused on the 1000 m depth contour near the main axis of the Labrador Current up to 51°30’N. PAL reported 13 icebergs on 17 and 21 October. Four of these icebergs drifted south of 48°N in late October and early November and are included in the total iceberg count for the 2015 Ice Year. While it is unusual for icebergs to drift south of 48°N during the fall, it is not unprecedented. In fact, this anomaly happened 20 times in October and 21 times in November since 1900.

At the end of October and into early November, PAL completed six survey flights in the vicinity of Davis Strait and Baffin Island which detected 239 icebergs and provided an early assessment of the iceberg population. PAL concluded activity for this quarter with two reconnaissance flights in mid-December that located a total of six icebergs off the Labrador coast and over Hamilton Bank.

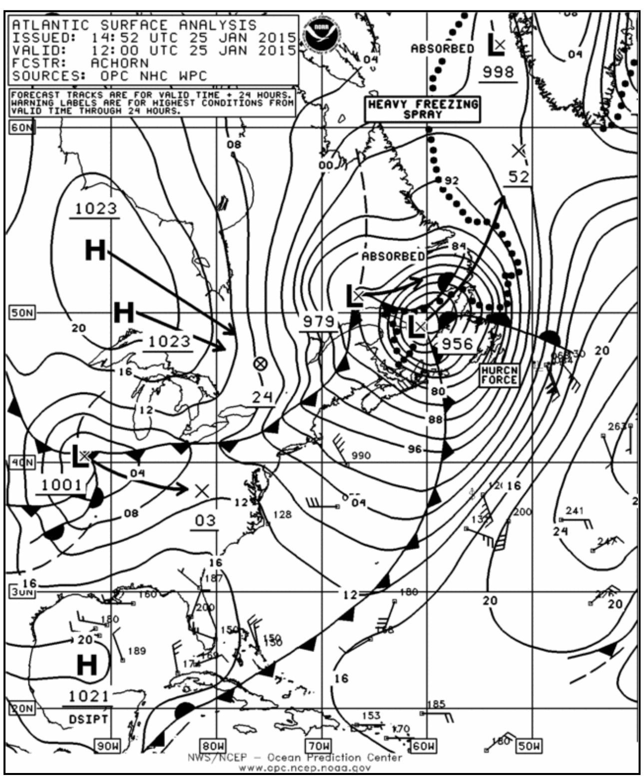


Figure 5. Atlantic Surface Analysis for 12Z on 25 January 2015 (NOAA/NWS, 2015a).

Other reconnaissance efforts included a Transport Canada aircraft that conducted four flights in November along the Labrador shelf and detected ten icebergs between 58°N and 60°N. In addition, CIS received several vessel reports including a growler visually sighted by the M/V VIKINGBANK approximately 450 NM east of the published Iceberg Limit. This report, along with other reports outside of the published Iceberg Limit, will be discussed in greater detail in the Operations Center Summary of this report. Finally, CIS acquired seven RADARSAT-2 synthetic aperture radar (SAR) satellite images which detected 32 radar targets along the Labrador shelf between 55°N and 60°N.

Due to the above normal air temperatures in October **(Figure 4)**, sea ice did not begin forming until late November beginning with new ice in Lake Melville during the third week of November. A swath of new and grey ice (seven to eight tenths concentration) formed east to approximately 30 NM from the Labrador coast and south to 53°20’N during the first week of December (CIS, 2015a). For the rest of the period, sea-ice coverage remained very close to the median. Early indications after the first quarter were consistent with the CIS outlook and did not suggest the extraordinary sea-ice growth and extreme iceberg conditions IIP observed for the remainder of the Ice Year.

January – March 2015

Mean air temperatures in Goose Bay began to drop in early January and remained well below normal until late April while temperatures in St. John’s remained normal to above normal until mid-February (**Figure 4**). Temperatures in St. John’s then drastically decreased to well below normal and remained much colder than normal until early May. Sea-ice growth was tempered by a series of intense low pressure systems that moved through the area in January. **Figure 5** shows an example of one such storm with a central atmospheric pressure of 956 millibars (mb) (NOAA/NCEI, 2015). This system and others like it brought relatively warm air and hurricane force winds to Newfoundland and southern Labrador causing significant ice destruction during January. Sea-ice coverage in the OPAREA remained at or below normal until the week of 26 February. In late February and March, low pressure systems began following a track to the north of Newfoundland such that the sea ice to the east and south of Newfoundland remained south of the center of these low pressure systems. This storm track resulted in predominantly offshore winds and dramatic sea-ice growth during March.

During March, the sea-edge edge grew steadily southeastward forming the shape of a tongue that followed the Labrador Current south to about 46°N. On 20 March, this tongue of ice broke apart, and a very large fragment drifted to approximately 45°40'N on 21 March **(Figure 6)** (CIS, 2015b). **Figure 7** shows the departure from normal ice concentration for 23 March with blue shades representing greater than normal and red shades showing less than normal sea-ice concentration based upon CIS statistics from 1981-2010 (CIS, 2015c). The extensive sea-ice coverage presented an increased risk of damage to IIP's drifting buoys and delayed the first deployment of the season until 24 March. Buoy deployments will be discussed further in the Ice Reconnaissance and Oceanographic Operations section of this report.

PAL conducted two ice reconnaissance sorties in support of CIS on 14 January. These flight were mostly over sea ice and focused efforts in the region between the Strait of Belle Isle and the 1000 m depth contour. These flights detected eight icebergs, all north of 52°N latitude. PAL conducted an additional eight flights for other Canadian Government needs. These flights stayed relatively close to Newfoundland and verified the iceberg population remained north of 52°N in January.

IIP sent its first IRD to St. John's on 05 February and conducted patrols of Notre Dame Bay/Strait of Belle Isle and the southeastern Iceberg Limit on 07 and 08 February, respectively. While IIP detected 20 icebergs, all within sea ice, it was clear the main population of icebergs remained well to the north. The southeastern Iceberg Limit flight located a single iceberg, at approximately 52°N and just outside of the 1000 m contour.

On 10 February, IIP conducted a survey flight up to 60°N latitude and found 135 icebergs along the Labrador shelf. The results from this patrol provided the first evidence that a significant number of icebergs

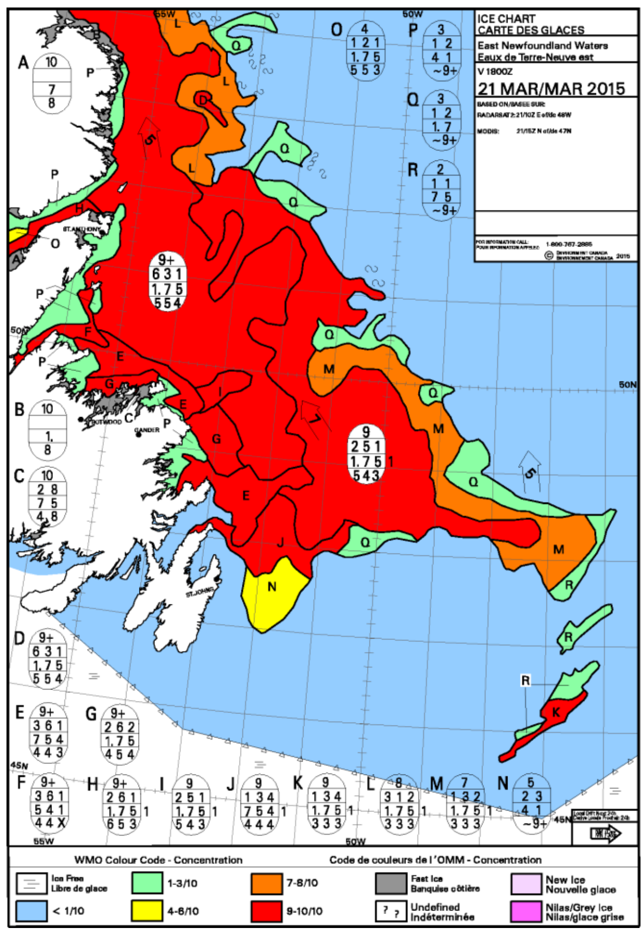


Figure 6. CIS sea-ice concentration for 21 March 2015 (CIS, 2015c).

were poised to enter the offshore branch of the Labrador Current and continue their drift southward. With the indication of a population of icebergs drifting towards the transatlantic shipping lanes in the coming months, CIIP anticipated a need for more intense reconnaissance during the latter part of the season and, in order to save HC-130J flight hours, considered cancelling the remaining flights scheduled for February. CIIP requested support from the CIS Director for CIS-sponsored PAL flights to provide reconnaissance over the iceberg population. Once this coverage was arranged, CIIP cancelled the IIP flights. This coordination was an excellent example of the importance and value of the NAIS partnership. PAL flew two patrols during the last half of February on the Grand Banks and in the Flemish Pass. No icebergs were sighted or drifted south of 48°N during the entire month of February, an observation consistent with the CIS prediction of a delay in the southward advance of icebergs into the shipping lanes.

IIP returned to the OPAREA on 06 March and conducted southern, eastern, and western Iceberg Limit patrols. IIP planned for another northern survey flight to 60°N, but it was cancelled due to poor weather conditions. These patrols detected a total of 169 icebergs.

The sea-ice edge receded slightly during the last two weeks of March. Both IIP

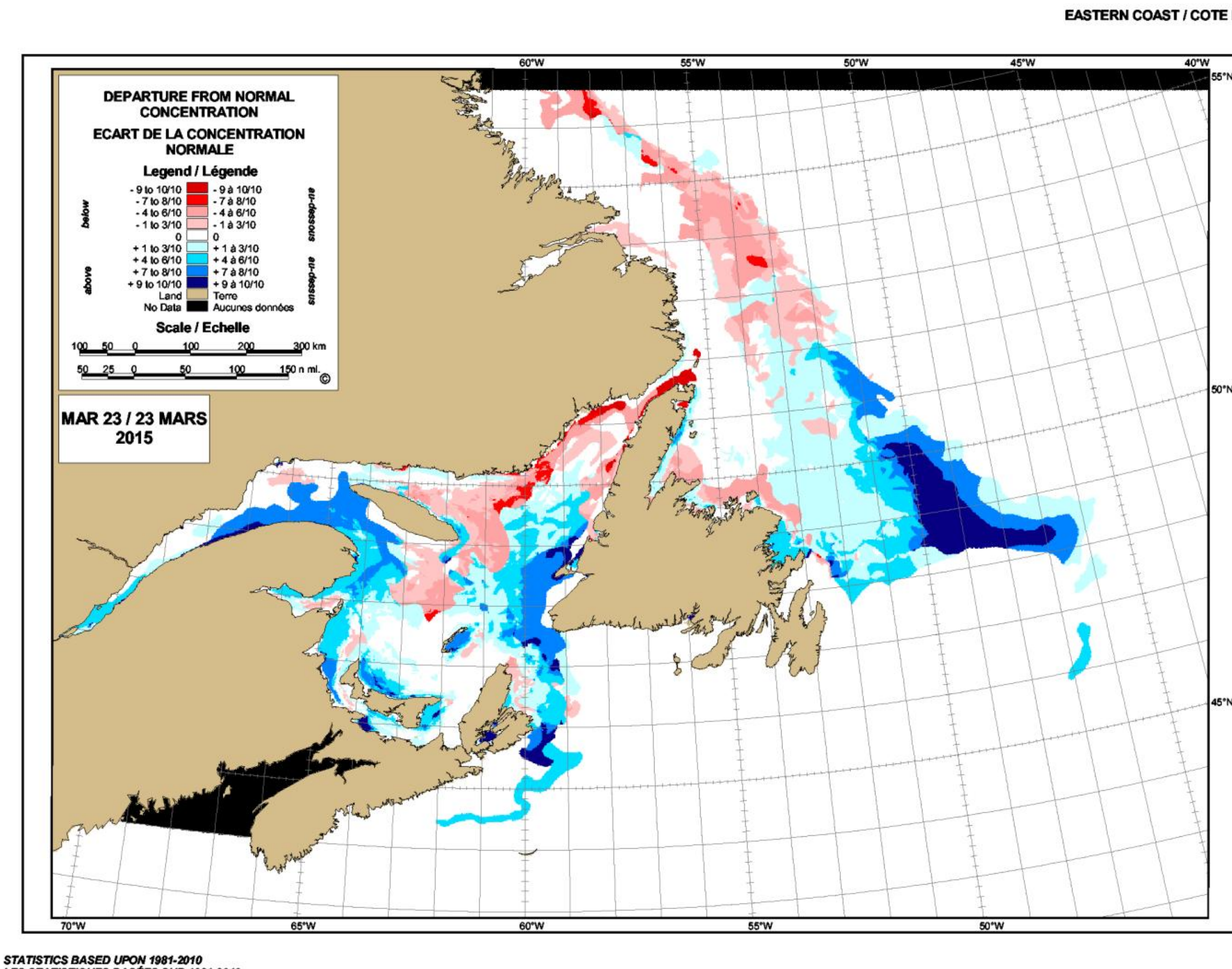


Figure 7. Departure from normal sea-ice concentration for 23 March 2015 (CIS, 2015c).

and PAL began observing a larger population of icebergs moving south of 48°N. During an eastern Iceberg Limit flight, IIP sighted a group of icebergs north of Flemish Cap out to 44°W suggesting drift to the east would be a reconnaissance concern this year. Further, IIP located 353 icebergs in a single flight on 24 March between 48°30'N and 54°N which would provide a steady supply of icebergs for the upcoming months.

April – June 2015

Average air temperatures remained between 1° to 3°C below normal at both Goose Bay and St. John's through early May **(Figure 4).** Predominant westerly winds off of Newfoundland during the first part of April caused the sea ice to linger and elongate along 48°N through mid-April in an east-west oriented tongue north of Flemish Cap out to nearly 46°W. The departure from normal sea-ice concentration graphic for 13 April (**Figure 8**) clearly shows this unusual eastward advance (CIS, 2015c). During the third week of April, several strong low pressure systems deflected the sea-ice tongue back into the main branch of the Labrador Current and caused another southward advance. As in March, a very large fragment of this ice tongue separated and drifted south to around 45°10'N. This event marked the southernmost extent of sea ice for 2015 on 27 April (**Figure 9**). The southernmost advance of the sea-ice edge

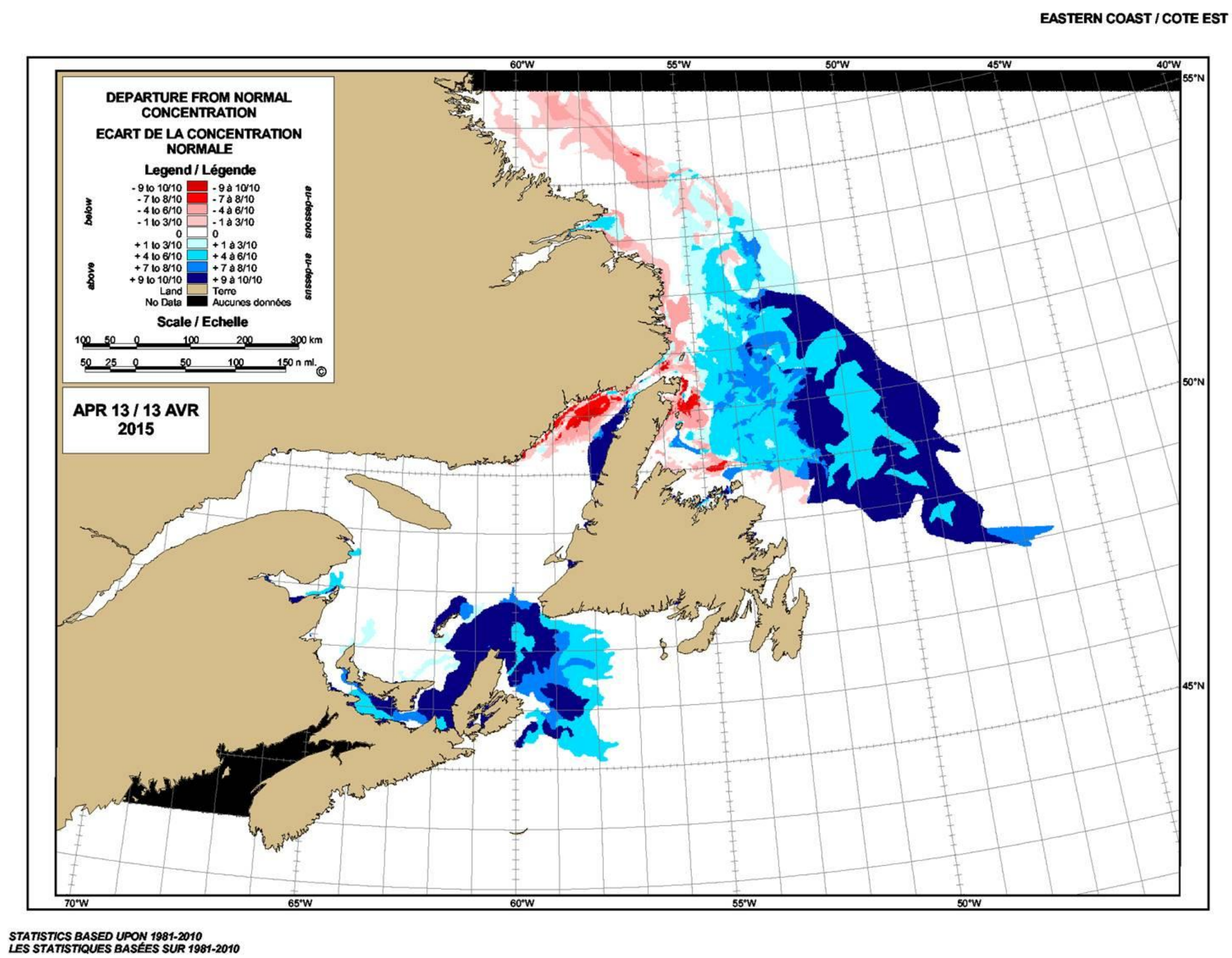


Figure 8. Departure from normal sea-ice concentration for 13 April 2015 (CIS, 2015c).

normally occurs in late March. This unusual situation of a delayed sea-ice maximum, coupled with the large number of icebergs sighted further north, provided further evidence suggesting 2015 would be another extreme year.

At the end of April, the sea-ice concentration began to rapidly diminish throughout the OPAREA. By the first week of May, there was no sea ice south of 48°N. By the third week of May, the Strait of Belle Isle became clear, and by the end of June, the sea ice retreated north of 57°N (CIS, 2015c). In the absence of sea ice, the large population of icebergs along the Labrador coast continued to drift further southward and eastward, north of Flemish Cap.

Iceberg conditions required IIP to send

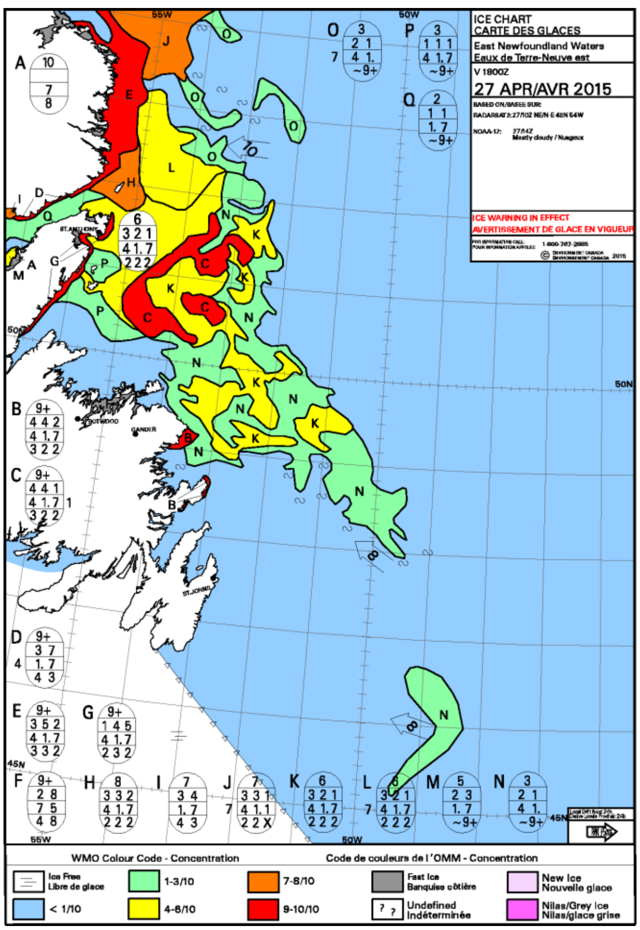


Figure 9. CIS sea-ice concentration for 27 April 2015 (CIS, 2015c).

two IRDs per month through the end of July. Though plagued by unfavorable weather, the first IRD in April conducted four reconnaissance flights covering the Iceberg Limit. These patrols detected a total of 154 icebergs. The southern Iceberg Limit patrol on 03 April searched the main axis of the Labrador Current down to 42°30'N confirming no icebergs had drifted outside of the limit. These results kept the southern Iceberg Limit at 44°30'N.

The eastern Iceberg Limit patrol flew out to 43°W on 07 April and detected the easternmost iceberg for the year at 49°20'N, 42°29'W. This sighting provided further confirmation of the presence of an eastward, cold water current flowing to the north of Flemish Cap. **Figure 10** shows an Advanced Very High Resolution Radiometer (AVHRR) sea surface temperature (SST) image for 01 April. While relatively few, high-quality AVHRR images were available due to persistent cloud cover during 2015, **Figure 10**

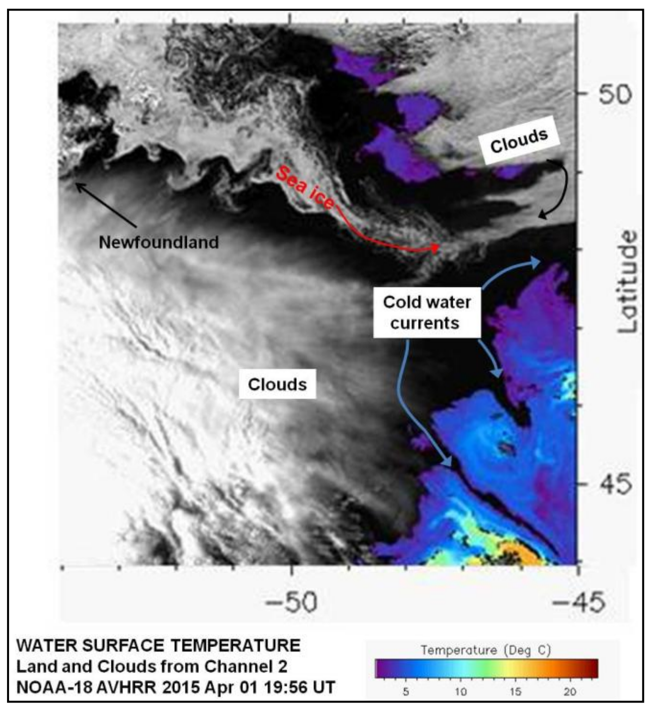


Figure 10. AVHRR SST Image from 01 April 2015. Image provided by the Ocean Remote Sensing Group, Johns Hopkins University Applied Physics Laboratory (JHU, 2015).

provides a rare look at the east-west sea-ice tongue described previously as well as the presence of the broad, eastward current that persisted throughout May and into June. The coldest water in this image is shown in black. In addition, two narrow, cold water jets can be seen in the southeastern portion of this image. These cold features provided viable paths, in addition to the main core of the Labrador Current, for icebergs to drift eastward and southeastward. IIP coordinated several reconnaissance flights over the regions of these cold features to ensure all icebergs setting the limit were detected. Their existence may have weakened the main branch of the southwestward flowing Labrador Current and restricted southward iceberg drift. This situation will be discussed in greater detail in the Atmospheric and Oceanographic Discussion later in this section.

The last IRD in April conducted only one patrol due to aircraft mechanical issues and poor weather conditions. Part of this patrol had to be flown using 10 NM track spacing due to a radar casualty in flight. Standard patrol track spacing is 25 NM with a fully-operable radar. During the visual portion of the flight, an IIP Ice Observer sighted a very large, tabular iceberg at 46°25'N, 47°10'W which became the southwestern limit-setting iceberg.

The difficulties encountered by IIP on the second April IRD were partially offset by the fact that the Iceberg Limit had not yet expanded outside of PAL's aircraft endurance range. PAL remained very active throughout

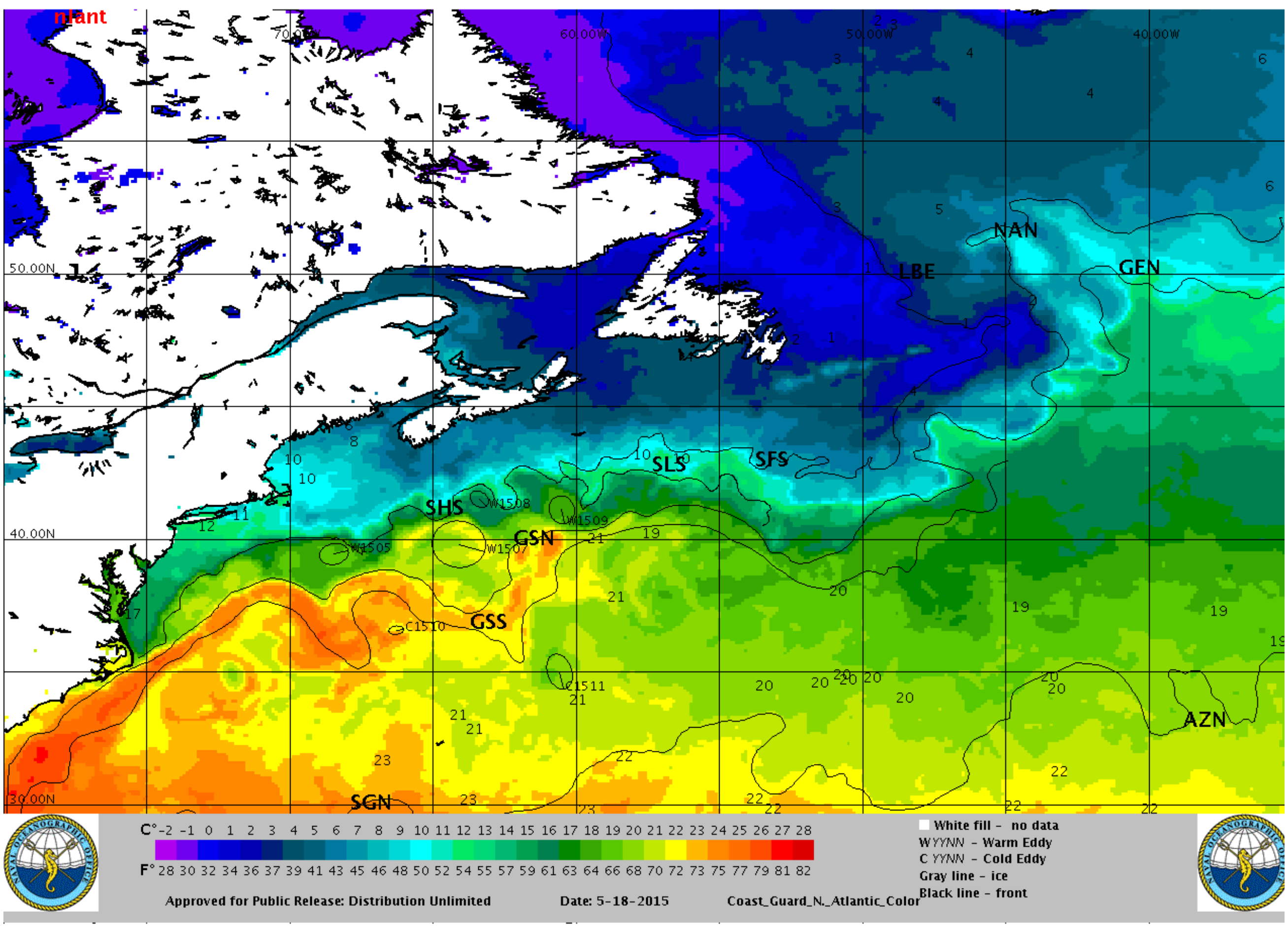


Figure 11. U.S. Naval Oceanographic Office, SST Ocean Features Analysis for 18 May 2015.

April, conducting numerous flights for CIS, the oil and gas industry, and other Canadian Government interests. These flights focused on locating icebergs posing a present or future threat to the oil and gas facilities on the Grand Banks. The data from these flights were crucial to maintaining an accurate iceberg picture during the latter part of April.

Even with persistent low visibility and generally poor weather conditions, IRD productivity improved during May. In total, IIP conducted nine patrols of the Iceberg Limit that located 121 icebergs and a survey patrol to 60°N on the Labrador coast that detected 713 icebergs. A flight on 15 May detected the southernmost iceberg for the year in position 42°51'N, 49°44'W. In late May, the number of icebergs entering the Strait of Belle Isle also increased. Correspondingly, IIP began a concerted effort to determine the iceberg population in this area to accurately establish the western Iceberg Limit. On 29 May, IIP located 108 icebergs in the Strait of Belle Isle.

During April and May, both IIP and PAL flights began observing icebergs drifting along the coast of Newfoundland and south of the Avalon Peninsula. In two southwestern Iceberg Limit flights, IIP detected 80 icebergs. Icebergs adrift in this area posed a particular hazard to vessels transiting to or from Montreal via Cabot Strait. In fact, on 30 April, a vessel reported an iceberg approximately 7.5 NM outside of the southwestern limit in position 45°32'N, 52°32'W which likely drifted along the coast of Newfoundland. A full listing of all sightings outside of the Iceberg Limit is included in the Operations Center Summary.

The eastern Iceberg Limit continued to expand in May. On 04 May, IIP's drift model predicted iceberg drift as far east as 37°24'W. These model predictions, coupled with the cold eastward current described earlier **(Figure 10)** and iceberg sightings north of Flemish Cap, created a situation that demanded reconnaissance flights over the relatively cold water to the east. **Figure 11** is the U.S. Naval Oceanographic Office Ocean Features Analysis product for 18 May which shows the eastward advance of cold water out to 43°W (Naval Oceanographic Office, 2015). This region east of Flemish Cap intersects the transatlantic shipping lanes in a location where icebergs are not normally observed and thus poses a particularly hazardous situation for transatlantic mariners. As a result, IIP sent two flights well to the east of Flemish Cap in May to confirm the predicted icebergs had melted. The flight on 30 May searched out to 38°30'W, over 500 NM east of St. John's.

Reconnaissance efforts in June continued to focus on the Iceberg Limit. In 2014, the southern limit progressed 75 NM further south than its southernmost latitude in 2015. The less extreme southern extent of the 2015 Iceberg Limit is likely due to the presence of a persistent meander in the North Atlantic Current that appeared to inhibit iceberg drift to the south as compared to 2014. This feature will be described in greater detail in the Atmospheric and Oceanographic Discussion. A reconnaissance flight on 17 June confirmed the southern limit-setting icebergs had melted, marking the beginning of a retreat of the southern Iceberg Limit.

Due to continued iceberg sightings near Sackville Spur and north of Flemish Cap, the eastern Iceberg Limit remained at 44°W through the end of June. The area south of Newfoundland (southwestern Iceberg Limit) and the waters west of the Strait of Belle Isle in the Gulf of St. Lawrence remained a concern throughout the month. IIP reconnaissance sighted the westernmost iceberg of the year in the Gulf of St. Lawrence on 15 June at 51°00'N, 58°46'W.

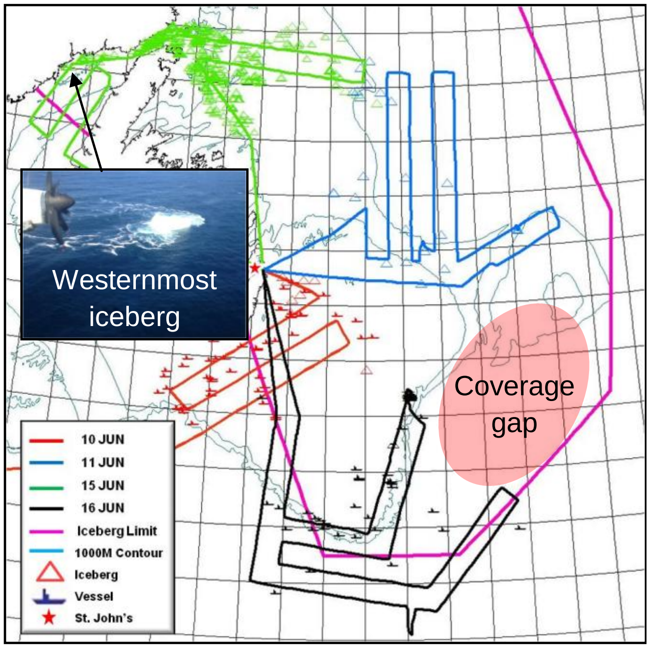


Figure 12. Flight patterns for mid-June IRD from 9-17 June 2015.

Figure 12 provides an excellent representation of the areas covered by the mid-June IRD and highlights some of the challenges faced by IRDs this year. While the four patrols pictured in **Figure 12** searched nearly 126,000 NM^2, the IRD was also grounded for four days due to weather issues both in the OPAREA and at the airport. This gap in coverage over the southeastern Iceberg Limit (shown by a red oval) became a priority for the second June IRD. Diversions in the flight tracks on 11 and 16 June can be seen as well. These diverts were necessary due to persistent low visibility which was frequent in the OPAREA from May through July. The atmospheric conditions that caused this challenging environment will be discussed in greater detail in the next segment of this section. The westernmost iceberg sighting on 15 June is also pictured in the upper left of **Figure 12**.

PAL remained active during June but generally focused their reconnaissance flights in the vicinity of the oil and gas facilities on the Grand Banks.

July – September 2015

Air temperatures for Goose Bay were slightly below normal while temperatures in St. John's remained well below normal during July. While sea-ice growth was no longer a concern, these relatively cold temperatures caused persistent foggy conditions in St. John's and in the iceberg search areas at sea.

Although SSTs on the Grand Banks and in the Labrador Current began increasing, a sizable population of icebergs kept the southern Iceberg Limit south of 45°N and the eastern Iceberg Limit east of 45°W throughout the entire month of July.

These conditions required CIIP to deploy two IRDs again in mid and late July. These nine patrols detected 242 icebergs. The final IRD conducted five patrols and searched over 138,000 NM^2. These patrols detected a total of 88 icebergs with most well north of 48°N. During a flight on 27 July, IIP visually confirmed a medium-sized, tabular iceberg in the Labrador Current around 45°15'N. Remarkably, the Iceberg Limit remained south of 45°N until 15 August.

Since icebergs no longer posed a significant hazard to transatlantic shipping, IIP concluded its reconnaissance for the 2015 Ice Year on 29 July with a patrol to 60°N. This patrol assessed the population of icebergs in preparation for a transition of responsibilities for creating and distributing NAIS iceberg products to CIS. IIP transferred this responsibility to CIS on 01 September.

In summary, **Figure 13** graphically shows the number of icebergs estimated to have drifted south of 48°N by month for the 2015 Ice Year. The monthly average was calculated using 115 years (1900 through 2014) of IIP records and is plotted as a solid red line for comparison. A summary of extreme iceberg positions, both sighted and

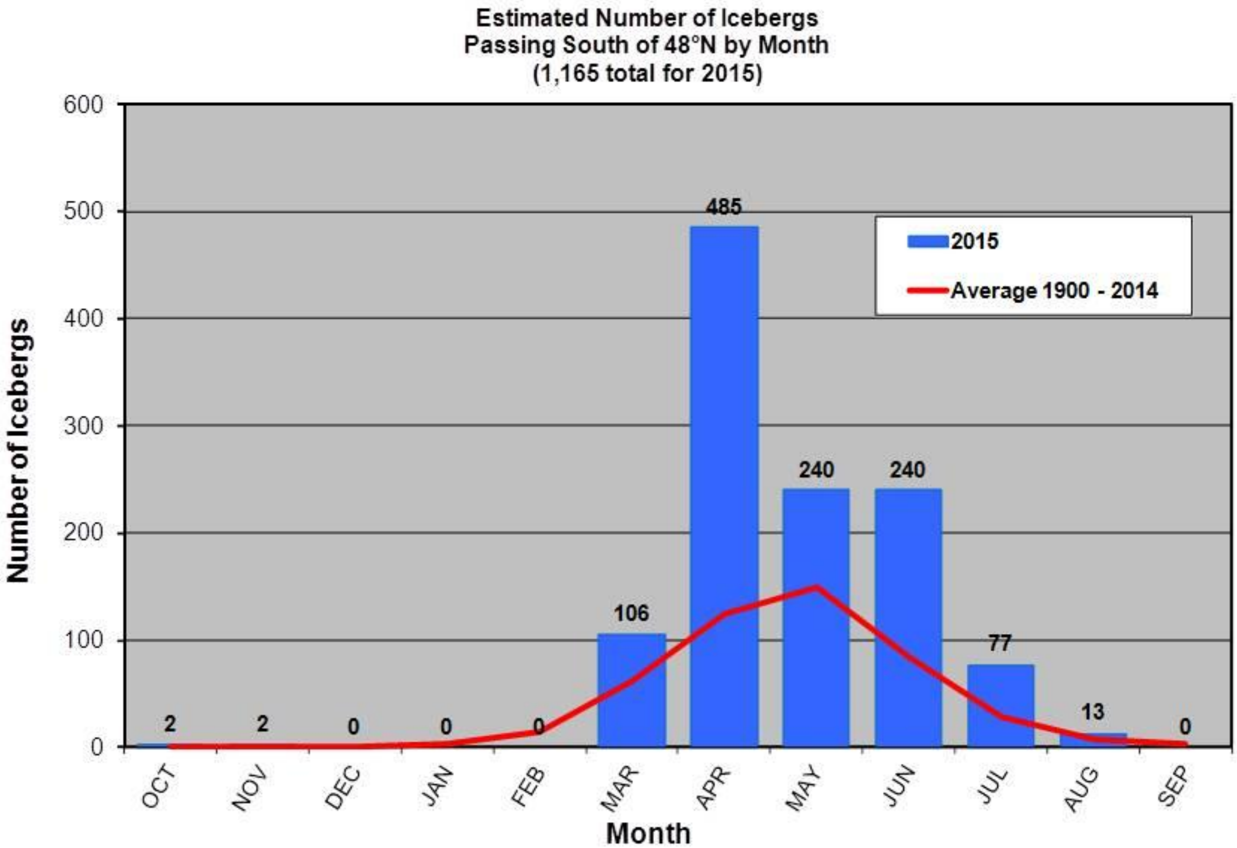


Figure 13. Estimated number of Icebergs drifted south of 48°N by month (1165 total for 2015).

drifted by modeling, along with the sighting source is presented in **Table 1**.

Atmospheric and Oceanographic Discussion

Atmospheric Discussion - The number of icebergs drifting south of 48°N is closely correlated with sea-ice coverage off of the Newfoundland and Labrador coasts. Sea-ice growth and extent depends upon atmospheric conditions during the critical winter months of December through March each year. Persistent, offshore (westerly) winds supply cold air from Newfoundland and Labrador promoting seaward sea-ice growth. Onshore winds, on the other hand, inhibit seaward sea-ice growth, leave icebergs exposed to open waters, and can cause grounding events limiting their movement toward the offshore branch of the Labrador Current.

Prevailing atmospheric conditions that govern sea-ice growth and extent during 2015 can be understood by using the North Atlantic Oscillation Index (NAOI). The NAOI represents the dominant pattern of winter-time atmospheric variability in the North Atlantic, fluctuating between positive and negative phases. North Atlantic Oscillation (NAO) dynamics have been extensively described by Hurrell, Kushnir, Ottersen and Visbeck (2003). 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 2014 through March 2015 was strongly positive at +3.56. By comparison, the NAOI for the same months during the extreme 2014 Ice Year was also strongly positive at +3.10. During the 2013 Ice Year,

Extreme Icebergs	Sighted				Drifted			
	Source	Date	Latitude	Longitude	Source	Date	Latitude	Longitude
Southern	IIP HC-130J	15-May-15	42-50.8N	49-44.5W	PAL Aircraft	17-Jun-15	41-42.1N	48-49.7W
Eastern	IIP HC-130J	07-Apr-15	49-20.0N	42-29.0W	IIP HC-130J	04-May-15	46-36.4N	37-25.9W
Western	IIP HC-130J	15-Jun-15	51-00.4N	58-46.2W	IIP HC-130J	28-Jun-15	50-42.3N	59-03.7W

Table 1. 2015 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.

when IIP observed only 13 icebergs drifting south of 48°N, the NAOI was moderately negative at -1.97. This correlation of NAOI to ice season severity supports the use of this index as a valuable tool to gain insight into the processes influencing iceberg conditions, particularly when the winter-time NAOI is greater than 1.00 for extreme years or less than -1.00 for light years.

While the station-based winter-time NAOI is a valuable measurement to explain variation in year-to-year iceberg conditions, it is not calculated until after the peak of the season has passed and thus, is not a predictive tool. To help understand atmospheric conditions in a timelier manner**,** IIP also monitors a daily NAOI that is constructed by the NOAA/NWS Climate Prediction Center. This index is based on the 500 mb height anomaly over the Northern Hemisphere projected onto the monthly mean 500 mb height (NOAA/NWS, 2015b). This index yields similar physical significance as the single, winter-time index described earlier, i.e., positive values indicate offshore winds with favorable sea-ice growth conditions and the opposite for negative values.

Figure 14 shows the daily 500 mb-based NAOI calculated from 01 December 2014 through 02 October 2015. Remarkably, in 2015 the NAOI became positive on 01 January and remained so until 20 April yielding a strongly positive index during the key sea-ice formation months (green shaded area in **Figure 14**). The atmospheric pressure patterns that caused the variations in the NAOI appear well correlated with changes in the sea-ice coverage through 16 February, as shown in the CIS weekly ice coverage for East Newfoundland waters (**Figure 15)**. During the weeks following each of the four NAOI relative minima indicated**,** the sea-ice coverage fell to below the median coverage for the 1980/81 through 2009/10 as

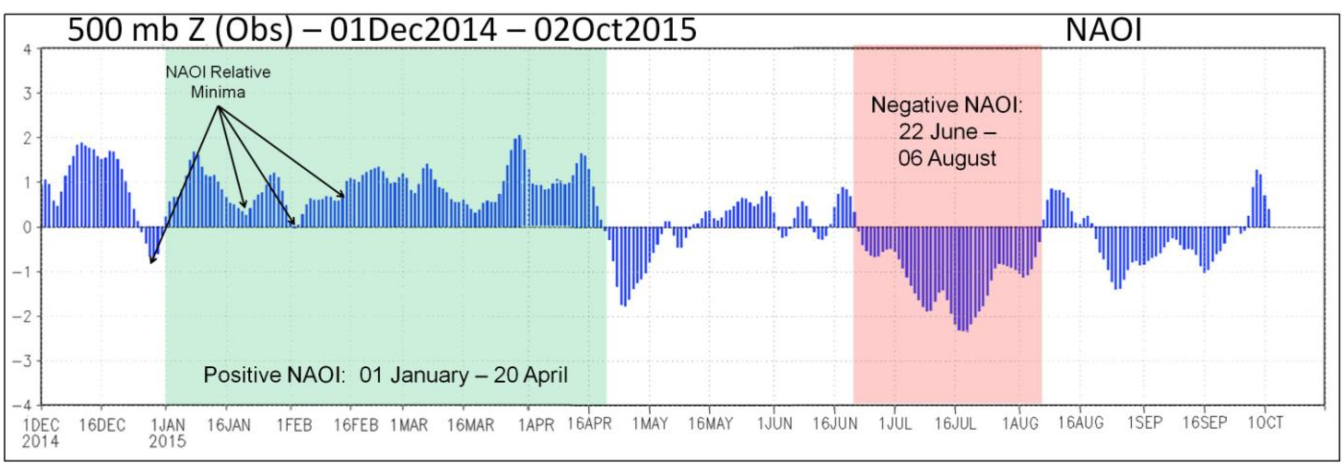


Figure 14. 500 mb NAOI for 01 December 2014 through 02 October 2015 (NOAA/NWS, 2015b).

shown by the green line in **Figure 15**. After 16 February, the NAOI remained positive until 20 April, supporting above-median sea-ice coverage above median through May. This extensive sea-ice coverage led to the observed extreme iceberg numbers described in the quarterly summaries above.

After 20 April, the NAOI became much more variable and entered a prolonged negative phase from 22 June to 06 August as shown with red shading in **Figure 14**. Most studies focus on the winter-time NAOI since the NAO from December through March accounts for a larger portion of the variations in atmospheric pressure when compared to summer-time variations (Hurrell, Hoerling and Folland, 2001). However, summer-time NAOI variations have been shown to modify the main storm track across the North Atlantic and impact European climate. Folland et al. (2009) investigated the impact on European climate of the summer-time NAO during the "high summer" months of July and August and found that storm tracks shift southward (toward the Bay of Biscay off of Europe) during a negative phase of the summer-time NAO and northward (toward Iceland) during a positive phase.

This phenomenon was particularly significant to IIP reconnaissance during late

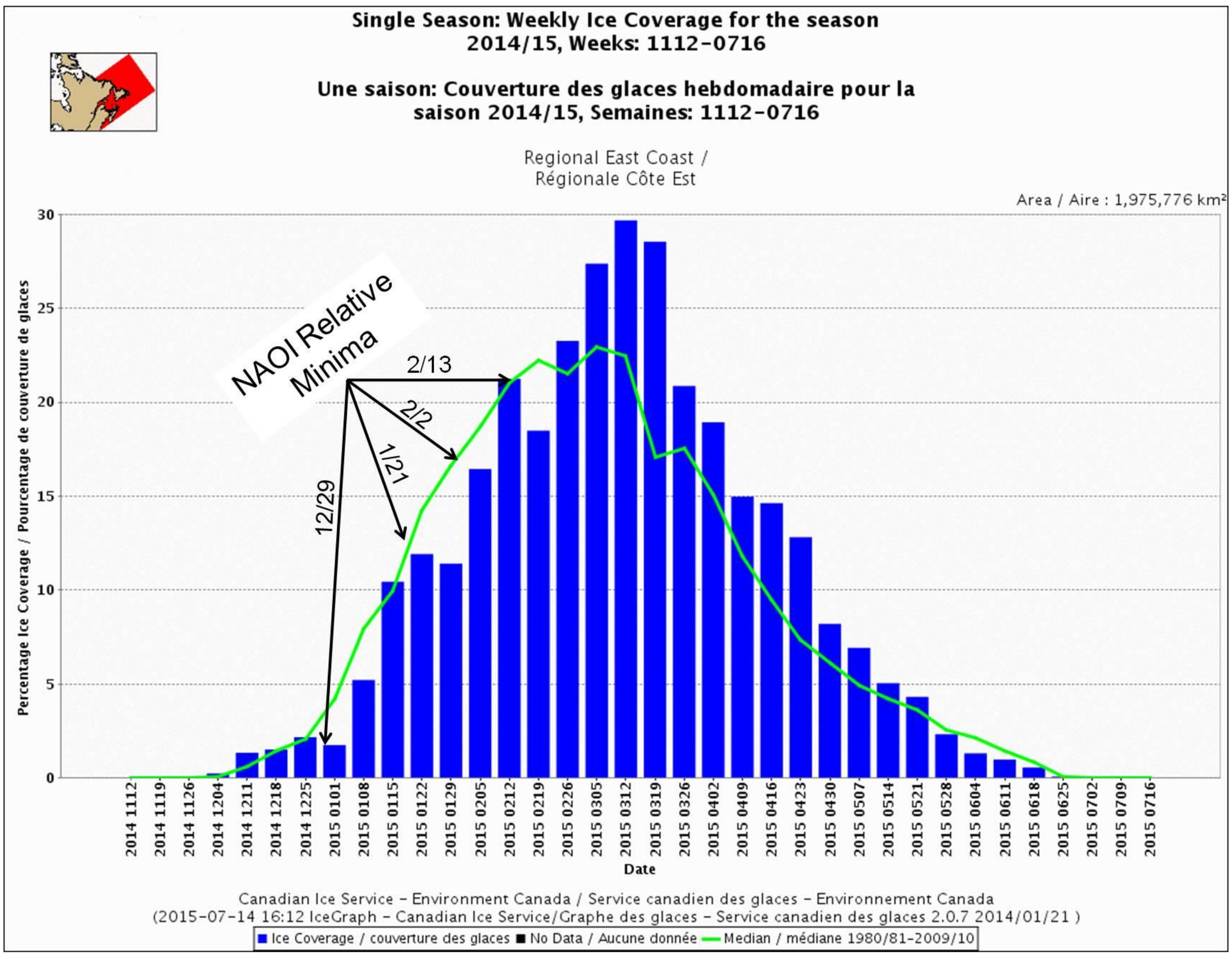


Figure 15. Weekly ice coverage for East Newfoundland Waters. The percent coverage is relative to the area shaded in red in the upper left map of this figure. Relative NAOI minima are indicated with arrows on the green median coverage line. These relative minima are also included in Figure 14 (CIS, 2015d).

June and July since the main storm track brought a series of low pressure systems just to the south of Newfoundland and through IIP's primary reconnaissance area near the southern Iceberg Limit. Not only did this southerly storm track create persistent low visibility in the OPAREA, making visual identification of icebergs challenging, it also frequently brought onshore winds from the North Atlantic causing the coldest average July temperatures in St. John's since 1993 as shown earlier in **Figure 4.** The impact of this storm track shift on operations will be discussed in greater detail in the Ice Reconnaissance and Oceanographic Operations section of this report.

Oceanographic Discussion – Icebergs drifting south of 48°N in the offshore branch of the Labrador Current followed multiple paths to establish the eastern, southeastern, and southern Iceberg Limit. To illustrate the movement of the ocean currents that transported icebergs south of 48°N, **Figure 16** shows the paths of four Surface Velocity Program (SVP) drifting buoys with 50 m drogues deployed by IIP in March, May, early-June, and mid-June 2015 (shown in magenta, green, gold and black, respectively). Three of these buoys were deployed in the same location at 48°00'N, 48°30'W, but all drifted along very different paths to the south and east. The fourth, deployed slightly further

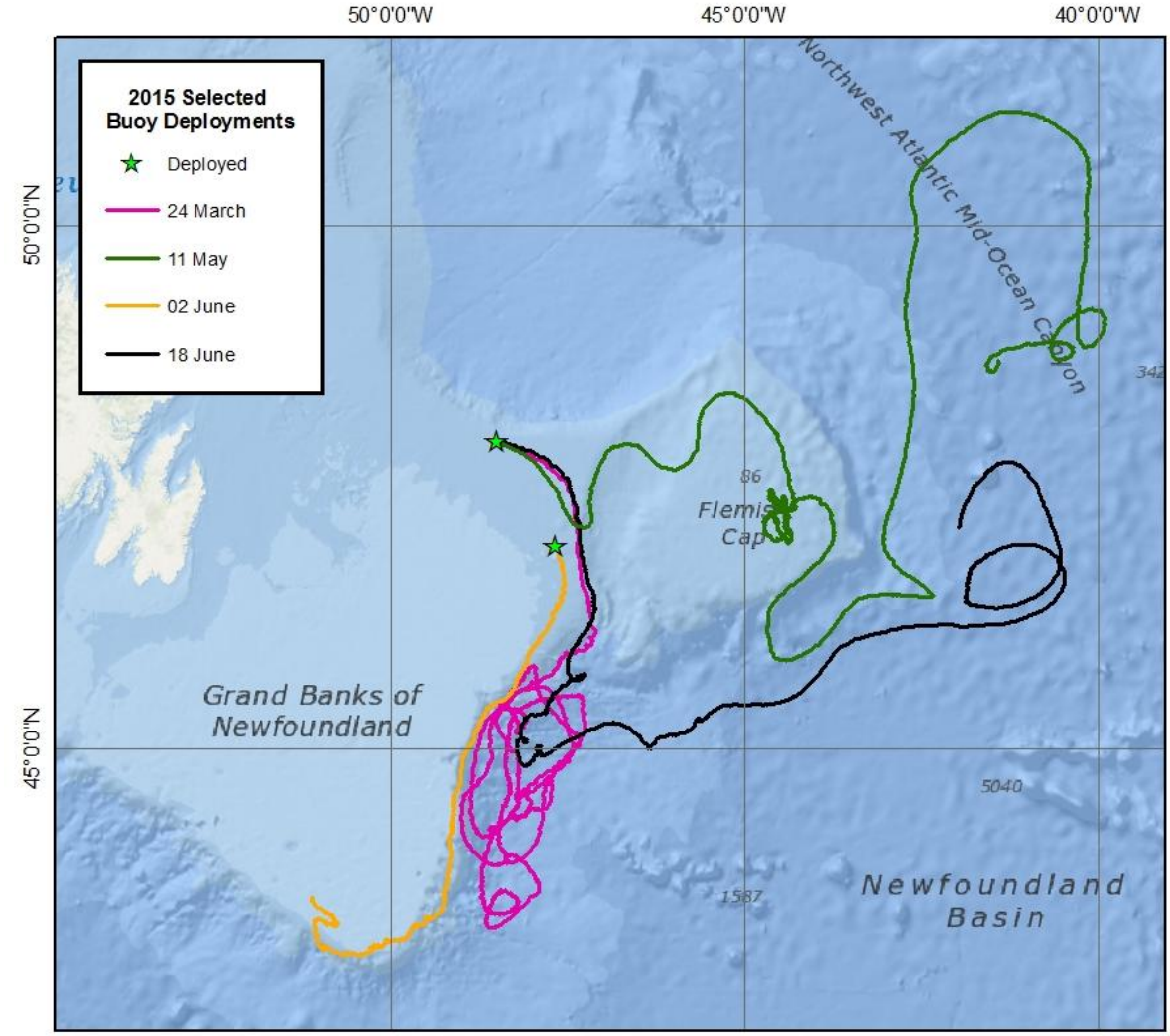


Figure 16. Drifting buoy tracks showing four different current paths for icebergs.

south within Flemish Pass (47°00'N, 47°40'W), followed yet another route.

The first drifting buoy, deployed on 24 March, is shown as the magenta-colored track in **Figure 16.** The buoy followed the 1000 m contour of the Grand Banks in the Labrador Current until encountering a meander of the North Atlantic Current around 17 April which halted the buoy's southward progress at approximately 44°N. At its southernmost extent, this drifter entered an eastward-flowing jet off of the Labrador Current and began drifting to the east first, then back to the north in a counter-clockwise direction. Meanwhile, 150 NM to the southwest, the main core of the Labrador Current split into two branches after encountering the North Atlantic Current - one flowing eastward and another, westward. This bifurcation is clearly visible in an AVHRR SST satellite image acquired on 17 April

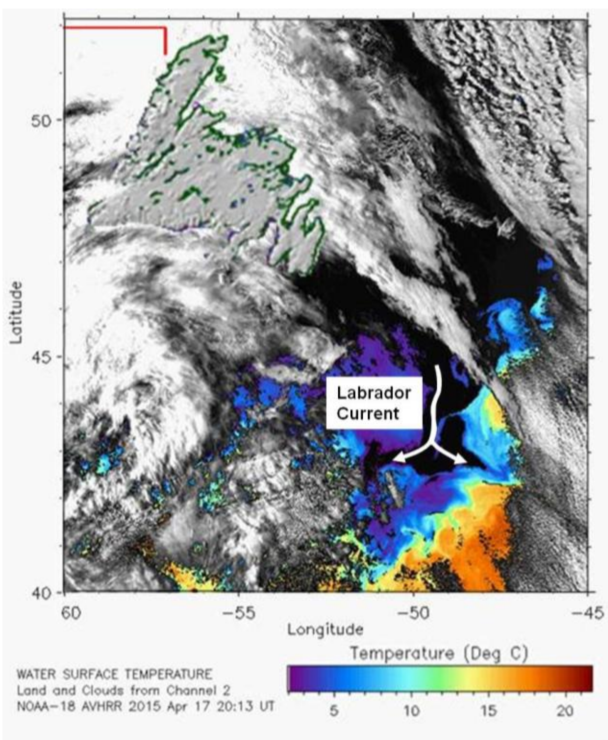


Figure 17. AVHRR SST Image from 17 April 2015 showing Labrador Current split. Image provided by the Ocean Remote Sensing Group, Johns Hopkins University Applied Physics Laboratory (JHU, 2014).

(**Figure 17**).

During a flight on 15 May, IIP located numerous icebergs near 43°N, 50°W that were transported by this westward-moving branch of the Labrador Current. This situation persisted well into June as shown by the gold-colored track of the buoy deployed on 02 June (**Figure 16**). This buoy followed a similar path as the buoy represented by the magenta-colored track until encountering the westward branch of the Labrador Current where it turned to the west along the 1000 m contour at the Tail of the Bank. This split of the Labrador Current along with the presence of the North Atlantic Current meander described above reduced the current's capacity to carry icebergs as far southward as observed in other extreme years. The 2015 oceanographic conditions were beneficial to transatlantic shipping compared to 2014 since the latitude for the southernmost-drifted iceberg in 2014 was 40°23'N**,** approximately 80 NM further south than in 2015.

The North Atlantic Current meander described above pushed northward in early May. In mid-May, a smaller counter-clockwise eddy formed in the northern segment of the meander and appeared to detach from the main current. The availability of near-real time drifting buoy data proved particularly valuable to the results of IIP's iceberg drift model. The left panel of **Figure 18** shows the location of the eddy described above on 26 May in an AVHRR SST image. A ten-day segment of the magenta-colored buoy track from 17 to 26 May is superimposed on the image. The right panel of **Figure 18** is an excerpt from BAPS showing each buoy position during the same time period with a red 'x'. The blue vectors represent mean currents which would have been used by the model in the absence of buoy data. The green vectors show the currents modified using the buoy data and directly applied to IIP's drift model. The estimated locations of the icebergs in the IIP database on 26 May are also shown in the right panel of **Figure 18**. Three of these icebergs impacted by the presence of this eddy are highlighted in yellow. Without the data from this drifting buoy, this small eddy would not have been detected, and these icebergs would have been erroneously projected to drift further south. As evidence to this statement, during a flight on 02 June, IIP located a small iceberg and a growler to the northeast of the icebergs highlighted in yellow in **Figure 18** in locations that were consistent with the drift pattern of the counterclockwise feature described herein.

The buoy tracks shown in green and black in **Figure 16** depict two eastward flowing paths also responsible for bringing icebergs toward the east and southeast. The drifting buoy represented by the green track followed a path south of Sackville Spur but north of Flemish Cap. This buoy remained in relatively cold water (less than 5°C) until around 44°30'W when it entered the North Atlantic Current and continued to drift outside of IIP's OPAREA. The buoy represented by the black track proceeded southward first through Flemish Pass and then turned eastward in mid-July.

The fact that three of the buoys shown in **Figure 16** were all deployed at the same location yet traveled in very different paths underscores the complexity of the Labrador Current system, particularly in the vicinity of the North Atlantic Current. The use of near real-time drifting buoy data to augment historical mean currents or to assess the accuracy of modeled current data, such as the Canadian East Coast Ocean Model (CECOM) is a key tool for understanding this dynamic environment.

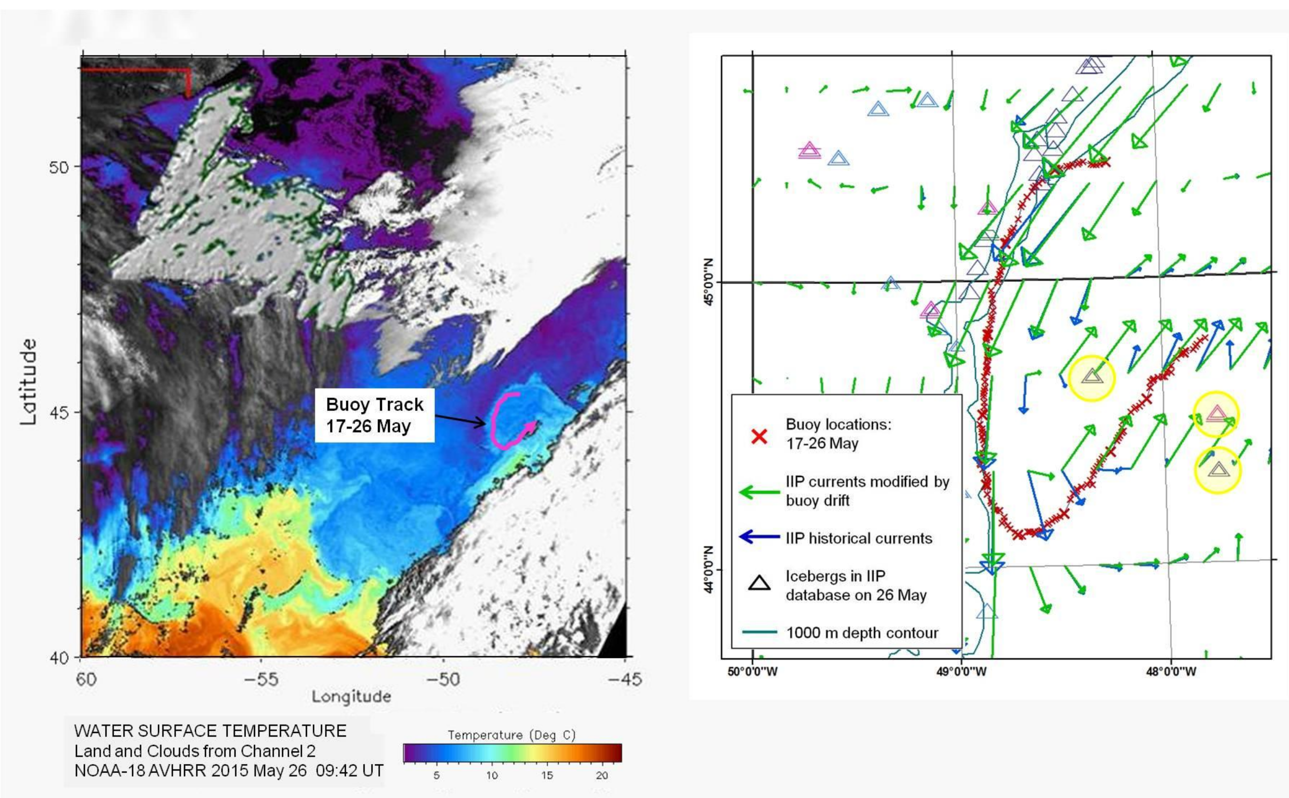


Figure 18. ***Left Panel*: AVHRR SST Image from 26 May 2015 with 10-day segment from a buoy track overlaid onto counter-clockwise eddy. Image provided by the Ocean Remote Sensing Group, Johns Hopkins University Applied Physics Laboratory (JHU, 2015). *Right Panel*: Modified and historical IIP currents with buoy track from 17-26 May**

Operations Center Summary

IIP's 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 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 necessary action to be taken at any time. The watch is responsible for receiving iceberg reports from a wide variety of sources including IRD flights, PAL flights, and merchant vessels. The watch then enters the reports into BAPS, produces iceberg warnings for the North Atlantic using the iceberg drift and deterioration computer model, and distributes the products to the maritime community.

To accomplish its mission, IIP works in concert with CIS and the U. S. National Ice Center (NIC) in a formal partnership known as the NAIS. One aspect of NAIS is the agreement to produce a single set of iceberg products for North America and share all iceberg reports between the United States and Canada. Generally, IIP is responsible for product generation from 01 February to 31 August, and CIS is responsible for product generation from 01 September to 31 January. CIS and IIP also serve as continuity of operation locations for one another. If one entity is unable to create the iceberg products, the other can assume responsibility for product generation until the issue is resolved. By formalizing the sharing of information and collaboration on product generation and distribution, NAIS ensures the maritime community consistently receives the most timely and accurate iceberg information available.

Products and Broadcasts

IIP creates two products for the maritime community each day, the NAIS65 iceberg chart (graphical representation) and the NAIS10 iceberg bulletin (text representation). They are normally released by 1830Z and are valid for 0000Z the following day. The iceberg chart is broadcast over radiofacsimile (RADIOFAX) and the internet. The iceberg bulletin is broadcast over SafetyNET, Navigational Telex, Simplex Teletype Over Radio (SITOR), and the internet.

During the 2015 Ice Season, products were released prior to 0000Z 99.1% of the time. On 25 February 2015, the CIS Product Distribution Service (PDS) failed to deliver the bulletin to subscribers, but the issue was resolved the following morning. On 27 April, IIP was unable to send the bulletin to CIS. The bulletin was successfully sent to CIS the next morning, and it was immediately distributed via the PDS. On every other day during the season, all products were released on time in all formats.

On occasion, IIP receives reports of an iceberg or a stationary radar target outside the published Iceberg Limit. These occasions prompt both short-term and long-term actions. The short-term actions will include issuing immediate warnings to mariners and can include sending out revised products. The long-term actions can include examining the reconnaissance schedule and the performance of the iceberg drift and deterioration model to see if the event was avoidable.

Any report of an iceberg or radar target outside the limit is passed to the appropriate Canadian Coast Guard (CCG) Marine Communications and Traffic Service (MCTS) center. The MCTS generates and transmits a Notice to Shipping (NOTSHIP) which is automatically forwarded to the National Geospatial-Intelligence Agency (NGA). NGA generates and transmits a Navigational Area (NAVAREA) IV Warning, a navigational warning sent by radio to all vessels operating within this area. NAVAREA IV is located in 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. The IIP OPAREA falls entirely within NAVAREA IV. If the report is received before 1400Z, the IIP watch revises the NAIS65 and NAIS10 products and distributes revised products valid for 1200Z. Formerly, the MCTS office that handled iceberg-related NOTSHIPs was located in St. John's, Newfoundland. Restructuring within the CCG resulted in MCTS Port aux Basques assuming this responsibility.

In Season Icebergs and Radar Targets Outside the Iceberg Limit

During the 2015 Ice Season, there were four occasions when icebergs or radar targets were reported outside of the published Iceberg Limit. When viewed in the context of 1,165 icebergs south of 48°N, this was less than 0.4% of the total number of icebergs that IIP tracked south of this latitude in 2015. That said, these cases represented potentially dangerous situations for vessels heeding IIP's Iceberg Limit. It is critical for IIP to document and learn from these instances to improve the future execution of the IIP mission.

1. On 30 April 2015, the M/V MIEDWE reported a stationary radar target south of the published Iceberg Limit in position 45°32'N, 52°36'W. Based on available information, the watch added the target as a generic iceberg to the iceberg database. A NOTSHIP was released, but because the report was received after 1400Z, the release deadline for revised products, it was not possible to release an updated product. Instead the iceberg was included in the next regularly-scheduled product released at 1830Z.
2. On 07 August 2015, analysis of a Sentinel-1a image taken on 02 August 2015 was received at IIP. All detected iceberg targets were added to IIP's iceberg database, with the exception of one target, located south of the published Iceberg Limit in position 44°20'N, 50°39'W. The decision was made not to include this observation as an iceberg in NAIS products due to its position, the time of year, SSTs, and recent aerial reconnaissance in the area. Instead, it was added as a radar target. Because the report was received shortly before the 1830Z time for normal product release, no revised product or NOTSHIP was sent. Instead, the radar target was added to the regularly-scheduled products.
3. On 08 August 2015, the iceberg drift and deterioration model predicted several of the icebergs added from the 02 August Sentinel-1a image had drifted south and just outside the published Iceberg Limit. Because this model run was conducted shortly before the 1830Z time for normal product release, the watch was able to take the positions of the icebergs into account in the 09 August 2015 products. No revised product or NOTSHIP was sent.
4. During the evening of 25 August 2015, a PAL reconnaissance flight sighted two icebergs just east of the published Iceberg Limit in the vicinity of 52°59'N, 52°32'W. A NOTSHIP was released, and revised products were sent out the following morning.

Because the second incident only involved a radar target, and the Iceberg Limit is not set on radar targets, there were three occasions when the published limit was inaccurate resulting in an Iceberg Limit accuracy of 98.6% for the 2015 Ice Season.

The series of events related to the Sentinel-1a imagery analysis in August underscores some of the difficulties inherent with using this type of data to create an operational product. The IIP watch received possible iceberg positions from a five-day old satellite image that were then cleared by the U.S. Coast Guard Maritime Intelligence Fusion Center Atlantic (MIFC LANT) and evaluated to be icebergs by the Center for Cold Ocean Resources Engineering's (C-CORE) iceberg detection software (IDS). Historically, IIP satellite correlation flights have shown this algorithm to be relatively accurate in identifying icebergs, but also prone to false positive returns. In satellite imagery from August, many of the "iceberg" targets seemed too far south given the time of year. In the absence of information beyond climatological data to rule them out, the decision was made to include them as icebergs, which dramatically expanded the limit to the south at a time of year when the limit is usually receding monotonically. A conservative, risk-adverse approach to product creation from satellite data could lead to future products with expansive limits. An artificially-expansive limit would result in a significant cost to transatlantic shipping. If experienced mariners lose their confidence in the fidelity of the NAIS iceberg products because they perceive them to be too conservative, they may be less likely to remain outside the limit. Likewise, if IIP were to ignore satellite reports of potential icebergs in the creation of its products, IIP would be assuming additional risk in the case of an iceberg collision outside of the published limit where a satellite identified targets. A carefully-nuanced approach is prudent as satellites are integrated into IIP operations. The Iceberg Reconnaissance and Oceanographic Operations section of this report discusses in greater detail IIP's plans to expand operational use of satellite reconnaissance.

Out of Season Icebergs and Radar Targets Outside the Iceberg Limit

Outside of the Ice Season, but during the Ice Year, there were three additional incidents involving iceberg reports outside the published limit, one before the season began and two after it ended.

1. On 07 October 2014, the M/V VIKINGBANK visually observed a growler over 500 NM east of Newfoundland, over 400 NM outside the limit. Overnight, the vessel identified a second suspected iceberg 100 NM to the west of the first iceberg. These reports were received by MCTS Port aux Basques and relayed to CIS. Due to the rarity of icebergs in these locations in October, IIP contacted the Master directly to confirm the report and, based on his certainty, both reports were added to the iceberg database by CIS as radar targets and displayed on the 10 October 2014 products. Radar targets were chosen despite the visual observation of at least one of the icebergs because the reports were isolated. If the reports had been added to the iceberg database as icebergs, the Iceberg Limit would have expanded unreasonably at a time of year when SSTs were still relatively warm and in regions where icebergs were not expected based on climatology.
2. On 06 September 2015, a RADARSAT-2 satellite image from 03 September 2015 was processed, and targets were added to the model by CIS. One of the radar targets added was just over 20 NM outside of the western Iceberg Limit in the Strait of Belle Isle. No NOTSHIP was released, and products were not revised because the timing of the report allowed it to be easily added to the 07 September product.
3. On 21 September 2015, M/V BALTIC FOX observed a suspected iceberg on radar in

the center of the Labrador Sea, over 130 NM east of the limit and 169 NM west of Greenland. The radar target was located at 59°N and well outside Canadian territorial waters. CIS added the radar target to the model, and it was reflected in the products. The Danish Meteorological Institute (DMI) was notified because of the target's proximity to Greenland. While the radar target remained in the model, it was advected solely by wind-driven currents because of the lack of mean current data in this part of the OPAREA. This incident suggests increased ship traffic to and from the Arctic. There is room for improvement in dealing with icebergs reported within the central Labrador Sea. IIP worked closely with DMI in 2015 and plans to continue full coordination within NAIS for improved service to the North Atlantic mariner. Work toward this end was a major outcome of the 2015 NAIS Conference, and new procedures concerning reports in this area of the OPAREA are forthcoming.

Three "in season" incidents and three "out of season" incidents make a total of six occasions during the Ice Year when the published limit was inaccurate for an Iceberg Limit accuracy of 98.4% for the 2015 Ice Year. The Iceberg Limit accuracy for the Ice Year is lower than the Iceberg Limit accuracy for the Ice Season because the Ice Season spans approximately half of the year.

Iceberg Reports

The Vessel of Opportunity Observation Program is an essential element of IIP's successful safety record. The voluntary contribution of individual vessels to this program is captured in Appendix A of this report. In 2015, 31 vessels from 13 flag states provided 122 informational reports regarding icebergs. These reports were from the most critical parts of the North Atlantic

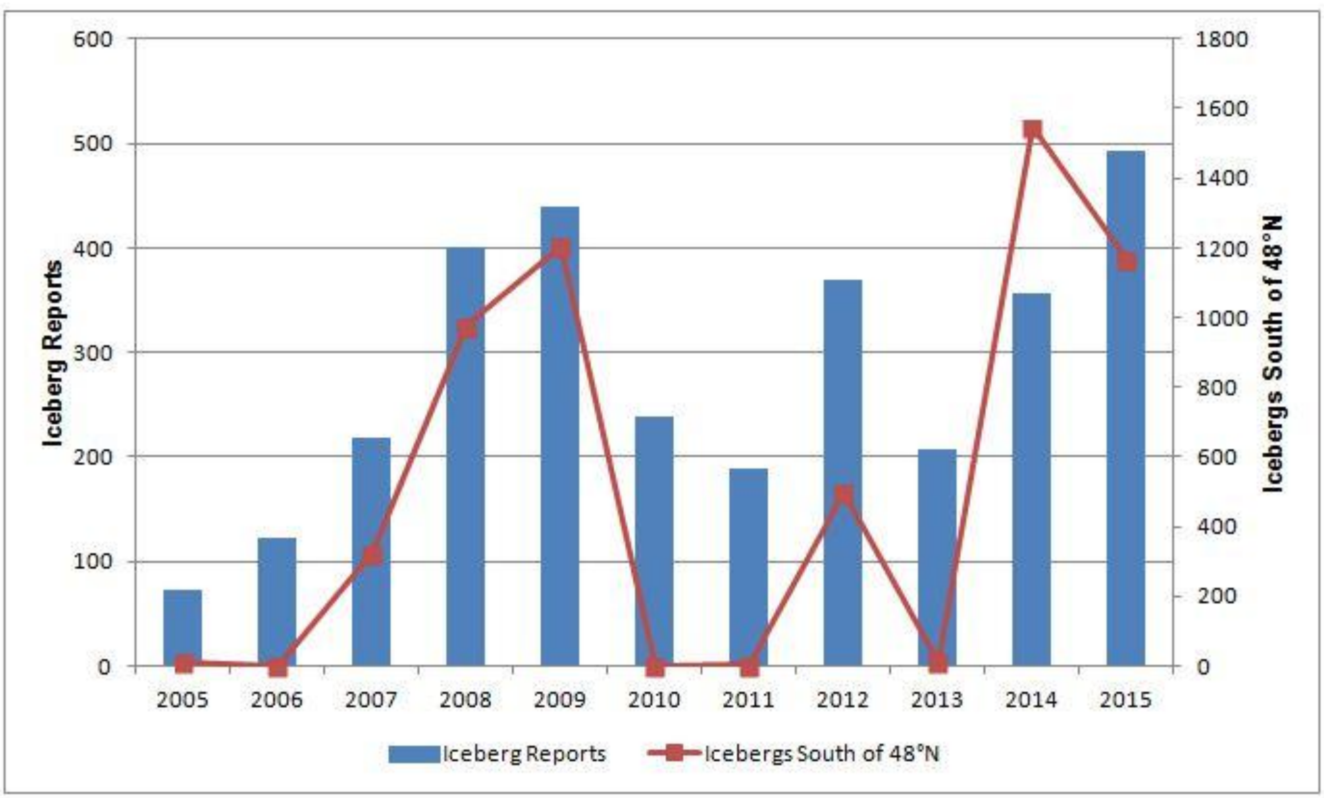


Figure 19. Total iceberg sighting messages received by IIP each year relative to Ice Season severity represented by number of icebergs crossing south of 48°N (2005-2015).

covered by NAIS products, the routes used by transatlantic vessel traffic. The number of these reports increased by over 37% from 2014. The significant increase was mainly driven by the large number of reports from vessels contracted by the oil and gas industry working with rigs on the Grand Banks of Newfoundland.

The 2015 Ice Season was very similar to the extreme season in 2014. On 30 January 2015, the Iceberg Limit moved south of 48°N. Although this was slightly later than in 2014, it was still well before the climatological mean. By 29 May 2015, the limit reached its southernmost extent, stretching down to 40°45'N, the approximate latitude of New York City, an average southernmost extent compared to climatology. On 16 August 2015, the limit finally moved north of 48°N, several weeks after the climatological mean and several days earlier than it did in 2014. During the 2015 Ice Season, IIP's OPCEN received, analyzed, and processed 492 iceberg messages. **Figure 19** shows the number of iceberg sighting reports received by IIP for each of the last ten seasons relative to the Ice Season severity. The first bar of **Figure 20** shows the distribution of these reports by source in 2015, and **Table 2,** Column 1 captures the numerical breakdown.

It is important to recognize the contracted reconnaissance conducted by PAL was done for a variety of clients including the

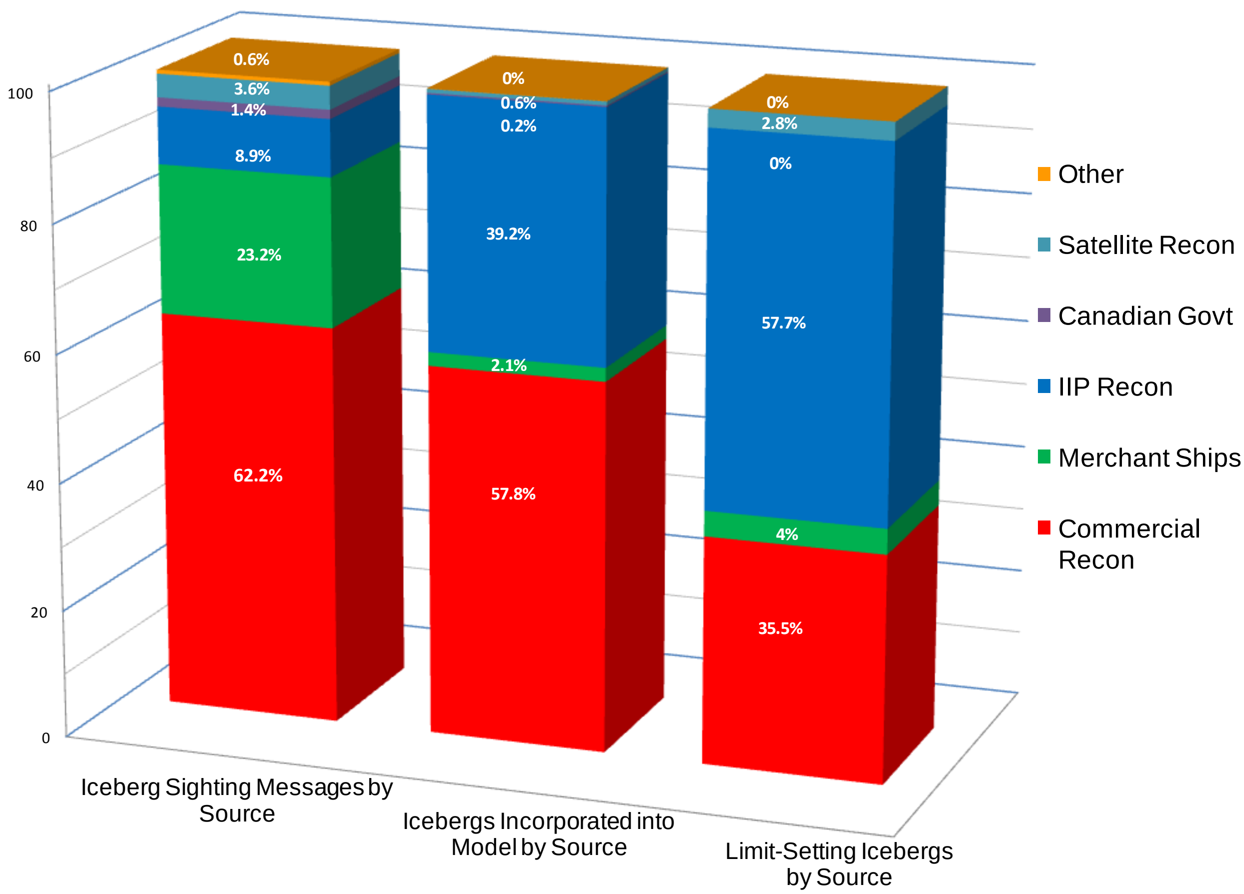


Figure 20. Percentage of iceberg sighting messages, icebergs incorporated into the iceberg database, and limit setting icebergs by reporting source in 2015.

Canadian government and the oil and gas industry. Regardless of the purpose of the flight, PAL shared its iceberg information with IIP. **Figure 21** shows the breakdown of PAL reconnaissance. The majority of the flights (56%) were flown for Canadian government organizations other than CIS, and another large portion (40%) were flown for the oil and gas industry. Only 4% of the flights were flown explicitly for CIS to fill iceberg reconnaissance gaps.

In total, the iceberg sighting messages contained position data for well over 15,000 icebergs. Before entering data from each message into the model, the contents were evaluated for accuracy and validity by the IIP watch. Atmospheric and oceanographic conditions, recent reconnaissance in the same area, and method of detection were all considered in this process. To ensure the best quality product, IIP's own iceberg sighting messages were given the same level of scrutiny as those from outside sources. After this process, 13,945 individual icebergs were incorporated into BAPS. The second bar of **Figure 20** shows distribution of these incorporated icebergs by source, and **Table 2,** Column 2 captures the numerical breakdown. Generally, each individual report from merchant ships contained small numbers of icebergs while IIP flight messages were typically the largest in terms of the number of icebergs.

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. IIP keeps track of the original reporting source of every limit-setting iceberg. The third bar of **Figure 20** shows limit-setting icebergs broken down by source, and **Table 2,** Column 8 captures the numerical breakdown. This distribution highlights the critical importance of IIP reconnaissance to the creation of an accurate product. With the Iceberg Limit stretching 240 NM west, 700 NM east, and 400 NM south of St. John's, Newfoundland in 2015, the distances involved exceeded the range of PAL aircraft. The high endurance of the HC-130J allowed IIP reconnaissance to concentrate on establishing the positions of the limit-setting icebergs even when the limit extended further than the climatological mean. PAL flights concentrated on the interior of the Grand Banks and waters closer to Newfoundland and Labrador regardless of the location of the Iceberg Limit.

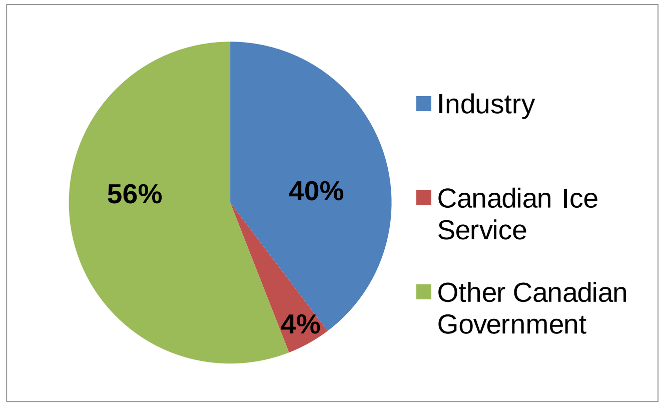


Figure 21. Breakdown of PAL aerial reconnaissance.

The western and southern limit extents were close to the climatological mean, but the eastern limit extent far exceeded this average. The extreme eastern extent of the limit was mainly due to oceanographic conditions summarized in the Ice and Environmental Conditions section of this

Reporting Source	Iceberg Sighting Messages	Icebergs Incorporated into Model	Limit-Setting Icebergs
Merchant Ships	115	297	38
Satellite Recon	15	84	27
IIP Recon	44	5475	554
Canadian Government	7	32	0
Commercial Recon	308	8053	341
Other	3	4	0
Total	492	13945	960

Table 2. Numbers of iceberg sighting messages, icebergs incorporated into the model, and limit-setting icebergs broken down by reporting source in 2015.

report. The maximum extent in 2015 was slightly less expansive than in 2014. In 2014, the patrol aircraft was diverted from IIP operations on several occasions for Search and Rescue cases in the vicinity of the IIP OPAREA. The loss of this resource for periods at the height of the Ice Season allowed the iceberg drift and deterioration model to continue to predict icebergs drifting to the east. During the lack of reconnaissance, IIP kept these icebergs in the database as a conservative measure for vessel safety.

Operational Testing of the NAIS Model

In 2007, IIP began exploring options for replacing the IIP iceberg drift and deterioration model. A new drift and deterioration model was developed by CIS in 2010. Now recognized as the "NAIS Model", this model incorporates a better representation of the subsurface structure of icebergs and includes the ability to use multi-layered modeled currents from sources such as the Canadian East Coast Ocean Model. The NAIS Model performed admirably in a series of scientific tests conducted in 2010. These tests involved comparing past predictions from the current IIP Model with the new NAIS Model using observed iceberg trajectories. The next step in this evaluation will be to move forward with an operational test of the model to assess its ability to replace or augment the existing IIP Model. This test will involve the IIP watch running both the IIP Model and the NAIS Model simultaneously on all observed icebergs.

BAPS Version 1.12, introduced in 2014, is capable of running multiple iceberg drift and deterioration models at the same time. Throughout the 2015 Ice Season, the IIP watch used the IIP Model to develop the product, but NAIS Model trajectories for each iceberg were also saved. Following the season, a side-by-side comparison of NAIS Model analysis with IIP Model analysis was conducted to qualitatively check the NAIS Model's performance. For the most part, the results were encouraging, but on several days, the results from the NAIS Model appeared unrealistic. The reasons for these deviations are still being investigated, and a complete report on the results of this test will be included as an appendix to the 2016 Annual Report.

Iceberg Reconnaissance and Oceanographic Operations

Ice Reconnaissance Detachment

The IRD is a sub-unit under CIIP, which is partnered with ASEC. During the 2015 Ice Season, 12 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. IIP created and distributed the NAIS iceberg warning products to the maritime community.

Throughout the 2015 Ice Season, IRDs operated out of the IIP's base of operations in St. John's, Newfoundland for a total of 102 days and conducted 49 ice reconnaissance patrols. Two days prior to the first IRD, ASEC flew an HC-130J to Quonset, RI 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 on 05 February, and the last IRD returned to Groton, CT on 31 July. Eight flights were cancelled due to weather, and thirteen flights were cancelled for aircraft maintenance or repairs. From a historical perspective, this year is currently considered the 13th most extreme iceberg season on record since 1900. While a hazard to shipping, the severe ice conditions provided valuable data and training and resulted in a highly-qualified IIP crew. A summary of IRD operations is provided in **Table 3**.

Aerial Iceberg Reconnaissance

The 2015 aerial iceberg reconnaissance operations were conducted using the 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 (ELTA) 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 ships and is used to differentiate vessels from icebergs on the radar.

Poor weather in IIP's OPAREA frequently made detecting and discriminating targets a challenge for IRD personnel. As a result, the use of radar in this environment is critical to IIP operations. In conditions where there was little or no visibility to the surface, the IRD relied on the ELTA's Inverse Synthetic Aperture Radar (ISAR) mode with imaging capability as the primary means of classifying targets. However, the ability to individually image high concentrations of radar targets in severe sea ice and low visibility conditions in 2015 proved to be particularly challenging.

IRD crews continued to rely on visual observations while operating over sea ice, rather than attempt to electronically classify hundreds of automatically acquired-targets on the radar screen. Most iceberg observations in sea ice were entered as visual sightings with radar target information supplementing

IRD	Deployed Days	Iceberg Patrols	Transit Flights	Logistics Flights	Flight Hours
1	9	3	3	0	36.1
2	8	4	2	0	35.2
3	8	4	2	0	40.2
4	9	4	2	0	34.3
5	8	2	2	0	19.8
6	8	6	2	0	46.3
7	8	4	2	0	37.9
8	8	5	2	0	47.0
9	9	4	2	0	38.2
10	8	5	2	0	41.6
11	9	5	2	0	39.0
12	10	4	2	2	51.1
Total	**102**	**50**	**25**	**2**	**466.7**

Table 3. Summary of IRD Operations.

those entries as available. In conditions of low visibility, no sea ice, and high target density, crews discovered a new practice of overlaying the radar picture on a latitude and longitude grid on the Common Operating Environment (COE) of the aircraft's mission system. This new procedure enabled the Radar Ice Observer (RIO) to record targets within Manual of Standard Procedures for Observing and Reporting Ice Conditions (MANICE) zones. These zones are defined by latitude and longitude and can include high numbers of icebergs according to any size or shape.

IRDs conducted 49 patrols for a total of 319 patrol hours and experienced 5.3 hours of ELTA radar casualties. The radar casualties occurred during three different patrols this season. Following the radar casualty on each of these patrols, only visual reconnaissance was used to detect and classify icebergs. IRDs operated without working radar for only 1.7% of total patrol time this season, a significant decrease from the 2014 season which had 38.5 hours of ELTA down time.

The availability of 360° coverage provided by the ELTA radar supports the use of 25 NM track spacing for patrol planning. In 2013, IIP collected sweep width data under calm conditions. The definition of "calm conditions" is less than 10 knots of wind and no sea state. The analysis of this data resulted in a recommendation to expand track spacing to 30 NM in calm conditions while maintaining a 95% probability of detection (POD) of small icebergs (15-60m). This level of POD is long-established by IIP's Reconnaissance Requirements. 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.

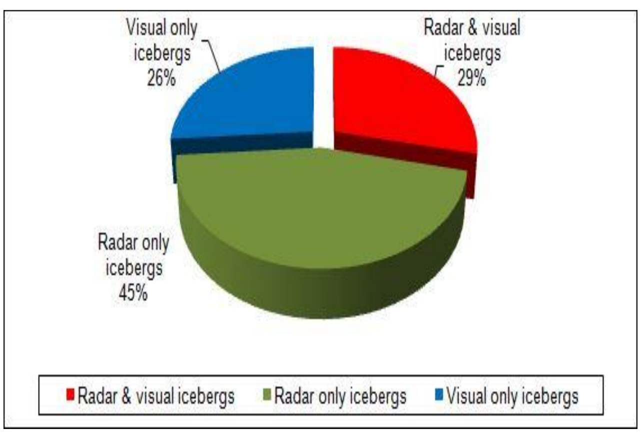


Figure 22. Iceberg sightings by method.

As described in the Operations Center Summary, 13,945 icebergs were incorporated into the BAPS model. IRD personnel detected 5,475 icebergs which accounted for 39% of the total icebergs added to the IIP database in 2015. Icebergs are detected in one of three ways: (1) combination of radar and visual, (2) radar only, or (3) visual only. This year, 29% of the icebergs were detected by both radar observations and visual sightings. The remaining icebergs were either detected only by radar (45%) or only by visual observations (26%) (**Figure 22**). The number of radar only sightings greatly increased this season, up 40% from only 5% in 2014. This increase in radar only sightings is attributed to poor OPAREA weather combined with aircraft speed restrictions discussed later in this section. As described in Ice and Environmental Conditions section, the storm track position south of Newfoundland late in the season resulted in frequent passage of low pressure systems across the IIP OPAREA. These systems created poor weather (low ceilings, low visibility) requiring greater reliance on radar observations.

IIP is working to improve radar detection of icebergs in sea ice by evaluating the ELTA radar's Strip Map SAR mode in the IIP operating environment. IIP planned a Strip Map SAR test flight this season, but the flight was aborted due to a mechanical issue. IIP also plans to conduct additional sweep width testing including modifying search altitudes to determine the best radar performance.

2015 Flight Hours

Figure 23 shows the breakdown of the 466.7 flight hours used during the 2015 Ice Season for IIP operations. The flight hours are broken down into three categories: patrol hours, transit hours, and logistics hours. Patrol hours are the hours used for iceberg reconnaissance. IIP flew 319.2 patrol hours this season. Transit hours are hours the aircraft transited to and from specific locations in support of the IIP mission. There were 136.7 hours used this season for transits to and from St. John's. Transit hours increased slightly from 2014 to 2015 due to a training day conducted at ASEC on the first IRD prior to beginning reconnaissance in St. John's. Transit hours were further increased due to eight patrols conducted on the way to or from Canada with starting or ending positions north or east of St. John's. These flights required longer transit times back to the U.S. Logistics hours are the hours used to support the IIP mission, that do not fall into the previous two categories. Logistics hours can be used to transport parts for an aircraft deployed on an IIP mission. This year, 10.8 logistics hours were used on IRD 12 to exchange the deployed aircraft in St. John's with a new aircraft from ASEC due to maintenance issues.

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 drifted south of 48°N. **Figure 24** shows a comparison of flight hours to number of icebergs drifted south of 48°N from 2005 to 2015. The red line indicates the IIP total flight hours. The blue bars indicate number of icebergs observed or drifted south of 48°N.

IIP was allotted 500 Maritime Patrol Aircraft flight hours for its operations in 2015.

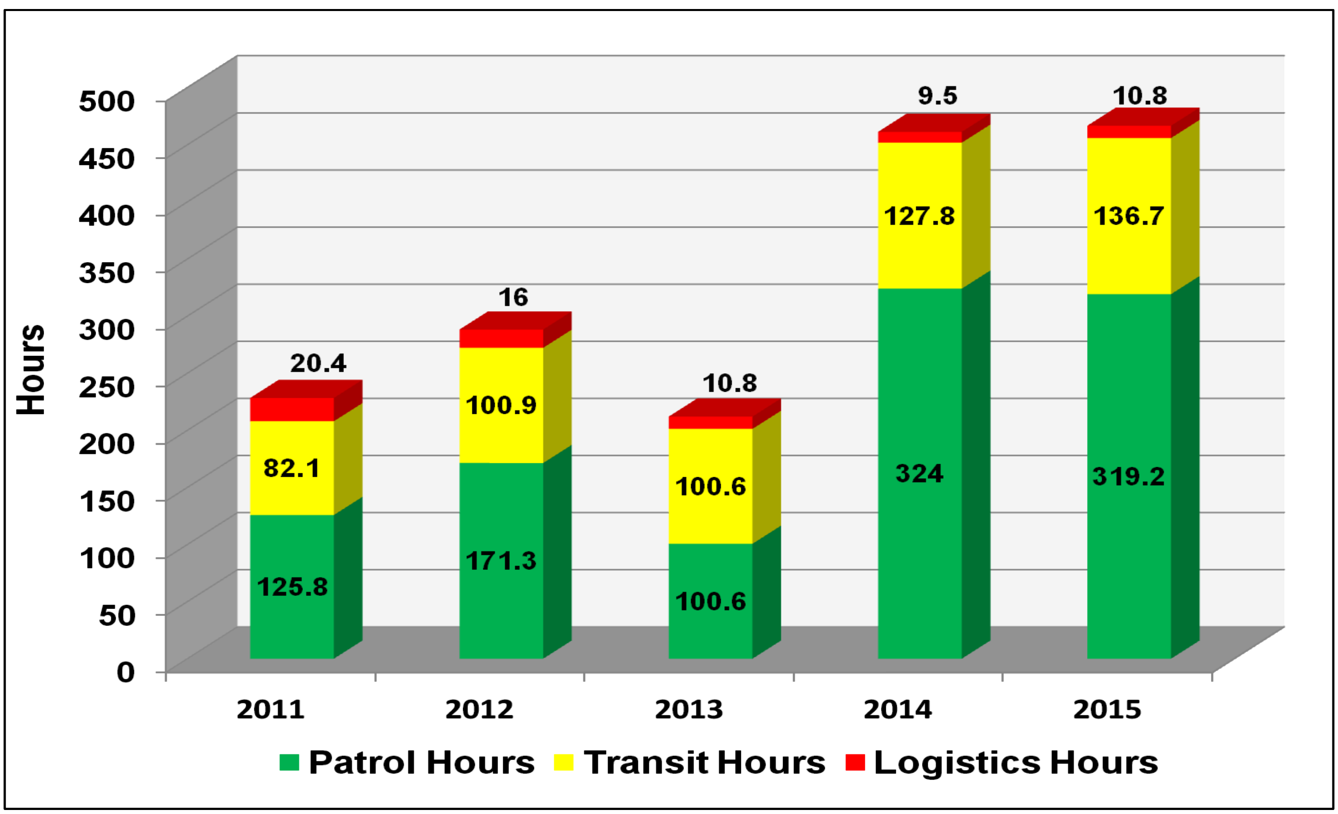


Figure 23. Summary of flight hours (2011-2015).

IIP used 466.7 hours compared to 461.3 in 2014. While the iceberg population was slightly smaller and less widespread this season, USCG restrictions on aircraft speed at patrol altitudes below 2,000 feet, which were established to preserve HC-130J airframes, limited how much area the aircraft could cover at patrols flown below this altitude. Patrol speeds were restricted to 190 KTS below 2,000 feet. This restriction significantly increased patrol time when conditions and iceberg density necessitated flying at lower altitudes.

In addition, the new flight altitude and speed requirements contributed to a higher percentage of icebergs detected by radar alone. Flights were often flown above 2,000 feet regardless of visibility to the surface when patrolling inside the published Iceberg Limit. Flying at this altitude was necessary to maintain higher flight speeds, manage patrol flight time, and meet crew rest requirements, while ensuring full coverage of the operational area.

During the 2015 Ice Season, eight patrols were incorporated into transit flights between St. John's and Groton. These patrols occasionally departed out of Quonset, RI (KOQU) due to its longer runway and the weight from additional fuel carried by the aircraft to complete patrols. IRD deployments were delayed six times due to weather and aircraft maintenance. These conditions made patrols in transit an operational necessity to maximize the efficiency of IIP's aerial reconnaissance.

NAIS Reconnaissance Results

IIP continued to leverage its NAIS partnership with CIS to maximize efficient use of aerial reconnaissance resources. Redundant reconnaissance was eliminated through coordinated flight planning. **Figure 25** depicts the NAIS flight hours for 2015. Data provided includes hours flown by each service. IIP flew 319.2 patrol hours, and CIS contracted PAL for a total of 118.9 hours. The combined total resulted in 585.6 hours in support of NAIS reconnaissance (**Figure 25)**.

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

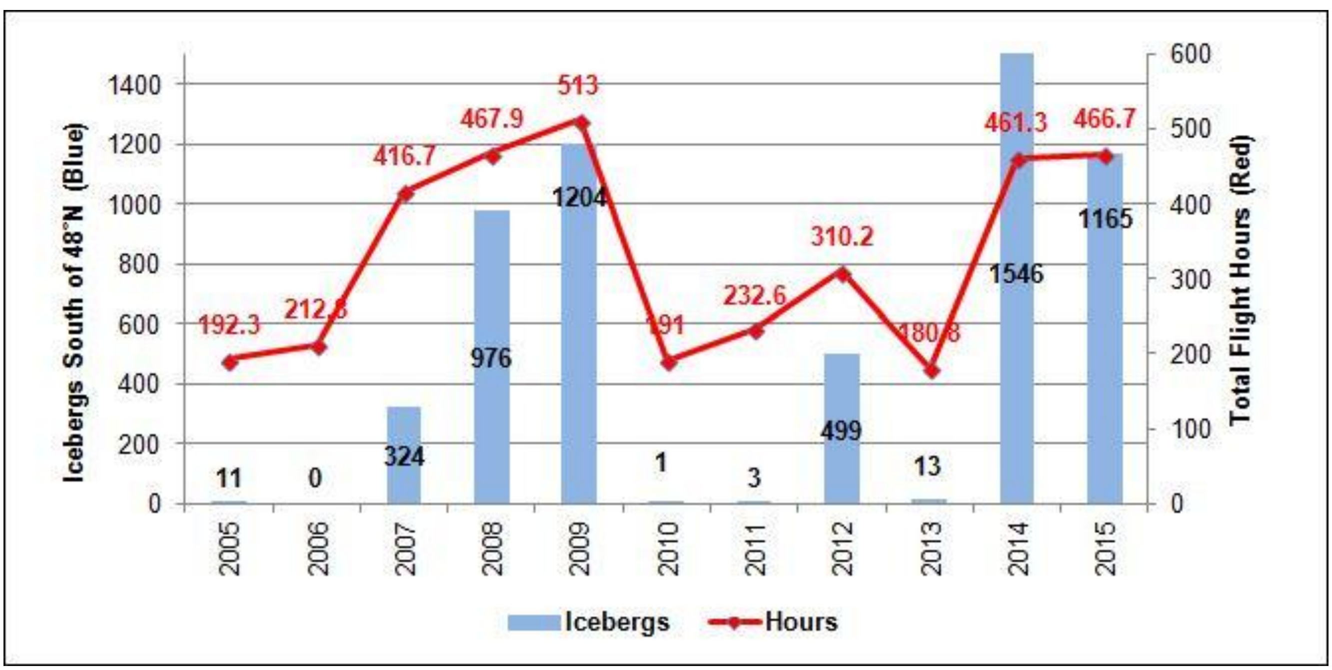


Figure 24. Flight hours versus icebergs south of 48°N (2005-2015).

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 has extended into areas “C”, “D”, and “E,” iceberg reconnaissance flights are focused in these regions as the iceberg distribution dictates and with the frequency indicated. Similar to the 2014 Ice Season, significant expansion occurred to the south and east during 2015, and once again area D was further divided into four quadrants to more clearly show coverage of the expansive limit. **Figure 26** shows a one-day snapshot of NAIS reconnaissance coverage from 31 August 2015.

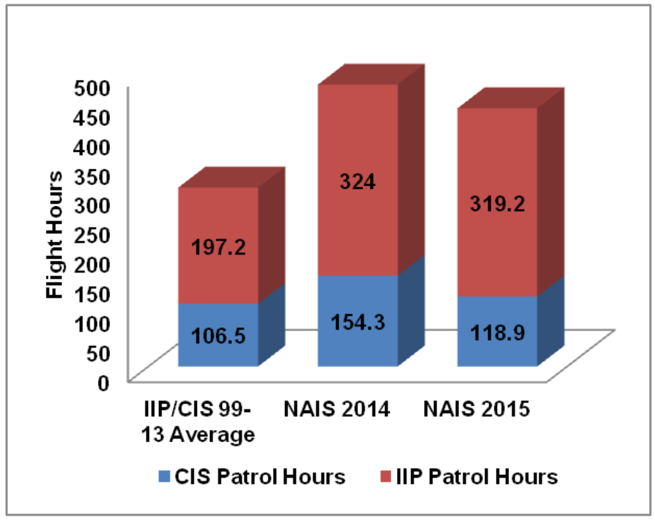


Figure 25. NAIS flight hours (February - August 2015).

Oceanographic Operations

IIP deployed drifting buoys on and near the Grand Banks of Newfoundland in order to collect near real-time ocean current information. The data were used to modify

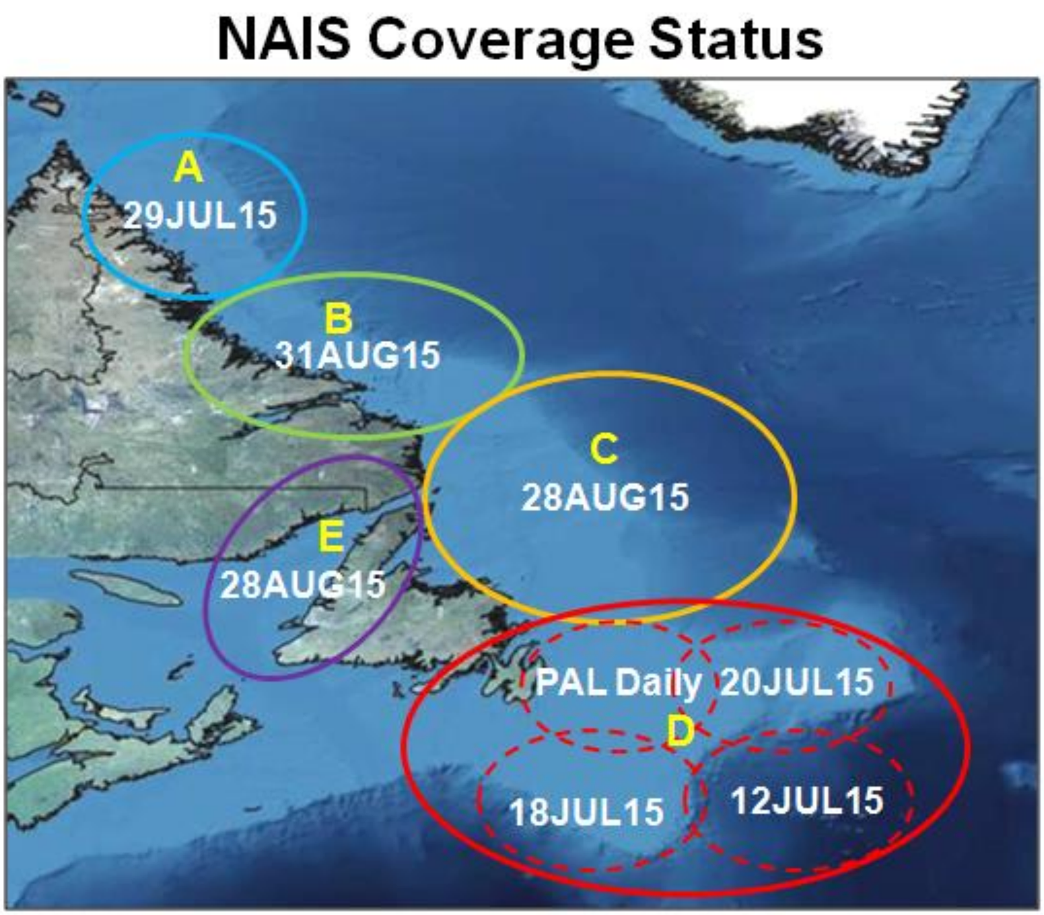


Figure 26. NAIS Coverage Status on 31 August 2015. Each day during the Ice Season, PAL conducted iceberg reconnaissance flights in the vicinity of the Grand Banks in support of the offshore oil and gas industry (Ellipse D). PAL provided these flight results to IIP.

the historical ocean currents database within BAPS and improved the accuracy of the model-calculated drift for each iceberg. The drifting buoys also collected SST information that was incorporated into the SST analysis product developed by the U.S. Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC). BAPS used both the current data and SSTs along with wind and wave data to forecast the drift and deterioration of icebergs.

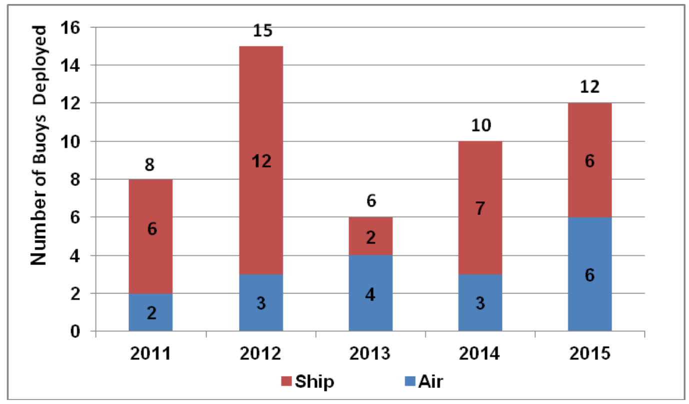


Figure 27. Deployed buoys by year.

IIP used drifting buoys based on the SVP design. The buoys deployed in 2015 were drogued at 15 m and 50 m. The drifters 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. The drifting buoys with the drogue centered at 15 m, the standard SVP drogue depth, were used to measure the currents in the shallower waters on the Grand Banks and in the inshore branch of the Labrador Current.

IIP used reconnaissance aircraft and 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. Ship deployments were conducted on or near the Grand Banks through a cooperative arrangement with CCG ships operating out of St. John's, NL. Air deployments were conducted offshore in regions outside of the normal range of the CCG ships.

In 2015, IIP coordinated the deployment of 12 SVP drifting buoys (**Figure 27**). Six 50 m buoys were air-deployed from USCG HC-130J aircraft, and six buoys (two 50 m and four 15 m) were deployed from CCG ships. All were successfully deployed without incident. However, two of the 15 m buoys deployed by CCG ships failed to report their position after deployment. **Figure 28** shows all of the buoy deployment locations and tracks for the 2015 season. The green stars represent the deployment location for each buoy.

As discussed in the 2014 Annual Report, IIP historically used an aerial deployment package that required pyrotechnic cutters to release the buoy from the packaging after it was deployed from the aircraft. Due to a pyrotechnic cutter supply shortage, IIP was required to develop an alternative deployment mechanism for the 2015 season. Collaboration between IIP, ASEC, and the USCG's Aviation Logistics Center (ALC) resulted in a new air deployment package using a dissolvable salt tab. This new system proved successful. All six air deployment packages performed flawlessly with a 100% success of the mechanism releasing once it made contact with the water.

In 2015, IIP also prototyped the use of SVP buoys using a new tracking system. Traditionally, IIP deployed buoys tracked by the Argos satellite system. In 2015, IIP deployed three Iridium buoys purchased by the USCG Office of Search and Rescue. These buoys are tracked by the Iridium satellite constellation. Both styles of buoys are deployed in the same manner. IIP found the Iridium buoys provided more frequent and more accurate position reports, ultimately improving the quality of the buoy's current data. Given the comparable costs for both systems, IIP determined SVP buoys tracked using the Iridium system are preferred for the IIP Drifting Buoy Program.

Commemorative Wreath Drops

Each year, IIP drops commemorative wreaths in conjunction with reconnaissance operations to remember the lives lost at sea in the North Atlantic Ocean. This year, IIP held a wreath dedication ceremony on 15 April 2015 to commemorate the 103rd anniversary of the sinking of the RMS TITANIC. The dedicated wreath was deployed from an HC-130J aircraft on 19 April 2015.

On 05 June 2015, IIP held a memorial ceremony at the USCG Academy in New London, CT commemorating the sacrifices of those serving as part of the Greenland Patrol during World War II. The wreath dedicated at the memorial service was deployed in the North Atlantic from an HC-130J aircraft on 18 June 2015.

2015 Satellite Reconnaissance

IIP expanded its use of satellite reconnaissance in 2015. As a result of meetings with CIS, NIC, NGA, and the Geospatial Intelligence (GEOINT) Branch of the USCG Intelligence Coordination Center (ICC) in December 2014, IIP developed a

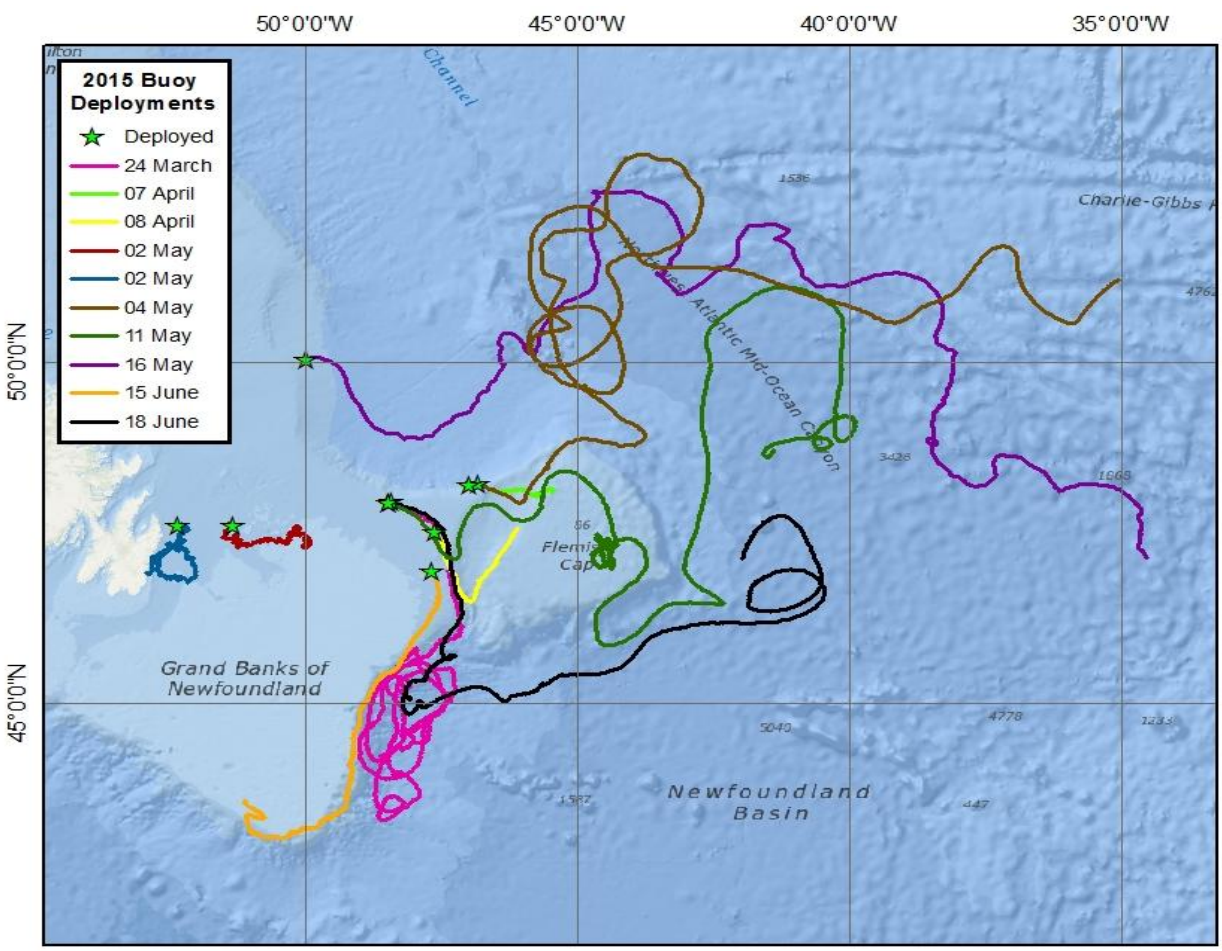


Figure 28. Composite buoy tracks.

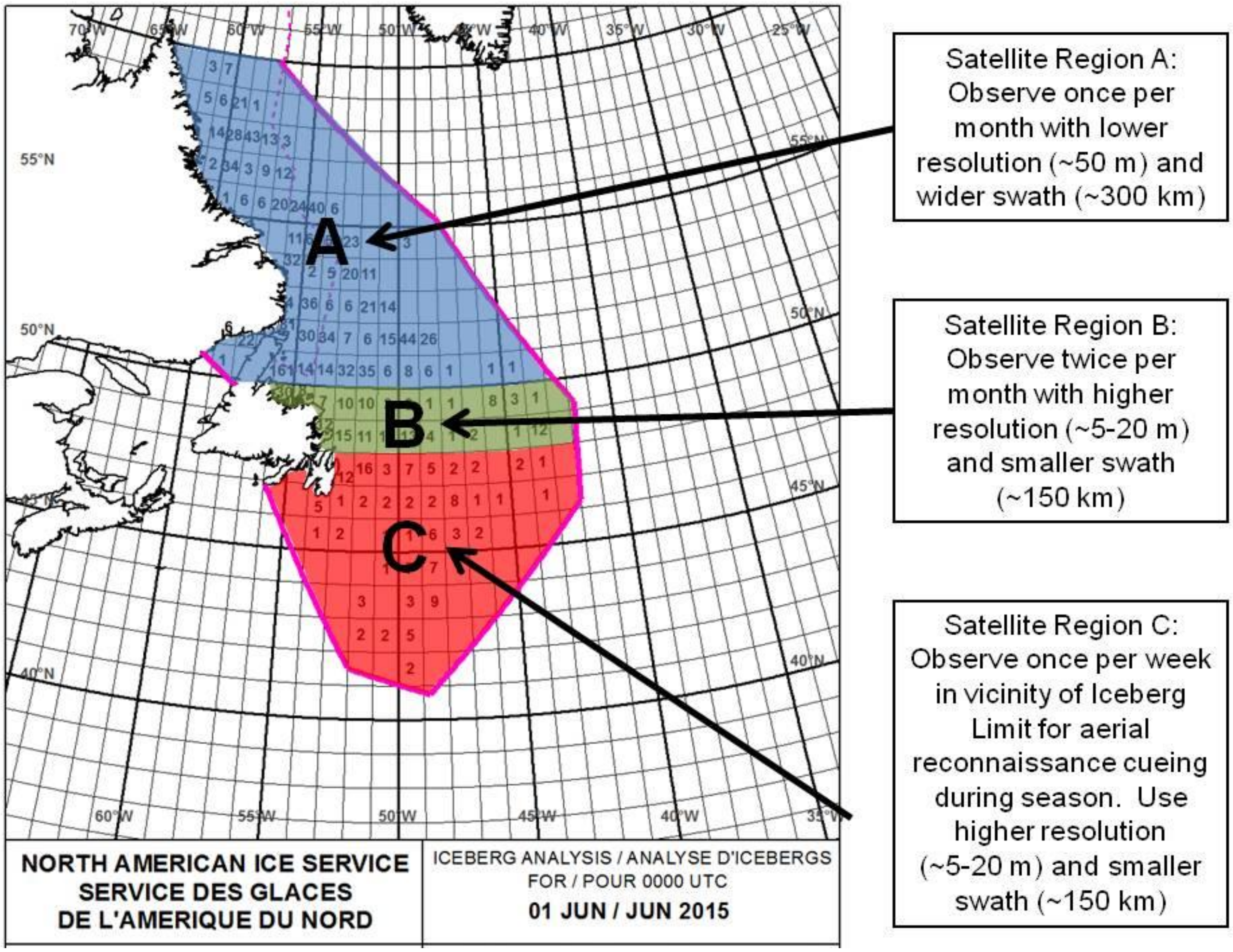


Figure 29. IIP Satellite Reconnaissance Strategy.

two-pronged satellite collection strategy, geographically based on the location of the transatlantic shipping lanes. To illustrate this strategy, **Figure 29** depicts three satellite regions overlaid on the NAIS Iceberg Chart for 01 June 2015. For each region, defined by its proximity to the transatlantic shipping lanes, guidelines for collection frequencies and general mode selection criteria are described below and presented in **Figure 29**.

The first part of IIP's strategy focused on the region of the IIP OPAREA north of 50°N (Satellite Region A in **Figure 29**). Satellite data collected in this area were intended to be used to augment the IIP database. 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. 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 4**.

The second part of IIP's satellite strategy focused on the OPAREA south of

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 4. Preferred Commercial Satellite Modes for iceberg detection in Satellite Region A (north of 50°N).

50°N where icebergs pose a greater hazard to transatlantic shipping (Regions B and C in **Figure 29**). Region B in **Figure 29** (between 48°N and 50°N) requires higher resolution images as specified in **Table 5**. Region B was separately identified from Region C because IIP intended to use this area to conduct concurrent aerial observations by IIP for continued satellite validation efforts. This area was selected due to its proximity to IIP's base of operations in St. John's, Newfoundland and associated ease of coordination.

Satellite Region C (south of 48°N) carries the highest risk of iceberg collision with transatlantic vessels and requires HC130-J aerial reconnaissance for primary detection. To support IIP's aerial reconnaissance, IIP planned to use satellite data to help determine areas of interest for flight planning. Satellite data detected in Region C would not be incorporated into the IIP database without other corroborating evidence as to the targets identity. Data for Region C would need to be the same quality as Region B as shown in **Table 5**.

The satellite imagery for regions A and B was intended to be procured through NIC from the Canadian RADARSAT-2 satellite under the Northern View program. Northern View is an arrangement between NGA and DND to share RADARSAT-2 imagery between the U.S. and Canada. This unique arrangement allows NIC to order imagery directly from MacDonald, Dettwiler and Associates Ltd. (MDA), the RADARSAT-2 provider. NIC obtained an additional imagery allocation under Northern View, specifically for IIP support in 2015. This support for IIP will be available through March, 2016.

Satellite	Preferred Acquisition Mode	Resolution	Scene size	Polarization	Incidence Angle
RADARSAT-2	Wide Fine	8 m	150 km x 170 km	Dual	> 35°
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 5. Preferred Commercial Satellite Modes for iceberg detection in Satellite Regions B and C (south of 50°N).

Imagery for Satellite Region C was to be requested through the same process or, if unavailable, provided from other commercial providers (COSMO-SkyMed, TerraSAR-X, etc.) and/or National Technical Means (NTM) to IIP by USCG ICC GEOINT.

IIP's selection process for satellite image collection is detailed in **Figure 30**. The blue boxes labeled A-H in the Northern region of the map represent standing collection requests for the 2015 Ice Season conducted on a routine schedule. IIP planned to include any icebergs detected in these collections in Iceberg Limit warning products in an effort to reduce the need for aerial reconnaissance in the far north of IIP's operational area. The purple ellipses labeled I-XVII represent selectable regions that IIP designated for collection on a weekly basis. Each Monday, IIP designated 2-3 ellipses for collection the following week based upon the current position of observed icebergs, the sea ice limit, and recent aerial reconnaissance. These designations were forwarded to NIC (for RADARSAT-2 image requests) and to USCG ICC GEOINT for other commercial provider and NTM requests. IIP planned to use these observations to cue aerial reconnaissance in order to make the most efficient use of available flight hours.

At the start of the 2015 Ice Season, IIP began submitting weekly imagery requests. However, due to high demand for RADARSAT-2 imagery from competing demands in this region from other users, IIP's requests were routinely overridden in favor of requests from home-country agencies (i.e. CIS, Canadian DND). Further, in 2015, there

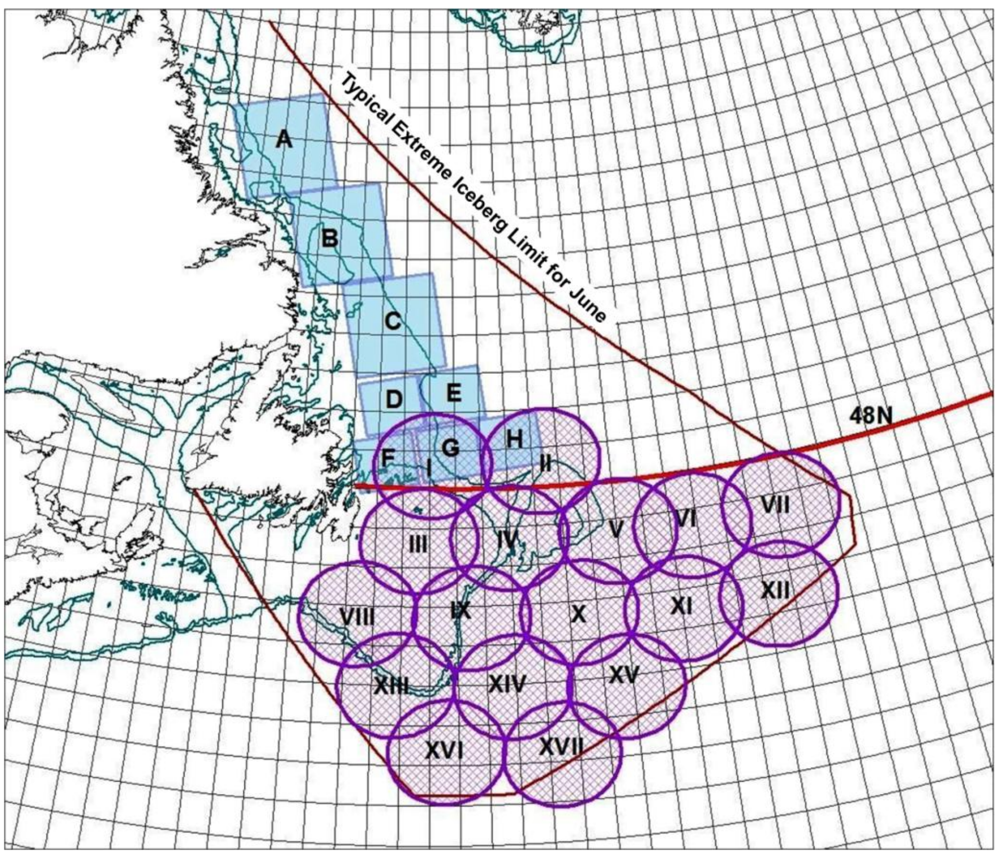


Figure 30. IIP regular collection boxes and weekly selection ellipses.

was no agreement for USCG ICC GEOINT to procure alternate commercial SAR imagery sources (TerraSAR-X, COSMO-SkyMed). An avenue to request and collect imagery must be made available for IIP to be able to use satellite imagery on a routine and reliable basis.

During the 2015 season, IIP did not have the internal staff nor an automated detection capability to analyze satellite imagery and detect icebergs. The intent was for the satellite imagery to be analyzed by one of IIP's partners (C-CORE, NIC, CIS) depending upon its source. In addition to ordering images, NIC offered to assign an analyst to manually analyze SAR imagery for possible iceberg target detection and to evaluate an in-house automated target detection algorithm. The algorithm is still being tuned for optimal iceberg detection and has yet to be used operationally. To date, IIP images have only been analyzed manually by NIC personnel, resulting in delayed delivery time and extending the latent period beyond operational usefulness.

Satellite Reconnaissance Results

During the 2015 season, NIC collected RADARSAT-2 imagery on 32 separate dates in support of IIP operations. Unfortunately, most of these images were either collected in locations outside of IIP's requested regions, or at lower resolution modes that were more useful to the Canadian Government agencies and not conducive to iceberg detections. **Figure 31** illustrates this problem by showing the images that were collected during the week of 09 March 2015 along with the purple ellipses IIP requested during that timeframe. Conflicts with RADARSAT-2 imagery in IIP's OPAREA will remain a significant obstacle for using this commercial product for routine

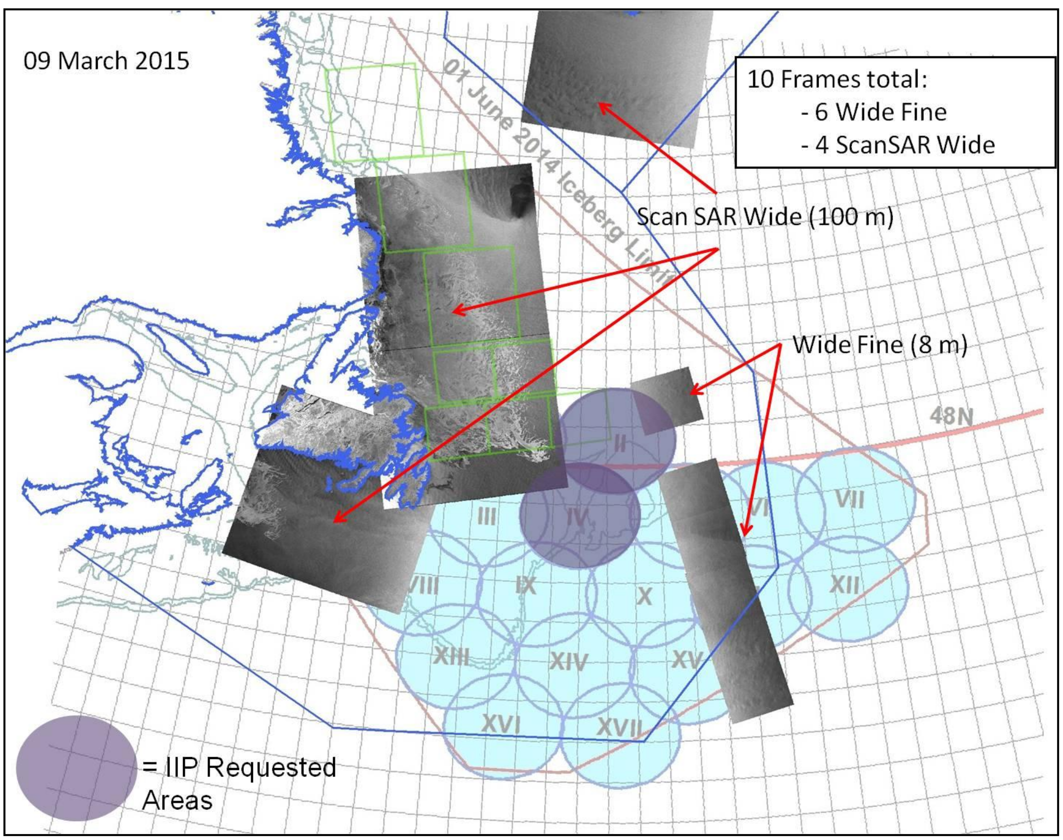


Figure 31. RADARSAT-2 images collected during week of 09 March 2015 provided by NGA and ordered through NIC. Purple ovals show IIP's primary areas of interest based on iceberg activity. IIP requested images in Scan SAR Narrow mode north of 50°N and Wide Fine mode south of 50°N.

iceberg reconnaissance operations. For the 2016 season, IIP intends to submit its desired collections several months in advance in order to gain representation in the Enhanced Marine Ordering Coordination (EMOC) Working Group which works to de-conflict Canadian Government requests for RADARSAT-2 data.

As it became clear consistent RADARSAT-2 data would not be available, IIP began to focus on data from the European Space Agency's (ESA) Sentinel-1a mission. The Sentinel-1a mission maintains a consistent collection schedule available to users several weeks in advance with actual imagery available online in near real-time. IIP collaborated through DMI to request that ESA extend the Sentinel-1a coverage south over the Grand Banks in its regular collection schedule in the Interferometric Wide Swath mode (20 m resolution, 250 km scene size). In June and July, IIP conducted four under-flights of Sentinel-1a passes. In addition, IIP coordinated with C-CORE to analyze two Sentinel-1a scenes for operational use and integration into BAPS. Finally, IIP requested C-CORE analysis to compare seven Sentinel-1a images with coincident RADARSAT-2 imagery, collected through NIC, in August. IIP is currently conducting comparative analysis for all Sentinel-1a images. While Sentinel-1a imagery shows great potential for IIP, it requires continued evaluation to determine its accuracy and reliability.   IIP will continue to evaluate Sentinel-1a during the 2016 season. Appendix B provides additional details on the advantages of using Sentinel-1a data.

Given the challenges experienced in 2015, it is clear IIP personnel need to be directly involved with ordering, processing, and analyzing satellite imagery. Support from NIC has been much appreciated, but success for IIP rests in the ability of its own staff to carry out the satellite reconnaissance mission.   With the proper training, IIP personnel are best-suited to determine locations for imagery collection in order to make decisions in real-time. Adding satellite imagery ordering and analysis to the IIP skill set must be a priority in the coming years. In June 2015, IIP was approached by C-CORE with an opportunity to acquire a license for its IDS. This capability would allow IIP to ingest and analyze satellite data within its own OPCEN. The intent of the proposal was to provide a joint license to both IIP and CIS under NAIS. While Fiscal Year 2015 funding did not permit the purchase of the software, it remains a priority for IIP in Fiscal Year 2016. IIP will work with its NAIS partners to consider this C-CORE option along with other avenues for gaining the capability to perform in-house satellite image analysis. Appendix B provides additional details on the history of IIP satellite reconnaissance and validation results to date.

References

Canadian Ice Service. (2014a). Seasonal Outlook, Gulf of St. Lawrence, East Newfoundland Waters and Labrador Coast, Winter 2014-2015. Issued by Canadian Ice Service of Environment Canada, 03 December 2014.

Canadian Ice Service. (2014b). Sea Ice and Iceberg Seasonal Outlook 2014-2015. Presented at IIP Annual Conference on 11 December 2014.

Canadian Ice Service. (2015a). Seasonal Summary for Eastern Canada – Winter 2014-2015, Retrieved 07 August 2015 from: http://www.ec.gc.ca/glaces-ice/default.asp?lang=En&n=E4444163-1.

Canadian Ice Service. (2015b). CIS Ice Charts of East Newfoundland Waters. Retrieved 07 October 2015 from: http://iceweb1.cis.ec.gc.ca/Archive/?lang=en.

Canadian Ice Service. (2015c). Departure from Normal Concentration Chart. Retrieved 25 March 2015 and 15 April from: http://www.ec.gc.ca/glaces-ice/default.asp.

Canadian Ice Service. (2015d). Single Season: Weekly Ice Coverage for the season 2014/2015. Retrieved 07 October 2015 from: http://iceweb1.cis.ec.gc.ca/Prod20/page2.xhtml?CanID=11091&lang=en.

Folland, C.K., J.R. Knight, H.W. Linderholm, D.R. Fereday, S. Ineson and J.W. Hurrell. (2009). The Summer North Atlantic Oscillation: Past, Present, and Future, J. Climate, 22, 1082-1103.

Hurrell, J.W., Y. Kushnir, G. Ottersen, and M. Visbeck. (2003). The North Atlantic Oscillation: Climate Significance and Environmental Impact, Geophysical Monograph Series, 134, 279.

Hurrell, James. (1995). NAO Index Data provided by the Climate Analysis Section, NCAR, Boulder, USA, Hurrell. Updated regularly. Retrieved on 07 October 2015 from: https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based.

Hurrell, J.W., M.P. Hoerling, and C.K. Folland. (2001): Climatic variability over the North Atlantic. *Meteorology at the Millenium: 150th Anniversary of the Royal Meteorological Society, Academic Press, London:* 143-151.

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

Johns Hopkins University. (2015). Applied Physics Laboratory Ocean Remote Sensing Group, Water Surface Temperature, Land and Clouds from Channel 2 NOAA-15 AVHRR 01 April, 17 April and 26 May 2015. Retrieved from: http://fermi.jhuapl.edu/avhrr/SW/.

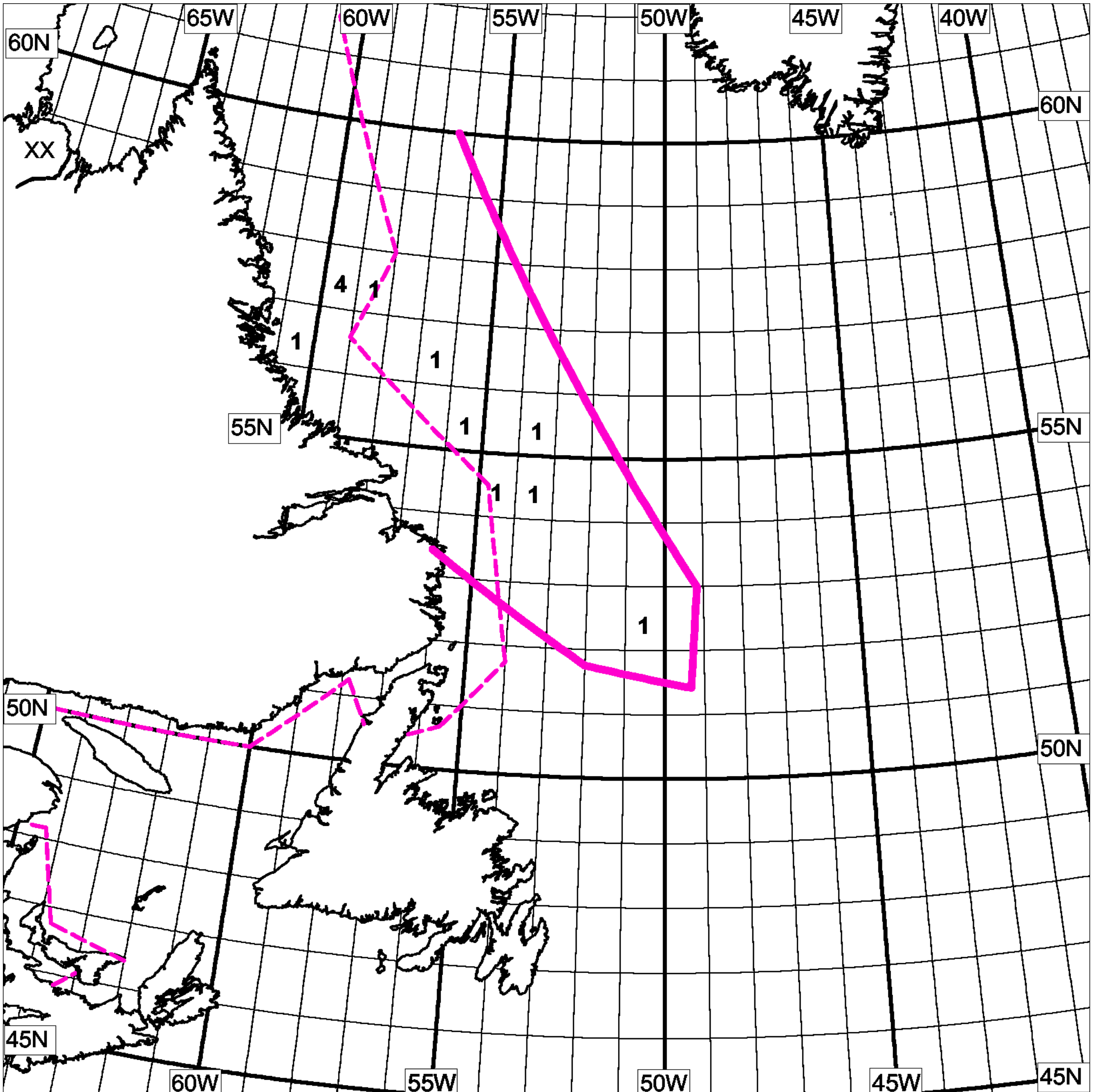
National Oceanic and Atmospheric Administration/National Weather Service. (2015a). National Centers for Environmental Prediction, Climate Prediction Center. Retrieved 03 October 2015 from: http://www.cpc.ncep.noaa.gov/products/global_monitoring/temperature/ecanada_1yrtemp.shtml.

National Oceanic and Atmospheric Administration/National Weather Service (2015b). NOAA Climate Prediction Center, Daily NAO Index. Retrieved 24 September 2015 from: http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao_index.html.

National Oceanic and Atmospheric Administration/National Centers for Environmental Information (2015). 12Z Atlantic Surface Analysis for 25 January 2015. Retrieved on 30 September 2015 from: http://nomads.ncdc.noaa.gov/ncep/charts.

Naval Oceanographic Office (2015). Ocean Features Analysis, Coast Guard North Atlantic Color, 18 May 2015. Retrieved on 20 May 2015 from: https://oceanography.navy.mil/legacy/web/cgi-bin/graphic.pl/metoc/337/19/0-0-5/1.

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 2015

ICEBERG LIMIT / LIMITE DES ICEBERGS

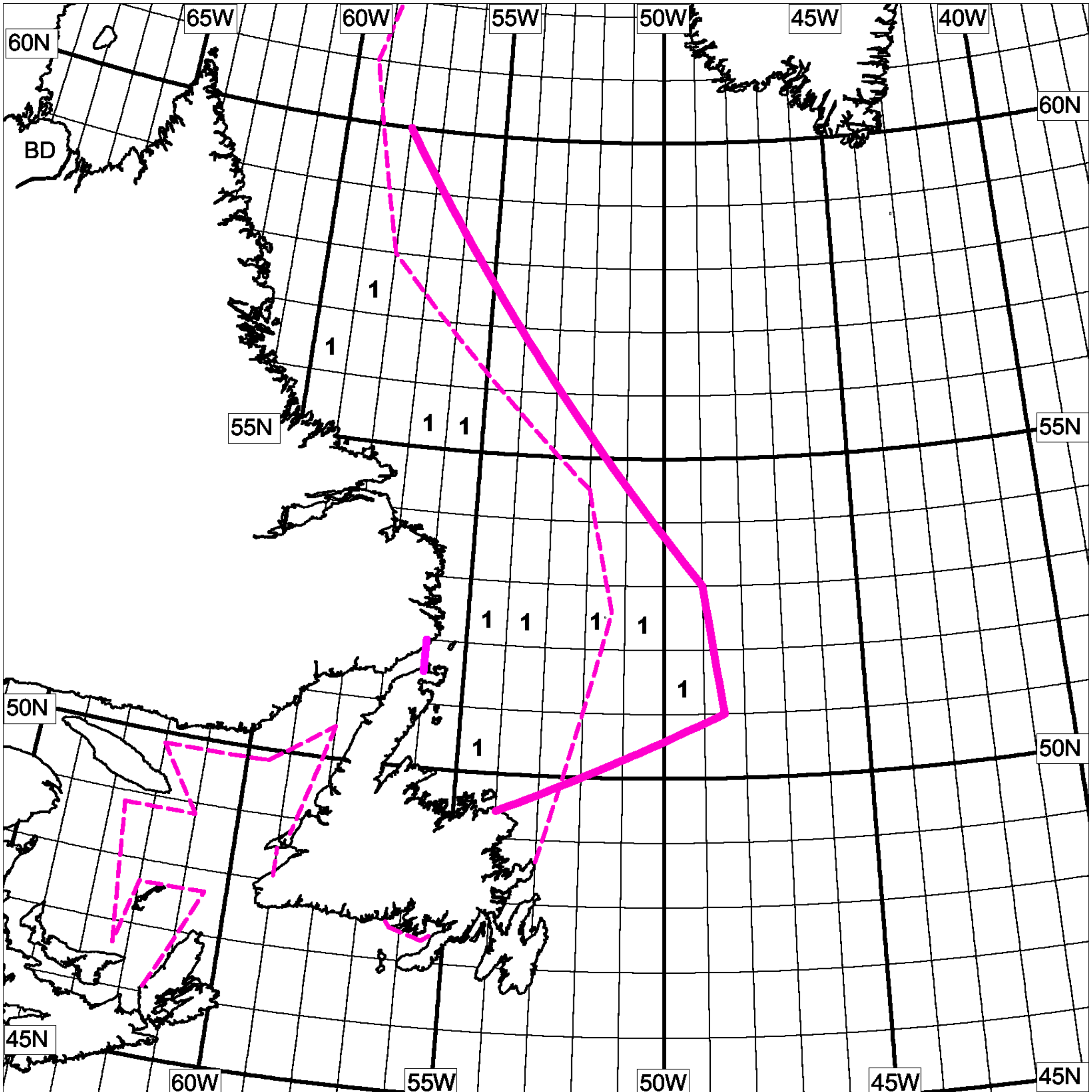
SEA ICE LIMIT / LIMITE DES GLACES

— 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 2015

ICEBERG LIMIT / LIMITE DES ICEBERGS

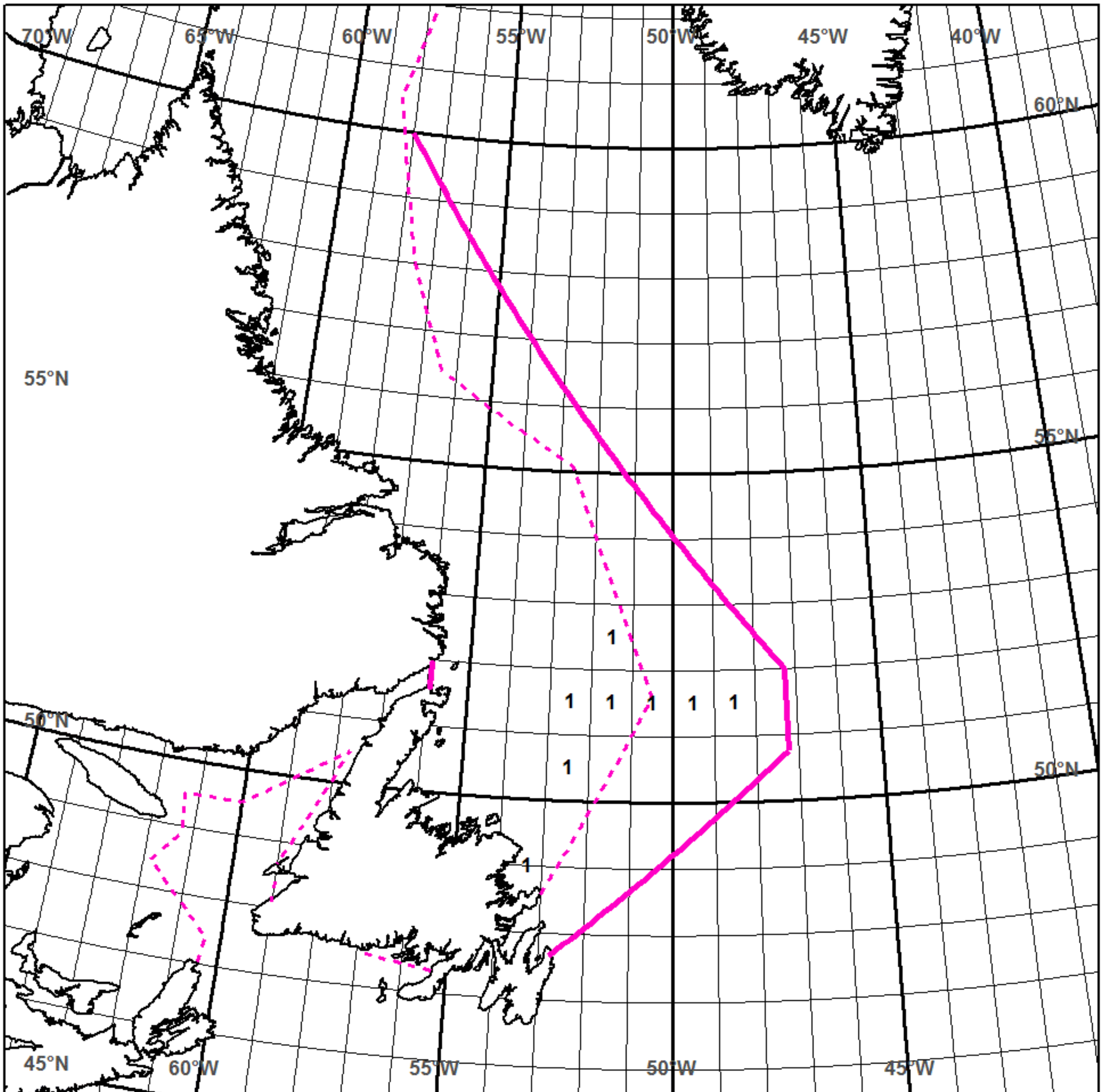
SEA ICE LIMIT / LIMITE DES GLACES

\# 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

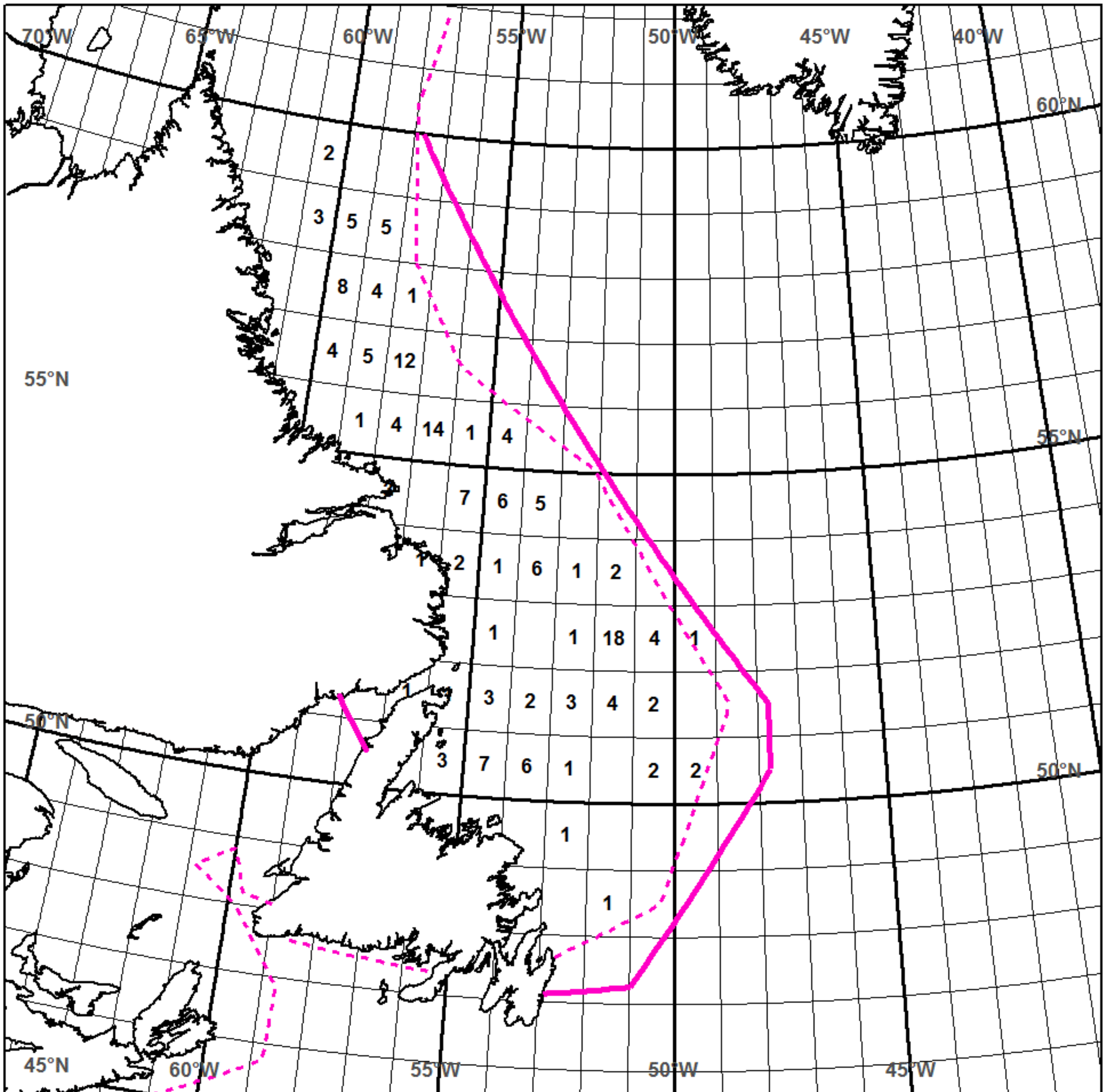
ICEBERG ANALYSIS / ANALYSE D'ICEBERGS
FOR / POUR 0000 UTC

01 FEB / FEV 2015

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 FEB / FEV 2015

ICEBERG LIMIT / LIMITE DES ICEBERGS

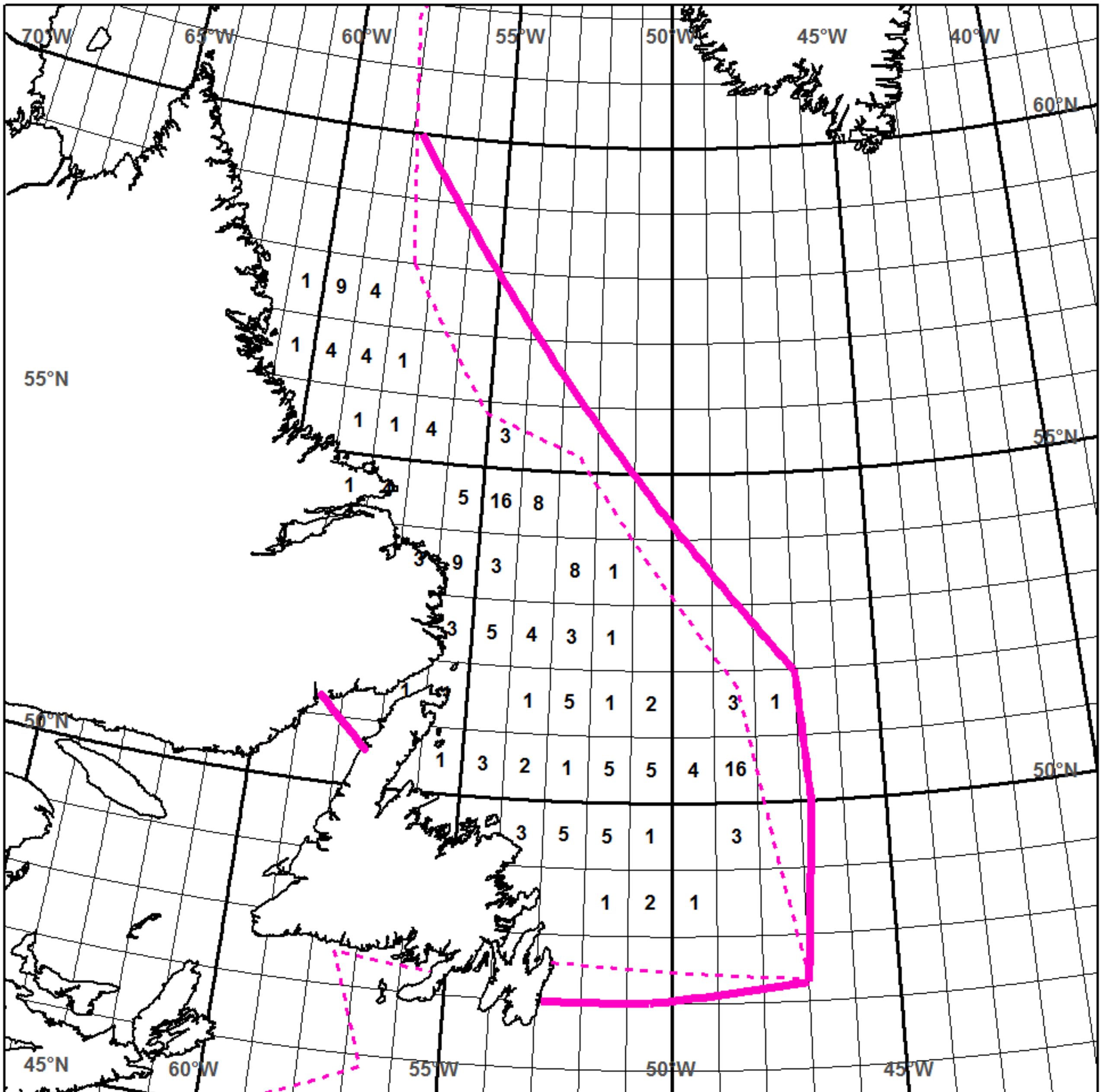
SEA ICE LIMIT / LIMITE DES GLACES

\# 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

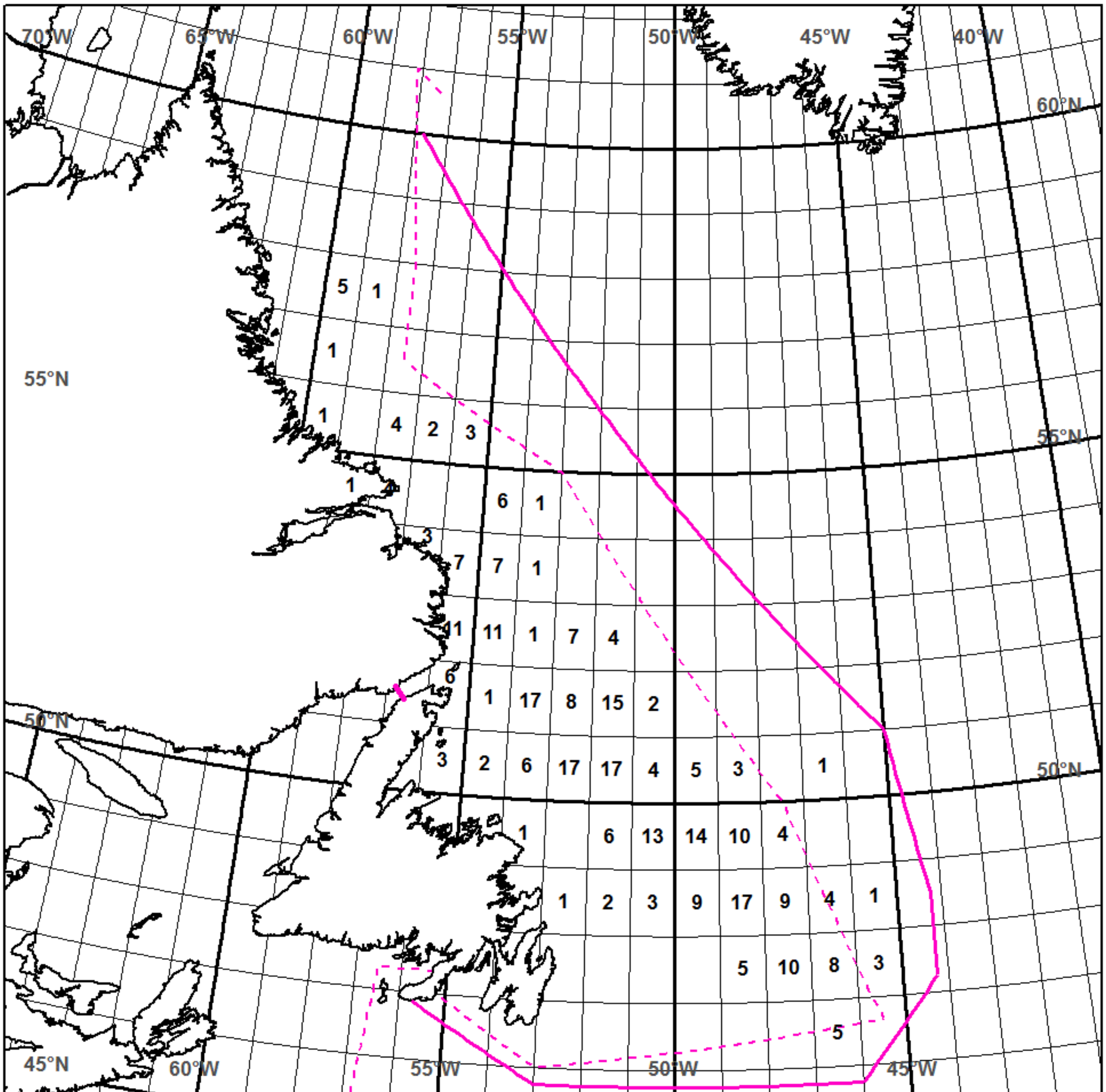
ICEBERG ANALYSIS / ANALYSE D'ICEBERGS
FOR / POUR 0000 UTC

1 MAR / MAR 2015

- 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 MAR / MAR 2015

ICEBERG LIMIT / LIMITE DES ICEBERGS

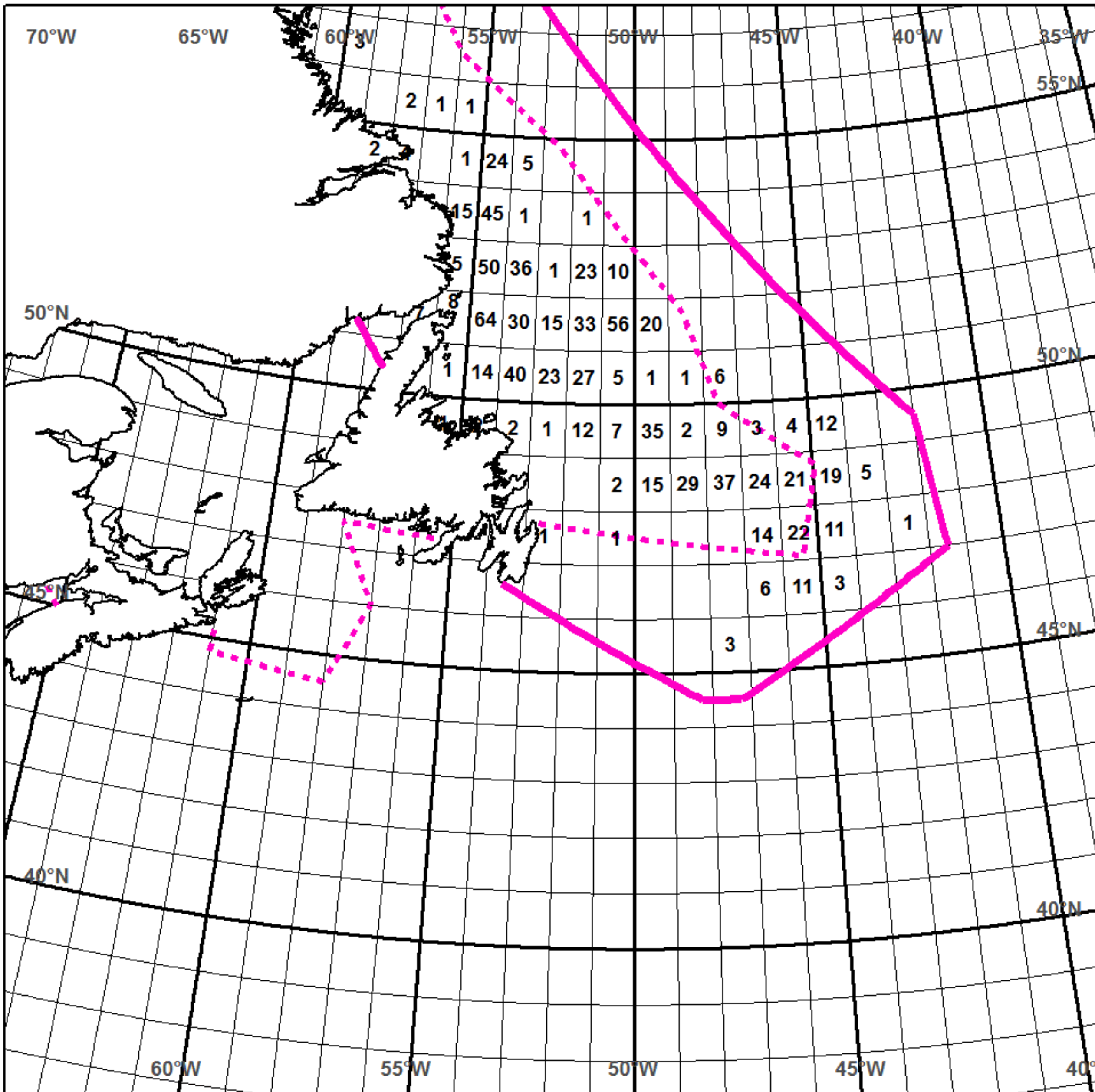
SEA ICE LIMIT / LIMITE DES GLACES

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

01 APR / AVR 2015

ICEBERG LIMIT / LIMITE DES ICEBERGS

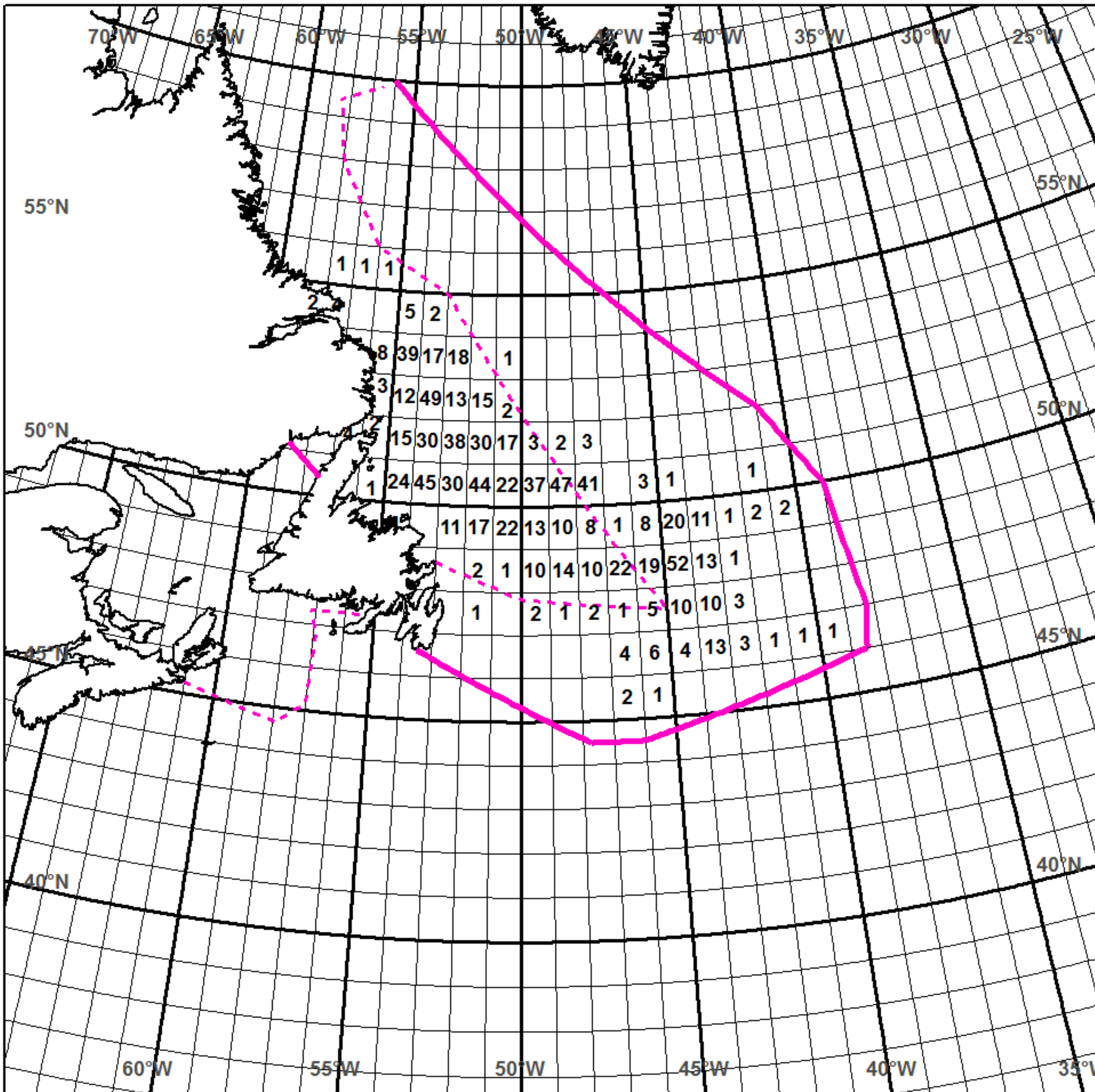
SEA ICE LIMIT / LIMITE DES GLACES

\# 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 APR / AVR 2015**

ICEBERG LIMIT / LIMITE DES ICEBERGS

SEA ICE LIMIT / LIMITE DES GLACES

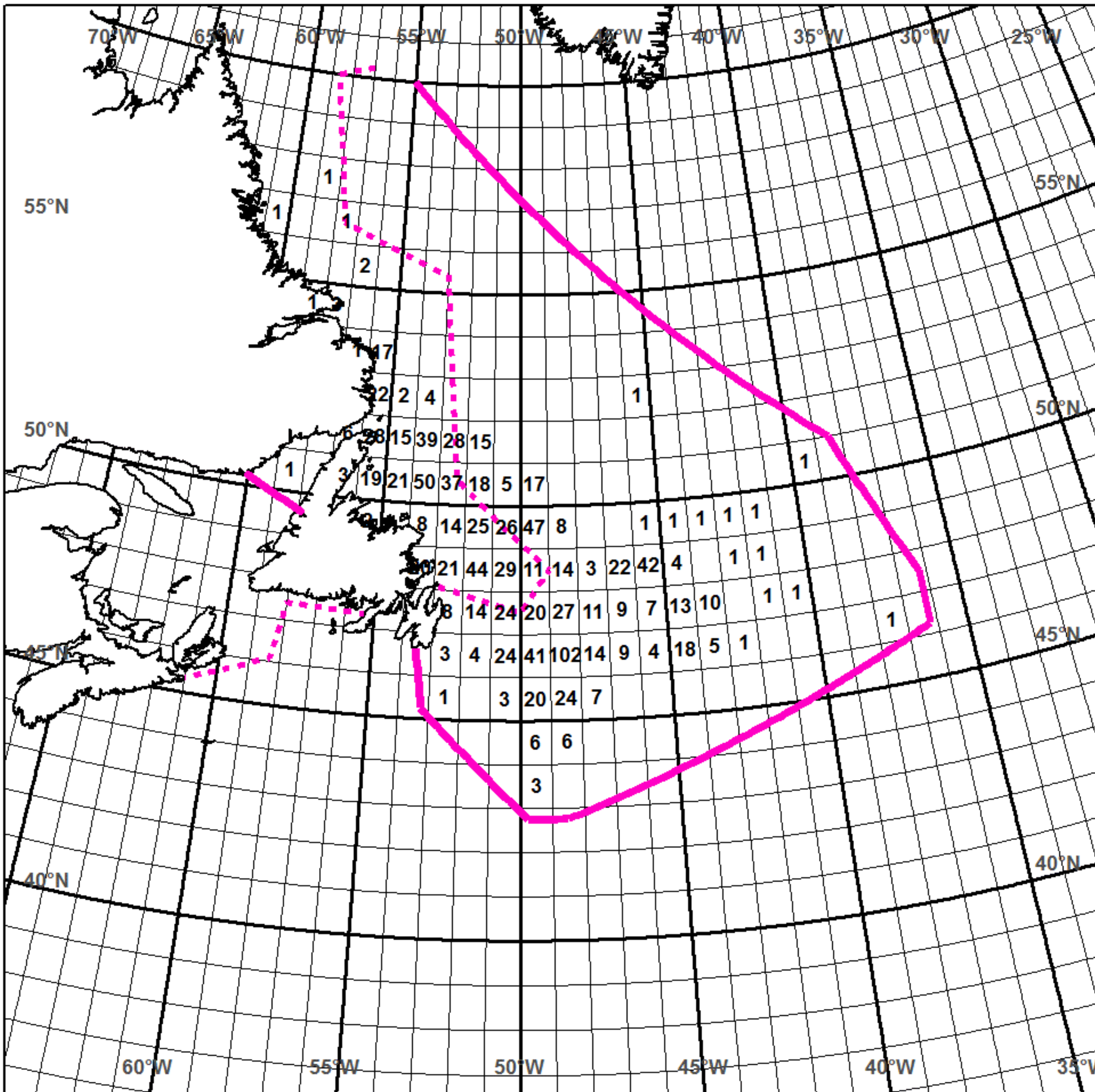
\# ICEBERGS PER DEGREE SQUARE
ICEBERGS PAR DEGRE CARRE

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

NOTE / NOTER:

Today we commemorate the 103rd anniversary of the sinking of the RMS Titanic.

Aujourd'hui souligne le 103ème anniversaire du naufrage du RMS Titanic.



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

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

01 MAY / MAI 2015

ICEBERG LIMIT / LIMITE DES ICEBERGS

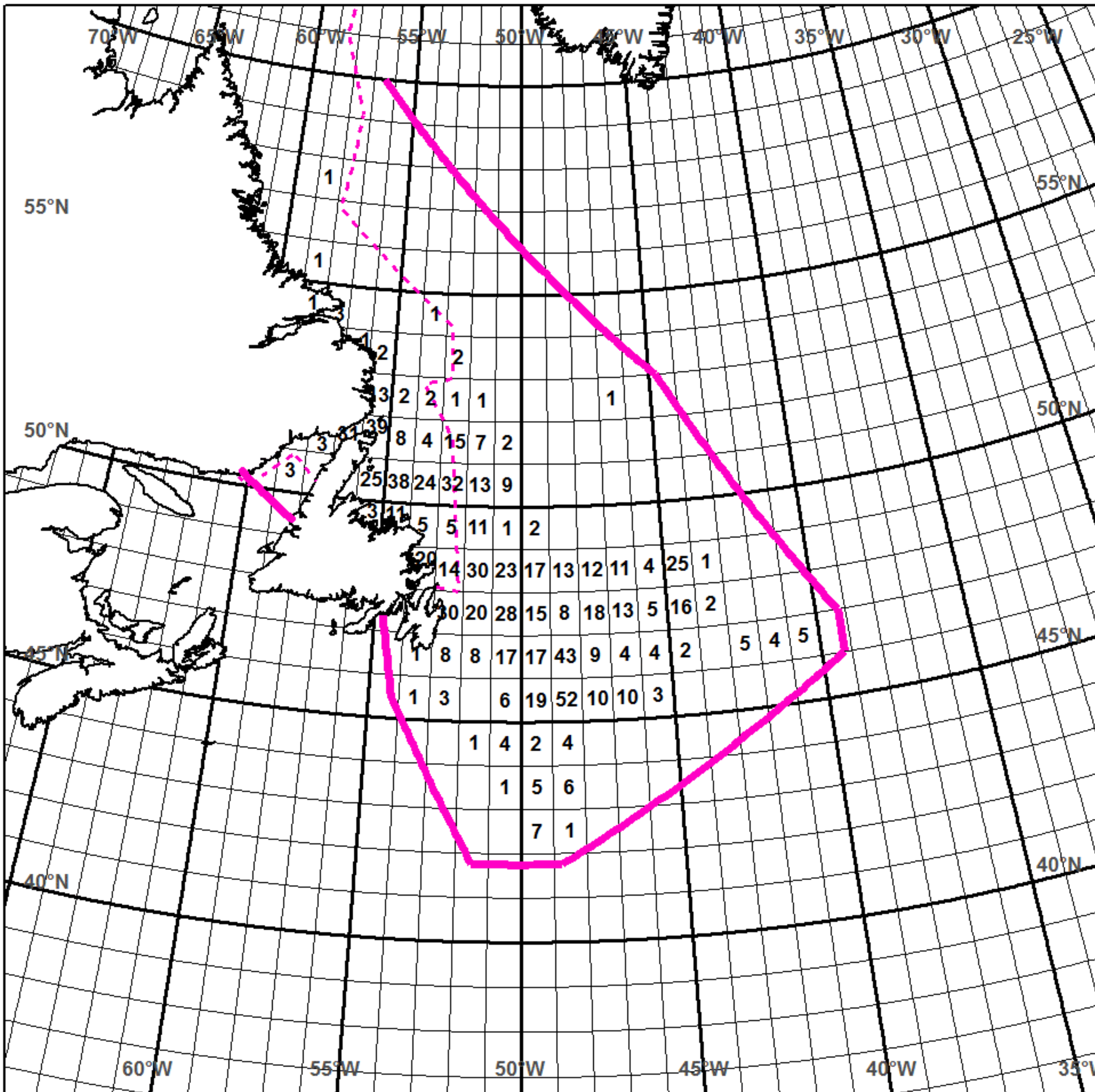
SEA ICE LIMIT / LIMITE DES GLACES

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 MAY / MAI 2015

ICEBERG LIMIT / LIMITE DES ICEBERGS

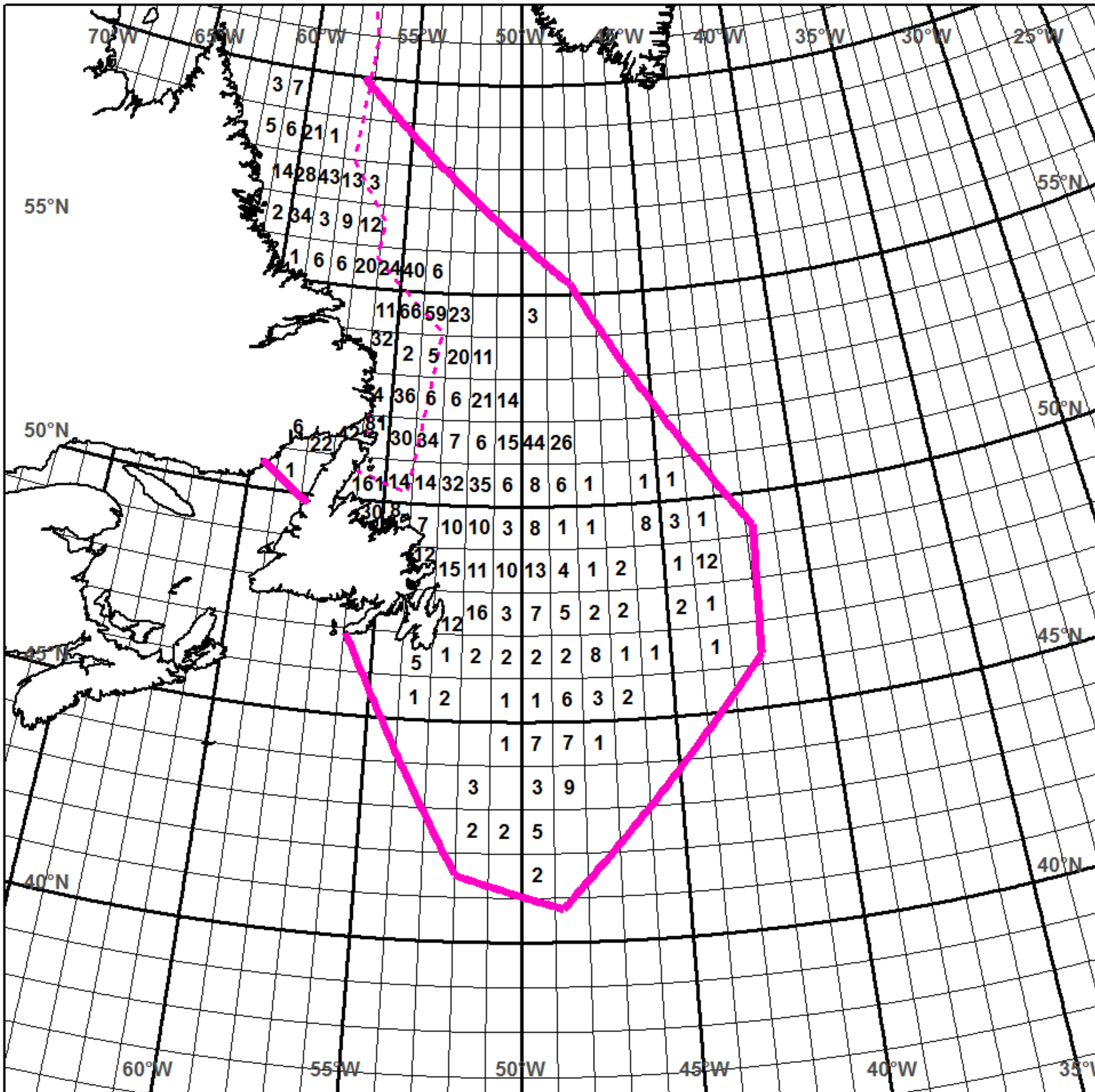
SEA ICE LIMIT / LIMITE DES GLACES

\# 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

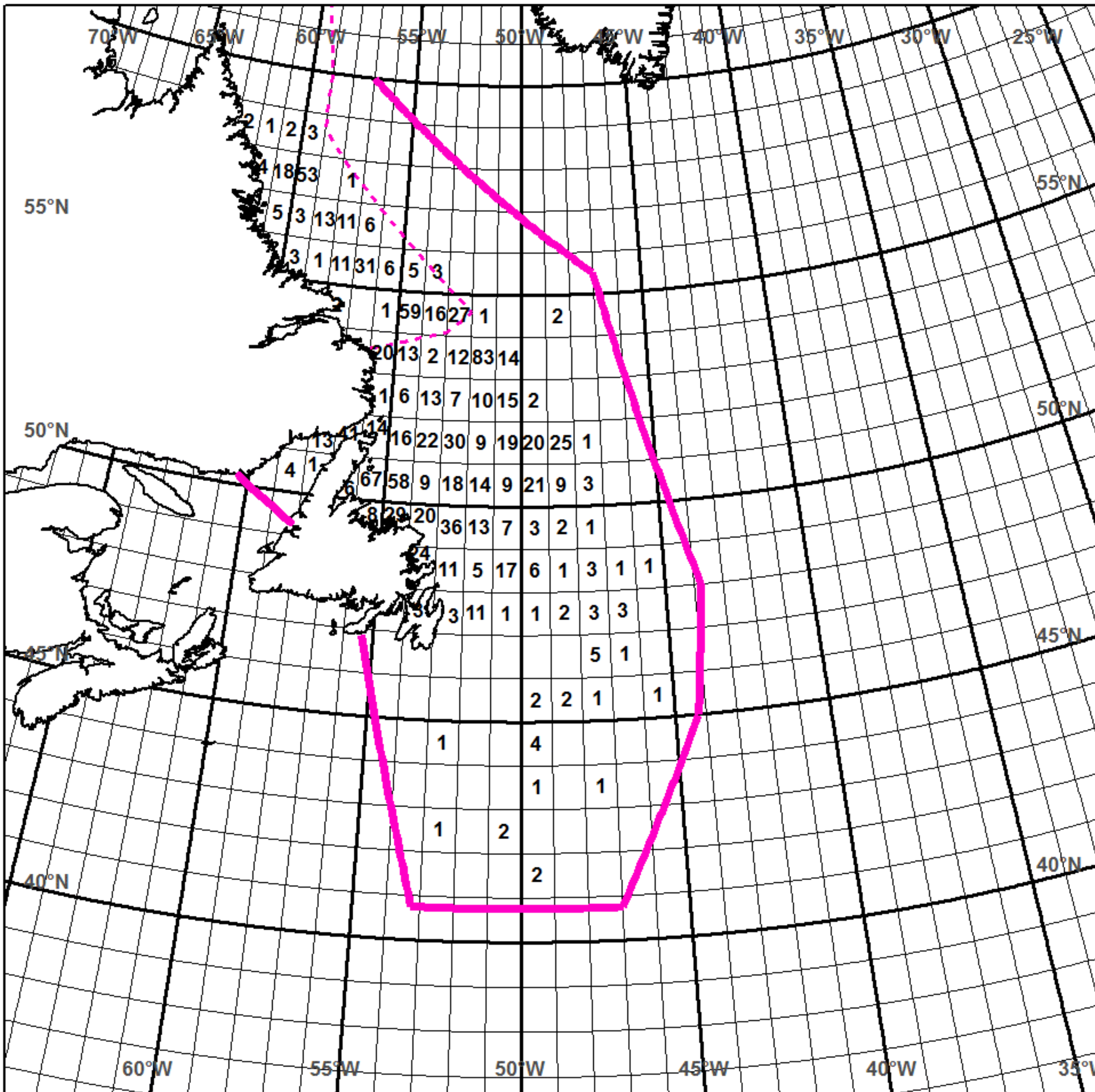
01 JUN / JUN 2015

(solid line)	ICEBERG LIMIT / LIMITE DES ICEBERGS
(dashed line)	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:

Significant reduction of iceberg limit.

Rèduction signiticative de la limite des icebergs.



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

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

15 JUN / JUN 2015

ICEBERG LIMIT / LIMITE DES ICEBERGS

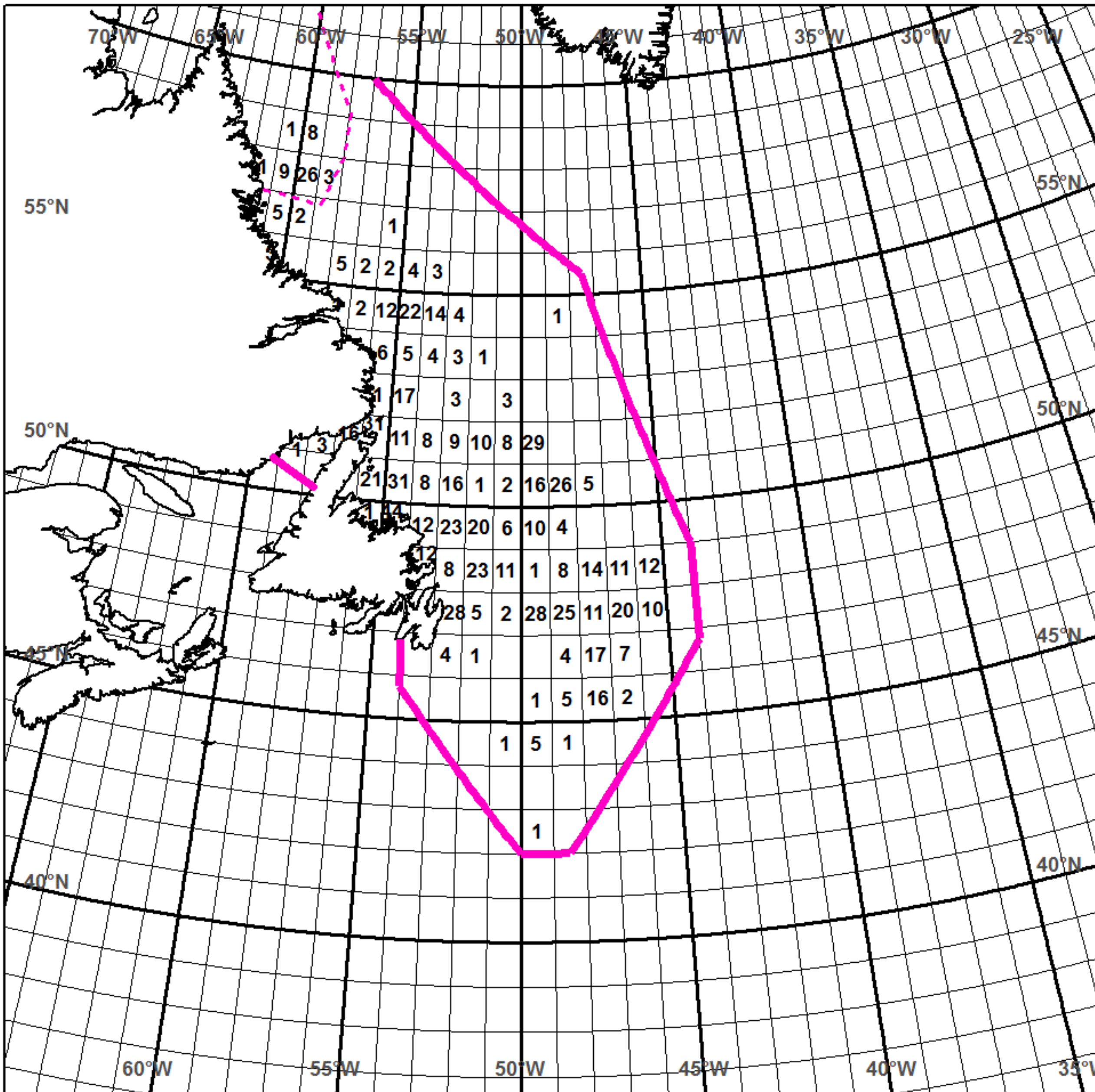
SEA ICE LIMIT / LIMITE DES GLACES

\# ICEBERGS PER DEGREE SQUARE
ICEBERGS PAR DEGRE CARRE

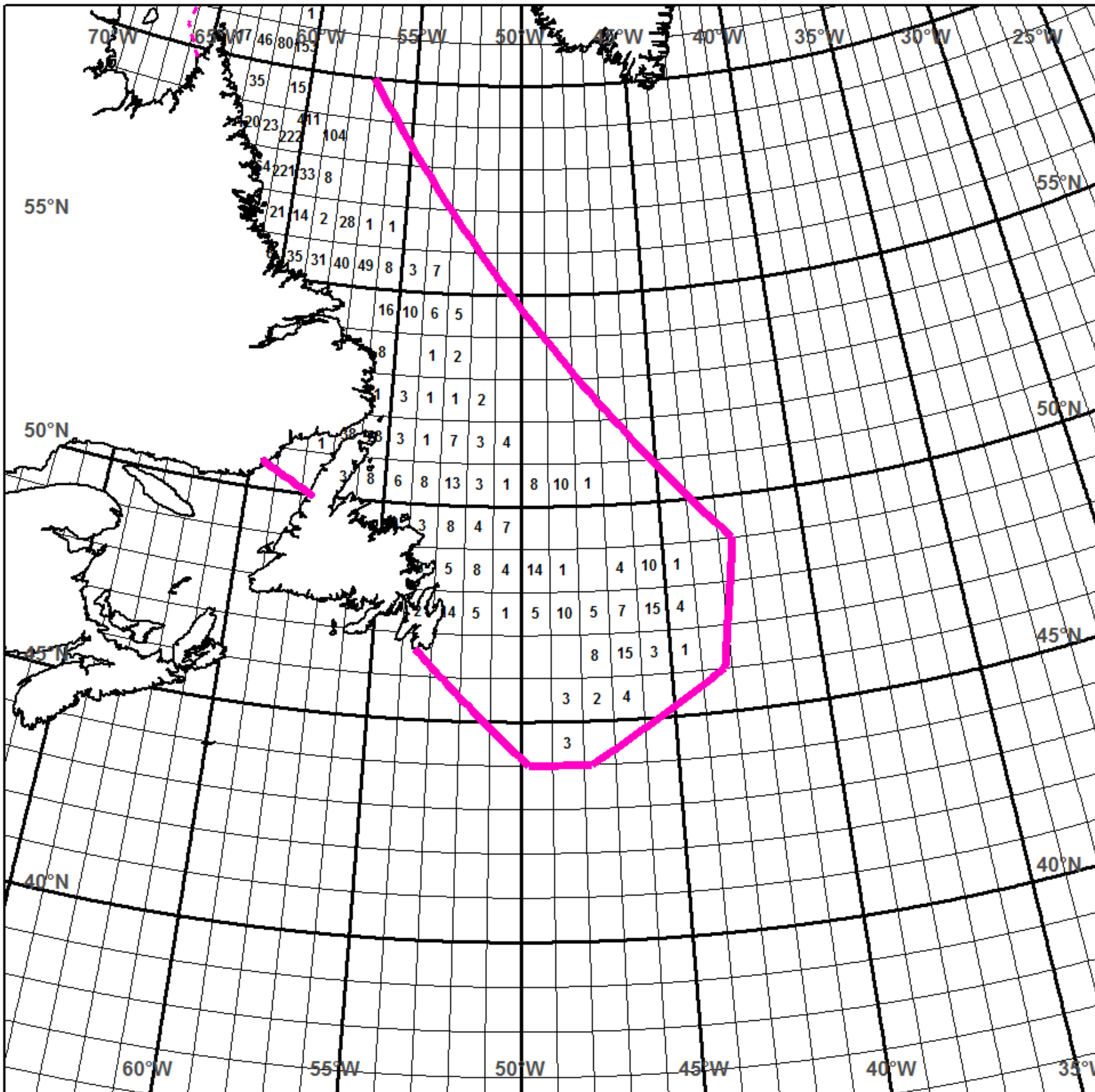
⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT
CIBLE RADAR A L'EXTERIEUR DE LA
LIMITE DES ICEBERGS

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 **01 JUL / JUI 2015**
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 JUL / JUI 2015

ICEBERG LIMIT / LIMITE DES ICEBERGS

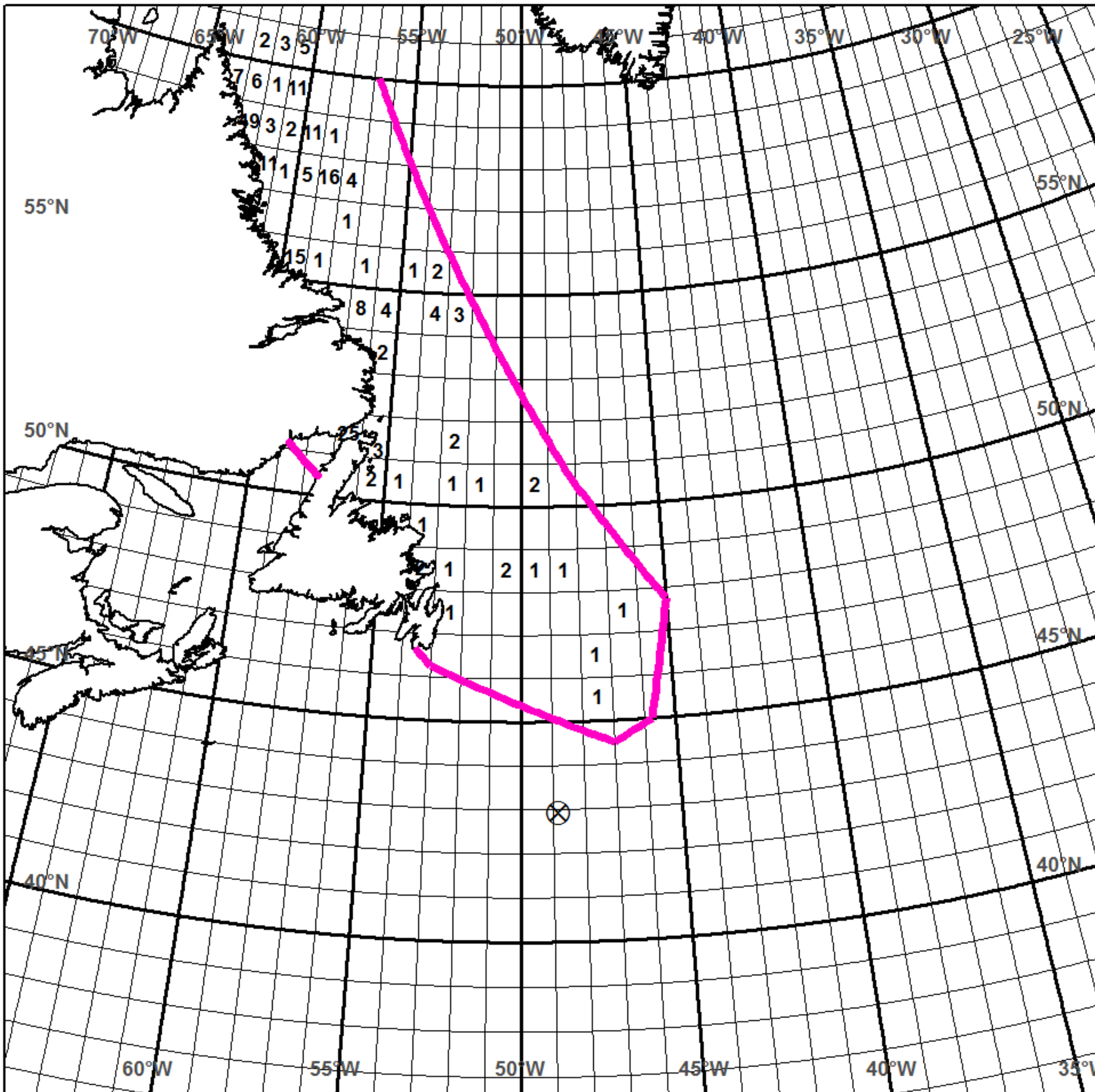
SEA ICE LIMIT / LIMITE DES GLACES

ICEBERGS PER DEGREE SQUARE
ICEBERGS PAR DEGRE CARRE

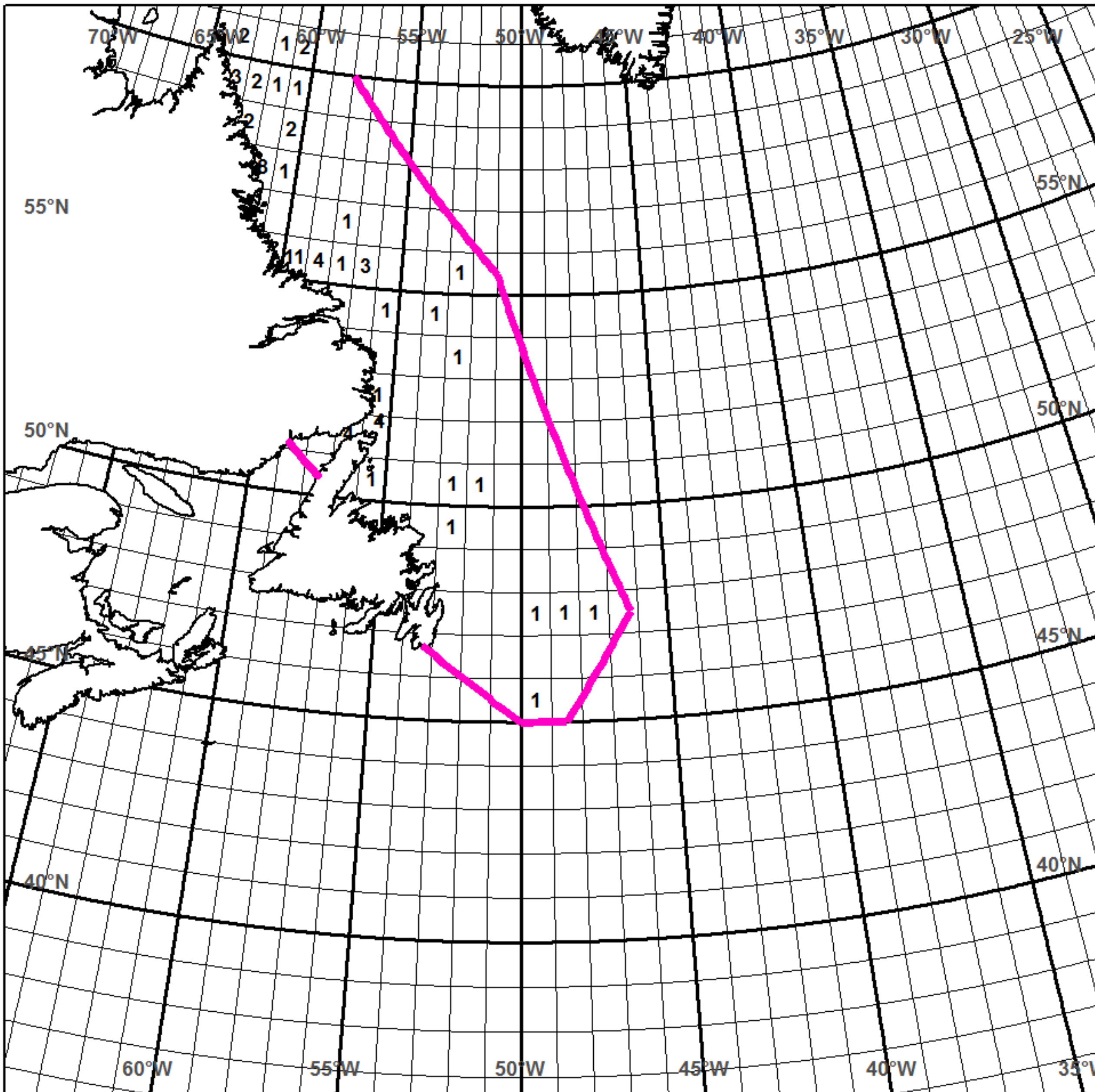
⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT
CIBLE RADAR A L'EXTERIEUR DE LA
LIMITE DES ICEBERGS

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 **01 AUG / AOU 2015**
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 AUG / AOU 2015

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:

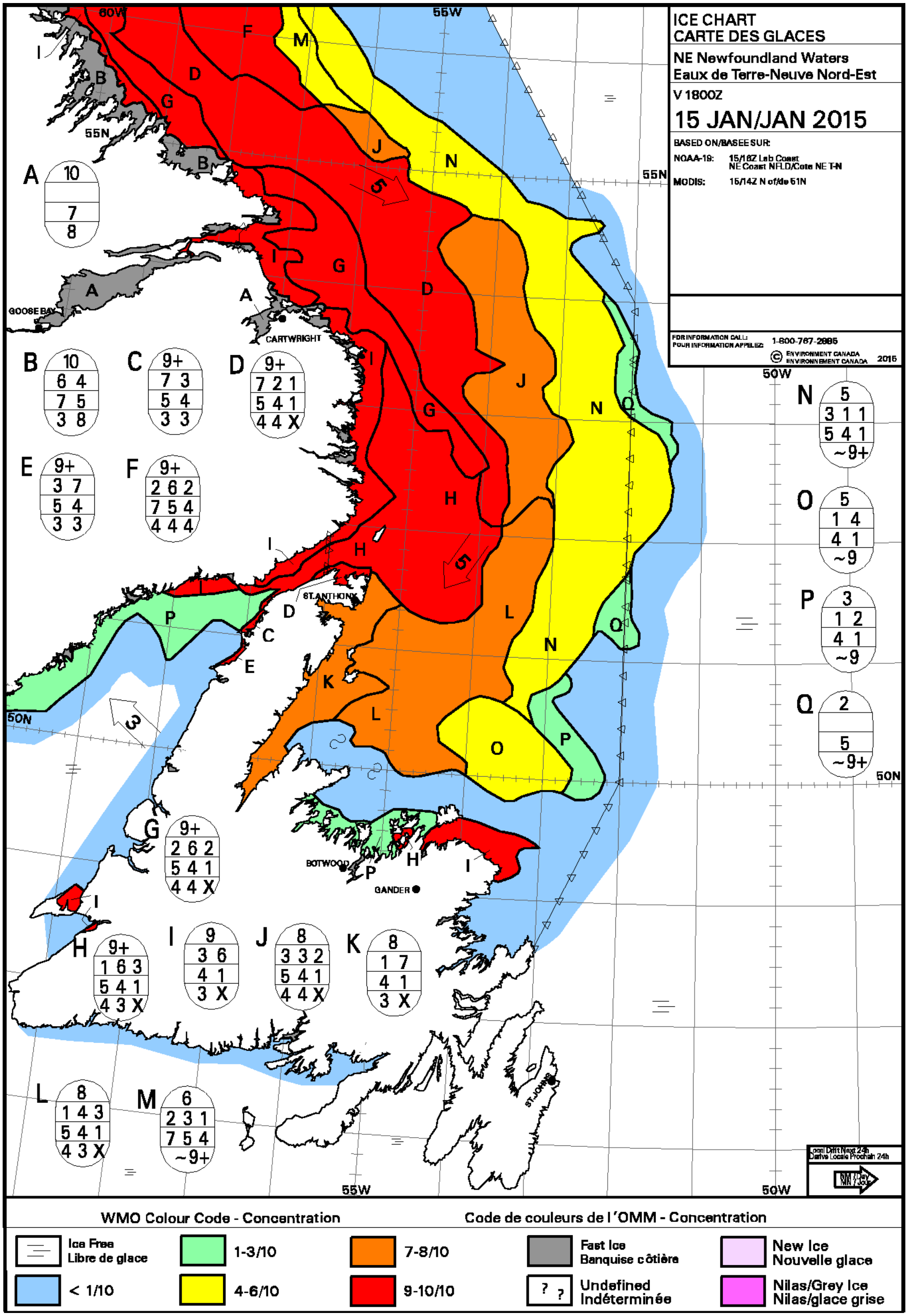
Significant reduction of iceberg limit.

Rèduction signiticative de la limite des icebergs.

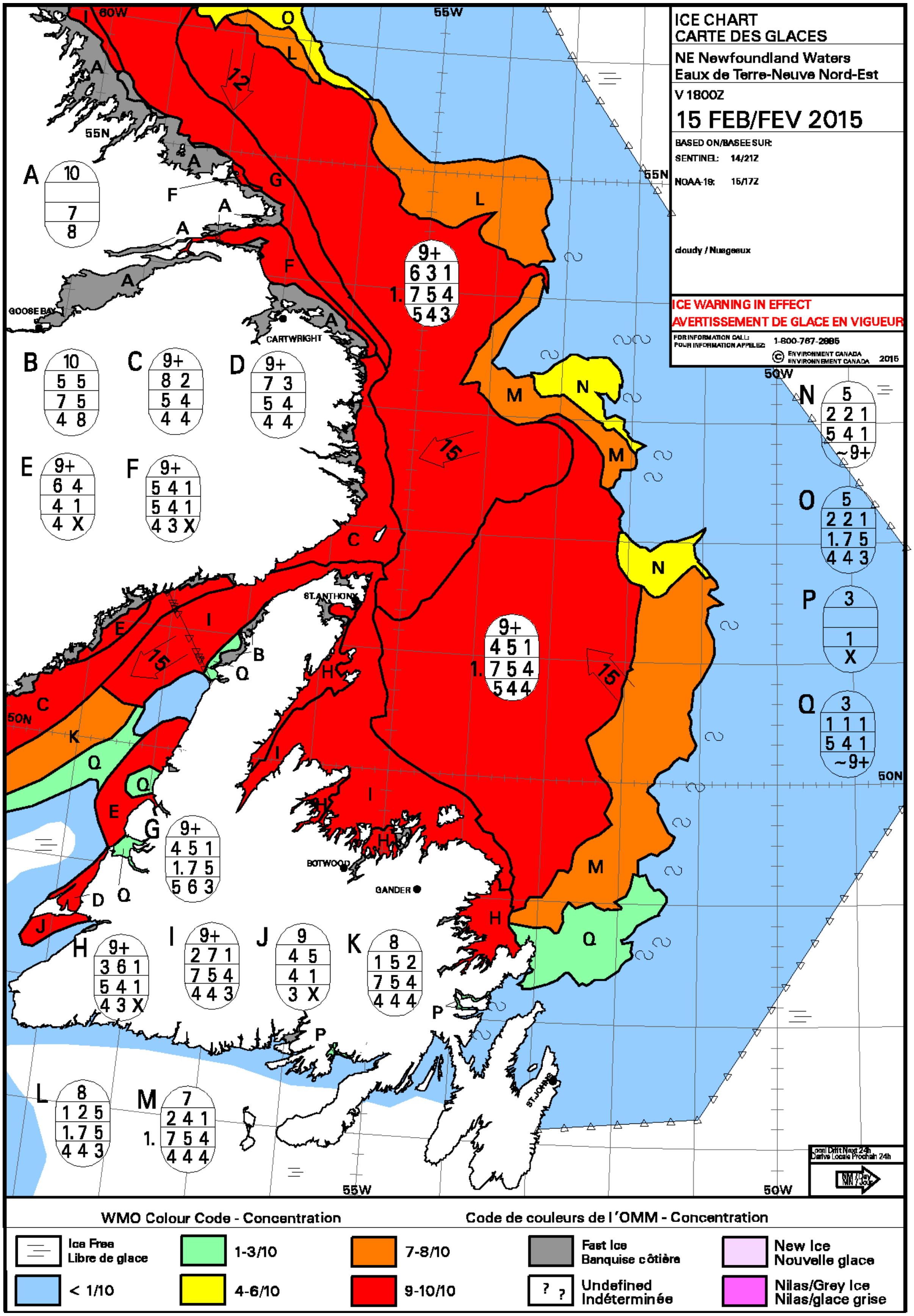
Monthly Sea-Ice Charts

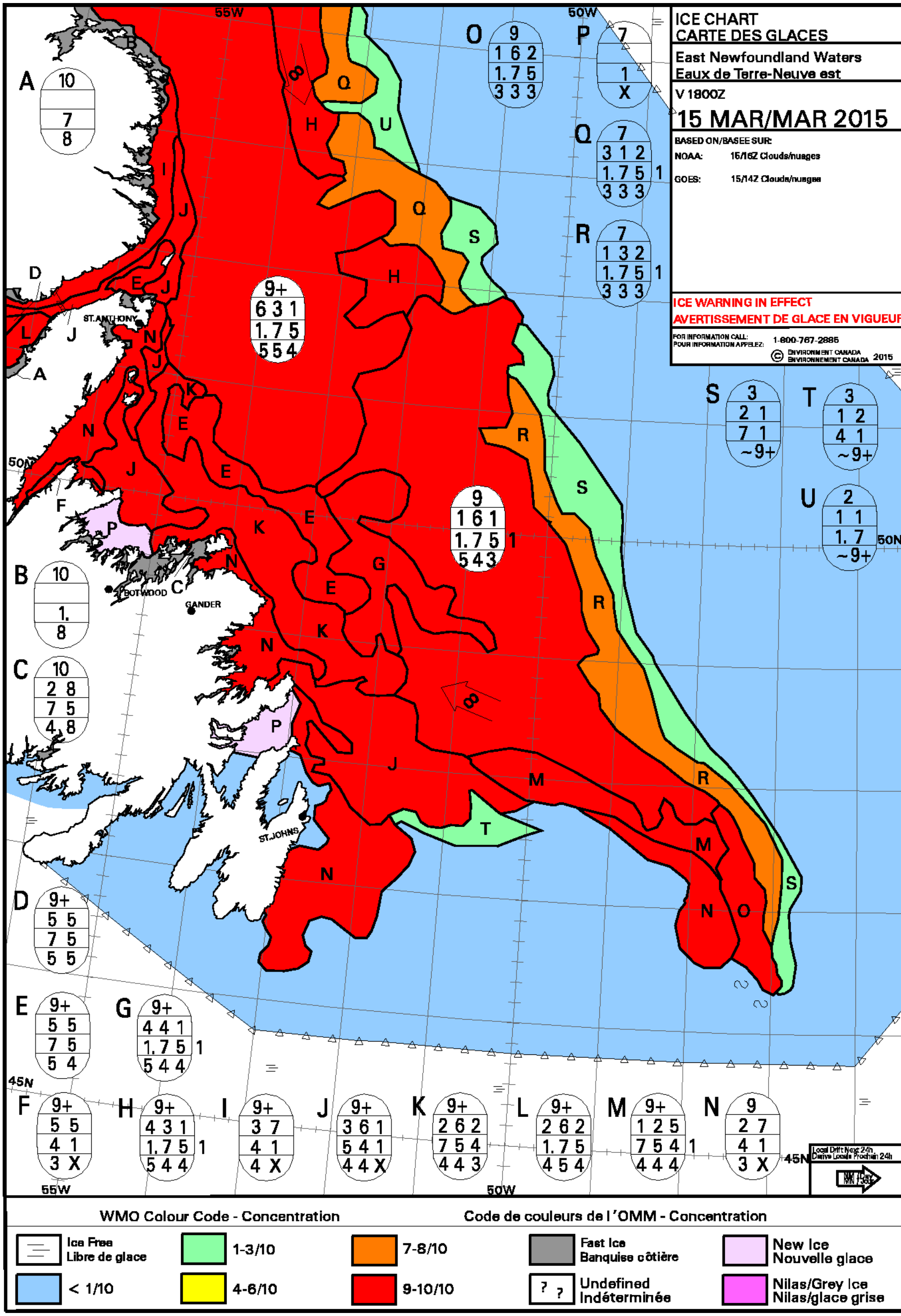
Sea-ice charts are reprinted with permission of the Canadian Ice Service.

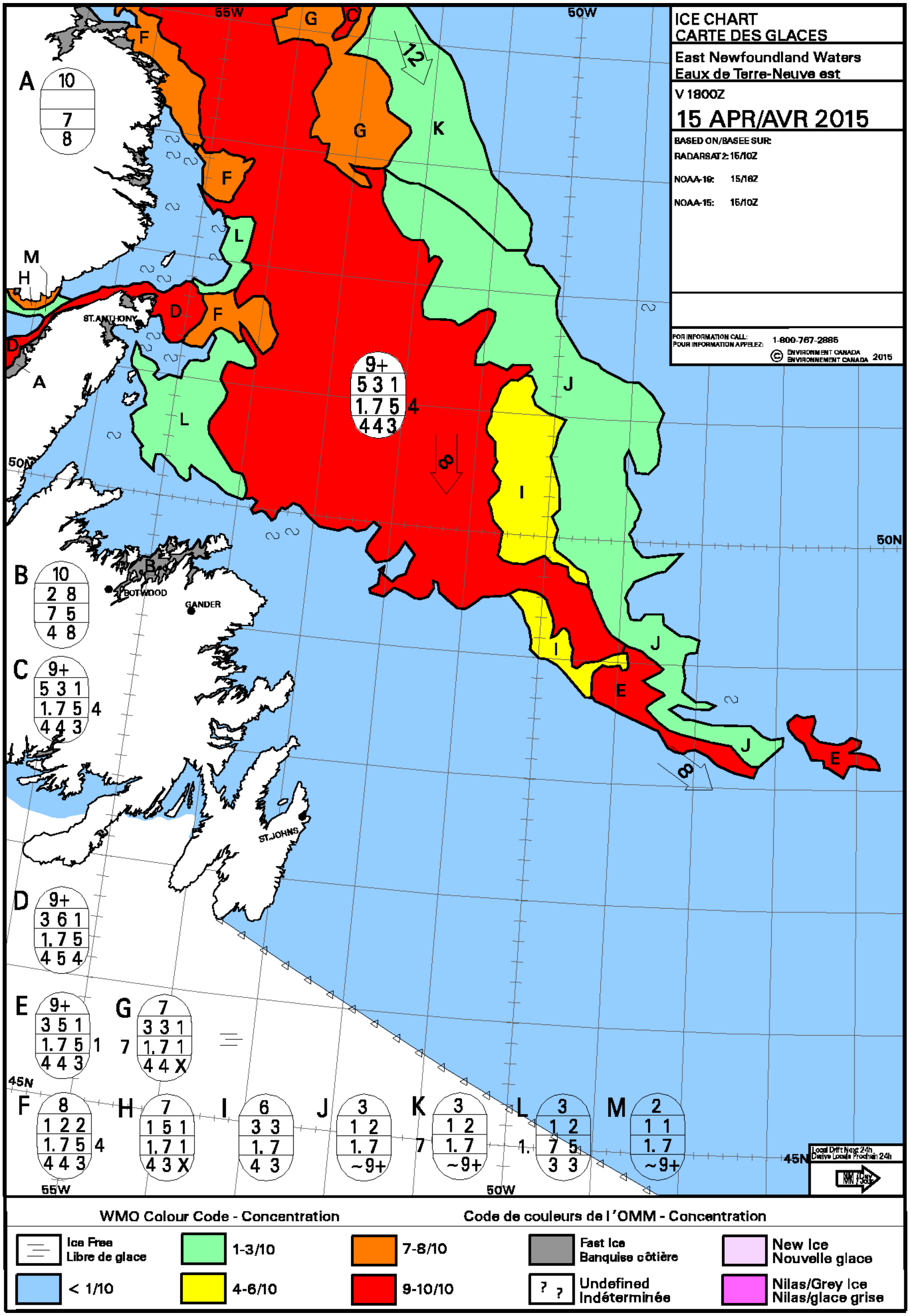
Sea ice symbols are in accordance with the World Meteorological Organization.

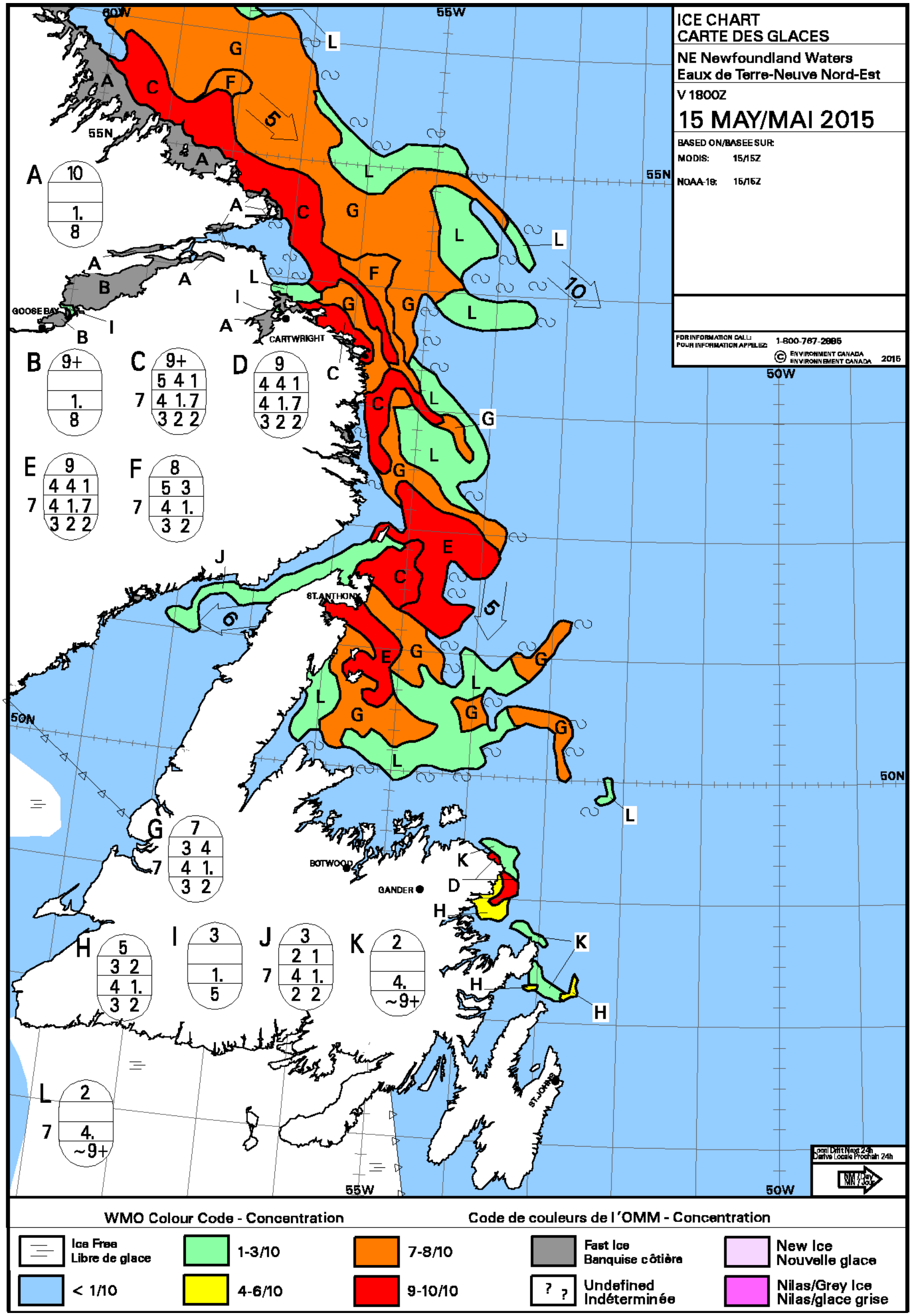


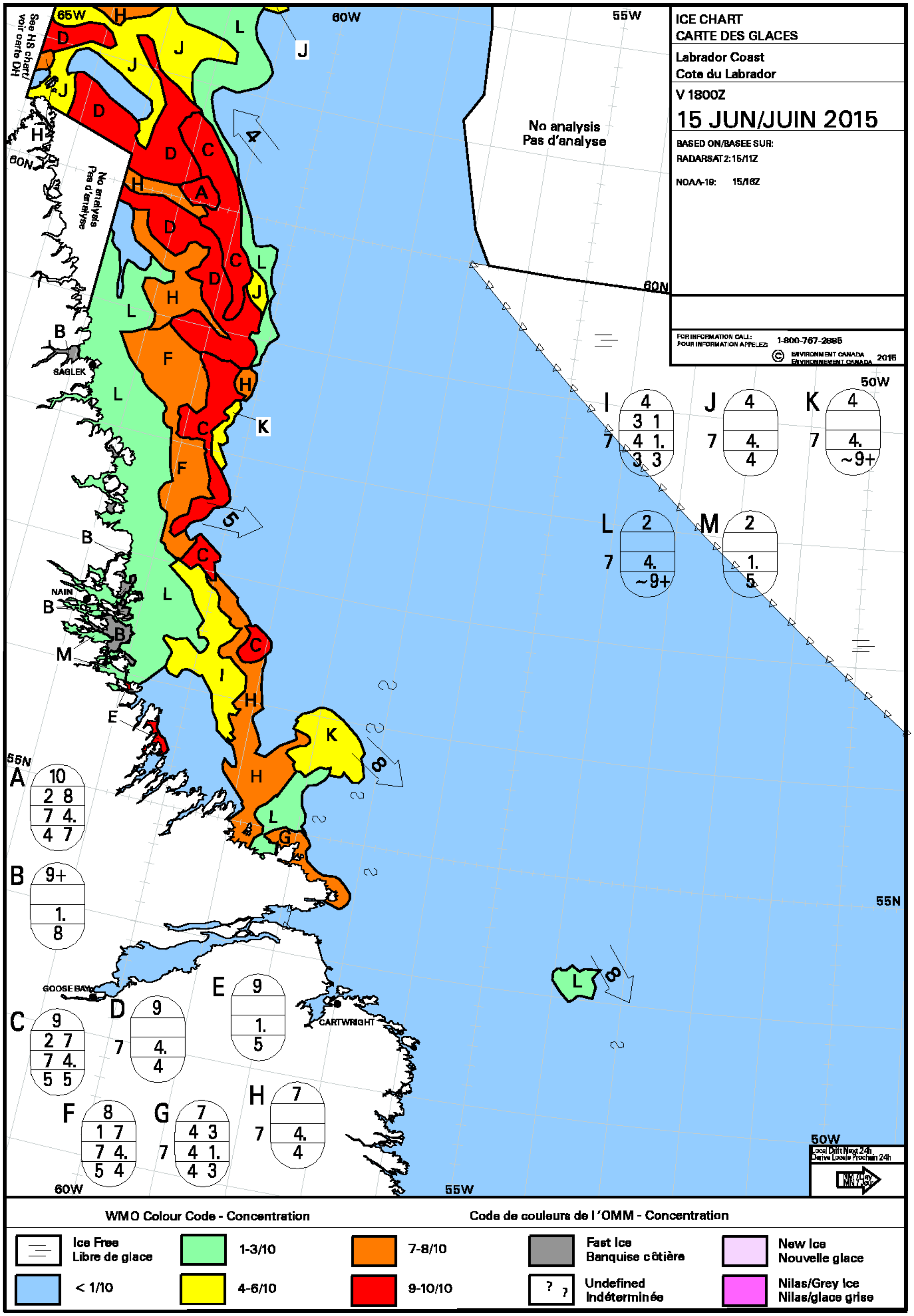
ICE CHART
CARTE DES GLACES
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 JAN/JAN 2015
BASED ON/BASEE SUR:
MODIS:
GOOSE BAY
CARTWRIGHT
ST.ANTHONY
BOTWOOD
GANDER
ST.JOHN'S
60W
55W
50W
55N
50N
WMO Colour Code - Concentration
Code de couleurs de l'OMM - Concentration
Ice Free
Libre de glace
< 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 2015
BASED ON/BASEE SUR:
SENTINEL: 14/21Z
NOAA-18: 15/17Z
cloudy / Nuageaux
ICE WARNING IN EFFECT
AVERTISSEMENT DE GLACE EN VIGUEUR
FOR INFORMATION CALL: POUR INFORMATION APPELEZ: 1-800-767-2885
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 2015
GOOSE BAY
CARTWRIGHT
ST.ANTHONY
BOTWOOD
GANDER
ST.JOHNS
60W
55W
50W
55N
50N
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 2015
BASED ON/BASEE SUR:
NOAA: 15/16Z Clouds/nuages
GOES: 15/14Z Clouds/nuages
ICE WARNING IN EFFECT
AVERTISSEMENT DE GLACE EN VIGUEUR
FOR INFORMATION CALL: POUR INFORMATION APPELEZ: 1-800-767-2885
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 2015
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 2015
BASED ON/BASEE SUR:
RADARSAT2: 15/10Z
NOAA-19: 15/16Z
NOAA-15: 15/10Z
FOR INFORMATION CALL: POUR INFORMATION APPELEZ: 1-800-767-2885
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 2015
55W
50W
50N
45N
ST.ANTHONY
BOTWOOD
GANDER
ST.JOHNS
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
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 MAY/MAI 2015
BASED ON/BASEE SUR:
MODIS: 15/15Z
NOAA-19: 15/15Z
FOR INFORMATION CALL: POUR INFORMATION APPELEZ: 1-800-767-2885
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 2015
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
Labrador Coast
Cote du Labrador
V 1800Z
15 JUN/JUIN 2015
BASED ON/BASEE SUR:
RADARSAT2:15/11Z
NOAA-19: 15/16Z
FOR INFORMATION CALL: POUR INFORMATION APPELEZ: 1-800-767-2885
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 2015
No analysis
Pas d'analyse
See HS chart/ voir carte DH
65W
60W
55W
50W
60N
55N
SAGLEK
NAIN
GOOSE BAY
CARTWRIGHT
Local Drift Next 24h
Derive 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

Acknowledgements

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

Airbus Defence and Space
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
Danish Meteorological Institute
European Space Agency
German Federal Maritime and Hydrographic Agency
MacDonald, Dettwiler and Associates Ltd.
National Geospatial-Intelligence Agency
Nav Canada Flight Services
NOAA National Weather Service
Provincial Aerospace Limited
Shell Torbay Aero Services
Transport Canada
USCG Air Station Elizabeth City
USCG Atlantic Area
USCG Aviation Training Center Mobile
USCG Communications Area Master Station Atlantic
USCG First District
USCG Headquarters
USCG Intelligence Coordination Center
USCG Maritime Fusion Intelligence Center Atlantic
USCG Navigation Center
USCG Research and Development Center
U. S. National 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 2015 Ice Season:

CDR G. G. McGrath
LCDR B. P. Morgan
Mr. M. R. Hicks
Mrs. B. J. Lis
LT R. H. Clark
LT S. M. Elliott
LT E. W. Thompson
CWO2 M. T. Zanetti
MSTCM V. L. Cates
YN1 J. J. Zwearcan
MST1 E. E. Lee
MST1 W. M. Savage
MST1 S. L. Skeen
MST2 M. J. Harrell
MST2 S. R. Miller
MST2 D. M. Morrisey
MST2 T. V. Withers
MST3 Z. P. Kniskern
MST3 J. J. Menard
MST3 B. M. Reel

Appendix A

Ship Reports for Ice Year 2015

Ships Reporting by Flag	Reports
ANTIGUA AND BARBUDA	
HANSE GATE	1
BAHAMAS	
MIEDWIE	1
CANADA	
AMUNDSEN	5
ATLANTIC KESTREL	1
ATLANTIC KINGFISHER	2
ATLANTIC OSPREY	4
BURIN SEA	1
GB ATLANTIC HAWK*	24
CCGS GEORGE R. PEARKES	1
MEARSK CHANCELLOR	10
MAERSK CHIGNECTO	19
MAERSK DETECTOR	13
MAERSK DISPATCHER	7
MATTEA	6
SCOTIAN SEA	7
SEA ROSE FPSO	1
CYPRUS	
ISADORA	1
DENMARK	
MAERSK BELFAST	1
MAERSK TACKLER	1
GERMANY	
MARIA S. MERIAN	1
GREECE	
MINERVA VASO	1
HONG KONG	
OOCL MONTREAL	1
OOCL BELGIUM	3
ISLE OF MAN	
KAREN KNUTSEN	1
JAMAICA	
PUFFIN	3
MARSHALL ISLANDS	
ADVANTAGE AVENUE	1
PRINCIMAR EQUINOX	1
SIMOA	2

PANAMA	
FUGRO SEARCHER	2
HIGH CURRENT	1
SINGAPORE	
BW LIONESS	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

Satellite Reconnaissance History, Transition, and Plan

CDR Gabrielle G. McGrath
Mr. Michael R. Hicks
December 2015

Position

The International Ice Patrol (IIP) initiated a transition to implement regular use of satellite reconnaissance into operations. A successful transition to satellite reconnaissance will reduce IIP's complete reliance on United States Coast Guard (USCG) aircraft to execute the mission. This appendix outlines the rationale behind IIP's decision to move forward with this transition. While this technology is not yet capable to be used exclusively to conduct the mission, it is IIP's position that satellite-derived synthetic aperture radar (SAR) iceberg data can be used to augment HC-130J patrols. As the Operational Commander for iceberg reconnaissance in the North Atlantic Ocean, IIP believes a tiered approach can be used from north to south based on the risk of iceberg collision to transatlantic shipping. IIP plans to use lower resolution satellite imagery with wider spatial coverage in its northern operating area off of the Labrador coast. Ice hazard reports in this region have minimal impact on transatlantic shipping. Further south, in the main transatlantic shipping lanes (i.e. south of 48°N latitude), IIP will seek to acquire higher resolution SAR imagery, sacrificing spatial coverage for improved confidence in iceberg detection and identification. Additional detail on this two-pronged strategy was presented in the Iceberg Reconnaissance and Oceanographic Operations section of IIP's 2015 Annual Report. The remainder of this appendix will discuss historical background, IIP's validation efforts, data acquisition/analysis lessons learned, and conclusions. This appendix forms the basis for a separate Concept of Operations for satellite iceberg reconnaissance.

Background

Since its inception, IIP focused on executing its mission in the most efficient way possible using all of the latest technologies. Whether transitioning from surface patrols to aerial reconnaissance or from visual flights to the dedicated use of increasingly more capable airborne radar, IIP consistently sought to improve its operations. In fact, one of the Ice Patrol's Core Values, "*Improvement*," truly captures the importance of staying abreast of technology in executing this important mission. The first record of IIP's interest in using satellites to detect icebergs was noted in 1975 during an internal unit assessment. LTJG Steve Osmer, a future Commander of IIP, wrote in the 1975 IIP Annual Report that the final phase of IIP's development would be the use of satellites (IIP, 1975). For the past two decades, IIP thoroughly researched and investigated this capability as it has improved over the last 40 years.

In November 1995, an external Mission Analysis recommended IIP formally investigate the use of satellite SAR data as an additional means to conduct iceberg reconnaissance (Pritchett and Armacost, 1995). Coincidentally in 1995, the Canadian Space Agency, in cooperation with the National Aeronautics and Space Administration, launched Canada's first commercial SAR system, RADARSAT-1. The following year, under the RADARSAT Application Development and Research Opportunity program, IIP began planning its first test to use RADARSAT-1 for iceberg detection. Four RADARSAT-1 images were acquired during the 1997 and 1998 Ice Seasons – one using ScanSAR Narrow beam mode (300 km swath, 50 m resolution) and three using Wide beam mode (150 km swath, 30 m resolution). IIP also successfully coordinated an HC-130H validation flight for one of the Wide mode images in 1998 (IIP, 1998). This first test documented challenges in detecting icebergs with a length of 15 m or smaller, even using Wide beam mode. IIP (1998) also performed a rough cost analysis which concluded that, although RADARSAT appeared to be an economical alternative to aerial reconnaissance, the challenges in reliably detecting small-sized targets would not fully meet IIP's International Convention for the Safety of Life at Sea (SOLAS) mandate to guard the Iceberg Limit. This report also documented the need for further study "to develop the expertise to quickly and accurately classify targets as ice/non-ice" and identified the Canadian Centre for Cold Ocean Research and Engineering (C-CORE) as a key agency involved in developing this expertise.

Beginning in 2000, IIP intensified efforts in improving its ability to use satellite SAR for iceberg reconnaissance by partnering with the Canadian Ice Service (CIS) and C-CORE as an end-user of satellite reconnaissance under a European Space Agency (ESA) initiative called Polar View. IIP agreed to provide its aerial reconnaissance results and conduct validation flights, when possible, to help refine an automated iceberg detection software (IDS) algorithm that was originally created by CIS and further developed by C-CORE. Under this program, IIP continued to receive data from RADARSAT-1, RADARSAT-2 (launched in 2007), and from ESA's Envisat mission. Both Envisat and RADARSAT-2 offered horizontal and vertical polarization options that were incorporated into C-CORE's automated IDS. IIP continued to provide reconnaissance results and to receive commercial satellite-derived data under Polar View at no-cost. All data were analyzed and processed by C-CORE. This work served to both improve IIP's familiarity with satellite data as well as to refine C-CORE's IDS.

During this time period, IIP also developed a close working relationship with the USCG Geospatial Intelligence (GEOINT) community to bring to bear additional U.S. Government and commercial resources for iceberg detection. This effort began in 1997 with a limited number of iceberg reports using classified systems provided by a USCG Marine Science Technician (MST) stationed at the U.S. National Ice Center (NIC) who had access to the USCG Intelligence Coordination Center (ICC) in Suitland, MD. This MST billet was originally assigned to IIP. IIP transferred this billet to the NIC to further support the implementation of satellite reconnaissance into operations. This arrangement, to gather classified USCG GEOINT imagery through the NIC MST, continued until 2009 when IIP began working directly with ICC for ordering and processing satellite imagery. This strong relationship with USCG GEOINT built a foundation upon which a transition from aerial reconnaissance to satellite SAR technology might be realized. In 2010, IIP began working with the USCG Maritime Intelligence Fusion Center Atlantic (MIFC LANT) to establish a process for vetting satellite-derived iceberg data. The MIFC LANT process is still in place and used routinely today.

To further investigate the feasibility of such a transition, in 2010, IIP initiated a space-borne reconnaissance study with Science Applications International Corporation (SAIC). This work was part of a multi-year effort to conduct a Concept of Operations analysis of all aspects of the IIP mission, including the use of commercial aerial reconnaissance and a customer study. Published in 2011, the SAIC report concluded: (1) Commercial satellite imagery providers cannot fully meet spatial resolution and temporal constraints required to conduct the IIP mission, (2) The difference between current performance and IIP requirements is not immense. Several SAR systems are capable of detecting icebergs (although not to IIP's requirements for establishing the limit), (3) Discrimination between an iceberg and a vessel, based solely on analysis of a satellite radar image, remains a difficult challenge, and (4) Cost estimates show that satellite imagery is competitive with HC-130J reconnaissance. The study recommended conducting a "real parallel benchmark test" to validate satellite detections through comparison with aerial reconnaissance and conducting a detailed cost-benefit analysis. Though a detailed cost-benefit analysis has not yet been conducted, IIP accelerated its efforts in validating satellite SAR technology for detecting icebergs.

IIP’s Validation Efforts – 2011 to 2015

2011

Following the SAIC report recommendation, IIP coordinated the collection of nine coincident RADARSAT-2 and TerraSAR-X images in 2011. RADARSAT-2 images were acquired through the Polar View program, and TerraSAR-X images were acquired through the NIC. The NIC has a unique arrangement whereby images funded by the National Geospatial-Intelligence Agency (NGA) can be obtained through direct communication with commercial satellite providers. IIP contracted with C-CORE to process and analyze the data using their IDS algorithm. No aerial validation was accomplished in 2011 due to weather and aircraft issues on planned attempts coupled with a very light season. Comparison of the data showed significant variations with a very low correlation between the two SAR systems (~30% of targets correlated). Possible explanations for this variability include the fact that data were collected in a variety of modes, that RADARSAT-2 is a C-Band radar where TerraSAR-X is X-Band, and that dual polarization was only available on RADARSAT-2.

2012

In 2012, IIP coordinated four coincident RADARSAT-2 collections with IIP HC-130J validation flights. Images were again acquired through C-CORE under the Polar View program at no-cost to IIP. Data for three Fine mode (50 km swath, 8 m resolution) showed a correlation of 69% while a single Wide Fine mode image (170 km swath, 8 m resolution) showed a 50% correlation with HC-130J reconnaissance. As expected, the Fine mode provided the best results but with a 50 km swath, this mode is too narrow to be operationally relevant. Detailed analysis results for 2011 and 2012 are documented in Appendix B of IIP’s 2013 Annual Report (IIP, 2013).

2013

Following the 2012 IIP Annual Meeting in Boston, MA, IIP initiated a project with the USCG Research and Development Center (RDC), the USCG ICC, and the Tactical Exploitation of National Capabilities (TENCAP) program within the USCG Office of Intelligence

(CG-257) to examine commercial satellite SAR reconnaissance methods along with National Technical Means (NTM) for iceberg detection. Due to classification, NTM results are not discussed in this appendix. During the first phase of this project, IIP acquired two commercial RADARSAT-2 Wide Fine images on 13 and 16 June 2013 via ICC that were procured by NGA through the TENCAP program. For these images, IIP collected a small amount of HC-130J validation data that were limited by low visibility and an inoperable radar. IIP compared results from the C-CORE IDS with ICC manual analyses. Data derived from both satellite analysis sources showed only marginal correlation with aerial reconnaissance - 49% and 37% for 13 and 16 June 2013, respectively. In addition, a German company, Airbus Defense and Space provided a TerraSAR-X ScanSAR mode image (100 km swath, 18 m resolution) at no-cost as a proof-of-concept demonstration on 16 June. This image showed a correlation percentage of 57% for targets sighted by IIP during the HC-130J flight that were also reported within the TerraSAR-X footprint.

2014

In 2014, IIP collected over 30 RADARSAT-2 and TerraSAR-X images. Due to the severe nature of the 2014 season, validation efforts were limited to the latter part of the iceberg season in June and July. IIP conducted validation flights on seven different dates, but only two of these dates, 15 and 26 June 2014, had icebergs present within the satellite footprint. These two images, both from the TerraSAR-X satellite, were again provided by Airbus Defense and Space at no-cost. Unfortunately, the iceberg population had quickly receded to the north of the planned image acquisition sites for the remaining five flights. Despite this limitation, the validation flights in June yielded some interesting results with respect to image analysis that will be discussed in the next section of this appendix.

Throughout the years, IIP's validation approach involved coordinating date, time, and location of a satellite pass with HC-130J flights. **Figure 1** shows a typical IIP flight that illustrates this approach using an example from a TerraSAR-X ScanSAR mode satellite pass with an HC-130J flight on 15 June 2014. The satellite results are provided courtesy of Airbus Defense and Space and are shown in the Google Earth™ picture in the upper left of **Figure 1** (Christmann and Lang, 2015). This satellite collection occurred approximately 75 NM east of St. John's, Newfoundland at 2101 UTC.

The validation portion of this flight occurred after completing several legs of an Iceberg Limit verification flight well to the east of the satellite pass. The IIP aircraft then flew two legs through the satellite area approximately 64 minutes prior to the pass. IIP recorded and photographed all icebergs detected during this portion of the flight. Observed icebergs are shown on the right of **Figure 1.** An IIP MST then compared targets detected during the flight with those reported by the satellite, factoring in iceberg drift during the time between the flight and the satellite pass. Only targets estimated to have a length greater than 15 meters were used for comparison, i.e. a *'small'*, '*medium*', *'large*', or '*very large*' iceberg by the Manual of Standard Procedures for Observing and Reporting Ice Conditions (MANICE) definition. These targets are indicated with the blue-shaded ovals in **Figure 1.** As can be seen in these photos, the conditions were exceptionally calm with clear visibility for most of the flight.

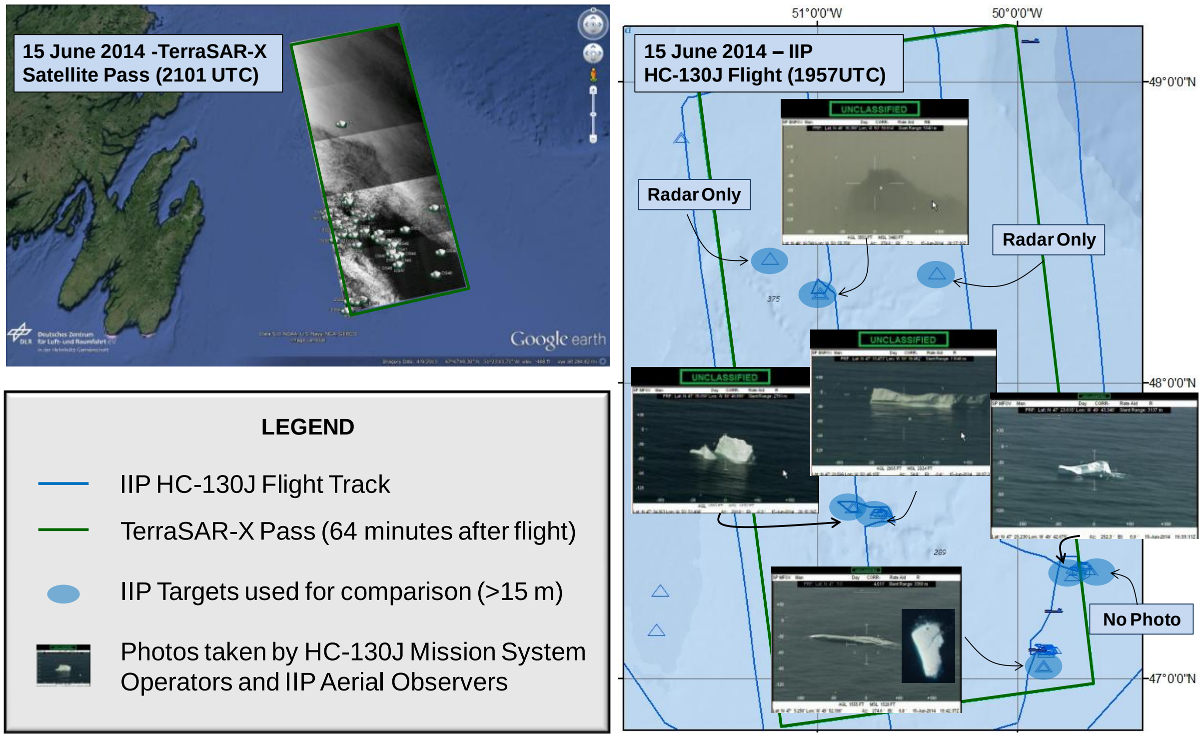


Figure 2. 15 June 2014 TerraSAR-X (upper left) with IIP HC-130J flight (right).

Visibility deteriorated in the northern portion of the flight as evidenced by the layer of fog shown in the northernmost photo. In fact, two targets could only be identified by the inverse synthetic aperture radar (ISAR) mode on the HC-130J ELTA radar. The ISAR mode produces a radar representation that shows prominent features of the target. While the USCG ELTA radar operators are well-trained, image interpretation with the ISAR mode is subjective, much like satellite SAR. Making a determination of iceberg versus small boat remains a challenge. This difficulty is especially true near the Grand Banks, where shipping traffic and iceberg density can be particularly high. The third iceberg to the north, shown in the picture of **Figure 1**, was visually identified through a thin veil of surface fog. This situation highlights the fact that IIP's HC-130J validation efforts should not be regarded as 'ground truth'. For this reason, in its analysis, IIP adopted the term, '***correlation percentage***' as an indicator of agreement between satellite-derived data and aerial reconnaissance rather than detection rate or other terminology that indicates perfect aerial validation. The correlation percentage is simply the ratio of the number of correlated targets reported by the satellite to the number of icebergs (15 m or more in length) observed during aerial reconnaissance. Uncorrelated targets were considered separately as a source for possible false positives or missed detections (either by the satellite or the aircraft).

2015

Validation efforts continued in 2015. As described in the Iceberg Reconnaissance and Oceanographic Operations section of IIP's 2015 Annual Report, IIP and NIC established a process to acquire RADARSAT-2 imagery under the Northern View program whereby NGA agreed to allocate funding for NIC to acquire imagery to support IIP's mission. Under this arrangement, NIC works directly with the RADARSAT-2 provider, MacDonald, Dettwiler and Associates Ltd. (MDA) to order imagery. However, since RADARSAT-2 is a Canadian SAR satellite system with intense Canadian Government demand, this process required early identification of areas of interest to ensure success and will be revisited during the 2016 season. While images were collected by NIC on 32 separate dates in 2015 under this agreement, IIP was not able to gather any significant RADARSAT-2 validation data during 2015 because most of these images were collected in locations outside of IIP's requested regions or at lower resolution modes not conducive to iceberg detection. A Wide Fine image was collected on 28 July in an area with icebergs but IIP could not collect validation data on this date due to operational requirements to conduct an iceberg limit flight on that date.

In 2015, Airbus Defense and Space again provided data to IIP at no cost from four TerraSAR-X ScanSAR images on 26 June, 29 June, 10 July, and 13 July. These images were centered approximately 100 NM off of the coast of Newfoundland near the offshore branch of the Labrador Current. Airbus collected two sets of images over a relatively short (three-day) time span in an effort to assess the feasibility for detecting and tracking icebergs. IIP planned to conduct validation flights on these dates, but due to weather and operational commitments, IIP only successfully obtained validation data on 10 July. Fortunately, on 26 and 29 June, PAL flew in the vicinity of the satellite acquisitions and collected useful validation data. PAL agreed to share their observations with Airbus to compare the results with detections from TerraSAR-X.

All images were analyzed using the C-CORE IDS. In addition, Airbus used a hybrid approach involving an automated detection scheme developed by the German Aerospace Center (Christmann and Lang, 2015). To maintain consistency, only C-CORE analyses were used to determine the correlation percentages presented below.

Results from this comparative analysis were mixed. Applying the same approach used for previous comparisons for the 2015 TerraSAR-X validation flights, PAL and IIP detected a total of 18 iceberg targets greater than 15 m in length. Seven of these correlated with TerraSAR-X targets for an overall correlation of 39% correlation reported through the C-CORE analysis. IIP also vetted the TerraSAR-X targets reported by C-CORE through MIFC to help positively identify these targets. This process revealed that six satellite-derived icebergs were incorrectly reported as vessels. Using MIFC or a similar vessel identification tool, such as the vessel Automatic Identification System (AIS) data, on the TerraSAR-X analysis would have yielded a much better correlation percentage of 72% (13 out of 18) for these TerraSAR-X images. This example underscores the importance of routinely integrating AIS or other vessel identification means into the satellite reconnaissance concept of operations.

As described in the Iceberg Reconnaissance and Oceanographic Operations section of IIP's 2015 Annual Report, IIP began receiving and evaluating SAR image data from ESA's Sentinel-1a satellite. Unlike all other commercial satellite imagery, Sentinel-1a data became publicly available through the internet at no cost in 2015. Sentinel-1a was designed to acquire data in a "pre-programmed operational mode to avoid conflicts and produce a consistent long-term data archive" (Sentinel Online, 2015). Data are acquired in four possible modes with resolutions ranging from 5 m to 40 m and coverage swaths between 20 km and 400 km. IIP identified the Interferometric Wide Swath (IWS) mode with 250 km coverage swath and 20 m resolution as the best Sentinel-1a mode for iceberg detection. Although the satellite was launched in 2014, IWS data was not available in IIP's OPAREA until 2015 when it became available through collaboration with the Danish Meteorological Institute. IIP collected limited validation data on two flights in June and four flights in July. Sentinel-1a image analysis and IIP validation is ongoing.

Preliminary results from Sentinel-1a validation efforts indicated a similar correlation percentage as other satellite systems reported herein. There were a significant number of uncorrelated targets which highlights the need to refine the automated detection algorithm toward the proper balance between missed detections and false positives. In 2015, false positives caused a challenging situation for the Commander, IIP (CIIP) in critical areas near the Iceberg Limit. After suspending iceberg reconnaissance flights for the year, IIP attempted to use Sentinel-1a data on 02 August 2015 to confirm no icebergs were present near the southern Iceberg Limit. The data were analyzed by C-CORE's IDS algorithm which reported a target in position 44°20'N 50°39'W, approximately 68 NM outside of the published Iceberg Limit. Due to its position, the time of year, sea surface temperatures, and recent aerial reconnaissance in the area, this target was deemed not to be an iceberg. However, in the interest of maritime safety, CIIP decided to report it as a radar target to alert mariners of the possible presence of a hazard. The ability to reduce false positives and properly communicate the existence of potential hazards will remain a significant challenge for CIIP in the transition to satellite reconnaissance.

Summary of Validation Results

From 2012-2015, IIP collected validation data on a total of 21 flights: three for RADARSAT-2 Fine mode, eight for RADARSAT-2 Wide Fine mode, six for TerraSAR-X ScanSAR mode and four for Sentinel-1a IWS mode. **Figure 2** summarizes these efforts by presenting results within a typical frame, drawn to scale, for each mode tested. The relative size of each mode illustrates the key trade-off between coverage and resolution that must be considered while employing satellite reconnaissance for iceberg detection. For consistency, results presented in **Figure 2** were all analyzed by C-CORE's IDS algorithm. The average correlation percentages for each mode are provided within the text in each frame where available. Though IIP has not tested the Wide ScanSAR mode of TerraSAR-X, this swath is included for comparison.

Figure 2 shows, for the two RADARSAT-2 modes tested, the correlation percentage was highest using the small area, high resolution Fine mode (50 km swath, 8 m resolution) as shown in green with a correlation percentage of 69%. Although this correlation percentage is very good, the swath size of the Fine mode is too narrow for cost-effective operational use since IIP would need approximately 45 Fine mode images to cover the same relative area a HC-130J searches on a single patrol. Not only is it difficult to de-conflict these acquisitions with other high priority users, but the cost is estimated at over $270K to cover the same area searched during a single HC-130J sortie. RADARSAT-2 Wide Fine mode (light blue) offers a wider swath with a similar resolution (170 km swath, 8 m resolution), but the correlation percentage was smaller at 42%. TerraSAR-X ScanSAR mode (orange) also has a good balance between coverage and resolution (100 km swath, 18 m resolution) with a 49%

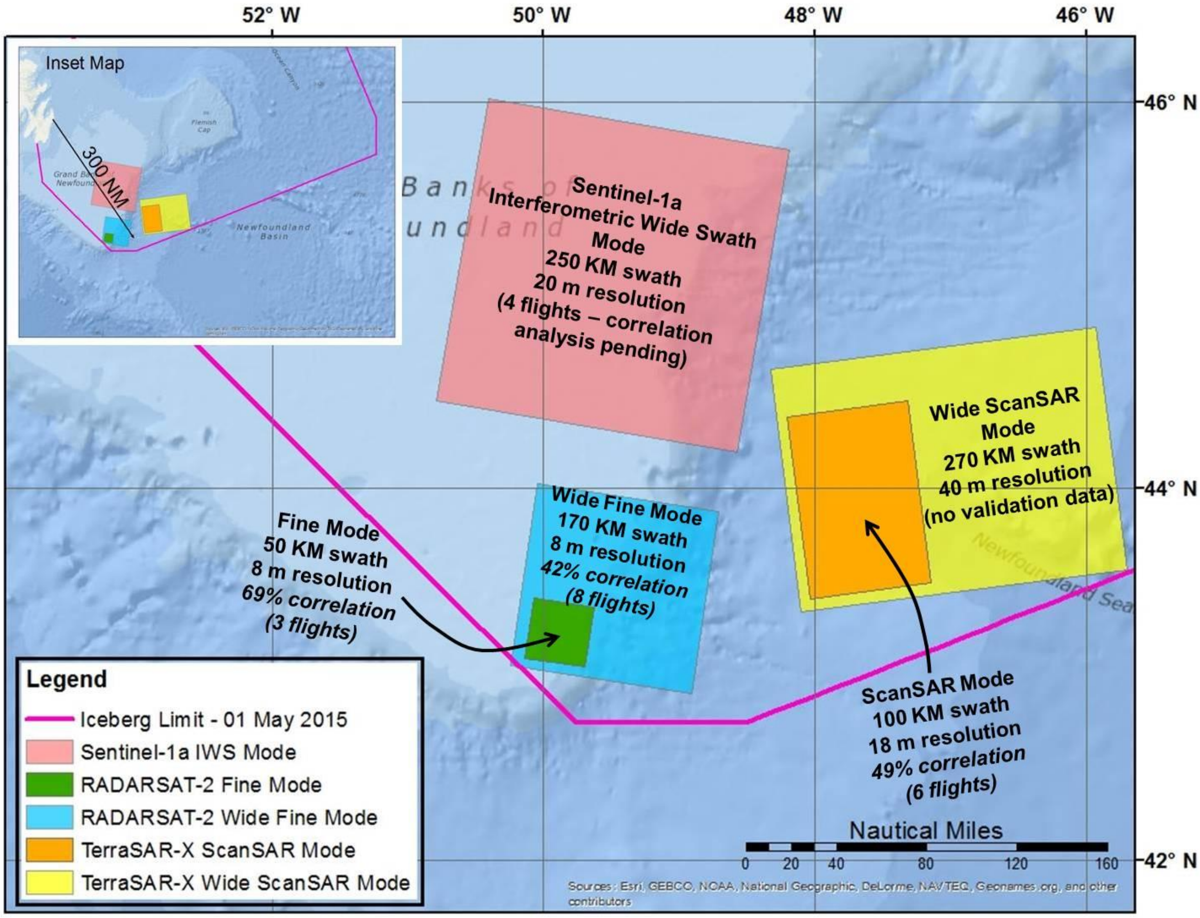


Figure 2. Satellite mode coverage vs. resolution comparison. Correlation percentages between satellite-derived data and aerial reconnaissance are noted within the text.

correlation. For these modes, between three and six images would be needed to cover a single HC-130J patrol area with a substantially smaller cost (approximately $26K) than Fine mode. The TerraSAR-X Wide ScanSAR mode (yellow) has a 270 km swath with a resolution of up to 40 meters. IIP contends the resolution of this mode is too low for reliable iceberg detection and identification. Sentinel-1a IWS mode has a 250 km swath with a resolution of 20 m, and images are publicly available at no cost.

To further demonstrate the level of satellite effort needed to conduct the IIP mission, the SAIC Study on satellite reconnaissance used the RADARSAT-2 Wide Fine mode to generate scenarios to estimate the number of images needed to search the Iceberg Limit for an entire Ice Reconnaissance Detachment. **Figure 3** was originally incorporated as part of the 2011 SAIC Study. This figure shows 45 overlapping Wide Fine RADARSAT-2 images that would be required every 14 days to provide 100% coverage of the Iceberg Limit. The cost of this imagery in 2011 was $410K. This $410K would be required every two weeks throughout the seven-month Ice Season in order to successfully monitor the iceberg danger to shipping. Even if funding were not an issue, the data conflict for the RADARSAT-2 satellite makes 100% coverage from RADARSAT-2 alone simply impossible. CIS and the Canadian Department of National Defense (DND) have priority for the use of this Canadian-owned satellite.

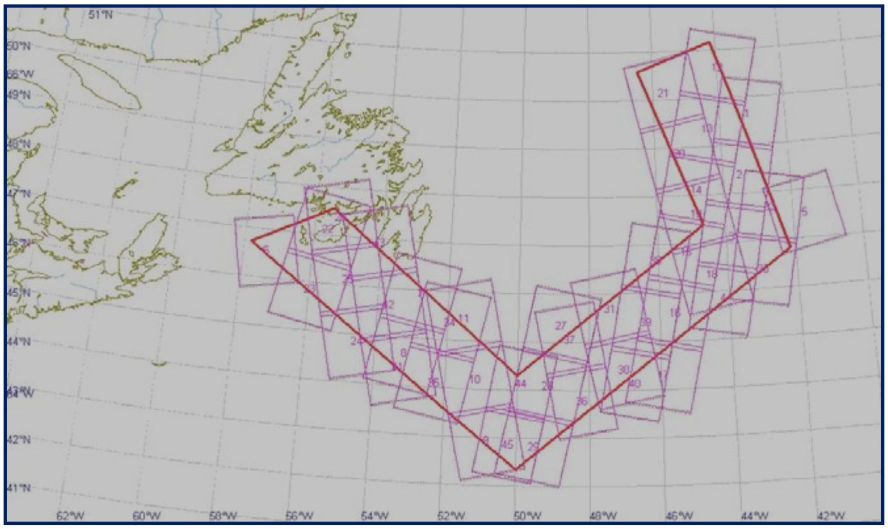


Figure 3. RADARSAT-2 Wide Fine Beam Mode coverage from the 2011 SAIC Study. Cost estimate is based on 2011 data.

Satellite Data Acquisition, Processing and Analysis

Satellite data processing, and analysis remains a critical variable in the routine incorporation of satellite data into operations. Unlike Electro-Optical (EO) imagery, SAR is "a combination of radar hardware, wave forms, signal processing and relative motion" (Richards, Scheer and Holm, 2010). While SAR offers distinct advantages over EO such as day/night operation and the ability to penetrate cloud cover, SAR data analysis demands a sophisticated approach with an appropriate blend of automated computer algorithm and manual human interpretation for success.

Both the USCG ICC and the NIC performed purely manual approaches to analyze RADARSAT-2 images. While these results showed close agreement with automated detection, it took many days to achieve this result where an automated approach can be completed in hours. Further, both CIS and NIC employ a manual approach to detect and identify large icebergs and ice island fragments in more remote areas where vessel traffic density is much lower and icebergs are much larger than in IIP's primary operating area. In fact, NIC does not actually identify any icebergs smaller than 1 km when conducting satellite imagery analysis.

As noted above, the majority of the data IIP used in its validation efforts has been processed and analyzed by C-CORE employing an automated/manual approach. Validation data from 2014 demonstrated the importance of employing the proper detection algorithm. **Figure 4** illustrates the variability between two independent analyses of the same TerraSAR-X data from 15 June 2014. The left panel shows a purely automated approach without any human oversight. In this panel, a series of 52 green triangles in the bottom left quadrant of the satellite pass were designated as 'Uncorrelated Targets' by IIP. Since visibility was clear during aerial reconnaissance on this day, and the IIP patrol did not report any targets here, these targets can be considered false positives, possibly from fishing gear with radar

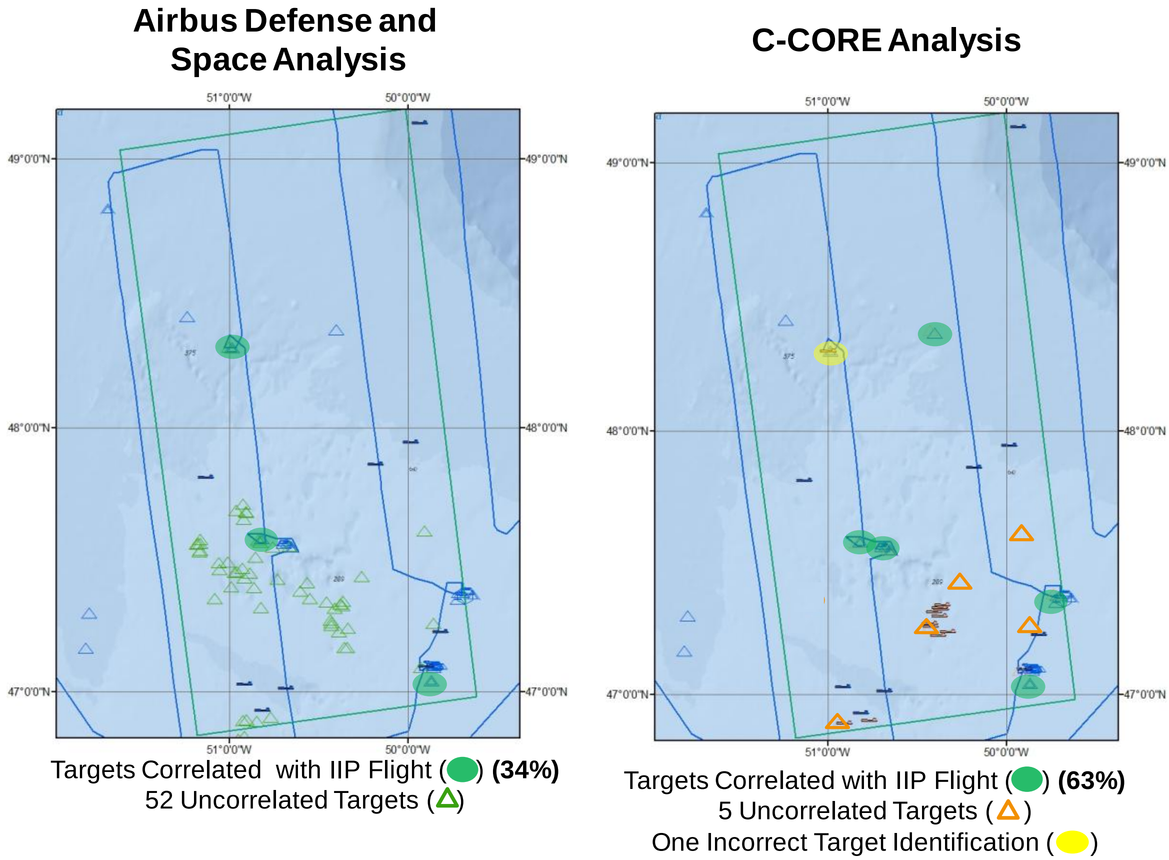


Figure 4. 15 June 2014 Airbus Defense and Space (left) and C-CORE (right) analyses of a 15 June 2014 TerraSAR-X image.

reflectors. In the C-CORE analysis (right panel), these targets were eliminated through human quality control. In general, the image analyzed by C-CORE showed a higher correlation than the Airbus Defense and Space analysis (63% vs. 34%). After reviewing the 15 June 2014 result, Airbus Defense and Space adopted a semi-automated routine, similar to the one used by C-CORE. This routine pre-selects candidate iceberg targets through an automated algorithm then employs skilled human analysts to carefully examine the automated results. The human analysts eliminate likely false positives or add any targets that may have been missed by the automated algorithm (Christmann and Lang, 2015). It is also important to note the C-CORE algorithm attempts to distinguish vessels from icebergs, while the Airbus algorithm reports a confidence level based on contrast between the target and background. This difference in the analysis procedure led to one incorrect target identification for C-CORE while there were none for the Airbus analysis. This incorrect target identification is depicted in the right panel of **Figure 4** by a yellow ellipse.

Lessons Learned

The following lessons learned summarize the challenges IIP experienced in satellite data acquisitions, processing, and analysis.

Data Acquisition

- To acquire sufficient satellite imagery to successfully implement the operational use of satellite iceberg reconnaissance, IIP should:
  - Continue to use the NIC arrangement with MDA for collecting RADARSAT-2 data.
  - Request ICC GEOINT support for commercial satellite imagery other than RADARSAT-2 e.g., TerraSAR-X.
  - Identify publicly-available Sentinel-1a data to support IIP Satellite Reconnaissance strategy.
  - Develop and communicate an image collection strategy by December each year for the following iceberg season.

- Proper satellite mode selection is key. For example:
  - In 2014, ICC requested several TerraSAR-X images in IIP's area of interest. However, these images were requested in StripMap mode which has a very high resolution (3 m) but only a 16 NM swath. For comparison, the swath of this mode is even less than the RADARSAT-2 Fine mode described earlier. This mode has no operational reconnaissance value.
  - In 2014, IIP also received several RADARSAT-2 images that were collected in the Ocean Surveillance, Very wide swath, Near incidence mode (OSVN). While this mode has a very wide swath (286 NM), its resolution varies between 28-100 m azimuthally, depending upon the location of the beam with respect to the satellite path. IIP was unable to collect any significant validation data with the OSVN mode in 2014. Recent discussions with CIS personnel suggest that IIP might revisit the use of this mode under benign sea state conditions.
  - Tables 4 and 5 in the Iceberg Reconnaissance and Oceanographic Operations section of IIP's 2015 Annual Report summarize preferred modes based on the proximity of the area of interest to the transatlantic shipping lanes.

Automated Detection Algorithms

- Through work with C-CORE, Airbus, ICC and NIC, it is clear the use of an automated detection algorithm with some level of human intervention is essential for operationally-relevant results. Thus, IIP plans to pursue a semi-automated approach to satellite SAR iceberg detection. Such an approach will use an automated detection algorithm to identify candidate iceberg targets followed by a human analyst to evaluate automated results for false positives or missed detections. IIP does not possess the IT infrastructure, automated software, or staff to analyze satellite imagery directly. Presently, IIP must rely on a third party to analyze SAR image data. In order to move forward with the operational use of satellite imagery, IIP must obtain the capability to analyze satellite imagery.

- IIP is working closely with NAIS partners to evaluate existing options and consider different approaches for automated detection. There are a number of different possibilities to perform this service, several of these options are:

- Procure the rights to an automated algorithm for use by North American Ice Service (NAIS) partners (CIS, NIC, or IIP). Licensure would include software installation, upgrades for new satellite system, and training for NAIS members on operating the application.
- Work with NAIS partners to identify an existing U.S. or Canadian Government algorithm.
- Work with NAIS partners to develop a new algorithm.

All of these options would require a commensurate change to IIP staffing in order to hire or train analysts to run the algorithm and to interpret and disseminate the results.

Operational Priorities

- The severity of the 2014 and 2015 Ice Seasons made dedicated validation flights extremely difficult. Because of the significant threat of an iceberg collision, IIP used most of its flight hour allocation on Iceberg Limit flights. All validation efforts to date have been accomplished as a part of normal reconnaissance detachments. The need to verify the Iceberg Limit outweighs validation efforts. IIP will continue to seek opportunities to collect satellite validation data while balancing the operational need to search the most critical iceberg danger areas.

Large File Data Transfer

- Both IIP and C-CORE had difficulty in downloading extremely large files via NGA's secure File Transfer Protocol (FTP) site. With the exception of the TerraSAR-X data from Airbus, all image data were transferred via DVD for the 2014 Ice Season. This resulted in an average delay of 11 days between the satellite pass and the receipt of data. IIP requires a more timely method for transferring large files to the analysis site. In 2015, IIP successfully downloaded RADARSAT-2 data via FTP through NIC and Sentinel-1a data from the ESA Scientific Data Hub with minimal delays. IIP will continue to work with data providers to improve its capability to transfer large data files.

Conclusions

The International Ice Patrol is prepared to begin using SAR satellite reconnaissance data operationally to execute its mission to monitor the iceberg danger in the North Atlantic Ocean. Successful operational use of satellite data is dependent upon understanding its technical limitations. Although validation results have shown marginal correlation between aerial and satellite reconnaissance, IIP has learned enough about the capabilities and limitations of various satellite systems and modes to begin incorporating this data into its operations in a more routine, systematic fashion.

After researching this technology over the past 20 years, IIP believes that it is time to implement a tiered approach to using this data. IIP's two-pronged deployment strategy mitigates the disadvantages of using satellite over aerial reconnaissance by relegating satellite detections to lower risk applications. This approach will enable IIP to use satellite capabilities to supplement the iceberg database to the north where vessel/iceberg discrimination is not as difficult and where vessel traffic is light while data to the south, in the transatlantic shipping lanes, will be used to better focus aerial reconnaissance flights.

IIP's current employment strategy is based on the ability to gain imagery at no cost from NGA through the NIC and/or USCG GEOINT. In addition, publicly-available data from Sentinel-1a offers a very attractive possibility to augment other commercial data. If sufficient imagery can not be routinely obtained through these sources, IIP will need to request funding to acquire commercial satellite imagery in order to successfully transition to satellite reconnaissance.

Assuming imagery can be obtained through U.S. Government and publicly-available resources, IIP believes that present and future staff will need to become proficient in image analysis. As such, implementing a computer-based, automated detection algorithm to cue human analysts to the presence of possible iceberg targets is a top priority. Gaining experience in image analysis for IIP staff is essential. With improved personnel proficiency coupled with future SAR satellite launches planned by ESA, Canada, and the U.S., IIP expects that future validation results will continue to improve. As confidence in satellite technology grows, IIP's reliance on USCG aviation resources will continue to decrease to create an optimal mix of reconnaissance resources and move IIP closer toward its vision to eliminate the risk of iceberg collisions.

References

Christmann, R. and Lang, O. (2015). TerraSAR-X for Iceberg Detection Applications. DeMarine-2 Validation Report (DLR FKZ 50EE1116).

IIP. (1975). Report of the International Ice Patrol in the North Atlantic (Season of 1975), Bulletin No. 61, Appendix A.

IIP. (1998). Report of the International Ice Patrol in the North Atlantic (1998 Season), Bulletin No. 84, Appendix C.

IIP. (2013). Report of the International Ice Patrol in the North Atlantic (2011 Season), Bulletin No. 99, Appendix B.

Pritchett, C.W. and Armacost, R.L. (1995). Mission Analysis Support for USCG International Ice Patrol, USCG R&D Center, November 1995. DTID accession number ADA304395.

Richards, M.A., Scheer, J.A. and Holm, W.A., *Principles of Modern Radar. Volume I: Basic Principles.* pp. 835-837, May, 2010.

Science Applications International Corporation (2011). “Scenario Development: A Study to Determine the Feasibility of using Space-Borne Iceberg Reconnaissance in IIP Operations: 31 May 2011.

Sentinel Online (2015). European Space Agency (ESA) Earth Observation Ground Segment Department User Services and Mission Planning Office
Via Galileo Galilei 00044 Frascati (Rome), Italy.