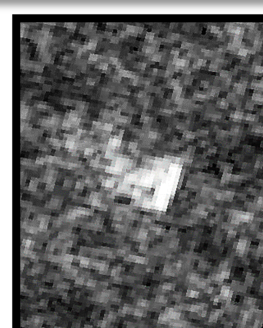
Homeland Security

United States Coast Guard

Report of the International Ice Patrol in the North Atlantic



★From Sea... To Sky... To Space★

2019 Season
Bulletin No. 105
CG-188-74

INTERNATIONAL
ICE PATROL

Bulletin No. 105
Report of the International Ice Patrol in the North Atlantic
Season of 2019
CG-188-74

Forwarded herewith is Bulletin No. 105 of the International Ice Patrol (IIP) describing the Patrol's services and ice conditions during the 2019 Ice Year. With 1,515 icebergs drifting into the transatlantic shipping lanes, the 2019 season was designated as an "Extreme" Ice Season – the most severe since 2014. While pre-season predictions forecasted 2019 to be a moderate year, the extensive sea ice coverage in March enabled many large and very large icebergs to persist, resulting in exceeding climatological extreme limits for much of April and May. The Ice and Environmental Conditions section presents a discussion of the meteorological and oceanographic conditions that created this extreme season. Additionally, the Operations section discusses the potential impact of increased satellite reconnaissance on the identification and count of icebergs. Similar to the uptick in count seen when IIP added radar operations to aerial reconnaissance in 1983, the full impact of expanded satellite coverage and improved analysis on iceberg counts is yet to be fully understood. However, while there may be some count bias due to changing methodology – 2019 was an extreme year by any measure.

Throughout 2019, IIP continued to develop new reconnaissance operations using synthetic aperture radar satellites for iceberg detection and identification. To improve satellite imagery analysis, particularly in sea ice, IIP developed novel imagery analysis techniques to better identify icebergs, continued the dedicated Satellite Dayworker position, and focused on improving the quality of analysis. Additionally, IIP teamed with the Department of Homeland Security Science and Technology Directorate to accelerate the development of machine learning based algorithms for automated iceberg detection and classification in satellite imagery. Results from this groundbreaking campaign will not only support algorithm development, but also improve iceberg drift and deterioration modeling; revolutionizing iceberg science.

To honor events inextricably linked with IIP history, two memorial and wreath dedication ceremonies were held in New London, CT. In April, IIP commemorated the 107th anniversary of the sinking of RMS TITANIC, and in June, IIP honored the sacrifices of those that were a part of the Greenland Patrol during World War II. Wreaths dedicated during the ceremonies were then flown on HC-130J aircraft and cast into the ocean during Ice Reconnaissance Detachments.

This report was prepared by all members of the IIP team. On behalf of the dedicated men and women of IIP, I hope that you enjoy reading this report of the 2019 season.

K. L. Serumgard
Commander, U. S. Coast Guard
Commander, International Ice Patrol

International Ice Patrol
2019 Annual Report
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Previous IIP Annual Reports may be obtained from the following sources:

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

Cover art: View of a single iceberg as seen from evolving iceberg reconnaissance methodology - from ships, to aircraft, to space. The top image was taken from the deck of USCGC JUNIPER on 02 May 2019. The bottom left was taken from the HC-130J camera at approximately 2,000ft on 14 May 2019. The bottom, center-top was from the HC-130J window at approximately 20,000ft on 13 May 2019. The bottom, center-bottom is from Sentinel-2 true color imagery on 04 May 2019 and bottom-right is from Sentinel-1 Synthetic Aperture Radar imagery on 05 May 2019.

1. Introduction

This is the 105th annual report of the International Ice Patrol (IIP) describing the 2019 Ice Year. It contains information on IIP operations, along with environmental and iceberg conditions in the North Atlantic from October 2018 to September 2019; focusing on the Ice Season (February to August 2019). To conduct aerial reconnaissance, IIP deployed 10 Ice Reconnaissance Detachments (IRD) to detect icebergs in the North Atlantic and Labrador Sea. The IRD's used HC-130J aircraft from U.S. Coast Guard (USCG) Air Station Elizabeth City (ASEC) and primarily operated from St. John's, Newfoundland. In addition to this reconnaissance data, IIP received iceberg reports from commercial aircraft and mariners in the North Atlantic. Further, IIP continued the progression toward incorporating satellite data into standard reconnaissance operations. IIP personnel analyzed iceberg and environmental data, using iceberg drift and deterioration models 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 from the model output. These iceberg warning products were then distributed to the maritime community. IIP also responded to individual requests for iceberg information in addition to these routine broadcasts.

As the cover images of this report show, IIP is undergoing an evolution of reconnaissance operations. From the early beginnings of ship based observations, to aerial reconnaissance, and now transitioning to sensors in space, the men and women of IIP continue to evolve operations, improve techniques, seek out new methods, advance science, and embrace technology to provide the most accurate iceberg monitoring and warning services to the international maritime community. This report focuses on a few areas of modernization – namely improved use of the Minotaur Mission System (MMS) Suite on the HC-130J aircraft, incorporation of space-based sensors into reconnaissance operations, and updated season severity metrics and in-season prediction capabilities, but these are not the only areas of effort. To improve the skills of our technical specialists, we transitioned three enlisted billets from Marine Science Technician to Intelligence Specialist ratings, providing improved Geospatial Intelligence competency. We increased partnerships with the USCG Intelligence Community to gain better understanding of space-based reconnaissance resources. We continued to address Information Technology needs, identifying the next generation of the BAPS while evaluating the resources required for "big data" management of satellite imagery. Finally, we introduced the distribution of iceberg warning information via the use of the U.S. government GovDelivery website, while continuing to explore alternate delivery methods that capitalize on electronic navigation now standard throughout the maritime community. In the words of one IIP long-timer – "It's an exciting time to be at IIP."

IIP was formed after the RMS TITANIC sank on 15 April 1912. Ever since 1913, with the exception of periods of World War, IIP has 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 2019 Ice Season, IIP was under the operational control of the Director of Marine Transportation (CG-5PW), Mr. Michael D. Emerson. CDR Kristen L. Serumgard 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.

2. Ice and Environmental Conditions

Operational Area

IIP is responsible for guarding the southeastern, southern, and southwestern limits of the region of icebergs, in the vicinity of the Grand Banks of Newfoundland. In conjunction with our NAIS partners, the Canadian Ice Service (CIS) and United States National Ice Center (USNIC), IIP examines environmental, meteorological, and climatological data to develop accurate iceberg warning products in the IIP Operational Area (OPAREA) (**Figure 2-1**). The extent and concentration of sea ice from January through March in the OPAREA plays a critical role in the number of icebergs that present a hazard to transatlantic shipping. Further, the confluence of the cold Labrador Current and warm Gulf Stream/North Atlantic Current make this area especially challenging for reconnaissance because of frequent fog and the presence of small-scale oceanographic features. This section describes the ice and environmental conditions during the 2019 Ice Year.

Ice Year Summary
Season Severity

After a light iceberg season in 2018, 2019 was the 10th most severe since 1900. By definition, the “Ice Year” spans the period between 01 October of the previous year and 30 September of

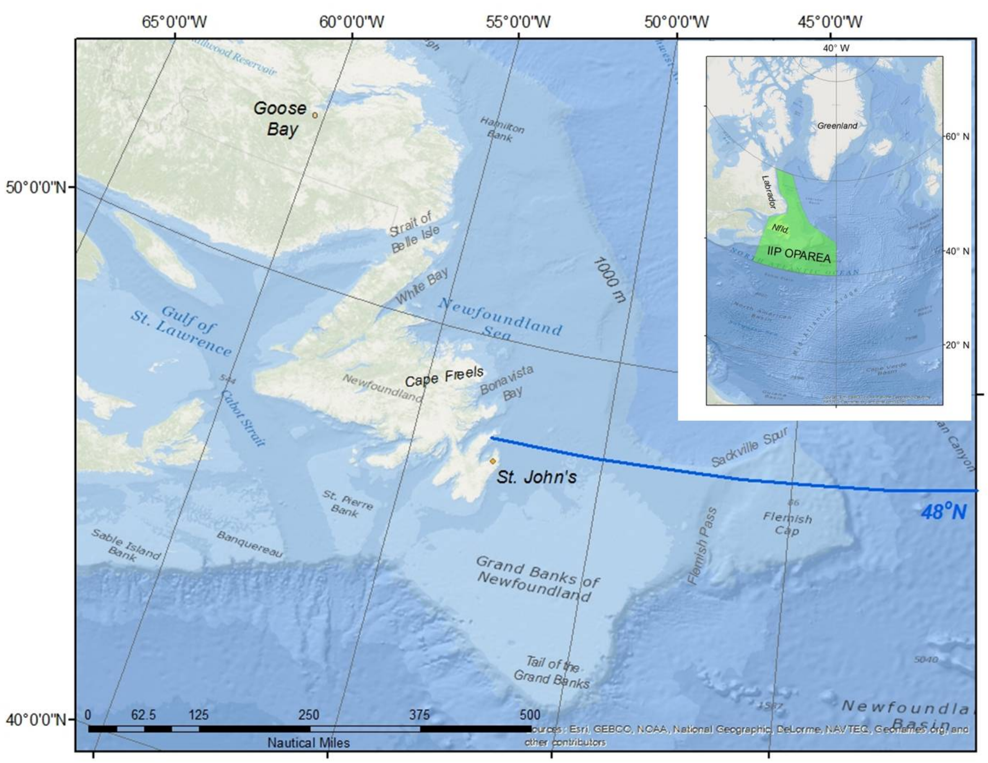

Figure 2-1. International Ice Patrol OPAREA in green. The latitude of 48°N is typically considered the northern boundary of the transatlantic shipping lanes. IIP measures season severity based on this line.

the current year. During the 2019 Ice Year, 1515 icebergs (not including bergy bits or growlers) crossed south of 48°N. Using IIP's normalized season severity metrics, revised in 2018 to account for varying observation methods since 1900, IIP classified the 2019 Ice Year as "Extreme". This is the second "Extreme" Ice Year in the past five years (1546 icebergs crossed south of 48°N in 2014).

Historical variability for this measurement is caused both by actual changes in season severity and by modifications to sighting methods **(Figure 2-2)**. The mean number of icebergs south of 48°N throughout IIP's entire iceberg data record (1900-2018) is 492.

Using revised normalized statistics, the average number of icebergs below 48°N for the modern reconnaissance era is 775. This period, from 1983-2018, is characterized by IIP's use of aircraft with sophisticated airborne radar systems, ship reports, and satellite reconnaissance. The use of iceberg drift and deterioration modeling also allowed inclusion of iceberg drift into the data record during this period (IIP, 2018).

In 2018, IIP developed a season severity predictive tool based on the new normalized statistics. To create this tool, IIP examined the years from 1983-2018 that corresponded to "Light", "Moderate", "Heavy", and "Extreme" years, establishing statistical benchmarks based on the

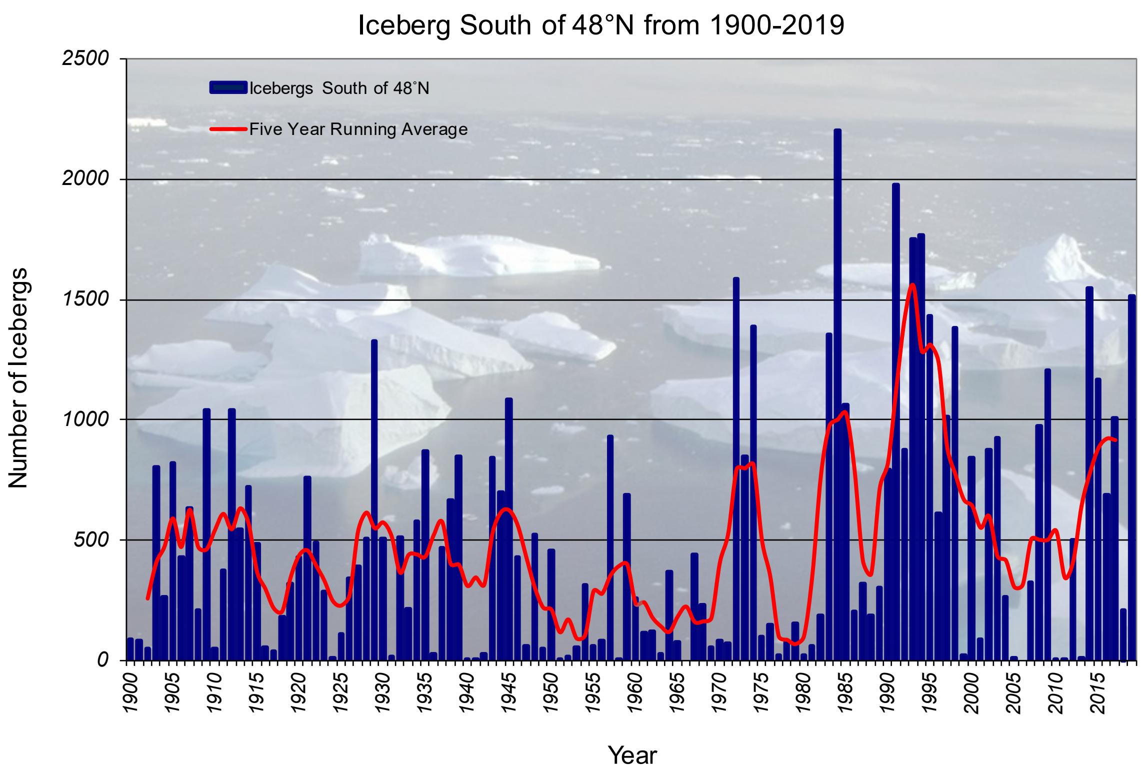

Figure 2-2. Icebergs crossing 48°N and five-year running average.

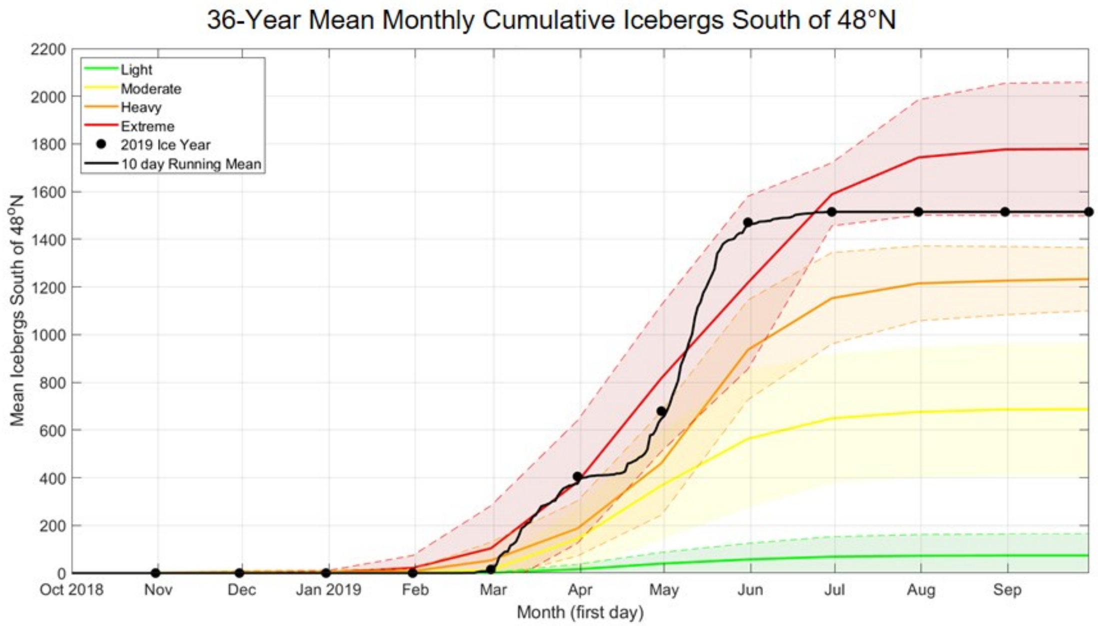

Figure 2-3. Icebergs crossing south of 48°N for the 2019 Ice Year plotted over the 36-year mean of monthly cumulative icebergs south of 48˚N from 1983 - 2018. The black solid line is the 10-day running mean. Colored solid lines indicate the mean number of icebergs that have passed south of 48˚N throughout the iceberg season in "Light" (Green), "Moderate" (Yellow), "Heavy" (Orange), and "Extreme" (Red) seasons. The dashed lines and shading indicate ±1σ from the mean. Season types are defined using the normalized iceberg count and the 50% standard deviation method developed in 2018 (IIP, 2018).

cumulative monthly mean number of icebergs for each severity class. IIP calculated a monthly range for each severity class that used the mean and standard deviation of the distribution for the cumulative number of icebergs in each month. **Figure 2-3** shows the results of this calculation with the observed monthly totals and a 10-day running mean of icebergs drifting south of 48°N during the 2019 Ice Year (IIP, 2018)

CIIP used this tool to assess iceberg severity while the season progressed. The solid black line, shown in **Figure 2-3,** indicates the 10-day running mean of this metric. By mid-March, it became apparent that 2019 would be a “Heavy”, or potentially “Extreme” year. This allowed CIIP to communicate season severity to USCG leadership to ensure that adequate aerial reconnaissance resources would be available into the summer months. In turn, the slope of the dashed line in **Figure 2-3** became nearly horizontal through June and July, giving CIIP an important clue to consider terminating further aerial reconnaissance. The ability to provide this type of quantitative predictor offers an invaluable tool for planning scarce and costly aerial reconnaissance deployments.

Additionally, the maximum extent of the Iceberg Limit also contributes to the severity of a season as it impacts the distance, and therefore time a vessel must divert to avoid iceberg encounters. Further, the number of flight hours required by IIP aerial reconnaissance is directly linked to the extent of the Iceberg

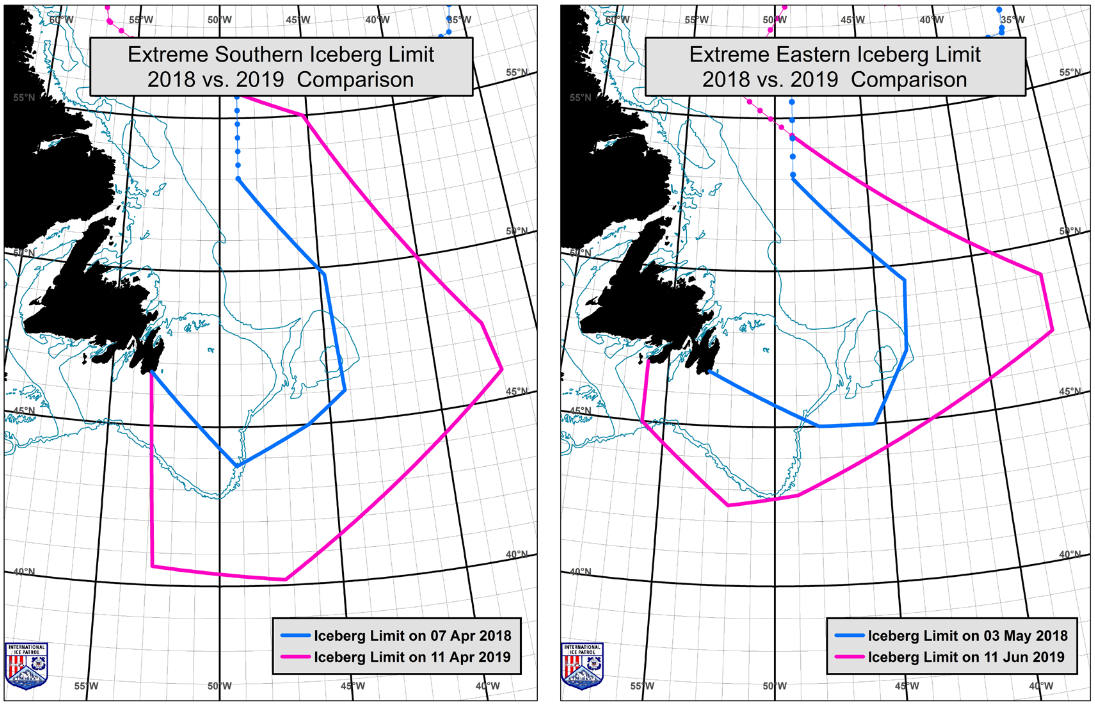

Figure 2-4. Southern and eastern maximum Iceberg Limit extent for 2018 (blue) and 2019 (magenta).

Limit; a more extensive Limit requires more flight hours.

Figure 2-4 compares the maximum extent of the Iceberg Limit for 2018 and 2019. The Iceberg Limit reached its southernmost latitude of 40°10'N on 11 April (**Figure 2-4**, left panel). The 2019 Iceberg Limit reached its easternmost extent of 36°50'W longitude on 11 June (**Figure 2-4**, right panel), and its westernmost extent of 62°45'W on 25 June (not shown).

Highlighting the extreme nature of the 2019 Ice Year, for the first three weeks in early April, the southern Iceberg Limit exceeded the extreme climatological limit by over 40 NM. Again in mid-June, the eastern Iceberg Limit exceeded the extreme climatological limit by more than 20 NM. Iceberg Limit climatology data is based on the period from 1975-2009.

Ice Year Environmental Conditions Overview

At IIP's Annual Partner Meeting on 12 December 2018, the CIS Senior Ice Forecaster provided a seasonal outlook for expected sea ice and iceberg conditions for 2019. CIS expected near normal sea ice extent for the Canadian East coast. The CIS forecaster noted that sea ice development in Hudson and Davis Strait was one to two weeks ahead of normal. Further, the North Atlantic Oscillation Index (NAOI) was projected to remain positive, bringing colder temperatures and offshore winds in early winter. These facts, coupled with unusually cold sea surface temperatures (SST) along the Labrador Coast and in Davis Strait, supported an outlook of 'near to above normal' iceberg conditions for 2019. (CIS, 2018a).

The 2019 Ice Year was characterized by a series of abrupt and dramatic shifts, both in sea ice coverage and icebergs drifting south of 48°N. Daily air temperature departures from mean at two key locations along the east coast of Canada show how air temperature influenced sea ice growth early in the year. **(Figure 2-5).** (NOAA/NWS, 2019a). Below normal temperatures, particularly in Goose Bay (**Figure 2-5, top panel)**, from October through early December caused sea ice to develop rapidly; around two weeks ahead of normal through mid-December (CIS, 2019a).

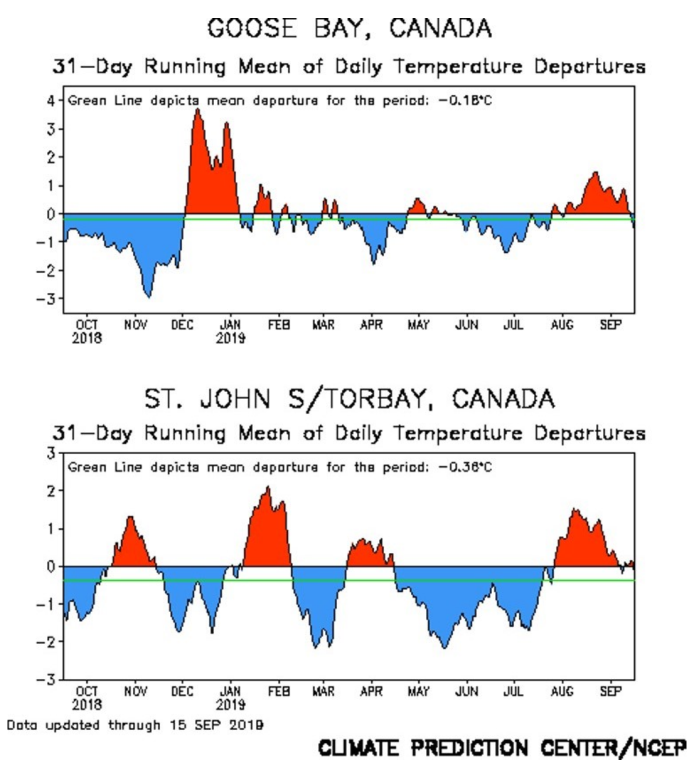

Figure 2-5. 31-day running mean of daily temperature departures for Goose Bay (top) and St. John's, Newfoundland (bottom). (NOAA/NWS, 2019a)

Beginning in late December, above normal temperatures persisted at both sites until the second week of February. Northwesterly winds during the second part of February brought favorable conditions for above median sea ice growth. Air temperatures remained mostly below normal at both locations, causing sea ice coverage for East Newfoundland and Southern Labrador Sea waters to fluctuate near the median through mid-March **(Figure 2-6)**.

Sea ice reached its southernmost extent in mid-March but retreated rapidly during the third week of March due to strong storm systems. The classic sea ice tongue, typically present during extreme Ice Years, formed over the offshore branch of the Labrador Current. However, by 26 March, sea ice had rapidly retreated to above 50°N and remained so for the remainder of the season. **(Figure 2-7)**.

Examining sea ice coverage for Eastern Newfoundland waters alone highlights the dramatic changes in this region **(Figure 2-8)**. The three-week period from 26 February through 12 March significantly exceeded median values; an abrupt decrease in coverage followed during the week of 19 March. This extensive, above-average sea ice coverage in the region at this critical time of the year was most likely a significant contributing factor to the extreme season.

The number of icebergs drifting south of 48°N followed similar dramatic monthly variability. The sudden reduction in sea ice coverage in mid-March left many icebergs adrift in the Labrador

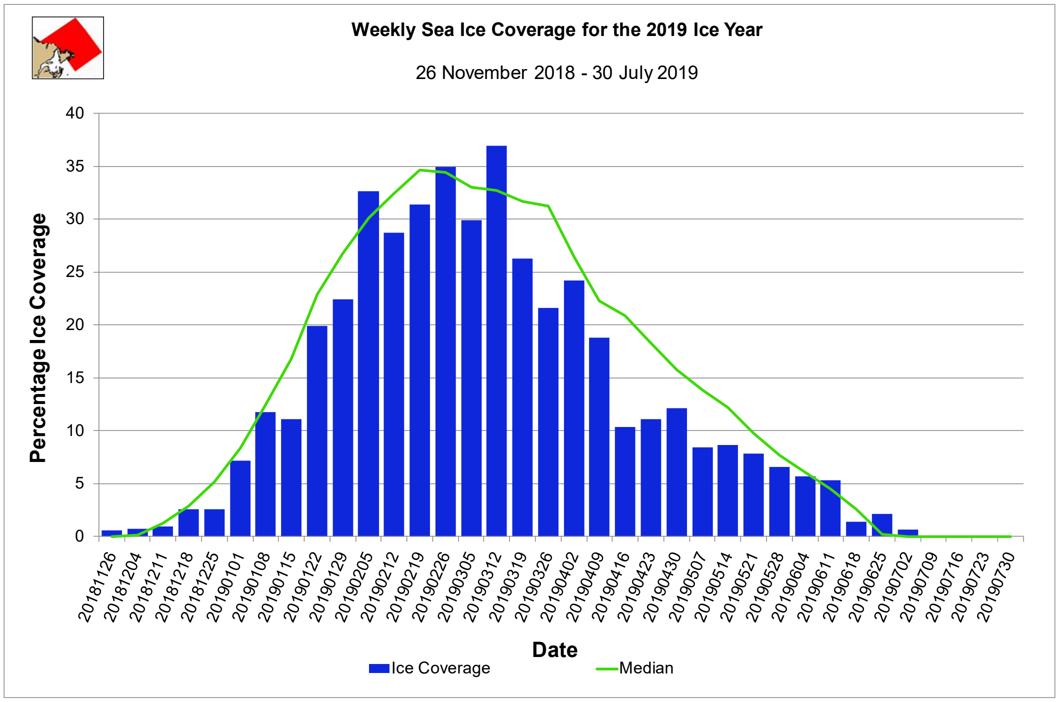

Figure 2-6. Weekly ice coverage for East Newfoundland and Southern Labrador Sea waters for 2018-2019. The percent coverage is relative to the area shaded in red in the upper left map of this figure (CIS, 2019b).

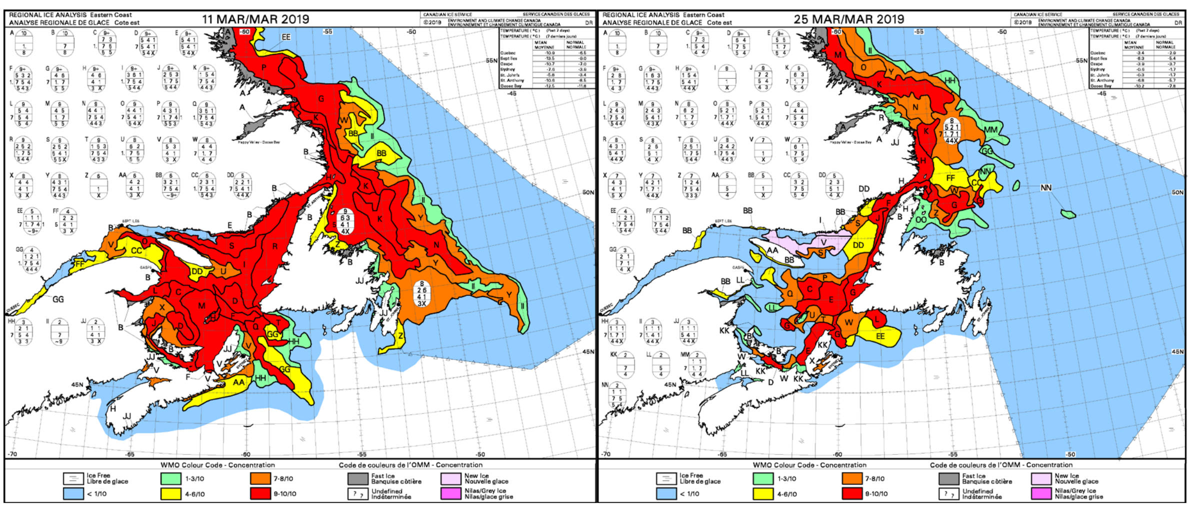

Figure 2-7. CIS Weekly Regional Ice Analyses for the Canadian East Coast for 11 March (left panel) and 25 March (right panel). (CIS, 2019c)

Current, leading to a large number of icebergs crossing into the shipping lanes for March and April. The presence of sea ice along the Labrador Coast in early April further north, led to an extreme number of icebergs observed or drifting south of 48°N in May. Remarkably, 792 icebergs crossed this latitude in May alone. The May peak is attributed to an extreme iceberg population, coupled with IIP and

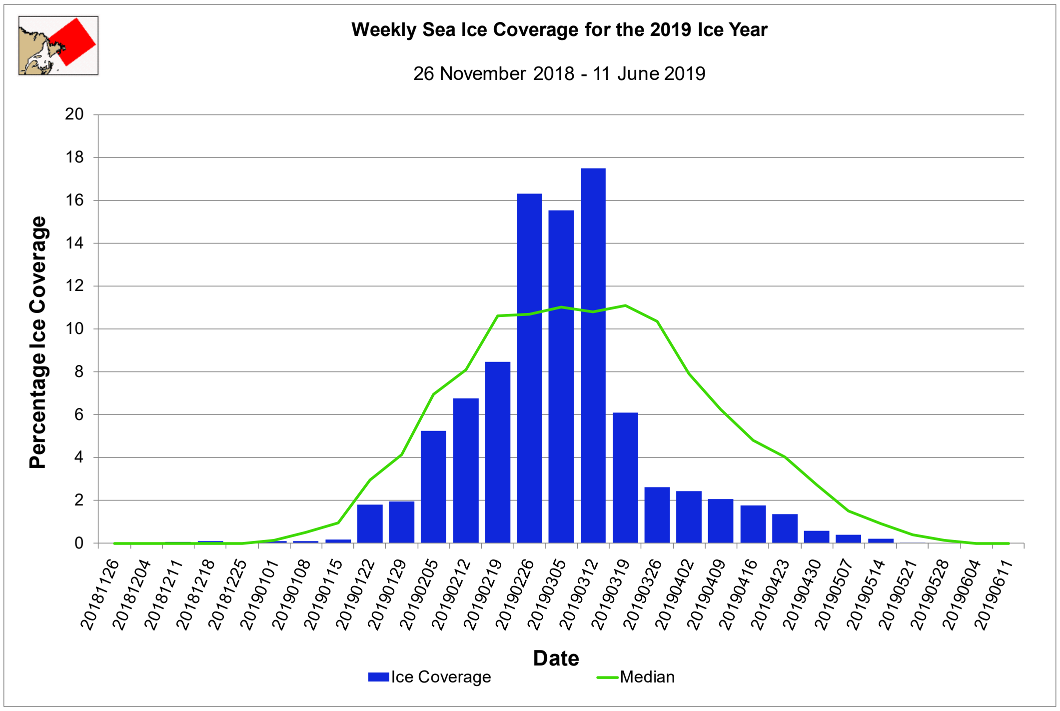

Figure 2-8. Weekly ice coverage for East Newfoundland waters only for 2018-2019. The percent coverage is relative to the area shaded in red in the upper left map of this figure (CIS, 2019b).

commercial reconnaissance patterns. Just as rapidly as the iceberg numbers increased in May, they experienced a similar decline through June and July. The next section details the quarterly ice and environmental conditions that led to this extraordinary Ice Year.

Quarterly Environmental Summaries October – December 2018

On 01 October, CIS had primary responsibility for disseminating daily Iceberg Limit warnings. CIS tracked 58 icebergs in BAPS to open the Ice Year.

Two isolated growlers, sighted by PAL Aerospace on 21 September, established the southeastern point of the Iceberg Limit at 50°N, 46°W outside of the 1,000 m depth contour. The remainder of the iceberg population, observed by satellite, was distributed within 150 NM of the Labrador and Newfoundland coasts.

The Ice Year started with below normal air temperatures from October through mid-December, causing sea ice to develop in the western parts of Lake Melville (Labrador) approximately two weeks earlier than normal (CIS, 2019a). Above to near normal air temperatures slowed sea ice growth to below median for the remainder of December **(Figure 2-6)**. By the end of December, sea ice had expanded to the southern part of Labrador, but had not yet entered the Strait of Belle Isle.

In October and November, PAL Aerospace conducted several iceberg reconnaissance flights on behalf of CIS, locating isolated icebergs near the 1,000 m contour. The drift of these icebergs caused the Iceberg Limit to protrude southeastward, although remaining north of 50°N for the entire quarter. With the growth of sea ice in December, reconnaissance focused on areas outside of the sea ice edge. By the end of December, only two icebergs remained in open water and the Iceberg Limit receded northward to 54°N. No icebergs were sighted or drifted south of 48°N during the first quarter of the Ice Year.

January-March 2019

Above normal air-temperatures in the region, recorded at both Goose Bay and St. John's, held sea ice coverage to below median until the first week of February. Persistent northwesterly winds, resulting from a low-pressure system tracking across Labrador in late January, brought sea ice coverage to above median by 05 February. Similar storm systems in mid-February caused sea ice coverage to fluctuate above and below median coverage, reaching maximum coverage for the year on 12 March **(Figure 2-6).** Sea ice continued to expand southeastward, creating an elongated tongue over the cold Labrador Current in Flemish Pass. A patch of thin first-year sea ice, approximately 60 NM long, drifted to its southernmost latitude of 42°50'N on 18 March (CIS, 2019c).

A low-pressure system in early-March followed a more northerly track than the February storms due to a strong high-pressure system south of the Canadian Maritimes. This resulted in several days of strong southwesterly winds over the Grand Banks that caused a rapid break-up of the sea ice tongue **(Figure 2-7)**. The sea ice edge retreated to north of 50°N by 26 March. The difference in mean wind direction between February and March highlights this shift in the atmospheric pattern that drove these changes in sea ice coverage **(Figure 2-**

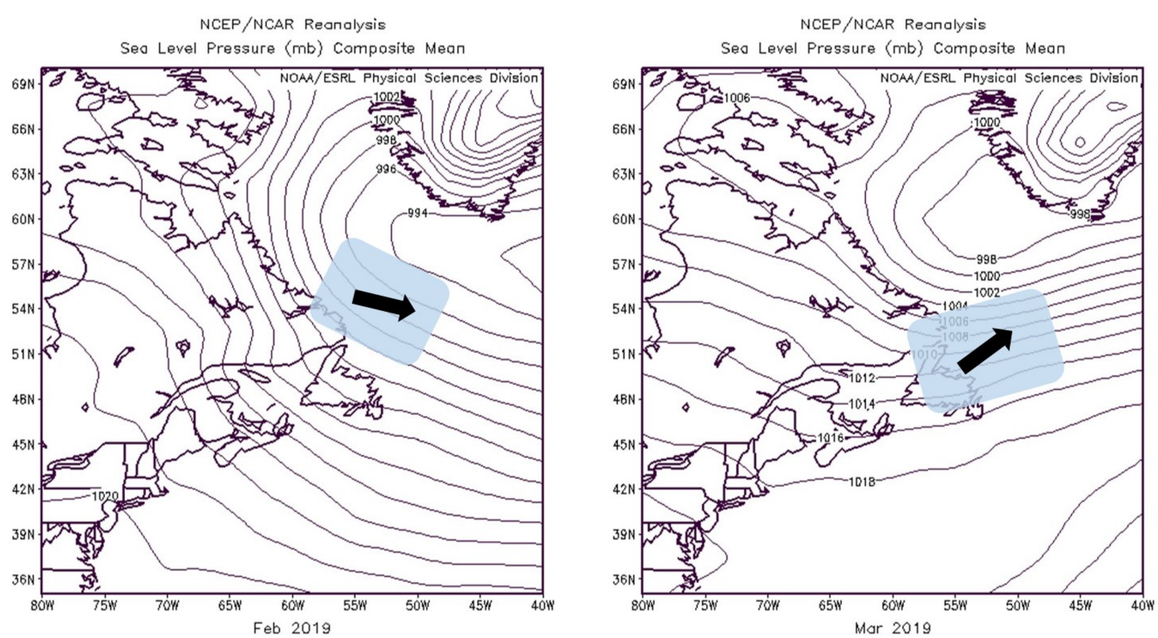

Figure 2-9. Composite Mean Sea Level Pressure for February (left panel) and March (right panel) 2019. Approximate wind directions are indicated by an arrow within the blue shaded regions. Mean wind speeds in the shaded regions were approximately 13 kts for February and 15 kts for March. (NOAA/ESRL PSD, 2019)

9) (NOAA/ERSL PSD, 2019). In this case, cold northwesterly winds from the Canadian continent in February brought conditions favorable for sea ice growth, while relatively warm southwesterly winds in March promoted sea ice deterioration.

PAL Aerospace iceberg reconnaissance flights beginning in mid-January observed only isolated icebergs within the advancing sea ice in the Newfoundland Sea, with none observed in the offshore branch of the Labrador Current until mid-February. Beginning on 19 February, aerial and satellite reconnaissance observed an increasing population of icebergs, mostly within sea ice, with only a few reported outside of the sea ice edge within the offshore branch of the Labrador Current. At the end of February, IIP estimated that 271 icebergs were present throughout the OPAREA. Though the Iceberg Limit extended to below 45°N, only 15 icebergs had been sighted or drifted south of 48°N during February.

IIP IRDs began deploying to the OPAREA in late February to verify the location of the southern and southeastern Iceberg Limits. The second IRD in mid-March included a northern survey flight along the Labrador Coast to 60°N. Results from this flight gave the first indicator of a significant iceberg population, poised to drift southward into the transatlantic shipping lanes. The *Iceberg Reconnaissance Operations* of this report (Section 4), provides a detailed narrative of each deployment for the year. PAL Aerospace continued its ice reconnaissance flights in support of the Grand Banks Oil and Gas Industry. C-CORE augmented aerial reconnaissance with the European Space Agency's (ESA) Sentinel-1 (SN1) satellite imagery along the 1,000m contour further north.

At the end of March, IIP estimated that 1,054 icebergs were present throughout the IIP OPAREA. The Iceberg Limit expanded southward to 41°N and eastward to 40°W. A total of 390 icebergs were sighted or drifted south of 48°N during the month of March.

April - June 2019

Sea ice remained north of 50°N for the remainder of the year and during the first week of April an elongated patch of thin first-year ice with 7-8/10 concentration extended 250 NM east of the Newfoundland Northern Peninsula at around 51°N (CIS, 2019c). A 30 NM section of open water separated the main pack of medium first-year sea ice at 52°N, along southern Labrador. This ice extended out to around 200 NM from the Labrador Coast, causing sea ice coverage to increase to near the median level on 02 April, and likely contributed to the dramatic increase of icebergs observed drifting into the shipping lanes in April through mid-May.

Satellite and aerial iceberg reconnaissance continued throughout the quarter. PAL Aerospace began conducting regular twice-daily flights on 19 April, generally between 47°N and 49°N in support of Grand Banks oil and gas facilities. In contrast, with the Iceberg Limit expanding both southward and eastward, IIP focused its patrols near the Iceberg Limits, leaving little opportunity to verify the iceberg population in the interior part of the OPAREA (in the Newfoundland Sea and northern Grand Banks). At the end of April, IIP estimated that 1,426 icebergs were in the OPAREA. During the month of April, 274 icebergs were sighted or drifted south of 48°N.

The daily number of icebergs crossing south of 48°N accelerated steadily from late-April through early-May, reaching a maximum of 116 icebergs in a single day on 13 May. In keeping with the sudden changes in sea ice conditions observed in 2019, the number of icebergs drifting into the shipping lanes then decreased sharply during the last week of May and continued to decline through June. At the end of May, IIP estimated that 1204 icebergs were in the OPAREA. During May, 792 icebergs were sighted or drifted south of 48°N.

A shift in atmospheric conditions along the Labrador Coast in early May caused this rapid decrease in the number of icebergs crossing into the shipping lanes during late May and June. Persistent high pressure over Greenland (6-8 mb above normal) and low pressure near the Flemish Cap further south (5 mb below normal) through June **(Figure 2-10)** established a predominantly onshore wind pattern. This pattern prevented the

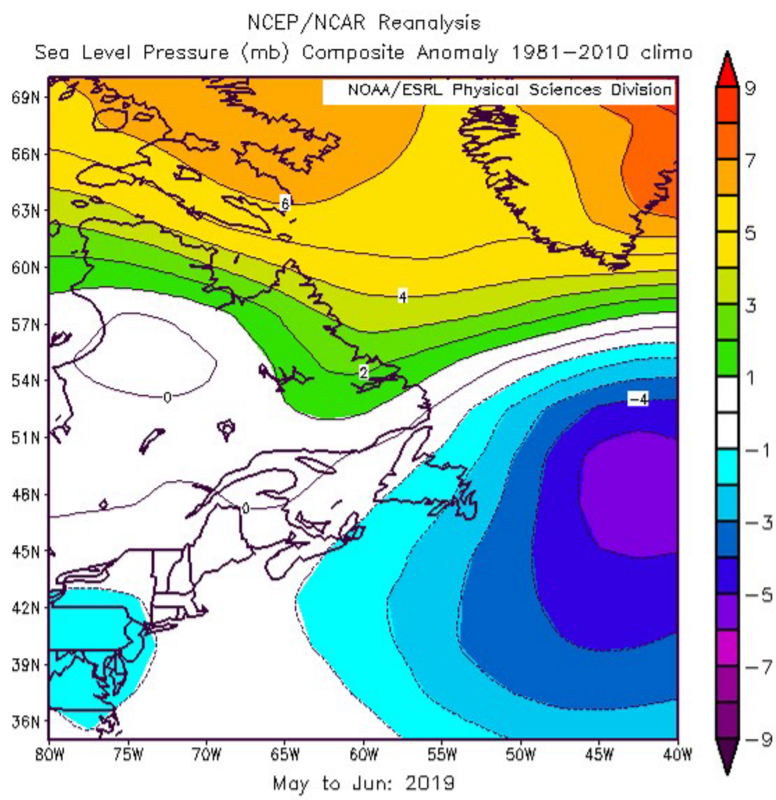

Figure 2-10. Composite Sea Level Pressure Anomaly (mb) for May through June referenced to 1981-2010 climatology. Higher than normal pressure over Greenland and below normal pressure east of Flemish Cap brought persistent easterly (onshore) winds from May to June. (NOAA/ESRL PSD, 2019)

large population of icebergs observed along the Labrador Coast in March and April from accessing the offshore branch of the Labrador Current for further transport south into the shipping lanes.

Further illustrating this situation, the 500 mb NAOI between 03 March and 30 June clearly shows the reversal in atmospheric pressure and resulting wind directions during this critical time of the Ice Year (NOAA, 2019a). The NAOI represents the difference in atmospheric pressure between northern areas of the Atlantic Ocean (Greenland and Iceland) and the central Atlantic (Azores) (NOAA, 2019b). With exception of a 9-day period during the second week of April, the NAOI was positive through 26 April. A positive NAOI is generally associated with offshore winds, sea ice growth, and favorable conditions for icebergs to enter the offshore branch of the Labrador Current for transport south. The opposite situation, a negative NAOI, from 27 April to 30 June, resulted from the atmospheric pattern, supporting onshore winds that drove sea ice and icebergs inshore. Despite a significant iceberg population near Hamilton Bank, this wind pattern ultimately prevented many of these icebergs from drifting further south. **(Figure 2-11)**. The last iceberg crossed 48°N on 22 June. During June, 44 icebergs were sighted or drifted south of 48°N.

Notably, the NAOI remained negative throughout most of the summer, coinciding with extreme weather events across the North Atlantic. During the last week of July, a record-setting heat wave began in Europe, due to anomalously high pressure over the European continent and low pressure over the central

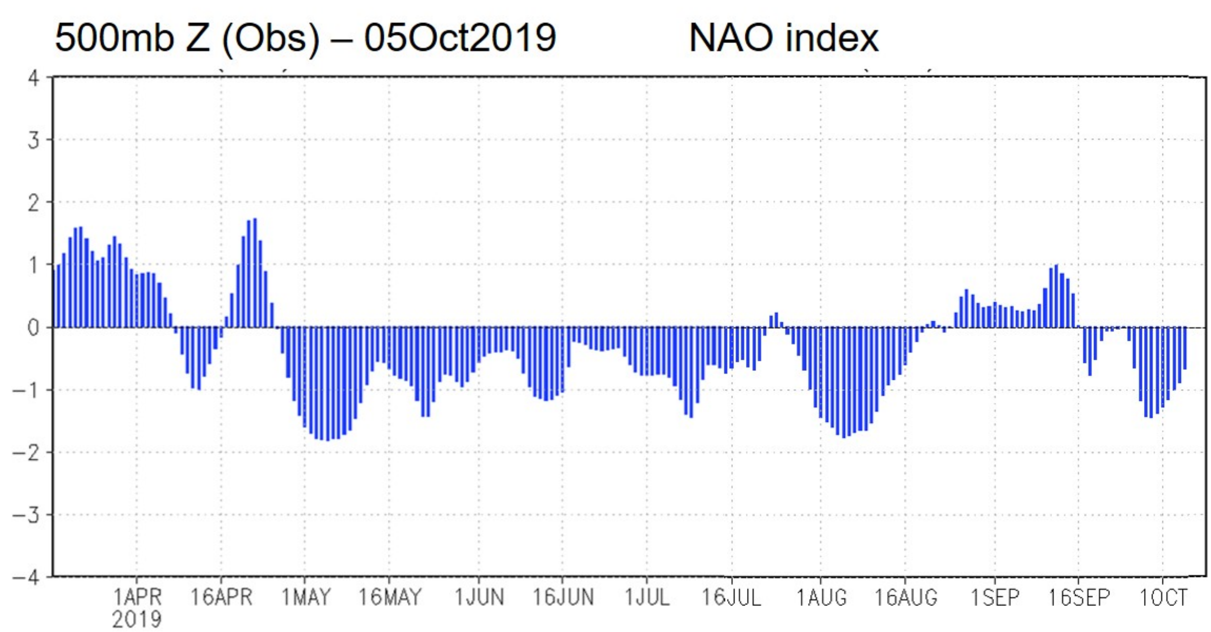

Figure 2-11. 500 mb NAOI on 05 October 2019 showing NAOI for 03 March through 05 October 2019. The 500 mb NAOI provides a statistical representation of differences in atmospheric pressure over the North Atlantic Ocean. Positive values are associated with offshore winds (03 March - 26 April) and negative values (27 April – 22 July) are associated with onshore winds. (NOAA/NWS, 2019b)

Atlantic (south of Greenland), bringing warm air northward. The high pressure anomaly shifted westward towards Greenland in early August, reaching an absolute minimum on 05 August. Persistent high pressure over Greenland led to below normal cloud cover, which accelerated melting over the Greenland ice sheet surface. The National Snow and Ice Data Center (NSIDC) estimated melt runoff of 55 billion tons between 30 July and 03 August; much higher than average (Scambos, 2019).

Oceanographic Observations

In addition to atmospheric conditions that affected the number of icebergs entering the shipping lanes, the effect of key oceanographic features in IIP's southern OPAREA created hazardous conditions for shipping from April through early June.

In April and May, IIP aerially deployed three Surface Velocity Program (SVP) drifting buoys with drogues centered at 50 m along the 1,000 m depth contour **(Figure 2-12)**. The Canadian Coast Guard (CCG) deployed three additional SVP buoys by ship at IIP's request. CCG deployed one, with a 50 m drogue, on the 1,000 m depth contour in a similar location as IIP's aerial deployments. The other two had 15 m drogues; CCG deployed these on the shelf, near the coast of Newfoundland to measure the inshore branch of the Labrador Current. IIP collected hourly Global Positioning System (GPS) buoy positions each day via the Iridium satellite system.

In June and July, as part of the Department of Homeland Security Science and Technology (DHS S&T) Directorate iceberg tagging campaign, a C-CORE team deployed 10 SVP buoys,

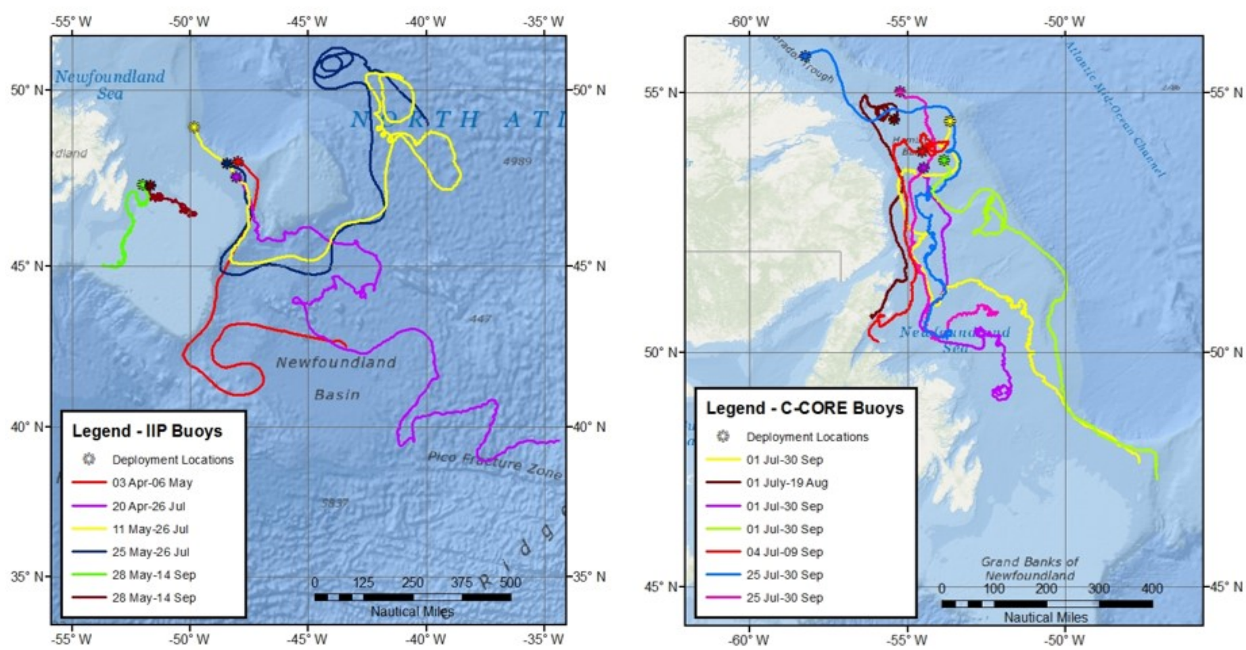

Figure 2-12. Tracks of SVP buoys deployed by IIP and Canadian Coast Guard (left) and C-CORE (right). Current estimates from these buoys provided valuable input data for IIP's iceberg drift model.

while performing iceberg tagging operations. C-CORE supplied seven of these SVP buoys; while the University of California, San Diego (UCSD) provided three additional SVP buoys. All 10 SVP buoys deployed by C-CORE had drogues centered at 15 m in depth. IIP acknowledges the Canadian Coast Guard, C-CORE and UCSD for their support in providing and deploying SVP buoys, both for the tagging project and for inclusion into IIP's iceberg drift model. Section 4 provides additional details on the DHS S&T iceberg tagging campaign.

Of the 16 SVP buoys deployed in 2019, 15 functioned normally, providing key current data that IIP incorporated into its iceberg drift model. One aerially deployed buoy yielded only sporadic GPS positions. IIP did not use data from this SVP buoy for drift model currents.

The interaction between the cold, southward flowing Labrador Current and the warm, northeastward flowing North Atlantic Current typically results in a complex oceanographic environment; the 2019 Ice Year was no exception. Both the SVP buoy drift **(Figure 2-12)** and Advanced Very-High Resolution Radiometer (AVHRR) SST imagery **(Figure 2-13)** clearly show this complexity. As seen in the AVHRR imagery in early April, the Labrador Current extended southward to near 40°N, almost 180 NM south of the Tail of the Grand Banks, bringing icebergs into the shipping lanes **(Figure 2-13).** The black-colored ribbon showing water with SST less than 2°C depicts the southernmost extent of the Labrador.

Buoy drift and SST analysis provided evidence that the Labrador Current appeared to weaken and shift northward beginning in early April throughout the remainder of the season. In April, three eastward flowing offshoots from the main branch of the Labrador Current developed south of Flemish Cap. These features likely contributed to the weakening of the Labrador Current and further complicated the oceanography in the area. The U.S. Naval Oceanographic Office (NAVO) Ocean Features Analysis product for 01 June highlights the complexity of the region showing five cold-core eddies **(Figure 2-14)**. One of these eddies formed near 40°W, causing icebergs to drift eastward beyond this longitude. The

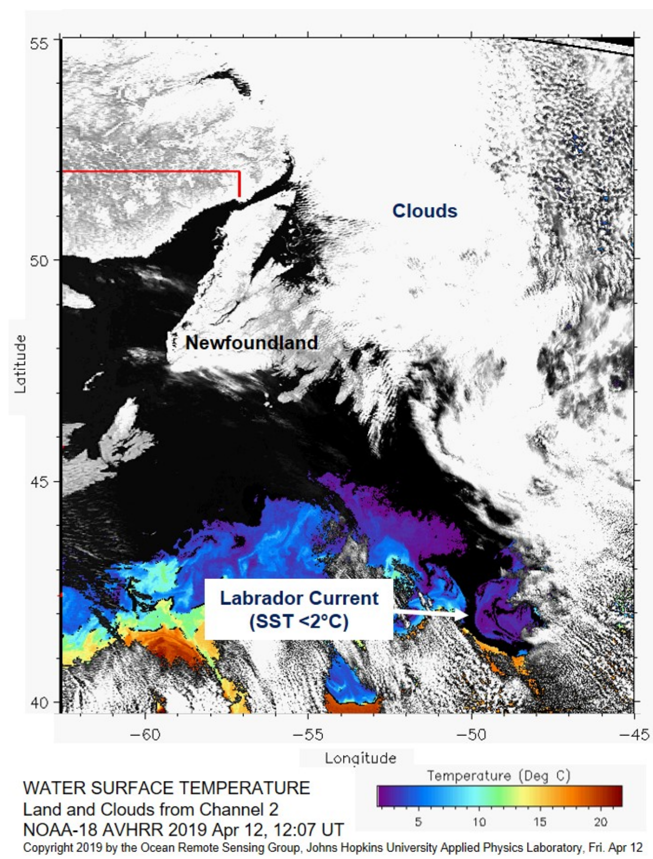

Figure 2-13. Advanced Very High Resolution Radiometer Sea Surface Temperature image for 12 April 2019. Land is light gray, cloud cover bright white, and black indicates cold water less than ~2°C. (JHU, 2019)

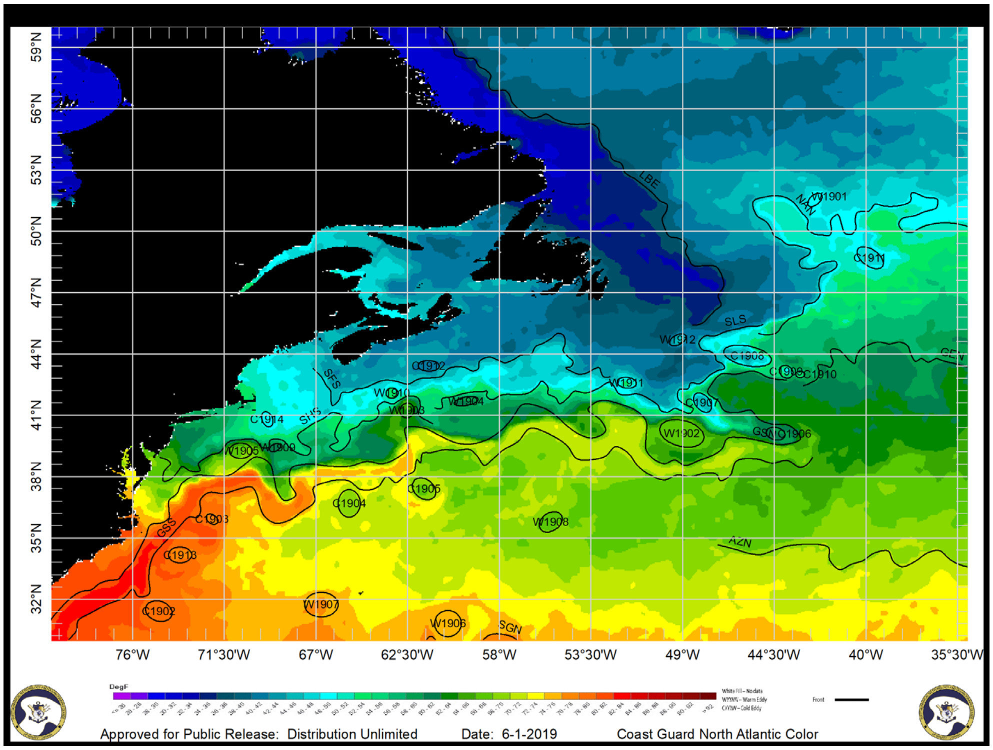

Figure 2-14. US NAVO Oceans Features Analysis for 01 June 2019. Numerous warm and cold core eddies show the oceanographic complexity in the area. The Cold Core eddy (C1911) centered at 40ºN played a key role in the eastward expansion of the Iceberg Limit in June. (NAVO, 2019)

Iceberg Limit reached its maximum eastward extent on 11 June because of these features.

The track of two SVP buoys between 01-11 June illustrates the path followed by icebergs during this time. Viewing the SVP buoy tracks and the Iceberg Limit, overlaid onto an SST image on 03 June provided insight to the environmental conditions at work **(Figure 2-15)**. The UK Meteorology Office (UKMO) provided SST data as part of the Group for High Resolution SST (GHRSST). The GHRSST SST data were obtained from the NASA Earth Observing System Data and Information System (EOSDIS) Physical Oceanography Distributed Active Archive Center (PO.DAAC) at the Jet Propulsion Laboratory,Pasadena, CA.

At the end of June, IIP estimated that 1,816 icebergs remained in the OPAREA. However, with the weakening Labrador Current, the number of icebergs drifting south of 48°N decreased rapidly. During June, 44 icebergs were sighted or drifted south of 48°N.

July – September 2019

Although air temperatures in July were slightly below normal, sea ice coverage continued to decline and did not influence iceberg conditions in IIP's OPAREA for the remainder of the year. Winds remained southeasterly and predominantly onshore for July and August, keeping the iceberg population close to the Labrador Coast. At the beginning of the quarter, 26 icebergs remained south of 48°N, with the majority of these located

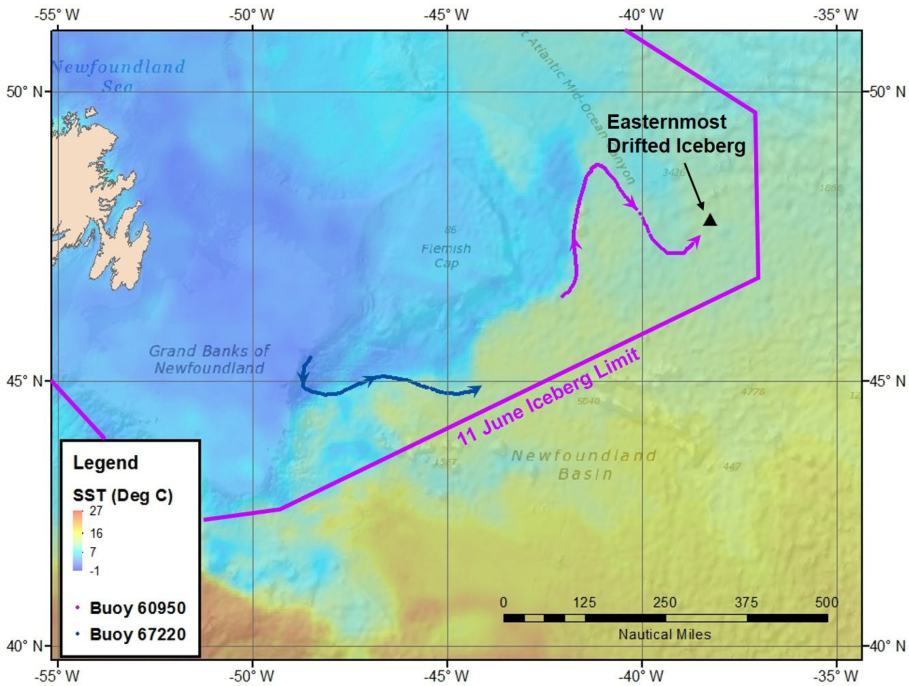

Figure 2-15. GHRSST image from 03 June with tracks of two SVP buoys from 01-11 June and easternmost Iceberg Limit. (UKMO, 2019).

within a few miles of the Avalon Peninsula. Over 1,700 icebergs remained north of 48°N and mostly confined to within 60 NM of the Newfoundland and Labrador Coast. Of these, 35 icebergs remained in the Strait of Belle Isle, posing a hazard to ships transiting the region to/from the Gulf of St. Lawrence.

IIP conducted a Northern Survey flight on 10 July to assess the remaining iceberg population. This patrol flew along the Labrador Coast to 59°N, detecting 361 icebergs. Since many of these icebergs were grounded or well inside the offshore branch of the Labrador Coast, IIP determined that the remaining iceberg population did not pose a serious threat to shipping and concluded its reconnaissance season. At the end of July, 814 icebergs remained in the OPAREA. No new icebergs were sighted or drifted south of 48°N for the remainder of the Ice Year. The total number of icebergs sighted or drifting south of 48°N was 1,515.

In summary, **Figure 2-16** graphically shows the number of icebergs estimated to have drifted south of 48°N by month for the 2019 Ice Year. A solid red line depicts the monthly averages for the entire 119 year record from 1900 through 2018. The monthly average for the modern reconnaissance era (1983-2018) is also included as a solid green line. The 2019 monthly totals for March, April, and May significantly exceeded the monthly averages for both periods. The variability within these months is also noteworthy and reflects the abrupt shifts in wind direction and sea ice coverage experienced during the spring. **Table 2-1** summarizes extreme iceberg positions, both sighted and drifted by modeling, along with the sighting source.

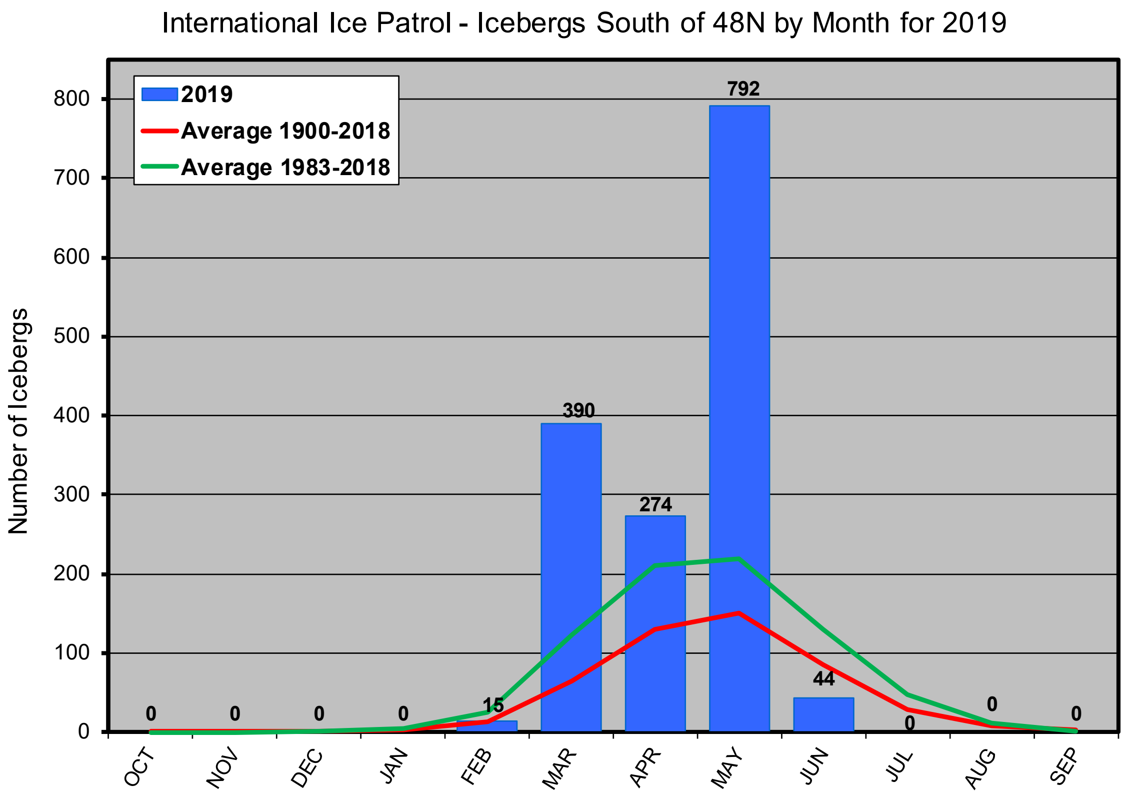

Figure 2-16. Icebergs south of 48°N by month for 2019 (1515 total). Monthly averages for the entire historical dataset (1900-2018) and for the modern reconnaissance era (1983-2018) are shown as red and green solid lines, respectively.

2019 Extreme Icebergs	Sighted				Drifted			
	Source	Date	Latitude	Longitude	Source	Date	Latitude	Longitude
Southern	M/V MSC BUSAN	18-May-19	41-29.7N	50-18.2W	IIP HC-130J	11-Apr-19	41-15.8N	48-18.7W
Eastern	Satellite (Sentinel-1B)	22-Mar-19	49-00.0N	42-40.6W	IIP HC-130J	11-Jun-19	47-53.4N	38-24.8W
Western	IIP HC-130J	25-May-19	50-02.5N	61-03.2W	IIP HC-130J	25-May-19	50-02.5N	61-03.2W

Table 2-1. 2019 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.

3. Operations Center Summary

The IIP OPCEN is the hub of IIP's information processing and dissemination. IIP OPCEN watch standers receive iceberg reports from a variety of sources, process the information, and create daily iceberg warning products that are distributed to mariners. Iceberg reports are received from IRD flights, Commercial Reconnaissance flights, Synthetic Aperture Radar (SAR) satellite imagery, and vessel sighting reports. After these reports are ingested, icebergs are added to IIP's iceberg database and processed through the drift and deterioration models on BAPS. Iceberg Limits are then defined to contain the modeled iceberg positions and daily NAIS warning products are created and distributed to mariners via numerous means.

Products and Broadcasts

IIP and CIS partner to create and distribute two versions of the daily Iceberg Limit in a text and graphic format. IIP's defined Ice Season encompasses the time IIP is actively deploying to St. John's, NL and IIP is producing products; typically when icebergs threaten the transatlantic shipping lanes. This year, the Ice Season ran from 05 February to 28 August (while the deployment period was 26 February – 11 July). During the remainder of the 2019 Ice Year, termed "out of season", CIS produced products, as the iceberg population is typically found farther north along the Canadian coast.

The text version, NAIS-10 bulletin, lists the latitude and longitude points of the Iceberg Limit and sea ice limits. The graphical version, NAIS-65 graphic, shows the forecasted Iceberg Limit and estimated concentrations of icebergs in 1˚x 1˚ latitude x longitude gridded bins. Examples of the NAIS-65 iceberg charts can be found in Section 7 of this report. Both products include information regarding the most recent reconnaissance, including the date, type, and coverage area. These two products are released between 1830Z and 2130Z and are valid for 0000Z the following day. During the 2019 Ice Season, all but one scheduled broadcast was met, with 99% of iceberg warning products released on time. On 26 March, a database resynchronization between CIS and IIP resulted in the late release of products at 2300Z.

IIP publicly distributes the NAIS iceberg warning products by a variety of methods. The NAIS-10 iceberg bulletin is broadcast over SafetyNET, Navigational telex (NAVTEX), Simplex Teletype Over Radio (SITOR), and posted on the internet. The NAIS-65 iceberg chart is broadcast over radio facsimile (Radiofax) and posted online. Both products are posted on IIP's website (https://www.navcen.uscg.gov/?pageName=iipProducts). Additionally, the NAIS-65 iceberg chart is available on the National Weather Service (NWS) Marine Forecast (http://tgftp.nws.noaa.gov/fax/marsh.shtml) and NOAA Ocean Prediction Center (OPC) (www.opc.ncep.noaa.gov/Atl_tab.shtml) websites. Keyhole Markup Language

(KML) files and ArcGIS shapefiles of the Iceberg Limit and sea ice limit are available on the IIP website for use with compatible mapping software. The daily Iceberg Limit is also a displayable layer within NOAA's Arctic Environmental Response Management Application (ERMA) mapping tool, (https://response.restoration.noaa.gov/maps-and-spatial-data/environmental-response-management-application-erma/arctic-erma.html).

Product Changes for 2019

Each year, IIP, in conjunction with CIS and the Danish Meteorological Institute (DMI), reviews products, procedures, and processes to improve content, delivery, and value to the mariner. For 2019, the most significant change to the products was the implementation of satellite reconnaissance from DMI into the creation of the Estimated Iceberg Limit south of Greenland. Approximately twice per week, DMI provided updates to the Estimated Limit based on Sentinel-1 reconnaissance and the results of a ship-iceberg discrimination algorithm. This satellite-derived limit was incorporated into the daily products, providing a relevant, reconnaissance-based limit to mariners in the North Atlantic and making history as the first Iceberg Limit to be derived solely by satellite reconnaissance.

Iceberg Reports

The IIP OPCEN received reports of icebergs from a variety of sources including IRD flights, commercial flights, ship reports, and satellite reconnaissance from IIP, CIS, and commercial sources (**Figure 3-1**). Collecting and processing iceberg reports from this wide array of sources bolsters IIP's reconnaissance mission. An important source contributing to IIP's successful safety record are the reports received from the maritime community transiting through the OPAREA. A list of the individual ships that made voluntary iceberg reports during the 2019 Ice Season is compiled in **Appendix A**.

Iceberg reports are received in various formats and are converted into a standard iceberg message (SIM) that contains information on the reported iceberg's time of sighting, position, size, shape, and any other amplifying information. Depending on the reporting source and time of year, SIMs may report zero icebergs or hundreds of icebergs. Overall, during the 2019 Ice Season, IIP received, analyzed, and processed 777 SIMs, 684 of which included iceberg sightings, approximately a 36% increase in SIMs with icebergs from the 2018 Ice Season. **Figure 3-2** provides a summary showing the number of SIMs received compared with the number of icebergs that drifted south of 48˚N for each year since 2008. The first columns of **Figure 3-1** and **Table 3-1** show the distribution of these iceberg messages by reporting source.

As discussed in Section 2, the 2019 Ice Season has been deemed an "Extreme" season in accordance with the updated season severity definitions (IIP, 2018). **Figure 3-3** shows the distribution of SIMs received and icebergs reported over the course of the season. Note the increase in reported icebergs from the end of April until mid-May. In June and July there were isolated spikes of increased numbers of icebergs. These can

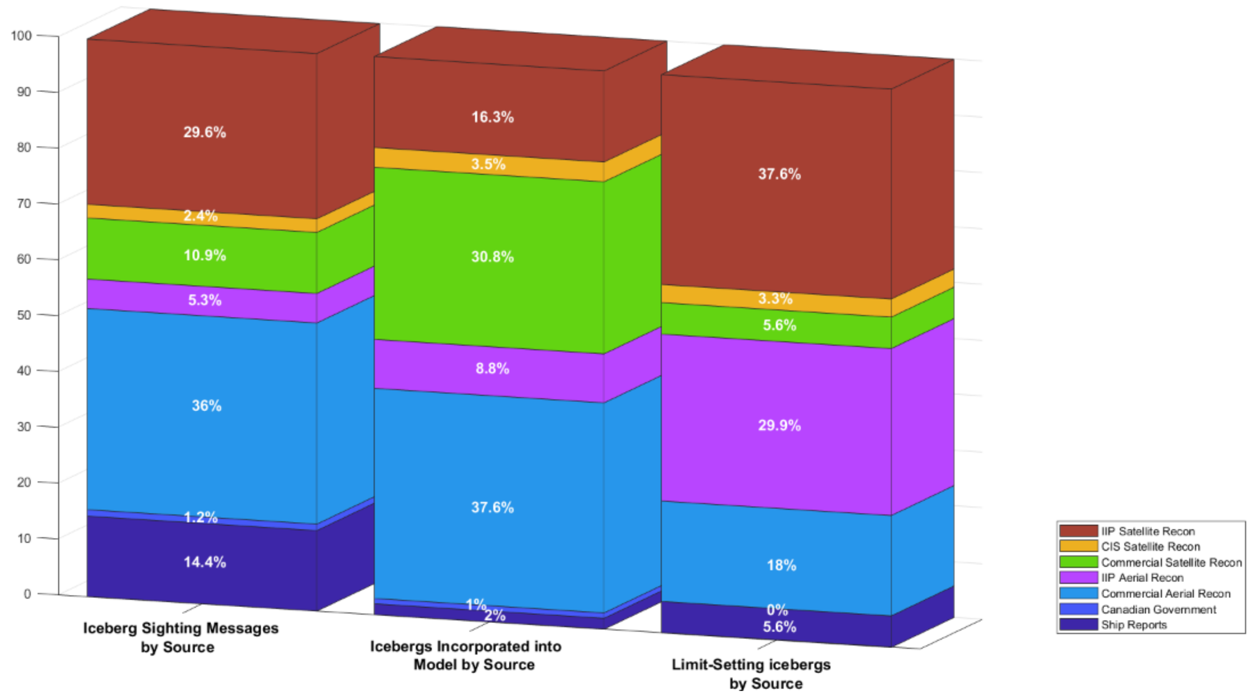

Figure 3-1. 2019 Standard Iceberg Message (SIM) information. The first bar (left) shows the percentage of SIMs received from each source. The second bar (center) shows the percent contribution from each source to the total number of iceberg observations that were included into the model. The third bar (right) shows the percentage of limit-setting icebergs reported by each SIM source. Here, the Canadian Government data does not include government funded commercial reconnaissance which is included in the Commercial Aerial Recon category. The Ship Report row includes SIMs from USCGC JUNIPER as part of the DHS S&T Iceberg Tagging Campaign, as well as reports from vessels contracted by the Oil and Gas Industry to track individual icebergs in the vicinity of the oil rigs on the Grand Banks.

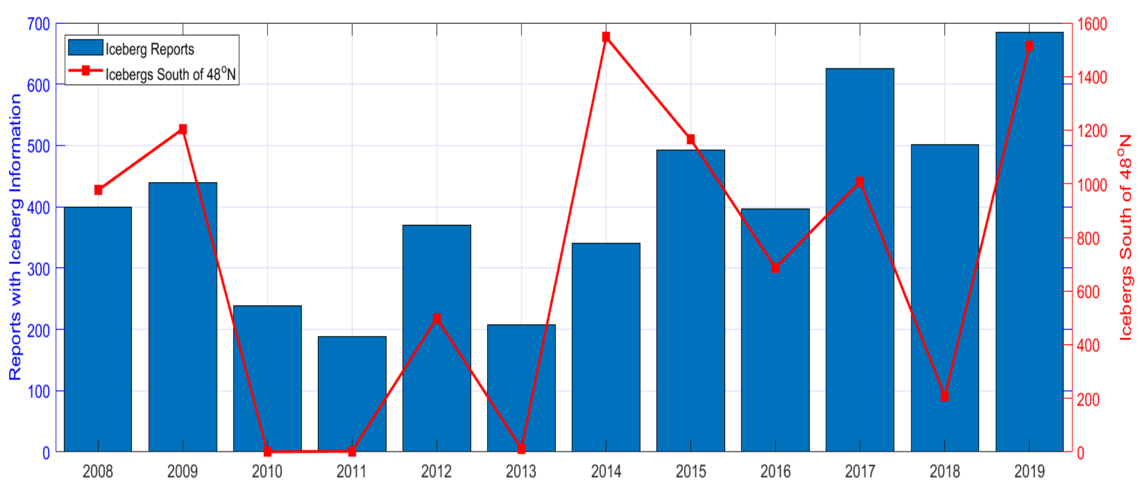

Figure 3-2. Record of the number of SIMs received that contained iceberg sigthings (blue bars) and the number of icebergs observed south of 48˚N (red line). Note that 2019 had the highest number of SIMs containing iceberg information and the second highest number of icebergs passing south of 48˚N.

Source	Total SIMS	Icebergs Incorporated into Model	Average Ice-bergs Per SIM	Limit Setting Icebergs
IIP Satellite Reconnaissance	230	3945	17	347
CIS Satellite Reconnaissance	19	858	45	30
Commercial Satellite Reconnaissance	85	7463	88	52
IIP Aerial Reconnaissance	41	2122	52	276
Commercial Aerial Reconnaissance	280	9110	33	166
Canadian * Government	9	234	26	0
Ship Reports **	112	473	4	52
Total	**777**	**24206**	**31**	**923**

Table 3-1. Detailed information of 2019 icebergs received from each SIM source. * The Canadian Government row does not include Government-funded Commercial Aerial Reconnaissance and mostly is made up of Canadian Coast Guard reports. ** The Ship Report row includes eight SIMs with 204 icebergs from USCGC JUNIPER as part of the DHS S&T Iceberg Tagging Campaign, as well as 39 SIMs with 56 icebergs from ice management vessels contracted by the Oil and Gas Industry in the vicinity of the oil rigs on the Grand Banks.

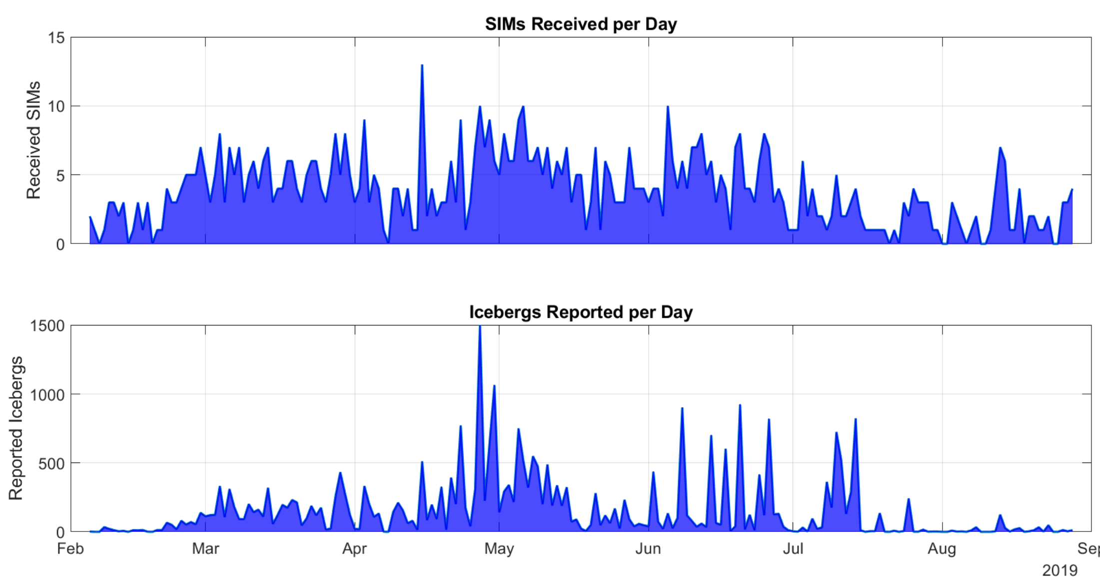

Figure 3-3. The number of SIMs received per day (top) and the number of icebergs reported per day (bottom) at the IIP OPCEN throughout the 2019 Iceberg Season. Note the spike in icebergs reported at the end of April into the first half of May, even though the number of SIMs received remained relatively constant from March through June.

be correlated to satellite passes over the vicinity of Hamilton Bank along the Labrador coast. These SIMs each reported hundreds of icebergs in nearly the same location. Due to the amount of satellite reconnaissance in the area, many of the icebergs were found to be grounded during this point in the season as they were resighted in approximately the same location for many satellite frames in a row. Of note, the iceberg drift and deterioration models did not consider the icebergs to be grounded and continued to drift them south along the Labrador Coast. The large number of icebergs reported in the same location was a challenge for the IIP OPCEN to process into the model and resulted in the use of large-scale mass-resighting of iceberg populations, termed "polygon add/polygon delete". Though this method does not retain the history of iceberg trajectories over time as a traditional resighting does, it was the most effective way of handling large numbers of icebergs in the same location at short repeat cycles and effectively corrected for the modeled southward drift of the icebergs despite them being aground.

A total of 30,984 icebergs, growlers, and radar targets were reported to IIP during the 2019 Ice Season. Of these, 24,206 (78%) were incorporated into the model. IIP watchstanders reviewed each report for accuracy and validity before the data was entered into BAPS. This included reviewing environmental conditions, other recent reconnaissance, and the detection method of each report. The 22% of reported icebergs that were not incorporated in the model included many that were coincident sightings where the OPCEN received reports of the same iceberg(s) from numerous sources at approximately the same time. In these circumstances, the OPCEN will only ingest the most recent position and most complete size information and take no action on older or less complete reports. This also includes instances in which multiple agencies analyzed the same satellite frame. In these cases, IIP added all unique icebergs from the two reports but took care to not add the same iceberg twice.

Satellite Reconnaissance

Table 3-1 and **Figure 3-1** show that the majority of icebergs, growlers, and radar targets incorporated into the model were from satellite reconnaissance (Commercial, CIS, and IIP satellite reconnaissance combined for a total of 12,266 icebergs, growlers, and radar targets added into the model from 334 SIMs). The Satellite Reconnaissance percentage in **Figure 3-1** was comprised of 230 satellite images that were processed and analyzed entirely by IIP staff; 19 SIMs were processed by CIS; and 85 SIMs, consisting of 238 satellite frames, were processed by C-CORE in support of the oil and gas industry and in support of the DHS S&T Iceberg Tagging Campaign. Of the 12,266 satellite-detected icebergs that were incorporated into the model during the 2019 Ice Season, 3,945 were from IIP satellite SIMs, 858 were from CIS satellite SIMs, and 7,463 were from C-CORE satellite SIMs.

Aerial Reconnaissance

This season, IIP conducted 41 reconnaissance flights, which accounted for 2,122 icebergs, growlers, and radar targets added or re-sighted into the BAPS model. On average, 52 icebergs were observed per IRD flight. Commercial aerial reconnaissance accounted for 9,110 icebergs added to the model; an average of 33 icebergs, growlers, or radar targets observed per flight. It should be noted that IRD flights have a primary mission of iceberg reconnaissance on every sortie; this is not necessarily the case for commercial flights.

The commercial aerial reconnaissance data in **Table 3-1** and **Figure 3-1** is from SIM reports made by PAL Aerospace, which was contracted by multiple sources. **Figure 3-4** shows the percentage of PAL Aerospace flights that were dedicated ice flights (funded by CIS or by the oil and gas industry) and other flights that reported icebergs as a byproduct of various other missions. Just over half (53%) of the total PAL Aerospace flights which reported icebergs were flown for primary missions other than iceberg reconnaissance. 41% of flights that reported icebergs were funded by the oil and gas companies concerned with icebergs in the vicinity of the offshore oil rigs (increased from 26% in 2018). The smallest portion, 5%, of PAL Aerospace flights that reported icebergs were funded by CIS specifically for iceberg reconnaissance in areas designated by either IIP or CIS. This willingness of PAL Aerospace to identify and share iceberg reconnaissance information regardless of funding source demonstrates a notable and significant commitment to maritime safety across the region.

The increase in Industry Ice Flights this "Extreme" Ice Season is notable because most of them were flown in the same patrol area, with morning and afternoon patrols of the same area on 18 days. On these same-day flights, a total of 393 icebergs were added to the model, with 3,047 icebergs resighted. The 393 additions to the model are interesting

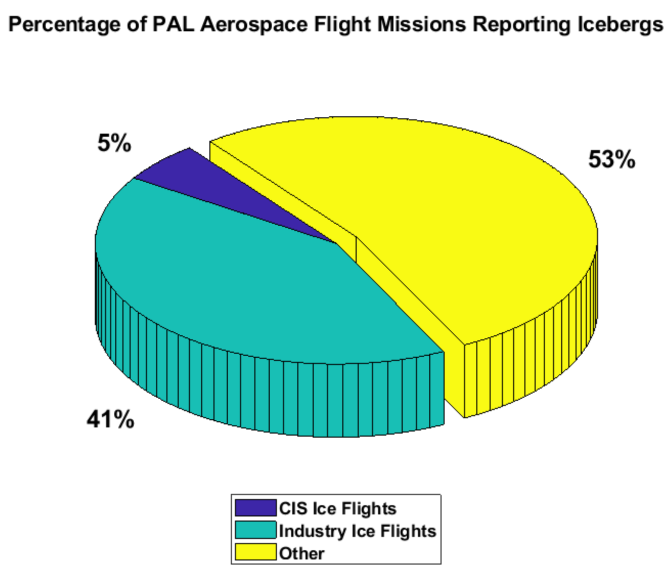

Figure 3-4. The percentage of PAL Aerospace flights by primary mission type that reported icebergs. The "Other" category includes flights that reported icebergs but with a primary mission other than iceberg reconnaissance.

because, in an ideal circumstance, a patrol of the same area on the same day would locate the same icebergs and such patrols would result in only resights. The fact that so many differences existed could be attributed to slight errors in reported position that prohibited iceberg resighting after short time intervals by our OPCEN policy or changes in weather or other factors that impacted probability of detection in the afternoon compared to the morning.

SIM Processing and Deletions

Identifying icebergs is only one part of the process. Once identified, icebergs are added or resighted in the active iceberg database, and then are drifted and deteriorated via numerical models in BAPS. Icebergs are removed or deleted from the active iceberg database as a result of modeled deterioration, recency of last sighting, or IIP aerial reconnaissance results. This season, 780 of the 9,537 icebergs added to the model were deleted based upon the results of IIP aerial reconnaissance indicating that no icebergs were present in the region identified by the modeled position. Due to the large numbers of icebergs reported in many SIMs this season, IIP made liberal use of "polygon add/polygon delete" procedures where all the icebergs within a defined area are resighted by deleting the older observations and adding the most recent observations in their place. As such, the number of deletions from other sources of reconnaissance is not indicative of the use of these sources to delete individual icebergs but as a method of resighting large populations of icebergs at one time. Resighting in this method accounted for 3,730 iceberg deletions, though a similar amount of icebergs were added back to the model in the most current position. Presently, commercial aerial reconnaissance and satellite reconnaissance do not meet necessary probability of detection standards to enable deleting icebergs from the database completely. This season, IIP continued to work with PAL Aerospace during CIS-funded iceberg reconnaissance flights to quantify environmental conditions, visibility, and radar range in order to facilitate deleting modeled icebergs from commercial reconnaissance results. The remainder of the modeled icebergs were typically deleted due to predicted melting and deterioration.

Limit-Setting Icebergs

Of all the icebergs sighted and modeled by IIP, the most important were the ones that defined the Iceberg Limit. Typically, between two and eight icebergs set the Iceberg Limit at any time. In the 2019 Ice Season the limit stretched approximately 655 NM east of St. John's at its maximum extent of 036˚44'W on 11 June, and approximately 444 NM south of St. John's to 40˚10'N on 11 April.

Compared to 2018, PAL Aerospace flights decreased as a reporting source of limit setting icebergs from 24% to 18%, and IIP aerial reconnaissance decreased from 42% to 30%. Reconnaissance from satellite imagery accounted for more than 46% of limit setting icebergs, compared to 30% in 2018, 22% in 2017, and only 2.1% in 2016.

Although a large number of icebergs incorporated into the model and setting the Iceberg Limit were observed by satellite, at this time, satellite reconnaissance is unable to reliably determine ice-free conditions due to low confidence in the ability to avoid false positives and false negatives. A false positive result is one in which a target is determined to be an iceberg where, in fact, there is not one. This can result in the needless expansion of the Iceberg Limit, negatively impacting shipping without a corresponding increase in safety. However, much more insidious occurrences are false-negatives in which it is determined there are no icebergs where, in fact, icebergs exist. This situation is especially dangerous and can result in the Iceberg Limit not encapsulating the iceberg hazard and placing ships in harm's way. Continued development of satellite imagery analysis is aimed at reducing these false conditions through increased understanding of the impact of satellite parameters, image quality, and environmental conditions on valid positive detection and classification of targets.

Given these considerations, the primary method for monitoring the Iceberg Limit remains aerial reconnaissance. Observing the exact location of limit-setting icebergs, especially those in the vicinity of transatlantic shipping lanes, continues to be a critical part of completing IIP's mission.

IIP Protocol for Icebergs Reported Outside of the Iceberg Limit

In the event that an iceberg or radar target is reported outside the published Iceberg Limit, the OPCEN Duty Watchstander (DWS) takes prompt action to ensure that the maritime community is quickly notified and the NAIS products are updated.

Typically, the first step is for the DWS to notify the Canadian Coast Guard Maritime Communication and Traffic Service (MCTS) Port aux Basques. In turn, MCTS issues a Navigational Warning (NAVWARN) which is the primary means of relaying critical iceberg information to the transatlantic shipping community and provides the IIP watchstanders with time to transmit revised products. The NAVWARN is sent via NAVTEX and forwarded to the U.S. National Geospatial-Intelligence Agency (NGA). NGA broadcasts the message as a Navigational Area (NAVAREA) IV warning message over SafetyNET and posts it to their website. NAVAREA IV is one of 21 Navigational Areas, designated by the World Wide Navigational Warning Service (WWNWS); the United States is the coordinator for NAVAREA IV.

If the report of an iceberg or radar target outside the limit is received by IIP during office hours (1200Z – 0000Z), products will be immediately revised by the OPCEN valid for 1200Z or 0000Z depending on the time received. If the report reaches IIP after office hours, products will be revised no later than 1400Z the following morning valid for 1200Z.

A total of eleven reports of icebergs or radar targets outside the published Iceberg Limit were received throughout the 2019 Ice Year; eight while IIP was producing products and three when IIP was not. Three of the reports were included in the product as radar targets due to the ambiguities associated with satellite reconnaissance. These cases highlight the challenges associated with the increasing use of space-borne reconnaissance. While SAR satellites have proven to be able to detect icebergs, classifying targets as an iceberg, vessel, or another item such as marine life, fishing gear, or weather features remains a challenge. SAR returns are quite open to interpretation. In all, IIP took a conservative approach to ensure that the maritime community received a timely warning of any possible target outside of the limit and kept the target plotted in the model until subsequent reconnaissance could verify its status.

The three reports received in January were all closely linked with the sea ice limit. Each reported iceberg during this time was within the sea ice limit, but outside the Iceberg Limit in greater than 4/10 sea ice concentration and gray or gray-white ice. These cases highlight the need to use all available resources to diligently investigate the leading edges of thick sea ice early in the year and incorporate the areas most likely to hold icebergs within the Iceberg Limit. **Appendix B** discusses IIP's 2019 efforts to improve the ability to detect and classify icebergs within sea ice during this dynamic and informative part of the season.

Three instances of icebergs outside of the Iceberg Limit along the Tail of the Grand Banks this season further highlight the need to utilize up-to-date high-resolution SST data to identify areas of cold water that could preserve icebergs farther south. This season, the IIP OPCEN began using daily SST products from the GHRSST in order to plan reconnaissance and make decisions on the extent of the Iceberg Limit in the dynamic area around the Tail of the Grand Banks.

The next section provides detailed information on each instance of an iceberg outside of the established Iceberg Limit. In each case, IIP relied on coordination with other data sources such as vessel Automated Identification System (AIS) and a collaborative exchange with a Coast Guard analysis center to help classify ambiguous targets as icebergs or ships. Access to this data and partnerships will continue to be key factors in space-borne reconnaissance efforts.

In-Season Icebergs and Radar Targets outside the Iceberg Limit

1. On 25 February 2018, a PAL Aerospace flight detected an iceberg approximately 32 NM from the published Iceberg Limit (**Figure 3-5**). A NAVWARN was issued but due to the timing of the report, products were not revised and the iceberg was included in the current day's iceberg product, which resulted in a significant expansion of the Iceberg Limit.

2. On 02 March 2019, a Sentinel-1B frame from 01 March was analyzed and a target was detected in single polarization 34 NM outside of the published Iceberg Limit. The target was one of seven that were sent to a Coast Guard analysis center to determine detailed correlation with vessel traffic. Given a lack of high confidence correlation with vessels in the area and ambiguity associated with a single pol satellite detection, the target was included in the product as a radar target outside of the Limit. (**Figure 3-6**).

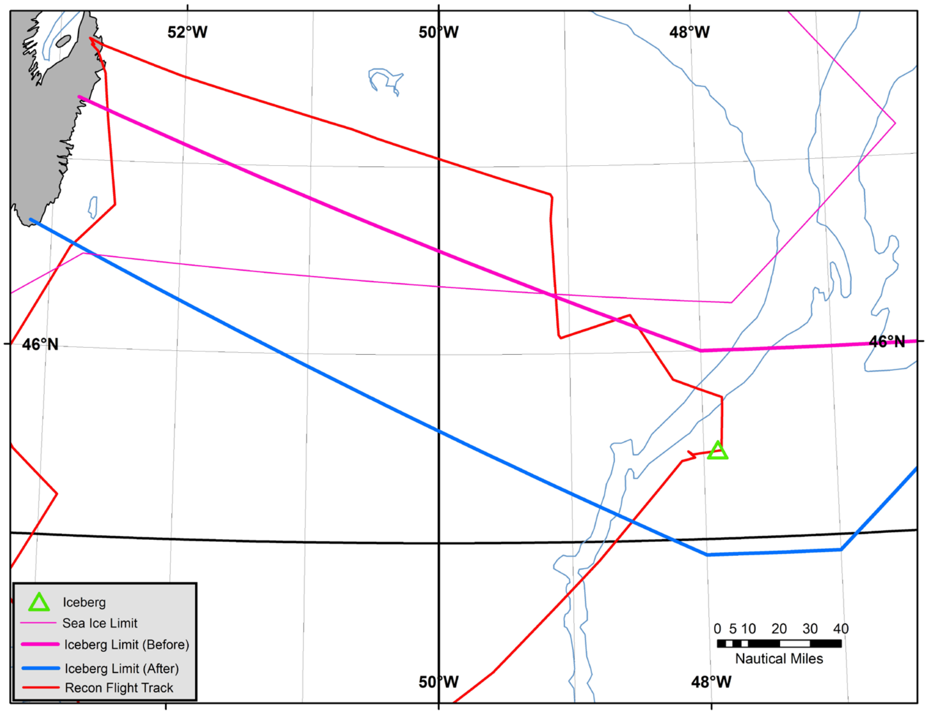

Figure 3-5. On 25 February 2019, A PAL Aerospace reconnaissance flight located an iceberg south of the published Iceberg Limit resulting in a significant expansion of the Limit.

3. On 18 March 2019, an IRD flight found two icebergs outside of the published Iceberg Limit in the Flemish Pass ("Iceberg Alley"). The report was sent directly to the IIP OPCEN from the aircraft via a phone-patch. A NAVWARN was issued and revised products were published. (**Figure 3-7**)

4. On 21 March 2019, the M/V TORONTO EXPRESS reported two icebergs 8 NM outside of the Iceberg Limit. NAVWARN was issued and the products were revised. (**Figure 3-8**)

5. On 18 May 2019, the IIP OPCEN noticed a NAVAREA IV Warning message containing a report of an iceberg outside of the Iceberg Limit by M/V GENOA EXPRESS. The iceberg had been sighted on 17 May, and reported directly to MCTS. As seen in **Figure 3-9**, this iceberg was also found in the cold tongue of Labrador Current water extending past the Tail of the Grand Banks.

6. On 19 June 2019, the IIP OPCEN analyzed a Sentinel-1B frame from 17 June after notification by DMI of three targets that they could not reliably classify as ships or icebergs. After analysis, it was still unclear but due to the likelihood of the targets being ships, they were included in the product as radar targets. (**Figure 3-10**)

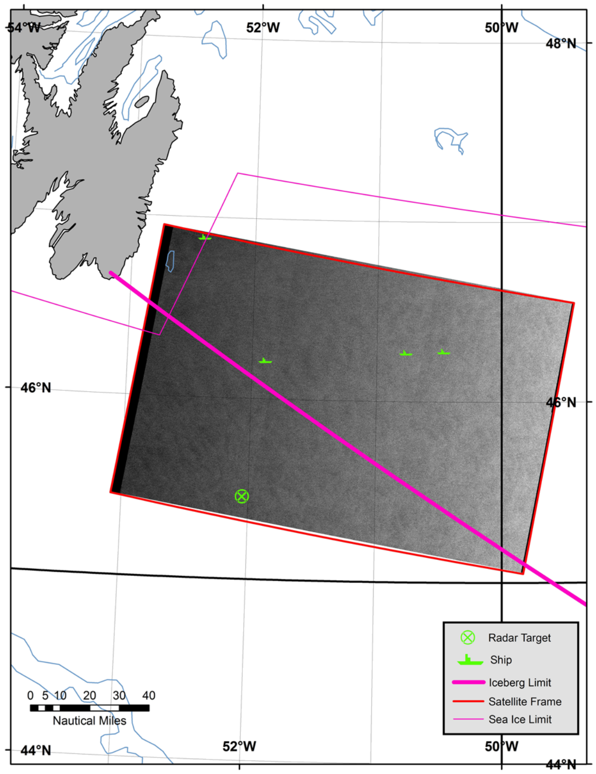

Figure 3-6. On 02 March 2019, the IIP OPCEN analyzed a Sentinel-1B frame from 01 March and detected an ambiguous target in HV polarization. It was included in the product as a radar target outside of the Limit.

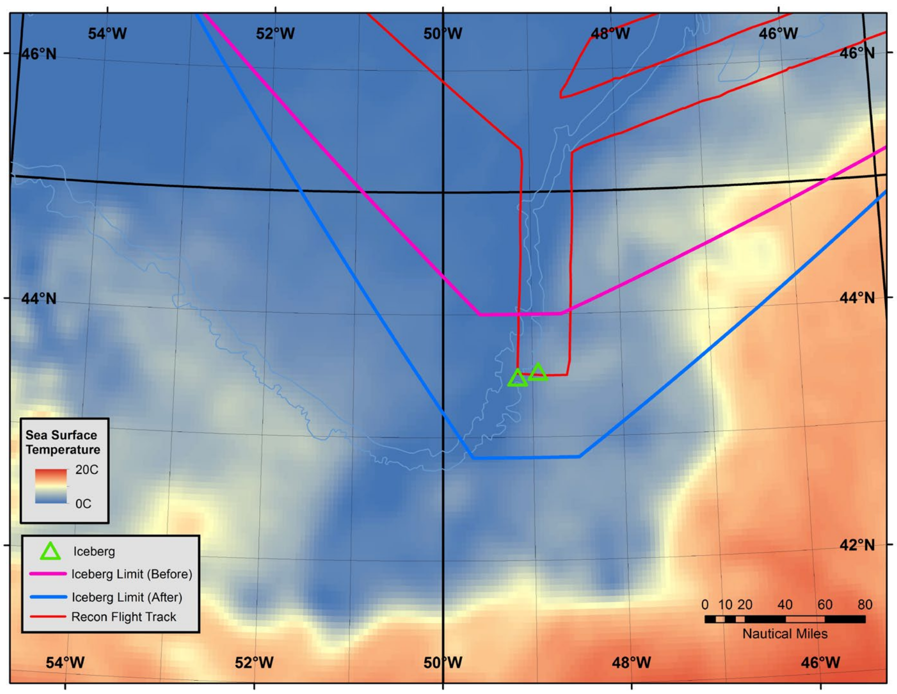

Figure 3-7. On 18 March 2019, an IIP reconnaissance flight detected two icebergs approximately 30 NM outside of the published limit. Here, the icebergs are overlayed on the daily Sea Surface Temperature product from the Group for High Resolution Sea Surface Temperature (GHRSST), to show the tongue of cold, Labrador Current water extending along the Tail of the Grand Bank in which the icebergs were detected.

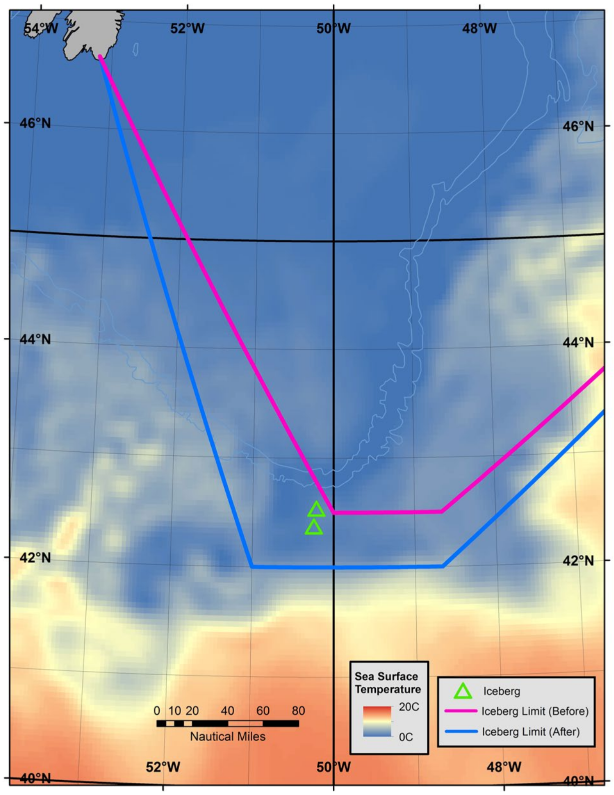

Figure 3-8. On 21 March 2019, M/V TORONTO EXPRESS reported two icebergs outside of the Iceberg Limit. Here, the icebergs are shown displayed over the Sea Surface Temperature from the Group for High-Resolution Sea Surface Temperature team (GHRSST) data set. Note that the icebergs are within the cold-water tongue extending past the Tail of the Grand Banks.

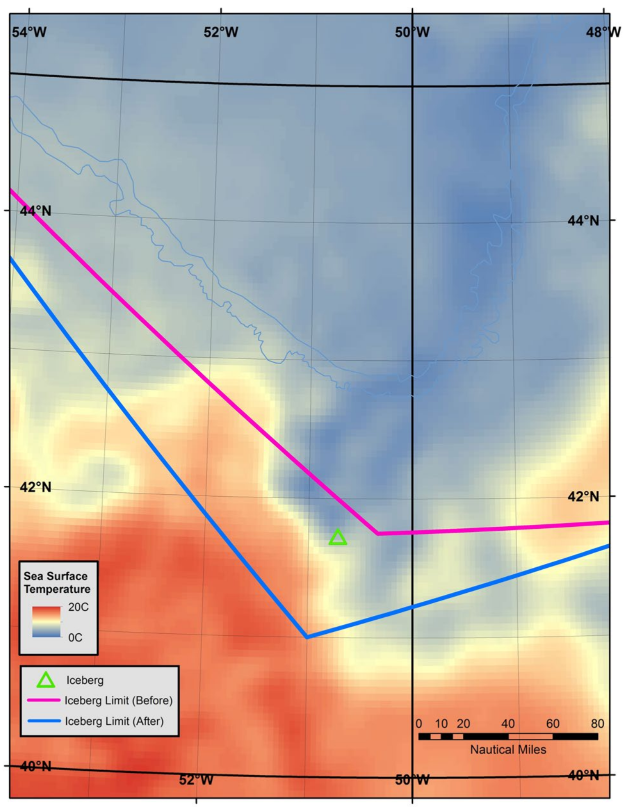

Figure 3-9. On 17 May 2019, M/V GENOA EXPRESS found an iceberg outside of the published Iceberg Limit. The IIP OPCEN received the report on 18 May and updated the Limit. Here, the iceberg is shown displayed over the Sea Surface Temperature from the Group for High-Resolution Sea Surface Temperature team (GHRSST) data set. Note that the icebergs are within the cold-water tongue extending past the Tail of the Grand Banks.

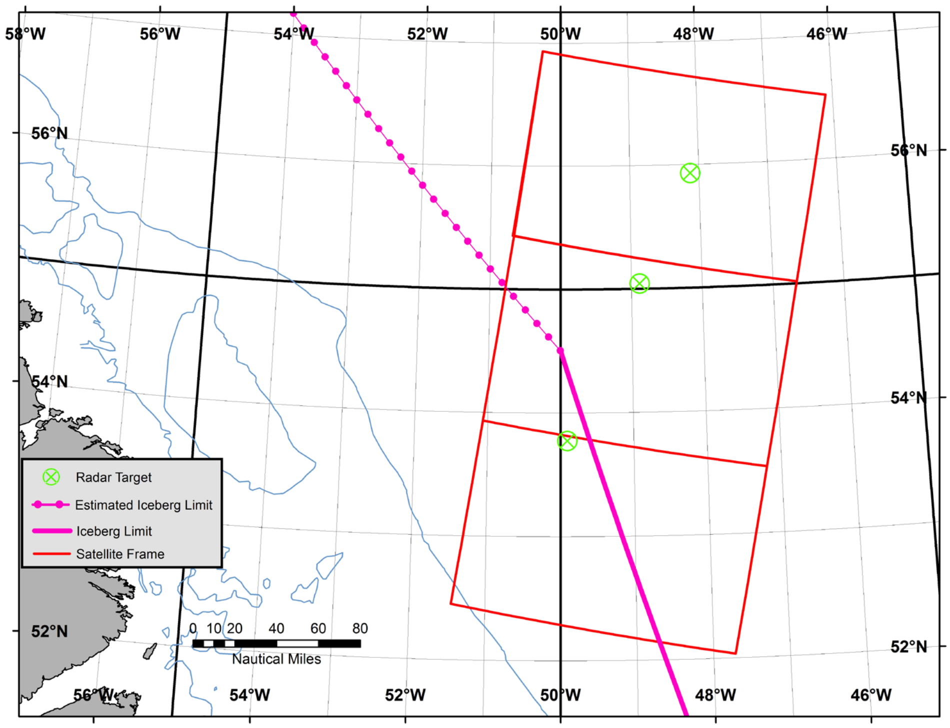

Figure 3-10. On 19 June 2019, three ambiguous Sentinel-1B targets from frames on 17 June were sent to the IIP OPCEN by DMI and were analyzed. The analysis was inconclusive and the contacts were added as radar targets.

7. On 14 July 2019, IIP received a SIM from CIS analysis of a RADARSAT-2 satellite frame. The frame had an ambiguous target in close proximity to a known vessel outside of the iceberg limit. After discussion with the analyst, it was agreed that the target was most likely an azimuth ambiguity associated with the nearby vessel, but the contact was conservatively added to the product as a radar target. (**Figure 3-11**).

8. On 27 August 2019, the IIP OPCEN analyzed a Sentinel-1B frame from 26 August and found a target outside of the Iceberg Limit. Given the analyst's confidence in the classification of the target, it was included in the model as an iceberg. A NAVWARN was issued and the Limit was expanded (**Figure 3-12**). The satellite detections are included in **Figure 3-13**.

Out of Season Icebergs and Radar Targets outside the Iceberg Limit

1. On 06 January 2019, a PAL Aerospace flight reported a small iceberg in sea ice 3 NM outside of the Iceberg Limit observed on 05 January. (**Figure 3-14**). Due to the timing of the report and the fact that the iceberg was well within sea ice, a NAVWARN was not issued and the iceberg was included in the next day's Limit.

2. On 07 January 2019, the M/V UMIAK reported an iceberg observed on 04 January embedded in 5/10 sea ice outside of the Iceberg Limit. (**Figure 3-15**). The Iceberg Limit was updated to include the iceberg but a NAVWARN was not sent due to the iceberg being within the sea ice and the timing of the report.

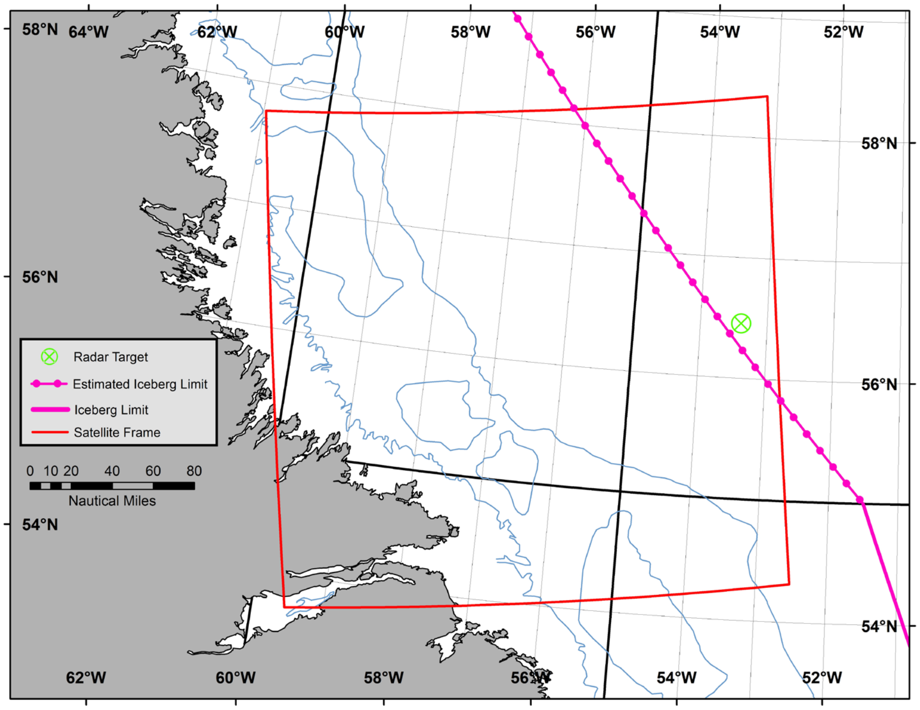

Figure 3-11. On 14 July 19, a target was detected outside of the established Iceberg Limit by CIS analysis of RADARSAT-2 imagery. The contact was added as a radar target due to its proximity to a vessel and the high possibility of the target being an azimuth ambiguity associated with the nearby vessel.

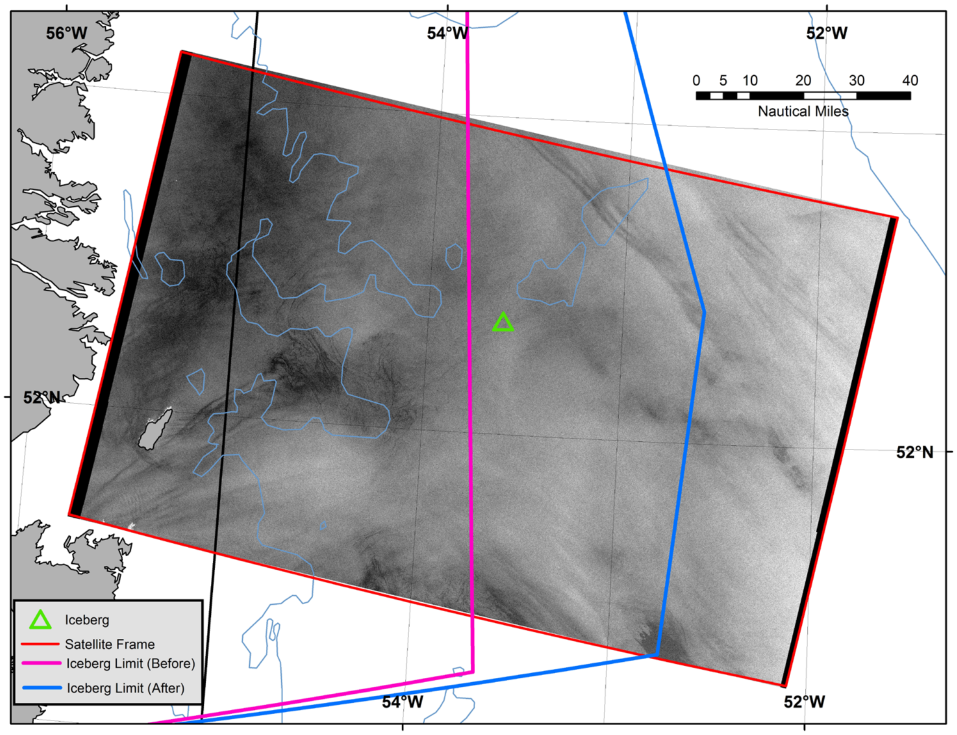

Figure 3-12. On 27 August 2019, the IIP OPCEN analyzed a Sentinel-1B frame from 26 August and found a target outside of the published Iceberg Limit. Given analyst confidence in the classification of the target it was included as an iceberg, a NAVWARN was issued and a significant expansion to the limit on that day's product resulted.

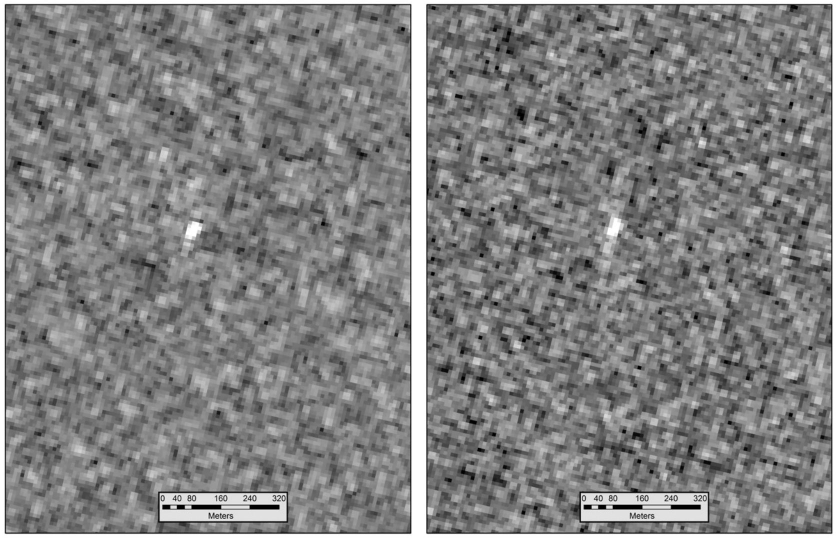

Figure 3-13. HH (left) and HV (right) image of the iceberg outside of the published Iceberg Limit on 27 August 2019.

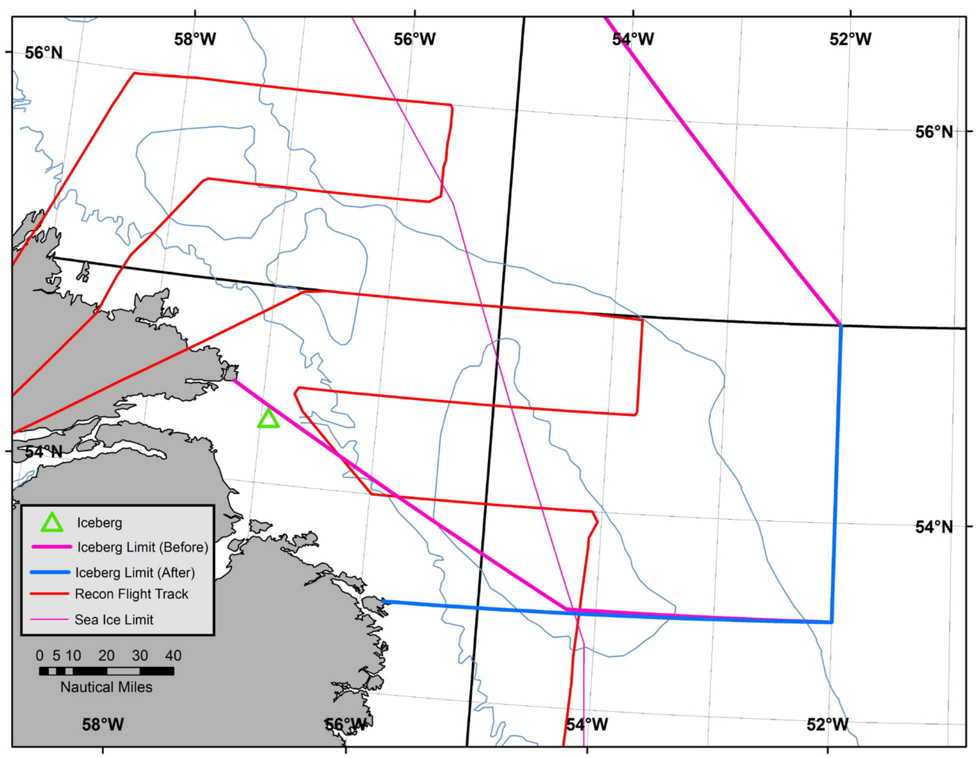

Figure 3-14. On 06 January 2019, a PAL Aerospace flight reported an iceberg observed on 05 January within sea ice and just outside of the published Iceberg Limit.

3. On 24 January 2019, a PAL Aerospace flight reported an iceberg observed within sea ice on 23 January. (**Figure 3-16**). Due to the timing of the report and the fact that the iceberg was well within sea ice, a NAVWARN was not issued and the iceberg was included in the next day's Limit.

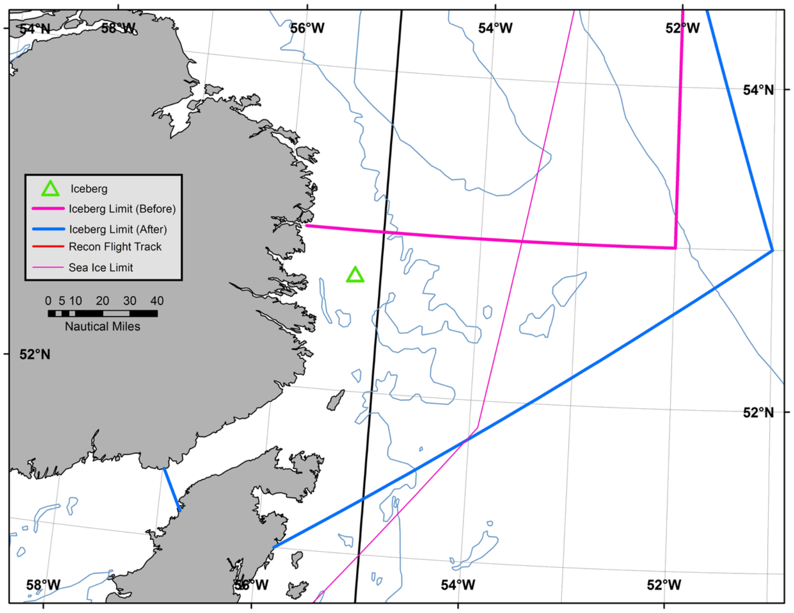

Figure 3-15. On 07 January 2019, the M/V UMIAK reported an iceberg observed on 04 January within sea ice and just outside of the published Iceberg Limit.

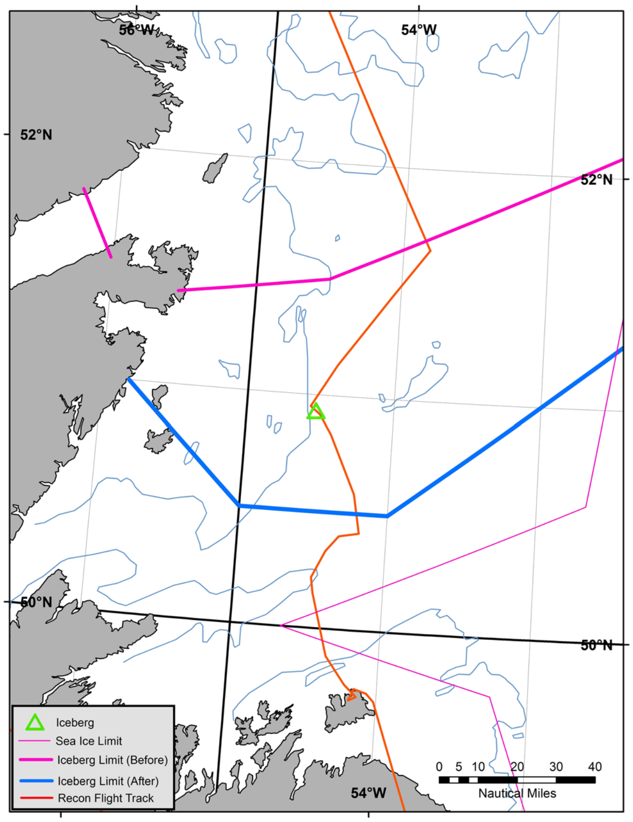

Figure 3-16. On 24 January 2019, a PAL Aerospace reconnaissance flight reported an iceberg observed within sea ice 33 NM outside the Iceberg Limit on 23 January.

4. Iceberg Reconnaissance Operations

Ice Reconnaissance Detachment

The IRD, a sub-unit under CIIP, partners with ASEC to conduct aerial iceberg reconnaissance. During the 2019 Ice Season, ten IRDs deployed to observe and report icebergs, sea ice, and oceanographic conditions in the North Atlantic Ocean. All observations from the IRDs are transmitted to the IIP OPCEN in New London, CT for processing and entry into BAPS. These observations provide critical Iceberg Limit information used by the IIP OPCEN to create the NAIS iceberg warning products that are distributed to the maritime community.

Over the 2019 Ice Season, IIP and ASEC crews deployed for 94 days, conducting 41 iceberg reconnaissance patrols on HC-130J air assets. The 2019 flight season spanned 136 days; 14 days shorter than the five-year (2015-2019) average of 150 days. Sea ice and iceberg distribution through January and into early February allowed IIP to delay the departure of the first IRD. Valuable climatology and long-term forecast data gathered and analyzed by CIS meteorologists greatly aided CIIP in the decision to delay, and provided invaluable support during the partial U.S. government shutdown in January 2019. The first IRD departed on 26 February, and the last IRD returned on 11 July. **Table 4-1** contains a summary of operations for each IRD.

Aerial Iceberg Reconnaissance

HC-130J aircraft equipped with two radars and an AIS integrated into the mission system suite were used to conduct aerial iceberg reconnaissance. The ELTA-2022 360° X-Band (ELTA) radar is capable of detecting and discriminating surface targets. The HC-130J Tactical Transport Weather Radar (APN-241) is capable of detecting surface targets, but cannot discriminate or classify targets as an iceberg, ship, or other object. The AIS receives information transmitted by AIS-equipped

IRD	Deployed Days	Iceberg Patrols	Transit Flights	Patrols en Route	Logistics Flights	Flight Hours
1	10	3	2	1	0	35.8
2	9	4	2	0	0	37.3
3	9	3	2	1	0	35.0
4	9	1	1	1	0	19.6
5	10	1	1	2	1	30.3
6	11	4	2	0	1	49.7
7	9	3	1	1	0	31.0
8	9	4	1	1	0	36.6
9	9	5	1	1	0	47.3
10	9	5	2	0	0	46.2
Total	**94**	**33**	**15**	**8**	**2**	**368.8**

Table 4-1. An overview of IRD days and flight hours used during the 2019 Ice Season.

ships for positive identification, and is used to differentiate vessels from icebergs on the radar.

The ability to employ ELTA radar significantly enhances reconnaissance capabilities. The 360° coverage provided by the ELTA radar supports the use of 25 NM track spacing for patrol planning. Under calm sea states, IIP is able to expand track spacing to 30 NM, while maintaining a 95% probability of detection (POD) of small icebergs (15 to 60m). Conditions supporting expanded track spacing did not occur during any of the IRD patrols in the 2019 Ice Season.

If the ELTA radar is inoperable, the IRD must fly patrols under "visual-only" specifications using 10 NM track spacing, covering 40% less area in a given time period. Further, visual-only patrols require areas with pristine environmental conditions; clear skies and visibility to the surface, which rarely occur in IIP's meteorologically active OPAREA. In 2019, there were no complete ELTA radar casualties that required reduced track spacing. However, the aircraft on IRD 9 suffered a casualty that assigned target positions detected by ELTA to the area around Elizabeth City, NC, but still populated on the ELTA screen correctly referenced to the aircraft. Further details about this casualty are described later in this section in the IRD 9 summary.

During the 2019 Ice Season, all IRDs were flown with MMS equipped aircraft. IIP and ASEC personnel continued to work together to improve effectiveness of the radar detection algorithm, especially in areas of heavy sea ice concentrations. The IRDs continued to have some challenges using the Inverse Synthetic Aperture Radar (ISAR) function to distinguish between ships and icebergs for radar targets; however, the ISAR feature was more effective than the beginning of the 2018 Ice Season. Updates to the MMS system late in the 2018 reconnaissance season improved the ability to ISAR icebergs.

IRD Operational Summary

The first IRD of 2019 began on 26 February with ASEC flying to the Groton-New London Airport (KGON) in Groton, CT to pick up the six IIP IRD crew, and flying back to ASEC for opening season air crew training on 27 February. IRD 1 did not depart for St. John's, NL on 28 February as scheduled because of forecasted high winds at St. John's International Airport (CYYT) throughout the evening that would have prevented the aircraft from hangaring, exposing it to potential damage and requiring post storm inspections.

On 01 March, IRD 1 departed ASEC and conducted a southern Iceberg Limit patrol enroute to St. John's, NL. The patrol began at approximately 43°30'N 50°W and patrolled north through a cold-water feature, and along the southern Iceberg Limit south of the Flemish Pass. This first patrol detected 17 ships and zero icebergs. A low level jet producing high winds at CYYT kept the aircraft grounded on 02 March; crew rest was conducted. The second patrol occurred on 03 March and covered the southeastern Iceberg Limit. Low to no visibility and high sea state conditions caused several diverts and required ending the patrol early; however, six icebergs and 11 radar targets believed to be icebergs were identified. All icebergs and radar targets were found north of 47°N. The third patrol on 04 March found 66 icebergs and one radar target between 49°N and 51°N during a patrol over the interior of IIP's OPAREA. This patrol found all icebergs along or inside the 1,000 m contour, east of 49°30'W; no icebergs were observed adrift in the offshore branch of the Labrador Current. Also on 04 March, CIIP remained in St. John's, NL to conduct opening season partner meetings with the Canadian Border Security Administration, C-CORE, and the Canadian Coast Guard. The patrol planned for 05 March was canceled because of high winds at CYYT. The IRD crew conducted the remaining opening season partner meetings with Canadian Forces, PAL Aviation Services, PAL Aerospace, Cougar Air, and St. John's Port Authority on 05 March. The final patrol of IRD 1 on 06 March flew the southeastern Iceberg Limit area and north over the Flemish Pass. Thirty-five icebergs were identified along the 1,000 m contour and in the Flemish Pass. IRD 1 returned to Groton, CT on 07 March. Although weather conditions were not ideal throughout IRD 1, the patrols were able to confirm icebergs were beginning to transit through the Flemish Pass and south of 47°N.

The second IRD arrived in St. John's, NL on 13 March. The first patrol, on 14 March, was a northern survey flight to identify the iceberg population that could drift into the shipping lanes during the 2019 Iceberg Season. Two hundred forty-seven icebergs were found between 55°N and 61°N, all inshore of the 1,000 m contour. Low to no visibility was present along the eastern (northbound) track leg, but no radar targets were detected in this area. On 15 March the presence of smoke and fumes in the plane cabin prior to take-off canceled the planned patrol allowing the aircrew to investigate and correct the source of smoke. On 16 March a low level jet west of CYYT and winds predicted above 30kt kept the IRD grounded; weekly maintenance was conducted. The plane was also grounded on 17 March due to low level jets in the primary and secondary patrol areas; crew rest was conducted. On 18 March the second patrol of IRD 2 covered the southeastern limit and cold-water feature along the 1,000 m contour from 43°30'N to 48°N and between 50°W and 43°W. Seventy-one icebergs were identified mainly in the Flemish Pass and south along the 1,000 m contour. Two of the seventy-one icebergs were found just outside the southern Iceberg Limit (refer to Section 3 for additional information about the icebergs outside the limit). The third patrol of IRD 2, on 19 March, flew the eastern Iceberg Limit, covering the Flemish Cap, northern section of the Flemish Pass, and Sackville Spur. One hundred thirty-four icebergs were identified between 47°N and 49°N west of 44°W. The patrol was ended early because visibility dropped to zero and thick cloud layers prevented effective radar only reconnaissance. The fourth and final flight of IRD 2 on 20 March was planned to cover two RADARSAT-2 frames and an interior area between 47°30'N to 50°N and 46°30'W and 51°45'W. However, thick cloud layers and low visibility required many diverts and limited coverage east of 49°W. Despite the limited visibility one hundred and sixty-seven icebergs were detected, with several in the offshore branch of the Labrador Current outside the 1,000 m contour. The IRD returned to Groton, CT on 21 March.

The third IRD of the season arrived in St. John's, NL on 27 March. Their first patrol on 28 March covered the southwestern Iceberg Limit south of the Avalon Peninsula and the interior area of the Grand Banks between the Avalon Peninsula and Flemish Pass. This patrol confirmed the position of the southwestern Iceberg Limit, verified no icebergs had drifted outside the limit and that no icebergs were present on the Grand Banks. The three icebergs identified by radar during the patrol were found offshore of the 1,000 m contour, two near the Sackville Spur north of 48°N and one south of the Flemish Pass, south of 45°N. The second patrol on 29 March covered the southern Iceberg Limit and cold-water feature between 41°N and 43°45'N, sighting 24 icebergs. On 30 March, IRD 3 flew an eastern Iceberg Limit patrol. No icebergs were sighted, but the patrol was cut short due to both deteriorating weather forecasted at CYYT and on scene weather conditions. The IRD conducted weekly maintenance on 31 March, and crew rest on 01 April. High winds and severe turbulence at CYYT and throughout the OPAREA on 02 April grounded the aircraft. The decision was made for IRD 3 to leave St. John's a day early because of a strong low-pressure system forecasted to sit over St. John's, NL through 06 April. On 03 April IRD 3 conducted a patrol enroute to Groton, CT. The patrol covered the Flemish Cap and deployed the first IIP SVP buoy with 50m drogue. The SVP buoy was successfully deployed in position 48°N 49°W. Additionally, the patrol identified 32 icebergs mainly on the northern portion of the Flemish Cap. The aircrew remained overnight in Groton, CT because of crew flight hour limitations, and returned to ASEC on 04 April.

IRD 4 arrived in St. John's, NL on 10 April. An eastern Iceberg Limit flight on 11 April was canceled due to a combination of weather conditions at CYYT and delayed takeoff to troubleshoot aircraft sensor failures. The first patrol of IRD 4 was a southwestern Iceberg Limit flight on 12 April. The patrol plan included dropping two memorial wreaths over the resting site of the RMS TITANIC, commemorating the tragic loss of life. As the aircrew prepared to deploy the memorial wreaths, the aircraft experienced a casualty of a pressurization valve and could not open the ramp. The patrol was ended after the aircrew's troubleshooting efforts were exhausted. One iceberg was sighted south of the tail of the Grand Banks during this patrol.

The aircraft was then grounded at

Figure 4-1. AMT2 Lester preparing to deploy the Titanic Memorial wreaths during a patrol on 18 April 2019 to honor the lives lost during the tragic sinking of the RMS TITANIC. The wreaths were dedicated during a ceremony at IIP on 10 April 2019.

CYYT for the next three days awaiting a new pressurization valve couriered from ASEC. The pressurization valve was installed and successfully tested on 15 April and the maintenance hold on the aircraft was lifted. However, poor OPAREA weather, including very low ceilings, thick cloud layers and extensive areas of icing, kept the plane grounded on 16 and 17 April. On 18 April IRD 4 was able to complete a patrol of the Flemish Pass, deploy a 50m SVP buoy in position 48°N 48°30'W, and deploy the two Titanic memorial wreaths (**Figure 4-1)** while enroute to Groton, CT. Thirteen icebergs were sighted near 48°N between 47°W and 50°W.

IRD 5's departure to St. John's, NL was delayed until 27 April due to a combination of weather at CYYT and aircraft maintenance. After being grounded at ASEC for unscheduled maintenance on 24 April, the ASEC IRD crew arrived at Quonset State Airport (KOQU) to pick up IIP crewmembers and begin the IRD on 25 April. The plane was shut down after arrival at KOQU to reboot the MMS. During the reboot, one of the aircrew discovered, a leak from the main landing gear. This grounded the plane for unscheduled maintenance. A logistics flight from ASEC delivered required parts to KOQU on the evening of 25 April. Maintenance was completed on 26 April, however weather at CYYT delayed IRD 5's departure another day.

On 27 April, IRD 5 conducted a patrol enroute of the southern Iceberg Limit and cold-water feature south of the tail of the Grand Banks between 42°N and 43°30'N. Six icebergs were sighted confirming the position of the southern Iceberg Limit. The second patrol on 28 April, covered the 1,000 m contour along the eastern side of the Grand Banks between 43°N and 46°30'N. Fifty-four icebergs were sighted, all were in the Flemish Pass or following along the 1,000 m contour and eastern edge of the Grand Banks. Poor OPAREA weather and high winds at CYYT grounded the IRD crew for the next three days. The final patrol of IRD 5 on 02 May flew in support of the USCGC JUNIPER (WLB-201) and DHS S&T Iceberg Tagging Campaign and through the western Iceberg Limit enroute to KGON. Additional information about the USCGC JUNIPER's mission and DHS S&T Iceberg Tagging Campaign is discussed in the satellite section of this section. Low visibility and thick cloud layers over the interior limited the patrol length, but 141 icebergs were still observed. This was the first western Iceberg Limit aerial reconnaissance by IIP during the 2019 ice season.

IRD 6 arrived in St. John's, NL on 08 May. During the transit into St. John's the IRD attempted to fly over and photograph a GPS tagged iceberg from the DHS S&T tagging project that was located off the coast of the Avalon

Figure 4-2. Aircrew preparing to deploy the last of IIP's aerial deployable 50m SVP buoys during a patrol on 11 May 2019.

Peninsula; however, a low cloud layer offshore prevented a visual sighting. Due to low ceilings and extensive fog throughout the OPAREA the plane was grounded on 09 and 10 May; crew rest was conducted on 10 May. The first patrol, on 11 May, was a western Iceberg Limit and 1,000 m contour flight with an SVP buoy drop in position 49°N 49°50'W (**Figure 4-2**). One hundred and fifteen icebergs were sighted, mostly within the Strait of Belle Isle. The second flight on 12 May was an interior flight, inside the 1,000 m contour and within Notre Dame Bay. Visibility was near zero throughout most of the flight, but 94 icebergs were detected and identified with MMS. The third patrol of IRD 6 was a southern Iceberg Limit flight on 13 May. This patrol sighted 19 icebergs, between 42°30'N and 45°N confirming the extent of the southern Iceberg Limit. An eastern Iceberg Limit flight on 14 May flying east of the Flemish Cap between 42° and 46°W found zero icebergs. After landing at CYYT on 14 May the aircraft suffered a casualty to the landing gear and tow bar. IRD 6 was grounded for unscheduled maintenance on 15 May awaiting parts, which were delivered by a logistics flight from ASEC later that day. Repairs and weekly maintenance were conducted on 16 May allowing the IRD to return home on 17 May.

IRD 7's deployment to St. John's, NL was delayed one day because of poor weather conditions at CYYT and throughout the OPAREA. IRD 7 conducted a southwestern Iceberg Limit patrol enroute to CYYT on 23 May. The planned patrol enroute was cut short because of a delayed departure; however, 38 icebergs were sighted south of the Avalon Peninsula. The second patrol, on 24 May, was a southern Iceberg Limit patrol. Only the two southern most legs between 40°30' and 42°N were completed because of a delayed take-off after investigating and clearing the source of smoke in the plane cabin prior to takeoff. No icebergs were sighted on this patrol, allowing the Iceberg Limit to shift northward by one degree. On 25 May IRD 7 completed a western Iceberg Limit and interior survey patrol sighting 145 icebergs. The majority of these icebergs were sighted in the Strait of Belle Isle, few were found near shore of Newfoundland in Notre Dame Bay, with none east of 52°W. The final patrol of IRD 7 on 26 May was an eastern Iceberg Limit patrol flying over the Flemish Cap and east to 42°30' W. Thick cloud layers and low surface visibility caused zero visibility throughout the majority of the patrol and cutting off the southern most leg of the patrol. Two icebergs east of the Flemish Cap were detected by the MMS.

IRD 7 was unable to complete any further patrols because of unscheduled maintenance for leaks in the liquid oxygen (LOX) system. Several leaks in the LOX system were identified and all except one leak was fixed on 27 May. A test of the system, with the one outstanding leak that could not be accessed for repair, passed the acceptable loss rate and the aircraft was cleared to fly. Low cloud ceilings, extensive fog and low surface visibility in the OPAREA on 28 May kept the plane grounded in favor of better weather for patrolling the southern Iceberg Limit on 29 May. However, on 29 May the aircraft was grounded again for unscheduled maintenance when the LOX levels significantly decreased while fueling. No further patrols were conducted and IRD 7 safely returned to KGON on 30 May.

IRD 8 deployed to St John's, NL on 05 June and conducted a patrol enroute of the southwestern Iceberg Limit. The patrol was shortened because of a delayed takeoff for unscheduled maintenance. Six icebergs were sighted south of the Avalon Peninsula. On 06 June, IRD 8 patrolled the southern Iceberg Limit south of the Tail of the Grand Banks. No icebergs were sighted and the southern Iceberg Limit was shifted north by two degrees latitude to 43°N. Two legs along the 1,000 m contour were cut from the 06 June patrol because of inclement weather developing at CYYT. Low ceiling and extensive fog throughout the OPAREA grounded IRD 8 on 07 June; crew rest was taken. The next patrol, a western Iceberg Limit and northern survey on 08 June, was delayed leaving CYYT to allow a weather system to move east and improve surface visibility in the patrol area. Eighty-five icebergs were sighted during the western Iceberg Limit portion of the patrol, however the planned northern survey portion was cut from the patrol because of the delayed takeoff. Weekly maintenance was conducted on 09 June because low cloud ceilings and extensive fog were present through much of the OPAREA. On 10 June, IRD 8 patrolled the southern Iceberg Limit area again over the Grand Banks between 43°N and 46°N, and did not detect any icebergs. The southern Iceberg Limit was shifted north by more than 1 degree latitude. On 11 June the planned patrol was canceled due to significant loss of LOX overnight, requiring unscheduled maintenance on the LOX system. A patrol of the eastern Iceberg Limit area was flown on 12 June, however it was cut short because the LOX levels fell below required minimums. No icebergs were sighted before the patrol was shortened. The IRD safely returned to ASEC on 13 June because weather conditions at KGON prevented landing there. IIP's crew was returned to KGON on an ASEC training flight in the evening of 13 June.

IRD 9 deployed to St. John's, NL from 19 June to 27 June. They conducted a patrol enroute on 19 June covering the southwestern Iceberg Limit identifying 10 icebergs and verified no icebergs drifted west outside the limit. The flight covered an area south of the Avalon Peninsula from 45°N to 47°N. During this patrol it was discovered that the GPS for the ELTA (EGI) was not functioning properly, prohibiting accurate positioning using the ELTA-MMS interface. The MMS interface reported the positions of aircraft and targets detected by ELTA in the vicinity of Elizabeth City, NC. Additionally, the non-functional EGI prohibited the acquisition of ISAR images for radar targets. However, on the ELTA screen targets populated correctly referenced to the aircraft position. Iceberg and ship positions were estimated using the target's distance and bearing from the aircraft, and when possible latitudes and longitudes were verified with the pilots APN-241 radar. Although the aircrew performed troubleshooting upon landing and over the next few days, EGI functionality was not restored. IRD 9 continued to patrol using their workaround with success for five additional patrols.

The second patrol of IRD 9, on 20 June, was a southern Iceberg Limit patrol flying from 43°N to 45°30'N over the eastern portion of the Grand Banks. No icebergs were sighted on this patrol which resulted in the Iceberg Limit shifting north by 2 degrees latitude. The next patrol, on 21 June, covered the eastern Iceberg Limit. Low visibility throughout most of the patrol and the inability to ISAR targets led to reporting seven radar targets and no confirmed icebergs. The aircraft was grounded the next two days because of a low pressure system moving through the area creating reduced surface visibility and low cloud ceilings with high winds at CYYT and in the OPAREA. These days were used as crew rest and aircraft maintenance days. The fourth patrol of IRD 9 was an interior patrol that occurred on 24 June. Good visibility over the patrol area led to the identification of thirteen icebergs and one radar target between 46°N and 50°N west of the 1,000 m contour. Twelve of the icebergs were found along the coastline of Newfoundland. A western Iceberg Limit and Notre Dame Bay patrol was conducted on 25 June in good visibility except over the eastern portion of Notre Dame Bay. This patrol identified sixty-one icebergs and one radar target, mainly in the Strait of Belle Isle and coastline around Notre Dame Bay.

The sixth and final patrol of IRD 9 was planned as Northern Search patrol with coverage over Hamilton Bank. IIP had received PAL aerial reconnaissance and satellite SIMs over Hamilton Bank identifying over 500 icebergs in a small cluster. Weather forecasts predicted extensive fog through the search area but an updated forecast showed an opening over Hamilton Bank at 1800Z. The patrol was delayed and shortened to take advantage of the predicted clearing. The patrol found the clearing and identified 646 icebergs and eleven radar targets between 53°N and 56°N and west of 53°W. **Figure 4-3** shows two images taken during the patrol of the numerous icebergs in the vicinity of Hamilton Bank. The northern legs of the patrol were canceled because of the dense fog bank north of 55°30'N. The results from this flight were not incorporated into the BAPS model because exact positions of that high volume of icebergs in a small area could not be acquired. IRD 9 returned to Groton, CT on 27 June.

IRD 10 departed on 03 July with a goal to determine the need for future IRDs in the 2019 Iceberg Season. Inclement weather conditions in all potential patrol areas on 04 July canceled the planned flight, so end of

Figure 4-3. Two images taken during IRD9's patrol of the Hamilton Bank area on 26 June 2019. The patrol identified 646 icebergs during the shortened Northern Survey patrol. The IRD identified many of the visually sighted icebergs to be aground near shore.

season partner meetings were conducted with the Canadian Coast Guard, C-CORE, PAL Aviation, and the Canadian Border Security Administration. The first patrol of IRD 10 was a western Iceberg Limit and 1,000 m contour patrol on 05 July. Visibility was at or near zero NM through the 1,000 m contour portion of the patrol. Seventy-two icebergs were identified, all within the Strait of Belle Isle or west of the 1,000 m contour. The second patrol covered the southern and eastern Iceberg Limits on 06 July. Twenty-one icebergs, including eighteen growlers, were found along the coast of the Avalon Peninsula. The eastern extent of the Iceberg Limit retracted from 47°W to 50°W based on the results of the 06 July patrol. On 07 July the IRD completed an interior patrol, west of the 1,000 m contour between 48°N and 52°30'N. The patrol identified twenty-nine icebergs all near shore and west of 53°W. A low pressure system and resulting extensive fog throughout the OPAREA kept the IRD grounded on 08 July; weekly maintenance and a meeting with PAL Aviation Services were conducted. The low pressure system and extensive fog/low visibility remained over the Labrador Coast on 09 July in the final high priority patrol area for IRD 10. Given favorable weather conditions throughout the interior, the decision was made to fly a coastline patrol around Newfoundland to verify icebergs near shore on 09 July. The shoreline patrol identified fifty-three icebergs along the Newfoundland coast, many in coves and hidden behind islands that may not be identified through regular interior flight plans. The final patrol of IRD 10 and the 2019 Ice Season was a northern survey on 10 July between 53°N and 59°N. The flight plan straddled the 1,000 m contour along the Labrador coast to not overlap with a recent PAL Aerospace flight, and flew further offshore than typical northern survey patrols. Reduced visibility north of 59°N led to cutting off the northernmost section of the patrol. The survey identified 361 icebergs along the Labrador coast. Three icebergs were detected near the 1,000 m contour, but the majority of the iceberg population was interior of the offshore branch of the Labrador Current and would likely melt and break apart before impacting the North Atlantic Shipping lanes. The distribution and total number of icebergs detected on IRD 10 enabled CIIP to cease IIP aerial deployments in early July. The IRD returned on 11 July completing the final deployment of the 2019 Iceberg Reconnaissance Season.

Figure 4-4 shows a breakdown of IIP's deployment days during the 2019 Ice Season in six categories: Operations, Transit, Weather,

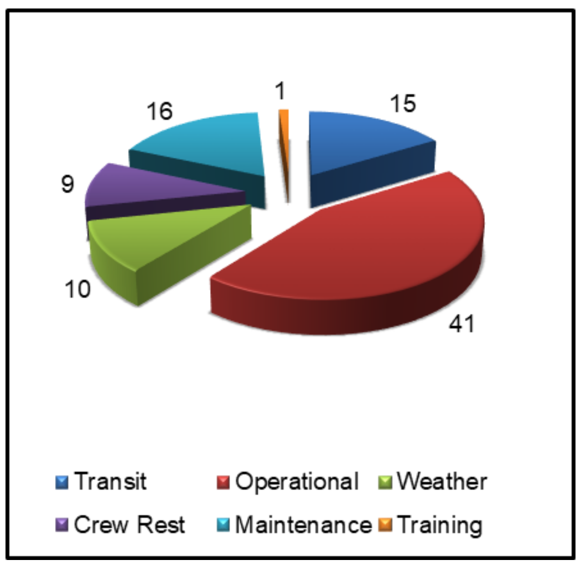

Figure 4-4. Break down of the total number of deployment days by IRD activity during the 2019 season. Crew Rest and Maintenance days include weather opportunity, unscheduled and scheduled days. Table 4-2 displays a further breakdown of Crew Rest and Maintenance days.

Maintenance, Crew Rest, and Training. In accordance with USCG regulations, the IRD normally takes one crew rest day as well as one maintenance day per deployment; otherwise, the plan is to fly every day. However, the prevailing OPAREA weather contributes significantly to the number and effectiveness of reconnaissance patrols. In 2019, weather conditions prevented patrols on 23% of the days deployed. The IRD crew capitalized on poor weather opportunities whenever possible to meet the required crew rest and maintenance days, in order to maximize operational iceberg reconnaissance flight days. **Table 4-2** shows a further break down of the crew rest and maintenance days into days taken when the weather conditions did not permit flights (opportunity days), days taken when conditions permitted flights, but required crew rest or maintenance had to be taken (scheduled) or days taken because required crewmembers for safety of flight or successful IRD operations could not fly or the plane was grounded for maintenance issues (unscheduled). Unscheduled maintenance impacted 11% of total deployed days in 2019. Finally, patrols executed while transiting between the U.S. and St. John's, NL are counted as an operational day vice transit day. There were eight patrols conducted during transits to or from St. John's, NL during 2019.

	Crew Rest	Aircraft Maintenance
Opportunity (Weather at CYYT/OPAREA)	8	4
Scheduled	1	2
Unscheduled	0	10
Total	9	16

Table 4-2. To the maximum extent possible IRD crews take the required crew rest and aircraft maintenance days when weather conditions do not support flying. These days are classified as Opportunity Days. Scheduled Crew Rest or Aircraft Maintenance Days are when operations require these days be taken, but the weather would support a patrol. Unscheduled Crew Rest days are when a crew member who fills a critical flight position is unable to fly, with no other member of the IRD crew qualified to fill the position, grounding the aircraft. Unscheduled Aircraft Maintenance Days occur when the aircraft is grounded due to unplanned maintenance issues.

IRD Iceberg Detections

IRD personnel detected 2,770 icebergs over the 10 IRDs in the 2019 Ice Season. Of the 2,770 sighted, 2,122 were incorporated into BAPS, which accounted for 8.8% of the total icebergs added during the 2019 Ice Season. Six hundred forty six icebergs from the last patrol of IRD 9 were not incorporated into the model because of the inoperable EGI function of MMS. The remaining IIP aerial reconnaissance icebergs not added or resighted in BAPS were due to overlapping reconnaissance with other reporting sources during the same reconnaissance period that were received, processed, and entered into BAPS before IRD flights were completed. The 8.8% of icebergs incorporated into BAPS from IRDs is significantly lower than the 32.6% in 2018; however, the criticality of these iceberg reports remained high. Priority areas of IRDs are to verify the Iceberg Limits. The extreme extents of Iceberg Limits throughout the 2019 season often meant flights had longer transits, covered less patrol area, and flew to verify the presence of one or two limit setting icebergs. Additionally, unscheduled maintenance and poor weather conditions limiting the number of available patrols, combined with the

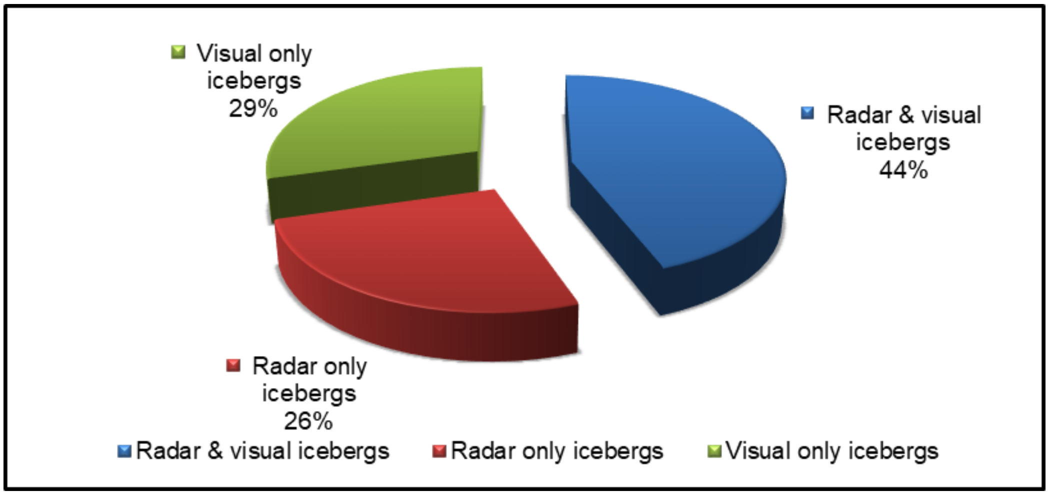

Figure 4-5. IRD iceberg detection methods for the 2019 Reconnaissance Season.

increased number of flights to cover the Iceberg Limits, led to fewer opportunities for patrolling over the interior and areas of higher iceberg concentration.

During IRD aerial reconnaissance, icebergs are detected in one of three ways: (1) with both radar and visual, (2) radar only, or (3) visual only means. This year, 44% of the icebergs were detected by both radar observations and visual sightings. The remaining icebergs were either detected only by radar (26%) or by visual detection alone (29%) (**Figure 4-5**). This is a significant shift in distribution of icebergs detected by both radar and visual from the previous four years (**Table 4-3**). Improvements to the MMS algorithms in 2018 resulted in an increased ability to ISAR targets and positively classify radar targets in sea ice. This is reflected in the higher percentage of radar and visual targets versus visual only icebergs identified in previous years. In addition to the improvements to the MMS detection algorithm, the increase in radar and visual icebergs can be attributed to a test by IIP personnel to identify radar icebergs detected on camera within 20 NM. Here, accurate length measurements were able to be captured enabling classification as radar and visual icebergs. Radar icebergs that were found and measured at their waterline using the MMS HD camera, and correlated with ISAR length measurements, accurately identifying the iceberg size, were recorded as visual and radar target, instead of radar only. Additionally, IIP continued to employ a two-tier approach in areas of favorable environmental conditions and high iceberg concentrations, focusing visual observations close to the aircraft and

Year	Radar & Visual Icebergs	Radar only Icebergs	Visual only Icebergs
2010	35%	37%	28%
2011	48%	37%	15%
2012	47%	10%	43%
2013	46%	17%	37%
2014	43%	5%	52%
2015	29%	45%	26%
2016	20%	32%	48%
2017	21%	39%	40%
2018	24%	31%	45%
2019	44%	26%	29%

Table 4-3. IRD iceberg detections by method for the last ten years.

radar observations away from the flight path enabling maximum detection efficiency. Visual only detections remained a significant portion of the total icebergs due to this two-tiered detection approach.

2019 Flight Hours

As in previous seasons, IIP was allotted 500 Maritime Patrol Aircraft flight hours for its operation during the 2019 Ice Season. IIP used 368.8 hours in 2019, only slightly higher than the 346.7 hours in 2018. These totals include patrol, transit, and logistics hours attributed to the IIP mission. However, the number of patrol hours in 2019 was 46 more than in 2018 due to two additional patrols and an increase in the use of patrols enroute during flights between the U.S. and Canada.

Figure 4-6 shows the breakdown of these hours over the past five Ice Seasons into the three categories: transit hours, patrol hours, and logistics hours. Transit hours are hours the aircraft transited to and from specific locations in support of the IIP mission without conducting reconnaissance operations. These flights are generally between Elizabeth City, NC and St. John's, NL, with a brief stop in Groton, CT to on load IIP personnel and equipment. There were 71.8 hours used this season for transits. Patrol hours are those hours associated with iceberg reconnaissance including flight time to and from the reconnaissance area. IIP flew 284.0 patrol hours this season. When a patrol is conducted during a regularly planned transit flight, the hours are counted as patrol hours vice transit hours and the flight is termed a patrol enroute. Patrols conducted enroute to or from St. John's, NL typically require longer flight times due to starting or ending positions south or east of St. John's, NL. Patrols during transit remain a mitigation tool for IIP to reduce the impact of poor weather or unplanned aircraft maintenance and to maximize IRD effectiveness. On eight occasions in 2019, IRDs conducted patrols enroute to

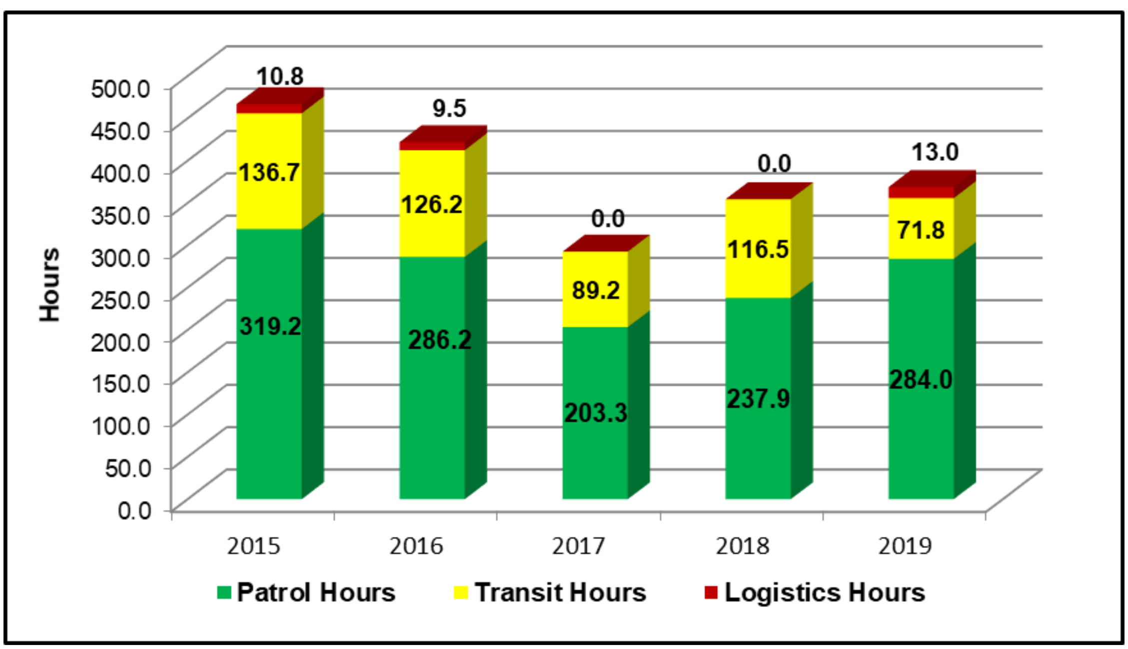

Figure 4-6. Flight hours broken down by patrol, transit, and logistics hours over the past five years.

or from the United States to St. John's, NL. Logistics hours are the hours used to support the IIP mission, but do not fall into the previous two categories. Logistics hours accrue when a Coast Guard aircraft is used to transport parts for an aircraft deployed on an IIP mission. Two logistics flights totaling 13.0 hours were accrued during the 2019 Ice Season. One flight brought parts to Quonset, RI during IRD 5 and the second brought parts to St. John's, NL during IRD 6.

The geographic and temporal distribution of icebergs, as well as the quantity of icebergs drifting south of 48°N, all contribute to the amount of reconnaissance needed to effectively monitor the iceberg danger and provide relevant warning products. **Figure 4-7** shows a comparison of flight hours to the number of icebergs that drifted south of 48°N from 2009 to 2019. The red line indicates IIP's total flight hours, the blue bars indicate the number of icebergs observed or drifted south of 48°N. Although the number of icebergs in the transatlantic shipping lanes in 2019 was the second highest in the last ten years, IIP expended less than 400 hours. This can be attributed to the high number of days partially or completely lost to weather and unscheduled maintenance. In 2019, 19 out of the 41 patrols were partly incomplete, with 6 ≥ 50% incomplete. In 2018 there were also 19 incomplete flights, however none were more than 40% incomplete.

Other Iceberg Reconnaissance Activities

NAIS Collaboration

In order to maximize aerial iceberg reconnaissance in the North Atlantic, IIP continued to utilize its NAIS partnership with CIS. IIP coordinated

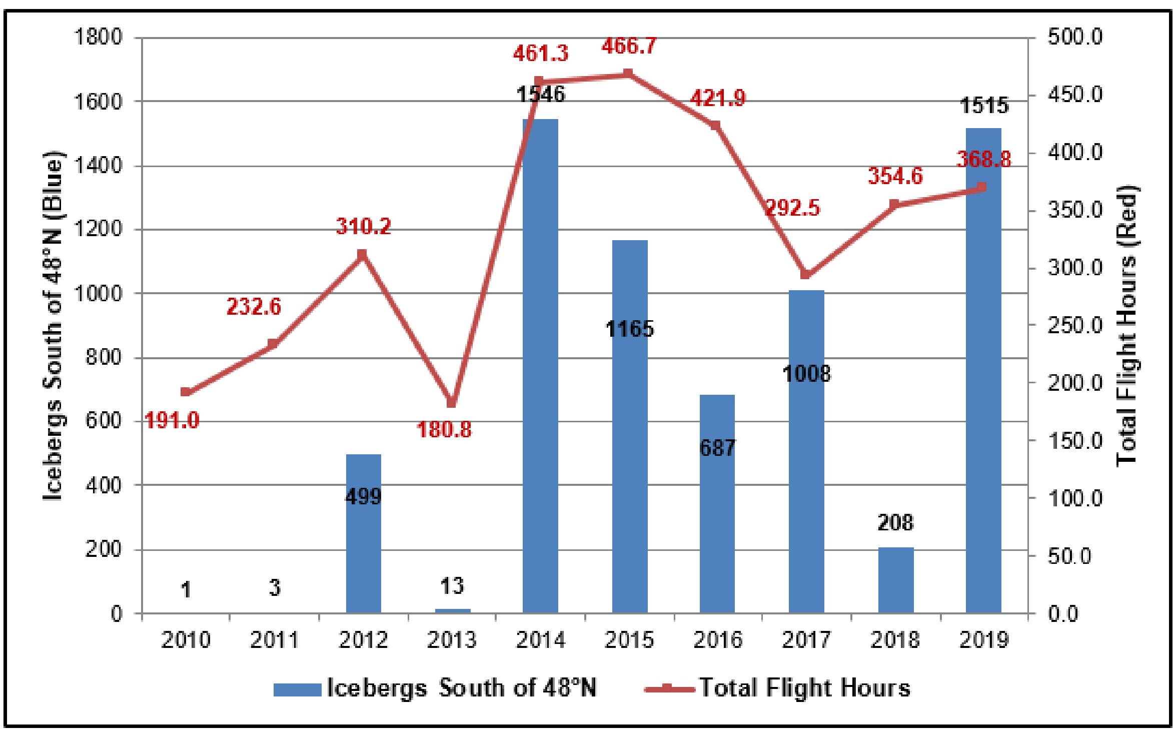

Figure 4-7. Comparison between IRD total flight hours per season and season severity, measured by number of icebergs sighted or drifted below 48N for the past 10 years. 2019 was the second most severe season over the past 10 but only used the 5th most flight hours.

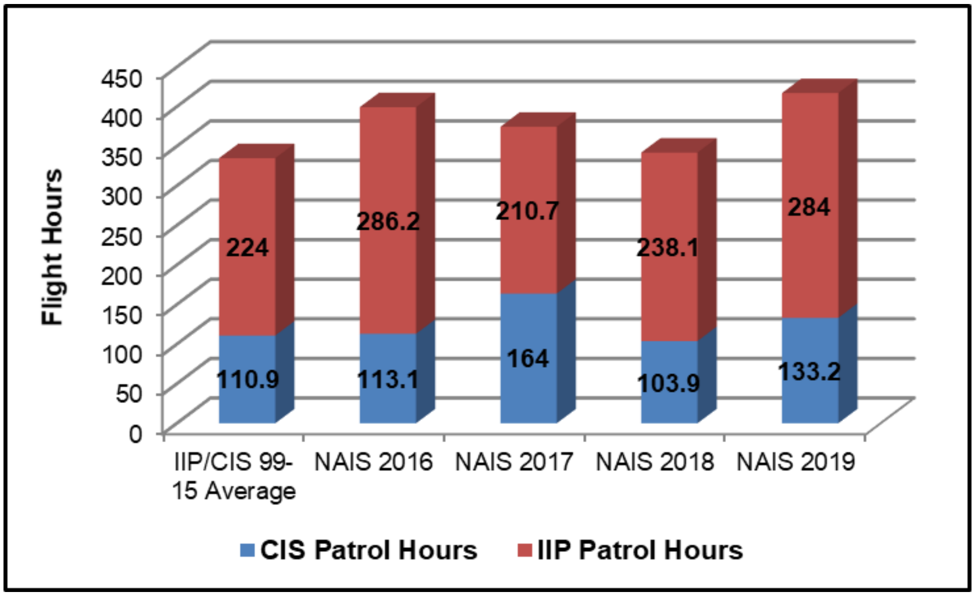

Figure 4-8. NAIS flight hours, a combination of IIP patrol hours and CIS funded PAL Aerospace patrol hours.

flight plans with CIS during periods when IRDs were not deployed to St. John's, NL. **Figure 4-8** depicts the NAIS flight hours for 2019. Data provided includes hours flown by each service. CIS contracted PAL Aerospace for 133.2 patrol hours resulting in a combined total of 417.2 patrol hours in support of NAIS reconnaissance.

The NAIS reconnaissance region is divided into seven areas based on the risk of iceberg collision for vessels in the transatlantic shipping lanes. Northern areas are monitored to determine the overall iceberg population early in the season and to predict the anticipated threat of icebergs drifting south in the Labrador Current. The focus of iceberg reconnaissance shifts as the iceberg population drifts south in early spring and retreats in late summer. The highest priority areas in the south, east, and west pose the greatest risk to transatlantic shipping when icebergs are present in these regions. To illustrate this tiered approach, **Figure 4-9** shows a one-day snapshot indicating the most recent reconnaissance coverage for areas across the NAIS reconnaissance region.

Ship Interactions

IRD on-scene patrol time in the HC-130J aircraft is mainly focused on locating and classifying icebergs using visual and radar reconnaissance methods. However, during patrols, the IRD will also communicate directly with the maritime community to request recent iceberg sighting information. This communication takes two forms: a sécurité broadcast to all vessels in vicinity of the aircraft, and direct calls to vessels identified by AIS. The information from the individual vessels is especially useful during periods of reduced visibility, or when numerous small vessels not equipped with AIS are present in the reconnaissance area. Vessel observations are valuable for confirmation of data provided by the aircraft's radar. During the 2019 season, IRDs made 70

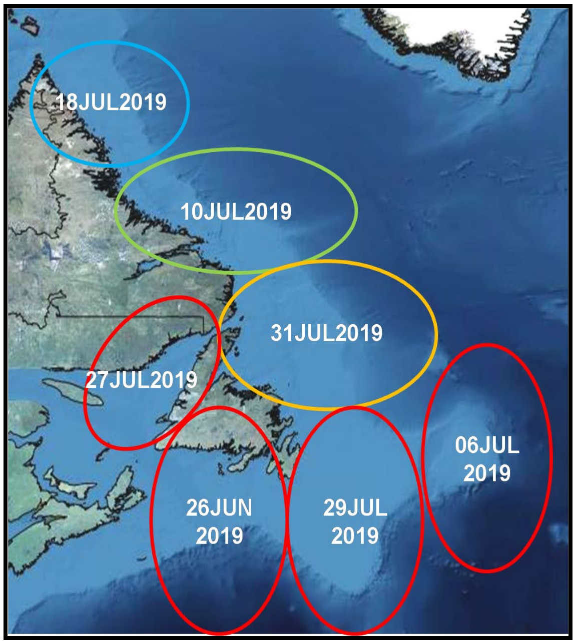

Figure 4-9. Example of NAIS reconnaissance coverage from 01 August 2019. Circle color indicated risk of iceberg collision for vessels in the transatlantic shipping lanes. Blue and green areas are low risk to transatlantic shipping and are monitored for iceberg population. Yellow indicates moderate risk and the area is monitored frequently early and late in the season when the Iceberg Limit is within this region. Red indicates high risk of icebergs affecting transatlantic shipping, and reconnaissance is focused on this area when the Iceberg Limit extends to these regions.

general sécurité broadcasts and 147 direct vessel callouts.

Satellite Reconnaissance

IIP satellite reconnaissance during the 2019 Iceberg Season, focused on continuing to refine the analysis process and incorporate improvements from the 2018 validation project. The majority of frames analyzed by IIP in 2019 remain from the ESA SAR Satellites Sentinel-1A and 1B. IIP continues to rely on Sentinel-1A/B imagery due to their consistent collection schedule, and open source, no-cost imagery available online in near real-time. IIP augmented this satellite reconnaissance with imagery from the Canadian C-Band SAR satellite system (RADARSAT-2) throughout the season. Additionally, during the 2019 Ice Season, IIP worked with DHS S&T on a major project to tag icebergs with GPS trackers. The goal of this project was to collect validated satellite iceberg images for developing an improved satellite iceberg detection algorithm using machine learning.

The RADARSAT-2 frames collected and analyzed in the 2019 Ice Season were obtained through IIP's NAIS partnership with USNIC under the Northern View arrangement between the U.S. National Geospatial-Intelligence Agency (NGA) and Canada's Department of National Defense. Having a dedicated person at USNIC to manage RADARSAT-2 ordering requests continued to prove invaluable toward the smooth collection of data. IIP balanced the RADARSAT-2 frames collected between supporting the DHS S&T tagging campaign, by acquiring frames in the area planned iceberg tagging area, and collecting frames near the Iceberg Limits.

IIP analyzed 230 individual satellite frames during the 2019 Ice Season. These 230 satellite frames comprised of 190 Sentinel-1A/B frames and 40 RADARSAT-2 frames. IIP's Satellite Dayworker (SDW) identified 4,864 icebergs and four radar targets in the 230 analyzed frames, of which 3,945 were added or resighted in BAPS. The four targets classified as radar targets were clear targets within the satellite images that could not be ruled out as ships. Section 3 contains a further breakdown of satellite icebergs reports received from all sources and the total numbers of satellite icebergs entered into BAPS.

The total number of frames analyzed in house by IIP decreased from the 305 in 2018. The decrease is attributed to improving the quality of satellite analysis conducted by IIP's SDW. In 2018, IIP focused on increasing capacity of satellite images analyzed through the development of the SDW position. In 2019 the emphasis shifted to improving the quality of the analysis utilizing new techniques to filter targets developed after the 2018 Ice Season. The updated filtering process increased the amount of time the IIP SDW spent analyzing individual frames, but improved the quality of target classification. Additionally, even though less frames were analyzed, IIP identified and incorporated more satellite icebergs into BAPS in 2019: 3,945 compared to 1,273 in 2018. Also, **Figure 4-10**, shows that the total percentage of satellite identified icebergs (from all sources) continued to increase in 2019. Highlighting the continued expansion of satellite imagery analysis in iceberg detections, and improved detection and identification processes. However, as with previous changes in iceberg reconnaissance methods, there may be error inflating the number of icebergs detected by satellite reconnaissance. IIP and others continue to improve the ability to detect and discriminate icebergs in SAR satellite imagery, reducing the error and inflation of satellite identified icebergs.

Satellite validation efforts after the 2018 Ice Season led to an improved filtering process of Sentinel imagery. Using results from concurrent IIP aerial reconnaissance and satellite frames, IIP was able to refine tactics used to filter possible targets, which included analyzing targets and identifying icebergs in greater than 7/10 sea ice for the first time. Refer to Appendix B for further information about IIP's improved detection of icebergs in sea ice and refined filtering process used during the 2019

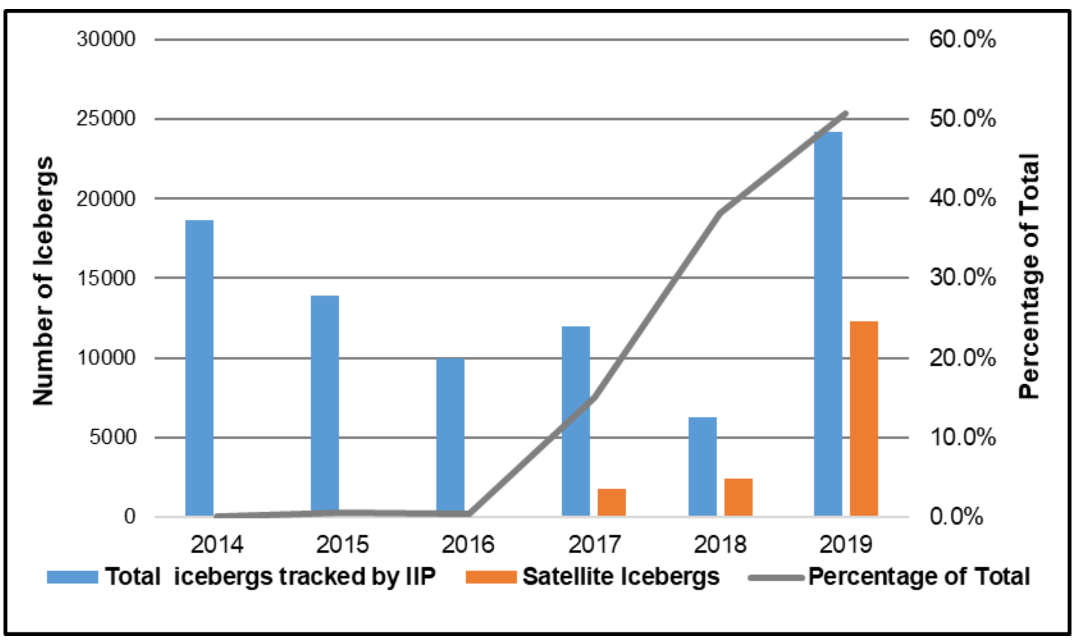

Figure 4-10. Comparison of the number of satellite iceberg detections (all sources) received at IIP and the total number of iceberg sightings from 2014-2019. The grey line shows the percentage of total iceberg sightings processed by IIP that were from satellite sources.

season.

However, IIP's validation project also highlighted the difficulty in acquiring a large enough data set of validated satellite icebergs needed to develop machine learning algorithms. Out of the 29 satellite frames concurrent with 15 IRD patrols in 2018, less than 25 correlated icebergs were identified. In 2019, the extreme extent of the iceberg distribution and priority of patrolling the Iceberg Limits did not allow any dedicated satellite validation patrols. The high number of satellite validation flights in 2018 occurred because the light iceberg season limit extents, but there was also an analogously lower number of potential validation targets.

DHS S&T Iceberg Tagging Campaign

IIP's satellite validation efforts to date have shown that collecting iceberg ground truth data for satellite machine learning algorithm development requires a dedicated project outside of IIP's normal IRD routine. In an effort to collect sufficient data for this purpose, DHS S&T funded and led a team to conduct a dedicated campaign during the 2019 Ice Season. IIP staff contributed to elements throughout the campaign including: test plan development, on-scene operations, satellite image collection, and preliminary data analysis. The goal of the project was to track icebergs with a wide array of shapes and sizes in sea ice and open water to develop a robust data set of validated icebergs in SAR satellite imagery. DHS S&T contracted C-CORE to fly custom built quadcopter drones from a vessel to deploy GPS-tracker beacons (i.e. "tag") onto icebergs. GPS-trackers would provide accurate positional data every thirty minutes for tagged icebergs, providing validation data of targets in coincident satellite imagery.

The DHS S&T team directed four deployment campaigns spanning from late April through early August. The first GPS tagging campaign deployment in April was conducted aboard the USCGC JUNIPER (WLB-201). IIP's Information Branch Chief sailed with JUNIPER to provide on-site iceberg expertise and to assist with beacon deployment. Due to its capability of operating in sea ice the USCGC JUNIPER was selected for the first deployment while sea ice was present in the OPAREA from late April

Figure 4-11. The two vessels used during the DHS S&T GPS tagging campaign, USCGC JUNIPER on left and F/V Patrick and William on the right. USCGC JUNIPER was used during voyage 1 in April 2019. F/V Patrick and William was used for voyages 2-4.

through early May (**Figure 4-11,** left panel). The three following deployments were conducted aboard the F/V Patrick and William, a contracted fishing vessel. The F/V Patrick and William conducted tagging operations from late May through early June, late June through early July, and late July through early August. IRD 9 coincided with the third GPS tagging voyage and flew over the Patrick and William as it was conducting tagging operations (**Figure 4-11,** right panel).

The DHS S&T team collected SAR satellite imagery to identify targets coincident with GPS-tracked iceberg positions. IIP augmented regular RADARSAT-2 imagery collection through the USNIC and Northern View arrangement to support the GPS Tagging project. Benefiting from its NAIS partnership, IIP coordinated closely with CIS to de-conflict RADARSAT-2 ordering. The validated iceberg position data and collected satellite imagery is being analyzed for iceberg detection algorithm development using automated machine learning processes. Detailed results will be published separately when available.

While drone delivery was a conceptually sound approach, the reality of flying a drone and tagging small icebergs (i.e. less than 60m in length), proved considerably challenging. Variable wind conditions in the immediate vicinity of the iceberg created an unstable environment for piloting and beacon deployment – particularly near small, irregularly shaped icebergs. Additionally, as observed by the tagging team at sea, small icebergs frequently broke apart and rolled, reducing the amount of time that beacons remained affixed. During the four campaigns, a total of 140 GPS trackers were deployed onto icebergs. Of these 140 trackers, only 67 remained on icebergs long enough to provide data for satellite validation. The majority of these tags lasted for one day or less.

A secondary goal for DHS S&T effort was to support iceberg drift model improvement. To that end, while underway, C-CORE personnel gathered additional data on the tagged icebergs and the ocean environment in which they drifted. This included 132 3-D iceberg profiles using photogrammetry and Light Detection and Ranging (LIDAR) remote sensing for the above water portion of the iceberg and hull-mounted multi-beam sonar for the underwater portion; 35 Conductivity, Temperature, Depth (CTD) profiles; six Acoustic Doppler Current Profiles (during Voyage 3), 10 SVP buoy deployments (as discussed in Section 2) and three wave measurement buoy deployments. IIP acknowledges and appreciates the US Coast Guard Academy Science Department for providing the CTD for collecting vertical water column profiles. This ancillary data will be available for future efforts to modernize IIP's iceberg drift and deterioration models.

Commemorative Wreath Deployments

Each year, IIP deploys commemorative wreaths in conjunction with reconnaissance operations to remember the lives lost at sea in the North Atlantic Ocean. This year, IIP held a memorial service and wreath dedication ceremony to commemorate the 107th anniversary of the sinking of RMS TITANIC in New London, CT on the morning of 10 April. The two wreaths dedicated during the ceremony were deployed from an HC-130J aircraft on 18 April (**Figure 4-2**). The wreaths were donated and dedicated to the victims of RMS TITANIC by the Titanic Society of Atlantic Canada, and Ms. Monica Adorno.

On 19 June, IIP held a memorial service and wreath dedication ceremony 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 24 June. The wreath was donated by the Navy League of the United States Bridgeport Connecticut Council.

5. Abbreviations and Acronyms

3-D	Three Dimension
AIS	Automatic Identification System
APN-241	HC-130J Tactical Transport Weather Radar
ASEC	U. S. Coast Guard Air Station Elizabeth City
AVHRR	Advanced Very High Resolution Radiometer
BAPS	iceBerg Analysis and Prediction System
C	Celsius
C-CORE	A not-for-profit research and engineering organization in St. John's, Newfoundland
CG-5PW	U. S. Coast Guard Director of Marine Transportation Systems
CCG	Canadian Coast Guard
CFAR	Constant False Alarm Rate
CIIP	Commander, International Ice Patrol
CIS	Canadian Ice Service, an operational unit of the Meteorological Service of Canada
CT	Connecticut
CTD	Connectivity Temperature Depth sensor
CYYT	St. John's International Airport
DHS S&T	Department of Homeland Security's Science and Technology Directorate
DMI	Danish Meteorological Institute
DWS	Duty Watch Stander
EGI	ELTA GPS
ELTA	ELTA Systems Ltd., a group and a wholly-owned subsidiary of Israel Aerospace Industries specifically referring to the ELM-2022A Airborne Maritime Surveillance Radar aboard the HC-130J
EOSDIS	Earth Observing System Data and Information System
ERMA	Environmental Response Management Application, NOAA
ESA	European Space Agency, owner of the Sentinel-1a satellite
ESRL PSD	Earth Systems Research Laboratory Physical Science Division
F/V	Fishing Vessel

GHRSST	Group for High Resolution Sea Surface Temperature
GPS	Global Positioning System
GRD	Ground Range Detected
HC-130J	U. S. Coast Guard Long Range Surveillance Maritime Patrol Aircraft
HD	High Definition
HH	Horizontal-Horizontal Polarization
HV	Horizontal-Vertical Polarization
IDS	Iceberg Detection Software
IIP	U. S. Coast Guard International Ice Patrol
IRD	Ice Reconnaissance Detachment
ISAR	Inverse Synthetic Aperture Radar
IW	Interferometric Wide Swath
JHU	Johns Hopkins University
KGON	Groton-New London Airport
KML	Keyhole Markup Language
KOQU	Quonset State Airport
kts	knots
LIDAR	Light Detection and Ranging
LOX	Liquid Oxygen
M/V	Motor Vessel
m	meter
mb	millibar
MCTS	Marine Communications and Traffic Service, Canadian Coast Guard
MMS	Minotaur Mission System
M/V	Motor Vessel
N	North (Latitude)
NAIS	North American Ice Service
NAOI	North Atlantic Oscillation Index
NASA	National Aeronautics and Space Administration
NAVAREA	Navigational Area
NAVO	U.S. Naval Oceanographic Office
NAVTEX	Navigational Telex
NAVWARN	Navigational Warning

NC	North Carolina
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NGA	U. S. National Geospatial-Intelligence Agency
NIC	U. S. National/Naval Ice Center
NL	Newfoundland and Labrador, Canada
NM	Nautical Mile
NOAA	National Oceanographic and Atmospheric Administration
NSIDC	National Snow and Ice Data Center
NWS	National Weather Service
OPAREA	Operational Area
OPC	Ocean Prediction Center
OPCEN	Operations Center
PAL Aerospace	Commercial aerial reconnaissance provider based in St. John's, Newfoundland.
PFA	Probability of False Alarm
POD	Probability of Detection
PO.DAAC	Physical Oceanography Distributed Active Archive Center
RADARSAT-2	Canadian C-Band SAR satellite system, owned and operated by MacDonald, Dettwiler, and Associates.
Radiofax	Radio Facsimile
RMS	Royal Mail Steamer
R/V	Radar/Visual
SafetyNET	Inmarsat-C Safety Net, automated satellite system for promulgating marine navigational warnings, weather, and other safety information.
SAR	Synthetic Aperture Radar
SDW	Satellite Dayworker
shp	Shape File
SIM	Standard Iceberg Message
SITOR	Simplex Teletype Over Radio
SN1	Sentinel-1 ESA C-Band SAR satellite system (A and B)
SOLAS	Safety of Life at Sea
SST	Sea Surface Temperature

SVP	Surface Velocity Program
UCSD	University of California San Diego
UKMO	United Kingdom Meteorological Office
U.S.	United States
USCG	U. S. Coast Guard
USCGC	U. S. Coast Guard Cutter
USNIC	U. S. National Ice Center
VH	Vertical-Horizontal Polarization
VV	Vertical-Vertical Polarization
W	West (Longitude)
WWNWS	World Wide Navigation Warning System
Z	Zulu – Coordinated Universal Time

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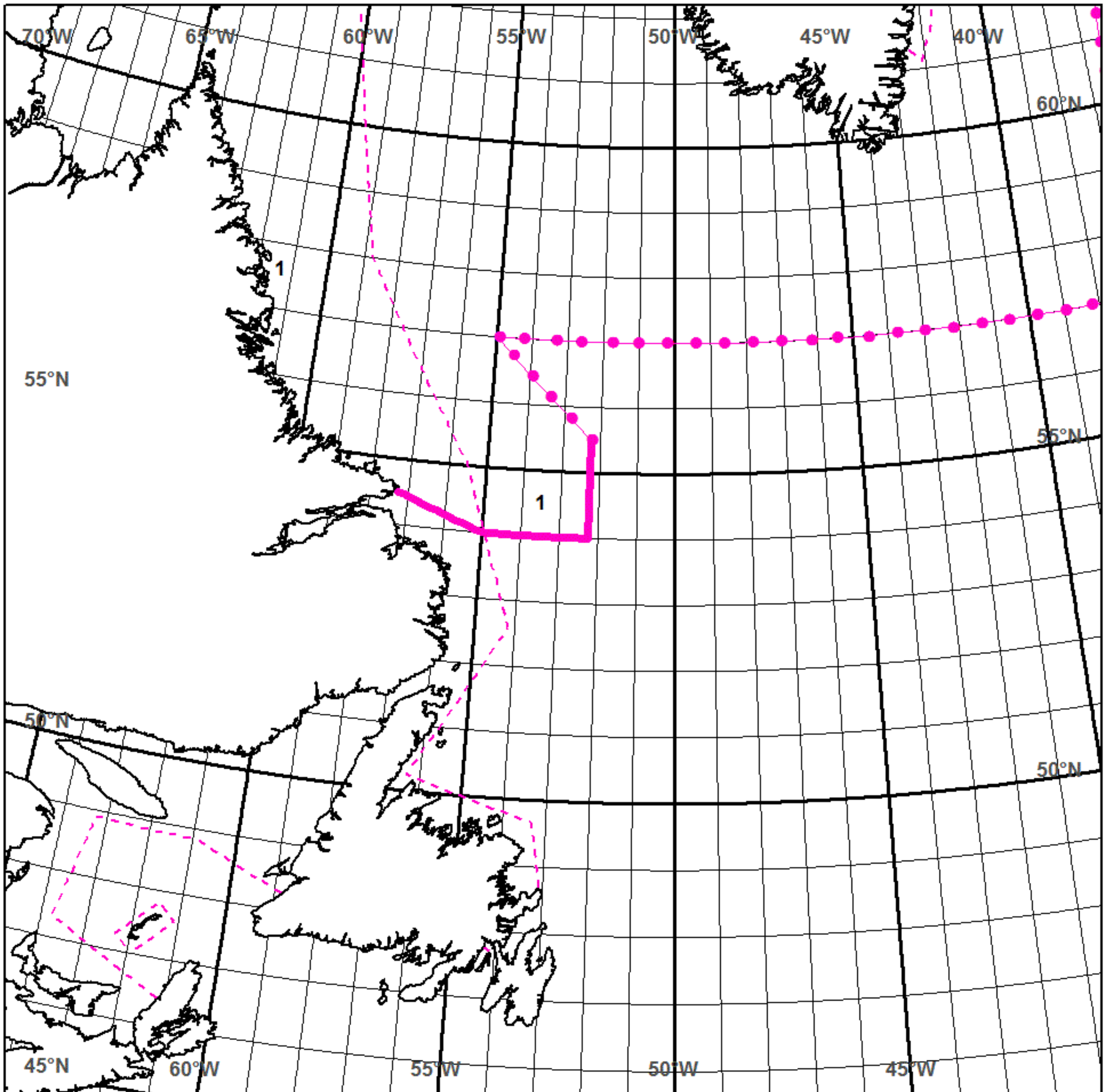
7. Semi-Monthly Iceberg Charts



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 JAN 2019

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

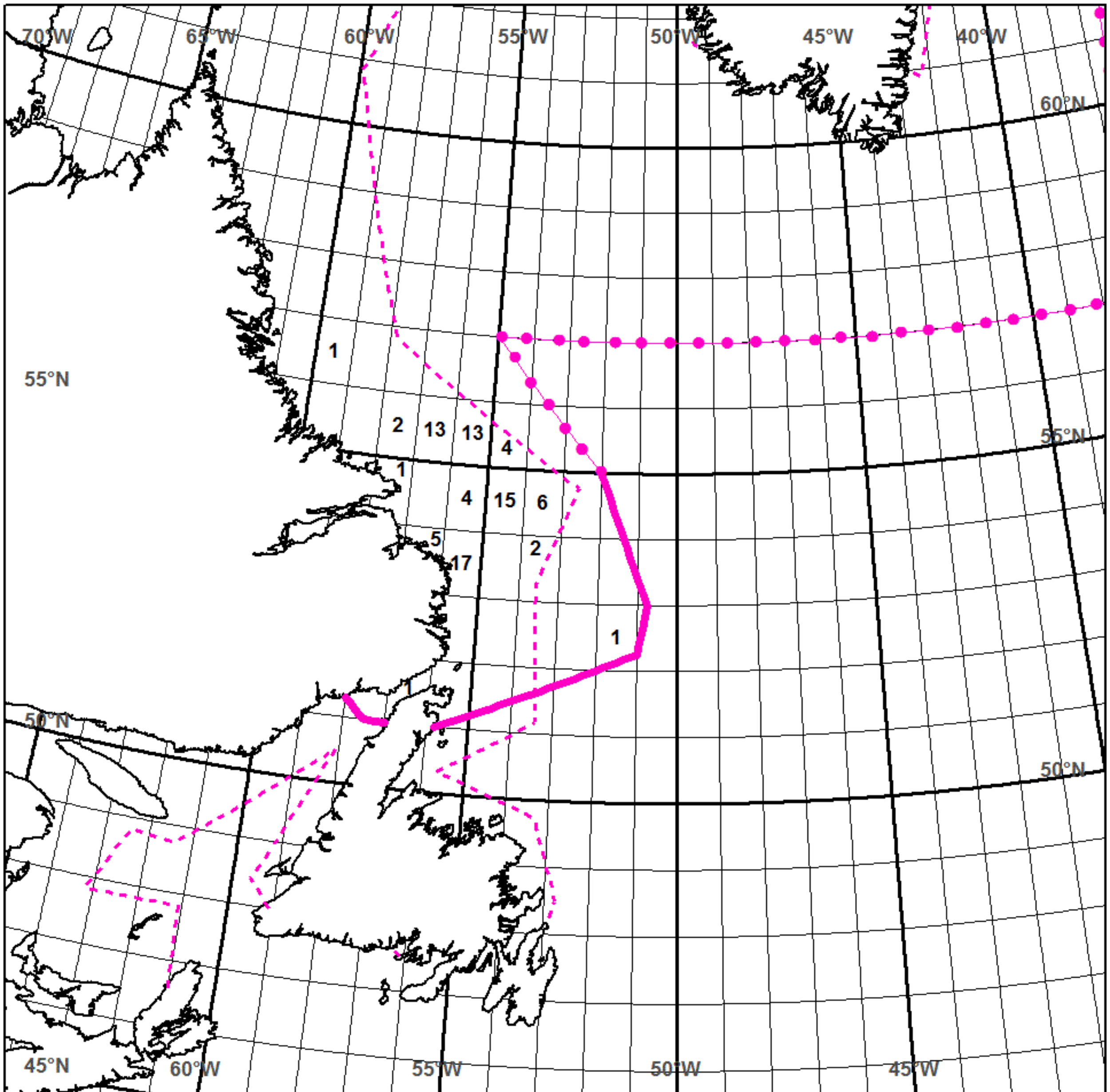
SEA ICE LIMIT

ICEBERGS PER DEGREE SQUARE

⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:

For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Southern Limit Iceberg Flight 14DEC18.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 JAN 2019

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

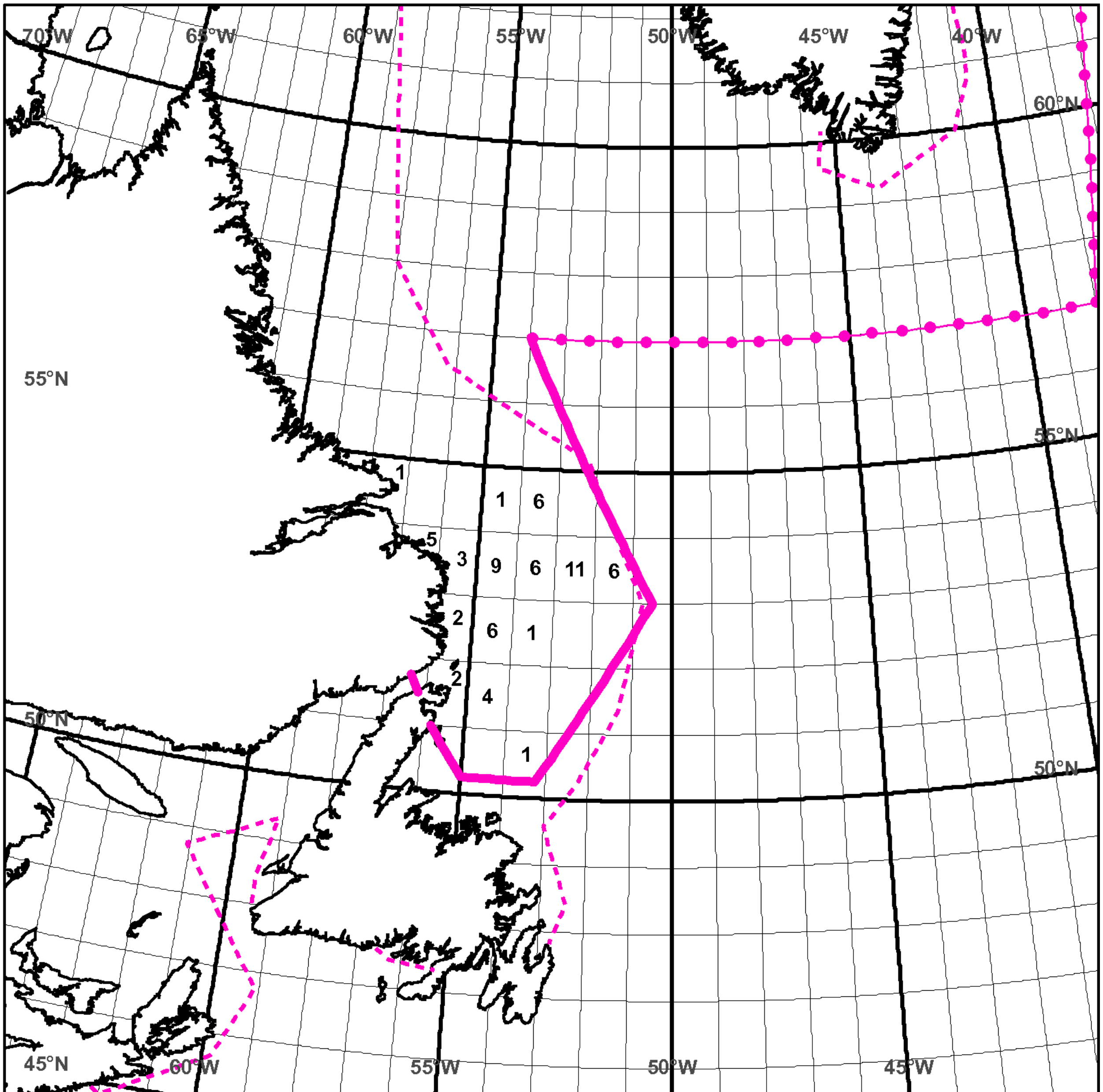
SEA ICE LIMIT

ICEBERGS PER DEGREE SQUARE

RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:

For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Southern Limit Iceberg Flight 05JAN19.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 FEB 2019

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

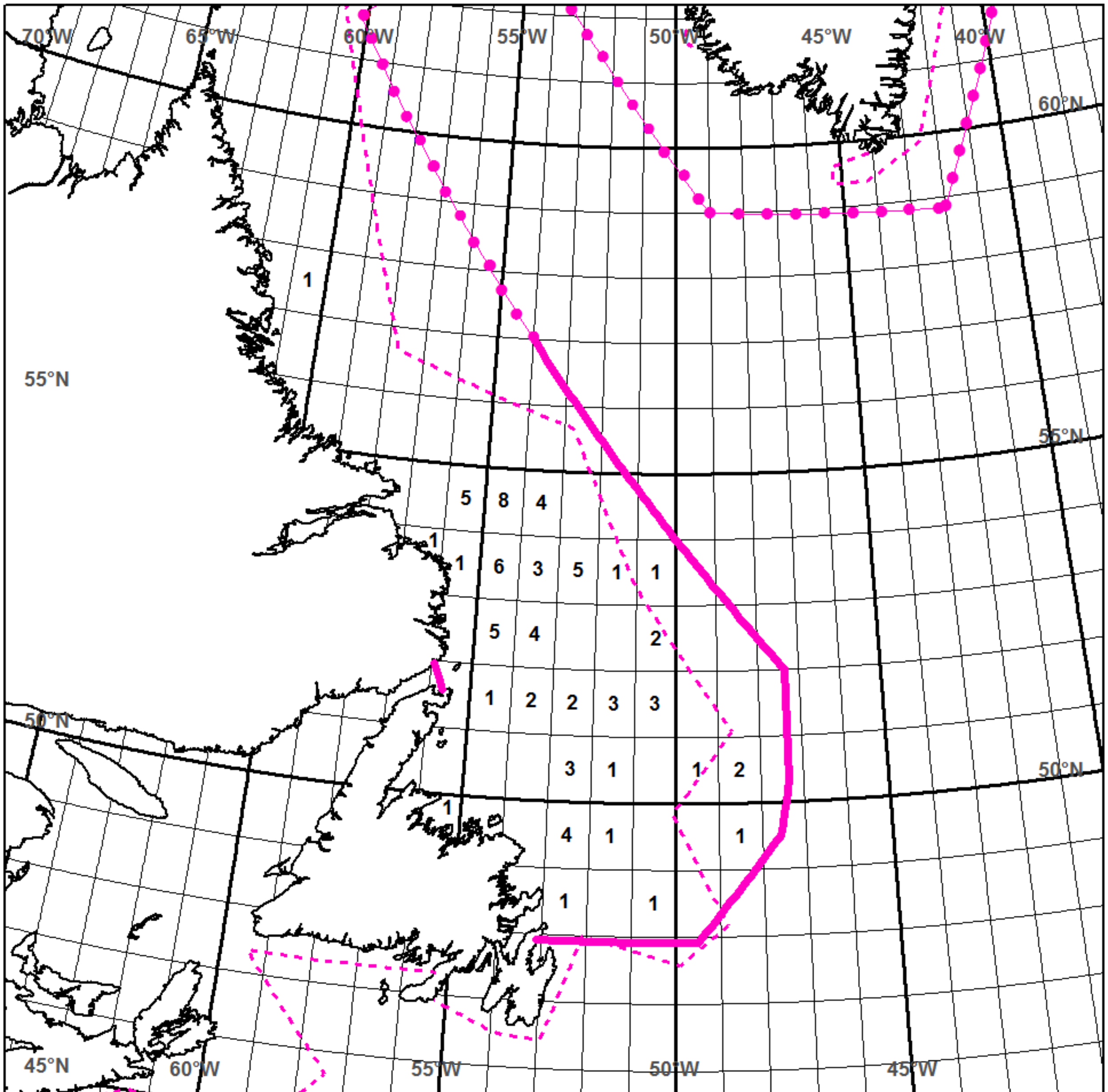
SEA ICE LIMIT

\# ICEBERGS PER DEGREE SQUARE

RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:

For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Interior General Flight 29JAN19.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 FEB 2019

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

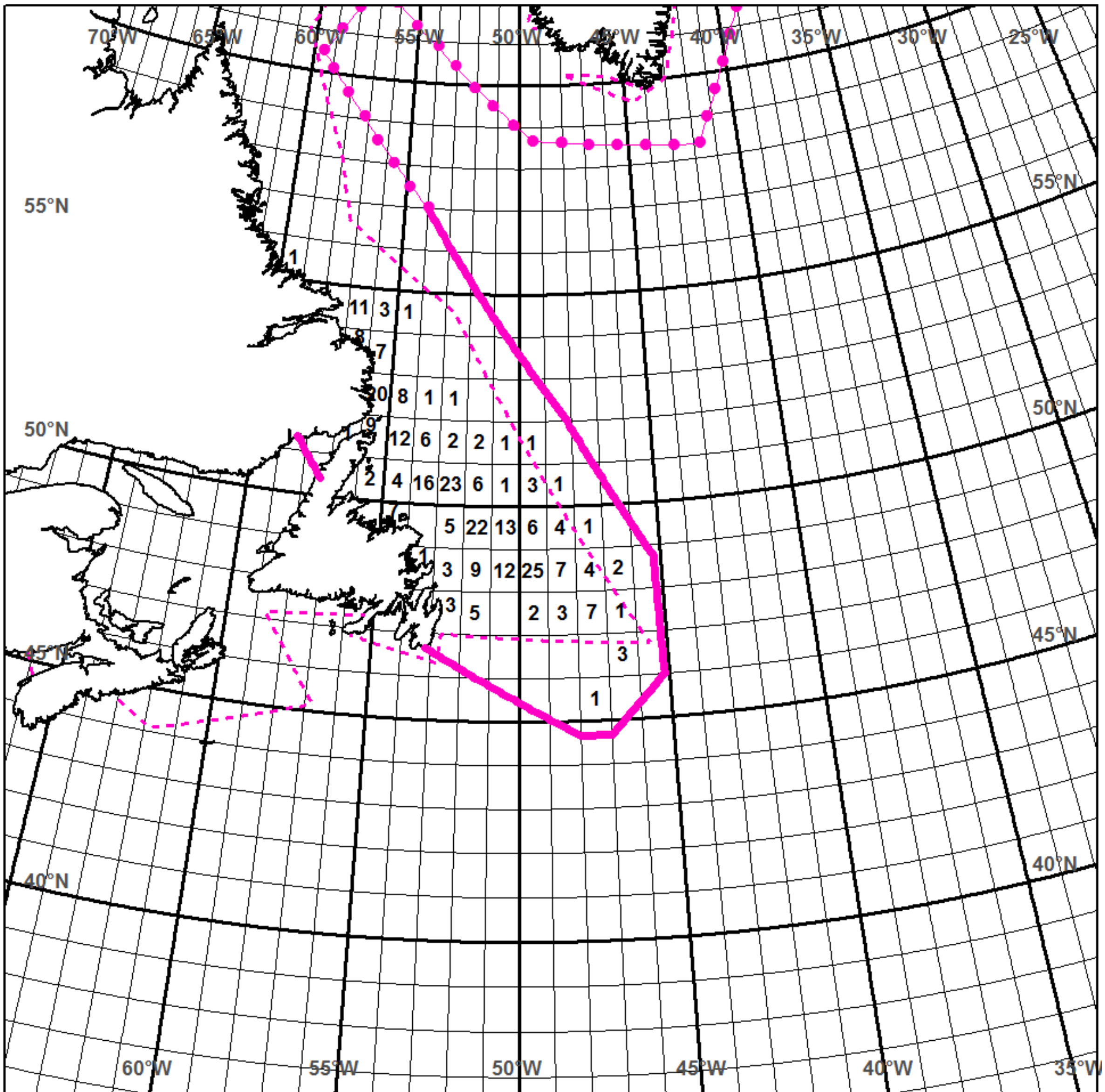
SEA ICE LIMIT

\# ICEBERGS PER DEGREE SQUARE

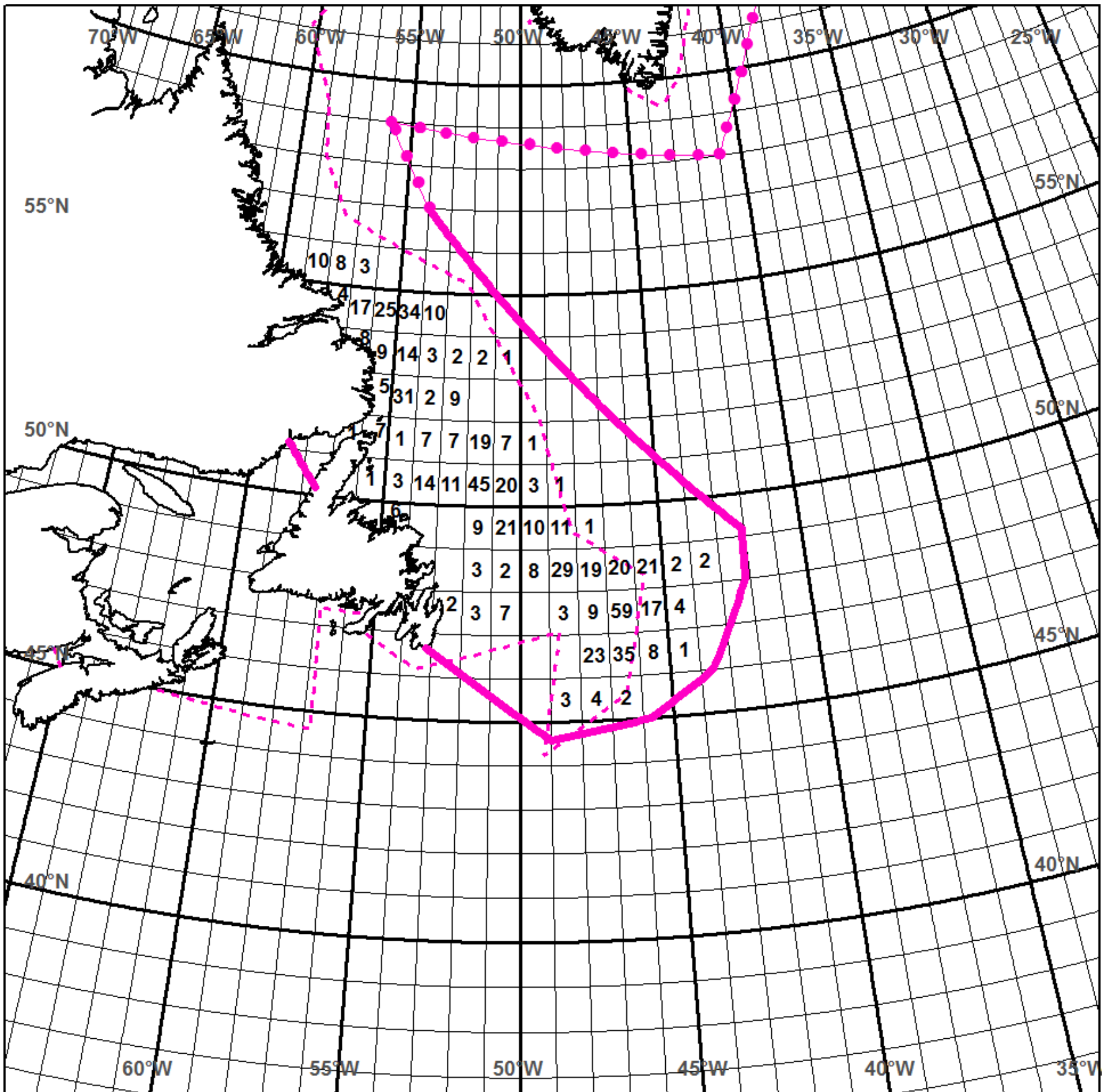
RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:

For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Interior Satellite Pass 12FEB19.



NORTH AMERICAN ICE SERVICE (NAIS)	ICEBERG ANALYSIS FOR 0000 UTC **01 MAR 2019**
ESTIMATED ICEBERG LIMIT ICEBERG LIMIT SEA ICE LIMIT # ICEBERGS PER DEGREE SQUARE ⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT	**NOTE:** **For more information:** **www.navcen.uscg.gov/iip** **www.ice-glaces.ec.gc.ca** **Most Recent Reconnaissance:** **Interior Iceberg Flight 28FEB19.**

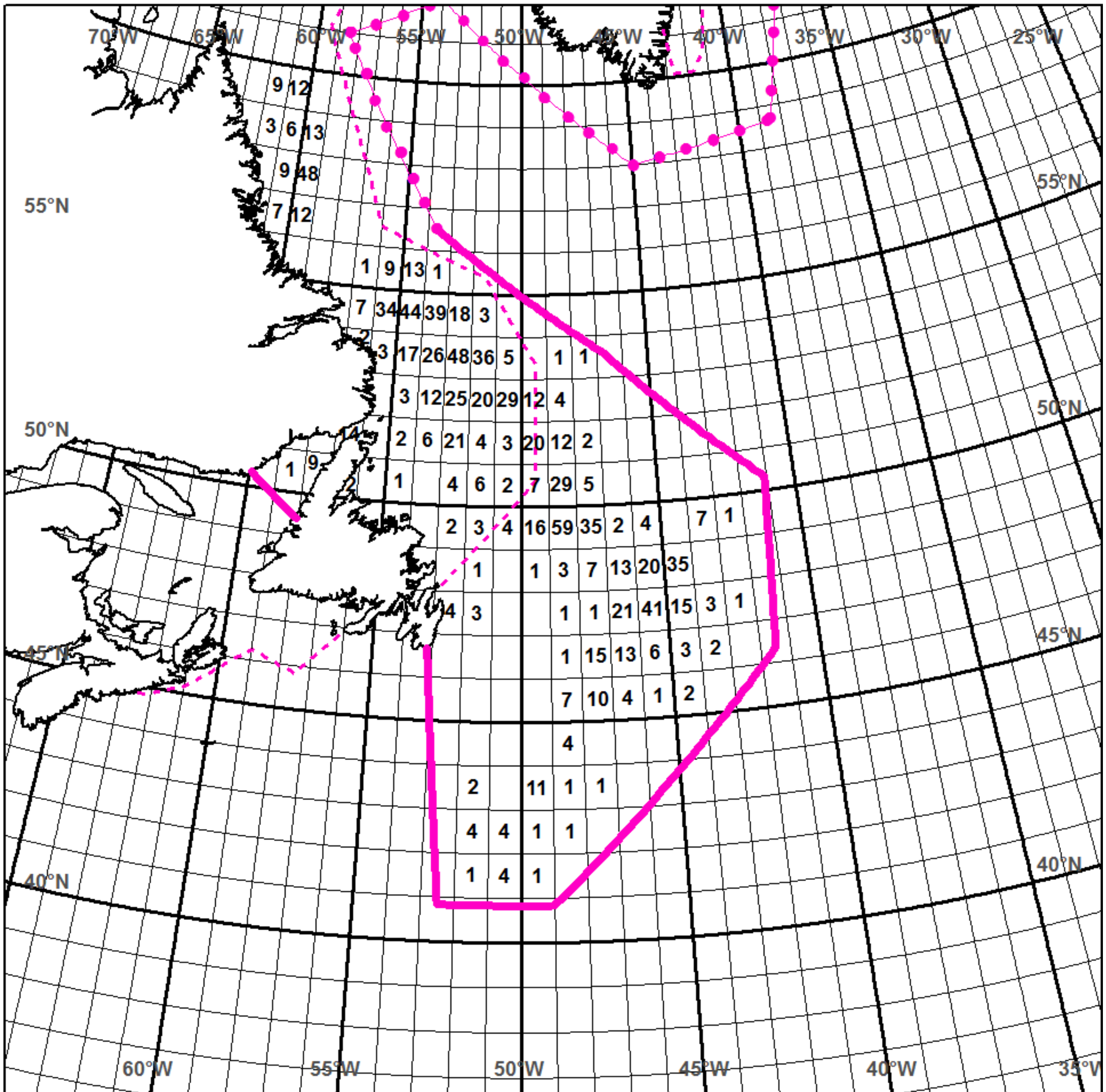


NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 MAR 2019

ESTIMATED ICEBERG LIMIT	**NOTE:**
ICEBERG LIMIT	**For more information:**
SEA ICE LIMIT	**www.navcen.uscg.gov/iip**
# ICEBERGS PER DEGREE SQUARE	**www.ice-glaces.ec.gc.ca**
⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT	**Most Recent Reconnaissance: Interior Iceberg Flight 14MAR19.**



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 APR 2019

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

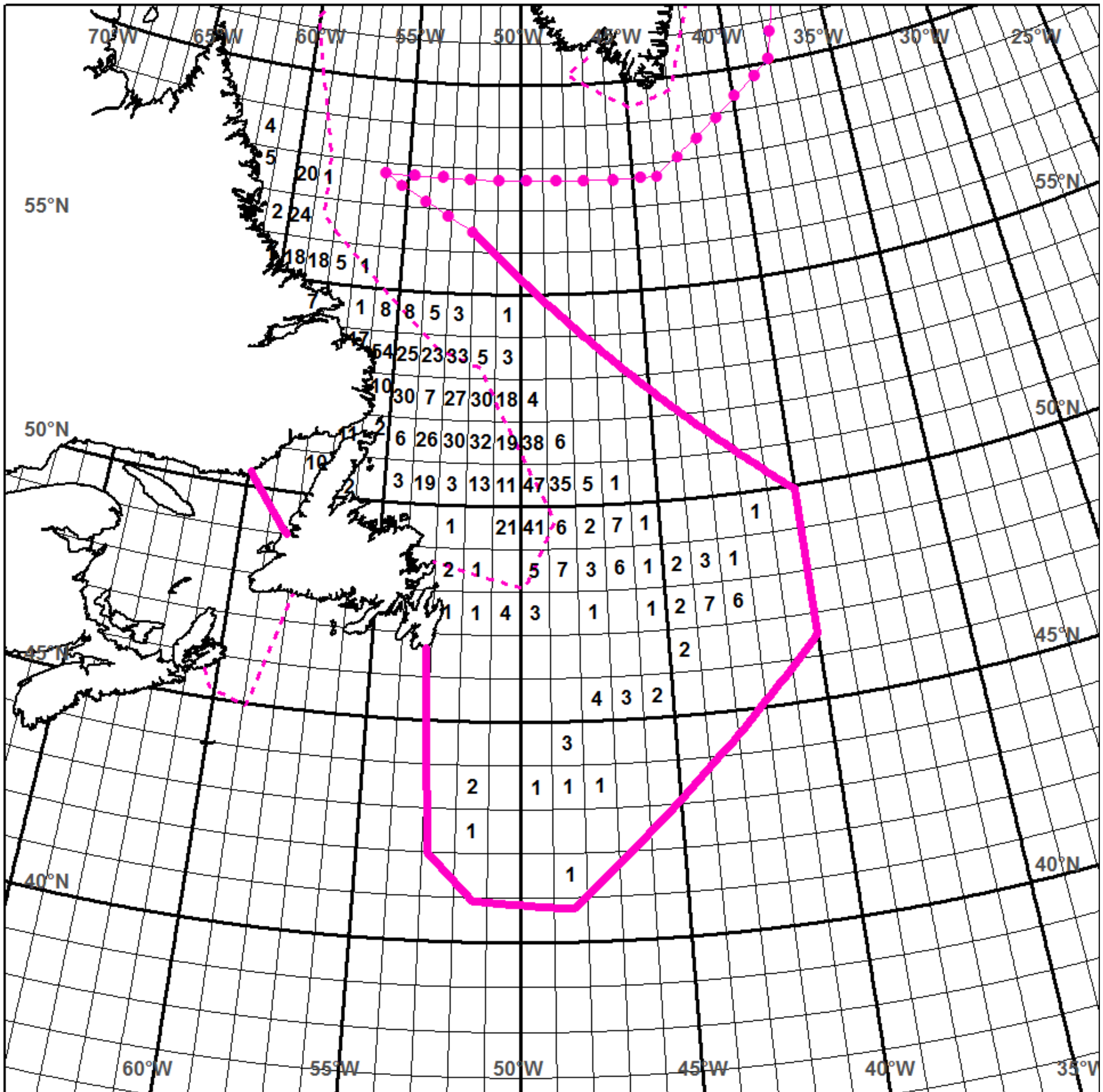
SEA ICE LIMIT

\# ICEBERGS PER DEGREE SQUARE

⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:

For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Eastern Limit Iceberg Flight 30MAR19.



NORTH AMERICAN ICE SERVICE (NAIS)

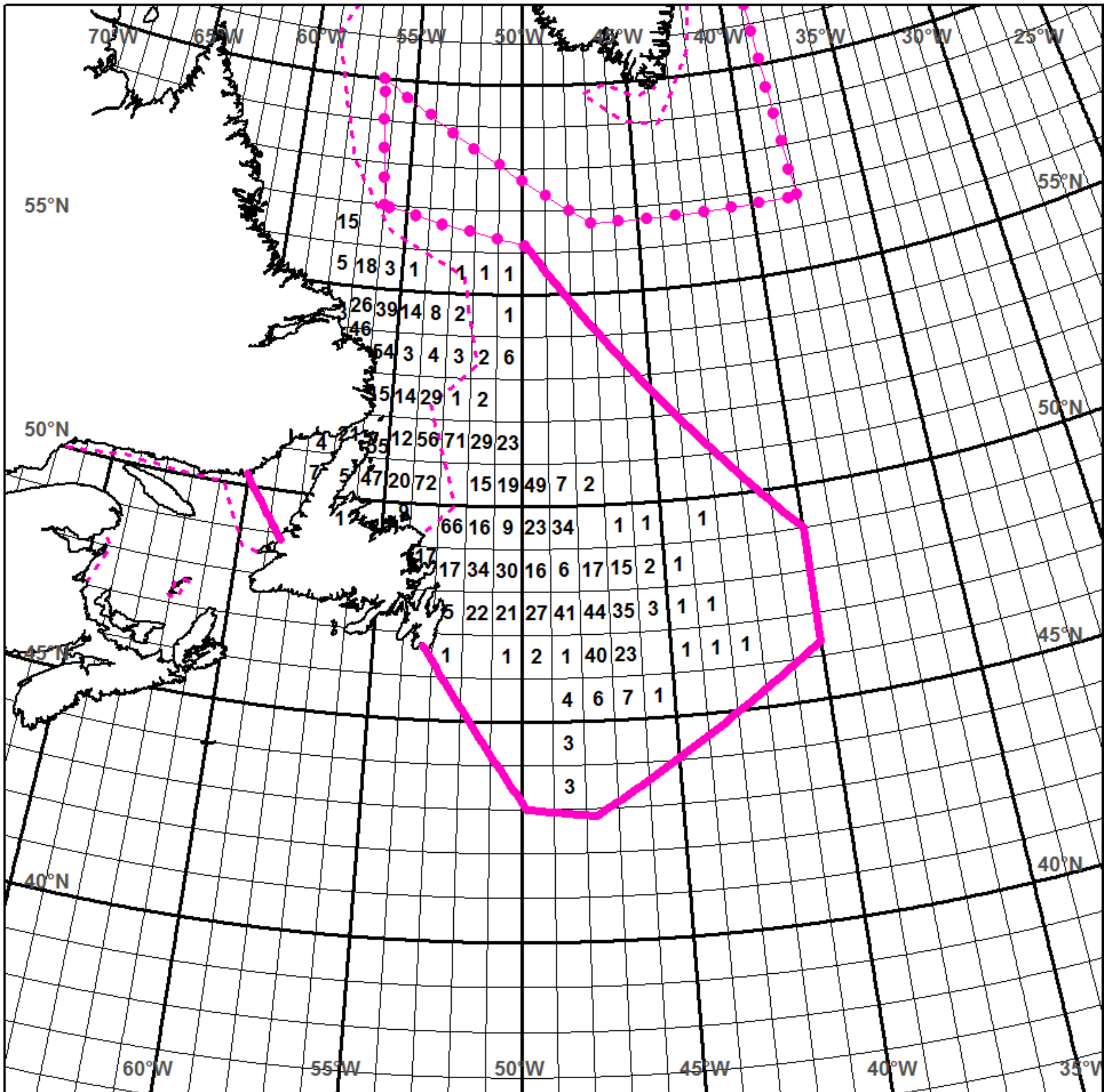
ICEBERG ANALYSIS FOR 0000 UTC

15 APR 2019

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

NOTE:

Significant reduction of iceberg limit due to predicted deterioration.
Today we commemorate the 107th anniversary of the sinking of the RMS Titanic.
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Southern Limit Iceberg Flight 12APR19.



NORTH AMERICAN ICE SERVICE (NAIS)

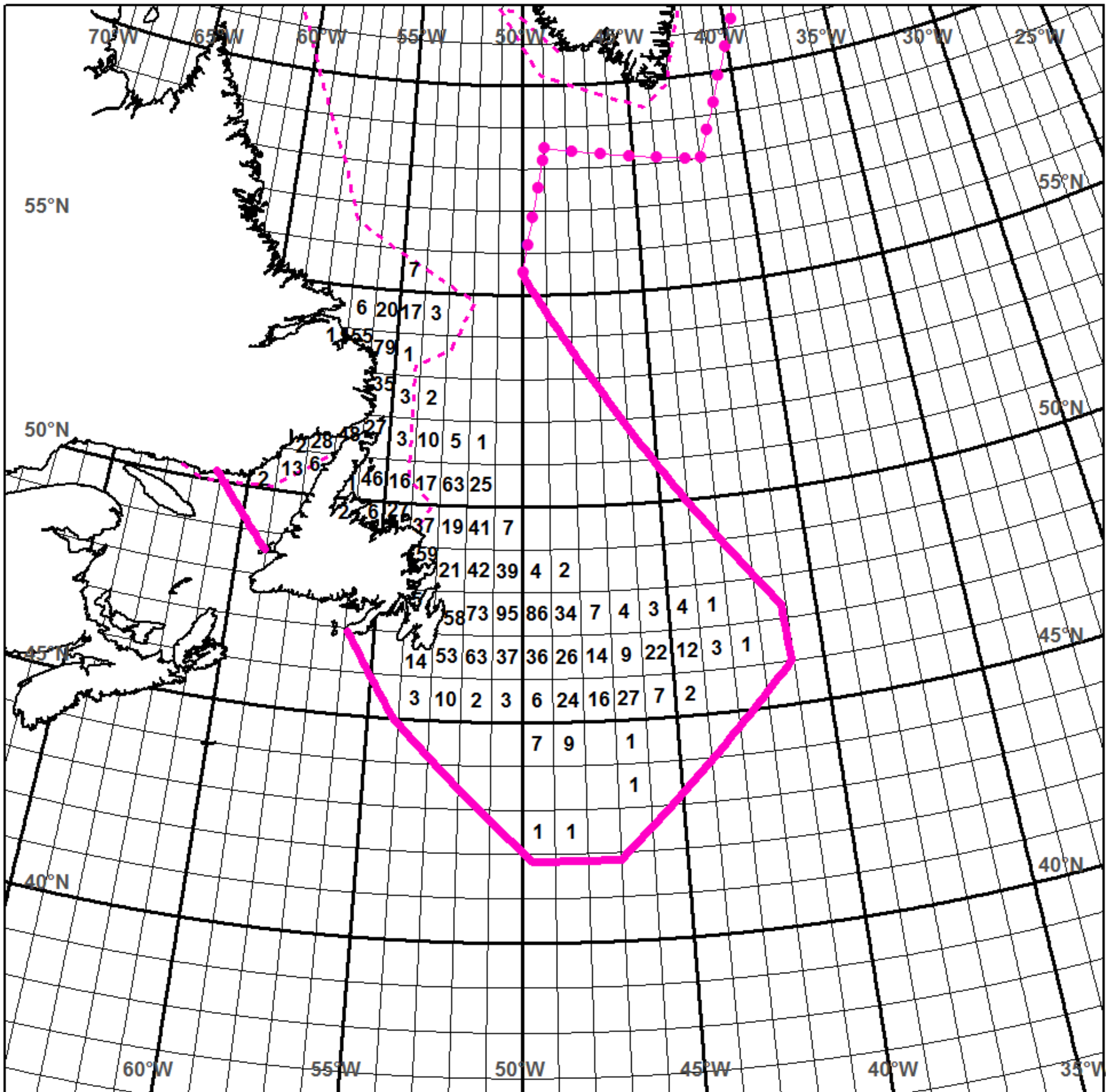
ICEBERG ANALYSIS FOR 0000 UTC

01 MAY 2019

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

NOTE:

For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Southern Limit Iceberg Flight 28APR19.



NORTH AMERICAN ICE SERVICE (NAIS)

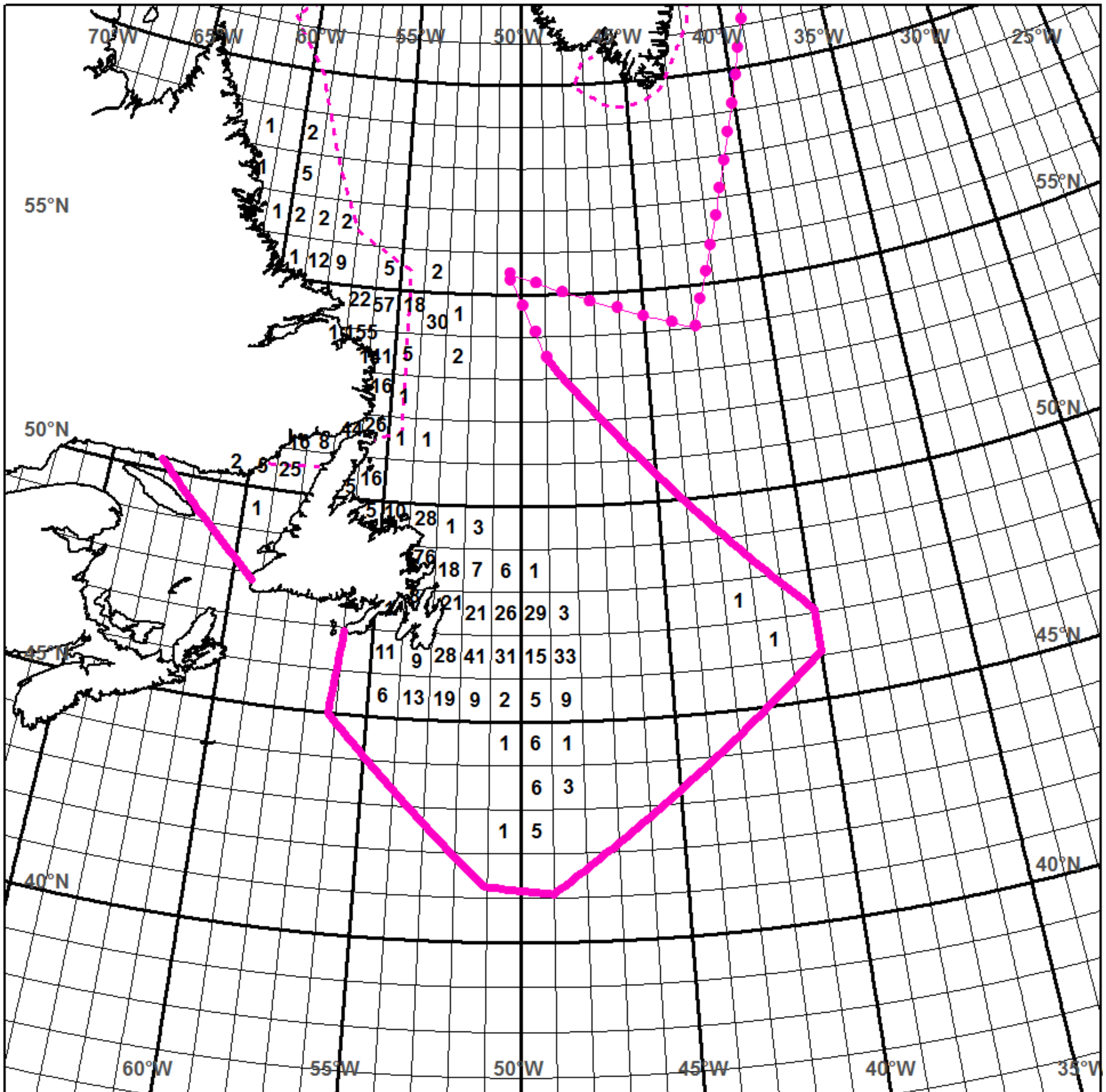
ICEBERG ANALYSIS FOR 0000 UTC

15 MAY 2019

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

NOTE:

For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Southeastern Limit Iceberg Flight 13MAY19.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 JUN 2019

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

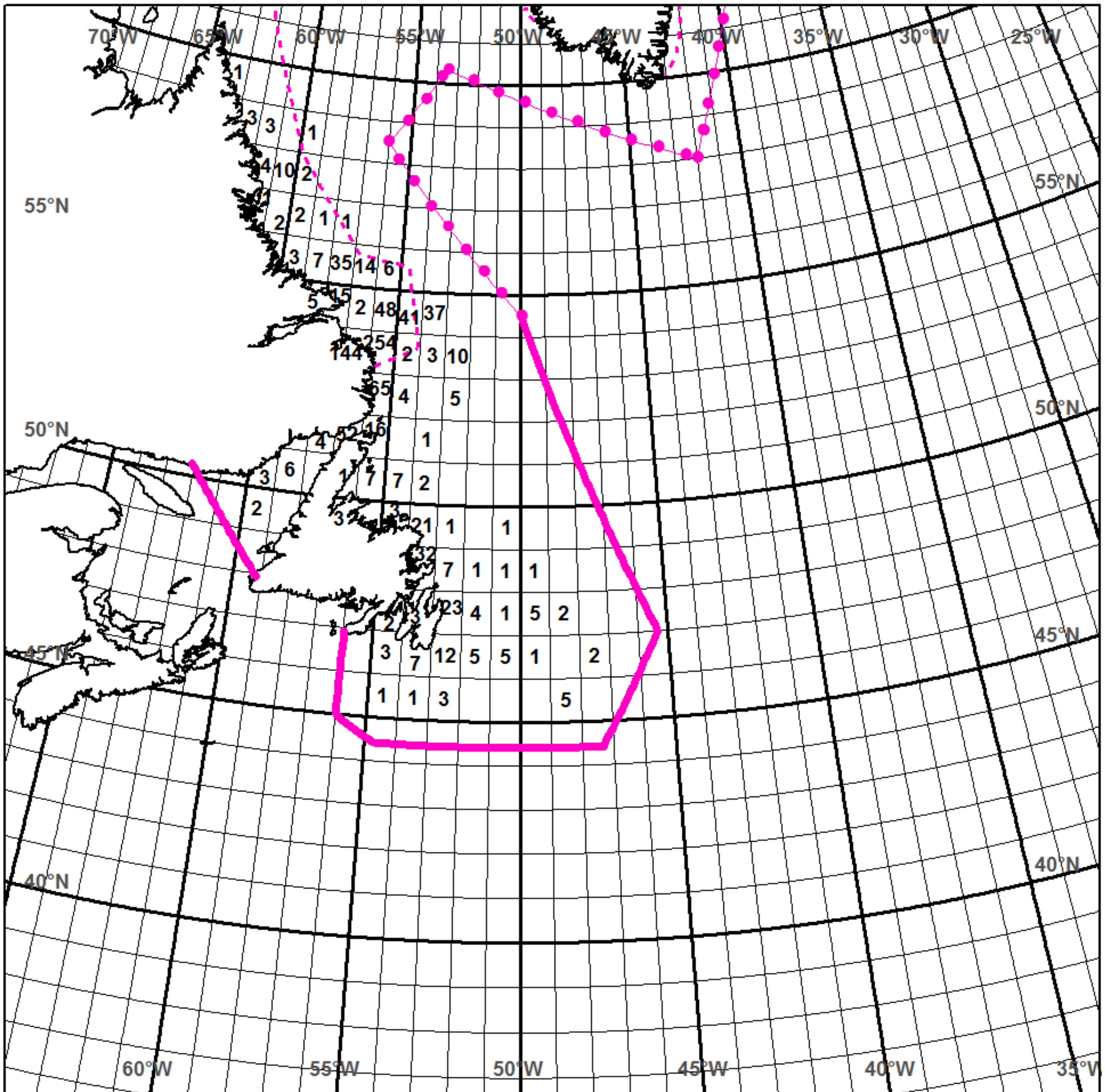
SEA ICE LIMIT

ICEBERGS PER DEGREE SQUARE

⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:

For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Eastern Limit Iceberg Flight 26MAY19.



NORTH AMERICAN ICE SERVICE (NAIS)

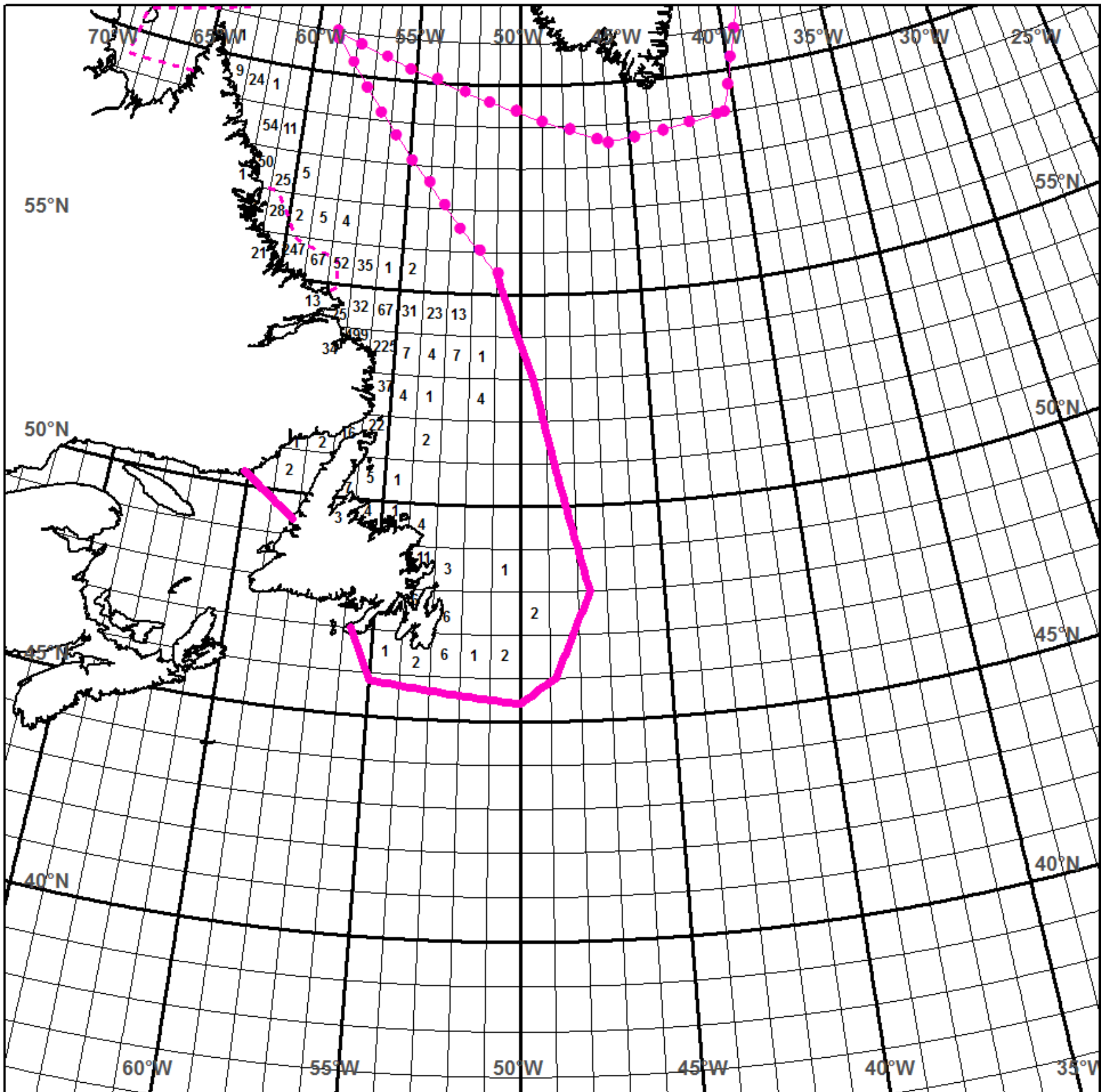
ICEBERG ANALYSIS FOR 0000 UTC

15 JUN 2019

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

NOTE:

For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Eastern Limit Iceberg Flight 12JUN19.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

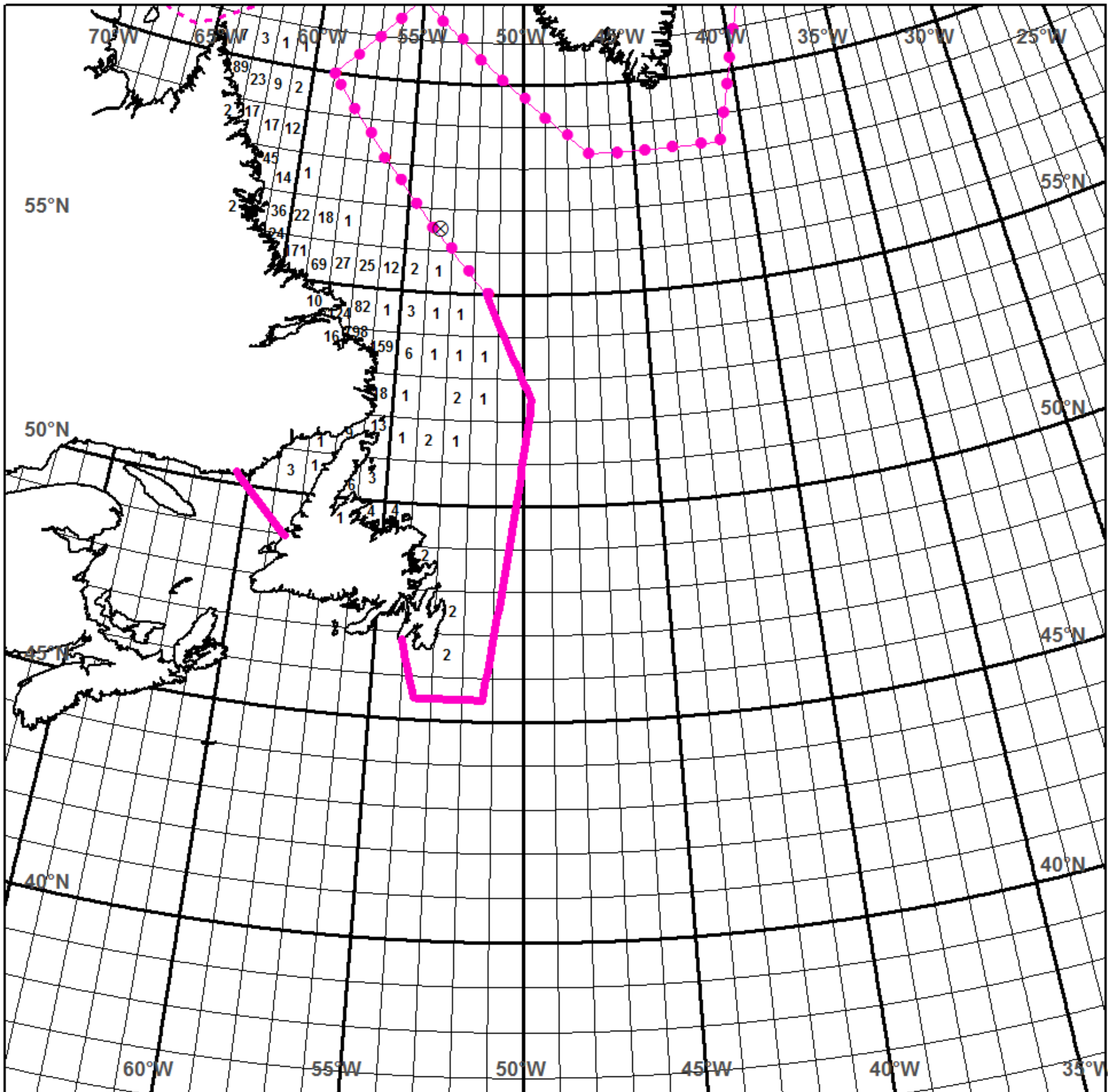
01 JUL 2019

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

NOTE:

Significant reduction of iceberg limit due to predicted deterioration.

For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Northern Survey Iceberg Flight 26JUN19.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 JUL 2019

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

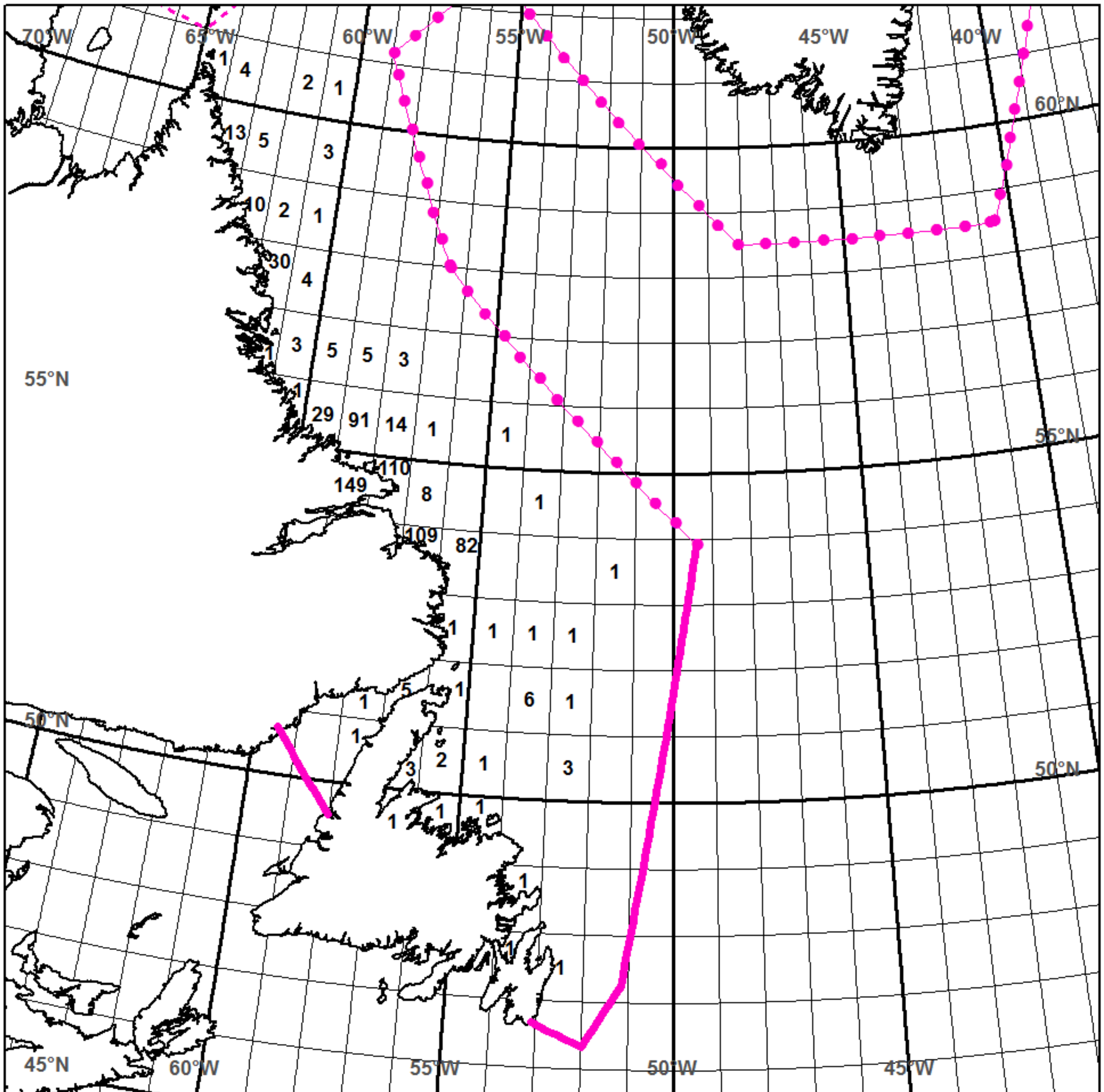
SEA ICE LIMIT

\# ICEBERGS PER DEGREE SQUARE

⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:

For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Northern Survey Iceberg Flight 10JUL19.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 AUG 2019

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

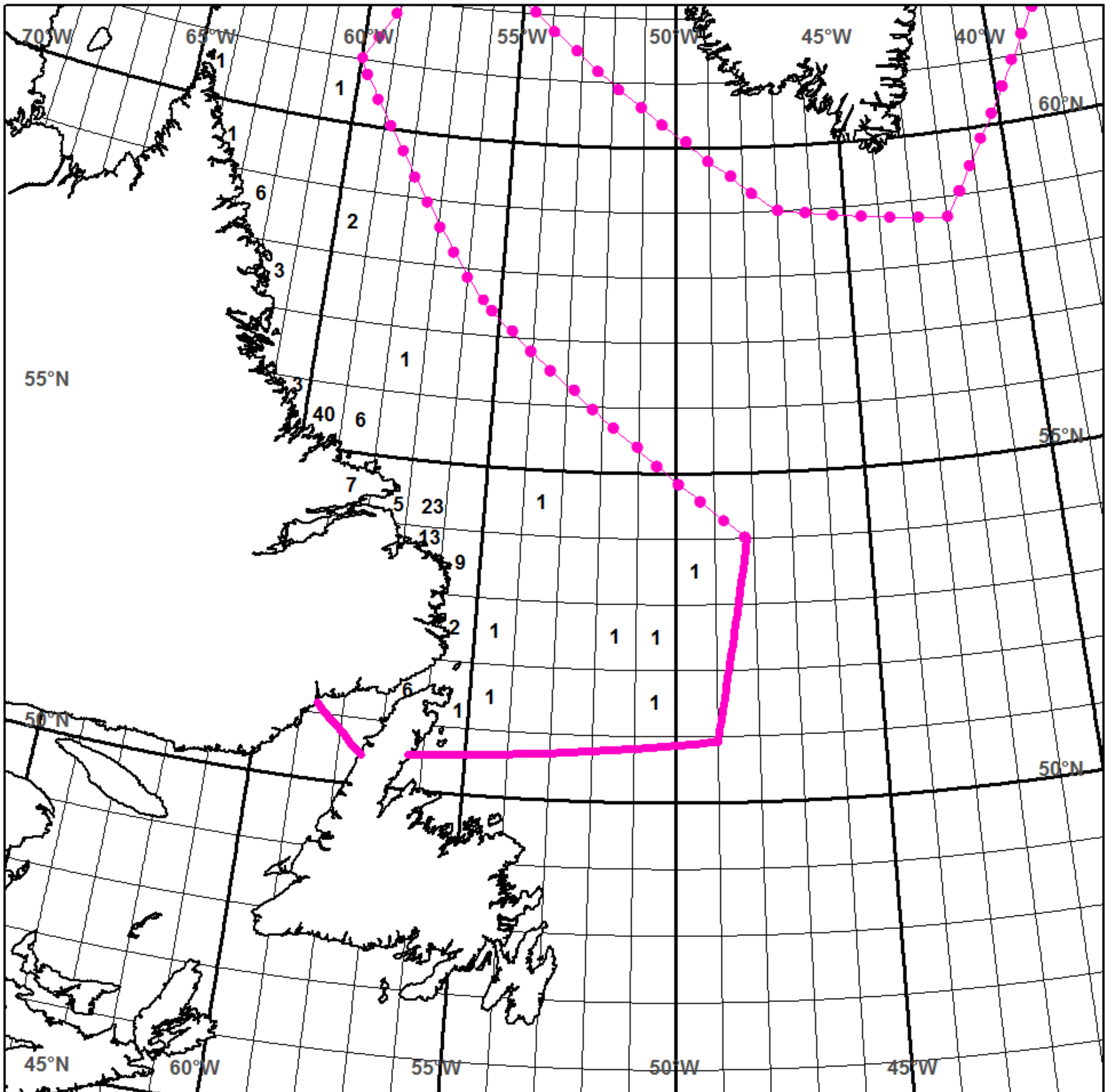
SEA ICE LIMIT

ICEBERGS PER DEGREE SQUARE

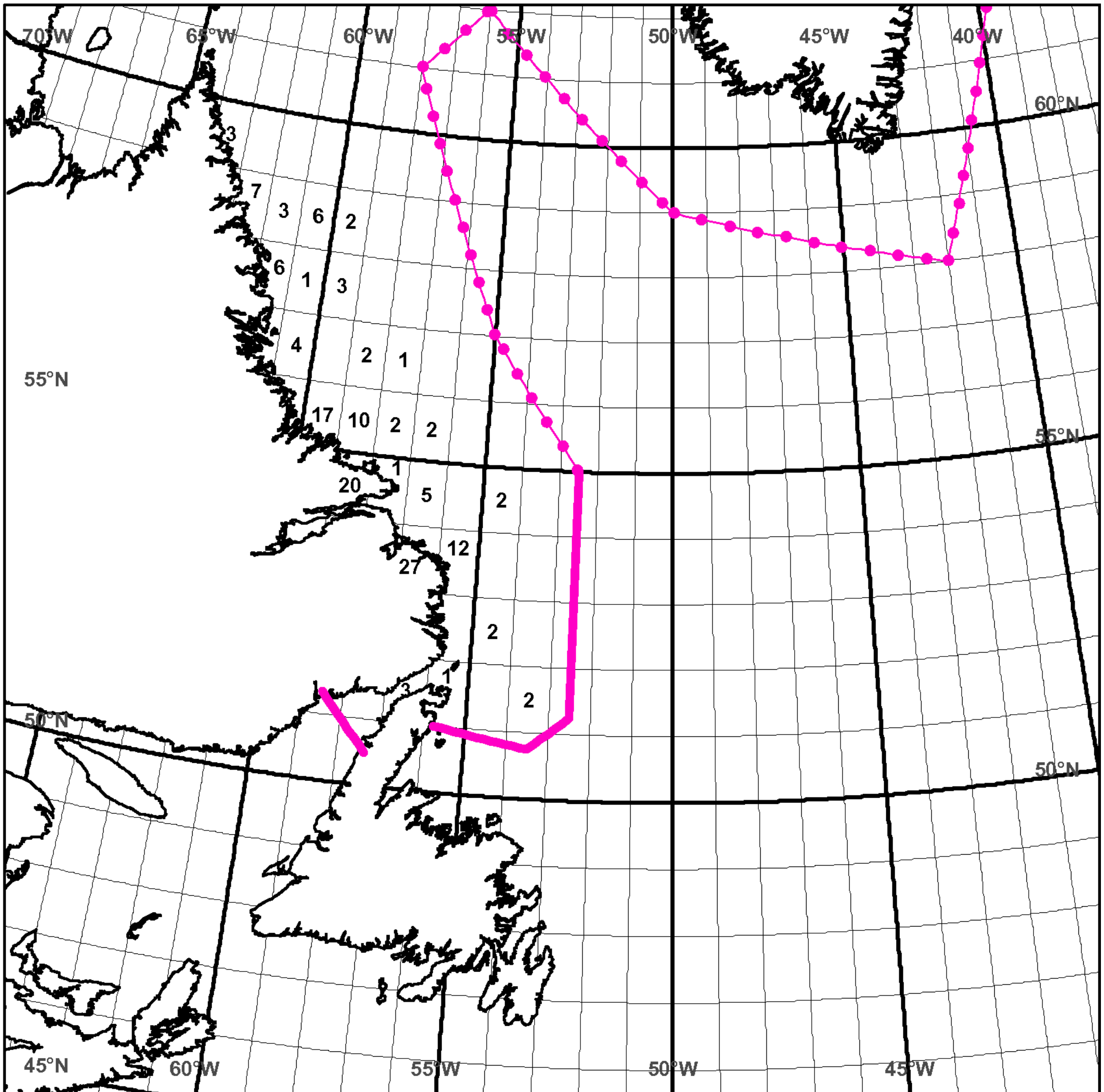
RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:

For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Eastern Limit General Flight 29JUL19.



NORTH AMERICAN ICE SERVICE (NAIS)	ICEBERG ANALYSIS FOR 0000 UTC **15 AUG 2019**
ESTIMATED ICEBERG LIMIT ICEBERG LIMIT SEA ICE LIMIT # ICEBERGS PER DEGREE SQUARE ⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT	**NOTE:** **For more information:** **www.navcen.uscg.gov/iip** **www.ice-glaces.ec.gc.ca** **Most Recent Reconnaissance:** **Interior General Flight 12AUG19.**



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 SEP 2019

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

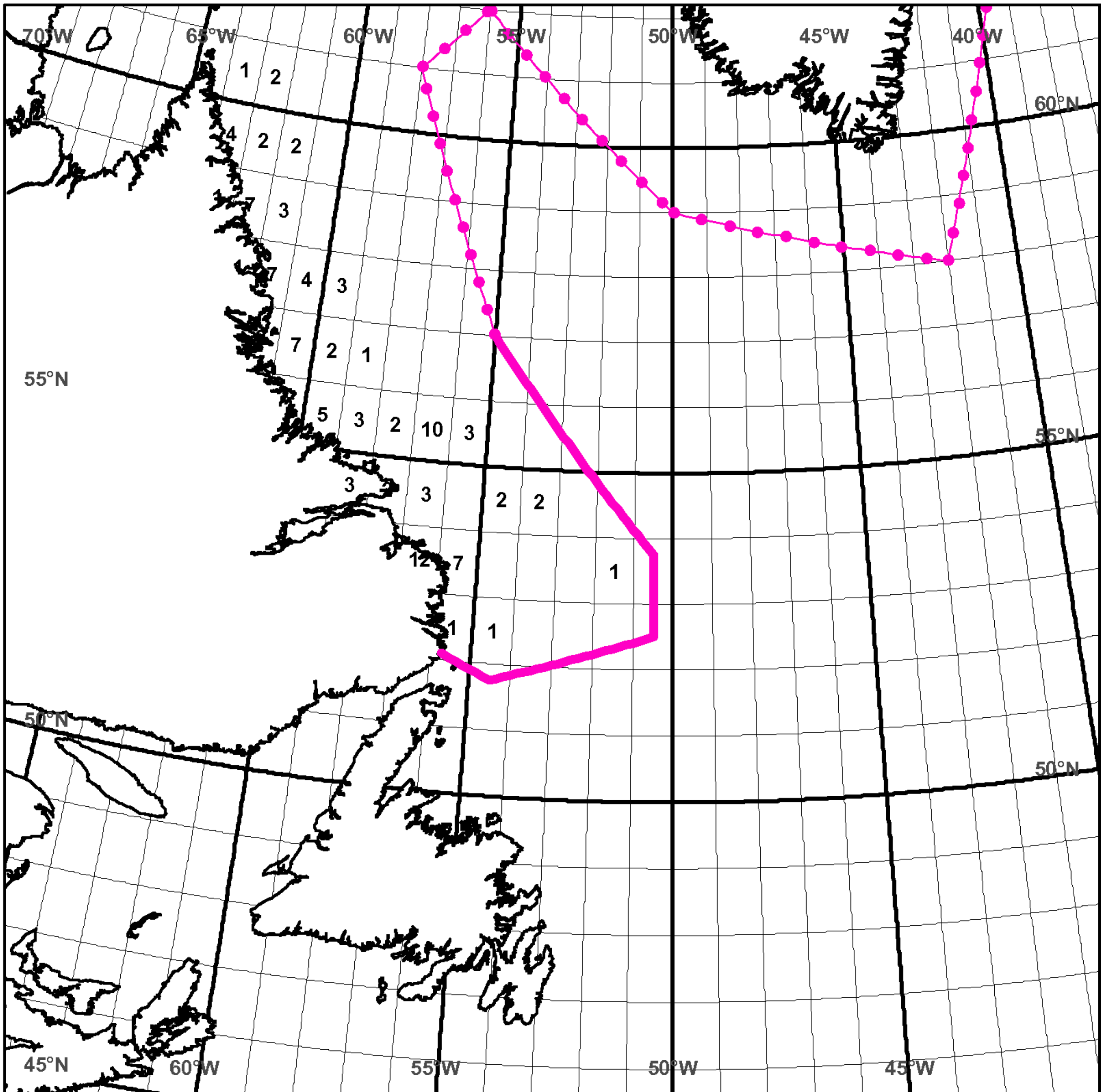
SEA ICE LIMIT

\# ICEBERGS PER DEGREE SQUARE

RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:

For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Southern Limit Iceberg Flight 28AUG19.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 SEP 2019

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

SEA ICE LIMIT

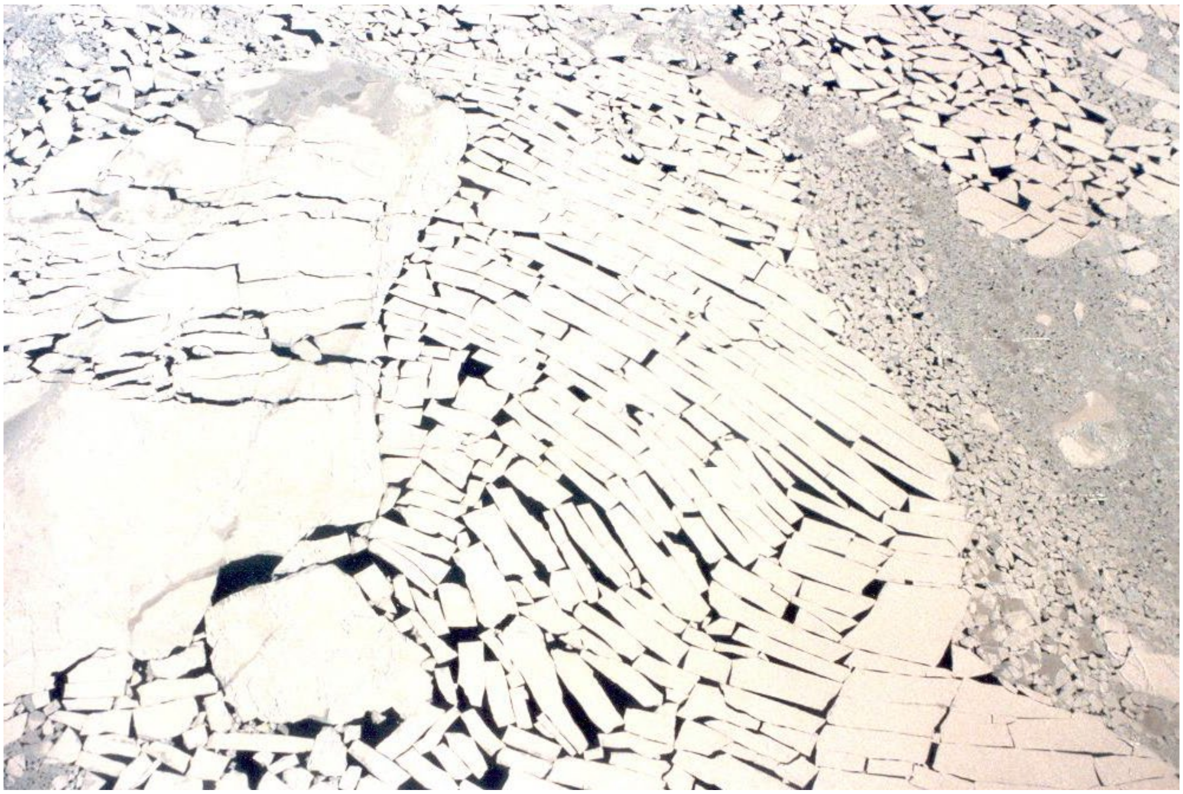
ICEBERGS PER DEGREE SQUARE

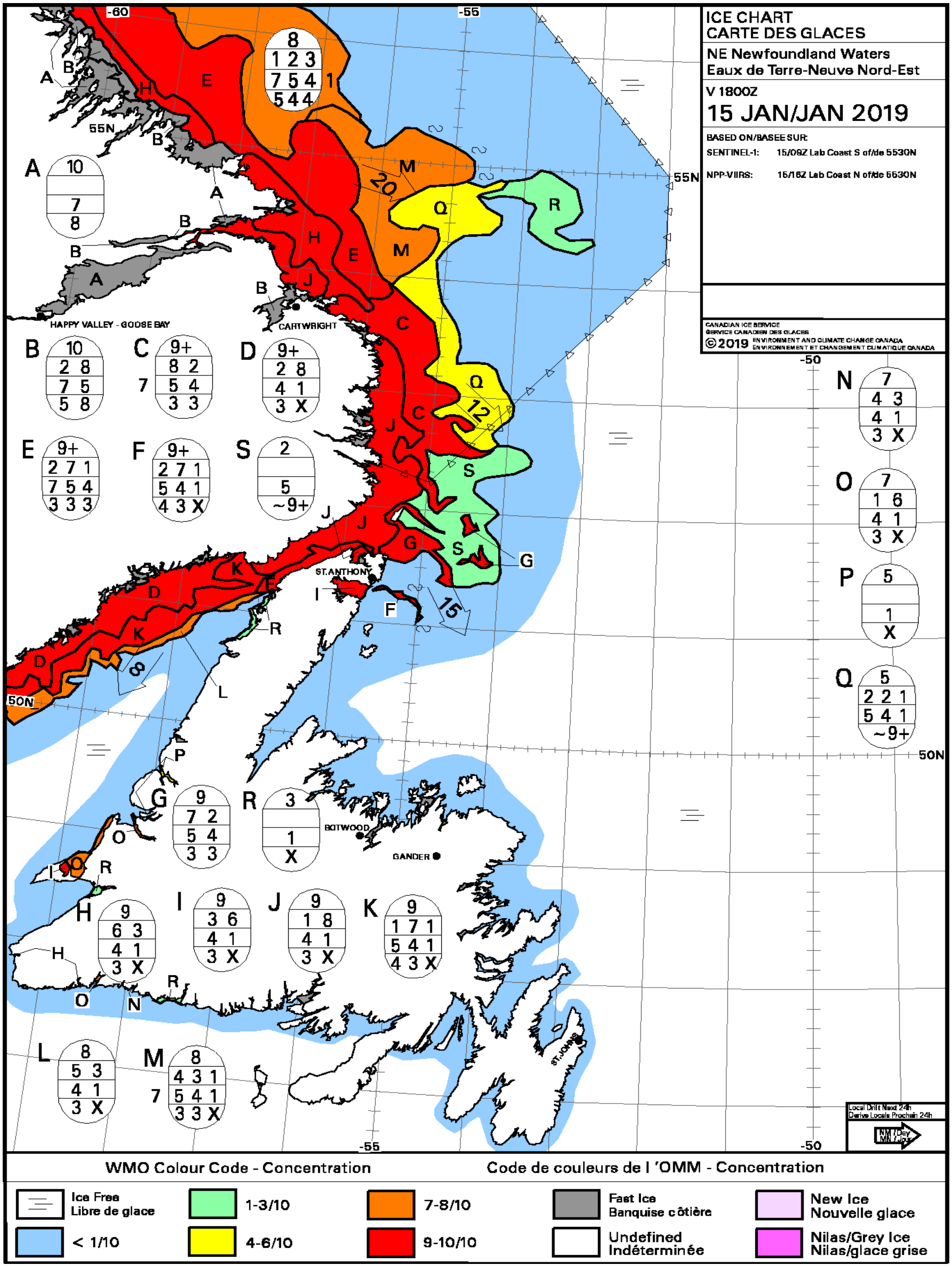
⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT

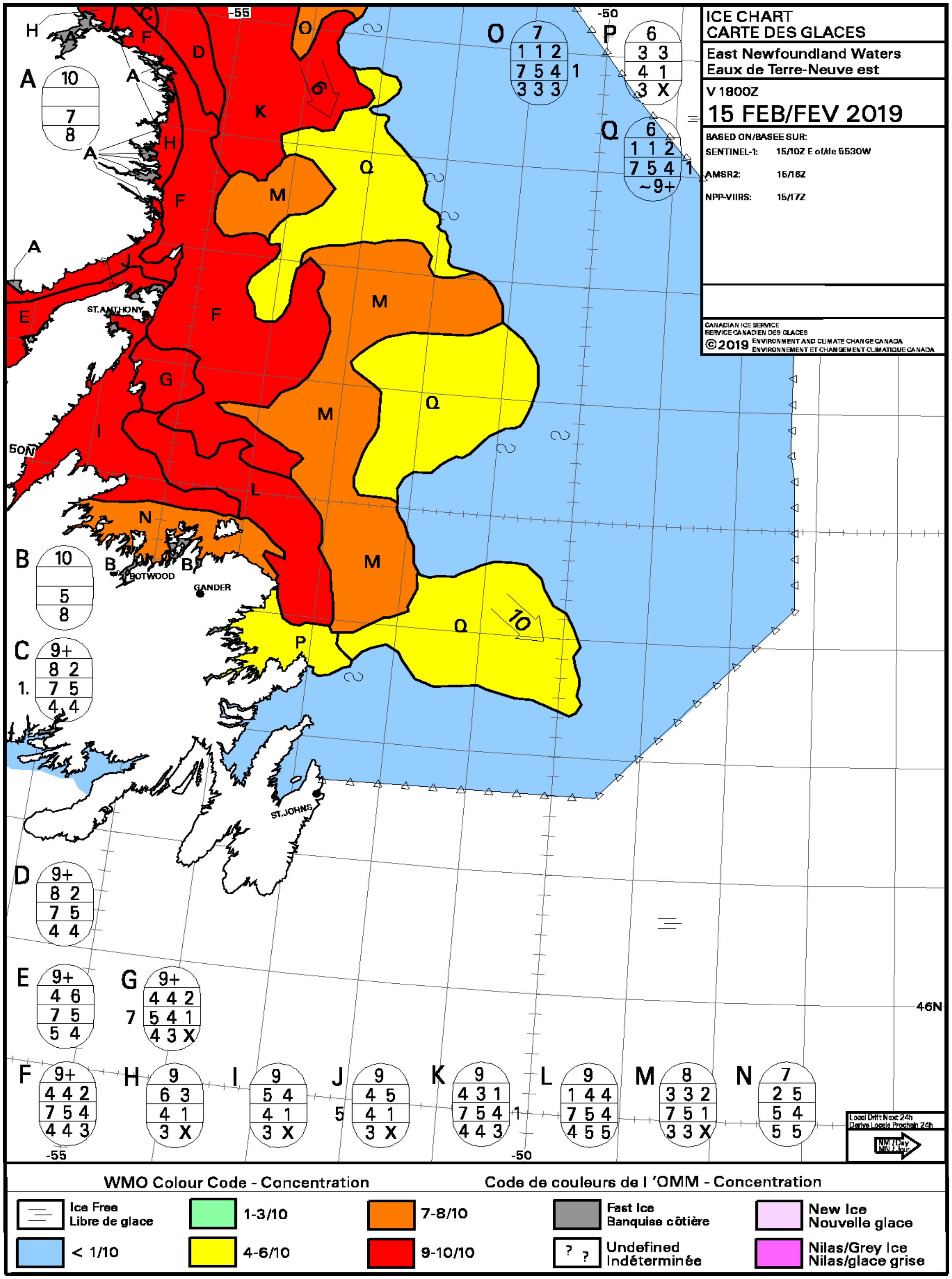
NOTE:

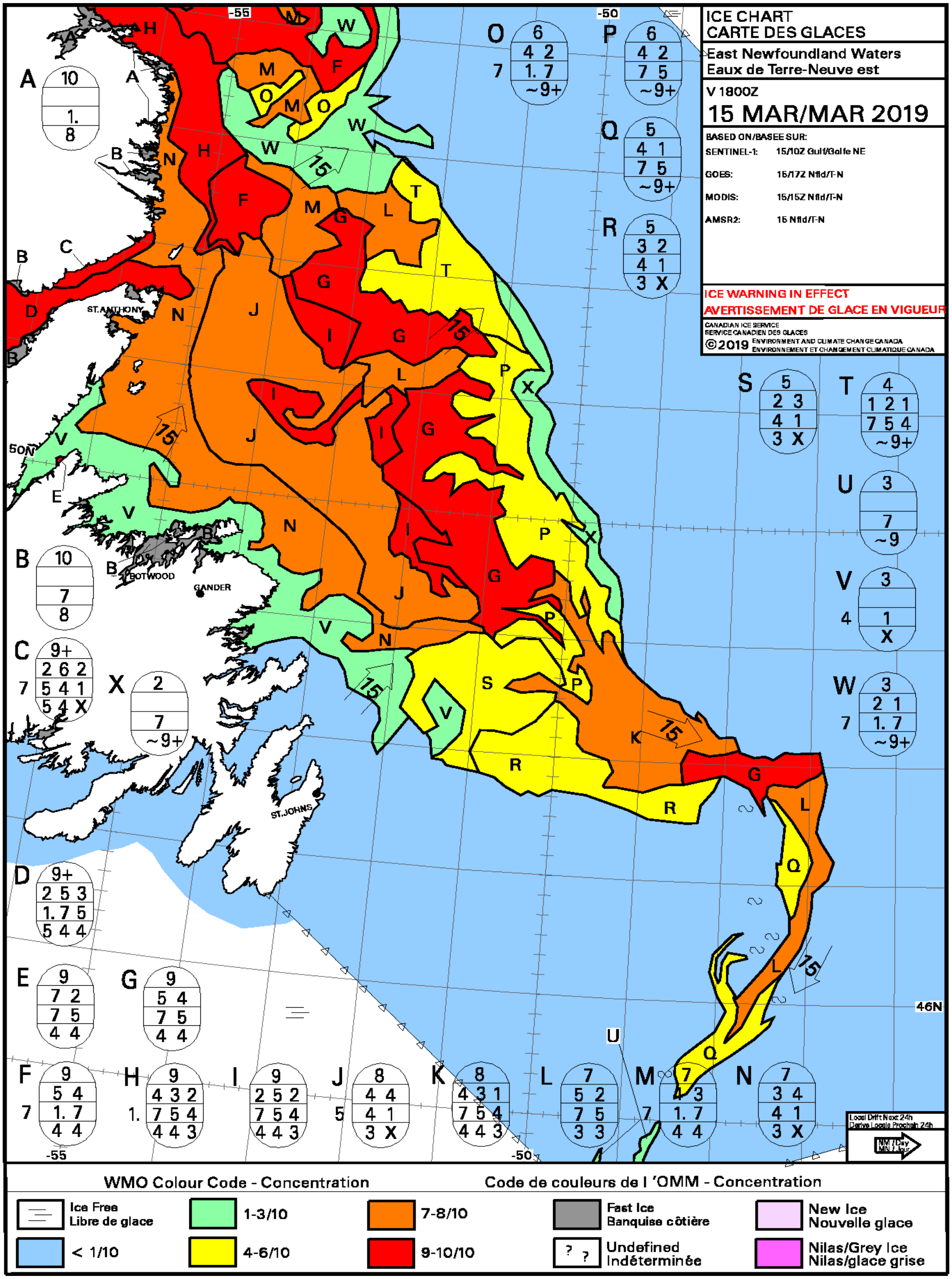
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Southern Limit Iceberg Flight 02SEP19.

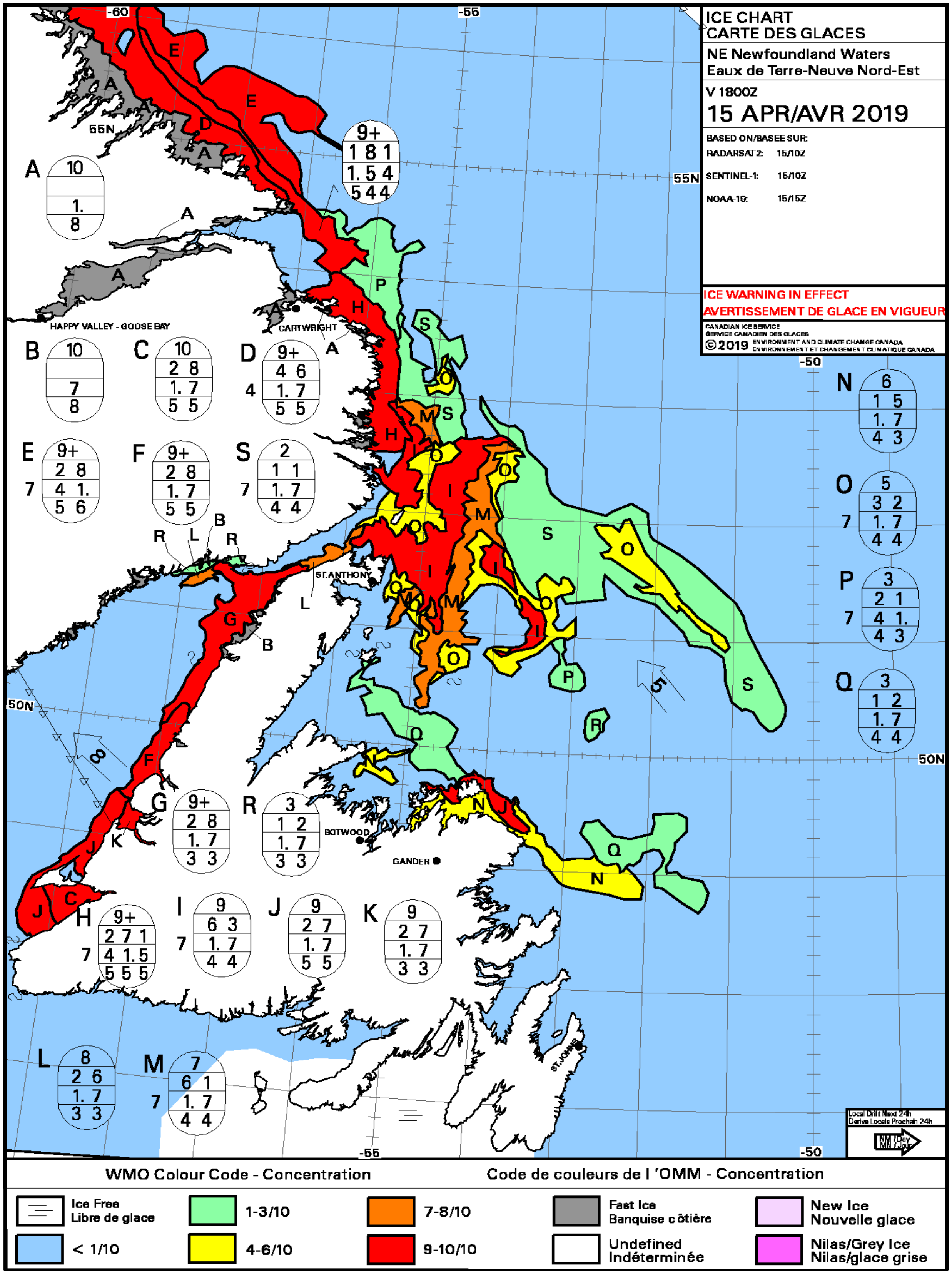
8. Monthly Sea-Ice Charts

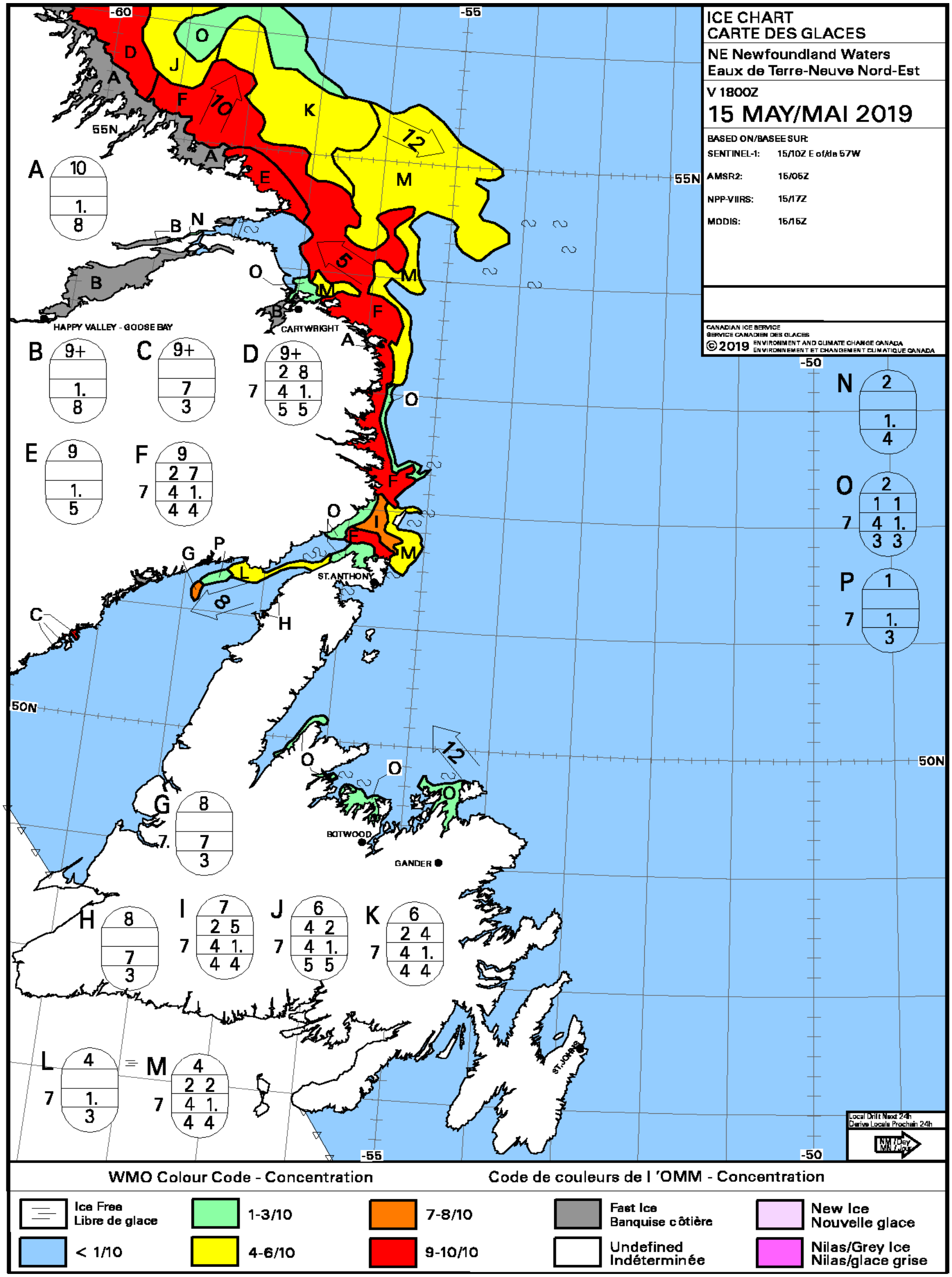


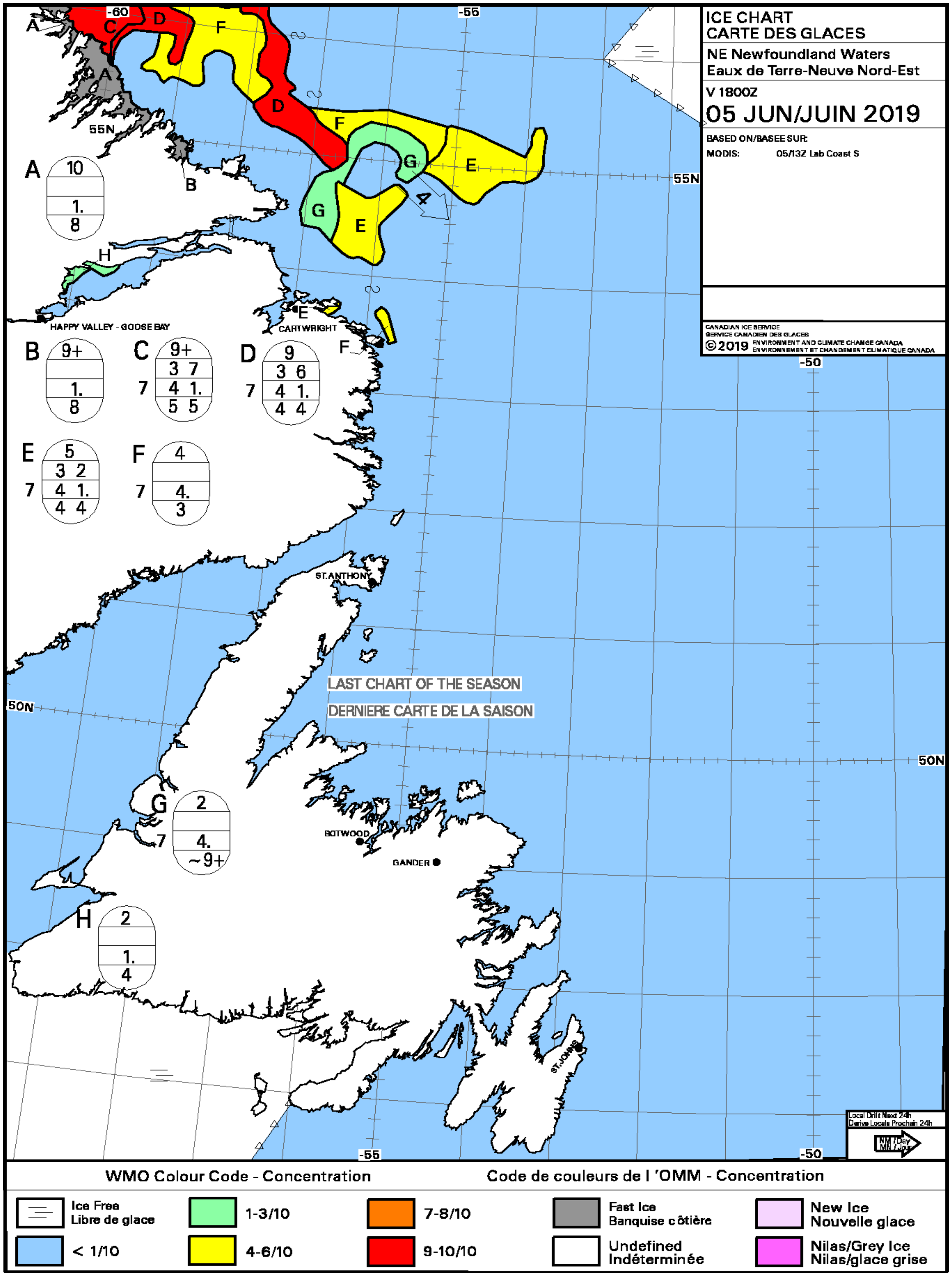

ICE CHART
CARTE DES GLACES
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 JAN/JAN 2019
BASED ON/BASEE SUR:
SENTINEL-1: 15/09Z Lab Coast S of/de 5530N
NPP-VIIRS: 15/16Z Lab Coast N of/de 5530N
CANADIAN ICE SERVICE
SERVICE CANADIEN DES GLACES
©2019 ENVIRONMENT AND CLIMATE CHANGE CANADA
ENVIRONNEMENT ET CHANGEMENT CLIMATIQUE CANADA
HAPPY VALLEY - GOOSE BAY
CARTWRIGHT
ST. ANTHONY
BOTWOOD
GANDER
ST. JOHN'S
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


ICE CHART
CARTE DES GLACES
East Newfoundland Waters
Eaux de Terre-Neuve est
V 1800Z
15 FEB/FEV 2019
BASED ON/BASEE SUR:
SENTINEL-1: 15/10Z E of/de 5530W
AMSR2: 15/16Z
NPP-VIIRS: 15/17Z
CANADIAN ICE SERVICE
SERVICE CANADIEN DES GLACES
©2019 ENVIRONMENT AND CLIMATE CHANGE CANADA
ENVIRONNEMENT ET CHANGEMENT CLIMATIQUE CANADA
ST.ANTHONY
BOTWOOD
GANDER
ST.JOHNS
50N
46N
-55
-50
Local Drift Next 24h
Dérive Locale Prochain 24h
NM / Day
MN / Jour
WMO Colour Code - Concentration
Code de couleurs de l 'OMM - Concentration
Ice Free
Libre de glace
< 1/10
1-3/10
4-6/10
7-8/10
9-10/10
Fast Ice
Banquise côtière
Undefined
Indéterminée
New Ice
Nouvelle glace
Nilas/Grey Ice
Nilas/glace grise


ICE CHART
CARTE DES GLACES
East Newfoundland Waters
Eaux de Terre-Neuve est
V 1800Z
15 MAR/MAR 2019
BASED ON/BASEE SUR:
SENTINEL-1: 15/10Z Gulf/Golfe NE
GOES: 15/17Z Nfld/T-N
MODIS: 15/15Z Nfld/T-N
AMSR2: 15 Nfld/T-N
ICE WARNING IN EFFECT
AVERTISSEMENT DE GLACE EN VIGUEUR
CANADIAN ICE SERVICE
SERVICE CANADIEN DES GLACES
©2019 ENVIRONMENT AND CLIMATE CHANGE CANADA
ENVIRONNEMENT ET CHANGEMENT CLIMATIQUE CANADA
ST.ANTHONY
BOTWOOD
GANDER
ST.JOHNS
50N
46N
-55
-50
Local Drift Next 24h
Dérive Locale Prochain 24h
NM / Day
MN / Jour
WMO Colour Code - Concentration
Code de couleurs de l 'OMM - Concentration
Ice Free
Libre de glace
< 1/10
1-3/10
4-6/10
7-8/10
9-10/10
Fast Ice
Banquise côtière
Undefined
Indéterminée
New Ice
Nouvelle glace
Nilas/Grey Ice
Nilas/glace grise


ICE CHART
CARTE DES GLACES
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 APR/AVR 2019
BASED ON/BASEE SUR:
RADARSAT 2: 15/10Z
SENTINEL-1: 15/10Z
NOAA-19: 15/15Z
ICE WARNING IN EFFECT
AVERTISSEMENT DE GLACE EN VIGUEUR
CANADIAN ICE SERVICE
SERVICE CANADIEN DES GLACES
©2019 ENVIRONMENT AND CLIMATE CHANGE CANADA
ENVIRONNEMENT ET CHANGEMENT CLIMATIQUE CANADA
HAPPY VALLEY - GOOSE BAY
CARTWRIGHT
ST.ANTHONY
BOTWOOD
GANDER
ST.JOHNS
55N
50N
-60
-55
-50
Local Drift Next 24h
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


ICE CHART
CARTE DES GLACES
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 MAY/MAI 2019
BASED ON/BASEE SUR:
SENTINEL-1: 15/10Z E of/de 57W
AMSR2: 15/05Z
NPP-VIIRS: 15/17Z
MODIS: 15/15Z
CANADIAN ICE SERVICE
SERVICE CANADIEN DES GLACES
©2019 ENVIRONMENT AND CLIMATE CHANGE CANADA
ENVIRONNEMENT ET CHANGEMENT CLIMATIQUE CANADA
HAPPY VALLEY - GOOSE BAY
CARTWRIGHT
ST.ANTHONY
BOTWOOD
GANDER
ST.JOHNS
55N
50N
-60
-55
-50
Local Drift Next 24h
Dérive Locale Prochain 24h
NM / Day
MN / Jour
WMO Colour Code - Concentration
Code de couleurs de l 'OMM - Concentration
Ice Free
Libre de glace
< 1/10
1-3/10
4-6/10
7-8/10
9-10/10
Fast Ice
Banquise côtière
Undefined
Indéterminée
New Ice
Nouvelle glace
Nilas/Grey Ice
Nilas/glace grise


ICE CHART
CARTE DES GLACES
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
05 JUN/JUIN 2019
BASED ON/BASEE SUR:
MODIS: 05/13Z Lab Coast S
CANADIAN ICE SERVICE
SERVICE CANADIEN DES GLACES
©2019 ENVIRONMENT AND CLIMATE CHANGE CANADA
ENVIRONNEMENT ET CHANGEMENT CLIMATIQUE CANADA
HAPPY VALLEY - GOOSE BAY
CARTWRIGHT
ST.ANTHONY
BOTWOOD
GANDER
ST.JOHNS
LAST CHART OF THE SEASON
DERNIERE CARTE DE LA SAISON
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
Local Drift Next 24h
Dérive Locale Prochain 24h

9. Acknowledgements

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

Canadian Coast Guard

Canadian Forces

Canadian Ice Service

Canadian Maritime Atlantic Command Meteorological and Oceanographic Centre

Canadian Meteorological Centre

C-CORE

Department of Fisheries and Oceans Canada

Danish Meteorological Institute

European Space Agency

German Federal Maritime and Hydrographic Agency

MacDonald, Dettwiler and Associates

Ms. Monica Adorno

National Geospatial-Intelligence Agency

Nav Canada Flight Information Center

Navy League of the United States, Bridgeport Connecticut Council

National Oceanic and Atmospheric Administration

National Weather Service

PAL Aerospace

PAL Aviation Services

Titanic Society of Atlantic Canada

Transport Canada

University of California, San Diego

USCG Air Station Elizabeth City

USCG Air Station Cape Cod

USCG Atlantic Area

USCG Aviation Training Center Mobile

USCG Academy Science Department

USCG Cutter JUNIPER (WLB-201)

USCG Director of Marine Transportation Systems

USCG Director of Intelligence and Criminal Investigations

USCG First District

USCG Maritime Fusion Intelligence Center Atlantic

USCG Navigation Center

USCG Research and Development Center

U.S. Department of Homeland Security Science & Technology Directorate

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 2019 Ice Year:

CDR K. L. Serumgard

CDR S. A. Koch

Mr. M. R. Hicks

Mrs. B. J. Lis

LCDR C. B. Bell

LT D. W. Rudnickas

MSTCM K. E. Brockhouse

MSTC M. A. Connell

MST1 S. A. Baumgartner

MST1 R. M. Harings

YN1 J. I. Vega

IS1 M. A. Patti

MST2 J. Ambro

MST2 J. J. Menard

MST2 M. J. Brown

IS2 V. A. Pacheco

MST3 J. L. Crocker

MST3 R. M. Hogan

MST3 J. J. Paulk

IS3 P. D. Miller

Appendix A

Ship Reports for Ice Year 2019

Ships Reporting by Flag	Reports
BAHAMAS	
JAGER ARROW	1
BERMUDA	
MONTREAL EXPRESS	1
M/V CORSIER	1
TORONTO EXPRESS	1
CANADA	
ATLANTIC ENTERPRISE	1
** AVALON SEA	21
CIEM PILOT	10
CLAUDE A DESGAGNES	1
CYGNUS	2
CCGS DES GROSEILLIERS	6
DORSET SPRIT	1
FRAM	1
HORIZON ENABLER	1
JANA DESAGNES	1
LEEWAY OYSSEY	1
** MAERSK CLIPPER	11
** MAERSK CUTTER	6
** MAERSK DETECTOR	1
MAERSK NEXUS	3
SINNA	1
* UMIAK 1	14
GIBRALTER	
ARA ANTWERPEN	1
HONG KONG	
GENOA EXPRESS	1
OOCL BELGIUM	1
OOCL MONTREAL	6
TAMPA BAY	1
LIBERIA	
NAUTICAL DEBORAH	6
MALDIVES ISLANDS	
MAAS CONFIDENCE	1
MARSHALL ISLANDS	
DUBAI ANGEL	1
STI EXCEL	1
NETHERLANDS	

BEATRIX	2
EEBORG	2
FRASERBORG	1
FULDABORG	1
QAMUTIK	2
ZUIDERDAM	2
PORTUGAL	
RCGS RESOLUTE	1
SYRIA	
PHOENICIA	1
UNITED KINGDOM	
ATLANTIC SUN	1
UNITED STATES	
***CGC JUNIPER	8
OCEAN GLORY	1
UNIDENTIFIED SHIPS	3

*   Denotes the CARPATHIA award winner.

** Denotes vessels contracted by the oil rigs to track icebergs.

***Denotes vessel used to track icebergs for the Tagging Campaign.

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. Aerial and Multispectral Ground-Truth Verification of Iceberg Detection and Classification Capability in Synthetic Aperture Radar Imagery

LT Don Rudnickas

B-1. Introduction

A key factor in making effective use of any remote sensing application is the processes by which an analyst extracts information (something meaningful) from the vast amounts of data (something measured) collected. For the International Ice Patrol (IIP), this comes in the form of finding the location and sizes of icebergs amid the pixel values of a Synthetic Aperture Radar (SAR) image. Simplified, the first step in the information extraction involves detection – the identification of possible targets within the image. Once likely targets are detected, they must be classified – assigned an identity such as “iceberg” or “ship”. This effectively results in the transition from raw pixel values received at the sensor (data) to identified targets useful to an analyst in making an Iceberg Limit for mariners (information). However, the quintessential question in remote sensing remains: how do we know? How do we know that our detections and classifications are correct? To answer the question, we must test our accuracy with ground-truthed targets that have been verified as icebergs or some other object by another sensor. When the ground-truthed target matches the SAR target, we have an accurate detection and classification. A false positive occurs when a SAR target has been detected and classified where no ground-truthed target exists. At IIP, this can result in the needless expansion of the Iceberg Limit. A false negative occurs when a ground-truthed target is not accurately detected or is misclassified resulting in a potentially dangerous situation where the Iceberg Limit may not include all icebergs. The former condition is a nuisance, the latter a danger.

This Appendix describes recent efforts by IIP to make process improvements and test our accuracy of iceberg detection and classification using ground-truthed icebergs located by aerial reconnaissance as well as in multispectral imagery from the Sentinel-2 satellite mission. Multi-spectral imagery is incredibly useful for verification purposes because icebergs are easily identified and interpreted by the human eye. However, it is not a viable tool for routine reconnaissance due to the predominantly cloudy and/or foggy conditions in the vicinity of the Grand Banks of Newfoundland.

This Appendix first presents some background information on the target detection process in Section B-2, then presents a case study from the 2018 verification effort with coincident aerial and satellite iceberg reconnaissance in Section B-3. Section B-4 describes the process improvements in pre-classification target filtering implemented as a result of the verification effort.

The importance of ground-truthed verification in determining reconnaissance capability is compounded when looking for icebergs within sea ice. Detecting icebergs within sea ice remains of critical importance to IIP as relatively thick first-year sea ice from Baffin Bay moves south in the Labrador Current early each year carrying embedded icebergs along with it toward the shipping lanes. The threat of these concealed icebergs was demonstrated by the 2017 “Iceberg Explosion” where the sudden, catastrophic destruction of sea ice by strong low-pressure systems beginning on 11 March 2017 released over 270 icebergs that passed south of 48˚N by the end of the month. In the immediate aftermath, four of these icebergs were found outside of the published Iceberg Limit (IIP, 2017) creating a potentially dangerous situation for transatlantic shipping and an operational challenge for IIP. While the rapid release experienced in 2017 was extraordinary, the eventual retreat of sea ice and release of icebergs directly into the shipping lanes is an annual occurrence. As such, IIP has focused efforts to quantify the population of icebergs held within sea ice to ensure the accuracy of the daily Iceberg Limit.

Detecting and classifying icebergs within sea ice has routinely been a challenge for IIP regardless of reconnaissance method. From an aircraft, visually identifying glacial ice in and amongst the white of sea ice is difficult when flying at 2,000 feet and 180 knots. This challenge is amplified from the several hundred-kilometer altitude of an orbiting SAR satellite as sea ice provides its own unique noise floor compared to open water, with the capability to mask embedded icebergs. Further, broken and rafted sea ice in a SAR image produces returns similar to an iceberg. Combining these two factors, sea ice has the capacity to produce large numbers of false positive iceberg targets as well as missed or misclassified targets resulting in false negative conditions.

Section B-5 presents a case study showing how the newly implemented 2019 pre-classification filtering process has improved our ability to classify icebergs within sea ice while Section B-6 provides the results of some ground-truthing work conducted using Sentinel-2 multispectral imagery that has shown that the IIP filtering process and target detection method is still not accurate enough to allow full confidence in our ability to classify the iceberg population within sea ice. Finally, Section B-7 offers some conclusions and the way forward.

B-2. Background

For satellite reconnaissance, the Satellite Dayworker (SDW) at IIP analyzes each satellite image using a process that IIP has developed in conjunction with Iceberg Detection Software (IDS) licensed from C-CORE, a company based in St. John’s, Newfoundland. The IDS provides an interface for the SDW to analyze a satellite frame using a chosen target detection method and thresholds. In the most basic sense, it outputs a shapefile (.shp) with locations of detections (i.e. SAR targets) for analysis within a Geographic Information System. For Sentinel-1 imagery, IIP analysts typically use a sliding window and Constant False Alarm Rate (CFAR) method of target detection. This method can generate thousands of targets for the analyst to classify, especially in or around sea ice. In order to manage this workload, IIP has established a filtering process that applies filters of wind magnitudes, vessel traffic, and sea ice concentration to reduce the number of targets that the analyst must classify but, if not tuned correctly, the filtering could result in classification errors by deleting iceberg targets before an analyst has a chance to analyze them.

For target detection, IIP primarily uses an adaptive threshold CFAR method in which a detection's signal is compared to a detection threshold value based on the noise level within a sliding window (typically 300 × 300 pixels centered on the target pixels). A K-Distribution is assumed to model the background ocean clutter within the window and targets are identified above a detection threshold based on the mean and standard deviation of the pixel values within the window and scaled for a desired Probability of False Alarm (PFA). For more detailed information on CFAR detection methods, the reader is referred to El-Darymli, et al. (2013). In general, using a smaller PFA allows for a smaller number of false alarms to be generated by increasing the detection threshold, meaning a fewer number of targets will be detected, but the targets will be of higher certainty. A larger PFA value results in a lower detection threshold, more targets detected with corresponding lower certainty, and more false alarms. For the remainder of this Appendix, we will refer to the PFA utilized as a CFAR value. An example of the effect of different CFARs on the analysis of a satellite frame can be made from the verification work in **Table B-1** and discussed in greater detail within Section B-3 of this Appendix. In the example shown in **Table B-1**, an IIP Aerial Reconnaissance flight within 8-10 hours of the satellite frame on 04 May 2018 detected 36 icebergs within the frame while, depending on the CFAR threshold utilized, the IDS detected between 682 (at CFAR 10^{-20}) and 2,612 (at CFAR 10^{-9}) targets.

Detection Method	Total Number of Targets	Targets by Confidence			
		High	Low	Percent High	Percent Low
Aerial Observation	36				
CFAR 10^{-9}	2612	796	1816	30%	70%
CFAR 10^{-10}	1749	665	1084	38%	62%
CFAR 10^{-11}	1473	619	854	42%	58%
CFAR 10^{-15}	1011	530	481	52%	48%
CFAR 10^{-20}	682	435	247	64%	36%

Table B-1. The number of targets detected on a coincident aerial reconnaissance and Sentinel-1 satellite frame on 04 May 2018. The Confidence in this context is an output field from the Iceberg Detection Software based on the ratio between the decibel level of the target pixels to the average of the background decibels. A ratio of 10:1 or greater is a High Confidence target, while less is a Low Confidence target.

B-3. 2018 Coincident Aerial and Satellite Verification

In 2018, a relatively light Iceberg Season enabled IIP to conduct USCG HC-130J aerial reconnaissance patrols in the same area and within 12 hours of 29 Sentinel-1 satellite image acquisitions providing an excellent opportunity to compare observations from the two platforms and verify the detection and classification capability of IIP's SAR process.

IIP's SDWs processed the Sentinel-1 frames in accordance with the standard SDW procedures (See **Supplemental Material B-1: 2018 SDW Filtering Sheet**) to detect and classify icebergs (termed "SDW classified icebergs") and, in a separate process, a select group of verification team members made up of the most experienced analysts determined what SAR targets correlated with each aerially observed target.

For the remainder of this Appendix, a "verified iceberg" refers to a target that has been confirmed to be an iceberg using either aerial observations or multispectral imagery. These are considered to be ground-truthed icebergs. For each verified iceberg, the verification team determined whether or not it was detected in the SAR image by finding a correlate-able SAR target. A verified iceberg with a correlated SAR target (termed a "correlated iceberg") is a result of an accurate SAR detection, and gives a measure of the accuracy of our sensors and target detection capability. Next, the verification team determined whether an SDW correctly classified the SAR target. For this Appendix, a positive, correctly classified SAR target is an SDW classified iceberg that was deemed by the verification team to correlate with a verified iceberg. This results from accurate detection as well as accurate classification and provides a measure of validation regarding the SDW procedures and analyst's ability. A misclassified SAR target is an SDW classified iceberg that could not be correlated to a verified iceberg. These are referred to as false positives and result from inaccurate classification by the SDW. When a verified iceberg was identified but a correlate-able SAR target was misclassified or the SAR target was filtered out after detection but before classification (i.e. there is no SDW classified iceberg but there was a SAR target) this is a false negative resulting from classification error. The verification team did not consider the SDW classification when finding correlate-able SAR targets. When a verified iceberg was identified but no correlate-able SAR target was detected it is referred to as a "non-correlated iceberg" and is a false negative that results from detection capability. These definitions are summarized in **Table B-2**.

	Verified Iceberg	No Verified Iceberg
SAR Target with SDW Classified Iceberg	Correctly Detected and Classified	Classification Error: False Positive
SAR Target without SDW Classified Iceberg	Classification Error: False Negative	Correctly Detected and Classified
No Correlate-able SAR Target	Detection Error: False Negative	Correct Non-Detection

Table B-2. Verification term definitions and outcomes of SDW Classification related to ground-truthed icebergs. A verified iceberg refers to a confirmed iceberg from a reconnaissance source other than SAR (in this case aerial observation or Sentinel-2 multispectral imagery) as determined by a member of IIP's verification team.

During the 2018 verification effort, 20 correlated icebergs were found. 15 of the 20 were in a satellite frame on 04 May 2018 (**Figure B-1**) which is used here as a case study. On this day, the Sentinel-1 pass along the northeast coast of Newfoundland occurred at 0941Z (**Figure B-1a**). The frame was a Ground Range Detected (GRD) Interferometric

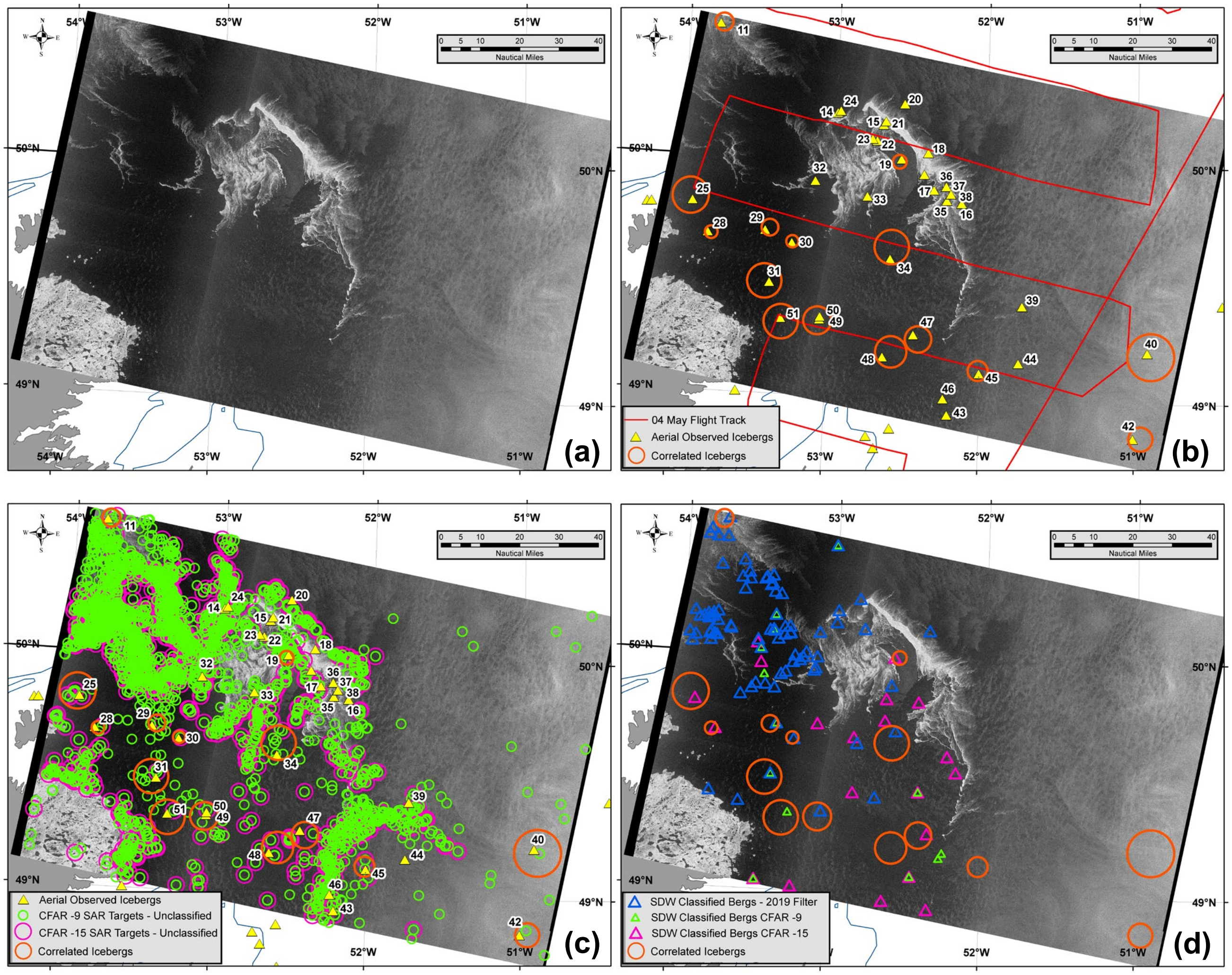


Figure B-1. Overview of the 04 May 2018 coincident Aerial reconnaissance and Sentinel-1 frame. (a) The HH polarization image. Note that in this frame, lower incidence angles are to the right of the map. (b) The HC-130J flight track and the icebergs that were observed. Those circled in orange are the verified icebergs. Note that circles are different sizes based on the model output for each SAR target. See Tables B-4 and B-5 for more detailed information on each detection. Target #50 was determined to be a growler shed from Target #49 after the satellite pass. (c) The satellite detections in CFAR 10^{-9} (green) and CFAR 10^{-15} (pink). (d) The results of three different SDW classifications of the frame.

Wide Swath (IW) with 20 m spatial resolution. The flight track took the HC-130J reconnaissance flight in a parallel search pattern with 25 NM track spacing (**Figure B-1b**) enabling 95% probability of detection of small icebergs (15 – 60 m waterline length). Within the geographic bounds of the Sentinel-1 frame, the HC-130J team recorded 36 icebergs between 1730Z and 1949Z (8-10 hours after the satellite pass). As part of the 2018 verification work, this frame was processed in accordance with the standard 2018 filtering sheet. In addition to CFAR 10^{-9}, the frame was analyzed by an SDW using the detections at CFAR 10^{-15} to classify all targets that remained after filtering (**Figure B-1d**). and the IDS was run at CFAR 10^{-10}, 10^{-11}, and 10^{-20} in order to test the detection effectiveness at different CFARs (**Table B-3)**. The CFAR 10^{-9} detections were used as starting points to run a "What If Model" within IIP's iceBerg Analysis and Prediction System (BAPS) from the time of the satellite pass until the end time of the flight. BAPS uses two iceberg drift

Detection Method	Total Number of Targets	Accuracy		
		# Targets Correlated with Verified Icebergs	% of Targets that matched Verified Icebergs	% of Aerially Verified Icebergs Correlated
Aerial Observation	35	35	100%	
CFAR 10^{-9}	2612	15	0.57%	43%
CFAR 10^{-10}	1749	14	0.80%	40%
CFAR 10^{-11}	1473	14	0.95%	40%
CFAR 10^{-15}	1011	13	1.29%	37%
CFAR 10^{-20}	682	12	1.76%	34%

Table B-3. Results of target detection at various CFAR False Alarm Thresholds on the 04 May 2018 coincident Aerial Reconnaissance and Sentinel-1 frame. Note: it was determined as part of the analysis of this frame that a 36th verified iceberg identified by the aircraft was a growler that had split from a larger, nearby iceberg at some point after the satellite pass. Therefore, for this phase of the analysis, the total number of targets was reduced to 35 to discount this growler.

and deterioration models: the IIP model (Mountain, 1980; Anderson, 1983) and the North American Ice Service (NAIS) model (Kubat et al., 2005). The model output was compared to the iceberg positions at the time of the flight as a guide to help predict the direction and distance to look for viable target correlations.

SAR targets identified by the IDS and feasible in accordance with the model predictions were examined by a member of the verification team. Only detections that were substantial enough to be recognized as a target from the background clutter and distinguished from sea ice were considered as correlate-able SAR targets. As such, there were instances where the IDS detected SAR targets but the verification team member discounted them as noise or sea ice. The verification team did not solely rely upon the IDS to detect targets but also conducted a visual scan of the area in the imagery to look for targets that were not detected by the IDS. The author acknowledges that this is not an absolute detection accuracy as the verification process is still reliant on the skill of the verification team member as an analyst, but it does provide a relative sense of accuracy given the capability of the sensors and the CFAR detection method. The details of the SAR target most likely to correlate with the aerial observation was recorded (**Table B-4**). As noted, 15 icebergs were verified in this manner in the 04 May frame. A 16th aerial target was determined to be a growler that most likely shed from a nearby medium iceberg within the 8-10 hours since the satellite pass. This growler was removed from subsequent analysis of the detection and classification accuracy. Images captured from the aircraft of the verified icebergs and their correlated SAR targets are presented in **Figure B-2**.

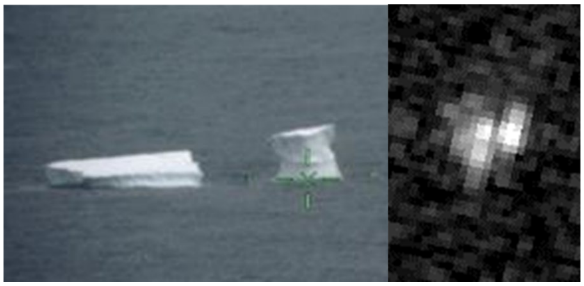
The remaining 20 aerially observed icebergs on 04 May were not correlate-able to a viable SAR target by the verification team and were non-correlated icebergs: false negative targets in the SAR analysis of this frame (**Table B-5**). This means that there was either no SAR target nearby the aerially observed verified iceberg or that there were nearby SAR targets that the verification team was either unable to distinguish from the background noise or classified as sea ice. Eight of these had images recorded from the aircraft and are presented in **Figure B-3**. Sea ice played a major part in these false negatives. 80% (16 of 20) of the non-correlated icebergs were near or within sea ice – highlighting the challenge of detecting and/or classifying icebergs in sea ice.

AERIALLY VERIFIED ICEBERGS CORRELATED WITH SATELLITE																		
FLIGHT OBSERVATIONS								CORRELATED SAR TARGETS										
ID	Obs Method	Date/Time (YYYYMMDDHHMMSS)	Lat. (N)	Lon. (W)	Sea Ice Conc.	Iceberg Size	Iceberg Shape	Lat. (N)	Lon. (W)	Waterline Length (m)	Confid-ence	Incidence Angle	Detection Pol	Classified 2018 Filter	Classified 2019 Filter	Detected CFAR-9	Detected CFAR-15	
19	VISUAL	20180504182500	50.015	-52.558	1/10	Medium	Domed	50.006	-52.601	52.4	High	40.2	HH	No	No	Yes	Yes	
25	R/V	20180504184400	49.802	-53.920	None	Small	Non-Tab	49.796	-53.904	61.8	High	45.1	HH	No	No	Yes	Yes	
28	R/V	20180504184900	49.670	-53.808	None	Small	Non-Tab	49.673	-53.761	73.0	High	44.4	HH	No	No	Yes	Yes	
29	R/V	20180504185200	49.690	-53.433	None	Medium	Non-Tab	49.708	-53.361	59.6	High	43.0	HH	Yes	Yes	Yes	Yes	
30	R/V	20180504185200	49.642	-53.255	None	Small	Non-Tab	49.645	-53.242	56.6	High	42.4	HH	No	Yes	Yes	Yes	
31	R/V	20180504185300	49.470	-53.390	None	Medium	Non-Tab	49.494	-53.385	55.4	High	42.8	HH	Yes	Yes	Yes	Yes	
34	R/V	20180504190100	49.590	-52.608	None	Large	Non-Tab	49.693	-52.579	60.0	High	39.8	HH	No	Yes	Yes	Yes	
40	R/V	20180504191900	49.217	-50.920	None	Small	Non-Tab	49.201	-50.881	53.0	Low	31.4	HH	No	No	Yes	No	
42	R/V	20180504192300	48.853	-51.007	None	Small	Non-Tab	48.873	-50.963	59.0	Low	31.3	HH	No	No	Yes	No	
45	VISUAL	20180504193800	49.117	-52.007	None	Growler	Non-Tab	49.157	-52.009	49.5	Low	36.7	HH	No	No	Yes	Yes	
47	R/V	20180504194300	49.272	-52.440	None	Small	Non-Tab	49.262	-52.352	55.0	High	38.3	HH	No	No	Yes	Yes	
48	R/V	20180504194400	49.173	-52.635	None	Large	Dry Dock	49.242	-52.504	79.9	High	39.0	HH	No	No	Yes	Yes	
49	R/V	20180504194600	49.322	-53.053	None	Medium	Non-Tab	49.343	-53.047	83.1	High	41.4	HH	No	Yes	Yes	Yes	
51	R/V	20180504194900	49.320	-53.305	None	Medium	Non-Tab	49.333	-53.262	55.8	High	42.2	HH	Yes	No	Yes	Yes	
11	R/V	20180504173000	50.558	-53.802	3/10	Medium	Non-Tab	50.572	-53.741	109.7	High	45.2	HH	No	Yes	Yes	Yes	

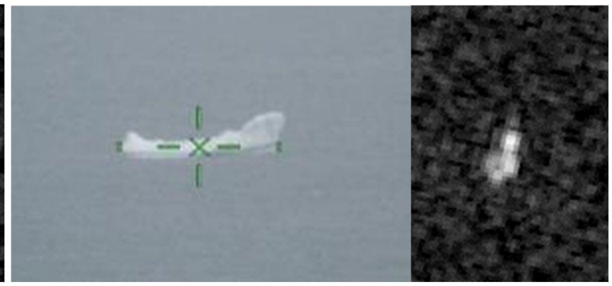
Table B-4. Correlated icebergs. Verified icebergs and their correlated SAR targets from the 04 May 2018 coincident flight and Sentinel-1 pass. The ID column is the unique identifier that the target was assigned. These numbers can be used to identify the target in Figures B-1 and B-2. The Observation (Obs) Method column refers to the method by which the iceberg was detected from the aircraft. "VISUAL" refers to icebergs that were observed only by the window observer in the aircraft, "RADAR" refers to icebergs that were identified only by the sensors on the aircraft, and "R/V" refers to targets that were observed through both methods. Refer to Table B-6 for more detail.

FLIGHT OBSERVATIONS NOT CORRELATED							
ID	Obs Method	Date/Time (YYYYMMDDHHMMSS)	Lat. (N)	Lon. (W)	Sea Ice Conc.	Iceberg Size	Iceberg Shape
14	R/V	20180504173800	50.202	-52.992	3/10	Small	Non-Tab
15*	R/V	20180504174400	50.158	-52.685	3/10	Small	Non-Tab
16*	RADAR	20180504182000	49.845	-52.250	Unk.	General	General
17*	RADAR	20180504182200	49.953	-52.405	Unk.	General	General
18	VISUAL	20180504182400	50.045	-52.383	8/10	Medium	Dry Dock
20	RADAR	20180504182500	50.250	-52.550	Unk.	General	General
21	R/V	20180504182600	50.173	-52.670	1/10	Medium	Non-Tab
22*	VISUAL	20180504182800	50.090	-52.723	1/10	Small	Non-Tab
23*	VISUAL	20180504182800	50.097	-52.753	1/10	Small	Non-Tab
24	R/V	20180504183100	50.210	-52.972	Trace	Small	Non-Tab
32*	R/V	20180504185700	49.908	-53.120	3/10	Medium	Domed
33	R/V	20180504185900	49.852	-52.773	7/10	Small	Non-Tab
35	VISUAL	20180504190500	49.888	-52.337	7/10	Medium	Non-Tab
36	RADAR	20180504190500	49.905	-52.257	Unk.	General	General
37*	RADAR	20180504190600	49.873	-52.225	Unk.	General	General
38	RADAR	20180504190800	49.835	-52.152	Unk.	General	General
39	R/V	20180504191400	49.405	-51.738	None	Small	Non-Tab
43	RADAR	20180504193600	48.937	-52.207	Unk.	General	General
44	VISUAL	20180504193700	49.163	-51.753	None	Growler	Non-Tab
46*	RADAR	20180504193800	49.005	-52.235	Unk.	General	General

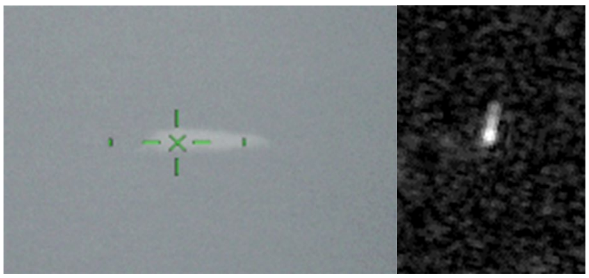
Table B-5. Non-correlated icebergs. List of icebergs observed by aircraft on 04 May 2019 but with no correlate-able SAR target detected in the coincident Sentinel-1 frame. The ID column is the unique identifier that the target was assigned. These numbers can be used to identify the target in Figures B-1 and B-3. The Observation (Obs) Method column refers to the method by which the iceberg was detected from the aircraft. "VISUAL" refers to icebergs that were observed only by the window observer in the aircraft, "RADAR" refers to icebergs that were identified only by the sensors on the aircraft, and "R/V" refers to targets that were observed through both methods. Refer to Table B-6 for more detail. * Denotes that an image was recorded of this iceberg from the aircraft (Figure B-3).



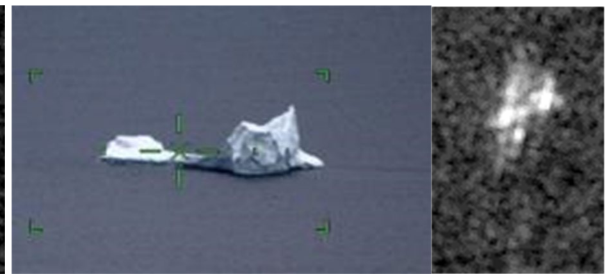
(a) Target #29



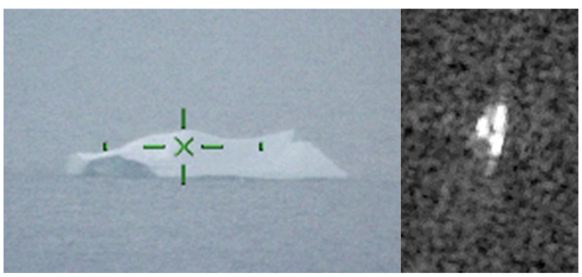
(b) Target #30



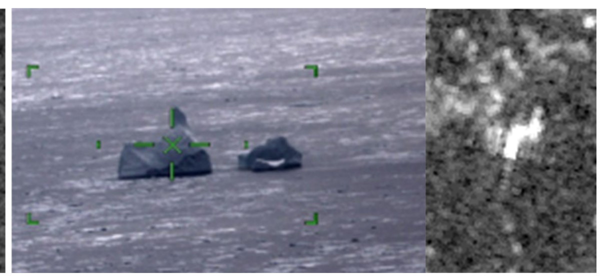
(c) Target #31



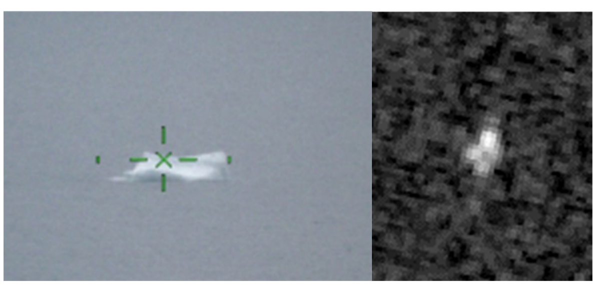
(d) Target #48



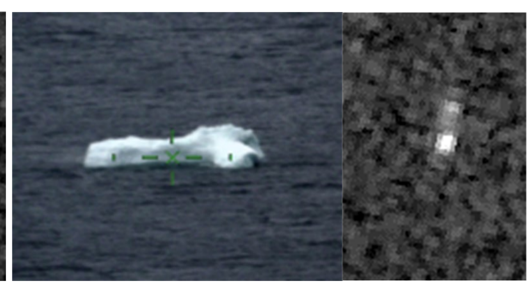
(e) Target #49



(f) Target #11

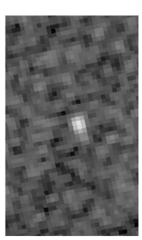


(g) Target #51

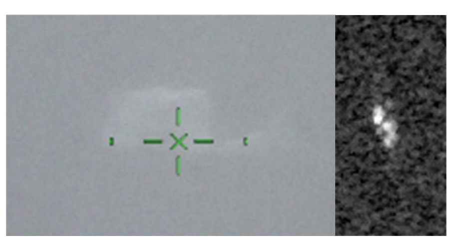


(h) Target #47

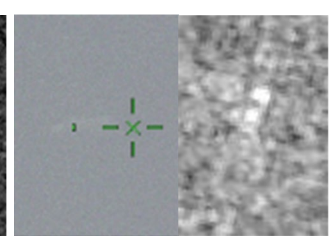
Visually verified iceberg - no image was recorded from the aircraft.



(i) Target #45



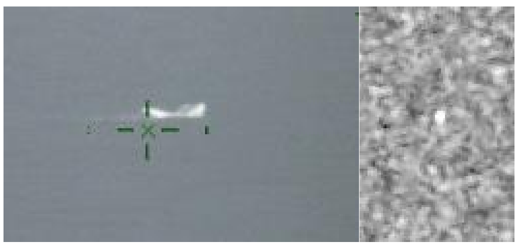
(j) Target #25



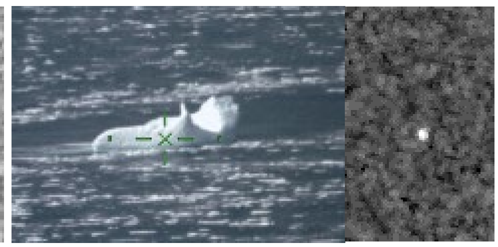
(k) Target #42

(l) Target #28

(m) Target #34



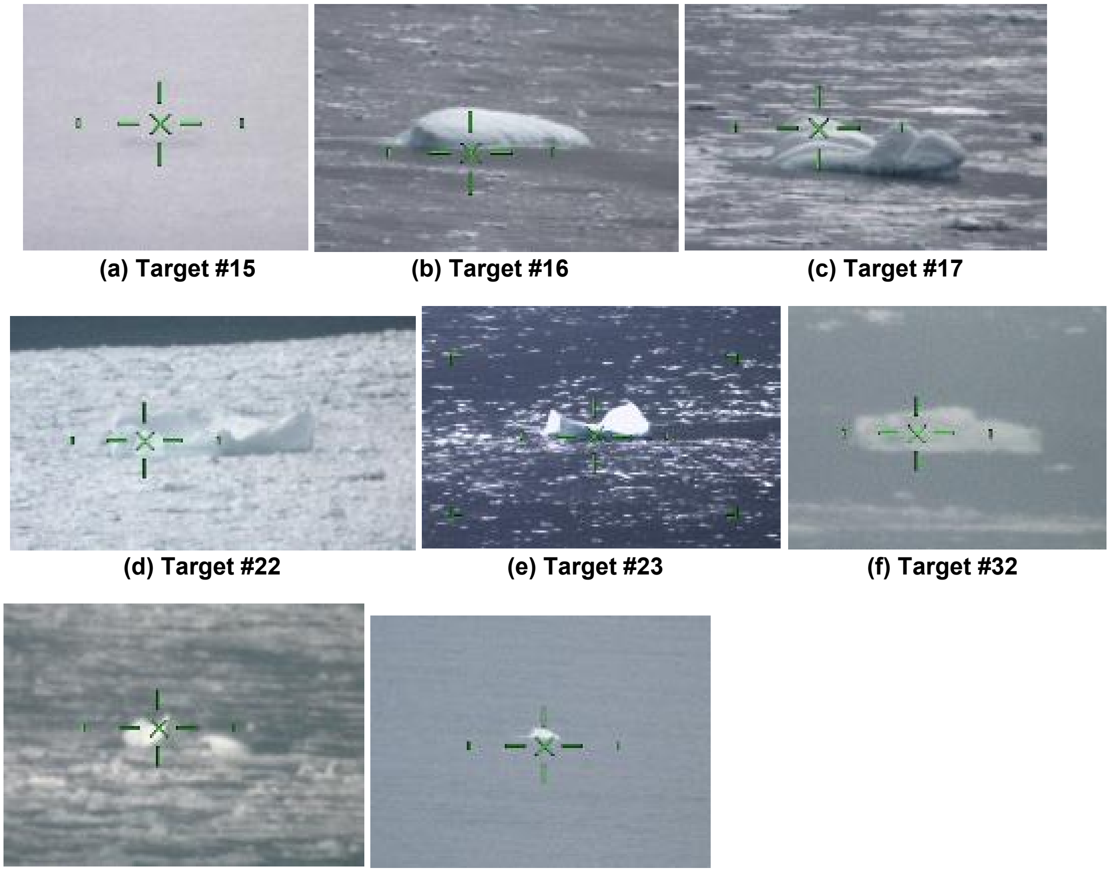
(n) Target #40



(o) Target #19

Figure B-2. Correlated icebergs. Images of coincident, verified icebergs and their correlated SAR targets on 04 May 2018. The camera image from the HC-130J (left) is alongside the corresponding Sentinel-1 target (right) in HH Polarization. The Target # for each subset corresponds with the IDs listed in Table B-4. Note that Target #45 was a growler observed visually only by the aircraft crew and there was no image recorded of the iceberg.

The method of aerial detection may have been a factor in these 20 non-correlated icebergs as well. **Table B-6** provides definitions of the aerial observation methods and summarizes the strengths and weaknesses of each. Of the 20 non-correlated icebergs, seven were observed by both radar and visual means, five were observed by visual means only, and the remaining eight were detected by radar only. In contrast, of the 15 correlated icebergs, 13 were detected by both radar and visual means, two were detected by visual means only, and none were radar only. 40% (eight of 20) of the non-correlated icebergs were observed using radar or other aircraft sensors only. Of these eight, four were visually verified as icebergs using the high definition camera but no size information was obtained, while the remaining four were identified using only Inverse Synthetic Aperture Radar (ISAR). ISAR is a sensor with output subject to interpretation and increased challenges in distinguishing icebergs from sea ice and, therefore, is not the best tool for ground-truthing since these detections are also based on sensors other than the human eye and are in need of their own verification. Icebergs identified by radar only are entered into the BAPS models as “general” icebergs, and are given a size of 120 m (longest medium) though they could have been sighted as growlers or as very large icebergs. This lack of accurate size information adds a complication to the verification process as it changes the way the BAPS models drift the iceberg and provides less information to the verification team member attempting to correlate it with a SAR target.



(a) Target #15 (b) Target #16 (c) Target #17

(d) Target #22 (e) Target #23 (f) Target #32

(g) Target #37 (h) Target #46

Figure B-3. Non-correlated icebergs. Images captured from the HC-130J flight on 04 May 2018 of satellite false negative icebergs – verified icebergs that were unable to be correlated to a SAR target in the coincident Sentinel-1 frame using IIP's current processes. While some (Target #15, #16, and #46 for example) are visually more worn and of lower profile than the majority of the correlated icebergs in Figure B-2, others (such as Target #32) have substantial edges that should have returned the SAR signal. For more information on each target, use the Target # in the captions to reference the ID column in Table B-5.

Observation Method	Description
Visual Only	The iceberg is sighted visually by an ice observer in the aircraft only. This method provides confirmation that the target is an iceberg and size information, but the position is estimated.
Radar Only	The iceberg is sighted using the aircraft sensors only. These include the high definition camera, the radar, as well as the Inverse Synthetic Aperture Radar (ISAR). This method provides accurate position information but uncertain size information. Use of the high definition camera can confirm the identity of the target, but radar and ISAR alone do not.
Radar and Visual (R/V)	The most detailed method providing the size information and visual confirmation of the iceberg identity from the ice observer combined with the accurate position information from the aircraft sensors.

Table B-6. Description of observation methods from aerial reconnaissance.

Of further note, 35% (seven) of the non-correlated but verified icebergs were recorded as small icebergs (15 – 60 m). Depending on where their sizes fell within this range, an iceberg of less than 20 m waterline length cannot reasonably be expected to be detected at the 20 m spatial resolution of a Sentinel-1 GRD IW frame. Two of the four medium icebergs (60 – 120 m waterline length) that were aerially detected but not correlated to a SAR target were only sighted visually and were within 7/10 or 8/10 sea ice concentrations – highlighting the challenge of detecting even medium-sized icebergs within sea ice from both aircraft sensors and satellite.

Table B-7 describes the results of the verification work on 04 May 2018. It should be noted that while 2018's light Iceberg Season allowed for aerial satellite verification flights, the low target density associated with a light season diminished the effectiveness of the verification flights due to fewer aerial targets per flight. In contrast, 2019 had high target density but reduced ability for satellite verification flights due to higher demand for Iceberg Limit patrols.

	Targets			Percentage			
	CFAR-9 (2018)	CFAR-15 (2018)	Both (2019)	CFAR-9 (2018)	CFAR-15 (2018)	Both (2019)	Detection and Classification Category
Verified Icebergs Correctly Classified as Icebergs by SDW	3	8	6	20%	53%	40%	Accurate Detection and Classification
Verified Icebergs Detected by SAR but Not Classified as Icebergs by SDW	12	7	9	80%	47%	60%	Classification Error: False Negative
SDW Classified Icebergs that did not Correlate with a Verified Iceberg (Non-Iceberg SAR Target)	10	26	76	77%	76%	93%	Classification Error: False Positive
Verified Icebergs not correlated with a SAR Target (Non-Correlated Icebergs)	20	20	20	57%	57%	57%	Detection Error: False Negative

Table B-7. Results of Satellite Dayworker (SDW) analysis of a verified Sentinel-1 frame on 04 May 2018. Here, the SDW processed the frame using the 2018 filter process with CFAR 10^{-9} and 10^{-15} detections separately. These results helped to develop the 2019 filter process. A subsequent analysis by a different SDW that used the 2019 filtering process is included here and demonstrates improvements over the 2018 filter process that used CFAR 10^{-9} alone. Note that the top two rows refer to the 15 correlated icebergs and the percentage of those that were classified as each category, while the third row is the percentage of SDW classified icebergs that were not correlated to verified icebergs and the fourth row refers directly to the number of non-correlated icebergs as a percentage of the total number of verified icebergs (35).

Though 2018 did not yield a large dataset, the verification work provided four key results:

1. **Using CFAR 10^{-15} at higher incidence angles detected all verified icebergs and reduced analyst workload**. On the 04 May frame, 100% of the correlated icebergs at incidence angles greater than 35˚ were detected by CFAR 10^{-15}. 100% of the correlated icebergs at incidence angles less than 35˚ were only detected at CFAR 10^{-9} (0% were detected at CFAR 10^{-15}). Though 100% of the correlated icebergs at greater than 35˚ incidence angles were also detected at CFAR 10^{-9}, using this value resulted in more than double the total number of targets for the

analyst to work through – i.e. many more uncorrelate-able SAR targets (**Tables B-3 and B-4)**.

2. **Detection accuracy was improved using CFAR 10^{-15}**. Using CFAR 10^{-15} on the 04 May frame resulted in 2.5 times better accuracy in detection of verified icebergs (53% of verified icebergs detected vs. 20% at CFAR 10^{-9}), and half as many false negative targets (47% vs. 80%; **Table B-7**) perhaps due to the fewer, but higher quality targets presented to the analyst.
3. **Rejecting Low Confidence detections rejected verified icebergs.** Of the correctly classified SAR targets from the entire verification effort, 75% (15 of 20) were High Confidence targets and 25% (five of 20) were Low Confidence. Confidence is described in detail in Section B-4.
4. **Verified icebergs were mostly detected in HH polarization.** Of the correlated SAR targets from the entire verification effort, only 10% (two of 20) were detected in both HH and HV polarizations (Dual-Pol) targets, with the remaining 90% (18 of 20) in HH polarization only.

B-4. 2019 Filtering Process

Based on the 2018 verification work and the results summarized in Section B-3 that icebergs were easier to detect in HH polarization at incident angles greater than 35˚, IIP refined the filtering sheet in 2019 (See **Supplemental Material B-2: 2019 SDW Filtering Sheet**). The 2019 filtering process was aimed at striking a balance between the number of targets for the SDW to analyze (efficiency) and the likelihood of these targets being valid targets (accuracy).

The 2018 SDW process utilized only High Confidence detections in CFAR 10^{-9}. The confidence level of a SAR detection is determined by the ratio of the target pixel decibel level to that of the mean background noise in the sliding window. If the ratio is 10:1 or greater, the target detection is High Confidence. If it is less, the detection is Low Confidence. In 2018 and earlier, the first step in the IIP filtering process was to immediately reject all Low Confidence targets, thus the analyst only considered High Confidence targets. Note from **Table B-1**, the example of 04 May 2018 shows that 70% of all targets detected at CFAR 10^{-9} were Low Confidence and were, therefore, deleted. For the same date, 20% of the SAR targets correlated with verified icebergs were Low Confidence detections, and would have been missed by the 2018 filtering process.

The main difference between the 2018 and 2019 filter sheets is the inclusion of two CFAR thresholds. CFAR 10^{-15} was utilized for the region of the frame with incidence angles greater than or equal to 35˚, while CFAR 10^{-9} was utilized for the area of the frame with incidence angles less than 35˚. This allowed the analyst to accept more false alarms in the area in which targets are more difficult to detect due to the decreased signal to noise ratio closer to the satellite. Further, the 2019 filter sheet eliminated the confidence level of the SAR target as a filtering factor.

When the 2019 filtering process was applied to the 04 May 2018 verification frame (**Table B-7**), the SDW identified six of the 15 correlated icebergs using the 2019 process

(40% accuracy compared to 20% from the 2018 filtering process). However, 60% of the correlated icebergs were still missed resulting in nine false negative targets due to classification error. Significant as well, was the 76 false positives identified in the frame. In areas close to the Iceberg Limit, these false positive and false negative detections and classifications result in inaccurate representation of the iceberg danger. It is important to point out that the quantification of accuracy presented in **Table B-7** shows that using CFAR 10^{-15} alone had the best results; this better performance drove the creation of the 2019 filter process and will be considered in further revisions of the filter process. Further, the results presented in Sections B-3 and B-4 are based mostly on the verification of a single Sentinel-1 frame. A more rigorous quantification of accuracy over a wider array of frames is needed to validate the 2019 filtering process.

As noted in Section B-3, 80% of the non-correlated, false negative icebergs in the 04 May 2018 frame were within sea ice, which provides complications both to detection and classification. In the next section, further validation of the filter process focusing on the challenge of detection and classification of icebergs in sea ice is directly addressed through examining satellite frames collected in February 2019.

B-5. February 2019 Icebergs within Sea Ice

The 2019 filtering sheet was put into operation on 08 February 2019. During the month of February, 16 Sentinel-1 frames with SAR targets in 9/10 sea ice concentrations or greater were analyzed by IIP SDWs (**Figure B-4**). These were used as a case study to test the effectiveness of the new filtering mechanism on icebergs within sea ice. For this

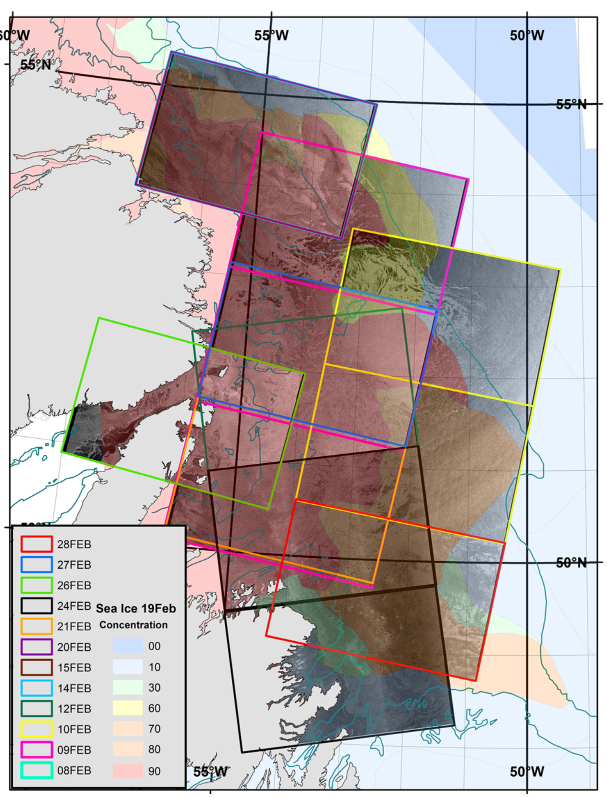


Figure B-4. February 2019 Sentinel-1 frames with targets in sea ice concentrations of 9/10 or greater utilized for the analysis of the 2019 filtering sheet on icebergs within sea ice. The colored shading represents the sea ice concentrations on 19 February as determined by the Canadian Ice Service.

case study, the number of SDW classified icebergs identified using the 2019 filtering sheet in each frame was tallied alongside the number identified with the 2018 filtering sheet. **Figure B-5** and **Table B-8** show the results of the tabulation: 151 more icebergs within sea ice were classified with the 2019 filtering sheet than would have been classified with the 2018 process during February 2019. Several characteristics of the classified

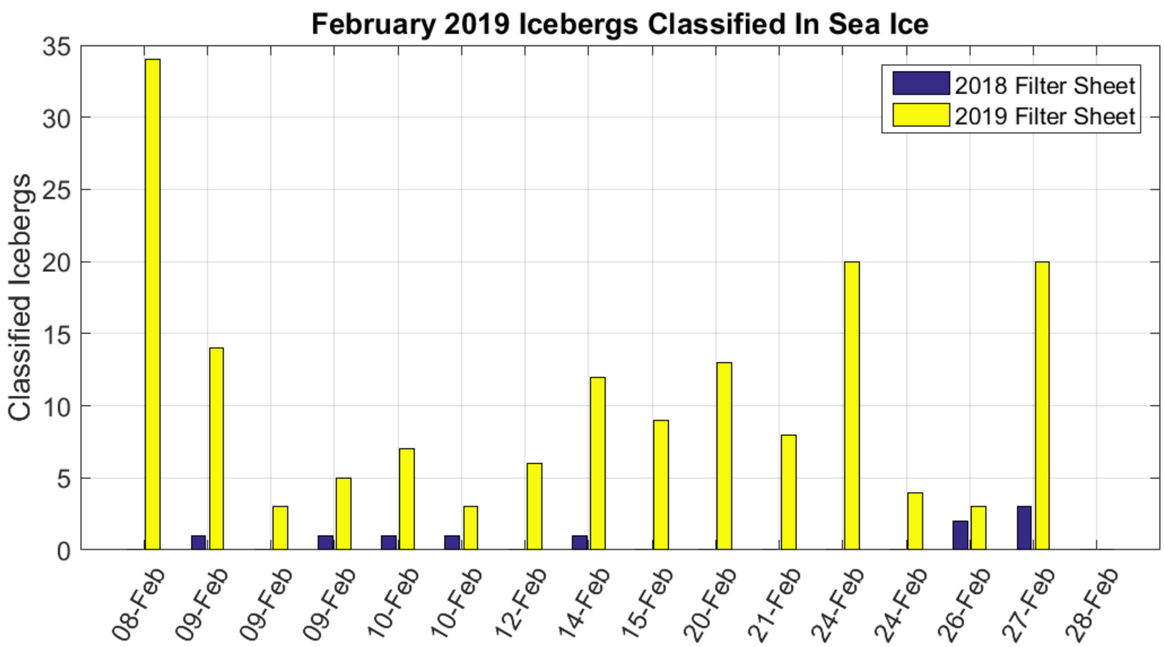


Figure B-5. Results of the 2018 vs. 2019 filtering process regarding SDW classified icebergs in Sentinel-1 frames with 9/10 or greater sea ice concentration during February 2019.

		Detection				Classification									
							Icebergs Classified by the New Filtering Process								
Date	Frame ID	CFAR-9 targets	CFAR-9 High Conf	CFAR-9 Low Conf	CFAR-15 targets	2018 Filter Sheet Icebergs	2019 Filter Sheet Icebergs	Dual Pol	HH/VV Only	HV/VH Only	High Conf	Low Conf	Both 9 and 15	>35 IA	<35 IA
8-Feb-19	881D	326	51	275	52	0	34	10	20	4	14	20	30	22	12
9-Feb-19	EB6E	187	22	165	17	1	14	2	10	2	9	5	14	14	0
9-Feb-19	4D3A	168	32	136	6	0	3	1	2	0	1	2	3	2	1
9-Feb-19	E814	444	103	341	17	1	5	2	3	0	1	4	5	1	4
10-Feb-19	BD76	762	74	688	90	1	7	4	2	1	4	4	7	7	0
10-Feb-19	3A44	290	9	281	4	1	3	1	2	0	3	0	3	3	0
12-Feb-19	72A1	208	9	199	8	0	6	1	2	3	2	4	6	6	0
14-Feb-19	F0EE	307	37	270	63	1	12	2	7	3	4	8	12	10	2
15-Feb-19	52D7	102	11	91	5	0	9	2	5	2	3	6	5	4	5
20-Feb-19	4338	450	53	397	66	0	13	2	5	6	6	7	13	13	0
21-Feb-19	3C48	180	12	168	13	0	8	2	6	0	2	6	7	5	3
24-Feb-19	0040	479	118	361	58	0	20	1	18	1	15	5	20	10	10
24-Feb-19	228A	166	19	147	7	0	4	0	4	0	4	0	4	4	0
26-Feb-19	8E09	269	64	205	35	2	3	2	1	0	1	2	2	1	2
27-Feb-19	C83A	208	33	175	36	3	20	4	10	6	11	9	20	20	0
28-Feb-19	49FA	116	17	99	31	0	0	0	0	0	0	0	0	0	0

Table B-8. Results of the February 2019 analysis of iceberg classifications in sea ice concentrations of 9/10 or greater. All values to the right of the Frame ID refer to the number of individual targets or icebergs in each category. All columns to the right of the 2019 Filter Sheet Icebergs column refer to the number of icebergs identified in each category by the 2019 filtering process. The "Both 9 and 15" column indicates the number of icebergs that were detected in both CFAR 10^{-9} and CFAR 10^{-15}. In the last two columns, "IA" refers to Incidence Angle.

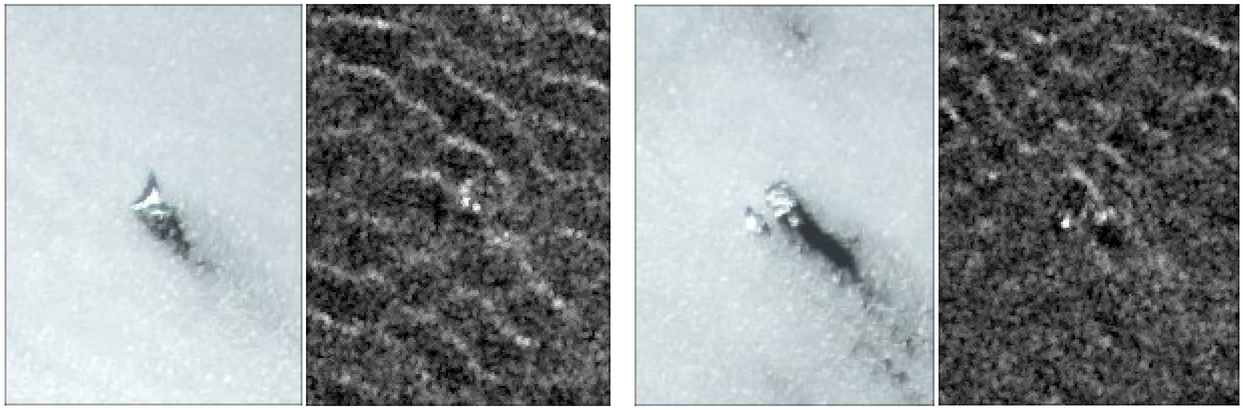
icebergs are apparent in **Table B-8**. First, when looking at the effectiveness of CFAR 10^{-9} vs. CFAR 10^{-15}, on average, 4% of the total CFAR 10^{-9} detections were classified as icebergs while 55% of total CFAR 10^{-15} detections were classified as icebergs showing a better chance of having viable targets presented to the SDW when using CFAR 10^{-15}. 75% of classified targets were detected at incidence angles greater than or equal to 35˚ and 93% of classified targets were detected in both CFAR 10^{-9} and CFAR 10^{-15}.

In the 2018 filtering process, for detections in sea ice concentrations of 7/10 or greater, only dual-pol targets were considered. Under the 2019 filtering mechanism, polarity in sea ice at incidence angles of 35˚ or greater was not a considered factor. Indeed, in February 2019 only 26% of SDW classified icebergs within sea ice were detected in dual-pol while the remaining 74% were detected in single-pol (59% in HH/VV, 15% in HV/VH). Additionally, in the 2018 filtering sheet, only High Confidence targets were analyzed. However, the 2019 filtering sheet did not consider confidence and 50% of classified targets were detected with Low Confidence that would never have been analyzed under the 2018 filtering process. Though the increased iceberg classifications are a positive result for IIP operations, the problem of ground-truthing whether the increased classifications were icebergs or just scattering features within the sea ice persisted as the presence of sea ice normally results in a large number of SAR detections that could correspond to false positives.

B-6. Multispectral verification shows the challenge of sea ice.

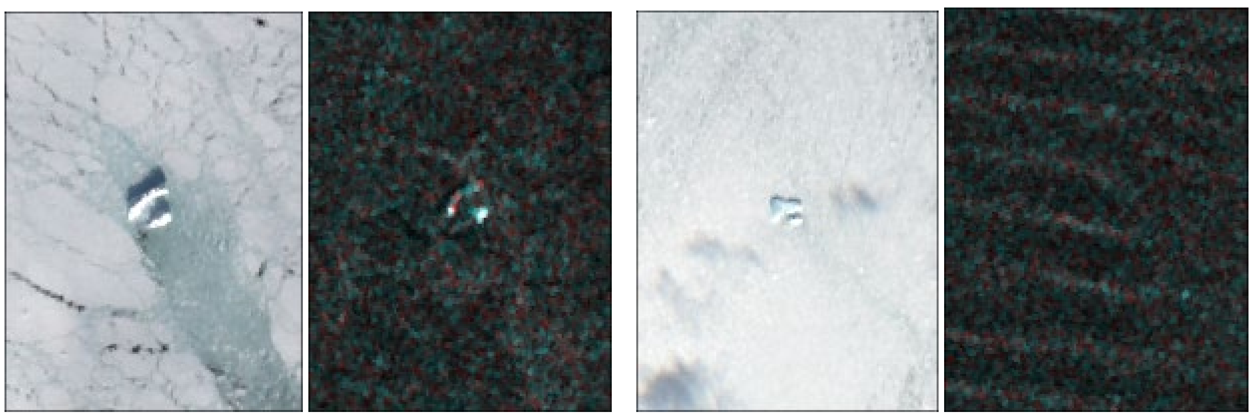
The severity of the 2019 Ice Season (10^{th} most severe since 1900) prevented any targeted aerial reconnaissance for satellite verification flights. Lacking this coincident verification in 2019, IIP turned to multi-spectral imagery for ground-truth when available. Sentinel-2 is a multi-spectral imaging mission consisting of two satellites each sampling 13 spectral bands at various resolutions. To make a true color image, Bands 4, 3, and 2 in RGB were built into a composite image at 10 m resolution. Of the 16 days in February with analyzed Sentinel-1 frames in 9/10 or greater sea ice concentration, three days (09, 20, and 24 February) had near-coincident, relatively cloud-free Sentinel-2 frames. Since the area of the Sentinel-2 frames is roughly a third of the size of the Sentinel-1 frames, not every SDW classified iceberg was able to be compared to the true color image. The Sentinel-2 true color images were visually inspected to locate icebergs. In the true color image, icebergs were most clearly identified by the shadow cast to the north of the icebergs since the satellite passed at 1507Z and, when in strong winds, by the disturbance of the sea ice around the iceberg. For many icebergs, there was a clear difference in pixel texture between the surrounding sea ice and the iceberg but, for IIP, this process remains strictly qualitative and based on the analyst's eye. Examples of correlated and non-correlated icebergs verified by Sentinel-2 multispectral imagery are shown in **Figure B-6**.

On the 09 February frame (Frame E814 in **Table B-8**), no SDW classified icebergs were identified in the Sentinel-1 frame within the area of the Sentinel-2 image and no verified icebergs were identified by visual inspection of the region of the Sentinel-2 image



(a) 130m iceberg Not Detected or Classified

(b) 90m iceberg Detected but Not Classified as an Iceberg



(c) 190m iceberg Detected and Classified Correctly

(d) 140m iceberg Not Detected or Classified

Figure B-6. Example comparison of verified icebergs (using multispectral satellite imagery) within sea ice and corresponding SAR image from coincident Sentinel-2 (left) and Sentinel-1 (right) imagery on 20 February 2019. Note that the SAR returns in (a) and (b) are HH polarization while (c) and (d) are showing a layer stacked method of display in which the HH, HV, HV bands are shown in RGB. (d) had no SAR return in either polarization nearby, presumably due to a rounded shape and lack of broken sea ice around the iceberg, differentiating it from the other examples shown here.

(accurate detection and classification). On 24 February (Frame 0040), five SDW classified icebergs were identified by SAR within the area of the Sentinel-2 frame but no verified icebergs were identified by visual inspection of the Sentinel-2 image (false positive due to classification error). A large number of broken up sea ice rafts were in the image that could provide edges for the SAR imagery to scatter resulting in misclassification. On 20 February (Frame 4338), 11 SDW classified icebergs from the SAR imagery were within the Sentinel-2 frame region but 106 verified icebergs were visually identified in the true color image. Of these 106, only five had been correctly classified by the SDW in the SAR image, resulting in six false positive icebergs and 101 false negative icebergs. It is also important to note that the 2018 filtering process resulted in zero SDW classified icebergs in this frame – no false positives but more false negatives and no accurate classifications, showing a small, but definitive, improvement in the filtering process.

Figure B-7 shows a subset of the 20 February imagery containing 18 of the 106 verified icebergs. Using CFAR 10^{-9} and 10^{-15}, five targets were detected. Three of the five were positively detected and classified by the SDW while two were positively detected but misclassified. The remaining 13 of the verified icebergs were not detected at all.

Throughout the region of the entire 20 February Sentinel-2 frame, **Table B-9** shows the number of IDS detections in the Sentinel-1 SAR image at different CFAR values within 1 NM (based on the estimated speed of the ice over the time between satellite passes) of the verified icebergs as an approximation of detection accuracy. This process resulted in 14% (CFAR 10^{-15}) and 35% (CFAR 10^{-9}) of the Sentinel-2 verified icebergs detected as SAR targets and clearly highlights the low detection accuracy for icebergs within sea ice using the current methods. An important point is that when increasing the CFAR, the percentage of verified icebergs detected in SAR increased dramatically, going to 93% with CFAR 10^{-5}. However, this also resulted in a corresponding dramatic increase in the number of SAR targets to analyze. As shown in **Table B-9**, only 6% of the CFAR 10^{-5} SAR targets were within 1 NM of a verified target, while 31% of the CFAR 10^{-15} SAR targets were. Clearly, there must be a balance between accuracy and effectiveness.

Figure B-7. Subset Sentinel-2 true color image from 20 February 2019. Here, three SDW classified icebergs from the SAR image (pink triangles) are compared with the 18 verified icebergs in the true color image (orange triangles). In this subset, the three SAR classified icebergs were accurately identified, however, the 15 false negatives shown here highlight the challenges that still exist with identifying icebergs within sea ice.

SAR Detection Method	Total Number of SAR Targets	SAR Targets w/in 1 NM of a Verified Iceberg	Verified Icebergs with a SAR Target w/in 1 NM	% of SAR Targets w/in 1 NM of a Verified Iceberg	% of Verified Icebergs with a SAR Target w/in 1 NM
CFAR -5	5601	340	99	6%	93%
CFAR -7	664	67	59	10%	56%
CFAR -9	205	37	37	18%	35%
CFAR -15	48	15	15	31%	14%
SDW Classification	**Total Classified Icebergs**	**Verified Icebergs Classified**		**% of SDW Classifications that were Verified Icebergs**	**% of Verified Icebergs Classified Successfully**
Sentinel-2 Verification	106				
2018 Filter Sheet	0	0		-	0%
2019 Filter Sheet	11	5		45%	5%

Table B-9. Estimation of detection accuracy at different CFAR values (top rows) and SDW classification accuracy (bottom rows) using the coincident Sentinel-1 and Sentinel-2 satellite passes on 20 February 2019. The Sentinel-2 frame was visually examined and 106 verified icebergs were identified. The Sentinel-1 frame was processed through the IDS at the indicated CFAR values and target detections within 1 NM (based on the estimated speed of the ice over the five hours between the passes) were identified. Note that the quality of the SAR detection is not reflected by these numbers, and there is no indication given in the top rows of this figure that any of the detections close to a verified iceberg would have been classified as an iceberg by the SDW. Indeed, the bottom rows show the classification results from the 2018 and 2019 filter processes. These are a better indication of classification accuracy: under the 2019 filter process, 45% of the SDW classified icebergs in the SAR image were verified icebergs from the Sentinel-2 image while only 5% of the verified icebergs identified in the Sentinel-2 image were classified successfully. Note that the 2018 filter process classified none of the verified icebergs.

B-7. Conclusion

The general scope of satellite reconnaissance can be broken into two main realms: detection – flagging certain pixels as possible targets, and classification – determining the nature or identity of the target. Classification is a challenge that requires analyst training, experience, a broad dataset of ground-truthed data, and, ideally, a reliable classification algorithm to rely on a defined set of signature characteristics that could be automated. While not an easy problem to solve, if the analyst were to err on the side of caution, the result is false positive iceberg classifications. While these are a possible inconvenience to transatlantic shipping by needlessly holding the Iceberg Limit farther out than required, they are far safer than misclassifying icebergs as sea clutter resulting in false negative targets. False negative targets would not inform the Iceberg Limit and therefore can be a safety risk to maritime traffic. Classification error is a significant challenge in the satellite reconnaissance process and is compounded by challenges with detection. An analyst or a machine learning algorithm cannot successfully classify what is not detected. Undetected icebergs will always be a false negative target – dangerous by definition.

This study has shown two primary conclusions: (1) that IIP's verification work has served to improve the processes for classifying icebergs within sea ice but (2) that the current methods of both detection and classification are still not accurate enough to reliably use as a primary reconnaissance methodology nor transition to automated detection and classification. IIP is currently conducting another round of verification work using results from the 2019 Department of Homeland Security's Science and Technology Directorate Iceberg Tagging Campaign as well as more Sentinel-2 multispectral imagery. The results collected from this work will be used to continue to refine the filtering process and to provide insight into better methods of detection.

Using the example of 04 May 2018, the need for improved detection and classification is clear. On this date, 35 icebergs were observed from an HC-130J aircraft and 15 of these verified icebergs were correlated with SAR targets successfully. As noted in **Table B-2**, false positive classifications are a direct result of classification errors while false negatives can be due to classification or detection errors. **Table B-7** shows the results of an IIP SDW analysis of the frame, resulting in false negatives (second row; nine by the 2019 process) and false positives (third row; 76 by the 2019 process) related strictly to misclassification. Misclassification can be a result of a filtering process that needs to be adjusted or of classification errors by the analyst. As IIP's SDWs become more experienced and the filtering process is continued to be refined, we should expect a corresponding improvement in classification ability. Of the 35 aerially observed targets on 04 May, 20 were not able to be correlated to SAR targets at all by the current CFAR detection method and SAR sensors that IIP utilizes.

Within sea ice, we have shown that high incidence angle detections are the most prevalent. Further, that most detections were made in single polarization (HH or VV). We have shown that it is more effective to focus on CFAR 10^{-15} at higher incidence angles than CFAR 10^{-9} as the percentage of viable targets compared to false alarms was improved. This study has shown that while we have made major strides in improving our ability to classify icebergs, ground-truthing work continues to show that we still have significant work to do to improve accuracy. At present, without additional data sources that can support the SAR analysis, we are unable to confidently quantify the number or size of the icebergs that we cannot see in a given image.

The 20 February 2019 example of coincident Sentinel-1 and Sentinel-2 images paints a compelling picture of the challenges associated with the current methods of satellite detection of icebergs within sea ice. While the 2019 filtering sheet, utilizing two different CFARs and capitalizing on the strengths of SAR at different incidence angles, helped to detect 151 more icebergs within 9/10 sea ice concentrations in the month of February 2019, the 101 missed icebergs in this one frame are quite sobering. With so many missed targets in one frame, we are faced with the need to improve not only the classification methods of discriminating icebergs from other targets, but the first step in the process: detecting icebergs to begin with. Utilizing larger CFAR values results in many more targets to analyze, but IIP must strike a balance between the ability to detect using a viable CFAR and not inundating analysts with the classification of unlikely targets. Further, without a strong, validated set of iceberg classification signatures, IIP cannot transition to a more automated analysis required to handle significant quantities of SAR data. For the problem of icebergs in sea ice, improvement may require a better method of target detection, increased automation to streamline the currently cumbersome pre-analysis work, as well as a reanalysis of levels of acceptable risk based on the fact that satellite reconnaissance will continue to provide both false positive and false negative targets.

Detecting and classifying icebergs within SAR imagery is a challenge, but not an insurmountable one, and certainly worth the effort invested in order to provide the most accurate depiction of iceberg risk to mariners operating in the North Atlantic. To improve, we must investigate new detection methods as well as data sources and sensors. For example, anecdotal evidence regarding L-Band SAR imagery has shown great promise at detecting icebergs within sea ice. While multispectral imagery is not capable of providing sufficient data for routine operational use, analysis of cloud-free imagery and development of automated target detection within such imagery can aid in improving detection and classification within the more operationally relevant SAR imagery. Further, continued collection of ground-truthed verification data by any means will refine not only our analyst's classification skills, but provide the necessary data for automated detection and classification algorithms that will become more and more relied upon as more SAR data becomes available. These efforts will provide the key to extracting essential maritime safety information from these valuable satellite sources.

B-8. References

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B-9. Supplemental Material

SATELLITE ANALYSIS IMAGERY FILTER - RECORD SHEET

Q:\1. SATELLITE DAY WORKER\Satellite Processing Guide\3. Analysis\3. Satellite Analysis Filter_Worksheet_20180402

Satellite Pass Date __________ Data ID _________ (Last 4 Alphanumeric digits of filename)

Once the satellite images have been run through IDS and the MOD_Output_DDMMM has been converted to a shapefile for editing in BAPS, the SDW shall then apply the following filters to the Export_Output_DDMMM attribute file to focus their analysis on those targets with greatest potential for iceberg detection and identifications. All targets not meeting one of these filters may be deleted from the attribute file and are not subject to individual analysis.

1. _______ Total number of targets in the unmodified Export_Output.shp attribute table.

First, perform deletions based on Attribute Table and/or Environmental Conditions

1. _______ Total number of **Low Confidence** Targets deleted
2. _______ Total number of **non dual-pol targets deleted in Sea Ice** Concentration. ≥ 7/10
3. _______ Total number of **HH-only or VV-only targets** deleted where winds > 15kts

Second, perform alterations based on ArcMap observations or correlated data.

1. _______ Total number of targets deleted as artifacts **at edge of satellite frame**.
2. _______ Total number of targets deleted as a **land feature**.
3. _______ Total number of targets reclassified as ships via **correlations with AIS data**.
   (These targets should be identified in MANICE and added to the 55555's group with time and position only)

The remaining targets in the attribute file should all be High Confidence in one of the categories below.

Confidence	Channels Detected	Wind Speed	Sea Ice Concentration
High	Dual Pol HH,HV or VV,VH	ANY	ANY
	* Single Pol HV or VH	ANY	<7/10
	Single Pol HH or VV and	< 15 kts	<7/10
* Reminder that these polarizations will not appear as bright as Dual Pol .			

Individually analyze the remaining targets and err on the side of iceberg if imagery is not conclusive.

1. _______ Total number of High Confidence Dual Pol Targets
   a. _______ Total # classified as icebergs. b. ______ Total # classified as ships
2. _______ Total number of High Confidence Single Pol (HV/VH in <7/10 sea ice) targets
   a. _______ Total # classified as icebergs. b. ______ Total # classified as ships
3. _______ Total number of High Confidence Single Pol (HH/VV in low winds/sea ice) targets.
   a. _______ Total # classified as icebergs. b. ______ Total # classified as ships

SUPPLEMENTAL MATERIAL B-1: 2018 SDW Filtering Sheet

SATELLITE ANALYSIS IMAGERY FILTER - RECORD SHEET

Q:\1. SATELLITE DAY WORKER\Satellite Processing Guide\3. Analysis\3. Satellite Analysis Filter_Worksheet_20190213

SDW: ____________________ SIM Message # _____________ (from SIM board)
Sat Pass Date _____________ Data ID _______ (Last 4 Alphanumeric digits of filename)

1. ☐ Run and load IDS for CFAR -9.
2. ☐ Run and load IDS for CFAR -15 (All of these targets **will be analyzed**)
3. _______ Total number of targets in the unmodified CFAR-9 "Master.shp" attribute table (**Editing and final MANICE will be produced from this**).

First, perform alterations based on ArcMap observations or correlated data.

1. _______ Total number of targets deleted as artifacts **at edge of satellite frame**.
2. _______ Total number of targets deleted as a **land feature**. (Add known islands to database)
3. _______ Total number of targets reclassified as ships via **correlations with AIS data**.
4. _______ Identify correlated -9/-15 targets in frame and **update "CLASS" column to "UNKWN"** (follow process guide above SDW workstation to complete this)

Next, select all targets with an **inc angle >35**. **Deselect/filter UNKWN targets out**.
(Follow process guide above SDW workstation to complete this)

1. _______ **Record number of remaining CFAR-9 targets deleted.**

For targets in the **<35 incidence angle area**, perform deletions using Environmental criteria.

1. _______ Total number of **non dual-pol targets deleted in Sea Ice** Concentration. ≥ 7/10
2. _______ Total number of **HH-only or VV-only targets** deleted where winds > 15kts

Apply the criteria below to remaining targets in the **< 35 Incidence Angle** area.

Incidence Angle	Channels Detected	Wind Speed	Sea Ice Concentration
< 35	Dual Pol HH,HV or VV,VH	ANY	ANY
	* Single Pol HV or VH	ANY	<7/10
	Single Pol HH or VV and	< 15 kts	<7/10
* Reminder that these polarizations will not appear as bright as Dual Pol .			

Individually analyze the remaining targets and err on the side of iceberg if imagery is not conclusive. (Also, **MIFC support** is available for targets near or outside the limit)

1. _______ Total number of Targets with >35 incidence angle to be individually analyzed
   Total classified as _____ icebergs _____ ships _____ R/Ts _____ Other (deleted from table)
2. _______ Total number of targets with < 35 incidence angle to be individually analyzed
   Total classified as _____ icebergs _____ ships _____ R/Ts _____ Other (deleted from table)

Notes:____
____
____

SUPPLEMENTAL MATERIAL B-2: 2019 SDW Filtering Sheet

INTERNATIONAL ICE PATROL