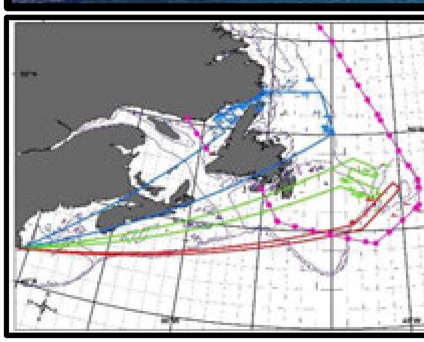
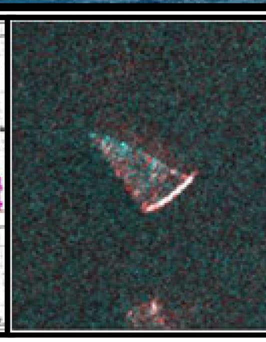
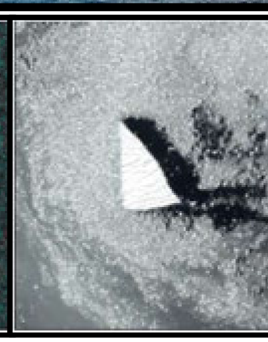
Homeland Security

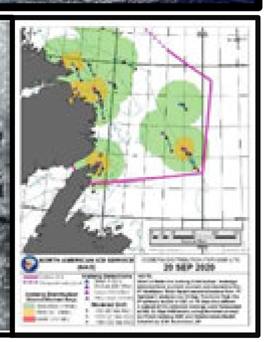
United States Coast Guard

Report of the International Ice Patrol in the North Atlantic









2020 Season
Bulletin No. 106
CG-188-75

INTERNATIONAL
ICE PATROL

Bulletin No. 106
Report of the International Ice Patrol in the North Atlantic
Season of 2020
CG-188-75

Forwarded herewith is Bulletin No. 106 of the International Ice Patrol (IIP) describing the Patrol's services and ice conditions during the 2020 Ice Year. With 169 icebergs drifting into the transatlantic shipping lanes, the 2020 season was designated as a "light" Ice Season – the lightest year since 2013, when only 13 icebergs were detected in shipping lanes. 2020 followed predictions that it would be a light season due to the slow formation of sea ice and warm temperatures at the end of 2019. This season follows the "extreme" season of 2019, when 1,515 icebergs were detected and underscores the dramatic annual variability in iceberg danger to transatlantic shipping.

The Ice and Environmental Conditions section presents a discussion of the meteorological and oceanographic conditions that resulted in this light season. Additionally, the Operations section discusses the potential impact of increased satellite reconnaissance on the identification and count of icebergs.

2020 marked the first year that the majority of icebergs were detected by satellite as opposed to aerial reconnaissance. Throughout 2020, IIP continued to develop and refine new reconnaissance techniques using synthetic aperture radar and multispectral imagery satellites for iceberg detection and identification. To continue driving improvements to satellite imagery analysis, IIP restructured the unit internally by disestablishing the Ice Information Branch, and forming the Satellite Reconnaissance Branch (SRB). The SRB is entirely dedicated to IIP's satellite reconnaissance efforts. For the first time, progress made in satellite reconnaissance techniques enabled IIP to provide a tailored ice warning product, based solely on satellite imagery, for two non-ice class Coast Guard cutters and partner nation vessels participating in operations off Greenland.

Each year, the Ice Patrol plans to honor events inextricably linked with IIP history, conducting memorial and wreath dedication ceremonies for RMS Titanic in New London, CT, and Halifax, Nova Scotia, followed by a commemoration of the sacrifices of the Greenland Patrol during World War II. Unfortunately, due to the global pandemic, these ceremonies were cancelled in 2020. IIP was still able to commemorate the loss of RMS Titanic with a special note on its 15 April iceberg warning product for mariners.

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 2020 season.

M. T. Hirschberg
Commander, U. S. Coast Guard
Commander, International Ice Patrol

International Ice Patrol
2020 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: Collection of images highlighting operations throughout the 2020 Ice Season. Top: image of USCGC CAMPBELL (WMEC-909) and an iceberg taken by the embarked aircrew during their deployment to the west coast of Greenland in August and September 2020. Bottom left: sample of iceberg reconnaissance flights conducted from Air Station Cape Cod during May and June 2020. Bottom center: imagery of an ice island fragment in Sentinel-1 Synthetic Aperture Radar imagery (center-left, October 29, 2019) and Sentinel-2 multispectral imagery (center-right, March 7, 2020) detected during the first operational use of Sentinel-2 imagery (Copernicus Sentinel data 2019 and 2020). Bottom right: prototype iceberg product including "Isolated", "Few", and "Many" contours of iceberg density and 24/48 hour forecasting of iceberg drift.

1. Introduction

This is the 106th annual report of the International Ice Patrol (IIP) describing the 2020 Ice Year. It contains information on IIP operations, along with environmental and iceberg conditions in the North Atlantic from October 2019 to September 2020; focusing on the Ice Season (February to August 2020). To conduct aerial reconnaissance, IIP deployed nine 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). The first three IRD's operated as normal from St. John's, Newfoundland. The next planned IRD was cancelled as the COVID-19 pandemic was beginning to surge, and the remaining IRD's deployed from USCG Air Station Cape Cod (ASCC) on board ASEC aircraft. 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 a daily 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.

IIP continues the evolution of its reconnaissance operations. From the early beginnings of ship-based observations, to visual aerial reconnaissance, to radar, and now transitioning to sensors in space, the men and women of IIP continue to innovate and embrace technology to provide the most accurate iceberg monitoring and warning services to the international maritime community. We continued to address Information Technology needs, and the upgrade to the next generation of BAPS is underway. IIP also continues to work with partners to improve algorithms guiding satellite detection of icebergs and improve the ability to differentiate ice hazards from ships, one of the greatest challenges in accurately detecting icebergs from space.

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 2020 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) through 23 June 2020, when she was relieved by CDR Marcus T. Hirschberg.

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

INTERNATIONAL ICE PATROL

2. Ice and Environmental Conditions

Operational Area

The following describes the ice and environmental conditions throughout IIP's Operational Area (OPAREA) during the 2020 Ice Year. IIP is responsible for guarding the southeastern, southern, and southwestern Iceberg Limits in the vicinity of the Grand Banks of Newfoundland. In conjunction with IIP's North American Ice Service (NAIS) partners, the Canadian Ice Service (CIS) and United States National Ice Center (USNIC), IIP monitors environmental, meteorological, and climatological data to develop accurate iceberg warning products in the OPAREA (**Figure 2-1**).

The extent and concentration of sea ice from January through April 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 due to frequent fog and the presence of small-scale oceanographic features. This section documents the atmospheric, oceanographic and sea ice that influenced iceberg conditions during the 2020 Ice Year.

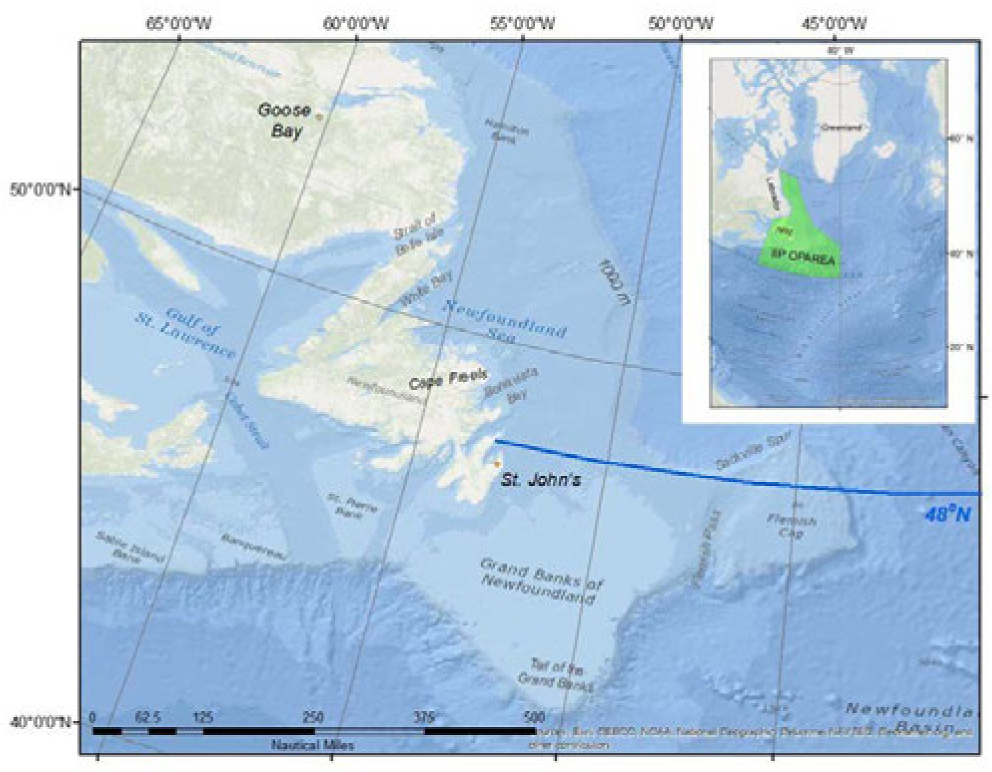


Figure 2-1. International Ice Patrol Operational Area (OPAREA) in green. The latitude of 48°N is typically considered the northern boundary of the transatlantic shipping lanes. IIP measures season severity based on this line.

Ice Year Summary
Season Severity

With only 169 icebergs crossing 48˚N (not including bergy bits or growlers), IIP classified 2020 as a “Light” year. By definition, the “Ice Year” spans the period between 01 October of the previous year and 30 September of the current year. IIP recently revised season severity classifications to account for varying observational methods and the use of iceberg modeling (IIP, 2018). Using these revised normalized metrics, the 2020 Ice Year ranks as 79th out of 117 in terms of icebergs crossing south of 48˚N. It was the lightest year on record since 2013, when only 13 icebergs crossed south of 48°N.

Throughout IIP’s historical record, the inter-annual variability for this measurement is caused both by variation in environmental conditions 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 (1900-2019) is 498. The average number of icebergs crossing 48°N for the modern reconnaissance era (1983-2019) is 795. The modern era 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. In 2017, IIP entered the next phase of reconnaissance and began incorporating satellite imagery into its routine operations. While this was a significant milestone, its impact on the number of icebergs crossing of 48°N remains unclear. IIP will continue to report this year and subsequent years under the modern reconnaissance era.

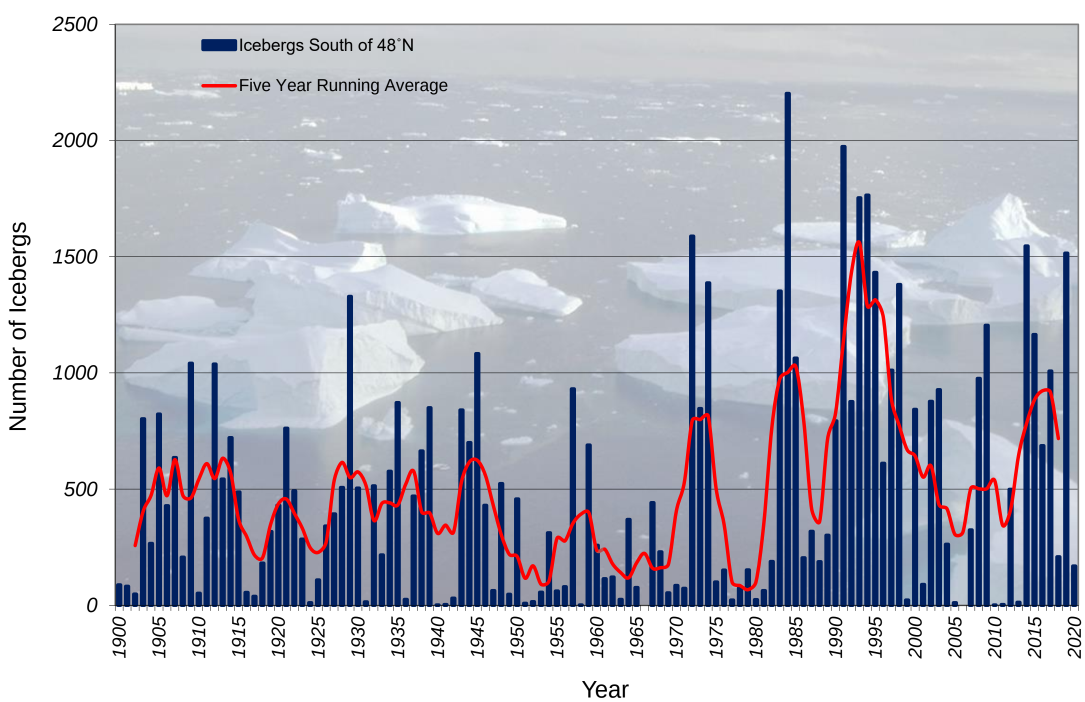


Figure 2-2. Icebergs crossing 48°N by year (blue bars) and five-year running average for 1900-2018 (red line).

During the season, IIP tracked iceberg severity daily, by using normalized statistics to compare current-year severity to statistical benchmark “Light,” “Moderate,” “Heavy,” and “Extreme” years during the modern reconnaissance era. IIP established these benchmarks using the cumulative monthly mean number of icebergs for each severity class. **Figure 2-3** shows the results of this calculation with the observed monthly total of icebergs drifting south of 48°N during the 2020 Ice Year. (IIP, 2018).

The use of this tool provided the IIP Commander (CIIP) with critical decision-making information as the season progressed. A black dashed line, shown in **Figure 2-3,** indicates daily changes in this metric. By mid-March, it became clear that 2020 would be a “Light” year. This indication allowed CIIP to make informed decisions under unprecedented aerial reconnaissance restrictions in response to the COVID-19 pandemic**. Appendix B** fully details the impact of the pandemic on IIP’s mission.

Ice Year Environmental Conditions Overview

Forecasts for positive North Atlantic Oscillation Index (NAOI) and near normal air and sea surface temperatures in Newfoundland prompted an ‘above normal’ outlook for iceberg activity in 2020 (CIS, 2019a). A positive NAOI typically promotes offshore winds and colder air temperatures along the Newfoundland and Labrador (NL) Coasts, ultimately creating conditions favorable for sea ice growth. However, several factors caused below median sea ice growth and corre-

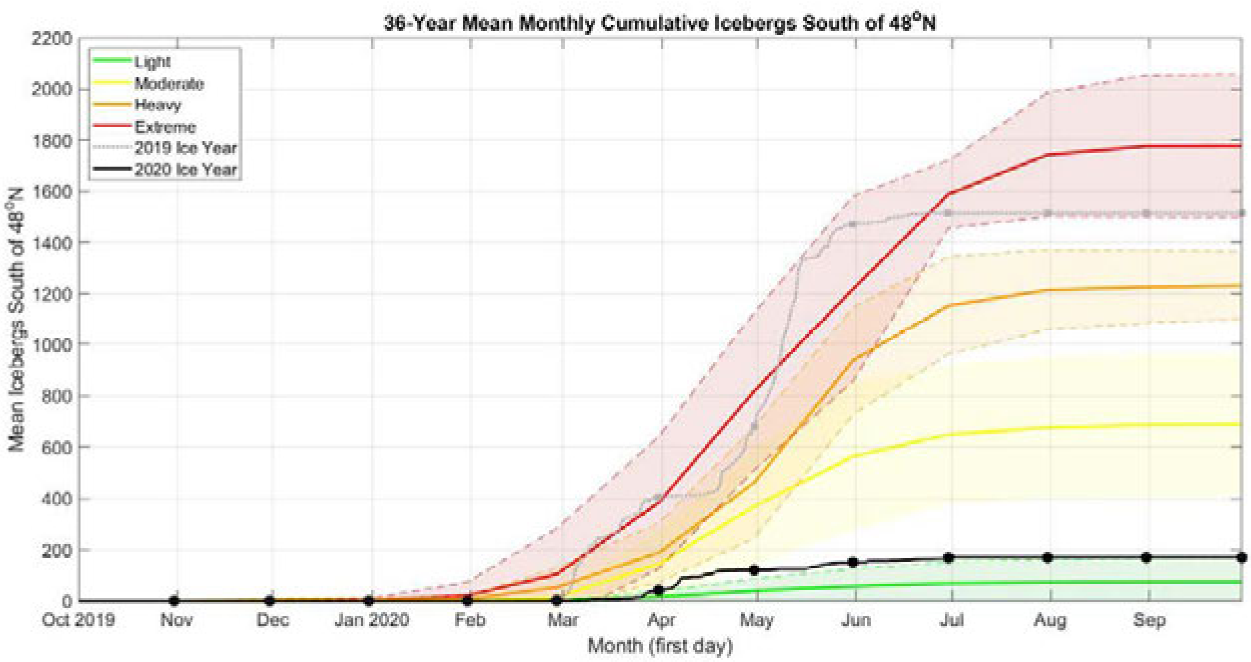


Figure 2-3. Icebergs crossing south of 48°N for the 2020 Ice Year (black line) plotted over the 36-year mean of monthly cumulative icebergs south of 48˚N from 1983 - 2018. Solid lines indicate the mean number of icebergs that have passed south of 48˚N throughout the iceberg season in "Light" (Green), "Moderate" (Yellow), “Heavy” (Orange), and "Extreme" (Red) seasons. The dashed lines and shading indicate ±1σ from the mean. The 2019 count is also plotted in gray for reference (IIP, 2018).

spondingly low number of icebergs drifting into the transatlantic shipping lanes this year.

Although the NAOI was positive for the majority of the critical sea ice formation months (January through March), the predominant wind pattern during this time was generally from a north-northwesterly direction, alongshore and parallel to the Labrador Coast, with only a minor offshore component compared to the 2019 Ice Year.

Wintertime sea ice growth along the NL Coasts can also be correlated to the sea ice formation further north in Davis Strait during the preceding months (CIS, 2019a). In late fall, Davis Strait sea ice development was approximately two weeks behind normal. In addition, average air temperatures during January through March were slightly above normal. Much like the observations of delayed sea ice development in November, sea ice development along the NL Coasts in the winter experienced a similar pattern that continued throughout March. By mid-April, ice melt was 1-2 weeks ahead of normal. Sea ice coverage remained below median levels for the entire Ice Year. All of these factors resulted in below normal sea ice coverage and ice thickness during the 2020 Ice Year.

The correlation between sea ice coverage and iceberg season severity is well established. Icebergs locked into sea ice are protected from exposure to the open seas, thereby slowing their melt, while icebergs exposed to open water deteriorate more rapidly due to wave erosion. The extent of sea ice from the NL coasts can also impede the shoreward movement of icebergs, keeping them in the offshore branch of the Labrador Current. With below median sea ice coverage in 2020, the number of icebergs available to drift into the shipping lanes was well below normal. In addition, the southern extent of the Labrador Current was approximately 120NM further north than in 2019, limiting the mechanism to carry the relatively small iceberg population southward and thereby decreasing the impact on transatlantic shipping.

The 2020 Ice Year showed dramatic contrasts with the previous “Extreme” year of 2019. Comparing key parameters in 2020 to those in 2019 is useful to provide insight into the factors influencing iceberg severity. For example, the Iceberg Limit reached its southernmost latitude of 43°05’N on 01 May (**Figure 2-4**, left panel). The 2019 Iceberg Limit is also plotted as a solid blue line for comparison. The 2020 Iceberg Limit reached its easternmost extent of 41°00’W longitude on 28 April (**Figure 2-4**, right panel) compared to 2019 which occurred in mid-June near 36°55’W. Since 2012, the maximum extent of the southern and eastern Iceberg Limit occurs in mid-May. Typically occurring in early-June, the western Iceberg Limit reached its extreme longitude at 62°17’W on 21 May. The remainder of this section uses additional comparison with 2019 for sea ice, sea surface temperature, and ocean currents to summarize the environmental conditions that influenced iceberg distributions for the 2020 Ice Year.

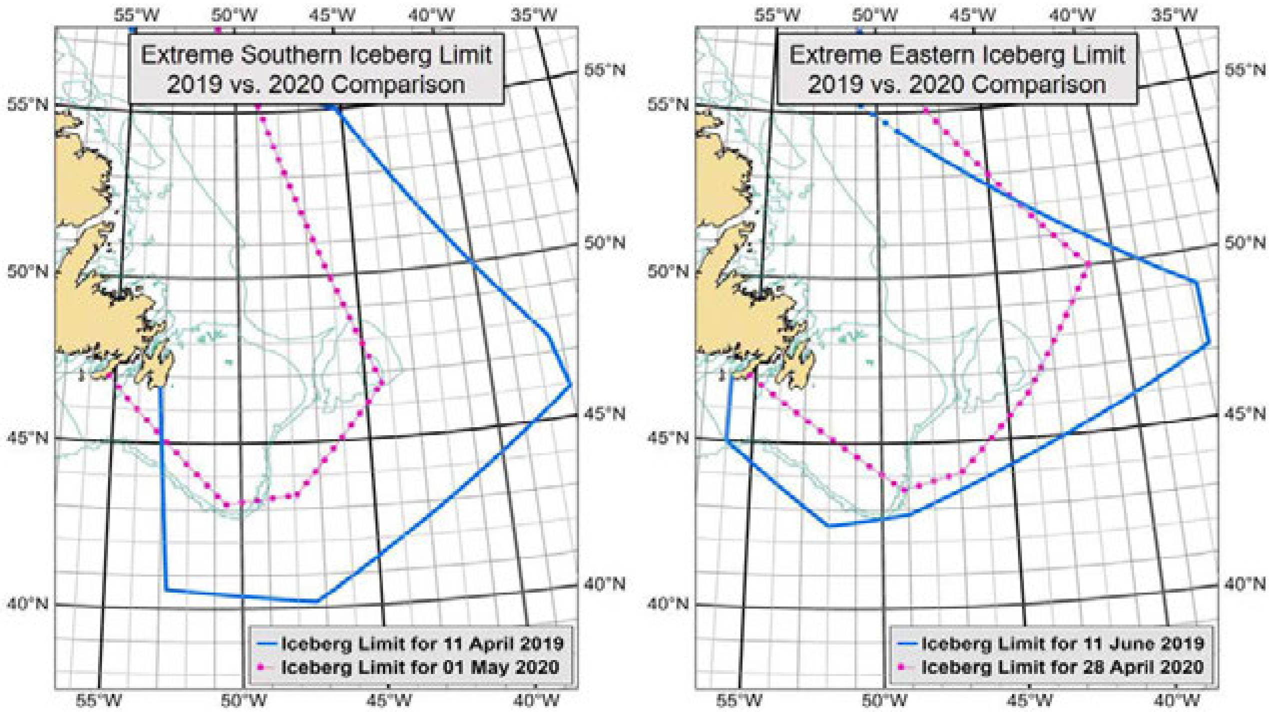


Figure 2-4. Southern and eastern maximum Iceberg Limit extent for 2020 (magenta) and 2019 (blue Note: IIP depicted the 2020 iceberg limit with a dotted line indicating "Estimated Limit," due to degraded aerial reconnaissance from COVID-19 travel restrictions.

Quarterly Environmental Summaries
October – December 2019

At the beginning of the Ice Year, CIS had primary responsibility for disseminating the NAIS daily Iceberg Limit warnings and were monitoring 53 icebergs in the iceBerg Analysis and Prediction System (BAPS). CIS relied primarily on satellite reconnaissance to assess iceberg danger. All icebergs were north of 53°N and within 120NM of the Labrador Coast. The majority of these icebergs were detected by satellite reconnaissance. The iceberg population remained roughly the same throughout the first two weeks of October but began to decline steadily for the remainder of the quarter.

An isolated iceberg detected in Notre Dame Bay by PAL Aerospace on 25 October caused the Iceberg Limit to extend south of 50°N. Another iceberg, detected on 06 November near the 1000-m depth contour by Sentinel-1 satellite pushed the Iceberg Limit eastward to 46°W but remained north of 50°N.

Below normal air temperatures in early November initiated early sea ice development along the Labrador Coast but by mid-November, average air temperatures reversed and remained slightly above normal throughout December. As a result, by the end of December, sea ice growth fell behind normal by approximately two weeks (CIS, 2020a).

As sea ice developed, CIS satellite reconnaissance focused on areas outside of the sea ice edge which likely resulted in a decrease in the number of icebergs appearing on the daily warning product. IIP is improving its capability to detect and identify icebergs in sea ice by using multi-spectral imagery when cloud cover permits (IIP, 2019). However, detecting icebergs in sea ice remains a significant challenge to satellite reconnaissance. By the end of December, nine icebergs remained and the Iceberg Limit receded northward to approximately 53°N. No icebergs were sighted or drifted south of 48°N during the first quarter of the Ice Year.

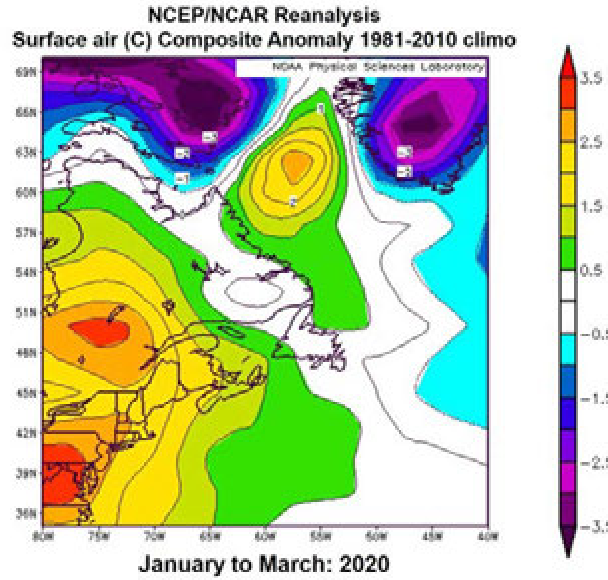


Figure 2-5. National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) Surface Air Temperature Composite Anomaly for January through March 2020. (NOAA/ESRL PSD, 2020)

January-March 2020

Slightly above normal air-temperatures persisted along the NL Coasts throughout the second quarter of the Ice Year. Air temperatures greater than 0.5°C above normal extended southward to near 50°N (**Figure 2-5**) in contrast to 2019 when this relatively warmer air remained north of 54°N. The air temperature anomaly rose to near 2.5°C in the northern Labrador Sea. This air temperature pattern, combined with predominantly north-northwesterly winds (parallel to the Labrador Coast), led to below median sea ice coverage for the entire Ice

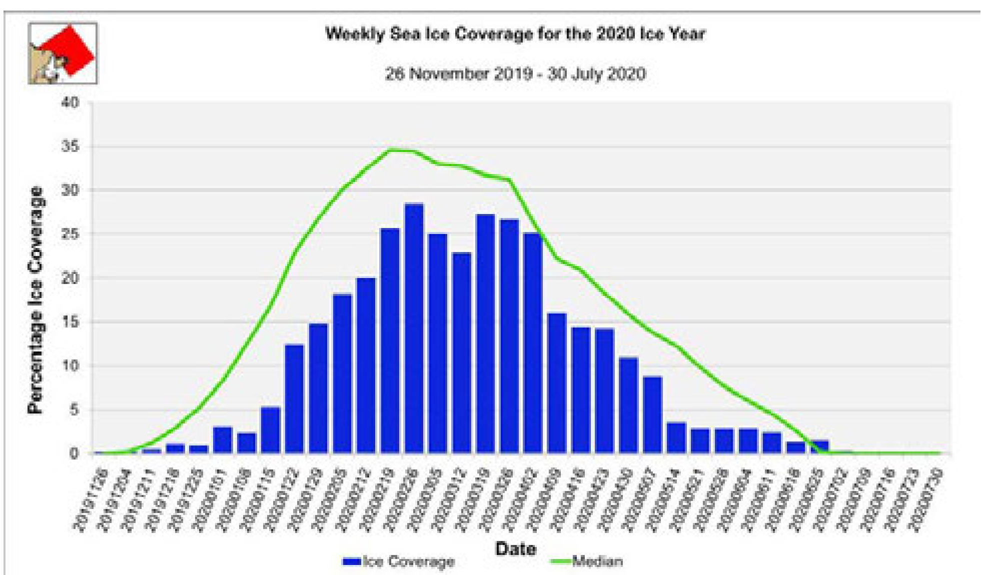


Figure 2-6. Weekly ice coverage for East Newfoundland and Southern Labrador Sea waters for 2019-2020. The percent coverage is relative to the area shaded in red in the upper left map of this figure (CIS, 2020b).

Year (**Figure 2-6**). In particular, the sea ice coverage during the three-week period from 26 February through 12 March, exhibited a steady decline averaging 8% below median coverage. During the same period in 2019, sea ice coverage averaged 0.5% above median. In addition to its impact on sea ice coverage, the air and sea surface temperature (SST) patterns also resulted in thinner sea ice during this quarter. In February, SSTs up to 1°C above normal were observed throughout the Newfoundland Sea (**Figure 2-7**, right panel) compared to 2019 with SSTs that were up to 1°C below normal in the same area (**Figure 2-7,** left panel). Above normal SSTs also extended further south in 2020 than in 2019 and likely contributed to the small number of icebergs drifting into the shipping lanes this year.

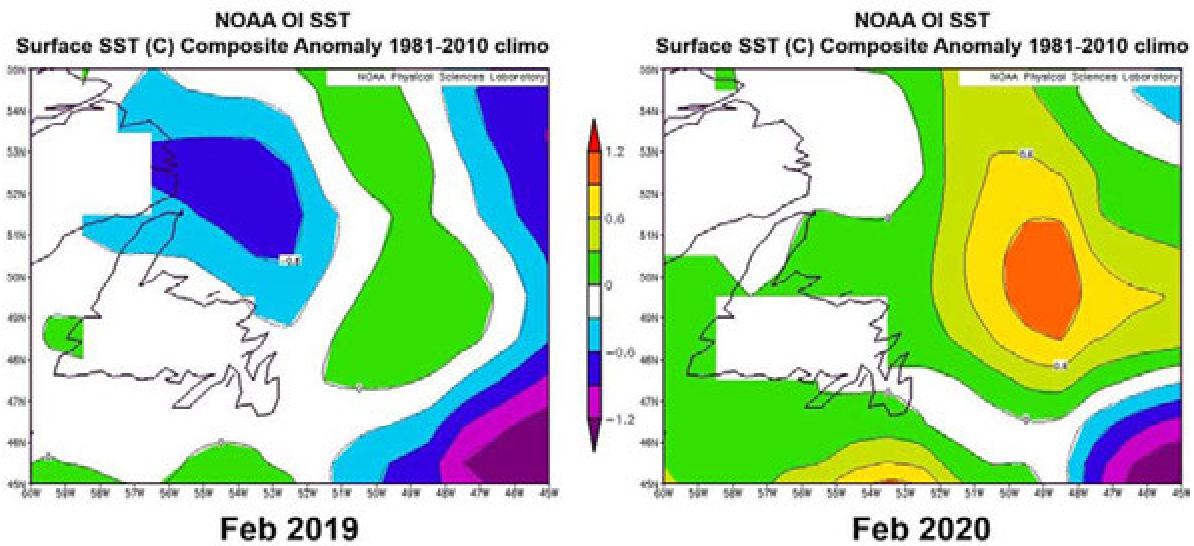
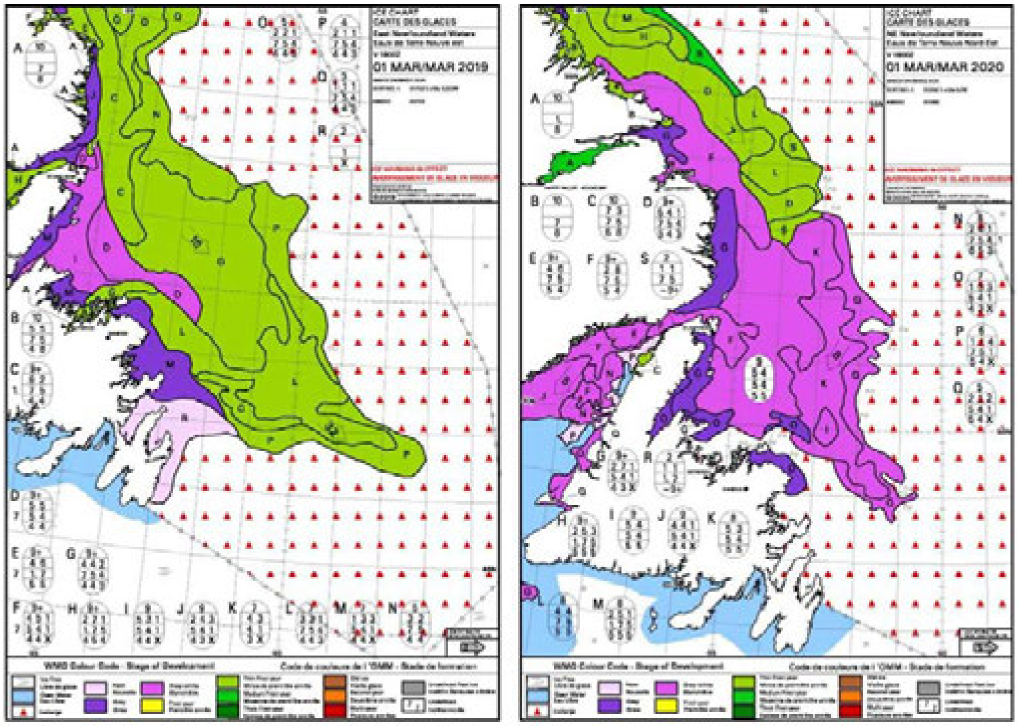


Figure 2-7. NOAA SST Composite Anomaly for February 2019 (left panel) and February 2020 (right panel). Composite SST anomaly based on NOAA's Optimum Interpolation analysis referenced to 1981-2010 SST climatology. (NOAA/ESRL PSD, 2020)

These environmental conditions led to delayed development of sea ice and left the ice susceptible to rapid compression and destruction, particularly during a series of three strong low pressure systems that tracked across NL in late March. Comparison of the 2020 and 2019 Sea Ice Stage of Development charts for 01 March shows predominantly Grey-White ice (thickness between 15-30 cm) in the NL region for 2020 (**Figure 2-8,** right panel) compared with Thin First-Year ice (30-50 cm) for 2019 (**Figure 2-8,** left panel). (CIS, 2020). Ultimately, below median extent and thickness of sea ice in February allowed for rapid destruction in late-March through early-April.

Iceberg distribution during the first two weeks of January remained similar to that observed during the last part of December, with few icebergs scattered along the Labrador Coast. On the first aerial reconnaissance flight of the calendar year (11 January), PAL Aerospace detected a single iceberg in sea ice near 55°N and close to the Labrador Coast. By the end of the month, 22 icebergs



01 March 2019 01 March 2020

Figure 2-8. CIS Sea Ice Stage of Development comparison for 01 March 2019 (left panel) with 01 March 2020 (right panel). (CIS, 2020c).

were being tracked along the Labrador Coast. The majority of these were within the sea ice edge and detected by satellite. The Iceberg Limit remained north of 52°N for most of January. No icebergs were sighted or drifted south of 48°N during January.

PAL Aerospace flights throughout February focused on detecting icebergs within the advancing sea ice and just outside of the ice edge near the 1000-m depth contour. These flights detected isolated icebergs, mostly within the sea ice edge. A PAL Aerospace flight detected a single medium iceberg, near 49°N, 50°W outside of the sea ice edge on 16 February. This iceberg drifted along the 1000-m depth contour and became the first iceberg to drift south of 48°N for the 2020 Ice Year.

IIP Ice Reconnaissance Detachments (IRD) began deploying to the OPAREA on 09 February to verify the location of the southern and southeastern Iceberg Limits and to assess the northern iceberg population up to 60°N. A flight over the southeastern Iceberg Limit on 09 February located no icebergs and a second flight on 10 February detected 38 icebergs along the Labrador Coast within the sea ice edge. By comparison, over the past five years, the first northern survey flights in the same area found an average of 305 icebergs. Both aerial and satellite reconnaissance efforts in February provided the first indications of a light Ice Year. During the month of February, one iceberg drifted south of 48°N. On average, 14 icebergs drift south of this latitude based on data collected between 1900 and 2020.

Aerial and satellite reconnaissance continued through March, detecting icebergs mostly within the advancing sea ice edge. The *Iceberg Reconnaissance Operations* section of this report (Section 4) provides a detailed narrative of each deployment for the year. Amidst the uncertainty of the COVID-19 pandemic, the light iceberg conditions allowed CIIP to safely cancel IIP's fourth IRD. (See Appendix B for additional details on IIP's response to the pandemic.)

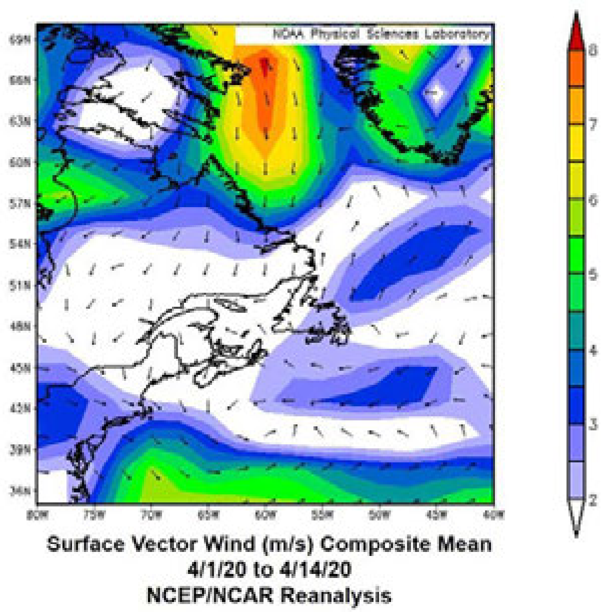


Figure 2-9. Surface Vector Winds Composite Mean for 01 through 14 April 2020. Color shading represents wind speed in meters per second and arrows show the mean wind direction. (NOAA/ESRL PSD, 2020).

At the end of March, the Iceberg Limit extended southward to approximately 45°N and eastward to 45°W. IIP estimated that 435 icebergs were present throughout the IIP OPAREA. A total of 41 icebergs were sighted or calculated to drift south of 48°N during the month of March.

April - June 2019

During the first two weeks of April, predominantly onshore winds caused sea ice coverage to decrease dramatically (**Figure 2-9**). By 13 April, the sea ice edge had receded above 50°N and continued to move northward while deteriorating rapidly through the remainder of the quarter on a pace 2-3 weeks ahead of normal (CIS, 2020a). Sea ice cleared the Strait of Belle Isle by 11 May and moved north of 55°N by 08 June. Sea ice coverage remained well below median until late June when the last section of sea ice melted.

The southern Iceberg Limit for 01 April remained approximately 150NM north of the median Iceberg Limit for early-April (**Figure 2-10**). This year's relatively compact iceberg distribution (compared to moderate and severe years) allowed IIP to focus its aerial reconnaissance flights on the southern, southeastern and western Iceberg Limits along with relatively cold water regions of the Labrador Current. Flight restrictions imposed by the COVID-19 pandemic led to increased transit times, significantly reducing on-scene search time to 2-3 hours per patrol. PAL Aerospace covered the area between 47°N to 49°N out to the 1000-meter contour in support of CIS and the Grand Banks oil and gas facilities. IIP satellite reconnaissance searched northern regions to assess the iceberg population. By the end of April, IIP estimated that there were 673 icebergs throughout the OPAREA up to 60°N. The Iceberg

Limit reached its eastern-most extent on 28 April. During April, 33 icebergs were sighted or drifted south of 48°N.

As the sea ice edge continued its northward retreat, the main iceberg population steadily deteriorated. Aerial and satellite reconnaissance monitored a significant population of icebergs in the Newfoundland Sea and in the Strait of Belle Isle from late April throughout May with relatively few icebergs offshore. A single PAL Aerospace flight, sponsored by CIS on 07 May, detected over 70 icebergs in the Newfoundland Sea and another 56 drifting through the Strait of Belle into the Gulf of St. Lawrence. These icebergs caused the western Iceberg Limit to reach its greatest extent of 62°05'W on 20 May.

Throughout May, isolated icebergs continued to set the southern and southeastern Iceberg Limit. IIP sighted the southernmost iceberg for 2020 on 28 May at 43°54'N, 47°37'W, approximately 290NM further north than the southernmost sighting in 2019. By the end of May, IIP estimated that approximately 600 icebergs were present throughout the IIP OPAREA. A total of 76 icebergs were sighted or drifted south of 48°N during the month of May.

IIP continued to monitor a steadily declining iceberg population throughout June. IIP conducted its final reconnaissance flight of the year on 30 June, detecting 28 icebergs near the eastern opening of the Strait of Belle Isle. By the end of June, 503 icebergs remained in

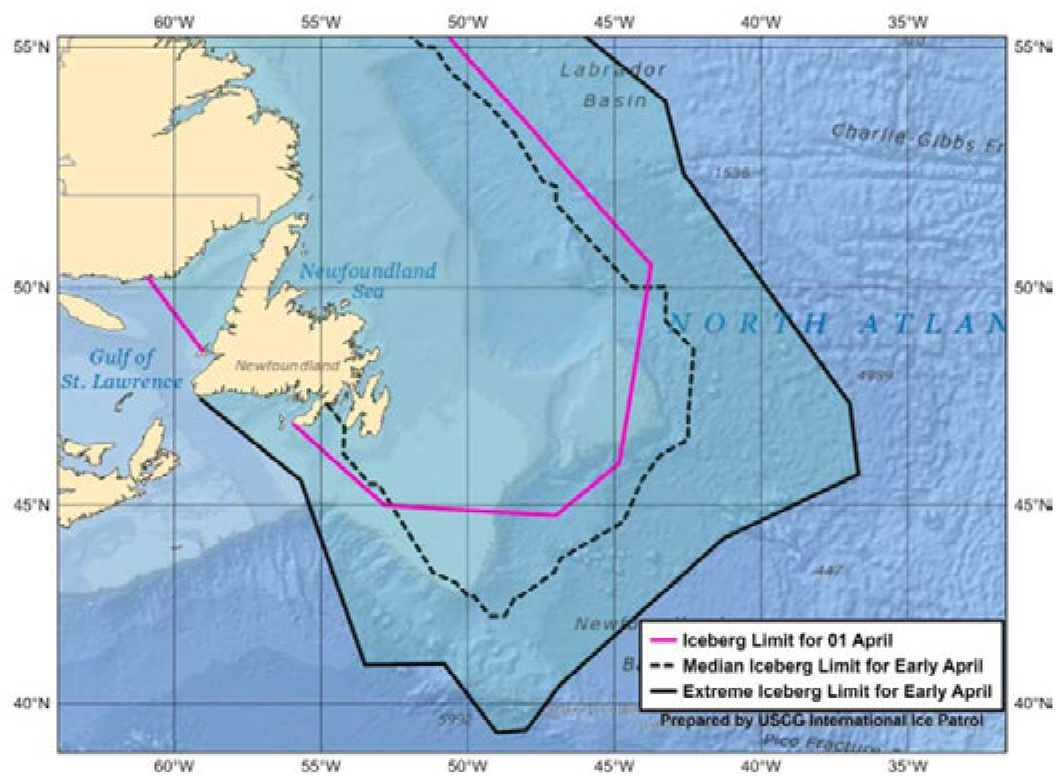


Figure 2-10. Iceberg Limit for 01 April (magenta line) compared to Median and Extreme Iceberg Limits for early April.

the IIP OPAREA. The majority of these (437) were north of 52°N and confined within 120NM of the Labrador Coast. Less than 10 icebergs remained in the offshore branch of the Labrador Current south 42°N. For the entire month of June, only 17 icebergs were sighted or drifted south of 48°N. During the modern era of iceberg reconnaissance (1983 – present,) an average of 125 icebergs cross into the shipping lanes during June.

As is typical for a "Light" Ice Year, IIP did not sight or receive any reports of icebergs south of 45°N in 2020. In contrast, 186 icebergs were sighted south of 45°N in 2019 with the southernmost sighting at 41°-30'N on 28 May. The extent of the Labrador Current and its interaction with the warm North Atlantic Current likely contributed to the limited southward advance of icebergs in 2020. Two SST images from the Group for High Resolution SST (GHRSST) image on 19 May 2019 (**Figure 2-11,** left panel) and 19 May 2020 (**Figure 2-11,** right panel) show the dramatic difference in the Labrador Current between the two years (UKMO, 2020). The approximate location of the southernmost iceberg sightings from each year are shown as a white triangle in each panel. In 2020, the Labrador Current south of 50°N appeared relatively warmer and less well-defined than in the previous year. Additionally, there is no pronounced eastward flow as observed in 2019. Ultimately, the oceanographic observations in 2020 resulted in

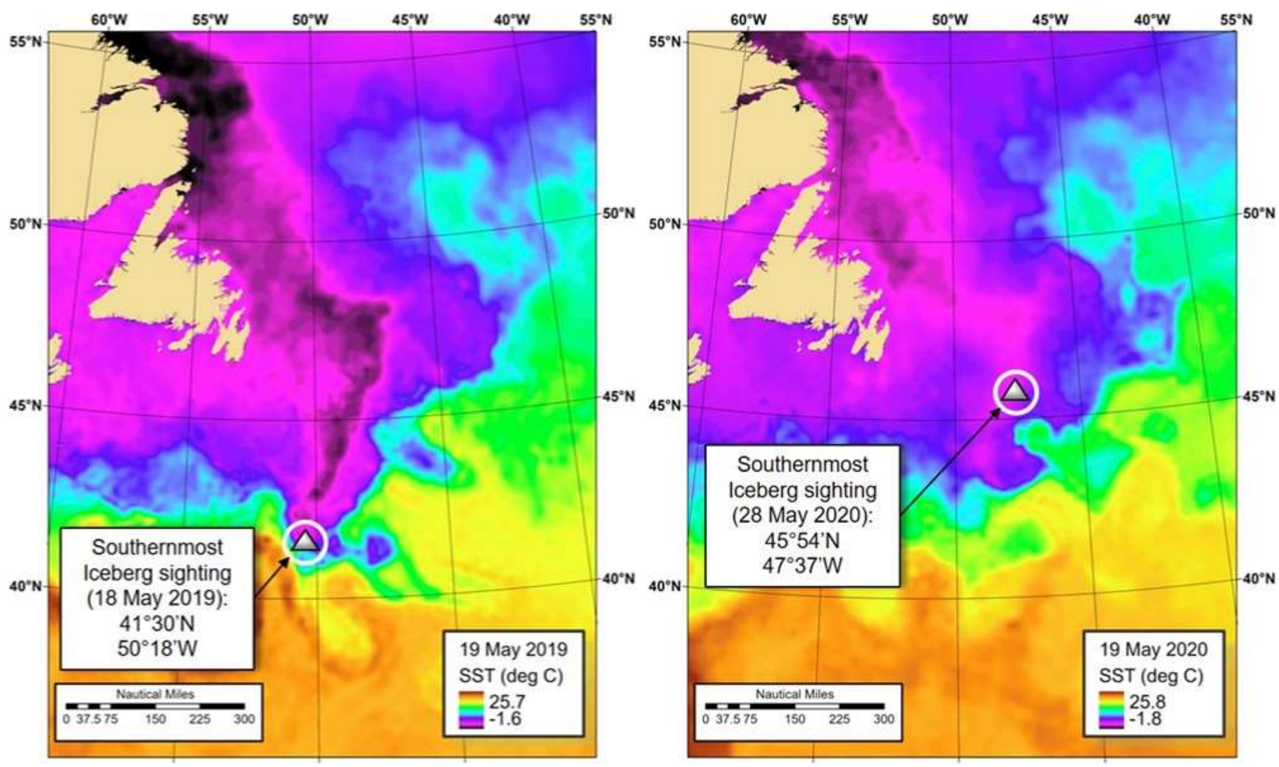


Figure 2-11. Group for High Resolution SST (GHRSST) images for 19 May 2019 (left panel) and 19 May 2020 (right panel). Location of extreme iceberg sightings for both years are shown with a circled triangle for reference. (UKMO, 2020).

more benign iceberg conditions for transatlantic shipping.

July – September 2019

Sea ice continued to deteriorate with the ice edge moving north of 56°N in the first week of July. Having concluded aerial reconnaissance on 30 June, IIP continued to monitor the iceberg population via satellite reconnaissance. On behalf of CIS, PAL Aerospace conducted two flights in July to confirm that no icebergs remained in the Labrador Current.

Throughout July, a sizable iceberg population remained along the Labrador Coast with isolated icebergs drifting near the 1000-m depth contour in the Labrador Current. During July, one iceberg drifted south of 48°N. No other icebergs were sighted or drifted south of this latitude for the remainder of the Ice Year.

By 01 August, 333 icebergs remained along the Labrador Coast but continued to deteriorate. By the end of the month, only 40 icebergs remained, mostly within 20NM of the Labrador Coast. IIP transferred iceberg monitoring responsibilities to CIS on 02 September. PAL Aerospace conducted two additional flights for CIS in September that searched the 1000-m depth contour and the opening to the Strait of Belle Isle. These flights detected no icebergs and concluded aerial reconnaissance for the Ice Year. On 30 September, 40 icebergs remained in the OPAREA, mostly along the Labrador coast and all north of 53°N. Of note, four icebergs, detected by Radarsat Constellation Mission (RCM) satellites were located in the offshore branch of the Labrador Current. The Iceberg Limit extended from the southern Labrador coast near 52N and out to 50°W, established by the RCM-sited icebergs.

Surface Velocity Program Buoy Deployments

Flight restrictions caused by the COVID-19 pandemic limited IIP's opportunity to deploy Surface Velocity Program drifting (SVP) buoys for ocean current measurements. IIP attempted one deployment in early March but the parachute failed during deployment, rendering the SVP buoy inoperable. Of note, USCGC CAMPBELL deployed four SVP buoys in August and September while engaged in an Arctic Patrol. CAMPBELL deployed three of these buoys off the Greenland Coast for research purposes and the fourth buoy in the Labrador Current to support the IIP iceberg models. Appendix C provides additional details on these buoy deployments.

In summary, **Figure 2-12** graphically shows the number of icebergs estimated to have drifted south of 48°N by month for the 2020 Ice Year. A solid red line depicts the monthly averages for the entire 120 year record from 1900 through 2019. The monthly average for the modern reconnaissance era (1983-2019) is also included as a solid green line. All 2020 monthly totals were significantly lower than the monthly averages for both periods. **Table 2-1** summarizes extreme iceberg positions, both sighted and drifted by modeling, along with the sighting source.

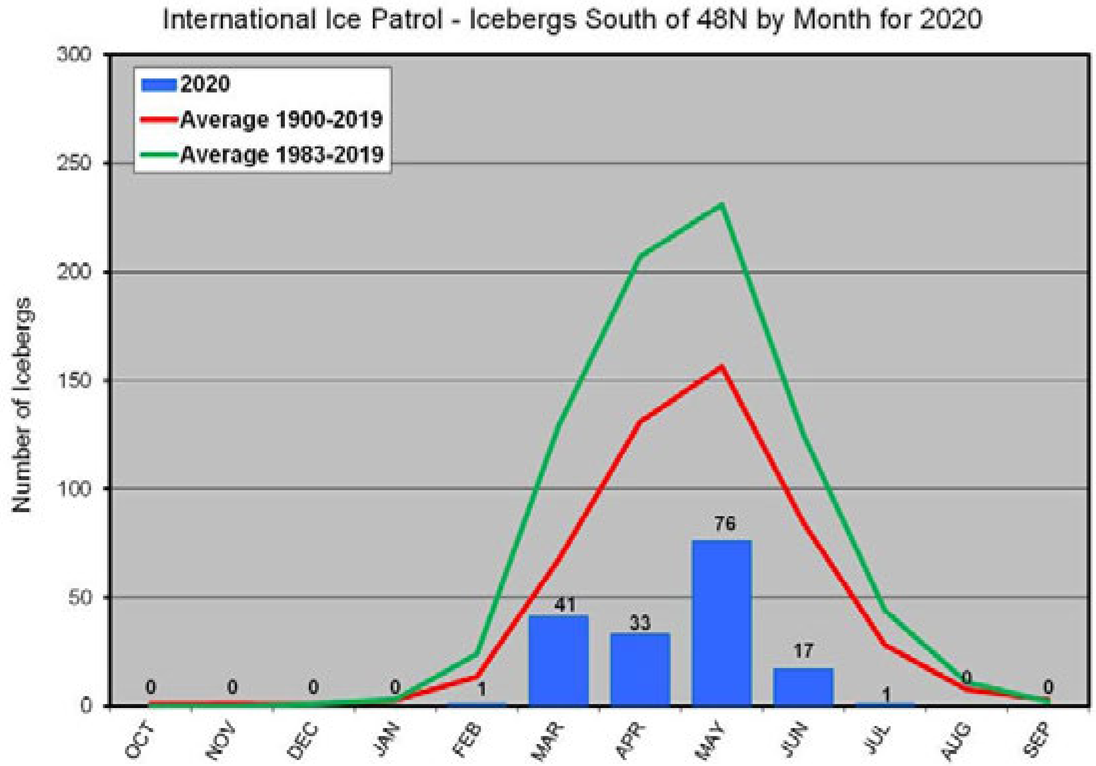


Figure 2-12. Icebergs south of 48°N by month for 2020 (169 total). Monthly averages for the entire historical dataset (1900-2019) and for the modern reconnaissance era (1983-2019) are shown as red and green solid lines, respectively.

2020 Extreme Icebergs	Sighted				Drifted			
	Source	Date	Latitude	Longitude	Source	Date	Latitude	Longitude
Southern	IIP HC-130J	28-May-20	45-54.1N	47-37.1W	PAL Aircraft	30-Apr-20	44-38.4N	49-39.8W
Eastern	PAL Aircraft	4-Apr-20	49-06.2N	45-52.0W	PAL Aircraft	24-Apr-20	47-53.4N	45-31.8W
Western	Satellite (Sentinel-1a)	20-May-20	50-08.9N	59-58.0W	Satellite (Sentinel-1a)	21-May-20	50-08.9N	59-55.5W

Table 2-1. 2020 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 watchstanders 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, satellite imagery, and vessel sighting reports. After these reports are received, 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 generating products; when icebergs typically threaten the transatlantic shipping lanes. This year, the Ice Season ran from 22 January to 01 September (while the deployment period was 03 February – 01 July). CIS published products during the remainder of the 2020 Ice Year, termed "out of season," when the iceberg population is typically found farther north along the Canadian coast.

The text version, the NAIS-10 bulletin, lists the latitude and longitude points along the Iceberg Limit and sea ice limits. The graphical version, the NAIS-65 product, 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 2020 Ice Season, 100% of iceberg warning products were released on time.

IIP publicly distributes the NAIS iceberg warning products via a variety of methods. The NAIS-10 iceberg bulletin is broadcast over SafetyNET, Navigational Telex (NAVTEX), Simplex Teletype Over Radio (SITOR), and posted online. The NAIS-65 iceberg chart is broadcast over radio facsimile (Radiofax) and posted online. Both products are available 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 charting 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 2020

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 2020, the partners discussed the importance of tracking the leading edge of gray and gray-white sea ice flowing south from Baffin Bay early in the season to prevent icebergs from drifting outside of the predicted warning limit (discussed in the Icebergs Outside the Limit subsection of this section). Ideas for prototype iceberg warning products were also discussed and were implemented to support the operations of USCGC CAMPBELL (discussed in more detail in **Appendix C**.) The outbreak of the COVID-19 pandemic did not hinder the daily release of iceberg warning products but did result in changes to the products that are described in detail in **Appendix B**.

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 mariners transiting through the OPAREA. A list of the individual ships that made voluntary iceberg reports during the 2020 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 2020 Ice Season, IIP received, analyzed, and processed 878 SIMs, 673 of which included iceberg sightings, approximately a 13% increase in total SIMs from the 2019 Ice Season, but a 2% decrease in SIMs with icebergs. This is significant given that 2020 was deemed a "Light" season in accordance with the season severity definitions (IIP, 2018). Most SIM sources decreased in quantity from 2019 except for IIP satellite SIMs (which doubled in number from 230 to 460), Canadian Coast Guard SIMs (which tripled from nine to 30), and commercial satellite SIMs (which showed a slight increase from 85 to 115). The IIP satellite SIMs doubled due to major advances in automation of processes and as a result of contingency operations due to COVID-19 that utilized two analysts to process imagery on most days (see **Appendix B** for more information). The Canadian Coast Guard SIMs tripled, which may have been a result of a request from IIP at the beginning of the COVID-19 Pandemic for increased ship reports due to reduced aerial reconnaissance (**Appendix B**). **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 2011 and shows that 2020 had the second highest number of SIMs with icebergs reported but the third lowest number icebergs to pass south of 48°N. The first columns of **Figure 3-1** and **Table 3-1** show the distribution of these iceberg messages by reporting source.

A total of 10,014 icebergs, growlers, and radar targets were reported to IIP during the 2020 Ice Season (a 67% decrease from 2019). Of these, 9,480 (95%) were incorporated into the model. IIP watchstanders reviewed each report for accuracy and validity before the data were entered into BAPS. This included reviewing environmental conditions, other recent reconnaissance, and the detection method of each report. Observed icebergs that can be correlated with already modeled icebergs are "resighted" to the model. If they cannot be resighted, they are added to the model. The number of adds corresponds to the number of unique sightings in a season. This season there were 2,633 additions to the model (26% of total sightings, and a 72% decrease from 2019).

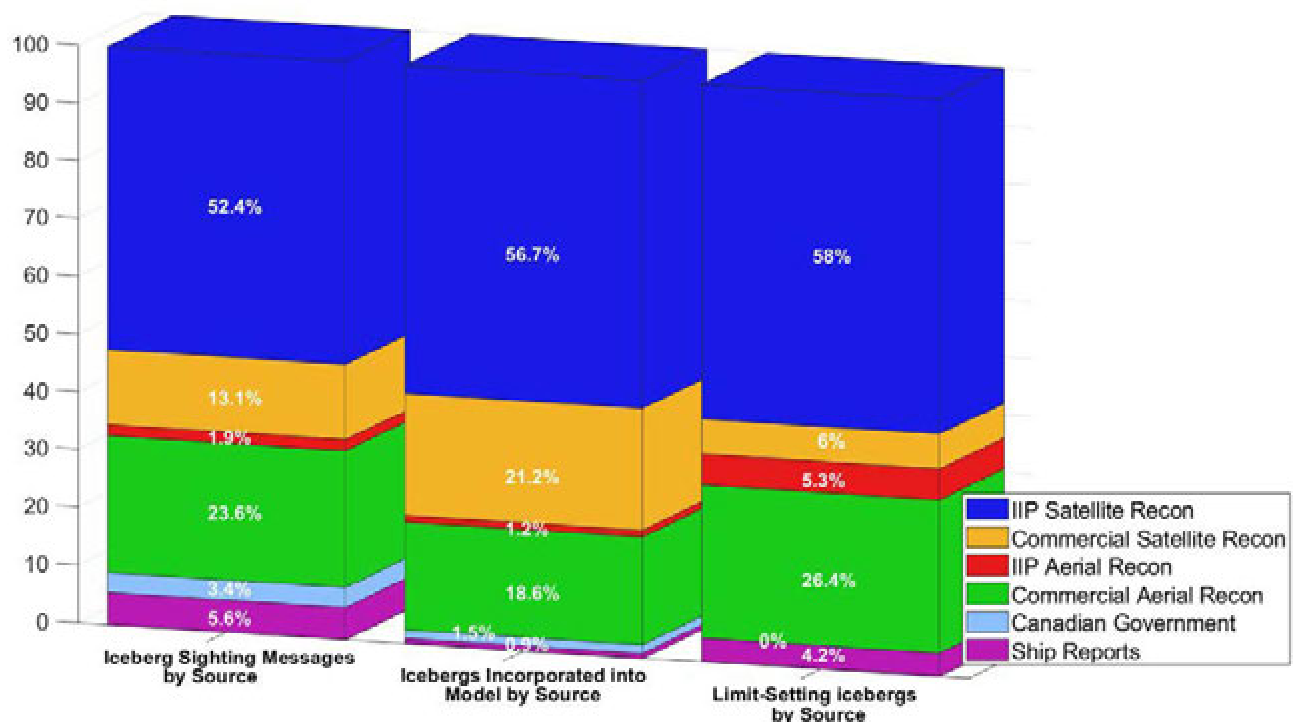


Figure 3-1. 2020 Standard Iceberg Message (SIM) information. The first bar (left) shows the percentage of SIMs received from each source. The second bar (center) shows the percent contribution from each source to the total number of iceberg observations that were included into the model. The third bar (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.

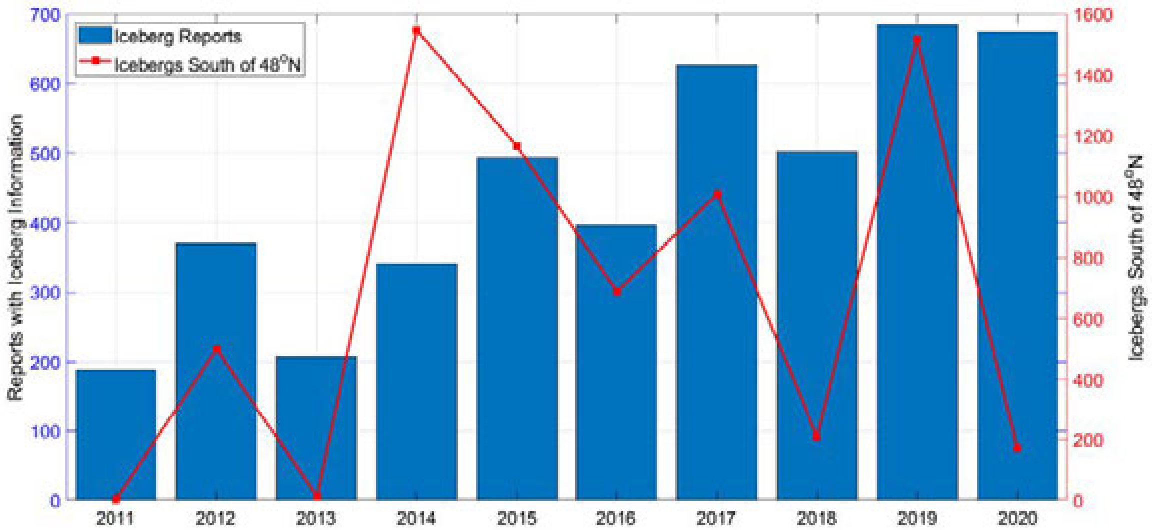


Figure 3-2. Record of the number of SIMs received that contained iceberg sightings (blue bars) and the number of icebergs observed south of 48˚N (red line). Note that 2020 had the second highest number of SIMs containing iceberg information and the third lowest number of icebergs passing south of 48˚N in the last 10 years.

Source	Total SIMS	Icebergs Incorporated into Model	Average Ice-bergs Per SIM	Limit Setting Icebergs
IIP Satellite Reconnaissance	460	5377	12	510
Commercial Satellite Reconnaissance	115	2006	17	53
IIP Aerial Reconnaissance	17	111	7	47
Commercial Aerial Reconnaissance	207	1760	9	232
Canadian * Government	30	140	5	0
Ship Reports **	49	86	2	37
Total	**878**	**9480**	**11**	**879**

Table 3-1. Detailed information of 2020 icebergs received from each SIM source.

*** The Canadian Government row does not include Government-funded Commercial Aerial Reconnaissance (which are included in the Commercial Aerial Reconnaissance source) and mostly is made up of Canadian Coast Guard reports.**

The 5% 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 and IIP satellite reconnaissance combined for a total of 7,383 icebergs, growlers, and radar targets added into the model from 575 SIMs.) The satellite reconnaissance percentage in **Figure 3-1** was comprised of 460 SIMs consisting of 505 satellite images that were processed and analyzed entirely by IIP staff; and 115 SIMs, consisting of 331 satellite frames that were processed by C-CORE, a St. John's based company that conducts satellite reconnaissance for icebergs in support of the oil and gas industry. Of the 7,383 satellite-detected icebergs that were incorporated into the model during the 2020 Ice Season, 5,377 were from IIP satellite SIMs and 2,006 were from C-CORE satellite SIMs. Both satellite sources together accounted for 85% of the additions to the model, compared to 68% of the additions in 2019. Of note, this season IIP used Sentinel-2 multispectral imagery to create SIMs for the first time. Of IIP's 460 satellite SIMs, 72 of them, consisting of 138 individual frames) were from Sentinel-2 imagery. Sentinel-2 multispectral imagery is an incredibly useful resource for IIP satellite reconnaissance as it has higher resolution (10m) than Sentinel-1 (20m) and results in very high confidence iceberg classifications, especially for icebergs greater than 30m in length. This season has shown the value of incorporating this sensor into IIP's satellite reconnaissance despite its lack of offshore coverage and inability to be used during frequent cloudy conditions.

Aerial Reconnaissance

This season, IIP conducted 17 reconnaissance flights, which accounted for 111 icebergs, growlers, and radar targets added or resighted into the BAPS model. On average, seven icebergs were observed per IRD flight (compared to 52 icebergs per IRD flight in 2019). The decrease in icebergs per flight is likely due to a combination of 2020 being a light iceberg season as well as the fewer patrol hours per flight due to COVID-19 contingency operations. (See **Appendix B**). Commercial aerial reconnaissance accounted for 1,760 icebergs added to the model; an average of nine 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** are from SIM reports made by PAL Aerospace, which was contracted by multiple sources. **Figure 3-3** 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. More than half (59%) of the total PAL Aerospace flights which reported icebergs were flown for primary missions other than iceberg reconnaissance. 32% of flights that reported icebergs were funded by the oil and gas companies concerned with icebergs in the vicinity of the offshore oil rigs (decreased from 41% in the 2019 "Extreme" season). The smallest portion, 9%, of PAL Aerospace flights that reported icebergs were funded by CIS specifically for iceberg reconnaissance in areas designated by either IIP or CIS. This was increased from 5% in the 2019 season. The increase is a direct result of cooperation by CIS to fund PAL Aerospace iceberg reconnaissance during mid-season rather than late season, to support IIP's reduced aerial reconnaissance due to the COVID-19 pandemic. The impetus and results of this outstanding cooperation are discussed in more detail in **Appendix B.** The 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.

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, 74 of the 2,633

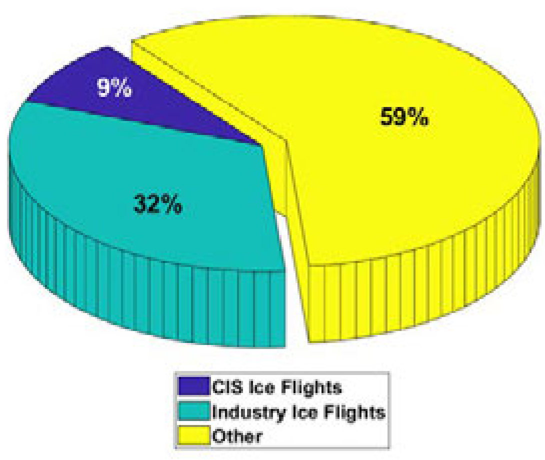


Figure 3-3. The percentage of PAL Aerospace flights by primary mission type that reported icebergs. The "Other" category includes flights that reported icebergs but with a primary mission other than iceberg reconnaissance.

unique icebergs (3%, compared to 8% in 2019) added to the model were deleted based upon the results of IIP aerial reconnaissance as no icebergs were present in the vicinity of the modeled position. In general, commercial aerial reconnaissance and satellite reconnaissance do not meet necessary probability of detection standards to meet IIP criteria for deleting icebergs from the database completely. Given the high confidence associated with Sentinel-2 reconnaissance, however, there is future promise for defined deletion criteria and incorporating this sensor for iceberg deletions. IIP continued to work with PAL Aerospace during CIS-funded iceberg reconnaissance flights to provide IIP-drawn flight plans, quantify environmental conditions, visibility, and radar range in order to meet IIP's criteria for deleting modeled icebergs from commercial reconnaissance results. This season, 174 modeled icebergs were deleted from CIS-funded PAL flights (7%). The remainder of the modeled icebergs (90%) 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, an average of four icebergs (minimum of one and maximum of seven) set the Iceberg Limit at any time. In the 2020 Ice Season the limit stretched approximately 460 NM east of St. John's at its maximum extent of 41°00'W on 28 April, and approximately 270 NM south of St. John's to 43°05'N on 01 May.

Compared to 2019, PAL Aerospace flights increased as a reporting source of limit-setting icebergs from 18% to 26%, and IIP aerial reconnaissance decreased from 30% to 5%. Reconnaissance from satellite imagery accounted for more than 64% of limit setting icebergs, compared to 46% in 2019, 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 using Synthetic Aperture Radar (SAR) 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, of greater concern 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 errors through increased understanding of the impact of satellite parameters, image quality, and environmental conditions on valid positive detection and classification of targets. Though there is much higher confidence associated with visible imagery, such as Sentinel-2, the Iceberg Limit is typically located offshore, outside of Sentinel-2 coverage.

Given these considerations, the more reliable 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.

Only one report of an iceberg or radar target outside the published Iceberg Limit was received throughout the 2020 Ice Year. This report was due to the ambiguities associated with satellite reconnaissance and highlights the challenges associated with the increasing use of space-borne reconnaissance. On 28 March 2020, a Sentinel-1A frame from 27 March was analyzed and two targets were detected among a group of vessels in single polarization within 10NM outside of the published Iceberg Limit. The targets were among several that were sent to Coast Guard Intelligence to determine whether the target was correlated to vessel traffic. Given a lack of high confidence correlation with vessels in the area and ambiguity associated with a single pol satellite detection, both targets were included in the product as radar targets outside of the Limit and NAVWARNs were issued. (**Figure 3-4**).

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 feature 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. IIP relied on coordination with other data sources such as vessel Automated Identification System (AIS) and a collaborative exchange with Coast Guard Intelligence 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 past seasons, several cases of icebergs outside the limit were closely linked with the sea ice limit, where icebergs had been undetected within the sea ice limit, but outside the Iceberg Limit in “open drift” sea ice concentrations or greater (four-tenths sea ice concentration or more) of gray or gray-white ice. In response to this, IIP and CIS worked closely together from December to February tracking the leading edge of the gray and gray-white sea ice drifting south from Baffin Bay. This sea ice makes identification of icebergs from satellite challenging and is very likely to include icebergs. Therefore, this leading edge was included within the iceberg limit as if it contained icebergs. We attribute the reduced number of icebergs outside the limit during the early part this year to this effort. Later in the year, IIP utilized an increased safety buffer to draw the Iceberg Limit in response to the reduced aerial reconnaissance due to the COVID-19 pandemic as discussed in **Appendix B.**

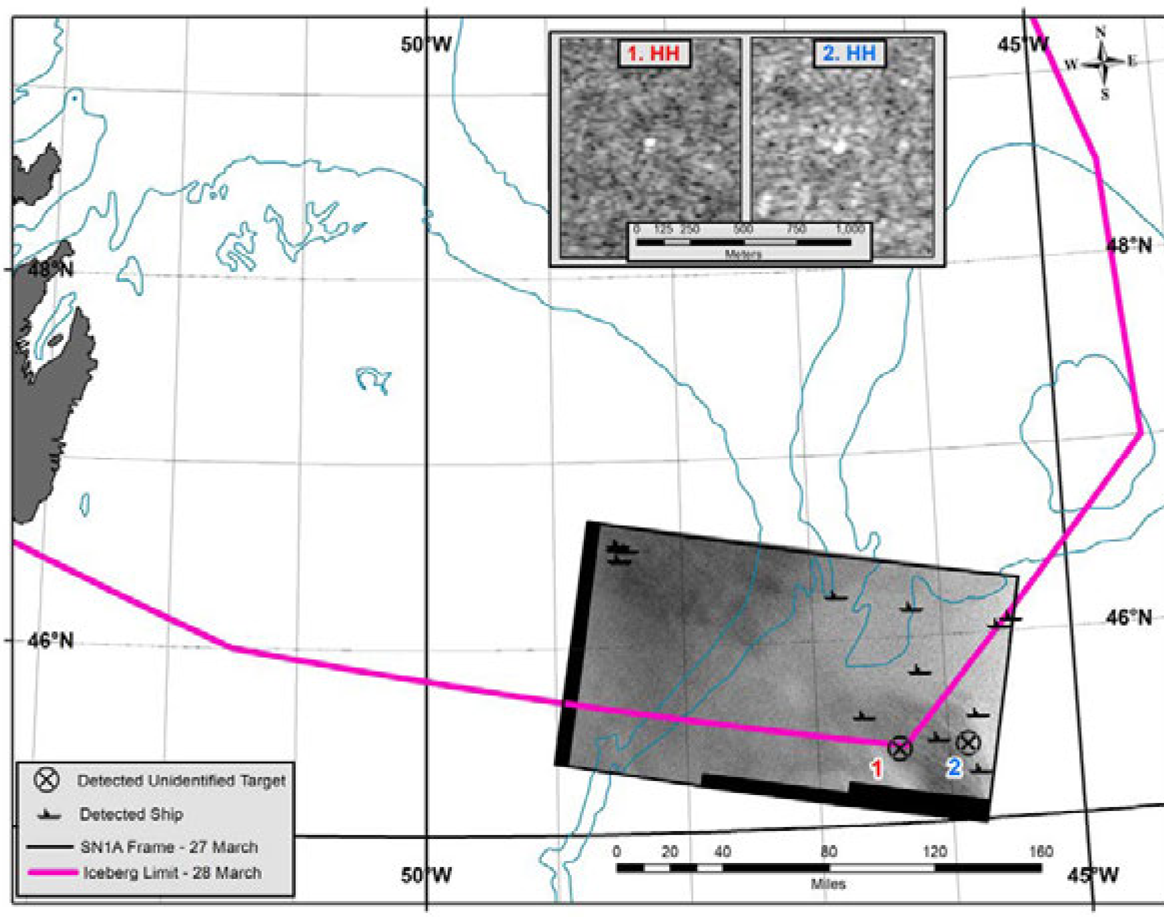


Figure 3-4. On 28 March 2020, a Sentinel-1A image from 27 March was analyzed and two unidentified targets were detected outside of the published Iceberg Limit. The two detections are displayed in the inset. A NAVWARN was issued and the two targets were added to the product as radar targets. Copernicus Sentinel data 2020.

4. Iceberg Reconnaissance Operations

Ice Reconnaissance Detachment

The IRD, a sub-unit under CIIP, partners with ASEC to conduct aerial iceberg reconnaissance. During the 2020 Ice Season, nine 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 2020 Ice Season, IIP and ASEC crews deployed for 59 days, conducting 17 iceberg reconnaissance sorties on HC-130J aircraft. The 2020 flight season spanned 149 days; 5 days longer than the five-year (2016-2020) average of 144 days. The first IRD departed on 03 February, with the last IRD returning on 01 July. The number of patrol days and reconnaissance sorties decreased by 38% and 56% respectively when compared to the 2019 season. This was due to travel restrictions imposed in response to the COVID-19 pandemic. Only the first three IRDs of the season were conducted out of St. John's, while the remaining six IRDs were all based out of Coast Guard Air Station Cape Cod (ASCC). This allowed IIP to continue to conduct aerial reconnaissance over the highest priority southern and eastern limit areas. But as a result of this change, 59% of all flight hours flown out of Cape Cod were transit hours to and from the OPAREA. **Table 4-1** contains a summary of operations for each IRD, and **Appendix B** outlines the challenges associated with working out of ASCC along with IIP's other adaptations to mission planning and execution in response to COVID-19.

IRD	Deployed Days	Iceberg Patrols	Transit Flights	Patrols en Route	Logistics Flights	Flight Hours
1	11	2	3	0	0	28.8
2	6	1	2	0	0	17.1
3	9	2	2	0	0	27.7
4	0	0	0	0	0	0.0
5	4	2	2	0	0	21.7
6	4	1	2	0	0	13.3
7	6	2	2	0	0	22.9
8	5	2	2	0	0	21.6
9	6	2	4	0	0	24.3
10	8	3	2	0	3	34.8
11	0	0	0	0	0	0.0
12	0	0	0	0	0	0.0
Total	**59**	**17**	**21**	**0**	**3**	**212.2**

Table 4-1. An overview of IRD days and flight hours used during the scheduled IRD's for 2020 Ice Season.

Aerial Iceberg Reconnaissance

HC-130J aircraft equipped with two radars and an Automatic Identification System (AIS) integrated into the mission system suite were used to conduct aerial iceberg reconnaissance. The ELTA-2022 360° X-Band (ELTA) surface search 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 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 2020 Ice Season, however track spacing was increased to 30 NM for all sorties conducted out of ASCC to best maximize area coverage for limited patrol times.

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. Only one ELTA radar casualty was experienced during the 2020 season, but the issue did not manifest itself until arriving on scene after the transit from Cape Cod to the OPAREA. Unfortunately, a visual-only patrol was impossible due to environmental conditions and the aircraft returned to base without conducting reconnaissance.

During the 2020 Ice Season, all IRDs were flown with The Minotaur Mission System (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 MMS is a software and hardware suite that allows for onboard networking of cameras, radar sensors, navigational instruments, and communications.

IRD crews also utilize the inverse Synthetic Aperture Radar (ISAR) onboard the HC-130J. This technique generates a high-resolution image of a target using the movement of the target to create an image frame. ISAR imagery is analogous to the SAR imagery IIP receives from satellites in that it is a still image created from radar energy pulses. The key difference between the two technologies is that SAR sensors onboard orbiting satellites rely on the movement of the sensor in orbit to create a "synthetic" image, while the ISAR uses the movement of the target to generate the image. This technology has proven extremely useful for identifying icebergs and distinguishing between icebergs and non-AIS ships in poor visibility.

IRD Operational Summary

The first IRD of 2020 began on 03 February with ASEC flying to the Groton-New London Airport (KGON) in Groton, CT to conduct annual egress training and flight-safety gear inspections for all IIP personnel. Upon completion of the training, five IIP IRD 1 crewmembers flew back to ASEC for opening season air crew training on 04 February. IRD 1 departed for St. John's, NL on 05 February.

On 06 February, IRD 1 was grounded at St. John's International Airport (CYYT) due to winds gusting at 36kts and predicted to remain above 30kts throughout the day, exceeding limitations for towing the C-130 and opening the hangar doors. On 07 February, IRD 1 crewmembers conducted opening season partner meetings with PAL Aviation Services, PAL Aerospace, C-CORE, Canadian Forces, Canadian Coast Guard, St. John's Port Authority, Cougar Air and CYYT Tower. The IRD was again grounded because of weather on 08 February; a low pressure system over the Avalon Peninsula creating wind gusts between 45-60kts and severe mechanical turbulence over St. John's kept the plane hangered. On 09 February, IRD 1 conducted the first patrol of the 2020 deployment season with an Eastern Limit patrol. No icebergs were sighted or detected by radar during the patrol, which observed limited visibility and high sea state. A northern survey patrol was conducted on 10 February, between 55° – 60°N, and 38 icebergs were identified. This flight was delayed due to troubleshooting and correcting a positioning system failure before taking off. Weekly maintenance was conducted on 11 February. The planned southern and eastern patrol on 12 February was canceled due to freezing rain and low cloud ceilings throughout the OPAREA, freezing rain at CYYT during takeoff, and predicted snow and high winds at landing. IRD 1 returned to Groton, CT on 13 February. Although weather conditions were not ideal throughout IRD 1, the patrols were able to confirm the iceberg population remained above 50N, and shoreward of the 1000m contour within sea ice. The second IRD was delayed and shortened to accommodate emergent tasking of the C-130J and because the iceberg population was still well above 48ºN, limiting risk to transatlantic maritime traffic. IRD 2 arrived at CYYT on 22 February. Forecasted freezing drizzle at CYYT and throughout the OPAREA along with low level wind shear forecasted to persist throughout the day at CYYT canceled the first scheduled patrol on 23 February. A southern and eastern iceberg limit patrol was flown on 24 February, which found 1 iceberg along the 1000m contour west of the Sackville Spur. Patrols on both 25 and 26 February were canceled because of weather; freezing drizzle at CYYT and throughout the OPAREA both days. The IRD returned to Groton, CT on 27 February.

IRD 3 arrived in St. John's on 05 March after a one day delay caused by a low pressure system producing freezing drizzle, icing, low ceilings and high winds over CYYT that would not have allowed the C-130J to land and hangar. On 06 March, a southern limit patrol was conducted, identifying zero icebergs, but conditions on scene were worse than predicted with a high sea state and low visibility throughout the patrol area. A strong low pressure system expected to bring snow and low visibility to CYYT in the early afternoon canceled the patrol on 07 March. Arrival time of the storm did not allow for an effective patrol to be conducted before returning to CYYT. The same system produced freezing drizzle throughout the OPAREA on 08 March, canceling the scheduled patrol. On 09 March an interior and 1000m contour patrol sighted 15 icebergs, all but one were found in Notre Dame Bay. Additionally, the IRD deployed a buoy in position 52° 11'N 50° 44'W, however the deployment box fell apart upon leaving the plane, detaching the buoy from the parachute. The SVP buoy, which IIP believes was damaged by the uncontrolled decent and impact with surface, never transmitted data. A northern interior patrol was scheduled for 10 March, but shortly after takeoff from CYYT the aircraft lost one of its two communication navigation integrated system processors forcing them to return to CYYT to troubleshoot and fix the processor. On 11 March, the plane was grounded again because of weather, freezing rain and ice pellets forecasted over St. John's throughout the day. IRD 3 returned to Groton, CT on 12 March. This would be the last IRD deployed to St. John's, NL for the 2020 season.

IRD 4 was originally scheduled from 18 – 26 March, however the surge of COVID-19 and rapidly changing travel guidance delayed the departure for St. John's until 20 March. Due to uncertainty, the IRD was canceled on 19 March and the aircraft was re-tasked to aid the COVID-19 response. **Appendix B** provides additional details on IIP's response to changing conditions and travel restrictions caused by the COVID-19 pandemic.

IRD 5 was the first reconnaissance detachment based out of ASCC's airfield (KFMH). In order to depart and return to KFMH, only two to three hours of the maximum allowed nine-hour flights were available for on-scene patrols. IIP and ASEC developed deployment date and flight plan scenarios to utilize best-predicted weather windows and conducted patrols on 05 and 06 April. . A patrol of the southeastern iceberg limit on 05 April recorded zero sightings but provided complete deletion coverage due to excellent weather conditions. The next day's patrol of the Southern Iceberg Limit and a prominent cold water feature observed similarly cooperative weather conditions and recorded zero sightings, and also recommended iceberg deletions for the area covered.

IIP and ASEC personnel arrived at KFMH on 16 April for IRD 6. On 17 April, a patrol of the southeastern limit during favorable weather conditions reported zero iceberg sightings. Eleven direct queries to surface vessels and oil rigs also resulted in no iceberg reports. On 18 April, low cloud ceilings throughout the day at KFMH prevented takeoff and the patrol was cancelled. IRD 6 ended the next day and the patrol aircraft returned to ASEC.

IRD 7 began on 29 April with ASEC and IIP personnel arriving in Cape Cod. On 30 April, a patrol of the southeastern limit began with zero visibility and 2-3m seas, but visibility quickly improved to 10 NM and seas abated slightly as the flight proceeded north. Zero icebergs were observed. Two vessels were queried directly and each reported no sightings. The aircraft experienced icing, so the patrol was cut short to maintain sufficient fuel reserves for the transit to KFMH and to allow for safe landing. The next day, 01 May, low ceilings at KFMH prevented a patrol. However conditions were favorable for an interior flight the following day, and the patrol ended with eight iceberg sightings, one vessel query with no iceberg sightings, and good deletion coverage. IIP personnel departed ASCC on 03 May and ASEC personnel departed on 04 May because of an aircraft casualty on 03 May.

The first patrol of IRD 8 was a southeastern limit patrol on 28 May. A limit-setting iceberg was located visually at the southern exit of Flemish Pass, one of two vessels responded to callouts, and the flight coverage was useful for deletion. Fog and a low ceiling prevented takeoff on 29 May. On 30 May, the last day of the IRD, a patrol of Flemish Pass and Sackville Spur resulted in no sightings but good deletion coverage.

IRD 9 began on 10 June. A western limit patrol on 11 June resulted in 20 iceberg sightings in excellent visibility. One direct vessel callout reported no iceberg sightings. Deletion was recommended for the coverage of the patrol, and a significant reduction in the western iceberg limit was published as a result of the flight. On 12 June, pre-flight checks revealed an ice protection warning on the aircraft. The aircrew was forced to fly back to ASEC and return the same day with a replacement aircraft. On 13 June, a patrol of the southeast limit and a cold water feature in the vicinity of Flemish Pass recorded zero iceberg sightings in poor visibility. Deletions were recommended based on radar coverage. IIP and ASEC personnel departed Cape Cod the following day.

The final IRD of the season began on 24 June. On 25 June, the aircraft was recalled for a search and rescue flight, and no iceberg reconnaissance was conducted. A southeastern limit patrol on 26 June found no icebergs due to zero visibility and a malfunctioning ELTA radar. Three vessels responded to direct callouts all reporting that they had been in the area for weeks and had not seen any icebergs. The flight was not used for deletions because of the radar casualty and poor visibility. On 27 June, the aircrew flew to ASEC to repair the radar and returned to Cape Cod the next day. On 29 June, a patrol of Flemish Pass along the 1000 m contour found no icebergs and received reports of no icebergs from three vessels that had been in the area for over a month. Bad weather approaching KFMH forced an early ending to the patrol, and deletions were recommended based on sea state and excellent radar coverage. The final patrol of the season on 30 June was a flight over the western limit and 1000m contour. The patrol observed 28 icebergs including re-sights of two bergs that were reported by a vessel that responded to a direct callout. A significant reduction in the western limit was published on 02 July based on this flight. 01 July marked the end of the IRD and the

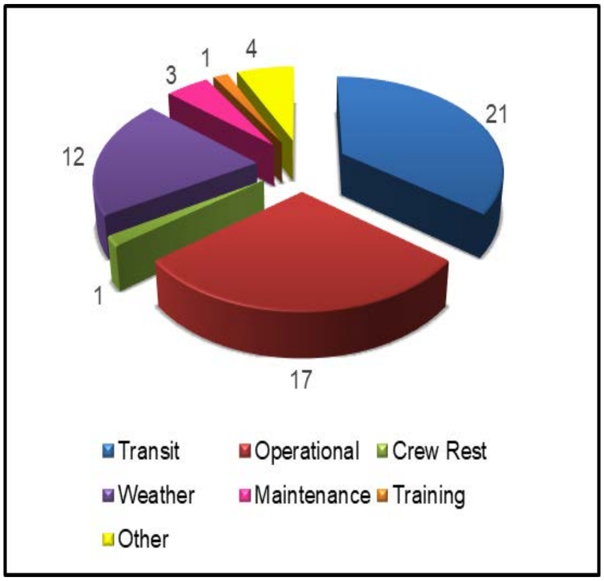


Figure 4-1. Break down of the total number of deployment days by IRD activity during the 2020 season. Crew Rest and Maintenance days include weather opportunity, unscheduled and scheduled days. Table 4-2 displays a further breakdown of Crew Rest and Maintenance days.

end of the 2020 IIP aerial reconnaissance season.

Figure 4-1 shows a breakdown of IIP's deployment days during the 2020 Ice Season in seven categories: "Operations," "Transit," "Weather," "Maintenance," "Crew Rest," "Training," and "Other." Examples of days in the "Other" category include time taken for partner meetings, higher priority tasking of the aircraft (search and rescue) while on an IRD, and logistics flights. In accordance with USCG regulations, the IRD normally takes one crew rest day as well as one maintenance day per 9-day deployment; otherwise, the intent is to fly every day. However, the prevailing OPAREA weather contributes significantly to the number and effectiveness of reconnaissance patrols. In 2020, weather conditions prevented patrols on 20% of the days deployed. When deployed to St. John's 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.

During IRD's 5-10, the deployment dates were chosen after careful evaluation of the predicted weather in both IIP's OPAREA and at KFMH to maximize the patrol days and their effectiveness (see **Appendix B** for more details). **Table 4-2** shows a further breakdown 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 of crew or maintenance issues (unscheduled). Unscheduled maintenance impacted 3% of total deployed days in 2020. Transit time took up the largest fraction of deployment days in 2020 (36%).

	Crew Rest	Aircraft Maintenance
Opportunity (Weather)	1	0
Scheduled	0	1
Unscheduled	0	2
Total	1	3

Table 4-2. Crew rest and aircraft maintenance days.

IRD Iceberg Detections

IRD personnel detected 111 icebergs over the nine IRDs in the 2020 Ice Season. Ten IRDs were scheduled, but one was cancelled before deployment. This was a considerable decrease in comparison to the 2019 Ice Season which sighted 2,770 icebergs by aerial reconnaissance. Of the 111 icebergs sighted, all were incorporated into BAPS, which accounted for 1% of the total icebergs added during the 2020 Ice Season. The 1% of icebergs incorporated into BAPS from IRDs is significantly lower than the 8.8% in 2019, which was already considered low in comparison to recent years.

The continued downward trend in aerial reconnaissance-reported icebergs in 2020 reflects a couple of key factors. Firstly, 2020 was a light ice season with respect to the number of icebergs crossing south of 48ºN, and with respect to the total area encompassed by the iceberg limits. Secondly, only the first three IRDs, with a combined five ice reconnaissance patrols, operated out of St. John's, Newfoundland. The fourth IRD was cancelled and IRDs five through ten operated from ASCC in

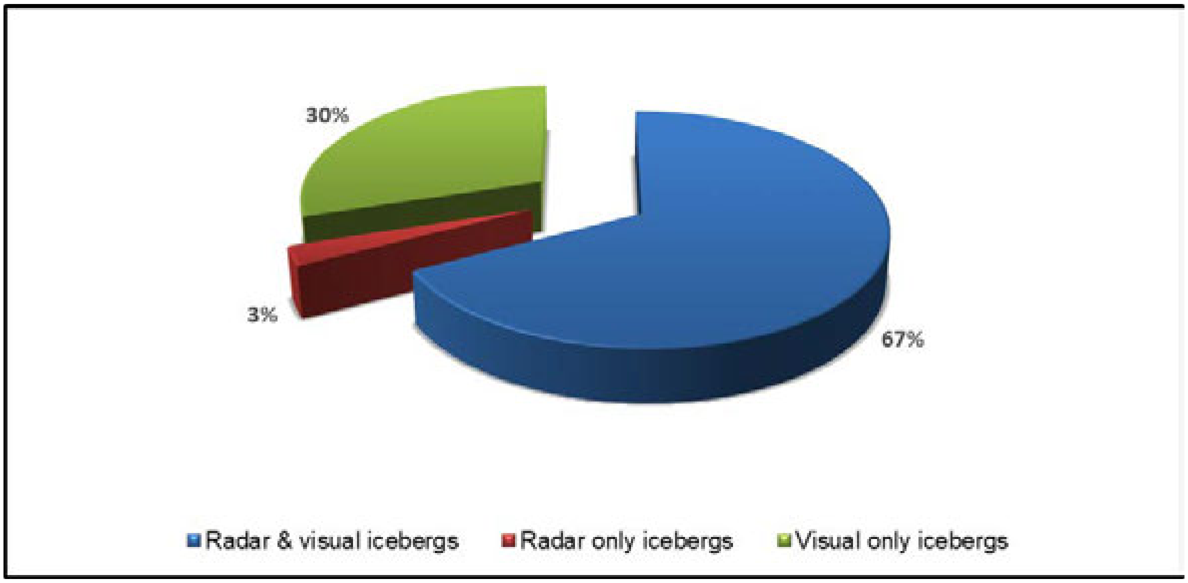


Figure 4-2. IRD iceberg detection methods for the 2020 Reconnaissance Season.

Sandwich, Massachusetts. IRDs operating from ASCC were four to six days long, while IRDs operating out of St. John's, NL are typically planned for nine days. In addition to shorter deployments, the change in locations significantly reduced the on-scene patrol time and the area patrolled per flight. On-scene patrol time was reduced due to approximately 6 hour transit times to reach and return from the OPAREA when operating from ASCC. Consequently, individual patrols almost exclusively focused on verifying deletions in reconnaissance areas near the southern and eastern Iceberg Limits, IIP's highest priority reconnaissance areas.

IRDs five through ten accounted for 12 patrols of the 17 patrols for the 2020 Ice Season. Nine of these patrols focused on the southern limit and the Grand Banks of Newfoundland near the 1000m contour and detected one iceberg. Two western limit flights and one interior patrol yielded 56 icebergs. Even with few icebergs detected, the criticality of these iceberg reports remained high as they served to verify the accuracy of the Iceberg Limits.

Figure 2-10, in the Ice and Environmental Conditions Section, depicts an example of a daily iceberg limit compared to a bi-weekly median and extreme limit from 1991-2018. For the 2020 ice season, daily limits were consistently well-contained by the corresponding median limits from the end of March through the end of the season below 50N. This, in conjunction with the limitations associated with operating from ASCC for IRDs five through ten, meant that most flights had longer transits, covered less patrol area, and flew primarily in areas where iceberg populations were expected to be low to verify the presence of one or two critical limit-setting icebergs. This, combined with days missed due to weather and maintenance meant fewer opportunities for patrolling over the interior and northern patrol areas which typically have higher concentrations of icebergs.

During IRDs, icebergs are detected in one of three ways: (1) with both radar and visual, (2) radar only, or (3) visual only. This year, 67% of the icebergs were detected by both radar observations and visual sightings. The remaining icebergs were either detected only by radar (3%) or by visual detection alone (30%) **(Figure 4-2).**

For the second consecutive Ice Season, there was a significant shift in distribution of icebergs detected by both radar and visual from the previous years (**Table 4-3).** During the 2020 Ice Season, icebergs identified via the aircraft's onboard Electro-Optical Infrared (EOIR) camera and via the ELTA radar were now categorized as radar and visual sightings. The camera's ability to detect targets from much farther ranges than typical human visual observation led to the increase within this category. In addition, continued training by IRD personnel in inverse synthetic aperture radar (ISAR) helped positively identify iceberg targets within sea ice. Visual only detection still accounted for a significant portion of total icebergs sighted. IIP personnel continue to employ a two-tier approach in areas of favorable environmental conditions, focusing visual observations close to the aircraft and radar observations away from the flight path enabling maximum detection efficiency. This tactic can result in visual-only iceberg detections within the range of the radar (and even detected on radar,) but due to the overall volume of icebergs in the patrol area there was not a need to have the radar position or detection information recorded.

Year	Radar & visual icebergs	Radar only icebergs	Visual only icebergs
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%	30%
2020	67%	3%	30%

Table 4-3. IRD iceberg detections by method from over the last ten years (2011-2020).

2020 Flight Hours

As in previous seasons, IIP was allotted 500 Maritime Patrol Aircraft flight hours for its operation during the 2020 Ice Season. IIP used 212.2 hours in 2020, considerably less than the 368.8 hours in 2019. These totals include patrol, transit, and logistics hours attributed to the IIP mission. **Figure 4-3** shows the breakdown of these hours over the past five Ice Seasons into three categories: transit hours, patrol hours, and logistic hours.

Transit hours are the hours the aircraft is transiting to and from specific locations in support of the IIP mission, without conducting reconnaissance. These flights are generally between Elizabeth City, NC and St. John's, NL, with a brief stop in Groton, CT to onload IIP personnel and equipment. Mid-season, when IRD's began flying out of Cape Cod, IIP personnel with IRD equipment drove to meet the aircraft in Sandwich, MA. There were 62.3 hours used this season for transits.

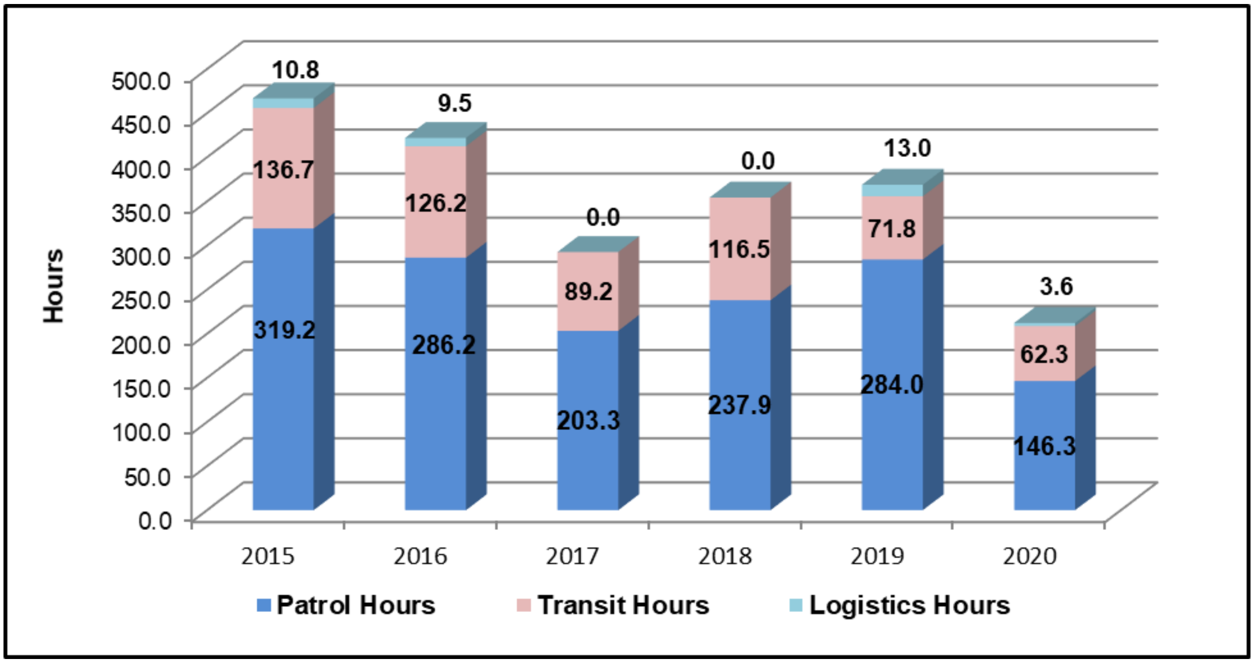


Figure 4-3. Flight hours broken down by patrol, transit, and logistics hours over the past five years.

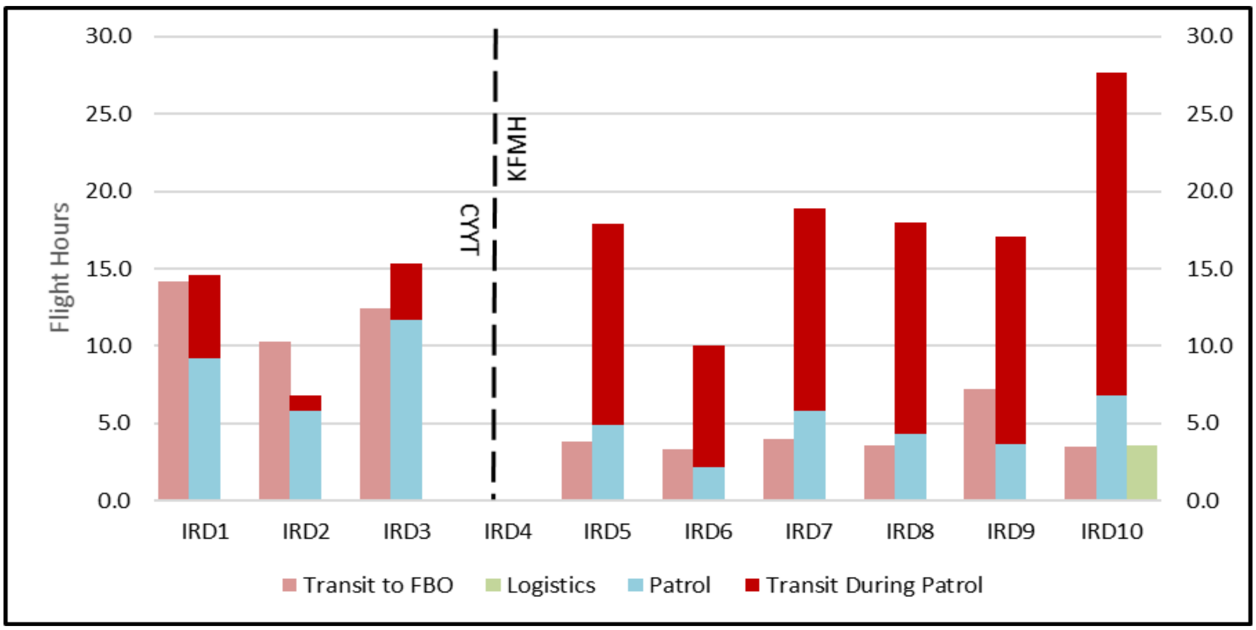


Figure 4-4. 2020 Flight hours broken down by IRD. The first three IRDs were based out of St. John's (CYYT) and all remaining IRDs were based out of Cape Cod (KFMH).

Patrol hours are those hours associated with iceberg reconnaissance including the flight time to and from the reconnaissance area. IIP flew 146.3 patrol hours this season. When a patrol is conducted during a regularly planned transit flight, such as a patrol while transiting back to Groton, CT, the hours are counted as patrol hours vice transit hours and the flight is termed a patrol en route. There were no patrols en route during this season. Due to the shift of operations to Cape Cod, IIP personnel spent much longer times during a patrol flying to and from the OPAREA. In 2020, 91.9 hours out of the logged

146.3 patrol hours (63%) were used for flying to the OPAREA. On average, it took two hours to fly to/from the OPAREA when operating out of St. John's. When flying out of Cape Cod, it took an average of seven hours to reach and return from the OPAREA. This made the typical nine-hour endurance of the aircraft much less efficient. **Figure 4-4** depicts a breakdown of flight hours for the 2020 season by IRD.

Logistics hours are the hours used to support the IIP mission, but do not fall into the previous two categories. Logistic hours accrue when a Coast Guard aircraft is used to transport parts for an aircraft deployed on an IIP mission. This season there were two logistics flights of 1.8 hours each, a flight from ASCC to ASEC and back to ASCC, to repair a radar casualty during IRD 10. During the same IRD, the aircraft was tasked for a search and rescue mission. Since the tasking occurred during an IRD deployment it was logged as a logistics day, but because the IRD was not on patrol and no IIP personnel were onboard, no IRD flight hours were logged.One benefit to deploying out of Cape Cod was the ease with which the aircraft was able to return to Elizabeth City for repairs in the middle of an IRD.

The spatial and temporal distribution of icebergs, as well as the quantity of icebergs drifting south of 48ºN, all contribute to the amount of reconnaissance needed to effectively monitor the iceberg danger and provide relevant warning products. **Figure 4-5** shows a comparison of flight hours to the number of icebergs that drifted south of 48ºN from 2010 to 2020. IIP flew 212.2 hours and saw 169 icebergs drift south of 48ºN, which is well below the 10-year average of 619 icebergs.

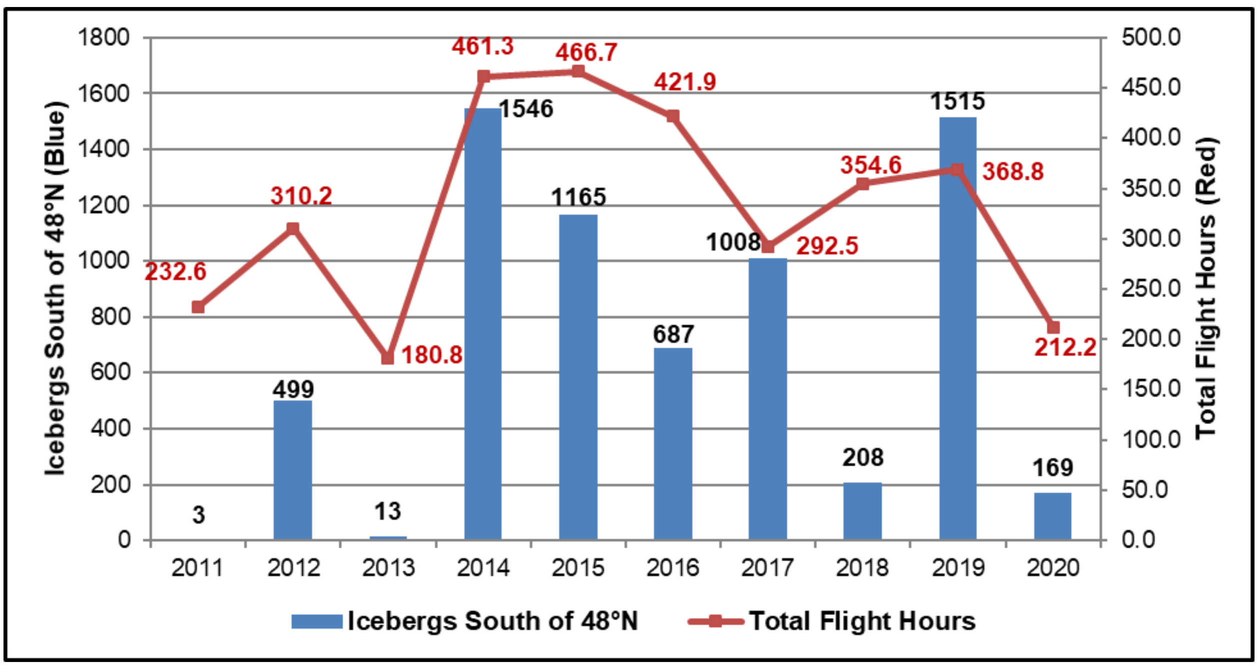


Figure 4-5. Comparison between IRD total flight hours per season and season severity, measured by number of icebergs sighted or drifted below 48ºN for the past 10 years. 2020 had the second fewest flight hours over the past ten years.

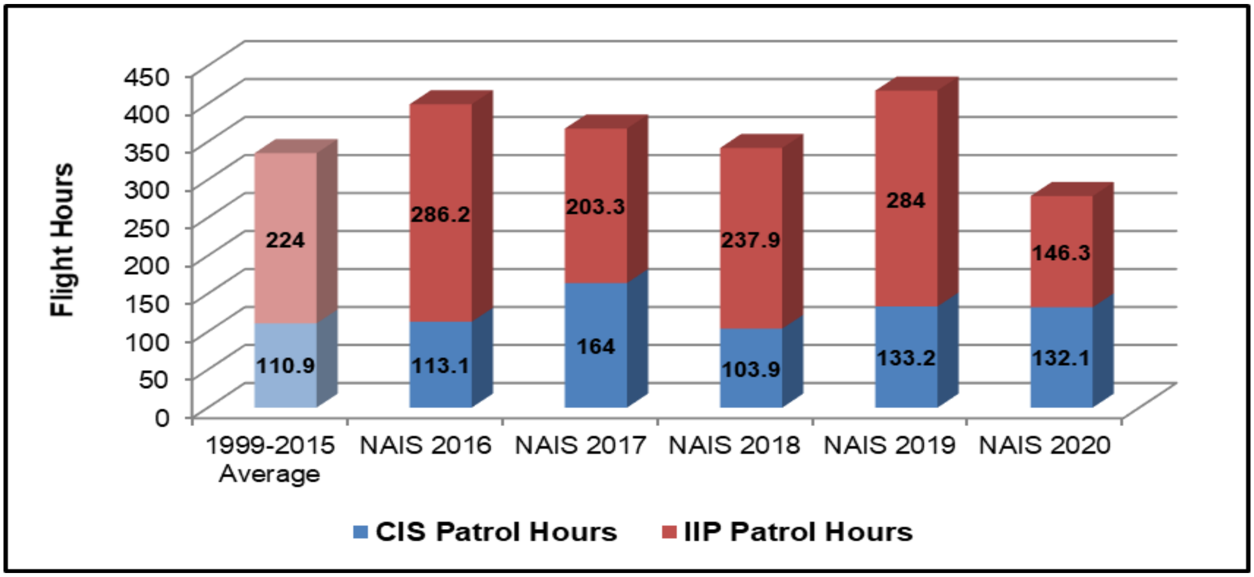


Figure 4-6. NAIS flight hours, a combination of IIP patrol hours and CIS funded PAL Aerospace patrol hours compared to the previous 5-year average.

Other Reconnaissance Activities:

NAIS Collaboration

In order to maximize aerial iceberg reconnaissance in the North Atlantic, IIP continued to leverage its NAIS partnership with CIS. IIP coordinated flight plans with CIS during periods when IRDs were not deployed to St. John's, NL between October 1, 2019 and September 1, 2020. In addition, during 2020, IIP worked closely with CIS to increase the use of CIS-funded PAL flights in April-June when IIP was conducting reduced aerial reconnaissance due to COVID-19 restrictions (**Appendix B**). **Figure 4-6** depicts the NAIS flight hours for 2020. Data provided includes hours flown by each service. CIS contracted PAL Aerospace for 132.1 patrol hours resulting in a combined total of 278.4 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

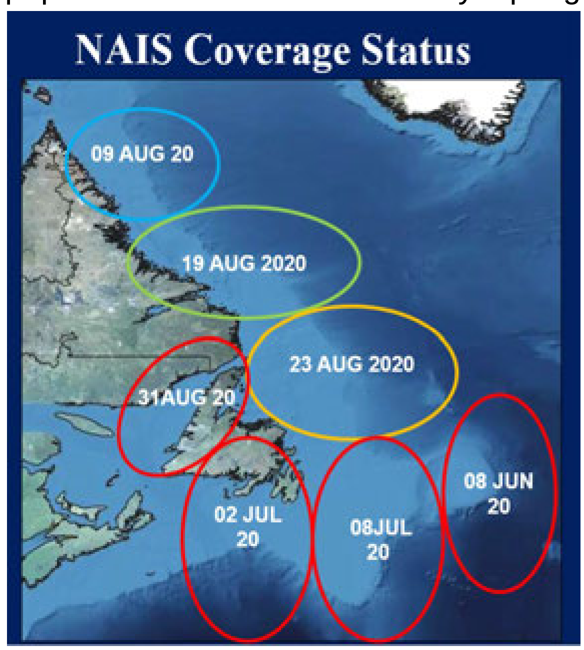


Figure 4-7. Example of NAIS reconnaissance coverage from 01 August 2019. Circle color indicated risk of iceberg collision for vessels in the transatlantic shipping lanes.

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 4-7** 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 2020 season, IRDs made 34 general sécurité broadcasts and 71 direct vessel callouts, a decrease of 51% and 52% respectively when compared to the 2019 season. Out of all vessels contacted directly, 69% responded to callouts.

Satellite Reconnaissance

IIP satellite reconnaissance during the 2020 Iceberg Season focused on the automation of processes and pursuing new capabilities. The majority of frames analyzed by IIP in 2020, as in 2019, are from the European Space Agency's Synthetic Aperture Radar 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 and for the first time IIP utilized Sentinel-2 Multispectral Imagery as a reconnaissance source for this season.

IIP analyzed 526 individual satellite frames during the 2020 Ice Season. These 526 satellite frames comprised of 341 Sentinel-1A/B frames, 47 RADARSAT-2 frames, and 138 Sentinel-2 Frames. IIP's Satellite Dayworker (SDW) identified 5,702 icebergs and 12 radar targets in the 526 analyzed frames, of which 3,558 were added or re-sighted in BAPS. The 12 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 iceberg reports received from all sources and the total number of satellite icebergs entered into BAPS.

The total number of frames analyzed in-house by IIP more than doubled from the 230 frames analyzed in 2019. The increase is directly attributed to increased automation of downloading and pre-analysis functions that were put into operational use in March 2020. Developing automated scripts to handle the majority of ArcGIS processing reduced the processing time per frame by at least 30 minutes and has enabled analysts to focus on classifying targets rather than "button-clicking" through tedious processes. **Figure 4-8** shows that the total percentage of satellite-identified

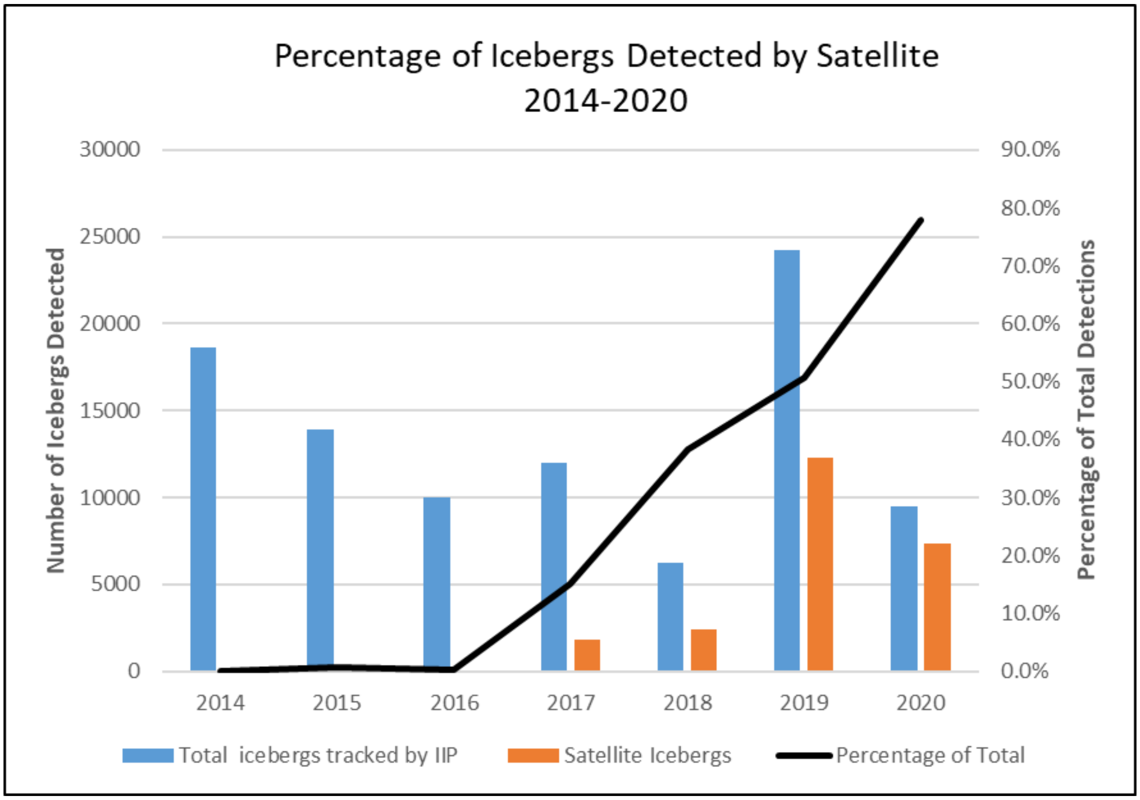


Figure 4-8. Comparison of the number of satellite iceberg detections (all sources) received at IIP and the total number of iceberg sightings from 2014-2020. The grey line shows the percentage of total iceberg sightings processed by IIP that were from satellite sources.

icebergs (from all sources) continued to increase in 2020, to more than three quarters during this Ice Season.

In March 2020, IIP made the first operational use of Sentinel-2 multispectral imagery for reconnaissance. The 138 Sentinel-2 frames analyzed from March through August resulted in 32% of the total icebergs reported by IIP's satellite reconnaissance effort. It should be noted in this number of frames, that each full Sentinel-2 frame covers approximately one third of the area of a Sentinel-1 interferometric wide swath frame within the Newfoundland area. Still, the number of frames processed is significant given the much higher confidence using these sensors. It is much easier to differentiate an iceberg from a ship or noise in multispectral imagery, especially for icebergs larger than 30m. Multispectral imagery is still limited in effectiveness due to cloud cover and the extent of coverage, as Sentinel-2 sensors do not collect offshore in the IIP area of operations, but it has proven an extremely valuable tool for locating icebergs drifting in the Labrador Current along the Labrador coast. In July 2020, IIP created an automated iceberg detection script that utilizes the spectral signature of each pixel in a multispectral image to identify potential icebergs for the analyst to classify. This script is still under development but was used operationally at the end of the 2020 Ice Season and will be in full operation for the 2021 Ice Season. More information on the iceberg detection script will be published separately.

IIP analyzed an additional 317 satellite frames (from all sensors) between August 8 and September 20 in support of USCGC CAMPBELL's deployment to the west coast of Greenland. This reconnaissance was used to create novel, tailored iceberg warning products. The products and lessons learned from the additional satellite reconnaissance are presented and discussed in **Appendix C**.

The RADARSAT-2 frames collected and analyzed in the 2020 Ice Season were obtained through IIP's NAIS partnership with USNIC under the Northern View arrangement between 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 USCGC CAMPBELL deployment (**Appendix C)** and collecting frames near the Iceberg Limits.

As IIP continues to enhance capabilities and expertise in Satellite Reconnaissance, the unit undertook an internal organizational change. Traditionally, IIP's personnel have been divided into three branches: Administration, Ice Operations (responsible for organizing reconnaissance), and Ice Information (responsible for product creation and dissemination.) In order to better build capability and pursue innovative methods and techniques in satellite reconnaissance, the unit restructured this year. The responsibilities of the legacy Operations and Information branches were combined into the new Operations Branch and a Satellite Reconnaissance Branch was created to take direct responsibility and oversight on the satellite reconnaissance effort, as well as research and development of new tactics, techniques, and procedures.

Commemorative Wreath Deployments

Typically each year, IIP deploys commemorative wreaths in conjunction with reconnaissance operations to remember the lives lost at sea in the North Atlantic Ocean. In addition to the wreath deployments, a ceremony in New London, CT is held each year, and a wreath dedication ceremony is also held every other year at the Fairview Lawn Cemetery in Halifax, NS where over one hundred Titanic victims are buried.

Restrictions on large gatherings pursuant to the COVID-19 outbreak prevented these annual events in 2020, and unfortunately no wreaths were deployed. However, the loss of RMS Titanic was commemorated with a special note on the 15 April NAIS-65 product.

5. Abbreviations and Acronyms

AIS	Automatic Identification System
APN-241	HC-130J Tactical Transport Weather Radar
ASEC	U. S. Coast Guard Air Station Elizabeth City
ASCC	U.S. Coast Guard Air Station Cape Cod
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
CIIP	Commander, International Ice Patrol
CIS	Canadian Ice Service, an operational unit of the Meteorological Service of Canada
CT	Connecticut
CYYT	St. John’s International Airport
DMI	Danish Meteorological Institute
DWS	Duty Watch Stander
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
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
GHRSST	Group for High Resolution Sea Surface Temperature
HC-130J	U. S. Coast Guard Long Range Surveillance Maritime Patrol Aircraft
HD	High Definition
IDS	Iceberg Detection Software
IIP	U. S. Coast Guard International Ice Patrol
IRD	Ice Reconnaissance Detachment
ISAR	Inverse Synthetic Aperture Radar

KFMH	Joint Base Cape Cod Airport
KGON	Groton-New London Airport
KML	Keyhole Markup Language
kts	knots
m	meter
mb	millibar
MA	Massachusets
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
NAVAREA	Navigational Area
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
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.
POD	Probability of Detection
RADARSAT-2	Canadian C-Band SAR satellite system, owned and operated by MacDonald, Dettwiler, and Associates.

RCM	Radarsat Constellation Mission, Canadian Government C-Band SAR satellite system
Radiofax	Radio Facsimile
RMS	Royal Mail Steamer
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
SOLAS	Safety of Life at Sea
SRB	Satellite Reconnaissance Branch
SST	Sea Surface Temperature
SVP	Surface Velocity Program
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
W	West (Longitude)
WWNWS	World Wide Navigation Warning System
Z	Zulu – Coordinated Universal Time

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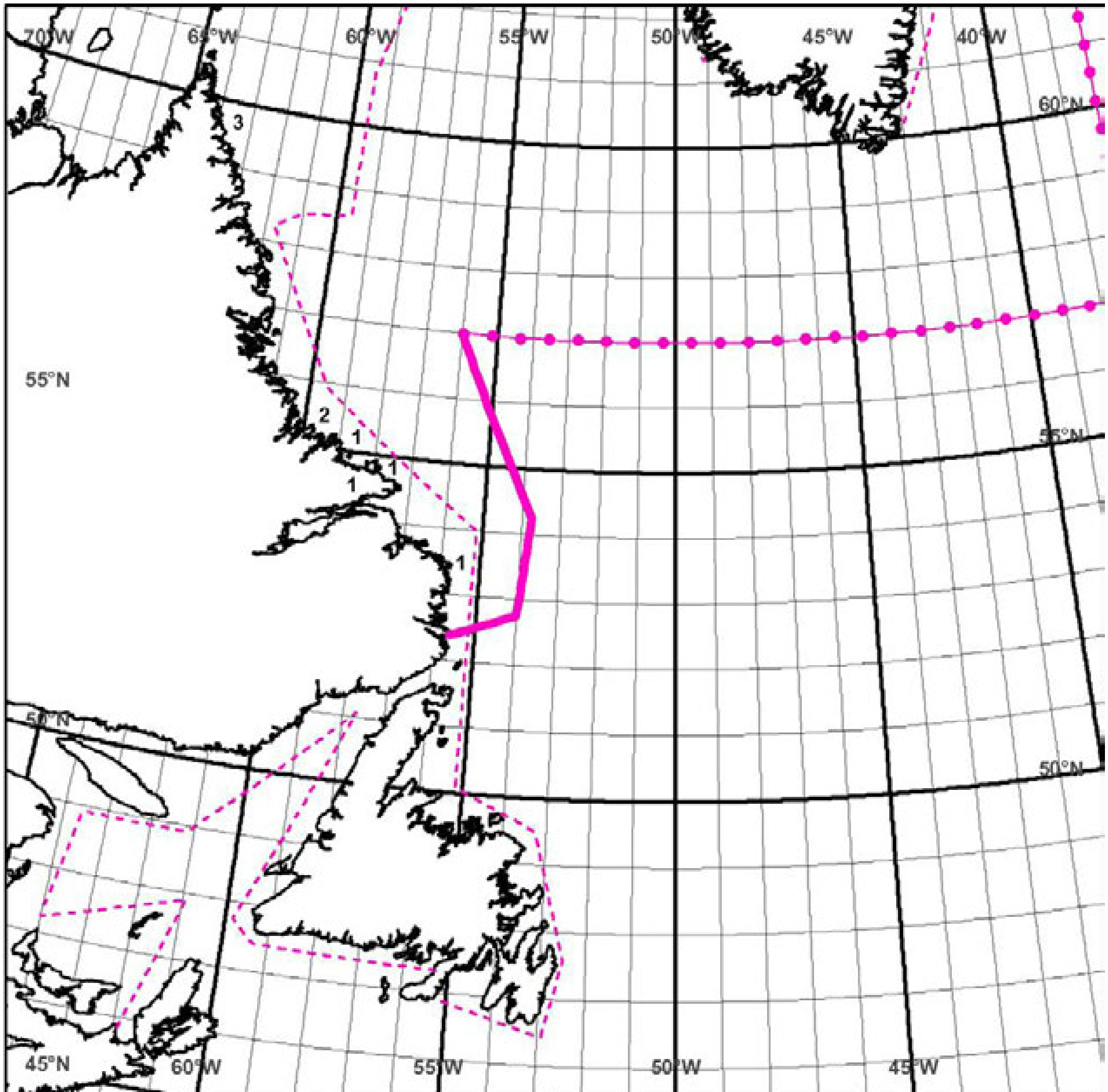
7. Semi-Monthly Iceberg Charts



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 JAN 2020

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

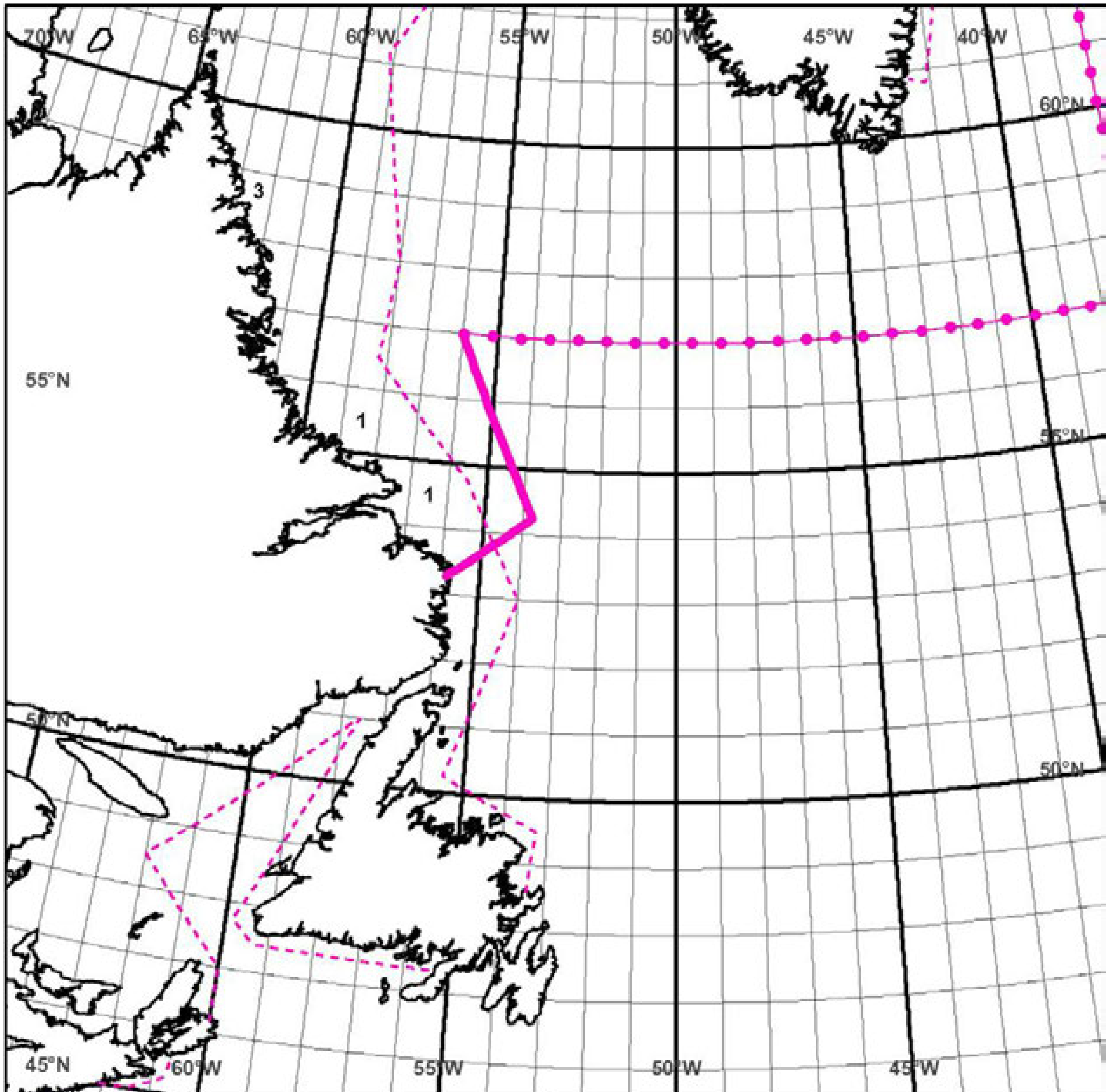
SEA ICE LIMIT

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 22DEC19.

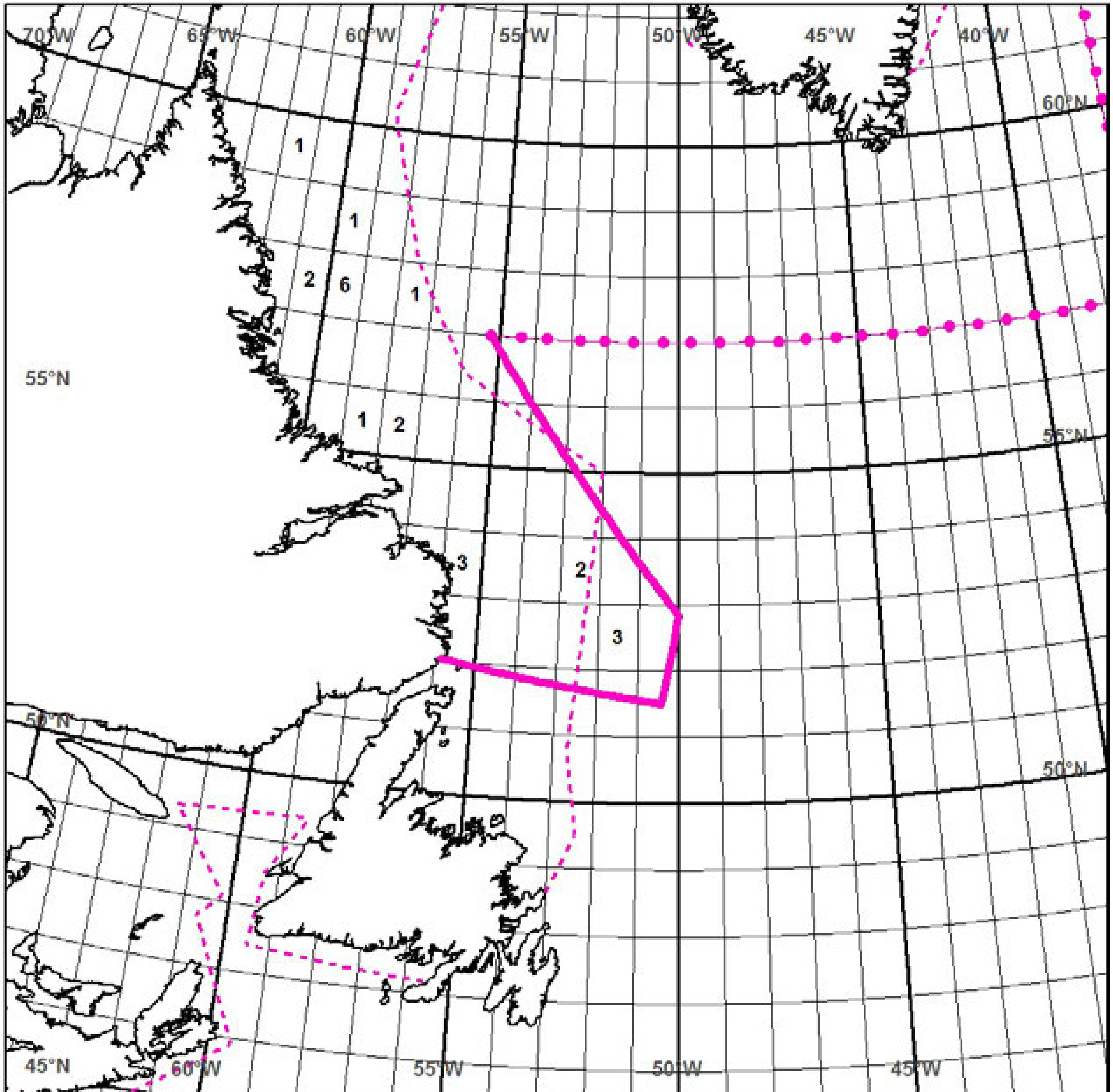


NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC
15 JAN 2020

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 11JAN20.

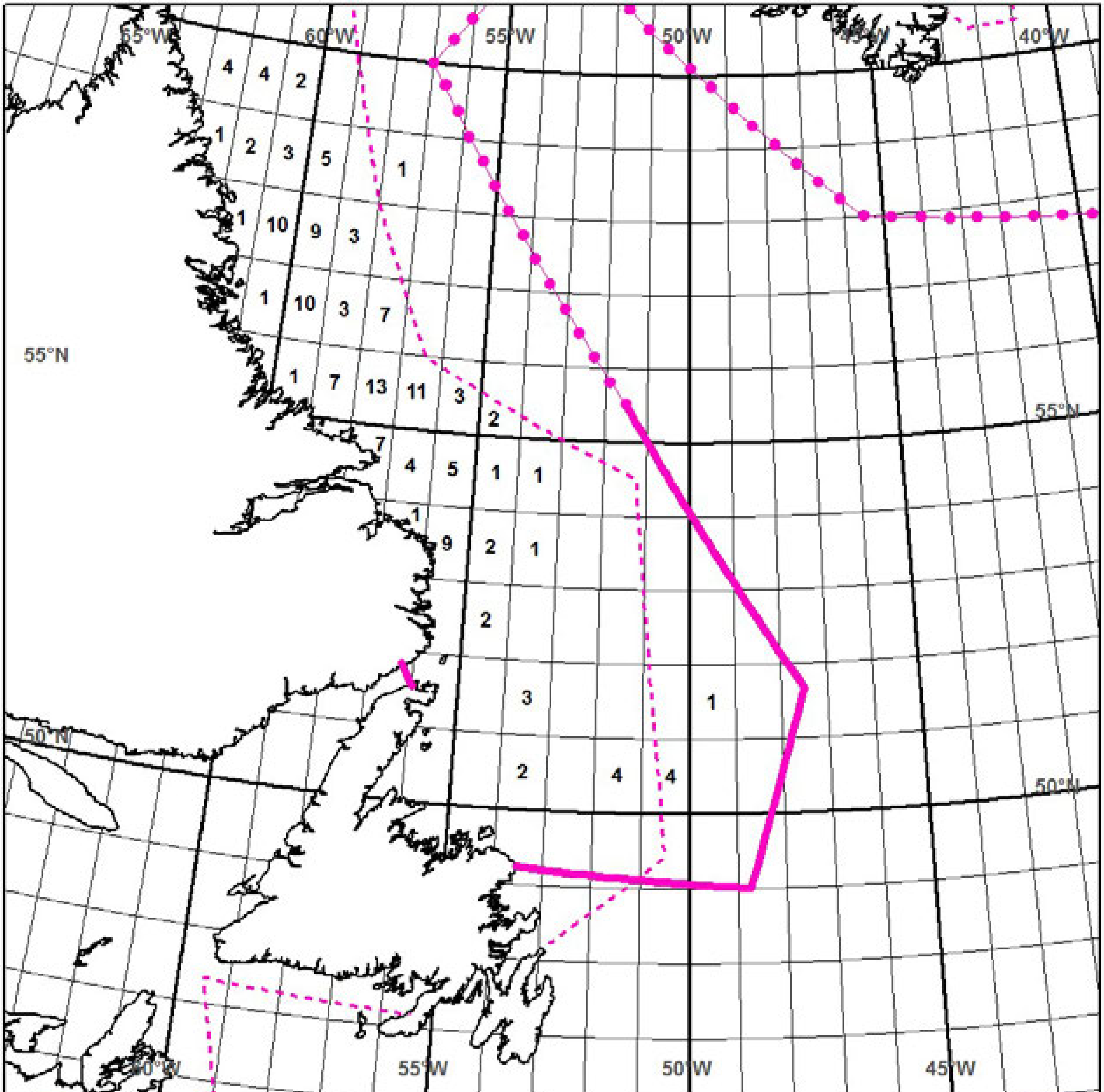


NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 FEB 2020

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:**
	Southern Limit Satellite Pass 29JAN20.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 FEB 2020

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

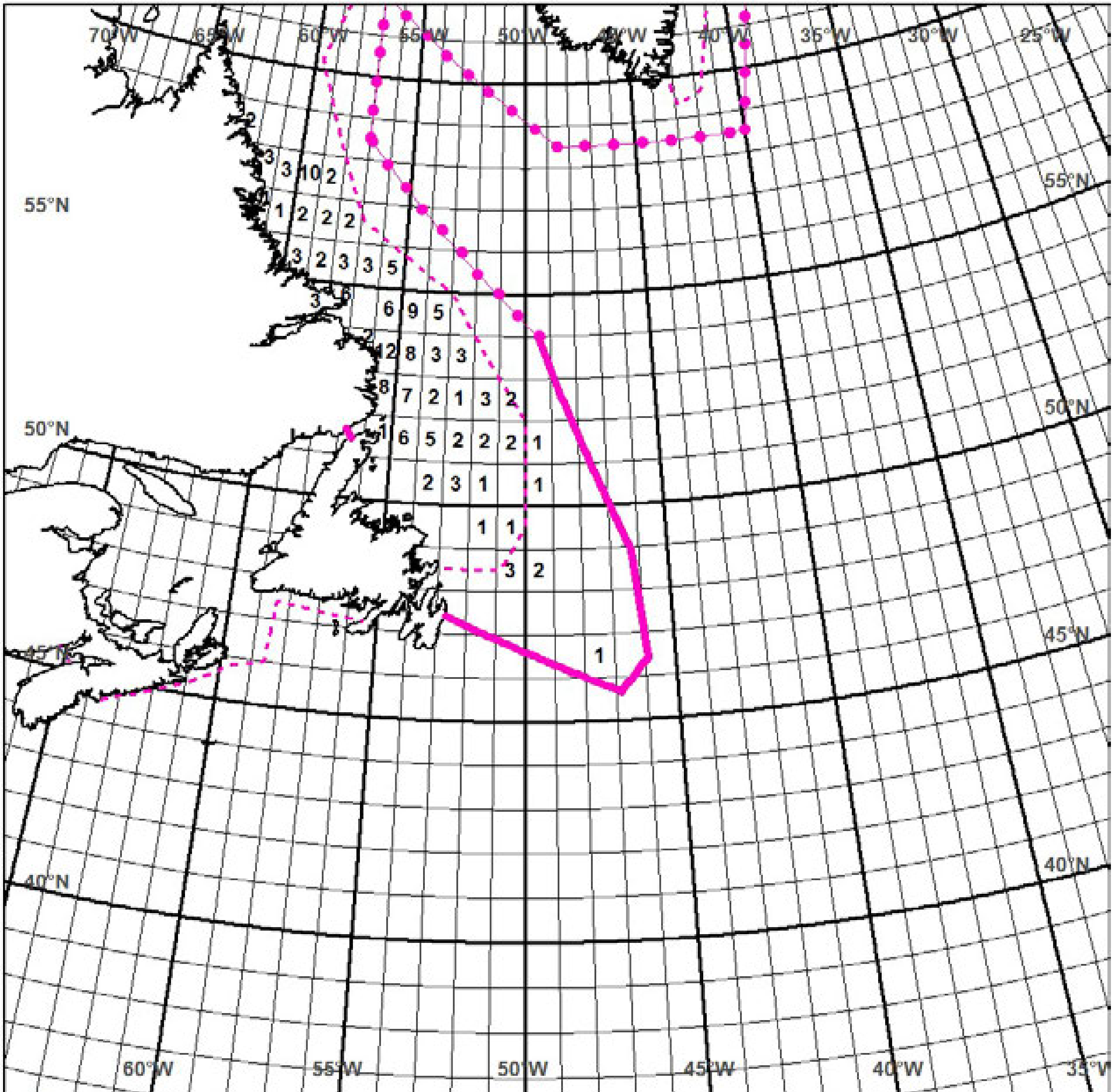
SEA ICE LIMIT

\# 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 10FEB20.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 MAR 2020

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

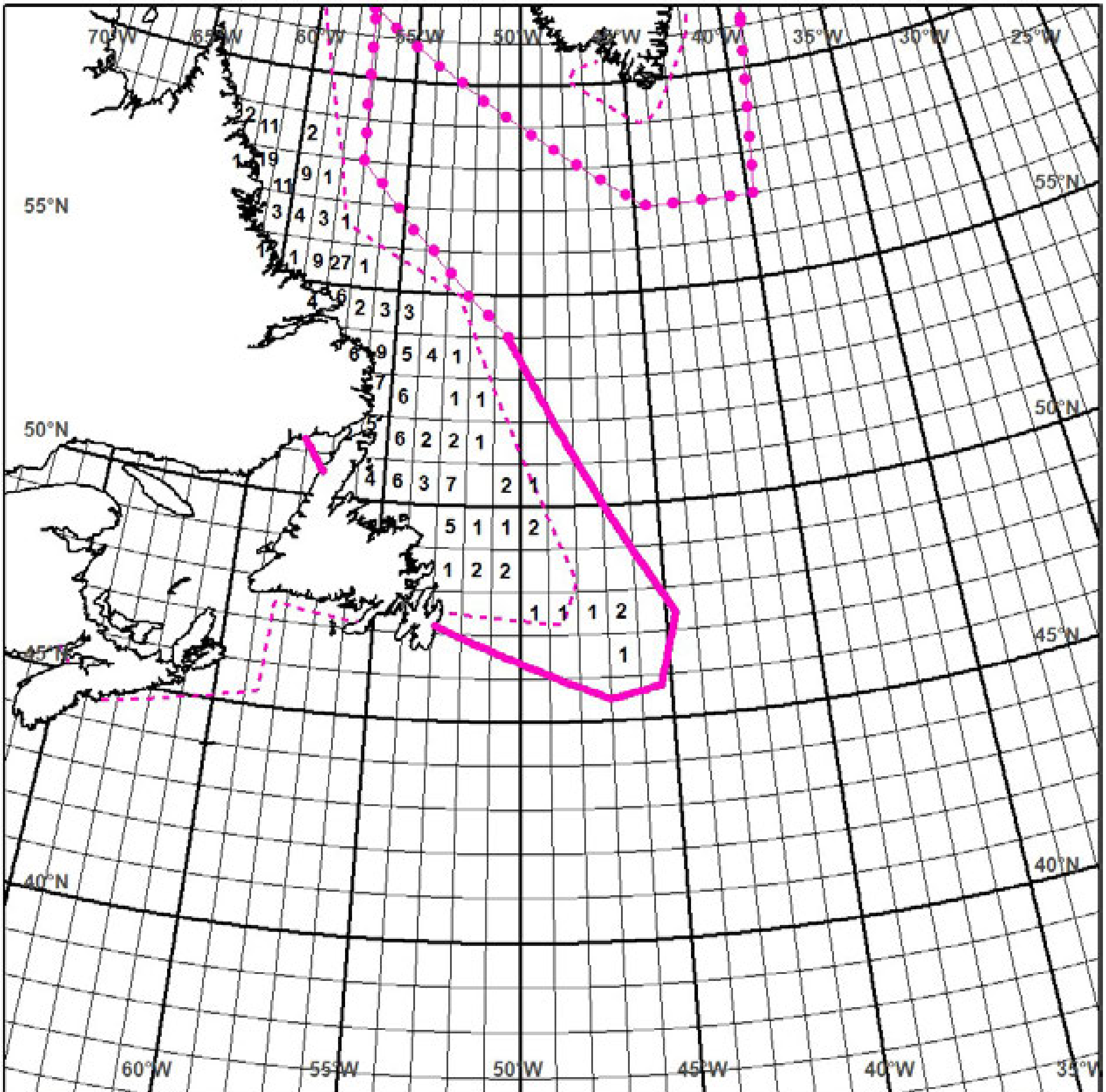
SEA ICE LIMIT

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 24FEB20.



NORTH AMERICAN ICE SERVICE (NAIS)

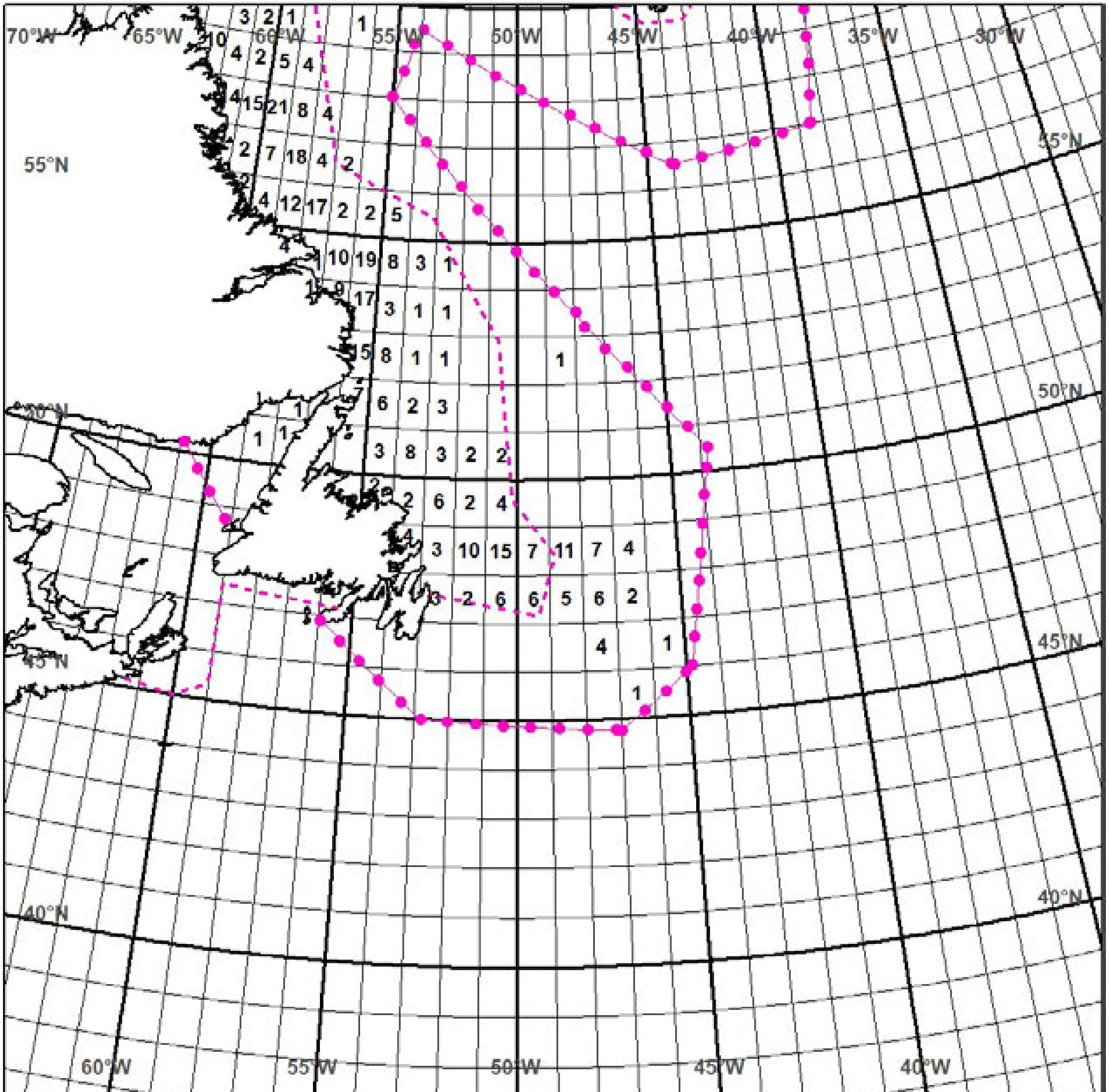
ICEBERG ANALYSIS FOR 0000 UTC

15 MAR 2020

- 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 09MAR20.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 APR 2020

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

SEA ICE LIMIT

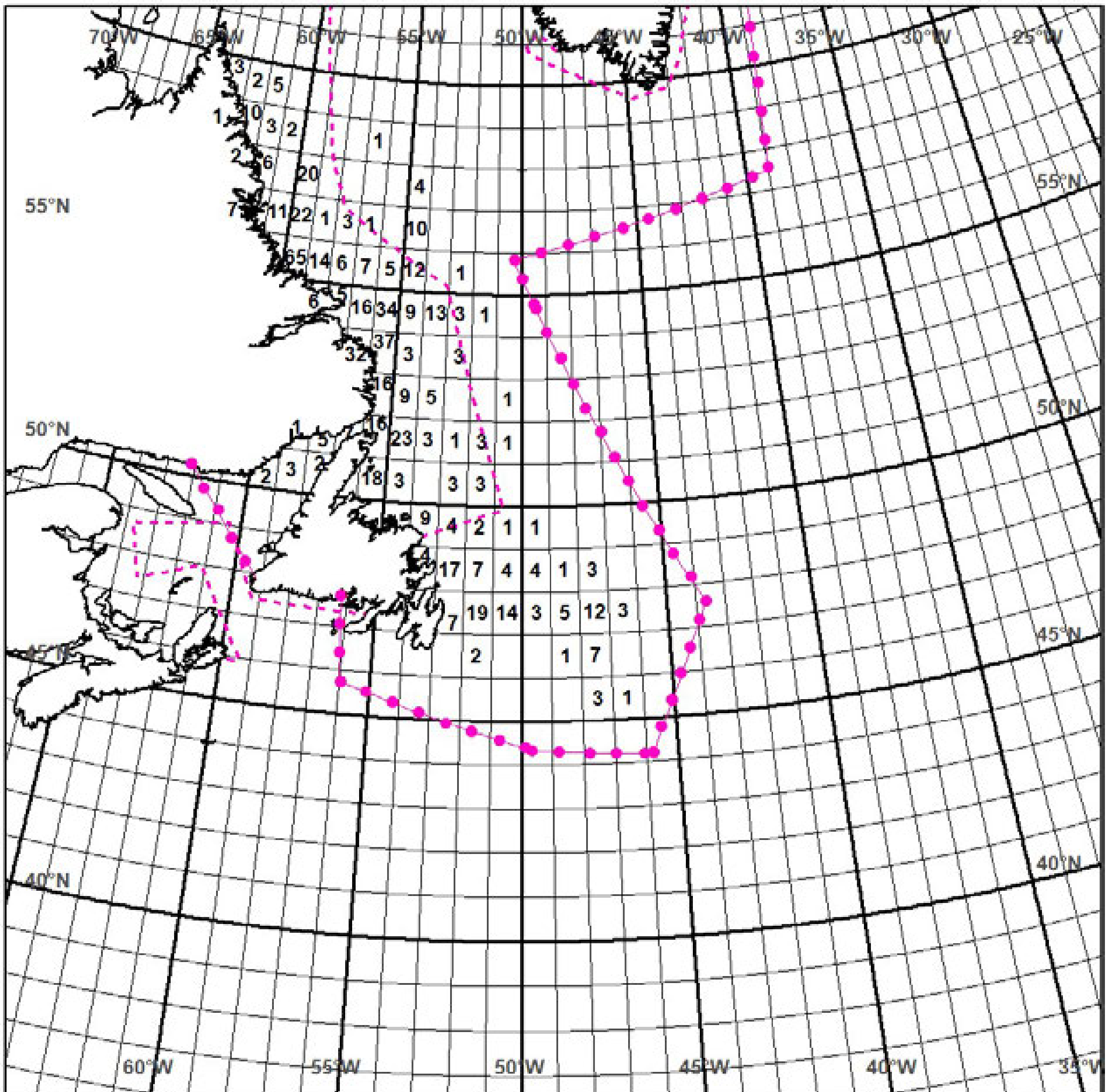
ICEBERGS PER DEGREE SQUARE

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 29MAR20.

WARNING! The International Ice Patrol is experiencing reduced iceberg reconnaissance. Please navigate with caution.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 APR 2020

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

SEA ICE LIMIT

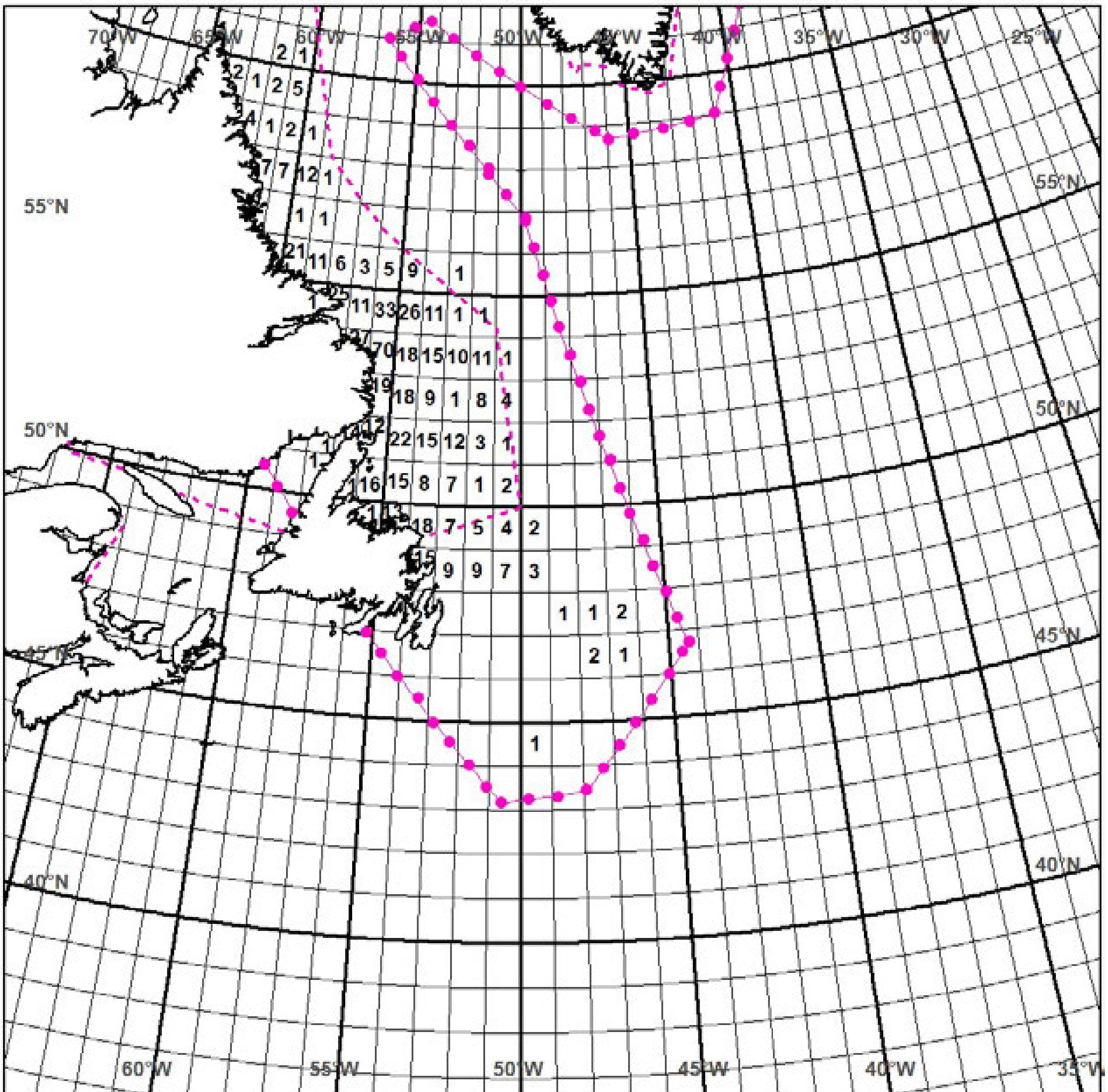
\# ICEBERGS PER DEGREE SQUARE

RADAR TARGET OUTSIDE ICEBERG LIMIT

NOTE:

Today we commemorate the 108th anniversary of the sinking of the RMS Titanic.

For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
WARNING! The International Ice Patrol is experiencing reduced iceberg reconnaissance. Please navigate with caution.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 MAY 2020

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

SEA ICE LIMIT

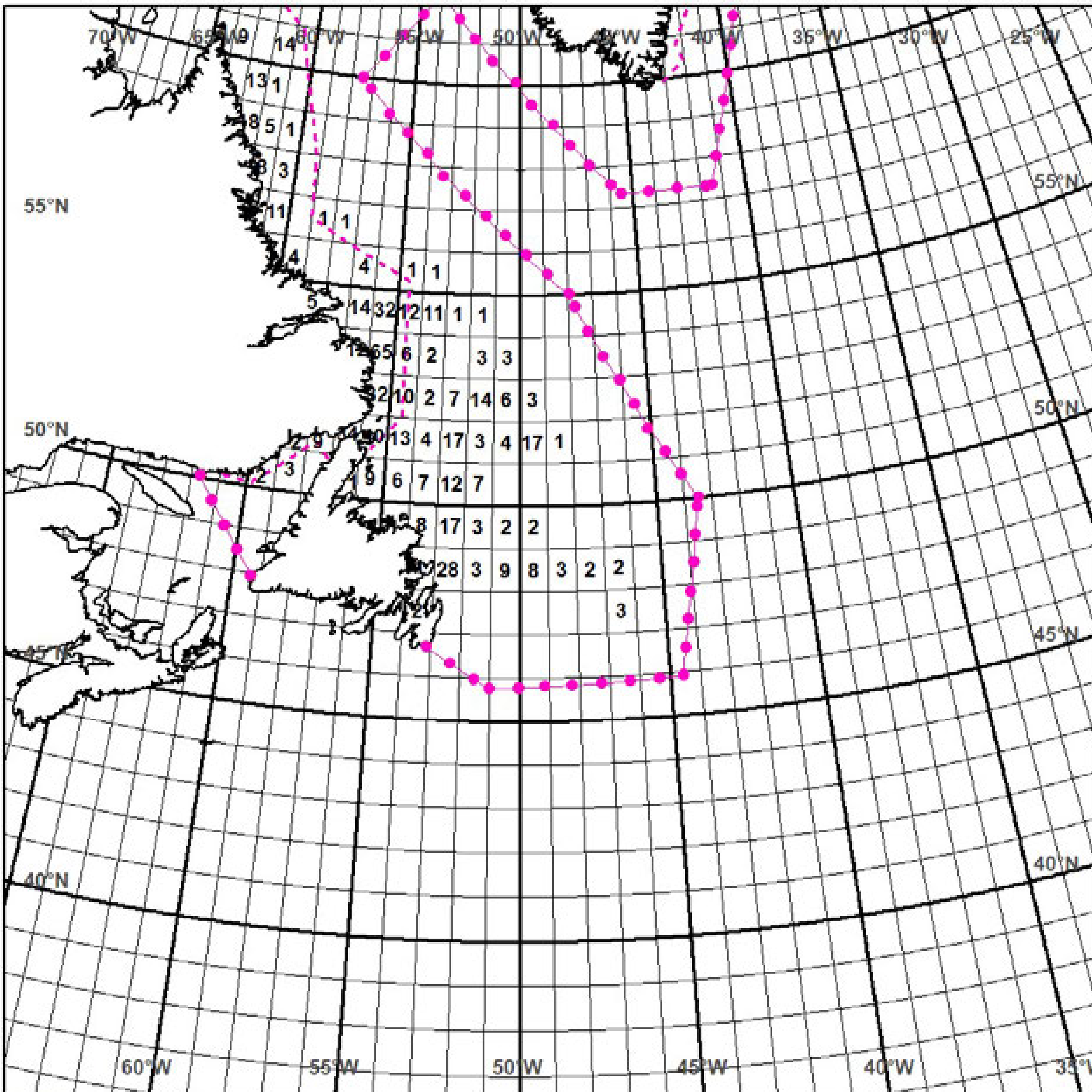
ICEBERGS PER DEGREE SQUARE

⊗ 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 29APR20.

WARNING! The International Ice Patrol is experiencing reduced iceberg reconnaissance. Please navigate with caution.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 MAY 2020

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

SEA ICE LIMIT

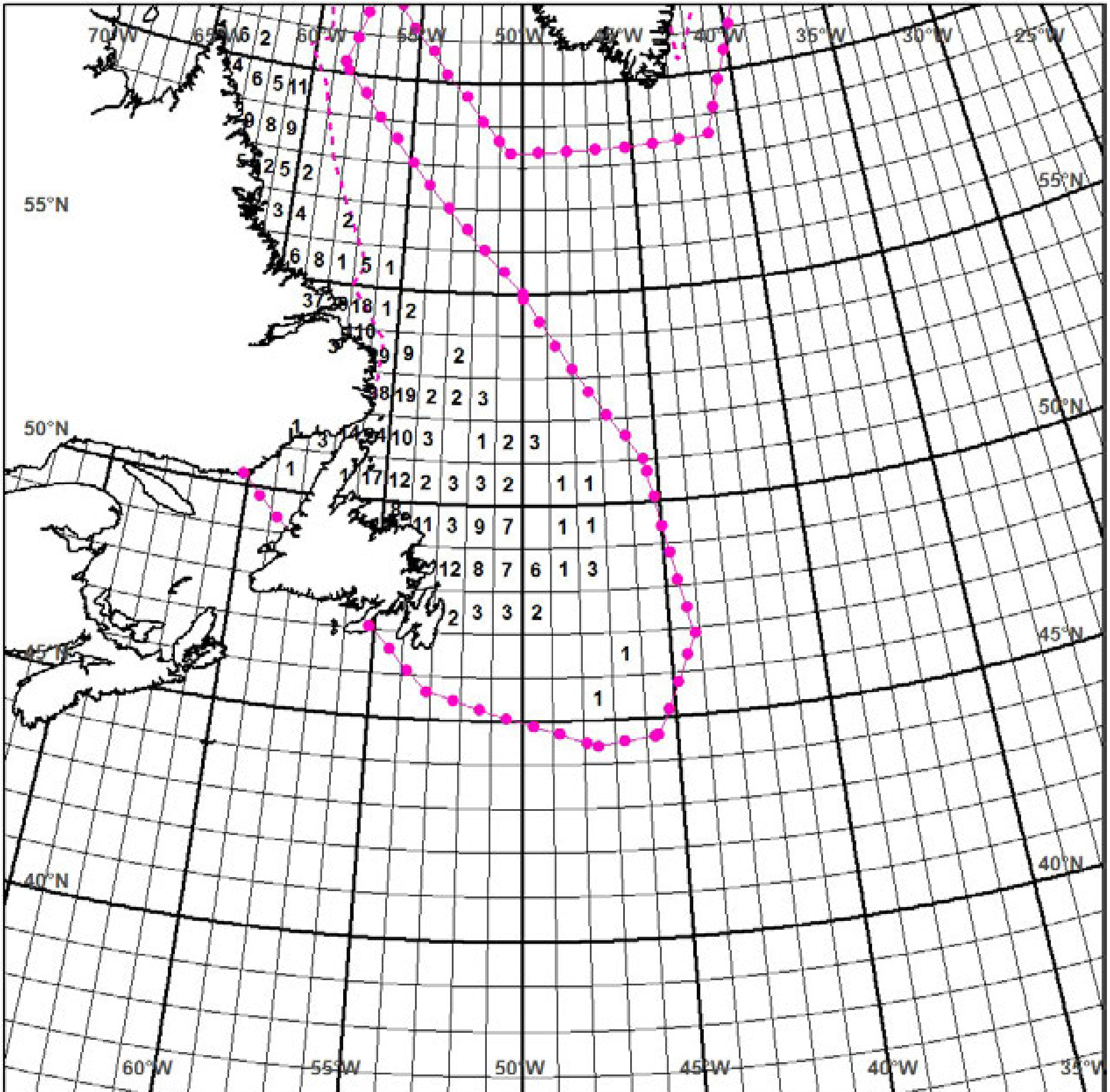
ICEBERGS PER DEGREE SQUARE

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 12MAY20.

WARNING! The International Ice Patrol is experiencing reduced iceberg reconnaissance. Please navigate with caution.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 JUN 2020

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

SEA ICE LIMIT

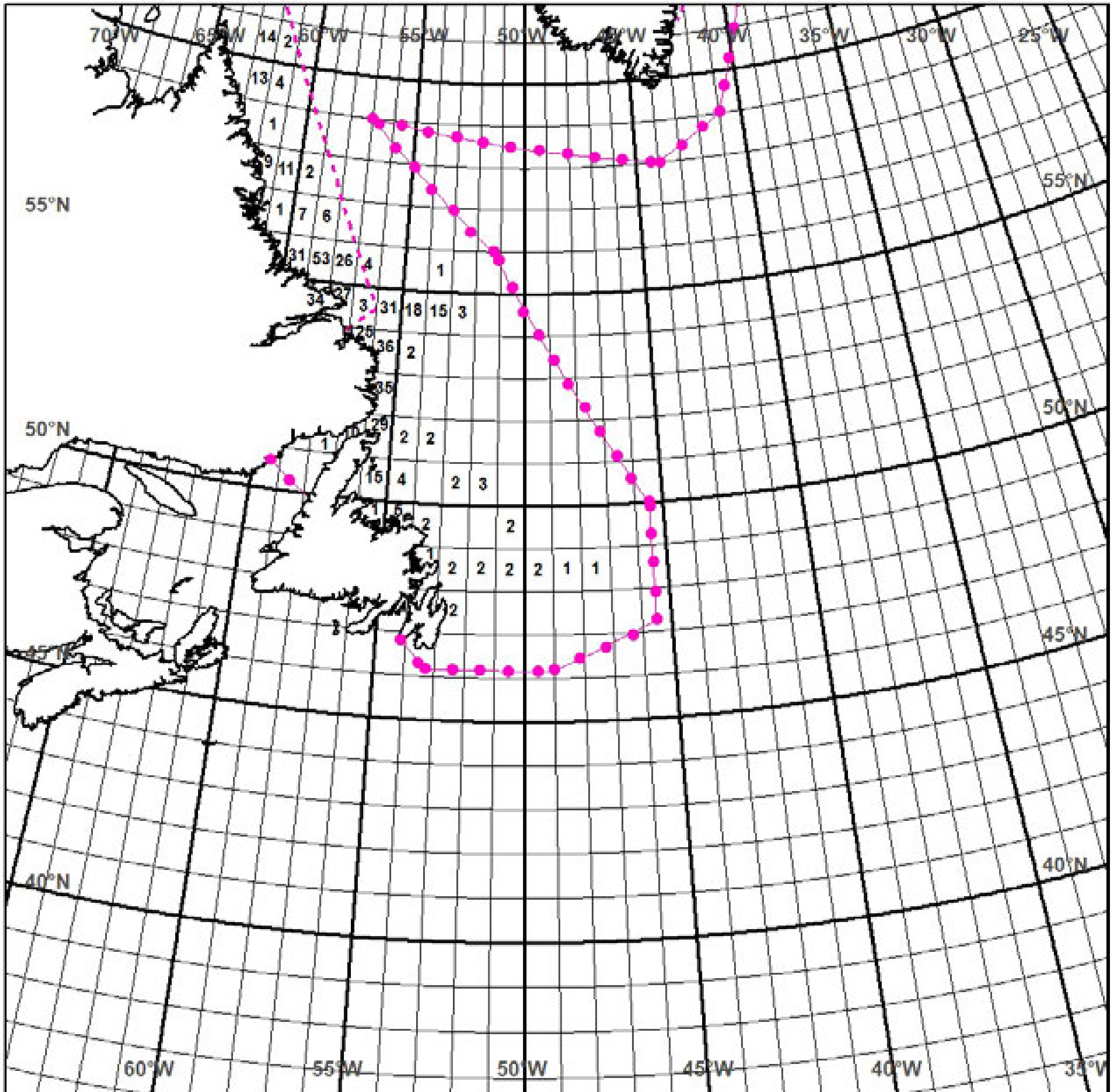
ICEBERGS PER DEGREE SQUARE

⊗ 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 30MAY20.

WARNING! The International Ice Patrol is experiencing reduced iceberg reconnaissance. Please navigate with caution.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 JUN 2020

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

SEA ICE LIMIT

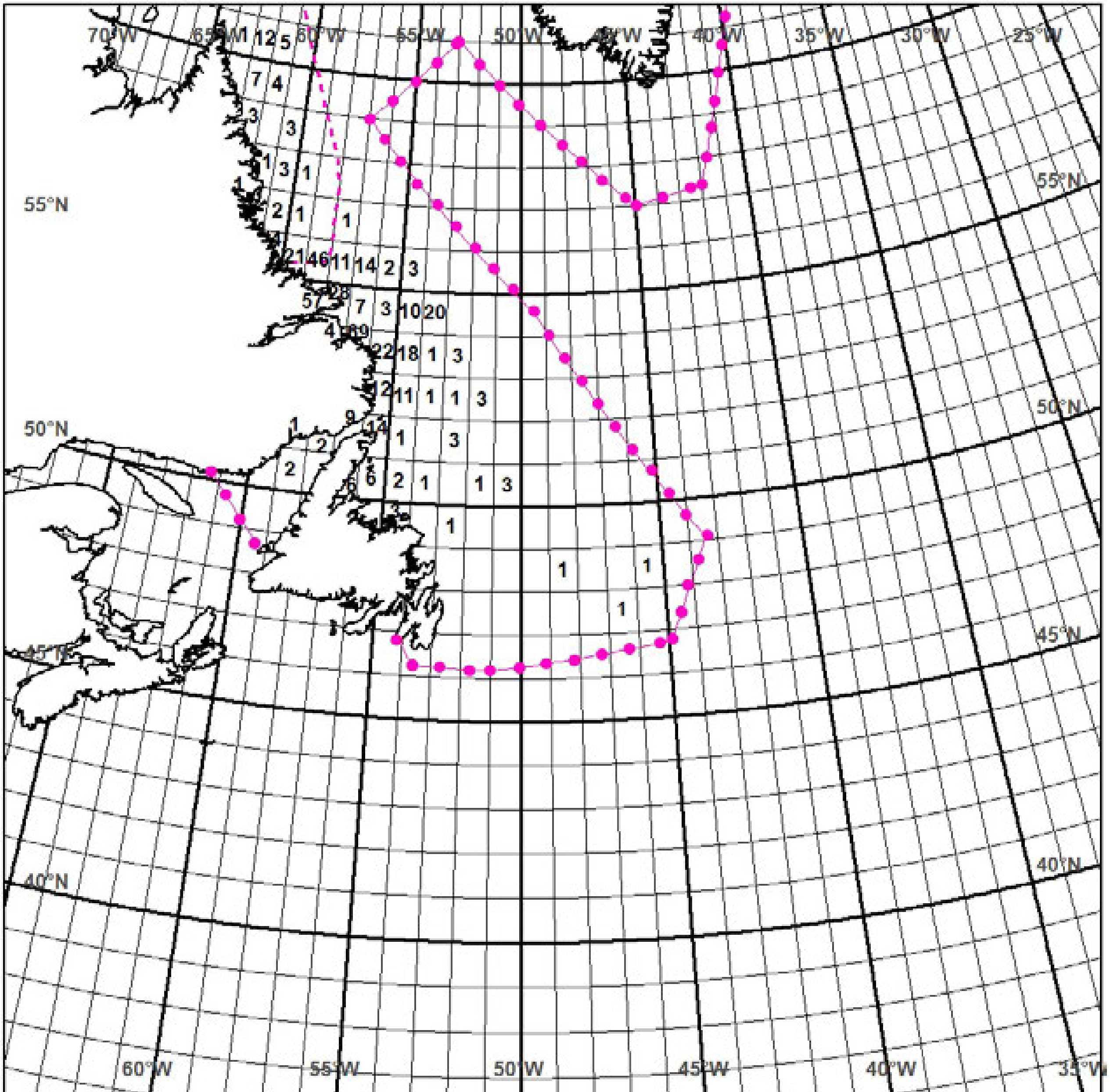
ICEBERGS PER DEGREE SQUARE

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 13JUN20.

WARNING! The International Ice Patrol is experiencing reduced iceberg reconnaissance. Please navigate with caution.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 JUL 2020

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

SEA ICE LIMIT

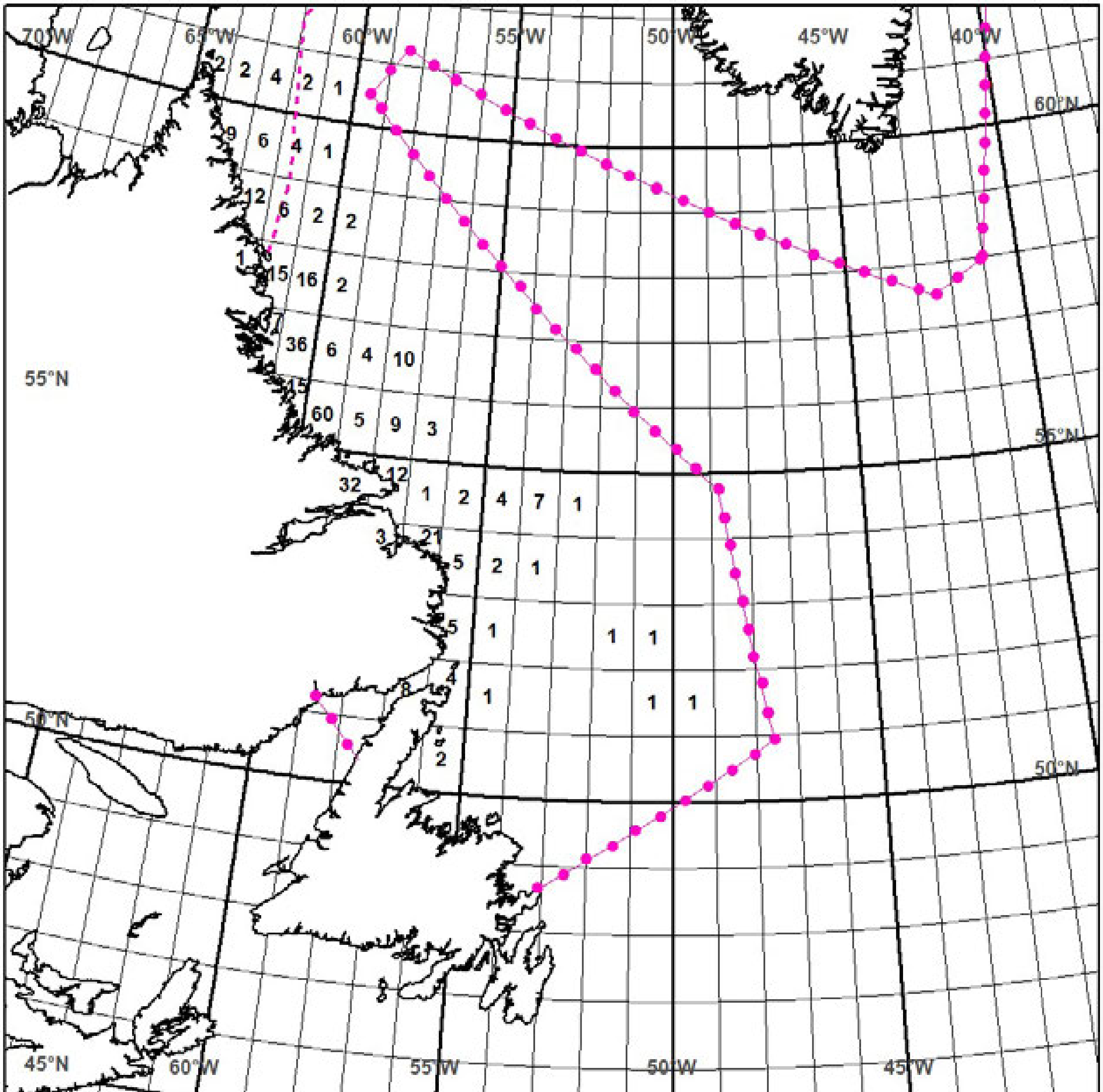
ICEBERGS PER DEGREE SQUARE

⊗ 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 29JUN20.

WARNING! The International Ice Patrol is experiencing reduced iceberg reconnaissance. Please navigate with caution.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

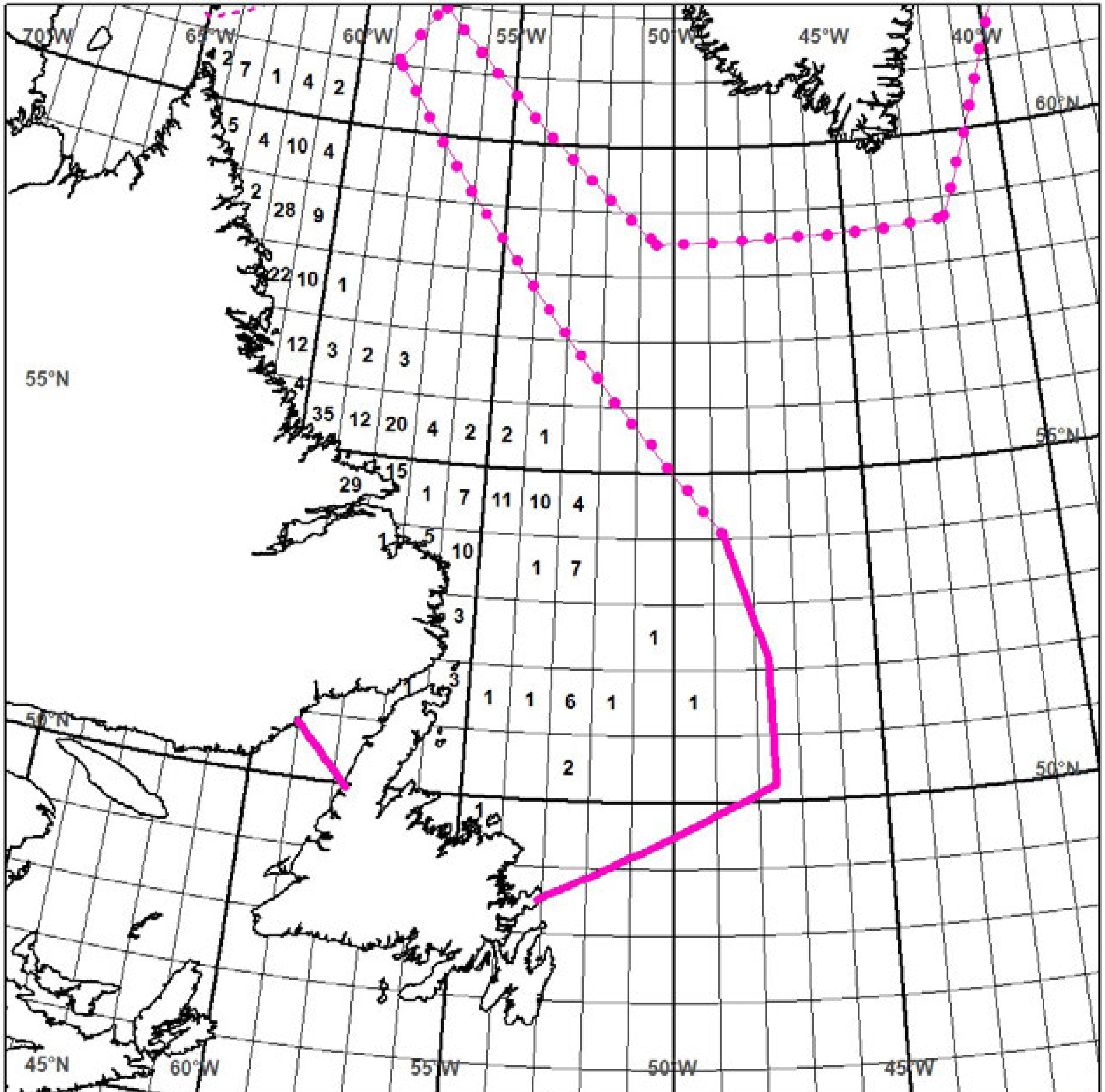
15 JUL 2020

●–●–●	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 08JUL20.

WARNING! The International Ice Patrol is experiencing reduced iceberg reconnaissance. Please navigate with caution.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

01 AUG 2020

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

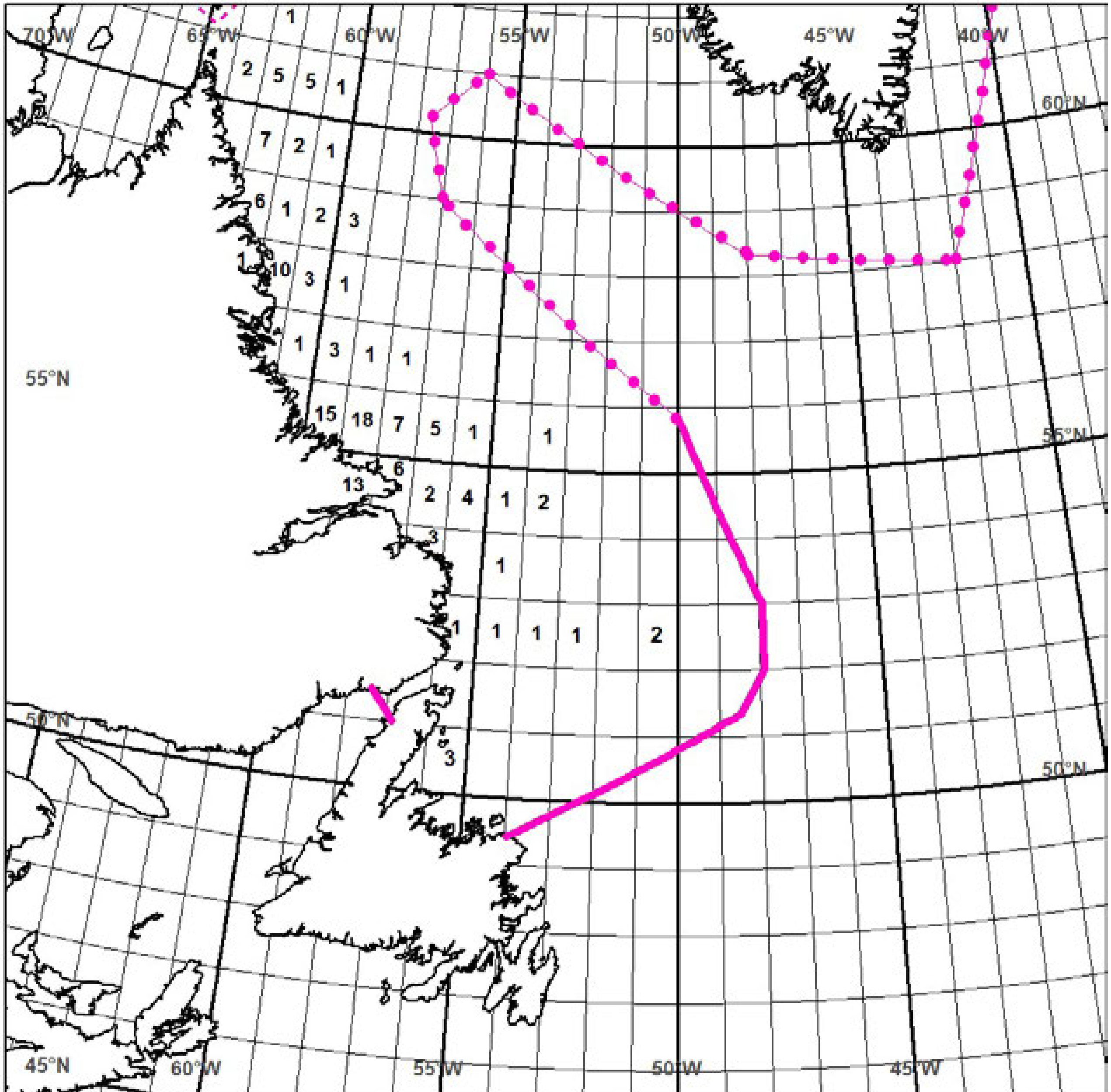
SEA ICE LIMIT

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 30JUL20.



NORTH AMERICAN ICE SERVICE (NAIS)

ICEBERG ANALYSIS FOR 0000 UTC

15 AUG 2020

ESTIMATED ICEBERG LIMIT

ICEBERG LIMIT

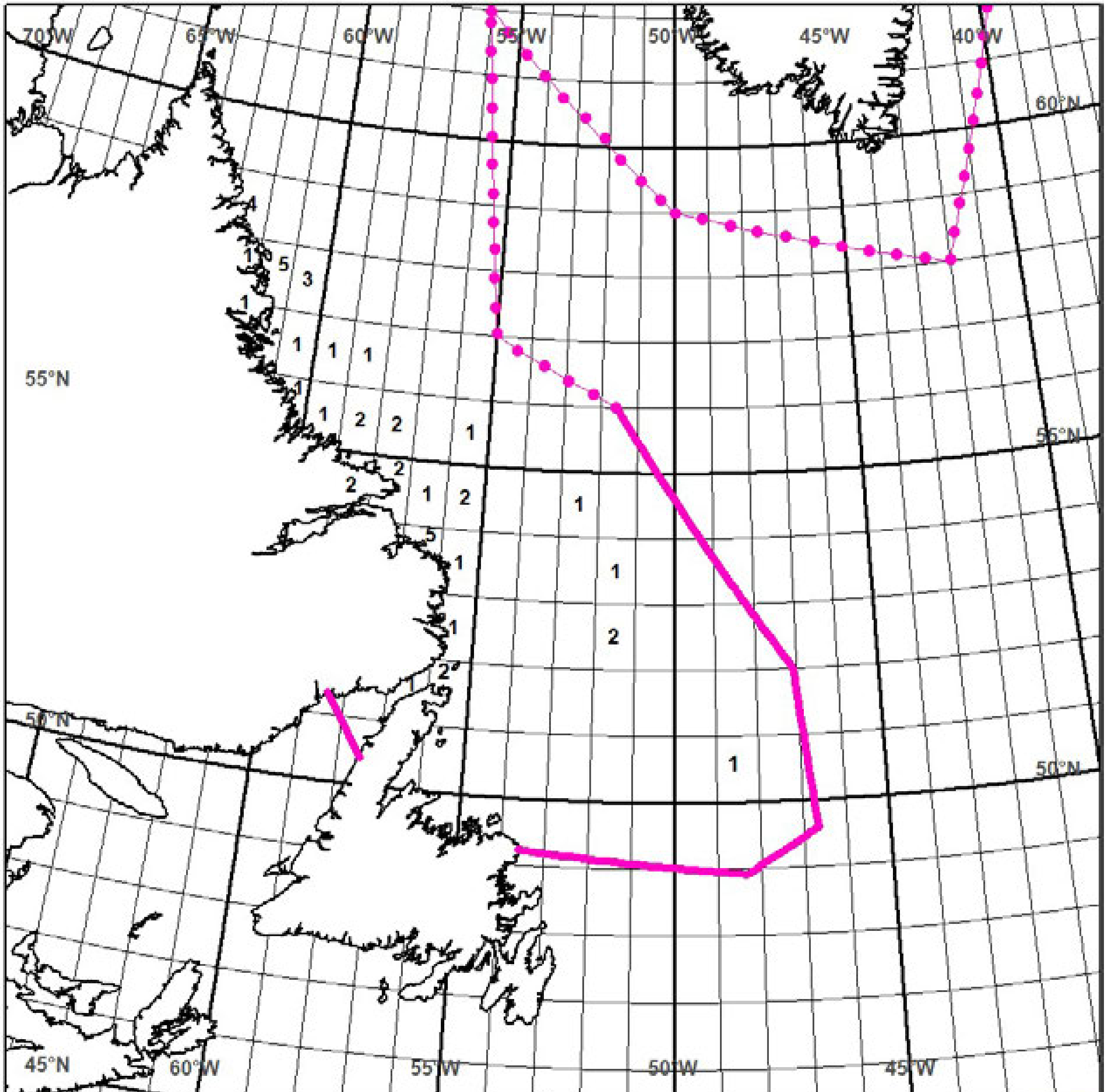
SEA ICE LIMIT

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 11AUG20.



NORTH AMERICAN ICE SERVICE (NAIS)

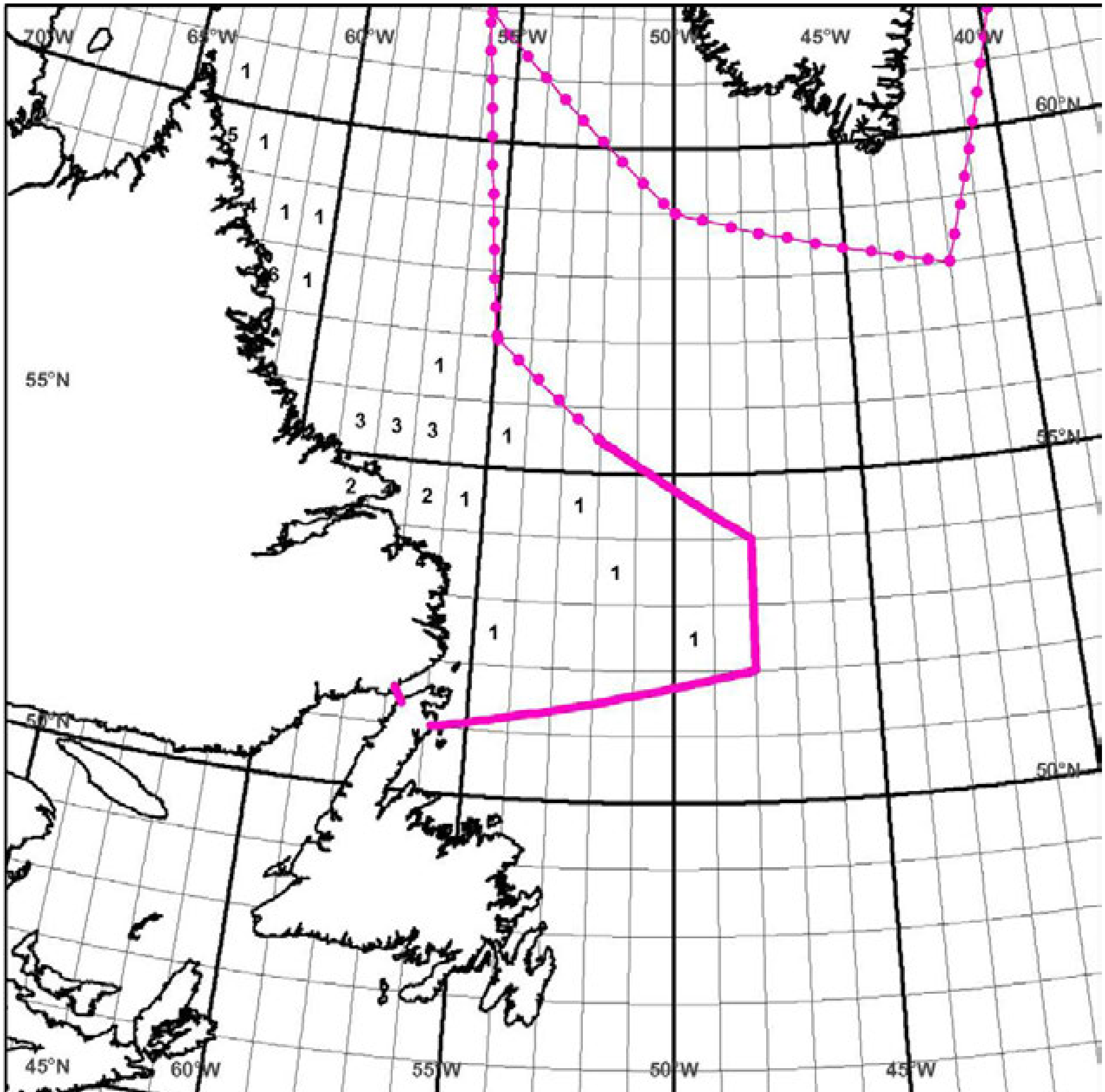
ICEBERG ANALYSIS FOR 0000 UTC

01 SEP 2020

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

NOTE:

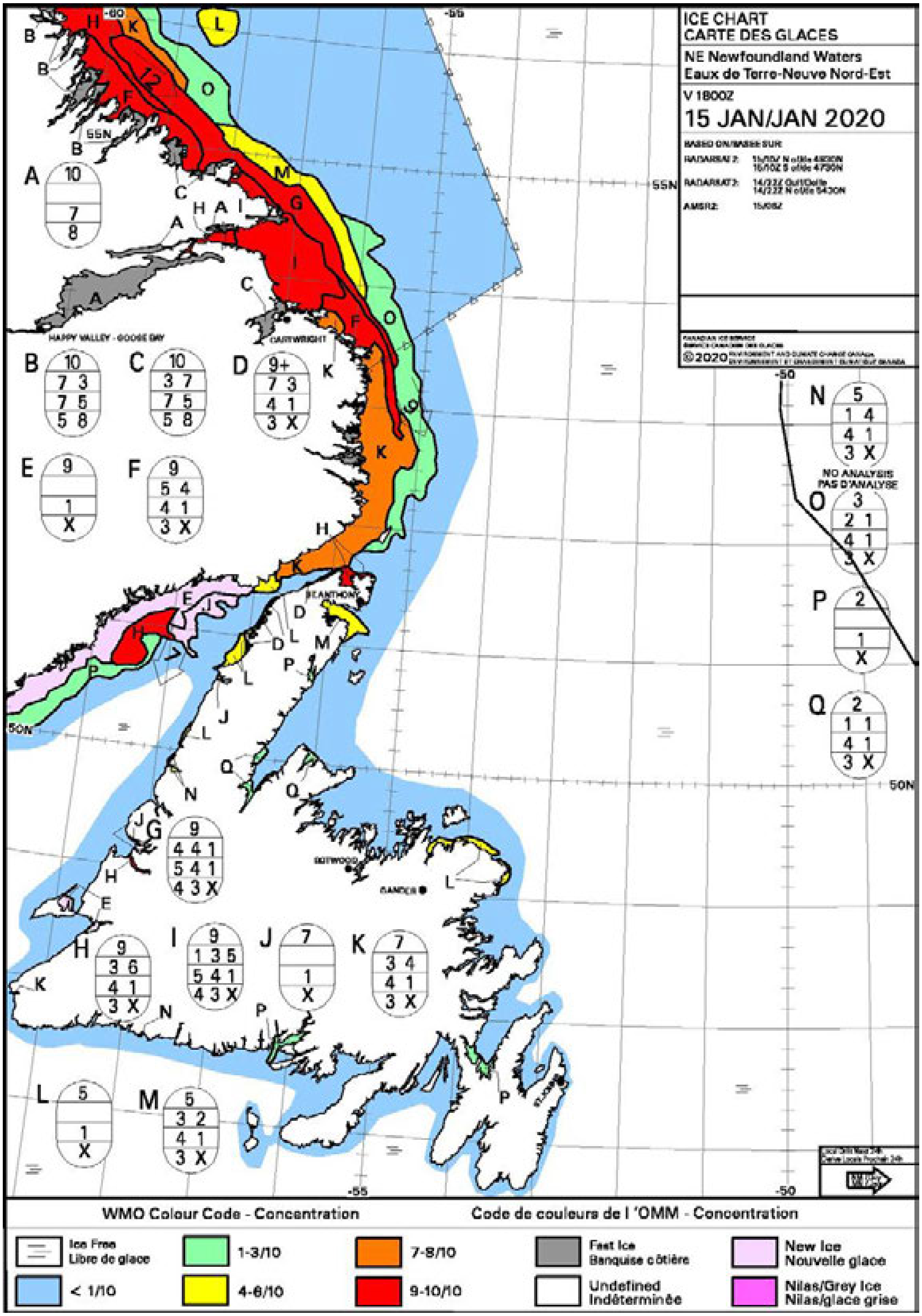
For more information:
www.navcen.uscg.gov/iip
www.ice-glaces.ec.gc.ca
Most Recent Reconnaissance:
Interior General Flight 23AUG20.

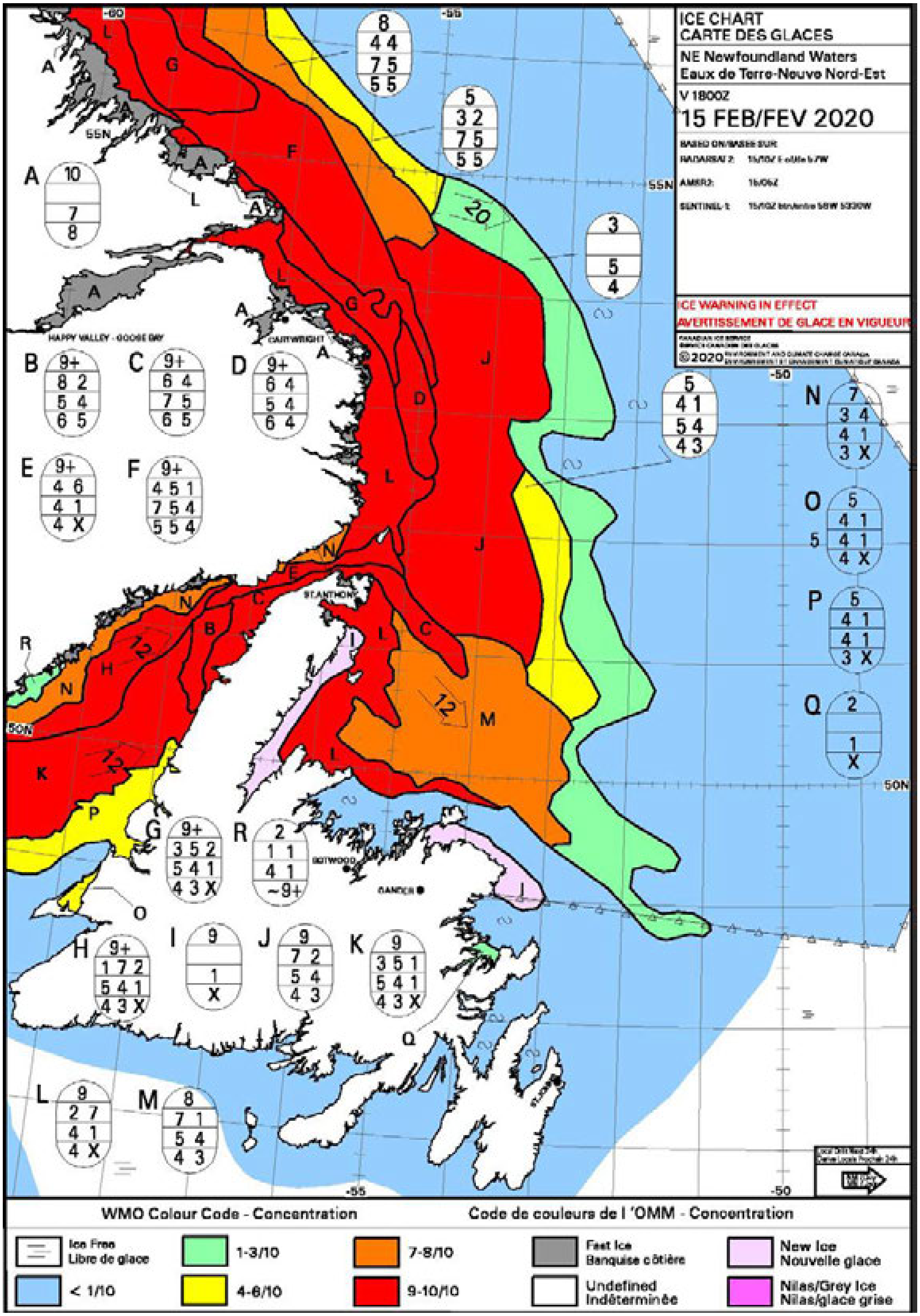


NORTH AMERICAN ICE SERVICE (NAIS)	ICEBERG ANALYSIS FOR 0000 UTC **15 SEP 2020**
ESTIMATED ICEBERG LIMIT ICEBERG LIMIT SEA ICE LIMIT # ICEBERGS PER DEGREE SQUARE ⊗ RADAR TARGET OUTSIDE ICEBERG LIMIT	**NOTE:** **For more information:** **www.navcen.uscg.gov/iip** **www.ice-glaces.ec.gc.ca** **Most Recent Reconnaissance:** **Interior General Flight 09SEP20.**

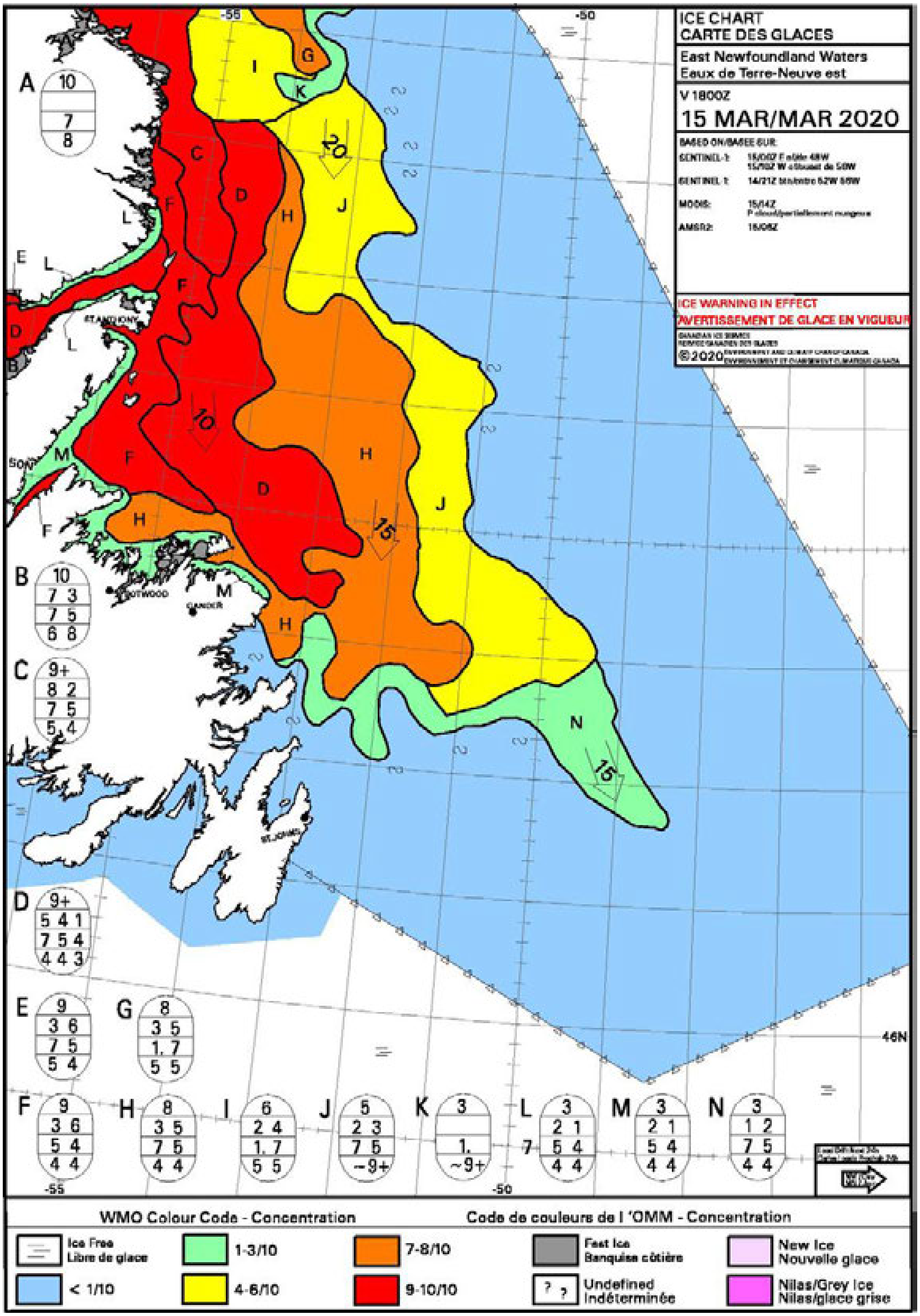
8. Monthly Sea-Ice Charts

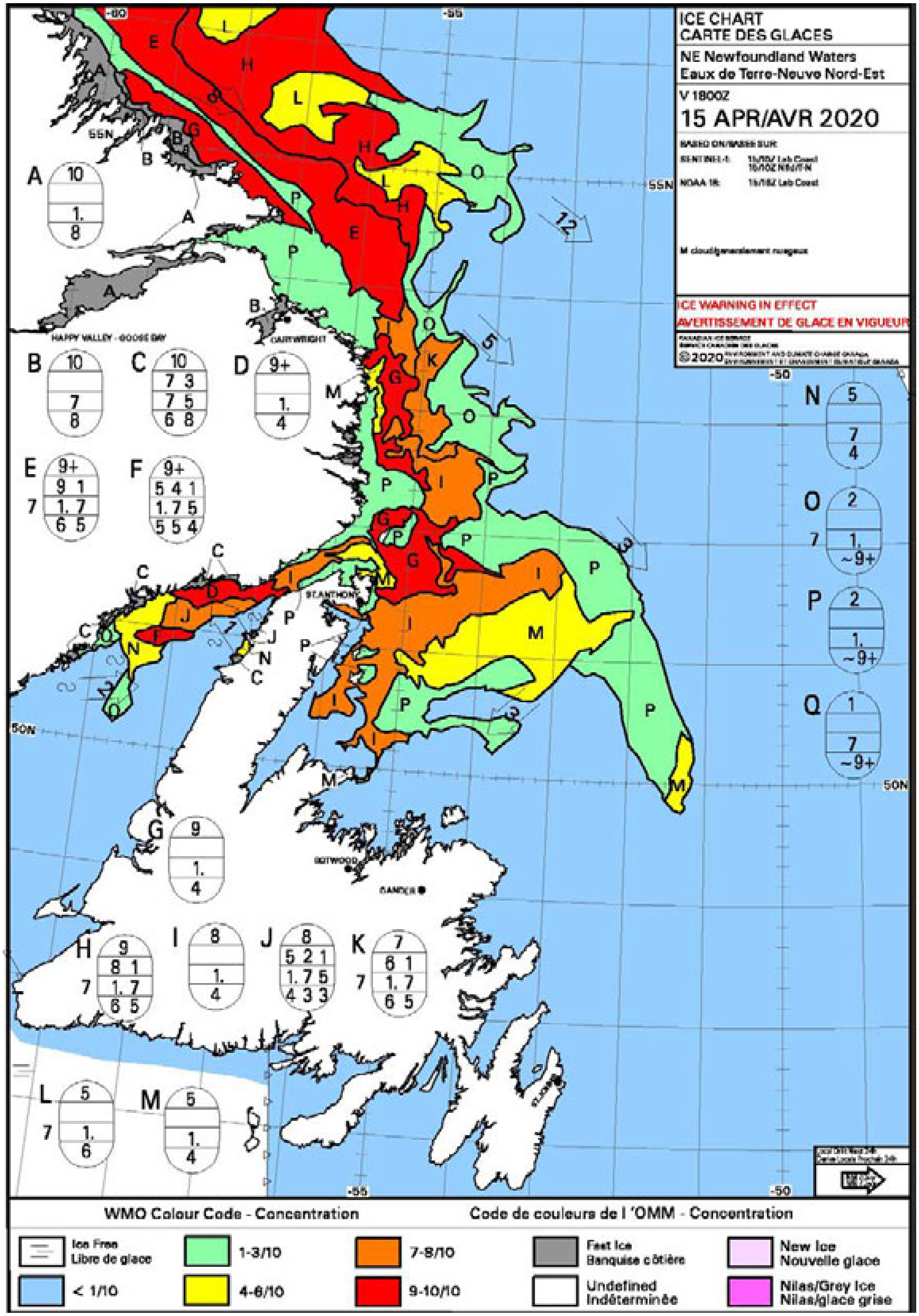
The following sea-ice charts for Northeast Newfoundland Waters are produced by the Canadian Ice Service.


ICE CHART
CARTE DES GLACES
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 JAN/JAN 2020
HAPPY VALLEY - GOOSE BAY
CARTWRIGHT
ST. ANTHONY
BOTWOOD
GANDER
NO ANALYSIS
PAS D'ANALYSE
55N
50N
-50
-55
WMO Colour Code - Concentration
Code de couleurs de l 'OMM - Concentration
Ice Free
Libre de glace
< 1/10
1-3/10
4-6/10
7-8/10
9-10/10
Fast Ice
Banquise côtière
Undefined
Indéterminée
New Ice
Nouvelle glace
Nilas/Grey Ice
Nilas/glace grise

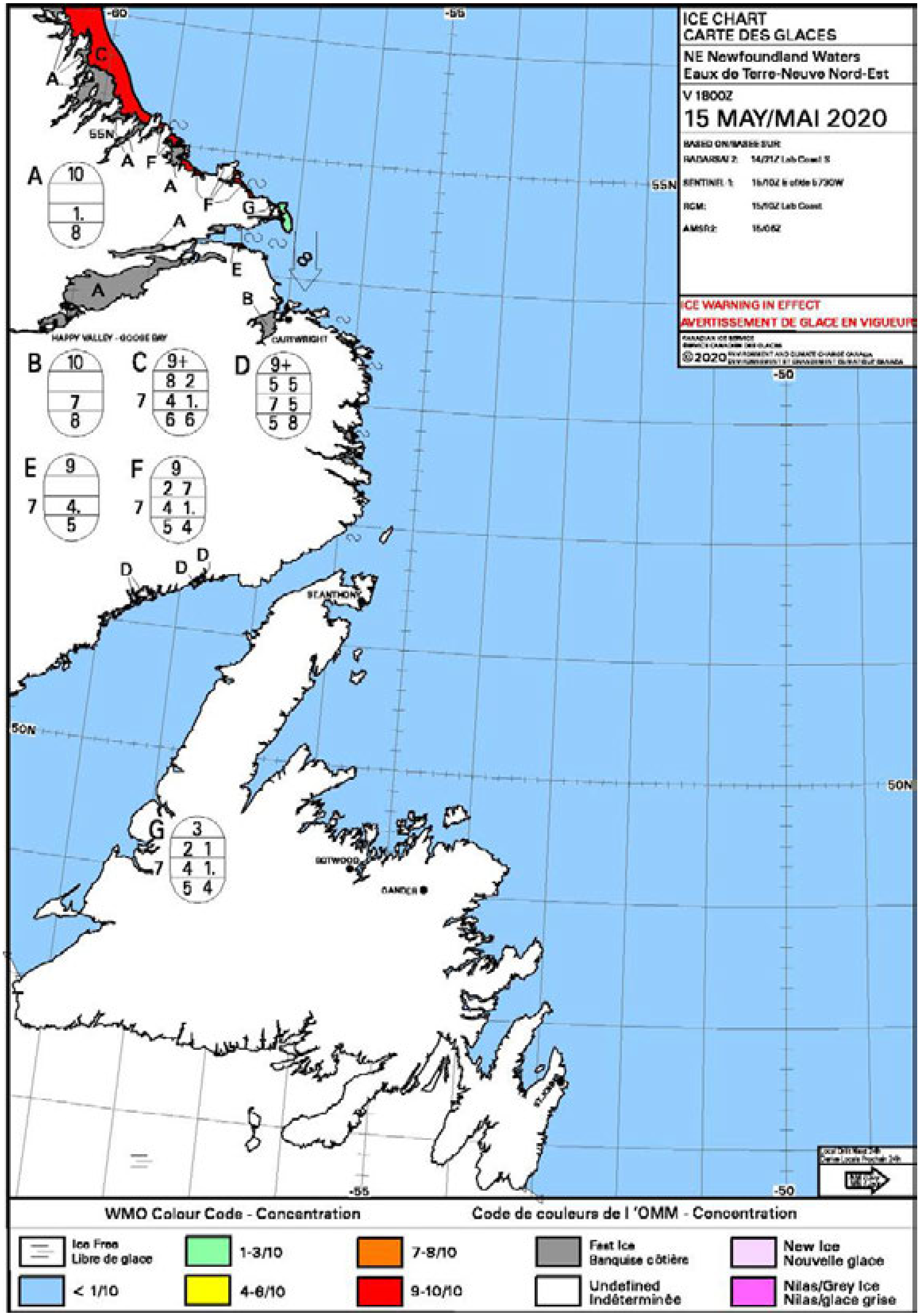


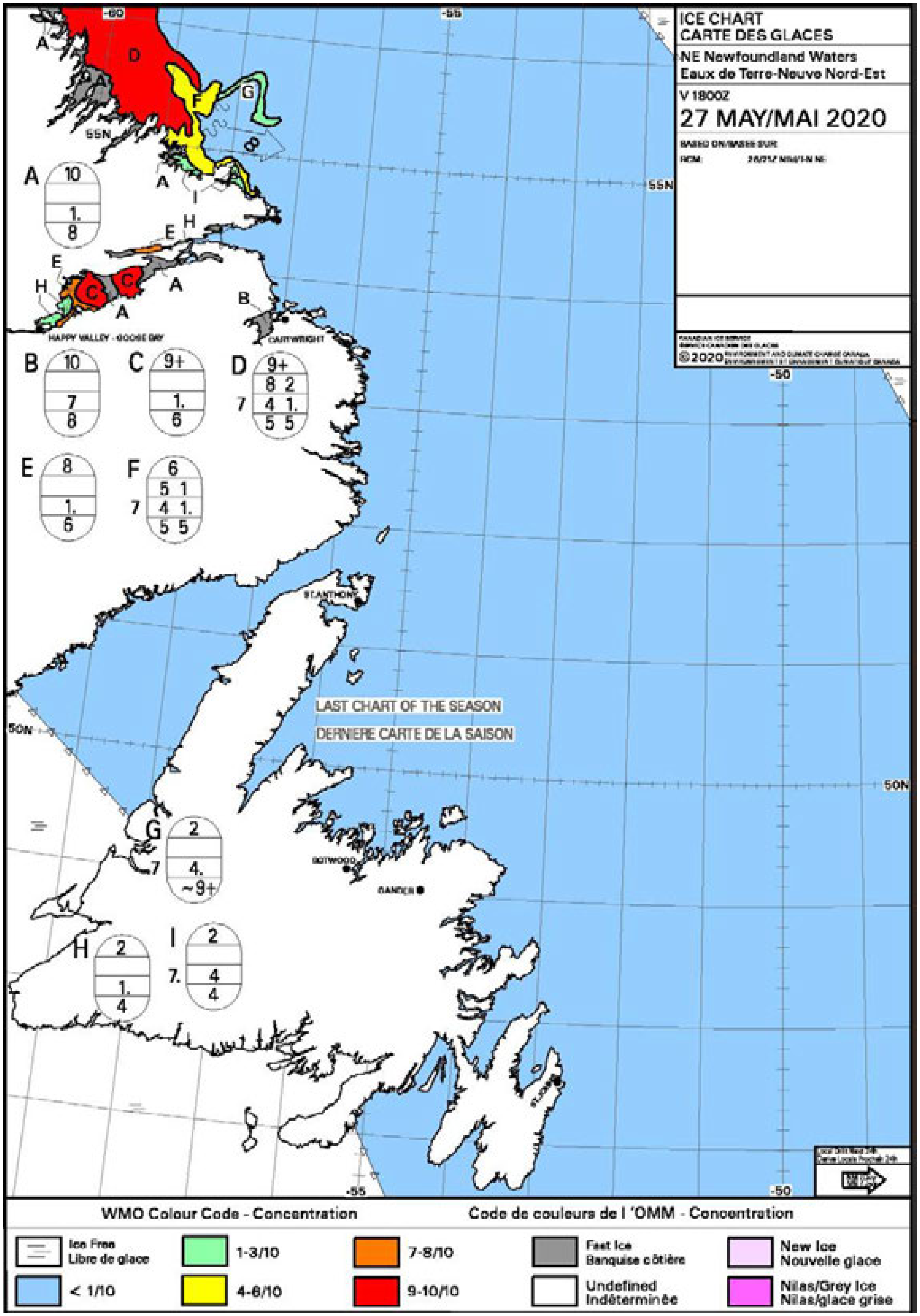
ICE CHART
CARTE DES GLACES
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 FEB/FEV 2020
ICE WARNING IN EFFECT
AVERTISSEMENT DE GLACE EN VIGUEUR
HAPPY VALLEY - GOOSE BAY
CARTWRIGHT
ST.ANTHONY
BOTWOOD
GANDER
WMO Colour Code - Concentration
Code de couleurs de l 'OMM - Concentration
Ice Free
Libre de glace
< 1/10
1-3/10
4-6/10
7-8/10
9-10/10
Fast Ice
Banquise côtière
Undefined
Indéterminée
New Ice
Nouvelle glace
Nilas/Grey Ice
Nilas/glace grise


ICE CHART
CARTE DES GLACES
East Newfoundland Waters
Eaux de Terre-Neuve est
V 1800Z
15 MAR/MAR 2020
BASED ON/BASEE SUR:
SENTINEL-1:
SENTINEL 1:
MODIS:
AMSR2:
ICE WARNING IN EFFECT
AVERTISSEMENT DE GLACE EN VIGUEUR
©2020
-55
-50
46N
ST. ANTHONY
BOTWOOD
GANDER
ST. JOHN'S
WMO Colour Code - Concentration
Code de couleurs de l 'OMM - Concentration
Ice Free
Libre de glace
1-3/10
7-8/10
Fast Ice
Banquise côtière
New Ice
Nouvelle glace
< 1/10
4-6/10
9-10/10
Undefined
Indéterminée
Nilas/Grey Ice
Nilas/glace grise



ICE CHART
CARTE DES GLACES
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 APR/AVR 2020
ICE WARNING IN EFFECT
AVERTISSEMENT DE GLACE EN VIGUEUR
HAPPY VALLEY - GOOSE BAY
CARTWRIGHT
ST ANTHONY
BOTWOOD
GANDER
WMO Colour Code - Concentration
Code de couleurs de l 'OMM - Concentration
Ice Free
Libre de glace
< 1/10
1-3/10
4-6/10
7-8/10
9-10/10
Fast Ice
Banquise côtière
Undefined
Indéterminée
New Ice
Nouvelle glace
Nilas/Grey Ice
Nilas/glace grise


ICE CHART
CARTE DES GLACES
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
15 MAY/MAI 2020
ICE WARNING IN EFFECT
AVERTISSEMENT DE GLACE EN VIGUEUR
©2020
-60
-55
-50
55N
50N
HAPPY VALLEY - GOOSE BAY
CARTWRIGHT
ST ANTHONY
BOTWOOD
GANDER
WMO Colour Code - Concentration
Code de couleurs de l 'OMM - Concentration
Ice Free
Libre de glace
< 1/10
1-3/10
4-6/10
7-8/10
9-10/10
Fast Ice
Banquise côtière
Undefined
Indéterminée
New Ice
Nouvelle glace
Nilas/Grey Ice
Nilas/glace grise


ICE CHART
CARTE DES GLACES
NE Newfoundland Waters
Eaux de Terre-Neuve Nord-Est
V 1800Z
27 MAY/MAI 2020
LAST CHART OF THE SEASON
DERNIERE CARTE DE LA SAISON
HAPPY VALLEY - GOOSE BAY
CARTWRIGHT
ST.ANTHONY
BOTWOOD
GANDER
55N
50N
-60
-55
-50
WMO Colour Code - Concentration
Code de couleurs de l 'OMM - Concentration
Ice Free
Libre de glace
< 1/10
1-3/10
4-6/10
7-8/10
9-10/10
Fast Ice
Banquise côtière
Undefined
Indéterminée
New Ice
Nouvelle glace
Nilas/Grey Ice
Nilas/glace grise

9. Acknowledgements

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

Aerospace Corporation

Canadian Coast Guard

Canadian Forces

Canadian Ice Service

Canadian Maritime Atlantic Command Meteorological and Oceanographic Centre

Canadian Meteorological Centre

Cold Regions Research Engineering Laboratory

C-CORE

Department of Fisheries and Oceans Canada

Danish Meteorological Institute

European Space Agency

German Federal Maritime and Hydrographic Agency

HDMS KNUD RASMUSSEN (P-570)

International Cooperative Engagement Program for Polar Research (ICE-PPR)

Joint Arctic Command

MacDonald, Dettwiler and Associates

National Geospatial-Intelligence Agency

National Research Council Canada

Nav Canada Flight Information Center

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 Assistant Commandant for Intelligence

USCG Atlantic Area

USCG Aviation Training Center Mobile

USCG Academy

USCG Cutter CAMPBELL (WMEC-909)

USCG Cutter TAHOMA (WMEC-908)

USCG Director of Marine Transportation Systems

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

U.S. Naval Research Laboratory

It is important to recognize the outstanding efforts of the personnel assigned to the International Ice Patrol during the 2020 Ice Year:

CDR M. T. Hirschberg

CDR K. L. Serumgard

CDR S. A. Koch

LCDR C. B. Bell

Mr. M. R. Hicks

Mrs. B. J. Lis

LT D. W. Rudnickas

LT A. R. Hamel

MSTC N. D. Brophy

MSTC M. A. Connell

MST1 S. A. Baumgartner

MST1 M. A. Berlin

YN1 W. R. Lawrence

YN1 J. I. Vega

IS1 M. A. Patti

IS1 V. A. Pacheco

MST2 J. Ambro

MST2 M. J. Brown

MST2 R. M. Hogan

MST3 J. P Leser

MST3 J. L. Crocker

IS3 P. D. Miller

Appendix A. Ship Reports for Ice Year 2020

Ships Reporting by Flag	Reports
BAHAMAS	
*ADMIRAL SCHMIDT	12
CANADA	
ARCTIC	4
ATLANTIC GRIFFON	1
CCGS DES GROSEILLIERS	3
CCGS LOUIS S. ST. LAURENT	11
CCGS PIERRE RADDISON	3
*CCGS HENRY LARSEN	12
HMCS GLACE BAY	1
MAERSK DETECTOR	3
MAERSK DISPATCHER	2
PAUL A. SACUTU	3
UMIAK 1	11
HONG KONG	
OOCL BELGIUM	5
MARSHALL ISLANDS	
FEDERAL BISCAY	1
FEDERAL YUKON	3
NUNAVIK	1
SONGA DIAMOND	1
NETHERLANDS	
VICTORIABORG	1
UNITED STATES	
NEIL ARMSTRONG	1

* Denotes the CARPATHIA award winner.

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

Appendix B. COVID-19 Impacts on 2020 Ice Season and International Ice Patrol's Mitigation Strategies

LCDR Caroline Bell

B-1. Introduction

The COVID-19 global pandemic began impacting the International Ice Patrol (IIP) in late March when cases rose in the U.S. and throughout the world. Travel restrictions and 14-day quarantine requirements for foreign deployments forced IIP to identify alternative options to meet its treaty obligation to monitor the risk of iceberg danger in the North Atlantic Ocean and provide relevant warning products to the maritime community. Through strong partnerships with the Canadian Ice Service (CIS), Air Station Elizabeth City (ASEC), and Coast Guard Atlantic Area (LANTAREA), and innovation by its skilled crew, IIP continued to conduct aerial reconnaissance in a limited fashion. The reduced USCG HC-130J aerial reconnaissance was augmented with increased commercial aerial reconnaissance and increased satellite reconnaissance to monitor the iceberg danger. Additionally, IIP implemented changes to the drift and deterioration model and iceberg warning product creation processes to provide more conservative iceberg limits for the maritime community. This appendix is intended to provide insight into the changes IIP made throughout the 2020 Ice Season to continue operations, and highlight key modernization steps and season severity details that enabled the effective implementation of these strategies.

B-2. Monitoring the Iceberg Danger with Reduced Iceberg Reconnaissance Detachments

On 12 March, IRD 3 returned from St. John's, Canada, having conducted IIP's 3rd, 4th and 5th patrol of the season. This would be IIP's last IRD deployment to St. John's for the 2020 Ice Season. As IRD 3 returned, COVID-19 began spreading rapidly around the world, leading to changes in USCG foreign travel guidance and quarantine policies. These changes made IRD deployments to St. John's, impossible for IIP and ASEC to sustain.

Given the uncertainty of how long COVID-19 would impact operations, IIP developed a three-pronged approach to continuing to monitor the iceberg danger given the restricted international travel. The three methods IIP employed to continue conducting iceberg reconnaissance consisted of increasing IIP-analyzed satellite reconnaissance, operating domestic IRDs deployed from USCG Air Station Cape Cod (ASCC), and coordinating with the CIS to increase the use of commercial aerial reconnaissance.

B-2-A. Satellite Reconnaissance

While satellite reconnaissance cannot replace the accuracy of aerial reconnaissance, it was determined that increased exploitation of satellite frames would provide valuable iceberg population data both inside the Iceberg Limit and along the Labrador coast. The following measures were taken to bolster IIP's satellite reconnaissance:

1) IIP more than doubled the number of frames analyzed per day to improve coverage in the OPAREA. The number of personnel analyzing satellite frames was doubled throughout the remainder of the season, and satellite analysis was conducted every day, as opposed to only during the work week.

2) Coordination between IIP's Intelligence Specialists and the Coast Guard's Maritime Intelligence Fusion Center Atlantic (MIFC LANT) assisted with the challenging task of determining whether a target was a vessel, or an iceberg.

3) IIP developed a script that automated many of the labor-intensive pre-filtering steps required to reduce the possible targets identified by the Iceberg Detection Software (IDS), significantly decreasing the amount of time required to analyze each frame.

4) For the first time, visible band imagery from Sentinel-2 satellites was used on a routine basis and incorporated into the iceberg database. While Sentinel-2 images require cloud-free conditions to be useful, when conditions permit, its higher resolution can more easily differentiate an iceberg from a ship than Sentinel-1's synthetic aperture radar (SAR).

5) A script and procedures were developed by IIP staff to automate the identification of targets in Sentinel-2 imagery, since the Iceberg Detection Software cannot ingest Sentinel-2 data. A process was also pioneered to leverage Sentinel-2's multispectral capabilities to "see" through thin, high clouds, increasing the quantity of useful Sentinel-2 imagery.

B-2-B. Domestic Iceberg Reconnaissance Detachment Deployments

IIP's Operations Branch worked closely with ASEC Assistant Operations Officer (AOPS) and the LANTAREA C-130 scheduler to provide alternate deployment options to conduct aerial reconnaissance from locations in New England. It was determined that USCG Air Station Cape Cod (ASCC) was the best option, balancing aircraft support, IRD logistics, available patrol time, and limiting the risk of COVID-19 from public contact. ASCC provided two intersecting runways with instrument landing systems (ILS), ramp space for the C-130 to remain overnight and available fuel, proving the best option for aircraft support services. With the increased transit times to the OPAREA resulting in reduced reconnaissance, IIP took the following actions to mitigate limited patrol time:

1) CIIP authorized changes to standard flight planning guidance while deploying from ASCC. Track spacing on all patrol legs was increased from 25 NM to 30 NM, allowing for two track legs to fully cover the maximum error circle around a modeled iceberg. This increase allowed IIP to cover more area during each patrol.

2) IRDs prioritized the southern Iceberg Limit, using two sorties to cover the Southern Limit to the maximum extent possible. The secondary priority was to cover the area just inside the Southern Limit and any areas of oceanographic significance, such as a cold water feature or cold core eddy that could prevent icebergs from deteriorating quickly.

B-2-C. Canadian Ice Service Procured Aerial Reconnaissance

CIS uses commercial aircraft though a Government contract with PAL Aerospace in St. John's, Newfoundland for iceberg reconnaissance. These flight hours are generally used from August through January, when IIP is not conducting IRDs. Given the uncertainty of IIPs ability to conduct aerial reconnaissance and limited area that could be covered from domestic deployment locations, IIP coordinated with CIS' Operations Manager to employ a portion of their commercial aircraft hours in April and May while the threat of iceberg danger to transatlantic maritime shipping is greatest.

1) IIP leveraged its outstanding partnership with the Canadian Ice Service (CIS) to plan additional PAL Aerospace commercial iceberg detection flights. CIS was able to secure an additional 45 flight hours in April and May using flight plans developed by IIP.

2) IIP watchstanders developed flight plans to meet deletion criteria and allow full coverage of modeled error circles around icebergs. IIP also requested, through CIS, amplifying on scene weather conditions including sea state and visibility for each flight.

3) Flight plans concentrated on areas out of reach from Cape Cod, including the eastern and western Iceberg Limits, and along the 1,000m contour. Commercial aircraft used by PAL for the CIS-contracted flights could conduct 4 hour patrols. These flights did not have the same endurance as a C-130J, but provided valuable reconnaissance of the eastern and western Iceberg Limits.

B-3. Provide Relevant Warning Products to the Maritime Community

Equally as important to conducting the reconnaissance portion of IIP's mission to monitor the danger, IIP is required to provide relevant warning products to the maritime community. IIP took a similar multi-faceted approach to providing relevant warning products to the maritime community to balance the limited aerial reconnaissance. IIP met its IMO SOLAS responsibility to find the balance of safety and maritime mobility by providing timely warning to mariners of the reduced iceberg reconnaissance, implementing changes to better use the two available iceberg drift and deterioration models, and changes to the daily warning products that remained throughout the 2020 Ice Season.

B-3-A. Warnings to Users

On 18 March IRD 4 was canceled, leaving a great deal of uncertainty in IIPs ability to conduct aerial reconnaissance for the foreseeable future. Through IRD 3, IIP unfavorable weather conditions caused a lower than average number of IIP aerial reconnaissance patrols. Combining the cancelation of IRD 4 with a low number of IRD patrols, CIIP directed warnings be issued to alert the maritime community of reduced reconnaissance around IIPs Iceberg Limits.

1) IIP notified the Canadian Marine Communications and Traffic Service Station (MCTS) to issue a NAVWARN broadcast alerting mariners of reduced aerial reconnaissance and to transit the Iceberg Limits with caution on 18 March. A similar warning was posted as a banner to the "Products" page of IIP's website.

2) Daily iceberg products beginning with those valid for 0000Z on 19 March included the text: "WARNING! The International Ice Patrol is experiencing reduced iceberg reconnaissance. Please navigate with caution."

3) The following note was included in the GovDelivery email distribution of IIPs daily warning products:
    a. "NOTE: The International Ice Patrol is experiencing reduced iceberg reconnaissance. In response, we are increasing our use of iceberg modeling to assess iceberg danger and are conservatively establishing the Iceberg Warning Limit to ensure it encompasses potential iceberg hazards for the safety of mariners. Additionally, the Iceberg Limit is now considered an Estimated Iceberg Limit as indicated on the NAIS-65 graphic and NAIS-10 Bulletin. Please navigate with caution and report all iceberg sightings to the International Ice Patrol or the nearest Canadian Coast Guard Marine Communications and Traffic Services Station."

B-3-B. Drift and Deterioration Modeling

Within BAPS, IIP is able to run two different iceberg drift and deterioration models, the IIP model and the NAIS model. The models vary in how they apply environmental conditions to the drift and deterioration of icebergs. The current BAPS software, however, does not allow the models to be run fully independent of each other, limiting the ability to conduct ensemble modeling for individual icebergs. IIP developed a method to better utilize the two drift and deterioration models available:

1) To create an ensemble of the two models. IIP's IT specialist implemented a parallel but separate system to run the NAIS model independently of the IIP model. The iceberg database was copied onto a separate BAPS workstation independent of the main BAPS workstation for the NAIS model.

2) The separate iceberg database allowed the watch officer to run the NAIS model independently of the IIP model. During each watch all iceberg messages, daily iceberg deletions, and model runs were conducted on both the NAIS and IIP model workstations.

3) The process doubled the workload of the OPCEN watchstanders, but leveraging the two models within BAPS separately allowed an ensemble approach to creating the daily Iceberg Limit.

B-3-C. Warning Product Generation

BAPS software inhibits IIPs ability to modify environmental inputs. Without aerial reconnaissance IIP also lost the ability to deploy surface velocity program buoys which are used to capture real-time current information in the climatological current database used by the IIP model. New, more conservative business rules were implemented in daily Iceberg Limit creation to account for the limitations to model results and limited aerial reconnaissance:

1) Icebergs would remain in the BAPS iceberg database until the modeled melt percentage was 200% or greater; increased from the 150% normal deletion criteria.

2) The buffer between modeled iceberg error circles and the limit was increased from 30NM to 45NM.

3) Results from the independent NAIS model and IIP model were used together for daily Iceberg Limit creation. Limits were drawn around the most extreme positioned icebergs from the two models.

4) All iceberg limits published beginning with the warning products valid for 0000Z 19 March became estimate iceberg limits, identified either through text on the NAIS 10 Bulletin or a dotted line on the NAIS 65 Chart.

B-4. Conclusion

Perhaps more important than any of the mitigation strategies IIP implemented to continue operations during the global COVID-19 pandemic was the fortuitously light Ice Season. IIP recorded 169 icebergs sighted or drifted below 48°N, compared to 1,515 in

2019. Environmental conditions south of 48°N did not favor the long survival of iceberg drifting to the tail of the Grand Banks. Limit setting icebergs remained more than 3 degrees further north than in 2019, with the southernmost berg reaching only 44°38.4'N in late April (**Section 2. Ice and Environmental Conditions**). Additionally, very few icebergs drifted near or over the Flemish Cap to expand the eastern Iceberg Limit. Commercial aircraft could reach icebergs near the Flemish Cap, but would have limited on scene time to search or meet IIP deletion criteria. IIP ingested around 14,000 fewer icebergs into the model in 2020, compared to 2019. These factors led to the success and short term sustainability of IIPs COIVD-19 mitigation strategies.

IIP was able to successfully provide iceberg warning products to the maritime community and continue to conduct monitoring of the iceberg danger in the North Atlantic, however, there were many challenges that made these efforts unsustainable as permanent changes. Key challenges include: 1) reduced on scene patrol time for domestic based IRD deployments limiting the area IIP could conduct aerial reconnaissance, 2) cost and endurance of commercially available aerial reconnaissance, 3) continued uncertainty of detecting and discriminating small icebergs in SAR imagery near critical limit areas, and 4) doubling the workload placed on IIP watchstanders processing iceberg messages in two separate models.

Steps taken during recent years to modernize IIP's operations, and the ingenuity and dedication of IIP's superb crew led to the success of the 2020 Ice Season in spite of the unprecedented circumstances.

Appendix C. Satellite-Derived, Tailored Iceberg Products in Support of USCGC CAMPBELL

LT Don Rudnickas, Mr. Michael Hicks

C-1. Introduction

Late in 2019, the International Ice Patrol (IIP) received a request to support USCGC CAMPBELL (WMEC-909) during their participation in international operations NANOOK and Search and Rescue Exercise ARGUS off the west coast of Greenland in 2020. CAMPBELL was to be the first vessel in its class to cross the Arctic Circle. As a non-ice class vessel with a crew that lacked polar experience, the ship was particularly vulnerable to damage from an iceberg collision in this hazardous region. Operations took place over

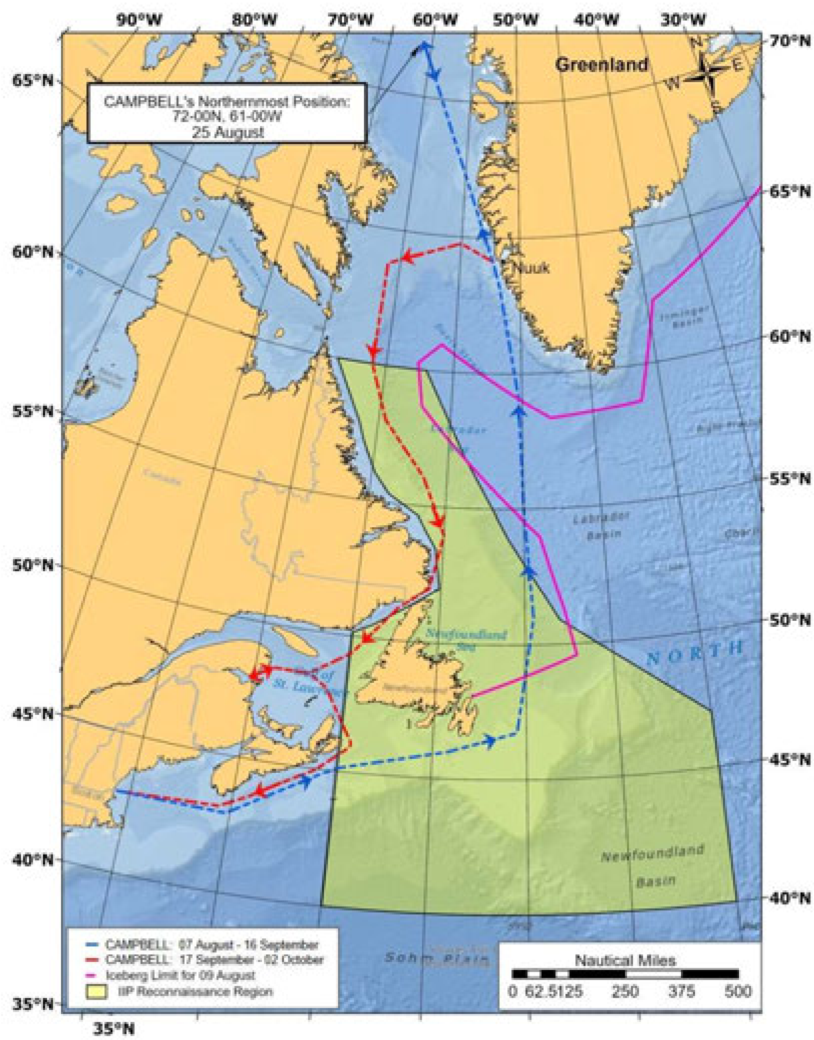


Figure C-1. IIP Reconnaissance Region with approximate track for CGC CAMPELL from 07 August – 02 October. CAMPBELL operated outside of IIP's normal OPAREA and inside the Iceberg Limit (magenta line) for 43 days during its Arctic Patrol.

1,200NM north of the Grand Banks of Newfoundland, IIP's typical operations area (OPAREA) **(Figure C-1)**. Without traditional aerial reconnaissance, IIP drew on its experience in satellite reconnaissance to provide a suite of detailed iceberg products, well beyond traditional Iceberg Limit products mandated for transatlantic shipping. CAMPBELL operated in or near iceberg waters from August 10 to September 20, 2020.

In total, IIP analyzed 317 satellite frames between August 8 and September 20, tracking over 11,000 individual icebergs, and provided 117 iceberg warning products. This Appendix describes the development process for IIP's prototype products, summarizes the tactical support provided by IIP to CAMPBELL and outlines the feedback and support by CAMPBELL to improve the IIP mission. Finally, it summarizes lessons learned from this unique experience.

C-2. Background

IIP has been investigating the use of remote sensing for iceberg detection and identification since the mid-1990s (IIP, 2018). In 2017, the availability of Sentinel-1 synthetic aperture radar (SAR) at no-cost, coupled with access to C-CORE's automated Iceberg Detection Software (IDS) empowered IIP to begin routinely incorporating SAR satellite-derived iceberg detections into its operations. During that year, IIP applied its new SAR image analysis skills to provide basic iceberg density products to USCGC MAPLE while sailing through Baffin Bay after its historic transit through the Northwest Passage. Today, with three years of experience analyzing multiple SAR targets, analyst proficiency has improved dramatically such that satellite-derived detections exceeded aerial and ship reports in 2020. Internally developed Python code has significantly reduced the need for human intervention during download of multiple images and execution of the iceberg detection software (IDS). Additional coding has also enabled automation of iceberg density calculations and production of density contours in ArcGIS.

In 2020, IIP reached a new milestone that brought multi-spectral imagery from Sentinel-2 satellites into operations. Unlike SAR imagery, cloud cover significantly limits the utility of this data source. To address this challenge, IIP developed another computer algorithm to exploit differences in responses to various objects in three different Sentinel-2 bands (utilizing blue, short-wave infrared, and thermal infrared wavelengths). This routine allows analysts to effectively 'see' through thin clouds, making Sentinel-2 an invaluable source for identifying ambiguous radar targets under optimal conditions.

C-2-A. Iceberg Limit vs. Iceberg Density Products.

Since its inception, IIP has communicated iceberg danger to transatlantic mariners by using the Iceberg Limit as its primary mechanism. In most cases, a ship remaining outside of the published limit will not encounter an iceberg. Since IIP frequently establishes the Iceberg Limit based on the position of a single iceberg, this product places a premium on the detection and proper identification of individual iceberg hazards approaching the Iceberg Limit. The cost of incorrectly designating a radar target as a hazard or, even worse, incorrectly identifying an iceberg as a ship or false alarm, is tremendous and still demands the use of aerial reconnaissance. This approach assumes that the primary user wants to transit across the Atlantic following the safest, most efficient path. IIP's traditional customers do not desire nor expect to see ice during their transit.

Providing iceberg information to a vessel that must operate in a region of known iceberg hazards requires a different approach. An iceberg density product seeks to inform a ship's captain of the likelihood of encountering icebergs during operations. Armed with information about the expected iceberg density (defined as the distance between icebergs within a depicted region on an iceberg chart), a ship's captain can reduce speed, adjust course, or take other precautions to improve its readiness to navigate safely in an iceberg dense environment. Recognizing this need, the ice services of the International Ice Charting Working Group (IICWG) defined iceberg density in very simple terms of Isolated, Few, and Many where iceberg density is designated as Isolated if there is more than 45NM between icebergs; Few if there is 10-44NM between icebergs; and Many if there is less than 10NM between icebergs.

Dramatic improvements in automation, both with SAR and multi-spectral imagery, positioned IIP to provide relevant and useful iceberg density products to CAMPBELL. This work sets the standard for future IIP support to the increasing number of Coast Guard and partner vessels transiting northern waters. However, it is important to note that the processes required to provide tailored products are still quite new to IIP staff and proved labor intensive, even with the automation steps described. Offering this level of support for extended periods, beyond an annual transit of a USCG cutter would require significant changes to personnel training and organizational staffing. IIP leadership must carefully consider human resources prior to committing to this level of support for future operations, particularly during the traditional iceberg reconnaissance season from February through July.

C-3. Satellite Reconnaissance

C-3-A. Satellite Coverage.

Prior to August 7, the Danish Meteorological Institute (DMI) provided IIP with results from their automated classification algorithm to detect and classify icebergs outside of IIP's OPAREA and IIP used these results to create the iceberg warning products. During CAMPBELL's deployment (after August 7), IIP conducted daily satellite reconnaissance for icebergs throughout the coast of Greenland, Davis Strait, and the Labrador Sea and used the results as the basis for prototype iceberg products. Sample Sentinel-1 coverage during the week of 10-16 August illustrates the advantage of satellite revisit rate in CAMPBELL's primary OPAREA **(Figure C-2, left).** Sentinel-2 coverage in northern latitudes **(Figure C-2, right)** is also more abundant than in IIP's typical OPAREA, further south.

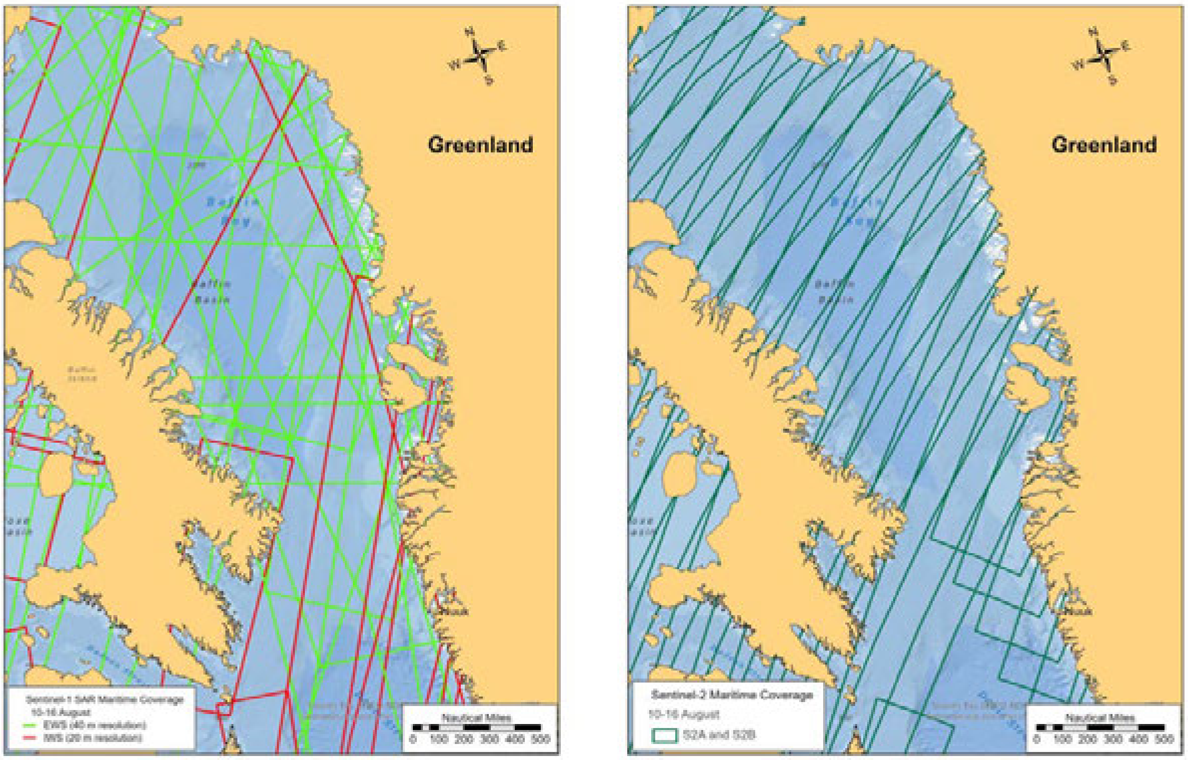


Figure C-2. Sentinel-1A and -1B maritime acquisition plan for 10-16 August (left). Red rectangles are Interferometric Wide Swath (IW) (250KM) and green are Extra Wide Swath (EW) (400KM). Sentinel-2A and -2B coverage (right panel).

Much like DMI, IIP used the European Commission's Sentinel-1 SAR imagery as its primary sensor for developing iceberg density products. As a polar-orbiting satellite, Sentinel-1 spatial coverage improves significantly at northern latitudes. In a typical week while supporting CAMPBELL, IIP downloaded more than 40 SAR images.

IIP analyzed a total of 317 satellite frames in support of CAMPBELL's deployment. These included Sentinel-1 Interferometric Wide Swath (IW), Sentinel-1 Extra Wide Swath (EW), Radarsat-2 Wide-Fine, Sentinel-2 Multispectral imagery, and Landsat-8 Operational Land Imager (OLI) imagery.

C-4. Prototype Iceberg Products Development

C-4-A. Iceberg Density Contours.

IIP began seeking feedback on content and display for iceberg information from the Commanding Officer and crew of CGC CAMPBELL in early May. On 04 May, IIP provided the first of many sample products to CGC CAMPBELL in order to get feedback on what the crew would like to have included (**Figure C-3**). During this process, CAMPBELL and

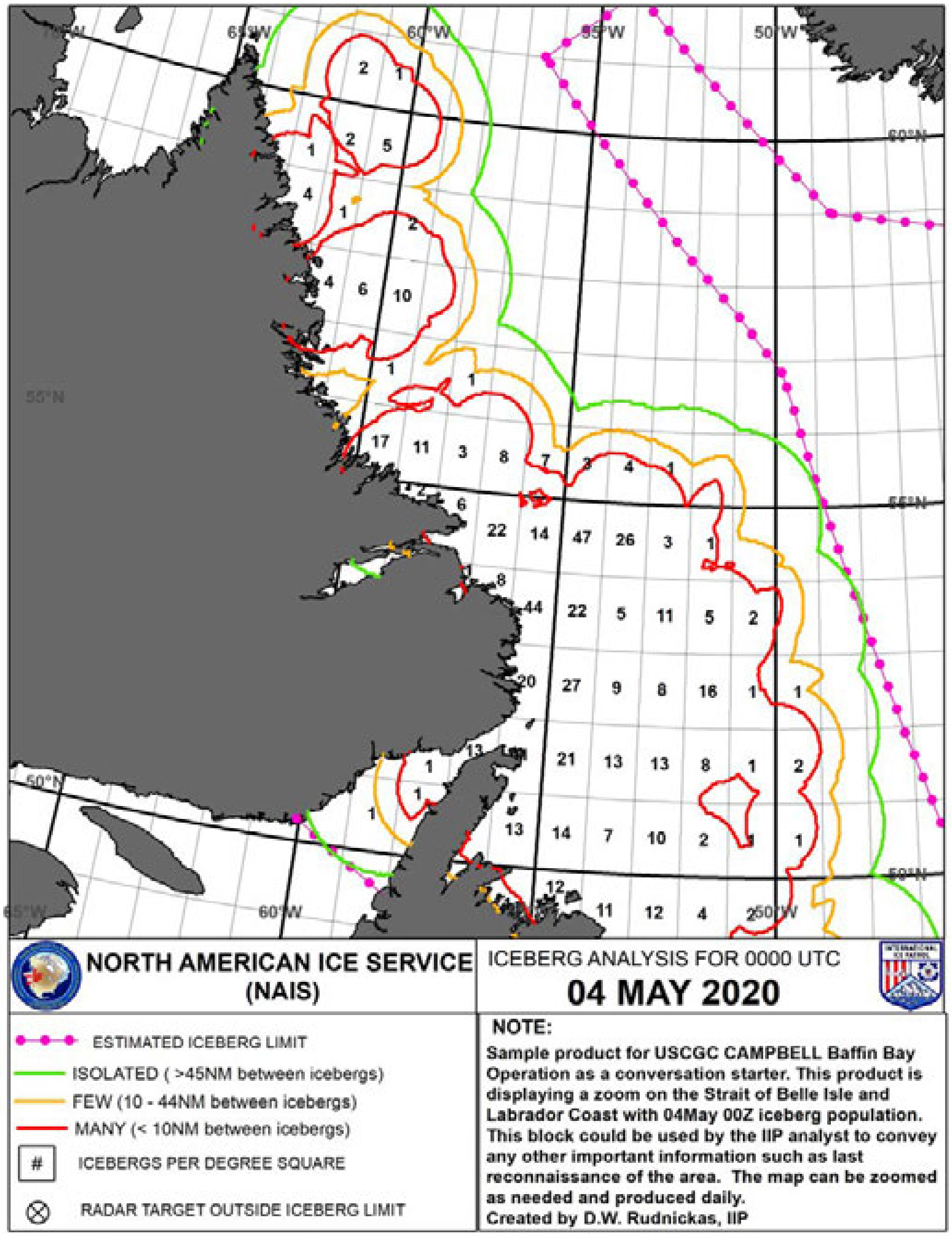


Figure C-3. The first of the prototype products supplied to CGC CAMPBELL. Includes the Isolated-Few-Many Contours, Iceberg Limits, and the number of icebergs within each 1°Latitude by 1°Longitude Grid Cell.

IIP identified three primary features: scalability, 24/48 hour forecasting, and depiction of iceberg distribution using internationally accepted standards.

From the beginning of this mission, IIP had already intended to use the support of CGC CAMPBELL to generate user feedback on contours of Isolated, Few, and Many to depict iceberg distribution. The Senior Ice Advisor at the Danish Meteorological Institute (DMI) pioneered its first operational use to guide vessels operating in a similar environment as CAMPBELL's planned OPAREA, demonstrating the usability and value of this information. IIP incorporated these contours on the first sample product and they were included on all subsequent scheduled products.

C-4-B. Ancillary Iceberg and Oceanographic Information.

During the product development process, CAMPBELL requested that IIP include several key pieces of ancillary information to improve their situational awareness. These included the:

(1) Location of individual icebergs on the plot. This is typically a level of detail not publically provided by IIP due to liability arising from model uncertainties though the value of including this data is not surprising. IIP provided detailed explanation of model uncertainties during an in-person briefing to CAMPBELL's crew in early July. For the products, IIP provided the location of the most recent sighting for each iceberg symbolized by size.

(2) Forecasted iceberg positions (+24/48 hour). IICWG also identified this as a highly desired piece of information for future iceberg products.

(3) Modeled 24-hour surface to 50m averaged current vectors from the Canadian East Coast Ocean Model (CECOM). To improve readability, IIP included these on small scale products only.

(4) IIP's daily published Iceberg Limit while CAMPBELL operated in its vicinity.

C-4-C. Product Scaling and Production Cycle.

IIP developed products based on the anticipated location of CAMPBELL over the coming days or at the request of the crew. Typically, IIP sent four products by e-mail every other day – two at a small scale (1:5,000,000) and two at a larger scale (1:2,000,000). **Figures C-4** and **C-5** are examples of small and large scale products, respectively, as the products looked toward the end of the deployment.

On several occasions, the crew requested additional products at higher resolution, including within fjords, in the vicinity of Nuuk, in Disko Bay, and along possible routes to assist with the avoidance of foul weather.

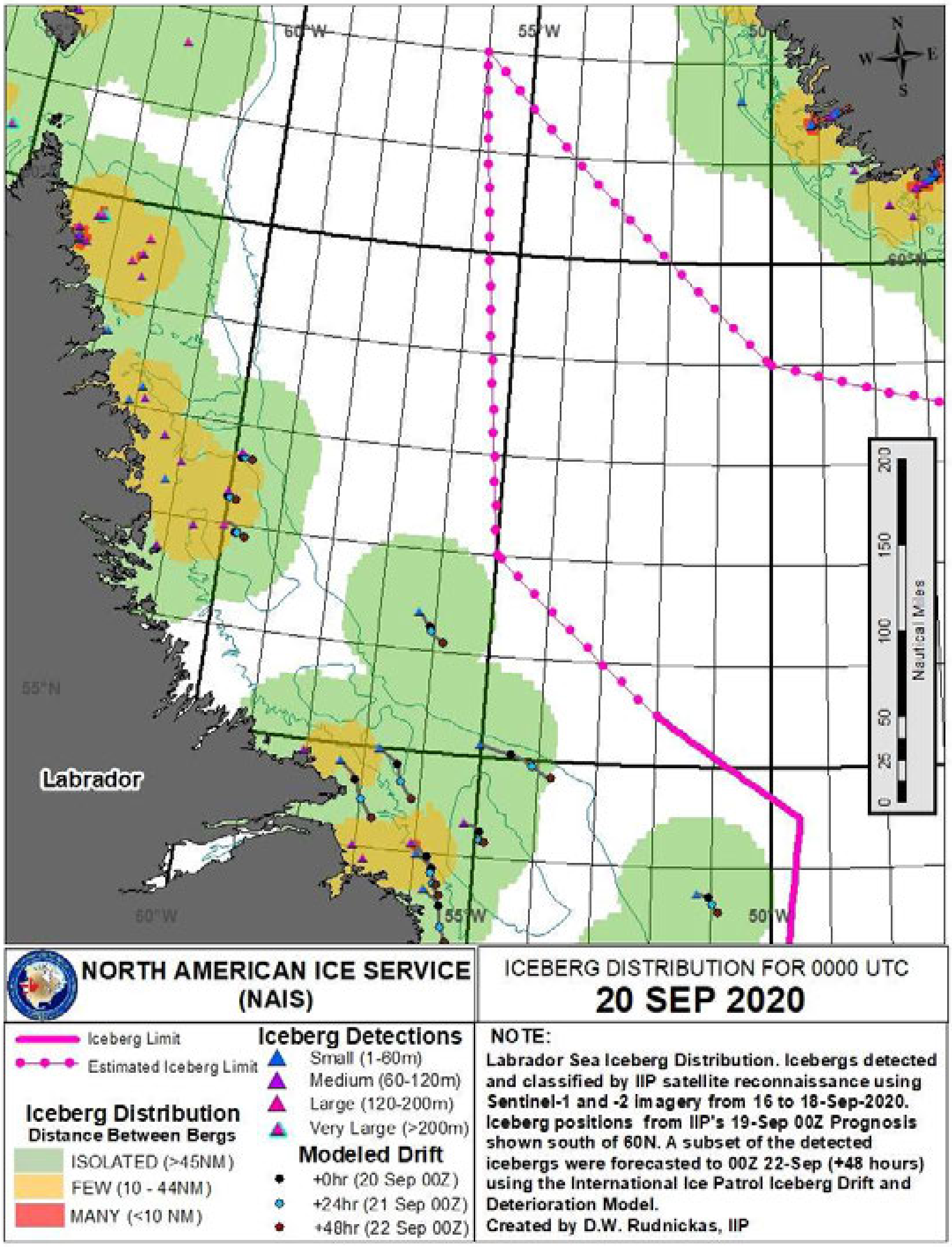


Figure C-4. The final version of the prototype iceberg products supplied to CGC CAMPBELL. In this case, a small-scale product showing the Labrador Coast. Includes the Isolated-Few-Many Contours, Iceberg Limits, and the individual positions of iceberg sightings symbolized by their estimated size and +24/48 hour modeling.

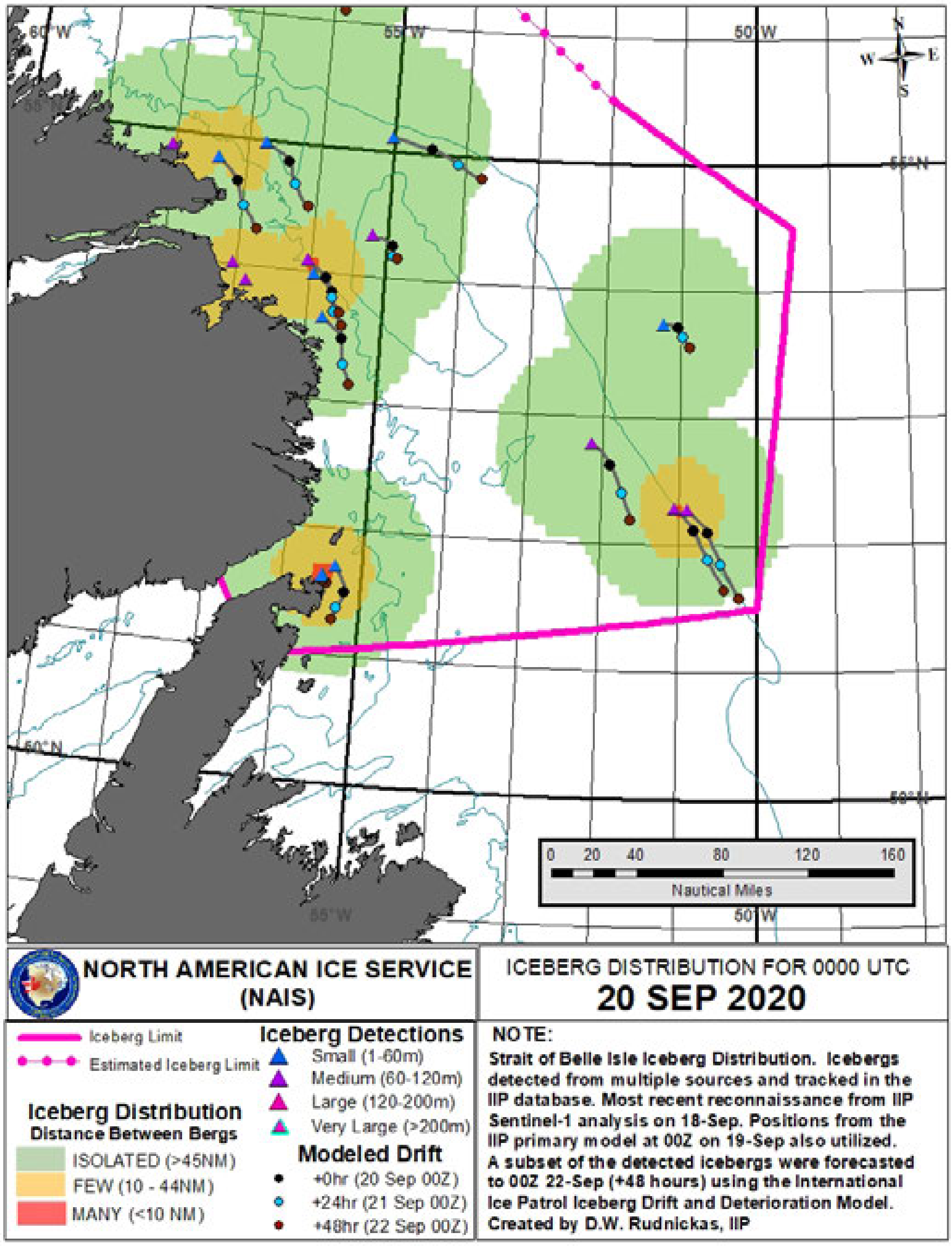


Figure C-5. The final version of the prototype iceberg products supplied to CGC CAMPBELL. In this case, a large-scale product showing the Approach to the Strait of Belle Isle. Includes the Isolated-Few-Many Contours, Iceberg Limits, the individual positions of iceberg sightings symbolized by their estimated size, and +24/48 hour modeling.

C-5. Support for other Vessels

Though CGC CAMPBELL was the primary recipient of all the iceberg warning products, several other involved vessels received them. Of note, CGC TAHOMA participated with short notice in the first two weeks of the exercises and became a primary addressee during that time. Two US Navy vessels, the 2nd Fleet Meteorological and Oceanographic Office, Danish vessels participating in the exercises, and their shore-side planning offices also received the products. Over the course of the mission, IIP received a request through the U.S. Secretary for the International Cooperative Engagement Program for Polar Research (ICE-PPR) to support a Danish vessel, HDMS KNUD RASMUSSEN, as it transited to Thule Air Force Base, Greenland. For this effort, IIP conducted iceberg reconnaissance in the northern areas of Baffin Bay and in the vicinity of Thule, providing several large and small scale products and providing the US National Ice Center (USNIC) with iceberg positions and the Isolated-Few-Many contours for a joint product. This transit, though ancillary to the CGC CAMPBELL mission, helped to exercise workflows and capabilities with the USNIC, one of IIP's key NAIS partners, and provided another audience with which to test aspects of the prototype products.

C-6. Product Feedback Survey Results

After support to CGC CAMPBELL had concluded, IIP distributed a user survey to all recipients of the products from July through September. The aim was to determine how the products were being used and which features were most valuable for a future product. Fourteen recipients responded to the survey. The full list of survey questions are included in the Supplemental Material of this Appendix and **Figure C-6** shows a graphic depiction of some of the key results.

Figure C-6 (a) and **(b)** show that 64% of respondents described themselves as vessel operators/navigators and the same number reported having no experience operating in the vicinity of icebergs. **Figure C-6 (c)** shows that users mostly utilized the products for daily navigation (0-24 hours) and least used the products for long-term planning (greater than 48 hours) and **(d)** shows that most users would like to see individual iceberg positions, sizes, and forecasted positions on scalable future charts. The low ranking of the published iceberg limit in this survey should be viewed through the lens of the target audience. The recipients of these products were operating within the published iceberg limit, and therefore, knowing its location was of little use to them. A vessel trying to avoid areas of icebergs entirely may respond to this ranked question differently.

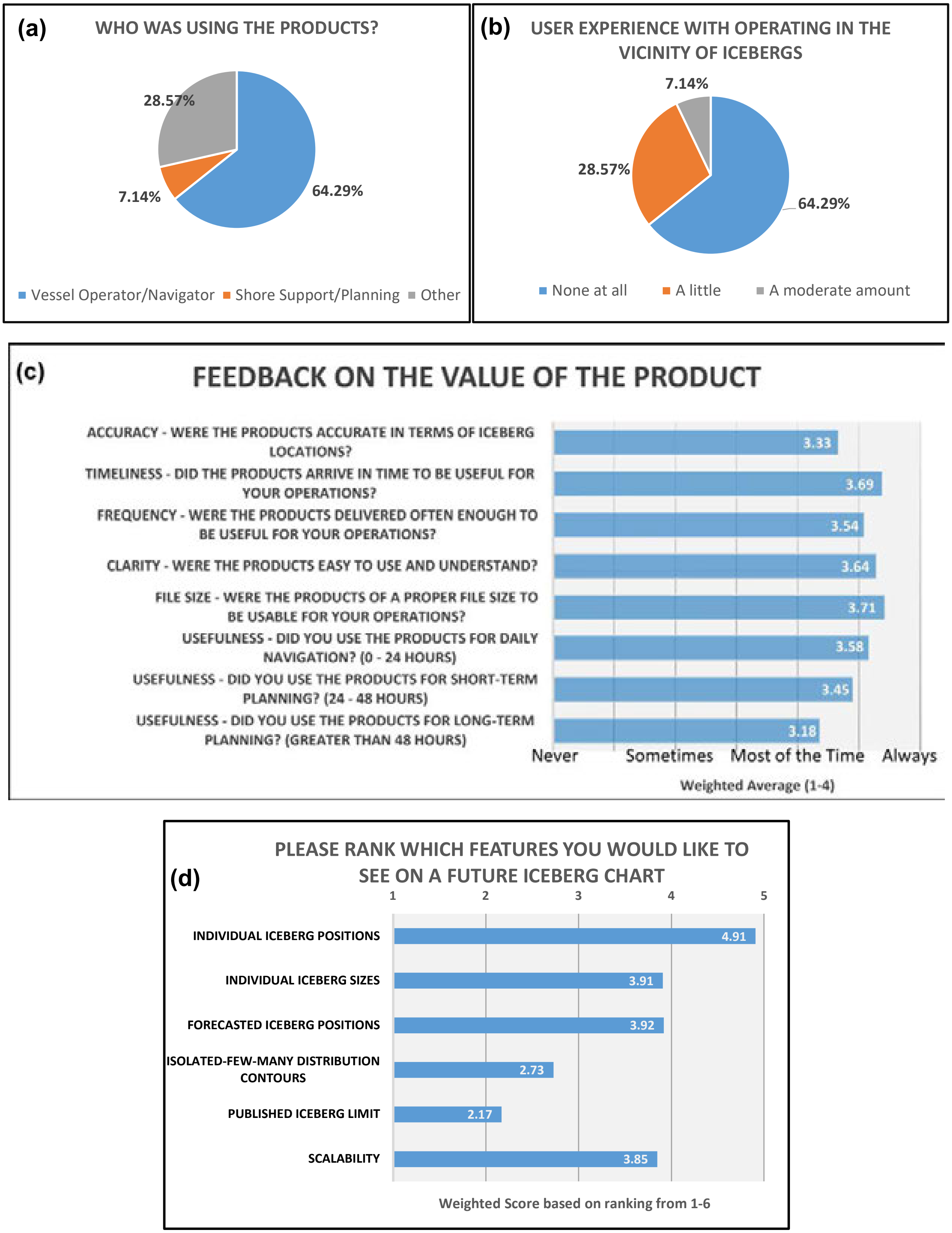


Figure C-6. Subset of results of the user survey (Supplemental Figure C-1) sent to all recipients of the prototype products. There were a total of 14 respondents.

C-7. Support from CGC CAMPBELL

In addition to providing real-time feedback on the prototype iceberg products, CAMPBELL provided IIP with other information. CAMPBELL deployed four 50m Surface Velocity Profiling (SVP) Buoys that will provide information on ocean currents that influence iceberg drift toward the transatlantic shipping lanes. **Figure C-7** shows their deployment locations and drift as of 14 October. These will continue to be monitored throughout their life-span. CAMPBELL also reported the positions and sizes of 44 icebergs sighted by the cutter (**Figure C-8**) that will be used as ground-truthed iceberg positions to help improve IIP's satellite detection and classification processes and ability.

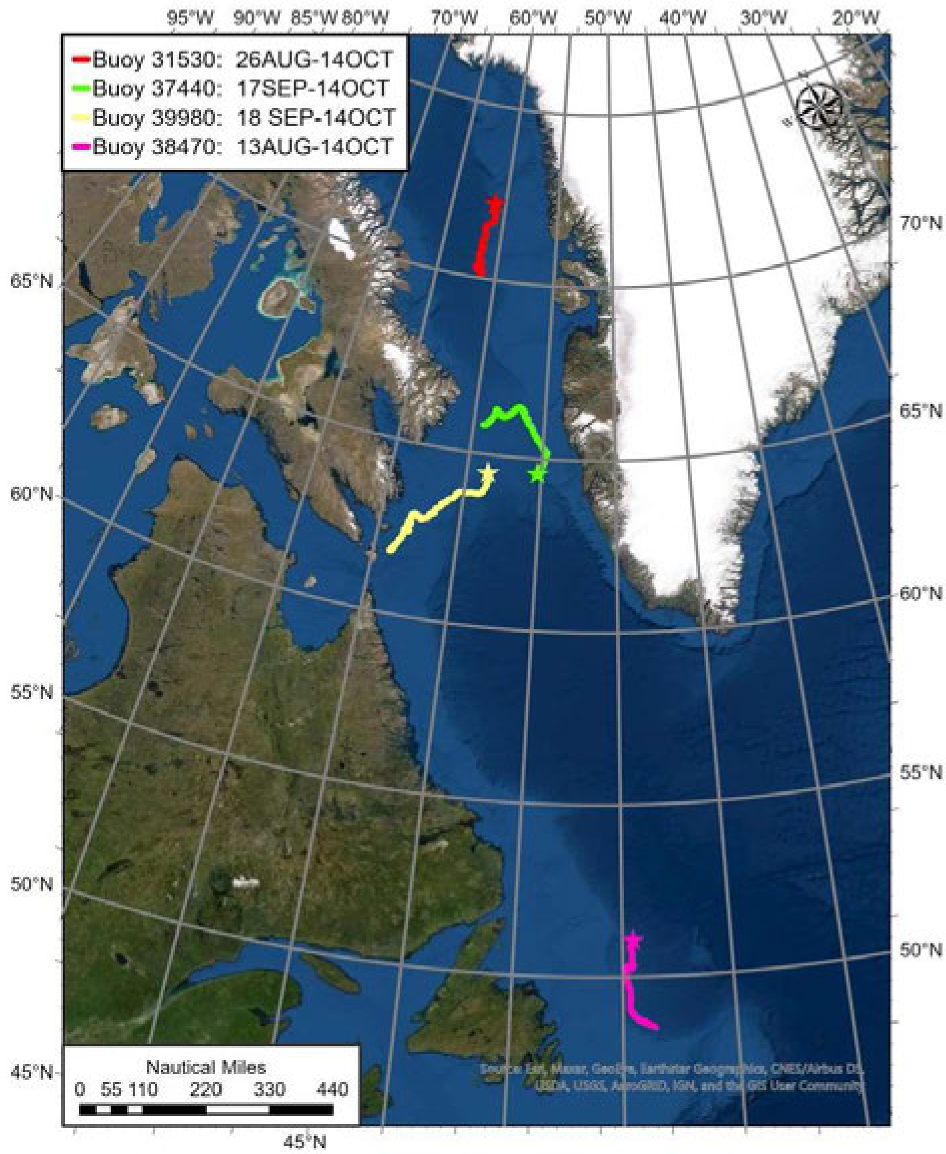


Figure C-7. Tracks of the surface velocity profiling (SVP) buoys deployed by CGC CAMPBELL as of 14 October, 2020. The stars indicate the deployment locations.

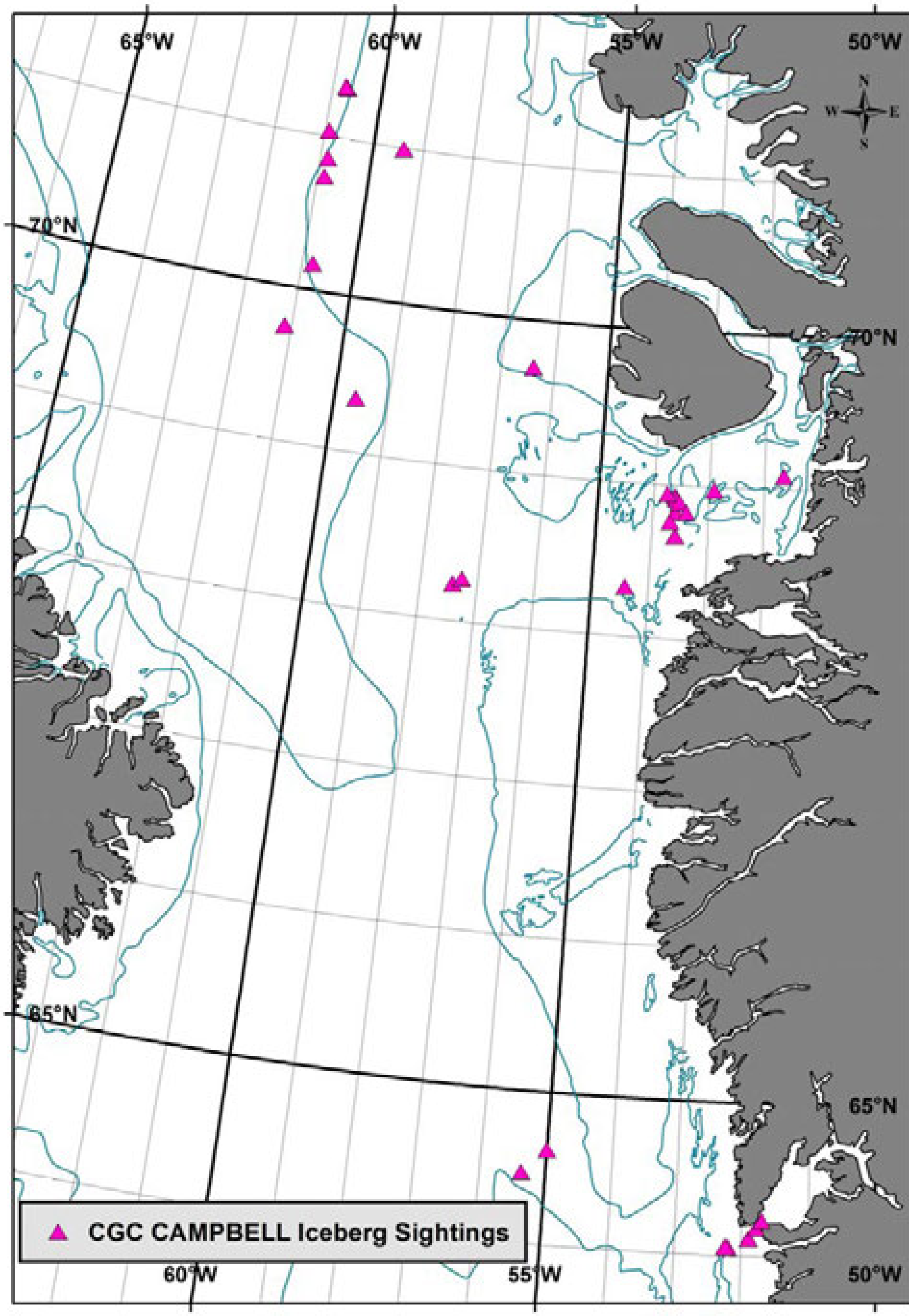


Figure C-8. All iceberg sightings reported to the International Ice Patrol by CGC CAMPBELL during August and September 2020.

C-8. Tactical-Level Support on the Return Transit

On September 17, CAMPBELL began their transit from Greenland back to their homeport of Portsmouth, NH. Due to a storm system passing through the Labrador Sea, the cutter transited northwest toward Baffin Island after leaving Nuuk with the plan to transit south along the Labrador coast and pass through the Strait of Belle Isle. This storm avoidance plan led to several direct, tactical-level support products. CAMPBELL's intended trackline took them toward a cluster of six icebergs on the southwest side of Davis Strait. After receiving the trackline, the IIP analyst began looking closely at these icebergs to continue to track their progress and determine whether they would be clear of the cutter's track, with clear detections using Sentinel-1 and Sentinel-2 imagery on September 14 and 15 (**Figure C-9)**. While creating the 18 September product, the IIP analyst could not find the icebergs in the most recent satellite imagery from 16 September. The same storm system that drove CAMPBELL to the northwest upon leaving Nuuk also made the

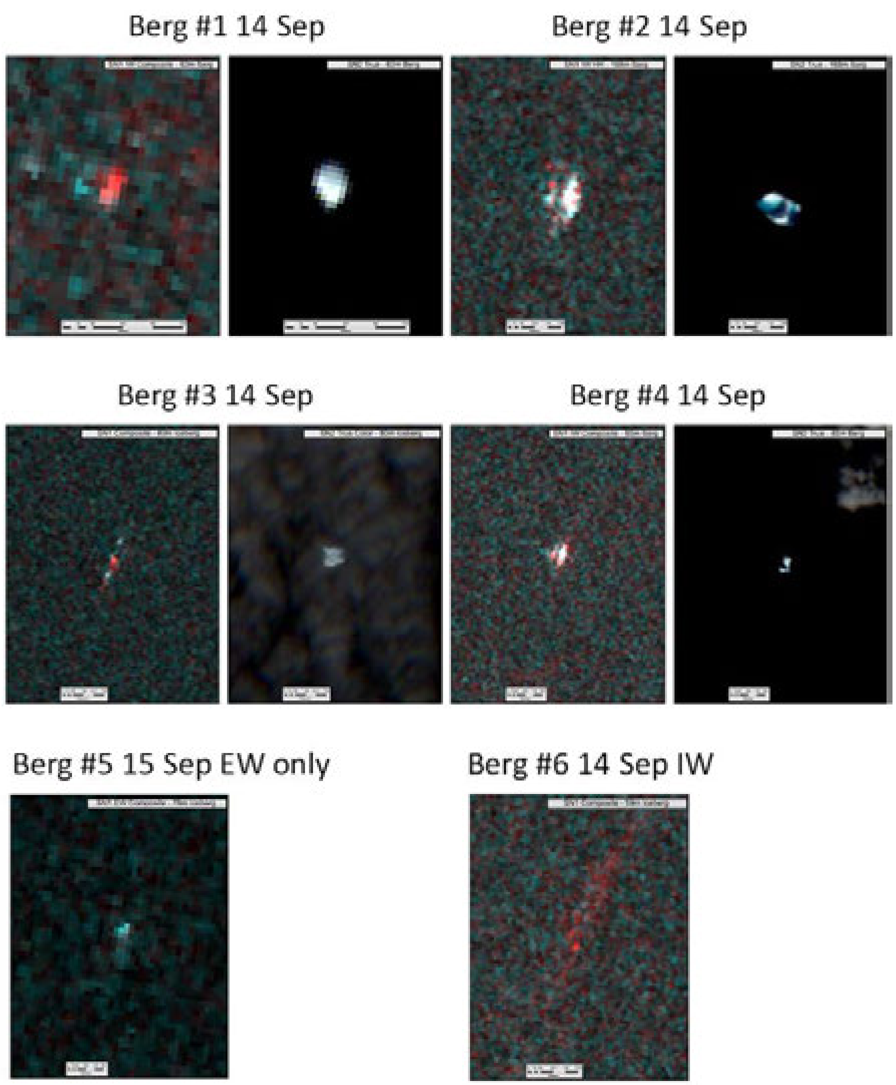


Figure C-9. Icebergs sighted in Sentinel-1 Imagery (HH-HV-HV in R-G-B; left) and Sentinel-2 (True Color; right). Iceberg numbers correspond to those in Figure C-12. Copernicus Sentinel data 2020.

winds and seas in the vicinity of these icebergs such that they could not be located in Sentinel-1, Sentinel-2, RadarSat-2, or Landsat-8 imagery (**Figures C-10** and **C-11**). Rough seas make it hard for the ship's radar to detect the icebergs and whitecaps make it challenging for a lookout to find icebergs. The IIP analyst became concerned that the iceberg drift model may not sufficiently capture the physical dynamics of the storm. Since the cutter planned to pass through the area in the pre-dawn hours of September 18, the IIP Analyst created a Cautionary Area around the modeled and observed positions of these six icebergs and communicated this concern directly to CAMPBELL's Commanding Officer (**Figure C-12**). CAMPBELL altered their course upon receipt of the Cautionary Area product to avoid the majority of the area.

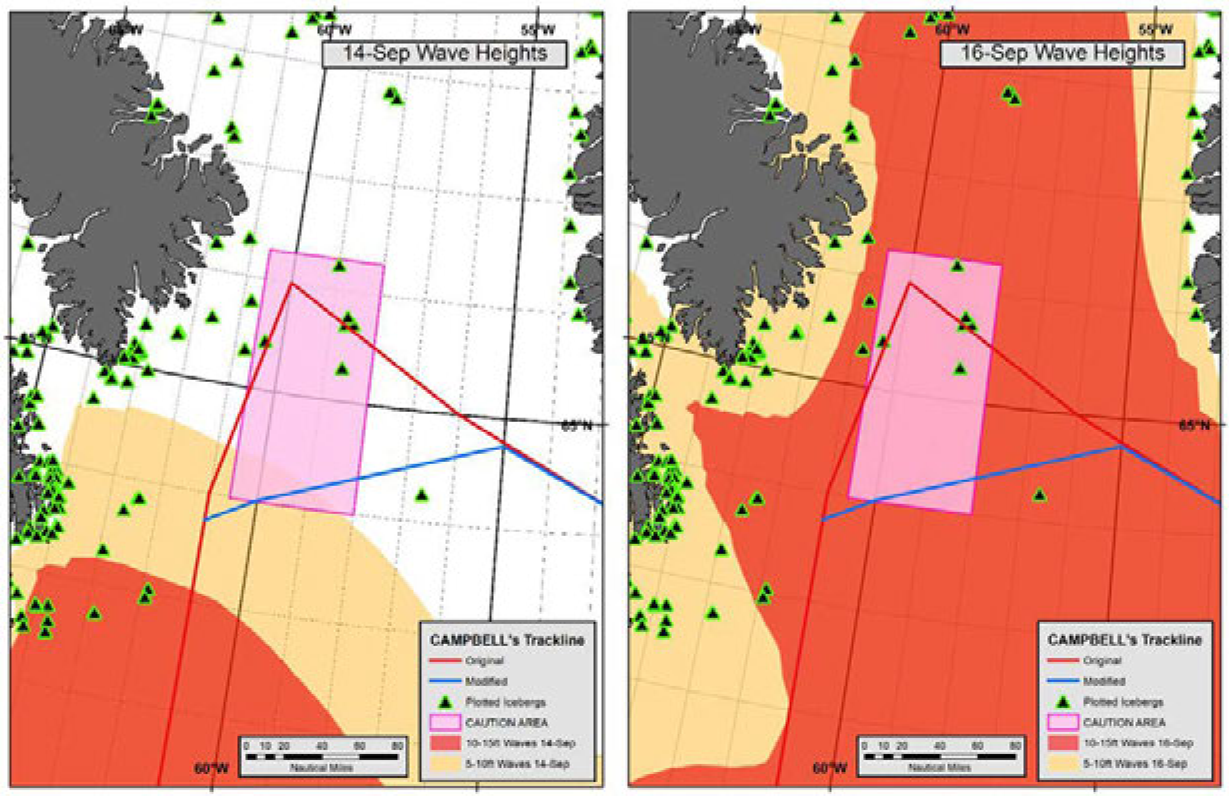


Figure C-10. Wave Heights (feet) from the Canadian East Coast Ocean Model (CECOM) shown on 14 September (left) and 16September (right). The waves were a major factor in not being able to locate the icebergs within the pink Caution Area on 16 September. CAMPBELL's original track is the red line and their modified track due to the creation of the Cautionary Area is shown in blue.

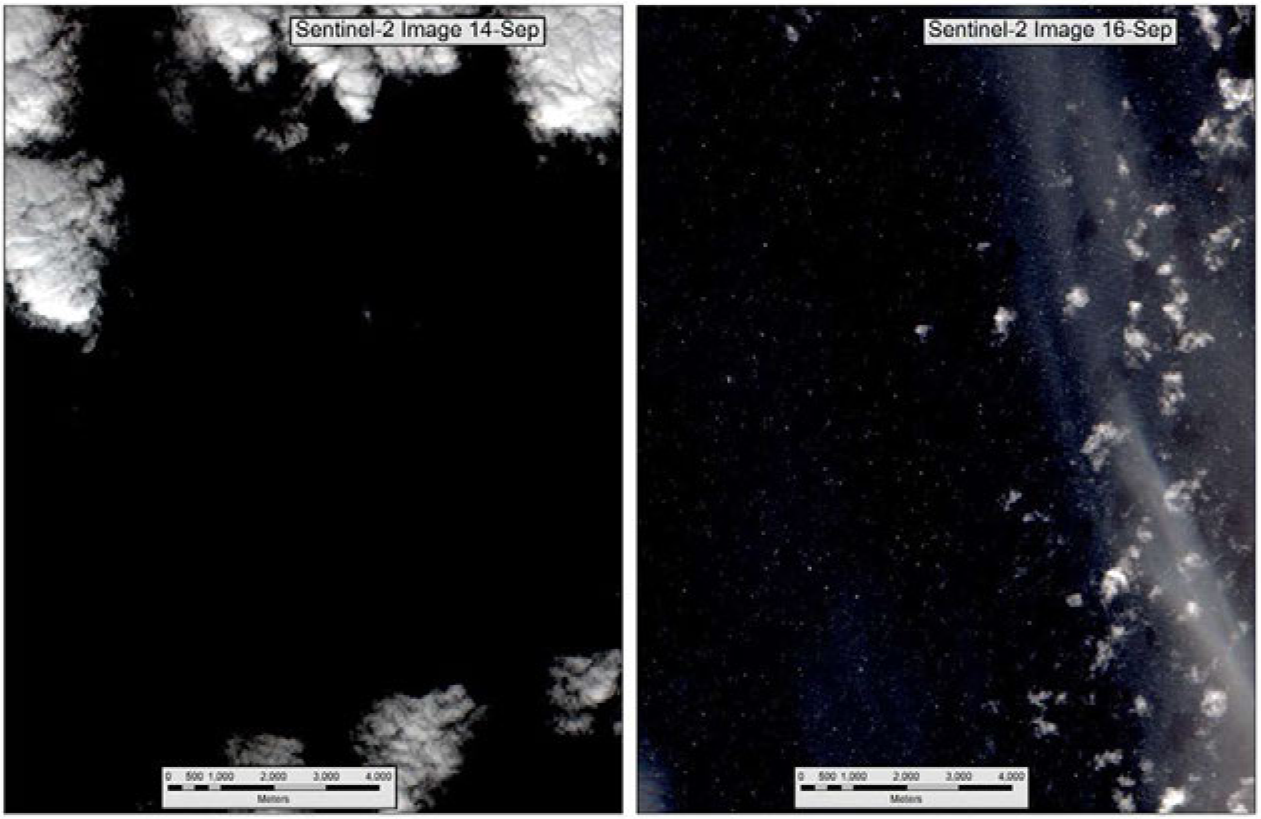


Figure C-11. Sentinel-2 imagery from 14 September (left) and 16 September (right). No known icebergs are visible in either image, but note the white caps in the image on the right that can easily obscure icebergs. Copernicus Sentinel data 2020.

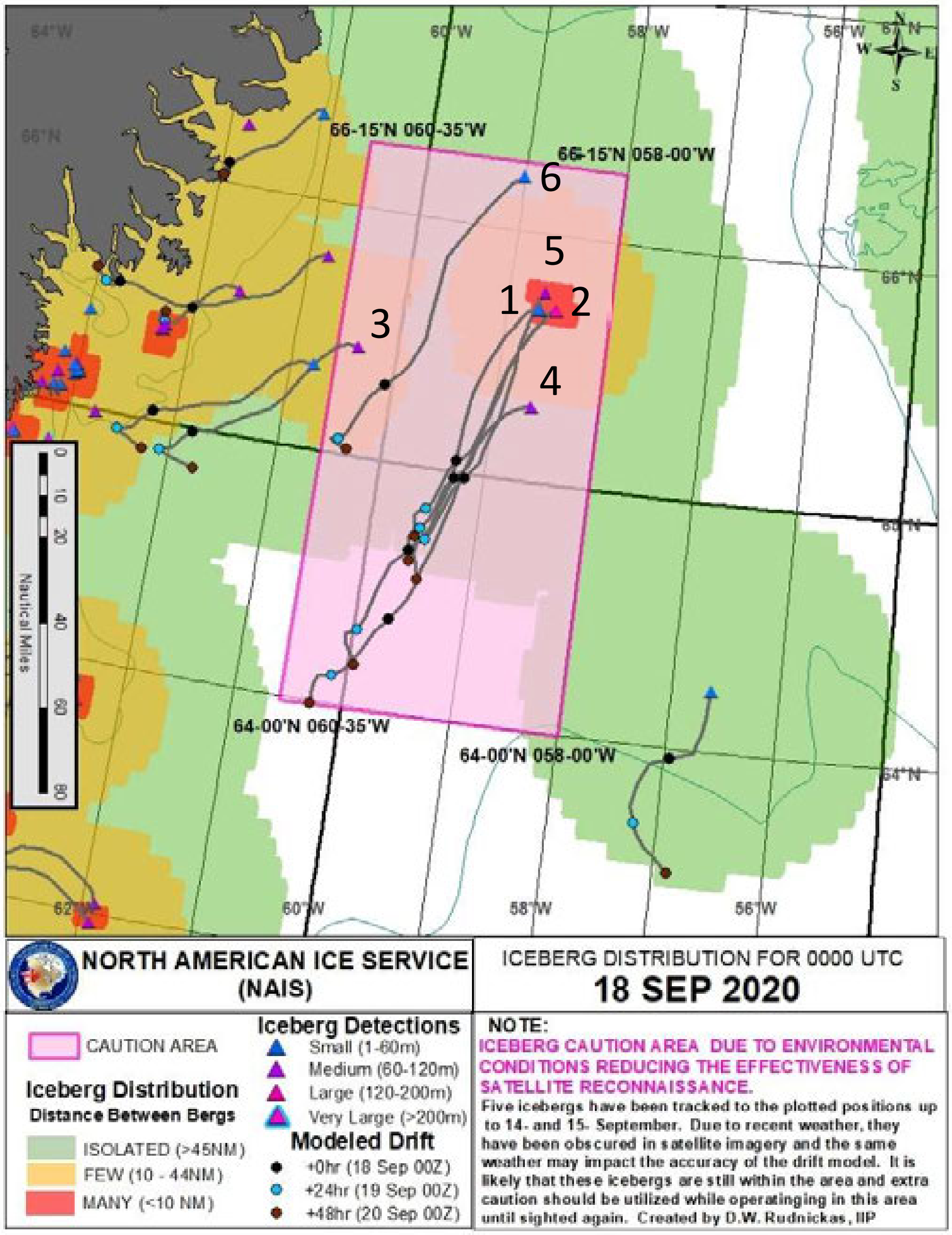


Figure C-12. Cautionary Area Product released on 17 September, valid for 18 September to warn CGC CAMPBELL of the loss of the ability to locate the six icebergs in Figure C-9 along their trackline.

On September 18, CAMPBELL was heading south along the Labrador Coast and preparing to travel through the Strait of Belle Isle. In Sentinel-1 Imagery from September 18, the IIP Analyst found two icebergs on or near the intended trackline of CAMPBELL (**Figure C-13**) and notified the cutter with an annotated graphic supplemental product (**Figure C-14**). The cutter reduced speed so that they would enter the area at daylight, giving the best opportunity to see the icebergs. On September 19, the IIP analyst located the first iceberg (approximately 70m in length) in Sentinel-1 and Sentinel-2 imagery (**Figure C-15, left and center)** and confirmed that it was drifting to the east, clear of CAMPBELL's trackline.

The IIP analyst continued to track CAMPBELL's progress toward the Strait of Belle Isle. On September 20, the analyst identified another target of potential concern (**Figure C-15(right)**) along the cutter's trackline. The target's position was immediately communicated directly to the cutter's Commanding Officer. The IIP analyst then created and distributed a supplemental product showing the projected drift of the target (**Figure 16**).

These case studies in the last days of CAMPBELL's operation highlight some key lessons learned from this mission.

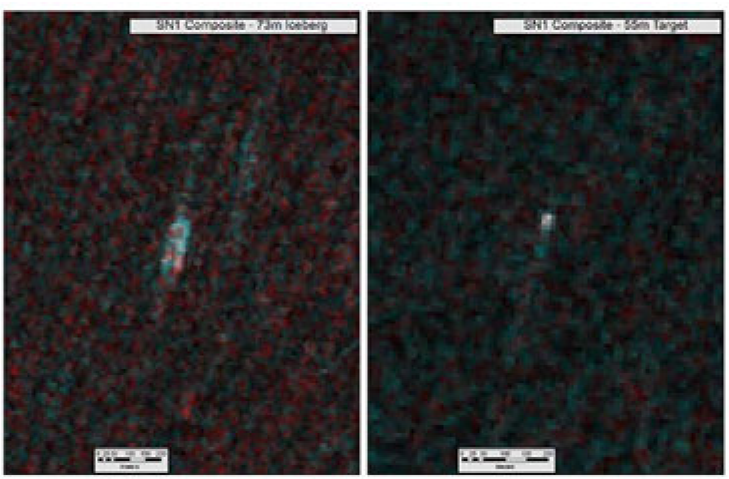


Figure C-13. Initial sightings in Sentinel-1 SAR imagery from 18 September of two targets on or near CAMPBELL's trackline. Both shown in Sentinel-1 composite imagery with bands HH-HV-HV in R-G-B. Copernicus Sentinel data 2020.

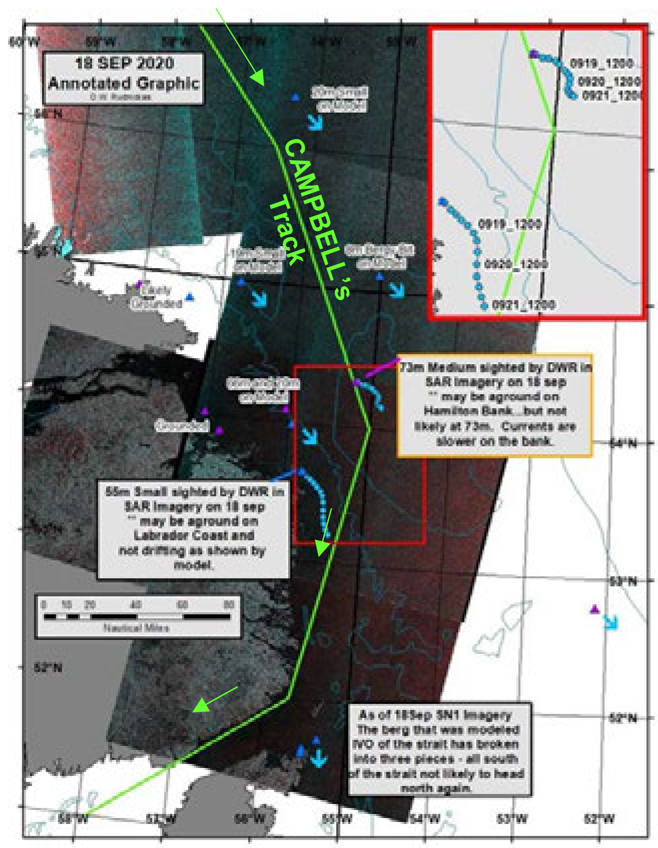


Figure C-14. Annotated Graphic Supplemental Product created on 18 September to report the positions of the two icebergs (within the red box) identified in Figure C-13 that were on or near CAMPBELL's intended trackline (green line). Copernicus Sentinel data 2020.

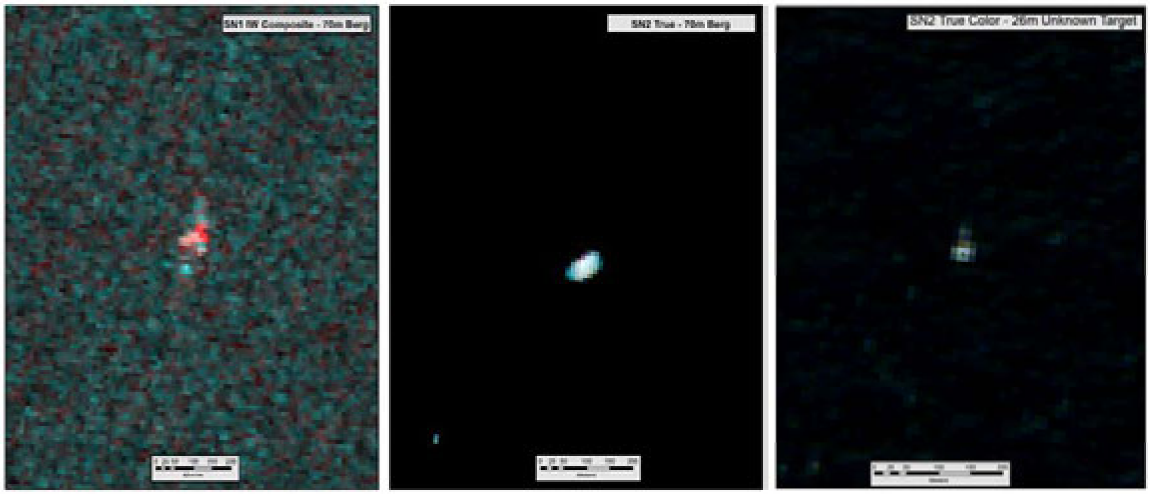


Figure C-15. Second and third sightings of the 70m iceberg in Sentinel-1 SAR imagery (left, HH-HV-HV in R-G-B) and Sentinel-2 Multispectral Imager (center, True Color: B4-B3-B2 in R-G-B) from 19 September of two targets on or near CAMPBELL's trackline that were included in the 19 September Supplemental Product (Figure C-16 (left). The right image is a 29m detection in Sentinel-2 Multispectral imagery (True Color: B4-B3-B2 in R-G-B) from 19 September that was treated as an iceberg, modeled and sent to CAMPBELL in a supplemental product on 20 September (Figure C-16 (right)). Copernicus Sentinel data 2020.

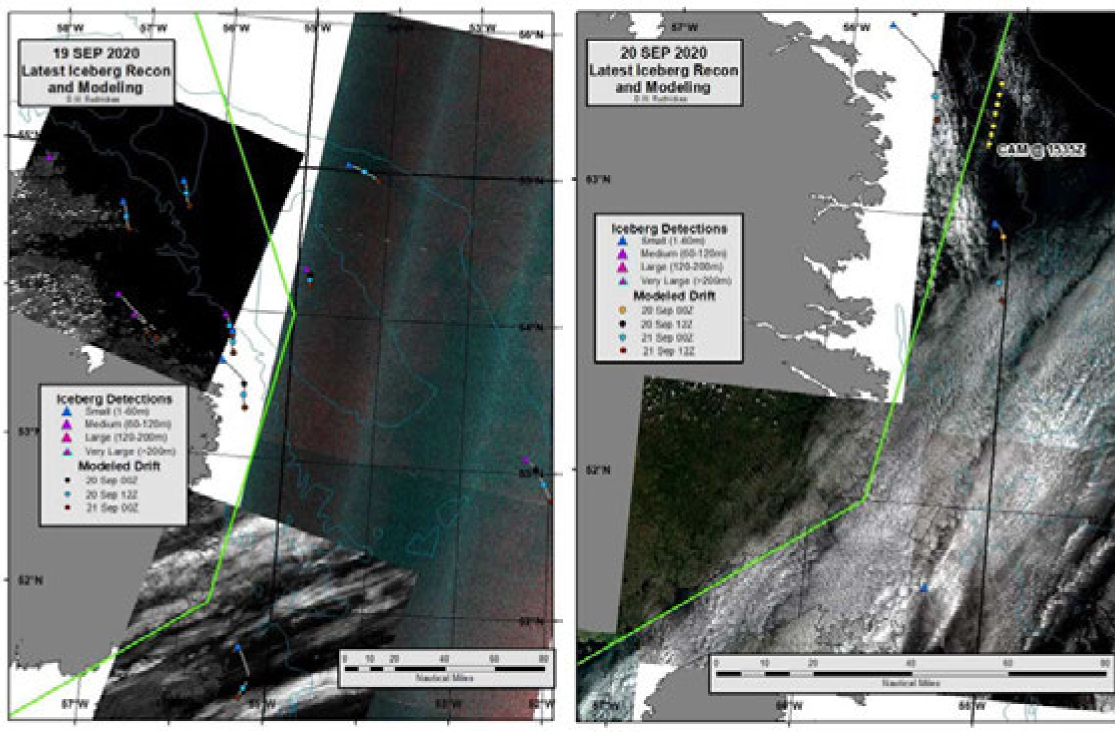


Figure C-16. Supplemental Graphics from 19 September (left) and 20 September (right) directly addressing the predicted drift of identified targets (Figure C-15) that were close to CAMPBELL's trackline. Copernicus Sentinel data 2020.

C-9. Lessons Learned and Technical Process

With exception of those few or isolated icebergs that establish the Iceberg Limit, IIP carries out its mission by tracking the iceberg population, and not by tracking individual icebergs. The final days of the CAMPBELL support products, however, highlighted the ability of a single analyst to bring multiple satellite sensors to bear in order to track specific targets of interest and provide the most accurate and timely warnings to a vessel. Clear communications with the crew of the vessel was essential for planning what satellite acquisitions would be available and understanding the limitations of reconnaissance when using satellites on a fixed orbit.

For most of the support time period, a single satellite analyst made the classifications of the icebergs in closest proximity to CAMPBELL's upcoming operations. This provided a level of consistency necessary for this type of direct support. Early in the mission, the primary analyst sought to delegate some of the satellite analysis work. In one instance, the duty analyst reported 30 icebergs in the area where CAMPBELL was operating where, the day before, the primary analyst had only observed one. Prior to being added to the products, the primary analyst inspected the classifications and all but one of the 30 icebergs were determined to be sea clutter. The one remaining iceberg matched the iceberg that had been on plot. Had the product gone out with 30 icebergs based on faulty classification, where the day before there had been only one, the integrity of the product and of IIP's reconnaissance would have been eroded. This level of accuracy required the most seasoned analysts and required consistency. Given the more frequent revisit period in higher latitudes, the primary analyst became familiar with the icebergs closest to CAMPBELL due to numerous consecutive sightings across multiple sensors and added a level of accuracy that would not have been possible with a less experienced analyst or analysis by different people each day. This experience highlights the situational awareness provided by a primary analyst for a particular region or mission, and for clear communication during duty rotation. The primary analyst did, however, delegate analysis of regions around the margin of the OPAREA to other analysts. These areas were not likely to be transited by CAMPBELL, were populated by hundreds of icebergs, and were observed frequently so that the small-scale products were up-to-date and accurate.

Technically speaking, this entire reconnaissance effort was done outside of IIP's standard active iceberg database and, with the exception of modeling, was done outside of the iceBerg Analysis and Prediction System (BAPS) that is used for normal operations. The CAMPBELL iceberg database was maintained as an ArcGIS shapefile and was curated by the primary analyst daily. Each day, the analyst compared the results of every satellite frame analyzed to the database shapefile and replaced the icebergs in the existing file with the most current observation. All results were then saved to a new shapefile that served as the basis for further density contour development. In this way, the database was carried forward to preserve a record of the tracked icebergs for each product day. Icebergs were kept in the database until they were re-sighted, usually after no longer than six days, depending on satellite pass availability and priority of the area for reconnaissance. As mentioned earlier in this Appendix, the frequent revisits of sun-synchronous near-polar orbiting satellites such as the Sentinel constellations at high latitude was key to keeping this iceberg database up to date without modeling each of the more than 11,000 icebergs that were tracked.

Once the database for each product day was created, a selection of icebergs of highest priority and those covering a varied area were selected for modeling. Typically, this number was kept to around 50 icebergs so that the modeling did not interfere with IIPs routine watch and the products could be generated in a timely manner. The modeling was accomplished by exporting a separate shapefile of icebergs to be modeled, parsing their positions, date/time of observation, and size/shape information into a text file formatted for BAPS. This text file was ingested into BAPS and a "What-if" model was initiated. Because there was no ocean current information for the IIP model north of 60°N, only the North American Ice Service (NAIS) model was utilized for the 24/48 hour forecasting until CAMPBELL reached the Labrador Coast on the return transit. The IIP model was utilized during the return transit along the Labrador coast.

As mentioned previously, IIP developed a Python script to conduct ArcGIS processing in order to generate the Isolated-Few-Many contours from the database shapefile. The script had to be run multiple times for most products because the iceberg density throughout such a large OPAREA resulted in intermediary files that exceeded ArcGIS' 2GB maximum file size. Typically, this required three to five separate sets of contours to be created based on geographic regions. The IIP analyst created each set of contours by generating buffers of 5NM, 22.5NM, and 45NM around the icebergs in an area. The buffer intersections were calculated and a simple weighting mechanism was applied to each intersection. Simply put, each 45NM buffer had a score of 1, each area of intersecting 22.5NM buffers also had a score of 1, and each area of intersecting 5NM buffers also had a score of 1. Each of these weighted score areas were converted to a raster and the rasters were added together. A pixel with a score of 3 (meeting all three conditions) was a Many area, a score of 2 (meeting only the 45NM buffer and 22.5NM intersection conditions) was a Few area, and a score of 1 (meeting only the 45NM buffer condition) was an Isolated area. Contours of each score were created from this summation raster. The contours were then inspected for continuity with the coastline and were converted to polygons for inclusion in the products. This method worked well, especially once automated. Inspecting for continuity was a time-consuming process that was complicated by inconsistencies in the dataset that IIP utilizes for the coastline. If IIP were to develop this type of product again, a new coastline dataset should be investigated. Further detail or questions about this process can be directed to the authors.

The Caution Area case study at the end of the CAMPBELL deployment highlights the limitations of satellite sensors due to environmental conditions. It is well-understood that Sentinel-2 Multispectral imagers can only be used in mostly cloud-free conditions, but as shown in this Appendix, their effectiveness can also be reduced due to high seas and whitecaps. Likewise for SAR sensors, even though they can penetrate cloud, the increased backscatter associated with high winds and waves can severely degrade the ability to detect icebergs. This limitation must be considered for any iceberg risk product derived from satellite reconnaissance and must be communicated with the product because the same conditions that limit the satellite sensors will also limit a vessel's sensors.

It is important to note that part of the success of using SAR imagery to confidently make iceberg classifications during this project was due to the condition of icebergs within the CAMPBELL OPAREA. The icebergs that were tracked in support of CAMPBELL were, in general, closer to the glacier from where they calved and therefore "younger" – larger and in better condition. That typically means that the icebergs have not rolled and have more sharp edges that have not been worn down by months or years of wind and sea erosion. When an iceberg rolls or erodes, it exposes a more rounded, smooth surface that does not reflect SAR energy as well. Further, the icebergs along Greenland and in Baffin Bay are in much colder water than later in their journey, reducing deterioration rates. When icebergs reach the typical IIP OPAREA, they are usually near the end of their existence. They are rapidly melting and calving, and are worn and eroded. As icebergs drift farther south into IIP's OPAREA, the frequency of satellite coverage decreases and the number of ships increases. Both the increased vessel traffic and the deteriorated condition of the icebergs complicates the use of SAR for iceberg detection and classification.

C-10. Conclusion

The support of CGC CAMPBELL was a significant workload and achievement for IIP. The cutter's safe operations and transit were the major driving force behind day-to-day operations, but the process resulted in significant improvements to IIP's capabilities and knowledge. CAMPBELL provided a platform for IIP to test prototype iceberg warning products, deploy oceanographic buoys, and gain crucial ground-truthed iceberg sightings that will help to develop IIP's satellite reconnaissance efforts. The processes, case studies, and lessons learned from this mission that are documented here are extremely valuable. The CAMPBELL experience highlighted IIP's capability to provide meaningful, satellite-based iceberg density products to a ship operating in an iceberg-rich environment with few other vessels. With an increasing focus on high latitude operations, IIP expects that similar services will be requested in the near future, and the foundation laid in support of CGC CAMPBELL will serve as a benchmark for future efforts. While IIP's proficiency in the use of satellite reconnaissance continues to grow, the accurate development of IIP's traditional Iceberg Limit product still requires the use of periodic aerial reconnaissance.

C-11. References

Copernicus Sentinel Data 2020

International Ice Patrol. (2018). Report of the International Ice Patrol in the North Atlantic (2018 Season), Bulletin No. 104, Appendix C.

C-12. Supplemental Material

Prototype Iceberg Products Feedback

Iceberg Products Feedback

Thank you for taking time to provide feedback on the International Ice Patrol's prototype iceberg warning products! Your time is appreciated and your input will help to inform the future of iceberg warning products in the North Atlantic.

1. How would you describe your role in using the products?

- ○ Vessel Operator/Navigator
- ○ Shore-side support/Planning
- ○ Other (please specify)

2. How much experience do you have with operating a vessel in the vicinity of icebergs?

○ None at all ○ A little ○ A moderate amount ○ A lot ○ A great deal

3. How do you use iceberg products in your operations? Please rank order the importance of iceberg products in your operational use. Where 1 is the top priority or most useful.

- Daily Operational Use for Navigation (0 - 24 hours)
- Short-term Planning (24 - 48 hours)
- Long-term Planning (Greater than 48 hours)
- General Situational Awareness

4. Overall, how satisfied were you with the prototype iceberg products you received?

○ Very dissatisfied ○ Dissatisfied ○ Neither satisfied nor dissatisfied ○ Satisfied ○ Very Satisfied

Comments

5. How useful were the following features of the prototype iceberg products?

	Not at all useful	Not so useful	Somewhat useful	Very useful	Extremely useful
Individual Iceberg Positions (Symbolized by Triangles)	○	○	○	○	○
Individual Iceberg Sizes (Color of Triangles)	○	○	○	○	○
Forecasted Iceberg Positions (+24/48 hour)	○	○	○	○	○
Isolated-Few-Many Iceberg Distribution Contours (Green-Amber-Red shading)	○	○	○	○	○
Published Iceberg Limit (Pink Line)	○	○	○	○	○
Small Scale Products covering a Large Area (i.e. "Zoomed Out")	○	○	○	○	○
Large Scale Products covering a Small Area (i.e. "Zoomed In")	○	○	○	○	○

Comments

6. Please rank the above features in terms of which is most important to you on a future iceberg product. (1-6; where 1 is your highest priority)

- Individual Iceberg Positions (Location of Triangles)
- Individual Iceberg Sizes (Color of Triangles)
- Forecasted Iceberg Positions (+24/48 hour positions)
- Isolated-Few-Many Contours (green-amber-red shaded areas)
- Published Iceberg Limit (pink line)
- Scalability of Products (ability to show zoomed in and zoomed out charts)

7. How useful was the Amplifying Information on the prototype iceberg products?

	Not at all useful	Not so useful	Somewhat useful	Very useful	Extremely useful
Ocean Currents	○	○	○	○	○
Satellite Imagery Displayed	○	○	○	○	○
Annotated Labels on the Map	○	○	○	○	○
Analyst Comments	○	○	○	○	○

Comments (Anything else you would like to see?)

8. Please provide some feedback on the value of the iceberg products in terms of:

	Never	Sometimes	Most of the time	Always	N/A
Accuracy - Were the products accurate in terms of iceberg locations?	○	○	○	○	○
Timeliness - Did the products arrive in time to be useful for your operations?	○	○	○	○	○
Frequency - Were the products delivered often enough to be useful for your operations?	○	○	○	○	○
Clarity - Were the products easy to use and understand?	○	○	○	○	○

File Size - Were the products of a proper file size to be usable for your operations?					
Usefulness - Did you use the products for daily navigation? (0 - 24 hours)					
Usefulness - Did you use the products for short-term planning? (24 - 48 hours)					
Usefulness - Did you use the products for long-term planning? (Greater than 48 hours)					

Comments

9. Please let us know any additional comments or suggestions for the iceberg products. Thank you!

Supplemental Figure D-1. Image of the User Survey sent to all recipients of the prototype iceberg products. The survey was generated and results collected via SurveyMonkey.com

Appendix D. Satellite Tracking of an Ice Island and Fragment From Petermann Glacier to Newfoundland

LT Don Rudnickas

D-1. Introduction

On March 7, 2020, the International Ice Patrol (IIP) utilized Sentinel-2 multispectral imagery to create a standard iceberg message for the first time. While analyzing the frame, an 800-meter-long iceberg was identified (**Figure D-1**). In consultation with Dr. Adrienne White at the Canadian Ice Service (CIS), it was determined that this iceberg was an ice island fragment based on its size, shape, and texture. Throughout the subsequent months, this ice island fragment was tracked using synthetic aperture radar (SAR)

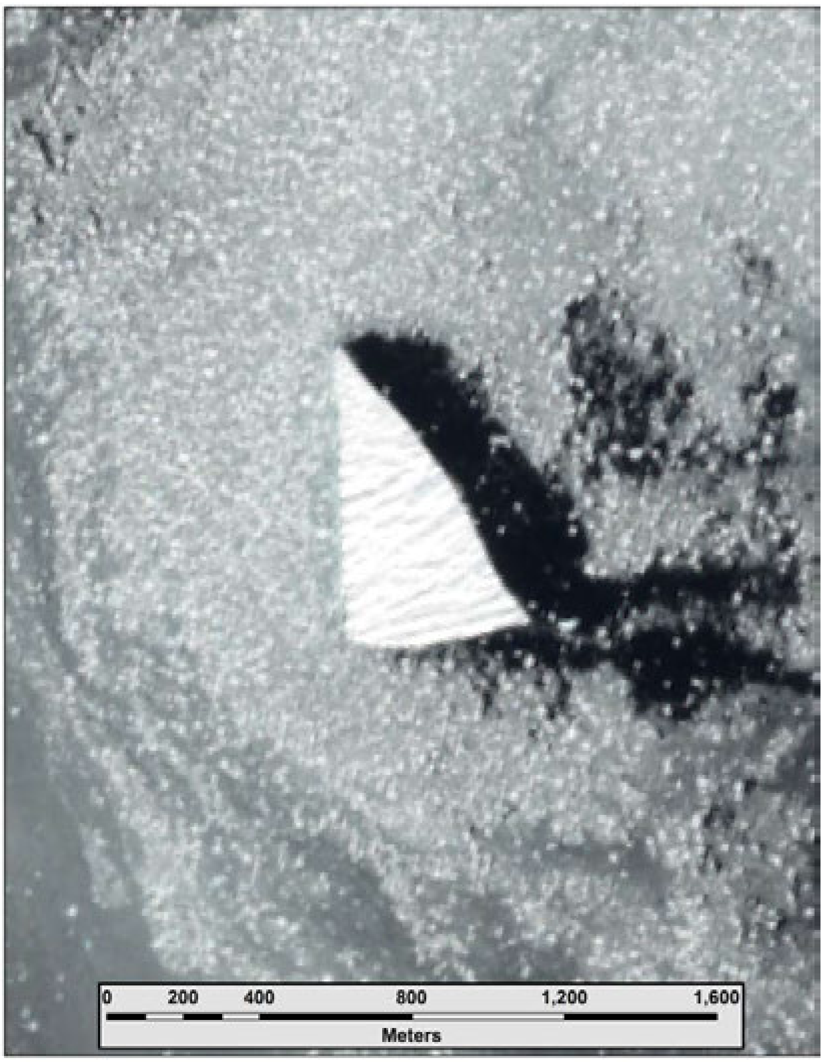


Figure D-1. The first sighting of "Pizza Berg", Ice Island Fragment 2020-001 from Sentinel-2 True Color Imagery on March 7, 2020 in position 56.81˚N 059.93˚W along the Labrador coast. Copernicus Sentinel data 2020.

satellite imagery, multispectral satellite imagery, and aircraft as it drifted down the coast of Labrador until it finally became grounded in Hare Bay south of St. Anthony, Newfoundland. It remained grounded until it finally broke apart during the latter half of June and beginning of July, 2020. The fragment was designated Ice Island Fragment 2020-001 (IIF-2020-001) by PAL Aerospace and IIP also adopted this descriptor, though it was affectionately referred to as “Pizza Berg” by IIP personnel. Follow-on efforts to determine the source of IIF-2020-001 led to tracking it back to the Petermann Glacier in 2017. This Appendix documents the tracking of this iceberg, what is known about its origin and eventual deterioration, subsequent tracking of the main part of Petermann Ice Island 2017-A, and lessons learned for satellite reconnaissance.

D-2. Background

By definition, an ice island is a large piece of floating glacial ice that has broken from the ice shelf, typically protruding about 5 meters above sea level, and with a surface area of a few thousand square meters to greater than hundreds of square kilometers (Canadian Ice Service, 2005). An ice island fragment is formed when a piece of the ice island breaks away and separates from the ice island as part of the deterioration process. Typically, these will be tabular icebergs of very large size and can be identified by a regularly undulating surface giving a ribbed appearance (CIS, 2005).

Ice islands, or fragments of them, pose a hazard to shipping and are monitored by IIP if they make it south of 60˚N along the Labrador coast. It is no surprise that such a large piece of glacial ice would be a significant hazard for mariners if it were to reach the transatlantic shipping lanes, however, a large, tabular iceberg would most likely be easy for a vessel to detect with radar. More insidious, would be the many icebergs of large and smaller size that could be calved from an ice island fragment as it deteriorates farther south, in a way, depositing well-preserved icebergs closer to the shipping lanes. Of special significance for the Grand Banks region, an ice island fragment reaching the petroleum industry infrastructure there, could pose a significant environmental and economic risk.

The 2017-A Petermann Ice Island (PII-2017-A) calved from the Petermann Glacier in northern Greenland in late July 2017 (**Figure D-2**). After major Petermann Glacier calving events of 31 km^2 in 2008, 253 km^2 in 2010, and 130 km^2 in 2012 (Münchow et al., 2014), the 2017 calving formed a more modest island with a surface area of 6.8 km^2. **Figure D-3** shows the track of PII-2017-A from July 26, 2017 until October 25, 2019. This tracking was conducted using Sentinel-1, Sentinel-2, and Landsat-8 sensors, initially in order to determine whether or not IIF-2020-001 was calved from PII-2017-A. As such, monthly sightings were sought until a change in size and shape was noticed and the desired resighting frequency was shifted to daily. It should be noted that there is most likely an opportunity to increase the frequency of sightings using these and other sensors in order to build a more complete dataset of the track of PII-2017-A during this time period.

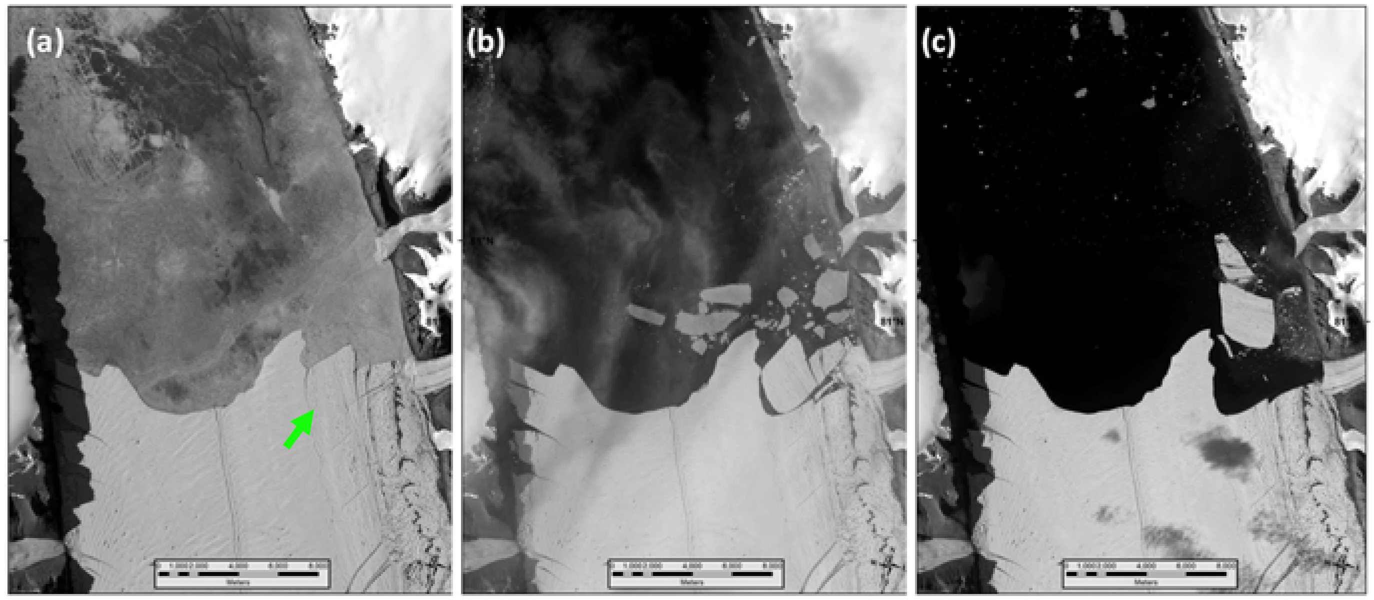


Figure D-2. The calving of Petermann Ice Island 2017-A. On July 18, 2017 (left) the ice island (green arrow) was still attached to the glacier, but close inspection reveals that fissures have formed in the glacier. By July 26 (center), the island had fully calved from the glacier and floated clear by July 29, 2017 (right). All images are from Landsat-8 Operational Land Imager shown in panchromatic (Band 8), courtesy of the U.S. Geological Survey.

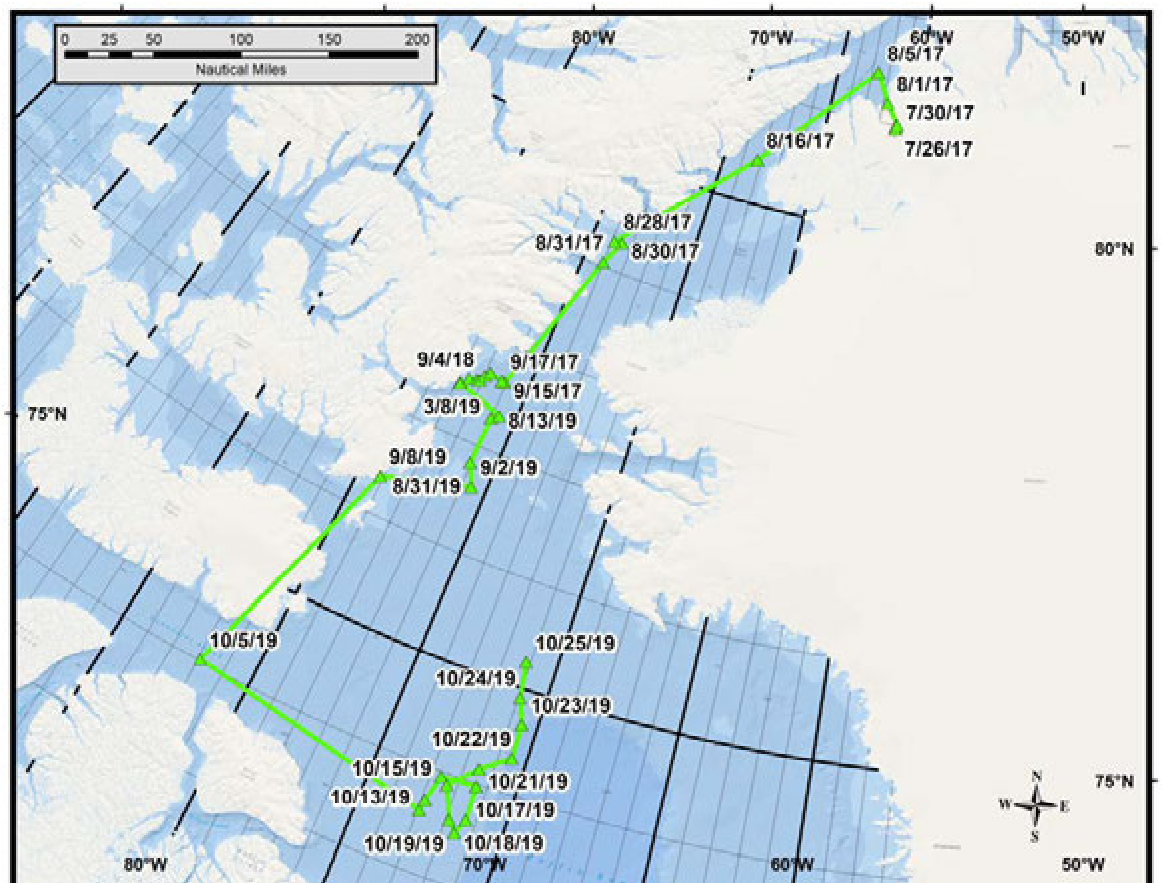


Figure D-3. Track-line of Petermann Ice Island 2017-A from July 26, 2017 through October 25, 2019. Note, the lack of position information between September 8 and October 15, 2019 was due to open source sensor availability and cloud cover.

By October 2017, PII-2017-A was aground along the southeast coast of Ellesmere Island where it remained for all of 2018 and the first half of 2019. In late July or early August, PII-2017-A was afloat again and experienced a major calving event around August 31, 2019, losing 2.2 km^2 of surface area. From August to October 2019, PII-2017-A drifted in the western portion of Baffin Bay. **Figure D-4** shows a sample of satellite observations of PII-2017-A during this time period. On the evening of October 24 or morning of October 25, 2019, PII-2017-A calved another 1.4 km^2 section (**Figure D-5**). Among this calved section was IIF-2020-001.

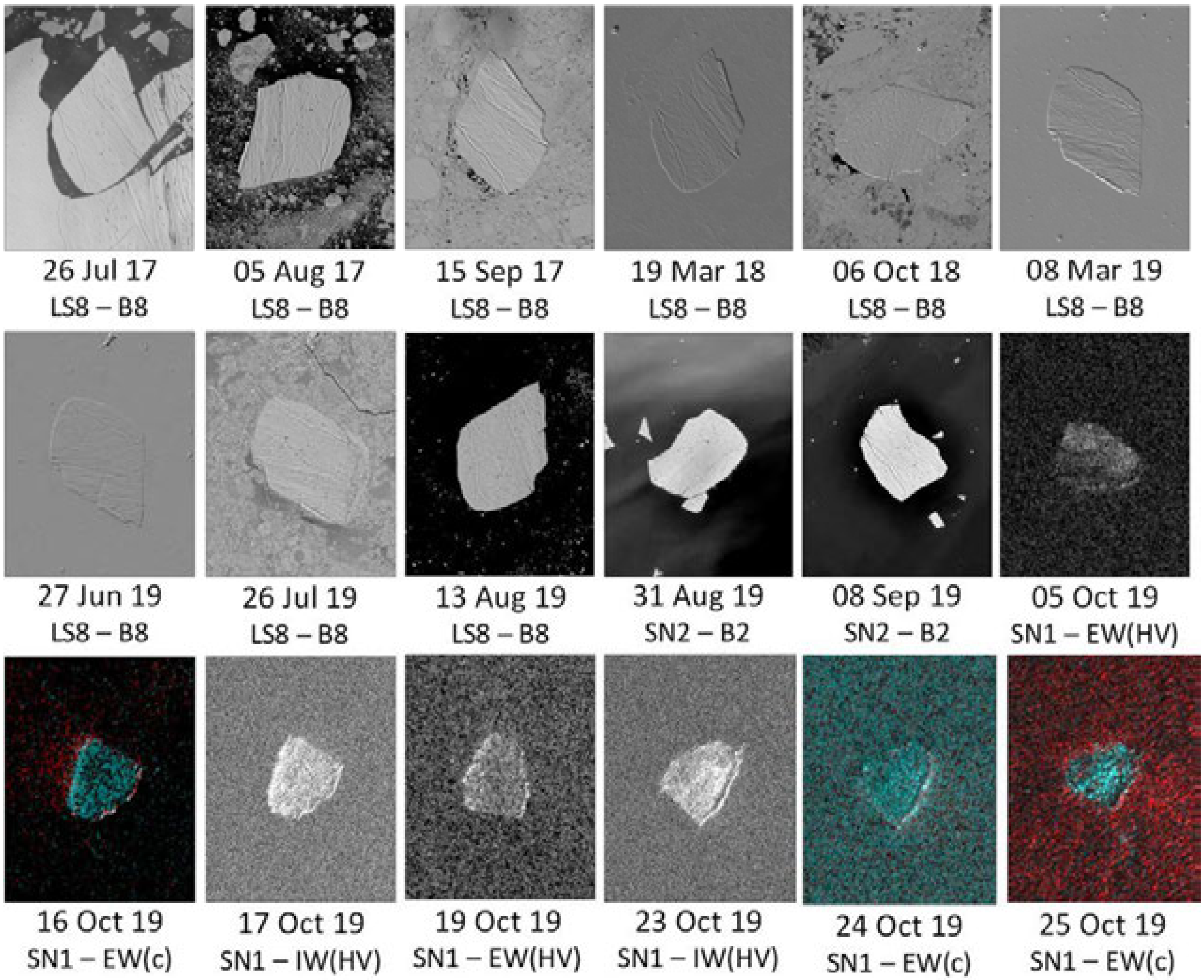


Figure D-4. Sample images of Petermann Ice Island 2017-A from calving on or about July 26, 2017 through October 25, 2019. All images are in precisely the same scale (1:24,000). LS8 refers to imagery from the Landsat-8 Operational Land Imager, SN2 is from Sentinel-2 Multispectral Imager, and SN1 is from Sentinel-1 Synthetic Aperture Radar (SAR). B8 refers to a panchromatic image utilizing Band 8 (15m resolution). B2 is a Sentinel-2 image using only the blue wavelength band (Band 2; 10m resolution), EW refers to Extra Wide Swath (50m resolution), IW is Interferometric Wide Swath (20m resolution). HH and HV refer to the polarization of the SAR imagery and (c) denotes the image is displayed as an R-G-B composite image with HH-HV-HV shown in R-G-B. Copernicus Sentinel data 2019. Contains modified Copernicus Sentinel data 2019. Landsat-8 imagery courtesy of the U.S. Geological Survey.

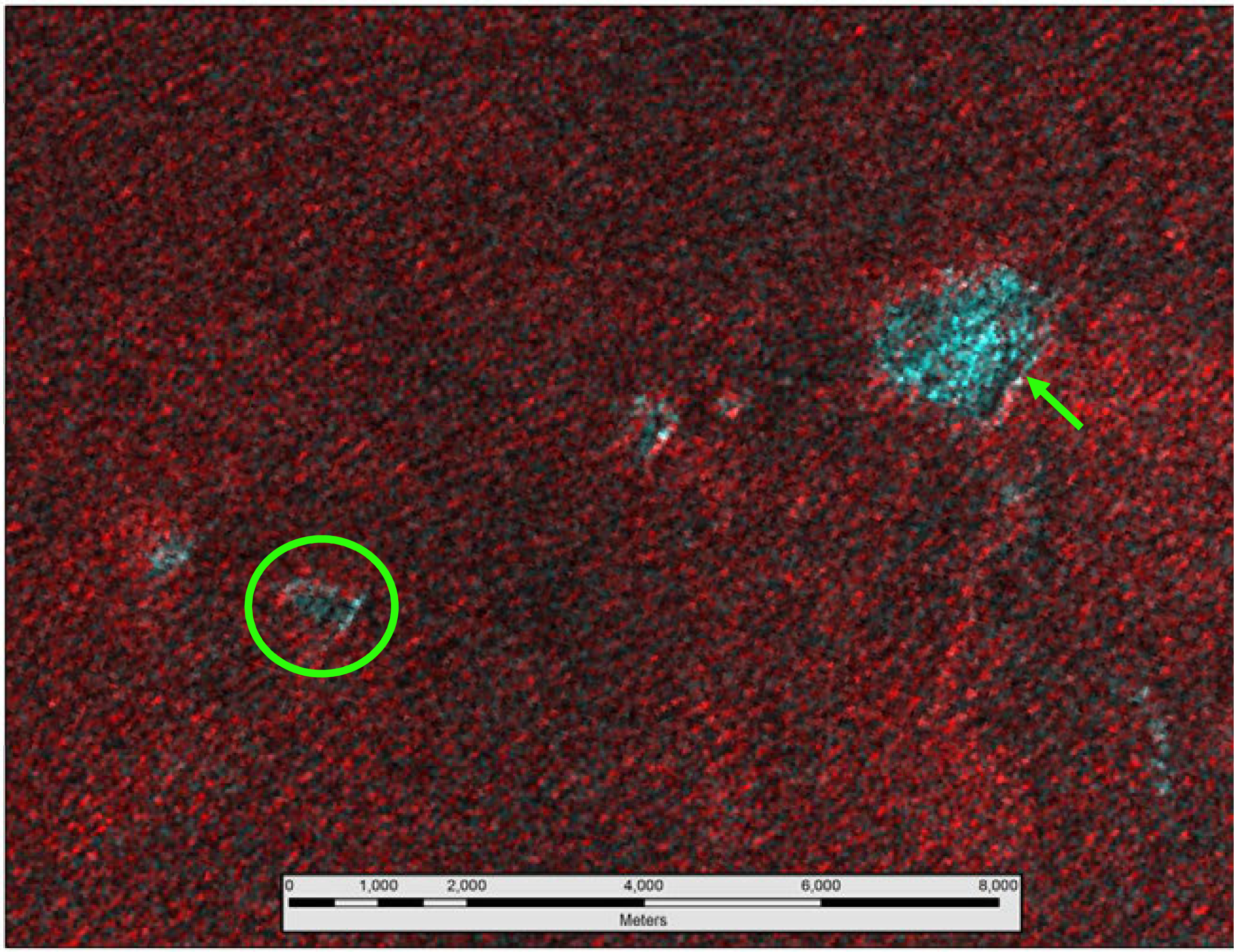


Figure D-5. Sentinel-1 Synthetic Aperture Radar imagery from October 25, 2019 showing the results of a recent calving event. The green circle marks the newly formed Ice Island Fragment 2020-001. The green arrow points out the remainder of Petermann Ice Island 2017-A. Image shown as a composite with HH-HV-HV in R-G-B. Copernicus Sentinel data 2019. Contains modified Copernicus Sentinel data 2019.

D-3. Tracking of Ice Island Fragment 2020-001

IIF-2020-001 started as an 800 m long, 500 m wide, 0.23 km^2 tabular iceberg. IIP first detected IIF-2020-001 in Sentinel-2 imagery from March 7, 2020 along the Labrador Coast (**Figure D-1**). After consultation with Dr. Adrienne White, an ice island expert at the CIS, IIF-2020-001 was officially declared an ice island fragment and IIP notified key partners in St. John's, Newfoundland, including PAL Aerospace and C-CORE. Between March and the end of April, IIP continued to track the daily positions of IIF-2020-001, as satellite imagery was available, drifting southward along the Labrador Coast and was supplemented by sighted positions from satellite analysts at CIS and C-CORE as well as aerial observations from PAL Aerospace. Sentinel-1, Sentinel-2, Landsat-8, Landsat-7,

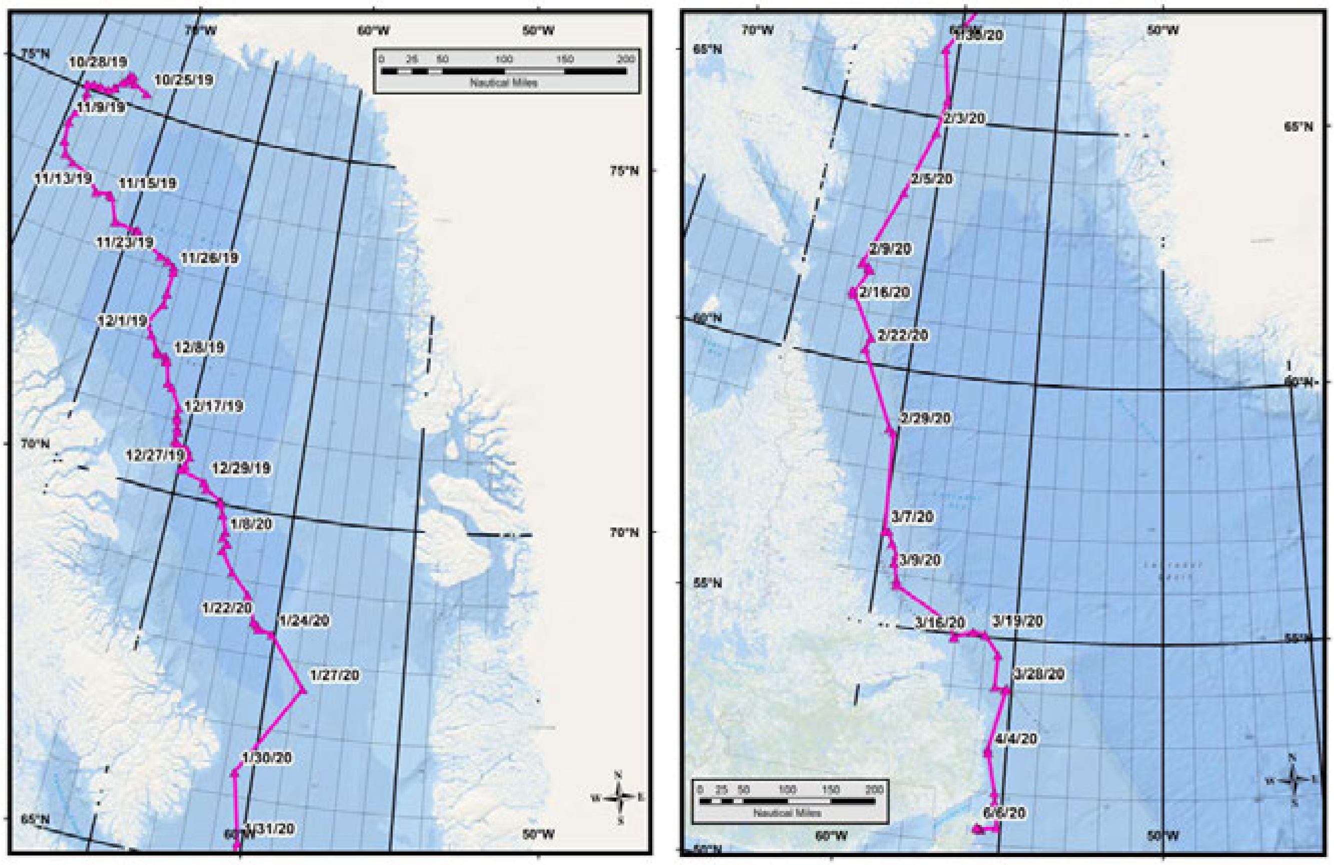


Figure D-6. Trackline of Ice Island Fragment 2020-001 from calving on October 25, 2019 in northern Baffin Bay until crossing the Davis Strait at the end of January 2020 (left) and from Davis Strait until grounding in Hare Bay, Newfoundland and deteriorating in June 2020 (right).

and Radarsat-2 (by CIS) satellite imagery were used throughout the tracking effort. **Figure D-6** presents the track of IIF-2020-001 from October 25, 2019 through June 6, 2020 and **Figure D-7** shows sample detections of the fragment throughout this time period. Between March 16 and March 23, IIF-2020-001 calved a 0.035 km^2 portion off the fragment's "tip" and calved another 0.026 km^2 section between April 3 and April 12. Between April 19 and April 22, IIF-2020-001 drifted into Hare Bay, south of St. Anthony's, Newfoundland and ran aground in approximate position 57˚17'N 055˚35'W. At the beginning of June, the fragment calved again into two large pieces and continued to break apart throughout the month. By July 6, 2020, IIF-2020-001 had fully deteriorated into small icebergs (**Figure D-8**).

Starting with the March 7, 2020 original sighting, the historical track of IIF-2020-001 was reconstructed using Sentinel-1, Sentinel-2, and Landsat-7 imagery. The presence of sea ice proved challenging for satellite detection with the relatively low freeboard of an ice island fragment compared to a taller, non-tabular iceberg. IIF-2020-001 was tracked backwards to February 9, 2020 near the mouth of Frobisher Sound before the presence of thick sea ice, cloud-cover, and synthetic aperture radar (SAR) scene availability frustrated the effort. Investigation of PII-2017-A from August through October, 2019 and daily sightings of the IIF-2020-001 with Sentinel-1 Interferometric Wide Swath (IW) and Extra-

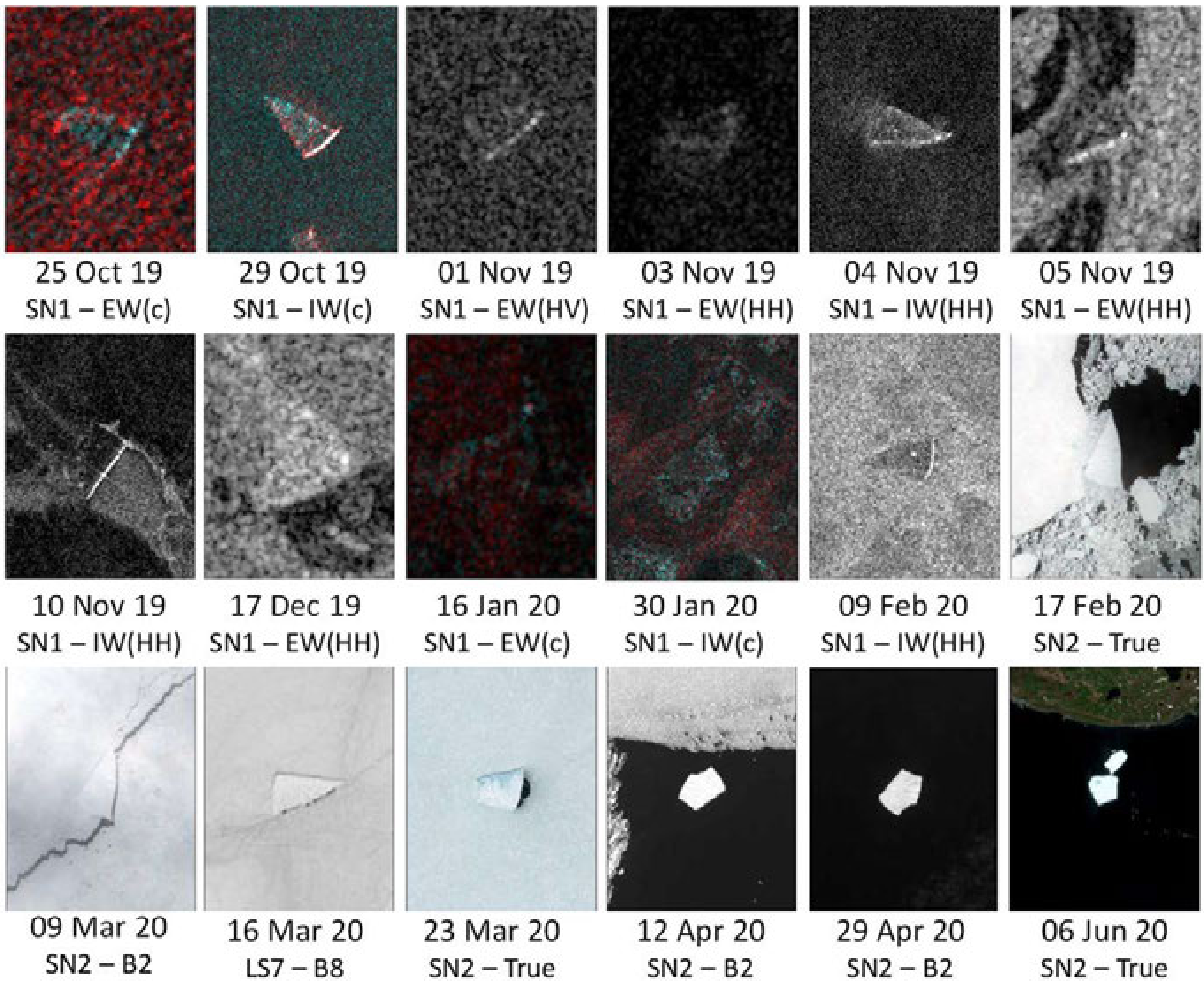


Figure D-7. Sample detections of Ice Island Fragment 2020-001 from its calving in northern Baffin Bay on October 25, 2019 through breaking up while aground in Hare Bay, Newfoundland on June 6, 2020. Note the arrival of sea ice in the imagery on November 5, that made detections with coarse resolution Sentinel-1 Extra Wide swath imagery challenging. All images are in precisely the same scale (1:10,000). LS7 refers to imagery from the Landsat-7 Enhanced Thematic Mapper Plus, SN2 is from the Sentinel-2 Multispectral Imager, and SN1 is from the Sentinel-1 Synthetic Aperture Radar (SAR). B8 refers to a panchromatic image utilizing Band 8 (15m resolution). B2 is a Sentinel-2 image using only the blue wavelength band (Band 2, 10m resolution). True refers to true color Sentinel-2 imagery with B4-B3-B2 in R-G-B. EW refers to Extra Wide Swath (50m resolution).IW is Interferometric Wide Swath (20m resolution). HH and HV refer to the polarization of the SAR imagery and (c) denotes the image is displayed as an R-G-B composite image with HH-HV-HV shown in R-G-B. Copernicus Sentinel data 2019, 2020. Contains modified Copernicus Sentinel data 2019, 2020. Landsat-7 imagery courtesy of the U.S. Geological Survey.

Wide Swath (EW) in the last days of October 2019 re-invigorated the search. In October, IIF-2020-001 was still in open water, and it was not until November 5, 2019 that sea ice surrounded the fragment. From this date until the February 10 Sentinel-2 sighting in visible band imagery, all sightings located as of the writing of this Appendix, were from Sentinel-1 SAR imagery. **Figure D-9** demonstrates difference between a 20 m resolution IW and a 50 m resolution EW detection of IIF-2020-001. In general, detections in IW were

Figure D-8. The deterioration of Ice Island Fragment 2020-001. Observations of the fragment aground in Hare Bay and breaking up on April 27 (left), June 6 (center), and July 6 (right) 2020. All images are from Sentinel-2 and displayed in true color (B4-B3-B2 in R-G-B). Copernicus Sentinel data 2020.

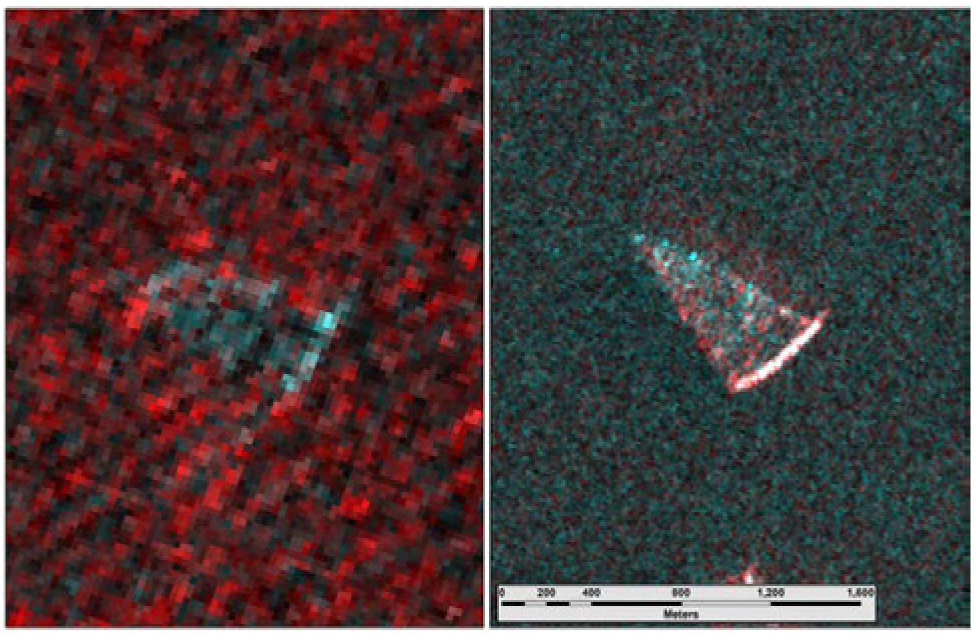


Figure D-9. October 25 Extra-Wide Swath (EW, 50m resolution) detection (left) and October 29 Interferometric Wide Swath (IW, 20m resoltuion) detection (right) highlighting the difference in resolution between the two modes. Both images are from Sentinel-1 and displayed as a composite image with HH-HV-HV in R-G-B at precisely the same scale (1:10,000). Copernicus Sentinel data 2019.

made with high confidence, but the prevalence of EW imagery at this latitude yielded many more sightings in this mode. As such, the track of IIF-2020-001 during the period of November 10, 2019 until February 9, 2020 is deemed to be "low confidence" or estimated.

D-4. Tracking of Petermann Ice Island 2017-A

After discovering when and from where IIF-2020-001 had calved, PII-2017-A was also tracked from October 25, 2019 until March 30, 2020. Being larger than the fragment, it was considerably easier to detect PII-2017-A throughout, even in EW imagery, and the track is shown in **Figure D-10** with high confidence. Sample detections throughout this time period are presented in **Figure D-11**. No noticeable calving events were observed after October 25, 2019 until March 2020. A March 27, 2020 IW SAR image is the last image of PII-2017-A as a cohesive ice island. There were no usable images on March 28

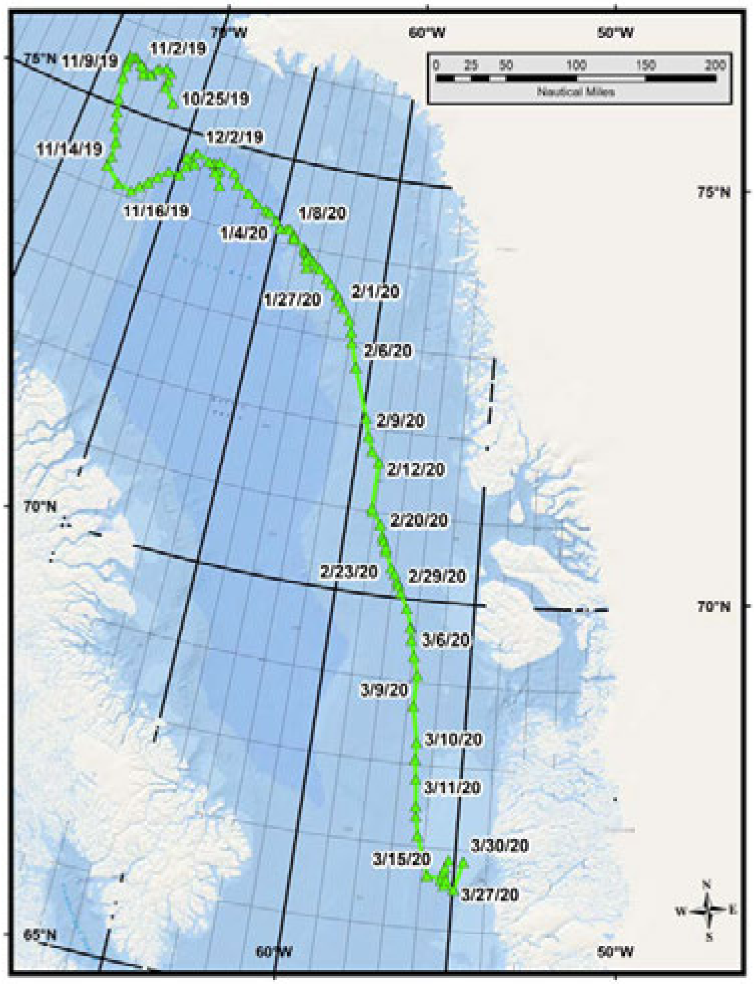


Figure D-10. Trackline of Petermann Ice Island 2017-A from northern Baffin Bay on October 25, 2019 through final grounding and destruction west of Sisimiut, Greenland on or about March 30, 2020.

or 29, but by March 30, PII-2017-A appears to have grounded west of Sisimiut, Greenland and suffered catastrophic deterioration. In imagery from March 30 through April 3, 57 pieces are visible and mostly aground in the vicinity of 66˚52'N 054˚43'W. In the last Sentinel-2 image on March 22, PII-2017-A had a surface area of 2.24 km^2. The total surface area of the identified pieces were calculated from Sentinel-2 imagery on April 1 to be 1.86 km^2. The missing 0.38 km^2 could be accounted for by loss during calving or by the inability to distinguish it from the surrounding sea ice. **Figure D-12** presents the true color image from after the catastrophic deterioration at the end of March.

D-5. Lessons Learned

While IIP tracks thousands of icebergs each Ice Season, the general strategy is to track the iceberg population and not individual icebergs. This study provided an opportunity to exercise the ability to track an individual iceberg over thousands of miles and multiple months using only satellite imagery. Even though PII-2017-A and IIF-2020-001 were significantly larger than the typical iceberg that IIP tracks and neither ended up directly impacting the transatlantic shipping lanes or Grand Banks petroleum infrastructure, there were worthwhile lessons learned for IIP's satellite reconnaissance effort.

Such large pieces of glacial ice were easily tracked in open water. In cloud-free, visual-band imagery, the distinctiveness of the white ice compared to the water made them

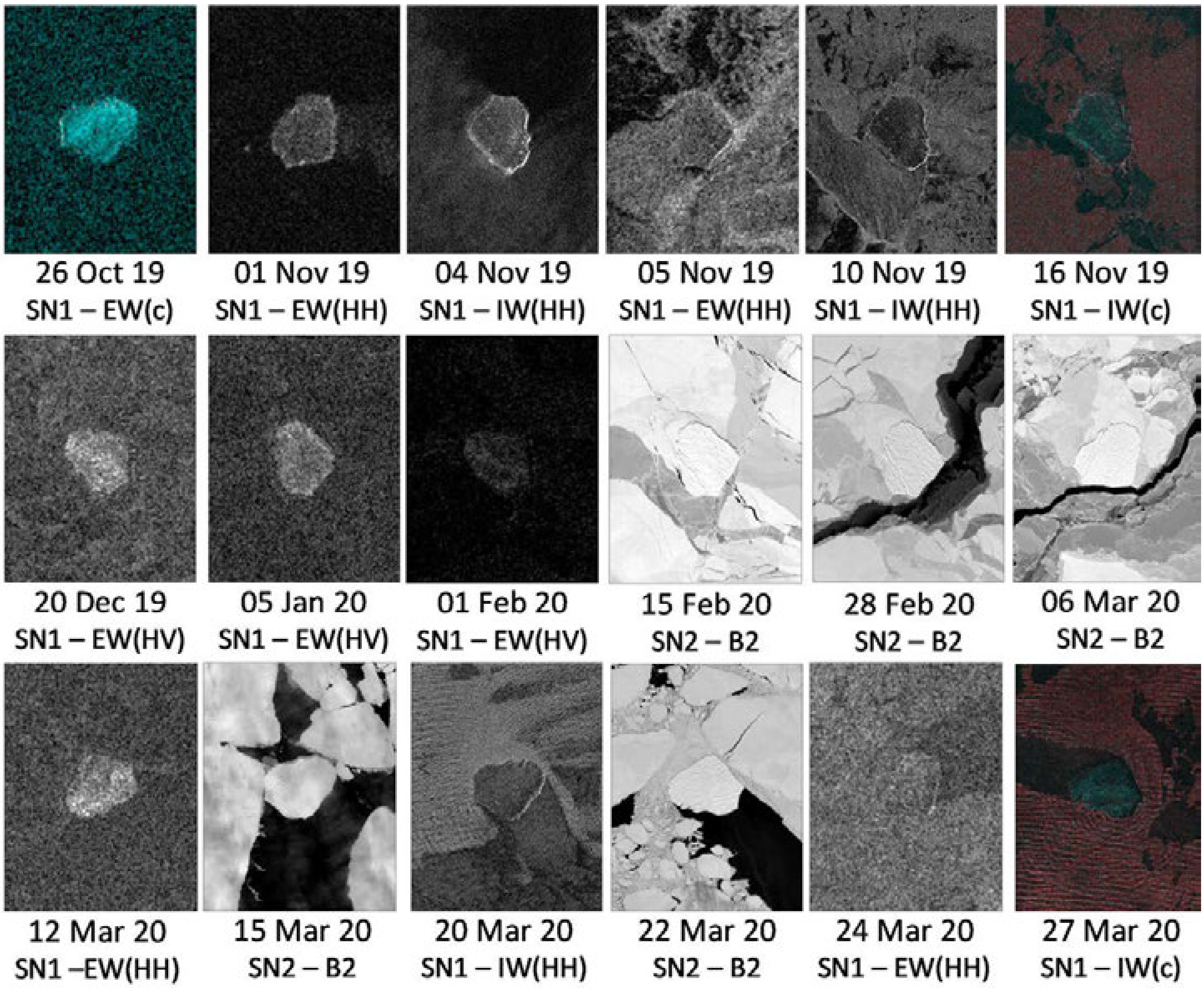


Figure D-11. Sample detections of Petermann Ice Island 2017-A from northern Baffin Bay on October 25, 2019 to March 27, 2020 the final image of the ice island before breaking up west of Sisimiut, Greenland. Note the arrival of sea ice in the imagery on November 5. All images are in precisely the same scale (1:24,000). SN2 refers to imagery from the Sentinel-2 Multispectral Imager and SN1 is from the Sentinel-1 Synthetic Aperture Radar (SAR). B2 is a Sentinel-2 image using only the blue wavelength band (Band 2, 10m resolution). EW refers to Extra Wide Swath (50m resolution). IW is Interferometric Wide Swath (20m resolution). HH and HV refer to the polarization of the SAR imagery and (c) denotes that the image is displayed as an R-G-B composite image with HH-HV-HV shown in R-G-B. Copernicus Sentinel data 2019, 2020.

easy to locate. In the presence of sea ice, the undulating texture of the glacial ice compared to the uniformity of the sea ice and the known shape of the iceberg being tracked was key in locating the island and fragment. For Landsat-7 and Landsat-8 imagery, utilizing the better resolution of the panchromatic band 8 (15m resolution) to identify the shape was beneficial and outweighed the loss of color information available from utilizing the other visible bands (30m resolution). For Sentinel-2, band 2 (blue wavelength; 10m

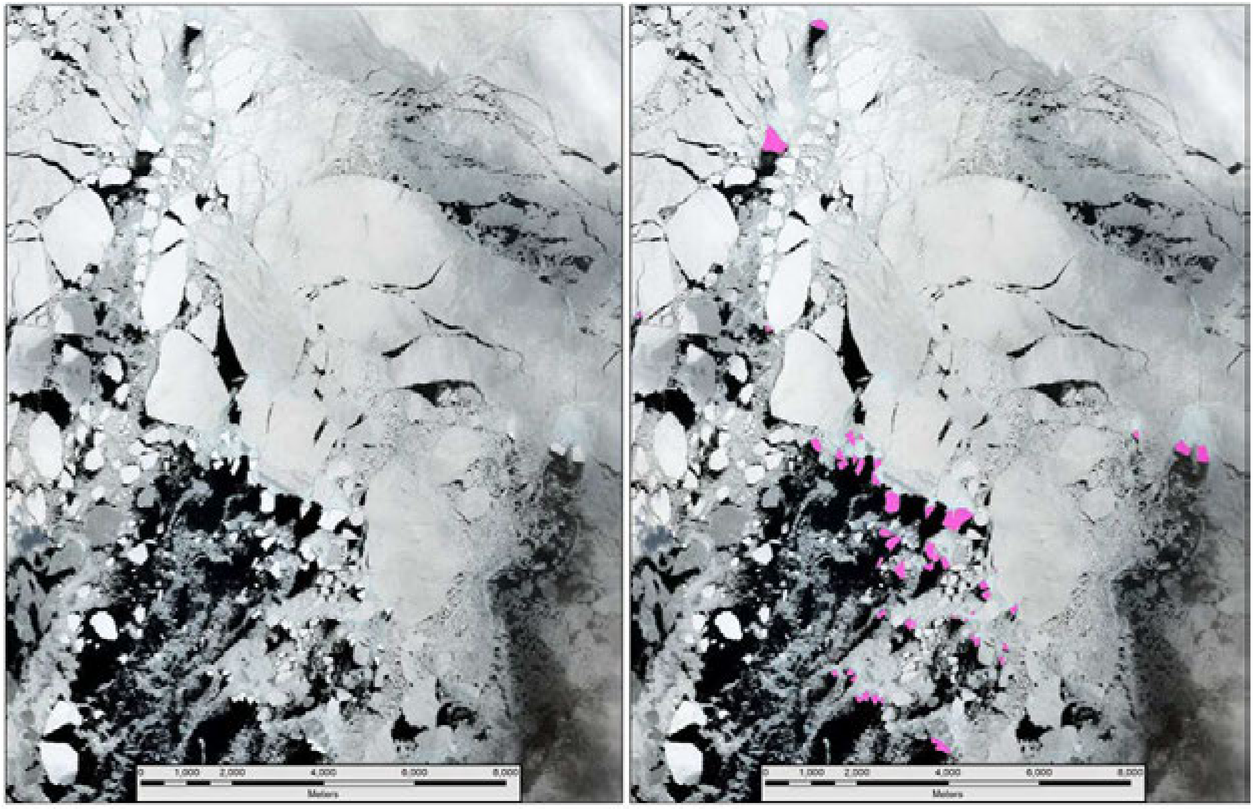


Figure D-12. Destruction of Petermann Ice Island 2017-A in the vicinity of 66˚52'N, 054˚43'W. Imagery from Sentinel-2 on April 1, 2020, displayed in true color with B4-B3-B2 in R-G-B. Both images are the same except the identified pieces of the ice island are highlighted in pink on the right image for reference. Copernicus Sentinel data 2020.

resolution) was utilized first, and in most cases, was sufficient for detecting texture, shape, and color, even within sea ice. True color images (B4-B3-B2 in R-G-B) were useful within broken floes of gray or gray-white sea ice and cloud-cover. **Figure D-13** shows an example of a detection of IIF-2020-001 using a pseudocolor image within thin clouds. The combination of B11-B8-B2 in R-G-B capitalizes on the lack of reflectance/emittance in the thermal and shortwave infrared wavelengths from ice to make white ice stand out to the eye as blue below thin clouds. Despite the reduction in resolution of the composite image due to the 20m resolution of band 11, this technique proved helpful in the detection of IIF-2020-001.

Though Landsat-7, Landsat-8, and Sentinel-2 multispectral imagery provide a higher level of confidence than SAR in identifying a target iceberg through use of texture, shape, and color, there are seasonal, geographic, and environmental limitations. These sensors cannot collect imagery without sunlight, which limits their use during winter months in high latitudes but extends their use during summer months. Further, they typically do not collect imagery far from shore and are subject to being rendered ineffective due to cloud-cover. As such, SAR remained the primary sensor for tracking the island and the fragment during the fall and winter and while both were far from shore within Baffin Bay.

Sentinel-1 HH and HV polarizations were both effective at identifying the island and fragment. IW imagery was preferred due to the finer resolution, but the prevalence of EW

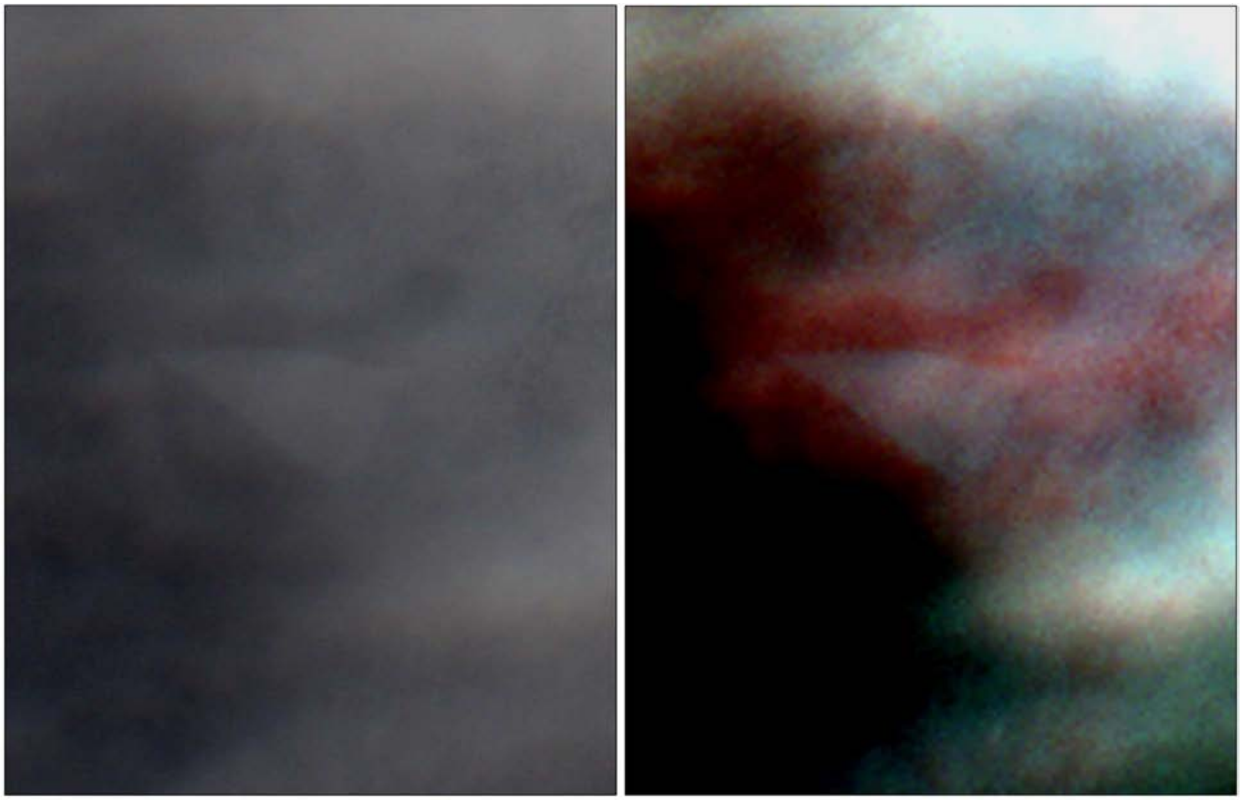


Figure D-13. Sentinel-2 imagery of Ice Island Fragment 2020-001 from March 12, 2020. True color (B4-B3-B2 in R-G-B) is shown on left and pseudocolor (B11-B8-B2 in R-G-B) on right. The fragment was initially only detected utilizing the pseudocolor image, capitalizing on the use of the thermal infrared band (B11) to distinguish ice from cloud, and this technique was utilized afterwards as a way to detect ice through thin cloud. Copernicus Sentinel data 2020. Contains modified Copernicus Sentinel data 2020.

imagery at higher revisit frequency, higher latitudes, and covering a larger area made the EW mode the dominant detection method for most of the track-line positions. Leveraging the characteristics of both polarizations through use of a composite image with HH-HV-HV in R-G-B was extremely helpful at guiding the eye to the target and discriminating it from surrounding sea ice or ocean waves. Though SAR was able to detect the different surface texture of the tabular icebergs from the surrounding water or sea ice, the energy reflectance from the edges of the tabular shape above the water and, especially, sea ice was the primary differentiating feature, most notably, in IW imagery. The reader is referred to **Figures D-4**, **D-7**, and **D-11** for examples of the differentiation in surface texture and edges in SAR.

The challenge of locating icebergs within sea ice as experienced with this project cannot be overstated. Though the 2,000m waterline length of PII-2017-A was typically located easily, the 800m waterline length of IIF-2020-001 in 50m EW imagery was extremely difficult to locate, especially once the sea ice floe had become fragmented itself. Even this 800m fragment was notably larger than most icebergs that IIP tracks. However, it should be considered that this tabular iceberg would generally have a lower freeboard (height above waterline) than a smaller, non-tabular iceberg would, decreasing the amount of target area for SAR energy to reflect from.

D-6. Conclusion

Using only open source satellite data (except for six Radarsat-2 sightings provided by CIS), this project documented the calving, drift, and deterioration of PII-2017-A over nearly three years, as well as that of IIF-2020-001. In all, this study recorded 159 observations of PII-2017-A and 122 of IIF-2020-001. This dataset is included in the Supplemental Material for this Appendix.

The fact that IIP located "Pizza Berg" in the first operational use of Sentinel-2 imagery was serendipitous. In the initial weeks of tracking the fragment, there was very real concern that it could pose a serious threat to the Grand Banks petroleum infrastructure and transatlantic shipping. Once it began to deteriorate and went aground within an enclosed bay, scientific curiosity took over. Where did it come from? Accurately tracking it back to PII-2017-A, observing it calving from the ice island, and tracking the ice island itself from calving from the Petermann Glacier to deterioration are a testament to the potential of satellite reconnaissance capabilities. This case demonstrates the developments made by IIP to date, and lends a sense of perspective and wonder to the IIP mission in the cryosphere. All icebergs tracked by IIP have a similar life history to "Pizza Berg," but most of the time our observations occur only at the end of this story as the icebergs approach the shipping lanes. This project provided the opportunity to tell the story of an individual iceberg, albeit a very large one, from beginning to end, from "birth" to "death," and to exercise the ability to bring multiple sensors and techniques to bear to effectively track it and to document the final journey of a piece of the Petermann Glacier for posterity.

D-7. Acknowledgements

The author would like to gratefully acknowledge the support of MST2 Joseph Ambro from IIP, Dr. Adrienne White and Doug Leonard from CIS, Mark Howell, Pamela Burke, and Kelley Dodge from C-CORE, and Ryan Crawford, Jonathan Chatman, and Brian Walsh, from PAL Aerospace for their contributions to the tracking of "Pizza Berg" from March through April of 2020.

D-8. References

Landsat-7 and Landsat-8 imagery courtesy of the U.S. Geological Survey.

2019 and 2020 Sentinel-1 and Sentinel-2 imagery downloaded from Copernicus Sentinel data.

Canadian Ice Service. 2005. MANICE, Manual of Standard Procedures for Observing and Reporting Ice Conditions. Government of Canada, Ottawa, Ontario.

Münchow, A., L. Padman, and H.A. Fricker. 2014. Interannual changes of the floating ice shelf of Petermann Gletscher, North Greenland, from 2000 to 2012. *Journal of Glaciology*. Vol 60(221): 489-499. DOI: 10.3189/2014JoG13J135

D-9. Supplemental Material

Petermann Ice Island 2017-A Observations											
Date	Lat	Lon	Time(Z)	Date	Lat	Lon	Time(Z)	Date	Lat	Lon	Time(Z)
7/26/2017	80.967	-60.995	1909	11/5/2019	75.587	-73.755	1217	1/23/2020	73.902	-63.408	1121
7/29/2017	80.993	-61.008	1940	11/6/2019	75.606	-73.851	1210	1/24/2020	73.857	-63.476	1112
7/30/2017	81.002	-60.957	1845	11/7/2019	75.563	-73.869	1201	1/25/2020	73.808	-62.975	1104
8/1/2017	81.183	-61.721	2148	11/7/2019	75.526	-73.886	2145	1/26/2020	73.790	-62.820	1055
8/5/2017	81.441	-62.621	2124	11/8/2019	75.472	-73.841	1153	1/27/2020	73.684	-62.424	2120
8/16/2017	80.403	-68.201	2244	11/9/2019	75.329	-73.817	1144	1/28/2020	73.633	-62.226	1129
8/28/2017	79.261	-73.877	1815	11/10/2019	75.075	-73.650	1137	1/29/2020	73.524	-61.894	2103
8/30/2017	79.270	-73.473	1802	11/10/2019	74.917	-73.491	2210	1/30/2020	73.515	-61.835	1112
8/31/2017	79.041	-74.022	2338	11/11/2019	74.743	-73.326	1218	1/31/2020	73.447	-61.704	1104
9/15/2017	77.650	-76.067	1803	11/12/2019	74.574	-73.050	1209	2/1/2020	73.381	-61.512	1056
9/17/2017	77.647	-76.211	1751	11/13/2019	74.396	-73.000	1202	2/3/2020	73.247	-61.177	1039
9/24/2017	77.675	-76.794	1757	11/14/2019	74.273	-73.038	1153	2/4/2020	73.107	-61.014	2105
10/6/2017	77.631	-76.972	1822	11/15/2019	74.114	-72.298	1145	2/5/2020	72.978	-60.916	1112
3/19/2018	77.573	-77.107	1757	11/16/2019	74.086	-71.634	1137	2/6/2020	72.701	-60.583	1104
4/11/2018	77.573	-77.106	1802	11/17/2019	74.169	-71.352	1129	2/8/2020	72.118	-59.858	2120
5/22/2018	77.573	-77.106	1756	11/18/2019	74.254	-71.045	1210	2/9/2020	71.895	-59.640	1039
8/8/2018	77.573	-77.106	1808	11/19/2019	74.347	-70.732	1201	2/10/2020	71.728	-59.429	2103
9/4/2018	77.546	-77.557	1750	11/20/2019	74.452	-70.329	1153	2/12/2020	71.607	-59.102	1104
10/6/2018	77.567	-77.228	1751	11/21/2019	74.457	-69.858	1444	2/15/2020	71.045	-59.111	1040
3/8/2019	77.477	-77.824	1744	11/23/2019	74.584	-69.666	1128	2/15/2020	71.000	-59.077	1552
4/9/2019	77.477	-77.823	1744	11/24/2019	74.636	-69.332	1124	2/18/2020	70.862	-58.725	1602
5/31/2019	77.477	-77.825	0045	11/29/2019	74.686	-69.762	1129	2/20/2020	70.715	-58.584	2121
6/27/2019	77.478	-77.823	0027	12/1/2019	74.770	-69.397	1112	2/21/2020	70.666	-58.520	1040
7/26/2019	77.477	-77.824	1809	12/2/2019	74.767	-69.353	1153	2/22/2020	70.587	-58.406	2103
8/13/2019	77.344	-75.714	1757	12/6/2019	74.710	-68.479	1122	2/23/2020	70.544	-58.384	1024
8/15/2019	77.298	-76.008	1745	12/9/2019	74.638	-68.193	1145	2/25/2020	70.349	-58.111	1057
8/31/2019	76.826	-76.048	1809	11/29/2019	74.686	-69.762	1129	2/26/2020	70.289	-57.972	1612
9/2/2019	76.618	-75.605	1733	12/1/2019	74.770	-69.397	1112	2/27/2020	70.194	-57.841	1111
9/8/2019	76.356	-79.124	1819	12/2/2019	74.767	-69.353	1153	2/28/2020	70.152	-57.772	1501
10/5/2019	74.018	-81.910	1225	12/6/2019	74.710	-68.479	1122	2/29/2020	70.068	-57.675	1024
10/13/2019	73.579	-72.935	1210	12/9/2019	74.638	-68.193	1145	3/1/2020	69.873	-57.394	1551
10/14/2019	73.690	-72.879	1202	12/13/2019	74.470	-67.983	2145	3/3/2020	69.650	-57.165	1049
10/15/2019	73.951	-72.634	1153	12/15/2019	74.610	-68.336	1144	3/4/2020	69.651	-57.191	1040
10/16/2019	73.976	-71.387	1144	12/17/2019	74.712	-68.733	1128	3/5/2020	69.506	-57.095	2102
10/17/2019	73.640	-71.348	1137	12/20/2019	74.716	-68.464	1152	3/6/2020	69.309	-56.956	1550
10/18/2019	73.487	-71.562	1128	12/25/2019	74.743	-68.241	1112	3/7/2020	69.091	-56.772	1016
10/19/2019	73.589	-71.881	1121	12/27/2019	74.668	-67.476	1144	3/9/2020	68.709	-56.797	1559
10/20/2019	73.894	-72.357	1202	12/29/2019	74.551	-67.218	1128	3/10/2020	68.270	-56.553	1041
10/21/2019	74.141	-71.496	1152	12/30/2019	74.476	-66.612	1122	3/10/2020	68.064	-56.550	2111
10/22/2019	74.336	-70.529	1145	12/31/2019	74.384	-66.174	1111	3/11/2020	67.821	-56.458	1033
10/23/2019	74.670	-70.571	1136	1/3/2020	74.339	-65.684	2121	3/12/2020	67.486	-56.372	1024
10/24/2019	74.911	-70.942	1218	1/4/2020	74.314	-65.493	1129	3/12/2020	67.364	-56.345	2054
10/25/2019	75.253	-71.167	1210	1/5/2020	74.240	-65.113	2104	3/13/2020	67.134	-56.226	1539
10/26/2019	75.398	-71.745	1201	1/6/2020	74.159	-64.883	1112	3/15/2020	66.660	-55.817	1530
10/26/2019	75.479	-71.720	2145	1/7/2020	74.174	-64.587	1103	3/18/2020	66.620	-55.369	2054
10/27/2019	75.579	-71.707	1153	1/8/2020	74.176	-64.443	1056	3/19/2020	66.717	-55.319	1017
10/28/2019	75.611	-71.981	1145	1/10/2020	74.127	-64.232	1128	3/20/2020	66.867	-55.189	1008
10/29/2019	75.578	-72.290	1137	1/11/2020	74.072	-64.177	1121	3/22/2020	66.769	-55.282	1519
10/29/2019	75.558	-72.402	2210	1/12/2020	74.090	-64.210	1112	3/22/2020	66.628	-55.227	2110
10/30/2019	75.484	-72.579	1128	1/15/2020	73.995	-63.662	2121	3/24/2020	66.559	-55.271	1025
10/30/2019	75.482	-72.609	1218	1/16/2020	73.964	-63.605	1130	3/27/2020	66.514	-54.970	1004
10/31/2019	75.454	-72.955	1209	1/17/2020	73.937	-63.541	1119	3/30/2020	66.862	-54.731	2054
11/1/2019	75.538	-73.060	1202	1/18/2020	73.926	-63.429	1112				
11/2/2019	75.554	-73.197	1153	1/19/2020	73.889	-63.397	1104				
11/3/2019	75.619	-73.560	1146	1/20/2020	73.861	-63.154	1056				
11/4/2019	75.597	-73.599	1137	1/22/2020	73.776	-63.393	1128				

Supplemental Table D-1. Observations of Petermann Ice Island 2017-A from July 26, 2017 through March 30, 2020.

Ice Island Fragment 2020-001 Observations									
Date	Lat	Lon	Time (Z)	Source	Date	Lat	Lon	Time (Z)	Source
10/25/2019	75.208	-71.377	1210	SN1 EW	1/4/2020	70.011	-63.016	1040	SN1 EW - low conf
10/26/2019	75.287	-72.157	1201	SN1 EW	1/6/2020	69.847	-62.832	1113	SN1 EW
10/26/2019	75.318	-72.414	2145	SN1 EW	1/8/2020	69.624	-62.591	1058	SN1 IW
10/27/2019	75.371	-72.554	1153	SN1 EW	1/8/2020	69.539	-62.639	1105	SN1 EW
10/28/2019	75.378	-72.366	1145	SN1 EW	1/10/2020	69.467	-62.429	1040	SN1 EW
10/29/2019	75.290	-72.557	1137	SN1 IW	1/12/2020	69.357	-62.571	1111	SN1 EW
10/29/2019	75.250	-72.775	2210	SN1 EW	1/16/2020	69.081	-62.022	1041	SN1 EW
10/30/2019	75.144	-73.102	1128	SN1 EW	1/18/2020	68.807	-61.267	2143	SN1 EW
10/30/2019	75.137	-73.116	1218	SN1 EW	1/22/2020	68.452	-60.872	1041	SN1 EW
10/31/2019	75.077	-73.387	1209	SN1 EW	1/22/2020	68.423	-60.737	2111	SN1 EW - low conf
11/1/2019	75.082	-73.828	1202	SN1 EW	1/23/2020	68.374	-60.643	1033	SN1 EW
11/2/2019	75.078	-74.205	1153	SN1 EW	1/24/2020	68.324	-60.110	1025	SN1 EW - low conf
11/3/2019	75.049	-74.559	1145	SN1 EW	1/27/2020	67.630	-58.679	2118	SN1 EW
11/4/2019	74.931	-74.394	1137	SN1 IW	1/30/2020	66.342	-60.635	1025	SN1 IW
11/5/2019	74.849	-74.314	1217	SN1 EW	1/31/2020	65.363	-60.148	1017	SN1 EW - low conf
11/6/2019	74.775	-74.327	1210	SN1 EW	2/3/2020	64.696	-60.438	1040	SN1 EW - low conf
11/7/2019	74.712	-74.391	1201	SN1 EW	2/5/2020	63.410	-61.404	1026	SN1 EW
11/7/2019	74.675	-74.444	2145	SN1 EW	2/9/2020	61.909	-62.583	1043	SN1 IW
11/8/2019	74.629	-74.579	1153	SN1 EW	2/10/2020	61.865	-62.305	1554	SN2
11/9/2019	74.476	-74.718	1144	SN1 EW	2/11/2020	61.820	-62.279	1025	SN1 IW
11/10/2019	74.213	-74.550	1138	SN1 IW	2/11/2020	61.794	-62.202	2142	SN1 EW
11/10/2019	74.055	-74.259	2210	SN1 EW	2/15/2020	61.292	-62.702	1552	SN2
11/11/2019	73.973	-73.752	1218	SN1 EW	2/16/2020	61.347	-62.765	2150	SN1 IW
11/12/2019	73.894	-72.854	1210	SN1 EW	2/17/2020	61.288	-62.650	1543	SN2
11/13/2019	73.702	-72.157	1202	SN1 EW	2/22/2020	60.506	-61.670	1541	SN2
11/14/2019	73.734	-71.477	1153	SN1 EW	2/24/2020	60.266	-61.806	1535	SN2
11/15/2019	73.710	-71.339	1145	SN1 EW	2/28/2020	58.816	-60.358	2149	SN1 IW
11/16/2019	73.407	-70.777	1137	SN1 IW	2/29/2020	58.737	-60.182	1027	SN1 IW
11/17/2019	73.371	-69.693	1129	SN1 EW	3/7/2020	56.807	-59.930	1526	SN2
11/19/2019	73.392	-69.612	1201	SN1 EW	3/8/2020	56.813	-59.791	2124	SN1 IW
11/20/2019	73.348	-69.669	1153	SN1 EW - low conf	3/9/2020	56.597	-59.607	1516	SN2
11/22/2019	73.265	-69.037	1138	SN1 IW - low conf	3/10/2020	56.369	-59.378	1028	CIS-RADARSAT
11/23/2019	73.136	-68.217	1130	SN1 EW	3/11/2020	56.229	-59.428	2148	SN1 IW
11/24/2019	73.099	-67.796	1121	SN1 EW - low conf	3/12/2020	55.898	-59.254	1526	SN2
11/25/2019	73.042	-67.469	1112	SN1 EW	3/12/2020	55.802	-59.245	2141	SN1 EW
11/26/2019	72.974	-67.418	1105	SN1 EW	3/15/2020	55.227	-57.340	1003	CIS-RADARSAT
11/27/2019	72.668	-67.448	1146	SN1 EW	3/16/2020	54.929	-57.047	1423	LANDSAT 7 ETM+
11/29/2019	72.509	-67.468	1130	SN1 EW	3/16/2020	54.935	-57.068	1507	SN2
11/30/2019	72.212	-67.958	1121	SN1 EW - low conf	3/18/2020	55.075	-56.430	2125	CIS
12/1/2019	72.060	-67.604	2143	SN1 EW - low conf	3/19/2020	55.037	-56.018	1004	CIS
12/2/2019	71.868	-67.183	1104	SN1 EW - low conf	3/22/2020	54.668	-55.519	0956	CIS
12/3/2019	71.824	-67.106	1057	SN1 EW	3/23/2020	54.055	-55.543	1457	SN2
12/5/2019	71.825	-66.734	2112	SN1 EW - low conf	3/26/2020	54.014	-55.204	1507	SN2
12/6/2019	71.764	-66.674	1122	SN1 EW	3/28/2020	54.044	-55.150	0956	SN1
12/8/2019	71.754	-66.615	1105	SN1 EW - low conf	4/3/2020	52.845	-55.591	0956	SN1
12/10/2019	71.470	-66.331	2120	SN1 EW	4/4/2020	52.771	-55.575	2124	CIS
12/11/2019	71.422	-66.118	1130	SN1 EW - low conf	4/12/2020	52.012	-55.264	1457	SN2
12/14/2019	71.163	-65.609	1105	SN1 EW - low conf	4/17/2020	51.832	-55.235	1457	SN2
12/15/2019	71.054	-65.608	1057	SN1 IW	4/19/2020	51.345	-55.113	1448	SN2
12/17/2019	71.000	-65.556	1129	SN1 EW	4/22/2020	51.280	-55.590	1457	SN2
12/18/2019	70.903	-65.481	1122	SN1 EW	4/24/2020	51.296	-55.634	2131	SN1
12/19/2019	70.839	-65.408	1112	SN1 EW	4/27/2020	51.303	-55.700	0956	SN1
12/22/2019	70.698	-65.430	1049	SN1 EW	4/27/2020	51.303	-55.700	1457	SN2
12/22/2019	70.678	-65.291	2120	SN1 EW	4/29/2020	51.303	-55.700	1448	SN2
12/24/2019	70.633	-64.847	1120	SN1 EW	5/9/2020	51.321	-55.706	0956	SN1
12/25/2019	70.531	-64.672	1113	SN1 EW	5/9/2020	51.321	-55.704	1448	SN2
12/26/2019	70.402	-64.768	1104	SN1 EW	5/10/2020	51.321	-55.705	0949	SN1
12/27/2019	70.338	-64.921	1057	SN1 IW	5/12/2020	51.321	-55.707	1457	SN2
12/29/2019	70.234	-63.845	1111	SN1 EW - low conf	6/6/2020	51.318	-55.733	1457	SN2
12/31/2019	70.164	-63.716	1112	SN1 EW	6/8/2020	51.318	-55.732	0957	SN1 - IW
1/3/2020	70.031	-63.036	2120	SN1 EW - low conf	6/9/2020	51.317	-55.731	0948	SN1 - IW

Supplemental Table D-2. Observations of Ice Island Fragment 2020-001 from October 25, 2017 through July 9, 2020. Note that "low conf" in the Source column denotes that the observation is estimated due to low confidence in the detection. These are mostly due to the presence of broken floes of sea ice in 50m resolution Synthetic Aperture Radar imagery.

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