Homeland Security

United States Coast Guard

Report of the International Ice Patrol in the North Atlantic

2023 Season

Bulletin No. 109

CG-188-78

Bulletin No. 109

Report of the International Ice Patrol in the North Atlantic

2023 Season

CG-188-78

Forwarded herewith is Bulletin No. 109 of the International Ice Patrol (IIP) describing ice conditions and IIP operations during the 2023 Ice Year (1 October 2022 – 30 September 2023). In Ice Year 2023, 385 icebergs drifted into transatlantic shipping lanes, marking the first "moderate" year of the current decade.

Satellite reconnaissance continues to serve as the primary means for iceberg detection along the coast of Newfoundland and Labrador and over the Grand Banks of Newfoundland. For the 2023 Ice Year, 87% of recorded icebergs were sighted by IIP, the Canadian Ice Service (CIS), or commercial satellite analysts using largely public imagery. IIP has stated in recent bulletins that we are committed to "the short-term elimination of the need for costly aircraft hours." However, this season saw several challenges including reduced commercial aerial reconnaissance, setbacks on research and development (R&D) initiatives, and the loss of the European Space Agency (ESA) Sentinel-1B (SN1B) synthetic aperture radar (SAR) satellite, which has led to a reassessment. Instead, IIP plans to continue to rely on a multi-layered solution to maximizing mariner safety while minimizing costs. Manned flights will continue to serve a role in the foreseeable future but with increased scrutiny on opportunities for reduction. While satellite imagery serves as the primary workhorse and the de-facto method for finding icebergs longer than 20 meters, there is no substitute for the scalpel-like precision offered by manned flights for confidently declaring vast expanses of ocean clear of icebergs. This task is of paramount importance as mariners depend on IIP's iceberg warning products to safely cross the North Atlantic Ocean.

The loss of SN1B to an onboard technical issue in 2021 had repercussions throughout the user community, including IIP. A 50% reduction (one of two satellites) in the availability of IIP's primary operational tool highlighted the need for redundant methodologies and a layered strategy. Even as IIP looks forward to the launch of Sentinel-1C and growing remote sensing capabilities, both flights and vessel reports will continue to be relevant to reconnaissance efforts for 2024 and beyond.

IIP saw continued growth in our area of responsibility. Of particular note, IIP provided customized iceberg warning products in support of the naval exercises ARGUS and NANOOK that took place in the Canadian and Greenlandic Arctic. Using data provided by CIS and the Danish Meteorological Institute (DMI), these tailored iceberg products were critical for these non ice-strengthened vessels to avoid iceberg threats and conduct successful exercises. Additionally, two IIP members deployed for the first time as ice observers onboard the polar icebreaker U.S. Coast Guard Cutter (USCGC) HEALY. IIP's ice observers worked in tandem with the United States National Ice Center's (USNIC) ice analysts also onboard HEALY providing crucial ice information to the cutter and directly contributed to the safe deployment of that mission. These examples highlight IIP's close collaboration with our North American Ice Service (NAIS) partners and demonstrate the increased integration with the USNIC as a result of IIP's 2021 relocation to the National Oceanic Atmospheric Administration (NOAA) Satellite Facility in Suitland, MD.

Each year, IIP honors the sinking of the Royal Mail Ship (RMS) TITANIC, the event that founded our history, by holding memorials and wreath dedications honoring those lost. This year, IIP held this annual ceremony here in Washington, DC. Two months later, the world witnessed the further loss of life at the RMS TITANIC site with the tragic implosion of the Titan Submersible. This incident occurred during an IIP deployment to Newfoundland and redirected the Coast Guard HC-130J assigned to Ice Patrol's mission to the search and rescue efforts. This mishap struck to the heart of our team's mission of safety of life at sea and did so with such proximity to our routine duties that it won't be soon forgotten. We are proud of our contributions to safe navigation in a highly dangerous part of the world and will continue to honor the lives of those lost this year and 111 years ago by continuing our mission to the best of our ability.

This 2023 Ice Year report was prepared by all members of the IIP team. On behalf of all of us, I hope that you enjoy reading it.

E. M. Caldwell
Commander, U. S. Coast Guard Commander,
International Ice Patrol

Acronyms and Abbreviations

AIS	Automatic Identification System
AOR	Area of responsibility
APN-241	Tactical Transport Weather Radar
ASEC	Air Station Elizabeth City
BAPS	IceBerg Analysis and Prediction System
CCG	Canadian Coast Guard
CBC	Canadian Broadcasting Corporation
CIIP	Commander, International Ice Patrol
CIS	Canadian Ice Service
CSA	Canadian Space Agency
CPC	Climate Prediction Center
CYYT	St. John’s International Airport
DMI	Danish Metrological Institute
DSA	Duty Satellite Analyst
DWS	Duty Watch Stander
ECMWF	European Centre for Medium-Range Weather Forecasts
EOIR	Electro-Optical Infrared
ERMA	Environmental Response Management Application
ESA	European Space Agency
GIS	Geographic Information System
HMCS	His Majesty’s Canadian Ship
IDS	Iceberg Detection System
IFM	Isolated/Few/Many
IICWG	International Ice Charting Working Group
IIP	International Ice Patrol
IRD	Ice Reconnaissance Detachment
ISAR	Inverse Synthetic Aperture Radar
KADW	Joint Base Andrews Airport

KML	Keyhole Markup Language
MCTS	Maritime Communication and Traffic Service
MSLP	Mean Sea Level Pressure
MWP	Mean Wave Period
NAIS	North American Ice Service
NAO	North Atlantic Oscillation
NAOI	North Atlantic Oscillation Index
NAVAREA	Navigational Area
NAVCEN	Navigation Center
NAVTEX	Navigational Telex
NAVWARN	Navigational Warning
NCEP	National Centers for Environmental Prediction
NGA	National Geospatial-Intelligence Agency
NL	Newfoundland
NM	Nautical Mile
NOAA	National Oceanic and Atmospheric Administration
NSIDC	National Snow and Ice Data Center
NSOF	NOAA Satellite Operations Facility
NWS	National Weather Service
OPC	Ocean Prediction Center
OPCEN	Operations Center
POD	Probability of detection
R&D	Research and Development
Radiofax	Radio facsimile
RCM	Radarsat Constellation Mission
RMS	Royal Mail Ship
RS2	Radarsat-2
SAR	Synthetic aperture radar
SAT	Surface air temperature
SIM	Standard Iceberg Message

SITOR	Simplex Teletype Over Radio
SN1(A/B)	Sentinel-1 (A/B)
SN2	Sentinel-2
SOLAS	Safety of Life at Sea
SST	Sea surface temperature
SWH	Significant wave height
UK	United Kingdom
US	United States
USCG	United States Coast Guard
USCGC	United States Coast Guard Cutter
USNIC	United States National Ice Center
WWNWS	World-Wide Navigational Warning Service

Table of Contents

1 Introduction

This is the 109th IIP annual report describing the 2023 Ice Year. It depicts IIP operations, along with environmental and iceberg conditions, in the North Atlantic from October 2022 to September 2023.

IIP deployed nine Ice Reconnaissance Detachments (IRDs) to detect icebergs in the North Atlantic Ocean and Labrador Sea in Ice Year 2023. These IRDs used HC-130J aircraft from U.S. Coast Guard (USCG) Air Station Elizabeth City (ASEC). IIP also received iceberg reports from commercial aircraft and mariners in the North Atlantic region. Further, IIP continued to incorporate satellite data into its 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) located in the NOAA Satellite Operations Facility (NSOF) at Suitland, MD. In accordance with the NAIS Collaborative Arrangement, IIP used BAPS to produce daily iceberg charts and text bulletins from the model output. These iceberg warning products were then distributed to the maritime community daily. In addition to these routine broadcasts, IIP also responded to individual requests for iceberg information.

IIP remains unequivocally committed to maintaining mariner safety as it explores adding new technology and tools to its iceberg reconnaissance mission. While iceberg aviation missions will continue for the foreseeable future, IIP remains committed to its continual advancement of its satellite reconnaissance program as the primary method for iceberg reconnaissance. IIP intends to develop a diverse and resilient system of collection platforms to provide an iceberg detection capability that leverages the benefits of both air and space reconnaissance.

IIP was formed after the RMS TITANIC sank on 15 April 1912. Since 1913, except for 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 2023 Ice Year, IIP was under the operational control of the Director of Marine Transportation (CG-5PW), Mr. Michael D. Emerson. CDR Marcus T. Hirschberg was Commander, IIP (CIIP) until 28 July 2023 when CDR Erin M. Caldwell assumed command.

For more information about IIP, including historical and current iceberg bulletins and charts, visit our website at https://www.navcen.uscg.gov/international-ice-patrol.

INTERNATIONAL
ICE PATROL

2 Ice and Environmental Conditions

2.1 International Ice Patrol Oceanographic Area of Responsibility

This section describes the ice and environmental conditions in the IIP oceanographic area of responsibility (AOR) during the 2023 northern hemisphere Ice Year (1 October 2022 to 30 September 2023). IIP has the statutory mission, encoded in international (International Maritime Organization 1974) and United States (US) law (Title 46, United States Code § 80301 2021), to monitor and warn of iceberg danger in the North Atlantic Ocean. Under this mission, IIP's AOR encompasses the area of ocean around the Grand Banks of Newfoundland, Canada, where icebergs pose a threat to vessels traversing North Atlantic shipping lanes (**Figure 2.1**).

As a part of its mission, IIP collects and reports daily iceberg data (numbers, distribution, and extent, or "limit") in its AOR (International Maritime Organization 1974). IIP reports these data as estimates, because IIP uses a combination of direct, imperfect measurement (human visual sighting and remote sensing detection) of icebergs or their absence, and computer modeled drift and deterioration of previously detected icebergs to estimate the daily iceberg population.

IIP's iceberg dataset is unique: due to the long history and singular mission of IIP since its formation in response to the sinking of the RMS TITANIC in 1912, it is likely the largest and most continuous, comprehensive, and accurate North Atlantic iceberg record. It is the authoritative dataset, and the only of its kind, for icebergs in IIP's AOR. For more information on the methods IIP employs to monitor icebergs in its AOR, see **Sections 3** and **4**.

2.1.1 Ice Year and Iceberg Season Background

The northern hemisphere Ice Year begins and ends roughly when sea ice (frozen saltwater ocean surface) reaches its minimum extent in the Arctic Ocean (September, see **Figure 2.1a**). Thus, midway through the Ice Year (March, in the northern hemisphere, see **Figure 2.1b**) corresponds to maximum sea ice extent (Fetterer, et al. 2017). Within a typical Ice Year, IIP considers the Iceberg Season in the North Atlantic to span the months in which icebergs (freshwater ice of land origin in the ocean) pose the greatest threat to the transatlantic shipping lanes, typically January through September, by drifting south of 48°N latitude, which is nearly on parallel with St. John's, Newfoundland (**Figure 2.1c** through **e** and **Figure 2.2**).

Icebergs in IIP's AOR originate from Arctic glaciers along the coast of western Greenland (see **Figure 2.1f**, *white diamonds*). At these glacial termini, ice calves (breaks off) into the ocean to become icebergs (individual pieces of floating glacial ice), which, amid sea ice and in open ocean, drift generally south in major currents in Baffin Bay and the Labrador Sea until, after several years, they reach the Grand Banks and intersect with major transatlantic shipping lanes (Larsen, et al. 2015, Newell 1993, Marko, et al. 1994, Wilton, Bigg and Hanna 2015).

Outside of the Iceberg Season, typically roughly October through December (see **Figure 2.2**), IIP transfers primary responsibility for monitoring and warning of icebergs in the North Atlantic and marginal Arctic seas to its close partner, CIS, within NAIS, as primarily Canadian vessels and coastline will be threatened during this time. During these months, IIP focuses on

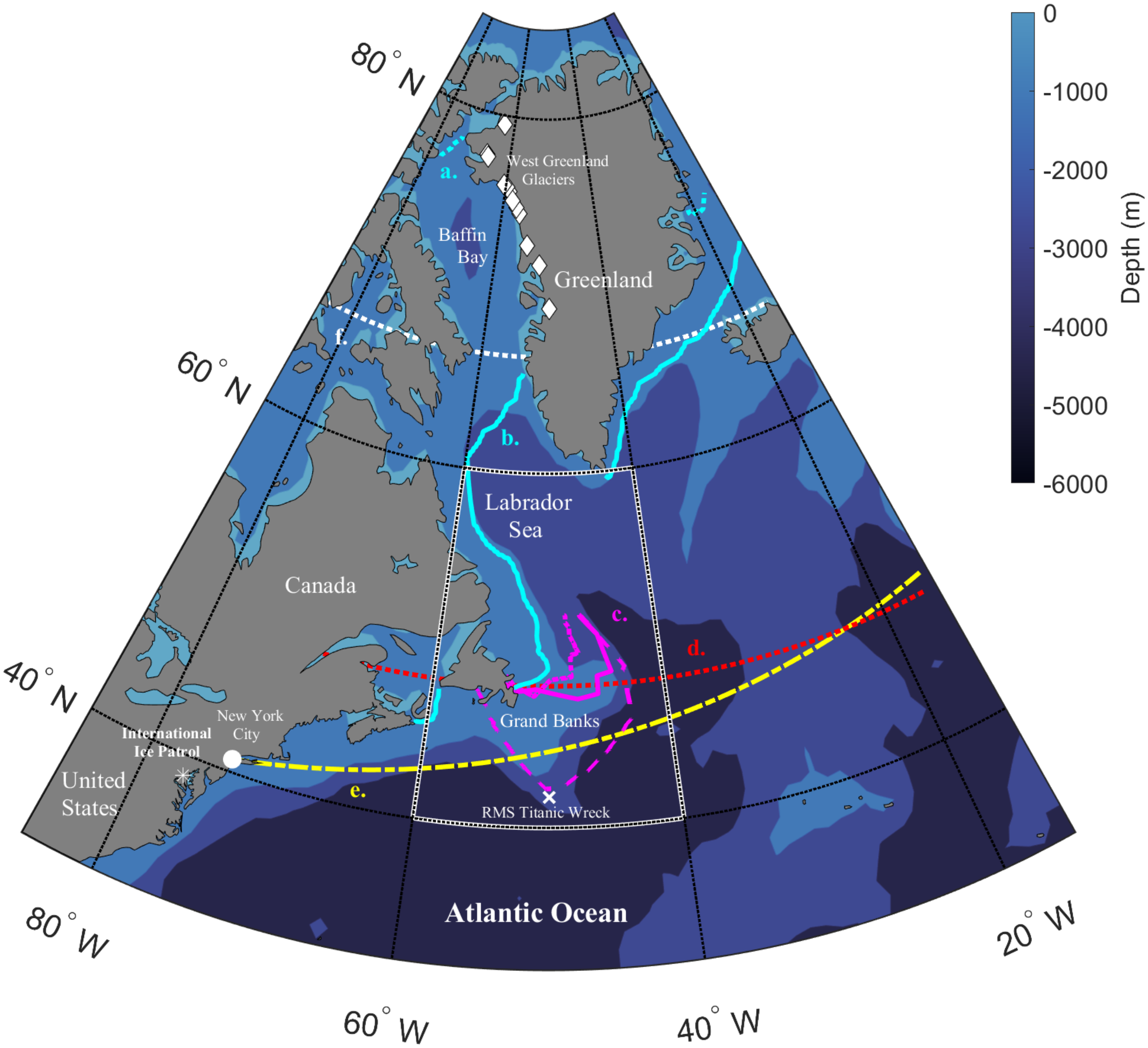

Figure 2.1. International Ice Patrol (IIP) approximate area of responsibility (AOR, *white outlined area*) around the Grand Banks of Newfoundland, Canada, in the North Atlantic Ocean, where icebergs threaten shipping lanes during the iceberg season. **a.** The median sea ice extent in September (at its yearly minimum, *cyan dotted line*) and **b.** March (at its yearly maximum, *cyan solid line*) for 1981 to 2010. **c.** The median mid-January (*dotted magenta line*), mid-May (*dashed magenta line*), and early-September (*solid magenta line*) iceberg limits for 1991 to 2020; prior to about 2010, IIP did not systematically monitor icebergs north of 52°N. **d.** 48°N (*red dotted line*); IIP considers this latitude as that south of which icebergs pose a significant threat to the shipping lanes, and records the daily, monthly, and yearly estimated number of icebergs which drift south of it. **e.** An example transatlantic shipping route *(yellow dashed line*) along a rhumb line between Southampton, United Kingdom (UK) and New York City, US. **f.** The Arctic Circle at roughly 66.5°N (*white dotted line*). Icebergs in IIP's AOR calve (break off) into the ocean primarily where Greenland glaciers terminate on the island's west coast (*white diamonds*) (Rignot and Kanagaratnam 2006). They drift south over years in major Arctic and North Atlantic currents and within sea ice, to IIP's AOR. The depiction of west Greenland glacial termini is not comprehensive but includes those which contribute most icebergs to IIP's AOR. Sea ice extents are from the National Snow and Ice Data Center (NSIDC) Sea Ice Index, Version 3 (Fetterer, et al. 2017). Iceberg limits are from IIP. See discussion in Section 2.1.

oceanographic research and scientific development of iceberg reconnaissance methods to advance the state of its iceberg warning and monitoring; however, IIP continues to accept reports of icebergs and actively communicates them to CIS.

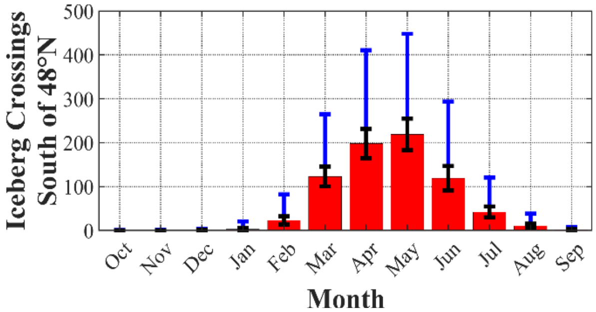

Figure 2.2. Mean estimated number of icebergs which cross south of 48°N each month for Ice Years 1983 to 2022 (*red bars*). The monthly standard deviation (absolute magnitude originating at the mean shown only, *blue capped lines*) and standard error (full range of error shown, *black capped lines*) of those estimated numbers are shown as error bars. 1983 marked the beginning of what IIP defines as the modern reconnaissance era, in which IIP began using modern airborne radar to detect icebergs and computer modeled iceberg drift and deterioration to estimate the daily iceberg population. Iceberg data is from IIP.

2.1.2 Iceberg Season Severity and Relationship to the Environment

IIP considers one of the metrics of the severity of a given Iceberg Season to be the total number of icebergs that drift south of 48°N latitude in an Ice Year (**Figure 2.3**) (Smith 1926, Trivers 1994). IIP classifies Iceberg Season severity for this metric as light for an iceberg number of 230 or less, moderate for 231 to 1036, severe for 1037 to 1398, and extreme for greater than 1398 (International Ice Patrol 2018). In 2018, IIP reestablished these classes and their thresholds to account for differing iceberg detection and monitoring methods through its history and into what IIP considers as its modern reconnaissance era (1983 to present), during which it has employed sophisticated airborne radar, computerized iceberg drift and deterioration models, and more recently, spaceborne sensors, to monitor icebergs. For a detailed discussion on this classification, see International Ice Patrol, 2018.

Another metric historically used by IIP to characterize Iceberg Season severity is season length, in which a longer season would correspond to greater severity as the duration of the iceberg threat to vessels traversing shipping lanes would be greater (Trivers 1994). Additionally, IIP has used the total areal extent of the known iceberg population over an Ice Year as a metric of Iceberg Season severity, given that a greater extent would correspond to icebergs threatening a greater portion of the shipping lanes (Trivers 1994, International Ice Patrol 2018).

The absolute number of icebergs that drift into IIP's AOR and south of 48°N latitude, their corresponding spatiotemporal distributions, and the duration of the Iceberg Season vary each year. However, patterns in these parameters emerge due to large-scale and long-term environmental forcings (Bigg, et al. 2014). Notably, large scale atmospheric and regional sea ice conditions have been shown to relate to North Atlantic iceberg conditions. Specifically, higher sea ice concentrations and greater sea ice extent are correlated with greater iceberg numbers and extent, because sea ice protects icebergs from destructive open ocean forces (waves and melting), and conversely from grounding in shallow coastal waters to melt quickly, as they drift south (Marko, et al. 1994, Trivers 1994).

In addition, it has been shown that the mode of the North Atlantic Oscillation (NAO), a temporal pattern of modification of the strengths of a large-scale predominately low surface pressure over Greenland and the Labrador Sea and a large-scale predominately high pressure over the mid North Atlantic, may correlate to iceberg conditions (Hanna, et al. 2011). The normal mode, indicated by a positive NAO index (NAOI) corresponds to a stronger Greenlandic low, offshore winds along the Labrador and northern Newfoundland coasts, increased storms through IIP's AOR, and increased precipitation. These conditions favor offshore transport of icebergs and a potential expansion of the iceberg limit, but also expose icebergs to open ocean where they deteriorate faster. Conversely, a negative NAOI corresponds to a weaker gradient between the Greenlandic low and North Atlantic high, onshore and alongshore-winds along the Labrador and northern Newfoundland coasts, decreased storms through the AOR, and decreased precipitation

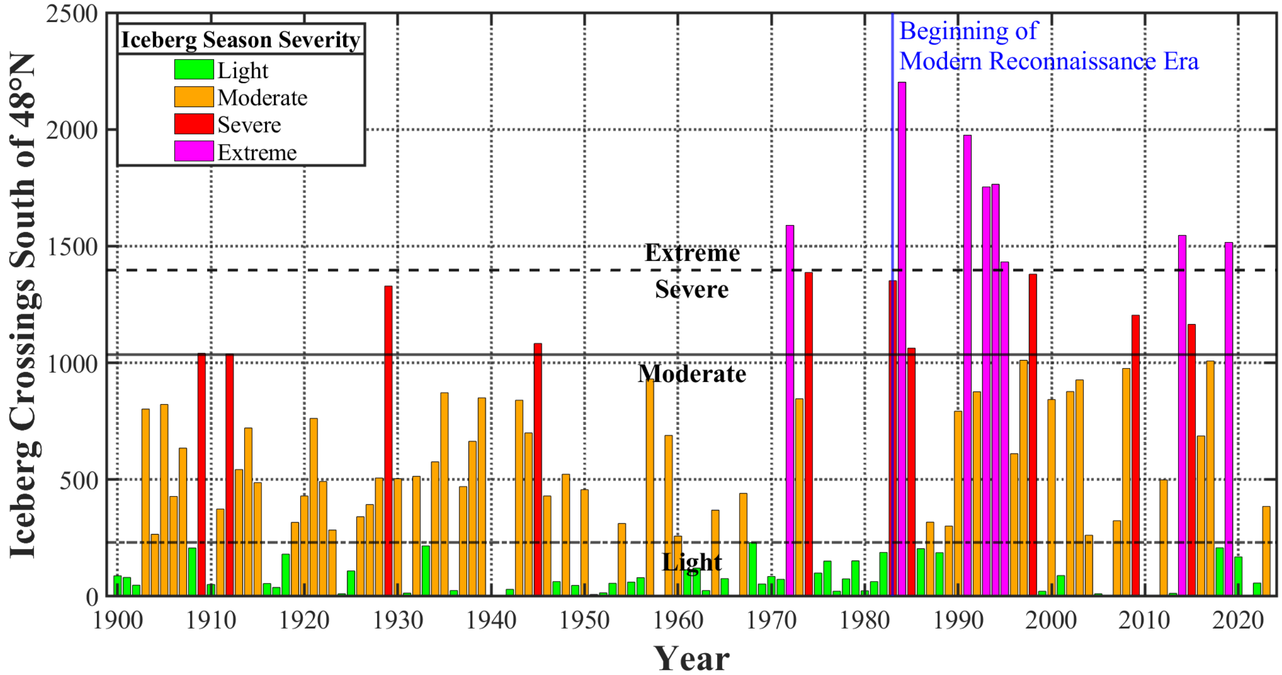

Figure 2.3. Estimated number of icebergs which crossed south of 48°N each Ice Year from 1900 to 2023. IIP classifies Iceberg Season severity in a given Ice Year for this metric as light (*green bars*) for an iceberg number of 230 or less (*black dot-dashed line*), moderate (*orange bars*) for 231 to 1036 (*black solid line*), severe (*red bars*) for 1037 to 1398 (*black dashed line*), and extreme (*magenta bars*) for greater than 1398 (International Ice Patrol 2018). Iceberg data is from IIP; prior to 1914, iceberg data is from the United States Hydrologic Office (Trivers 1994). The beginning of the modern reconnaissance era (1983) is shown as a blue solid line.

(Fettweis, et al. 2013, Noël, et al. 2014). These conditions instead favor onshore transport of icebergs and a contracted iceberg limit, but also harbor icebergs inshore within calmer ocean conditions and coastal sea ice.

While these relationships are known between sea ice, the atmosphere, and icebergs, they remain a topic of ongoing study.

2.2 Ice and Environmental Conditions in the 2023 Ice Year

In Ice Year 2023, 385 icebergs drifted south of 48°N (see **Figure 2.3**, *rightmost orange bar*), classifying the 2023 Iceberg Season as moderately severe for this metric, according to the approach adopted by IIP in 2018 (International Ice Patrol 2018). Icebergs first drifted south of 48°N in March 2023, two months later than the 1983 to 2022 mean, and stopped drifting south after July 2023, two months earlier than the 1983 to 2022 mean (**Figure 2.4a**), shortening the 2023 Iceberg Season from normal by four months.

Ice Year 2023 was characterized by a strong mean negative NAOI starting in the second quarter (**Figure 2.4b**), but from October 2022 to January 2023, the NAOI roughly followed the 1983 to 2022 monthly mean, rising from a negative fraction to greater than one. It might be expected that under such conditions, offshore transport of icebergs would begin to threaten the transatlantic shipping lanes in January, as normal. However, sea ice development during the first two quarters was slower than normal (Canadian Ice Service - Environment Canada 2023) and increasing offshore transport of icebergs prior to their encapsulation in sea ice would have exposed them to deterioration by the open ocean, preventing more icebergs from drifting farther south earlier. Ultimately, these conditions (slow sea ice development and strong offshore winds) into the second quarter may have reduced the potential maximum iceberg extent during the Ice Year.

The NAOI began decreasing in February to below-normal negative values through the rest

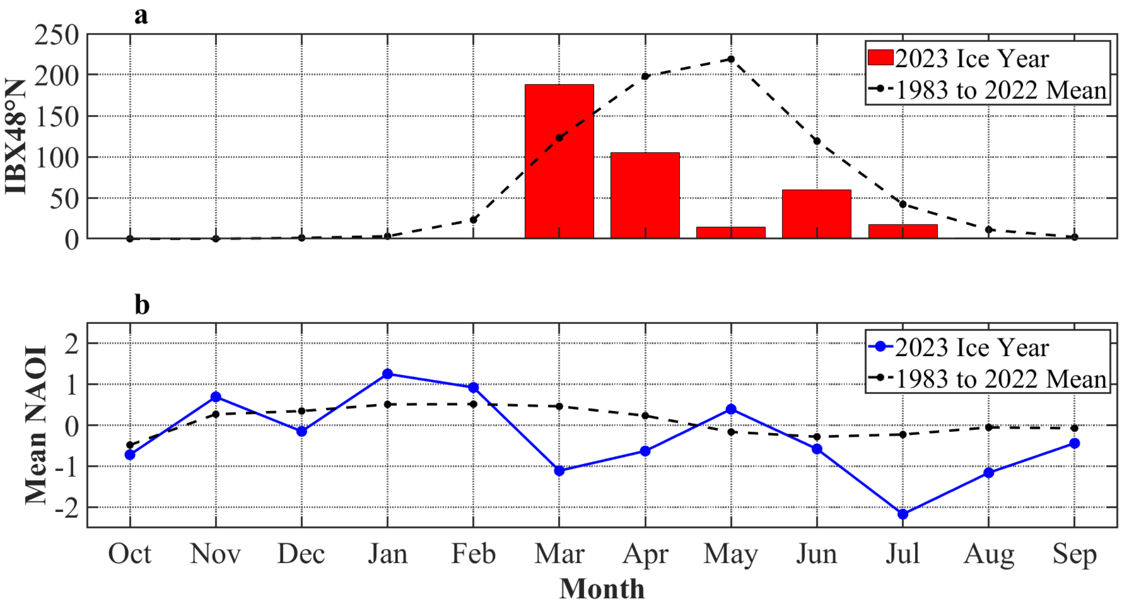

Figure 2.4 Ice and environmental conditions throughout the 2023 Ice Year. **a.** Number of monthly icebergs which crossed south of 48°N (IBX48°N, *red bars*) in Ice Year 2023. The 1983 to 2022 mean number of monthly icebergs which cross south of 48°N is shown in black. **b.** Mean monthly North Atlantic Oscillation Index (NAOI, *blue dotted solid line*) for Ice Year 2023. The 1983 to 2022 mean monthly NAOI is shown in black. Mean monthly NAOI values are from the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Prediction (NCEP) Climate Prediction Center (CPC) (NOAA/NWS NCEP Climate Prediction Center n.d.).

of the Ice Year, reaching a positive value again only in May (see **Figure 2.4b**). Winds correspondingly turned on- and alongshore in the AOR, and the number of icebergs which drifted south of 48°N remained below normal in each remaining month of the Ice Year after March, as many were coastally constrained. All NAOI values reported here are from the NOAA National Centers for Environmental Prediction (NCEP) Climate Prediction Center (CPC) (NOAA/NWS NCEP Climate Prediction Center n.d.).

Sections 2.2.1 through **2.2.4** describe in detail the ice and environmental conditions in each quarter of the 2023 Ice Year.

2.2.1 October to December 2022

In IIP's AOR, surface air temperatures (SATs, 2-m) remained above-freezing through most of this first Ice Year quarter, cooling to freezing along the Labrador coast in the northwestern AOR in December (**Figure 2.5**). Sea surface temperatures (SSTs) in the AOR remained above-freezing through November but cooled through the quarter, especially within the Labrador Current and over the northwestern Grand Banks, reaching freezing along the Labrador coast in the northwestern AOR in December (**Figure 2.6**). All SATs and SSTs reported here are from the Fifth Generation European Centre for Medium-Range Weather Forecasting (ECMWF) Reanalysis (ERA5) monthly averaged data on single levels from 1940 to present (Hersbach, et al. 2023).

While in the Arctic, expansion of sea ice began after mid-September 2022 (United States National Ice Center 2022), sea ice remained north and west of IIP's AOR throughout the quarter (**Figure 2.7**) under the above-freezing temperatures. Sea ice extent remained noticeably less than the 1981 to 2010 median in December in the AOR. All sea ice extents reported here are from the NSIDC Sea Ice Index, Version 3 (Fetterer, et al. 2017).

The mean monthly NAOI increased in general through the first quarter, from negative in October to positive in November and near-zero in

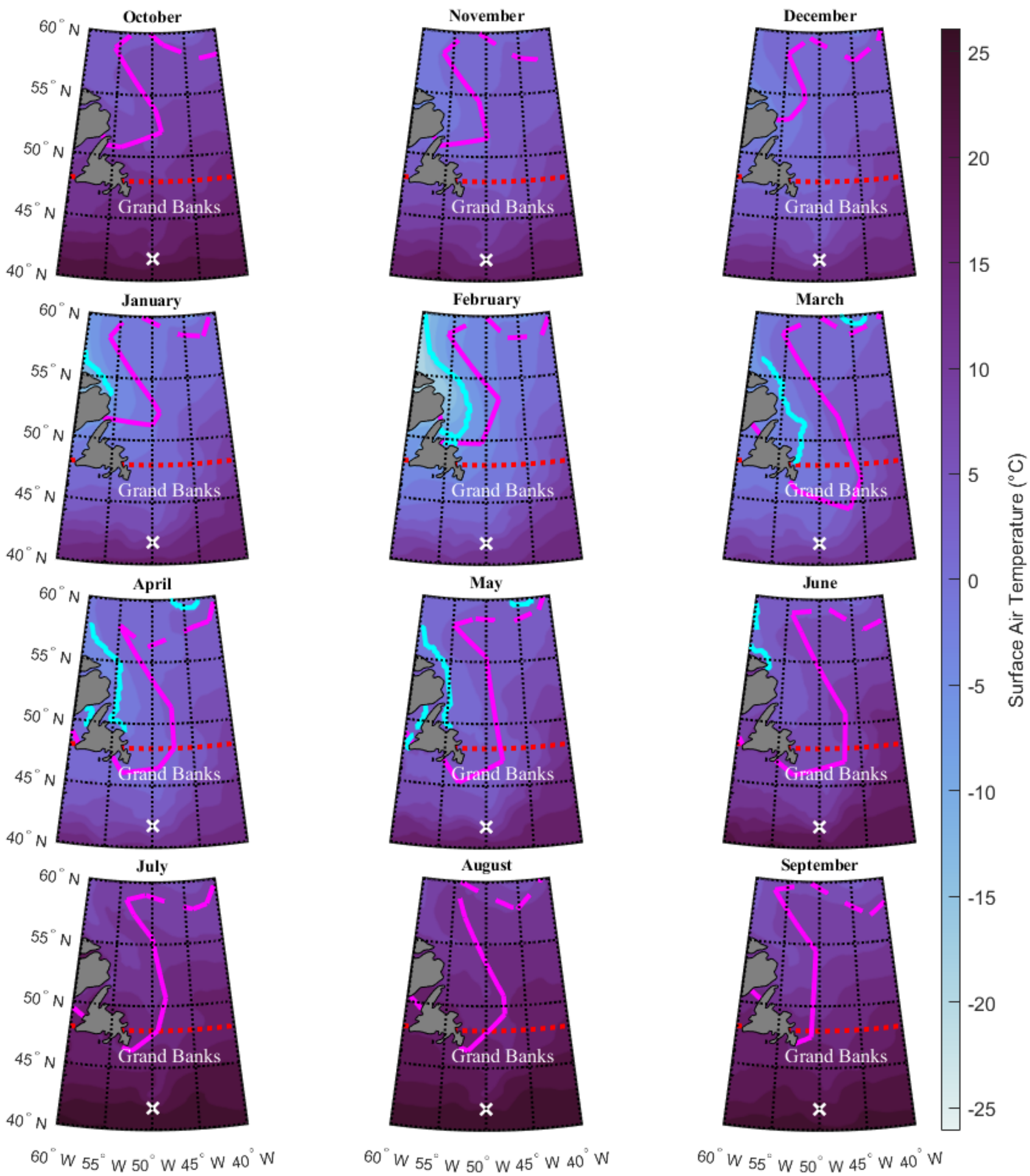

Figure 2.5. Mean monthly surface air temperatures (SATs) in IIP's AOR throughout the 2023 Ice Year. Median monthly sea ice extents (*cyan solid lines*) and mid-month iceberg limits (*magenta solid lines*) are shown. SATs are from the ERA5 monthly averaged data on single levels from 1940 to present (Hersbach, et al. 2023). Sea ice extents are from the NSIDC Sea Ice Index, Version 3 (Fetterer, et al. 2017). Iceberg limits are from IIP.

December (**Figure 2.4b**). Mean sea level pressures (MSLPs) reflected this shift in large-scale atmospheric mode, declining markedly in November (**Figure 2.8**). Winds were correspondingly strongly offshore through November, turning slightly alongshore in December (**Figure 2.9**), consistent with the sign of the NAOI during the quarter. In addition, total precipitation increased in November especially (**Figure 2.10**), dropping slightly in December,

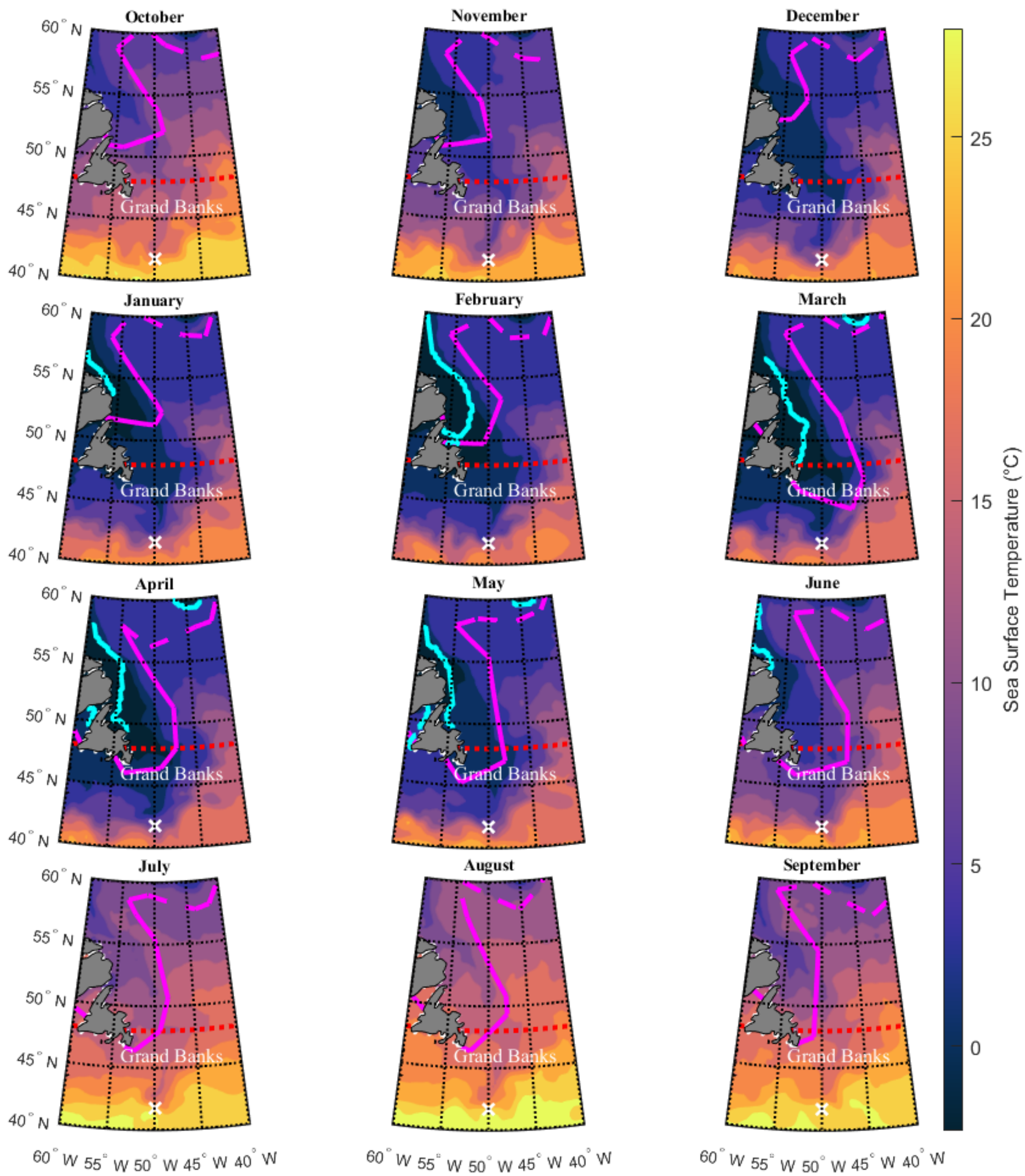

Figure 2.6. Mean monthly sea surface temperatures (SSTs) in IIP's AOR throughout the 2023 Ice Year. Median monthly sea ice extents (*cyan solid lines*) and mid-month iceberg limits (*magenta solid lines*) are shown. SSTs are from the ERA5 monthly averaged data on single levels from 1940 to present (Hersbach, et al. 2023); areas of white indicate no data. Sea ice extents are from the NSIDC Sea Ice Index, Version 3 (Fetterer, et al. 2017). Iceberg limits are from IIP.

again consistent with the NAOI through the period. All MSLPs, wind data, and precipitation rates are from the ECMWF ERA5 monthly averaged data on single levels from 1940 to present (Hersbach, et al. 2023).

The ocean responded in turn, with wave energy increasing in November (see significant

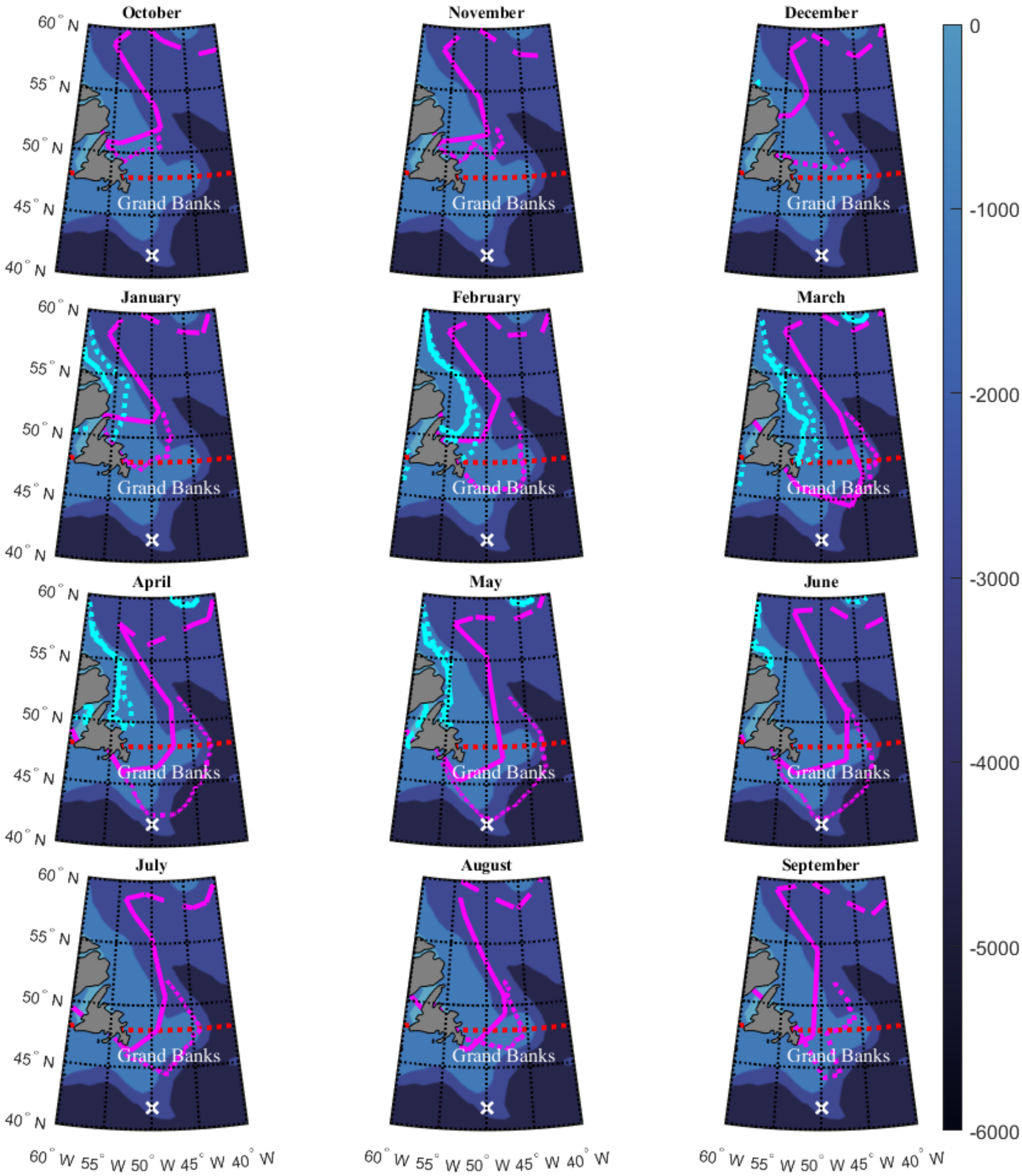

Figure 2.7. Median monthly sea ice extents (*cyan solid lines*) and mid-month iceberg extents (*magenta solid lines*) in IIP's AOR throughout the 2023 Ice Year in comparison to median monthly sea ice extents for 1981 to 2010 (*cyan dotted lines*) and mid-month iceberg limits for 1991 to 2020 (*magenta dotted lines*). Sea ice extents are from the NSIDC Sea Ice Index, Version 3 (Fetterer, et al. 2017). Iceberg limits are from IIP.

wave heights, SWHs, **Figure 2.11** and mean wave periods, MWPs, **Figure 2.12**) and dropping slightly but remaining high into December. All SWHs and MWPs are from the ECMWF ERA5 monthly averaged data on single levels from 1940 to present (Hersbach, et al. 2023).

Forced by strong offshore winds into heightened open ocean waves and storm activity,

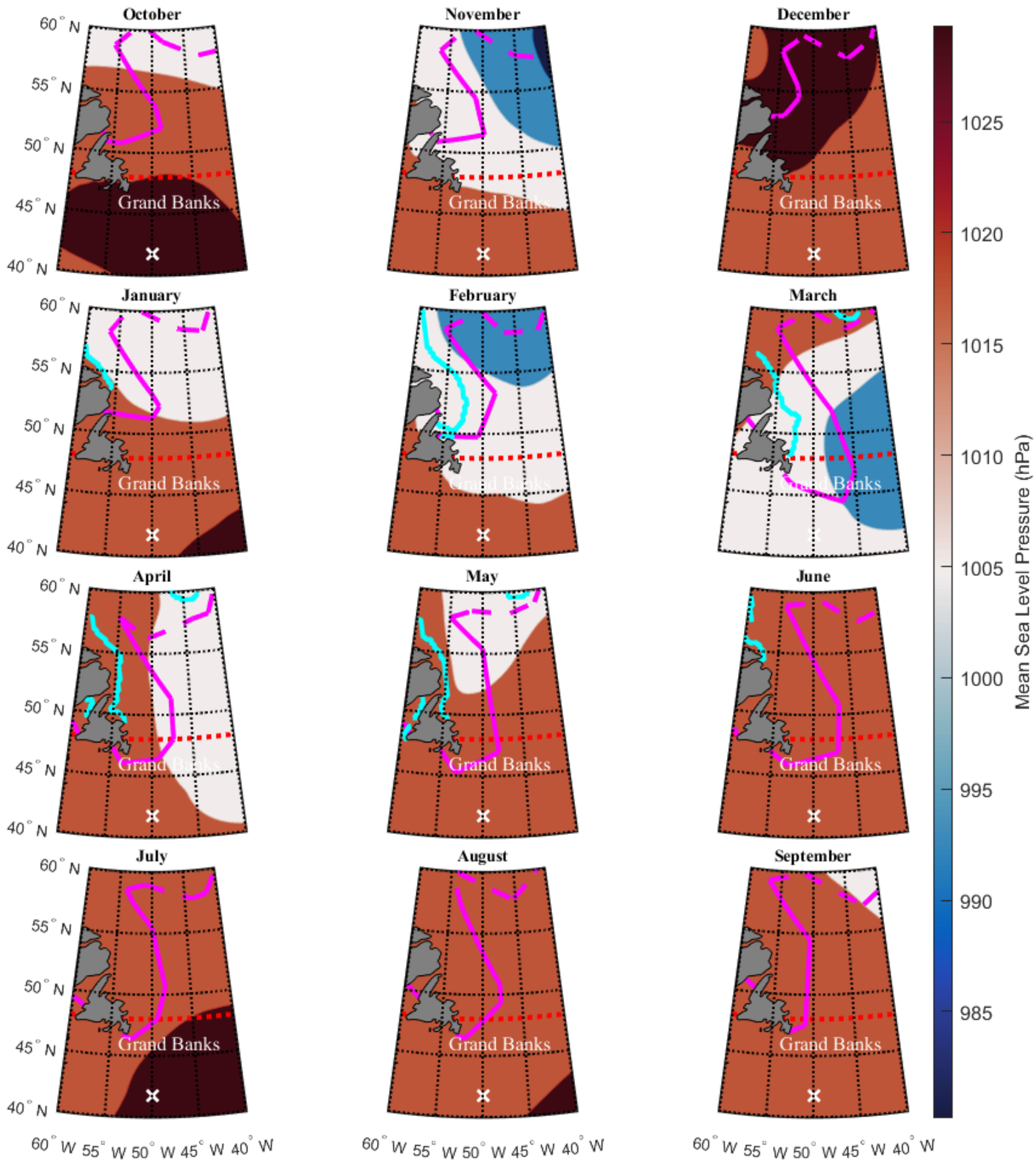

Figure 2.8. Mean monthly mean sea level pressures (MSLPs) in IIP's AOR throughout the 2023 Ice Year. Median monthly sea ice extents (*cyan solid lines*) and mid-month iceberg limits (*magenta solid lines*) are shown. MSLPs are from the ERA5 monthly averaged data on single levels from 1940 to present (Hersbach, et al. 2023). Sea ice extents are from the NSIDC Sea Ice Index, Version 3 (Fetterer, et al. 2017). Iceberg limits are from IIP.

and above-freezing temperatures, from October to December 2022, the iceberg limit correspondingly contracted from about 51°N to 53°N, remaining within each mid-month median iceberg extent for 1991 to 2020 (see **Figure 2.7**). No icebergs crossed south of 48°N during this first quarter of the Ice Year (see **Figure 2.4a**).

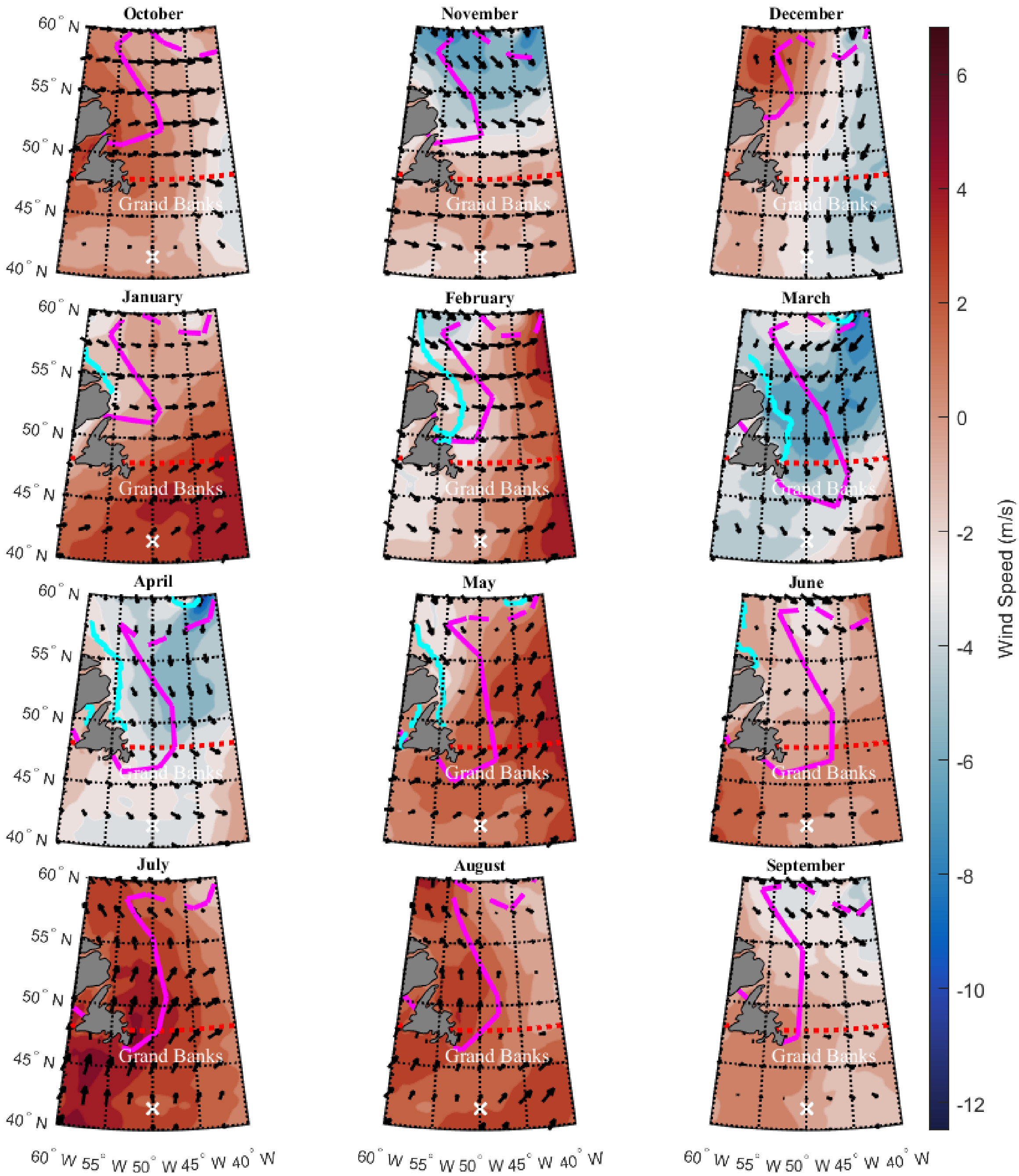

Figure 2.9. Mean monthly wind velocities in IIP's AOR throughout the 2023 Ice Year. Median monthly sea ice extents (*cyan solid lines*) and mid-month iceberg limits (*magenta solid lines*) are shown. Wind data are from the ERA5 monthly averaged data on single levels from 1940 to present (Hersbach, et al. 2023). Sea ice extents are from the NSIDC Sea Ice Index, Version 3 (Fetterer, et al. 2017). Iceberg limits are from IIP.

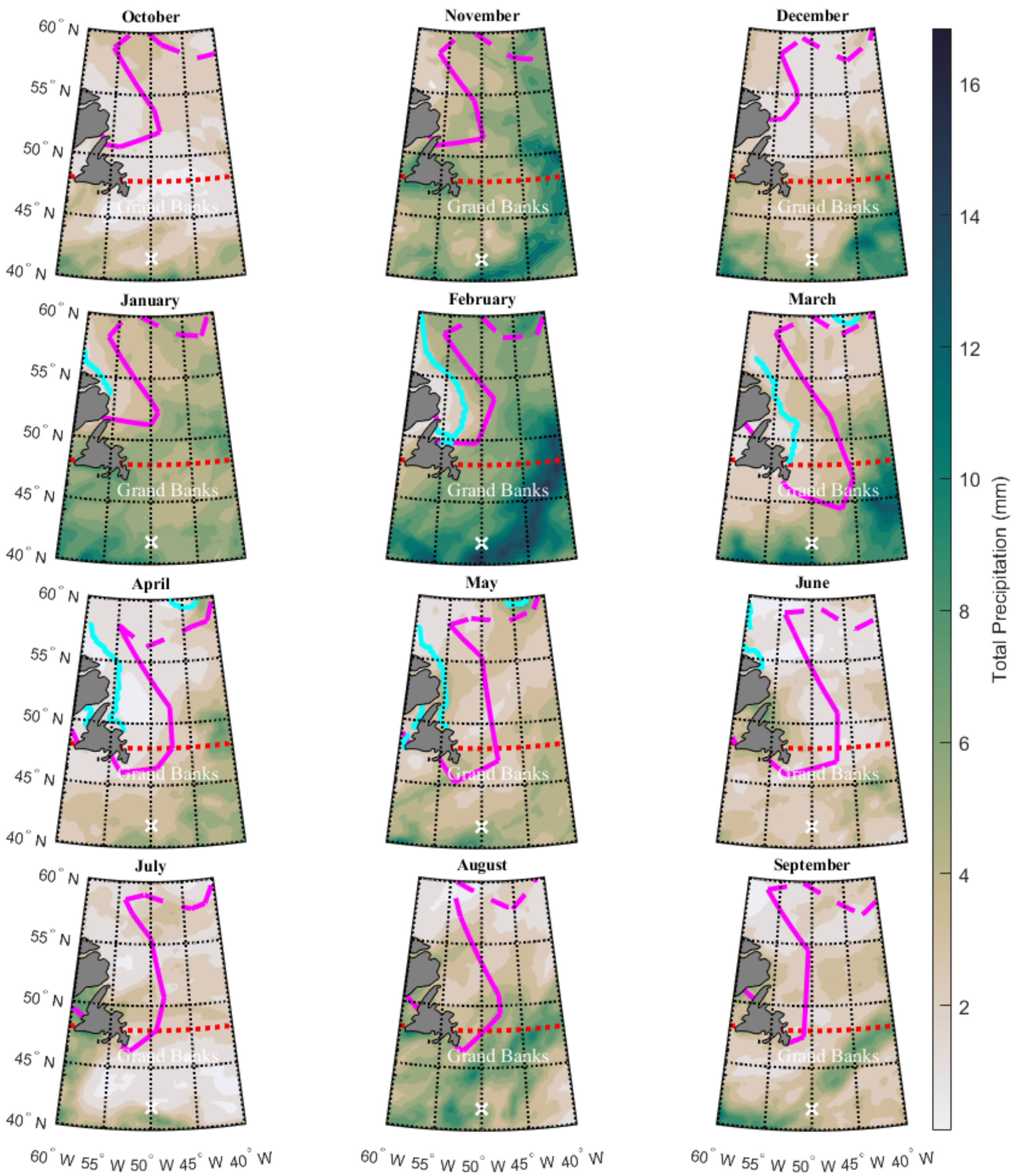

Figure 2.10. Mean monthly total precipitation in IIP's AOR throughout the 2023 Ice Year. Median monthly sea ice extents (*cyan solid lines*) and mid-month iceberg limits (*magenta solid lines*) are shown. Precipitation data are from the ERA5 monthly averaged data on single levels from 1940 to present (Hersbach, et al. 2023). Sea ice extents are from the NSIDC Sea Ice Index, Version 3 (Fetterer, et al. 2017). Iceberg limits are from IIP.

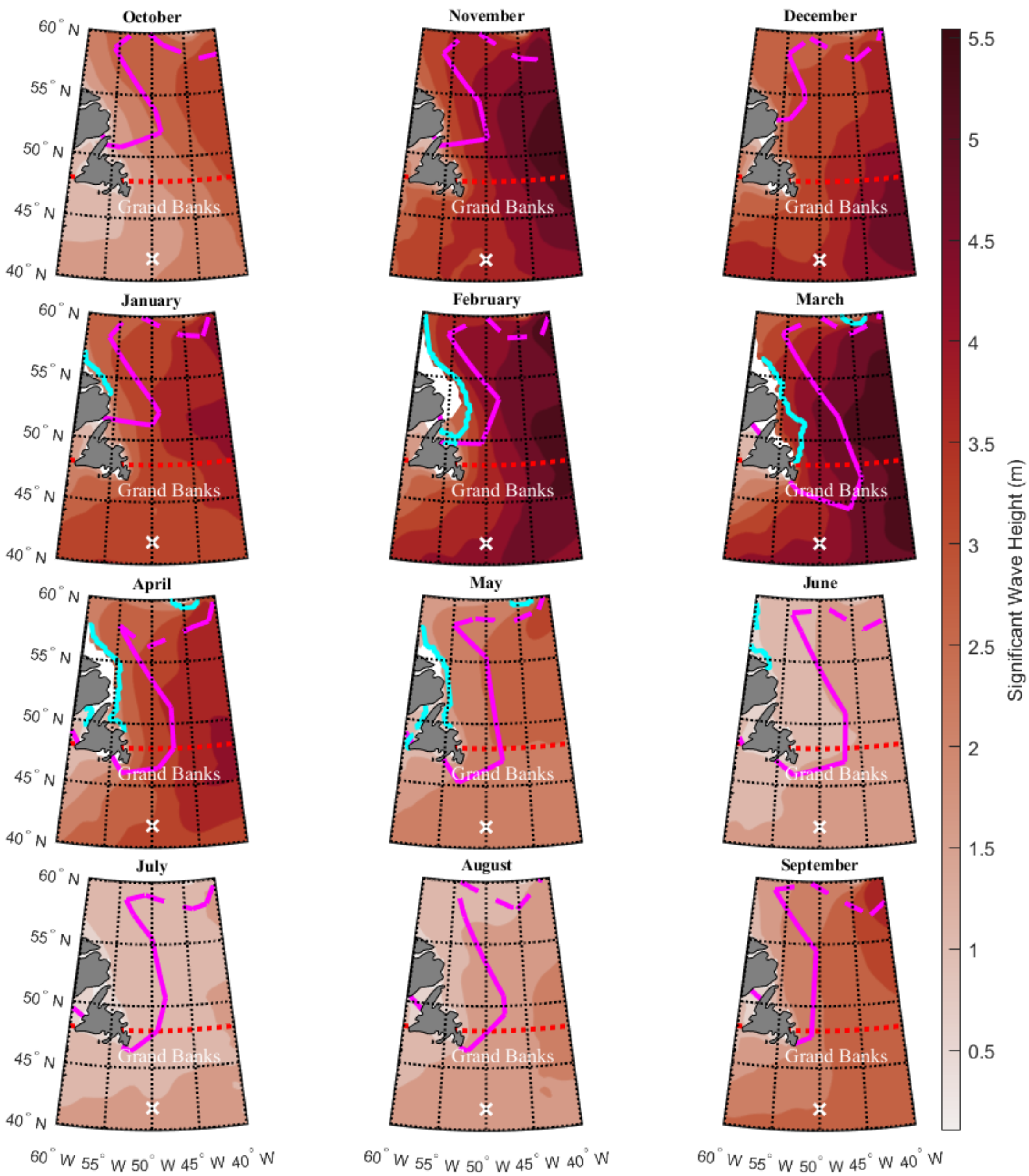

Figure 2.11. Mean monthly significant wave heights (SWHs) in IIP's AOR throughout the 2023 Ice Year. Median monthly sea ice extents (*cyan solid lines*) and mid-month iceberg limits (*magenta solid lines*) are shown. SWHs are from the ERA5 monthly averaged data on single levels from 1940 to present (Hersbach, et al. 2023); areas of white indicate no data. Sea ice extents are from the NSIDC Sea Ice Index, Version 3 (Fetterer, et al. 2017). Iceberg limits are from IIP.

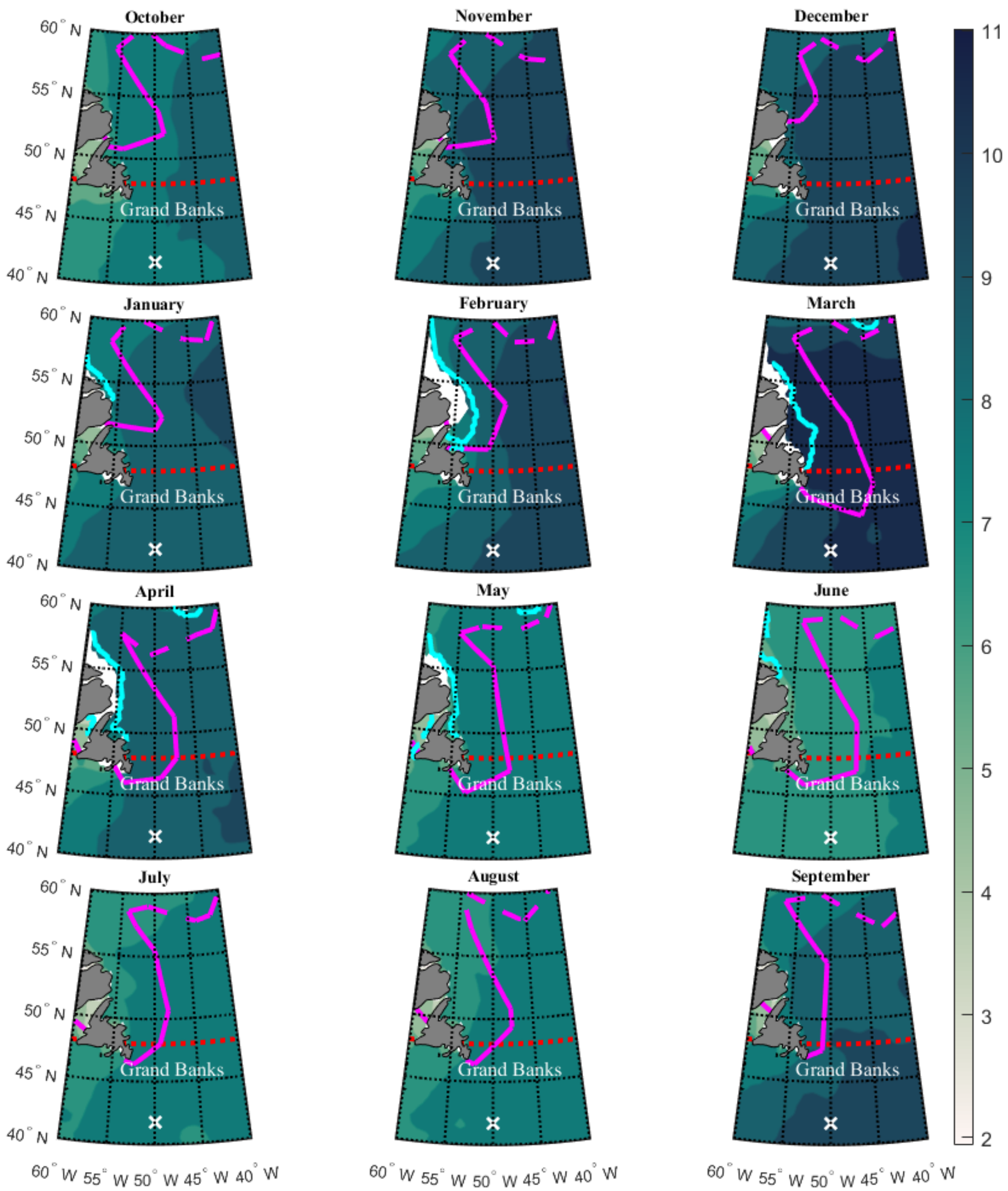

Figure 2.12. Mean monthly mean wave periods (MWPs) in IIP's AOR throughout the 2023 Ice Year. Median monthly sea ice extents (*cyan solid lines*) and mid-month iceberg limits (*magenta solid lines*) are shown. MWPs are from the ERA5 monthly averaged data on single levels from 1940 to present (Hersbach, et al. 2023); areas of white indicate no data. Sea ice extents are from the NSIDC Sea Ice Index, Version 3 (Fetterer, et al. 2017). Iceberg limits are from IIP.

2.2.2 January to March 2023

SATs in the AOR continued to cool in the second Ice Year quarter, reaching their minimum below-freezing values extending over the Labrador Sea and Grand Banks in February (see **Figure 2.5**). SSTs also continued to cool through March, notably in the Labrador Sea and over the Grand Banks, with the Labrador Current bringing freezing water further southeastward in each month of the quarter (see **Figure 2.6**).

The sea ice edge closely followed the spatiotemporal distribution of freezing SATs and SSTs during the quarter (see **Figure 2.7**). Starting in January, sea ice expanded south and east into the AOR from the Labrador coast at about 55°N, reaching its maximum extent within the AOR in March, at about 48°N on the Newfoundland Coast. The sea ice extent remained within the 1981 to 2010 median in each month, nearing the eastern median only in February and the tip of the southern median on the Newfoundland Coast only in March. 2023 was the first year since 2017 in which sea ice reached St. John's harbors (CBC News 2023).

The mean monthly NAOI remained positive through February, though decreased through the quarter to become negative in March (see **Figure 2.4b**). MSLPs remained low with steep gradients in the AOR through March, perhaps indicating a lag in regional atmospheric response to the large-scale mode in the final month of the quarter (see **Figure 2.8**). Consistent with the sign of the NAOI, the continuing low local surface pressures, and the closeness of areas of constant pressure (isobars), offshore winds increased in January and remained offshore until turning strongly on- and alongshore in March (see **Figure 2.9**). Additionally, total precipitation remained high, increasing notably in February, and decreasing in March over the northern AOR and the Grand Banks (see **Figure 2.10**).

Meanwhile, ocean wave energy increased rapidly through the quarter, with SWHs (see **Figure 2.11**) and MWPs (see **Figure 2.12**) reaching maximum values over the largest portion of the AOR in March. This is consistent with the state of the atmosphere (mostly positive-mode NAO) during this time.

From January to March, icebergs drifted further south and east within the growing sea ice pack in the AOR. The iceberg limit expanded south and east outside of the expanding sea ice edge, rapidly reaching south of 48°N to a maximum mid-month extent in March (see **Figures 2.7** and **2.4a**). Increased ocean wave activity may have served to break up the sea ice edge and release icebergs into the surrounding ocean during this quarter, hastening their demise. In each month of the quarter, the iceberg limit remained within the mid-month median iceberg limit for 1991 to 2020. One hundred and eighty-eight icebergs drifted south in the quarter, all within March, greater than the 1983 to 2022 mean for this month.

2.2.3 April to June 2023

SATs warmed in the third Ice Year quarter, reaching above-freezing throughout the AOR in June (see **Figure 2.5**). SSTs warmed as well, with freezing water over the Grand Banks and in the Labrador Current retreating northwestward along the coast through May, leaving only above-freezing surface waters in the AOR in June (see **Figure 2.6**).

In April, sea ice began to retreat north and west, on par with the median 1981 to 2010 extent, through June (see **Figure 2.7**). June was the last month in which sea ice was present in the AOR during the 2023 Ice Year.

The slope of the mean monthly NAOI plateaued during the quarter, though the NAOI remained negative except in May (see **Figure 2.4b**). Consistently, higher MSLPs moved over the AOR (see **Figure 2.8**), pressure gradients shoaled, wind speeds decreased (see **Figure 2.9**), and precipitation dropped (see **Figure 2.10**). Winds remained on- and alongshore in the quarter except in May, when they turned northeast over the Grand Banks.

Open ocean waves were attenuated in kind, markedly through June, during which SWHs over the Grand Banks reached no greater than a meter or so (see **Figure 2.11**), and MWPs reduced to half of their values in March (see **Figure 2.12**).

Calmer oceanic and atmospheric conditions might allow icebergs to persist longer and reach further south, and typically, icebergs are the greatest threat to the shipping lanes in the third quarter (see **Figure 2.3**). However, the calmer environmental conditions during this quarter corresponded to predominately on- and alongshore winds due to the phase of the NAOI. In response, a below-mean number of icebergs drifted south of 48°N (for the quarter sum of one-hundred and seventy-nine, see **Figure 2.4a**), and the iceberg limit remained well within the 1991 to 2020 median (see **Figure 2.7**), in each month of the third quarter (see **Figures 2.1 and 2.2**).

Both a mean negative NAOI since the second quarter, corresponding to the confinement of icebergs alongshore (reflected in the narrow shape of the iceberg limit, see **Figure 2.7**), and exposure of icebergs to deteriorating forces early in the Ice Year may have resulted in their earlier deterioration farther north, contributing to the lower iceberg numbers south of 48°N during this quarter. Even so, the southern iceberg limit continued to threaten shipping lanes, remaining south of 48°N.

2.2.4 July to September 2023

In the final quarter of Ice Year 2023, SATs warmed rapidly, reaching their maximum over the AOR in August (see **Figure 2.5**). SSTs warmed rapidly too (see **Figure 2.6**), shattering North Atlantic temperature records for the summer months (Aubourg 2023). Temperatures over the Grand Banks and within the Labrador Current surface waters reached 15°C to 20°C.

In response, the sea ice edge retreated fully from the AOR in July and remained well north through the rest of the Ice Year (see **Figure 2.7**).

The mean monthly NAOI remained negative through September (see **Figure 2.4b**), decreasing to a minimum in July. MSLPs correspondingly remained high (see **Figure 2.8**), winds remained strongly on- and alongshore (though turned predominately north through August, see **Figure 2.9**), and precipitation rates remained low (see **Figure 2.10**). Precipitation only increased slightly in August, perhaps in reflection of the NAOI becoming less negative during that month.

The ocean remained calmer through the quarter (see **Figures 2.11 and 2.12**) in the AOR, with SWHs and MWPs increasing slightly into September, consistent with the value of the NAOI during the period.

Without sea ice, in warming conditions, and with northward prevailing winds, the south and eastern iceberg limits finally contracted slightly north and west through September, as the western limit contracted in the Strait of Belle Isle (see **Figure 2.7**). However, the southern iceberg limit remained just south of 48°N through the rest of the Ice Year. Even so, only eighteen icebergs drifted south of 48°N in this quarter; all, except for one in August, crossed this latitude in July.

2.3 Summary

The timing of sea ice and atmospheric phenomena during Ice Year 2023 may have led it to having just-moderate Iceberg Season severity. Relatively slow sea ice development and below-normal extent, together with strong offshore winds consistent with a greater-than-normal positive NAOI in the early part of the Ice Year, may have primed icebergs for accelerated deterioration from waves and surrounding oceanic and atmospheric heat by exposing them early to the open ocean. In addition, the strongly mean negative phase of the NAOI from March onward ensured that heightened onshore winds kept icebergs shoreward during the peak of the iceberg season when they would normally pose the greatest threat to the shipping lanes, and when open ocean conditions were relatively favorable to icebergs.

Based on the total number of icebergs that crossed south of 48°N, Ice Year 2023 was moderate: the first non-light year since Ice Year 2019. But based on the below-normal season length and monthly iceberg extents, 2023 might also be considered having relatively lighter iceberg conditions. Still, iceberg extent continued to threaten shipping lanes through September—a reminder that regardless of Iceberg Season severity, the presence of icebergs at all poses a danger to the mariner navigating nearby.

3 Operations Center Summary

The OPCEN is the hub of IIP's iceberg information processing and dissemination. OPCEN personnel stand watch to receive and process iceberg reports, analyze ice and environmental conditions, and create and distribute daily iceberg warning products. Iceberg reports are generated by and received from vessels and external and internal aerial and satellite reconnaissance. IIP processes iceberg reports to update sighted iceberg locations and properties within IIP's iceberg database. Positions of icebergs within the database are then estimated for the same times (0000Z and 1200Z) daily via iceberg drift and deterioration computer models using BAPS. Iceberg limits are then defined to contain the modeled iceberg positions for 0000Z the next day and distributed to mariners within the NAIS daily warning products.

3.1 Iceberg Warning Product

IIP and CIS partner to create and distribute the NAIS daily iceberg warning products. IIP takes responsibility for product generation and dissemination, including deploying personnel to St. John's, Newfoundland (NL), generally during the active Iceberg Season, for aerial iceberg reconnaissance. In Ice Year 2023, IIP took this responsibility from 19 January to 7 September 2023. The operational statistics contained in this section are taken exclusively from this period. CIS publishes the iceberg warning products generally outside of the Iceberg Season (7 September 2022 to 18 January 2023 and 8 September to 30 September 2023 during the 2023 Ice Year), when the iceberg population threatens primarily the Canadian coastline.

The NAIS iceberg warning products are generated in text (NAIS-10 bulletin) and graphic (NAIS-65 chart) form. The NAIS-10 bulletin lists the latitude and longitude points along the iceberg and sea ice limits and the NAIS-65 charts the forecasted iceberg limit and estimated number per square degree. Semi-monthly NAIS-65 iceberg charts are shown in **Section 5**. Both products include information regarding the most recent iceberg reconnaissance, including date, type, and coverage. The products are released daily between 1830Z and 2130Z and are valid for 0000Z the following day. During the 2023 Ice Year, all iceberg warning products were released on time.

IIP publicly disseminates the NAIS iceberg warning products through various means. The NAIS-10 bulletin is broadcast over SafetyNET, Navigational Telex (NAVTEX), and Simplex Teletype Over Radio (SITOR); the NAIS-65 chart is broadcast over radio facsimile (Radiofax) and posted to the National Weather Service (NWS) Marine Forecast (https://www.weather.gov/marine/marsh) and NOAA Ocean Prediction Center (OPC) (https://ocean.weather.gov/Atl_tab.php) websites. Both products are posted daily on IIP's product webpage (https://www.navcen.uscg.gov/north-american-ice-service-products).

The daily iceberg and sea ice limits are also posted to the IIP product website as geographic information system (GIS) compatible files (Keyhole Markup Language, KML, files and ESRI shapefiles). Additionally, the daily iceberg limit is available as a displayable layer within several online mapping applications: NOAA's Environmental Response Management Application (ERMA) mapping tool for the Arctic (https://erma.noaa.gov/arctic) and Atlantic (https://erma.noaa.gov/atlantic), and the USCG Navigation Center (NAVCEN) website (https://www.navcen.uscg.gov/international-ice-patrol-map).

3.1.1 Iceberg Warning Product Changes for 2023

Each year, IIP and its NAIS partners, CIS and DMI, review NAIS iceberg products, procedures, and distribution processes to improve product content, delivery, and value for the mariner. For 2023, no major changes were implemented. Minor graphical updates to the NAIS-65 chart were discussed at the annual NAIS meeting; these changes will be considered by the NAIS (CIS/IIP/USNIC) Operations Committee in 2024.

3.2 Iceberg Reports

During the 2023 Iceberg Season, the OPCEN received reports of icebergs from IIP and commercial flights, ship reports, and satellite reconnaissance from IIP, CIS, and commercial sources. The wide variety of reporting sources helps IIP to better estimate the state of the iceberg population by diversifying available iceberg reconnaissance data for comparison. This comparison is particularly important for analysts verifying targets in satellite imagery against those sighted by aircraft and increases confidence in semi-automated satellite analysis routines.

Mariners transiting the AOR remain a vital source of iceberg reporting for IIP to maintain its positive safety record. **Table 3.1** lists ships that made voluntary iceberg reports while IIP was responsible for the iceberg products.

Once received, iceberg reports (**Figure 3.1**) are converted into standard iceberg messages (SIMs) which include specific iceberg characteristics (time of sighting, position, size, shape) and any other relevant information. Iceberg messages are still transmitted even if the message does not include any reported icebergs. A message with no reported icebergs can be useful for confirmation of their absence, especially when generated with high-confidence source (e.g., aerial reconnaissance or cloud-free optical imagery). In the 2023 Ice Year, IIP received, analyzed, and processed 916 SIMs, 642 of which included iceberg sightings. Most SIMS originated from IIP satellite imagery analysis (58%), followed by C-CORE (commercial) satellite reconnaissance (21%). **Table 3.2** provides further detail on the number and source of SIMs received while IIP held product responsibility.

Icebergs which enforce the shape of the drawn iceberg limit due to their proximity to the maximum iceberg extent are termed “limit-setting” icebergs. The number of limit-setting icebergs is limited by product generation procedure to eight or less. Icebergs further inside the maximum extent (interior to the iceberg population or near land) do not affect the shape of the iceberg limit. The number of limit-setting icebergs per reporting source can be seen in **Table 3.2** and **Figure 3.1**.

A total of 20,288 icebergs, growlers, and radar targets were incorporated into the model from iceberg reports, an increase over 2022 by 32% (15,410 targets). This increase corresponded to both a larger population of icebergs in the area and a greater number of targets reported by commercial partners.

Reported icebergs that could be correlated with existing icebergs in IIP’s database are “re-sighted” to the database with their more recently reported position. If an iceberg cannot be correlated to an existing database iceberg, it is added to the database. In an Ice Year, the number of icebergs added corresponds to the number of unique iceberg sightings. In Ice Year 2023, there were 7,671 icebergs added to the database, which was 32% of all database actions taken (add, delete, re-sight, no action) through the year.

Reported icebergs that are not added to or resighted (no action) in the iceberg database often originate from coincident reports from multiple sources. In these circumstances, the OPCEN will only include the most recent position and size of the most complete iceberg report received. Additionally, multiple coincident reports from different sources may conflict. In these cases, only unique targets across the reports are added to the database.

Ships Reporting by Flag Reports

BAHAMAS	
Lubie	2
CANADA	
Arvik 1	1
CGGS Amundsen	1
CGGS Molly Kool	1
* CGGS Terry Fox	9
CGGS Vincent Massey	4
HMCS Harry DeWolf	3
Oceanix Connaigra	1
Nukumi	1
Umiak 1	1
HONG KONG	
Hong Fu	1
MALTA	
Ineos Inspiration	1
Tysla	1
NETHERLANDS	
Americaborg	1
Zaadam	1
NORWAY	
Altera Thule	1
PANAMA	
Lowlands Sky	1

Table 3.1. 2023 Ship reports by Nation of Origin. IIP recognizes the vessel that submits the most iceberg reports each year. This distinction is named for the CARPATHIA, the vessel that served the rescue of705 survivors from the TITANIC disaster. *Denotes the CARPATHIA award winner.

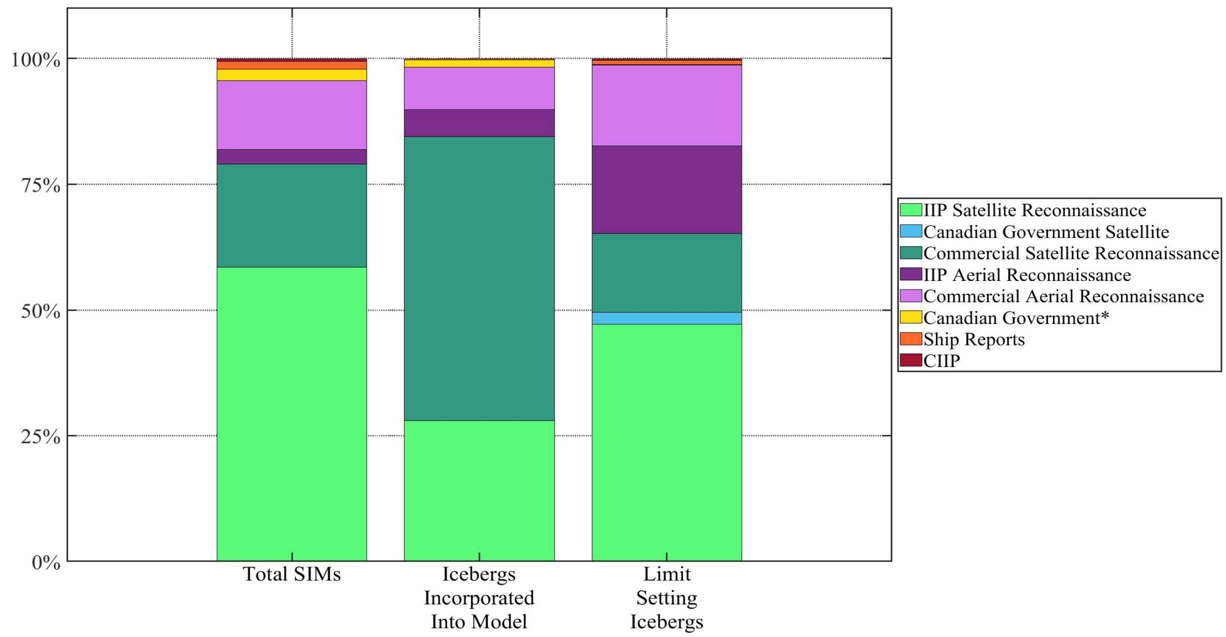

Figure 3.1. Proportion of total SIMs, icebergs incorporated into the model, and limit setting icebergs by reporting source.

Source	Total SIMS	Icebergs Incorporated into Model	Average Icebergs Per SIM	Limit Setting Icebergs
IIP Satellite Reconnaissance	535	5,661	12	442
Canadian Government Satellite	0	0	0	0
Commercial Satellite Reconnaissance	188	11,432	61	147
IIP Aerial Reconnaissance	26	1,073	41	163
Commercial Aerial Reconnaissance	126	1,710	14	151
Canadian Government*	21	304	14	1
Ship Reports	14	33	2	8
CIIP	5	12	2	3
Total	**915**	**20,225**	**21**	**937**

Table 3.2. Detailed information of 2023 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 is mostly made up of Canadian Coast Guard reports.

3.3 Iceberg Reconnaissance

3.3.1 Satellite Iceberg Reconnaissance

IIP both generates iceberg reports from internal (OPCEN) satellite analysis and receives reports from externally generated (commercial) satellite analysis. In the 2023 Ice Year, 5,661 icebergs from 535 iceberg reports generated by IIP satellite reconnaissance were added to the database, and 11,492 icebergs from 189 reports generated by commercial satellite reconnaissance were added. In Ice Year 2023, commercial satellite reconnaissance was provided by C-CORE, a company in St. John's that monitors icebergs for oil and gas industry clients.

Overall, 17,153 icebergs, growlers, and radar targets from satellite reconnaissance iceberg reports were added to the iceberg database, accounting for 85% of database additions. See **Section 4** for detailed information on IIP satellite iceberg reconnaissance.

3.3.2 Aerial Iceberg Reconnaissance

This season, IIP conducted 26 iceberg reconnaissance flights which generated 1,073 icebergs, growlers, and radar target additions and re-sightings into the iceberg database. See **Section 4** for detailed information on IIP aerial iceberg reconnaissance.

Commercial aerial reconnaissance accounted for 1,710 iceberg additions from 126 reports to the iceberg database. It should be noted that while IRD flights have a primary mission to detect icebergs, commercial flights which generate iceberg reports may not. The commercial aerial reconnaissance data in **Table 3.2** and **Figure 3.1** correspond to SIM reports made by PAL Aerospace. PAL Aerospace is contracted to conduct iceberg reconnaissance over the AOR by both CIS and the oil and gas industry; they also fly other missions for different clients. **Figure 3.2** shows the PAL Aerospace flights that were dedicated ice flights (funded by CIS or the oil and gas industry) and other flights that reported icebergs as a byproduct.

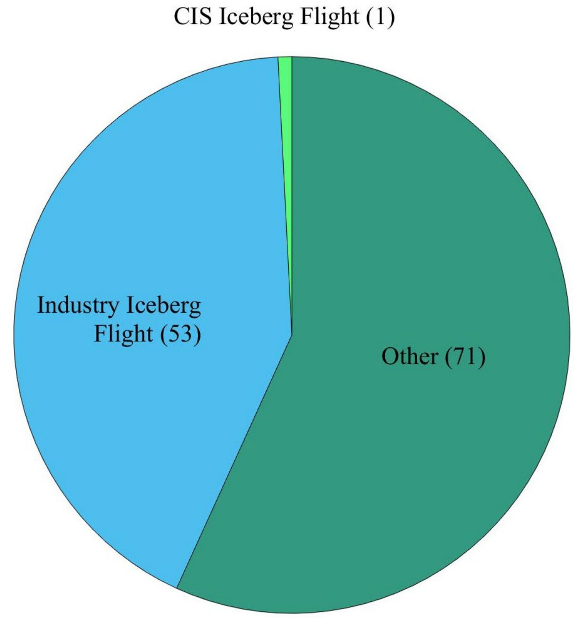

Figure 3.2. PAL Aerospace flights by primary mission type that reported icebergs. The "Other" category includes flights that reported icebergs but with a primary mission other than iceberg reconnaissance.

More than half (57%) of the PAL Aerospace flights that reported icebergs were flown for primary missions other than iceberg reconnaissance. 42% of flights that reported icebergs were funded by the oil and gas companies concerned with icebergs in the vicinity of the offshore oil rigs. The smallest portion (less than 1%) were funded by CIS specifically for iceberg reconnaissance in areas designated by either IIP or CIS. 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.

3.4 Iceberg Deletions

The drift and deterioration of icebergs in the IIP database was estimated via numerical models executed in BAPS. Icebergs were deleted from the active iceberg database based on modeled deterioration, time since last sighting, or recent reconnaissance results. This season, 485 icebergs, growlers, and radar targets were deleted when no icebergs were detected during IIP aerial reconnaissance flights in the vicinity of the modeled position. An iceberg may be deleted from the database based on one of three factors: 1) its modeled positional circle of uncertainty ("error circle") must be declared iceberg-free based on recent reconnaissance, 2) its "time on drift" must exceed 30 days, or 3) its predicted degree of melt must be between 125 to 150%, based on its proximity to the iceberg limit.

An iceberg error circle may be declared free of icebergs from either a high-confidence reconnaissance flight or, from cloud-free, high-resolution optical imagery. While satellite imagery usually covers an error circle, it may not allow for high-confidence iceberg deletion due to cloud-cover, imagery resolution, ocean wave radar backscatter, target ambiguity, or other factors. Currently, for this reason, IIP rarely deletes database icebergs using satellite imagery; the exception is for high-resolution optical (e.g., Sentinel-2, or SN2) imagery with little cloud cover and reduced ocean noise, which allows the analyst to have high confidence in the absence of icebergs.

Similarly, a commercial flight might fly over a modeled position, but may not cover the error circle entirely, leaving a chance that the iceberg was missed. For this reason, deletes are also not typically based on the results of commercial flights. In 2023, PAL Aerospace flew CIS-funded iceberg reconnaissance flights using IIP-drawn flight plans. This allowed IIP to plan commercial flights based on internal criteria for deleting modeled icebergs. This season, 60 modeled icebergs were deleted from CIS-funded PAL flights.

In the case of predicted melt, IIP employs a conservative approach for estimating when an iceberg melted entirely. The model provides a melt factor based on the original sighted position between 0-500%. An iceberg that has melted 100% by deterioration calculations has theoretically melted to nothing, while an iceberg that has melted to 500% has endured enough environmental factors (wave action, sea surface temperature, etc.), that it could have melted five times over. IIP typically deletes icebergs at 125% or 150% based on their proximity to the iceberg limit.

3.5 Limit-Setting Icebergs

The single most important icebergs monitored by IIP are limit-setting icebergs. Typically, an average of four icebergs (minimum of one and maximum of seven) set the iceberg limit at any time.

In Ice Year 2023, the iceberg limit stretched 332 NM east of St. John's to 48o05'N, 044o35'W at its maximum easternmost extent on 28 March 2023 (**Figure 3.3**). Soon after, on 30 March, the limit reached its southernmost extent at 43o40'N, 049o10'W, 285 NM south of St. John's (**Figure 3.4**).

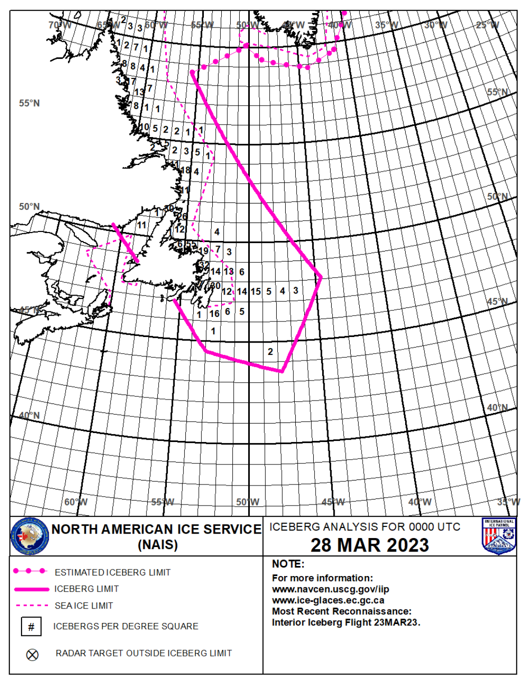

Figure 3.3. Easternmost extent of the iceberg limit on March 28th.

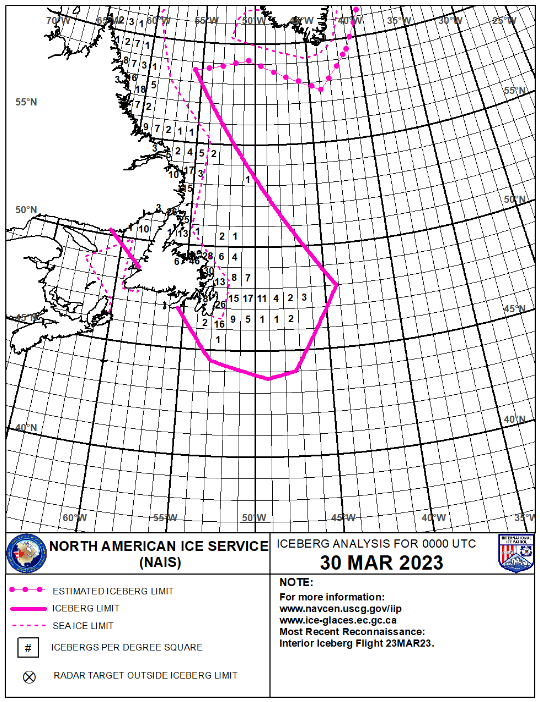

Figure 3.4. Southernmost extent of the iceberg limit on March 30th.

Reconnaissance from satellite imagery was the leading source for spotting limit-setting icebergs (65%) in 2023. This was an increase from 2022 (49%).

Although many of the icebergs incorporated into the model and setting the iceberg limit were observed by satellite, it is often difficult to reliably determine ice-free conditions from SAR imagery due to low confidence in analysis (the difficulty in eliminating 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 icebergs do, in fact, 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 detection and classification of targets.

For now, IIP considers the most reliable method for monitoring the iceberg limit to be aerial reconnaissance. It should be noted that this may change as IIP continues to exploit satellites for iceberg reconnaissance and gains confidence in the method. Currently, in-flight observation of limit-setting icebergs, especially those nearest transatlantic shipping lanes, remains a critical part of completing IIP's mission.

3.6 Icebergs Reported Outside of the Iceberg Limit

If an iceberg or radar target is reported outside of the published iceberg limit, the OPCEN Duty Watch Stander (DWS) takes prompt action to warn the maritime community.

Typically, the first step is for the DWS to notify the Canadian Coast Guard (CCG) Maritime Communication and Traffic Service (MCTS) Port aux Basques. In turn, MCTS issues a Navigational Warning (NAVWARN), which is the primary means of relaying immediate iceberg information to the transatlantic shipping community, while IIP watch standers generate and 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 satellite (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 watch hours (1200Z to 0000Z), products will be immediately revised by the OPCEN valid for 1200Z or 0000Z, depending on the time received. If the report reaches IIP outside of these hours, products will be revised by 1400Z the following morning valid for 1200Z.

Classifying targets of iceberg size in SAR imagery as icebergs, vessels, or "other" (such as marine life, fishing gear, or weather artifact) remains a challenge. SAR backscatter can be similar between different classes of targets and is sometimes unintuitive for analysts to interpret. In cases where SAR analysis yields ambiguous target results outside of the iceberg limit, IIP takes a conservative approach to ensure that the maritime community receives a timely warning and keeps the target in the database until subsequent reconnaissance verifies otherwise. IIP relies on coordination with other data sources such as those vessels providing an Automatic Identification System (AIS) and with Coast Guard Intelligence to help reduce target ambiguities.

In past years, several cases of icebergs outside of the iceberg limit were closely linked with the sea ice limit, in which they were undetected within sea ice (from deteriorated aerial or satellite reconnaissance), but subsequently broke free and drifted outside of the published iceberg limit at the time. In response, IIP policy requires that the sea ice limit generated by CIS (and thus the leading edge of sea ice) be contained within the iceberg limit.

3.6.1 Icebergs Detected Outside of the Iceberg Limit in 2023

6 March 2023

The OPCEN received an iceberg message from a PAL industry flight that took place the same day. The flight contained a total of 88 iceberg observations. The easternmost iceberg was detected visually and by radar at 47°49'N and 47°57'W, five miles inside of the iceberg limit. After its drift was modeled from its original sighting, its error circle protruded outside of the iceberg limit, indicating a possibility that it had drifted outside of the limit. PAL aerospace was called to confirm the report. MCTS and NGA were contacted, and warnings were issued. Due to the timing of the report and in consultation with CIIP, products were not revised.

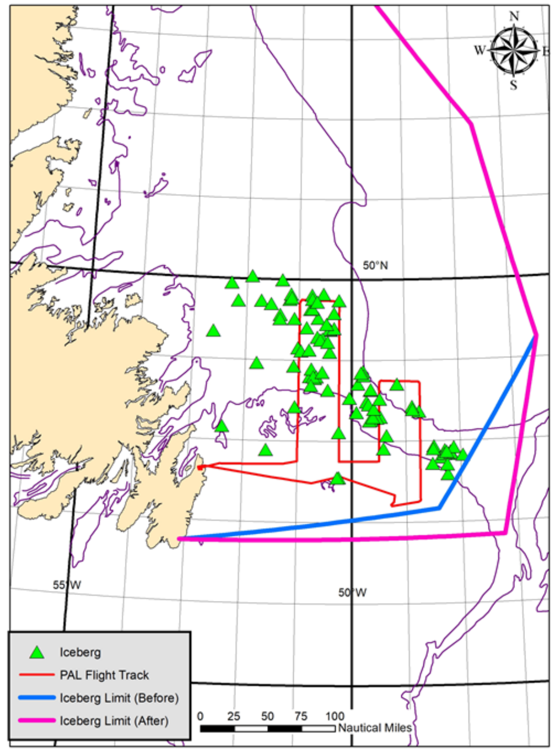

Figure 3.5. Iceberg outside of the limit case, 6 March 2023

16 March 2023

The OPCEN received a ship report of an iceberg outside the advertised iceberg limits in position 46°33’N, 053°54’W. IIP watch standers made notifications to MCTS and NGA, and warnings were issued. IIP revised products to reflect the new iceberg sighting and redistributed products.

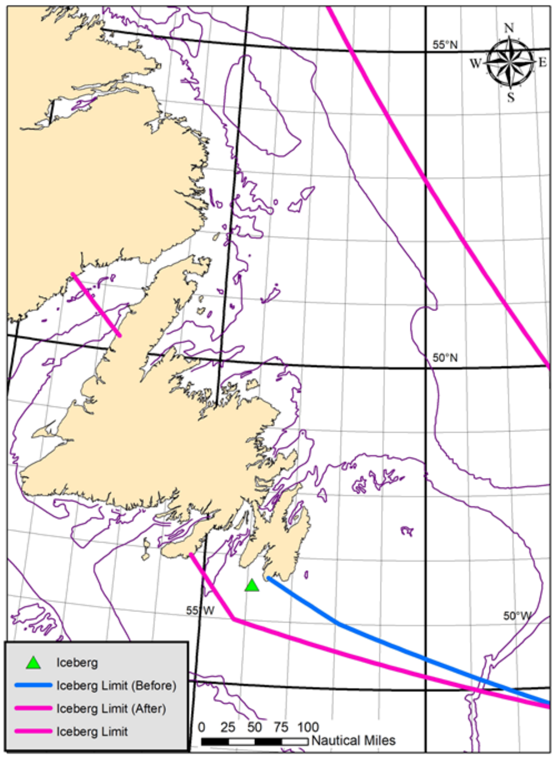

Figure 3.6. Iceberg outside of the limit case, 16 March 2023

7 May 2023

On the morning of 7 May 2023, minutes before an IRD flight was to take off from CYYT, the OPCEN received a report of three icebergs near Prince Edward Island from a PAL Aerospace flight. The message reported three icebergs, excluding size or shape information, along the east coast of the island – a highly unusual location for icebergs. Watch standers attempted to confirm the sightings with PAL, but the crew that flew the flight was not able to be reached.

After consultation with CIS and the deployed IRD team, the IRD flight was redirected to investigate the targets while NAVAREA IV and NAVWARN messages were released via MCTS and NGA. No immediate changes were made to the iceberg limit until the targets could be verified by the IIP flight, as any icebergs spotted in or near Cabot Strait could lead to an iceberg limit that encompasses the St. Lawrence Seaway, a highly trafficked shipping lane connecting the Atlantic Ocean to the Great Lakes of North America.

The IRD confirmed the absence of icebergs in the reported location with high confidence and communicated the results immediately to the IIP OPCEN. Notifications were made to CIS, MCTS, and NGA to cancel the iceberg-outside-the-limit warning messages. Later, it was determined that there was a coding error with this report, and there were no icebergs in the area.

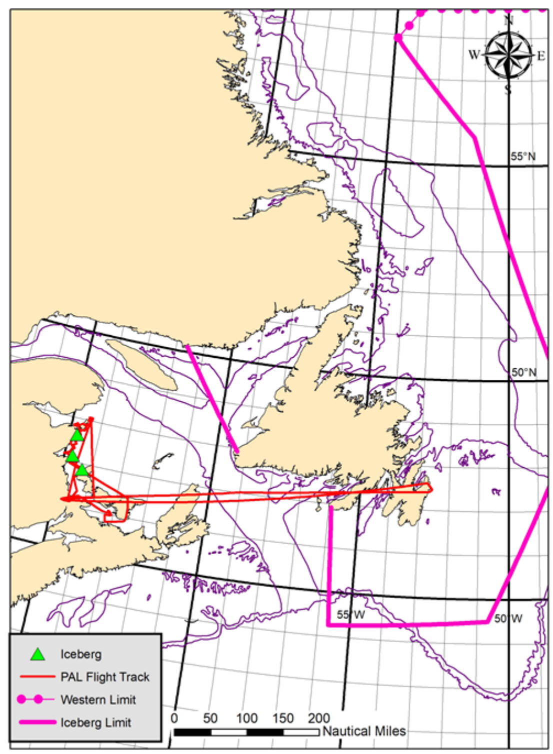

Figure 3.7. Iceberg outside of the limit case, 7 May 2023

13 August 2023

The CCG icebreaker His Majesty’s Canadian Ship (HMCS) HARRY DEWOLF reported a radar target outside the limit near St. John's, NL to CIS. CIS notified the IIP OPCEN minutes before the normal time of product release. There was little time to attempt to corroborate the accuracy of the report using other means, but the reliability of the reporting source was factored heavily in the decision to revise the already drafted products to encompass the reported radar target.

The watch then ingested the report as an iceberg and included it within newly drawn limits. No NAVWARN or NAVAREA IV messages were released due to the proximity to normal distribution time.

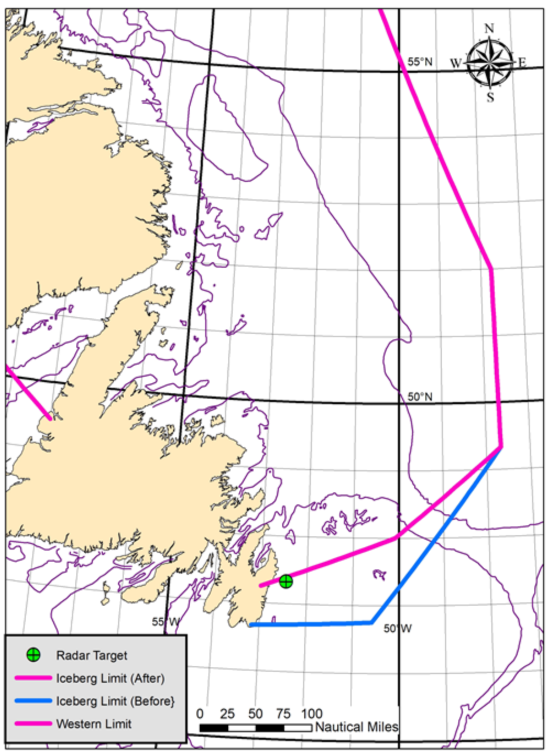

Figure 3.8. Iceberg outside of the limit case, 13 August 2023

22 August 2023

The OPCEN received an iceberg message from PAL from an industry flight on the previous day. A single radar target in the report was ingested into BAPS and modeled forward in time. The predicted drift placed the iceberg outside of the limit. The watch contacted PAL to attempt to confirm the target, but they were unable to provide further information.

After efforts to correlate the target with a vessel did not yield any useful results, NAVWARN and NAVAREA IV messages were requested. After the messages were requested, PAL informed IIP that the target was entered erroneously into the iceberg message. IIP was able to recall the NAVWARN from MCTS, however, NGA had already released the NAVAREA IV warning message. Products were released with the target included as an iceberg to avoid conflicting information already published in the NAVAREA IV message. The iceberg was counted as an entry into the database and south of 48°N but was removed the next day.

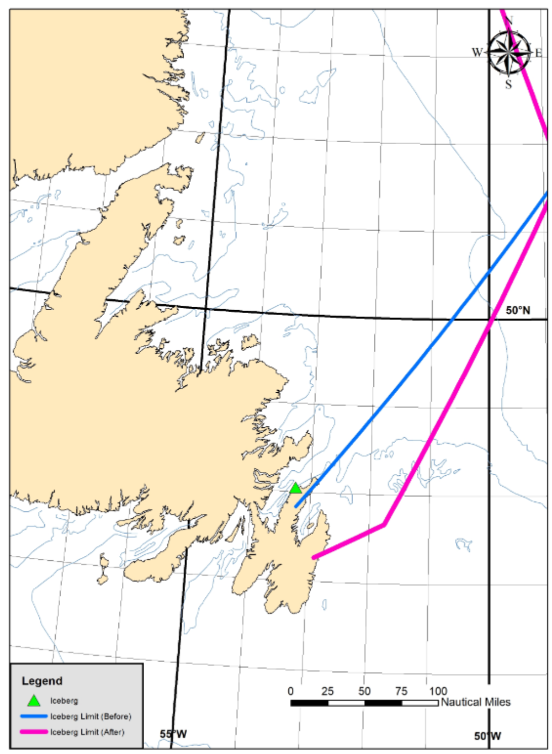

Figure 3.9. Iceberg outside of the limit case, 22 August 2023

3.7 Risk-Based Iceberg Products and Tailored Support

IIP continued support for specific customers transiting north to eastern Canada and western Greenland. USCGC SYCAMORE and USCGC FORWARD operated in the waters of the Labrador Sea and Baffin Bay over the course of 2023. USCGC SYCAMORE is a 225-ft sea-going buoy tender with an ice-strengthened hull, and USCGC FORWARD is a 270-ft medium endurance cutter with no ice strengthening. Neither crew had useful experience operating near icebergs and depended on IIP for daily updates on the iceberg population in their respective operating areas. Each cutter received a daily iceberg hazard chart known as the "Isolated/Few/Many" (IFM) product from IIP, which depicted iceberg proximity, and, by proxy, density, which could be used to make risk assessments concerning their intended movements.

The IFM product remains a novel endeavor for IIP but continues to gain popularity and relevance with specific customers. The IFM chart uses three distance thresholds (10 NM or less, 10 to 45 NM, and greater than 45 NM) to indicate how close plotted icebergs are to each other and draw corresponding contours around regions that correspond with each distance threshold. **Figure 3.10** depicts an example of this product.

New to 2023 was a significant update and upgrade to the IFM product. After joint evaluation with the International Ice Charting Working Group (IICWG) Iceberg Risk Product Task Team, a different metric was displayed on IFM charts to depict iceberg concentration instead of proximity. These products were provided to USCGC FORWARD. Existing definitions of iceberg density were re-used to define areas of iceberg concentration as Isolated (0 to 1 icebergs), Few, (2 to 8 icebergs), Many (more than 8 icebergs) and Many (more than 30 icebergs).

These metrics indicate the potential iceberg count at any location selected on the provided product using the same green/yellow/red contours to indicate increasing risk. This version of the product also filled in the entire area enclosed by the iceberg limit with an "isolated" area to indicate that the risk of encountering an iceberg existed at any point inside the limit and was also created using modern ArcGIS Pro software. An example of this product is provided in **Figure 3.11.**

This capability is the result of much effort and collaboration between IIP and DMI, as well as with other government and commercial agencies through IICWG. In these two cases of customized support, IIP relied heavily on its NAIS partnership with DMI. DMI employs an automated iceberg detection and classification algorithm that quickly and accurately sorts through satellite images to find the thousands of icebergs in its waters surrounding Greenland. IIP relied on that output to create IFM products, drifting the icebergs using the NAIS drift and deterioration model to predict the location of relevant icebergs when cutters were transiting nearby. Proximity contours were drawn using the modeled error circles, a conservative method used to show positional uncertainty. Results were sent out daily to the supported cutters.

USCGC SYCAMORE participated in the annual search and rescue exercise ARGUS with units representing France, Denmark, and Greenland. Twenty-two products were produced by six different analysts between 1 and 22 June 2023. SYCAMORE reported modifying the ship's intended track line daily based off the provided products.

USCGC FORWARD represented the U.S. contingent in the annual Operation NANOOK along with vessels from France, Canada, England, and Denmark. Thirty-two products were produced by seven different analysts between 9 and 28 August 2023. Since the list of participating vessels was published ahead of the exercise, IIP offered and delivered products to all the participating units in the exercise to include HMCS HARRY DEWOLF, French Ship (FS) GARONNE, and the

Meteorology and Oceanography Operations Centre in Halifax.

USCGC FORWARD's after-action report read, "FWD relied heavily on...IIP production to inform route planning. While in Arctic waters, FWD adjusted track line almost daily based on IIP production identifying iceberg concentrations. While transiting South, FWD sailed along IIP's iceberg limit line for iceberg mitigation and did not observe icebergs visually or by radar. Highly recommend that assets deploying to the northern latitudes frequently consult IIP production when route planning."

IIP predicts the demand signal for tailored support to grow as more Navy and Coast Guard assets not accustomed to ice navigation begin to push farther and farther north.

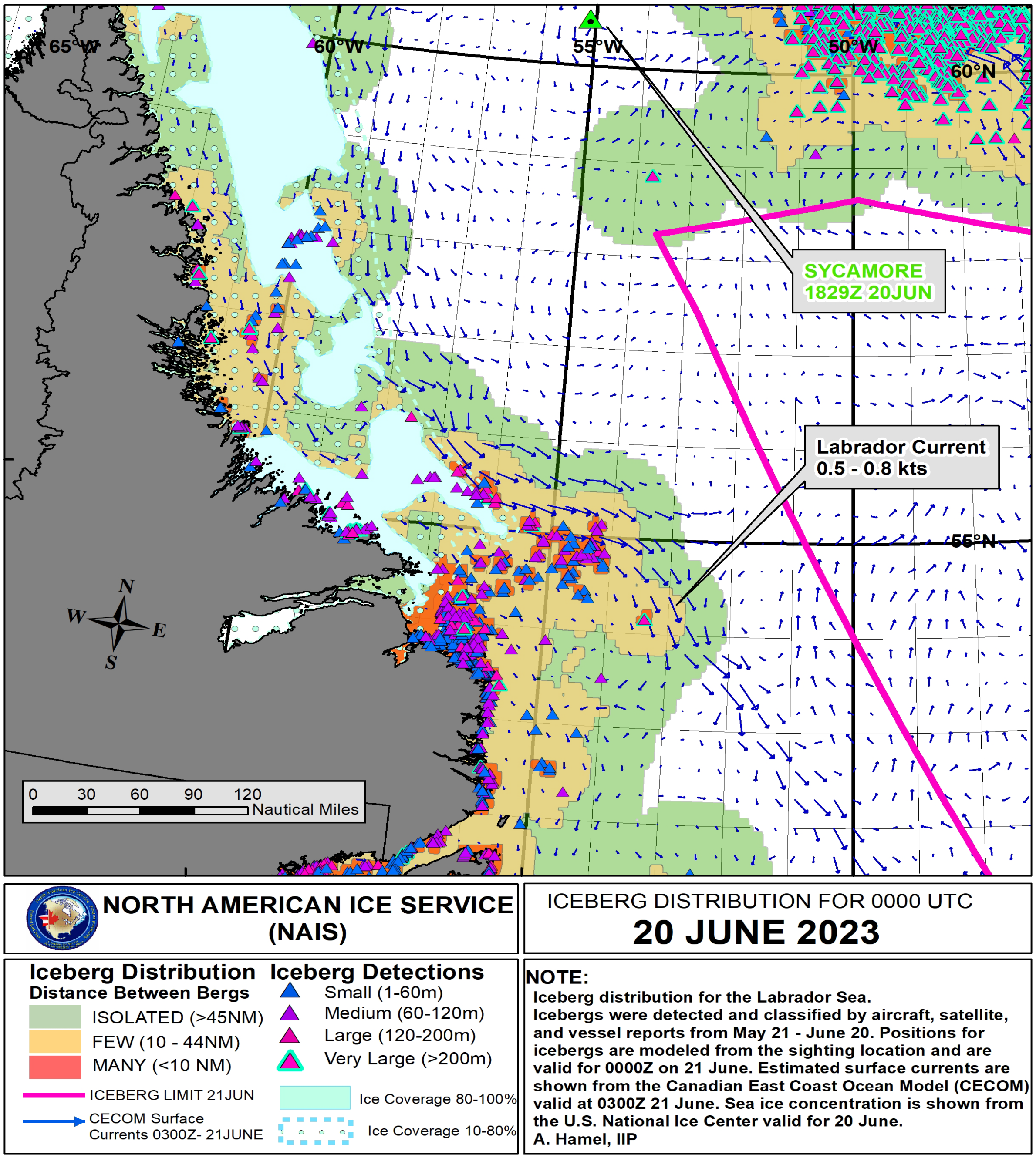

Figure 3.10. Isolated/Few/Many Product sent to USCGC SYCAMORE for exercise ARGUS

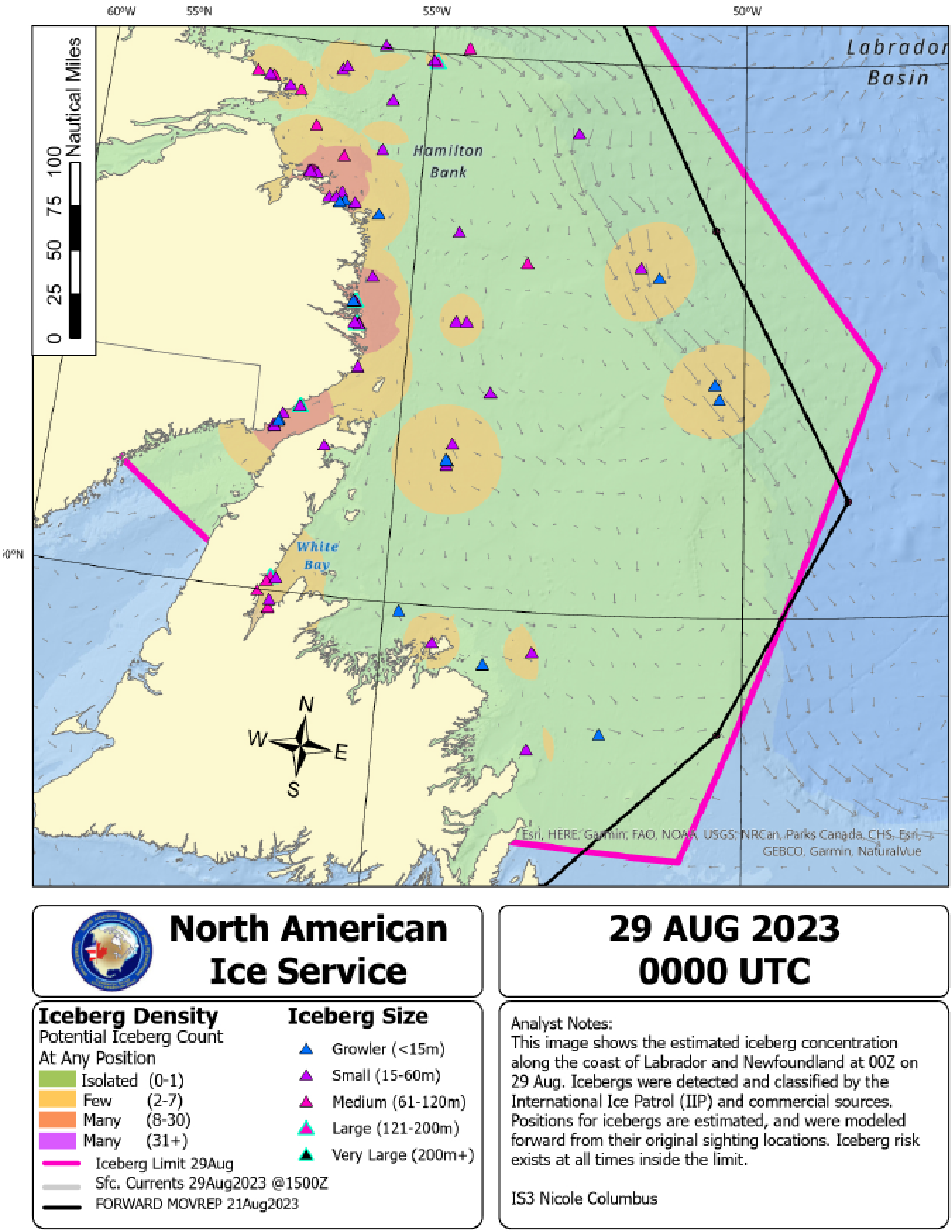

Figure 3.11. Isolated/Few/Many Product sent to USCGC FORWARD for exercise NANOOK.

4 Iceberg Reconnaissance Operations

4.1 Iceberg Reconnaissance Detachments

The IRD is a sub-unit within IIP which partners with CG ASEC to conduct aerial iceberg reconnaissance. During the 2023 Ice Year, nine IRDs deployed to observe and report icebergs, sea ice, and oceanographic conditions in the North Atlantic Ocean. These critical observations were reported to the IIP OPCEN in Suitland, MD for processing and incorporation into BAPS, and used to create and distribute the iceberg limit and NAIS iceberg warning products daily. See **Section 5** for semi-monthly NAIS iceberg warning products in Ice Year 2023.

Between February and June, IIP and ASEC conducted 26 iceberg reconnaissance sorties over 70 deployed days on HC-130J aircraft. The flight season spanned 134 days, near the five-year (2017-2021) mean of 138 days. IRDs 1 through 7 were flown as scheduled, however, IRD 8 was canceled to reduce the operational tempo for deploying members and allow for the reassignment of the HC-130J to higher priority missions. **Table 4.1** contains a summary of operations for each IRD.

4.2 Aerial Iceberg Reconnaissance Equipment

IRDs were conducted using HC-130J aircraft equipped with two radars and an integrated AIS in the mission system suite. One radar is the ELTA-2022 360° X-Band surface-search radar, which can detect and differentiate surface targets automatically (as iceberg, ship, or "other") by utilizing AIS input. The other is the HC-130J Tactical Transport Weather Radar (APN-241), which can detect surface targets, but cannot differentiate them automatically.

The 360° coverage provided by the ELTA radar allows IIP to plan for patrols with up to 30 NM flight ground track spacing. This Ice Year, IIP planned 22 out of 26 flights with 30 NM ground track spacing while maintaining the probability of detection (POD) of small icebergs (15 to 60m) at 95%. The remaining flights were planned with 10 NM ground track spacing due to malfunctioning aircraft radar.

When the ELTA radar was inoperable, the IRD drew flight plans under "visual-only" specifications using 10 NM ground track spacing which covers 40% less area compared to flights with radar coverage. Good reconnaissance

IRD	Deployed Days	Iceberg Patrols	Transit Flights	Patrols enroute	Logistics Flights	Flight Hours
1	9	2	2	0	1	36.7
2	7	3	2	0	0	27.6
3	8	3	2	0	0	30.3
4	7	1	2	0	0	17.4
5	9	4	2	0	0	37.5
6	9	3	1	1	0	23.4
7	9	4	2	0	0	38.2
8	0	0	0	0	0	0.0
9	9	1	0	2	0	19.2
10	3	1	1	1	0	19.5
Total	**70**	**22**	**14**	**4**	**1**	**249.8**

Table 4.1. An overview of days and flight hours used during the scheduled IRD's for the 2023 Ice Season.

conditions (at least 50% visibility and few to no white caps) are preferred for visual-only patrols, but they are relatively rare in IIP's meteorologically active AOR.

All IRDs were flown with Minotaur Mission System-equipped aircraft. Minotaur is a software and hardware suite that allows for onboard networking of cameras, radars, navigational instruments, and communications. This also allowed OPCEN watch standers to communicate directly with aircraft personnel in flight.

IRD crews also frequently utilized the inverse synthetic aperture radar (ISAR), a function of the ELTA radar. ISAR uses target motion to generate high-resolution images of such targets. ISAR imagery is analogous to the satellite SAR imagery IIP analyzes, in that it is created using radar energy pulses in the microwave band of the electromagnetic spectrum. However, SAR relies on the motion of the platform carrying the radar (e.g., satellite motion in orbit), and not that of the target, to generate an image (**Figure 4.1**). This technology has proven extremely useful for identifying and distinguishing icebergs from ships, especially in poor visibility and for those ships which do not transmit AIS.

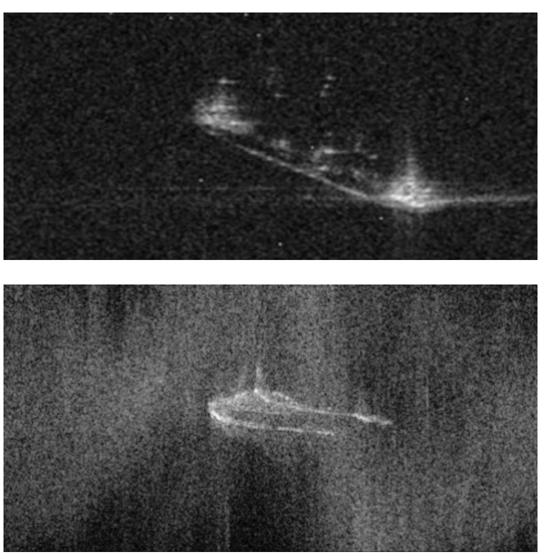

Figure 4.1. ISAR imagery of a ship (top) and an iceberg (bottom).

4.3 Deployment Season Summary

Figure 4.2 shows the use of IIP's deployment days during the 2023 Ice Year by category (Operational, Transit, Patrol/Transit, Weather, Maintenance, Crew Rest, and Other). The Other category includes IIP partner meetings, higher priority aircraft tasking (e.g., search and rescue), and logistics flights. In accordance with USCG regulations, the IRD normally takes one day of crew rest and one maintenance day per nine-day deployment; otherwise, the intent is to fly every day. Operations took up the most deployment days in 2023 (31%).

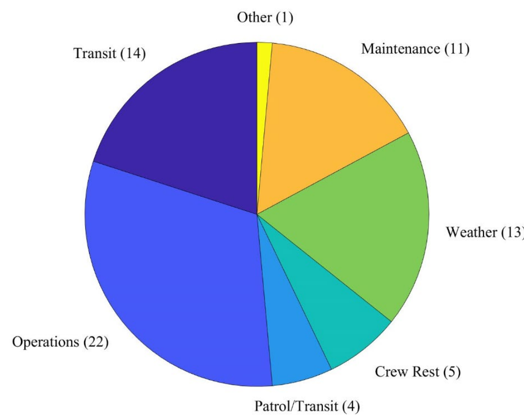

Figure 4.2. Utilization of days for the 2023 Ice Season.

The prevailing weather in the AOR contributed significantly to the number and effectiveness of reconnaissance patrols. Weather conditions prevented patrols on 19% of the days deployed. The IRD crews capitalized on poor weather opportunities, when possible, to meet the required rest and maintenance days. This maximized operational iceberg reconnaissance on favorable weather days.

Four out of the 52 days were used for unscheduled maintenance or waiting for replacement parts to arrive at the deployment location. As in past seasons, IRDs based out of St. John's encountered significant logistical challenges with transporting spare parts to the deployed aircraft.

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), when crew rest or maintenance was required (scheduled), and when issues with maintenance occurred (unscheduled).

	Crew Rest	Aircraft Maintenance
Opportunity (Weather)	4	5
Scheduled	1	3
Unscheduled	0	3
Total	5	11

Table 4.2. Crew rest and aircraft maintenance days for the 2023 Ice Season.

4.3.1 IRD Summaries

The first IRD of Ice Year 2023 (IRD 1) began on 8 February 2023. The flight departed Joint Base Andrews (airport code KADW) for a transit to St. John's, Newfoundland (airport code CYYT). On 9 February, the flight was grounded due to a missing tow bar in the hangar. ASEC arranged for delivery of the tow bar, which was arranged via a separate flight that afternoon. This round-trip flight accounted for the only logistics hours of the season (see **Section 4.5** for further details on flight hours). On 10 February, the patrol spotted nine icebergs and one ship, diverting once from the planned flight route. On 11 February the flight was grounded due to high winds at CYYT; instead, a visit was conducted with PAL Ice and Environmental Services. A rest day was used on 12 February. On 13 February, a patrol of Hamilton Bank resulted in the detection of 62 icebergs and two ships, with two diverts from the planned route. A scheduled maintenance day was conducted on 14 February. On 15 February, the crew was grounded due to high winds and low clouds at CYYT. An engine alarm on 16 February led to a take-off delay and the cancelation of a patrol enroute to KADW.

IRD 2 departed KADW on 24 February 2023. IRD 2 was grounded on 25 February due to reduced visibility and strong crosswind gusts at CYYT, exceeding safe takeoff and landing requirements for the HC-130J. On 26 February, takeoff was delayed due to low visibility at CYYT. Runway conditions at CYYT did not improve as anticipated, presenting significant safety concerns for landing due to restricted visibility and 25 kt+ crosswinds; ultimately the flight was canceled. On 27 February, a patrol over the interior of the iceberg population was conducted, identifying a total of 14 icebergs with three diverts. During the flight, IRD 2 lost radio communications due to suspected icing on the aircraft antenna. The de-icing system also malfunctioned, but only after the patrol legs of the flight were completed and the flight was already on its way back to CYYT. The patrol on 27 February took off as scheduled but was shortened when high winds and turbulence caused crew fatigue and sickness. A southern interior patrol conducted on 28 February identified 71 icebergs with two diverts. On 1 March, a western limit/Hamilton Bank flight identified 25 icebergs and two ships with two diverts. IRD 2 departed CYYT early on 2 March, due to inclement weather at CYYT, and returned to KADW.

IRD 3 departed KADW on 8 March 2023. A crew rest day was taken on 9 March due to high winds preventing takeoff. On 10 March, the plane was grounded due to high winds and poor visibility; a training day was conducted for IIP personnel instead. A scheduled maintenance day was conducted on 11 March. On 12 March, a patrol over the western limit and the interior identified 34 icebergs and four ships. On 13 March, takeoff was delayed due to an engine de-icing valve malfunction. A delayed patrol of the southern interior and over the eastern cliff of the continental shelf in the AOR (1,000-m depth) detected 39 icebergs. On 14 March, a southern limit patrol resulted in six icebergs and 18 ships detected with one divert. On 15 March, the IRD crew transited back to KADW.

IRD 4 departed KADW on 22 March 2023. On 23 March, low visibility at CYYT delayed the planned patrol, resulting in an amended flight plan. IRD 4 conducted a western limit and interior flight identifying 76 icebergs and one ship, with one radio callout to a vessel and one divert. The patrol on 24 March was canceled due to inclement weather which included strong winds, deteriorating visibility, low cloud ceilings, and snow. On 25 March, a crew rest day was used due to a low cloud base and high seas in the patrol area. On 26 March, the aircraft was grounded due to weather in the patrol area, as well as an aircraft issue involving the cabin pressurization system. On 27 March, the crew used a maintenance day due to inclement weather at CYYT, however, the air crewmembers could not resolve the cabin pressurization issue and further discovered a leak in the onboard oxygen system. Because of the multiple aircraft issues, the IRD departed CYYT on 28 March (two days early). The HC-130J cabin pressure was manually controlled for the 6-hour transit back to KADW.

IRD 5 was scheduled to depart on 5 April 2023, but the HC-130J was grounded at ASEC due to unscheduled maintenance which delayed the start of the IRD; the IRD departed for CYYT on 6 April. On 7 April, the plane was grounded due to poor weather conditions at CYYT. On 8 April, a southern limit patrol was conducted, resulting in the sighting of no icebergs and 13 ships, with one radio callout and two diverts. On 9 April, the western limit and 1,000-meter contour were patrolled, detecting 93 icebergs and four ships, with one radio callout and one divert. Scheduled maintenance was conducted on 10 April; IIP members used the time to conduct training and meet with PAL Ice and Environmental Services to discuss the possibility of PAL hosting ice observer training for IIP members in future seasons. On 11 April, a southern limit patrol detected 53 icebergs and nine ships, with two radio callouts and one divert. To commemorate the sinking of the RMS TITANIC, memorial wreaths were deployed from the HC-130J on this patrol near the wreckage site. On 12 April, a patrol of Hamilton Bank detected 45 icebergs and two ships, with three diverts. Before the flight, a film crew from the Discovery Channel Canada conducted on-site interviews with IIP and ASEC personnel. The interviews contributed to the show “East Harbor Heroes” which documented the challenges confronting the shipping industry in Newfoundland during the winter season. The crew transited back to KADW on 13 April.

IRD 6 began on 19 April 2023 with a patrol enroute to CYYT. On 20 April, the IRD was grounded due to low cloud ceilings and fog persisting throughout the day. An eastern limit patrol conducted on 21 April detected only one iceberg, with one radio callout to a vessel. On 22 and 23 April, a crew rest day and maintenance day were used due to low cloud ceilings and persistent fog over CYYT. On 24 April, a western limit patrol identified six icebergs and six ships, with two radio callouts. Fog and low clouds over CYYT grounded the plane again on 25 April. On 26 April, a southern limit patrol spotted four icebergs and seven ships, with one radio callout and three diverts. During this flight the IIP crew was accompanied by a German media group on a public affairs flight. The IRD returned to KADW on 27 April.

IRD 7 was scheduled to begin on 3 May 2023, however, the aircraft was delayed at ASEC for two days due to unscheduled maintenance; the IRD departed for CYYT on 5 May. On 6 May, a western limit patrol detected 19 icebergs and 15 ships, with one divert. On 7 May, the IRD conducted a one-hour patrol of the Gulf of St. Lawrence, detecting no icebergs and 9 ships. A southern limit patrol flown on 8 May detected one iceberg and six ships, with two radio callouts and two diverts. A scheduled maintenance day took place on 9 May. A western limit and interior patrol flown on 10 May detected 253 icebergs and six ships, with four diverts. Reporters from the Canadian Broadcasting Corporation (CBC) accompanied the flight and conducted interviews. The IRD transited back to KADW on 11 May.

IRD 8 was canceled to manage the deployment tempo for IIP team members, and to allow for the reassignment of the HC-130J to higher priority missions by USCG operational commanders.

IRD 9 began on 31 May with a patrol enroute to CYYT, detecting two icebergs and two ships, with three diverts. A western limit patrol on 1 June detected 67 Icebergs and 20 ships, with one divert. Due to heavy fog at CYYT, the IRD was grounded from 2 June through 7 June. One day was used as a crew rest day and another as a maintenance day. On 7 June, the IIP team visited C-CORE for a partner meeting; C-CORE and PAL were also able to visit the hangar for a tour of the plane and offices. On 8 June, the IRD transited back to KADW with a patrol enroute over the southern limit, detecting no icebergs.

IRD 10 departed KADW and transited to CYYT on 16 June 2023. On 17 June, the IRD conducted a western limit patrol detecting 126 icebergs and 26 ships, with one radio call out and three diverts. From 18 June through 21 June, the IRD was grounded due to deployment of the HC-130J to conduct search and rescue operations in support of the Titan submersible incident. On 22 June, the IRD transited back to KADW with a patrol enroute over the southern limit, detecting one iceberg and 21 ships, with one divert.

4.4 2023 IRD Iceberg Detections

IRD personnel detected 1,073 icebergs over the nine IRDs. All but two of these icebergs were incorporated into the iceberg database, accounting for 7% of icebergs incorporated in 2023. No action was taken on these two icebergs because the reconnaissance occurred outside of the geographical boundaries of the model (for one iceberg) and because of conflicting coincident reconnaissance (the other iceberg).

During IRDs, iceberg detections are categorized in one of three ways: 1) both visually and by radar, or by camera alone, 2) by radar alone, or 3) only visually. Iceberg detections made with the Electro-Optical Infrared (EOIR) camera onboard are counted as both visual and radar sightings because of the camera's ability to see much farther than the human eye and in the infrared. The EOIR camera is equipped to identify more precise geographical positions of icebergs than observers in flight, who rely on range and bearing to estimate position.

In 2023, 71% of the icebergs detected by an IRD were sighted via concurrent radar observations and visual sightings, or by the camera alone. Only 1% of the remaining icebergs were detected by radar only, and 28% were detected visually only **(Table 4.3).** Concurrent radar and visual detection have increased since 2014, illustrating how significant the radar and camera sensors have become to aerial iceberg reconnaissance methods and accuracy.

Year	Radar & visual icebergs	Radar only icebergs	Visual only icebergs
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%
2021	69%	8%	23%
2022	38%	2%	60%
2023	71%	1%	28%

Table 4.3. IRD iceberg detections by method from over the last ten years (2014-2023).

IIP personnel employed a two-tiered iceberg reconnaissance approach in favorable environmental conditions to maximize detection efficiency, focusing visual observations near the aircraft and radar observations farther away. This tactic often resulted in visual-only reported iceberg detections because, even when these icebergs were within range of and detected by the radar, observers needed to sight and record high volumes of icebergs in flight and time did not allow for corroboration of those sightings with the radar.

4.5 2023 Flight Hours

As in previous seasons, IIP was allotted 500 Maritime Patrol Aircraft flight hours for its operation during the Iceberg Season. IIP used 249.8 total hours in 2023. This total includes patrol, transit, and logistics hours attributed to the IIP mission (**Figure 4.4**).

Transit hours are the hours the aircraft is transiting between specific locations in support of the IIP mission, without conducting reconnaissance. These flights are between Elizabeth City, NC and St. John's, NL, with a brief stop at Joint Base Andrews in Prince George's County, MD to load IIP personnel and equipment. There were 102 hours used this season for transits.

Patrol hours are those during which the IRD conducts iceberg reconnaissance, including flight time to and from the reconnaissance area. IIP flew 138.7 patrol hours this season. When a patrol is conducted during a regularly planned transit flight, such as a patrol while transiting back to Joint Base Andrews, the hours are accounted for accordingly. There were four patrols enroute during this season, of which 40.6 hours (29% of patrol hours) were used for flying to/from the reconnaissance area. On average, it took two hours to fly to the reconnaissance area from CYYT in 2023 (**Figure 4.5**).

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 was one round-trip logistics flight totaling 9.1 hours.

The spatial and temporal distribution of icebergs, as well as the number drifting south of 48°N, all contribute to the amount of reconnaissance needed to effectively monitor the iceberg danger and provide relevant warning products. **Figure 4.6** shows a comparison of flight hours to the number of icebergs that drifted south of 48°N from 2013 to 2023. In Ice Year 2023, IIP flew 249.8 hours and estimated a total count of 385 icebergs which drifted south of 48°N. This was an Iceberg Season with moderate severity, with 385 icebergs being greater the threshold (300) for light season severity.

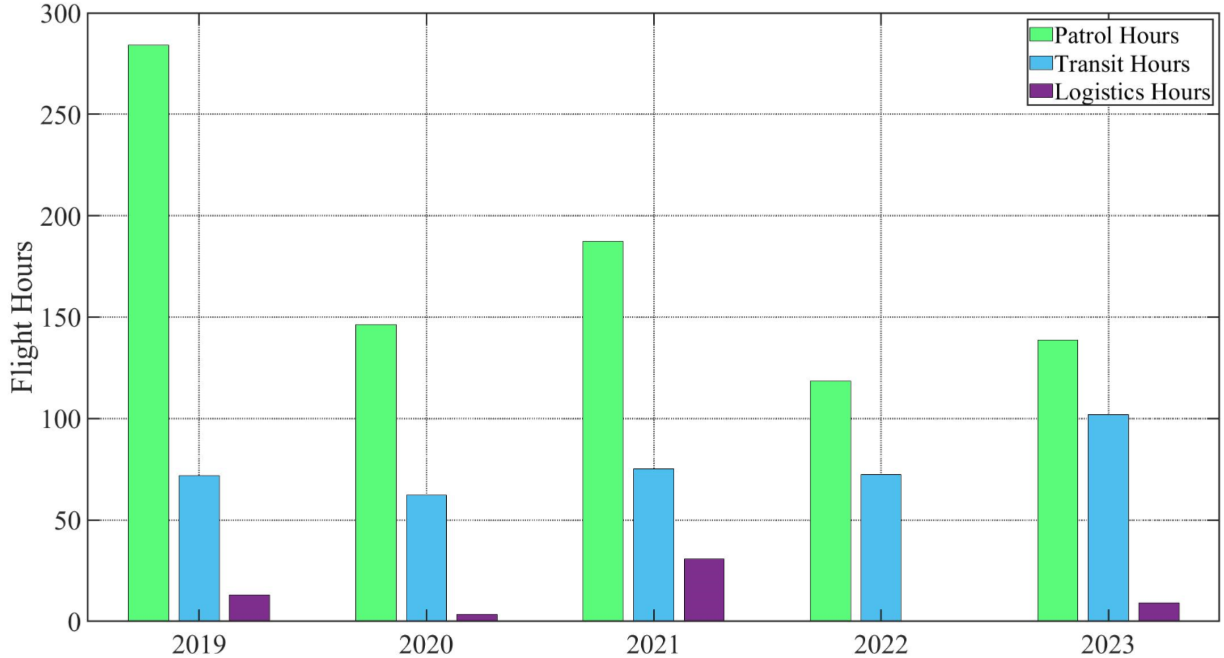

Figure 4.4. Flight hours broken down by patrol, transit, and logistics hours over the past five years.

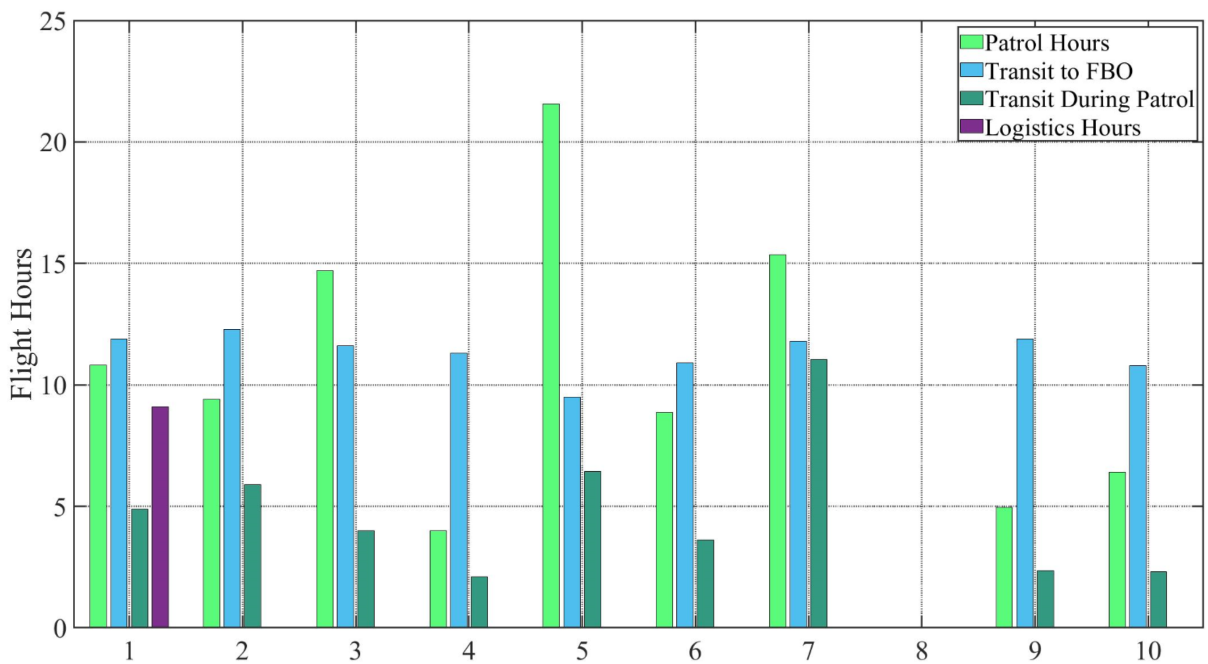

Figure 4.5. 2023 Flight hours broken down by IRD. FBO refers to a Fixed Base of Operations, the staging area for reconnaissance flights.

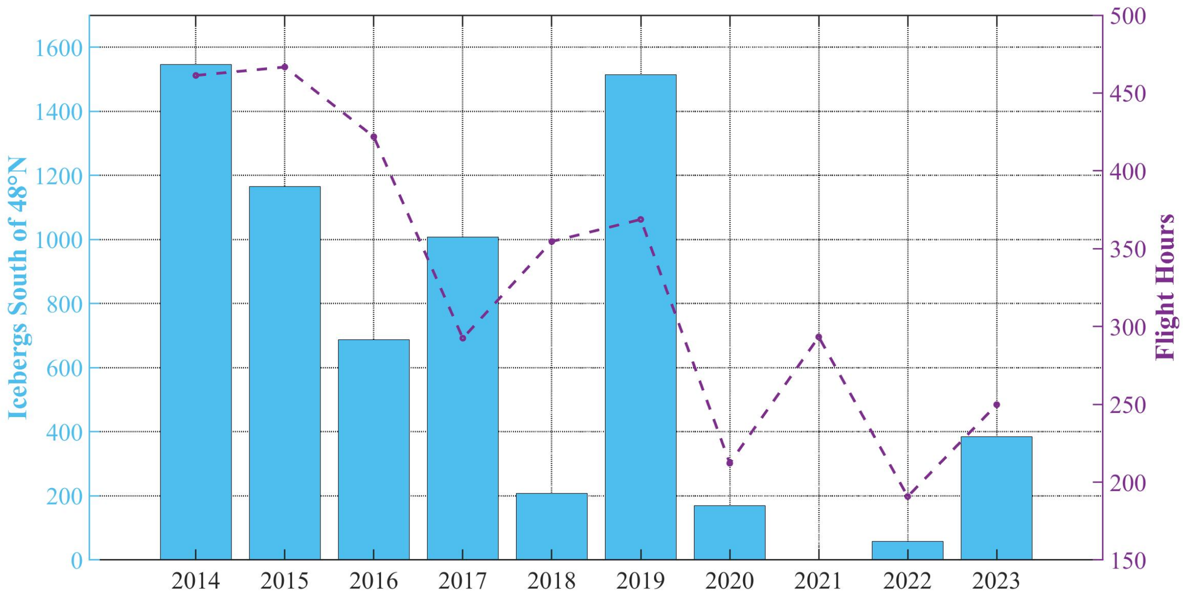

Figure 4.6. Comparison between total IRD flight hours per season and season severity, measured by number of icebergs sighted or drifted below 48°N for the past 10 years. More icebergs south of 48°N may require increased reconnaissance efforts.

4.6 Satellite Reconnaissance

4.6.1 Satellite Collections

IIP iceberg satellite reconnaissance is conducted daily by a qualified watch stander (Duty Satellite Analyst, DSA) when IIP has responsibility for the NAIS iceberg warning products. Each morning, the DSA is responsible for communicating with the OPCEN for daily or emergent reconnaissance requirements and to deconflict (avoid redundancy) with commercially provided iceberg reconnaissance. The DSA will take in all relevant information and determine image priority based on sensor characteristics and strategic region (**Figure 4.7**).

The satellite reconnaissance strategic regions help analysts prioritize which satellite imagery to download each morning. Strategic Region A is the portion of the IIP AOR south of 52°N, where icebergs pose the greatest threat of collision with transatlantic vessels in the vicinity of the Grand Banks and the Strait of Belle Isle. Higher resolution satellite imagery is required for monitoring this area, as icebergs here are smaller due to advanced deterioration, and are usually in

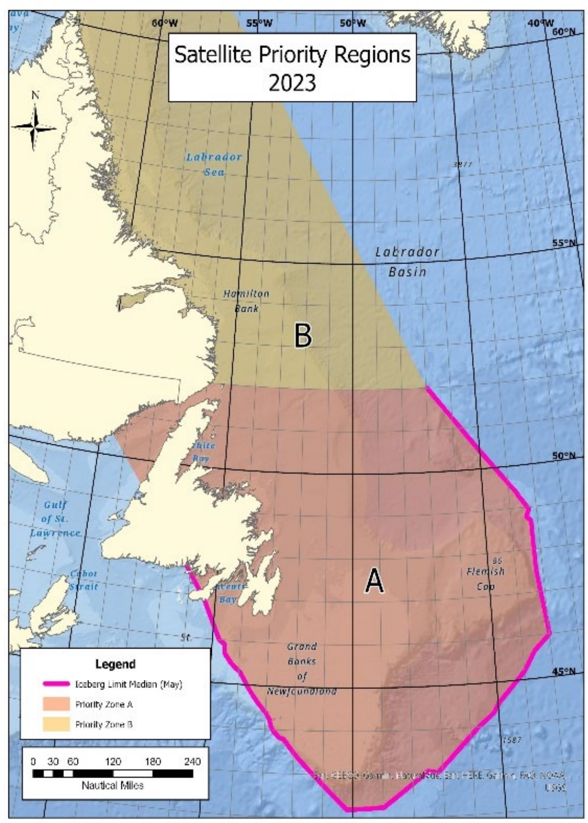

Figure 4.7. Graphic depicting satellite reconnaissance priority regions within the IIP AOR. South of 52°N is generally the area analysts should consider high priority for satellite imagery, where icebergs pose the greatest threat to shipping lanes.

the open ocean. Generally, there are also more ships and fishing gear in this region, making discrimination of ship and iceberg targets more challenging for analysts.

Region B is the portion of the IIP AOR north of 52°N, where DSAs analyze satellite imagery of greater areal coverage, but reduced resolution. Such imagery allows the DSA to identify larger, slower moving icebergs, often trapped in sea ice, in a greater area. This region contains the population of icebergs which may eventually drift into high-traffic shipping lanes ("feeder" icebergs). The presence of sea ice in this region early in the season can make target detection more difficult.

IIP continues to rely on ESA's SN1A and SN2 sensors, which both follow a consistent collection schedule and remain publicly available online in near real-time. It is worth noting the SN1B failure in December 2021 still hinders IIP's satellite reconnaissance capabilities tremendously, as satellite passes cover the AOR half as frequently. This reduced coverage and frequency makes consistent satellite analysis more difficult. Despite this, SN1A remains a useful sensor for reconnaissance of Region A due to its spatial resolution, as noted in **Table 4.4**.

Multispectral imagery from SN2 can be an incredibly useful resource for IIP satellite reconnaissance as it results in very high confidence iceberg classifications. The scenes, imaged in the optical band, are more intuitive for analysts to determine what is and what is not an iceberg compared to SN1A, due to the similarity in visual appearance to objects in life and photography. However, frequent cloud cover in the AOR renders many SN2 images unusable for analysis.

This year, IIP also continued operational use of imagery from the Canadian Space Agency's (CSA) Radarsat Constellation Mission (RCM), a direct result of the important partnership between IIP and CIS. While previously RCM has been used for monitoring the northern AOR, and usually a lower priority sensor for DSAs, several medium to large icebergs that drifted south of 52°N were detected and tracked using RCM imagery (generated in lower resolution modes) in these higher priority southern regions.

Radarsat-2 (RS2) imagery became available near the end of the 2023 Ice Year and was used in reducing the iceberg limit before product handoff to CIS.

4.6.2 Satellite Analysis

Once sensor and region priority are considered, analysts download the chosen images from the previous 24 hours, or download relevant imagery as directed by the watch supervisor or IIP Chief Scientist. The DSA will proceed to run the selected satellite frames through an Iceberg Detection System (IDS). IIP analyzes most SAR imagery using a commercial IDS provided by C-CORE. For SN2 images, an electro-optical sensor, IIP utilizes an algorithm written in-house which

Satellite Reconnaissance Priority Matrix				
Priority	**Sensor**	**Frequency**	**Resolution**	**Mode**
1	Sentinel-1A (IW)	12 days	20 m	HH/ HV
1	Radarsat-2 (Wide-Fine)	24 days	8 m	Single-Pol or Dual-Pol
2	Sentinel-2	5 days	10 m	EO
3	Radarsat Constellation Mission (RCM)	Daily	50 m	HH/ HV

Table 4.4. Satellite systems and capabilities used by IIP satellite analysts.

exploits the spectral properties of image targets to detect icebergs.

The DSA then reviews an IDS-generated shapefile that contains up to hundreds of potential iceberg targets. By looking at the size, shape, location relative to sea ice, and pixel properties of each individual target, the DSA can make a classification determination and decide if a target is an iceberg, ship, or noise/clutter. The DSA will then generate a SIM, which is handed off to the OPCEN watch standers for incorporation into BAPS, where the satellite detected icebergs are added or resighted to the IIP iceberg model.

4.6.3 Satellite Iceberg Detections

IIP satellite reconnaissance during the 2023 Iceberg Season relied primarily on SN1A, SN2, and RCM. Watch standers at IIP analyzed 754 individual satellite images to generate a total of 535 SIMS during the 2023 Ice Year. Often, analysts will generate one SIM from multiple satellite images, particularly for SN2, which explains the difference between number of images analyzed and SIMs generated. The breakdown of total frames analyzed at IIP can be seen in **Figure 4.8.** Despite the SN1B failure, this satellite sensor remains the primary workhorse of IIP satellite reconnaissance. Also included in this graphic are two RS2 images that were analyzed near the southern iceberg limit prior to product handoff to CIS.

IIP's analysts identified at total of 6,209 icebergs in satellite imagery in Ice Year 2023, of which 5,661 were added or resighted to the database. The total number of images analyzed in-house by IIP increased from 682 frames in 2022 to 754 frames in 2023, as seen in **Figure 4.9**. As IIP continues to improve its satellite program, streamline analysis methods, and develop DSA expertise and training, we expect an increase in future satellite reconnaissance in balance with IIP aerial reconnaissance.

On the other hand, the percentage of icebergs detected by all satellite sources that are incorporated into the iceberg model decreased, as seen in **Figure 4.10**, from 89% in 2022 to 85% in 2023. This may be attributed to the moderate iceberg season experienced in 2023 compared to the light iceberg season of 2022, as IIP received iceberg reports from iceberg flights and ship reports containing more icebergs in 2023. There was a steep increase in the percentage of icebergs detected by satellite between 2014 and 2020, after which this number approaches a plateau between 80-90% of total icebergs detected. IIP posits that it will likely remain there while the IIP aviation mission continues. According to this metric, satellite reconnaissance is the primary method for iceberg detection and has been since 2019. However, it is important to note the current difficulties in achieving criteria for iceberg deletion using satellite imagery alone.

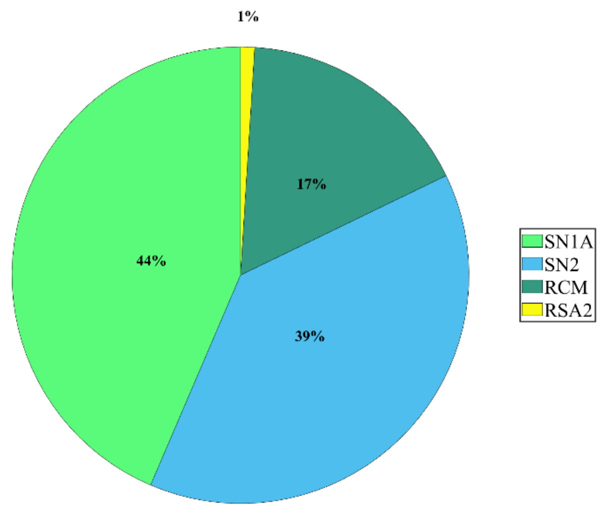

Figure 4.8. Percentage of total frames analyzed by satellite at IIP.

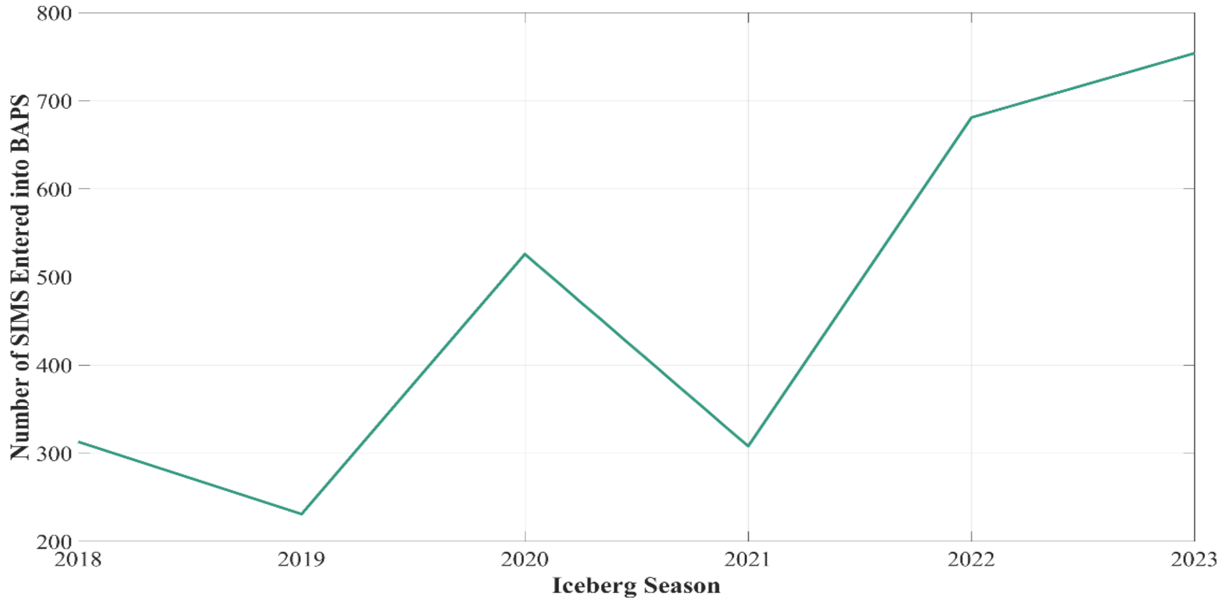

Figure 4.9. Frames analyzed each year by IIP satellite analysts.

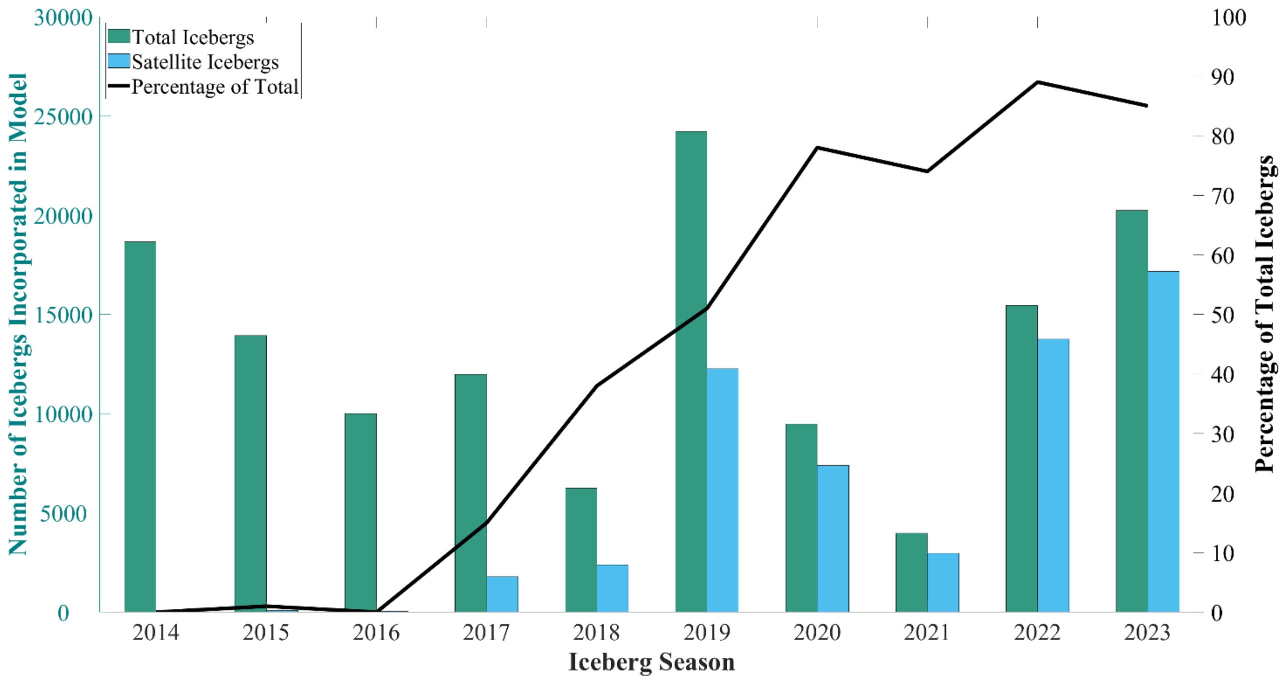

Figure 4.10. Number and percentage of icebergs detected by satellite between 2014 and 2023.

4.6.4 Northern Survey

In December 2022, IIP conducted a satellite Northern Survey between 55°N and 70°N along the coast of Labrador, east coast of Baffin Island, and southwestern Baffin Bay. The goal was to estimate the "upstream" iceberg population that could drive aerial reconnaissance decision-making in the early part of IIP's iceberg reconnaissance season.

The survey investigated 26 RCM images from 14 to 18 December 2022, detecting a total of 299 icebergs. Analysis distilled these total detections down to 81 individual icebergs, as seen in **Figure 4-11**. Of these icebergs, 15 were detected along the coast of Greenland drifting north in the west Greenland current, while the remaining 66 icebergs were observed in the survey area. Within the survey area, 79% of the icebergs were detected in gray-white to first-year sea ice. Sea ice helps to insulate icebergs from ocean waves which quickly deteriorate them. For that reason, these icebergs were deemed the most likely to drift south through the winter, and potentially into shipping lanes, with the movement of the sea ice.

IIP's satellite analysts continue to refine the methodology for repeatable Northern Survey results year to year, building a data set that may be useful in correlating season severity (number of icebergs detected south of 48°N) with icebergs detected in a Northern Survey. The data collected since IIP started implementing satellite analysis in 2017 can be seen in **Figure 4.12**. Continuing to build a comprehensive data set may be useful in the future for attempting to predict season severity several months before the peak of the iceberg season.

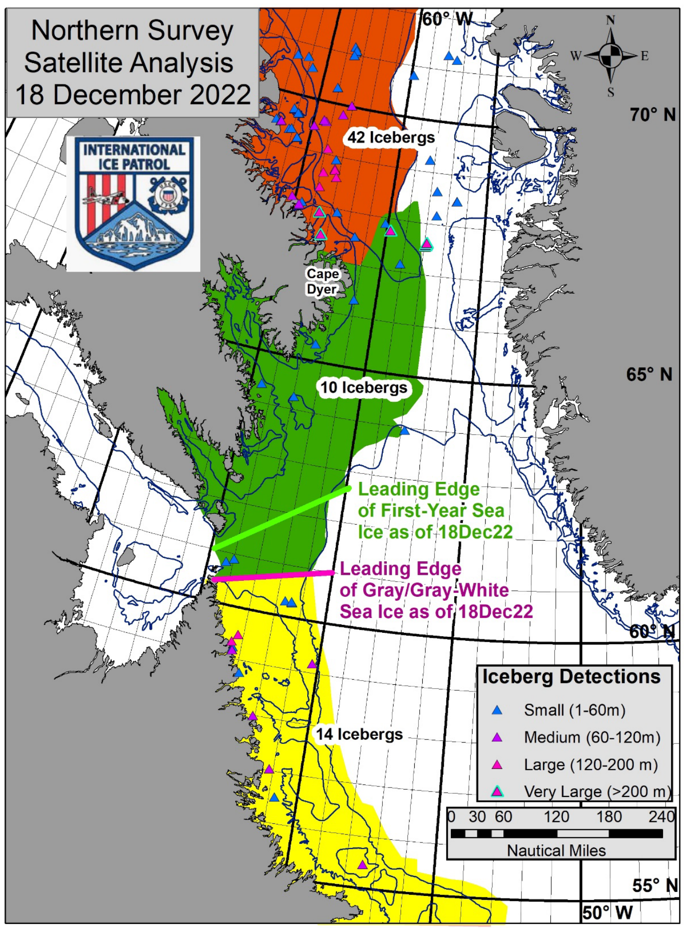

Figure 4.11. Results of the December 2022 Northern Survey. Iceberg data collected using the Canadian Space Agency's (CSA) Radarsat Constellation Mission (RCM) satellite. The reconnaissance area is divided into four iceberg populations: yellow indicates icebergs free of sea ice; green indicates icebergs within gray-white to first-year sea ice; red represents icebergs within other thicker sea ice; and those without color are assumed to be flowing north along the West Greenland current. Seventy-nine percent of icebergs were detected within gray-white to first year sea ice.

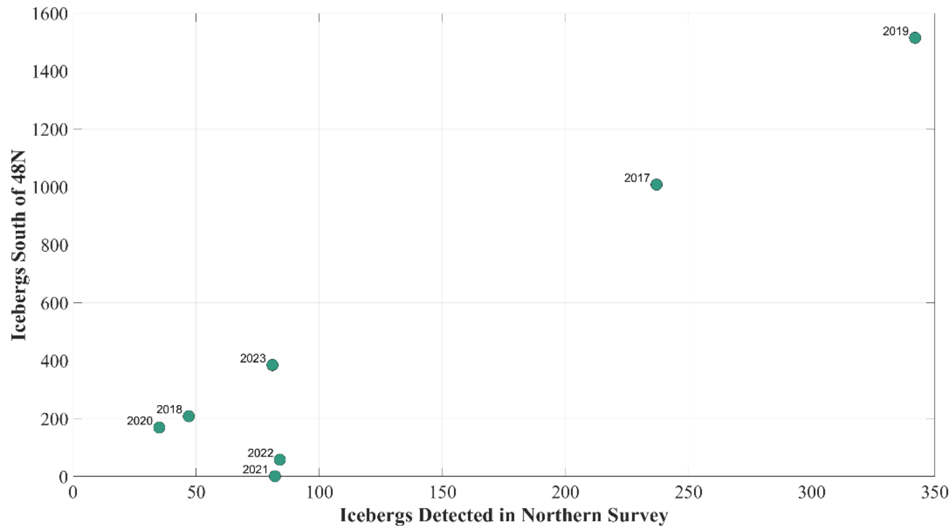

Figure 4.12 Comparison between iceberg detections in Northern Surveys and iceberg crossings South of 48 N between 2017 and 2023.

4.7 Other Reconnaissance Activities

4.7.1 NAIS Collaboration

IIP continued to leverage its NAIS partnership with CIS in 2023. IIP coordinated flight plans with CIS during periods when IRDs were not deployed to St. John's. While CIS does contract flights year-round, only a single flight was contracted to PAL Aerospace during the 2023 Ice Year. **Figure 4.13** depicts the hours flown this year and the past five years.

4.7.2 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 the vicinity of the aircraft, and direct call outs 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 2023 season, IRDs made 17 general sécurité broadcasts and eight direct vessel callouts. Out of all vessels contacted directly, 75% responded to radio callouts.

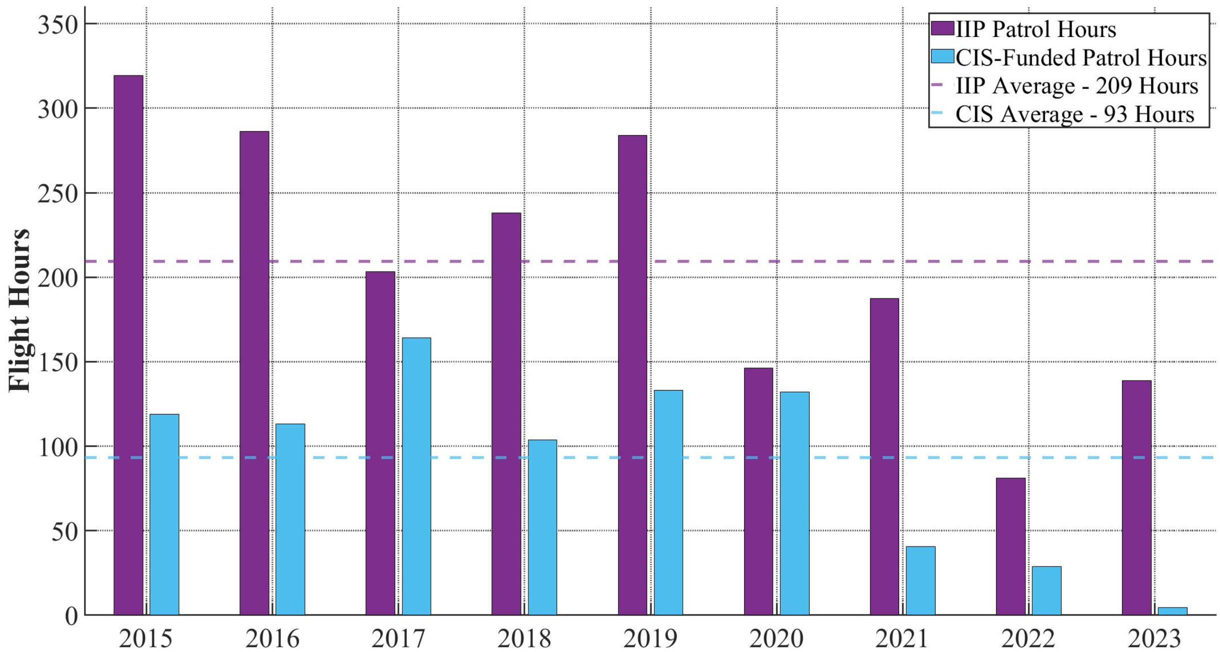

Figure 4.13. NAIS flight hours, a combination of IIP patrol hours and CIS funded PAL Aerospace patrol hours compared to the previous 10-year average. More icebergs south of 48°N may require increased reconnaissance efforts.

5 Semi-Monthly Iceberg Charts

5.1 Chart Description

The NAIS-65 Iceberg Chart is released daily by IIP (in the active Iceberg Season) and CIS (generally outside of the active Iceberg Season). It depicts the iceberg limit which delineates the iceberg population from open water, the estimated distribution of icebergs within this limit, and the sea ice limit.

The iceberg limit is comprised of the following: the iceberg limit over the Grand Banks and east of Newfoundland and Labrador (**Figures 5.1** through **5.24**, *solid magenta line to the south and east of Newfoundland and Labrador*), the iceberg limit to the west of Newfoundland (western limit, *solid magenta line within the Strait of Belle Isle and the Gulf of St. Lawrence*), and the Greenland iceberg limit (*dotted magenta solid line south of Greenland*, from DMI). The Grand Banks iceberg limit is the primary component of the chart, as it affects transatlantic navigation, and IIP allots the most detection and monitoring efforts to ensure its accuracy and reliability.

The western iceberg limit is drawn when icebergs drift south into the Strait of Belle Isle and the Gulf of St. Lawrence, which is a heavily trafficked area. If icebergs begin to approach Anticosti Island, IIP may elect to split the western limit into two segments to account for icebergs to the north and south of the island. Rarely, when icebergs drift south of the line between Port aux Basques, Newfoundland and the southeastern tip of Anticosti Island, IIP may draw the iceberg limit across Cabot Strait between Newfoundland and Cape Brenton Island. This would likely adversely affect shipping traffic, as vessels headed to the St. Lawrence Seaway would have to cross the iceberg limit.

The Greenland iceberg limit (termed the "estimated iceberg limit") is provided by DMI to IIP and CIS semi-weekly. DMI uses an automated approach to detect icebergs around Greenland and does not model an individual iceberg's drift and deterioration as IIP does. For this reason, the Greenland iceberg limit is assigned a lower level of confidence and reported in the NAIS iceberg warning products as estimated. The Greenland iceberg limit affects primarily specialized ice navigators who take on their own risk by crossing it.

The sea ice limit (see **Figures 5.1** through **5.24,** *dashed magenta line*) is provided daily by CIS and delineates ice-covered from ice-free waters. The sea ice limit provides no additional information on sea ice concentration or stage of development and is meant only as a rough indicator of the presence or absence of sea ice.

Finally, the estimated distribution of icebergs is depicted as the estimated number of icebergs per square degree. IIP does not report the individual estimated locations of the icebergs in the database due to uncertainties associated with iceberg detection and modeling. The reported iceberg distribution should not be used for navigation.

It should be noted that IIP may report radar targets within the NAIS iceberg warning products. Radar targets are targets detected by spaceborne, aircraft, or vessel radars that were observed with low confidence (were indistinguishable as icebergs, vessels, or other targets). In the NAIS-65 chart, radar targets are depicted as small circles encompassing an "x". IIP attempts to minimize the number of radar targets reported and prioritizes reconnaissance to investigate and accurately classify them.

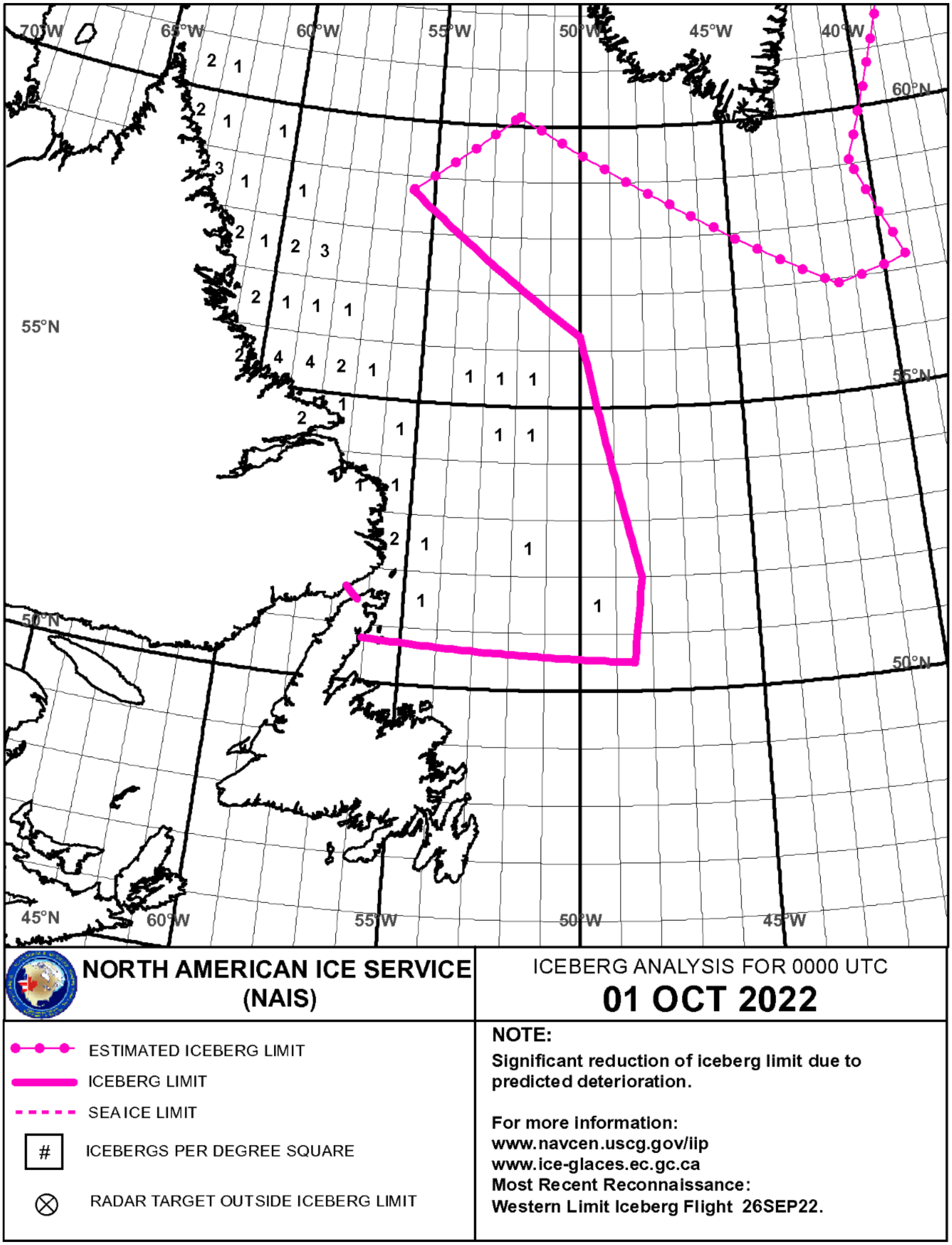

Figure 5.1. NAIS-65 Iceberg Chart from 1 October 2022

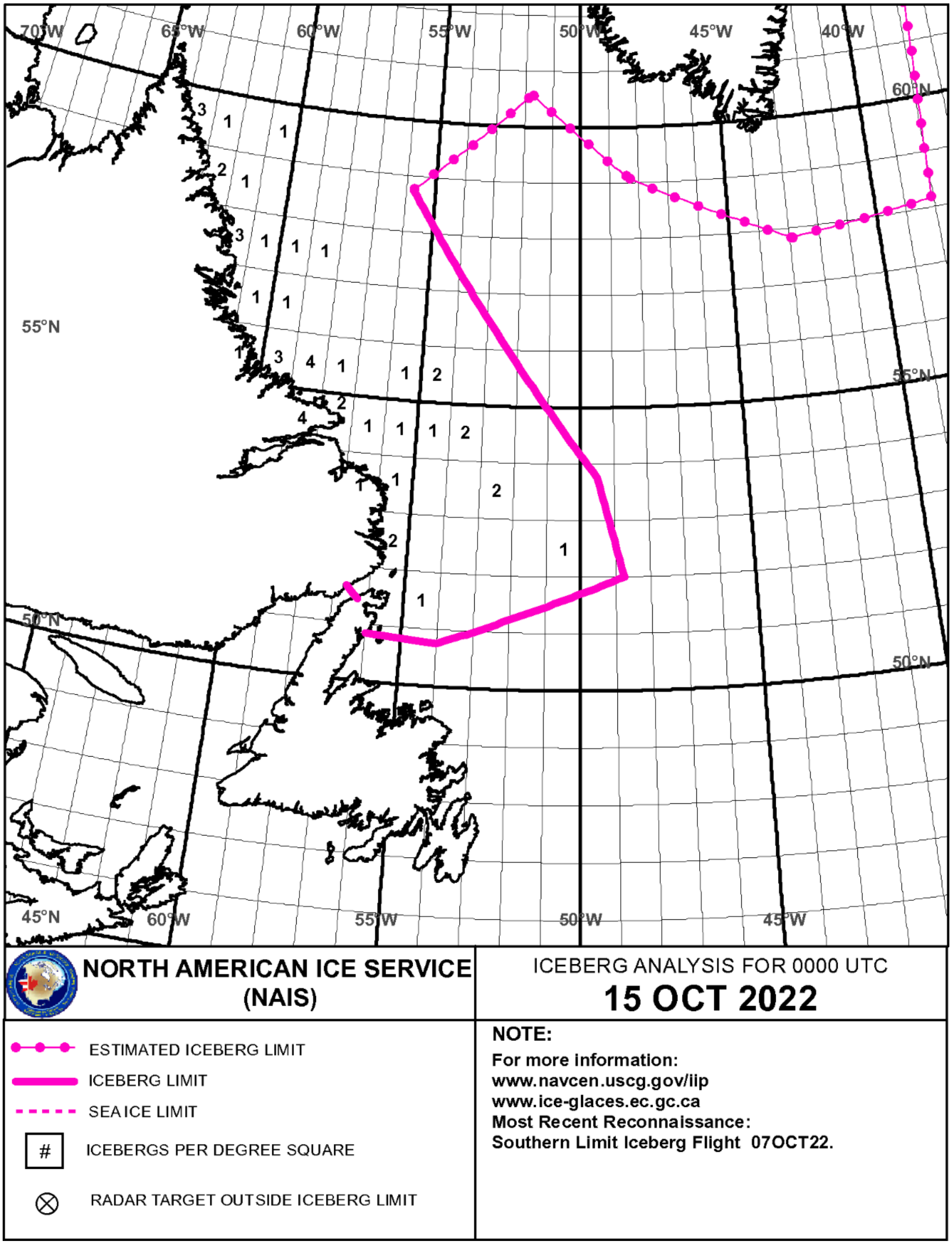

Figure 5.2. NAIS-65 Iceberg Chart from 15 October 2022

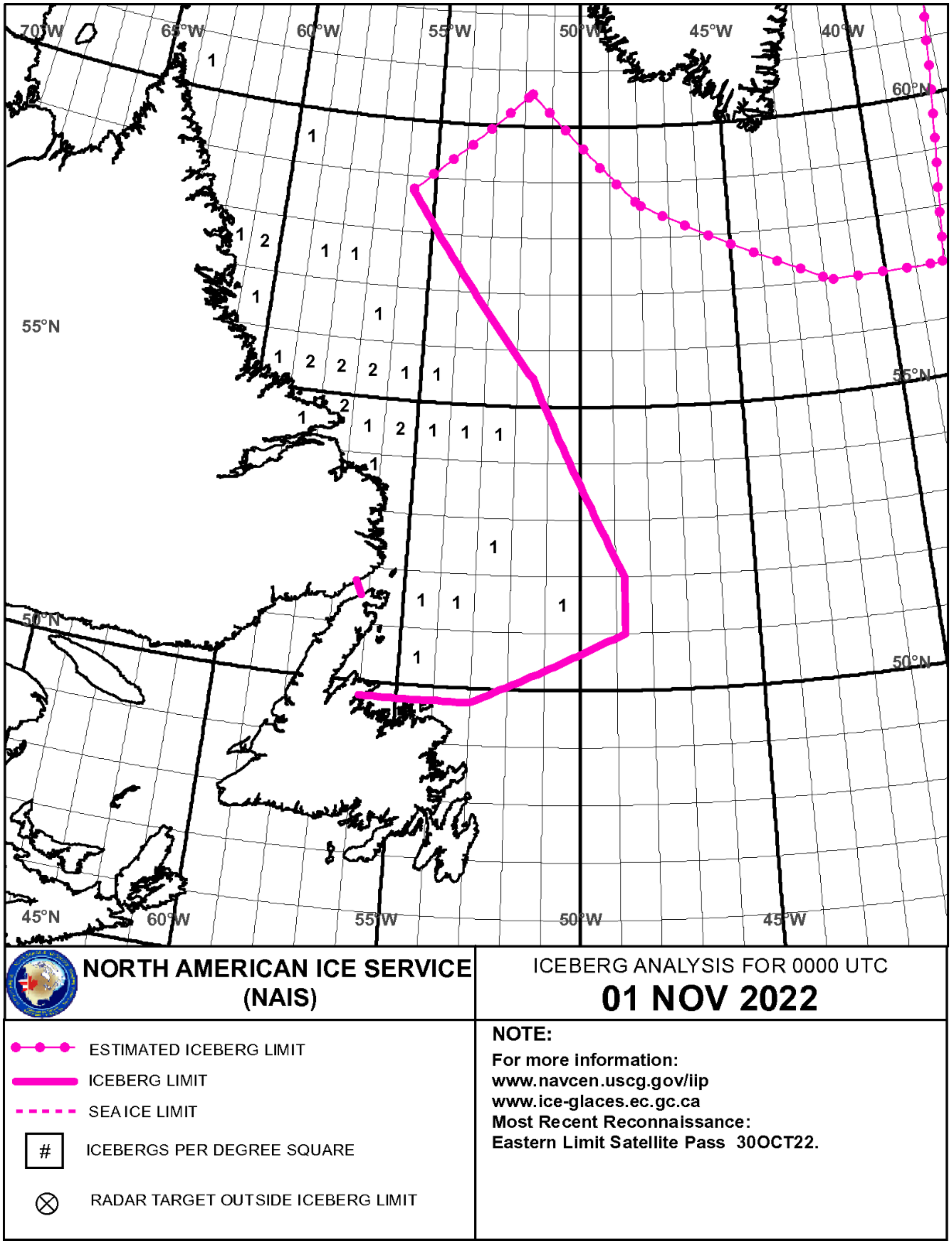

Figure 5.3. NAIS-65 Iceberg Chart from 1 November 2022

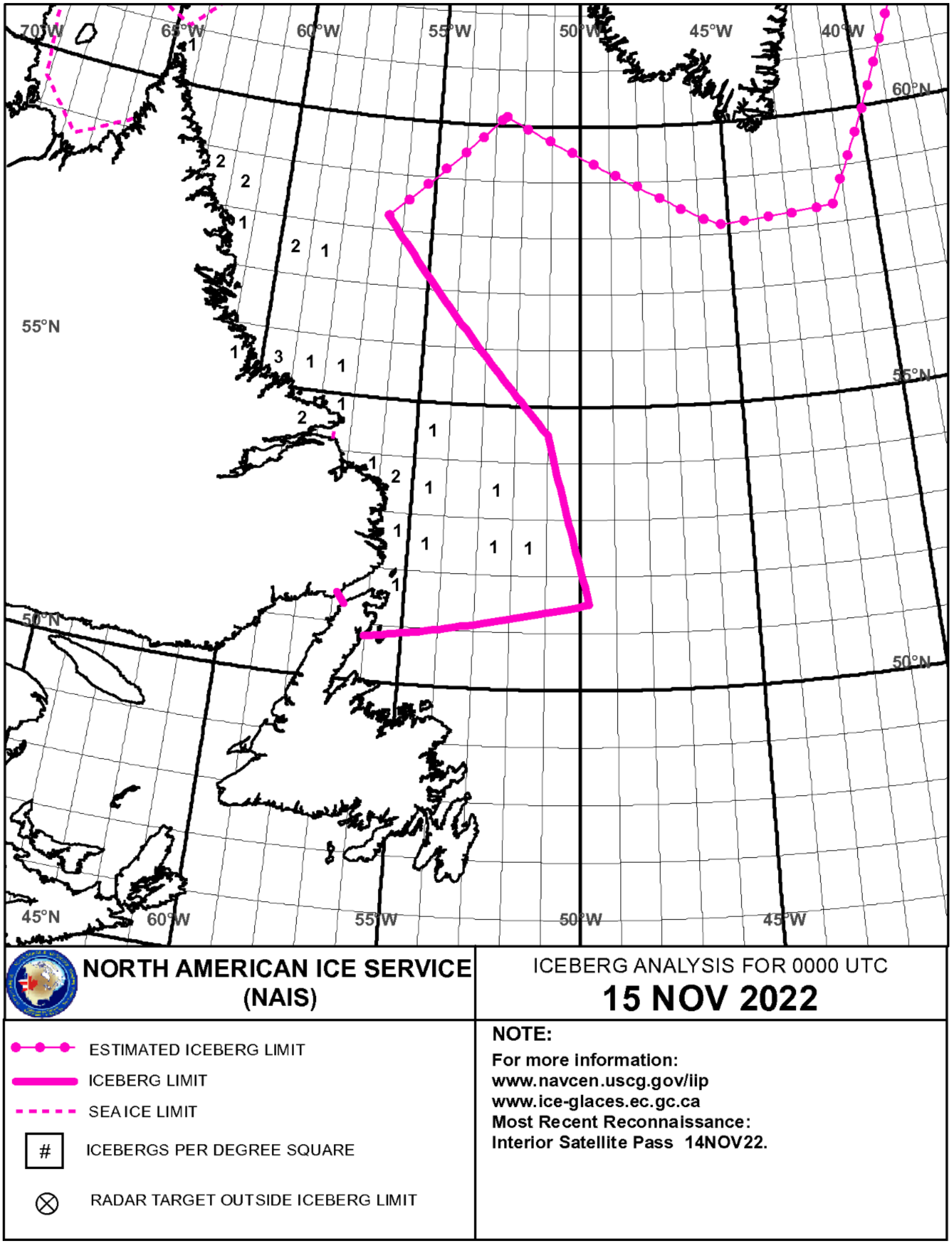

Figure 5.4. NAIS-65 Iceberg Chart from 15 November 2022

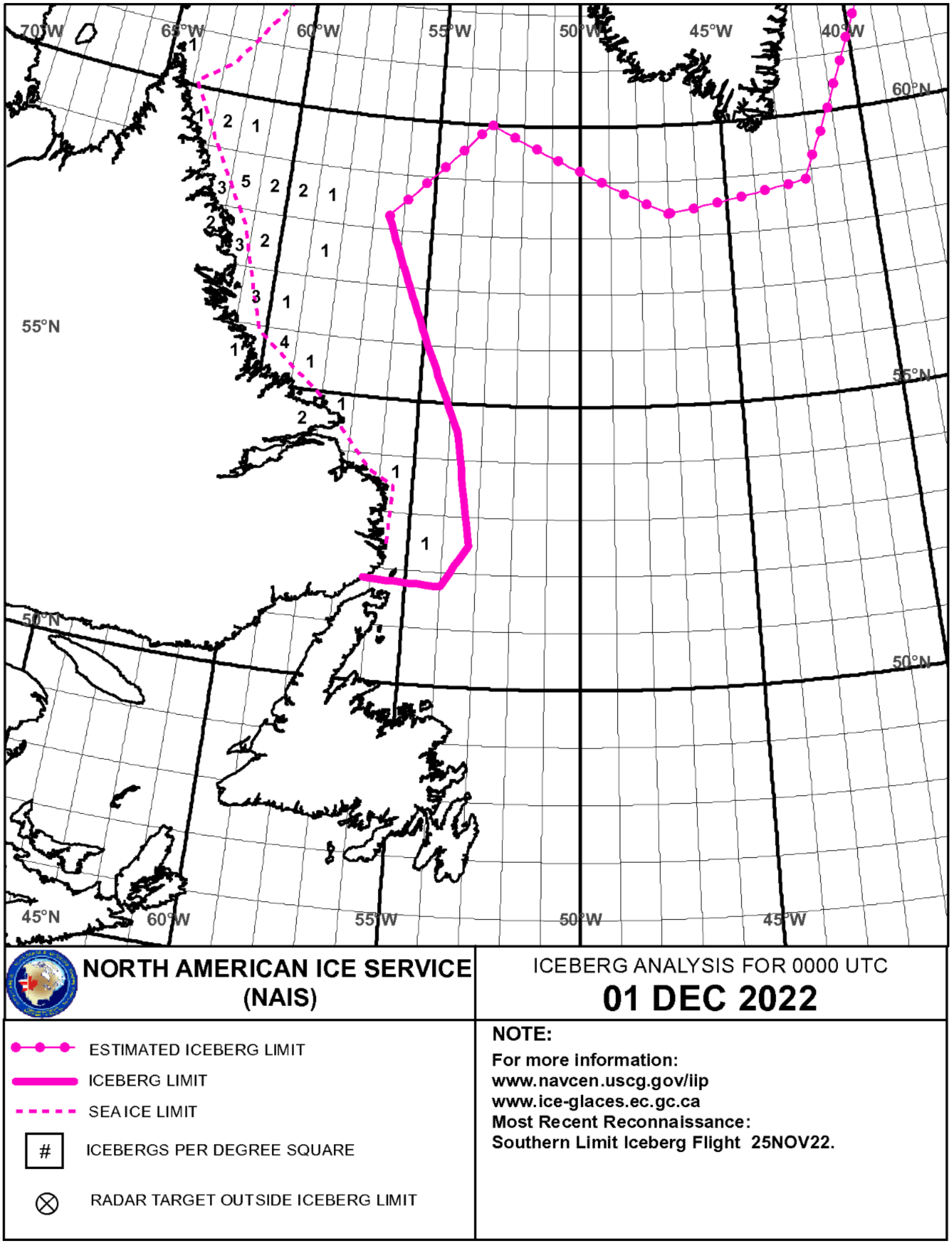

Figure 5.5. NAIS-65 Iceberg Chart from 1 December 2022

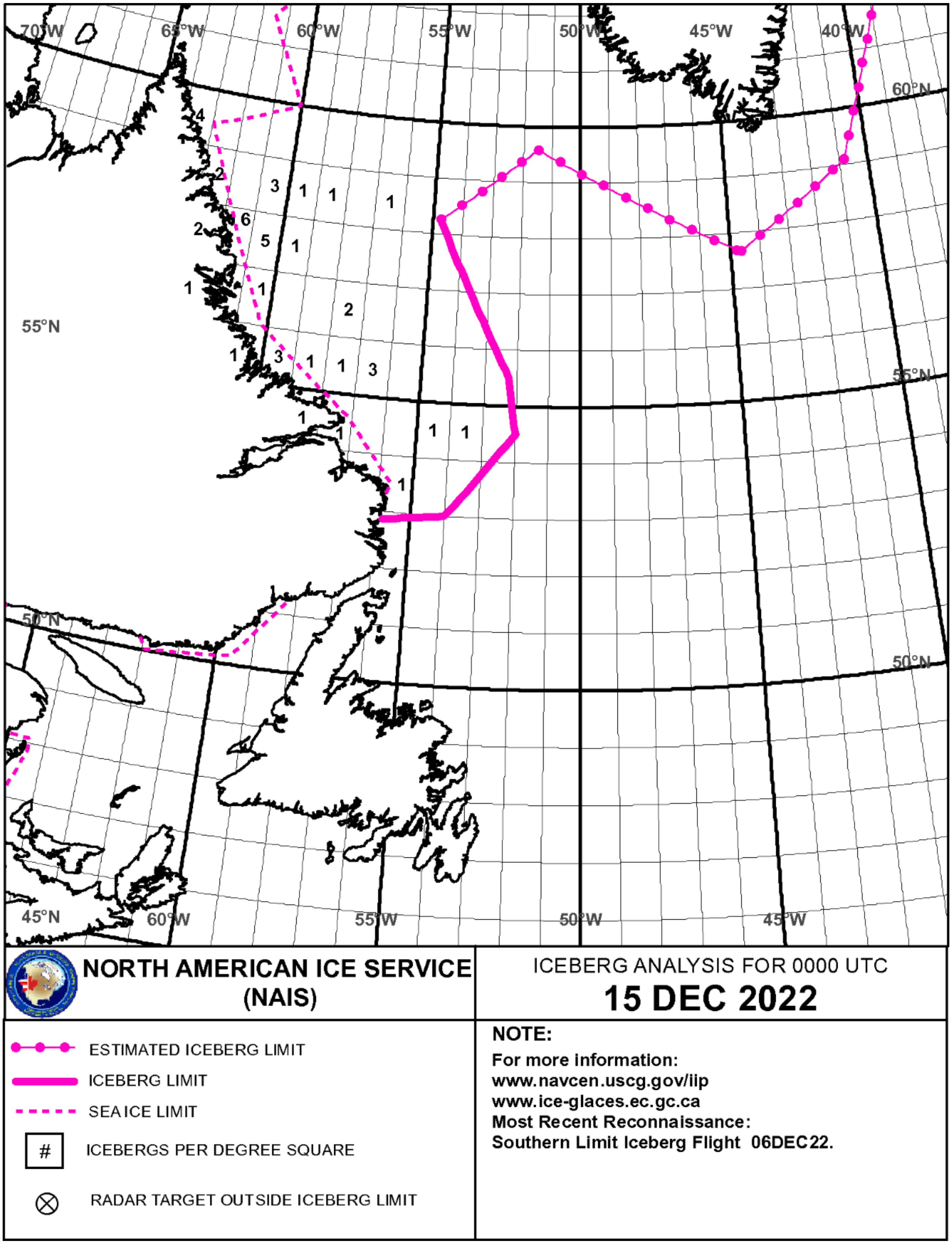

Figure 5.6. NAIS-65 Iceberg Chart from 15 December 2022

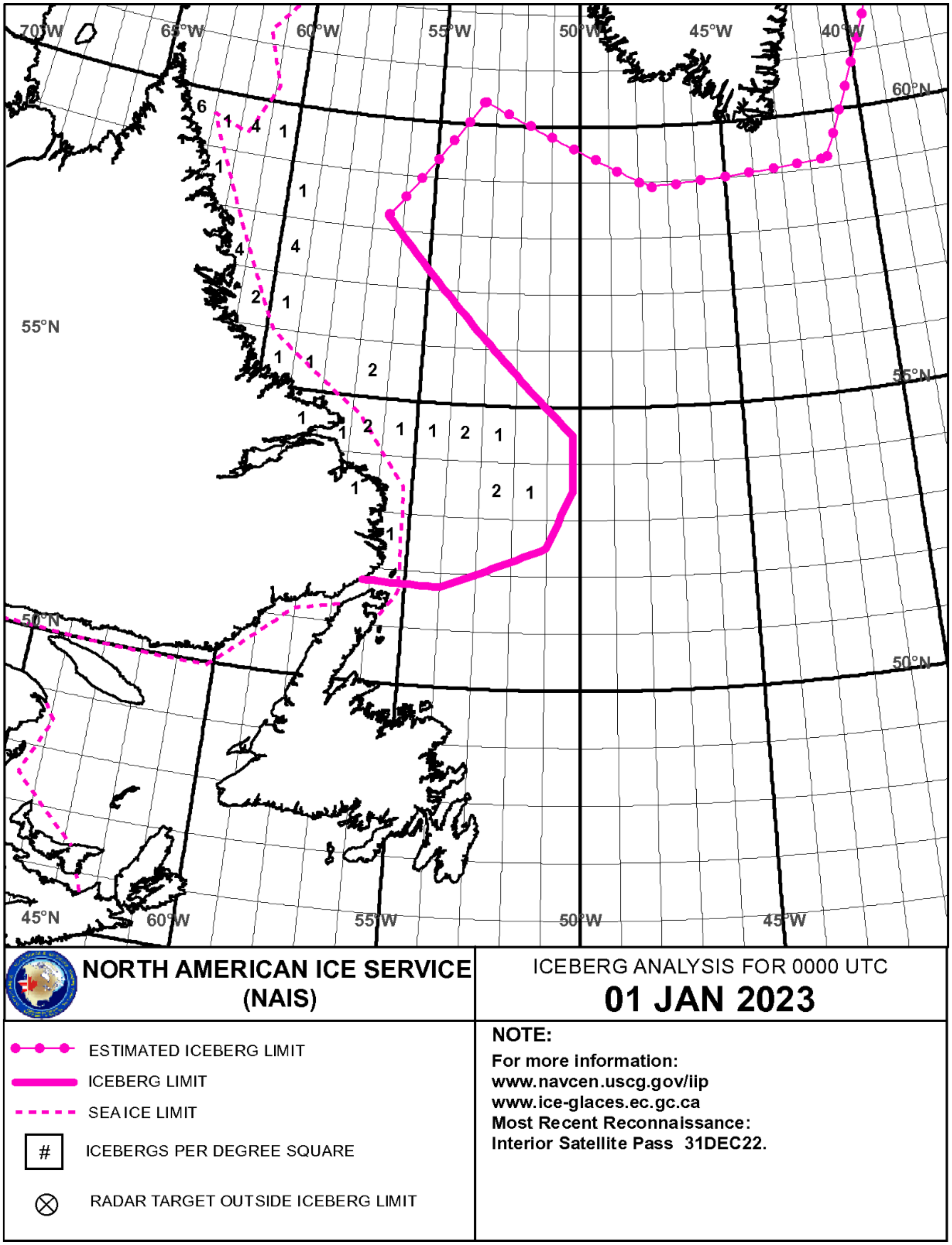

Figure 5.7. NAIS-65 Iceberg Chart from 1 January2023

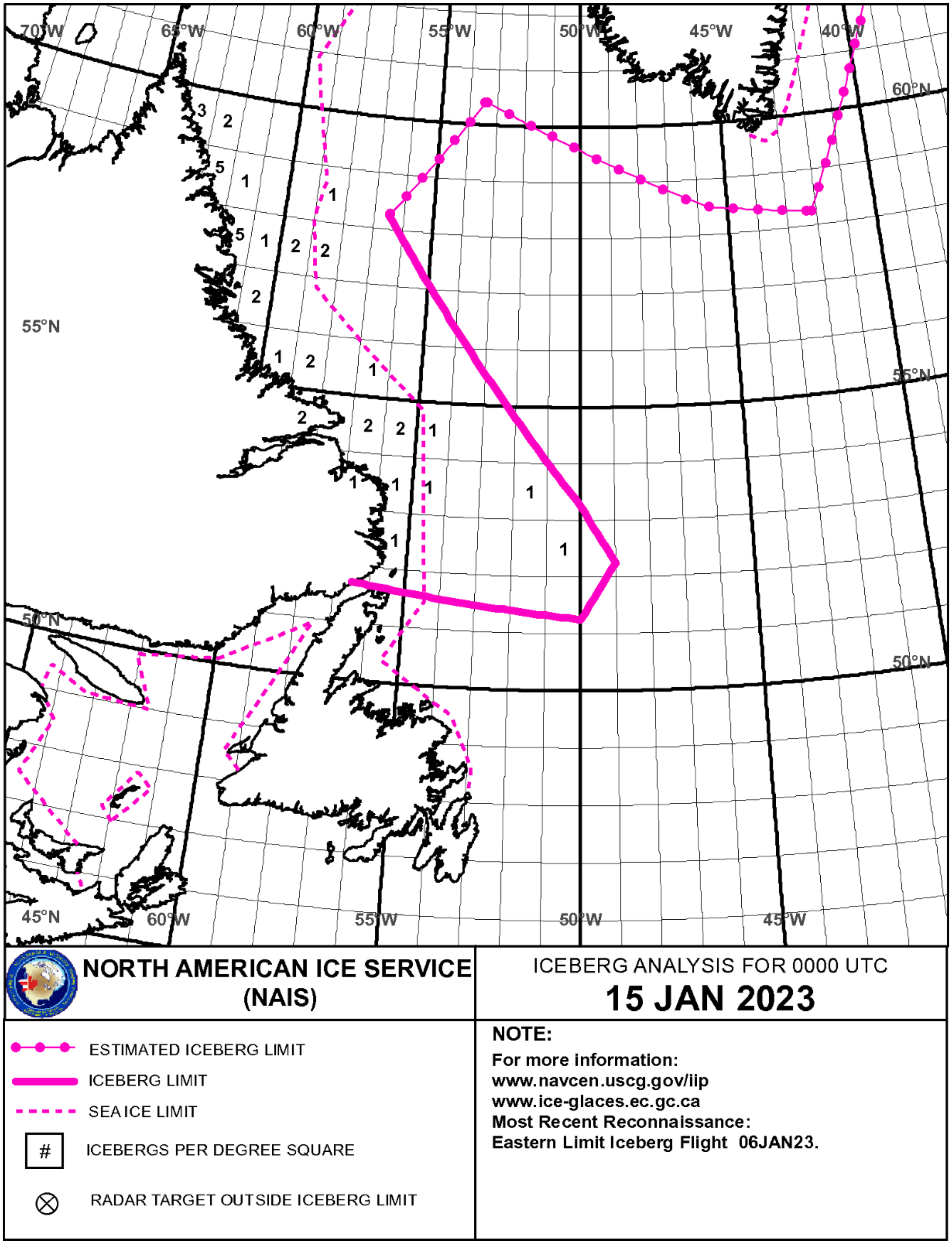

Figure 5.8. NAIS-65 Iceberg Chart from 15 January 2023

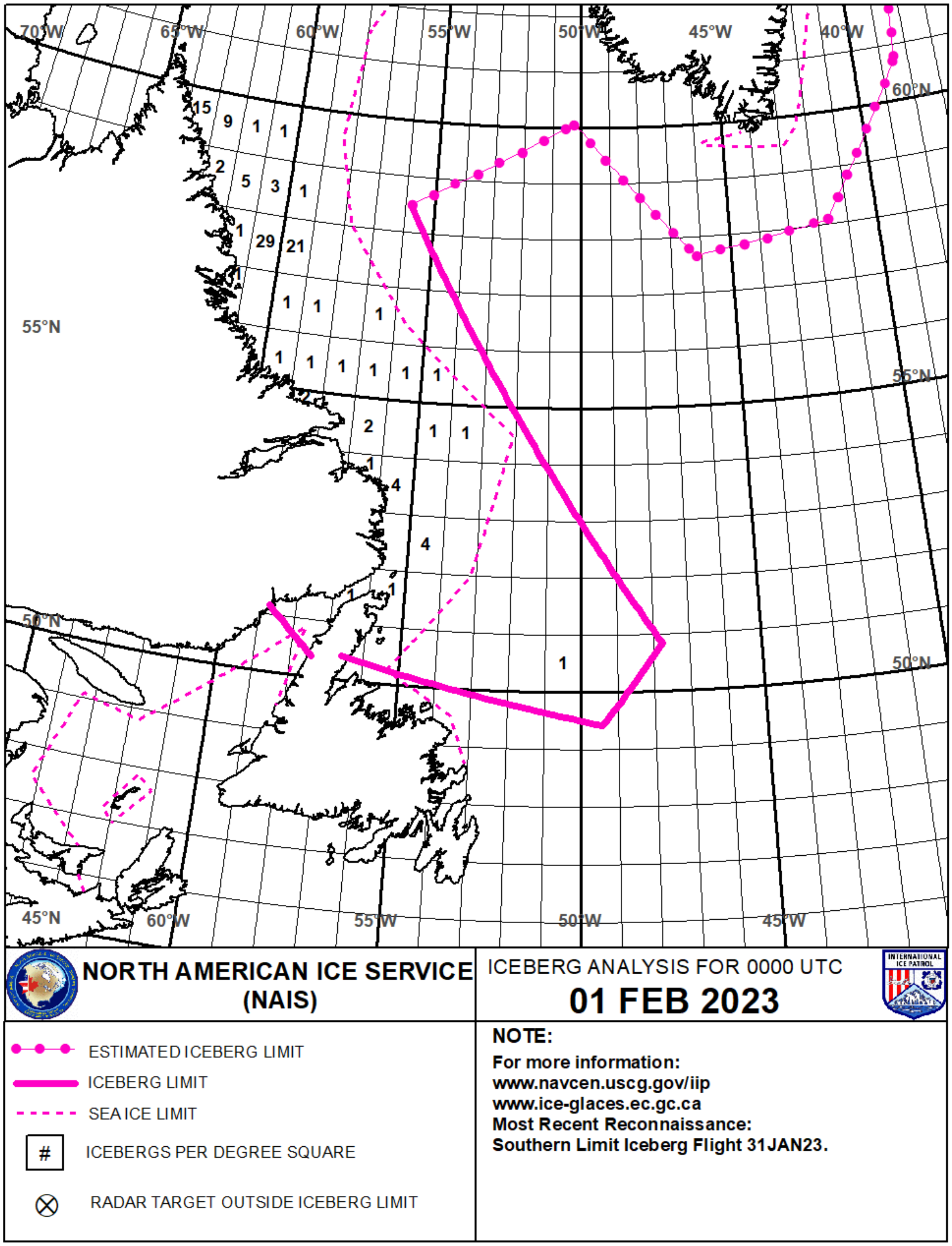

Figure 5.9. NAIS-65 Iceberg Chart from 1 February 2023

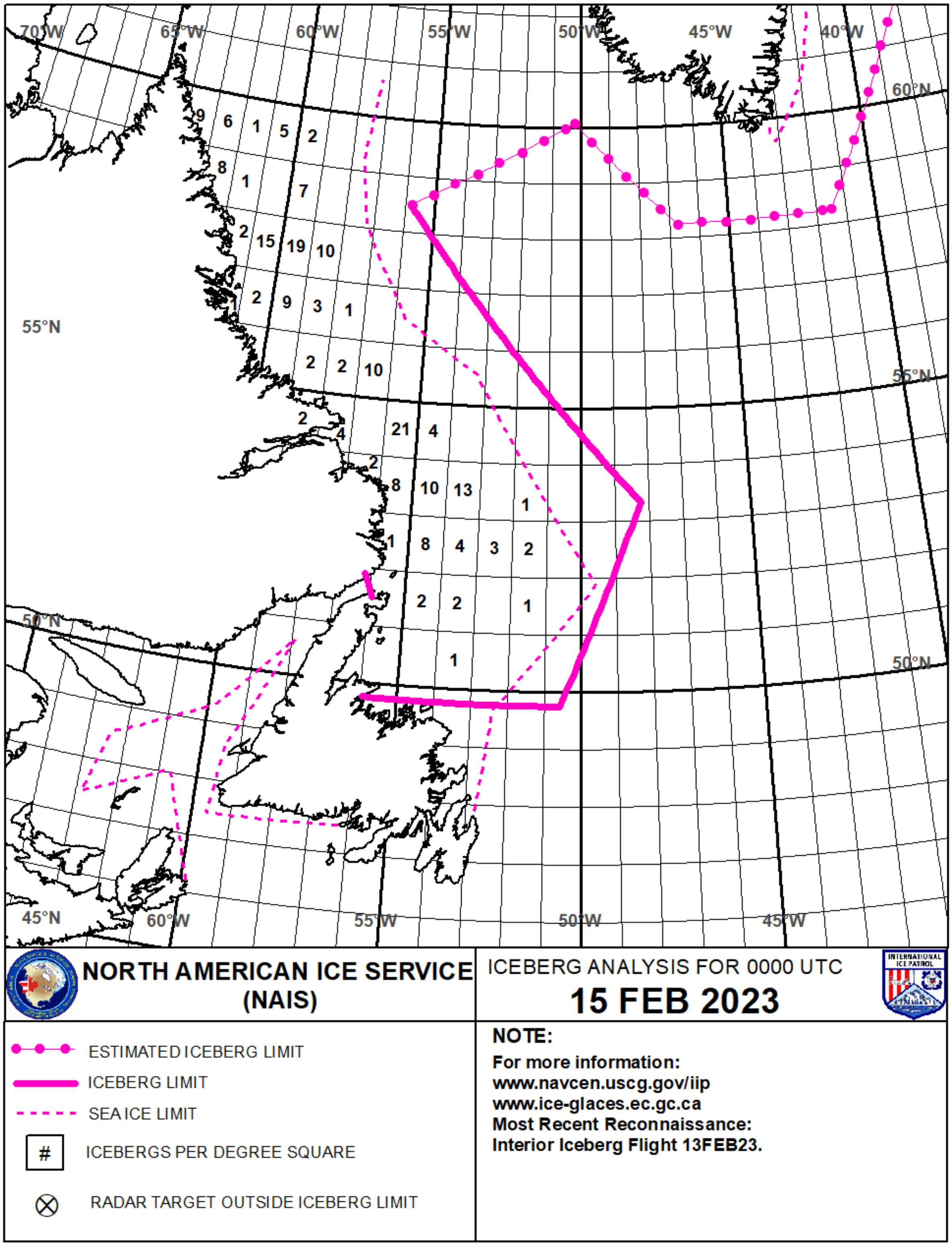

Figure 5.10. NAIS-65 Iceberg Chart from 15 February 2023

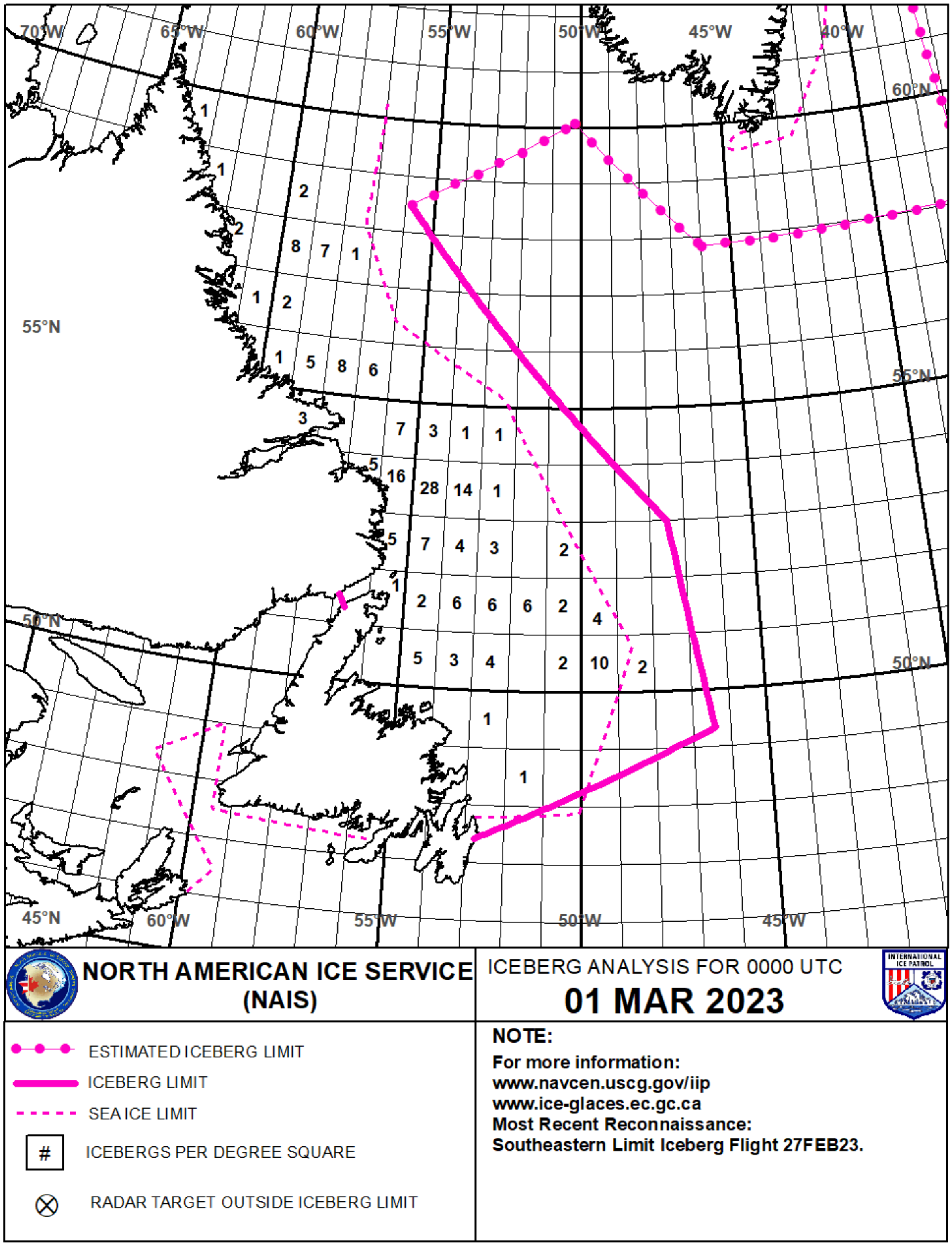

Figure 5.11. NAIS-65 Iceberg Chart from 1 March 2023

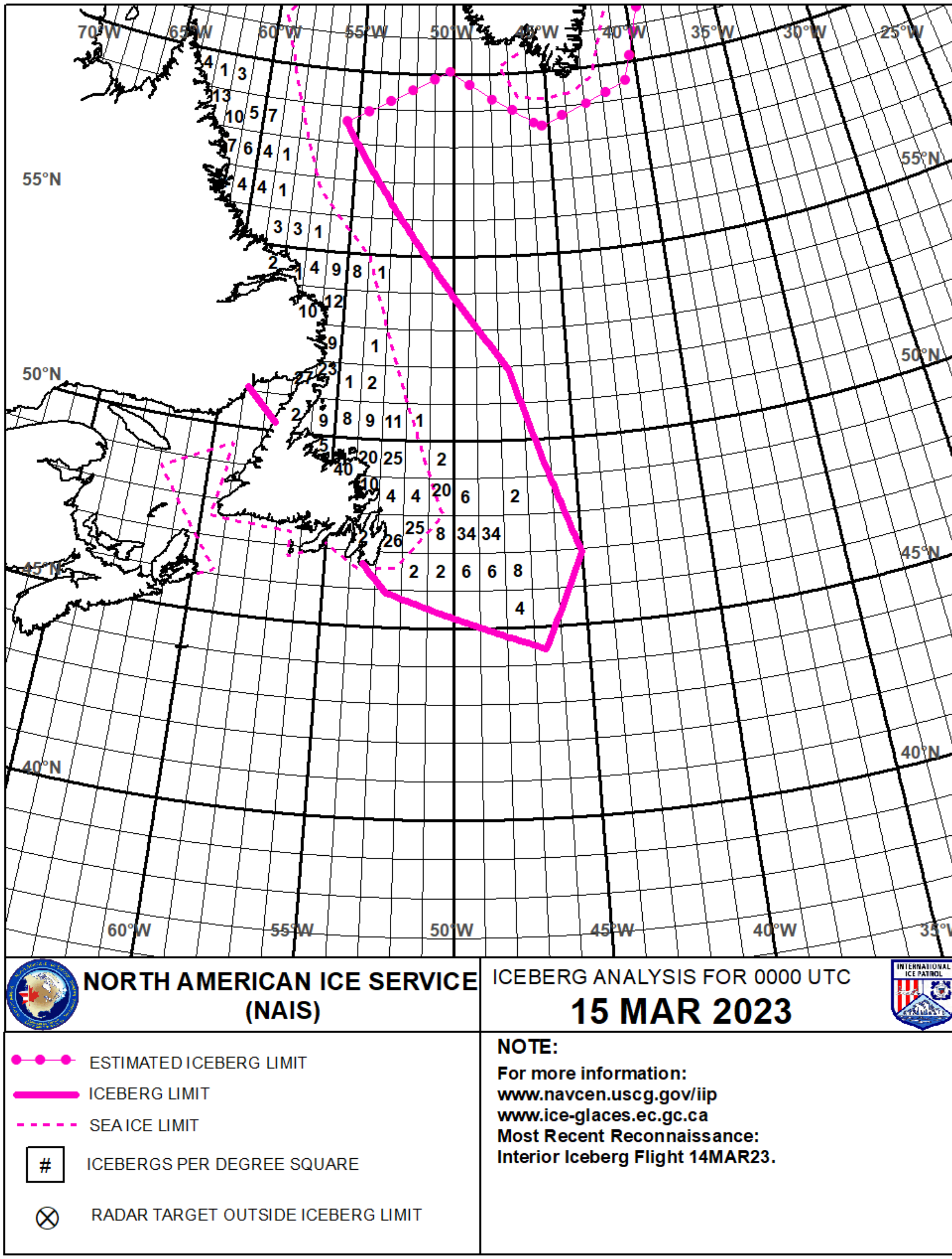

Figure 5.12. NAIS-65 Iceberg Chart from 15 March 2023

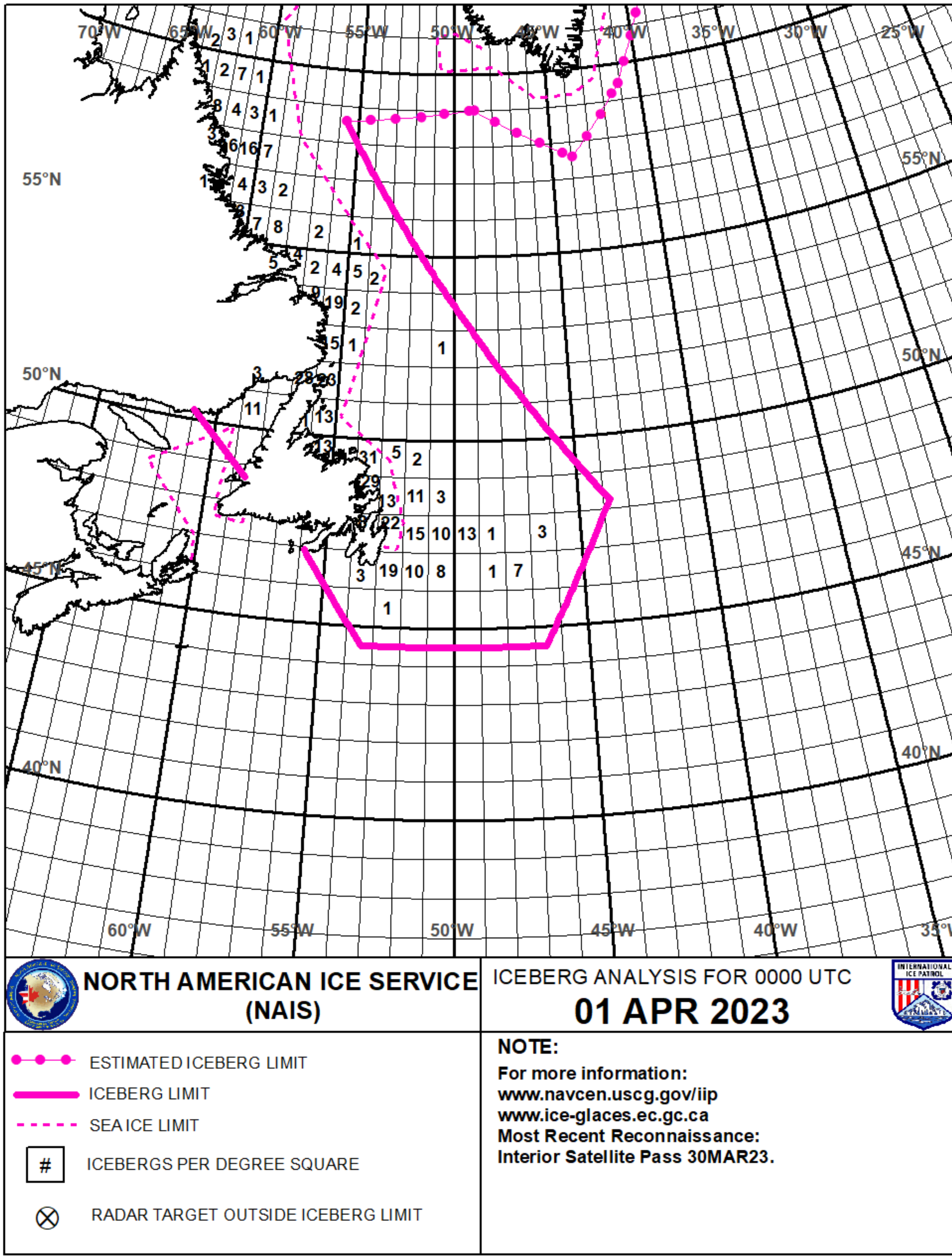

Figure 5.13. NAIS-65 Iceberg Chart from 1 April 2023

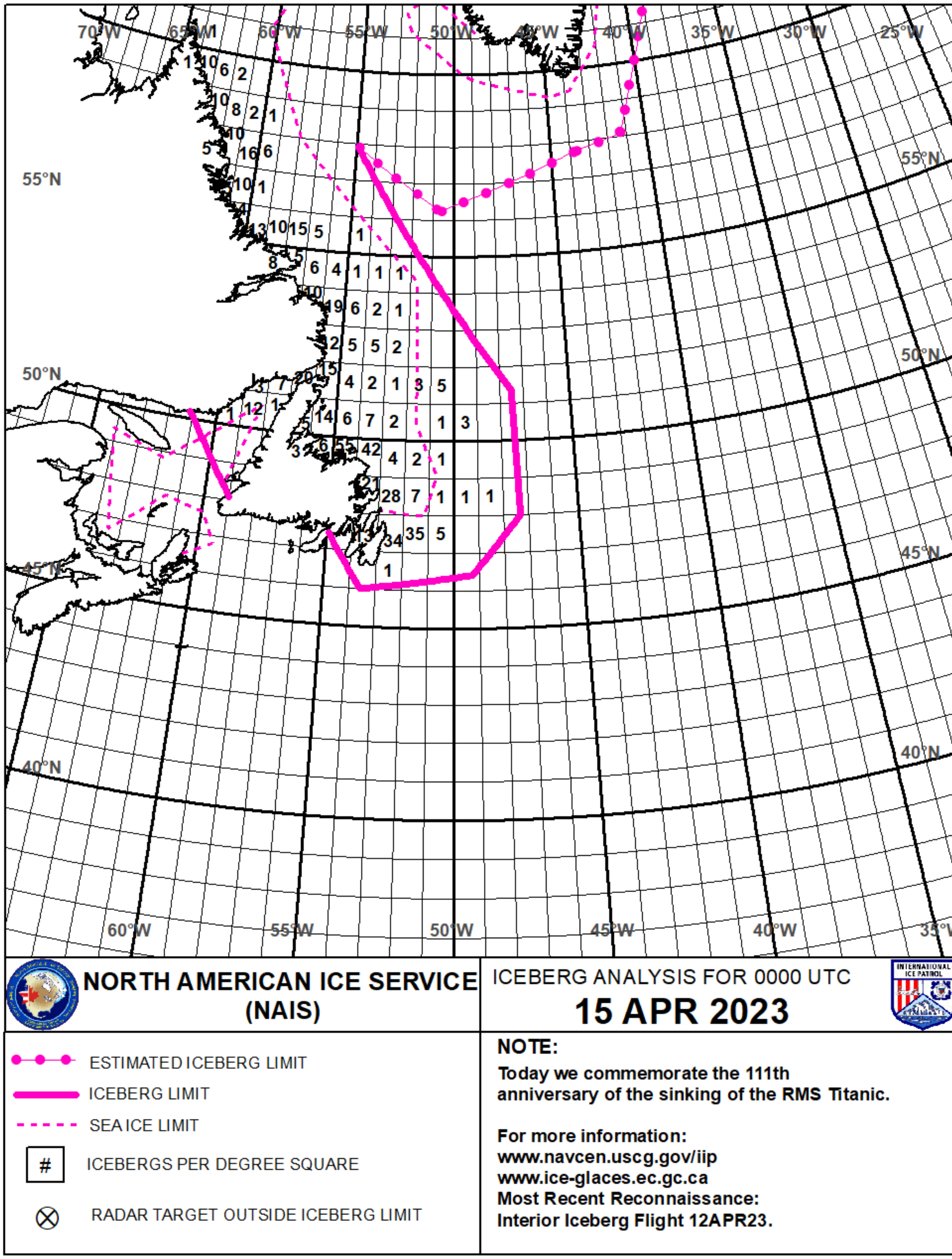

Figure 5.14. NAIS-65 Iceberg Chart from 15 April 2023

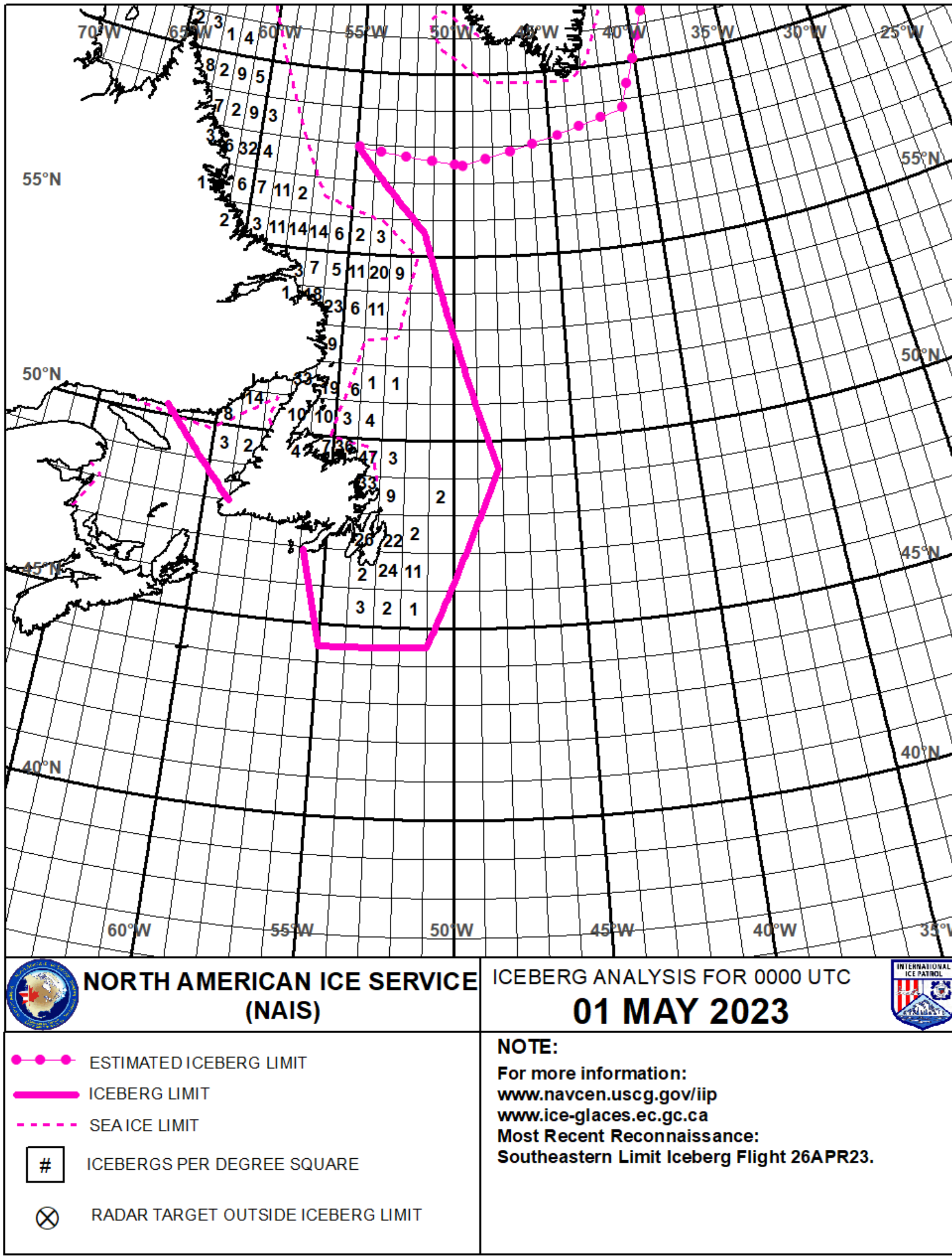

Figure 5.15. NAIS-65 Iceberg Chart from 1 May 2023

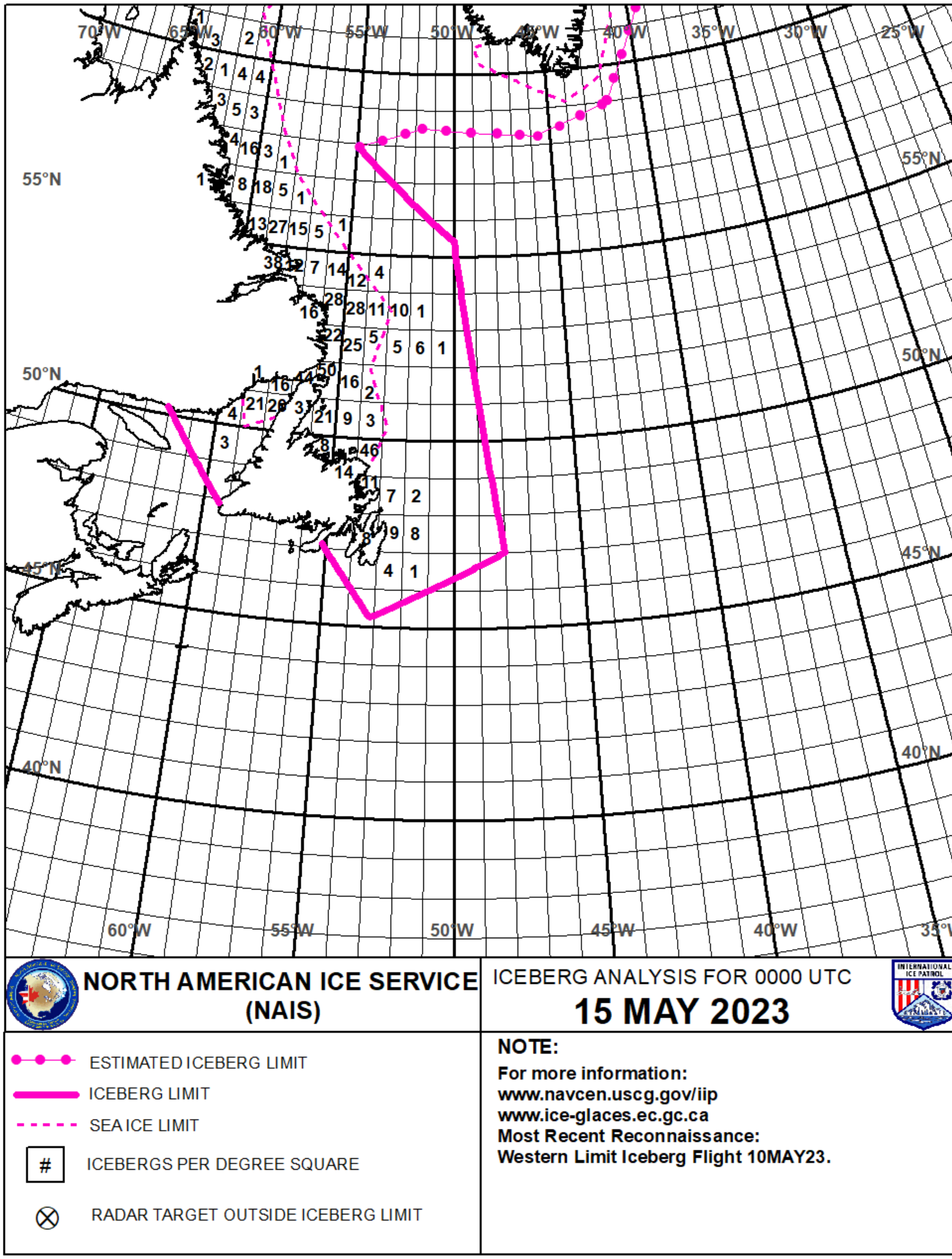

Figure 5.16. NAIS-65 Iceberg Chart from 15 May 2023

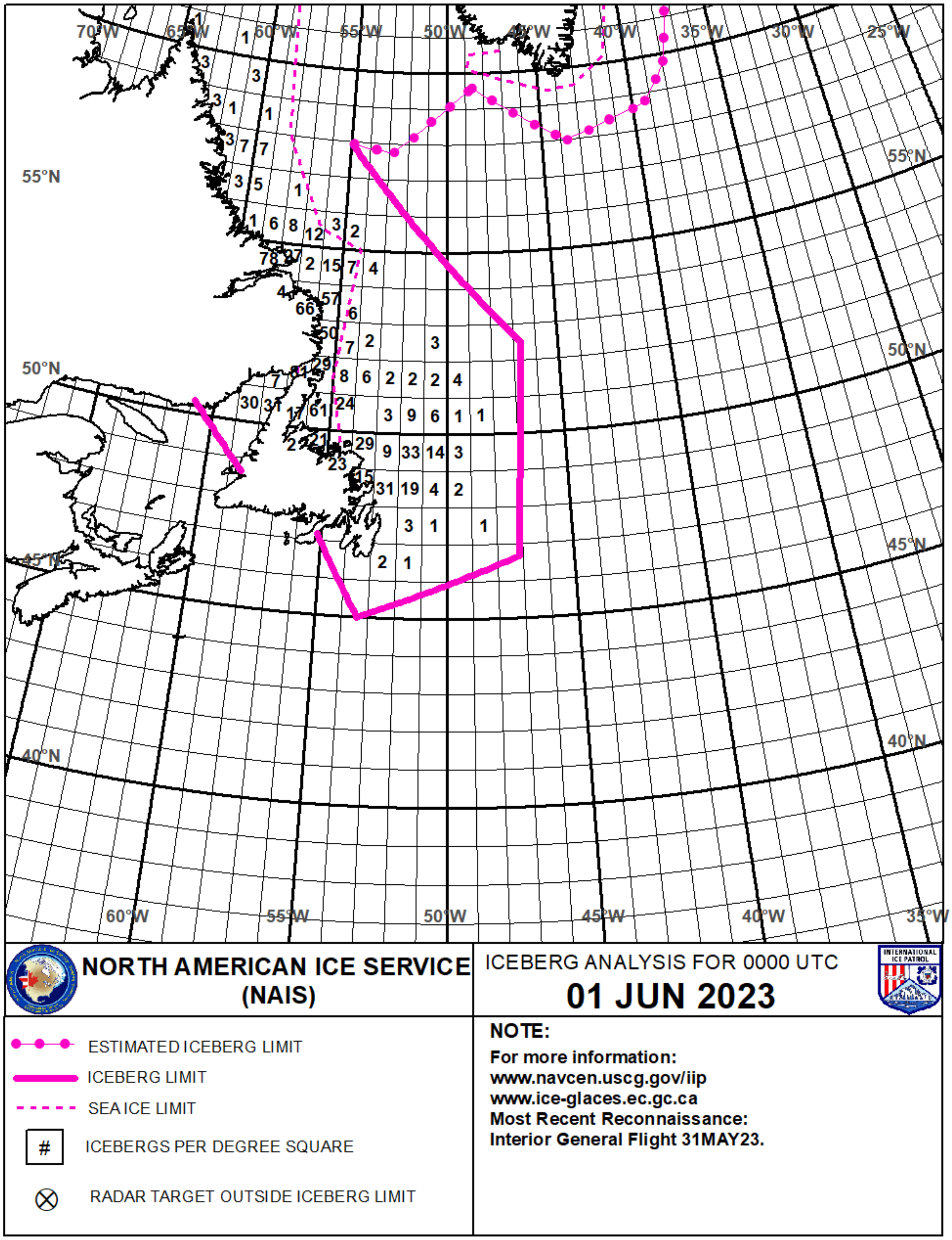

Figure 5.17. NAIS-65 Iceberg Chart from 1 June 2023

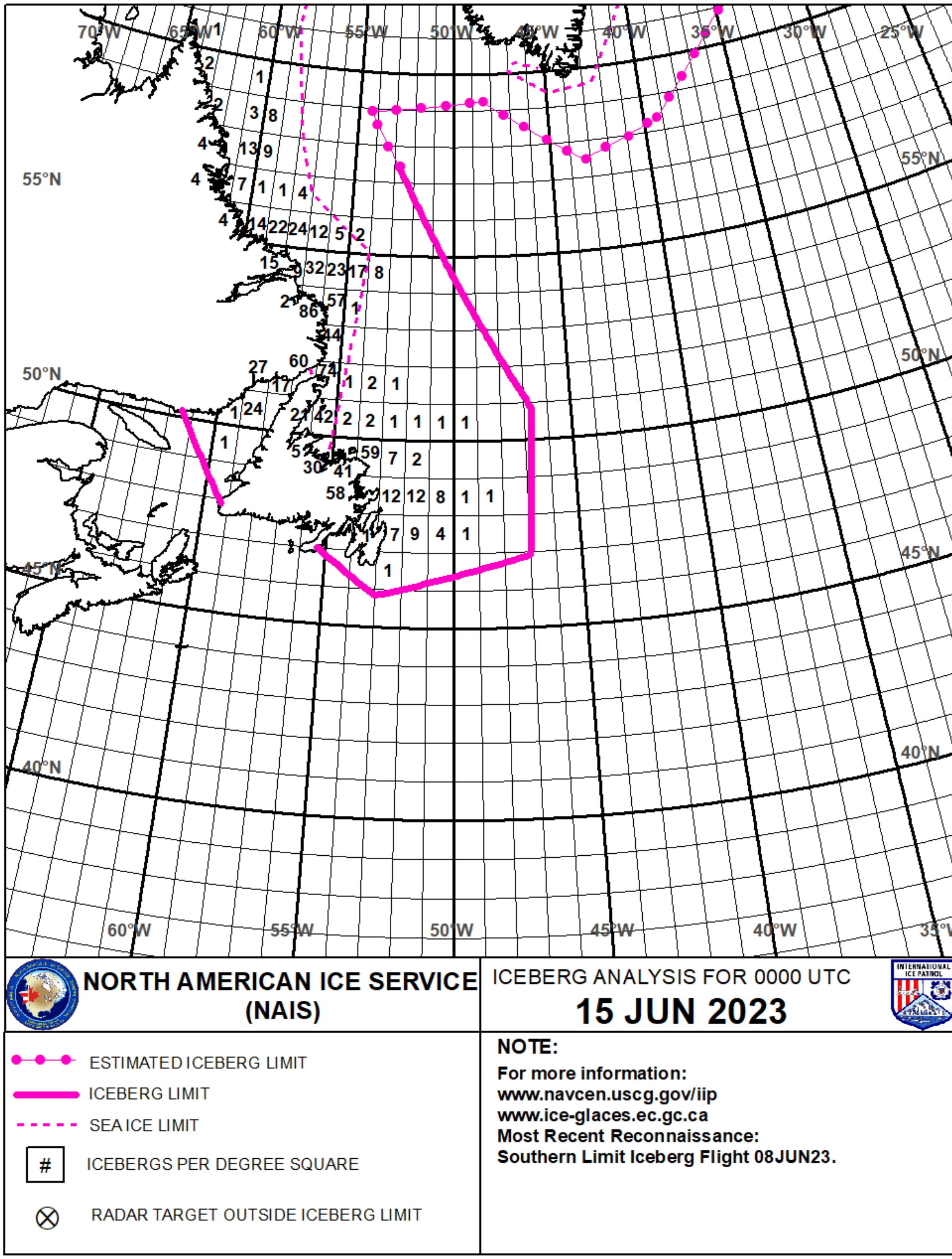

Figure 5.18. NAIS-65 Iceberg Chart from 15 June 2023

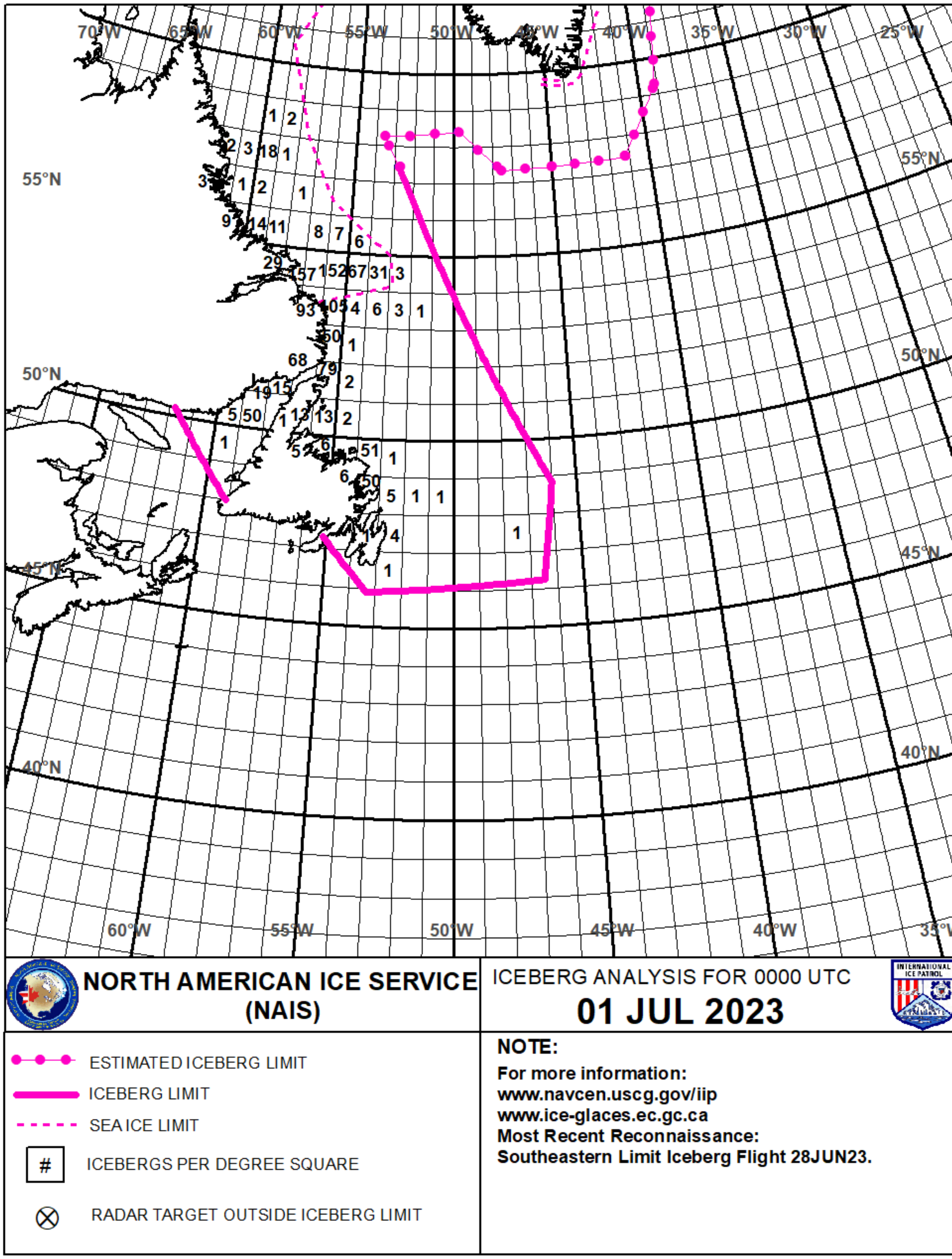

Figure 5.19. NAIS-65 Iceberg Chart from 1 July 2023

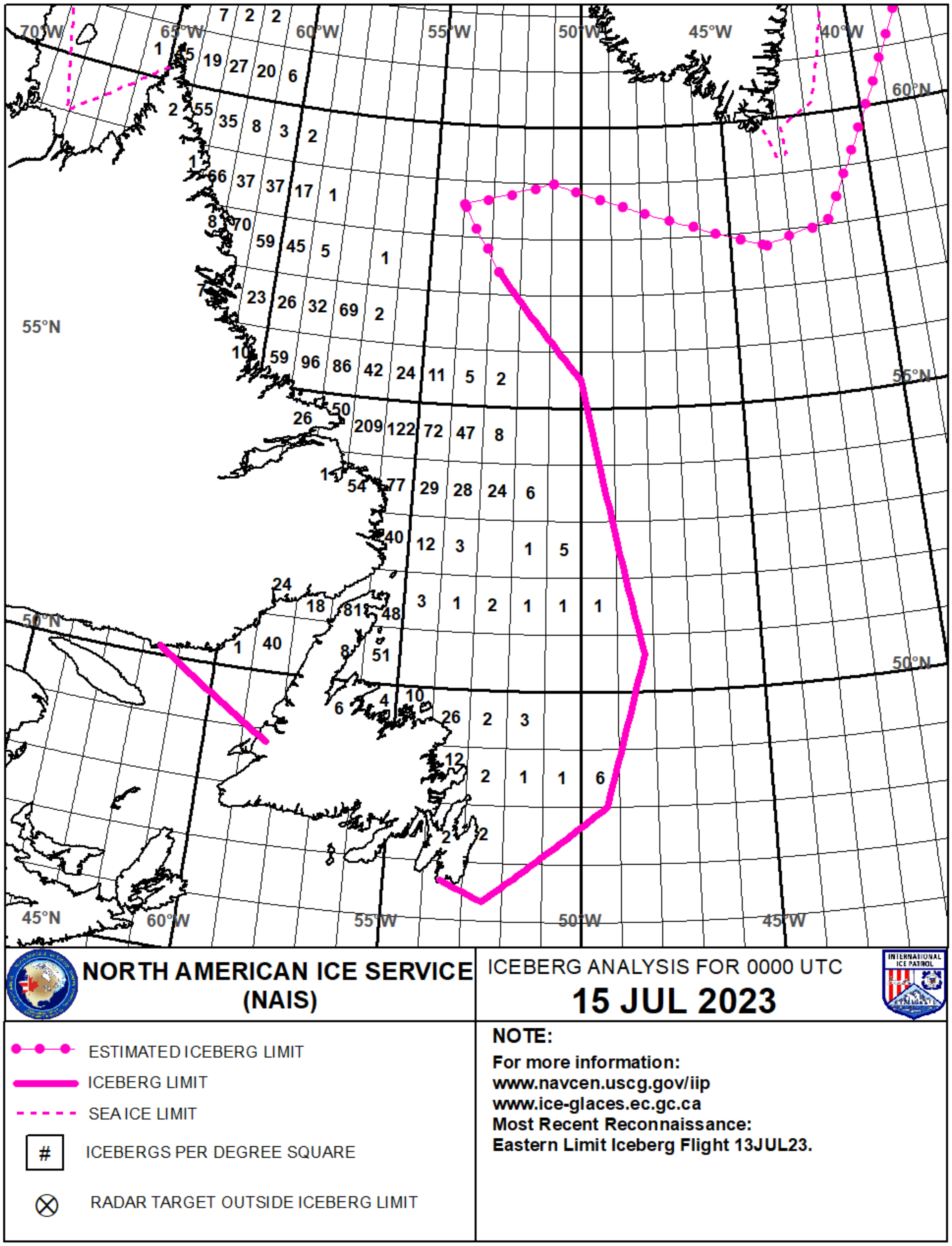

Figure 5.20. NAIS-65 Iceberg Chart from 15 July 2023

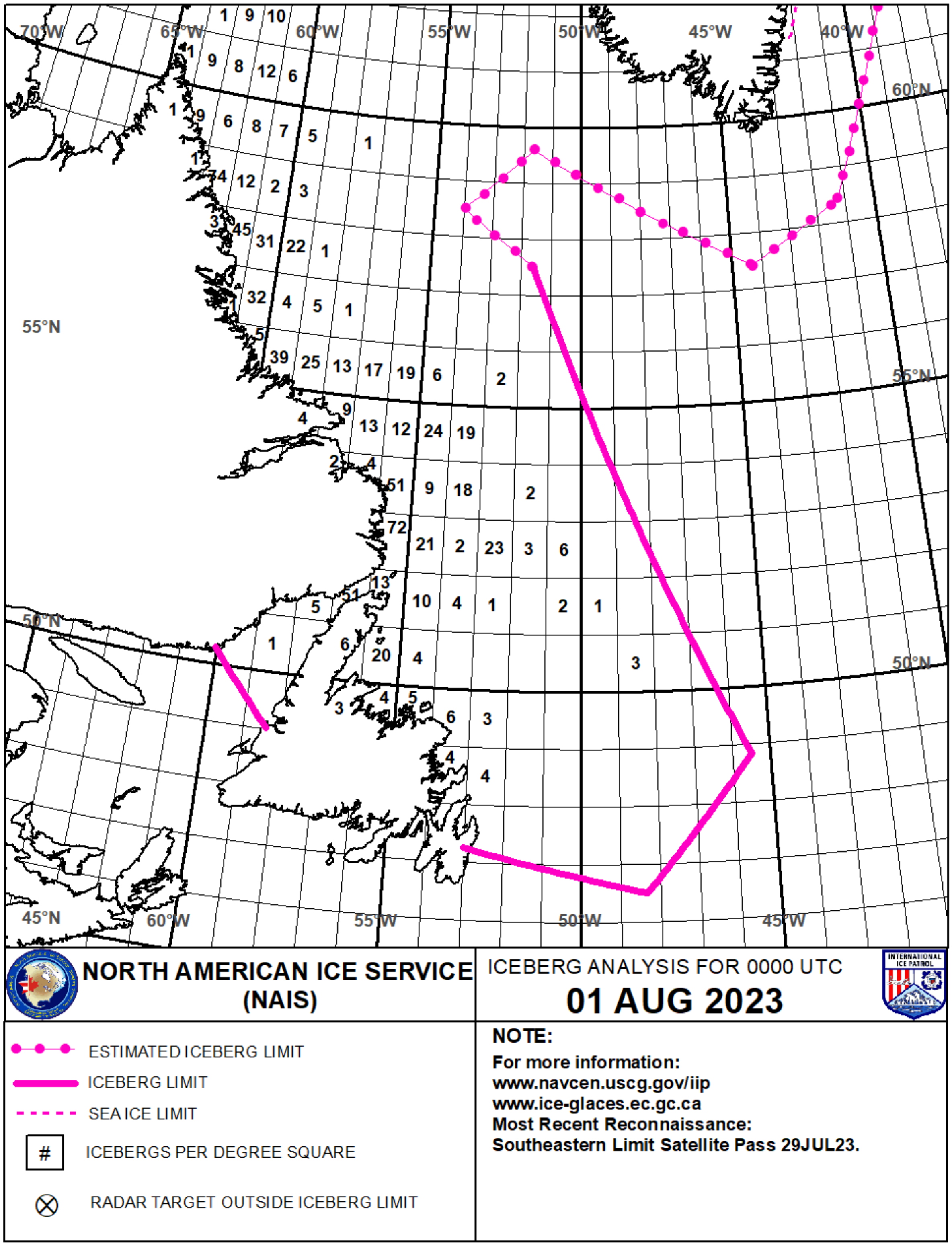

Figure 5.21. NAIS-65 Iceberg Chart from 1 August 2023

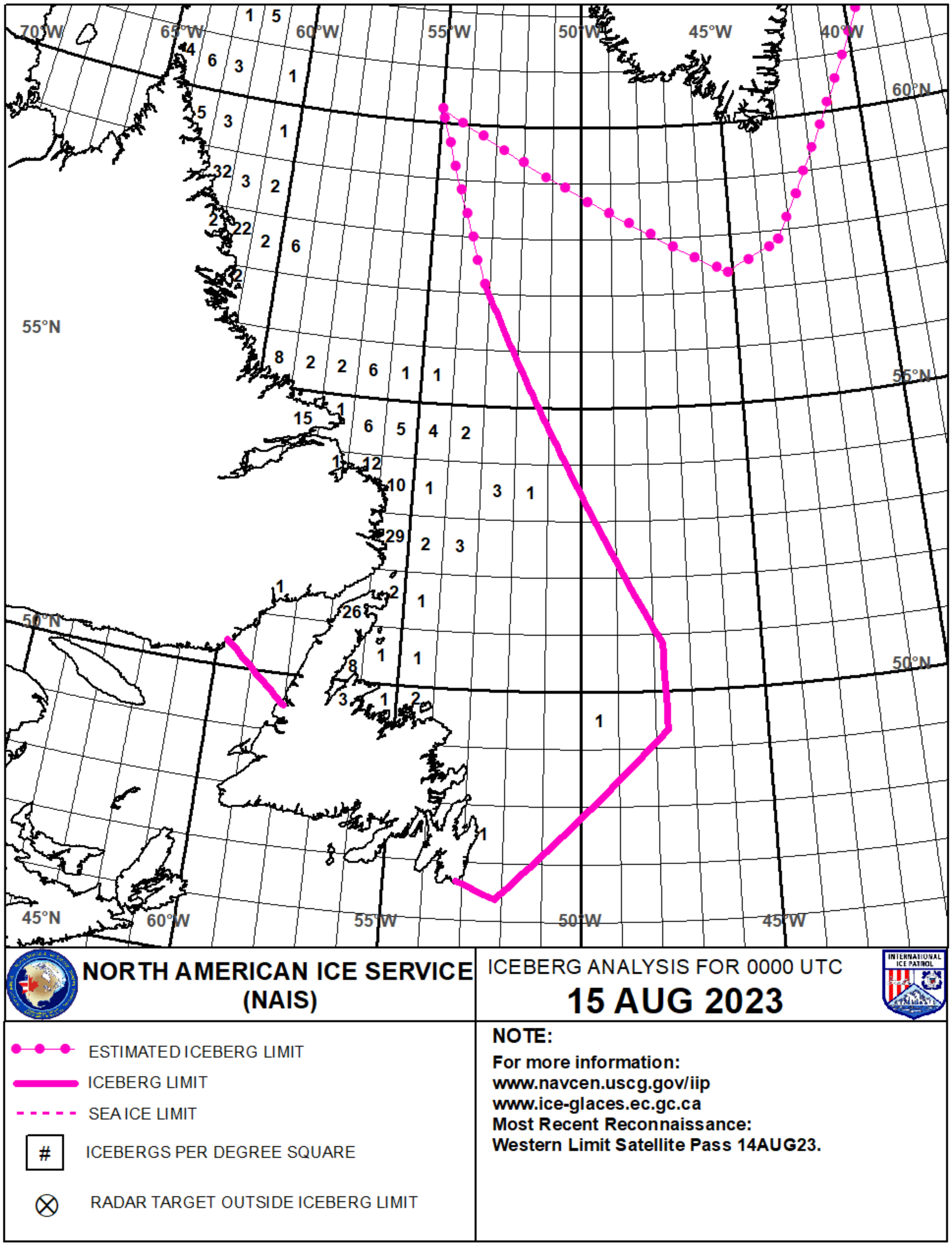

Figure 5.22. NAIS-65 Iceberg Chart from 15 August 2023

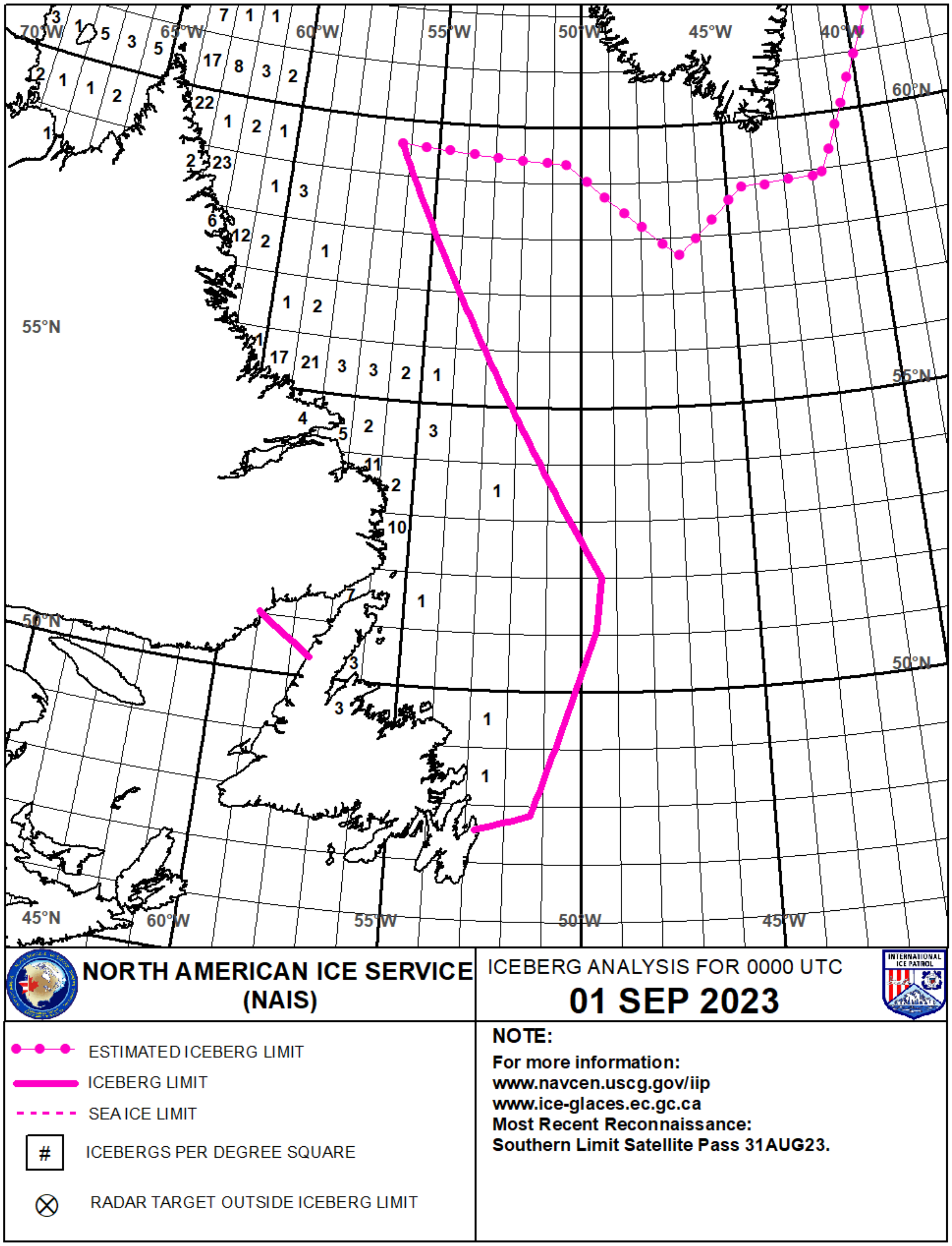

Figure 5.23. NAIS-65 Iceberg Chart from 1 September 2023

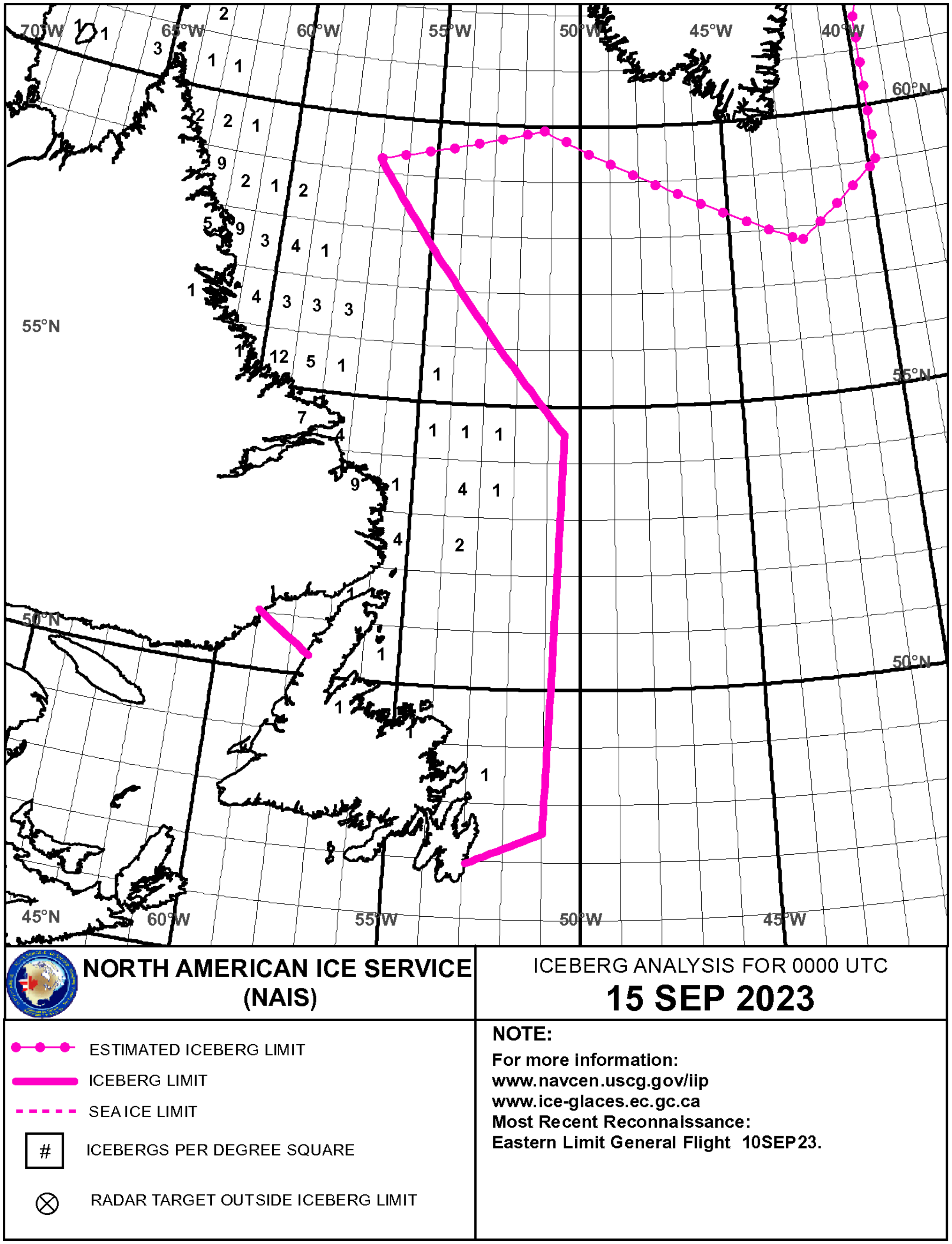

Figure 5.24. NAIS-65 Iceberg Chart from 15 September 2023

Data and Acknowledgements

Iceberg data are from IIP. Sea ice extents are from the NSIDC, Sea Ice Index, Version 3 (Fetterer, et al. 2017). NAOI values are from the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Prediction (NCEP) Climate Prediction Center (CPC) (NOAA/NWS NCEP Climate Prediction Center n.d.). Temperature, pressure, wind, precipitation, and wave data are from the ECMWF ERA5 Reanalysis monthly averaged data on single levels from 1940 to present (Hersbach, et al. 2023).

IIP Commander, Erin Caldwell, wrote **Section 1**. IIP Chief Scientist/Oceanographer, Alexis Denton, wrote **Section 2**. IIP Iceberg Operations Branch Chief, Alex Hamel, and Satellite Reconnaissance Branch Chief, Shelby Griswold, wrote **Sections 3** and **4**. Alex Hamel wrote **Section 5** and Jonathon Ruegg compiled the images in **Section 5**. **Appendix A** was written by Alex Hamel; Jason Leser created **Figure A-1**. Erin Caldwell, Alexis Denton, Alex Hamel, Shelby Griswold, and Jennifer Sabal contributed to editing of all sections.

IIP Members During the 2023 Ice Year

The following people were IIP members ("Ice Picks") during the 2023 Ice Year (in alphabetical order by surname): IS3 Erik Balboa, MSTC Michael Berlin, MSTC Nicole Brophy, MST1 Mara Brown, CDR Erin Caldwell, IS3 Nicole Columbus, MST2 Bryan Dames, Dr. Alexis Denton, IS3 Jacob Dominguez, ISC Trevor Doubek, LCDR Alex Hamel, CDR Marcus Hirschberg, LT Shelby Griswold, YN1 Amelia Lawrence, MST2 Jason Leser, MST2 Maite Loughlin, IS2 Phillip Miller, LCDR Rebecca Prendergast, IS2 Jonathon Ruegg, Jennifer Sabal, IS3 John Samyn, and IS1 Dallas Shaw. IIP acknowledges all of its 2023 Ice Year members for their individual and collective contribution to the IIP mission and for working on providing data, statistics, and figures which are reported here.

References

Aubourg, Lucie. 2023. *N. Atlantic ocean temperature sets record high: US agency.* Phys.org, July 29. Accessed November 7, 2023. https://phys.org/news/2023-07-atlantic-ocean-temperature-high-agency.html.

Bigg, G. R., H. L. Wei, D. J. Wilton, Y. Zhao, S. A. Billings, E. Hanna, and V. Kadirkamanathan. 2014. "A century of variation in the dependence on ice sheet surface mass balance and regional climate change." *Proceedings of the Royal Society* 470 (20130662): 14. Accessed November 6, 2023. doi:http://dx.doi.org/10.1098/rspa.2013.0662.

Canadian Ice Service - Environment Canada. 2023. *Single Season: Weekly Ice Coverage for the season, Regional East Coast.* July 10. Accessed November 7, 2023. https://iceweb1.cis.ec.gc.ca/Prod/page3.xhtml.

CBC News. 2023. *St. John's is on ice: See the city's harbour packed with sea ice for the first time in 6 years.* Newfoundland, March 17. Accessed November 7, 2023. https://www.cbc.ca/news/canada/newfoundland-labrador/st-johns-sea-ice-gallery-1.6781030.

ESRI. n.d. *How Line Density works.* Accessed November 1, 2023. https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-line-density-works.htm.

Fetterer, Florence, K Knowles, Walt Meier, Matt Savoie, and Ann Windnagel. 2017. "Sea Ice Index, Version 3." National Snow and Ice Data Center. Accessed September 7, 2023. doi:https://doi.org/10.7265/N5K072F8.

Fettweis, X., E. Hanna, C. Lang, A. Belleflamme, M. Erpicum, and H. Gallée. 2013. "Brief communication "Important role of the mid-tropospheric atmospheric circulation in the recent surface melt increase over the Greenland ice sheet"." *The Cryosphere* 7: 241-248. Accessed November 7, 2023. doi:https://doi.org/10.5194/tc-7-241-2013.

Hanna, Edward, Philippe Huybrechts, John Cappelen, Konrad Steffen, Roger C. Bales, Evan Burgess, Joseph R. McConnell, et al. 2011. "Greenland Ice Sheet surface mass balance 1870 to 2010 based on Twentieth Century Reanalysis, and links with global climate forcing." *Journal of Geophysical Research* 116 (D24121): 20. Accessed November 7, 2023. doi:https://doi.org/10.1029/2011JD016387.

Hersbach, H., B. Bell, P. Berrisford, G. Biavati, A. Horányi, J. Muñoz Sabater, J. Nicolas, et al. 2023. "ERA5 monthly averaged data on single levels from 1940 to present." Copernicus Climate Change Service (C3S) Climate Data Store (CDS). Accessed October 20, 2023. doi:10.24381/cds.f17050d7 .

International Ice Patrol. 2018. "Report of the International Ice Patrol in the North Atlantic." Department of Homeland Security, United States Coast Guard, New London, CT. Accessed September 14, 2023. https://www.navcen.uscg.gov/sites/default/files/pdf/Annual_Report_2022_Season.pdf.

International Maritime Organization. 1974. "International Convention for the Safety of Life at Sea, 1974." International Maritime Organization. https://treaties.un.org/doc/Publication/UNTS/Volume%201184/volume-1184-I-18961-English.pdf.

Larsen, Poul-Henrik, Marc Overgaard Hansen, Jørgen Buus-Hinkler, Klaus Harnvig Krane, and Carsten Sønderskov. 2015. "Field tracking (GPS) of ten icebergs in eastern Baffin Bay, offshore Upernavik, northwest Greenland." *Journal of Glaciology* (Cambridge University Press) 61 (227): 421-437. Accessed September 11, 2023. doi:https://doi.org/10.3189/2015JoG14J216.

Marko, J. R., D. B. Fissel, P. Wadhams, P. M. Kelly, and R. D. Brown. 1994. "Iceberg Severity off Eastern North America: Its Relationship to Sea Ice Variability and Climate Change." *Journal of Climate* 7: 1335-1351. Accessed September 11, 2023. doi:https://doi.org/10.1175/1520-0442(1994)007%3C1335:ISOENA%3E2.0.CO;2.

Newell, John P. 1993. "Exceptionally Large Icebergs and Ice Islands in Eastern Canadian Waters: A Review of Sightings from 1900 to Present." *Arctic* 46 (3): 205-211. Accessed September 11, 2023. doi:https://journalhosting.ucalgary.ca/index.php/arctic/article/view/64400.

NOAA/NWS NCEP Climate Prediction Center. n.d. "Daily NAO index since January 1950." Accessed November 6, 2023. https://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao.shtml.

Noël, B., X. Fettweis, W. J. van de Berg, M. R. van den Broeke, and M. Erpicum. 2014. "Sensitivity of Greenland Ice Sheet surface mass balance to perturbations in sea surface temperature and sea ice cover: a study with the regional climate model MAR." *The Cryosphere* 8: 1871-1883. Accessed November 7, 2023. doi:https://doi.org/10.5194/tc-8-1871-2014.

Rignot, Eric, and Pannir Kanagaratnam. 2006. "Changes in the Velocity Structure of the Greenland Ice Sheet." *Science* 311 (5763): 986-990. Accessed September 6, 2023. doi:10.1126/science.1121381.

Smith, Edward H. 1926. "Summary of Iceberg Records in the Northwestern North Atlantic, 1880-1926." In *International Ice Observation and Ice Patrol Service in the North Atlantic: Season of 1926*, by International Ice Observation and Ice Patrol Service, 75-77. Accessed October 13, 2023. https://www.navcen.uscg.gov/international-ice-patrol-annual-reports.

2021. "Title 46, United States Code § 80301." Accessed August 30, 2023. https://www.govinfo.gov/content/pkg/USCODE-2021-title46/pdf/USCODE-2021-title46.pdf.

Trivers, Geoffrey. 1994. "International Ice Patrol's Iceberg Season Severity." In *Bulletin No. 80: Report of the International Ice Patrol in the North Atlantic, Season of 1994*, by International Ice Patrol, 49-59. Groton, Connecticut. Accessed October 13, 2023. https://www.navcen.uscg.gov/international-ice-patrol-annual-reports.

United States National Ice Center. 2022. *Arctic Sea Ice at Minimum Extent - 2022.* September 26. Accessed November 1, 2023. https://usicecenter.gov/PressRelease/ArcticMinimum2022.

Wilton, David J., Grant R. Bigg, and Edward Hanna. 2015. "Modelling twentieth century global ocean circulation and iceberg flux at 48°N: implications for west Greenland iceberg discharge." *Progress in Oceanography* 138: 194-210. Accessed September 12, 2023. doi:https://doi.org/10.1016/j.pocean.2015.07.003.

Appendix A – Vessel Traffic Data

A.1. Introduction

IIP produces and distributes the daily iceberg limit with the transatlantic mariner as the intended primary beneficiary of the product. The iceberg limit is intended to assist vessel masters and navigators in avoiding ice altogether instead of navigating in it. While IIP and CIS have an impeccable record of distributing a reliable daily product, it is often hard to measure how it is being used by our target audience, if at all. Feedback requests addressed to the commercial fleet from IIP have historically produced few replies and little useful data for improving or evaluating the product.

To attempt to better understand if, and how, the product is used by IIP's customers, vessel data from the CG NAVCEN were examined and compared to the iceberg limit from IIP's most recent extreme iceberg season in 2019. The goal of this project was to characterize how vessels considered the iceberg limit when route planning.

Ideally, traffic data that showed vessels staying outside the limit would indicate a high rate of reliance on the IIP product, while little change in traffic behavior coinciding with drastic changes in the iceberg limit would indicate that navigators weren't receiving, or choosing to accommodate for, the iceberg limit. Fortunately, this study found that IIP's primary customer was typically navigating outside of the iceberg limit in the 2019 Iceberg Season.

A.2. Background

In 2019, 1,515 icebergs were estimated to have crossed into shipping lanes south of 48°N. This is well above IIP's definition for an extreme season (more than 1,036 icebergs south of 48°N). See Section 2 of this report for more information on season severity. The population was estimated to have persisted well south and east of the typical median extents of the iceberg limit into May and June (Figure A.1). Titanic sank near 43°N at the tail of the Grand Banks, and the iceberg limit extended as far south as 40°N in April of 2019. Because of the severe nature of the season, it was chosen as a fitting scenario to examine how vessels accounted for the iceberg limit in their voyage planning.

Commercial vessels of a certain tonnage are required to report their position using AIS. This data is received and archived by the NAVCEN for a variety of purposes. For the sake of this study, it was used to focus on traffic patterns in the area between Europe and North America north of 40°N.

A.3. Methods

CG NAVCEN offers government customers the option to view vessel traffic "heat maps" over specified areas for specified periods. IIP requested all archived vessel positions in the box bounded by 40ºN, 55ºN, 030ºW, and 065ºW from 1200Z on 1 January to 1200Z on 30 July 2019 for five-minute intervals. All AIS data and methods described in this appendix are from the CG NAVCEN.

Because of gaps in AIS data reports from vessels operating far from land, or without satellite reporting options, the historical track line from any one vessel is unlikely consistent. The AIS record may have temporal

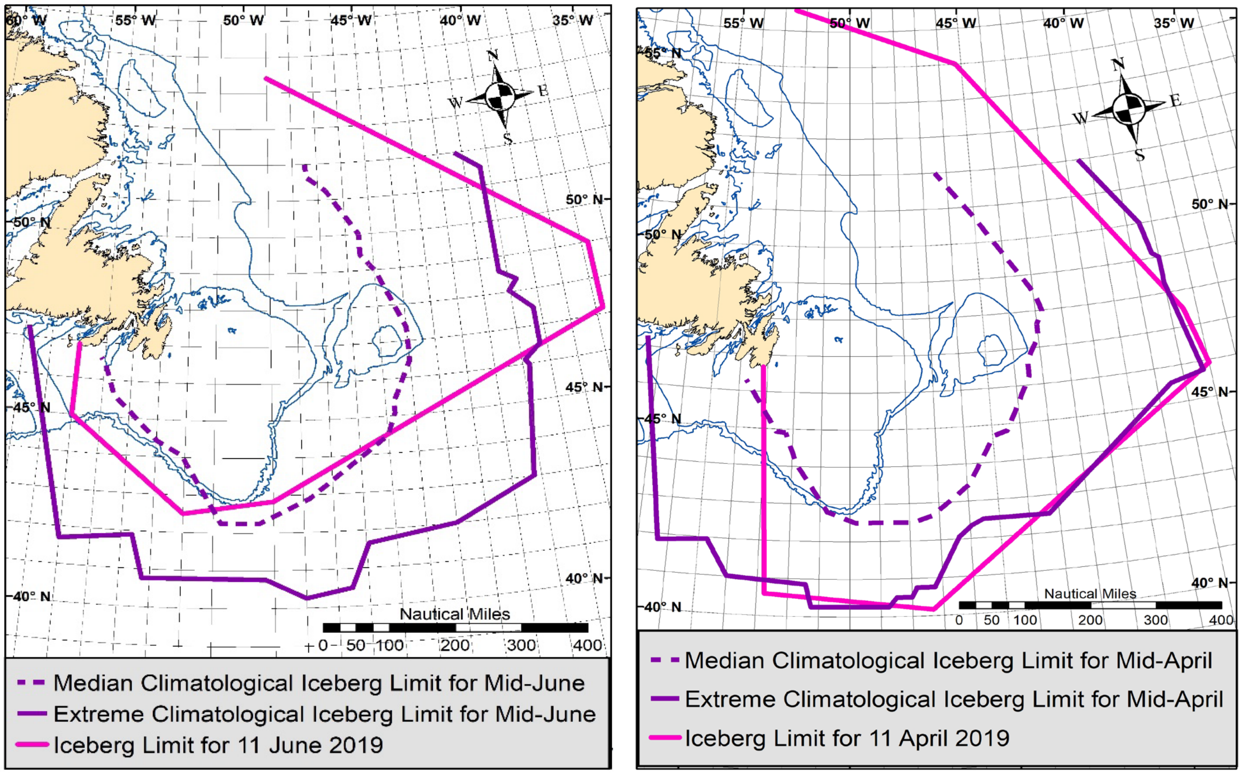

Figure A.1 Iceberg limits with the easternmost (left) southernmost (right) extents in 2019 are overlaid with the corresponding median and maximum climatological limits from 1991-2020.

gaps ranging from minutes to days, or more. To account for this, vessel track lines were generated using consecutively reported positions no greater than 30 minutes apart. Any position reported more than 30 minutes after the prior position marked the start of a new track line segment (NAVCEN).

To generate the heat map of track lines, the "Line Density" geoprocessing tool from ESRI's ArcGIS Pro mapping software was used to depict the number of track lines which passed through a gridded cell (**Figure A.2**). Output cells were assigned increasingly warmer colors as more segments passed through or near them and were weighted by the length of the track segment contained within a defined radius. The cell colors were assigned on a green to red spectrum to correspond with "low" and "high" designations for traffic density, respectively. The discrete numerical breaks between each color on the spectrum ("tracks per grid cell") were assigned based on the number and distribution of input tracks per period and varied with each image.

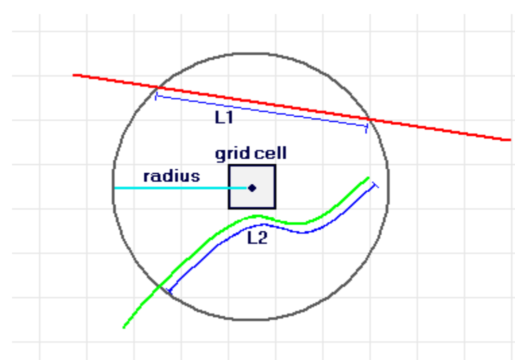

Figure A.2. This image from ESRI depicts how the Line Density tool arrives at a value for each gridded cell. The area of interest is broken up into a grid, with the track segments falling on top of the grid. For each cell in the grid, a circle is drawn around its center point. For each track that passes through the circle, the length of the track (L1 and L2 in the figure) is multiplied by any applicable weighting factors (none in this study) and added to same value for every other segment that passes through the circle. That sum is divided by the area of the circle (ESRI n.d.).

Density tool analysis of the track lines was performed on two-week segments of the given data. Although the iceberg limit is updated each day, analysis on only one day of traffic data would not yield meaningful insight on vessel route decisions based on the iceberg limit. Two-week segments were useful to capture the large-scale changes in the limit, and the corresponding large-scale changes in traffic.

After the density calculations were performed on each two-week batch of track line segments, IIP overlaid the corresponding iceberg limit files for the first, middle, and last day of each period. This was done to indicate how the limit changed over the two-week period, even if it was largely static.

Results

Figures **A.3** through **A.16** show the results of this analysis. The data provided by NAVCEN is overlaid with the iceberg limits from the beginning, middle, and end of each period. Specific analyses of relevant scenarios are included within.

Figure A.3 depicts the first two-week period of the study. This was the default state of shipping absent any effects imposed by the presence of icebergs. The iceberg limit for the duration of the two weeks remained well above 50°N and well north of the primary transatlantic shipping lane. One prominent corridor of vessel traffic crossing the Atlantic Ocean from Europe is visible, along with other areas of high concentration in the St. Lawrence Seaway, South of the Grand Banks, and at a convergence point between traffic coming from Europe and traffic coming from Africa at 60°W.

Figure A.4 again shows the base state of traffic in the area, however this time the route between St. John's, Newfoundland and a cluster of offshore oil rigs is slightly more prominent. The number of fishing vessel tracks proceeding north along the 1,000-meter bathymetric contour from St. John's also increased over the first half of the month. These two traffic patterns persist year-round and are agnostic to the movement of the iceberg limit due to the nature of the work being performed. They are noticeable in each image.

The iceberg limit began to protrude into shipping lanes beginning in **Figure A.6.** There is little noticeable impact on traffic, however far fewer vessels transited the area compared to the previous three periods. The reason for this was not considered, but February in the North Atlantic Ocean is known to be a particularly hazardous part of the year, and it can be speculated that more storms lead to fewer crossings.

Figure A.7 depicts the first disruption of the primary Europe-North America traffic route by the iceberg limit. The once prominent corridor is visibly more diffuse, with areas of highest vessel traffic concentration remaining outside of the limit.

Figure A.8 depicts an interesting result, which is that very few tracks passed inside of the iceberg limit depicted in purple, which was the position of the limit on the first day of the period. This observation,

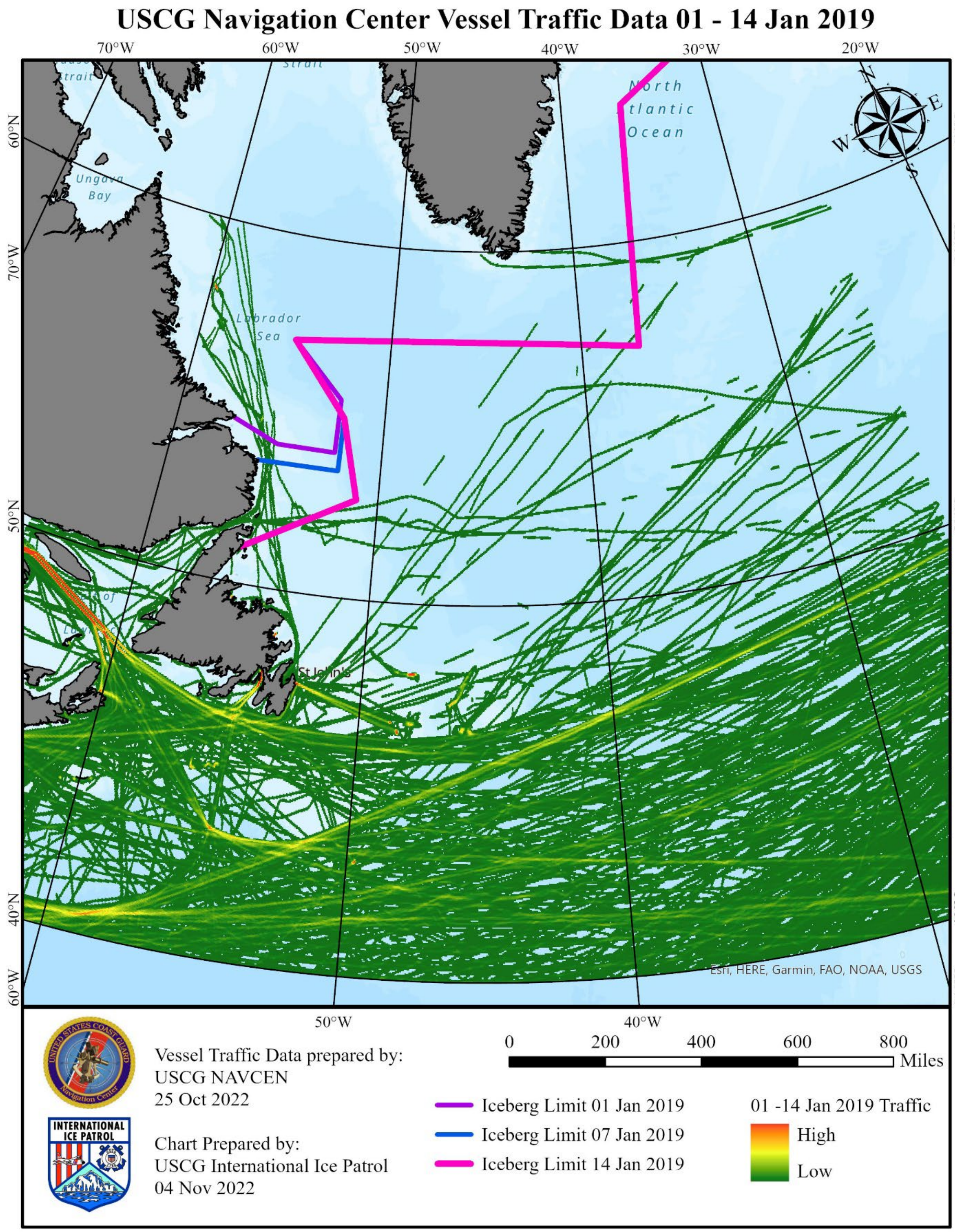

Figure A.3. NAVCEN Vessel traffic and IIP iceberg limits for 01 – 14 Jan 2019.

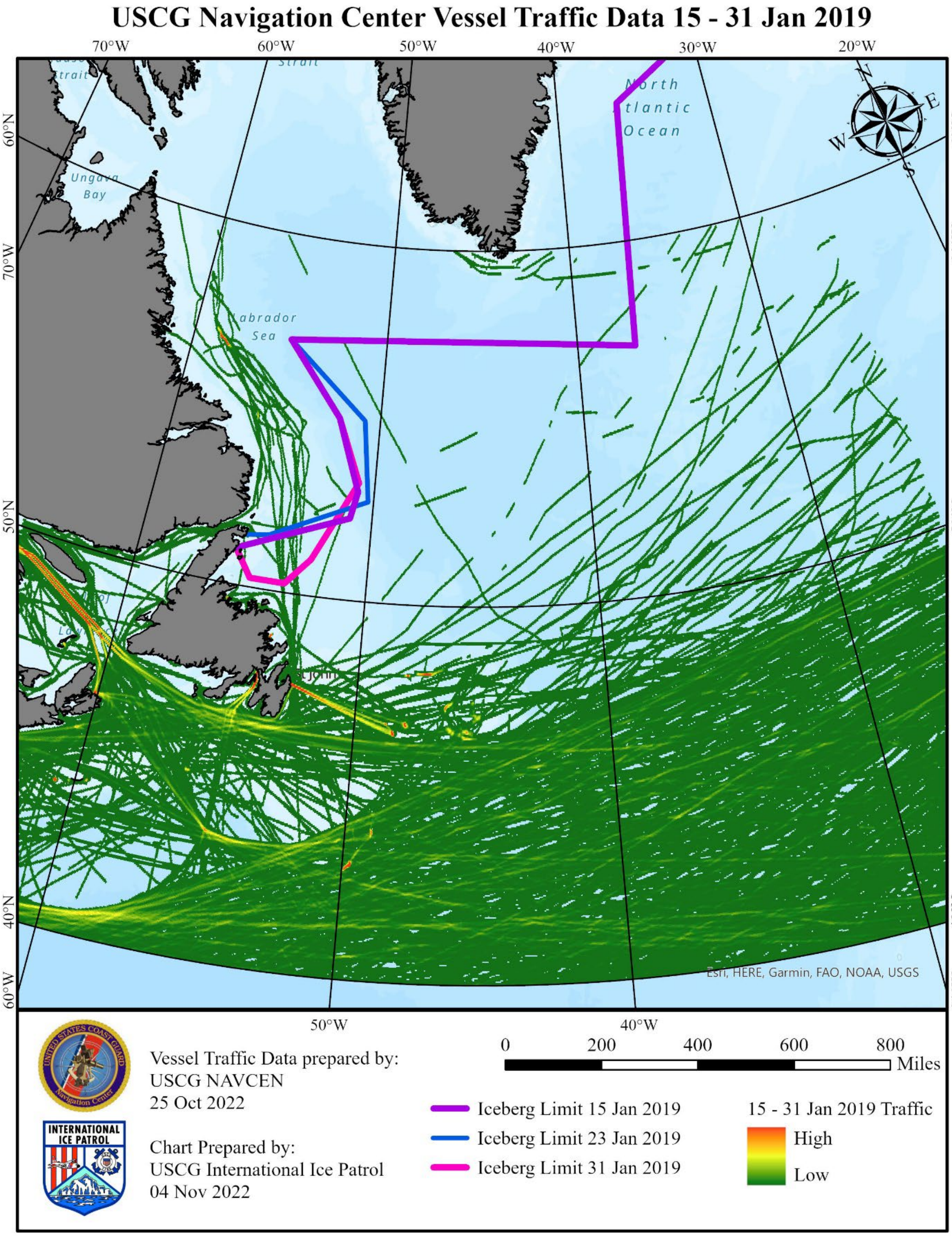

Figure A.4. NAVCEN Vessel traffic and IIP iceberg limits for 15 – 31 Jan 2019.

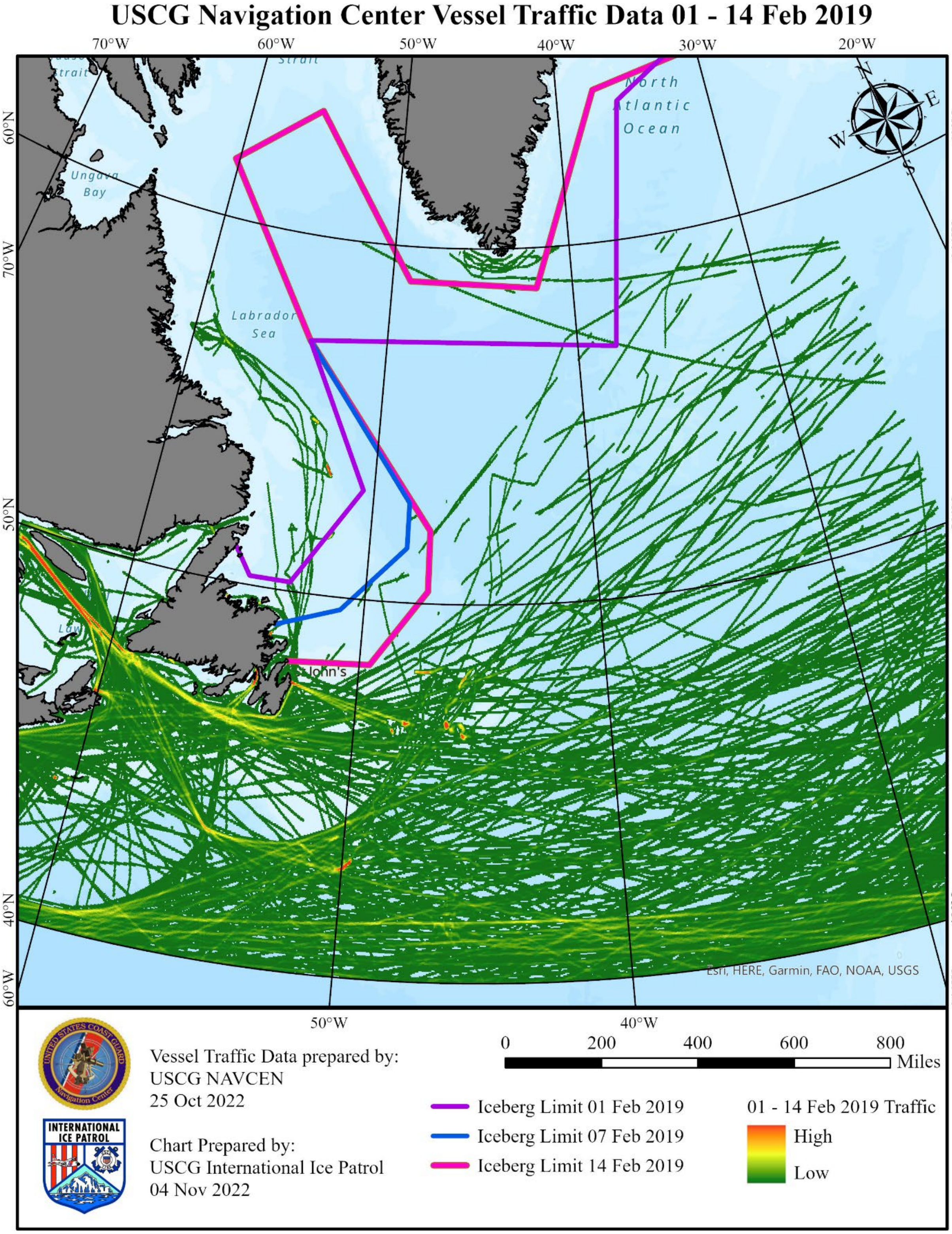

Figure A.5. NAVCEN Vessel traffic and IIP iceberg limits for 01-14 February 2019.

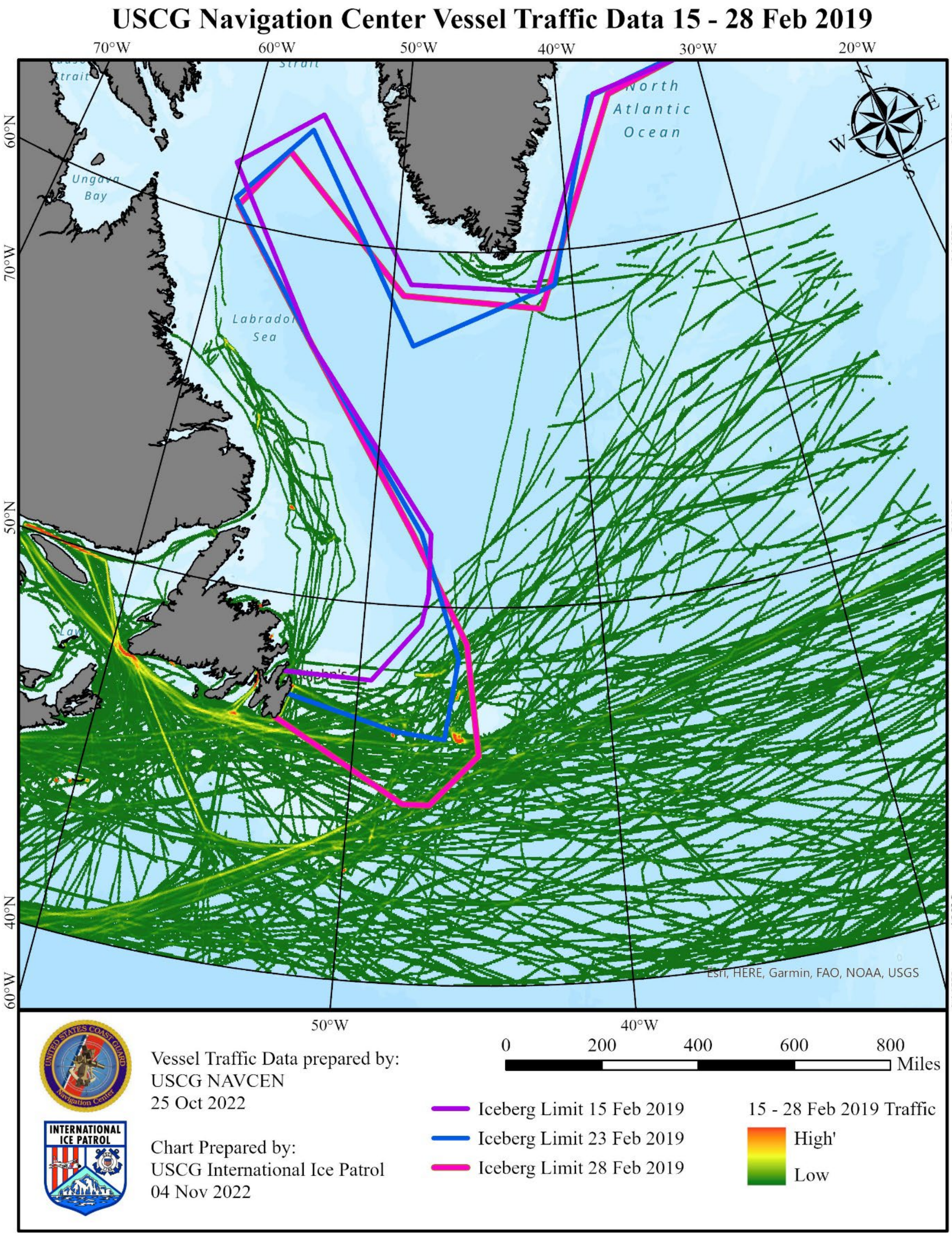

Figure A.6. NAVCEN Vessel traffic and IIP iceberg limits for 15-28 February 2019.

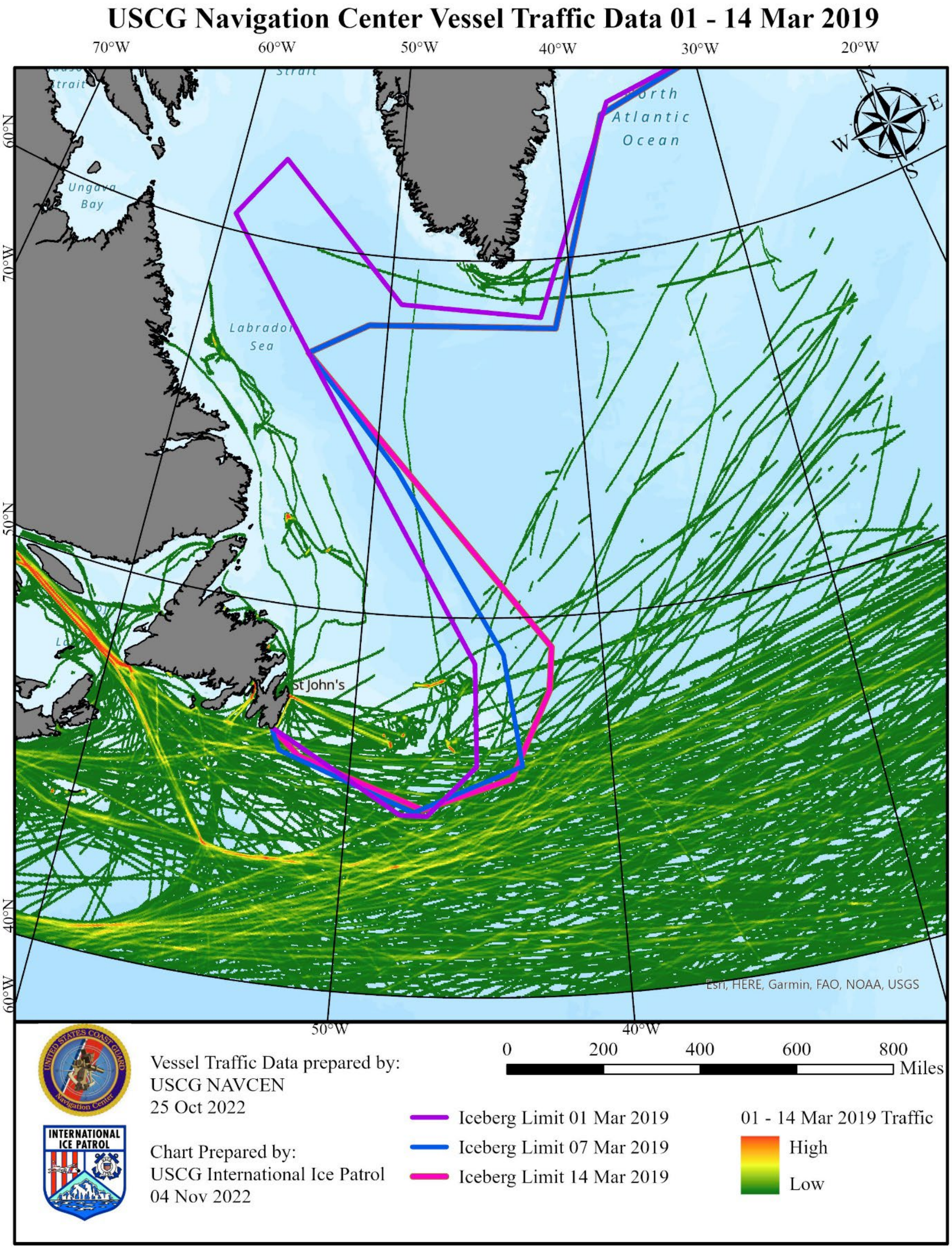

Figure A.7. NAVCEN Vessel traffic and IIP iceberg limits for 01-14 March 2019.

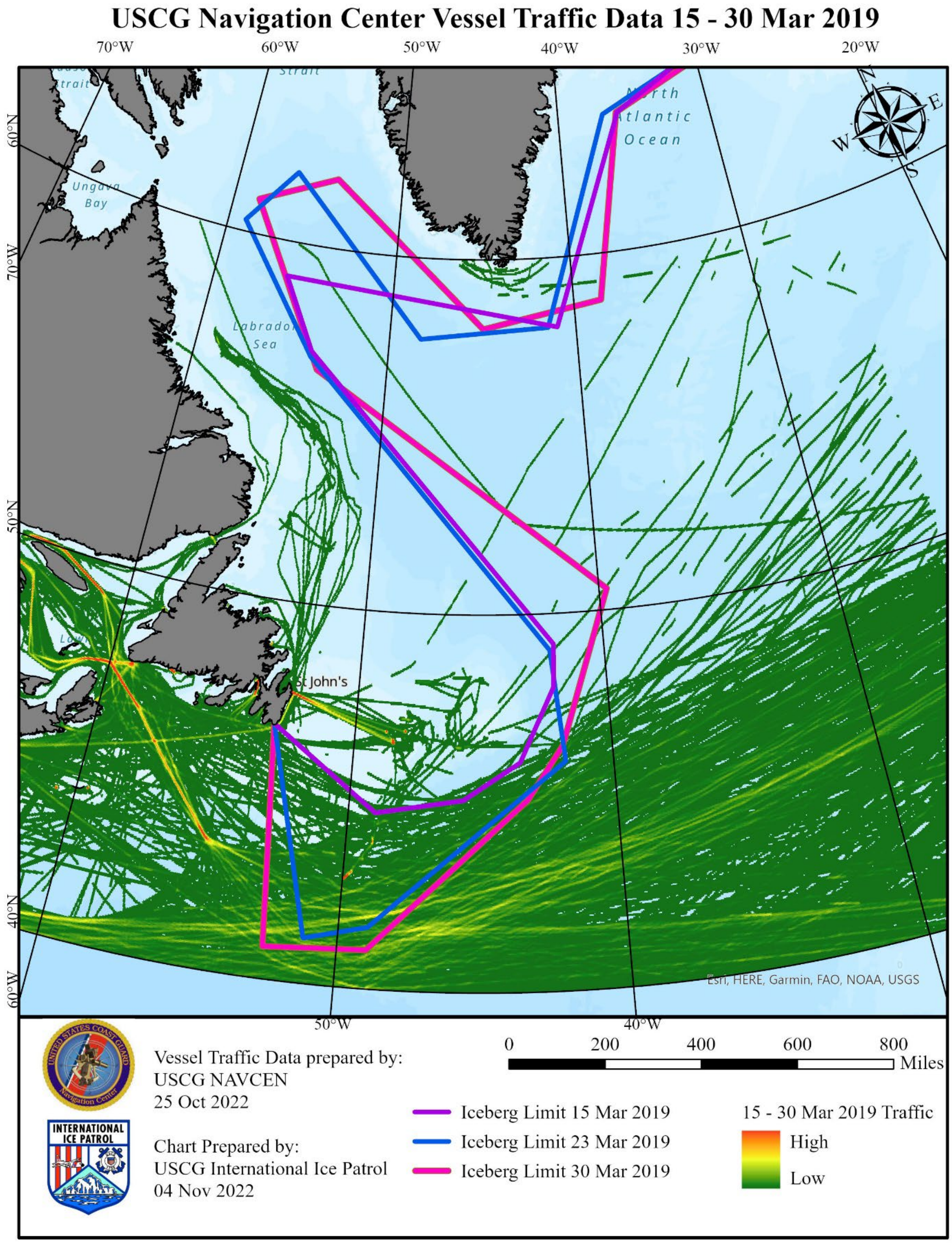

Figure A.8. NAVCEN Vessel traffic and IIP iceberg limits for 15-30 March 2019.

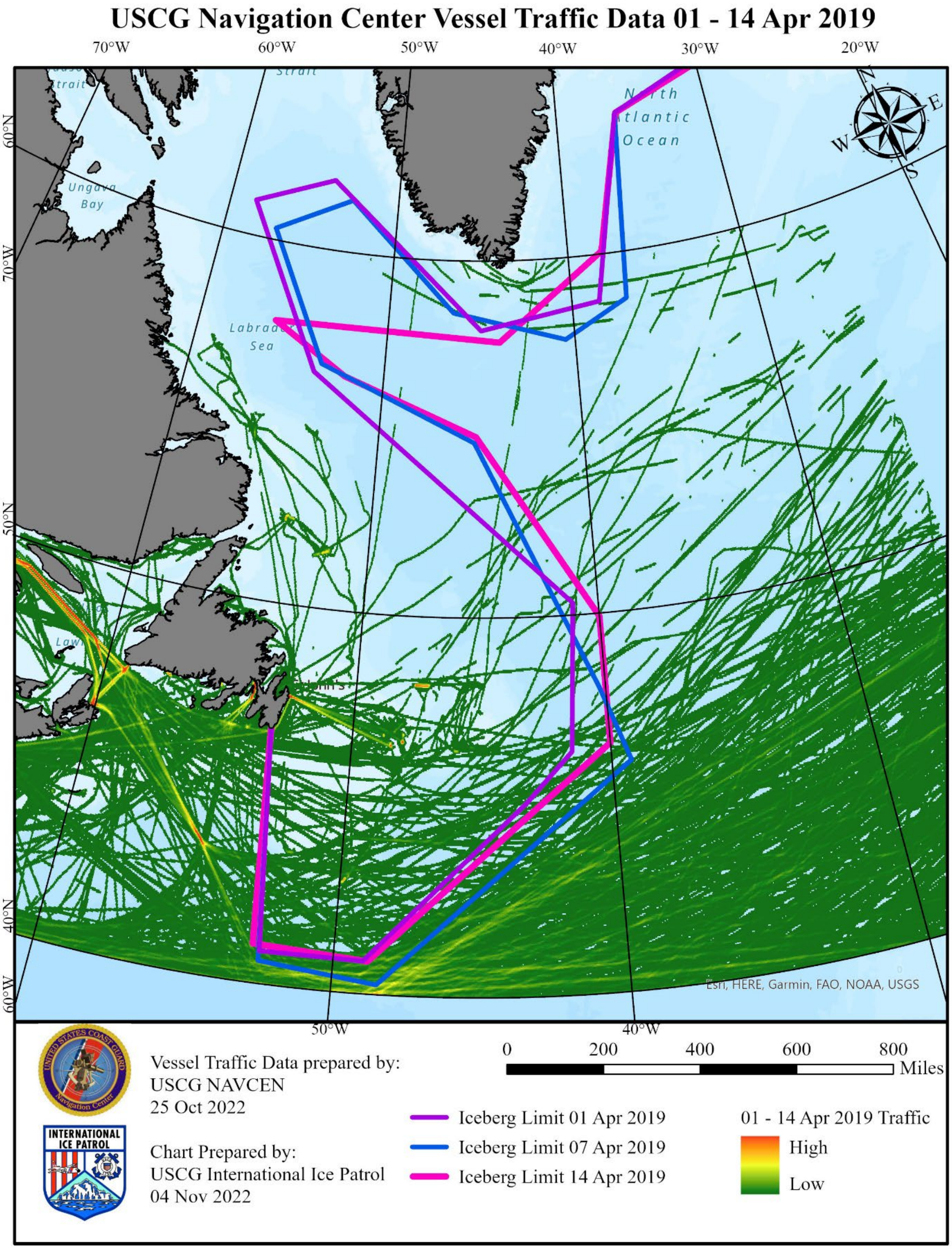

Figure A.9. NAVCEN Vessel traffic and IIP iceberg limits for 01-14 April 2019.

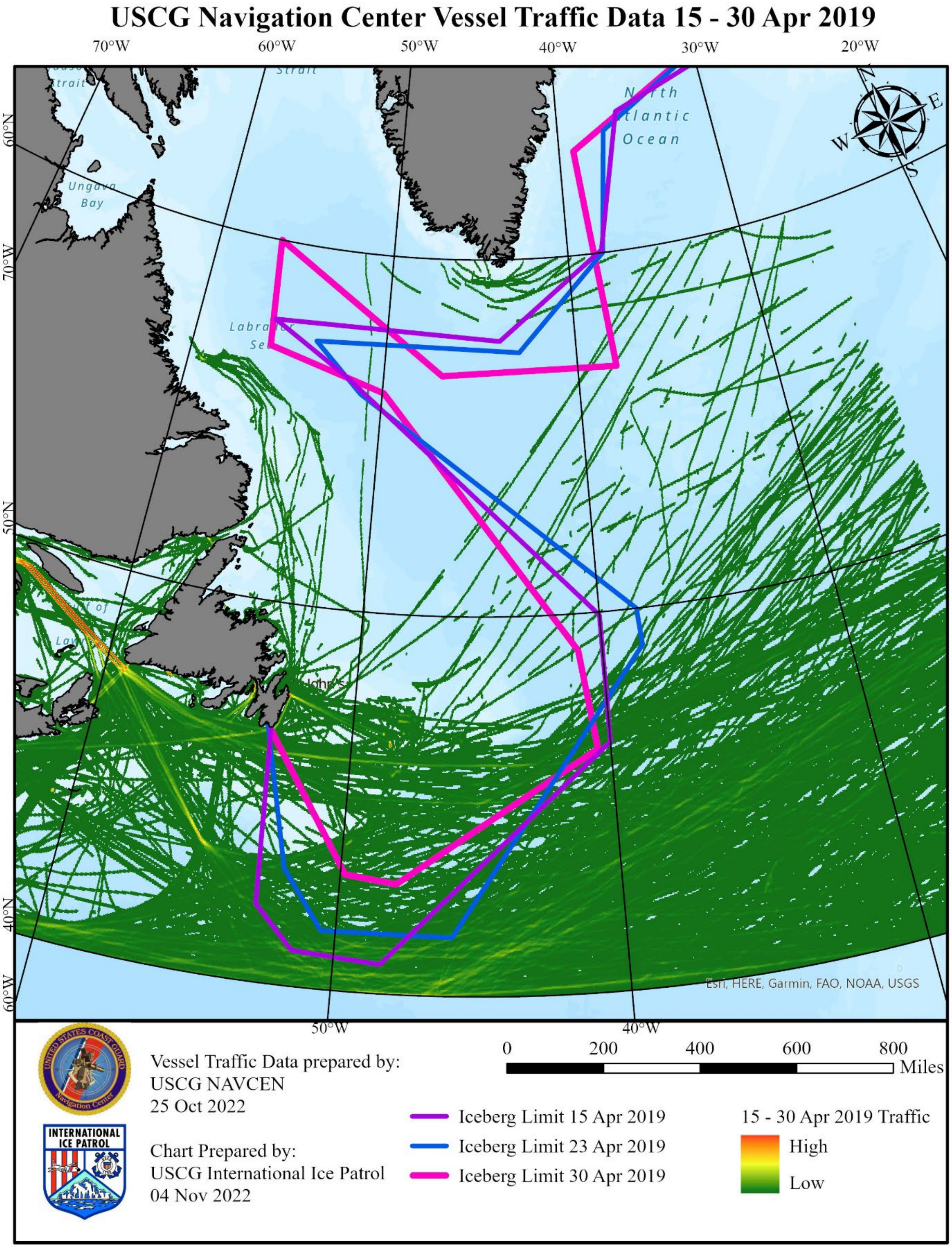

Figure A.10. NAVCEN Vessel traffic and IIP iceberg limits for 15-30 April 2019.

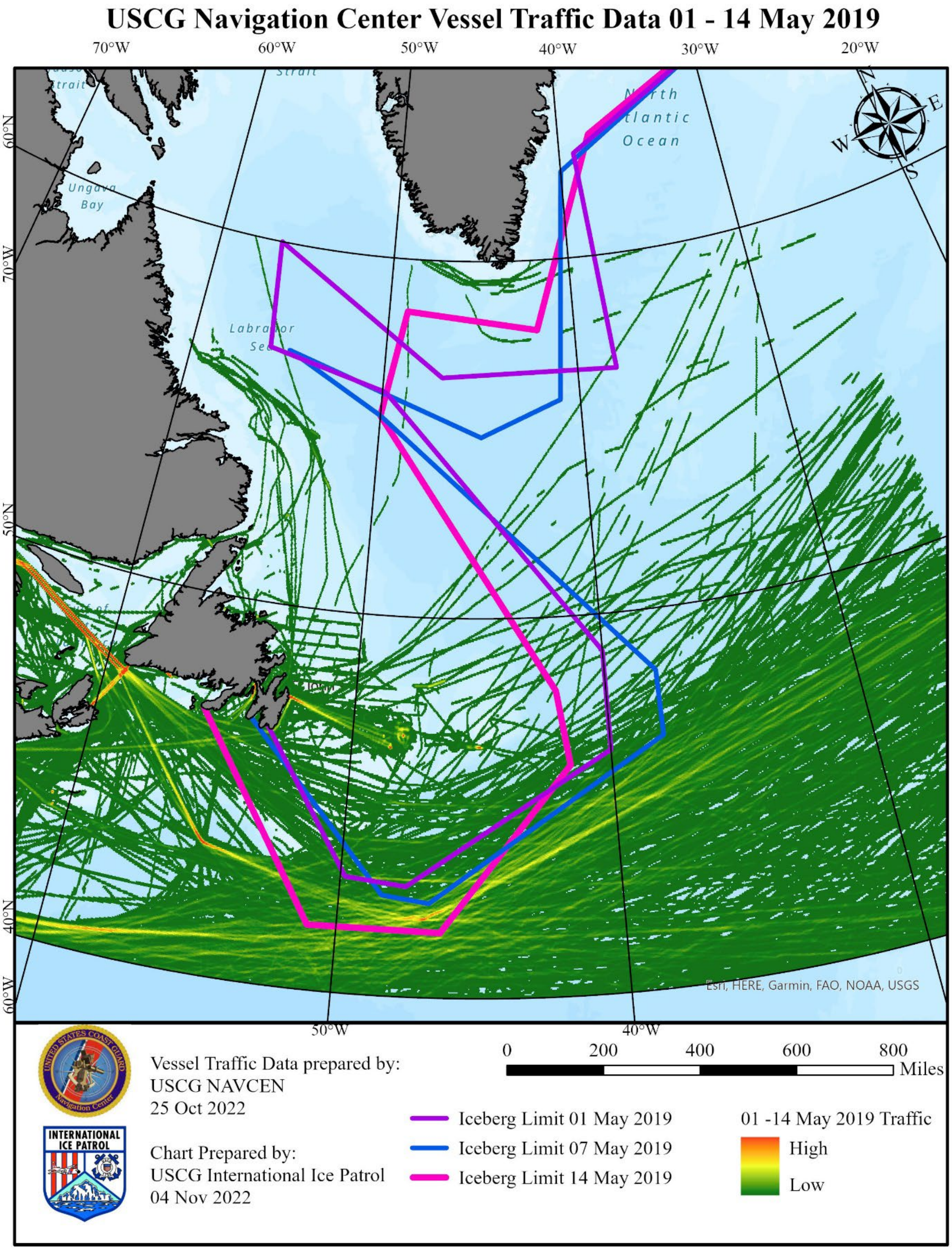

Figure A.11. NAVCEN Vessel traffic and IIP iceberg limits for 01-14 May 2019.

USCG Navigation Center Vessel Traffic Data 15 - 31 May 2019

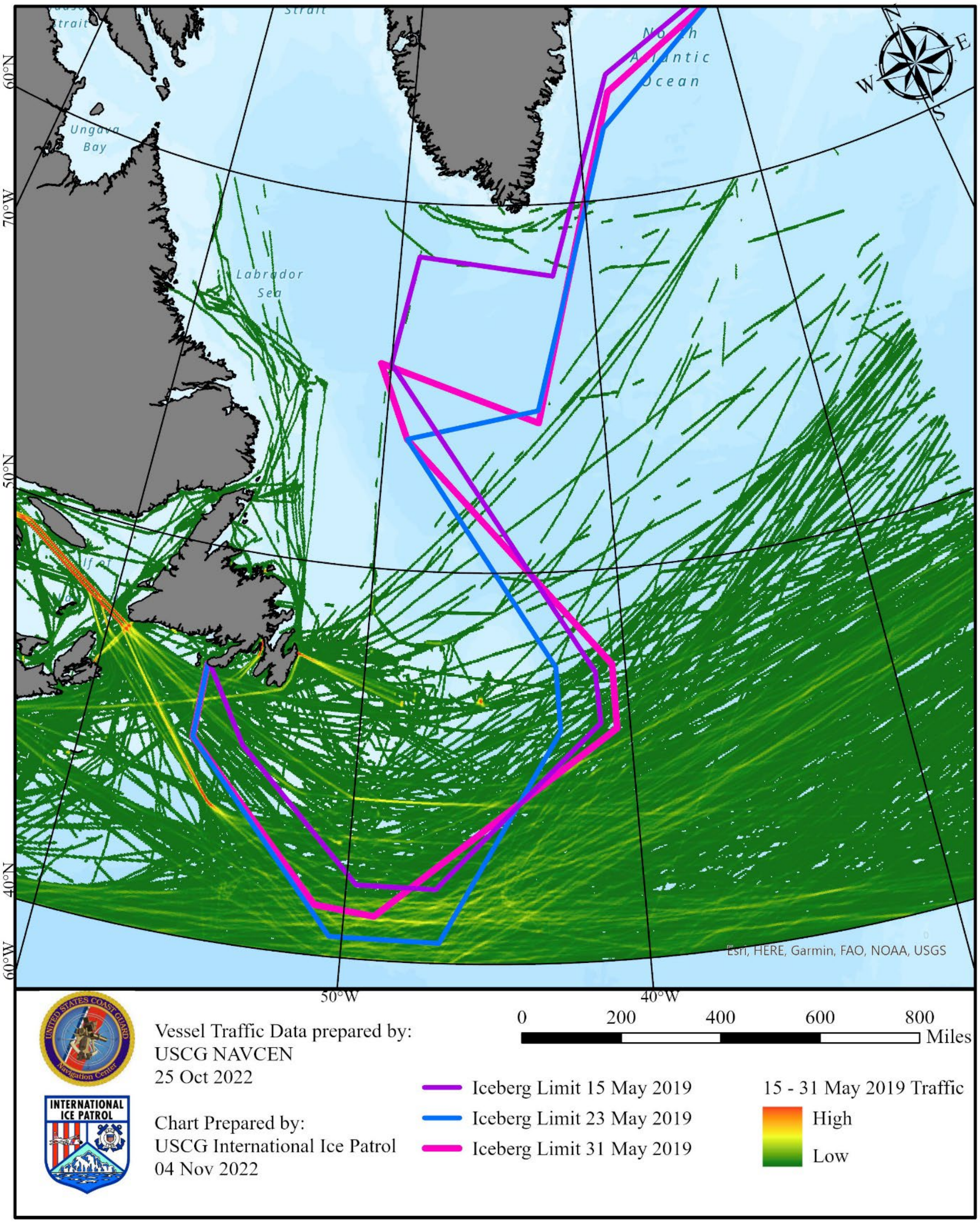

Figure A.12. NAVCEN Vessel traffic and IIP iceberg limits for 15-31 May 2019.

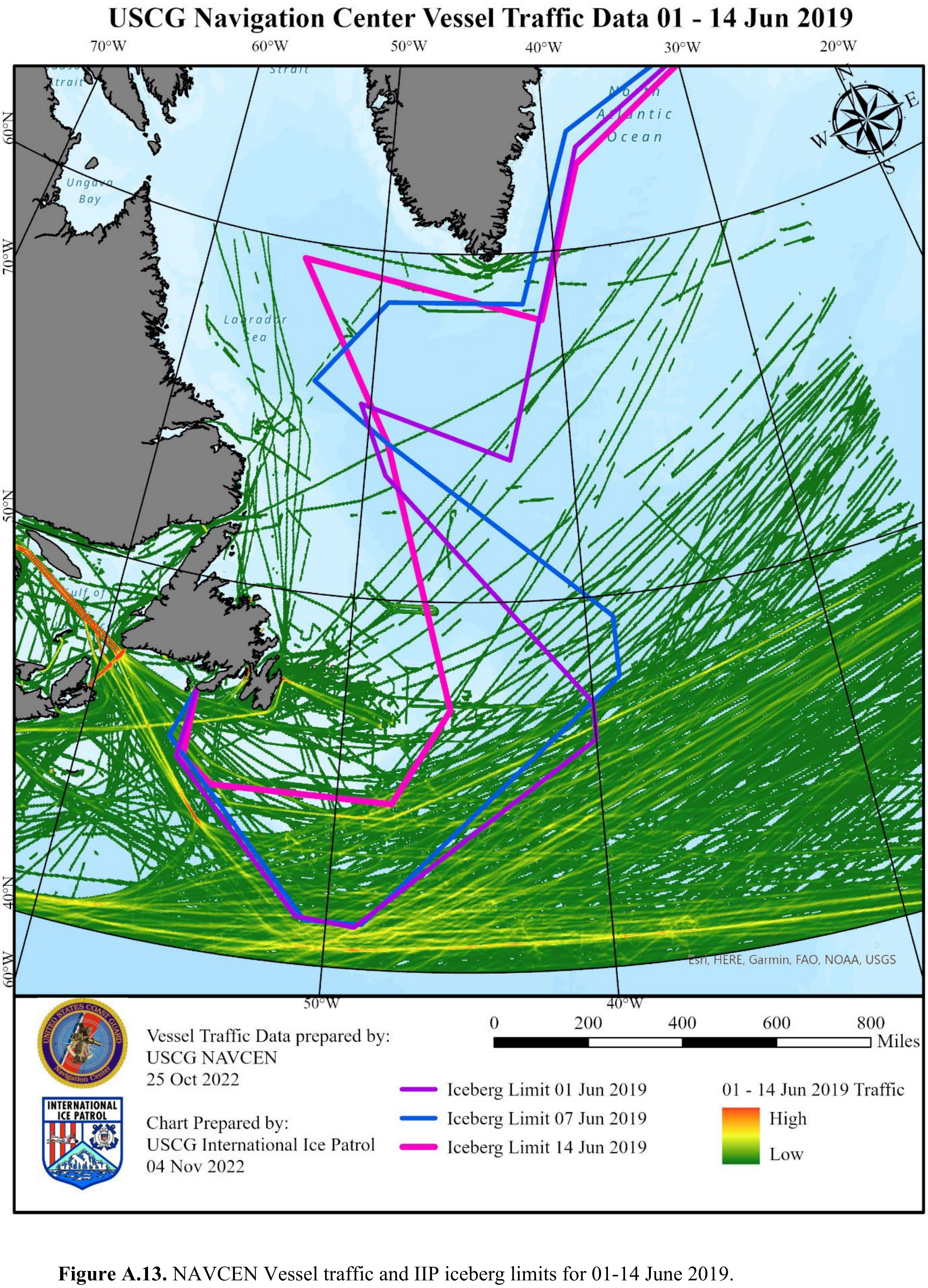

Figure A.13. NAVCEN Vessel traffic and IIP iceberg limits for 01-14 June 2019.

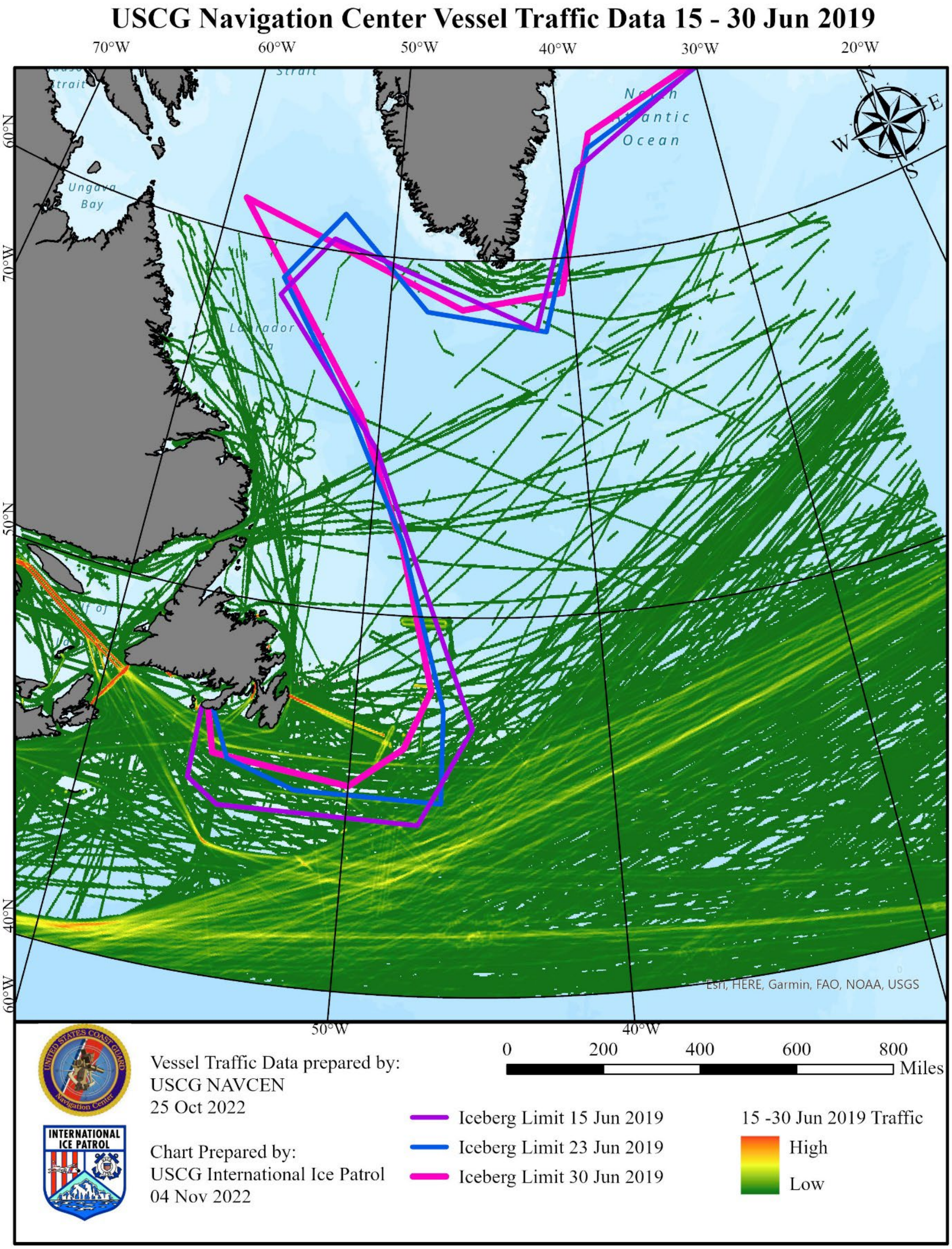

Figure A.14. NAVCEN Vessel traffic and IIP iceberg limits for 15-30 June 2019.

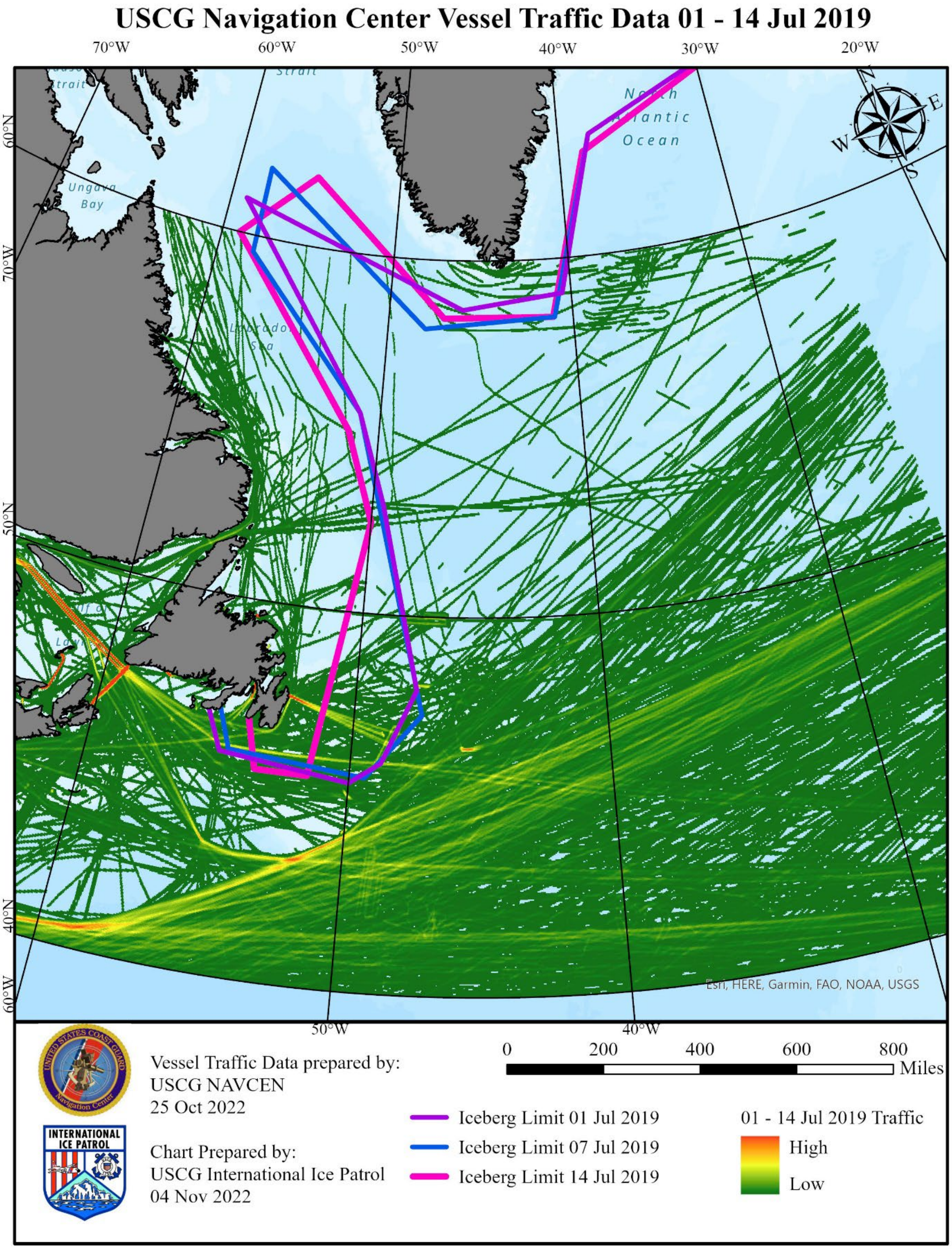

Figure A.15. NAVCEN Vessel traffic and IIP iceberg limits for 01-14 July 2019.

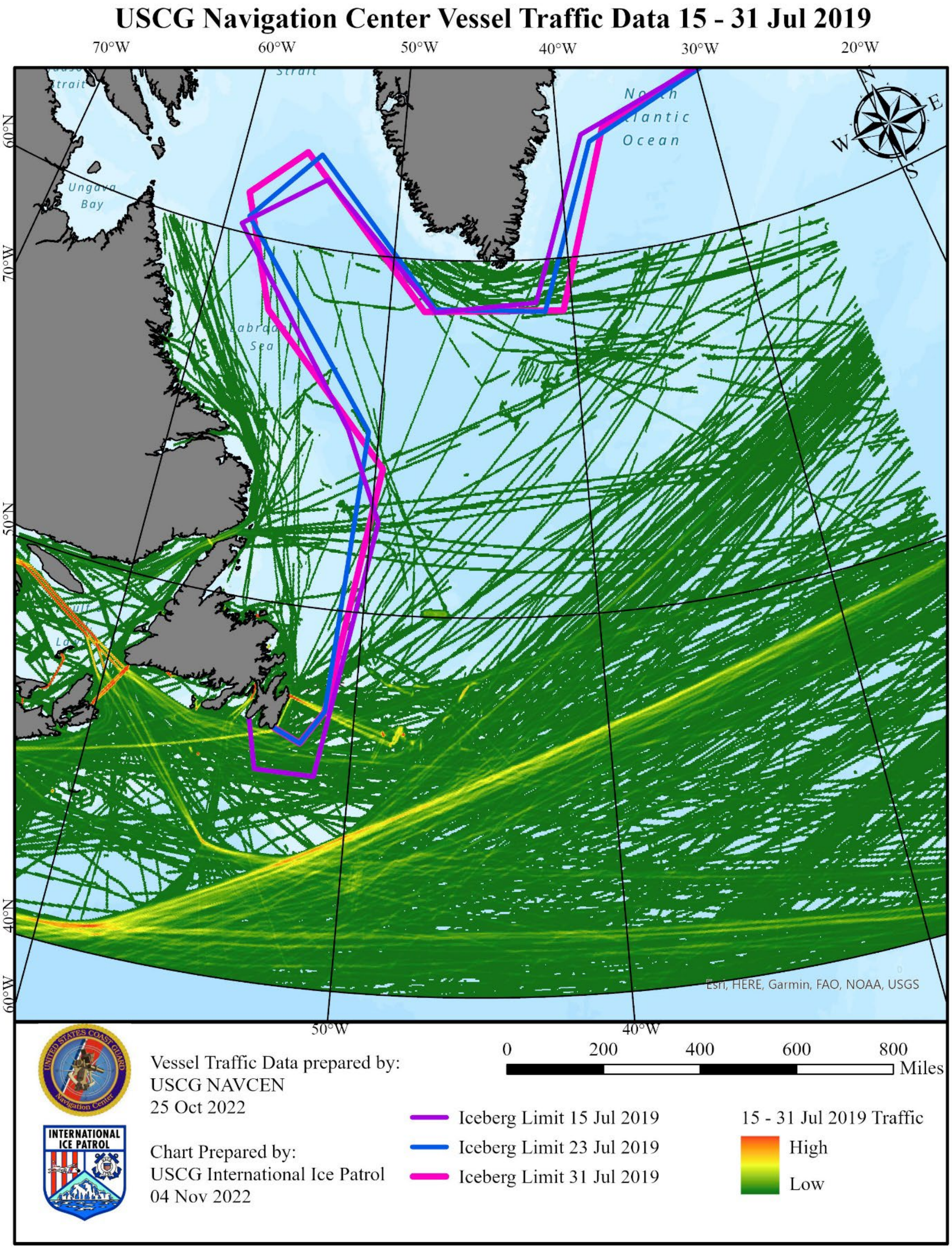

Figure A.16. NAVCEN Vessel traffic and IIP iceberg limits for 15-31 July 2019.

combined with the high concentration of traffic near or outside of the iceberg limits for the middle and end of the period, lead to the conclusion that traffic largely remained outside of the limit during the period.

Figure A.9 again shows a high vessel concentration right at the corner point of the iceberg limit, which stayed relatively static throughout the whole period as depicted by the consistent positions of the limits at the beginning, middle, and end of the period.

Figures A.11 through **A.14** tell the most convincing story of the study, which is that the most prominent transatlantic shipping lanes from Europe and Africa are significantly displaced by the position of the iceberg limit. Where concentrated and easily observable corridors existed earlier in the winter, tracks were concentrated more along the edges of the iceberg limit. Significant movement in the limit was also mirrored by significant shifts in traffic. **Figures A.13** and **A.14** show the limit receding northward, and traffic concentrations also shifting northward as it moves. This can be seen by noting that the limit on the first day of the period in each of those figures (purple line) is the southernmost of the three limits. As IIP removed icebergs from the database due to predicted drift and deterioration, the limit was reduced, and traffic followed.

Figures A.15 and **A.16** depict a return to the base state shown in **Figures A.3** and **A.4**. With the iceberg population having receded well north of the shortest route between Europe and North America, traffic again converged to a single-track line.

A.4. Conclusion

A simple but effective study of vessel positions during the extremely severe Iceberg Season of 2019 showed that IIP's daily iceberg product had large and measurable impacts on transatlantic traffic lanes between North America and Europe/Africa. As the limit expanded over the course of winter and spring, most transatlantic vessels headed expansion and largely remained outside of the limit. Once the limit reached its maximum extent in May and began to recede, traffic again followed its movements. While not all vessel traffic remained exclusively outside of the iceberg limit during the season, most did in areas of highest concentration. This result excludes known exceptions for journeys originating or ending at ports inside the limit for fishing, oil rig support, and other purposes. Based on these data, IIP deduces with high confidence that the daily product is serving the typical transatlantic mariner to avoid icy waters.

A.5. Acknowledgements

The data analysis for this study was conducted by Mr. Louie Baytan, U.S. Coast Guard Navigation Center. Alex Hamel set the area parameters for data collection, overlaid IIP iceberg limits, and wrote this appendix. **Figure A-1** was created by Jason Leser.

A.6. References

ESRI. n.d. How Line Density works. Accessed November 1, 2023. https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-line-density-works.htm.