



Ice conditions and ship access to the Steensby Inlet port site

Fednav Limited
For Baffinland Iron Mines

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Executive summary

This report was prepared by Fednav in response to a request from Baffinland. The purpose of this work is to update the summary of ice conditions and ship access along the approaches to the Steensby Inlet port site since the last report issued in 2011.

The analysis is based on historical ice conditions from 2005 to 2019 which are derived from ice charts and satellite imagery. Other data sources were used, including climatic and metocean data as well as technical and scientific publications covering sea ice and Arctic navigation.

The conclusions drawn from this analysis in terms of shipping feasibility consider Fednav's long-term shipping experience in Arctic regions and ice-covered waters.

Ice conditions

Year-round conditions along the route to the Steensby Inlet port site were assessed, including potential shipping hazards.

By the end of spring, the ice in Foxe Basin has reached the thick first-year ice stage (>120cm thick). Breakup of the fast ice in Steensby Inlet occurs on average around July 17. The entirety of the route to the Steensby port site becomes open water, on average, by September 3. Freeze-up begins along the route, on average, by October 24. The average date when fast ice has developed across Steensby Inlet is November 27. Winter ice conditions are challenging in Foxe Basin and Hudson Strait due to heavy pressure and significant ice movement.

Vessel access

The following conclusions can be drawn from the analysis of ice conditions and vessel access along the route to Steensby Inlet:

- 1) Light or non-ice class vessels could be used to access Steensby Inlet during the shoulder period, prior to and following the open water season, on average, between the following dates:

Established average non-ice class accessibility dates:

- › Average beginning of season: August 18
- › Average end of season: October 21
- › Average season length: 65

Established average 1C ice class accessibility dates:

- › Average beginning of season: August 15
- › Average end of season: October 30
- › Average season length: 77

Established average 1A ice class accessibility dates:

- › Average beginning of season: August 8
- › Average end of season: November 18
- › Average season length: 101

- 2) The average open water season (no ice along route) is from September 3 to October 26 (52 days), however there is still considerable interannual variability in terms of the nominal open water season.

Open water season length:

- › Average open water season: 52 days
- › Longest open water season: 84 days
- › Shortest open water season: 25 days

- 3) To extend the use of light ice class ships, such as 1A ice class vessels, much into the shoulder periods at the beginning and the closing of the season, icebreaker support would be required.

It is estimated that an icebreaker escort could allow a 1A ice class vessel to reach the Steensby port site 1 to 2 weeks earlier than if it were to proceed unescorted, as well as reduce potential delays in the beginning of the shipping season due to a late ice clearing.

After freeze-up along the route to Steensby Inlet, the use of an icebreaker escort could extend the shipping season for 1A vessels. However, as the ice concentration and ice edge extend rapidly in the fall, if attempting to significantly extend the season, an escort of approximately 400NM would be required. It is important to consider the practicality, limitations, and commercial viability of such extensive escorting operations.

- 4) There is no discernible trend towards a significantly longer shipping season for ships of lower ice classes.

Since the 2011 report, an additional 10 years of data is included in our historical assessment of ice conditions. This data shows greater variability in certain ice events than the previous decade, namely in the length of the open water season. Over the last decade (2010-2019), there has been more years when the seasonal ice persisted for a longer time than during the previous decade (2000-2009).

- 5) The most significant change that has been observed over the recent years, compared with the previous decade, is the minimal presence of old ice in Foxe Basin.

In the 1990's and 2000's, there were occasional occurrences of old ice (drifting multi-year ice and persistent first-year ice turning into second-year ice at the end of the melt season) in low concentrations close to the approach to Steensby Inlet. The last time that this rare

phenomenon occurred was in 2010. With the drastic reduction of old ice and consistent melt of seasonal ice in the Canadian Arctic, due to climate change, it is now unlikely that there will be old ice in Foxe Basin. As such, the limitation based on the presence of old ice that was presented in the 2011 study is not relevant anymore.

- 6) Given our extensive operational experience with PC 4 vessels in Hudson Strait, we strongly recommend the use of PC 4 for year-round shipping to Steensby Inlet.
- 7) The option of using a PC 5 vessel with icebreaking support to the vessel during the winter months has been deemed unrealistic.

The use of a PC 5 is limited during a large part of the winter due to the thickness of the ice, which reaches the thick first-year stage by mid-February, and the high level of pressure on the ice cover. In addition the distance from open water in Baffin Bay to Steensby Inlet is more than 800 NM. Consequently, at the peak of winter PC 5 vessels will require a minimum of 800 NM of icebreaking support each way, from the eastern entrance to Hudson Strait to Steensby Inlet. The logistics and risks of such a long escort operation, and in such heavy and dynamic ice conditions as what will be experienced (at a minimum) from February to May, make this an impractical option.

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Glossary

AIRSS	Arctic Ice Regime Shipping System
ASPPR	Arctic Shipping Pollution Prevention Regulations
AWPPA	Arctic Water Pollution Prevention Act
Beset	A situation where a ship is surrounded with ice and unable to move.
Break-up	Moment when ice starts to fracture in late spring or summer.
Close pack	Ice in high concentration, in which pieces are mostly in contact with one another.
Concentration	Ratio expressed in tenths (/10) describing the area of water surface covered by ice as a fraction of the whole area.
Consolidated ice	Ice in a concentration of 10/10, in which pieces are frozen together.
Decayed / Decaying ice	Ice that is in the process of melting and clearing away.
Fast / Land fast ice	Ice that forms and remains fast along the coast.
First-year ice	Sea ice of not more than one (1) winter's growth; thicker than 30 cm.
Floe	Any relatively flat piece of ice 20 m or more across.
Fracturing	Breaking or rupturing of the ice cover. Applies to very close pack, compact, consolidated or land fast ice.
Freeze-up	Moment when the freezing process begins in fall or early winter.
Hummocking	Ice pieces being piled haphazardly over one another and forced upwards, forming an uneven surface like a hillock (a hummock)
IACS	International Association of Classification Societies Ltd.
Ice field	A vast area of floating ice, greater than 10 km across, consisting of any floe size and ice type.
Ice-free	Area where ice is not present at all.
Ice-infested waters	Waters where ice is present.
Ice input	Ice that is due to drift from the surroundings and not from local formation.
Ice regime	A region of ice with more or less consistent ice conditions. Takes into account several factors such as concentration, thickness, age, state of decay, roughness.

<i>In situ</i> melting	Part of the clearing process that only concerns the melting component and excludes the drifting component.
Keel	The submerged part of a ridge.
Kinematic summer	Beginning of the summer season with ice break-up onset.
Lead	Fracture or passageway through the ice that is navigable by a surface vessel.
Melt pond	A puddle that forms on the surface of the ice due to melt.
Mobile ice / Mobile pack	Ice that is not consolidated and may drift with winds and currents.
Multi-year ice	Old ice which has survived at least two (2) summer's melt.
Old ice	Ice that has survived at least one (1) summer's melt. Can be subdivided into second-year ice and multi-year ice.
Open drift	Ice in low concentration, in which pieces are mostly not in contact with one another.
Open water	Area of freely navigable water in which ice can be seen in concentrations less than 1/10 (traces).
Pack ice	Any area of ice (excluding land fast ice). Normally used for areas with concentration higher than 6/10.
POLARIS	The Polar Operational Limit Assessment Risk Indexing System
Polynya	A geographically fixed region of open water (or low average sea ice thickness) that is isolated within thicker pack ice.
Pressure event	A situation of continuous external forcing on the ice during several days.
Rafting	Ice pieces overriding others. Most common in new and young ice.
Ridge / Pressure ridge	A linear pattern of broken ice forced upwards by pressure.
RIO	Risk Index Outcome
RIV	Risk Index Value
Rotten ice	Ice which has a honey-combed pattern and is in an advanced stage of decay.
Sail	The freeboard portion of a ridge.
Second-year ice	Old ice which has survived only one (1) summer's melt.

Shear zone	Area adjacent to the land fast ice where mobile ice becomes highly ridged and dense due to the pressure of the pack ice against the fast ice edge. The shear zone can consolidate and sometimes becomes part of the land fast ice.
Thaw hole	Vertical holes in ice that form when surface puddles melt through to the underlying water.
Thermo-dynamic summer	Beginning of the summer season with melt onset.
ZDS	Zone/Date System

1. Introduction

This report was prepared by Fednav Ice Services in response to a request from Baffinland Iron Mines. The purpose of this work is to update the summary of ice conditions and ship access along the approaches to the Steensby Inlet port site since the last report issued by Enfotec (now Fednav Ice Services) in 2011.

The analysis is based on historical ice conditions from 2005 to 2019 which are derived from Canadian Ice Service ice charts and satellite imagery. Other data sources were used, including climatic and metocean data as well as technical and scientific publications covering sea ice and Arctic navigation.

The report begins by describing ice conditions that can be encountered along the route. Year-round conditions are assessed, including potential ice hazards. Although the 2005-2019 period was used as background data for the analysis, images and ice charts included in the report are not older than 2010 in order to illustrate ice conditions that are most representative of the current reality.

Principles of the International Maritime Organization (IMO) Polar Code, and the Canadian Arctic Shipping Safety and Pollution Prevention Regulations (ASSPPR) were used as the basis to define access along the route. This report focusses on the evaluation of non-ice class vessels, 1C and 1A ice class vessels, and Polar Classes 4 and 5. To conduct this analysis, 15 years of weekly ice data were analyzed in order to have a realistic representation of expected ice conditions for shipping to Steensby Inlet.

Beyond compliance to regulation, the report presents an assessment of the different vessel types' capability to successfully operate in ice. Fednav's knowledge of ice conditions and navigational challenges in the Arctic is added to the regulatory-based shipping window thresholds, in order to provide a comprehensive appraisal of the situation. This assessment serves as the foundation for Fednav's recommendations regarding vessel requirements for the project.

Finally, the impacts of climate change on Arctic sea ice are discussed. The report is consistent with the current paradigm of the scientific community as it recognizes that there is indeed a trend of decreasing seasonal ice cover over the Arctic. Nonetheless, changes in sea ice also bring additional year to year variability and challenges related to ice movement.

2. Ice conditions along the route to Steensby Inlet

Steensby Inlet is in the northern part of Foxe Basin, on the western side of Baffin Island. The route from Europe involves transiting Hudson Strait, then heading north across Foxe Basin.

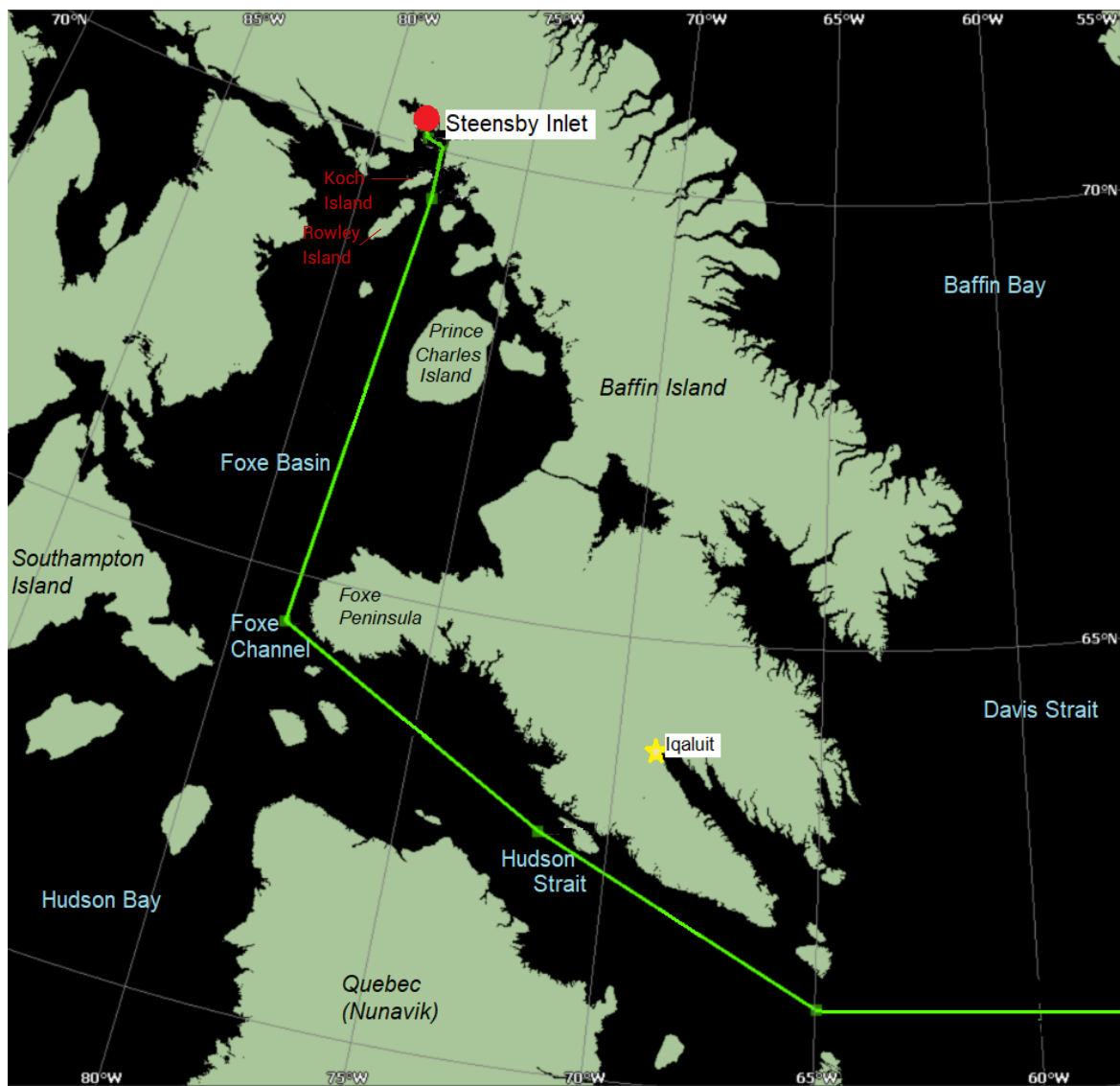


Figure 1. Route to Steensby Inlet with surrounding area.

The route to Steensby Inlet (Figure 1) involves a long segment of about 700 to 900 NM through the pack ice of Hudson Strait and Foxe Basin during winter. The fast ice portion is short, in comparison with the fast ice leading to Milne Inlet port, with an average distance of 40 NM at the peak of winter. The route identified in Figure 1 shows navigation to the east of Koch and Rowley Islands. This ice assessment is based on the vessels being permitted to navigate west of these islands when the prevailing ice conditions are preferable for safe navigation on the western side of these islands.

Foxe Basin is a broad waterbody that is covered with seasonal ice for several months of the year. The climate is polar, with average air temperatures below 0°C for 8 months of the year (Figure 2,3). Predominant winds over Foxe Basin during the winter are from the west and northwest. The predominant currents in Foxe Basin run from Fury and Hecla Strait, down the western side of Foxe Basin, and eastward along the southern portion of the Hudson Strait (Figure 4). During the ice-covered season, a combination of winds and currents influence the flow of ice southward through Foxe Basin and eastward through the Hudson Strait, towards Baffin Bay.

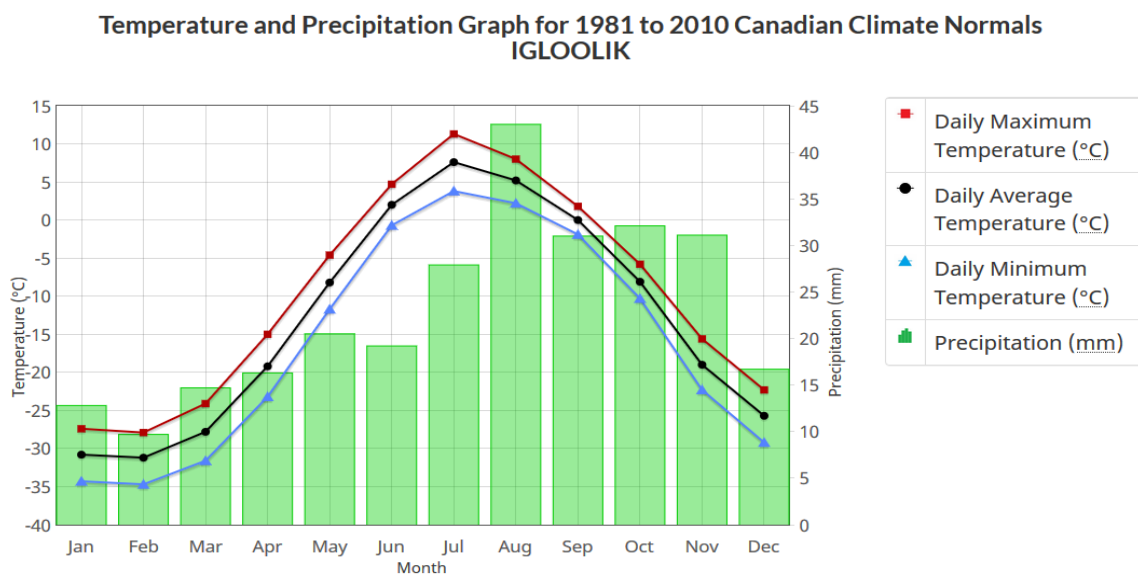


Figure 2. Monthly max, min, and average temperature and average monthly precipitation for Igloolik, Nunavut from 1981 to 2010 (Source: Environment and Climate Change Canada).

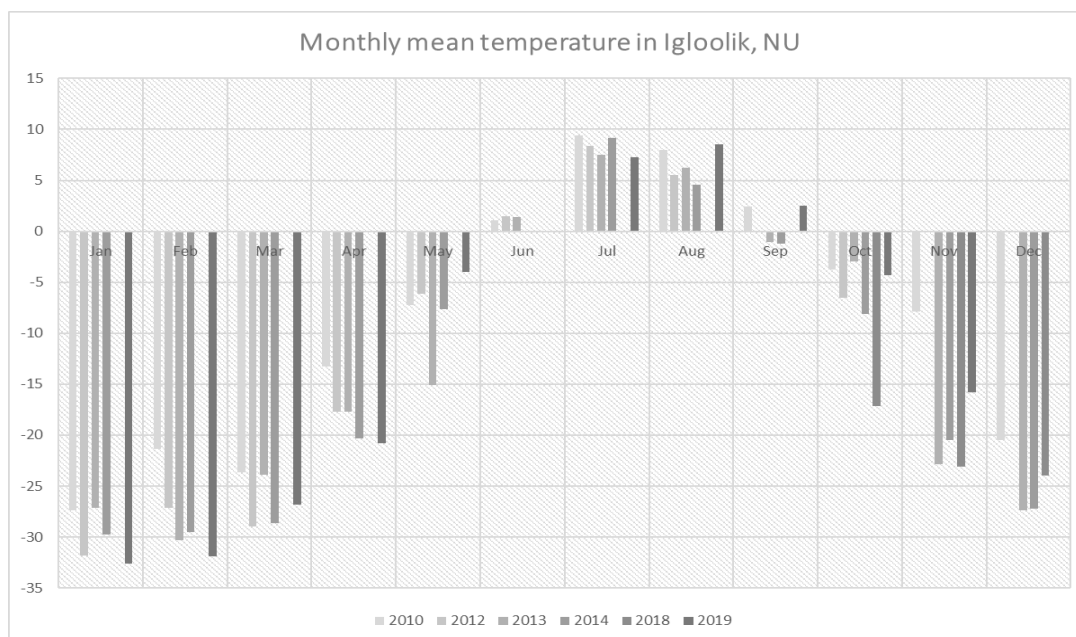


Figure 3. Monthly mean air temperatures for Igloolik, Nunavut, for 2010, 2012, 2013, 2014, 2018 and 2019 (Source of data: Environment and Climate Change Canada).

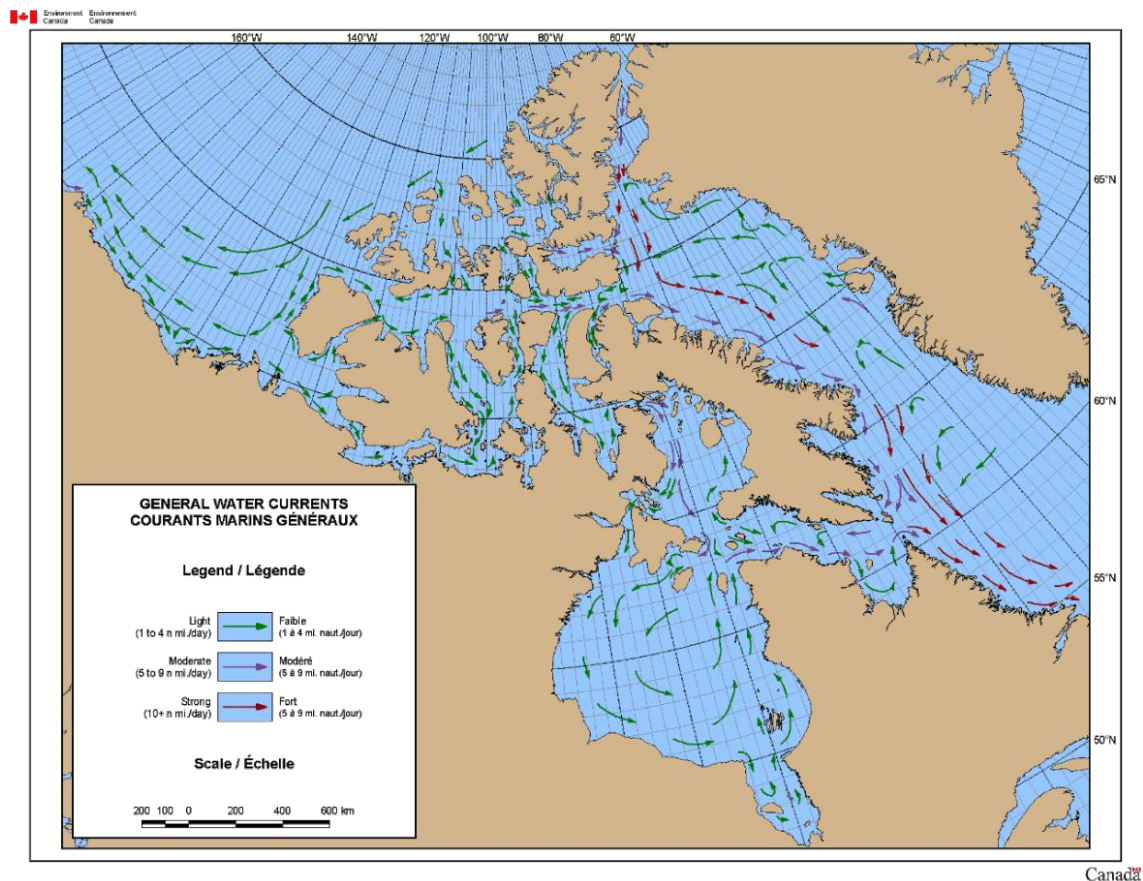


Figure 4. Surface currents in the Canadian Arctic (Source: Environment Canada).

In the following section, ice conditions will be defined according to seasons: 2.1 – Breakup and summer; 2.2 – Freeze-up and fall; 2.3 – Winter and spring. The analysis of ice conditions is based on weekly ice charts from the Canadian Ice Service (CIS) for the period of 2005 to 2019, and on occasional satellite imagery from two sensors:

- 1) NASA's MODIS (optical) satellite sensors, with daily coverage but subject to cloud cover and daylight limitations in northern regions;
- 2) ESA's Sentinel-1 (synthetic aperture radar) satellite sensors, with variable occasional coverage, but not subject to cloud cover and daylight limitations in northern regions.

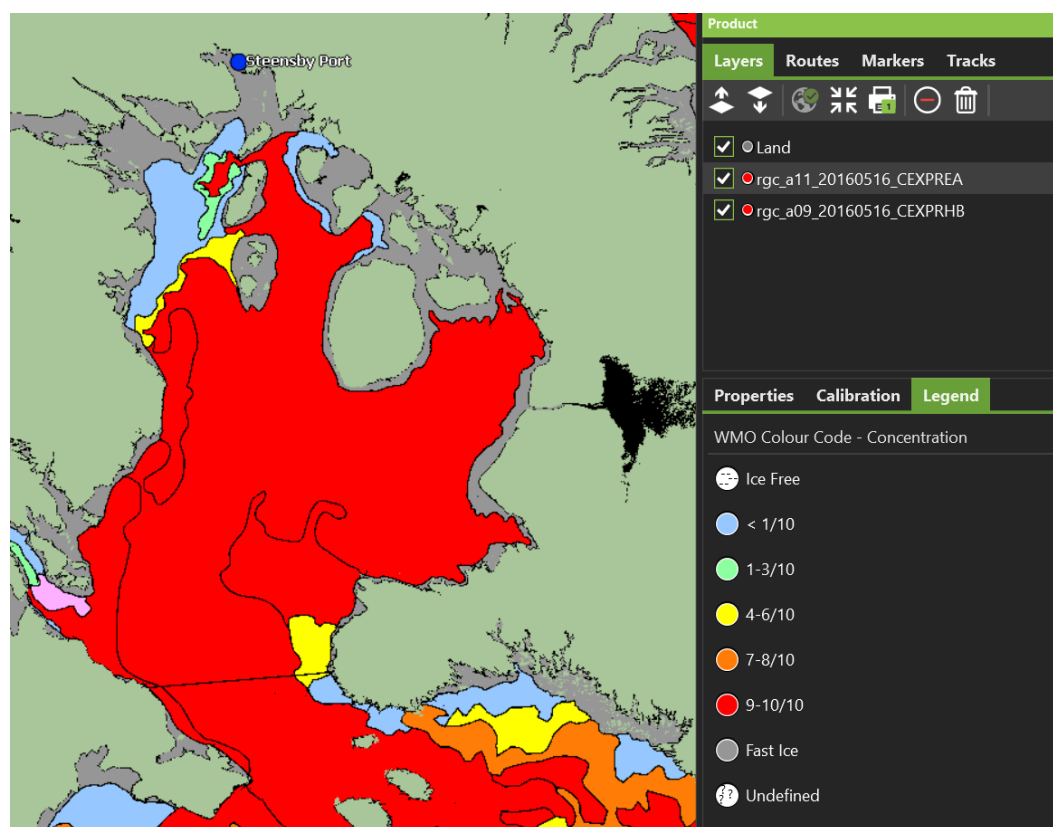
2.1 Breakup and summer / open water season

By the end of spring, the ice in Foxe Basin has reached the thick first-year ice stage, which means a thickness of more than 120 cm. Ice measurements in the fast ice in Steensby Inlet have shown that level ice thickness reaches between 1.3 and 1.8 m. With the deformation that occurs in the pack ice cover all winter long, the ice in Foxe Basin is likely to be between 1 and 4 m thick.

The melt onset starts progressively when the days become significantly longer, in April, as more sunlight reaches the surface and creates some minor melting within the ice cover. Once there are signs of melt in the ice, its resistance diminishes significantly with the advent of ice decay. The pace of the melting process increases when temperatures reach above the freezing level by mid-May.

Typically, the ice concentration first diminishes in areas where the ice is thinner, such as in the northwestern section of Foxe Basin where a polynya is located. The southeastern portion of Foxe Basin, specifically between Foxe Channel and Prince Charles Island, also decays faster than the rest of the area in June and early July because of the presence of polynyas. The central portion of Foxe Basin tends to take the longest to fully clear of ice, particularly between Prince Charles Island and Steensby Inlet, where ice lingers for several weeks, well into August and sometimes even September.

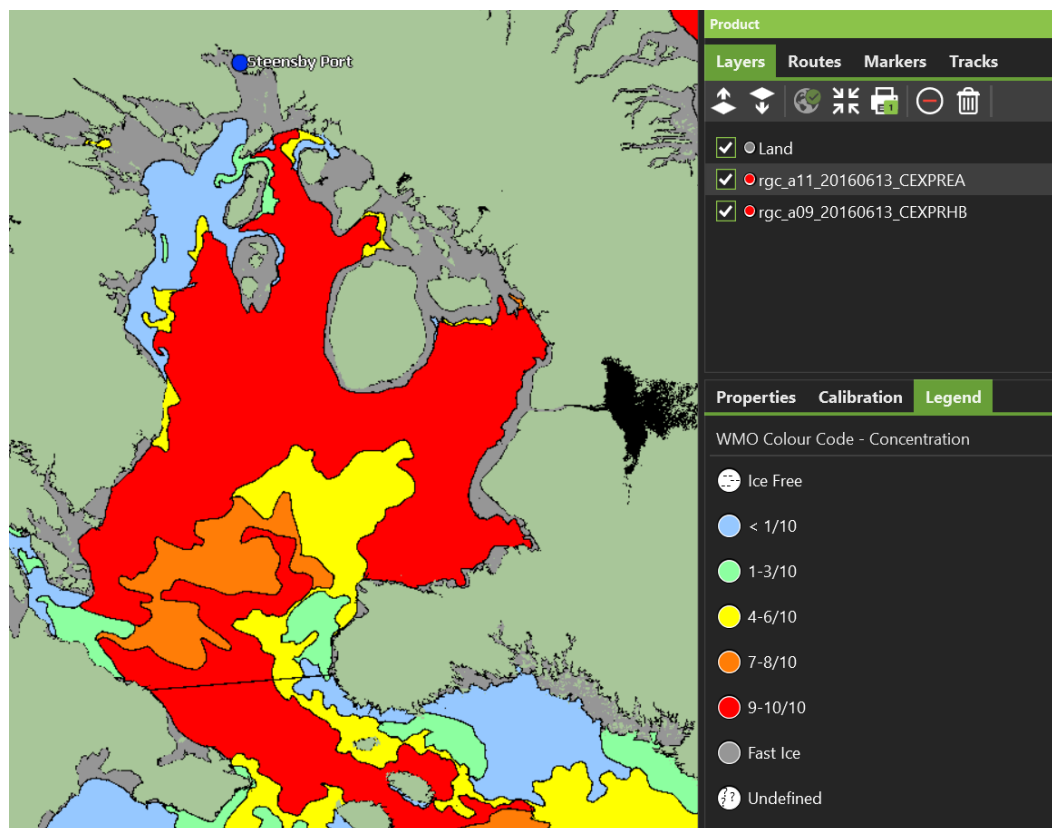
The following series of ice charts from summer 2016 show the typical sequence of ice clearing in Foxe Basin, along the route to Steensby Inlet. The charts were produced by the Canadian Ice Service and projected in IceNav, showing the ice regimes color coded based on the total concentration.



May 16, 2016

The NW portion of Foxe Basin is open water and light ice cover.

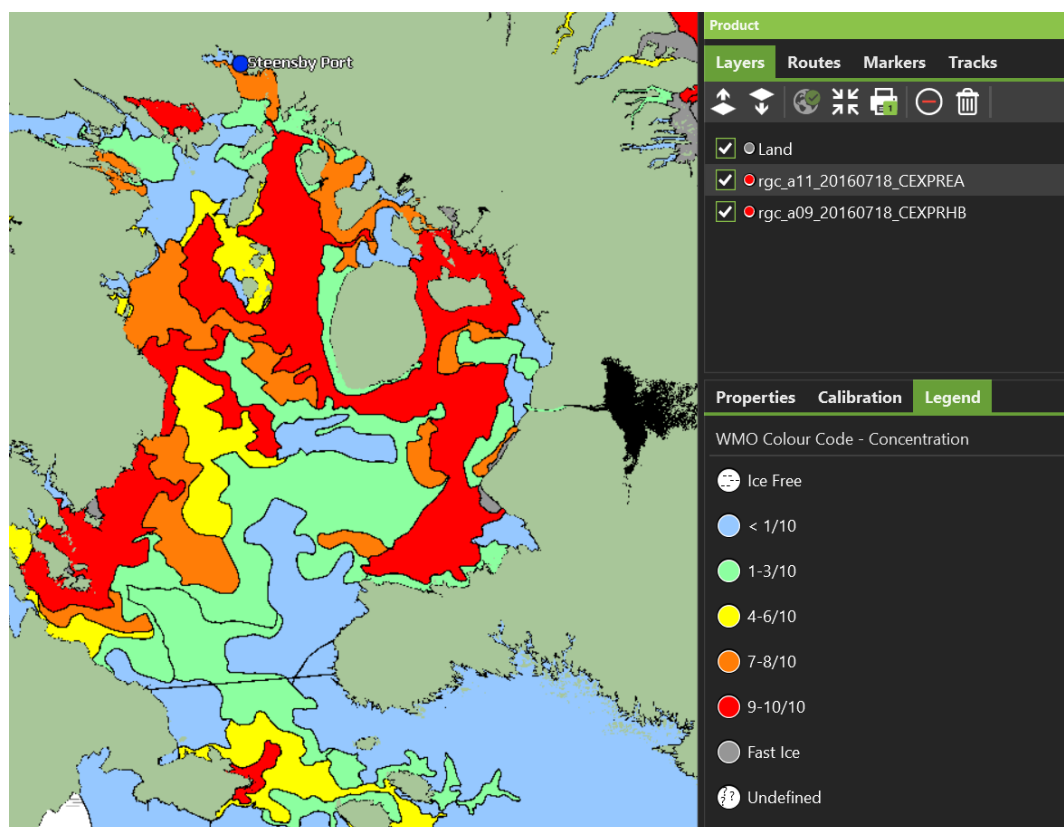
The area surrounding Foxe Peninsula also has a lighter ice cover with areas of open water.



June 13, 2016

The open water area in the NW portion of Foxe Basin is expanding.

Ice regimes become lighter in the southern part of Foxe Basin and the eastern part of Foxe Channel, along Foxe Peninsula.

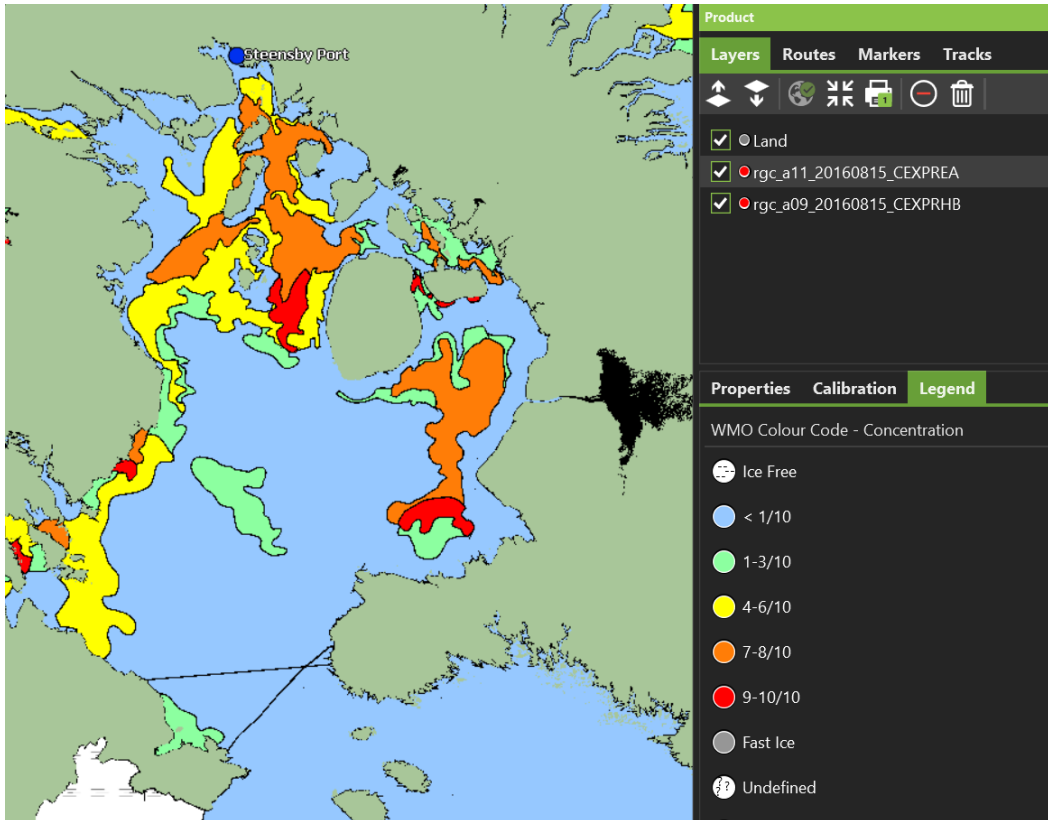


July 18, 2016

The fast ice has fractured in Steensby Inlet.

The pack ice is dispersing everywhere in Foxe Basin and Foxe Channel.

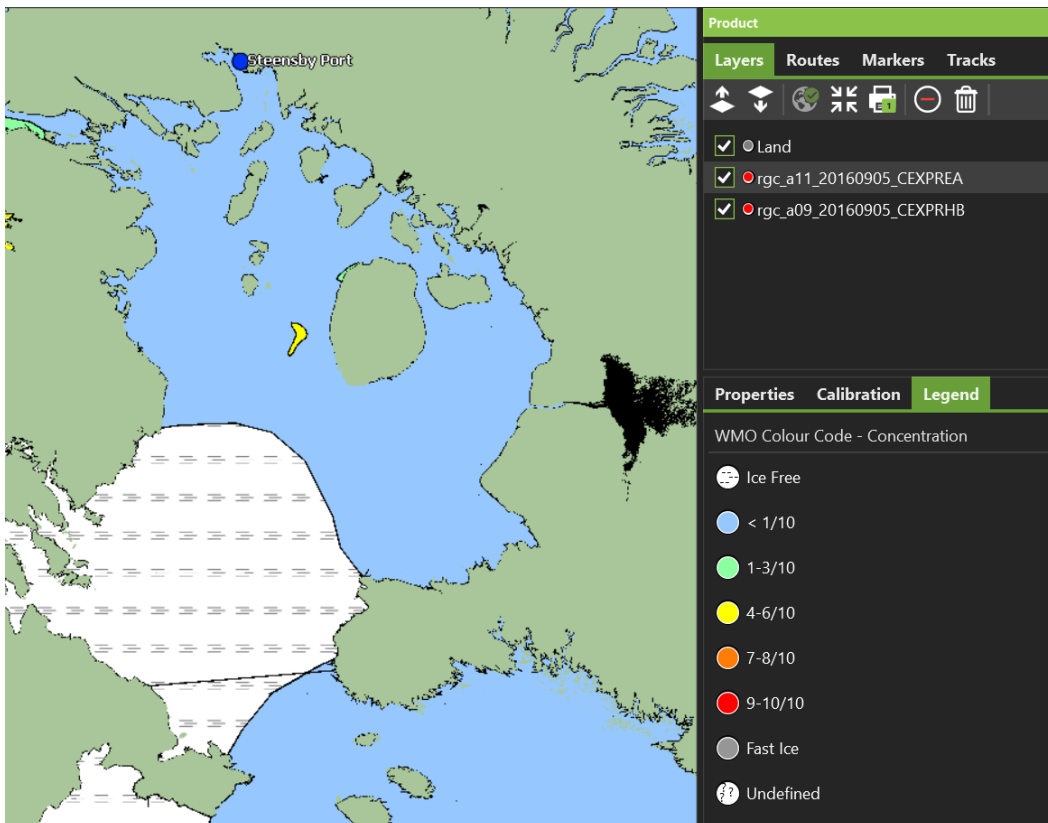
The shipping route between Prince Charles Island and Steensby Inlet is still predominantly covered with 9/10 of ice, although it is heavily decayed.



August 15, 2016

The ice cover is dispersed, and a large part of the route is now in open water.

The area between Prince Charles Island and Steensby Inlet remains covered in ice up to 8/10 concentration.



September 5, 2016

The shipping route is now completely open water or ice free.

Breakup of the fast ice in Steensby Inlet occurs on average around July 17 (Table 1). There is, however, a large variability with the timing of this event. Over the last 15 years, the earliest time at which the fast ice broke was July 1 (2019) and the latest was July 27 (2015). A trend towards earlier breakup is observed, but it is not a linear trend (Figure 5). The variability in the breakup date is 26 days.

As for the timing at which the route becomes open water, the average date is September 3 (Table 1). Over the last 15 years, the earliest date of open water was August 12 (2019) and the latest date was September 28 (2015). As for the timing of fast ice breakup, there is great variability in the date at which the area becomes open water (Figure 6).

The timing of fast ice breakup, as well as the pace at which the pack ice disperses at the beginning of summer, are not necessarily meaningful factors for the timing of fully open water conditions throughout Foxe Basin. The dispersion of the pack ice cover is subjected to air temperatures, wind speeds and directions, precipitations and currents. Weather conditions play a major role in the timing of ice events. As they are both variable and unpredictable over a long-time range, it is difficult to forecast the pace at which clear-up of the ice cover will unfold.

Once the ice cover is completely melted, conditions remain fully open water or ice free until fall begins and freeze-up starts again. There is no drifting ice coming into Foxe Basin through Fury and Hecla Strait and there are no icebergs in the area.

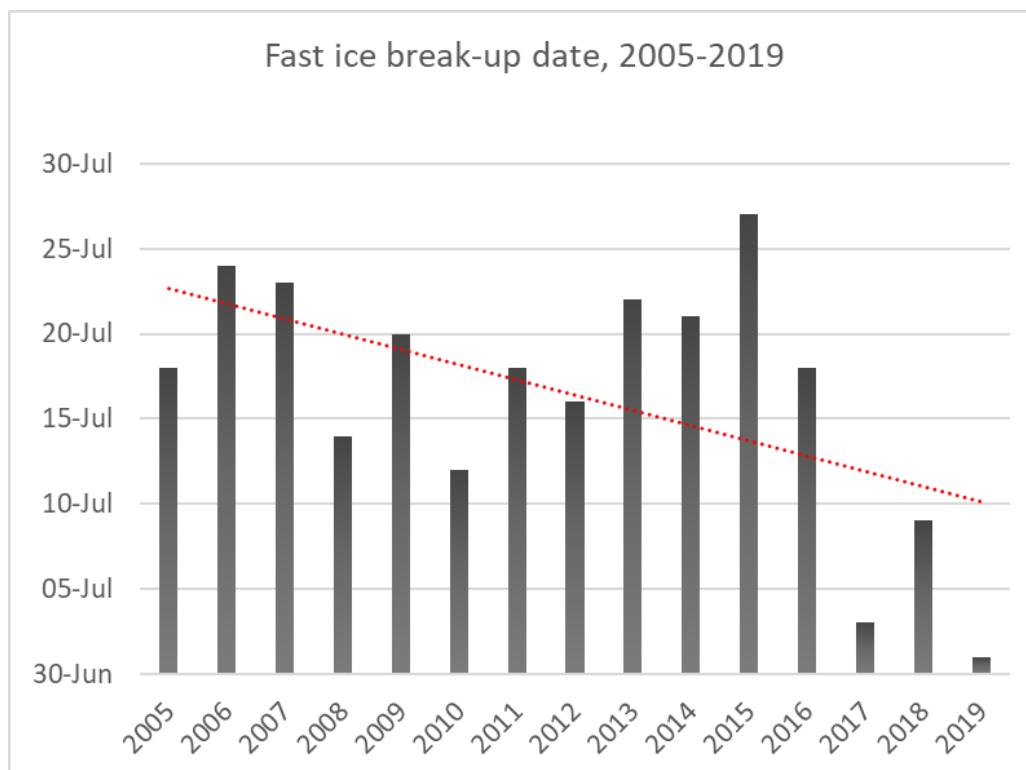


Figure 5. Date of fast ice breakup along the route to the Steensby Inlet port from 2005 to 2019.

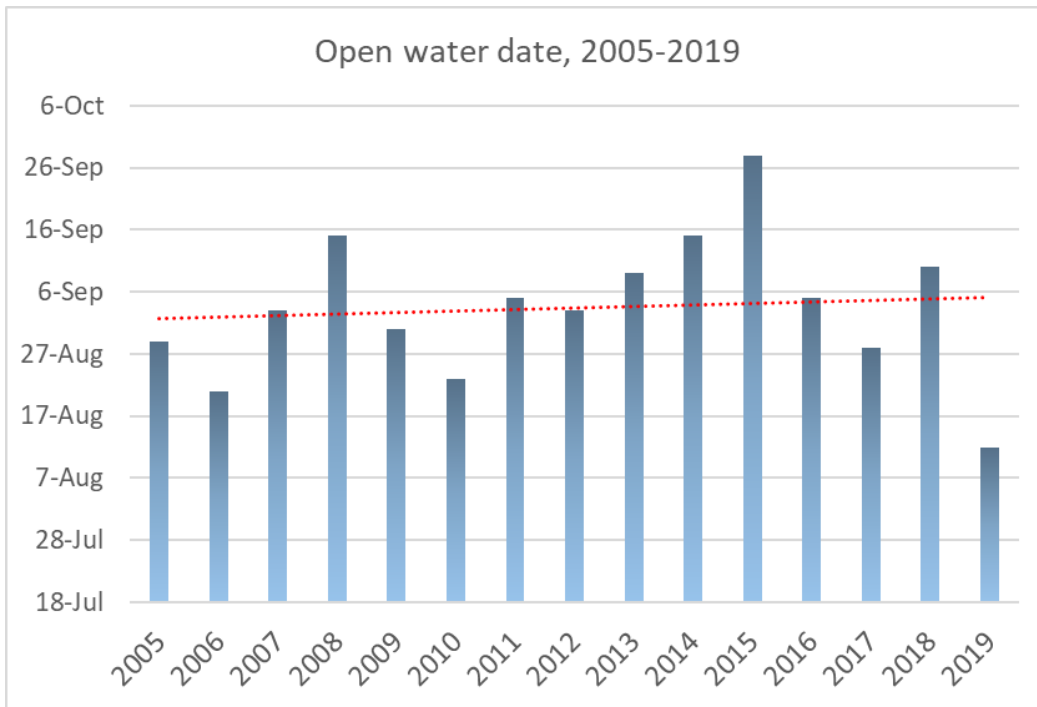


Figure 6. Date of open water along the route to the Steensby Inlet port site from 2005 to 2019.

Table 1. Breakup and open water dates along the route to the Steensby Inlet port site over last 15 years, based on weekly CIS ice charts.

Year	Fast ice Breakup	Open water	Freeze-up	Open water season length	Ice remnants or drifting ice during OW season
2005-06	July 18	Aug 29	Nov 7	70	n/a
2006-07	July 24	Aug 21	Nov 13	84	n/a
2007-08	July 23	Sept 03	Oct 29	56	n/a
2008-09	July 14	Sept 15	Oct 20	35	n/a
2009-10	July 20	Aug 31	Oct 12	44	n/a
2010-11	July 12	Aug 23	Nov 15	84	n/a
2011-12	July 18	Sept 05	Oct 24	49	n/a
2012-13	July 16	Sept 03	Oct 29	56	Until mid-Sept
2013-14	July 22	Sept 09	Oct 14	35	n/a
2014-15	July 21	Sept 15	Oct 13	25	n/a
2015-16	July 27	Sept 28	Oct 26	28	Until late Sept
2016-17	July 18	Sept 05	Oct 17	33	n/a
2017-18	July 03	Aug 28	Oct 23	64	n/a
2018-19	July 09	Sept 10	Oct 15	28	Through all Sept
2019-20	July 01	Aug 12	Nov 4	84	n/a
Average	<i>July 17</i>	<i>Sept 3</i>	<i>Oct 26</i>	<i>52</i>	<i>n/a</i>
Variability	<i>26 days</i>	<i>47 days</i>	<i>43 days</i>	<i>59</i>	<i>n/a</i>

2.2 Freeze-up and fall

At the end of the open water season, lower air temperatures and reduced sunlight hours both influence a relatively rapid freeze-up of Foxe Basin. Air temperatures near the Steensby port site, in Igloodik, drop consistently below zero in October, with a monthly average temperature of -8°C , and become considerably colder in November, with a monthly average temperature of -19°C .

Freeze-up in Foxe Basin normally begins in mid to late October, with new ice beginning to develop along the northern coasts of Foxe Basin, near the Steensby port site. Sea ice extends south from the northern coastline, and often extends through Fury and Hecla Strait from the Gulf of Boothia, which is normally fully ice-covered by the time new ice begins to develop in Foxe Basin. This flow of ice occurs as a result of the prevailing currents which run from the Gulf of Boothia, through Fury and Hecla Strait, to Foxe Basin, before continuing through the Hudson Strait (Figure 4 and Figure 7).

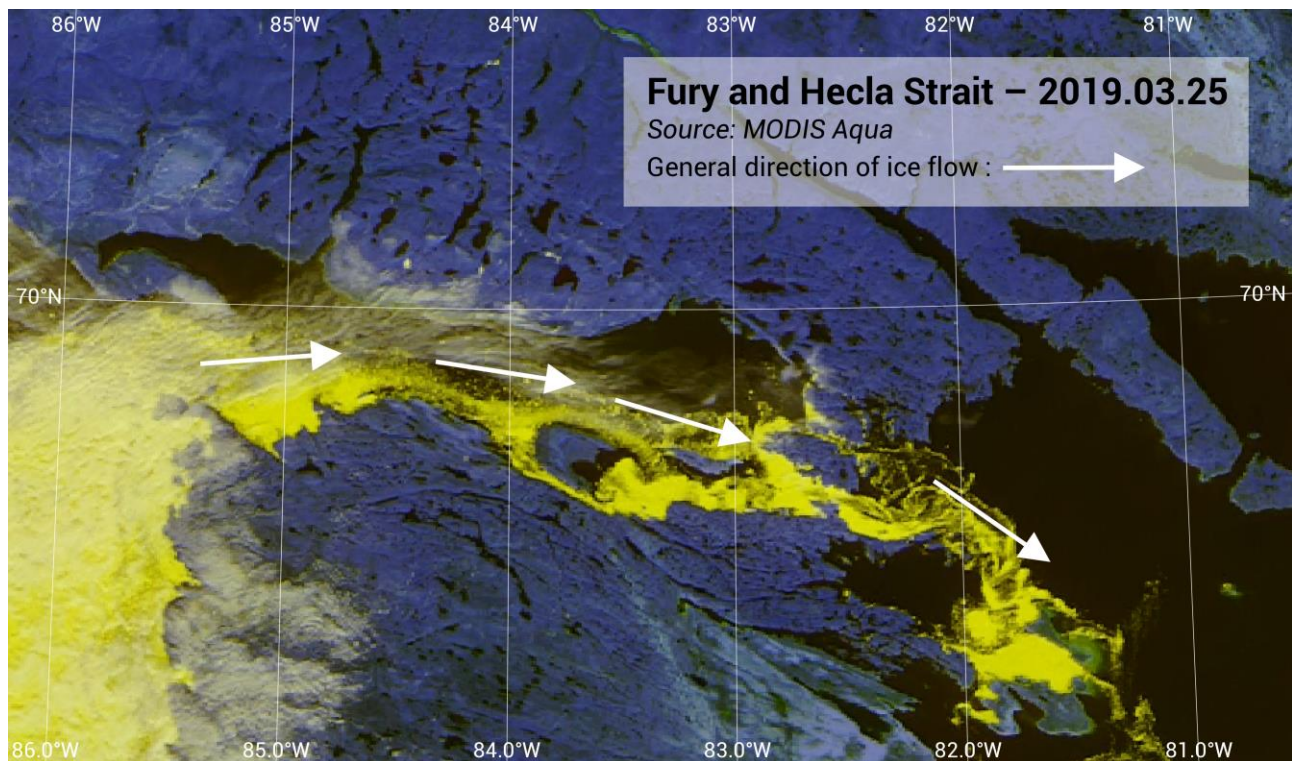
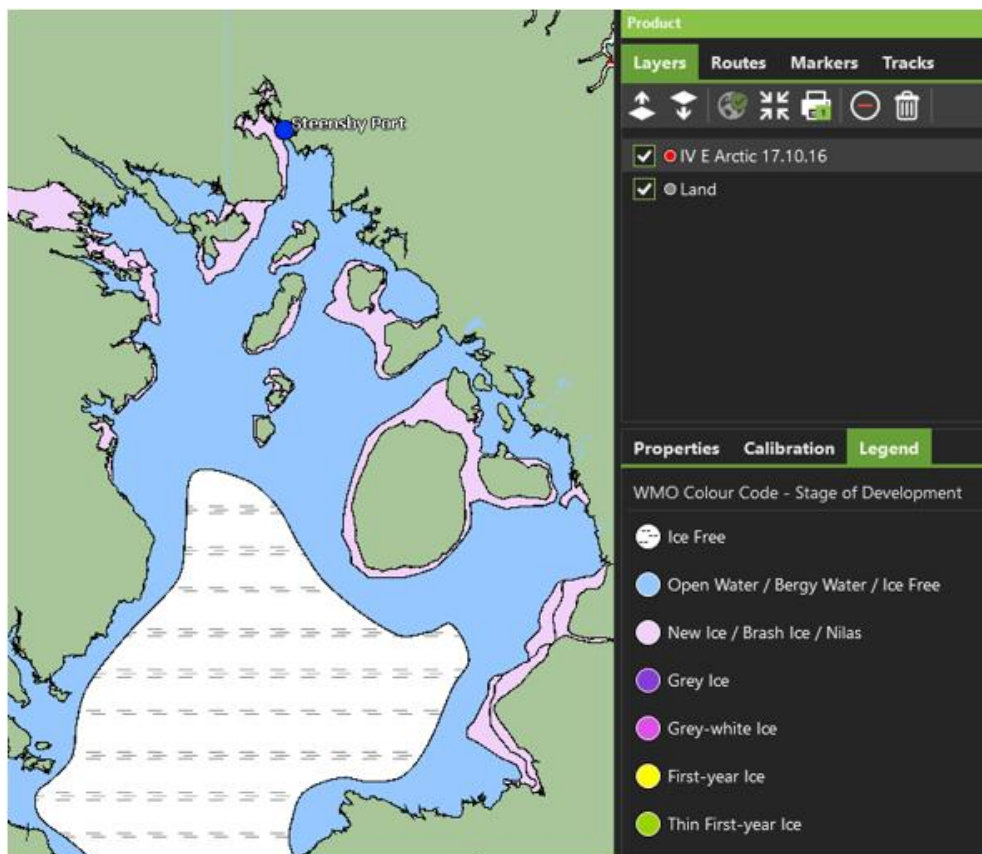


Figure 7. Flow of ice direction in Fury and Hecla Strait (Source: MODIS Aqua).

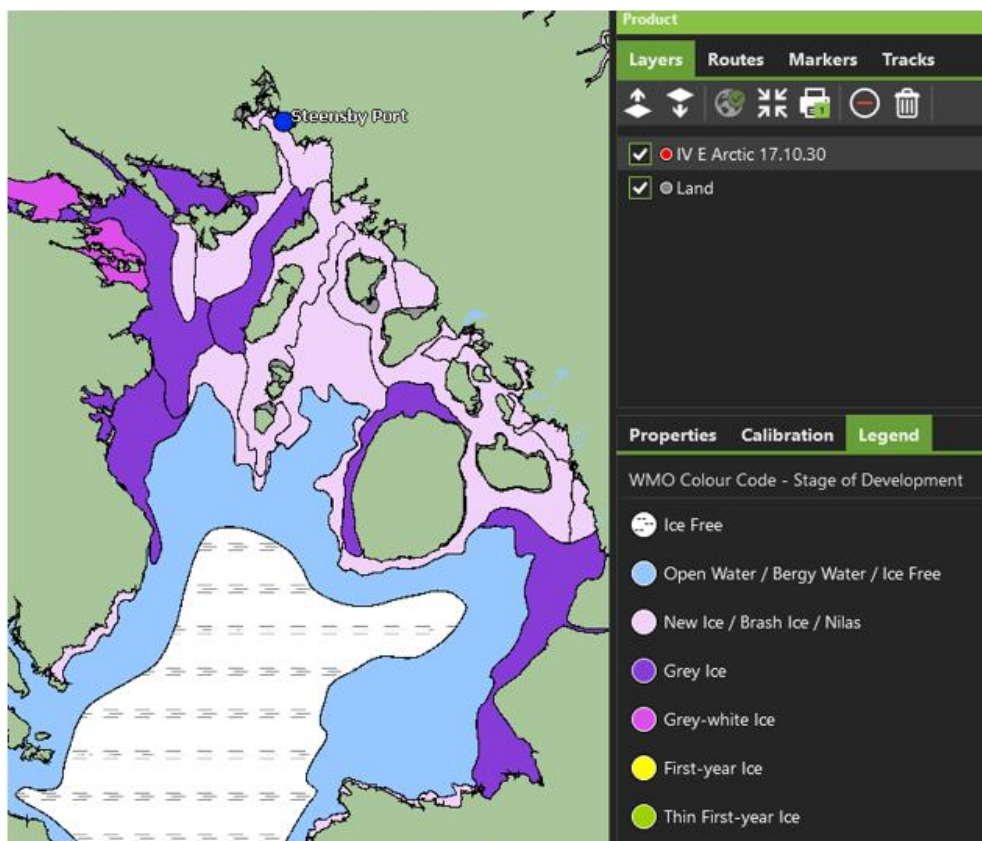
During the month of November, new ice expands southward through Foxe Basin. By the end of November, the ice thickness in Foxe Basin often grows to the thin first-year ice stage of development (30-70 cm thick) in some areas. In December, the ice cover extends eastward through Hudson Strait.

The following series of ice charts from fall 2017 show the typical sequence of freeze-up in Foxe Basin, along the route to Steensby Inlet. The charts were produced by the Canadian Ice Service and projected in IceNav, showing the ice regimes color coded based on the predominant stage of development of ice for each regime.



October 16, 2017

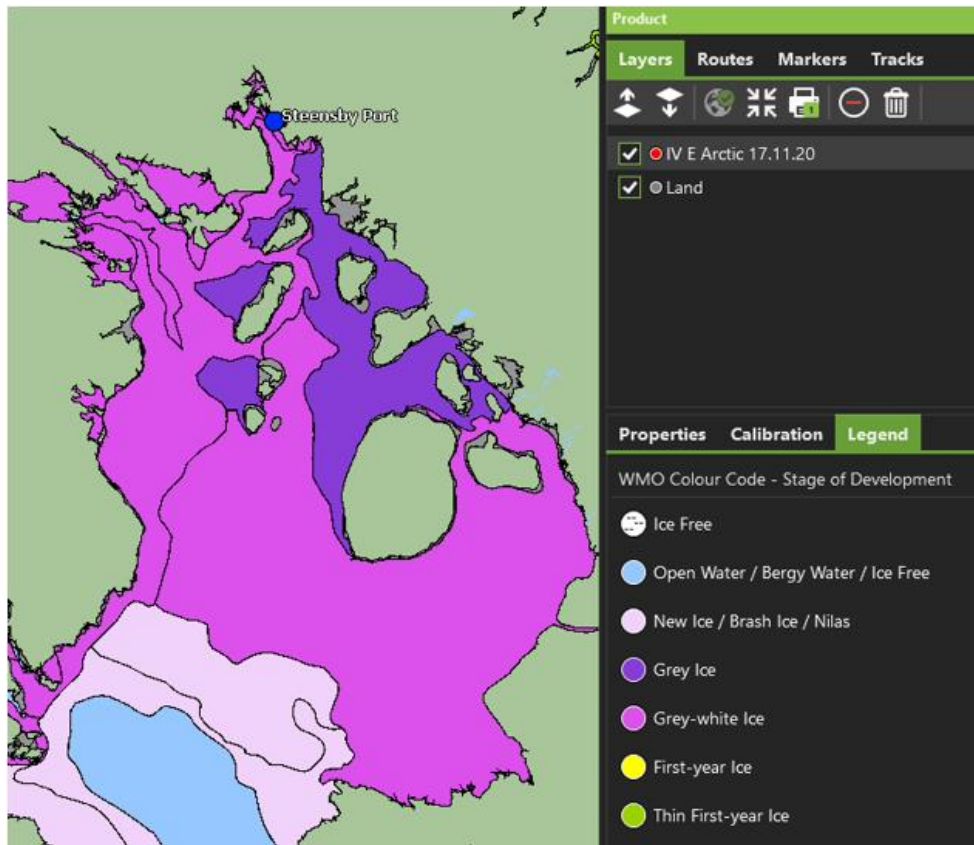
The shipping route to the Steensby port site is still open water and ice free. However, some new ice is beginning to form along the northern coastline of Foxe Basin near the Steensby port site.



October 30, 2017

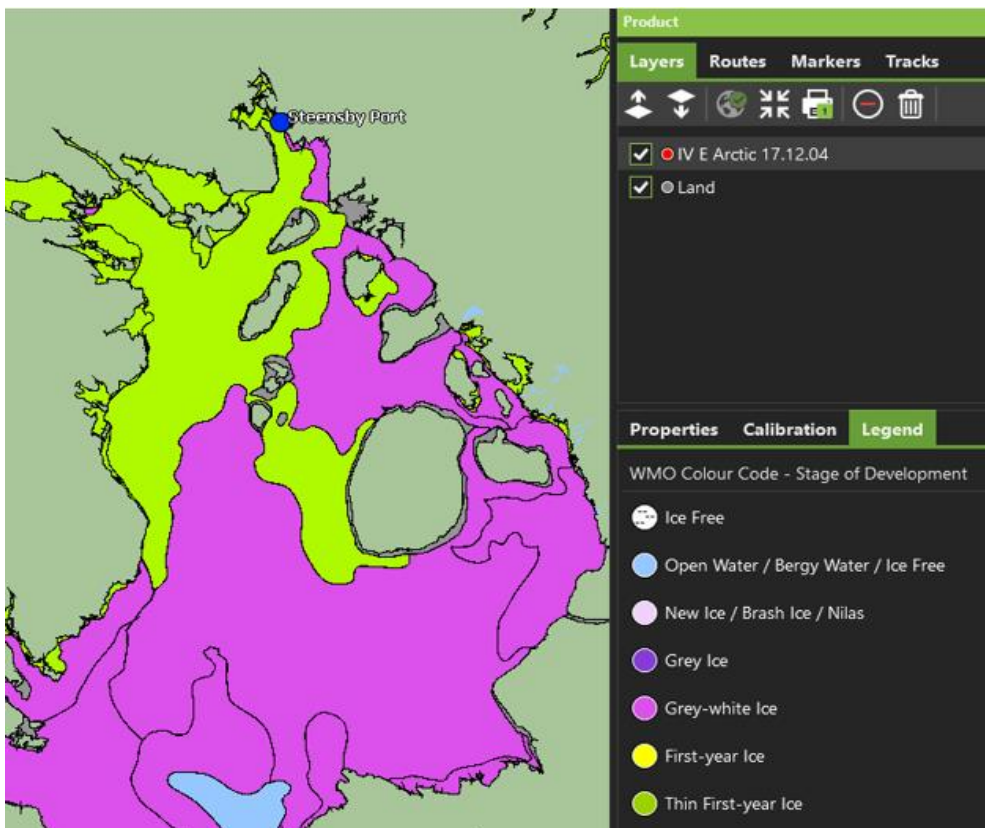
New ice has extended south, now covering the northern half of Foxe Basin.

The predominant ice thickness has grown to the stage of development of grey ice (10-15cm) in some areas south of Steensby port, and to grey-white ice (15-30cm) in Fury and Hecla Strait.



November 20, 2017

Foxe Basin is almost completely ice covered with a predominant ice type of grey-white ice (15-30cm).



December 4, 2017

Foxe Basin is completely ice covered with a predominant ice type of grey-white ice (15-30cm) and thin first year ice (30-70cm).

Although there is a small area of open water in the southeastern portion of Foxe Basin present, the sea ice has extended to through the western portion of the Hudson Strait at this time.

New ice, which is less than 10 cm thick, generally begins to form in Foxe Basin during the second half of October. The average date, over the last 15 years, for new ice development along the route to the Steensby port site was October 26 (Table 2). Similar to the breakup, there is a large variability with the timing of freeze-up in fall. Over the last 15 years, the earliest time at which new ice began forming was October 8 (2018), and the latest was November 15 (2010). There has been 38 days of variability in the date when new ice started to form along the route to the Steensby port in the last 15 years.

After new ice has formed and is no longer avoidable by ships transiting to Steensby Inlet, some of the ice along the route can reach the grey ice stage of development (10-15 cm thick). By the end of November, there is often grey-white ice (15-30 cm) that has developed along the route to the port site. Over the last 15 years, the average date at which an ice regime containing grey-white ice was unavoidable en route to Steensby Inlet was November 8. Once again, the interannual variability of this date is high: it was 45 days. As for the thin first-year ice stage of development (30-70 cm thick), the average date at which this type of ice could not be avoided was December 3. The variability of this date was 48 days.

Year to year variability in freeze-up patterns are a function of many different factors. Surface air temperatures, cumulative cooling and freezing degree-days, sea surface temperatures and regional winds can all impact the timing of freeze-up. In addition, early formation of new ice does not ensure fast development of a full ice cover in the area, or that the ice will thicken quickly. Local temperatures and winds influence the progression of ice growth after freeze-up, and changes in local conditions can impact the timing of the freeze-up and ice development significantly.

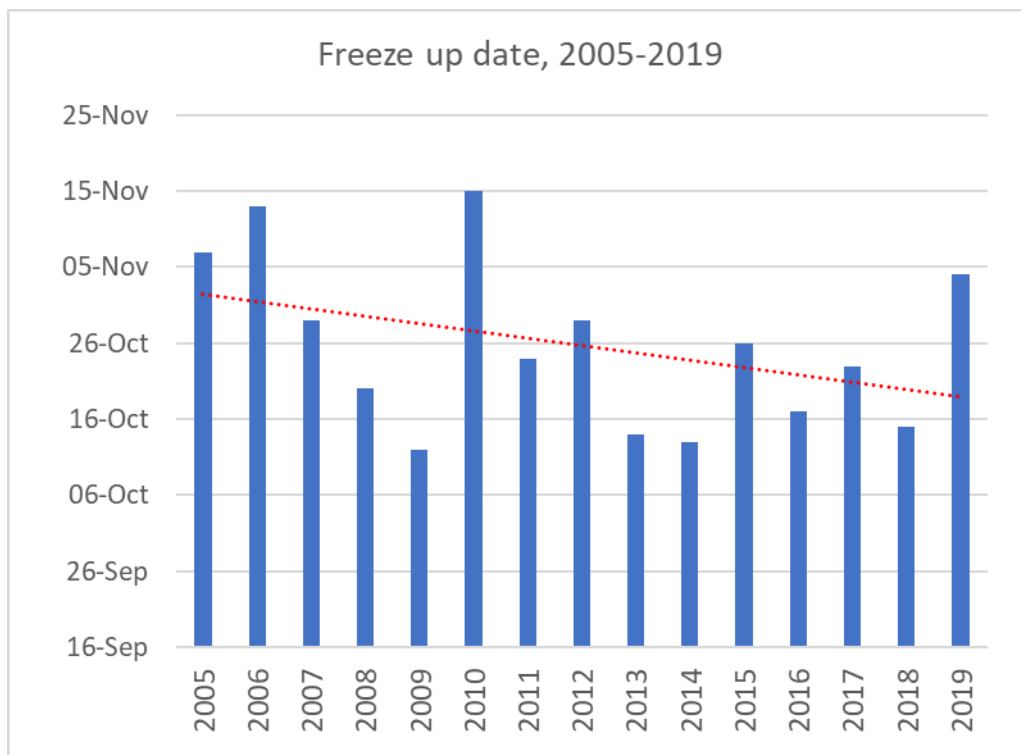


Figure 8. Yearly freeze-up dates along the route to Steensby Inlet from 2005 to 2019.

Table 2. Dates of freeze-up progression, along the route to the Steensby Inlet port site over last 15 years, based on weekly CIS ice charts.

Year	New ice	First GI	First GWI	Thin FY ice	Fast ice in Steensby port
2005-06	07-Nov	07-Nov	14-Nov	01-Jan	n/a
2006-07	13-Nov	13-Nov	27-Nov	18-Dec	04-Dec
2007-08	29-Oct	29-Oct	05-Nov	19-Nov	19-Nov
2008-09	20-Oct	20-Oct	27-Oct	17-Nov	17-Nov
2009-10	12-Oct	12-Oct	26-Oct	23-Nov	16-Nov
2010-11	15-Nov	15-Nov	06-Dec	03-Jan	27-Dec
2011-12	24-Oct	24-Oct	07-Nov	05-Dec	12-Dec
2012-13	29-Oct	29-Oct	12-Nov	26-Nov	26-Nov
2013-14	14-Oct	14-Oct	28-Oct	25-Nov	18-Nov
2014-15	20-Oct	20-Oct	27-Oct	24-Nov	01-Dec
2015-16	26-Oct	26-Oct	02-Nov	30-Nov	09-Nov
2016-17	17-Oct	17-Oct	07-Nov	28-Nov	14-Nov
2017-18	30-Oct	30-Oct	13-Nov	04-Dec	04-Dec
2018-19	08-Oct	15-Oct	22-Oct	19-Nov	12-Nov
2019-20	04-Nov	04-Nov	25-Nov	16-Dec	23-Dec
Average	26-Oct	26-Oct	08-Nov	03-Dec	27-Nov
Variability	38 days	34 days	45 days	48 days	48 days

2.3 Winter and spring

Along the route to the Steensby Inlet port site, ice starts forming in the northern part of Foxe Basin, then expands southwards through the Basin, then eastwards across Hudson Strait. Ultimately, the Foxe Basin and Hudson Strait are fully covered with ice for most of the winter and spring. The earlier freeze-up and later breakup in Foxe Basin gives more time for ice to thicken in Foxe Basin compared to Hudson Strait. At its peak, ice in Foxe Basin is predominantly made up of thick first-year ice, reaching more than 120cm in thickness, while at that time, Hudson Strait is usually dominated by medium first-year ice, between 70 and 120 cm thick. Although it has not been a common occurrence in recent years, multi-year ice floes can migrate to Foxe Basin through Fury and Hecla Strait, and can cause multi-year ice to be present in trace form in localised parts of Foxe Basin.

Dominant currents tend to displace the ice pack toward the south in the Hudson Strait and in Foxe Basin, creating polynyas where ice is usually much thinner (Figure 9). Therefore, lighter ice conditions typically prevail along the southern coast of Baffin Island, in the Hudson Strait, and in the Northern portion of Foxe Basin. Easterly winds, combined with the localised south-easterly current, can also contribute to a displacement of the pack at the western end of the Foxe Peninsula, thus spawning an area of thinner ice.

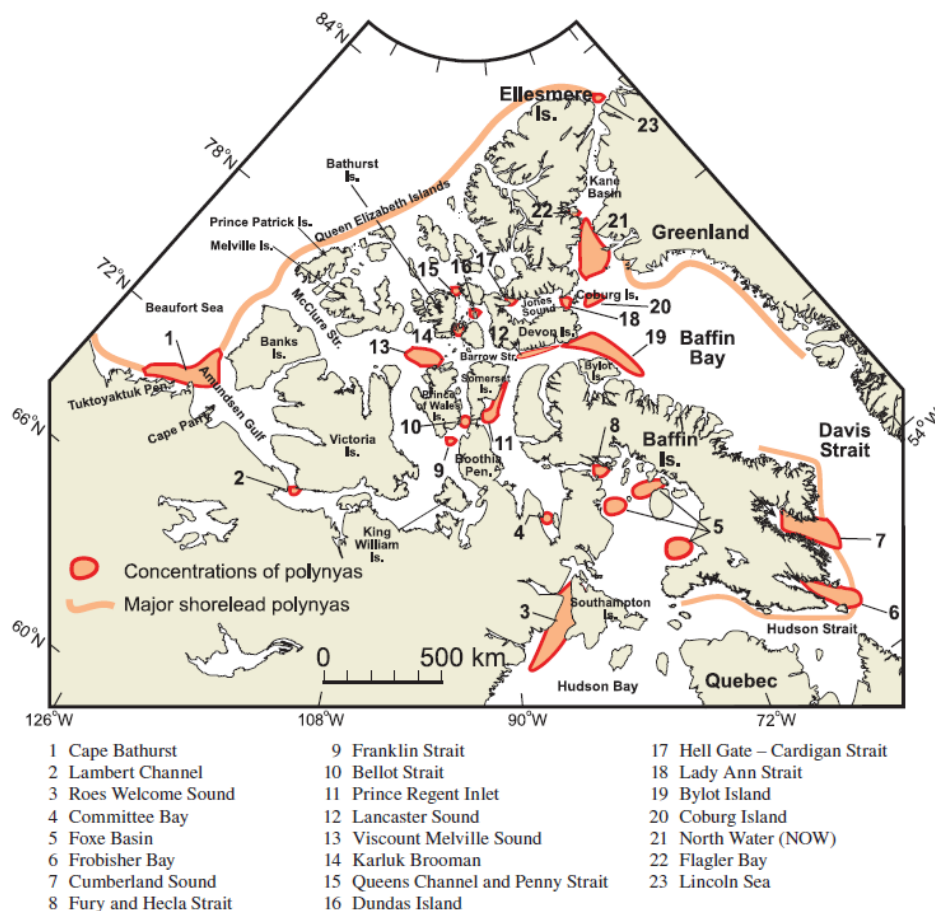


Figure 9. Map of known polynyas in the Canadian Arctic, adapted from Barber and Massom (2007) and Stirling (1981) (Source: Hannah et al., 2009).

Dominant ocean currents, combined with the coastal morphology of Hudson Strait and Foxe Basin, create natural choke points where ice pressure can significantly build up. Prevailing winds can also contribute to the build up of pressure and create formidable challenges that can significantly slow down or stop even high ice class vessels. The pack is in constant motion and sways back and forth because of tidal forces, but eventually makes it way south, through Foxe Basin, and east through Hudson Strait. As such, ice eventually passes through the choke points. The process crates ridges and deformation within the ice, much of which remain as the pressure subsides, when the ice is no longer choked. Also, because the tide is one factor in the build up of pressure along the route to Steensby Port, there is a cyclical subsidence in pressure throughout the day as the tide changes.

One of these choke points is the narrow section at the eastern end of Hudson Strait, between Cape Chidley and Resolution Island. There, the pack ice that floes in an eastward direction is compacted by the land masses, thus creating pressure within the pack. Thick first-year ice with multi-year ice inclusion, icebergs and bergy bits flowing south from Baffin Bay, through the western section of Davis Strait, interfuses with the ice outputted from Hudson Strait, thus exacerbating this navigational obstacle. Some of this ice from Davis Strait can even migrate westward into the Hudson Strait, carried

by currents along the southern shore of Baffin Island, sometimes up to Big Island, before getting redirected eastward, then flushed out of Hudson Strait into Davis Strait (Figure 10).

The southern part of Foxe Basin is also an area where ice pressure can build up. There, the ice that flows in a generally southwards direction is forced through Foxe Channel, between the Foxe Peninsula and the Bell Peninsula. Mill Island, Salisbury Island and Nottingham Island, where Foxe Channel meets Hudson Strait, further restricts the movement of the ice pack. Furthermore, the vast circumscribed expanse that is Foxe Basin is conducive to the inception of severe winds, which compresses the ice pack. These factors, combined to the ebb and flow of the ice resulting from the tide, are conducive to the build up of pressure and ensuing ridging and deformation (Figure 10).

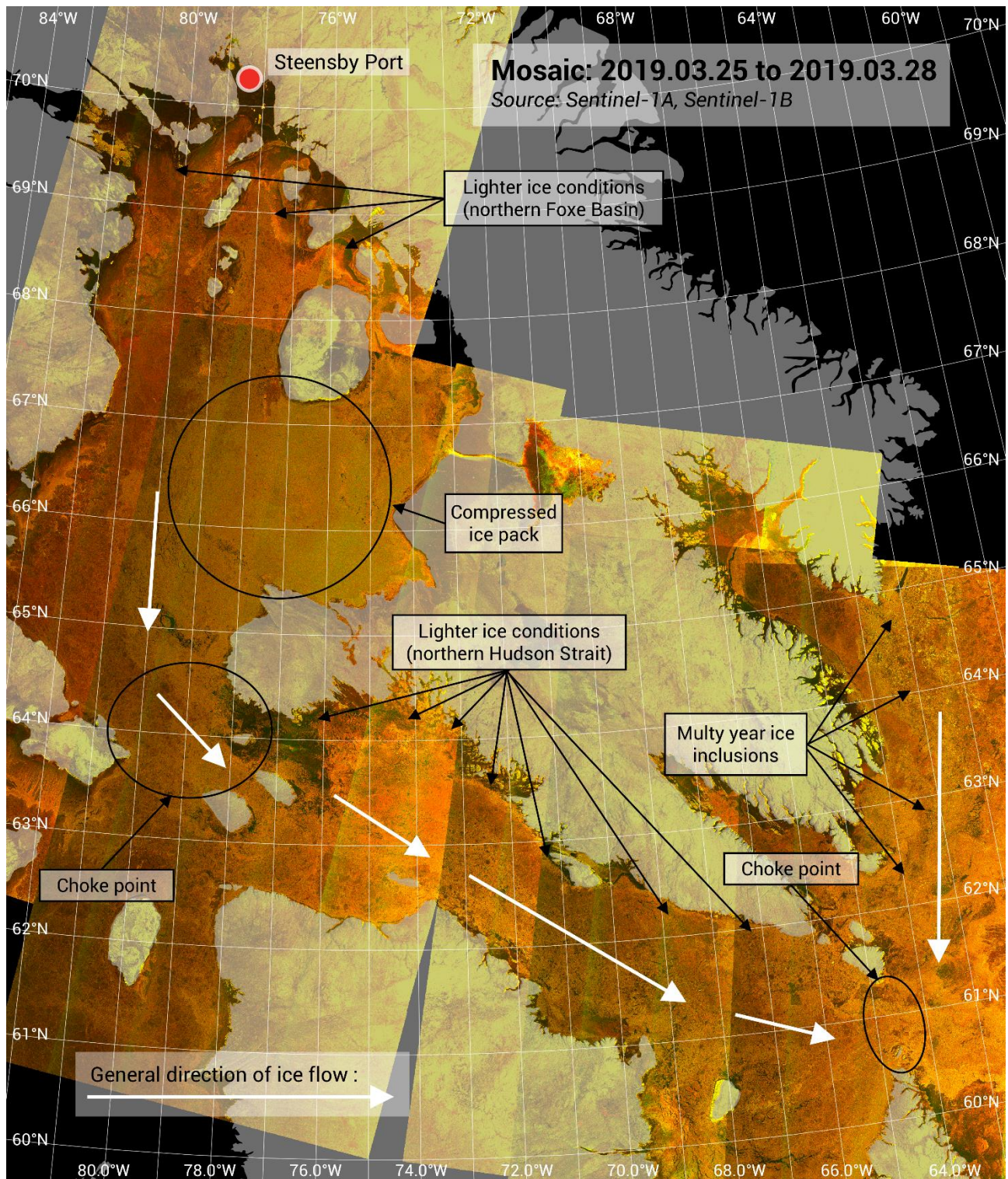


Figure 10. Satellite image mosaic of Foxe Basin and Hudson Strait, March 25–28, 2019 (Source: Sentinel-A and Sentinel 1B).

In winter and spring, judicious routing through the localised areas where ice conditions are lighter can lessen the effort needed to reach to Steensby Port. However, the natural choke points, the ebb and flow of the tide, the ice pressure, and the prevalent ridging and deformation of the ice that is encountered in other parts of the route make accessing the Steensby Inlet port site a challenge, even for high ice class vessels.

3. Vessel access to port site

In determining vessel access to the port site, this section focuses on the waterways that span from the eastern side of the Hudson Strait, through Foxe Basin, to the Steensby Inlet port site. This is the primary area where sea ice will be encountered by ships transiting to the port site.

Determining vessel access to the port is a complex task, especially when shipping scenarios outside of the open water or light ice seasons are evaluated. There is a somewhat significant volume of information covering the area available, consisting mostly of ice charts and satellite images. This data was used to model ship access based on the regulatory framework in place in Canada, as well as the framework put in place by the International Maritime Organization (IMO) Polar Code. However, because of the nature of the data used, this model can only depict a partial picture of the uniqueness of navigating in the Canadian Arctic during the ice infested season.

This said, there is limited shipping experience through heavy ice in the region, and most of that experience was gained by Fednav, through the navigation of the Hudson Strait to Deception Bay, as well as in higher latitudes of the Canadian Arctic, for the Polaris and Nanisivik mining projects. The knowledge gained by these projects in Canadian ice-covered waters has been utilized in order to critically evaluate and supplement the results of the modeling undertaken and, ultimately, to establish Fednav's recommendations regarding vessel access to the port site.

3.1 Regulatory framework

Several pieces of legislation govern shipping in the Canadian Arctic, but the main one is the *Arctic Water Pollution Prevention Act* (AWPPA). One of the key regulations of the AWPPA is the *Arctic Shipping Pollution Prevention Regulations* (ASPPR), which concerns "navigation in coastal waters within Canadian jurisdiction north of latitude 60°N" (Transport Canada). The ASPPR covers various aspects related to safe shipping in Arctic waters, such as: ship construction requirements, bunkering stations, Arctic Pollution Prevention certificates, Ice Navigators, fuel, sewage, oil leaks, etc. Ship access is also outlined in the ASPPR under three systems: the Zone/Date system (ZDS), the Arctic Ice Regime Shipping System (AIRSS) and the IMO's POLARIS.

All these systems include the notion of ice classes. The ice classifications systems used in Canada's waterways north of 60°N consist of the 'Type' and the Arctic Class systems, which are defined in the ASPPR, as well as the International Association of Classification Societies Ltd. (IACS) Polar Class

system. Although still in use for existing ships, the Arctic Class system has been superseded by the IACS Polar Classes.

Table 3 and Table 4 give an overview of the operational profiles of 'Type' and Polar Class vessels. A more thorough description of the classifications systems used in Canada is given in Appendix II.

Table 3. ASPPR 'Type' Descriptions.

ASPPR 'Type'	Stage of development supported (10/10 concentration)	Maximum Ice Thickness
Type A	Medium first-year	120 cm
Type B	Thin first-year second stage	70 cm
Type C	Thin first-year first stage	50 cm
Type D	Grey-white ice	30 cm
Type E	Grey ice	15 cm

Table 4. IACS Polar Class Descriptions.

Polar Class	Ice Description
PC 1	Year-round operation in all Polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice which may include multi-year ice inclusions
PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/fall operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/fall operation in thin first-year ice which may include old ice inclusions

The Zone/Date system dates from the original 1972 enactment. It divides the waterways of the Canadian Arctic north of 60°N into 16 Shipping Safety Control Zones. Permissible access dates for each zone are based on the ice classification of the vessel. Basically, each zone is characterized by a "level of severity" based on historical ice conditions: Zone 1 has the most severe ice conditions, while Zone 16 has the lightest (the ZDS map and table of entry dates can be found in Appendix II). However, it became apparent that the ZDS was too rigid to properly capture the changing ice conditions of the Canadian Arctic and the seasonal variability, as it did not consider the real-time conditions that the vessels were facing. There were many examples of vessels encountering severe ice conditions within the allowable access windows, and other situations where vessels were denied access to areas of light ice conditions.

In 1996, Transport Canada proposed the introduction of the Arctic Ice Regime Shipping System as part of the ASPPR. Ships that have a classification that is included in the ZDS (Arctic Class and 'Type' vessels) only need to use the AIRSS when they transit outside of the dates defined in ZDS in order to validate the vessel's access in a given area according to current ice conditions. Recent changes to

regulations have resulted in a new methodology that has superseded AIRSS. The POLARIS methodology is now the standard methodology used by ships navigating globally in polar waters,

POLARIS and the Polar Code

On January 1st, 2017, the International Maritime Organization (IMO) put in place an *International Code for Ships Operating in Polar Waters* – the Polar Code. This regulation is mandatory under both the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (MARPOL). (For more information on the Polar Code regulation refer to [IMO Circular MSC.1/Circ.1519](#).)

In accordance with the Polar Code, new and existing ships must have a valid Polar Ship Certificate establishing the ships operational limits, including limitations related to ship structural ice capabilities. The IMO has identified certain methodologies, such as AIRSS, that are acceptable to assess the operational capabilities and limitations of a given ship in ice. Along with the Polar Code, a new methodology was created, based in part on AIRSS. This new methodology is named The Polar Operational Limit Assessment Risk Indexing System (POLARIS).

Extracted from the revised Arctic Water Pollution Prevention Act, as presented in the Canada Gazette on January 10th 2018:

"While similar in scope and intent, AIRSS and POLARIS are nevertheless two unique methodologies for assessing a vessel's operational capabilities and limitations in ice conditions. Accordingly, Transport Canada recognizes that the use of either AIRSS or POLARIS by identical vessels in identical ice regimes could produce minor differences in operating outcomes depending upon which system is used. To help address certain situations where this variance could occur, the Regulations will therefore require that all Polar Class vessels and/or all vessels built after January 1, 2017 (the international entry-into-force date of the Polar Code), and that do not use the ZDS must use POLARIS. All other vessels built before this date are afforded the option of using either AIRSS or POLARIS if operating outside of the ZDS."

For the purpose of this assessment, only POLARIS will be used to assess vessel accessibility to Steensby Inlet.

Using input from historic or current ice charts, or in situ observations, POLARIS uses the concept of Risk Index Values (RIVs), related to an evaluation of the relative risk of different ice types, to assess the limitations of the ship operating in a given ice regime. POLARIS uses a four-step process to determine if a vessel should be navigating in a specific area:

- 1) Defining the **ice regime**: an ice regime is a defined area in which ice conditions are more or less the same. For planning purposes, this can be done with the use of satellite imagery or ice charts. When a voyage is underway, *in situ* observations are used to determine the actual ice conditions;
- 2) Obtaining **Risk Index Values** (RIVs) that are associated with the vessel's ice class. These multipliers represent the risk of damage according to the vessel's capabilities for a specific ice type;
- 3) Calculating **Risk Index Outcome** (RIO) within the area of operation;
- 4) Determining if special considerations should be taken with regards to the results of the previously calculated RIO;

a. Risk Index Values (RIVs)

Every ice type (including open water) is given a numerical value that is dependent on the ice category of the vessel; that numerical value is the RIV. The RIV reflects the level of risk or operational constraint that an ice type poses to each vessel class. The ice types in POLARIS conform to the WMO nomenclature, with two exceptions: "medium first-year ice less than 1 m thick", and "light multi-year ice". "Medium first-year ice under 1m thick" should only be used in the place of "medium first-year ice" when the operator can confidently confirm the medium ice in the regime is less than 1 m thick. Similarly, "light multi-year ice" should only be used in place of "heavy multi-year ice" when the operator can confidently confirm that the multi-year ice in the regime is less than 2.5 m thick.

Table 5. Polaris Risk Index Values per vessel type (Source: IMO).

Ice Class	Ice-Free	New Ice	Grey Ice	Grey White Ice	Thin First Year ice 1st Stage	Thin First Year Ice 2nd Stage	Medium First Year Ice less than 1 m thick	Medium First Year Ice	Thick First Year Ice	Second Year Ice	Light Multi Year Ice, less than 2.5 m thick	Heavy Multi Year Ice
PC1	3	3	3	3	2	2	2	2	2	2	1	1
PC2	3	3	3	3	2	2	2	2	2	1	1	0
PC3	3	3	3	3	2	2	2	2	2	1	0	-1
PC4	3	3	3	3	2	2	2	2	1	0	-1	-2
PC5	3	3	3	3	2	2	1	1	0	-1	-2	-2
PC6	3	2	2	2	2	1	1	0	-1	-2	-3	-3
PC7	3	2	2	2	1	1	0	-1	-2	-3	-3	-3
IA Super	3	2	2	2	2	1	0	-1	-2	-3	-4	-4
IA	3	2	2	2	1	0	-1	-2	-3	-4	-5	-5
IB	3	2	2	1	0	-1	-2	-3	-4	-5	-6	-6
IC	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8
Not Ice Strengthened	3	1	0	-1	-2	-3	-4	-5	-6	-7	-8	-8

b. Calculating the Risk Index Outcome (RIO)

For any ice regime, a RIO is calculated by taking the sum of the products of the concentration of the ice types present (in tenths) in the region and their RIVs in the following equation:

$$\text{RIO} = (\text{Ca} \times \text{RIVa}) + (\text{Cb} \times \text{RIVb}) + (\text{Cc} \times \text{RIVc})$$

Where:

RIO = Risk Index Outcome;

Ca = concentration in tenths of ice type "a";

RIVa = risk index value for ice type "a"

The term on the right-hand side of the equation (a, b and c) is repeated for each ice type present, including open water. Ice traces are not included in the calculation.

For example, with a 1A Super ice class vessel, an ice regime containing 5/10 of multi-year ice, 2/10 of thin first-year ice (second stage) and 3/10 of grey-white ice would result in the following risk index outcome:

$$\text{RIO} = (\text{Ca} \times \text{RIVa}) + (\text{Cb} \times \text{RIVb}) + (\text{Cc} \times \text{RIVc})$$

$$\text{RIO} = (5 \times -4) + (2 \times 1) + (3 \times 2)$$

$$\text{RIO} = -20 + 2 + 6$$

$$\text{RIO} = -12 \text{ (Operation subject to special consideration)}$$

For a PC 3 vessel, the same ice regime would result in the following risk index outcome:

$$\text{RIO} = (\text{Ca} \times \text{RIVa}) + (\text{Cb} \times \text{RIVb}) + (\text{Cc} \times \text{RIVc})$$

$$\text{RIO} = (5 \times -1) + (2 \times 2) + (3 \times 3)$$

$$\text{RIO} = -5 + 4 + 9$$

$$\text{RIO} = 8 \text{ (Normal Operation)}$$

The RIO is therefore unique to the particular ice regime and the ice class of the ship operating within its boundaries. Unlike the AIRSS, where the access into a regime is either permitted or denied based on the IN calculated, when using POLARIS, a RIO will either inform that normal operations can be assumed through a given regime, or that additional considerations must be made (Table 6). Given a positive RIO, normal operations can be assumed, i.e. no changes made to navigation. Given a RIO less than 0 but greater or equal to -10, operation through the regime is considered an elevated risk operation. Given a RIO of less than -10, the operation is subject to special considerations.

Table 6. Risk Index Outcome criteria.

<i>RIO_{SHIP}</i>	<i>Ice classes PC1-PC7</i>	<i>Ice classes below PC 7 and ships not assigned an ice class</i>
$RIO \geq 0$	Normal operation	Normal operation
$-10 \leq RIO < 0$	Elevated operational risk*	Operation subject to special consideration**
$RIO < -10$	Operation subject to special consideration**	Operation subject to special consideration**

Ships operating in an elevated risk regime should reduce their speeds in accordance with the suggested speed limits in Table 7. Further measures could also include additional watchkeeping or icebreaker support. A regime with elevated risk should be avoided when possible, and if identified and included in voyage planning, contingency measures should be put into place.

Table 7. Recommended speed limit for elevated risk operations.

Ice Class	Recommended Speed Limit
PC 1	11 knots
PC 2	8 knots
PC 3-5	5 knots
Below PC 5	3 knots

Extreme caution should be taken by the Captain and officers when navigating into a regime where a calculated RIO indicates the operation is subject to special consideration. Further reductions in speed, re-routing, and other special measures should be completed when operating in regimes subject to special consideration. During voyage planning, such regimes should be avoided.

c. Bonus and subtraction application

POLARIS calculations will take into consideration Ice Decay when it is confirmed by ice information or when it is visually observed. When operating in decayed ice conditions, the RIVs in Table 8 can be used to calculate the RIO of the ice regime.

The POLARIS methodology also acknowledges that ships operating under icebreaker support have a different risk profile when compared to ships operating independently. When following an icebreaking vessel, the RIO should be calculated based on the ice immediately ahead of the ship, i.e. the ice in the track of the escorting vessel. It is important to consider if the icebreaking vessel has a narrower beam

than the vessel being escorted. In this situation, both the ice in the track and the unbroken ice on the edge of the track must be used to calculate the RIO of the regime.

The icebreaking vessel should calculate its own RIO in the regime and should not be escorting a vessel if the calculated RIO through a regime is less than 0. The escorting operations should also be reconsidered if the escorted vessel enters a regime where a calculated RIO identifies the operation is subject to special considerations.

When voyage planning, historical ice charts can be used, and, as a general rule, a value of +10 can be added to a calculated RIO for a vessel that will be escorted by an appropriate icebreaking vessel. It is important to remember that this is an average value and could differ greatly in various conditions. The RIO should always be modified with the ice ahead of the ship when the icebreaking operations are taking place.

Table 8. Risk Index Values – decayed ice conditions (Source: IMO).

Ice Class	Ice-Free	New Ice	Grey Ice	Grey White Ice	Thin First Year ice 1st Stage	Thin First Year Ice 2nd Stage	Medium First Year Ice, less than 1 m thick	Medium First Year Ice	Thick First Year Ice	Second Year Ice	Light Multi Year Ice, less than 2.5 m thick	Heavy Multi Year Ice
PC1	3	3	3	3	2	2	2	2	2	2	1	1
PC2	3	3	3	3	2	2	2	2	2	1	1	0
PC3	3	3	3	3	2	2	2	2	2	1	0	-1
PC4	3	3	3	3	2	2	2	2	1	0	-1	-2
PC5	3	3	3	3	2	2	2	2	1	-1	-2	-2
PC6	3	2	2	2	2	1	2	1	0	-2	-3	-3
PC7	3	2	2	2	1	1	1	0	-1	-3	-3	-3
IA Super	3	2	2	2	2	1	1	0	-1	-3	-4	-4
IA	3	2	2	2	1	0	0	-1	-2	-4	-5	-5
IB	3	2	2	1	0	-1	-1	-2	-3	-5	-6	-6
IC	3	2	1	0	-1	-2	-2	-3	-4	-6	-7	-8
Not Ice Strengthened	3	1	0	-1	-2	-3	-3	-4	-5	-7	-8	-8

a. Fednav's analysis of the use of POLARIS

The scope of POLARIS is limited to preventing structural damage to the ship from impacts with sea ice. Moreover, POLARIS-based results assume that ship crews and operators exercise caution with respect to ice conditions, and emphasize the responsibility of the Master for the safety of the ship. For instance, it is assumed that speeds are reduced, when the ice conditions warrant it, in order to avoid full speed collision with dangerous ice floes. Other types of hazards or peculiarities related to ice navigation are not considered at all in POLARIS, namely pressure on the ice.

The ability of a ship to successfully make progress in ice is not the purpose of the POLARIS. This is important to note as, in some cases, being unable to make progress in the ice can lead to hazardous situations. For example, a ship that is making slow progress through an ice field might end up in a threatening situation if the motion of the ice pack causes the vessel to drift towards a shoal or uncharted territory.

Similarly, efficiency is not a concern under POLARIS. Therefore, a ship allowed to navigate in an ice regime might be able to make some progress while still being underpowered. This means that not only will it take time to navigate through the regime, but the load on the engine might be very high and the amount of fuel burned would be high as well. In some circumstances, the entire fuel supply can be depleted in a single transit if the vessel is unsuitable for the journey.

This highlights the fact that POLARIS does not eliminate the need for prudence and adequate planning from both ship operators and crews. POLARIS does prevent grossly inadequate vessels from navigating in ice infested waters that exceed their capabilities. However, simply being granted access to an ice regime cannot guarantee a safe transit. The experience of the crew and operator is crucial.

3.2 Access to Steensby Port based on the Zone/Date System

Ships travelling to the Steensby port must navigate through Shipping Safety Control Zones (SSCZ) 8, 14 and 15 (the ZDS map and table of entry dates can be found in Appendix II).

Between the three SSCZ control zones that must be transited (8, 14, and 15), Zone 8 has the most limited access period.

Using the ZDS zone 8 restrictions, access to the Steensby port is as follows:

- Non ice class ships (Type E) - between August 20 and October 20
- Ships with an ice class of DNV 1C (Type D) - between August 15 and October 20
- Ships with an ice class of DNV 1B (Type C) - between August 10 to October 25
- Ships with an ice class of DNV 1A (Type B) - between August 10 and October 31.

As stated, the ZDS does not consider seasonal variability as it does not involve an assessment of the real-time conditions that the vessels are facing. There are many examples of vessels encountering severe ice conditions within the allowable access windows, and other situations where vessels were denied access to areas of light ice conditions. When assessing the accessibility of vessels of different ice classes for a given route, Fednav uses the ZDS as guide but deepens the analysis by evaluating

historical weekly ice conditions within and outside of the Zone/Dates. Calculating the RIOs outside of the thresholds defined by the ZDS provides a finer assessment of the shipping windows for different ice classes.

3.3 Vessel access by ice class and shipping window

Fednav has assessed the potential access windows for non-ice class, 1C, 1A, and polar class ships to Steensby Inlet. The 2011 accessibility study provided to Baffinland detailed shipping windows primarily based on the Zone/Date system, as it was the most reliable reference from which to derive such information. Fednav's expanded experience with vessels of various ice classes, as well as a better understanding of ice dynamics in the Hudson Strait, combined with recent increased access to remotely sensed data, allows for finer estimations of the shipping seasons for each ice class.

This section details Fednav's findings from a historical assessment of the dates until which light ice class ships would have been able to safely navigate to and from the Steensby Inlet port site over the last 15 years. These dates are conservative estimates based on Fednav's experience of operating ships of various ice classes in an Arctic environment during the freeze-up, breakup, and winter periods. The ZDS and POLARIS are also taken into consideration.

Sea ice freeze-up

When investigating vessel access during the freeze-up period, ice conditions along the route to the Steensby port site were assessed using weekly regional ice charts published by the Canadian Ice Service for the last 15 years. Based on this more recent data, and Fednav's additional understanding of the capabilities of ships of different ice classes, there have been some updates to the proposed end of season dates for the non-ice class, 1C and 1A ice class vessels in comparison to the conclusions made in the 2011 report.

Table 9 shows the regulatory closing dates for the non-ice class, 1C and 1A vessels based on the ZDS, in addition to the proposed acceptable dates provided in the 2011 report and the updated proposed dates.

Fednav's proposed end of season date for non-ice class ships is now closer to the closing date based on ZDS, on October 21. This date is the average last week of open water or very low ice concentration conditions along the route to the Steensby port site before the freeze-up along the route.

The proposed end of season date for 1C ice class vessels is October 30, which is 5 days later than what had been proposed in the 2011 report, and 10 days later than the closing date based on ZDS.

As for 1A ice class vessels, Fednav's proposed end of season date is November 18, which is 18 days later than both what had been reported in the 2011 report and the closing date based on ZDS.

Table 9. Comparison of the proposed date for the end of the shipping season between three assessments: Zone/Date system, AIRSS calculation as presented in the 2011 report, and Fednav assessment with data from 2005 to 2019.

Ship Ice Class	ZDS closing date	2011 AIRSS based assessment	Updated 2019 assessment (based on 2005 – 2019)
Non-Ice Class	20-Oct	25-Oct	21-Oct
1C	20-Oct	25-Oct	30-Oct
1A	31-Oct	31-Oct	18-Nov

It is important to remember, however, that there is considerable interannual variability between the end of season dates for the different ice classes over the past 15 years. During the fall, freeze-up occurs relatively quickly in northern Foxe Basin. The development of ice in this area, near the port site, is the limiting factor at the end of the shipping season. Table 10 shows the average date (also presented as Fednav's proposed end of season date) for each ice class, as well as the earliest and latest dates that were deemed acceptable to have a vessel of that ice class navigating to or from the Steensby port site over the last 15 years. The yearly dates are shown in Table 11.

The interannual variability between when light ice class vessels would have been deemed safe to navigate to or from the port site is important to consider as it shows the period of time during which there would need to be flexibility in using either a higher ice class ship or having icebreaker support, if deemed necessary. The latest dates in Table 10 also give an idea of how late in the season lighter ice class vessels may be utilized during a year of late freeze-up. It must be noted, however, that the possibility of extending a shipping season will need to be evaluated on a year-by-year basis, i.e. depending on current local conditions as well as the short term forecast of ice conditions.

Table 10. Proposed end of shipping season dates for non-ice class, 1C and 1A ice class vessels compared to the earliest and latest dates, over the last 15 years.

Ship Ice Class	Average Date	Earliest Date	Latest Date
Non-Ice Class	21-Oct	08-Oct (2018)	08-Nov (2010)
1C	30-Oct	15-Oct (2018)	18-Nov (2019)
1A	18-Nov	02-Nov (2009)	13-Dec (2010)

Table 11. Last week of accessibility to Steensby Port site for non-ice class, 1C and 1A ice class vessels during freeze-up based of weekly CIS ice charts from the last 15 years.

Year	Non-Ice Class	1C	1A	Fast ice in port
2005-06	31-Oct	07-Nov	14-Nov	01-Feb
2006-07	06-Nov	13-Nov	27-Nov	04-Dec
2007-08	22-Oct	29-Oct	12-Nov	19-Nov
2008-09	13-Oct	20-Oct	10-Nov	17-Nov
2009-10	12-Oct	19-Oct	02-Nov	16-Nov
2010-11	08-Nov	15-Nov	13-Dec	27-Dec
2011-12	17-Oct	31-Oct	28-Nov	12-Dec
2012-13	29-Oct	05-Nov	19-Nov	26-Nov
2013-14	14-Oct	21-Oct	11-Nov	18-Nov
2014-15	13-Oct	20-Oct	17-Nov	01-Dec
2015-16	19-Oct	26-Oct	09-Nov	09-Nov
2016-17	17-Oct	31-Oct	07-Nov	14-Nov
2017-18	23-Oct	31-Oct	27-Nov	04-Dec
2018-19	08-Oct	15-Oct	05-Nov	12-Nov
2019-20	04-Nov	18-Nov	09-Dec	02-Dec
Average	21-Oct	30-Oct	18-Nov	22-Dec
Variability	31 days	34 days	41 days	53 days
ZDS	20-Oct	20-Oct	31-Oct	n/a

Icebreaker support after freeze-up

After freeze-up along the route to Steensby Inlet, the use of an icebreaker escort could extend the shipping season for 1A vessels.

When solely considering ice thickness en route to Steensby Inlet, the use of an icebreaker escort could theoretically increase the shipping window of lighter ice class vessels by 1 to 2 weeks, and in some years up to 3 weeks. It is important, however, to consider the practicality, limitations and commercial viability of such extensive escorting operations. After freeze-up, it is often the ice concentration and extent that would be the limiting factor for an escorted 1A vessel, rather than the ice thickness. Quickly after freeze-up, the ice edge extends to cover nearly all of Foxe Basin, with concentrations normally reaching 9+/10. At this time, extending the season with icebreaker support would mean approximately 400 NM of ice escort in predominantly thin first-year ice. Although 1A vessels are, under POLARIS, able to transit in ice up to medium first-year in thickness, escorting operations over such a significant distance in a 9+/10 concentration of thin first-year ice will present increased risks for both vessels.

Within an ice cover of thin first-year ice, ice deformation and pressure events can occur which can make escorting operations especially challenging. Indeed, in ice of this nature, which is highly susceptible to pressure build up and deformation, the heavy winds that are characteristic of Foxe Basin, combined with tidal forces, can spawn ice conditions that can slow down or halt the progress of a 1A ship. When this happens, the icebreaker must backtrack and perform freeing maneuvers, which can, at times, be difficult and time consuming.

In a pressured ice regime of 9+/10, even at times when the ship can maintain progress through the pack ice, the track behind the icebreaker closes quickly, thus limiting the benefit of having icebreaker support. In addition, an escort operation enduring such a significant distance would significantly increase the time required for the vessels to reach the Steensby Inlet port. Given this is an operation requiring a quick turn around of vessels from the port, extending the season significantly with icebreaker escort would likely result in extensive and frequent delays to the regular schedule.

Another significant factor to consider when using icebreaker support late into the season is the formation of fast ice in Steensby Inlet. On average, the Inlet is covered in fast ice by November 27. In the last 15 years however, the Inlet has been covered in fast ice as early as November 9 (2015) (Table 11). If similar restrictions exist for breaking land fast ice in Steensby Inlet, as they do for the Milne Inlet port site, the development of land fast ice will likely be the limiting factor for the end of the shipping season with light ice class vessels.

Nonetheless, using icebreaker support at the end of the shipping season with 1A vessels has the potential to add a few weeks to the shipping season by making the ice cover more manageable for light ice class vessels. Equally important, the escort can increase the level of comfort for ship owners and crew, thus inciting them to attempt a voyage that they might otherwise shy away from. However, given the aforementioned constraints, for the purpose of this study, we have attempted to establish what we believe to be limitations to the period when icebreaking assistance can be practically effective.

Sea ice breakup

To investigate vessel access during the breakup period, ice conditions along the route to the Steensby port site were evaluated using weekly regional ice charts published by the CIS for the last 15 years. Satellite imagery was also assessed during this review to better understand the ice conditions depicted in the ice charts. Based on this more recent data, and Fednav's additional understanding of the capabilities of ships of different ice classes, there have been some updates to the proposed start of season dates for the non-ice class, 1C and 1A ice class vessels in comparison to the conclusions made in the 2011 report, and to the "opening" dates discussed earlier this year. The dates established show when, during the shoulder season after breakup, Fednav estimates that vessels of lighter ice classes could safely navigate unescorted to Steensby Inlet.

Table 12 presents the regulatory opening dates based on the ZDS for the beginning of the shipping season for the non-ice class, 1C and 1A ice class vessels, in addition to the proposed acceptable dates provided in the 2011 report, and the updated proposed dates.

Fednav's proposed beginning of season date for non-ice class ships, August 18, is 2 days earlier than the opening date based on the ZDS. This date is the average first week when there was a route of very low ice concentration conditions along the route to the Steensby port site before the open water season.

The proposed beginning of season date for 1C vessels is August 15, which is 5 days later than what had been proposed in the 2011 report, and the same as the opening date based on ZDS. As for 1A ice class vessels, Fednav's proposed beginning of season date is August 8, which is 2 days later than both what had been reported in the 2011 report and the opening date based on ZDS.

Table 12. Comparison of the proposed date for the beginning of the shipping season between three assessments: Zone/Date System, AIRSS calculation as presented in the 2011 report, and Fednav assessment with data from 2005 to 2019.

Ship Ice Class	ZDS opening date	2011 AIRSS-based assessment	Updated 2019 assessment (based on 2005 – 2019)
Non-Ice Class	20-Aug	20-Aug	18-Aug
1C	15-Aug	20-Aug	15-Aug
1A	10-Aug	10-Aug	08-Aug

During the spring, the breakup and clearing of ice occurs relatively quickly along the route to the Steensby port site. Clearing of sea ice in central and northern Foxe Basin is normally the limiting factor for the start of the shipping season. It is important to remember, however, that there is considerable yearly variability over the past 15 years between the beginning of season dates for the different vessel ice classes. Since the 2011 report, an additional 10 years of data has been included in the historical assessment of ice conditions. This data shows greater variability in certain ice events than the previous decade, namely in the length of the open water season. Over the last decade (2010-2019), there has been more years when the seasonal ice persisted for a longer time than during the previous decade (2000-2009). This is of importance for the confidence in using light or non ice class vessels as they are at most risk when ice is present.

Based on the ZDS, access to zone 8 (Foxe Basin) is permitted by a 1C ice class vessel as of August 15, and by a 1A ice class vessel as of August 10. From Fednav's assessment, these dates are not always representative of the ice conditions during that period over the last 15 years. There are times, in the last 15 years, when it would have been highly recommended to use icebreaker support for lower ice class vessels, even within the acceptable Zone/Date period for their ice class.

There is indeed great variability in the dates of the beginning of season. For instance, the earliest and latest dates over the last 15 years were in 2019 and 2018, respectively (Table 13).

In 2018, there was a late breakup of sea ice where a 1A ice class vessel would likely not have been able to sail without icebreaker support prior to the week of August 20. At that time, tactical navigation

by a seasoned Master would have been warranted around areas of higher ice concentration. The 2018 accessibility date of August 20 was nearly 2 weeks later than the permitted date based on the ZDS for a 1A ice class vessel in this area.

Alternatively, in spring 2019, there was an early breakup; a 1A ice class vessel would likely have been able to sail to the Steensby port site the week of July 22, without icebreaker support. This is over 2 weeks prior to when the ZDS permits 1A ice class vessels to navigate in this area. Figure 11 and Figure 12 show the difference in ice conditions between the two consecutive years on August 10 and 11. In 2018 there was still a significant ice regime with 9/10 of decayed thick first-year ice along the route to the port site. Around the same date in 2019, most of Foxe Basin as well as the entire route to the Steensby port site were open water and ice free conditions.

Table 13. Proposed beginning of shipping season dates for non-ice class, 1C and 1A ice class vessels compared to the earliest and latest dates, over the last 15 years.

Ship Ice Class	Average Date	Earliest Date	Latest Date
Non-Ice Class	18-Aug	05-Aug (2019)	27-Aug (2018)
1C	15-Aug	29-July (2019)	27-Aug (2018)
1A	08-Aug	22-July (2019)	20-Aug (2018)

Table 14. First week of accessibility to Steensby Port site for non-ice class, 1C and 1A ice class vessels during breakup based off weekly CIS ice charts from the last 15 years.

Year	1A ice class	1C ice class	non ice class
2005-06	08-Aug	08-Aug	15-Aug
2006-07	31-Jul	07-Aug	07-Aug
2007-08	06-Aug	20-Aug	27-Aug
2008-09	18-Aug	25-Aug	25-Aug
2009-10	10-Aug	17-Aug	17-Aug
2010-11	02-Aug	09-Aug	09-Aug
2011-12	08-Aug	15-Aug	15-Aug
2012-13	06-Aug	13-Aug	13-Aug
2013-14	12-Aug	19-Aug	19-Aug
2014-15	11-Aug	25-Aug	25-Aug
2015-16	10-Aug	24-Aug	24-Aug
2016-17	08-Aug	15-Aug	22-Aug
2017-18	07-Aug	14-Aug	21-Aug
2018-19	20-Aug	27-Aug	27-Aug
2019-20	22-Jul	29-Jul	05-Aug
Average	07-Aug	15-Aug	18-Aug
Variability	29	29	22

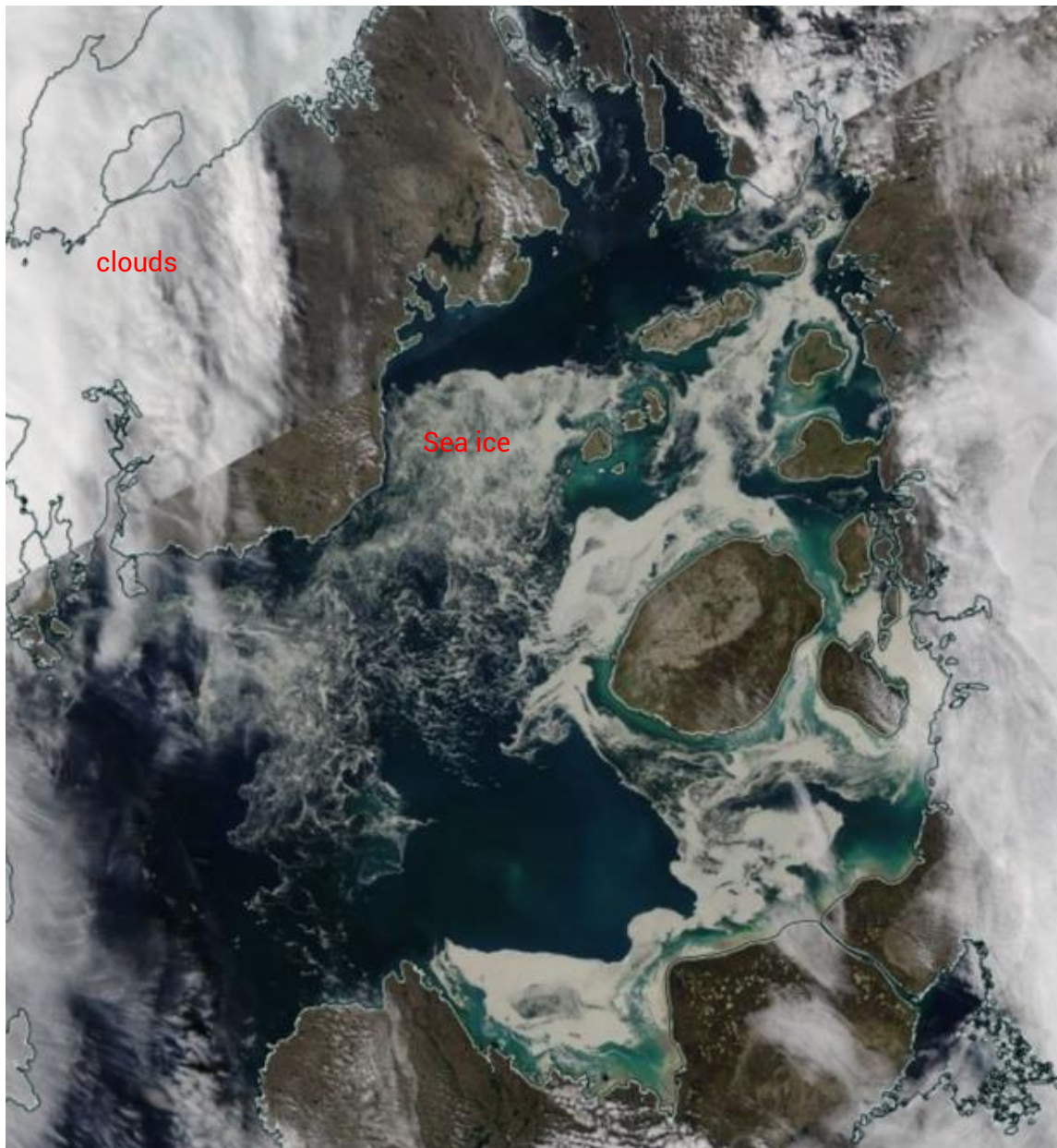


Figure 11. MODIS image showing ice conditions in Foxe Basin on August 11, 2018.



Figure 12. MODIS image showing open water condition in Foxe Basin on August 10, 2019.

Icebreaker support prior to breakup

From the assessment of the conditions over the last 15 years, it is apparent that there is significant yearly variability in breakup patterns and timing. In some years, there were regimes of decayed thick first-year ice that lingered late into the summer and early fall. With icebreaker support, using lower ice class ships (such as 1A and 1C) would still be a feasible option for accessing the Steensby port during the shoulder season prior to full open water conditions, even during the heavier ice years. Using icebreaker support would allow for more predictability in the start date of the shipping season with

lower ice class vessels. Furthermore, it could likely minimize the amount delay for the beginning of the season that might occur in a year with late ice breakup and clearing.

Based on the assessment of the last 15 years, it is estimated that an icebreaker escort would often allow a 1A ice class vessel to access to the Steensby port site 1 to 2 weeks earlier than if it were to proceed unescorted. The average date over the last 15 years at which a 1A ice class vessel under escort could likely access the Steensby port site was July 26 (Table 15). This date is 13 days earlier than the average access date of the same vessel type, without icebreaker escort. For the assessment period, between 2005 and 2019, there was 34 days of variability in the estimated first access date. The latest date of accessibility of a 1A ice class vessel under icebreaker escort was established to be August 11 (2008) followed by August 8 (2018).

Table 15. First week of accessibility to Steensby Port site for 1A ice class vessels transiting unescorted and under icebreaker escort during breakup based off weekly CIS ice charts from the last 15 years.

Year	1A ice class	1A ice class with escort
2005-06	08-Aug	25-Jul
2006-07	31-Jul	17-Jul
2007-08	06-Aug	30-Jul
2008-09	18-Aug	11-Aug
2009-10	10-Aug	03-Aug
2010-11	02-Aug	26-Jul
2011-12	08-Aug	01-Aug
2012-13	06-Aug	23-Jul
2013-14	12-Aug	29-Jul
2014-15	11-Aug	28-Jul
2015-16	10-Aug	03-Aug
2016-17	08-Aug	18-Jul
2017-18	07-Aug	17-Jul
2018-19	20-Aug	08-Aug
2019-20	22-Jul	08-Jul
Average	08-Aug	26-Jul
Variability	29 days	34 days

It is important to note that the estimated start date in any given year would be subject to the discretion of the navigating vessel's and icebreaker's Masters. Operating at this time of the year in Foxe Basin would require tactical navigation around and through areas of high ice concentration (up to 9/10) of decayed thick first-year ice. In addition, local winds can cause the remaining ice pack to amalgamate into vast expanses along the route to Steensby Inlet, resulting in ice conditions, either due to ice concentration or ice pressure, that can slow down or stop the vessel, thus delaying the transit

significantly. These conditions can also exceed the comfort level of the navigators which might prevent the vessel to pursue a transit altogether, until the challenging conditions subside.

Because the melting process is in effect at that time of the year, a vessel that is slowed down or stopped, whether preemptively or because it is unable to proceed through the ice, will ultimately be faced with more favorable navigation conditions as the ice melts. Nevertheless, when navigating at the beginning of the season, local conditions must be monitored closely and extreme caution must be taken.

It should also be noted that vessels following in the wake of the escort vessel are more likely to encounter difficulties at the beginning of the season than at the end of the season. At the beginning of the season, the ice that remains is thick first-year ice over 120 cm thick, even if it is broken up by the icebreaker. Due to the thickness of the ice, it would be recommended to use 1A ice class vessels until the ice is significantly dispersed. Indeed, a 1A ice class vessel can contend with higher concentrations of thick first-year ice if the rest of the regime is composed of open water. This cannot, however, be achieved when the escorting vessel breaks fast ice: the resulting regime will likely consist of 9/10 of thick first-year ice, since the ice floes remain in the track after having been broken. The first access dates established in Table 15 therefore occur after the clearing of fast ice from Steensby Inlet.

Once breakup has occurred, it may be preferable to wait for the ice to become less concentrated through Foxe Basin (7/10 or less would be a reasonable threshold) before sending a 1A ice class vessel behind an icebreaker. This is to ensure that it can follow the escort safely and efficiently, without taking the risk of becoming halted or having to perform a close escort, which can be highly risky due to the collision potential.

At the established dates of 1A ice class vessel accessibility with escort, over the last 15 years, there was generally still a significant amount of thick first-year ice that remained along the route. An example of the prevailing conditions on August 11, 2018 is shown in Figure 13. At this date, two days after the established acceptable start of season date for an escorted 1A ice class vessel, escort operations would still be required for over 75 miles through a regime with a high concentration of decayed thick first-year ice. Escort operations covering such a distance in such a difficult ice regime would require both vessels to significantly reduce speed to ensure safe operations. It should be considered that reduced speeds through a large portion of the Foxe Basin will increase the transiting time to and from the Steensby port site and could cause delays at the beginning of the season.

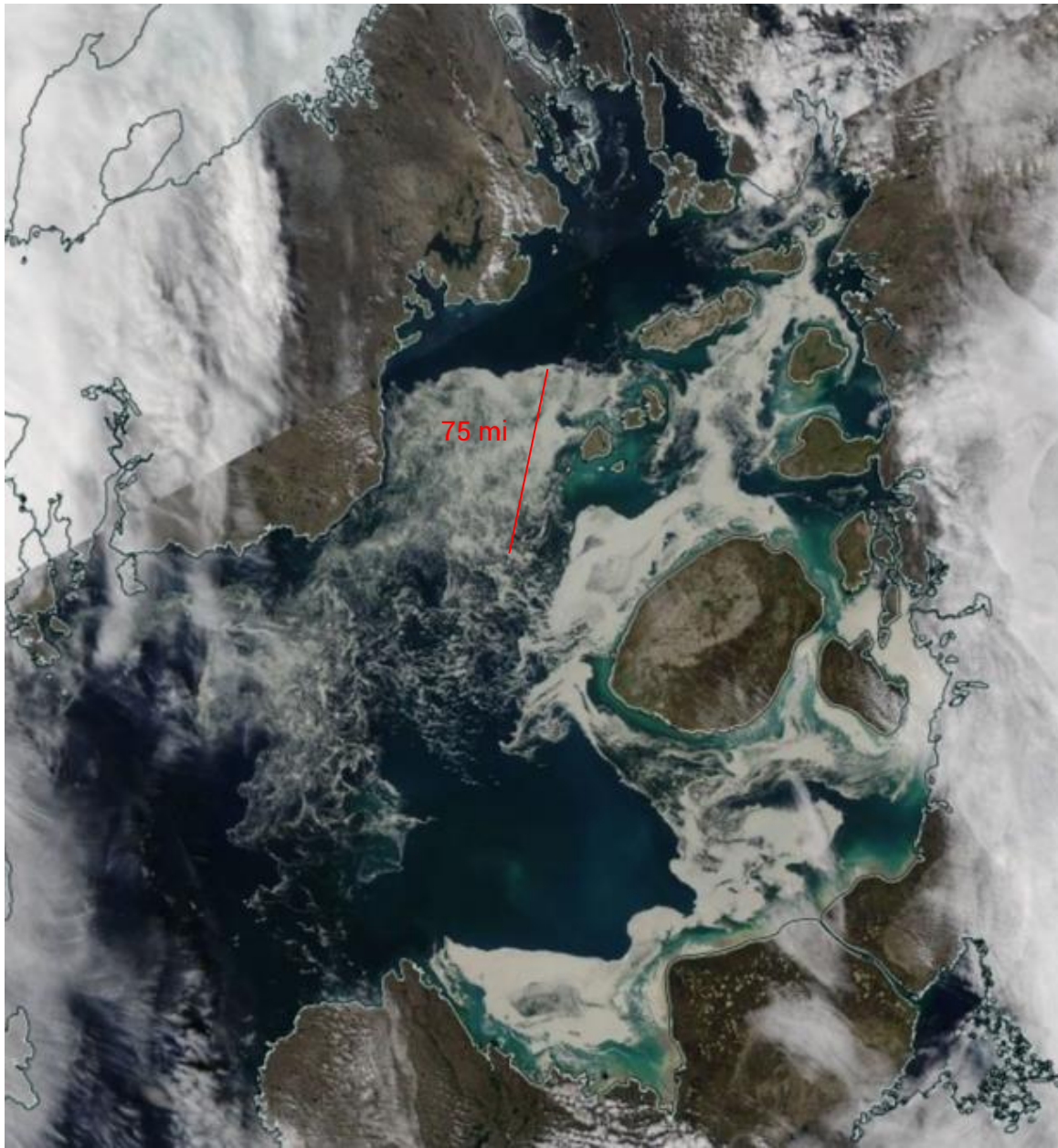


Figure 13. Ice conditions on August 11, 2018, with red line showing area requiring icebreaker support for a 1A vessel (Source: MODIS).

Year-round shipping with icebreaking bulk carriers

Based on the analysis of weekly ice charts for the last 15 years along the route to the Steensby Inlet port site, and from Fednav's experience navigating the Hudson Strait during the winter, we have developed the following assessment of necessary vessel ice class for winter shipping to the port site.

Seasonal ice cover in Foxe Basin begins to form, on average, in the second half of October. The freeze-up of Foxe Basin occurs about a month earlier than the freeze-up in Hudson Strait. This means that the ice in Foxe Basin reaches the stage of thick first-year ice prior to the ice in the Hudson Strait, and

that the ice reaches a greater thickness in Foxe Basin at the peak of winter. Measurements in the fast ice of Steensby Inlet have indicated that the level ice can reach a thickness of 2 m at the end of the growth season.

Fednav has gained experience navigating in the winter months through the Hudson Strait since 1998. During such time, there have been many difficult ice situations that caused extensive delays even for a PC 4 vessel (MV Arctic). Even prior to entering the Hudson Strait, by Resolution Island, the MV Arctic has become beset and significantly delayed due to heavy ice pressure in deformed thick first-year ice. The MV Nunavik, also a PC 4 vessel but more powerful, has been performing well, but it is believed that the conditions the ship operates in the peak of winter are at the limits of its capabilities. It must be kept in mind that the ice conditions in Foxe Basin are bound to be more challenging than those in Hudson Strait.

Transiting through heavily ridged ice, whether it is under pressure or not, requires enough propulsion power in order to allow the vessel to keep its momentum. This is not a factor that the Polar Classes account for in their classification. The design of the vessels that will transit to Steensby Inlet year-round will need to take the power requirements into consideration. From a practical point of view, Fednav believes that a vessel design similar to our existing bulk carriers – PC 4 – would perform well for year-round shipping to Steensby Inlet.

Given Fednav's added experience in navigating the Hudson Strait during winter with two PC 4 vessels, as well as the knowledge and familiarity that has developed over recent years with the use of Polar Classes, it can be expected that a vessel with lower ice class than PC 4 would often struggle in areas of high ice pressure from February until the melt onset in May. The passage between Hudson Strait and Davis Strait, the western end of Hudson Strait, as well as Foxe Channel are areas of known high ice pressure that would result in significant delays for a lower ice class vessel, such as a PC 5 vessel, on a regular basis.

In 2011, Enfotec's study presented the PC 5 as the bare minimum, with a preference for PC 4. Since completing our assessment in 2011, Fednav has acquired more experience in the operation of PC ships in the region, with five winters of operating a powerful PC 4 vessel (MV Nunavik) in Hudson Strait. As a result of that experience, Fednav no longer believes that PC 5 vessels are a viable option for efficient and reliable operation for the trade to Steensby.

A PC 5 is described to be for "year-round operations in medium first-year ice with some old ice inclusions". The ice cover in Foxe Basin and Hudson Strait typically reach the thick first-year stage of development around mid-February; this is beyond the capability of a PC 5. The Polar Classes are not necessarily based on the dynamic aspect of sea ice, nor on vessel performance. As such, it is unknown how well a PC 5 would withstand deformed thick first-year ice pressure.

In comparison, a PC 4 can independently perform "year-round operations in thick first-year ice with some old ice inclusions". This is not only based on theoretical performance, but Fednav's own experience gained in recent years. This corresponds to the conditions that would be encountered each year along the route to Steensby Inlet. The hull of a PC 4 is proven to withstand the rigours of operating in deformed thick first-year ice pressuring the vessel.

The option of using a PC 5 vessel but providing icebreaking support to the vessel during the winter months has been deemed unrealistic. The distance from open water in Baffin Bay to Steensby Inlet is

more than 800 NM. Consequently, at the peak of winter PC 5 vessels will require a minimum of 800 NM of icebreaking support each way, from the eastern entrance to Hudson Strait to Steensby Inlet. The logistics and risks of such a long escort operation, and in such heavy and dynamic ice conditions as what will be experienced (at a minimum) from February to May, make this an impractical option.

Through the winter, Foxe Basin and Hudson Strait are covered by 9+/10 of mostly thick first-year ice, which is commonly deformed and under pressure. Icebreaker escort in such conditions will not provide substantial benefit to the transiting PC 5 vessel. Indeed, in a pressured ice regime of 9+/10, the track behind the icebreaker will close quickly, resulting in the PC 5 vessel struggling to navigate through ridged thick first-year ice. It is also extremely likely that attempting an ice escort in these challenging ice conditions could present an additional risk to operations.

4. Climate change: potential implications for shipping

4.1 Climate change in the Arctic

The effects of climate change are increasingly apparent across the globe, but perhaps nowhere more so than in the Arctic.

Little heat from the sun reaches the high latitudes, resulting in a predominantly cold climate. The ice and snow brought upon by this climate have bright surfaces that reflect the rays of the sun. Consequently, thermal retention of ice and snow is low. As global temperatures rise, the melting of ice and snow accelerates which exposes ever larger areas of water and land. Dark surfaces such as water and land absorb and retain considerably more solar energy than bright reflective surfaces such as ice and snow. In lower latitudes, the solar energy that is absorbed by the land and water is quickly dissipated as evaporation, yielding clouds and ensuing precipitations. In the Arctic, the colder temperatures are less favorable to evaporation so more of the solar energy that is absorbed by those dark surfaces brings about an increase in temperature. Moreover, the atmosphere is much thinner in the Arctic than at lower latitudes, so it takes less time for the air to warm up than further south. (ACIA, 2004)

Global warming causes ice to retreat further and snow to melt faster than it has in the past. As these reflective surfaces shrink, heat-absorbing areas of exposed land and water expand. This leads to an increasingly strong cycle where temperatures keep rising while sea ice increasingly retreats and snow melt accelerates. This positive feedback loop is known as the Arctic Amplification (Figure 14).

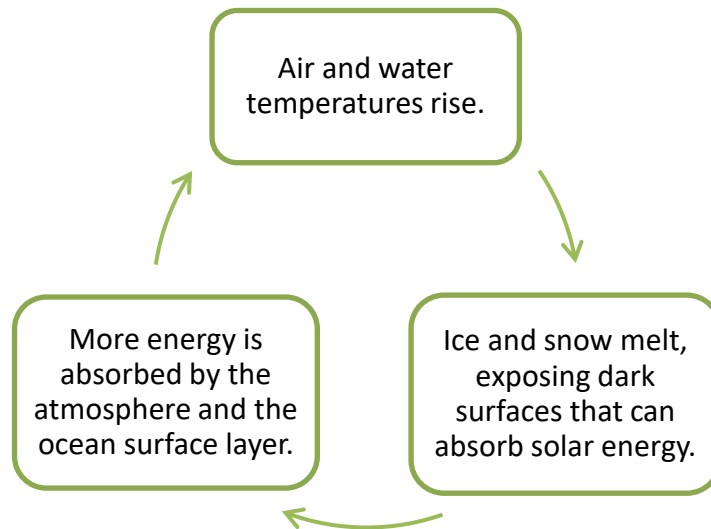


Figure 14. Schema illustrating the concept of Arctic Amplification.

4.2 Recent changes in Arctic Sea ice

Climate change is the result of a combination of natural and anthropogenic factors. Natural climate change is observed over thousands of years. To that effect, cyclical patterns of glacial and interglacial periods have been widely documented. The scope of this study, however, will be limited to a much shorter period. Recent changes (early 1970's and onward) and how these changes are affecting ice and access for marine shipping in the Canadian Arctic will be assessed.

Much has been reported in the press regarding the recent melting of the Arctic ice cap. Indeed, the edge of the summer ice cover is retreating further north, and open water is now observed in areas that are generally covered (partially or completely) with old ice all summer. The extent and estimated volume of minimum Arctic sea ice reached an all-time low in September 2012, beating the previous record of 2007 (Table 16). The 2019 minimum extent was the second lowest on record.

Table 16. September ice extent from 2007 to 2019 (Source: NSIDC).

Year	September minimum ice extent (millions of square kilometers)
2007	4.16
2008	4.59
2009	5.12
2010	4.62
2011	4.34
2012	3.39
2013	5.05
2014	5.03
2015	4.43
2016	4.17
2017	4.67
2018	4.66
2019	4.15
1979-1998 average	6.79
1980 - 2009 average	6.32
1990 - 2019 average	5.47

Even though the recording of Arctic wide sea ice data is relatively recent (since 1979), the recurrence of summer low ice extents and the continuous loss of multi-year ice are revealing a trend that is increasingly difficult to deny. Some models estimate that “nearly sea ice-free”¹ summers in the Arctic may occur as soon as the 2030’s, while others predict it will happen in the 2040-2060 timeframe (Wang and Overland, 2012). After 2012’s record summer minimum ice cover, some scientists claimed that an ice free Arctic summer season could occur even sooner, in 2016 (Vidal, 2012), which did not happen. The wide range of predictions that are based on these models reveals the ample level of uncertainty surrounding the future of the Arctic ice cover.

Climatic models use a wide variety of parameters to build scenarios, which can change depending on the weight attributed to each parameter, as well as the results from interactions between these parameters. They also consider various external or anthropogenic stresses that are based on speculation. Furthermore, these models are not meant to predict the extent of sea ice decline from one season to the next, but rather to predict changes over several years, even decades. They also offer little precision – if at all – at the local scale. For these reasons, using climatic models for project planning purposes is impractical, since reliable local predictions, on a short or medium timeframe, would be required.

There are important implications to Arctic projects if, indeed, summer ice conditions become lighter in the future. If the observed trend of sea ice changes in the Arctic from the last 40 years does continue, a lengthening of the shipping season and changes in the nature of ice hazards are to be expected, as

¹ “Nearly sea-ice free” is considered to be the point where the ice cover will drop below 1 million sq. km.

well as lower requirements for the ice-strengthening of ships (ice class). However, the last 40 years have shown that this trend is not linear. Although there is little doubt that a point of no return has been reached, mostly due to the considerable loss of multi-year ice that occurred in the last decades, it is not yet known if recent trends will keep up with the rapid pace that prevailed within that timeframe. While the impact of Arctic Amplification on sea ice is substantial, it remains difficult to quantify and predict the extent of the phenomenon. The following section provides further insight on the recent changes affecting sea ice and outlines shipping-related issues.

4.2.1 Changes in ice dynamics

Studies have demonstrated that sea ice has experienced significant changes in the past decades. Many types of changes have been observed such as changes in extent, concentration, volume and seasonal patterns of the sea ice; all of which have direct implications on shipping in the Arctic.

a. Ice extent

One of the most striking changes of the Arctic sea ice cover is the reduced extent during summer. Since 1979 – when satellite imagery was first used to monitor the circumpolar ice cover – a significant decrease in summer sea ice extent has been observed. This causes regions that used to be impracticable for navigation to become more frequently open, and, as such, creates new opportunities for shipping. Annually, September is the time when the ice cover reaches its minimum extent. Figure 15 illustrates that, notwithstanding the significant interannual variability, there is a trend towards a decreasing extent of Arctic summer sea ice.

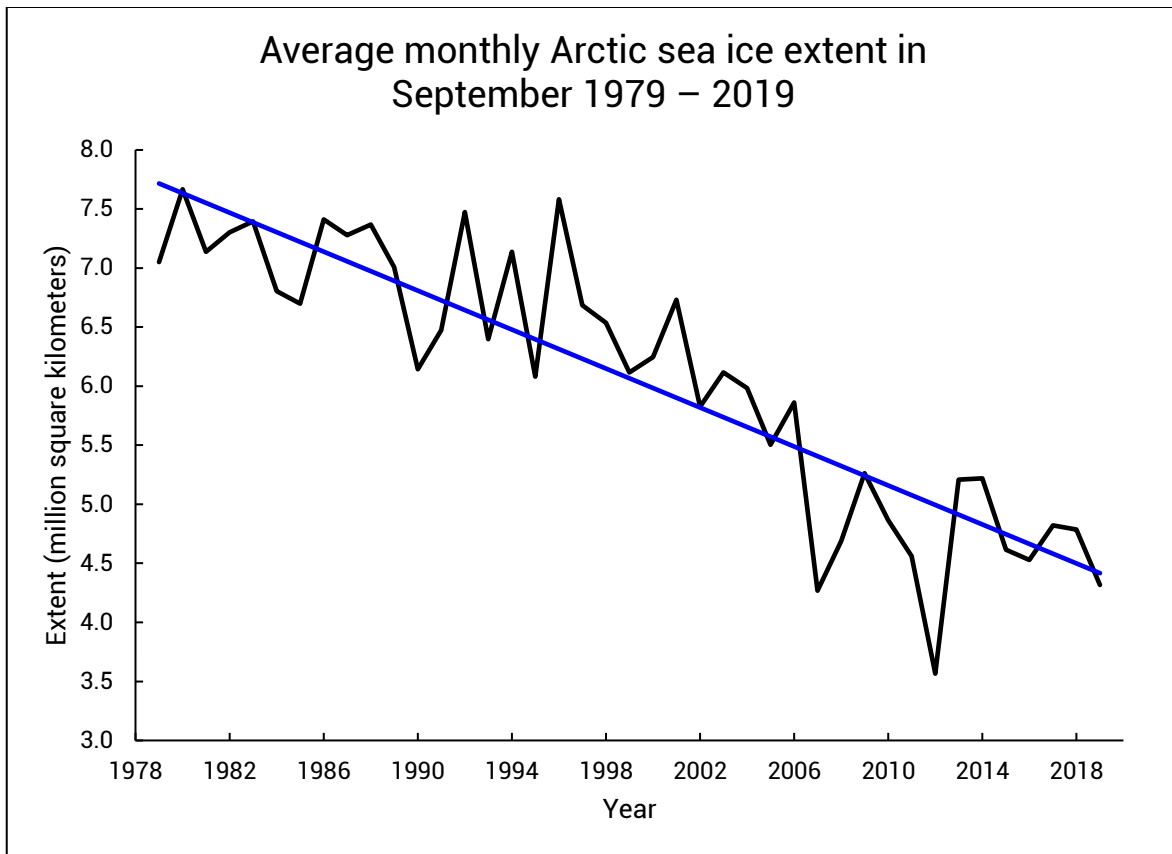


Figure 15. Average monthly Arctic sea ice extent in September, 1979-2019 (Source: NSIDC).

In winter, the change in sea ice extent is less extreme, but still significant (Figure 16). Even though the extent of the ice cover also diminishes, ice will always be, for a foreseeable future, a prominent feature in the Arctic during winter. This is due to the low angle of the earth's surface relative to the rays of the sun with the geographic proximity to the North Pole. The poles receive very limited daylight during winter, which minimizes the amount of solar energy that can be converted into heat.

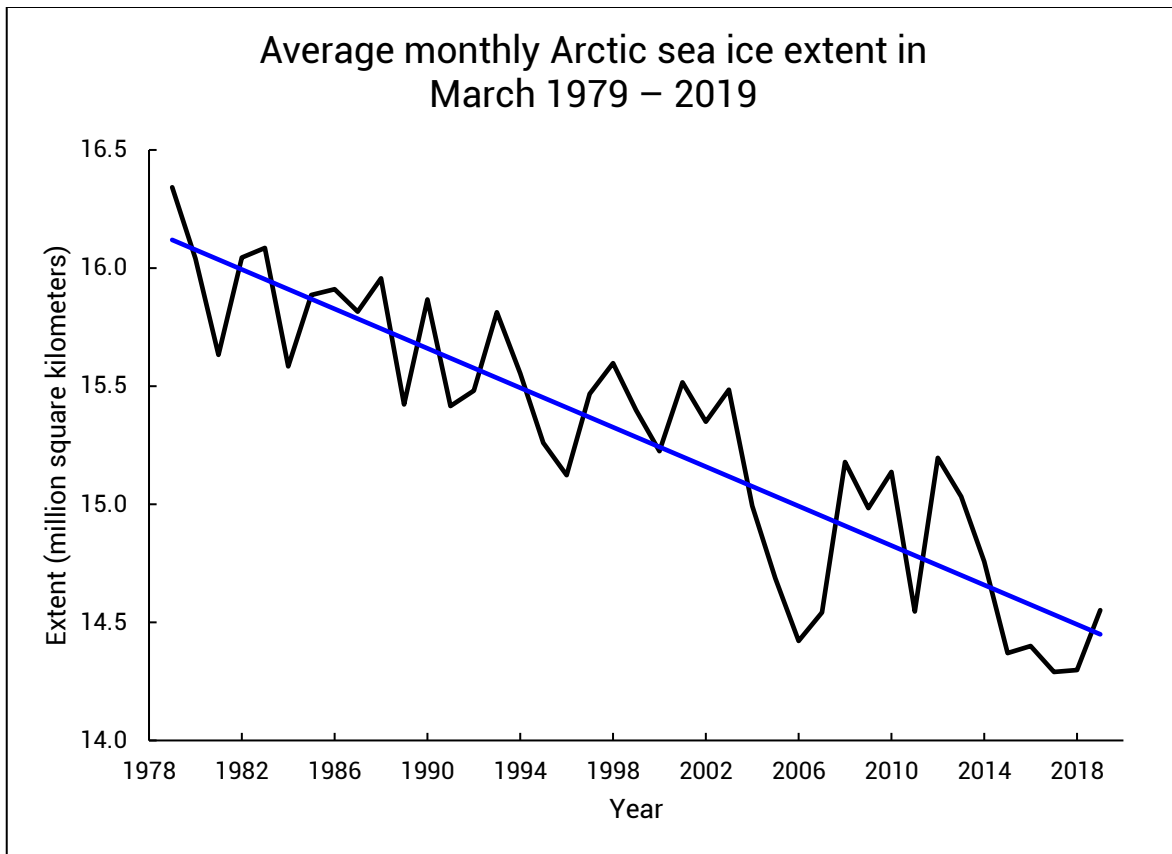


Figure 16. Average monthly Arctic sea ice extent in March, 1979-2019 (NSIDC).

At an hemispheric scale, 2019 was representative of the declining trends in the yearly minimum and maximum ice extent observed since systematic satellite monitoring of the ice extent began in 1979 (Figure 15 and Figure 16).

b. Ice concentration

In addition to the decrease in extent, a reduction in sea ice concentration has been observed as well. Ice concentration is the proportion of an area that is covered with ice as opposed water, indicated in tenths (/10) or in percentage. Ice in lower concentration tends to thaw more quickly since the more prevalent water absorbs more energy than the ice, thus accelerating the rate at which the temperature of the liquid water is rising which, in turn, quickens the thawing process. Areas with lower concentrations of ice are also more easily navigable and can be accessible for vessels of low ice class.

Reduced concentrations have been measured over vast expanses of sea ice, both when the maximum seasonal ice extent is reached (Figure 17) as well as its minimum (Figure 18).

Some experts believe that there may be less ice in high latitudes than what is measured using satellites, especially in the spring and summer. At that time, the recurrent occurrence of fog and the presence of melt water puddles have indeed been known to hinder the accurate satellite detection of sea ice. The reports from a research vessel sailing at high latitudes during the summer of 2012

corroborate this hypothesis. Indeed, concentrations as low as 50% at 83°N had been observed, while ice charts derived from satellite data depicted close pack ice (concentration of 9/10) (Vidal, 2012(a)).

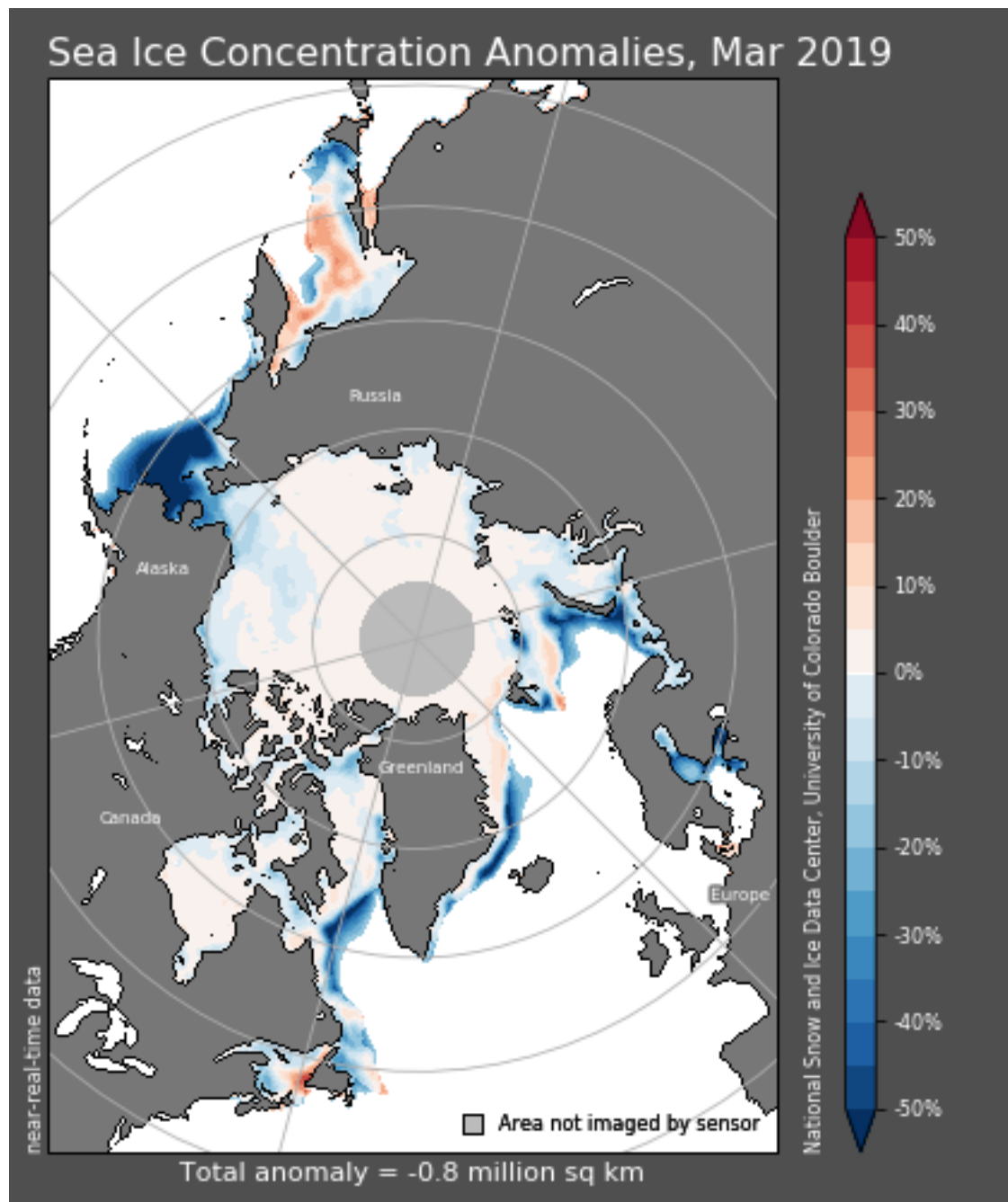


Figure 17. Difference in sea ice concentration from the 1981-2010 mean for March 2019 (Source: NSIDC).

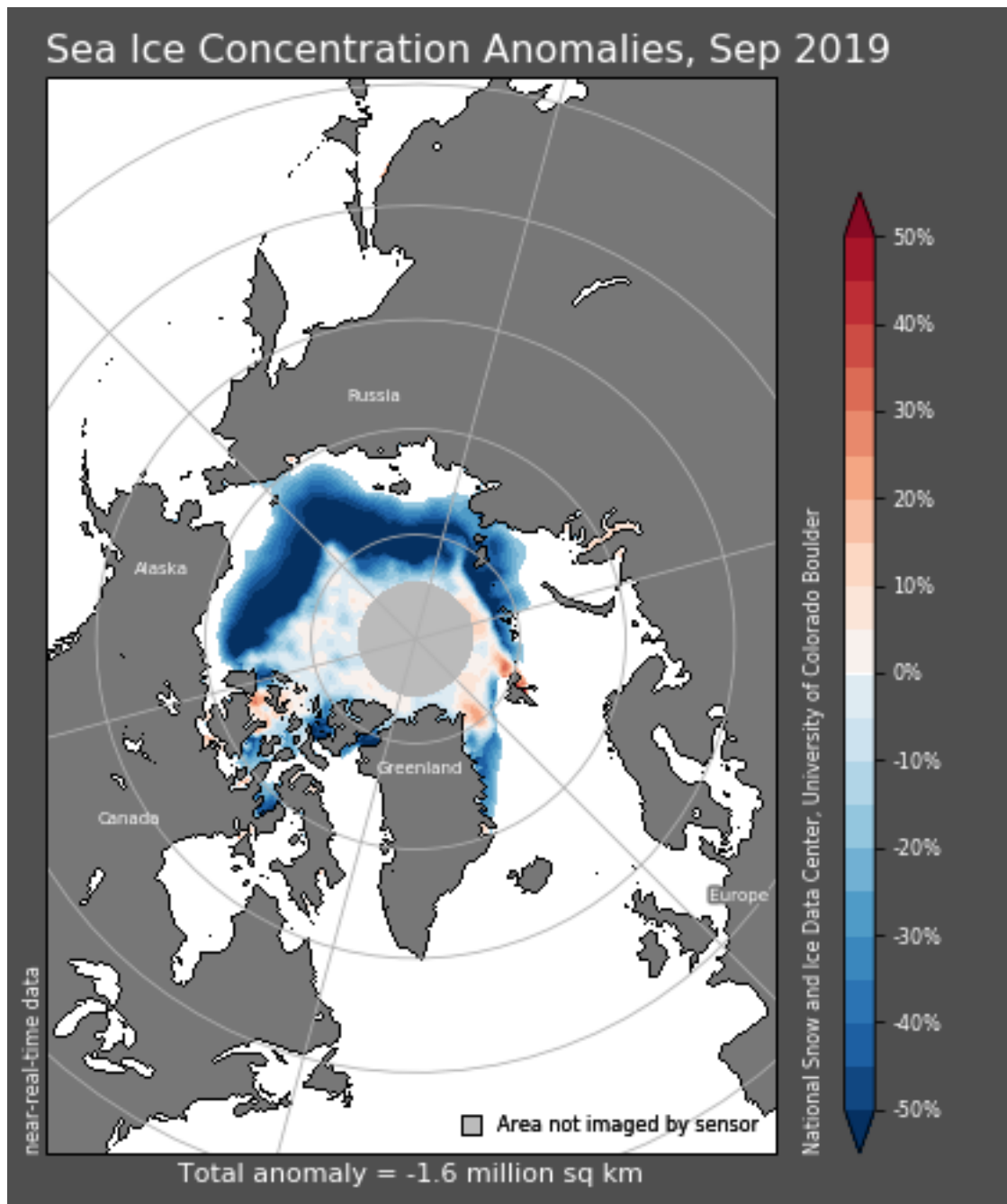


Figure 18. Difference in sea ice concentration from the 1981-2010 mean for September 2019 (Source: NSIDC).

c. *Ice volume*

Ice volume is a good indicator of the state of the Arctic sea ice cover. Volume is related to thickness, which is associated to the age (or stage of development) of the ice. The older the ice, the thicker it is and the more volume it contributes to the cryosphere. When the ice cover retreats and multi-year ice melts, a large amount of the total ice volume is lost. This change has been well observed over the

Arctic Ocean in the last decade. According to some estimates, multi-year ice accounted for about 70% of the Arctic winter ice cover in the mid 1980's, then dropped to 20% by 2012 (Stroeve *et al.*, 2014). Figure 19 illustrates how the age profile of Arctic sea ice has changed over the past 30 years; it is especially noticeable in September, at summer minimum.

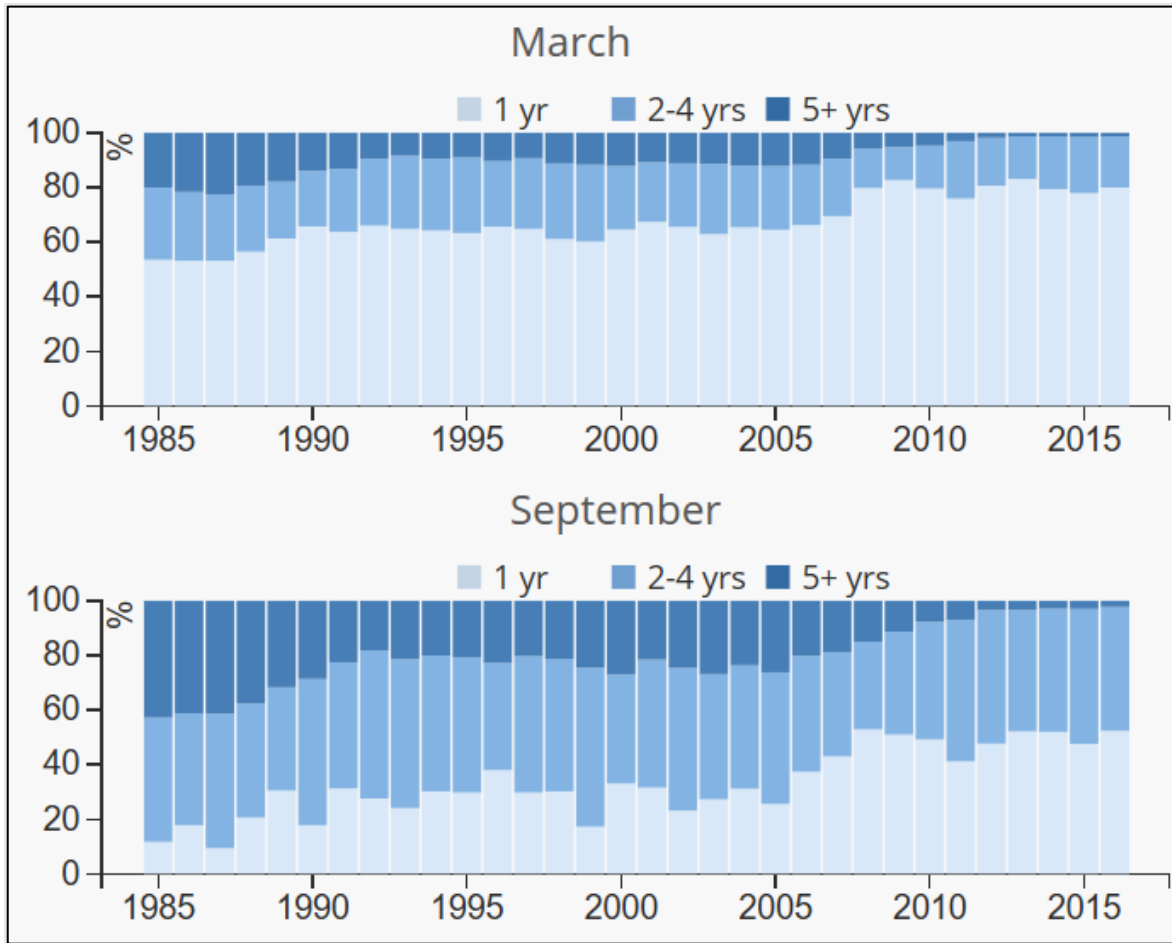


Figure 19. Distribution of ice extent over the Arctic, according to age (Source: NSIDC).

The disappearance of old ice impacts the overall profile of the sea ice cover. Old ice is more solid and denser than first-year ice because it contains less brine (salt water) and less void spaces. It is also more resistant to melt and deformation than first-year ice. First-year ice is also more vulnerable to stormy weather than old ice: it breaks apart easily under strong winds and waves. Likewise, first-year ice also tends to deform significantly under pressure stresses such as winds, currents and tides, which can hamper navigation (Stern and Lindsay, 2009). Nevertheless, for shipping, the reduction of multi-year ice generally translates into a reduced risk for vessels and, once again, a potential opening of new routes, albeit while increasing the likelihood of ice pressure events that can impede navigation.

d. Seasonal patterns

The aforementioned changes in the sea ice cover have an impact on the seasonal dynamics, more specifically on the melt and freeze patterns. Over the entire Arctic, ice tends to start melting earlier than before, and the fall freeze-up occurs later. As it is becoming thinner and scarcer, the ice cover becomes weaker and therefore more vulnerable to melt. Stroeve *et al.* (2014), observed that the length of the melt season has been increasing at a rate of 5 days per decade from 1979 to 2013, and it seems that this trend is not linear: it is becoming more pronounced. The change is more manifest in September, i.e. at the end of the melt season, than in spring or early summer. According to that same study, freeze-up occurred 6 days later during the 2000-2012 period than in the 1982-1999 period.

There are regional differences, though. The areas that tend to have a predominantly seasonal ice cover, such as the Bering Sea or the Greenland Sea, present a higher interannual variability: some years will see a late freeze-up, while others will see it happening earlier than before. Weather patterns play a large role in local ice distribution as well. It can influence the rate of clear-up at the beginning of summer, and the persistence of the ice cover in fall. When ice is more vulnerable (low concentration, low stage of development, advance decay...), it is more susceptible to short-term effects caused by weather systems, and particularly to wind, the impacts of which are highly significant for navigation as they can hinder or facilitate navigation at a local scale.

4.2.2 Local changes and impacts on shipping

The satellite record and analysis of CIS ice charts reveal that the trends observed across the Arctic of an earlier breakup and later freeze-up also prevail in Foxe Basin and Hudson strait. This change is especially apparent in Hudson strait, with a median breakup happening 1.05 days earlier per year since 1980, and a freeze-up starting 0.75 day per year later. The trend is slightly less apparent in Foxe Basin, with breakup beginning 0.70 day per year earlier, and freeze-up starting 0.62 day a year later. Figure 20 shows how the changing breakup and freeze-up date trends have been evolving locally. Figure 21 shows the median date per region of the breakup and freeze-up, as well as the median open water season length (Andrews *et al.*, 2018).

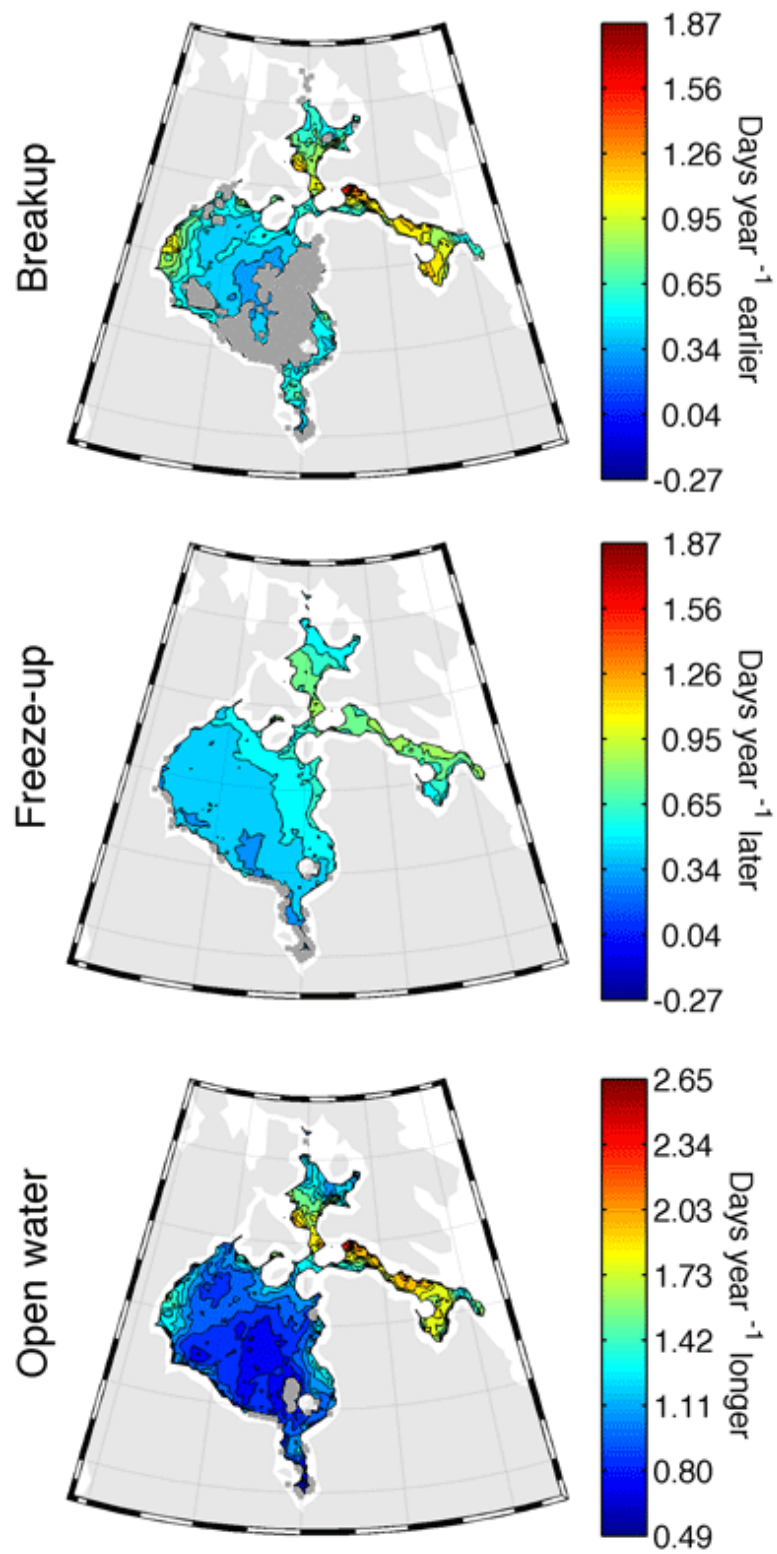


Figure 20. Median standard deviation in breakup, freeze-up, and open water timing for 1980–2014 (Source: Andrews et al., 2018).

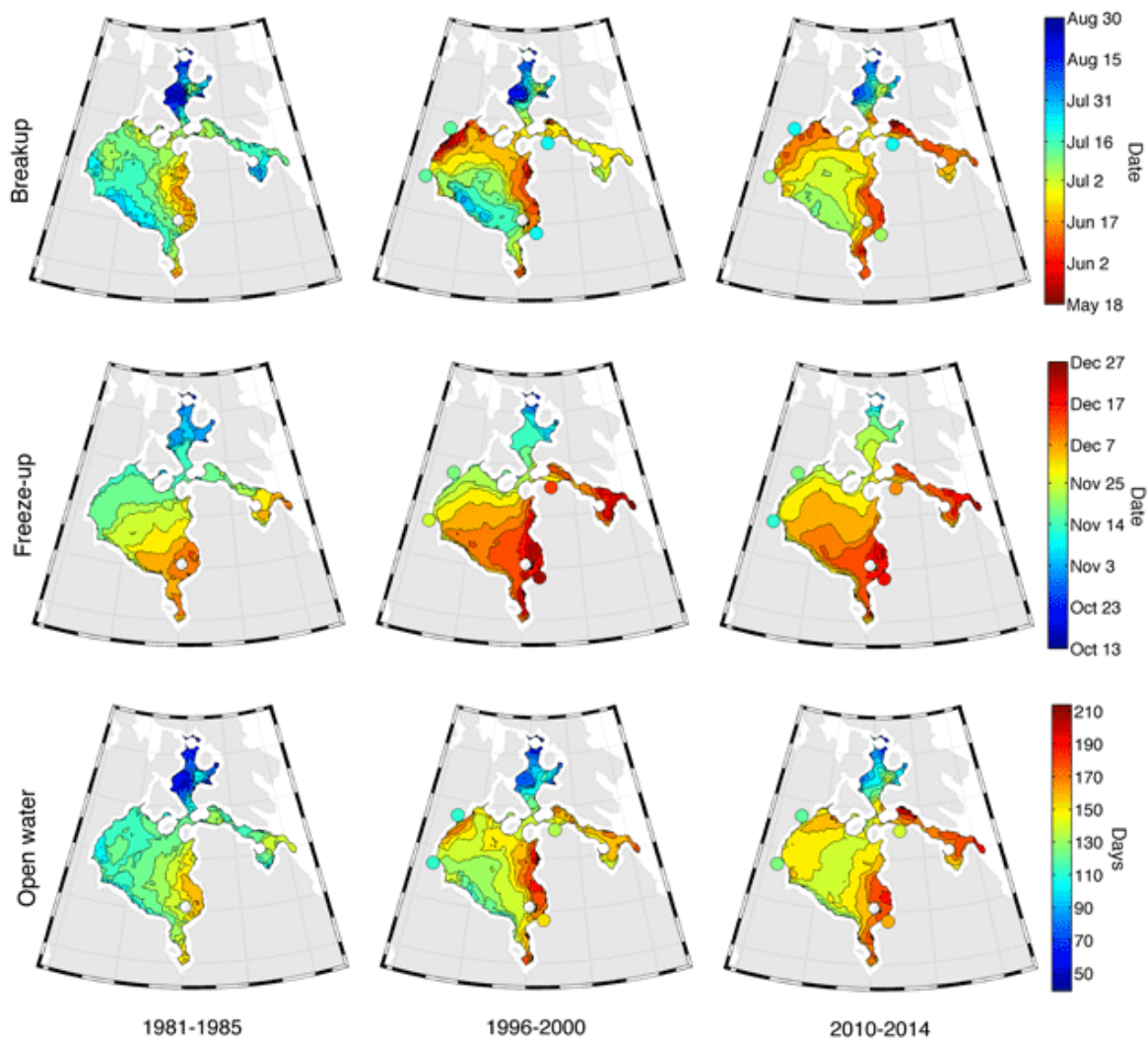


Figure 21. Median breakup, freeze-up, and open water for 1981–1985, 1996–2000, and 2010–2014 (Source: Andrews et al., 2018).

There is a significant yearly variability in the date of the breakup and freeze-up. In Hudson Strait, standard deviations of 17.10 days and 13.11 days in the breakup and freeze-up dates, respectively, have been measured. For Foxe Basin, standard deviations of 15.44 days have been observed for the breakup and of 11.84 days for the freeze-up. Figure 22 illustrates the localized variations in breakup and freeze-up dates (Andrews et al., 2018).

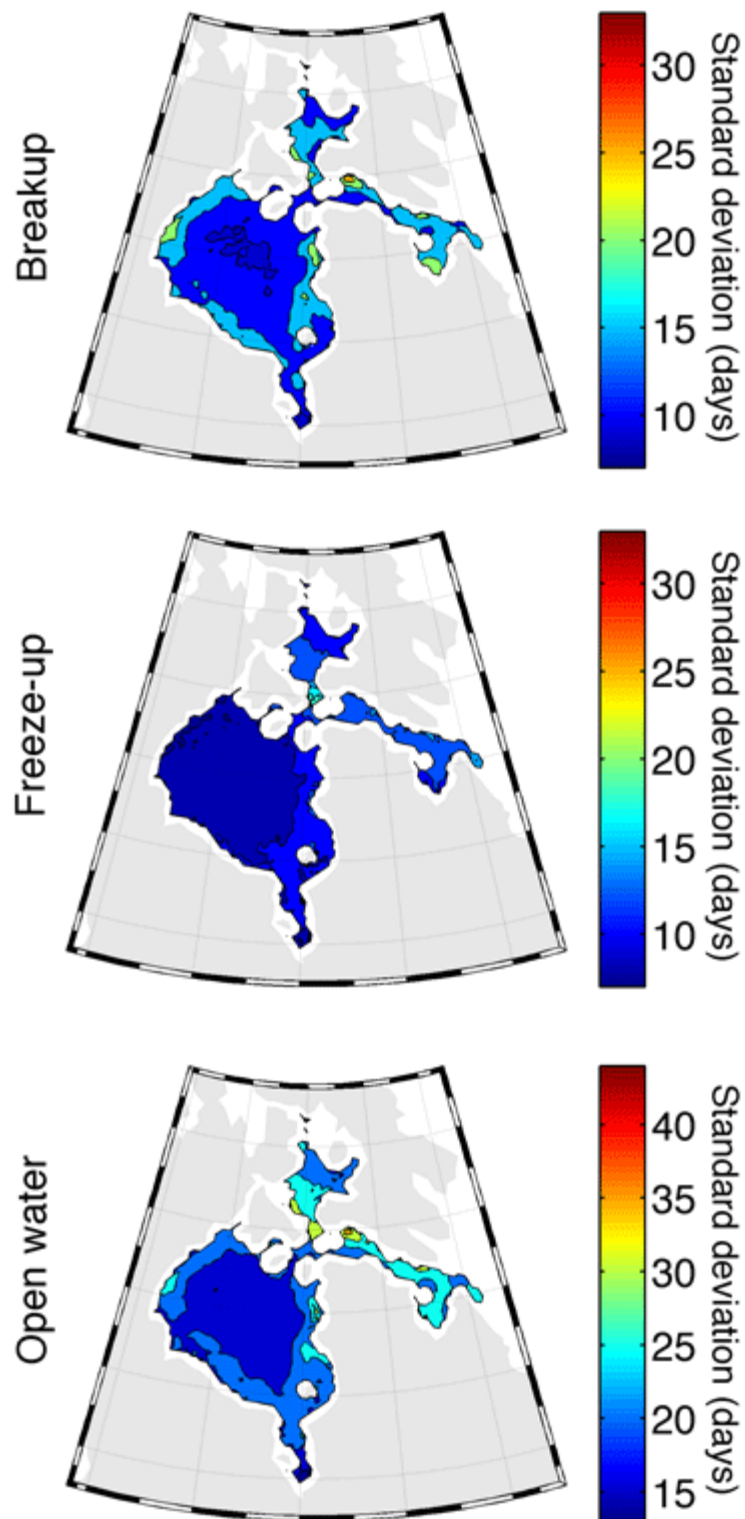


Figure 22. Median standard deviation in breakup, freeze-up, and open water timing for 1980–2014 (Source: Andrews et al., 2018).

5. Limits of the study

This study assesses ice conditions along the approaches to the Steensby Inlet port site, including the conditions from freeze-up to breakup in Foxe Basin and the Hudson Strait. The analysis is based on past conditions in the eastern Canadian Arctic and sub-Arctic through use of ice charts from the Canadian Ice Service, satellite images (from MODIS and Sentinel-1), metocean data, and *in situ* observations. This study focuses on the time period between 2005 and 2019 as, with climate change, investigating the ice conditions from the previous decade no longer shows relevant patterns. Although 15 years is a sufficient period of time to understand general patterns and variability between years, it is not an extensive study period. In addition, the historical data available detailing the ice cover in the Canadian Arctic, in the form of ice charts, is often only available on a weekly basis.

Changes in the climate and ice conditions have been observed in the recent past. While it is likely these conditions will keep evolving in a similar fashion, it is impossible to know with absolute certainty whether the trends observed in the recent past will continue at the same pace. Although it is possible to speculate on the future of the Canadian Arctic climate, there remains a high level of uncertainty in these predictions. Regardless of the uncertainty that exists, the last few decades' worth of data show that, as a result of Arctic amplification, the climate is changing faster in the Arctic than in the rest of the world.

Notwithstanding the frequency and length of the record of data on the Arctic mentioned above, the limited amount of data on the Canadian Arctic constitutes, in itself, another limit that impacts some aspects and conclusions of this study. Field studies about ice dynamics in the Arctic are quite sparse, and our knowledge of the ice conditions is restricted by what can be captured through satellite imagery and what can be extrapolated from meteorological data. Nonetheless, ice analysis from remotely sensed products, whether it is satellite imagery, aircraft imagery, or ice charts, is always subject to a certain amount of interpretation. In addition, the area in question has never been transited in the winter months, and although Fednav has gained significant experience navigating the Hudson Strait in the winter, ice dynamics do differ in Foxe Basin along the route to the port site.

Fednav's extensive knowledge of ice dynamics and its impact on navigation, and its unique shipping experience in the Hudson Strait throughout the winter, add substantial depth and insight to the analysis performed. This said, while Fednav does have firsthand shipping experience in heavy ice along part of the route to Steensby Port, year-round shipping across Foxe Basin has never been accomplished, and winter shipping in the Canadian Arctic has only existed since 1998. Consequently, our conclusions and recommendations are based, to some degree, on hypothetical analysis. Nevertheless, Fednav's expertise with winter navigation in the Hudson Strait is unmatched. Because of this, it is the foundation for the conclusions with respect to ice class required for safe winter navigation to the Steensby port site.

6. Conclusions and recommendations

This study presents an analysis of ice conditions and vessel access along the route to the Steensby Inlet port site. In light of this analysis, the following conclusions can be drawn:

- 1) Light or non-ice class vessels could be used to access Steensby Inlet during the shoulder period, prior to and following the open water season, on average, between the following dates:

Established average non-ice class accessibility dates:

- › Average beginning of season: August 18
- › Average end of season: October 21
- › Average season length: 65

Established average 1C ice class accessibility dates:

- › Average beginning of season: August 15
- › Average end of season: October 30
- › Average season length: 77

Established average 1A ice class accessibility dates:

- › Average beginning of season: August 8
- › Average end of season: November 18
- › Average season length: 101

- 2) The average open water season (no ice along route) is from September 3 to October 26 (52 days), however there is still considerable interannual variability in terms of the nominal open water season.

Open water season length:

- › Average open water season: 52 days
- › Longest open water season: 84 days
- › Shortest open water season: 25 days

- 3) To extend the use of light ice class ships, such as 1A ice class vessels, much into the shoulder periods at the beginning and the closing of the season, icebreaker support would be required.

It is estimated that an icebreaker escort could allow a 1A ice class vessel to reach the Steensby port site 1 to 2 weeks earlier than if it were to proceed unescorted, as well as reduce potential delays in the beginning of the shipping season due to a late ice clearing.

After freeze-up along the route to Steensby Inlet, the use of an icebreaker escort could extend the shipping season for 1A vessels. However, as the ice concentration and ice edge extend rapidly in the fall, if attempting to significantly extend the season, an escort of approximately

400NM would be required. It is important to consider the practicality, limitations, and commercial viability of such extensive escorting operations.

- 4) There is no discernible trend towards a significantly longer shipping season for ships of lower ice classes.

Since the 2011 report, an additional 10 years of data is included in our historical assessment of ice conditions. This data shows greater variability in certain ice events than the previous decade, namely in the length of the open water season. Over the last decade (2010-2019), there has been more years when the seasonal ice persisted for a longer time than during the previous decade (2000-2009).

- 5) The most significant change that has been observed over the recent years, compared with the previous decade, is the minimal presence of old ice in Foxe Basin.

In the 1990's and 2000's, there were occasional occurrences of old ice (drifting multi-year ice and persistent first-year ice turning into second-year ice at the end of the melt season) in low concentrations close to the approach to Steensby Inlet. The last time that this rare phenomenon occurred was in 2010. With the drastic reduction of old ice and consistent melt of seasonal ice in the Canadian Arctic, due to climate change, it is now unlikely that there will be old ice in Foxe Basin. As such, the limitation based on the presence of old ice that was presented in the 2011 study is not relevant anymore.

- 6) Given our extensive operational experience with PC 4 vessels in Hudson Strait, we strongly recommend the use of PC 4 for year-round shipping to Steensby Inlet.

- 7) The option of using a PC 5 vessel with icebreaking support to the vessel during the winter months has been deemed unrealistic.

The use of a PC 5 is limited during a large part of the winter due to the thickness of the ice, which reaches the thick first-year stage by mid-February, and the high level of pressure on the ice cover. In addition, the distance from open water in Baffin Bay to Steensby Inlet is more than 800 NM. Consequently, at the peak of winter PC 5 vessels will require a minimum of 800 NM of icebreaking support each way, from the eastern entrance to Hudson Strait to Steensby Inlet. The logistics and risks of such a long escort operation, and in such heavy and dynamic ice conditions as what will be experienced (at a minimum) from February to May, make this an impractical option.

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Appendix I: Ice navigation in the Canadian Arctic

Shipping in ice infested waters requires extensive knowledge of the local conditions, adequate vessel reinforcement and ice capabilities, as well as experience in ice navigation. Sea ice is rarely an even surface: deformation and motion of the ice creates a highly dynamic environment. Ice conditions are also significantly variable, both in time (within a season and from one year to another) and regionally. When planning ice navigation operations, it is essential to bear in mind the highly variable and unpredictable aspects of ice movement.

This section is meant to provide the reader with an understanding of the main concepts related to sea ice, in particular the ones that are important for navigating in ice-covered waters.

Definition of ice conditions

Defining ice conditions is complex. To simplify matters, an ice regime – i.e., a region of ice with more or less consistent ice conditions (Transport Canada) – can be described by several parameters, namely:

- 1) concentration, which is defined in tenths or percentage;
- 2) thickness, which is linked to the stage of development or age of the ice;
- 3) form, which refers mainly to floe size.

These parameters are required in the definition of ice conditions in order to evaluate if a vessel has the capability to navigate through an ice regime.

Concentration plays an important role in determining if a route is navigable. For example, the Canadian Ice Service (CIS) generally defines a navigable area as having a concentration of less than 6/10, even though some vessel classes not designed to navigate in ice may encounter difficulties in making progress through ice of that concentration. This said, icebreakers and suitably ice-classed cargo vessels are able to navigate at constant (yet not necessarily full) speed in concentrations higher than 6/10. Concentration is commonly described with the general terms listed in Table 1 - A.

Table 1 - A. Arrangement of the ice in terms of concentration
(Source: Environment Canada – Canadian Ice Service, 2002).

Terms	Concentration (in tenths)
Open water	Less than 1/10
Very open drift	1/10 – 3/10
Open drift	4/10 – 6/10
Close pack	7/10 – 8/10
Very close pack	9/10 – 9+/10
Compact / Consolidated	10/10

Ice thickness also gives an indication on whether a vessel should or should not enter an ice regime. While there is no strict definition or standard, it is generally assumed that a minimum ice class is required when the ice thickness exceeds about 30 cm. Naturally, the requirements for vessel design increase as the ice thickens because, as the ice grows and ages, it gains strength. For instance, ice that has survived at least one summer's melt is considered old ice. As it ages, it becomes thicker and denser, which makes it more hazardous for ships of lower ice class. For this reason, it is important to identify the ice types present in an ice regime in order to determine whether the vessel has the capability to operate safely within this regime. Ice types are defined according to their thickness, such as described in table 1 – A.

Table 1 - B. Stages of development of sea ice
(Source: Environment Canada – Canadian Ice Service, 2002).

Ice type (stage of development)	Thickness
New	Less than 10 cm
Young	10-30 cm
Grey	10-15 cm
Grey-white	15-30 cm
First-year	30 cm +
Thin first-year	30-70 cm
Medium first-year	70-120 cm
Thick first-year	120 cm +
Old	2 m +
Second-year	2 m +
Multi-year	2 m +

The form of the ice is an additional indicator of the development and severity of ice conditions (Table 1 - C). For example, ice floes can be several kilometers wide; when possible, a vessel will try to avoid these large floes. In contrast, an ice regime comprised of small floes and ice strips is easier for navigation as it does not require breaking the ice. Furthermore, determining the form of the ice can help distinguish consolidated (fast) ice from mobile ice.

Table 1 - C Forms of ice (Source: Environment Canada – Canadian Ice Service, 2002).

Form of ice	Floe size
Pancake ice	n/a
Small ice cake or Brash ice	Less than 2 m
Ice cake	2-20 m
Small floe	20-100 m
Medium floe	100-500 m
Big floe	500-2000 m
Vast floe	2-10 km
Giant floe	10 km +
Fast ice	n/a

Deformation and motion processes

Except for ice that is consolidated (land fast ice), sea ice is generally not a static feature. It is subject to constant change and movement caused by winds, tides and ocean currents. Ice deformation occurs continuously in the pack ice, but in some areas, deformation processes can cause an impediment to navigation.

Ridging is one of the most problematic deformation processes for navigation. It occurs when ice floes are being pressed together and forced upwards, forming a linear pattern – i.e., a ridge, as seen in Figure 1 - A. The freeboard portion (the ice above the surface) of a ridge is called a sail, and it can reach several meters in height. The pressure on a ridge also forces ice downwards and creates a keel, which is the submerged part that is not visible from the ship or on satellite images. The depth of the keel can be roughly estimated with a theoretical ratio of 1:3 to 1:4.5 meaning that it can be up to four times the height of the sail (Kovacs *et al.*, 1973). This ratio varies according to the different ice types that compose the ridge. As the strength of the ice changes with age and thickness, it impacts the way that the ice reacts to pressure.

Ice motion can also contribute to harsh ice conditions, especially through shearing processes which are generally accompanied by ridging. Shearing involves rotational movements of the ice against an immobile feature, which is usually the edge of the land fast ice. A shear zone is identified when the mobile ice adjacent to the land fast ice becomes highly ridged and dense as current, tidal or wind-induced pressure pushes the pack ice against the consolidated ice. The ice rubble caused by the continuous pressure can eventually consolidate. Shearing can lead to the formation of huge ice “walls” several meters thick. These are serious impediments to navigation, even for highly ice-capable ships. Shear zones can sometimes be visible on satellite images as bright linear patterns close to the edge of the fast ice. They are often recurrent at specific locations and can extend over great distances, such as the known shear zone on the mid-Labrador coast which can extend for hundreds of nautical miles along the coast with a width in excess of 20 NM.

Other deformation processes include rafting and hummocking. Rafting refers to ice pieces overriding others and is most common in new and young ice. Hummocking occurs when ice pieces are being piled haphazardly over one another and forced upwards, forming an uneven surface like a hillock, which is referred to as a hummock.

In contrast, divergence of the ice cover results in the formation of leads, which are openings in the pack. Leads can be caused by the fracture of the pack, or by the movement of ice floes in opposing directions. Fracturing is observed when deformation reaches the point of rupture, and is associated with very close pack or compact ice. When navigating in pack ice, the presence of leads is advantageous. Leads allow the displacement of ice floes. As a result, when navigating in an ice regime that has several leads, floes are more easily shifted sideways by the vessel. In this case, not much icebreaking is required. When leads are not as plentiful and icebreaking is required, the broken pieces of ice still have room to move around and therefore the load imposed to the ship is not as high as if the pack was very close. Depending on the structure of the leads, it is sometimes possible to follow them and avoid breaking ice altogether.

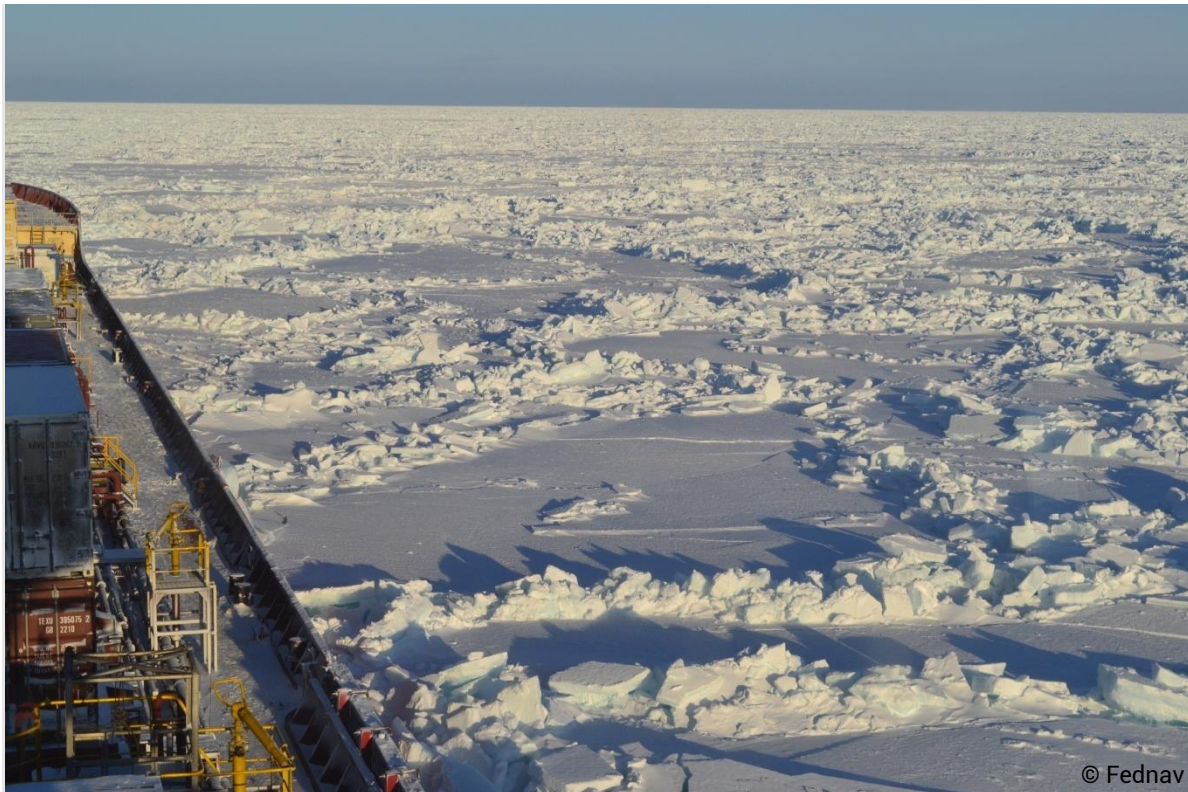


Figure 1 - A. Ridges in Hudson Strait in February 2013.

Ship's track and refreezing

An icebreaking ship can transit through close pack ice and land fast ice. Breaking ice in a mobile pack is different than in consolidated ice, and the refreezing process is equally different. Overall, it is important to note that when a vessel breaks the ice, it does not crush it: it mainly separates the ice crystals so as to create smaller pieces of ice.

In the mobile pack, the interaction between the ice and the ship varies according to the concentration in a given ice regime. When the ice cover is an open drift (concentration less than 6/10), ice floes are mostly pushed sideways, as they have room to move in the remaining open water. In close pack conditions, the ice pieces will be pushed under the adjacent ice cover and displaced sideways once they are broken. After the passage of the vessel, the track eventually closes as the surrounding ice moves. The speed at which the track closes is mostly due to the speed and direction of the pressure forces. Therefore, it can be very rapid (a matter of minutes) or rather slow (perhaps hours). Air temperature well below zero also plays a role in refreezing the open water left by the ship's track.

In land fast ice, the process is different. As the ship progresses and breaks the ice, it displaces the pieces under the adjacent ice cover. Some of that ice is milled by the propeller, creating some smaller rubble, but much of the ice survives in larger pieces. Once the ship has passed, the bulk of broken ice

resurfaces in the track. Therefore, it is not simply a line of open water that needs to refreeze, but rather, after a short while, the ice pieces of broken ice that refloat into the track (Figure 1 - B). It is then a mixture of water and ice pieces that reconsolidates. In contrast to the close pack, the fast ice zone cannot exert any pressure on the ice surrounding the track to help in closing the track. Refreezing time is thus a function of air temperatures. When the temperature is above 0°C, the track will not reconsolidate. When the temperature is below 0°C, the track will reconsolidate. Fednav's icebreaking experience has shown that a track can take from a mere few hours to up to 24 hours to refreeze.



Figure 1 - B. Ship's track in land fast ice.

Icebergs and other glacial ice features

Glacial ice is a serious navigational hazard. It includes icebergs, growlers, bergy bits and ice islands. It is mostly present in the Arctic during summer, especially in August and September. Baffin Bay, Davis Strait and Labrador Sea receive a high number of icebergs during summer. Glacial ice has a different profile than sea ice since its origin is land-based (glaciers) and it is formed from compressed snow. Although it is less dense than sea ice, glacial ice has an irregular crystal structure, which makes it stronger than sea ice. With a proportion of about 90% of its mass being below the surface of the water, icebergs are largely influenced by currents while drifting.

Icebergs tend to partially disintegrate as they drift, resulting in the creation of bergy bits and growlers. Bergy bits have an average area of 100-300 square meters, while growlers occupy a maximum area of 20 square meters. These glacial ice features are more dangerous than icebergs because they are much more difficult to detect, even with an ice detection radar. Growlers, which are often the size of a small car, can create important damage to the hull of a vessel due to the great strength of the ice. As visibility is often poor in the Arctic during summer due to bad weather (storms, waves, fog, clouds, etc), there are ways to decrease the risk of incident when navigating in bergy waters, notably: 1) using a high quality ice detection radar, and 2) sailing at reduced speed.

Appendix II: Supplemental information on Arctic shipping regulations

A vessel built for ice navigation must conform to requirements that enable it to transit in ice-covered waters. A number of ice classification systems exist and each of them typically has different ratings depending on hull strengthening, displacement, engine power and/or other requirements. In Canada, ships that transit north of the 60th parallel must do so in accordance to their ice class as defined by the ASPPR or the IACS classification systems and must follow specific regulations.

ASPPR Ice classes

The ASPPR describes 14 ice classes for ships. These classes are subdivided in two categories, the 'Type' vessels and the Arctic Class vessels. The ASPPR has specific requirement for the nine Arctic Classes. This said, Arctic Classes have been superseded by the IACS Polar Classes (see below) so vessels are no longer issued an Arctic Class classification. However, existing vessels that still have an Arctic Class can navigate in the Canadian Arctic within the framework outlined in the ASPPR.

The other five ice classes are the 'Type' vessel classes. Type E vessels are open water vessels. Type A vessels have the most ice strengthening of the 'Type' vessels. Table 2 - A gives an overview of the 'Type' vessels capabilities.

Table 2 - A. ASPPR 'Type' Descriptions.

ASPPR 'Type'	Stage of development supported (10/10 concentration)	Maximum Ice Thickness
Type A	Medium first-year	120 cm
Type B	Thin first-year second stage	70 cm
Type C	Thin first -year first stage	50 cm
Type D	Grey-white ice	30 cm
Type E	Grey ice	15 cm

Contrary to the Arctic Class vessels, there are no requirements specifically described in the ASPPR for the 'Type' vessels. Instead, a vessel is assigned a specific 'Type' class based on the construction standards determined by specified organisations for different classes of ships. These are outlined in a table in Schedule V of the ASPPR (Table 2 - B). Therefore, any ship that conforms to construction standards that are listed in Schedule V of the ASPPR is a 'Type' vessel, meaning those ships can use the hybrid system of the ASPPR.

The hybrid system of the ASPPR is used for vessels whose ice class are integrated in the Zone/Date system (see below). With the hybrid system, if a vessel is denied access to a specific safety control zone according to the Zone/Date system, it can use the more flexible AIRSS instead to determine if it can gain entry to the zone.

Table 2 - B. Schedule V of the ASPPR – Construction Standards for Types A, B, C, D and E Ships (Source: Minister of Justice).

Item	Column I Type of Ship	Column II American Bureau of Shipping	Column III Bureau Veritas	Column IV Det Norske Veritas	Column V Germanischer Lloyd	Column VI Lloyd's Register of Shipping	Column VII Nippon Kaiji Kyokai †	Column VIII Polski Rejestr Statkow †	Column IX Register of Shipping of the USSR	Column X Registro Italiano Navale	Column XI Registrul Naval Roman
1.	Type A	A1 Ⓢ Ice Strengthening Class AA AMS or A1 Ⓢ Ice Strengthening Class 1AA AMS	1 3/3E glace I-super or 1 3/3E Ice Class 1A Super	1 A 1 ICE A* or 1 A 1 ICE 1A*	100 A 4 E 4 MC	100 A1 Ice Class 1* LMC or 100A1 Ice Class 1A Super LMC	NS* (Class 1A Super Ice strengthening) MNS* or NS* Class AA IS MNS*	*KM YLA or *KM YL	KM Ⓢ YAA or KM Ⓢ YA	100A-1.1 RG 1* or 100A-1.1 1AS	<u>RNR</u> ⚓ <u>M</u> CM O G 60 or <u>RNR</u> ⚓ <u>M</u> CM O G 50
2.	Type B	A1 Ⓢ Ice Strengthening Class A AMS or A1 Ⓢ Ice Strengthening Class 1A AMS	1 3/3E glace I or 1 3/3E Ice Class 1A	1 A 1 ICE A or 1 A 1 ICE 1A	100A 4 E 3 MC	100A1 Ice Class 1 LMC or 100A1 Ice Class 1A LMC	NS* (Class 1A Ice strengthening) MNS* or NS* Class A IS MNS*	*KM L1	KM Ⓢ A1	100A-1.1 RG 1 or 100A-1.1 1A	<u>RNR</u> ⚓ <u>M</u> CM O G 40
3.	Type C	A1 Ⓢ Ice Strengthening Class B AMS or A1 Ⓢ Ice Strengthening Class 1B AMS	1 3/3E glace II or 1 3/3E Ice Class 1B	1 A 1 ICE B or 1 A 1 ICE 1B	100 A 4 E 2 MC	100A1 Ice Class 2 LMC or 100A1 Ice Class 1B LMC	NS* (Class 1B Ice strengthening) MNS* or NS* Class B IS MNS*	*KM L2	KM Ⓢ A2	100A-1.1 RG 2 or 100A-1.1 1B	<u>RNR</u> ⚓ <u>M</u> CM O G 30
4.	Type D	A1 Ⓢ Ice Strengthening Class C AMS or A1 Ⓢ Ice Strengthening Class 1C AMS	1 3/3E glace III or 1 3/3E Ice Class 1C	1 A 1 ICE C or 1 A 1 ICE 1C	100 A 4 E 1 MC	100A1 Ice Class 3 LMC or 100A1 Ice Class 1D LMC	NS* (Class 1C Ice strengthening) MNS* or NS* Class C IS MNS*	*KM L3 or KM L4	KM Ⓢ A3	100A-1.1 RG 3 or 100A-1.1 1C	<u>RNR</u> ⚓ <u>M</u> CM O G 20
5.	Type E	A1 Ⓢ AMS	1 3/3E	1 A 1	100 A 4 MC	100A1 LMC	NS* MNS*	*KM	KM Ⓢ	100A-1.1	<u>RNR</u> ⚓ <u>M</u> CM O

† The mark * in these columns is optional.¹⁹

IACS Polar Classes

In the past, classification societies as well as the governments of Canada and Russia each had a set of construction rules that were used to assign ice classes to ships according to their own specific classification system. There was general agreement amongst the various parties on the rules that govern vessels designed for use in the Baltic Sea: these are often called the Finnish-Swedish Baltic Ice Classes. However, these rules did not apply for the High Canadian Arctic because the ice conditions are much more severe there than in the Baltic Sea. In addition, the rules defined by each of these parties for vessels transiting in Polar Regions were highly variable, with little agreement amongst the group.

The IACS regroups 13 classification societies who, in August of 2006, adopted the Unified Requirements for Polar Vessels to overcome the discrepancies in the classification rules used by each society. The IACS Unified Requirements for Polar Vessels are now the standard by which all IACS members need to classify Polar Vessels built after July 1st, 2007. The Polar Class system is accepted by Transport Canada and has superseded the Arctic Class system outlined in the ASPPR. The general operating profile of the various Polar Classes (denoted PC) are described in Table 2 - C.

Table 2 - C. IACS Polar Class Descriptions (Source: IACS).

Polar Class	Description of operating profile
PC 1	Year-round operation in all Polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice which may include multi-year ice inclusions
PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/fall operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/fall operation in thin first-year ice which may include old ice inclusions

The inevitable question arises as to how these new Polar Classes compare to the previous ice classes to which existing vessels have been built. This question becomes even more complicated by the fact that although IACS members have agreed to a unified set of Polar rules (the Unified Requirements), most still intend to keep their own existing ice class rules. Table 2 - D is an **estimate of equivalency** that Enfotec has developed based on a combination of the operational profiles and construction standards of the various classes. There is an overlap between the top two Finnish-Swedish classes and the bottom two Polar Classes, with the PC 6 being generally equivalent to the 1A Super and the PC 7 being equivalent to the 1A. The equivalencies noted below are Fednav's estimates only as there are no officially recognized equivalencies accepted by government agencies or IACS for the Polar Classes. The issue of equivalency is very contentious and the subject of much on-going debate.

Table 2 - D. Fednav's Table of Nominal Polar Ice Class Equivalencies.

Polar Class	ASPPR	DNV
PC 1	Arctic Class 10	POLAR-30
PC 2	Arctic Class 8	POLAR-25
PC 3	Arctic Class 6	POLAR-20
PC 4	Arctic Class 4	POLAR-15 Ice 15
PC 5	Arctic Class 3	POLAR-10 Ice-10
PC 6	Arctic Class 2 Type A	Ice-1A Super
PC 7	Type B	Ice-5 Ice-1A

It is also important to note that a vessel built to PC 6 will be given a 1A Super designation by the Finnish-Swedish administrations but a vessel built to 1A Super will not be given a PC 6 equivalency by IACS. The same is also true for a vessel built to PC 7 as it will be given 1A but not the other way around. In the Canadian context, Transport Canada intends to adopt the IACS Unified Requirements. The timing of when this adoption will occur has not been yet determined. However, operators can now build to the PC classes and Transport Canada will assign an equivalency to the ASPPR for the vessel until such time as the classes are formally adopted.

Canadian regulations

Several pieces of legislation govern shipping in the Canadian Arctic, but the main one is the *Arctic Water Pollution Prevention Act* (AWPPA). One of the key regulations of the AWPPA is the *Arctic Shipping Pollution Prevention Regulations* (ASPPR), which concerns all "navigation in coastal waters within Canadian jurisdiction north of latitude 60°N" (Transport Canada). The ASPPR covers various aspects related to safe shipping in Arctic waters, such as: ship construction requirements, bunkering stations, Arctic Pollution Prevention certificates, Ice Navigators, fuel, sewage, oil leaks, etc. Ship access is also outlined in the ASPPR under two systems: the Zone/Date system (ZDS) and the Arctic Ice Regime Shipping System (AIRSS).

Zone/Date system (ZDS)

The ZDS dates from the original 1972 enactment and divides the waterways of the Canadian Arctic north of 60°N into 16 Shipping Safety Control Zones, as illustrated in Figure 2 - A. Permissible

access dates for each zone, based on the ice classification of the vessel, are described in Figure 2 - A.

Each zone is characterized by a "level of severity" based on historical ice conditions: Zone 1 has the most severe ice conditions, while Zone 16 has the lightest.

(For further information, visit <http://www.tc.gc.ca/eng/marinesafety/debs-arctic-acts-regulations-zds-1824.htm>.)

However, it became apparent that the ZDS was too rigid to properly capture the changing ice conditions of the Canadian Arctic and the seasonal variability, as it did not take into account the real-time conditions that the vessel was facing. There were many examples of vessels encountering severe ice conditions within the allowable access windows and other situations where vessels were denied access to areas of light ice conditions. It is to circumvent these limitations in the ZDS that the more flexible AIRSS was created.

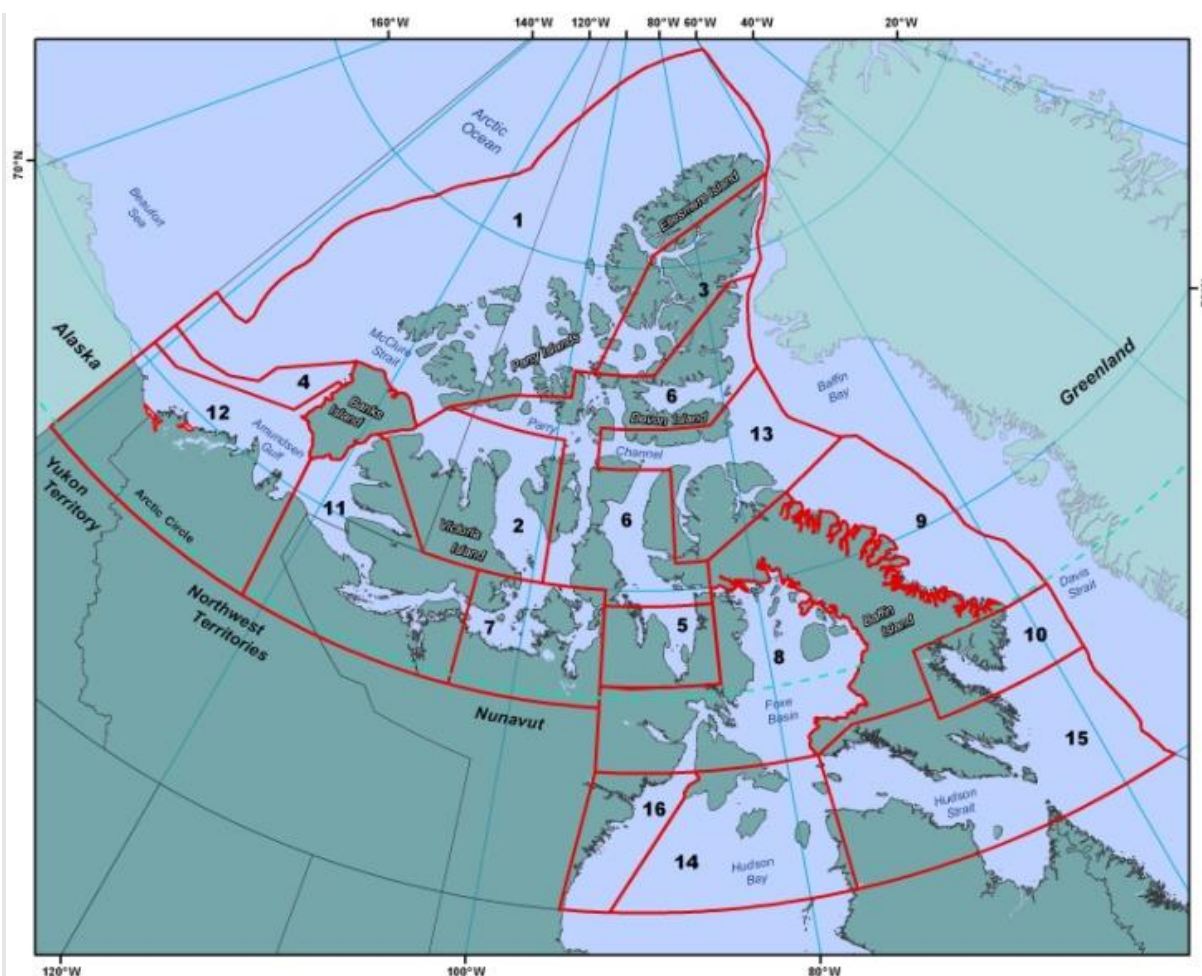


Figure 2 - A. Zone/Date system map (Source : Transport Canada).

Table 2 - E. Allowable entry dates by ice class and Zone (Source: Transport Canada).

Category	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15	Zone 16
Arctic Class 10	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>
Arctic Class 8	July 1 to Oct. 15	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>
Arctic Class 7	Aug. 1 to Sept. 30	Aug. 1 to Nov. 30	July 1 to Dec. 31	July 1 to Dec. 15	July 1 to Dec. 15	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>
Arctic Class 6	Aug. 15 to Sept. 15	Aug. 1 to Oct. 31	July 15 to Nov. 30	July 15 to Nov. 30	Aug. 1 to Oct. 15	July 15 to Feb. 28	July 1 to Mar. 31	July 1 to Mar. 31	<i>All Year</i>	<i>All Year</i>	July 1 to Mar. 31	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>	<i>All Year</i>
Arctic Class 4	Aug. 15 to Sept. 15	Aug. 15 to Oct. 15	July 15 to Oct. 31	July 15 to Nov. 15	Aug. 15 to Sept. 30	July 20 to Dec. 31	July 15 to Jan. 15	July 15 to Jan. 15	July 10 to Mar. 31	July 10 to Feb. 28	July 5 to Jan. 15	June 1 to Jan. 31	June 1 to Feb. 15	June 15 to Feb. 15	June 15 to Mar. 15	June 1 to Feb. 15
Arctic Class 3	Aug. 20 to Sept. 15	Aug. 20 to Sept. 30	July 25 to Oct. 15	July 20 to Nov. 5	Aug. 20 to Sept. 25	Aug. 1 to Nov. 30	July 20 to Dec. 15	July 20 to Dec. 31	July 20 to Jan. 20	July 15 to Jan. 25	July 5 to Dec. 15	June 10 to Dec. 31	June 10 to Dec. 31	June 20 to Jan. 10	June 20 to Jan. 31	June 5 to Jan. 10
Arctic Class 2	<i>No Entry</i>	<i>No Entry</i>	Aug. 15 to Sept. 30	Aug. 1 to Oct. 31	<i>No Entry</i>	Aug. 15 to Nov. 20	Aug. 1 to Nov. 20	Aug. 1 to Nov. 30	Aug. 1 to Dec. 20	July 25 to Dec. 20	July 10 to Nov. 20	June 15 to Dec. 5	June 25 to Nov. 22	June 25 to Dec. 10	June 25 to Dec. 20	June 10 to Dec. 10
Arctic Class 1A	<i>No Entry</i>	<i>No Entry</i>	Aug. 20 to Sept. 15	Aug. 20 to Sept. 30	<i>No Entry</i>	Aug. 25 to Oct. 31	Aug. 10 to Nov. 5	Aug. 10 to Nov. 20	Aug. 10 to Dec. 10	Aug. 1 to Dec. 10	July 15 to Nov. 10	July 1 to Nov. 10	July 15 to Oct. 31	July 1 to Nov. 30	July 1 to Dec. 10	June 20 to Nov. 30
Arctic Class 1	<i>No Entry</i>	<i>No Entry</i>	<i>No Entry</i>	<i>No Entry</i>	<i>No Entry</i>	Aug. 25 to Sept. 30	Aug. 10 to Oct. 15	Aug. 10 to Oct. 31	Aug. 10 to Oct. 31	Aug. 1 to Oct. 31	July 15 to Oct. 20	July 1 to Oct. 31	July 15 to Oct. 15	July 1 to Nov. 30	July 1 to Nov. 30	June 20 to Nov. 15
Type A	<i>No Entry</i>	<i>No Entry</i>	Aug. 20 to Sept. 10	Aug. 20 to Sept. 20	<i>No Entry</i>	Aug. 15 to Oct. 15	Aug. 1 to Oct. 25	Aug. 1 to Nov. 10	Aug. 1 to Nov. 20	July 25 to Nov. 20	July 10 to Oct. 31	June 15 to Nov. 10	June 25 to Oct. 22	June 25 to Nov. 30	June 25 to Dec. 5	June 20 to Nov. 20
Type B	<i>No Entry</i>	<i>No Entry</i>	Aug. 20 to Sept. 5	Aug. 20 to Sept. 15	<i>No Entry</i>	Aug. 25 to Sept. 30	Aug. 10 to Oct. 15	Aug. 10 to Oct. 31	Aug. 10 to Oct. 31	Aug. 1 to Oct. 31	July 15 to Oct. 20	July 1 to Oct. 25	July 15 to Oct. 15	July 1 to Nov. 30	July 1 to Nov. 30	June 20 to Nov. 10
Type C	<i>No Entry</i>	<i>No Entry</i>	<i>No Entry</i>	<i>No Entry</i>	<i>No Entry</i>	Aug. 25 to Sept. 25	Aug. 10 to Oct. 10	Aug. 10 to Oct. 25	Aug. 10 to Oct. 25	Aug. 1 to Oct. 25	July 15 to Oct. 15	July 1 to Oct. 25	July 15 to Oct. 10	July 1 to Nov. 25	July 1 to Nov. 25	June 25 to Nov. 10
Type D	<i>No Entry</i>	<i>No Entry</i>	<i>No Entry</i>	<i>No Entry</i>	<i>No Entry</i>	<i>No Entry</i>	Aug. 10 to Oct. 5	Aug. 15 to Oct. 20	Aug. 15 to Oct. 20	Aug. 5 to Oct. 20	July 15 to Oct. 10	July 1 to Oct. 20	July 30 to Sept. 30	July 10 to Nov. 10	July 5 to Nov. 10	July 1 to Oct. 31
Type E	<i>No Entry</i>	<i>No Entry</i>	<i>No Entry</i>	<i>No Entry</i>	<i>No Entry</i>	<i>No Entry</i>	Aug. 10 to Sept. 30	Aug. 20 to Oct. 20	Aug. 20 to Oct. 15	Aug. 10 to Oct. 20	July 15 to Sept. 30	July 1 to Oct. 20	Aug. 15 to Sept. 20	July 20 to Oct. 31	July 20 to Nov. 5	July 1 to Oct. 31

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