Baffinland

TECHNICAL SUPPORTING DOCUMENT

Mary River Project | Phase 2 Proposal | FEIS Addendum | August 2018

TSD 16

Ice Conditions Report

ICE CONDITIONS TECHNICAL SUPPORTING DOCUMENT SUMMARY

The Ice Conditions Study Technical Supporting Document provides an assessment of ice conditions and vessel access to Milne Inlet, Nunavut for the Phase 2 Proposal's and includes new information collected or published since submission of materials for the Approved Project. The Phase 2 Proposal builds on the extensive baseline studies and assessments carried out since 2011 for the larger Approved Project and is thus closely linked to the FEIS and previous addendums. The analysis is based on historical ice conditions from 1980 to 2016 derived from ice charts and satellite imagery. Other data sources were used, including climatic data and technical or scientific publications covering sea ice and Arctic navigation.

Year-round conditions along the route to Milne Inlet are assessed, including a risk assessment of four shipping windows as well as potential shipping hazards and routing options. Results from the model suggest that the nominal open water season is from August 5th to October 15th and shoulder shipping windows can be considered, but should be evaluated every year based on the ice conditions prevailing that year. In the channels close to Milne Inlet (Pond Inlet, Milne Inlet, Navy Board Inlet and Eclipse Sound), the typical timeframe is short between the first signs of ice formation in mid- October and the consolidation into land fast ice over 30 cm thick in mid-November.

The impacts of climate change on Arctic sea ice are also discussed in this study. The report is in line with 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 challenges related to ice movement.

A model was used to generate simulated routes from the Canadian Ice Service regional charts from 1983 to 2012. The generated routes are meant to avoid or reduce the distance spent in the harshest ice regimes. Ice Numerals (IN) were calculated for each ice regime encountered for vessel Polar Classes PC 2 to PC 7 and Types A to E. The result of this modeling, combined with Transport Canada's Arctic Ice Regime Shipping System (AIRSS), as well as Fednav's knowledge of ice conditions and navigational challenges in the High Arctic, were used to define the shipping seasons for different vessel ice classes.

A number of conclusions were made regarding the potential shipping seasons, as well as the type of vessels that should be used during each season considering the type of ice that will likely be encountered. Ice conditions are the most challenging from mid-February to late May, although difficult ice conditions prevail in fall, early winter and spring and may only be handled by high Polar Class vessels.

RÉSUMÉ DES DOCUMENTS D'ASSISTANCE TECHNIQUE EN CAS DE CONDITIONS DE GLACE

Le document d'assistance technique sur l'étude des conditions de glace comporte une évaluation des conditions de glace et de l'accès des navires à Milne Inlet, au Nunavut, pour la proposition de la phase 2 et comprend les nouveaux renseignements recueillis ou publiés depuis la soumission des documents pour le projet approuvé. La proposition de la phase 2 est fondée sur les études préliminaires et les évaluations complètes réalisées depuis 2011 pour l'ensemble du projet approuvé et est donc étroitement à l'énoncé des incidences environnementales (EIE) et aux addendas précédents. L'analyse est basée sur les conditions de glace historiques telles qu'évaluées de 1980 à 2016 à partir de cartes des glaces et de l'imagerie satellitaire. D'autres sources de données ont été utilisées, notamment des données climatiques et des publications techniques ou scientifiques concernant la couverture de glace de mer et la navigation dans l'Arctique.

Les conditions du trajet vers Milne Inlet sont évaluées tout au long de l'année, et comprennent une évaluation des risques de quatre fenêtres d'expédition ainsi que les risques potentiels d'expédition et les options d'acheminement. Les résultats du modèle suggèrent que la saison nominale d'eaux libres s'étend du 5 août au 15 octobre et que des fenêtres d'expédition d'épaule peuvent être considérées, mais devraient être évaluées chaque année en fonction des conditions de glace prévalant cette année-là. Dans les chenaux près de Milne Inlet Pond Inlet, Milne Inlet, Navy Board Inlet et Eclipse Sound), on remarque que la fenêtre entre les premiers signes de formation de glace à la mi-octobre et la consolidation en banquise côtière de plus de 30 cm à la mi-novembre est plutôt courte.

Les impacts des changements climatiques sur la glace de mer arctique sont également abordés dans cette étude. Le rapport est conforme à ce qu'on retrouve dans la communauté scientifique, car il reconnaît qu'il existe effectivement une tendance à la diminution de la couverture de glace saisonnière dans l'Arctique. Néanmoins, les changements dans la couverture de la glace de mer apportent également des défis supplémentaires liés au mouvement des glaces.

Un modèle a été utilisé pour générer des itinéraires simulés à partir des cartes régionales du Service canadien des glaces de 1983 à 2012. Les itinéraires ainsi générés ont pour but d'éviter ou de réduire la distance parcourue dans les régimes de glace les plus rigoureux. Les numéraux glaciels (NG) ont été calculés pour chaque régime de glace pour les classes polaires PC 2 à PC 7 et les types A à E. Le résultat de cette modélisation, combiné à ceux du Système des régimes de glaces pour la navigation dans l'Arctique (SRGNA) de Transports Canada, ainsi qu'à la connaissance de la Fednav de l'état des glaces et des défis de navigation dans l'Extrême-Arctique, pour définir les saisons de navigation pour différentes classes de glace de navire.

Un certain nombre de conclusions ont été tirées concernant les saisons de navigation potentielles, ainsi que le type de navires qui devraient être utilisés au cours de chaque saison, compte tenu du type de glace qui sera probablement rencontré. Les conditions de glace sont les plus difficiles de la mi-février à la fin mai, bien que des conditions de glace difficiles prévalent à l'automne, au début de l'hiver et au printemps; il n'est possible d'y faire face qu'avec des navires de classe polaire élevée.

ᓯᑰᑉ ᐃᓕᖅᑯᓯᖏᓄᑦ ᐱᓯᕆᐊᑐᔪᑦ ᐃᑲᔪᐃᔾᔪᑎᖓ ᑎᑎᖅᑲᖅ ᐅᓂᒃᑳᓕᐊᖅ

ᓯᑰᑉ ᐃᓕᖅᑯᓯᖏᓄᑦ ᐱᓯᕆᐊᑐᔪᑦ ᐃᑲᔪᐃᔾᔪᑎᖓ ᑎᑎᖅᑲᖅ ᐅᓂᒃᑳᓕᐊᖅ ᓴᖅᑭᑎᑦᑎᔪᖅ ᕿᒥᕐᕈᐃᓂᕐᒥᒃ ᓯᑰᑉ ᐃᓕᖅᑯᓯᖏᓂᒃ ᐊᒻᒪ ᐅᒥᐊᕐᔪᐊᑦ ᐃᓱᖅᐸᓪᓕᐊᓂᖏᑦ ᕿᙳᐊᓄᑦ, ᓄᓇᕘᒥᑦ ᒦᑦᑕᒫᖓ ᐱᓕᕆᐊᒃ ᒪᕐᕈᒋᓕᖅᑕᖓᓚᑦ ᐅᒃᑑᑎᖓᓚᑦ ᐊᒻᒪᓗ ᐃᓚᐅᓪᓗᑎᒃ ᓄᓪᓚᑦ ᑲᑎᖅᓱᑕᐅᓯᒪᔪᑦ ᐅᕝᕙᓘᓐᓃᑦ ᓴᖅᑭᑕᐅᓯᒪᔪᑦ ᑲᑎᖅᓱᒐᑦ ᑎᑎᕋᐅᓯᐅᔪᓪᓘᓐᓃᑦ ᑕᐃᑲᙵᓂᑦ ᑎᑎᕋᐅᓯᑦ ᓯᕗᓪᓕᖅᐸᑦ ᑐᓐᓂᕆᔭᐅᓚᐅᖅᑎᓪᓗᒋᑦ ᐊᖏᖅᓯᒪᔭᒧᑦ ᐅᓯᑦᓂᐊᓐᓂᐊᓂᓗᒧᑦ. ᐱᓕᕆᐊᒃ ᒪᕐᕈᒋᓕᖅᑕᖓᓚᑦ ᐅᒃᑑᑎᖓ ᐃᓚᒋᐊᕆᔭᖅᑲᖅᑐᖅ ᖄᖓᒍᑦ ᐊᖏᕚᔦᑦ ᑐᙵᕙᑦ ᖃᐅᔨᕚᓃᑦ ᐊᕙᓛᓄᑦ ᑕᒪᓐᓇᓗ ᕿᒥᕐᕈᐃᓂᖅ ᑕᐃᑲᖓᑦ 2011−ᒥ ᒦᑦᑕᒫᖓ ᐃᓗᐃᑦᑑᔪᒧᑦ ᐊᖏᖅᓯᒪᔭᒧᑦ ᐅᓯᑦᓂᐊᓐᓂᓪᓗᒧᑦ ᑕᐃᒫᓪᓗ ᐊᒃᑐᐊᓂᖅᑲᖅᑐᑦ ᑭᖑᓪᓕᖅᐸᑉ ᐊᕙᑎᓕᓂᕆᒧᑦ ᐊᒃᑐᐃᓂᐅᑐᐃᓐᓇᕆᐊᓖᑦ ᐅᓂᒃᑳᖏᓄᑦ (FEIS) ᓯᕗᓂᐊᒍᓪᓗ ᐅᐃᒍᑎᐊᖅᑕᐅᓂᑰᔫᒃᑯᑦ. ᕿᒥᕐᕈᐃᓂᖓ ᑐᙵᔫᖅ ᓯᕗᓂᐊᒍᑦ ᐊᑐᖅᓯᒪᔪᑐᖅᑲᑦ ᑐᕝᕙᓚ ᐃᓕᖅᑯᓯᖏᑦ ᐊᑯᓐᓂᐊᒍᑦ 1980 ᐊᒻᒪ 2016 ᑲᑎᖅᓱᖓᑦ ᓯᑯᓄᑦ ᓄᓇᙳᐊᓕᐊᑦ ᐊᒻᒪᓗ ᖁᒻᒨᒃᑎᑕᐅᓯᒪᔫᒃᑯᑦ ᐋᔾᔨᓕᐅᖓᓂᒃ. ᐊᓯᖏᑦ ᓇᐃᓴᐅᑎᑦ ᐊᑐᖅᑕᐅᒋᓪᓗᑎᒃ, ᐃᓚᖅᑲᖅᑐᑦ ᓯᓚᐅᑉ ᖃᓄᐃᑦᑑᓂᖏᓐᓂᒃ ᐊᒻᒪᓗ ᐱᓯᕆᑐᔪᑦ ᖃᐅᔨᓴᖅᑎᓪᓘᓐᓃᑦ ᑎᑎᕐᖅᓯᒪᔭᖏᓂᒃ ᑎᑎᕋᐅᓯᖅᑲᖅᑐᑦ ᓯᑰᑉ ᒥᒃᓵᓄᑦ ᐅᑭᐅᖅᑕᖅᑐᒥᓪᓗ ᐃᖏᕐᕋᔭᖕᓂᕐᒧᑦ.

ᐊᕐᕌᒍᓕᒫᖅ ᐃᓕᖅᑯᓯᓇᓲᖏᑦ ᐊᖅᑯᑖᒍᑦ ᐅᒥᐊᔾᔪᐊᑉ ᕿᙳᐊᓄᑦ ᕿᒥᕐᕈᓇᒃᑕᐅᓱᑦ, ᐱᖃᓯᐅᑎᓪᓗᒍ ᐅᓗᕆᐊᓇᐅᑎᓲᓄᑦ ᕿᒥᕐᕈᐃᓐᑦ ᑎᓴᒪᑦ ᐅᒥᐊᔾᔪᐊᒃᑯᑦ ᒪᑐᐃᖓᓂᕆᓲᖏᑦ ᓴᖅᑐᐃᓐᓇᕆᐊᓖᓪᓗ ᐅᒥᐊᕐᔪᐊᓄᑦ ᐅᓗᕆᐊᓇᖅᑐᑦ ᐊᖅᑯᑎᒋᔭᐅᔾᔮᓇᖅᑐᓪᓗ ᐊᓯᙵᖏᑦ. ᓴᖅᑭᓯᒪᔪᑦ ᑕᑯᓐᓇᕈᑎᑦᑎᒍᑦ ᖃᓇᓴᐅᔭᒃᑯᑦ ᑕᑯᒃᓴᕈᐃᓪᓗᑎᒃ ᐱᐅᓛᖅ ᓯᑯᖃᖏᓐᓂᐊ ᐋᕐᕌᓯ 5 ᑎᑭᓪᓗᒍ ᐅᑐᐱᓇ 15 ᑖᒃᑯᐊ ᐱᓇᓱᐊᕈᓰᒃ ᐊᕙᑖᒍᑦ ᐃᓱᒪᒋᔭᐅᔾᔭᓇᓪᓗᑎᒃ, ᑭᓯᐊᓂ ᐊᕐᕌᒍᑖᕐᖅ ᑕᑯᓇᓇᐊᖅᑲᓲᑦ ᐱᓪᓗᒥᒃ ᐋᔩᕐᑲᑦᑕᖏᓐᓂᖓ ᑐᕝᕙᓚ ᐃᓕᖅᑯᓯᖓ. ᐊᖅᑯᑎᖏᒍᑦ ᖃᓂᓛᖑᔪᑦ ᕿᙳᐊᓄᑦ (ᑐᖅᓱᑲᑦᑕᒃ, ᕿᙳᐊ, ᑦᓪᓗᕈᑎᓕᐊᓇᐊᖅ ᐊᒻᒪᓗ ᑕᓯᐅᔭᖅ), ᐊᑐᓚᔪᓲᖅ ᐅᓪᓗᖏᑦ ᓇᐃᑑᕗᑦ ᓯᑯᓯᒋᐊᓐᓂᐊᑕ ᐋᒃᑑᕝᕚᐅᑉ ᕿᑎᖅᐸᓯᐊᓂ ᐊᒻᒪᓗ ᑐᕚᕈᓇᐊᓐᓂᖓ ᐃᔾᔪᓯᔭᓃᖅᓗᓂ 30 ᓴᓐᑎᑦᑕᐅᑉ ᐅᖓᑖᓄᑦ ᓄᕕᐱᓇ ᕿᑎᕈᑐᐊᒻᒪᑦ.

ᐊᒃᑐᐃᓂᖅᑲᓐᓂᖏᑦ ᓯᓚᐅᑉ ᐋᔨᕆᔭᓐᓃᓐᓂᖓᓄᑦ ᐅᑭᐅᖅᑕᖅᑑᑉ ᓯᑯᕆᓲᖓᓄᑦ ᐅᖅᑲᐅᓯᐅᕆᕗᑦ ᖃᐅᔨᓵᕐᖑᔪᒥ. ᐅᓂᒃᑳᓕᐊᖅ ᒪᓕᒡᓗᓂ ᖃᐅᔨᓴᖅᑏᑦ ᐃᓚᕇᕐᖑᔪᓂᒃ ᐃᓕᓴᖅᓯᓯᒪᒻᒪᑕ ᓄᕈᑉᐸᑦᑕᐊᓂᖓᑕ ᐊᐅᓯᕆᐊᓐᓂᐊᑕ ᓯᑯᕆᔩᕐᕆᑦ ᐅᑭᐅᖅᑕᖅᑐᓕᒫᒥ. ᑭᓯᐊᓂᑦᑕᐅᖅ, ᐊᓯᔾᔨᕈᑏᑦ ᓯᑯᖃᓐᓂᐊᓄᑦ ᖃᒃᑲᓐᓂᐊᒍᑦ ᑕᑯᔅᓴᕈᐃᓰᑦ ᓵᑦᓯᐅᔪᓂᒃ ᐊᒃᑐᐊᔪᑦ ᓯᑯᖓ ᐊᐅᓚᓂᕆᔭᕐᖏᓄᑦ.

ᖃᕆᓴᐅᔭᒃᑯᑦ ᑕᑯᓐᓇᐅᑎᒥᒃ ᓴᖅᑮᓪᓗᑕ ᐃᓂᓕᐅᕆᙳᐊᖅᑐᑦ ᑲᓇᑕᐅᑉ ᓯᑯᓕᕆᔨᕐᖏᑕ ᐊᒡᒍᖅᓯᒪᔪᓄᑦ ᓯᑯᖃᓐᓂᐊᓄᑦ ᓄᓇᙳᐊᖏᓂᒃ ᐊᕐᕌᒍᖏᑕ 1983 ᑎᑭᓪᓗᒍ 2012. ᓴᖅᑭᑕᐅᔪᑦ ᐃᓂᙳᐊᖏᑦ ᓴᓂᖅᑯᑎᓇᓱᒃᓗᑎᒃ ᐊᑐᓗᐊᖅᑕᐃᓕᒪᓪᓗᑎᒃ ᐊᖅᑰᓴᓇᓂᒻᒥᒃ ᓯᑯᖃᑏᑦ ᐃᒪᖏᓐᓂᒃ. ᓯᑰᑉ ᓇᐃᓴᐅᑎᖏᑦ (IN) ᐊᑐᖅᑕᐅᓪᓗᑎᒃ ᓇᓗᓇᐃᖅᓱᒋᑦ ᐊᑐᓂ ᓯᑯᖃᓐᓂᐊᑕ ᐃᓕᖅᑯᓯᐊᓄᑦ ᐅᒥᐊᔾᔪᐊᑦ ᓯᑯᓯᐅᖅᑏᑦ ᐃᓂᓪᓚᖓᔭᖏᓄᑦ PC 2 ᑎᑭᓪᓗᒍ PC 7 ᐊᒻᒪᓗ ᐅᒥᐊᔾᔪᐊᑦ ᐃ−ᒥᑦ >−ᒧᑦ. ᑕᑯᔅᓴᕆᓚᐅᖅᑐᖅ ᑕᐅᑐᙳᐊᕈᑎᑦᑎᒍᑦ, ᒪᓕᒃᓗᒍ ᑲᓇᑕᐅᑉ ᐃᖏᕐᕋᔪᓕᕆᔾᔪᑦ ᐅᑭᐅᖅᑕᖅᑐᒥ ᓯᑰᑉ ᐃᓕᖅᑯᓯᐊᓄᑦ ᐅᒥᐊᔾᔪᐊᒃᑰᕈᑖ (AIRSS), ᐊᒻᒪᑦᑕᐅᖅ ᕙᑦᓈᕝᑯᑦ ᖃᐅᔨᒪᓂᖓ ᓯᑰᑉ ᐃᓕᖅᑯᓯᖏᓄᑦ ᐅᒥᐊᔾᔪᐊᒃᑯᓪᓗ ᓈᖓᔭᓇᐊᖃᓲᖏᑦ ᖁᑦᑎᒃᑑᑉ ᐅᑭᐅᖅᑕᖅᑐᐊᓂ, ᐊᑐᖅᑕᐅᓪᓗᑎᒃ ᑭᒡᓕᓯᓂᐊᖅᓱᑎᑦ ᐅᒥᐊᔾᔪᐊᑦ ᐅᓪᓗᖁᑎᔅᓴᖏᑦ ᐊᔾᔨᒌᖏᑦᑐᓄᑦ ᓯᑯᓯᐅᕈᓐᓇᖅᑐᓄᑦ.

ᖃᔅᓯᓪᓚᓪ ᐃᓱᒪᓕᐅᕆᓃᑦ ᑎᑭᑕᐅᓪᓗᑎᒃ ᐱᓪᓗᒋᑦ ᐅᒥᐊᔾᔪᐊᑦ ᐅᓪᓗᖁᑎᔅᓴᖏᑕ ᑭᒡᓕᖏᑦ, ᖃᓄᐃᑦᑑᔪᓪᓗ ᐅᒥᐊᔾᒧᐊᑦ ᐊᑐᕆᐊᓕᖏᑦ ᑕᖅᕿᑦ ᒪᓕᒃᑯᒋᑦ ᖃᓄᐃᑦᑑᓂᖓ ᓯᑰᑉ ᐃᓕᖅᑯᓯᐊ ᐊᑐᓐᓂᐊᖅᑖᒍᑦ. ᓯᑰᑉ ᐃᓕᖅᑯᓯᖏᑦ ᐱᓯᕆᑐᓵᕐᒍᓰᑦ ᕖᕝᕗᐊᕆᐅᑉ ᕿᑎᐊᓂ ᑎᑭᓪᓗᒍ ᒪᐃ ᐃᓱᖅᐸᓯᐊ, ᐱᓯᕆᐋᑐᔪᒥᒃ ᓯᑯᓕᕆᔩᕐᒍᒋᓪᓗᑎᒃ ᐅᑭᐊᒃᓵᒃᑯᑦ, ᐅᑭᐅᓕᓵᒃᑯᑦ ᐅᐱᕐᙲᒃᑯᓪᓗ ᑕᒪᒃᑯᐊ ᑭᓯᐊᓂ ᖁᑦᑎᓖᑦ ᓯᑯᓯᐅᑎᖏᓄᑦ ᐅᒥᐊᔾᔪᐊᓄᑦ ᐊᓂᒍᖅᑕᐅᔭᓇᕐᓴᖅᓱᑎᒃ.

Baffinland

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Ice Conditions Study

Ice conditions and ship access to the Milne Inlet port site - Update

Mary River mine site

Prepared by
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For
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Information
Integration
Innovation

ENFOTEC

Enfotec Technical Services Inc.
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Ice conditions and ship access to the Milne Inlet port site – Update

Authors
Pascale Bourbonnais, Alexis Dorais, Marie-Andrée Giguère, Tim Keane

Performing organization
Enfotec Technical Services Inc.
1000 de la Gauchetière West
Suite 3500
Montréal, Québec H3B 4W5
Canada

Client
Baffinland
2275 Upper Middle Road East
Suite 300
Oakville, Ontario L6H 0C3
Canada

Abstract
This study provides an update on the description of the ice conditions and an assessment of vessel access to Milne Inlet, Nunavut, for the Mary River mining site.

Key words
Shipping assessment, ice study, Milne Inlet

Distribution / Availability
Subject to terms of release by Baffinland

Executive summary

This report was prepared by Enfotec Technical Services 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 Milne Inlet port site. The analysis is based on historical ice conditions from 1980 to 2016 derived from ice charts and satellite imagery. Other data sources were used, including climatic data and technical or scientific publications covering sea ice and Arctic navigation. The conclusions drawn from this analysis also take into account Fednav's long-term shipping experience in the Arctic.

Ice conditions

Year-round conditions along the route to Milne Inlet are assessed, including potential shipping hazards and routing options. The nominal open water season is from August 5th to October 15th, resulting in a shipping window of 71 days. In the channels close to Milne Inlet (Pond Inlet, Milne Inlet, Navy Board Inlet and Eclipse Sound), the typical timeframe is short between the first signs of ice formation in mid October and the consolidation into land fast ice over 30 cm thick in mid-November.

Winter ice conditions are challenging in northwestern Baffin Bay due to heavy pressure and tremendous ice movement. Ice grows to the thick first-year stage (120 cm and more) in this region, whereas it is thinner (up to 70 cm) and less pressured in eastern Baffin Bay. In the channels close to Milne Inlet, the land fast ice grows up to 1.6 - 1.8 m thick and may contain old ice inclusions which have drifted in the area before the ice formed. The time when ice conditions are the most challenging is from mid-February to late May. Still, the difficult ice conditions that prevail in fall, early winter and spring can only be handled by high Polar Class vessels. By early June, ice begins to decay and clears away completely by the first days of August. At that time, drifting ice with inclusions of old ice can be expected, especially close to the entrance to Pond Inlet and Navy Board Inlet.

The impacts of climate change on Arctic sea ice are also discussed in this study. The report is in line with 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 challenges related to ice movement.

Vessel access

A model was used to generate simulated routes from the Canadian Ice Service regional charts from 1983 to 2012. The generated routes are meant to avoid or minimize the distance spent in the harshest ice regimes. Ice Numerals (IN) were calculated for each ice regime encountered for vessel Polar Classes PC 2 to PC 7 and Types A to E. The result of this modeling, combined with Transport Canada's Arctic Ice Regime Shipping System (AIRSS) as well as Fednav's knowledge of ice conditions and navigational challenges in the High Arctic were used to define the shipping seasons for different vessel ice classes.

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

1) The **nominal open water season** is from **August 5th to October 15th (71 days)**.

2) Shipping seasons, as herein described, are based on an assessment of interannual variability of ice conditions. The **high confidence shipping window**, especially for ships of lighter ice class (Types A to E and PC 6 and 7) should be **considered as a guide only** and strategic decisions will necessarily be made each year with respect to the provisional opening and closing dates for vessels of different ice classes.

3) On some years, it is expected that a **shoulder window** will allow the shipping season to be extended beyond the high confidence shipping window for certain classes of ships. This will need to be assessed on a year-by-year basis as there is high variability in terms of length and timing of the shoulder period.

4) Provision for **access to icebreaking services** will be strongly recommended for all 'Type' vessels as well as PC 6 and 7 ships during the shoulder periods at the beginning and the closing of the season. In comparison, Polar Classes 5 and higher can engage ice and face a certain amount of pressure on the ice cover.

5) **Type E** vessels (no ice class) are not meant to encounter any significant amount of ice at all. The high confidence shipping window is therefore defined as the average period of open water, about **August 5th to October 15th (71 days)**, with a shoulder window possibly extending the season by about a week. Extending the season will likely require an icebreaker escort.

6) **Type B, C and D and PC 7** vessels can encounter a certain amount of ice. The high confidence window is from **August 5th to October 15th (71 days)**, with an additional shoulder window that can add 10 to 30 days to the season, depending on the ice class. Extending the season will likely require an icebreaker escort.

7) **Type A and PC 6** vessels have a slightly longer high confidence shipping window, from **July 25th to October 15th (82 days)** and the shoulder window can extend the season by up to 25 days. Extending the season might require an icebreaker escort.

8) **PC 5** vessels can navigate with high confidence from **July 20th to December 31st (164 days)**, with a shoulder window possibly extending the season through January. Vessel speeds are expected to be lower from mid-November onward.

9) **PC 4** vessels can navigate with high confidence from **June 15 to February 15 (246 days)**, with a shoulder window covering the rest of the year. Indeed, the combination of substantial ice thickness and heavy pressure in western Baffin Bay is likely to result in **slow progress** and **possible interruptions** through the voyages from early or mid February to late May or even mid June.

10) **PC 2 and 3** vessels can navigate **year-round** to Milne Inlet. Progress may be slow from early February to mid June, but voyages are expected to remain efficient. They will likely face periods where their **ability to make progress is reduced** when ice is under high pressure.

11) **Alternate routing via Navy Board Inlet** should not be considered as a primary choice, but rather as an option to be assessed on a case-by-case basis. The **risk of old ice occurrence** and ridged fast ice is greater in this channel than in Pond Inlet.

Extending the shipping season much beyond the open water season will undoubtedly require the use of Polar Class ships. Polar Class ships can be faced with highly challenging conditions over hundreds of nautical miles, even when optimal routes have been selected. Not only can the time needed to navigate the routes be substantial, but the load on the engine and the amount of fuel required can be extremely high as well. Beyond the financial consequences, the capacity to carry sufficient fuel to navigate the whole route is a serious concern.

Shipping to and from Milne Inlet will require close monitoring of the ice conditions in order to ensure that ships are out of harm's way when ice conditions exceed a vessel's capabilities. This will also enable ice navigators on board the vessels to plan safe routes that avoid or minimize ice hazards. Since the AIRSS alone will not suffice to ensure that a ship's safety is not jeopardized, the experience and careful planning of the operators, ice navigators and crew will be essential. In addition, due to the inherent variability of ice conditions, flexibility will be needed in planning the shipping operation.

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Glossary

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)
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.
***In situ* 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.
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.
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.

Abbreviations

AIRSS	Arctic Ice Regime Shipping System
ASPPR	Arctic Shipping Pollution Prevention Regulations
CIS	Canadian Ice Service
IACS	International Association of Classification Societies
IN	Ice Numeral
IM	Ice Multiplier
MODIS	Moderate Resolution Imaging Spectroradiometer
NSIDC	National Snow and Ice Data Center
PC	Polar Class
ZDS	Zone/Date System

1. Introduction

This report was prepared by Enfotec Technical 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 Milne Inlet projected port site. The analysis is based on historical ice conditions from 1980 to 2016 derived from ice charts and satellite imagery. Other data sources were used, including climatic data and technical or scientific publications covering sea ice and Arctic navigation. The conclusions drawn from this analysis also take into account Fednav's long-term shipping experience in the Arctic.

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 1980-2016 period was used as background data for the analysis, images and ice charts included in the report are not older than 2004 in order to illustrate ice conditions that are closer to the current reality.

Transport Canada's Arctic Ice Regime Shipping System (AIRSS) is used to define access along the routes on a year-round basis. Vessel classes Type A to E and Polar Classes 2 to 7 have been evaluated. To conduct this analysis, 30 years of ice data were analyzed. This is a standard in climate science in order to include the variability and the extreme years that can be encountered and therefore provide a good profile of ice conditions.

Vessel access to Milne Inlet is then analyzed, with regards to different vessel ice classes. This analysis goes beyond the regulatory-based thresholds that define the shipping windows. Fednav's knowledge of ice conditions and navigational challenges in the High Arctic is added to the assessment in order to provide a complete profile of the situation.

Under a different approach, but with the same data as a baseline, a risk analysis is undertaken for four proposed shipping windows. This brings a different perspective on the shipping potential and the challenges involved for each option. Additionally, the alternate route through Navy Board Inlet instead of Pond Inlet is analyzed.

The impacts of climate change on Arctic sea ice are also discussed. The report is in line with 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 challenges related to ice movement.

2. Ice conditions along the route to Milne Inlet

Milne Inlet is located in the northern part of Baffin Island, at 72°N, 81°W. From the Arctic Circle (66°N) to the port site, the route comprises a total distance of about 900 nautical miles. Milne Inlet can be approached via two options: 1) south of Bylot Island, through Pond Inlet and Eclipse Sound, or 2) north of Bylot Island, through Lancaster Sound, Navy Board Inlet and Eclipse Sound (Figure 1).

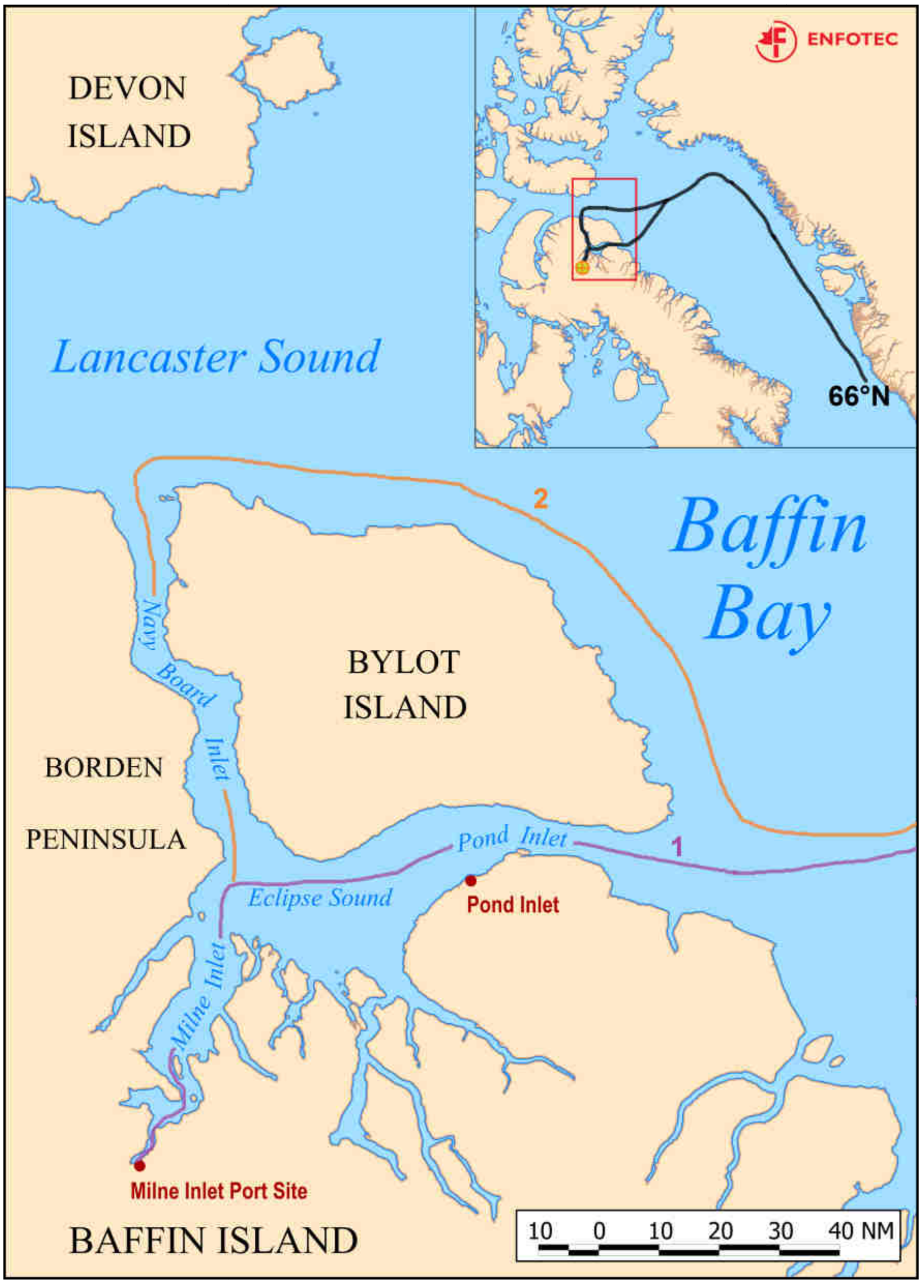


Figure 1 Approaches to Milne Inlet.

The route to Milne Inlet includes a long segment in the mobile ice pack of Baffin Bay (approximately 800 NM) from the Arctic Circle to the entrance to Pond Inlet or Lancaster Sound. Option 1 – via Pond Inlet – adds 100 NM to the route, whereas Option 2 – via Lancaster Sound and Navy Board Inlet – adds 175 NM to the route.

Ice conditions will be defined according to seasons: 1- Break-up and summer; 2- Freeze-up and fall; 3- Winter and spring. Since conditions are far from homogenous in Baffin Bay and the approaches to Milne Inlet, the region was sub-divided into 6 zones (Figure 2) that reflect specific ice conditions.

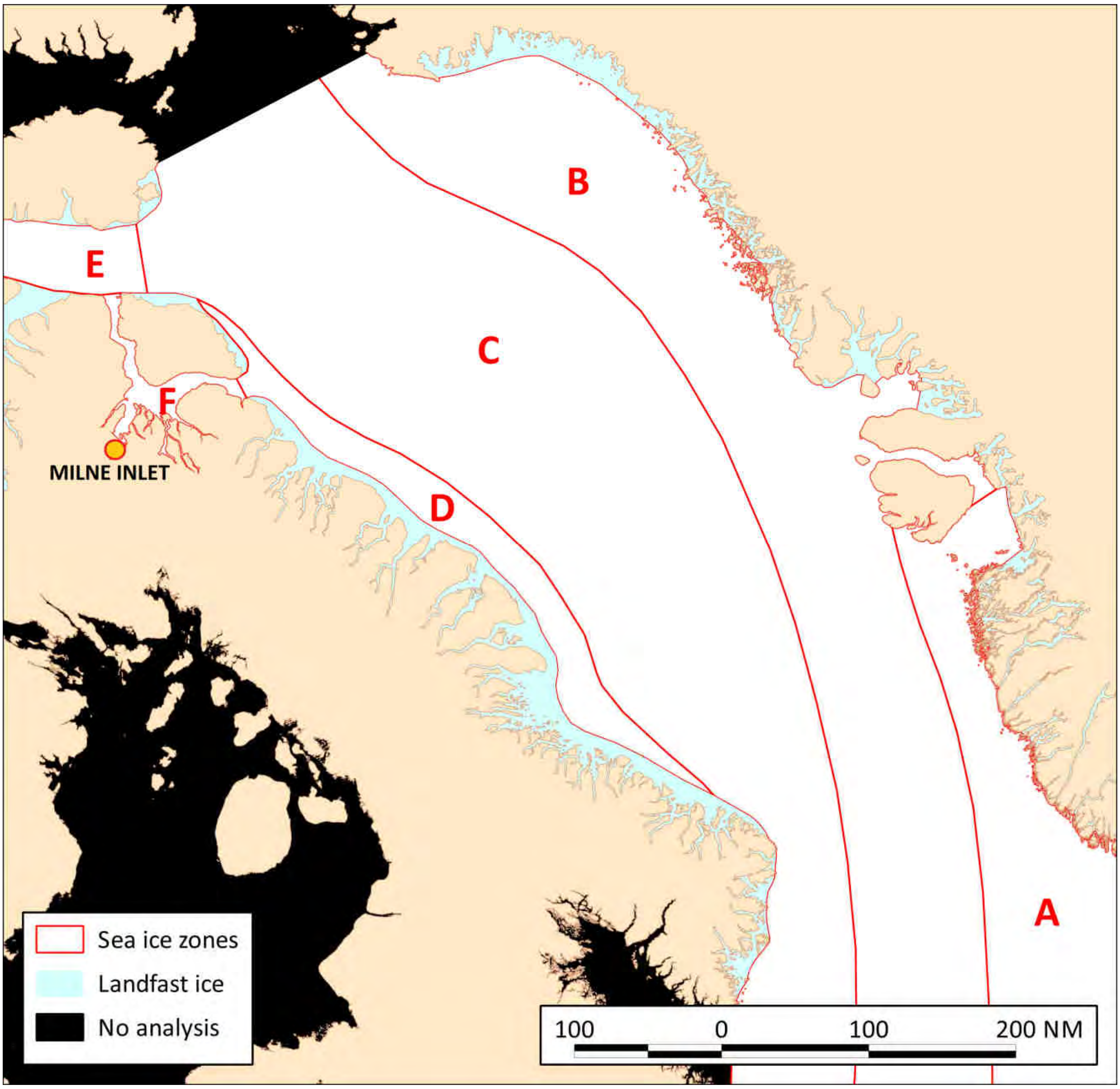


Figure 2 Map of zones along the route to Milne Inlet.
(Zone A – West Greenland Lead, Zone B – East Baffin Bay, Zone C – West Baffin Bay, Zone D – Baffin Coast Shear Zone, Zone E – Lancaster Sound and Zone F – Land Fast ice)

2.1 Break-up and summer

Even though the approaches to Milne Inlet are completely ice covered for a large part of the year, the region opens for navigation during a few weeks in summer. Above 0°C temperatures typically begin in early June, with a few odd days of above 0°C temperatures occurring in May as well. Table 1 shows the average value of cumulative temperature below and above 0°C for each month at Pond Inlet. It is only in July and August that temperatures remain above the freezing level all month long. The Midnight Sun period (daylight 24 hours a day) begins in early May and goes on until early August, when the days begin to gradually shorten. By mid-September, temperatures begin to drop below the freezing point.

Table 1 Degree-days in Pond Inlet, based on 1981-2010 average (Environment Canada).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Below 0°C (Freezing degree-days)	1035.5	948	927.1	655.4	289.3	13.5	0	0.5	51.9	293.5	647.5	874	5736.1
Above 0°C (Melting degree-days)	0	0	0	0	2.2	84	205.5	149.6	30.9	0.9	0	0	473

Degree-days for a given day represent the number of Celsius degrees that the mean temperature is above or below a given base.

When the first signs of break-up occur, the ice has already been melting at the surface for over a month. This is the typical delay in the high Arctic between thermo-dynamic summer (when ice begins to melt) and kinematic summer (when ice begins to break-up). As a result, the ice remains quite thick, but it softens in the interval between thermo-dynamic and kinematic summer. Before break-up, the ice contains many puddles and melting ponds. The beginning of kinematic summer, or break-up, marks the transition to free ice drift conditions (Stern and Lindsay, 2009), a stage that must be monitored carefully in order to ensure safe navigation and the choice of an optimal route.

Zones A, B, C, D – Baffin Bay

The first area to clear up in early summer is eastern Baffin Bay – Zones A and B. The clearing of the northern part of the bay can also be observed by the end of spring (Figure 3). North Water, a vast polynya located in northern Baffin Bay, is the main factor causing the early clearing. Although some thin ice can form, this warm microclimate remains mostly open during winter thanks to winds, tides and an ice arch at its northern limit. In mid-June, an open water route begins to form along the coast of Greenland due to the warm West Greenland Current, and expands all the way to Lancaster Sound by mid-July (Figure 4).

Western Baffin Bay (Zones C and D) clear up a few weeks later; open drift ice regimes can be seen until mid-August. Although there is often lingering ice until late August in central Baffin Bay, in addition to several icebergs all summer long, the route is completely open during several weeks, until late September.

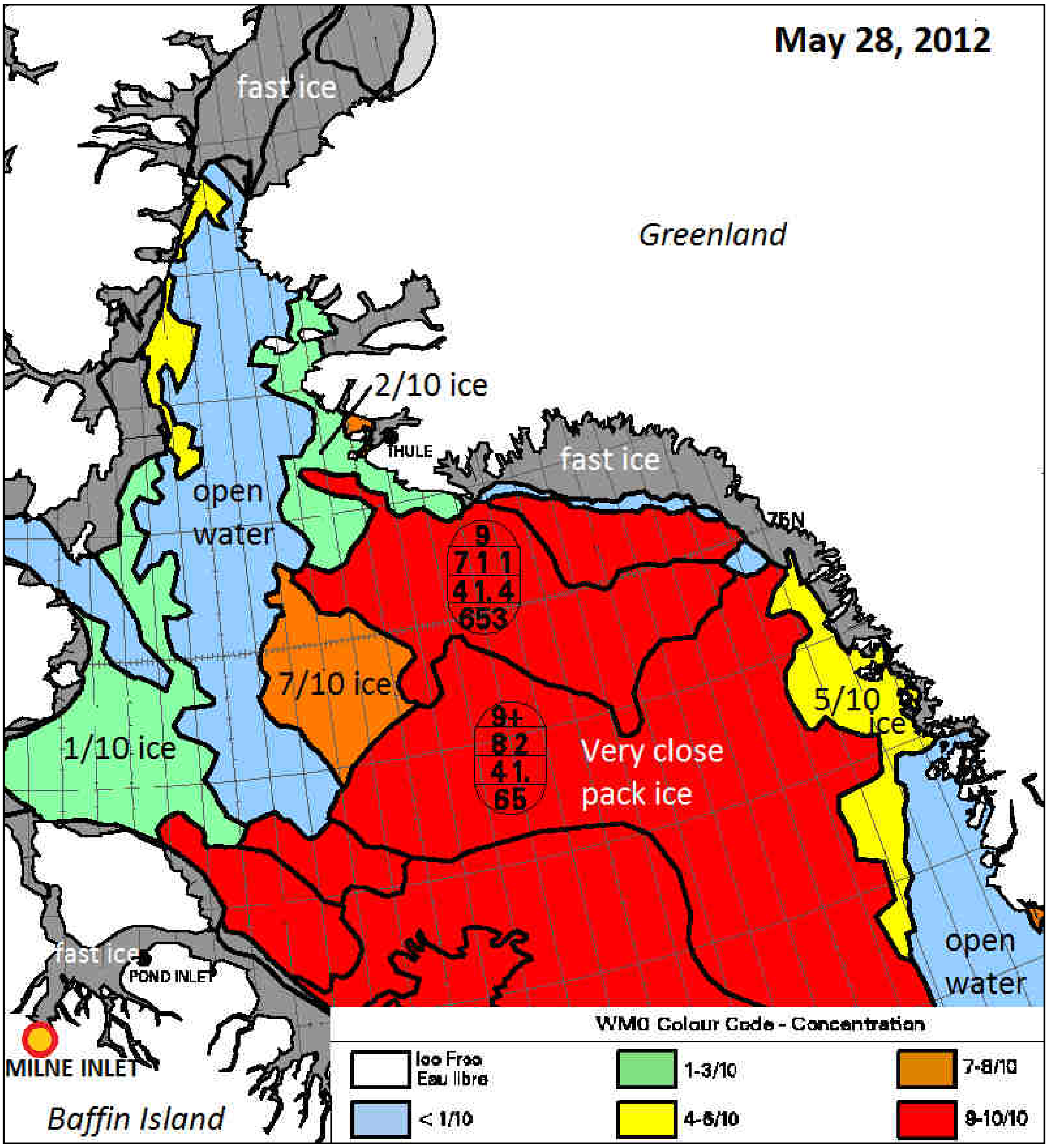


Figure 3 Ice chart on May 28, 2012 (Canadian Ice Service).

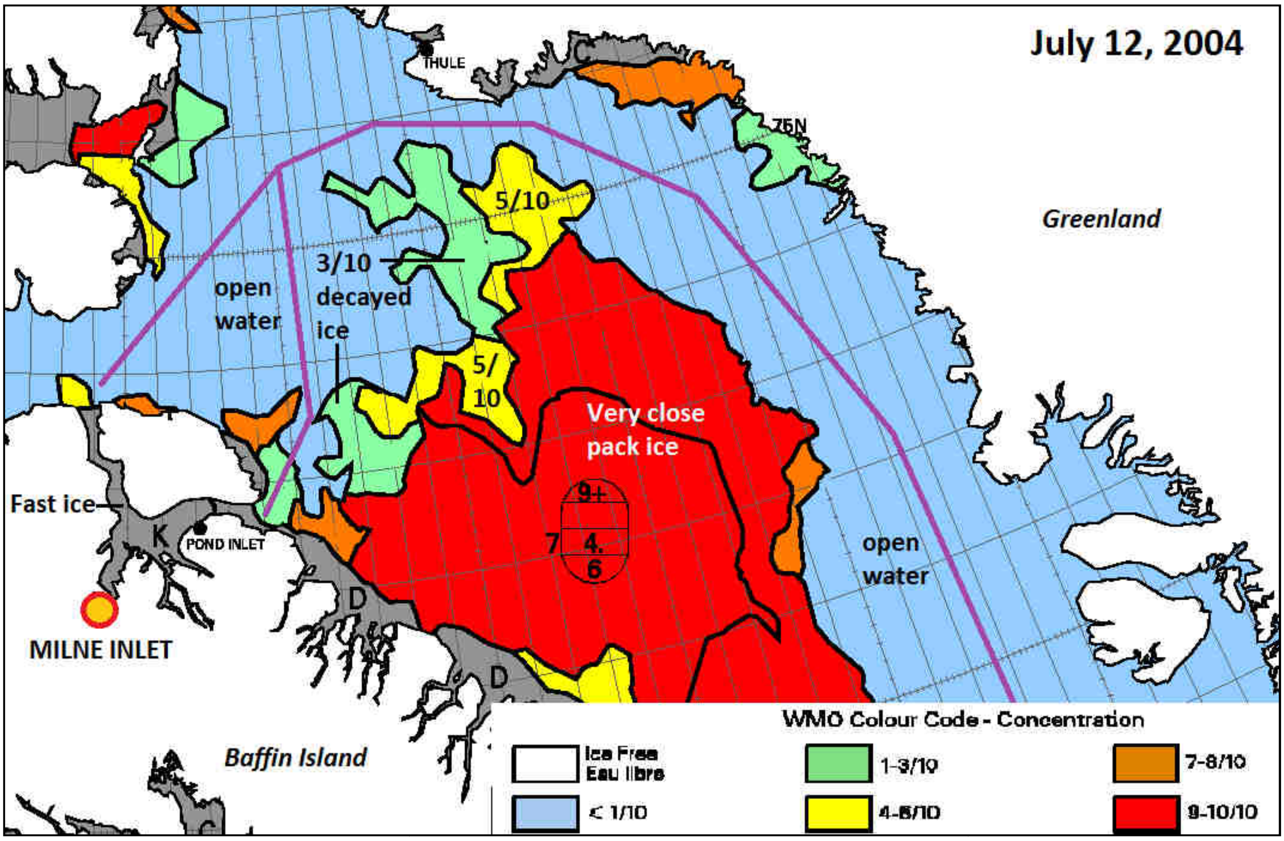


Figure 4 Ice chart on July 12, 2004 (Canadian Ice Service).

Old ice occurrences in Baffin Bay in late summer are frequent and they mostly originate from Nares Strait. However, these ice regimes are generally in low concentration and at an advanced stage of decay. Old ice takes more time than first-year ice to melt as it is denser; small pieces can linger until late summer and even throughout the season in isolated areas. When carefully monitored, it can be avoided by slightly modifying the route. Figure 5 identifies patches of drifted old ice in central Baffin Bay in August.

In addition to sea ice, the West Greenland Current pattern, which flows northward and northwestward along the coast of Greenland, is also responsible for distributing icebergs that calve off western Greenland, namely in Disko Bay (southeast to Disko Island) and drift across Baffin Bay. While many icebergs tend to drift southward and southeastward along the Baffin Island coast all the way to the Labrador Sea, icebergs of a mass in excess of 1 million ton tend to drift to the north (Tang *et al.*, 2004). Figure 5 shows that the waters of Baffin Bay are identified as “bergy waters”, which is typically the case for several weeks in late summer and early fall.

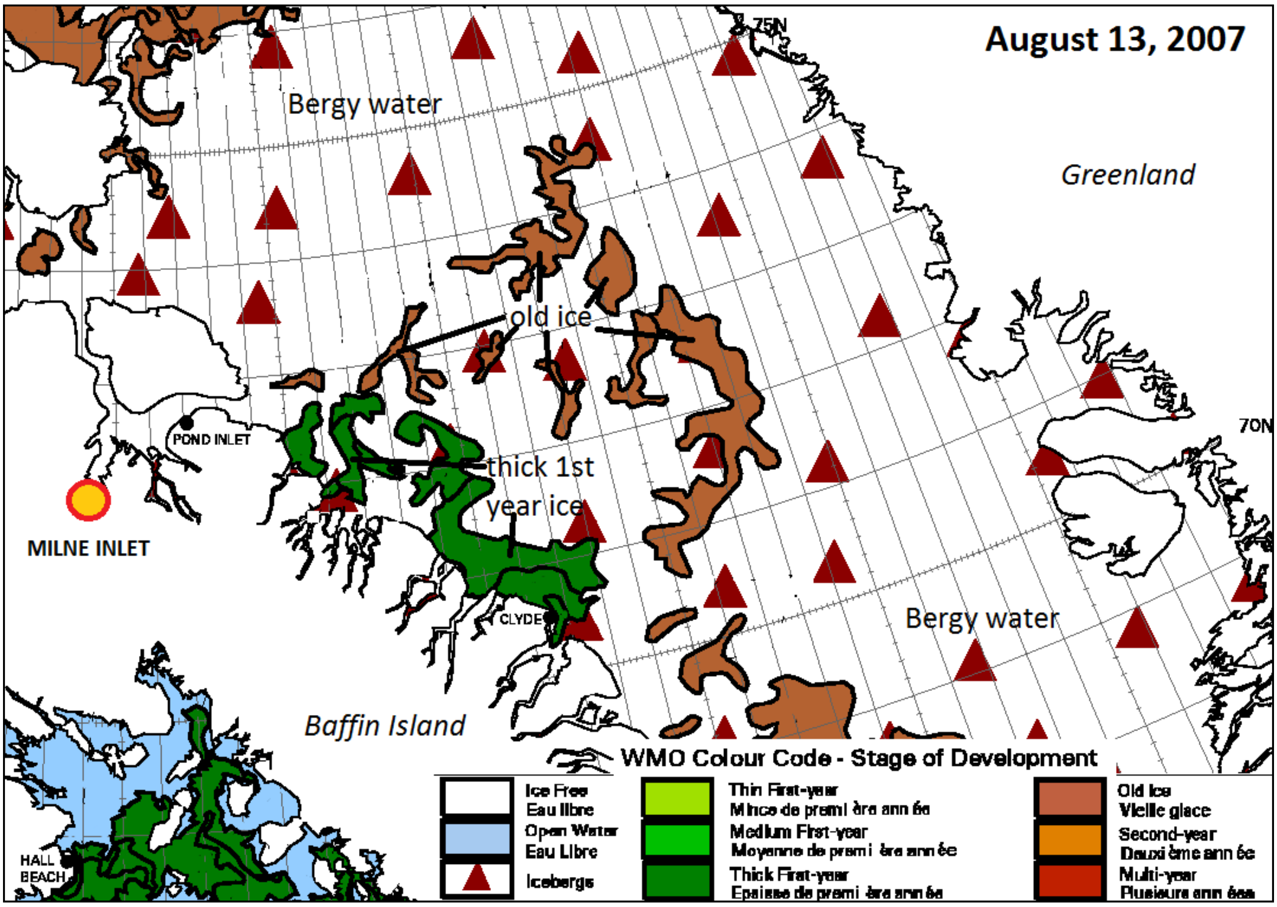


Figure 5 Ice chart on August 13, 2007 (Canadian Ice Service).

Zone E – Lancaster Sound

Lancaster Sound usually shows a break-up sequence that goes from east to west and begins around the first days of July (1981-2010 median date). Still, there is high interannual variability in the onset date of the break-up. Ice does not always consolidate in the sound and break-up tends to occur later when the channel is consolidated during winter. Break-up can start as early as mid-June and as late as early August. Figure 6 and Figure 7 illustrate how different the ice conditions can be in Lancaster Sound at the same date on two different years. In 2011, the channel had cleared rapidly by early July, while in 2012, at same date, the land fast ice had only recently broken up.

Regardless of the onset timing of clear-up, Lancaster Sound normally becomes widely open water later in the summer. However, small inclusions of drifting old ice coming from the channels of the High Arctic must be carefully monitored, as well as icebergs that tend to drift into the eastern entrance of the channel due to the intrusive flow of the Baffin Current (Marko *et al.*, 1982; Fissel *et al.*, 1982). These drifting ice floes are very thick as they are composed mainly of ridged thick first-year ice and inclusions of old ice that have drifted from western Parry Channel or the many waterways in the higher latitudes.

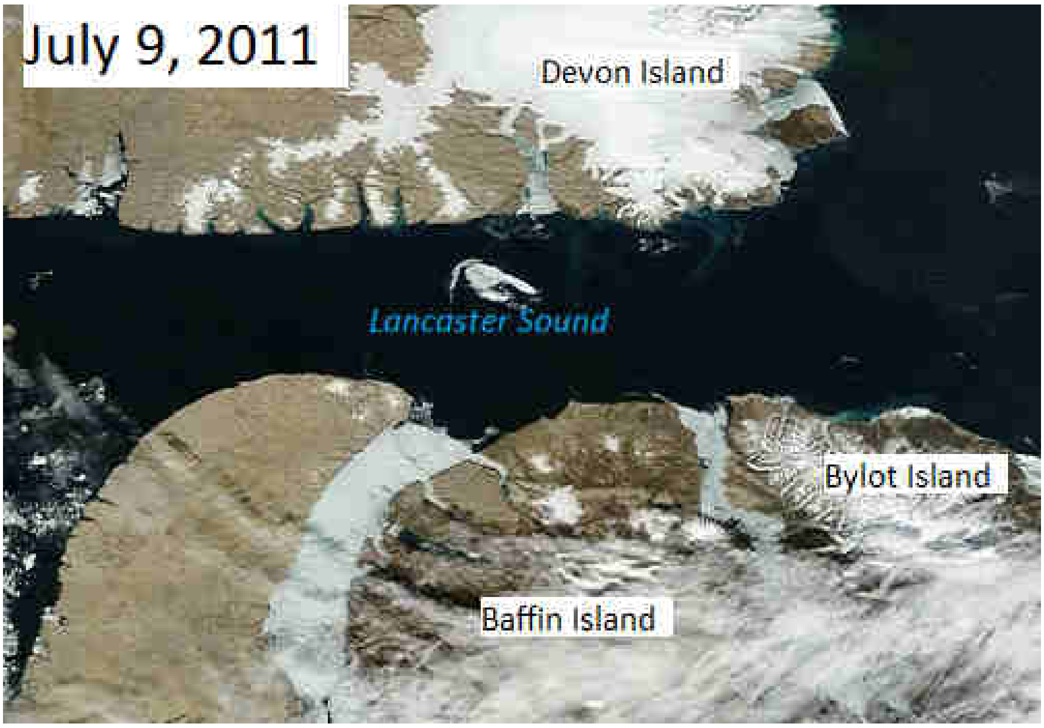


Figure 6 MODIS image on July 9, 2011 (Canadian Ice Service).

Figure 7 MODIS image on July 9, 2012 (Canadian Ice Service).

Zone F – Internal waterways

In the land fast ice of Navy Board Inlet, Eclipse Sound, Pond Inlet and Milne Inlet, the sequence of clearing events is quite rapid. The area goes from a complete thick land fast ice cover to no ice at all in a short period. Although the melting process begins in June at the surface of the ice, first break-up signs generally appear in mid-July. Within 3 to 4 weeks everything has melted away. Once clear-up is complete – usually around August 10th at the latest – the channels remain open water until early October.

Figure 8 shows ice conditions in Milne Inlet and its approaches shortly after break-up of the fast ice (July 18). At that time, ice concentration is high and floes are large. These ice conditions can be challenging for vessels that do not have icebreaking capability, as interaction between vessel and ice will be inevitable in the narrow passages. Such vessels will be unable to navigate around these floes, and neither can they effectively engage ice of that type. The narrowness of the channels can create choke points that may impede navigation for several days until these blockages clear up.

Figure 9 shows the same area 11 days later (July 29): there is almost no ice left in Milne Inlet, Eclipse Sound and Pond Inlet. However, Navy Board Inlet and the southern shore of Lancaster Sound are more packed with ice, likely due to winds and currents pushing the ice towards the shore and into the channel. This sequence is typical of summer conditions in the High Arctic. Lancaster Sound is a very dynamic area and mobile ice can drift into the narrower channels nearby, especially in Navy Board Inlet, even a few days or weeks after in-situ melting has occurred. Some of this ice is drifting from the channels north of Lancaster Sound and may contain old ice.

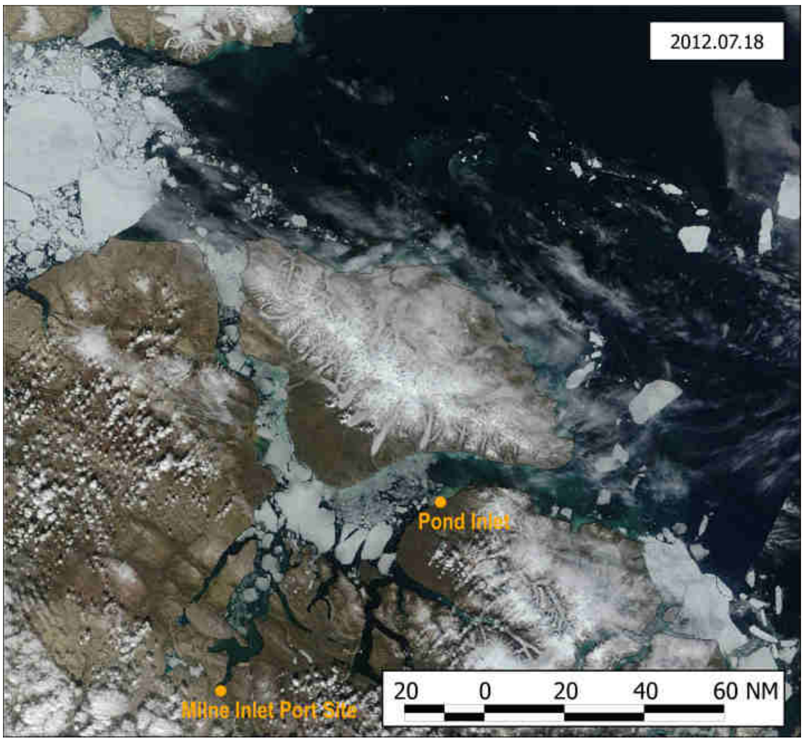


Figure 8 MODIS image on July 18, 2012 (NASA).

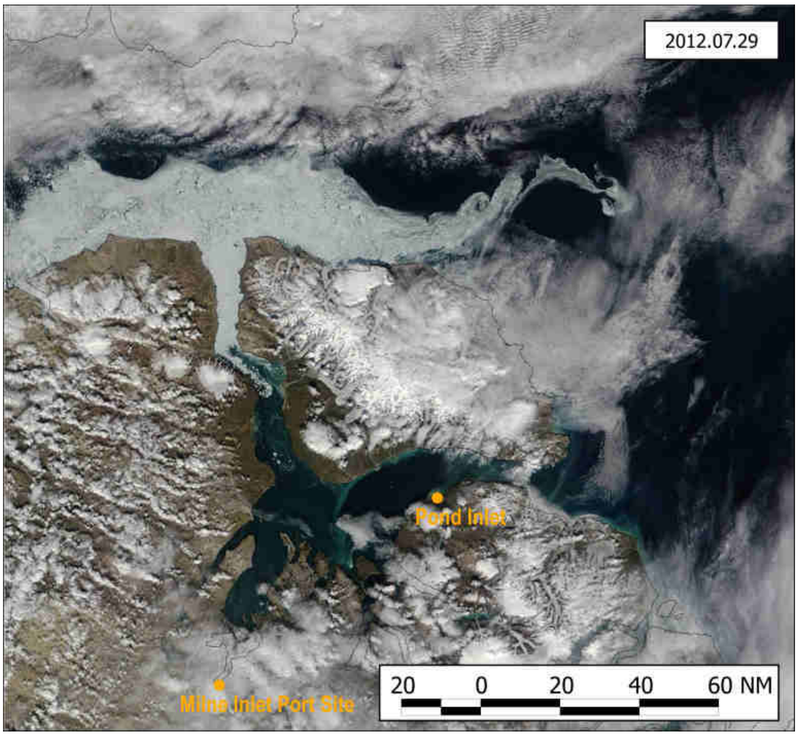


Figure 9 MODIS image on July 29, 2012 (NASA).

Summary

August 5 to October 15 has been defined as the open water season. As demonstrated in Table 2, over the past 20 years, the average open water season was of 68 days. The average opening date was on August 6, and the average closing date was on October 14. Starting date is identified as the moment where the entire area covering the shipping route is open water; closing date is identified as the moment where freeze-up begins. However, a significant variability has been observed over the past years in the season length, as well as in the starting and closing dates. This variability demonstrates the importance of assessing each season's duration and start and end dates on a case-by-case basis.

Further analysis of this shipping window is provided in section 4.

Table 2 Open water shipping season for years 1997 to 2016.

Year	Break-up	Open water	Freeze-up	Season length	Presence of drift ice during the open water season
1997	July 24	August 7	October 2	56 days	Late Aug. / early Oct.
1998	July 16	August 10	October 19	70 days	No
1999	July 26	August 18	October 11	54 days	No
2000	July 12	July 31	October 16	77 days	No
2001	July 23	August 15	October 15	61 days	No
2002	July 27	August 15	October 21	67 days	No
2003	July 15	August 1	September 29	59 days	Mid Aug. / late Sept.
2004	July 19	August 11	October 18	68 days	Late Sept. / early Oct.
2005	July 29	August 15	October 14	60 days	No
2006	July 14	July 28	October 23	87 days	No
2007	July 19	August 6	October 11	66 days	No
2008	July 18	August 1	October 6	66 days	No
2009	July 17	August 6	October 12	67 days	No
2010	July 15	August 5	October 11	67 days	No
2011	July 8	July 29	October 21	84 days	No
2012	July 12	August 18	October 15	58 days	No
2013	July 20	August 9	October 7	59 days	No
2014	July 24	August 9	October 23	75 days	No
2015	July 17	July 25	October 19	86 days	No
2016	July 11	July 23	October 10	78 days	Early Oct.
Average	*July 18*	*August 6*	*October 14*	*68 days*	
Variability	*21 days*	*26 days*	*24 days*	*33 days*	

2.2 Freeze-up and fall

The sequence of freeze-up events is very rapid. As air temperature begins to drop below 0°C in the area of Pond Inlet in September (Figure 10), conditions become favorable to freeze-up. Arctic waters only have a short period of time in summer during which water temperature can rise, therefore it takes little time for the water to cool down enough for ice to form.

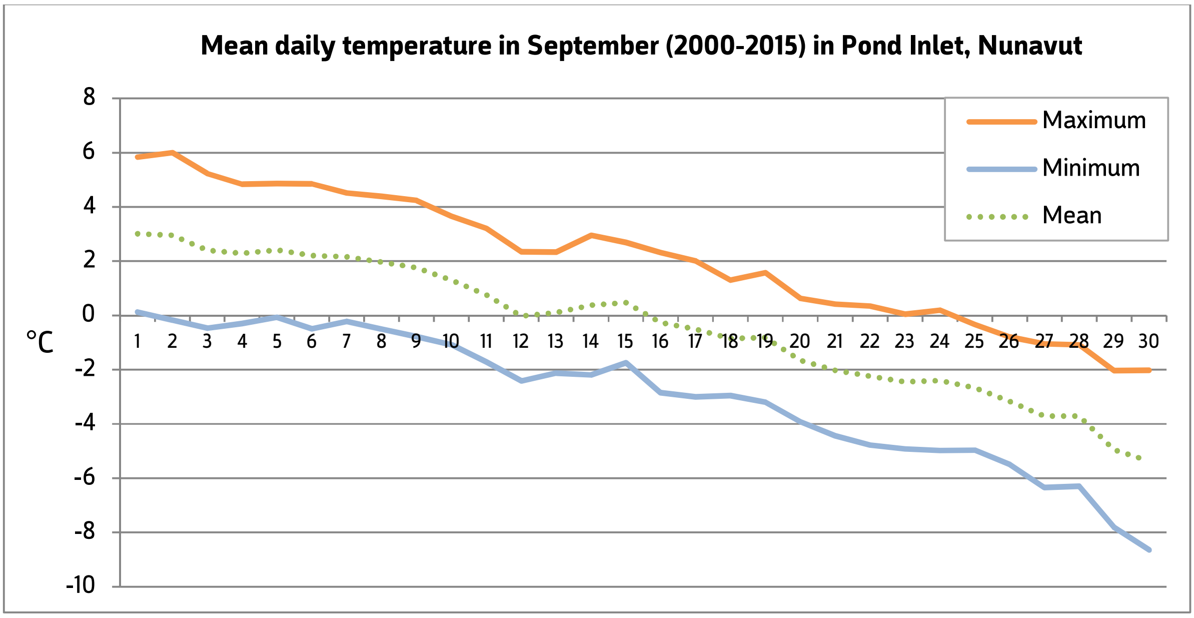


Figure 10 Daily temperatures in Pond Inlet in September (Environment Canada).

Table 3 Freeze-up dates in the approaches to Milne Inlet from 1997 to 2016.identifies the date at which freeze-up began in the approaches over a period of 20 years. Lancaster Sound is generally the first area where ice forms in fall, due to lingering floes that trigger ice growth more rapidly than open water. Navy Board Inlet tends to freeze-up slightly earlier than Milne and Pond Inlets, also due to drifting ice coming from Lancaster Sound. Baffin Bay begins to freeze up later than the channels.

Table 4 shows the date at which the ice had reached various stages of development along the approaches to Milne Inlet over the same time period. New ice (less than 10 cm) normally begins to appear in the second week of October, and grows rapidly. It turns into grey-white ice (15-30 cm) by the first week of November, and becomes thin first-year ice (30-70 cm) around November 15th. In 2009, less than one month passed between the first appearance of new ice and the moment it thickened to thin first-year ice, turning shortly after into fast ice. This gives an idea of the rapid growth rate ice can reach in the High Arctic.

Table 3 Freeze-up dates in the approaches to Milne Inlet from 1997 to 2016.

Year	Milne Inlet	Eclipse Sound	N. Board Inlet	Pond Inlet	Lancaster	Baffin Bay
1997	October 2	October 2	October 2	October 2	September 25	October 5
1998	October 19	October 19	October 19	October 19	October 19	October 26
1999	October 11	October 11	October 11	October 15	October 11	October 18
2000	October 16	October 16	October 9	October 23	October 9	October 16
2001	October 15	October 15	October 15	October 15	October 15	October 15
2002	October 21	October 21	October 14	October 21	October 18	October 28
2003	September 29	September 29	September 29	September 29	October 6	October 10
2004	October 18	October 25	October 18	October 18	October 4	October 25
2005	October 14	October 14	October 14	October 14	October 7	October 14
2006	October 20	October 20	October 13	October 21	October 13	October 27
2007	October 25	October 19	October 19	October 12	October 11	October 5
2008	October 16	October 16	October 10	October 20	October 10	October 10
2009	October 16	October 16	October 12	October 12	October 9	October 15
2010	October 9	October 8	October 8	October 8	October 8	October 15
2011	October 27	October 24	October 21	October 21	October 14	October 14
2012	October 13	October 15	October 12	October 26	October 25	October 26
2013	October 11	October 25	October 4	October 24	October 3	October 4
2014	October 23	October 23	October 17	October 24	October 16	October 24
2015	October 14	October 19	October 12	October 21	October 12	October 19
2016	October 10	October 10	October 10	October 10	October 3	October 17
Average	*October 15*	*October 16*	*October 12*	*October 16*	*October 10*	*October 17*
Variability	*28 days*	*26 days*	*22 days*	*27 days*	*30 days*	*24 days*

Table 4 Dates of various stages of development along the routes to Milne Inlet from 1997 to 2016.

Year	New ice < 10 cm	Grey ice 10-15 cm	Grey-white ice 15-30 cm	1st year ice > 30 cm	Fast ice
1997	October 2	October 9	October 16	October 30	November 13
1998	October 19	October 26	November 2	November 23	November 16
1999	October 11	October 18	October 25	November 1	November 8
2000	October 16	October 23	October 30	November 6	November 6
2001	October 15	October 22	November 5	November 12	November 5
2002	October 21	October 28	November 4	November 18	November 4
2003	September 29	October 13	October 27	November 3	November 10
2004	October 18	October 25	November 1	November 8	November 15
2005	October 14	October 17	October 31	November 7	Late December
2006	October 23	November 9	November 13	November 27	November 27
2007	October 11	October 22	October 29	November 12	November 19
2008	October 6	October 27	November 3	November 24	November 24
2009	October 12	November 2	November 5	November 9	November 16
2010	October 11	November 1	November 8	November 22	November 15
2011	October 21	October 24	November 7	November 21	November 14
2012	October 15	October 29	November 5	November 19	November 19
2013	October 7	October 21	November 4	November 15	November 4
2014	October 23	October 27	November 7	November 17	October 27
2015	October 19	October 26	November 2	November 13	November 9
2016	October 10	October 17	October 24	November 28	November 16
Average	*October 14*	*October 24*	*November 2*	*November 14*	*November 12*
Variability	*24 days*	*31 days*	*28 days*	*29 days*	*31 days*

After freeze-up begins, it takes some time before the ice becomes fast in Navy Board Inlet, Eclipse Sound, Milne Inlet and Pond Inlet. The duration of this time period varies from one year to another and is subject to local weather conditions. During the short period where the ice is not consolidated within these channels, thin first-year ice (up to 70 cm) can be deformed into ridges a few meters thick if it is closely packed and under pressure. In 2005, the ice in the approach to Milne Inlet only became fast in late December, whereas it normally does so in mid to late November. Therefore, the ice was under the influence of winds and currents for a period of about 2 months. There is a strong likelihood that this ice took a long time to become fast because it was under external stresses. Consequently, it was probably heavily deformed when it became consolidated. These ridges then remain part of the fast ice cover all winter long.

Lancaster Sound becomes closely packed with ice rapidly after the first appearances of ice in early to mid-October. It tends to become ice covered a few days earlier than Milne, Pond and Navy Board Inlets. Freeze-up starts in mid or late September in Barrow Strait, sometimes around remaining pieces of ice that have survived summer's melt, and extends to the east within a few weeks. Fednav's past experience in this channel in November has shown that it is a very challenging area, even for icebreaking vessels. Ice thickens rapidly to the 30-70 cm range and remains highly mobile. As a result, ridging and heavy pressure can be observed by early November.

Baffin Bay takes a long time to become fully ice covered. Ice expands southward from Nares Strait and first concentrates in the northwestern portion of the bay. As air and water temperatures decrease, the ice cover grows rapidly. Figure 11 and Figure 12 show how much ice conditions can change in Baffin Bay in fall in a one week interval. Zone A (the West Greenland lead) and the southern portion of Zone B (East Baffin) often remain open water through fall, after the rest of the bay has become covered by very close pack ice. Icebergs and other forms of glacial ice are also a prominent feature in fall and may become embedded within the pack as the ice cover expands.

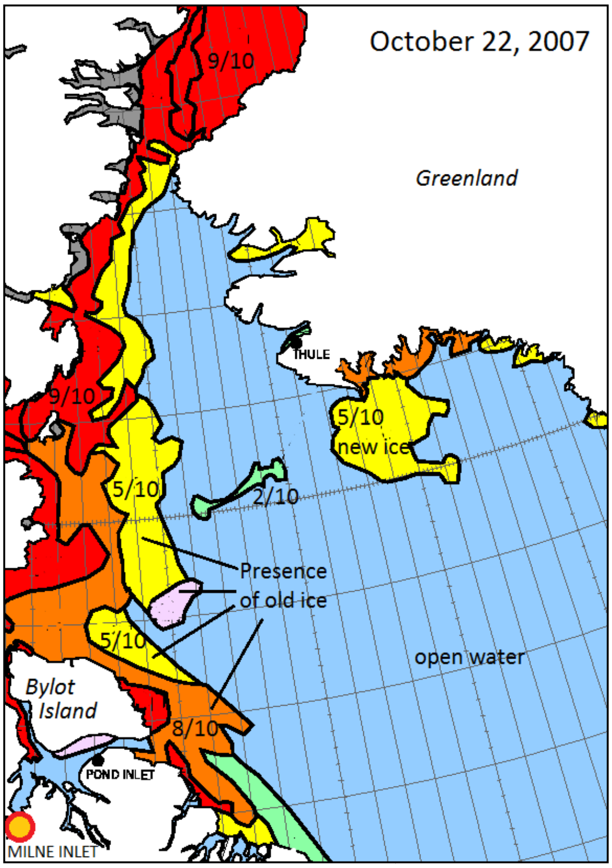


Figure 11 Ice chart on October 22, 2007
(Canadian Ice Service)

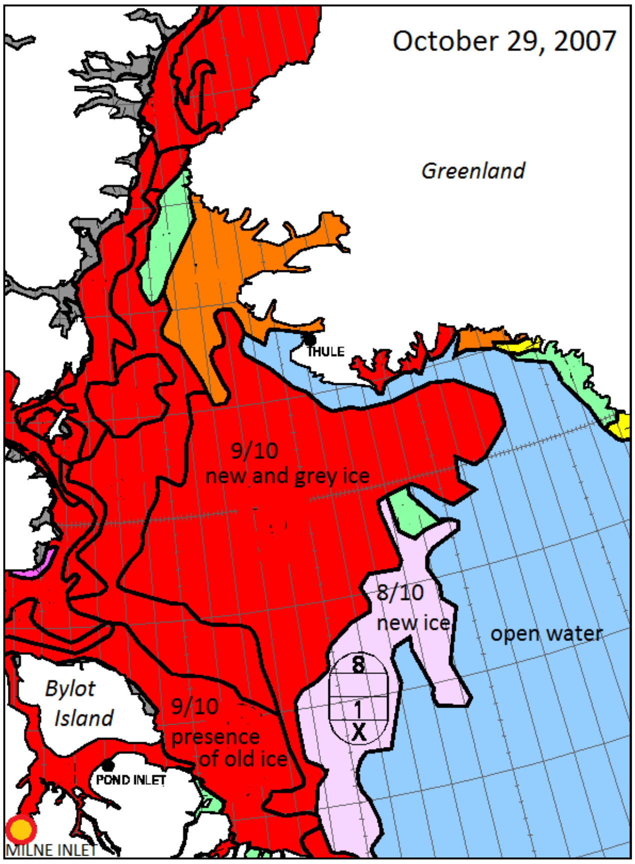


Figure 12 Ice chart on October 29, 2007
(Canadian Ice Service)

2.3 Winter and spring

Ice prevails over the entire route from November to June (8 months). Still, there are significant differences in ice dynamics along the route during winter and spring.

Zone A – West Greenland Lead

Ice conditions in Baffin Bay are influenced by two currents, the West Greenland Current and the Baffin Island Current (Figure 13). The West Greenland Current, an ocean current that originates from a branch of the Gulf Stream, follows the western Greenland coast northward and brings warm water up to latitude 75°N. This current is responsible for the presence of an open water or thin ice lead in southeastern Baffin Bay during winter.

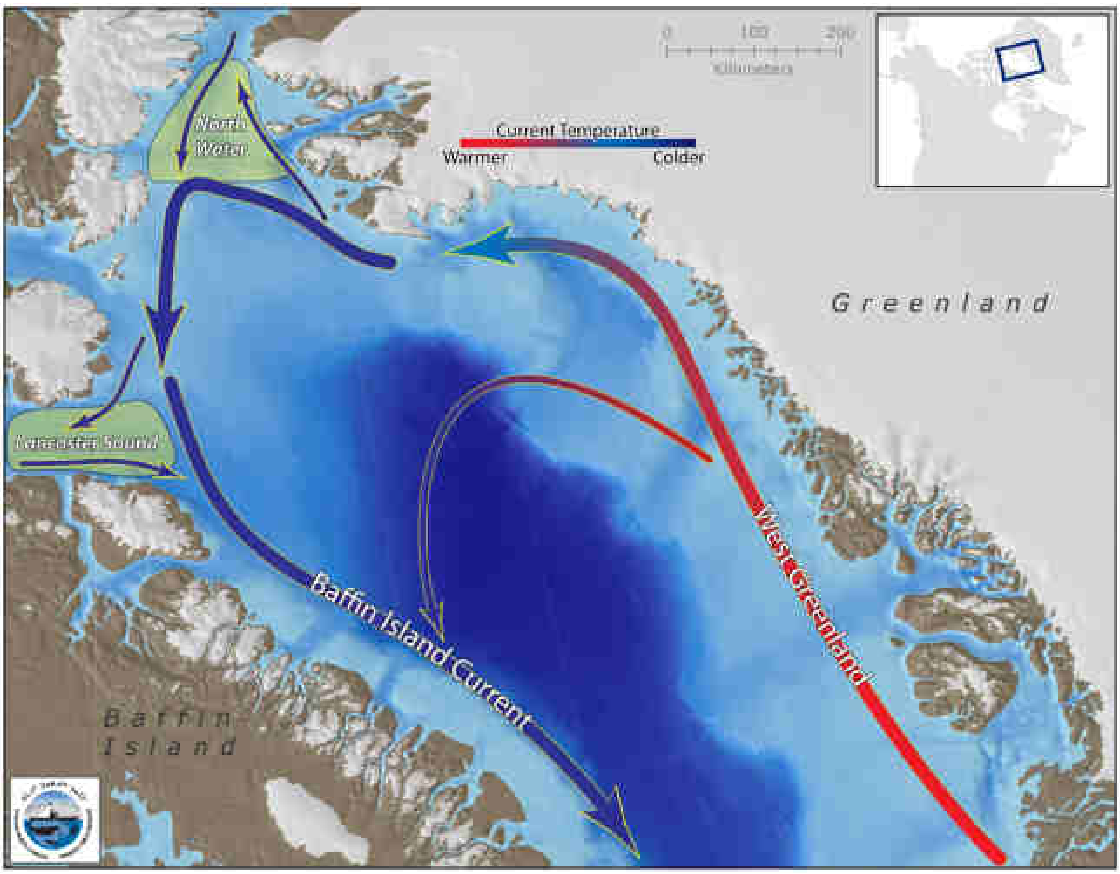


Figure 13 Currents of Baffin Bay (Oceans North Canada).

Ice conditions are highly variable from one year to another. In what are considered like normal ice years, the lead tends to remain open or partially ice covered up to Disko Island, such as in February 2005 (Figure 14). In heavy ice years, the pack ice can cover almost the entire route along Greenland coast, with very little open water, as it was the case in February 2008 (Figure 15). These conditions persisted throughout winter and lightened only when spring clear-up began in the southern part of

Baffin Bay in mid-April. In light ice years, the Baffin Bay pack is narrower. Therefore, the open water lead reaches higher latitudes. In February 2011, the west Greenland lead remained opened up to 74°N (Figure 16), more than 300 NM further north than on normal ice years.

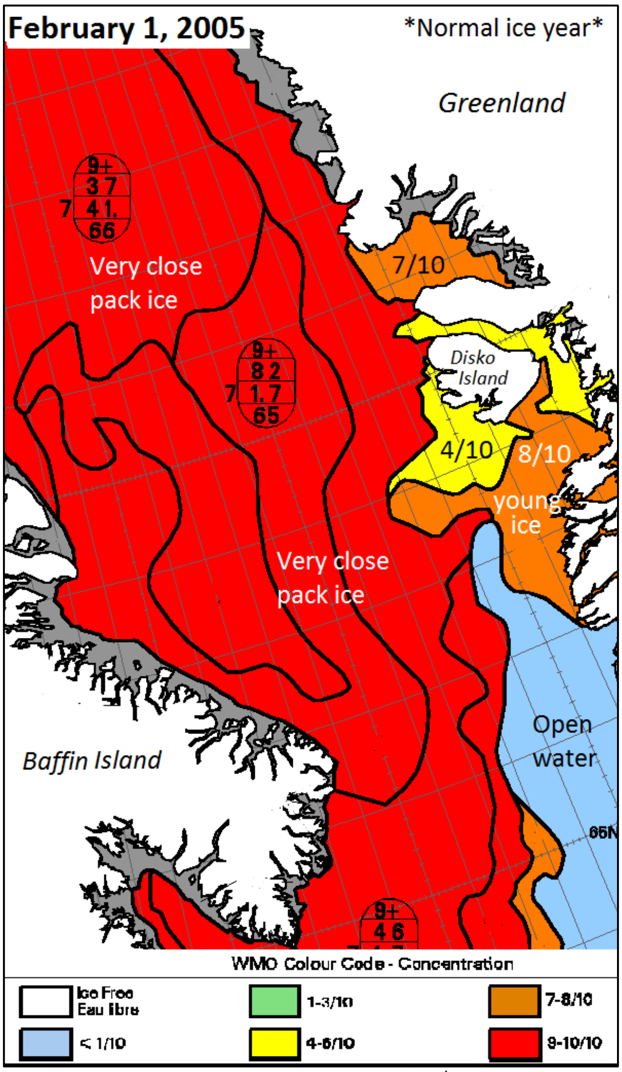


Figure 14 Ice chart on February 1st, 2005
(Canadian Ice Service)

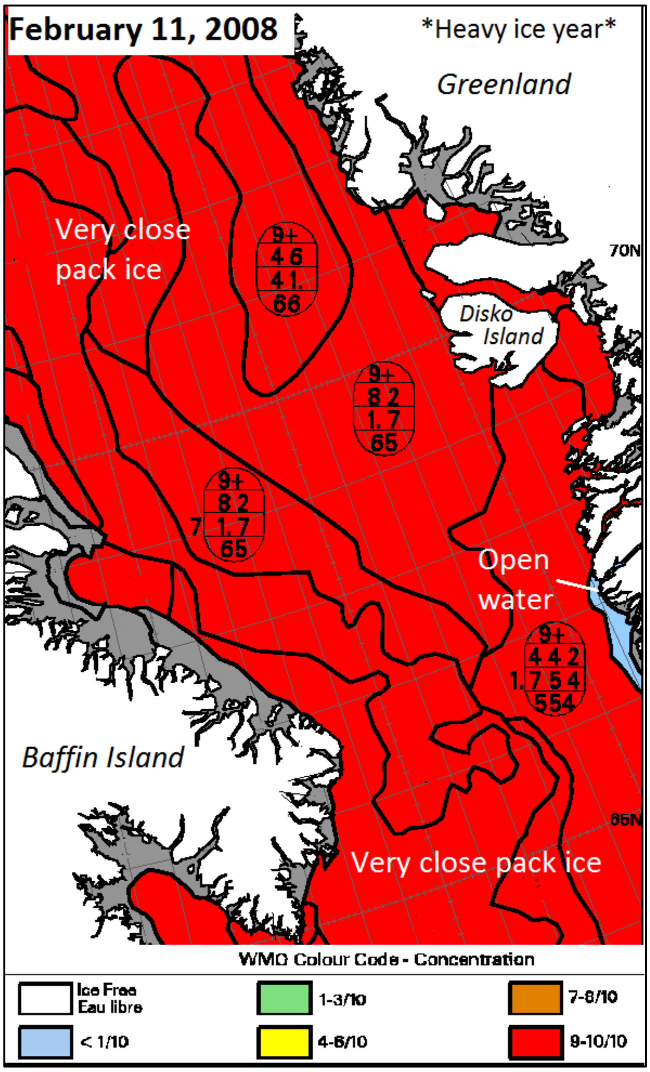


Figure 15 Ice chart on February 11, 2008
(Canadian Ice Service)

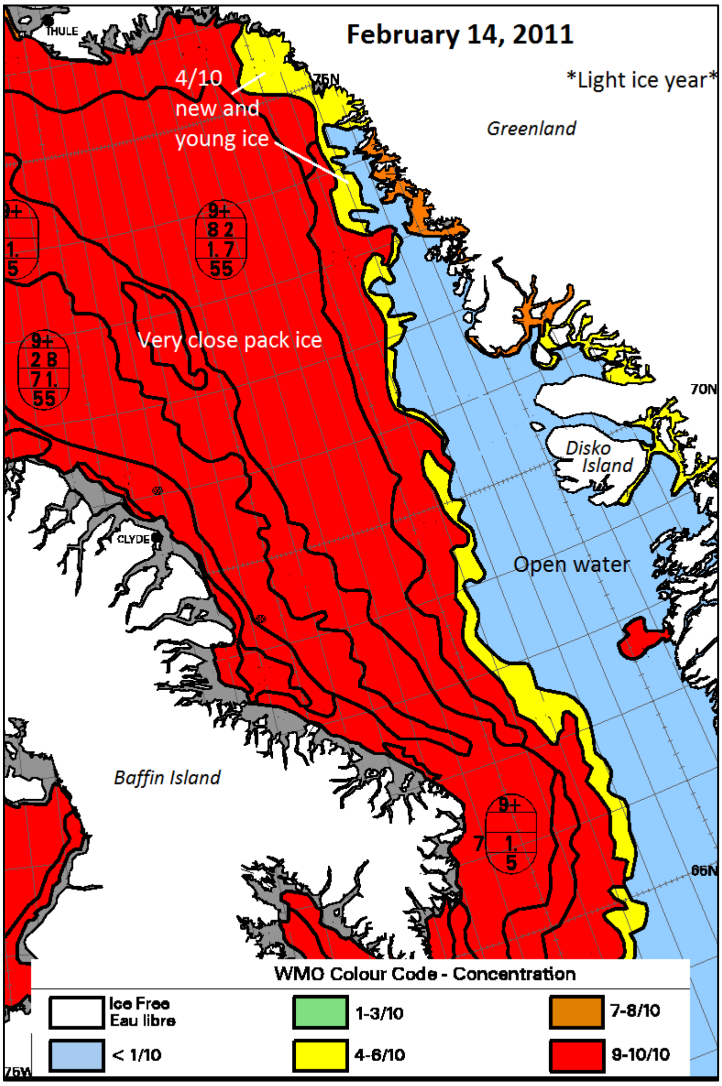


Figure 16 Ice chart on February 14, 2011 (Canadian Ice Service)

Zone B – East Baffin Bay

An area of relatively level thick first-year ice prevails in the eastern part of Baffin Bay. This area is also under the influence of the warm West Greenland Current. As it travels north, the current gradually weakens and disperses westward across Baffin Bay, as shown in Figure 13. The relatively light and diverging ocean currents in this part of Baffin Bay produces little pressure or ridging on the ice cover over the winter period. Predominant easterly winds also favor divergence of the ice cover in this area. Frequent leads can be seen in the pack (Figure 17), which makes navigation easier. Old ice is only present in traces in that zone, thereby reducing risk level for ships. First-year ice can reach a thickness of 1.2 to 1.4 m by the end of winter, and floes are giant (over 10 km wide). Along the coast of Greenland, land fast ice becomes more than 2 m thick by late winter.

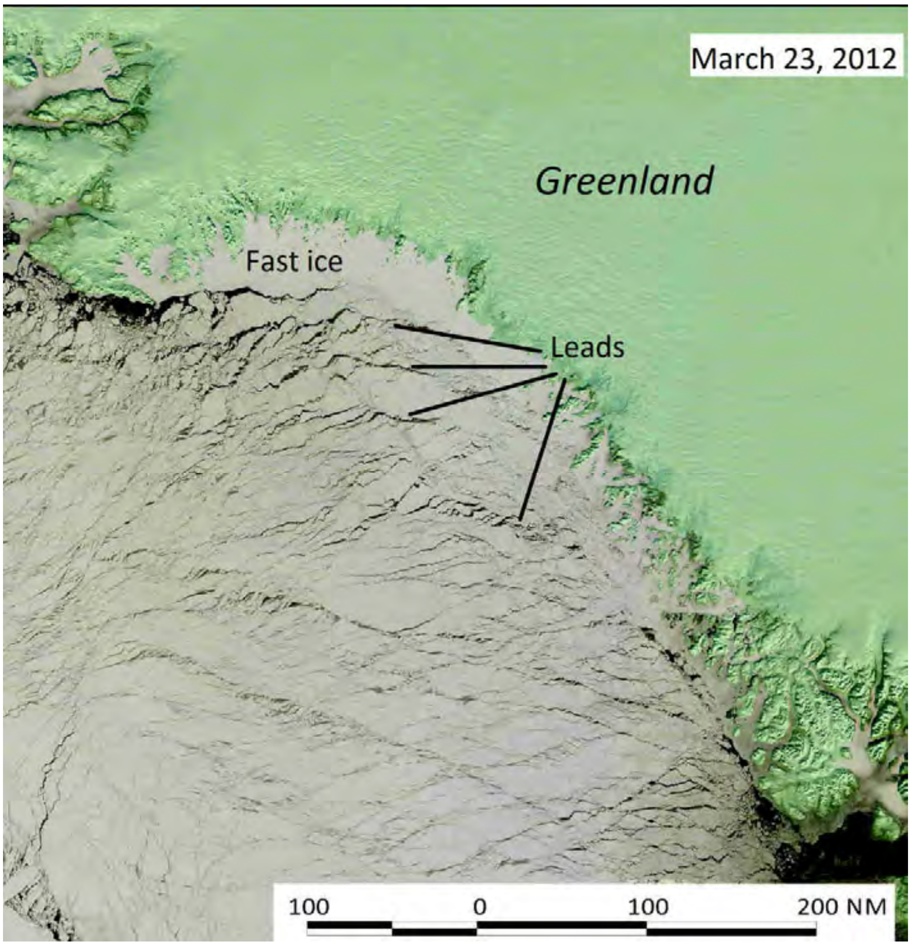


Figure 17 MODIS image on March 23, 2012 (NASA).

Zone C – West Baffin Bay

Around latitude 75°N, the West Greenland current has cooled down and moves west across the bay before turning southward. It then follows the Baffin Island coast and becomes the Baffin Island Current. Combined with the southward current flowing from the North Pole through Nares Strait (Figure 18), this merger of currents creates a highly mobile pack. Current speeds are moderate (5 to 9 nm/day) to strong (10+ nm/day) in western Baffin Bay. Predominant northerly and easterly winds also play an important role in the severity of ice conditions in that zone.

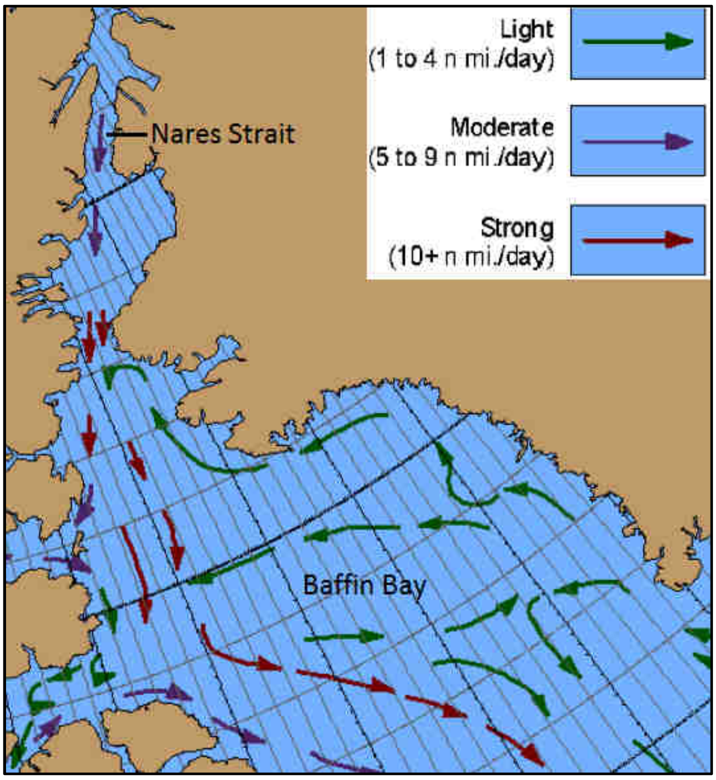


Figure 18 General surface currents in Baffin Bay and Nares Strait (Environment Canada).

Zone C is known to present some of the most difficult ice conditions for shipping in the eastern Canadian Arctic during winter. There are two main reasons that explain this level of severity:

1. The pack in western Baffin Bay includes **old ice of polar origin** that drifts south through Nares Strait. Although this process begins as early as the end of summer, it mostly becomes problematic during winter as this old ice becomes embedded within the pack. As the pack ice grows and drifts during winter, the old ice becomes: 1) increasingly difficult to detect; 2) harder to avoid and 3) spread out over the entirety of Baffin Bay, down to Davis Strait and eventually to the entrance of Hudson Strait. Old ice presence in the pack, as can be seen in Figure 19, peaks in mid-February. Soon after that time, an ice arch is formed at the southern end of Nares Strait, stopping the southward flow of polar old ice. As winter progresses, the old ice field gradually drifts southward. Nonetheless, old ice is always found in central Baffin Bay in winter and spring.

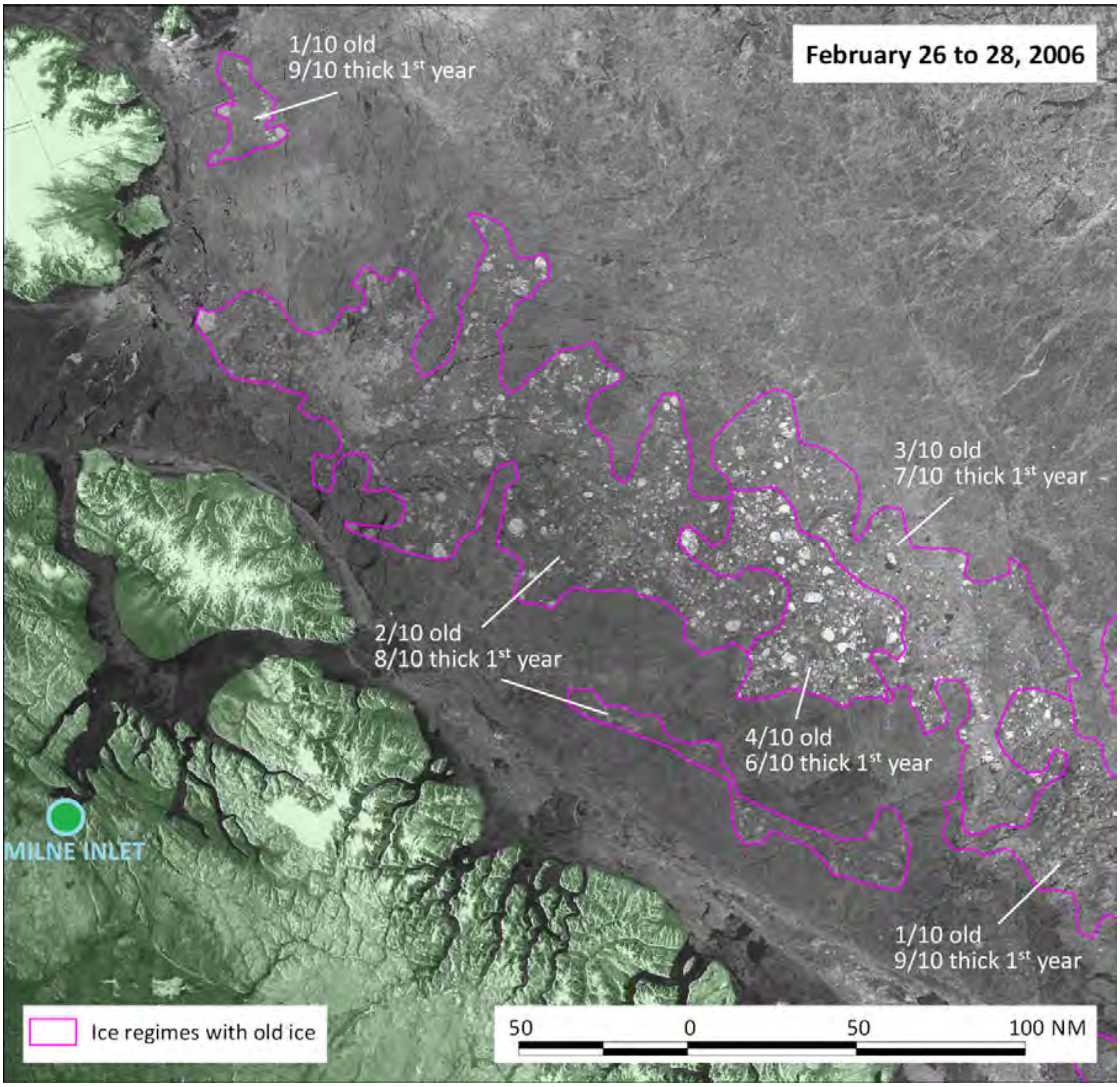


Figure 19 RADARSAT image mosaic on February 26 to 28, 2006 (Polar Data Catalogue)

2. A zone of **pressure and heavy ridging** is created each winter in the developing ice pack of western Baffin Bay. In addition to the surface currents described above, there are three elements explaining this process. 1) The high concentration of the ice, the direction of predominant currents (Figure 18) and winds create a favorable environment for the deformation of the ice cover. 2) Low pressure systems tend to be common during winter over the eastern Canadian Arctic (Figure 20). The mid-winter storms into Baffin Bay bring recurrent northeasterly winds that cause heavier ridging on the central and western side of Baffin Bay. 3) Some ice floes that originate from the area of the Arctic Ocean that contains the oldest and thickest multi-year ice (some floes are known to exceed 5 meters in thickness) drift south to western Baffin Bay. While this old ice is more resistant to pressure, the greater thickness of the floes causes them to move at a slightly different rate in response to winds and currents

than the thinner first-year ice floes around them do, resulting in the deformation of the first-year floes.

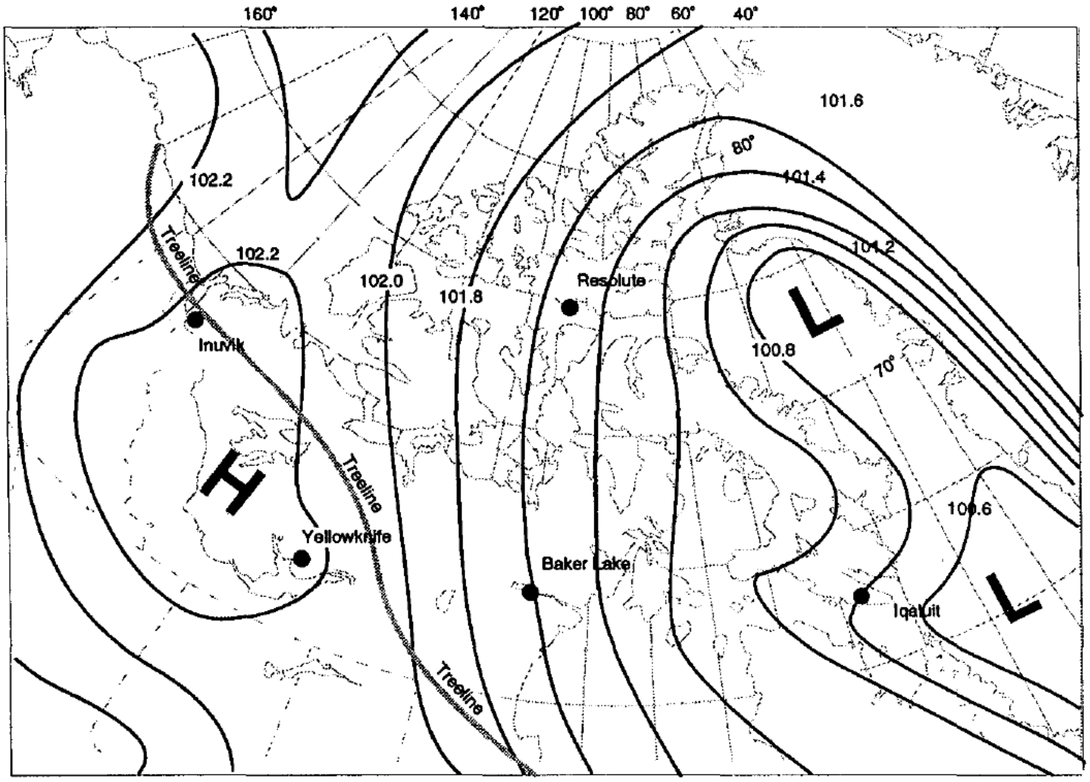


Figure 20 Mean pressure pattern over the Canadian Arctic in January (Stewart *et al.*, 1995).

Ice hazards that can cause serious impediments to navigation, such as those defined in Appendix I, are characteristic of Zone C. For instance, the inability to navigate in Zone C through pressured ice fields with high concentrations of old ice forced Fednav's MV ARCTIC to abandon early winter voyages to the Polaris and Nanisivik mines on two occasions, in December 1986 and again in December 1989.

Zone D – Baffin Coast Shear Zone

A prominent feature of the ice regime of Baffin Bay in winter is the formation of a shear zone along the east coast of Baffin Island (See Appendix I for more on shear zones and the shearing process). This shear zone results from the continuous abrasion and compaction of the mobile pack against the land fast ice that forms along the coast of the island. As it is driven southward by currents and winds, the ice – which is mostly about 1.5 m thick by mid-winter – deforms into a shear zone that eventually consolidates. Additionally, the recurrent presence of storms during winter brings strong northeasterly winds that amplify the shearing process along the Baffin coast. As a result, ridges created by the constant grinding and colliding can reach a thickness of 20 m.

However, there seems to be a slight reduction in the shearing process at the eastern entrance of Pond Inlet. In fact, diverging currents (as indicated on Figure 21) could be limiting the formation of a very severe shear zone, in comparison to the rest of the Baffin Island coast. Nonetheless, the entrance to Pond Inlet remains subject to high pressure from the mobile pack.

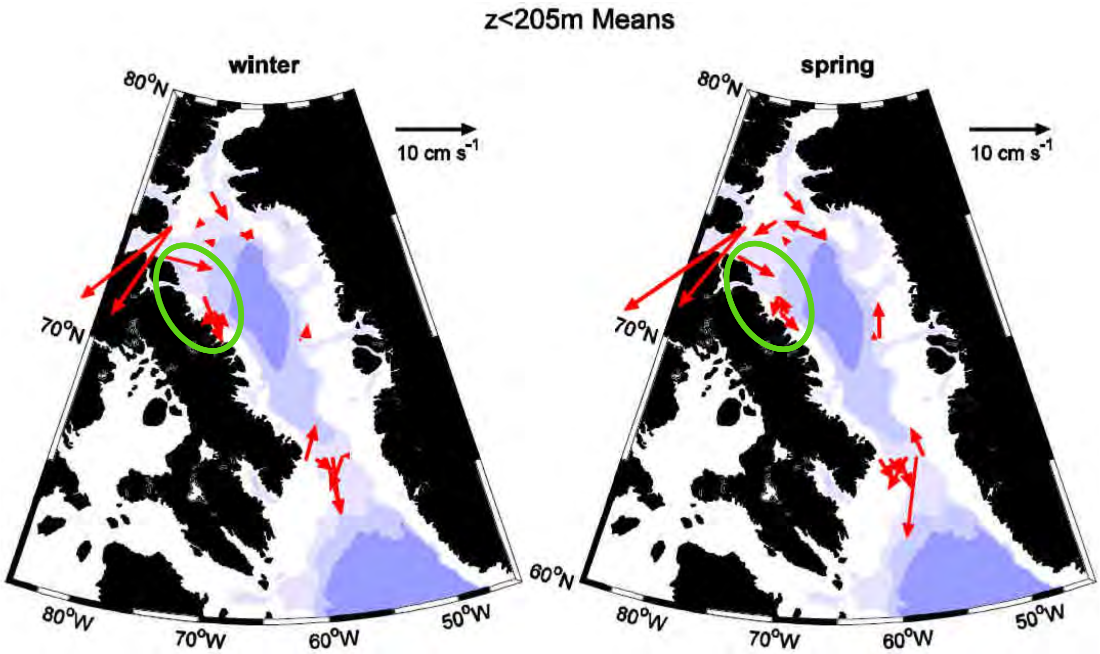


Figure 21 Mean currents for depths less than 205 m in winter and spring over Baffin Bay (Tang *et al.*, 2004).

Figure 22 shows the entrance to Pond Inlet and the mobile ice regime that generates ridging against the land fast ice. As opposed to the Baffin Island shear zone, delimited in orange on the image, the pressured zone at the entrance of Pond Inlet shows a recent relief in ice pressure. Indeed, new ice can be observed in what were probably fractures a few days before; signs of fracture are recognizable due to their linear and angular pattern. The pressured zone outside of the entrance to Pond Inlet is about 40 x 20 NM (74 x 37 km). As a result, a ship would likely have to transit through 20 NM of high ridges and recurrent ice pressure. Nonetheless, this zone can break-off and reform a few times during winter, likely increasing the thickness of the resulting ridges.

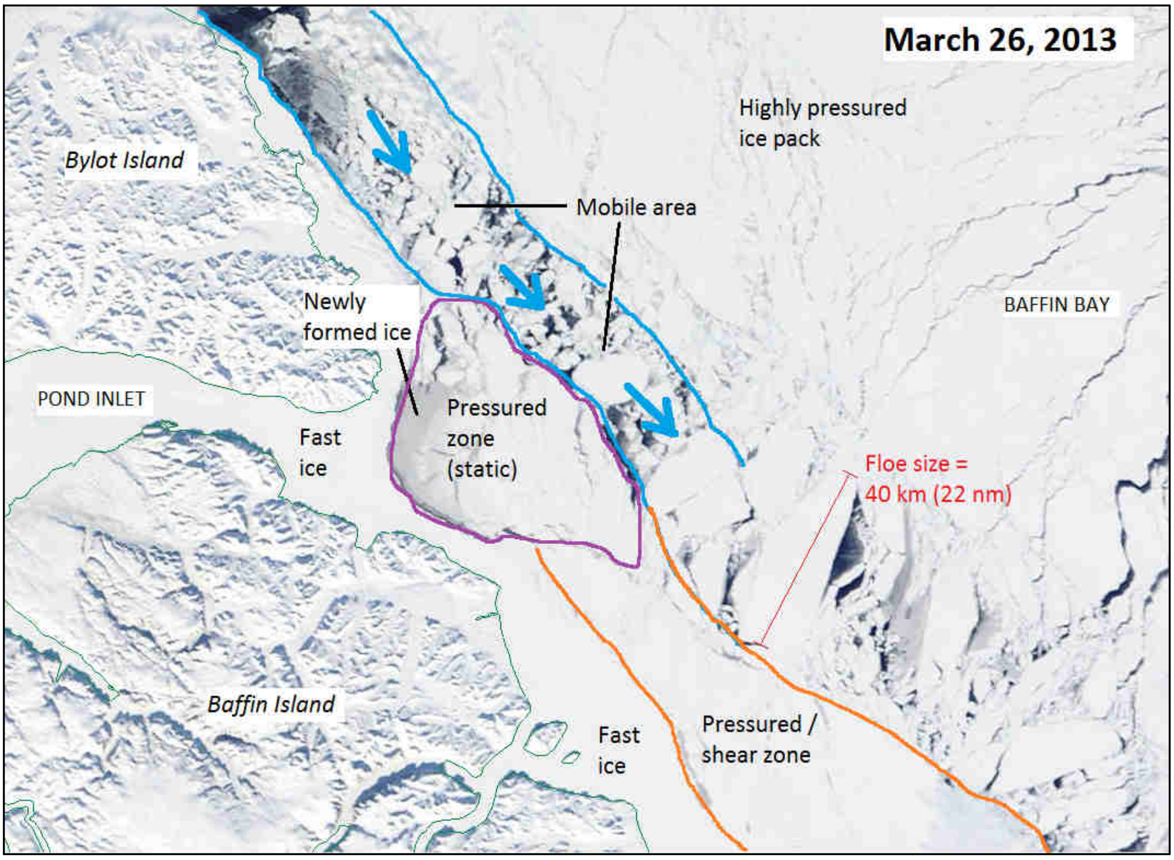


Figure 22 MODIS image on March 26, 2013 (NASA).

To have more precision on the shearing process, it is essential to look at images over time as this phenomenon is highly dynamic and is a function of time. The recently released satellite Sentinel-1 now provides high resolution SAR imagery that is publicly available. Images acquired between one and three times per week from fall 2015 to spring 2016 were used to perform a temporal analysis of the evolution of the state of the ice cover in Pond Inlet during winter. During fall 2015, the ice was mobile in the inlet and included vast (2-10 km) to giant (>10 km) floes that regularly moved in and out of the inlet. By the end of December 2015, the ice became static, and at that point the fast ice edge almost reached the eastern tip of Bylot Island. Over the following months, the sea ice pack of Baffin Bay drifted and grinded regularly against the fast ice edge, creating zones of deformed ice that were subject to fracture and reform into the known shear zone of Pond Inlet. By mid-April, the fast ice edge seemed to have expanded slightly further east, beyond the tip of Bylot Island. According to this sequence, it seems that the shear zone builds up over a long period and ends up becoming part of the fast ice.

Figure 23, Figure 24 and Figure 25 indicate the evolution of the shear zone throughout winter and highlight the different forms that it takes as it builds up. Indeed, the added zone to the fast ice of Pond Inlet shows more textured brightness on the image, meaning it is likely to be highly ridged and dense. The edge of the zone is not linear: it is more like a concave arch, which reveals that it is formed by pressured ice grinding against the edge and not by in-situ consolidation of non-moving ice.

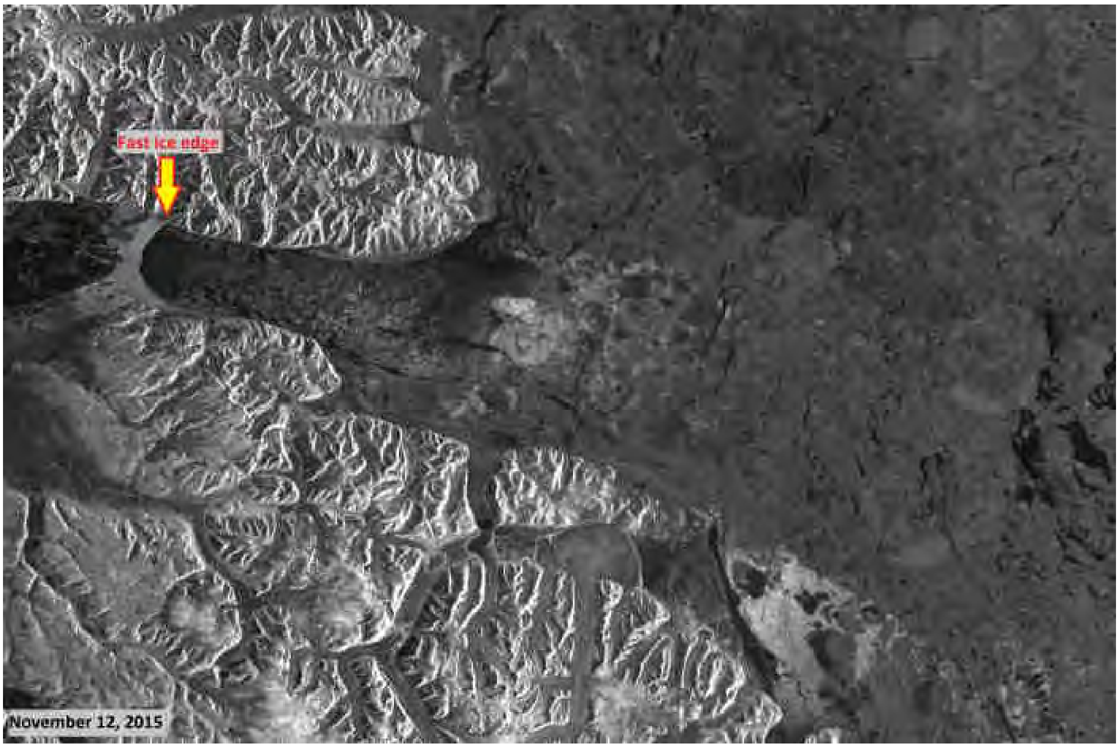


Figure 23 Sentinel-1 satellite image on November 12, 2015 (ESA).

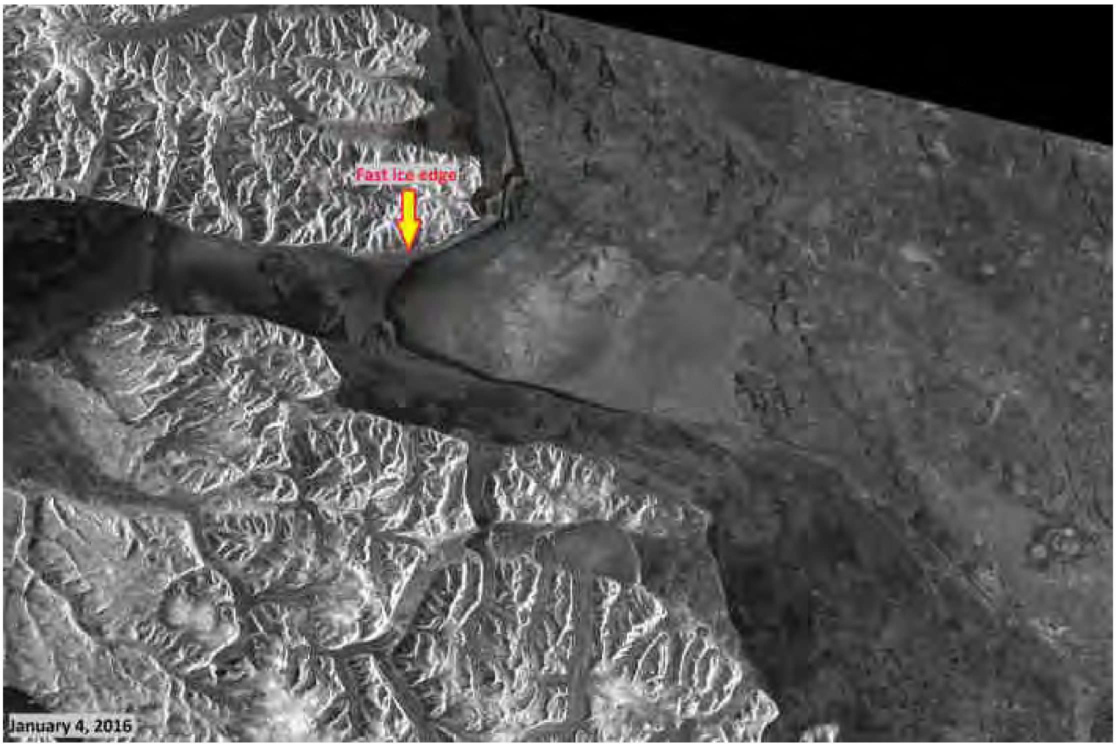


Figure 24 Sentinel-1 satellite image on January 4, 2016 (ESA).

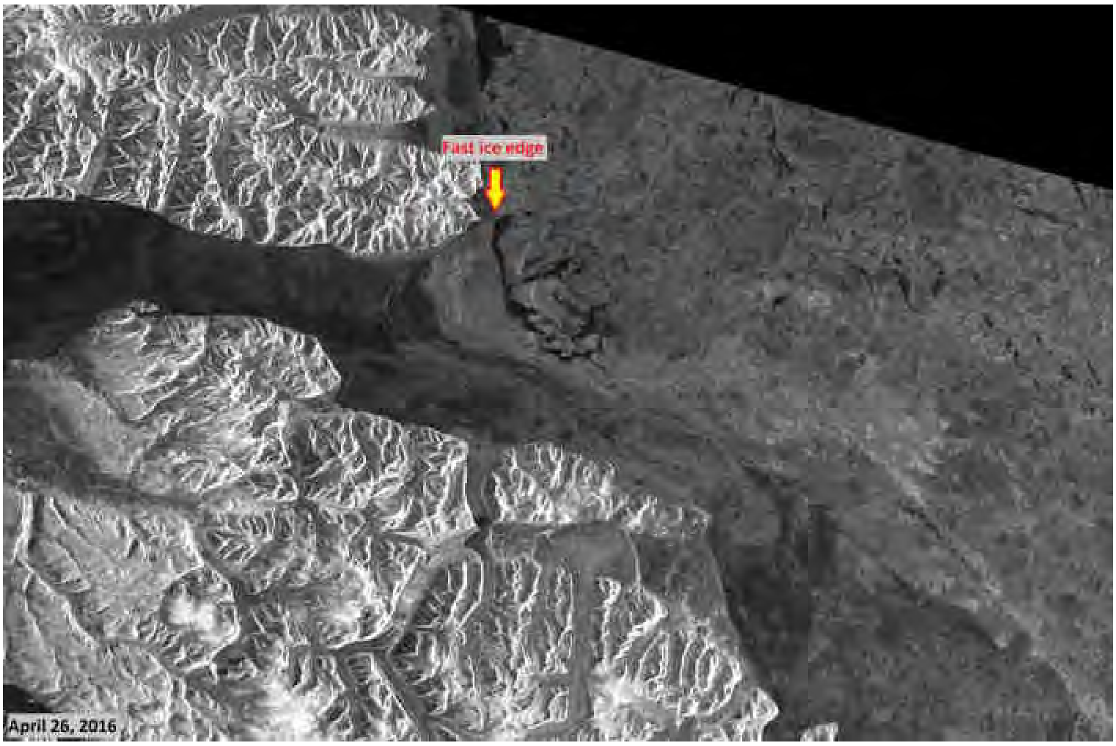


Figure 25 Sentinel-1 satellite image on April 26, 2016 (ESA).

Zone E – Lancaster Sound

Ice conditions in Lancaster Sound are very dynamic. The channel is wide (45 NM, or 83 km) and there are multiple predominant currents of various strength and direction (Figure 26). As a result, the ice remains mobile all winter long. Conditions in Lancaster Sound can be compared to those of Hudson Strait, where a westward current flows in the northern portion of the channel while an eastward current flows in the southern portion. On certain years, the channel becomes consolidated around March and remains as such until break-up, in July. This phenomenon occurs approximately once every 5 to 8 years. The land fast ice edge location varies: while on some years it sits at the eastern entrance of Lancaster Sound, on other years it can be in Barrow Strait, as far as Resolute. Typically, the fast ice stops at Prince Leopold Island, located northeast of Somerset Island, close to the delimitation between Barrow Strait and Lancaster Sound. The rest of the channel is covered by very close pack mobile ice (Figure 27). In most winters, the ice will consolidate and fracture a few times during the season.

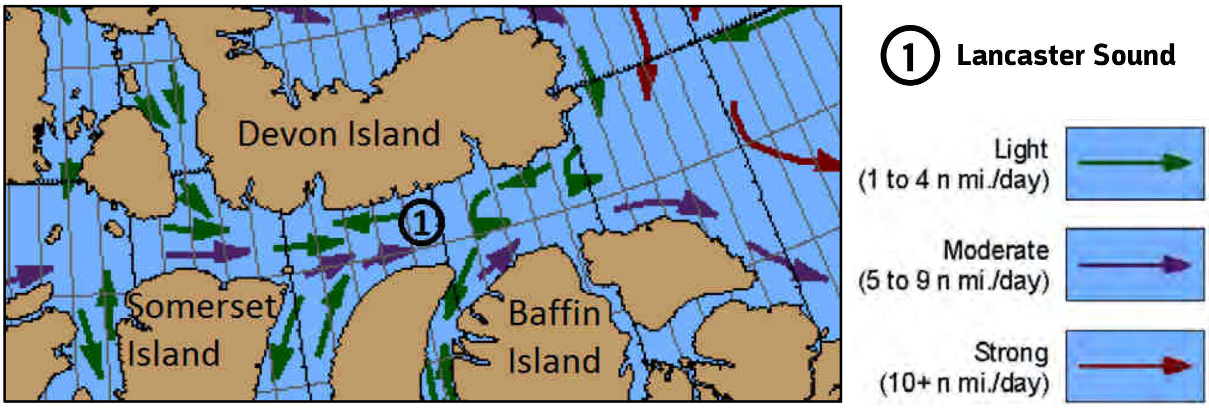


Figure 26 General surface currents in Lancaster Sound (Environment Canada).

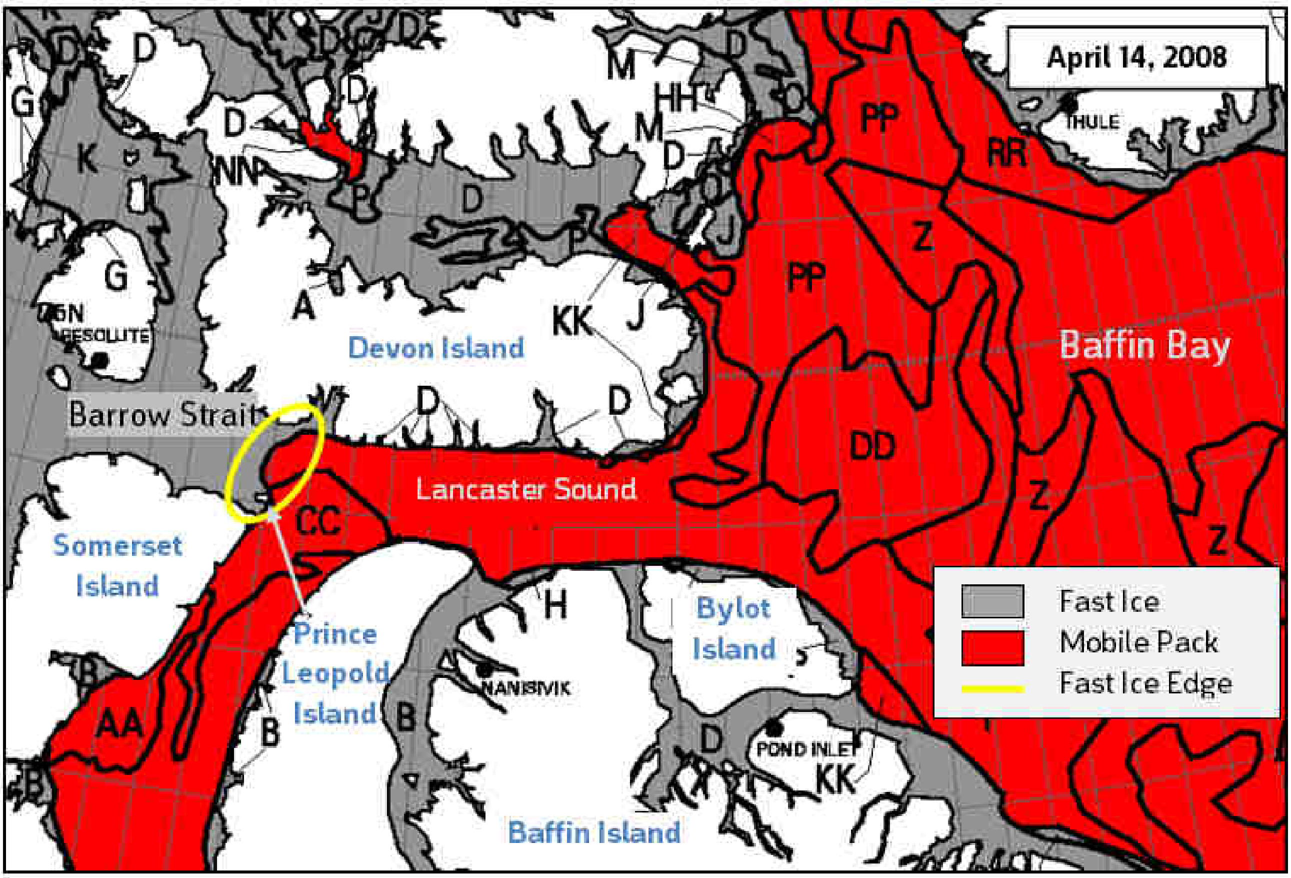


Figure 27 Ice chart on April 14, 2008 (Canadian Ice Service).

In most ice seasons, the ice in Lancaster Sound grows to the thick first-year stage (more than 120 cm), while remaining unconsolidated. That ice is thus subject to external pressure forces such as currents, winds and tides. As a result, ridging and rafting are prominent features of the landscape, especially in spring, and can become potential serious hazards for shipping. Ridges can reach a thickness of about

15 m or more in Lancaster Sound (Prinsenberg, 2009). Coming from Baffin Bay and entering Lancaster Sound westward can be challenging as the ship has to navigate against the direction of the current and ice drift.

Zone F – Internal waterways

The land fast ice in the internal waterways (Navy Board Inlet, Milne Inlet, Eclipse Sound and Pond Inlet) reaches a thickness ranging between 1.6 and 2 m at the peak of winter. While it was initially believed that the fast ice was relatively level, newly accessible data has shown that it is not always the case. The three to four weeks (sometimes more) of ice formation in fall, before the ice cover becomes consolidated, cause the newly formed as well as drifted ice floes to be under wind and current stress. Thus, the floes are subject to hummocking and ridging, and the resulting features remain embedded within the ice cover once it is consolidated.

Access to two new datasets has provided insightful input to further improve Enfotec's understanding of this remote area's winter ice conditions. In addition to the data provided by the new satellite Sentinel-1, a set of Radarsat-1 and 2 images acquired once every winter since 1997 was purchased to obtain a good view of the state of the fast ice cover in the middle of winter both in Pond Inlet and Navy Board Inlet. This data illustrates the difference between the two channels, which is further discussed in section 4 in which a comparative analysis of the two route options is done.

As an overview, it can be stated that the fast ice in Pond Inlet, Eclipse Sound and Navy Board Inlet is different than fast ice in a small bay in the lower or sub Arctic. It is mainly composed of pieces of drifting ice that have become consolidated, instead of ice forming and consolidating in-situ. Floe delimitation as well as ridges and rubble are visible on the imagery within the fast ice zone. This means that transiting through this fast ice might end up being more difficult than through the pack ice. While the pack ice may contain leads and fractures when it is not under pressure, providing some loosening in the pack for the icebreaker to move the floes aside as it transits, this is not the case within the fast ice cover.

3. Vessel access to port site

In determining vessel access to the port site, this section focuses on the waterways that span the northern tip of the West Greenland Lead to the Milne Inlet port site. It is there that most of the sea ice is likely to be encountered by a ship transiting to the Milne Inlet port site through Baffin Bay.

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 available, consisting mostly of ice charts and satellite images, which cover the area. This data was used to model ship access based on the regulatory framework in place in Canada. However, because of the nature of the data used, this model can only depict a partial picture of the peculiarity of navigating in Baffin Bay.

This said, there is limited shipping experience through heavy ice in the region and most of that experience was gained by Fednav through the Polaris and Nanisivik projects. The knowledge gained by these as well as other Fednav projects in Canadian ice-covered waters was utilized in order to critically evaluate and supplement the result of the modeling undertaken and, ultimately, to establish Fednav's recommendations regarding vessel access to the port site.

3.1 Methodology

3.1.1 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 two systems: the Zone/Date system (ZDS) and the Arctic Ice Regime Shipping System (AIRSS).

Both 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 5 and Table 6 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 5 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 6 IACS Polar Class Descriptions (IACS).

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 and 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 take into account 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. The conjoint use of the ZDS and the AIRSS is referred to as the ASPPR Hybrid System. Ships of a class that is not defined in the ZDS must use the AIRSS at all time when transiting in Canadian waters north of the 60th parallel.

The AIRSS 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. Strategically, *in situ* observations are used to determine the actual ice conditions;
2) Obtaining **ice multipliers** 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 **ice numerals** within the area of operation;
4) Determining if entry should **be allowed or denied** with regards to the results of the previously calculated ice numerals;

a. Ice multipliers

Every ice type (including open water) is given a numerical value that is dependent on the ice category of the vessel, which is the ice multiplier (IM). The value of the IM reflects the level of risk or operational constraint that the particular ice type poses to each vessel class. Although Transport Canada has accepted the new IACS Polar Classes, they have yet to incorporate them into the AIRSS rules. Table 7 incorporates 'Type' class multipliers – as per the current IM table – as well as PC class multipliers – which are based on a proposed table that is currently in use even though it has not yet been officially integrated in the regulations. It is also possible for a ship that does not belong to any of the predetermined categories to be assigned specific IMs by Transport Canada in order to use the AIRSS.

Table 7 Ice Multipliers by vessel ice class.

	Ice type and code								
Ship Category	**Open Water / Brash Ice**	**Grey Ice**	**Grey White Ice**	**Thin First-Year 1st Stage**	**Thin First-Year 2nd Stage**	**Medium First-Year**	**Thick First-Year**	**Second-Year**	**Old / Multi-Year**
	1 or 2	**4**	**5**	**7 or 8**	**7 or 9**	**1.**	**4.**	**8.**	**7. or 9.**
PC 3	2	2	2	2	2	2	2	1	-1
PC 4	2	2	2	2	2	2	2	-1	-2
PC 5	2	2	2	2	2	2	1	-2	-4
PC 6	2	2	2	2	2	1	0	-2	-4
Type A	2	2	2	2	2	1	-1	-3	-4
PC 7	2	2	2	2	2	0	-1	-3	-4
Type B	2	2	1	1	1	-1	-2	-4	-4
Type C	2	2	1	1	-1	-2	-3	-4	-4
Type D	2	2	1	-1	-1	-2	-3	-4	-4
Type E	2	1	-1	-1	-1	-2	-3	-4	-4

Calculating the ice numeral

For any ice regime, an ice numeral (IN) is calculated by taking the sum of the products of the concentration of the ice types present (in tenths) in the region and their ice multipliers in the following equation:

$$IN = (Ca \times IMa) + (Cb \times IMb) + (Cc \times IMc)$$

Where:

IN = ice numeral;
Ca = concentration in tenths of ice type "a";
IMa = ice multiplier 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 PC 5 vessel, an ice regime containing 5/10 of old ice, 2/10 of thick first-year ice and 3/10 of thin first-year ice would result in the following ice numeral:

$$IN = (Ca \times IMa) + (Cb \times IMb) + (Cc \times IMc)$$
$$IN = (5 \times -4) + (2 \times 1) + (3 \times 2)$$
$$IN = -20 + 2 + 6$$
IN = -12 *(ACCESS DENIED)*

For a PC 3 vessel, the same ice regime would result in the following ice numeral:

$$IN = (Ca \times IMa) + (Cb \times IMb) + (Cc \times IMc)$$
$$IN = (5 \times -1) + (2 \times 2) + (3 \times 2)$$
$$IN = -5 + 4 + 6$$
IN = 5 *(ACCESS GRANTED)*

The IN is therefore unique to the particular ice regime and the ice class of the ship operating within its boundaries. A Master would acquire ice information along the intended route and would not navigate into an area that contained a negative numeral for the vessel.

b. Bonus and subtraction application

<u>Decay Bonus:</u> In order to further refine the Ice Numerals system, a decay bonus can sometimes be applied. In winter, ice is at its maximum strength due to cold temperatures. Cold temperatures reduce the amount of brine (small pockets of salt water, often in a liquid state, that induce fragility to the ice) and liquid water within the ice by freezing it. As temperatures increase in spring and early summer, the volume of liquid increases, thereby decreasing the strength of the ice. The loss of strength can be very rapid: after a few weeks of daily average temperatures equal to or above 0°C, the ice loses most of its winter strength. First-year ice, for example, can lose 90% of its strength (Langlois *et al.*, 2003). At that point, ice can be considered "decayed" and the IM for certain ice types can be raised by 1. The decay bonus can be applied only to old ice (multi- and second-year), thick first-year ice and medium

first-year ice. The bonus has to be applied with care and is limited to periods where thaw holes and rotten ice are significantly present and observed within the ice regime.

Icebreaker Escort: No provisions or modifications were specifically made to address icebreaker escort in the Ice Numerals system. However, in a situation where the icebreaker is able to modify a regime (i.e. change the characteristics such that the numeral changes), the navigator is then allowed to consider the track of the icebreaker as a modified regime in the calculation of the numeral for that regime. For example, a ship that follows an icebreaker will sail through ice regimes that contain more open water than before the icebreaker's passage. Nonetheless, the navigator must consider the effects of wind, tides and currents on the regime to ensure it remains modified for the transit. If pressure is such that the icebreaker's track closes rapidly, the Ice Numeral should not be modified.

Roughness: The system can take ice roughness into consideration – i.e. ridging or any deformation process that can be problematic for navigation. Transport Canada states that:

"[…] if the ice regime has an overall concentration of 6 tenths or greater and more than one third of an ice type is deformed by ridges, rubble or hummocking, the Ice Multiplier for the deformed ice must be decreased by 1" (Canadian Hydraulics Centre, 2003).

c. Fednav's analysis of the AIRSS

The scope of the AIRSS is limited to preventing structural damage to the ship from impacts with sea ice. Moreover, the AIRSS assumes that ship crews and operators exercise caution with respect to ice conditions and emphasizes 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 the AIRSS, namely pressure on the ice.

The ability of a ship to successfully make progress in ice is not the purpose of the AIRSS. 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 threatened 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 for the AIRSS. 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 the AIRSS does not eliminate the need for prudence and adequate planning from both ship operators and crews. The AIRSS 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.

On a related note, not all aspects of sea ice are effectively described by the ice regime concept upon which the AIRSS is founded upon, some of which have substantial impacts on navigation. Ice dynamics is probably the archetypical example of such a limitation.

3.1.2 Model for calculating INs along the route

The AIRSS was used as a first step to determine the shipping season for each vessel ice class to the Milne Inlet proposed port site. 30 years of data, from January 1983 to December 2012, was acquired from the Canadian Ice Service (CIS). This data is constituted of every regional ice chart that was produced during that period, for a total of 1050 charts. A model was used to generate simulated routes from the regional charts. In order to cover the section of the route where most of the ice is located, the model is setup to generate routes that originate from the Milne Inlet port site and end in the northern part of the West Greenland Lead (69°15'N, 55°5'W). The generated routes are meant to avoid or minimize the distance spent in the harshest ice regimes. Figure 28 shows an example of a voyage simulated by the model from a CIS regional chart, where the route seeks to avoid difficult ice regimes even though it ends up elongating the distance traveled.

INs were calculated for each ice regime encountered by a vessel on a simulated voyage for classes Type A to E and PC 3 to 7. No IN can be calculated for PC 2 vessels as this is an unrestricted class.

When calculating the INs, a decay bonus was applied in order to take into account the weakening effect of melt on the sea ice. This bonus was applied for the voyages sampled from June to mid-September. This period corresponds to the time of the year where recorded average temperatures are above 0°C at the few weather stations located in the area (Environment Canada). It was not possible to apply a roughness subtraction as deformation processes are localized and associated with real-time conditions. Incorporating these factors in a retrospective analysis cannot be done for lack of appropriate available information.

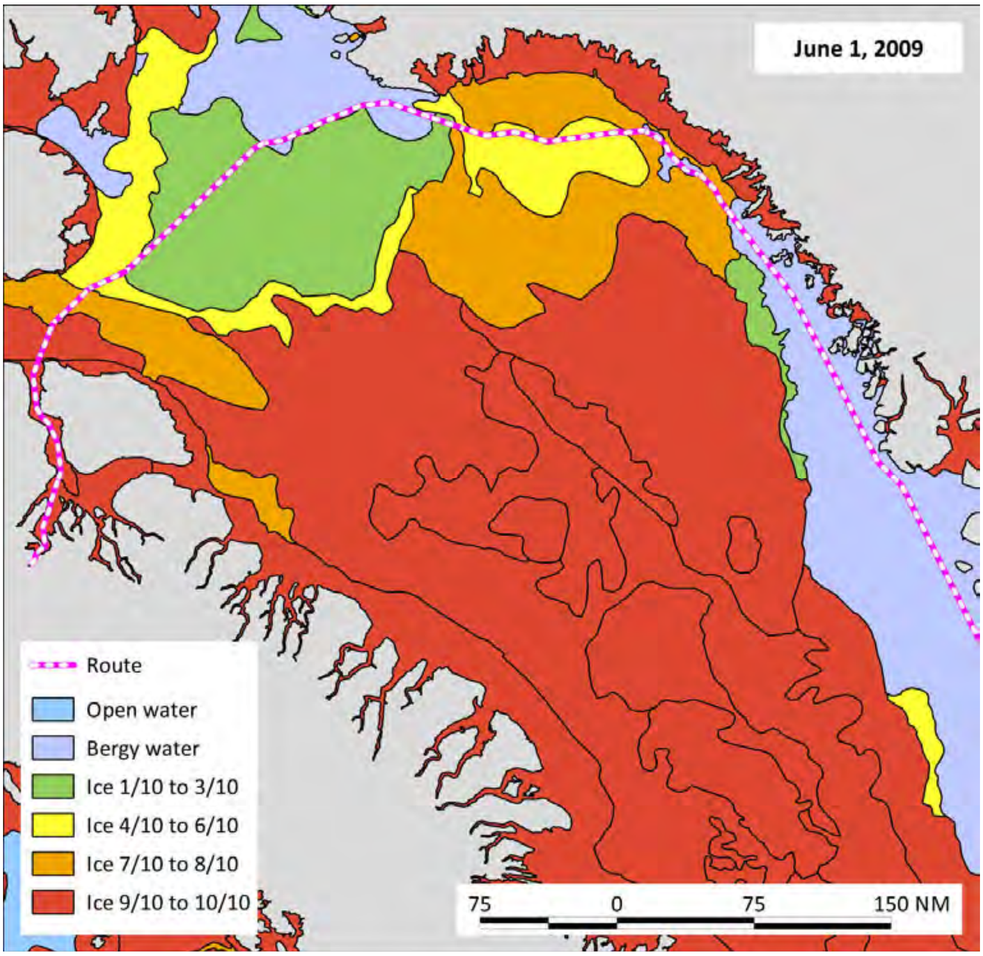


Figure 28 Simulated route for a PC4 vessel (based on CIS data).

3.2 Access by vessel Ice Class: AIRSS results and practical assessment

The data that was outputted by the model was divided in 24 half-month intervals. The 16th day of each month was used to split the months in halves. Table 8 and Table 9 are synthesis of the data that was outputted from the model.

Over the years, regional charts have been produced at a higher frequency from mid-June to the end of November (65 charts over 30 years, on average, for each half month interval) than during the December to May period. Therefore, the output from the model is more representative for the half month intervals of this period than for the other period, where the number of available charts over the 30 years can be much lower.

3.2.1 Temporal variations in the results

In order to discern patterns that could have resulted from the recent effects of climate change, the synthesis of the results was subdivided in decadal periods in addition to the full 30-year period. Indeed, there are fewer years when the route goes through negative ice regimes during the 2003 to

2012 period than during the preceding decade. In that same timeframe, the portion of the route in negative ice regimes is shorter. This could be due to climate change, namely the diminished presence of old ice (section 4).

The results from the 1983 to 1992 period, when compared to the following two decades, do not show the same trend. In fact, the CIS ice charts that were used to build our model seem to show that ice conditions were milder from in 1983 to 1992 than in the next two decades. While this could very well be true, it is important to bear in mind that the methodology used to produce ice charts has changed significantly over the years. Aircrafts equipped with synthetic aperture radars were used to produce the oldest charts utilized in the model. The launch of RADARSAT-1 in 1995 shifted the paradigm from using aircrafts to using satellites. The launch of Envisat in 2002 and, subsequently, RADARSAT-2 in 2007 also had a significant impact. Not only did the extra satellites improved coverage, but those satellites also provide multi polarized images which make it easier to distinguish the different stages of development of the ice.

Table 8 Percentage of years where simulated voyages encountered negative IN ice regimes.

		Ice	January		February		March		April		May		June		July		August		September		October		November		December	
		clas	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
	Decay factor applied		No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
[redacted]	Number of simulated voyages		24	18	24	14	25	17	29	22	42	25	47	64	62	69	65	68	65	62	65	70	64	60	31	18
	Number of years in the simulation		22	14	22	13	22	14	22	14	25	16	28	30	30	30	30	30	30	30	30	30	30	30	23	12
	Percentage of years where simulated voyages encountered negative IN regimes	Type E	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	56.67%	13.33%	3.33%	10.00%	16.67%	66.67%	100.00%	100.00%	100.00%	100.00%
		Type D	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	56.67%	13.33%	3.33%	6.67%	6.67%	40.00%	83.33%	100.00%	100.00%	100.00%
		Type C	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	56.67%	13.33%	3.33%	6.67%	6.67%	40.00%	83.33%	100.00%	100.00%	100.00%
		Type B	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	96.67%	46.67%	10.00%	3.33%	6.67%	6.67%	20.00%	46.67%	50.00%	56.52%	83.33%
		Type A	68.18%	85.71%	90.91%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	57.14%	40.00%	56.67%	40.00%	10.00%	0.00%	3.33%	6.67%	6.67%	20.00%	33.33%	30.00%	34.78%	33.33%
		PC7	81.82%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	57.14%	40.00%	56.67%	40.00%	10.00%	0.00%	3.33%	6.67%	13.33%	23.33%	33.33%	36.67%	43.48%	50.00%
		PC6	59.09%	50.00%	77.27%	69.23%	81.82%	64.29%	72.73%	71.43%	72.00%	68.75%	32.14%	16.67%	20.00%	6.67%	3.33%	0.00%	0.00%	6.67%	6.67%	23.33%	33.33%	46.67%	47.83%	33.33%
		PC5	54.55%	42.86%	45.45%	7.69%	54.55%	42.86%	36.36%	42.86%	36.00%	43.75%	10.71%	6.67%	3.33%	0.00%	0.00%	0.00%	0.00%	3.33%	6.67%	23.33%	33.33%	46.67%	43.48%	33.33%
		PC4	13.64%	7.14%	4.55%	0.00%	4.55%	0.00%	9.09%	14.29%	16.00%	18.75%	3.57%	0.00%	3.33%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	6.67%	10.00%	10.00%	13.04%	16.67%
		PC3	4.55%	0.00%	0.00%	0.00%	0.00%	0.00%	4.55%	0.00%	8.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.33%	6.67%	3.33%	4.35%	8.33%
		PC2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
[redacted]	Number of simulated voyages		2	8	2	8	2	8	2	8	6	7	11	22	20	25	21	22	22	20	22	24	21	21	7	5
	Number of years in the simulation		2	8	2	8	2	8	2	8	5	6	9	10	10	10	10	10	10	10	10	10	10	10	6	5
	Percentage of years where simulated voyages encountered negative IN regimes	Type E	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	80.00%	20.00%	0.00%	10.00%	20.00%	90.00%	100.00%	100.00%	100.00%	100.00%
		Type D	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	80.00%	20.00%	0.00%	10.00%	10.00%	40.00%	80.00%	100.00%	100.00%	100.00%
		Type C	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	80.00%	20.00%	0.00%	10.00%	10.00%	40.00%	80.00%	100.00%	100.00%	100.00%
		Type B	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	50.00%	20.00%	0.00%	10.00%	10.00%	20.00%	40.00%	60.00%	50.00%	80.00%
		Type A	0.00%	87.50%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	33.33%	10.00%	50.00%	40.00%	0.00%	0.00%	0.00%	10.00%	10.00%	20.00%	30.00%	30.00%	33.33%	20.00%
		PC7	50.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	33.33%	10.00%	50.00%	40.00%	0.00%	0.00%	0.00%	10.00%	20.00%	20.00%	30.00%	40.00%	50.00%	40.00%
		PC6	0.00%	25.00%	50.00%	50.00%	50.00%	37.50%	50.00%	50.00%	40.00%	50.00%	22.22%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	10.00%	20.00%	30.00%	50.00%	33.33%	20.00%
		PC5	0.00%	25.00%	0.00%	12.50%	0.00%	12.50%	0.00%	12.50%	0.00%	16.67%	22.22%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	10.00%	20.00%	30.00%	50.00%	33.33%	20.00%
		PC4	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	16.67%	11.11%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	10.00%	0.00%	0.00%	0.00%
		PC3	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	0.00%	0.00%	0.00%
		PC2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
[redacted]	Number of simulated voyages		10	0	10	0	10	0	10	0	16	4	15	21	22	22	21	23	21	22	21	23	21	19	6	0
	Number of years in the simulation		10	0	10	0	10	0	10	0	10	4	9	10	10	10	10	10	10	10	10	10	10	10	6	0
	Percentage of years where simulated voyages encountered negative IN regimes	Type E	100.00%	na	100.00%	na	100.00%	na	100.00%	na	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	70.00%	10.00%	10.00%	10.00%	30.00%	80.00%	100.00%	100.00%	100.00%	na
		Type D	100.00%	na	100.00%	na	100.00%	na	100.00%	na	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	70.00%	10.00%	10.00%	10.00%	10.00%	70.00%	90.00%	100.00%	100.00%	na
		Type C	100.00%	na	100.00%	na	100.00%	na	100.00%	na	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	70.00%	10.00%	10.00%	10.00%	10.00%	70.00%	90.00%	100.00%	100.00%	na
		Type B	100.00%	na	100.00%	na	100.00%	na	100.00%	na	100.00%	100.00%	100.00%	100.00%	100.00%	90.00%	70.00%	0.00%	10.00%	10.00%	10.00%	30.00%	60.00%	50.00%	50.00%	na
		Type A	90.00%	na	100.00%	na	100.00%	na	100.00%	na	100.00%	100.00%	77.78%	80.00%	80.00%	60.00%	20.00%	0.00%	10.00%	10.00%	10.00%	30.00%	50.00%	30.00%	33.33%	na
		PC7	90.00%	na	100.00%	na	100.00%	na	100.00%	na	100.00%	100.00%	77.78%	80.00%	80.00%	60.00%	20.00%	0.00%	10.00%	10.00%	20.00%	40.00%	50.00%	40.00%	50.00%	na
		PC6	80.00%	na	90.00%	na	80.00%	na	70.00%	na	80.00%	75.00%	33.33%	30.00%	40.00%	20.00%	10.00%	0.00%	0.00%	10.00%	10.00%	40.00%	50.00%	60.00%	50.00%	na
		PC5	70.00%	na	60.00%	na	70.00%	na	30.00%	na	40.00%	50.00%	11.11%	10.00%	10.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	40.00%	50.00%	60.00%	50.00%	na
		PC4	10.00%	na	0.00%	na	10.00%	na	10.00%	na	30.00%	0.00%	0.00%	0.00%	10.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	20.00%	30.00%	33.33%	na
		PC3	0.00%	na	0.00%	na	0.00%	na	10.00%	na	20.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	10.00%	10.00%	16.67%	na
		PC2	0.00%	na	0.00%	na	0.00%	na	0.00%	na	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	na
[redacted]	Number of simulated voyages		12	10	12	6	13	9	17	14	20	14	21	21	20	22	23	23	22	20	22	23	22	20	16	13
	Number of years in the simulation		10	6	10	5	10	6	10	6	10	6	10	10	10	10	10	10	10	10	10	10	10	10	9	7
	Percentage of years where simulated voyages encountered negative IN regimes	Type E	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	20.00%	10.00%	0.00%	10.00%	0.00%	30.00%	100.00%	100.00%	100.00%	100.00%
		Type D	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	20.00%	10.00%	0.00%	0.00%	0.00%	10.00%	80.00%	100.00%	100.00%	100.00%
		Type C	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	20.00%	10.00%	0.00%	0.00%	0.00%	10.00%	80.00%	100.00%	100.00%	100.00%
		Type B	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	20.00%	10.00%	0.00%	0.00%	0.00%	10.00%	40.00%	40.00%	66.67%	85.71%
		Type A	60.00%	83.33%	80.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	60.00%	30.00%	40.00%	20.00%	10.00%	0.00%	0.00%	0.00%	0.00%	10.00%	20.00%	30.00%	33.33%	42.86%
		PC7	80.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	60.00%	30.00%	40.00%	20.00%	10.00%	0.00%	0.00%	0.00%	0.00%	10.00%	20.00%	30.00%	33.33%	57.14%
		PC6	50.00%	83.33%	70.00%	100.00%	90.00%	100.00%	80.00%	100.00%	80.00%	83.33%	40.00%	20.00%	20.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	20.00%	30.00%	55.56%	42.86%
		PC5	50.00%	66.67%	40.00%	0.00%	50.00%	83.33%	50.00%	83.33%	50.00%	66.67%	0.00%	10.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	20.00%	30.00%	44.44%	42.86%
		PC4	20.00%	16.67%	10.00%	0.00%	0.00%	0.00%	10.00%	33.33%	10.00%	33.33%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	11.11%	28.57%
		PC3	10.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	14.29%
		PC2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 9 Portion of route over negative IN ice regimes derived from model.

		Ice clas	January		February		March		April		May		June		July		August		September		October		November		December	
			Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
	Decay factor applied		No	No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
[redacted]	Number of simulated voyages		24	18	24	14	25	17	29	22	42	25	47	64	62	69	65	68	65	62	65	70	64	60	31	18
	Number of years in the simulation		22	14	22	13	22	14	22	14	25	16	28	30	30	30	30	30	30	30	30	30	30	30	23	12
	Portion of rout over negative IN ice regimes derived from model	Type E	70.38%	76.94%	83.53%	89.96%	90.84%	88.14%	89.59%	79.12%	70.19%	51.96%	35.74%	28.82%	21.07%	10.54%	2.99%	0.25%	0.01%	0.05%	0.53%	7.98%	27.55%	45.55%	53.88%	62.03%
		Type D	55.81%	65.75%	72.92%	74.47%	83.80%	84.33%	83.57%	72.66%	68.47%	51.07%	35.10%	28.41%	21.02%	10.54%	2.99%	0.25%	0.01%	0.03%	0.08%	2.55%	14.34%	30.32%	43.10%	45.54%
		Type C	55.81%	65.75%	72.92%	74.47%	83.80%	84.33%	83.57%	72.66%	68.47%	51.07%	35.10%	28.41%	21.02%	10.54%	2.99%	0.25%	0.01%	0.03%	0.08%	2.55%	14.34%	30.32%	43.10%	45.54%
		Type B	27.71%	44.46%	52.70%	56.21%	70.47%	67.76%	73.52%	61.93%	61.22%	47.06%	31.19%	24.65%	19.13%	9.18%	2.64%	0.29%	0.01%	0.03%	0.08%	0.51%	1.12%	3.74%	5.44%	14.90%
		Type A	3.72%	14.85%	23.39%	34.93%	56.88%	46.42%	61.91%	47.60%	50.12%	41.23%	9.17%	9.99%	7.99%	5.77%	1.26%	0.00%	0.01%	0.03%	0.08%	0.19%	0.63%	0.65%	1.00%	2.24%
		PC7	10.06%	23.26%	31.63%	43.17%	62.66%	50.83%	66.57%	52.66%	54.16%	42.43%	9.23%	9.99%	8.12%	5.86%	1.26%	0.00%	0.01%	0.03%	0.18%	0.19%	0.63%	1.45%	1.92%	4.15%
		PC6	3.14%	1.76%	7.73%	4.07%	7.76%	3.56%	6.75%	5.13%	6.19%	6.19%	2.76%	2.67%	2.22%	3.43%	0.71%	0.00%	0.00%	0.03%	0.08%	0.20%	0.65%	1.44%	1.24%	1.28%
		PC5	2.20%	1.34%	2.09%	2.03%	2.60%	1.33%	2.15%	1.84%	1.25%	2.25%	1.23%	0.13%	0.06%	0.00%	0.00%	0.00%	0.00%	0.02%	0.08%	0.20%	0.65%	1.44%	1.15%	0.61%
		PC4	0.37%	0.01%	0.02%	0.00%	0.06%	0.00%	0.03%	0.12%	0.10%	0.46%	0.36%	0.00%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.29%	0.70%	0.16%	0.28%
		PC3	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	0.00%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.16%	0.27%	0.09%	0.16%
		PC2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
[redacted]	Number of simulated voyages		2	8	2	8	2	8	2	8	6	7	11	22	20	25	21	22	22	20	22	24	21	21	7	5
	Number of years in the simulation		2	8	2	8	2	8	2	8	5	6	9	10	10	10	10	10	10	10	10	10	10	10	6	5
	Portion of rout over negative IN ice regimes derived from model	Type E	73.44%	83.52%	74.09%	85.73%	73.29%	87.99%	92.23%	72.52%	69.20%	60.80%	38.40%	34.09%	23.96%	12.66%	4.43%	0.37%	0.00%	0.05%	0.14%	9.44%	30.79%	51.46%	58.15%	86.29%
		Type D	56.57%	73.25%	67.04%	68.80%	73.29%	82.43%	92.23%	66.24%	64.18%	60.80%	38.24%	32.89%	23.81%	12.66%	4.43%	0.37%	0.00%	0.05%	0.06%	3.76%	17.31%	32.64%	38.01%	73.44%
		Type C	56.57%	73.25%	67.04%	68.80%	73.29%	82.43%	92.23%	66.24%	64.18%	60.80%	38.24%	32.89%	23.81%	12.66%	4.43%	0.37%	0.00%	0.05%	0.06%	3.76%	17.31%	32.64%	38.01%	73.44%
		Type B	31.78%	54.99%	36.33%	56.94%	56.99%	70.53%	68.67%	56.40%	54.29%	53.71%	31.57%	25.69%	19.47%	10.88%	4.96%	0.37%	0.00%	0.05%	0.06%	0.28%	0.97%	7.55%	3.40%	13.37%
		Type A	0.00%	25.51%	29.22%	34.92%	40.75%	40.75%	44.56%	47.67%	40.06%	44.34%	9.70%	13.34%	2.43%	4.19%	0.00%	0.00%	0.00%	0.05%	0.06%	0.28%	0.40%	0.73%	0.83%	3.80%
		PC7	8.40%	38.22%	29.22%	47.22%	52.58%	44.46%	64.98%	50.79%	45.01%	47.27%	10.17%	13.34%	2.56%	4.37%	0.00%	0.00%	0.00%	0.05%	0.14%	0.28%	0.40%	2.38%	1.34%	5.12%
		PC6	0.00%	0.63%	6.48%	5.63%	6.62%	2.38%	6.62%	3.53%	5.16%	5.39%	1.79%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.05%	0.06%	0.29%	0.38%	1.26%	0.64%	0.01%
		PC5	0.00%	0.62%	0.00%	3.54%	0.00%	0.01%	0.00%	0.00%	0.00%	0.48%	1.19%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.05%	0.06%	0.29%	0.38%	1.26%	0.64%	0.01%
		PC4	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.20%	0.51%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%
		PC3	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%
		PC2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
[redacted]	Number of simulated voyages		10	0	10	0	10	0	10	0	16	4	15	21	22	22	21	23	21	22	21	23	21	19	6	0
	Number of years in the simulation		10	0	10	0	10	0	10	0	10	4	9	10	10	10	10	10	10	10	10	10	10	10	6	0
	Portion of rout over negative IN ice regimes derived from model	Type E	77.44%	na	95.40%	na	94.43%	na	93.42%	na	70.40%	57.55%	41.28%	32.82%	24.53%	13.33%	4.23%	0.00%	0.02%	0.03%	1.51%	13.63%	37.05%	50.29%	60.00%	na
		Type D	58.06%	na	85.26%	na	87.34%	na	89.98%	na	69.43%	56.15%	40.15%	32.82%	24.53%	13.33%	4.23%	0.00%	0.02%	0.03%	0.19%	3.84%	19.76%	34.93%	52.09%	na
		Type C	58.06%	na	85.26%	na	87.34%	na	89.98%	na	69.43%	56.15%	40.15%	32.82%	24.53%	13.33%	4.23%	0.00%	0.02%	0.03%	0.19%	3.84%	19.76%	34.93%	52.09%	na
		Type B	30.45%	na	63.68%	na	74.25%	na	79.64%	na	63.45%	53.18%	35.96%	30.34%	23.25%	11.85%	3.27%	0.00%	0.02%	0.03%	0.19%	1.26%	2.04%	2.51%	8.27%	na
		Type A	7.21%	na	34.29%	na	60.98%	na	72.49%	na	57.18%	51.96%	10.02%	10.06%	11.64%	7.26%	2.36%	0.00%	0.02%	0.03%	0.19%	0.27%	1.35%	0.52%	0.90%	na
		PC7	14.59%	na	42.20%	na	62.76%	na	72.78%	na	60.99%	51.96%	10.02%	10.06%	11.64%	7.26%	2.36%	0.00%	0.02%	0.03%	0.41%	0.28%	1.35%	1.24%	5.03%	na
		PC6	5.88%	na	10.58%	na	10.11%	na	8.06%	na	8.83%	15.71%	5.01%	6.90%	4.85%	5.91%	1.57%	0.00%	0.00%	0.04%	0.20%	0.30%	1.41%	2.52%	0.98%	na
		PC5	3.82%	na	3.55%	na	3.35%	na	2.44%	na	1.89%	4.21%	0.55%	0.43%	0.12%	0.00%	0.00%	0.00%	0.00%	0.00%	0.20%	0.30%	1.41%	2.52%	0.98%	na
		PC4	0.12%	na	0.00%	na	0.15%	na	0.07%	na	0.26%	0.00%	0.00%	0.00%	0.14%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.04%	0.88%	2.23%	0.51%	na
		PC3	0.00%	na	0.00%	na	0.00%	na	0.07%	na	0.17%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.04%	0.49%	0.86%	0.48%	na
		PC2	0.00%	na	0.00%	na	0.00%	na	0.00%	na	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	na
[redacted]	Number of simulated voyages		12	10	12	6	13	9	17	14	20	14	21	21	20	22	23	23	22	20	22	23	22	20	16	13
	Number of years in the simulation		10	6	10	5	10	6	10	6	10	6	10	10	10	10	10	10	10	10	10	10	10	10	9	7
	Portion of rout over negative IN ice regimes derived from model	Type E	63.99%	71.67%	75.21%	95.60%	90.78%	88.27%	87.03%	82.88%	70.31%	45.94%	30.39%	19.30%	14.36%	5.10%	0.37%	0.16%	0.00%	0.06%	0.00%	0.82%	15.39%	34.84%	47.69%	52.70%
		Type D	53.81%	59.74%	63.61%	82.02%	82.70%	86.02%	78.78%	76.33%	68.98%	44.75%	29.86%	19.30%	14.36%	5.10%	0.37%	0.16%	0.00%	0.00%	0.00%	0.00%	6.35%	23.50%	41.49%	34.81%
		Type C	53.81%	59.74%	63.61%	82.02%	82.70%	86.02%	78.78%	76.33%	68.98%	44.75%	29.86%	19.30%	14.36%	5.10%	0.37%	0.16%	0.00%	0.00%	0.00%	0.00%	6.35%	23.50%	41.49%	34.81%
		Type B	24.75%	36.03%	46.28%	55.24%	69.63%	65.29%	70.49%	65.09%	61.51%	41.98%	27.58%	17.87%	14.26%	4.72%	0.25%	0.08%	0.00%	0.00%	0.00%	0.00%	0.37%	0.89%	2.97%	15.49%
		Type A	1.43%	6.32%	13.34%	34.94%	56.22%	51.45%	57.73%	47.56%	47.49%	36.61%	8.07%	8.69%	6.65%	3.72%	0.04%	0.00%	0.00%	0.00%	0.00%	0.00%	0.18%	0.68%	0.64%	1.64%
		PC7	6.57%	11.28%	23.24%	37.77%	64.12%	56.50%	63.11%	53.73%	51.45%	37.30%	8.07%	8.69%	6.65%	3.72%	0.04%	0.00%	0.00%	0.00%	0.00%	0.00%	0.18%	0.68%	0.65%	3.78%
		PC6	1.37%	2.66%	5.56%	1.98%	6.12%	4.60%	5.99%	6.05%	4.38%	3.87%	1.77%	0.82%	0.19%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.20%	0.61%	1.21%	1.77%
		PC5	1.21%	1.91%	1.21%	0.00%	2.42%	2.51%	2.24%	2.89%	1.10%	2.56%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.20%	0.61%	1.04%	0.85%
		PC4	0.64%	0.02%	0.04%	0.00%	0.00%	0.00%	0.00%	0.19%	0.00%	0.21%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.11%	0.39%
		PC3	0.18%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.22%
		PC2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

3.2.2 Shipping window per vessel ice class

The results from the model give a good indication that the 'Type' vessel classes have a very short window in which they can be expected to operate. However, as mentioned above, using only the AIRSS cannot be considered as a definitive way to assess a class of ship's suitability for a particular project. This line of thought is especially important when assessing the modeled results for the PC classes where the low incidence of negative IN must be put into perspective. The distance of the transit in the ice can be quite substantial and some areas, such as Zones C and D (section 2.3), are severely affected by ice dynamics.

To that effect, Table 10 gives a comparison of the shipping windows according to the ZDS, the AIRSS and Fednav's perspective. Fednav's perspective adds the notion of ice dynamics and takes into account the actual capability of the vessel to make significant progress in ice. The shoulder season identified in the table relates to the possibility to extend the shipping season beyond the high confidence shipping window. The possibility to extend a shipping season will need to be evaluated on a year-by-year basis, i.e. depending on current conditions as well as the short term forecast of ice conditions. Indeed, there is high variability as to the length and timing of the shoulder periods, both at the beginning and at the end of the shipping season.

PC 5 is the lowest evaluated ice class that is actually an icebreaker. The lesser ice classes (Type A to D and PC 6 and 7) are not designed to engage (and break) ice. They cannot be expected to make significant progress when ice regimes are too challenging for their capabilities, even when the AIRSS allows access to the ice regimes. The Type E vessel is a designation for an open water vessel. While these types of vessels can perform in the presence of ice in low concentration and/or of little thickness, their capabilities are quickly exceeded. This does not mean that open water or light ice class vessels are unsuitable for trade to Milne Inlet. However, they can only be used for a short shipping window, the length of which can vary from one year to the next.

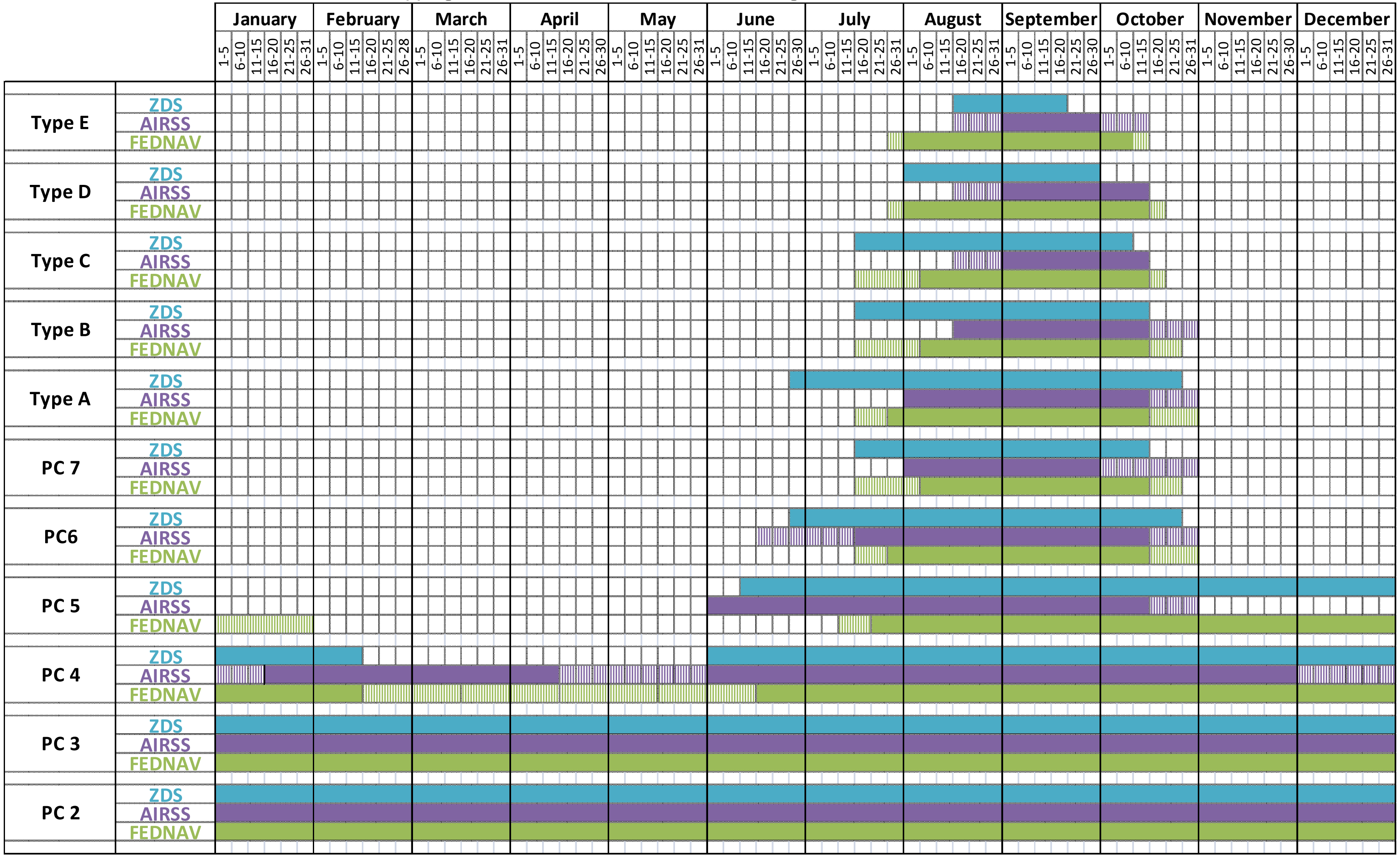
The shipping window is progressively longer when moving up the Polar Classes. A PC 5 ship, for example, is limited to medium first-year ice (70-120 cm). In Baffin Bay, ice tends to grow to thick first-year stage, i.e. in excess of 120 cm. When such is the case, usually by February 1st, a PC 5 vessel should no longer be used. The PC 5 vessel class is also limited in the amount of pressure it can sustain without getting damaged or beset. A PC 4 vessel can navigate in thick first-year ice (120 cm and beyond), but also has limited capabilities when faced with highly pressured ice. PC 2 and 3 vessels can contend with thicker ice and more pressure. Their ability to make progress can be reduced, but they are expected to be able to navigate year-round in this region with good efficiency.

Nevertheless, Baffin Bay quickly becomes a very challenging environment when ice conditions worsen. As such, even vessels with considerable icebreaking power will likely encounter conditions exceeding their operational capabilities. The ships can be faced with highly challenging conditions over hundreds of nautical miles, even when optimal routes have been selected. Pressure and ice drift can force the ship to slow down or even interrupt a voyage. As a result, not only can the time required to reach the destination be substantial, but the load on the engine and the amount of fuel required can be extremely high as well. Beyond the financial consequences, the capacity to carry sufficient fuel to navigate the whole route is a serious concern.

In order to navigate year-round to Milne Inlet efficiently, PC 3 is the minimum ice class required and PC 2 is likely to be more suitable. Having a higher ice class entails that more steel is used to build the hull, which increases the weight and inertia of the ship. Engine power is also increased. This means that vessels of such classes are far more likely to be able to make progress at a reasonable rate, even in the extreme ice conditions they will no doubt encounter at the peak winter conditions. Still, certain areas of Baffin Bay that must be transited to reach Milne Inlet will be challenging even for the highest ice class vessels.

Shipping to and from Milne Inlet will require close monitoring of the ice conditions in order to ensure that ships are out of harm's way when ice conditions exceed a vessel's capabilities. This will also enable ice navigators on board the vessels to plan safe routes that avoid and minimize ice hazards. Since the AIRSS alone will not suffice to ensure that a ship's safety is not jeopardized, the experience and careful planning of the operators, ice navigators and crew will be essential. In addition, due to the inherent variability of ice conditions in Baffin Bay, flexibility will be needed in planning the shipping operation.

Table 10 Shipping season for each vessel class according to the ZDS, the AIRSS and Fednav.



based on 10% or less occurrences of negative IN over 1983 to 2012, on semi-monthly intervals.

shoulder season based on 11 to 30% of negative IN over 1983 to 2012, on semi-monthly intervals.

high-confidence season as suggested by Fednav.

shoulder season as suggested by Fednav.

4. Risk assessment of four shipping windows

4.1 Open water season: August 5 to October 15 (71 days)

Results from the model suggest that the open water season should be defined as being from August 5 to October 15, for a total of 71 days (considering October 15 as the closing date). It is also believed that a shoulder window can be considered, yet it should be evaluated every year based on the ice conditions prevailing that year.

Vessel access: probability of being refused/granted access based on AIRSS

The model created by Enfotec calculates the probability of encountering negative Ice Numerals along the route with different types of vessels. It demonstrates that a Type E (no ice class) vessel would have encountered a negative IN somewhere along the route to Milne Inlet 57% of the time in the first half of August over the 30-year period of 1983-2012. It must be noted though that the model uses 15-day periods to provide averaged results, yet the daily and weekly ice charts show that ice was often encountered during the first days of August. Nonetheless, there are still random years where the ice has drifted and remained in place for a prolonged period until mid-August. As for October, the amount of time when negative INs were seen along the route was of 17% for the first half of the month, and 67% for the second half.

The decadal breakdown of Enfotec's model results indicates that the probability to encounter negative INs in the first half of August was much higher in the 1980's than in recent years: they were observed 80% of the time over the period from 1983 to 1992, while it decreased to 20% for the 2003-2012 decade. Same goes for the second half of October: the percentage was of 90% for the 1983-1992 decade and dropped to 30% for the 2003-2012 period. This recent time period is more representative of the ice conditions that are seen today and that are expected to be encountered for the years to come. With the observed and projected impacts of climate change on the amount of ice present in the Arctic during summer, a return towards 1970's harsher ice conditions is unlikely on the near and long term. Notwithstanding this belief, it must be remembered that at the macro level, localized ice conditions can be such that site specific conditions can vary greatly year over year. In other words, total sea ice extent is not necessarily a reliable indicator of relative ease of access.

Analysis of season length and variability

August 5 to October 15 is defined as the average season. However, a significant variability has been observed over the past years. Over the 20 years of data, open water dates have been as early as July 23 (2016) and as late as August 18 (1999, 2012); freeze-up dates have been as early as September 29 (2003) and as late as October 20 (2006). As such, a shoulder window of 5 to 10 days minimum should be considered around the starting and closing dates (both before and after these dates as a preventive measure).

While the average season length was of 68 days over the period of 1997 to 2016, there is a 33-day variability over that period. The shortest season was observed in 1999 (54 days) and the longest was in 2006 (87 days). However, the evolution of season length is not linear. Figure 29 is a graphical representation of season length for the entire period of study; the red line indicates the trend, which is very weak towards the increase in duration. For example, the years 2012 and 2013 had a short season, with only 56 days of open water. Summer 2016 was also an interesting case: break-up and open water occurred very early (respectively 7 and 14 days earlier than average), yet freeze-up began 4 days earlier than the average date, in part due to the presence of drifting old ice in the area. Still, the entire open water season was of 78 days, 10 days more than the average season length. Overall, the numbers show that short seasons have occurred relatively frequently since 1997, as recent as 2012 and 2013; however, long seasons have been somewhat more frequent in the most recent half of the period of study.

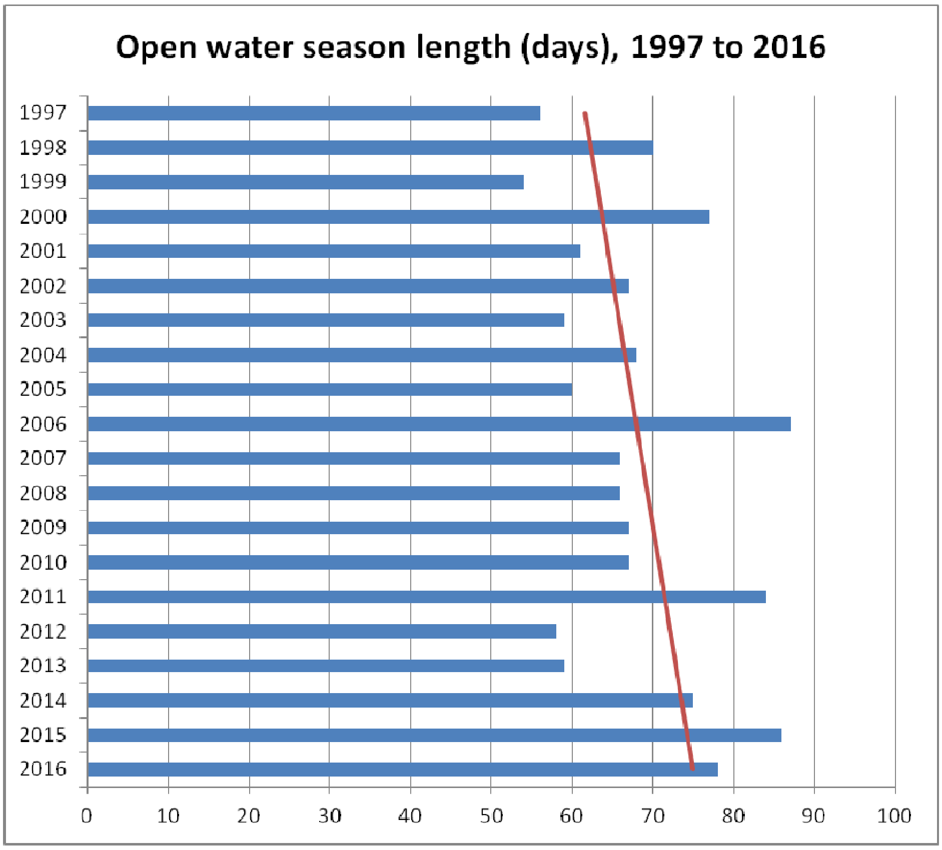


Figure 29 Representation of season length, in days.

Although it would be logical to believe that freeze-up occurs later when break-up and open water occur early, statistics show that there is no correlation to that effect. Similarly, the delay between break-up and open water varies widely from one year to another: the average time over the 20-year period of study is 19 days, but it has been as rapid as 8 days (2015) and as slow as 37 days (2012). Many variable factors can play a role in triggering or preventing ice break-up, clear-up and formation, namely winds, air temperature and drift ice input. The great year-to-year variability in the dates of all events (break-up, open water and freeze-up) demonstrates the impact that external factors can have on the ice.

4.2 Extended season: July 25 to October 31 (98 days)

Vessel access: probability of being refused/granted access based on AIRSS

An extended open water season covering the period from July 25 to October 31 (98 days, considering that October 31 would be the closing date) was analysed. This operation would more than likely require the participation of ice class vessels at the beginning and the end of the season.

Results from Enfotec's model indicate that the use of 1A and 1C ice class vessels would bring little benefit at the beginning of the season. Over the 30-year period of 1983-2012, a 1A vessel would have encountered negative INs 97% of the time in the second half of July, while it would be 100% of the time for both 1C and open water (non ice class) vessels. The numbers remained the same even after breakdown into decades, meaning that even in recent years the use of these vessels would still have been problematic. The reason is that the ice remains very thick even when it's melting, and these vessels cannot force ice that is thicker than the thin first-year type. As it often takes several days for the ice concentration to go from very close pack ice (9/10) to open drift (4/10 to 6/10) after break-up has occurred, it is likely that these vessels will not be able to transit the ice regimes before the first days of August. The use of a 1A or a 1C vessel to start shipping ahead of the open water date may only add a few days to the season.

The use of these vessels could be more efficient at the end of the season, since non ice class vessels can only face ice that is 15 cm thick maximum (grey ice). While a non ice class vessel can start encountering negative INs as soon as the beginning of October, even late September when drifting old or first-year ice gets into the channel, the significant risk for a 1A vessel starts in the second half of October. Over the 1983 to 2012 timeframe, a 1A vessel would have encountered negative INs 20% of the time during the second half of October, while this number goes up to 40% for a 1C vessel and to 67% for a non ice class vessel. Over the 2003-2012 decade, it was only 10% the time that both vessel types had negative INs during this period, while the non ice class vessel still had negative INs 30% of the time.

Analysis of season length and variability

The use of 1A ice class vessels is an interesting option when there is no drifting old ice within the channel. As indicated in table 1, there were only 4 years out the 20 years of the period of study when drifting ice (thick first-year or old ice) migrated all the way into the navigation channel. Most of the time, the area is clear when freeze-up begins in early or mid October. A 1A vessel would likely be able to withstand the ice conditions that prevail until the end of October. While these vessels do not have icebreaking capabilities, the ice cover remains frail and not consolidated until November. As for 1C vessels, it would likely be more recommended to use them for season extension only during light ice years, i.e. when freeze-up occurs later than the average date. They can still operate efficiently in ice that is up to about 30 cm, but they might begin to experience some difficulties and frequent interruptions beyond that thickness.

The extension of the open water season until the end of October with the help of 1A or 1C vessels may be a reasonable option, but only to the extent that such vessels are available on the market.

Additionally, the decision to use these vessels should be done on a year-by-year basis, based on the conditions during summer and the expected freeze-up forecast. Consequently the lead time allotted to make such a decision can be quite short, and will be dependent on the available means and resources to get an adequate freeze-up forecast within sufficient time. The Canadian Ice Service provides a public 30-day outlook that is updated twice a month, but it does not give precise dates: the timing of events is estimated with a weekly range (for example: freeze-up will begin on the 2nd week of October). However, the development of a tailored forecasting model by a group of researchers is feasible and would likely provide more precision on the timing of freeze-up, but requires an investment as this kind of service is not offered as a public service. Otherwise, the lead time to make a decision to prolong the season with 1A or 1C vessels would be about 3 weeks, a timeframe during which things might change in terms of ice formation and drift.

There may be years where these vessels should not operate until the end of October. The season closure of 2016 is a good example of a case of this, due to the presence of old ice in moderate concentration and vast floes and the early freeze-up. Having said this, the capability of support equipment (tugs and workboats) also needs to be considered in term of its ability to operate in ice regimes comprised of rubble grey and grey-white ice (up to 30 cm thick).

4.3 Extended season with support vessels: July 15 to November 15 (123 days)

An extended shipping season covering the period from July 15 to November 15 (123 days, considering that November 15 would be the closing date) was analyzed. This operation would require the participation of DNV ICE-17 (equivalent to PC 3 for the calculation of AIRSS accessibility) ice management vessels at the beginning and the end of the season.

Vessel access: probability of being refused/granted access based on AIRSS

Enfotec's model calculated that over the 30-year period of 1983-2012, a DNV ICE-17 vessel would have encountered positive numerals all the time in July. As for the end of the season, negative numerals were only encountered 3% of the time in late October and 7% of the time in early November. In the 2003-2012 decade, which is likely more similar to conditions that are expected in the future, access would have been permitted at all times. As a result, a DNV ICE-17 vessel would have no issue transiting through (and breaking) the ice along the route to Milne Inlet during the extended shipping season.

Analysis of season length and variability

Vessels that are following in the wake of the ice management or escort vessel are more likely to encounter difficulties at the beginning of the season, when the ice is thick (up to 1.7 m), even if it is broken up by the icebreaker. Due to the thickness of the ice pieces, it would be recommended to use ice class vessels (ideally 1A) until the ice is more dispersed. Indeed, a 1A ice class vessel can likely contend with up to 5/10 of thick first-year ice if the rest of the regime is composed of open water. This cannot 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. After break-up has occurred, it may be required to wait for the ice to become less concentrated (7/10 or less would be a reasonable threshold) before sending a 1A vessel behind an icebreaker so as 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.

In fall, the extension of the season until mid-November would require an escort for 400 to 500 NM in Baffin Bay all the way to Milne Inlet. Although the ice only reaches the thin first-year ice (30-70 cm) stage by that time, low air temperatures lead the track to re-form rapidly after the icebreaker has passed. A vessel with 1A ice class could probably navigate safely under escort until the ice reaches 70 cm and/or becomes fast. In the channels between the port site and the entrance to Baffin Bay, ice becomes fast on average in mid November, almost always before it grows to 70 cm. The threshold date for 1A vessels to operate to Milne Inlet should then be the date when the ice becomes fast. Indeed, the design of these ships is not meant for breaking ice; even though their hull has sufficient reinforcement to face up to 80 cm of ice, they do not necessarily have icebreaking power. Regaining momentum after stopping in a broken ice track within an area of fast ice can be difficult without sufficient engine power, even when following an escort vessel.

Taking these concepts into account, Table 11 defines the feasibility of extended shipping windows with 1A ice class vessels and DNV ICE-17 escort vessels based on ice chart data. The targeted dates are July 20 and 25 for the opening, which is considered feasible when break-up has occurred and ice concentration is of 7/10 or less along the route. For closing, the targeted dates are November 5 and 10, and the decisive factor to evaluate shipping feasibility is the timing when ice becomes fast.

Table 11 Feasibility of specific opening and closing dates for escorted 1A vessels over the 1997-2016 period.

Year	Opening on July 20	Opening on July 25	Closing on Nov. 5	Closing on Nov. 10
1997	NO	NO	YES	NO
1998	NO	NO	YES	YES
1999	NO	NO	NO	NO
2000	NO	NO	NO	NO
2001	NO	NO	NO	NO
2002	NO	NO	NO	NO
2003	NO	YES	YES	NO
2004	NO	NO	YES	YES
2005	NO	NO	YES	YES
2006	NO	YES	YES	YES
2007	NO	YES	YES	YES
2008	NO	NO	YES	YES
2009	NO	YES	YES	YES
2010	YES	YES	YES	YES
2011	YES	YES	YES	YES
2012	YES	YES	YES	YES
2013	NO	YES	NO	NO
2014	NO	NO	NO	NO
2015	NO	NO	YES	NO
2016	YES	YES	YES	YES
Accessibility	**4 / 20**	**9 / 20**	**14/20**	**11/20**

Feasibility of each window, based on historical data from 1997 to 2016, would have been the following:

- July 20 to November 5 (108 days): 4 years out of 20
- July 20 to November 10 (113 days): 4 years out of 20
- July 25 to November 5 (103 days): 8 years out of 20
- July 25 to November 10 (108 days): 7 years out of 20

These results confirm the conclusion that the use 1A ice class vessels under escort would be more relevant to prolong the shipping season in fall than to start it earlier in spring.

4.4 8 ½ month season: June 20 to March 10 (263 days)

Based on the model results, it is estimated that PC 4 vessels can navigate year-round to Milne Inlet. The combination of substantial ice thickness and heavy pressure in western Baffin Bay is likely to result in slow progress and possible interruptions through the voyages from early February to late May or even mid June. As well, PC 2 and 3 vessels can navigate year-round to Milne Inlet. Progress may be slow from early February to mid June, but voyages are expected to remain efficient. They will likely face periods where their ability to make progress is reduced when ice is under high pressure.

As DNV ICE-17 vessels are considered to be equivalent to Polar Class 3, it can be assumed that they would be able to operate efficiently during the proposed 8 ½ month shipping season. Over this timeframe, their use would be required under the following estimated schedule:

- June 20 to July 25 (36 days): solo operation
- July 26 to August 4 (10 days): escort operation
- August 5 to October 9 (66 days): not required for operation (open water season)
- October 10 to November 5 (27 days): escort operation
- November 6 to March 10 (125 days): solo operation
- March 11 to June 19 (101 days): not required for operation (black-out)

The analysis of satellite imagery acquired between November 2015 and June 2016 indicates that the worst time to attempt the transit of Pond Inlet would have been in April and May. Ice floes in Baffin Bay can range between 2 and 12 km in diameter. This pack drifts toward the inlet and presses against the fast ice edge. The pressure is such that there are wide areas that become consolidated and move as one giant floe (up to 50 NM wide), in which several thick and wide floes are embedded. This kind of ice may require a lot of backing and ramming.

The fast ice in Pond Inlet, Eclipse Sound and Navy Board Inlet is different than fast ice in a small bay in the lower or sub Arctic. It is mainly composed of pieces of drifting ice that have become consolidated, instead of ice forming and consolidating in-situ. Floe delimitation as well as ridges and rubble are visible on the imagery within the fast ice zone. This means that transiting through this fast ice might end up being more difficult than through the pack ice during the peak of winter. While the pack ice may contain leads and fractures when it is not under pressure, providing some loosening in the pack for the icebreaker to move the floes aside as it transits, this is not the case within the fast ice cover.

4.5 Routing options: Navy Board Inlet versus Pond Inlet

Shipping to Milne Inlet via Lancaster Sound and Navy Board Inlet results in an additional 130 NM of steaming when compared to the primary route through Pond Inlet. In addition to the extra distance and time en-route, this alternate route presents unique challenges. This section will first describe general ice conditions in Navy Board Inlet and Lancaster Sound throughout the year, and then provide a comparative analysis of the ice-related challenges of shipping to Milne Inlet through either Navy Board Inlet or Pond Inlet.

Navy Board Inlet is covered in fast ice for about 8 months. Similar to the other internal waterways in the approach to Milne Inlet, ice reaches the thick first-year stage (>120 cm) at the peak of winter. However, the composition of the ice cover in Navy Board Inlet differs from Pond Inlet due to the more frequent presence of old or glacial ice and to the deformation of the ice during freeze-up. In summer, the channel becomes open water around the same time as Pond Inlet, some years earlier and others later. However, freeze-up tends to occur a few days earlier in Navy Board Inlet.

In winter, ice is highly dynamic in Lancaster Sound and rarely becomes fast. The opposing currents that regulate circulation in this vast channel (Figure 30) create pressure on the ice cover, which becomes highly deformed into ridges. In spring and summer, the ice that drifts in Lancaster Sound is very thick: it is composed mainly of ridged thick first-year ice and inclusions of old ice that have drifted from western Parry Channel or the many waterways in the higher latitudes. In fall, Lancaster Sound tends to become ice covered a few days earlier than Milne, Pond and Navy Board Inlets. Freeze-up starts in mid or late September in Barrow Strait, sometimes around remaining pieces of ice that have survived summer's melt, and extends to the east within a few weeks.

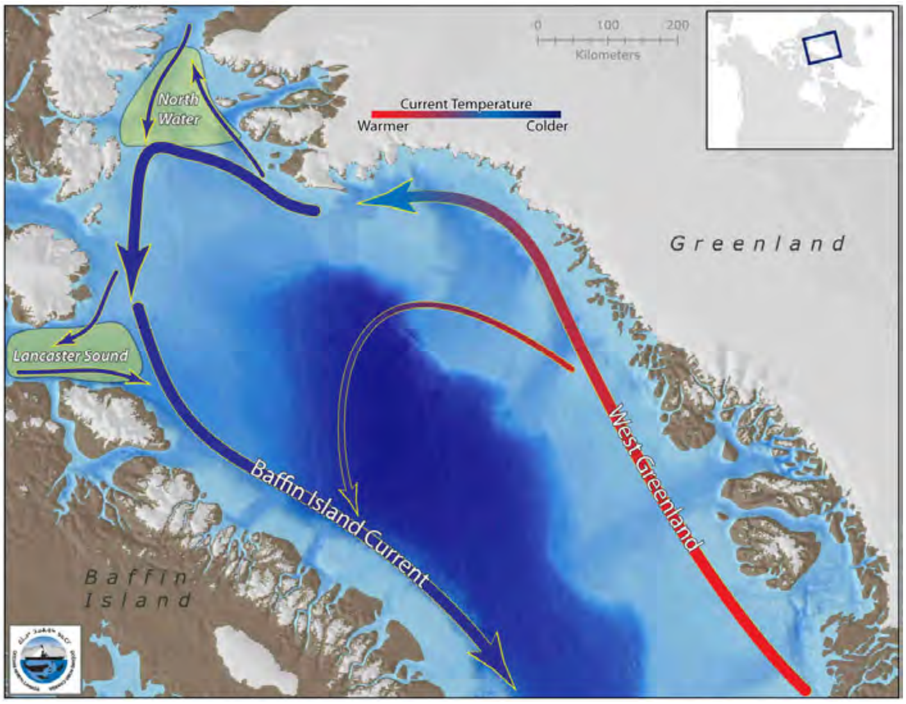


Figure 30 Currents of Baffin Bay (Oceans North Canada).

4.5.1 Ice analysis: comparison between route options

There are three main challenges with the perspective of shipping to Milne Inlet in winter: the presence of old ice; the shear zone at the entrance to internal waterways; and the level of deformation in the fast ice cover. These challenges were analyzed for each route option. For this purpose, several methods and tools were used. An analysis of 18 high resolution satellite images was done, one for each ice season between 1997 and 2016 (with the 2006-2007 season missing because no image were acquired during that time over the area of interest) to ascertain the ice conditions in winter. The identification of old ice occurrences in the fast ice before break-up, in July, was done from Canadian Ice Service daily ice charts and with the help of the satellite images taken in winter. Additionally, oceanographic and climatologic knowledge was used to further understand the dynamic processes that affect the ice.

1) Presence of old ice

The presence of old ice in winter is mostly observed along the route via Navy Board Inlet and Lancaster Sound. Traces or low concentration have been observed a few times in recent years within the fast ice cover. However the more frequent occurrences are in Lancaster Sound and Baffin Bay. There were only a few ice seasons where old ice was observed in the approach via Pond Inlet. Only the 2000-2001 ice season was characterised by a substantial presence of old ice within the fast ice cover.

In Navy Board Inlet, in fall, old ice or glacial ice inclusions can become embedded into the fast ice when pieces drift into the waterway. This is caused by the intrusion of currents into the channel. The Baffin Current (also called "Baffin Island Current"), which flows mainly southward from Nares Strait along the eastern shore of Baffin Island, shows regular intrusions into eastern Lancaster Sound in summer and early fall. A field program using satellite-tracked drifters carried out in 1978 and 1979 in this area showed that this subsurface current divergence penetrates 35 to 75 km westward on the northern side of Lancaster Sound and then deviates southeastward. It also sometimes enters Navy Board Inlet (Figure 31) (Fissel *et al.*, 1982).

It can be deduced from this observation that the old ice that is sometimes seen in Navy Board Inlet is brought in by the intrusion of Baffin Current. The floes that can be seen in the channel originate mainly from Lancaster Sound, but it could also be, in a lesser probability, glacial ice from northern Baffin Bay. Table 12 indicates the amount of old ice in the fast ice cover in Navy Board Inlet and Pond Inlet for the past 20 years (1997 to 2016) in mid-July, just before break-up occurs, based on Canadian Ice Service's daily ice charts.

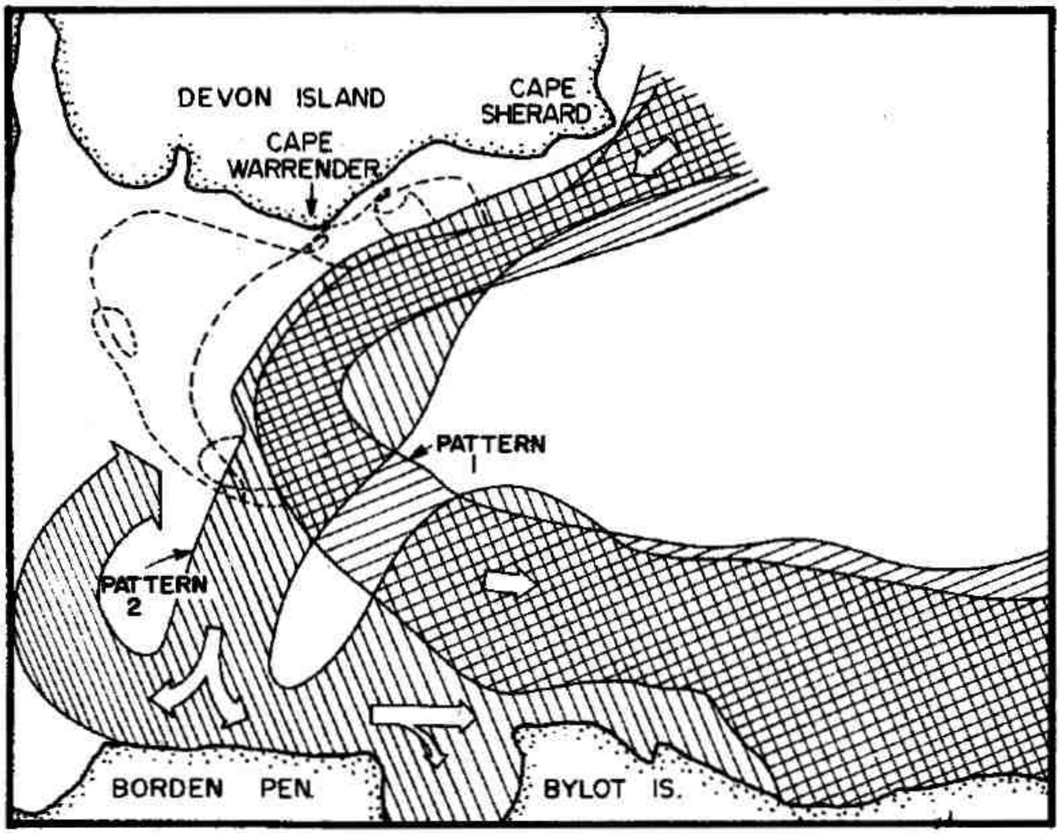


Figure 31 Envelopes containing drifter tracks obtained in 1979 in eastern Lancaster Sound, divided according to two patterns. Shown separately as dashed lines are the tracks of four drifters which departed from the major flow patterns (Fissel *et al.*, 1982).

Table 12 Amount of old ice within the fast ice cover (10/10) before break-up, 1997-2016.

Year	Navy Board Inlet	Pond Inlet
1997	1/10	1/10
1998	3/10	3/10
1999	Traces	Traces
2000	Traces	Traces
2001	2/10	2/10
2002	6/10	Traces
2003	Traces	Traces
2004	2/10	2/10
2005	Traces	Traces
2006	Traces	Traces
2007	Traces	Traces
2008	Traces	Traces
2009	Traces	Traces
2010	1/10	Traces
2011	3/10	2/10
2012	Traces	None
2013	None	Traces
2014	4/10	None
2015	2/10	2/10
2016	Traces	Traces

The old ice can be identified as “traces” although it cannot be distinguished on a satellite image. Based on the normal movement and composition of the ice, it is not rare that old ice is seen in small pieces and consists in less than 1/10 of the cover. “Traces” of old ice can also include glacial ice, although this occurrence is more rare. Over the 20 years of analyzed data, the presence of old ice in the fast ice cover occurred as indicated in Table 13.

Table 13 Presence of old ice in Navy Board Inlet and Pond Inlet over the 1997 to 2016 period.

	Navy Board Inlet	Pond Inlet
None / traces	11 / 20 (55% of time)	14 / 20 (70% of time)
1/10 to 3/10	7 / 20 (35% of time)	6 / 20 (30% of time)
4/10 to 6/10	2 / 20 (10% of time)	0 / 10 (0% of time)

The data shows that although old ice presence is slightly more pronounced in Navy Board Inlet, it is not immensely different as Pond Inlet. Further to that, the analysis of the extent of ice regimes comprising old ice provides further input to the evaluation of the two routing options. Old ice tends to enter the area through Navy Board Inlet in fall. It can drift southward all the way to Eclipse Sound and even into Pond Inlet. Consequently, the extent of ice regimes containing old ice is much greater in Navy Board Inlet. The old ice is present throughout the entire channel, while in the case of Pond Inlet, it is generally limited to a short area at the junction to Baffin Bay or, even more frequent, to Eclipse Sound. On any given year when old ice is present in both Navy Board and Pond Inlet, the extent is generally always greater in the first one.

2) Shear zones

A shear zone is an ice feature that seems to be present in all places where highly concentrated mobile sea ice converges with land fast ice. Consequently, there is a shear zone both at the entrance to Pond Inlet and to Navy Board Inlet. They are different from each other, due to the geographical distribution of land and water around them as well as the ocean circulation that drives the movement of the ice. The transit of the shear zone at the entrance to Pond Inlet is somewhat longer (in distance) than in the one leading to Navy Board Inlet. The latter sometimes seems to be quite compact, includes more rubble ice and is slightly more subject to old ice inclusions.

The behavior and the level of difficulty of a shear zone cannot be fully understood only from satellite imagery, as there is significant but poorly researched 3-dimensional component to it. Field observation and first-hand navigation experience is the only known way to gain a complete perspective of this ice feature and the impediment it constitutes to icebreaker navigation. Unfortunately, there has been no transit through this area in winter months to date.

Nevertheless, an analysis of last winter's Sentinel-1 satellite imagery (October 2015 to June 2016) has provided some insight on the typical behavior of the shear zone in Navy Board Inlet. Figure 32 on March 14, 2016 illustrates the distribution of various ice formations at the entrance to the inlet. The first fast ice edge has a concave form and delimitates the level fast ice and a more rubbled zone, in which ice floes and ridges have consolidated. The middle line is due to a fracture of the whole shear zone that occurred in mid January, after which it reformed all the way up to the last line, further offshore. As a whole, the shear zone has a length of about 6 NM.

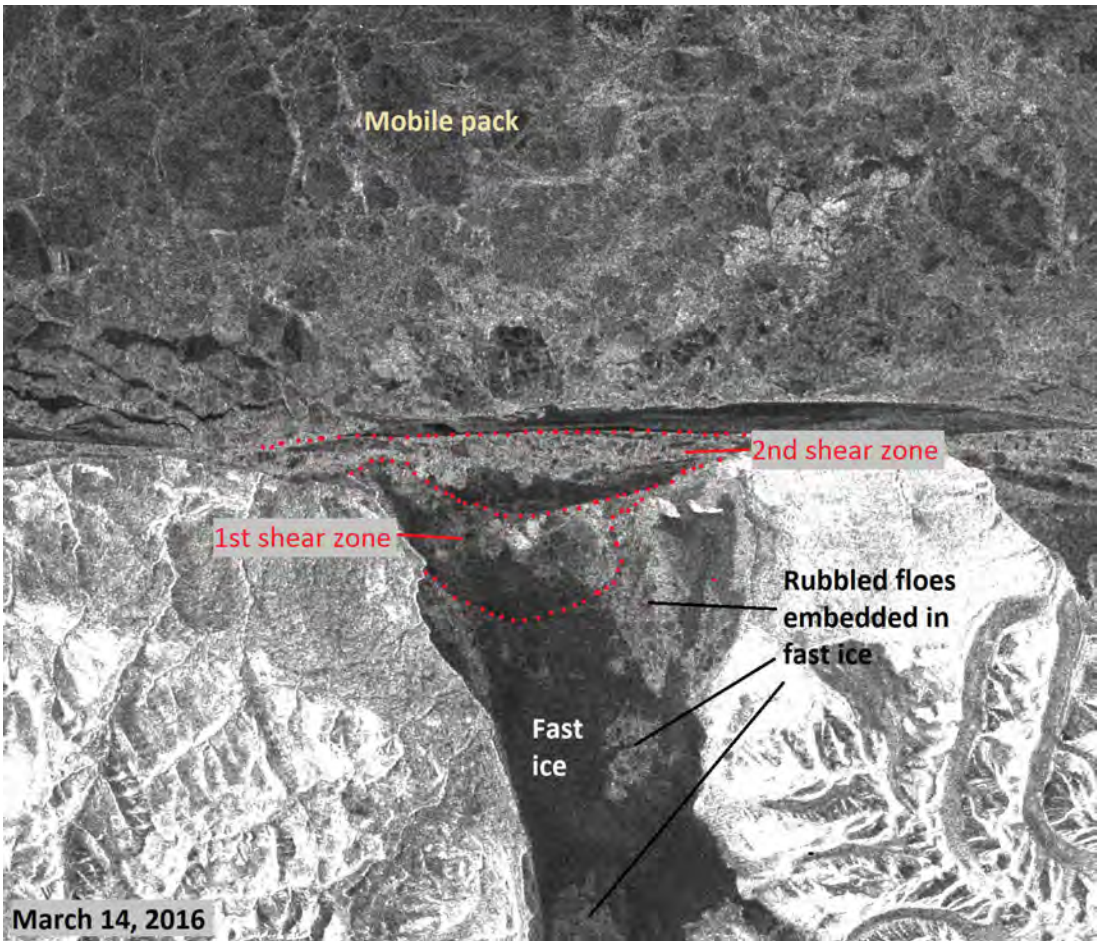


Figure 32 Sentinel-1 satellite image on March 14, 2016 (ESA).

3) Ice deformation

Deformed ice within the fast ice cover, as identified from the interpretation of satellite imagery, seems to be more frequent in Navy Board Inlet than in Pond Inlet. This may be due to stronger subsurface currents that drag the newly formed ice southward in fall and forces it to converge. When the ice is still somewhat thin, the convergence results in hummocking, which appears as a small hillock (Figure 33). As the ice thickens, before it sets into fast ice, the pressure creates ridging, which has a more linear look (Figure 34). When this deformed ice becomes fast, it is much more challenging for the icebreaker to break than level fast ice that has sustained minimal deformation.

Firsthand knowledge from Fednav's experience transiting in Lancaster Sound until late November is that the ice cover is heavily deformed and highly dynamic during fall and winter. The long winter months allow the ice to thicken to well above 120 cm, and this ice is constantly under the strain of winds and currents. In addition, the ice that drifts into Lancaster Sound and Navy Board Inlet in late fall includes not only old ice, but also heavily deformed thick first-year ice originating Parry Channel during winter and spring. When this ice remains in place as freeze-up begins, it becomes embedded within the ice cover and can be several meters thick. It presents itself as irregular structures resulting from the rafting of ice floes when they are under pressure, creating in heavy ridges.

Figure 33 Hummock ice in Estonia (Jaak Sarv Photography, www.jaakphoto.com).

Figure 34 Ridged thin and medium first-year ice in Hudson Strait (Fednav).

4.5.2 Recommendations regarding the Navy Board Inlet route alternative

The main challenge of shipping through Navy Board Inlet in winter is due to inclusions of old ice embedded into the fast ice cover. Such inclusions are often difficult to distinguish and thus present a somewhat hidden danger to vessels transiting what otherwise appears to be a homogenous regime. Old ice is far denser and provides high resistance for the vessel. The resistance is much greater than in drift ice, where old ice is more likely to be displaced, whereas in fast ice, it remains static. The same can be said of heavily ridged or rubble thick first year ice that has been embedded into the fast ice. In addition, each refreeze sequence after the passage of the vessel will make the next transit more difficult, as the structure of the ice will become more irregular.

As indicated in table 1, over a 20-year period there were nine years during which old ice was present (more than just traces) within the fast ice of Navy Board Inlet. Pond Inlet receives less substantial old ice input, and therefore the old ice zone that must be transited to reach Milne Inlet is generally much greater if using the route via Navy Board Inlet. Rubble ice was observed in Navy Board Inlet in 12 of the 17 satellite images, as opposed to only three times in Pond Inlet. This leads to the conclusion that Navy Board Inlet is not a suitable choice as the primary shipping route to Milne Inlet because of the higher risk that it presents for the vessels, both in terms of safety and route efficiency. Analysis of the last 18 years of satellite imagery shows that Pond Inlet would have been a preferable route option most of the time.

We thus conclude that the route to Milne Inlet via Navy Board Inlet and Lancaster Sound should be considered as an alternative only during the open water season and shoulder seasons when ice has not fully formed or is in an advanced state of decay.

5. Climate Change: updates and potential implications for shipping

5.1 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 precipitation occurs. 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 of 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 the sea ice to retreat further than it has in the past. As this reflective surface shrinks, the heat-absorbing area expands. This leads to an increasingly strong cycle where temperatures keep rising and sea ice increasingly retreats. This positive feedback loop is known as the Arctic Amplification (Figure 35).

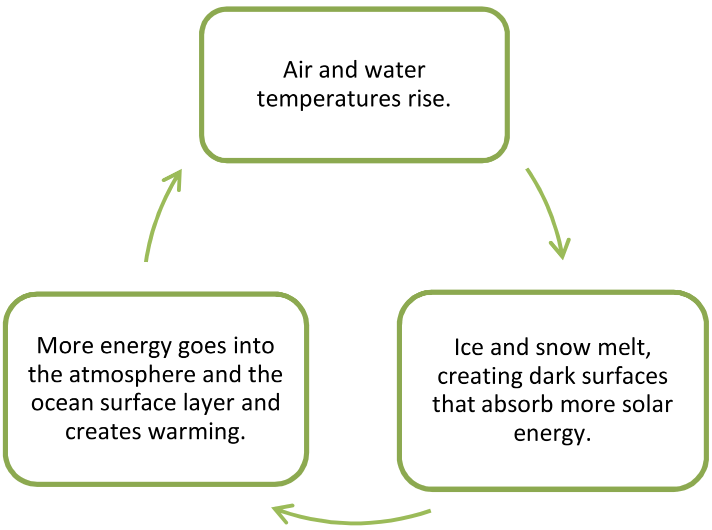


Figure 35 Schema explaining the concept of Arctic Amplification.

5.2 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 through 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 14). The 2016 extent was the same as in 2007.

Table 14 September ice extent from 2007 to 2016 (NSIDC).

Year	September minimum ice extent (in millions of square kilometers)
2007	4.15
2008	4.59
2009	5.12
2010	4.62
2011	4.34
2012	3.39
2013	5.06
2014	5.02
2015	4.43
2016	4.14
1979-2000 average	6.70
1981-2010 average	6.22
2007-2016 average	4.49

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 have 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 these models generate confirms the great level of uncertainty regarding the future of the Arctic ice cover.

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

Climatic models use a wide variety of parameters to build scenarios, which can change depending on the weight attributed to each parameter and the result from interaction between these parameters. They also take into account 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 none 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 are 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 well as lower requirements for the ice-strengthening of ships (ice class). However, the last 40 years have shown that the 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 of the last decades. 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.

5.2.1 Changes in ice dynamics

Most studies have demonstrated that sea ice has experienced significant changes in the past decades. Many aspects of these changes can be observed such as extent, concentration, volume and seasonal patterns; 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. Annually, September is the time when the ice cover reaches its minimum extent. Figure 36 illustrates that, notwithstanding the significant interannual variability, there is a trend towards a decreasing extent of Arctic summer sea ice, especially since 2007.

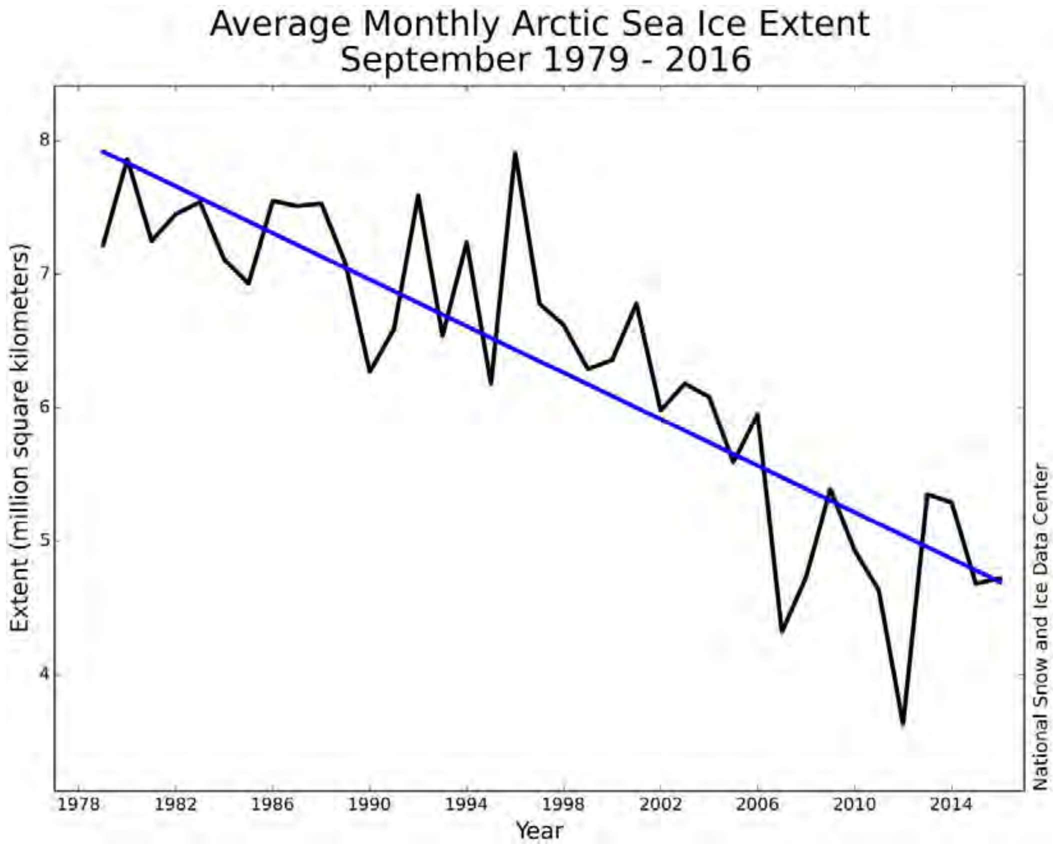


Figure 36 Average monthly Arctic sea ice extent in September, 1979-2016 (NSIDC).

In winter, the change in sea ice extent is slightly less drastic, but still noticeable (Figure 37). Even though the extent of the ice cover also diminishes, ice will always be 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 combined 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.

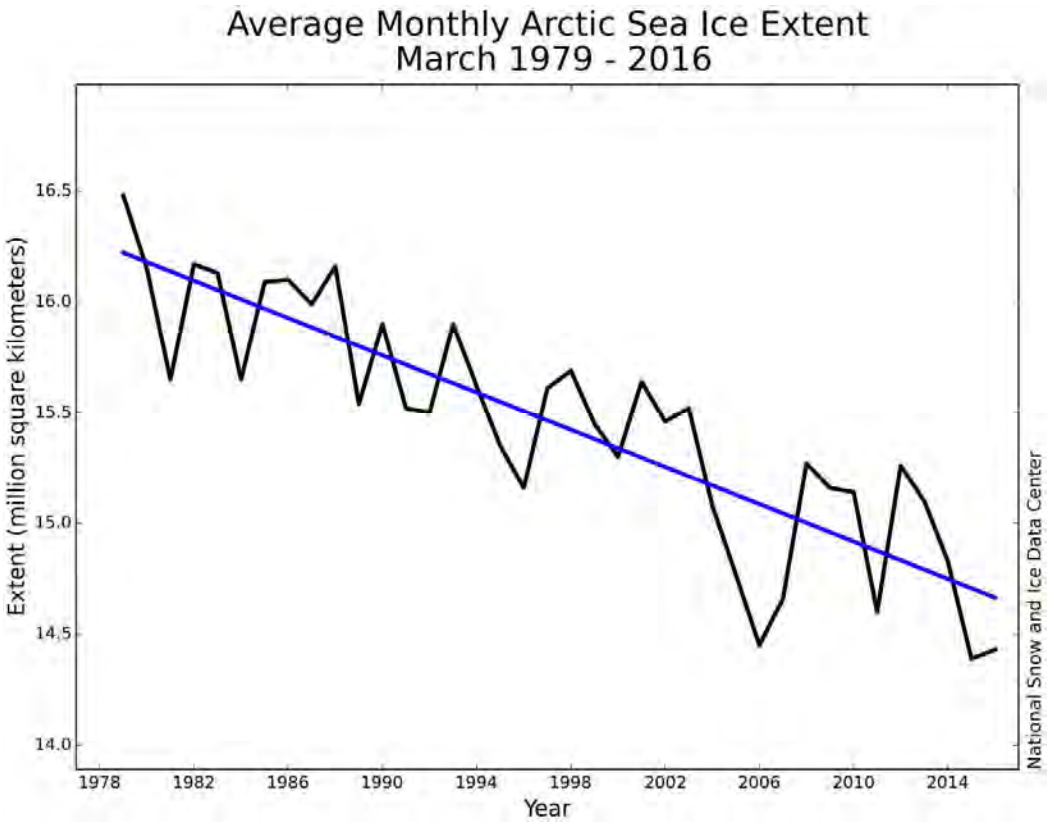


Figure 37 Average monthly Arctic sea ice extent in March, 1979-2016 (NSIDC).

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. Figure 38 and Figure 39 illustrate the departure from normal concentration in the Western Arctic on October 1st, 2012 and on September 26th, 2016. The great amount of pink and red in these maps show that ice used to be present in higher concentrations in the Canadian Arctic (normal is based on 1981-2010 data). Ice in lower concentration tends to thaw quicker since the more prevalent water absorbs more energy than the ice, which results in increased warming.

Some experts believe that there may be less ice in high latitudes than what is detected by satellites. 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 vessel sailing at high latitudes during the summer of 2012 corroborate this hypothesis. Indeed, concentrations as low as 50% at 83°N have been observed, while ice charts derived from satellite data depicted close pack ice (concentration of 9/10) (Vidal, 2012).

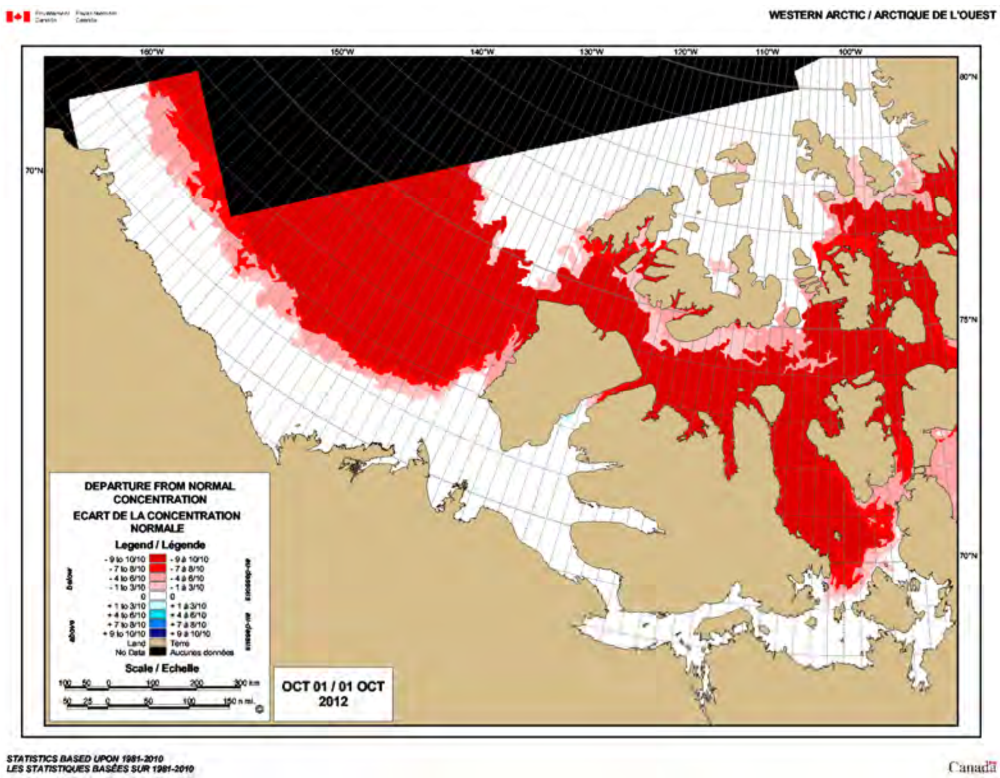


Figure 38 Departure from normal concentration on October 1st, 2012 (Canadian Ice Service).

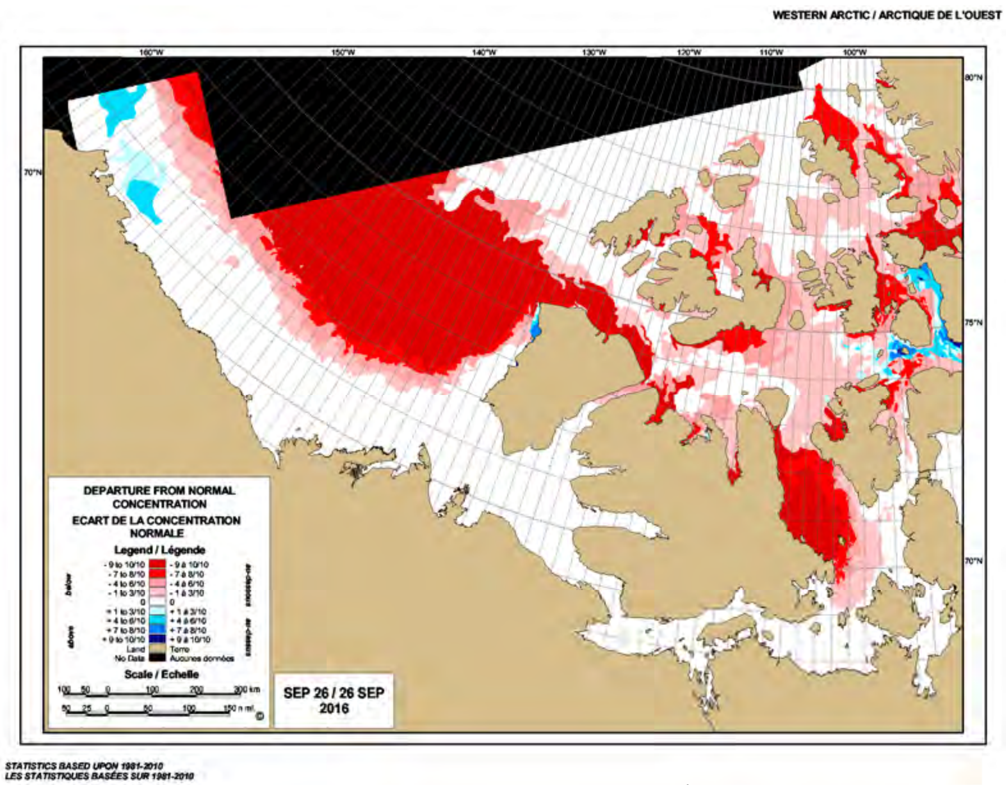


Figure 39 Departure from normal concentration on September 26th, 2016 (Canadian Ice Service).

c. *Ice volume*

Ice volume says a lot about the "health" 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 gets. When the ice cover retreats, more old ice melts, thereby allowing an increase in the concentration of thinner first-year ice. This change has been observed both over the Arctic Ocean as well as in the channels of the Canadian Arctic Archipelago in the last decade. Figure 40 illustrate how the age profile of Arctic sea ice has changed within a few years.

The disappearance of old ice impacts the overall profile of sea ice cover. Old ice is more resistant than first-year ice because it contains less brine (salt water) and less void spaces, making it much more solid and dense. It is 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. In winter, first-year ice also tends to deform significantly under pressure stresses such as winds, currents and tides (Stern and Lindsay, 2009). If first-year ice becomes predominant during winter, more ridging, shearing and rafting of the ice cover can likely be expected. These processes can create serious impediments to navigation, even for highly ice-capable ships.

In addition, more old ice incursions from the Arctic Ocean into the channels of the Canadian Arctic Archipelago can be expected. As the old ice cover melts, it fractures and tends to migrate more easily. This situation can lead to recurrent old ice input within some of the channels, such as Lancaster Sound. Drifting old ice floes must be monitored as their movement can be difficult to predict, especially since old ice is more resistant to melt that younger ice. They can also cause the blockage of narrower passages, or become embedded within the pack when freeze-up begins.

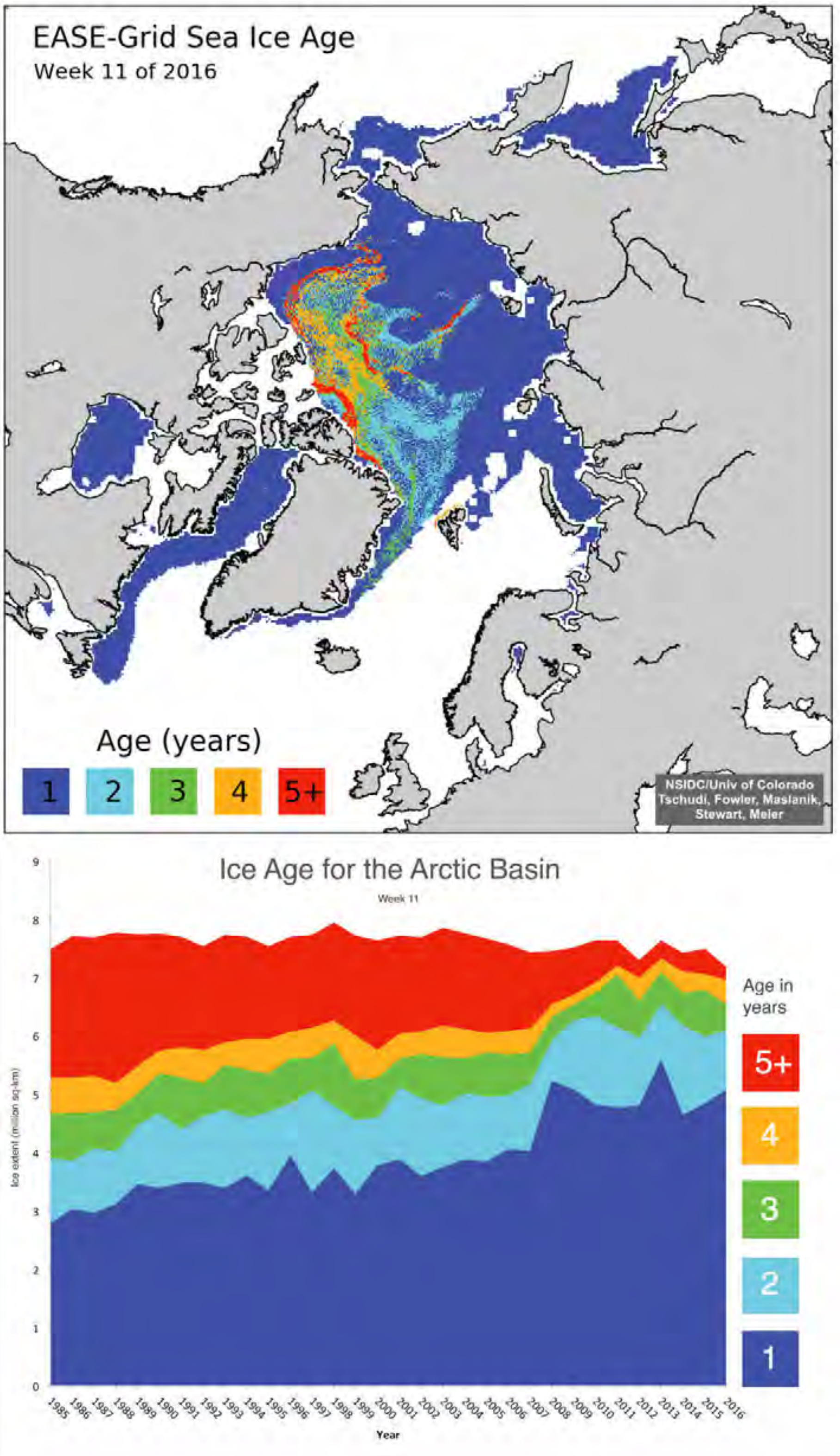


Figure 40 Distribution of ice extent according to age (NSIDC).

d. Seasonal patterns

One of the critical factors of sea ice retreat is the lengthening of the melt season. On average, between 1979 and 2007, the melt season length increased by close to 20 days (Markus *et al.*, 2009). Both the beginning (melt onset) and end (freeze onset) of the melt season have changed: the season starts earlier than before, and ends later. Data demonstrates that there is now a significant extension of the navigable season (defined as the period during which ice concentration is of less than 6/10) and the open water season (less than 1/10 of ice), especially in fall. In 2012, freeze-up over the Canadian Arctic began two weeks later than normal, on average. In 2016, ice melt was generally 2 to 3 weeks earlier than the 1981-2010 normal over the Eastern Arctic region and even up to 5 to 6 weeks earlier than normal over northern Baffin Bay.

For example, as illustrated in Figure 41, the median concentration (based on 1981-2010 data) in mid-October over eastern Parry Channel is about 93%. However, since 2006 the concentration in mid-October has ranged from less than 10% to above 95%. The trend shows a decrease in ice concentration of 7.24% per decade since 1968. This is a clear sign that freeze-up is now occurring later in the season.

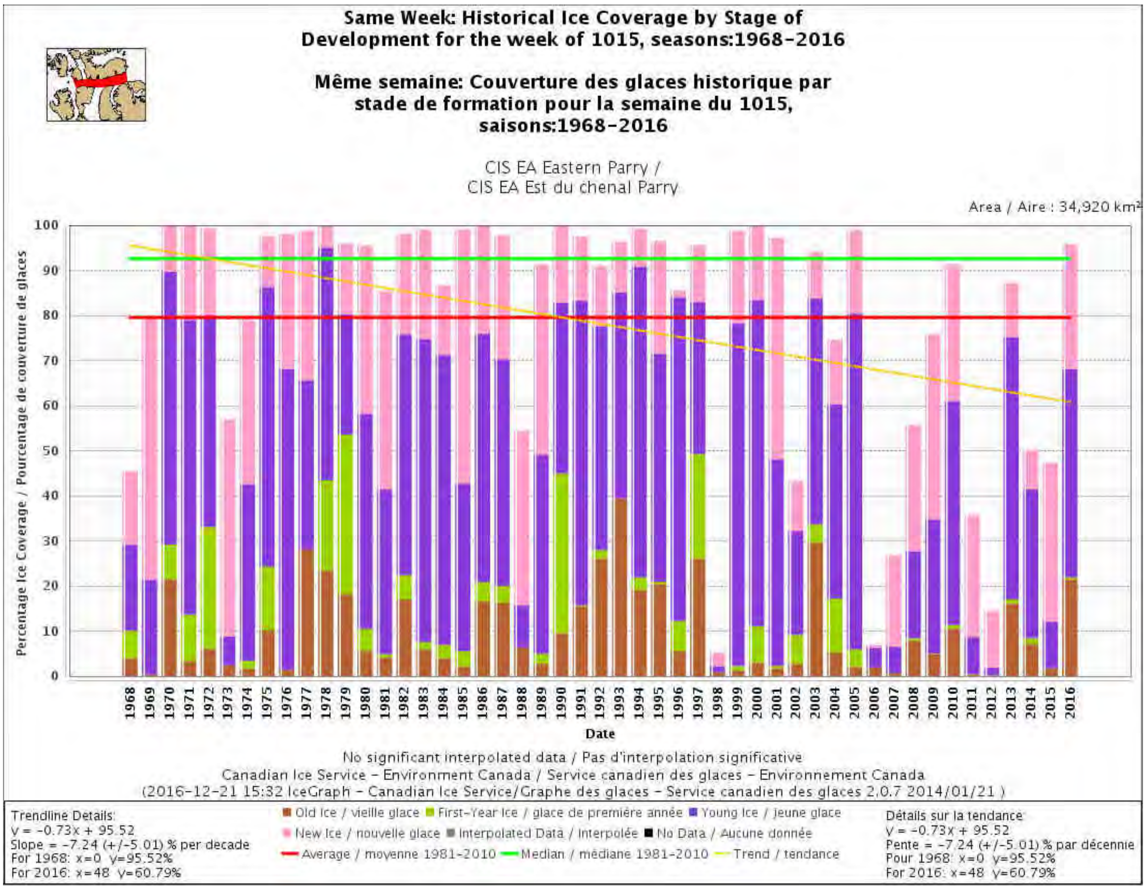


Figure 41 Ice coverage over Eastern Parry Channel around October 15, 1968-2016 (Canadian Ice Service).

5.2.2 Local changes and impacts on shipping

Climate change is a process that evolves over decades and centuries while global temperature measurements date only from the 1850's. Furthermore, data from Canadian Arctic weather stations is not available before the late 1960's or the 1970's, depending on the station. Therefore, it is only possible to evaluate temperature changes based on a 30 to 40-year record of data. This section identifies changes in climate and sea ice at a local scale over the area of interest for the proposed project.

a. A climatic indicator: the Melting Degree Day (MDD)

Several variables can be used to assess the presence of a warming trend and, consequently, its effect on melt. The Melting Degree Day (MDD) is an important measure of the amount of melting occurring each summer. It represents a cumulative value of all average daily temperature above 0°C and has proved to be a good indicator of ice melt. Figure 42 illustrates the variation of yearly cumulative MDD values in Pond Inlet.

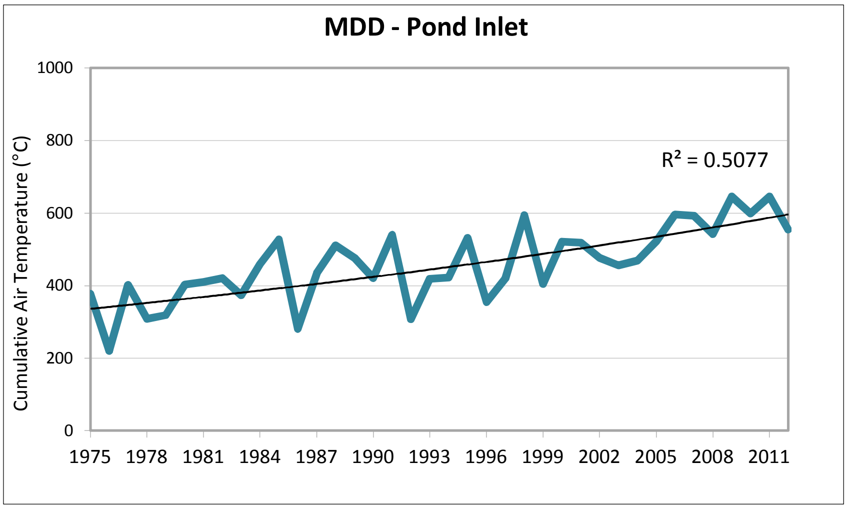


Figure 42 Cumulative air temperature above 0°C in Pond Inlet, 1975-2012 (National Climate Data and Information Archive, www.climate.weatheroffice.gc.ca).

One interesting aspect about this graph is the high interannual variability. There is a difference of over 200 MDD between 1985 and 1986. This does not reduce the importance of rising temperatures, though, as demonstrated by the significant rising trend (R^2 = 0.507) which is even more pronounced since 2000.

In comparison, Figure 43 depicts the number of days that temperatures have been above 0°C. The trend in number of days above 0°C is weaker than for the cumulative value of air temperature above 0°C. For example, if the average temperature used to be 2°C in August and it is now 5°C, the number of days above 0°C has not changed, but the cumulative temperature is now higher. Still, the last 10 years show a higher number of above 0°C days than any 10-day period since 1975.

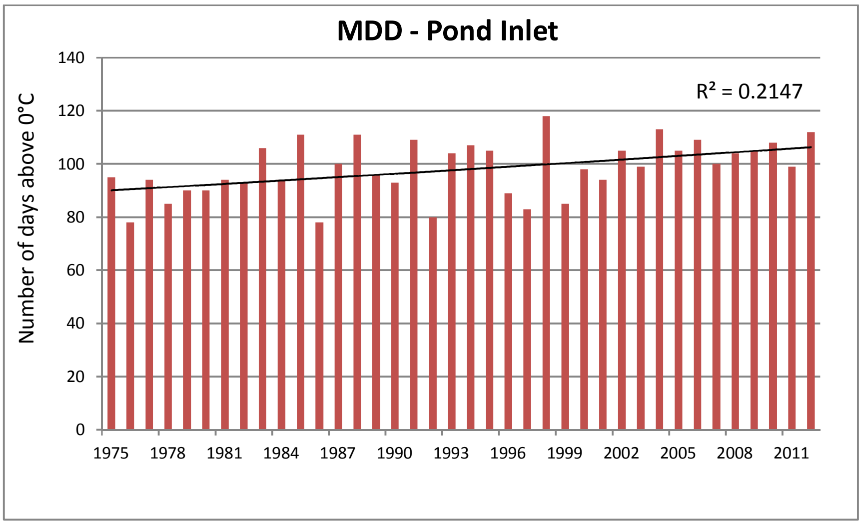


Figure 43 Number of days with temperatures above 0°C in Pond Inlet, 1975-2012 (National Climate Data and Information Archive, www.climate.weatheroffice.gc.ca).

b. *Areas affected by ice-related changes*

Changes in sea ice have been observed over the entire circumpolar Arctic, yet they have been more pronounced on the Eurasian (Russian) side (Smith and Stephenson, 2013). The Canadian Arctic might have a higher capability to retain polar ice due to its archipelagic geography. Indeed, the mosaic of land and water channels can allow ice to linger in areas that are less subject to wind or current induced ablation. It can also create microclimates favorable to ice formation or maintenance. However, this does not hinder the fact that the region is and will be seeing further changes to its ice cover. More specifically, there are areas where changes are more pronounced than others and have significant implications on navigation outlooks.

According to Mudge *et al.* (2012), Baffin Bay has shown significant changes in sea ice extent between 1979 and 2006. An average sea ice loss of about 9% per decade was observed, with the largest reductions taking place during summer. Consequently, the onset of the melting season is now occurring earlier than before, as illustrated in the graphs representing the northeastern portion of Baffin Bay (Figure 44). The significant reduction in ice concentration since 2000 is particularly obvious in mid and late July (outlined by the blue rectangles on the graphs).

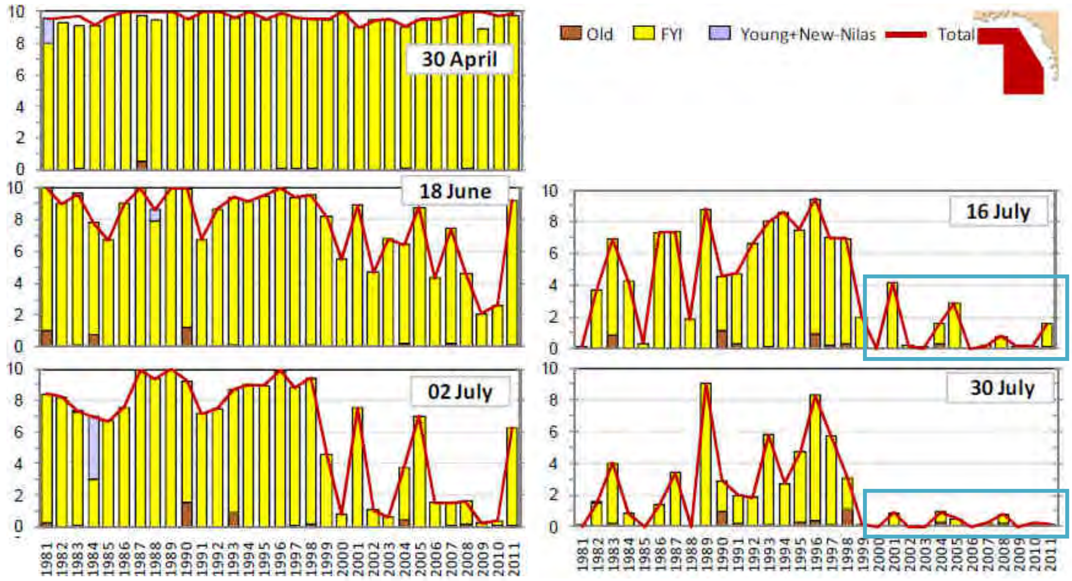


Figure 44 Evolution of ice concentrations in NE Baffin Bay in spring and fall, 1981-2011 (Mudge *et al.*, 2012).

In fall, the onset of freeze-up and ice growth is also showing signs of change. The ice cover develops slightly later nowadays, namely in the western part of Baffin Bay. As illustrated in Figure 45, the amount of ice that reaches the first-year stage (in green on the graph) by early November seems to be decreasing, meaning that new ice forms later than normal, and warmer than normal temperatures are likely preventing ice growth. The years 2006 and 2012 showed a particularly late ice formation in Baffin Bay. The presence of old ice (in brown) is also at a low level since 2002. Figure 45 also highlights the high variability between the years around the same date.

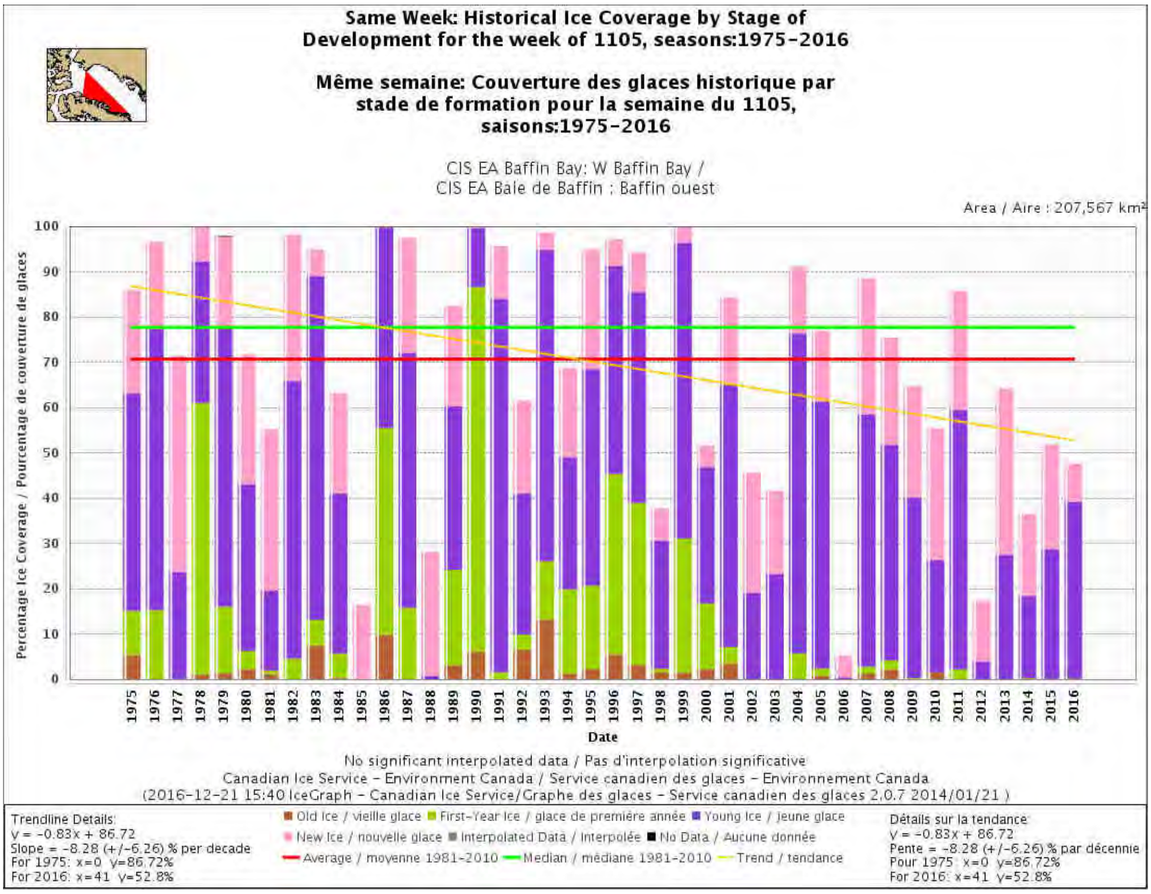


Figure 45 Ice coverage per stage of development over western Baffin Bay in November, 1975-2016 (Canadian Ice Service).

Lancaster Sound has the reputation of being a difficult area for navigation when ice is present. Tides, currents, polynyas and the broad channel width contribute to a highly dynamic ice environment where pressure events can be frequent. The conditions can vary greatly in this area from one year to another. Figure 46 shows that, in late July, Lancaster Sound has fluctuated from being nearly ice-free to being covered with close pack ice in an irregular pattern since 1968. Figure 46 also illustrates the inconsistent presence of old ice which originates from waterways north of the channel (High Arctic). Although it is hard to define a trend in old ice concentration, it seems like it has been lighter since 1995.

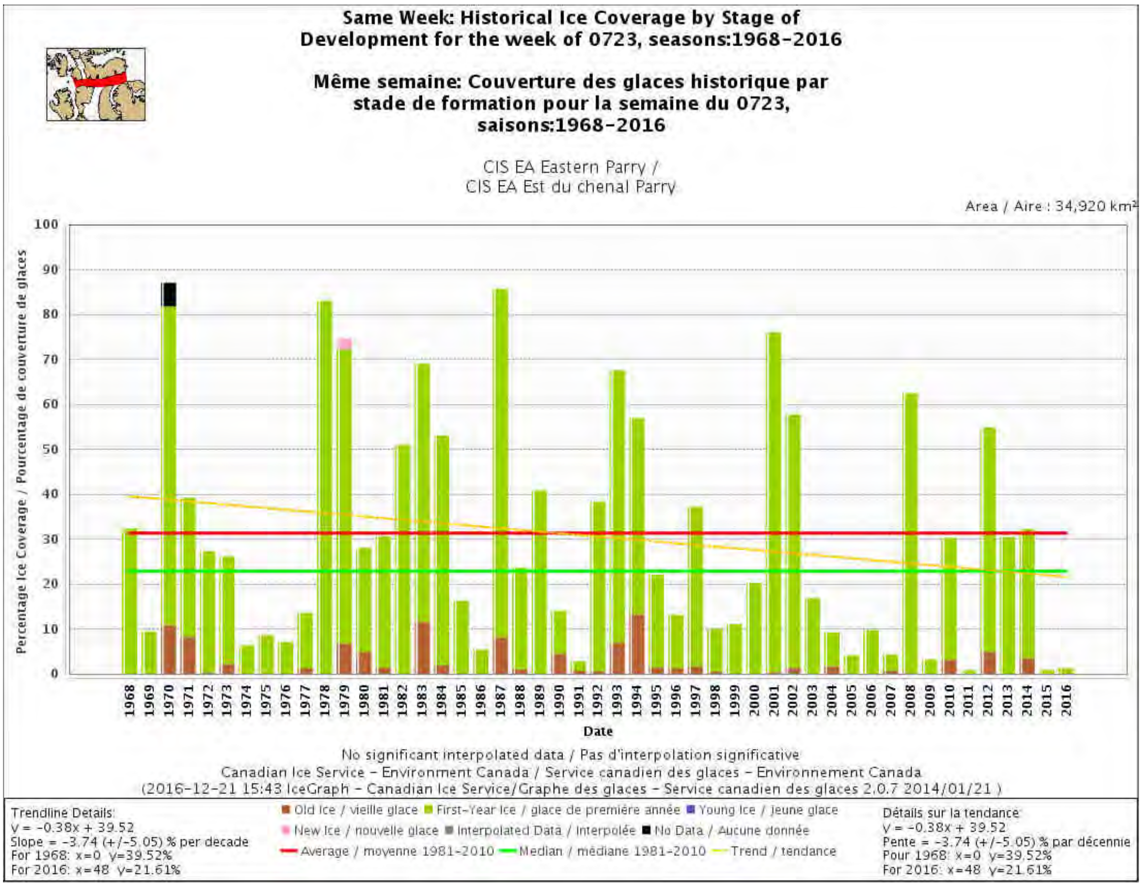


Figure 46 Ice coverage per stage of development over Lancaster Sound in late July, 1968-2016 (Canadian Ice Service).

The small gain in old ice concentration in mid-July 2012 and 2014 is likely a result of greater ice drift within the archipelago. Indeed, the old ice present in Lancaster Sound could not have originated from in-situ formation since all of the ice cover had melted during the previous summer. It could only have originated from elsewhere in the archipelago, likely from the waterways north of Parry Channel. This concords with the hypothesis presented in section 5.2.1, that old ice may become more mobile as the polar pack starts to break apart due to a warmer climate.

In Lancaster Sound, the variation in thickness and concentration can be substantial as much at the inter-seasonal as the intra-seasonal level, as can be seen in Figure 47 and Figure 48 where the data covers the eastern portion of Parry Channel. In early summer 2012, the channel was significantly more ice-covered than normal for several weeks; it was the opposite for 2016 at same time of the year. In 2012, break-up occurred late and ice lingered for several weeks in the channel, which was not the case for 2016. In August 2012, the ice cleared up completely and freeze-up began two weeks later than normal in fall. In early September 2016, old ice had drifted in the channel and triggered early freeze-up. Overall, the channel was widely open for at least 9 weeks during the summer of 2012, while there was always some ice at some point during the summer of 2016.

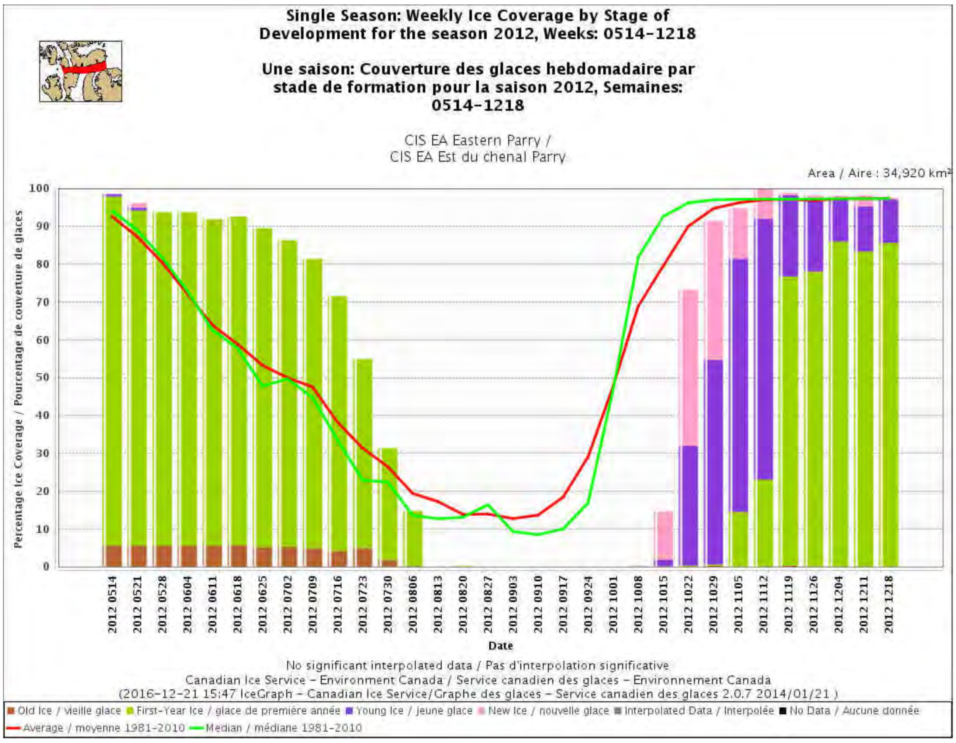


Figure 47 Ice coverage per stage of development over Eastern Parry Channel in 2012 (Canadian Ice Service).

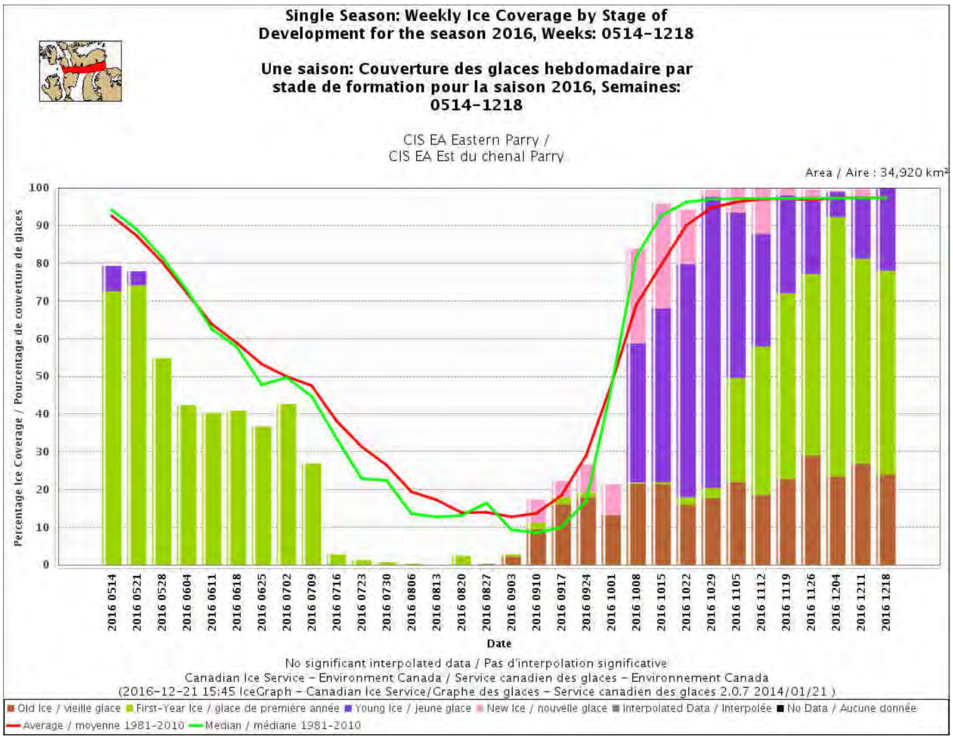


Figure 48 Ice coverage per stage of development over Eastern Parry Channel in 2016 (Canadian Ice Service).

c. Conclusions on climate change in the Arctic

Notwithstanding the importance of temperature increase and sea ice decline in the Arctic, the variability of the climate can be considerable in this remote area. The time period over which ice data has been recorded is not yet long enough to define reliable trends. Still, the trends that are observed provide a strong indication that **warming will intensify** in the Arctic. The temperatures and ice conditions of the last decade are quite different from what was observed from 1970 to 2000. If these trends continue, seasonal ice melt will be greater and ice conditions will be increasingly different from what currently prevails. We can also expect longer shipping seasons in open or low ice concentration waters.

In light of the above, the high variability in summer conditions also reinforces the reality that **shipping in the Arctic involves a great deal of unpredictability**. Winter shipping will undoubtedly remain highly challenging, even with old ice disappearing, as many ice hazards will continue to make navigation difficult and risky. Deformation patterns in the sea ice, namely, are expected to increase in frequency and in amplitude. In addition, the changing climate and the fact that models are constantly being adjusted with new data and predictions also increase the level of difficulty in planning shipping operations in the Canadian Arctic.

6. Limits of the study

This study assesses ice conditions in Baffin Bay and the approaches to Milne Inlet based on an analysis of past conditions in the eastern Canadian Arctic. 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 keep up at the same pace since 30 years is too short a time to extract trends with full confidence. Therefore, although it is possible to speculate on the future of the Canadian Arctic climate, there remains a high level of uncertainty in these predictions. Still, the last few decades' worth of data do hint that the climate is changing faster in the Arctic than in the rest of the world due to Arctic amplification.

Notwithstanding the 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 has repercussions on numerous aspects of this study. Field studies about ice dynamics in the High 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. Old ice and rubble thick first-year ice can often look very similar on a SAR image (Synthetic Aperture Radar, such as the Sentinel, Radarsat and TerraSAR-X satellites). As such, time series showing the formation of the land fast ice would be more revealing of the ice dynamics and composition, but they are impossible to assemble over a significant period of time due to the limited number of archived images available. So far, the only source that has provided such time series is the Sentinel-1 satellite, but it was only recently launched in spring 2014. In addition, the area in question has never been transited in the winter months, and neither is there a comparable operation in terms of ice conditions or specific classes of vessels elsewhere.

However, Fednav's shipping experience in early summer and late fall in the area studied brings significant additional information to our analysis. On a related note, Fednav's general knowledge of ice dynamics and its impact on navigation adds valuable insight to the analysis. This said, while Fednav does have firsthand shipping experience in heavy ice in this region from the Nanisivik and Polaris projects, year-round shipping has never been done that far north. In fact, winter shipping in the Canadian Arctic has only been underway since 1998. Consequently, some of our conclusions and recommendations are based, to some degree, on hypothetical analysis. This is especially true considering that vessels with some of the ice classes evaluated in the study (i.e. PC 3 and PC 2) have not yet been built.

The information and recommendations provided herein are given based on reasonable and informed interpretation of the available data, as well as some theoretical knowledge and extrapolation from Fednav's experience navigating in ice-covered waters.

7. Conclusions

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

1) The **nominal open water season** is from **August 5th to October 15th (71 days)**.

2) Shipping seasons, as herein described, are based on an assessment of interannual variability of ice conditions. The **high confidence shipping window**, especially for ships of lighter ice class (Types A to E and PC 6 and 7) should be **considered as a guide only** and strategic decisions will necessarily be made each year with respect to the provisional opening and closing dates for vessels of different ice classes.

3) On some years, it is expected that a **shoulder window** will allow the shipping season to be extended beyond the high confidence shipping window for certain classes of ships. This will need to be assessed on a year-by-year basis as there is high variability in terms of length and timing of the shoulder period.

4) Provision for **access to icebreaking services** will be necessary for all 'Type' vessels as well as PC 6 and 7 ships during the shoulder periods at the beginning and the closing of the season. In comparison, Polar Classes 5 and higher can engage ice and face a certain amount of pressure on the ice cover.

5) **Type E** vessels (no ice class) are not meant to encounter any significant amount of ice at all. The high confidence shipping window is therefore defined as the average period of open water, about **August 5th to October 15th (71 days)**, with a shoulder window possibly extending the season by about a week. Extending the season will likely require an icebreaker escort.

6) **Type B, C and D and PC 7** vessels can encounter a certain amount of ice. The high confidence window is from **August 5th to October 15th (71 days)**, with an additional shoulder window that can add 10 to 30 days to the season, depending on the ice class. Extending the season will likely require an icebreaker escort.

7) **Type A and PC 6** vessels have a slightly longer high confidence shipping window, from **July 25th to October 15th (82 days)** and the shoulder window can extend the season by up to 25 days. Extending the season might require an icebreaker escort.

8) **PC 5** vessels can navigate with high confidence from **July 20th to December 31st (164 days)**, with a shoulder window possibly extending the season through January. Vessel speeds are expected to be lower from mid-November onward.

9) **PC 4** vessels can navigate **year-round** to Milne Inlet. The combination of substantial ice thickness and heavy pressure in western Baffin Bay is likely to result in **slow progress** and **possible interruptions** through the voyages from early February to late May or even mid June.

10) **PC 2 and 3** vessels can navigate **year-round** to Milne Inlet. Progress may be slow from early February to mid June, but voyages are expected to remain efficient. They will likely face periods where their **ability to make progress is reduced** when ice is under high pressure.

11) **Alternate routing via Navy Board Inlet** should not be considered as a primary choice, but rather as an option to be assessed on a case-by-case basis. The **risk of old ice occurrence** and ridged fast ice is greater in this channel than in Pond Inlet.

Extending the shipping season much beyond the open water season will undoubtedly require the use of Polar Class ships. However, as the ice cover forms and develops over Baffin Bay, Polar Class ships can be faced with highly challenging conditions over hundreds of nautical miles, even when optimal routes have been selected. Not only can the time needed to navigate the routes be substantial, but the load on the engine and the amount of fuel required can be extremely high as well. Beyond the financial consequences, the capacity to carry sufficient fuel to navigate the whole route is a serious concern.

Shipping to and from Milne Inlet will require close monitoring of the ice conditions in order to ensure that ships are out of harm's way when ice conditions exceed a vessel's capabilities. This will also enable ice navigators on board the vessels to plan safe routes that avoid or minimize ice hazards. Since the AIRSS alone will not suffice to ensure that a ship's safety is not jeopardized, the experience and careful planning of the operators, ice navigators and crew will be essential. In addition, due to the inherent variability of ice conditions in Baffin Bay, flexibility will be needed in planning the shipping operation.

References

ACIA, 2004. *Impacts of a Warming Arctic: Arctic Climate Impact Assessment*, Cambridge University Press.

Environment Canada, 2002. *MANICE – Manual of Standard Procedures for Observing and Reporting Ice Conditions*, by Canadian Ice Service.

Environment Canada. *National Climate Data and Information Archive.*

Environment Canada, 2012. *Sea Ice Climatic Atlas – Northern Canadian Waters 1981-2010*, by Canadian Ice Service.

Fissel, D.B., D.D. Lemon and J.R. Birch, 1982. *Major Features of the Summer Near-Surface Circulation of Western Baffin Bay, 1978 and 1979*, in Arctic, vol. 35, no. 1, p. 180-200.

International Association of Classification Societies (2011). *Requirements concerning Polar Classes.*

Kovacs, A, W.F. Weeks, S. Ackley and W.D. Hibler III, 1973. *Structure of a Multi-Year Pressure Ridge*, in Arctic, vol. 26, no. 1.

Langlois, D.J., R. De Abreu, M.F. Gauthier, G. Timco and M. Johnston, 2003. "Early results of the Canadian Ice Service Ice Strength Chart", in *Proceedings of the 17th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC '03)*, vol. 1.

Marko, J.R., J.R. Birch and M.A. Wilson, 1982. *A Study of long-term satellite-tracked iceberg drifts in Baffin Bay and Davis Strait*, in Arctic, vol. 35, no. 1.

Markus, T., J.C. Stroeve and J. Miller, 2009. *Recent changes in Arctic sea ice melt onset, freezeup, and melt season length*, in Journal of Geophysical Research, vol. 114.

Minister of Fisheries and Oceans Canada, 2012. *Ice Navigation in Canadian Waters*, by Canadian Coast Guard.

Minister of Justice, 2013. *Arctic Shipping Polution Prevention Regulation.*

Mudge, T.D., D.B. Fissel, M.M. de Saavedra Alvarez, J.R. Marko and K. Borg, 2012. *The Changing Ice Regime of Northeastern Baffin Bay*, for ICETECH 2012.

Prinsenberg, S., J. Hamilton, I. Peterson and R. Pettipas, 2009. "Observing and interpreting the seasonal variability of the oceanographic fluxes passing through Lancaster Sound of the Canadian Arctic Archipelago", in J.C.J. Nihoul and A.G. Kostianoy (ed.), *Influence of Climate Change on the Changing Arctic and Sub-Arctic Conditions*, Springer Netherlands.

Smith, L.C. and S.R. Stephenson, 2013. *New Trans-Arctic shipping routes navigable by midcentury*, in Proceedings of the National Academy of Sciences (PNAS), vol. 110, no. 13.

Stern, H.L. and R.W. Lindsay, 2009. *Spatial scaling of Arctic sea ice deformation*, in Journal of Geophysical Research, vol. 114.

Stewart, R.E., D. Bachand, R.R. Dunkley, A.C. Giles, B. Lawson, L. Legal, S.T. Miller, B.P. Murphy, M.N. Parker, B.J. Paruk and M.K. Yau, 1995. *Winter storms over Canada*, in Atmosphere-Ocean, vol. 33, no. 2.

Tang, C.C.L., C.K. Ross, T. Yao, B. Petrie, B.M. DeTracey and E. Dunlap, 2004. *The circulation, water masses and sea ice of Baffin Bay*, in Progress in Oceanography, vol. 63.

Timco, G. W., A. Collins, I. Kubat, 2009. *Scientific Analysis of the ASPPR Hybrid System for Type B Vessels*, Canadian Hydraulics Center.

Timco, G.W.,A. Collins, I. Kubat, 2011. *Ice Severity for Polar Class Vessels: Input into the ASPPR Arctic Shipping Regulations*, Canadian Hydraulics Center.

Transport Canada, 2003. Arctic *Ice Regime System Pictorial Guide*, Canadian Hydrolics Center.

Transport Canada, 2012. *Zone/Date System Map and Dates of Entry Table*.

Vidal, J., 2012. "Arctic expert predicts final collapse of sea ice within four years", in *The Guardian*, September 13th 2012.

Vidal, J., 2012. "Arctic Is there even less Arctic sea ice than the satellites show?", in *The Guardian*, September 17th 2012.

Wang, M. and J.E. Overland, 2012. "A sea ice free summer Arctic within 30 years: An update from CMIP5 models", in *Geophysical Research Letters*, vol. 39.

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.

Table 1 Arrangement of the ice in terms of concentration (Canadian Ice Service).

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 2.

Table 2 Stages of development of sea ice (Canadian Ice Service).

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 (**Erreur ! Source du renvoi introuvable.**). 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 3 Forms of ice (Canadian Ice Service).

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. 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 cost 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 Ridges in Hudson Strait in February 2013 (Fednav).

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 2). 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 2 Ship's track in land fast ice (Fednav).

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 60^{th} 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 4 gives an overview of the 'Type' vessels capabilities.

Table 4 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 5). 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 5 Schedule V of the ASPPR – Construction Standards for Types A, B, C, D and E Ships (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✪ УЛА or KM✪ УЛ	100A-1.1 RG 1* or 100A-1.1 1AS	RNR/CM ⚓ M/O G 60 or RNR/CM ⚓ M/O G 50
2.	Type B	A1 Ⓔ Ice Strengthening Class A AMS or A1 Ⓔ Ice Strengthening Class 1A AMS	1 3/3E glace 1 or I 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✪ Л1	100A-1.1 RG 1 or 100A-1.1 1A	RNR/CM ⚓ M/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✪ Л2	100A-1.1 RG 2 or 100A-1.1 1B	RNR/CM ⚓ M/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✪ Л3	100A-1.1 RG 3 or 100A-1.1 1C	RNR/CM ⚓ M/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	RNR/CM ⚓ M/O

† The mark * in these columns is optional."

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 vessel 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 6.

Table 6 IACS Polar Class Descriptions (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 7 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 Enfotec'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 7 Enfotec'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 3. Permissible access dates for each zone, based on the ice classification of the vessel, are described in Table 8. 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.

(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 (section **Erreur ! Source du renvoi introuvable.**).

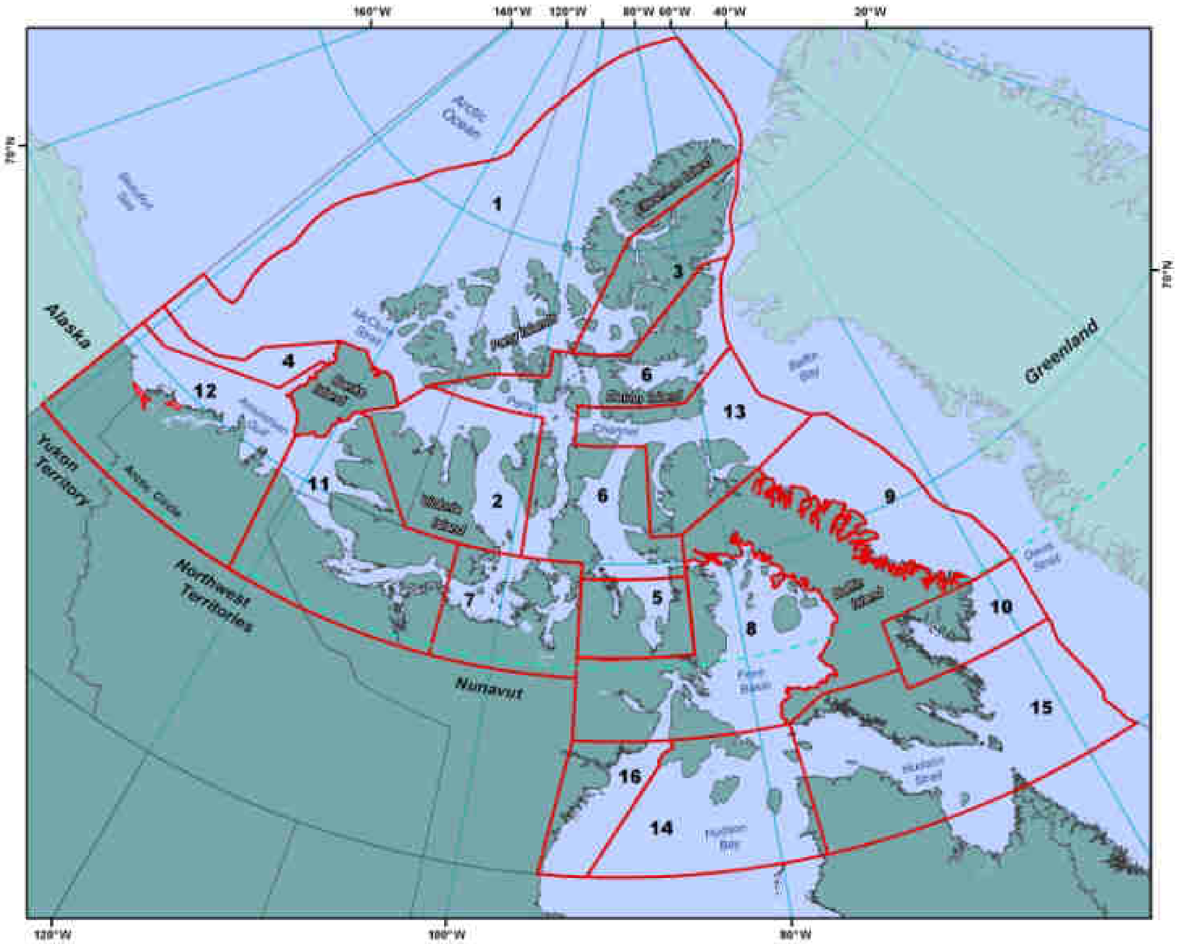


Figure 3 Zone/Date system map (Transport Canada).

Table 8 Allowable entry dates by ice class and Zone (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	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*
Arctic Class 8	July 1 to Oct. 15	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*
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	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*
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	*All Year*	*All Year*	July 1 to Mar. 31	*All Year*	*All Year*	*All Year*	*All Year*	*All Year*
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	*No Entry*	*No Entry*	Aug. 15 to Sept. 30	Aug. 1 to Oct. 31	*No Entry*	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	*No Entry*	*No Entry*	Aug. 20 to Sept. 15	Aug. 20 to Sept. 30	*No Entry*	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	*No Entry*	*No Entry*	*No Entry*	*No Entry*	*No Entry*	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	*No Entry*	*No Entry*	Aug. 20 to Sept. 10	Aug. 20 to Sept. 20	*No Entry*	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	*No Entry*	*No Entry*	Aug. 20 to Sept. 5	Aug. 20 to Sept. 15	*No Entry*	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	*No Entry*	*No Entry*	*No Entry*	*No Entry*	*No Entry*	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	*No Entry*	*No Entry*	*No Entry*	*No Entry*	*No Entry*	*No Entry*	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	*No Entry*	*No Entry*	*No Entry*	*No Entry*	*No Entry*	*No Entry*	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

References

Minister of Justice, 2013. *Arctic Shipping Polution Prevention Regulation.*

Transport Canada, 2012. *Zone/Date System Map and Dates of Entry Table.*

Appendix III: Comments on the use of ice charts

Weekly ice charts are used in this assessment to define the dates of all events (break-up, new ice, etc.). As defined by the Canadian Ice Service:

> "Regional ice charts show the analysis of ice conditions for a given region valid on Mondays. They are based on an analysis and integration of data from: satellite imagery, weather and oceanographic information, visual observations from ship and aircraft. Satellite imagery is collected over a few days in order to have complete coverage of the area."

Consequently, while their coverage and frequency provide a generalized profile of ice conditions over a region, their level of precision is not as high as the daily chart to represent the timing of specific ice events. Daily ice charts can sometimes be available for single areas, but they do not cover the entire period of study: namely, they were not available at all for the years 1997 to 2003, and they often end in early or mid October at the latest. Therefore, weekly charts were used throughout this assessment so as to ensure consistency.

Ice chart production relies on human interpretation and is thus intrinsically biased (charts are influenced by the interpreter's experience, skills and knowledge). Their level of precision also depends on the quality of the data. Over the time period that is used for the current assessment, there has been tremendous evolution in the quality and resolution of the imagery used to produce ice charts. For example, the arrival of the satellite Radarsat-2, in 2007, provided superior capability for ice detection and monitoring, compared to Radarsat-1 (launched in 1995), and allowed more refined interpretation of the ice conditions. Before Radarsat, the charts were based on aerial reconnaissance and data extrapolation. In addition, the knowledge about ice dynamics and climatology also improved with time, therefore enhancing the precision of the charts.

Finally, the spatial resolution of ice charts cannot depict localized ice events, nor ice conditions that change rapidly over a short timeframe. This is especially true for regional charts as they represent generalized ice conditions, but can also be observed on daily ice charts. As a result, an ice event (ex. a drifting old ice floe that blocks a navigation passage in part or in whole) that can have a significant impact on navigation may not appear on a chart.

Appendix IV: Radarsat imagery, 1997 to 2015

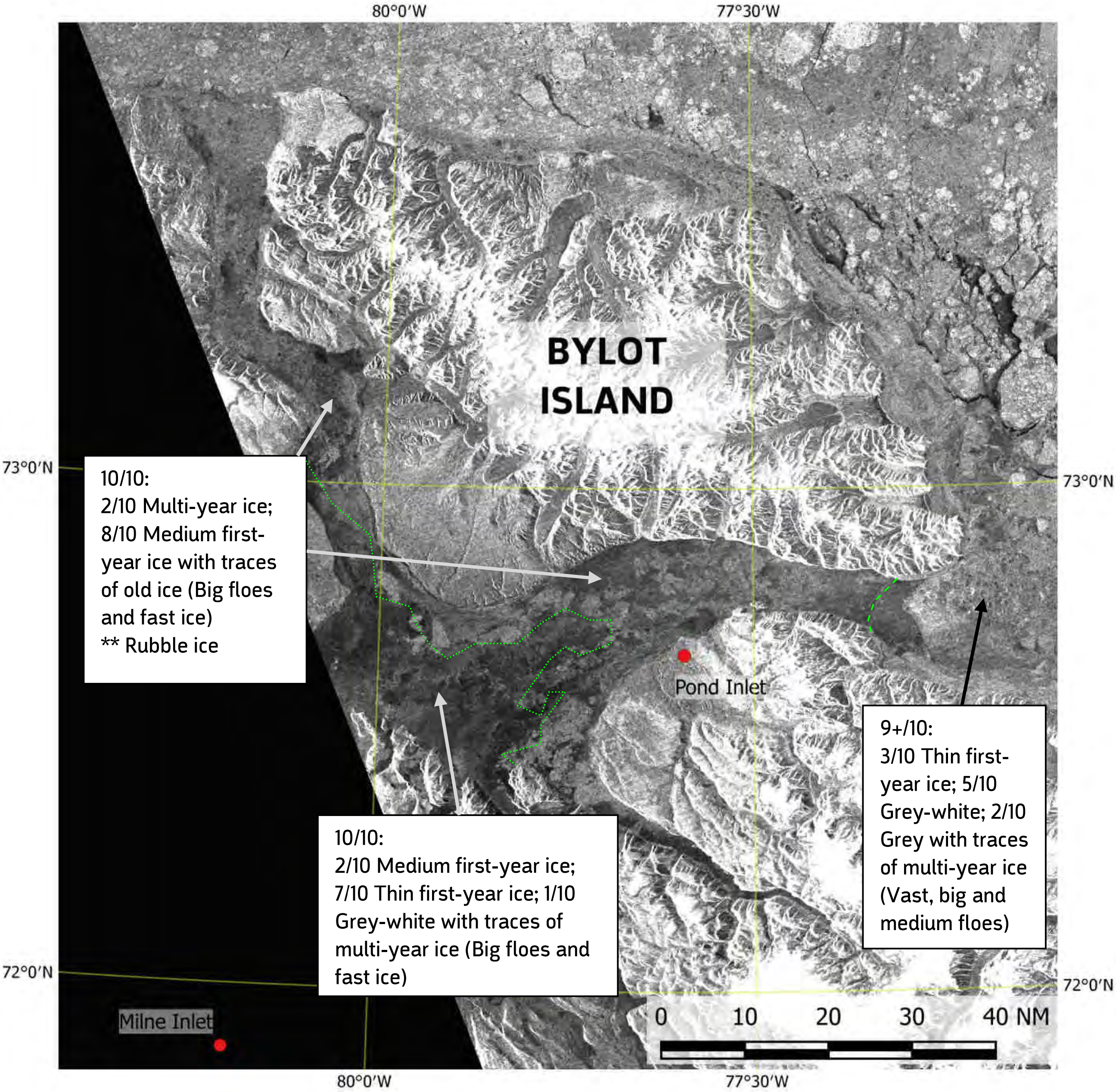


Figure 4 RADARSAT-1 Image acquired on November 20th, 1997 (Polar Data Catalogue).

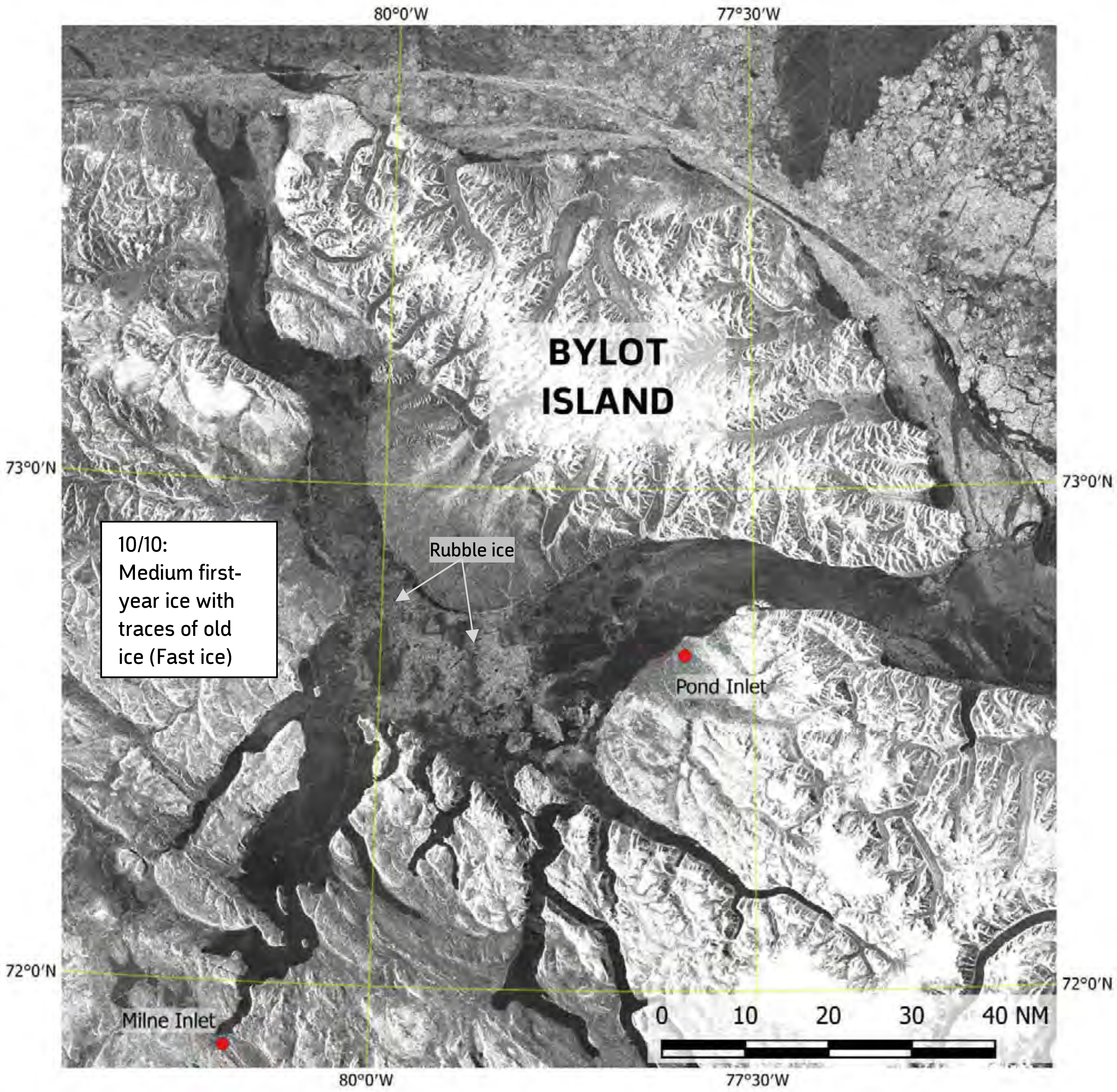


Figure 5 RADARSAT-1 Image acquired on February 1st, 1999 (Polar Data Catalogue).

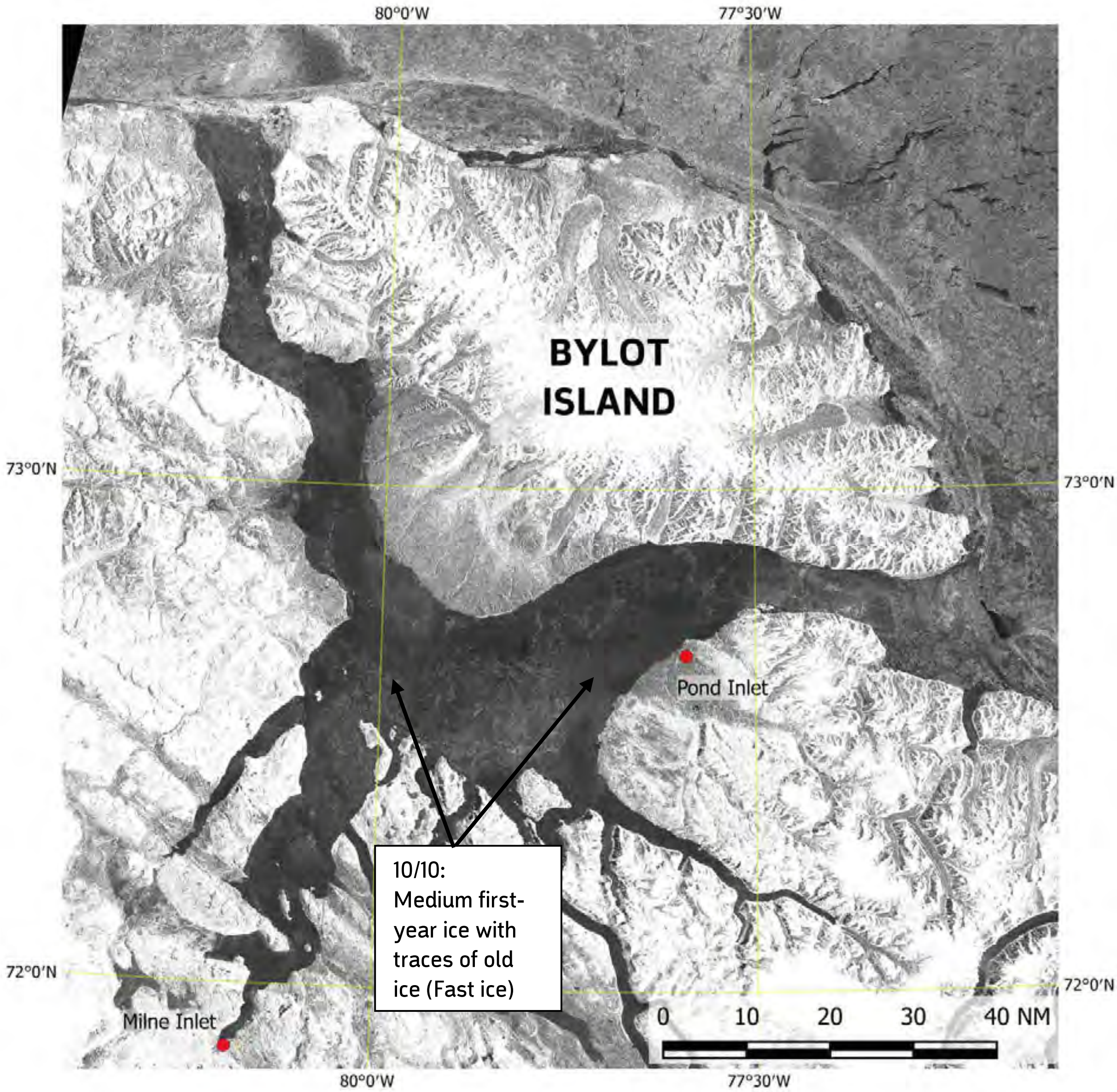


Figure 6 RADARSAT-1 Image acquired on February 4th, 2000 (Polar Data Catalogue).

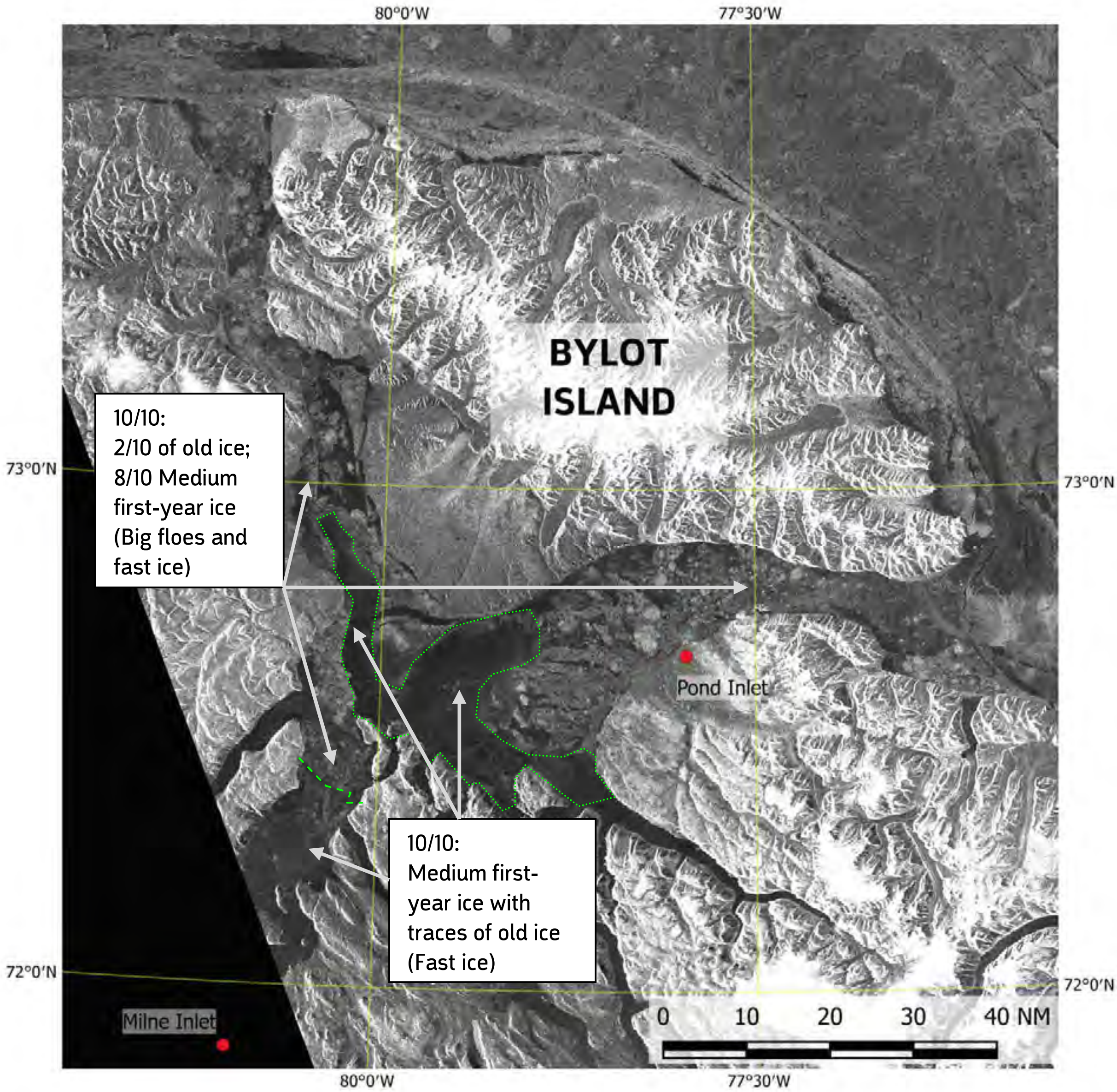


Figure 7 RADARSAT-1 Image acquired on February 1st, 2001 (Polar Data Catalogue).

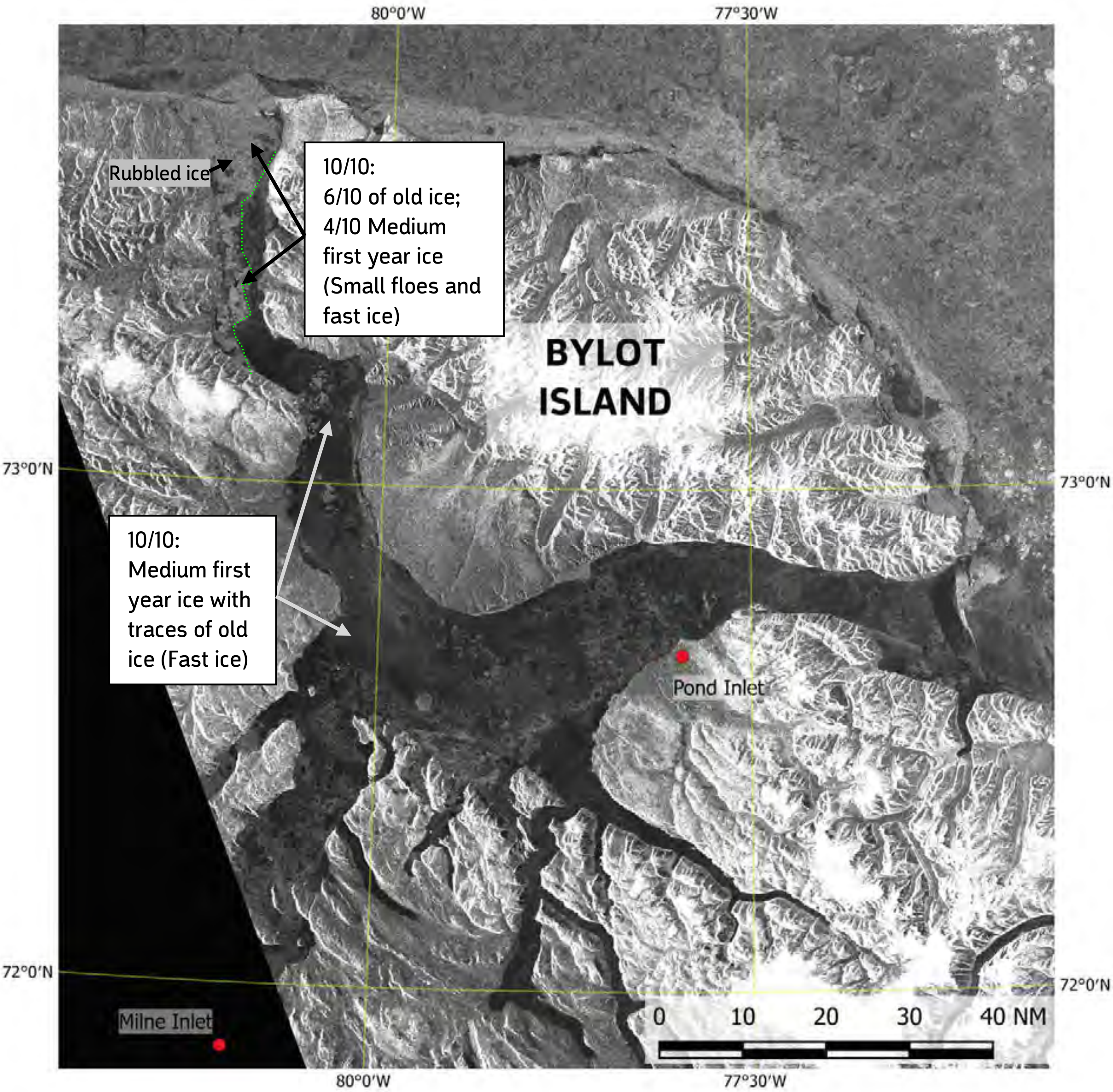


Figure 8 RADARSAT-1 Image acquired on January 27th, 2002 (Polar Data Catalogue).

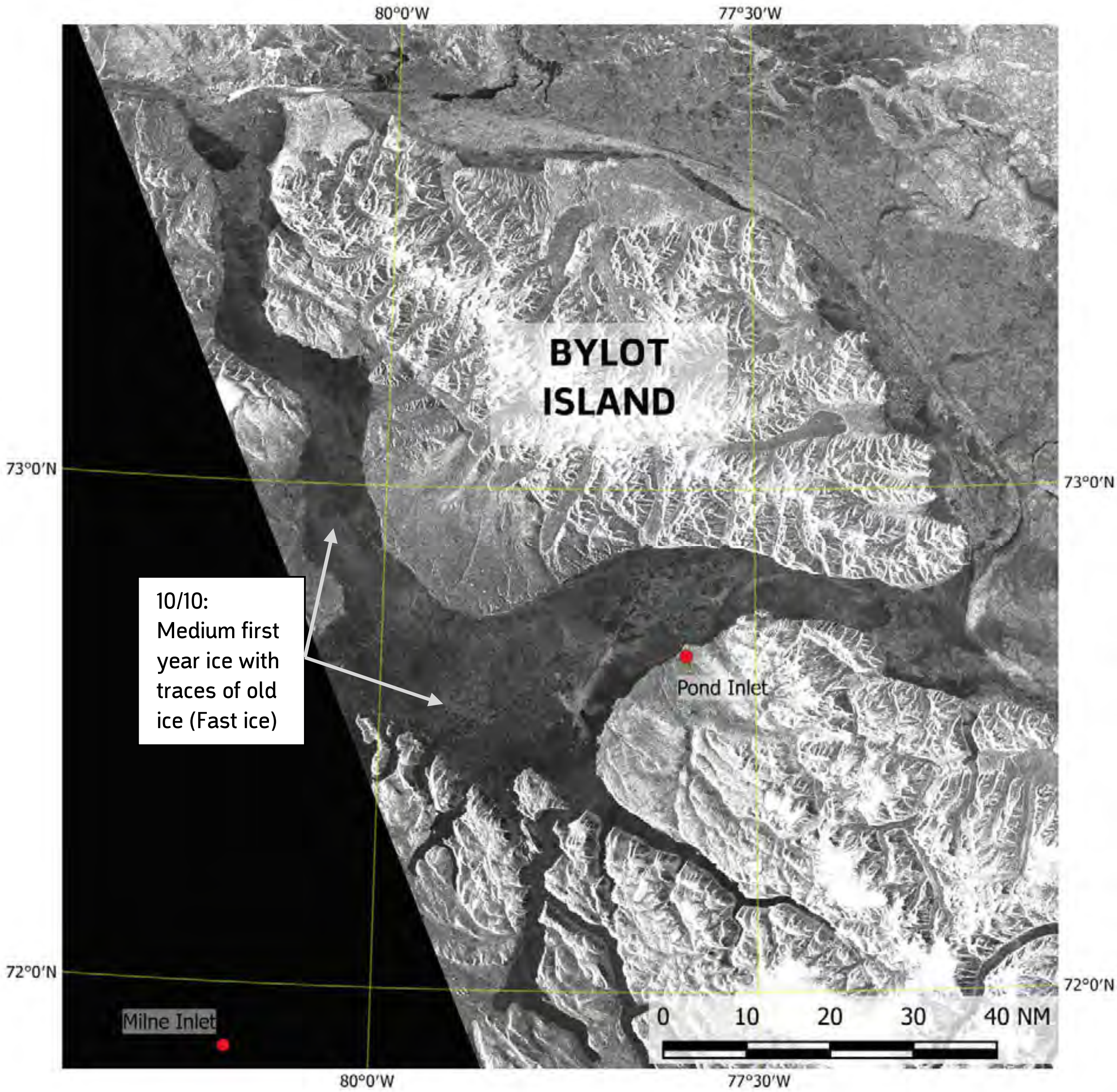


Figure 9 RADARSAT-1 Image acquired on January 29th, 2003 (Polar Data Catalogue).

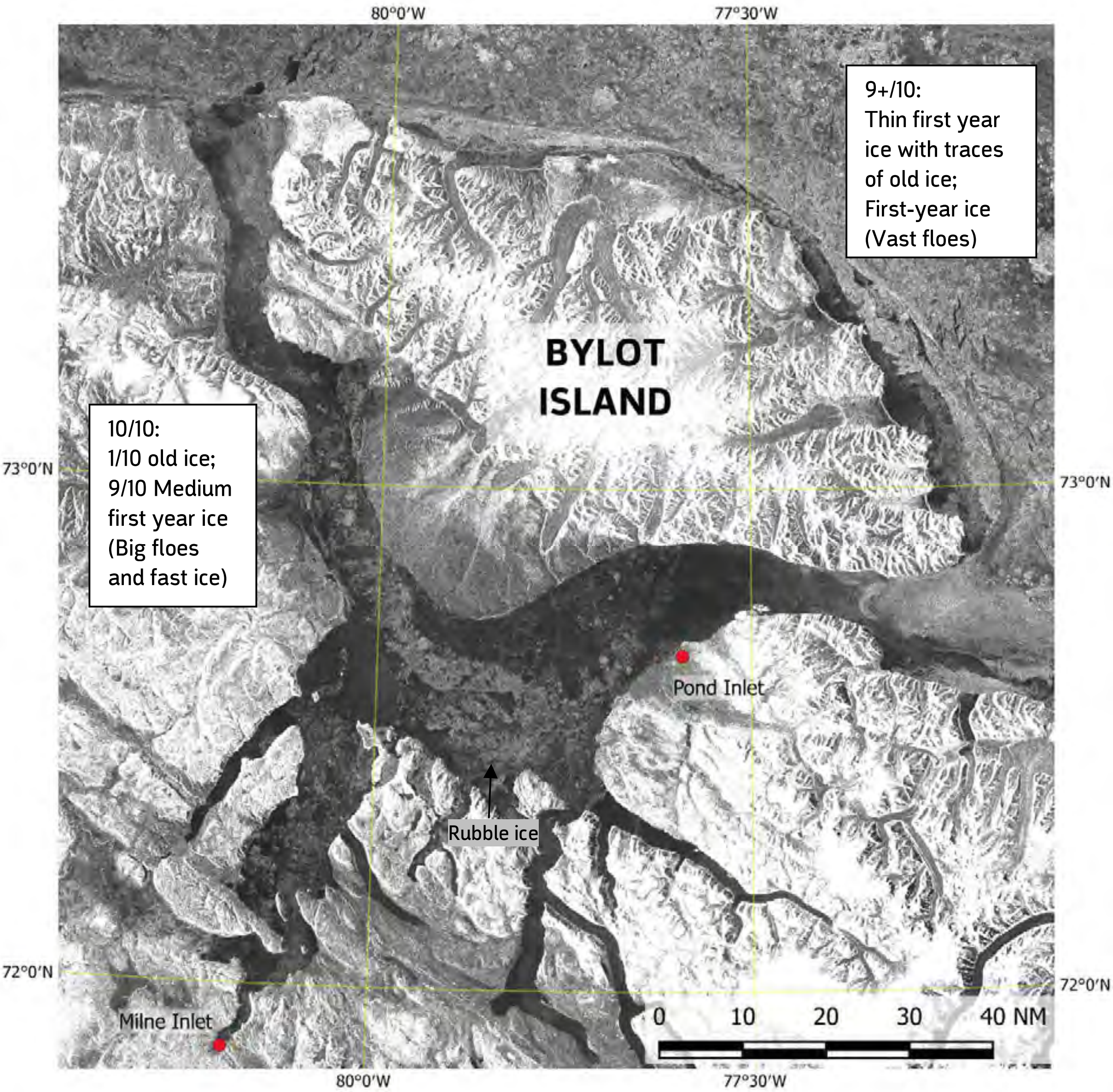


Figure 10 RADARSAT-1 Image acquired on January 26th, 2004 (Polar Data Catalogue).

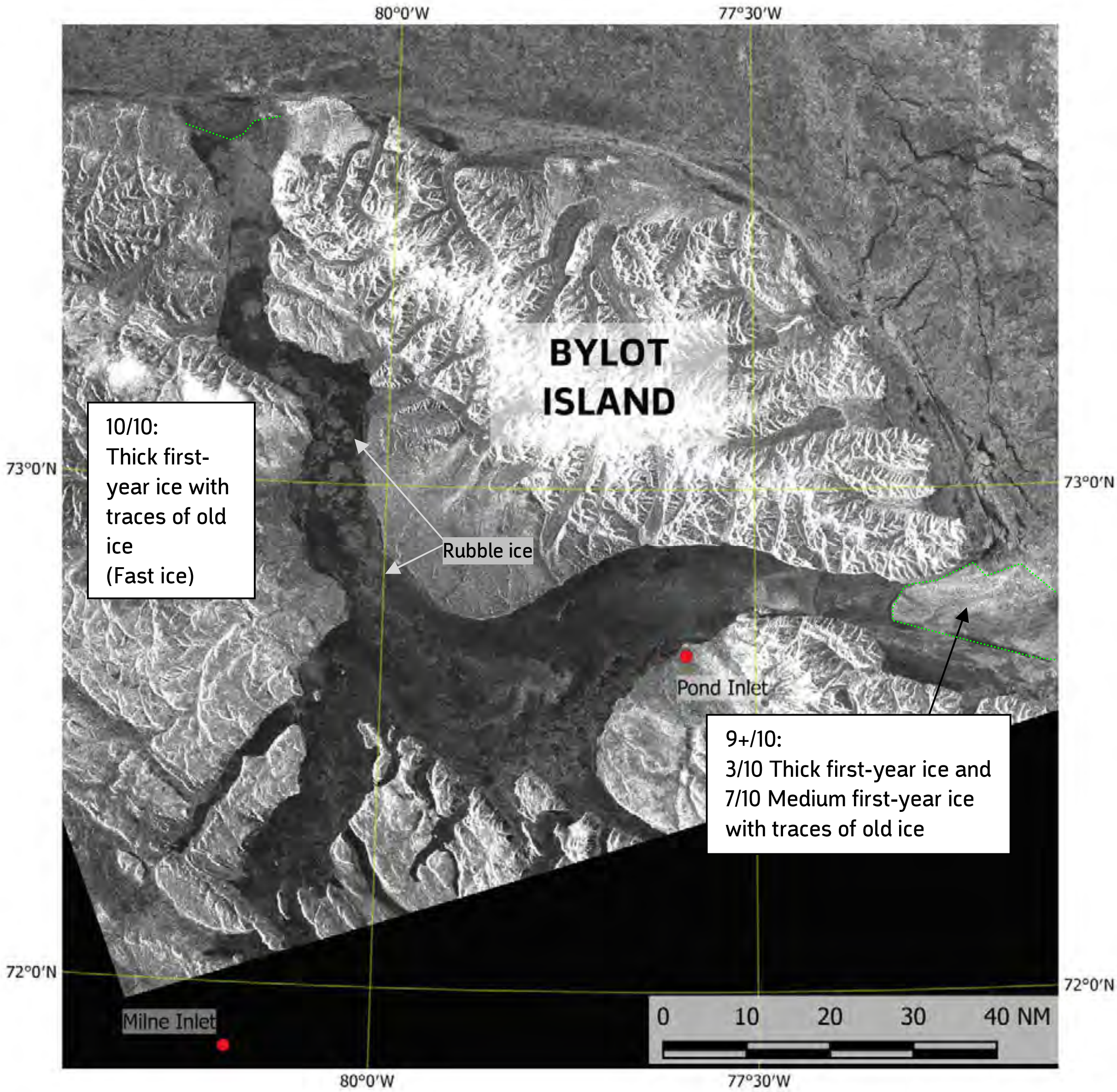


Figure 11 RADARSAT Image acquired on January 28th, 2005 (Polar Data Catalogue).

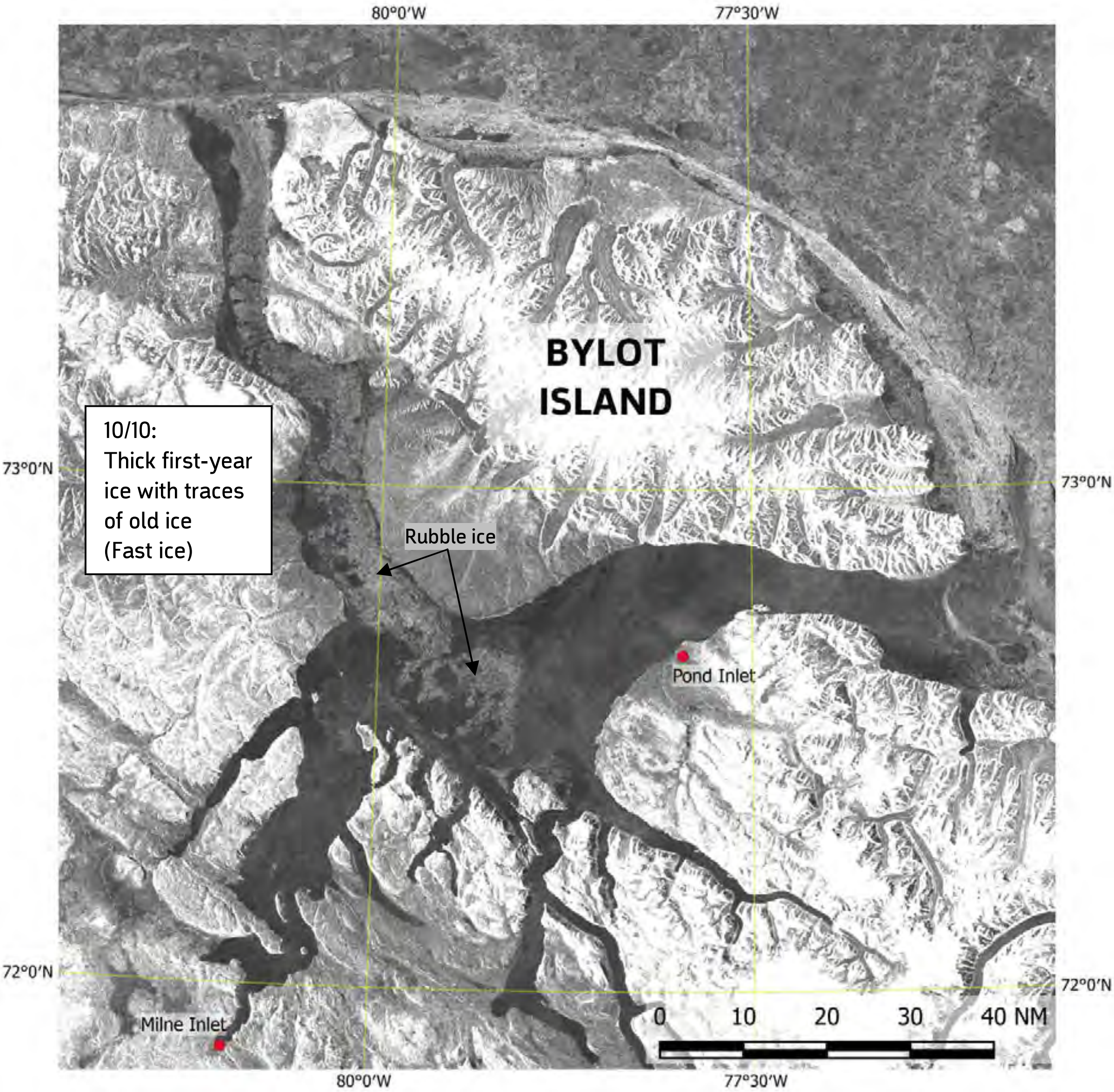


Figure 12 RADARSAT Image acquired on January 29th, 2006 (Polar Data Catalogue).

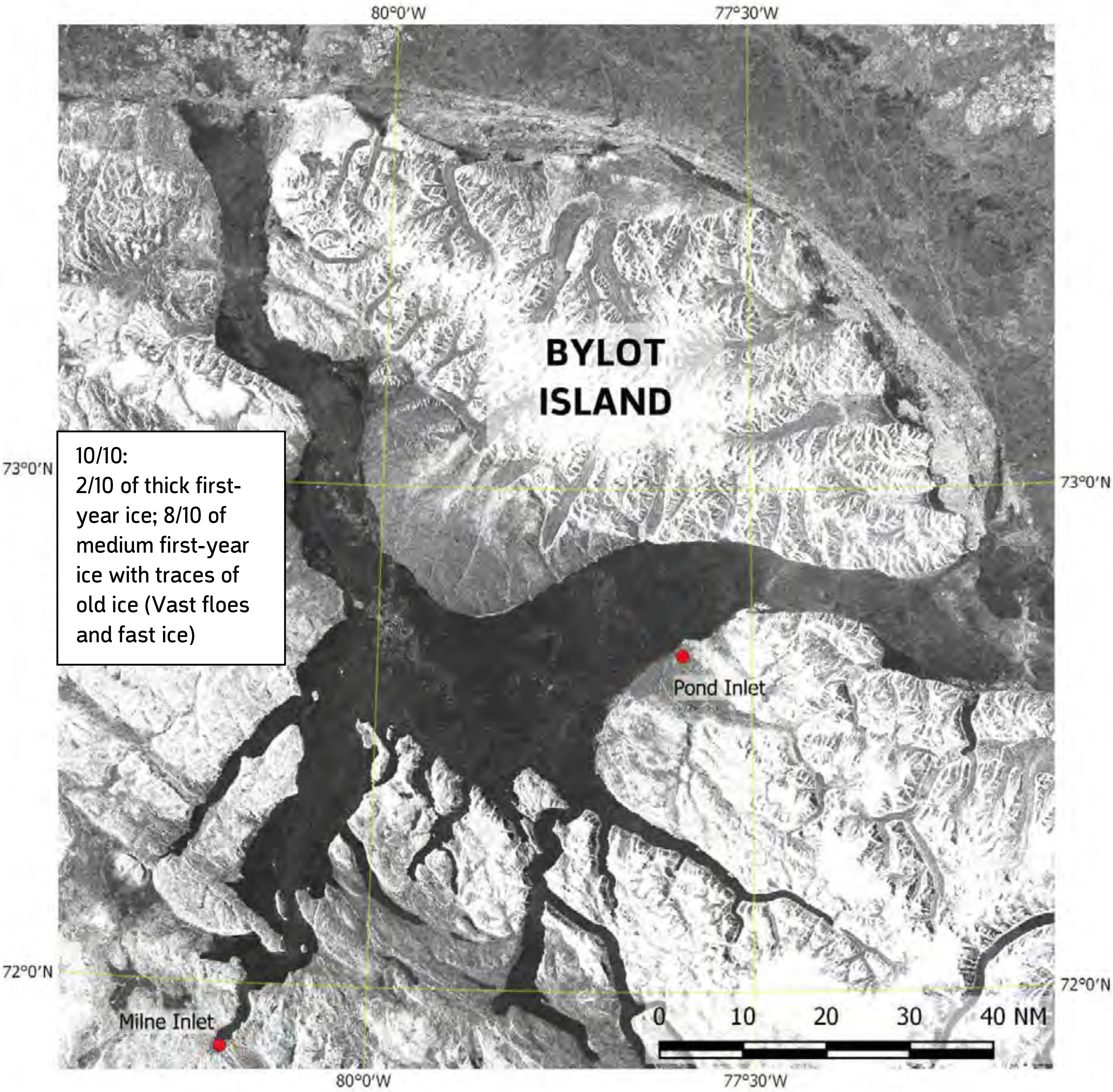


Figure 13 RADARSAT-1 Image acquired on January 19th, 2008 (image acquired by Enfotec).

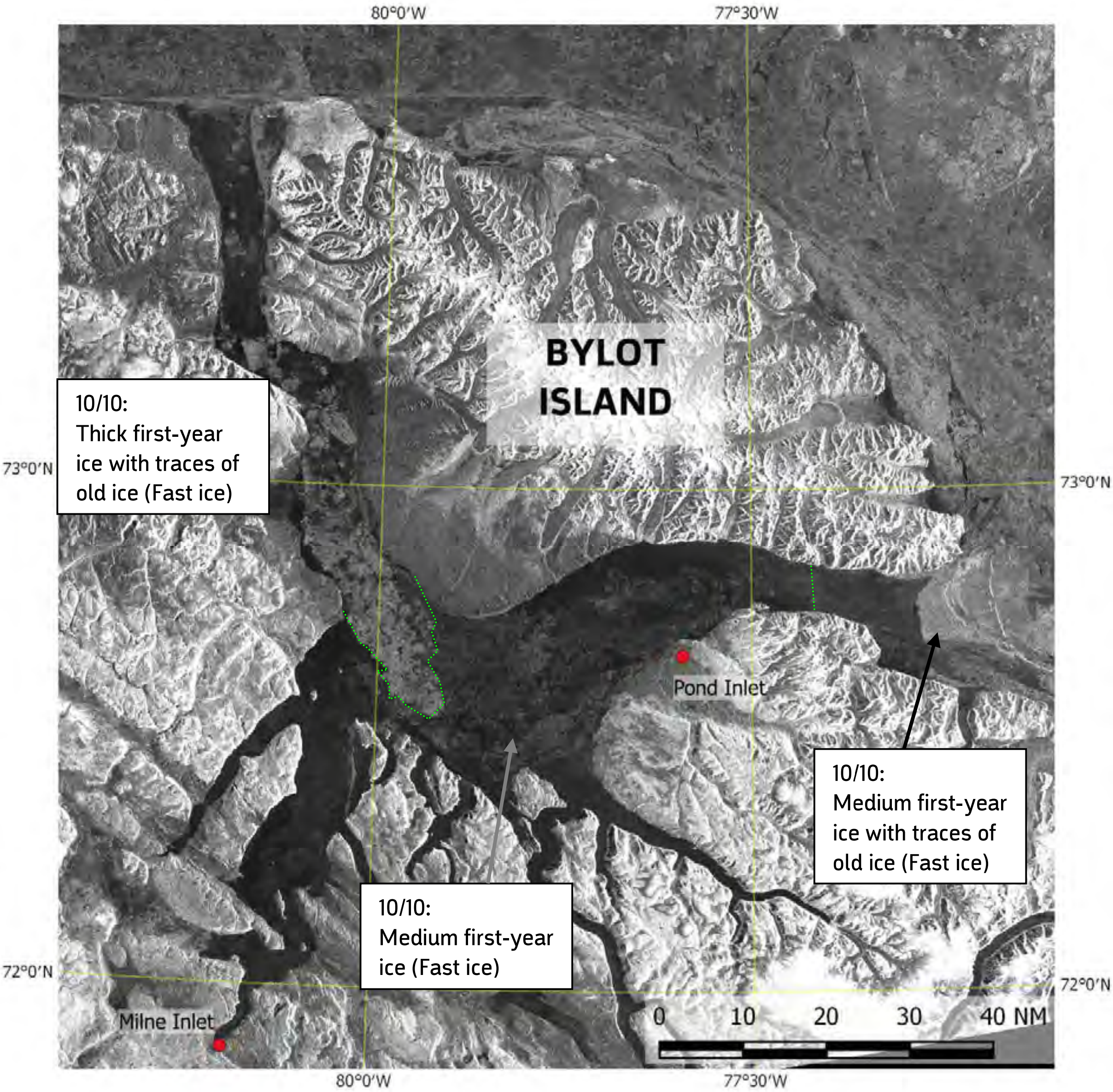


Figure 14 RADARSAT-2 Image acquired on January 30th, 2009 (image acquired by Enfotec).

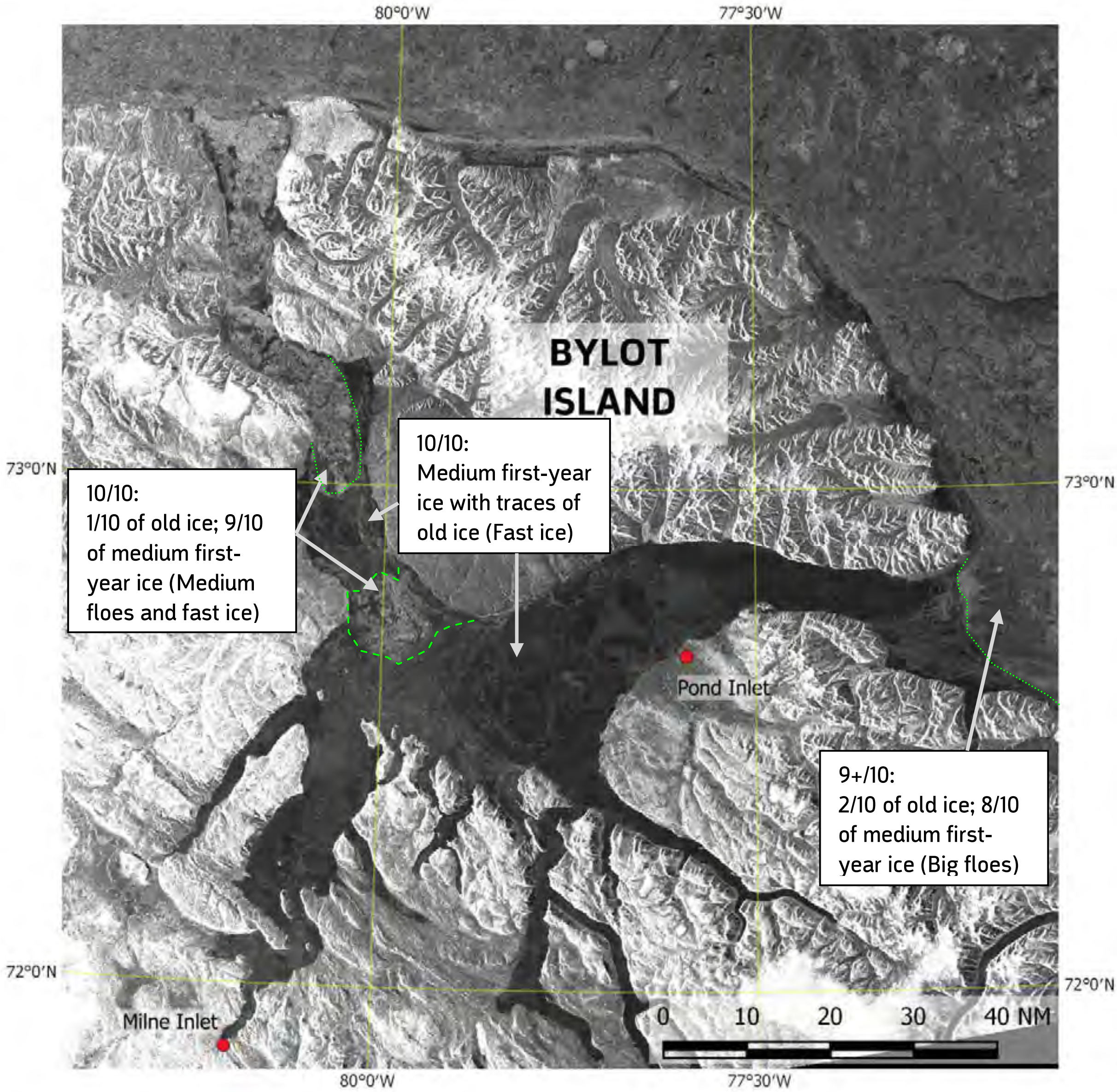


Figure 15 RADARSAT-2 Image acquired on January 31st, 2010 (image acquired by Enfotec)

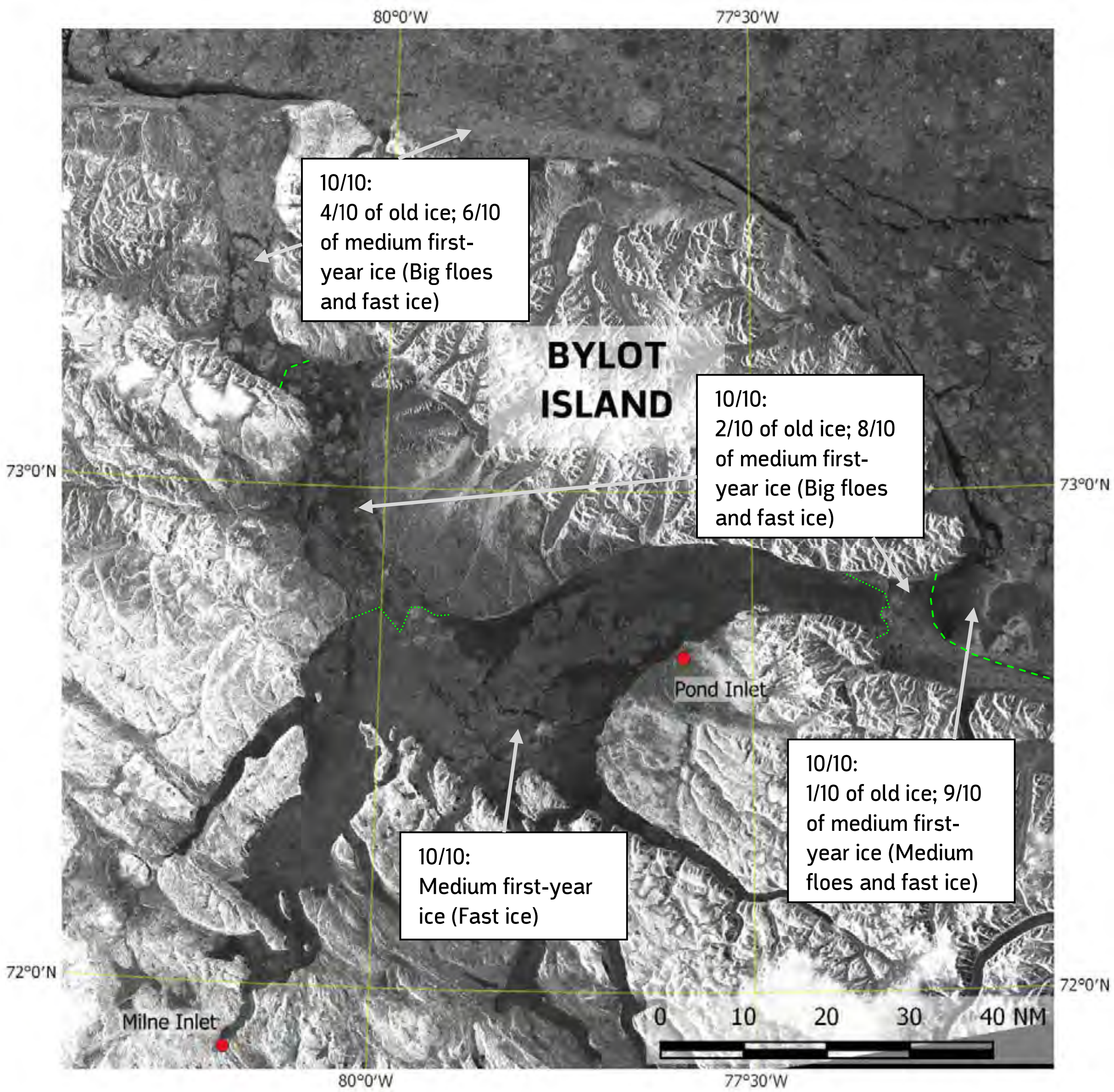


Figure 16 RADARSAT-2 Image acquired on January 15th, 2011 (image acquired by Enfotec).

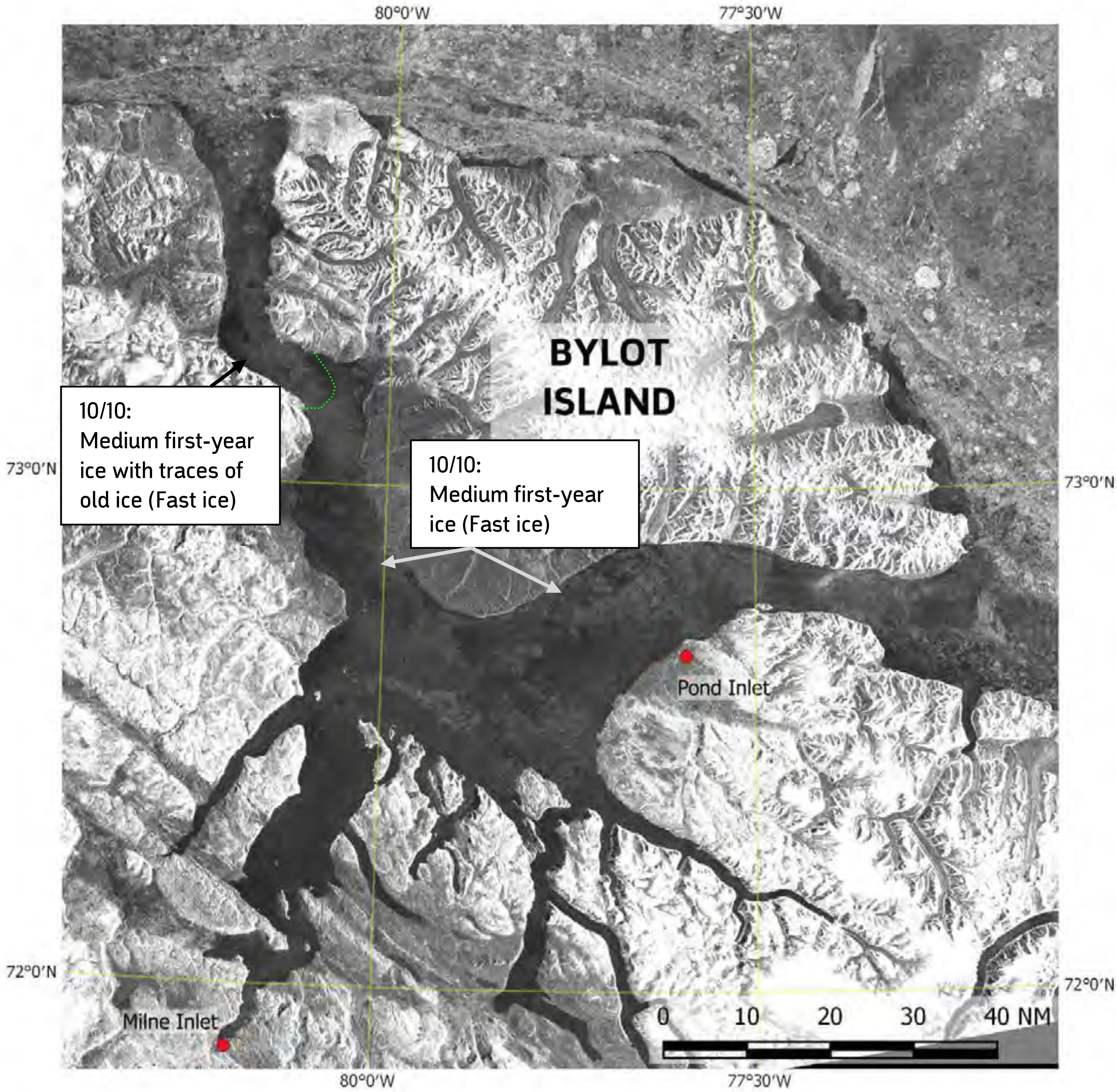


Figure 17 RADARSAT-2 Image acquired on January 15th, 2012 (image acquired by Enfotec).

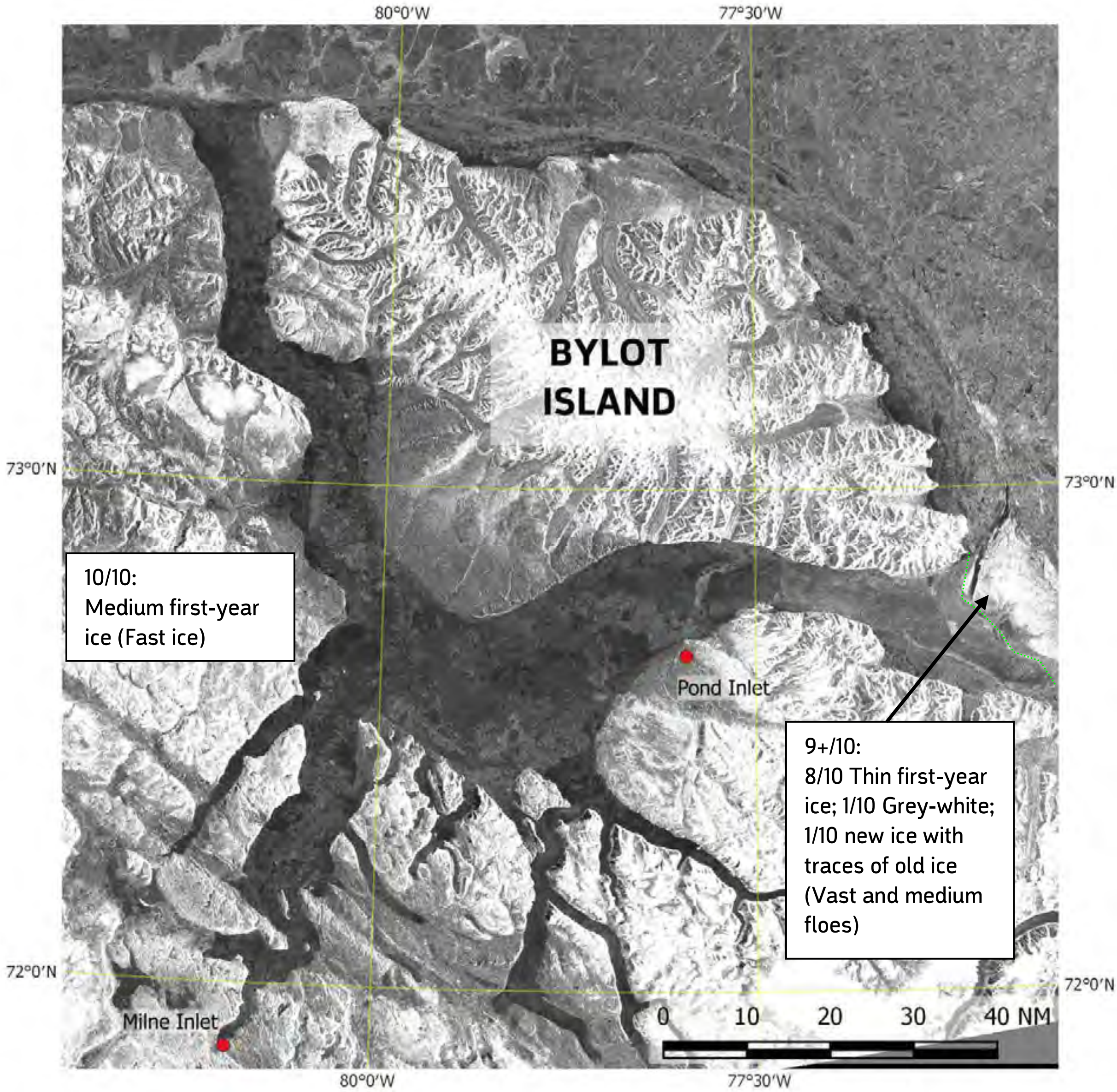


Figure 18 RADARSAT-2 Image acquired on January 19th, 2013 (image acquired by Enfotec).

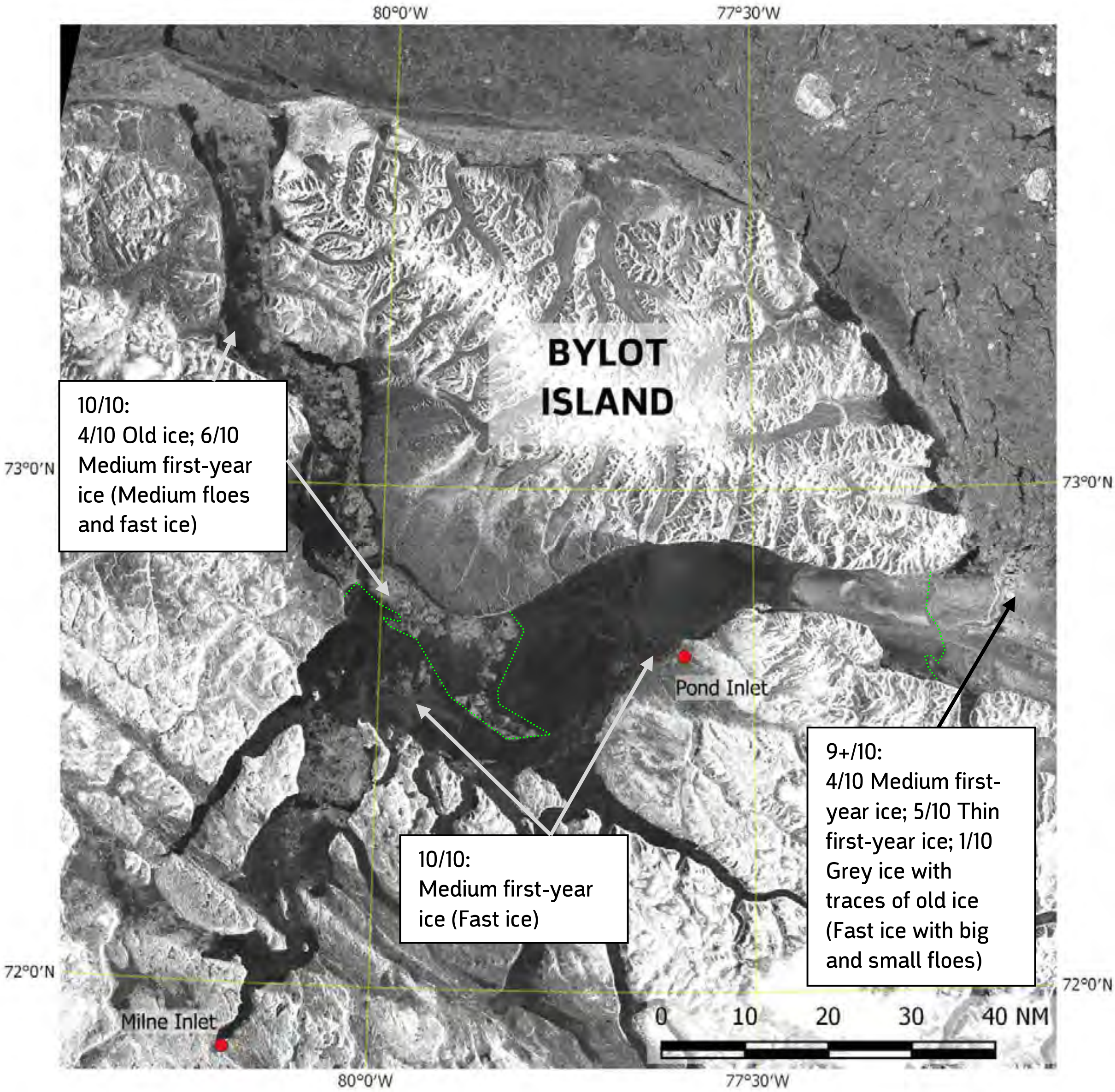


Figure 19 RADARSAT-2 Image acquired on January 11th 2014 (image acquired by Enfotec).

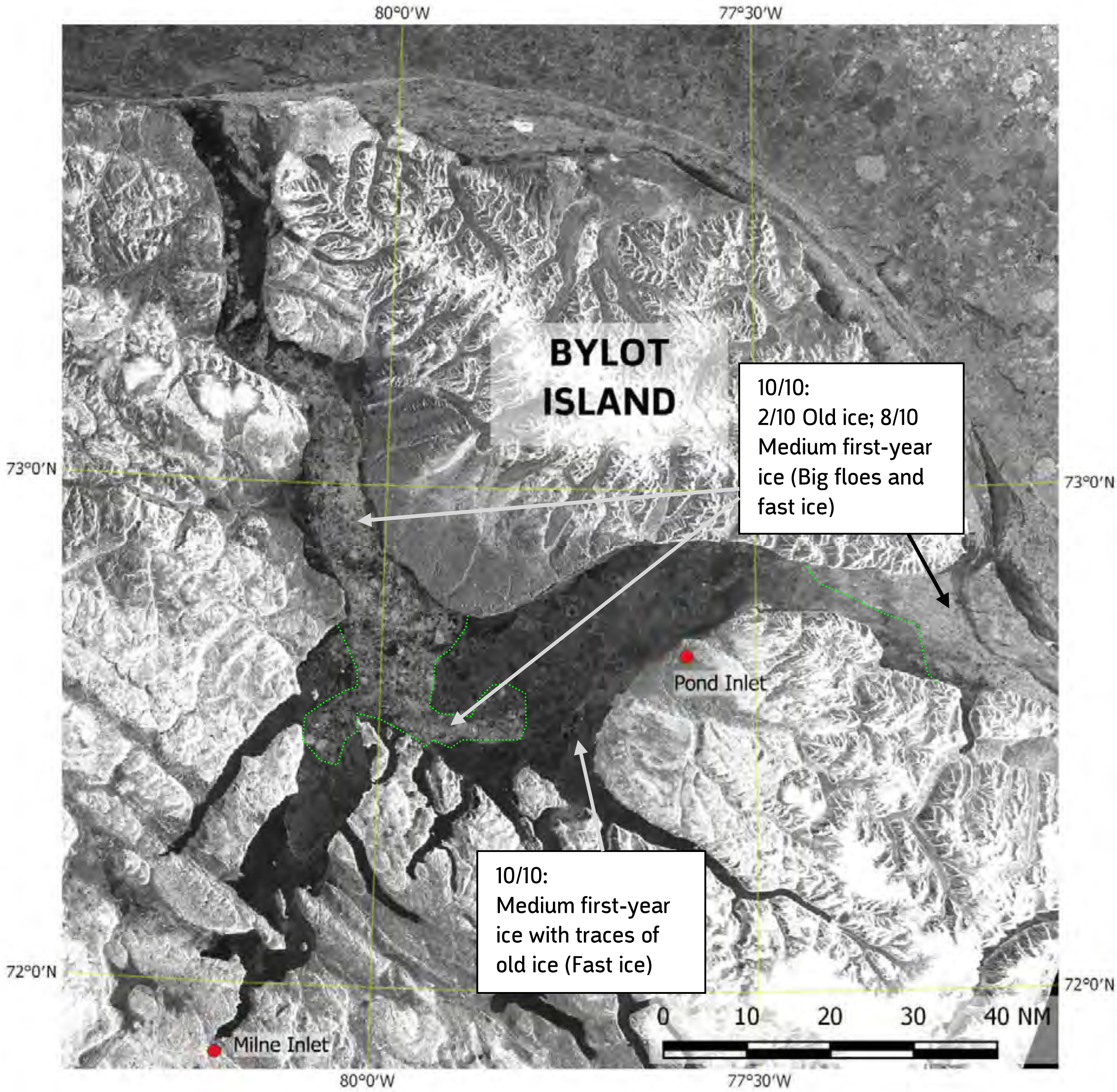


Figure 20 RADARSAT-2 Image acquired on January 24th, 2015 (image acquired by Enfotec).

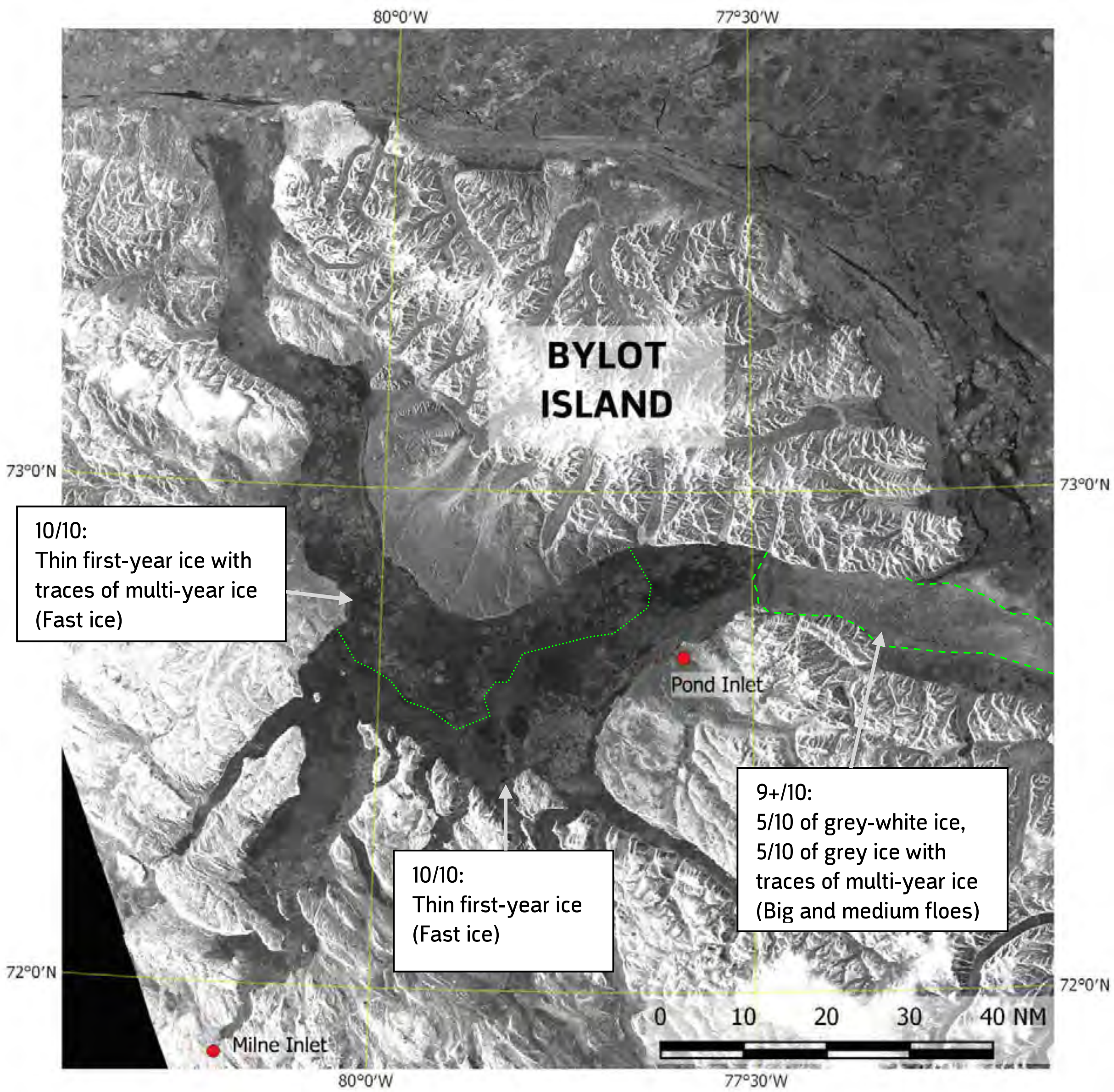


Figure 21 SENTINEL-1 Image acquired on December 7th, 2015 (Polar View).