TECHNICAL SUPPORTING DOCUMENT

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TSD 19

Fuel Spill Modelling Report





FUEL SPILL MODELLING TECHNICAL SUPPORTING DOCUMENT SUMMARY

The Fuel Spill Modelling Technical Supporting Document provides the results of a fuel spill modelling assessment for shipping activities along the Northern Shipping Route from Baffin Bay through Pond Inlet, Eclipse Sound, and Milne Inlet. This document is used as input to the assessment of effects on the marine environment.

Two spill scenarios are included that release 1 ML of intermediate fuel oil from an ore carrier at locations along the Northern Shipping Route. These include a mid-July sea ice break-up scenario in Eclipse Sound and a mid-October sea ice freeze-up scenario at the mouth of Milne Inlet. A spill distribution probability map for each spill scenario location is presented showing the probability that fuel would reach any particular location on the map, should a spill occur.

For the mid-July scenario at Eclipse Sound, the majority of the simulated trajectories reach shore. For these scenarios, ice temporarily keeps the fuel offshore and delays any drift to the shorelines. As the break-up season progresses, the spill trajectories spend increasingly more time in ice of lesser concentrations, approaching open water. For the mid-October scenario the number of trajectories reaching shore decreases steadily as freeze-up progresses. The ice keeps the fuel offshore and effectively traps the fuel in the ice as it freezes.

The spill modelling results highlight the importance of spill prevention and fuel spill response plan preparedness to minimize any adverse effects in the unlikely event of a fuel release of any size during vessel traffic into Milne Inlet.

RÉSUMÉ DU DOCUMENT D'ASSISTANCE TECHNIQUE SUR LA MODÉLISATION EN CAS DE DÉVERSEMENTS DE CARBURANT

Le document d'assistance technique sur la modélisation en cas de déversements de carburant comporte les résultats d'une évaluation de modélisation en cas de déversements de carburant dans le cadre des activités maritimes le long de la route maritime nord de la baie de Baffin jusqu'à Pond Inlet, Eclipse Sound et Milne Inlet. Ce document est utilisé pour l'évaluation des impacts sur le milieu marin.

Deux scénarios de déversement sont inclus et simulent la libération de 1 ML de mazout intermédiaire d'un transporteur de minerai à divers endroits le long de la route de navigation du Nord. Un de ces scénarios implique, notamment, une situation de désintégration de la glace de mer à la mi-juillet dans Eclipse Sound et une situation de gel de la glace de mer à la mi-octobre à l'embouchure de Milne Inlet. Une carte de probabilité de distribution des déversements pour chaque emplacement de scénario de déversement est présentée, montrant la probabilité que le carburant atteigne tout endroit donné sur la carte, dans l'éventualité d'un déversement.

Pour le scénario de la mi-juillet à Eclipse Sound, la majorité des trajectoires simulées atteignent la rive. Pour ces scénarios, la glace garde temporairement le combustible au large et retarde toute dérive vers les rivages. Au fur et à mesure que la saison de désintégration des glaces progresse, les trajectoires de déversement passent de plus en plus de temps dans une eau contenant moins de glaces et s'approchent de l'eau libre. Pour le scénario de la mi-octobre, le nombre de trajectoires atteignant le rivage diminue régulièrement à mesure que la prise des glaces progresse. La glace garde le carburant au large et emprisonne efficacement le carburant dans la glace lorsqu'elle gèle.

Les résultats de la modélisation en cas de déversements soulignent l'importance de la prévention des déversements et de la préparation du plan d'intervention en cas de déversement afin de minimiser les impacts négatifs dans le cas improbable d'un déversement de combustible de tout volume au cours d'une opération de transport maritime dans Milne Inlet.

ᐅᖅᓱᐊᓗᒃᓴᒥᒃ ᑯᕕᔪᑦ ᑕᐅᑐᙵᐊᕈᑎ ᐱᔭᕆᐊᑐᓯᑦ ᐃᑲᔪᐃᔾᔪᑎᑦ ᑎᑎᕋᖅᓯᒪᔪᑦ ᐅᓂᒃᑳᖏᑦ

ᐅᓇ ᐅᖅᓱᐊᓗᒃᓴᒥᒃ ᑯᕕᔪᑦ ᑕᐅᑐᙵᐊᕈᑎ ᐱᔭᕆᐊᑐᓯᑦ ᐃᑲᔪᐃᔪᑦ ᑎᑎᕋᖅᓯᒪᔪᖅ ᐱᑕᖃᖅᑎᑦᑎᕗᖅ ᓴᖅᑭᑕᐅᓂᑰᔪᓂᒃ ᖃᕆᓴᐅᔭᐅᑉ ᑕᐅᑐᙵᐊᕈᑖᑕ ᐅᖅᓱᐋᓗᒃᓴᒥᒃ ᑯᕕᔪᖃᕋᔭᕐᓂ ᕿᒥᕐᕈᓇᒍᑕᐅᓪᓗᓂ ᐅᒥᐊᕐᔪᐊᒃᑯᑦ ᐱᓕᕆᐊᖃᖅᑎᓪᓗᑎᑦ ᐅᔭᕋᖅᓂᐊᖅᑐᑦ ᐊᑐᖅᐳᑎᒃ ᐅᒥᐊᕐᔪᐊᕐᓂᒃ ᐃᙱᕋᔪᑦ ᐅᐊᙳᑦ ᐅᒥᐊᕐᔪᐊᑦ ᐊᖅᑯᑖᑦ ᕿᑭᖅᑖᓅᑉ ᐃᒪᕙᐊᓂᑦ ᐊᖅᑯᕕᖅᐳᒍ ᑐᖅᓯᒃᑕᒃ, ᑕᓯᐅᔭᖅ, ᑕᑲᓄᖓ ᕿᙳᐊᑕ ᑲᖏᖅᐳᐊᓄᑦ. ᐅᓇ ᑎᑎᕋᖅᓯᒪᔪᖅ ᐊᑐᖅᑕᐅᔪᖅ ᑐᓐᓂᖅᓴᐅᑉᐳᓂ ᕿᒥᕈᐃᓂᖏᓄᑦ ᐊᒃᑐᐃᓂᖃᕐᓂᖓᓄᑦ ᑕᑯᐅᑉ ᐊᕙᑎᐊᓄᑦ.

ᒪᕐᕈᒃ ᑯᕕᔪᓄᑦ ᑕᐅᑐᙵᐊᒫᒃ ᐃᓚᓕᐅᑎᔭᐅᓯᒪᕗᒃ ᑯᕕᔪᖃᑉᐳᑎᒃ 1 ᒥᓕᐊᓐ ᓖᑕᓂᒃ ᕿᑎᕋᖅᑐᒧᑦ ᐅᖅᓱᐋᓗᒃᓴᐅᑉ ᕿᓂᖅᑐᐊᓂᒃ ᓴᕙᕋᔭᒃᓴᒧᑦ ᐅᓯᒃᖃᑦᖃᑎᐅᑉ ᐅᒥᐊᕐᔪᐊᕌᓘᑉ ᓂᕈᐊᖅᑕᐅᔫᑉ ᐃᓂᕆᔭᕆᒍᑦ ᐊᑐᖅᑎᓪᓗᕆᑦ ᐅᐊᙳᑦ ᐅᒥᐊᕐᔪᐊᑦ ᐊᖅᑯᑖᓂᒃ. ᑖᒃᑯᐊ ᐱᕐᑲᓯᐅᔾᔾᓪᓗᑎᒃ ᔪᓚᐃᑉ ᕿᑎᓪᓗᐊᖓᒍᑦ ᑐᕙᐃᔭᕐᓂᕐᒥᒃ ᑕᐅᑐᙵᐊᕈᑎᒥᒃ ᑕᓯᐅᔭᕐᒥᑦ ᐊᒻᒪᑦᑕᐅᖅ ᐅᑐᐱᕆᐅᑉ ᕿᑎᓪᓗᐊᖓᒍᑦ ᓯᑯᕙᓪᓕᐊᓕᖅᑎᓪᓗᒍ ᑕᐅᑐᙵᐊᒐᖅ ᑕᑲᓇᓂ ᐹᖓᓂ ᕿᙳᐊᑕ ᑲᖏᖅᓱᐊᓂ. ᑯᕕᔭᐅᔪᖅ ᐃᖏᕋᕙᓪᓕᐊᓂᖓᓄᑦ ᖃᓅᓇᔭᑐᐃᓐᓇᑎᐊᖅᑲᕐᓂᖓᓄᑦ ᓄᓇᙳᐊᓕᐊᕆᓯᒪᔭᖅ ᐊᑐᓂᑦ ᑯᕕᔪᓄᑦ ᑕᐅᑐᙵᐊᒐᓄᑦ ᐃᓂᖓᓄᓪᓗ ᐅᓂᒃᑳᕆᔭᐅᓯᒪᕗᑦ ᓴᖅᑮᔭᖅᓗᓂ ᖃᓅᓇᔭᑐᐃᓐᓇᑎᐊᖅᑲᕐᓂᖓᓄᑦ ᐅᖅᓱᐋᓗᔅᓴᐅᑉ ᑎᑭᒃᑲᔭᕐᓂᕆᔭᖓ ᓇᓪᓕᐊᑐᐃᓐᓇᖅ ᐃᓂᐅᔪᖅ ᓄᓇᙳᐊᒥ, ᑯᕕᔪᖅᑲᕐᓂᕈᓂ.

ᑖᔅᓱᒧᖓ ᔪᓚᐃᑉ ᕿᑎᓪᓗᐊᖓᒍᑦ ᑕᐅᑐᙵᐊᒐᒧᑦ ᑕᓯᐅᔭᕐᒥ, ᐊᕆᓖᙳᔪᑦ ᑕᐅᑐᙵᐊᒐᓂᑦ ᐃᖏᕋᓂᕆᑦ ᓯᒃᔭᒧᑦ ᑎᑭᐅᑎᓇᔭᖅᐳᑎᒃ. ᑕᐅᑐᙵᐊᒐᕐᓄᑦ ᑖᒃᑯᓄᖓ, ᓯᑯᖅᑲᕐᓂᐊ ᐅᖅᓱᐊᓗᒃᓴᒥᒃ ᐃᒪᕐᑏᑎᑦᑎᑲᐃᓐᓇᖅᐳᓂ ᐃᕆᕋᔭᖅᓂᖓ ᐊᔭᕆᑲᐃᓐᓇᖅᓯᒪᓪᓗᒍ ᑎᑭᓐᓂᐊ ᓯᒡᔭᕆᓄᑦ. ᑕᐃᒪᓕ ᓯᑯᐃᔭᖅᐸᓪᓕᐊᑎᓪᓗᒍ, ᑕᒪᒃᑯᐊ ᑯᕕᓂᐅᑉ ᐃᕆᕋᔭᖅᓂᕆᑦ ᓯᑯᖅᑲᕐᓂᕐᒦᕆᓐᓇᖅᐳᑎᒃ ᓄᕗᑉᐸᓪᓕᐊᔪᓂᒃ, ᑲᑎᙳᐃᓐᓇᖅᐳᑎᒃ, ᐊᐅᔭᕈᕋᓯᖅᓂᐊᓄᑦ. ᑕᐃᒪᓕ ᑕᒪᑐᒨᖓ ᐅᑐᐱᕆᐅᑉ ᕿᑎᓪᓗᐊᖓᒍᑦ ᑕᐅᑐᙵᐊᒐᕐᒧᑦ ᐅᓄᕐᓂᕆᑦ ᐃᕆᕋᓂᕐᓂᐊᓄᑦ ᑎᑭᐅᑎᔪᑦ ᓯᒃᔭᖓᓄᑦ ᑲᑦᑉᐸᓪᓕᐊᕆᓇᖅᐳᑎᒃ ᓯᑯᕙᓪᓕᐊᓂᖓ ᒪᓕᒃᐳᒍ ᑯᕝᕙᐅᔫ. ᓯᑯᖓ ᐅᖅᓱᐊᓗᒃᓴᖓᓂᒃ ᐃᓖᓃᕆᓐᓇᖅᑎᑦᑎᓲᖅ ᐊᒻᒪᓗ ᐊᕙᓗᓪᓗᒍ ᕿᓂᖅᑐᖓ ᓯᑯᕙᓪᓕᐊᔫᑉ ᕿᑎᖓᒍᑦ ᖁᐊᖅᐸᓪᓕᐊᑎᓪᓗᒍ.

ᑯᕕᔪᑦ ᖃᓇᓴᐅᔭᒃᑯᑦ ᑕᐅᑐᙵᐊᕈᑖᑕ ᓴᖅᑭᑎᖅᑕᖅᑭᑦ ᓲᕐᓗ ᓇᓗᓇᐃᕆᕗᖅ ᐊᑑᑎᖃᓪᓕᕆᖅᓂᐊᑕ ᑯᑦᑕᐃᓕᒪᑎᑦᑎᓂᐅᑉ ᐊᑐᒐᒃᓴᖅᑭᓐᓂᒃ ᐊᒻᒪᑦᑕᐅᖅ ᑯᕕᔪᑦ ᐅᖅᓱᐊᓗᒃᓱᑦ ᑲᒪᕆᔭᖃᑖᓄᑦ ᐸᕐᓈᖑᓯᒪᔪᓂᒃ ᐊᒃᐸᓯᒡᔫᒥᖁᓪᓗᒍ ᐱᐅᕆᑦᑐᒥᒃ ᐊᒃᑐᐃᓂᖃᕐᓂᖅᑭᑦ ᑕᒪᓐᓇ ᑕᑯᔪᒥᓇᕆᑦᑑᒐᓗᐊᖅ ᑕᐃᒪᐃᑳᓪᓚᓐᓂᕈᓂ ᐅᖅᓱᐋᓗᒃᓴᖅ ᑯᕕᔭᐅᓗᓂᒃ ᐃᕆᕋᔭᖃᑦᑕᕐᓂᕆᒍᑦ ᐅᒥᐊᕐᔪᐊᑦ ᑕᑉᐱᑯᖓ ᕿᙳᐊᑕ ᑲᖏᖅᓱᐊᓄᑦ.

FINAL

BAFFINLAND IRON MINES CORPORATION MARY RIVER PROJECT - PHASE 2 PROPOSAL

Technical Supporting Document No.19

Fuel Spill Modelling: Northern Shipping Route Sea Ice Shoulder Seasons

Milne Inlet, Eclipse Sound, Pond Inlet

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IMPORTANT NOTICE

This report was prepared exclusively for Baffinland Iron Mines Corporation by Amec Foster Wheeler Environment & Infrastructure, a Division of Amec Foster Wheeler Americas Limited (Amec Foster Wheeler). The quality of information, conclusions and estimates contained herein is consistent with the level of effort involved in Amec Foster Wheeler's services and based on: i) information available at the time of preparation, ii) data supplied by outside sources and iii) the assumptions, conditions and qualifications set forth in this report. This report is intended to be used by Baffinland Iron Mines Corporation only, subject to the terms and conditions of its contract with Amec Foster Wheeler. Any other use of, or reliance on, this report by any third party is at that party's sole risk.

EXECUTIVE SUMMARY

Under contract to Baffinland Iron Mines Corporation (Baffinland), Amec Foster Wheeler Environment & Infrastructure, a Division of Amec Foster Wheeler Americas Limited (Amec Foster Wheeler), has completed a sea ice shoulder seasons water fuel spill modelling assessment in support of the Mary River Project's Phase 2 Proposal. The setting of the fuel spill modelling assessment is Baffinland's port at Milne Inlet, Nunavut.

This follows on a previously undertaken open water fuel spill modelling assessment completed to address the Nunavut Impact Review Board (NIRB) requirements for the Mary River Project's Early Revenue Phase (Amec Foster Wheeler, 2015).

The purpose of fuel spill trajectory modelling is to inform spill response. Specific information sought for spill response agencies and other stakeholders includes estimation of the marine and any shoreline areas potentially affected together with the initial weathering fate of the spilled fuel.

As part of the Phase 2 Proposal, two fuels will be transported along "the Northern Shipping Route" from Baffin Bay through Pond Inlet, Eclipse Sound, and Milne Inlet to the port site at the head of Milne Inlet. Arctic diesel will be shipped by fuel tanker and unloaded by means of flexible hoses to shore; intermediate fuel oil (IFO) will be carried for powering of the ore carriers.

Shipping is expected to occur during the open water season, from approximately mid-July to mid-October, and not commence until the sea ice has retreated and melted from the shipping route. Nevertheless, the potential exists for some sea ice presence during the shoulder seasons, and so two spill-in-ice scenarios have been identified – near the times of break-up and freeze-up – to further inform spill response preparedness efforts. This report presents the results of this fuel spill modelling effort.

Based on the timing of sea ice break-up, the period around mid-late July and at a location along the shipping route in Eclipse Sound has been selected for the first scenario. At the end of the open water season, for freeze-up, the early-mid October period is reasonable to capture times when the ice is forming and closing the shipping route into Milne Inlet, and for which fuel might possibly enter into the new ice; a location at the mouth of Milne Inlet is selected for this second scenario.

Both scenarios consider a hypothetical release of 1 ML of IFO fuel from an ore carrier; the modelling is completed using the Amec Foster Wheeler software, OST. OST computes spill probability distributions to indicate geographical regions (e.g., Pond Inlet, Eclipse Sound, Navy Board Inlet and Milne Inlet) which might be affected as a result of a spill, how frequently and how soon. The spill modelling scenarios completed in this study assume no intervention, response or containment efforts.

Wind, ocean tide and current, and sea temperature which might affect the trajectory and fate of a fuel spill, were assessed for use in the spill models. Winds for input to the spill models were selected following comparison of a number of sources. These included: the meteorological station at Milne Port, Environment Canada's climate station at Pond Inlet, Meteorological Service of Canada (MSC) North

Atlantic wind and wave hindcast winds in Baffin Bay just east of the entrance to Pond Inlet, and reanalysis winds from the European Centre for Medium-Range Weather Forecasts (ECMWF), ERA Interim (ERAI) class, Atmospheric Model gridded over the study area. While the ERAI wind speeds were judged to be a bit low compared to measurements from the Milne camp site, and at times, also at Pond Inlet, they provide a long 30 year time series record over the entire study area and were selected to provide reasonable wind inputs for the spill model.

The high resolution HYbrid Coordinate Ocean Model (HYCOM) ocean circulation model was used to derive both a grid of July and October mean near-surface ocean currents, and an estimate of sea water temperature. July and October current speeds average about 13 cm/s with maximum speeds of up to about 85 to 90 cm/s (1.65 to 1.75 knots). Mean sea surface temperatures are about 3°C in July and about -0.6°C in October.

Weekly regional ice charts from the Canadian Ice Service are employed to characterize the sea ice concentrations and types (thicknesses) of ice encountered. Advection of a spill in the presence of ice is determined from the ice concentration at that location. For ice concentrations ≤ 3/10 the drift is modelled as if in open water (as a function of wind and current); for ice concentrations > 6/10, the fuel spill drift is modelled as the ice drift velocity; and for ice concentrations between 4/10 and 6/10 a weighted average of the open water and ice drift velocities is used.

For both of spill scenario locations, the OST spill model predicts the path of all possible trajectories for each day in the break-up or freeze-up period selected for each of 14 years, 2000-2013. Trajectories are followed until they reach shore, the fuel weathers below 5%, or the trajectory reaches a boundary of the spill model domain. The location, time to shore and amount of fuel loss for each trajectory is logged, from which overall statistics of the percent trajectories ashore, the time to shore, and amount of weathering can be tabulated; these statistics are derived for each of 13 geographical regions defined to cover the spill model domain.

A spill probability map for each spill scenario locations is presented showing the probability that fuel would reach any particular location on the map. Shoreline region statistics are included that report percent of trajectories ashore, and minimum, mean and maximum times to shore.

For the mid-July scenarios at Eclipse Sound, 99% of the 294 simulated trajectories reach shore. The greatest percentage of trajectories reach shore at Eclipse Sound Southwest (46%) and Bylot Island South (26%) in times that are as short as 34 and 8 hours respectively. The mean times to shore range from 56 and 83 hours for Dufour Point and Bylot Island South to the north, to over 10 days for Pond Inlet. It is often the case that the fuel will need to wait for the ice to melt or retreat from the spill's path. In this way, the resultant times to shore are in general increased for the ice scenario as opposed to a no ice simulation (for which results are similarly presented). The effect of the ice for the mid-July break-up scenarios is to keep the fuel offshore and delay any drift to one of the shorelines. As the break-up season progresses, the spill trajectories spend increasingly more time in ice of lesser concentrations, approaching open water.

The effect of ice for the mid-October scenarios is to keep the fuel offshore and delay any drift to one of the shorelines and in practice, effectively trap the fuel in the ice as it freezes. The spill trajectories spend increasingly less time in ice of lesser concentrations as the freeze-up progresses. Unlike in mid-July, when trajectories eventually reach shore, for the freeze-up in October there can be numerous days where ice conditions prevent the spill from reaching shore; and with the onset of winter, the fuel is trapped in the ice. The number of trajectories reaching shore decreases steadily as the freeze-up progresses. At the beginning of the modelled freeze-up on 5 October all but one (in 2003) of the simulations reaches shore. By 25 October the converse is true: just one of the simulations (in 2011) reaches shore.

It is particularly relevant to note that since any given ice year is likely somewhat different it will be the actual conditions encountered that year, and that time in the October freeze-up that will determine the outcome. For the 294 freeze-up scenarios 41% of the trajectories do not reach shore. There is noticeable variability year by year: In 2003, due to an early freeze-up, none of the trajectories reach shore – the fuel being trapped in ice at the spill location. In the low ice year 2011, all of the 21 (5-25 October) trajectories reach shore.

For the spill in ice simulations, 59% of the trajectories reach shore (all trajectories reach shore in the no ice case). Only three regions see first shoreline contact: Tremblay Sound (28% of the time), Eclipse Sound Southwest (19%) and Lavoie Point (13%). This is due to their close proximity to the spill site at the Mouth of the Milne Inlet. These are the same regions reached in the no ice simulations. There is 1% to the head of Milne Inlet with no ice, and under ice conditions no trajectories reach that region. Mean times to shore are on the order of 38 to 45 h, as soon as 6 h (for Tremblay Sound and Eclipse Sound Southwest), and as long as just over 10 days for Tremblay Sound.

The spill modelling results highlight the importance of spill prevention and fuel spill response plan preparedness to minimize any adverse effects in the unlikely event of a fuel release of any size during vessel traffic into Milne Inlet.

TABLE OF CONTENTS

EXECUTIVE SUMMARY ... 3

1.0 INTRODUCTION ... 9
- 1.1 Objectives ... 9
- 1.2 Background ... 9
- 1.3 Spill Scenario Selection ... 13
- 1.4 Report Structure ... 14

2.0 SEA ICE CONDITIONS ... 16
- 2.1 Sea Ice Climatic Atlas, Eastern Arctic ... 16
- 2.2 Ice Conditions as Input to Fuel Spill Modelling ... 16
  - 2.2.1 Import of CIS Weekly Ice Charts for OST ... 16
  - 2.2.2 Selection of Ice Years for Spill Modelling ... 17
- 2.3 Ice Conditions, Northern Shipping Route ... 22
  - 2.3.1 Selection of Ice Weeks for Spill Modelling ... 28

3.0 SPILL TRAJECTORY MODELLING: OST ... 33
- 3.1 Model Setup ... 33
  - 3.1.1 Model Theory Overview ... 33
  - 3.1.2 Model Geometry ... 34
  - 3.1.3 Transport (Advection) ... 36
  - 3.1.4 Weathering ... 38
- 3.2 Model Input ... 44
  - 3.2.1 Wind ... 44
  - 3.2.2 Ocean Currents ... 48
- 3.3 Model Output ... 52
  - 3.3.1 Individual Day Spill Trajectory Plots ... 52
  - 3.3.2 Shoreline Zone Definitions ... 52
  - 3.3.1 Composite Fuel Distribution Probability Maps ... 54
  - 3.3.2 Presentation and Interpretation of Results ... 54

4.0 RESULTS, MID-JULY, ECLIPSE SOUND ... 56
- 4.1 Shoreline Statistics ... 64

5.0 RESULTS, MID-OCTOBER, MILNE INLET: MOUTH ... 68
- 5.1 Shoreline Statistics ... 72

6.0 CLOSURE ... 78

7.0 REFERENCES ... 79

LIST OF TABLES

Table 1-1: Spill Scenario Locations ... 13
Table 2-1: Weekly Ice Concentration, MR1 Milne Inlet: Bruce Head, 2000-2014 ... 24
Table 2-2: Weekly Ice Concentration, MR2 Milne Inlet: Mouth, 2000-2014 ... 25
Table 2-3: Weekly Ice Concentration, MR3 Eclipse Sound, 2000-2014 ... 26
Table 2-4: Weekly Ice Concentration, MR4 Pond Inlet: West, 2000-2014 ... 27
Table 2-5: Weekly Ice Concentration, MR5 Pond Inlet: East, 2000-2014 ... 28
Table 3-1: OST Spill Model Grid Setup ... 35

Table 3-2: IFO 180 Weathering: Evaporation Loss as a Function of Wind Speed 44
Table 3-3: IFO 180 Weathering: Water Column Loss as a Function of Wind Speed 44
Table 4-1: Eclipse Sound, mid-July Break-up, Scenario Dates 22 Jul, 1 Aug 2004, Trajectory Statistics59
Table 4-2: Eclipse Sound, mid-July Break-up, Scenario Dates 30 July 2005, 2008, Trajectory Statistics62
Table 4-3: Eclipse Sound, mid-July, Earliest, Latest and Mean Times to Shore 67
Table 5-1: Milne Inlet: Mouth, mid-October, Earliest, Latest and Mean Times to Shore 76

LIST OF FIGURES

Figure 1-1: Environmental Processes that affect oil behaviour and weathering in open water and in ice. (Source: from NRC 2014, modified from Daling et al. 1990 and A. Allen)...............................11
Figure 1-2: Spill Scenario Locations 14
Figure 2-1: Arctic Sea Ice Extents since 1979 compared to 1979-2000 Average 18
Figure 2-2: Weekly Ice Chart, Eastern Arctic, 22 July 2013..19
Figure 2-3: Ice Concentration, Week of 22 July 2013, Pond Inlet..20
Figure 2-4: Ice Concentration, Week of 29 July 2013, Pond Inlet..21
Figure 2-5: Ice Concentration, Week of 05 August 2013, Pond Inlet..21
Figure 2-6: Weekly Mean Ice Concentration, Northern Shipping Route 23
Figure 2-7: Weekly Maximum Ice Concentration, Northern Shipping Route...23
Figure 2-8 Mean and Maximum Weekly Ice Concentration, MR1 Milne Inlet: Bruce Head 24
Figure 2-9 Mean and Maximum Weekly Ice Concentration, MR2 Milne Inlet: Mouth 25
Figure 2-10 Mean and Maximum Weekly Ice Concentration, MR3 Eclipse Sound...................................26
Figure 2-11: Mean and Maximum Weekly Ice Concentration, MR4 Pond Inlet: West 27
Figure 2-12 Mean and Maximum Weekly Ice Concentration, MR5 Pond Inlet: East 28
Figure 2-13 Weekly Ice Concentration, 16 July to 6 August, 2000 to 2014, MR3 Eclipse Sound 30
Figure 2-14 Weekly Ice Concentration, 1 to 29 October, 2000 to 2014, MR2 Milne Inlet: Mouth...............31
Figure 2-15 Interpolated Daily Ice Concentration, MR3 Eclipse Sound, 2000-2014..................................32
Figure 2-16 Interpolated Daily Ice Concentration, MR2 Milne Inlet: Mouth, 2000-2014 32
Figure 3-1: OST Spill Model Grid 36
Figure 3-2: Intermediate Fuel Oil 180 Physical Parameters (Source: ASA Updated Oil Database, OILMAP v 6.10.2.0) 39
Figure 3-3: IFO 180 Weathering: Evaporation Loss as a Function of Sea Temperature (Source: OILMAP)41
Figure 3-4: Sea Temperature, September (Source: HYCOM) 42
Figure 3-5: IFO 180 Weathering: Evaporation Loss as a Function of Wind Speed (Source: OILMAP).....43
Figure 3-6: IFO 180 Weathering: Water Column Loss as a Function of Wind Speed (Source: OILMAP) .43
Figure 3-7: Wind Comparison, July 2007 45
Figure 3-8: Wind Comparison, October 2007...46
Figure 3-9: Wind Roses, July and October, 1984-2013 47
Figure 3-10:Wind Data Source Locations (ERAI grid points denoted with blue squares)..........................48
Figure 3-11:Current Speed, July to October, Northern Shipping Route..49
Figure 3-12:Milne Inlet, HYCOM Surface Mean Currents, July..50
Figure 3-13:Milne Inlet, HYCOM Surface Mean Currents, October 51
Figure 3-14:Definition of Geographical Regions for Interpretation of Shoreline Statistics 53
Figure 4-1: Spill Distribution Probability Plot, Eclipse Sound, mid-July, no Ice..56
Figure 4-2: Spill Distribution Probability Plot, Eclipse Sound, mid-July, Ice...57
Figure 4-3: Eclipse Sound, 20 July to 9 August, 2004, Spill Trajectories for No Ice and Ice Scenarios.....58

Figure 4-4: Eclipse Sound, Weekly Ice Chart Excerpts, 19 July to 9 August, 2004....58
Figure 4-5: Eclipse Sound, Spill Displacement due to Wind and Ice Concentration, 1 August 2004....60
Figure 4-6: Eclipse Sound, 30 July, 2000-2013, Spill Trajectories for No Ice and Ice Scenarios....61
Figure 4-7: Eclipse Sound, mid-July, Spill Distribution Probability Difference for No Ice and Ice....63
Figure 4-8: Eclipse Sound, mid-July, Time in Ice....64
Figure 4-9: Eclipse Sound, mid-July, Percentage of Trajectories Reaching Shore....65
Figure 4-10:Eclipse Sound, mid-July, Mean Times to Shore....66
Figure 4-11:Eclipse Sound, mid-July, IFO 180, Fuel Weathering....67
Figure 5-1: Spill Distribution Probability Plot, Milne Inlet: Mouth, mid-October, no Ice....68
Figure 5-2: Spill Distribution Probability Plot, Milne Inlet: Mouth, mid-October, Ice....69
Figure 5-3: Milne Inlet: Mouth, 5 to 25 October, 2008, Spill Trajectories for No Ice and Ice Scenarios....70
Figure 5-4: Milne Inlet: Mouth, 15 October, 2000-2013, Spill Trajectories for No Ice and Ice Scenarios....71
Figure 5-5: Milne Inlet: Mouth, mid-October, Spill Distribution Probability Difference for No Ice and Ice....72
Figure 5-6: Milne Inlet: Mouth, mid-October, Time in Ice....73
Figure 5-7: Daily Percent Trajectories Ashore, Milne Inlet: Mouth, mid-October....74
Figure 5-8: Annual Percent Trajectories Ashore, Milne Inlet: Mouth, mid-October....74
Figure 5-9: Milne Inlet: Mouth, mid-October, Percentage of Trajectories Reaching Shore....75
Figure 5-10:Milne Inlet: Mouth, mid-October, Mean Times to Shore....76
Figure 5-11:Milne Inlet: Mouth, mid-October, IFO 180, Fuel Weathering....77

LIST OF APPENDICES

APPENDIX A: SEA ICE CONDITIONS, EASTERN ARCTIC AND POND INLET

1.0 INTRODUCTION

1.1 Objectives

To support planning and assessment of Baffinland Iron Mines Corporation's (Baffinland's) Mary River Project – Phase 2 Proposal, , Amec Foster Wheeler Environment & Infrastructure, a Division of Amec Foster Wheeler Americas Limited (Amec Foster Wheeler), has undertaken a sea ice shoulder seasons fuel spill modelling assessment for the Northern Shipping Route in the Canadian Arctic. This follows on a previously undertaken open water fuel spill modelling assessment completed to address the Nunavut Impact Review Board (NIRB) requirements for the Mary River Project's Early Revenue Phase (Amec Foster Wheeler, 2015).

The purpose of fuel spill trajectory modelling is to inform spill response. Specific information sought for spill response agencies and other stakeholders includes estimation of the marine and any shoreline areas potentially affected together with the initial weathering fate of the spilled fuel.

As part of the Mary River Project's Phase 2 Proposal, two fuels will be transported along "the Northern Shipping Route" from Baffin Bay through Pond Inlet, Eclipse Sound, and Milne Inlet to the port site at the head of Milne Inlet. Arctic diesel will be shipped with fuel tanker and unloaded by means of flexible hoses to shore; intermediate fuel oil (IFO) will be carried for powering of the ore carriers.

Shipping is expected to occur during the open water season, from approximately mid-July to mid-October, and not commence until the sea ice has retreated and melted from the shipping route. Nevertheless, the potential exists for some sea ice presence during the shoulder seasons, and so two spill-in-ice scenarios have been identified – near the times of break-up and freeze-up – to further inform spill response preparedness efforts. This report presents the results of this fuel spill modelling effort.

1.2 Background

Along the Northern Shipping Route, sea ice break-up[1] is earliest about the week of 16 July for the head of Milne Inlet, the mouths of Tay Sound and Oliver Sound in southern Eclipse Sound, and for portions of the eastern entrance to Pond Inlet. For the remainder of this region - the majority of Milne Inlet, Eclipse Sound, Navy Board Inlet and Pond Inlet, break-up is the week of 30 July[2]. On average, for Milne Inlet

[1] Break-up refers to a particular length of time in which ice disappears in a given area (generally 1 to 2 weeks). However, breakup does not necessarily imply a decay or melt of ice, but can also indicate a movement of ice out of a particular area (Source: CIS Ice Glossary https://ec.gc.ca/glaces-ice/default.asp?lang=En&n=501D72C1-1&def=show0C69D02D6#C69D02D6)

[2] In this report, Canadian Ice Service (CIS) historic short dates are used. CIS weekly Eastern Arctic regional ice analysis charts covers the week centred on the chart date, e.g., the chart for 22 July 2013 is representative for the period 19 to 25 July and has an associated historic date of 23 July. Historic dates are used by CIS when summarizing or aggregating ice information over many years, including the climatic ice atlases. The CIS regional charts (e.g., Eastern Arctic) are analyzed for Mondays (e.g., 22 July 2013). (S. McCourt, pers. comm.)

and the western portion of Eclipse Sound, freeze-up[3] occurs the week of the 8 October, while for eastern Eclipse Sound and Pond Inlet, freeze-up is later during the week of 22 October.

The weathering and fate of spilled fuel in the Arctic is modified by the presence of ice and colder temperatures. Changes in fuel due to weathering affect spill response options and oil interactions with organisms and ecosystems. The key processes that affect fuel weathering in the marine environment – both open water and in ice - are illustrated in Figure 1-1. Several of the key observations include:

- Ice acts as a physical barrier or retardant, will impede the spread of fuel and provide some containment. Fuel on water with concentrations less than 3/10 ice coverage will drift as in open water, whereas ice concentrations greater than 3/10 are generally taken as the condition at which the behaviour of fuel changes significantly over an open water condition. Under such conditions fuel will be largely trapped among and drift with the ice.
- In closer, more concentrated, pack ice or brash ice (ice in chunks up to 2 m in diameter) fuel slicks may not reach their equilibrium thickness as spreading is slowed or stopped by the presence of ice floes in close contact or by slush. This can result in a smaller, confined slick area and greater oil thicknesses compared with open water. Ice leads and deformed ice features may create pools of fuel further reducing spreading.
- At cold temperatures fuel will be denser and more viscous than in warmer conditions. This will contribute to increased viscosity (and hence reduced spreading) and a reduced rate and degree of evaporation. Fuel trapped under ice will not evaporate, while fuel on top of the ice or in leads will.
- Ice presence will tend to dampen wind waves. With less wave energy emulsification of fuel (which reduces the rate of other weathering processes) is uncommon, usually being decreased or does not occur.
- Natural dispersion – the breakup of a slick into droplets of varying sizes which become mixed into the upper layers of the water column – will occur at lower rates with reduced wave conditions due to ice, even though ice floe motion can be a source of surface turbulence.

[3] At Freeze-up (This term refers to a particular length of time in which ice appears in a given area (generally 1 to 2 weeks). However, freezeup does not necessarily imply a growth of ice, but can also indicate a movement of ice into a particular area. (Source: CIS glossary)

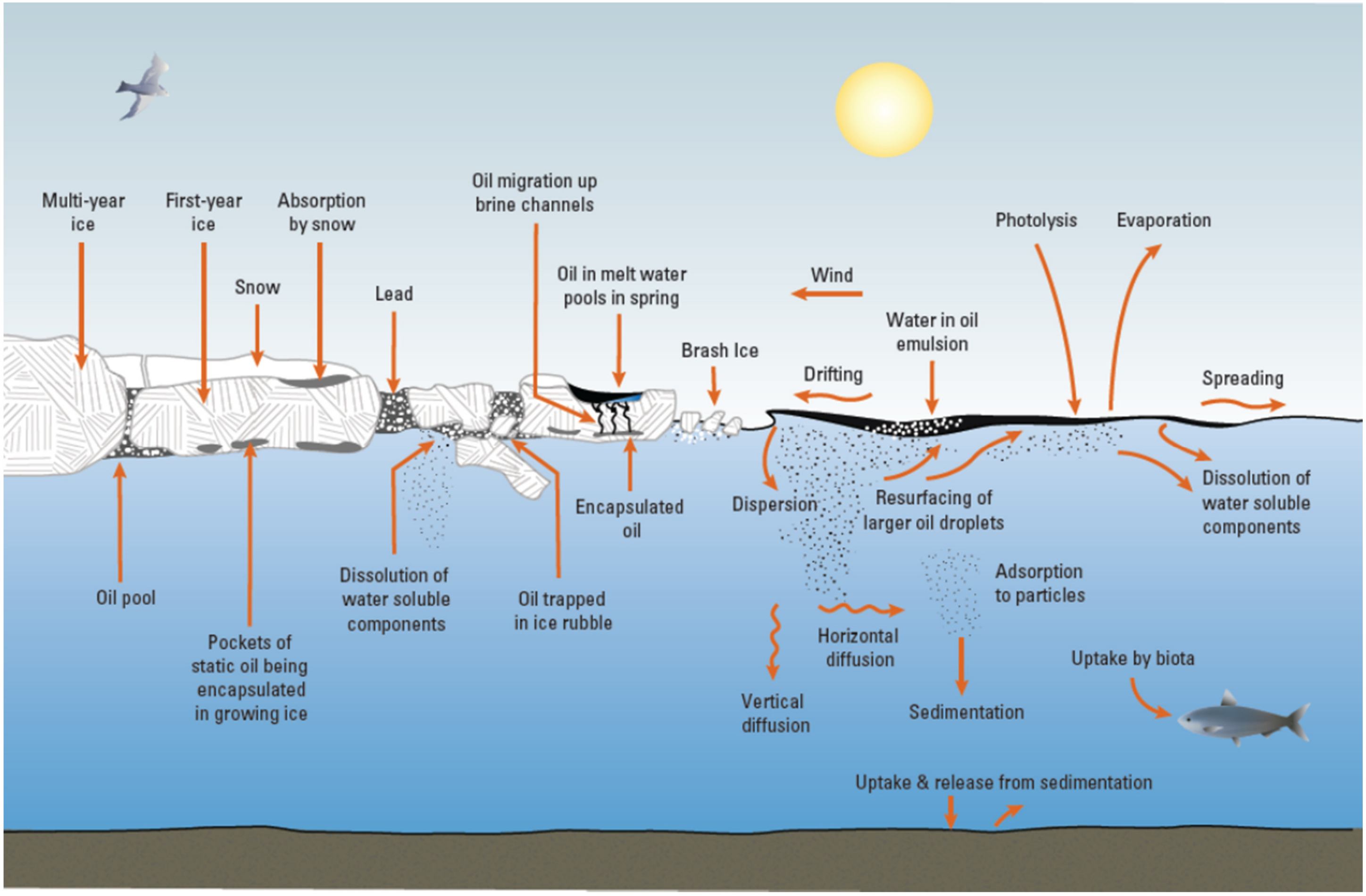


Figure 1-1: Environmental Processes that affect oil behaviour and weathering in open water and in ice. (Source: from NRC 2014, modified from Daling et al. 1990 and A. Allen)

Considering the sea ice shoulder seasons for the Northern Shipping Route, the behaviour of a spill in the presence of ice will experience some differences at break-up and at freeze-up.

<u>Break-up</u>

At the time of ice break-up, a spilled fuel slick near ice will in general initially adhere to the ice edge and broken ice surfaces in the vicinity of the incident. Whatever fuel adheres to the ice will drift and weather with the ice and be dispersed in accordance with the ultimate fate of this ice, e.g., fuel will be released as sheens, broken thin oil films or patches wherever the ice melts. Spreading will be slower with increasing ice conditions compared with open water (NRC, 2003). Any fuel that is submerged under broken ice or beneath the ice will not be exposed to wind and wave action, will be less likely to spread and experience reduced natural dispersion. Fuel at the ice edge or that spills or washes onto the ice will be exposed to wind and wave action and increased dispersion into the water column.

Freeze-up

During freeze-up cold temperatures will play a role in making spilled fuel denser and more viscous than in conditions that are otherwise warmer. If ambient air and water temperatures approach the fuel's pour point it will cease to flow.

New ice at the time of freeze-up consists of frazil or grease ice (new crystalline ice in a slush form). Spreading of fuel on water with new ice is very slow. Fuel may be frozen into any brash ice and fuel spilled under new ice will likely become encapsulated by new ice quickly forming beneath it within about 12 to 24 hours. This is based on extensive observations of the behaviour of fuel spilled under ice at different times during the Arctic winter

Fuel on ice surfaces will remain with the ice. Fuel on or under snow will be absorbed into the snow. Once in snow or ice, winds will have little effect on spreading and dispersion. Any 'free flowing" fuel not otherwise adhering to the ice can be spread by (tidal) currents under ice (NRC, 2003), although transport may be limited unless (tidal) currents are greater than a threshold current speed needed to initiate and sustain movement of about 20 cm/s). Trapped fuel will remain until melting onto open water the following year.

Spill Fate Prediction

Not only is fuel spilled under constantly changing ice conditions difficult to contain and recover, it is difficult to track and predict its weathering and drift. There are numerous challenges with spill in ice trajectory modelling. Elements of these may include (e.g., Drozdowski et al., 2011):

- Characterization of the ice cover, e.g., ice concentration and ice drift
- Characterization of fuel and ice interactions on, in and under the snow and ice; processes that are difficult to model and occur on small-scales - much smaller than sea ice models which may have resolutions of 10 to 100 km
- Description of wind, current, and ice as spill model inputs, either from measured or reanalysis data or sea-ice models with good resolution
- The rubble ice field that can develop between landfast ice and mobile offshore pack ice: this can limit the movement of fuel and also store fuel through the winter, releasing it on melt the following year
- Tracking of the fuel in ice. Local monitoring may be limited; the use of airborne and satellite remote sensing and ice beacons are potential resources

For the spill in ice modelling for the Northern Shipping Route shoulder seasons presented in this report, good characterizations of the sea ice are available and are combined with a trajectory model that incorporates ice concentration to estimate fuel drift. The modelling outputs include estimates of the likely spill trajectory paths and weathering fates including estimate of fuel amounts evaporated, remaining on the surface, and that have reached shore.

1.3 Spill Scenario Selection

Based on the timing of sea ice break-up, the period around mid-late July (e.g., 23 July) is reasonable to capture periods where the ice is melting and retreating and clearing from the shipping route; a location in Eclipse Sound is selected for this scenario. At the end of the open water season, for freeze-up, the early-mid October (e.g., 8 October) period is reasonable to capture times then the ice is forming and closing the shipping route into Milne Inlet, and for which fuel might possibly enter into the new ice; a location at the mouth of Milne Inlet is selected for this scenario. The exact spill day and year ranges considered are discussed is Section 2.2 where the ice climatology for the region is reviewed.

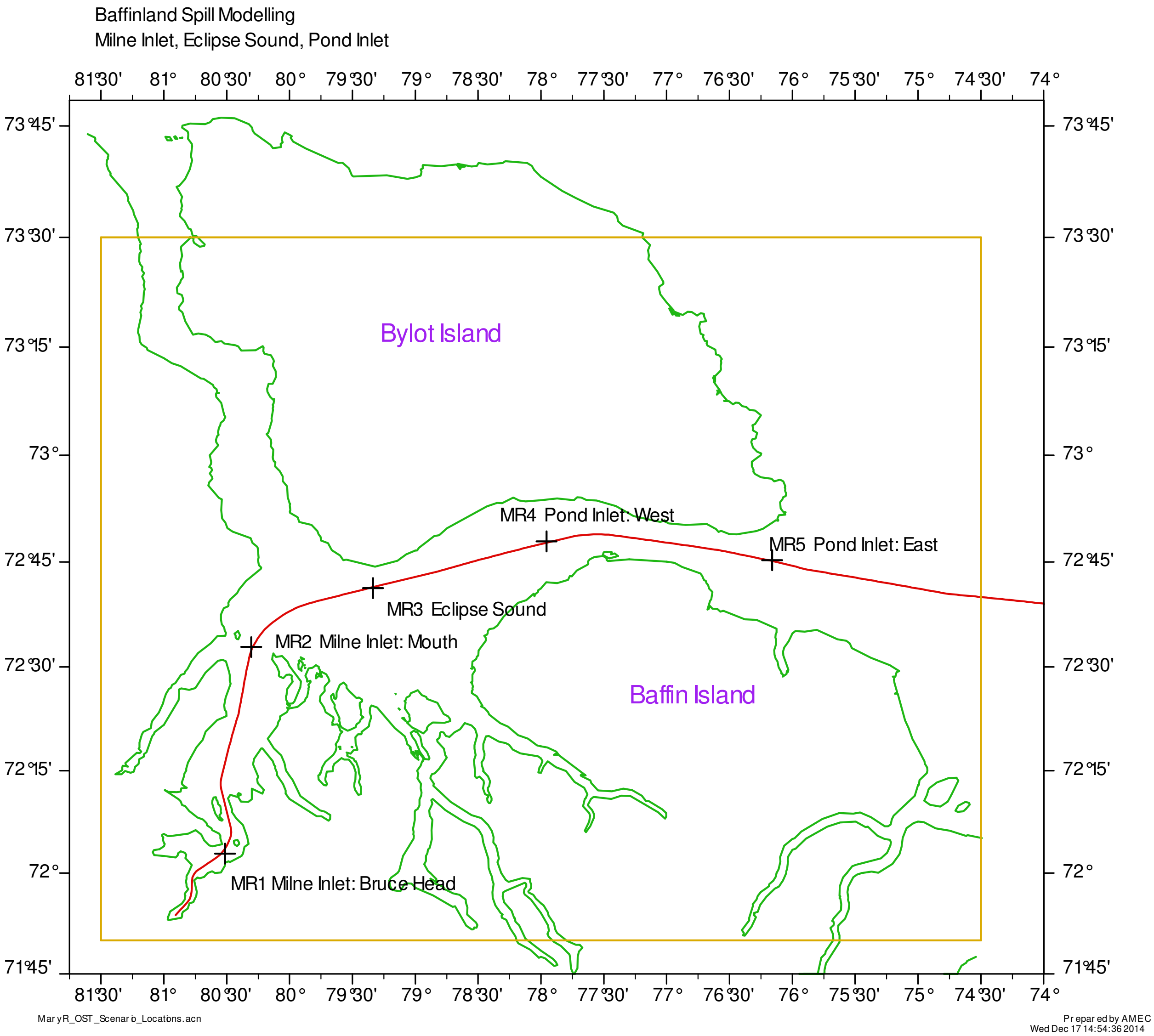
The two spill scenario locations selected along the shipping route are listed in Table 1-1 and are shown in Figure 1-2. These are two of the same locations used for the Northern Shipping Route open water season spill modelling (Amec Foster Wheeler, 2015).

Both scenarios consider a hypothetical release of 1 ML of IFO fuel from an ore carrier; the modelling is completed using the Amec Foster Wheeler software, OST. OST computes spill probability distributions to indicate geographical regions (e.g., Pond Inlet, Eclipse Sound, Navy Board Inlet and Milne Inlet) which might be affected as a result of a spill, how frequently and how soon. These results are presented in Sections 4.0 and 5.0.

The spill modelling completed in this study assumes no intervention, response or containment and that the slick is assumed to freely discharge (during a very short duration) from the damaged vessel.

Table 1-1: Spill Scenario Locations

Spill ID	Location	Latitude (N)	Longitude (W)	Spill Dates
MR3	Eclipse Sound	72° 41.27'	79° 20.18'	20 Jul (historic week of 23 Jul minus 3 days) to 9 August
MR2	Milne Inlet: Mouth	72° 32.86’	80° 18.33'	5 Oct (historic week of 8 Oct minus 3 days) to 25 Oct



Note: Fuel spill scenarios for the open water season (September month) have been previously modelled at Northern Shipping Route locations MR1 to MR5 (Amec Foster Wheeler, 2015)

Figure 1-2: Spill Scenario Locations

1.4 Report Structure

Section 2 of the report presents a review of sea ice condition for the Northern Shipping Route from Baffin Bay through Pond Inlet, Eclipse Sound, and Milne Inlet to the port site at the head of Milne Inlet. This section presents both the historical data as well as describes the ice input strategy for the spill model. Pertinent details of the OST trajectory model theory and setup, input and output data, and presentation of simulation results presented in Section 3. Spill probability maps and shoreline statistics are presented in Sections 4 and 5 for the mid-July Eclipse Sound and mid-October mouth of Milne Inlet scenarios. Closure is provided in Section 6. References follow in Section 7. Additional information on ice conditions extracted from the 30-year CIS ice atlas, Eastern Arctic region, is included in Appendix A.

2.0 SEA ICE CONDITIONS

This section provides an overview of ice conditions historically encountered from July to October in the Northern Shipping Route study area: Milne Inlet, Eclipse Sound, Navy Board Inlet, and Pond Inlet.

2.1 Sea Ice Climatic Atlas, Eastern Arctic

The Canadian Ice Service (CIS) Sea Ice Climatic Atlas, Eastern Arctic (CIS, 2013) provides descriptions of the ice regime for Baffin Island and approaches. The products in the atlas were obtained from a statistical compilation of the regional charts for the years 1981 to 2010. This includes weekly charts of median ice concentration, median ice concentration when ice is present, frequency of presence of sea ice, frequency of presence of old ice, and median of predominant ice type when ice is present.

Freeze-up and Break-up

As noted in the Background section above, along the Northern Shipping Route, sea ice break-up is earliest about the week of 16 July for the head of Milne inlet, for the mouths of Tay Sound and Oliver Sound in southern Eclipse Sound, and also portions of the eastern entrance to Pond Inlet. For the remainder of this region, break-up is the week of 30 July[4]. On average, for Milne Inlet and the western portion of Eclipse Sound, freeze-up occurs the week of the 8 October over about two weeks, while for eastern Eclipse Sound and Pond Inlet, freeze-up is later during the week of 22 October (Appendix A, Charts of freeze-up and break-up dates for the Eastern Arctic).

Appendix A also presents a series of weekly snapshots of the various ice chart types for the study domain and Pond Inlet region.

2.2 Ice Conditions as Input to Fuel Spill Modelling

2.2.1 Import of CIS Weekly Ice Charts for OST

The Canadian Ice Service regional weekly ice charts, in ArcINFO Workstation interchange file format (.e00), were downloaded (CIS, 2015) and imported into ArcMap using the “Import from e00” conversion tool. The interchange file contains all associated egg code[5] data and related information. Once the data were imported in ArcMap a spatial join was executed using the imported ArcINFO coverages and a predefined set of 1077 points to cover the Milne Inlet model domain which resulted in

[4] In this report, Canadian Ice Service (CIS) historic short dates are used. CIS weekly Eastern Arctic regional ice analysis charts covers the week centred on the chart date, e.g., the chart for 22 July 2013 is representative for the period 19 to 25 July and has an associated historic date of 23 July. Historic dates are used by CIS when summarizing or aggregating ice information over many years, including the climatic ice atlases. The CIS regional charts (e.g., Eastern Arctic) are analyzed for Mondays (e.g., 22 July 2013). (S. McCourt, pers. comm.)
[5] egg codes present basic ice concentration, stages of development (thickness) and form or floe size of ice information (CIS, 2005).

a final vector shapefile containing all associated egg code data. These steps were duplicated on 173 files (for weeks in July through October during 2000 to 2014) and merged into a single vector file.

The vector file was then exported to an Excel spreadsheet to be used for further ice characterization and for input to the spill modelling.

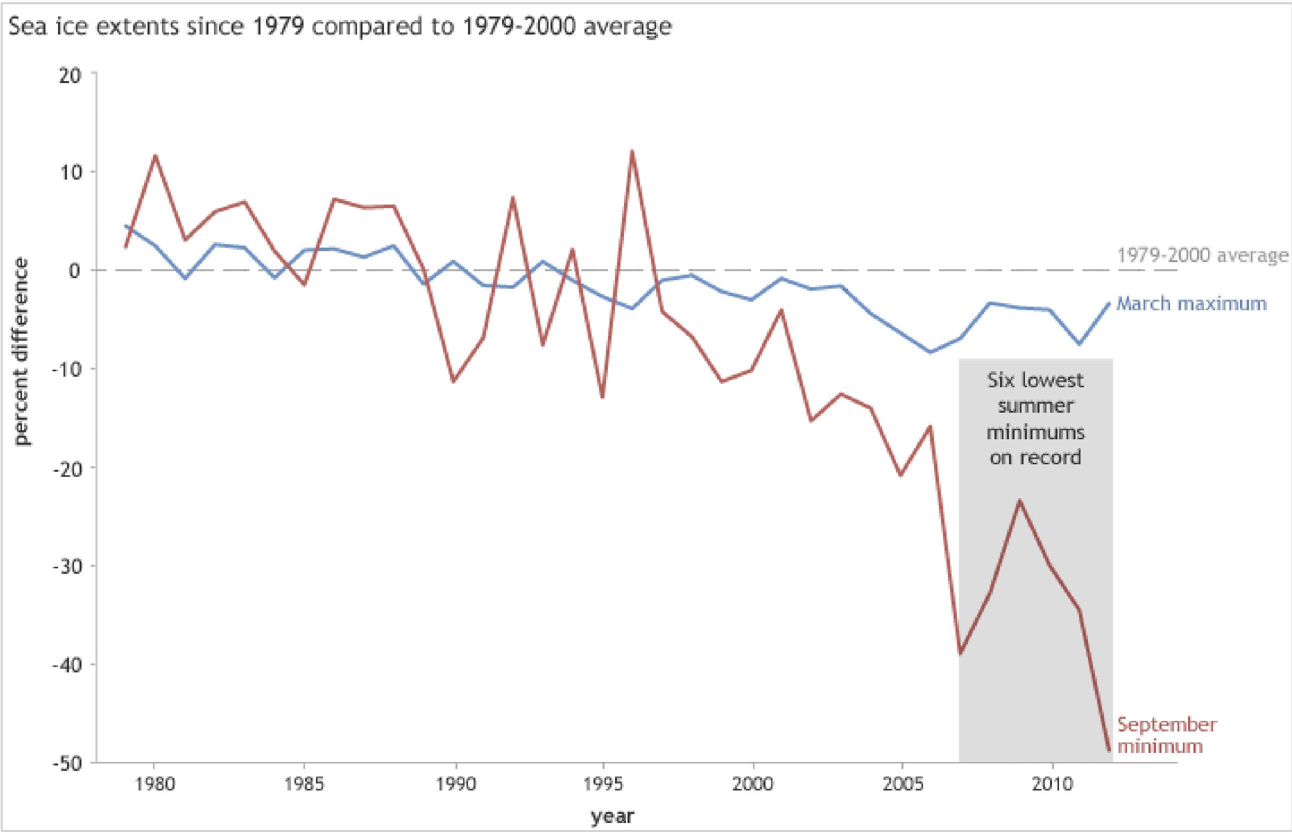
2.2.2 Selection of Ice Years for Spill Modelling

The Arctic has undergone substantial warming since the mid-20th century. Greenland ice sheets have been losing mass and glaciers have continued to shrink almost worldwide over the past two decades. The average rate of ice loss from the Greenland ice sheet has very likely increased from 34 Gt/yr over the period 1992 to 2001 to 215 Gt/yr over the period 2002 to 2011. Sea surface temperatures were anomalously high in at least the last 1,450 years (IPCC, 2013).

Based on reconstructions over the past three decades, the annual mean Arctic sea ice extent decreased over the period 1979 to 2012 with a rate very likely in the range of 3.5 to 4.1 percent per decade, and the summer sea ice minimum has similarly decreased in the range 9.4 to 13.6 percent per decade. Since 1979, the sea ice spatial extent has decreased in every season, and in every successive decade (IPCC, 2013).

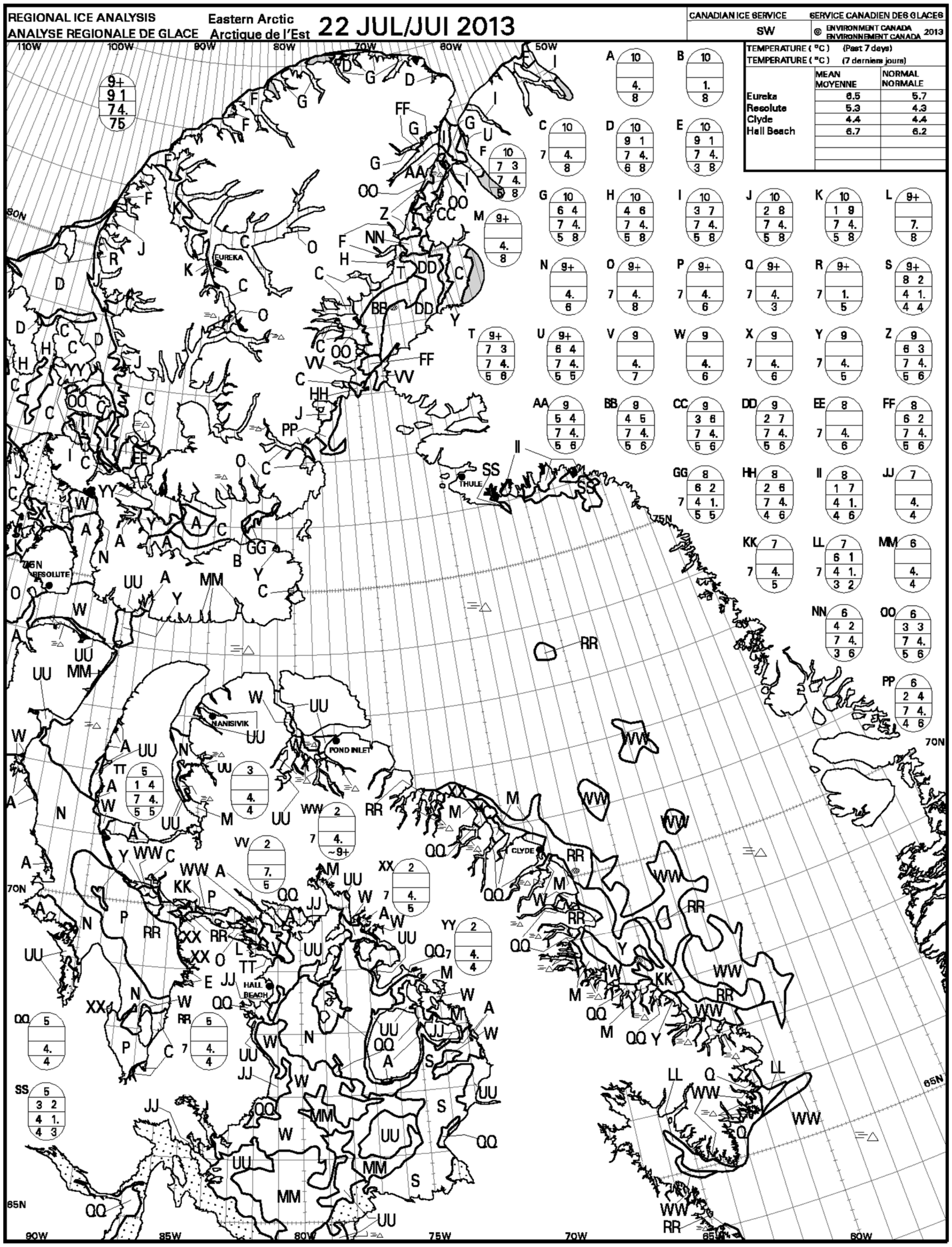
The recent decline in sea ice extent shown in Figure 2-1 illustrates the dramatic drop. Kennedy (2013) also notes “Overall, since satellite-based measurements began in the late 1970s, Arctic sea ice extent has decreased in all months and virtually all regions, with the exception of the Bering Sea during winter. The average melt rate in September is now -91,600 square kilometers per year or -13 percent per decade relative to the 1979-2000 average. Summer ice declines have been especially rapid since 2001.”

The set of historical week regional charts (.e00 and black and white .gif images, e.g., Figure 2-2) for July through November for 1984 through 2014 were downloaded; however, only the years 2000 through 2014 were imported to spreadsheets. This more recent period was selected for the spill modelling in an attempt to capture a range of ice conditions which might be most representative of those likely to be encountered with the present climate.



Source: Kennedy, 2012

Figure 2-1: Arctic Sea Ice Extents since 1979 compared to 1979-2000 Average



Source: CIS 2015

Figure 2-2: Weekly Ice Chart, Eastern Arctic, 22 July 2013

An illustration of the translation from ice chart .e00 file to ice concentration for use in the spill modelling is shown in Figure 2-3 to Figure 2-5 for three weeks from 22 July to 5 August. The egg codes, e.g., UU and W for 22 July, present basic ice concentration, stages of development (thickness) and form or floe size of ice values (CIS, 2005). For example, for 22 July 2013, for the UU egg, the ice is 3/10 total concentration of thick first-year ice (> 120 cm) in medium floes of 100-500 m. For the WW egg, the ice is 9/10 total concentration of thick first-year ice in vast floes of 2-10 km. The ice concentrations shown in the right hand maps over the spill model grid are those used.

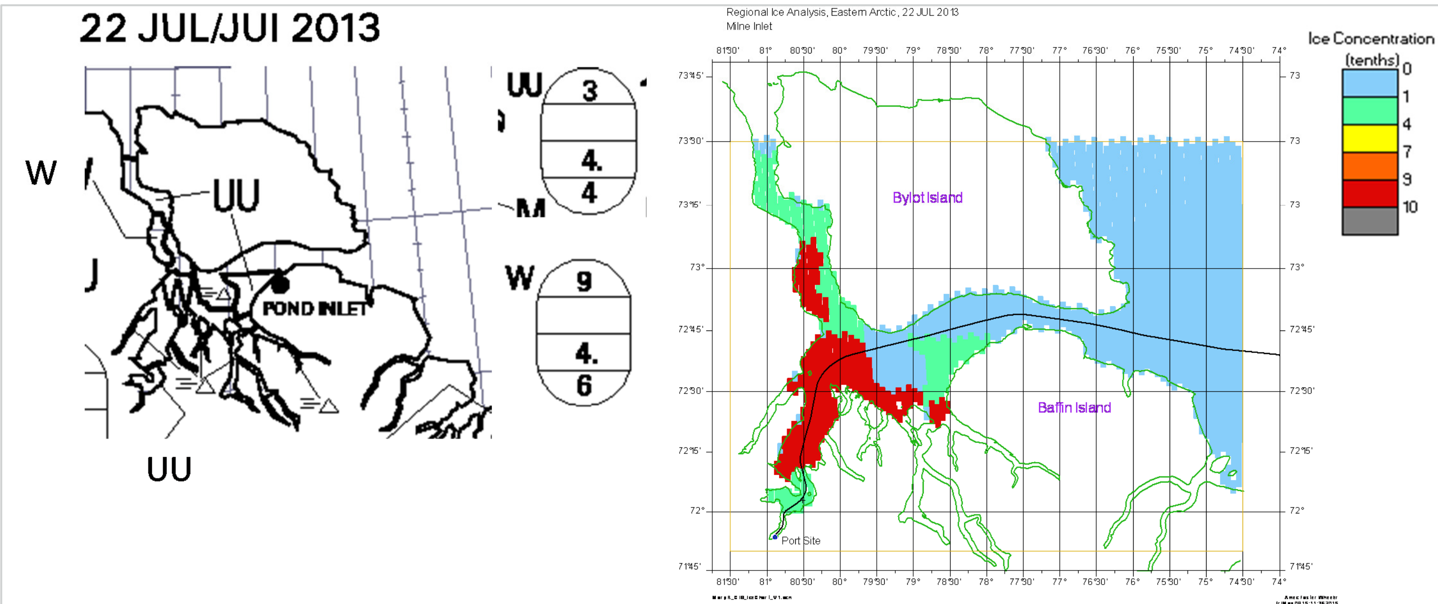


Figure 2-3: Ice Concentration, Week of 22 July 2013, Pond Inlet

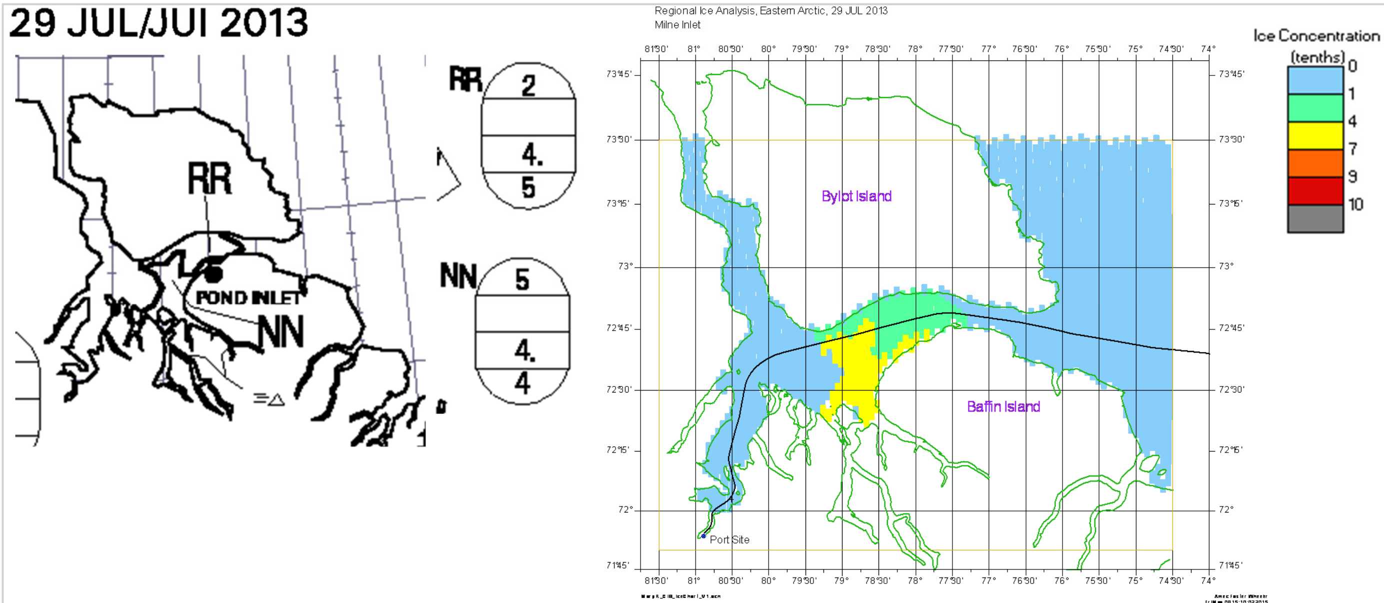


Figure 2-4: Ice Concentration, Week of 29 July 2013, Pond Inlet

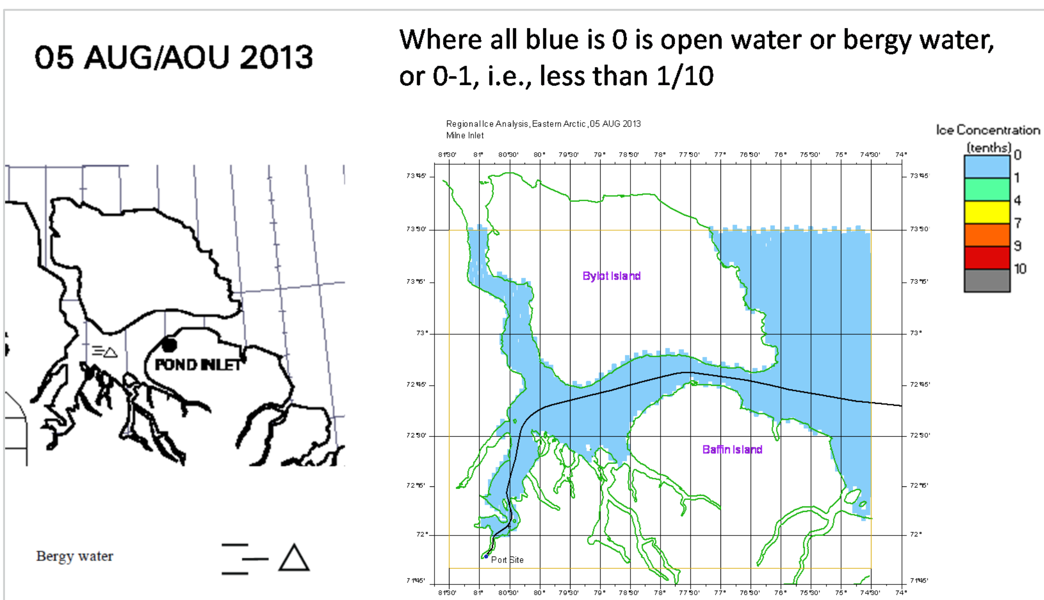


Figure 2-5: Ice Concentration, Week of 05 August 2013, Pond Inlet

2.3 Ice Conditions, Northern Shipping Route

A good summary of ice conditions for the Northern Shipping Route is presented in the Sailing Directions (Fisheries and Oceans Canada, 2014) and is repeated below:

> *“The whole area from Pond Inlet to Navy Board Inlet is covered every winter by a continuous sheet of shore-fast ice which attains a thickness of about 1.5 to 1.8 m. First melting comes along the shorelines, particularly at the mouths of rivers in the inlets and bays. At the same time the open tongue of the “North Water” creeping south opens the entrance to Pond Inlet, and the open water gradually spreads westward until a general break-up in situ of the ice in Tasiujaq (Eclipse Sound) takes place. Later, the ice retreats southward in Navy Board Inlet, and once the general break-up occurs any ice left tends to drift south into the west end of Tasiujaq. The latter area is almost always the last to become clear of ice. Generally, the ice of western Pond Inlet and Tasiujaq breaks up about the middle of July and, once broken up, can melt within a few days if conditions are favourable. Occasionally a westerly wind packs the ice into the narrows of Pond Inlet, forming a temporary barrier, but this seems relatively rare. The break-up pattern is fairly well-established and is relatively unhindered, as the ice involved is almost entirely local ice of one year’s growth. Little ice comes in during the open season from either Baffin Bay or Lancaster Sound, for the reason that by the time the local ice breaks up, the parts of those waters close to the entrances of Pond Inlet and Navy Board Inlet are usually ice free.*
>
> *Caution. Winds and strong currents drive ice back and forth in western Tasiujaq and in and out of the outer parts of Milne Inlet itself, until the ice finally melts. “*

(Pond Inlet, p. 4-7, Fisheries and Oceans Canada, 2014)

The mean and maximum total ice concentration, Ct, for five locations along the shipping route (they are the five open water spill scenario locations) for the weeks of 16 July through 29 October are presented in Figure 2-6 and Figure 2-7. These statistics are based on the years 2000 through 2014.

Mean total ice concentrations at the end of the ice season (historic week 16 Jul) range from 4.2 at Milne Inlet: Bruce Head (MR1) and 4.4 at Pond Inlet: East (MR5) to 9.3 at the Mouth of Milne Inlet. By the week of 30 Jul mean total ice concentrations range from 0.3 at Milne Inlet: Bruce Head to 2.9 in Eclipse Sound (MR3). This is consistent with the sailing directions observation above that first melting comes along the shorelines and at mouths of rivers in the inlets and bays.

For the ice freeze-up and start of the winter ice season, for the week of 01 Oct, mean total ice concentrations are about 1/10 or less; and are 0/10 at the Pond Inlet: East location near Baffin Bay. By the week of 15 Oct, the mean ice concentration is 4.4 at Milne Inlet: Bruce Head and 2.4 to 3.5 at the other four locations. By the last week of October (29 Oct) mean total ice concentrations range between 7.5 and 8.8.

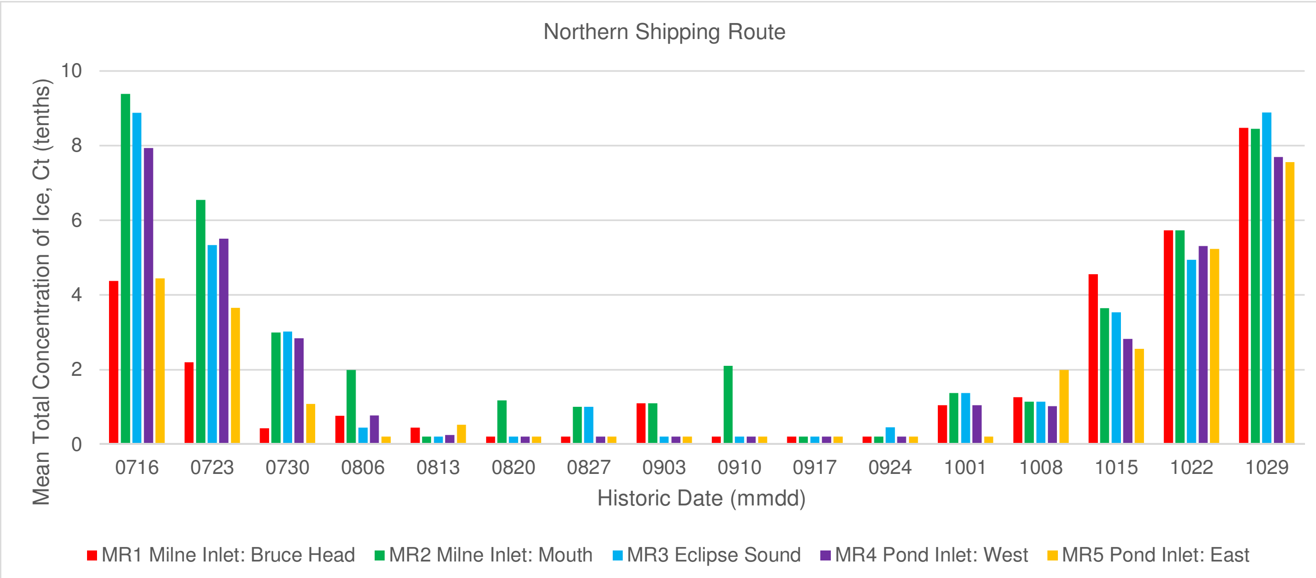


Figure 2-6: Weekly Mean Ice Concentration, Northern Shipping Route

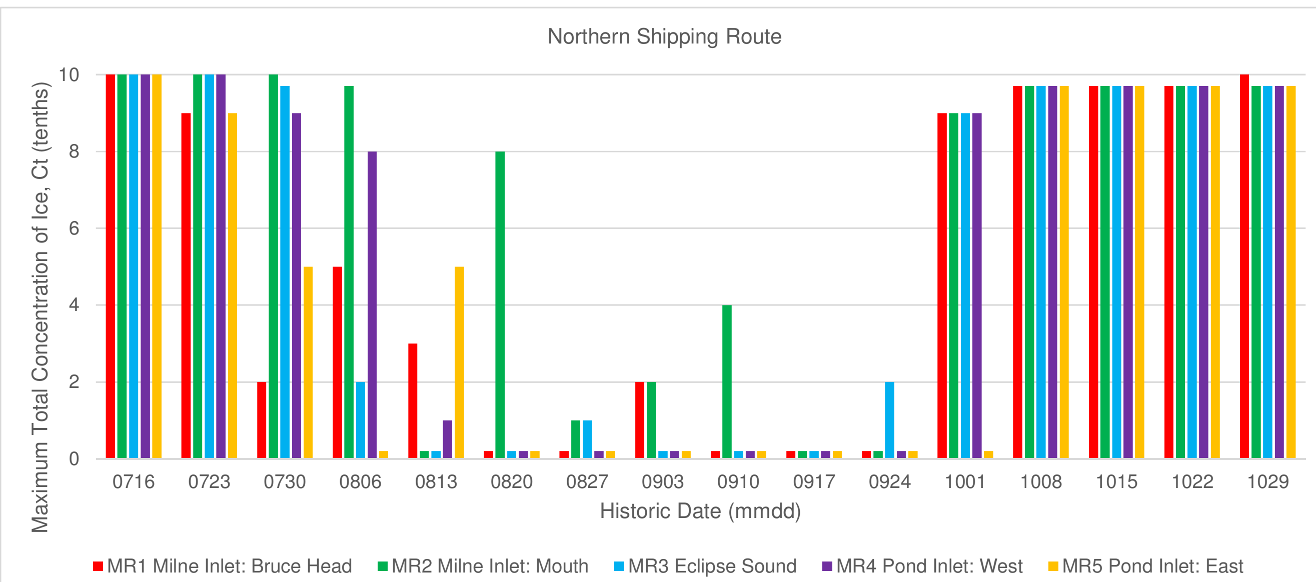


Figure 2-7: Weekly Maximum Ice Concentration, Northern Shipping Route

Maximum total ice concentrations at the end of the ice season are 9/10 to 10/10 through the week of 23 Jul. Through the first half of August total ice concentrations at Milne Inlet: Bruce Head (MR1) can still be as large as 5/10 the week of 06 Aug and 3/10 the week of 08 Aug, but reach a maximum of 2/10 in Eclipse Sound (MR3) the week of 06 Aug. Through the first week of August (06 Aug) the greatest ice concentrations of 9+/10 can be encountered at the mouth of Milne Inlet and at Pond Inlet: West (MR4) at 8/10.

For the ice freeze-up and start of the winter ice season, for the week of 01 Oct, maximum total ice concentrations are 9/10 at all locations except still 0/10 at the Pond Inlet: East location and entrance to Baffin Bay. By the week of 8 Oct, maximum ice concentrations of 9+/10 can be experienced at all five locations.

Table 2-1 to Table 2-5 together with Figure 2-8 to Figure 2-12 present alternative visualizations of the mean and maximum ice concentrations by historic week at each of the five Northern Shipping Route locations.

Table 2-1: Weekly Ice Concentration, MR1 Milne Inlet: Bruce Head, 2000-2014

Weekly Ice Concentration (when ice is present) (tenths)
MR1 Milne Inlet: Bruce Head

Historic Date (mmdd)	0716	0723	0730	0806	0813	0820	0827	0903	0910	0917	0924	1001	1008	1015	1022	1029	Annual Mean
2000	9.7	0.2	0.2	0.2	0.2						0.2	0.2	0.2	4.0	9.7	9.7	3.1
2001	0.3	0.3	0.2	0.3	1.0	0.2					0.2	0.2	0.2	9.7	9.7	9.7	2.7
2002	10.0	0.2	0.2	2.0	3.0	0.2		0.2	0.2	0.2	0.2	9.0	0.2	9.7	9.7	9.7	3.6
2003	9.7	8.0	0.2	0.2	0.2	0.2	0.2	2.0	0.2	0.2	0.2	4.0	9.7	9.7	9.7	9.7	4.0
2004	9.7	2.0	0.2	0.2	0.2					0.2	0.2	0.2	0.2	9.0	6.0		2.6
2005	8.0	7.0	0.2	5.0	0.2						0.2	0.2	0.2	9.0	6.0	9.7	4.2
2006	3.0	0.2	0.2	0.2	0.2							0.2	0.2	0.2	6.0	8.0	1.8
2007	0.2	9.0	1.0	0.2	0.2							0.2	0.2	0.2	0.2	9.7	2.1
2008	0.2	0.2	1.0	0.2	0.2	0.2						0.2	2.0	0.2	7.0	8.0	1.8
2009	4.0	0.2	0.2	0.2	0.2	0.2						0.2	0.2	0.2	2.0	3.0	1.0
2010	0.2	0.2	2.0	0.2	0.2						0.2	0.2	3.0	9.0	9.7		3.2
2011	0.2	0.2	0.2	0.2	0.2							0.2	0.2	0.2	5.0	7.0	1.4
2012	0.2	0.2	0.2	0.2	0.2	0.2						0.2	0.2	2.0	2.0	8.0	1.2
2013	0.2	3.0	0.2	0.2	0.2	0.2						0.2	0.2	5.0	3.0	8.0	1.9
2014	10.0	2.0	0.2	2.0	0.2	0.2						0.2	2.0	0.2	0.2	10.0	2.5
Mean	4.4	2.2	0.4	0.8	0.4	0.2	0.2	1.1	0.2	0.2	0.2	1.0	1.3	4.6	5.7	8.5	2.5
Maximum	10.0	9.0	2.0	5.0	3.0	0.2	0.2	2.0	0.2	0.2	0.2	9.0	9.7	9.7	9.7	10.0	4.2

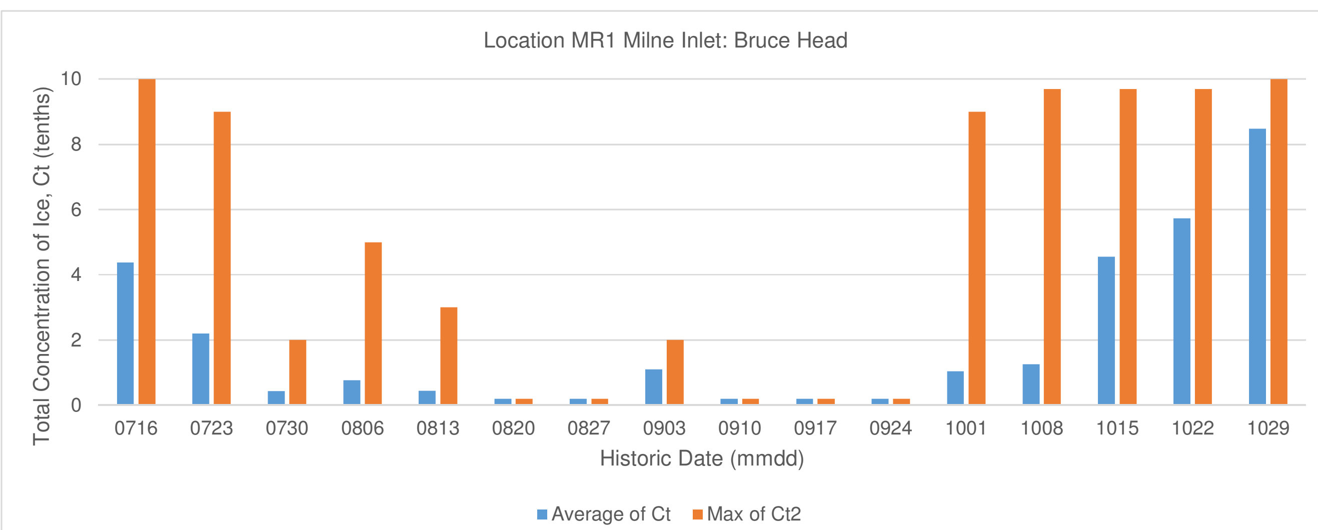


Figure 2-8 Mean and Maximum Weekly Ice Concentration, MR1 Milne Inlet: Bruce Head

Table 2-2: Weekly Ice Concentration, MR2 Milne Inlet: Mouth, 2000-2014

Weekly Ice Concentration (when ice is present) (tenths)
MR2 Milne Inlet: Mouth
Historic Date (mmdd)

	0716	0723	0730	0806	0813	0820	0827	0903	0910	0917	0924	1001	1008	1015	1022	1029	Annual Mean
2000	9.7	9.7	0.2	0.2	0.2						0.2	0.2	0.2	4.0	9.7	9.7	4.0
2001	10.0	9.7	8.0	7.0	0.2	0.2					0.2	0.2	0.2	9.7	9.7	9.7	5.4
2002	10.0	10.0	10.0	9.7	0.2	0.2		0.2	0.2	0.2	0.2	9.0	0.2	9.7	9.7	9.7	5.3
2003	10.0	10.0	0.2	0.2	0.2	8.0	1.0	2.0	4.0	0.2	0.2	9.0	9.7	9.7	9.7	9.7	5.2
2004	9.7	2.0	0.2	2.0	0.2					0.2	0.2	0.2	0.2	0.2	6.0		1.9
2005	10.0	9.7	9.0	0.2	0.2						0.2	0.2	0.2	9.0	6.0	9.7	4.9
2006	9.0	2.0	0.2	0.2	0.2							0.2	0.2	0.2	6.0	8.0	2.6
2007	9.0	9.0	1.0	0.2	0.2							0.2	0.2	0.2	0.2	9.7	3.0
2008	10.0	9.0	1.0	0.2	0.2	0.2						0.2	2.0	0.2	7.0	8.0	3.5
2009	10.0	0.2	2.0	0.2	0.2	0.2						0.2	0.2	0.2	9.7	3.0	2.4
2010	5.0	5.0	2.0	0.2	0.2						0.2	0.2	3.0	9.0	9.7		4.0
2011	9.0	0.2	0.2	0.2	0.2							0.2	0.2	0.2	0.2	7.0	1.8
2012	9.7	3.0	1.0	0.2	0.2	0.2						0.2	0.2	2.0	2.0	8.0	2.4
2013	9.7	9.0	0.2	0.2	0.2	0.2						0.2	0.2	0.2	0.2	8.0	2.6
2014	10.0	9.7	9.7	9.0	0.2	0.2						0.2	0.2	0.2	0.2	9.7	4.5
Mean	9.4	6.5	3.0	2.0	0.2	1.2	1.0	1.1	2.1	0.2	0.2	1.4	1.1	3.6	5.7	8.5	3.6
Maximum	10.0	10.0	10.0	9.7	0.2	8.0	1.0	2.0	4.0	0.2	0.2	9.0	9.7	9.7	9.7	9.7	5.4

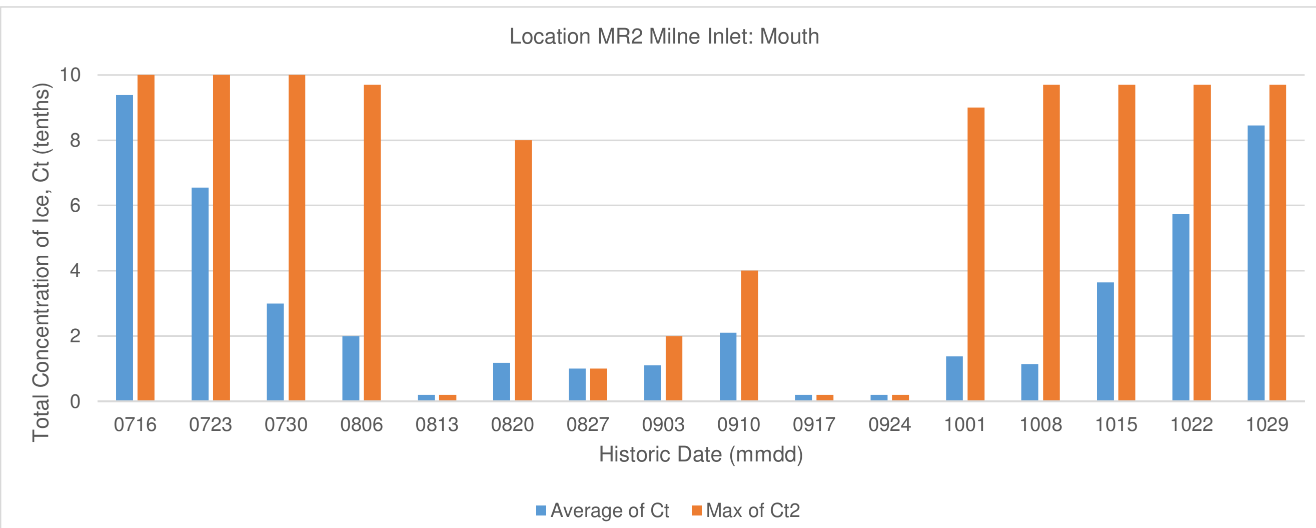


Figure 2-9 Mean and Maximum Weekly Ice Concentration, MR2 Milne Inlet: Mouth

Table 2-3: Weekly Ice Concentration, MR3 Eclipse Sound, 2000-2014

Weekly Ice Concentration (when ice is present) (tenths)
MR3 Eclipse Sound
Historic Date (mmdd)

	0716	0723	0730	0806	0813	0820	0827	0903	0910	0917	0924	1001	1008	1015	1022	1029	Annual Mean
2000	9.7	0.2	0.2	0.2	0.2						0.2	0.2	0.2	4.0	9.7	9.7	3.1
2001	10.0	9.7	8.0	0.2	0.2	0.2					0.2	0.2	0.2	9.7	9.7	9.7	4.8
2002	10.0	10.0	2.0	2.0	0.2	0.2		0.2	0.2	0.2	0.2	9.0	0.2	0.2	3.0	9.7	3.2
2003	10.0	9.0	0.2	0.2	0.2	0.2	1.0	0.2	0.2	0.2	0.2	9.0	9.7	9.7	9.7	9.7	4.3
2004	10.0	9.0	0.2	0.2	0.2					0.2	2.0	0.2	0.2	0.2	6.0		2.6
2005	10.0	9.7	9.0	0.2	0.2						0.2	0.2	0.2	9.0	8.0	9.7	5.1
2006	9.0	2.0	0.2	0.2	0.2							0.2	0.2	0.2	6.0	8.0	2.6
2007	10.0	0.2	0.2	0.2	0.2							0.2	0.2	0.2	0.2	9.7	2.1
2008	10.0	9.0	7.0	0.2	0.2	0.2						0.2	2.0	0.2	7.0	7.0	3.9
2009	10.0	9.0	7.0	0.2	0.2	0.2						0.2	0.2	8.0	9.0	8.0	4.7
2010	5.0	2.0	0.2	0.2	0.2						0.2	0.2	3.0	9.0	5.0		3.2
2011	0.2	0.2	0.2	0.2	0.2							0.2	0.2	0.2	0.2	7.0	0.9
2012	9.7	0.2	1.0	0.2	0.2	0.2						0.2	0.2	2.0	0.2	8.0	2.0
2013	9.7	0.2	0.2	0.2	0.2	0.2						0.2	0.2	0.2	0.2	9.7	1.9
2014	10.0	9.7	9.7	2.0	0.2	0.2						0.2	0.2	0.2	0.2	9.7	3.8
Mean	8.9	5.3	3.0	0.4	0.2	0.2	1.0	0.2	0.2	0.2	0.5	1.4	1.1	3.5	4.9	8.9	3.2
Maximum	10.0	10.0	9.7	2.0	0.2	0.2	1.0	0.2	0.2	0.2	2.0	9.0	9.7	9.7	9.7	9.7	5.1

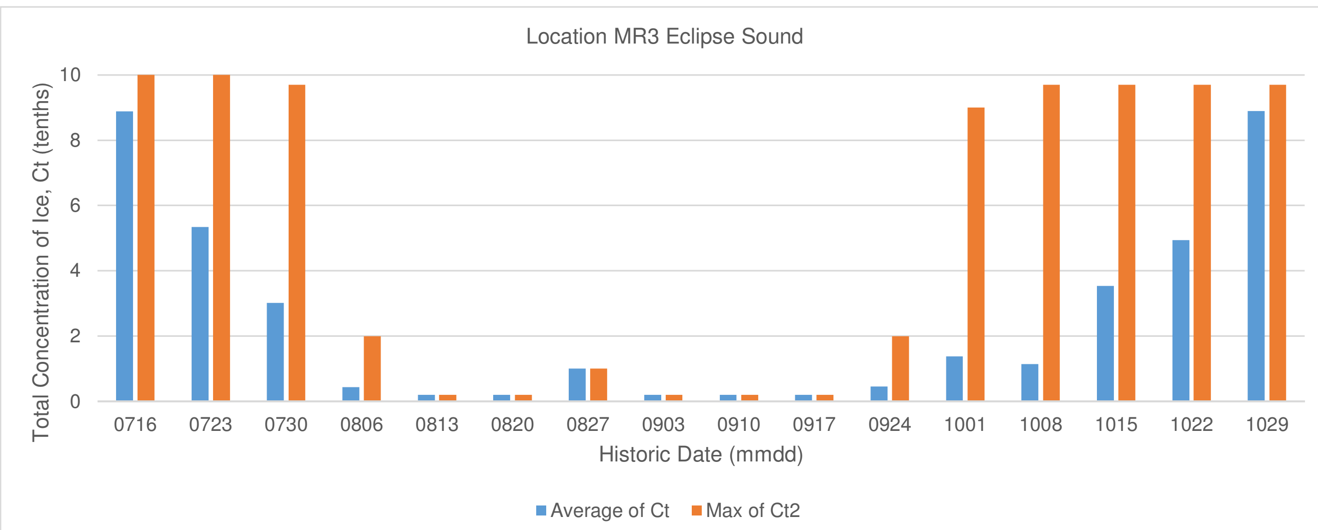


Figure 2-10 Mean and Maximum Weekly Ice Concentration, MR3 Eclipse Sound

Table 2-4: Weekly Ice Concentration, MR4 Pond Inlet: West, 2000-2014

Weekly Ice Concentration (when ice is present) (tenths)
MR4 Pond Inlet: West
Historic Date (mmdd)

	0716	0723	0730	0806	0813	0820	0827	0903	0910	0917	0924	1001	1008	1015	1022	1029	Annual Mean
2000	0.2	0.2	0.2	0.2	0.2						0.2	0.2	0.2	0.2	9.7	9.7	1.9
2001	10.0	9.7	0.2	0.2	0.2	0.2					0.2	0.2	0.2	9.7	9.7	9.7	4.2
2002	10.0	10.0	8.0	0.2	0.2	0.2		0.2	0.2	0.2	0.2	9.0	0.2	0.2	3.0	9.7	3.4
2003	10.0	9.0	4.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	4.0	9.7	9.7	9.7	9.7	4.2
2004	10.0	9.0	9.0	0.2	0.2					0.2	0.2	0.2	0.2	0.2	6.0		3.2
2005	10.0	9.7	0.2	0.2	0.2						0.2	0.2	0.2	9.0	6.0	9.7	4.1
2006	9.0	7.0	0.2	0.2	0.2							0.2	0.2	0.2	6.0	8.0	3.1
2007	10.0	0.2	0.2	0.2	0.2							0.2	0.2	0.2	7.0	9.7	2.8
2008	10.0	9.0	9.0	0.2	0.2	0.2						0.2	0.2	3.0	7.0	7.0	4.2
2009	10.0	9.0	2.0	1.0	0.2	0.2						0.2	0.2	0.2	0.2	0.2	2.1
2010	0.2	0.2	0.2	0.2	0.2						0.2	0.2	3.0	9.0	9.7		3.0
2011	0.2	0.2	0.2	0.2	0.2							0.2	0.2	0.2	5.0	7.0	1.4
2012	9.7	0.2	0.2	0.2	1.0	0.2						0.2	0.2	0.2	0.2	0.2	1.1
2013	9.7	0.2	2.0	0.2	0.2	0.2						0.2	0.2	0.2	0.2	9.7	2.1
2014	10.0	9.0	7.0	8.0	0.2	0.2						0.2	0.2	0.2	0.2	9.7	4.1
Mean	7.9	5.5	2.8	0.8	0.3	0.2	0.2	0.2	0.2	0.2	0.2	1.0	1.0	2.8	5.3	7.7	3.0
Maximum	10.0	10.0	9.0	8.0	1.0	0.2	0.2	0.2	0.2	0.2	0.2	9.0	9.7	9.7	9.7	9.7	4.2

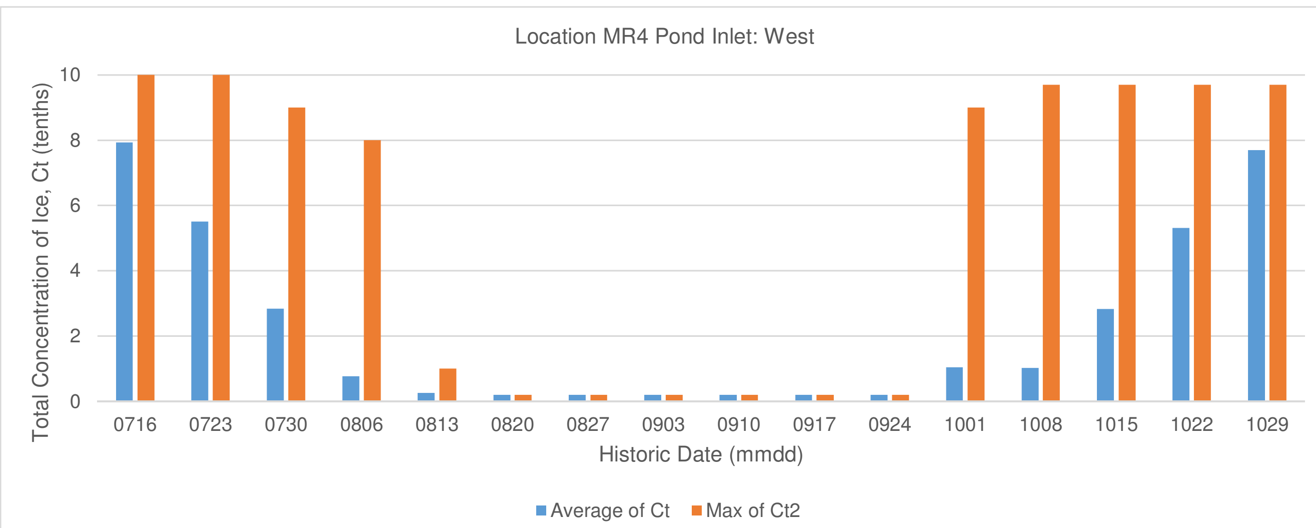


Figure 2-11: Mean and Maximum Weekly Ice Concentration, MR4 Pond Inlet: West

Table 2-5: Weekly Ice Concentration, MR5 Pond Inlet: East, 2000-2014

Weekly Ice Concentration (when ice is present) (tenths)
MR5 Pond Inlet: East
Historic Date (mmdd)

	0716	0723	0730	0806	0813	0820	0827	0903	0910	0917	0924	1001	1008	1015	1022	1029	Annual Mean
2000	0.2	0.2	0.2	0.2	0.2						0.2	0.2	5.0	0.2	9.7	9.7	2.4
2001	2.0	3.0	4.0	0.2	0.2	0.2					0.2	0.2	0.2	9.7	9.7	9.0	3.2
2002	9.7	9.0	0.2	0.2	0.2	0.2		0.2	0.2	0.2	0.2	0.2	0.2	0.2	3.0	9.7	2.2
2003	2.0	5.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	9.7	9.7	9.7	9.7	3.0
2004	7.0	2.0	4.0	0.2	0.2					0.2	0.2	0.2	8.0	6.0	6.0		3.1
2005	0.2	0.2	0.2	0.2	0.2						0.2	0.2	0.2	3.0	6.0	9.7	1.8
2006	10.0	9.0	0.2	0.2	0.2							0.2	0.2	0.2	0.2	0.2	2.1
2007	10.0	6.0	1.0	0.2	0.2							0.2	0.2	8.0	0.2	9.7	3.6
2008	10.0	3.0	5.0	0.2	0.2	0.2						0.2	0.2	0.2	7.0	9.7	3.3
2009	9.0	5.0	0.2	0.2	0.2	0.2						0.2	0.2	0.2	9.7	8.0	3.0
2010	2.0	7.0	0.2	0.2	0.2						0.2	0.2	5.0	0.2	7.0		2.7
2011	4.0	2.0	0.2	0.2	0.2							0.2	0.2	0.2	9.7	7.0	2.4
2012	0.2	0.2	0.2	0.2	5.0	0.2						0.2	0.2	0.2	0.2	6.0	1.2
2013	0.2	0.2	0.2	0.2	0.2	0.2						0.2	0.2	0.2	0.2	9.7	1.1
2014	0.2	3.0	0.2	0.2	0.2	0.2						0.2	0.2	0.2	0.2	0.2	0.5
Mean	4.4	3.7	1.1	0.2	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	2.0	2.6	5.2	7.6	2.4
Maximum	10.0	9.0	5.0	0.2	5.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	9.7	9.7	9.7	9.7	3.6

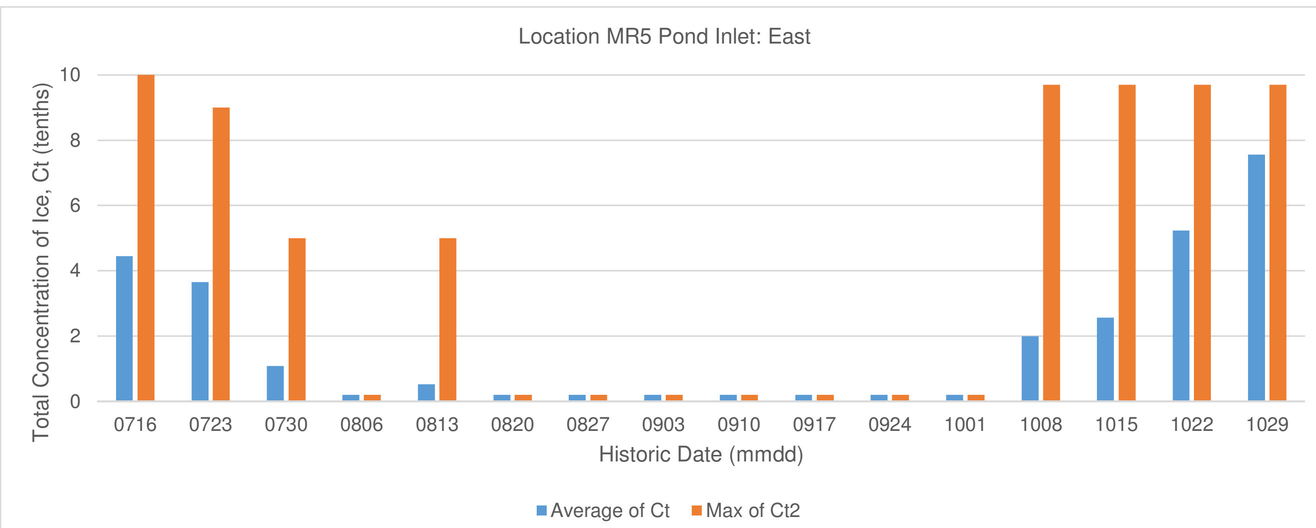


Figure 2-12 Mean and Maximum Weekly Ice Concentration, MR5 Pond Inlet: East

2.3.1 Selection of Ice Weeks for Spill Modelling

The start dates for spill scenarios, 20 July and 5 October, are three days before the corresponding CIS weekly ice chart historic dates of 23 July and 8 October. In this way, the utility of those charts is maximized for the mid-July and mid-October time periods. A three week “shoulder season” period of daily scenario spills is considered, e.g., a spill on 20 July, a spill on 21 July, …, a spill on 9 August. Each mid-July and mid-October period is modelled for the 14 years 2000 to 2013. Spills are considered to happen on each day for a three week "shoulder season" period.

The weekly charts for each year were inspected and provided as input for the spill model; typically this consisted of a chart each week of each year, though those weeks in August or September with no ice were not analysed and therefore in the spill model it is assumed if a week's chart is not present (for the model) in August of September (for the MR3 mid-July spill) then there is open water (Ct=0); conversely if a week's chart is not present in October or November (for the MR2 mid-Oct spill) then there is landfast ice (Ct=10).

The recent historical records of ice concentration at Eclipse Sound for mid-July and Milne Inlet: Mouth for mid-October are presented below in Figure 2-13 and. Figure 2-14.

There was no ice for the week of 13 August for any of the years. And by the first week of November things will be near 10/10 concentration (9+/10 for most of the area for week of 2 Nov 2009). These figures illustrate the important observation that conditions experienced one week may be quite different in one year compared to another.

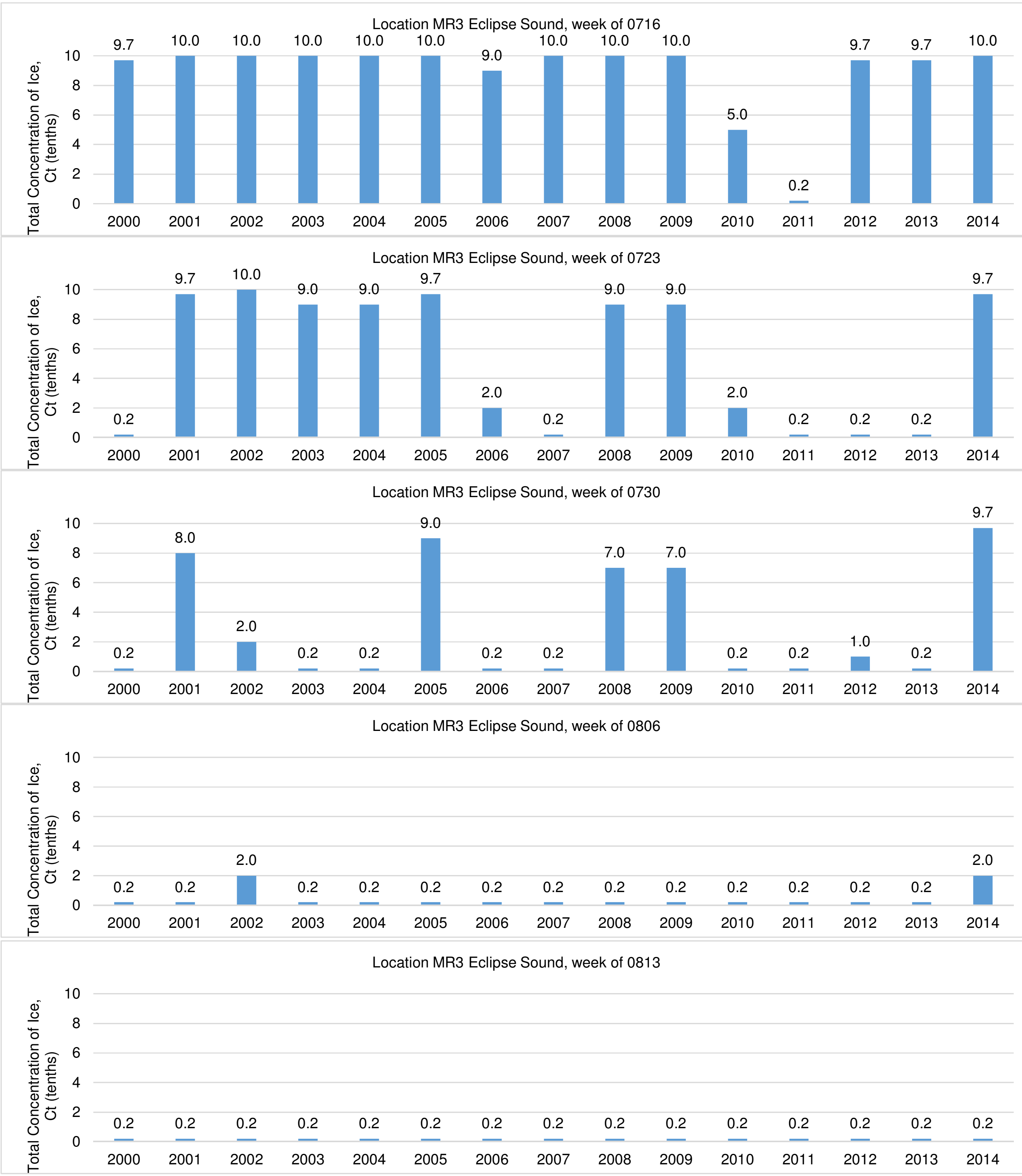


Figure 2-13 Weekly Ice Concentration, 16 July to 6 August, 2000 to 2014, MR3 Eclipse Sound

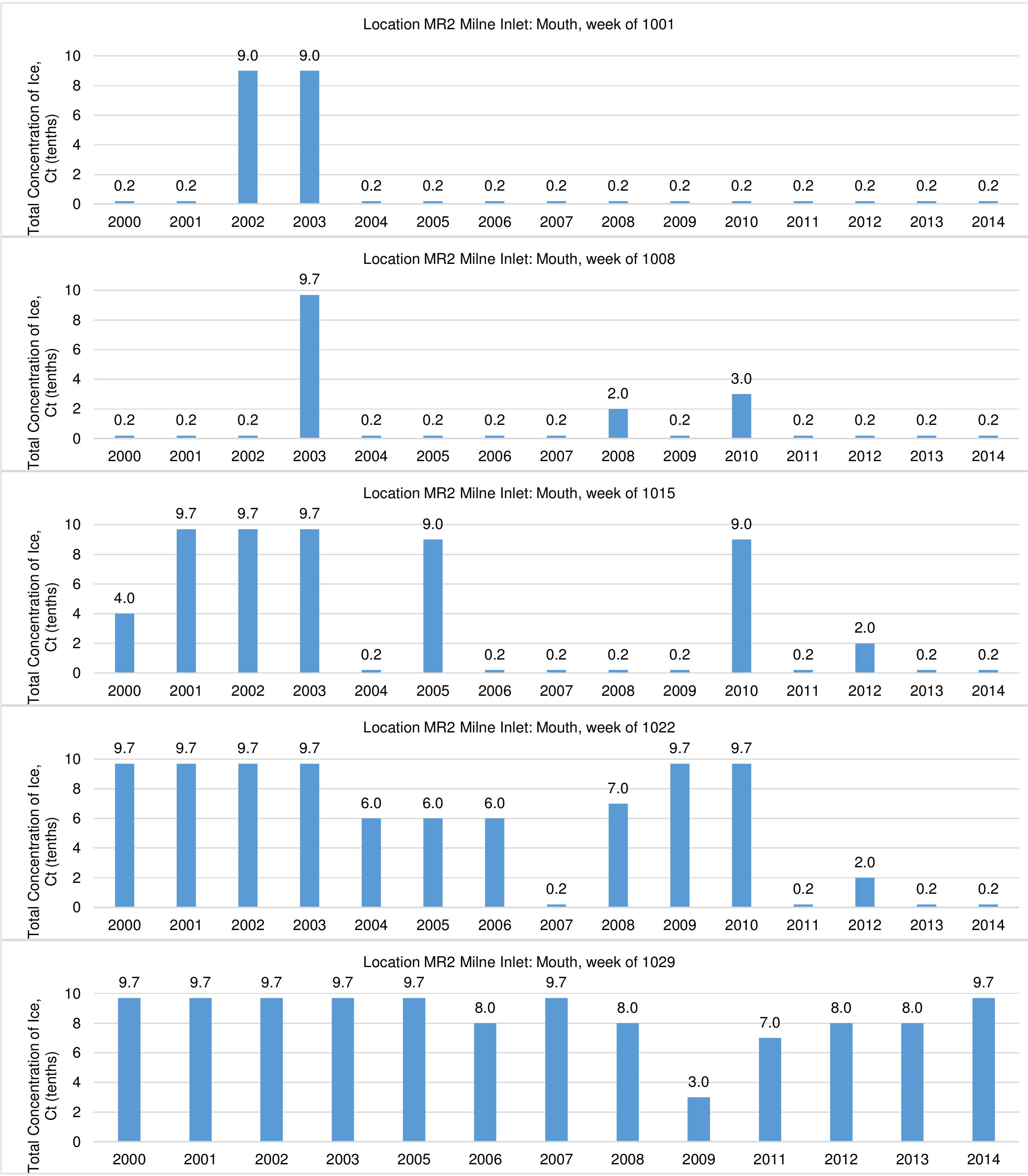


Figure 2-14 Weekly Ice Concentration, 1 to 29 October, 2000 to 2014, MR2 Milne Inlet: Mouth

As a further improvement for the model input, the weekly charts were interpolated to a daily basis as illustrated in Figure 2-15 and Figure 2-16.

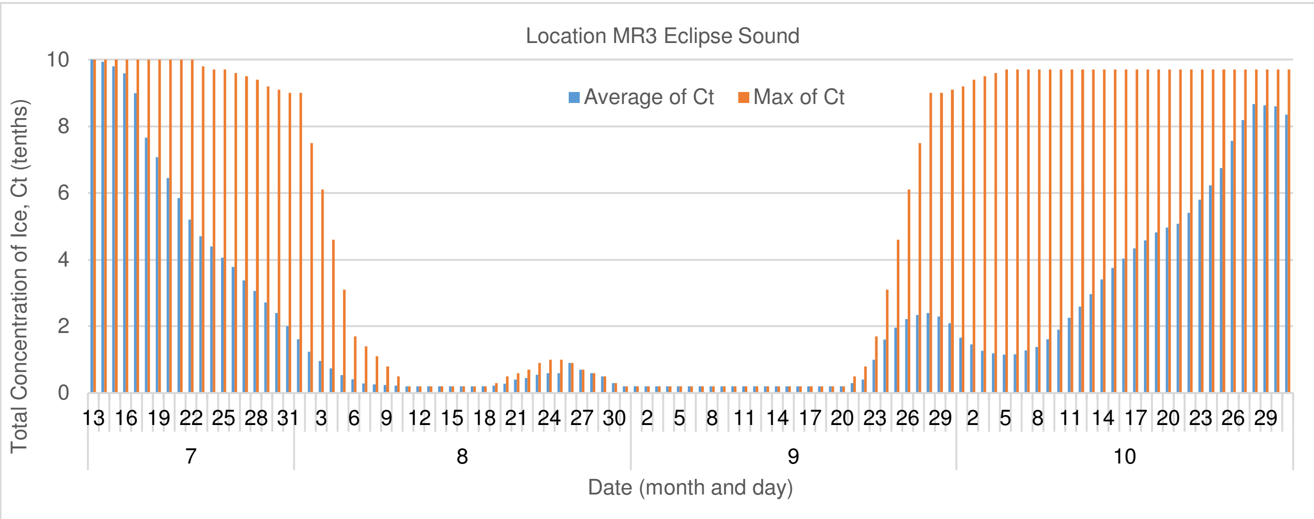


Figure 2-15 Interpolated Daily Ice Concentration, MR3 Eclipse Sound, 2000-2014

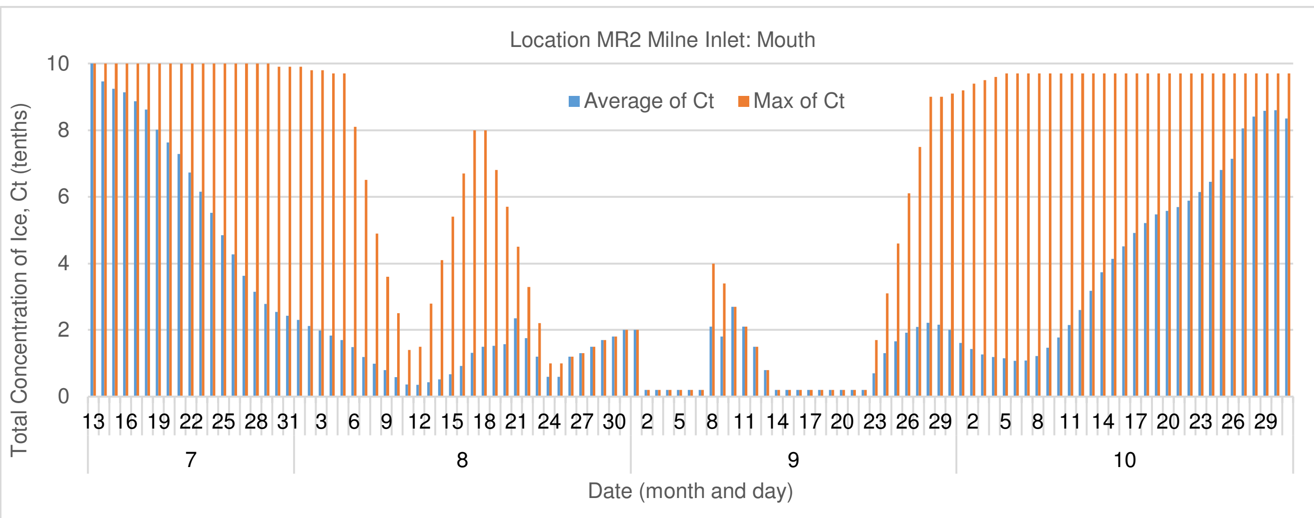


Figure 2-16 Interpolated Daily Ice Concentration, MR2 Milne Inlet: Mouth, 2000-2014

3.0 SPILL TRAJECTORY MODELLING: OST

The sea ice shoulder seasons spill scenarios were modelled by making use of the numerical computer model OST developed by Amec Foster Wheeler to determine probabilistic spill trajectories. To accompany the delivery of the fuel spill trajectory results, a description of the model and techniques used, and observations based on the modelling activity are presented.

3.1 Model Setup

3.1.1 Model Theory Overview

A fuel spill trajectory model is defined for purposes of the present discussion as a computerized sequence of calculations designed to predict some aspects of the behaviour of fuel spilled on the surface of water. Such behavioural aspects may include the transport (advection), and/or the spreading, and/or the weathering of spills. Attention is generally restricted to the behaviour of fuel on the sea surface.

Fuel spill trajectory scenario models (as distinguished from real-time models) are typically employed to provide a prediction of potential spill behaviour. Scenario models attempt to predict typical (or most probable) and extreme answers, for a given spill site, to such questions as:

- What is the likely speed and direction of slick motion?
- What combination of environmental (wind and current) conditions generates the most severe spill scenario?
- How frequently do such conditions occur?

A distinction is drawn between the two basic types of scenario models: deterministic and statistical. The differences relate not so much to the mechanics of the model but to the nature of wind and current data input to the model. A deterministic scenario model employs actual or hindcast data as input to the advection aspect of its calculations. These data may possibly be modified to be made more representative of the site under consideration, but the root of the input is a measured or hindcast time-series of values. Deterministic scenario model mechanics are such that input of a given data series will always yield the identical predicted output. Thus, to gain statistical significance in the interpretation of output, deterministic models must be run on a variety of input data sets or must group predictions by some appropriate time average (such as monthly, or, as selected for the shoulder season modelling here, for a three week period).

In contrast, the statistical variety of scenario model employs some volume of measured data as a standard or guide to creating a synthetic input data set. This approach is most commonly encountered with wind input. The synthetic data, generated by some statistical process (Monte Carlo simulation, Markov chain) employing a random number generator, are the input to the scenario model. Each iteration of the model, commencing with a specific set of fixed parameters except for the random number seed used in the synthesis, which changes each time, will generate a distinctly different predicted output.

Such models must also be run a sufficient number of times to assure statistical significance in the interpretation of the output data.

3.1.2 Model Geometry

The transport (and spatial extent) and fate of a spill is modelled as a function of time. A spill time step is assigned which is appropriate for the geographic scale and model grid of the study area and the wind and current conditions which will be used in the model to transport the spill. At each time step in the model a new location and spill volume is calculated. Selection of too large a time step may yield to inaccurate results. Too small a time step makes for overly intensive computations in the model. For the Milne Inlet domain, a time step of 15 minutes is appropriate (using winds for the given hour over each of those four time steps).

A grid is employed in the model to track the spatial extent of the spill. The grid serves three simultaneous purposes, these being: (i) it serves as the gridded coordinate system for the computation of successive displacements of the slick over each time step; (ii) it is the spatial grid upon which the winds and surface current vectors are mapped; and (iii) it provides a coordinate system for summarizing the predicted first contacts with the shorelines. This single grid is therefore referenced at various times as the model or computational grid, the wind or current grid, and the external grid.

The model grid is a Cartesian grid which includes the northern portion of Baffin Island, Bylot Island, Pond Inlet, Eclipse Sound, and Milne Inlet. The model grid has its origin at 73° 30' N latitude, 81° 30' W longitude, and extends eastward to 74° 30' W longitude and southward to 71° 50' N latitude.

Grid element dimensions are defined as 24” latitude, or 740 m in the north-south (Y) direction and 80” longitude, or 735 m in the east-west direction, i.e., on the order of 740 m x 740 m. The choice of a Cartesian grid requires the specification of a fixed east-west (X) grid scale, and consequently demands the Mercator projection of land elements on the grid. The computational grid is of minimal consequence to the model user who is simply interested in viewing printed and plotted model output. All results appearing as printed output refer to geographical coordinates and distances which are exactly computed and are independent of grid dimensions. Model output plots of fuel distribution probabilities represent all computational grid elements as appropriately scaled rectangles and thus are valid as representing correct relative positions.

Along with the geographical (longitude, latitude) coordinates and the Cartesian (X, Y) coordinates employed with the computational grid, a column (J) and row (I) coordinate system is also imposed to identify grid elements. In the present case, with the grid spanning 7° of longitude and 1° 40’ of latitude, and with 24” row by 80” column grid element definitions, these latter coordinates range as follows:

- Column (J) 1 - 315
- Row (I) 1 - 250

The model grid is summarized in Table 3-1 and illustrated in Figure 3-1 where lines for every second row and column are drawn. The computational grid boundaries are shown as a gold rectangle in the spill probability figures in Sections 4.0 and 5.0.

Table 3-1: OST Spill Model Grid Setup

	Grid Size						**Cell Size (latitude x longitude)**	
Domain	**latitude**	**longitude**	**# rows**	**# columns**	**latitude (km)**	**longitude (km)**	**latitude**	**longitude**
Milne Inlet Eclipse Sound, Pond Inlet	1° 40’ 71° 50' to 73° 30' N	7° 74° 30' to 81° 30' W	250	315	185	231.5 (at 72°40’ N)	24” or 740 m	80” or 735 m

Note: grid mid-latitude is at 72° 40’N

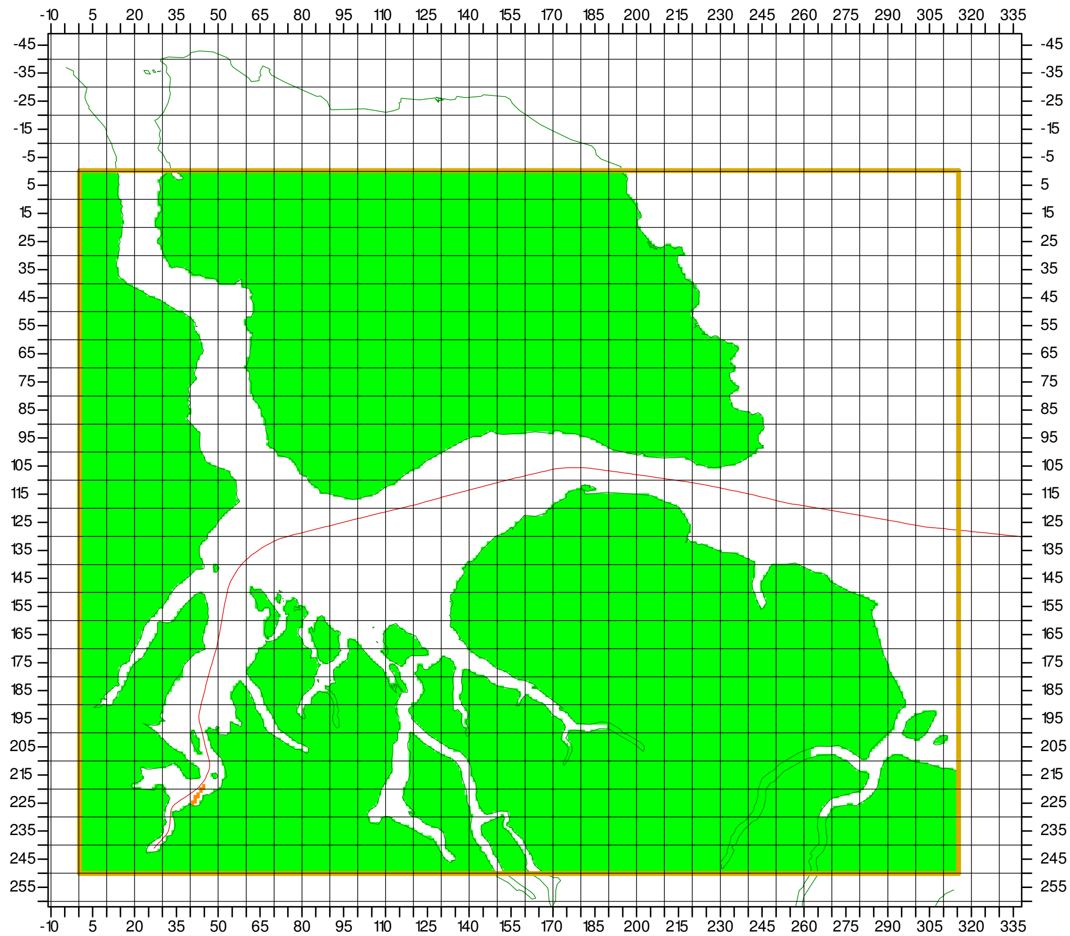


Figure 3-1: OST Spill Model Grid

3.1.3 Transport (Advection)

A simple transport computation is employed to simulate the advection of a point (assumed to represent the centroid of a slick) through two-dimensional space (representing the sea surface).

At any given time the point is assumed to be subject to two independent displacing forces. The presence of an ocean surface current is assumed to displace the point (centroid) in the direction of the current at 100% of the current speed. Simultaneously, but independently, the presence of wind is assumed to generate an instantaneous surface current directed 10° (Westeng, et al., 1977) to the right of the wind (in the northern hemisphere) and having a magnitude of 3.0 to 3.5% of the wind speed. A value of 3.5% is used in the model. This current is also assumed to directly transport the slick. During freeze-up wind-induced currents are likely to somewhat slow the mixing process and thereby delay the cooling and freezing of the water.

Over the time-step of the available wind data the vector sum of the displacements due to surface current and due to wind-driven surface currents is computed to yield a new slick position. Sequential vector additions are computed over each successive time-step until the simulation terminates on one of two endpoint conditions:

- a coastal boundary is reached, or
- an external grid boundary is reached

A third possibility for ending a trajectory in the model is if the percent fuel weathered rises above 95%.

The selection of the current vector and the wind vector to be employed in the transport computation at any given time during the simulation is determined strictly by the present location of the slick centroid.

Spill in Ice Approach

The behaviour of spills within sea ice has been observed for small test spills in the Beaufort Sea, the Scotian Shelf and the Barents Sea. At low ice concentrations, typically below 3/10, the advection of spills is essentially unimpeded by the ice. When the ice concentration approaches 10/10, the spill tends to follow the drift of the ice. From general observations of sea ice behaviour, floes will interact significantly with each other when ice concentrations are 8/10 or greater.

Fuel will move with the ice at relatively high sea concentrations. Greater than 50-70% (LOOKNorth 2014) and 60% (EPPR 2015) are thresholds commonly referenced.

An ice concentration of 6/10 is selected as a reasonable upper bound on the conditions at which a spill will not behave independently of the ice.

The OST spill model has the option of including ice presence with the following algorithm:

- For ice concentrations ≤ 3/10, the fuel spill drift is modelled as if in open water
- For ice concentrations > 6/10, the fuel spill drift is modelled as the ice drift velocity
- For ice concentrations between 4/10 and 6/10, it is expected that the behaviour of spilled fuel will be influenced to some extent by the ice and a weighted average of the open water and ice drift velocities is used.

No sea ice drift information was available for the Northern Shipping Route domain. As a result, ice drift velocities of zero were assumed. In practice, the presence of sea ice will tend to slow down the advection of the spill, reduce evaporation and dispersion, and keep the fuel away from shore.

For the model implementation at ice concentrations of 6/10 or above there will be no movement of the spill.

When fuel is kept away from shore, it can potentially travel with the sea ice farther from the initial spill location than in open water conditions. When fuel is trapped under the ice its movement may be limited unless tidal currents are sufficiently large, e.g., a threshold current speed of about 20 cm/s, as noted in the background section.

For the present model implementation, the wind velocity is available hourly and so a one hour time step is employed. The interpolated (from weekly regional) daily ice charts are used. The ice conditions at the model grid point nearest the trajectory are used each day.

3.1.4 Weathering

The scenario trajectory model is provided with a switch to globally control the use of weathering routines. If weathering routines are enabled, a series of subroutines are executed after the displacement computation (described above) is completed in each time step. The processes of evaporation and vertical dispersion or loss into the water column, are simulated to yield estimates of the total volume of fuel remaining. This is expressed as a percentage of initial spill volume. If weathering is switched off, these calculations are omitted.

IFO 180 carried for ship propulsion was modelled. Based on fuel specification sheets for the project and use of the RPS ASA OILMAP (RPS 2014) updated oil database IFO 180 was selected for the ore carrier's IFO fuel (Figure 3-2).

Upon release in the marine environment, fuel oil is subject to weathering processes, including spreading, evaporation, dissolution, dispersion of fuel droplets into the water column, photochemical oxidation, emulsification, microbial degradation, adsorption onto particulate matter, ingestion by aquatic organisms, sinking and sedimentation (Payne et al., 1991). Immediately after the fuel is spilled, it starts spreading over the sea surface, at a rate that is largely dependent on the viscosity (resistance to flow) of the fuel. The rate of spreading also depends on the wind speed, significant wave height, as well as the presence of tidal and mean currents.

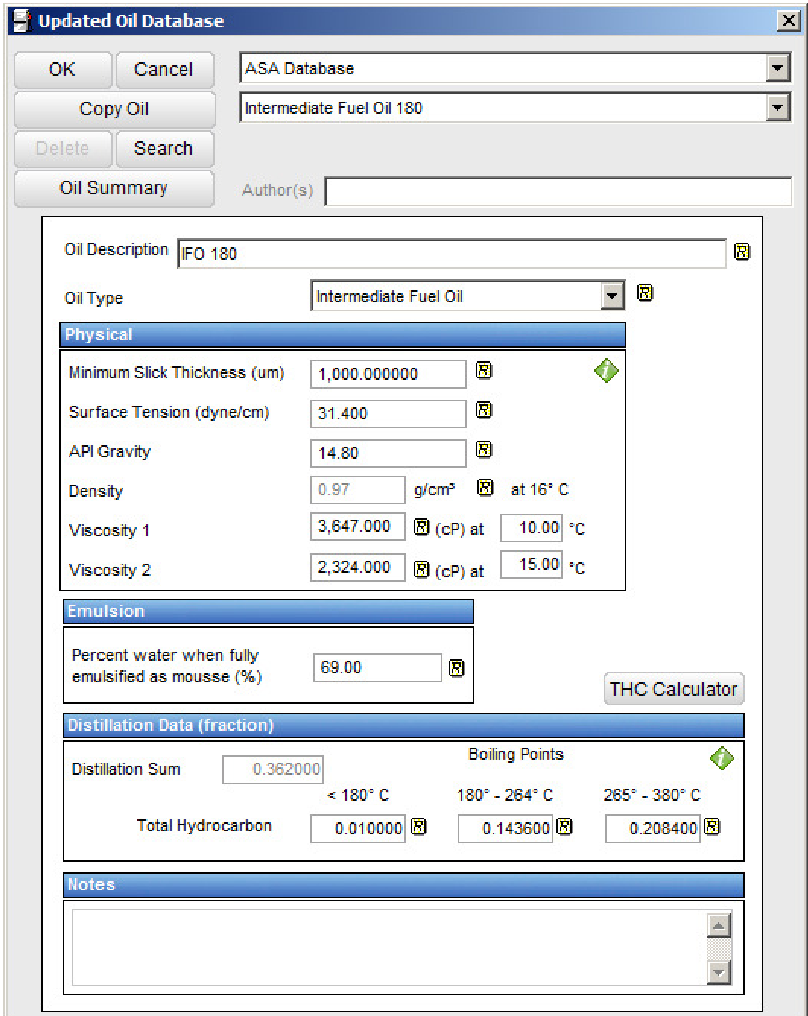


Figure 3-2: Intermediate Fuel Oil 180 Physical Parameters (Source: ASA Updated Oil Database, OILMAP v 6.10.2.0)

Another property of fuel that is especially significant in Arctic conditions is the pour point, which is the lowest temperature at which the fuel will flow, typically at -30℃ (ESTD, Environment Canada, 2010). At temperatures below the pour point, the fuel solidifies rapidly and the spreading is minimized.

During periods of high winds and waves, the fuel can form narrow bands that are aligned with the wind direction, a state in which the slick movement is controlled by the sea state rather than the fuel properties (ITOPF, 2010).

Another major weathering process within the first days of a spill is evaporation. According to ITOPF (2010), most of the fuel components with a boiling point under 200℃ tend to evaporate within the first few days.

The fuel fraction that is not lost to evaporation or dilution in water is eventually broken up into droplets of varying sizes which are subject to dispersion. The process of dispersion, often accelerated by the application of dispersants, contributes towards faster biodegradation, dissolution and sedimentation of the spilled fuel. Dispersion can be hindered by emulsification of the fuel under the action of waves, which is a common cause for the persistence of spilled fuel in the marine environment. On a time scale longer than a week, the dominant weathering processes become biodegradation by microorganisms and sedimentation and sinking processes (ITOPF 2010).

Primary environmental parameters that effect the weathering of spilled fuel include sea temperature, winds and ice.

Model Implementation

For weathering algorithm development for the OST model, scenarios of IFO 180 fuel were simulated with the OILMAP software which calculates the evaporation, dispersion, and remaining percentage for a given spill scenario where the user defines a fuel product type, weather conditions, properties of the receiving water, and the amount of fuel released.

Illustration of the weathering of IFO 180 fuels for a range of sea temperatures, and constant wind speed of 5 m/s, is presented in Figure 3-5 and Figure 3-6.

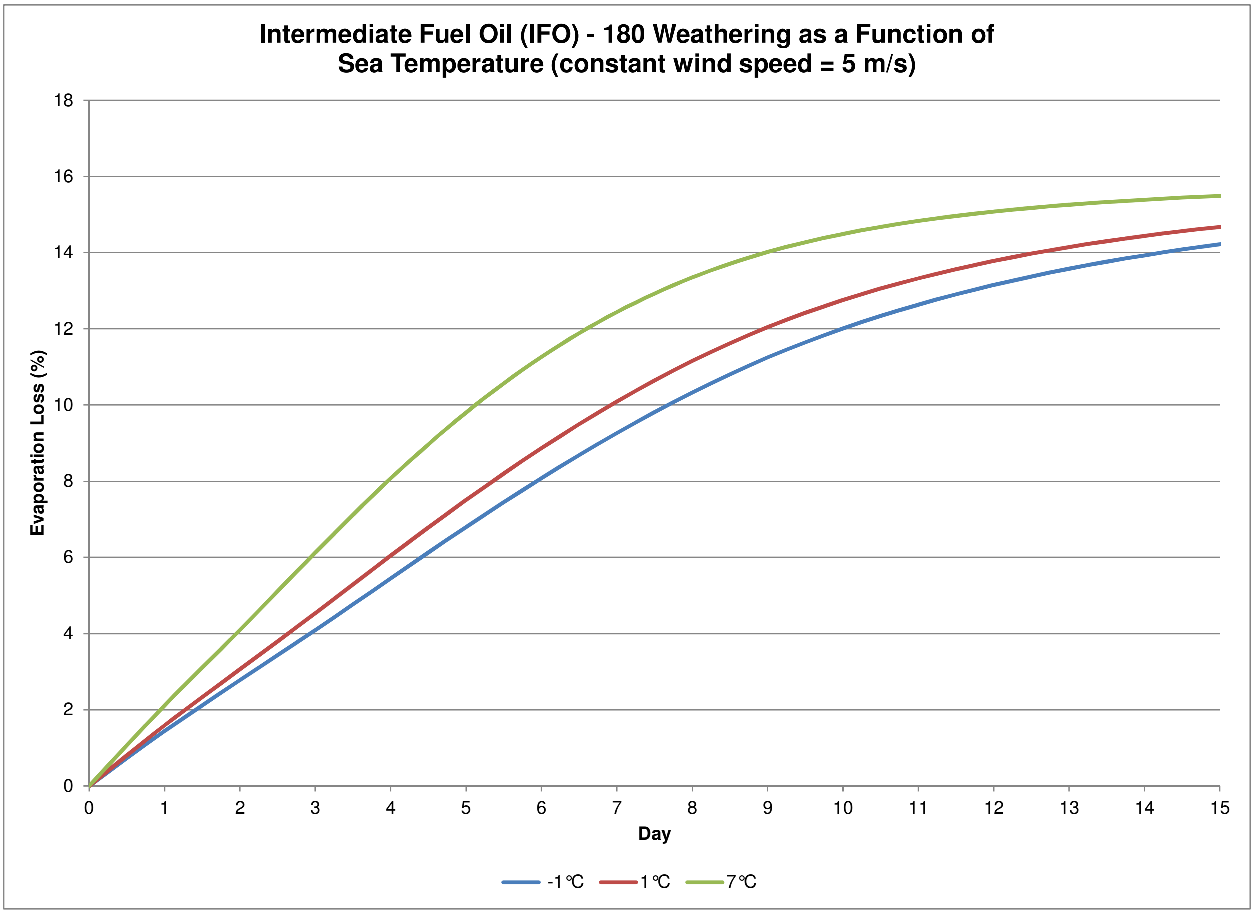


Figure 3-3: IFO 180 Weathering: Evaporation Loss as a Function of Sea Temperature (Source: OILMAP)

Modelled values for sea temperature are available from the HYbrid Coordinate Ocean Model (HYCOM), implemented as part of the global Real-Time Ocean Forecast System (Atlantic) model of the National Oceanic & Atmospheric Administration (NOAA) (National Weather Service, 2014). The experiments (data) for September 2008 to July 2014 were used. Near-surface – as the average of the 0 and 10 m depths – sea temperatures over the study area, average from -0.6℃ in October to 4.2℃ in August (Figure 3-4). From a conservative view, for less evaporation loss, 1℃ is selected for the spill weathering.

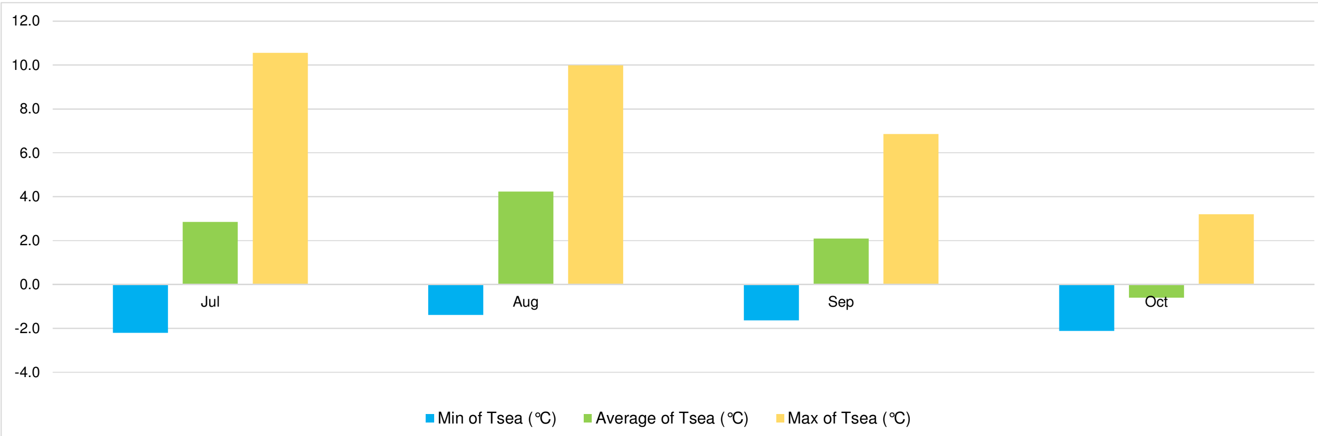


Figure 3-4: Sea Temperature, September (Source: HYCOM)

With an assumed 1℃ sea temperature in hand, estimates of the likely weather losses due to evaporation and to dispersion into the water column were prepared again using OILMAP. These results are shown in Figure 3-5 and Figure 3-6 for a range of wind speeds for both fuel types. These results are also tabulated in Table 3-2 and Table 3-3.

These tables were in turn implemented in the OST weathering routine; with the appropriate fuel type lookup applied. The lookup is simply based on time into the spill, and wind speed, and was used to calculate the percentage weathering losses, at each time step in the trajectory simulations. The spill modelling does not treat a specific volume of fuel, rather the percentage fuel remaining – less what is lost due to evaporation and water column dispersion - is estimated, and provided in the OST outputs; in this way one can apply the percentages to any chosen volume.

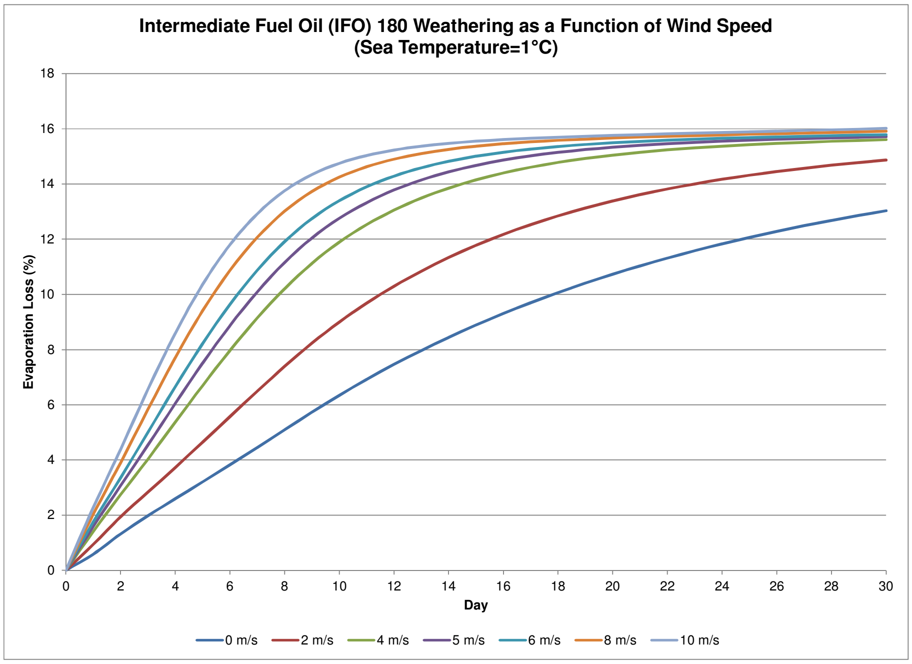


Figure 3-5: IFO 180 Weathering: Evaporation Loss as a Function of Wind Speed (Source: OILMAP)

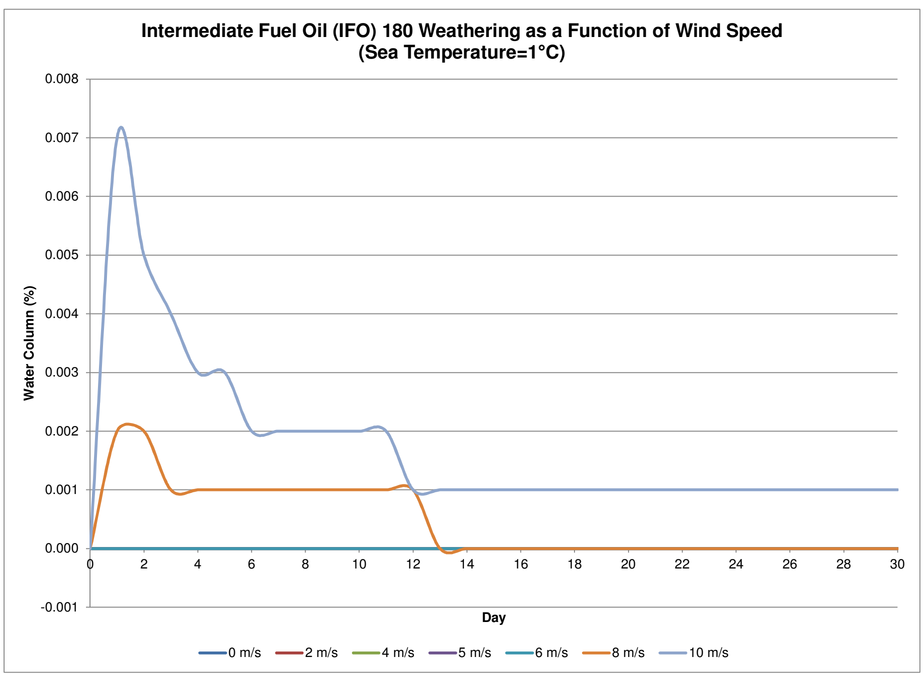


Figure 3-6: IFO 180 Weathering: Water Column Loss as a Function of Wind Speed (Source: OILMAP)

Table 3-2: IFO 180 Weathering: Evaporation Loss as a Function of Wind Speed

Wind Speed (m/s)	Evaporation Loss Rate (% per day) for time into Spill (days)				
	0-1 days	**2**	**3-4**	**5-9**	**10+**
0-1	0.6	0.7	0.6	0.6	0.3
1-3	0.9	1.0	0.9	0.9	0.3
3-4.5	1.4	1.3	1.3	1.2	0.2
4.5-5.5	1.6	1.5	1.5	1.2	0.2
5.5-7	1.8	1.6	1.6	1.2	0.1
7-9	2.0	1.9	1.9	1.2	0.1
9+	2.3	2.1	2.1	1.2	0.1

Table 3-3: IFO 180 Weathering: Water Column Loss as a Function of Wind Speed

Wind Speed (m/s)	Water Column Loss Rate (% per day) for time into Spill (days)		
	0-2 days	**3-9**	**10+**
0-7	0.0	0.0	0.0
7-9	0.002	0.001	0.0
9+	0.006	0.002	0.001

3.2 Model Input

3.2.1 Wind

Winds for input to the spill models were selected following comparison of a number of sources. These included:

- the met station at the Milne port site
- Environment Canada climate stations at Pond Inlet
- MSC North Atlantic wind and wave hindcast winds just east of the entrance to Pond Inlet
- European Centre for Medium-Range Weather Forecasts (ECMWF), ERA Interim (ERAI) class, Atmospheric Model winds at 10 m, gridded over the study area

While the ERAI wind speeds were judged to be a bit low compared to measurements from the Milne camp site, and at times, also at Pond Inlet, they provide long time-series records over the entire study area and were selected to provide reasonable wind inputs for the spill model.

The winds from Pond Inlet and two ERAI locations in Eclipse Sound are illustrated for July and October months in time series plots in Figure 3-7 and Figure 3-8, and with wind roses in Figure 3-9.

Four ERAI grid points were selected for the OST spill model as shown in Figure 3-10: winds at the grid point nearest a given scenario location were selected for each scenario's model input. For the two shoulder season scenarios in Eclipse Sound and at the mouth of Milne Inlet, the ERAI_725_790 winds were used.

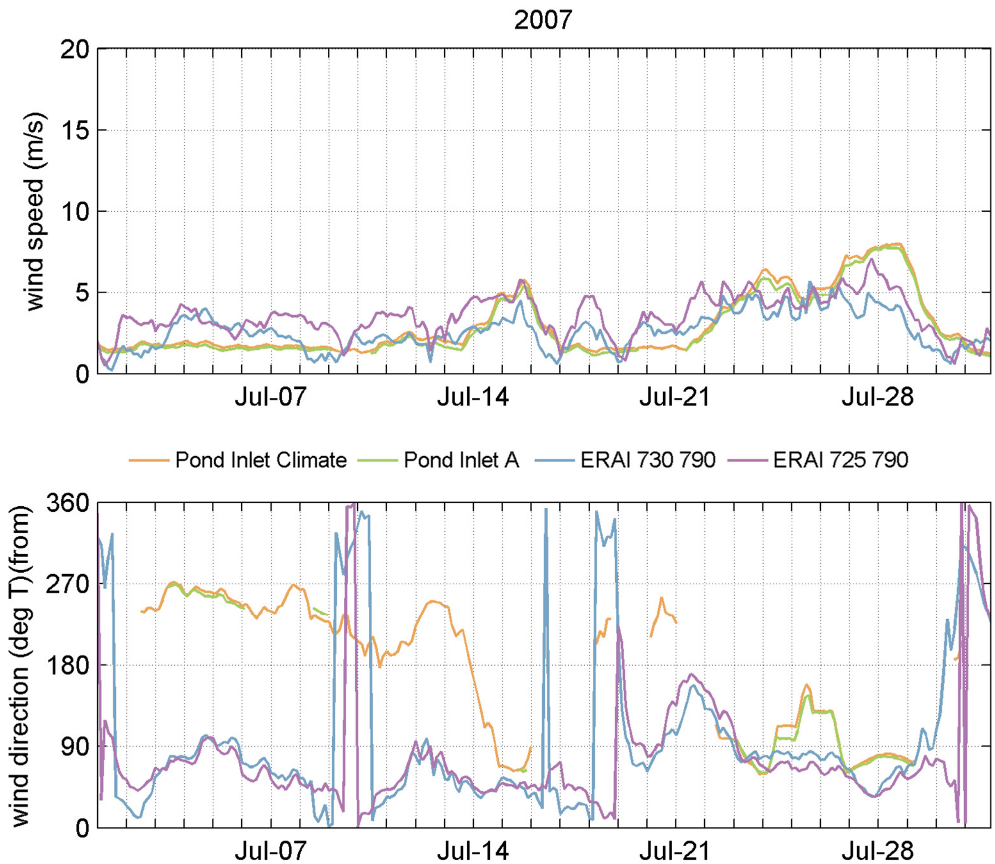


Figure 3-7: Wind Comparison, July 2007

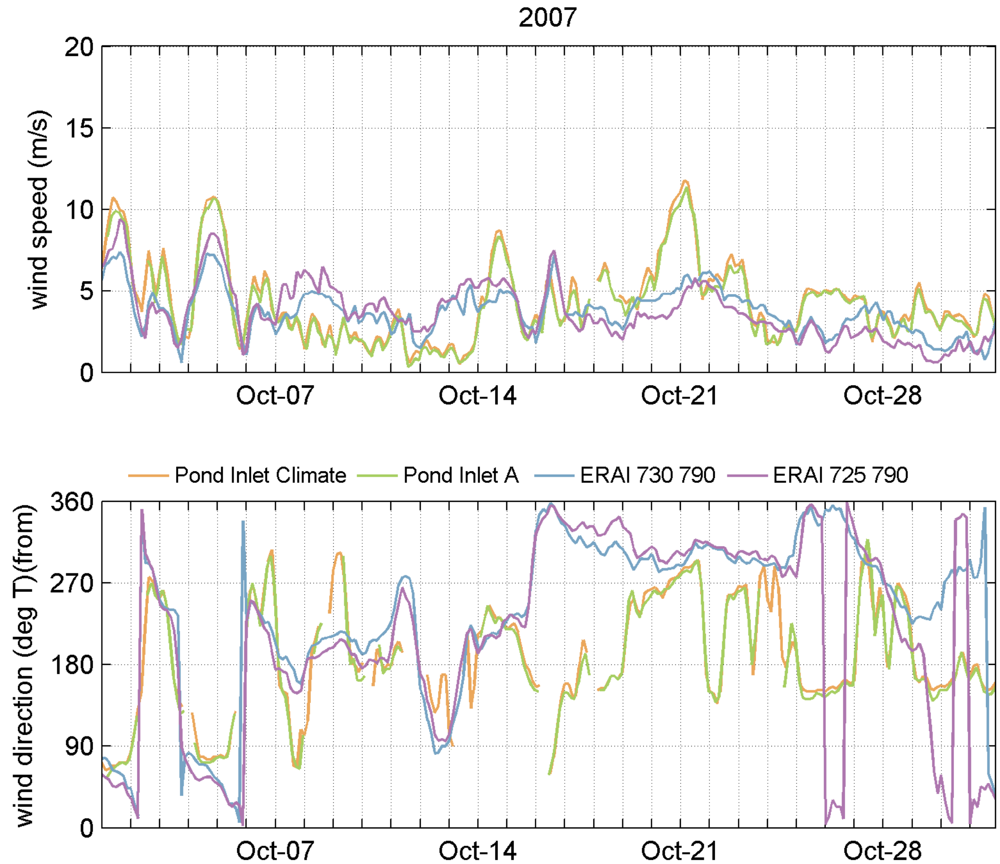


Figure 3-8: Wind Comparison, October 2007

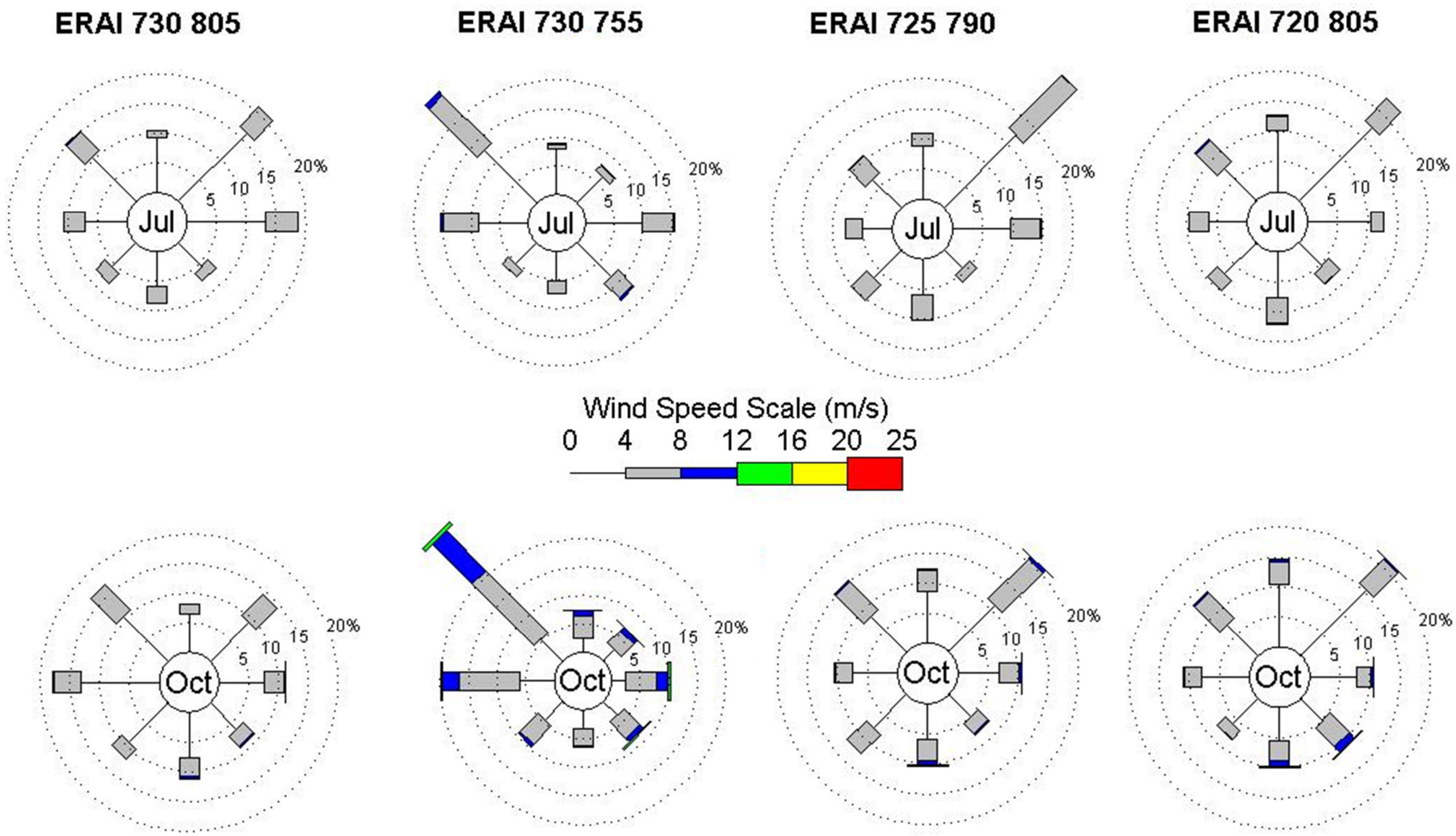


Figure 3-9: Wind Roses, July and October, 1984-2013

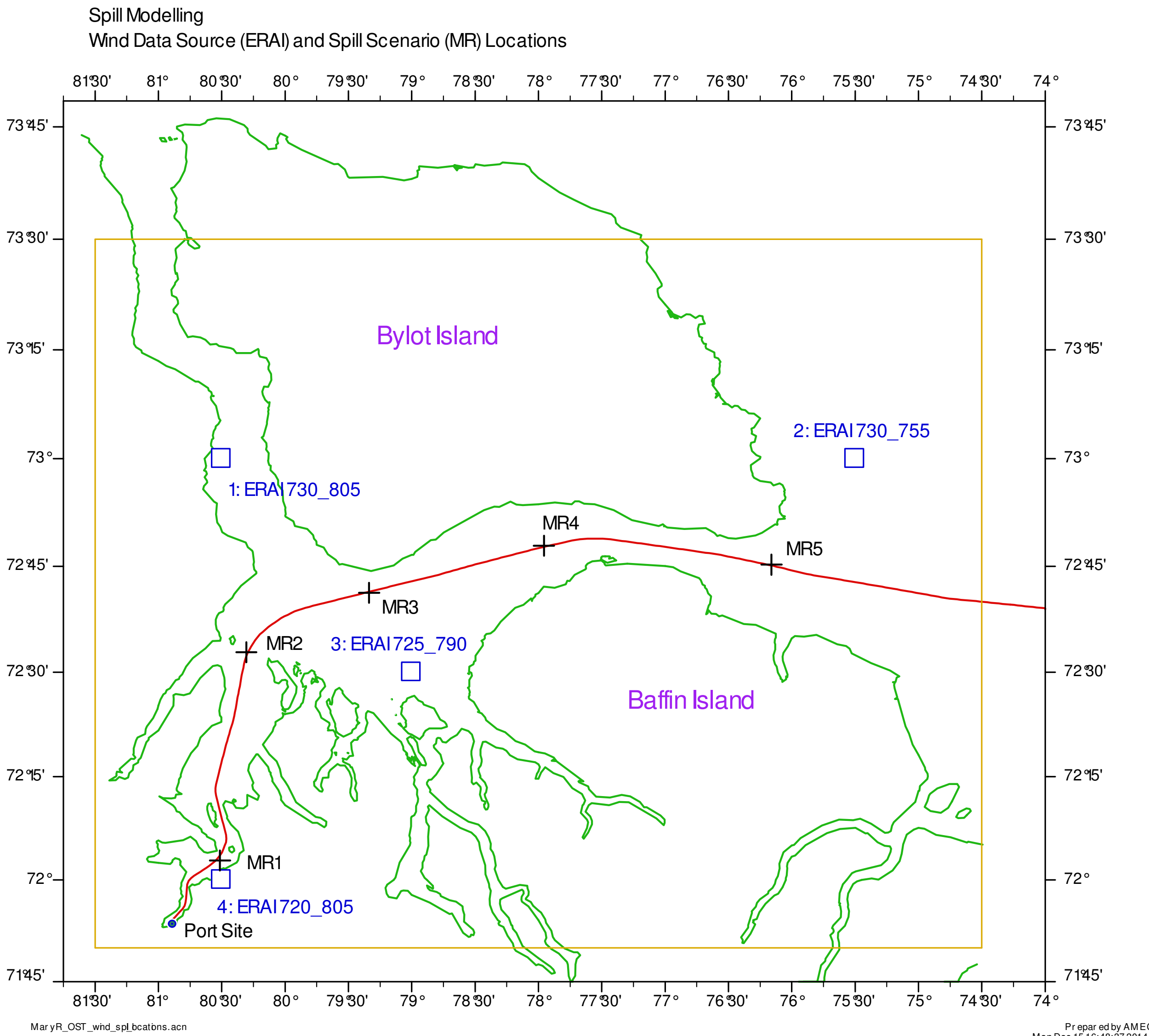


Figure 3-10: Wind Data Source Locations (ERAI grid points denoted with blue squares)

3.2.2 Ocean Currents

The high resolution ocean circulation model, the HYbrid Coordinate Ocean Model (HYCOM), is implemented as part of the Real-Time Ocean Forecast System (Atlantic) HYCOM model of the National Oceanic & Atmospheric Administration (NOAA) (National Weather Service, 2014). HYCOM current model experiments for July and October months from 2008 to 2013 were downloaded for an area near Baffin Island encompassing the spill model domain. The model yields one value per day at depth levels of 0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500, ..., 1400, 1500 m. The grid spatial resolution ranges from 2.5 to 3.0 km. For the spill model, mean current velocities were calculated for the average of the 0 and 10 m depths to yield an estimate of near-surface ocean current. Statistics for these are shown in Figure 3-11. These are the residual currents. Tidal currents are small on the order of less than 5 cm/s and not considered in the model. Given the effect of winds on the currents, over the period of six years there is a wide variability in maximum currents, ranging from about 50 to 85 cm/s in July and 49 to 88 cm/s in October. Mean current speeds in July and October are 13 cm/s.

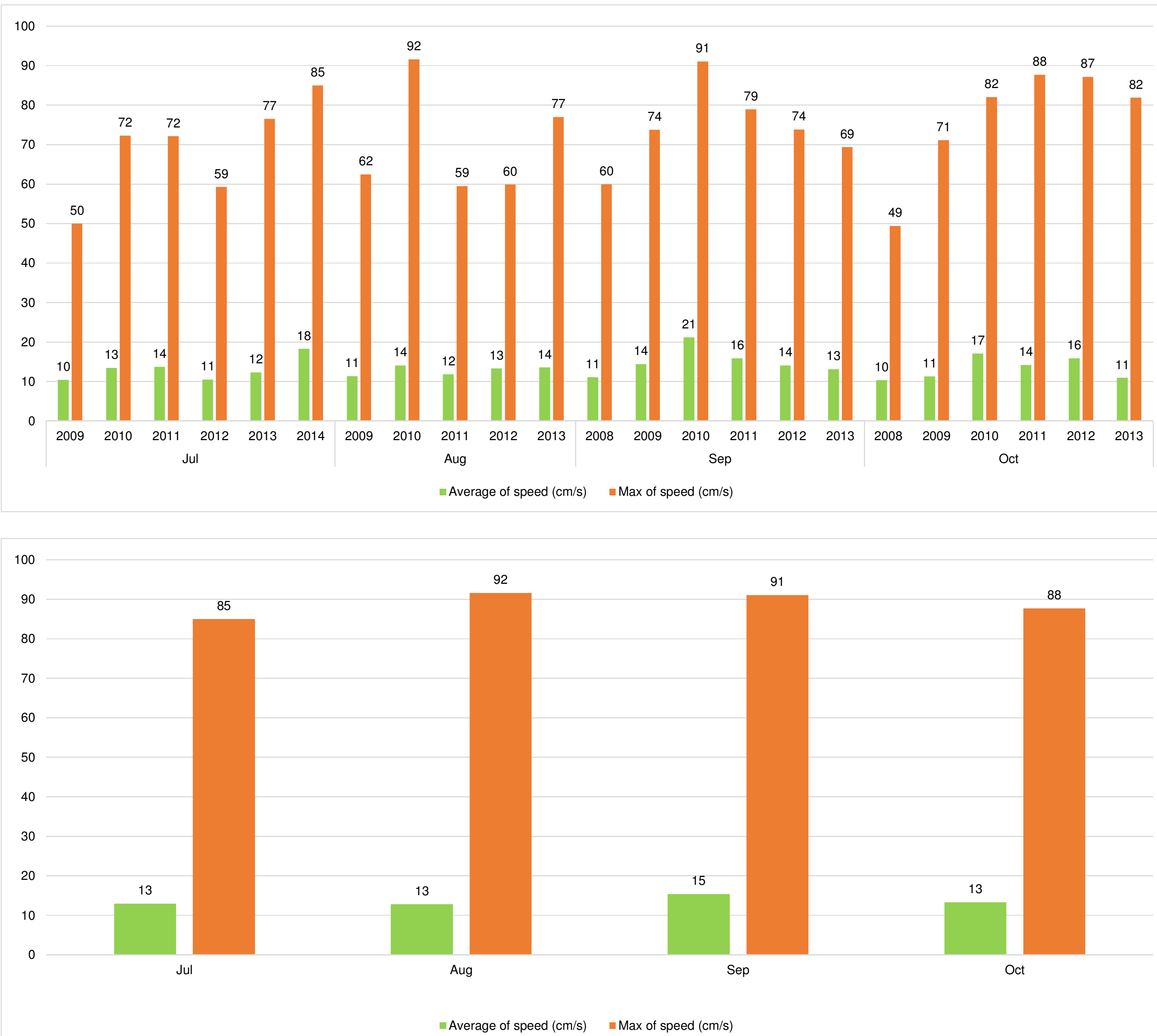


Figure 3-11: Current Speed, July to October, Northern Shipping Route

Spatial current grids for July and October are shown in Figure 3-12 and Figure 3-13. A 25 cm/s vector scale is shown: depending on location some current vectors are larger, others smaller than this length.

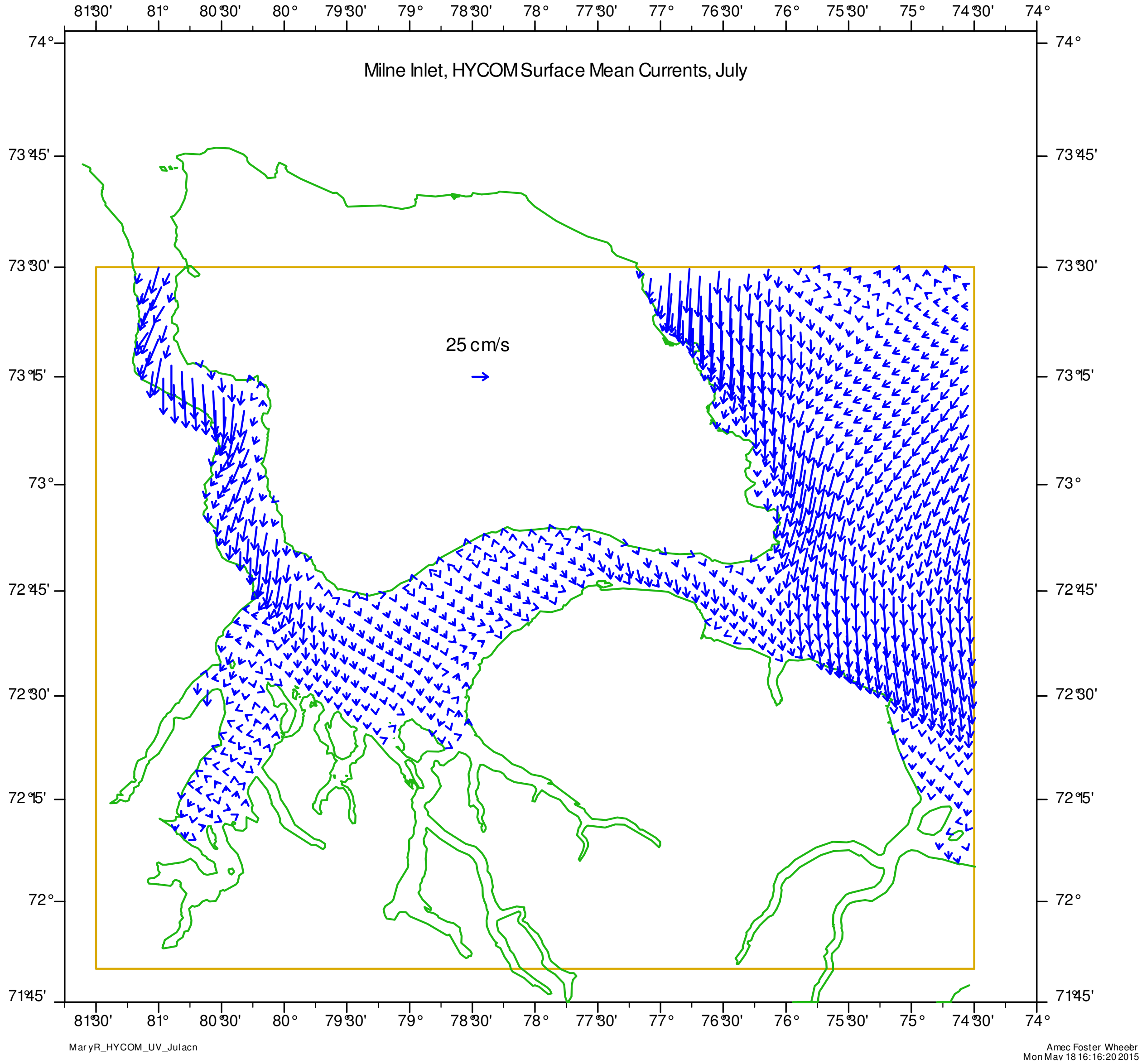


Figure 3-12: Milne Inlet, HYCOM Surface Mean Currents, July

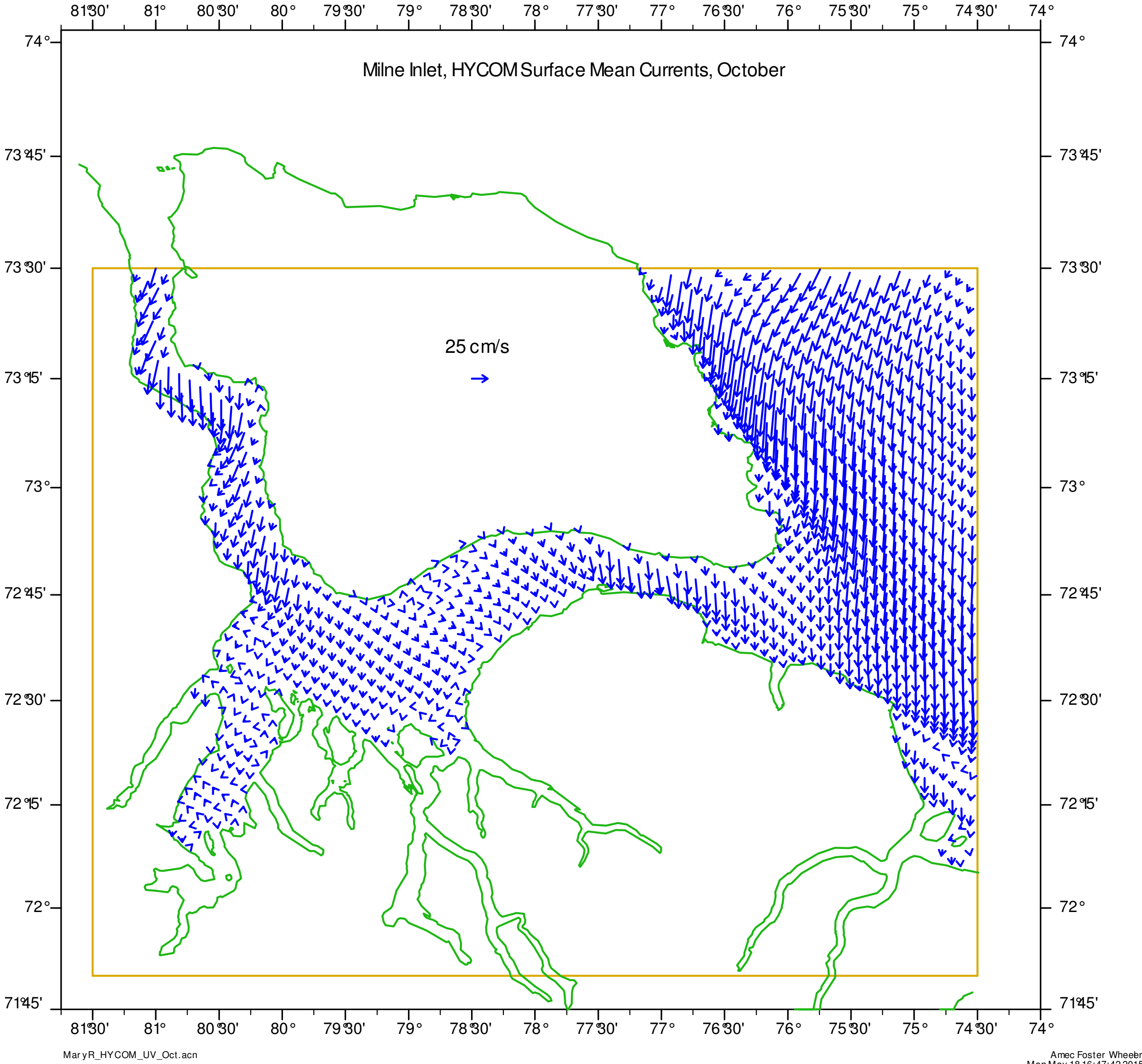


Figure 3-13: Milne Inlet, HYCOM Surface Mean Currents, October

3.3 Model Output

3.3.1 Individual Day Spill Trajectory Plots

The basic spill modelling result is generated by introducing a spill on any given day of a given month, e.g., July or October, of any year, at the scenario location. The trajectory of the spill is computed over an ensuing time interval until the trajectory eventually terminates on a coastline or on an external model grid boundary (e.g., latitude 73°30’N at the north of the model grid) or until a maximum duration of thirty days is reached. For example, a spill initiated on 20 July 2000 would take as input the portion of the 2000-2013 wind time-series that commences on 20 July 2000. The model trajectory then traces out the path the spill would take over the subsequent thirty days: 20 July, 21 July, … 18 August or until, as noted above, the trajectory terminates on a coastline or model grid boundary. Any spill that continues into August uses the corresponding August winds, currents and ice. The daily (interpolated from weekly) ice chart in effect on the given day is used for determining ice concentration at the spill’s location.

This trajectory is one “representative case” and illustrates the possible geographical distribution of fuel which could have evolved for a spill originating on that day in the given month and year (e.g., 20 July 2000).

The start dates for spill scenarios, 20 July and 5 October, are three days before the corresponding CIS weekly ice chart historic dates of 23 July and 8 October. In this way, the utility of those charts is maximized for the mid-July and mid-October time periods. A three week “shoulder season” period of daily scenario spills is considered, e.g., a spill on 20 July, a spill on 21 July, …, a spill on 9 August. Each mid-July and mid-October period is modelled for the 14 years 2000 to 2013.

Note: spills are considered to happen on each day for a three week “shoulder season” period.

3.3.2 Shoreline Zone Definitions

For a scenario in which at least one trajectory terminates ashore, the fuel distribution probability calculations yield an accompanying set of shoreline summary statistics. These statistics identify, by geographical region, the percentage of trajectories that reach shore, and the earliest, mean, and latest times to shore. For the Milne Inlet study area 13 regions are defined to cover the model domain. These regions are illustrated in Figure 3-14.

Companion model output listings report statistics for each day/year trajectory as follows:

- row and column of the grid cell where the trajectory ended
- “ORI” land (‘I’) or water (‘O’) designation of the end point
- range, bearing, and latitude and longitude or the end point
- whether the trajectory reached shore or a model boundary
- elapsed time of the trajectory, until it ended
- path length and mean speed

- percent of original fuel volume remaining after weathering

By introducing a spill at the beginning of each day of either the mid-July (20 Jul to 9 Aug) or mid-October (5-25 Oct) periods for each of the 14 years of wind and ice data, and superimposing the resulting 294 (21 x 14) daily trajectories on a single plot, a representative indication of possible slick motion for that time period is achieved. This is quantified through a count of the number of individual trajectories that travel through a given square, e.g., a count of 6 is 2% of the 294 trajectories so that one can estimate a 2% probability of fuel reaching that grid square. This is described further in Section 3.3.1.

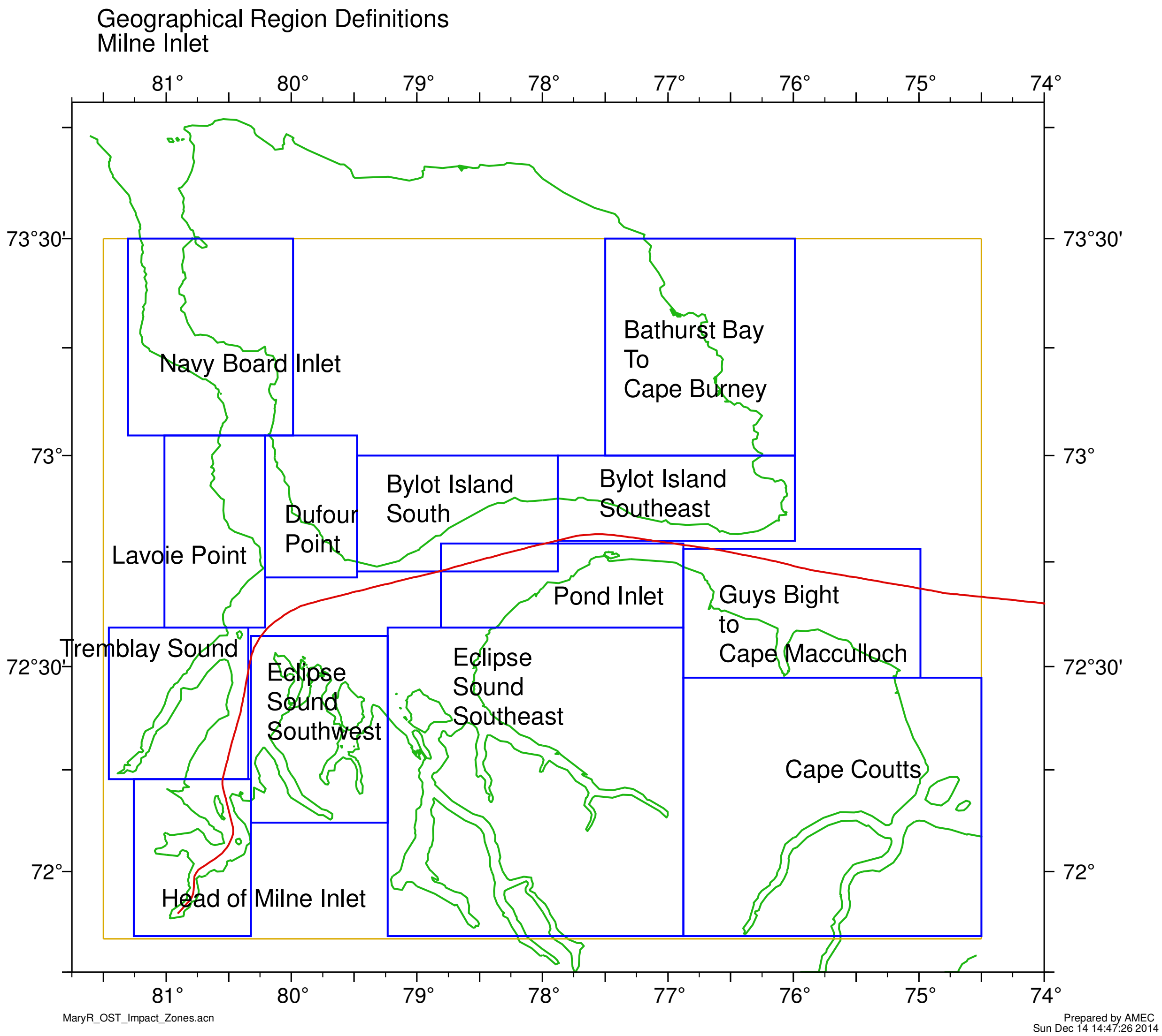


Figure 3-14: Definition of Geographical Regions for Interpretation of Shoreline Statistics

3.3.1 Composite Fuel Distribution Probability Maps

To define the probability of fuel distribution for either the mid-July or mid-October 3-week period, every possible spill originating each day over the 14 year duration of the wind record is considered. That is, all possible trajectories (up to 21 days at 14 per day) are simulated. For each element or cell of the computational grid (350 columns by 250 rows) a record of the number of trajectories passing through that element is maintained. By knowing the total number of trajectories simulated for a given time period, it is thus possible to identify the percentage of those trajectories which passed through any particular grid element. Due to the large number of trajectories simulated for a given time period, e.g., mid-July, this percentage can be interpreted as the probability that fuel released at the spill site for that time of year, would reach the particular grid element. Grid elements having similar levels of probability can be grouped to present a contoured display of fuel distribution probabilities.

The probable directions of slick motion and probable spill destinations are now more precisely defined by the probability plots than by a representative case, or individual day, scenarios. The basic probability plots have been developed from simulations of every possible day spill over the duration of the available 14-year wind record.

3.3.2 Presentation and Interpretation of Results

The spill probability maps employ the following colour code.

Probability Range	**Colour**
25% < P < 100%	Orange
15% < P < 25%	Red
5% < P < 15%	Pink
2% < P < 5%	Yellow
1% < P < 2%	Light Blue
0% < P < 1%	Grey

Land is shown in green. The shipping route is shown in red.

The percentages can be interpreted as presenting the probability that fuel would reach any particular location on the map, given a spill originating on any day of the particular time period. In this instance, the 25%, 15%, 5%, 2%, 1%, and 0% contours of probability are illustrated.

Orange contours indicate that 25 to 100% of all trajectories will pass through that location (grid cell in the model). Grey contours indicate that 1% or less of all trajectories (in the case of 294 simulations, 1 to 3 of 294 trajectories) will pass through that location.

There is no implication that a spill could cover the entire zone enclosed by a contour, only that the fuel would drift through or be located at some position within this zone. The contours represent the maximum possible affected zone and in reality any spill would be likely to affect only some modest subset of the region, depending on wind and current conditions over the duration of the spill, and the weathered fate of the spill slick.

These probabilities are derived from scenarios in which the hypothetical spills are both uncontained and unmanaged, conditions that would be limited given an appropriate fuel spill emergency contingency planning and response plan in place.

4.0 RESULTS, MID-JULY, ECLIPSE SOUND

This section presents spill probability plots for the mid-July spill scenario in Eclipse Sound. Two scenarios were run for mid-July: with no ice and with ice (Figure 4-1 and Figure 4-2). The probability distributions are quite similar which is not entirely unexpected given use of the same winds and currents and limited movement of the slick with ice.

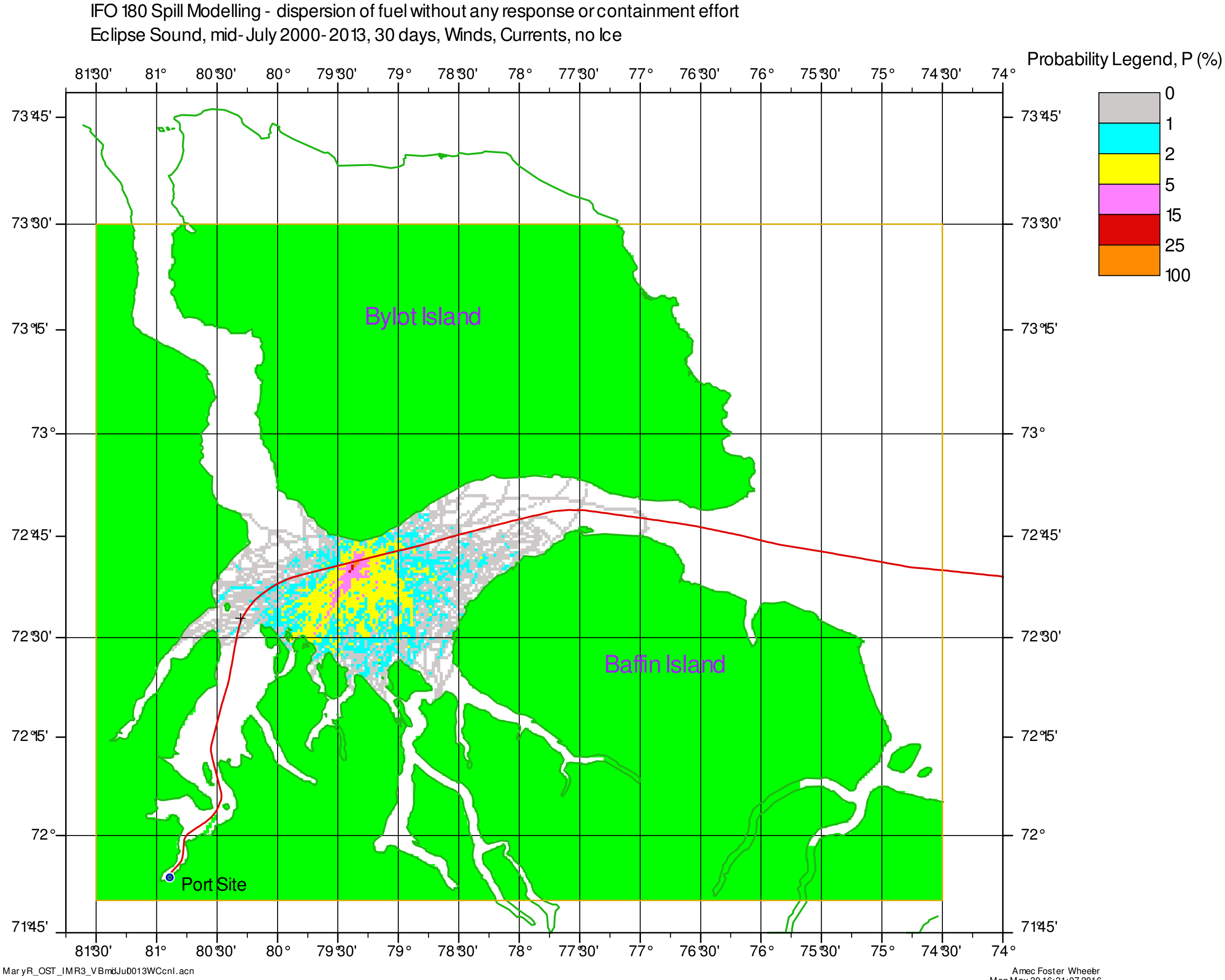


Figure 4-1: Spill Distribution Probability Plot, Eclipse Sound, mid-July, no Ice

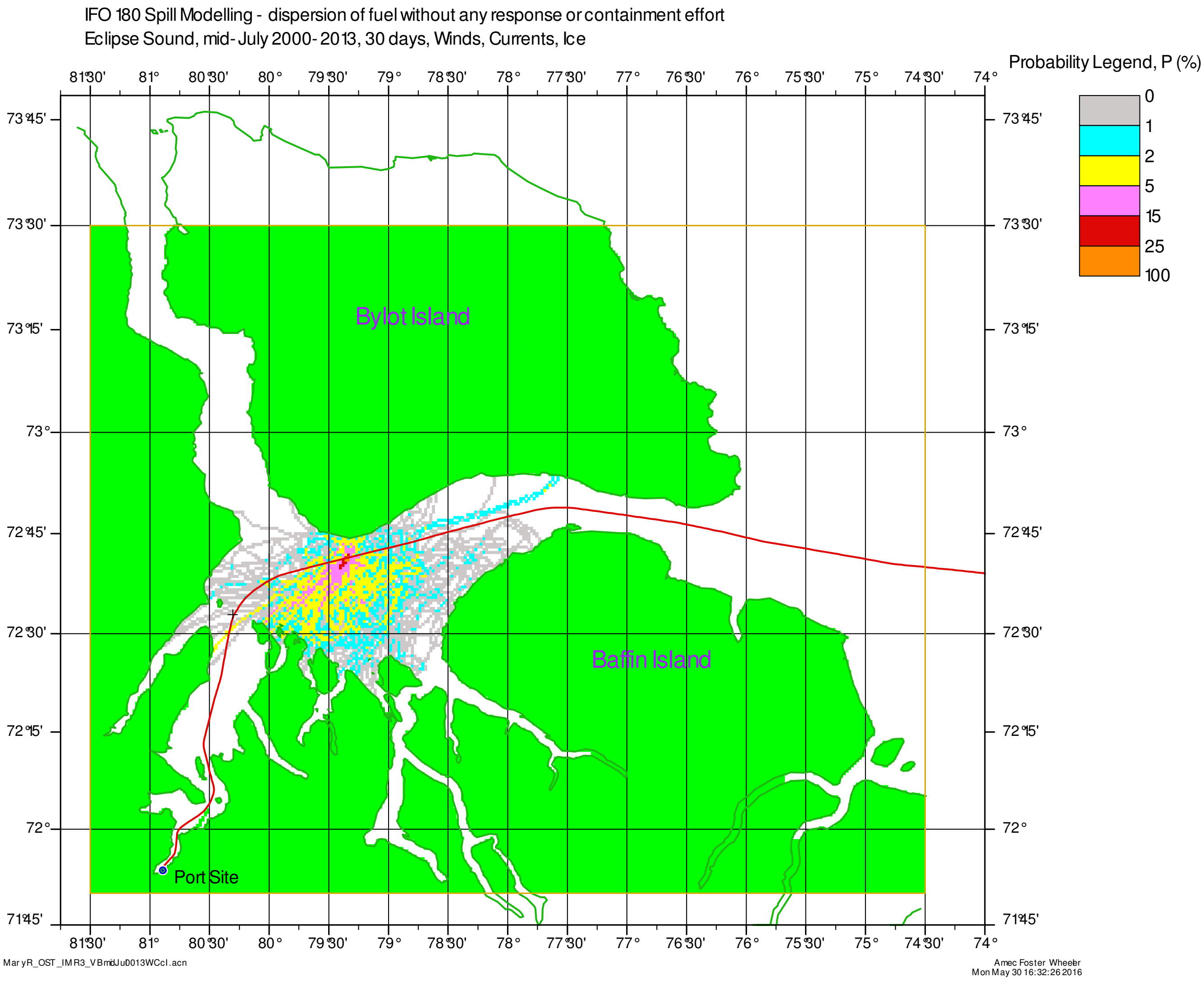


Figure 4-2: Spill Distribution Probability Plot, Eclipse Sound, mid-July, Ice

It is important to note these figures are of the probabilities of the spill trajectory reaching or travelling through a given location and do not permit a direct comparison of trajectories, one by one, under the no ice or ice scenarios. The inherent differences that exist in the model results, and are tallied with the probability maps, are illustrated and briefly discussed in two example subsets of the total of 294 (21 days, 14 years) break-up scenario trajectories. The end point of the trajectories (orange: no ice, blue: ice) are identified with their month-day or year.

The first example in Figure 4-3 shows trajectories for all of the break-up days in 2004. The associated weekly sea ice charts, from which daily ice concentrations were interpolate, are shown in Figure 4-4.

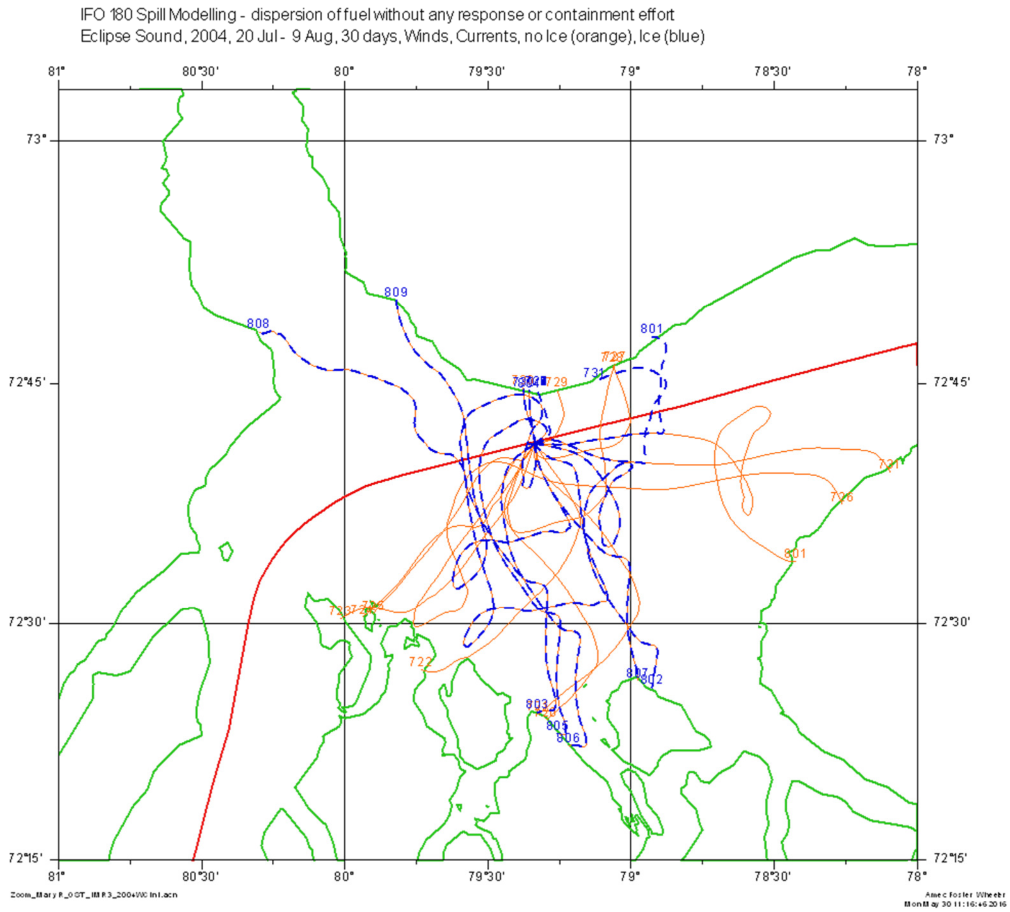


Figure 4-3: Eclipse Sound, 20 July to 9 August, 2004, Spill Trajectories for No Ice and Ice Scenarios

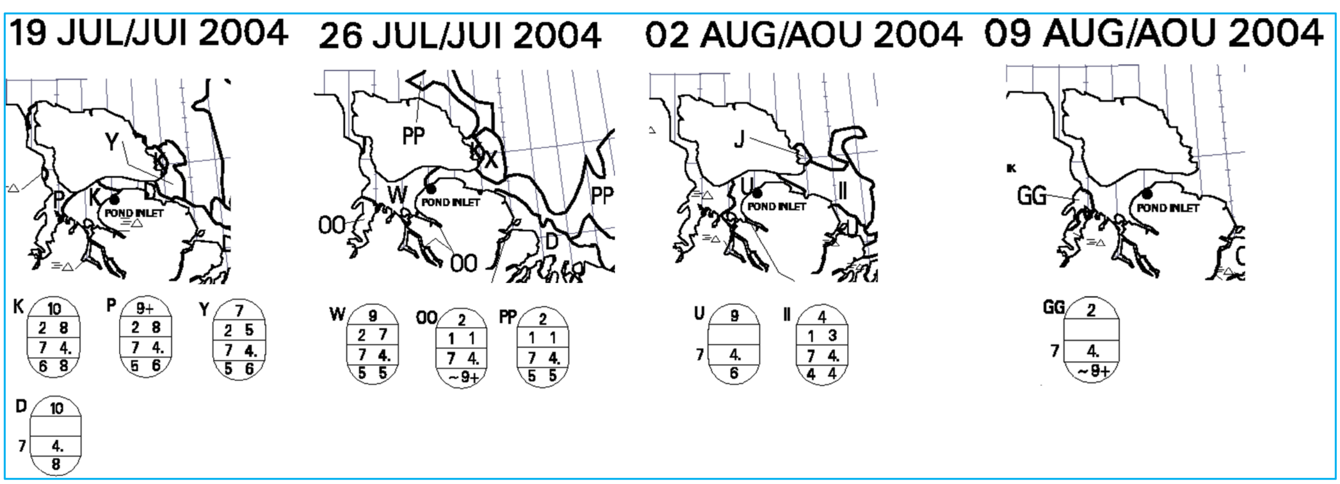


Figure 4-4: Eclipse Sound, Weekly Ice Chart Excerpts, 19 July to 9 August, 2004

Table 4-1 lists, for the duration (elapsed time) of a given day's trajectory, in addition to some basic distance and time statistics, the number of days (N), and percent of the time, the sea ice is encountered in a given concentration, Ct, range:

- Ct0.3 – bergy water (Ct=0.2) or open water
- Ct1 – Ct between 0.3 and C1: in the scenario runs C1 equals 3/10
- Ct2 – Ct between C1 and C2, in the scenario runs C2 equals 6/10
- Ct10 - Ct between C2 and 10/10

Table 4-1: Eclipse Sound, mid-July Break-up, Scenario Dates 22 Jul, 1 Aug 2004, Trajectory Statistics

Site	Ice	Month	Day	Year	Range (km)	Bearing (degT)	Ashore	Elapsed Time (h)	Path Length (km)	Mean Speed (km/d)	% at End Point	Ct min	Ct mean	Ct max	N Ct0.3	N CtC1	N CtC2	N Ct10	% Ct0.3	% CtC1	% CtC2	% Ct10
Eclipse Sound	No	7	22	2004	29	205	YES	89	37.3	10.1	95.9	0	0	0	88	0	0	0	98.9	0	0	0
Eclipse Sound	Yes	7	22	2004	6	0	YES	199	7.6	0.9	91	3.1	8.2	9.5	0	0	30	168	0	0	15.1	84.4
Eclipse Sound	No	8	1	2004	34	114	YES	175	71.3	9.8	91.6	0	0	0	174	0	0	0	99.4	0	0	0
Eclipse Sound	Yes	8	1	2004	18	47	YES	117	27.1	5.6	94.4	0.2	4.1	9	54	0	13	49	46.2	0	11.1	41.9

The 22 July (id 722) trajectory under no ice reaches shore to the southwest at Cape Hatt on Baffin Island in just under four days, while in ice, the trajectory reaches shore on Bylot Island just east of Dufour Point in just over eight days. The mean ice concentration during this eight and a half days is about 8/10, and with a minimum concentration of about 3/10. These have the effect of limiting the drift: the path length is limited to about 8 km (compared with 37 km for the open water drift, no ice scenario) and the drift speed is less than one tenth (0.9 km/day in ice, 10.1 km/day with no ice).

The 1 Aug (id 801) date provides an illustration of a trajectory that actually reaches shore in sooner time with ice considered. This is due to the ice keeping the spill at sea for about six weeks at which time the ice melts and the wind shifts to a largely southerly flow taking the trajectory north to Bylot Island east of Dufour Point 18 km to the northeast of the spill location. Conversely, ignoring the ice conditions, the winds keep that trajectory offshore longer with a little loop in the orange trajectory, evident in the figure that moves things to the north, though not sufficient to reach shore. Two and a half days later the trajectory reaches shore 34 km to the south-southeast near Tunulaqtaiik Point. The east-west (x) and north-south (y) components of the wind displacements together with ice concentration are shown for these two events (with ice, YES, or no ice, NO) in Figure 4-5.

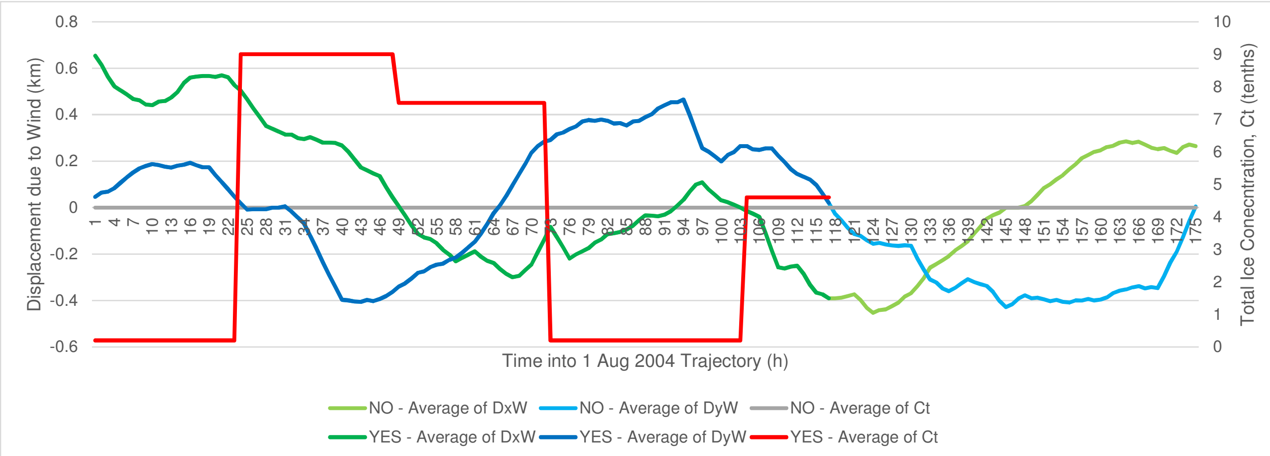


Figure 4-5: Eclipse Sound, Spill Displacement due to Wind and Ice Concentration, 1 August 2004

A second illustration is provided in Figure 4-6 and companion Table 4-2 shows trajectories for all July 30th's for all 14 years of the scenario.

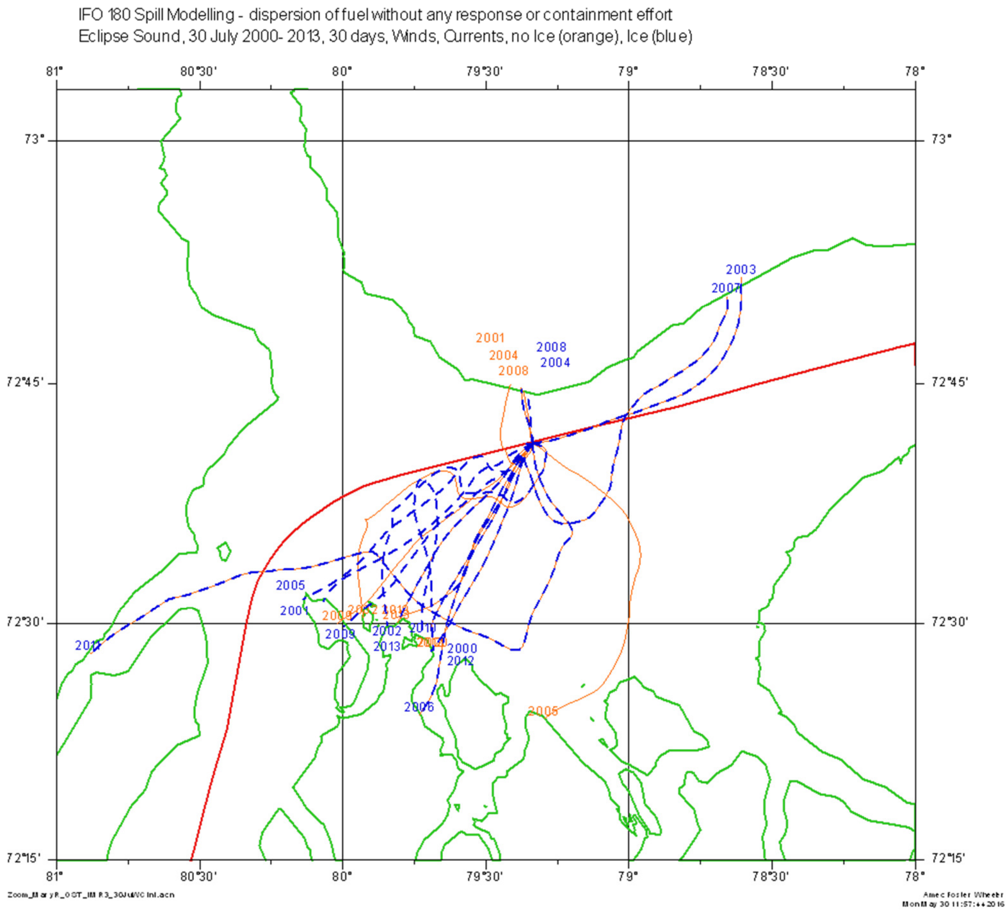


Figure 4-6: Eclipse Sound, 30 July, 2000-2013, Spill Trajectories for No Ice and Ice Scenarios

Table 4-2: Eclipse Sound, mid-July Break-up, Scenario Dates 30 July 2005, 2008, Trajectory Statistics

Site	Ice	Month	Day	YEAR	RANGE (km)	BEARING (degT)	Ashore	Elapsed Time (h)	Path Length (km)	Mean Speed (km/d)	% at End Point	Ct min	Ct mean	Ct max	N Ct0.3	N CtC1	N CtC2	N Ct10	% Ct0.3	% CtC1	% CtC2	% Ct10
Eclipse Sound	No	7	30	2000	26	204	YES	68	26.9	9.48	96.8	0	0	0	67	0	0	0	98.5	0	0	0
Eclipse Sound	Yes	7	30	2000	26	204	YES	68	26.9	9.48	96.8	0.2	0.2	0.2	67	0	0	0	98.5	0	0	0
Eclipse Sound	No	7	30	2001	7	337	YES	43	13.2	7.36	98	0	0	0	42	0	0	0	97.7	0	0	0
Eclipse Sound	Yes	7	30	2001	30	225	YES	175	30.5	4.18	91.6	2	5	8	0	78	48	48	0	44.6	27.4	27.4
Eclipse Sound	No	7	30	2002	28	223	YES	141	42.6	7.26	93.8	0	0	0	140	0	0	0	99.3	0	0	0
Eclipse Sound	Yes	7	30	2002	26	194	YES	164	49.5	7.25	92.7	2	3	7	0	137	0	26	0	83.5	0	15.9
Eclipse Sound	No	7	30	2003	30	50	YES	39	33.9	20.83	97.1	0	0	0	38	0	0	0	97.4	0	0	0
Eclipse Sound	Yes	7	30	2003	30	50	YES	39	33.9	20.83	97.1	0.2	0.5	2.7	34	4	0	0	87.2	10.3	0	0
Eclipse Sound	No	7	30	2004	7	346	YES	11	6.7	14.53	99.2	0	0	0	10	0	0	0	90.9	0	0	0
Eclipse Sound	Yes	7	30	2004	6	347	YES	11	6.4	14.02	99.2	3.1	2.8	3.1	0	0	10	0	0	0	90.9	0
Eclipse Sound	No	7	30	2005	32	176	YES	105	42.7	9.77	95.4	0	0	0	104	0	0	0	99	0	0	0
Eclipse Sound	Yes	7	30	2005	45	235	YES	223	50.3	5.41	90.1	0.2	5.5	9.1	20	0	106	96	9	0	47.5	43
Eclipse Sound	No	7	30	2006	34	201	YES	71	34.3	11.58	96.1	0	0	0	70	0	0	0	98.6	0	0	0
Eclipse Sound	Yes	7	30	2006	34	201	YES	71	34.3	11.58	96.1	0.2	0.2	0.2	70	0	0	0	98.6	0	0	0
Eclipse Sound	No	7	30	2007	27	52	YES	120	45.8	9.17	94.5	0	0	0	119	0	0	0	99.2	0	0	0
Eclipse Sound	Yes	7	30	2007	27	52	YES	120	45.8	9.17	94.5	0.2	0.2	0.2	119	0	0	0	99.2	0	0	0
Eclipse Sound	No	7	30	2008	6	348	YES	13	6.2	11.49	99.2	0	0	0	12	0	0	0	92.3	0	0	0
Eclipse Sound	Yes	7	30	2008	6	353	YES	28	5.9	5.08	98.3	4.7	4.5	4.7	0	0	27	0	0	0	96.4	0
Eclipse Sound	No	7	30	2009	30	226	YES	70	30.6	10.49	96.4	0	0	0	69	0	0	0	98.6	0	0	0
Eclipse Sound	Yes	7	30	2009	27	224	YES	71	27.3	9.22	96.3	0.5	2.7	3.6	0	22	48	0	0	31	67.6	0
Eclipse Sound	No	7	30	2010	25	217	YES	59	26.6	10.81	96.9	0	0	0	58	0	0	0	98.3	0	0	0
Eclipse Sound	Yes	7	30	2010	29	205	YES	207	34.7	4.02	90.3	0.8	5.3	9.7	0	76	35	95	0	36.7	16.9	45.9
Eclipse Sound	No	7	30	2011	56	244	YES	173	83.7	11.61	91.4	0	0	0	172	0	0	0	99.4	0	0	0
Eclipse Sound	Yes	7	30	2011	56	244	YES	173	83.7	11.61	91.4	0.2	0.3	0.5	128	44	0	0	74	25.4	0	0
Eclipse Sound	No	7	30	2012	26	205	YES	40	26.6	15.98	97.5	0	0	0	39	0	0	0	97.5	0	0	0
Eclipse Sound	Yes	7	30	2012	26	205	YES	40	26.6	15.98	97.5	1	1	1	0	39	0	0	0	97.5	0	0
Eclipse Sound	No	7	30	2013	26	216	YES	34	26	18.32	97.6	0	0	0	33	0	0	0	97.1	0	0	0
Eclipse Sound	Yes	7	30	2013	26	216	YES	34	26	18.32	97.6	0.2	0.2	0.2	33	0	0	0	97.1	0	0	0

A comparison of the two spill distribution probability maps is presented in Figure 4-7. The figure shows the difference in probability between the no ice and ice scenarios. For each grid cell the difference between ‘no ice’ and ‘ice’ is calculated. A negative value of 5% in red for example indicates that it is 5% more likely a spill trajectory will pass through that (grid cell) location in the ice scenario than in the no ice. Differences of 0% (i.e., same likelihood with ice and no ice) are not shown.

For the mid-July break-up scenario, there are quite similar extents to the spill probability zones of influence under both ice and no ice, as is also evident in Figure 4-1 and Figure 4-2 scenarios. About 80% of these differences are just ±1% (light blue, light red) showing very little difference in the likelihood of reaching a particular location under the no ice or ice scenarios.

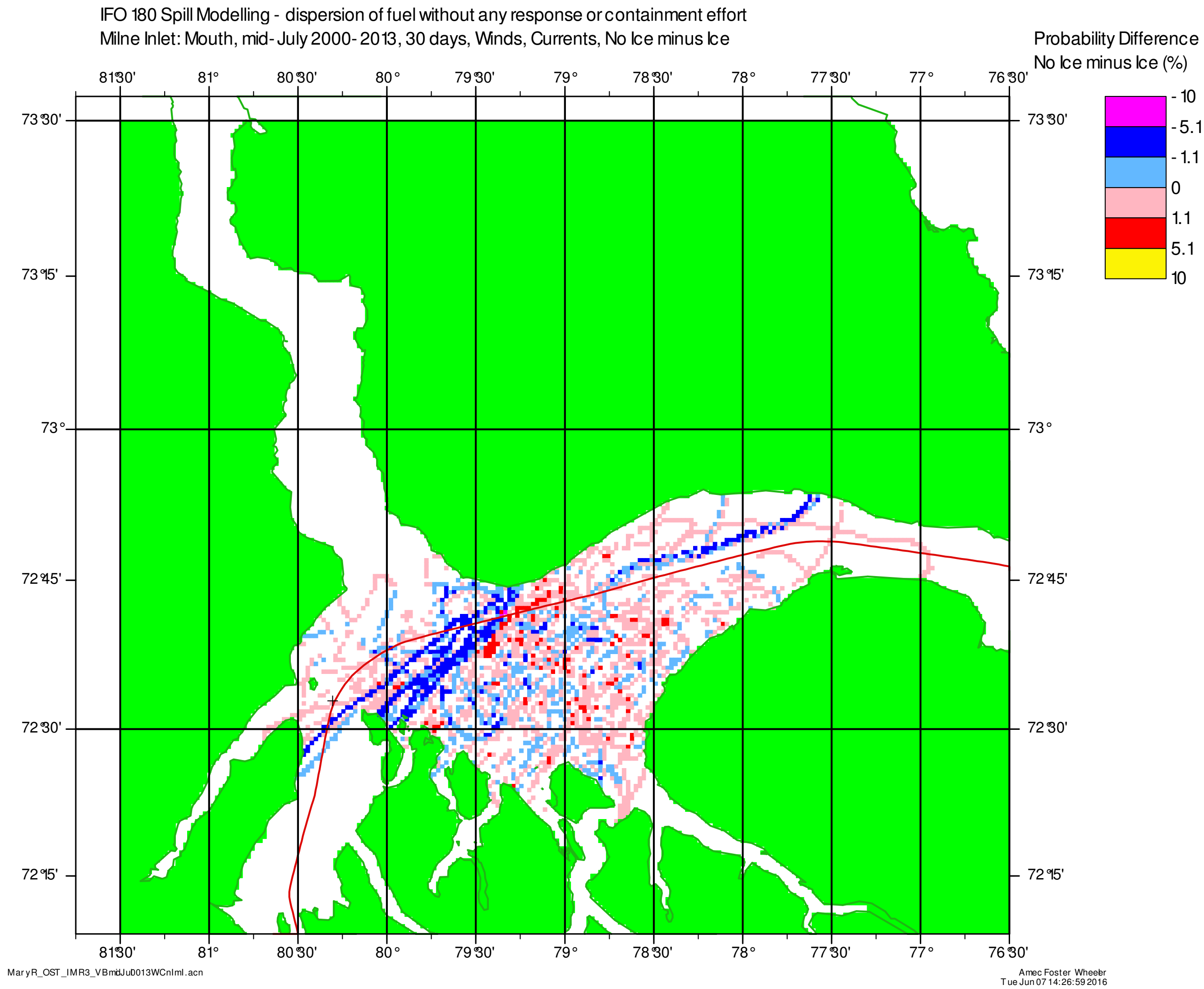


Figure 4-7: Eclipse Sound, mid-July, Spill Distribution Probability Difference for No Ice and Ice

One feature evident in the map is a narrow band (in blue) stretching southwest to northeast from Ragged Island at the mouth of Milne Inlet to Dufour Point across the western part of Eclipse Sound. These locations represent areas with slightly greater likelihood (2 to 5%) of seeing a spill trajectory in the ice scenario than in the no ice case. This is likely due to the occasional presence of sea ice in this western end of Eclipse Sound during the break-up. Unless winds and currents direct the drift to the east, the conditions will keep the spill up against the sea ice edge for a period of time limiting drift to the west.

What is also different between the two scenarios (no ice, ice) is the times to shore and regions affected. This is the subject of the next section.

4.1 Shoreline Statistics

The effect of ice for the mid-July scenarios is to keep the fuel offshore and delay any drift to one of the shorelines. As illustrated in Figure 4-8, the spill trajectories spend increasingly more time in ice of lesser concentrations as the break-up season progresses. Each bar in the figure tallies the mean percentage of time in each of the four ice ranges (Ct0.3 to Ct10) for that calendar day over all 14 years of the simulation. For example, for a spill originating on 20 July, about 41% of the time one can expect the trajectory to be trapped or held up in ice of concentration greater than 6/10 (C2) and 40% in ice of 4/10 to 6/10 (open drift). By contract, beginning 1 August, trajectories will spend a bit over half the time in bergy water and just under 20% in ice of concentration greater than 6/10 (close pack/drift).

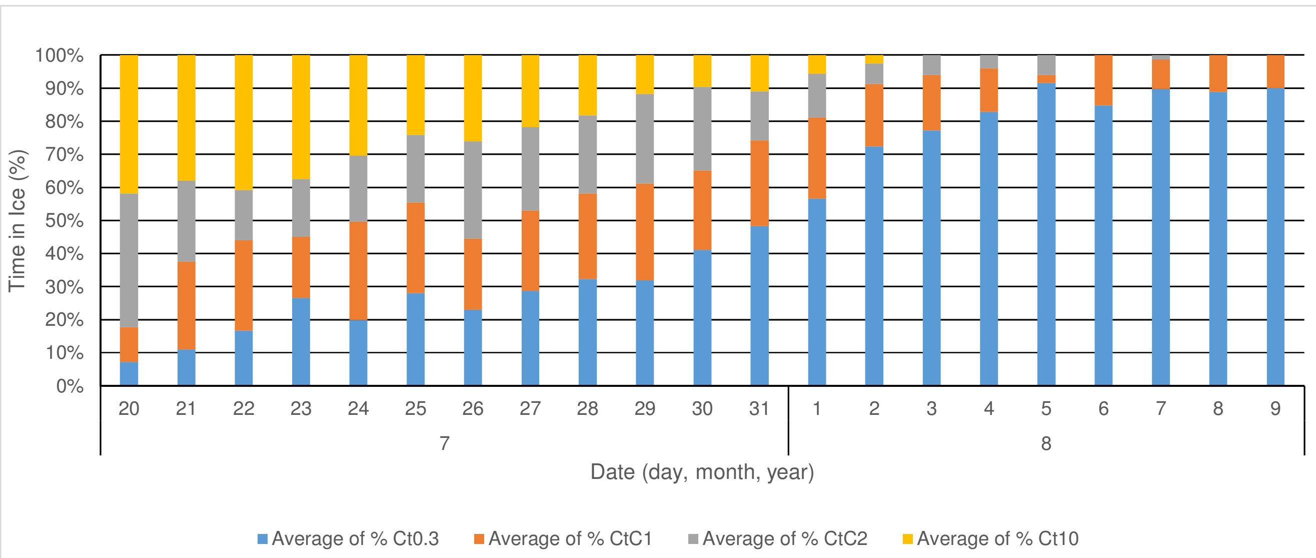


Figure 4-8: Eclipse Sound, mid-July, Time in Ice

Figure 4-9 reports the percentage of trajectories reaching shore. Figure 4-10 reports the mean time to shore for each region. Figure 4-11 show statistics for the mean percent of fuel remaining at the end of each trajectory. Table 4-3 reports the earliest, latest and mean times to shore for each geographical region, for the spill with no ice and spill with ice scenarios.

Except for three trajectories on July 1, 23, 25 in 2002, all of the simulated trajectories reach shore for the spill considering ice scenario. The greatest percentage of trajectories reach shore at Eclipse Sound Southwest (46%) and Bylot Island South (26%) in times that are as short as 34 and 8 hours respectively. For the ice scenario, the mean times to shore range from 56 and 83 h for Dufour Point and Bylot Island South to the north, to over 10 days for Pond Inlet (based on 11 trajectories ashore in the ice scenario, compared with 18 for the no ice).

It is often the case that the fuel will need to wait for the ice to melt or retreat from the spill's path. In this way, the resultant times to shore are in general increased for the ice scenario. For some of the regions close to the MR3 spill location such as Lavoie Point and Dufour Point the mean times to shore for spills in ice are less than 10 hours longer less compared with the no ice scenario. For most of the other regions mean times are on the order of 1.5 to 2.5 days (or just over 3 days for Tremblay Sound) longer in the ice scenario.

There is no difference in earliest times to shore since there will be some years in the ice scenario when there is no actual ice present so that the simulation will look the same as the no ice case. The one exception is for Eclipse Sound Southeast where the earliest times to shore in the ice scenario are 11 hours longer. On average, for all regions, the maximum times to shore are 2 days longer in the ice scenario.

The comparison of times to shore statistics is not always straightforward, e.g., the trajectory spill for the no ice year-day that yielded the latest time to shore may not have even reached shore in the ice situation (and hence not be included in the statistics) so that direct comparison in this way is not possible.

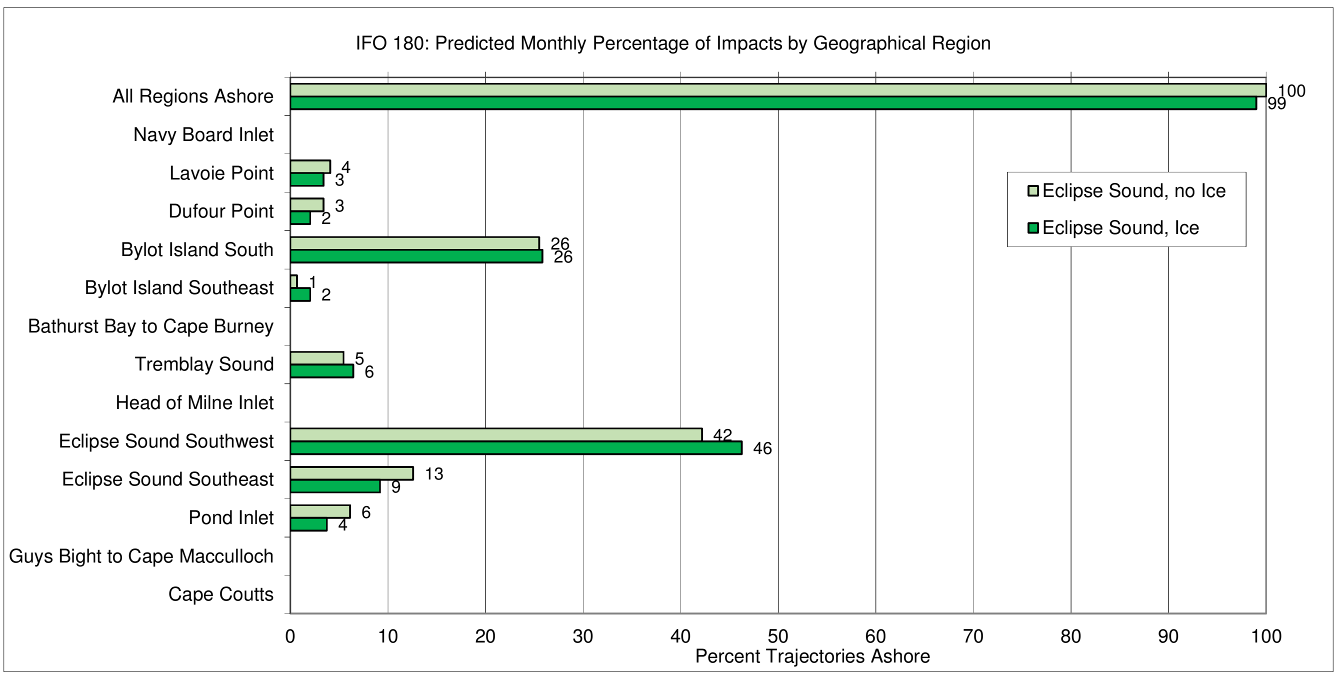


Figure 4-9: Eclipse Sound, mid-July, Percentage of Trajectories Reaching Shore

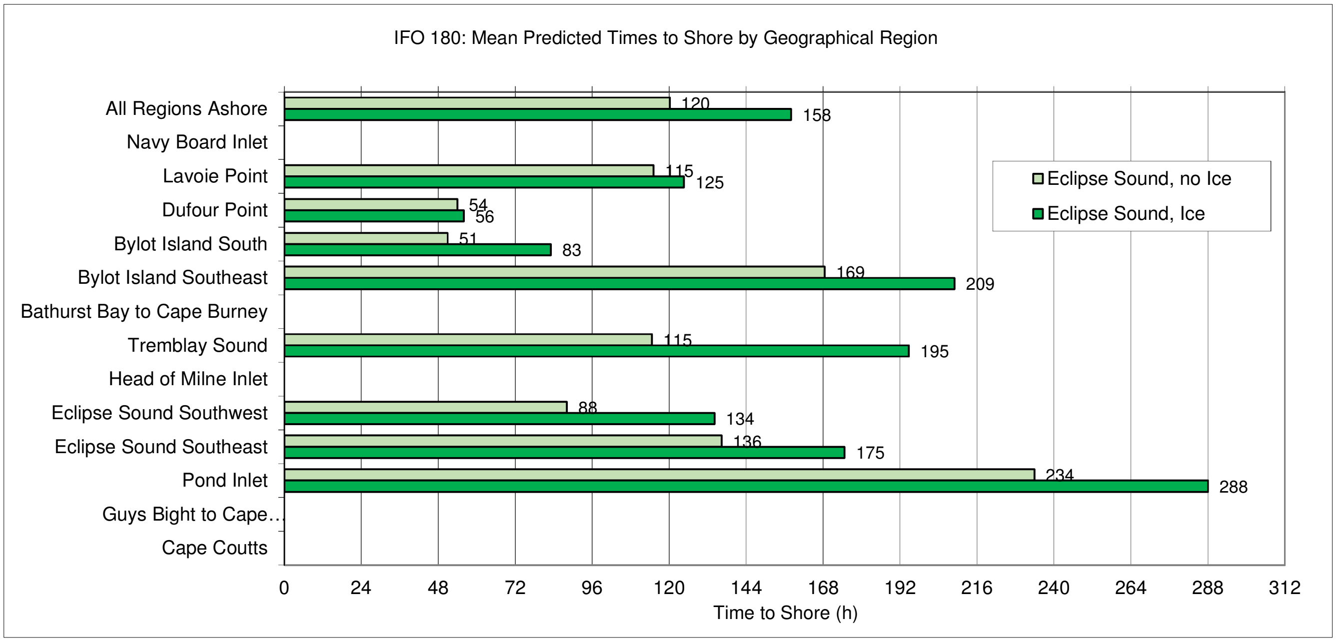


Figure 4-10: Eclipse Sound, mid-July, Mean Times to Shore

Table 4-3: Eclipse Sound, mid-July, Earliest, Latest and Mean Times to Shore

	Eclipse Sound, no Ice			Eclipse Sound, Ice		
Region	Earliest (h)	Latest (h)	Mean (h)	Earliest (h)	Latest (h)	Mean (h)
All Regions Ashore	7	669	120	8	716	158
Navy Board Inlet						
Lavoie Point	73	219	115	73	226	125
Dufour Point	19	153	54	19	153	56
Bylot Island South	7	263	51	8	282	83
Bylot Island Southeast	151	186	169	151	267	209
Bathurst Bay to Cape Burney						
Tremblay Sound	76	173	115	82	463	195
Head of Milne Inlet						
Eclipse Sound Southwest	34	297	88	34	425	134
Eclipse Sound Southeast	38	669	136	49	716	175
Pond Inlet	54	665	234	54	672	288
Guys Bight to Cape Macculloch						
Cape Coutts						

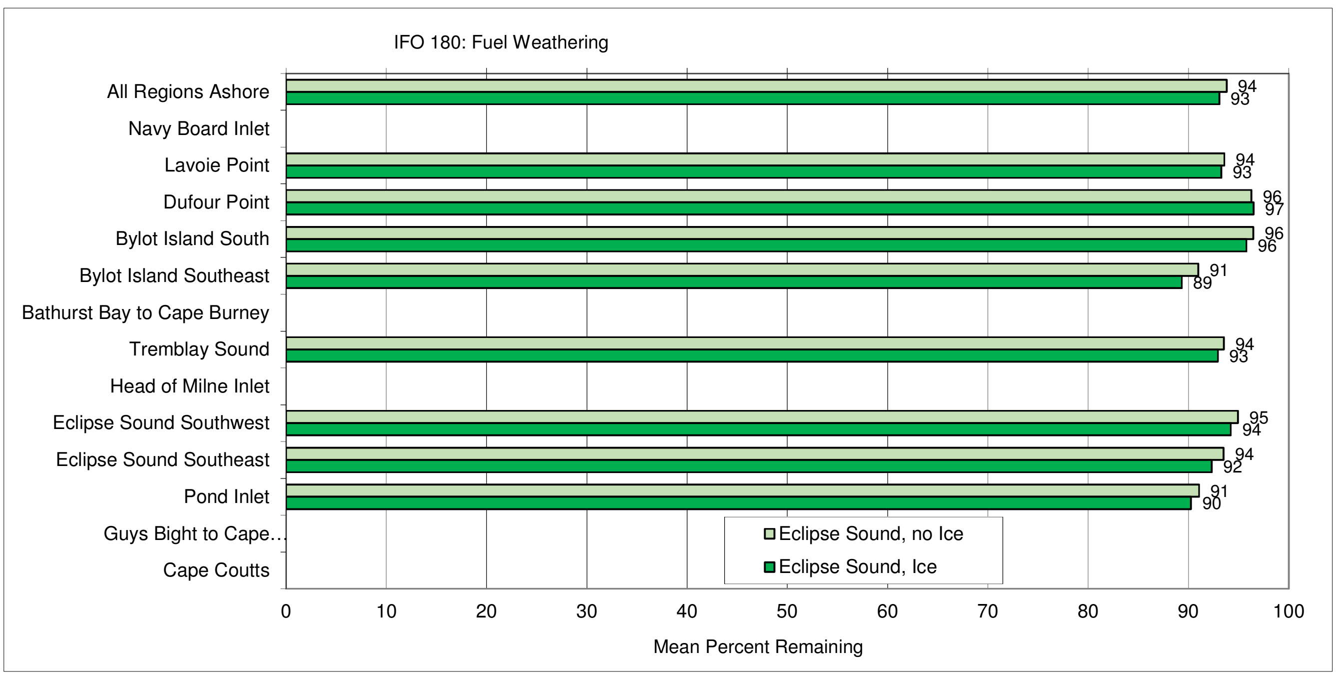


Figure 4-11: Eclipse Sound, mid-July, IFO 180, Fuel Weathering

5.0 RESULTS, MID-OCTOBER, MILNE INLET: MOUTH

This section presents spill probability plots for the mid-October spill scenario at the mouth of Milne Inlet. Two scenarios were run for mid-October: with no ice and with ice (Figure 5-1 and Figure 5-2). The probability distributions are quite similar with a slightly reduced extent seen for the ice scenarios.

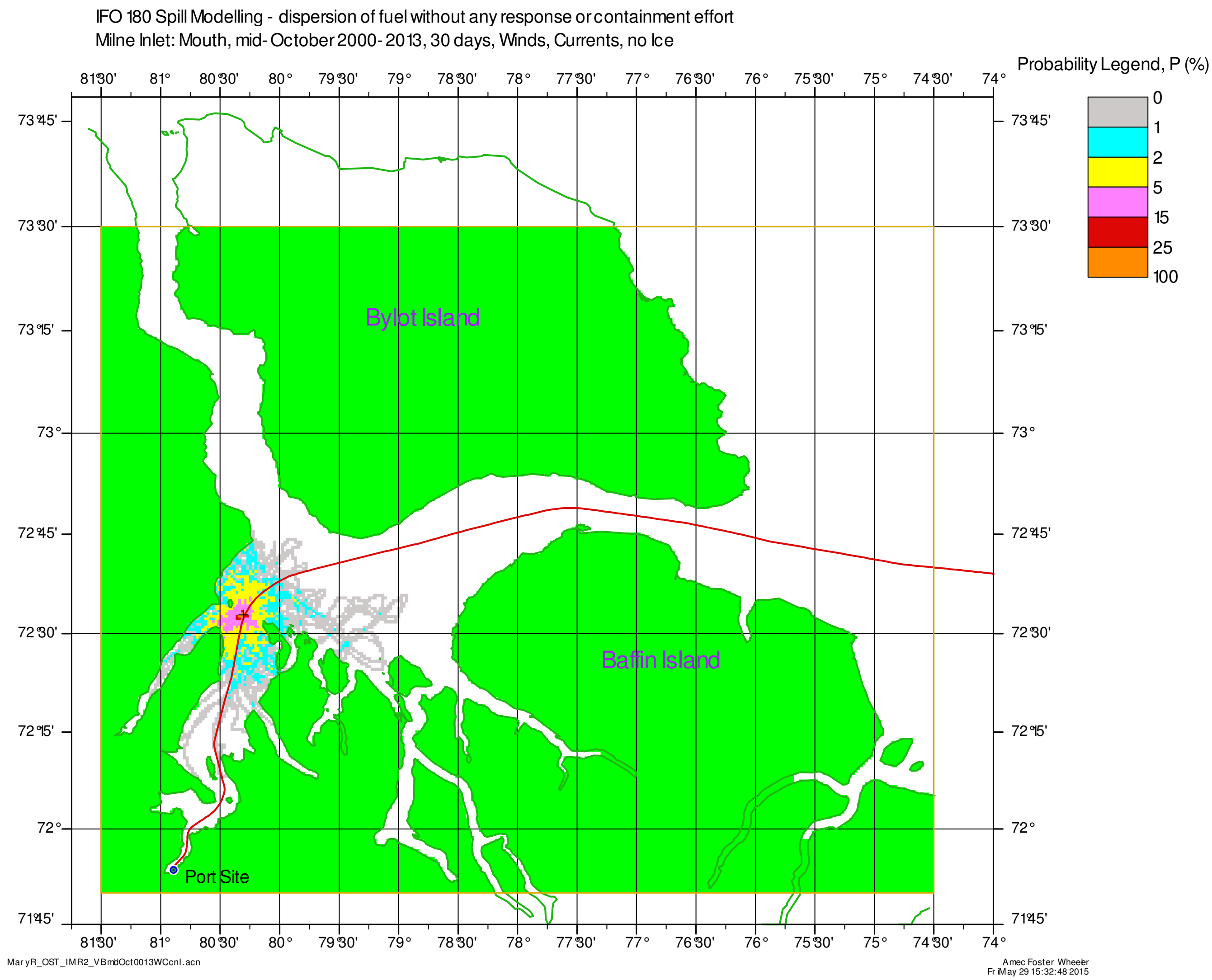


Figure 5-1: Spill Distribution Probability Plot, Milne Inlet: Mouth, mid-October, no Ice

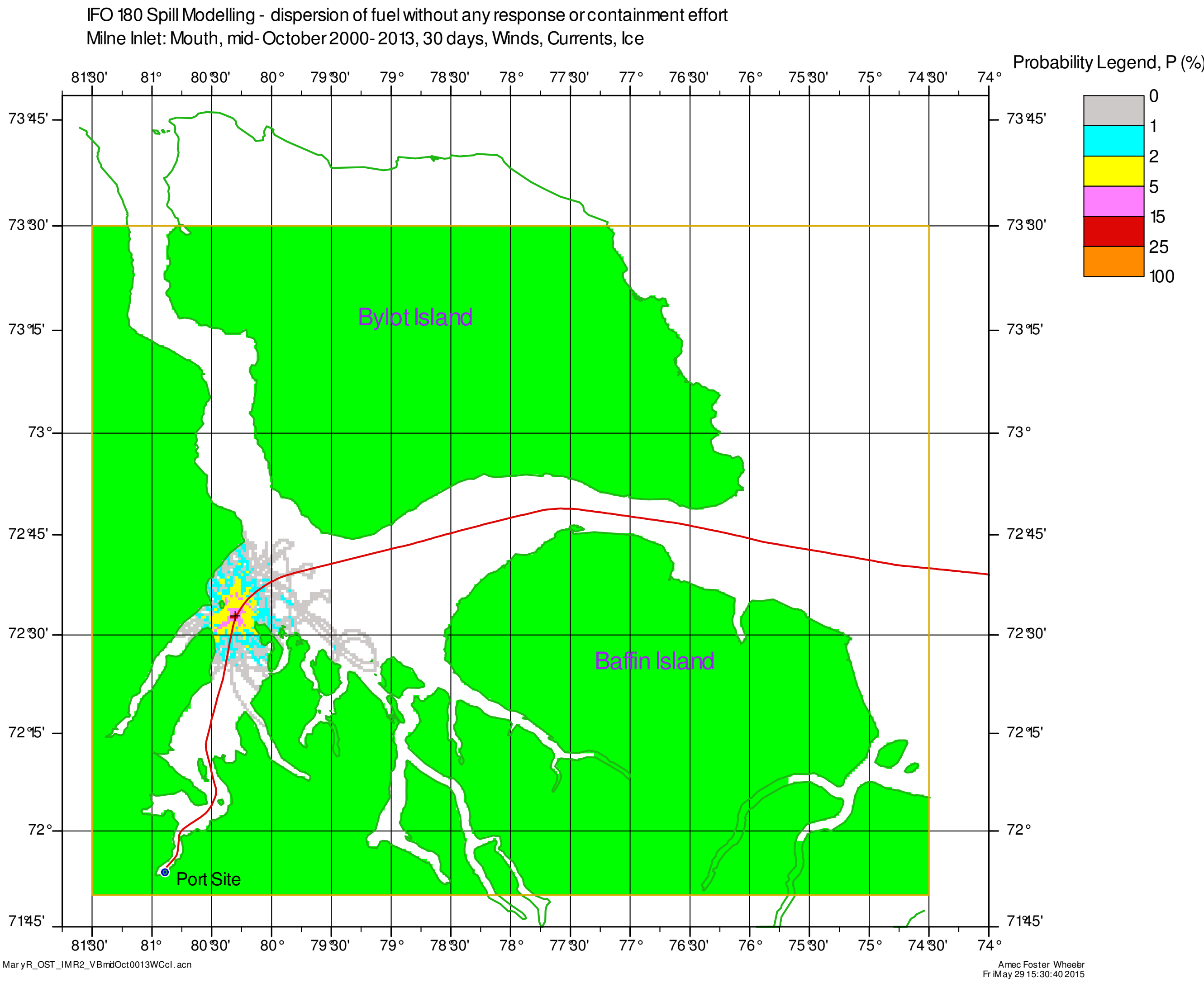


Figure 5-2: Spill Distribution Probability Plot, Milne Inlet: Mouth, mid-October, Ice

As noted for the mid-July results, it is important to recognize these figures are of the probabilities of the spill trajectory reaching or travelling through a given location and do not permit a direct comparison of trajectories, one by one, under the no ice or ice scenarios. The inherent differences that exist in the model results, and are tallied with the probability maps, are illustrated in two example subsets of the total of 294 (21 days, 14 years) break-up scenario trajectories. The end point of the trajectories (orange: no ice, blue: ice) are identified with their month-day or year.

The first example in Figure 5-3 shows trajectories for all of the freeze-up days in 2008. A second illustration in Figure 5-4 shows 15 October for all years 2000 to 2013.

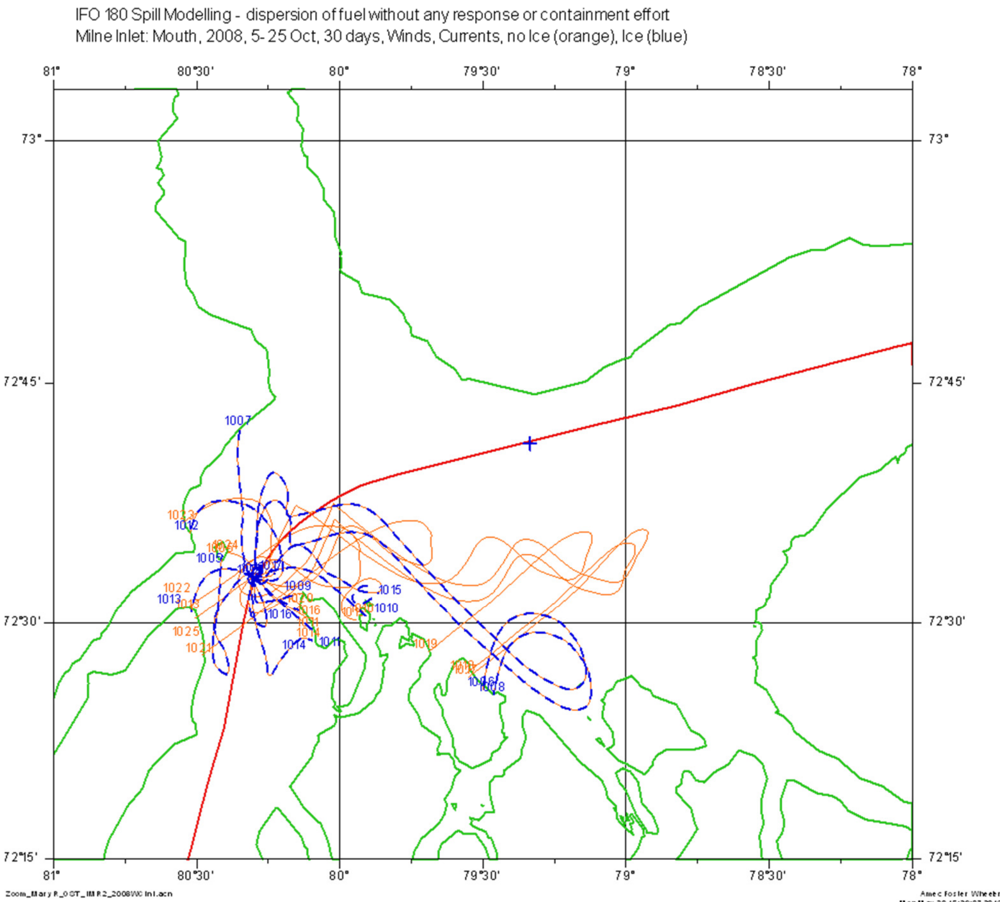


Figure 5-3: Milne Inlet: Mouth, 5 to 25 October, 2008, Spill Trajectories for No Ice and Ice Scenarios

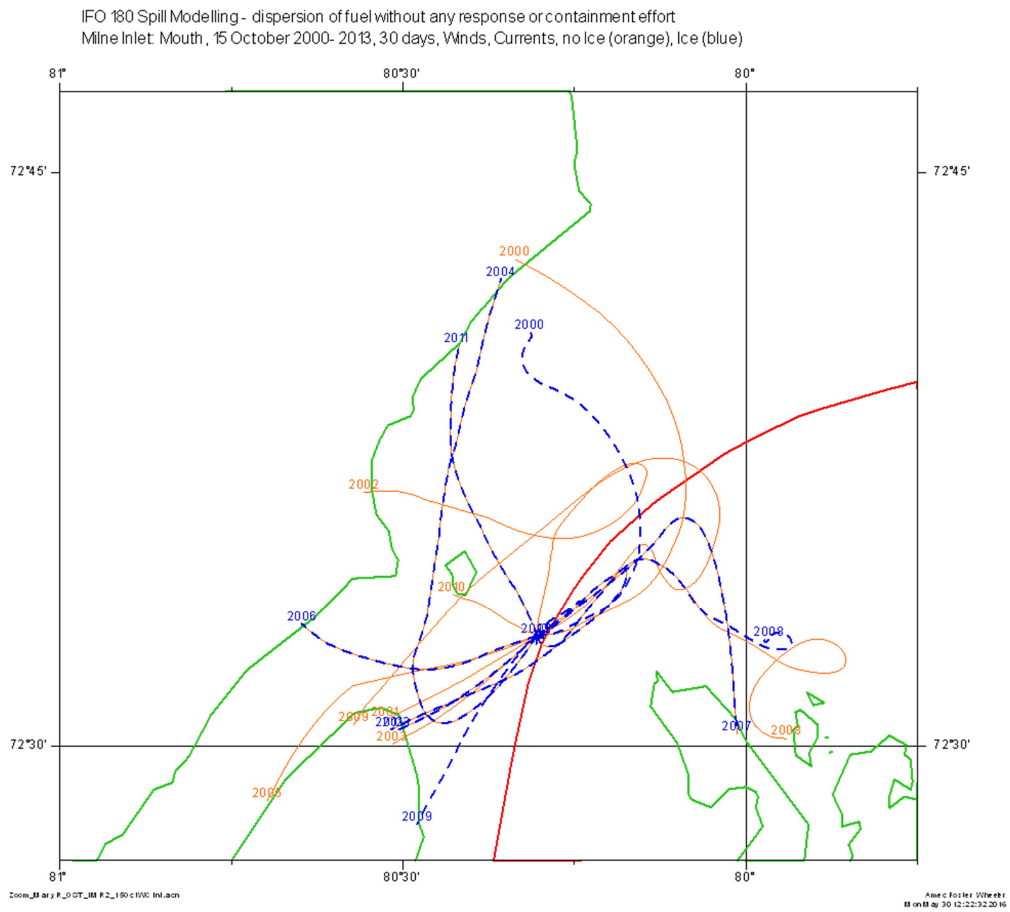


Figure 5-4: Milne Inlet: Mouth, 15 October, 2000-2013, Spill Trajectories for No Ice and Ice Scenarios

Returning to a comparison of the two spill distribution probability maps (Figure 5-1, Figure 5-2), as presented above for the mid-July scenario, Figure 5-5 presents the difference in probability between the no ice and ice scenarios. For each grid cell the difference between 'no ice' and 'ice' is calculated. For the mid-October freeze-up scenario, while there are similar extents to the spill probability zones of influence under both ice and no ice, Figure 5-5 shows there are mostly positive values indicating a slightly greater likelihood of most areas being reached under the no ice scenario. Most of the positive (probability) differences are in the 0 to 1% range, less than a fifth are in the 1 to 5% range and at seven cells, in the immediate region of the spill scenario location, the differences are as high as 9%. As evidenced by the few blue or magenta grid squares, there are very few locations more likely to see the spill drift with ice considered.

What is also different between the two scenarios (no ice, ice) is the times to shore and regions affected. This is the subject of the next section.

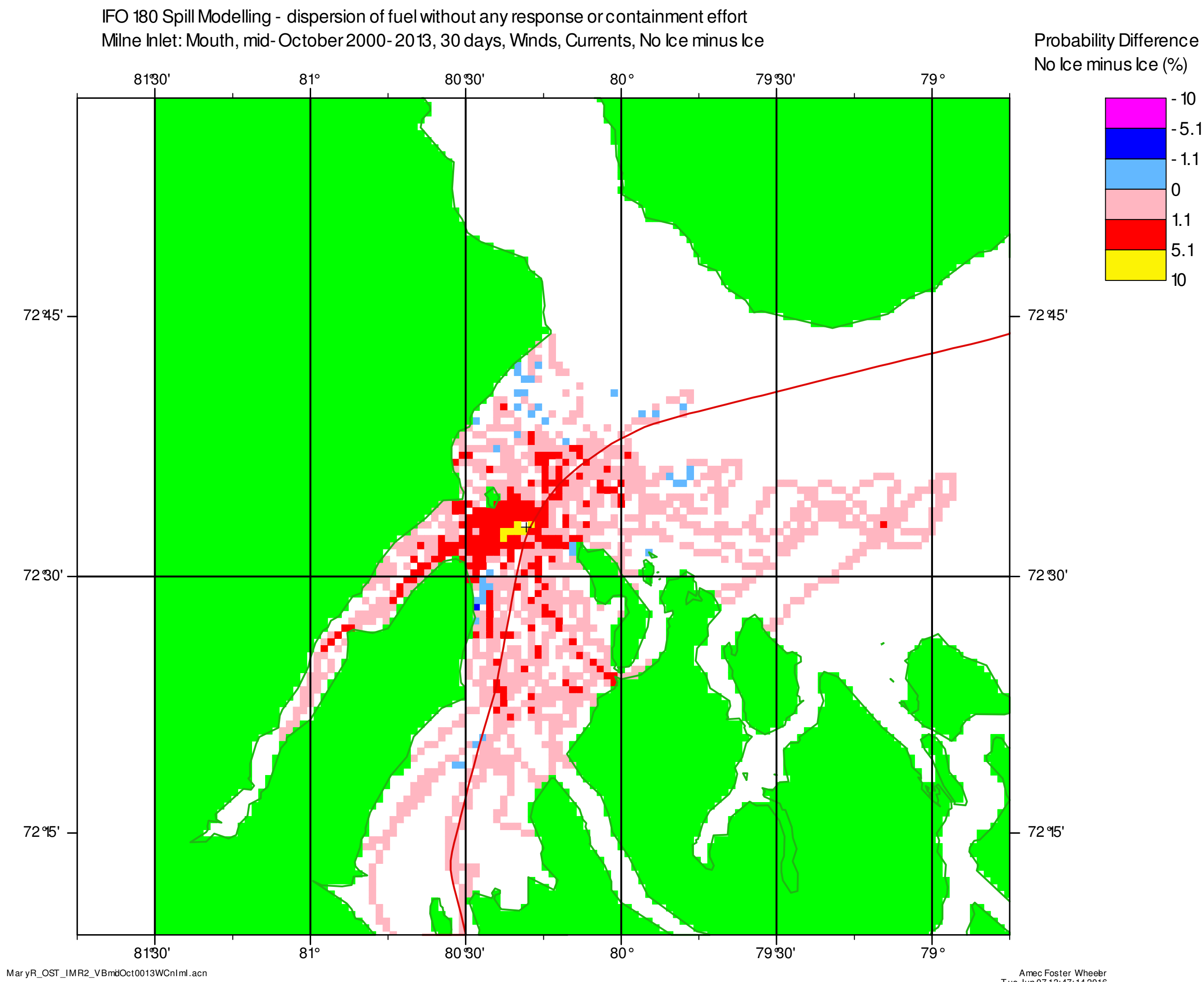


Figure 5-5: Milne Inlet: Mouth, mid-October, Spill Distribution Probability Difference for No Ice and Ice

5.1 Shoreline Statistics

The effect of ice for the mid-October scenarios is to keep the fuel offshore and delay any drift to one of the shorelines and in practice, effectively trap the fuel in the ice as it freezes. As illustrated in Figure 5-6, the spill trajectories spend increasingly less time in ice of lesser concentrations as the freeze-up progresses. Each bar in the figure tallies the mean percentage of time in each of the four ice ranges (Ct0.3 to Ct10) for that calendar day over all 14 years of the simulation. For example, for a spill originating on 7 October, one can expect a trajectory to spend about 76% of the time in bergy water, and just 7% in greater than 6/10. By 25 October, 91% of the time one can expect the trajectory to be trapped or held up in ice of concentration greater than 6/10.

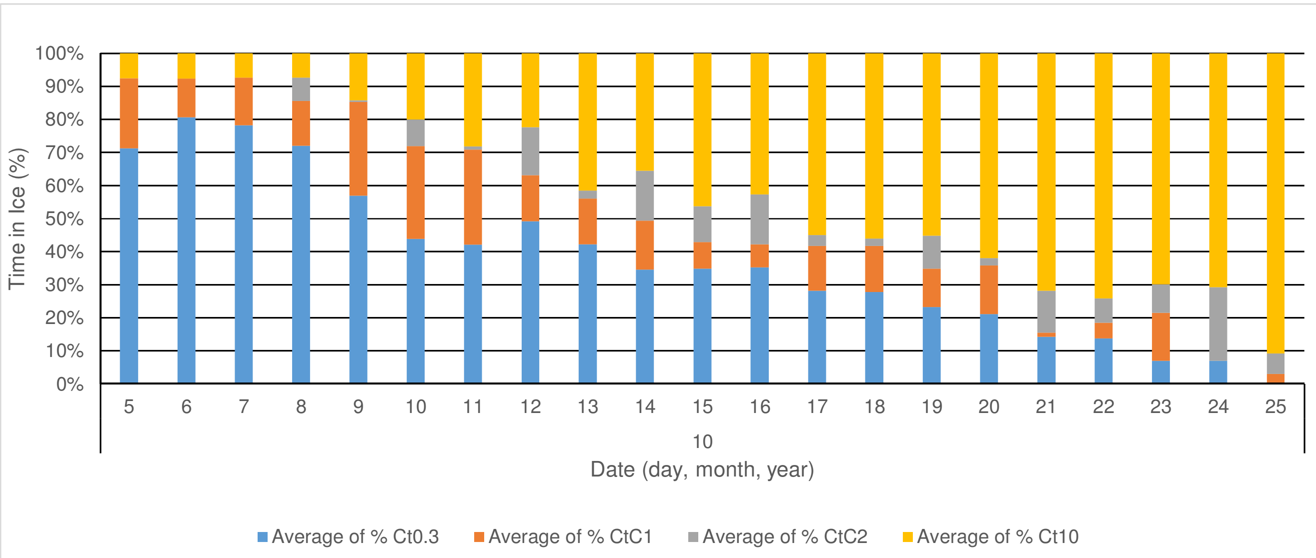


Figure 5-6: Milne Inlet: Mouth, mid-October, Time in Ice

Unlike in mid-July, when trajectories eventually reach shore, for October there can be numerous days where ice conditions prevent the spill from reaching shore; and with the onset of winter, the fuel is trapped in the ice. The number of trajectories reaching shore decreases steadily as the freeze-up progresses as illustrated in Figure 5-7 where on 5 October all but one (in 2003) of the simulations reaches shore. By 25 October the converse is true: just one of the simulations (in 2011) reaches shore.

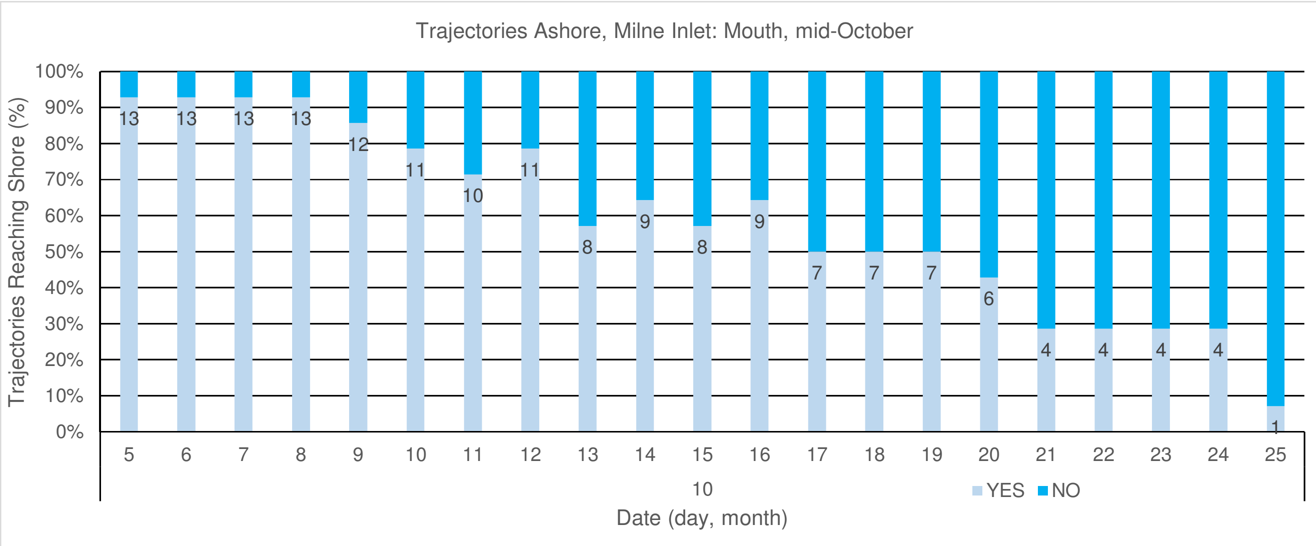


Figure 5-7: Daily Percent Trajectories Ashore, Milne Inlet: Mouth, mid-October

This is general pattern one could expect. What is perhaps more relevant is that since any given ice year is likely somewhat different it will be the actual conditions encountered that year, and that time in the October freeze-up that will determine the outcome. This is illustrated in Figure 5-8 which shows the tally of all 294 freeze-up scenarios by year and noticeable variability year by year: 41% of the year-day trajectories do not reach shore. In 2003, due to an early freeze-up, none of the trajectories reach shore – the fuel being trapped in ice at the spill location. In the low ice year 2011, all of the 21 (5-25 October) trajectories reach shore.

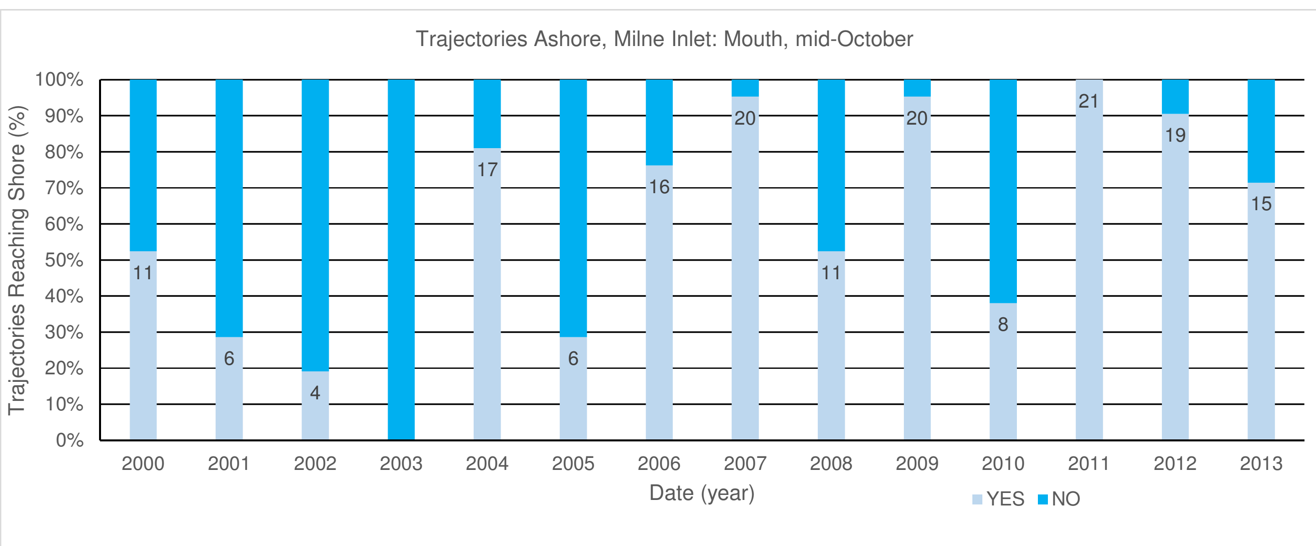


Figure 5-8: Annual Percent Trajectories Ashore, Milne Inlet: Mouth, mid-October

Figure 5-9 reports the percentage of trajectories reaching shore. Figure 5-10 reports the mean time to shore for each region. Figure 5-11 show statistics for the mean percent of fuel remaining at the end of each trajectory. Table 5-1 reports the earliest, latest and mean times to shore for each geographical region, for the spill with no ice and spill with ice scenarios.

For the spill in ice simulations, 59% of the trajectories reach shore (all trajectories reach shore in the no ice case). Only three regions see first shoreline contact: Tremblay Sound (28% of the time), Eclipse Sound Southwest (19%) and Lavoie Point (13%). This is due to their close proximity to the spill site at the Mouth of the Milne Inlet. These are the same regions reached in the no ice simulations. There is 1% to the head of Milne Inlet with no ice, and under ice conditions no trajectories reach that region.

Mean times to shore are on the order of 38 to 45 h, as soon as 6 h (for Tremblay Sound and Eclipse Sound Southwest), and as long as just over 10 days for Tremblay Sound.

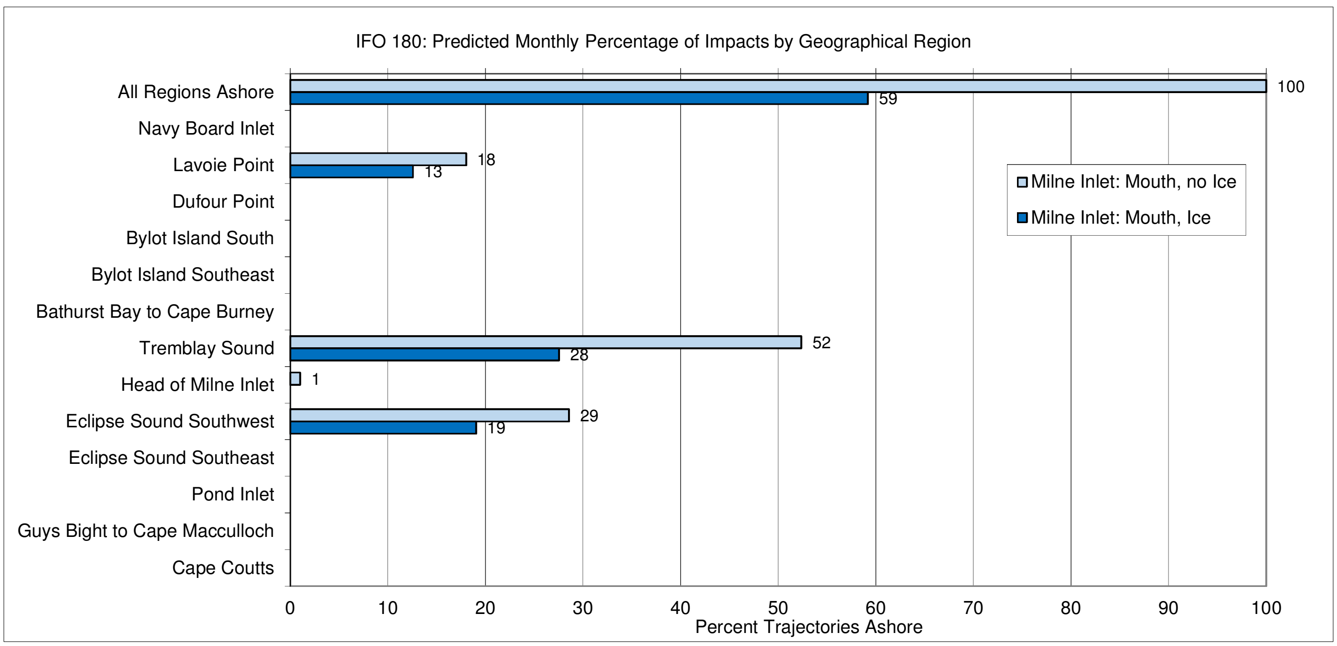


Figure 5-9: Milne Inlet: Mouth, mid-October, Percentage of Trajectories Reaching Shore

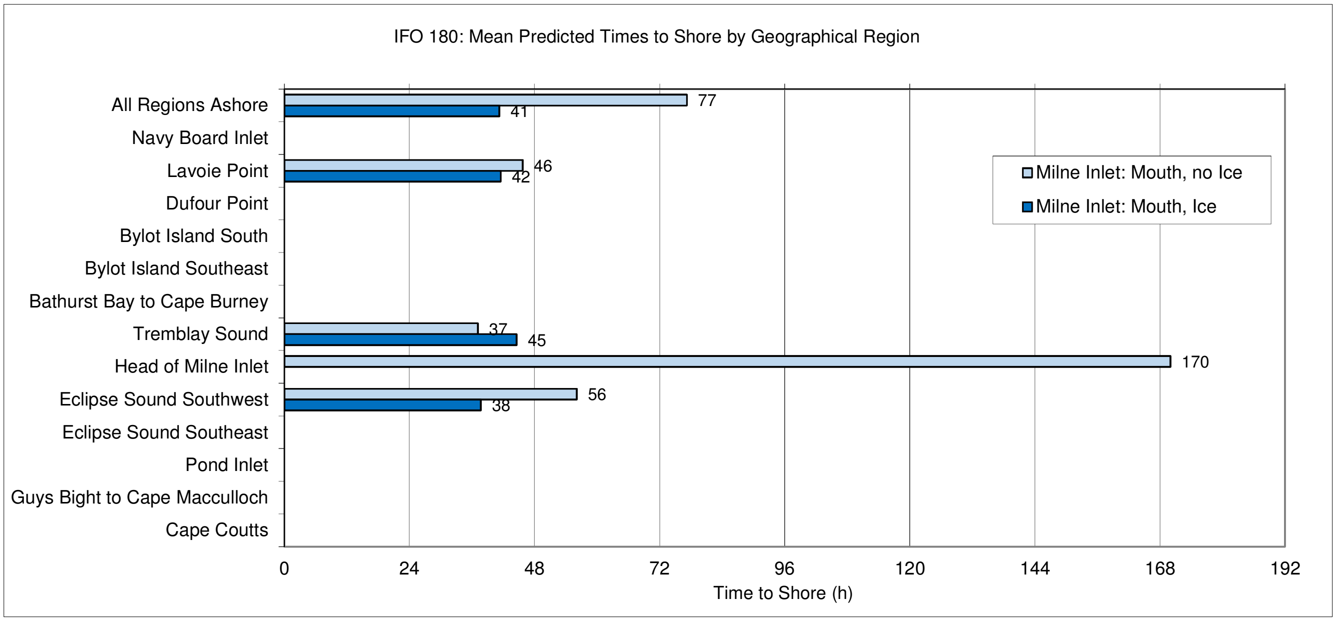


Figure 5-10: Milne Inlet: Mouth, mid-October, Mean Times to Shore

Table 5-1: Milne Inlet: Mouth, mid-October, Earliest, Latest and Mean Times to Shore

	Milne Inlet: Mouth, no Ice			Milne Inlet: Mouth, Ice		
Region	Earliest (h)	Latest (h)	Mean (h)	Earliest (h)	Latest (h)	Mean (h)
All Regions Ashore	5	226	77	5	259	41
Navy Board Inlet						
Lavoie Point	14	176	46	14	95	42
Dufour Point						
Bylot Island South						
Bylot Island Southeast						
Bathurst Bay to Cape Burney						
Tremblay Sound	6	177	37	6	259	45
Head of Milne Inlet	114	207	170			
Eclipse Sound Southwest	5	226	56	5	196	38
Eclipse Sound Southeast						
Pond Inlet						
Guys Bight to Cape Macculloch						
Cape Coutts						

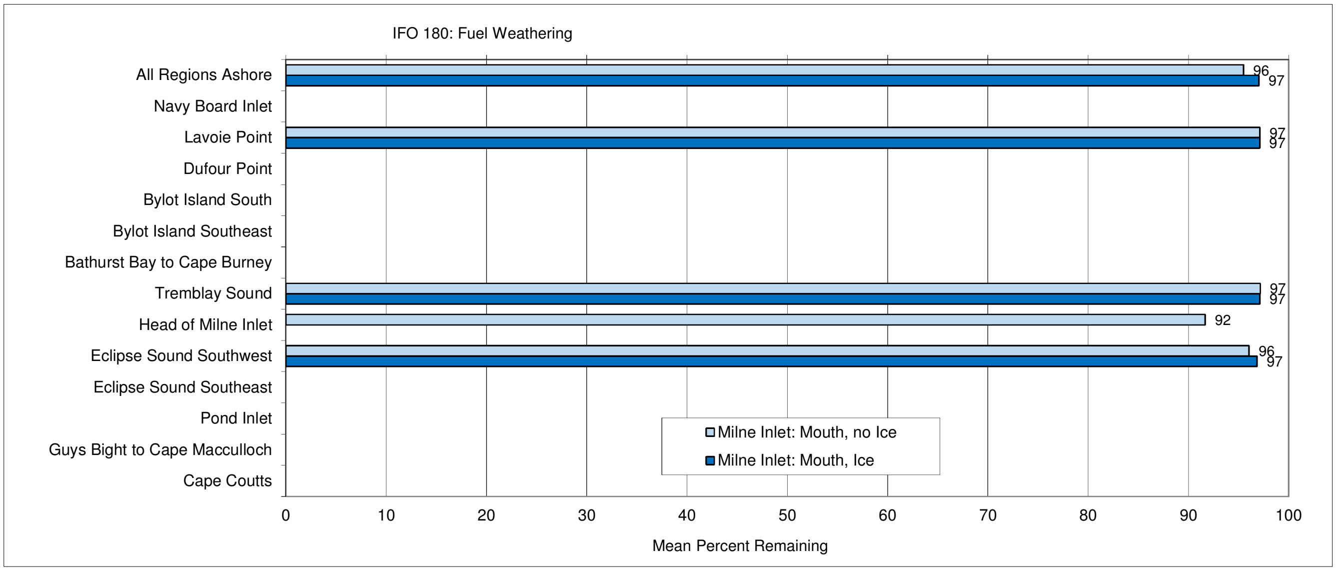


Figure 5-11: Milne Inlet: Mouth, mid-October, IFO 180, Fuel Weathering

6.0 CLOSURE

This report presents, for Baffinland and the Mary River Project, a sea ice shoulder seasons water fuel spill modelling assessment for Milne Inlet, Nunavut. Two spill scenarios are included that release 1 ML of IFO fuel from an ore carrier at locations along the Northern Shipping Route from Baffin Bay through Pond Inlet, Eclipse Sound, and Milne Inlet to the port site at the head of Milne Inlet. These include a mid-July sea ice break-up scenario in Eclipse Sound and a mid-October sea ice freeze-up scenario at the mouth of Milne Inlet.

The Amec Foster Wheeler spill model software, OST, spill model inputs for wind, current and sea ice are described.

Results of the model presented include spill probability maps for both spill scenario locations together with statistics of the percent of trajectories ashore, and minimum, mean and maximum times to shore. Model results are presented with and without consideration of sea ice to facilitate some assessment of the effects of sea ice presence.

Yours sincerely,

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Additional Reading

OSRL, March 2015. Baffinland Iron Mines Corporation. Spill at Sea Response Plan (SSRP).

APPENDIX A: SEA ICE CONDITIONS, EASTERN ARCTIC AND POND INLET

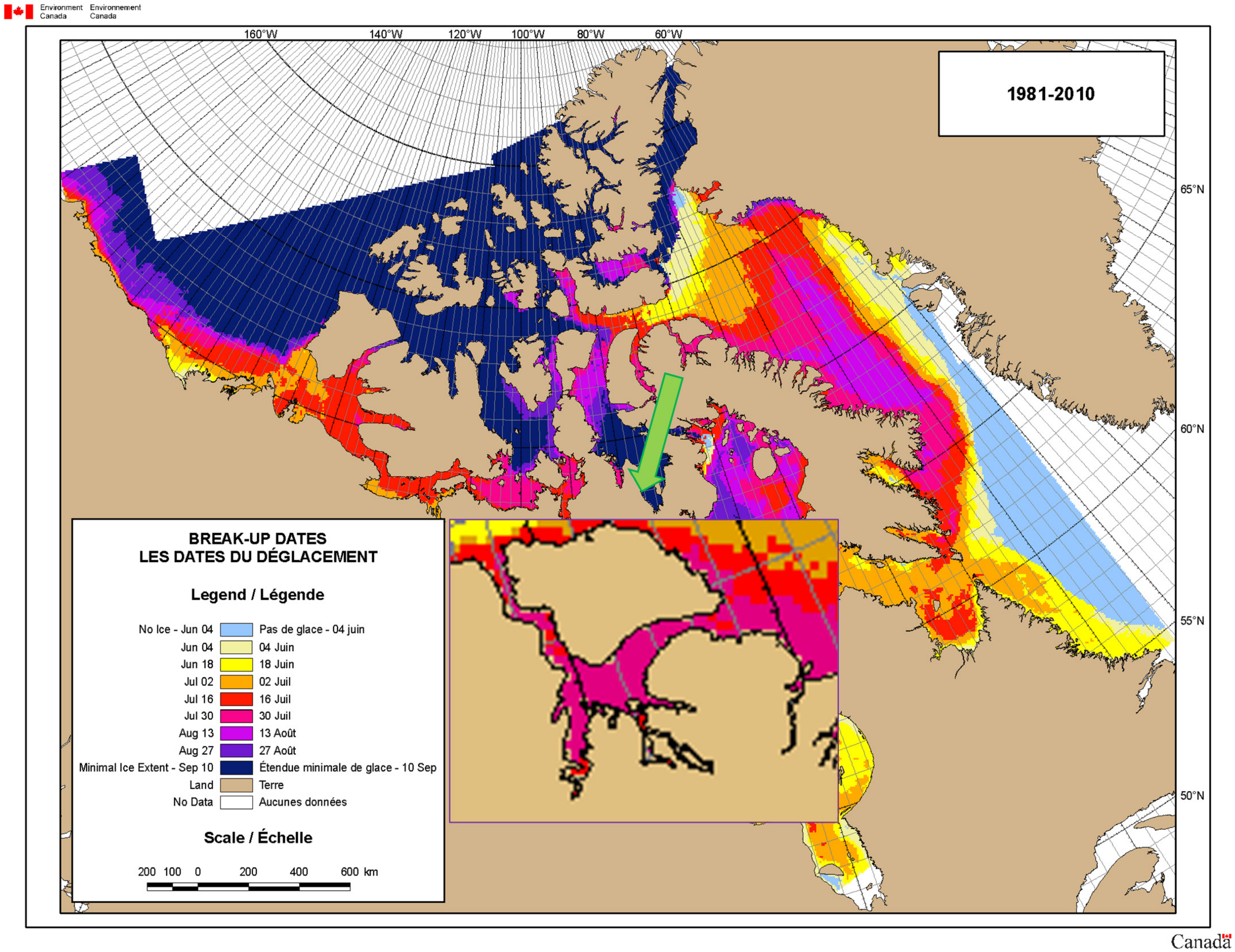


Chart of break-up dates for Eastern Arctic
Source: CIS, 2013
The "Dates of Freeze-up and Break-up" depict the extent of ice on a bi-weekly basis during the freeze-up and break-up seasons. They provide a pictorial representation of the evolution of ice during those periods. These products are constructed using the Median of Ice Concentration charts and thus the confidence level is high.

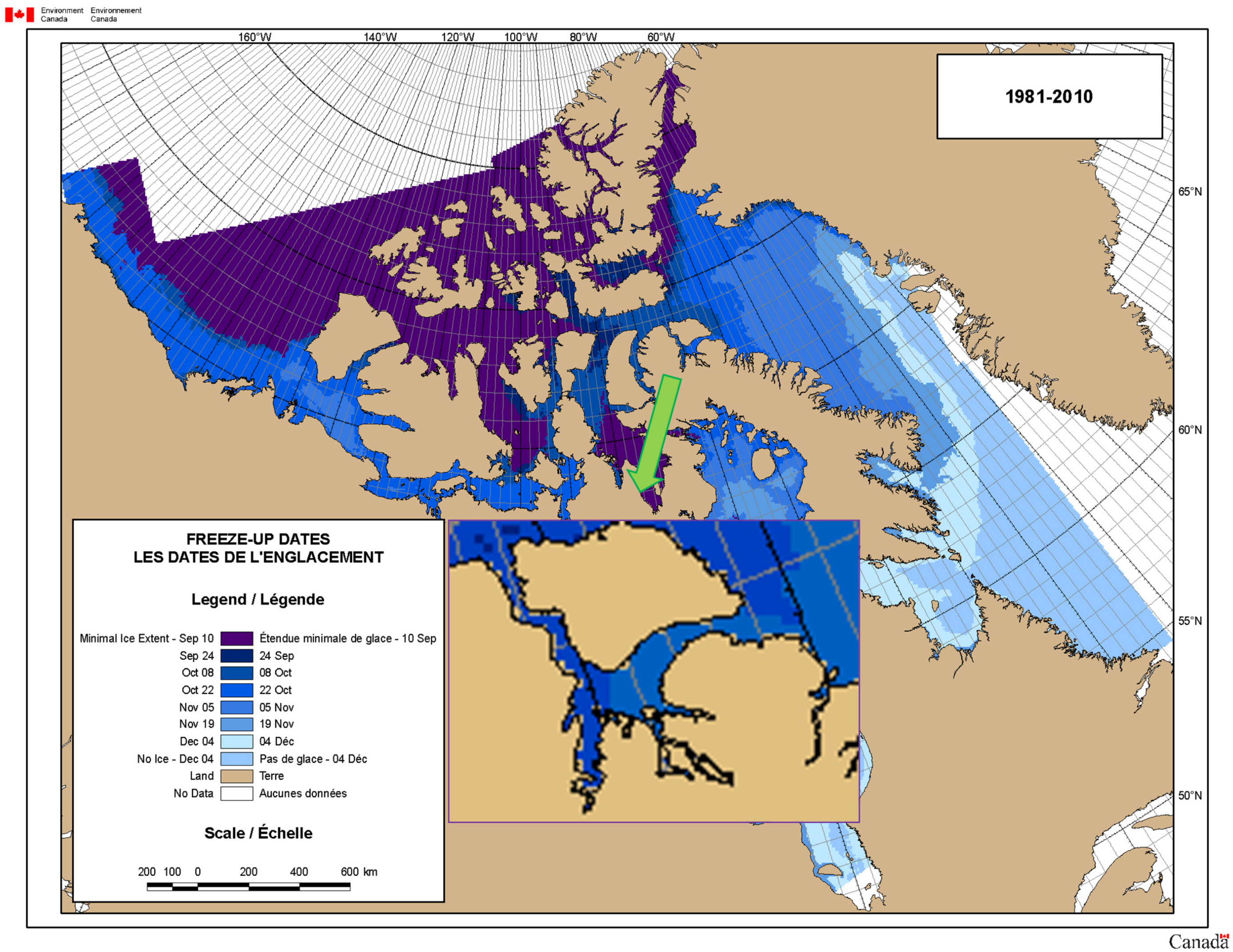
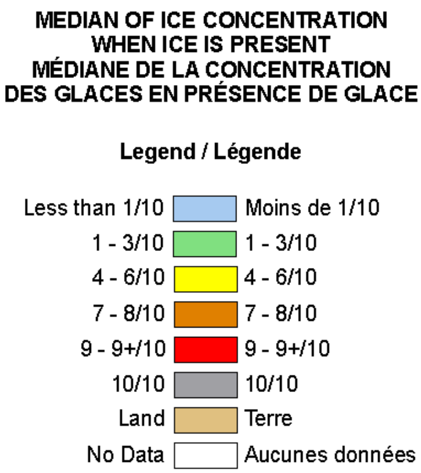
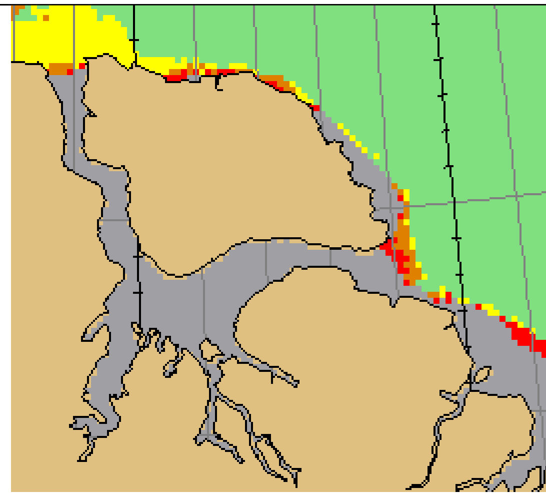


Chart of freeze-up dates for Eastern Arctic
Source: CIS, 2013

Will look to compress these into two pages for each ice chart type.

Median of Ice Concentration, When Ice is Present, Source: CIS, 2013





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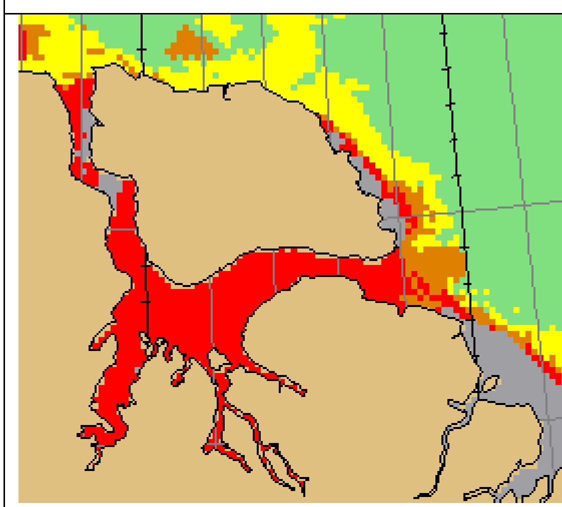

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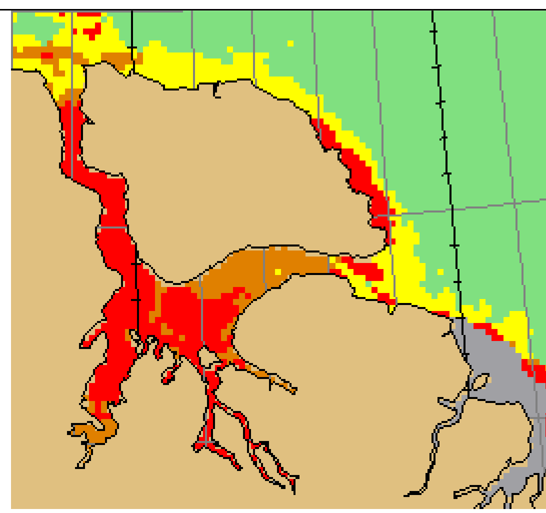

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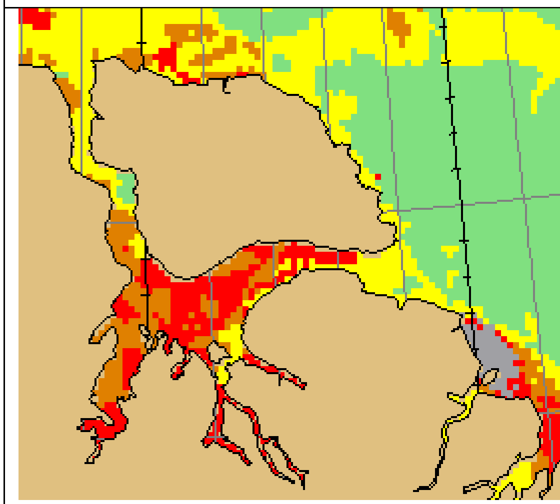
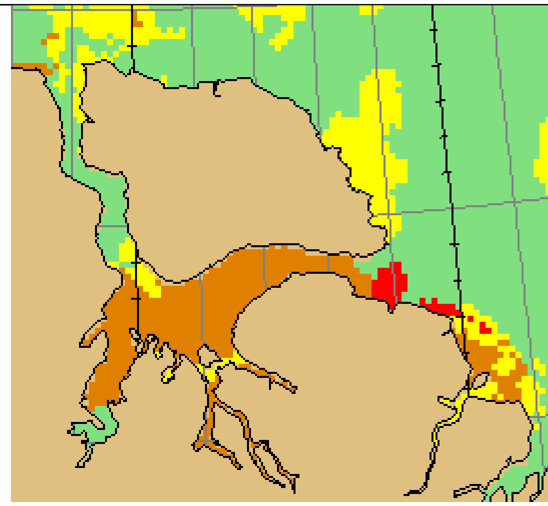
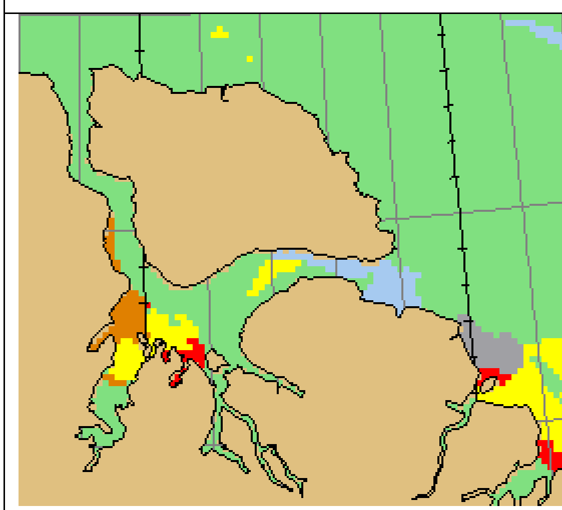
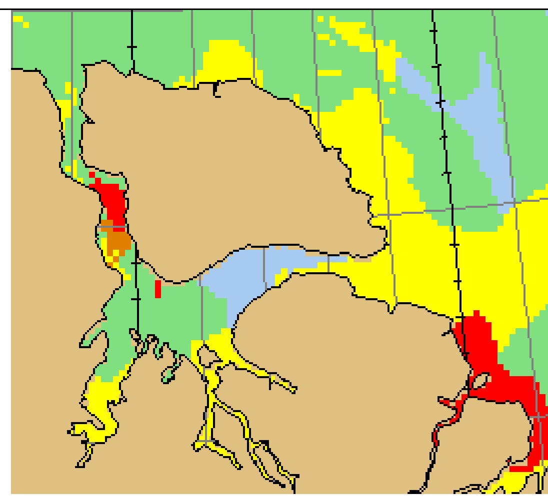
 06 AUG	 13 AUG
 20 AUG	 27 AUG

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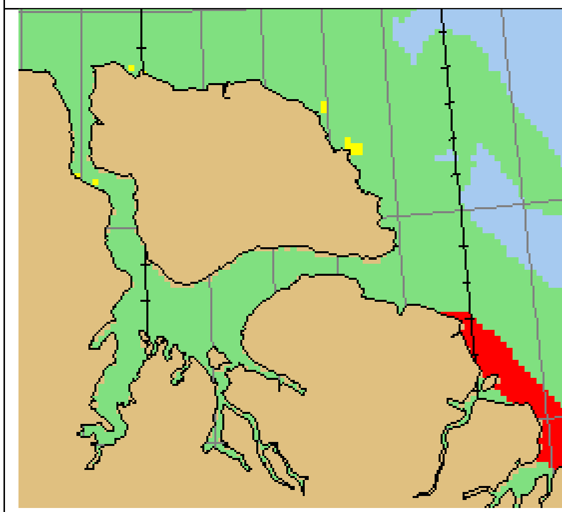
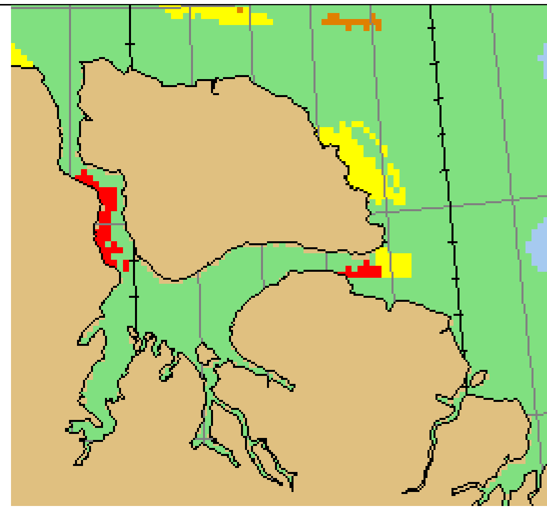
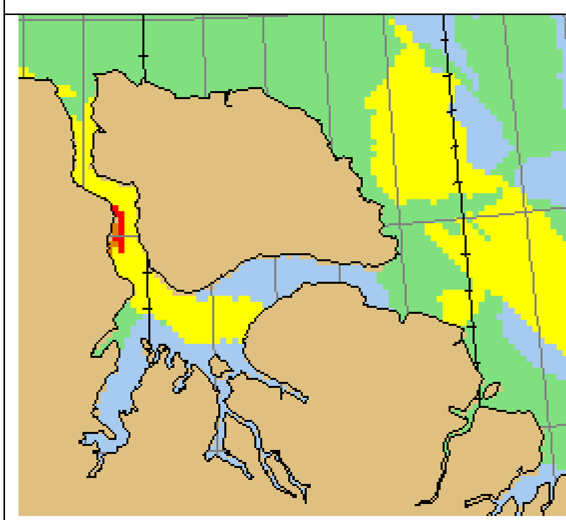
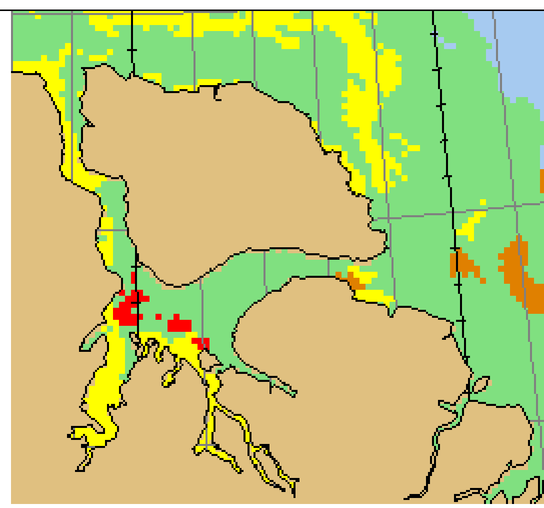
 03 SEP	 10 SEP
 17 SEP	 24 SEP

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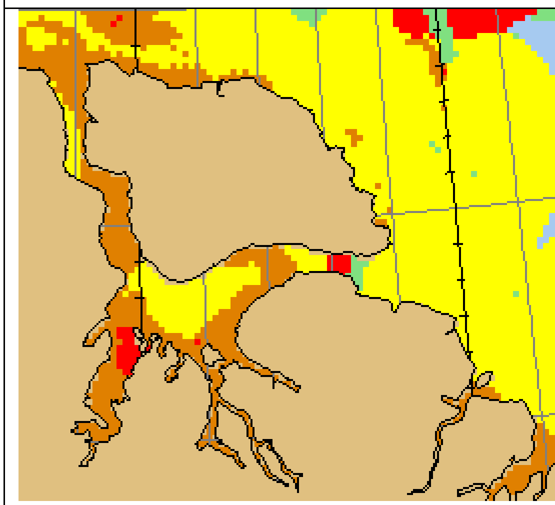
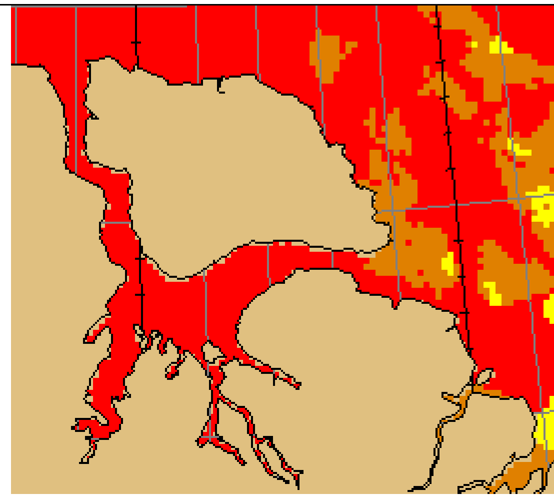
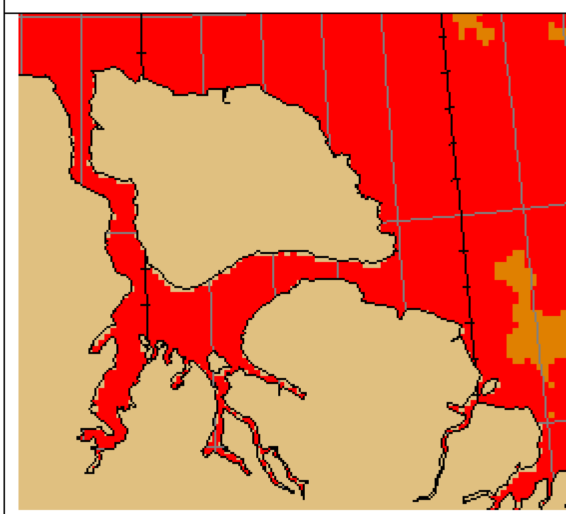
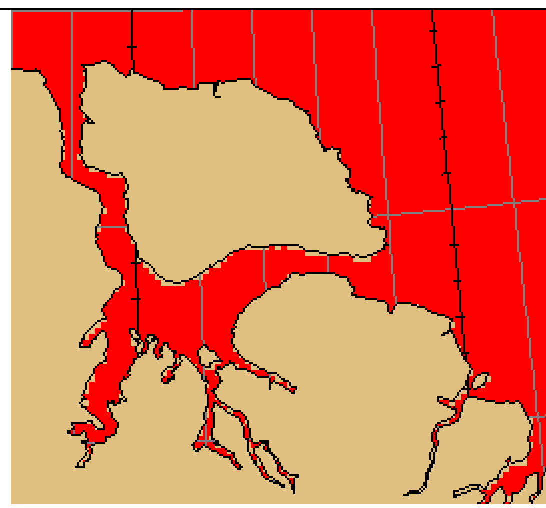
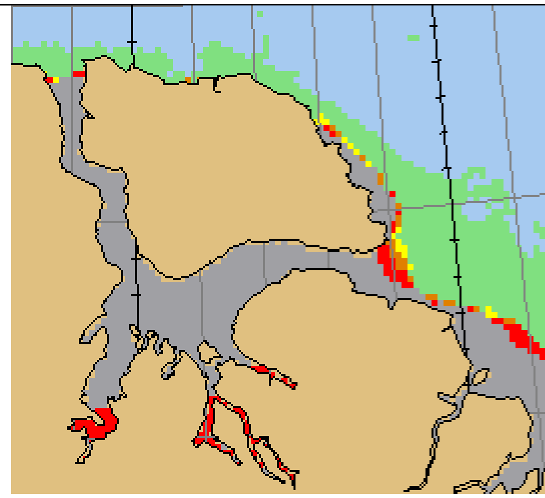
 01 OCT	 08 OCT
 15 OCT	 22 OCT

Median of Ice Concentration, Source: CIS, 2013

MEDIAN OF ICE CONCENTRATION
MÉDIANE DE LA CONCENTRATION DES GLACES

Legend / Légende

Less than 1/10	Moins de 1/10
1 - 3/10	1 - 3/10
4 - 6/10	4 - 6/10
7 - 8/10	7 - 8/10
9 - 9+/10	9 - 9+/10
10/10	10/10
Land	Terre
No Data	Aucunes données



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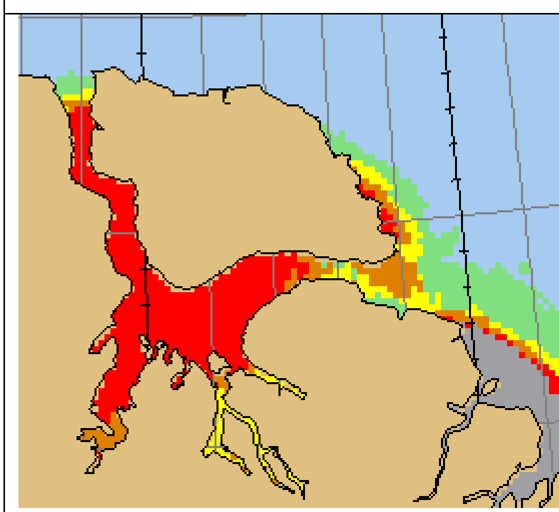

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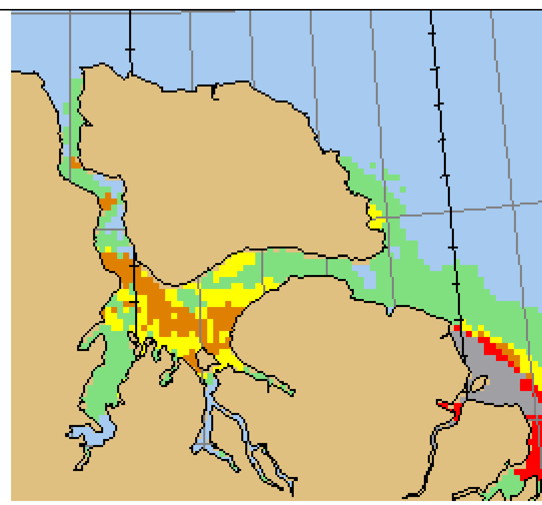

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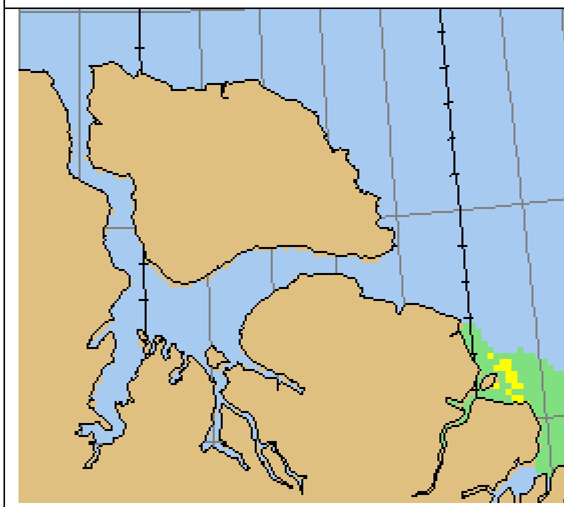

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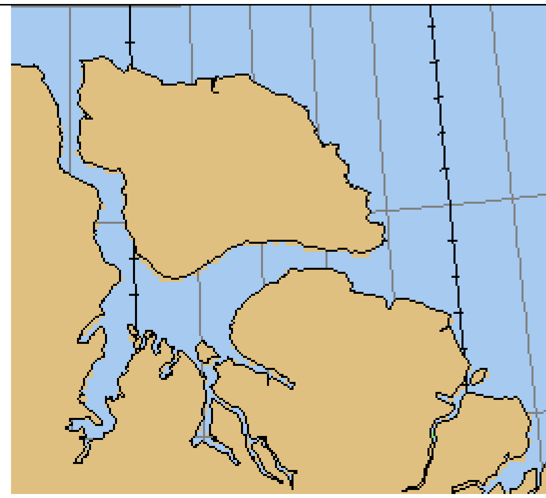

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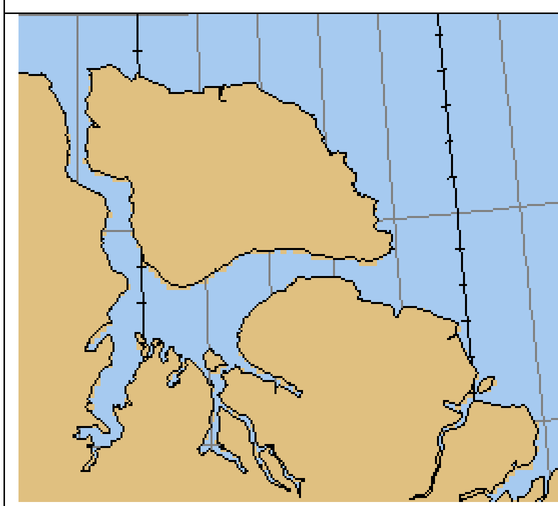

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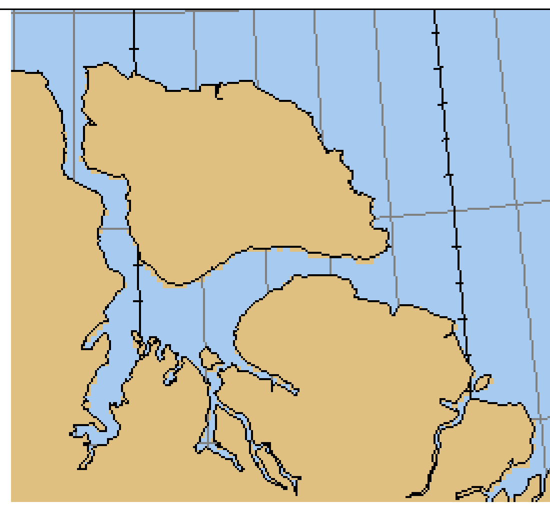

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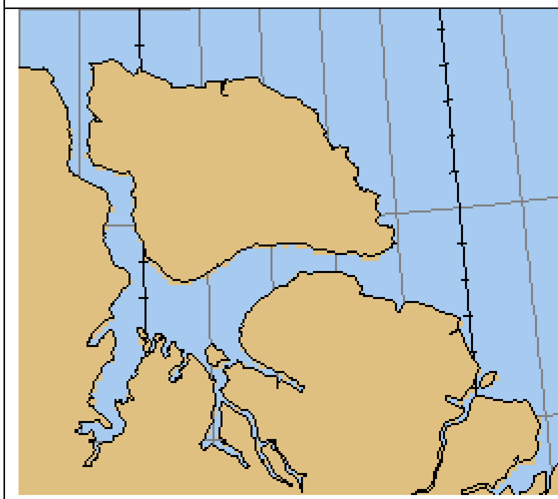
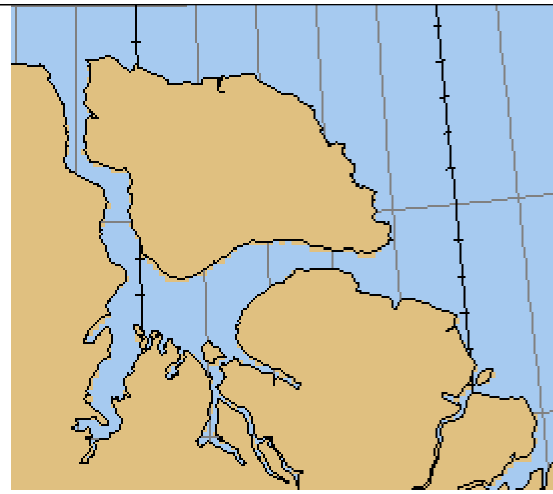
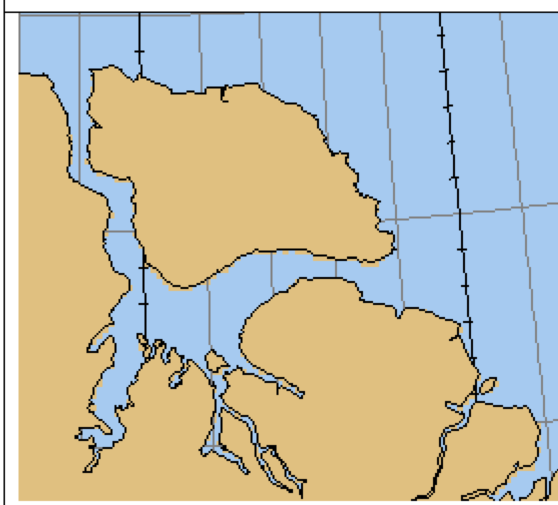
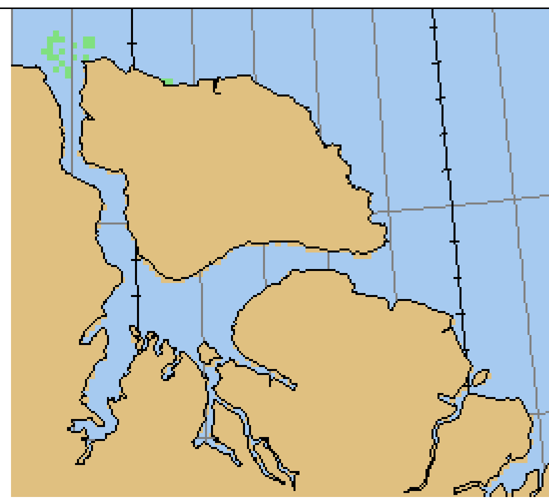
 03 SEP	 10 SEP
 17 SEP	 24 SEP

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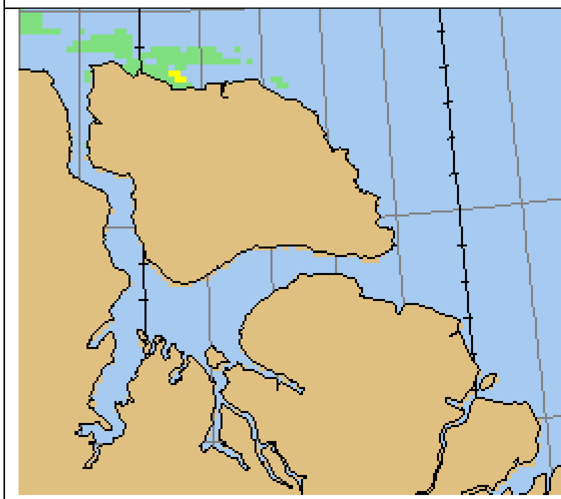
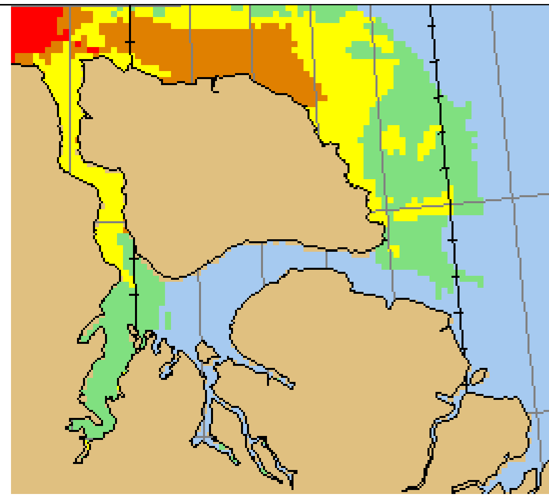
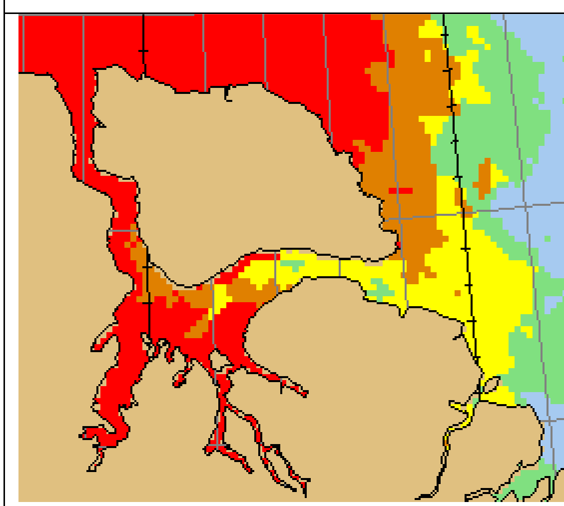
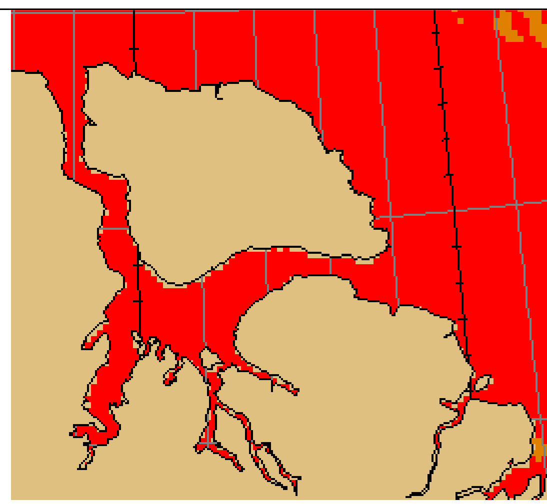
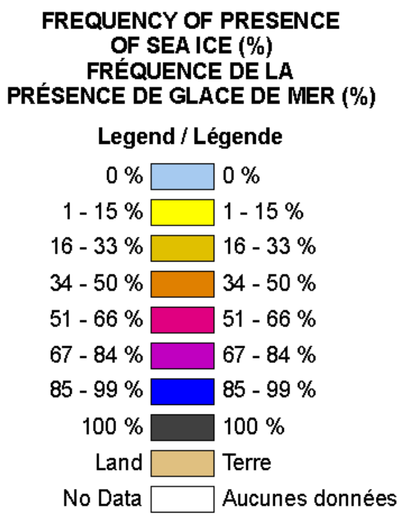
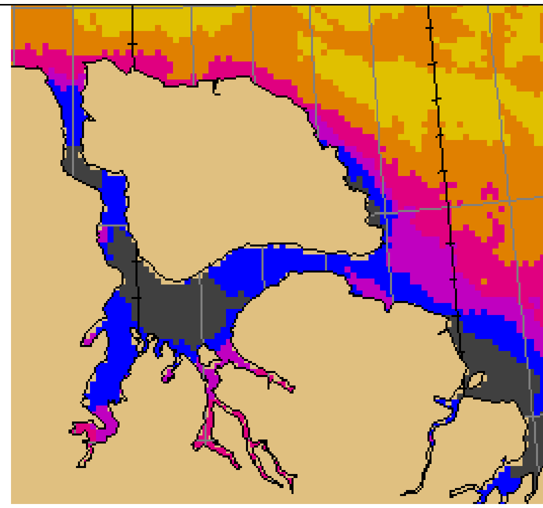
 01 OCT	 08 OCT
 15 OCT	 22 OCT

Frequency of Presence of Sea Ice (%), Source: CIS, 2013





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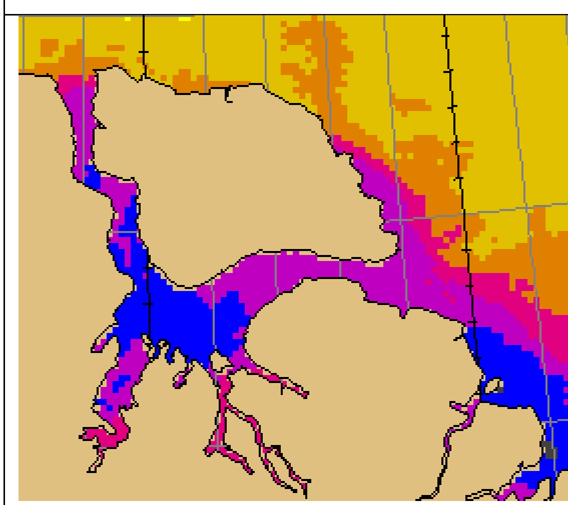

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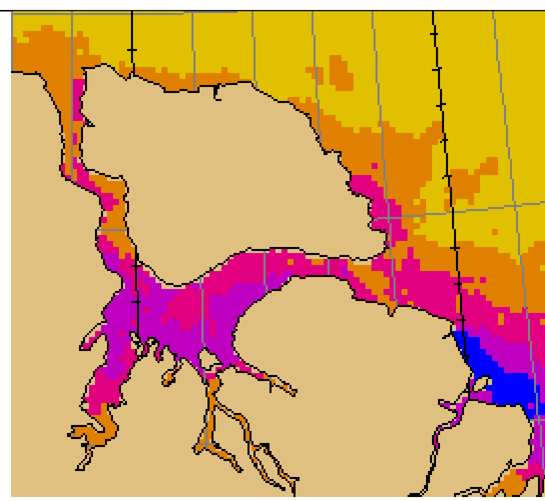

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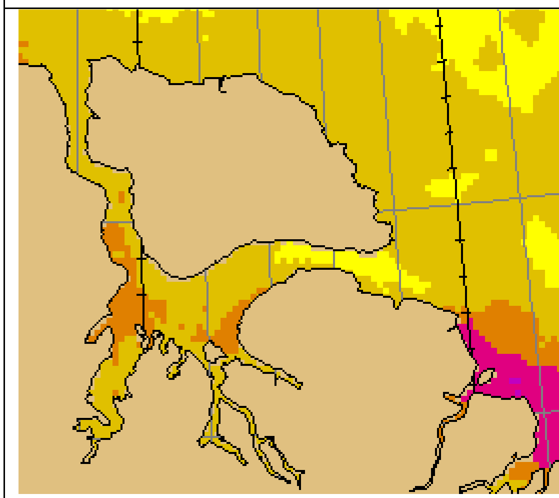
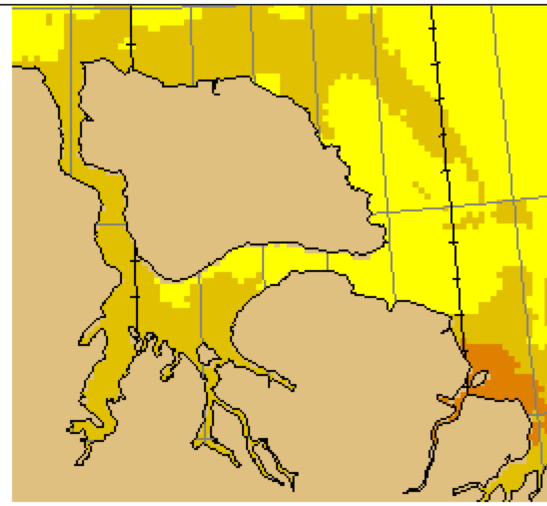
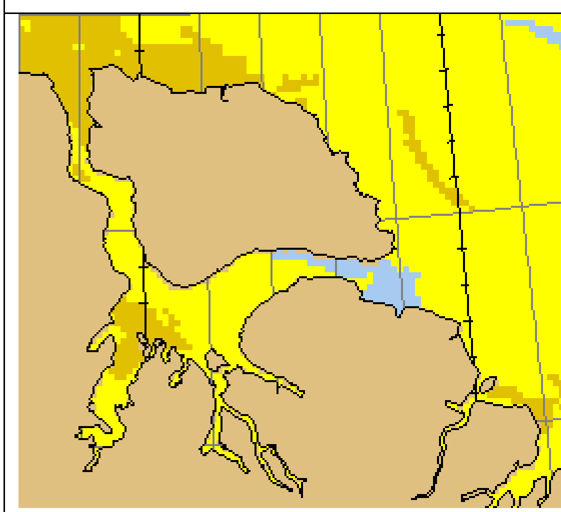
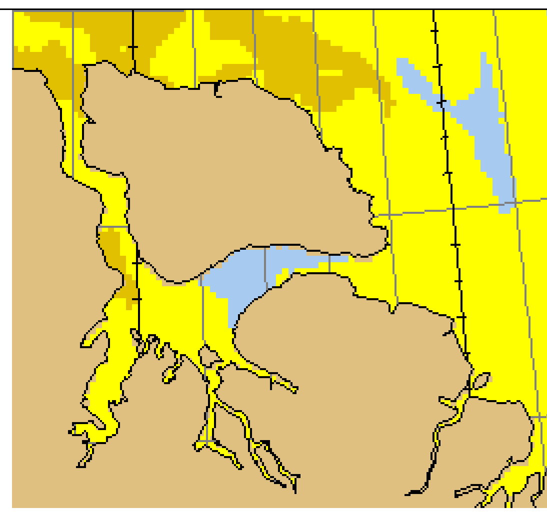
 06 AUG	 13 AUG
 20 AUG	 27 AUG

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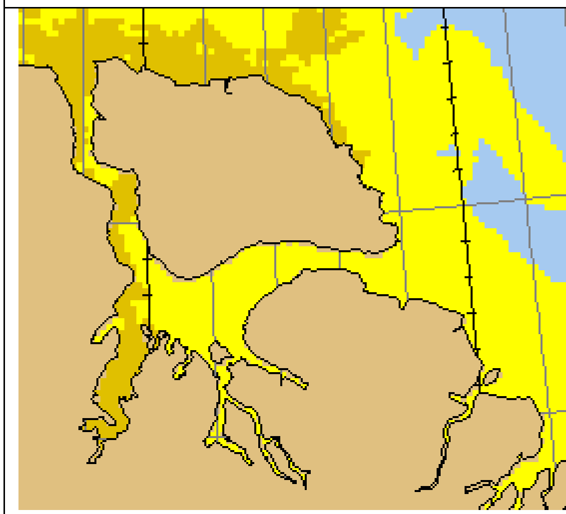

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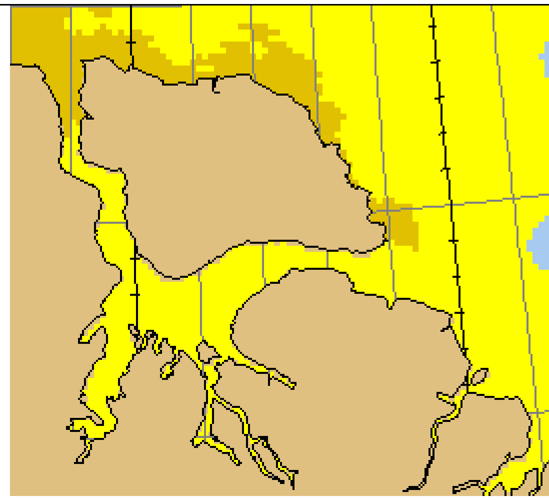

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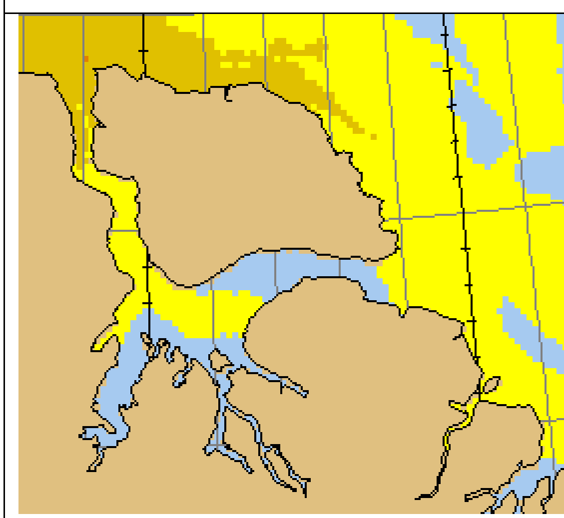

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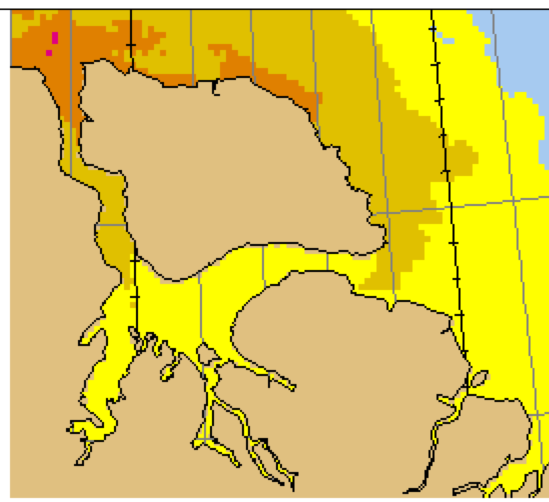

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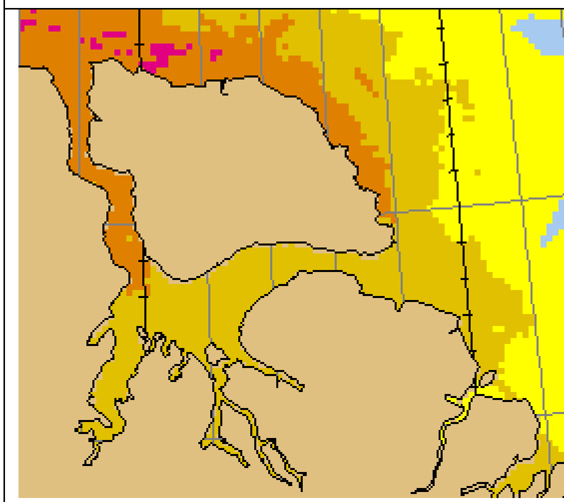
Frequency of Presence of Sea Ice (%), Source: CIS, 2013



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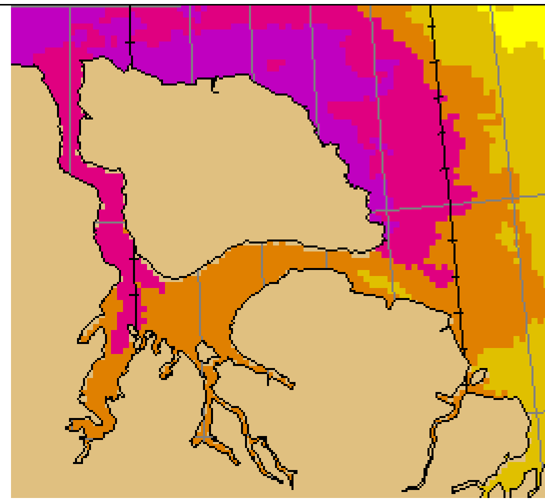

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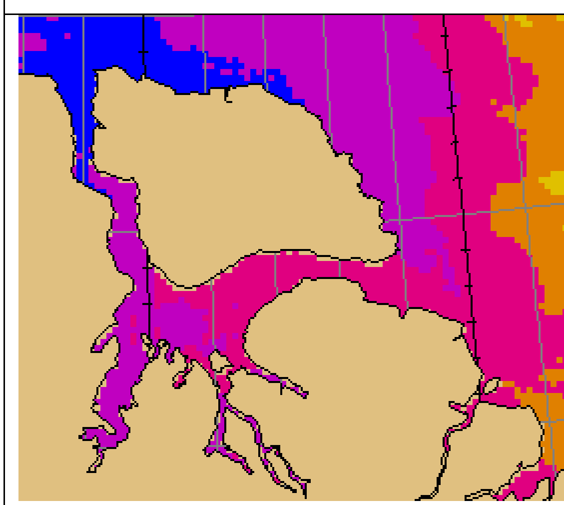

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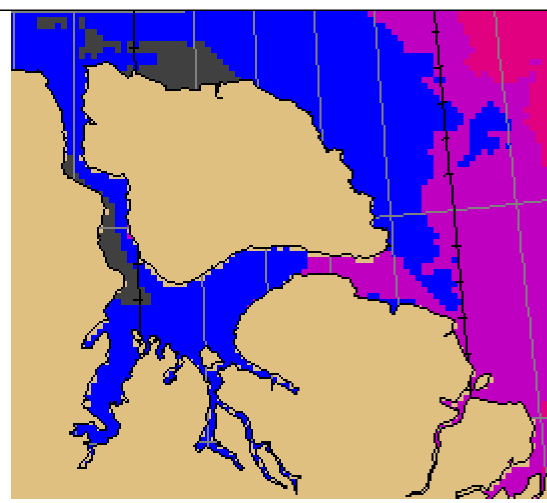

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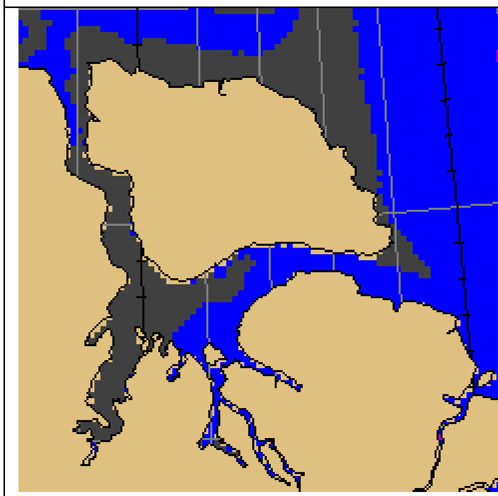
Frequency of Presence of Sea Ice (%), Source: CIS, 2013



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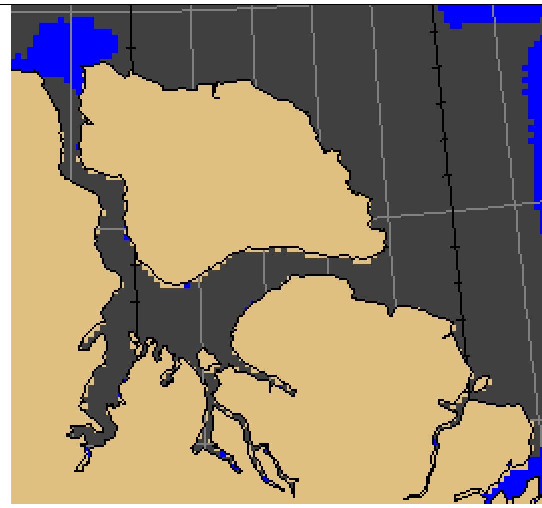
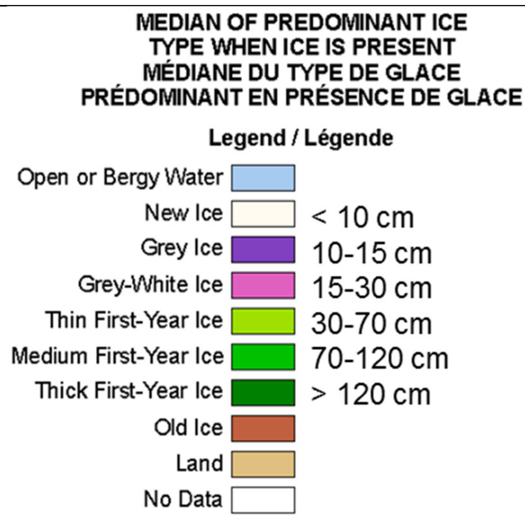
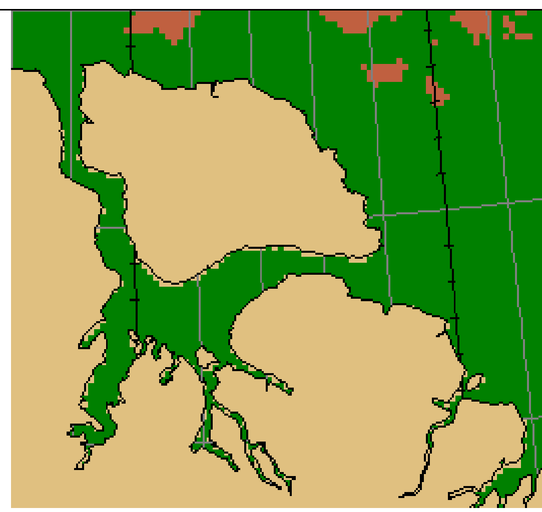


05 NOV

Median of Predominant Ice Type When Ice is Present, Source: CIS, 2013





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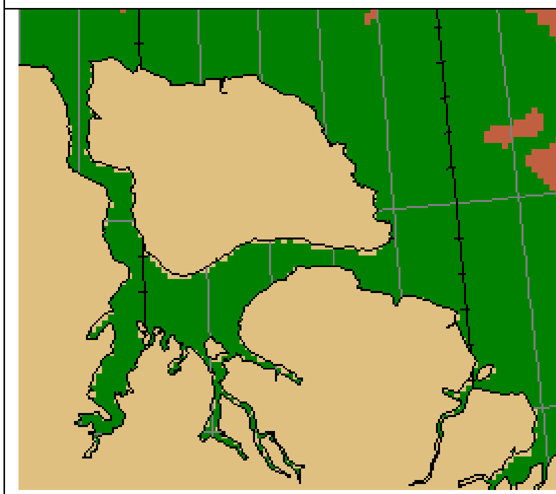
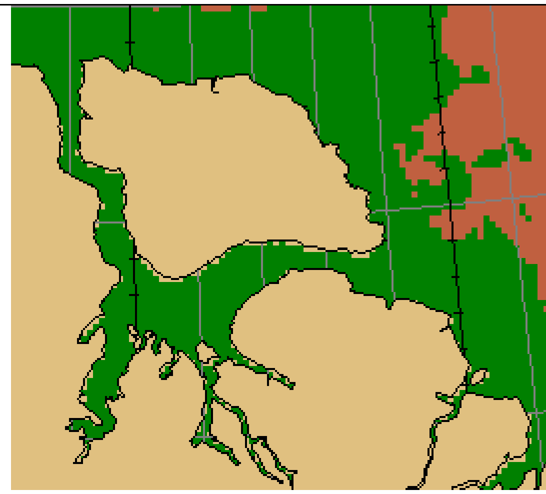
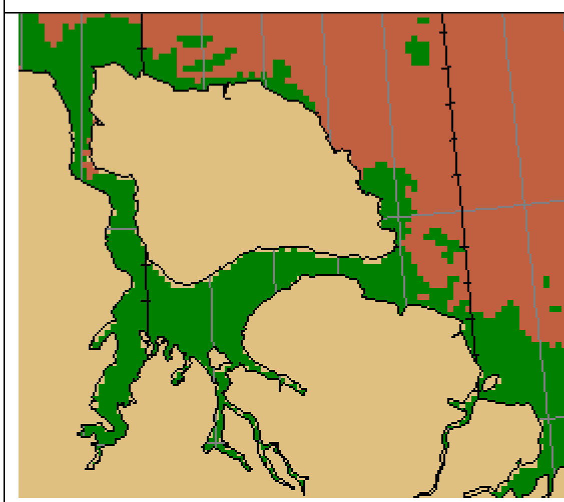
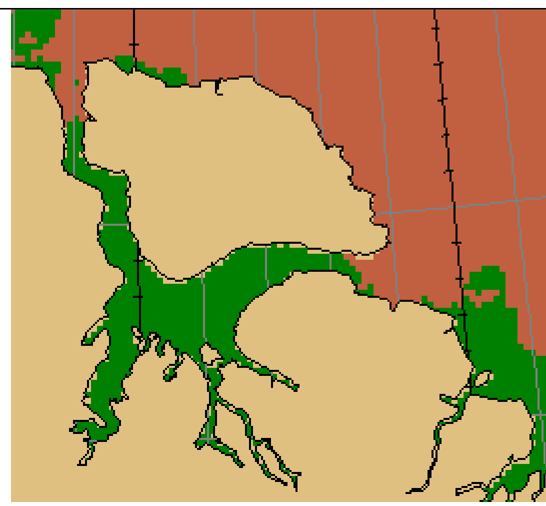
 23 JUL	 30 JUL
 06 AUG	 13 AUG

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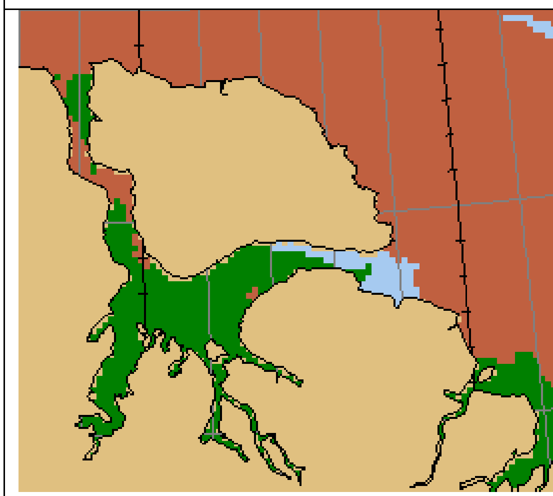

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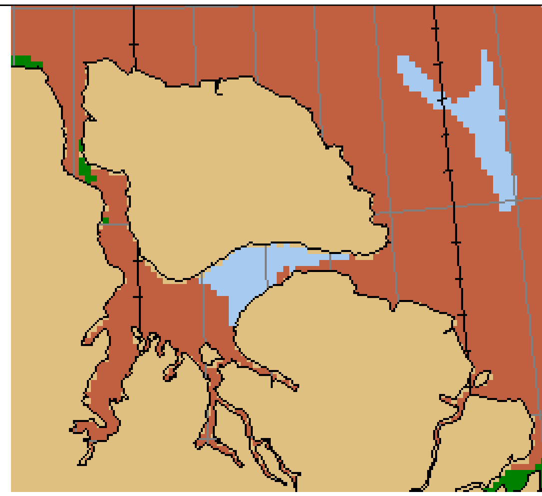

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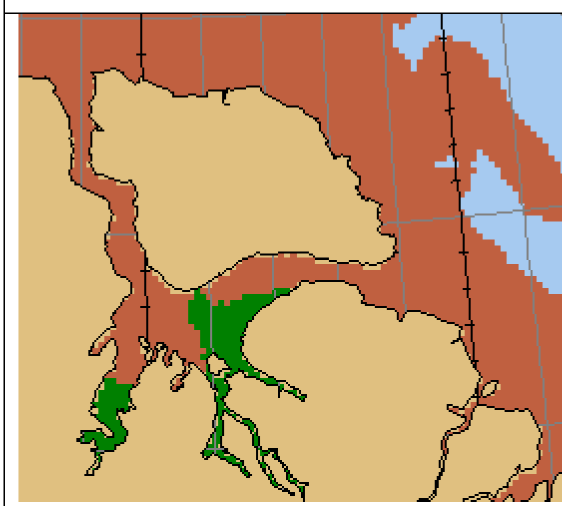

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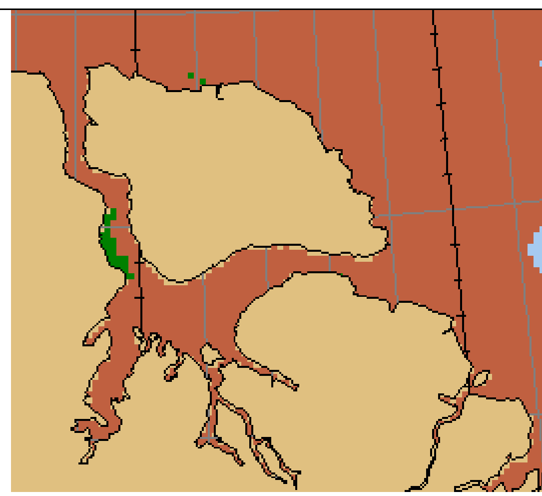

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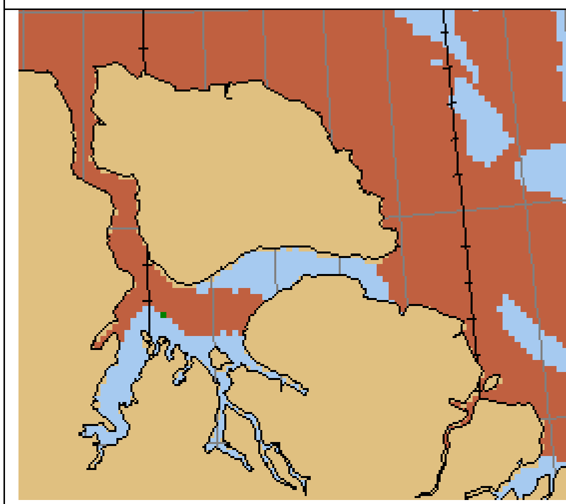
Median of Predominant Ice Type When Ice is Present, Source: CIS, 2013



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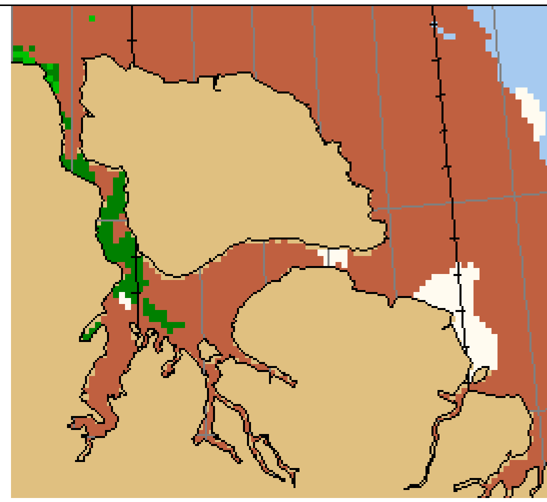

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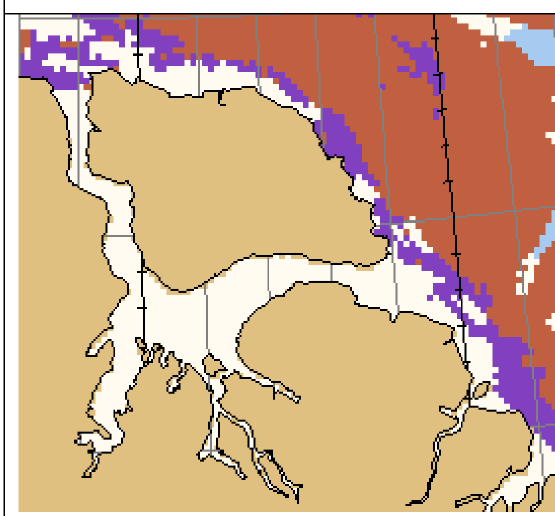

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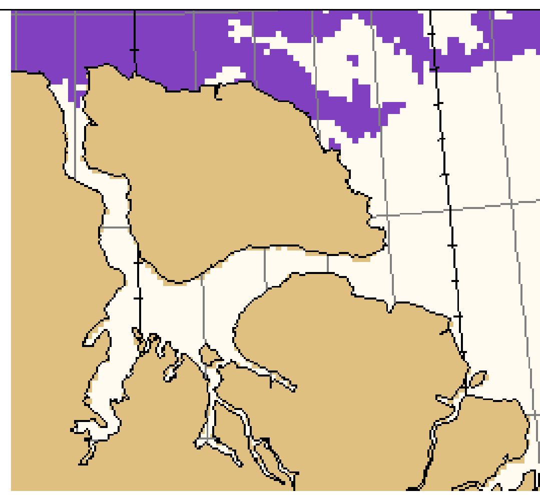

08 OCT

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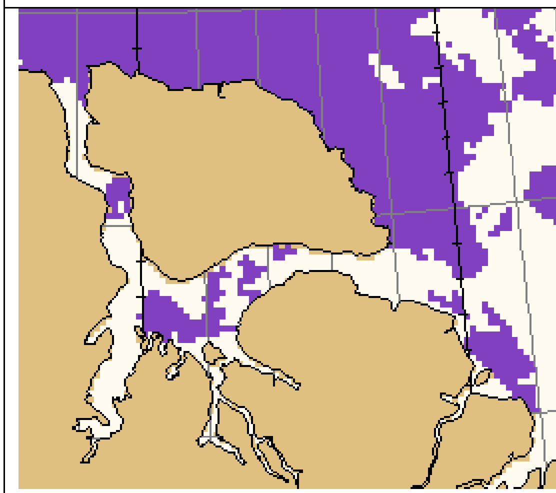
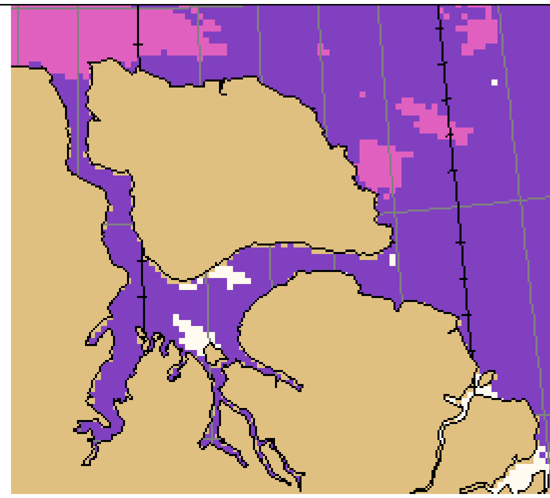
<tr><td>
15 OCT</td><td>
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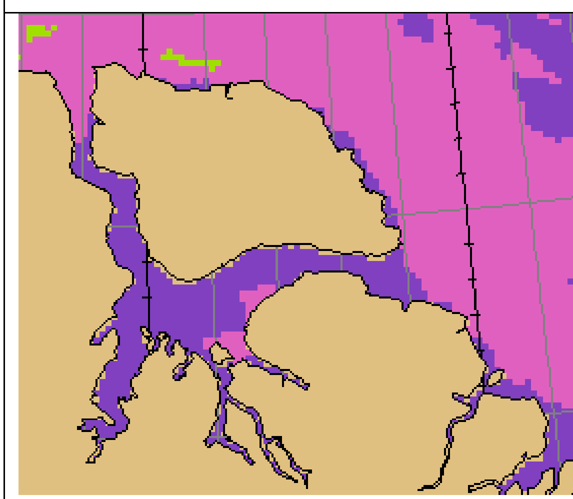
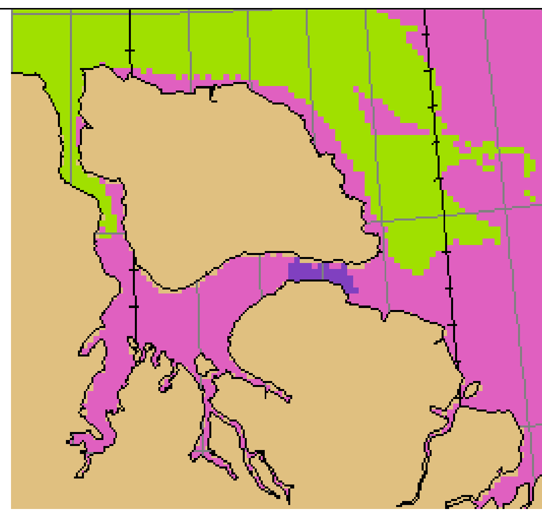
<tr><td>
29 OCT</td><td>
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