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Report

HFO IN THE ARCTIC-PHASE II

NORWEGIAN ENVIRONMENT AGENCY

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HFO in the Arctic-Phase II

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1 EXECUTIVE SUMMARY

1.1 Text

2 INTRODUCTION

The Recommendation 1B of the 2009 Arctic Marine Shipping Assessment (AMSA) report states "the Arctic states, in recognition of the unique environmental and navigational conditions in the Arctic, decide to cooperatively support efforts at the IMO to strengthen, harmonize and regularly update international standards for vessels operating in the Arctic."

Following this recommendation Norway proposed, and member governments approved at PAME I-2010, a project to identify environmental risks related to the use and carriage of heavy fuel oils (HFO) by ships in the Arctic region and to develop possible options for mitigating those risks. Phase I of the project culminated on 18 January 2011 with the issuance of a report prepared by Det Norske Veritas entitled Heavy fuel in the Arctic (Phase I) (DNV Reg No.: 2011-0053/12RJ7IW-4). The Report provided up-to-date, albeit time-limited information on vessel traffic in the Arctic region, estimated the proportion of this traffic operating on HFO, discussed environmental risks related to use and carriage of HFO, and summarized international regulations regarding HFO use and carriage.

At PAME 1-2012, the member states agreed to have the assigned co-leads develop the project description and Terms of Reference for a follow-up study (referred to as the Phase-II) to the study presented in 2011.

3 OBJECTIVE

Arctic shipping is high up on the agenda today and it is expected to receive increasing attention in the years to come. The main reason is the increased maritime traffic in the region and in particular the perspectives, with the diminishing sea ice, of a much shorter sea route between Asia and Europe. Also the expected surge in oil and gas related industries in the area will invariably result in an even further increase in ship activities.

The first "Heavy fuel in the Arctic – Phase I" study [Ref] concluded that the vessels operating in the Arctic region were relatively small vessels operating mainly on distillate fuels. However, with the expected rise in the inter-continental trading pattern plus an increase in the oil and gas related activities, most likely an increase in the average ship size is to be expected and consequently a proportional increased the use of Heavy Fuel Oil (HFO). Hence, a good understanding of the shipping activities as well as the risks and vulnerabilities involved is of key importance.

The study has addressed the following tasks:

- A full year traffic description based on satellite based AIS recordings of the Arctic region (as defined in the IMO Polar Code) indicating ship types and sizes. Ship operating hours and energy consumption with according emissions to air and water is calculated and tabulated. The same algorithms, but slightly refined (from the Phase I study [Ref\\]) for estimating the vessels operating on HFO is re-utilized for the Phase II.
- A regulatory gap analysis looking in to the existing regime controlling the use and carriage of HFO in the Arctic.
- A risk analysis related to the use and carriage of HFO in the Arctic split in the following tasks:
  - Task 1: HAZID Workshop for identifying hazards and risk reducing measures: Which hazards may occur? Propose risk-reducing measures that are relevant in order to obtain an acceptable risk level.
  - Task 2: Risk Assessment: how often can we expect an oil spill to occur and what are the likely consequences?
  - Task 3: Cost benefit assessment: Determining the cost effectiveness of the risk reducing measures. A qualitative discussion?
  - Task 4: Recommendations for decision-making. What actions should be taken?

It is important to note that the future (2020) international requirements for sulphur content in fuel will apply in the Arctic. After 2020 the 0.5% sculpture cap will change the type of bunker fuel (unless scrubbers are used). It is however important to note that this will still not be fuel to a marine gas oil standard and the actual effects of this fuel shift should be carefully evaluated. DNV is using the in-house fuel oil laboratory (DNV Petroleum Services) for this.

4 METHODOLOGY

4.1 General

4.2 Arctic delimitation (Part1)

The tender defines the geographical area to be covered by this assignment to be the same as used in the 2009 AMSA report and hence also the HFO in the Arctic Phase I report. This is the definition used in the IMO's Guidelines for Ships Operating in Ice-Covered Waters (Figure 4-1). As regards geographical application, ‘Arctic ice-covered waters’ is defined in Section G-3.2 as: *[waters] located north of a line from the southern tip of Greenland and thence by the southern shore of Greenland to Kape Hoppe and thence by a rhumb line to latitude 67º03’9 N, longitude 026º33’4 W and thence by a rhumb line to Sørkapp, Jan Mayen and by the southern shore of Jan Mayen to the Island of Bjørnøya, and thence by a great circle line from the Island of Bjørnøya to Cap Kanin Nos and thence by the northern shore of the Asian Continent eastward to the Bering Strait and thence from the Bering Strait westward to latitude 60º North as far as Il’pyrskiy and following the 60th North parallel eastward as far as and including Etolin Strait and thence by the northern shore of the North American continent as far south as latitude 60º North and thence eastward to the southern tip of Greenland; and in which sea ice concentrations of 1/10 coverage or greater are present and which pose a structural risk to ships.*

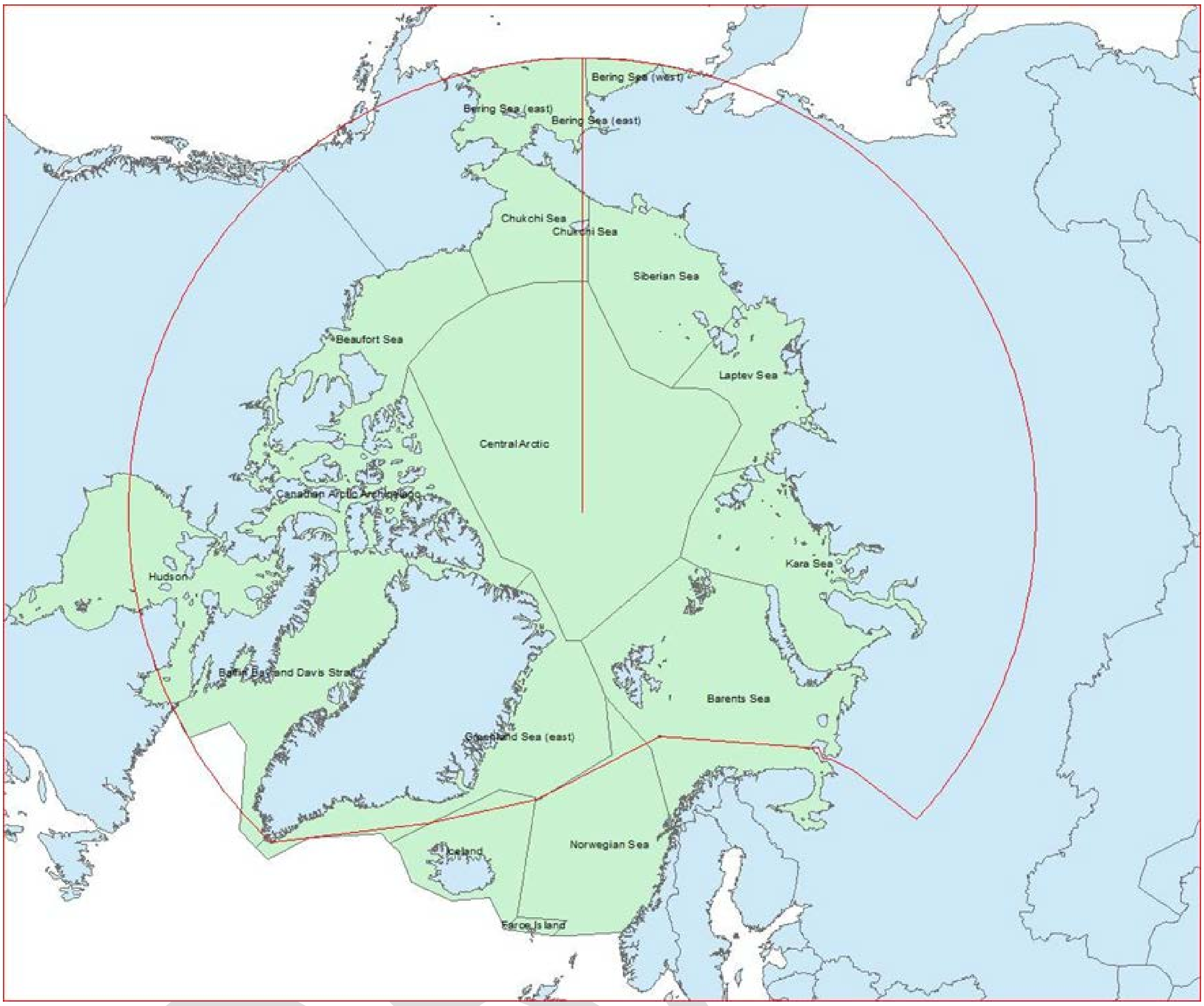

Figure 4-1 – The Arctic as defined according to the IMO Guideline – Sector division as per Large Marine Ecosystem as defined by US National Oceanic and Atmospheric Administration (NOAA)

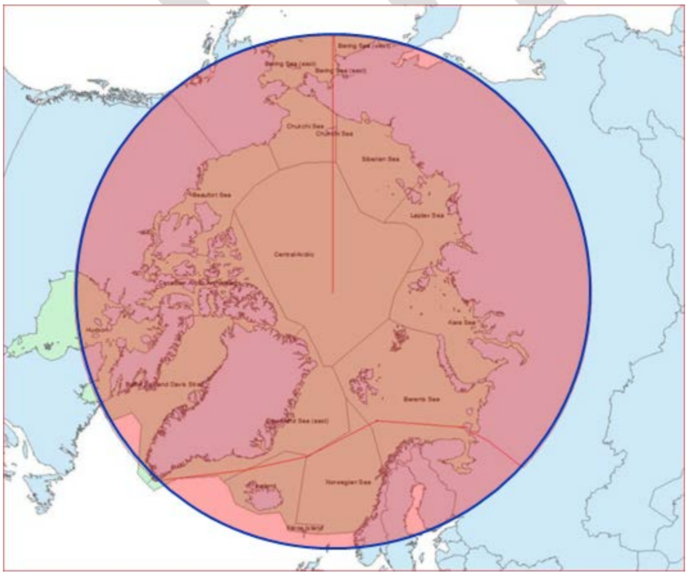

Figure 4-2 – The Arctic as defined as north of 60°N

It is important to note that defining the Arctic above 60° for the full circle as illustrated in Figure 4-2 above makes a huge difference to the amount of ship activity as compared to the IMO Guideline Arctic definition used in this study as is clearly illustrated in Figure 4-3. The ice-free areas around Iceland and north/west of Norway constitutes a major proportion of the ship traffic north of 60°N.

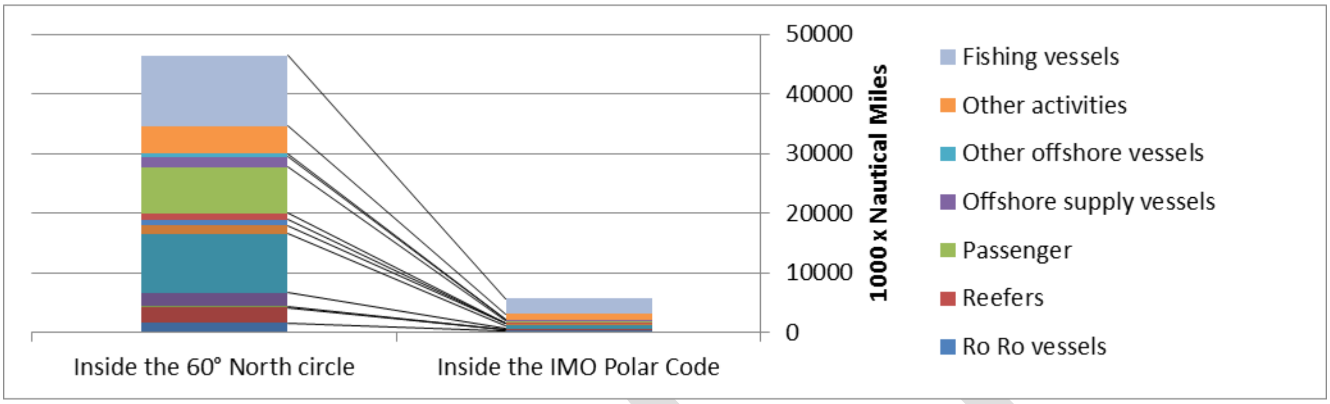

Figure 4-3 – Total sailed distance north of 60°N vs. inside the Arctic as defined in the IMO Guideline

4.3 Fuel oil definitions (Part1)

In this report, heavy fuel oil (HFO) is regarded equivalent to oil with characteristics as specified by IMO in the amendments to MARPOL considering the protection of Antarctica from pollution from heavy grade oil, including:

- crude oil having a density, at 15°C, higher than 900 kg/m3;
- oil, other than crude oil, having a density, at 15°C, higher than 900 kg/m3 or a kinematic viscosity, at 50°C, higher than 180 mm2/s; or
- bitumen, tar and their emulsions.

HFO under this definition will typically include residual marine fuel or mixtures containing mainly residual fuel and some distillate fuel (such as intermediate fuel oil - IFO), corresponding to the RM(A, B, D .. etc) qualities under the ISO 8217 Specification of Marine Fuel. In industry terminology, such fuel may be called by different names, such as “heavy fuel oil”, “heavy diesel oil”, “residual fuel”, “bunker”, or just “fuel oil”, or other.

Lighter products that do not exceed the specifications in the above definition will typically include distillate fuel - in this report referred to as marine gas oil (MGO) and marine diesel oil (MDO), or just distillates, normally corresponding to qualities within the DM(X, A, Z, B) of ISO 8217. Although the term marine diesel oil (MDO) as applied in this report refers to distillate fuels, MDOs may contain a small fraction of residuals, however not to an extent posing the specific environmental challenges associated with heavy fuel oil spills. Marine gas oil (MGO) represents pure distillate fuels.

4.3.1 HFO discussion

Define the different characteristics of HFO with regard to the different types, how it behaves when disposed to water, viscosity as a function of temperature and finally how cold water and high viscosity may reduce the potential risk of spill in case of a ruptured fuel oil tank.

4.4 Vessel traffic – 2012 – from satellite based AIS data (Part1)

The Solas Section V (Safety of Navigation) Regulation 19 requires Automatic Identification System (AIS) to be fitted aboard all tankers and ships of 300 gross ton, upwards engaged in international voyages, cargo ships of 500 gross ton, and upwards not engaged on international voyages and all passenger ships irrespective of size. Our material indicate that also ships not required to carry an AIS transponder carry such safety devices and hence the traffic picture generated may be expected to be representative of the actual traffic.

The requirement for Automatic Identification System (AIS) transponders on-board ships has over the last years revolutionized our knowledge of ship traffic, their environmental footprint and the subsequent risks involved. AIS is an automatic tracking system used on ships and by Vessel Traffic Services (VTS) for identifying and locating vessels by electronically exchanging data with other nearby ships and AIS Base stations.
AIS transponders automatically broadcast information, such as their position, speed, and navigational status, at regular intervals via a VHF transmitter built into the transponder. The information originates from the ship's navigational sensors, typically its global navigation satellite system (GNSS) receiver and gyrocompass. Other information, such as the vessel name and VHF call sign is also transmitted regularly. This data is submitted at regular intervals to nearby vessels, land based stations and lately to dedicated satellites (AISSat-1). This has opened for a completely new way of ship traffic surveillance, subsequent emissions and risk calculations related to their operation.

Based on the AIS data from January 1st to 31st of December 2012, a comprehensive illustration of shipping activities in the region is established. All records for the full year from 60°N and up are collected comprising in excess of 20 mill record. This data set is then cut (the northern part of the Norwegian Sea and the Behrens Sea is removed) according to the IMO Polar Code definition as illustrated in Figure 4-1 with the use of the ArcGIS mapping and spatial analysis tool. This brings the number of records down to approximately 1.4 million records clearly illustrating how dominating the traffic north of Norway is in this context. Based on the data set a series of plots illustrating the ship traffic in the region are generated.

Based on the above described data we will generate a series of geographical plots such as:

- Ship paths through the Arctic
  - Paths indicating ship category – each month
  - Paths indicating fuel type – each month
  - Paths for vessels likely carrying HFO
- Plot density plots of the traffic including:
  - Density of traffic – each month
  - Density of vessels using HFO – each month
  - Density of vessels carrying HFO – each month
  - Density of total amount of HFO – each month
- Separate the Arctic in different regions
- Projected density – 2030/50

4.5 Vessel demography in the Arctic (Part1)

Based on the 1.4 million records from the Arctic region the unique number of vessels is identified and the vessels are listed. This data is then coupled with the comprehensive DNV ship database for adding all relevant ship particulars and categories. Each vessel defined by its unique numbers, firstly based on the IMO number, then the MMSI number and then finally on the call sign or vessel name should none of the previous match. The remaining vessels will be kept in the data set, but will not be part of the calculations due to the missing data. The vessels will be categorized in the 13x7 type matrix (see Table 4-1) used for the Phase I study [ref] with 13 ship types based on the Lloyds standard ship break-down structure – category 5 and 7 size-groups based on Gross Tonnes.

Table 4-1 - Ship type and size categories

Ship types	Size categories (gross ton)
Oil tankers	<1000 1000-4999 5000-9999 10000-24999 25000-49999 50000-99999 >100000
Chemical and product tankers*	
Gas tankers	
Bulk carries	
General cargo	
Container vessel	
Reefers	
Ro Ro vessels	
Passenger	
Offshore supply vessels	
Other offshore vessels	
Other activities	
Fishing vessels	

For a breakdown of the different ship categories and the different sub-categories, please see Appenddix II for details

4.6 Vessels operating on HFO (Part1)

The identification of vessels operating on HFO in the Arctic is done by collecting AIS data and paring the data with other databases for ship specific information and test results on supplied fuel qualities. In addition, the vessel type/size groups where HFO is dominating are identified. For the vessels in these groups with no specific identification of fuel type, a separate evaluation of the machinery type and characteristics is performed prior to finally deciding the fuel type. The analysis has been carried out as a step-vice process as described below.

- The entire data set was then organized in a matrix as described in Table 4-1.

The AIS data set for ship movements in the Arctic was paired with the DNV Ship Register to incorporate ship specific information not found in the AIS data source. Additionally, the AIS data set was paired with the DNV Petroleum Services (DNVPS) database containing detailed fuel information from more than 7 million fuel samples. The DNVPS undertakes fuel quality testing and holds a database with fuel test information for more than10,000 vessels worldwide. Pairing of the datasets was done primarily by matching IMO number. If not successful, call sign, or finally ship names were applied for identification.

- These vessels were then assessed with respect to their machinery data obtained through pairing the data with ship data base as well as searching for information in relevant databases (for Russian vessels the fuel type is specified in the Russian Register which provided valuable input). Based on the exercise the vessels were categorized as HFO/non-HFO vessels, all laid out as a matrix as shown in the Table 5-5.

The following assumptions have been made:

- All vessels having registered DNVPS samples of HFO are defined as a vessel carrying HFO bunker oil onboard.
- A vessel will choose to operate on HFO in the Arctic with the same considerations as for normal worldwide operation.
- Vessels with large, long stroke and slow speed (< 200 RPM) machinery are generally assumed to operate on HFO unless otherwise stated.

Results from the analysis are found in section 5.8

4.7 Calculation of air emissions

The fuel and air emission calculations for main engines are derived from the ship activity. This means that the emissions from the main engines are calculated when the ship is moving. The main engine fuel consumption and emissions are based on AIS-registered vessel work (speed over ground) held against the ship speed capabilities. The auxiliary engine fuel consumptions and emissions are not dependent of the ship movement, but rather the operational status of the ship (i.e. loading/unloading, operation of cranes, etc.).

The following sections give a description of methodology for calculation of fuel consumption and emissions for main and auxiliary engines.

The calculation of fuel consumed in boilers and as pilot fuel in incinerators is not included. The boiler fuel oil consumption, for crude and product tankers, is by far the larger of the two representing about 2% of the total. For the crude and product tankers the boiler fuel oil consumption can range between 5% and 35% of the total fuel consumed, ref. Marintek lead consortium

$$Me\_FuelConsumption = \frac{Me\_kW\_total \bullet Me\_LoadFactor \bullet Me\_SFOC \bullet SecondsNextPoint}{1000000 \bullet 3600} \quad \textbf{(1)}$$

1 Me_FuelConsumption = main engine fuel consumption for the specific period of time (ton fuel)
2 Me_kW_total = total installed main engine power (kW)
3 Me_SFOC = specific fuel oil consumption for main engines (gram fuel per kWh)

The calculation of main engine fuel consumptions are performed for each ship for a specific time period (ΔT). The time period represents the time between two following ship positions (AIS) messages. For the given time period the appurtenant sailing distance is calculated. The time period and sailing distance are stored in the database together with information identifying the actual ship. The time period between two position will vary slightly with the frequency of incoming AIS messages.

Based on the time period and sailing distance, the average ship speed over ground (knot) can be calculated. The formula for calculating the average ship speed over ground is presented in equation 1.

$$Speed\_SOG = \frac{DistanceNextPoint}{SecondsNextPoint} \bullet \frac{3600}{1852} \qquad \textbf{(2)}$$

1 Speed_SOG = Ship speed over ground (knot)
2 DistanceNextPoint = calculated sailing distance between two ship positions (meters)
3 SecondsNextPoint = specific time period for the appurtenant sailing distance (seconds)

By comparing the average ship speed over ground and the ship speed capabilities (defined as service speed), the main engine load factor can be calculated. The formula for calculating the main engine load factor is presented in equation 3.

$$Me\_LoadFactor = \left(\frac{Speed\_SOG}{ServiceSpeed} \right)^3 \qquad \textbf{(3)}$$

1 Me_LoadFactor = given as fraction between 0 and 1, representing 0 to 100% engine load
2 ServiceSpeed = Ship service speed at 80-85% engine load (knot)

It should be noted that the services speed is normally achieved when the main engines run at about 80-85% load. By using the total installed power in the calculations the fuel consumption might be over estimated. However the presented service speed is normally representative only for ideal conditions. Ageing of vessel and fouling of the ship's hull will result in more power demand to maintain the actual service speed. For that reason the calculations assume 100% engine load for achieving the service speed (i.e the speed given in the ship register),

By multiplying the total engine power, engine load factor and specific fuel consumption for the given period of time, the total amount of fuel consumed for the actual segment is calculated. The formula for calculating the main engine fuel consumption is presented in equation 4.

$$Me\_FuelConsumption = \frac{Me\_kW\_total \bullet Me\_LoadFactor \bullet Me\_SFOC \bullet SecondsNextPoint}{1000000 \bullet 3600} \qquad \textbf{(4)}$$

4 Me_FuelConsumption = main engine fuel consumption for the specific period of time (ton fuel)
5 Me_kW_total = total installed main engine power (kW)
6 Me_SFOC = specific fuel oil consumption for main engines (gram fuel per kWh)

4.7.1 Auxiliary engine fuel oil consumption

The fuel consumption for auxiliary engines is not dependent on the ship speed, but rather on the onboard activities (i.e. in port, loading, operation of cranes, pumps, etc.).

Traditionally marine emission inventories differentiate between auxiliary engine loads for the two modes "at sea" and "harbour". For the AIS based accounting system there is no information which can be used for setting the actual auxiliary engine load. This means that the emission calculations will be based on the traditional settings, "at sea" or "harbour" mode. The calculations will differentiate between the two modes by checking the average ship speed. If the Speed_SOG > 0.3 knot equation 5 shall be used (at sea mode); else equation 6 should be used (harbour mode).

$$AUX\_FuelAtSea = \frac{AUX\_kW\_total \bullet FactorA \bullet AUX\_SFOC \bullet SecondsNextPoint}{1000000 \bullet 3600} \quad (5)$$

1 AUX_FuelAtSea = auxiliary engine fuel consumption for the specific period of time “at sea” mode (ton fuel)
2 AUX_kW_total = total installed auxiliary engine power (kW)
3 AUX_SFOC = specific fuel oil consumption for auxiliary engines (gram fuel per kWh)
4 FactorA = auxiliary engine load factor for ships operating in the mode “at sea”

$$AUX\_FuelHarbour = \frac{AUX\_kW\_total \bullet FactorB \bullet AUX\_SFOC \bullet SecondsNextPoint}{1000000 \bullet 3600} \quad (6)$$

1 AUX_FuelHarbour = auxiliary engine fuel consumption for the specific period of time at “harbour” mode (ton fuel)
2 FactorB = auxiliary engine load factor for ships operating in the mode “harbour”

4.7.2 Calculation of emissions to air

The calculations of emissions to air are based on applying the fuel consumption and the appurtenant emission factors for each pollutant. The emission factors are given as kg pollutant per ton fuel, ref section 4.7.3. The formula for calculating NOx emissions from the main engines are presented in equation 7.

$$Me\_NOxEm = Me\_FuelConsumption \bullet Me\_NOxEmFactor \bullet \frac{1}{1000} \quad (7)$$

1 Me_NOxEm = NOx emission for the specific time period (ton NOx)
2 Me_NOxEmFactor = NOx emission factor for main engines (kg NOx per ton fuel)

The formula for calculating NOx emissions from auxiliary engines are presented in equation 8.

$$AUX\_NOxEm = (AUX\_FuelAtSea + AUX\_FuelHarbour) \bullet AUX\_NOxEmFactor \bullet \frac{1}{1000} \quad (8)$$

1 AUX_NOxEm = NOx emission for the specific time period (ton NOx)
2 AUX_NOxEmFactor = NOx emission factor for auxiliary engines (kg NOX per ton fuel)

The emission calculations for the other components are made by replacing the NOx emission factors with the emission factor for the actual component in question.

4.7.3 Emission factors for gas compounds

The emission factors denote the amount of pollutant as function of the fuel consumption (kg pollutant per ton fuel). For the gas compounds CO2, nmVOC, CH4, N2O, CO, BC and OC are the emission factors based on recognised emission factors, ref. E&P forum (1993), LR (1995) EMEP/CORINAIR (1999), ref /2/.

The NOx emission from an engine depend on several factors, such as combustion temperature, gas detention time in the combustion chamber and more. The NOx emission factors are therefore highly dependent on the specific engine installed. The NOx emission factor for an engine is therefore collected from the engine specific EIAPP certificate whenever available. Where not available, the emission factors presented in Table 4-2 are applied, ref /2/.

Table 4-2 Emission factors for gas compounds

Gas component	Emission factors for engines (kg / ton fuel)		
	Slow Speed Engine RPM < 200	**Medium Speed 200 < Engine RPM< 750**	**High Speed Engine RPM > 750**
CO2_EmFactor (kg/ton fuel)	3170	3170	3170
NOx_EmFactor (kg/ton fuel)	87	57	57
nmVOC_EmFactor (kg/ton fuel)	2.4	2.4	2.4
CH4_EmFactor (kg/ton fuel)	0.3	0.3	0.3
N2O_EmFactor (kg/ton fuel)	0.08	0.08	0.08
CO_EmFactor (kg/ton fuel)	7.4	7.4	7.4
BC_EmFactor (kg/ton fuel)	0.18	0.18	0.18
OC_EmFactor (kg/ton fuel)	0.608	0.608	0.608

Different emission factors depending on the fuel type are used. For the auxiliary engines, it is assumed that all engines use distillate fuels only. The emission factors for both SO2 and PM are given in Table 4-3.

Table 4-3 Emission factors for SO2 and particulate matters (PM)

Gas component	Emission factors for engines (kg / ton fuel)	
	Residual fuel (1) (2.7% Sulphur)	**Distillate fuel (2) (0.5% Sulphur)**
SO2_EmFactor (kg/ton fuel)	54	10
PM_EmFactor (kg/ton fuel)	7.6	1.2

(1) Slow and medium speed engines
(2) High speed and auxiliary engines

4.8 Error-sources in emission calculations

4.8.1 Uncertainties due to AIS data flow

The following are identified as error sources for the AIS data flow:

- AIS system down-time (transponder, data lines, satellite and servers)
- The AIS ship identification data (SourceMMSI, IMOnumber and CallSign) can be missing in the incoming AIS data flow, or the data hold information which can not be automatically linked with the ship register.
- The calculation of sailing distance and related time is for the incoming AIS data made for each ship for a defined time period. If the start and stop period for the incoming AIS data crosses midnight, the recordings are excluded from the dataset. This means that the period crossing midnight (equals about 0.7% of registered time) is excluded.

1.1 Uncertainties due to data missing in the Ship register

The following are identified as error sources for the ship register:

- There will always be missing data in ship registers and to some extent errors in the registrations. Missing data is regarded as the major source for errors in the AIS based environmental accounting system. However the missing data may be mitigated using average values established from similar ship types and size categories.
- The Ship Register holds data on more or less all merchant ships above 100 GT. However, the AIS data also include vessels which normally are not recorded in the ship registers. This applies typically for small ships (>100GT) which for various reasons have an AIS transmitter.
- Fuel consumption and air emissions for ships having diesel electric power generation will be overestimated when operating "at sea" mode, and not accounted for in "harbour" mode. The main reason for this is that only total installed diesel electric power is registered in the ship register, not allocated between main engines and auxiliary engines. Thus in the described accounting system, no consumption is allocated to auxiliary engines (the main contributor in "harbour" mode), and too much consumption is allocated to main engines (the main contributor in "at sea" mode).

1.2 Uncertainties in fuel consumption calculations

In this study, calculation of fuel consumption and hence air emissions are based on an estimated usage of installed power (kW). The power usage is estimated based on the actual AIS-measured work (i.e. speed over ground) held against the capacity of the ship (such as the service speed). The main potential error sources with this approach are as follows:

- As of today, we don't know exactly the actual engine load for the service speeds recorded in the ship register. In addition, not all ships in the ship register has been allocated with a certain service speed, thus we have to extrapolate from comparable ships. Although indicated service speeds normally represent about 85% engine load, experience show that to be able to maintain such speed after some time in operation (taking into account fouling of wet surfaces, ageing of ships etc) a higher engine load will be required. Thus the project has decided to define the engine load for given service speed as 100 % of installed power. This may somewhat overestimate the consumption and emission figures.
- For some ship types, especially offshore supply and service vessels, a significant proportion of the total installed power may represent redundancy power. Such "spare" power potential is not necessarily contributing to the AIS registered speed over ground. The algorithms include this power in the calculations, thus calculations for offshore supply vessels may be overestimated.
- The AIS-measured speed for offshore vessels does not necessarily reflect the actual work that has been carried out. For example, the power usage of an anchor handling vessel may be substantial even if the sailed distance over time is low. The same may apply to tugs. In a system that estimates power usage based on measured speed, the consumption and emissions for such ships therefore be underestimated.

4.9 Vessels transporting HFO in the Arctic

A 13x7 matrix listing the vessel types and size group will also contain the proportion of vessels operating on HFO within each category/size-group.

4.10 GAP analysis of existing regulatory regimes

To be completed

4.11 Risk analysis for the present and projected use for HFO in the Arctic

Risk is calculated for vessel traffic related to the use and transport of oil in the Arctic, based on the traffic picture provided in Chapter 5.

Risk is a function of the expected frequency (probability) and consequences for a given event, of which the consequences are estimated with respect to spills of fuel oil (HFO). This does not take into consideration any environmental damage to sensitive areas.

Discharge potential in this context is the likelihood of accidental discharge of heavy fuel oil caused by a shipping accident.

The risk analysis consists of the following main tasks:

- **Task 1: HAZID Workshop for identifying hazards and risk reducing measures:** *What hazards may occur? Propose risk reducing measures that are relevant in order to obtain an acceptable risk level.*
- **Task 2: Risk Assessment:** *how often can we expect an oil spill to occur and what are the likely consequences?*
- **Task 3: Cost benefit assessment:** *Determining the cost effectiveness of the risk reducing measure. What would it cost and how much is it likely to improve the situation?*
- **Task 4: Recommendations for decision making.** *What actions should be taken?*

Accident frequencies for the various accident categories are estimated based on ship accident statistics recorded in the IHS Fairplay Casualty Database. This data, combined with estimated distances sailed, result in accident base frequencies per sailed nautical mile, within accident and ship categories.

Previous analyses have shown that it can be assumed that the probability of a ship accident is proportional to the distance sailed, ref /1/. Thus, the accident frequencies and traffic can provide estimates of the expected number of accidents. However, the historical data consists of accidents from all over the world, and will therefore need adjustments adapting to arctic conditions. The likelihood of various accidents also depends on variables such as distance to shore and the amount of traffic in a particular area. These parameters are accounted for by adjusting the base frequency accordingly depending on location provided in the ship traffic information.

There exists statistics that describe the extent of damage to ships that have been involved in various accidents. Given that there has been a shipping accident, it is possible to calculate the probability of different damages and spills. This report will use empirical data from DNV (ref. /3/) on the probability of emission given an accident. Spill potential will be expressed as the expected frequency of spill within the various spill categories.

5 SHIP TRAFFIC AND EMISSIONS

The AIS based environmental accounting system used for this study differs from traditional calculation methods since actual activity profiles for ships are continuously monitored and calculated. The system registers all ship activities within the selected region (at sea or in port) enabling for accurate calculations of the fuel consumption and emissions to air.

5.1 AIS data

By introduction of the Automatic Identification System (AIS) and by making its use mandatory for ships above 300 GRT and for all passenger ships, a simple and efficient way of collecting detailed ship traffic information was created. The system was initially introduced as an aid to navigation, offering simple means for one ship to determine the identity, position, course and speed of all ships in its vicinity. As of today, AIS works on VHF radio and this limits the range of coverage to about 40-60 nm. Thus, AIS data was initially used for monitoring coastal shipping only, but with the introduction of dedicated AIS satellites, also intercontinental open sea traffic could be included in the data material.

The AIS data have several fields giving specific information on ship identification and ship particulars. However the ship particulars presented in the AIS source are limited and links with a comprehensive and consistently updated ship register is required for achieving a data quality sufficient for consistent emission and risk calculations. Linking the AIS data and quality ship registers enables in-depth analysis and calculations for environmental accounting, risk analysis, analysis of voyage performance, Energy Efficiency Operational Index (EEOI), etc.

Connecting the AIS data and the ship register is done through the fields IMO number and Callsign. The MMSI field is unique for each ship and for that reason can be used as an additional source, but this field is at the moment not included in the ship register.

DNV have a unique register of all DNV classified ships and in addition a register of all ships above 100 gross ton (Lloyds Fairplay). Both registers are consciously monitored and updated and any changes of ship particulars will be captured. The ship registers contain loads of data fields which contain information that potentially can be used in an accounting system or giving valid input for improving the emission and discharge calculations.

5.2 Baseline ship demographics

Throughout 2012 a total of 1347 unique vessels made at least one voyage through the Arctic as defined in paragraph 4.2. As may be seen in Table 5-1 and Figure 5-1, the absolute majority are relatively small vessels mostly in local traffic. The dominating ship types are fishing vessels and the category called "Other activities" comprising vessels such as tugs, local community vessels and research vessels. (See Appendix II for details)

Table 5-1 Number, type and size of unique ships

Ship type	Number of unique vessels							
	<10000 GT	1000 - 4999 GT	5000 – 9999 GT	10000-24999 GT	25000-49999 GT	50000-99999 GT	≥100000 GT	**Total**
Oil tanker		44	6	7	17	3		**77**
Chemical/Prod tanker	1	19	11	11	4			**46**
Gas tanker							1	**1**
Bulk carrier		2	2	26	46			**76**
General cargo	7	85	33	7	1			**133**
Container vessel			9	8				**17**
RoRo	5	1		1				**7**
Reefer	2	36	21	5				**64**
Passenger	8	14	7	16	13	10	3	**71**
Offshore supply vessel	4	29	3	1				**37**
Other offshore service vessel	11	2		2				**15**
Other activities	108	75	29	18	3			**233**
Fishing vessel	243	305	22					**570**
Total	**389**	**612**	**143**	**102**	**84**	**13**	**4**	**1347**

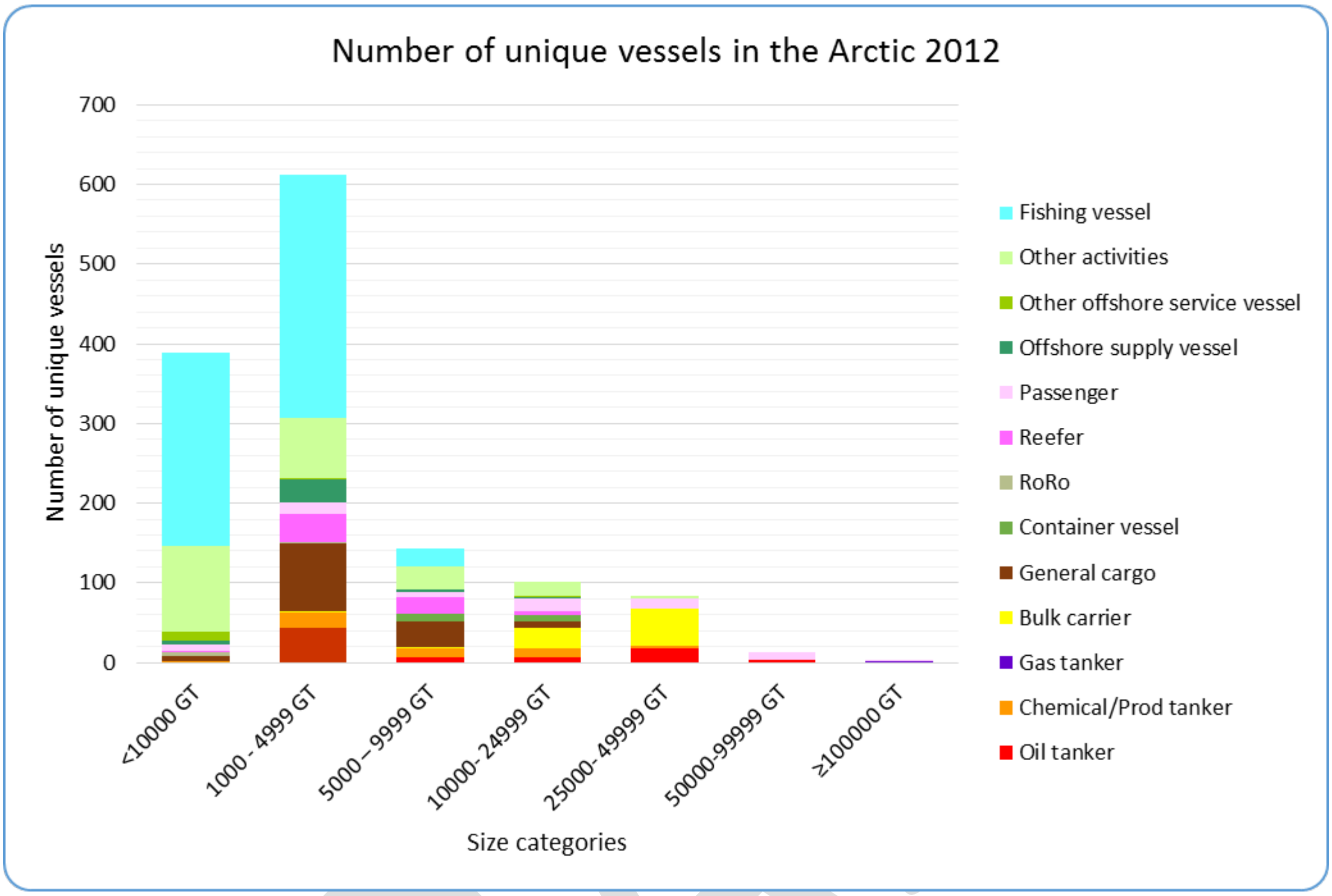

Figure 5-1 - Number and types/size of unique vessels in the Arctic

5.3 Ship activity maps

Based on several million position codes, the data was recalculated to be represented as lines and plotted on Google Earth. The calculations are based the use of the Ramer-Douglas-Peucker [3, 4] line simplification algorithm and the tolerance parameter to identify points that may be dropped from the track with minimal loss of information. The algorithm will typically drop points that lie on or close to straight lines with constant speed, thus minimizing the amount of data involved.

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Table of emission factors to be included

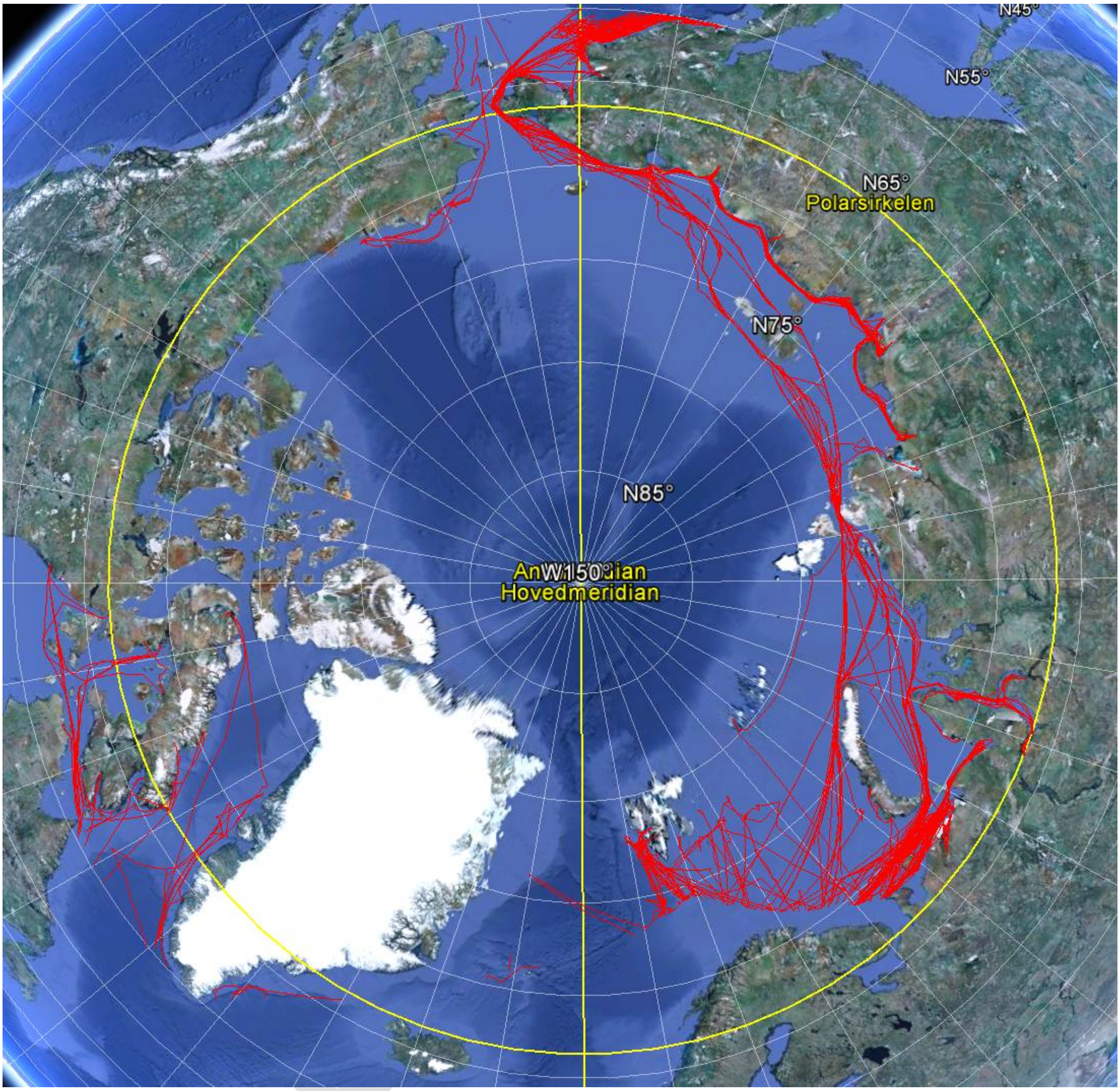


Figure 5-2 - Oil tanker traffic in the Arctic – 2012

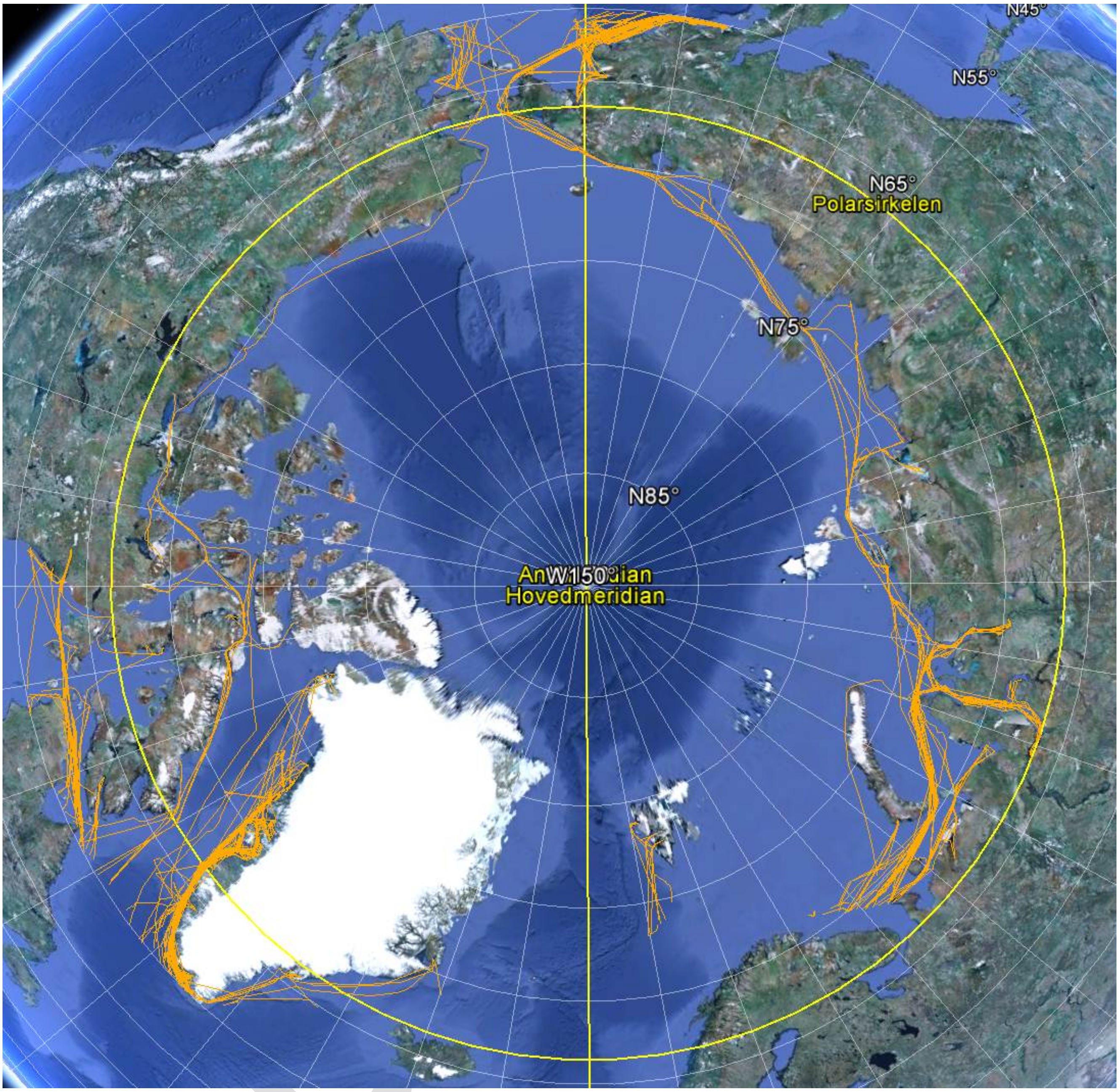


Figure 5-3 - Chemical and product tankers in the Arctic – 2012

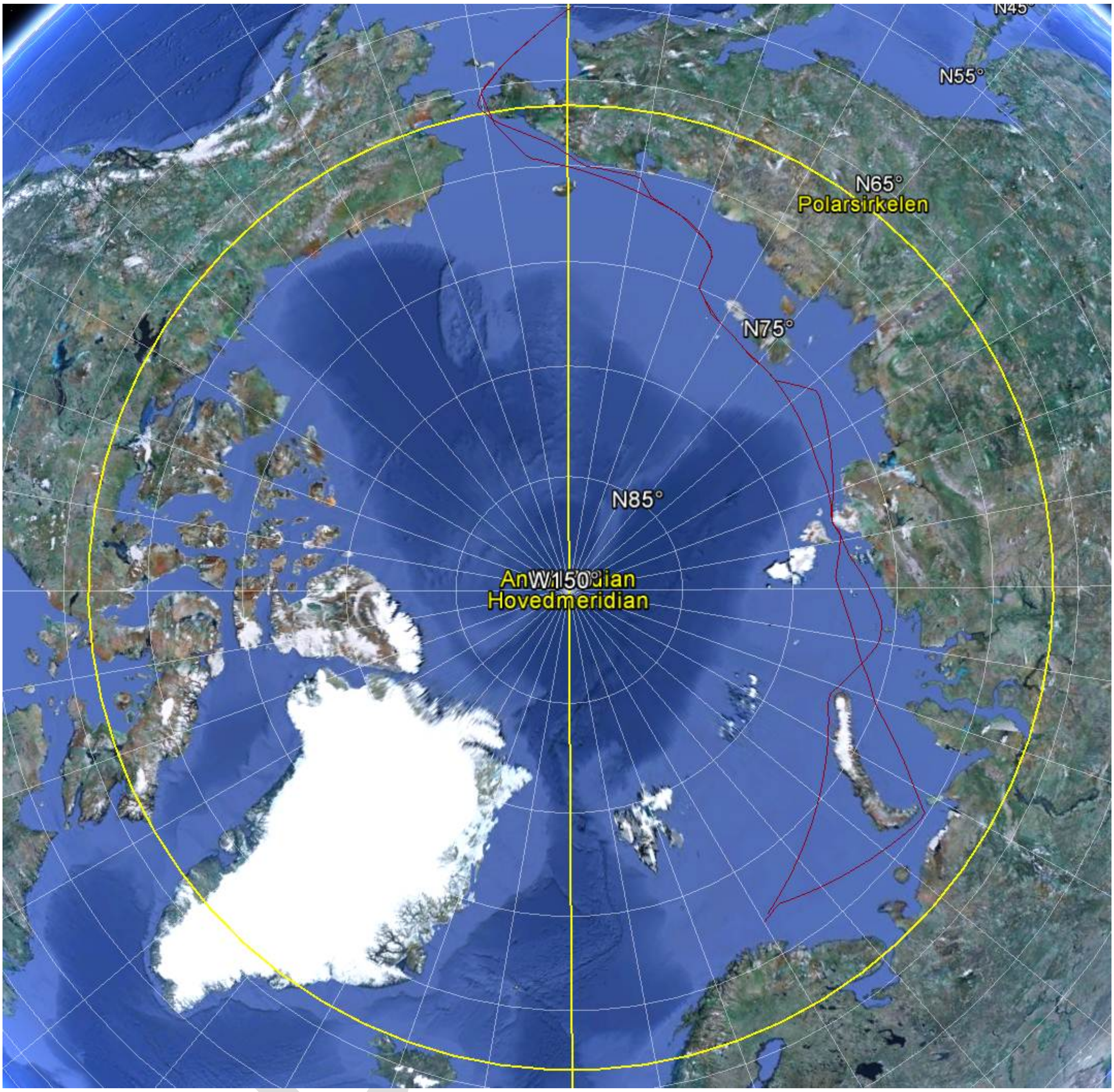


Figure 5-4 - Gas tankers in the Arctic – 2012

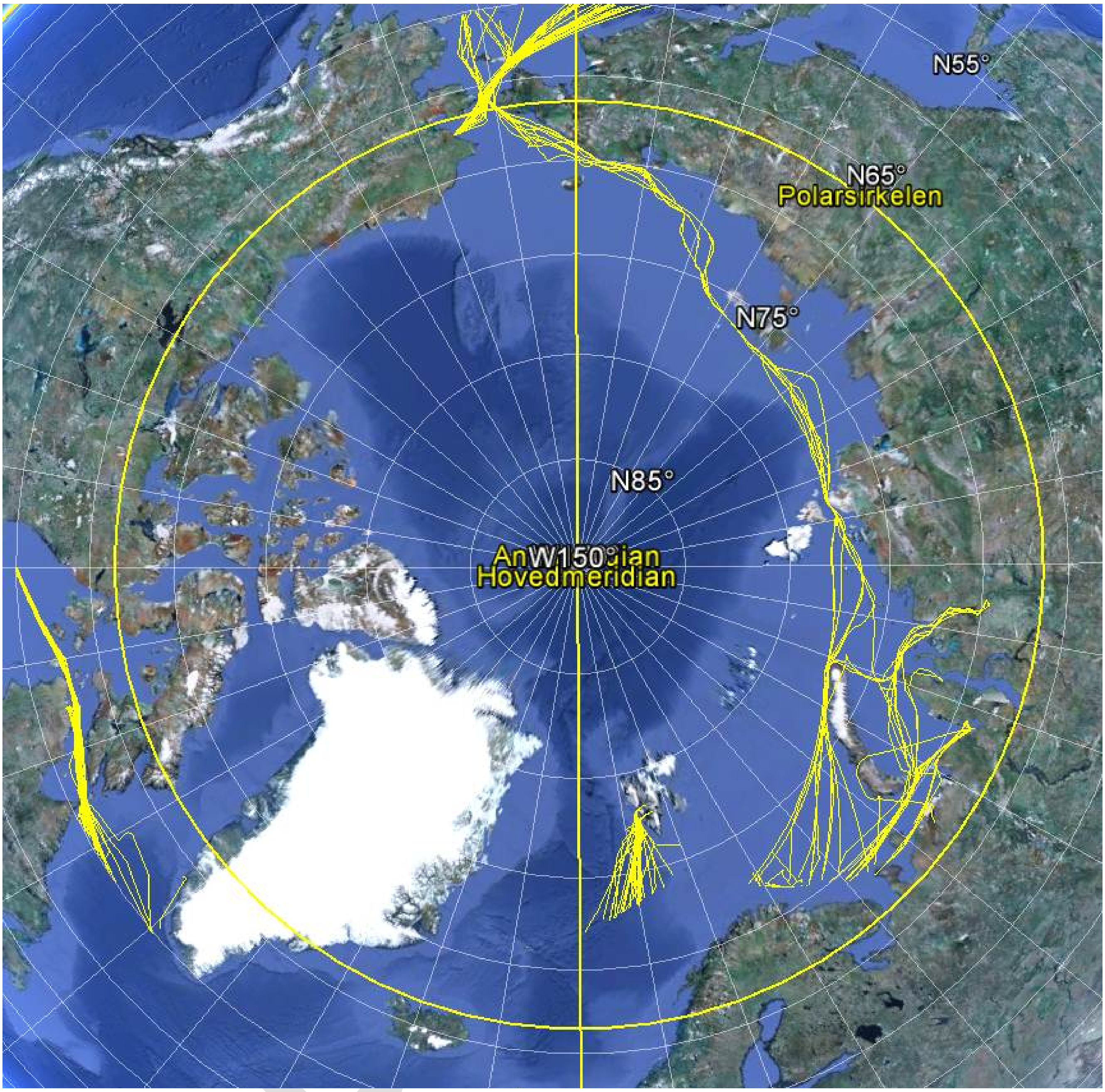


Figure 5-5 – Bulk carrier traffic in the Arctic – 2012

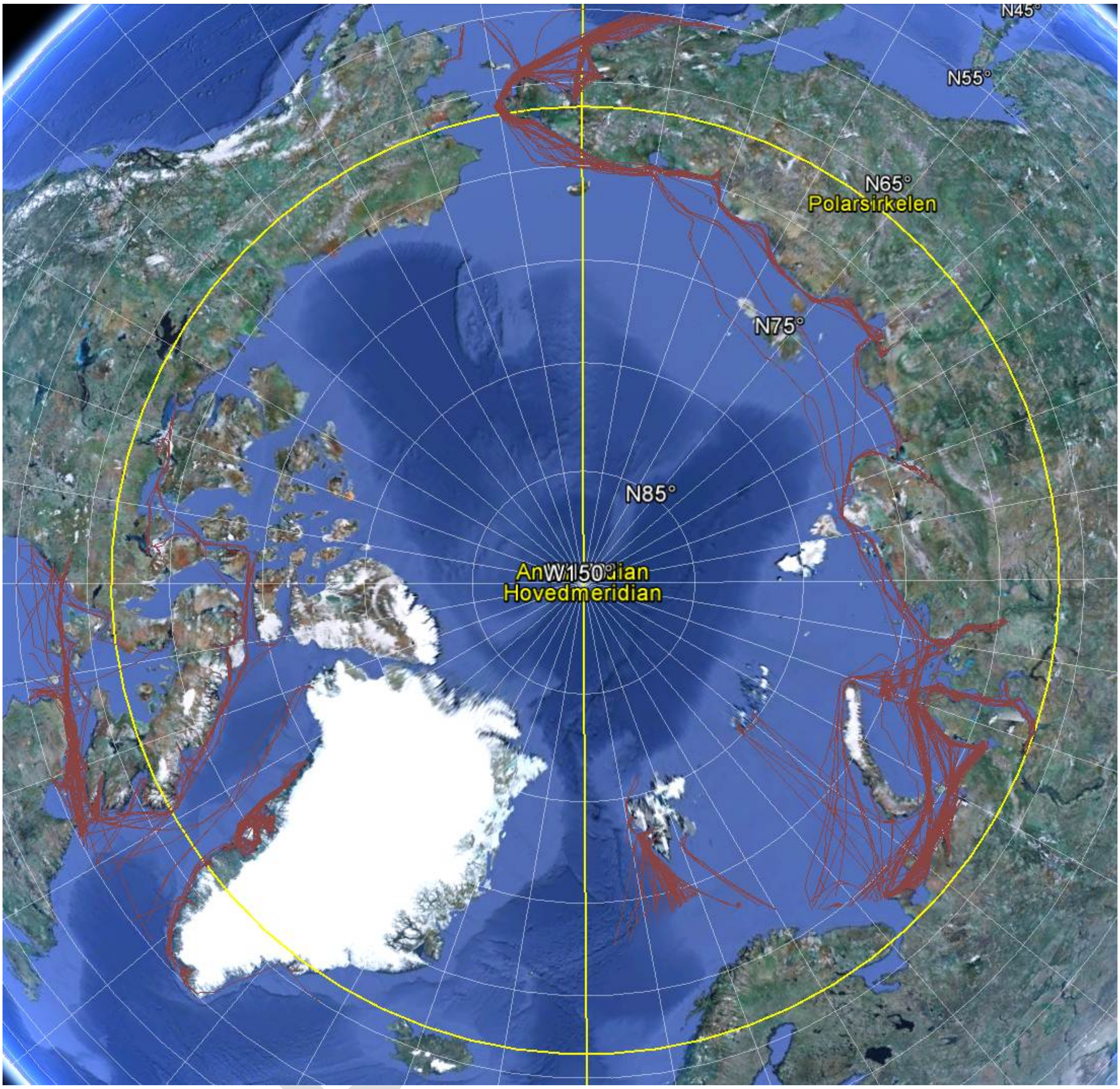


Figure 5-6 - General cargo vessel traffic in the Arctic

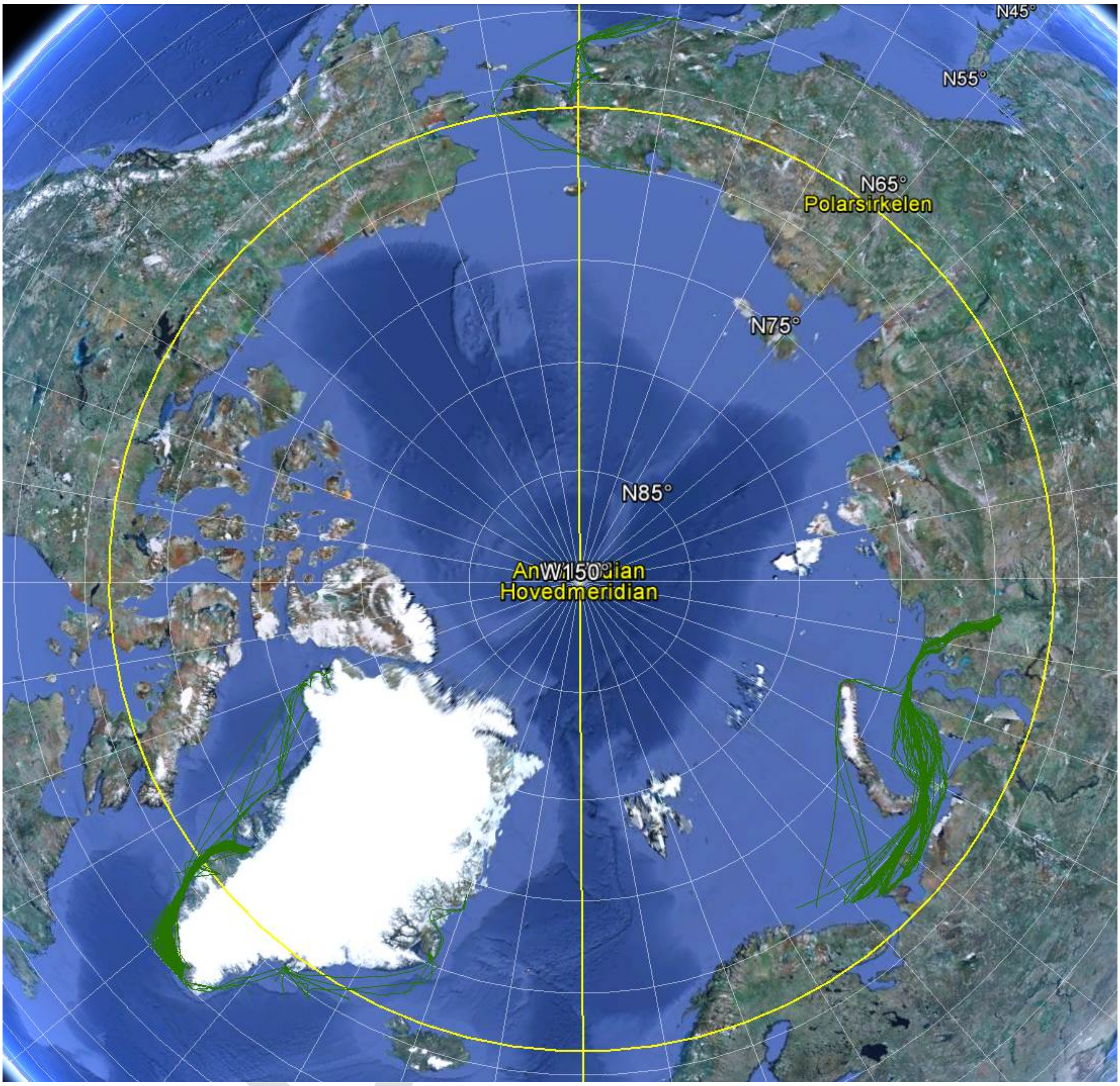


Figure 5-7 - Container vessel traffic in the Arctic 2012

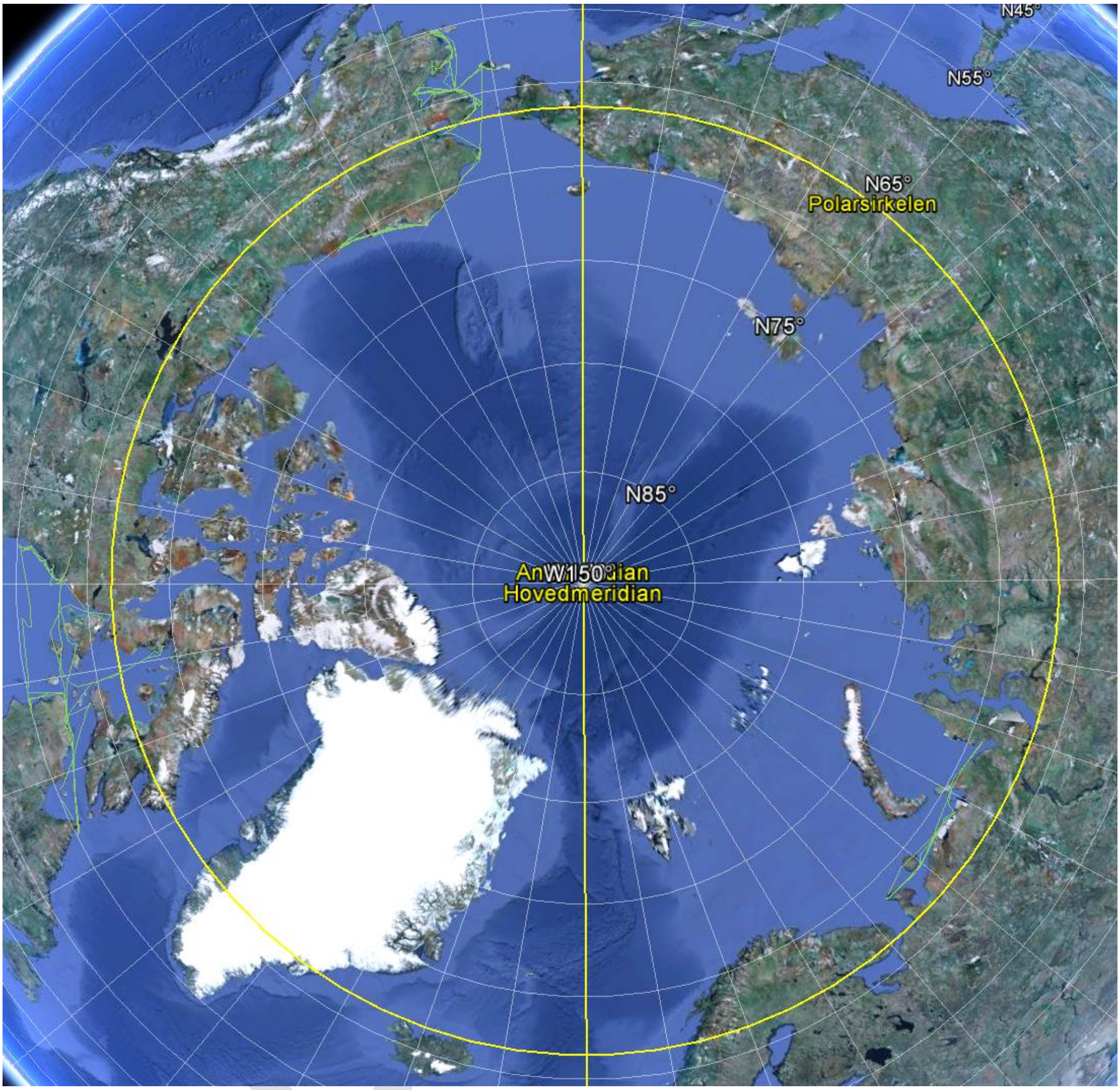


Figure 5-8 - RoRo vessel traffic in the Arctic – 2012

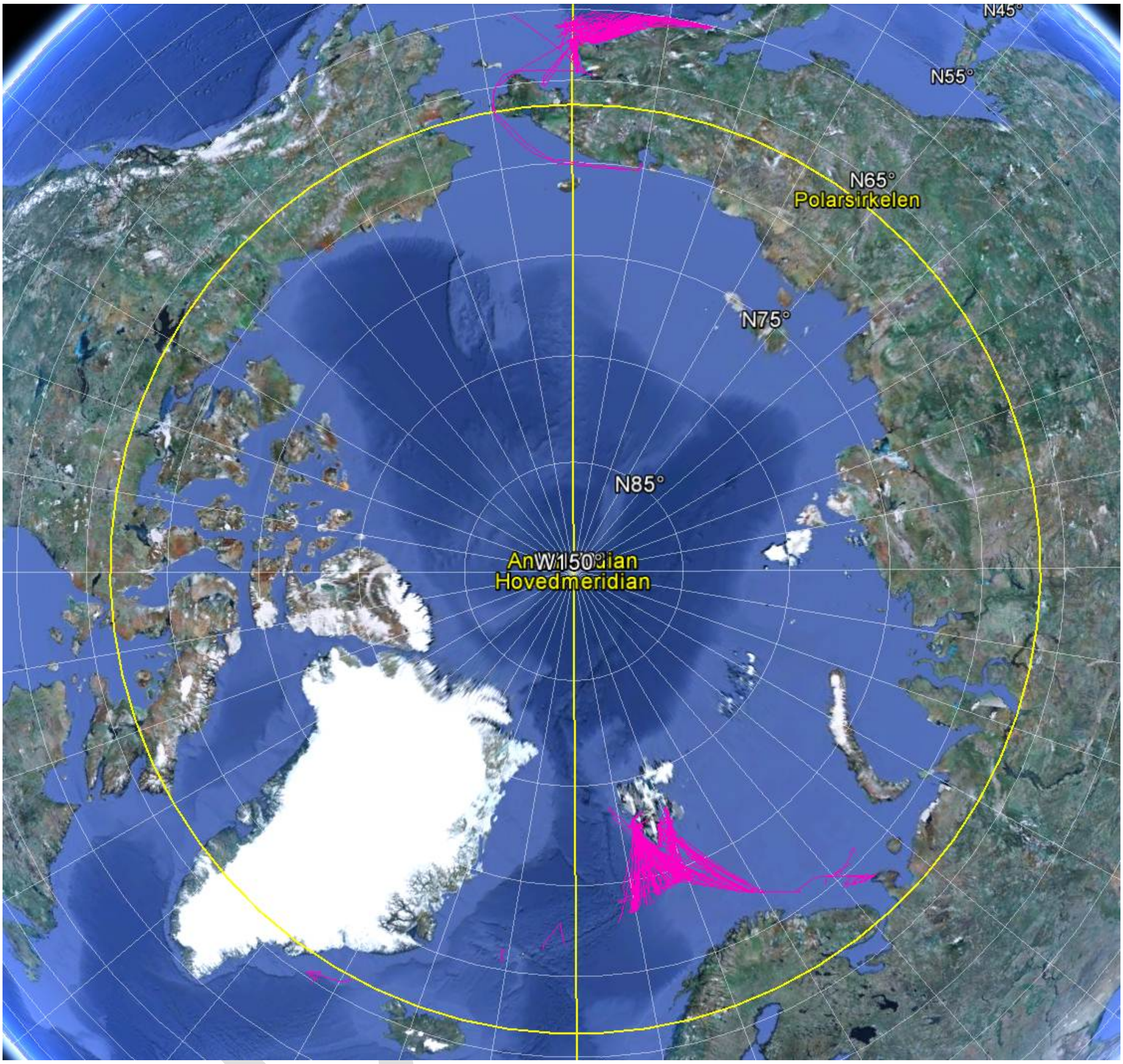


Figure 5-9 - Reefers on the Arctic – 2012

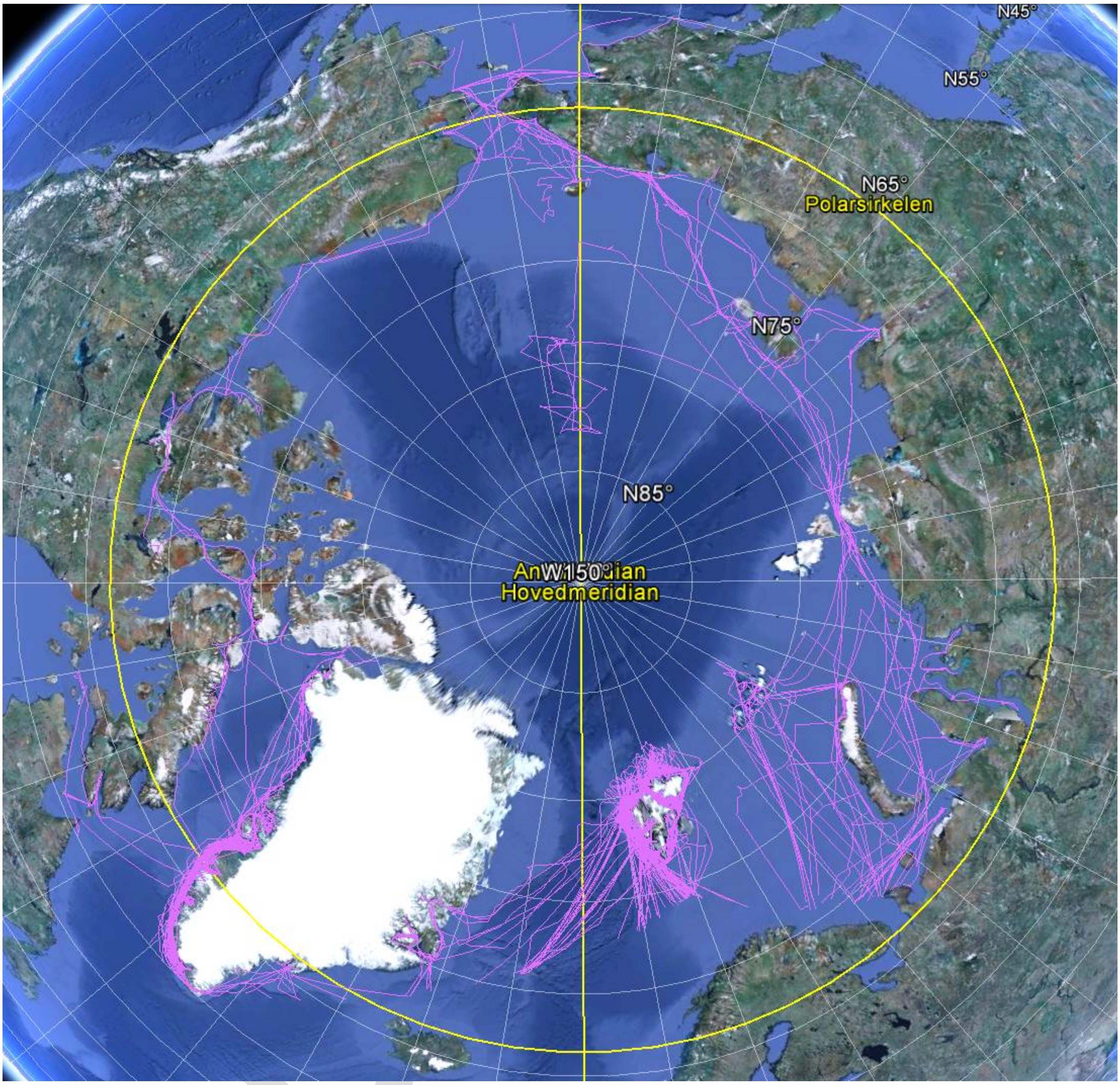


Figure 5-10 - Passenger vessel traffic in the Arctic – 2012

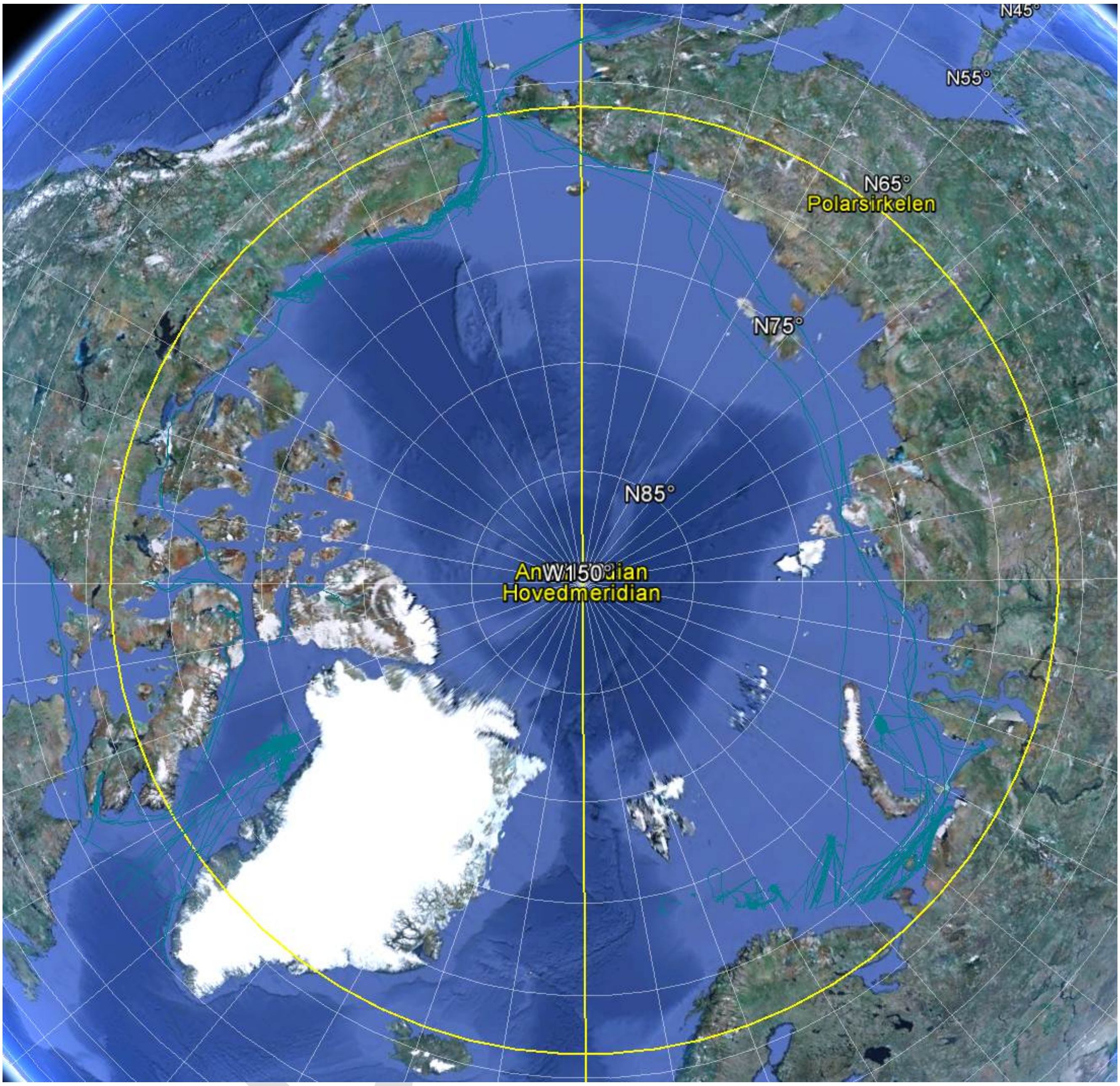


Figure 5-11 - Offshore supply vessel traffic in the Arctic – 2012

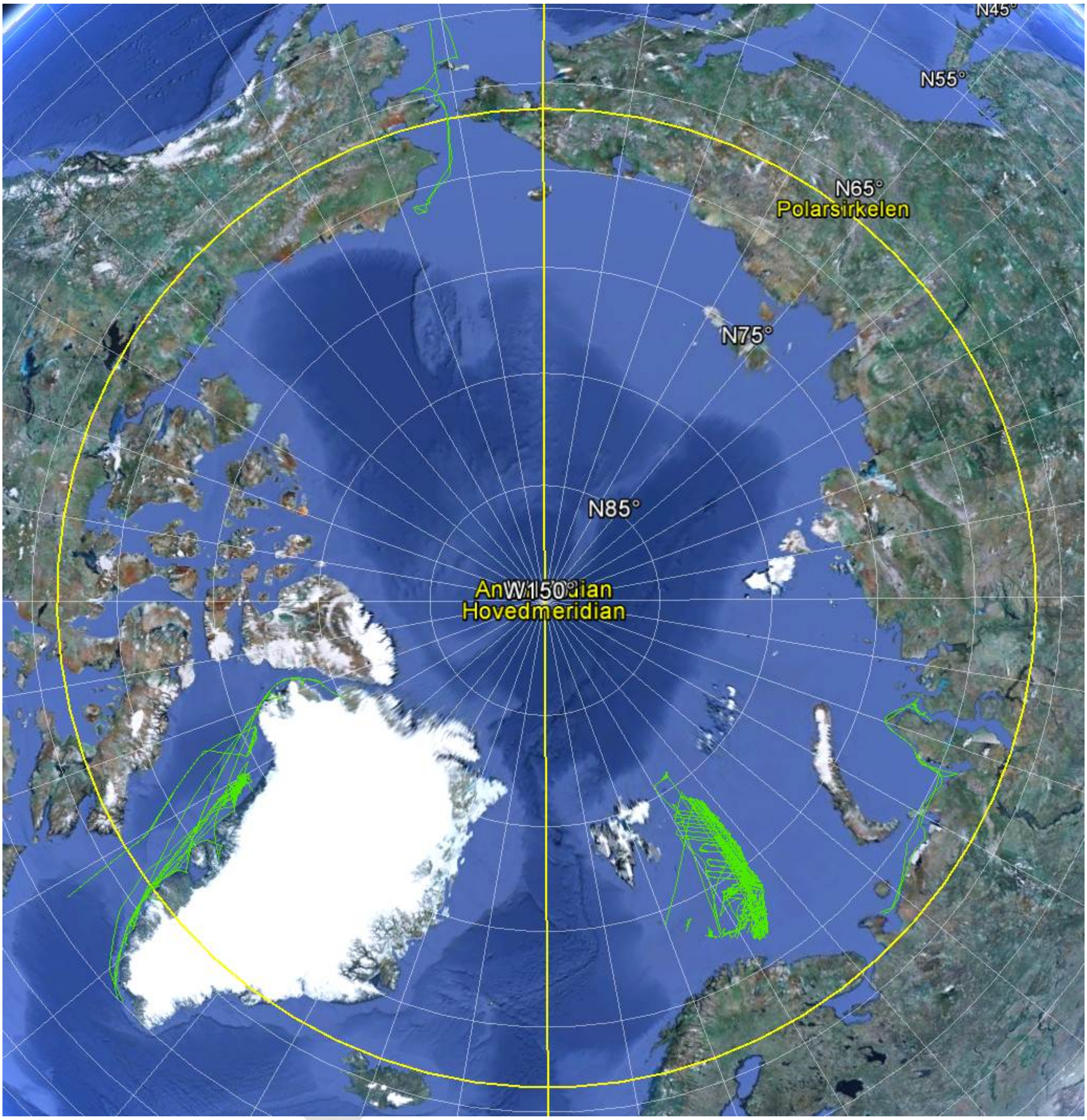


Figure 5-12 - Other offshore vessel traffic in the Arctic - 2012

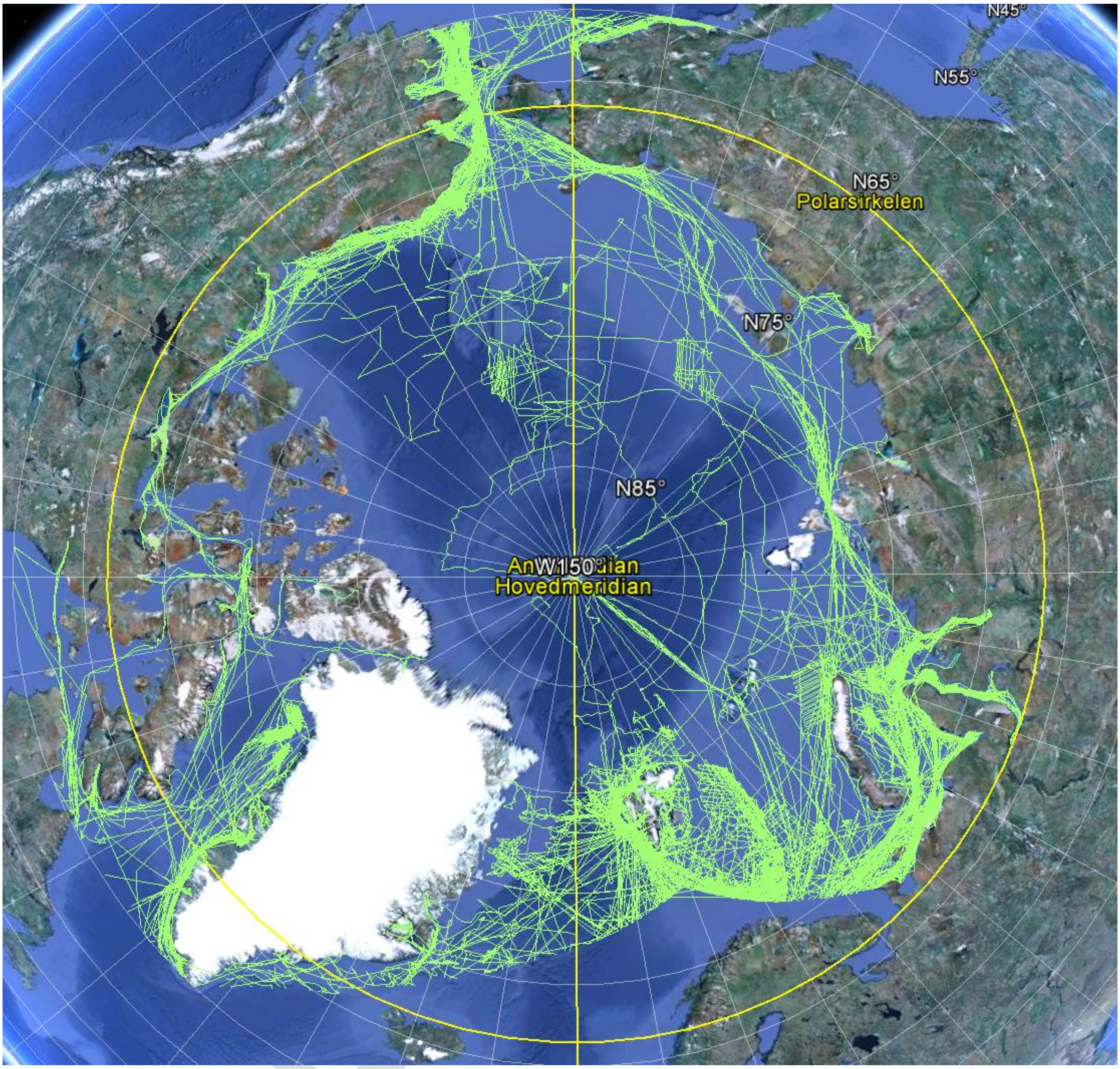


Figure 5-13 – "OtherAactivities" vessel traffic in the Arctic - 2012

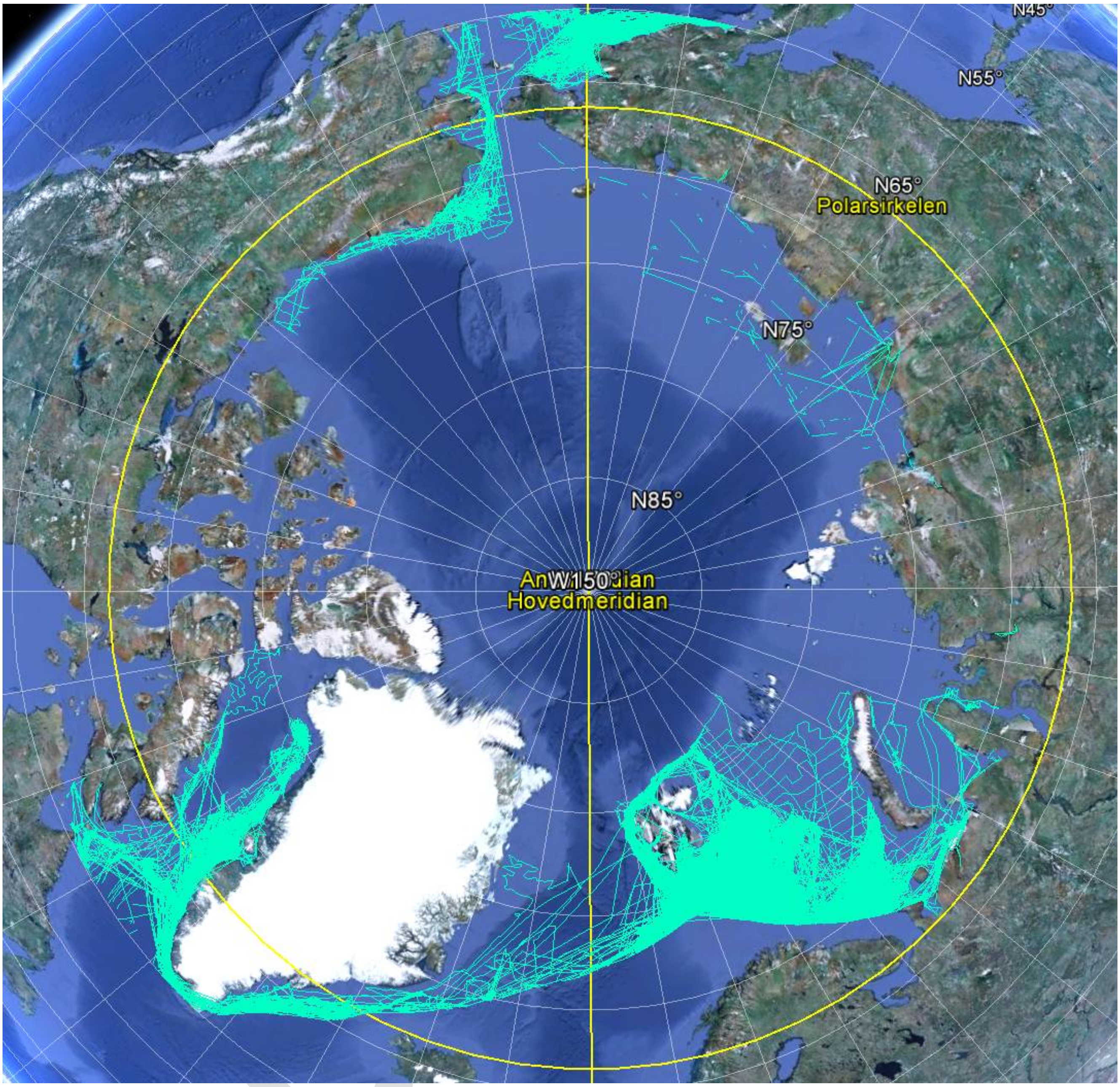


Figure 5-14 - Fishing vessel traffic in the Arctic - 2012

5.4 Operational hours in the Arctic

Table 5-2 - Ship operational hours in the Arctic

Ship type	Operational hours - 2012							
	<10000 GT	1000 - 4999 GT	5000 – 9999 GT	10000-24999 GT	25000-49999 GT	50000-99999 GT	≥100000 GT	Total
Oil tanker		38054	4978	10533	12449	20		**66034**
Chemical/Prod tanker	128	29545	10934	7689	1840			**50135**
Gas tanker							545	**545**
Bulk carrier		1788	186	10164	14709			**26848**
General cargo	7419	88164	34006	7533	279			**137401**
Container vessel			13446	20848				**34294**
RoRo	5381	570		1561				**7512**
Reefer	348	24992	15410	4989				**45738**
Passenger	28520	30017	6008	8069	2863	442	276	**76197**
Offshore supply vessel	3576	50484	5841	2462				**62364**
Other offshore service vessel	18008	848		3506				**22362**
Other activities	188984	97342	46494	27480	2967			**363267**
Fishing vessel	401128	548872	16685					**966685**
Total	**653493**	**910677**	**153989**	**104834**	**35107**	**462**	**821**	**1859382**

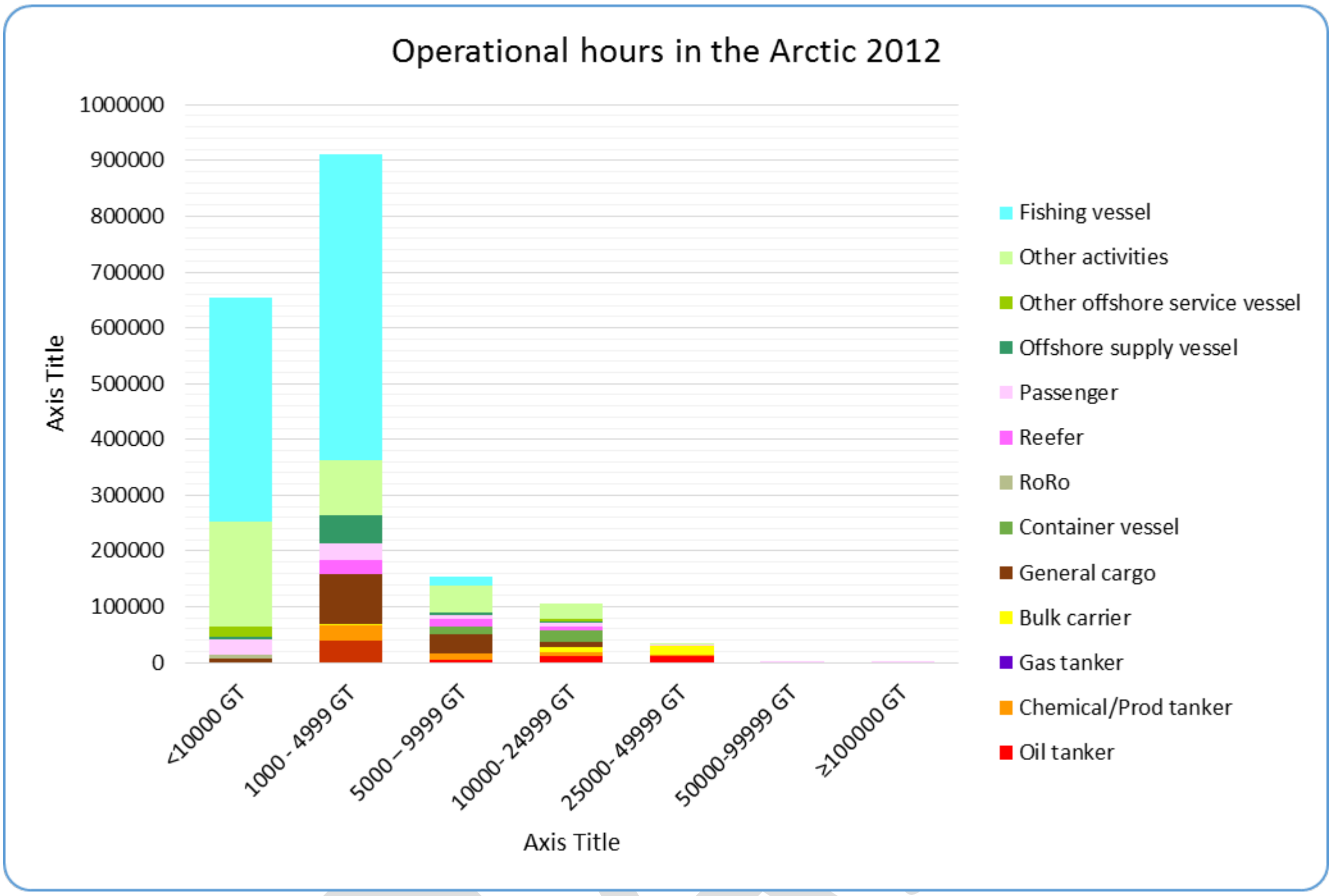


Figure 5-15 - Operational hours of the different ship types/sizes in the Arctic

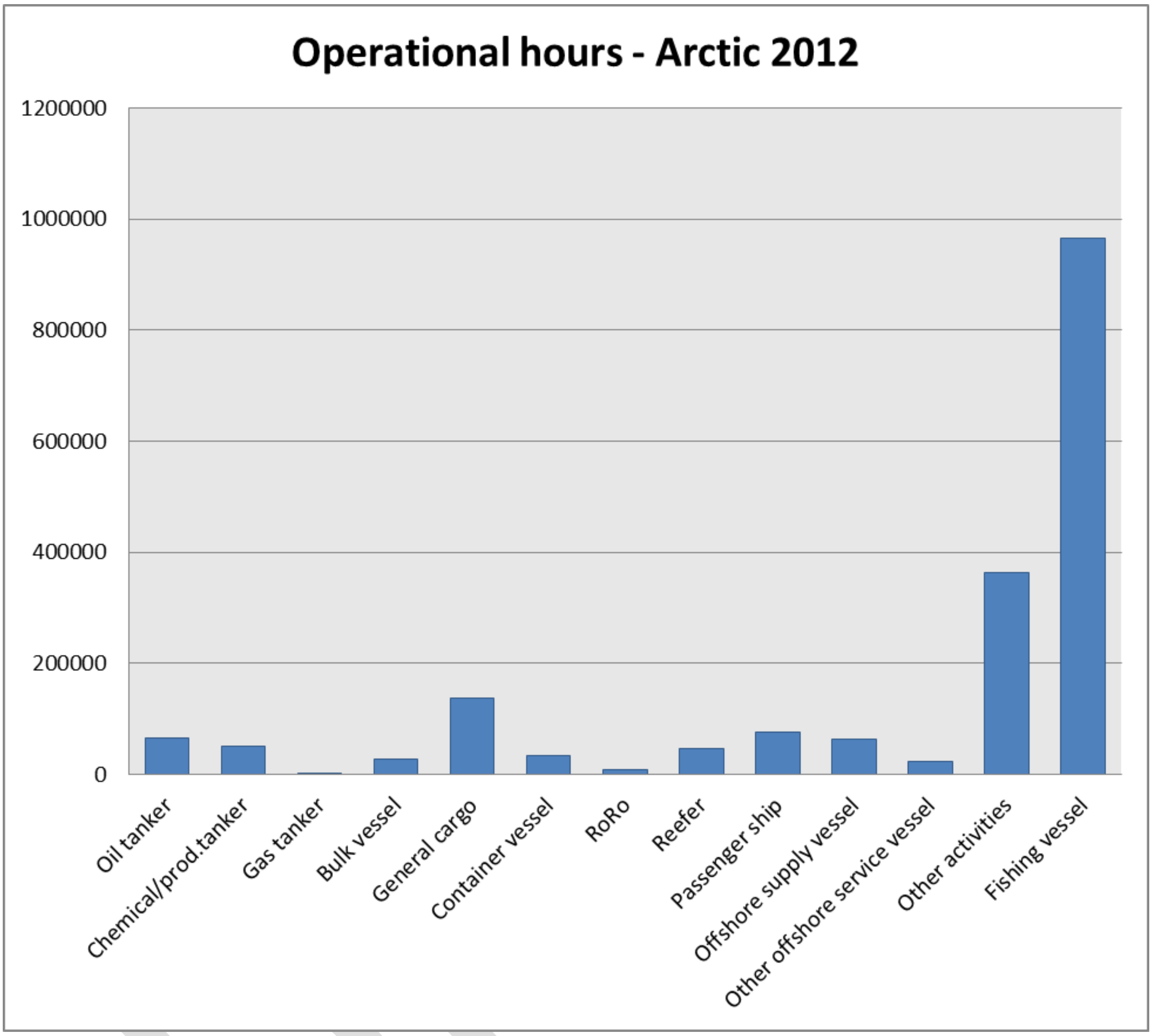


Figure 5-16 - Operational hours of the different ship types in the Arctic

5.5 Sailed distance in the Arctic

Table 5-3 - Sailed distance in the Arctc

Ship type	Sailed distance in the Arctic - 2012							
	<10000 GT	1000 - 4999 GT	5000 – 9999 GT	10000-24999 GT	25000-49999 GT	50000-99999 GT	≥100000 GT	**Total**
Oil tanker		145268	17919	53659	85868	124		**302836**
Chemical/Prod tanker	456	119123	47503	41945	8029			**217057**
Gas tanker							6769	**6769**
Bulk carrier		6014	1276	45794	81519			**134602**
General cargo	21219	322840	138514	44042	1153			**527769**
Container vessel			77491	200997				**278487**

RoRo	14352	2198		7463				**24014**
Reefer	673	57410	24852	7787				**90722**
Passenger	54729	148497	41247	60272	28078	5384	3547	**341753**
Offshore supply vessel	11597	153734	13773	6753				**185857**
Other offshore service vessel	45704	1852		4545				**52100**
Other activities	341621	306442	171018	134485	4219			**957785**
Fishing vessel	955999	1572398	46300					**2574697**
Total	**1446350**	**2835776**	**579894**	**607741**	**208866**	**5507**	**10316**	**5694450**

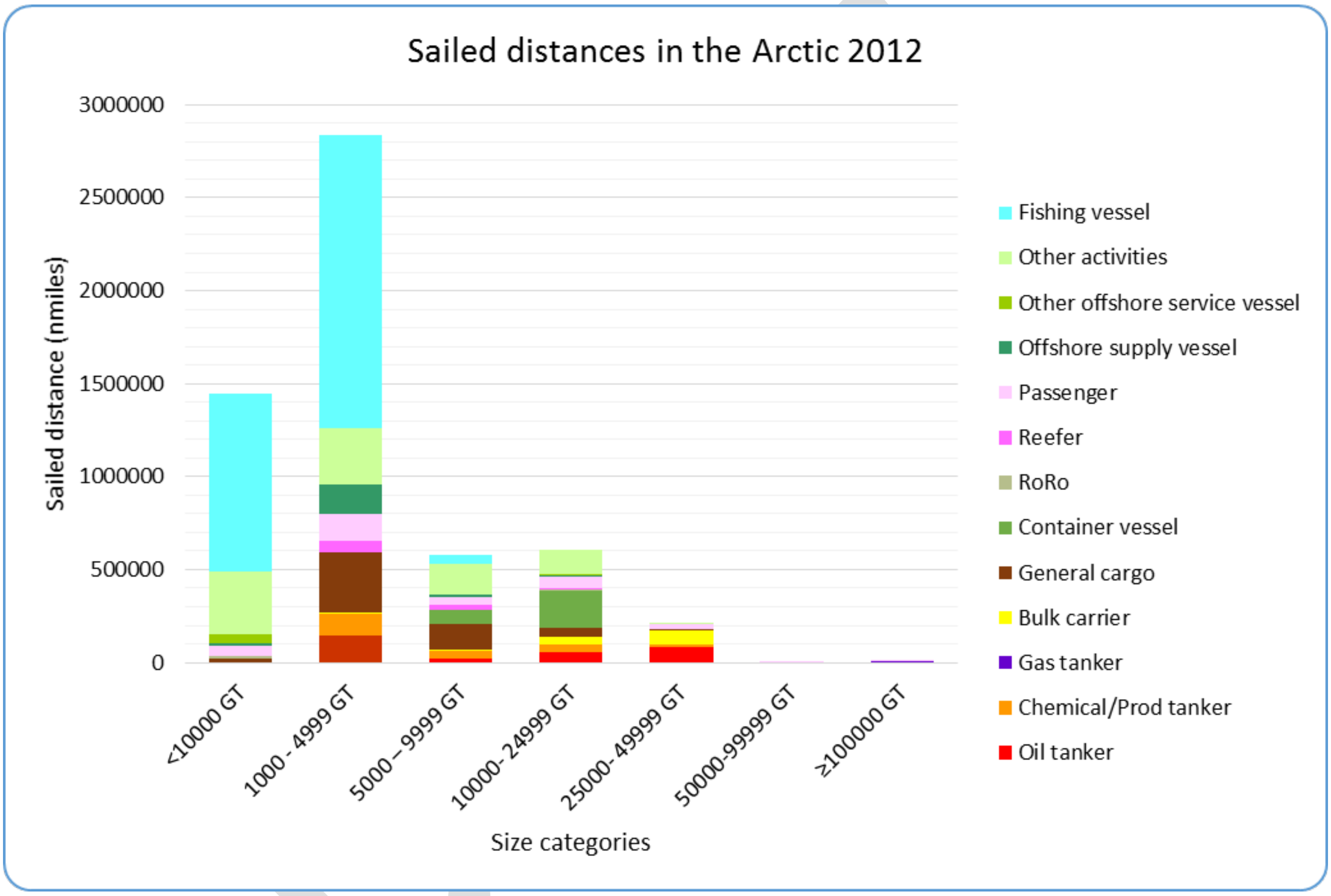


Figure 5-17 - Sailed distance of the different ship types/sizes in the Arctic

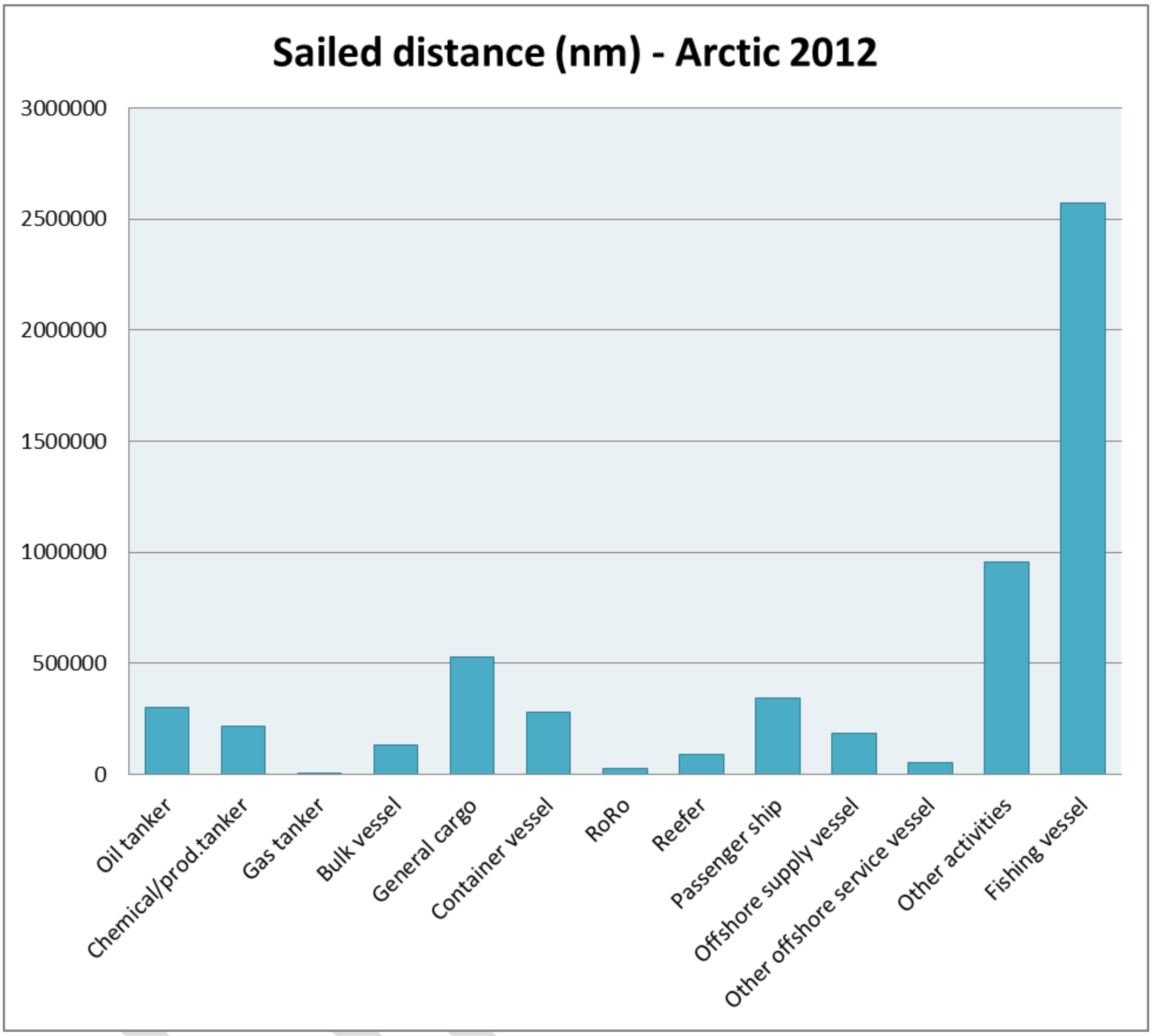


Figure 5-18 - Operational hours of the different ship types in the Arctic

5.6 Emission from shipping in the Arctic – 2012

Table 5-4 – Fuel consumption and emission (ton)

Fuel & Emissions	Fuel	CO2	NOx	SO2	PM	BC
Oil tanker	21192	67599	1429	204	115	3,8
Chemical/Prod tanker	13173	41882	748	89	42	2,4
Gas tanker	1025	3272	74	16	6	0,2
Bulk carrier	12750	40745	944	143	85	2,3
General cargo	18310	58043	969	76	23	3,3
Container vessel	36253	115823	2680	398	236	6,5
RoRo	734	2338	47	6	4	0,1
Reefer	4911	15577	234	23	8	0,9
Passenger	20653	65795	1309	184	94	3,7
Offshore supply vessel	13087	41485	595	26	17	2,4
Other offshore service vessel	988	3132	46	3	1	0,2
Other activities	59735	189361	2923	176	72	10,8
Fishing vessel	87813	278367	3888	158	105	15,8
Total	**290624**	**923419**	**15886**	**1503**	**807**	**52,3**

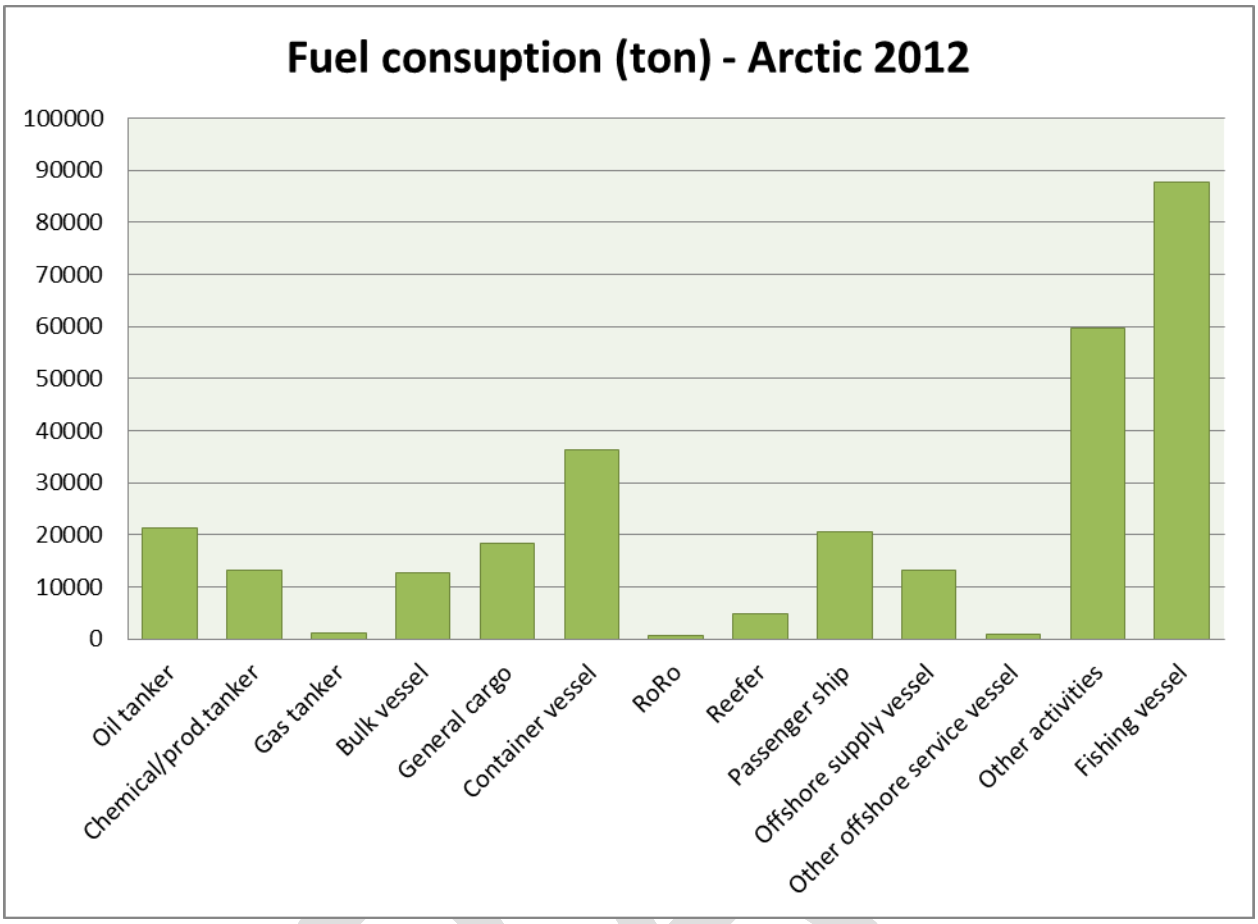


Figure 5-19 - Burned fuel between ship types in the Arctic

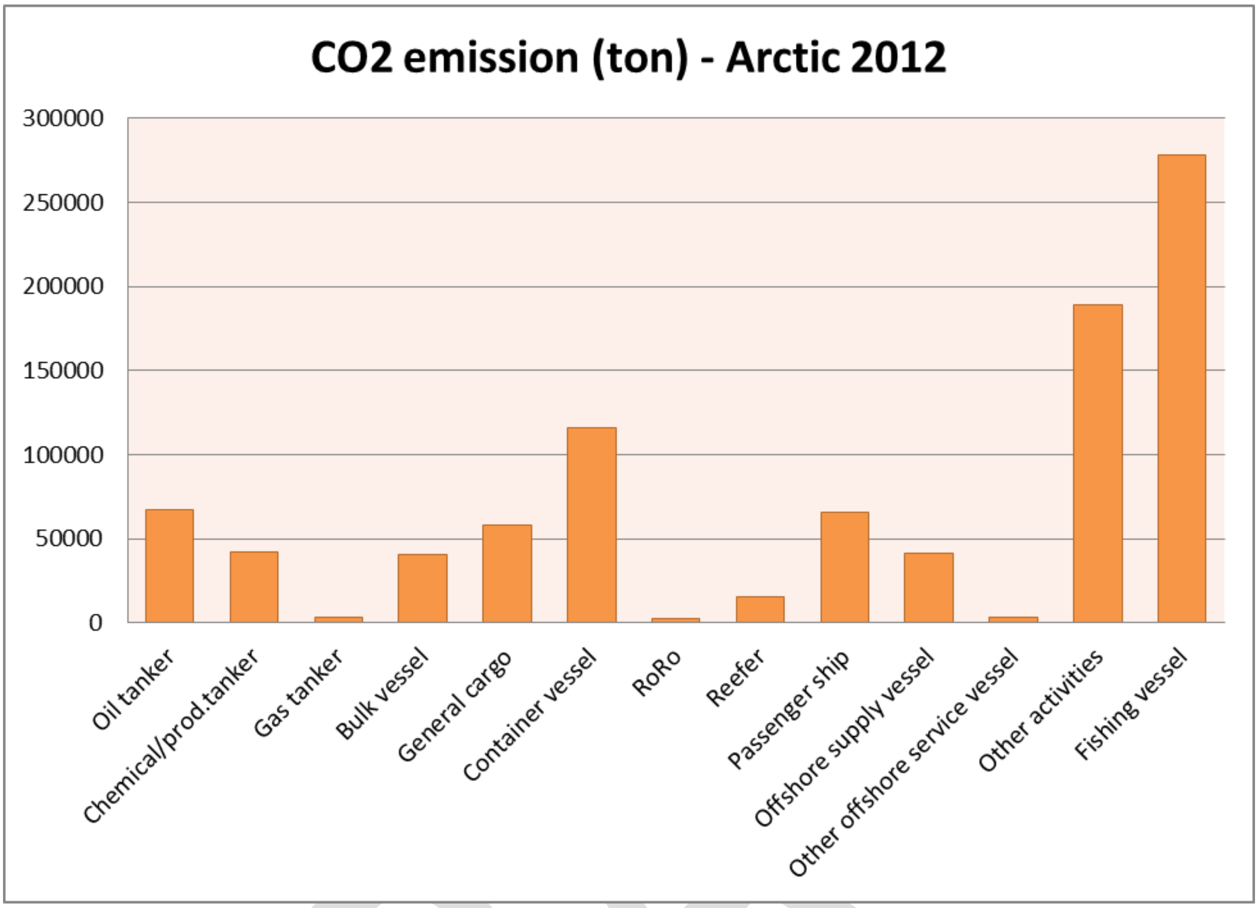


Figure 5-20- CO2 emission from shipping between ship types in the Arctic

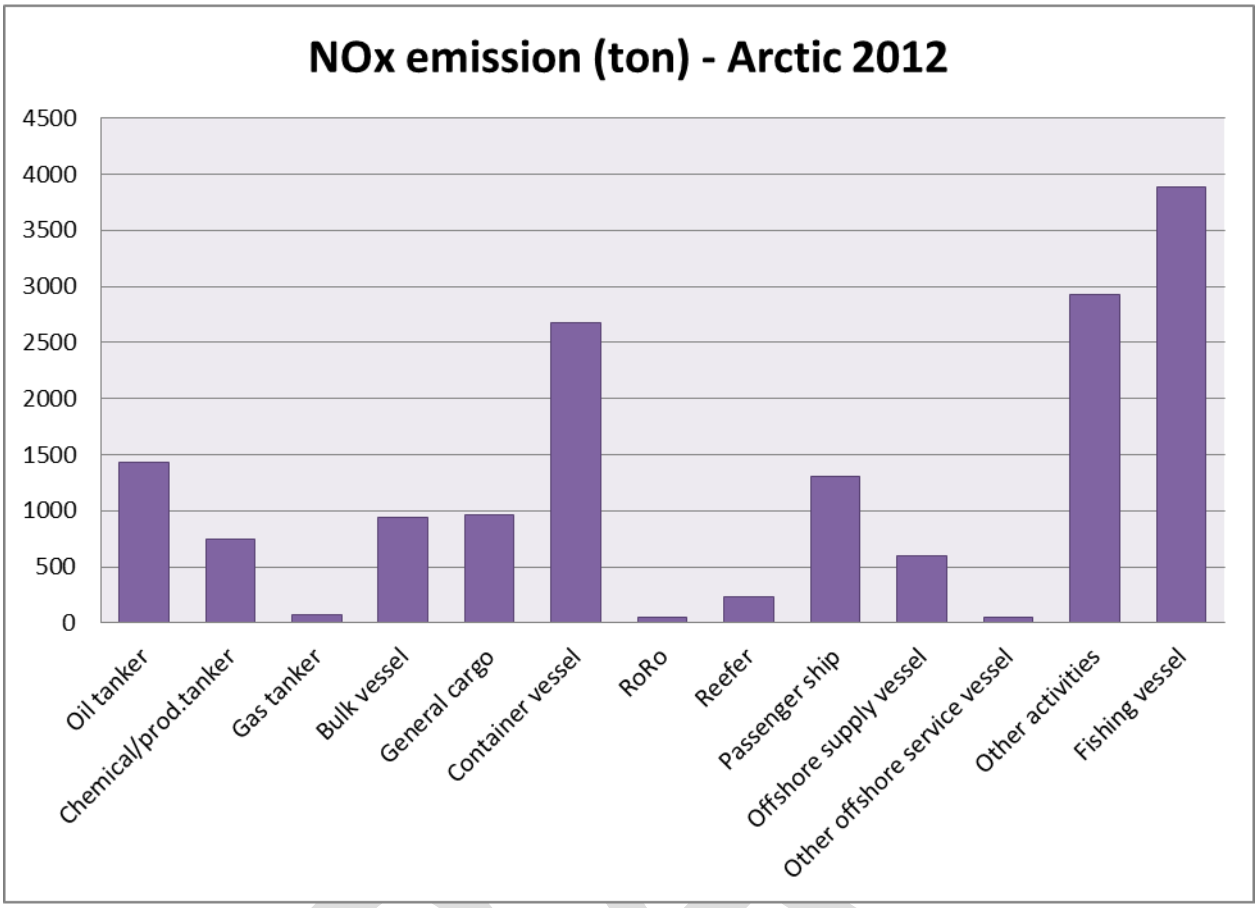


Figure 5-21 - NOx emission from shipping between ship types in the Arctic

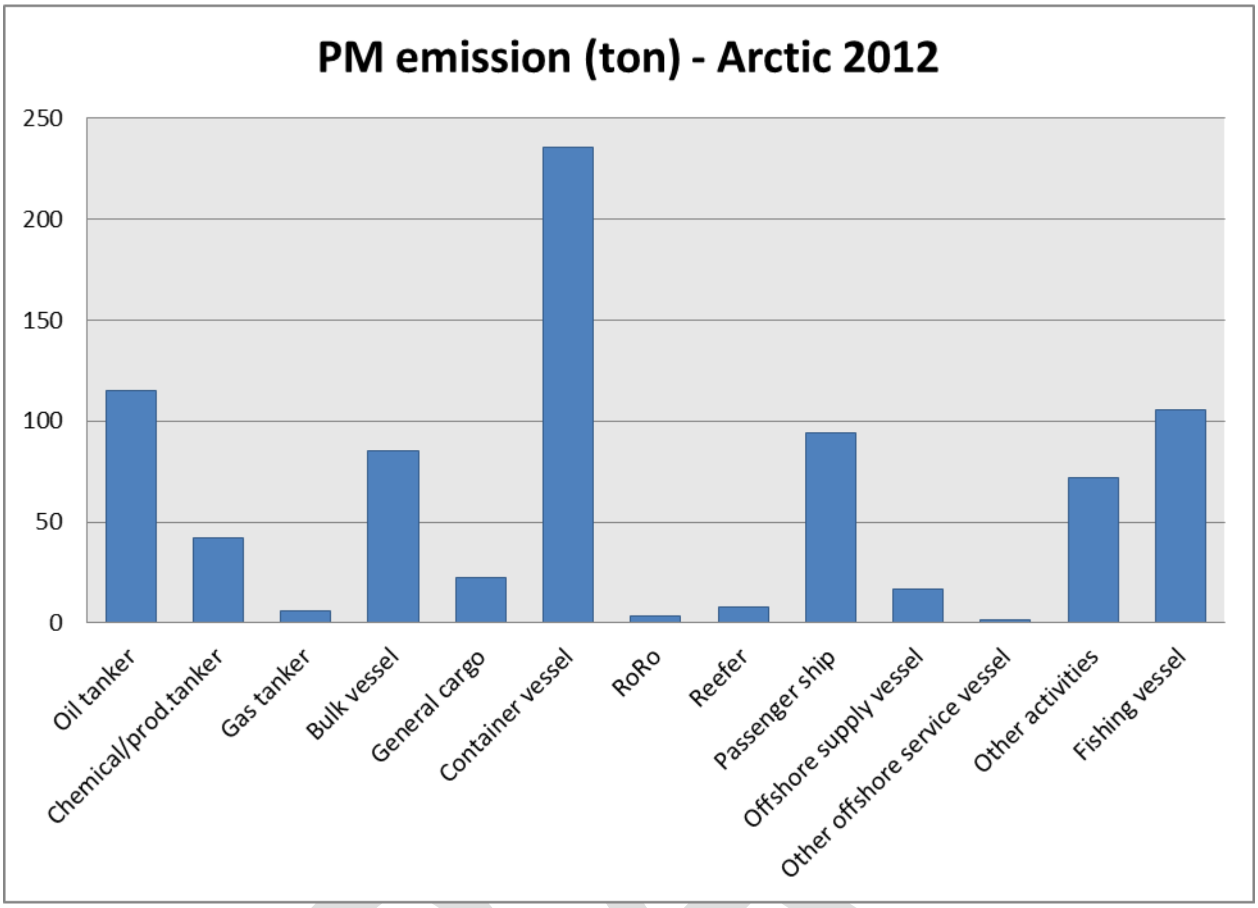


Figure 5-22 -PM emission from shipping between ship types in the Arctic

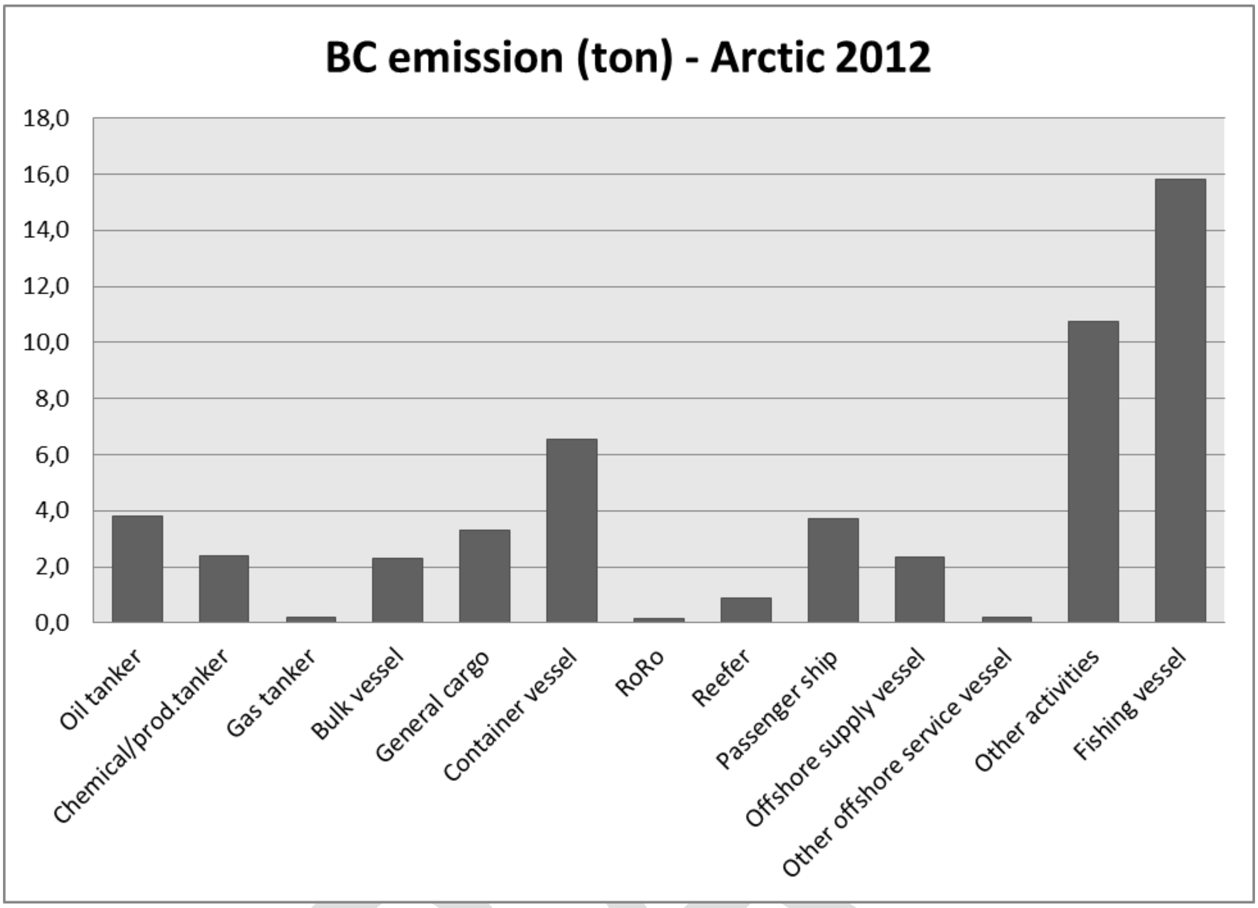


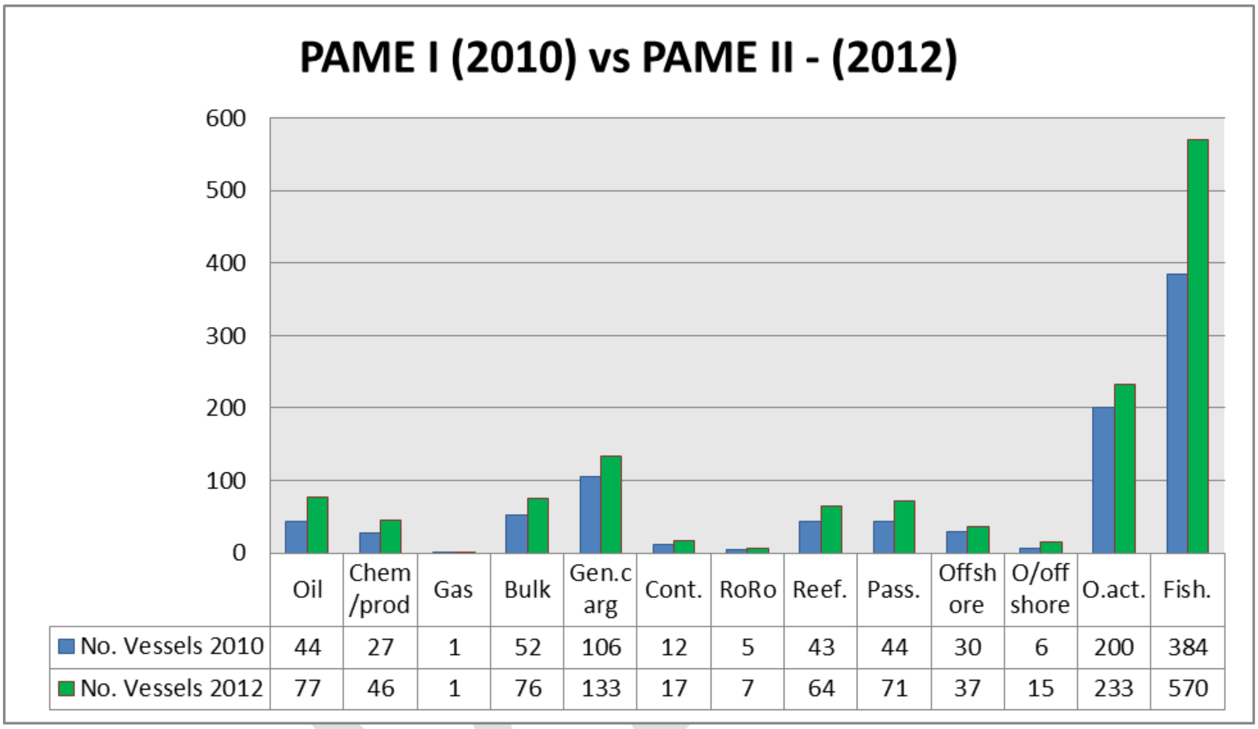
Figure 5-23 - BC emission from shipping between ship types in the Arctic

5.7 Comparison with the PAME-I study and the PAME-II

The study "Heavy fuel in the Arctic – Phase I" [Ref] was the first study to utilize the ship traffic data recorded by the dedicated AIS satellite AISSat-1. The satellite was launched in May 2010 and started recording and submitting data from August the same year. This coincided with the start-up of the project and hence the project was able to utilize data from the satellite from August through to November. It was argued that even though the data covered only 4 months of the year, these were the 4 most busy months and sufficient for establishing an inventory of unique vessels operating in the region. Most vessels operating in the Arctic are dedicated for Arctic operation and hence they will operate in the region when operation is possible.

It is therefore interesting to compare the vessel inventory from the 2010 set with the full year 2012 set established in this study. However, the number of unique vessels is not an ideal measure for activity. Operational hours or sailed distance is a better indicator for such comparisons, but this was not part of the results calculated in the Phase I study.

The comparison is illustrated in Figure 5-24 below and it indicates the assumption made on the Phase-I report is mainly sound. Most vessels categories show a growth in numbers, some of which may be explained by a general underestimate from not cowering the full year in 2010 but also a likely increase in the maritime activity within the region. The number of fishing vessels has increased relatively more in numbers between the two data sets. This may have been expected as the majority of the fishing activity is in the year-round ice-free parts of the Barents Sea and with great seasonal variations in the population of vessels.



	Oil	Chem /prod	Gas	Bulk	Gen.c arg	Cont.	RoRo	Reef.	Pass.	Offsh ore	O/off shore	O.act.	Fish.
No. Vessels 2010	44	27	1	52	106	12	5	43	44	30	6	200	384
No. Vessels 2012	77	46	1	76	133	17	7	64	71	37	15	233	570

Figure 5-24 - number and types of unique vessels recorded in 2010 vs 2012

The Phase-I study registered 954 unique vessels within the Arctic whereas the 2012 full year figure is 1347 which indicates a 41% higher. However, if we keep the fishing vessel out of the equation we go from 570 to 777 vessels which is a 36% increase in the number of vessels.

5.8 Vessels operating on HFO in the Arctic

The methodology for identifying the vessels operating on HFO is outlined in paragraph 4.3.

Table 5-5 – Unique vessels in the Arctic – Assumed operating on HFO in Brackets

	Number of unique vessels							
Ship type	<10000 GT	1000 - 4999 GT	5000 – 9999 GT	10000-24999 GT	25000-49999 GT	50000-99999 GT	≥100000 GT	**Total**
Oil tanker		44(8)	6(1)	7(7)	17(17)	3(3)		**77(36)**
Chemical/Prod tanker	1(1)	19(9)	11(11)	11(11)	4(4)			**46(36)**
Gas tanker							1(1)	**1**
Bulk carrier		2(1)	2(2)	26(26)	46(46)			**76(75)**
General cargo	7(1)	85(15)	33(13)	7(7)	1(1)			**133(37)**
Container vessel			9(6)	8(8)				**17(14)**
RoRo	5()	1()		1(1)				**7(1)**
Reefer	2()	36(14)	21(17)	5(5)				**64(36)**
Passenger	8()	14(2)	7(7)	16(15)	13(13)	10(10)	3(3)	**71(50)**
Offshore supply vessel	4(1)	29(6)	3(1)	1()				**37(8)**
Other offshore service vessel	11()	2()		2()				**15()**
Other activities	108(2)	75(3)	29(4)	18(14)	3(3)			**233(26)**
Fishing vessel	243(5)	305(37)	22(9)					**570(51)**
Total	**389**(10)	**612**(95)	**143**(71)	**102**(94)	**84**(84)	**13**(13)	**4**(4)	**1347(371)**

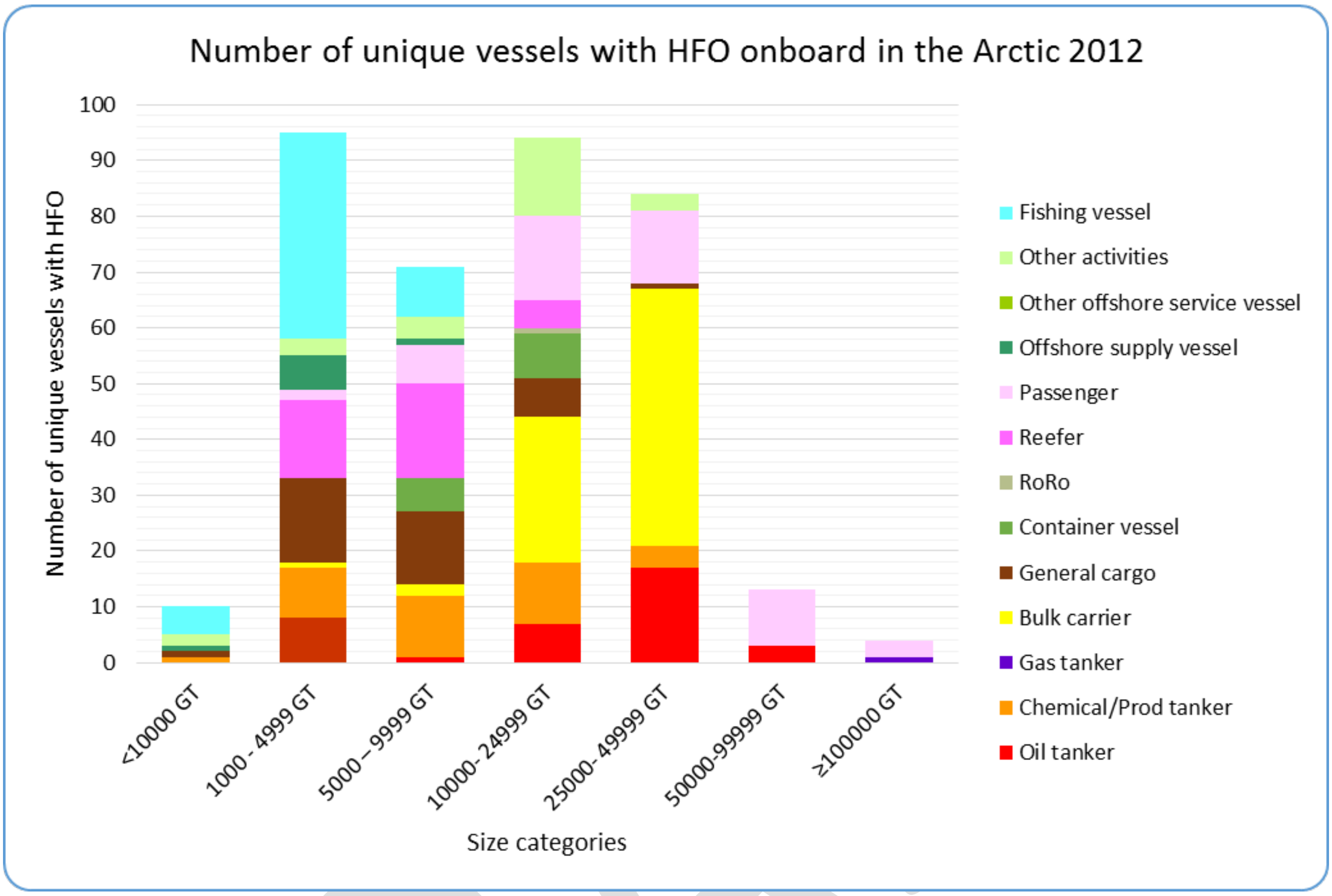


Figure 5-25 - Number of unique vessels operating on HFO in the Arctic

Table 5-6 - % of vessels operating with HFO in the Arctic

	% of HFO vessels in the Arctic							
Ship type	<10000 GT	1000 - 4999 GT	5000 – 9999 GT	10000-24999 GT	25000-49999 GT	50000-99999 GT	≥100000 GT	**Total**
Oil tanker		**18 %**	**17 %**	**100 %**	**100 %**	**100 %**		**47 %**
Chemical/Prod tanker	**100 %**	**47 %**	**100 %**	**100 %**	**100 %**			**78 %**
Gas tanker								**100 %**
Bulk carrier		**50 %**	**100 %**	**100 %**	**100 %**			**99 %**
General cargo	**14 %**	**18 %**	**39 %**	**100 %**	**100 %**			**28 %**
Container vessel			**67 %**	**100 %**				**82 %**
RoRo	**0 %**	**0 %**		**100 %**				**14 %**
Reefer	**0 %**	**39 %**	**81 %**	**100 %**				**56 %**
Passenger	**0 %**	**14 %**	**100 %**	**94 %**	**100 %**	**100 %**	**100 %**	**70 %**
Offshore supply vessel	**25 %**	**21 %**	**33 %**	**0 %**				**22 %**
Other offshore service vessel	**0 %**	**0 %**		**0 %**				**0 %**

Other activities	**2 %**	**4 %**	**14 %**	**78 %**	**100 %**			**11 %**
Fishing vessel	**2 %**	**12 %**	**41 %**					**9 %**
Total	**3 %**	**16 %**	**50 %**	**92 %**	**100 %**	**100 %**	**100 %**	**28 %**

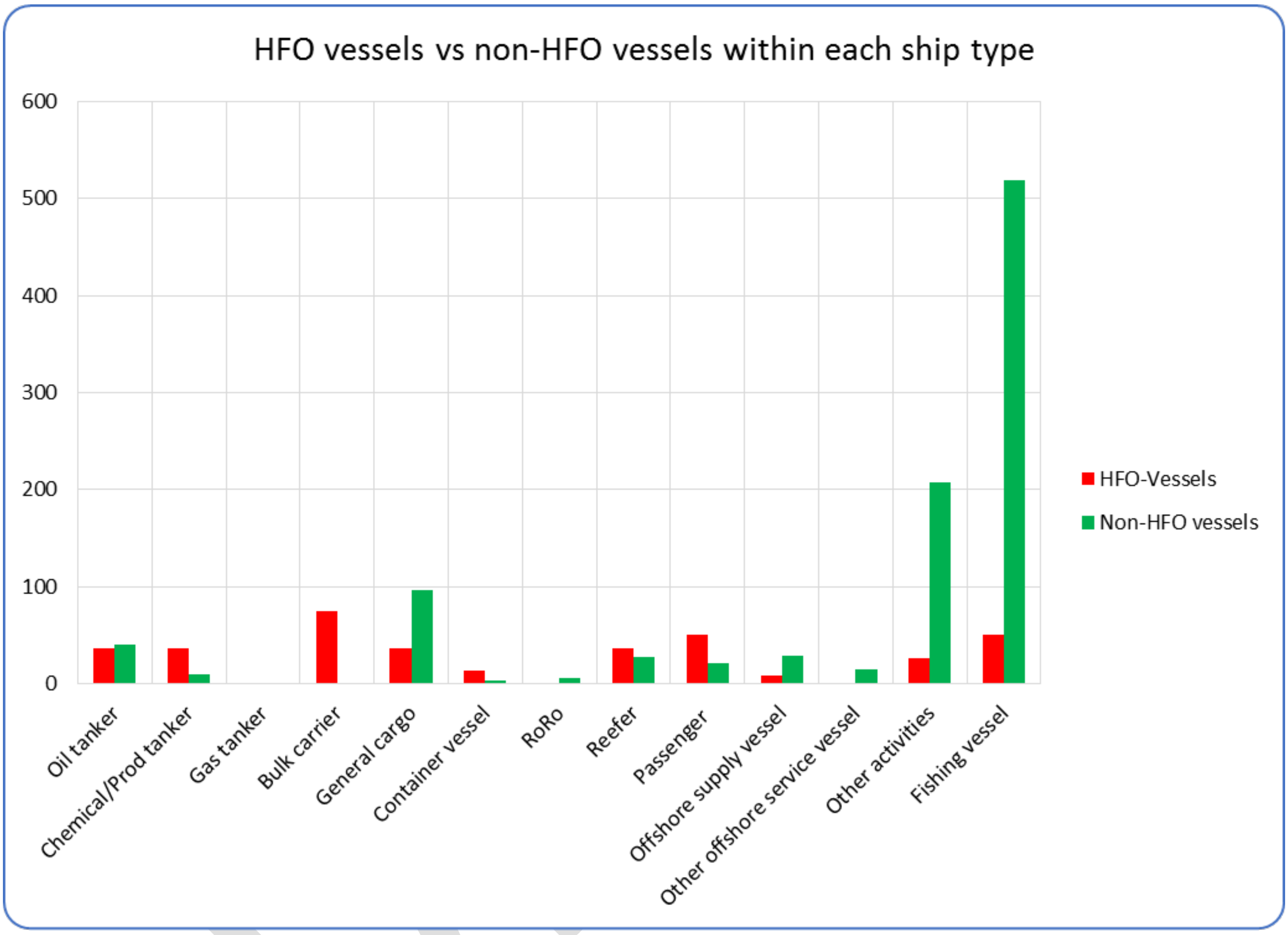


Figure 5-26 - Number of HFO vessels versus non-HFO vessels within each ship type

5.8.1 Amounts of fuel on ships in the Arctic

Table 5-7 – Tons HFO bunker fuel onboard the vessels - Assuming 65% tank filling

	tons bunker fuel onboard - HFO (Assuming 65% filling level)							
Ship type	<10000 GT	1000 - 4999 GT	5000 – 9999 GT	10000-24999 GT	25000-49999 GT	50000-99999 GT	≥100000 GT	**Total**
Oil tanker		1898	347	6075	39356	10141		**57817**
Chemical/Prod tanker	58	2305	4801	11091	6207			**24463**
Gas tanker							5201	**5201**
Bulk carrier		302	906	29415	94557			**125179**
General cargo	63	3434	5009	6752	1571			**16831**
Container vessel			3345	7238				**10583**
RoRo				637				**637**
Reefer		3489	7881	3997				**15367**
Passenger		413	3147	16046	24792	42443	17207	**104047**
Offshore supply vessel	13	1164	389					**1565**
Other offshore service vessel								**0**
Other activities	30	678	2015	11460	6581			**20763**
Fishing vessel	206	9474	4421					**14100**
Total	**370**	**23156**	**32261**	**92711**	**173064**	**52584**	**22408**	**396554**

Table 5-8 – Tons non-HFO bunker fuel onboard the vessels - Assuming 65% tank filling

	tons bunker fuel onboard - Non-HFO (Assuming 65% filling level)							
Ship type	<10000 GT	1000 - 4999 GT	5000 – 9999 GT	10000-24999 GT	25000-49999 GT	50000-99999 GT	≥100000 GT	**Total**
Oil tanker		5907	1707	0	0	0		**7614**
Chemical/Prod tanker	0	2000	0	0	0			**2000**
Gas tanker							0	**0**
Bulk carrier		186	0	0	0			**186**
General cargo	202	12199	8542	0	0			**20943**
Container vessel			1068	0				**1068**
RoRo				0				**0**
Reefer		3697	1764	0				**5461**
Passenger		2413	0	0	0	0	0	**2413**
Offshore supply vessel	159	4142	997					**5298**

Other offshore service vessel								**0**
Other activities	3940	12499	11454	0	0			**27892**
Fishing vessel	11465	41957	6167					**59588**
Total	**15766**	**84999**	**31698**	**0**	**0**	**0**	**0**	**132464**

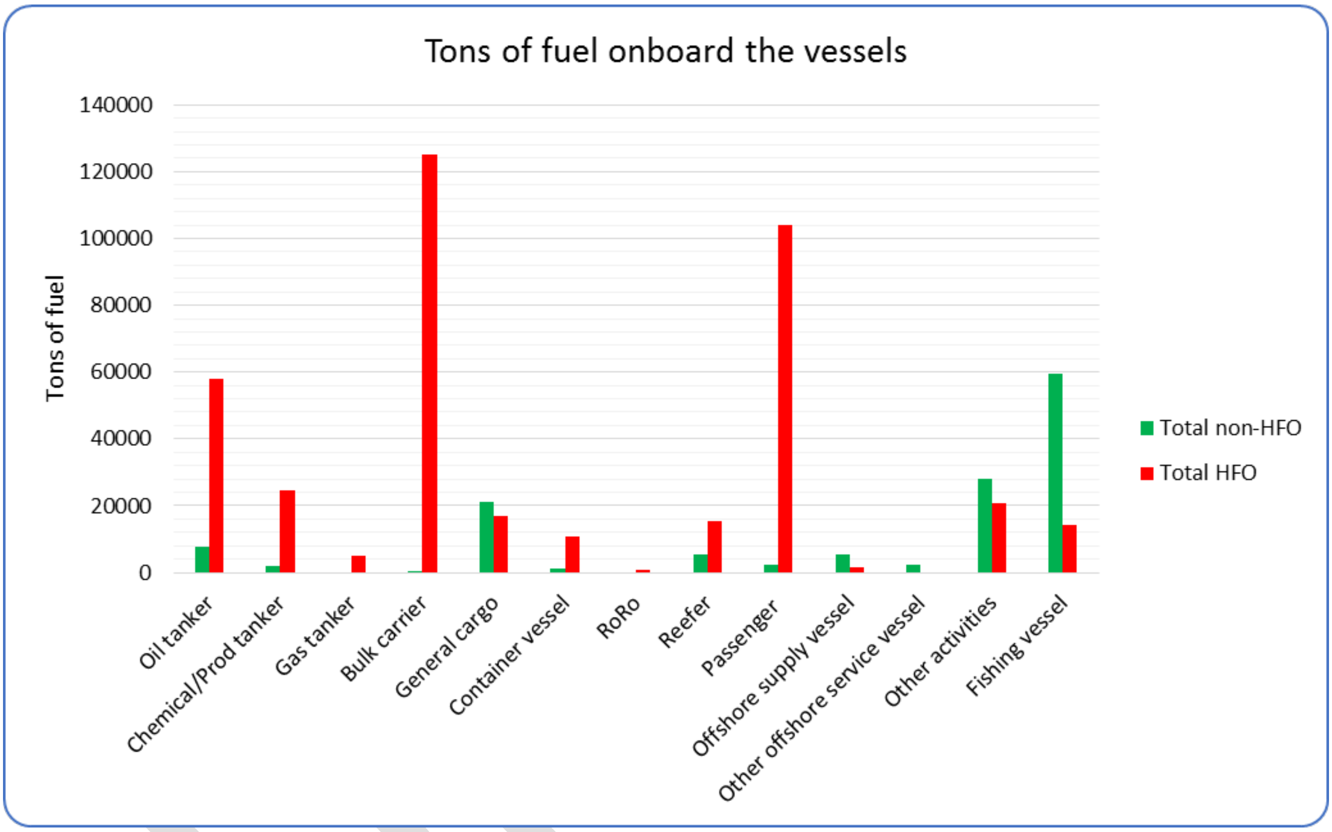


Figure 5-27 - Estimated tons of fuel in vessels in the Arctic

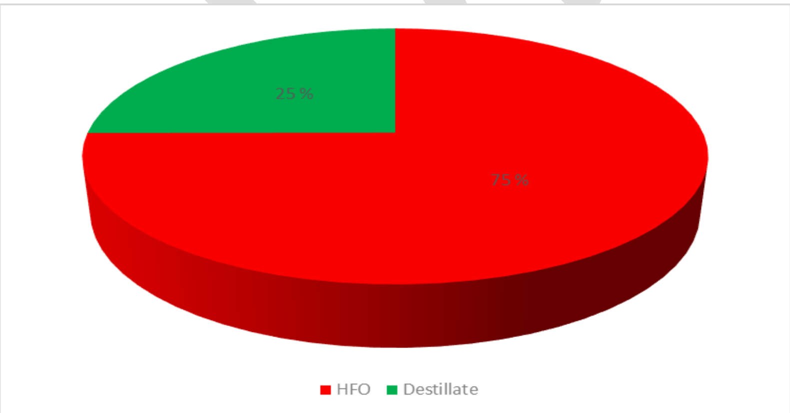


Figure 5-28 - Proportion HFO versus distillate fuel onboard ships in the Arctic

5.9 Expected traffic development

2030 – 2050

The purpose of this study has been to quantify the emission to air of pollutants in the Arctic from shipping activity in 2030 and 2050. The motivation for the study is the general trend of decreasing ice cover of the Arctic Ocean, which most climate models predict will continue through the 21st century, opening the Arctic for increased human activity. This study has focused on two forms of shipping activity: Transpolar shipping using the Arctic as a shortcut between Asia and Europe, and shipping related to petroleum extraction, both of which are negligible today.
To quantify the emissions from future transpolar shipping we have investigated the economic feasibility of diverting seaborne container trade between Asia and Europe from the Suez Canal route to
the Arctic, thereby saving up to 40 % of the distance. For the purposes of this study we have constructed four possible sea routes across the Arctic Ocean. These four routes have been compared on
key metrics such as transit time, fuel consumption, ice conditions, uncertainties in fee regimes etc., and based on this, route 3 was selected for use in the modelling. We have evaluated two different scenarios for Arctic shipping, using double-acting vessels (which can handle heavy ice conditions) which operate in the Arctic year-round, and ice-classed conventional vessels (which can only handle light ice conditions) which use the Arctic route only part of the year, when the ice conditions permit.
Future projections of ice conditions in the Arctic Ocean have been used to calculate transit times and fuel consumption, which have been used to calculate costs for the two alternative scenarios. The costs of the Arctic transit scenarios have been compared with the costs of a similar scenario for Suez Canal traffic. These cost comparisons, along with projections of the future trade volume between Asia and Europe, have been combined to quantify the number of ship passages per year across the Arctic, which in turn yields the amount of emissions to air.
Emissions from shipping related to petroleum extraction have been calculated based on gridded future projections of production of oil and gas in the Arctic, which have been provided by CICERO. We have located transhipment ports, as well as assumed shipping routes between fields and transhipment ports and between transhipment ports and ports outside the Arctic. The number of ship passages per year on these routes have been derived from the production data. In the end, gridded emission values have

been produced using the same procedure as for transit shipping.

The model developed in this study indicate that transpolar shipping will be feasible in 2030 and 2050 for trade between Northern Asia (Tokyo hub) and Northern Europe (Rotterdam). The model is mainly sensitive to the price of fuel, and to the length of the navigable season in the Arctic Ocean, which is determined by ice conditions. Our modelling predicts that about 8 % and 10 % of the total container trade between Asia and Europe will pass through the Arctic in 2030 and 2050 respectively. These cargo flows correspond to 480 and 850 annual transpolar passages in 2030 and 2050 respectively. We estimate that transpolar shipping will reduce global CO2-emissions with about 1.17 Mt and 2.92 Mt in 2030 and 2050 respectively. These numbers represent reductions of roughly 0.1% in 2030 and 0.15% of global ship emissions in 2050.

Results from the modelling of oil and gas-related shipping give emissions that are 40 % higher than the emissions from transpolar shipping in 2030, and 90 % higher in 2050. In total, the shipping related to oil and gas extraction in the Arctic that have been modelled in this study will emit about 5.3 Mt CO2 in 2030, and about 10.7 Mt CO2 in 2050, which amounts to about 0.5 % of the total global ship emissions in both years [8, 19, 22].

6 REGULATIONS ON THE USE OF HFO IN THE ARCTIC

6.1 Summary from the PAME-1 report

6.2 Overview of regulations controlling the use and carriage of HFO

6.3 Regulatory gaps and the effects of these

7 RISK ESTIMATIONS

7.1 HAZID Workshop for identifying hazards and risk reducing measures

7.2 Risk Assessment

7.3 Cost benefit assessment

7.4 Recommendations for decision making

8 REFERENCES

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/2/ FSA – Crude Oil Tankers, MEPC 58/17/2, July 2008

/3/ Risknet, Continually updated

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/2/ Douglas, D.H. and T.K. Peucker, *ALGORITHMS FOR THE REDUCTION OF THE NUMBER OF POINTS REQUIRED TO REPRESENT A DIGITIZED LINE OR ITS CARICATURE.* Cartographica: The International Journal for Geographic Information and Geovisualization, 1973. 10(2): p. 112-122

/2/ Det Norske Veritas. Environmental Accounting System for Norwegian Shipping – EASNOS phase 1. DNV report 2002-1645, January 2003.

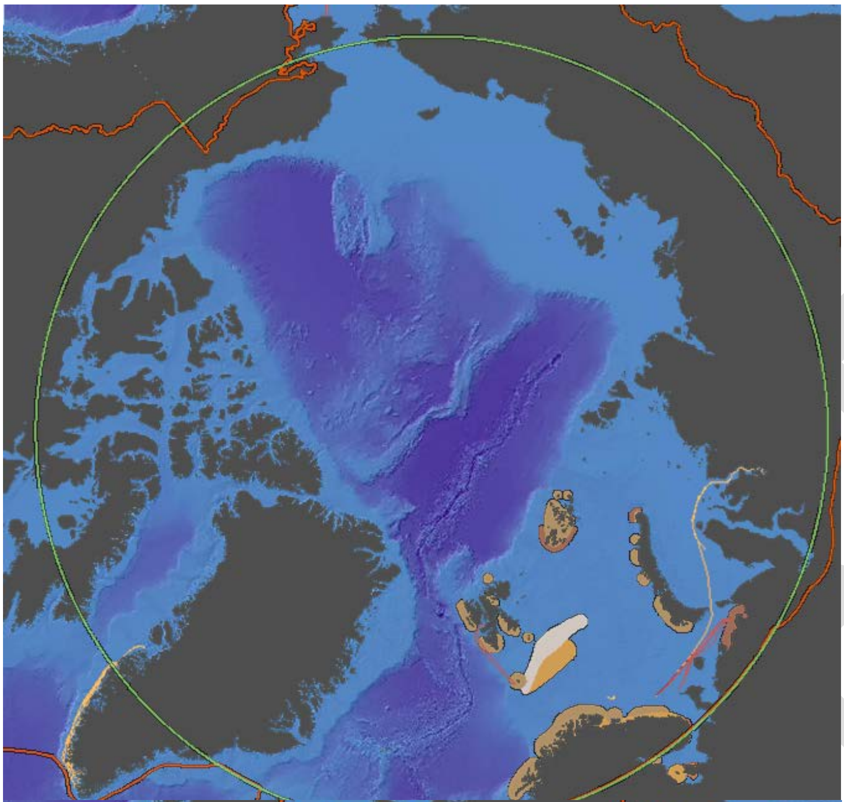
/3/

/4/ DNV and Lloyds ship register – DNV datawarehouse

/5 Norges Sipsforskningsinstitutt 1977. Kartlegging av oljeholdig avfall fra skip med anløp I Norske havner. OR 347.11302.07.

APPENDIX I

8.1 Oil tanker (red), Chemical tanker (orange) and Gas tanker (green)



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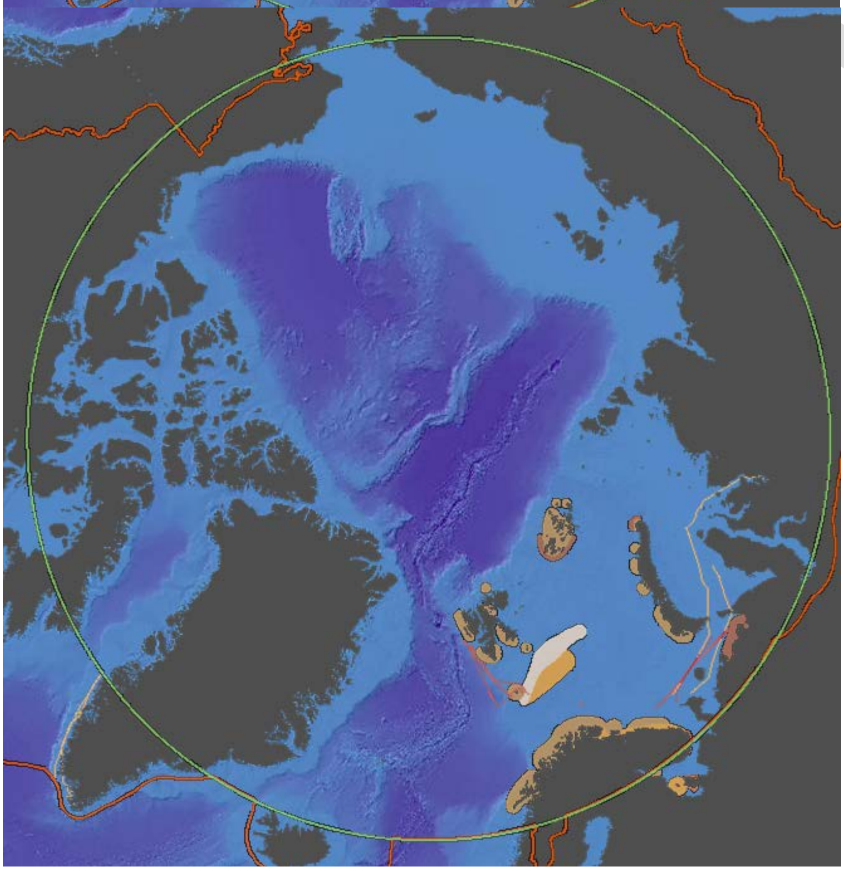

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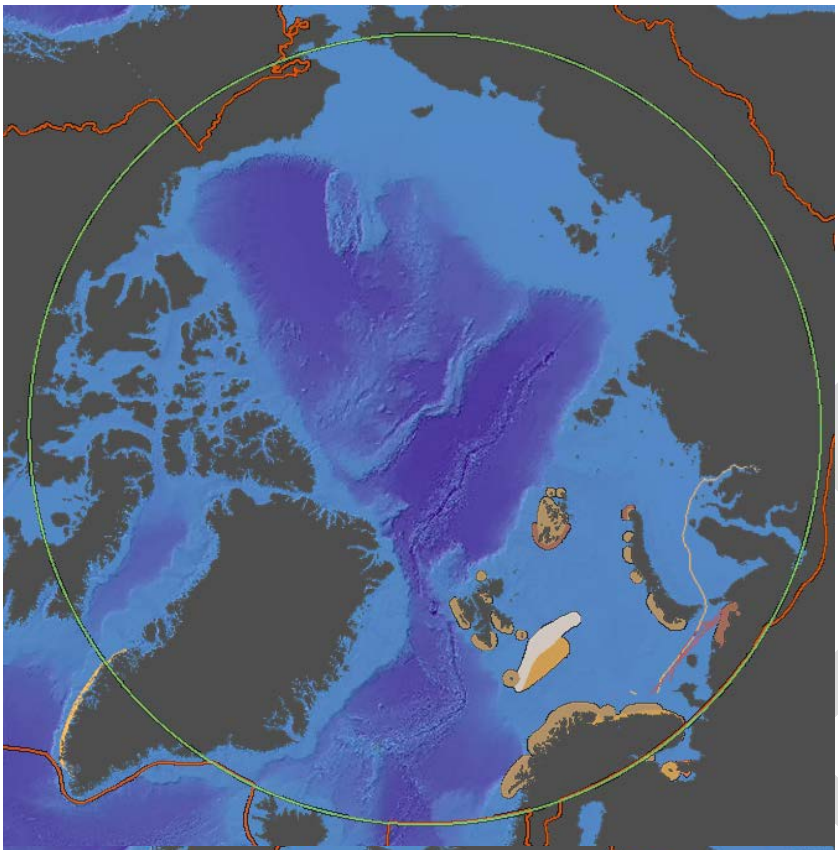

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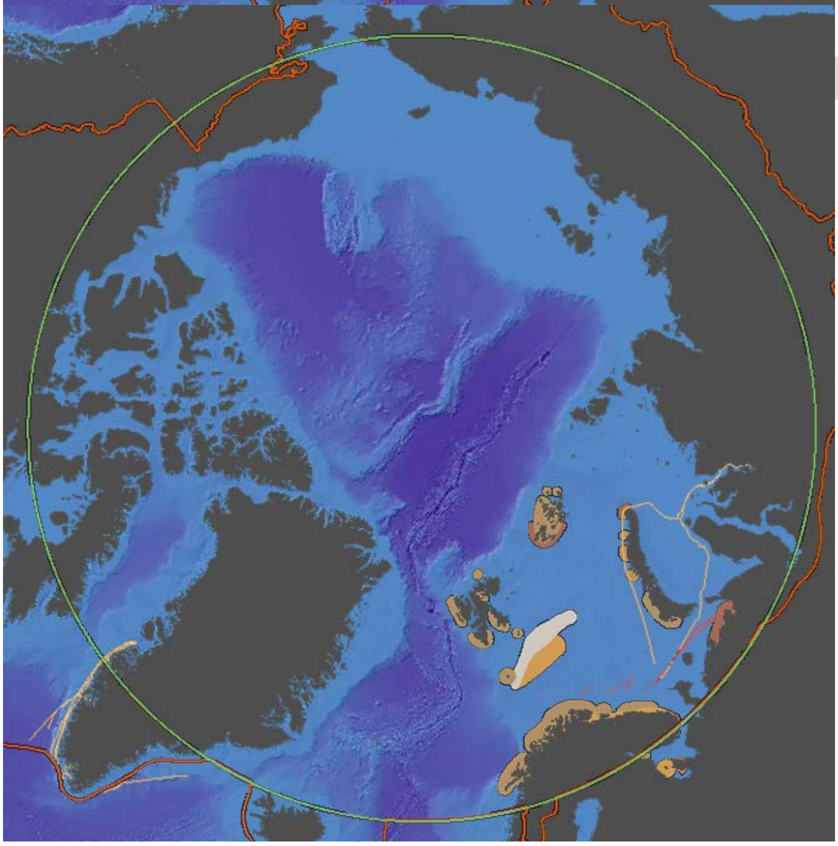

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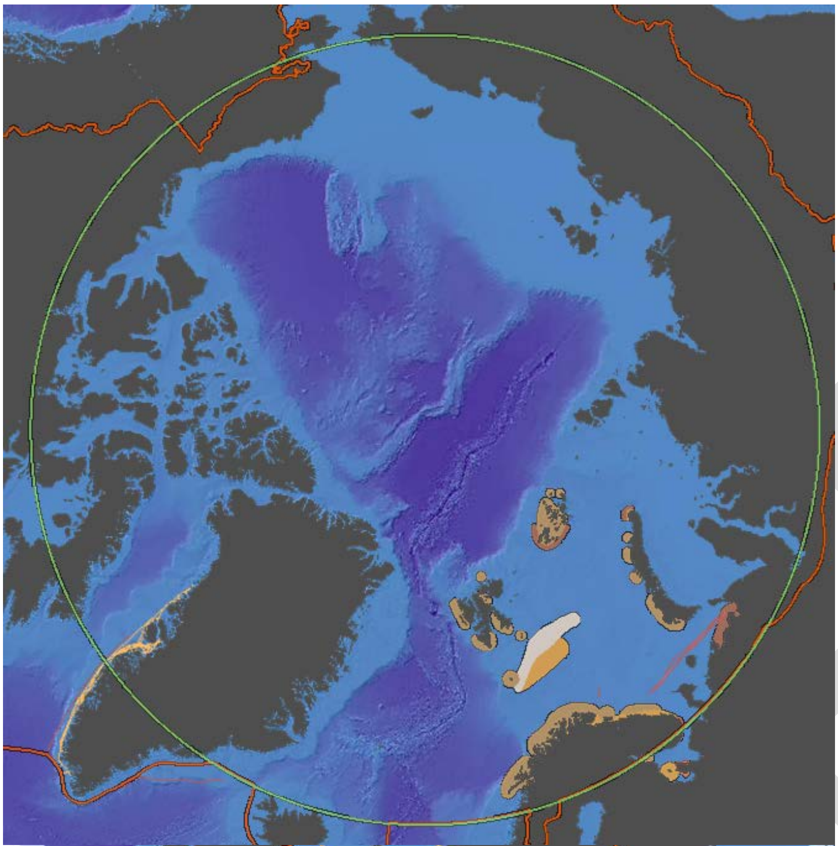

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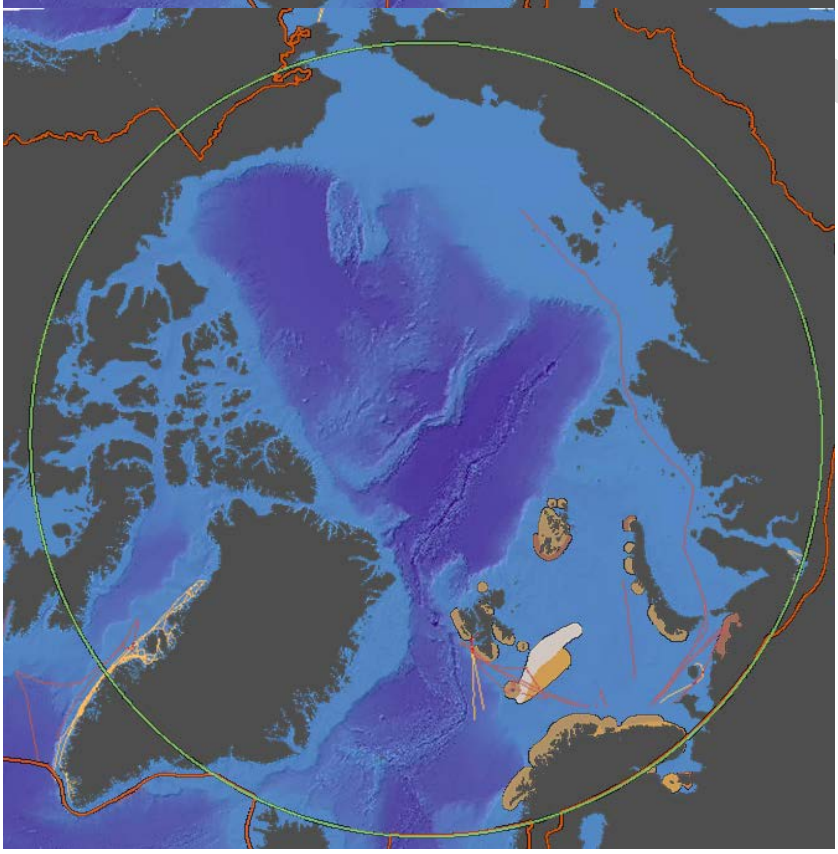

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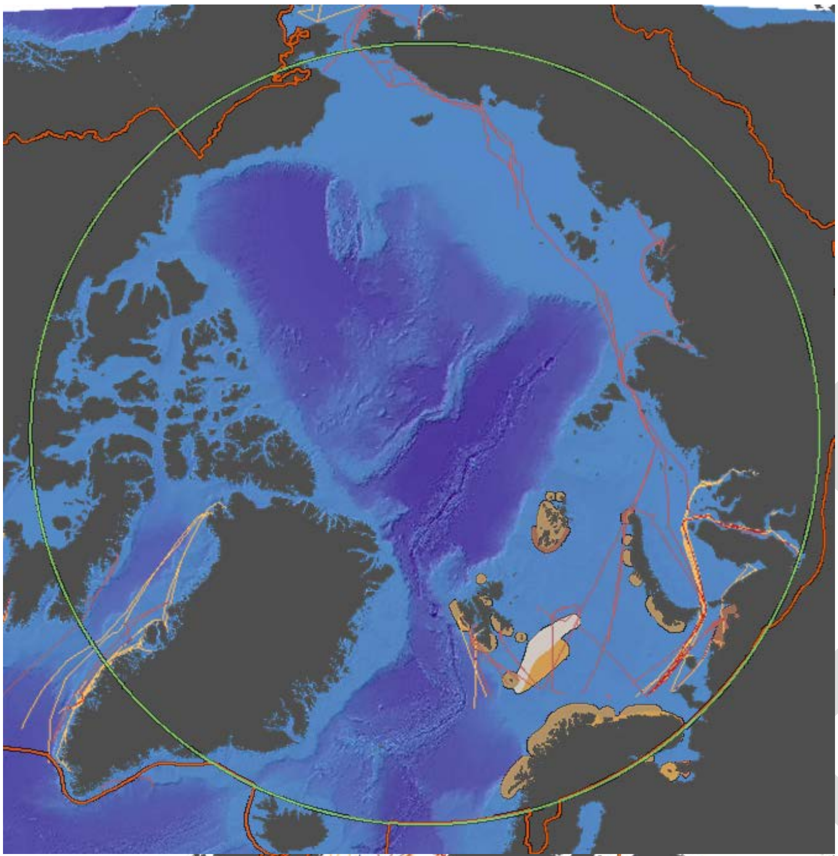

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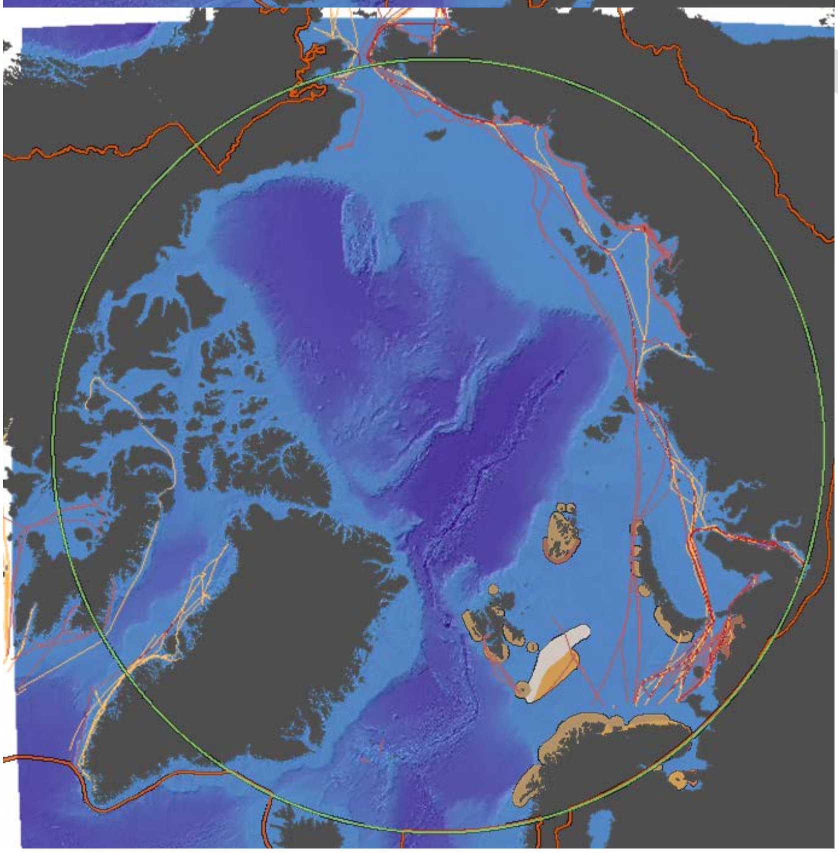

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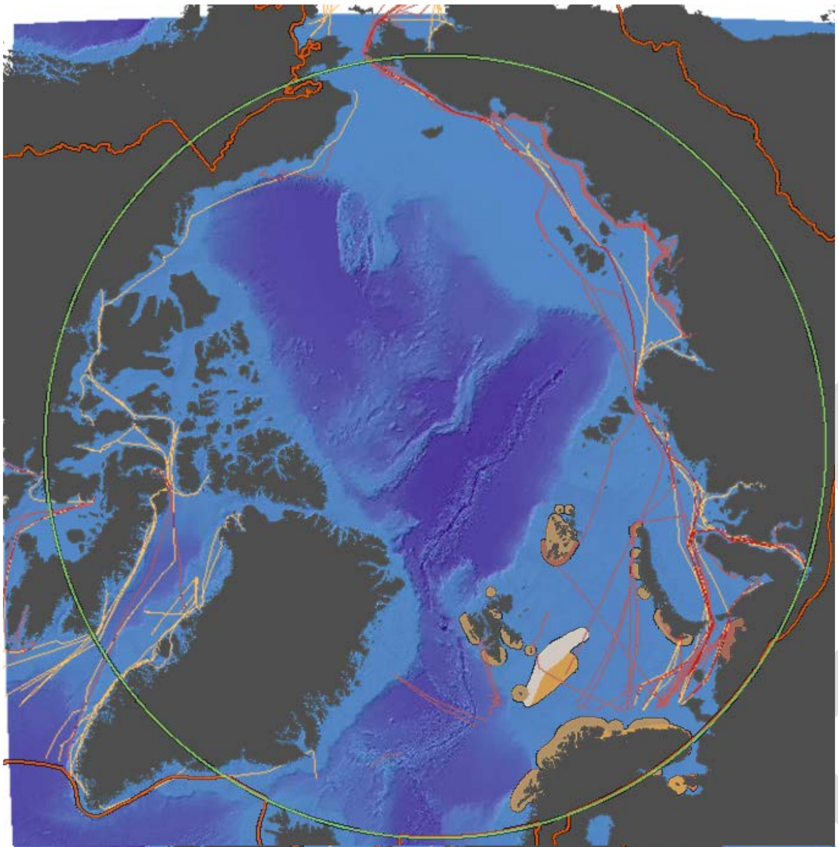

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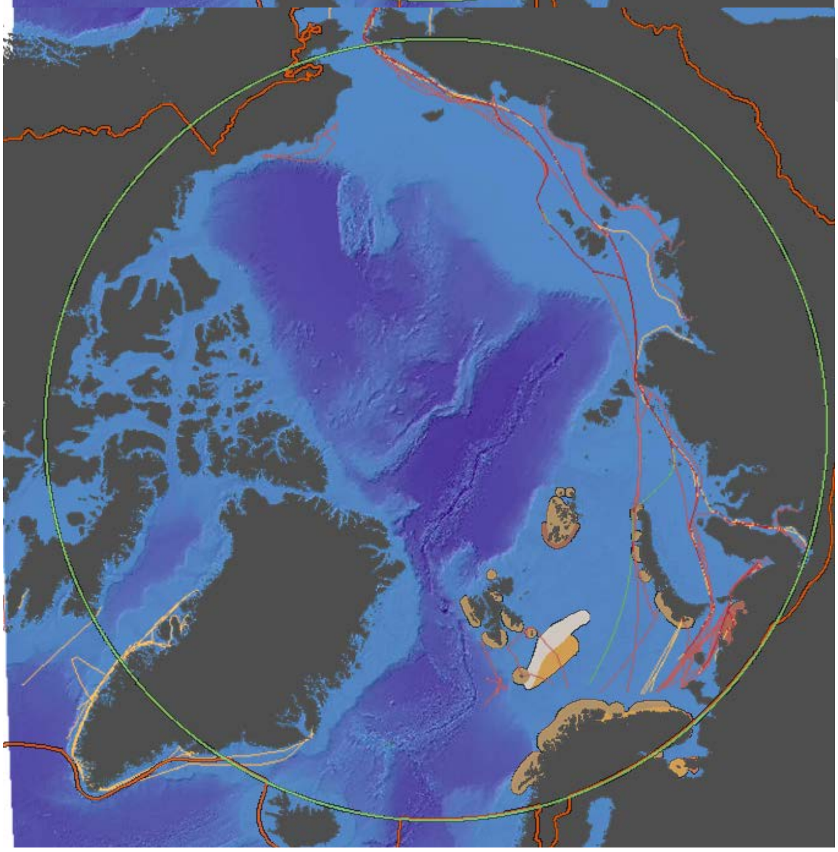

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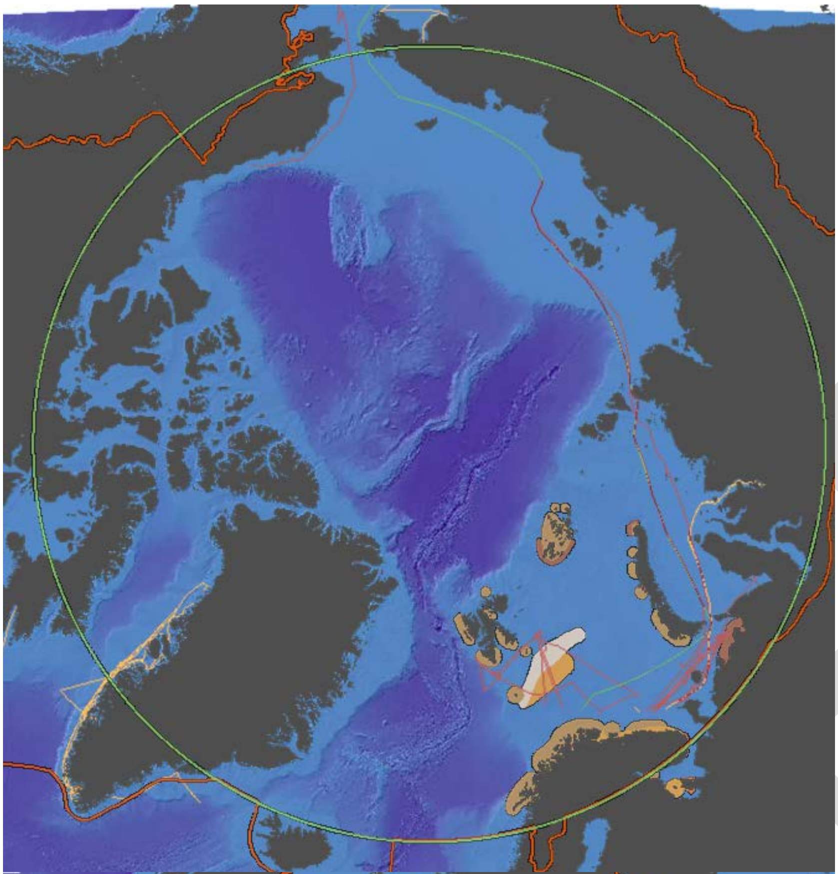

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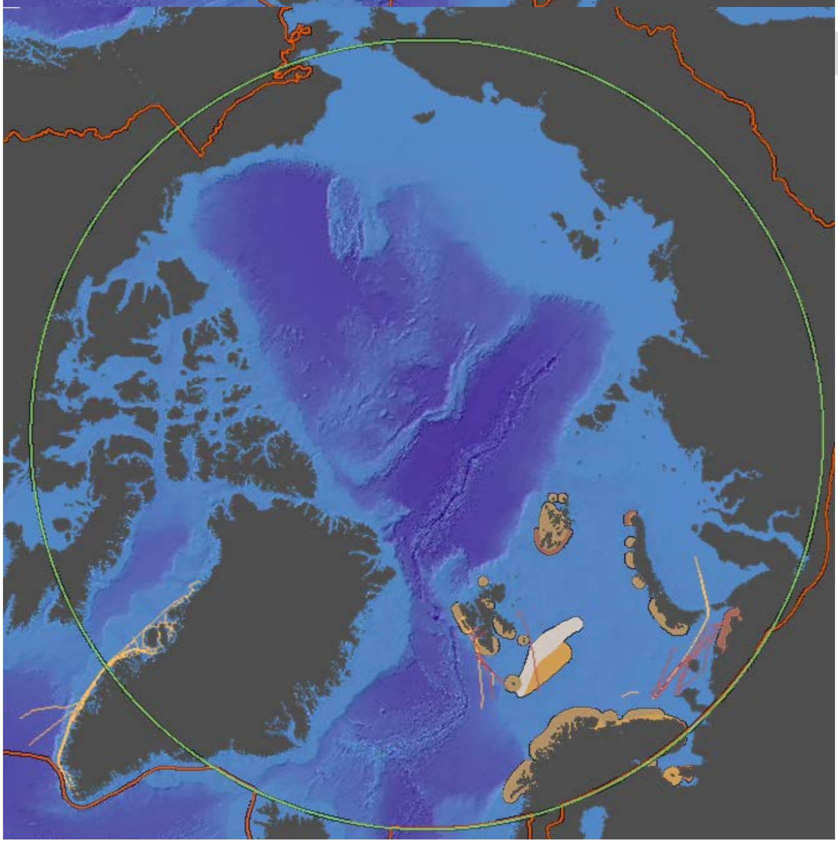

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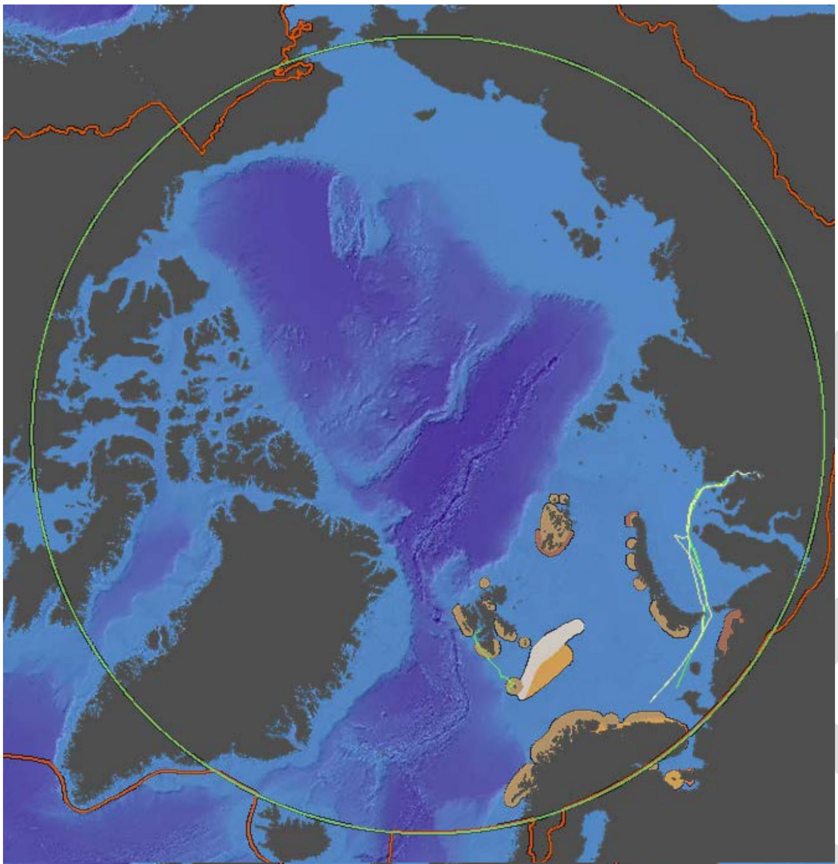
8.2 Bulk carrier (yellow) and General cargo (green)



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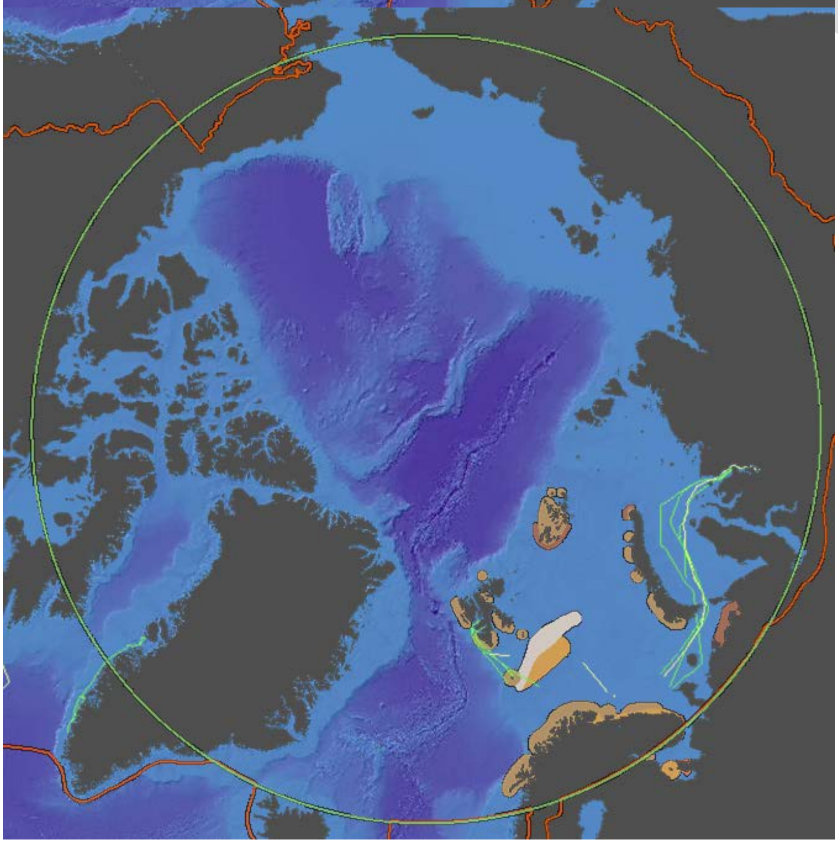

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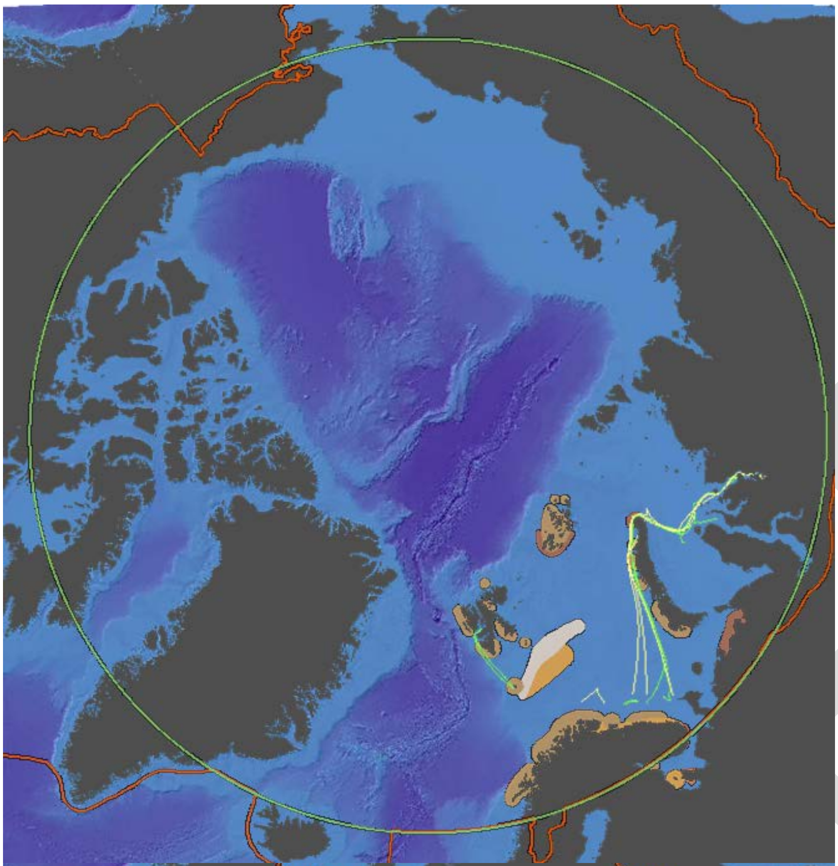

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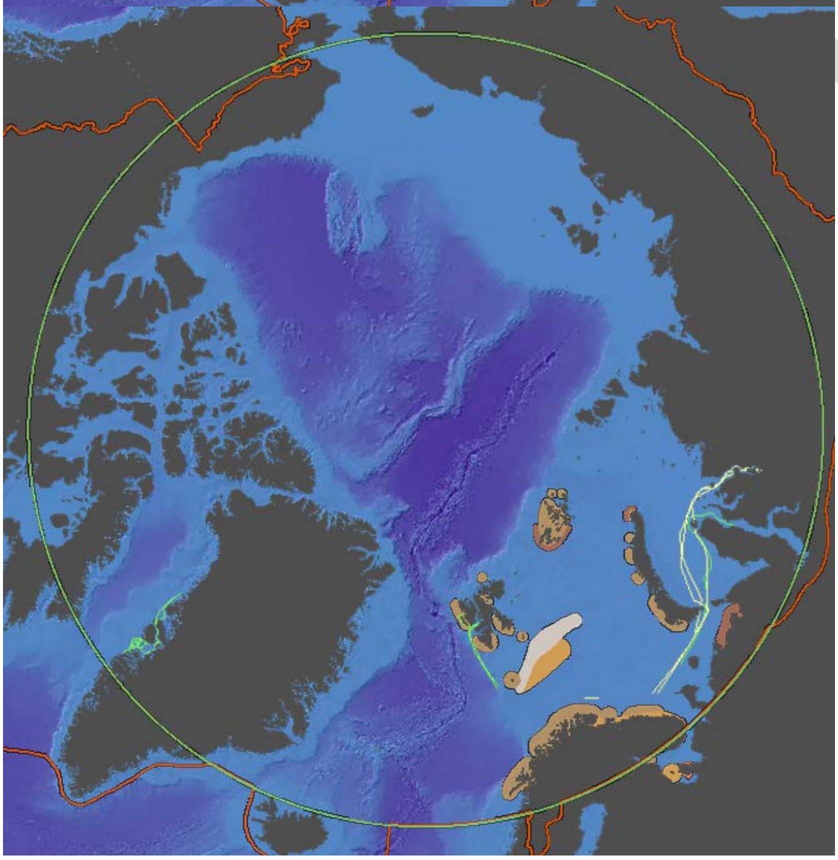

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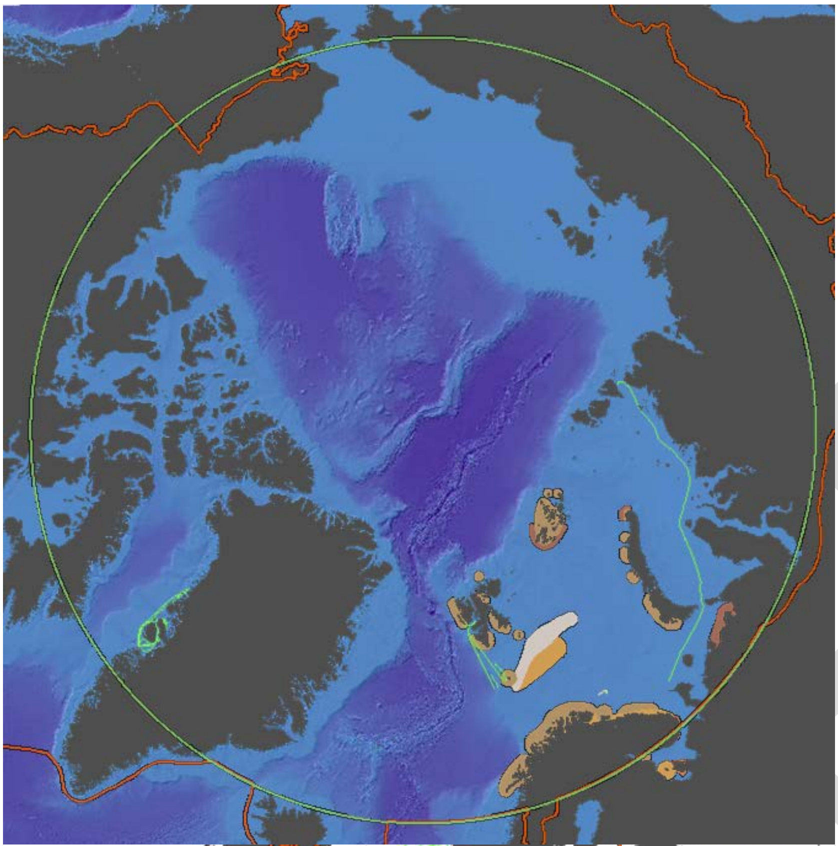

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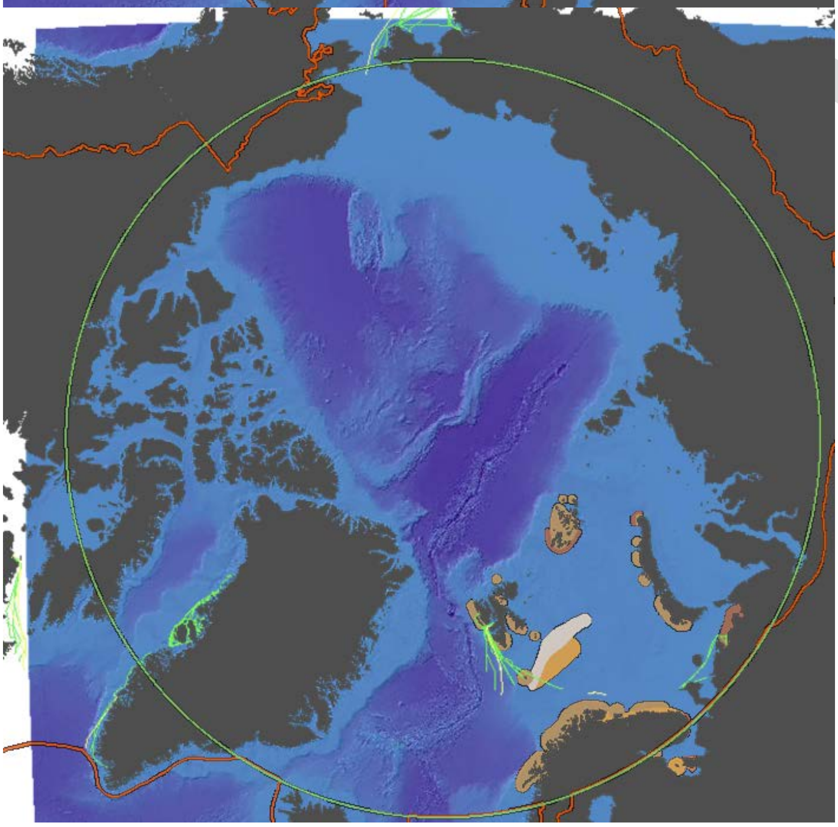

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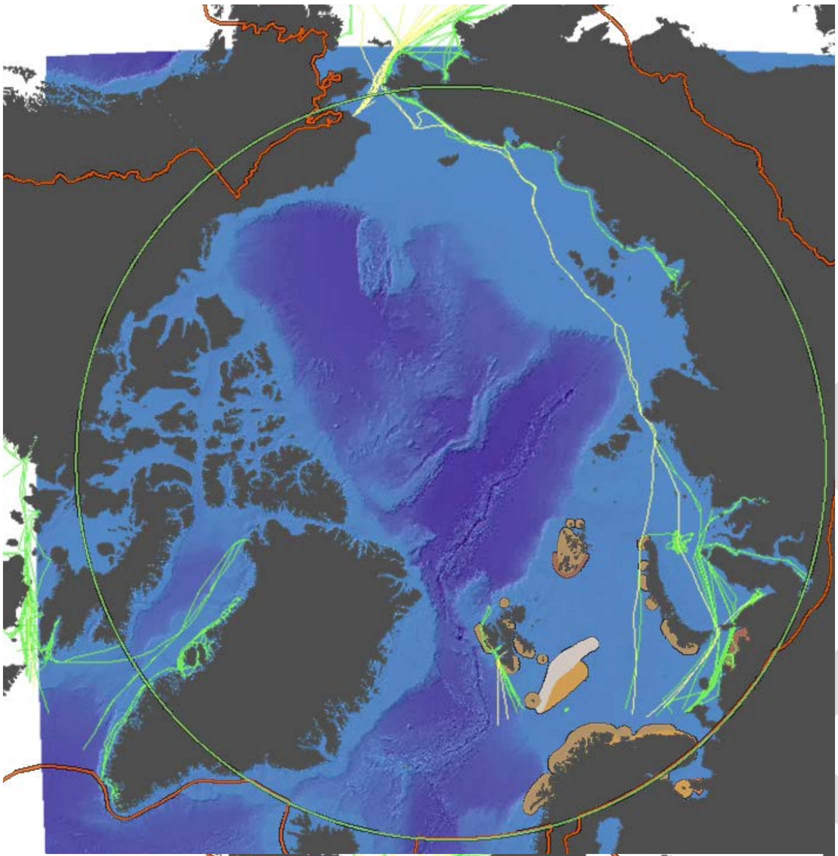

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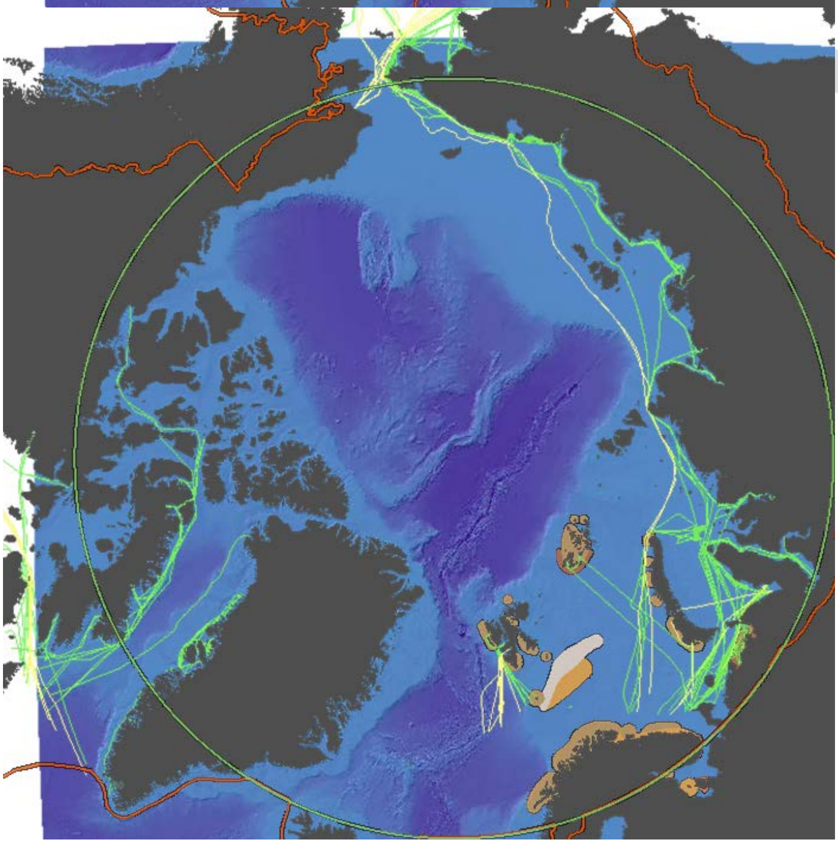

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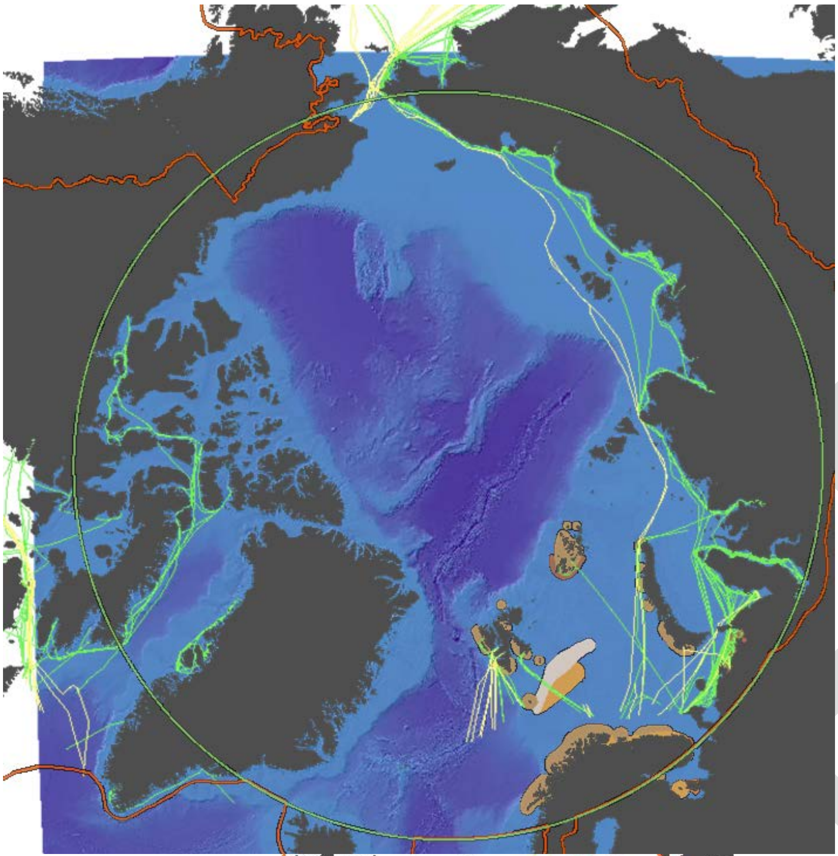

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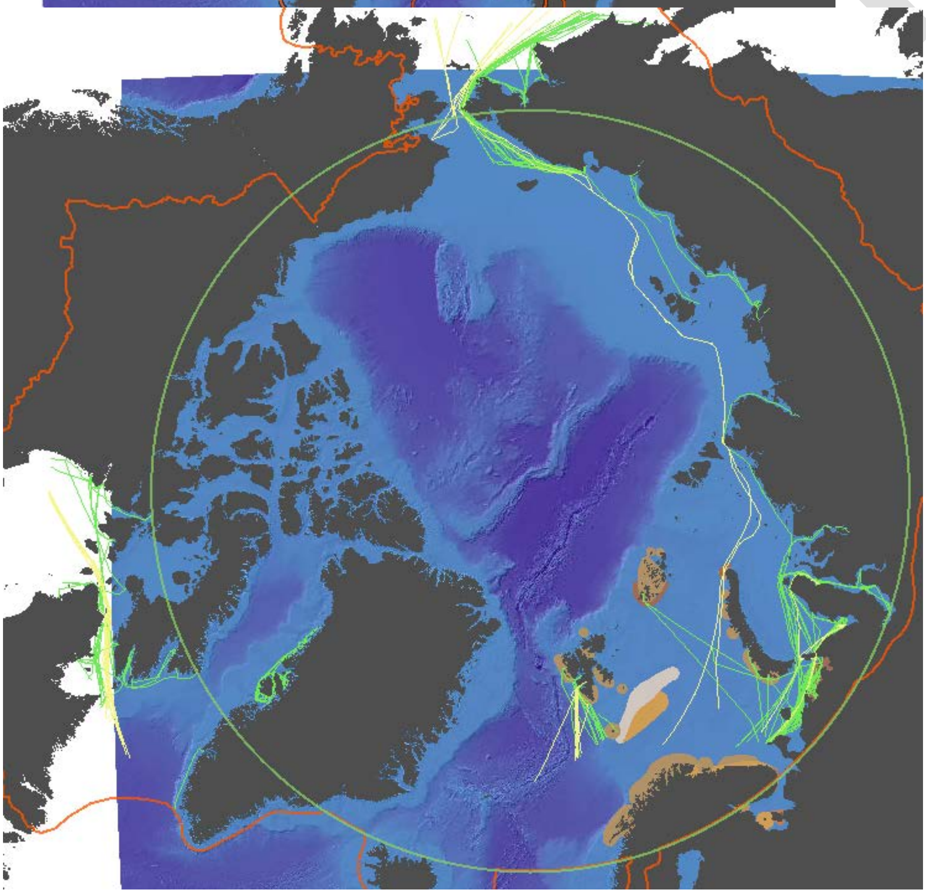

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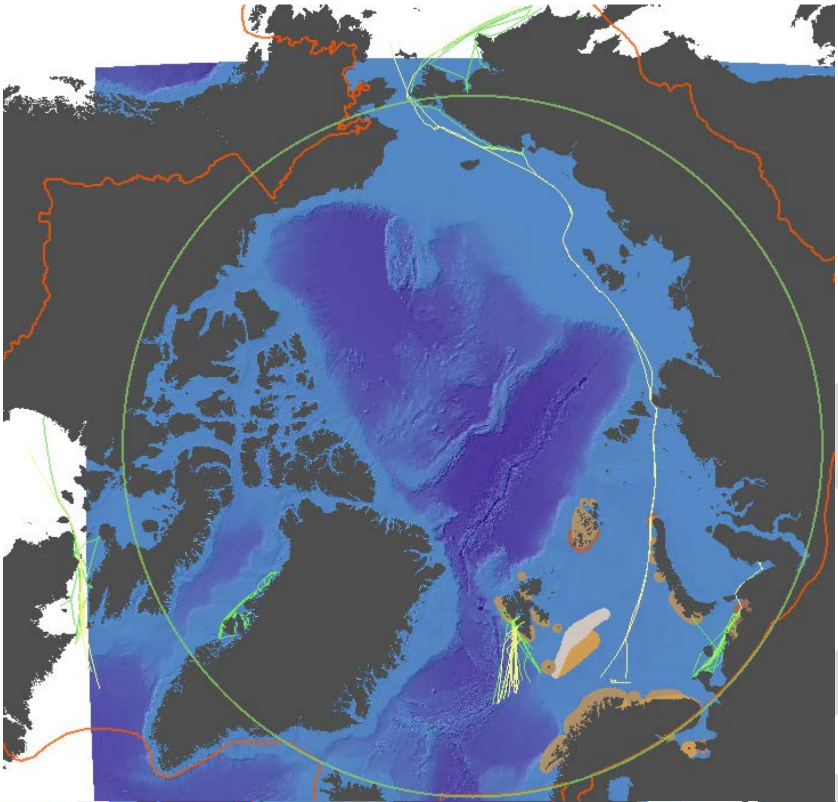

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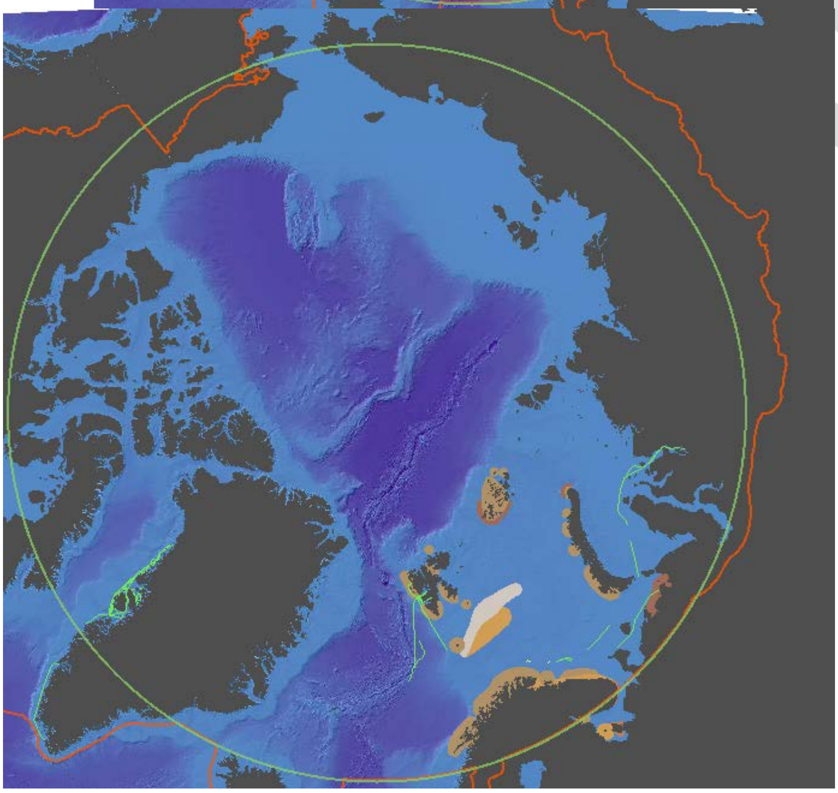

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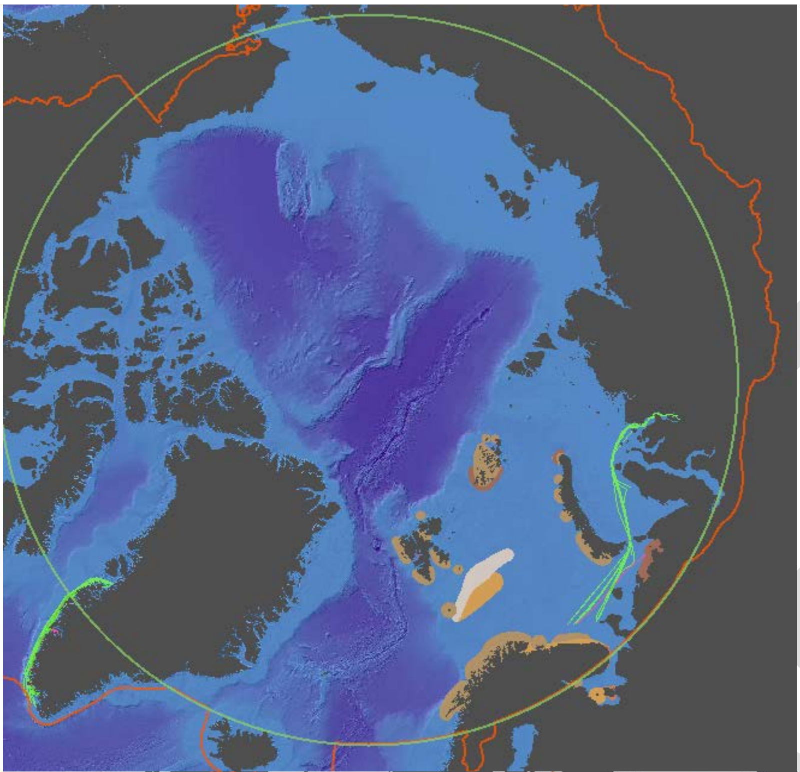
8.3 Container vessels (green), Ro-Ro vessels (red) and Passenger vessels (pink)



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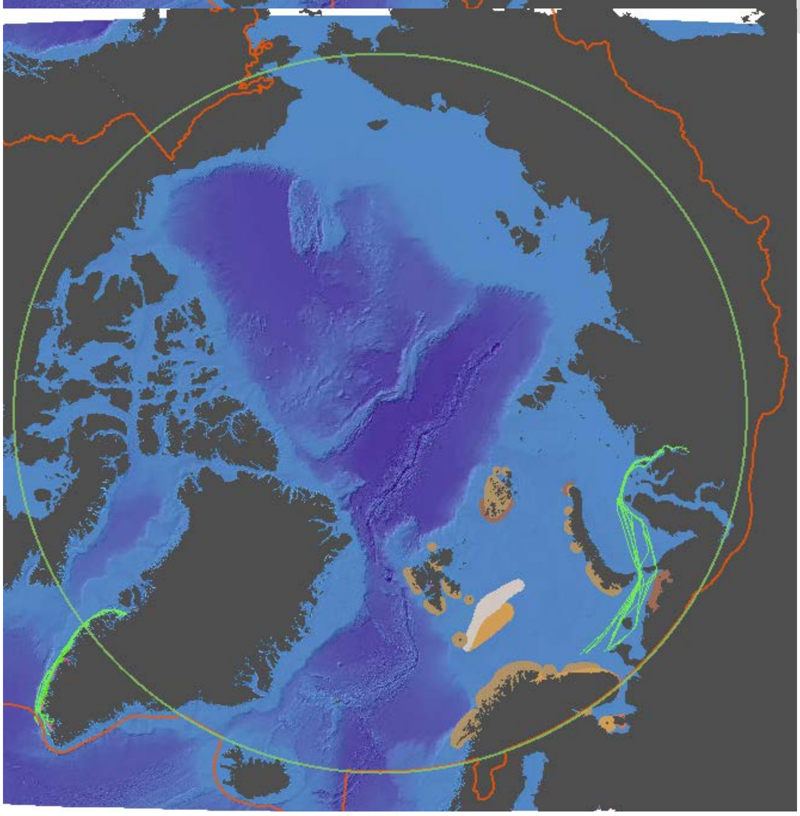

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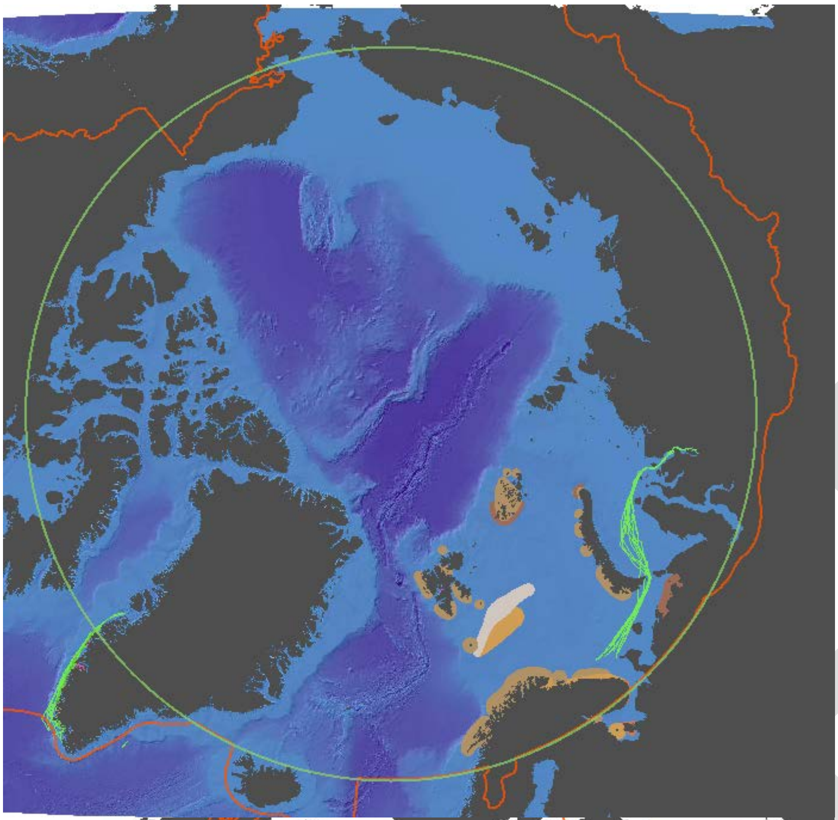

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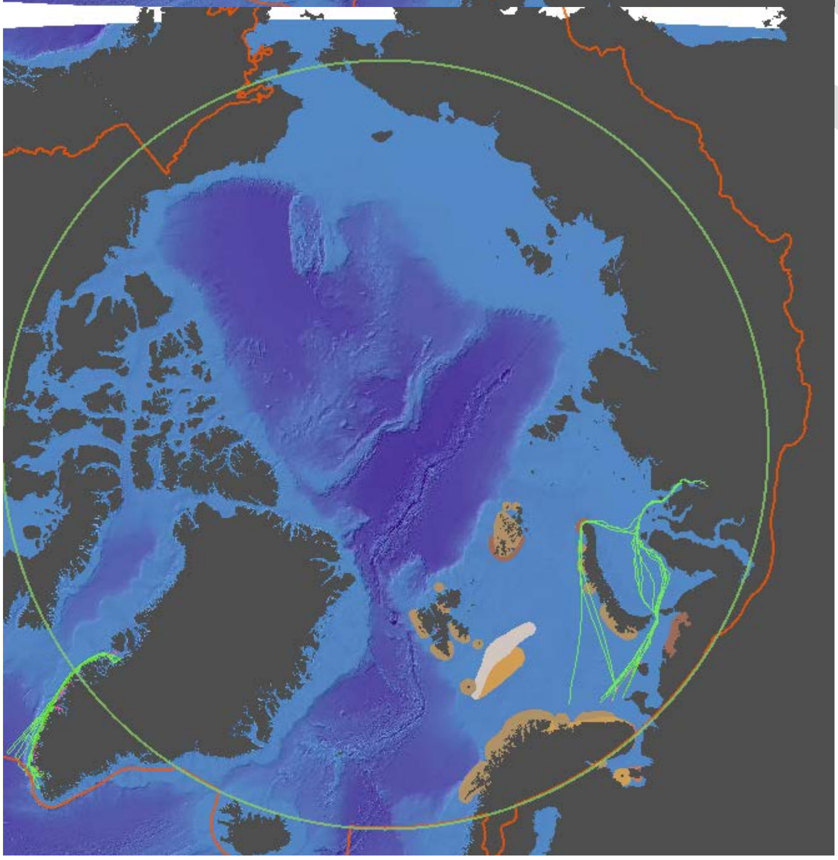

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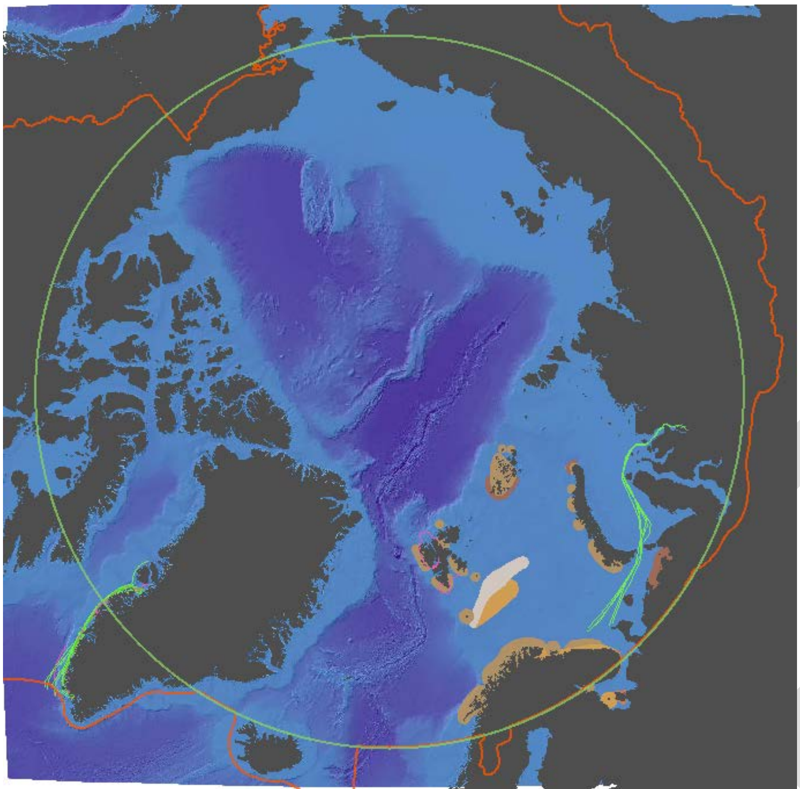

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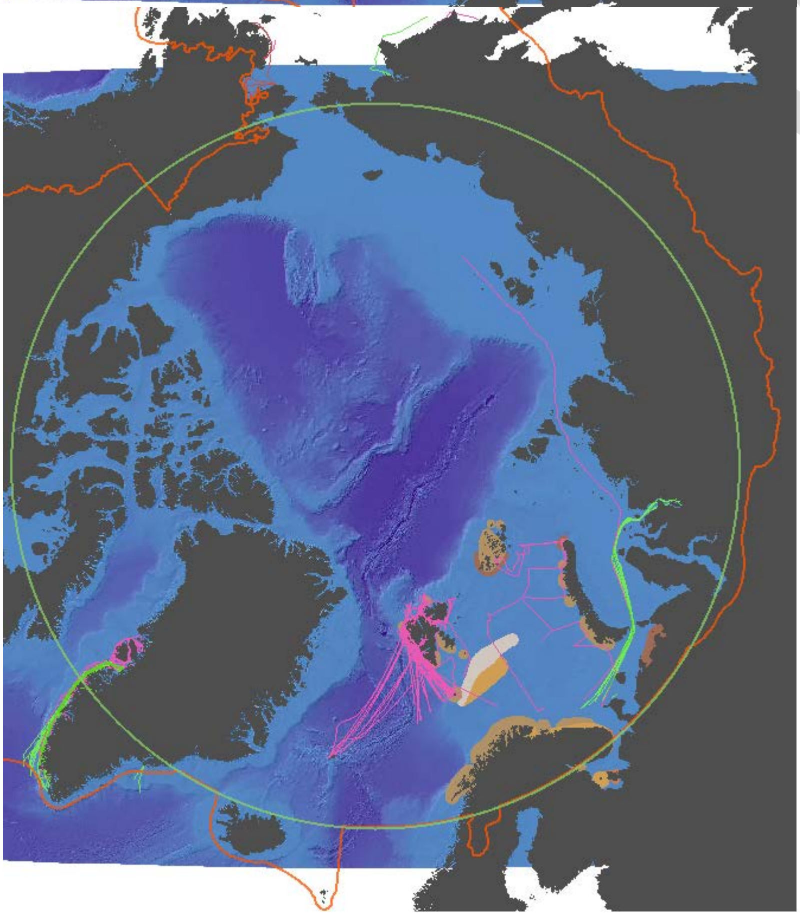

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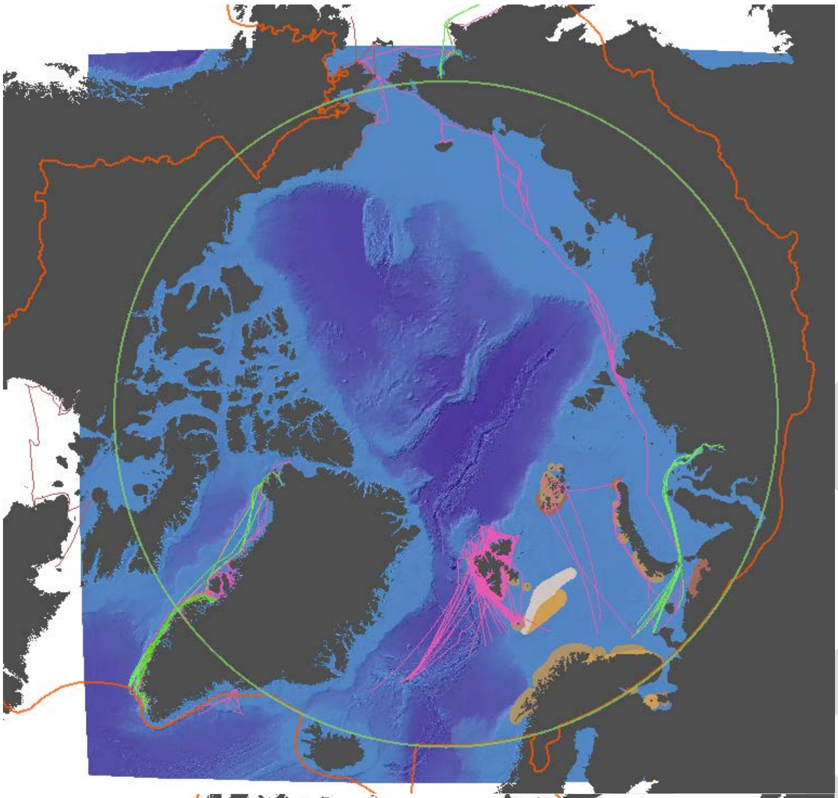

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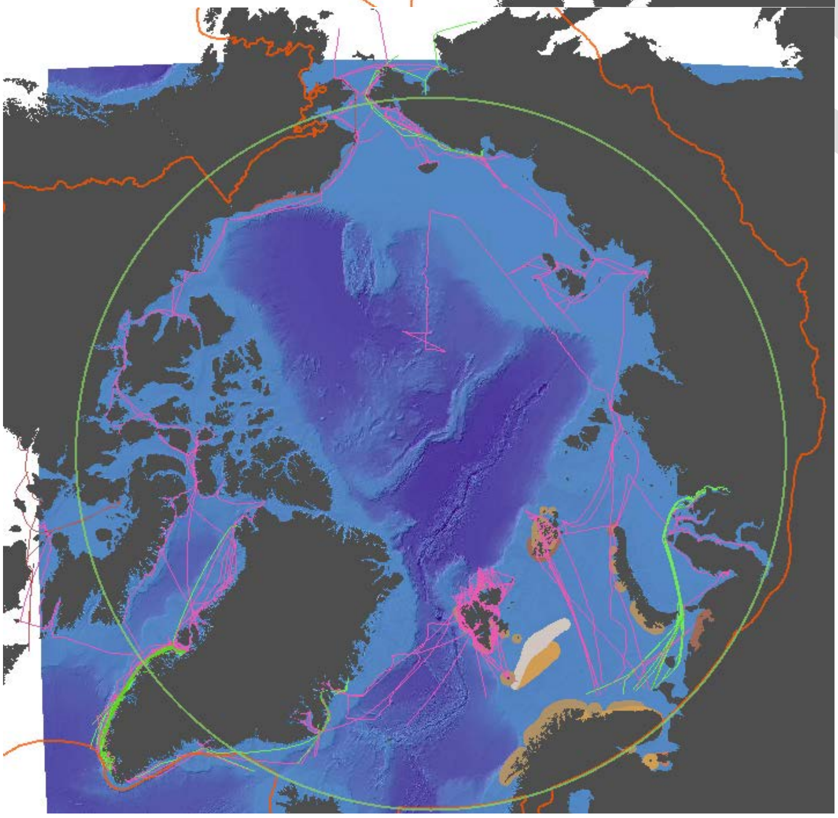

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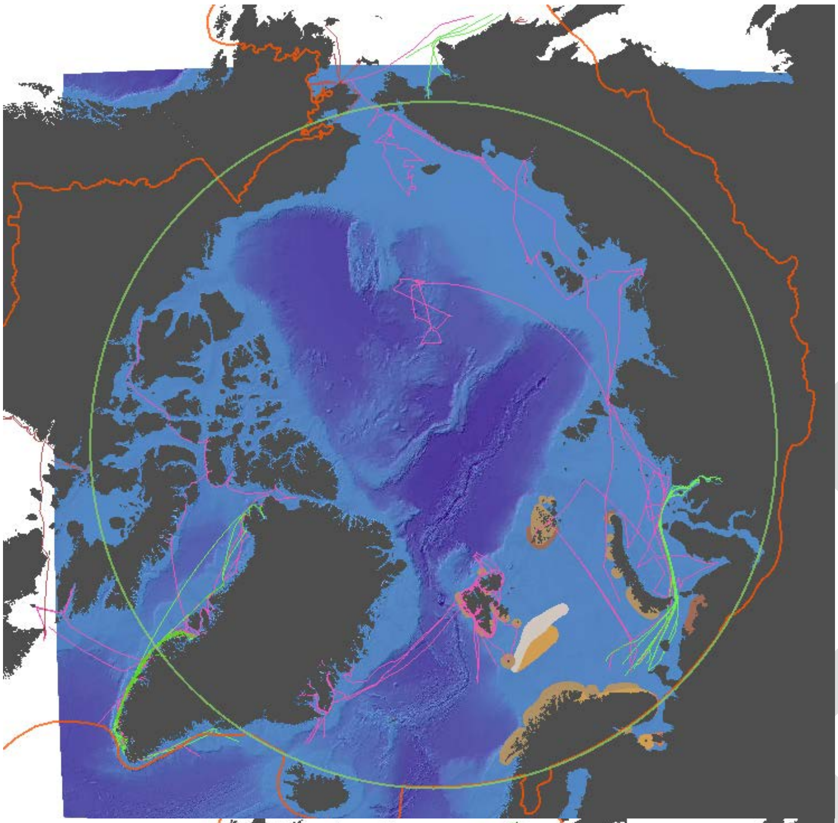

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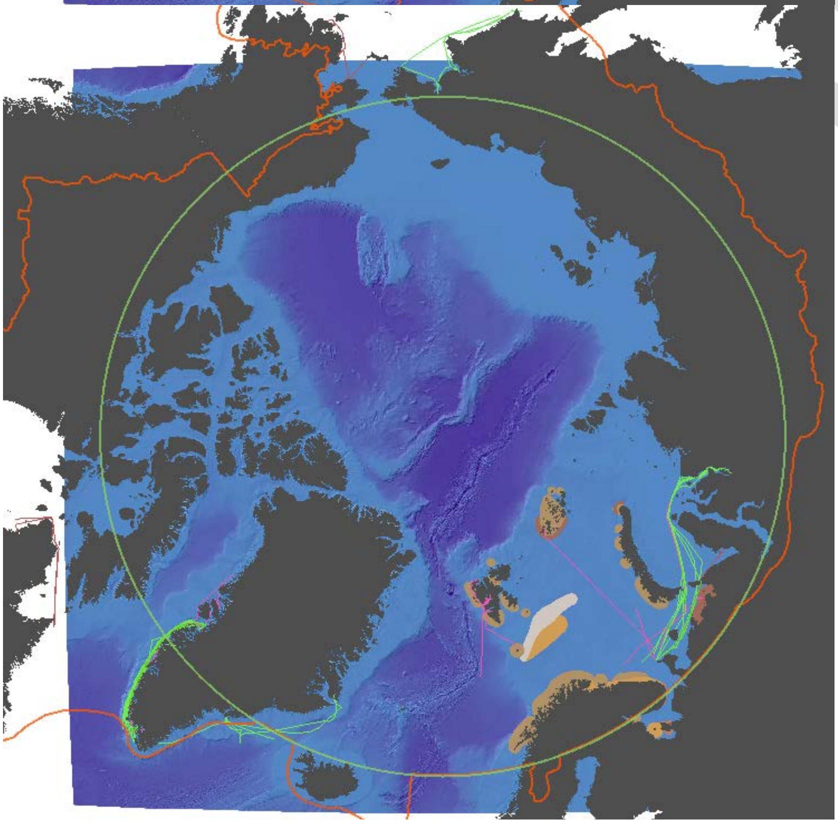

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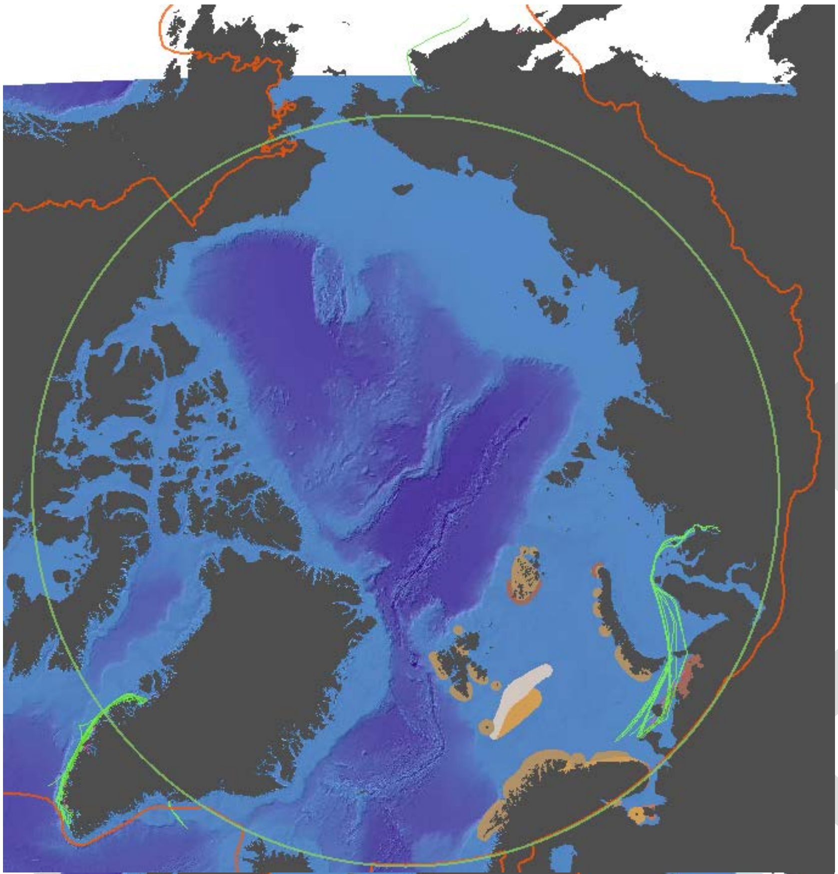

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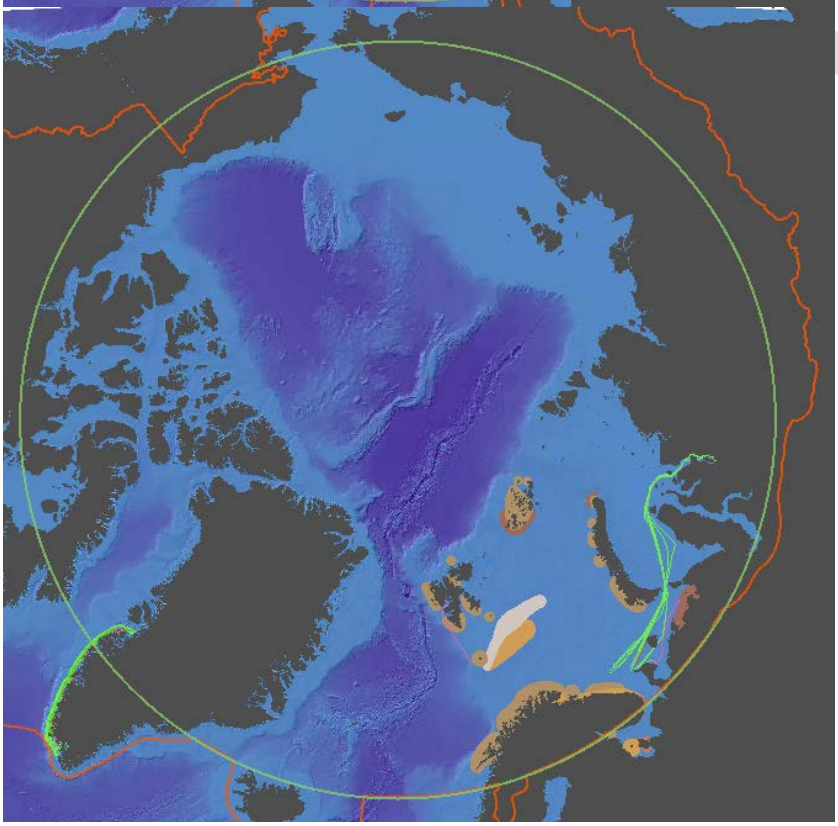

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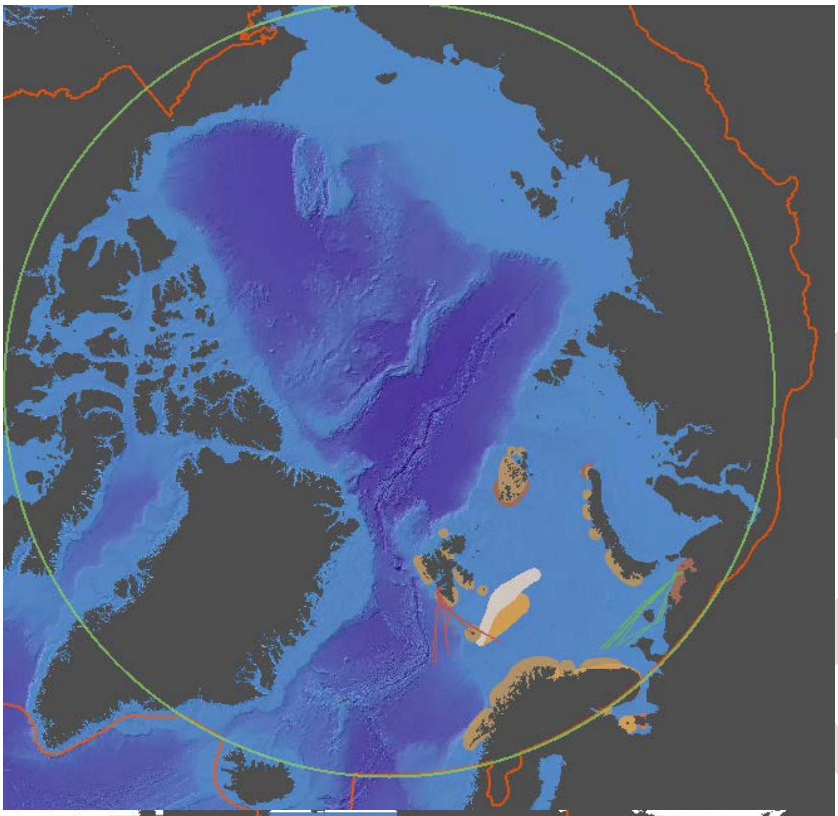
8.4 Reefers (brown) and Offshore supply vessels (green)



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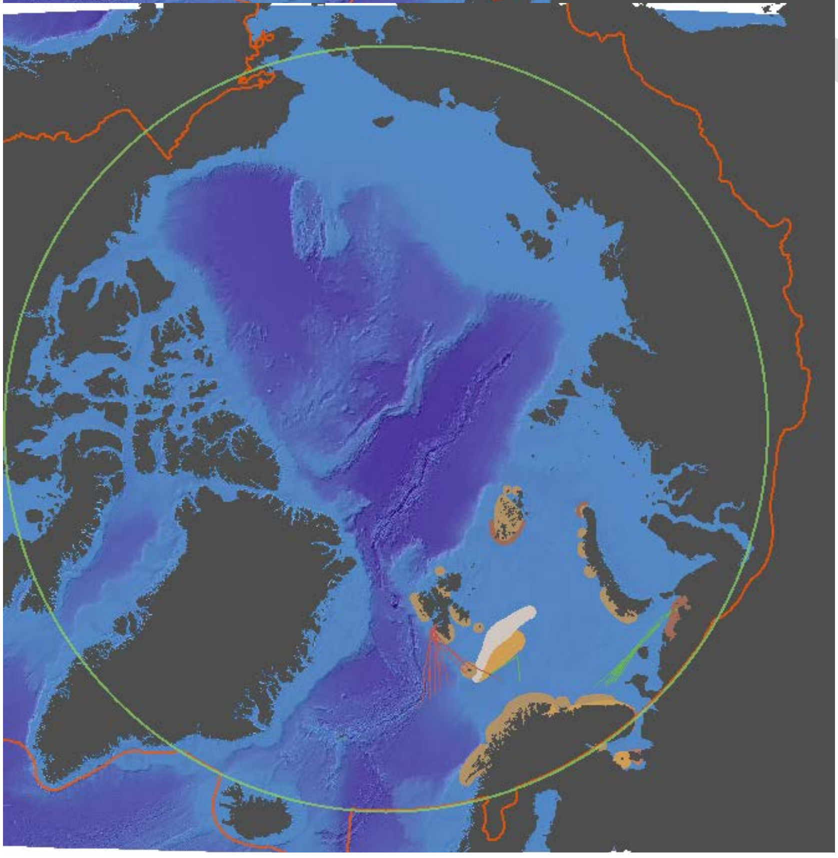

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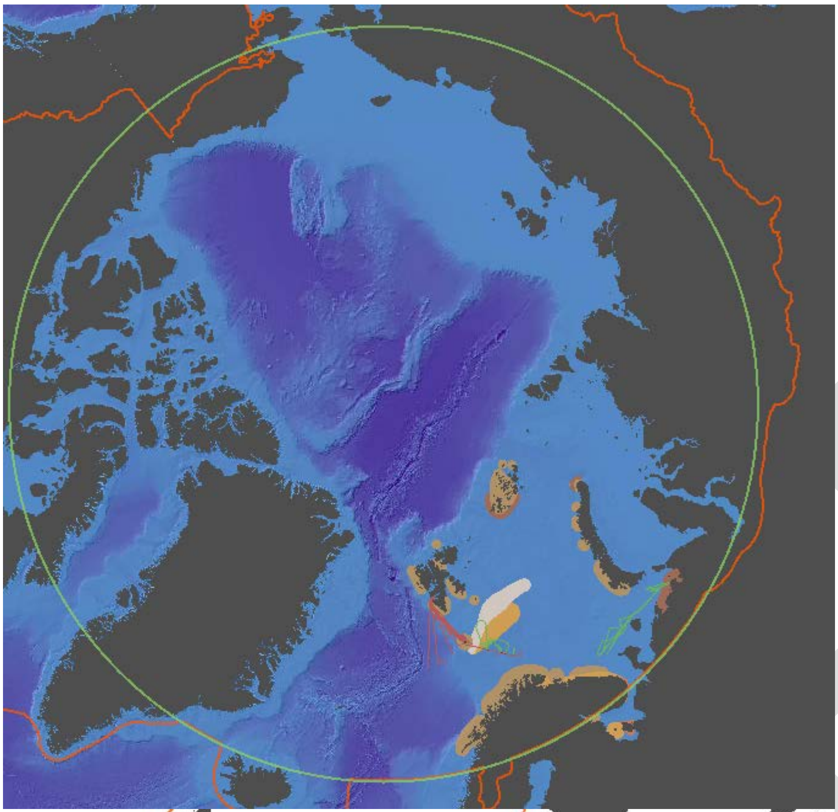

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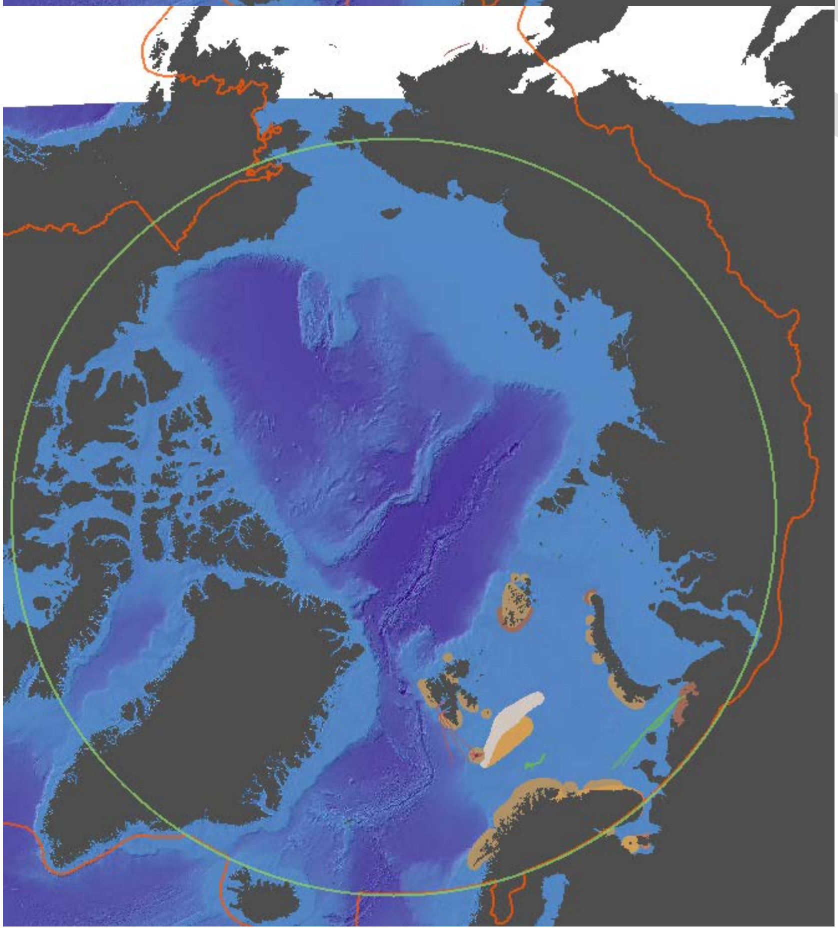

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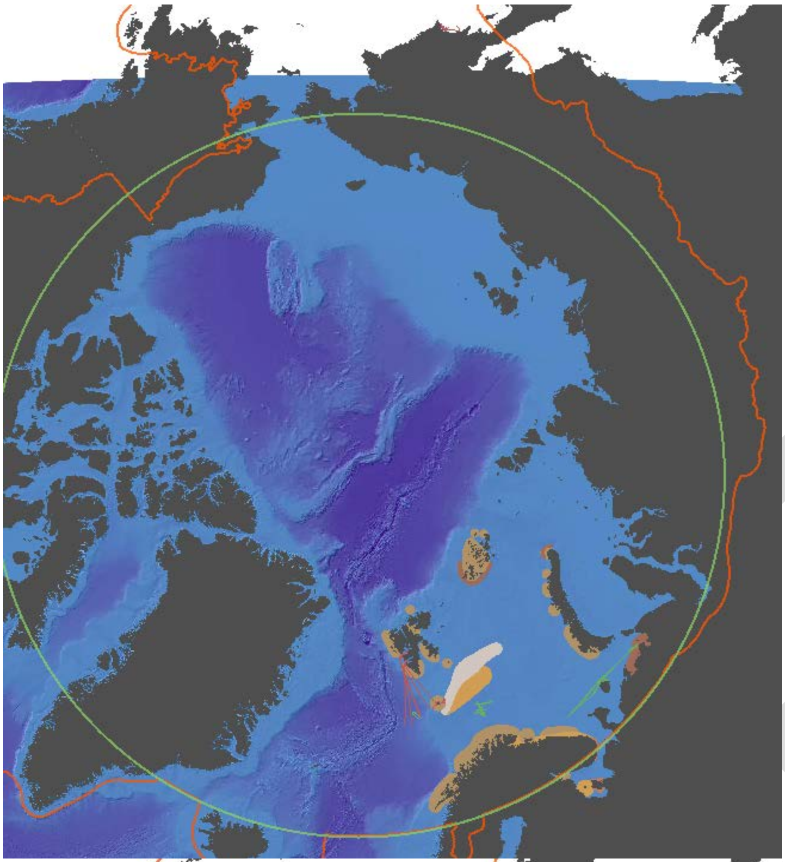

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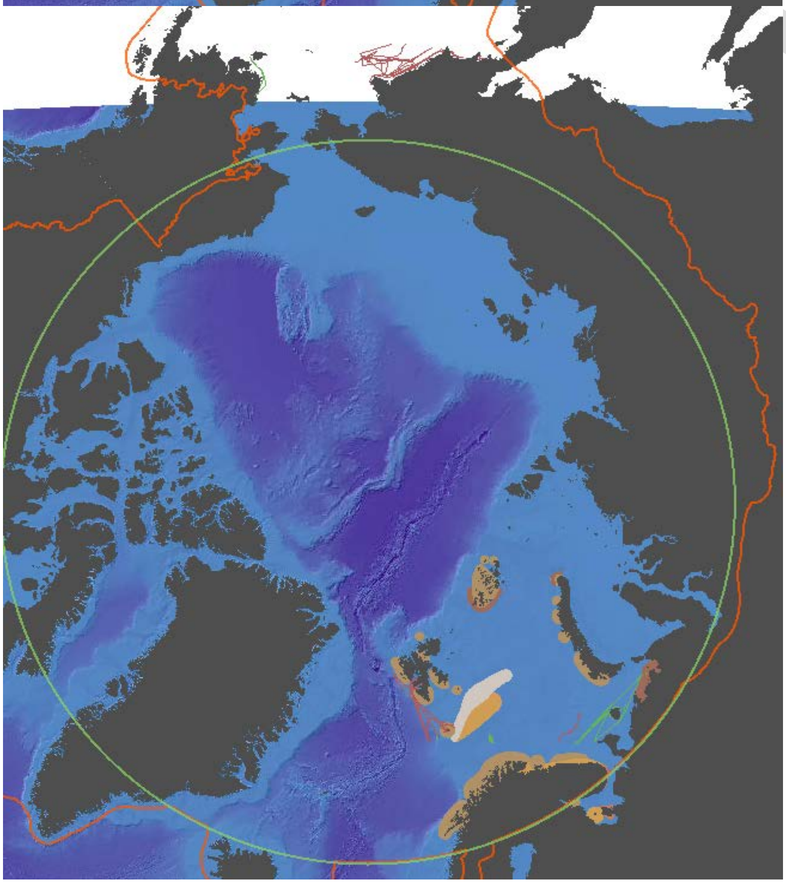

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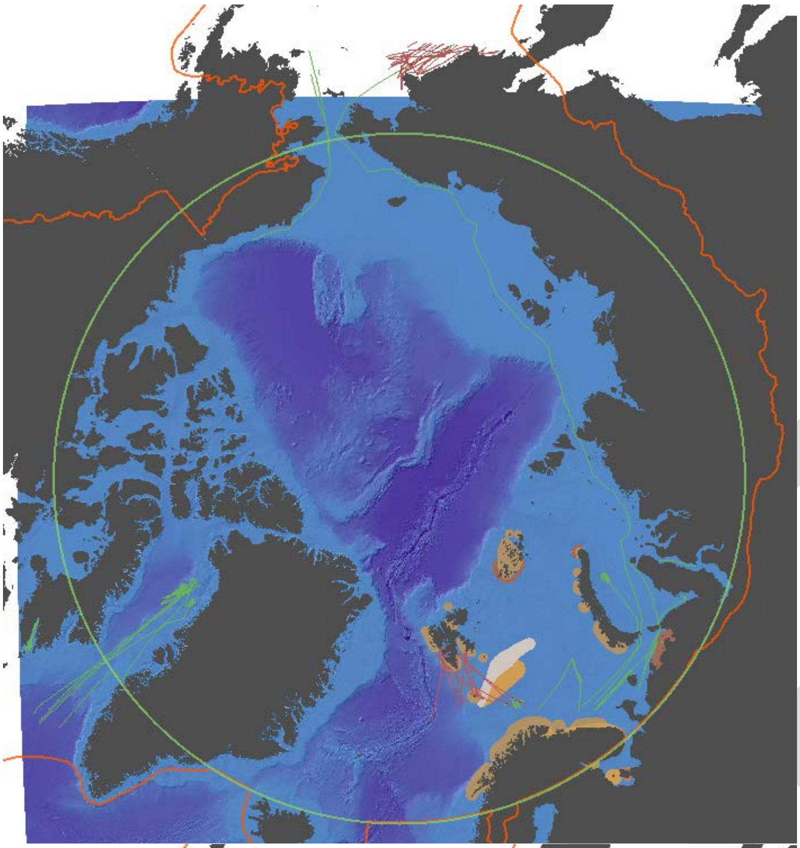

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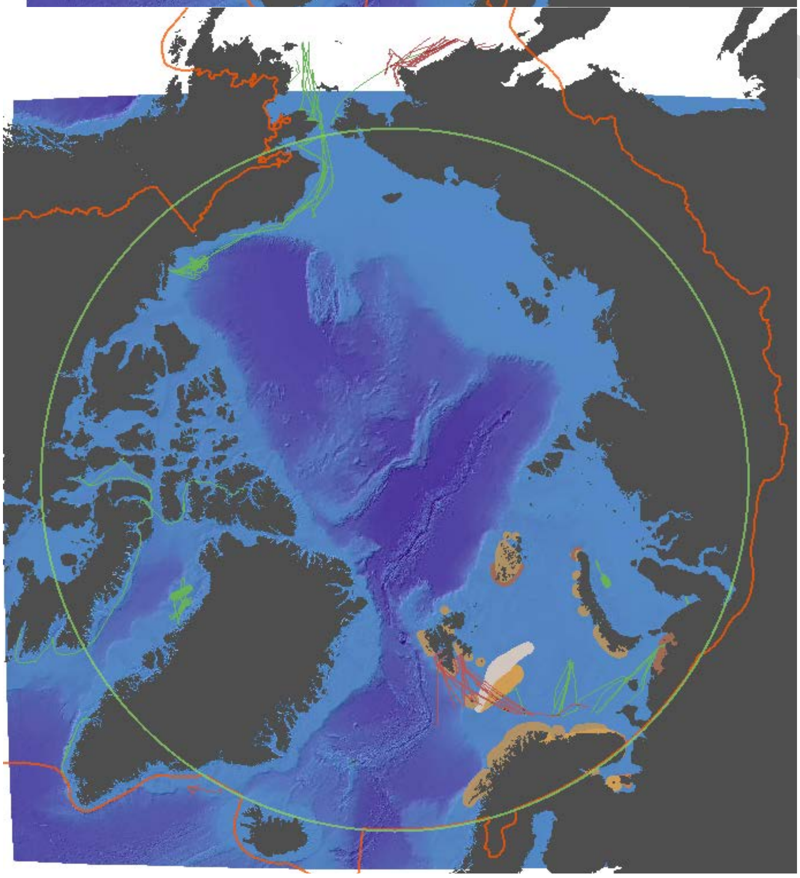

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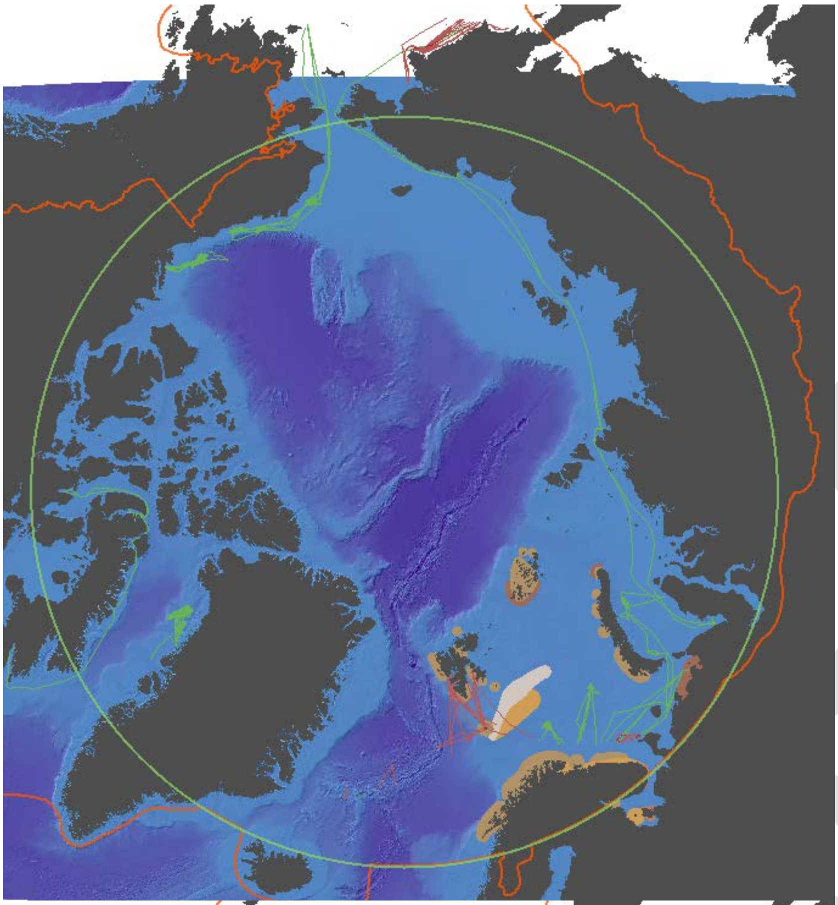

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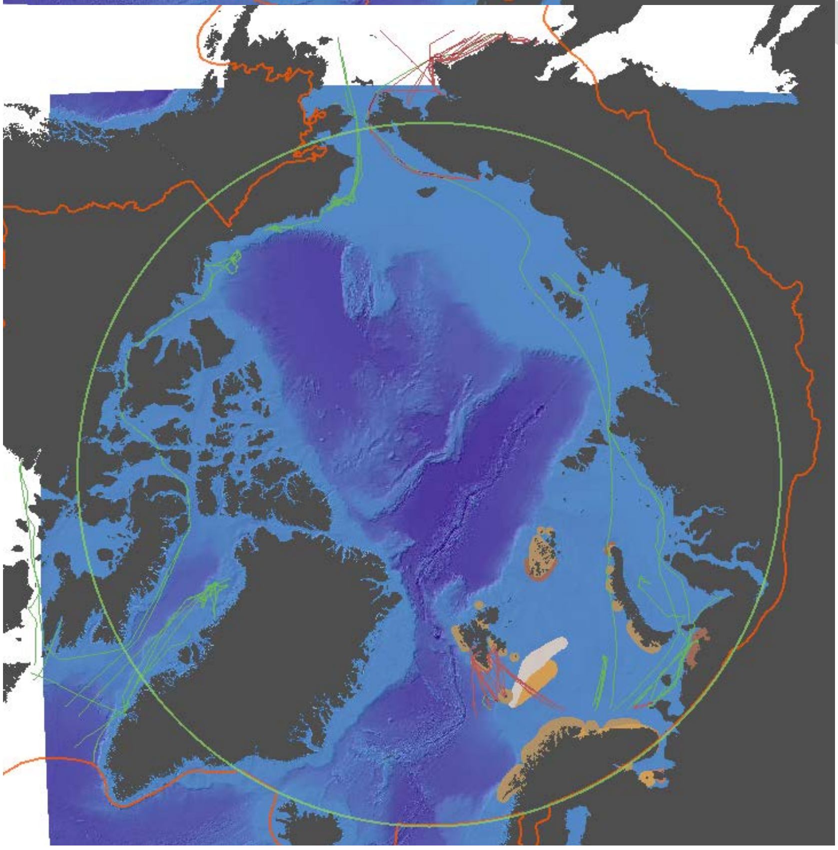

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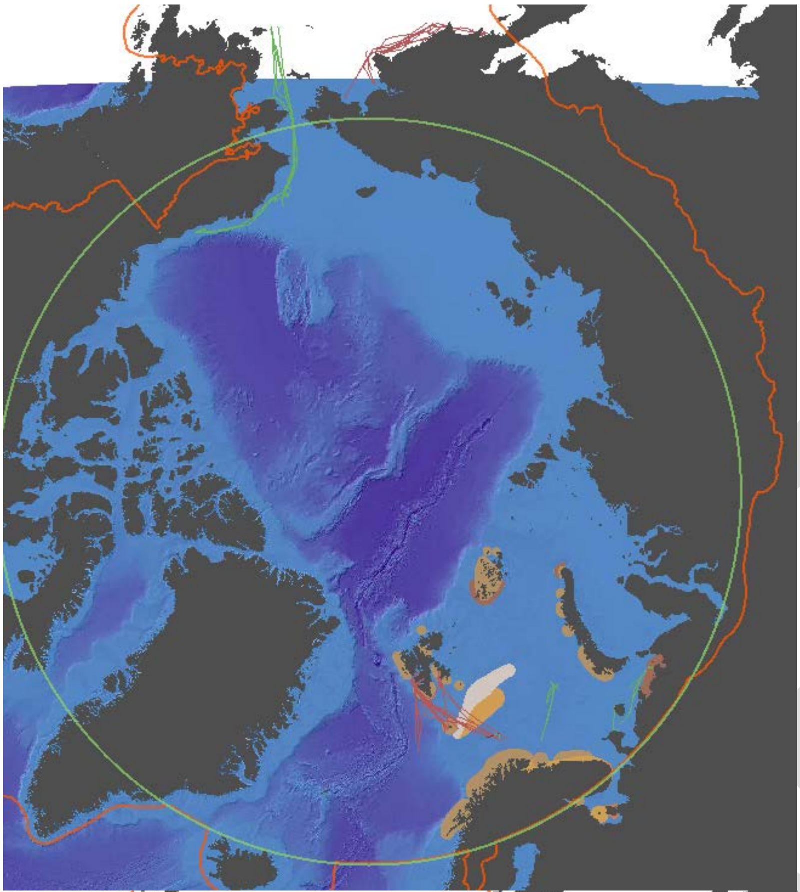

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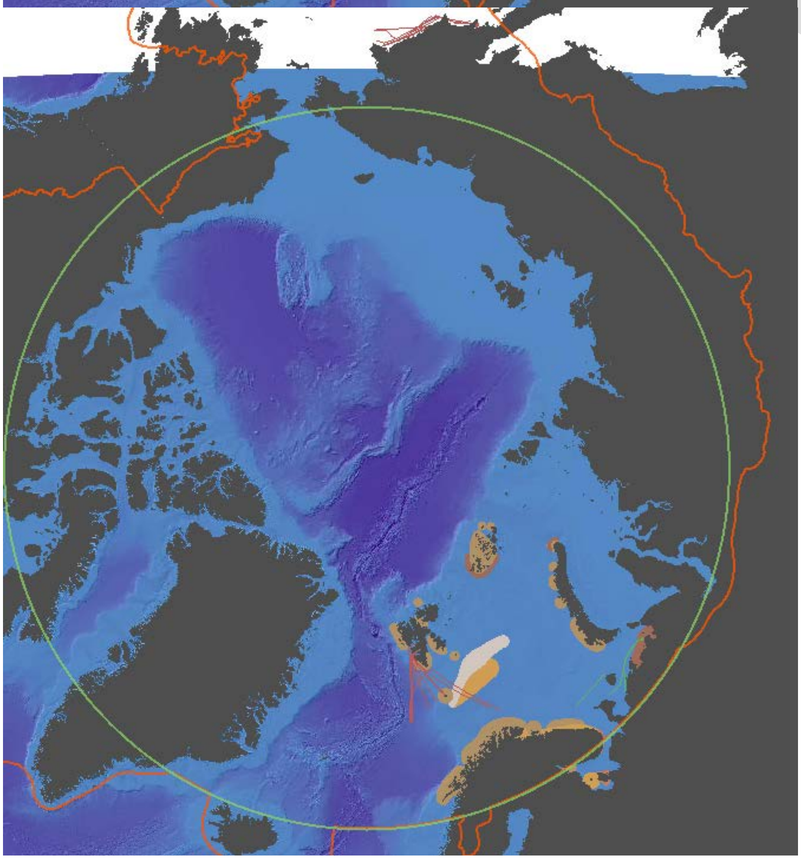

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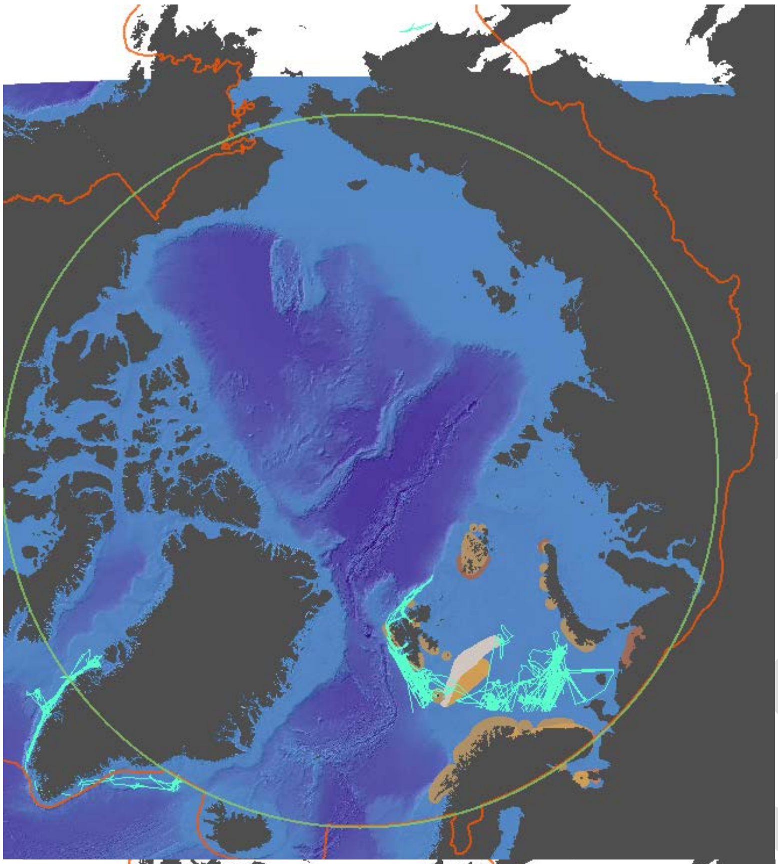
8.5 Other offshore vessels (red) and Fishing vessels (turquoise)



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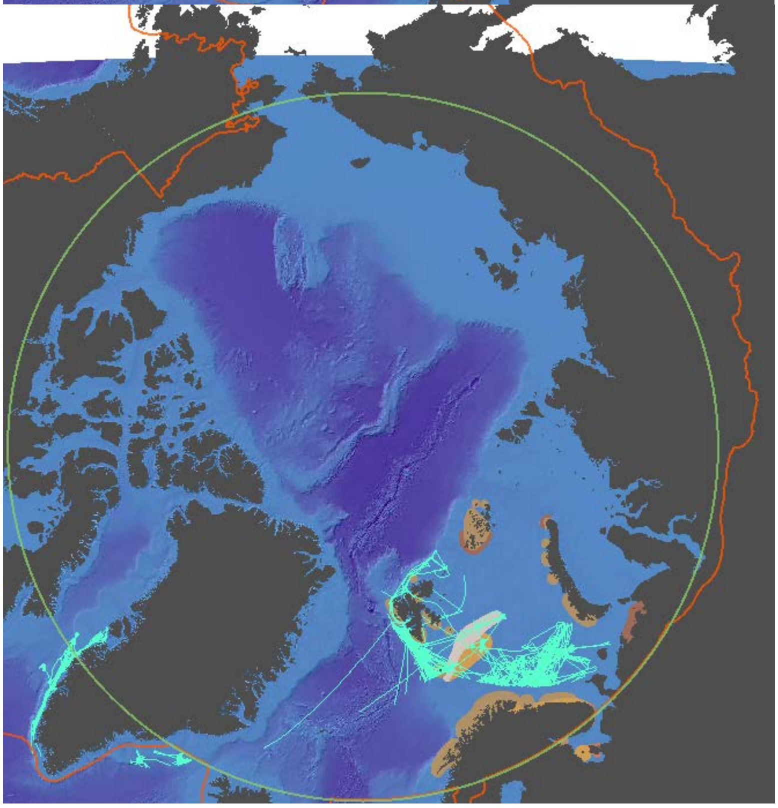

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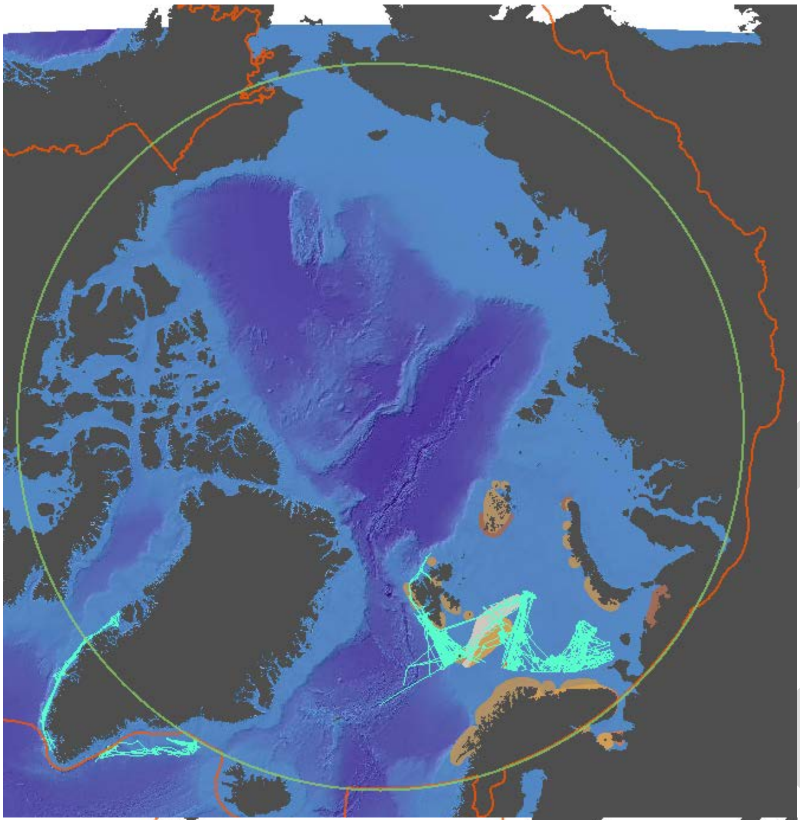

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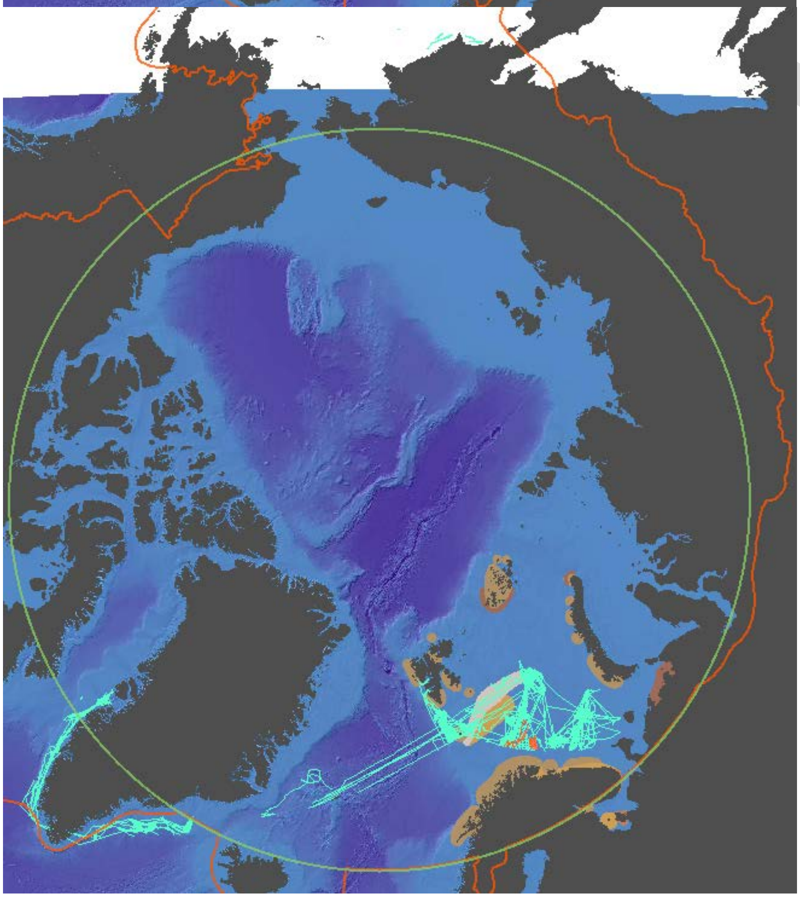

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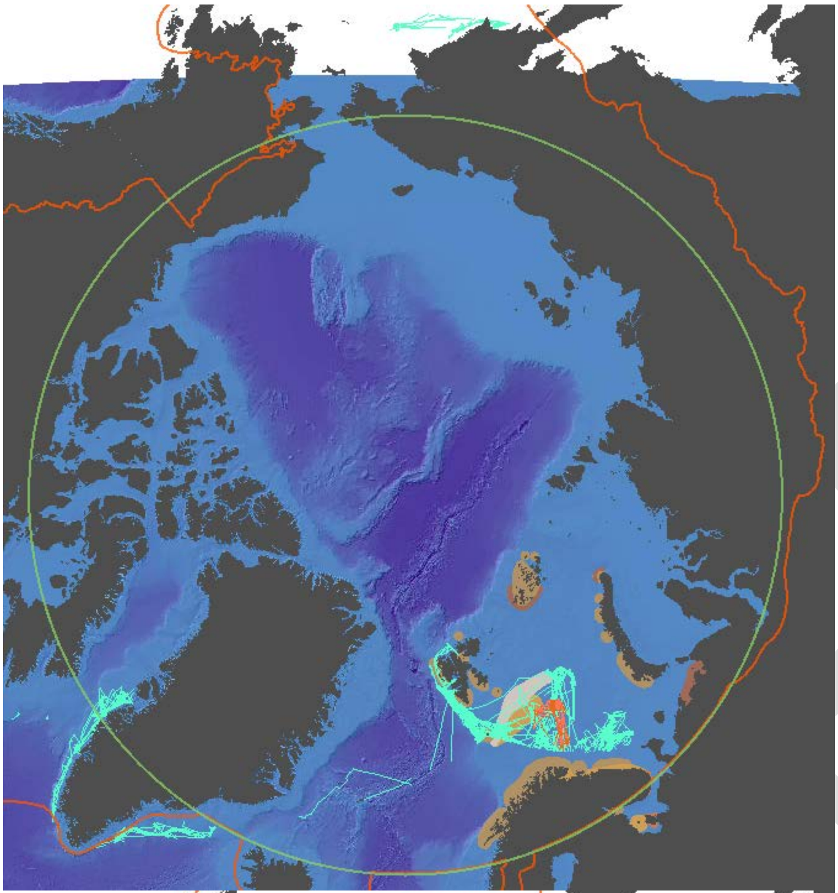

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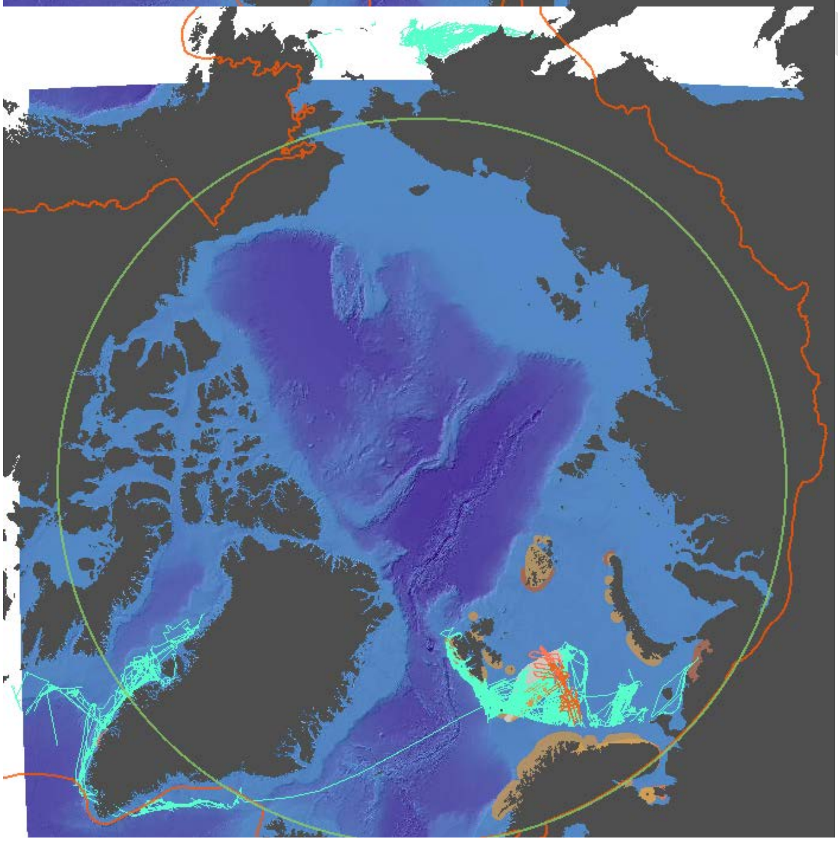

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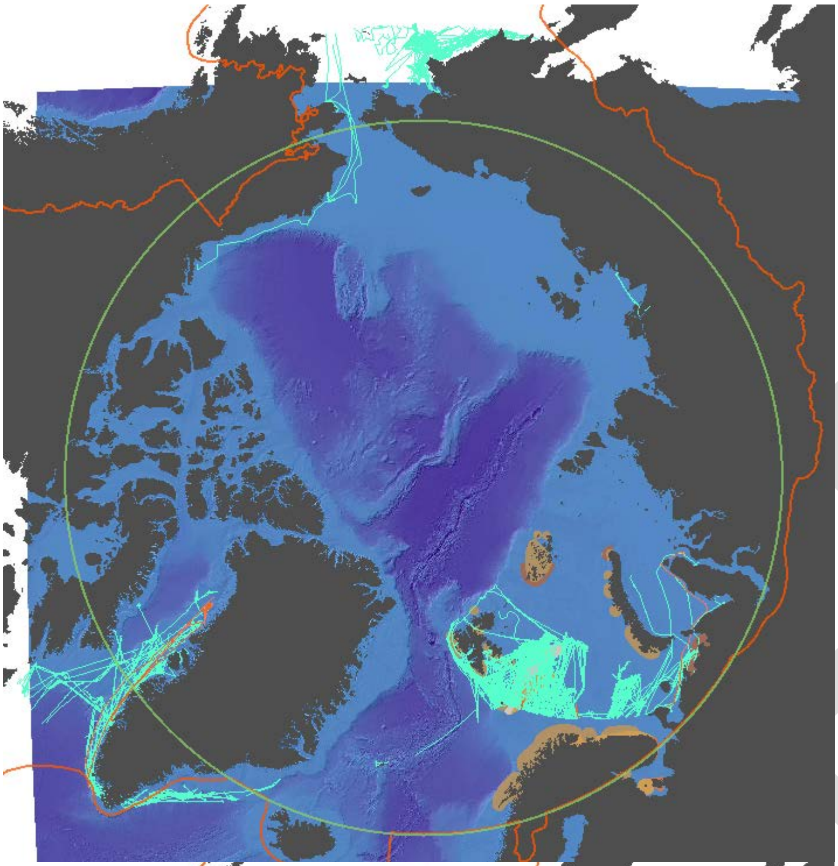

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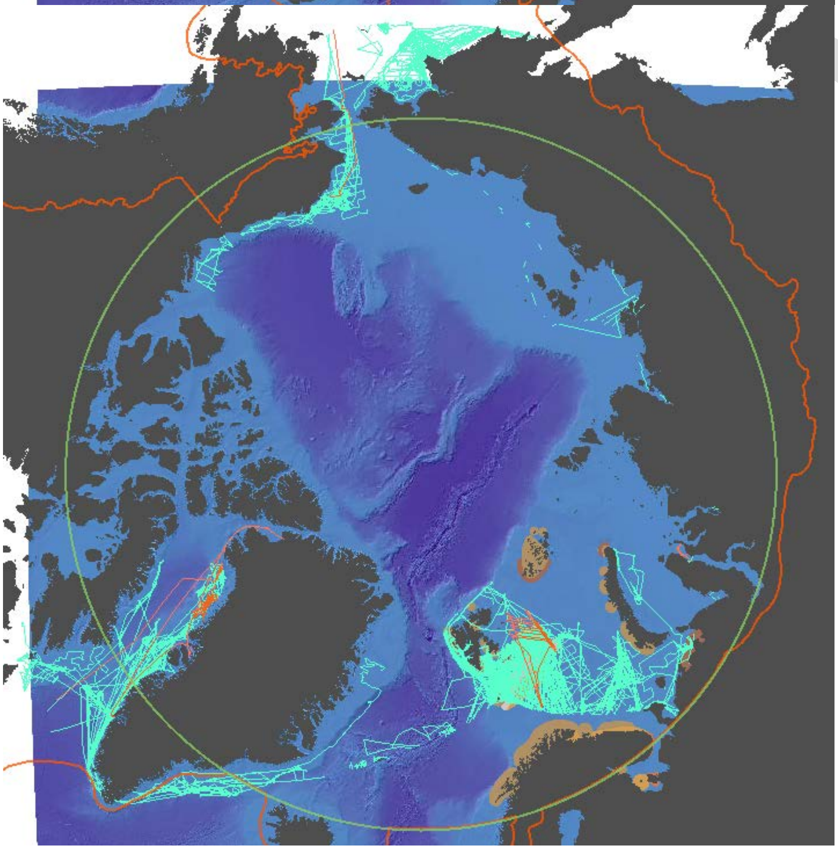

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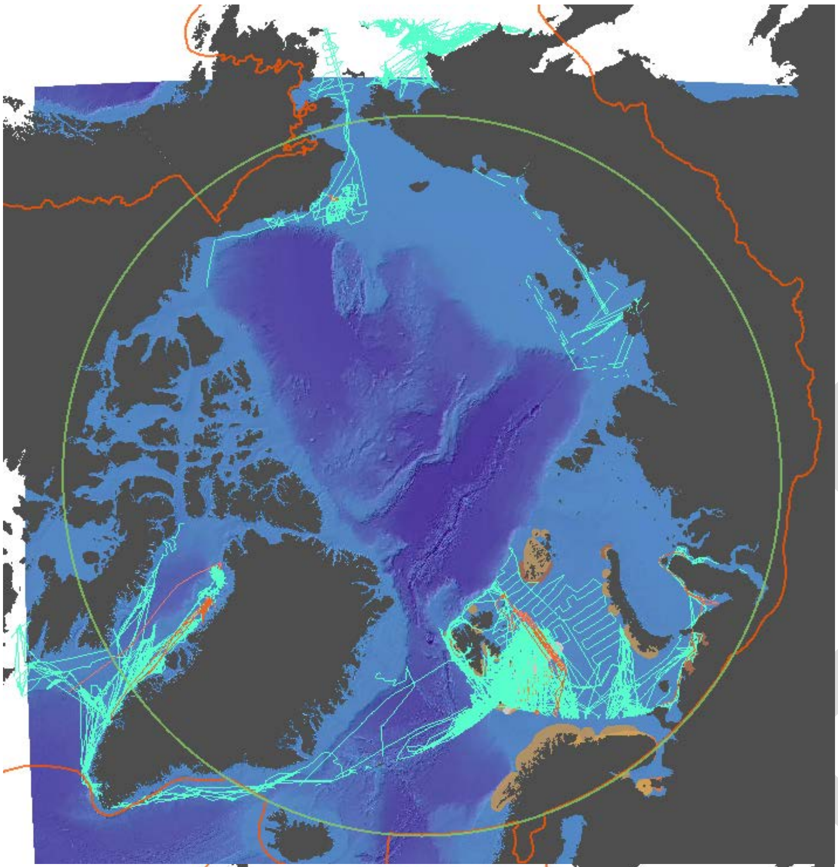

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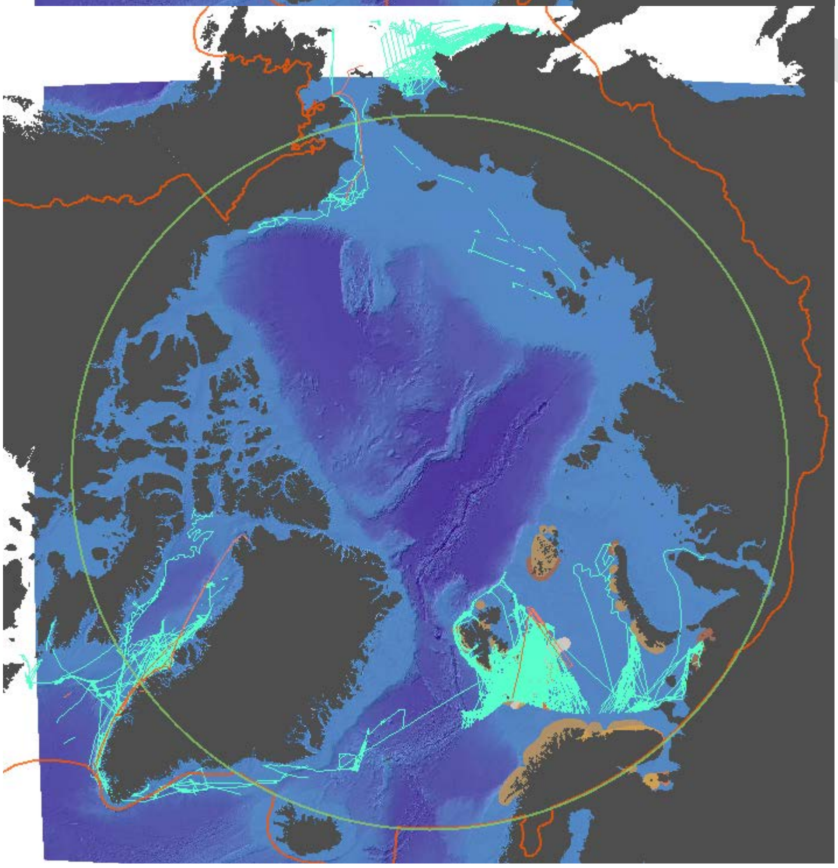

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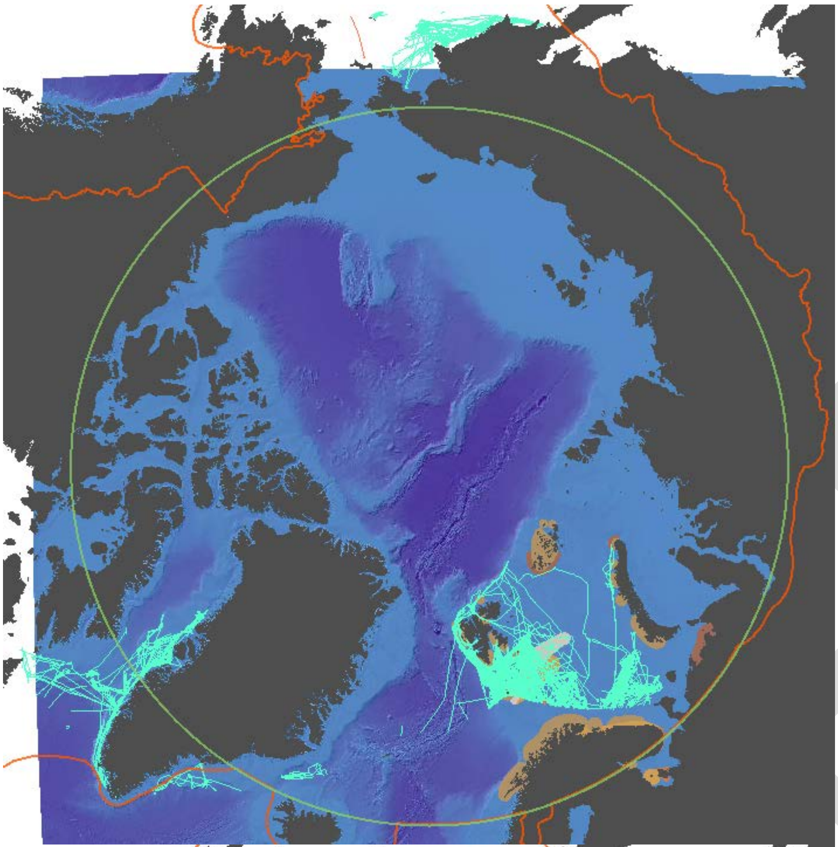

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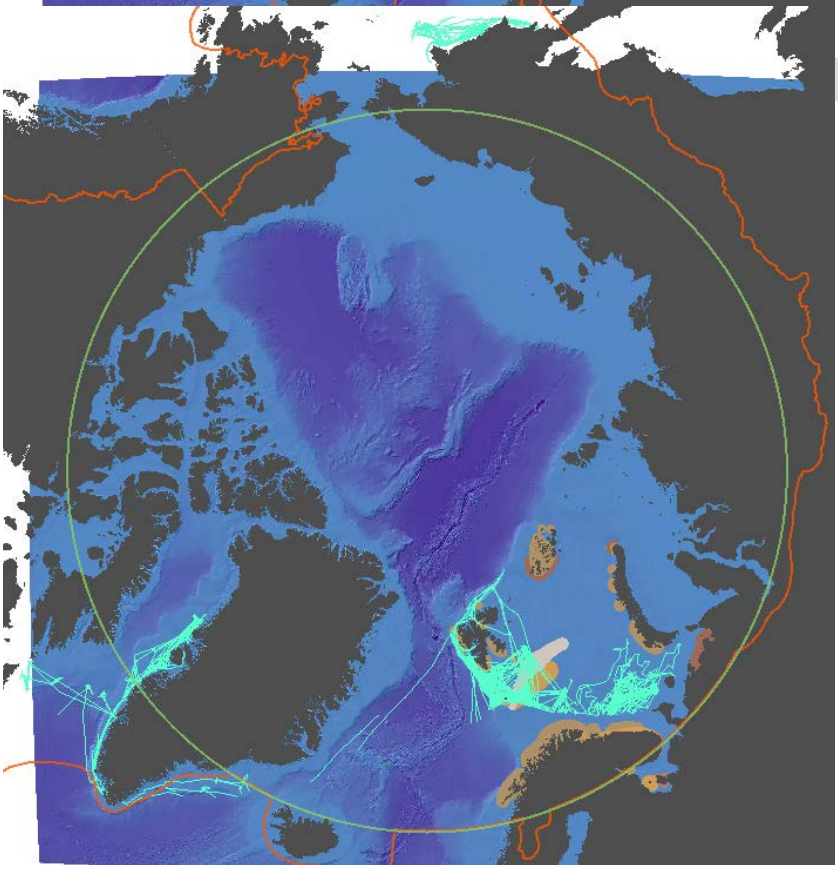

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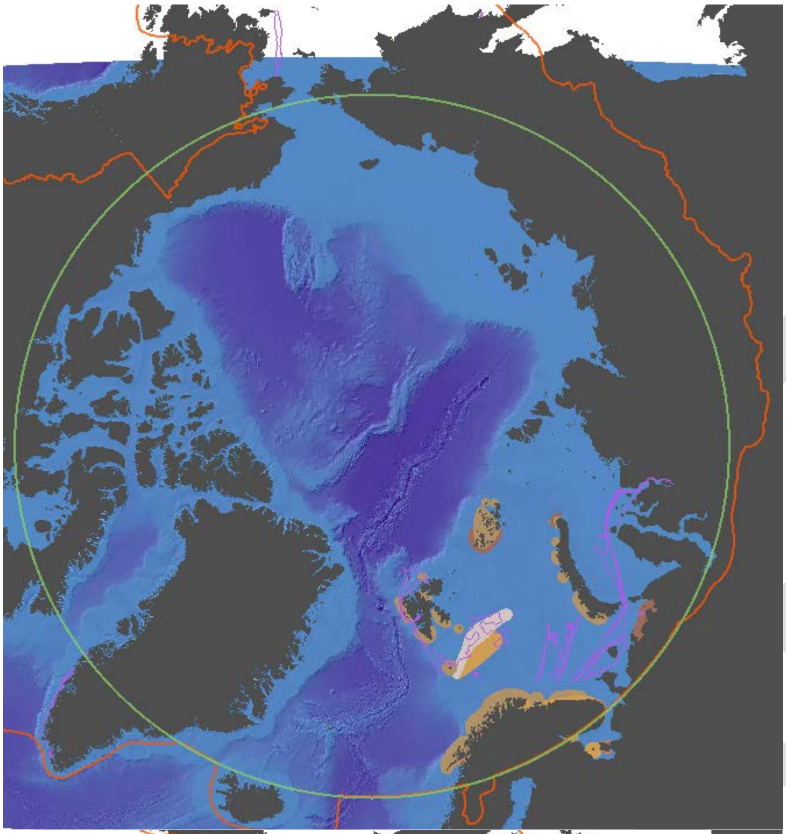
8.6 Other activities (purple)



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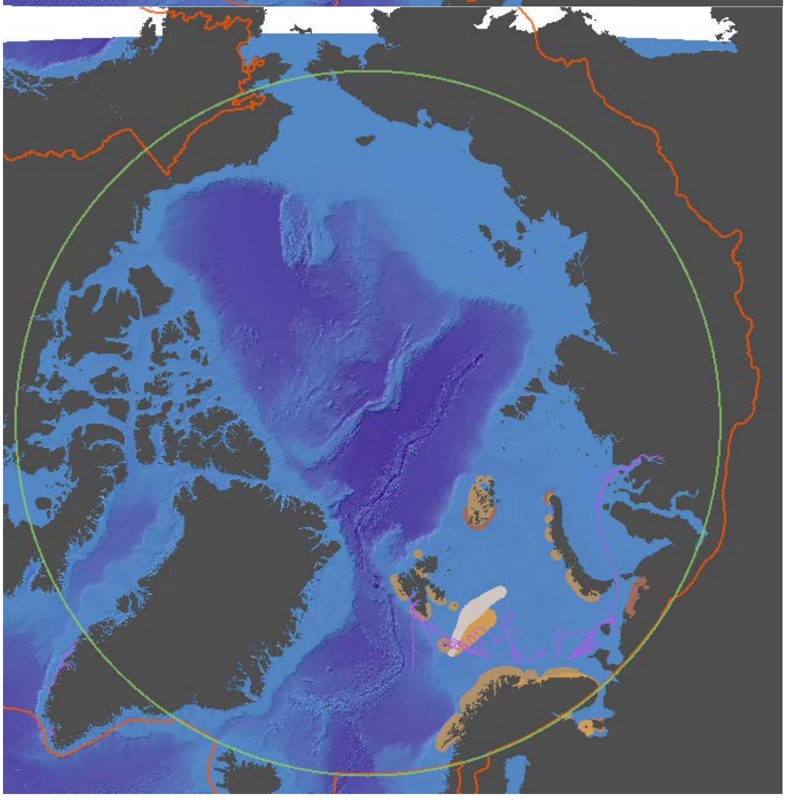

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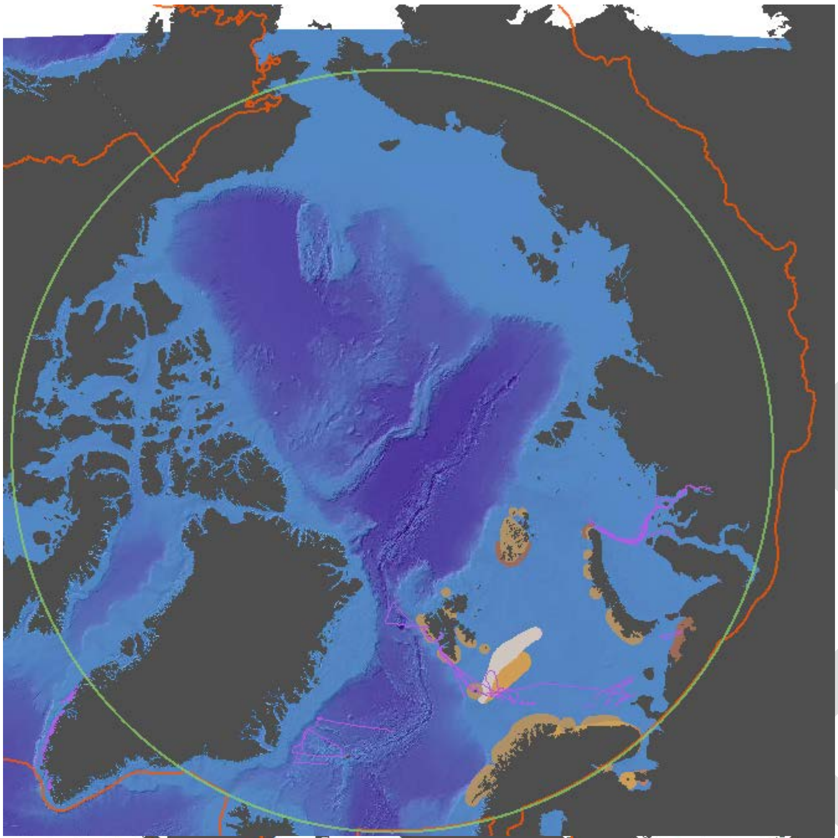

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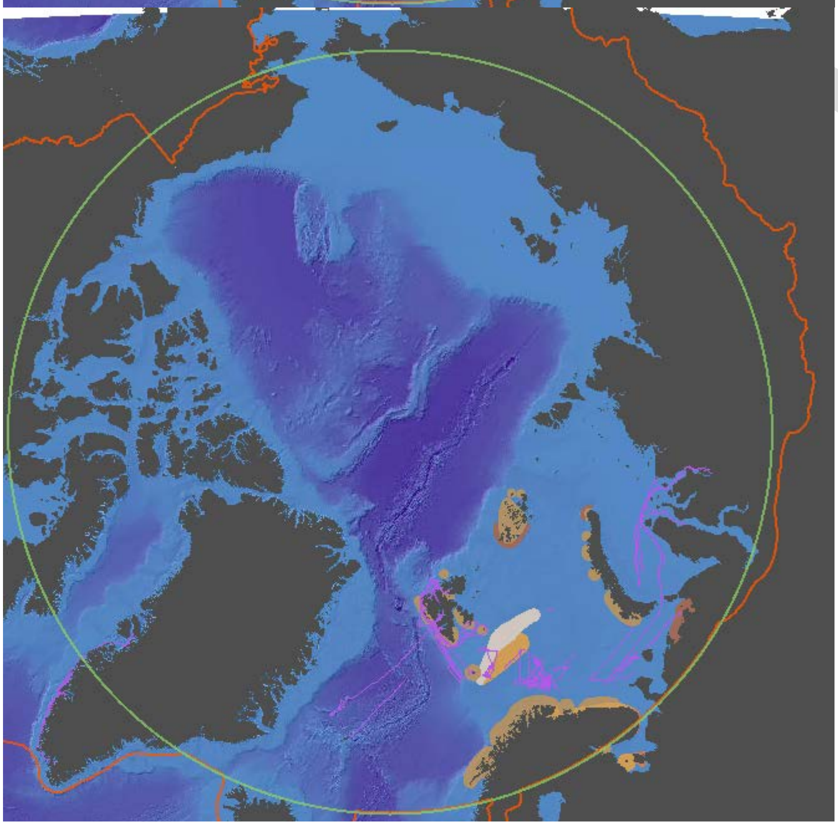

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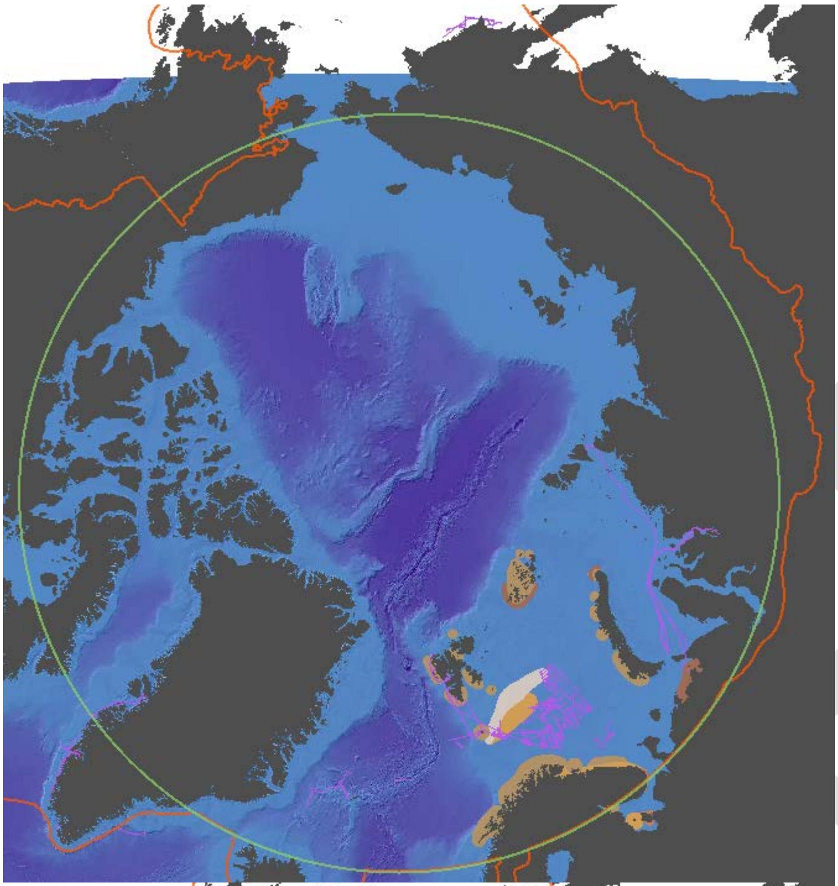

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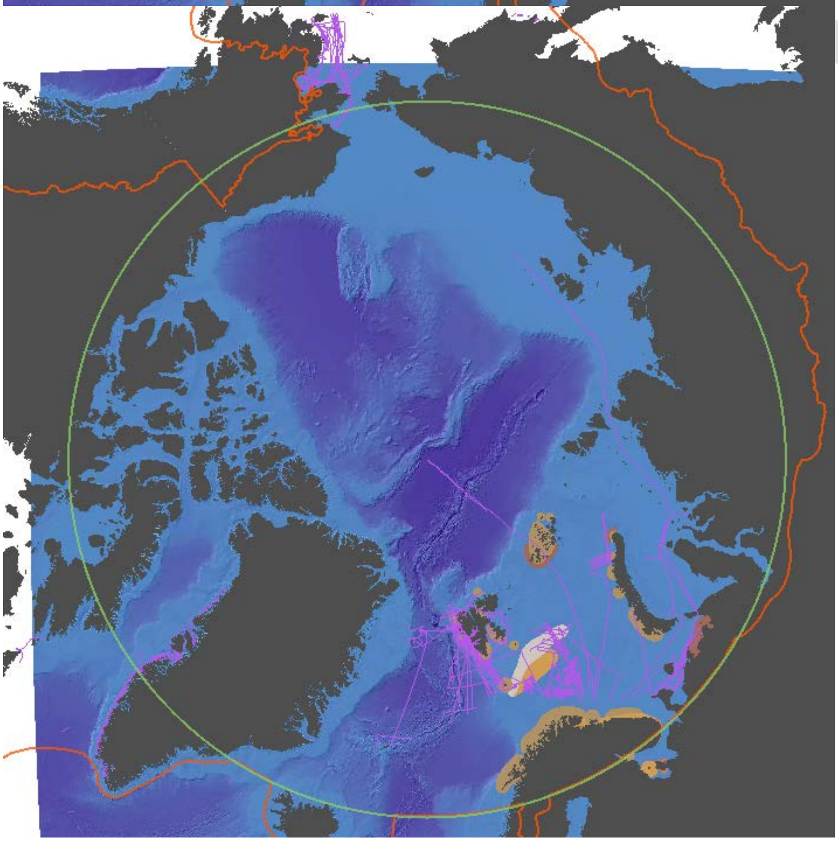

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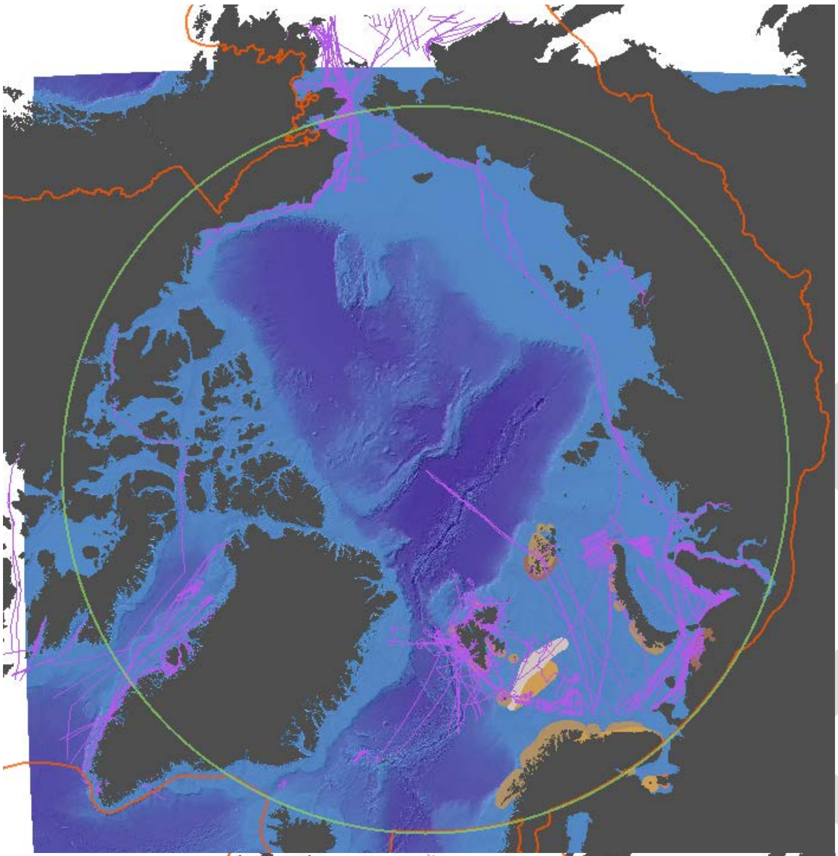

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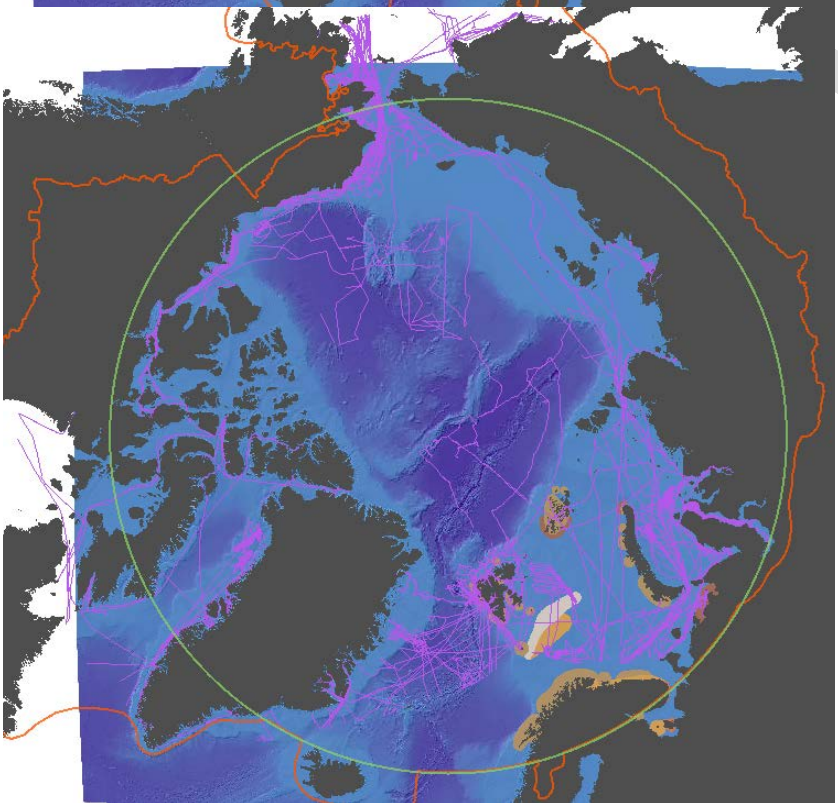

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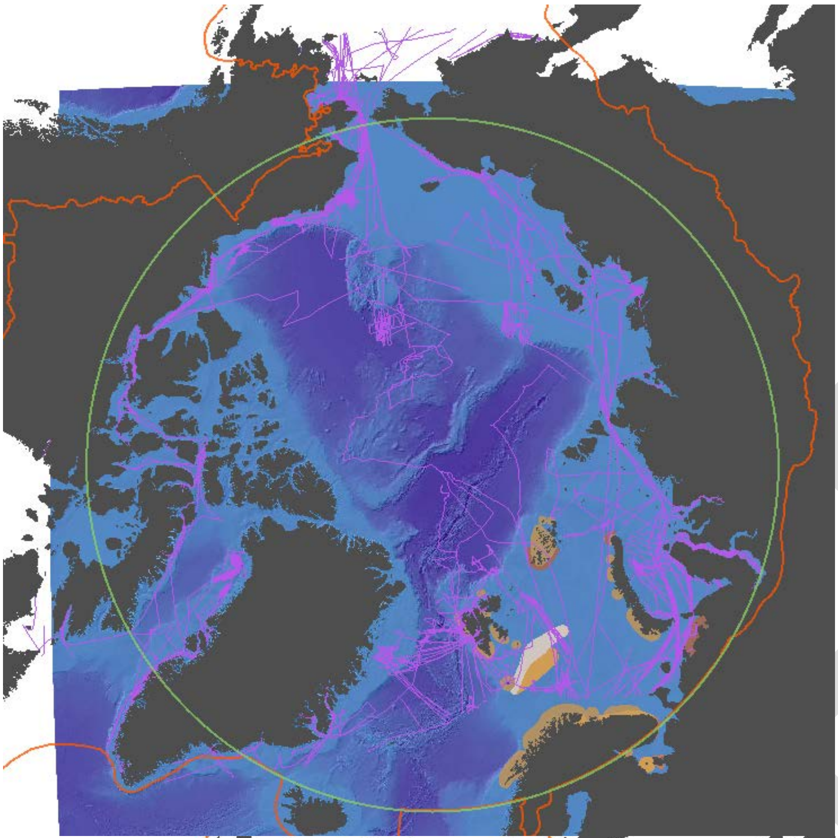

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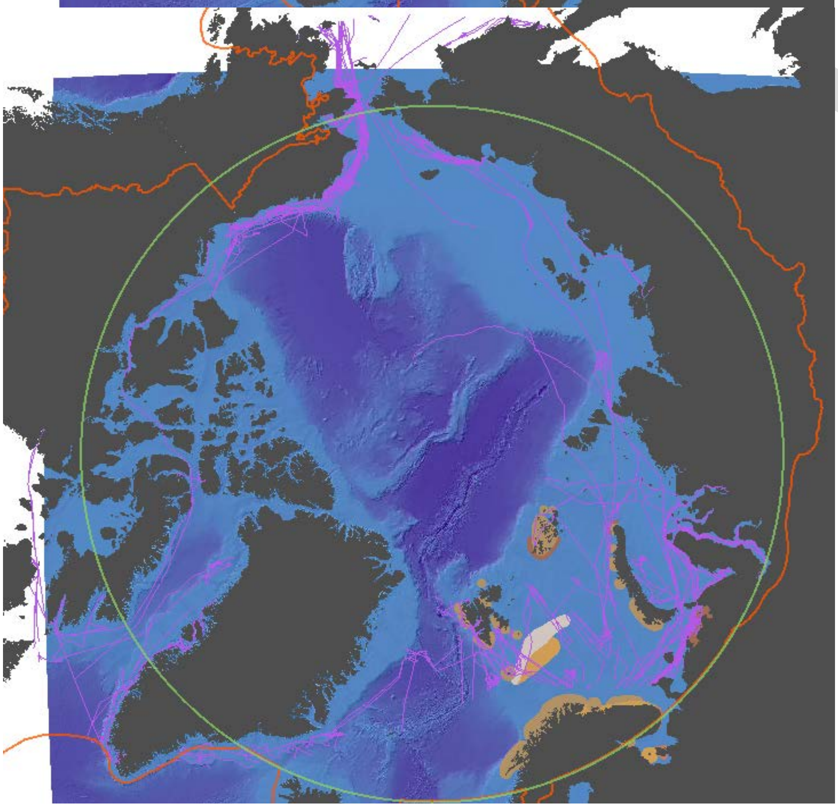

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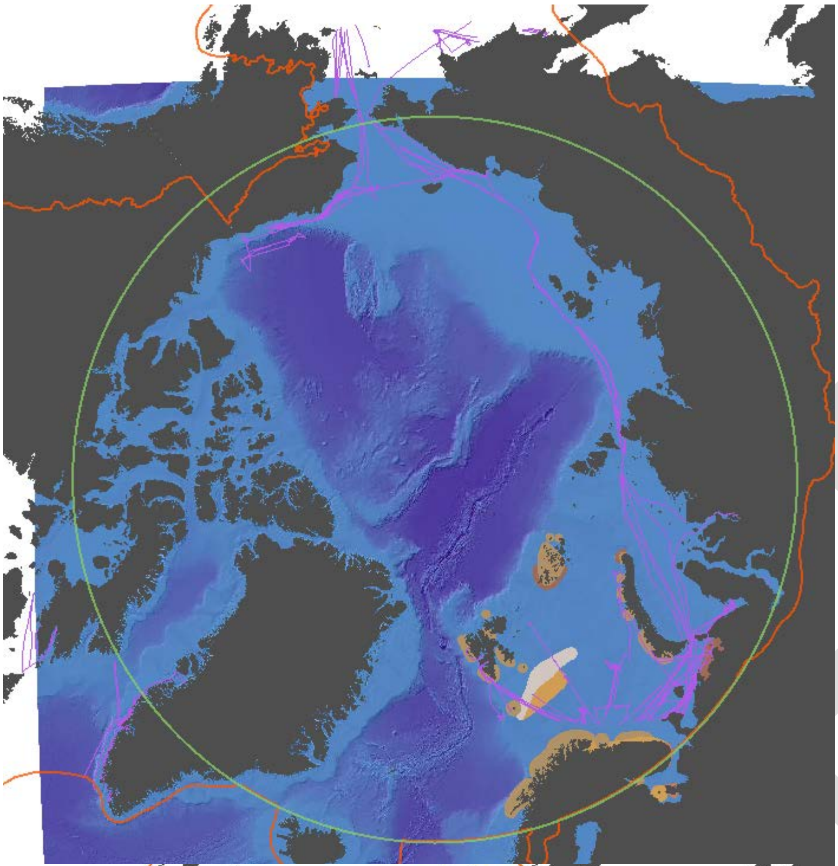

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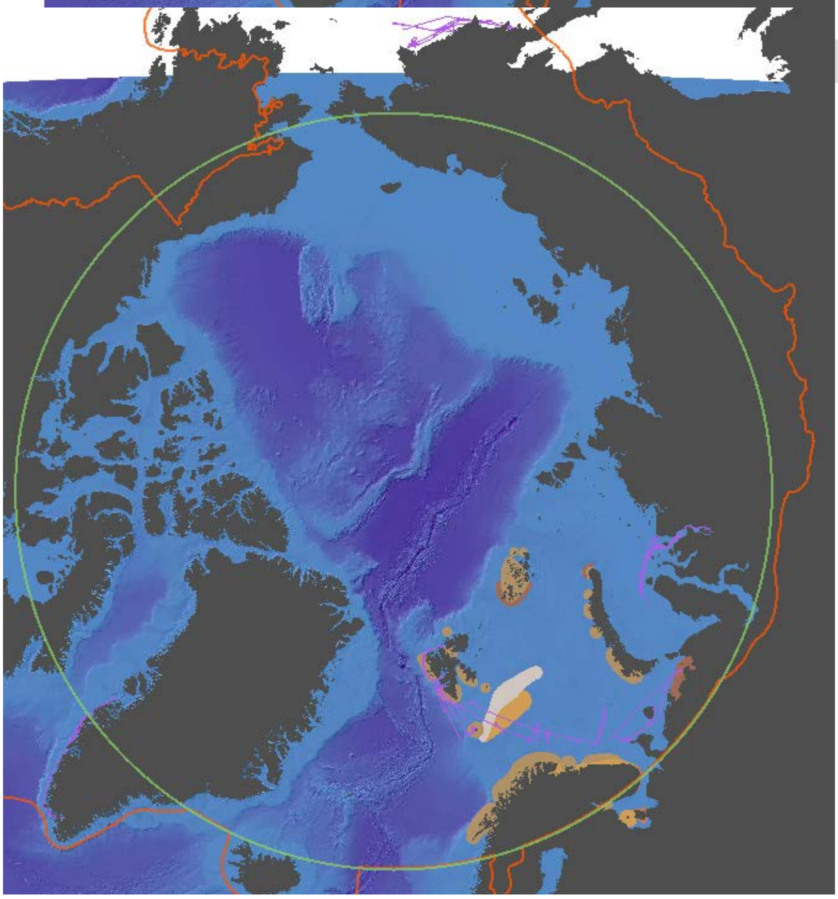

Dec

APPENDIX II

Ship type (as used in this study	Lloyds category 3	Lloyds category 4	Lloyds category 5
Oil tankers	Oil	Bitumen Tanker	Asphalt/Bitumen Tanker
Oil tankers	Oil	Crude Oil Tanker	Crude Oil Tanker
Oil tankers	Oil	Oil Products Tanker	Products Tanker
Oil tankers	Oil	Oil Products Tanker	Products Tanker Barge, propelled
Chemical/Product Carriers	Chemical	Chemical Tanker	Chemical Tanker
Chemical/Product Carriers	Chemical	Chemical Tanker	Molten Sulphur Tanker
Chemical/Product Carriers	Chemical	Chemical Tanker	Parcels Tanker
Chemical/Product Carriers	Chemical	Chemical/Oil Products Tanker	Chemical/Products Tanker
Chemical/Product Carriers	Chemical	Edible Oil Tanker	Edible Oil Tanker
Chemical/Product Carriers	Chemical	Fruit Juice Tanker	Fruit Juice Tanker
Chemical/Product Carriers	Chemical	Vegetable Oil Tanker	Vegetable Oil Tanker
Chemical/Product Carriers	Chemical	Wine Tanker	Wine Tanker
Chemical/Product Carriers	Other Liquids	Edible Oil Tanker	Alcohol Tanker
Chemical/Product Carriers	Other Liquids	Molasses Tanker	Molasses Tanker
Chemical/Product Carriers	Other Liquids	Water Tanker	Water Tanker
Gasstankere (LGT)	Liquefied Gas	LNG Tanker	LNG Tanker
Gasstankere (LGT)	Liquefied Gas	LPG Tanker	LPG Tanker
Gasstankere (LGT)	Liquefied Gas	LPG Tanker	LPG/Chemical Tanker
Bulk Carriers	Bulk Dry	Bulk Carrier	Bulk Carrier
Bulk Carriers	Bulk Dry	Bulk Carrier	Bulk Carrier (with Vehicle Decks)
Bulk Carriers	Bulk Dry	Bulk Carrier	General Cargo/Tanker (Container/oil/bulk - COB ship)
Bulk Carriers	Bulk Dry / Oil	Bulk/Oil Carrier	Bulk/Oil Carrier (OBO)
Bulk Carriers	Bulk Dry / Oil	Bulk/Oil Carrier	Ore/Bulk/Products Carrier
Bulk Carriers	Bulk Dry / Oil	Ore/Oil Carrier	Ore/Bulk/Products Carrier
Bulk Carriers	Bulk Dry / Oil	Ore/Oil Carrier	Ore/Oil Carrier
Bulk Carriers	General Cargo	General Cargo Ship	General Cargo/Tanker (Container/oil/bulk - COB ship)
Bulk Carriers	Other Bulk Dry	Aggregates Carrier	Aggregates Carrier
Bulk Carriers	Other Bulk Dry	Cement Carrier	Cement Carrier
Bulk Carriers	Other Bulk Dry	Limestone Carrier	Limestone Carrier
Bulk Carriers	Other Bulk Dry	Refined Sugar Carrier	Refined Sugar Carrier
Bulk Carriers	Other Bulk Dry	Urea Carrier	Urea Carrier
Bulk Carriers	Other Bulk Dry	Wood Chips Carrier	Wood Chips Carrier, self unloading
Bulk Carriers	Self Discharging Bulk Dry	Self-Discharging Bulk Carrier	Bulk Cargo Barge, self discharging, propelled
Bulk Carriers	Self Discharging Bulk Dry	Self-Discharging Bulk Carrier	Bulk Cargo Carrier, self discharging

General Cargo	General Cargo	Deck Cargo Ship	Deck Cargo Ship
General Cargo	General Cargo	General Cargo Ship	General Cargo Barge, propelled
General Cargo	General Cargo	General Cargo Ship	General Cargo Ship
General Cargo	General Cargo	General Cargo Ship	General Cargo Ship (with Ro-Ro facility)
General Cargo	General Cargo	General Cargo Ship	General Cargo/Tanker
General Cargo	General Cargo	General Cargo Ship	General Cargo/Tanker (Container/oil/bulk - COB ship)
General Cargo	General Cargo	General Cargo Ship	Open Hatch Cargo Ship
General Cargo	General Cargo	Palletised Cargo Ship	Palletised Cargo Ship
General Cargo	Other Dry Cargo	Barge Carrier	Barge Carrier
General Cargo	Other Dry Cargo	Heavy Load Carrier	Submersible
General Cargo	Other Dry Cargo	Livestock Carrier	Livestock Carrier
General Cargo	Other Dry Cargo	Pulp Carrier	Pulp Carrier
Container vessel	Container	Container Ship	Container Ship (Fully Cellular)
Container vessel	Container	Passenger/Container Ship	Passenger/Container Ship
RORO lasteskip	Ro-Ro Cargo	Landing Craft	Landing Craft
RORO lasteskip	Ro-Ro Cargo	Ro-Ro Cargo Ship	Rail Vehicles Carrier
RORO lasteskip	Ro-Ro Cargo	Ro-Ro Cargo Ship	Ro-Ro Cargo Ship
RORO lasteskip	Ro-Ro Cargo	Vehicles Carrier	Vehicles Carrier
Reefers	Refrigerated Cargo	Refrigerated Cargo Ship	Refrigerated Cargo Ship
Passenger	Passenger	Passenger Ship	Car Carrier
Passenger	Passenger	Passenger Ship	Passenger Ship
Passenger	Passenger	Passenger Ship	Undefined Lloyds Type Level 5
Passenger	Passenger	Passenger Ship	Wing In Ground Effect Vessel
Passenger	Passenger / General Cargo	Passenger/General Cargo Ship	General Cargo/Passenger Ship
Passenger	Passenger/Ro-Ro Cargo	Passenger/Landing Craft	Passenger/Landing Craft
Passenger	Passenger/Ro-Ro Cargo	Passenger/Ro-Ro Cargo Ship	Passenger/Ro-Ro Ship (Vehicles)
Passenger	Passenger/Ro-Ro Cargo	Passenger/Ro-Ro Cargo Ship	Rail Vehicles Carrier
Offshore supply vessels	Offshore Supply	Offshore Supply Ship	Anchor Handling Tug Supply
Offshore supply vessels	Offshore Supply	Offshore Supply Ship	Offshore Support Vessel
Offshore supply vessels	Offshore Supply	Offshore Supply Ship	Platform Supply Ship
Offshore supply vessels	Offshore Supply	Offshore Tug/Supply Ship	Anchor Handling Tug Supply
Offshore supply vessels	Offshore Supply	Offshore Tug/Supply Ship	Offshore Tug/Supply Ship
Other Offshore vessels	Other Offshore	Drilling Ship	Drilling Ship
Other Offshore vessels	Other Offshore	FSO (Floating, Storage, Offloading)	FSO, Oil
Other Offshore vessels	Other Offshore	Offshore Processing Ship	FPSO, Gas
Other Offshore vessels	Other Offshore	Offshore Processing Ship	FPSO, Oil
Other Offshore vessels	Other Offshore	Offshore Processing Ship	Undefined Lloyds Type Level 5
Other Offshore vessels	Other Offshore	Offshore Support	Accommodation Ship

		Vessel	
Other Offshore vessels	Other Offshore	Offshore Support Vessel	Diving Support Vessel
Other Offshore vessels	Other Offshore	Offshore Support Vessel	Offshore Support Vessel
Other Offshore vessels	Other Offshore	Pipe Burying Vessel	Pipe Burying Vessel
Other Offshore vessels	Other Offshore	Pipe-Layer	Pipe Layer
Other Offshore vessels	Other Offshore	Standby-Safety Vessel	Offshore Support Vessel
Other Offshore vessels	Other Offshore	Standby-Safety Vessel	Standby Safety Vessel
Other Activities	Dredging	Dredger	Dredger (unspecified)
Other Activities	Dredging	Dredger	Suction Dredger
Other Activities	Dredging	Hopper Dredger	Hopper/Dredger (unspecified)
Other Activities	Dredging	Hopper Dredger	Hopper/Suction Dredger
Other Activities	Other Activities	Buoy/Lighthouse Vessel	Buoy & Lighthouse Tender
Other Activities	Other Activities	Cable-Layer	Cable Layer
Other Activities	Other Activities	Crane Ship	Crane Ship
Other Activities	Other Activities	Crane Ship	Pipe Layer Crane Vessel
Other Activities	Other Activities	Crane Ship	Undefined Lloyds Type Level 5
Other Activities	Other Activities	Crewboat	Crew Boat
Other Activities	Other Activities	Fire-Fighting Vessel	Fire Fighting Vessel
Other Activities	Other Activities	Hospital Vessel	Hospital Vessel
Other Activities	Other Activities	Icebreaker	Icebreaker
Other Activities	Other Activities	Patrol Vessel	Patrol Vessel
Other Activities	Other Activities	Pilot Vessel	Pilot Vessel
Other Activities	Other Activities	Pollution Control Vessel	Pollution Control Vessel
Other Activities	Other Activities	Pollution Control Vessel	Research Survey Vessel
Other Activities	Other Activities	Salvage Ship	Icebreaker
Other Activities	Other Activities	Salvage Ship	Salvage Ship
Other Activities	Other Activities	Search & Rescue Vessel	Search & Rescue Vessel
Other Activities	Other Activities	Tank-Cleaning Vessel	Tank Cleaning Vessel
Other Activities	Other Activities	Tender (Unspecified)	Supply Tender
Other Activities	Other Activities	Training Ship	Training Ship
Other Activities	Other Activities	Utility Vessel	Tank Cleaning Vessel
Other Activities	Other Activities	Utility Vessel	Undefined Lloyds Type Level 5
Other Activities	Other Activities	Work/Repair Vessel	Work/Repair Vessel
Other Activities	Other Activities cont./	Dry Storage	Bulk Cement Storage Ship
Other Activities	Research	Research Vessel	Research Survey Vessel
Other Activities	Towing / Pushing	Pusher Tug	Pusher Tug
Other Activities	Towing / Pushing	Tug	Icebreaker
Other Activities	Towing / Pushing	Tug	Tug

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