DET NORSKE VERITAS™

REPORT

HFO IN THE ARCTIC-PHASE 2

2013-1542-16G8ZQC-5/1

DNV Doc. No./Report No.: 2013-1542-16G8ZQC-5/1
Date of Issue: 2013-12-13
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MANAGING RISK DNV

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Date of Issue: 2013-12-13	Revision No.:	DNV Document No.: 2013-1542-16G8ZQC-5	DNV Organisation Unit: BDL Environment and Operations
Project No.: PP066148	Report No.: 1	Report Title: 2013-1542-16G8ZQC-5/1	

Task and Objective:

This study is carried out on behalf of The Protection of the Arctic Marine Environment Working Group (PAME) and it is financed by the Norwegian Ministry of Foreign Affairs.

PAME is one of six Arctic Council working groups and is the focal point of the Arctic Council's activities related to the protection and sustainable use of the Arctic marine environment.

Based on AIS based ship movement data for 2012, the study addresses the following issues:

- Describe a full year (2012) of maritime traffic based on satellite AIS recordings in the Arctic region, including vessel composition (type and size), geographical distribution, sailed distances and operating hours throughout the year.
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Keywords:

Reference to part of this report which may lead to misinterpretation is not permissible

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MANAGING RISK

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Table of Contents

1 EXECUTIVE SUMMARY

This study is carried out on behalf of The Protection of the Arctic Marine Environment Working Group (PAME). PAME is one of six Arctic Council working groups and is the focal point of the Arctic Council's activities related to the protection and sustainable use of the Arctic marine environment.
The study is a direct follow-up to the Phase 1 study on the use and carriage of heavy fuel oil (HFO) in the Arctic (DNV, 2011). The Phase 1 study was the first to assess the maritime traffic in the Arctic using satellite based Automatic Identification System (AIS) data. Due to the short period of operation of the satellite, only four months of data was available for this study.
It was therefore agreed to undertake a phase-2 of the study, this time with a full year of ship traffic data available. Based on data for 2012, the study addresses the following issues:

- Describe a full year (2012) of maritime traffic based on satellite AIS recordings in the Arctic region, including vessel composition (type and size), geographical distribution, sailed distances and operating hours throughout the year.
- Modelling of fuel consumption and emission to air
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Figure 1-1 shows the data flow in the project providing the basis for the different analysis performed as part of the study.

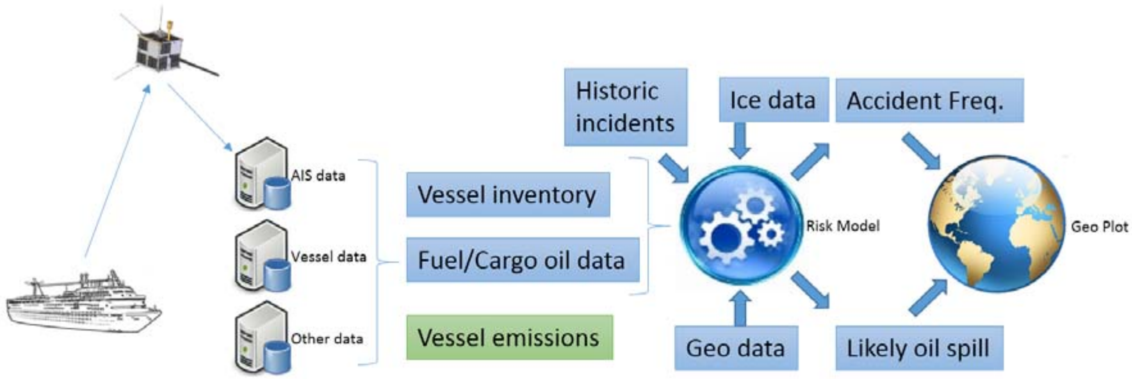

Figure 1-1 - Data management in project

1.1 Heavy fuel oil

In this report, heavy fuel oil (HFO) is regarded equivalent to oil with characteristics as specified by IMO in MARPOL on the protection of Antarctica from pollution from heavy grade oil. After 2020/2025 the global 0.5% sulphur cap will change the type of bunker fuel in use, towards lighter products/distillates (unless scrubbers are used). It is however important to note that this will still not be fuel to a marine gas oil standard. The actual characteristics of this fuel shift with respect to evaporation, dissolving, dispersion, water uptake/emulsification and environmental effects compared to the HFO we have today, is uncertain. Note that a ban on the use and carriage of HFO as a control option in the Arctic is defined outside the scope of this report.

1.2 Vessel demography and fuel use

Based on the data analysis, a total of 1347 unique vessels were found to operate in the Arctic throughout 2012. It is worth noting that because most Arctic maritime traffic is situated in the periphery of the Arctic, a small change in delimitation of the area will potentially make a huge difference in the amount of traffic.

Table 1-1 - Number of unique vessels identified in the Arctic throughout 2012 (vessels identified as operating on HFO in brackets)

	Number of unique vessels							
Ship type	<1000 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)**

By combining several data sources, the vessels using HFO as bunker fuel was identifies. Out of the 1347 vessels, 371 (28%) were most likely using HFO as fuel. Generally, the larger ocean going vessels are using HFO whereas the smaller and more numerous fishing vessels and “other activities” vessels use distillate fuels. It is worth noting that even though the vessels that are using distillate fuel represents 72 % of the vessels in numbers, the bunker mass on-board the HFO vessels counts for 75% of the total bunker mass of all the ships.

Two vessel types are likely to carry the majority of oil bulk cargo in the region. Oil tankers will generally carry crude oil, but may also include different types of distilled products. Chemical/Product tankers will likely carry an even more widespread mix of products ranging from HFO to vine and fruit juice. However, in the Arctic the cargo is likely to be mix of different qualities of distilled oil products intended for heating and machinery. The total cargo carrying capacity of the vessels identified in the Arctic region is listed in Table 1-2.

Table 1-2 - Sum of oil carriage capacity of all oil/product tankers (ton)

	Sum of dead weight							
Ship type	<10000 GT	1000 - 4999 GT	5000 – 9999 GT	10000-24999 GT	25000-49999 GT	50000-99999 GT	≥100000 GT	Total
Oil tanker		112538	40784	152075	1023656	293390		**1622443**
Chemical/Prod tanker	1041	94144	102815	282616	164061			**644677**

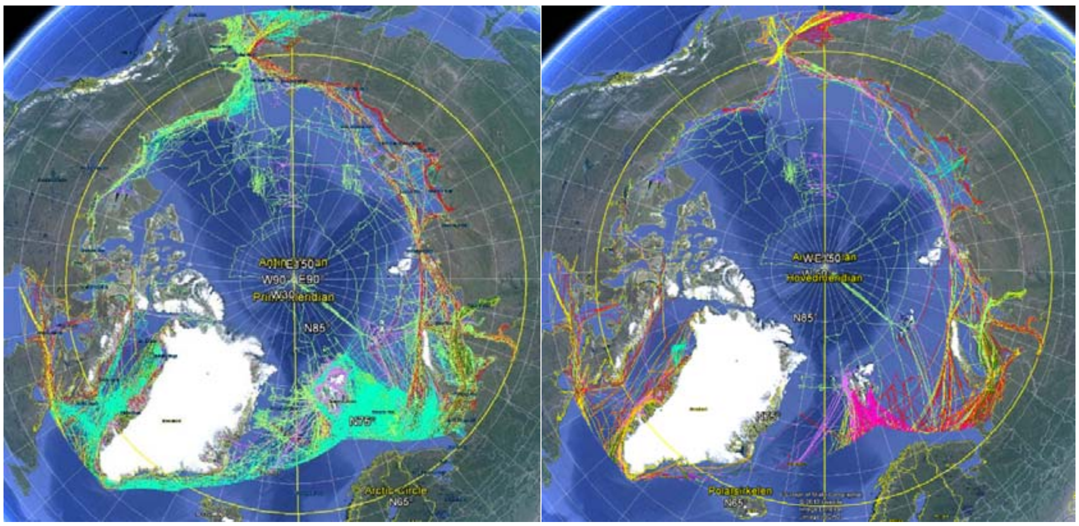

Figure 1-2 - Vessel tracks - all vessels (left) vs. vessels using HFO (right)

It is estimated that the registered ships in the Arctic consumed a total close to 88 000 tons of fuel in 2012. The corresponding calculated emissions are tabulated in Table 1-3 below.

Table 1-3 – Estimated fuel consumption and subsequent emissions (ton)

Ship types	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**

1.3 Oil spill risk assessment

Having established the full vessel inventory and activity maps, this data could then be fed in to the risk analysis model. It is important to be aware that the risk analysis has been performed for a huge geographical area and consequently with a course resolution. Hence, only the larger trends are identified. Also, the risk analysis does not include any environmental vulnerability data and hence does not identify environmental impact or regions of particular sensitive nature, restricting the risk analysis to the spill potential.

The likely accident frequencies of five following incident types leading to oil spill were calculated:

- Grounding
- Collision
- Hull/machinery failure
- Fire/explosion
- Ice related damage

Table 1-4 shows the identified accident return periods of the different incidents calculated. The results indicate that with the 2012 traffic level in the Arctic, an incident resulting in a spill of oil could on average be expected once every 1.6 years. The generally very low ship density in the Arctic region leads to low collision risks

Table 1-4 – Return period - years between likely incident leading to oil spill

Years between incident leading to oil spill							
Row Labels		Grounding	Collision	Hull/Mach	Fir/Exp	Ice_High	**Total**
1	**Oil tanker**	22	669	169	95	837	**15.6**
2	**Chemical/Prod tanker**	26	806	236	132	1491	**19.3**
3	**Gas tanker**	6675	116646	8427	7959	3130	**1384**
4	**Bulk carrier**	187	4041	425	402	553	**81.7**
5	**General cargo**	19	488	110	104	736	**13.2**
6	**Container vessel**	39	1006	211	199	192	**24.0**
7	**RoRo**	379	9898	2446	2310		**279**
8	**Reefer**	162	4075	648	612	6128	**102**
9	**Passenger**	24	644	162	153	2718	**17.8**
10	**Offshore supply vessel**	187	3743	313	295	782	**74.2**
11	**Other offshore vessel**	1093	18203	1111	1050		**354**
12	**Other activities**	14	359	58	55	93	**8.4**
13	**Fishing vessel**	16	313	22	21	386	**6.3**
Grand Total		**2,8**	**70,3**	**10,0**	**8,8**	**39.1**	**1.6**

As is illustrated in Figure 1-3, even though the most likely incident in the Arctic is an “Other Activity” vessel damaged by ice, the grounding of a tanker represents by far the greatest spill potential, and therefore the estimated highest average oil spill mass per year. Note that the likely oil spill risk was not estimated related to ice damage, only the frequency for ice damage leading to oil spill. This is due to lack of spill volumes in the available data material for this incident mode.

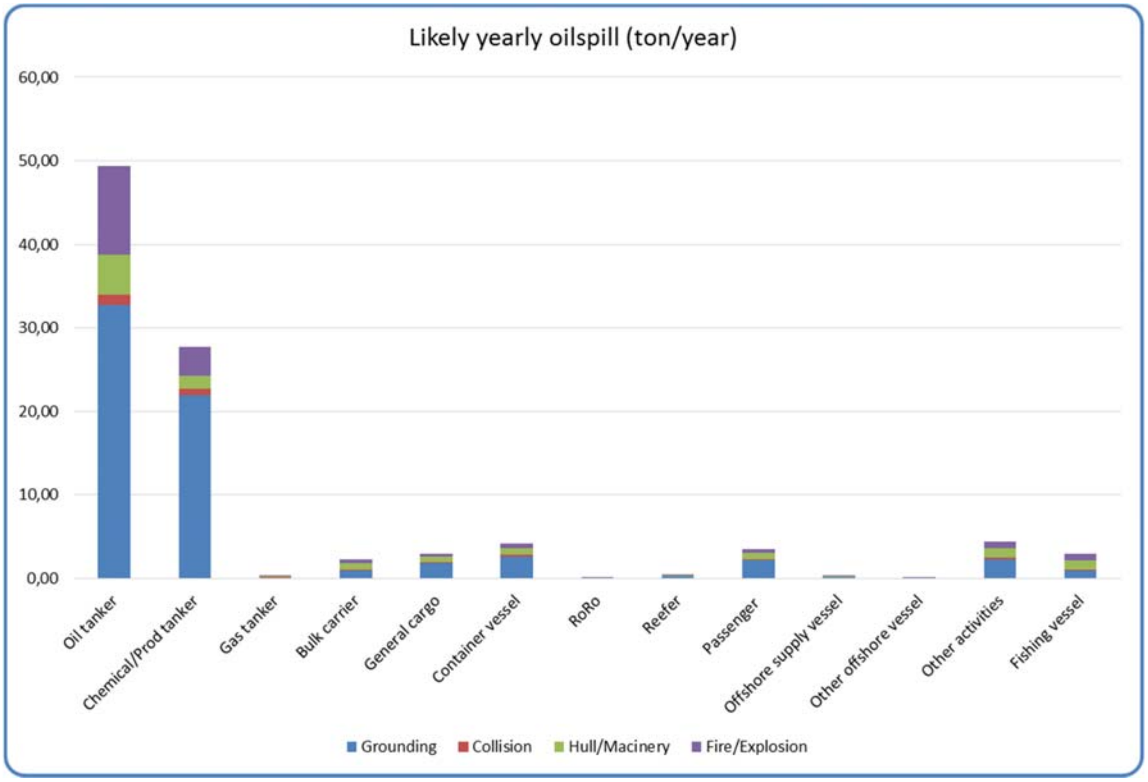

Figure 1-3 – Average likely oil spill mass from all accident modes (but not ice) per year

As part of the risk analysis, the estimated accidental frequencies were quantified in geographical areas of 1x1 degree. Hence, the estimated average annual oil spill mass from each incident mode were calculated for each square. This data was then plotted identifying the estimated risk of oil spill for each area as shown in Figure 1-4 below.

Figure 1-4

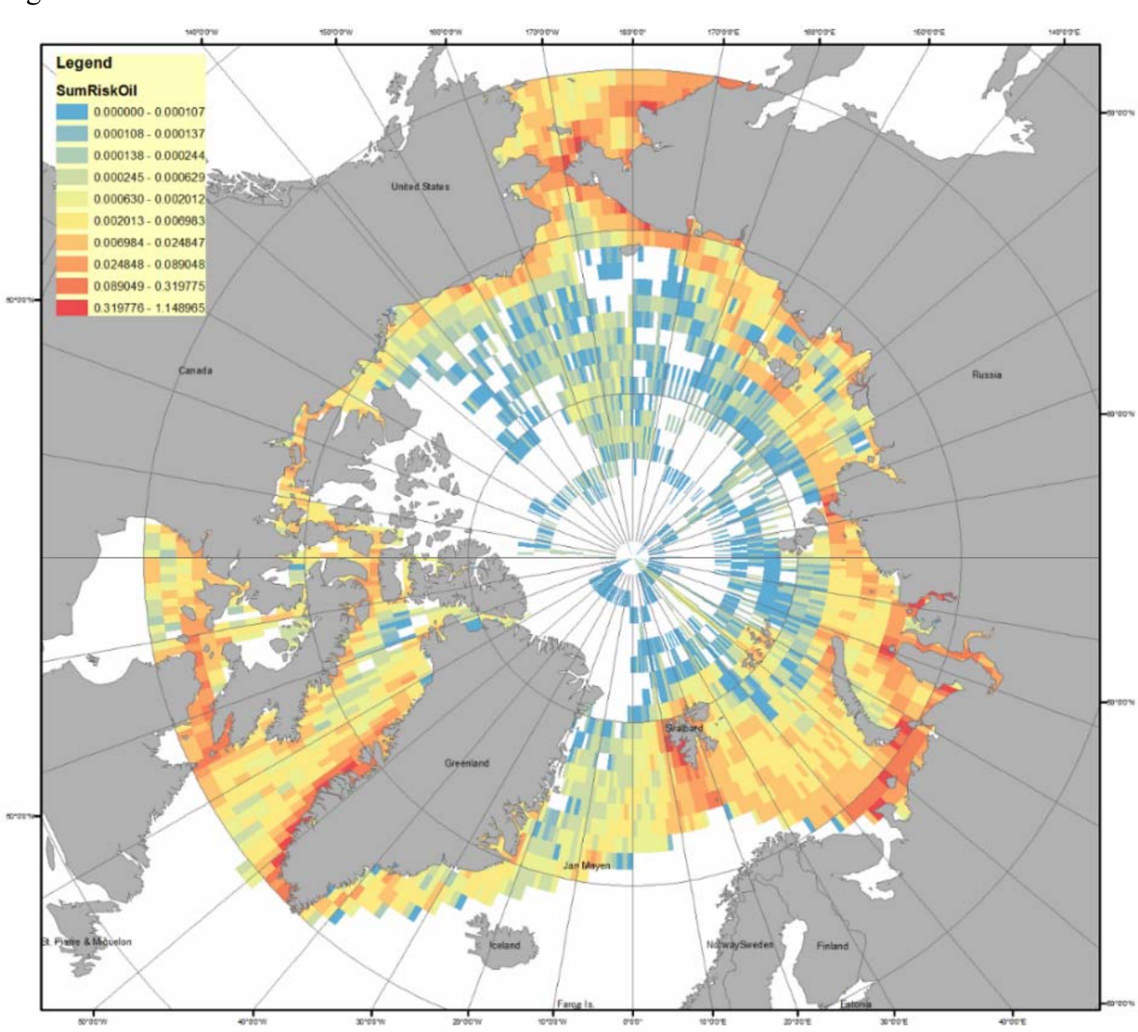

Figure 1-4 - Average likely oil spill mass from all accident modes per year – ton likely oil spill per 1x1 degree area

Groundings of large oil and product tankers in the Russian coastal areas of the Barents Sea and the Kara Sea are identified is identified to represent the incident with highest risk of oil spill in the Arctic. Other areas of higher risk are the eastern part of the Chukchi Sea and the Bering Sea as well as south east Greenland and the strait in to Hudson Bay which are all areas of regular oil tanker traffic.

It is worth noting that the calculated risk frequency generally resembles the activity level of each vessel category, but not for all categories. The categories other activities and passenger vessels are generally over-represented on grounding and ice related risk in our data. This is a group of vessels which generally operate locally and close to land, and consequently the grounding risk is high. Also, other activities comprise ice breakers which frequently operate in ice and hence the calculated ice damage frequency is high. However, the ice damage probability is likely to be over-estimated as these vessels have sufficient ice strengthening for the operation. This also applies to the Russian side of the Barents Sea and the Kara Sea, which turn out as high risk areas for ice damages. This is due to relatively high winter/ice traffic to and from Varandey and Dudinka. However, these are operated by dedicated ice-strengthened vessels designed for full year Arctic operation. Hence when applying generic models for calculating ice risk, the calculated risk of ice damage is likely to be exaggerated for these vessels and the areas they populate. The same will apply to the traffic along the Northern Sea Route where, in case of ice, the vessels are either icebreakers or escorted by such vessels.

It may be considered for future studies to expand the accident frequencies to distinguish between vessel categories, vessels class notations, effects of vessel age, as well as refine the parameters used to distinguish the Arctic conditions. This may not considerably influence the calculated oil spill masses, but it may shift the risk picture, in particular the ice incidents maps.

1.4 Risk control measures

The risk analysis gives indications regarding the main accident types, the main ship categories involved, and the geographical distribution of risk. Such indications are useful in discussing risk control measures. Obviously, any discussion on additional risk control measures should not re-assess control measures already implemented or in the pipeline. In the Arctic, the major upcoming regulatory development is the mandatory Polar Code.
The draft Polar Code covers a range of additional requirements to the design, construction, and operation of ships, as well as to the equipment carried on-board and the training of the crew. Also, search and rescue matters relevant to the ship operation in the polar waters are included. It is noted that the main approach for the Polar Code to reduce environmental risk, is the same as the one used for reducing risk of loss of lives and property; that is the additional requirements for safe design, construction and operation of ships to reduce the likelihood and consequences of accidents, given the particular polar conditions.

In DNVs view, the Polar Code process covers the fundamental hazard identification and risk reducing measures for shipping in the Arctic relating to requirements to the design, construction, and operation of ships, as well as to the equipment carried on-board and the training of the crew. Another class of measures is therefore discussed, relating to the designation of particular geographic areas for additional protection by IMO. PAME is currently exploring the need for international designated areas for the Arctic high seas (i.e. outside the national jurisdictions of the Arctic coastal states. DNV is assisting PAME in this work).

Among the tools available for protection of an area, it is expedient to focus on the Particularly Sensitive Sea Area (PSSA) tool when targeting pollution from acute spills rather than operational spills. PSSAs can be designated along with a host of Associated Protective Measures (APM) Ship routing measures and ship reporting systems may be most relevant in terms of reducing risk from acute oil pollution, including from HFO spills. Examples include measures such as:

- Traffic separation schemes, traffic lanes and separation zones
- Areas to be avoided,
- Recommended routes and precautionary areas to direct traffic away from certain areas posing particular risk or containing particular environmental elements.

It is important to note that the criteria for designating a PSSA covers not only the risk from shipping activity (as outlined in this report), but also the vulnerability of the area in question in terms of ecosystems and biological resources. While such an assessment is beyond the scope of this report, some insight might be drawn from the risk analysis which shows that the risk is concentrated in certain key areas. It is noted that several of the areas with elevated risk levels are also found to contain areas of heightened ecological significance as reported in the AMSA II (C) study by Skjoldal et al. (2009). In such areas, it is likely that measures such as Areas to be avoided, or “Recommended tracks” under a PSSA could give significant risk reduction. Due consideration should be given to possible additional protection measures, such as provided for under the PSSA tool, in further studies.

1.4.1 Cost benefit assessment of selected Risk Control Options (RCO)

Based on the risk assessment carried out in this study the highest risk for oil spill related to the traffic patterns and composition found in the Arctic is related to groundings in general and groundings of oil tankers in particular. With this in mind, eight Risk Control Options (RCO) were identified and evaluated.

Both the cost and the expected effect were rated for eight selected RCOs with the scores High-Medium and Low.

The highest combined scores were assigned to measures regulating the traffic patterns at places combining challenging navigation with vulnerable nature and vessels with high potential for spills.

The two RCO found to give the highest potential return of investment were:

- Traffic limitations (e.g. number of vessels, vulnerable time of year, traffic channels, designation of areas to be avoided, etc.)
- Slower steaming speeds (in certain control areas – and potentially dedicated for tankers) to reduce likelihood of hull penetration in the event of an accident

1.5 Expected traffic development

Estimating future activities in the Arctic is inherently difficult due to large uncertainties in sea-ice extent, resource availability, future economic development, and future policies.

Several studies exist, some optimistic with regard to future activity by midcentury. However, no study has been identified which covers all aspects of Arctic shipping (transits, destinations (O/G shipping, fisheries, cruise), modeling future activity using a unified set of assumptions and drivers. Thus, describing the future activity in quantitative terms is not possible in this report, making any clear images of the future of shipping in the Arctic stating the traffic volumes

The following general observations can be made:

- Ice conditions is an important driver for change, but is, in isolation, no impetus for more shipping.
- Estimating future activities in the Arctic is inherently difficult due to large uncertainties in sea-ice extent, resource availability, future economic development, and future policies.
- In a few decades, the ice is expected to melt in the summer, and gradually larger areas could be sailed in the melt season of vessels with lower ice class. Winter conditions will continue to be challenging.
- There will likely be a limited number of transits before 2020, and destination activity will dominate (as today).
- The container and line traffic may represent large volume of transit traffic in the Arctic Ocean in the future, although estimates of this are highly uncertain.
- Major developments in destination traffic are largely driven by extraction and export of resources from the Arctic. Development of such resources for extraction will take time, but shipping activity related to O&G may potentially exceed the future transit activity.

As we are now in the position to extract more than 3 years of traffic collected by the AIS-Sat1 satellite, for the first time we will be able to map the traffic trends in the region. This will likely provide valuable input to our understanding of the maritime activity in the Arctic.

2 INTRODUCTION

This study is carried out on behalf of The Protection of the Arctic Marine Environment Working Group (PAME) and financed by the Norwegian Environmental Agency.
PAME is one of six Arctic Council working groups and is the focal point of the Arctic Council's activities related to the protection and sustainable use of the Arctic marine environment.

The Recommendation 1B of the 2009 Arctic Marine Shipping Assessment (AMSA) report states that "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 the identified risks.
18 January 2011 DNV submitted, on behalf of PAME, the first mapping of the Arctic shipping activity based on satellite collected AIS data entitled Heavy fuel in the Arctic (Phase 1) (DNV, 2011). The Phase I" study concluded that the vessels operating in the Arctic region were generally relatively small vessels operating mainly on distillate fuels. However, larger vessels powered by HFO represented about 20% of the identified vessels. With the expected rise in the inter-continental trading pattern and in addition, an increase in the oil and gas related activities, an increase in the average ship size is to be expected, and consequently a proportional increase in the use of Heavy Fuel Oil (HFO). Due to the limited operational life of the AIS satellite, the study was only able to collect 4 months of data. PAME decided to perform a follow-up study, this time with a full year of registered traffic. 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-2) to the study presented in 2011.

3 OBJECTIVE

Arctic shipping is on the agenda today and it is expected to receive increasing attention in the years to come. The main reason is the expected 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. In addition, the expected surge in oil and gas related activities will also add to the maritime activity in the region.

Recommendation I(B) of the 2009 Arctic Marine Shipping Assessment (AMSA) (Arctic Council, 2009) provides: "*That 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*."

The objective of this study is to provide a more comprehensive picture if the maritime traffic, fuel types and oil cargo in the Arctic. Further, the study will bring forward an assessment of the risk and control options which are available.

Based on AIS based ship movement data for 2012, the study addresses the following issues:

- Describe a full year (2012) of maritime traffic based on satellite AIS recordings in the Arctic region, including vessel composition (type and size), geographical distribution, sailed distances and operating hours throughout the year.
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This study's overall main objective is to provide PAME with a solid foundation for their activities related to the protection and sustainable use of the Arctic marine environment and the process of making recommendations for improvement to the Arctic Council.

4 STUDY APPROACH AND DELIMINATION

4.1 General

This study uses AIS data for establishing the maritime activity in the Arctic region. The activity provides the basis for further estimations of emissions as well as the risk of accident associated with the shipping activity. Details of approach and methodology are given in the respective chapters presenting the results for the different topics

Figure 4-1 shows the data flow in the project providing the basis for the different analysis performed as part of the study.

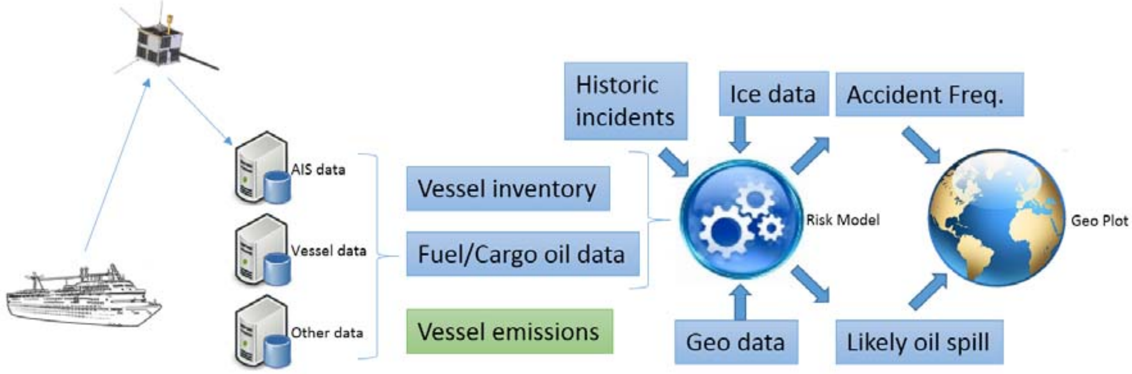


Figure 4-1 - Data management in project

4.2 Arctic delimitation

For use in this study the Arctic area uses the same definition as used in the proposed IMO's Guidelines for Ships Operating in Ice-Covered Waters (IMO, Guidelines for ships operating in polar waters, 2010) as shown in Figure 4-2. As regards to 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."*

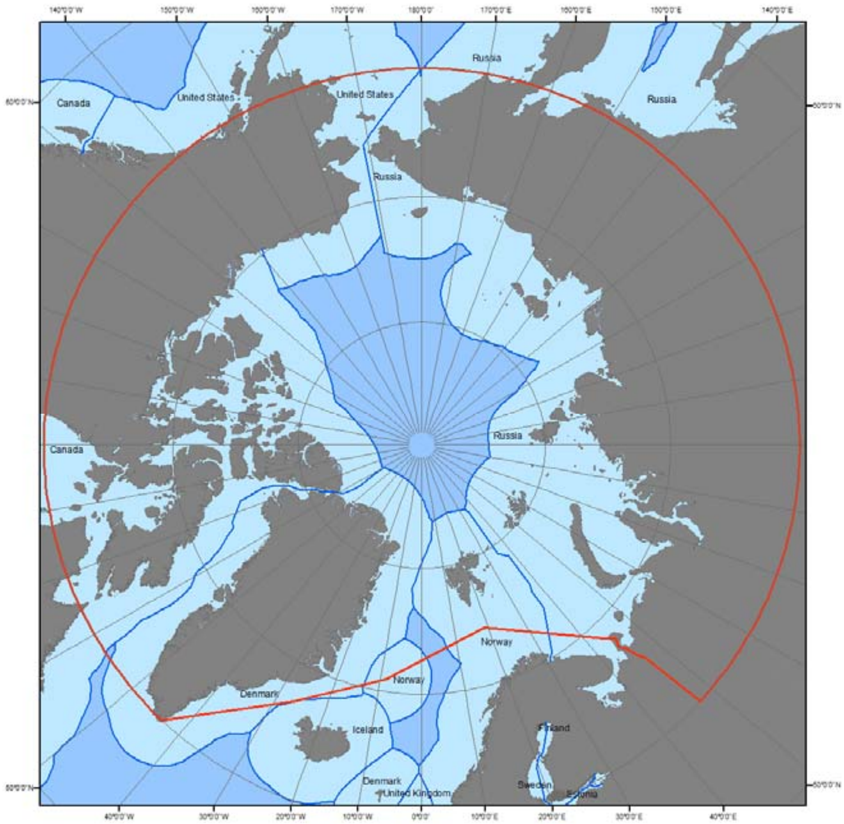


Figure 4-2 – The Arctic as defined according to the IMO Guideline the Arctic high seas (Source; DNV using data from "http://www.marineregions.org per 12. December 2012)

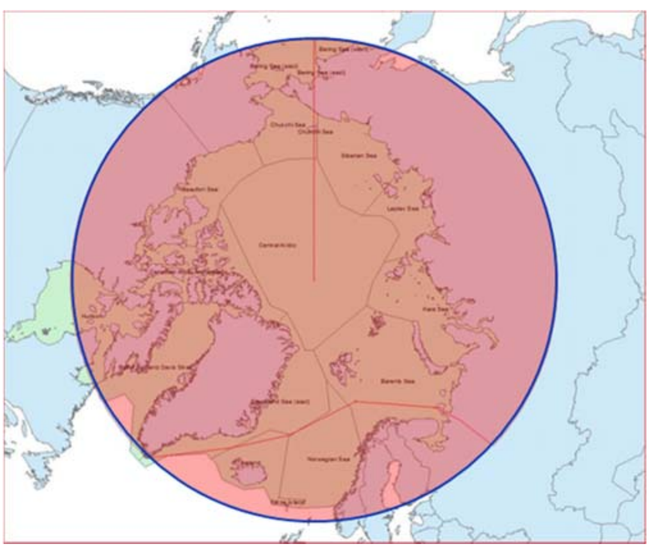


Figure 4-3 – The Arctic as defined as north of 60°N

It is important to note that defining the Arctic above 60°N 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 Polar Code 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. It is likely that the large traffic volumes outside the defined region used in this study will contribute to the overall risk within the region. However, the effects of this will not be accounted for in this study.

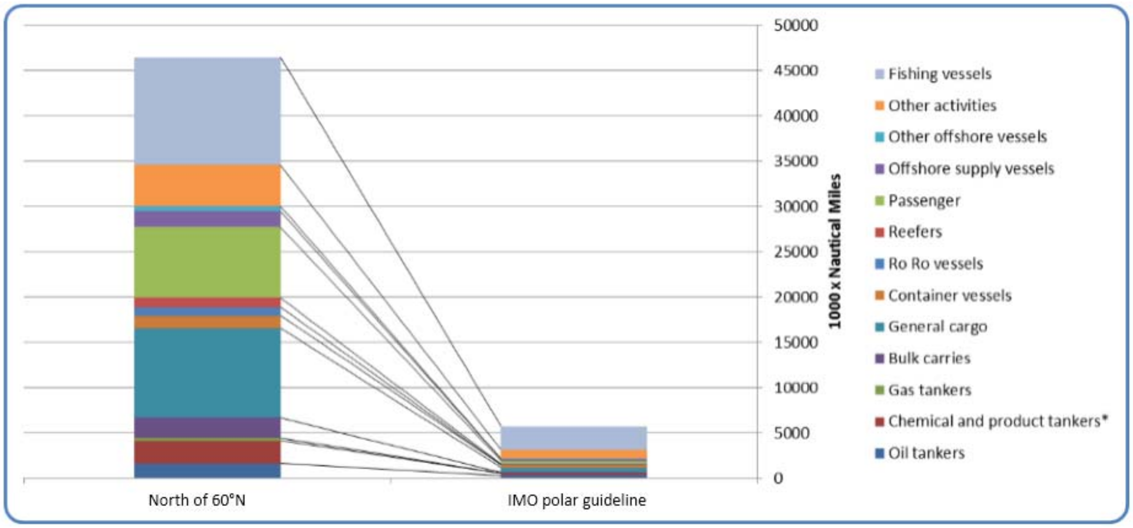


Figure 4-4 – Total sailed distance north of 60°N vs. inside the Arctic as defined in the IMO Polar Code Guideline

4.3 Fuel oil definitions

In this report, heavy fuel oil (HFO) is regarded equivalent to oil with characteristics as specified by IMO in MARPOL on 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. Marine gas oil (MGO) represents pure distillate fuels.

4.3.1 HFO with future regulations

After 2020/2025 the global 0.5% sulphur cap will change the type of bunker fuel in use, towards lighter products/distillates (unless scrubbers are used). It is however important to note that this will still not be fuel to a marine gas oil standard. The actual characteristics of this fuel shift with respect to evaporation, dissolving, dispersion, water uptake/emulsification and environmental effects compared to the HFO we have today, is uncertain.

5 INVENTORY OF SHIP TRAFFIC, FUEL USE AND AIR EMISSIONS

5.1 Vessel traffic – 2012 – from satellite based AIS data

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 and 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 is expected to be representative for most of the actual traffic in the area.

The requirement for Automatic Identification System (AIS) transponders on-board ships has over the last years revolutionized our knowledge of ship traffic, its 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. This has opened for a completely new way of ship traffic surveillance as well as emission- and risk calculations related to their operation.

A challenge with the satellites' receiver is the capacity of handling large number of signals. Today 52 000 ships have installed the necessary equipment to transmit the ordered information, and in some areas the traffic is way above what the receiver can handle. Typically, this will be the situation when the satellite is recording from the North Sea, the Baltic Sea and the Mediterranean over which the receiver will idle and only a small proportion is transmitted. Within the Arctic region as used in this study however, the coverage is close to 100%.
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 Barents Sea is removed) according to the "IMO Guidelines for ships operating in polar waters" definition as illustrated in Figure 4-2 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.

Figure 5-1 - The AIS-Sat I in orbit (The Norwegian Space Agency)

5.2 Vessel demography in the Arctic

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 is defined by its unique identifiers, 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 5-1) used for the Phase 1 study (DNV, 2011) with 13 ship types based on the Lloyds standard ship breakdown structure – category 5 and 7 size-groups based on Gross Tonnes.

Table 5-1 - 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 full breakdown of the different ship categories, see Appendix E.*

5.2.1 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 5-2 and Figure 5-2, the absolute majority are relatively small vessels less than 5000GT. Further, the dominating ship types are fishing vessels and the category “Other activities” comprising vessels such as tugs, local community vessels and research vessels. (See Appendix E for details on the complete breakdown of ship types).

Table 5-2 Number, type and size of unique ships

	Number of unique vessels							
Ship type*	<1000 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**

* *For a full breakdown of the different ship categories, please see Appendix E*

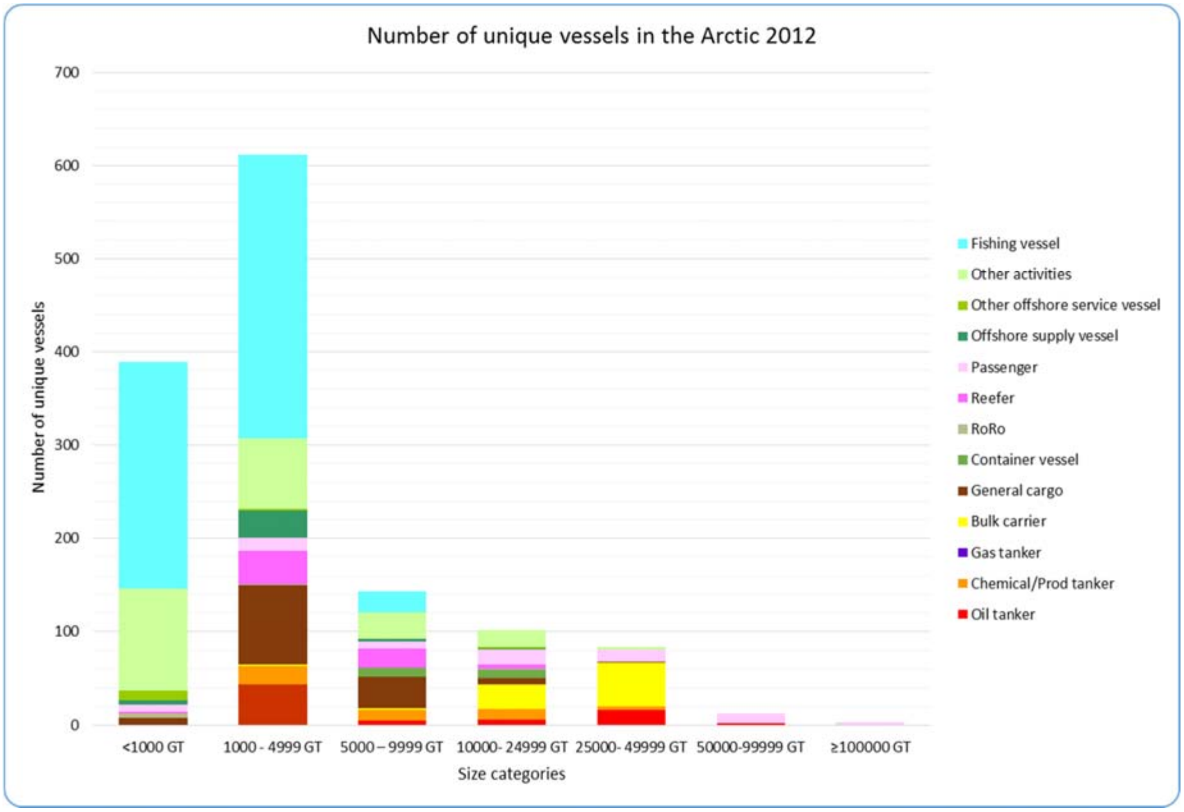


Figure 5-2 - Number and types/size of unique vessels in the Arctic

Figure 5-2 shows the distribution of vessel size and category. Note that the colours illustrating vessel type is matching the colour coding used in the traffic maps used in this report such as in Figure 5-3.

5.2.2 Ship activity maps

Based on several million position codes (points), the data was recalculated to be represented as lines and plotted geographically. The calculations are based the use of the Ramer-Douglas-Peucker (Douglas, 1973) 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.

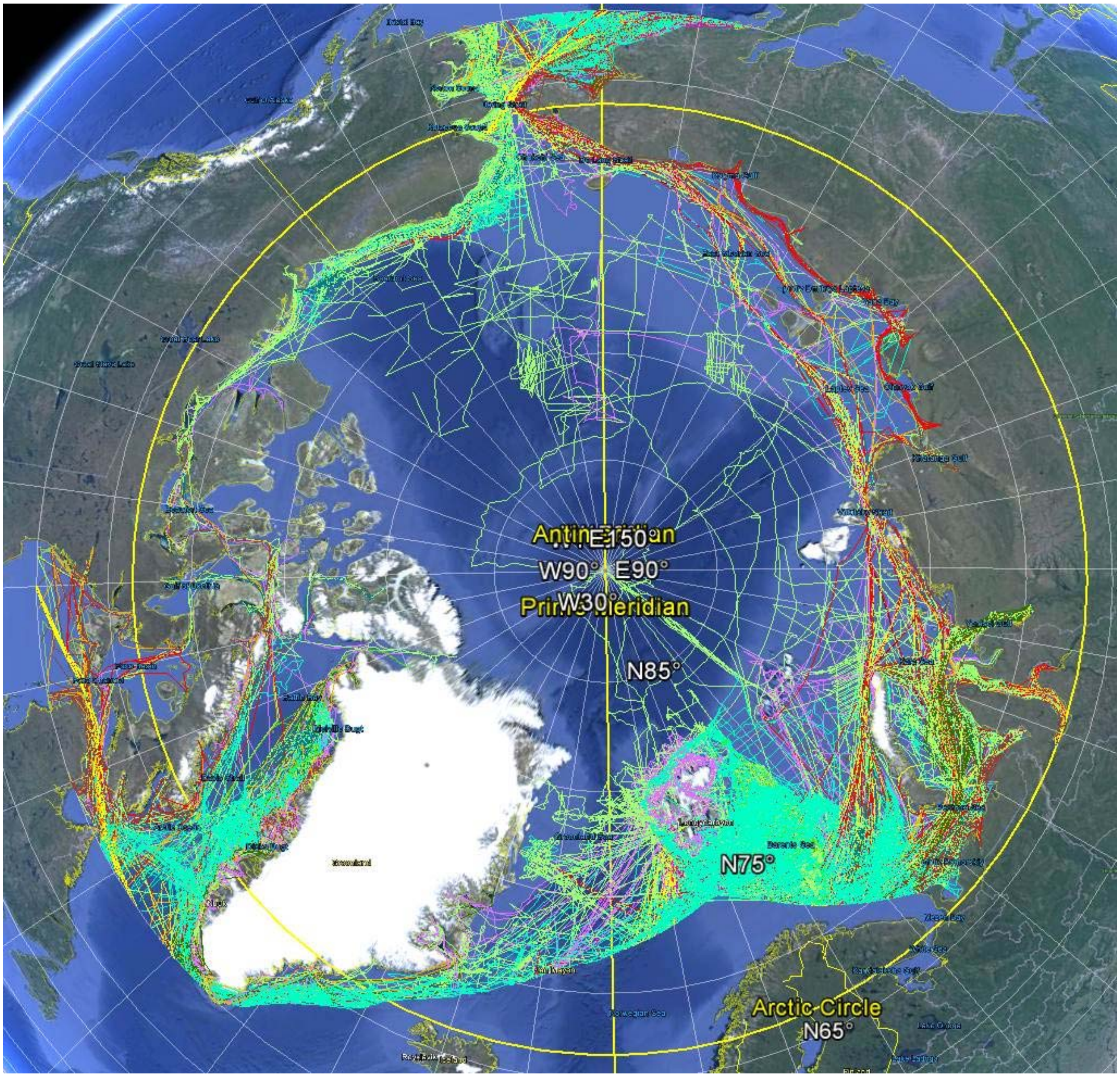


Figure 5-3 - All ship types throughout 2012

Figure 5-3 shows a full year of ship tracks superimposed on the map of the Arctic. Note that the colours represent the different vessel categories and follows the same regime as in Figure 5-2 above.

Ship traffic sorted by each ship type is presented in Appendix B

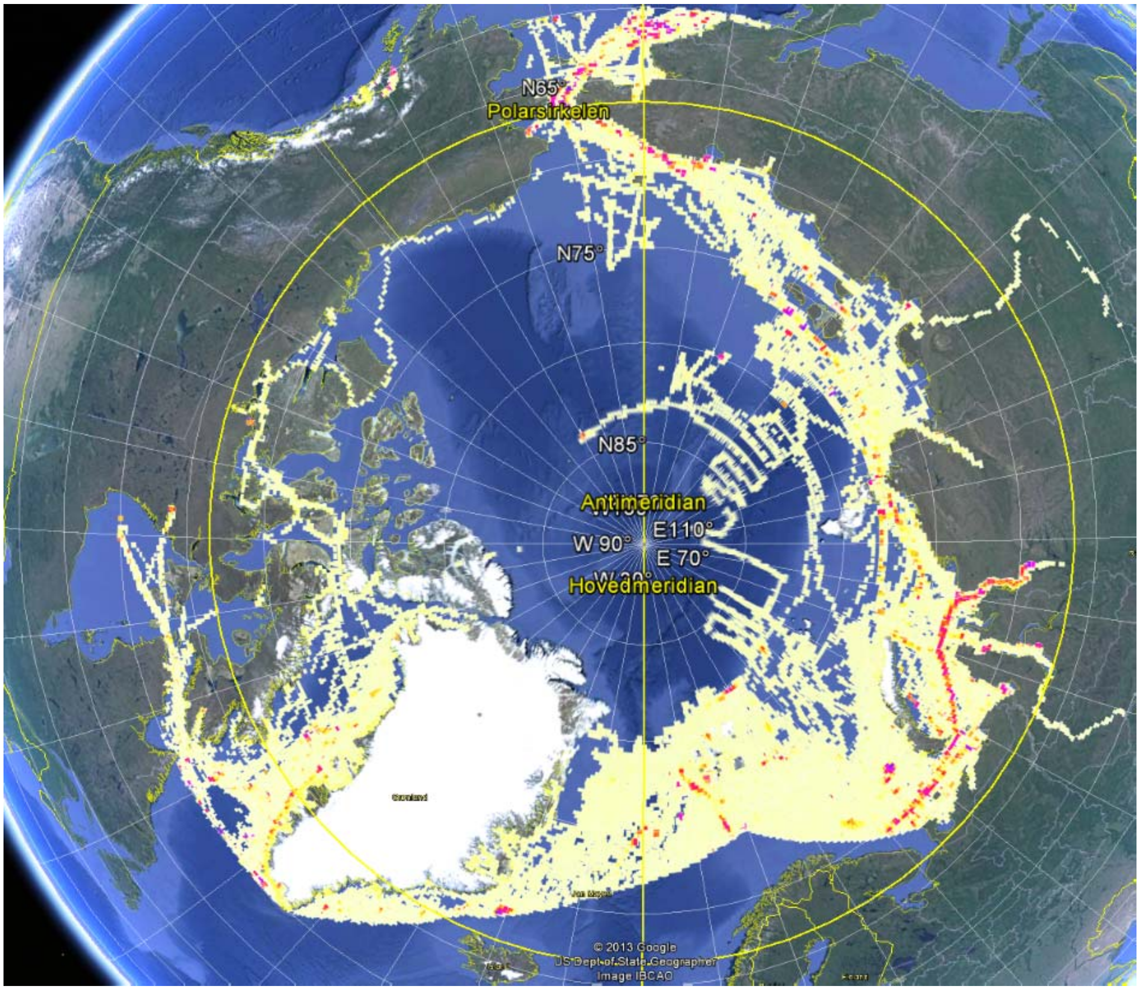


Figure 5-4 - Ship traffic density throughout a year (Purple is the highest density)

Figure 5-4 shows the traffic density oven an entire year in the Arctic. The map shows what is denoted as "Point Density" with grid cells of 10 x 10 km. The density of points featuring around each output raster cell is calculated. Conceptually, a neighborhood is defined around each raster cell center, and the number of points that fall within the neighborhood is totaled and divided by the area of the neighborhood.

As shown in Figure 5-4 above the Arctic ship traffic is generally skewed towards the Norwegian Sea and the Russian coastline. The traffic is subject to large seasonal variations and the density for each month is presented in Appendix B.

5.2.3 Operation hours of ships in the Arctic

Table 5-3 - Ship Operation hoursin the Arctic

Ship type*	Operation hours- 2012							
	<1000 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**

* *For a full breakdown of the different ship categories, see Appendix E.*

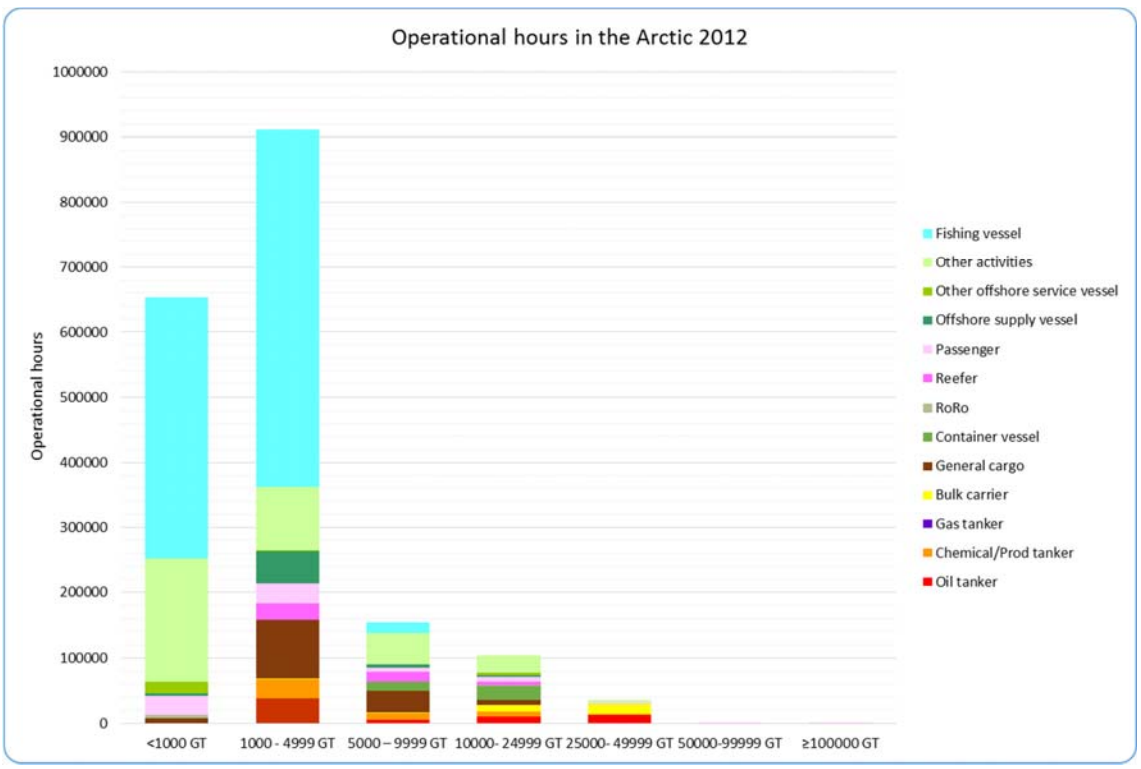


Figure 5-5 - Operation hoursof the different ship types/sizes in the Arctic

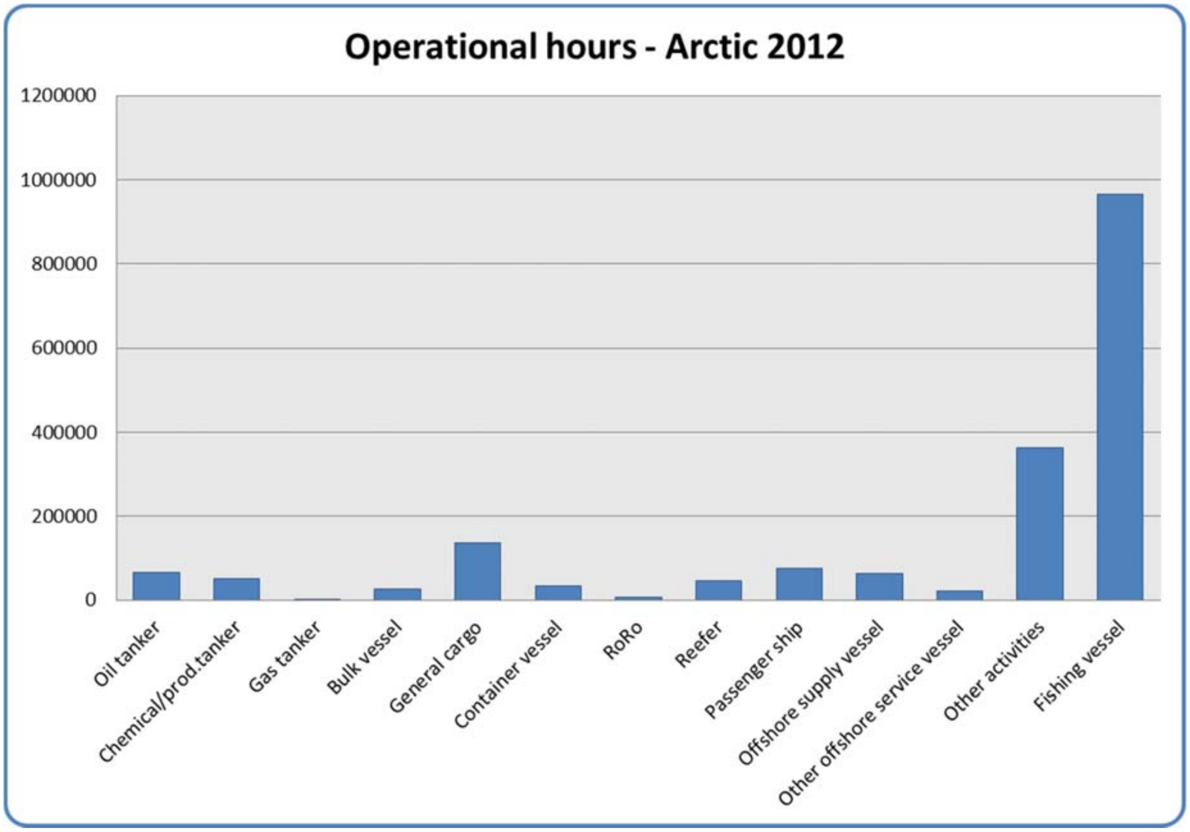


Figure 5-6 - Operation hours by vessel category

5.2.4 Sailed distance in the Arctic

Table 5-4 - Sailed distance in the Arctic

Ship type	Sailed distance in the Arctic - 2012							
	<1000 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**

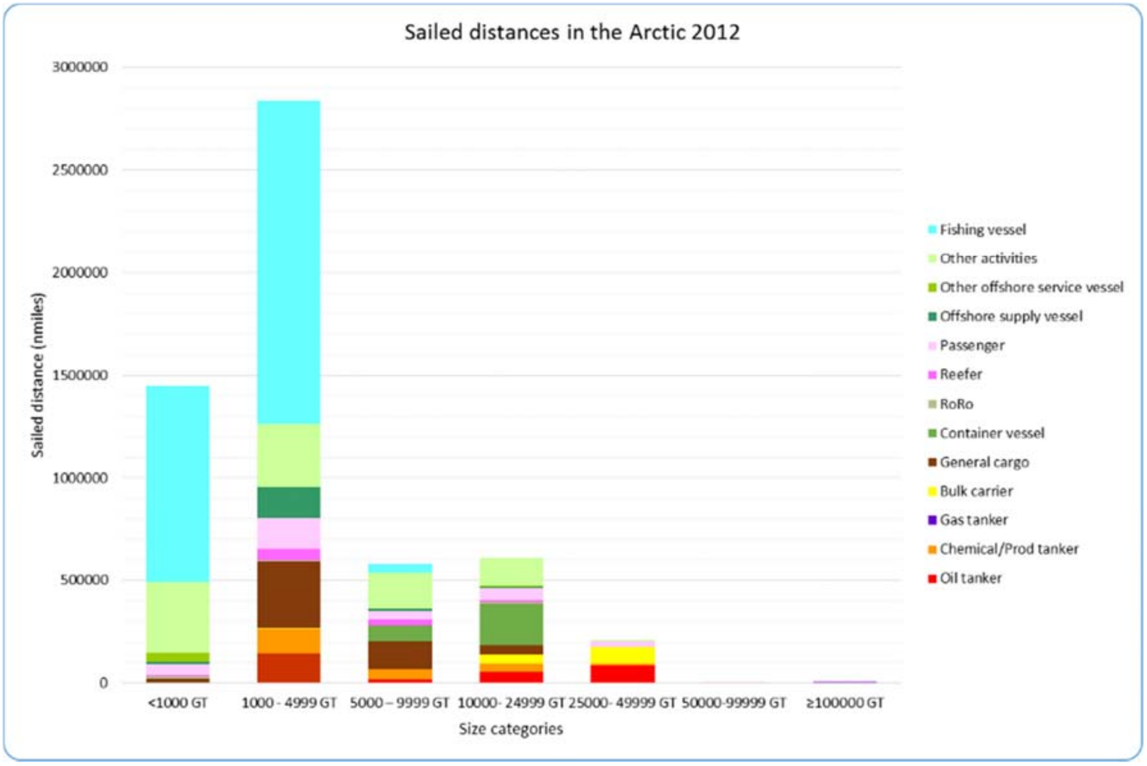


Figure 5-7 - Sailed distance of the different ship types/sizes in the Arctic

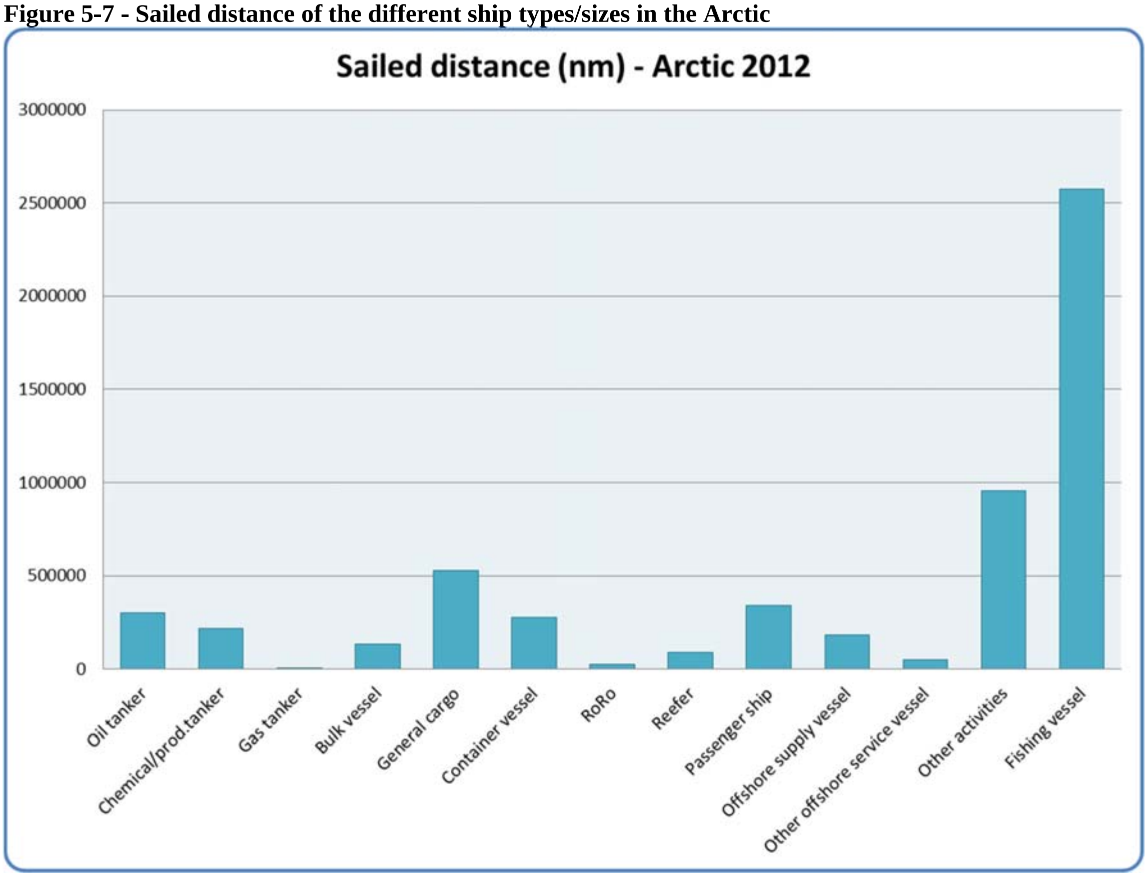


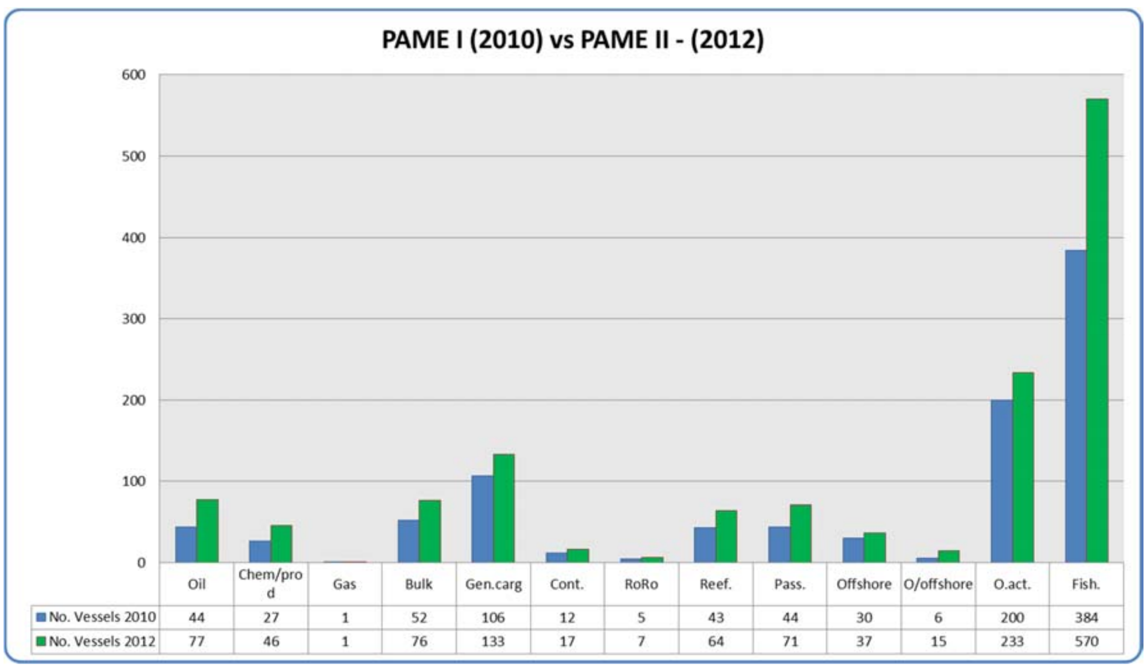
Figure 5-8 – Sailed distance of the different ship types in the Arctic

5.2.5 Comparison with the PAME-1 study and the PAME-2

The study "Heavy fuel in the Arctic – Phase 1" (DNV, 2011) 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 November. It was argued that even though the data covered only 4 months of the year, these were the four most busy months and potentially sufficient for establishing an inventory of the 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. Operation hours or sailed distance would have been a better indicator for the maritime activity in a region than the number of unique vessels, but this was unfortunately not part of the results calculated in the Phase 1 study. One should therefore be careful using this comparison as an indicator of any changes in maritime activity between 2010 and 2012.

The comparison is illustrated in Figure 5-9 below and it indicates that the assumptions on ship traffic made on the Phase-I report is mainly sound. Most vessels categories show a growth in numbers. The number of fishing vessels has increased relatively more in numbers between the two data sets. This may be related to the fact that the majority of the fishing activity is in the year-round ice-free parts of the Barents Sea and hence with substantial activity also in the period not cowered in the Phase I study.



	Oil	Chem/prod	Gas	Bulk	Gen.carg	Cont.	RoRo	Reef.	Pass.	Offshore	O/offshore	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 5-9 - number and types of unique vessels recorded in 2010 vs. 2012

The Phase 1 study registered 954 unique vessels within the Arctic whereas the 2012 full year figure is 1347 - 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.

5.3 Vessels operating on HFO

The identification of vessels operating on HFO in the Arctic is done by combining the AIS-based data set with other databases for ship specific information and test results on supplied fuel qualities. In addition, a qualitative assessment of HFO use by different ship type/size groups has been undertaken. For the vessels in these groups with no specific identification of fuel type, an evaluation of the machinery type and characteristics is performed prior to the final assumption on the fuel type. The analysis has been carried out as an iterative process as described below:

- The entire data set was organized in a matrix as described in Table 5-1. The AIS data set for ship movements in the Arctic was then paired with the DNV Ship Register to incorporate ship specific information not found in the AIS data source.
- 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.
- The complete set was then assessed with respect to machinery data from the DNV ship database regarding the engine particulars.
- Finally other data sources was used such as the Russian Register which provided valuable input regarding the fuel type the vessel is using.

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 (DNV, DNV Petroleum Services Database, 2013) samples of HFO are defined as vessels carrying HFO bunker oil.
- 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.
- Vessels which are listed in the Russian Register (Russian Maritime Regiser, 2013) as HFO users.

Table 5-5 – Unique vessels in the Arctic – assumed operating on HFO in brackets

Ship type	Number of unique vessels							
	<1000 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)**

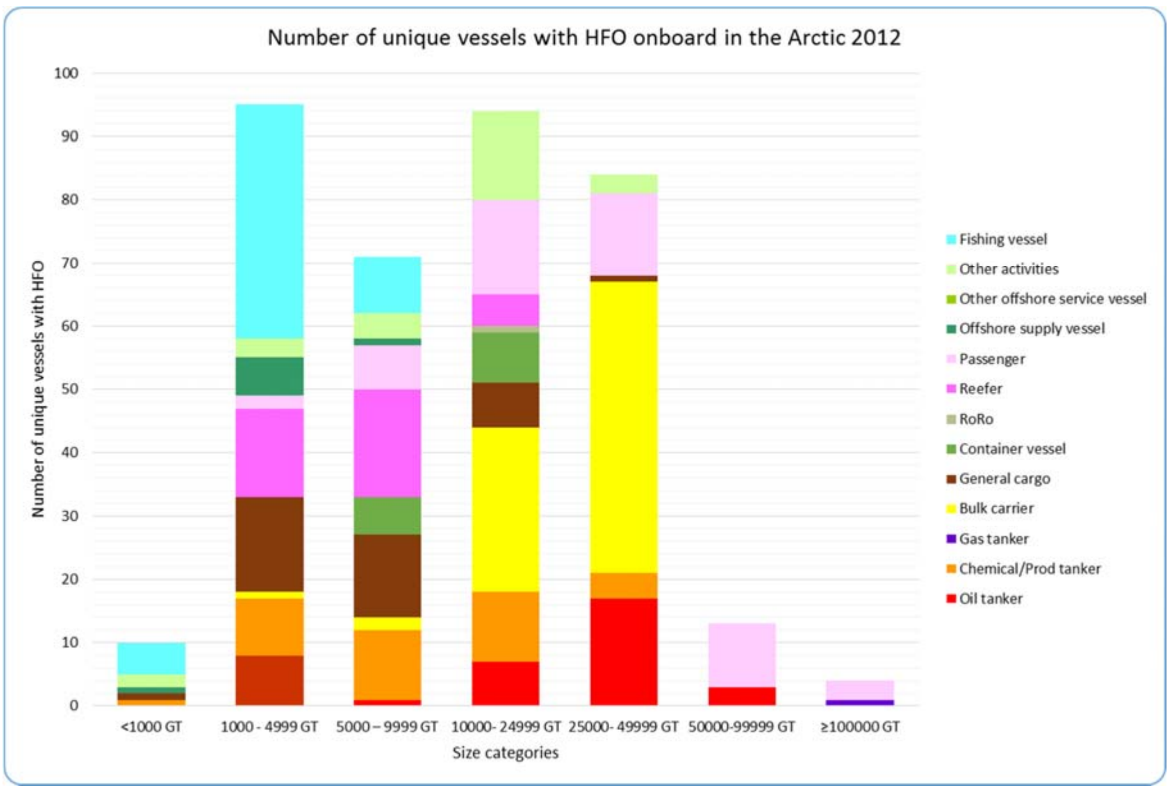


Figure 5-10 - Number of unique vessels operating on HFO in the Arctic

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

Ship type	% of HFO vessels in the Arctic							Total
	<1000 GT	1000 - 4999 GT	5000 – 9999 GT	10000-24999 GT	25000-49999 GT	50000-99999 GT	≥100000 GT	
Oil tanker		18 %	17 %	100 %	100 %	100 %		47 %
Chemical/Prod tanker	100 %	47 %	100 %	100 %	100 %			78 %
Gas tanker							100 %	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 %

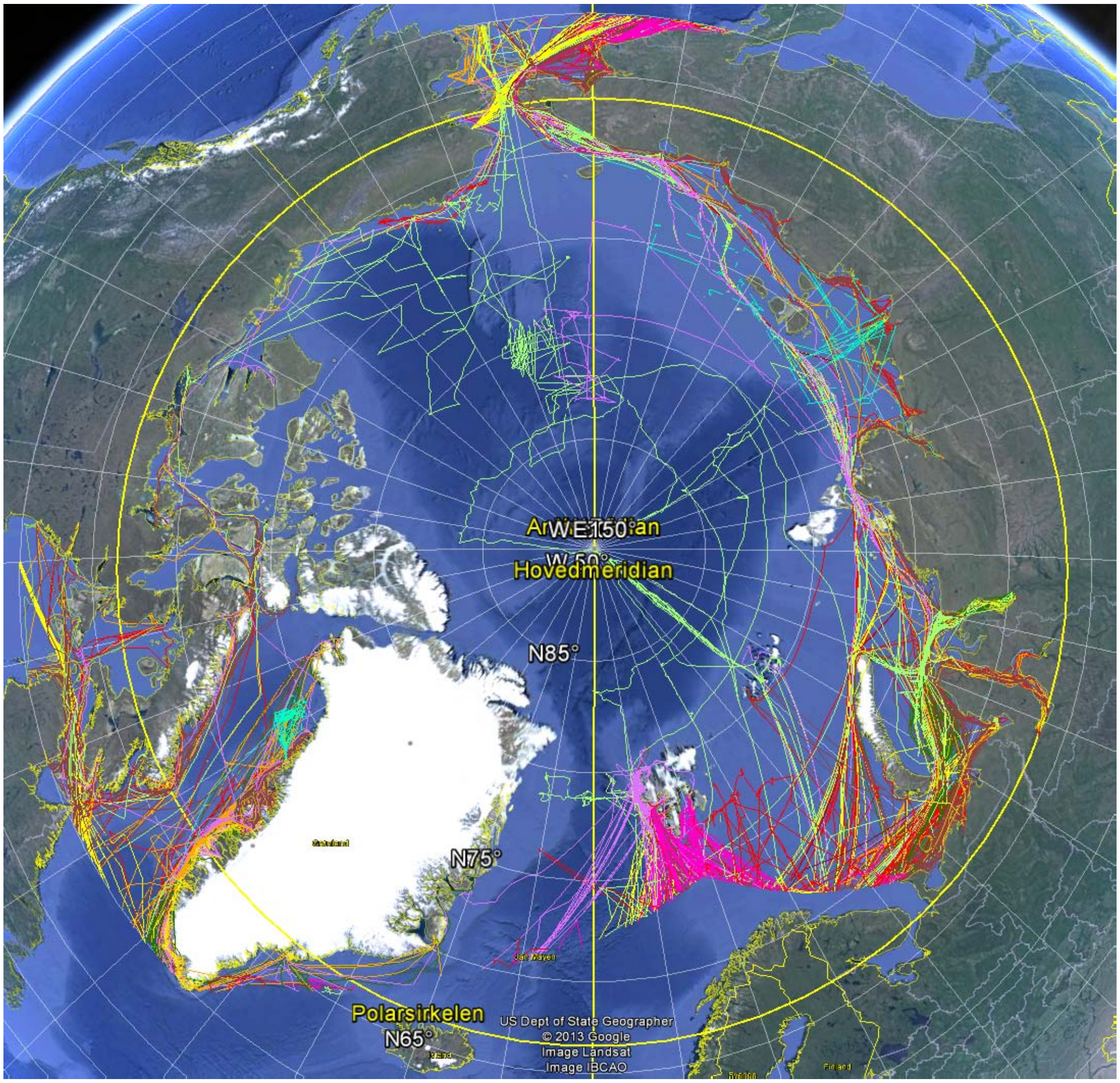


Figure 5-11 - Vessel tracks of vessels operating on HFO in 2012 (Colours follow the same convention as in Figure 5-10)

For individual plots of each vessel category, see Appendix B.

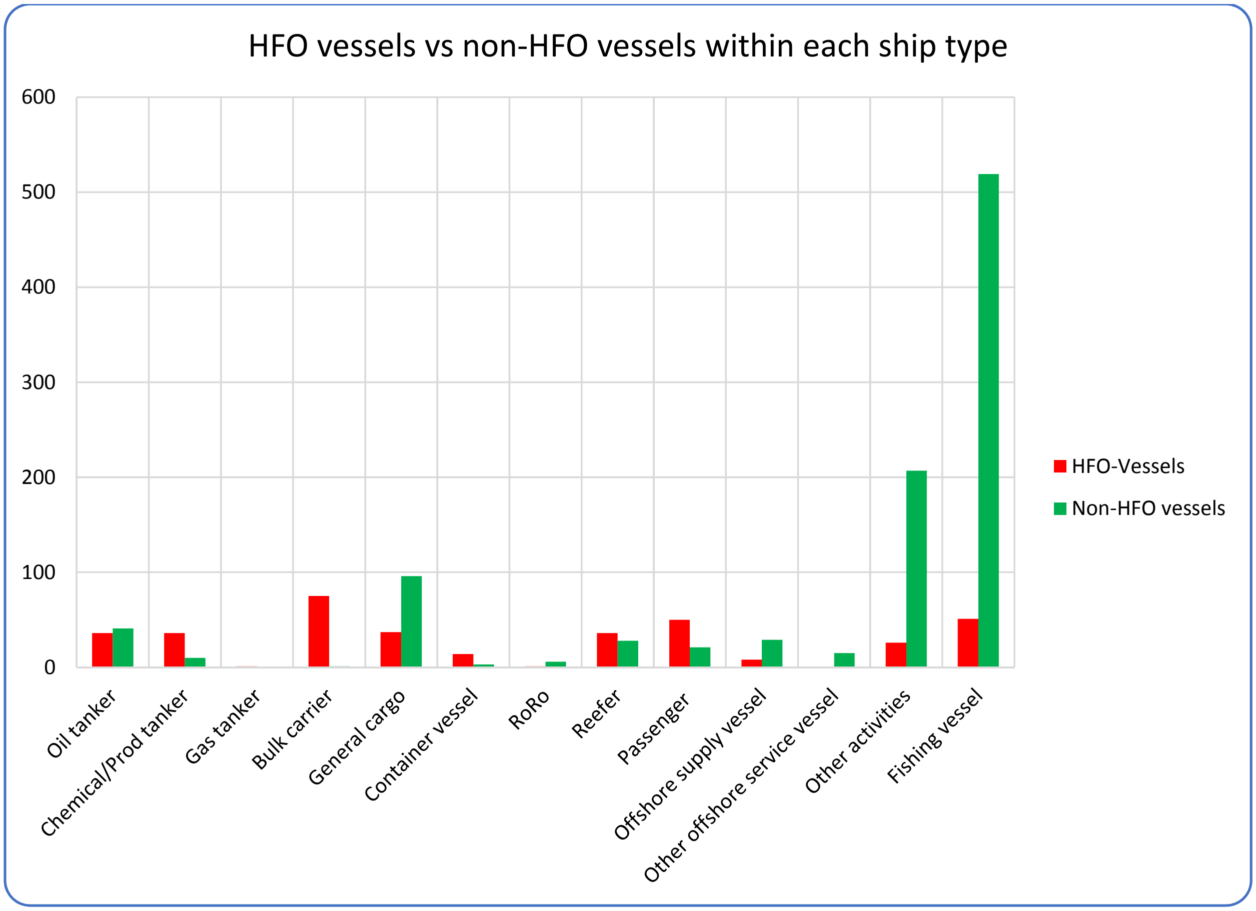


Figure 5-12 - Number of HFO vessels versus non-HFO vessels within each ship type

5.3.1 Amounts of fuel on-board ships in the Arctic

Bunker capacity is a parameter often poorly represented in the main ship databases available. Hence, we were not able to extract reliable bunker mass for each vessel from our data sets. Instead, based on an earlier study of bunker capacity versus deadweight (Breda, 1981) we established enough data points to perform a regression analysis resulting in the following formula.

Bunker capacity = 29.777*DW-55431

The formula was applied to all vessels in the selection and thus provides the basis for both the bunker mass calculation and the oil spill risk evaluation. For the mass calculations, a 65% filling level was assumed.

Table 5-7 – Tons HFO bunker fuel on-board the vessels - assuming 65% tank filling

	tons bunker fuel on-board - 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 destillate 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**

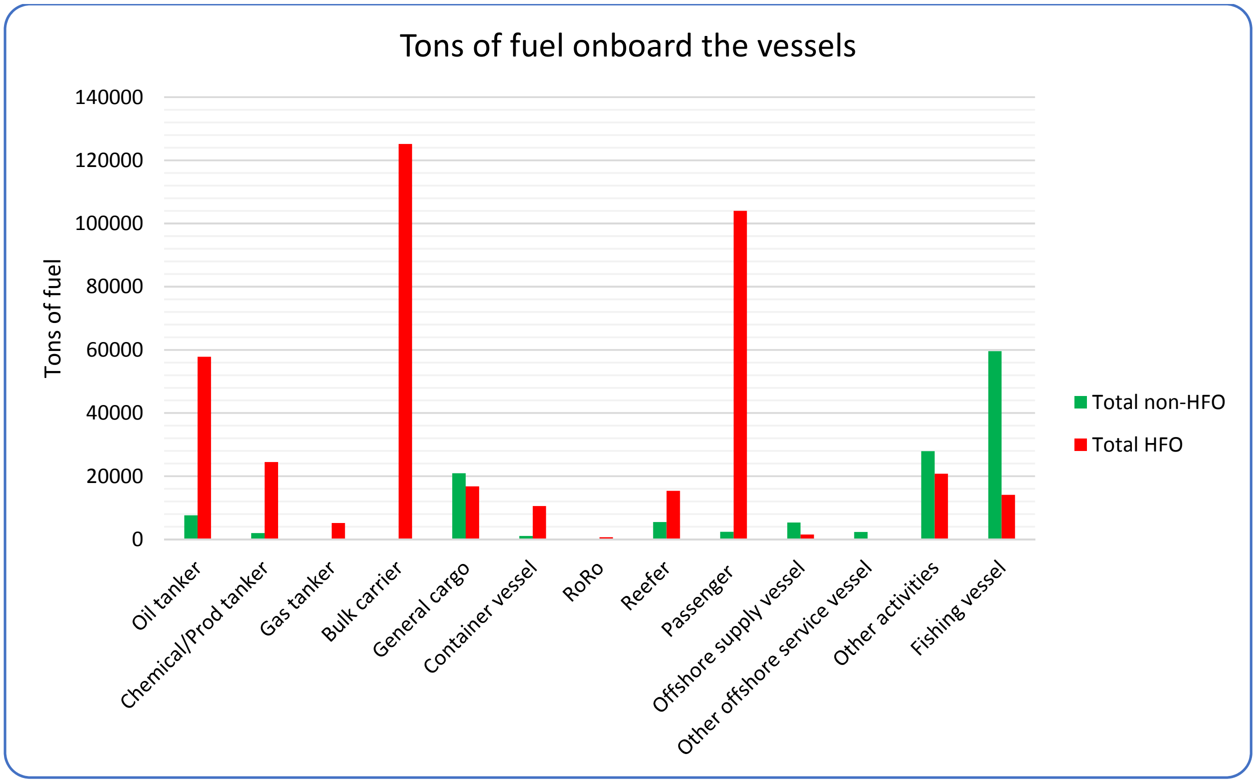


Figure 5-13 - Estimated tons of fuel in vessels in the Arctic

Figure 5-14 and Figure 5-15 clearly illustrates that although by far the majority of vessels use distillate fuel, the volume of HFO carried as fuel is far greater due to the larger size vessels using HFO. The total estimated volumes can be seen as the total bunker spill potential in case all vessels operating in the Arctic suffered a fatal causality with all fuel oil spilled.

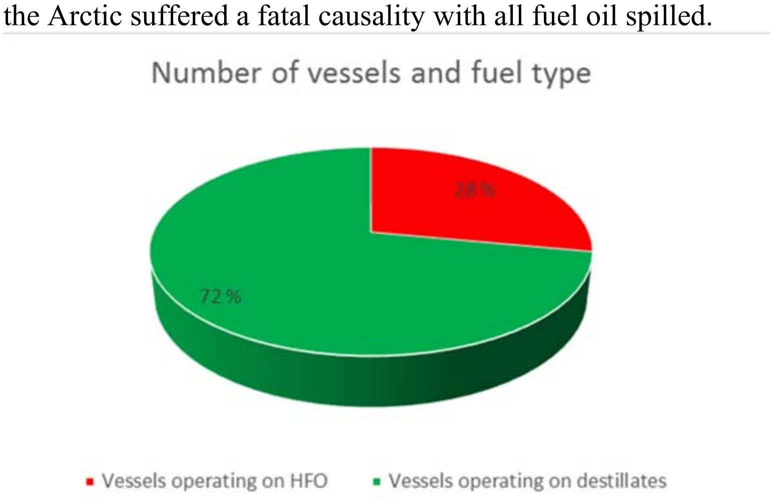


Figure 5-14 - Proportion of vessels using HFO versus distillate fuel in the Arctic

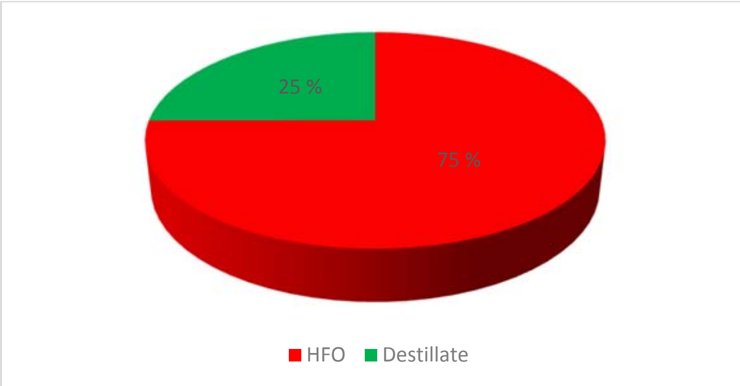


Figure 5-15 - Proportion HFO versus distillate fuel on-board ships in the Arctic

5.4 Oil carrying capacity

Two vessel types are likely to carry the majority of oil bulk cargo in the region. Oil tankers will generally carry crude oil, but may also include different types of distilled products. Chemical/Product tankers will likely carry an even more widespread mix of products ranging from HFO to vine and fruit juice. However, in the Arctic the cargo is likely to be mix of different qualities of distilled oil products intended for heating and machinery. The total cargo carrying capacity of the vessels identified in the Arctic region is listed in Table 5-9. These are built on the figures used in the oil risk assessment as presented in Section 6.

Table 5-9 - Sum of oil carriage capacity of all oil/product tankers (ton)

	Sum of dead weight							
Ship type	<10000 GT	1000 - 4999 GT	5000 – 9999 GT	10000-24999 GT	25000-49999 GT	50000-99999 GT	≥100000 GT	Total
Oil tanker		112538	40784	152075	1023656	293390		**1622443**
Chemical/Prod tanker	1041	94144	102815	282616	164061			**644677**

5.5 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 shipspeed 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.). For the calculations used in this study, we differentiate between the two modes by checking the average ship speed.

5.5.1 Emission from shipping in the Arctic – 2012

In this study, we are looking in the two first points comprising the emissions to air.

For a more complete description the calculations and methodology, see Appendix A.

Table 5-10 – Estimated fuel consumption and subsequent emissions (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**

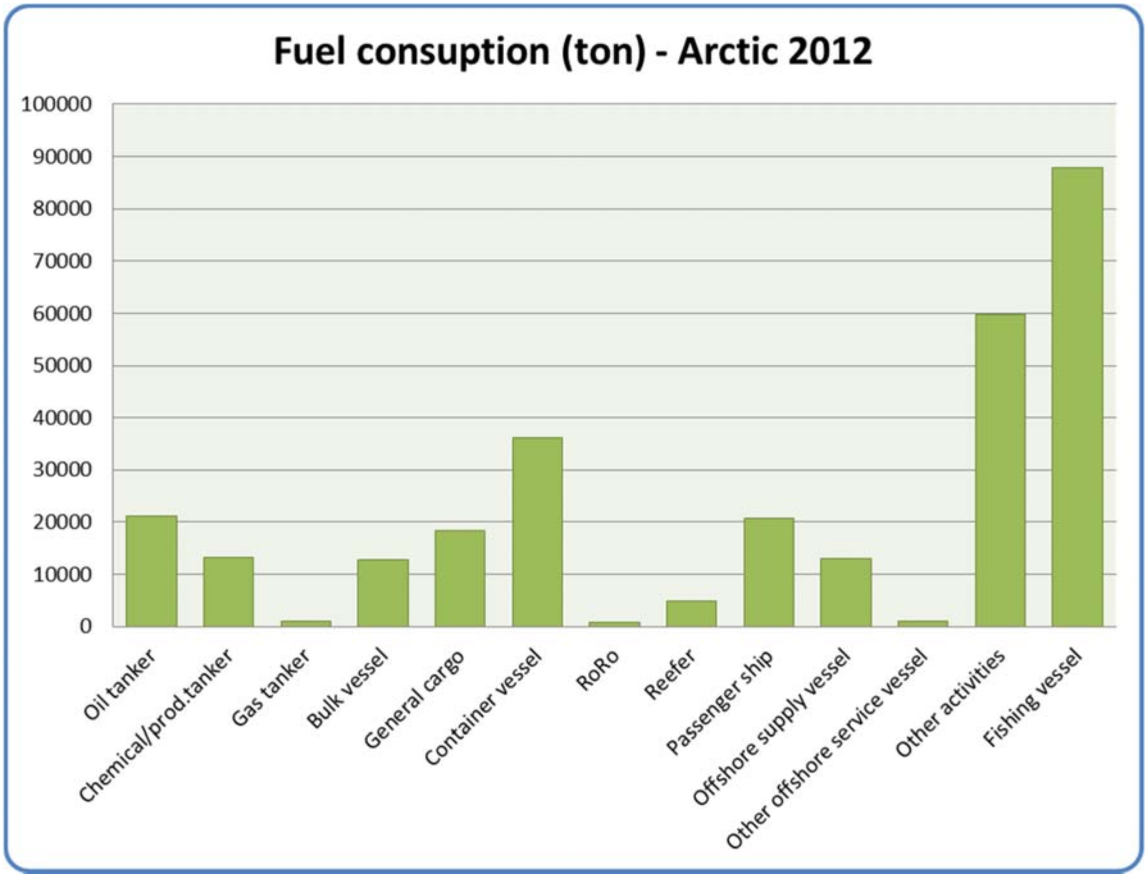


Figure 5-16 – Estimated fuel consumption for different ship types in the Arctic

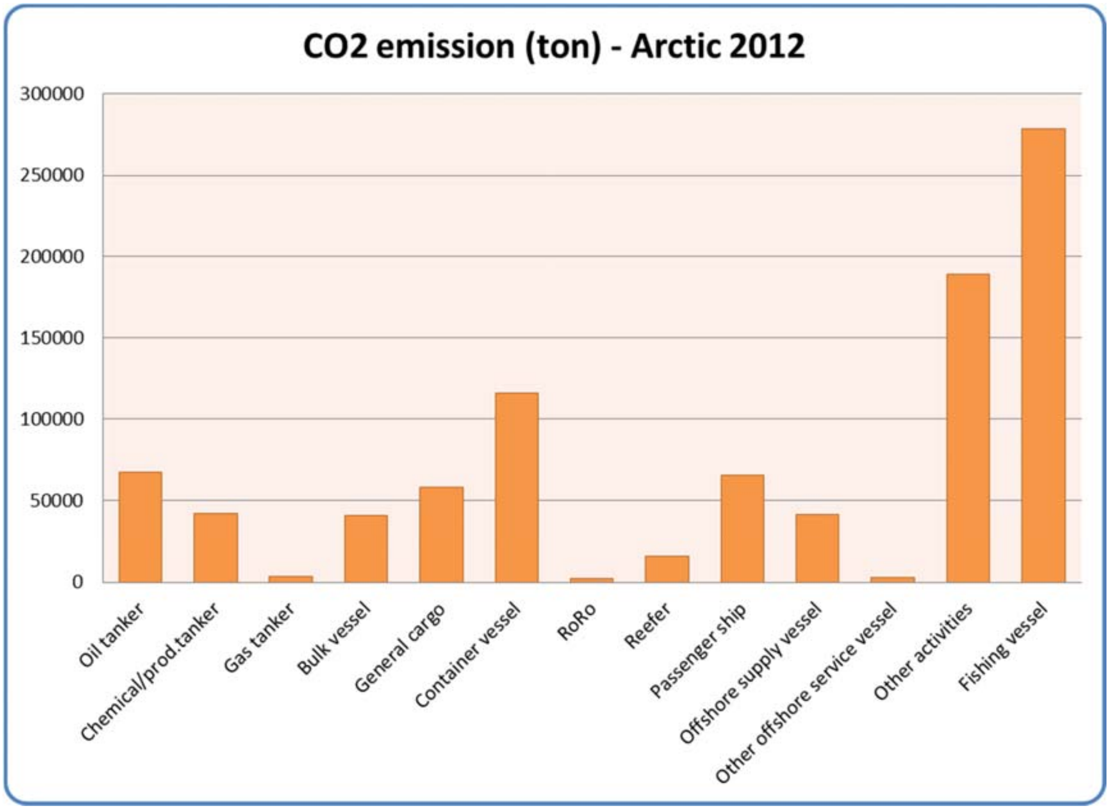


Figure 5-17- CO2 emission from different ship types in the Arctic

The CO_2 emission is proportional to the fuel consumption as shown in Figure 5-16 and Figure 5-17. This is also the case for black carbon (BC) emission but as is shown in Appendix A, the factors used in the estimation of NO_x, SO_2 and PM vary with engine and fuel types and hence the different charts will look different as well.

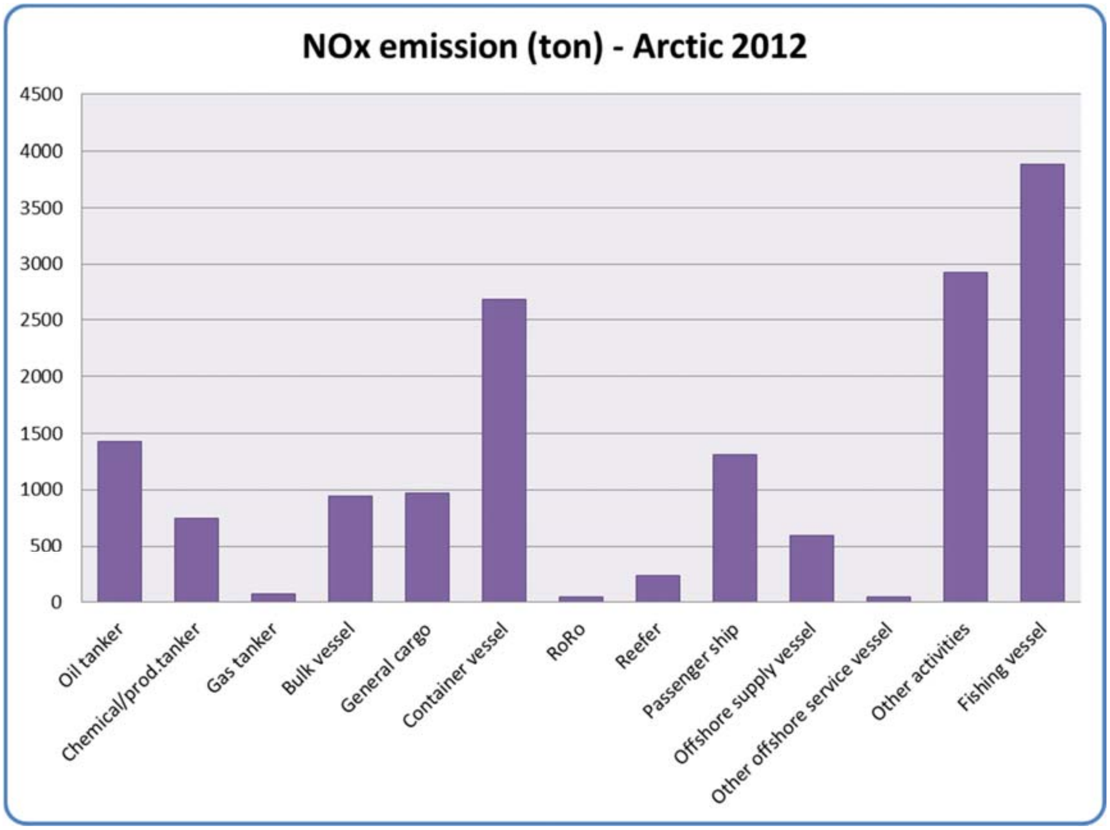


Figure 5-18 - NOx emission from different ship types in the Arctic

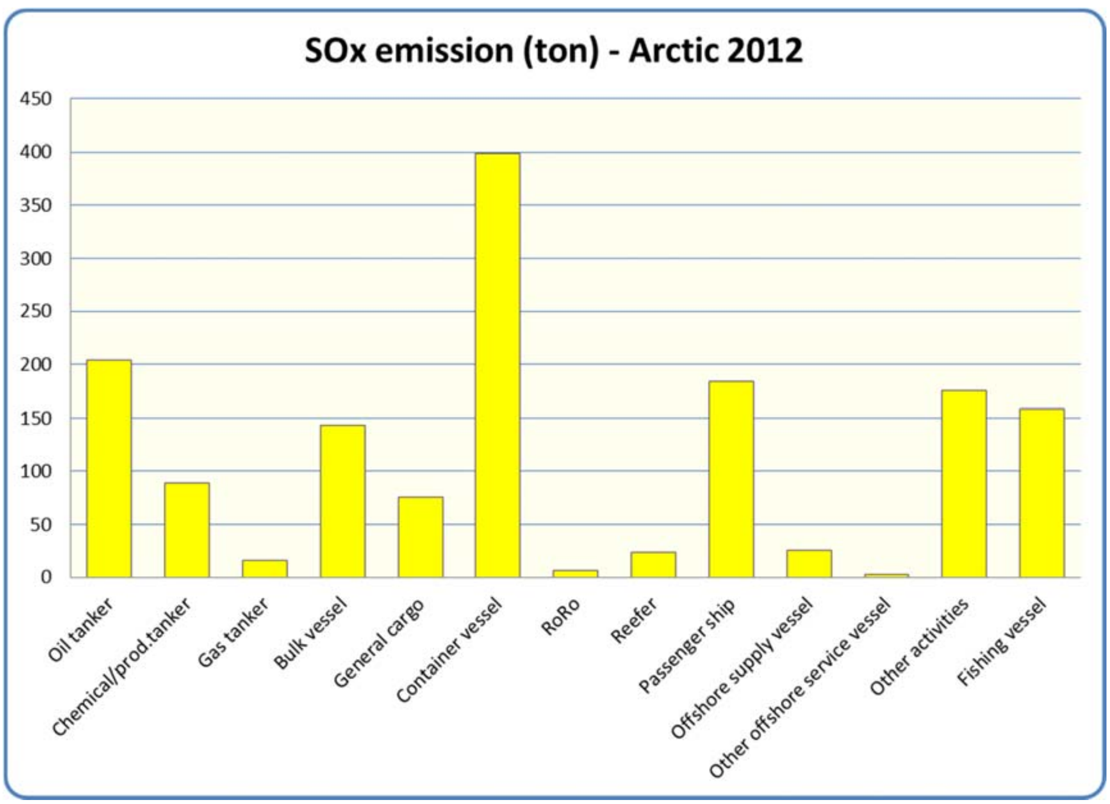


Figure 5-19 – SOx emission from different ship types in the Arctic

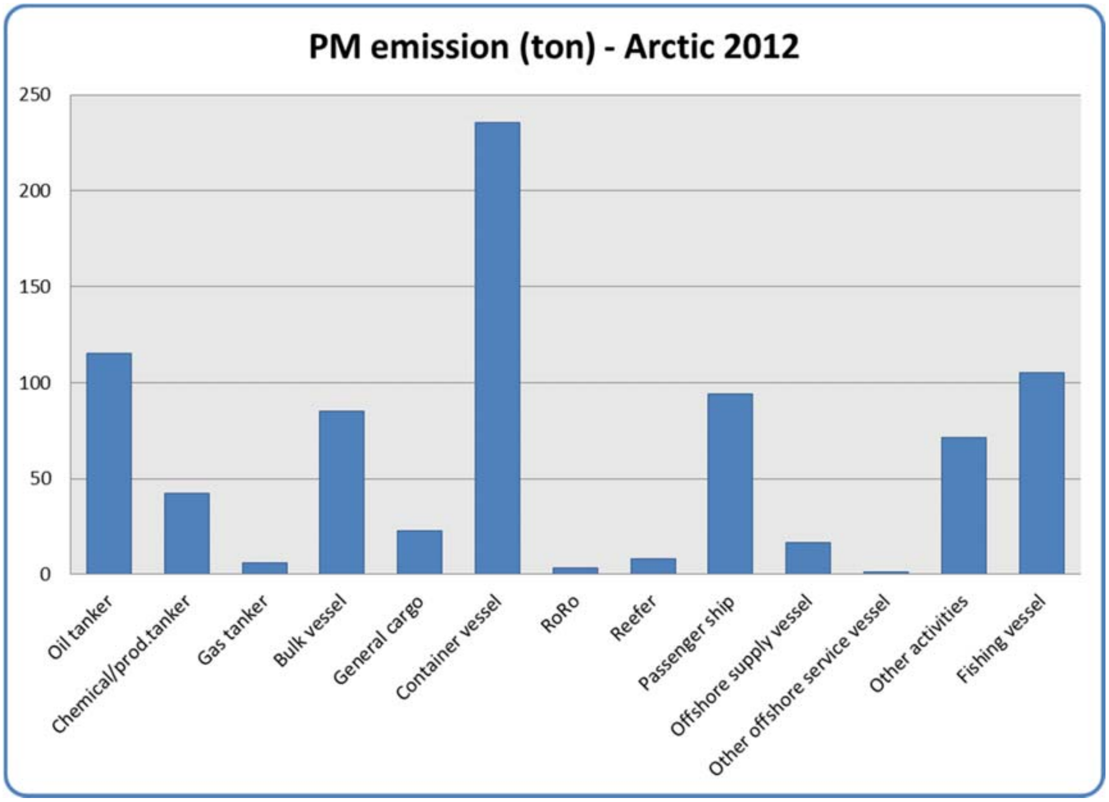


Figure 5-20 -PM emission from different ship types in the Arctic

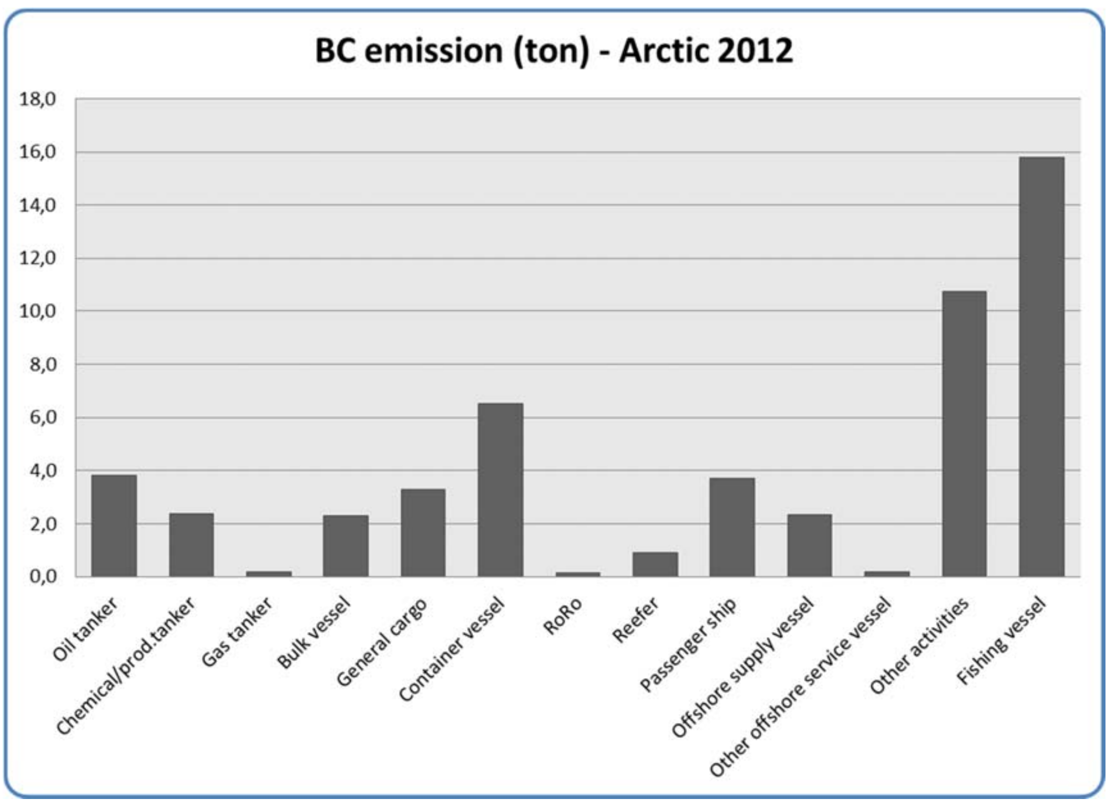


Figure 5-21 - BC emission from different ship types in the Arctic

6 INCIDENT RISK AND RISK OF OIL SPILL IN THE ARCTIC

"Navigating ships in cold areas and in ice pose additional risk elements and challenges beyond what the shipping industry are used to from world-wide operations. The risk elements related to general world-wide operation are well known based on several hundred years of experience. The experience from Arctic navigation is more limited and hence relevant statistics is not always available. The anticipated increase in commercial shipping will pose a set of new risks and challenges, related to type of operation, ship types and sizes, experience of crew etc.

An important and particular Arctic hazard comes from the increased loads on the ship hull and the machinery system due to ice impacts, giving additional requirements to the design of the hull structure, the machinery system and the appendices connected to the vessel. In addition, the low ambient temperature put extra demand on the material quality of the hull and the functionality of the many components onboard related to the ship operation and safety. Some of the main challenges related to operation in cold climate are listed section 6.1.

A schematic illustration of the total risk picture can be seen in Figure 6-1where the known risk elements from worldwide operation are used as basis. Some of these risk elements could be collisions, groundings, structural failures, fire etc. For Arctic shipping, some of these risks will be higher. In addition there will be some new risk elements which are not found in world-wide operation, e.g. ice loads, icing, freezing in etc. Likewise, there will be risk elements in worldwide operation which are lower or not applicable for Arctic operation.

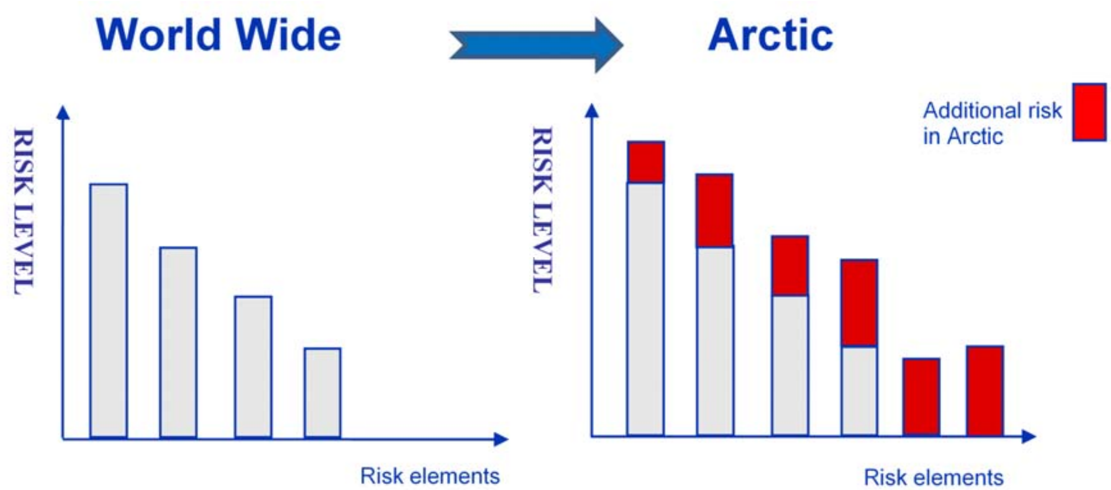


Figure 6-1 - Risk elements worldwide versus the Arctic

In the literature, the risk is usually defined as a function of the probability of an incident and the magnitude of the consequence of the incident. Hence, the risk can be reduced either by limiting the probability of an event or limiting the consequence of an event when it happens.
The ship activity documented in Section 5.1 clearly illustrates that the general activity level in the Arctic is low and consequently limited incident data is available for this region.

6.1 Hazard factors

Most of the maritime activity in the Arctic will likely continue to take place in areas with open water and limited ice and with main activities happening during the summer period. Only a limited number of vessels with higher ice class will operate in heavy ice far north during the winter season. The reduced presence of ice during the summer and increased oil and gas activities will also likely attract more ship operators. For maritime activities in the Arctic, risk shaping factors related to safety culture, operational measures, competence and training are all factors that may be difficult to quantify, however their impact on the total risk picture are significant.

The Polar Code Hazard Identification Workshop (IMO, 2011) identified the following contributing factors to the risk of Arctic shipping:
Contributing Factors

- Ice bergs as collision hazard.
- Ship pushed aground by moving ice.
- Ice bergs as ship crush hazard (structural failure).
- Ice on ship superstructure (loss of stability, foundering).
- Extreme cold leading to brittleness of metal (structural failure).
- Extreme cold or icing leading to technical failure of equipment, including emergency or backup equipment that might fail on demand due to extreme cold or icing.
- Long response times and limited emergency response capability.
- Weak or non-existent conventional navigational aids (lights, distinguishable features for bearings, etc.)
- Poor navigational charts
- High latitude effects on navigation systems (lack of GPS, cosmic radiation effects)
- Variations of magnetic north/ south
- Long days or long nights resulting in interrupted sleep patterns, loss of alertness, poor decision making
- Weak primary radar returns from icy shorelines
- Difficulty of distinguishing sea ice from wave clutter with primary radar
- Extremely low visibility or low visibility for long periods of time
- Extreme sea state (wave height)
- Extreme wind speed
- Darkness
- Extreme brightness due to low sun, 24 hours per day

6.2 Risk analysis for the use and carriage of oil in the Arctic

Figure 6-2 shows the data flow in the project providing the basis for the different analysis performed as part of the study. The data collected by the AIS-Sat1 satellite is received at the DNV data centre and processed. The processing includes identifying the vessels and matching these with other relevant data sources. Performing this process, a full overview if the vessel demography is established and mapped. This data then provides the input to the DNV risk model which calculates five modes of risk frequencies and four modes of spill masses of bunker oil and cargo oil. Finally the risk data is tabulated and mapped identifying the high-risk regions in the Arctic with respect to oil spills.

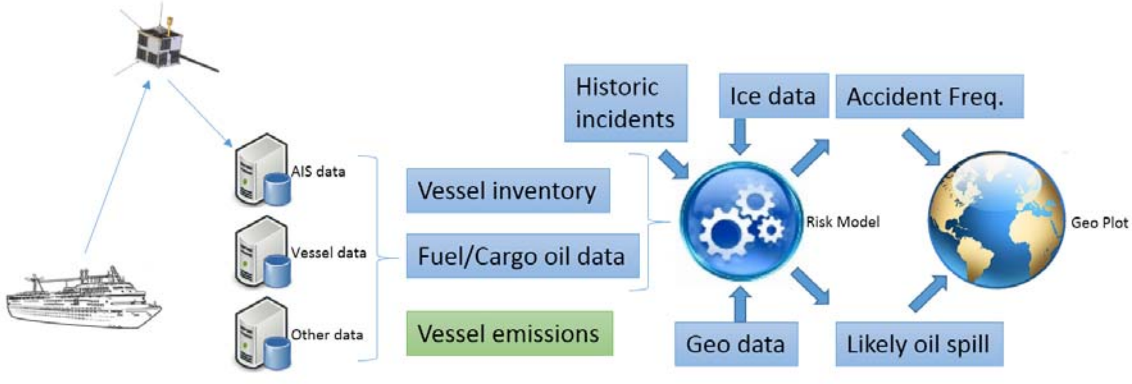


Figure 6-2 - Data management in project

It is important to acknowledge that risk analysis over such vast areas as the Arctic will have to be at a high level with a relatively coarse resolution. Also, this analysis is identifying the likely incident and oil spill scenarios of the Arctic traffic only.

The frequencies of incidents and resulting likely oil spill mass is calculated for vessel traffic related to the use and transport of oil in the Arctic, based on the traffic picture provided in Chapter 5.2.

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

The risk analysis has split potential oil spills in three groups:

- Cargo oil.
- Bunkers - HFO fuel – bunker tanks are assumed to be 65% full.
- Bunkers - distillate fuel – bunker tanks are assumed to be 65% full.

Cargo oil includes all types of oil and the ship categories Oil Tankers and Chemical/Prod tankers are assumed to be the carriers of this type of cargo as bulk. According to the Lloyds ship breakdown structure presented in Appendix E, these vessel categories comprises vessels carrying liquid bulk cargo ranging from asphalt and residuals, crude oil to fruit juice and vine. It is assumed that the latter is not part of the transport chain within the Arctic and that the major bulk is crude oil or different versions of distillates.

Oil tankers are assumed to carry oil cargo half the distance they sail, and are thus modelled as carrying only bunkers the other half of the sailed distance.

6.2.1 Accident frequencies

In previous analyses, it has been shown that it can be assumed that the probability of an accident is proportional to the distance sailed, (DNV, 2002). Based on accident frequencies per nautical mile and traffic data, it is then possible to estimate the expected number of accidents.

The Arctic is a region with unique operational challenges with regards to safety and is also an area poorly represented in accident statistics due to, among other things, very limited traffic. Thus, accident frequencies originally developed for traffic in the Barents Sea (DNV, 2012) have been used in this project due to operational similarities with the ArcticThe Accident frequencies for the Barents Sea where based on serious[1] shipwrecks leading to spill of oil products or bunker fuel recorded in international statistics from IHS Fairplay Causality Database (IHS Fairplay, 2012). Combined with the estimated distance traveled per type of vessel within the same period, accident frequencies per sailed

[1] Shipwrecks are defined as either non-serious or serious in the IHS Fairplay database

nautical mile where developed. These general data where evaluated against the Norwegian Maritime Directorate accident database to be representative for conditions in the Barents Sea. The frequencies are not differentiated with regards to vessel categories.

It may be considered for future studies to expand the accident frequencies to distinguish between vessel categories, vessels class notations, effects of vessel age, as well as refine the parameters used to distinguish the Arctic conditions. This may not considerably influence the calculated oil spill masses, but it may shift the risk picture, in particular the ice incidents maps.

The accident frequencies are estimated within each of the four accident categories as defined by IHS Fairplay Causality Database below (IHS Fairplay, 2012) plus Ice risk with is not a category in the database, but is manually extracted from the database through free-text identification.

Grounding:
Includes ships reported hard and fast for an appreciable period of time as well as incidents reported touching the sea bottom. This category includes entanglement on under water wrecks or obstructions.

Collision:
Striking or being struck by another ship, regardless of whether under way, anchored or moored. This category does not include striking under water wrecks. (IHS Fairplay, 2012)

Hull/Machinery:
Includes ships lost or damaged as a result of hull/machinery damage or failure which is not attributable to any other categories[2]*.*

Fire/Explosion:
Where the fire and/or explosion is the first event reported (except where first event is a hull/machinery failure leading to fire/explosion).
Note: It therefore follows that casualties involving fires and/or explosions after collisions, stranding etc., are categorised under 'Collision', 'Stranding'. Scavenge fires and crankcase explosions are included in this category.

Ice damage:
Where ice is part of the reported damage. If oil spill is reported, the incident is tagged. Since this is not a formal risk category in the HIS Fairplay database, this category is more limited to what may be calculated based on the data. For example no oil spill volumes may be derived.

Table 6-1 shows the accident categories assessed, and corresponding base frequencies used. In the risk analysis it is differentiated between accidents resulting in spill of oil products (i.e. cargo) and spill of fuel, each with its own likelihood of occurring:

- Cargo oil. This category includes oil and chemical products tankers with cargo. They are assumed to carry cargo half the distance they sail.
- Bunkers. This category includes all ships in the analysis.

[2] I.e. not attributable to any of the other accident categories in the IHS Fairplay database.

Table 6-1 - Base accidental frequencies per nautical mile for different accident categories

	Grounding	Collision	Hull/Machinery	Fire/Explosion	Ice related[3]
Base Frequency [1/Nm] – Spill of oil products	5.79E-08	2.65E-08	4.72E-09	3.32E-08	1.1E-05
Base Frequency [1/Nm] – Spill of bunker fuel	2.6E-08	1.8E-08	1.7E-08	1.8E-08	

Statistics describing the extent of damage to ships that have been involved in groundings, collisions, structural failures or fire/explosions do exists. Given that there has been a shipping accident, it is possible to calculate the probability of different spill masses. This calculation uses empirical data from DNV experience (RiskNet, 2013) on the probability of released mass by accident.

It should also be noted that recent studies documenting underreporting of accidents in the major databases indicate that the accident frequencies shown herein could be too low (Psarros et al, 2010) perhaps by a factor 2 or more.

6.2.2 Estimations of spill mass given an accident

Statistics describing the extent of damage to ships that have been involved in groundings, collisions, structural failures or fire/explosions do exists. Given that there has been a shipping accident, it is possible to calculate the probability of different spill sizes. This calculation uses empirical data from DNV experience (RiskNet, 2013) on the probability of emission by accident.

Oil tankers and Chemical/Prod tankers are calculated with regards to carriage of both oil products and bunker fuel. Oil spill risk for the other vessel categories is only calculated with regards to bunker fuel. Bunker fuel is either HFO or Distillate.

Given an accident, likelihoods of spills within four spill categories are used. Each spill category is define as a share of cargo oil carried or bunker capacity. E.g. given an oil tanker having a serious (as defined in the IHS Fairplay database (IHS Fairplay, 2012) grounding accident, there is a likelihood of 3% that it will result in spilling 60% of the content of one cargo tank.
See Appendix C for further details on the estimations of spill mass given an accident.

6.3 Risk Results – estimated annual accident frequencies

Accident frequencies per annum are calculated by combining the accident frequencies per nautical mile with distance travelled. Considering the traffic of 2012 in the Arctic, a total of 5,831,278 nautical miles where sailed. All results are assuming this traffic level.

[3] Any incidents due to problems with ice. Frequency applies only to sailed distances with ice coverage of 70% or more. See Appendix C for details. Also – note that no likely oil spill is calculated for this incident category.

Table 6-2 and Figure 6-3 show the total estimated annual accident frequencies. These represent the expected annual number of accidents within each accident category resulting in spill of HFO, distillate or oil cargo (irrespective of spill mass). Due to the ice damage frequency being conceptually different from the other accident categories, the frequencies of ice related accidents and frequencies of ice related accidents leading to oil spill are shown in Figure 6-4. See Appendix C for further details on the development of the ice related accident category and its limitations.

Table 6-2- Estimated annual accident frequencies from Arctic shipping (number of incidents per year leading to an oil spill)

	Grounding	Collision	Hull/ Machinery	Fire/ Explosion	**Total**
Oil tanker	0,0449	0,0015	0,0059	0,0106	**0,0629**
Chemical/Prod tanker	0,0380	0,0012	0,0042	0,0076	**0,0510**
Gas tanker	0,0001	0,0000	0,0001	0,0001	**0,0004**
Bulk carrier	0,0053	0,0002	0,0024	0,0025	**0,0104**
General cargo	0,0535	0,0020	0,0091	0,0096	**0,0743**
Container vessel	0,0257	0,0010	0,0047	0,0050	**0,0364**
RoRo	0,0026	0,0001	0,0004	0,0004	**0,0036**
Reefer	0,0062	0,0002	0,0015	0,0016	**0,0096**
Passenger	0,0416	0,0016	0,0062	0,0065	**0,0559**
Offshore supply vessel	0,0054	0,0003	0,0032	0,0034	**0,0122**
Other offshore vessel	0,0009	0,0001	0,0009	0,0010	**0,0028**
Other activities	0,0697	0,0028	0,0171	0,0182	**0,1078**
Fishing vessel	0,0609	0,0032	0,0445	0,0471	**0,1556**
Total	**0,3547**	**0,0142**	**0,1003**	**0,1136**	**0,5829**

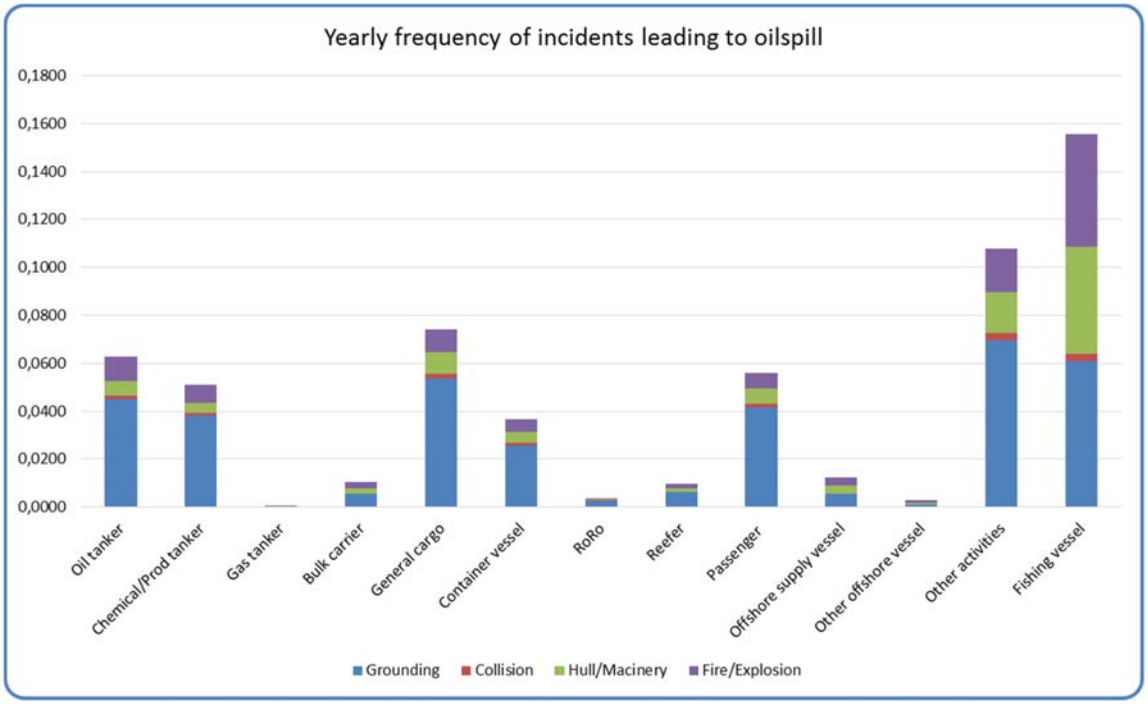


Figure 6-3 - Estimated number of annual incidents leading to oilspill

It is worth noting that the general calculated risk resembles the activity level of each vessel category, but not quite. The category “Other Activities” and passenger vessels are generally over-represented on grounding and ice related risk in our data. This is due to the fact that this group of vessels operates a lot in sheltered waters close to land and consequently the grounding risk is higher. Also, the “Other Activities” vessels comprise ice breakers which frequently operate in ice. However, the ice risk is likely to be over-estimated as these vessels have sufficient ice strengthening for the operation. The same will apply to the container vessels, which also is a group of vessels identified with a high risk of ice damage. But the major part of the in-ice operation by container vessels is based on the year-round operation to Dudinka in Russia by dedicated ice strengthened vessels.

Note also that the calculated ice damage frequency is conceptually slightly different as the IHS Casualty database (IHS Fairplay, 2012) has no specific category related to ice. Instead, a free-text search of the reported text has been performed and the incident thus classified as ice-related. These incidents are used as basis for the risk analysis with regards to ice. Therefore the ice damage frequency is not directly comparable to the other casualty categories. See Appendix C for further details on the development of the ice related accident category and its limitations

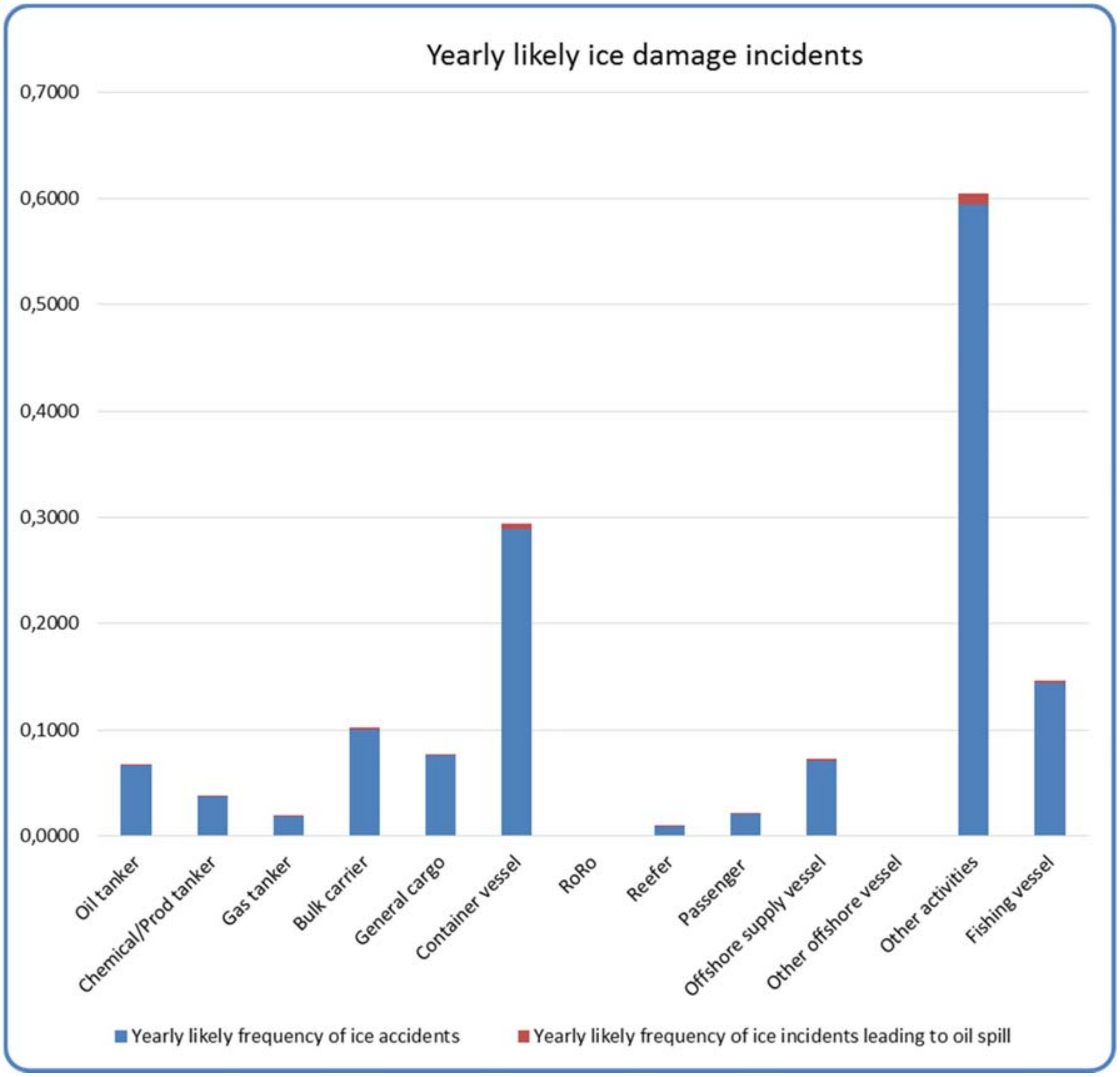


Figure 6-4 - Average number of annual ice damage incidents – Incidents with no oil-spill and leading to oils pill

Table 6-3 gives the accident return periods corresponding to the frequencies in Table 6-2. The results indicate that with the 2012 traffic level in the Arctic, a serious accident resulting in an oil spill could on average be expected once every 1.6 years. The most frequent single incident risk mode is an “other activity” vessel damaged by ice (but no reported oil spill), which likely will happen every 1.7 years but will only result in an oil spill every 93 years. It is important noting that this estimation does not take in to account the fact that many of the vessels in this category are icebreakers or vessels with ice class. Hence, the likely damage return period is likely to be higher. Figure 6-5 clearly illustrate that even though ice damage is a relatively frequently reported incident, only a small proportion is reported to result in oil spills.

The generally very low ship density in the Arctic region leads to low collision risks.

Table 6-3 – Estimated number of years between incidents leading to an oil spill from Arctic shipping

Years between incident leading to oil spill							
Row Labels		Grounding	Collision	Hull/Mach	Fir/Exp	Ice_High	**Total**
1	**Oil tanker**	22	669	169	95	837	**15.6**
2	**Chemical/Prod tanker**	26	806	236	132	1491	**19.3**
3	**Gas tanker**	6675	116646	8427	7959	3130	**1384**
4	**Bulk carrier**	187	4041	425	402	553	**81.7**
5	**General cargo**	19	488	110	104	736	**13.2**
6	**Container vessel**	39	1006	211	199	192	**24.0**
7	**RoRo**	379	9898	2446	2310		**279**
8	**Reefer**	162	4075	648	612	6128	**102**
9	**Passenger**	24	644	162	153	2718	**17.8**
10	**Offshore supply vessel**	187	3743	313	295	782	**74.2**
11	**Other offshore vessel**	1093	18203	1111	1050		**354**
12	**Other activities**	14	359	58	55	93	**8.4**
13	**Fishing vessel**	16	313	22	21	386	**6.3**
Grand Total		**2,8**	**70,3**	**10,0**	**8,8**	**39.1**	**1.6**

6.4 Risk Results – Estimated annual oil spill

Given the estimated spill frequency leading to an oil spill and the estimated spill mass, an annual spill mass is calculated (as explained in Appendix C).

Table 6-4 and Figure 6-6 show the total estimated annual spill mass. Figure 6-7 illustrates the same but split in to HFO, Distillate fuel and Oil products spilt within each accident mode and vessel category. It is important to note that even though there exists a HFO ban within the Svalbard archipelago, this has not been accounted for in the risk analysis. Hence, the estimated likely annual HFO oil spill is likely to be overestimated within this region and likewise, the distillate fuel spill will be underestimated.

Table 6-4 - Estimated annual spill mass (tons) from Arctic shipping (Ice incidents spills not calculated)

	Grounding	Collision	Hull/ Machinery	Fire/ Explosion	Total
Oil tanker	32,72	1,32	4,70	10,64	49,4
Chemical/Prod tanker	21,91	0,79	1,52	3,56	27,8
Gas tanker	0,10	0,01	0,13	0,08	0,3
Bulk carrier	0,92	0,08	0,82	0,51	2,3
General cargo	1,86	0,13	0,61	0,38	3,0
Container vessel	2,67	0,19	0,81	0,50	4,2
RoRo	0,05	0,00	0,02	0,01	0,1
Reefer	0,24	0,02	0,10	0,06	0,4
Passenger	2,16	0,15	0,76	0,47	3,5
Offshore supply vessel	0,17	0,01	0,14	0,09	0,4
Other offshore vessel	0,01	0,00	0,02	0,01	0,04

Other activities	2,28	0,17	1,19	0,73	4,4
Fishing vessel	0,96	0,09	1,14	0,71	2,9
Total	66,05	2,98	11,96	17,76	98,8

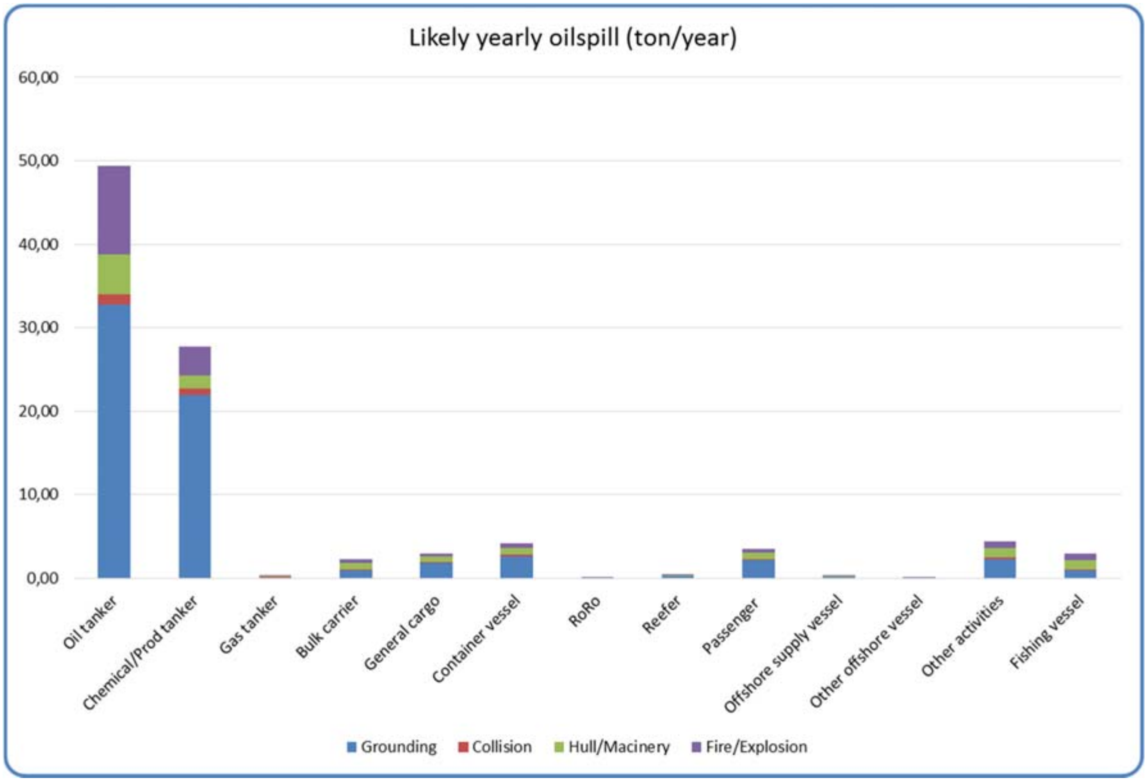


Figure 6-6 - Estimated annual spill volumes (tons) from Arctic shipping (all accident modes)

Even though the most likely incident in the Arctic is a fishing vessel damaged by ice, the grounding of a tanker represents by far the greatest spill potential, and therefore the likely highest yearly average oil spill.

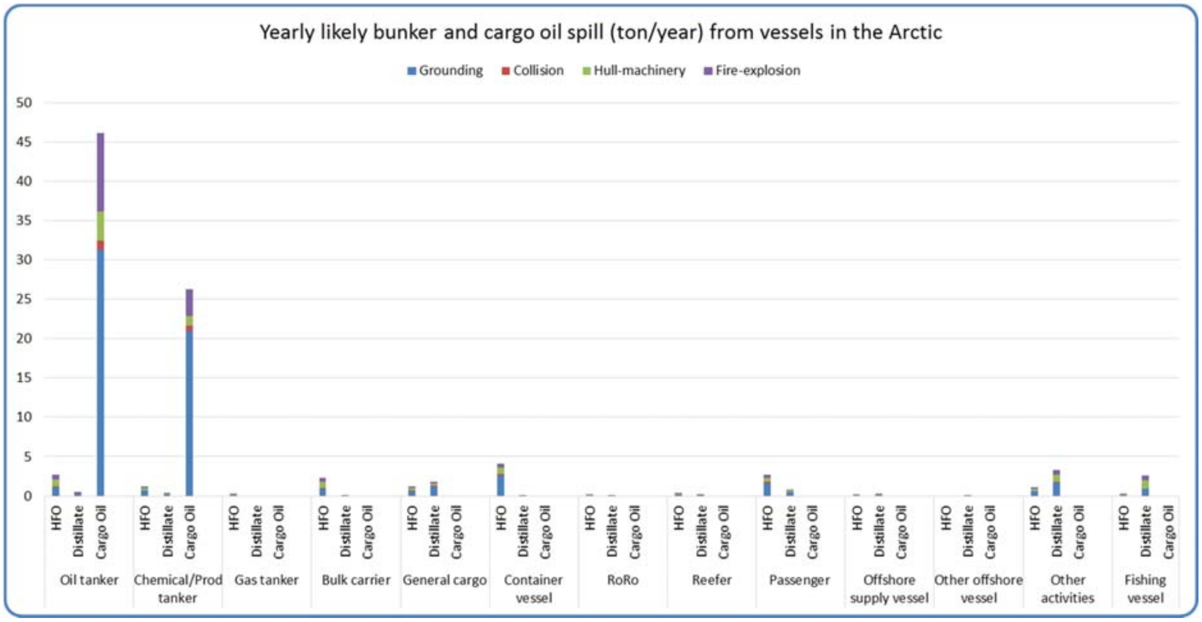


Figure 6-7 Estimated annual spill mass (tons) from Arctic shipping (four main accident modes)

Due to the cargo oil being the dominating estimated spills, Figure 6-8 illustrates the bunker oil separately.

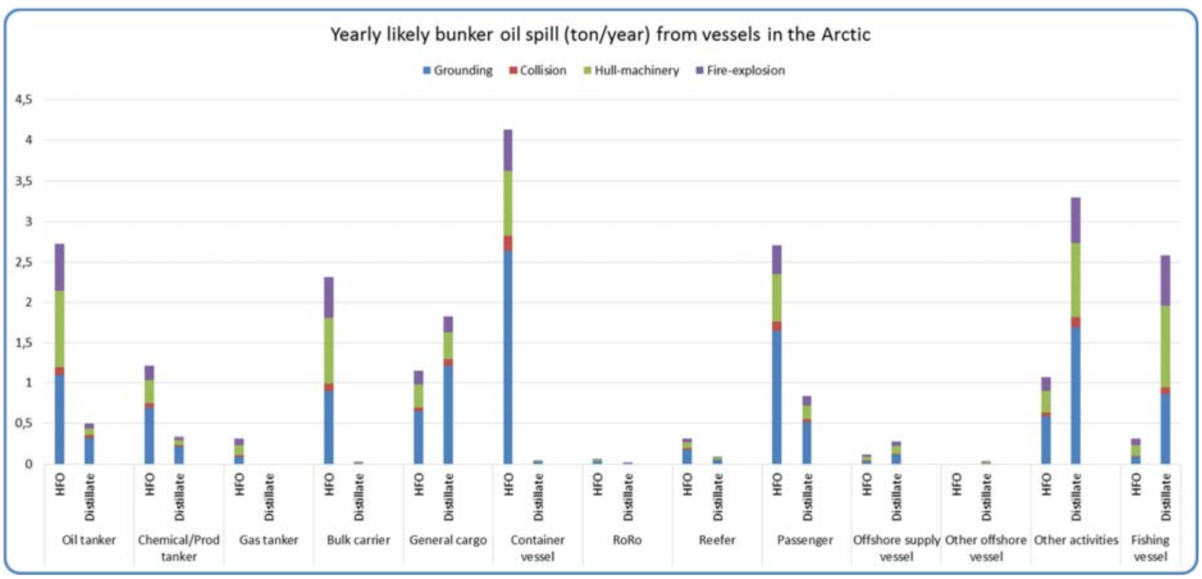


Figure 6-8 - Estimated annual spill mass (tons) from Arctic shipping (four main accident modes)) – bunker oil only

6.5 Risk Results - Geographical distribution of risk

The figures in this section identify the geographical distribution of estimated annual oil spill mass in the Arctic and comprise all incidents modes. Appendix D shows a full geographical breakdown of the different modes of oil spill.

Plotting the calculated risk data geographically shows the combination of frequency and spill mass expressed as the annual average mass of oil spill to sea per 1x1 degree quadrant.

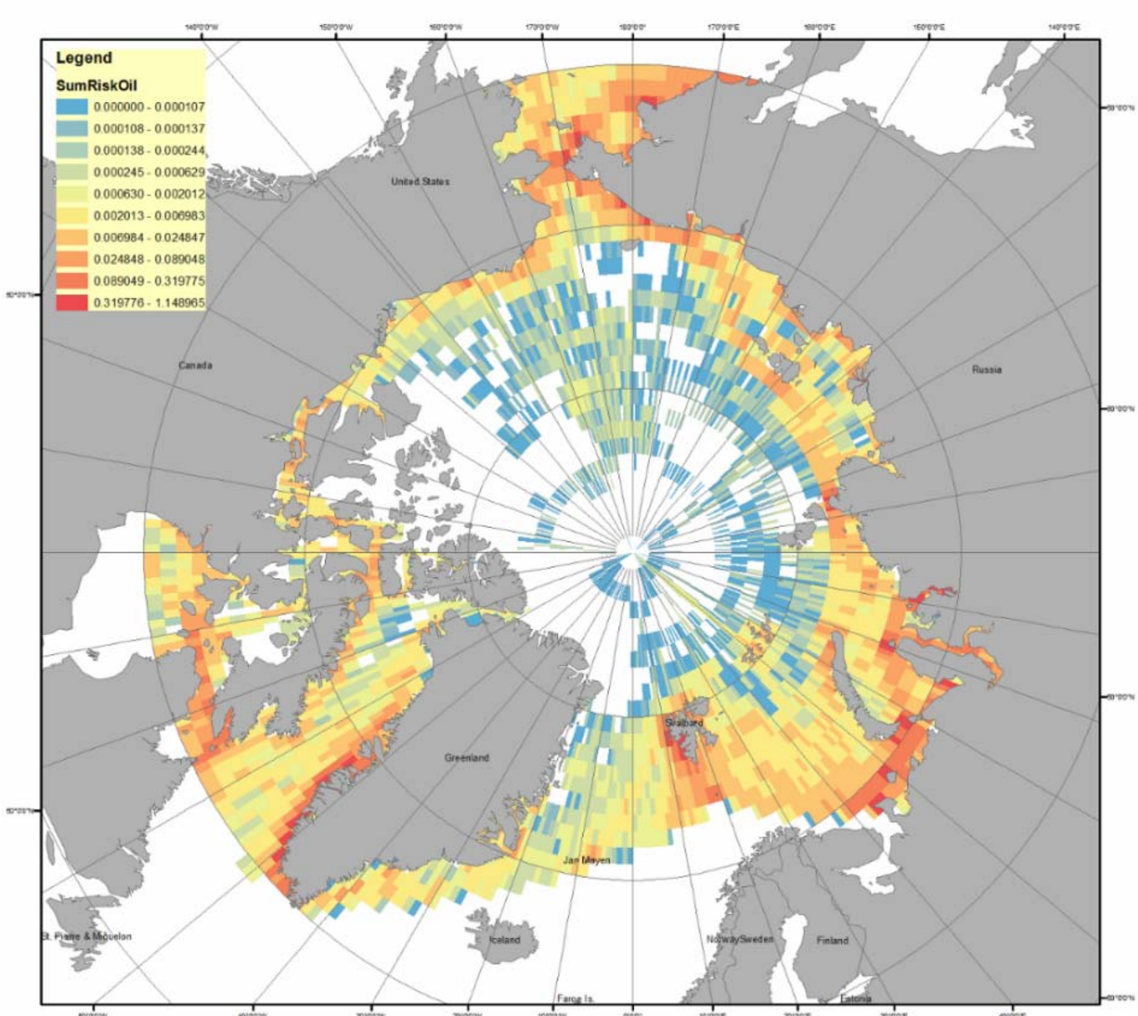


Figure 6-9 - Estimated annual oil spill mass (tons per 1x1 degree grid cells) - all risk components (but not ice)

Groundings of large oil and product tankers in the Russian coastal areas of the Barents Sea and the Kara Sea are identified is identified to represent the incident with highest risk of oil spill in the Arctic. Other areas of higher risk are the eastern part of the Chukchi Sea and the Bering Sea as well as south east Greenland and the strait in to Hudson Bay which are all areas of regular oil tanker traffic.

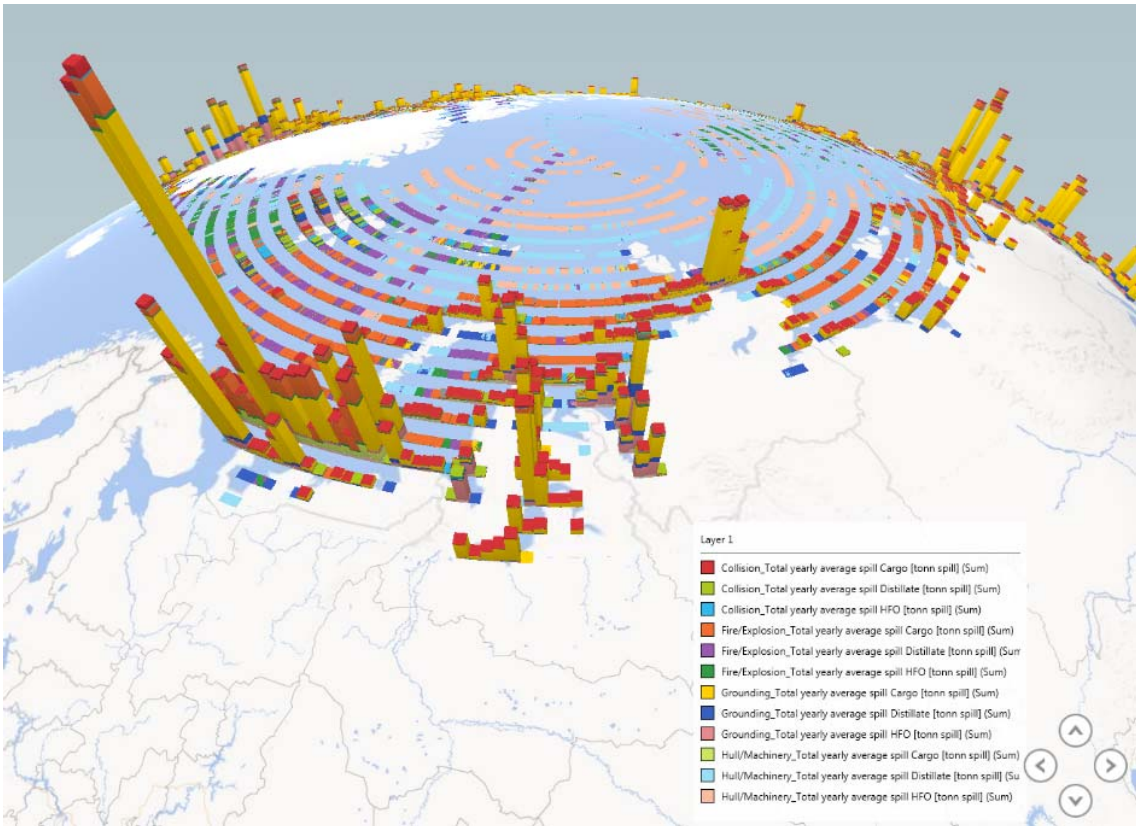


Figure 6-10 - Estimated annual oil spill mass (tons per 1x1 degree grid cells) - all risk components (but not ice) - Russian north coast

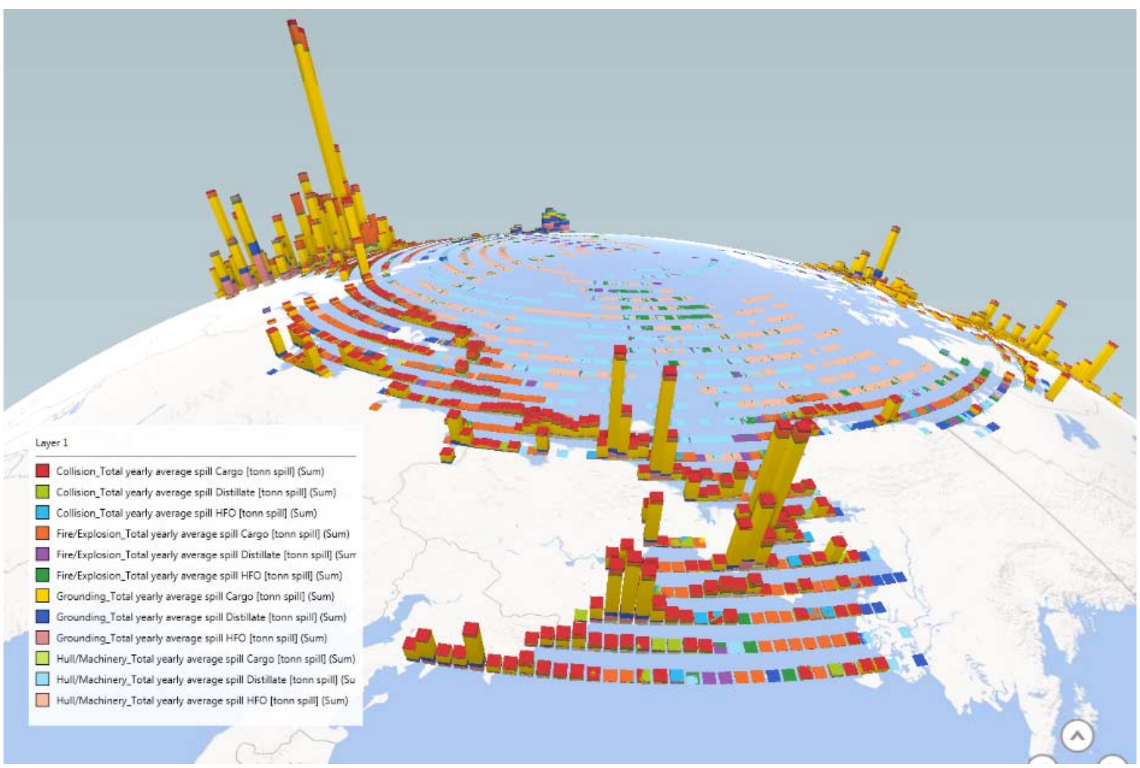


Figure 6-11 - Estimated annual oil spill mass (tons per 1x1 degree grid cells) - all risk components (but not ice) - Behring strait

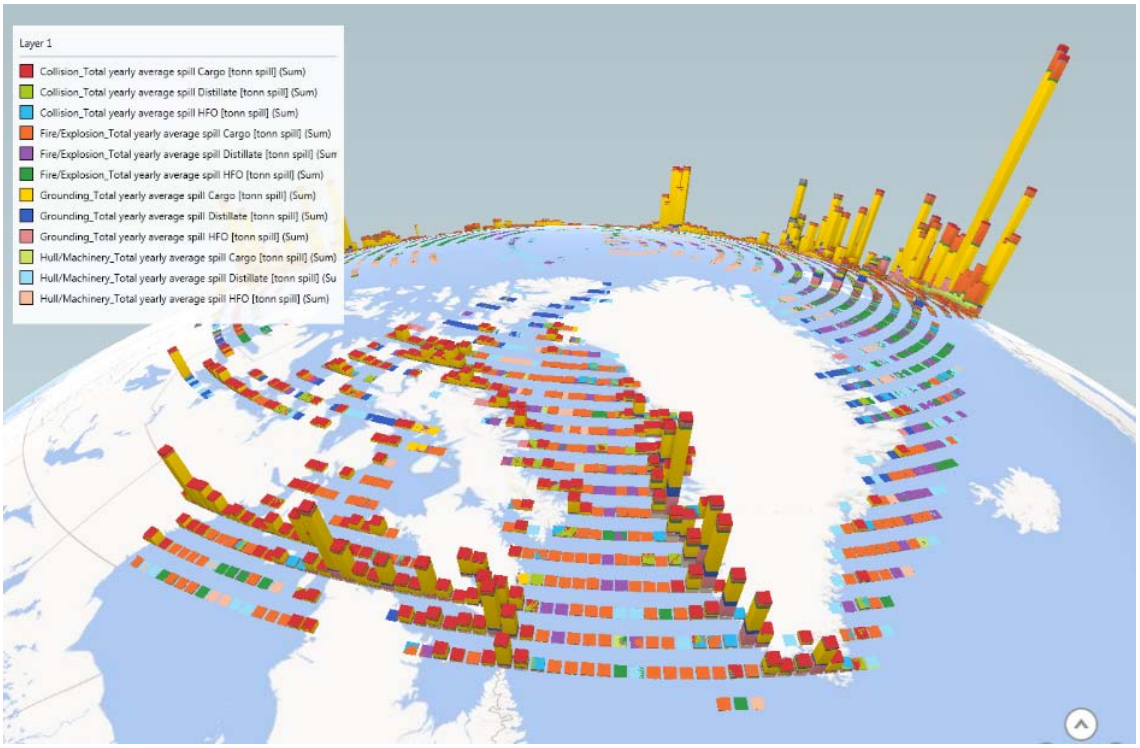


Figure 6-12 - Estimated annual oil spill mass (tons per 1x1 degree grid cells) - all risk components (but not ice) – Greenland/Canada

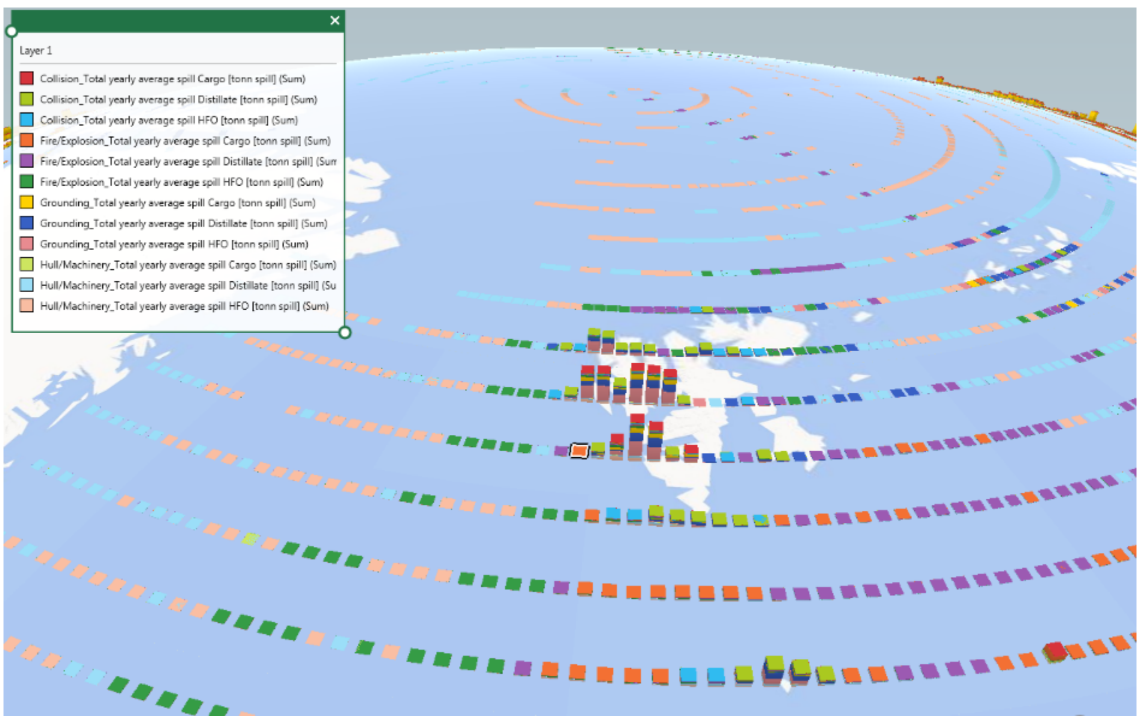


Figure 6-13 - Estimated annual oil spill mass (tons per 1x1 degree grid cells) - all risk components (but not ice) – Spitsbergen

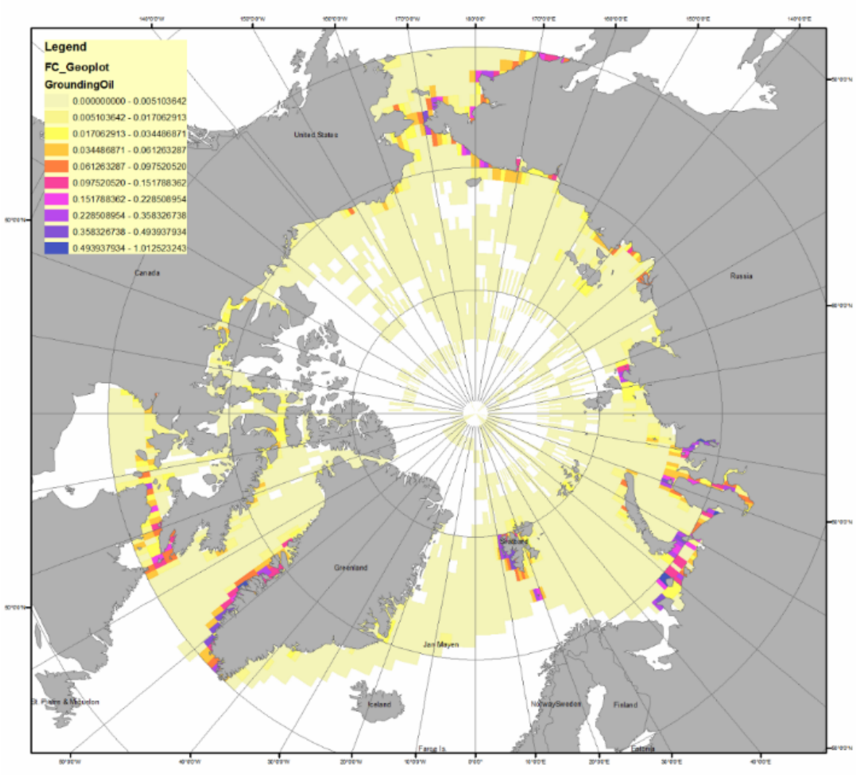


Figure 6-14 - Estimated annual oil spill mass (tons per 1x1 degree grid cells) - grounding

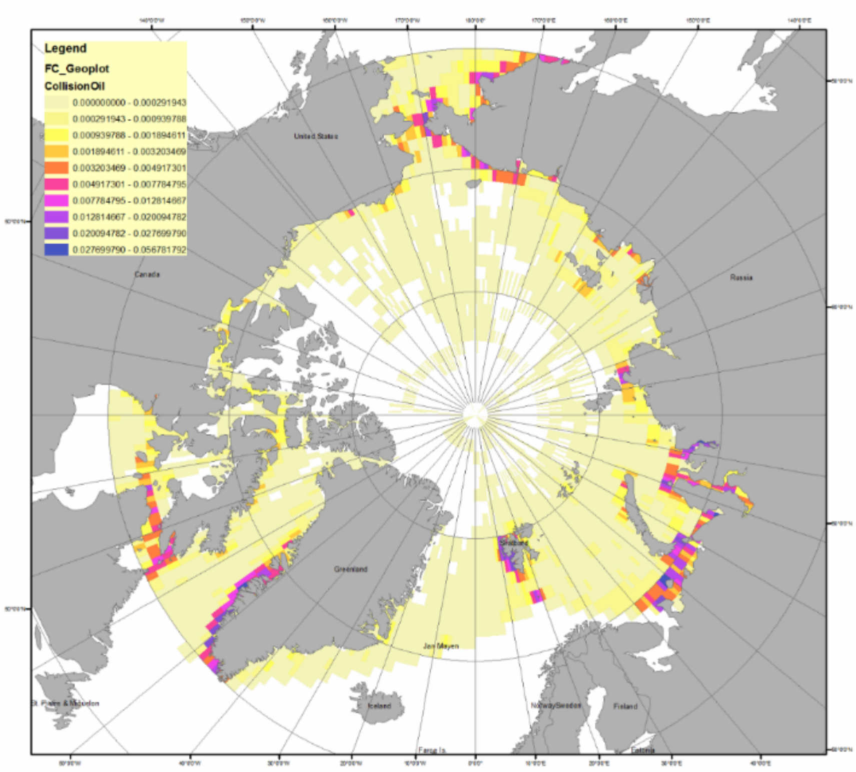


Figure 6-15 - Estimated annual oil spill mass (tons per 1x1 degree grid cells) collision

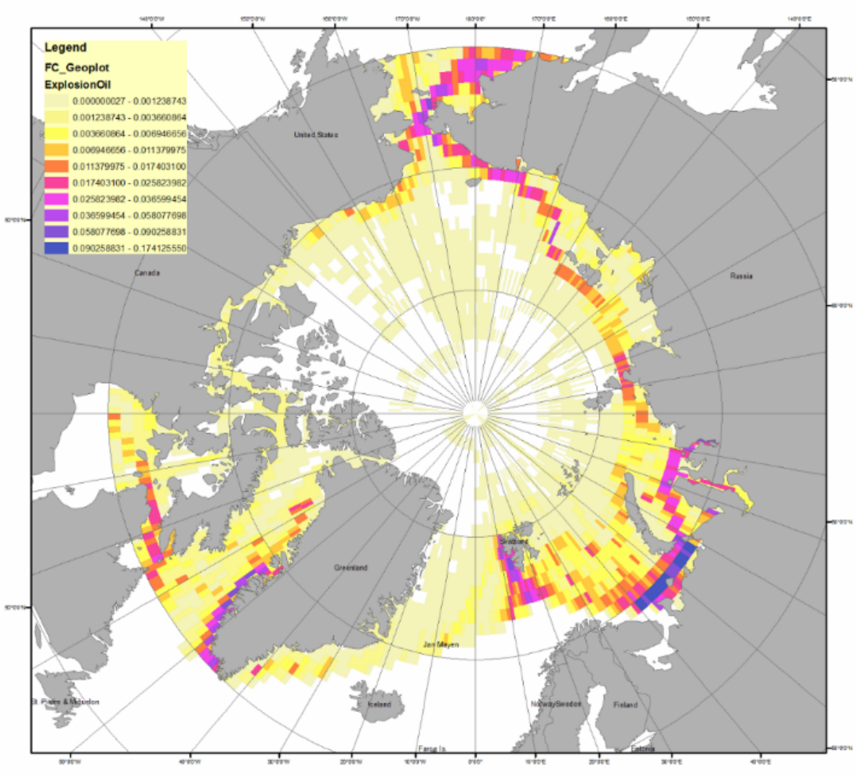


Figure 6-16 - Estimated annual oil spill mass (tons per 1x1 degree grid cells) fire/explosion

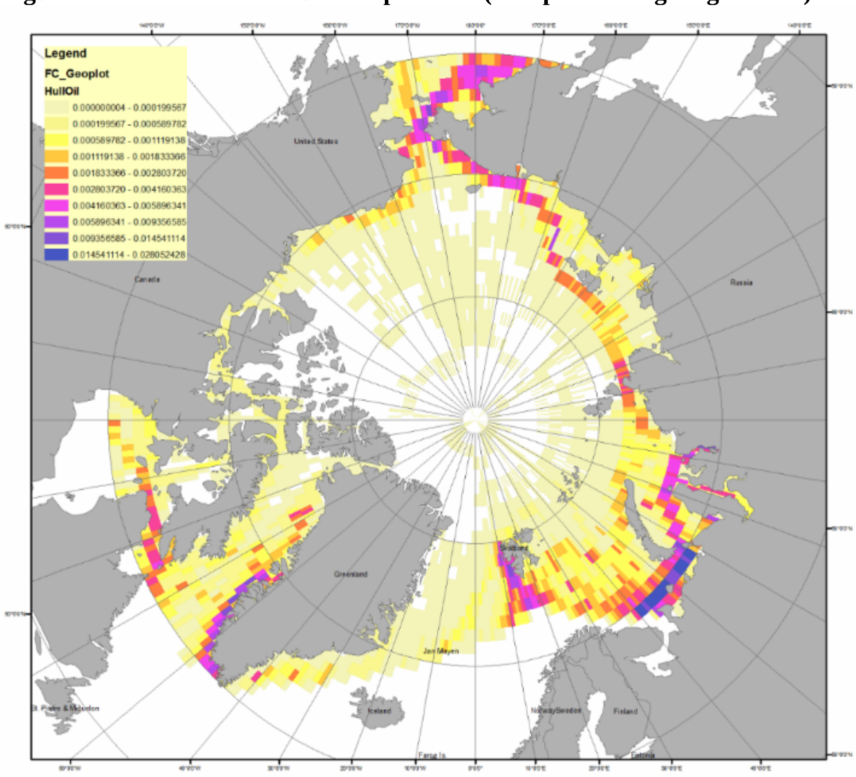


Figure 6-17 - Estimated annual oil spill mass (tons per 1x1 degree grid cells) from hull/mach damage

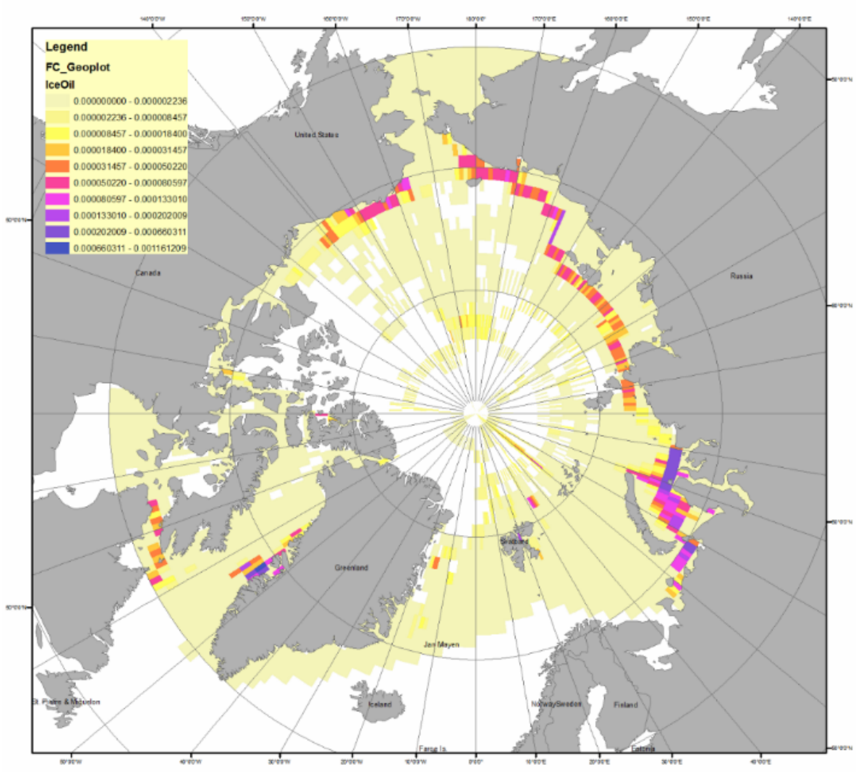


Figure 6-18 - Likely number of ice related incidents leading to oil spill (no spill mass estimated) (Incidents per 1x1 degree quadrant)

In Figure 6-18 the Russian side of the Barents Sea and the Kara Sea are marked as high risk areas for ice damages. This is due to relatively heavy winter/ice traffic to and from Varandey and Dudinka. However, these are operated by dedicated ice-strengthened vessels designed for full year Arctic operation. Hence when applying generic models for calculating ice risk, the calculated risk of ice damage is likely to be exaggerated for these vessels and the areas they populate. The same will apply to the traffic along the Northern Sea Route where, in case of ice, the vessels are either icebreakers or escorted by such vessels.

7 ASSESSMENT OF RISK MITIGATION OPTIONS

The above section provides a high-level overview of the risk of oil spill from shipping in the Arctic. The analysis gives indications regarding the main accident types, the main ship categories involved, and the geographical distribution of risk. Such indications are useful in discussing risk control measures. In this section the main risk features emerging from the above analysis is highlighted with the aim to identify risk control options suited for mitigation of the main risks. The identified risk control options are then assessed in a high-level cost-benefit analysis.

7.1 Main risk features

The analysis identifies the likely accident frequency of five different casualty modes as well as the likely bunker oil and cargo spill per year, and shows that the most likely accident mode leading to oil spill is groundings with a likely return period of 2.8 years (as shown in Table 7-1).
The risk may be reduced through either reduction of frequency or consequence, or both.

Table 7-1 - Years between likely incident leading to oil spill

Grounding	Collision	Hull/Mach	Fir/Exp	Ice_High
2.8 years	70 years	10 years	8.8 years	39 years

When looking at the likely volumes of oil spill from ship accidents (see Figure 6-6), this picture is even more pronounced towards groundings as the most severe mode of accidents, and with tankers in particular. It is clear from the risk assessment performed as part of this study that it is relevant to focus the attention to measures addressing the risk of groundings in general and grounding for tankers in particular.

Further insight might be drawn from the risk analysis, in particular Figure 6-14. The map show that the risk is concentrated in certain key areas; the entrance to the Hudson Bay, the west coast of Greenland, the West coast of Svalbard, the Russian coastline from the Kara Sea and westward, and the Behring straight region. The risk in all these areas is dominated by grounding risk and associated with a “high” concentration of tanker traffic.

7.2 Risk control options

Assessment of additional risk control measures in this report should go beyond measures already implemented or in the pipeline. For shipping in the Arctic, the main current regulatory development is the work with a mandatory Polar Code under IMO. The Polar Code will include a series of risk reducing measures for ships operating in Arctic waters. Thus, this section provides a brief overview of the main features of the Code (as drafted per Dec 2012). Further, possible additional measures will be discussed, including a high-level consideration of the applicability of such measures seen in light of the current risk picture.

7.2.1 Measures discussed in the Polar Code

The mandatory polar code is currently under development by the IMO, and tThe content of the draft Polar Codecode is subject to on-going debate and therefore in flux. Thus, a discussion of the content must be limited to the broad features of the text.

Firstly, the mandatory Polar Code clearly signals that the IMO acknowledge that ships operating in the Arctic and Antarctic environments are exposed to a number of additional risks. Poor weather conditions and the relative lack of good charts, communication systems and other navigational aids pose challenges for mariners. The remoteness of the areas makes rescue or clean-up operations difficult and costly. Cold temperatures may reduce the effectiveness of numerous components of the ship, ranging from deck machinery, navigation equipment and, emergency equipment to sea suctions. When ice is present, it can impose additional loads on the hull, propulsion system and appendages.

Secondly, the Polar Code covers a range of additional requirements to the design, construction, and operation of ships, as well as to the equipment carried on-board and the training of the crew. In addition, search and rescue matters relevant to ships operating in the polar waters are included. The main way of the Polar Code to reduce environmental risk is the same as for reducing risk for loss of lives and property; that is the additional requirements for safe design, construction and operation of ships to reduce the likelihood and consequences of accidents, given the particular polar conditions. The Polar Code will also include additional requirements for environmental protection that are not covered by the additional safety provisions. So far it seems such additional environmental requirements at least will address regular discharges from normal operations, by way of stricter regulations for certain effluents compared to other areas.

7.2.2 Additional measures

The wide scope of the Polar Code means that risk control relating to the construction, design and operation of vessels is best left out of a discussion of further additional risk mitigation measures in this report. In DNVs judgement, it is therefore more fruitful to discuss another class of measures, relating to the designation of particular geographic areas for additional protection by IMO. PAME is currently exploring the need for international designated areas for the Arctic high seas (i.e. outside the national jurisdictions of the Arctic coastal states. DNV is assisting PAME in this work (DNV-DII, 2013). This work explores some measures that have not yet been applied in the Arctic (nor are they part of the scope of the Polar Code).

There are essentially two available instruments available to the IMO for protecting designated areas:

1. Special Areas (SA), designated under specific annexes to MARPOL.
2. Particularly Sensitive Sea Areas (PSSA), not designated under MARPOL

In light of the findings in (DNV-DII, 2013) and the risk picture presented in this report, it is expedient to focus on the PSSA tool. PSSAs can provide additional protection through measures that may reduce the likelihood and consequences of accidents (acute pollution), in addition to measures that targets operational emissions and discharges. In contrast, SAs only provides additional protection from the operational pollution.

When an area is approved as a PSSA, specific measures (Associated Protective Measures – APMs) shall be used to control the maritime activities in the area, in particular measures such as routing measures and ship reporting systems/Vessel Traffic Services (VTS). Also new measures may be developed (approved by IMO) and applied in PSSAs. Member states can also pursue such APMs independently in an area—without PSSA designation. In contrast to measures such as a total HFO-ban or Special Area/ECA designation under MARPOL, PSSA designation enables a tailor made use of risk reducing measures in high-risk areas and for high-risk traffic. It is noted that APMs may also be implemented in an area without the PSSA status. However, it is considered that the process of establishing a PSSA may be important in itself, representing a thorough evaluation of the sensitivity of an area to damage by international shipping activities. The signal effect of a PSSA can also be of importance in terms of highlighting an area within which mariners are encouraged to exercise extra caution.

Ship routing measures and ship reporting systems may be the most relevant in terms of reducing risk from acute oil pollution, both bunker oil or cargo oil. Examples include:

- Measures such as traffic separation schemes, traffic lanes and separation zones/line and roundabouts may reduce risk from ship collisions (given the low traffic density in the Arctic this in not a relevant measure)
- Areas to be avoided, recommended routes and precautionary areas to direct traffic away from certain areas posing particular risk or containing particular environmental elements.

In general, areas to be avoided should be established in places where inadequate survey or insufficient provision of aids to navigation may lead to danger of stranding;

- where local knowledge is considered essential for safe passage;
- where there is the possibility that unacceptable damage to the environment could result from a casualty; or
- where there might be hazard to a vital aid to navigation.

As exemplified in the Wadden Sea PSSA, measures could also be tailored to specific categories of ships posing particular risks, for instance due to the type of fuel or cargo they carry. It is referred to the results of the PAME work on protective designated area measures for a more detailed description and assessment of available regulative tools (DNV-DII, 2013).

It is important to note that the criteria for designating a PSSA covers not only the risk from shipping activity (as outlined in this report), but also the vulnerability of the area in question in terms of ecosystems and biological resources. Such vulnerability assessments have been made e.g. by the AMSA II C study (Skjoldal et al, 2013) Figure 7-1 Areas of heightened ecological significance in the Barents Sea LME. (From Skjoldal et al. (2013))provides an example of the vulnerability mapping, which should be paired with an assessment of the impact from shipping.

Such an assessment is however beyond the scope of this study.
Relevant particular risk reducing measures are listed and evaluated with regards to cost-benefit in Table 7-2.

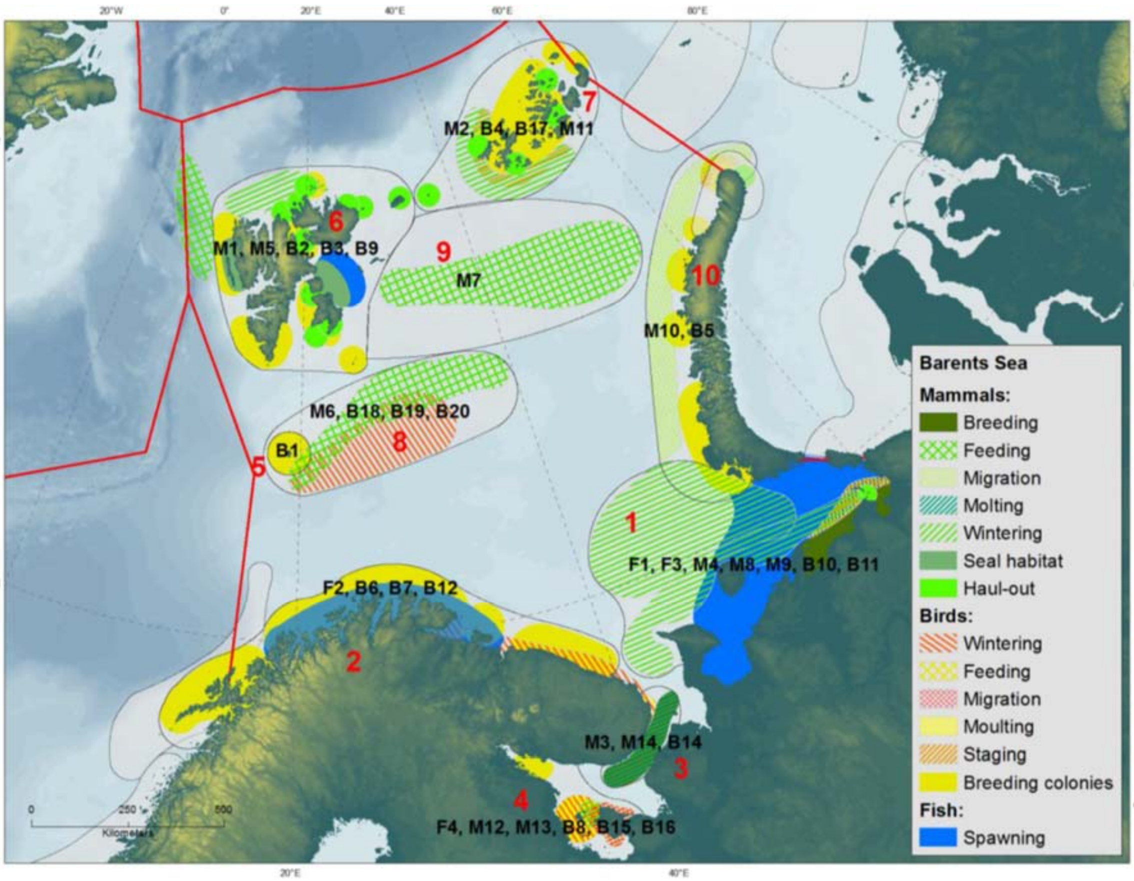


Figure 7-1 Areas of heightened ecological significance in the Barents Sea LME. (From Skjoldal et al. (2013))

7.1 Cost–benefit considerations for relevant risk control options

This section presents a high-level qualitative assessment of costs and benefits for relevant risk control options (RCO). Figure 7-2 shows the rating mechanisms applied for the high-level cost-benefit assessment performed in this study.

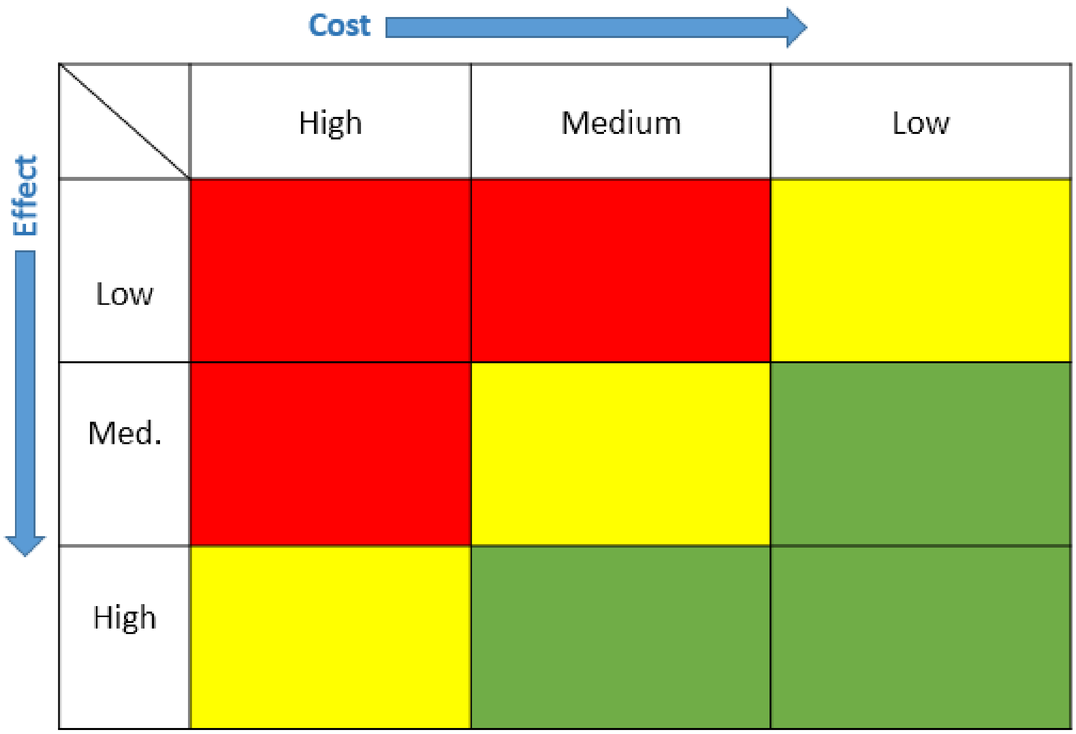


Figure 7-2 - Cost effectiveness rating matrix

Based on the risk assessment carried out in this study, the highest risk for oil spill related to the traffic patterns and composition found in the Arctic is related to groundings in general and groundings of oil tankers in particular. With this in mind, eight Risk Control Options (RCO) were identified and evaluated,

Table 7-2 - Cost effectiveness rating of different risk controll options (RCO)

	RCOs	Risk reducing effect (High-Medium-Low)	Comment	Cost level (h-m-l)	Cost-effectiveness rating
1	Ship routing and reporting	H	Ship routing measures and ship reporting systems may be the most relevant in terms of reducing risk from acute oil pollution, both bunker oil or cargo oil. Such measures may be "Areas to be avoided", "recommended routes" and "precautionary areas" to direct traffic away from certain areas (in certain periods) posing particular risk or containing particular environmental elements. These measures may also be directed towards certain vessel types (eg. tankers) where relevant.	L	
2	Better hydro-geographical data to improve navigation and to avoid higher risk situations	M	Could be targeted towards the most sensitive areas, thus limiting cost. Most relevant for vessels not moving along regular routes. Should include increasing the detailing level of some of the already mapped areas – safe anchoring etc.	M	
3	Slower steaming speeds (in certain control areas – and potentially dedicated for tankers) to reduce likelihood of hull penetration in the event of an accident	M	May be implemented as part of RCO1 within "Special areas" as an alternative to (or supplement to) de-routing. May have a significant effect on spill risk from tankers (double hull) where the energy of impact is critical to the outcome.	L	
4	Aids to local navigation e.g. such as simple markings and lights	L	Several Arctic communities see increased population and thus increased ship traffic. The local infrastructure may not have kept up with the growth in traffic and	L	

			hence even relatively simple navigational aids may reduce the risk of grounding.		
5	Mandatory requirement for pilots	H	Local knowledge will always be among the major mitigation factors when it comes to grounding. A unified requirement for pilots (at least for certain vessels) is considered to be effective.	H	
6	Facilitation of LNG as fuel for certain trades and regions.	M (Ref. bBunker only)	Possible measures (infrastructure development etc) may be tailored for new trades (f.ex new offshore installations) likely only relevant for new vessels. Also reduces air emissions and operational oily waste production.	H	
7	Real time ice information and ice forecasts	L	Forced diversion from sailing plan due to unforeseen ice conditions may impose and increased grounding risk (Ref. Exxon Valdez). Linked to availability of data communication when in port which is a problem at some locations .	M	
8	Tug/ice breaker response services including oil spill mitigation equipment	M	High effect if coverage is sufficiently high. The effect of tug response services is considerable in avoiding groundings of vessels adrift (DNV, 2010). In combination with a VTS central and traffic lanes systems, the probability of successful assistance of a tug is 98%. There are however few places in the Arctic where the traffic is sufficiently concentrated for this to be considered to be cost effective unless combination use may be implemented.	H	

8 EXPECTED TRAFFIC DEVELOPMENT

When considering the need for introducing mitigation measures to reduce the risk of oil spill in the Arctic, it is natural not to limit the considerations to the current traffic levels, but also to consider future traffic developments. There is a general expectation to strong growth in Arctic shipping activities in the coming decades. There are mainly three drivers behind this expectation; firstly, that climate change is dramatically reducing the summer ice cover in the region, easing access. Secondly, vast natural resources are available for extraction in the region, and thirdly that the Arctic seas routes between Asia and the West may be considerably shorter compared to the more traditional routes, saving up to 40 % of the distance. While it is beyond the scope of this report to forecast future traffic development in the Arctic, the following section will outline the broad development trends identified in the literature.

8.1 Driving forces of shipping in the Arctic

Traffic in the polar areas is either destination traffic or transit traffic. Proper modelling will have to be based on socio-economic development in the region, the development of the world economy and demand for Arctic resources, geopolitical and regulatory conditions and technical conditions for the practical implementation of maritime traffic, as port infrastructure and availability of icebreaker assistance. Data and forecasts of sea ice extent is also an important concern for future ship traffic in the Arctic Ocean region. This is closely related to climate change in the Arctic, which is of course a key research topic. ((Midtgard et al, 2012).

Recent trends indicate longer seasons with less sea-ice cover and reduced thickness (Serreze et al, 2007) (Boe et al, 2009) implying improved ship accessibility around the margins of the Arctic Basin. Climate models project an acceleration of this trend and opening of new shipping routes and extension of the period during which shipping is feasible (ACIA, 2005), (Boe et al, 2009). Some analysts have suggested that the Arctic may be ice free in September as early as 2030 (Wang, M. and Overland, J. E, 2009) though others suggested 2066–2085 (Boe et al, 2009) (Overland, J.E. and Wang, M, 2013) estimate nearly ice free summers in the Arctic by 2060 at the latest, and possibly as early as 2020 using three different approaches. One approach used by (Overland, J.E. and Wang, M, 2013) is climate model projections.

One set of projections estimate that the navigation season (defined as 25% open water and 75% sea-ice cover) for the Northern Sea Route (NSR) may increase from the current 70 days per year, to 125 days mid-century, and over 160 days in 2100 ((ACIA, 2005) - Chapter 16). Ships with ice-breaking capability may extend the navigation season even further. By mid-century the NSR is navigable by open water vessels in any given year with 94% probability (compared to 40% in the past few decades). The North West Passage (NWP) will be navigable by vessels without ice strengthening with a probability of 53%. This study clearly shows the technical potential for transiting the Arctic, but makes no assessment of the magnitude of the traffic.

(Khon V et al, 2010) found that models predict that at the *end of this century* there will be free passage of the NSR for 3–6 months of the year and the NWP for 2–4 months. This may make the NSR up to 15% more profitable than the Suez Canal route (Khon V et al, 2010), but they did not estimate future ship traffic in the Arctic.

8.2 Recent studies have indicated a large increase in Arctic shipping

A series of studies trying to predict the trends and future of Arctic shipping have been performed over the last decade. Though all predict a considerable increase in traffic and in the intercontinental traffic in particular, the most prominent common denominator is the large degree of uncertainty.

- (Granier C. et al, 2006) took a scenario from an earlier study (Eyring V. et al, 2005) and assumed either 12.5% or 25% of the emissions were shifted to the Arctic in 2050.
- (Khon V et al, 2010) found that models predict that at the end of this century there will be free passage of the NSR for 3–6 months of the year and the North West Passage (NWP) for 2–4 months. This may make the NSR up to 15% more profitable than the Suez Canal route, but they did not estimate future ship traffic in the Arctic.
- (Paxian A et al, 2010) estimated present-day and future emission inventories that included polar routes. The ship traffic along the polar routes was estimated using an algorithm that estimated the shortest distance between two ports without included ship performance or cost considerations. They estimated fuel consumption along the NSR and NWP to increase by a factor of 9 and 13, respectively, from 2006 to 2050 (Paxian A et al, 2010)
- (Corbett J et al, 2010) constructed detailed inventories of all Arctic shipping activities, including transits of the NSR, NWP and other polar routes with reduced sea-ice extent. Transits were estimated using a fixed percentage diversion of global traffic (1–5 %) and were found to be 2–4 times greater than Paxian et al. (2010) and similar to (Granier C. et al, 2006) (Corbett J et al, 2010). In terms of polar transits these studies, however, do not explicitly model ship performance and economic costs of shipping in Arctic conditions.
- (Peters G et al, 2010) presents results from a techno-economic model from DNV which accounts for the most relevant factors. They projected 480 transit voyages, or about 8% of the total container trade between Asia and Europe, in 2030 and 850 transits voyages, or about 10% of all container traffic between Asia and Europe, in 2050. Peters et al (2011) also model emissions from shipping related to petroleum extraction based on gridded future projections of production of oil and gas in the Arctic. 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 terms of risk, it is likely that this will increase in the years to come, considering traffic levels in isolation (i.e. disregarding other factors such as the Polar Code and MARPOL fuel sulfur regulations etc.) However, within the next decade, no major leaps in activity levels are expected.

8.3 Traffic development - summary

Estimating future activities in the Arctic is inherently difficult due to large uncertainties in sea-ice extent, resource availability, future economic development, and future policies.

Several studies exist, some optimistic with regard to future activity by midcentury. However, no study has been identified which covers all aspects of Arctic shipping (Transits, destinations (O/G shipping, fisheries, Cruise), modeling future activity using a unified set of assumptions and drivers. Thus, describing the future activity in quantitative terms is not possible in this report, making any clear images of the future of shipping in the Arctic stating the traffic volumes and years

The following general observations can be made.

- Ice conditions is an important driver for change, but is, in isolation, no impetus for more shipping.
- Estimating future activities in the Arctic is inherently difficult due to large uncertainties in sea-ice extent, resource availability, future economic development, and future policies.
- In a few decades, the ice is expected to melt in the summer, and gradually larger areas could be sailed in the melt season of vessels with lower ice class. Winter conditions will continue to be challenging.

- There will likely be a limited number of transits before 2020, and destination activity will dominate (as today).
- The container and line traffic may represent large volume of transit traffic in the Arctic Ocean in the future, although estimates of this are highly uncertain.
- Major developments in destination traffic are largely driven by extraction and export of resources from the Arctic. Development of such resources for extraction will take time, but shipping activity related to O&G may potentially exceed the future transit activity.

9 REGULATIONS ON THE USE AND CARRIAGE OF HFO IN THE ARCTIC

This chapter deals with existing regulation for the use and carriage of HFO, the development of additional safety and environmental requirements under the Polar Code and potential gaps wrt. regulation of HFO, and other available risk reducing legislative measures of particular interest currently discussed by other work processes in PAME. The Chapter has some overlap with the discussions in Chapter 7, especially with regard to designated area tools and associated protective measures.

9.1 Existing regulations

9.1.1 General

Existing international regulation of shipping contains common provisions in all areas that aim to reduce accidental risk and prevent pollution. In addition, certain instruments provide area specific additional risk reducing measures.

Fundamentally, the main way of reducing risk from oil pollution from ships – HFO or not – is the same as for reducing loss of lives; that is to ensure the safe design, construction and operation of ships to avoid the likelihood of accidents, as well as the consequences when accidents occur. The most important of all treaties dealing with maritime safety is the SOLAS convention, while the MARPOL convention regulates pollution prevention, including oil pollution. Also to be mentioned among IMO instruments as of relevance to ships operating in the Arctic is:

- The STWC-Convention with newly adopted guidance for training and competency of officers and masters on ships in polar regions
- The UNCLOS Convention giving coastal states the right to adopt and enforce non-discriminatory laws and regulations for the prevention, reduction and control of marine pollution from vessels in ice-covered areas within the limits of the exclusive economic zone.
- Guidance for passenger ships operating in areas remote from SAR facilities (MSC.1/Circ.1184) Enhanced planning arrangements for ships operating in remote areas, including close cooperation and liaison with relevant RCCs.
- Guidelines on voyage planning for passenger ships operating in remote areas (A.999(25)) Recommends additions to yoyage and passage plan, such as details on ice and ice formations, ice navigators, operational limitations due to ice, safe distance to icebergs, carriage of special or enhanced equipment.
- Guidelines for ships operating in polar waters (a mandatory Polar Code is under development.
- Mandatory ship reporting system "In the Barents Area (Barents SRS)" The following categories of ships passing through or proceeding to and from ports and anchorages in the Barents SRS area are required to participate in the ship reporting system, by reporting to either Vardø VTS centre or Murmansk VTS centre: all ships with a gross tonnage of 5,000 and above; all tankers; all ships carrying hazardous cargoes; a vessel towing when the length of the tow exceeds 200 metres; and any ship not under command, restricted in their ability to manoeuvre or having defective navigational aids.

The following sections do not address the various safety and risk reducing instruments in general, but rather describe relevant existing requirements for the use and carriage of HFO; some applicable in all areas and some more area specific.

As shown, except from a few national and local requirements, no particular additional regulations on the use or carriage of HFO are in place in the Arctic.

9.1.2 Use of HFO as ships fuel

9.1.2.1 General

Marine fuel property standards are reported from standardization organisations such as ISO. The fuel property criteria include parameters such as kinematic viscosity and density, which governs the classification of fuels on a heavy fuel oil gradient (residual fuels) and different distillate qualities. The requirements also contains limits for sulphur content, however this does not define the fuel in terms of residual/heavy fuel oils versus distillates.

Except from in a few areas, international maritime regulations does not specifically regulate when and where to use heavy fuel oils versus lighter products. Marine engines are however required to run on suitable fuel ensuring a safe and reliable operation, which practically enables for use of a range of fuel types from light distillate marine gas oils and diesel oils to the heavier intermediate fuels and residual fuels.

The following cases describe special regulations of direct or indirect relevance for the use of heavy fuel oils:

9.1.2.2 Sulphur requirements under revised MARPOL Annex VI

Effect on HFO use in Arctic: Potentially

SOx-emissions from ships are regulated by a requirement for maximum sulphur content in fuels. In other areas, the requirements imply a gradual reduction from today’s 4,5 % to 0,5 % towards 2020/2025).

The sulphur regulation does not imply a requirement on *type of fuel*, such as residual/heavy fuels versus distillates/lighter fuels along a gradient of density or viscosity. Thus any fuel type meeting the sulphur limits, including heavier fuel qualities, will be compliant. In addition, the alternative of using exhaust gas cleaning technology (scrubbers) to remove the sulphur while running on sulphur rich fuels will be accepted.

Although the coming sulphur requirements does not principally rule out the use of heavy fuel oils, they will likely lead to higher share of lighter products and distillates, particularly in ECAs after 2015 with maximum 0,1% sulphur allowed (which will require the “purest” marine distillate quality, i.e. marine gas oil – MGO). Until 2015, in ECAS, both residual fuels and distillates (MGOs and MDOs) meeting maximum 1% sulphur will be in use.

However the full effect of future sulphur requirements on fuel type demand and availability is still unknown. For instance, we don’t know how the 0,5% global sulphur requirement from 2020/25 impact typical fuel quality in use with regard to the broad heavy fuel-distillate fuel gradient and environmental properties in terms of for instance viscosity and density.

9.1.2.3 HFO ban within the Svalbard archipelago – national local regulation

Effect on HFO use in Arctic: Yes

To avoid major pollution from heavy fuel oil in the event of an accident, ships sailing in the three largest national parks of Svalbard are from 1.1.2010 not allowed to use or carry heavy fuel oil. In these areas, the fuel shall be within the DMA quality (marine gas oil) according to the ISO 8217 fuel standard.

An exemption applies for the shortest, most secure route via:

- The north-west part of South Spitsbergen national park, for sailings to and from the Svea mine.

- The northern part of Forlandet national park and the southern part of North-West Spitsbergen national park for sailings to and from Ny-Ålesund up to 01.01.2015.
- North-West Spitsbergen national park for sailings to Magdalenefjorden up to 01.01. 2015

9.1.2.4 HFO ban in Antarctica – IMO area specific regulation

Effect on HFO use in Arctic: Yes, locally

From 1 August 2011, a new MARPOL regulation to protect the Antarctic from pollution by heavy grade oils entered into force. The amendments to MARPOL includes a new Chapter 9 with a new regulation 43, which would prohibit the carriage, in bulk as cargo, or carriage and use as fuel, of:

- crude oils having a density, at 15°C, higher than 900 kg/m3;
- oils, other than crude oils, 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.

It is worth noticing that the Antarctica HFO ban opens for the use of a range of different distillate qualities, while the HFO ban around Svalbard only permits MGO, which is the “cleanest” marine diesel quality.

9.1.2.5 Additional fuel requirements in California

Effect on HFO use in Arctic: Not directly

In California (US), additional fuel requirements are adopted for ocean-going vessel main (propulsion) diesel engines, auxiliary diesel engines, and auxiliary boilers when operating within 24 nautical miles of the California Coastline. Vessel owners/operators would be required to use the marine distillate fuels shown in Table 1. In contrast to IMO and EU legislation, these requirements do actually set a requirement for type of fuel to be used (distillate fuels), not only sulphur content.

Table 1: Fuels Complying with the Requirements

Effective Date	Fuel**
July 1, 2009 (except auxiliary engines)*	Phase I Fuel Requirement Marine gas oil (DMA) at or below 1.5% sulfur; or Marine diesel oil (DMB) at or below 0.5% sulfur
January 1, 2012	Phase II Fuel Requirement Marine gas oil (DMA) or marine diesel oil (DMB) at or below 0.1% sulfur

* The fuel requirements for auxiliary engines will become effective when the regulation becomes legally effective, which is expected to occur early in 2009.

** DMA and DMB are marine grades of fuel as defined in Table I of International Standard ISO 8217.

9.1.2.6 Additional EU legislation on sulphur content of fuels

Effect on HFO use in Arctic: Not directly

The EU legislation basically reflects that of IMO MARPOL Annex VI, including 0,1% sulphur requirements in EU waters in ECAs. However, an important difference is that the 0,5% sulphur requirements outside ECAs shall take effect from 2020, without the IMO possibility for postponing to 2025. As for the IMO requirements, the EU legislation does not set requirements for the type of fuel to be used on a density and viscosity gradient, but rather regulates the sulphur content in the fuel.

9.1.3 Carriage of HFO

Prevention of pollution from carriage of oil (including heavy grade oils) as fuel or cargo is regulated by IMO MARPOL Annex I with provisions for the construction of oil tankers and other ships, requirements for equipment and operational discharge control, and more.

The essential part of the regulations is the requirements for segregated ballast and double hull for the cargo areas of oil tankers. It is not within the scope of this report to elaborate on the full extent of MARPOL Annex I oil carriage requirements. Basically, these regulations ensure that oil in cargo (regardless of grade) is only allowed on tankers with double hull, in the Arctic as in other areas. However, the double hull requirements under MARPOL in theory do not 100 % rule out carriage of oil as cargo in single hull tanks on board:

- Small tankers (double side protection not required for tanks < 700m3 on tankers < 5000 dwt. However double bottom required whatsoever)
- Ship types that carry oil even if they are not classified as tankers, for instance offshore supply ships that may carry significant volumes of oil in supply for different offshore activities

This may be seen as a potential "gap" in oil pollution prevention regulations in areas with high risk, in the Arctic and in other areas.

IMO adopted in March 2006 an amendment to MARPOL Annex I to include a new regulation 12A for machinery spaces of all ships on oil fuel tank protection. The regulation applies to all ships delivered on or after 1 August 2010 with an aggregate oil fuel capacity of 600 m3 and above. It includes requirements for the protected location of the fuel tanks (double hull) and performance standards for accidental oil fuel outflow. A maximum capacity limit of 2,500m3 per oil fuel tank is included in the regulation. These requirements are intended to prevent oil pollution from incidents involving HFO as well as other fuel qualities; however the fuel tank protection does not distinguish between heavy fuel oils and lighter products.

The requirements do not 100 % rule out carriage of fuel oil in single hull tanks, as the requirements do not apply to tanks smaller than 600 m3. This may be seen as a "gap" in oil pollution prevention regulations in areas with high risk, in the Arctic as well as in other areas.

The following cases describe additional regulations of direct or indirect relevance for pollution prevention from carriage of oil, including heavy grade oils.

9.1.3.1 Operational discharges from cargo areas of an oil tanker in Special Areas

Effect on HFO carriage in Arctic: No

Regulation 34 of MARPOL Annex 1 prohibits the operational discharge of oil and oily mixtures from the cargo areas of oil tankers, such as oil and oily water from tank washing operations (slop), while in a Special Areas (as defined in regulation 1 of Annex 1 – does not include any Arctic areas). Outside special areas, such discharge is allowed when all the following conditions are satisfied:

- the tanker is more than 50 nautical miles from nearest land;
- the tanker is proceeding *en route;*
- the total quantity of oil discharged to sea does not exceed 1/30000 of the total quantity of the particular cargo of which the residue formed a part
- the tanker has in operation a compliant oil discharge monitoring and control system and slop tank arrangement.

9.1.3.2 HFO ban in Antarctica – IMO area specific regulation

Effect on HFO carriage in Arctic: No

The carriage of heavy grade oils is prohibited in Antarctic waters.

9.1.3.3 HFO ban within the Svalbard archipelago – national local regulation

Effect on HFO carriage in Arctic: Yes

The carriage of heavy grade oils is prohibited in certain areas of the Svalbard archipelago, see details in 9.1.2.3.

9.1.3.4 Additional requirements in certain Particularly Sensitive Sea Areas (PSSAs)

Effect on HFO carriage in Arctic: No

Particularly Sensitive Sea Areas (PSSA) are areas that need special protection through action by IMO because of its significance for recognized ecological or socio-economic or scientific reasons and which may be vulnerable to damage by international maritime activities. When designated as a PSSA, specific measures shall be used to control the maritime activities in that area, such as routeing measures, strict application of MARPOL discharge and equipment requirements for ships; and installation of a Ship Reporting System (SRS)/Vessel Traffic Services (VTS). Thus, in contrast to Special Areas, where MARPOL has pre-defined the measures, PSSA status opens for a tailor-made application of measures.

Currently 12 PSSAs has been designated, where special requirements apply to the carriage of heavy grade oils in two areas, as follows:

- PSSA Paracas National Reserve (Peru) is an area to be avoided for ships > 200 gt carrying hydrocarbons and hazardous liquids in bulk.
- PSSA Western European Waters (Belgium, France, Ireland, Portugal, Spain, United Kingdom) has mandatory reporting for single hull tankers carrying heavy grades of fuel oil

9.2 IMO Polar Code in development – no particular provisions for use or carriage of HFO

Through the development of a mandatory Polar Code, IMO acknowledge that ships operating in the Arctic and Antarctic environments are exposed to a number of additional risks. Poor weather conditions and the relative lack of good charts, communication systems and other navigational aids pose challenges for mariners. The remoteness of the areas makes rescue or clean-up operations difficult and costly. Cold temperatures may reduce the effectiveness of numerous components of the ship, ranging from deck machinery and emergency equipment to sea suctions. When ice is present, it can impose additional loads on the hull, propulsion system and appendages.

The Polar Code is planned to cover the full range of additional design, construction, equipment, operational, training, search and rescue and environmental protection matters relevant to ships operating in the polar waters.

The main way for the Polar Code to reduce environmental risk is the same as for reducing risk for loss of lives and property; that is the additional requirements for safe design, construction and operation of ships to reduce the likelihood and consequences of accidents, given the particular polar conditions.

The Polar Code will also include additional requirements for environmental protection that are not covered by the additional safety provisions. So far it seems such additional environmental requirements at least will address regular emissions and discharges from normal operations, by way of stricter limits or zero discharge provisions for certain effluents (tank washings, bilge water, sewage etc), compared to other areas. In addition, it may follow by the Polar Code that certain categories of ships (based on the ice conditions they are allowed to operate under) will face stricter requirements than normal MARPOL with regard to separation from the outer shell of tanks used for the carriage of oil and oily mixtures.

Also, for all ships, it is likely that the Polar Code will require that the oil pollution emergency plan required by MARPOL Annex I shall take into account operation in polar waters.

9.3 Protective designated area measures – reducing risk from oil spills?

PAME is currently exploring the need and application of international protective designated area measures available for the Arctic High Seas. DNV is assisting PAME in this work. Although not yet finalized, and with a different geographical scope (high seas) than the HFO report, this work explores some measures that have not yet been applied in the Arctic (nor are they part of the scope of the Polar Code).

A discussion on the use of the PSSA tool (Particularly Sensitive Sea Areas) is an essential part of this work. When approved as a PSSA, specific measures can be used to control the maritime activities in the area, such as strict application of MARPOL discharge and equipment requirements for ships (see above), and other measures such as routing measures and ship reporting systems/Vessel Traffic Services (VTS). Also new measures may be developed (approved by IMO) and applied in PSSAs Member states can also pursue some of these measures independently in an area—without a PSSA application.

Ship routing measures and ship reporting systems may be relevant in terms of reducing risk from acute oil pollution, including from HFO. Examples include:

- Measures such as traffic separation schemes, traffic lanes and separation zones/line and roundabouts may reduce risk from ship collisions
- Areas to be avoided, recommended routes and precautionary areas to direct traffic away from certain areas posing particular risk or containing particular environmental elements. In general, areas to be avoided should be established in places where:
    - inadequate survey or insufficient provision of aids to navigation may lead to danger of stranding;
    - where local knowledge is considered essential for safe passage;
    - where there is the possibility that unacceptable damage to the environment could result from a casualty; or
    - where there might be hazard to a vital aid to navigation.
- Ship Reporting Systems /VTS, see described for the existing Barents SRR in Section 9.1.1.

As exemplified in the Wadden Sea PSSA and Section 9.1.3.4, such measures could also be tailored to specific categories of ships posing particular risks, for instance due to the type of fuel or cargo they carry.

In contrast to Special Area/ECA designation under MARPOL, the above tools, either in combination with or independent of PSSA designation, enables a tailor made use of existing and new risk reducing measures in high risk areas for high risk ship traffic.

It is referred to Chapter 7 and the results of the PAME work on protective designated area measures for a more detailed description and assessment of available regulative tools.

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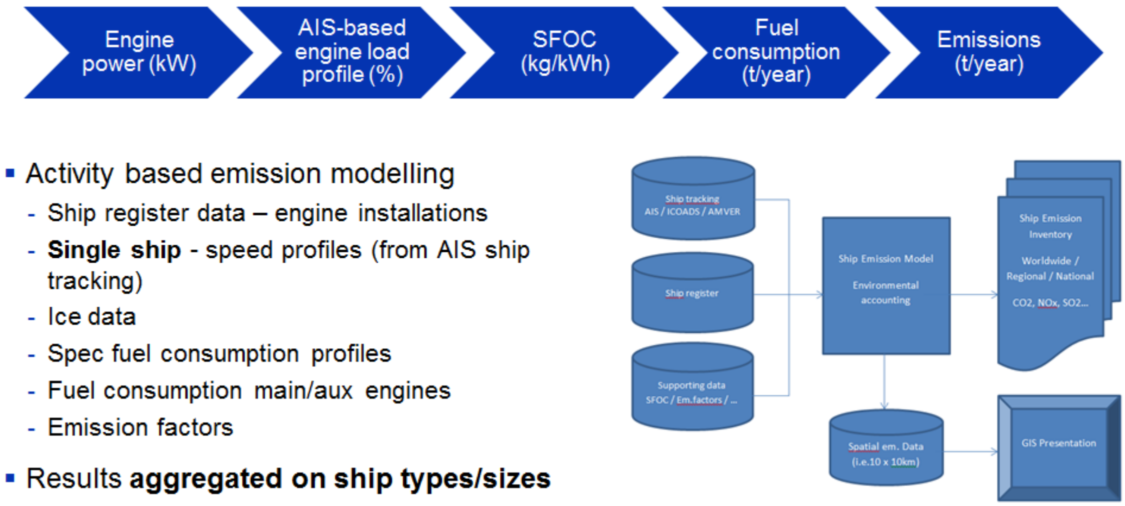
Appendix A
Emission Calculation Methodology

1. Emission calculation methodology

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



Appendix Figure 1 - outline of emission calculation methodology

The calculation of main engine fuel consumptions are performed for each ship for a specific time period. 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 actual ship speed profile (over ground) can be calculated. 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.

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 overestimated. 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 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, (Marintek consortium, 2008)

2. Auxiliary engine fuel oil consumption

The fuel consumption for auxiliary engines is not dependent on the ship speed, but rather on the on-board 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.

3. 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

4. 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, (Marintek consortium, 2008)

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 Appendix Table 1are applied (Marintek consortium, 2008).

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

Appendix Table 1 - Emission factors for gas compounds

Different emission factors depending on the fuel type are used. For the auxiliary engines, it is assumed that all engines use distillate fuels only.

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

Appendix Table 2 - Emission factors for SO2 and particulate matters (PM)

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

5. Error-sources in emission calculations

See Appendix A for a detailed description of the methodology and the potential error sources.

a) 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.
- The AIS satellite makes 16 orbits every day. Hence, for the Arctic, a passage will appear every 1.5 hours. This means that the longest periods between recordings will generally be less than an hour but depending on the position and the coverage, it may be up to 1.5 hours. When the transponder is within coverage, the intervals are generally 5-6 minutes.

b) 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.

c) 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 (service speed). The main potential error sources with this approach are as follows:

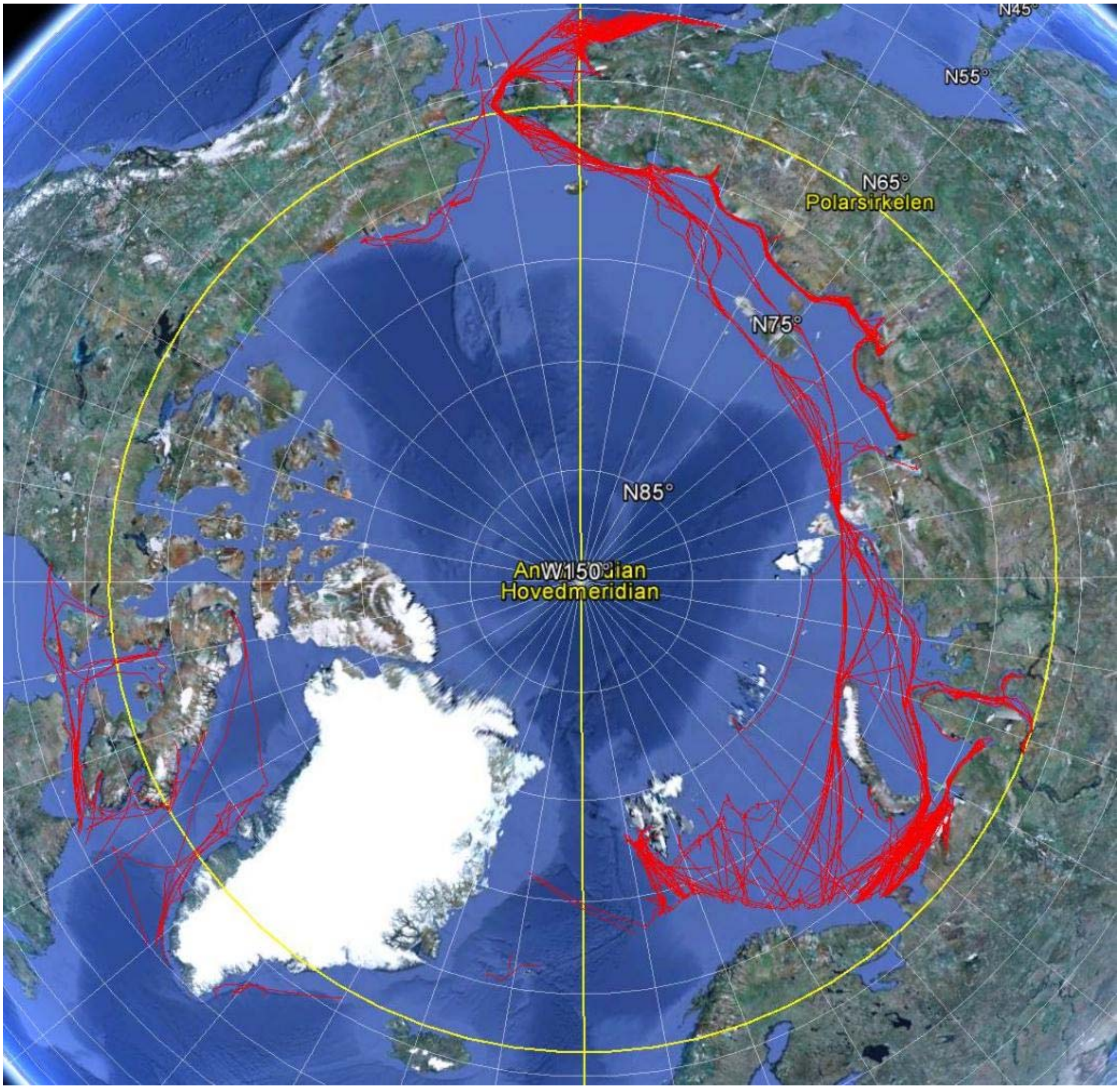
- As of today, we don't know exactly the actual engine load for the service speeds recorded in the ship register. In addition, not all ships in the ship register has been allocated with a certain service speed, thus we have to extrapolate from comparable ships. Although indicated service speeds normally 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.

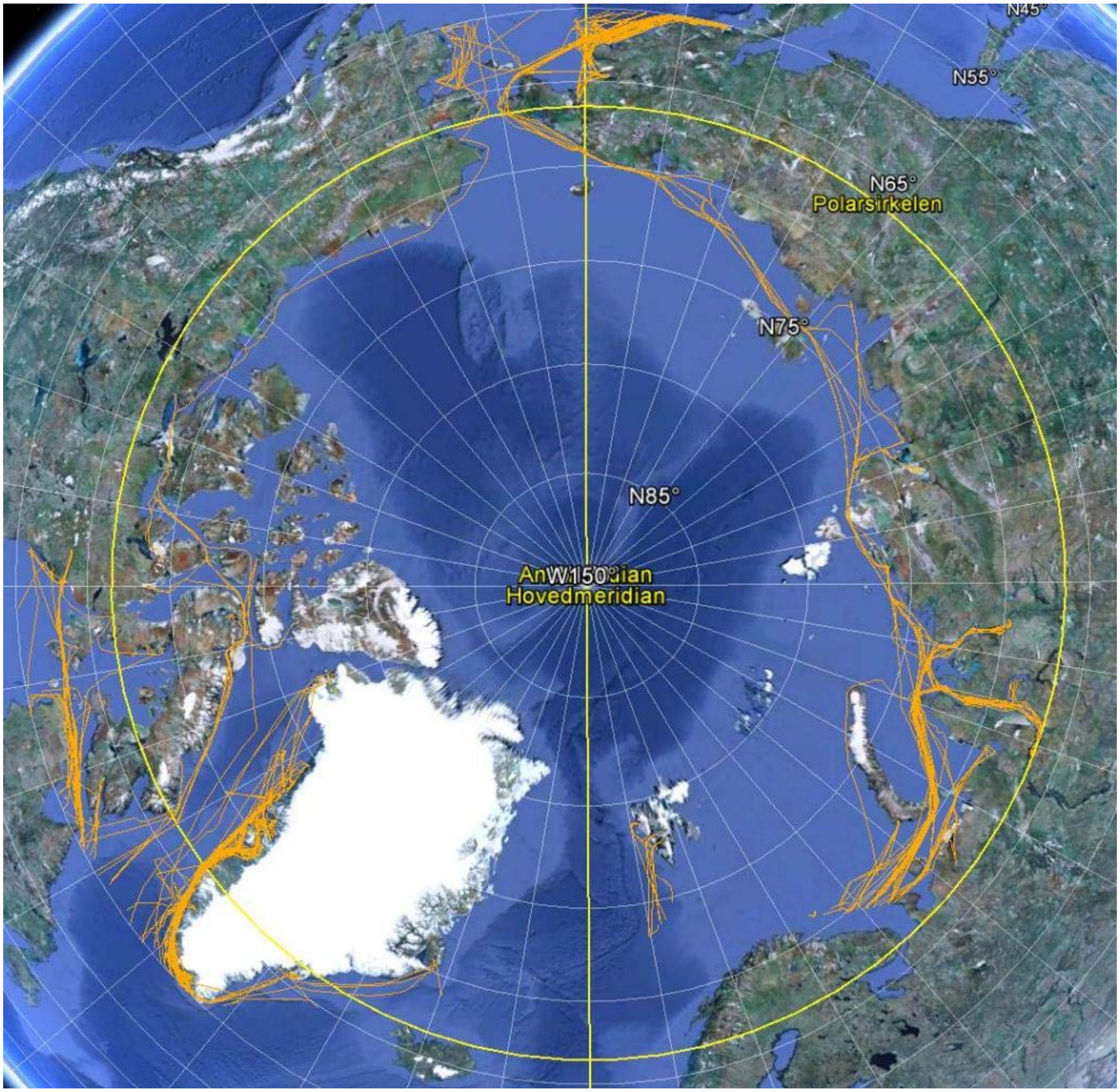
- Fuel consumption and air emissions for ships having diesel electric power generation will be overestimated when operating "at sea" mode, and not accounted for in "harbour" mode. The main reason for this is that only total installed diesel electric power is registered in the ship register, not allocated 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).

Appendix B
SHIP TRAFFIC MAPS

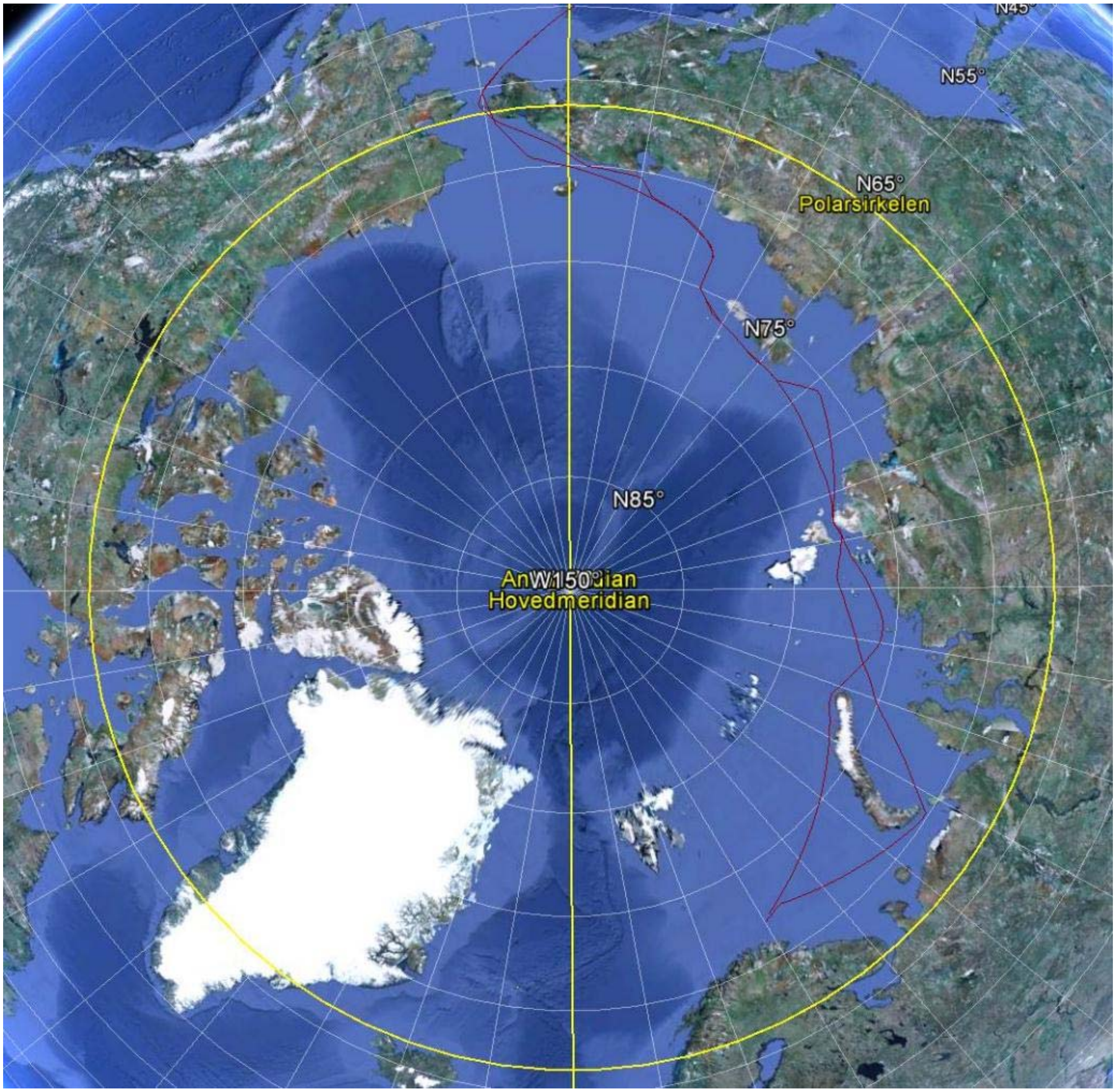
1. Each vessel category – one full year - 2012



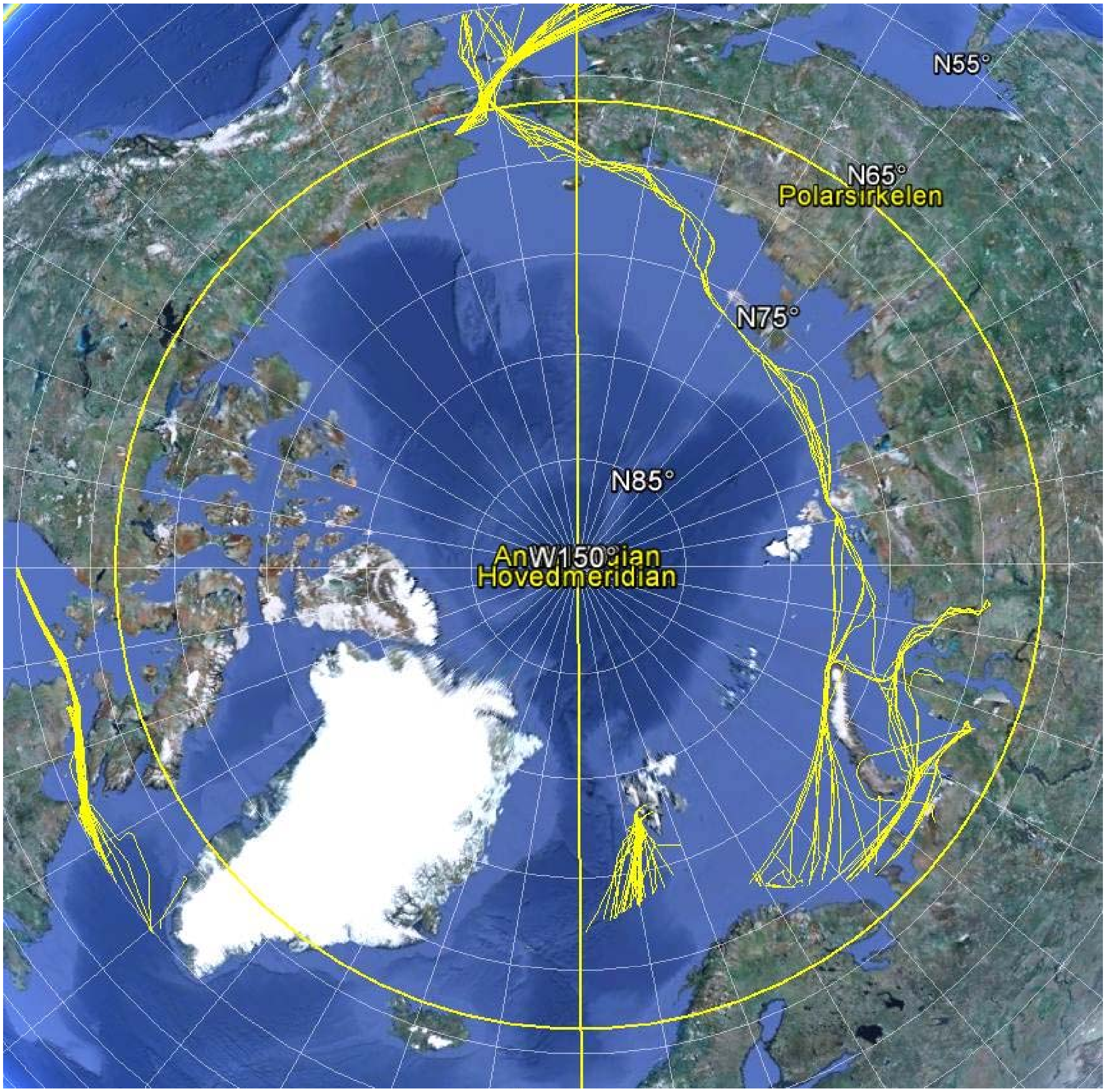
Appendix Figure 2 - Oil tanker traffic in the Arctic – 2012



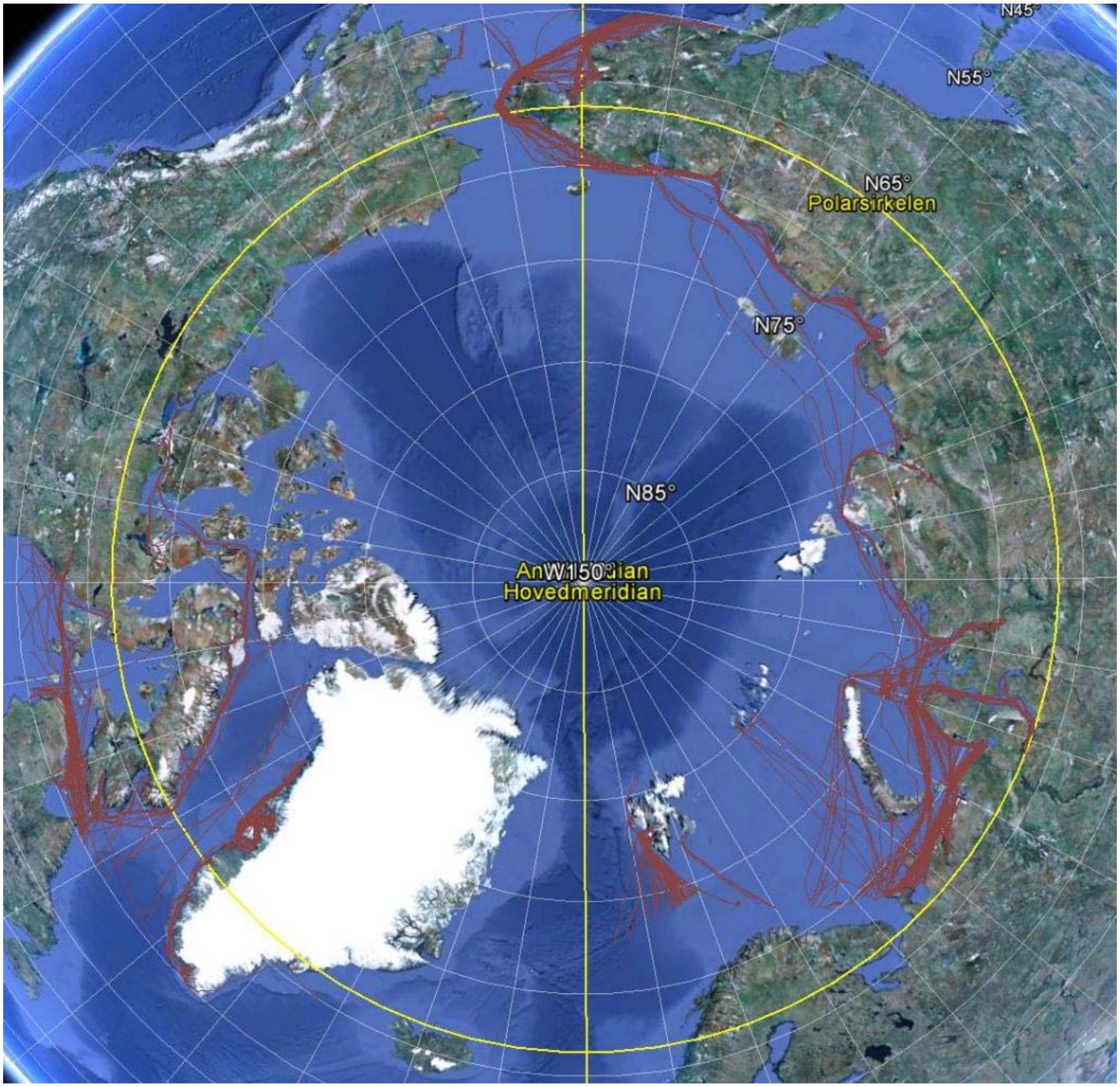
Appendix Figure 3 - Chemical and product tankers in the Arctic – 2012



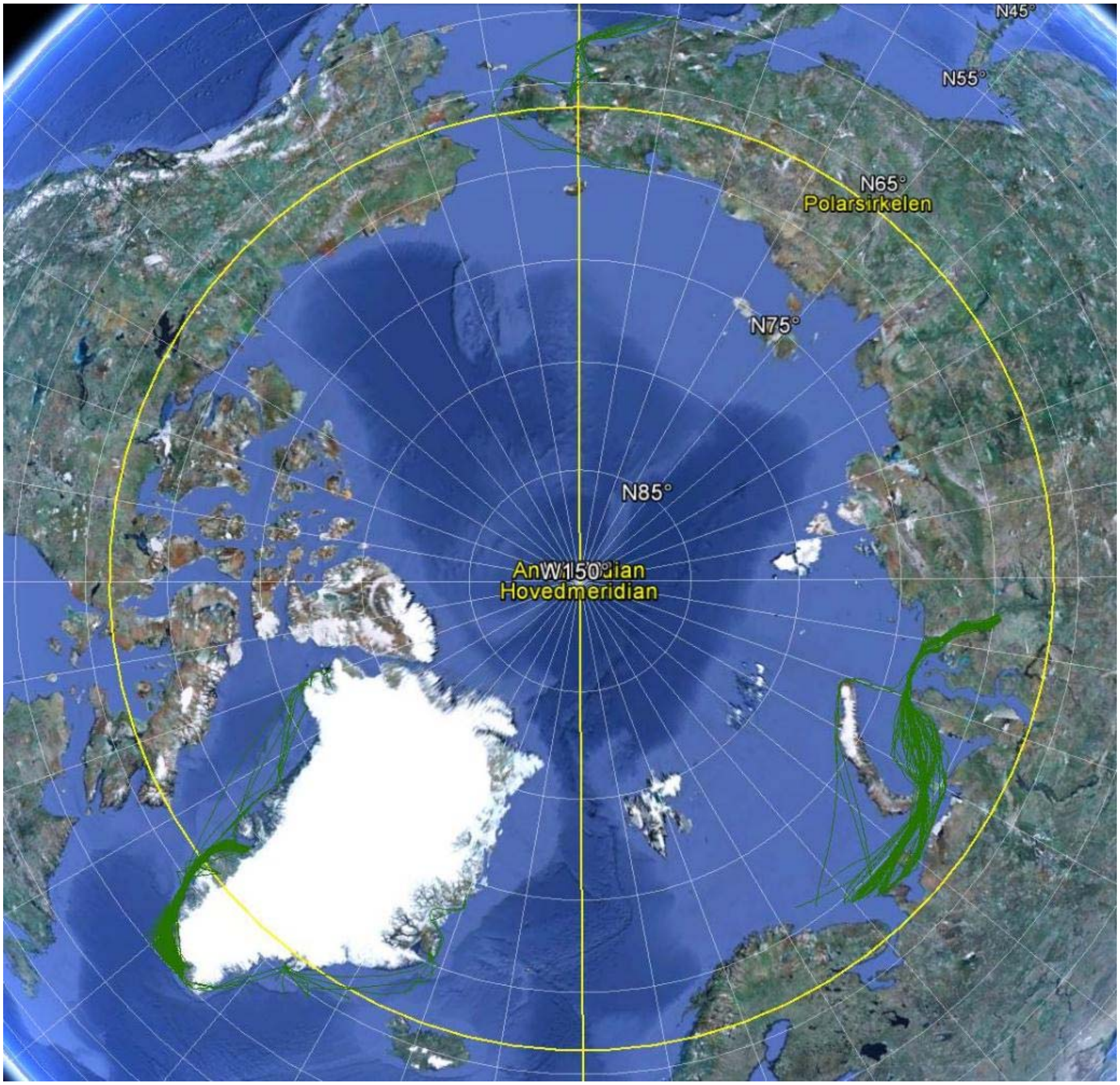
Appendix Figure 4 - Gas tankers in the Arctic – 2012



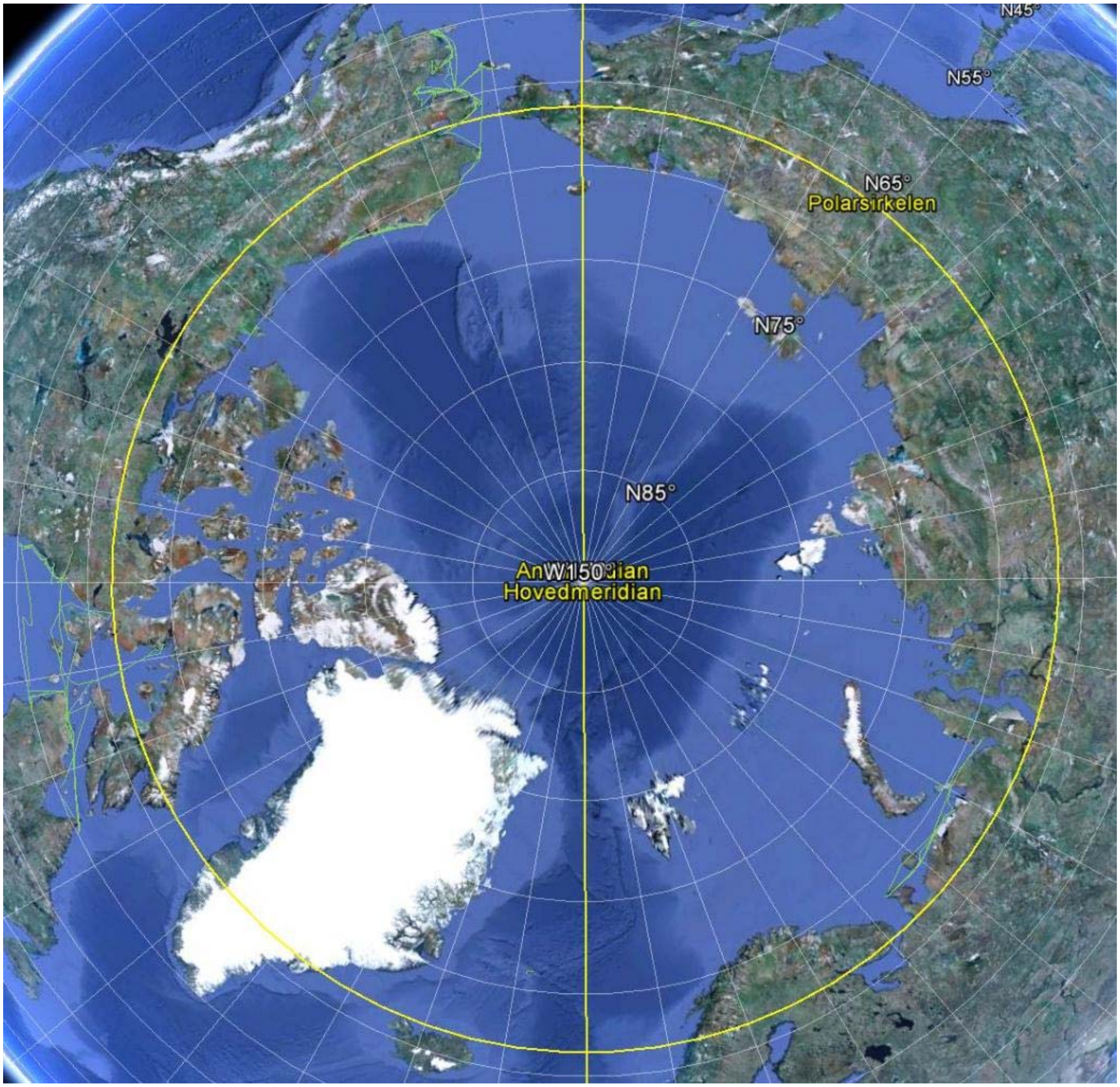
Appendix Figure 5 – Bulk carrier traffic in the Arctic – 2012



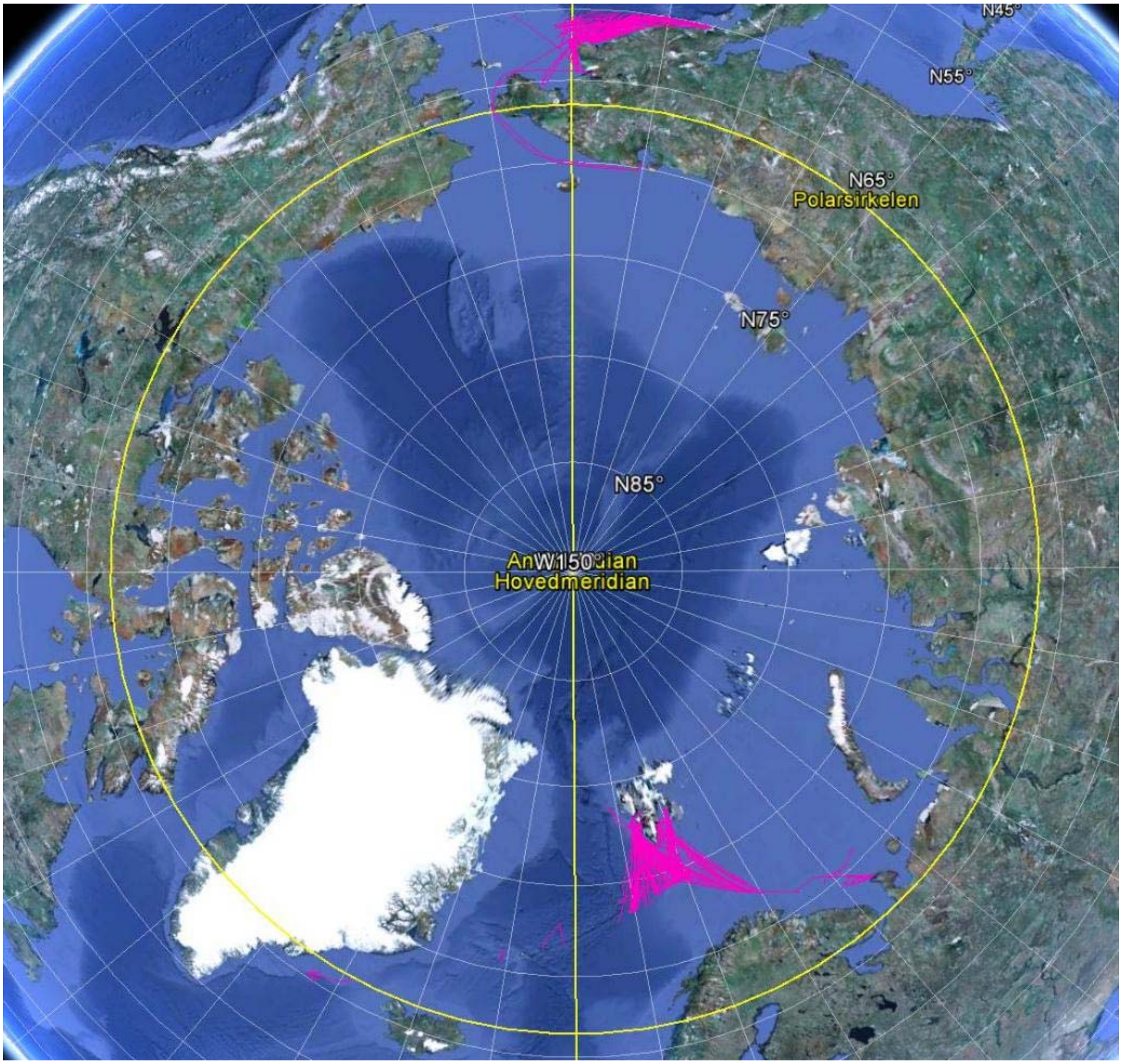
Appendix Figure 6 - General cargo vessel traffic in the Arctic



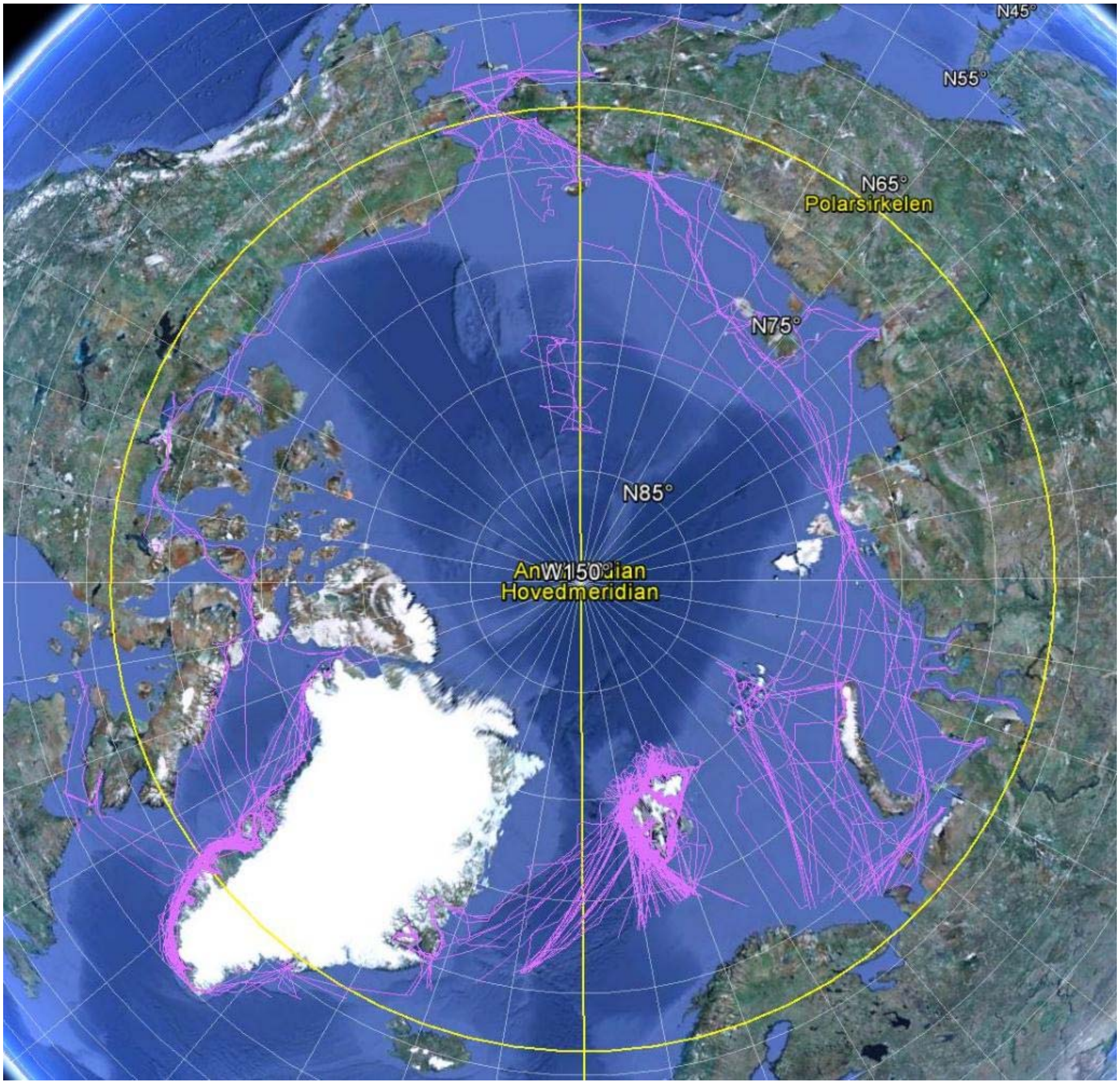
Appendix Figure 7 - Container vessel traffic in the Arctic 2012



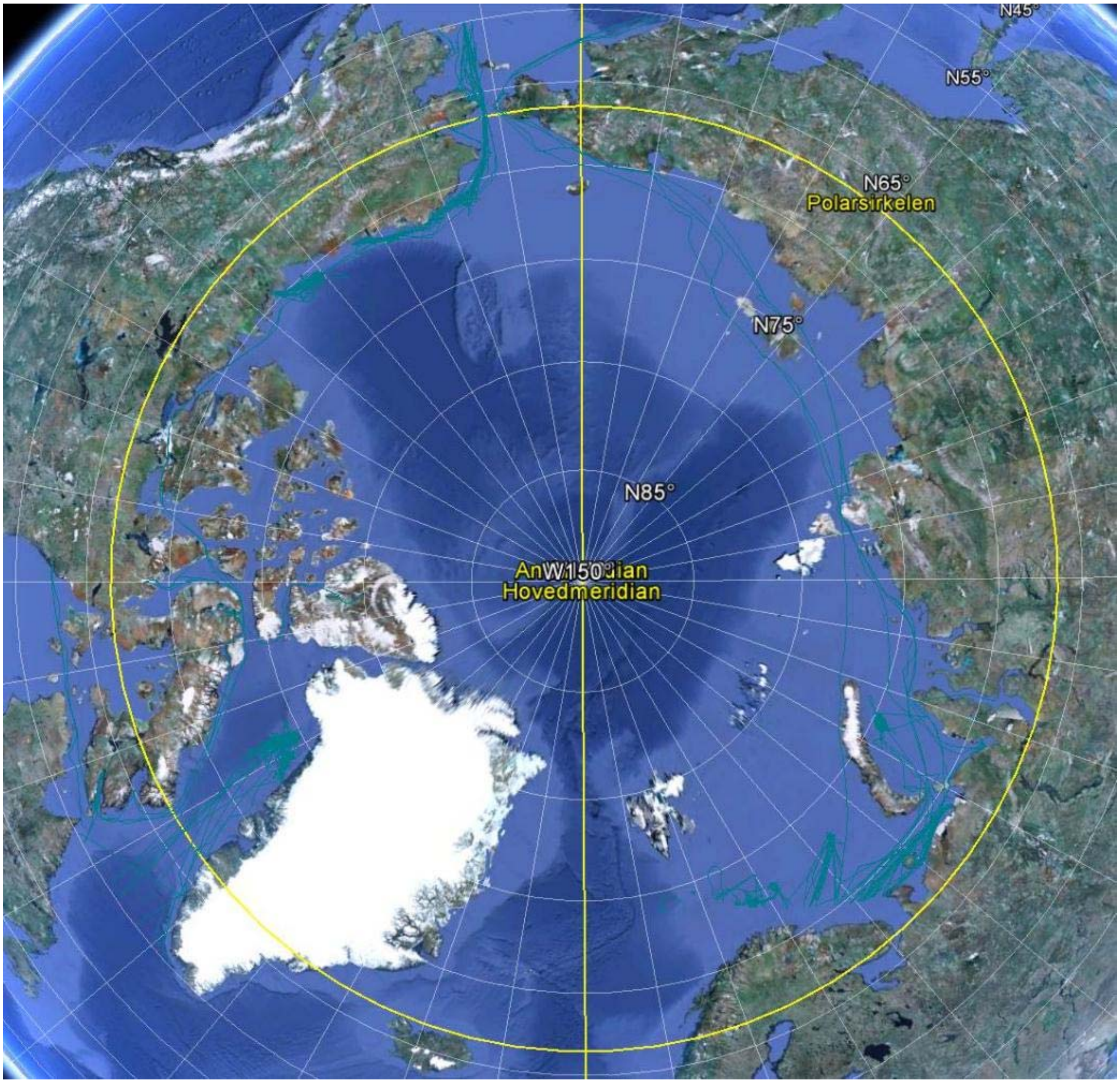
Appendix Figure 8 - RoRo vessel traffic in the Arctic – 2012



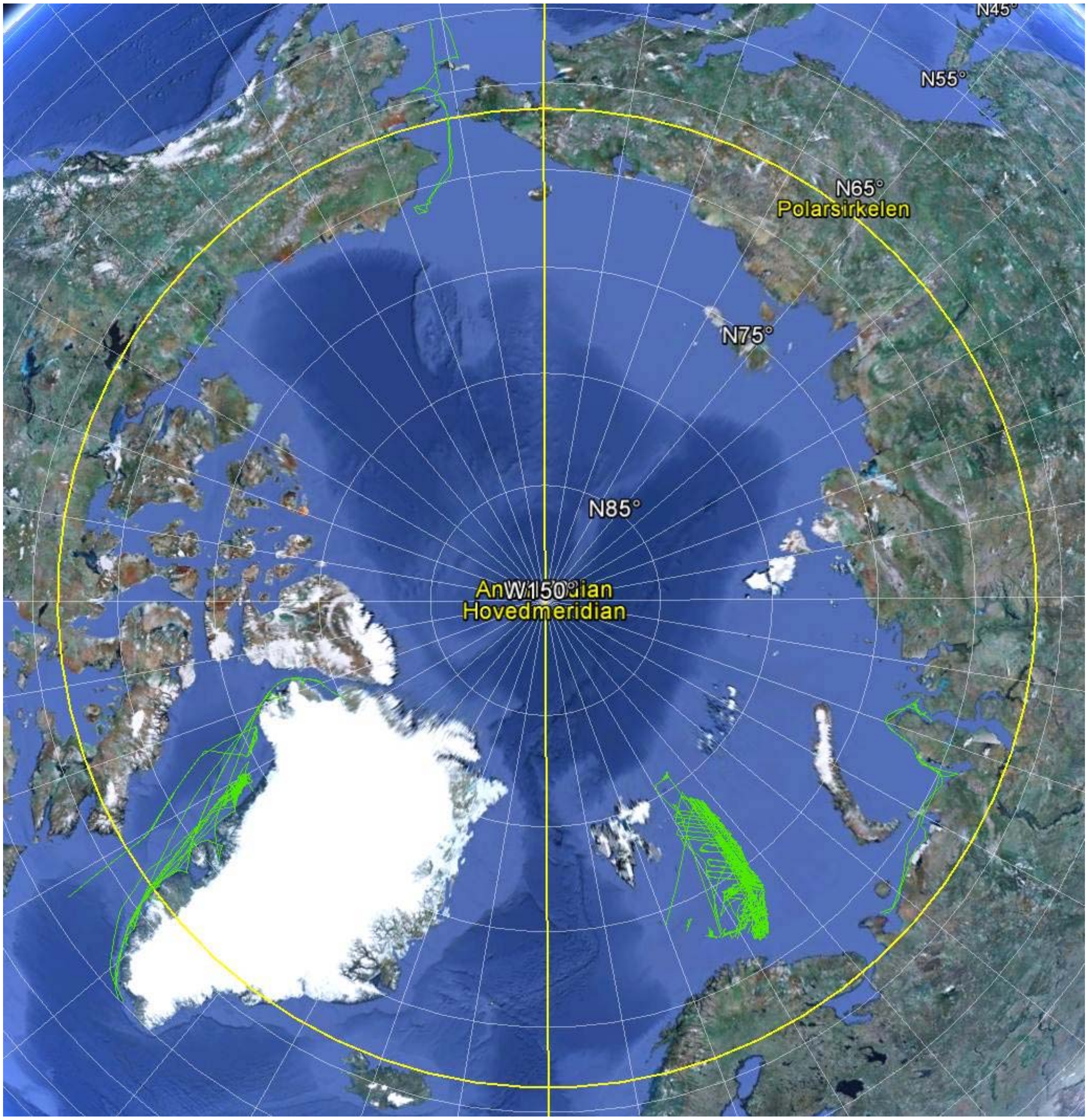
Appendix Figure 9 - Reefers on the Arctic – 2012



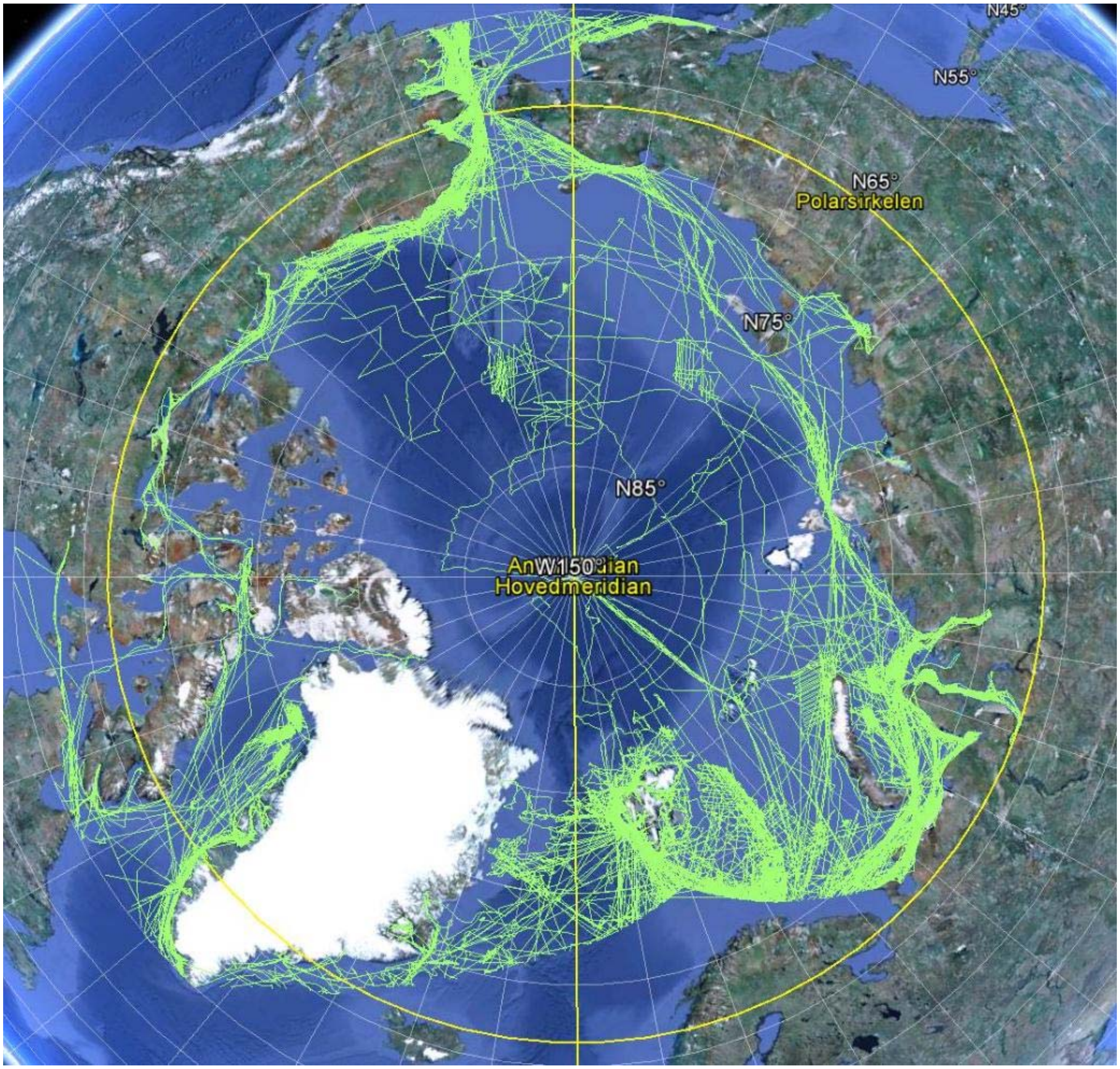
Appendix Figure 10 - Passenger vessel traffic in the Arctic – 2012



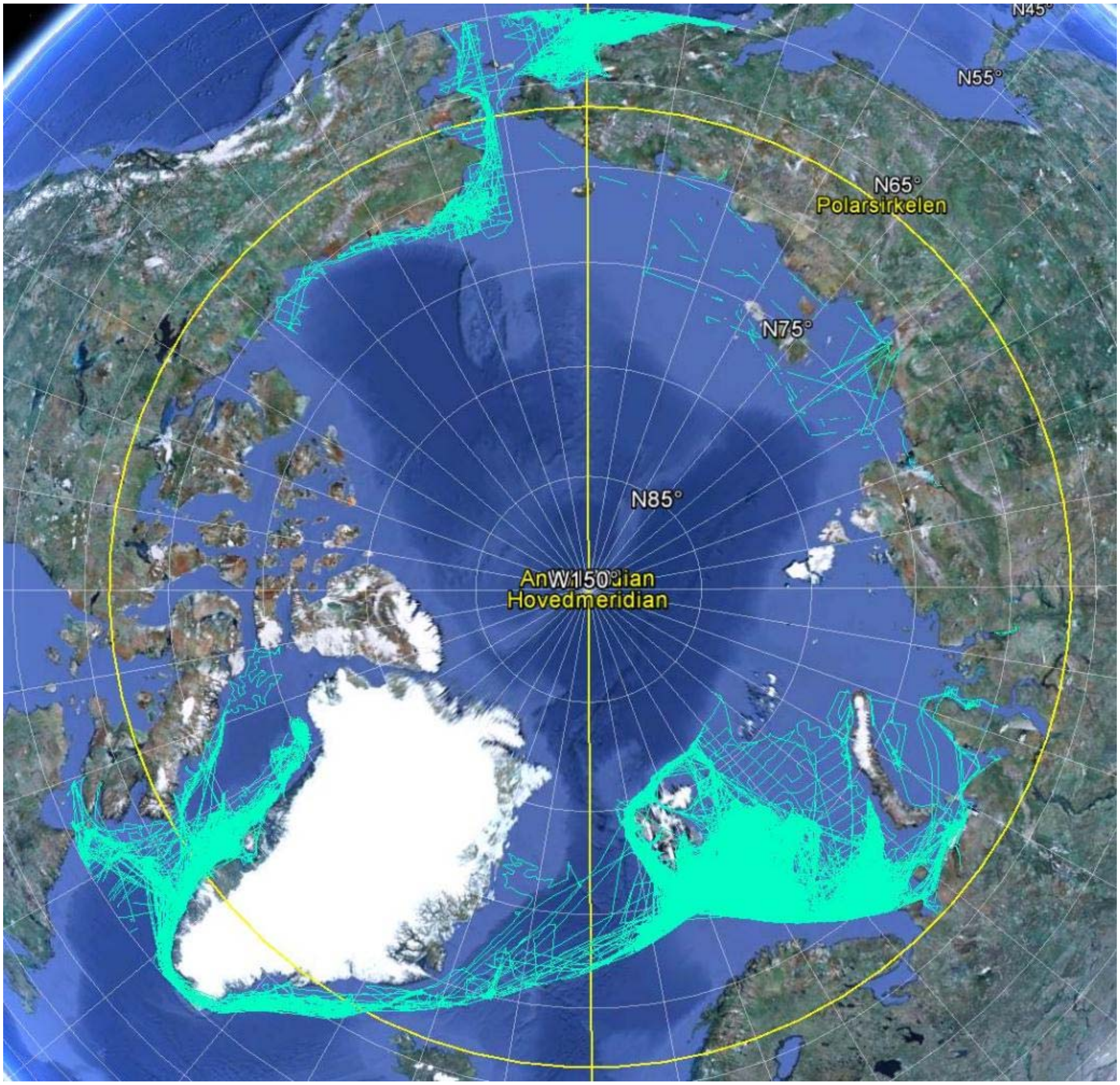
Appendix Figure 11- Offshore supply vessel traffic in the Arctic – 2012



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

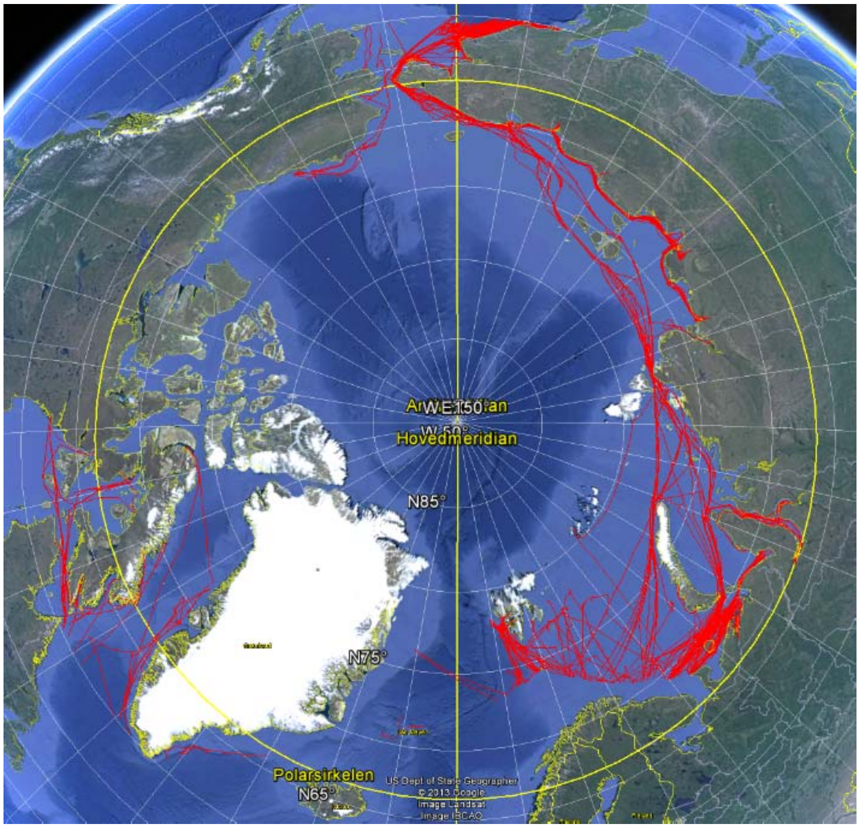


Appendix Figure 13 – "Other Aactivities" vessel traffic in the Arctic - 2012

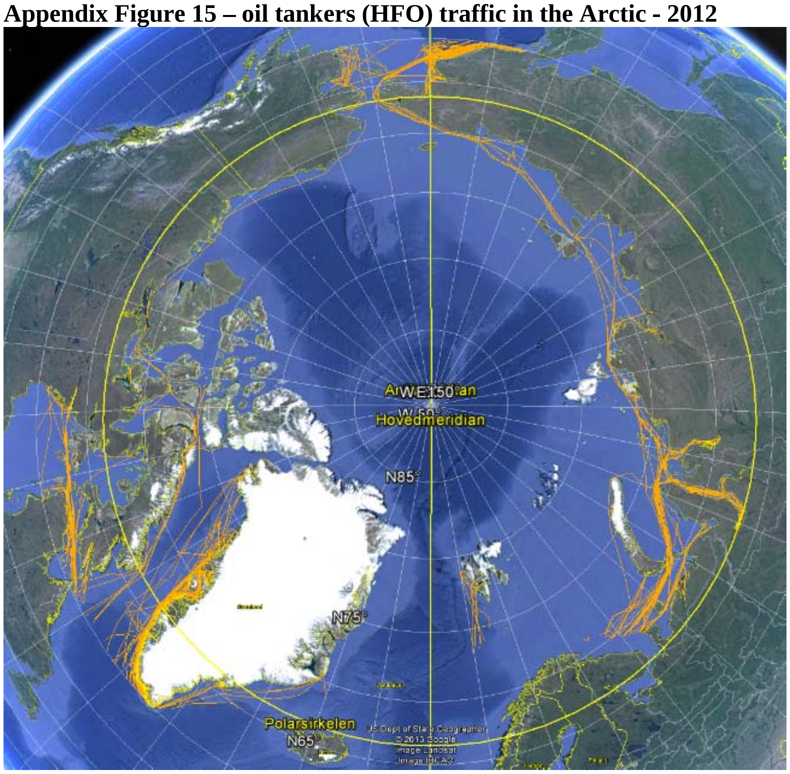


Appendix Figure 14 - Fishing vessel traffic in the Arctic - 2012

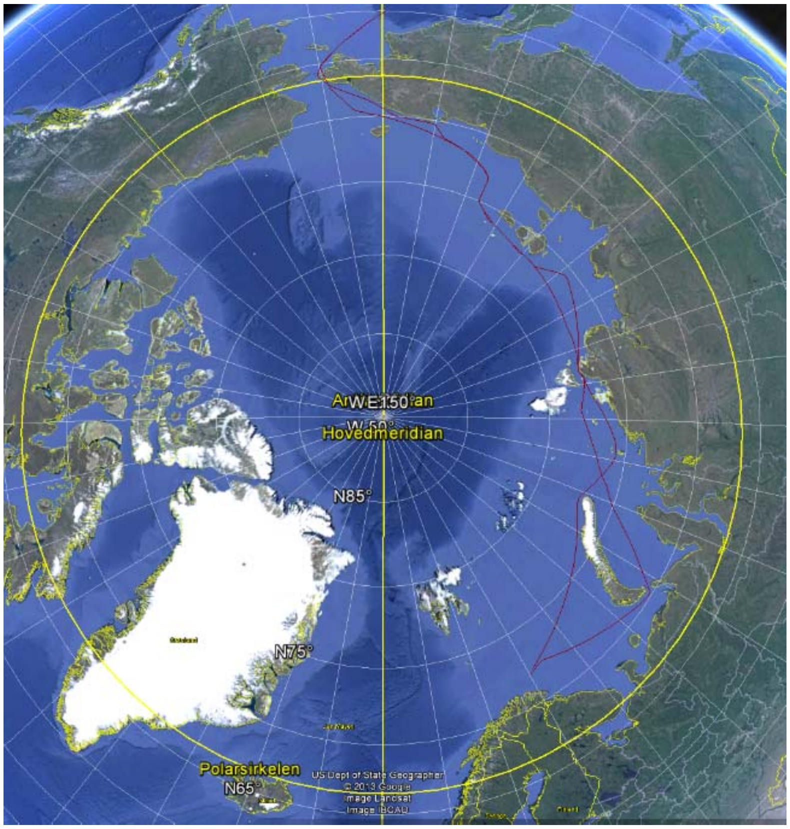
2. Each vessel category – one full year – 2012 – HFO vessels only



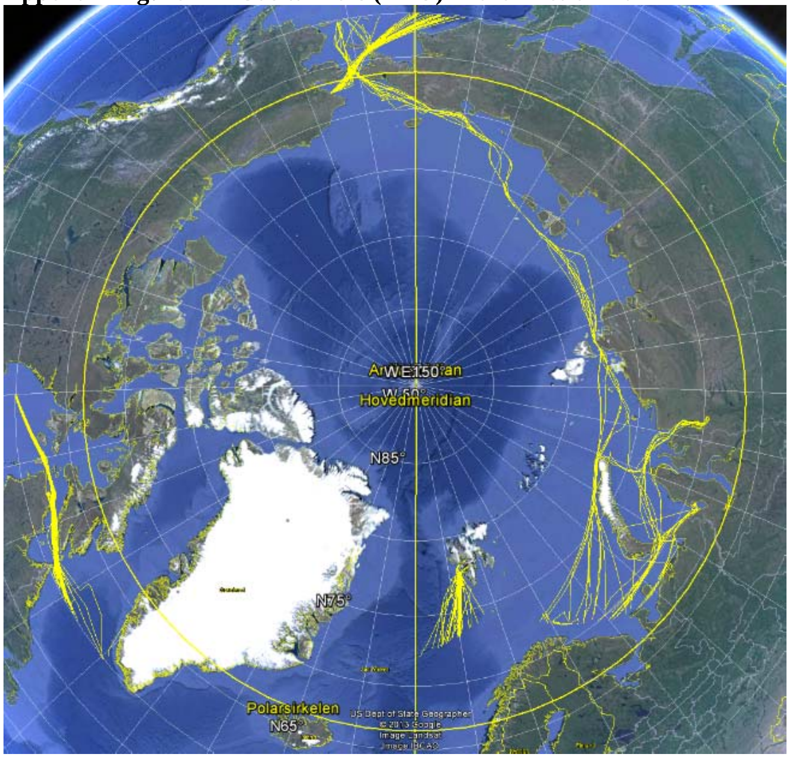
Appendix Figure 15 – oil tankers (HFO) traffic in the Arctic - 2012



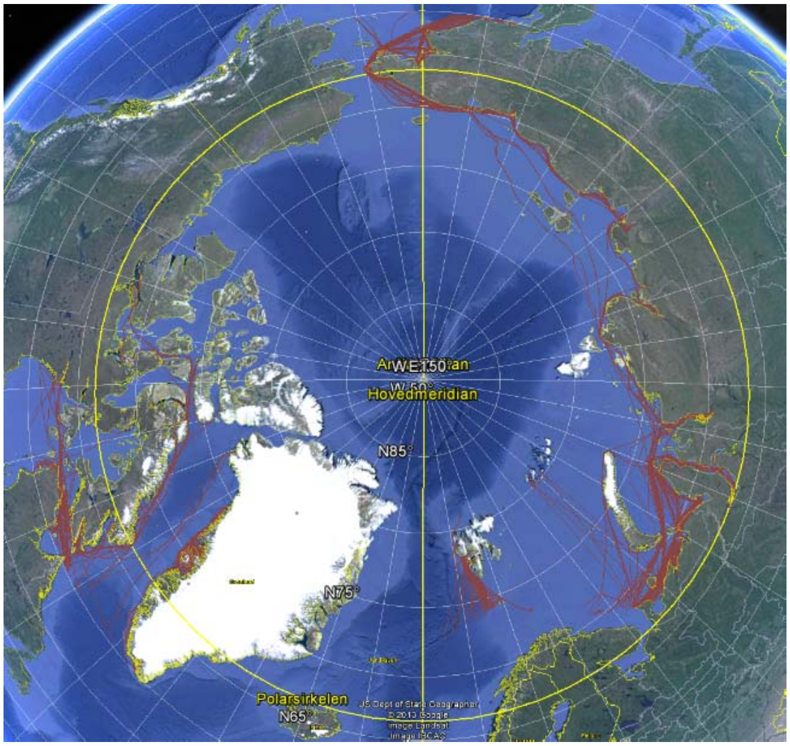
Appendix Figure 16 - Chemical and product tankers (HFO) in the Arctic - 2012



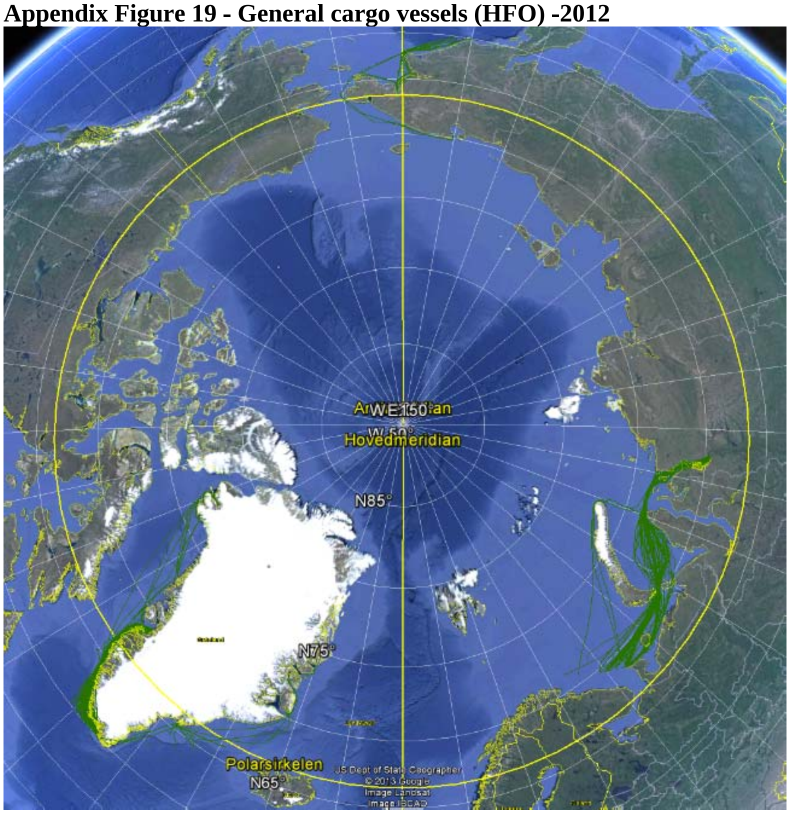
Appendix Figure 17 - Gas tankers (HFO) in the Arctic – 2012



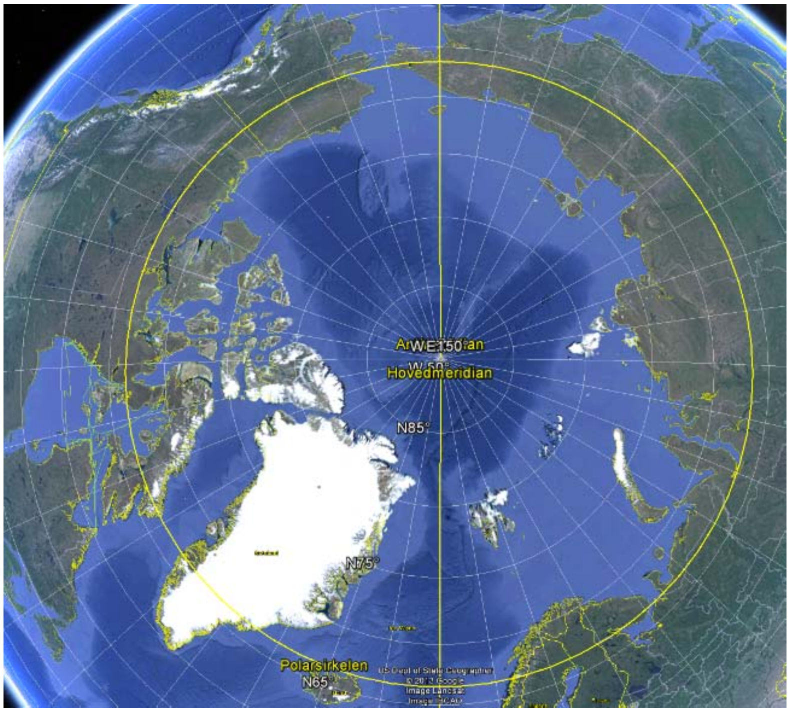
Appendix Figure 18 - Bulk carriers (HFO) in the Arctic 2012



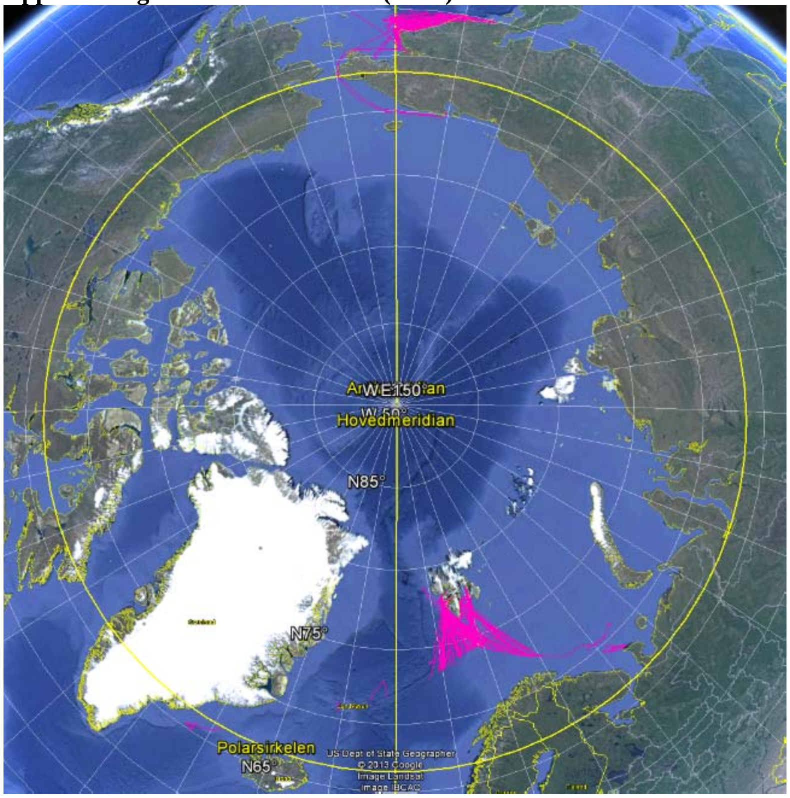
Appendix Figure 19 - General cargo vessels (HFO) -2012



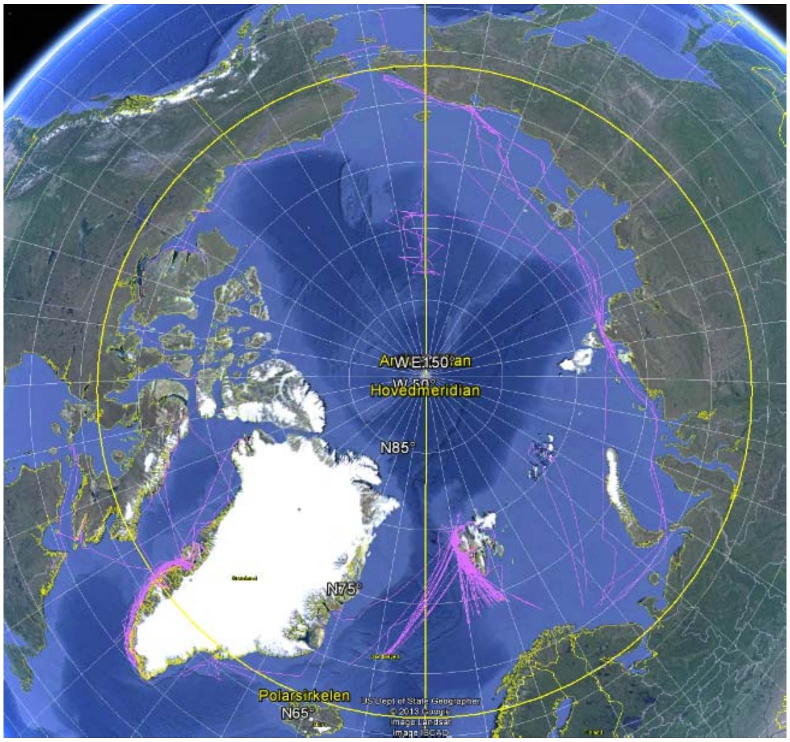
Appendix Figure 20 - Container vessels (HFO) – 2012



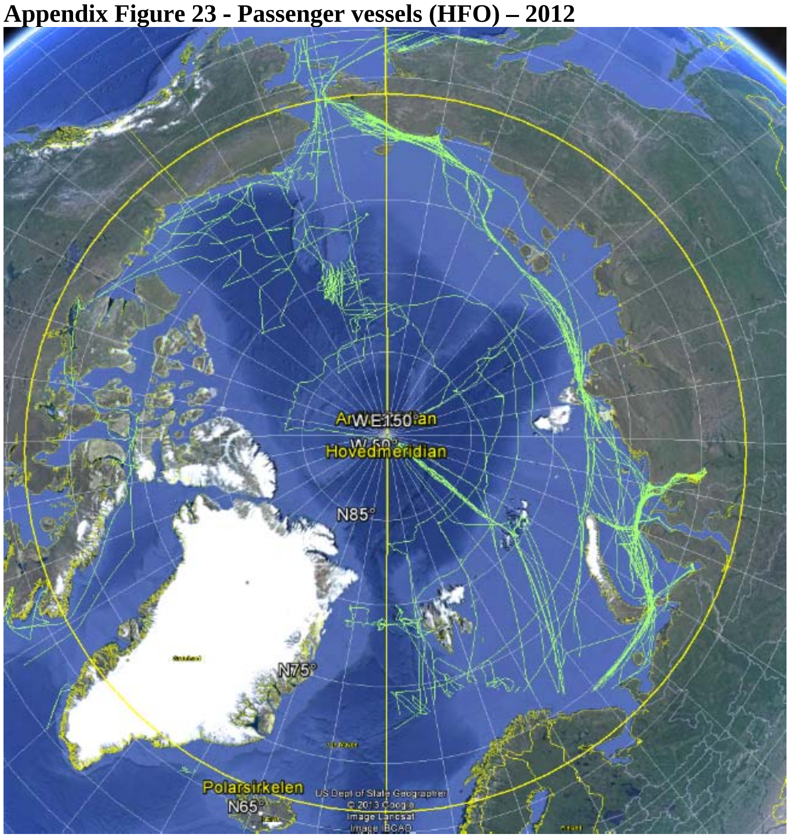
Appendix Figure 21 - RoRo vessels (HFO) -2012



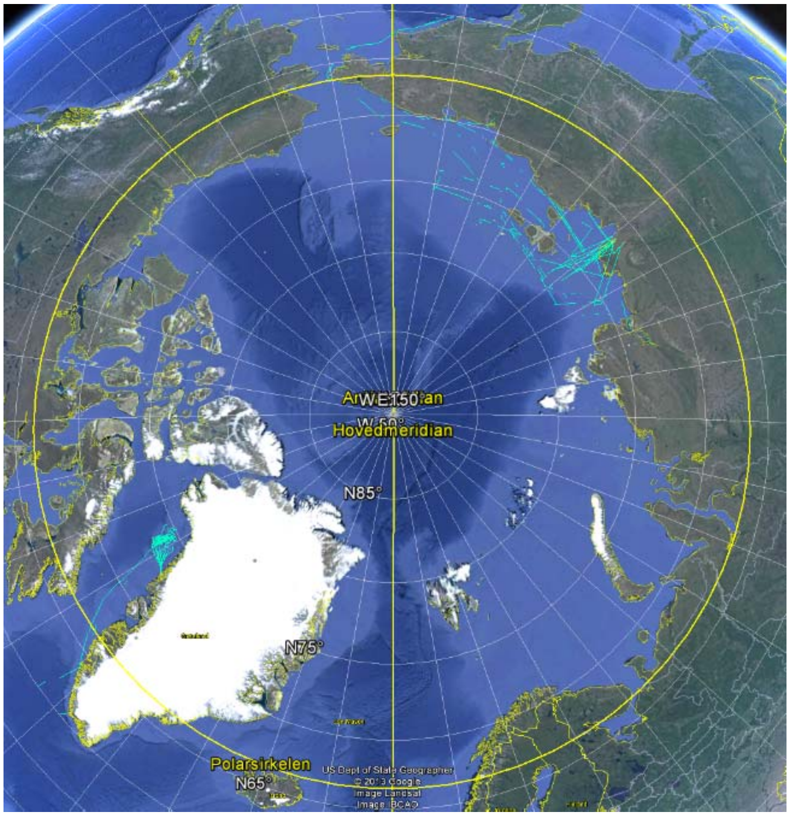
Appendix Figure 22 - Reefers (HFO) - 2012



Appendix Figure 23 - Passenger vessels (HFO) – 2012



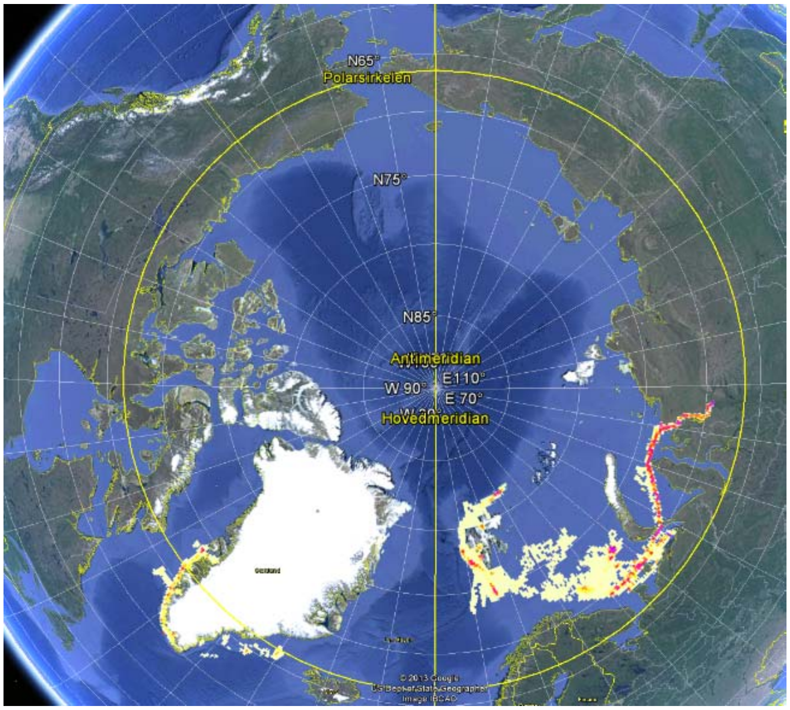
Appendix Figure 24 - Other activities (HFO) – 2012



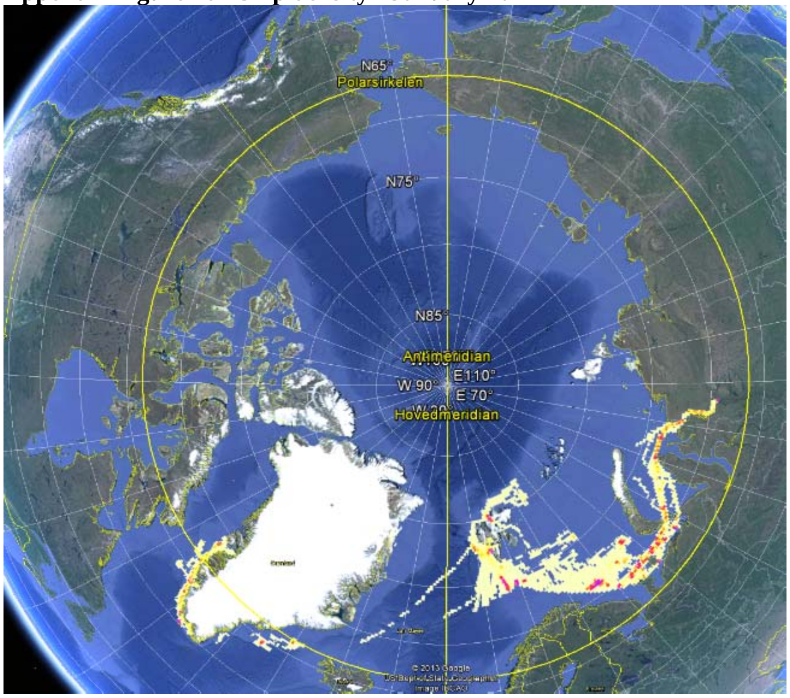
Appendix Figure 25 - Fishing vessels (HFO) - 2012

3. Ship density – each month throughout a full year

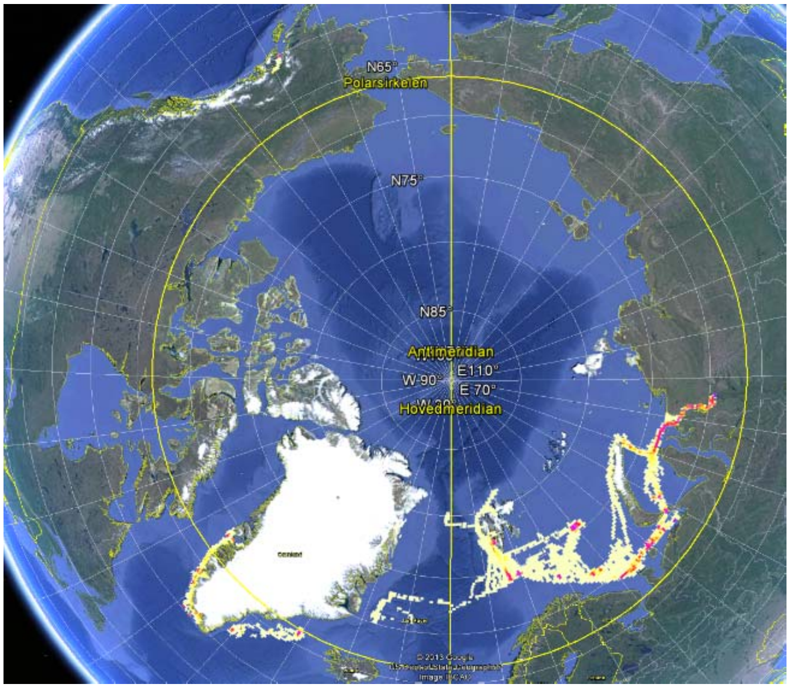
In this section, the ship traffic density in the form of sum of sailed distance per 1x1 degree area is presented.



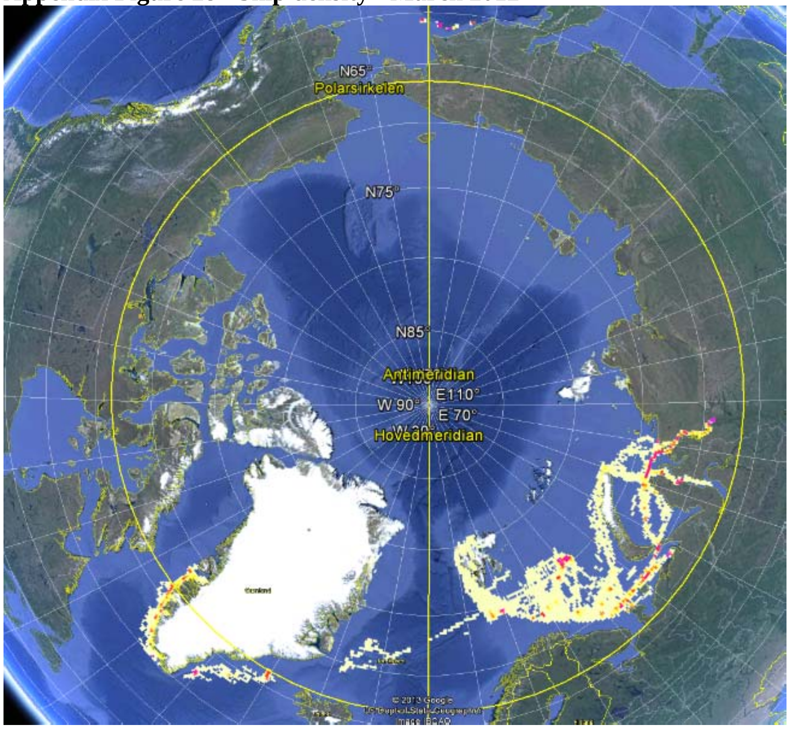
Appendix Figure 26 - Ship density - January 2012



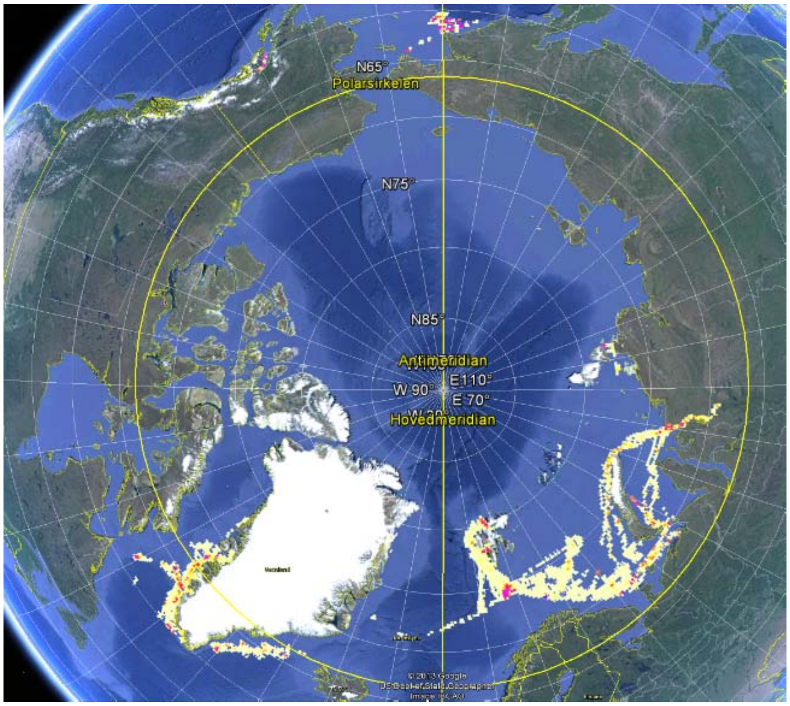
Appendix Figure 27 - Ship density - February 2012



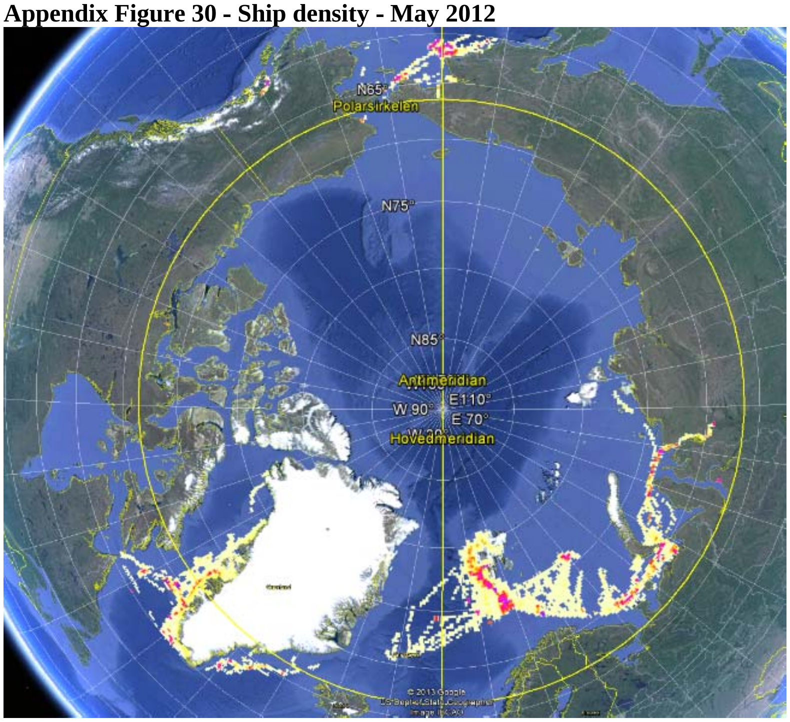
Appendix Figure 28 - Ship density - March 2012



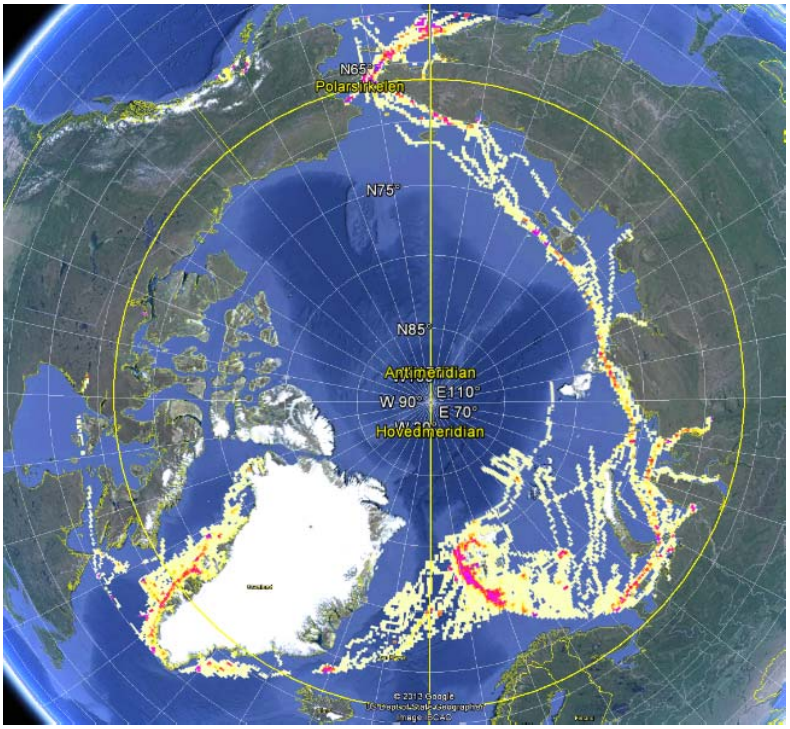
Appendix Figure 29 - Ship density - April 2012



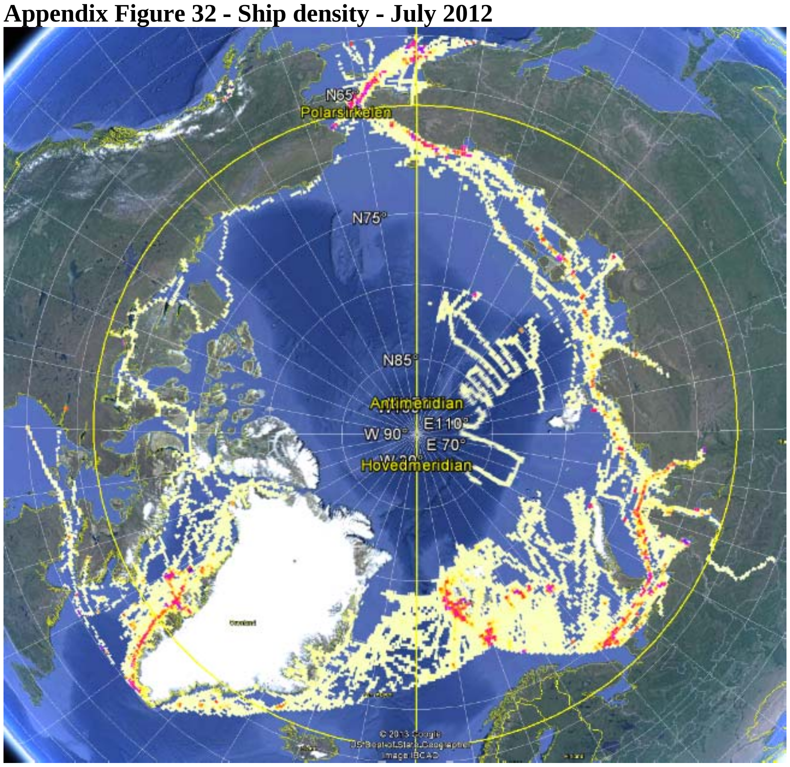
Appendix Figure 30 - Ship density - May 2012



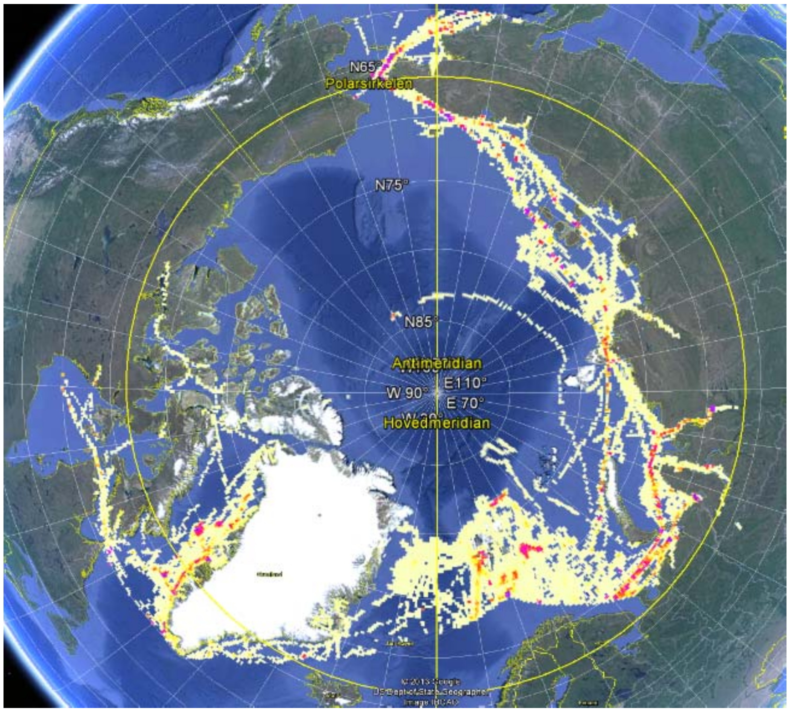
Appendix Figure 31 - Ship density - June 2012



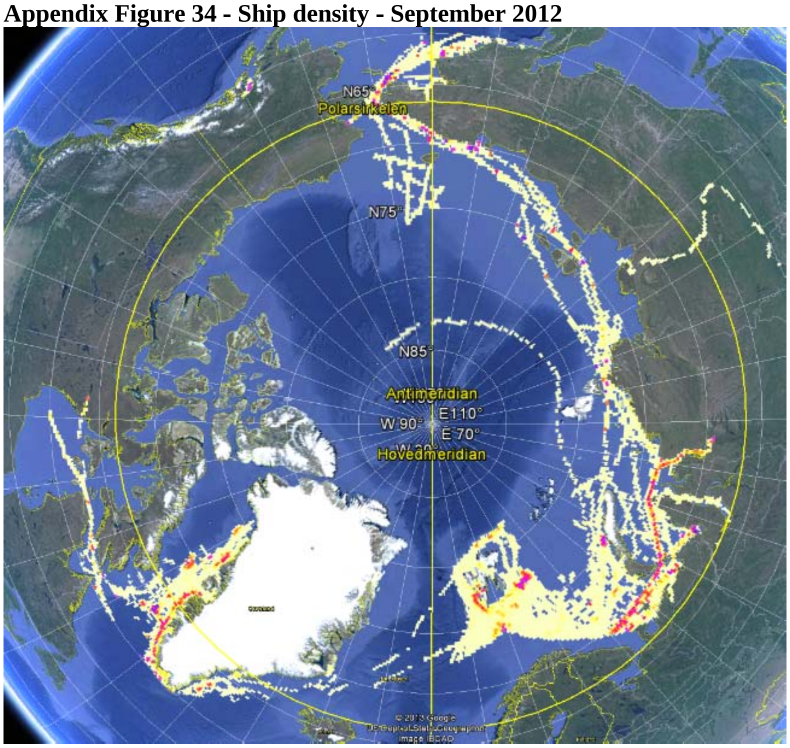
Appendix Figure 32 - Ship density - July 2012



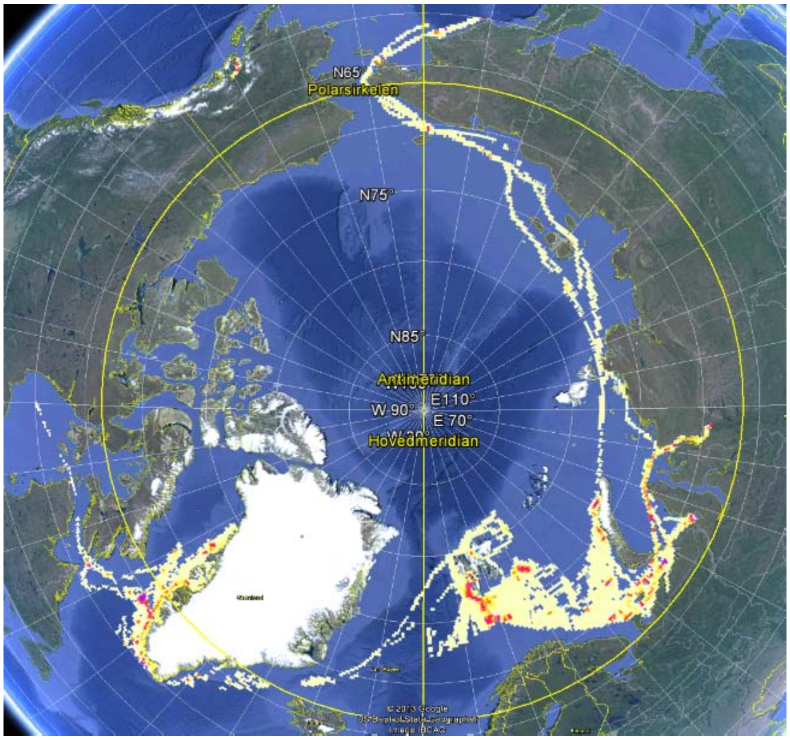
Appendix Figure 33 - Ship density - August 2012



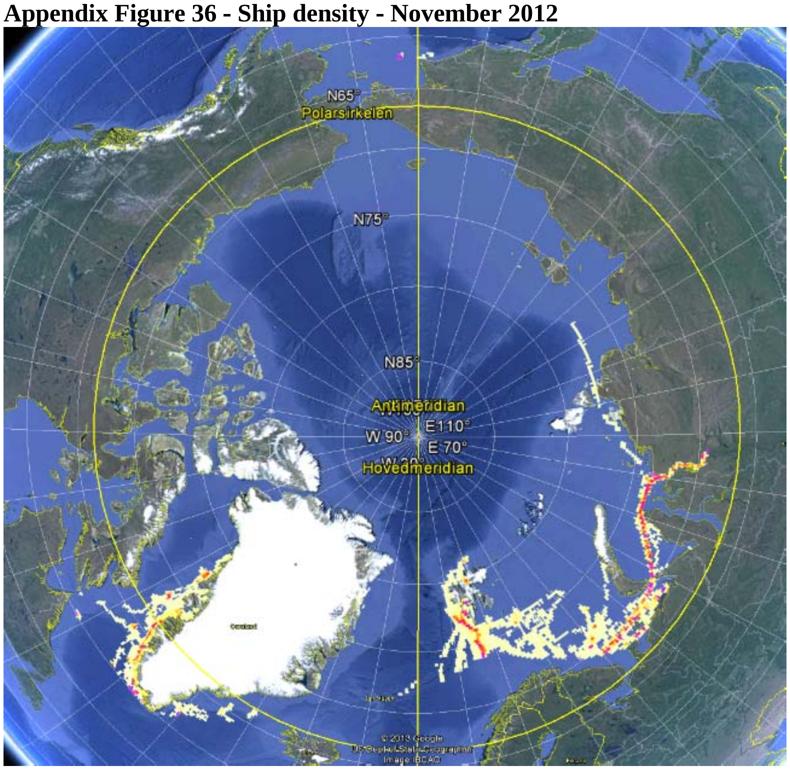
Appendix Figure 34 - Ship density - September 2012



Appendix Figure 35 - Ship density - October 2012



Appendix Figure 36 - Ship density - November 2012



Appendix Figure 37 - Ship density - December 2012

Appendix C
Risk Analysis Details

1. Risk details

All extensive values are the total of

Appendix Table 3- Geographic cell specific data handled in the risk model

Inputs	Outputs
• Vessel category • Distance to shore • Month of year • Sailed distance • Sum of HFO ton mile • Sum of Distillate ton mile • Sum of Crude ton mile • Ice coverage	• Annual accident frequencies of each category • Annual accident frequencies of category 1-4 spills • Annual average spill mass, based on accidents frequencies • Annual average spill masss within each of the spill categories 1-4, based on accidents frequencies

The values "Sum of HFO ton mile" and "Sum of Distillate ton mile" are calculated for *each unique combination* of geographic cell, vessel category, vessel size category and month of year, according to Equation 1.

$$\sum_i Nm_i \times Fuel_i$$

Equation 1: Sum of HFO ton mile and Sum of Distillate ton mile

Where,

i: Unique vessel
Nm: Sum of nautical miles sailed by vessel *i* in cell number *n*[Nm]
Fuel: Fuel capacity of vessel *i* [ton]

Equation 2 shows the similar calculation made to create the value "Sum of Crude ton mile", also calculated for *each unique combination* of geographic cell, vessel category, vessel size category and month of year.

$$\sum_i Nm_i \times Crude_i$$

Equation 2: Sum of Crude ton mile

Where,

i: Unique vessel
Nm: Sum of nautical miles sailed by vessel *i* in cell number *n*[Nm]
Crude: Crude oil cargo capacity of vessel *i* [ton]

2. Base frequencies

Accident frequencies, indicating how often an accident is likely to happen, within each of the four accident categories Grounding, Collision, Hull/Machinery and Fire/Explosion, are estimated based on statistics from the IHS Fairplay Causality Database (IHS Fairplay, 2012). The frequencies are generic and applied regardless of ship category. Below are the definitions of these accidents as defined by IHS Fairplay.

Grounding:

Includes ships reported hard and fast for an appreciable period of time as well as incidents reported touching the sea bottom. This category includes entanglement on under water wrecks or obstructions. (IHS Fairplay, 2012)

Collision:
Striking or being struck by another ship, regardless of whether under way, anchored or moored. This category does not include striking under water wrecks. (IHS Fairplay, 2012).

Hull/Machinery:
Includes ships lost or damaged as a result of hull/machinery damage or failure which is not attributable to categories 1-7 or category 9[4]. (IHS Fairplay, 2012).

Fire/Explosion:
Where the fire and/or explosion is the first event reported (except where first event is a hull/machinery failure leading to fire/explosion).
Note: It therefore follows that casualties involving fires and/or explosions after collisions, stranding etc., are categorised under 'Collision', 'Stranding'. Scavenge fires and crankcase explosions are included in this category. (IHS Fairplay, 2012).

The number of accidents from the accident database divided by the estimated total distance traveled within the same time period gives the accident rates per sailed nautical mile, seen in Appendix Table 4. Section 4 details the adjustment of these frequencies based on factors that influence the likelihood of accidents.

Appendix Table 4 - Base frequencies

	Grounding	Collision	Hull/Machinery	Fire/Explosion	Ice related[5]
Base Frequency [1/Nm]	5.79E-08	2.65E-08	4.72E-09	3.32E-08	1.1E-05

Appendix Table 5**Error! Reference source not found.** show the accident category of ice related accidents. This is not a standard accident category in the IHS Fairplay Causality Database, and the details of this frequency are presented in Appendix C.

3. Likelihoods and spill sizes

Appendix Table 5 shows the likelihood of each of the four spill categories, given the occurrence of one of the five accident types (DNV, Sannsynlighetsanalyse for skipstrafikk i Barentshavet sørøst, DNV rapport 2012-1174, 2012)

Appendix Table 5 - Spill likelihoods

	Grounding	Collision	Hull/Machinery	Fire/Explosion	Ice related[5]
Likelihood of category 1 spill	0.74	0.71	0.79	0.12	N/A
Likelihood of category 2 spill	0.13	0.115	0	0.24	N/A
Likelihood of category 3 spill	0.03	0.095	0	0.58	N/A
Likelihood of category 4 spill	0.1	0.08	0.21	0.06	N/A
Likelihood of spill, unknown size[6]	N/A	N/A	N/A	N/A	0.02

[4] I.e. not attributable to any of the other accident categories in the IHS Fairplay database.
[5] Any incidents due to problems with ice. Frequency applies only to sailed distances with ice coverage of 70% or more.
[6] For ice related accidents the expected amount is not estimated. Only the likelihood of having a spill regardless of size. See section h) for details.

Appendix Table 6 shows the spill size categories, defined according to share of oil spilt given an accident, (DNV, Sannsynlighetsanalyse for skipstrafikk i Barentshavet sørøst, DNV rapport 2012-1174, 2012)Values in categories 1-3 are the share of oil/fuel spilt from one tank. E.g. a value of one corresponds to the entire contents of one tank is spilt, and a value of two corresponds to the entire contents of two tanks are spilt. Values in category 4 represent the share of oil/fuel spilt from the total available volume from all tanks. The values for category 4 are all equal to one, implying an accident where all cargo oil or fuel on the vessel is lost.

Crude oil volumes for oil tankers are approximated to their total DWT. Appendix Table 7 shows the number of tanks between which these volumes are assumed to be distributed, (DNV, 2012).

Appendix Table 6- Spill size categories

	Grounding	Collision	Hull/Machinery	Fire/Explosion	Ice related[6]
Category 1 spill, share of oil/fuel spilt from one tank	0	0	0	0	N/A
Category 2 spill, share of oil/fuel spilt from one tank	0.3	1	0	0.04	N/A
Category 3 spill, share of oil/fuel spilt from one tank	0.6	2[7]	0	0.2	N/A
Category 4 spill, share of oil/fuel spilt from the total available volume	1	1	1	1	N/A

Appendix Table 7- Estimated number of cargo oil cargo tanks on oil tankers

Vessel gross ton size category [GT]	0 - 1000	1000 - 4999	5000 - 9999	10000 - 24999	25000 - 49999	50000 - 99999	> 100000
Estimated number of oil cargo tanks	4	4	4	6	6	8	12

The estimated average bunker capacity within each geographic cell is multiplied by 0.65 to adjust for the fact that all vessels on average will have somewhere between full and empty tanks. Spill of cargo oil from oil tankers is estimated by attributing half the distance sailed to fully laden oil cargo and the other half to empty cargo tanks and 65% filled fuel tanks.

4. Adjustment factors

d) Adjustment of grounding frequency

The base frequency of grounding accidents is multiplied by an adjustment factor based on the distance between the centers of each respective cell to the closest shore, to account for distance to shore affecting the likelihood of a Grounding accident. Appendix Table 8 shows the adjustment factors (DNV, Statoil Risk Picture Tankers, Appendix C, 2012).

[7] A collision accident resulting in the loss of the content in two tanks

Appendix Table 8- Adjustments to grounding frequencies

Distance to coast category	Adjustment
Coast, 0 - 2 Nm	10
Coast, 2 - 10 Nm	5
Coast, 10 - 35 Nm	1
Open sea (Grounding not relevant)	0

e) Adjustment of collision frequency

The base frequency of collision accidents is multiplied by adjustment factors based on the distance between the centres of each cell to the closest shore as well as on the traffic density.
Appendix Table 9 shows the adjustment factors for distance and traffic density (DNV, Statoil Risk Picture Tankers, Appendix C, 2012) and (DNV, Statoil Risk Picture Tankers, Appendix G, 2012). The entire Arctic region in this report is assessed as "Low traffic density areas".

Appendix Table 9 - Adjustments to collision frequencies

Distance to coast category	High traffic density	Medium traffic density	Low traffic density
Coast, 0 - 2 Nm	15	3	0.5
Coast, 2 - 10 Nm	7	1.5	0.25
Coast, 10 - 35 Nm	3	0.7	0.1
Open sea (Grounding not relevant)	0.6	0.15	0.02

5. Ice Risk

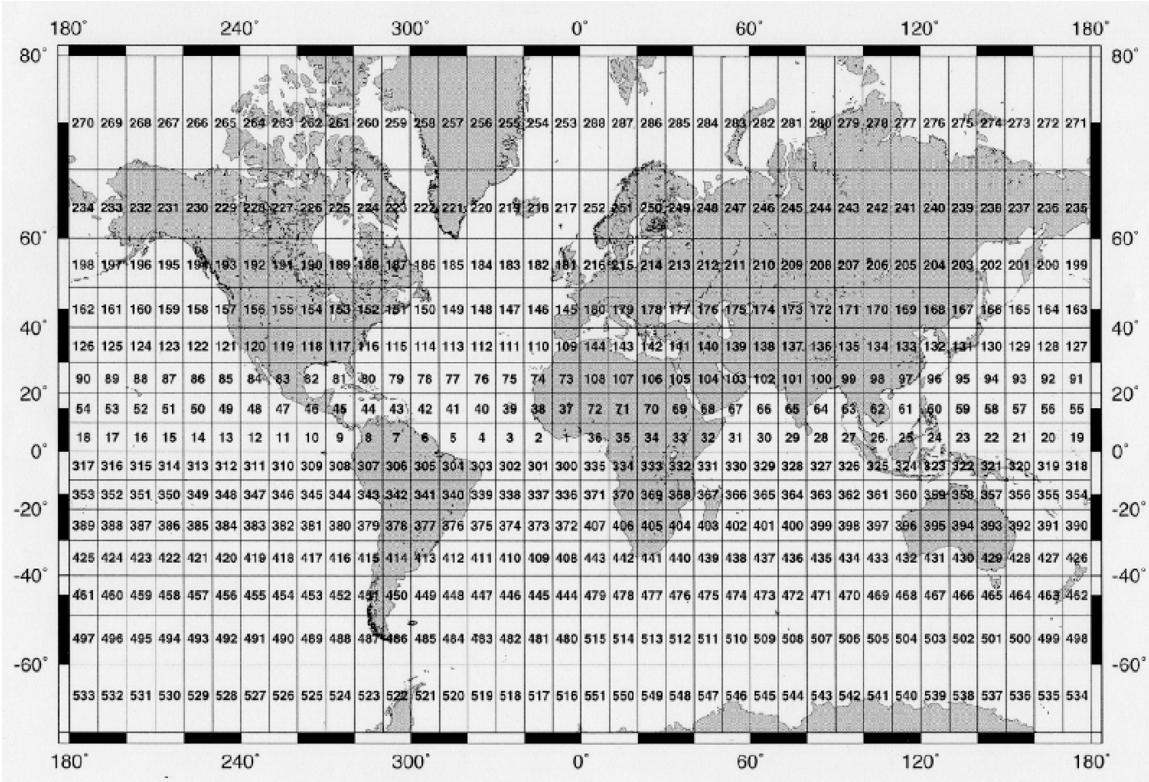
f) Ice coverage

Ice coverage data for each cell has been provided as a percentage of covered area on the 15th day in each month. For a few cells the ice data was not available and in such cases, the average ice concentration values of the surrounding cells containing ice data, were used as an approximation.
Due to lack of 2012 ice data in cells south of 66 degrees latitude near the Bering Strait, calculations of ice related risk for this area return no risk due to ice.

g) Frequency of ice related accidents

The IHS Fairplay (IHS Fairplay, 2012) database uses the Marsden grid system (Appendix Figure 38) to indicate the locations of accidents. To gather data on ship accidents in the Arctic, this project uses grids 217 to 288 (i.e. everything north of 60 degrees latitude) as an approximation. The number of accidents *related* to ice within these cells in the period 1990-2012 where found in (IHS Fairplay, 2012) The number of nautical miles sailed resulting in the aforementioned number of accidents, is unknown. As an approximation, the sum of nautical miles sailed in the Arctic during 2012 (based on AIS data) in more than 70% ice coverage has been used as the annual average. Thus, the number of ice related accidents found, where divided by 23 (23 years in the period 1990-2012) times the approximated annual average sailing distance.

- Accidents related to ice within Marsden grids 217 to 288, in the period 1990-2012: **32**
- Sum Nm in Arctic region during 2012, in ice coverage over 70%: **127,703**



Appendix Figure 38 - Marsden grid system

h) Probability of oil spill from ice related accidents

All accidents registered in IHS Fairplay related to ice that occurred anywhere in the world during the period 1990 to 2012 were found in (IHS Fairplay, 2012). The share of these accidents that resulted in an oil spill was 1 in 50. This has been used as the approximation of the likelihood of oil spill given an accident related to ice. Only spill vs. no spill has been estimated, not oil spill volumes.

- Accidents related to ice worldwide (1990-2012): **167**
- Accidents related to ice worldwide, with spill of oil (1990-2012): **3**

6. Risk calculations

All calculations are made for unique combinations of geographic cell, month of the year, size category and vessel category. Each geographic cell has AIS information about total sailed distance for each month of the year. This, in combination with accident frequencies per nautical mile, gives the annual expected accident frequencies, given the traffic situation recorded in 2012.

i) Spill volume calculations

$$aV_{Cn} = [(DtNm + HtNm) \times S_1 \times (1 - S_2) + S_2 \times \frac{CtNm}{C}] \times F_a \times A \times P_{na} \times S_n$$

Equation 3: Spill category spill volume for oil tankers

aV_{Cn}: Sum of annual volume of category *n* spills due to a category *a* accident, where *n* goes from 1 to 4.[Ton/year]

CtNm: Sum of Crude ton Nautical miles. The sum of the product of each tanker's nautical miles sailed multiplied with the tanker cargo capacity. [Ton*Nm/year]

DtNm: Sum of Distillate fuel ton Nautical miles. The sum of the product of each vessel's nautical miles sailed multiplied with the vessel's distillate fuel capacity. [Ton*Nm/year]

HtNm: Sum of HFO fuel ton Nautical miles. The sum of the product of each vessel's nautical miles sailed multiplied with the vessel's HFO fuel capacity. [Ton*Nm/year]

S_1: Share of fuel capacity on average present in a vessel at any given time. Set to 65%

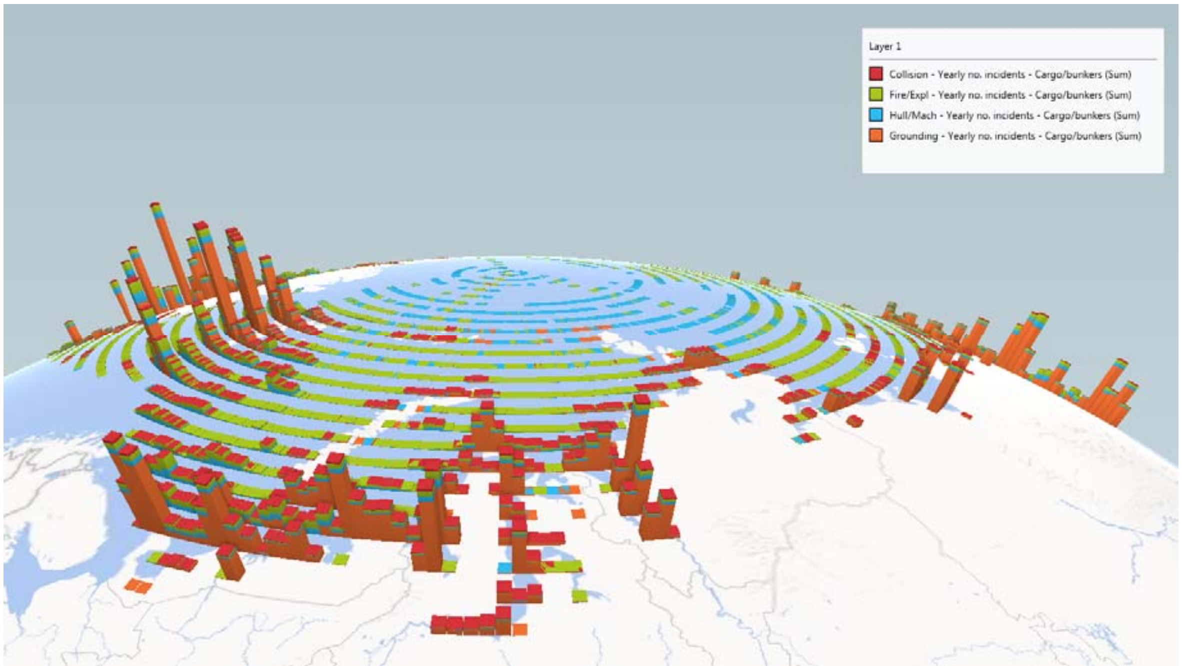
S_2: Share of total voyage time any tanker is fully laden with oil cargo. Set to 50%.

C: Number of cargo oil tanks on the oil tanker (see Appendix C [cargo tank]

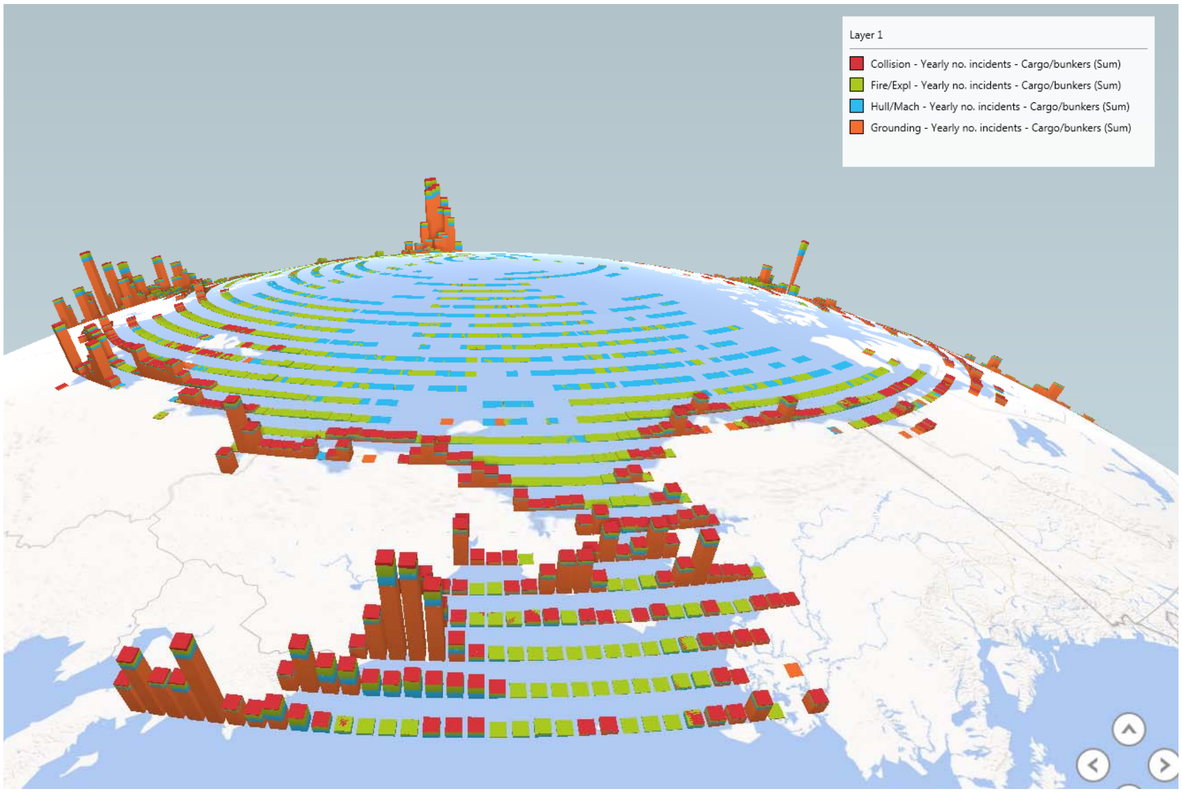
S_n: Share of the total volume of one cargo tank or fuel tank spilt given a category *n* spill [1/cargo tank]

Appendix D
Risk Data Geoplots

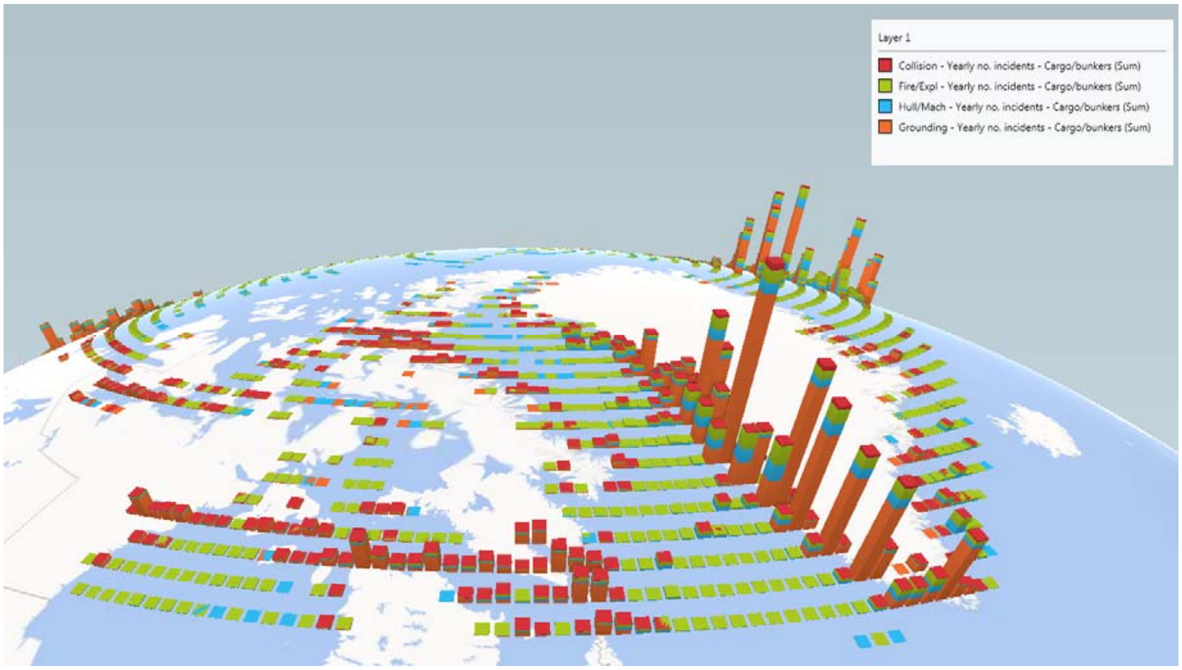
1. Incidence risk frequency – Annual number of likely incidents



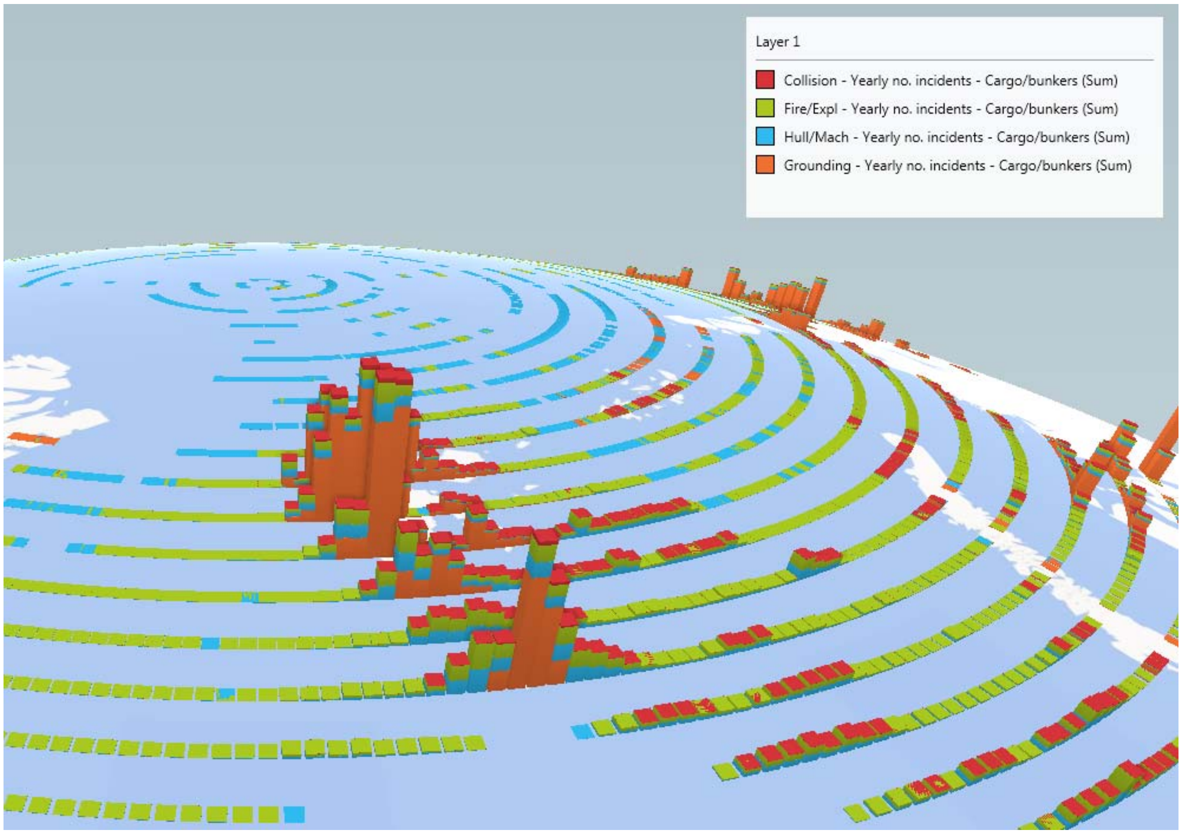
Appendix Figure 39 – Incident risk resulting in oil spill - Russian north coast



Appendix Figure 40 – Incident risk resulting in oil spill – Bering Strait

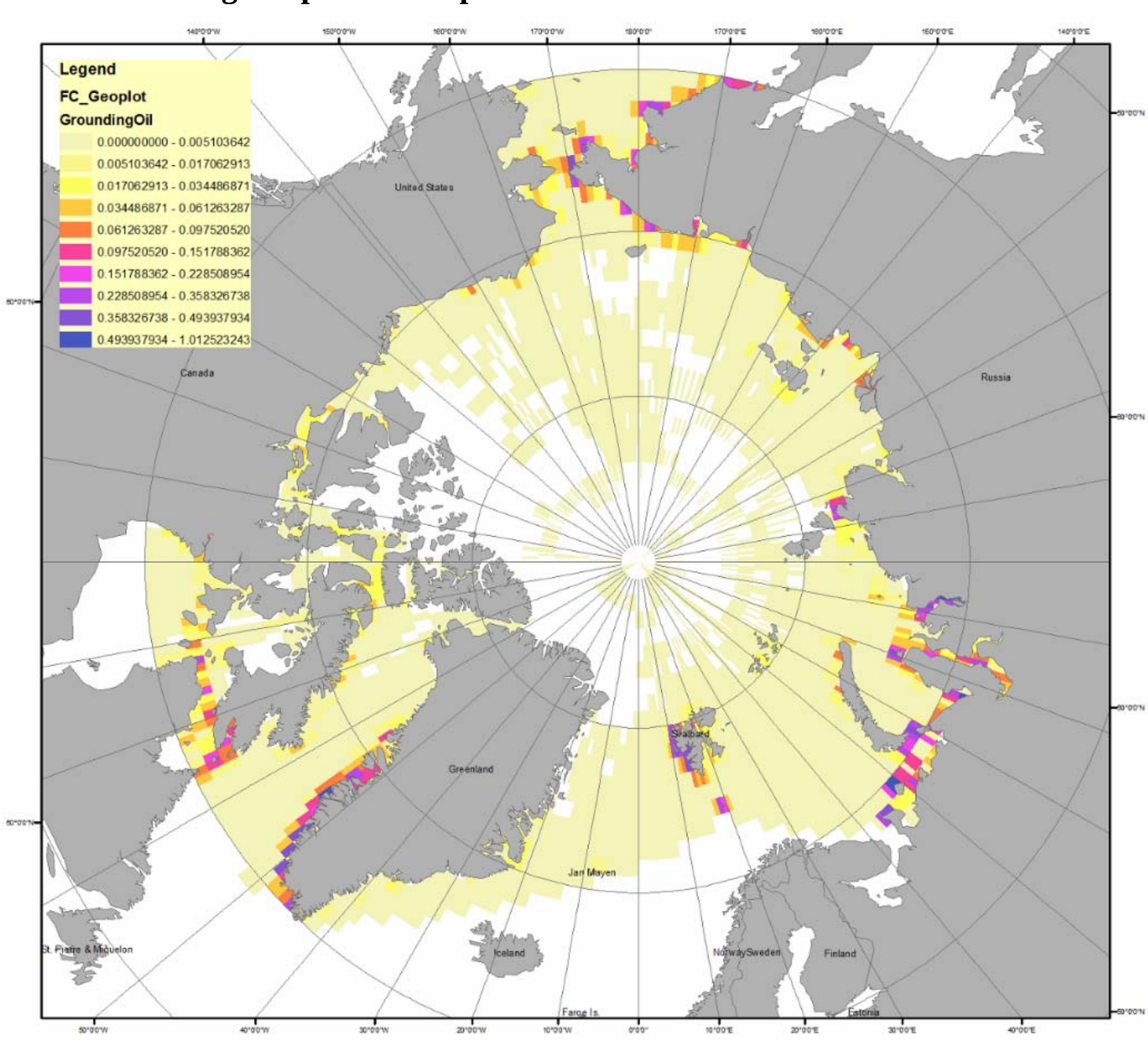


Appendix Figure 41 – Incident risk resulting in oil spill – Canada/Greenland

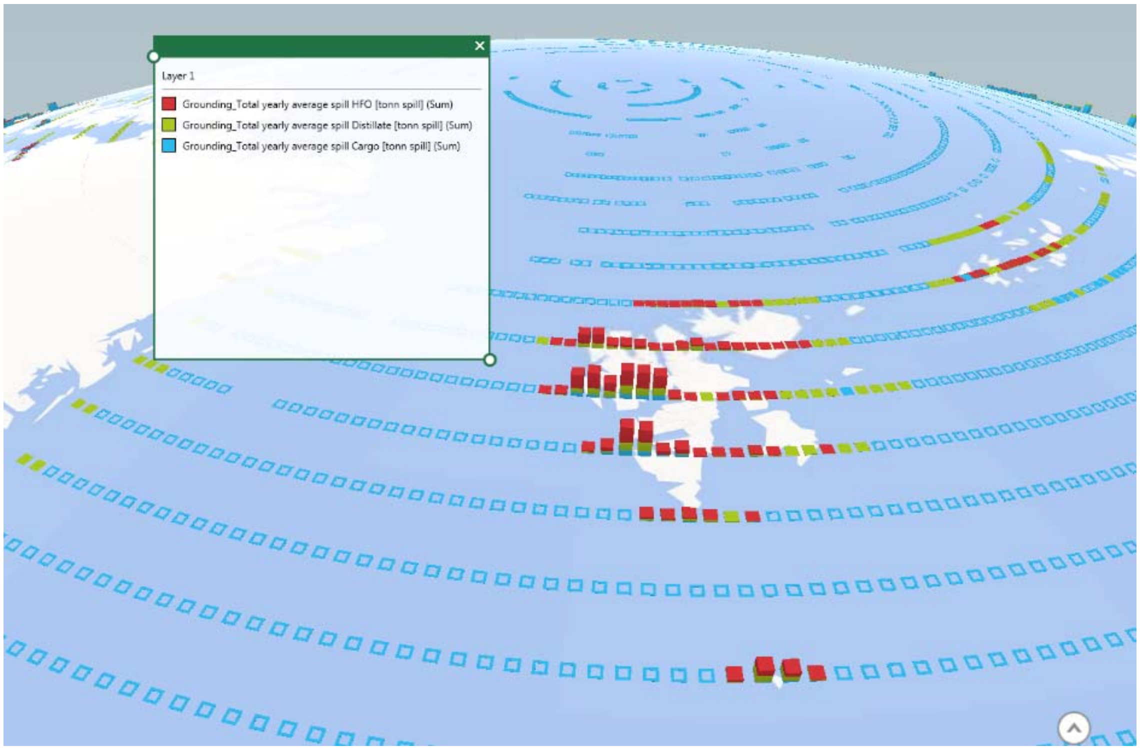


Appendix Figure 42 – Incident risk resulting in oil spill - Spitsbergen

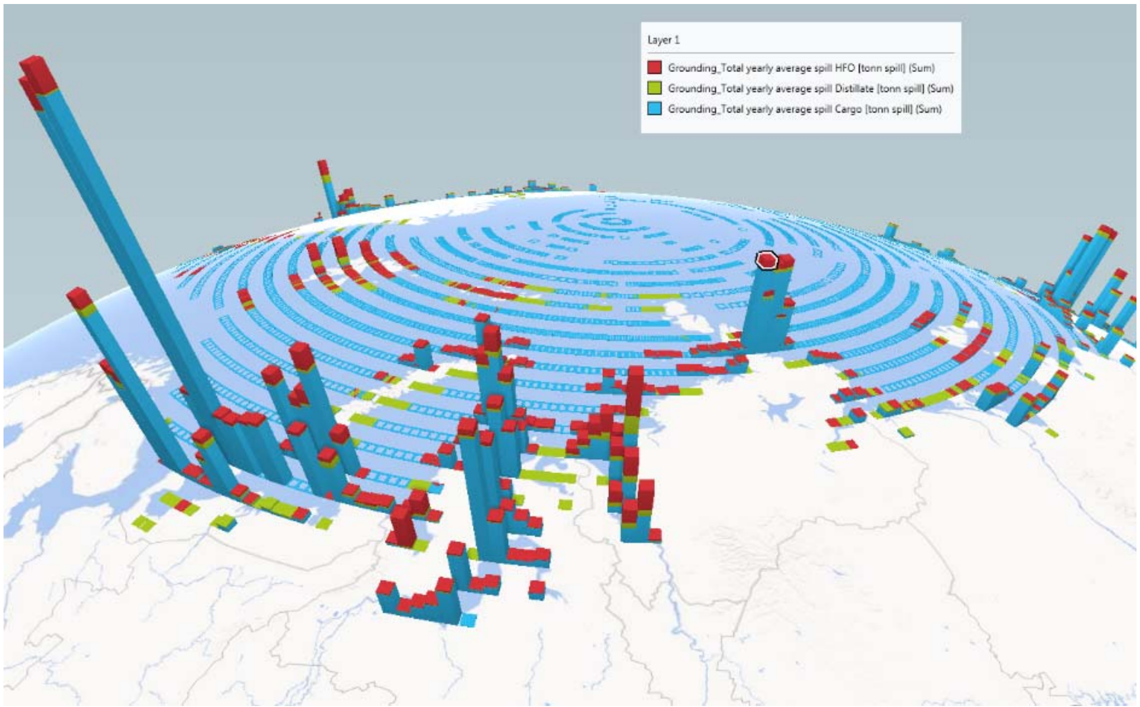
2. Grounding oil spill risk maps



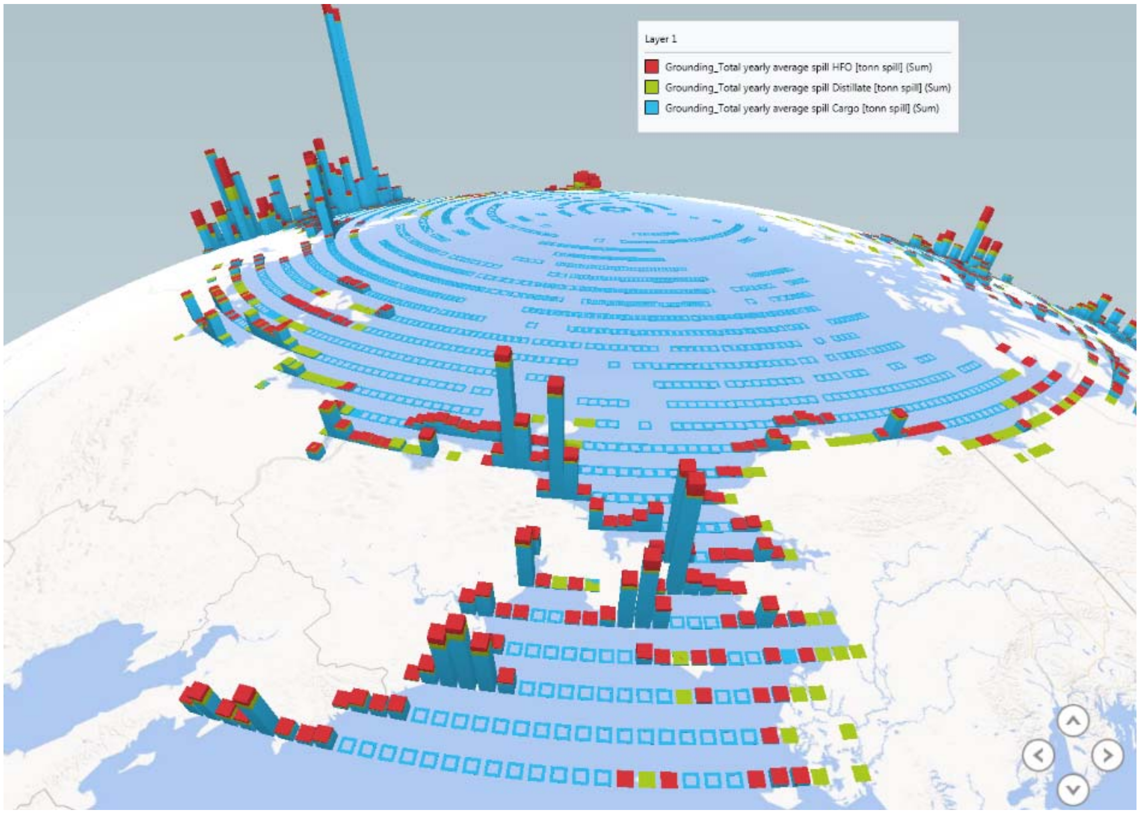
Appendix Figure 43 - Annual average oil spill – Grounding



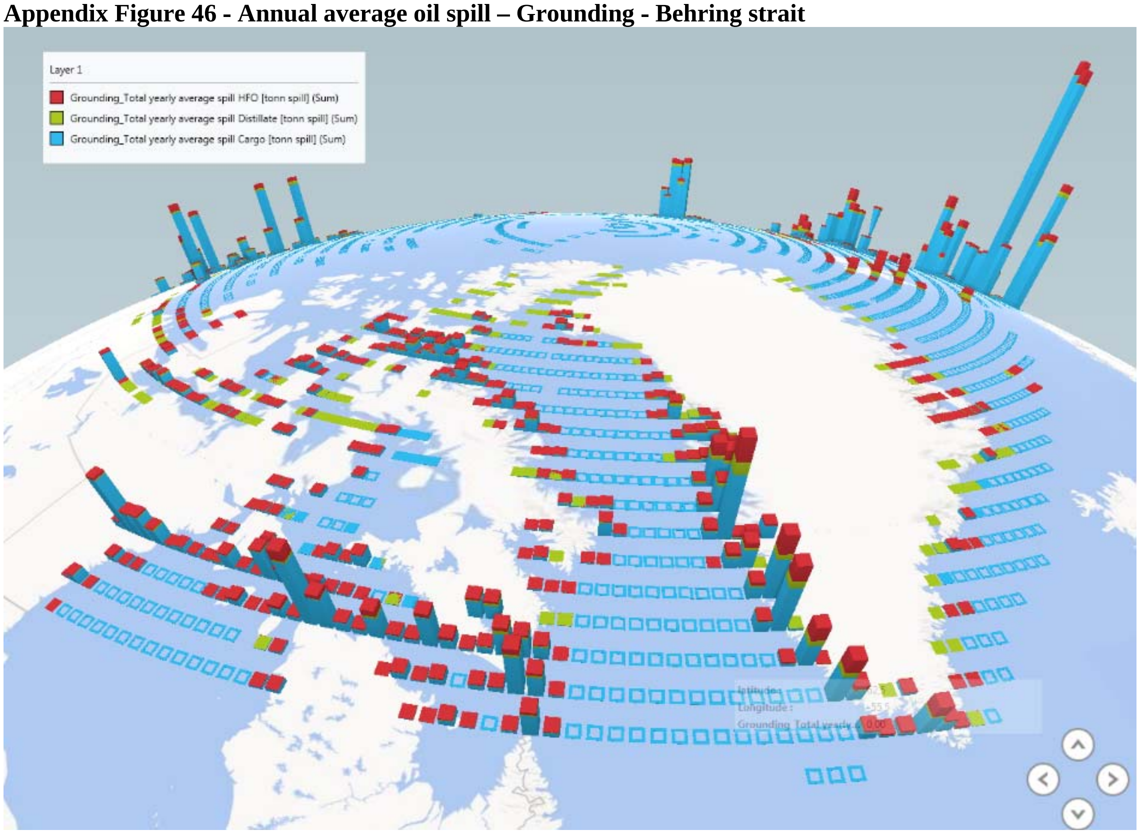
Appendix Figure 44 - Annual average oil spill – Grounding – Spitsbergen (Note - HFO ban zone not accounted for)



Appendix Figure 45 - Annual average oil spill – Grounding - Russian north coast

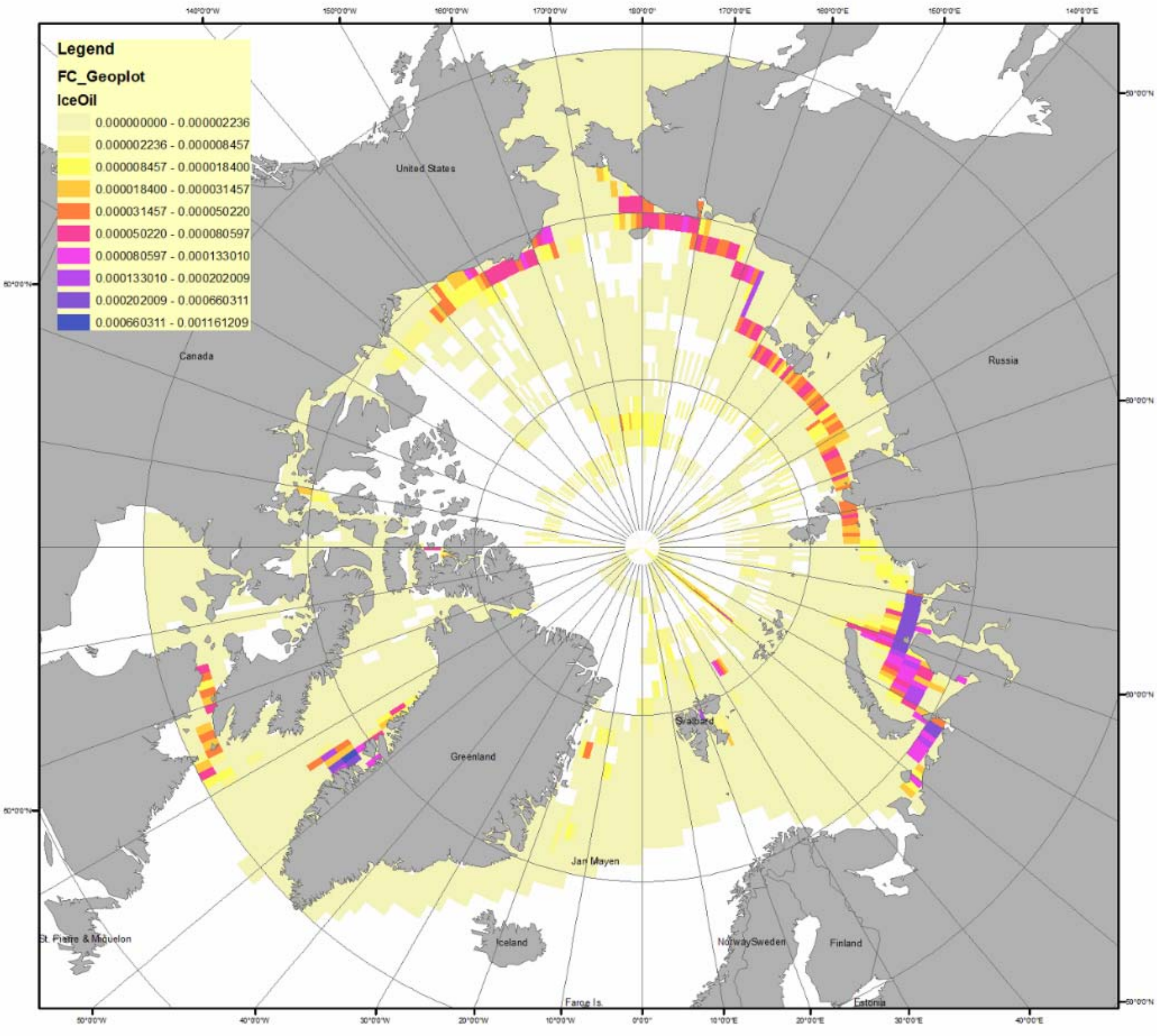


Appendix Figure 46 - Annual average oil spill – Grounding - Behring strait

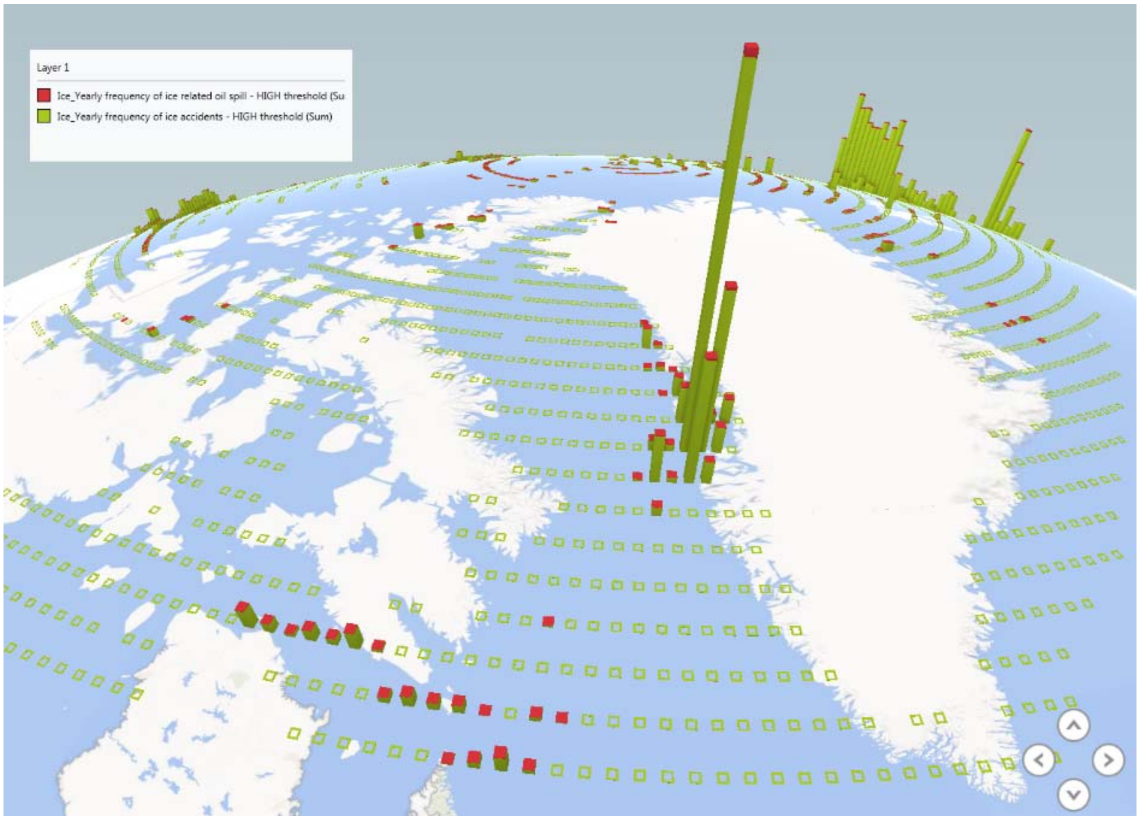


Appendix Figure 47 - Annual average oil spill - Grounding - Canada/Greenland

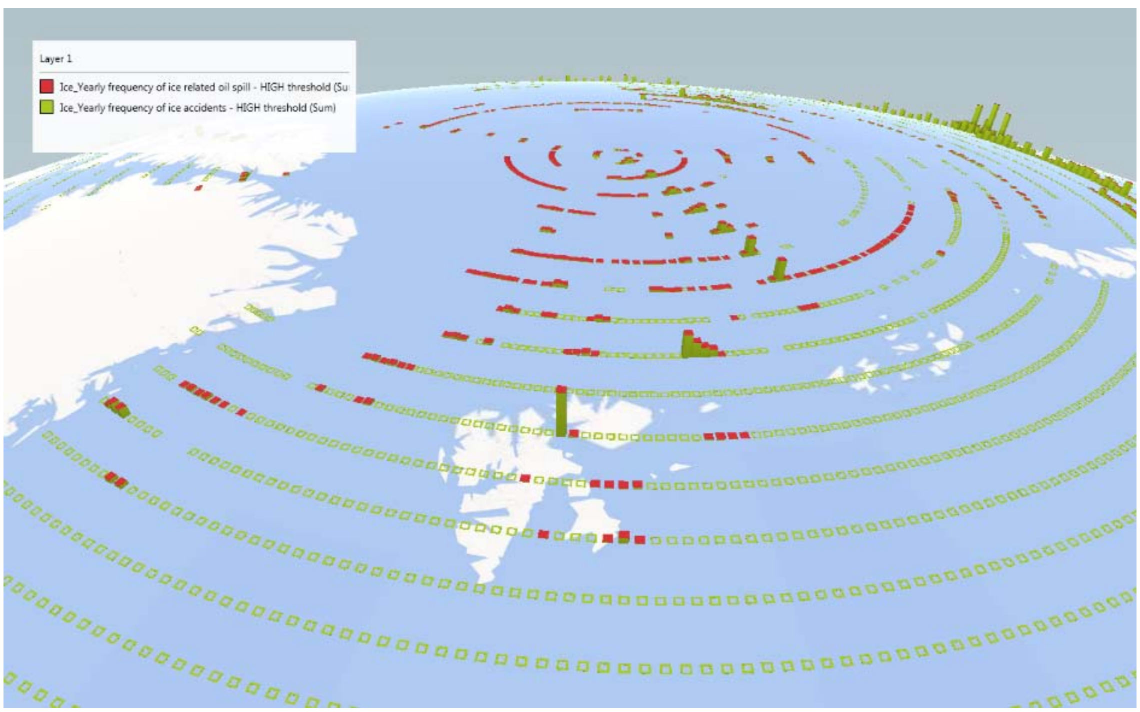
3. Ice related risk frequency maps



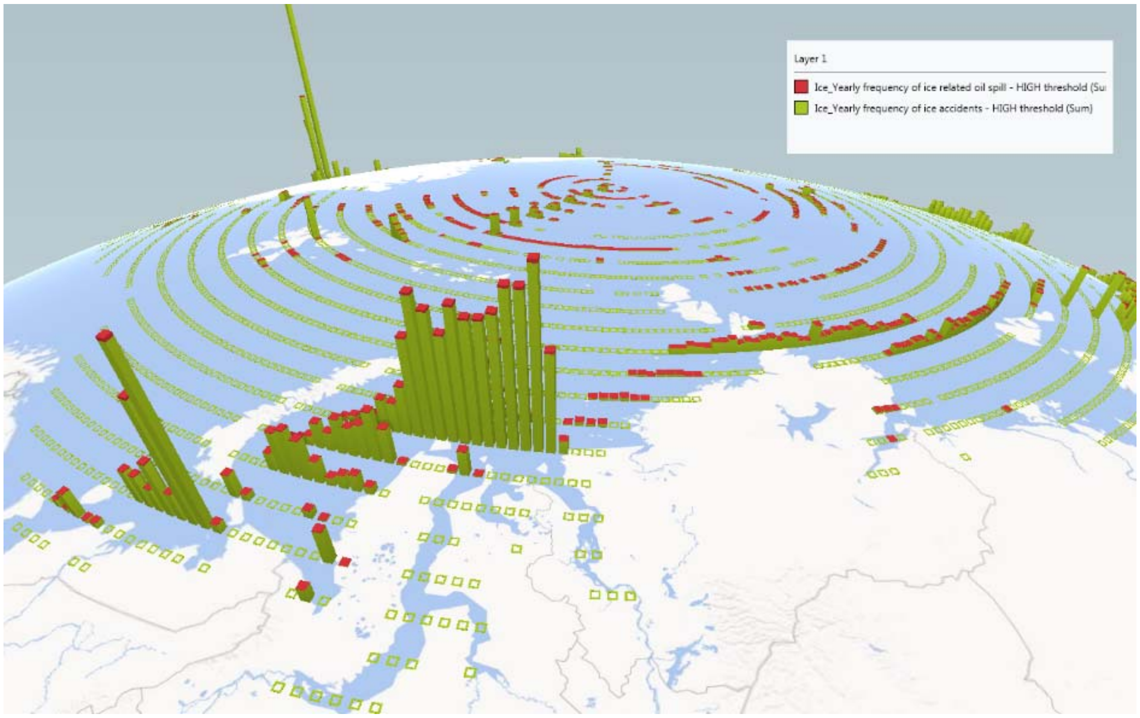
Appendix Figure 48 – Ice damage risk frequency



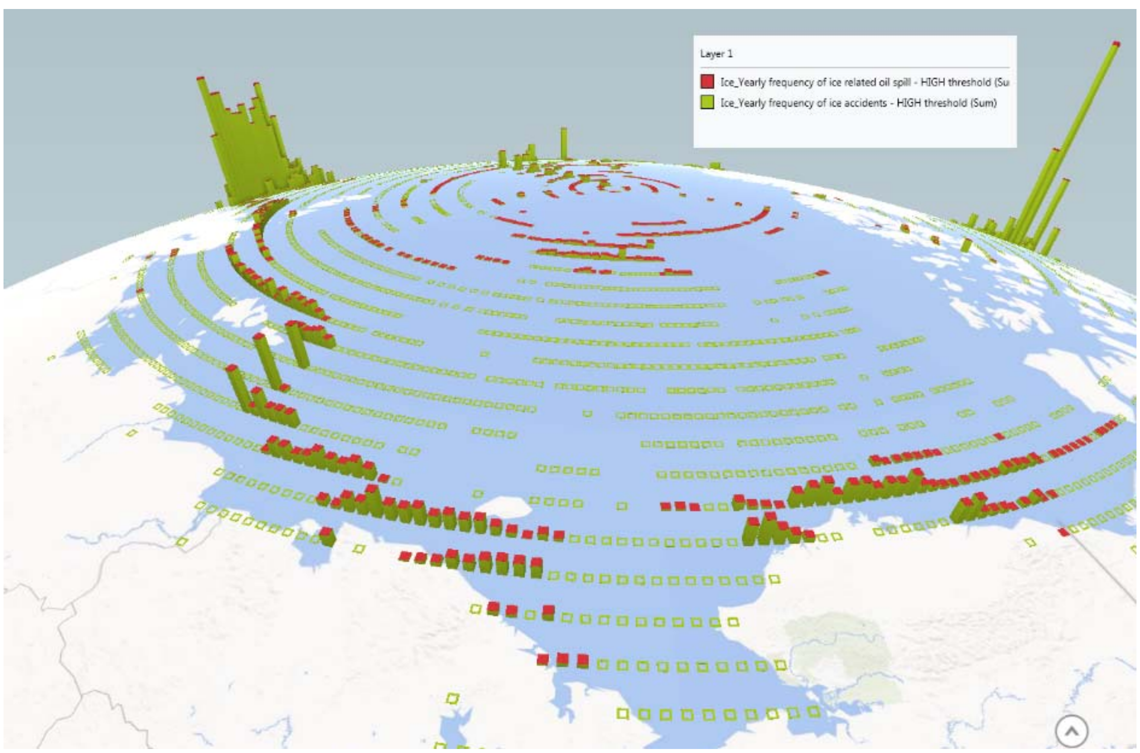
Appendix Figure 49 - Ice damage risk frequency (non-oil spill and oil spill) – Baffin Bay



Appendix Figure 50 - Ice damage risk frequency (non-oil spill and oil spill) – Spitsbergen and the Central Polar Sea

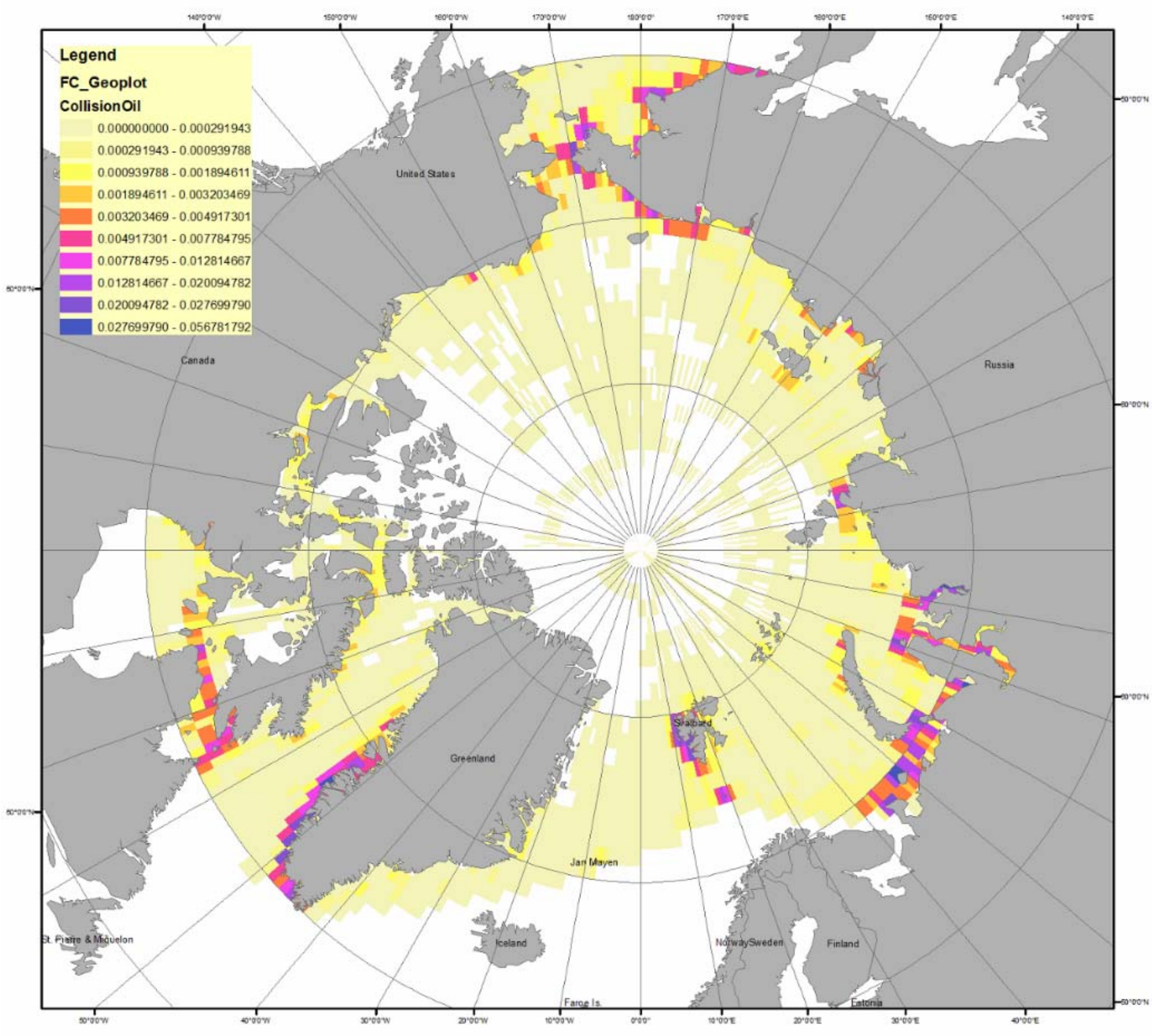


Appendix Figure 51 - Ice damage risk frequency (non-oil spill and oil spill) – Russian north coast (Note that most traffic in ice in this region is consist of vessels with ice class – and hence the risk is likely over-estimated)

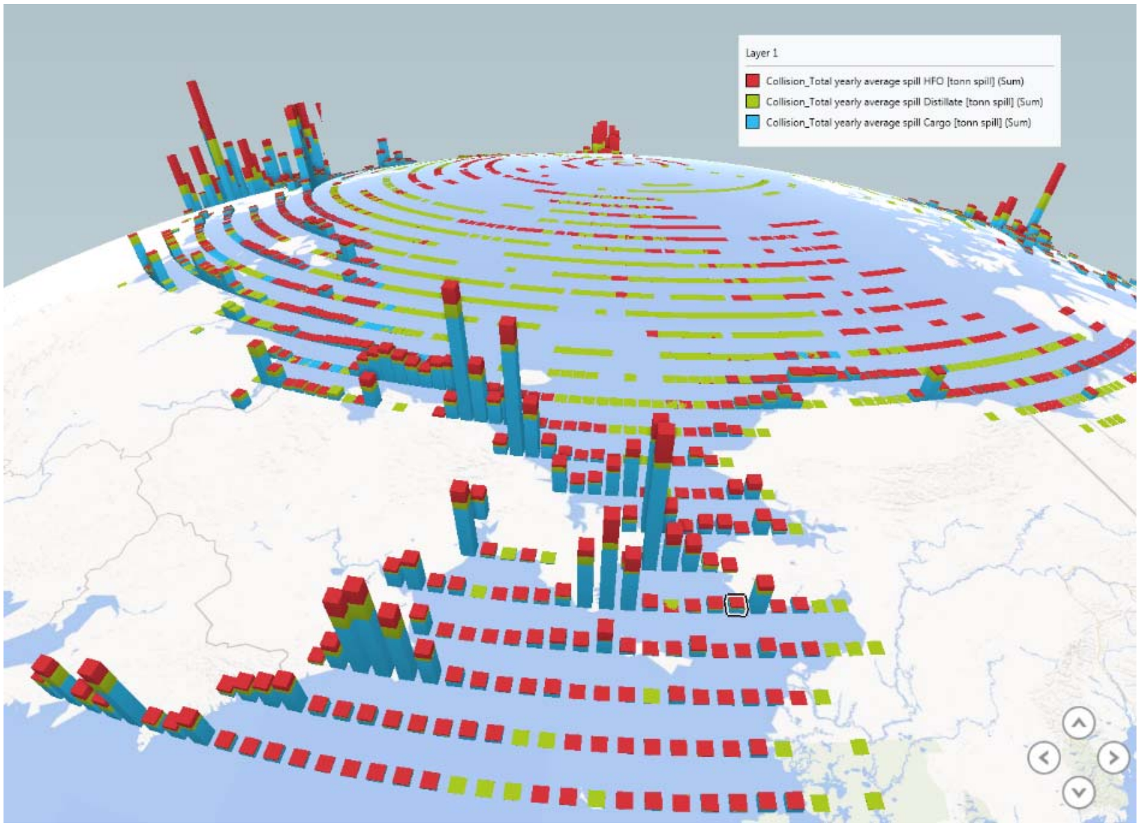


Appendix Figure 52 - Ice damage risk frequency (non-oil spill and oil spill) – Behring Strait (Note that no ice data was available for the Behring Sea)

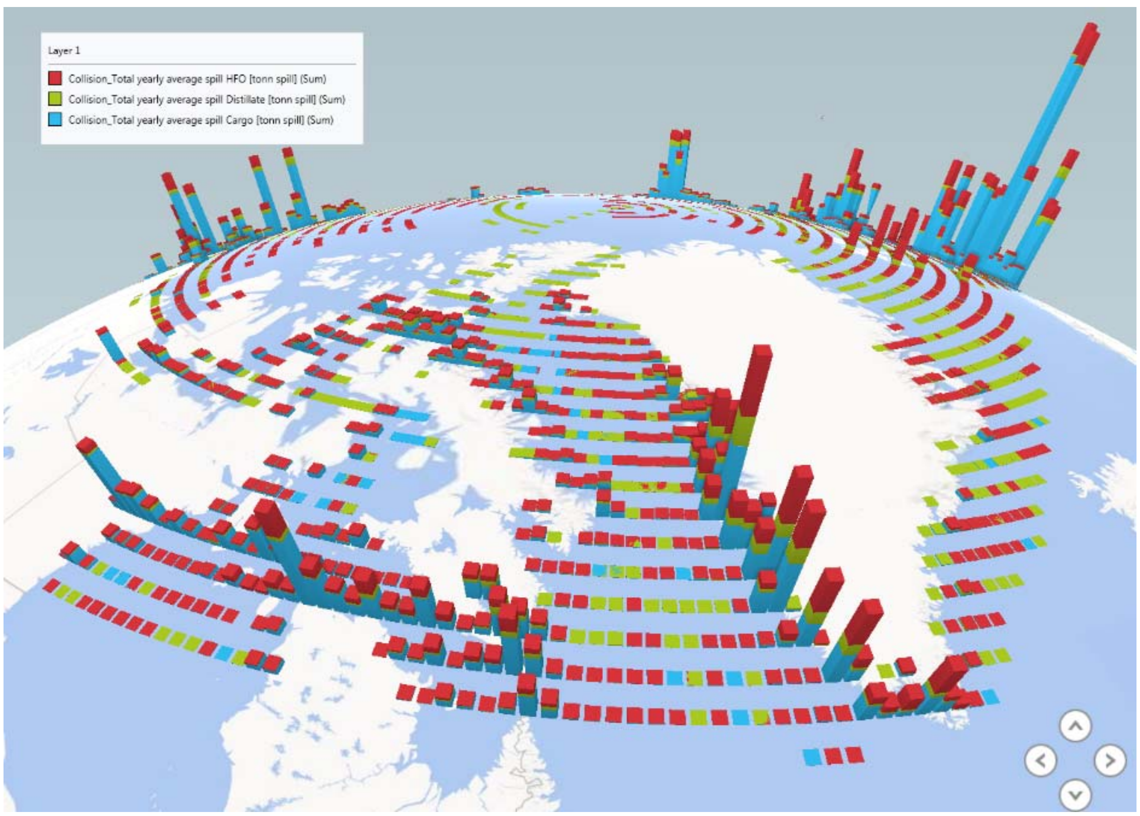
3. Collision risk maps



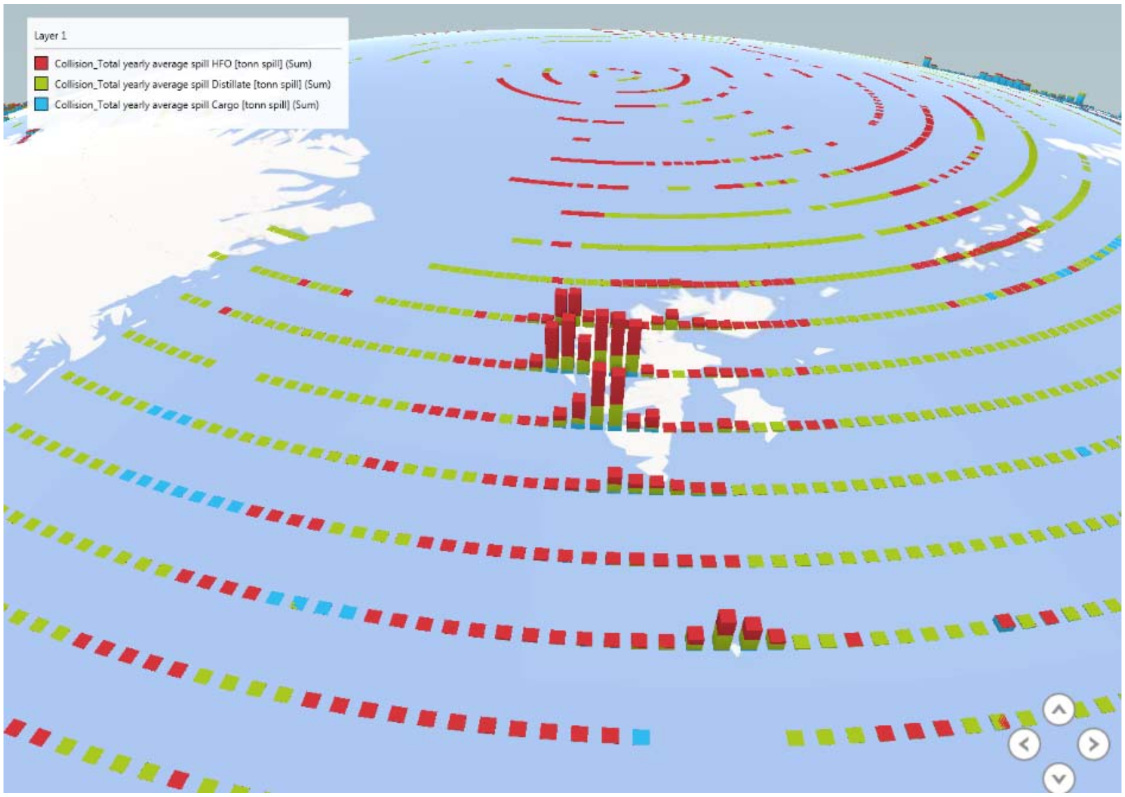
Appendix Figure 53 - Annual average oil spill – Collision



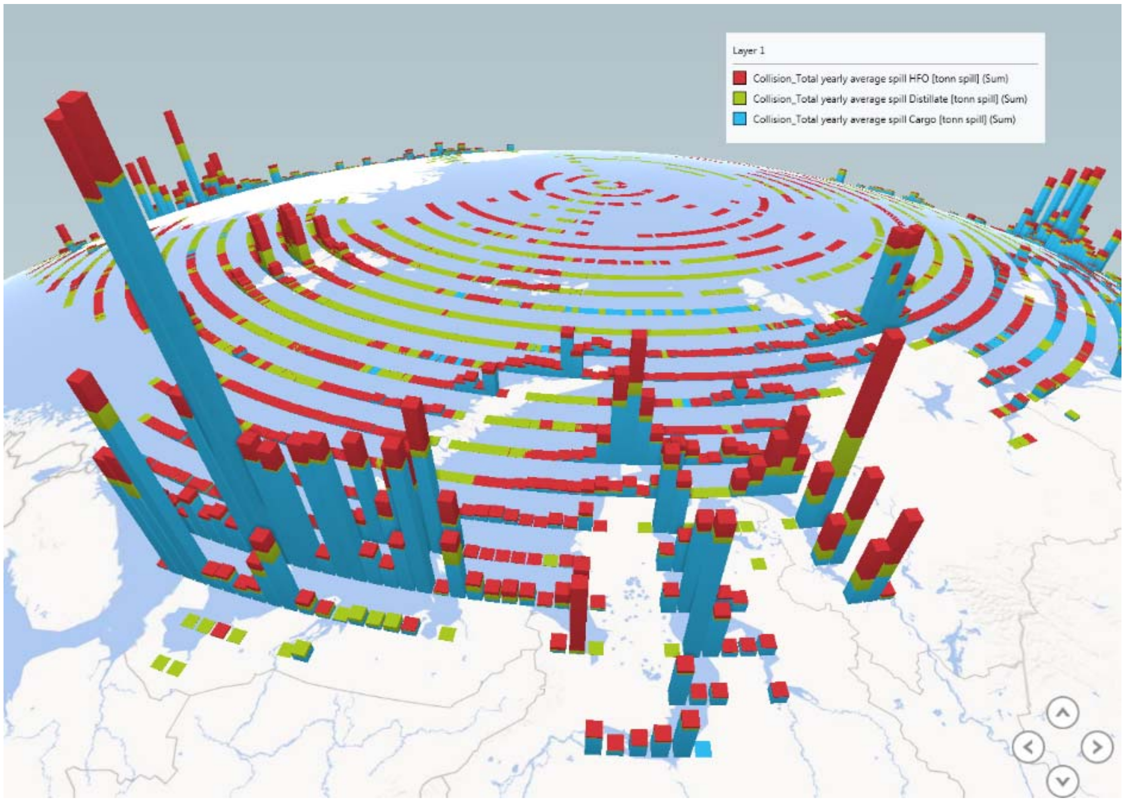
Appendix Figure 54 - Annual average oil spill – Collision - Behring strait



Appendix Figure 55 - Annual average oil spill – Collision - Canada/Greenland

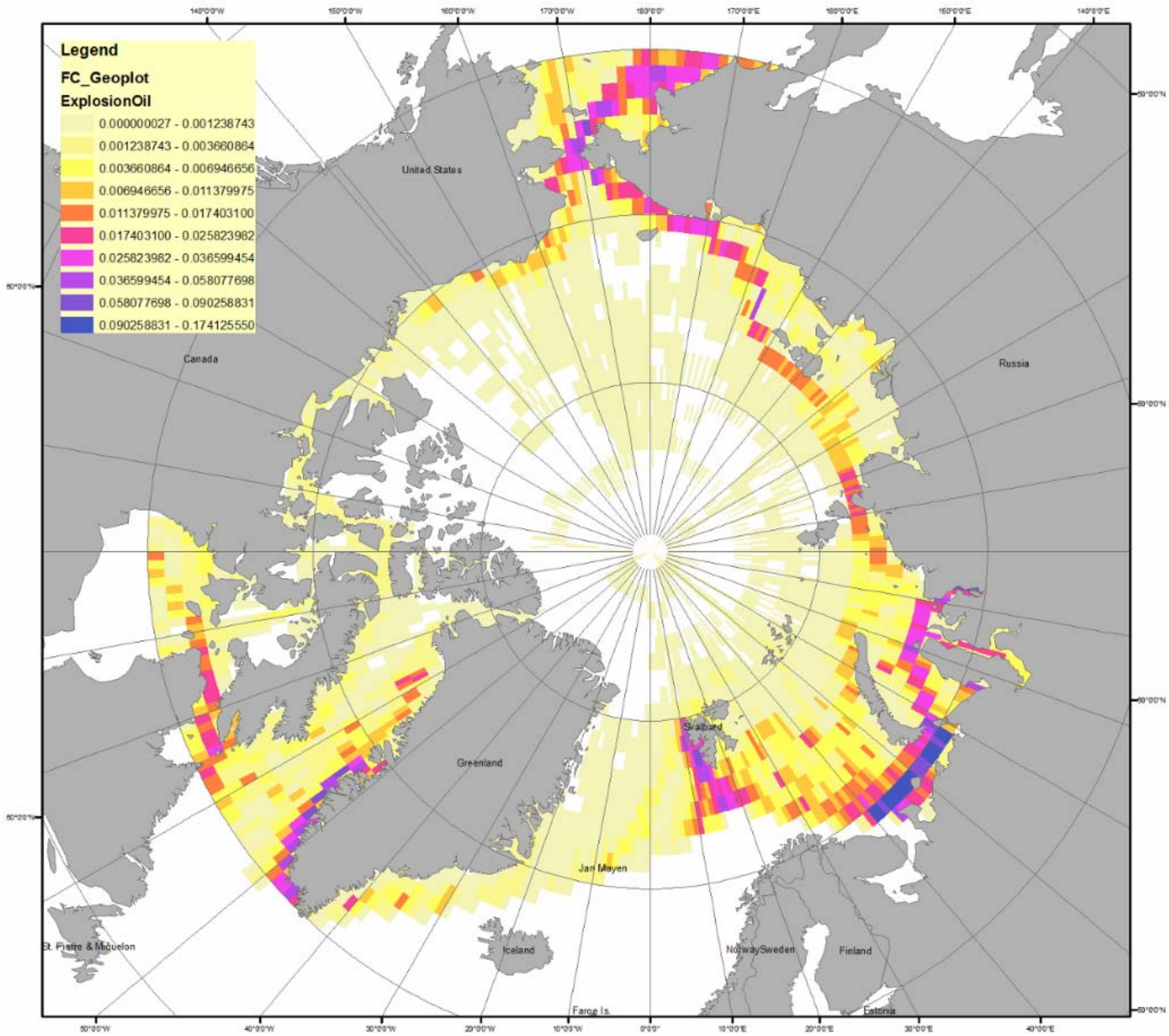


Appendix Figure 56 - Annual average oil spill – Collision – Spitsbergen (Note ban on HFO is not accounted for)

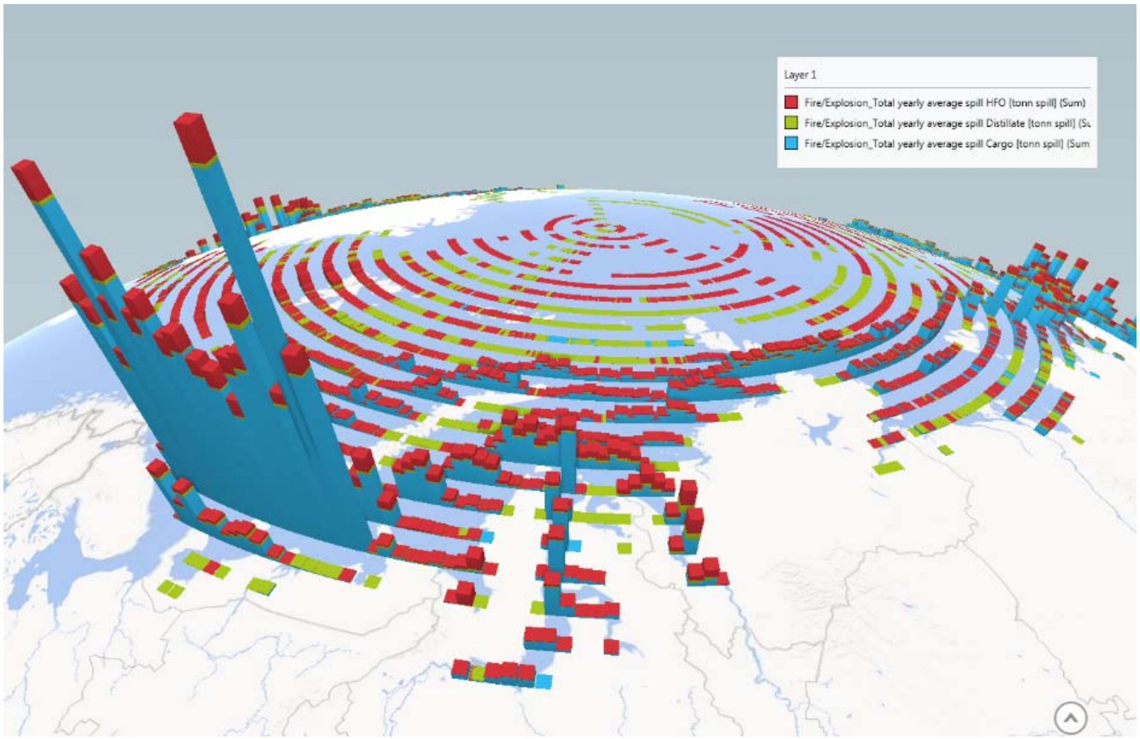


Appendix Figure 57 - Annual average oil spill – Collision - Russian north coast

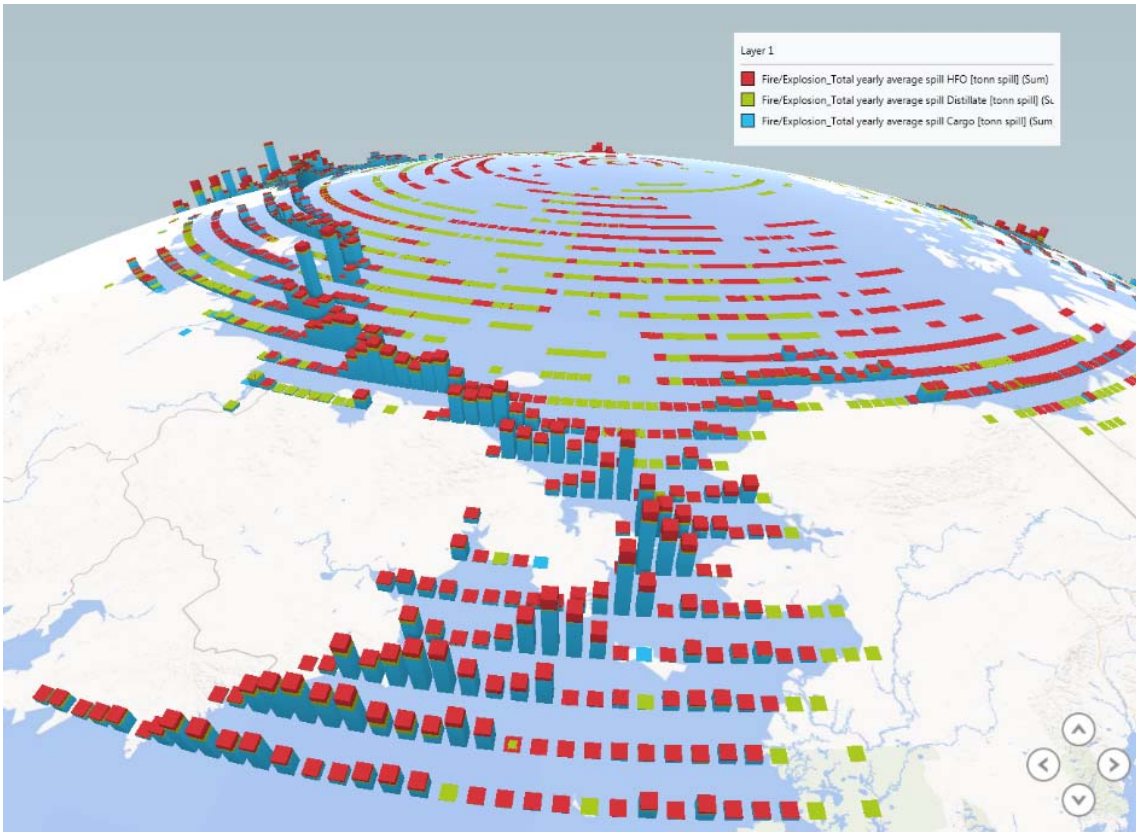
4. Fire/explosion oil spill risk maps



Appendix Figure 58 - Annual average oil spill – Fire/ explosion

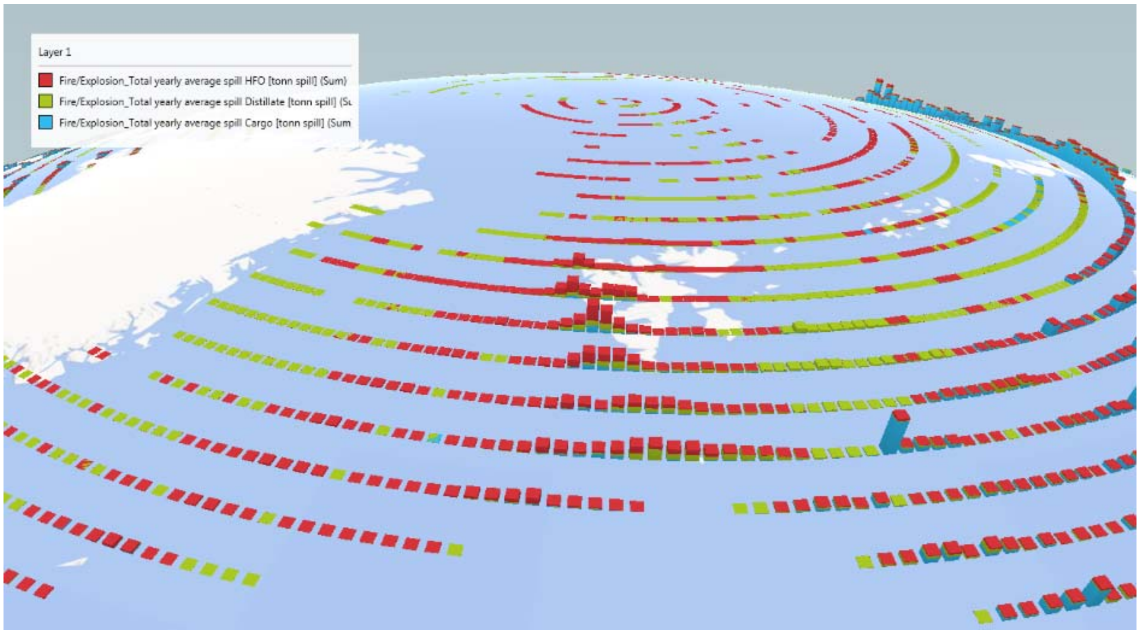


Appendix Figure 59 - Annual average oil spill – Fire/ explosion - Russian north coast



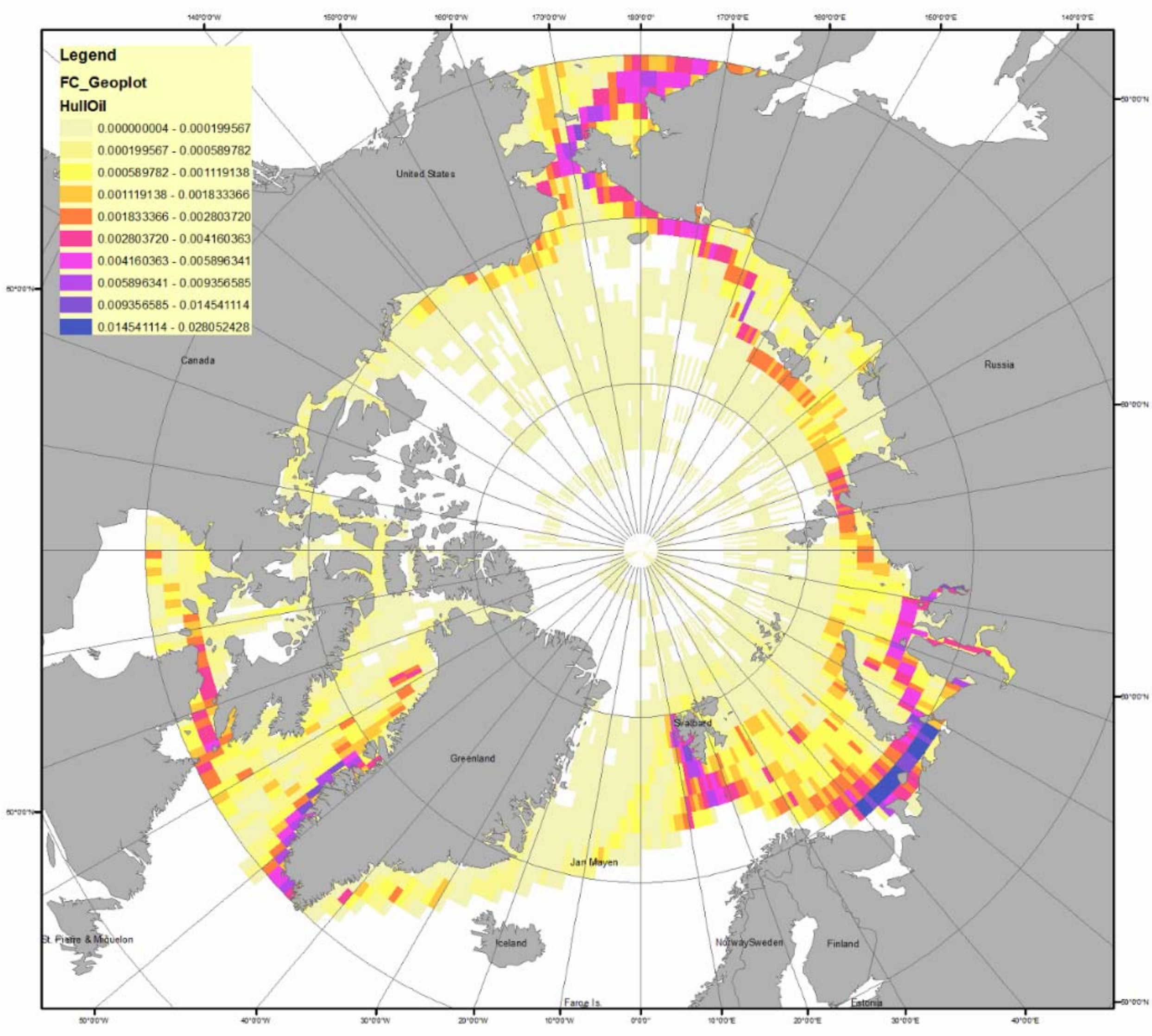
Appendix Figure 60 - Annual average oil spill – Fire/ explosion - Behring Strait

Appendix Figure 61 - Annual average oil spill – Fire/ explosion – Canada/Greenland

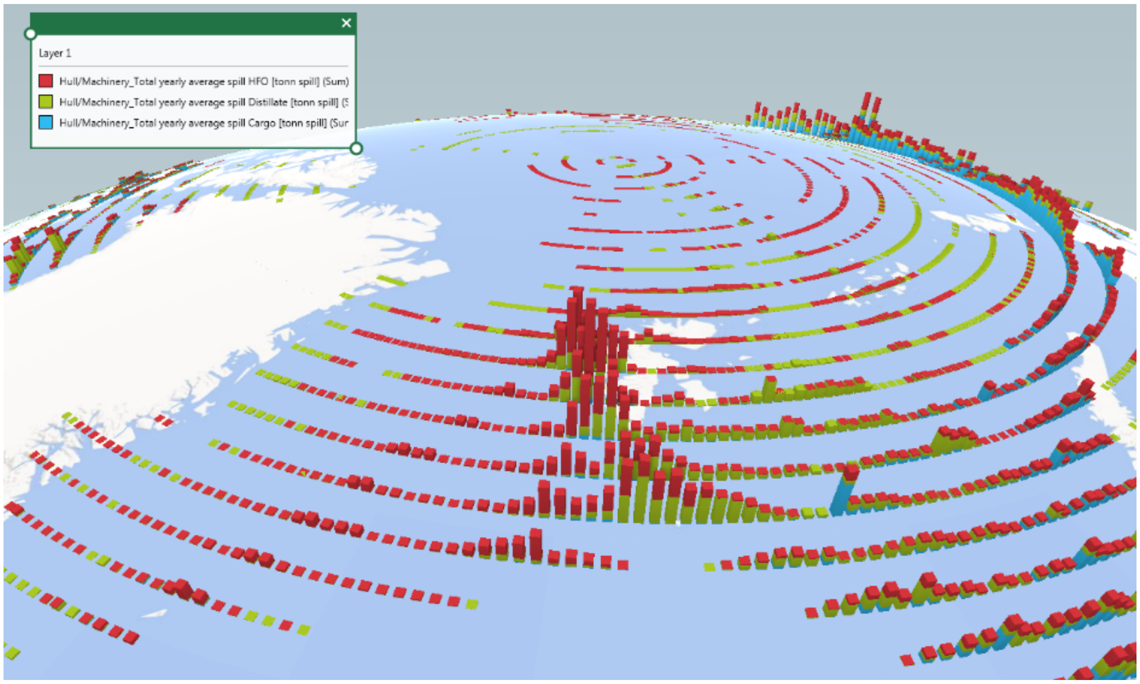


Appendix Figure 62 - Annual average oil spill – Fire/ explosion – Spitsbergen

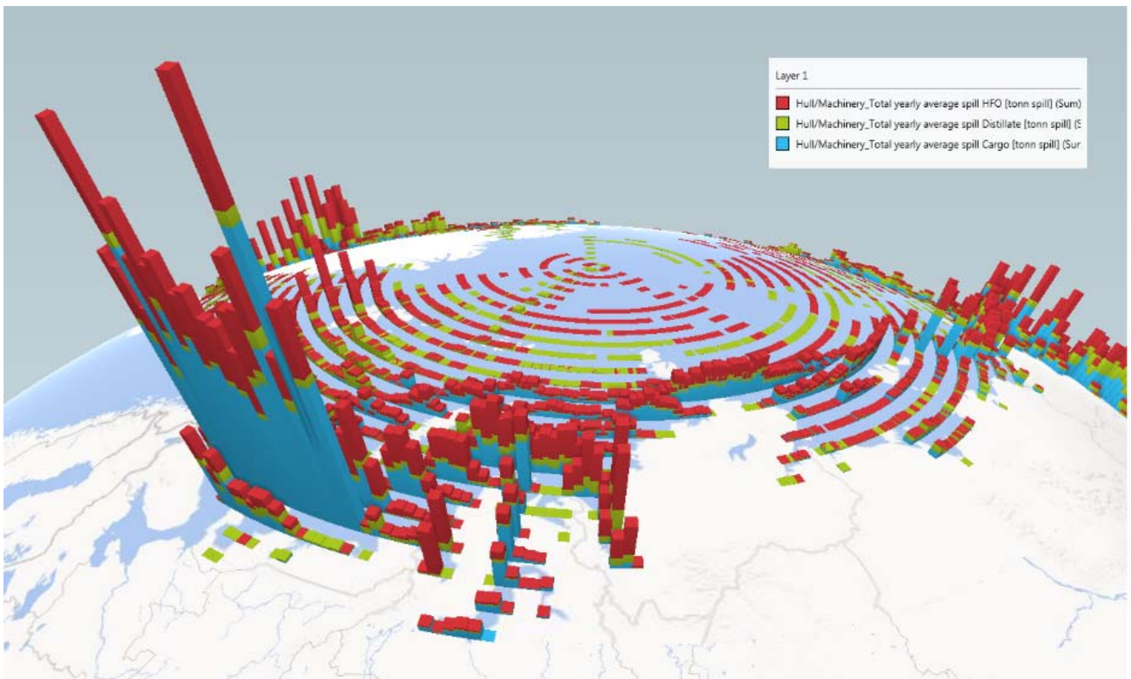
5. Hull/machinery oil spill risk maps



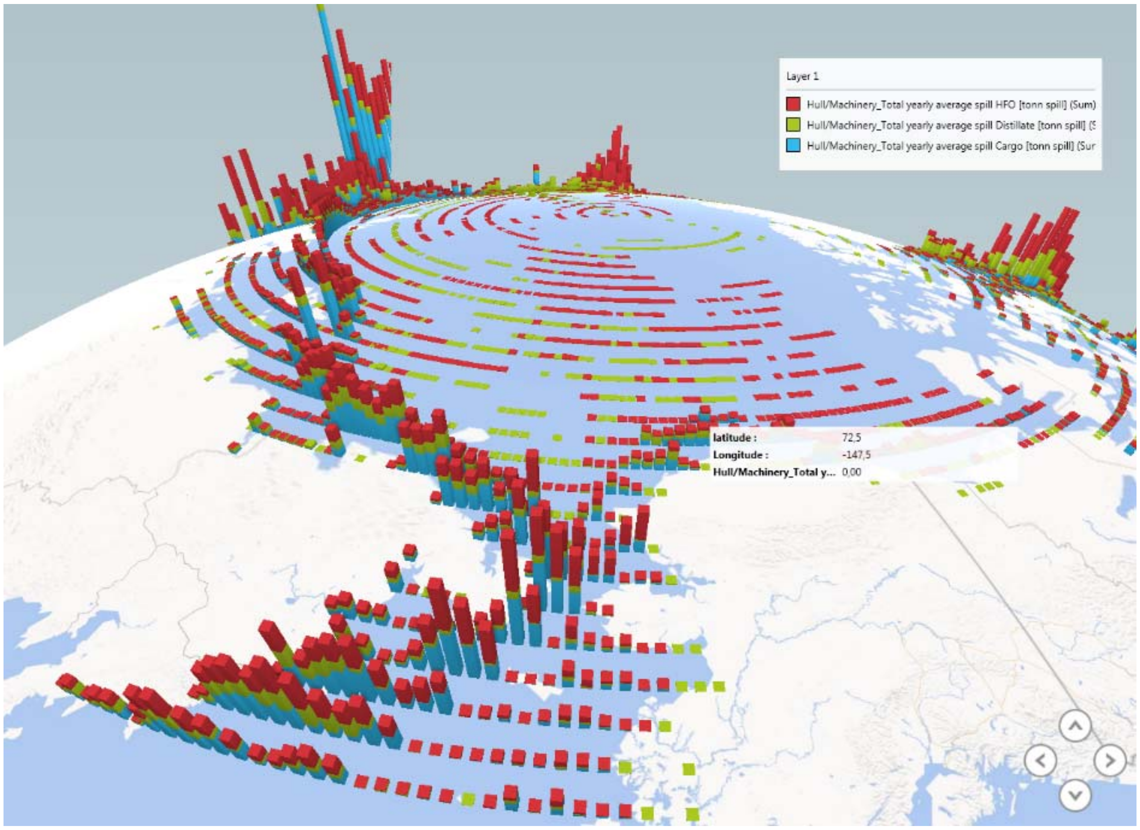
Appendix Figure 63 - Annual average oil spill – Hull/machinery



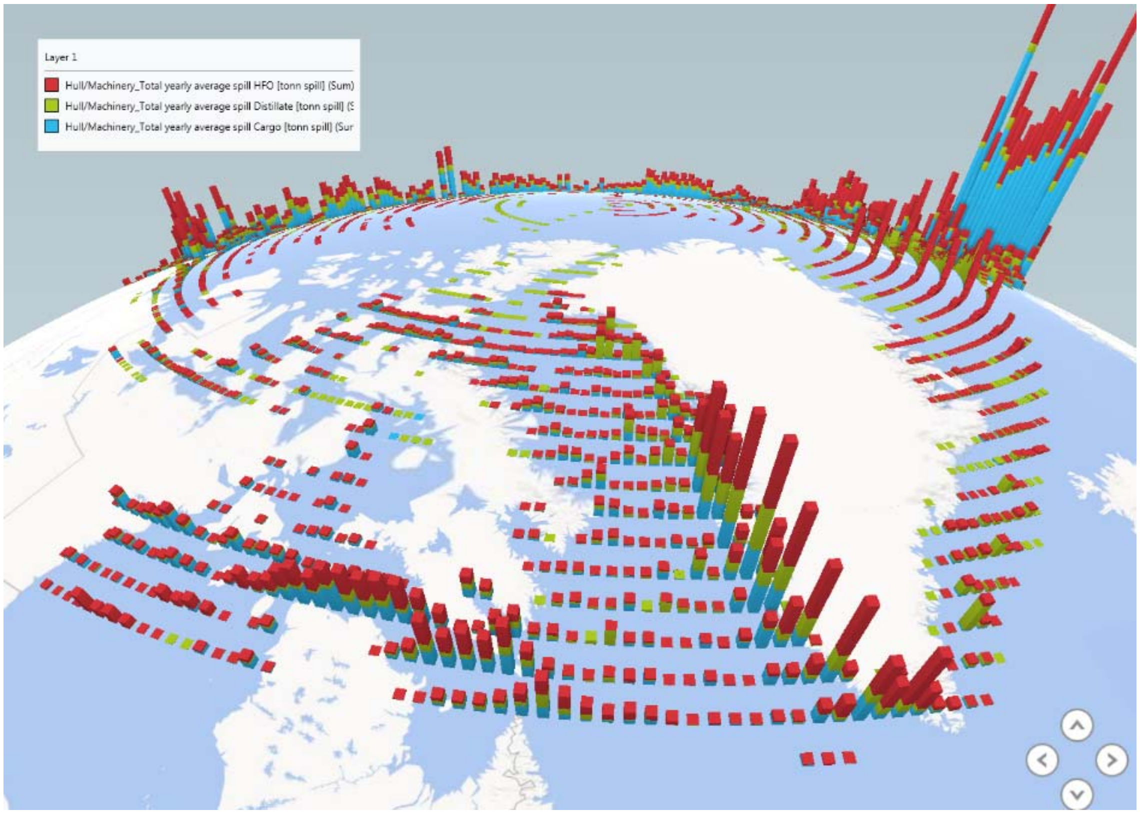
Appendix Figure 64 - Annual average oil spill – Hull/machinery – Spitsbergen



Appendix Figure 65 - Annual average oil spill – Hull/machinery – Russian north coast



Appendix Figure 66 - Annual average oil spill – Hull/machinery – Behring Strait



Appendix Figure 67 - Annual average oil spill – Hull/machinery – Canada/Greenland

Appendix E

Lloyds Ship Category Break Down System

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 Vessel	Accommodation Ship
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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