1 RISK ESTIMATIONS

1.1 General

Accident frequencies indicate how often an accident is likely to happen. These are estimated within each of the four accident categories: Grounding, Collision, Hull/Machinery and Fire/Explosion, based on statistics from the IHS Fairplay Causality Database Ref./8/. An additional the accident category of ice related accidents, i.e. any incidents related to ice regardless of consequence, has been established.

1.2 Base frequencies

Table 1-1 gives the accident rate per sailed nautical mile, calculated as the number of accidents from the accident database Ref./8/ divided by the estimated total distance traveled within the same time period. These are adjusted based on factors that influence the likelihood of accidents, detailed in Section 1.4.

Table 1-1 - Base frequencies

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

1.2.1 Accident category definitions

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. Ref. /8/.

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. Ref./8/.

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[2]. Ref./8/.

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 categorized under 'Collision', 'Stranding'. Scavenge fires and crankcase explosions are included in this category. Ref./8/.

[1] Any incidents due to problems with ice. Frequency applies only to sailed distances with ice coverage of 70% or more.
[2] I.e. not attributable to any of the other accident categories in the IHS Fairplay database.

1.3 Likelihoods and spill sizes

Table 1-2 shows the likelihood of each of the four spill categories, given the occurrence of one of the five accident types Ref./9/.

Table 1-2 - Spill likelihoods

	Grounding	Collision	Hull/Machinery	Fire/Explosion	Ice related[1]
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[3]	N/A	N/A	N/A	N/A	0.02

Table 1-3 shows the spill size categories, defined according to share of oil spilt given an accident, Ref./9/. 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. Table 1-4 shows the number of tanks between which these volumes are assumed to be distributed, Ref./9/.

Table 1-3 - Spill size categories

	Grounding	Collision	Hull/Machinery	Fire/Explosion	Ice related[3]
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[4]	0	0.2	N/A
Category 4 spill, share of oil/fuel spilt from the total available volume	1	1	1	1	N/A

Table 1-4 - Estimated number of crude oil cargo tanks on crude oil tankers

Vessel gross ton size category [GT]	0 - 1000	1000 - 4999	5000 - 9999	10000 - 24999	25000 - 49999	50000 - 99999	> 100000
Estimated number of crude 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 crude oil from oil tankers is estimated by attributing half the distance sailed to fully laden crude cargo and the other half to empty cargo tanks and 65% filled fuel tanks.

[3] For ice related accidents the expected amount is not estimated. Only the likelihood of having a spill regardless of size. See section 1.5.3 for details.

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

1.4 Adjustment factors

1.4.1 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. Table 1-5 shows the adjustment factors Ref./6/.

Table 1-5 - 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

1.4.2 Adjustment of collision frequency

The base frequency of collision accidents is multiplied by adjustment factors based on the distance between the centers of each cell to the closest shore as well as on the traffic density. Table 1-6 shows the adjustment factors for distance and traffic density Ref./6/ and /7/. The entire arctic region in this report is assessed as Low traffic density areas.

Table 1-6 - 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

1.5 Ice Risk

1.5.1 Ice coverage

Ice coverage data for each cell has been provided as a percentage of covered area on the 15th day in each month. In the cases where ice data was not available for a cell, 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.

1.5.2 Frequency of ice related accidents

The IHS Fairplay database uses the Marsden grid system (Figure 1-1) 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 Ref./8/. 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 yearly average.

Thus, the number of ice related accidents found, where divided by 23 (23 years in the period 1990-2012) times the approximated yearly 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**

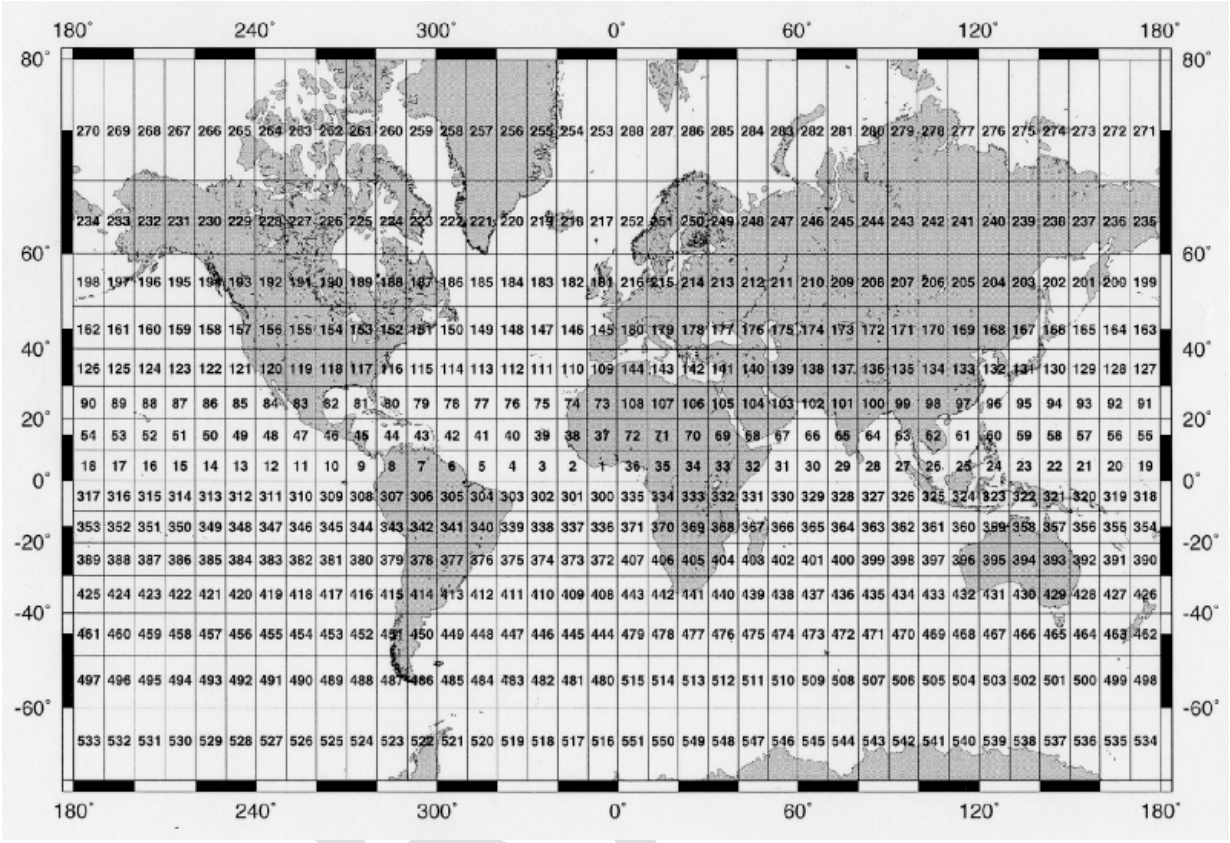

Figure 1-1: Marsden grid system

1.5.3 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 Ref./8/. 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**

1.6 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 yearly expected accident frequencies, given the traffic situation recorded in 2012.

1.6.1 Frequency calculations

$$aF_{Cn} = Nm \times F_a \times A \times P_{na}$$

Equation 1: Spill category frequency within an accident category

$$aF = \sum_{n=1}^{4} aF_{Cn}$$

Equation 2: Accident frequency

Where,

aF_{Cn}: Frequency of a category *n* spill due to a category *a* accident, where *n* goes from 1 to 4. [1/year]

Nm: Sum of nautical miles sailed [Nm]

F_a: Base frequency of accident category *a* [1/Nm]

A: Adjustment factor. Applies only to Grounding and Collision which are adjusted for distance to shore and traffic density.

P_{na}: Probability of a category *n* spill given a category *a* accident.

aF: Total frequency of category *a* accidents [1/year]

1.6.2 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 crude oil tankers

aV_{Cn}: Sum of yearly 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 crude 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% (Section 1.3)

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

C: Number of crude oil tanks on the crude oil tanker (see **Error! Reference source not found.**). [cargo tank]

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

1.7 Results – Yearly likely oil spill

Table 1-7 - Yearly likely oil spill from all accident modes

	Grounding	Collision	Hull/ Mach	Fire/ Expl	Ice	**Total**
Oil tanker	9,92	0,76	0,77	4,81	0,0012	**16,26**
Chemical/Prod tanker	2,50	0,16	0,10	0,61	0,0007	**3,37**
Gas tanker	0,27	0,03	0,04	0,22	0,0003	**0,56**
Bulk carrier	2,51	0,20	0,23	1,42	0,0018	**4,36**
General cargo	5,07	0,32	0,17	1,05	0,0012	**6,61**
Container vessel	7,26	0,45	0,23	1,40	0,0051	**9,34**
RoRo	0,14	0,01	0,01	0,03	0,0000	**0,19**
Reefer	0,66	0,04	0,03	0,17	0,0002	**0,90**
Passenger	5,87	0,38	0,21	1,31	0,0003	**7,77**
Offshore supply vessel	0,46	0,04	0,04	0,25	0,0012	**0,78**
Other offshore vessel	0,03	0,00	0,01	0,03	0,0000	**0,07**
Other activities	6,19	0,42	0,33	2,04	0,0104	**9,00**
Fishing vessel	2,61	0,22	0,32	1,97	0,0025	**5,12**
Total	**43,48**	**3,03**	**2,47**	**15,31**	**0,0250**	**64,32**

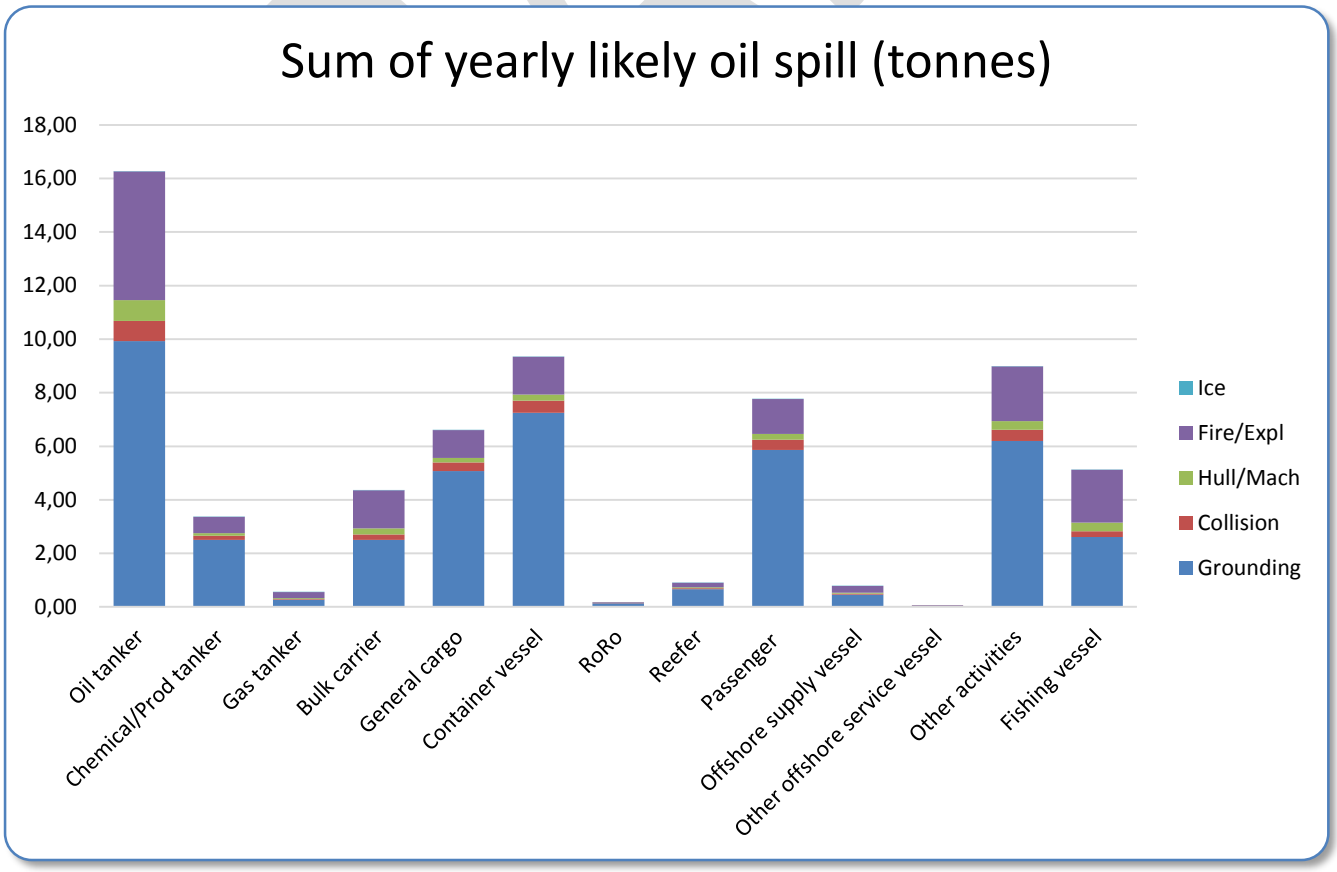

Figure 1-2 - Likely oil spill from all accident modes

Table 1-8 - Yearly average likely oil spill from grounding

	< 1000 GT	1000 - 4999 GT	5000 - 9999 GT	10000 - 24999 GT	25000 - 49999 GT	50000 - 99999 GT	>= 100000 GT	**Grand Total**
Oil tanker		1,88	0,29	2,22	5,53	0,00		**9,92**
Chemical/Prod tanker	0,00	0,83	0,48	1,02	0,16			**2,50**
Gas tanker							0,27	**0,27**
Bulk carrier		0,05	0,01	0,92	1,53			**2,51**
General cargo	0,02	2,30	1,75	0,96	0,04			**5,07**
Container vessel			1,41	5,85				**7,26**
RoRo	0,03	0,01		0,11				**0,14**
Reefer	0,00	0,25	0,25	0,15				**0,66**
Passenger	0,09	1,16	0,81	1,55	1,34	0,50	0,42	**5,87**
Offshore supply vessel	0,00	0,30	0,07	0,08				**0,46**
Other offshore service vessel	0,01	0,00		0,01				**0,03**
Other activities	0,41	0,91	1,32	3,19	0,36			**6,19**
Fishing vessel	0,43	2,05	0,13					**2,61**
Total	**0,99**	**9,76**	**6,52**	**16,06**	**8,96**	**0,50**	**0,69**	**43,48**

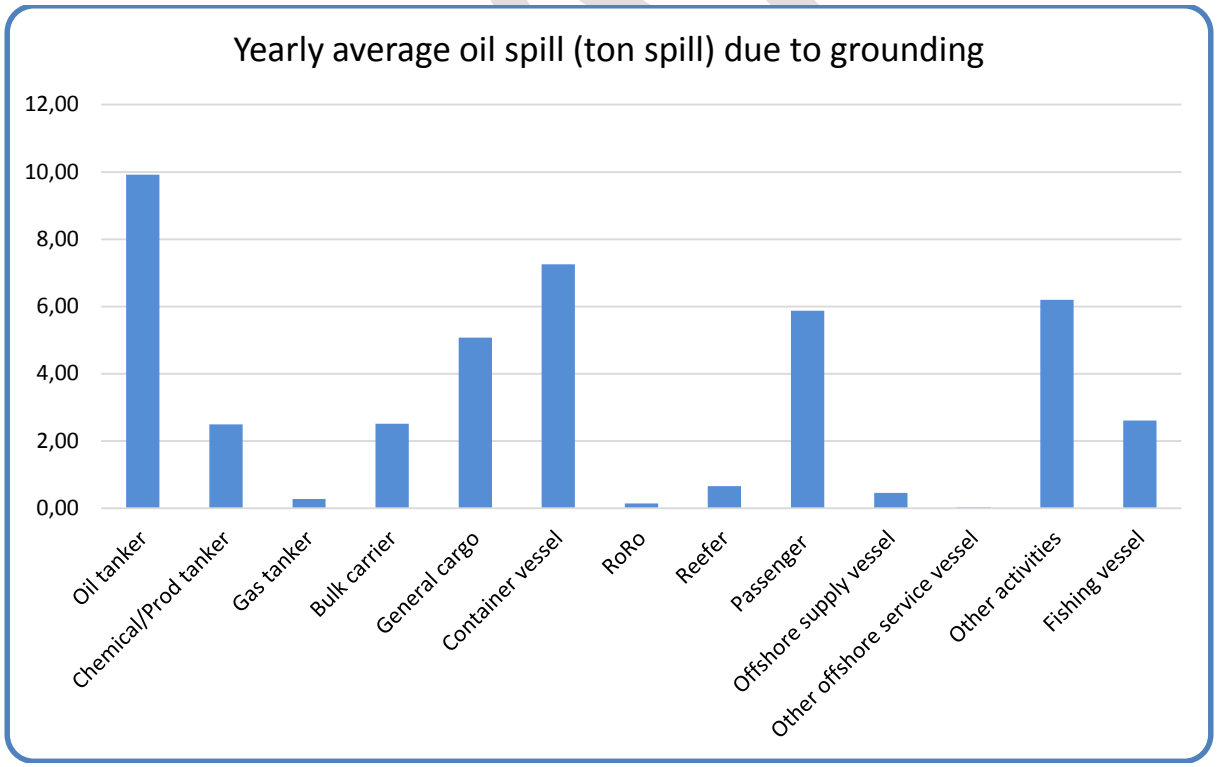

Figure 1-3 - Yearly average likely oil spill due to grounding

Table 1-9 - Yearly average oil spill (ton spill) due to collision

	< 1000 GT	1000 - 4999 GT	5000 - 9999 GT	10000 - 24999 GT	25000 - 49999 GT	50000 - 99999 GT	>= 100000 GT	**Grand Total**
Oil tanker		0,12	0,02	0,15	0,47	0,00		**0,76**
Chemical/Prod tanker	0,00	0,05	0,03	0,06	0,01			**0,16**
Gas tanker							0,03	**0,03**
Bulk carrier		0,00	0,00	0,06	0,13			**0,20**
General cargo	0,00	0,14	0,11	0,06	0,00			**0,32**
Container vessel			0,09	0,36				**0,45**
RoRo	0,00	0,00		0,01				**0,01**
Reefer	0,00	0,02	0,02	0,01				**0,04**
Passenger	0,01	0,07	0,05	0,10	0,09	0,03	0,03	**0,38**
Offshore supply vessel	0,00	0,02	0,01	0,01				**0,04**
Other offshore service vessel	0,00	0,00		0,00				**0,00**
Other activities	0,03	0,06	0,09	0,22	0,02			**0,42**
Fishing vessel	0,04	0,17	0,01					**0,22**
Total	**0,07**	**0,66**	**0,43**	**1,05**	**0,72**	**0,03**	**0,05**	**3,03**

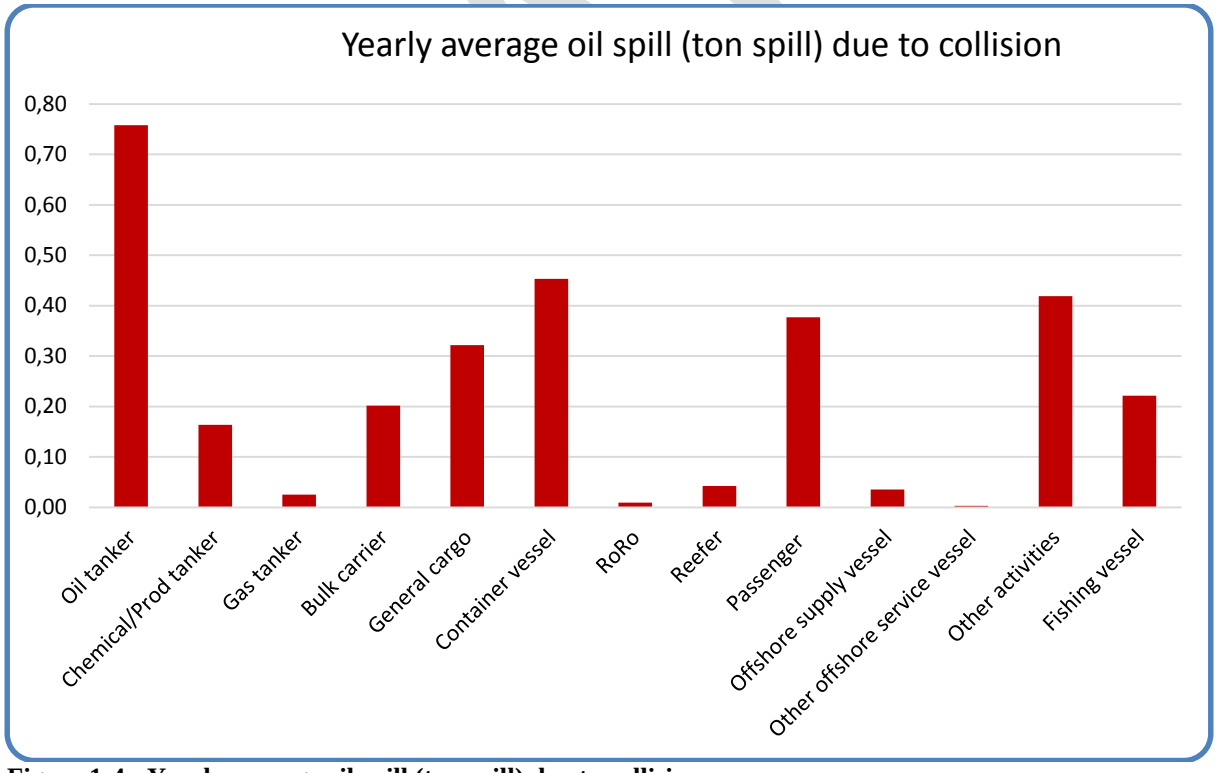

Figure 1-4 - Yearly average oil spill (ton spill) due to collision

Table 1-10 - Yearly average oil spill (ton spill) due to collision

	< 1000 GT	1000 - 4999 GT	5000 - 9999 GT	10000 - 24999 GT	25000 - 49999 GT	50000 - 99999 GT	>= 100000 GT	**Grand Total**
Oil tanker		0,056	0,018	0,111	0,588	0,001		**0,774**
Chemical/Prod tanker	0,000	0,027	0,021	0,036	0,014			**0,098**
Gas tanker							0,036	**0,036**
Bulk carrier		0,001	0,001	0,053	0,173			**0,228**
General cargo	0,001	0,058	0,061	0,047	0,002			**0,169**
Container vessel			0,040	0,186				**0,226**
RoRo	0,001	0,000		0,005				**0,006**
Reefer	0,000	0,010	0,011	0,006				**0,027**
Passenger	0,001	0,029	0,019	0,063	0,055	0,024	0,020	**0,211**
Offshore supply vessel	0,001	0,028	0,005	0,006				**0,040**
Other offshore service vessel	0,002	0,000		0,003				**0,005**
Other activities	0,013	0,054	0,084	0,171	0,007			**0,329**
Fishing vessel	0,052	0,243	0,023					**0,318**
Total	**0,070**	**0,507**	**0,284**	**0,687**	**0,839**	**0,024**	**0,056**	2,467

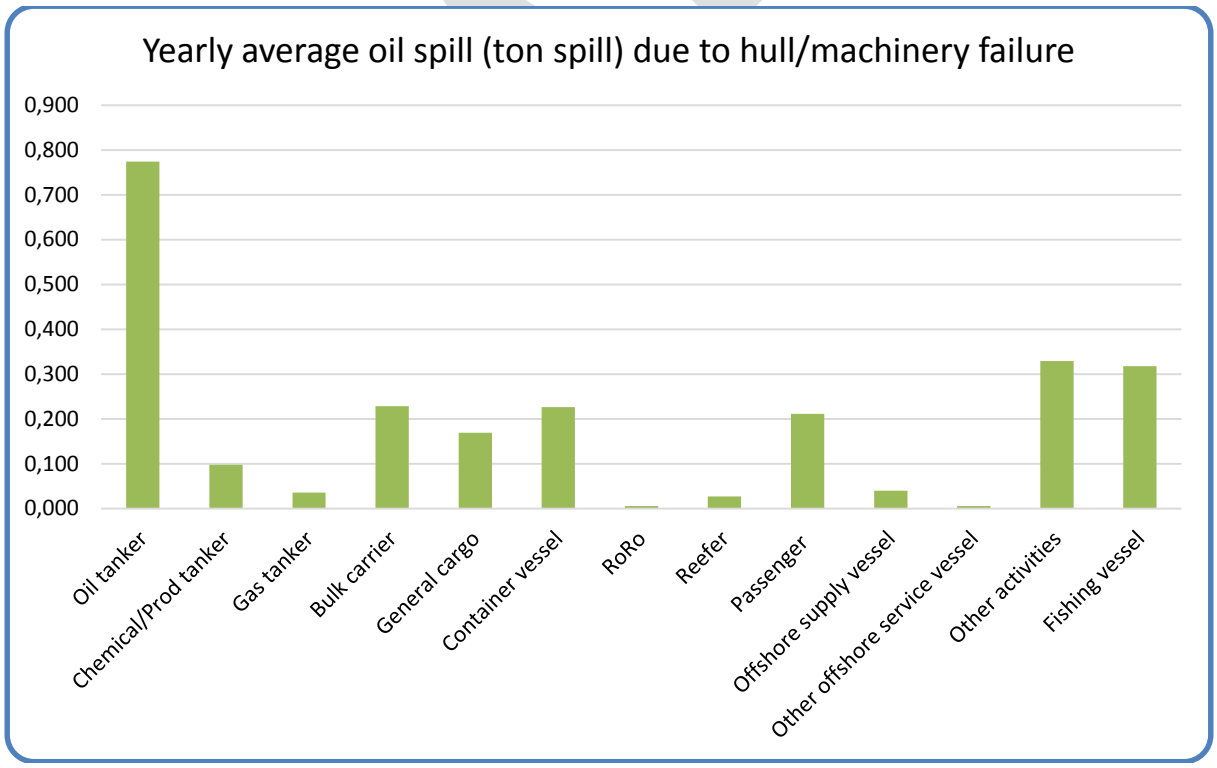

Figure 1-5 - Yearly average oil spill (ton spill) due to hull/machinery failure

Table 1-11 - Yearly average oil spill (ton spill) due to fire/explosions

	< 1000 GT	1000 - 4999 GT	5000 - 9999 GT	10000 - 24999 GT	25000 - 49999 GT	50000 - 99999 GT	>= 100000 GT	**Grand Total**
Oil tanker		0,35	0,11	0,69	3,65	0,01		**4,81**
Chemical/Prod tanker	0,00	0,17	0,13	0,22	0,09			**0,61**
Gas tanker							0,22	**0,22**
Bulk carrier		0,01	0,00	0,33	1,07			**1,42**
General cargo	0,01	0,36	0,38	0,29	0,01			**1,05**
Container vessel			0,25	1,15				**1,40**
RoRo	0,00	0,00		0,03				**0,03**
Reefer	0,00	0,06	0,07	0,04				**0,17**
Passenger	0,01	0,18	0,12	0,39	0,34	0,15	0,13	**1,31**
Offshore supply vessel	0,00	0,17	0,03	0,03				**0,25**
Other offshore service vessel	0,01	0,00		0,02				**0,03**
Other activities	0,08	0,33	0,52	1,06	0,05			**2,04**
Fishing vessel	0,32	1,51	0,14					**1,97**
Total	**0,43**	**3,15**	**1,76**	**4,26**	**5,21**	**0,15**	**0,35**	**15,31**

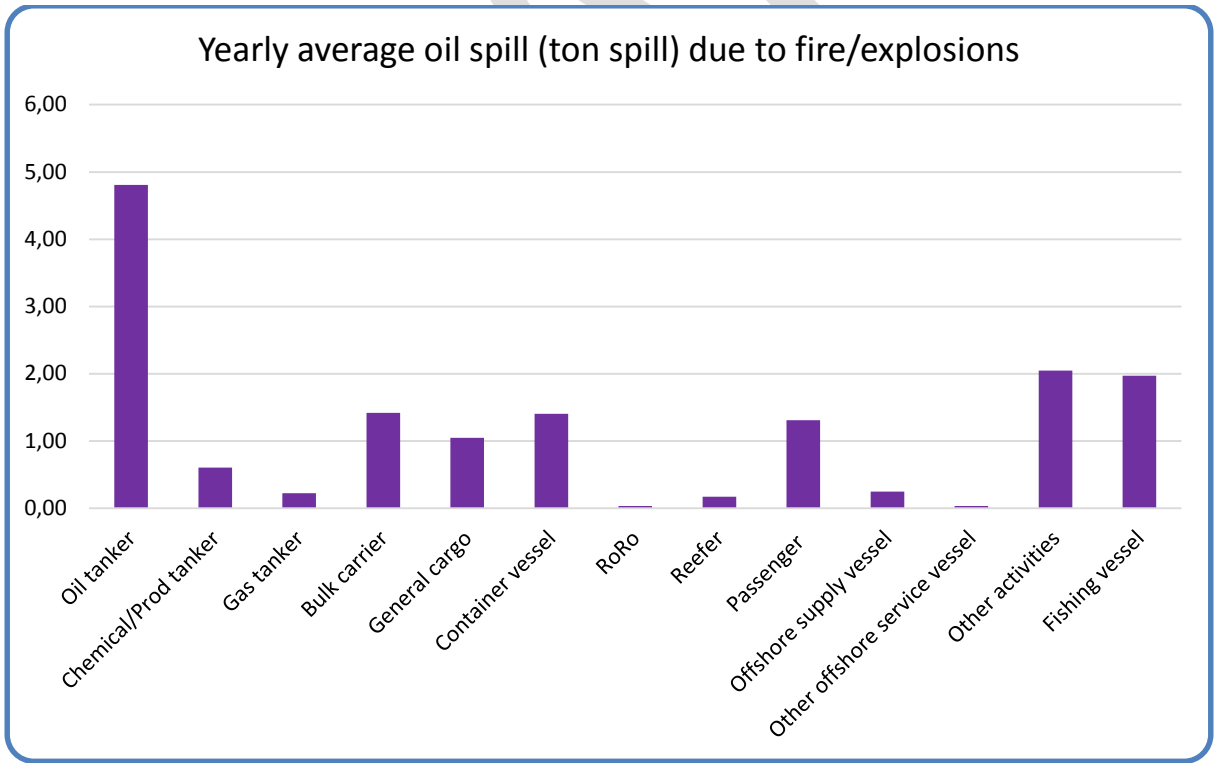

Figure 1-6 - Yearly average oil spill (ton spill) due to fire/explosions

Table 1-12 - Yearly average oil spill (ton spill) due to ice damage

	< 1000 GT	1000 - 4999 GT	5000 - 9999 GT	10000 - 24999 GT	25000 - 49999 GT	50000 - 99999 GT	>= 100000 GT	**Grand Total**
Oil tanker		0,35	0,11	0,69	3,65	0,01		**4,81**
Chemical/Prod tanker	0,00	0,17	0,13	0,22	0,09			**0,61**
Gas tanker							0,22	**0,22**
Bulk carrier		0,01	0,00	0,33	1,07			**1,42**
General cargo	0,01	0,36	0,38	0,29	0,01			**1,05**
Container vessel			0,25	1,15				**1,40**
RoRo	0,00	0,00		0,03				**0,03**
Reefer	0,00	0,06	0,07	0,04				**0,17**
Passenger	0,01	0,18	0,12	0,39	0,34	0,15	0,13	**1,31**
Offshore supply vessel	0,00	0,17	0,03	0,03				**0,25**
Other offshore service vessel	0,01	0,00		0,02				**0,03**
Other activities	0,08	0,33	0,52	1,06	0,05			**2,04**
Fishing vessel	0,32	1,51	0,14					**1,97**
Total	**0,43**	**3,15**	**1,76**	**4,26**	**5,21**	**0,15**	**0,35**	**15,31**

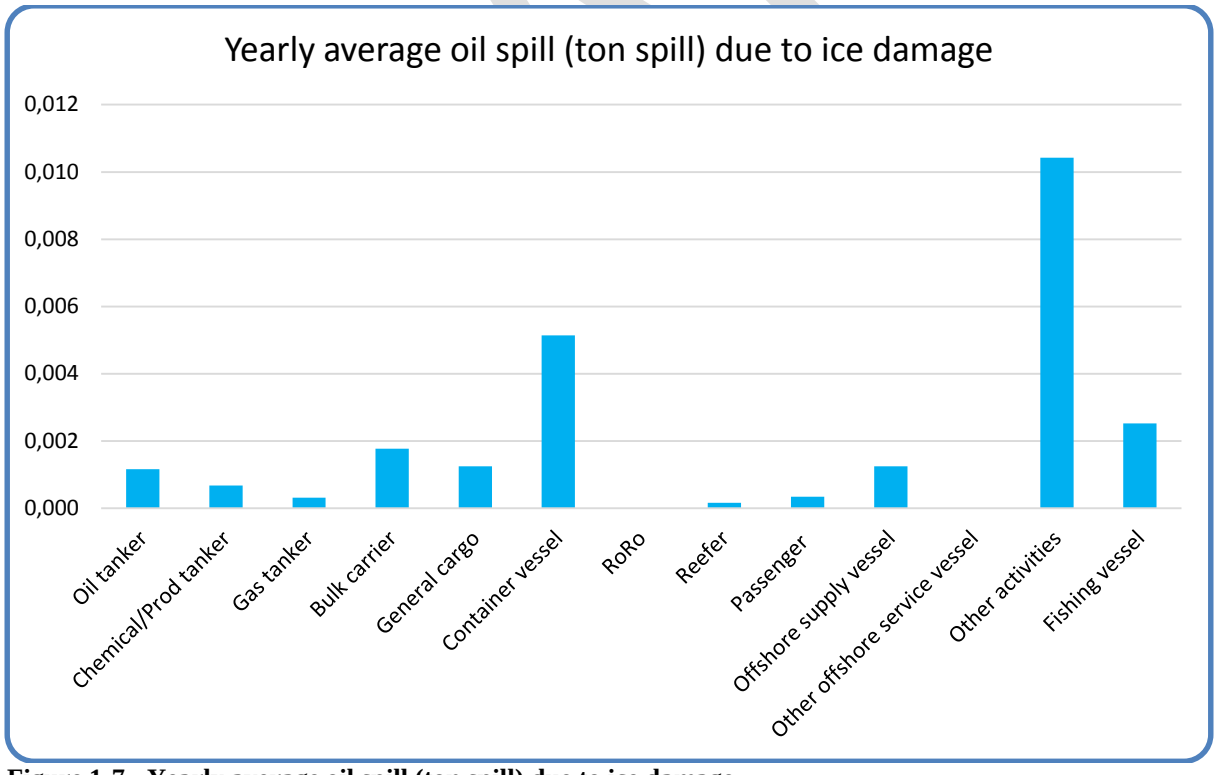

Figure 1-7 - Yearly average oil spill (ton spill) due to ice damage

1.8 Risk maps – Geographical distribution

All risk related data used in this study is geographically positioned and grouped within each 1 x 1 degree cell. This provides the input to the risk analysis performed and consequently all risk calculations are calculated for each cells containing traffic throughout 2012.
Each column in the plots represents the calculated yearly oil spill for the given 1 x 1 degree cell.

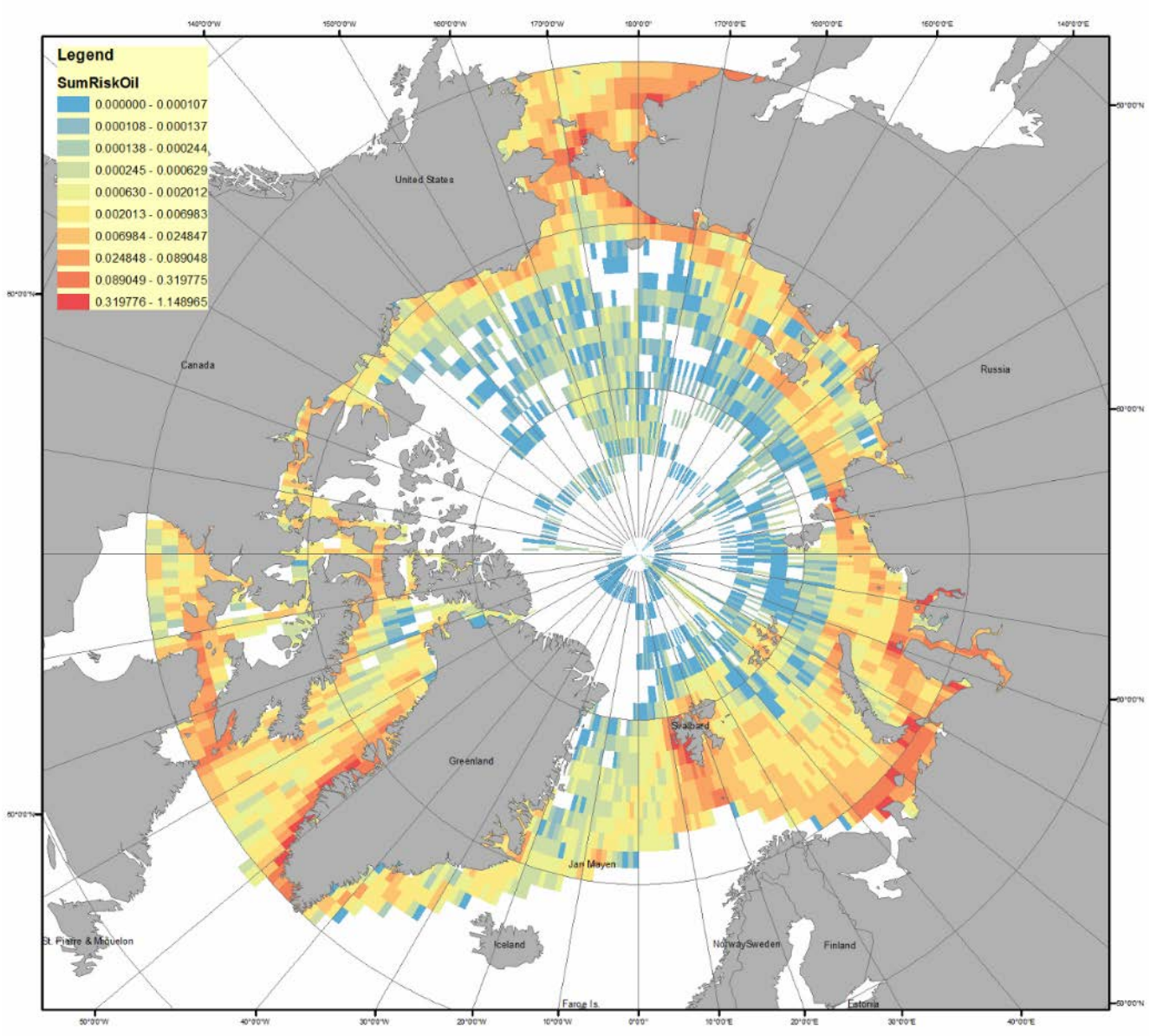

Figure 1-8 - Yearly average oil spill - all risk components

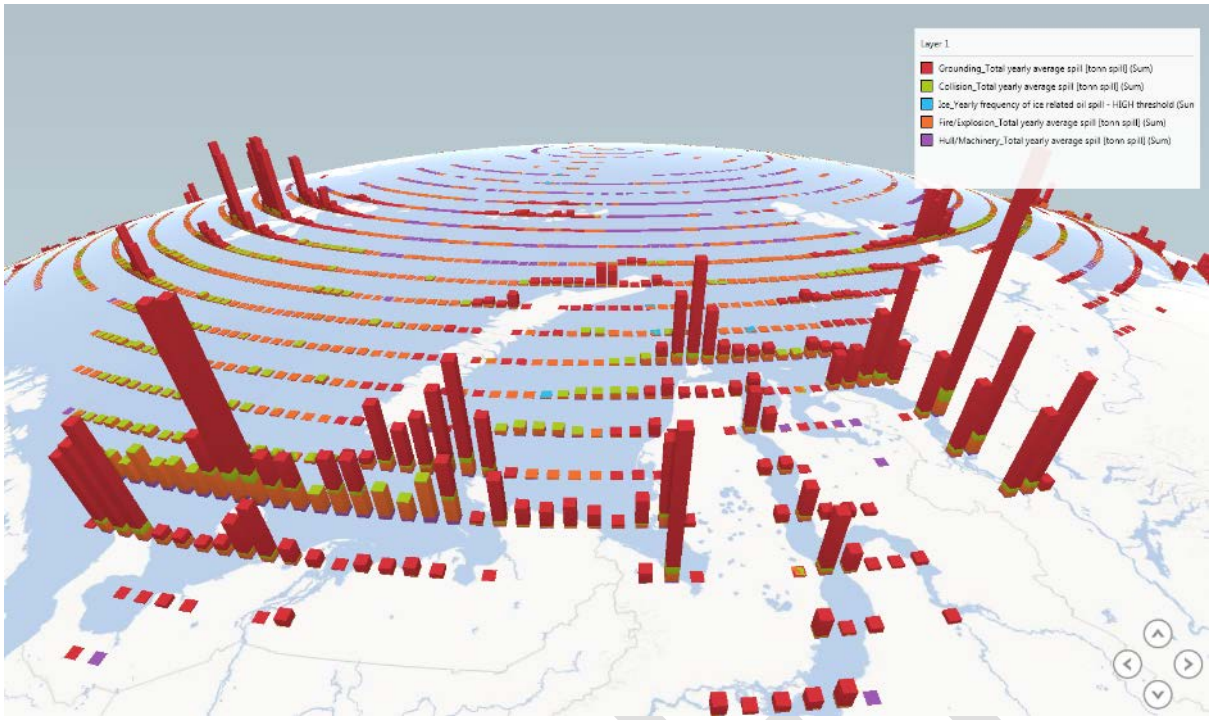

Figure 1-9 - Yearly average oil spill - all risk components - Russian north coast

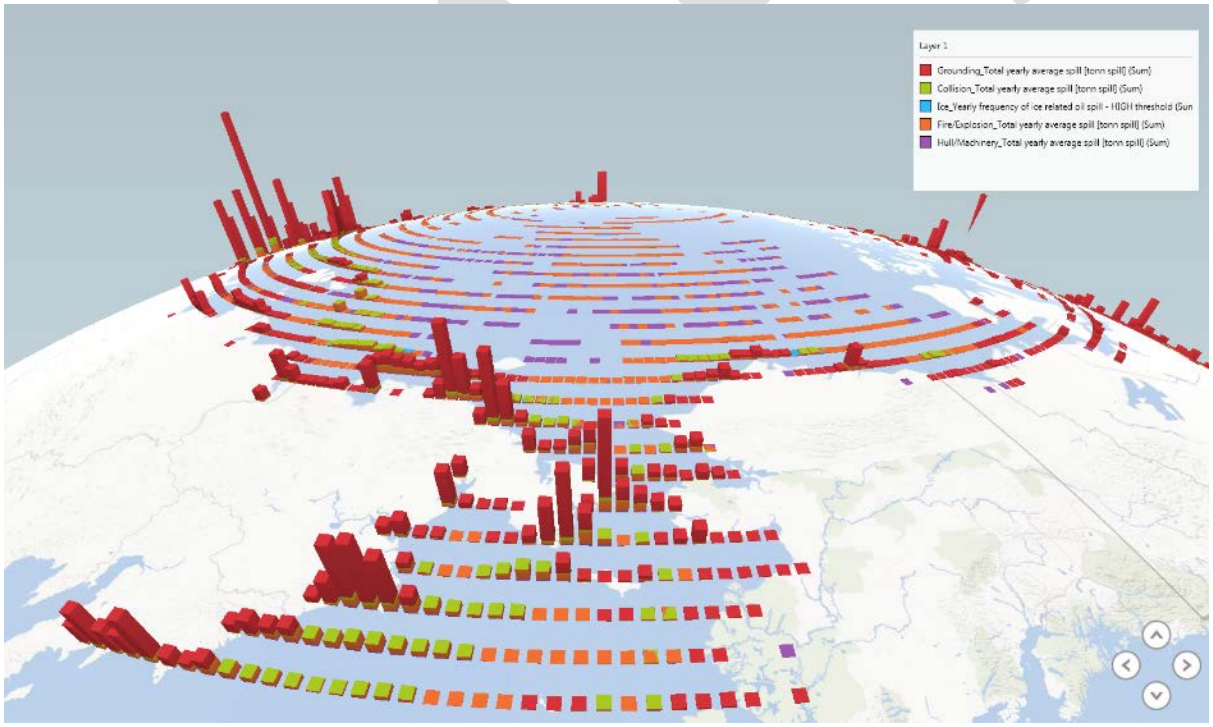

Figure 1-10 - Yearly average oil spill - all risk components - Behring strait

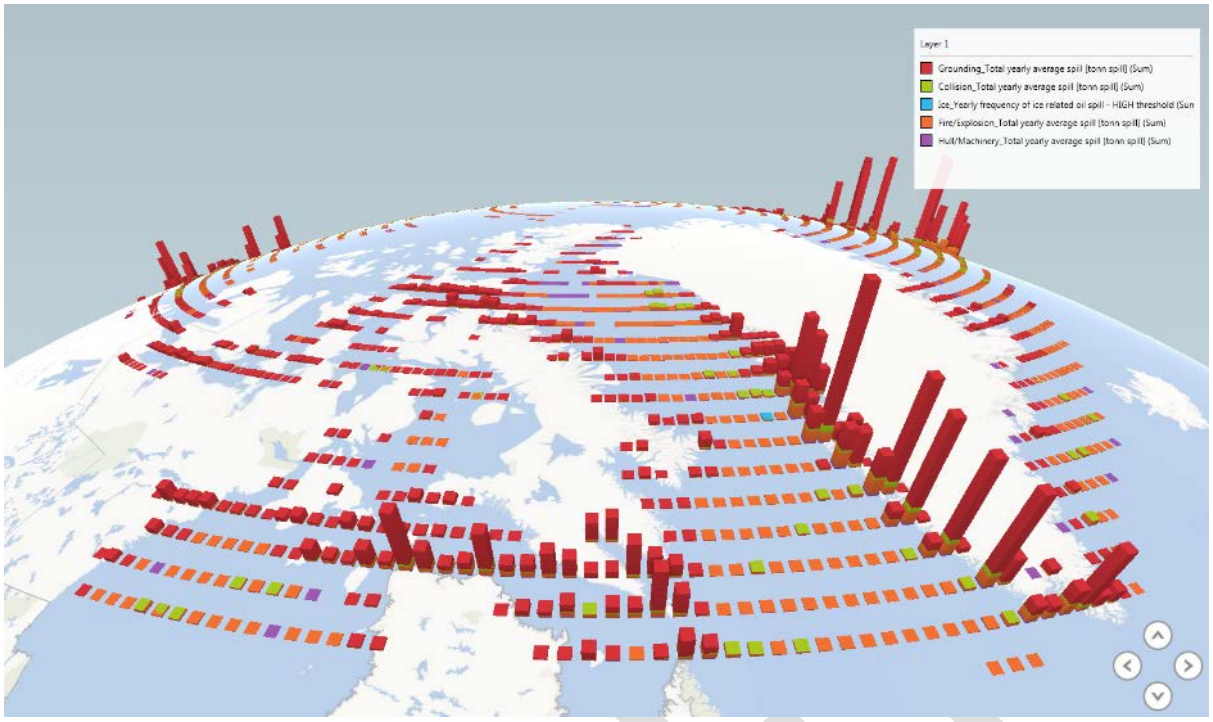

Figure 1-11 - Yearly average oil spill - all risk components – Baffin Bay

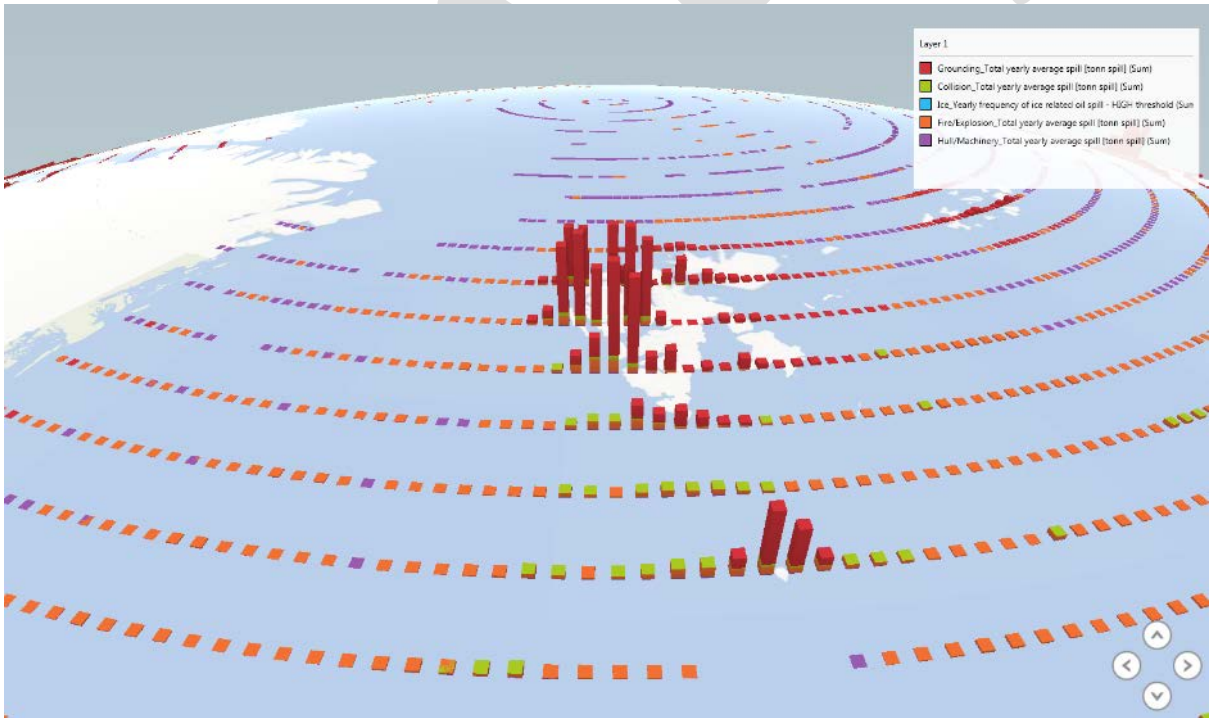

Figure 1-12 - Yearly average oil spill - all risk components – Spitsbergen

1.8.1 Grounding oil spill risk maps

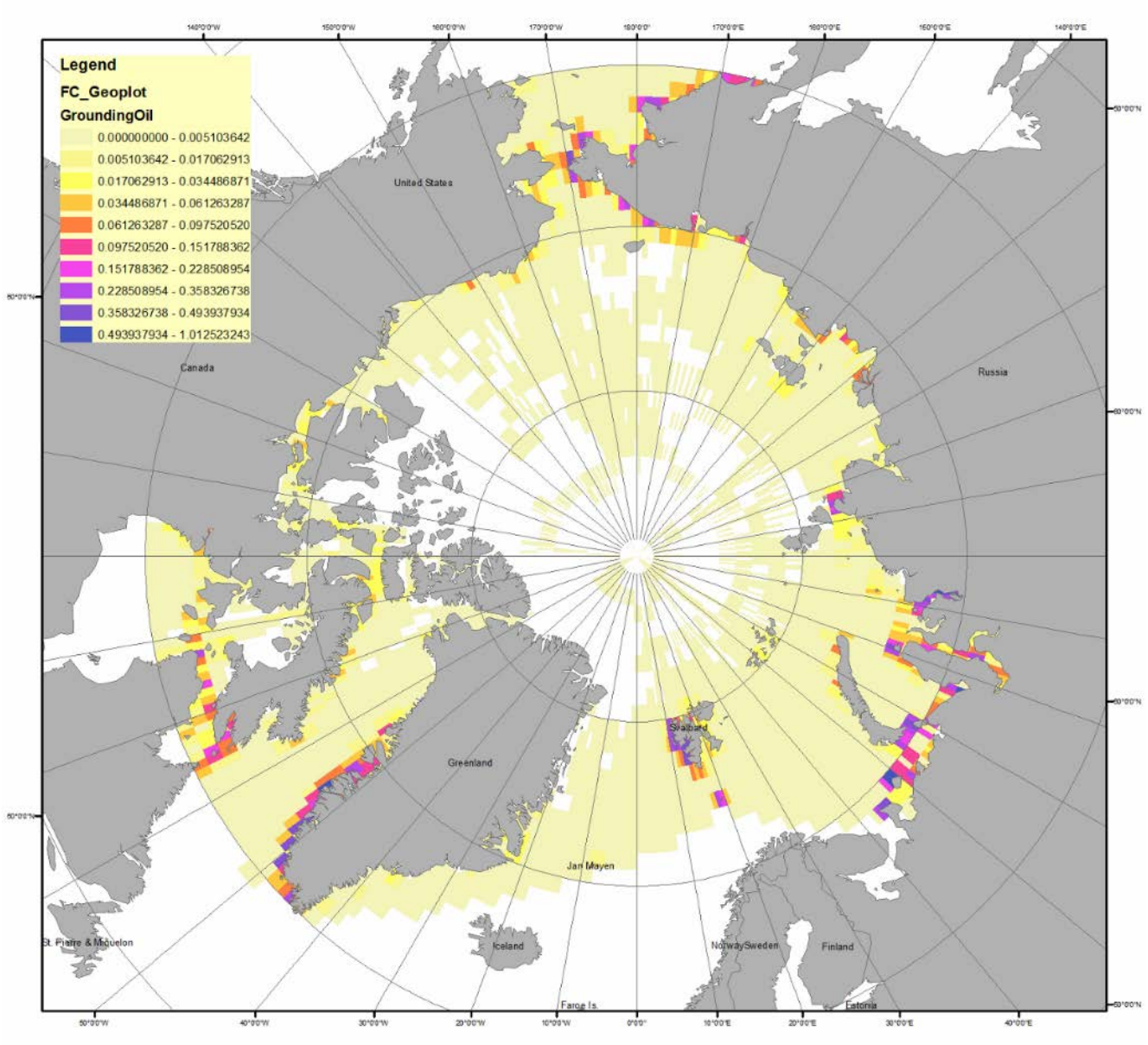

Figure 1-13 - Yearly average oil spill – Grounding

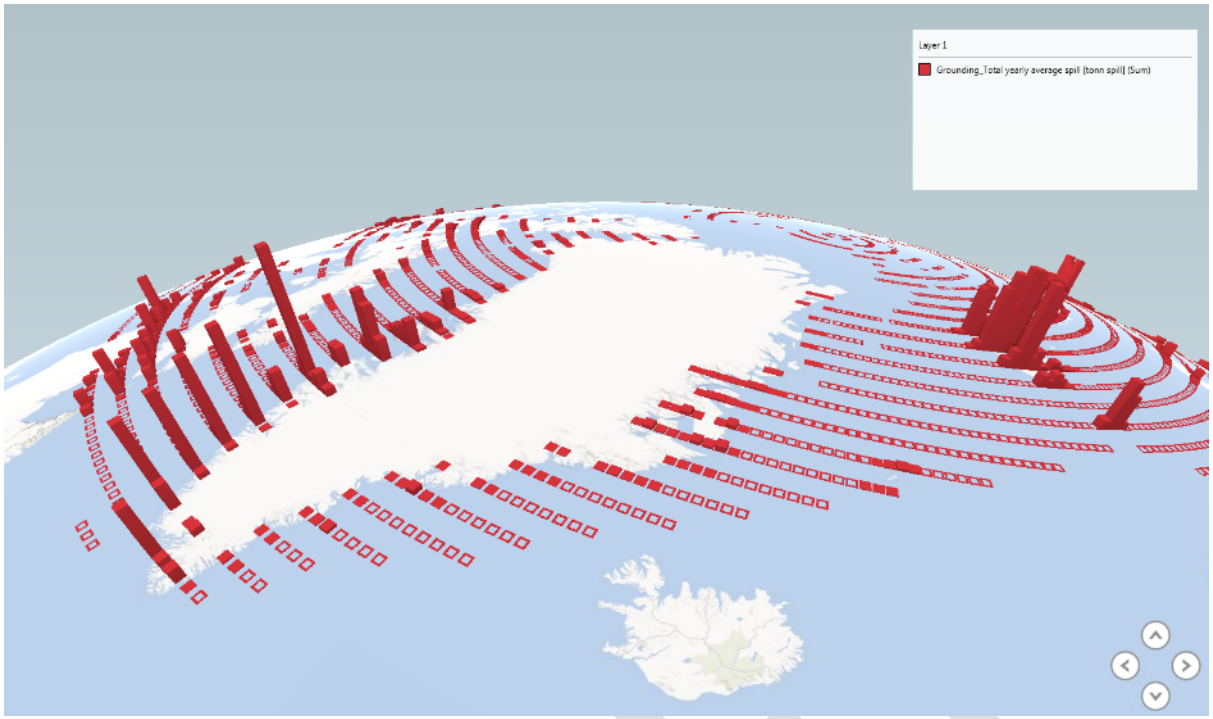

Figure 1-14 - Yearly average oil spill – Grounding - Greenland and Spitsbergen

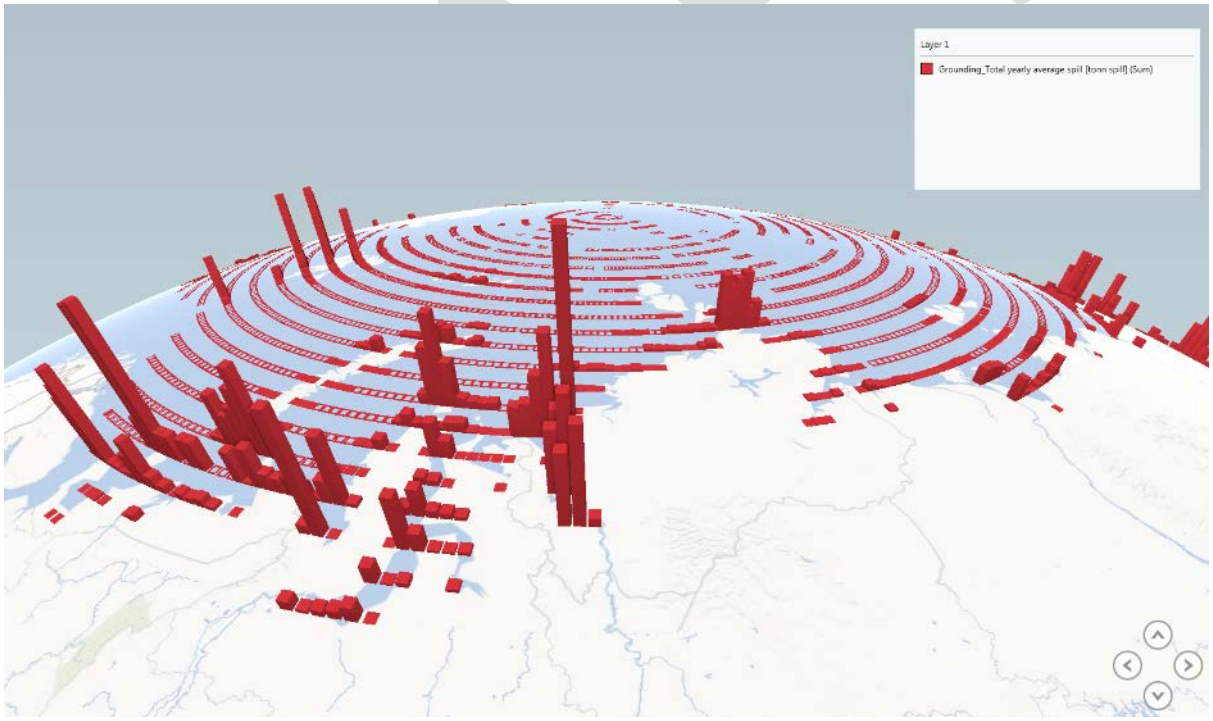

Figure 1-15 - Yearly average oil spill – Grounding - Russian north coast

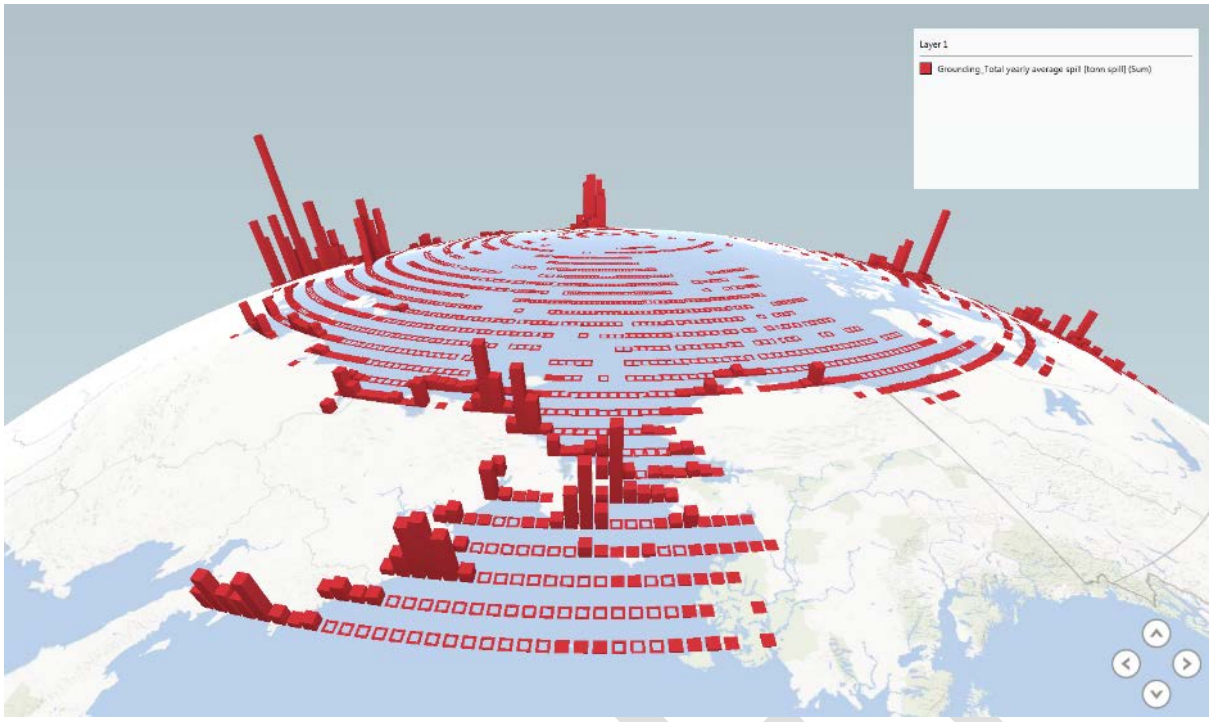

Figure 1-16 - Yearly average oil spill – Grounding - Behring strait

1.8.2 Collision risk maps

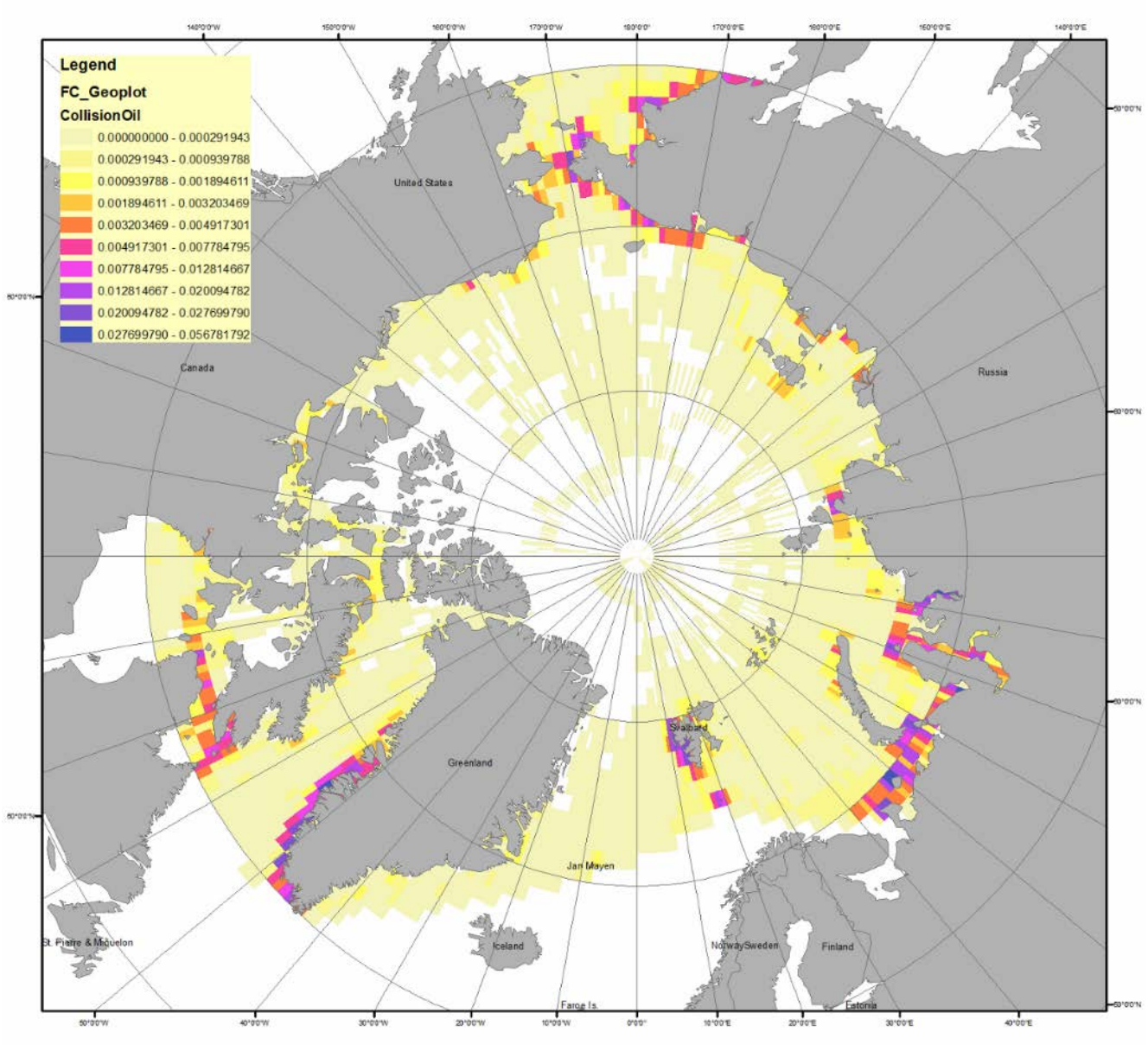

Figure 1-17 - Yearly average oil spill – Collision

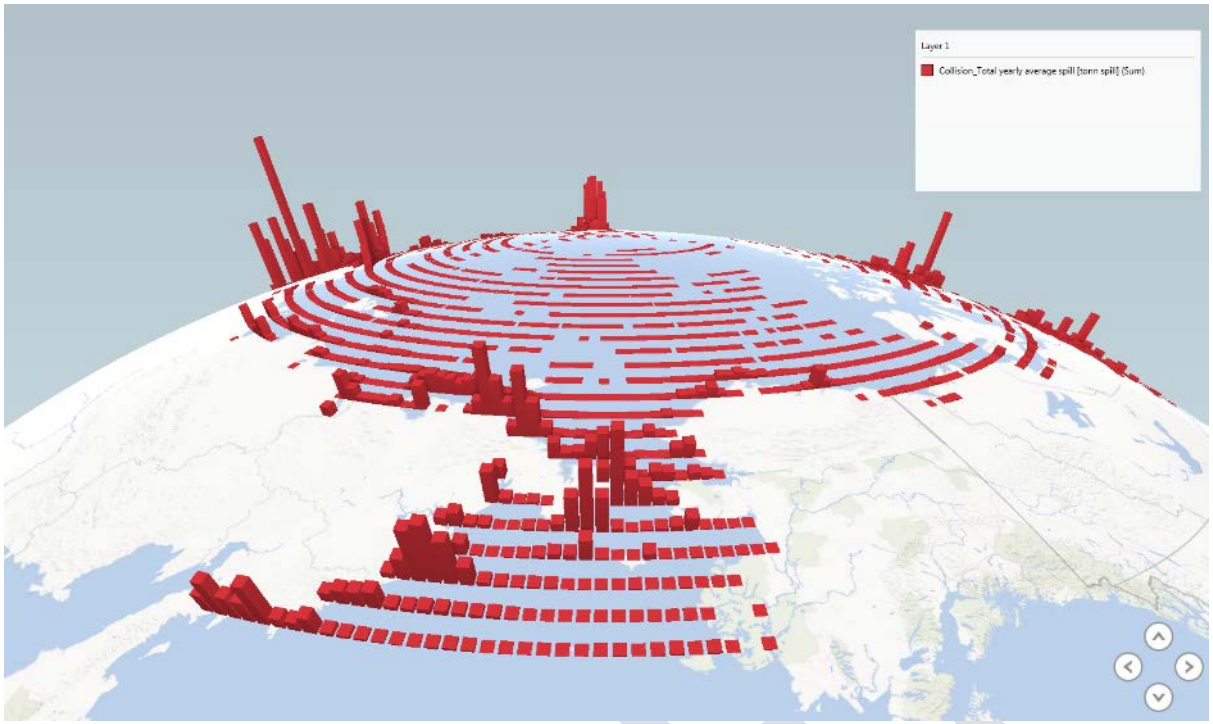

Figure 1-18 - Yearly average oil spill – Collision - Behring strait

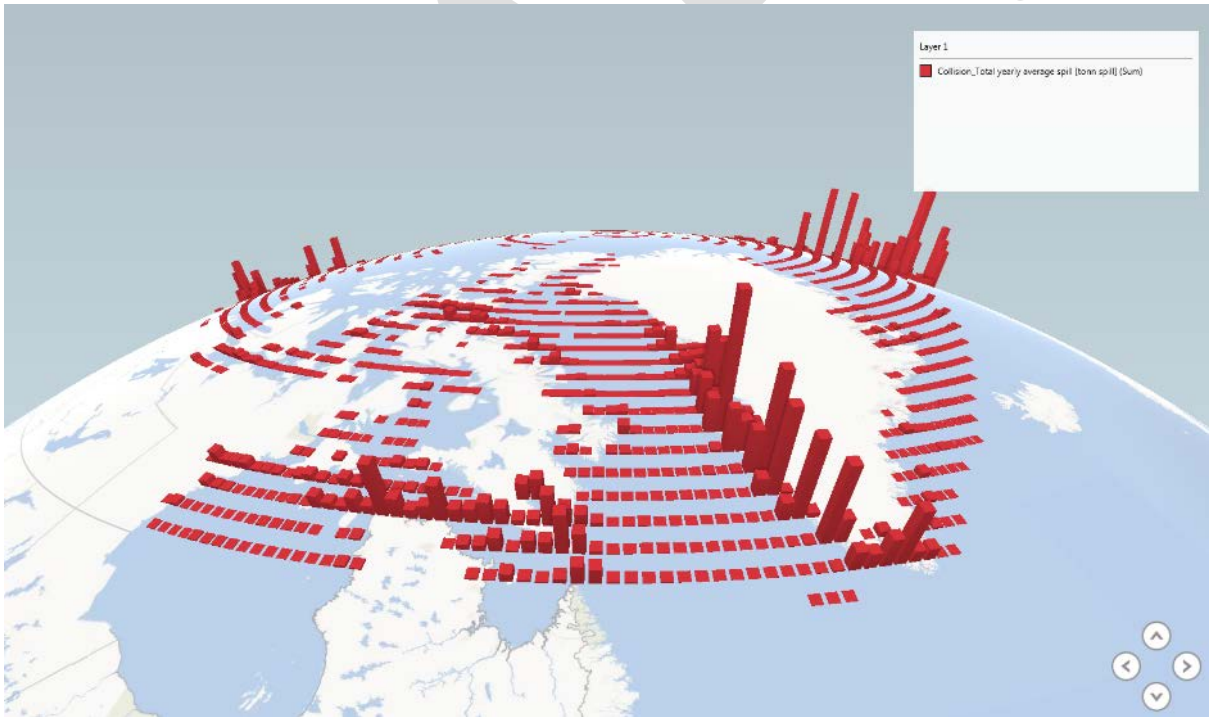

Figure 1-19 - Yearly average oil spill – Collision - Baffin Bay

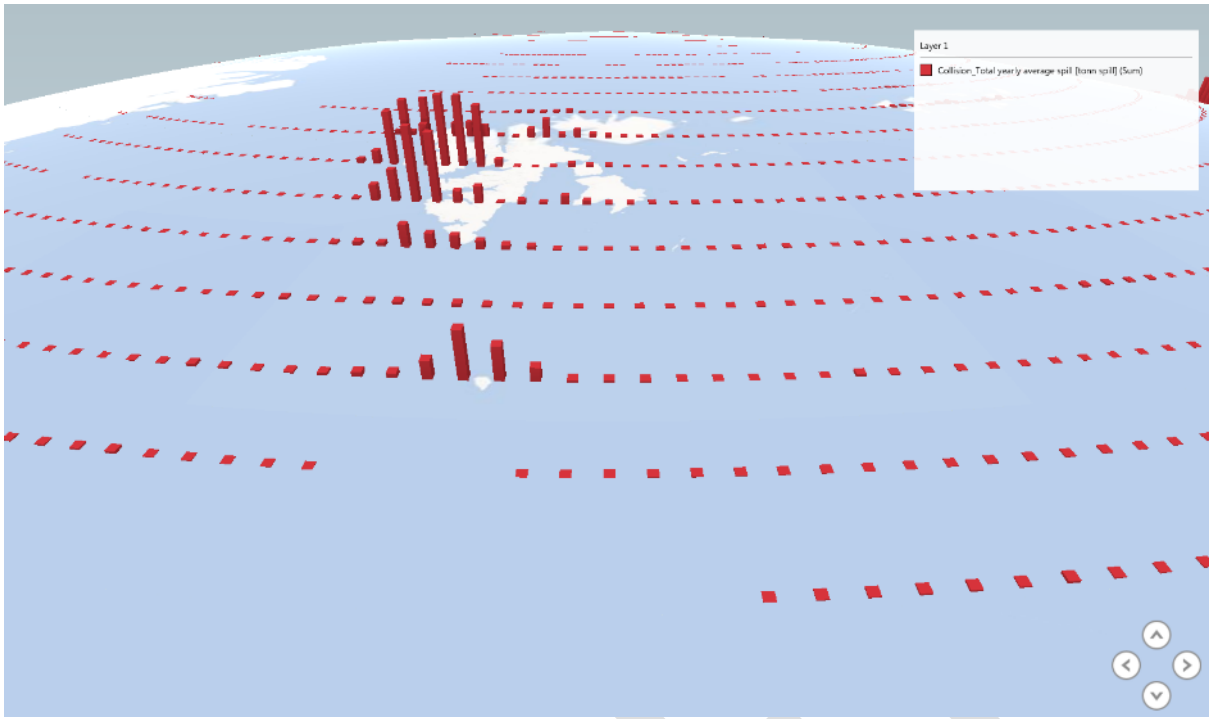

Figure 1-20 - Yearly average oil spill – Collision – Spitsbergen

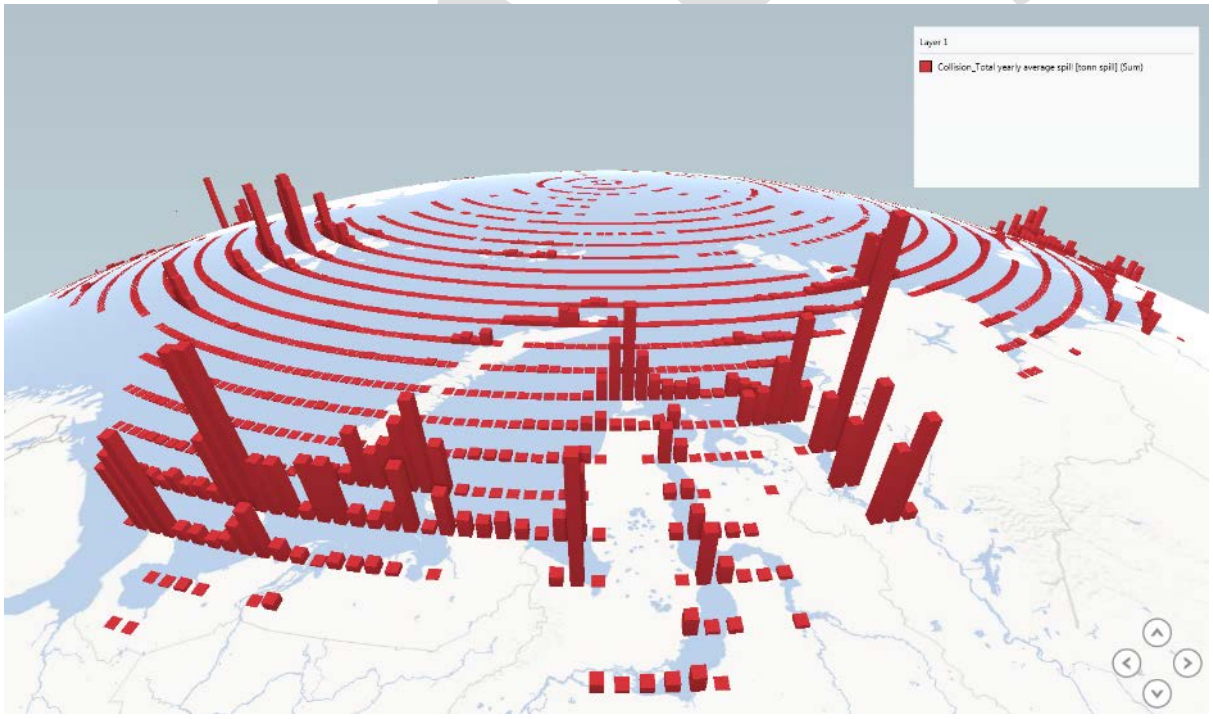

Figure 1-21 - Yearly average oil spill – Collision - Russian north coast

1.8.3 Fire/explosion oil spill risk maps

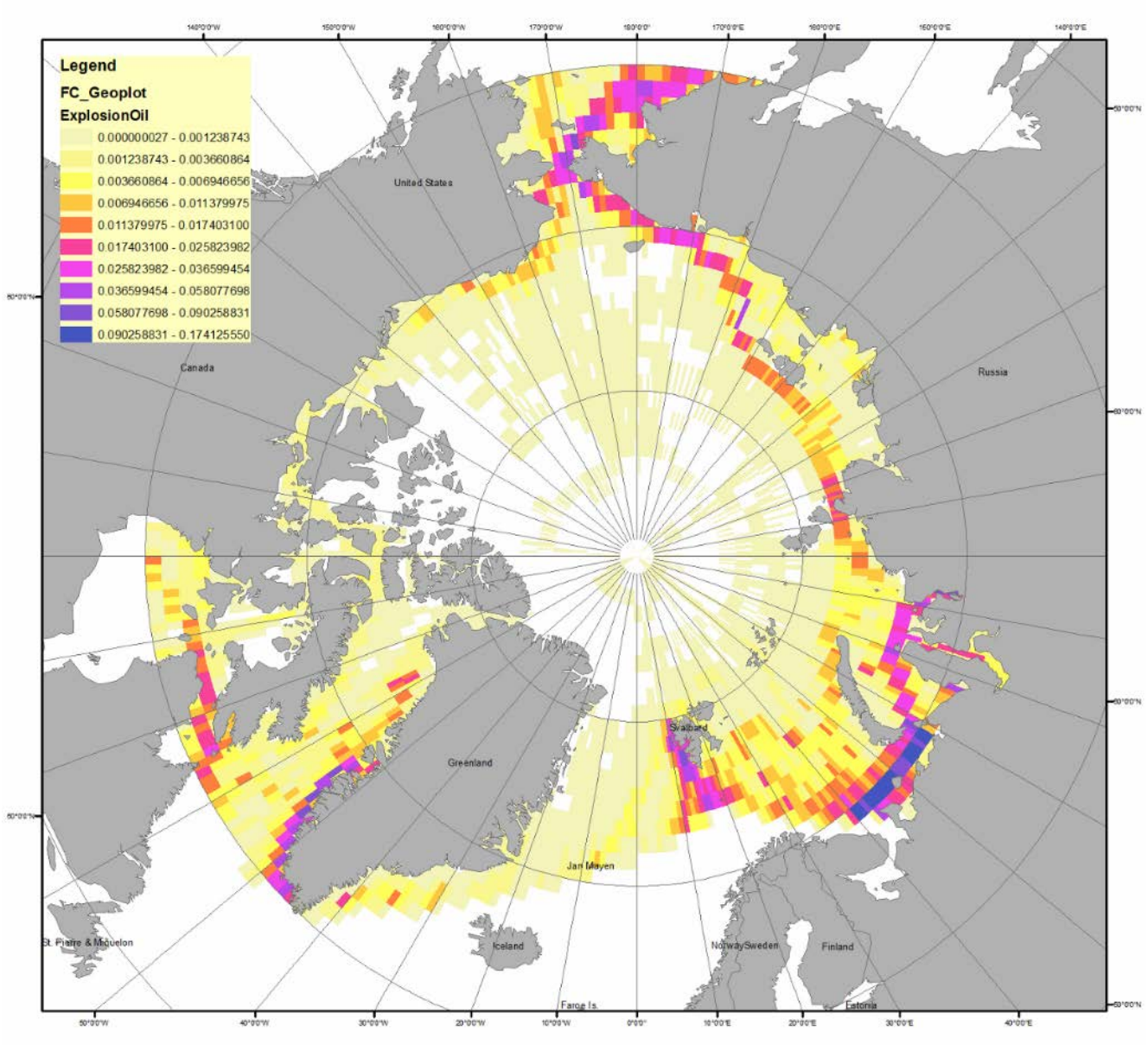

Figure 1-22 - Yearly average oil spill – Fire/ explosion

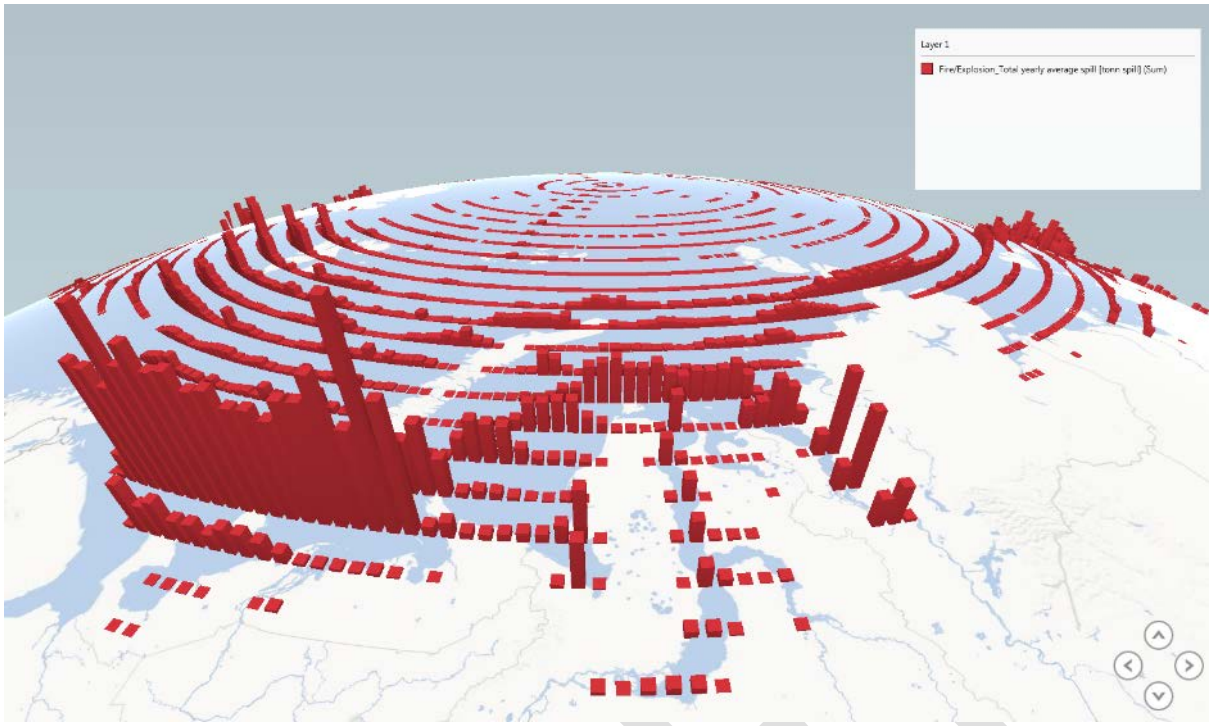

Figure 1-23 - Yearly average oil spill – Fire/ explosion - Russian north coast

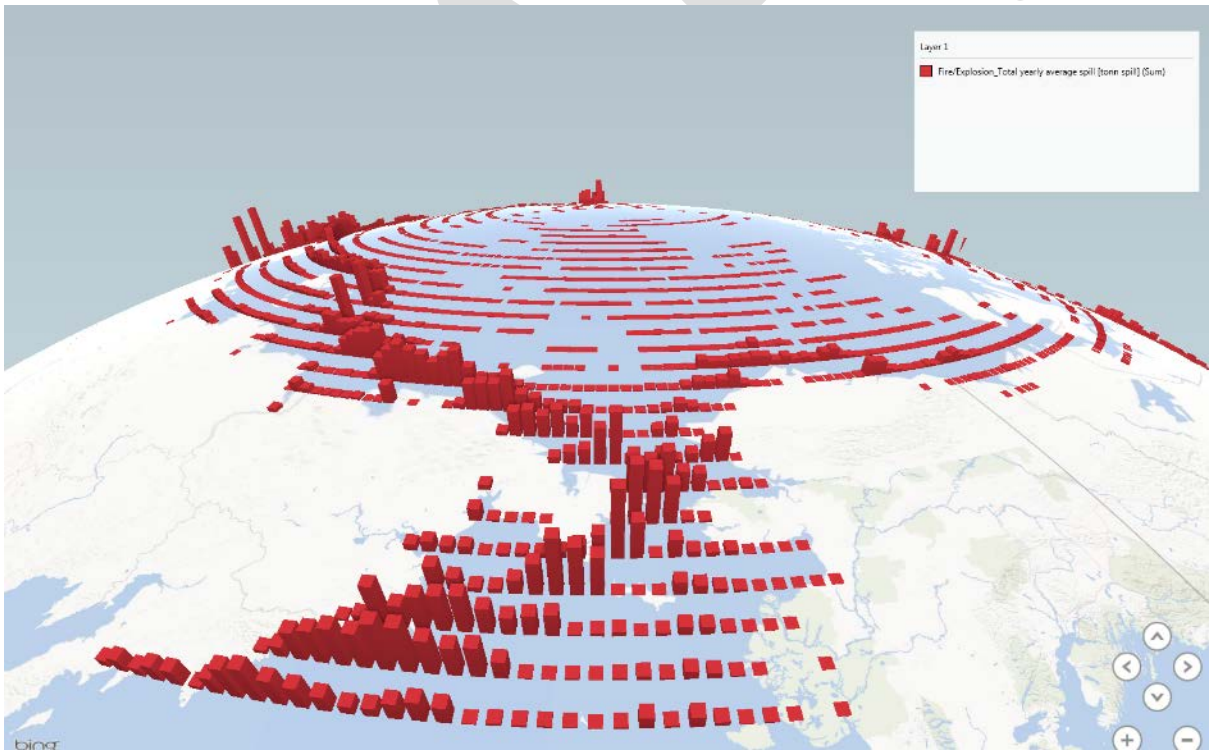

Figure 1-24 - Yearly average oil spill – Fire/ explosion - Behring Strait

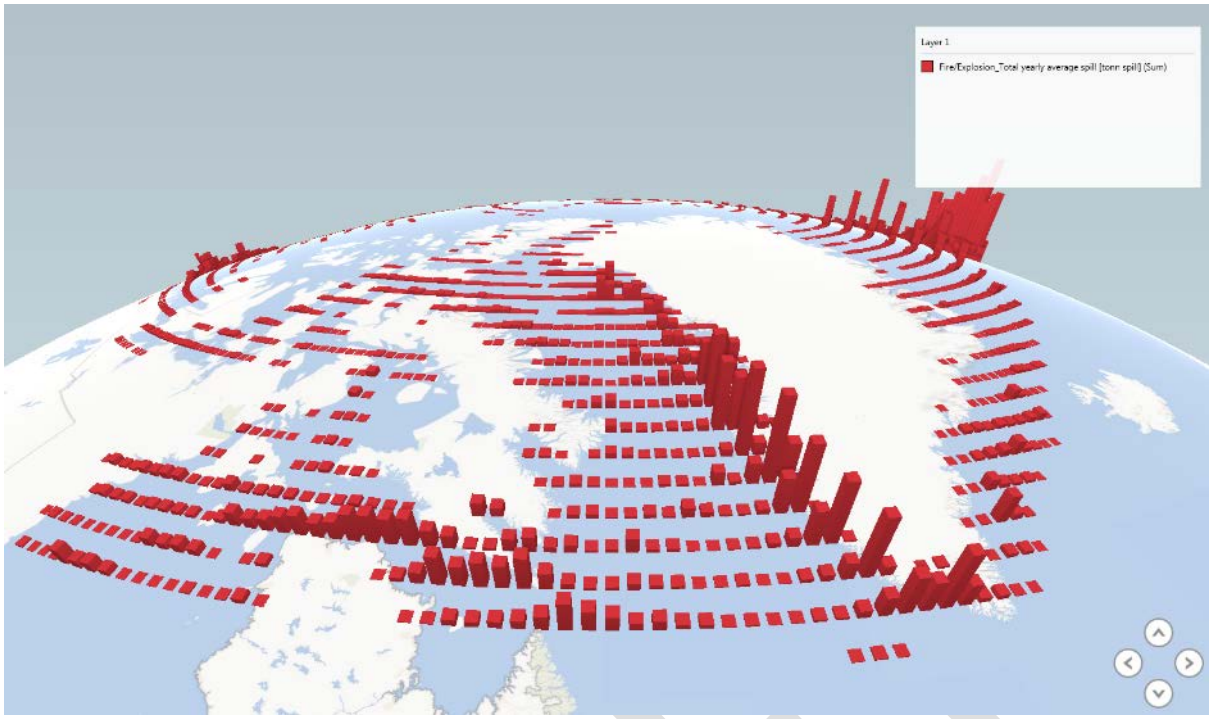

Figure 1-25 - Yearly average oil spill – Fire/ explosion - Baffin Bay

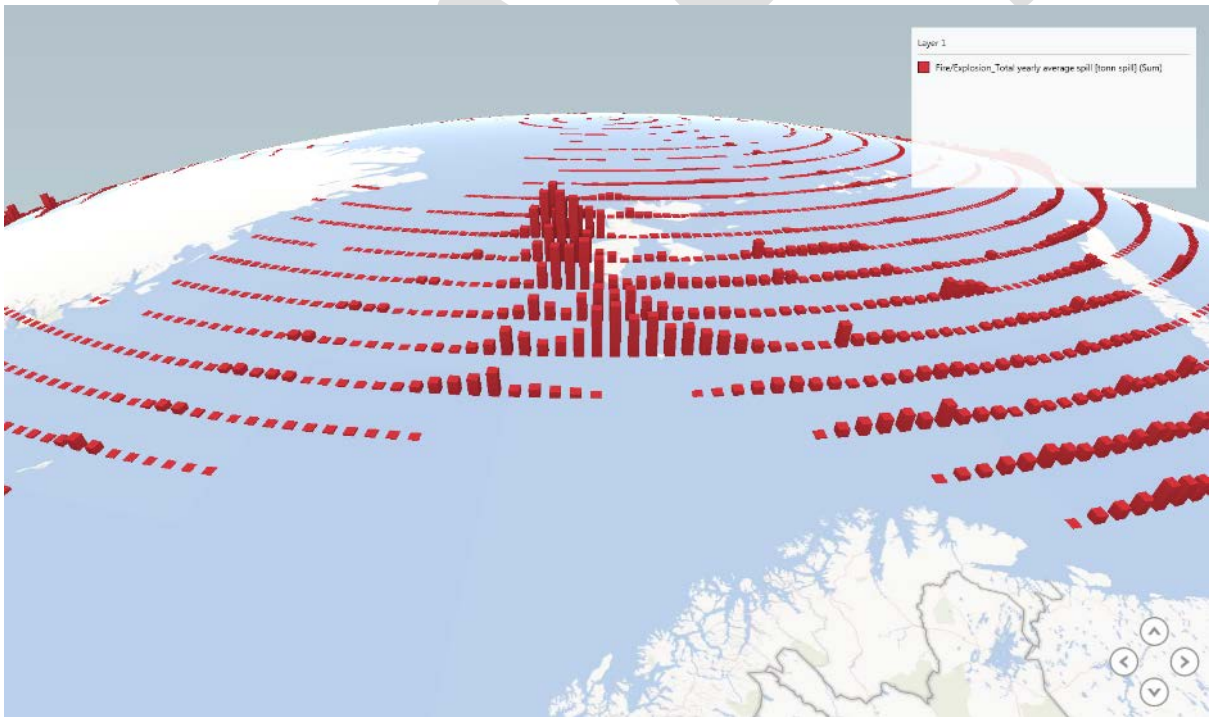

Figure 1-26 - Yearly average oil spill – Fire/ explosion – Spitsbergen

1.8.4 Hull/machinery oil spill risk maps

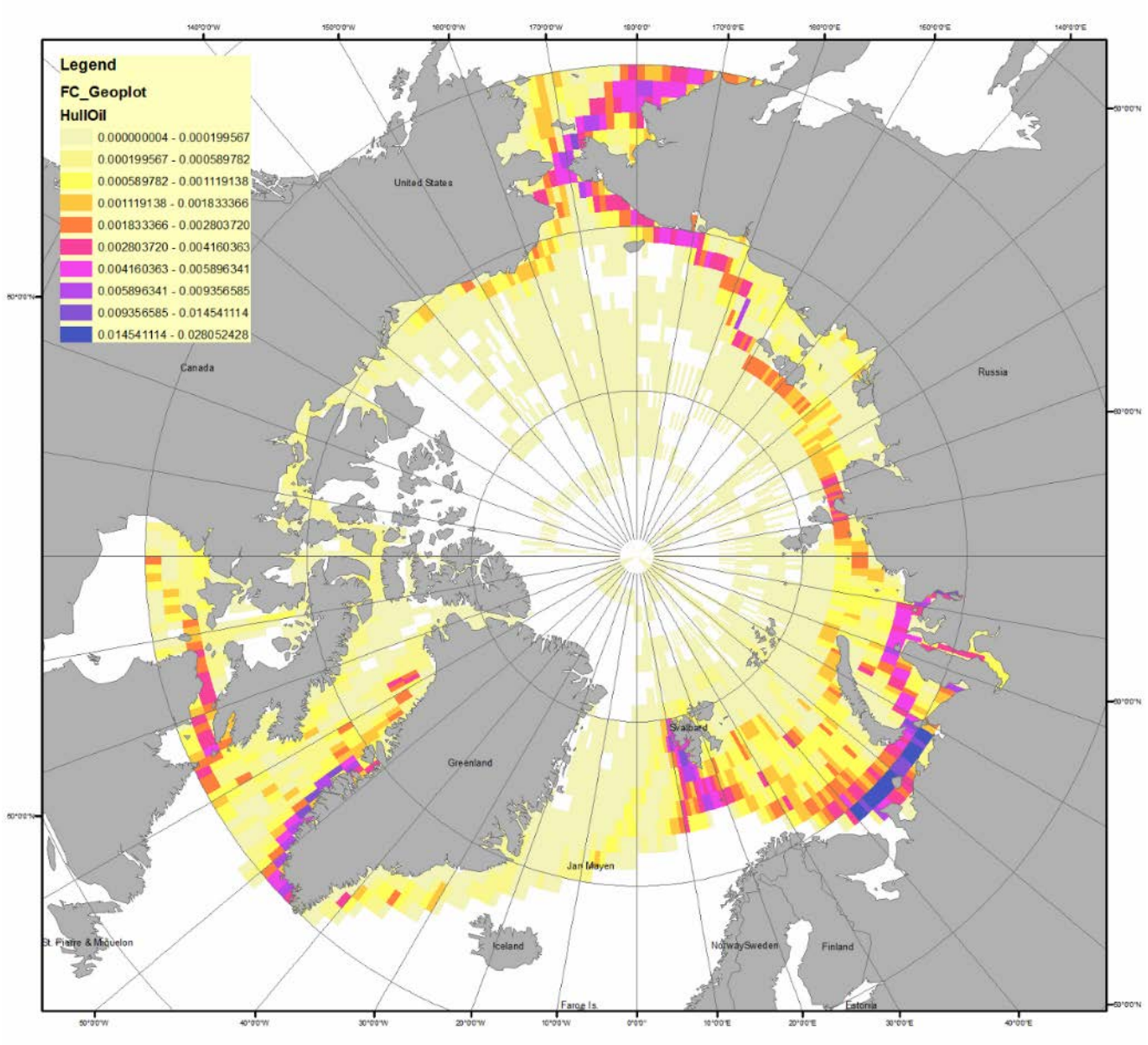

Figure 1-27 - Yearly average oil spill – Hull/machinery

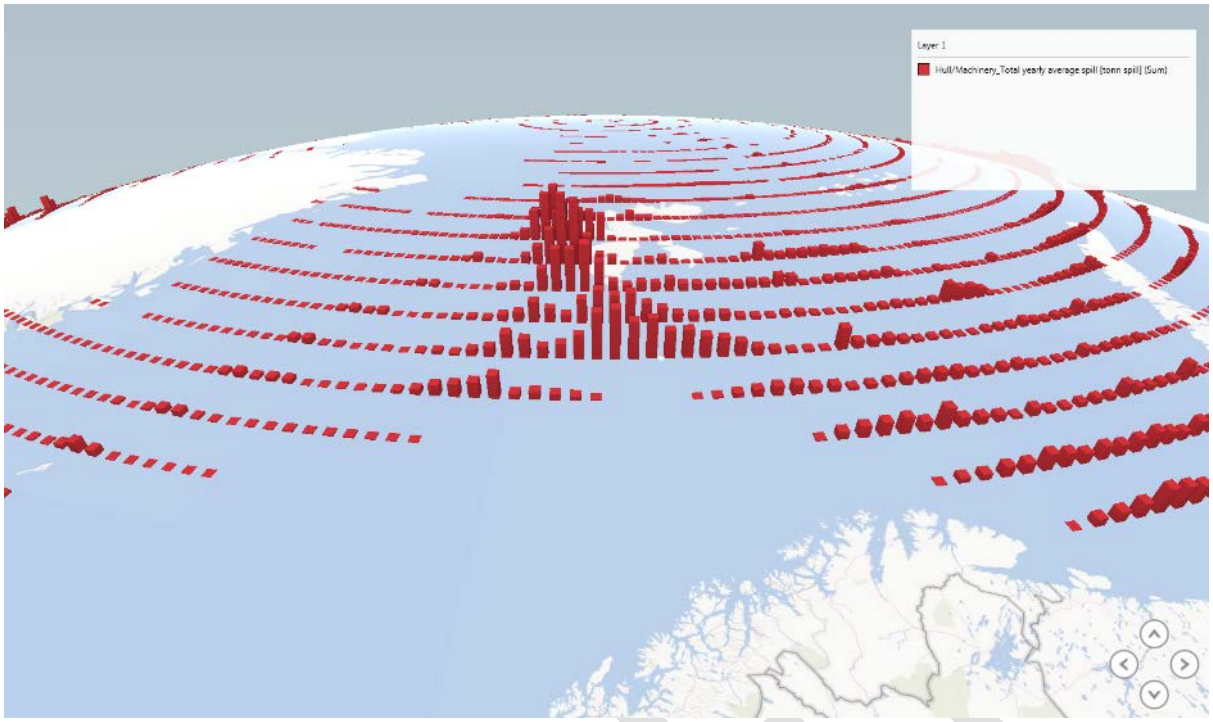

Figure 1-28 - Yearly average oil spill – Hull/machinery – Spitsbergen

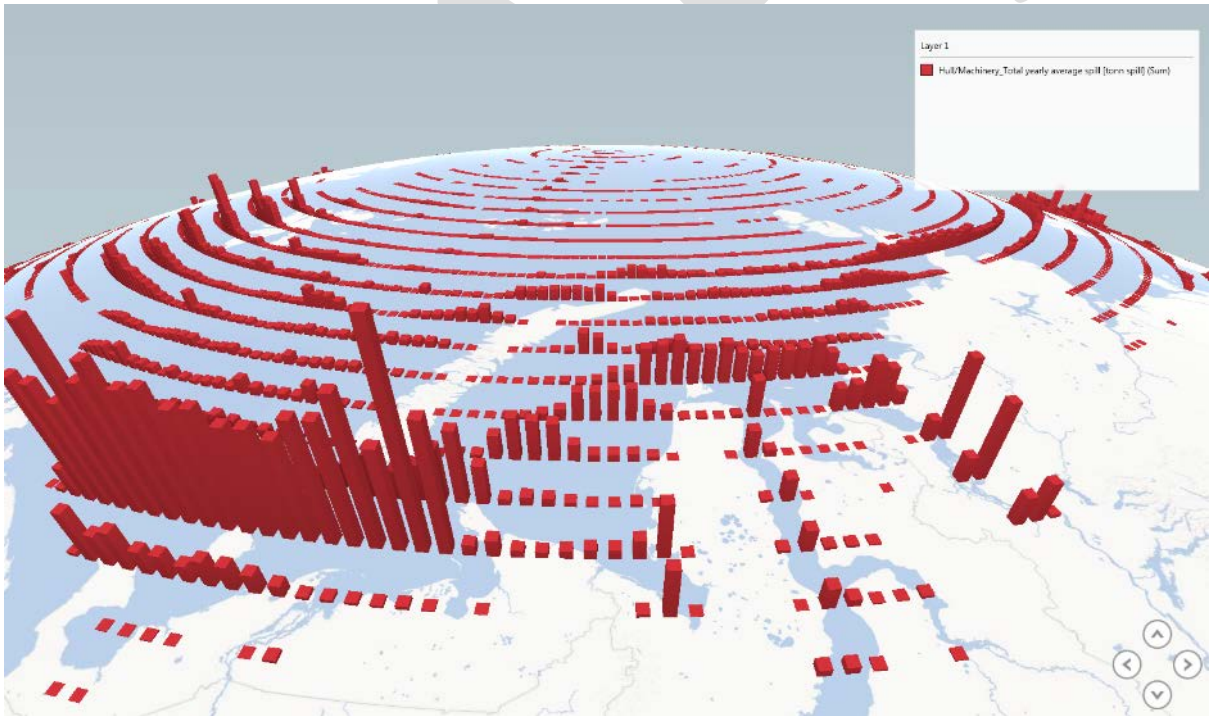

Figure 1-29 - Yearly average oil spill – Hull/machinery – Russian north coast

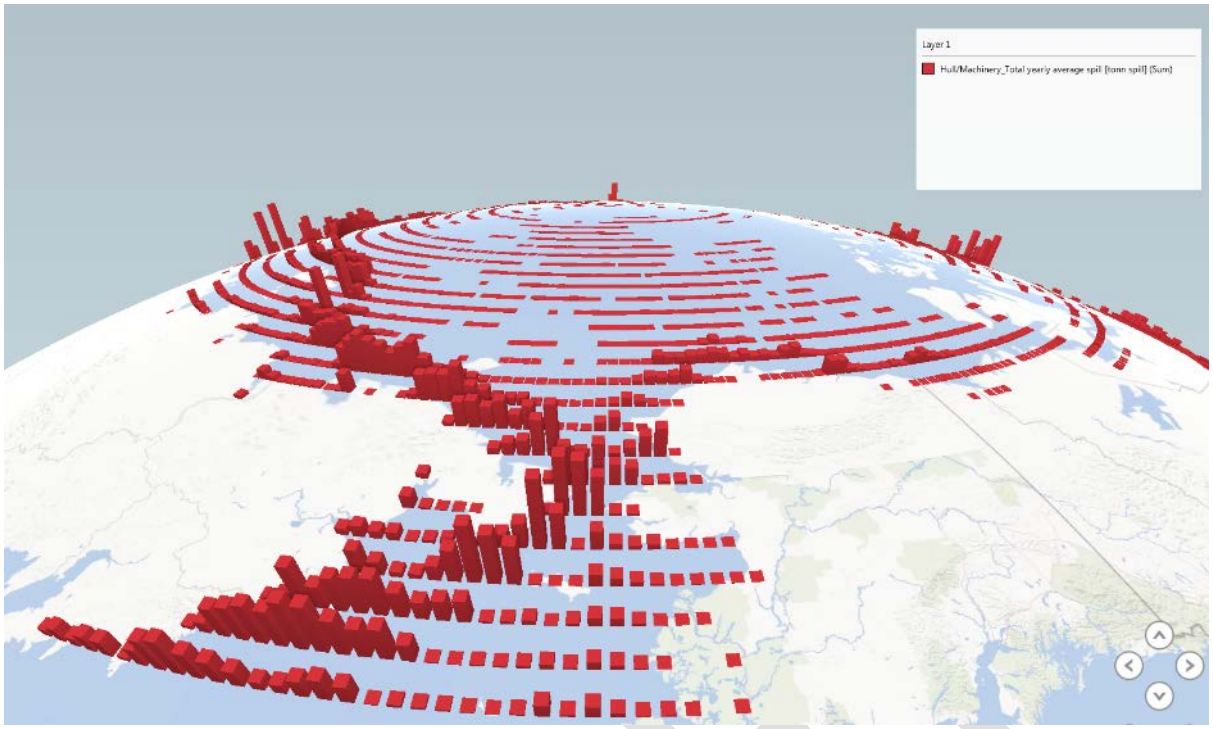

Figure 1-30 - Yearly average oil spill – Hull/machinery – Behring Strait

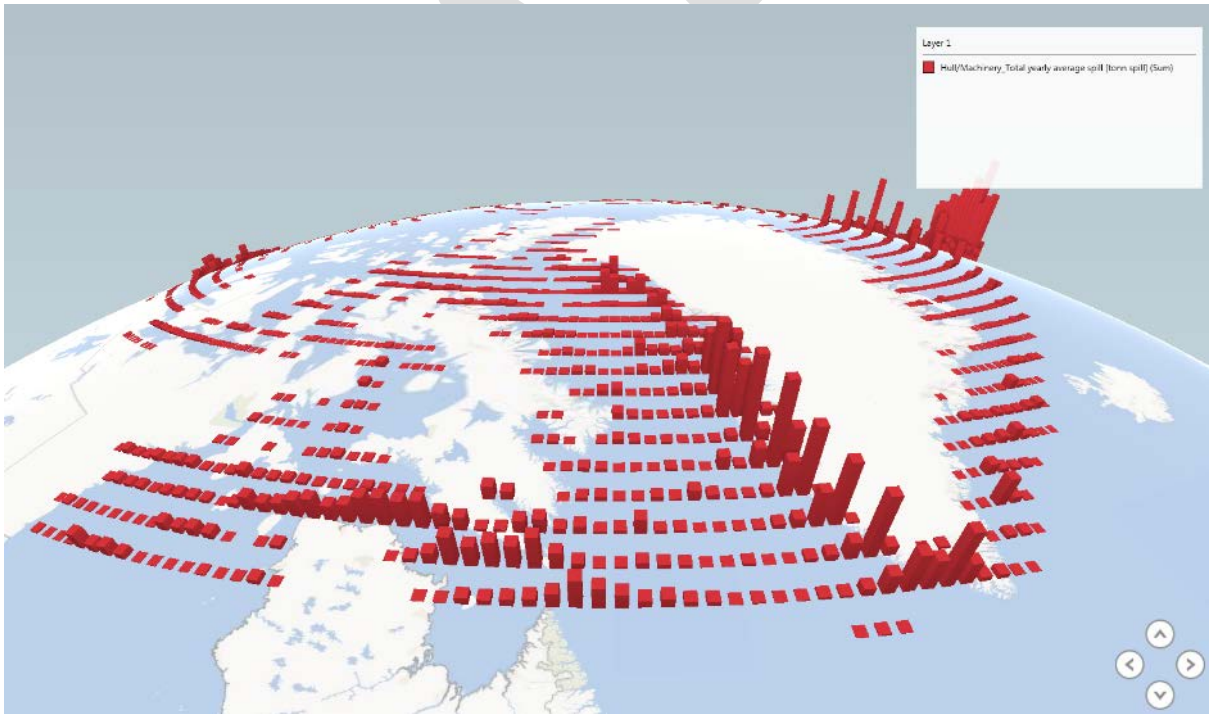

Figure 1-31 - Yearly average oil spill – Hull/machinery – Baffin Bay

1.8.5 Ice related oil spill risk maps

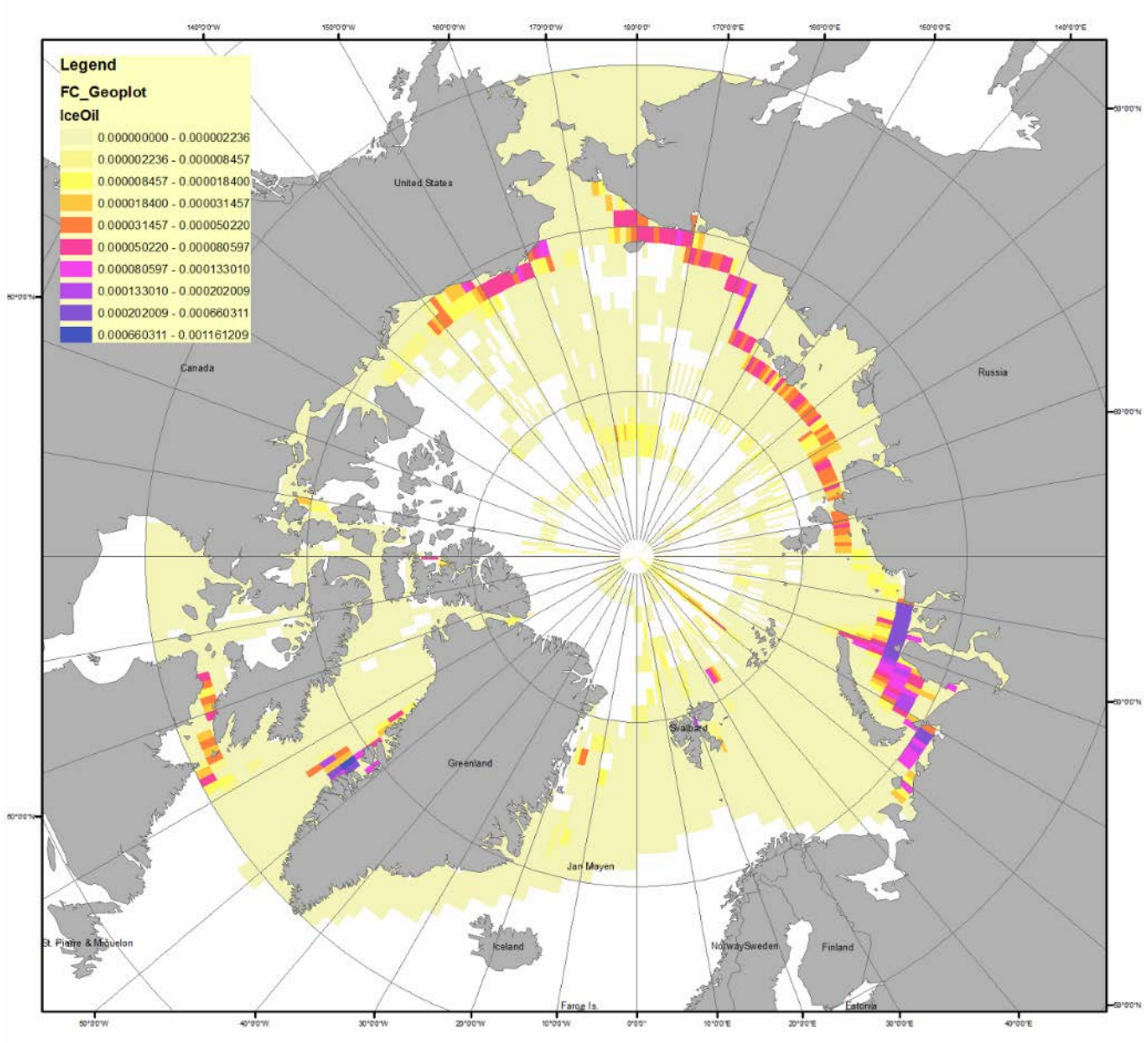

Figure 1-32 - Yearly average oil spill – ice related

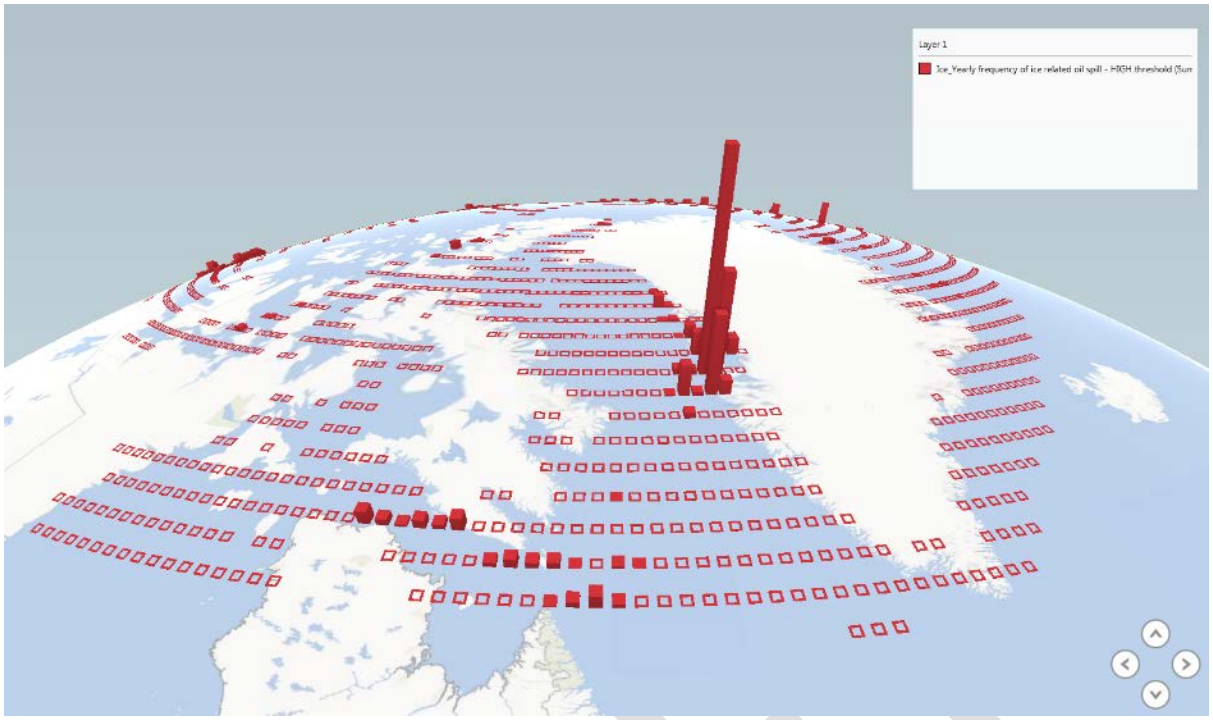

Figure 1-33 - Yearly average oil spill – ice related – Baffin Bay

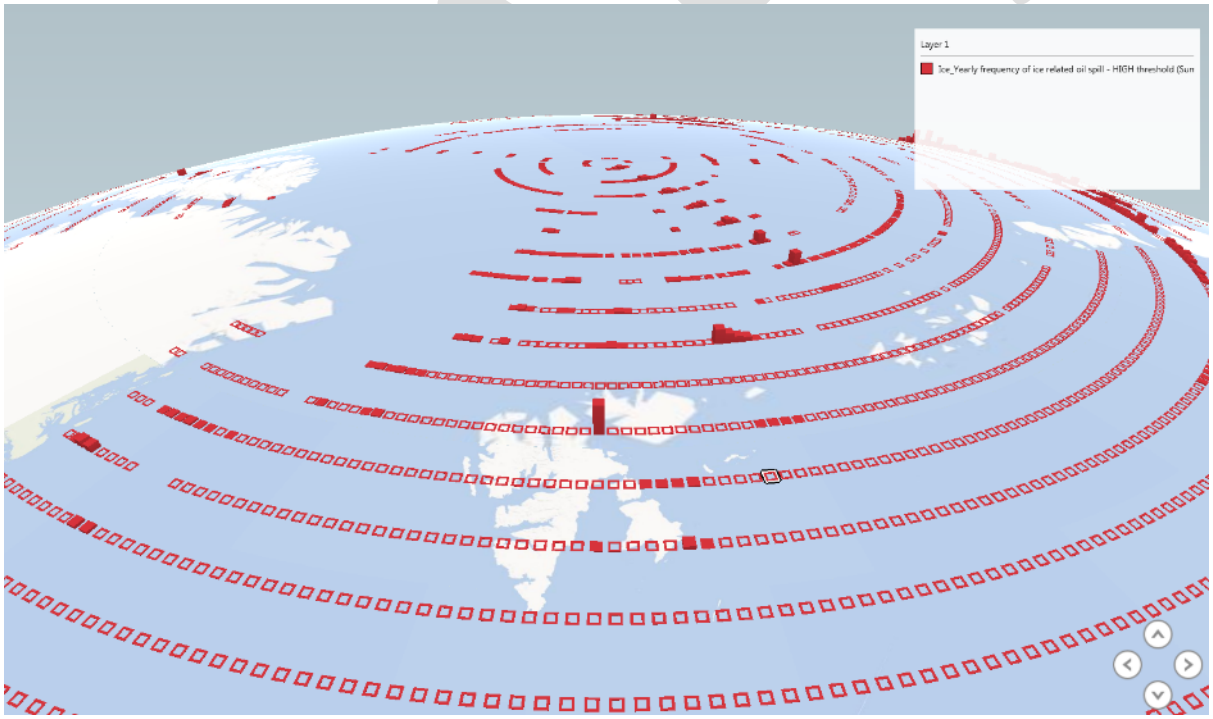

Figure 1-34 - Yearly average oil spill – ice related – Spitsbergen and the Central Polar Sea

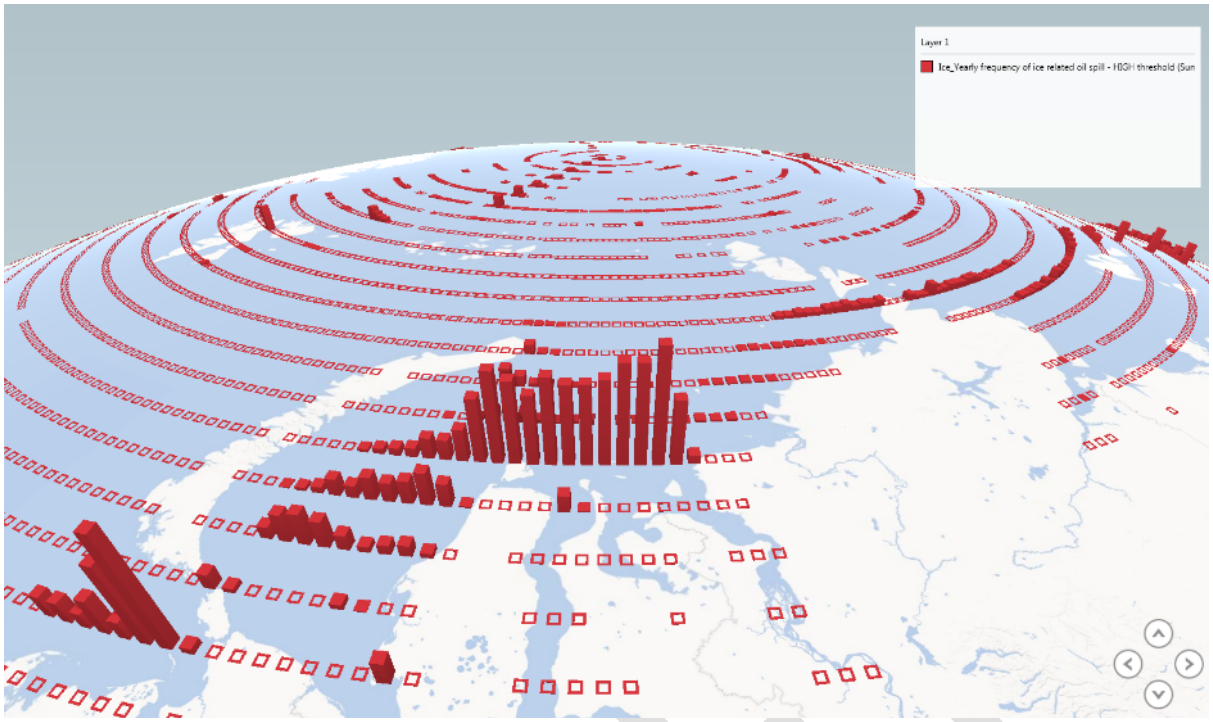

Figure 1-35 - Yearly average oil spill – ice related – Russian north coast

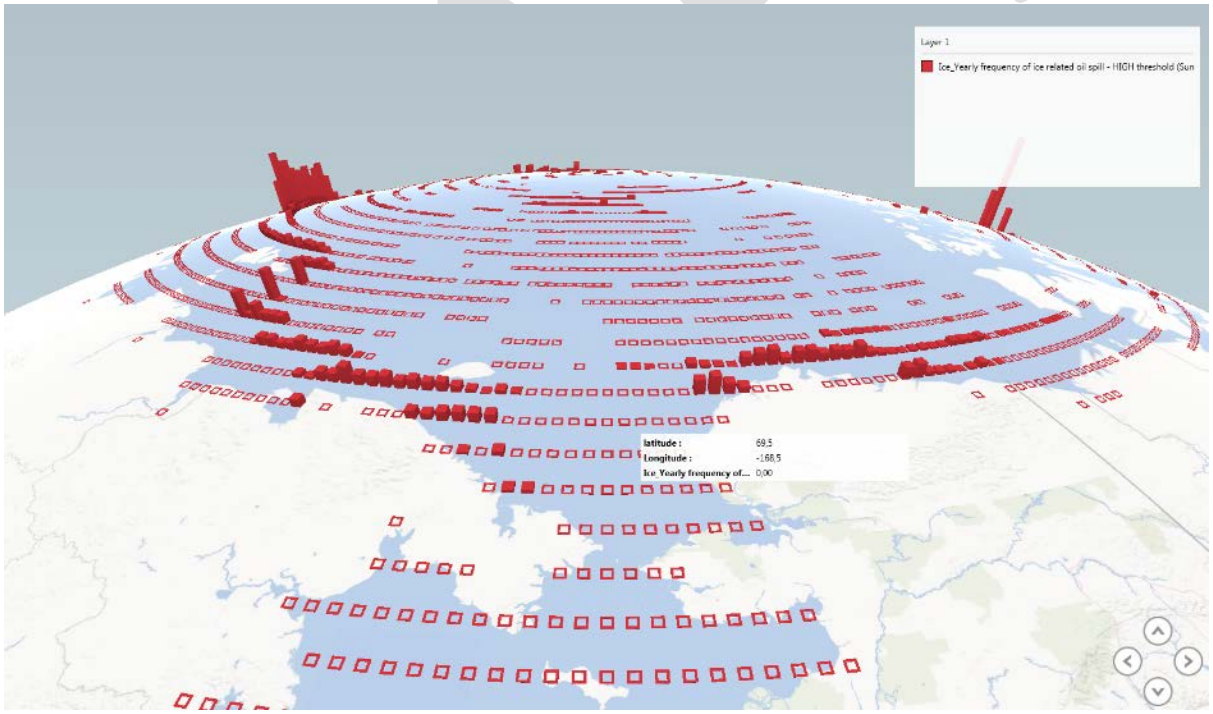

Figure 1-36 - Yearly average oil spill – ice related – Behring Strait (Note that no ice data was available for the Behring Sea)