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Oil Spill Contingency Planning in the Arctic-Recommendations

WP 4	Environmental Protection and Management System for the Arctic
WP 4.2.2.4	Oil Spill Contingency Planning in the Arctic-Recommendations

Authors: Karl-Ulrich Evers, Hamburgische Schiffbau-Versuchsanstalt GmbH (HSVA)
Ice and Environmental Technology, Hamburg, Germany

Kristin R. Sørheim and Ivar Singsaas,
SINTEF Materials and Chemistry, Marine Environmental Technology
Trondheim, Norway.

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"OIL SPILL CONTINGENCY PLANNING IN THE ARCTIC - RECOMMENDATIONS "

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PARTNERS:

Aker Finnyards	FIN
Royal Wagenborg	NL
Hamburg University of Applied Sciences	D
Tecnomare SpA	I
Merenkulun turvallisuuskoulutuskeskus	FIN
Central Marine Research and Design Institute	RU
Arctic and Antarctic Research Institute	RU
Hamburgische Schiffbau-Versuchsanstalt GmbH	D
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Fortum Oil and Gas	FIN
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Short Description

The objective of this task in Work Package 4 of the ARCOP program is to provide recommendations to oil spill contingency planning in Arctic areas. This constitutes a basis of an environmental protection and management system in the Arctic region. This task is mainly focusing on recommendations of oil spill response along the shipping route from the loading terminal at Varandey to the transhipment terminal at the Murmansk Sea port. Along this route the tankers will meet various type of ice and open water conditions during year round shipping. The risk of environmental pollution caused by oil spill increases associated with the loading and transportaion of oil products.

The recommendation according to a contingency plan is focused on response techniques in open water, ice-infested water with respect of utilizing mechanical recovery, dispersant and *in-situ* burning. The strategy with respect on shoreline cleanup is focused on the natural processes and use of *in-situ* techniques. In a case with oil spill, the combating strategy will strongly depend on response time, the ice conditions, weather/current/wave conditions, availability of equipments, possibility of assistance e.g. of helicopters. In addition, the properties of the oil products, amount of oil spilled and duration of the spill are important aspects in selection of oil spill response technology.

Today there is no proven response method for recovery of large-scale oil spills in ice-infested waters. The preferred response for the scenario as described for the shipment in ice from Varandey towards Murmansk may be a combination of mechanical recovery and use of in-situ burning.

Author(s)

Name	Company
Karl-Ulrich Evers	Hamburgische Schiffbau-Versuchsanstalt GmbH (HSVA) - Ice and Environmental Technology - Hamburg, Germany
Kristin R. Sørheim and Ivar Singsaas	SINTEF Materials and Chemistry, Marine Environment Technology

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The shipping route from the loading terminal at Varandey to Murmansk sea port has long distance to land which requires that the spill response technology can be used off-shore, mainly from larger vessel like icebreakers, ice going tug boats and supply vessels, with possible assistance from helicopters and fixed wind aircraft for monitoring and/or surveillance, dispersant application and ignition of *in-situ* burning.

If an oil spill incident should occur in the Arctic conditions, the combating strategy will strongly depend on response time, the ice conditions, weather/current/wave conditions, availability of equipments, possibility of assistance e.g. of helicopters. In addition, the properties of the oil products, amount of oil spilled and duration of the spill are important aspects in selection of oil spill response technology.

Today there is no proven response method for recovery of large-scale oil spills in ice-infested waters. The preferred response for the scenario as described for the shipment in ice from Varandey towards Murmansk may be a combination of mechanical recovery and use of in-situ burning. In order to secure short response time, it is recommended that the icebreakers assisting the oil tanker carry at least one skimmer of the brush type or rope mop type and igniters for in-situ burning. At the same time additional equipment should be stored at the Varandey terminal and/or Kolguyev Island, preferably with helicopters for fast transport and deployment. There is a need for winterisation of existing equipment and field-testing to demonstrate the capability. There is also a need for development of equipment or strategies for systems to handle larger oil spill in ice-infested waters.

The strategy with respect on shoreline cleanup is focused on the natural processes and use of *in-situ* techniques. It is important to attain a well documented knowledge about how the natural processes occurs in the different scenarios in the case of an oil spill incident should happen along the coastline or with short drifting time toward the coastline due to wind and/or current. This knowledge about the natural processes in this region can be used with advantage to develop a modelling tool to predict the restitution time of the polluted area in respect of the amount of oil released, type of the oil product, shoreline conditions and duration of the spill, weather and waves.

1 Introduction

ARCOP (Arctic Operational Platform) is a research and a technology development project with the overall objective to form an operational platform for the development of oil and gas in the Arctic region.

The objective of this task in Work Package 4 of the ARCOP program is to provide recommendations to oil spill contingency planning in Arctic areas. This constitutes a basis of an environmental protection and management system in the Arctic region. This task is mainly focusing on recommendations of oil spill response along the shipping route from the loading terminal at Varandey to the transhipment terminal at the Murmansk Sea port. Along this route the tankers will meet various type of ice and open water conditions during year round shipping.

Within the ARCOP transportation area there are various activities related to exploration, development, production and transportation of oil products, and the level of activities is expected to increase significantly in the years to come. Total amount of crude oil shipped from Varandey in 2002 was 240 thousand tons. The present oil handling capacity of the terminal is thought to be 1,5 million tons per year, but in short time frame (after 2005) the volume of oil shipment is expected to reach 3 million tons per year (Moreinis *et al.*, 2005). The increasing activity in oil and gas exploration, production and transportation in this area of concern presents an increased risk for oil spill incidents. Shipping of oil products is one of the activities that contribute to pollution in the Arctic. It is important to establish robust contingency planning, which include efficient oil spill response strategies to meet the challenges in this vulnerable Arctic region.

In general oil pollution as reported by Semanov (1995) may occur by:

- Discharge of unseparated bilge water due to human error
- Oil spillage during bunkering operations at low temperature due to damaged hoses and leaky flanges
- Escape of oil when transferred within a ship due to valve leakage caused by freezing
- Pipe and valve freezing
- Damage to cargo oil tanks resulting in penetration of oil into the segregated ballast tanks
- Disregard of washing procedures for the cargo oil tanks on oil tankers and fuel oil tanks on other ships
- Failure of limiting oil content (of effluent) alarm
- Inadequate coordination between actions taken by the ship crew and shore personnel during bunkering and cargo oil loading.
- Loading or unloading of tankers (in ice or open waters)
- Tanker accident along the shipping route from Varandey to Murmansk, in ice or in open waters

With respect to the ARCOP transportation scenario it is assumed that the most frequent type of an oil spill will occur during loading or unloading process, i.e. at the terminal in Varandey, or in Murmansk. Most of such spills will likely be small spills (few litres to some cubic meters), caused by all sorts of minor accidents or mishaps. Slightly larger spills could happen during oil loading process due to a breaking hose or an open valve. Spills happening during loading or unloading will be of moderate size. A leakage during transfer of oil will be stopped as soon as the pumping stops after detecting the leakage.

A tanker accident along the shipping route could create a major oil spill. The ARCOP shipping scenario indicates that a maximum damage will break four tanks (due to accident with another tanker, which hits to the tanker's side with high speed and cuts the tanker in two parts). The maximum amount of the crude oil that may be spilled is about 40 000 tons.

A considerable part of the shipping route of concern is covered with ice during several months in the winter and early spring. The western part, towards the Murmansk fjord is all-year ice-free water, while the eastern part towards the Pechora Sea is covered with persistent seasonal ice. Figure 1.1 gives an example of ice coverage and wind fields in the transport area in March (Johansen *et al*., 2005). Severe ice conditions can occur in March and the shipping route through ice can exceed 700 km with thick ice. In this ice-covered area larger vessels like icebreakers, ice going tugboats and supply vessels are required as carrier for oil spill response equipment.

The ARCOP shipping scenario is characterized by the following main parameters (Evers *et al*., 2004, Saarinen *et al.* 2004):

- Cargo: Crude oil from Varandey to Murmansk (year around)
- Tanker alternatives: 120 000 dwt, 90 000 dwt and 60 000 dwt tankers
- Size of the biggest crude oil tank is about 10 000 dwt (in 120 000 dwt tanker)
- Due to design of tankers, the defined ARCOP ice conditions for the shipping scenario are very detailed. Here we only refer some of the parameters:

Ice thickness (average winter max)	1.1 m
Rafted ice with a maximum ice thickness	2.4 m
Average ice pressure intensity (0-3)	1
Average ice drift speed	0.2 m/s
Ice drift direction	irregular (wind driven)
Maximum ice concentration	100 %
Time of year	March
Minimum air temperature in March	- 44° C
Typical air temperature in March	-14.4°C

Based on hydro meteorological station data, average air temperature in the Varandey area in March is -14.4 deg. C (recorded minimum is - 44°C, maximum is +3°C). Near Murmansk the temperature is slightly higher by about 4°C. However, this is applicable to the coastal line. Air temperature in this part of the sea is 2°C to 5°C higher (depending on location: due to Gulf Stream influence; gradient of air temperature is very significant).

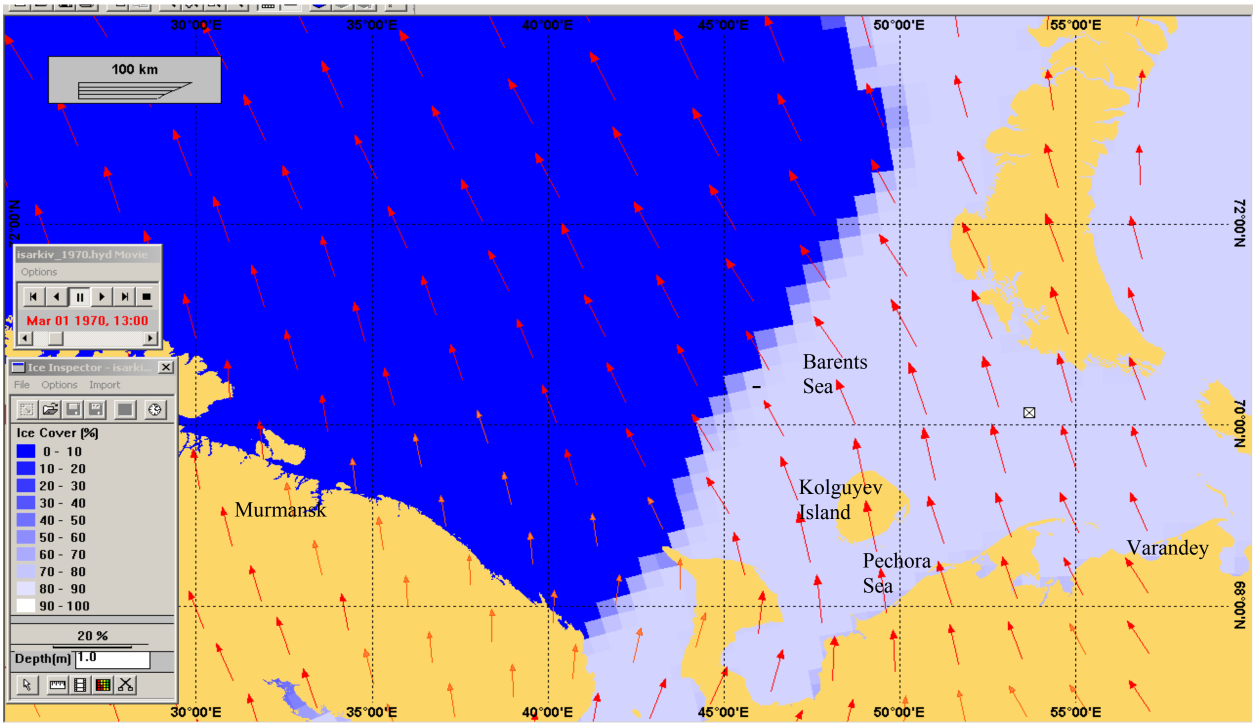


Figure 1.1 *Examples of ice coverage and wind fields in the transport area from Varandey to Murmansk as per March. Data at 24-hour intervals in 20 × 20 km resolution. Data provided by the Norwegian Meteorological Institute.*

2 Description of Environmental Conditions

2.1 Meteorological and Hydrological Parameters of the Barents Sea and Pechora Sea

For contingency planning and efficient oil spill response at sea, environmental conditions are important factors affecting oil spill response operations. Strass *et al*, 1997, and Saarinen *et al.* 2004, present a comprehensive overview of the metocean parameters in the Barents Sea and Kara Sea, which is described in the following sections.

2.1.1 Western Barents Sea

Wind

The spatial variation of the wind conditions in the western Barents Sea is shown in figure 2.1. The figure indicates the average wind speed and direction based on data from the 10-year observation period 1977-1986. The highest wind speed appears around Bjørnøya (Bear Island) and decreases towards east and north. The wind speed becomes also more evenly distributed with direction towards the east and north. The three solid lines shown in figure 2.1 are isolines for an average wind speed of 8 m/s, 8.5 m/s and 9.0 m/s (Strass *et al.*, 1997).

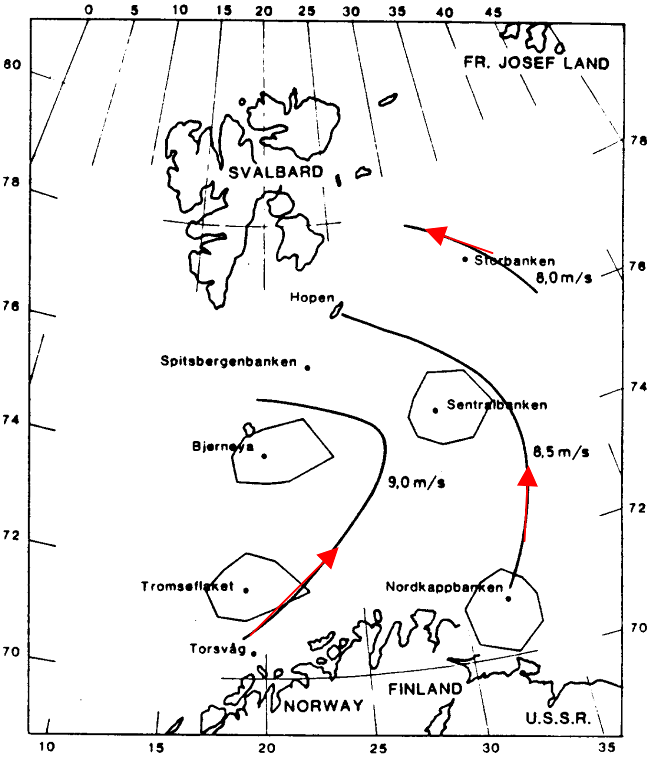


Figure. 2.1 Average wind speed and its direction of variation in the western Barents Sea. The winds are coming from the given directions (after Torsethaugen, 1989)

Temperatures

Both marine air and sea surface temperatures tend to decrease from south to north and from west to east reflecting not just atmospheric, but also oceanic factors. Air and sea surface temperature conditions are mildest in the south of the region. It is here that the warm Norwegian Atlantic Current splits into the northbound West-Spitsbergen Current and the eastbound North Cape (Nordkapp) and Murmansk currents.

Local variations occur within the overall pattern of increasing severity from South West (SW) to North West (NW). For example, the input of cold polar water to the east of Bjørnøya contributes to the markedly colder oceanic conditions in the immediate vicinity of the island, compared to those to the west and east. Conditions in the South East (SE) can, at times, be as extreme as those in the north owing to the proximity of the continental landmass (Løset *et al.*, 1988).

Sea ice regularly covers the whole of the northern area around and to the east of Bjørnøya from November through May. The ice margin is closely tied to the polar front, which exerts a significant control on conditions in the north of the region. The lowest air and sea temperatures tend to occur during the late winter and/or early spring. The highest temperatures are experienced in the late summer.

Average air temperatures range from below 0°C to close to 10°C during the course of the year. Figure 2.2 shows the observed minimum air temperature in the western Barents Sea (Iden and Tønnesen, 1988). Average sea surface temperatures in open water range from a low of 3°C in winter in the north to 12°C in summer in the SW. The seasonal cycle in the sea surface temperature is most distinct in the southern areas. Low temperature conditions, air temperature of -10°C and below, and sea surface temperatures of 0°C and below, can occur in all but the summer months over most of the region. They are most frequent in northern areas (Strass *et al.*, 1997).

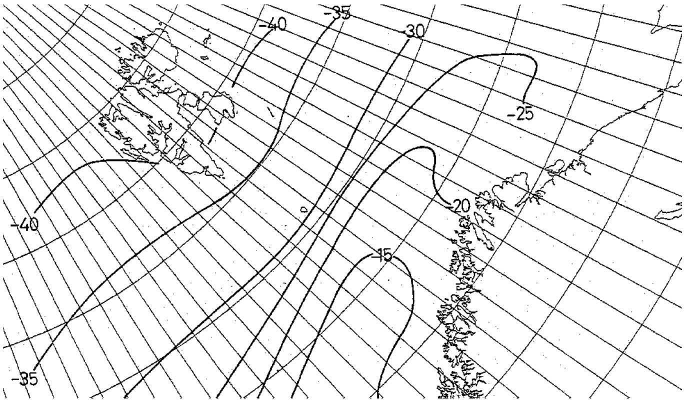


*Figure 2.2 Observed minimum air temperatures (°C) in the western Barents Sea (*Iden *et al.*, *1988)*

Current

The water masses of the Barents Sea consist mainly of Norwegian Coastal Water; relatively warm Atlantic Water and cold Arctic Water (figure 2.3). The Norwegian Atlantic and Norwegian coastal currents enter the Barents Sea from the south and SW. Surface current speeds of 0.75-0.80 m/s are measured in the zone between the Norwegian Coastal Current and the Norwegian Atlantic Current at Tromsøflaket. Off Finnmark, the Norwegian Atlantic Current splits into several branches of which one is the North Cape Current (NC). This current follows the coast just outside the coastal current. The North Cape current can be identified as far east as 30°E. The average speed of the NC current is 0.10-0.12 m/s. Further east, the NC splits into several branches with the major one following the bottom slope off Murmansk turning northward towards Novaya Zemlya (Bjerke and Torsethaugen, 1989).

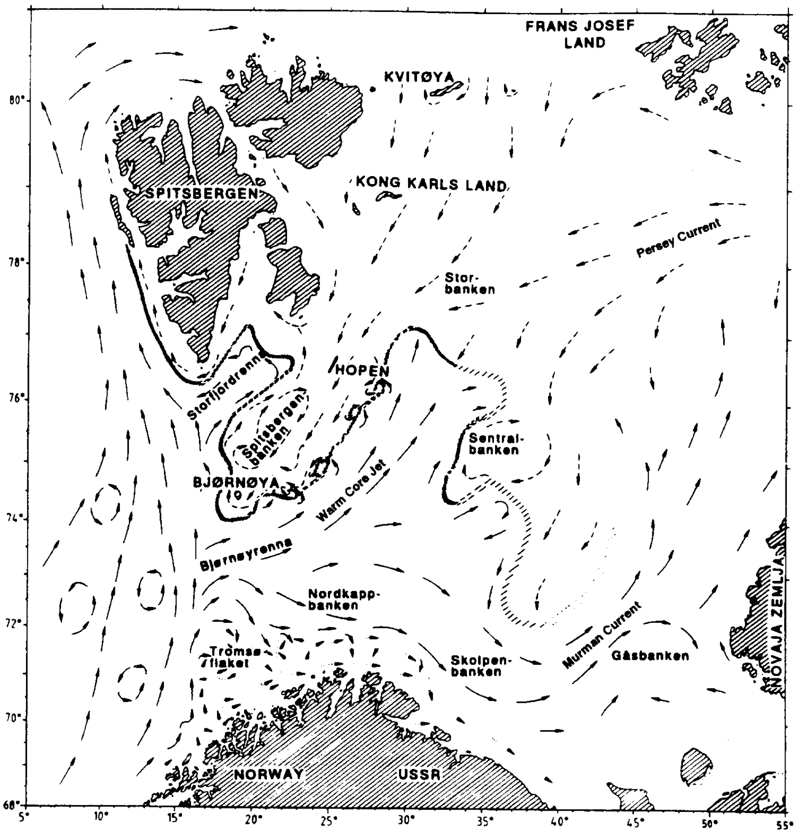


Figure 2.3 Features of the ocean surface currents in the Barents Sea showing that relatively warm Atlantic Water enters the southwestern part of the sea and flows NE, while relatively cold Arctic Water in the northwestern part flows SW (Loeng, 1991)

Waves

In general, the wave climate in the Barents Sea appears to be somewhat milder than in the North and Norwegian Seas. Most storms in the Barents Sea are dominated by SW winds, which have the longest fetch. Swells from the Atlantic Ocean and the Norwegian Sea enter the Barents Sea and fade out towards the east.

2.1.2 Pechora Sea

Several meteorological stations border the Pechora and Kara Seas. One is located on the northern side of Kolguyev Island with regular observations from 1945. In Varandey, statistics exist from 1945 and in Khodovarikha from 1940. The hydrometeorological reference book (USSR, 1986a) summarizes data on air temperature, wave parameters, currents and ice for several periods from 15 to 45 years (Strass *et al.*, 1997).

Wind

The prevailing wind direction depends on the season. During winter, SW wind dominates. In summer, winds are moderate and unstable, prevailing from the north or NW. As much as 80-85 % of the storm durations in that period are less than 12 hours. According to the Russian territory division (SNIP, 1987), the examined region onshore falls under district (zone) 7, characterized by 10 min mean wind speeds in winter up to 37 m/s (return period, R_p = 5 years).

The 50-year extreme wind speed (R_p = 50 years) lasting 6-7 hours (long-term period averaging) is equal to 26 m/s. The frequency of wind speeds higher than 16 m/s is close to 12 %. The greatest wind speeds occur from December to February (USSR, 1986a; USSR, 1990). The wind speed during different seasons, based on 30 years of data, is shown in table 2.1. The 10 min wind speeds have been measured at a height of 10 m, 3-4 times a day (Strass *et al.*, 1997).

Table 2.1 Average monthly wind speeds and directions ($\overline{U}$, m/s) wind speed standard deviations (σ_U, m/s), average frequencies during month ($\overline{n}$,%) of these speeds at Kolguyev Island. Periods of observation: 1945-1951, 1953-1977 (USSR, 1986a).

Month	Parameter	Wind direction							
		N	NE	E	SE	S	SW	W	NW
January	$\overline{U}$	10.0	9.4	9.9	8.5	8.8	10.1	9.4	10.5
	σ_U	5.5	4.6	4.6	4.4	5.2	5.2	5.0	5.4
	$\overline{n}$	7	11	9	15	31	32	11	8
May	$\overline{U}$	7.5	7.4	8.1	8.2	7.1	7.2	6.5	7.2
	σ_U	4.3	3.9	4.3	4.6	3.8	3.6	3.4	4.1
	$\overline{n}$	17	15	16	10	10	17	19	20
July	$\overline{U}$	7.2	6.1	6.4	6.7	6.6	7.0	6.0	6.9
	σ_U	4.1	3.5	3.4	3.4	3.5	3.5	3.1	3.8
	$\overline{n}$	2.1	17	18	14	11	10	14	19
October	$\overline{U}$	10.8	10.3	9.3	7.9	6.9	7.7	7.9	10.4
	σ_U	5.6	4.9	4.9	4.4	4.3	4.4	4.1	5.0
	$\overline{n}$	16	14	9	16	21	22	12	14

Air temperature

The number of days with temperatures below 0°C is about 230 in a year. February is the coldest month with a mean temperature of -18.3°C and an absolute minimum observed temperature of -48°C, both at Varandey. The variation of the mean temperature from December to March is small. Figure 2.4 shows a substantial decrease in the air temperature from the west (North Kolguyev) to the eastern location, Varandey (USSR, 1986a). The annual mean temperature is -2.9°C for the North Kolguyev location while it is -5.6°C for Varandey.

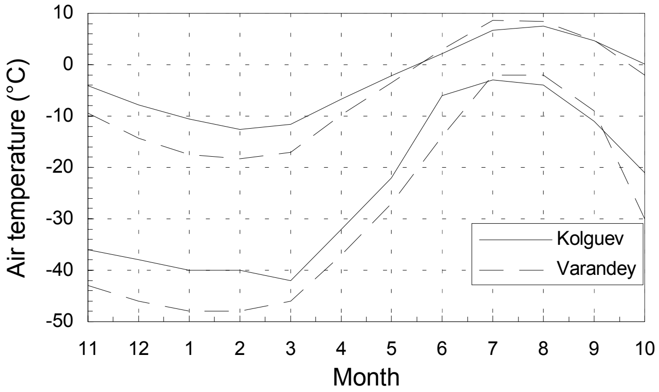


Figure 2.4 Monthly extreme minimum and average daily minimum air temperatures in North Kolguyev and Varandey, Pechora Sea. The data derives from the period 1936-1979 for the North Kolguyev Site and 1940-1980 for Varandey (USSR, 1986a)

Current

The general direction of water motion (current) during tides is from the SE to the NW. During ebb tides it is the reverse. The speed of tidal currents (spring tide) can reach 0.4 m/s. The maximum of ebb-tide currents is 1 m/s (Gorshkov and Faleev, 1980; Korppoo *et al.*, 1988).

Waves

The wave regime is substantially influenced by the bordering shorelines, the region is fully protected from the north, east and south, and the water depths are relatively small. The highest waves enter from the NW and the intensity falls from west to east. The storm season usually starts in October and causes occasionally extreme waves up to 11.5 m at water depths of 20-30 m in October-November (Mischenko, 1995). However, average waves of 2-3 m height prevail (Strass *et al.*, 1997). The presence of sea ice totally controls the wave regime in the winter and spring months. In the summer, the waves very rarely exceed 3-4 m.

2.1.3 Summary of meteorological and hydrological parameters in the Barents Sea and Pechora Sea

From the overview of metocean data from the western Barents Sea and the Pechora Sea the major conclusions are as followed:

- The highest wind speed in the western Barents Sea occurs around Bjørnøya and decreases towards the east and north. The spatial variation is greatest in the spring. Both marine air and sea surface temperatures in the western Barents Sea tend to decrease from south to north and from west to east.
- The average wave height in the western Barents Sea decreases slightly towards the east. The directional distribution shows that the highest waves enter from southwest (SW).
- The prevailing wind direction in the Pechora Sea during winter is SW. In summer, winds are moderate, and prevail from the north or NW. As much as 80-85 % of the storm durations in that period are less than 12 hours. The frequency of wind speeds higher than 16 m/s is close to 12 %. The greatest wind speeds occur from December to February.
- The number of days in the Pechora Sea with air temperature below 0°C is about 230 in a year. February is the coldest month with a mean temperature of -18.3°C and an absolute minimum temperature of -48°C. The variation of the mean temperature from December to March is small. The annual mean temperature is -2.9°C for the North Kolguyev location while it is -5.6°C for Varandey.
- The highest waves in the Pechora Sea enter from the NW and the intensity drops from the west to the east. The storm season usually starts in October and causes occasionally extreme waves up to 12 m at water depths of 20-30 m in October-November. However, average waves of 2-3 m height prevail.
- A comparison of the metocean data from these seas shows an eastern decrease in most parameters except for marine sea surface and air temperatures.

2.2 Ice conditions

2.2.1 Ice Conditions in the Barents Sea

In addition to the meteorological and hydrological conditions like temperature, wind, current and waves also the ice conditions in particular the type of ice (level ice, rafted ice, ridges and hummocks), ice thickness, the spatial and temporal distribution of the ice cover, mechanical properties, floe size distribution, and ice drift are of importance with respect to efficient oil spill response operations.

Today statistical information about ice conditions, in particular total ice concentration, in the Barents Sea and Pechora Sea is provided for example by the Ice Services of the Arctic and Antarctic Research Institute (AARI), St. Petersburg, Russia and the National Ice Center, Washington D.C., USA. Figure 2.5a to 2.5d (ice charts) visualize examples of ice analysis showing different ice conditions from satellite images for the years 2002 to 2005. (ref: Ice Center Arctic and Antarctic Research Institute (AARI), St. Petersburg, Russia)

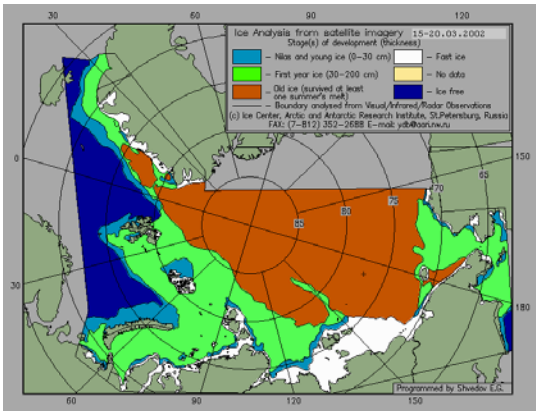


Figure 2.5a Stage(s) of development in March 2002

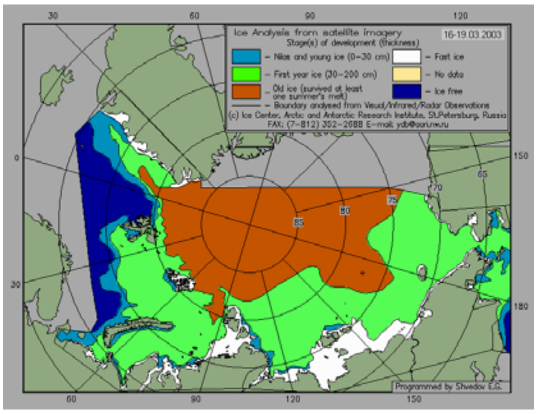


Figure 2.5b Stage(s) of development in March 2003

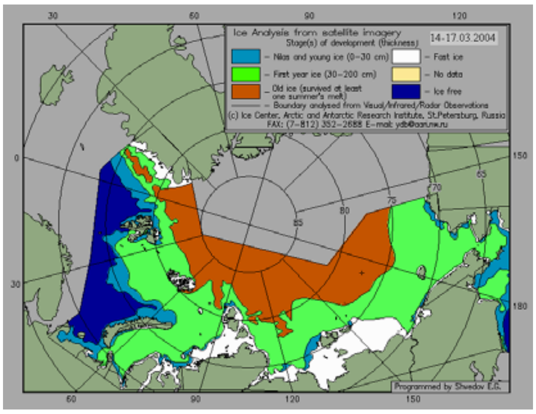


Figure 2.5c Stage(s) of development in March 2004

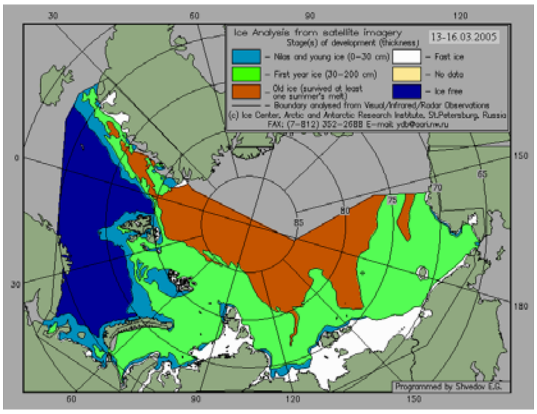


Figure 2.5d Stage(s) of development in March 2005

In general the eastern Barents Sea is ice free, where as in the southern part of the Pechora Sea young ice and nilas up to 30 cm thickness is predominant. Between Kolguyev Island and the western part of the Kara Gate (50° E to 55° E) first year ice of 30 cm – 200 cm thickness has to be considered. Along the shoreline of the Varandey region land fast ice is still observed in March.

The marginal ice zone (MIZ) in the Barents Sea is normally composed of distinct ice floes, which increase in size with increasing distance from the ice edge. For instance, Løset *et al.*(1997) reported from the 1988 IDAP (Ice Data Acquisition Program) survey in the western Barents Sea that the MIZ consisted of a relatively narrow edge zone (< 5 km wide) with floes typically 5-10 m across. Brash ice occupied most of the surface area between the floes in the edge zone. For the transition zone, 5-65 km from the edge, the mean floe size in general increased with distance from the ice edge as shown in figure 2.6.

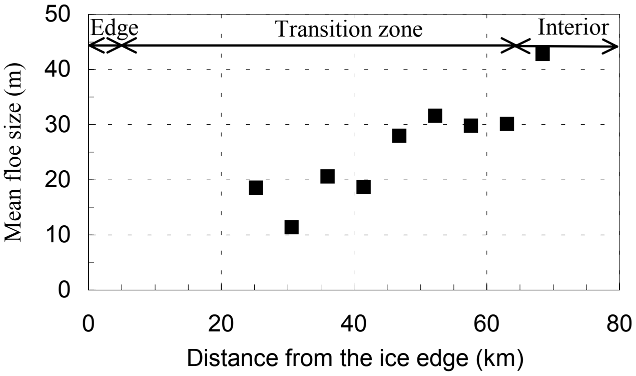


Figure 2.6 Increase of mean floe size with distance normal to the ice edge (Løset et al.., 1997).

Ridges

Ice pressure ridges are usually formed during the deformation of floating sea ice covers. They are either developed from first-year or multi-year ice, or a combination of the two types of ice. In general, data on pressure ridges from the Barents Sea are very sparse.

In 1980, extensive investigations were made from the Swedish icebreaker 'Ymer'. The ice surface topography was profiled by using a laser mounted on the bridge of icebreaker 'Ymer'. Using a cut-off height of 1.0 m, a mean density as low as 2.1 sails per km was recorded with a mean sail height of 1.34 m. Less than 1.2 % of the ridges exceeded 3.0 m in sail height (Løset *et al.,* 1997).

It was reported (Overgaard *et al.,* 1983) that the ice extent in the summer of 1980 was close to the 1971-1980 average, but more ice than normal occurred in the eastern part. During late June that year, much ice had drifted into the Barents Sea from the Arctic Ocean. The ice was about 90% first-year during this expedition in the Barents Sea. The ice concentration varied greatly, with large areas of diffuse ice cover. North of the line connecting Spitsbergen, Kvitøya and Franz Josef Land, the ice concentration was above 8/10 and multi-year ice was dominant. The mean floe thickness in the Barents Sea was estimated at 0.9-1.2 m. North of the line, where multi-year ice became dominant; the average thickness exceeded 1.5-2 m.

2.2.2 Ice Conditions in the Pechora Sea

The existence of first-year ice of local origin is one of the characteristic features of the Pechora Sea. Ice drifts from the Kara Sea through the Kara Gate and from the White Sea through the Pomorsky Strait into the eastern part of the Pechora Sea only sporadically.

The ice period lasts from the end of October/mid November until the end of July/early August (Mironov *et al*., 1994; Gorshkov and Faleev, 1980). The ice conditions in the eastern part of the Pechora Sea are more severe than in the western part. In particular, the average duration of the ice season in the western part is 185 days, while in the east it is 240 days (maximum 300 days). The most extensive ice cover is observed in March-April, when 10/10 of the sea surface is covered with ice (Spichkin and Egorov, 1995).

Ice formation

There is a great scatter in the times of ice freeze and melt/retreat. The ice-free period can vary from 0 to 130 days. For instance, the ice-free period for the Prirazlomnoye Field is about 110 days (Mironov *et al.*, 1996). Histograms of the dates of ice clearance in the area and associated dates of ice formation as well as ice-free duration in the Pechora Sea are shown in figure 2.7. Four periods of long and four periods of short duration of ice cover were observed during the last 54 years. Three significantly different ice zones form in the Pechora Sea: land fast, floating (drift ice) and intermediate (shear zone), where drift ice interacts with fast ice.

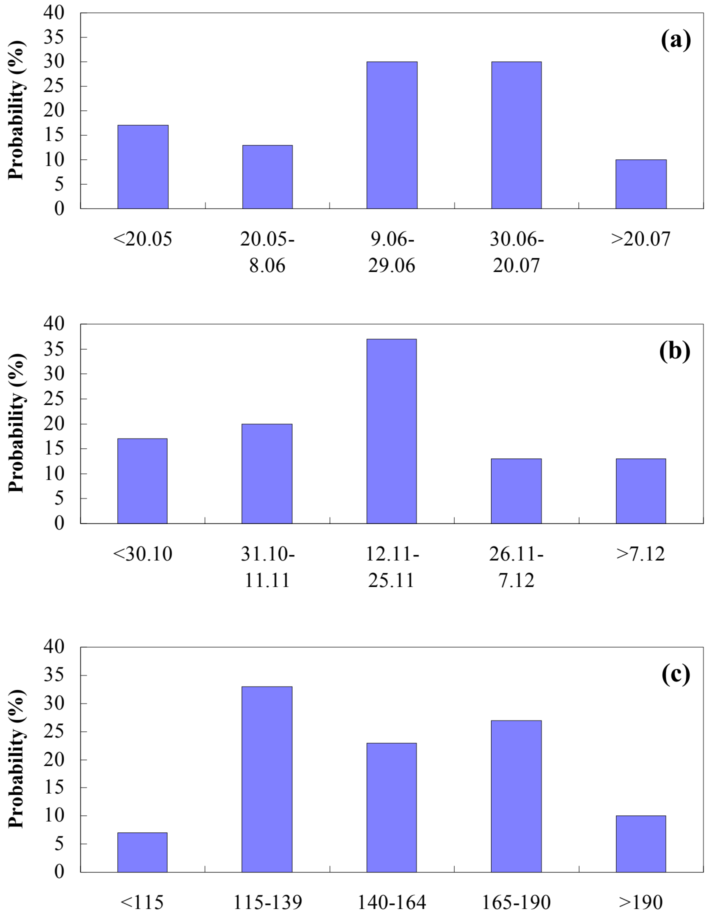


Figure 2.7 Histograms of dates of a) ice clearance, b) ice formation, and c) ice free days in the Pechora Sea (after Mironov et al., 1996)

Landfast ice

The landfast ice zone during the extreme years extends 10-15 km offshore, reaching depths at 12-15 m. The fast ice formation lasts until the end of February, fracturing starts in April-May in the western part of the sea and in the end of June - in the eastern part. The same trend yields zones located closer to the external fast ice boundary. In particular, in the Prirazlomnoe Field, steady fast ice formation is observed in the middle of December, leaving the area in the last part of June (Mironov et al., 1994).

Fast ice is not steady, and fracturing occurs very often during winter. This may lead to the formation of hummock fields with as much as 60-80 % of the sea surface being covered by ridges. The level ice thickness typically reaches 0.8-1.1 m. In the boundary of land fast and drift ice zones intensive hummocking takes place. Then, hummock fields and grounded ridges (stamukhas) are formed. Grounded ridges shield fast ice and protect it from destruction.

Drift ice

Wind and current (including tidal currents) cause ice movement. The prevailing drift direction in the winter is from the north, while drift from the west and SW prevails in the spring. Table 2.2 presents ice drift speeds in the Pechora Sea (Gorshkov and Faleev, 1980; USSR, 1986a; Zubakin *et al.*, 1987). When including currents and waves, the drift speed will normally be higher.

Table 2.2 Ice drift speeds in the Pechora Sea.

Region	Ice drift speed due to wind (m/s)	
	Average	Maximum
East	0.09	0.6
West	0.15	1.0

Ice thickness

The maximum average thickness of the sea ice in the eastern part of the Pechora Sea is 1.1 m, but the absolute maximum amounts to 1.6 m (Riska, 1995). Fig. 2.13 shows the probability distribution function of ice thickness for April (the month with maximum ice thickness). Formation of rafted ice at a thickness up to 2.5 m is considered to be possible in the conditions of dynamic interaction of ice fields, but the probability of such phenomena is not defined. In the majority of cases, the area of drift ice fields is approximately 0.2-4 km^2 but sometimes ice floes with area more than 78 km^2 can be found (Golovin et al., 1996).

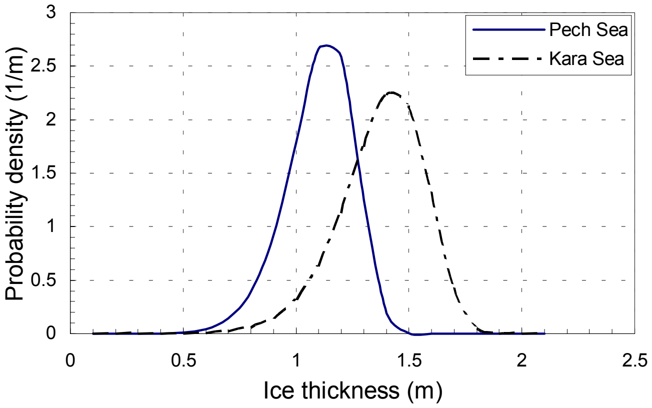


Figure 2.13 Probability distribution of ice thickness in the Pechora and Kara Seas (April)

Shear zone

This zone is situated between the land fast and the drift ice zones, and is characterised by the most intensive ice field interactions. Significant amounts of ridges, hummocks and stamukhas are formed in the shear zone. The width of the zone can vary from some hundred metres to kilometres.

Ridges

The frequency of ice ridges (ridge density) increases from the shore to the external fast ice boundary and from the west to the east. In the drift ice zone, the amount of ridges decreases with increasing distance from the shear zone. In the Varandey headland region, the ridging intensity (sea surface covered by hummocks) in February can reach 60-80 %, and in April, 80-100% (Romanov, 1993). In the landfast ice zone, the ridging intensity can be equal to 60-80% and in some local areas, a few kilometres long, up to 100% (total).

In the western part of the Pechora Sea (the north Kolguyev region) the ridging intensity is approximately 20-40% on average, but can reach 60-80% in the fields of maximum compacting. The ridges of the area consist of blocks 0.3-0.6 m thick (sometimes up to 1.1 m) and 2-4 m long. The sail height is in the range of 0.5 to 2.5 m in 80 % of the cases, while in 10 % of the occasions it exceeds 2.5 m. The maximum ridge height of 4.6 m was observed in the southern part of the Pechora Sea (Golovin *et al.*, 1996). The consolidated ridge layer thickness is twice (according to some sources 2.5 times) as large as that for level ice thickness. On the other hand, some authors affirm that ridge consolidation in the winter is very low (Spichkin and Egorov, 1995). The ridge keel depth in the Pechora Sea is on the average up to 3-6 m, but can sometimes reach 12 m and more.

Grounded hummocks (stamukhas)
Grounded hummocks usually form at the edge of the fast ice. They are located at water depths of 7-15 m. As mentioned by Spichkin & Egorov (1995) and Losev & Gorbunov (1977) stamukhas were not observed at water depths exceeding 20 m. Very often, stamukhas form a chain at the same place from year to year. In the Pechora Sea they are located mainly in the vicinity of the Matveev and Dolgy Islands and along the southern extremity of Novaya Zemlya.
Stamukhas consist mostly of ice blocks that are not consolidated. Their porosity is 30-35 %. The sail height can reach 7-12 m while the length can be hundreds of metres. The prevailing length is 30-150 m.

2.2.3 Summary of ice conditions in the Barents Sea and Pechora Sea

From the description of ice conditions in the Barents Sea and the Pechora Sea the major conclusions are as followed:

- The most common type of ice in the Barents Sea is first-year ice. The ice thickness can be up to 2 m for undeformed first-year ice and 3-5 m for multi-year ice. In general, multi-year ice floes are observed on several occasions but rather seldom south of Hopen Island.

- The landfast ice zone in the Pechora Sea may extend 10-15 km offshore, reaching depths of 12-15 m. The average drift ice speed due to wind in the Pechora Sea is 0.09 m/s in the east and 0.15 m/s in the west, with maximum values of 0.6 m/s and 1.0 m/s, respectively.

- The maximum average level ice thickness of the sea ice in the eastern part of the Pechora Sea is 1.1 m, but the absolute maximum is 1.6 m. The frequency of ice ridges increases from the shore to the external fast ice boundary and from the west to the east.

- The ridges in the Pechora Sea consist of blocks 0.3-0.6 m thick (sometimes up to 1.1 m) and 2-4 m long. The sail height is in the range of 0.5 to 2.5 m in 80 % of the cases, while in 10 % of the occasions it exceeds 2.5 m.

3 Properties of transported oils

The oils transported from the Varandey area to Murmansk have at present two main sources, oil loaded at the Varandey terminal and oil shipped from the Kolguyev Island. In the near future it is also planned shipping from the Prirazlomnoe field, where the oil commercial production is expected to start during 2006 (Shavykin *et al*., 2005).
Information about the weathering properties of the oils is crucial for an efficient oil spill response. The weathering properties of different oil types being shipped from the Varandey area to Murmansk are not well known. However, some physical-chemical data have been given for the oils in question (Singsaas, 2005). Table 3.1 shows a tentative classification of three oil qualities from Timan-Pechora oil province, where oils from Kolguyev and Varandey are being shipped to Murmansk while oil from Ukhtinsk is exported through the Yaroslaval pipeline.

Table 3.1 Tentative classifications of three oil qualities for export from the province of Timan-Pechora

Oil quality	Export	Total export 2002, mill. ton	Density, g/cm^3	Sulphur, %	Tentative classification
Kolguyev	Western Europe, shipment	0.1	0.78	0.19	Light paraffinic oil, low level of sulphur
Varandey	Western Europe, shipment	0.2	0.90	1.98	Asphaltenic, high level of sulphur
Ukhtinsk	Yaroslaval, pipeline	10.5	0.85	0.82	Light paraffinic oil, Medium level of sulphur

3.1 Oil transported from the Varandey terminal

The port of Varandey has a storage capacity of 415 000 m^3 of oil. The oil is pumped from the storage facilities to an offshore loading facility by a 4.8 kilometres long underwater pipeline with a capacity of 5000 tons of oil per hour. The oil is delivered to the terminal from the northern oil fields of the Nenets Autonomous Region via a local pipeline system. Ice-reinforced tankers of 20000 tons deadweight ship the oil. In 2004, the Varandey oil terminal shipped 560 000 tons of oil to the Kola Bay.

The transported oils from the Varandey terminal to Murmansk consist of a blend from different oils deposits. The oil properties based on their physical and chemical composition can vary from one deposit to another. The properties of the stored oils can therefore change both in a long and short terms manner. Due to oil spill response techniques it is important to provide sufficient analytical information about the blends preferably analyzed over time. Weathering studies should be carried out for transported oils to get knowledge how the properties of oils will change over a time range. Weathering is defined as all changes in oil composition which take place after a spillage, including evaporation, dissolution, emulsification, oxidation and biological decomposition. Even if the physical and chemical composition of the blend can vary, it may be possible over a time period to get average values, which can further be used as input to model tools.

3.2 Characteristics of crude oils from Varandey

As a part of a previous project performed by SINTEF, physical and chemical characteristics of three Russian crudes from the Varandey area have been supplied by Dr. Semanov at CNIIMF in 2003. The models used by SINTEF require weathering data of the oils to give best possible predictions in oil spill response analysis. Since weathering data were not available for these oils, it was decided to compare physical-chemical data like density, viscosity (20 ºC), pour point, asphaltenes, paraffin's (wax), in addition to true boiling point curve (TBP) for these oils with similar data for Norwegian crude oils. The objective was to identify a Norwegian crude oil with comparable data and use the weathering data for the Norwegian crude oil as input to the models. Tables 3.2 to 3.4 show the similarities in physical-chemical properties and evaporation between the Norwegian crude oil (Troll) and the oils from the Varandey area. The Russian crude oils have lower content of paraffinic compounds compared to the Troll crude oil, and have at the same time a higher content of asphaltenes compared to the Norwegian crude. Figure 3.1 visualize the similarities in the true boiling point curve for the oils. The extrapolation of TBP curve of the Varandey oils indicates that these oils follow the TBP curve of the Troll crude oil in a fairly good manner. The analytical match between the Troll crude oil and the three oil types from the Varandey area was regarded to be reliable to allow weathering data for the Troll oil to be used as input to the models when performing oil spill response analysis by the SINTEF models (Johansen *et al.*, 2005). Oil spill response analysis is further described in chapter 4.

Table 3.2 Physical and chemical properties of Troll crude and three crude oils from the Varandey area

Physical and chemical characteristic	Number of oil well			**Troll**
	3	**4**	**9**	
Density B at 20°C, g/cm^3	0.8944	0.8971	0.9071	**0.893**
Viscosity at 20°C, mm^2/c	26.23	28.19	40.75	**27 (13°C)**
Viscosity at 50°C, mm^2/c	11.86	10.26	12.22	
Oil chilling (pour) temperature, °C	-49	-47	-45	**-39**
Flash point, closed cup. °C	-37	-37	8	**-**
Molecular weight	249	240	251	**-**
Water, %	traces	1.4	2.6	**-**
Tars, %	16.41	14.16	13.21	**-**
Asphaltens, %	4.40	4.26	4.47	**0.2**
Paraffins (wax), %	0.84	0.50	0.41	**2.0**
Melting temperature of paraffins, °C	57.5	56	66.6	**-**
Pressure of saturated vapor, mm.	285	200	18.5	**-**

Table 3.3 True boiling point curves for Varandey crude oils

Well no.	**Sublimated (vol %.) by temperature, °C**												
	100	**120**	**140**	**150**	**160**	**180**	**200**	**220**	**240**	**250**	**260**	**280**	**300**
3	1.2	2.7	5	7	8	11.5	14.5	18	21.5	23	25	29.5	40
4	1.6	2.4	5	6	7,5	10	13	16.5	19	21.5	24.5	28	38
9	1	1.6	2.8	4	4.8	9	12	15	18	21	23	29	37

Table 3.4 True boiling point curve for Norwegian Troll crude oil

Oil type	**Sublimated (vol %.) by temperature, °C**									
	65	**90**	**150**	**180**	**240**	**320**	**375**	**420**	**525**	**565**
Troll	1.4	3	9.6	13.8	24.5	45.7	57.2	63.6	83.8	88

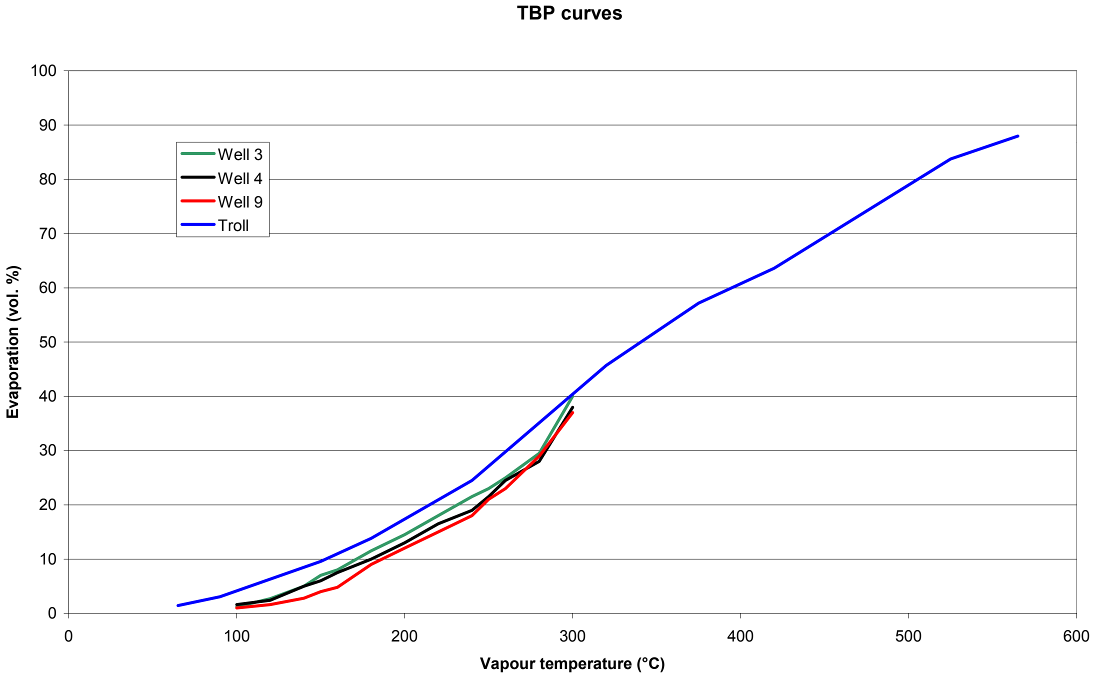


Figure 3.1 Comparison of true boiling point curve for the Norwegian Troll crude oil and the three Varandey crude oils from different wells

4 Oil spill response analysis

Oil drift simulation and oil spill response analysis are important tools as a basis for oil spill contingency planning in the Arctic region. The stochastic simulations were performed by using a modelling tool called OSCAR (Oil Spill Contingency And Response) model system. This modelling tool is a 3-dimensional model running under a Windows operating system (Reed et al, 1995 a, b). The OSCAR model tool is developed by SINTEF and is one of several models operating within the Marine Environmental Modelling Workbench (MEMW). The model allows multiple release sites, each with a specified beginning and end to the release. This allows time-variable releases at a given location, as well as throughout the study area. Both oil spill scenarios and stochastic scenarios with variable start times can be calculated. The model has been used to perform oil spill response analyses for two given sites along the shipping route from Varandey to Murmansk (Johansen et al, 2005).

Different possible oil spill response options were simulated based on the offshore oil recovery system standardized by the Norwegian Clean Seas Association for Operating Companies (NOFO). The different oil response options considered in the present study represent combinations of two or more of these systems, each with different response times, i.e. sum of mobilization and transport times. The response options used for the two spill locations are summarized in Table 4.1.

The two hypothetical spill sites were:

- Western spill site: Murmansk Fjord: E 33^{o} 24’ 00”, N 69^{o} 27’ 00”
- Eastern spill site: Pechora Sea: E 53^{o} 41’ 30”, N 70^{o} 07’ 30”

At both locations, the oil spills are presumed to amount to 10 000 m^3, released over a 10 hour period. The spilled oil is represented by the Troll crude oil from the North Sea with fresh oil properties similar to the Varandey crude oils.

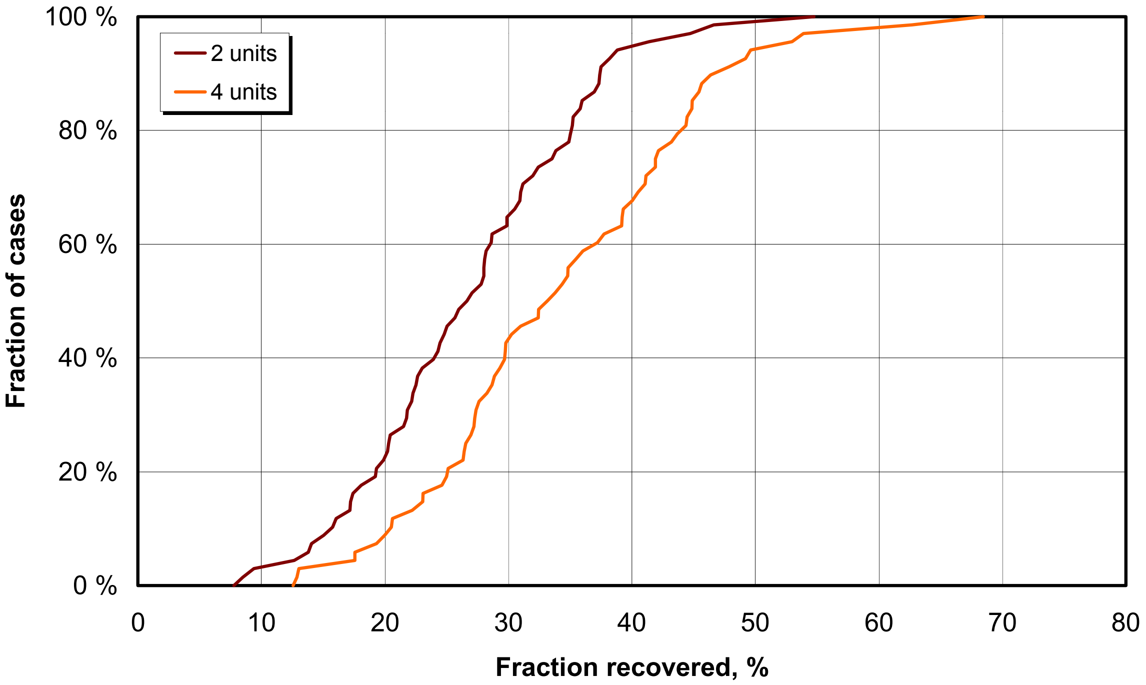
Table 4.1 Oil spill response options in Murmansk Fjord and Pechora Sea

	Murmansk Fjord	*Pechora Sea*
1. Base case	- One system mobilized from an oil response base in Murmansk Fjord with 6 hours response time. - One system from Norway with 18 hours response time.	Two systems mobilized from an oil response base near the Varandey oil terminal with 6 and 12-hour response times.
2. Strengthened response	Base case + one additional system from Murmansk with 12 hours response time.	Base case + one system from Murmansk with 40 hours response time.
3. Maximum response	Strengthened response + one additional system from Norway with 30 hours response time.	Strengthened response + one additional system from Murmansk with 46 hours response time.

4.1 Western spill site: Murmansk Fjord

Figure 4.1 shows the statistical distribution of recovered oil and stranded oil for two response options (the base case option and the maximum response option, refers to Table 4.1). The distribution of stranded oil with no response is given for reference. The results show that the maximum response option causes a significant, but less than proportional increase in the amounts of oil recovered, compared with the base case option. However, the results also show that the maximum response effort gives a rather limited reduction in stranded oil, compared to the base case option.

This trend is partly caused by the fact that the spill location is located close to the shoreline. As a result, significant amounts of oil may reach the shoreline before arrival of the oil response systems. However, the spill scenario also implies release of large amounts of oil in a comparatively short time (10 000 m^3 in 10 hours). As no realistic response option can cope with such a release in real time, the response operation must continue after the end of the spill. By using NOFO's method for calculating system capacity, we find that four NOFO systems might theoretically recover such a spill in about 2 days. In theory, increasing the number of systems and reducing the response time for all systems to a minimum can obtain a significant improvement in the response performance, but these options will be limited by practical considerations.



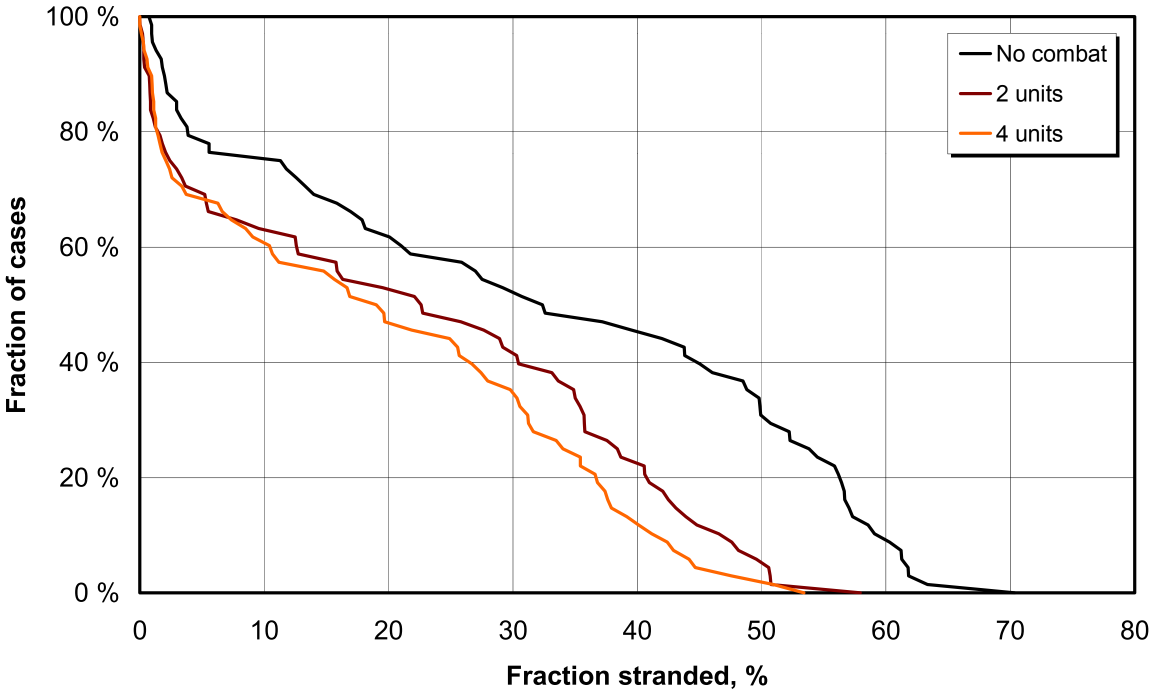


Figure 4.1 Statistical distribution of recovered oil (top) and stranded oil (bottom) for the Murmansk Fjord autumn scenario. The top graph shows results for the base case response option (2 units), and the maximum response option (4 units). The bottom graph compares stranded oil for the same response options with stranded oil with no response.

4.2 Eastern spill site: Pechora Sea

Figure 4.2 shows the results from the statistical simulations and figure 4.3 the results from the single scenario simulations for the eastern spill site (Pechora Sea). For this location, traditional oil response will be limited to the ice-free season, and oil recovery simulations have only been made for autumn. Today we do not have sufficient knowledge about the effectiveness of different oil spill response options to perform similar simulations for ice-infested waters. Figure 4.2 shows that use of the base case response option (2 units) gives a significant increase in recovered oil and a similar reduction in the stranded amounts of oil.

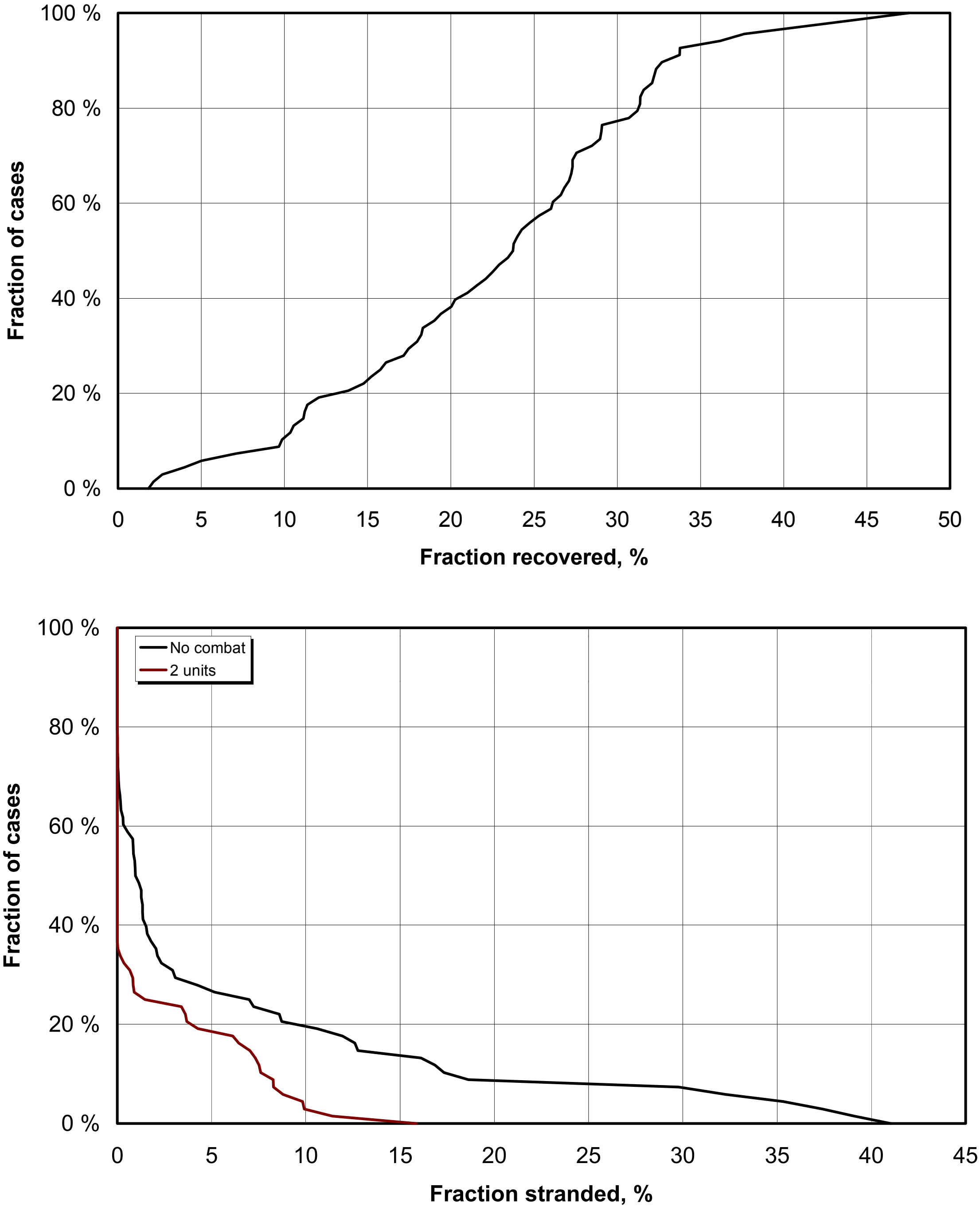
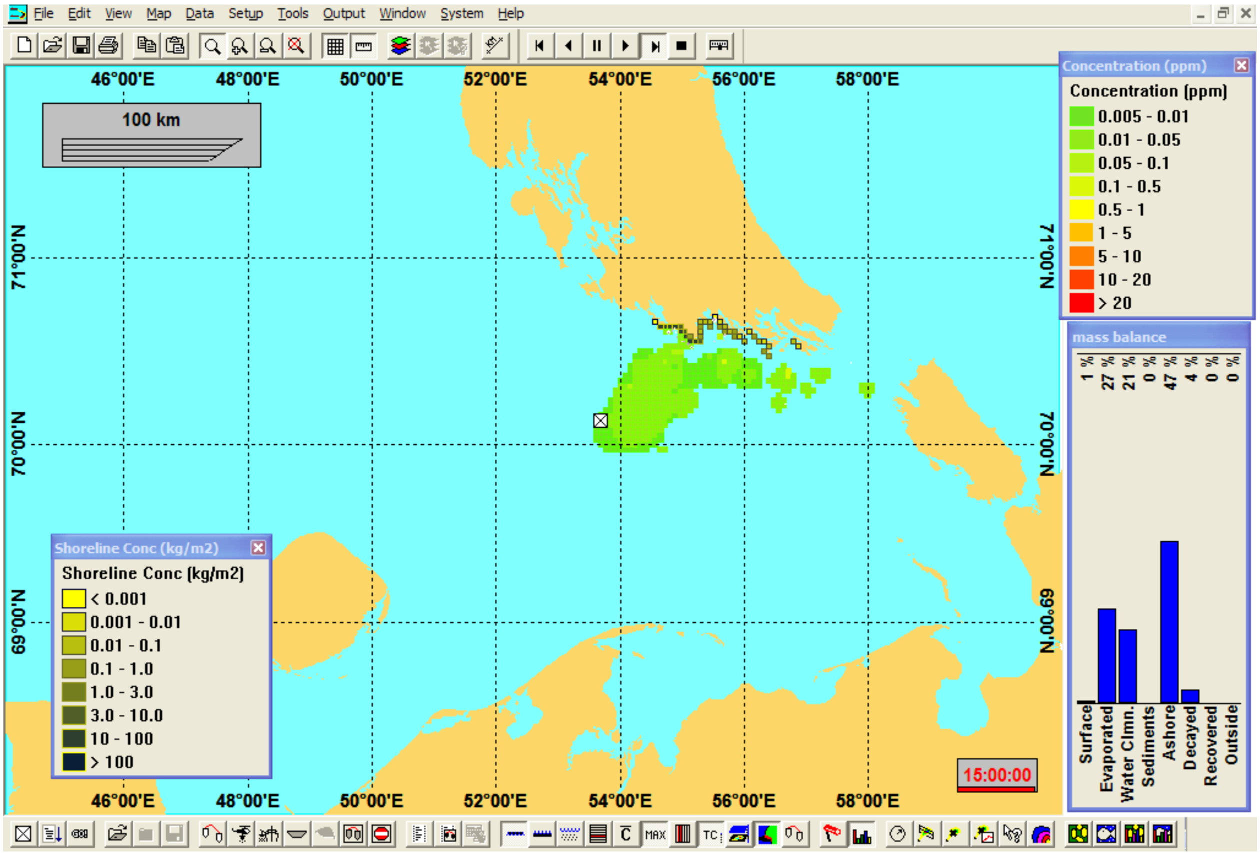


Figure 4.2 Statistical distribution of recovered oil (top) and stranded oil (bottom) for the Pechora Sea autumn scenario. The top graph shows results for the base case response option (2 units), The bottom graph compares stranded oil for the same response option with stranded oil with no response.



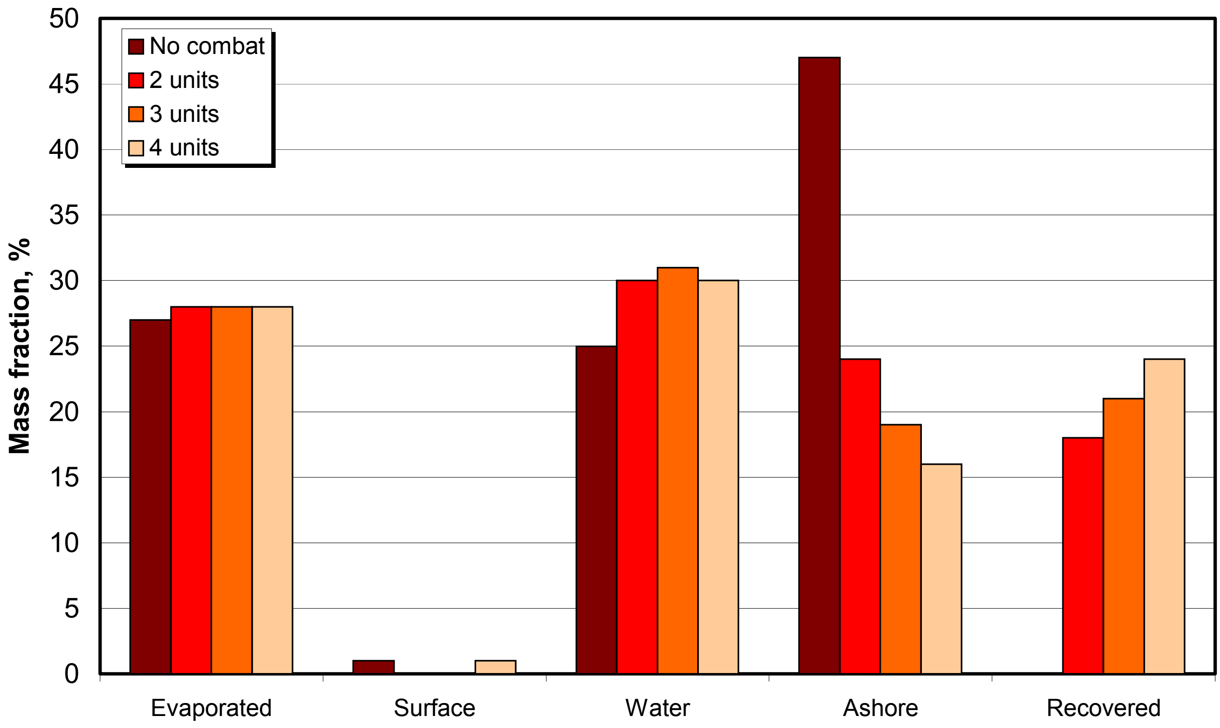


Figure 4.3 *Results of single scenario simulations for the eastern spill site. The map (top) shows the situation after 15 days with the no response option, while the bar chart compares the mass balance for this case and the other response options.*

For this spill site, single scenario simulations have been performed to demonstrate the possible gain of an increasing response effort. The simulations were made for the oil drift scenario with maximum amounts of stranded oil. The map in Figure 4.4 shows the situation after 15 days with no oil spill response, while the bar chart on the same figure shows the mass balance for the different response options compared with the mass balance for the no response case. The bar chart indicates that significant reductions in stranded amounts of oil can be obtained by strengthened response efforts. This trend is due to the fact that the spill takes place at a considerable distance from the shore, i.e. 70 km, with a drift time to shore of more than 2 days, i.e. 60 hours.

4.3 Summary of oil spill response analysis

The simulations performed indicate that the oil spill response used is more effective for the Pechora Sea spill site compared to the Murmansk Fjord site. This is mainly due to that the Pechora Sea site has a considerably longer distance to the shore and that significant amounts of oil could be recovered before it reached the shorelines. For both these spill scenarios oil spill response equipment capable of operating in rough seas is required. The equipment should also have the capacity to recover large amounts of oil per time unit due to the large oil spill. However, much of the shipping route from Varandey to Murmansk must be considered as remote areas with long sailing time from potential response bases and the response time will be a critical factor for an effective combat operation.

In the winter time with sea ice present in the Varandey area and parts of the sailing route, an effective oil spill response will be much more challenging. Due to the presence of ice, drift and spreading of the oil and the possibility for drift of oil to the shorelines will be considerably reduced compared to open water (figure 4.4). At the same time the use of conventional oil spill response equipment and tactics, as used in these simulations, will be much more difficult. This means that alternative response methods and strategies must be evaluated. Recommendation for oil spill response strategies is further discussed in chapter 6, herein. In any case the effectiveness of an oil spill response action in ice-infested waters will be lower compared to open waters, but oil spill response action will also be dependant on the ice conditions and the prevailing weather conditions.

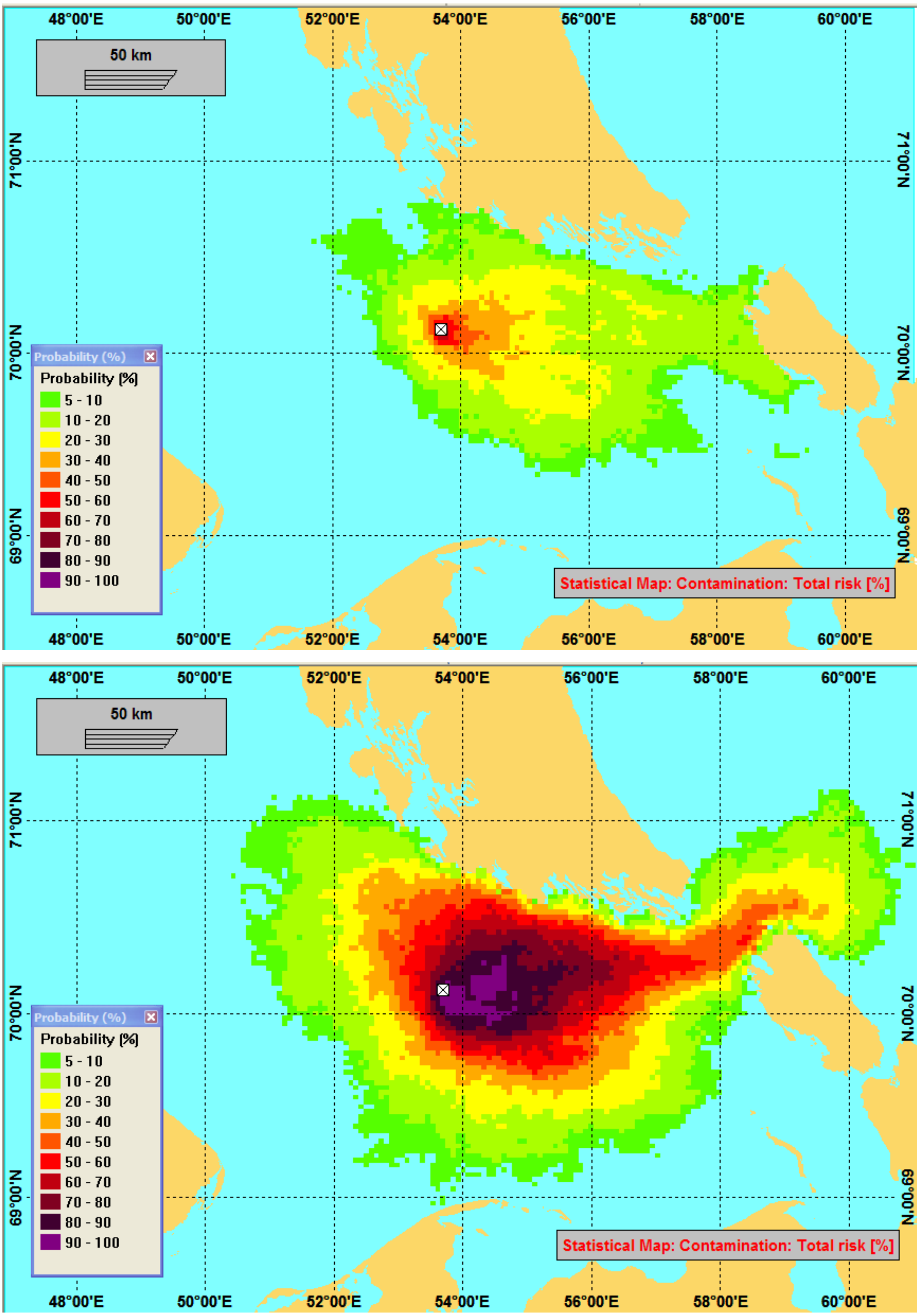


Figure 4.4 Statistical oil drift simulations for the Pechora Sea spill site. The maps show the area of influence for the spring scenario (top), and the autumn scenario (bottom). The marked difference between the spring and autumn simulations are mainly due to the presence of sea ice in the spring.

5 Oil spill contingency resources

The oil spill contingency resources along the shipping route from Varandey to Murmansk are located in the transshipment port in Murmansk, the loading terminals in Varandey and Kolguyev Island, and in addition combating equipments stored at the icebreakers. The knowledge about the availability of oil spill response resources is an important task to predict the response time in different oil spill scenarios. The choice of oil spill response techniques are highly depending on the conditions of the oil spill, which also includes the accessibility to the spill either from offshore or from the landside and the environmental conditions (referred in chapter 2). In addition, it is important to focus on required number of trained equipment operators and the availability of maintenance personnel in accordance to an operational plan.

The operation controls headquarter of the Murmansk region (OCH) is responsible for organization of accidental oil spill response and coordination of oil spill response (OSR) forces and means at sea. Murmansk Basin Emergency and Salvage Department (MBESD) is a state enterprise under the Ministry of Transportation of Russia and are responsible for two tasks in the sea: 1) rescue and salvage operations, and 2) oil spill response. MBESD implements oil spill prevention and response activities during reloading and transshipment.

Oil spill prevention and response services at the Varandey terminal and the oil shipment facilities of the Kolguyev terminal are provided by MBESD. The Murmansk sea port is today a huge transportation unit and during the last two years, three (the fourth are under building) off-shore oil transshipment terminals (called RPK) were installed at the Kola Bay built for shipping oil export (Bambulyak *et al.*, 2005). MBESD also provide oil spill prevention and response services for the offshore oil transshipment terminals at the Kola Bay (RPK-1, constructed by Murmansk Shipping Company, RPK-2 White Sea Services and RPK-3 Belokamenka of Rosneft). Today, the MBESD specialized vessel “Agat” is on watch during each oil shipment in the summer season, while in the winter season spill prevention equipments is located on the icebreaker “Kapitan Nikolajev” which is assigned to assists offshore oil shipment.

Tables 5.1 to 5.5 gives an overview of existing crafts and equipments of the organizations involved in OSR, Murmansk. It should be emphasised that the tables are summaries of the original table, which refers to “Oil, spill contingency plan for the Murmansk oblast, St.Petersburg 2004”. The information listed herein, are focused on a short overview of descriptions and capacities of equipments and vessels stored at the Murmansk seaport.

Table 5.1 List of vessels in Murmansk seaport – floating facilities

Vessels of MBASU in Murmansk sea port	Description
M/S Umka	Sweep and recover of oil by booms and skimmers, pumping oil from damage ship
MS Svetlomor	Sweep and recover of oil by booms and skimmers, pumping oil from damage ship, oil recovery
BD Marcap	Speed boom deployer
VOSS Agat	Sweep and recover of oil by booms and skimmers, pumping oil from damage ship
Bot"Mob-20"	
Inflatable "Achiles type"	

MBSAU: Murmansk Salvage and Towage Company (analogous to MBESD)

Table 5.2 List of oil spill response equipments in Murmansk

OSR equipment of MBASU in Murmansk	Capacity m^3/h
Booms "Ocean 2000"	
Boom "Expandy"	
Rosweep	
Pump Framo (2 typer)	1000 and 450
Skimmer "Walosep W-2"	45
Skimmer "Desimi250"	70
Foxtail VAB 4-9	30
Foxtail VAB 2-6	9
Submersed pump "Flugt"	100
Washing set	
Separator "Roset"	

MBSAU: Murmansk Salvage and Towage Company (analogous to MBESD)

Table 5.3 List of vessels in Murmansk seaport

Floating vessels of MASKO[*)] in Murmansk sea port	Capacity m^3
Oil skimmer"HMC-15"	18
Tanker "Damansky"	1080
Tanker "Dnepr"	1200
Tanker "Don"	1200

[*)] **MASKO** Company Ltd was created on June 1, 1995. **MASKO**, is a company which operates the service vessels at the Port of Murmansk

Table 5.4 Overview of equipments – Navy

Equipments of Navy
Helicopter KA-27 (MI-8)
Tanker
Tag, Salvage ship
Oil skimmer MUS-558
Oil skimmer MUS-467
Boat Ecopatrul-1412
Fireboat 14611
Booms 1000m
Trucks
Fire tanks

Table 5.5 Equipments of other enterprises

Equipments of other enterprises	Owner	Quantity	Function
Supplier ship "Neftegas" type	Arctimornefterasvedka	4	Deliver of equipments, work in order
Fish boats	Traflot	2	Boom deployment, work in order
Cargo ships	Murmansk shipping compan	2	Deliver of equipments
Oil skimmer	Murmansk fishing port	2	Boom 500 m, work in order
Oil skimmer	White sea oil base	1	Booms 1000m, work in order
Tags	Rosneftmurmansnefteprodu	4	Boom deployment, work in order. 1 t sobents on board

6 Recommendations for oil spill response strategies

Severe winter conditions represents a challenge to oil spill response such as low temperature, sea ice, lack of daylight and the difficultness of detection, monitoring and surveillance of oil spills. Within the all year round shipping route from the loading terminal in Varandey to the transhipment terminal at Murmansk there are areas with long distances to the mainland which implies longer sailing time for mobilization, transportation as well as support from aircraft stationed on-shore. Long distance to mainland is more inconvenient and can possible increase the oil spill preparedness and the logistic costs, which requires more carefully planning and organization.

The main focus of a contingency planning should be concerned to the following subjects:

- Response time
- Oil spill response techniques (mechanical recovery, *in-situ* burning, dispersant, bioremediation)
- Combating equipments (booms, skimmer etc.)
- Training (personnel, mobilization and equipment technology)
- Environmental risk analysis
- Mapping natural resources (include use of Net Environmental Benefit Analysis (NEBA) and oil spill risk assessment tools)
- Fate and behaviour of transported oil (properties, type of oil products, amount of oil transported)
- Identifying lack of knowledge concerning the issuses stated above to provide sufficient knowledge which subjects need further documentations/research, improvement and/or developments. Oil spill response concepts in Arctic and ice-infested waters are e.g. described in Singsaas *et al.*, 2005.

The obtained overall knowledge results in an “operational tool” which improves the possibility to implement a robust contingency plan for operations in open water, ice-infested water and in coastal areas.

Environmental risk analysis such as Oil spill risk assessment and Net Environmental Benefit Analysis (NEBA) should be used in oil spill contingency planning. These analyses are essential within the planning process for instance at the areas around sea port and at oil handling facilities (e.g. loading terminals) to carry out the optimum response options in these areas. NEBA is a methodology for comparing and ranking the net environmental benefit associated with multiple management alternatives, and is a useful tool to evaluate applied response technologies in response to an oil spill, this in accordance to evaluate the benefits and risk of utilize dispersant, in-situ burning and different cleanup technologies. In addition, these analyses can be used to determine the environmental sensitive areas.

6.1 Climatic conditions and infrastructure

Climatic conditions will have a considerable influence upon the effectiveness of an oil spill response. As a part of the “A tudy of consequences of year –round petroleum activity in the area of Lofoten and Barents Sea” (Singsaas *et al.*, 2005), the influence of climatic conditions and infrastructure on the oil spill response in the northern and Arctic areas was discussed.

Wind and waves

Wind and wave statistics for northern areas including the Barents Sea indicate that the conditions both in the summer and winter season is approximately similar to the North Sea or even better. This means that the effectiveness for the oil spill response equipment and the possibility to perform combat actions is not reduced compared to the North Sea. If we define an "upper limit" on for instance 15 m/s wind speed and/or 4 m significant wave height for use of mechanical recovery equipment, this will give a "time window" for use based on wind and wave statistics as indicated in Table 6.1, which is comparable for instance to the North Sea.

Table 6.1 "Time window" for use of mechanical recovery in the Barents Sea as a function of wind and wave statistics based defined "upper limits".

Area	Month	"Upper limit" 15 m/s wind speed	"Upper limit" 4 m significant wave height
Barents Sea	June	Ca. 98 % of the time	Ca. 98 % of the time
	January	Ca. 85 % of the time	Ca. 72 % of the time

Darkness

The daylight conditions in the Barents Sea are somewhat poorer than in the North Sea in the winter season, primarily the months from November to February. In the summer season the conditions is better than further south, with midnight sun from May to July. With the present oil spill response there are limitations with respect to operations in darkness. The major challenge is to detect the oil and collect it effectively in a boom and there is a need to develop equipment for better detection of oil spill in darkness and low visibility.

Low temperatures and icing/freezing

Icing of vessels due to low temperatures and sea spray is well known for those who sail in the Barents Sea in the winter season. For the oil spill response it is icing of the oil spill response equipment and the human factor that contributes the major challenge connected to low temperatures and harsh weather. Pumping of high viscous emulsions due to a high degree of weathering and/or low temperatures can cause a problem. For hoses, pumps etc. that can be inactive for periods, freezing and ice creation can become a problem. Also systems for application of dispersants can be subjected to icing/freezing. The viscosity of the dispersant can also increase under low temperatures, changing the spraying pattern or even plugging the nozzles. It is assumed, however, that many of the challenges connected to use of oil spill response equipment during low temperatures can be solved by relative simple practical means.

Infrastructure

To be able to plan and perform an effective oil spill response knowledge and information about the infrastructure in the area/region is very important. It is also important that the oil spill contingency is based on the possibilities and limitations that the prevailing infrastructure gives.

Compared to the areas further south, for instance the North Sea area, the infrastructure in the Barents Sea region is less accessible with long distances from central ports/airports to oil activities/transportation and remote areas. Short response time is often important in oil spill contingency and hence, an accessible infrastructure is important.

6.2 Oil spill response in open waters

For an effective oil spill response operation in the open sea it is necessary to use equipment dedicated to operate under rough weather conditions. This means large vessels to be used as a working platform for the equipment and booms, skimmers and other kind of equipment capable of operating in rough seas. In more sheltered areas like e.g. the Kola Bay, less robust equipment dedicated to be utilized closer to shorelines with reduced wave activity can be used. The preferred response options to oil spills in open waters offshore is mechanical recovery in combination with dispersants use. Dispersants could be used as an alternative to mechanical recovery for small oil spills and a supplement for larger oil spills.

6.2.1 Mechanical recovery

The Norwegian Clean Seas Association for Operating Companies (NOFO) is an oil spill response organization established by the operating companies on the Norwegian continental shelf. NOFO has 14 oil spill response systems and each system comprises a boom with a swath of approximately 180 m, referred as “A” in figure 6.1, towed by two vessels; a main vessel “C” and a towing vessel “D”. The maximum towing speed of the system is 1 knot. The *Transrec* weir skimmer “B” is connected to the main vessel via a buoyant hose. The nominal pump capacity of the *Transrec* skimmer is 350 m^3/h, but the effective skimming rate during oil recovery operations is presumed to be approximately half of this rate. The main vessel has a 1000 m^3 storage tank for recovered oil. The system is found to operate efficiently at sea states up to about 3 m significant wave height.

Figure 6.1 Offshore oil recovery system standardized by NOFO. A: Boom; B: Transrec skimmer; C: Main vessel; D: Towing vessel.

In case of an offshore oil spill in open water along the shipping route from Varandey to Murmansk it is recommended to use similar offshore recovery systems. The systems should be capable of operating under rough weather conditions and the recovery capacity should be large enough to handle fairly large oil spills.

In the oil spill response analysis performed (Johansen *et al.*, 2005) for a spill of 10 000 m^3 of oil at two locations, the outlet of the Murmansk Fjord and north-east of Kolguyev Island, 4 such systems were used as input to the analyses (refers to chapter 4). The analyses indicated good effect by use of these systems, but more important than the number of recovery systems seems to be short response time. Obvious place for storage of such systems are the Murmansk area, the Varandey area and Kolguyev Island. In the wintertime, when icebreakers assist the tanker, the icebreakers could form the working platform for such a system, to assure quick response time. However, the icebreakers are dependant on assisting vessel for towing the booms.

6.2.2 Use of dispersants

On the Norwegian continental shelf several oil companies are now including use of dispersants as part of their oil spill contingency. Dispersants can be used as an alternative to mechanical recovery for small oil spills and as a supplement for larger oil spills. The potential use of dispersants is based on a Net Environmental Benefit Analysis (NEBA), which is regularly done as part of the oil spill contingency planning.

The aim of using dispersants is to remove the oil spill from the sea surface to prevent the oil from damaging vulnerable biological resources like e.g. sea birds at sea or vulnerable resources along the shorelines. The concentration of hydrocarbons in the water column will increase by use of dispersants and there is a concern in many countries about the biological effects by use of dispersants. However, the initially high concentrations of dispersed oil and partially water-soluble oil components will be rapidly diluted to concentrations below those that cause negative effects on a wide variety of marine life. Dilution of the oil as small droplets in the water column will increase the biological degradation due to increased surface between oil and water where the microorganisms are active.

According to the Norwegian regulations for use of dispersants, effectiveness and potential environmental damage by use of dispersants shall be evaluated and documented before a dispersing action can take place. This contributes the internal control that dispersants are used within the frames outlined in the Oil Spill Response Plan.

A decision model for use or not use of dispersants has been worked out in Norway (e.g. Singsaas et al., 2005). The decision model is based on the following criteria:

1. Is natural dispersion already a dominating process?

2. Which biological resources are threatened by the oil spill, and how will the use of dispersants influence on these?

3. Can the dispersed oil be effectively diluted in the sea?

4. Will the effectiveness be reduced based on oil type and weathering degree?

5. Will the effectiveness be reduced due to low salinity (brackish water)?

6. Will the effectiveness be reduced due to bad weather conditions (wind/fog)?

7. Application equipment – how to apply the dispersant in a correct way?

8. Application equipment – is there sufficiently short response time and treatment capacity?

9. How will the effectiveness of the dispersant action be monitored?

10. When and to what criteria shall the dispersant action be terminated?

These criteria must be fulfilled in order to evaluate the use of ,dispersants in Norwegian waters. Today dispersants can be applied on an oil slick from three different working platforms:

- Aerial application from fixed-wing aircraft. Different systems are in operation. OSRL in Southampton (UK) has 200 tons of dispersants stored in Southampton and Shetland and uses a Hercules aircraft equipped with an ADDS-pack system for application.

- Aerial application by helicopter. In Norway an under sling bucket has been developed for application. This system requires that dispersant for reloading is stored close to the spill site (e.g. a production platform or a vessel) to avoid long flying distances.

- Boat application. Several systems are available. A newly developed system has been successfully tested by Hydro in Norway (figure 6.2). The advantage of such a system is that large amounts of dispersant can be stored on the vessel and normally the response time can be short.

Figure 6.2 Newly developed system for application of dispersants from a vessel.

It is recommended that the icebreakers assisting the oil tanker are equipped with application equipment and have some dispersant stored onboard. This will give a fast response and give a high degree of opportunity to combat small oil spills effectively. However, there is a lack about the effectiveness of use of dispersant in ice-infested water.

6.3 Oil spill response in ice-infested waters

Generally, oil spills in ice are far more complicated to combat compared to oil spills in open waters. Apart from the normally long distances from existing infrastructure, the oil is less accessible in ice-covered waters. The oil can be spilled on ice/snow, in open pools between ice floes, in open channels behind vessels or even under the ice as shown in figure 6.3. There are several challenges connected with oil spill response techniques of oils in ice and cold water, which are related to:

- Detection/ monitoring of oil
- Limited access to oil
- Increased oil viscosity
- Contamination of ice with oil/cleaning of ice
- Migration of oil in the ice
- Deflection of oil together with ice

- Limited flow of oil to recovery device
- Separation of oil from ice
- Winterization due to icing/freezing of equipment
- Strength considerations of equipment
- Personnel operating in cold environment

Traditional use of booms and skimmers can be difficult. However, there are also some advantages with oil spills in ice compared to open waters. The weathering rate is normally much slower for an oil spill in ice. This means that emulsification rate and hence viscosity increase may be slowed down resulting in an increased window of opportunity for use of most response techniques (e.g. the Marginal Ice Zone (MIZ) experiment in 1993, Brandvik *et al*., 2004). The spreading of oil will be normally also much slower resulting in a large oil film thickness that may be favourable for the oil spill response.

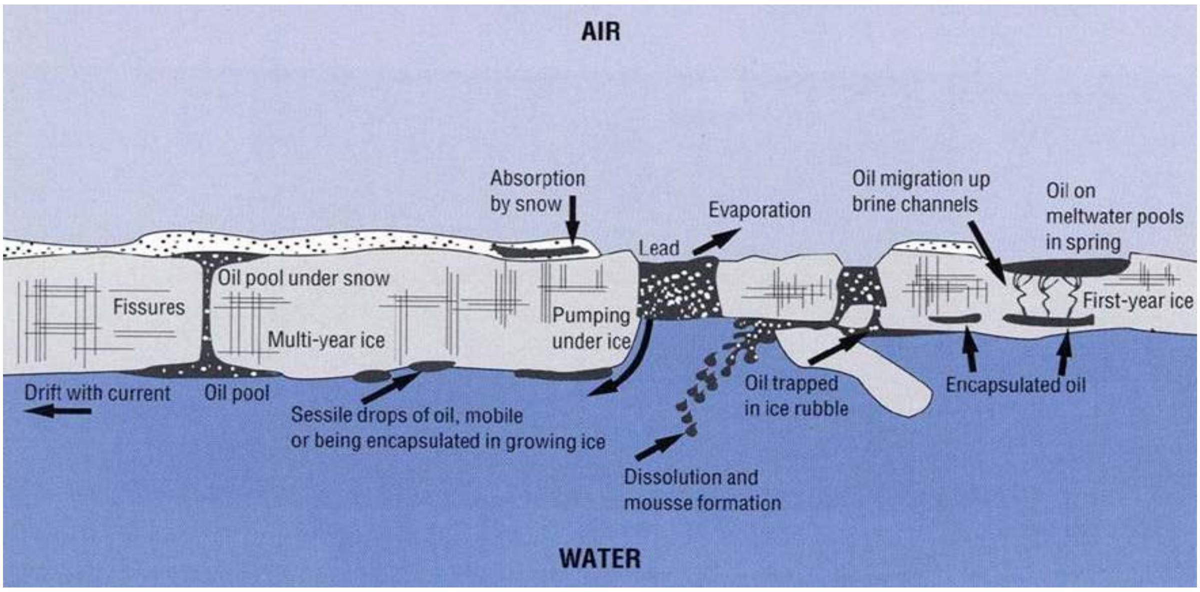


Figure 6.3 Potential oil spreading and behaviour in ice-infested waters.

The ice concentration can become a governing factor in making decisions about equipment selection. The ice can act as a natural containment in a variety of ice features such as floes, snow and ridge. In a case of a spill the oil can be located on ice, among ice floes and oil under ice, which also requires a different approach to the problem.

Table 6.2 gives an indication of expected operational limits of different response methods as a function of ice coverage. Few of these methods have actually been tested in ice-infested waters, so there are large uncertainties attended with the listed technologies. It should also be mentioned that there are major differences in capacity (e.g. amount oil removed per time unit) between the different methods.

Table 6.2 Indication of expected operational limits of different response methods as a function of ice coverage

		Ice coverage									
Response method	Open water	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	100 %
Mechanical recovery:											
- Traditional configuration (boom and skimmer)	━━	━━	━━	┅┅	┅┅						
- Use of skimmer from icebreaker			━━	━━	━━	━━	━━	━━	━━	┅┅	┅
- Newly developed concepts (Vibrating unit; MORICE)				━━	━━	━━	━━	━━	┅┅		
In-situ burning:											
- Use of fireproof booms	━━	━━	━━	┅┅							
- In-situ burning in dense ice				━━	━━	━━	━━	━━	━━	━━	┅┅
Dispersants:											
- Fixed-wing aircraft	━━	━━	┅┅								
- Helicopter	━━	━━	━━	━━	┅┅	┅┅	┅┅				
- Boat spraying arms	━━	━━	━┅	┅┅							
- Boat "spraying gun"	━━	━━	━━	┅┅	┅┅						

6.3.1 Working platform

Along the shipping route from Varandey to Murmansk the maximum ice coverage can typically extend from Varandey to approximately half the distance to Murmansk. Icebreakers assist each tanker and the icebreakers should constitute the main working platform for the oil spill response equipment. In addition it could be beneficial to have some oil spill response equipment stored in onshore bases, e.g. at the Varandey terminal and Kolguyev Island. Helicopters could be used for fast transportation and deployment of equipment.

6.3.2 Recommended response measures

A typical spill scenario for the shipping route in February and March would be dense ice with a shipping lane with smaller and larger ice floes broken by icebreakers. The broken channel will be the potential spill site. Due to the dense ice the weathering of the oil will be slow and hence the "time window" will increase for use of in-situ burning and dispersants as potential response methods.

Mechanical recovery could be used without deployment of booms. Testing and use in oil spills have shown that both disc and drum skimmers allow small ice forms to pass the recovery mechanism as oil is being collected (Evers *et al*, 2004). Rope mop skimmers also have a potential, but this is, as most skimmers, dependent on a certain thickness of the oil/emulsion. Both of these skimmer types (disc/drum and rope mop skimmers) are based on the adhesion principle and show reduced recovery rate for very light oils and/or oil with low weathering degree (e.g. fresh crude oil). Weir skimmers are based on a self-levelling edge over which oil and water flow and are often used for oil recovery in open waters. When oil and water is flowing over the edge, ice will easily follow and can create problems with ice jamming in the pump house. A diverse number of skimmers have been considered for removing oil in ice (Evers *et al.*, 2004). The Lori Brush Skimmer was found to offer the highest potential for recovering viscous oil in broken ice. Recently Lamor has developed an Arctic Brush Skimmer that has shown to be a promising alternative especially for use in oil loading terminal areas. It must be emphasised that none of these skimmer types have been thoroughly tested in severe ice conditions as can be found in the Pechora and Kara seas, but it can be expected that they could function in high ice coverage as indicated in table 6.2, but probably with reduced recovery rate.

Some novel concepts have shown promising results. The MORICE skimmer was developed through a project from 1995 to 2002. The skimmer has been tested both in basin facilities and in the field and could be used in broken ice with 70 % ice concentration on a large scale. So far the skimmer has not been industrialized and only a harbour sized prototype exists. In Finland an Ice Vibrating Unit has been designed by the Finnish Environmental Institute to be used in the presence of broken ice and brash ice in a typical shipping channel in Finnish waters. Two to three units are now being built for use in the Gulf of Finland. However, it has not been demonstrated and no effort has been made to make the Vibrating Unit system suitable also in Arctic conditions.

It appears that no proven system for large-scale oil spills in ice-infested waters exists. The skimmers described above have the potential to work in some ice scenarios, but have not been demonstrated for ARCOP scenarios.

In-situ burning has a potential in ice-infested waters. In general, the applicability of burning can be divided into three broad ice concentration ranges:

- *Ice coverage from open water to 3/10.* In this low ice coverage the spreading and movement of oil will not be affected by the presence of ice and open water in-situ burning techniques, e.g. fireproof booms can be used. However, the “time window” can be reduced due to high energetic conditions and a high degree of weathering.

- *Ice coverage from 3/10 to 7/10.* This range turns out to be the most difficult from an *in-situ* burning perspective. The use of booms will be difficult, if not impossible. The main challenge is large areas of open water in between the ice floes and the spreading of oil to a thickness below what can be ignited. There are ongoing projects in Canada to study the use of herders to concentrate the oil up to thicknesses where it can be ignited.

- *Ice coverage from 6-7/10 to 9/10.* At this ice coverage ice floes may contain the oil so the slick gets thick enough to be ignited and burn effectively. Normally the weathering is slow under such conditions and the “time window” for use of *in-sit*u burning will increase compared to open water conditions.

Oil can also be successfully burned on solid ice, in melting pools, and in snow even with up to 70 % snow by weight.

There exist two main types of igniters for *in-situ* burning:

- Igniters for use from a vessel. Both portable propane or butane torches, or weed burners and rags or sorbent pads soaked in diesel have been used successfully many times to ignite oil slicks on water.
- Igniters for use from helicopter. There are currently two types available, the Dome igniter and the Helitorch igniter.

The icebreakers assisting the oil tanker could carry igniters of the first type or ignition could be carried out by use of helicopter, either from the icebreaker or from an onshore base. The ARCOP study area characterised with dense drifting ice and a shipping lane with typically large ice pieces and which can be closed quite rapidly due to wind and currents could be a relevant scenario for *in-situ* burning. There must be a sufficient distance between the vessels and the burning area to ensure safety.

Use of dispersants normally requires lower ice concentration than expected to be found in the ARCOP scenario. The weathering of the oil will be slow increasing the “time window” for use of dispersants. The main challenge will be to apply the dispersant in an effective manner and helicopter application may be the best method. Another challenge is the low energy condition as an effective use of dispersants, which requires some wave energy to start the dispersing process. However, studies are ongoing to look upon the potential to apply dispersants for later dispersing when the oil approaches the ice edge. That requires dispersants that have the ability to stay in the oil and not leaking to the surrounding water or ice. Another option under investigation is to use vessels to create artificial turbulence by propellers to initiate the dispersing process.

At the present time, the use of dispersants can not be recommended for the scenario as described in this ARCOP study area. However, later in the spring during the melting period use of dispersants can have a potential and can be an effective response option in lower ice coverage.

<u>Conclusion</u>: Today there is no proven response method for recovery of large-scale oil spills in ice-infested waters. The preferred response for the scenario as described for the shipment in ice from Varandey towards Murmansk may be a combination of mechanical recovery and use of in-situ burning. It is recommended that the icebreakers assisting the oil tanker carry at least one skimmer of the brush type or rope mop type and igniters for in-situ burning. At the same time additional equipment should be stored at the Varandey terminal and/or Kolguyev Island, preferably with helicopters for fast transport and deployment. There is a need for winterisation of existing equipment and field-testing to demonstrate the capability. There is also a need for development of equipment or strategies for systems to handle larger oil spill in ice-infested waters.

6.4 Shoreline cleanup

A strategy for shoreline cleanup is an important part of the contingency plan for accidental oil spills in the Arctic region. The contingency plan should primary be focused on the philosophy to minimize the harm caused by an oil spill, not necessarily the needs to provide methods to clean up all the spilled oil. It is important to attain a well documented knowledge about how the natural processes occurs in the different scenarios in a case of an oil spill incident should happen along the coastline or with short drifting time toward the coastline due to wind and/or current. This knowledge about the natural processes in this region can be used with advantage to develop a modelling tool to predict the restitution time of the polluted area in respect of the amount of oil released, type of the oil product, shoreline conditions and duration of the spill, weather and waves.

The disadvantages of most frequent used response techniques are the requirements of logistic and need for much personnel. Several response techniques are in addition tremendously time-consuming. It could be difficult to get access to the contaminated area with massive cleanup equipments and a large group of personnel if an oil spill incident should occur in this vulnerable region.

The strategy and main focus in shoreline cleanup should be addressed to the following subjects:

- Identify the areas with specific concerns along the transport coastline and the areas should be planned based on unique factors. The areas could be divided into sections of major concern, moderate concern and minor concern based on activity of both biological - and human resources (natural recourses).

- Define release scenarios including oil type, the influence of oil type and volume of the released oil. This includes the identification of both, the type and quality of the oil.

- Identify shoreline category possibly influenced by oil.
- Identify the topography and access to the shorelines of concern.

It is recommended to develop and improve *in-situ* techniques which stimulate the natural processes concerning following techniques:

- Bioremediation /biological degradation[*)]
- Use of dispersants[*)]
- Shoreline cleaning agents[*)]
- *In-situ* burning[*)]
- Passive collection with sorbent
- Washing /flushing (variable combination of pressure and water temperature)

The *in-situ* techniques labelled with [*)] need a specific approval prior to use. It should be emphasised that Russian regulation prohibits the use of dispersants as a primary response strategy as long as mechanical recovery method can be used. In Western Europe (e.g. Norway) the use of dispersant is an often preferred strategy in the case of relative small oil spills. *In-situ* burning could for instance have a potential as a countermeasure on remote shorelines or inaccessible mudflats in Arctic areas. This technique could especially be useful for large quantities of less weathered oil.

Mechanical recovery, manual recovery and natural attenuation (need monitoring) are in addition important tools in oil spill countermeasures on shorelines, but these techniques are not part of *in-situ* techniques which have the overall objective to stimulate natural processes.

7 Conclusions

The shipping route from the loading terminal at Varandey to Murmansk sea port has long distance to land which requires that the spill response technology has to stationed off-shore, mainly from larger vessels like icebreakers, ice going tug boats and supply vessels, with possible assistance from helicopters and fixed wing aircraft for monitoring and/or surveillance, dispersant application and ignition of *in-situ* burning.

If an oil spill incident should occur in the Arctic conditions, the combating strategy will strongly depend on response time, ice conditions, weather/current/wave conditions, availability of equipments, and possibility of assistance e.g. of helicopters. In addition, the properties of the oil, amount of oil spilled and duration of the spill are important aspects in selection of oil spill response methods and technology.

Today there is no proven response method for recovery of large-scale oil spills in ice-infested waters. The preferred response for the scenario as described for the shipment in ice from Varandey towards Murmansk may be a combination of mechanical recovery and use of in-situ burning. In order to secure short response time, it is recommended that the icebreakers assisting the oil tanker carry at least one skimmer of the brush type or rope mop type and igniters for in-situ burning. At the same time additional equipment should be stored at the Varandey terminal and/or Kolguyev Island. The size of the equipment should preferably be tailor-made for fast transportation by helicopters and easy deployment. There is a need for winterization of existing equipment and field-testing to demonstrate the capability. There is also a need for development of equipment or strategies for systems to handle larger oil spill in ice-infested waters.

The strategy with respect to shoreline cleanup is focused on the natural processes and use of *in-situ* techniques. It is important to attain a well documented knowledge about how the natural processes occurs in the different scenarios in case of an oil spill incident should happen along the coastline or with short drifting time toward the coastline due to wind and/or current. This knowledge about the natural processes in this region can be used to develop a modelling tool to predict the restitution time of the polluted area in respect of the amount of oil released, type of the oil product, shoreline conditions and duration of the spill, weather and waves.

8 References and Bibliography

Bambulyak, A and Fransen, B, 2005: “Oil transported from the Russian part of the Barents Sea”. Svanhovd miljøsenter, status per January 2005.

Bjerke, P.L. and K. Torsethauge , 1989: “Environmental Conditions on the Norwegian Continental Shelf”. NHL Report STF60 A89052, Trondheim, 281 p.

Brandvik, P.J., Singsaas, I., Daling, P.S., 2004: “Oil Spill R&D in Norwegian Arctic Waters with special Focus on Large-scale Oil Weathering Experiments”. Paper at the 2004 Interspill Conference, Trondheim

Buist, I., 2004: “In Situ Burning for Oil Spills in Ice-covered Waters”. Paper at the 2004 Interspill Conference, Trondheim

Dickins, D.F., Buist, I., 1999: “Countermeasures for ice covered waters”. Pure Appl.Chem, Vol.71, No. 1, pp. 173-191

Evers,K.-U., Jensen, H.V., Resby,J.M., Ramstad,S., Singsaas,I., Dieckmann,G. and Gerdes, B. (2004) : “State-of-the-Art Report on Oil Weathering and on Effectiveness of Response Alternatives”, Report of ARCOP Workpackage 4 Environmental Protection and Management System for the Arctic, GROWTH Project GRD2-2000-30112 "ARCOP", available as ARCOP WP 4 Report 4.2.1.1(a), 2004, http://www.arcop.fi

Evers, K-U, Singsaas, I, Sørheim K.R, 2005:” Oil Spill response concepts in Arctic and Ice-infested Waters –improvement and development”, ARCOP Workpackage 4 Environmental Protection and Management System for the Arctic, GROWTH Project GRD2-2000-30112 "ARCOP", available as ARCOP WP 4 Report 4.2.1.2 2004, http://www.arcop.fi

Fingas, M.F., Fieldhouse, B., Mullin, J.V., 1997:”Proceedings of the Twentieth Arctic and Marine Oil spill program, Technical Seminar”. Environment Canada, Ottawa, ON, pp.21-42.

Golovin, N.V., Koptev, N.S , Maiorov, O.N. and Khvedynych ,1996: “The Ice Investigations in the Pechora and Kara Seas”. Proceedings of the PolarTech Conference, St. Petersburg, 1996, Vol. 4, pp. 38-39.

Gorshkov, S.G. and Faleev, V.I.,Eds., 1980: “Atlas of the Oceans. The Arctic Ocean”. USSR Ministry of Defence.

Iden, K.A. and H. Tønnesen (1988): ”Kart over lufttemperatur i området mellom Norge og Svalbard. The Norwegian Meteorological Institute”, Report No. 24/88 Klima, Oslo, 20 p. (in Norwegian).

Jensen, H.V., 2004: “Mechanical Recovery in Cold and Ice-infested Waters related to the ARCOP project”. Paper at the 2004 Interspill Conference, Trondheim

Johansen, Ø., Høverstad, B.A, Skognes, K., Evers, K.-U., 2005: “Simulation of oil drift and spreading and oil spill response analysis, ARCOP WP4. Environmental Protection and Management System for the Arctic, GROWTH Project GRD2-2000-30112 "ARCOP", available as ARCOP WP 4 Report D4.2.2.2/D4.2.2.3, http://www.arcop.fi

Korppoo, S., S. Kobus and P. Salonen, 1988: “Problems of Using Floating Production Units in Arctic Conditions”. Proceedings of the International Conference on Technology for Polar Areas (PolarTech), Trondheim, Vol. 2, pp. 507-521.

Loeng, H. (1991): “Features of the Physical Oceanographic Conditions in the Barents Sea”. Polar Research, Vol. 10(1), pp. 5-18.

Løset, S., S. Vefsnmo, J. Karas and M. Kelly, 1988: “Environmental Conditions in the Barents Sea in Regard to Icing”. Proceedings of the International Conference on Technology for Polar Areas (Polartech), Trondheim, Vol. 2, pp. 393-407

Løset, S. (1991): “Ice Dynamics in the Marginal Ice Zone”. SINTEF NHL Report STF60 F91011, Trondheim, 40 p.

Løset, S., Shkhinek, K., Strass, P., Gudmestad, O.T., Michalenko, E.B. and Kärnä, T. (1997): “Ice Conditions in the Barents and Kara Seas”, Proceedings of the 16th International Conference on Offshore Mechanics and Arctic Engineering, Yokohama, 13-18 April 1997, Vol. IV, pp. 173-181.

Losev, S.M. and Gorbunov, Yu. A. (1977): Studying of Stamukhas according to Aerophotographs. Tr. AANII, t. 343, pp. 127-132.

Mironov, E., Spinchkin, V.A. and Egorov, A.,1994: “Season Variability and Their Variations in the Region of Mastering of the Barents and Kara Seas Offshore”. Proceedings of the First International Conference on Development of the Russian Arctic Offshore (RAO-93), St. Petersburg, September 21-24, 1993, pp. 110-121.

Mironov, E., Spichkin, V.A. and Bychenkov, Y.D.,1996: “Provision of Safety and Efficiency for Constructing Offshore Structures on the Shelf of the Barents and Kara Seas Based on Monitoring and Forecasting of the Ice State”. Proceedings of the Polar. Tech. Conference, St. Petersburg, 1996, Vol. 4, pp. 161-169.

Mischenko, S.M., 1995: “Wave Parameters in the Kara and Pechora Seas”. St. Petersburg State Technical University, 21 p.

Moreinis, F.A., Belajshov V.A, Batskikh U.M, Zubkova A.A, Shtrek A.A, Volikovskaya M.V, 2005: “Description of the Loading Event in Ice at the Varandey Terminal”, ARCOP WP5.

Overgaard, S., Wadhams, P. and Leppäranta, M., 1983: “Ice Properties in the Greenland and Barents Seas during Summer”. Journal of Glaciology. Vol. 29, pp. 142-164.

Owens, C.K., 2004: “Regional Considerations Influencing Oil Spill Response in Arctic Offshore Environments”. Paper at the 2004 Interspill Conference, Trondheim

Reed, M., O.M. Aamo, and P.S. Daling, 1995a. OSCAR, a Model System for Quantitative Analysis of alternative Oil Spill response Strategies. In: Proc. 18th Arctic Marine Oilspill Technical Seminar, Environment Canada, Ottawa, Ontario. pp. 815-834.

Reed, M., O.M. Aamo, P.S. Daling, 1995b. Quantitative Analysis of Alternate Oil Spill Response Strategies using OSCAR. Spill Science and Technology Bulletin, vol. 2 no. 1. pp. 67-75.

Report on scientific research: Oil spill contingency plan for the Murmansk oblast, St.Petersburg 2004

Riska, K., 1995: "Ice Conditions along the North-East Passage in View of Ship Trafficability Studies". Proceedings of the Fifth (1995) International Offshore and Polar Engineering Conference, The Hague, Vol. II, pp. 420-427.

Romanov, I., 1993: "Ice Cover of the Arctic Basin". St: Petersburg 1991, 192 p.

Saarinen, S., Mironov, E., Lavrenov, I. and Stepanov, I. (2004) : "Design basis for the transportation system", Report of ARCOP Workpackage WP3.1 Selection of transportation scenario, GROWTH Project GRD2-2000-30112 "ARCOP", WP 3.1 Report D 3.1.3, restricted

Singsaas, I., Sørheim K.R 2005:" Oil Spill response concepts in Arctic and Ice-infested Waters – Improvement and development. SINTEF report STF80MK A05195

Singsaas, I, 2005: "Oversikt over oljeaktivitet i Russland - egenskaper til oljene og transportveier", SINTEF Report STF80MK A05311

Singsaas, I., Nordtug T., Resby J.L., 2005: "Strategy and decision model for use of dispersant on the Balder, Jotun and Ringhorne oil fields, SINTEF Report STF80MK A05106

Singsaas, I., Ramstad, S., Johansen, Ø., 2005: "Utredning av konsekvenser av helårlig petroleumsvirksomhet i området Lofoten – Barentshavet" (Norwegian language), SINTEF Report STF66 F03030

Semanov, G. et al. (1995): INSROP Working Paper ; SUB-PROGRAM II. Environmental Factors. II-6. Environmental Safety of Navigation. II.6.1. Control of Pollution from Ships on the NSR, St. Petersburg 1995.

Shavykin, A., Gennady I., 2005: "Russian oil Properties and Routes for its Transportation for export through the ports on the Barents and the White Seas", Draft version. Murmansk Marine Biological Instiriute, 2005.

SNIP, 1987: "Construction Codes and Regulations. Loads and Forces". SNIP 2.01.07-85. Gosstroy of USSR, M.: 1987. Appendix: Maps of the USSR territory divisions on the base of climate characteristics, 34 p.

SNIP, 1996: "Changes to the Russian Code SNIP 2.06.04-82*". Gosstroy, Moscow.

Spichkin, V. and Egorov, A. (1995): Dangerous Ice Phenomena in the Barents and Kara Seas Offshore. Proceedings of the Second International Conference on Development of the Russian Arctic Offshore (RAO-95), St. Petersburg, 1995.

Strass, P., Løset, S., Shkhinek, K, Gudmestad, O.T. , Kärnä, T.,Michalenko, E.B., 1997: Metocean Parameters of the Barents Sea and Kara Sea – An Overview, Proceedings of the 16th International Conference on Offshore Mechanics and Arctic Engineering, Yokohama, 13-18 April 1997, Vol. IV, pp. 165-172

Torsethaugen, K., 1989: “Wind and Waves in the Barents Sea”. Naturdatakonferanse, Harstad, 26-28. Sept. 1989. SINTEF Report STF60 A89094, 33 p.

USSR, 1986a: “Hydrometeorological Conditions from the Offshore Zone of USSR Seas” (in 13 Volumes). Reference Book, Vol. 6, Barents Sea. Vipusk 1, 2. Leningrad, Gydrometeoizdat, 1986, 95 p.

USSR, 1990: “Hydrometeorology and Hydrochemistry of the USSR Seas (in 10 Volumes)”. Vol. 1, Barents Sea. Vipusk 1. Hydrometeorological Conditions. Leningrad Gydrometeoizdat, 1990, 280 p.

Vefsnmo, S., Jensen, H.V., Singsaas, I., Guenette, C., 1996:”Oil Spill Response in Ice Infested Waters”. SINTEF Report no.: STF22 F96202.

Zubakin, G.K., Denisov, V.V. and Soboleva, D.R., 1987: “Some Results of Investigations of Currents and Ice Drifting in the South-East part of the Barents Sea”. Tr. AANII, t. 410, pp. 64-75.