Appendix 6A

Oil Spill and Cooling Water Discharge Modelling

AECOM

NKX-1 Oil Spill and Discharge Modelling

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A Report Produced By

More Energy Ltd

Contents

Figures & Tables

Figures

Tables

Abbreviations

Abbreviation	Definition
2D	Two-dimensional
3D	Three-dimensional
GEBCO	General Bathymetry Chart of the Oceans
ITOPF	International Tank Owners Pollution Federation
LC50	Lethal concentration for fifty percent of a population
MEMW	Marine Environmental Modelling Workbench
NKX-1	North Khali Exploration Well 1
OSCAR	Oil Spill Contingency and Response
P10, P50, P90	A value which would not be exceeded in 10%, 50% or 90% of scenarios
PLUME3D	Near-field plume sub-model
ppb	Parts per billion
ppm	Parts per million
SINTEF	Stiftelsen for industriell og teknisk forskning (Foundation for Scientific and Industrial Research)
SWAP	South West Absheron Peninsula

1 Introduction

1.1 The project

AECOM has commissioned More Energy Ltd on behalf of BP Exploration (Caspian Sea) Ltd to undertake a spill and cooling water discharge modelling study to establish the expected extent of the impacts associated with the following releases to sea. These are the worst case releases that could be associated with the drilling of the proposed North Khali (NKX-1) exploration well in the Caspian Sea. The proposed well location (oil) lies approximately 20 kilometres (km) from the Azerbaijani mainland in a water depth of approximately 22 metres (m). The NKX-1 well with be the first of three exploration wells planned for the Shallow Water Absheron Peninsula (SWAP) Contract Area. The SWAP Contract Area comprises three Prospective Areas as shown in Figure 1. The NKX-1 well is located in the North East Prospective Area.

The objective of the modelling was firstly to establish the expected extent of the impacts associated with a release of hydrocarbons by establishing:

- Where hydrocarbons are likely to travel;
- How the oil and diesel is likely to disperse over time (both on the sea surface and in the water column);
- Expected behaviour of oil and diesel sheens on the surface;
- The extent to which oil is likely to arrive on the shoreline; and
- Where hydrocarbon concentrations could exceed certain thresholds in the water column.

Secondly, the modelling was conducted to establish the expected effect of the discharge of cooling water from the jack up drilling rig.

The scenarios modelled have been identified in conjunction with the BP project team.

This report presents the results of work undertaken to model these releases and determine their extent.

The OSCAR (Oil Spill Contingency and Response) model version 11.0 from SINTEF (Stiftelsen for industriell og teknisk forskning) was used to model the crude oil and marine diesel release scenarios. OSCAR computes surface and subsurface transport, behaviour, weathering and fate of oil using a Lagrangian (particle tracking) approach, enabling explicit tracking of each particle's location and behaviour through time. The Dose-Related Risk and Effect Assessment Model (DREAM) published by SINTEF (v9.01) was used to model cooling water discharges. DREAM consists of a dispersion model based on 2D wind and 3D current data which was used to examine the mixing of the cooling water with ambient waters.

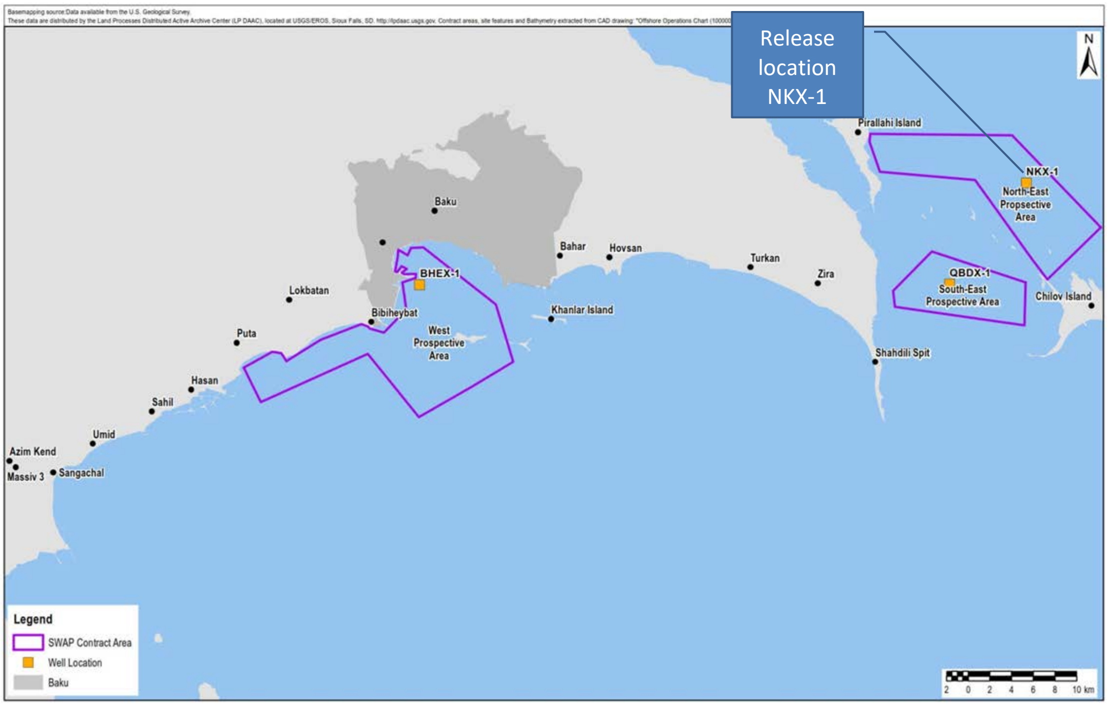


Figure 1: SWAP Prospective Areas and Proposed Exploration Well Locations

1.2 Scope of work

1.2.1 Oil spill modelling

The scope of work was to model oil releases resulting from the drilling of exploration well NKX-1 and to determine their extent.

Modelling is undertaken using the oil weathering and dispersion model OSCAR (v11.0) by SINTEF. Inputs to the models included 3D metocean data and discharge parameters provided by BP that are specific to the Caspian Sea operations. Agreed scenarios have been modelled relating to different release scenarios for:

- Scenario 1: Diesel release; and
- Scenario 2: Blowout of crude oil.

Stochastic modelling of Scenario 1 and 2 is undertaken demonstrating how the trajectory and fate of the oil changes under variable metocean conditions representative of summer and winter conditions. The outputs from the stochastic modelling are summarised as follows.

Stochastic analysis of >100 runs:

- Probability of predicted visible oil slick above threshold;
- Profile of beaching times;
- Profile of the mass of accumulated oil onshore;
- Averaged mass balance statistics over model duration;
- Maximum exposure times of oil on surface and in the water column; and
- Minimum arrival times of oil on surface and on the shoreline.

For the worst case scenarios of amount of hydrocarbons reaching the shoreline in summer and winter periods, deterministic modelling is undertaken to predict the mass balance fate of the oil over time, the development and appearance of the surface oil slick and the behaviour of oil in the water column.

Deterministic model for worst case beaching (largest volume):

- Maximum extent and thickness of the visible oil slick on the surface;

- Distribution and density of oil reaching the shore;
- Maximum oil concentrations in the water column over time;
- Mass balance versus time profile for surface oil, oil in the water column, shoreline oil, evaporation and biodegradation;
- Areas of the water surface and volumes of the water column affected over time by certain oil concentrations or dilutions; and
- Deposition pattern and concentration of oil in sediments.

Thickness thresholds for oil on the sea surface and oil on the shoreline as well as oil concentrations in the water column based on good international industry practice were agreed with BP.

1.2.2 Cooling water discharge modelling

Cooling water discharges were modelled using the dispersion model DREAM by SINTEF.

DREAM uses its near-field sub-model PLUME3D to predict initial turbulent dispersion and advection, followed by wider-scale dispersion once momentum and buoyancy effects have subsided. Outputs are provided in temperature change relative to the ambient water column temperature profile. The nature of thermal dispersion is rapid, and the model is focussed on a short period of time at a high resolution to provide a detailed representation of the plume. This gives a clear indication of the extent of the initial mixing zone to allow comparison with international standards. This approach means it is limited in showing a time-series of results in dynamic conditions, so representative high and low current conditions are chosen for modelling by observing the current records for summer and winter conditions separately.

2 Modelling software used

2.1 The Oil Spill Contingency and Response Model (OSCAR) model

The SINTEF OSCAR software is a sophisticated multifunction model that incorporates models of plume behaviour, oceanic dispersion, wind forcing, wave turbulence, oil weathering and behaviour including physical and chemical processes, environmental interaction, ecological impact and spill response. The model has been developed over 30 years and is the subject of verification and calibration by numerous field experiments both on surface spills and subsea releases e.g. as described in Reed *et al.* (1995 and 1996) and Johansen *et al.* (2001) as well as operational experience. The weathering of oil and its physical state are computed using the embedded Oil Weathering Model developed by the SINTEF oil weathering laboratories in Trondheim, supported by decades of research into oil chemistry and behaviour.

The model calculates and records the transport and distribution of a contaminant in three-dimensional space and time, on the water surface, along shorelines, in the water column, and in sediments, along with losses by evaporation and biodegradation. For subsurface releases the near field part of the simulation is conducted with a multi-component integral plume model that is embedded in OSCAR. The near field model accounts for buoyancy effects of oil and gas, as well as effects of ambient stratification and cross flow on the dilution and rise time of the plume.

Single oil spill scenarios can be completed for a specified meteorological period (deterministic modelling), or multiple scenarios with varying start times can be compiled to calculate statistics such as the probability of some event e.g. oil reaching ashore or the fastest time of arrival (stochastic modelling). These releases can be set as single static, multiple or moving sites.

Relevant parameters are chosen based on recommendations from SINTEF via the model documentation, training courses and dialogue. Outputs are generated by collating particle properties over a grid, set to capture the main areas of interest as the plume develops and disperses. Various model parameters can affect the quality of outputs including the metocean data used, the number of particles chosen and the size of the grid applied and a balance is struck between model complexity, the output required and practical run times. All such inherent uncertainties require conclusions to be drawn carefully and using experience.

The model is capable of evaluating the effectiveness of oil spill response strategies and allows the assignment of specific operational tactics for simulated containment, storage, booming, skimming and dispersant operations. This can be coupled with biological impacts on plankton and fish to support net environmental benefit analysis.

2.1.1 Types of analysis

For each hydrocarbon release scenario, the following analyses were undertaken. OSCAR is an extremely capable model that can offer many different statistics on any particular spill, and the analyses given below are judged to be the most useful in understanding potential environmental impact.

Stochastic simulation:

- Probability of oil on surface at any time;
- Minimum arrival time of oil;
- Probability of oil on shoreline at any time;
- Maximum mass of oil on shoreline (and distribution of outcomes);
- Minimum arrival time of oil on shoreline (and distribution of outcomes); and
- Density of oil on shoreline.

From the stochastic analysis, a 'worst case' of metocean conditions is identified that causes the maximum amount of oil to reach shorelines.

To reflect differences in sea temperature profiles between summer and winter, separate summer and winter stochastic simulations are undertaken.

Deterministic simulation:

- Mass balance plot for evaporation, dissolved, dispersed, sediment, shoreline, biodegraded and outside grid; and
- 'Swept area' of individual spill on surface and water column.

A deterministic simulation is run for the cases that result in the most oil on shore in summer and winter conditions.

2.1.2 Modelling domain

Since the Caspian Sea is a closed waterbody, the model boundary never extends beyond the physical shoreline (see Figure 2). Metocean data is also available for the whole area. Consequently, the size of the model boundary can be as large as necessary to encompass the entire dispersion of the release within the modelling period.

3D current data and 2D wind data was obtained for the period 2006 - 2009 covering this area and imported into the model. Using this area, all oil is accounted for.

In common with other areas of the world with strong currents, it is not efficient to capture all oil particles indefinitely as some may persist for many months, and the metocean/model area/model duration is chosen to maximise accuracy in the area of greatest significant impacts. Model accuracy also decreases as distance increases as uncertainties accumulate and any wider scale results should be treated as being more indicative further from the source. Potential impacts can be assessed from this information, and may be compared with background levels of oil in the environment.

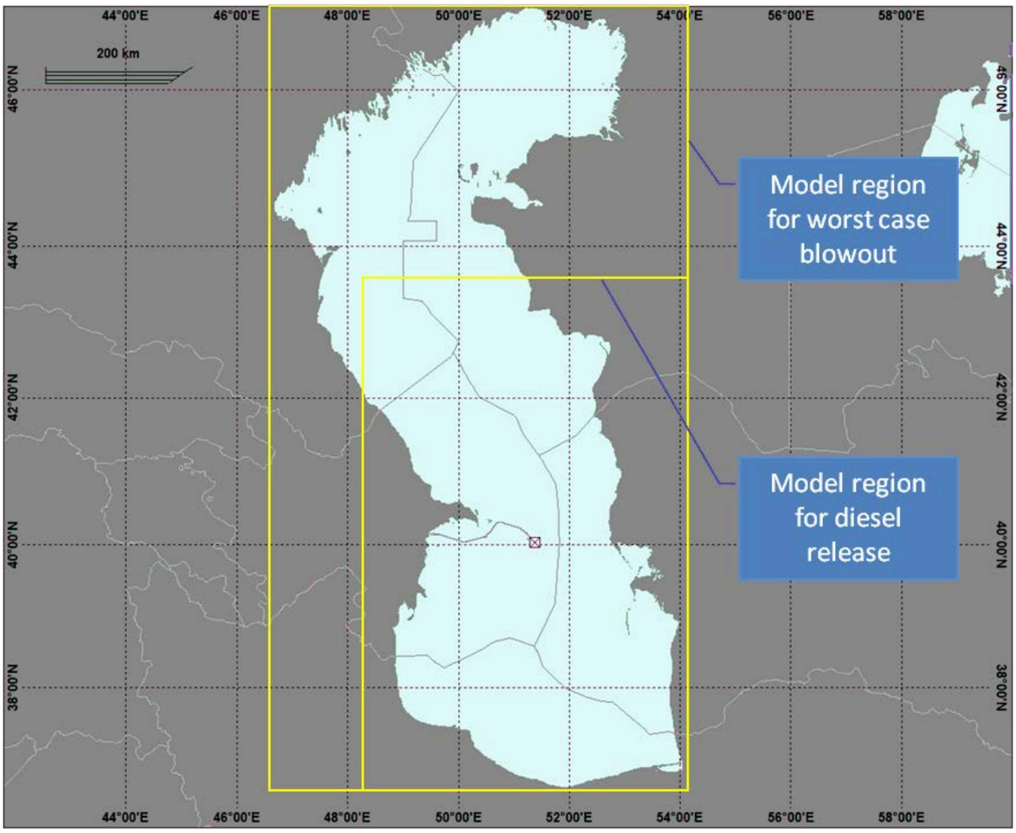


Figure 2: Modelling regions used

2.1.3 Environmental thresholds (hydrocarbon)

Sophisticated models such as OSCAR are capable of tracking the fate of oil in increasingly smaller and smaller concentrations and masses, beyond the point at which oil presents a significant risk or is even detectable against background levels. In order to ensure the model outputs reflect the risks, while still retaining a precautionary approach, thresholds are normally applied to thicknesses of surface oil, concentrations in the water column and densities of shoreline oiling.

The thresholds adopted in this study are described in Table 1 for:

- Shoreline oiling;
- Thickness of surface sheen; and
- Total oil in the water column.

Table 1: Thresholds for oil significance adopted

Category	Threshold	Justification
Shorelines	100 ml/m² (approx. equal to 86 g/m²).	The International Tank Owners Pollution Federation (ITOPF) guidelines for the recognition of oil on shorelines (ITOPF, 2011) include shoreline oil density. The definition for 'light oiling' is selected as the most appropriate threshold and is described in the guidelines as equivalent to a volume threshold of 0.1 litre/m², or less than 0.2 litres of oil per metre strip along a 2m deep beach which is assumed in the model. The 0.1 litre/m² threshold (considered a 'stain' or 'film') is assumed as the lethal threshold for invertebrates on hard substrates and sediments (mud, silt, sand, gravel) in intertidal habitats based on Owens & Sergy (1994) and French-McCay (2009). This would be enough to coat the animal and likely impact its survival and reproductive capacity, while stain <0.1 litre/m²) would be less likely to have an effect (French-McCay, 2009). Values have also been adopted for 'Moderate oiling' of 1 litre/m², and 'Heavy oiling' of 10 litre/m², also derived from ITOPF.
Sea Surface	0.04 µm (microns) silvery grey - rainbow sheen	Interpretations of significance of surface oil thickness vary widely. The presence of a visible sheen is likely to interfere with other users of the sea such as fishing operations and a visible sheen can occur between 0.04 and 0.3 µm as identified by the Bonn Agreement Oil Appearance Code (BAOAC). This is highly dependent on weather conditions, and the lower level of 0.04 µm is only visible under ideal conditions. Tests performed by O'Hara and Morandin (2010) indicated that significant changes in feather structure did not necessarily occur at a thickness of 0.04 µm, but began to be visible at 0.1 µm. Oil spill response in the form of containment or dispersant use is normally not attempted when oil is below a thickness of 5 µm.
Water Column	58 ppb (parts per billion) (total oil)	Research completed by Statoil (2006) and Det Norsk Veritas (2008) resulted in the development of species sensitivity dose-response curves to assess the impact to organisms from different water column hydrocarbon concentrations. A 5th percentile LC_{50}[1] for total hydrocarbon concentrations was found to be 58 ppb. This value of 58 ppb is used within this modelling as the lower threshold for potential acute toxicological responses and concentrations below this threshold are not reported from OSCAR. 58 ppb is a conservative lethal exposure value for marine fauna as it is below the LC_{50} for 95% of species and is lower than the OSPAR recommended predicted no-effect concentration of 70 ppb (OSPAR, 2014). At this concentration mortality is highly unlikely however toxicological effects may be both short and long-term.
Sediments	10 mg/kg No-effect concentration (NOEC)	Patin (2004) describes broad ecotoxicological thresholds for oil in sediments, noting that there is a wide range depending the species present. Patin recommends threshold of 10 mg oil per kg of sediment (mg.kg) as a level that would be below NOECs for most species; 10-100 mg/kg where reversible effects would be expected; 100 - 1,000 mg/kg where sublethal effects would be expected and above 1,000 mg/kg as a level where acute toxic effects would begin to be observed.

[1] Lethal Concentration 50%. The concentration of a chemical which kills 50% of a sample population

		Concentrations of oil in sediment are calculated assuming a mixed layer of 5 cm of surficial sediment, although this can vary between 2-10 cm (Trauth *et al.* (1997). A bulk saturated sediment specific gravity of 1.9 is assumed.

2.2 Dose-Related Risk and Effect Assessment Model (DREAM)

2.2.1 Description

Cooling water discharges have been modelled using the SINTEF DREAM model. The model predicts the fate of materials discharged to the marine environment (their dispersion and physico-chemical composition over time). Along with OSCAR, DREAM is part of the suite of models within the Marine Environmental Modelling Workbench (MEMW) developed by SINTEF and shares much of the validation experience discussed above. Additionally, the DREAM model underwent significant development in the late 1990s and 2000s including its use in the Environmental Risk Management System joint industry project. Model details and development can be found in the technical reports at www.sintef.no/erms/reports as well as papers such as Reed *et al.* (2001) and Reed and Hetland (2002). The model has been validated in field trials relating to produced water plumes including Durell (2006) and Niu and Lee (2013), which found "*The DREAM model was also compared with field data … The results indicated that DREAM predicted both the dilution and trajectory very well*". This has been confirmed in a further study *"The comparison of modelled and empirical data showed that the DREAM model can effectively predict plume behaviour. The results agreed well with the monitoring data and simulated the location of the plume as it changed continuously with the tidal currents"* (Niu *et al.*, 2016).

The model has been developed to predict the dispersion of chemical plumes in the water column along with a variety of other physico-chemical processes such as thermal effects, evaporation, biodegradation, transition from droplet to dissolved states to adsorbed into sediments, and the dynamic equilibrium of these states dependent on local environmental conditions. The calculations are based on a Lagrangian 'particle' approach using a cloud of individual particles to represent the components of the discharge, combined with a near field plume model including advection by density, thermal and momentum forces and a far-field model for subsequent horizontal and vertical dispersion of particles. The plume model takes into account effects from water stratification on the near-field mixing and geometrical configuration of the outlet. Once the plume has been trapped by the prevailing structure of the water column, dissolved particles undergo ongoing horizontal and vertical dispersion while solids or droplets can continue to fall or rise in the water column and potentially deposit on the seabed or reach the surface and, in the case of oil droplets, form a sheen. Wave turbulence driven by wind speed and fetch is also incorporated into the surface layers of the water column.

2.2.2 Modelling domain

Figure 3 shows the model domain used for cooling water discharge modelling. The area has been selected by experience and iteration to contain the nearfield plume and the area within which temperatures return to close to ambient. In this particular situation this results in a small area 200 m by 200 m around the discharge.

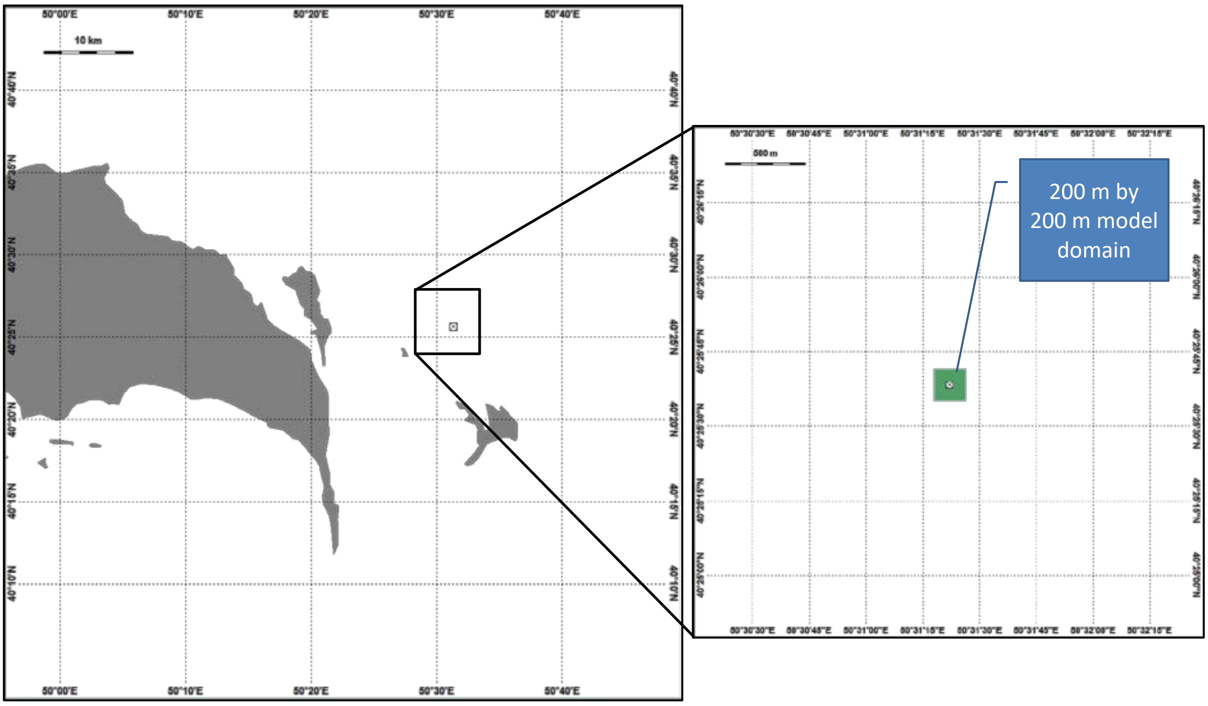


Figure 3: Modelling region used for cooling water discharge modelling

2.2.3 Environmental thresholds (thermal discharges)

There are international standards for what is normally acceptable in terms of thermal discharges such as the Environmental, Health and Safety Guidelines (International Finance Corporation and World Bank Group, 2007), which state

> *"Temperature of wastewater prior to discharge does not result in an increase greater than 3°C of ambient temperature at the edge of a scientifically established mixing zone which takes into account ambient water quality, receiving water use and assimilative capacity among other considerations."*

Such a mixing zone is normally taken to be at the edge of the advection zone, e.g. at the edge of a 'surface boil', where the discharge rises to the surface, and where the nearfield turbulent plume collapses to give way to slower mixing processes. For marine releases, however, this behaviour does not always occur clearly, and a limit of 100 m is often used as an outer limit for acceptability, where the discharge must not cause a temperature change of more than 3°C (e.g. International Office for Water, 2008).

3 Model input data

3.1 Metocean data

Three-dimensional water column current and two-dimensional wind data were generated by the Space and Atmospheric Physics Group at Imperial College and provided by BP for a period covering 2006-2009. A snapshot of currents in the Caspian region can be seen in Figure 4 for the surface layer (which includes wind-driven currents) and a snapshot of two-dimensional winds is shown in Figure 5.

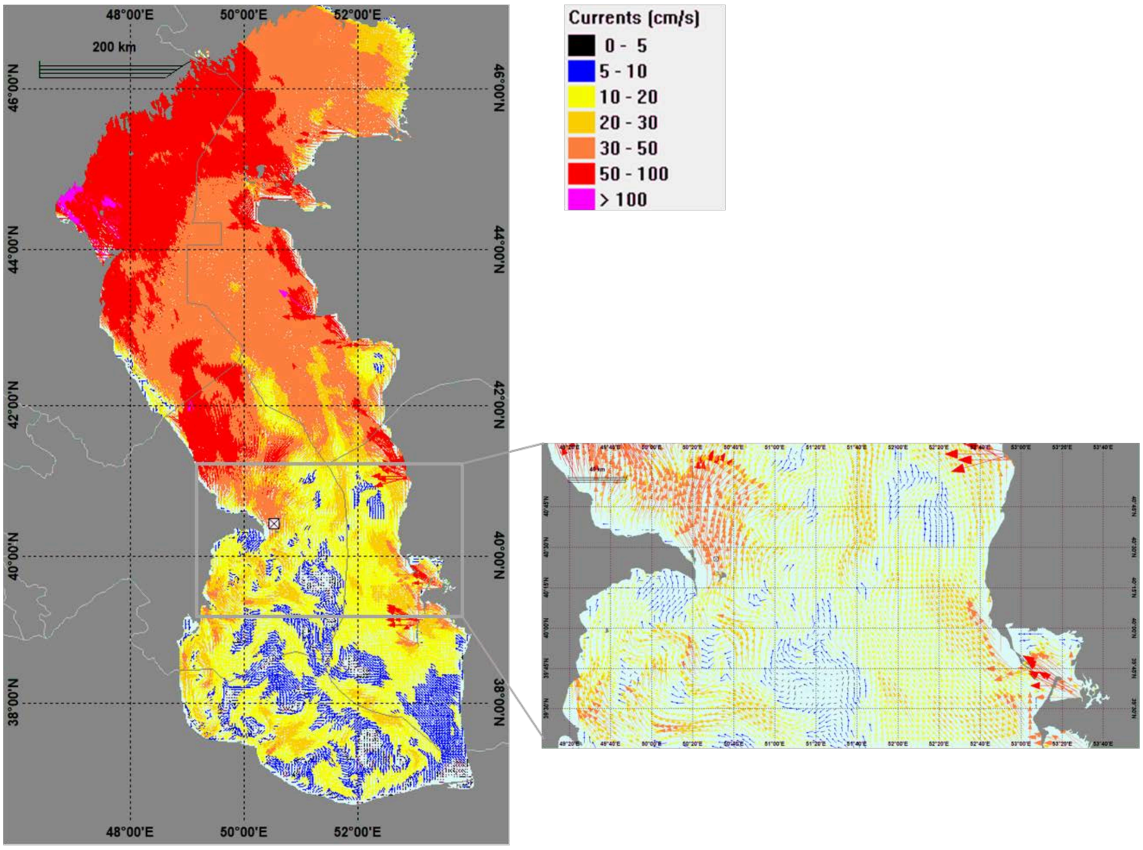


Figure 4: Example of instantaneous surface currents

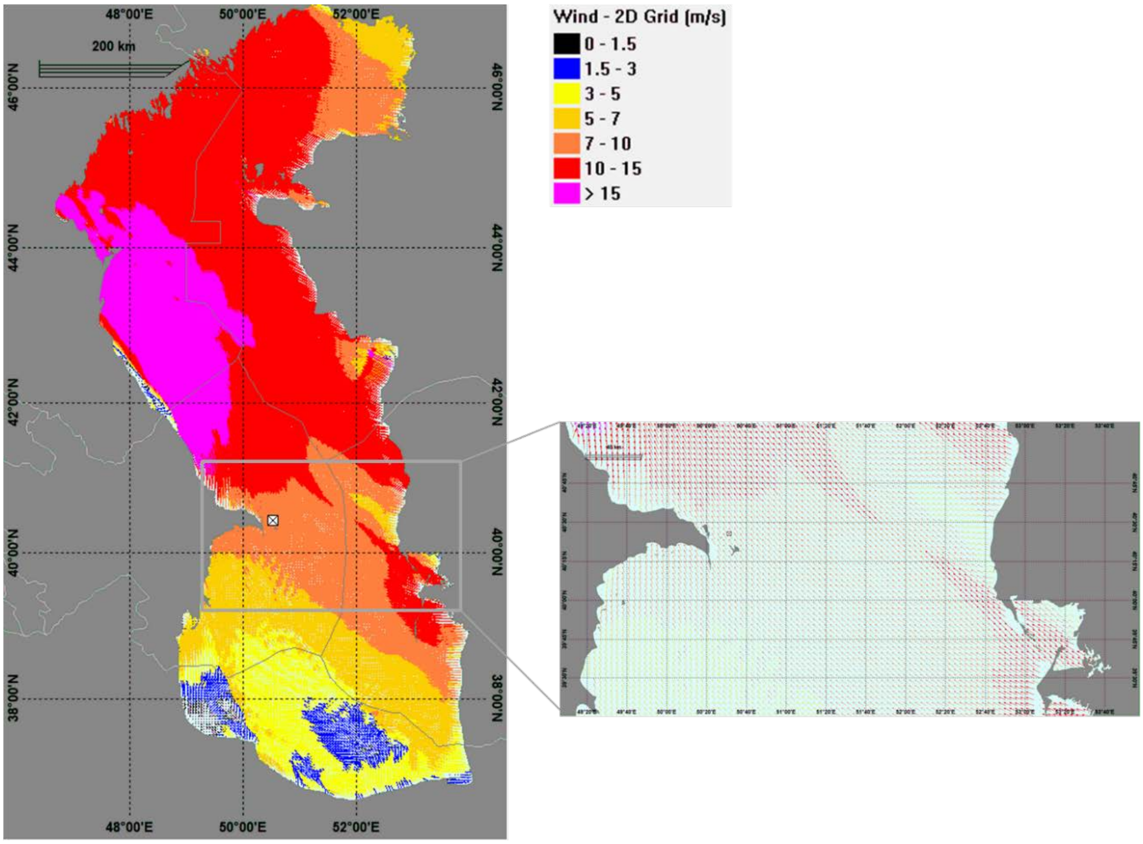


Figure 5: Example of instantaneous winds

Typical surface air temperatures and water column salinity averages were taken from Siamak *et al.* (2010) and AETC (2011) and are summarised in Table 2 .

The seawater temperature-depth profiles used in the modelling are shown in Figure 6. The values were taken from a BP Shah Deniz site survey (*per. comm.* 2013) and Kosarev (1974).

Table 2: Ambient conditions

Parameter	Summer	Winter
Surface air temperature (°C)	25	0
Salinity average (mg/l)	12.5	12.5

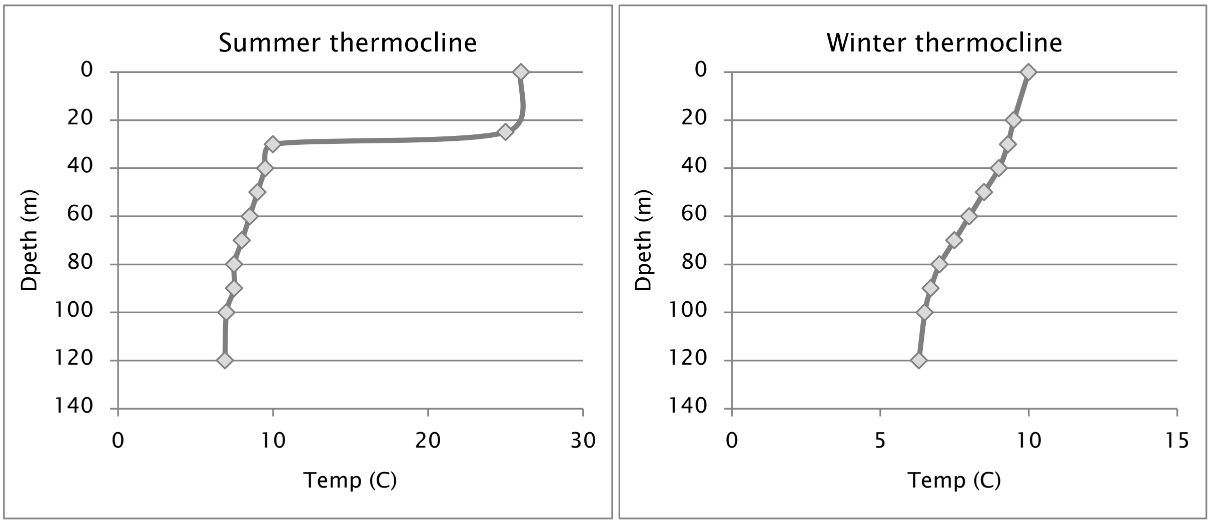


Figure 6: Summer and winter temperature-depth profiles

3.2 Bathymetry data

Bathymetry data is taken from the General Bathymetric Chart of the Oceans (GEBCO) '08' 30-arc-second grid, which has been translated into MEMW format. In turn, bathymetric grids for the Caspian Sea region were provided to GEBCO by Dr. John Hall, Geological Survey of Israel, based on bathymetric soundings digitised from Russian hydrographic charts (Hall, 2002). This differs to more recent survey data collected via ongoing projects. Currently, it is problematic to merge localised survey data with the wider GEBCO data, and changes in bathymetry would also require re-running of a hydrodynamic model to provide accurate currents. It is therefore preferable to retain the coupled bathymetry and currents even if there are some discrepancies, than attempt to merge different datasets. Oil movement largely depends on near-surface currents, which are affected little by such changes in bathymetry and the prevailing GEBCO data has been used in the model.

The bathymetry data used in the modelling is represented in Figure 7.

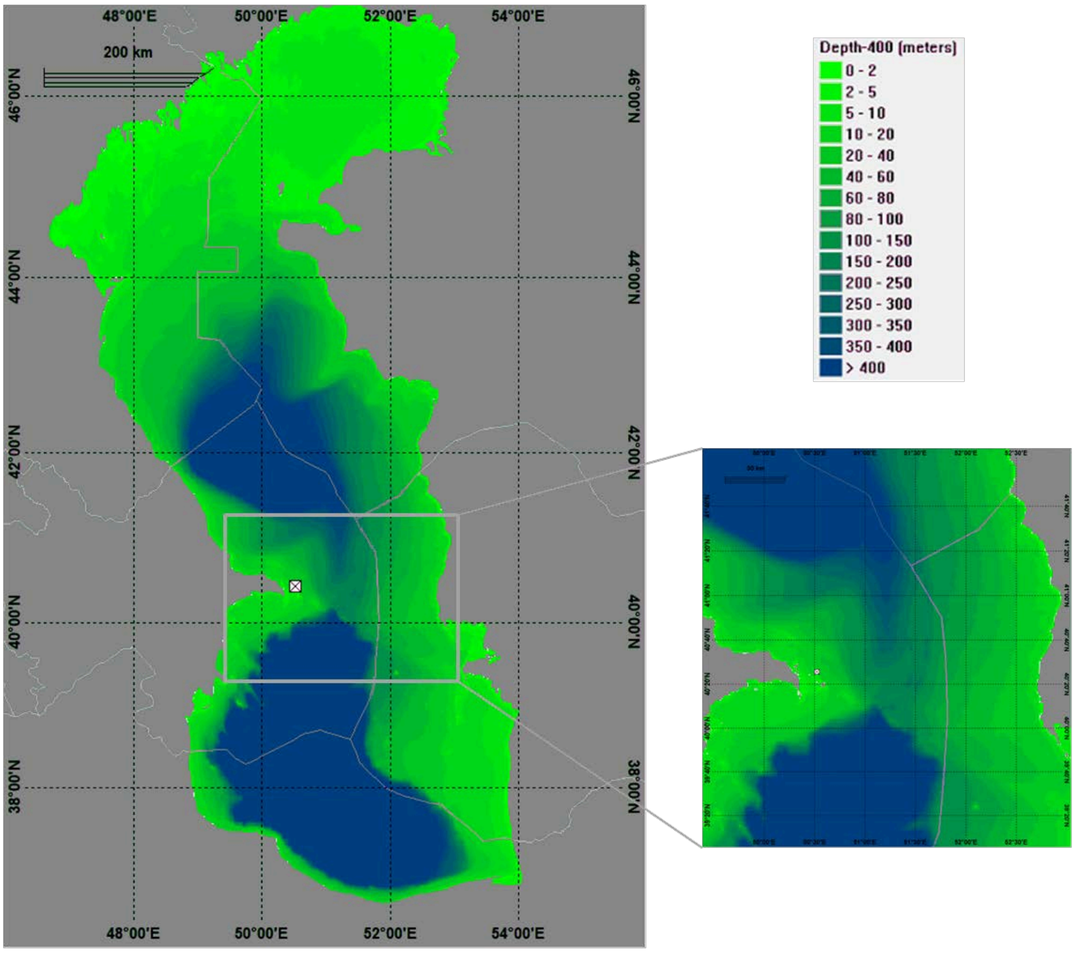


Figure 7: Regional bathymetry data used in model

3.3 Release model parameters

Key model parameters are shown in Table 3. These are chosen using experienced judgment from training received from SINTEF, the software User Guide, experience of using the model over 15 years and direct dialogue with SINTEF software developers.

3.4 Oil characterisation

The oil type used in the modelling was chosen from the OSCAR database to most closely represent the oil characteristics provided by BP of the NKX-1 well. The main oil properties are shown in Table 4. Further analysis of the oil and its weathering properties are recommended to reduce the uncertainties of the study.

Table 3: Key model settings

Model parameter	Setting used	Notes
Grid size	Blowout: 1500 m in X and Y direction, 75 m in Z direction Diesel Spill: 1000 m in X and Y direction, 75 m in Z direction	Tested to ensure results are not sensitive to changes in grid size.
Model time step	Computational time step: 20 minutes Output time step: 1 hour	Short enough to describe early stages of dispersion and ensure particles maintain continuous deposition
Number of particles	Solid/Droplet particles 20,000 Dissolved particles 10,000	Maximum recommended number of particles is 30,000 per category. Dissolved particles remain in a more homogenous pattern and fewer particles are required for equivalent accuracy.
Modelling period	Blowout: 120 days (39 days post-release) Diesel spill: 30 days (30 days post-release)	The majority of model particles have deposited or evaporated by this time. Significant environmental impacts are expected to have manifested in this time.

Table 4: Main oil properties

Property	BP provided value (analogous oil selected from OSCAR database)	Notes
Name of oil type	Abershon oil (Hago 2ss HA (IKU))	Oil type identified as most closely representing the anticipated NKX-1 oil
Specific gravity	0.887 – 0.925 (0.915)	Oil is buoyant and classed as Group IV by ITOPF
Pour Point	30 °C (30 °C)	Oil is liquid above the pour point. The crude has a high pour point and is likely to be semi-solid at ambient temperatures
Viscosity	3.5-34 (390 centipoise at 13 °C)	Further analysis is recommended to understand the oil viscosity and how readily it flows and spreads.
Asphaltene content	- (not recorded)	The presence of asphaltene would indicate the potential of the oil to form an emulsion.
Wax content	0.05 – 0.4% (not recorded)	Relatively low wax content.

3.5 Cooling water discharge model parameters

Key model parameters are shown in Table 5. These are chosen using experienced judgment from training received from SINTEF, the software User Guide, experience of using the model over 15 years and direct dialogue with SINTEF software developers.

Table 5: Key model settings – cooling water discharges

Model parameter	Setting used	Notes
Grid size	1 m by 1 m horizontally and 0.75 m depth	Fine cell size to capture small and rapidly dispersing plume
Model time step	1 second	Short enough to describe early stages of dispersion and ensure particles maintain a continuous plume
PLUME 3D	On, set to vertically downwards	Creates representative initial dynamic plume
Tracer properties	Neutrally buoyant, non-degradable, non-evaporative, completely soluble.	The plume is modelled using an inert tracer in the flow. It does not decay, evaporate or interact with the seabed. Dose rate 1000 parts per million (ppm)
Number of particles	Dissolved particles 200,000.	Greater than maximum recommended value in order to maintain a continuous plume in a fine grid and avoid false plume 'detachment' issues
Distance to nearest neighbour	Turned on	A continuous plume is expected and this feature helps to preserve plume continuity

The model is run for approximately 15 minutes. In this time, the near-field plume has stabilised in all cases allowing the potential zone of impact to be identified confidently.

4 Scenarios modelled

Table 6 and Table 7 presents the modelling scenarios which were provided by BP.

This includes the following.

1. A release of diesel from the jackup rig diesel storage, representing the largest credible spill of diesel. This is represented by the Marine Diesel oil type in the OSCAR model. A discharge duration of 1 hour is assumed to represent a puncturing of the tank.

2. A worst case blowout. If the jackup rig is anchored in a water depth of 22 m, a surface blowout release is modelled (rig cannot move off-site) which is usually worst case for surface and shoreline impacts. The release includes a mixture of oil and associated gas – the well is expected to be dry with no water anticipated to flow. A declining flow rate is modelled over a period of 81 days, the length of time calculated by BP to drill a relief well and arrest the blowout. In reality, it is extremely rare for blowouts to continue for this long, so the results are conservative.

3. A release of cooling water from the rig at a continuous rate of 750 US gallons per minute (approximately 0.05 m^3/s) via an 8-inch caisson. A discharge temperature that is 5.5°C above surface ambient temperature is adopted. The release is modelled until stable conditions are observed. A discharge depth of 5 m has been provided. Note that with the resulting discharge velocity of around 1.5 m/s, if there is gas present in the caisson then gas entrainment is very likely by the plunging liquid jet, which can give rise to a surfacing plume rather than a sinking plume. Gas entrainment is not considered in the modelling, and this uncertainty is discussed in Section 6.1.3.

Table 6: Oil spill modelling scenarios

Scenario ID	Spill Site	Spill Event	Oil Type	Spill Rate		Spill Duration	Total Spilled Volume
1	NKX-1 well location	Surface release of diesel fuel from diesel storage tank	Diesel	600 m3/hr		1 hour	600 m3
2	NKX-1 well location	Surface blowout release - worst case, declining release rate	Hago 2ss HA (IKU)	Oil1	Rate 1: 65,431 bbl/day	81 days (time to drill relief well)	810,019 m3
					Rate 2: 62,492 bbl/day		
					Rate 3: 59,846 bbl/day		
				Gas	Rate 1: 26.17 MMscf/day		
					Rate 2: 25 MMscf/day		
					Rate 3: 23.94 MMscf/day		

Note 1: Rate 1 for 30 days, Rate 2 for 30 days, Rate 3 for 21 days

Table 7: Cooling water discharge modelling scenarios

Scenario ID	Discharge flowrate (m3/s)	Pipe internal diameter (mm)	Discharge depth (m)	Season	Discharge Temperature °C	Ambient Temperature at release point °C	Current velocity[1] (m/s)
3	0.05	203	5	Summer	31.5	25	0.68
							0.12
				Winter	15.5	10	1.10
							0.16

Note 1: Given the shallow water depth, currents vary significantly through the water depth, so these values are approximate and relate to near-seabed conditions where the plume stabilises.

5 Results

This section presents the results of the modelling studies. The results of the oil spill modelling are presented in Section 5.1 and 5.2 and Section 5.3 presents the cooling water release modelling results.

For the hydrocarbon releases, key outputs from the deterministic modelling are shown in Table 6. Following the stochastic modelling (presented below), selected deterministic runs were conducted in both 'summer' and 'winter' with an overview of the results shown in Table 8 and discussed in Section 5.1 and 5.2. Note that the 'summer' scenario releases begin and end between April - September inclusive, and the 'winter' scenario releases begin and end between October - March inclusive. This captures the release with worst-case shoreline oiling, which occurs in winter.

Table 8: Deterministic results summary for hydrocarbon release scenarios

Scenario	Release location	Maximum surface extent of sheen above 0.04 µm (km)		Minimum time to beaching (days)[1]		Time until water column concentration[1] <58 ppb (days)[2]		Maximum mass onshore (tonnes)[3]	
		Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
1. Diesel	NKX-1 well	17.4	14.9	0.25	0.5	2	9	275	184
2. Blowout	NKX-1 well	459.7	470.2	0.5	6.25	> 120	> 120	50,681	64,684

Notes: 1. Dissolved and dispersed oil in water column.

2. Time from start of release

3. Mass of oil onshore excludes associated water. Crude oil is predicted to be present in an emulsion, and the mass of emulsion is expected to be around 3.3 times the mass of oil.

5.1 Scenario 1 - Diesel release results

5.1.1 Overall description of diesel behaviour from stochastic and deterministic modelling

The OSCAR model tracks the fate of diesel through the simulation as shown in Figure 8, which represents the winter conditions, but which is generally representative of the fate of diesel released at any point in the year.

Initially the majority of the diesel is present on the sea surface, and over the first two days around 20% evaporates and an increasing percentage reaches the shore. Dispersion and dissolution into the upper water column takes place close to the release point. Biodegradation also progresses relatively quickly such that a very small fraction of diesel on the water surface is left after 30 days (less than 0.44%). Ultimately 44% evaporates, 24% is biodegraded, 7% is in the water column, 19% comes ashore and 6% is deposited in sediments. Diesel can reach the shore approximately 6 hours after the initial release.

The resultant slick is relatively small and short-lived. Although it will tend to move in a single direction dependent on the exact metocean conditions at the time, the analysis of over 100 different sets of metocean data suggest that there are no dominant directions.

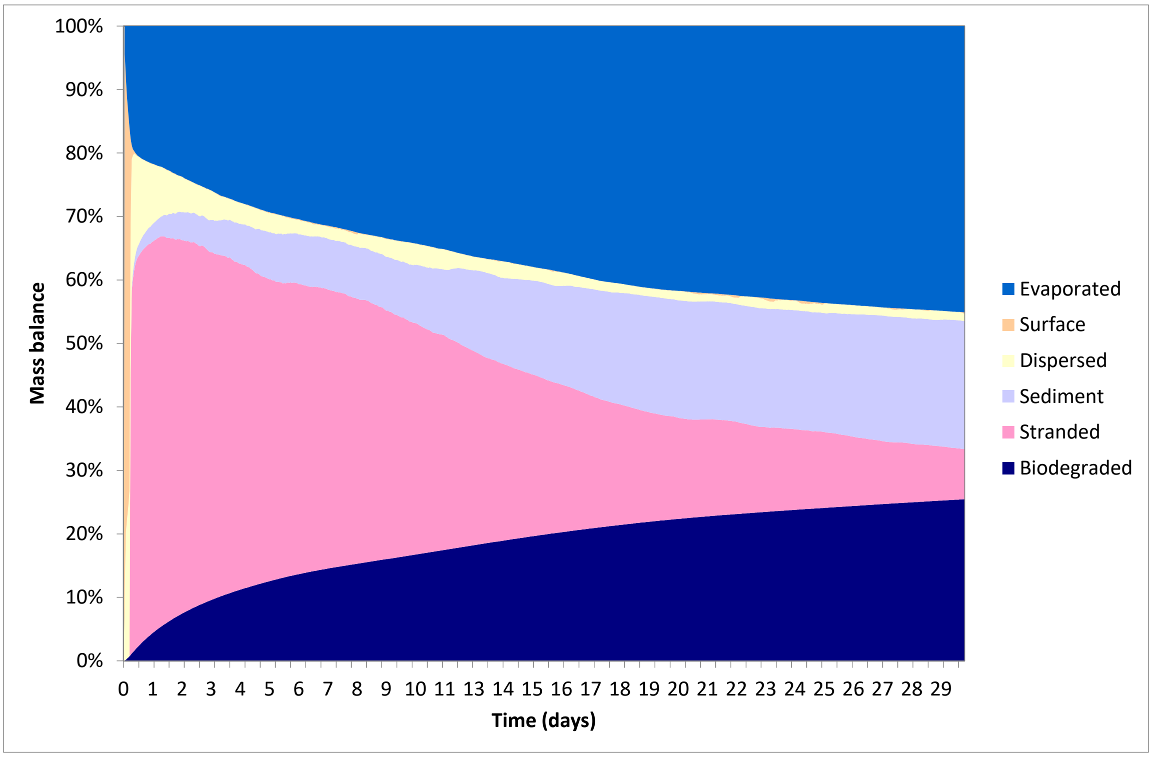


Figure 8: Diesel spill: Fate of oil during modelling period – winter

5.1.2 Stochastic modelling

Stochastic simulations in summer and winter conditions were generated encompassing over three years of varying metocean data for the 600 m^3 diesel spill scenario using 102 model runs evenly spaced through the three years' data. From these results, the worst weather periods were chosen to run deterministic scenarios under summer and winter conditions.

Table 9 summarises the key statistics for minimum beaching time and mass of shoreline diesel, and Figure 9 summarises the results in terms of simulation start date for each of these simulations. Figure 9 indicates there is low seasonal bias to the results, showing the quantity of diesel reaching shore is not correlated to the season in which the release occurs. There are a few metocean conditions in March and November/December when much larger volumes reach shore than at other times, whereas for the vast majority of conditions, less than 50 tonnes of oil (diesel) is predicted to reach shore. On release into the sea, diesel persists for relatively short periods of time and is not therefore exposed over longer periods to prevalent metocean conditions.

Table 9: Stochastic results summary

Scenario	Percentile[1]	Minimum time to beaching (days)	Mass of hydrocarbon accumulated onshore (tonnes)[2]
Diesel release	P10	0.13	5
	P50	0.38	12.9
	P90	1.25	21.1
	Worst	0.14	275

Note:

1. P90 means that in 90% of scenarios modelled, this value or less would result.
2. Mass of oil onshore excludes associated water, but this is predicted to be zero in any case since diesel is not predicted to form a stable emulsion.

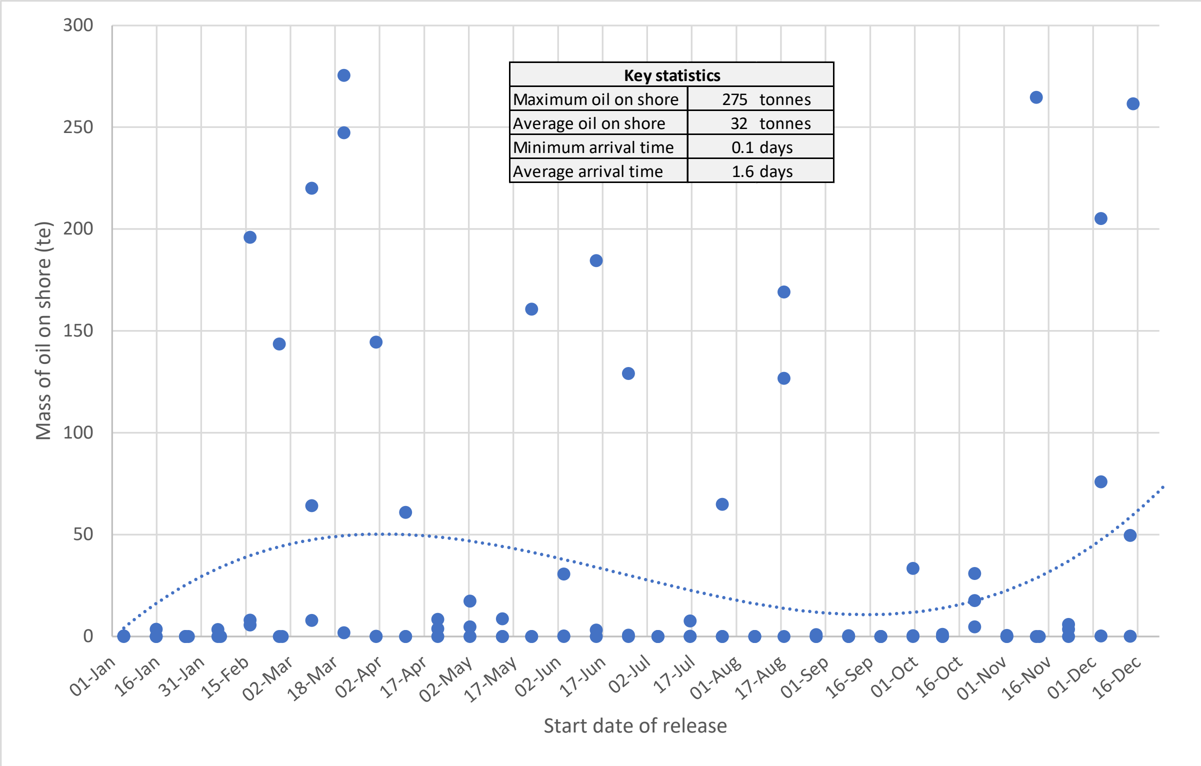


Figure 9: Distribution of oil (diesel) on shore from summer and winter stochastic analyses

Note: the average oil on shore (15 tonnes) differs slightly to the P50 (median) mass which is 13 tonnes, since the data is not linearly distributed. This data is shown in a distribution curve in Figure 10, along with minimum times of arrival ashore.

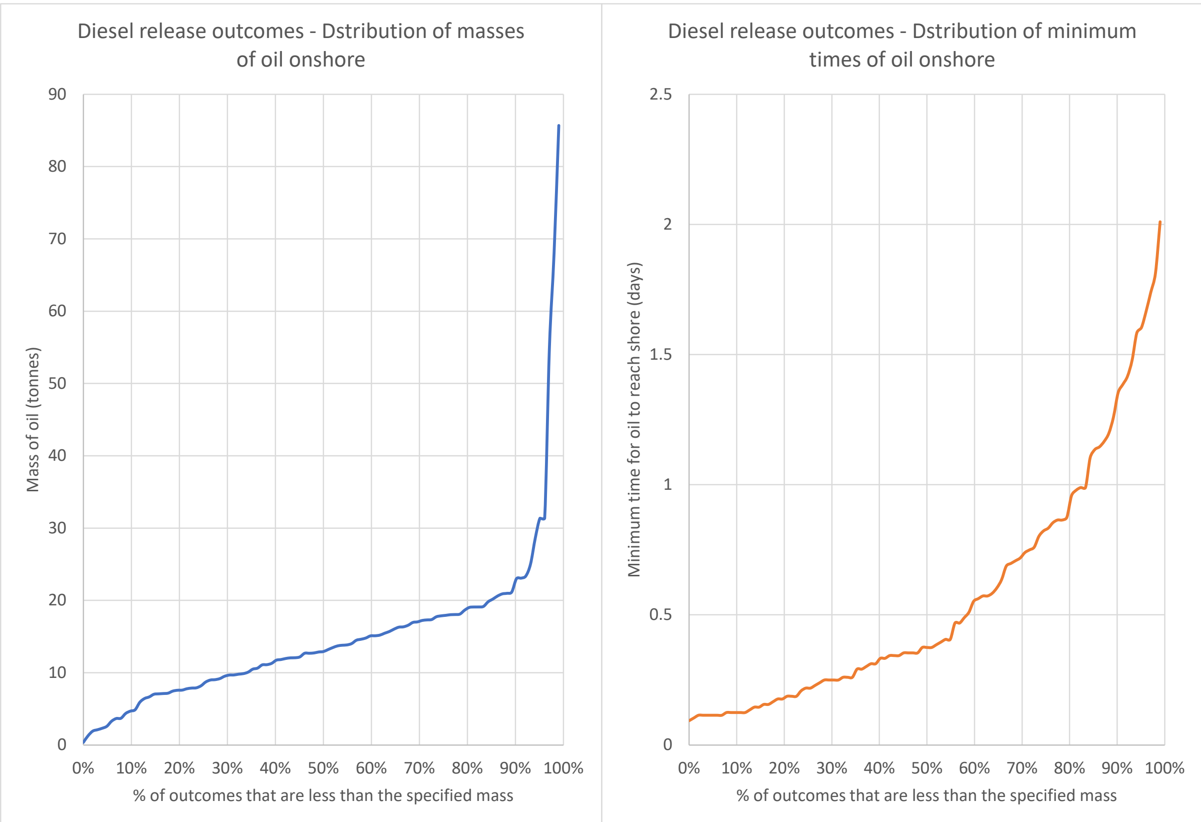


Figure 10: Statistical distribution of shoreline oil and minimum arrival times from summer and winter stochastic analyses (diesel release)

OSCAR statistical outputs are shown as follows:

- Probability of oil on the surface above the threshold of 0.04 µm (Figure 11 and Figure 12);
- Minimum arrival time of oil on the surface (no threshold) (Figure 13 and Figure 14);
- Probability of oil on the shoreline above the threshold of 100 ml/m^2 (Figure 15 and Figure 16);
- Minimum arrival time of oil on the shoreline (no threshold) (Figure 17 and Figure 18);
- Probability of oil in the water column above the threshold of 58 ppb (Figure 19 and Figure 20).

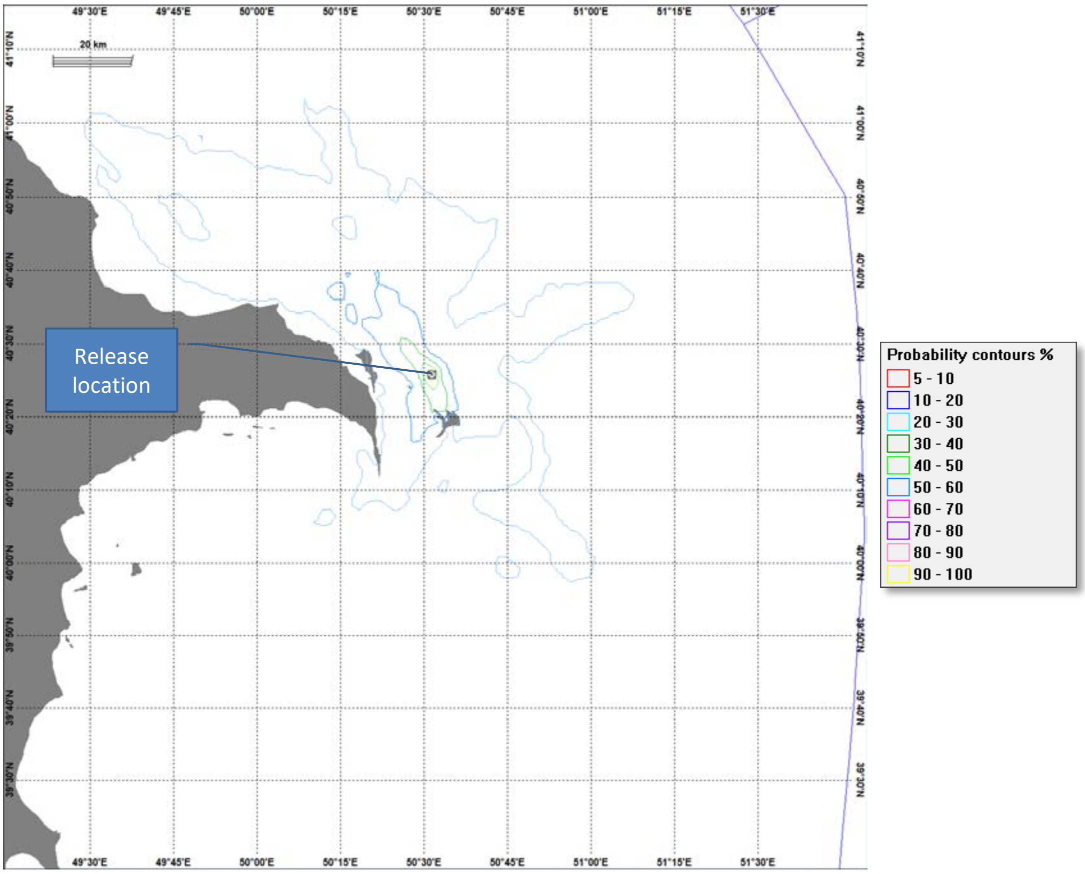


Figure 11: Diesel spill: Probability of surface oil above threshold of 0.04 μm (summer)

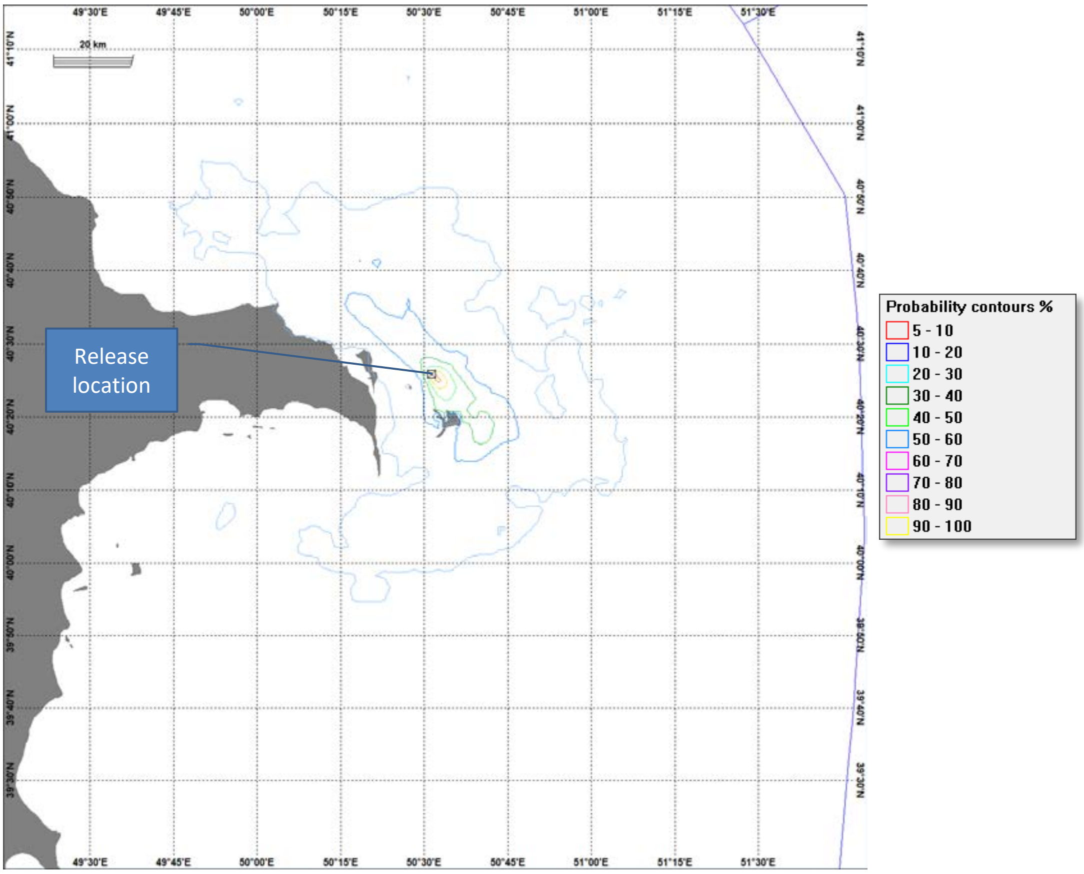


Figure 12: Diesel spill: Probability of surface oil above threshold of 0.04 μm (winter)

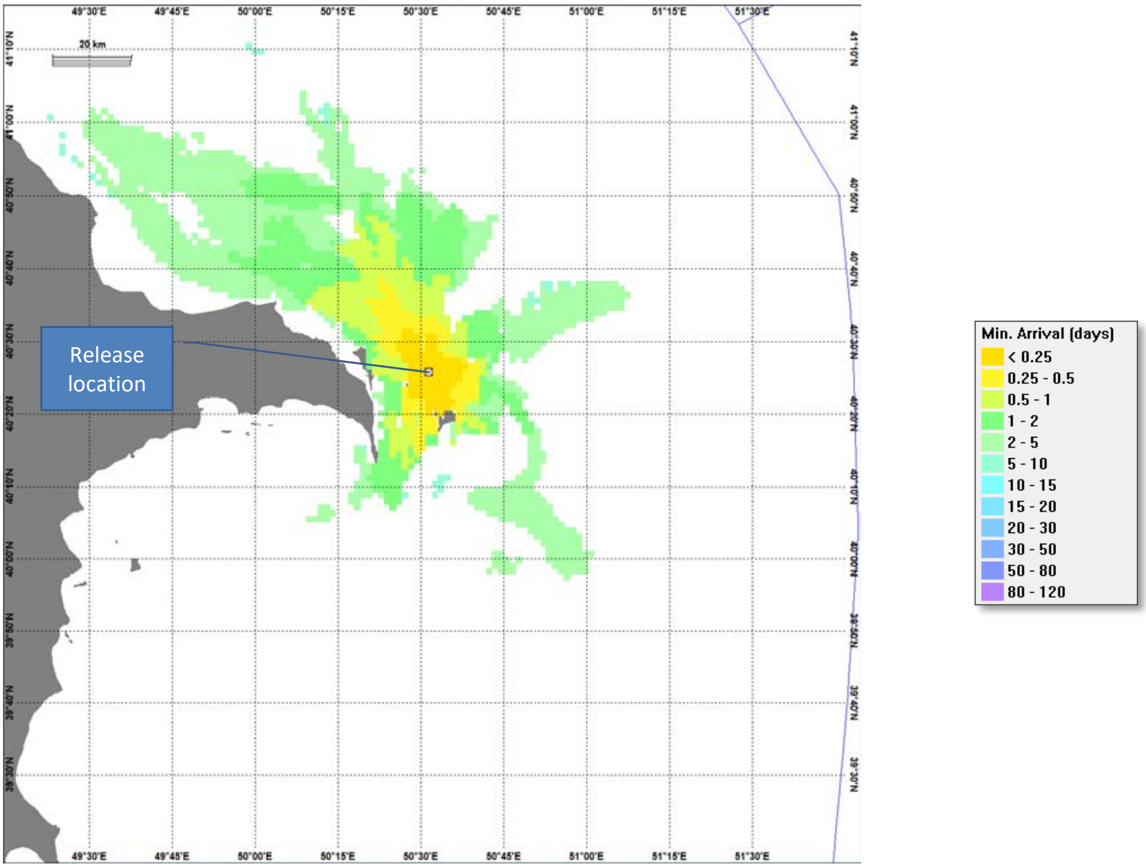


Figure 13: Diesel spill: Minimum arrival time of oil on surface (summer)

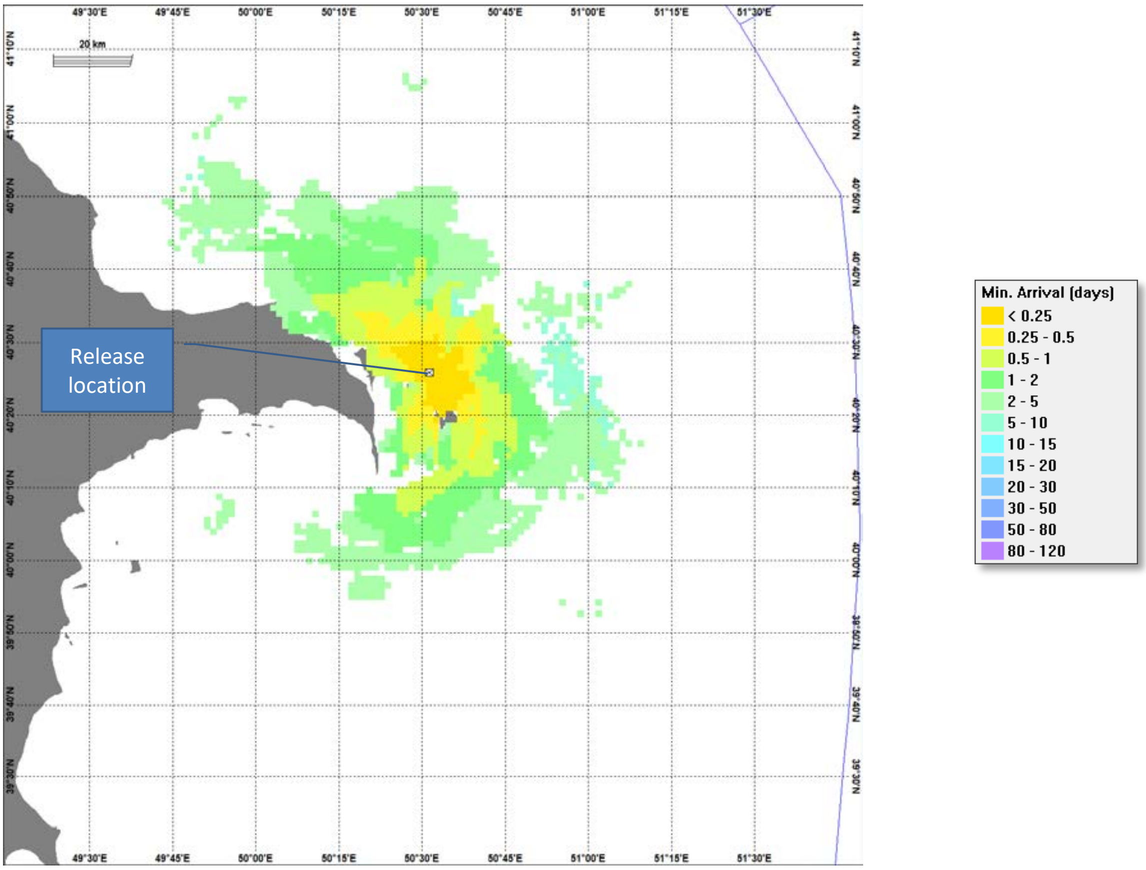


Figure 14: Diesel spill: Minimum arrival time of oil on surface (winter)

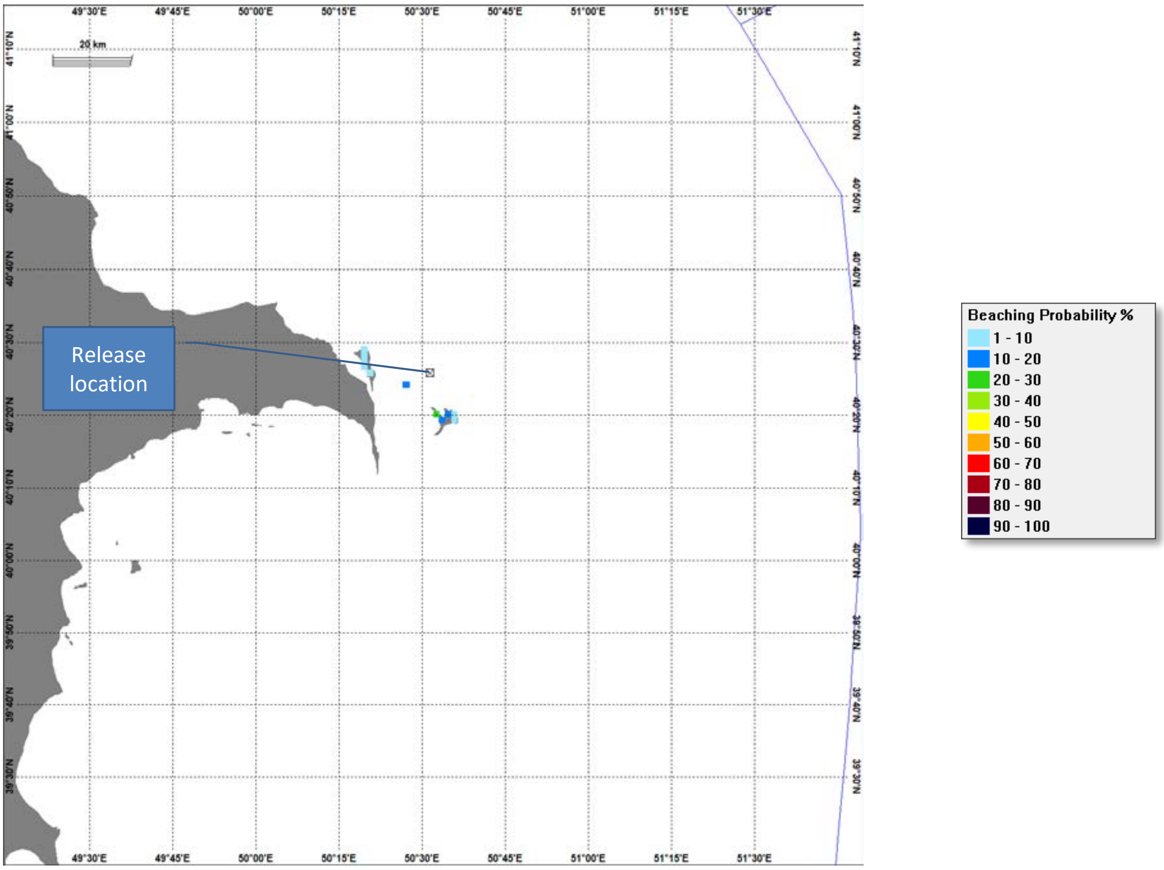


Figure 15: Diesel spill: Probability of oil on shoreline above threshold of 100 ml/m² (summer)

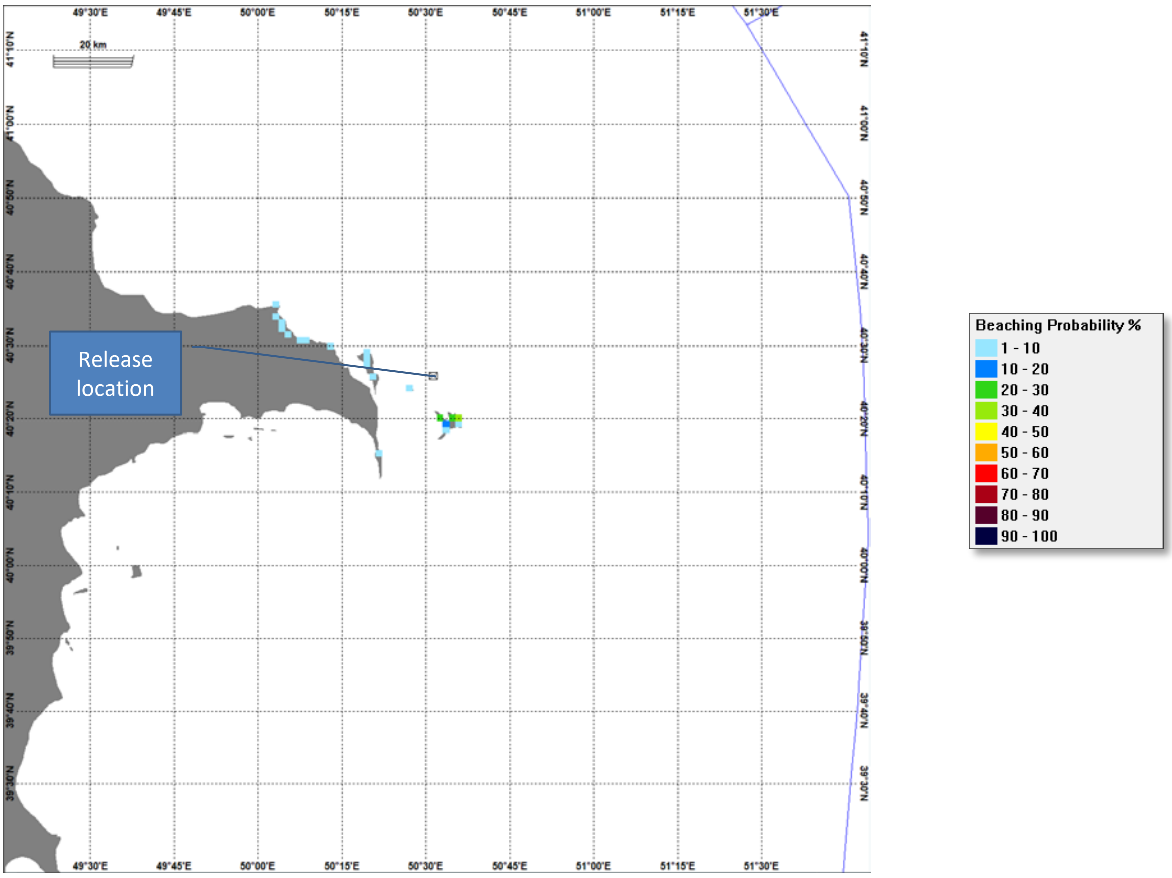


Figure 16: Diesel spill: Probability of oil on shoreline above threshold of 100 ml/m² (winter)

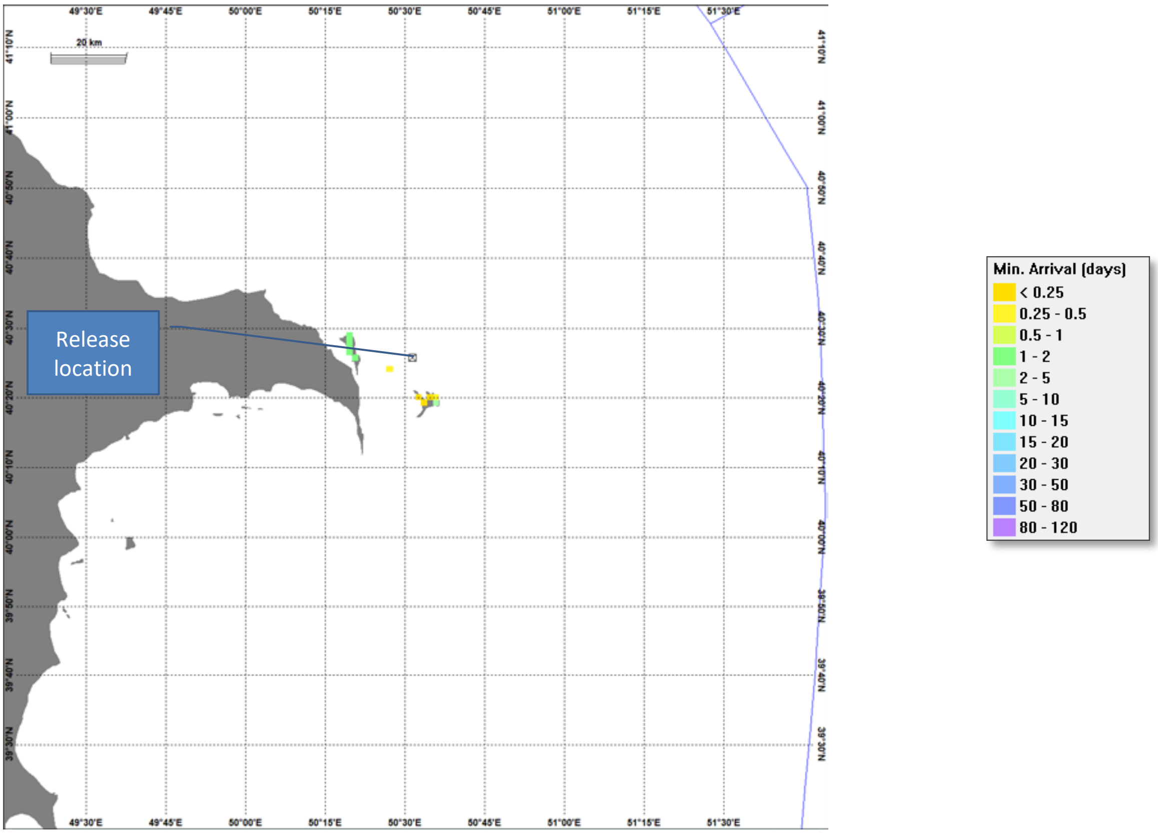


Figure 17: Diesel spill: Minimum arrival time of oil on the shoreline (summer)

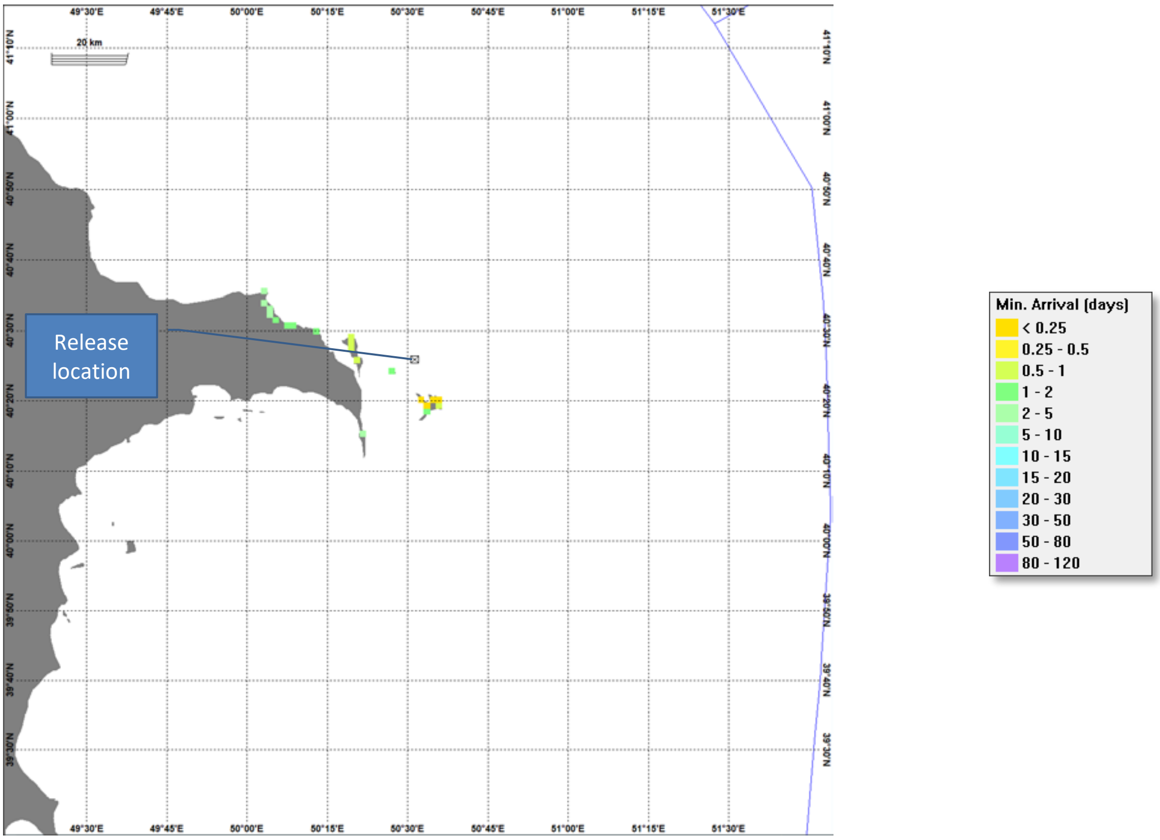


Figure 18: Diesel spill: Minimum arrival time of oil on the shoreline (winter)

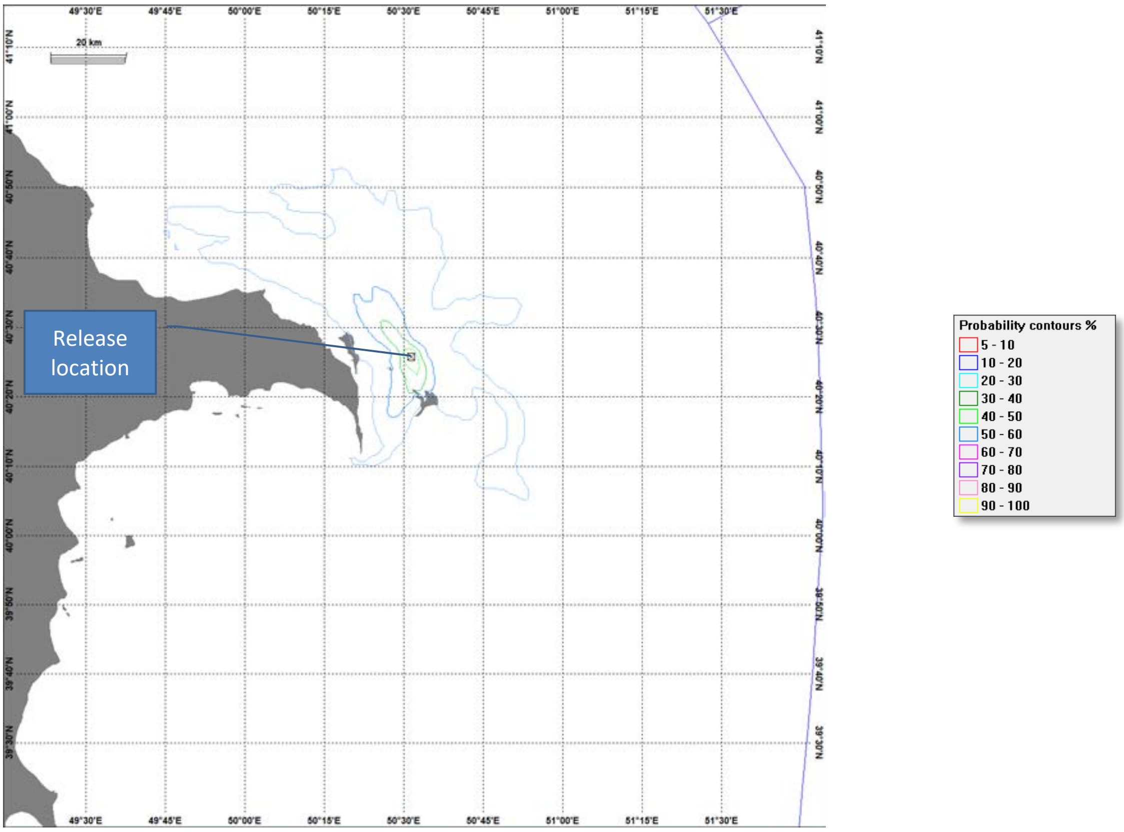


Figure 19: Diesel spill: Probability of oil in water column above threshold of 58 ppb (summer)

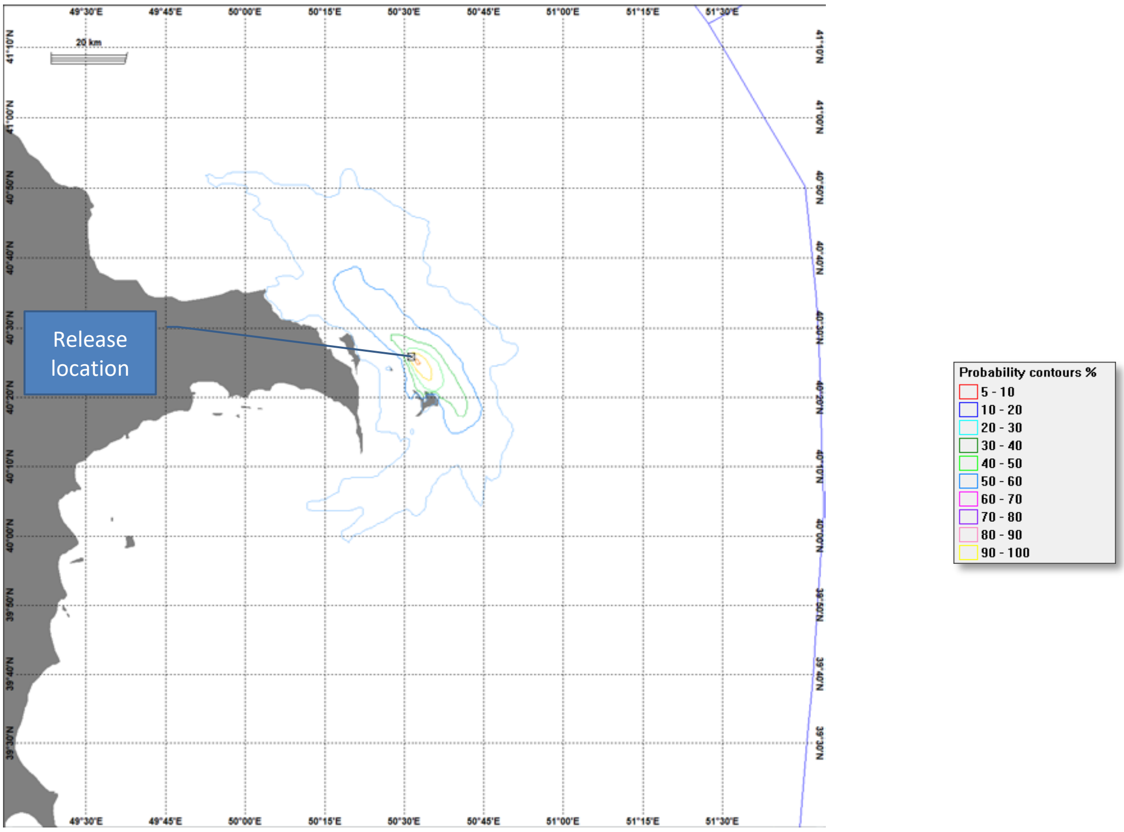


Figure 20: Diesel spill: Probability of oil in water column above threshold of 58 ppb (winter)

5.1.3 Deterministic modelling

Key outputs from the deterministic modelling are shown in Table 10.

Table 10: Deterministic results summary for diesel spill scenario

Scenario	Release location	Maximum surface extent of sheen above 0.04 µm (km)		Time until water column concentration[1] <58 ppb (days)[2]	
		Summer	Winter	Summer	Winter
Diesel spill 600 m^3	NKX-1 well	17.4	14.9	2	9

Notes: 1. Dissolved and dispersed oil in water column.

2. Time from start of release

The timing of the summer and winter deterministic scenarios is chosen to match the cases with the maximum mass of diesel reaching shore in each season.

5.1.3.1 Diesel on surface

Diesel on the sea surface is predicted to travel less than 20 km in these two sets of conditions before it drops below the lowest recognised visible thickness under ideal viewing conditions (Figure 21 and Figure 22). Since these cases are confined by land at their endpoints, it is possible that the sheen could extend further if metocean conditions were to take the diesel in an offshore direction.

Thicker areas of diesel that are more likely to be associated with environmental impacts are restricted to a smaller radius around the spill.

Since these cases are confined by land at their endpoints, it is possible that the sheen could extend further if metocean conditions were to take the diesel in an offshore direction.

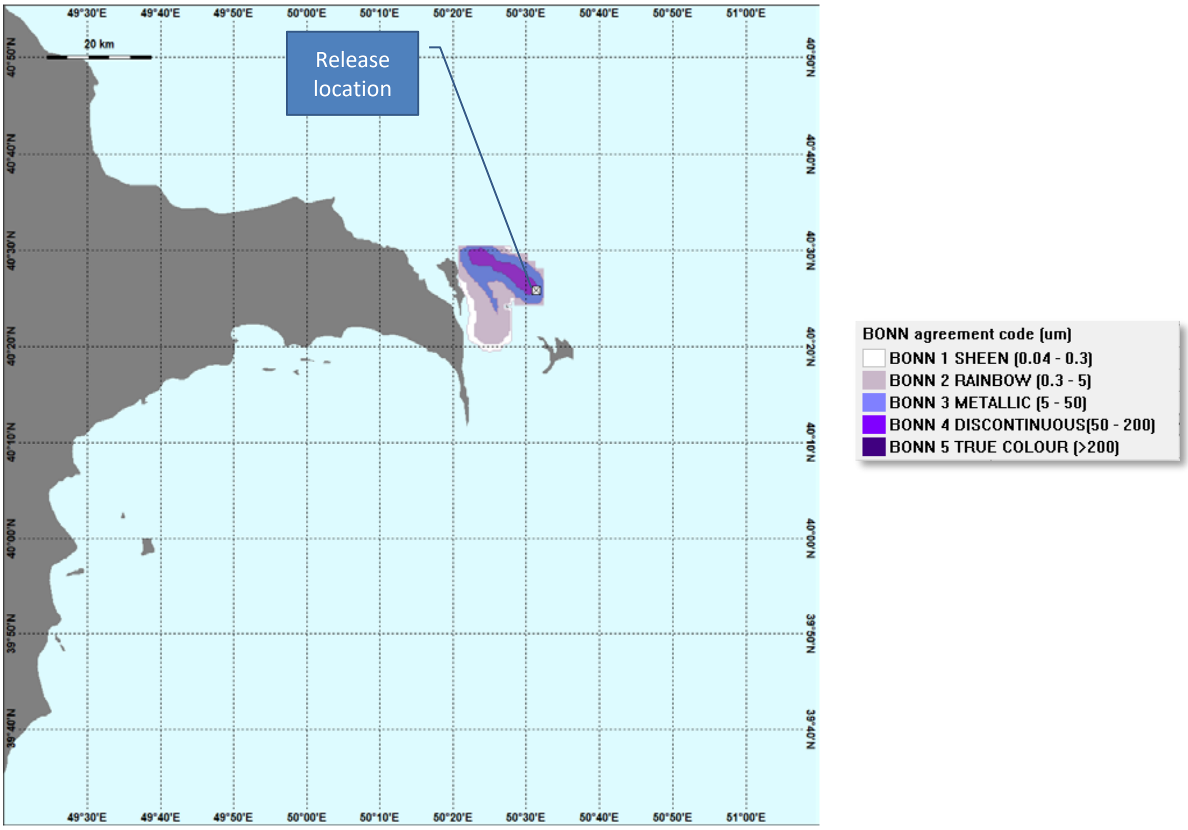


Figure 21: Diesel spill: Cumulative area of surface sheen - summer

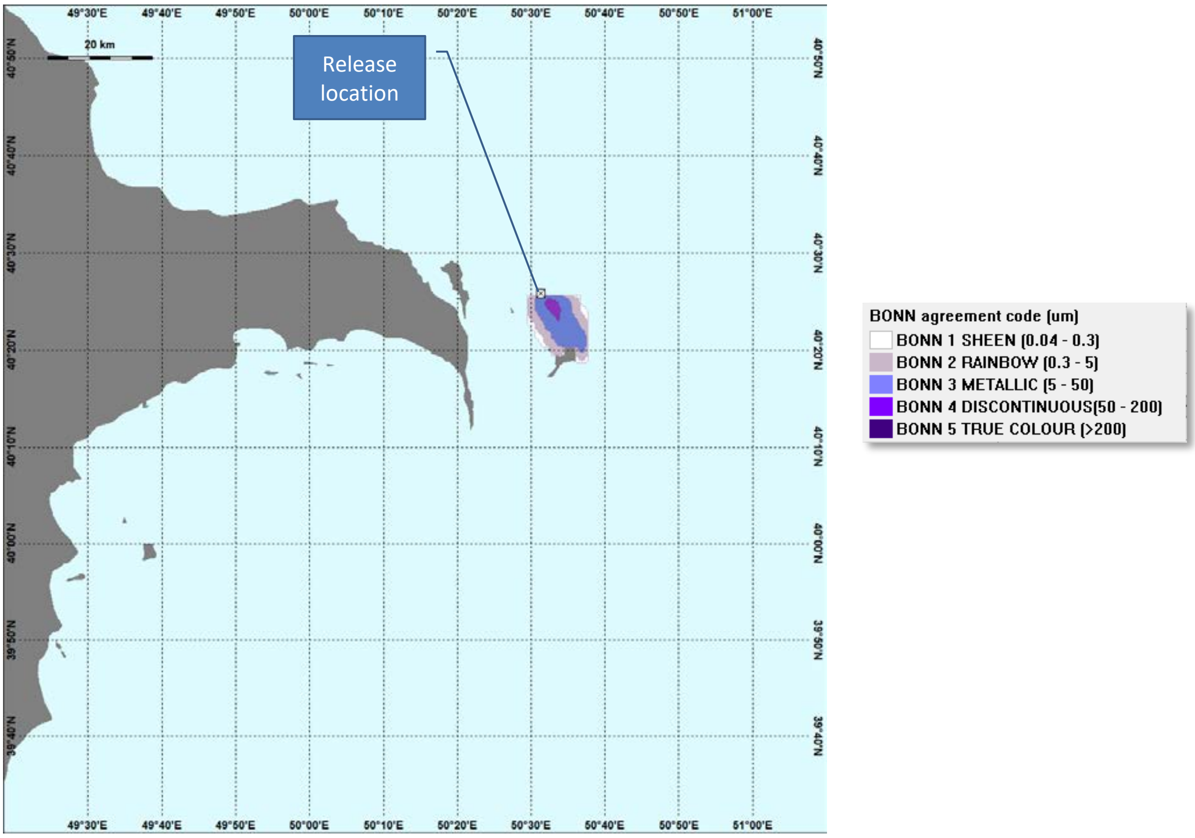


Figure 22: Diesel spill: Cumulative area of surface sheen - winter

5.1.3.2 *Diesel on shore*

Diesel accumulation on shore for the summer deterministic case is shown in Figure 23 and the winter deterministic case is shown in Figure 24. These represent the deposition of diesel on the shore at the end of the simulation when the maximum length of coastline is affected. This distribution is very similar to the distribution at which the maximum mass of shoreline deposition occurs, and so this is not shown in addition. The summer case results in diesel reaching shoreline along the Azerbaijan coast. The case presented for winter results in more localised shoreline deposition. A mixture of areas of very light, light and moderate deposition are present.

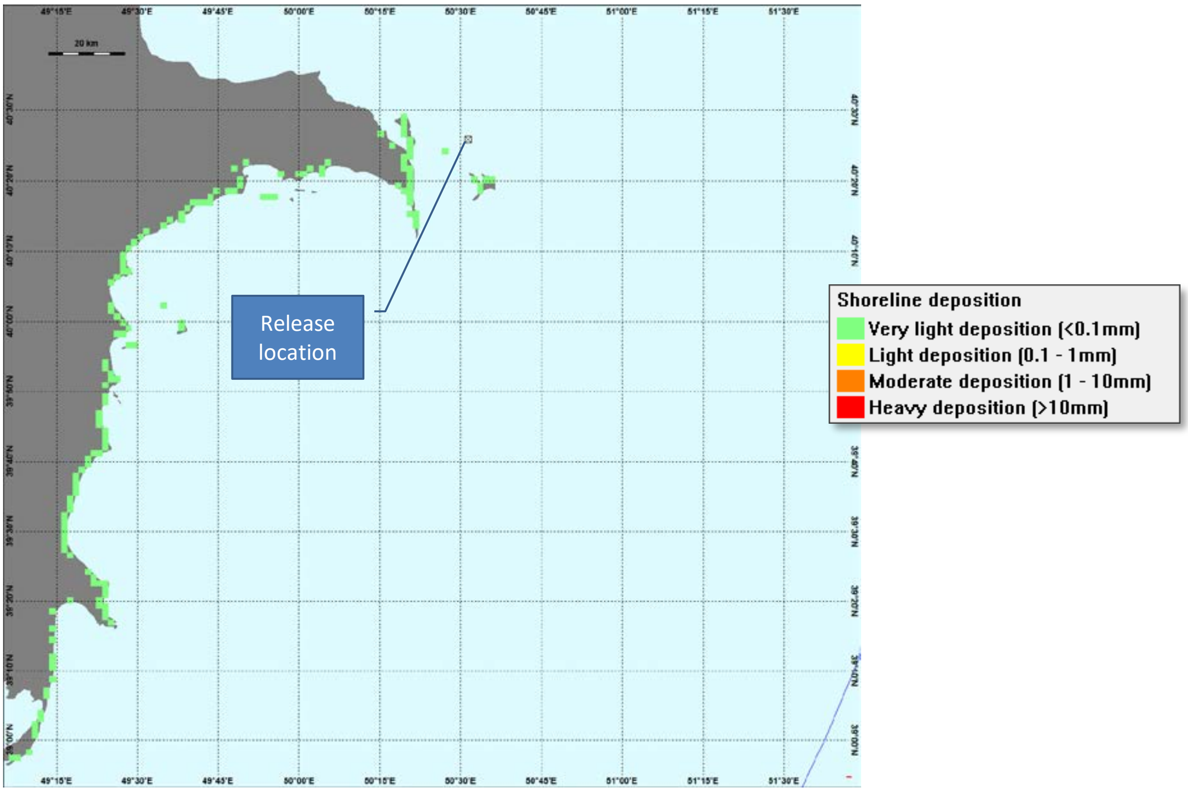


Figure 23: Diesel on shore - summer

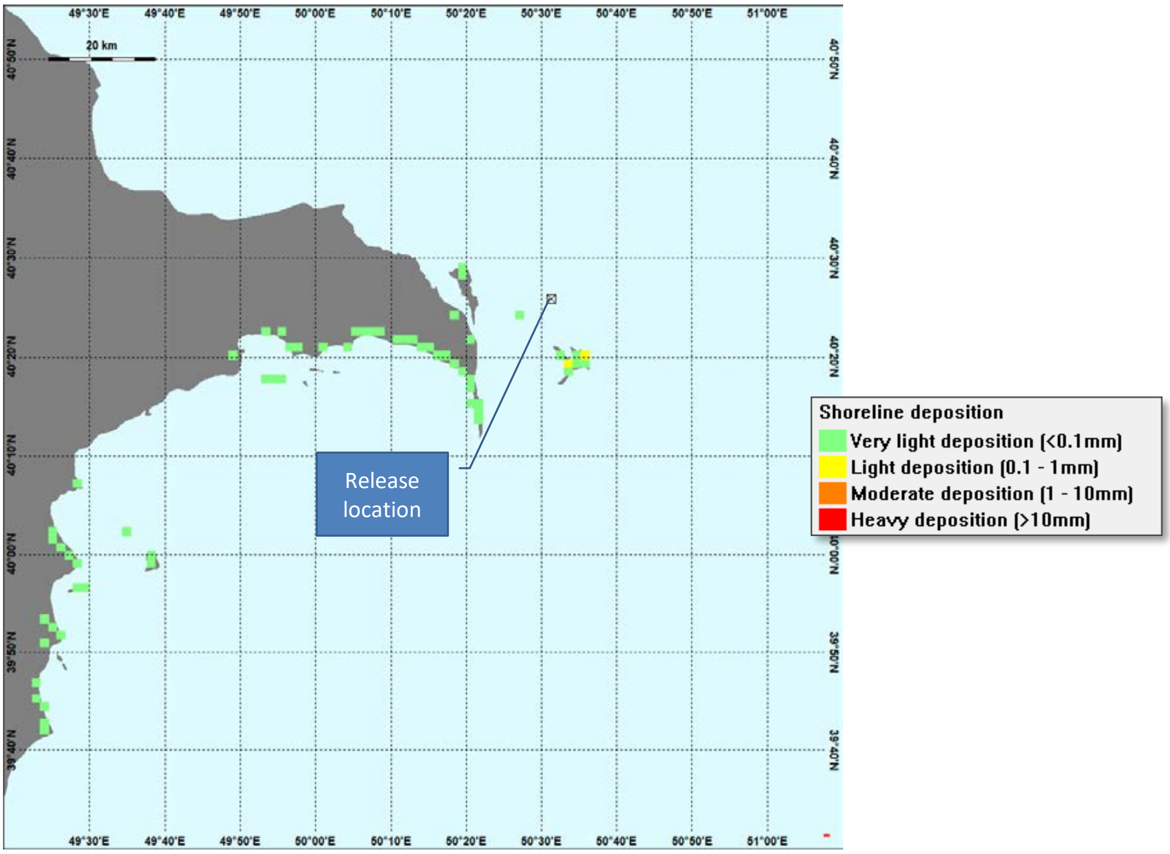


Figure 24: Diesel on shore - winter (length of shoreline affected at end of simulation)

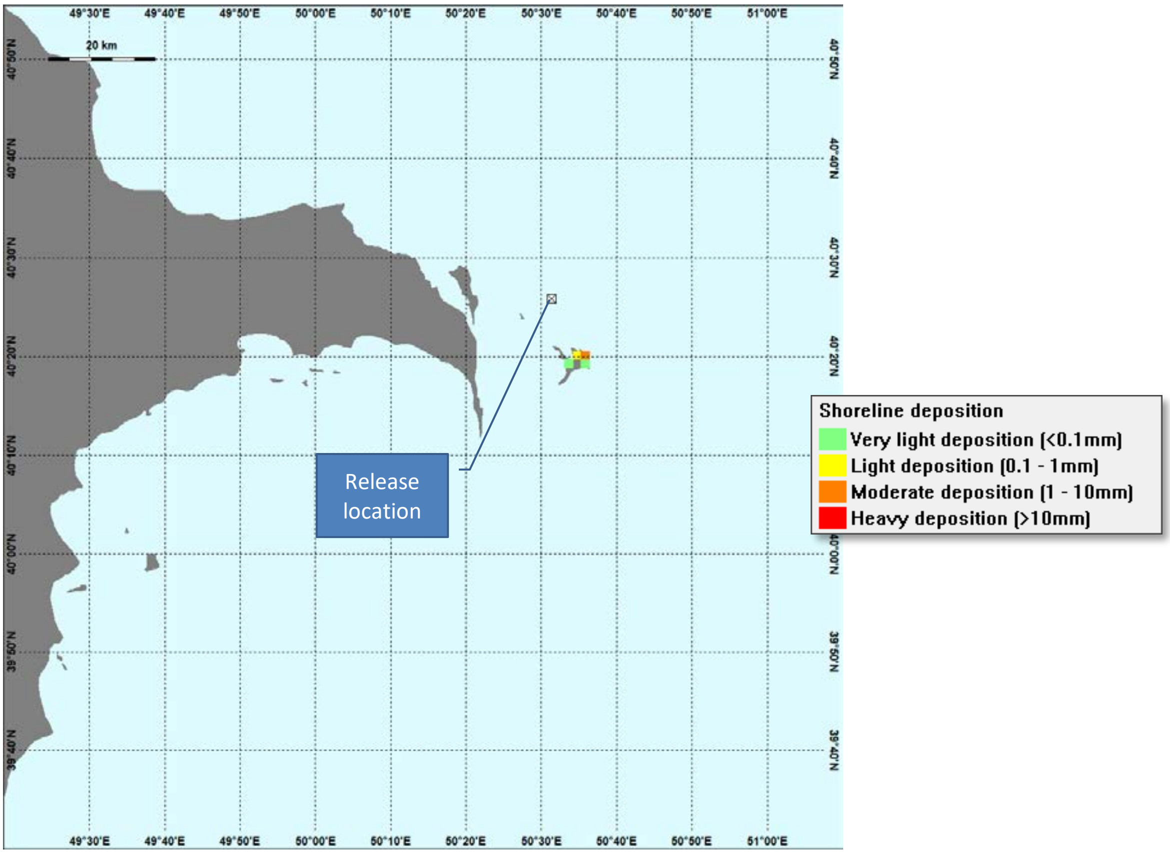


Figure 25: Diesel on shore - winter (maximum mass of diesel on shoreline)

5.1.3.3 *Diesel in the water column*

The extent of diesel in the water column is confined to 20 km from the release and tracks the path of the surface release. The area is affected for up to 9 days after the release before the oil disperses below the threshold levels, as shown in Figure 26 and Figure 27 representing the deterministic cases run in summer and winter including both dissolved and dispersed oil in the water column. In each figure, the output is the total area the diesel has covered as it has moved away from the release location. The cross section through the water column shows that the release remains in the upper sections of the water column, particularly in the case presented for winter.

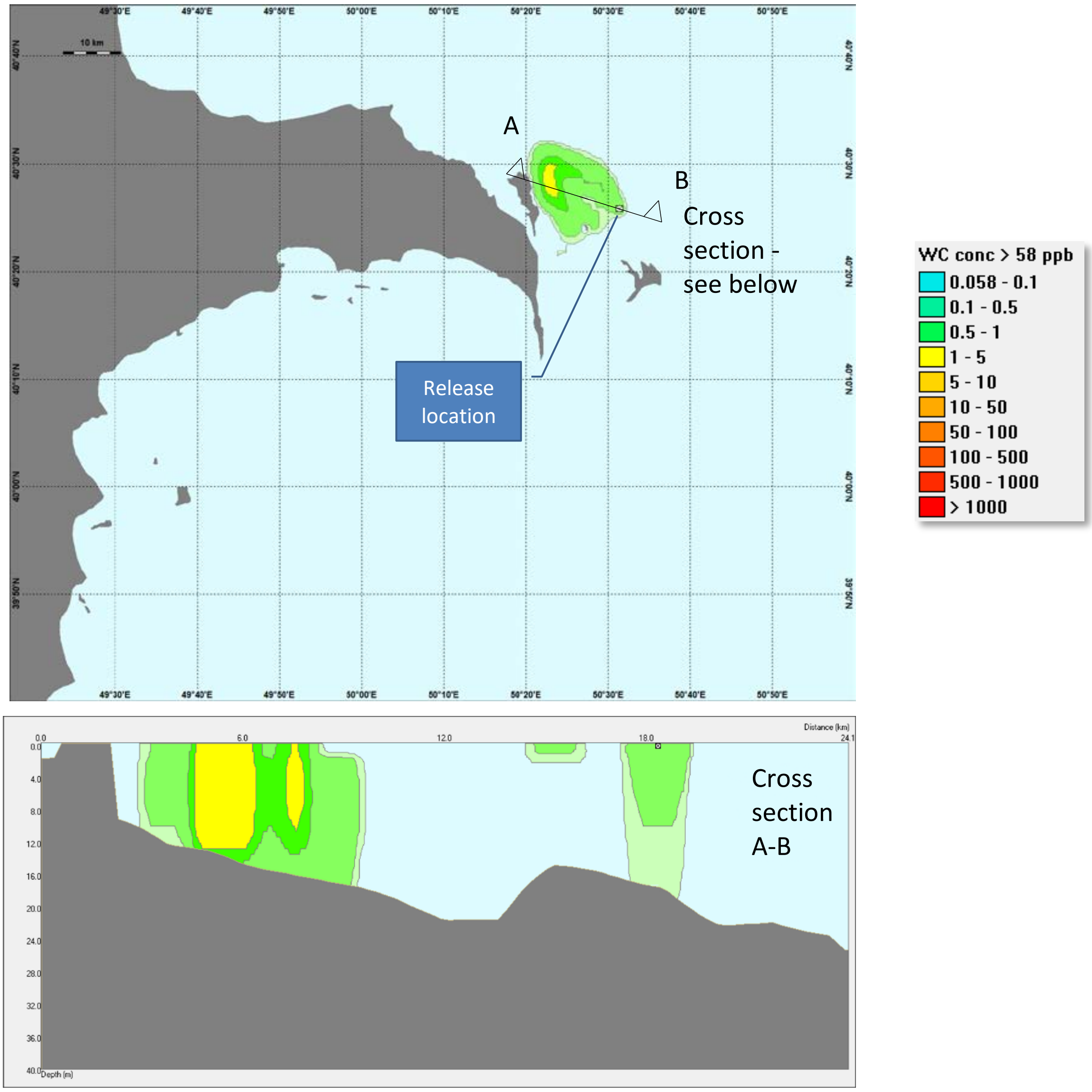


Figure 26: Diesel spill: maximum affected area of water column during simulation - summer

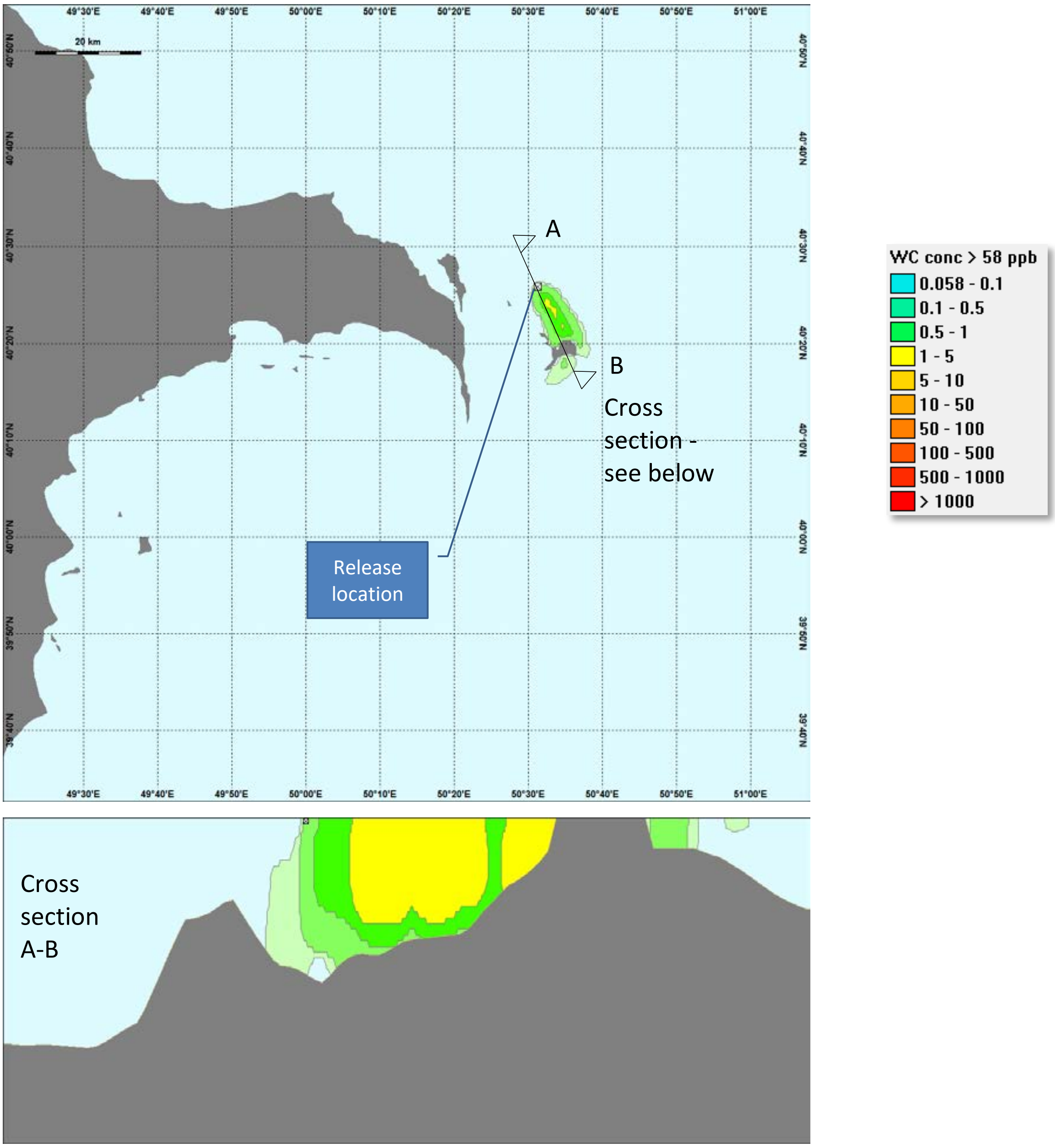


Figure 27: Diesel spill: maximum affected area of water column during simulation - winter

5.1.3.4 Diesel in sediments

By the end of the scenario, around 6% of the diesel is predicted to have deposited in sediments, predominantly in the adjacent shallow waters of the Absheron peninsula. In summer, the areas of deposition above 10 mg/kg is shown in Figure 28 and occupies a small area around 3 km by 1 km towards the shoreline. In the winter scenario in Figure 29, two areas further south are affected, approximately 3 km by 2 km each in area. This is likely to have a short term and localised effect. The potential impact of oil (including diesel) in sediments is discussed in more detail in section 5.2.3.4.

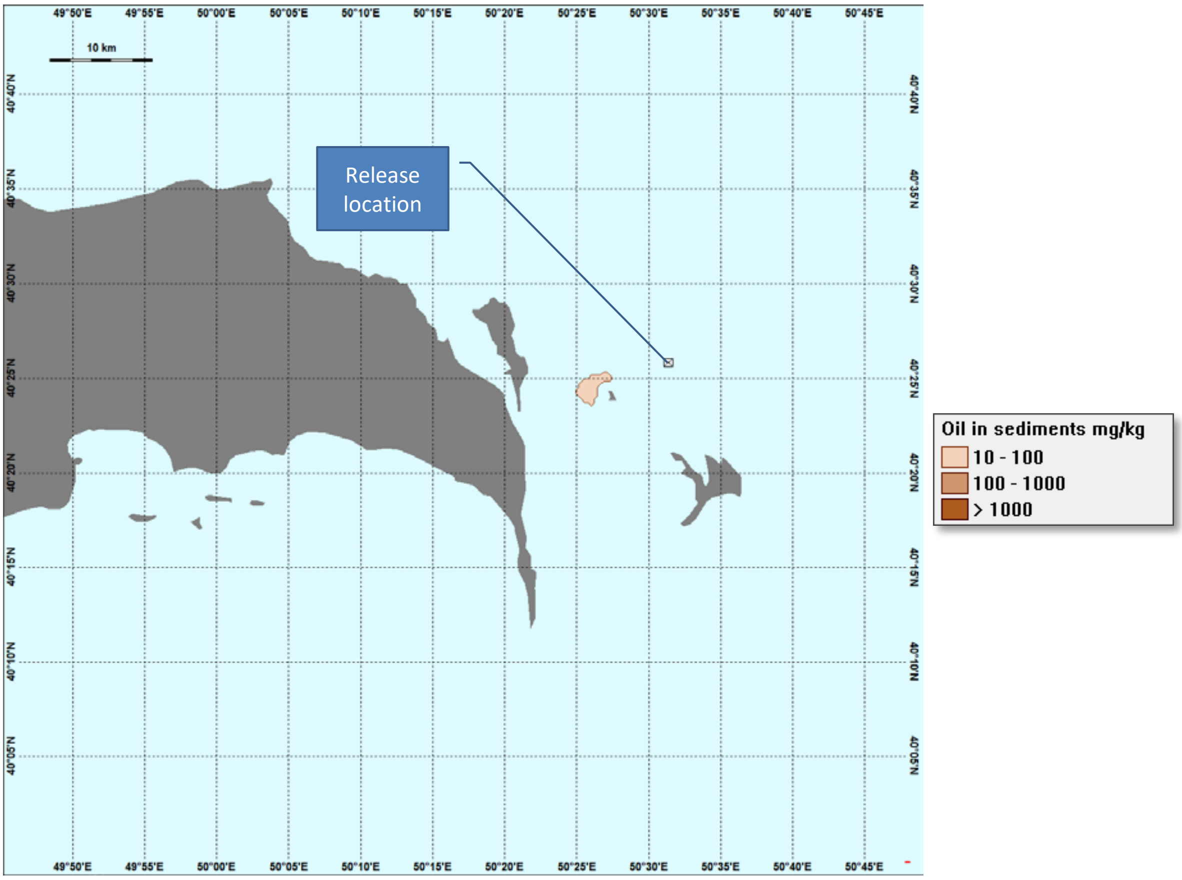


Figure 28: Worst case blowout: maximum mass of diesel deposited in sediments - summer

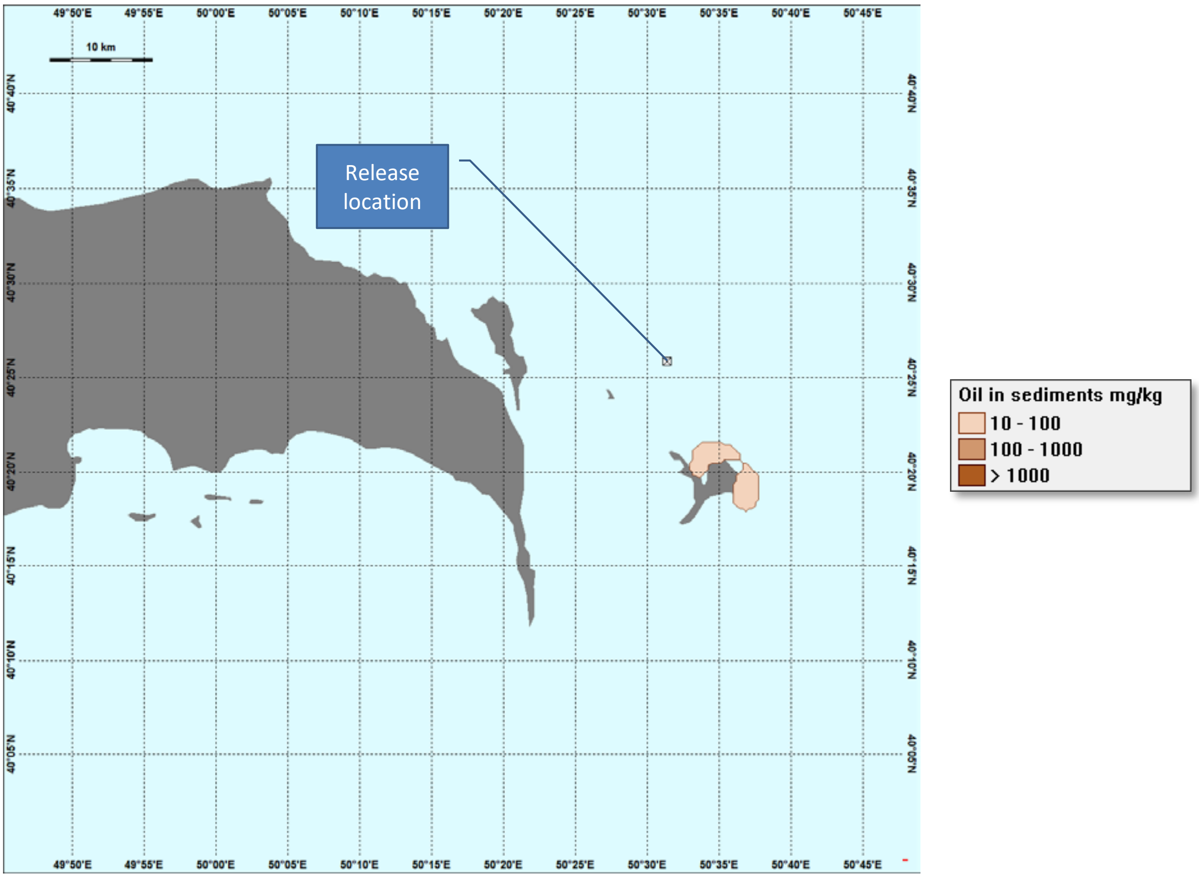


Figure 29: Worst case blowout: maximum mass of diesel deposited in sediments - winter

5.2 Scenario 2 – Worst case blowout results

5.2.1 Overall description of oil behaviour from stochastic and deterministic modelling

The OSCAR model tracks the fate of oil through the simulation as shown in Figure 30, which represents the winter conditions, but which is generally representative of the fate of oil released at any point in the year.

Initially the majority of the oil is present on the sea surface. During the modelled period, some oil gradually evaporates, reaching around 11% of the total spilled oil volume by the end of the simulation period (120 days). During the blowout period of 81 days, oil is continually supplied to the sea surface, and oil on the surface remains significant until after the end of this period. Dependent on the wind and waves, oil can be mixed into the water column and some oil can subsequently re-surface during calmer periods. After around half a day, oil begins to deposit in sediments, eventually accounting for around 57% of the oil at the end of the simulation. In this example, oil reaches the shore after approximately 2 days, although the fraction on shore does not exceed approximately 8% of the total throughout the simulation period.

Ultimately 11% of the oil evaporates, 22% is biodegraded, 2% remains in the water column, 57% is deposited in sediments with approximately 8% on the shoreline and a relatively high <1% remains on the sea surface.

In this example, the majority of oil initially moves south towards southern Azerbaijan. After day 19, however, the winds and currents shift and oil is moved northwards, oiling the north Azeri coast and travelling into the northern Caspian. Although the precise movement of the surface oil is dependent on the exact metocean conditions at the time, the analysis of over 100 different sets of metocean data suggest that these two directions are dominant, and that the most likely locations to receive oil on shore are Azerbaijan, Russia and northern Iran.

The area of water column affected tends to track the surface oil location and is predominantly mixed within the upper 30 m of the water depth over the course of the simulation, although transient concentrations above the threshold may occur down to 70 m depth over a wide area.

Oil reaches shore in substantial amounts, quickly, with the 50^{th} percentile values for initial shoreline oiling being 0.38 days and 34,675 tonnes of oil, and a maximum shoreline oiling value of 64,684 tonnes.

The oil is predicted to emulsify to a water content of 60% within 6 hours of release and remain in a stable emulsion state for a long period thereafter. Therefore, in term of masses of emulsion at the shoreline, the results should be interpreted as being 3.3 times the mass of oil.

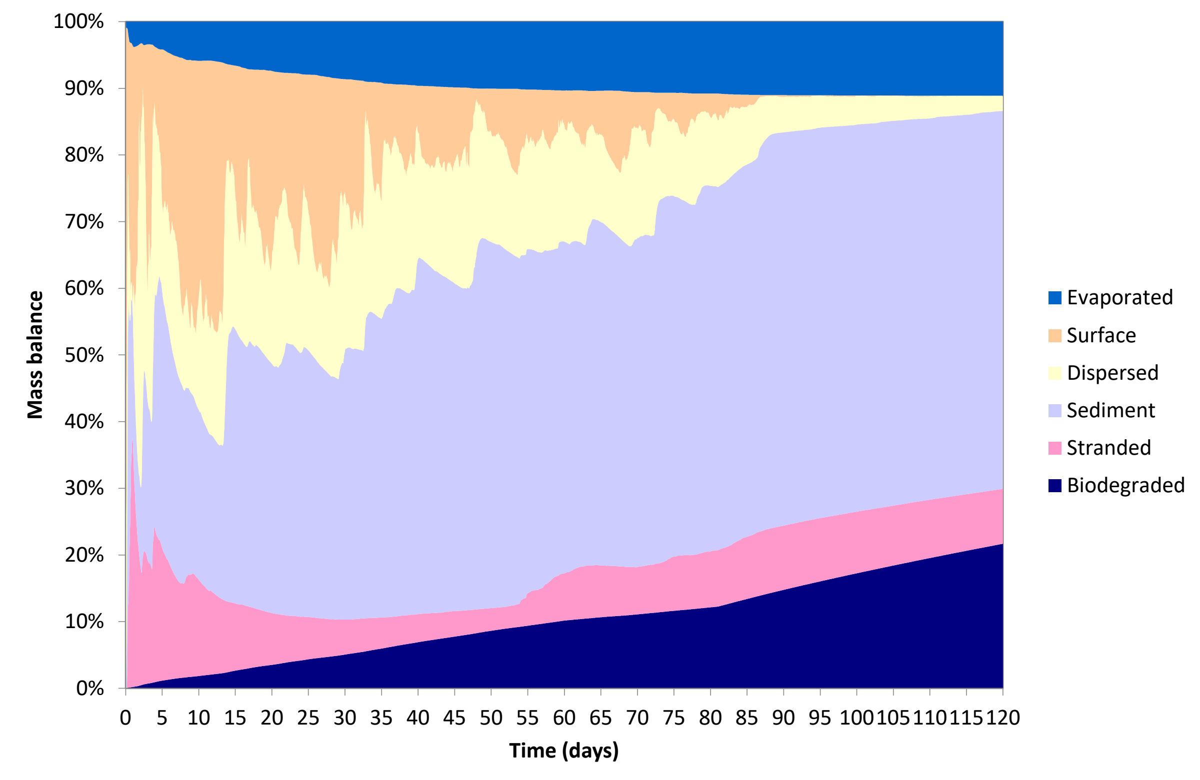


Figure 30: Worst case blowout: Fate of oil during modelling period – winter

5.2.2 Stochastic modelling

Stochastic simulations were generated encompassing year-round varying metocean data for the worst case blowout scenario of 810,019 m^3 of crude oil using 102 model runs evenly spaced through the three years' data. From these results, the worst weather periods were chosen to run deterministic scenarios under summer and winter conditions.

The results for shoreline oiling for each of these simulations are represented in Figure 31 and statistics summarised in Table 11. There is a clear seasonal bias to the results, showing blowout start times of February - May are likely to result in much larger volumes of oil arriving on shore than at other times of the year. Between September and December, the likely amounts of oil reaching shore are far lower.

Table 11: Stochastic results summary

Scenario	Percentile[1]	Minimum time to beaching (days)	Mass of oil accumulated onshore (tonnes)[2]
Worst case blowout	P10	0.13	17,212
	P50	0.38	34,675
	P90	1.25	46,669
	Worst	0.14	64,684

Notes:

1. P90 means that in 90 % of scenarios modelled, this value or less would result.
2. Mass of oil onshore excludes associated water. Crude oil is predicted to be present in an emulsion, and the mass of emulsion is expected to be around 3.3 times the mass of oil.

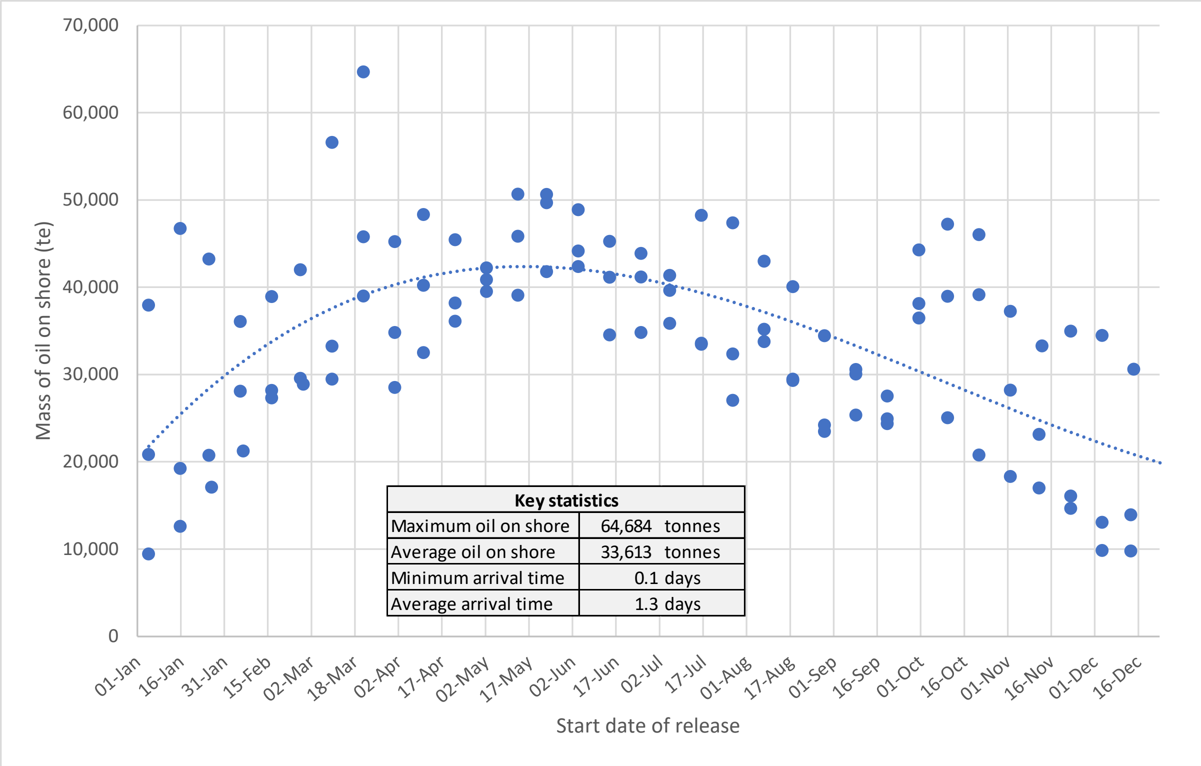


Figure 31: Seasonal distribution of oil on shore from stochastic analysis

1. Notes: The average oil on shore (33,613 tonnes) differs slightly to the P50 (median) mass given above.
2. Mass of oil onshore excludes associated water. Crude oil is predicted to be present in an emulsion, and the mass of emulsion is expected to be around 3.3 times the mass of oil.

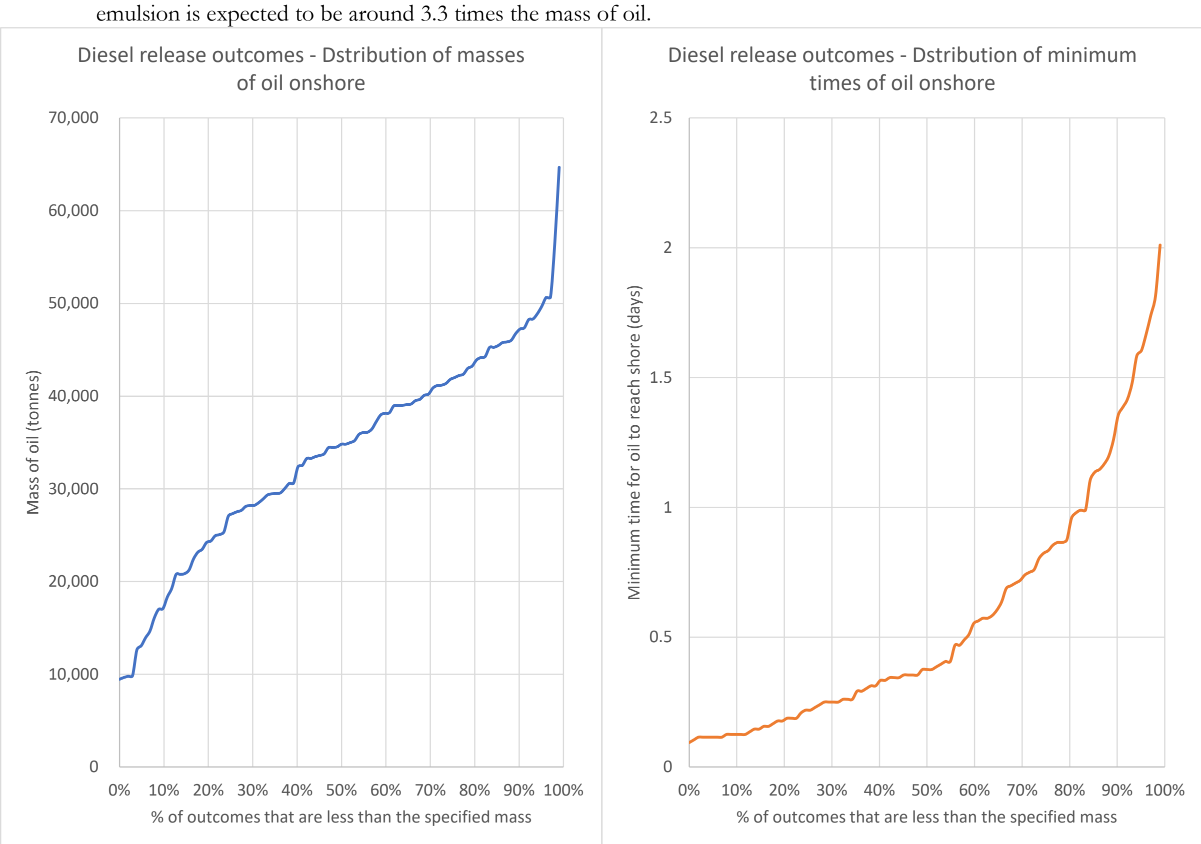


Figure 32: Statistical distribution of shoreline oil and minimum arrival times from summer and winter stochastic analyses (diesel release)

OSCAR statistical outputs are shown as follows:

- Probability of oil on the surface above the threshold of 0.04 µm (Figure 33 and Figure 34);
- Minimum arrival time of oil on the surface (no threshold) (Figure 35 and Figure 36);
- Probability of oil on the shoreline above the threshold of 100 g/m^2 (Figure 37, Figure 38 and Figure 39);
- Minimum arrival time of oil on the shoreline (no threshold) (Figure 40, Figure 41 and Figure 42); and
- Probability of oil in the water column above the threshold of 58 ppb (Figure 43 and Figure 44).

Note that the arrival time of oil at the shoreline above the threshold may be different to the arrival time on the adjacent sea surface above threshold, although any differences are usually small.

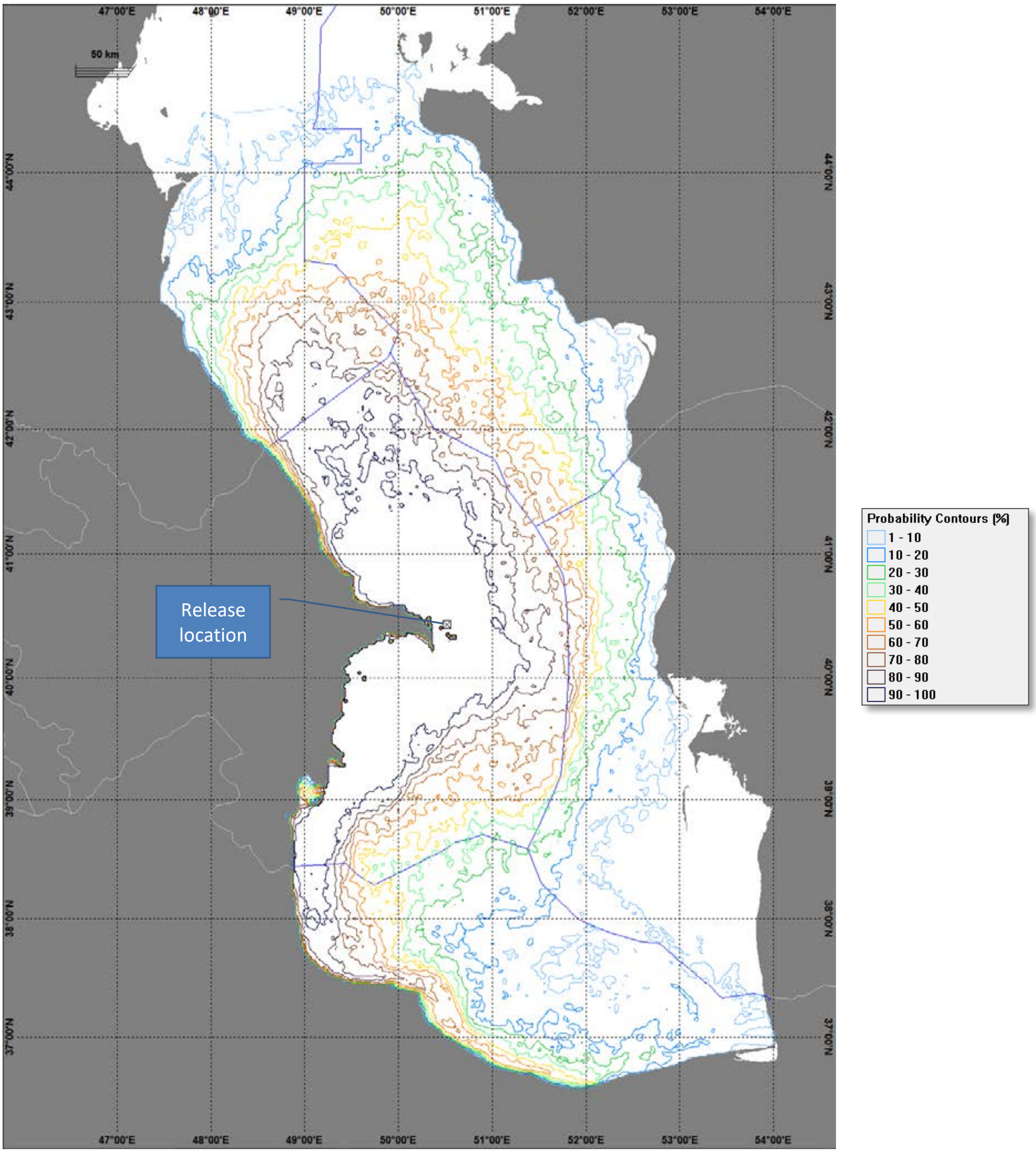


Figure 33: Worst case blowout: Probability of surface oil above threshold of 0.04 µm (summer)

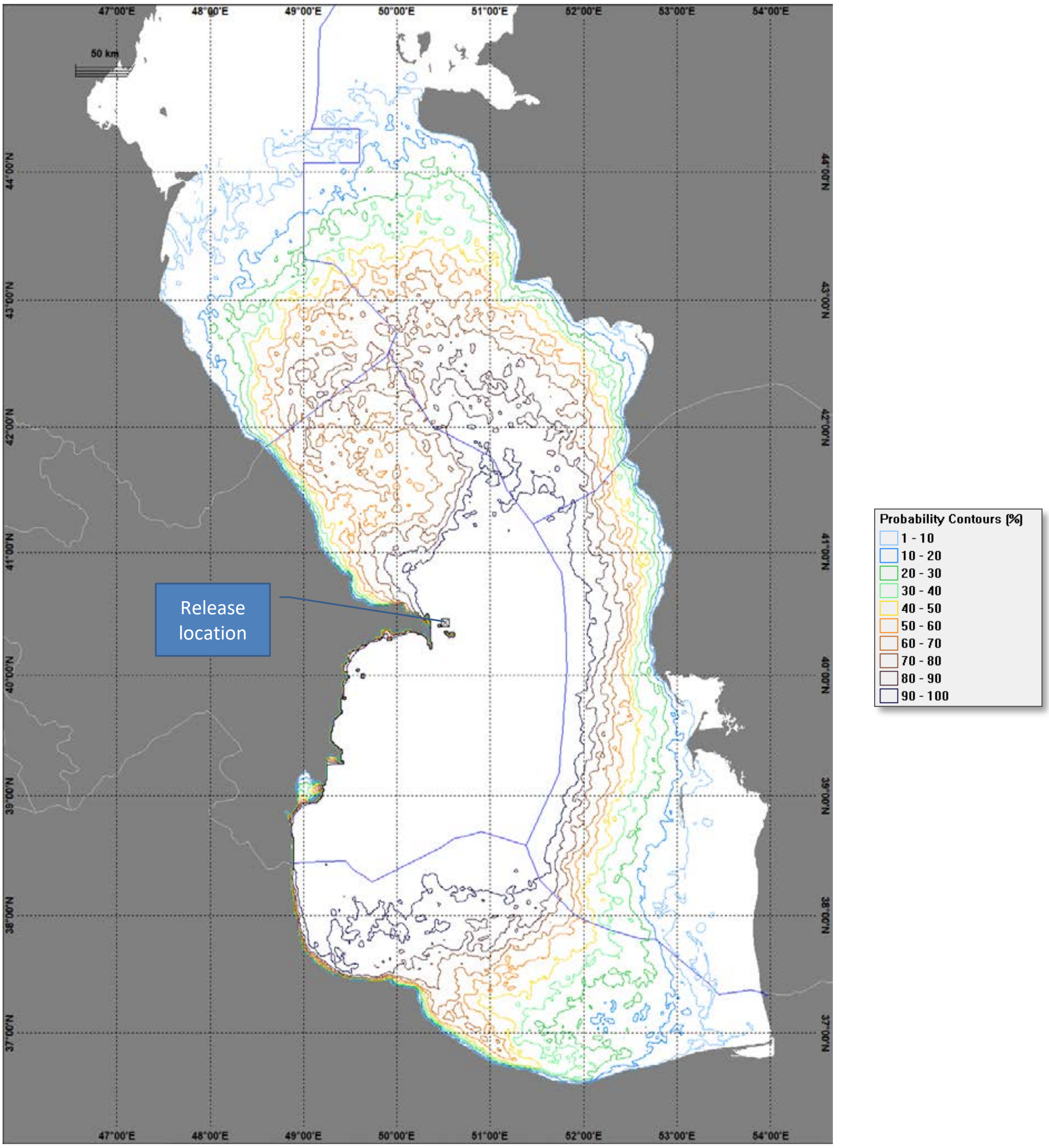


Figure 34: Worst case blowout: Probability of surface oil above threshold of 0.04 µm (winter)

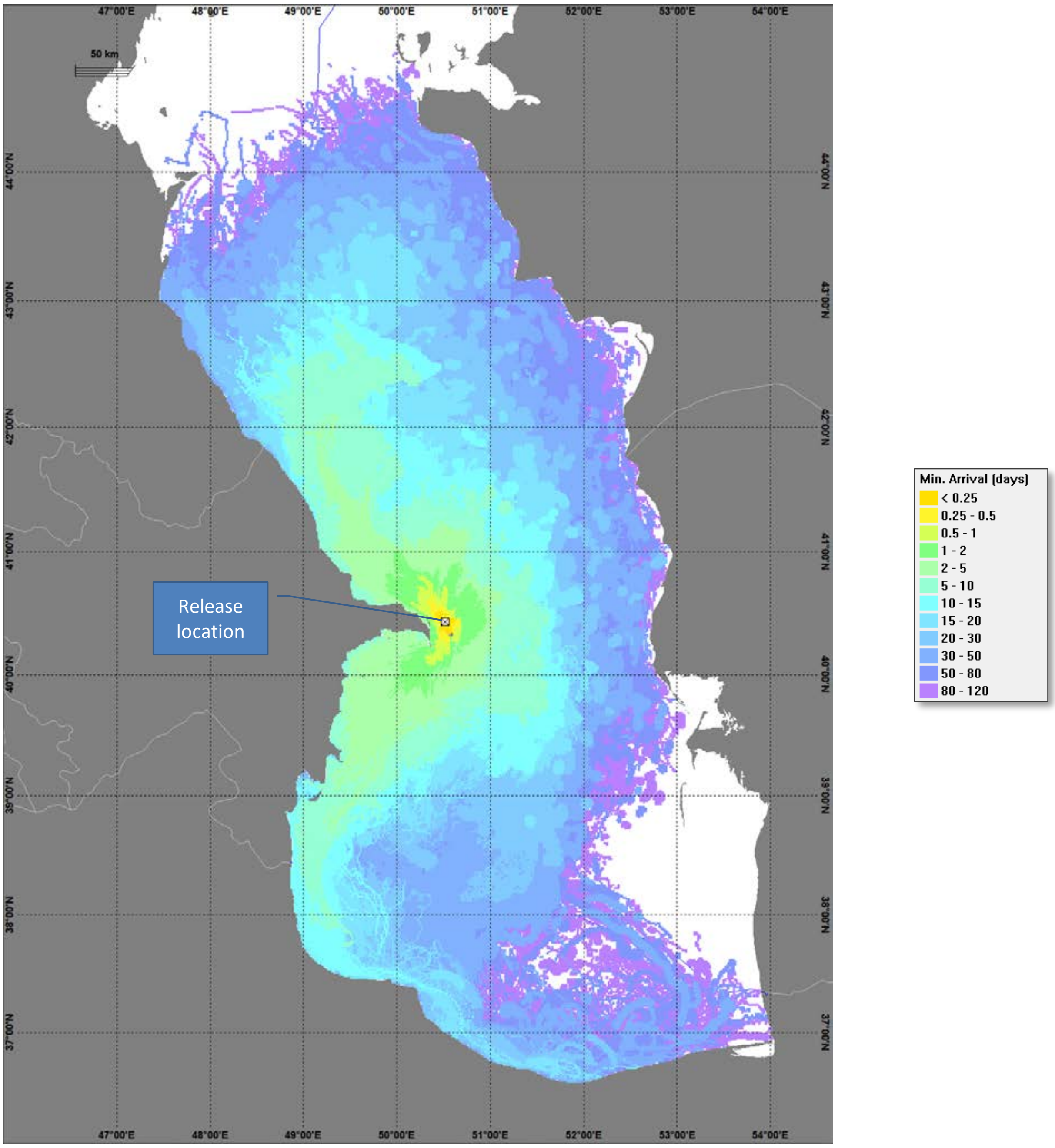


Figure 35: Worst case blowout: Minimum arrival time of oil on surface (summer)

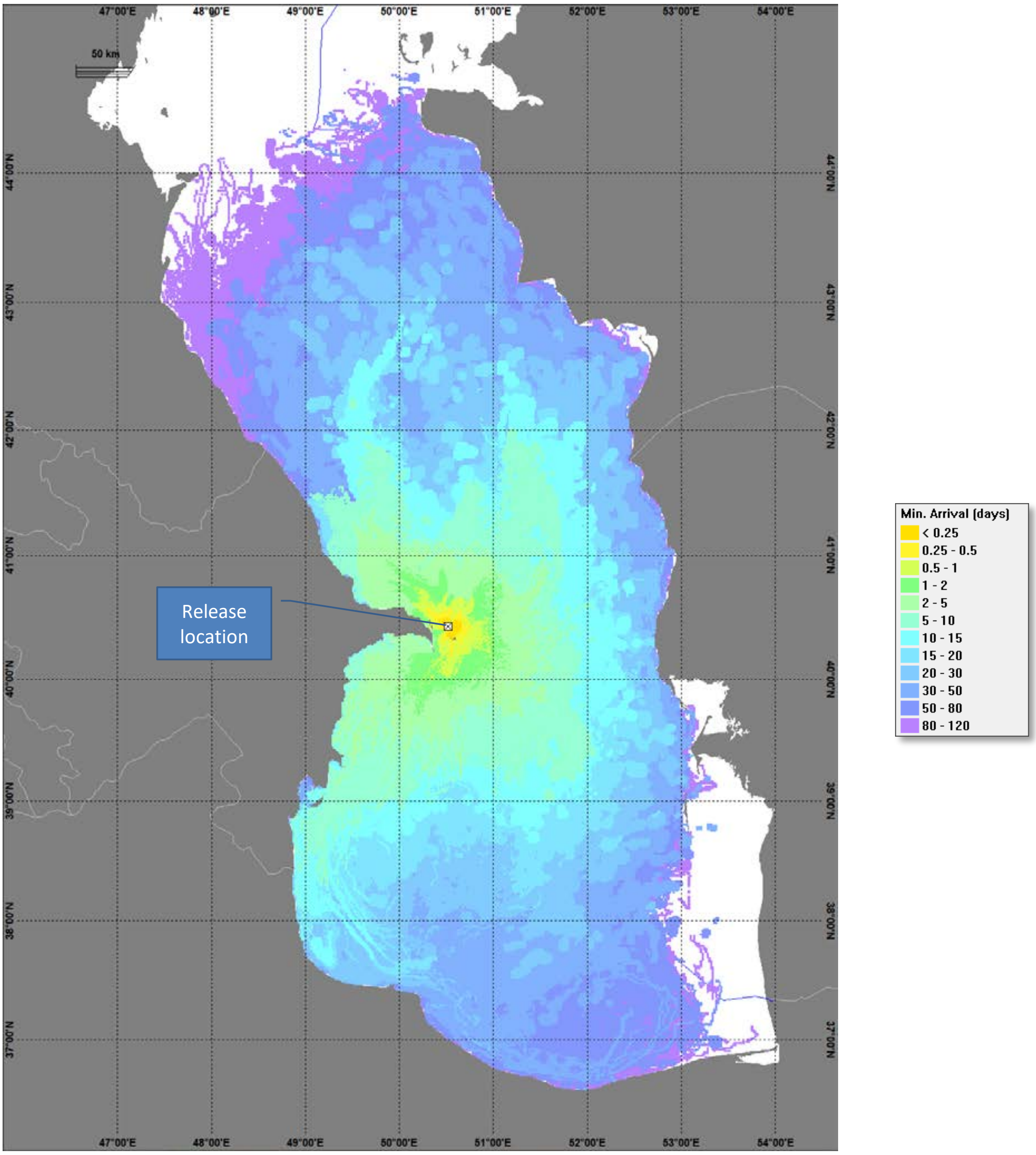


Figure 36: Worst case blowout: Minimum arrival time of oil on surface (winter)

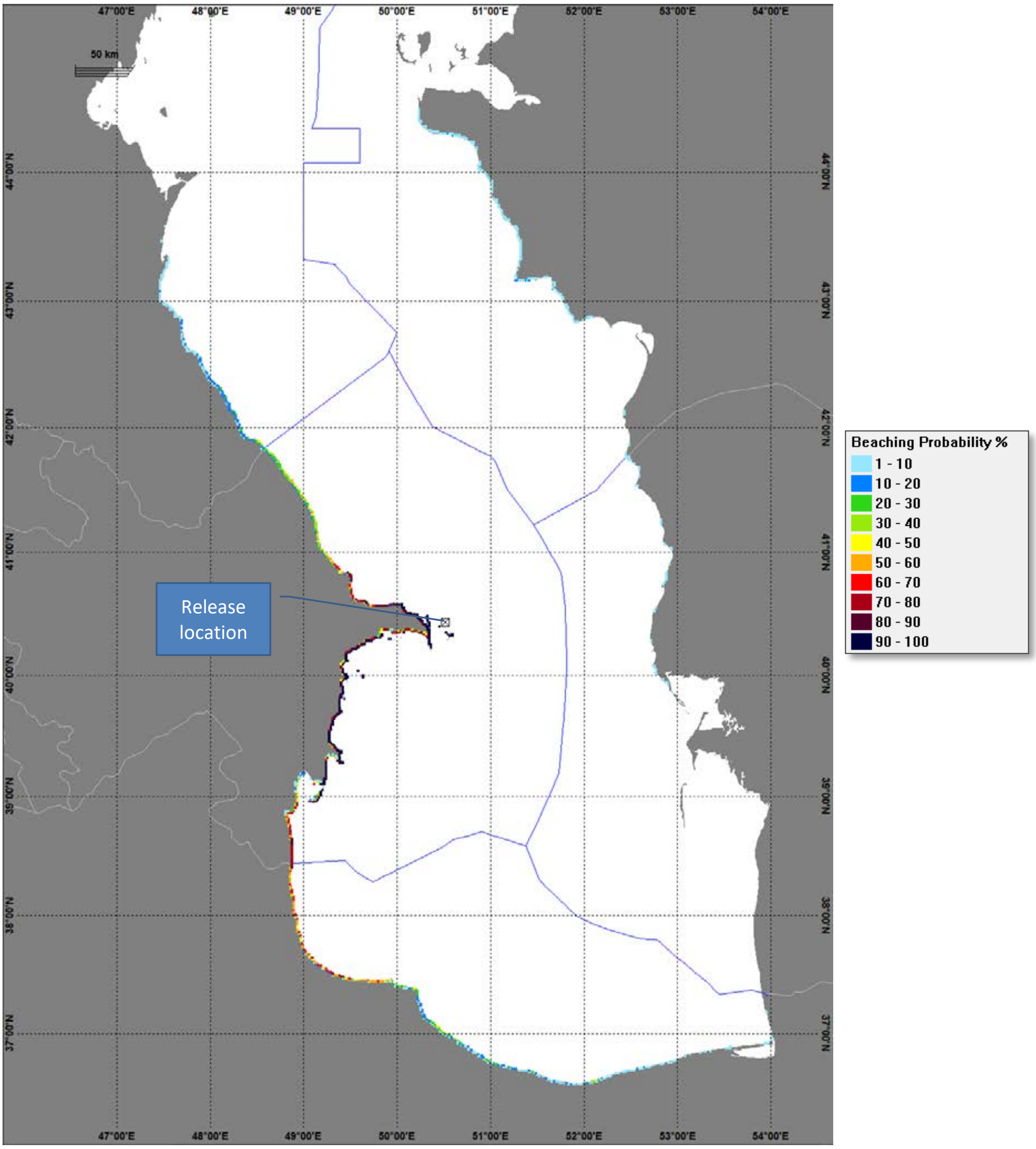


Figure 37: Worst case blowout: Probability of oil on shoreline above threshold of 100 ml/m^2 (summer)

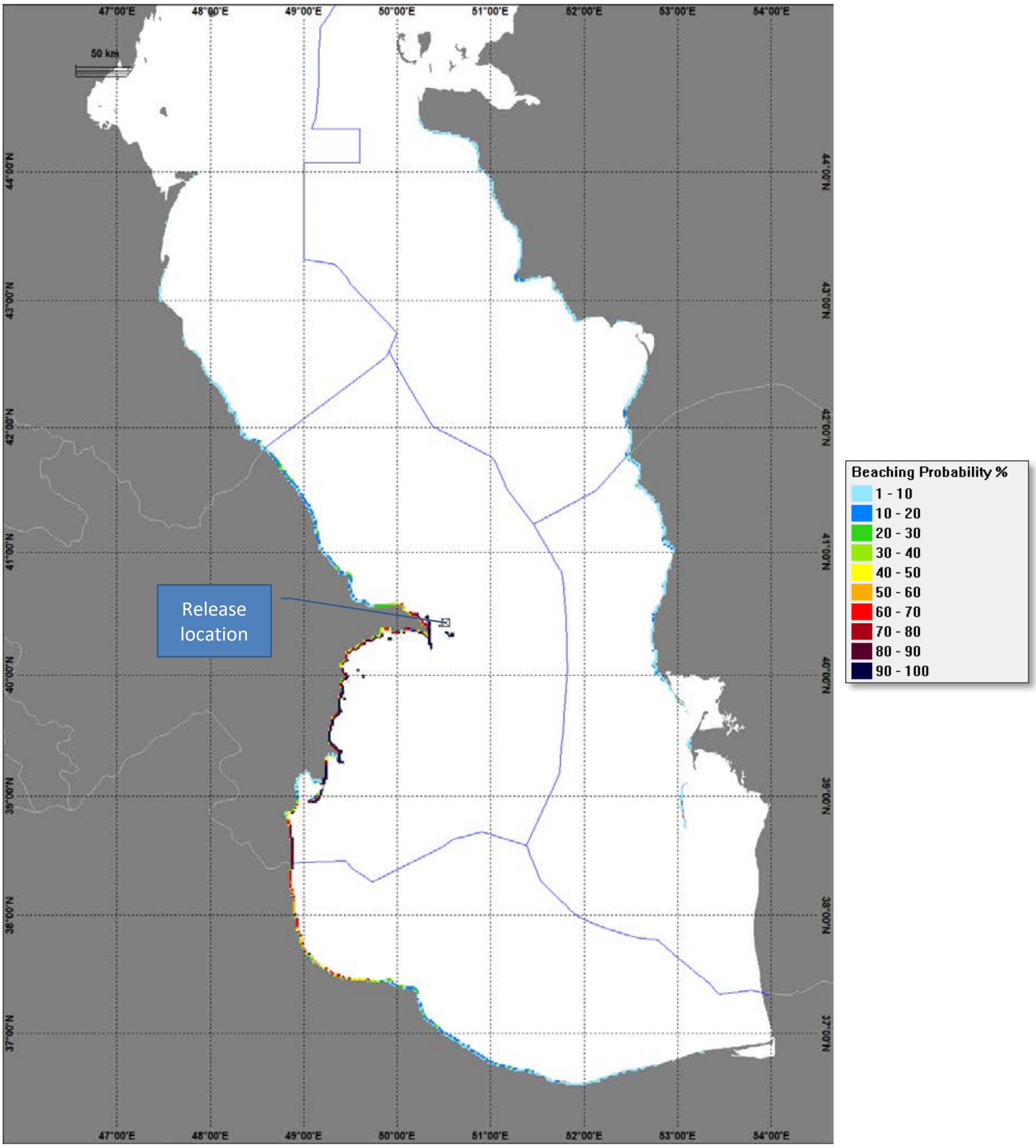


Figure 38: Worst case blowout: Probability of oil on shoreline above threshold of 100 ml/m^2 (winter)

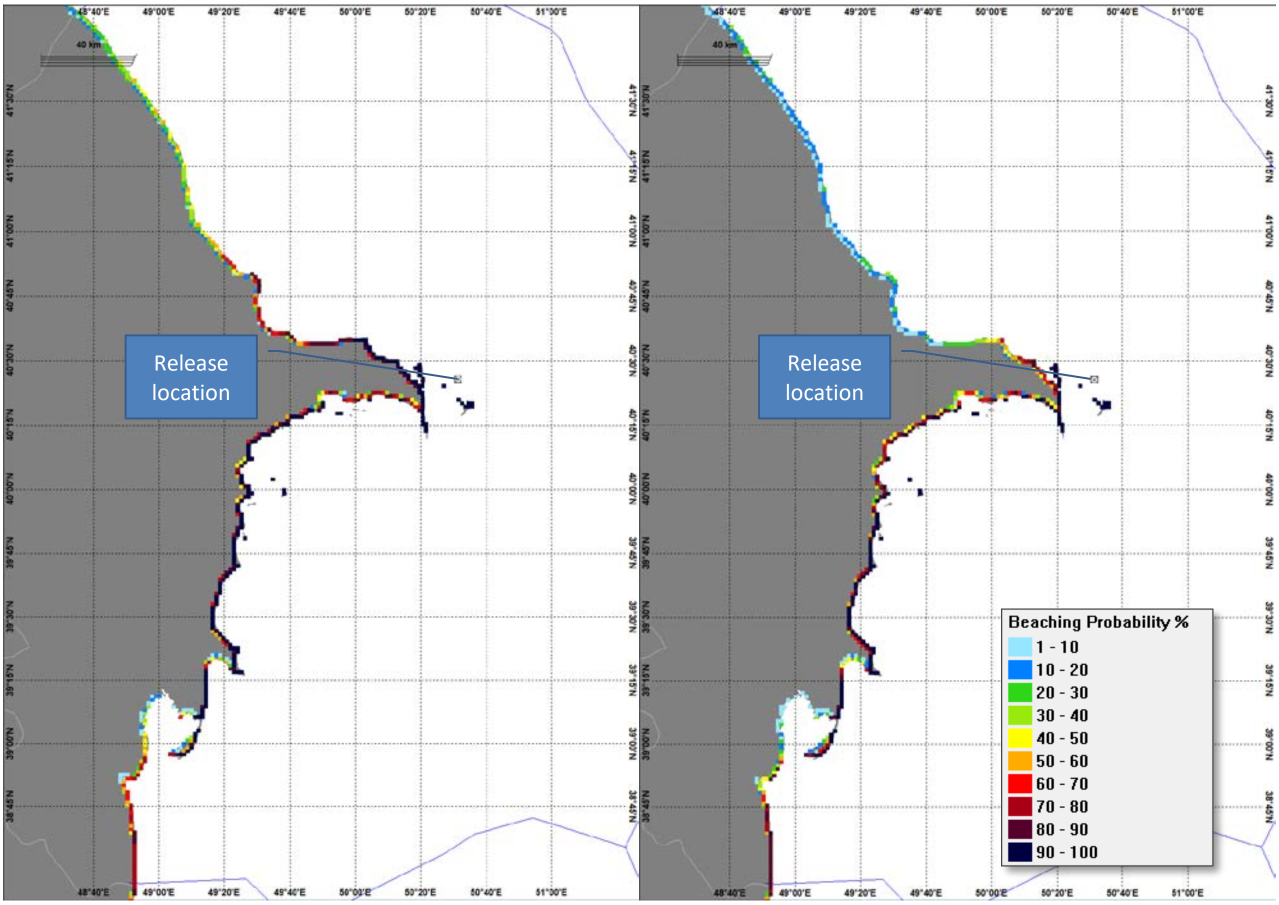


Figure 39: Worst case blowout: Probability of oil on shoreline above threshold of 100 ml/m² along shoreline of Azerbaijan (winter)

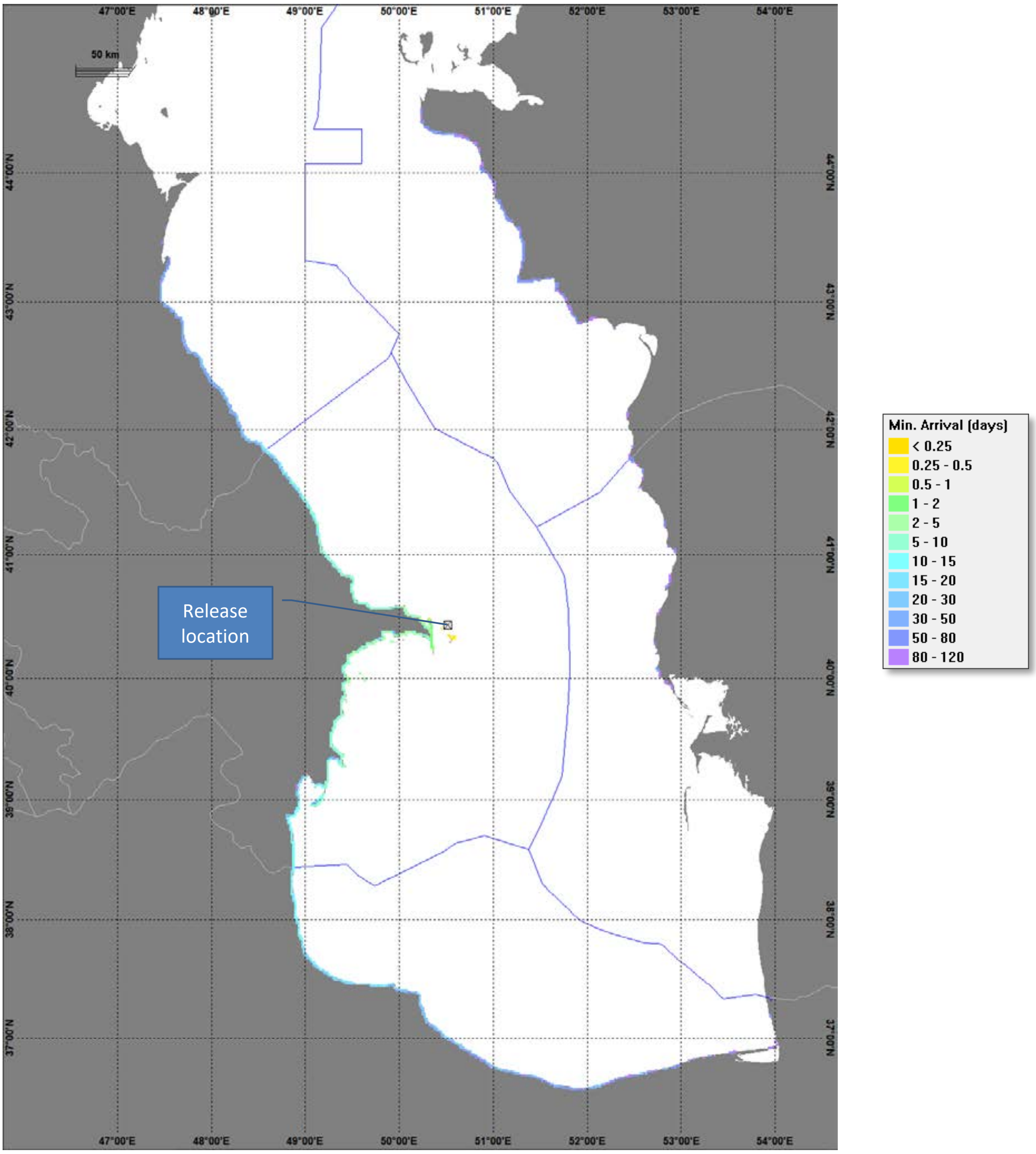


Figure 40: Worst case blowout: Minimum arrival time of oil on shoreline (summer)

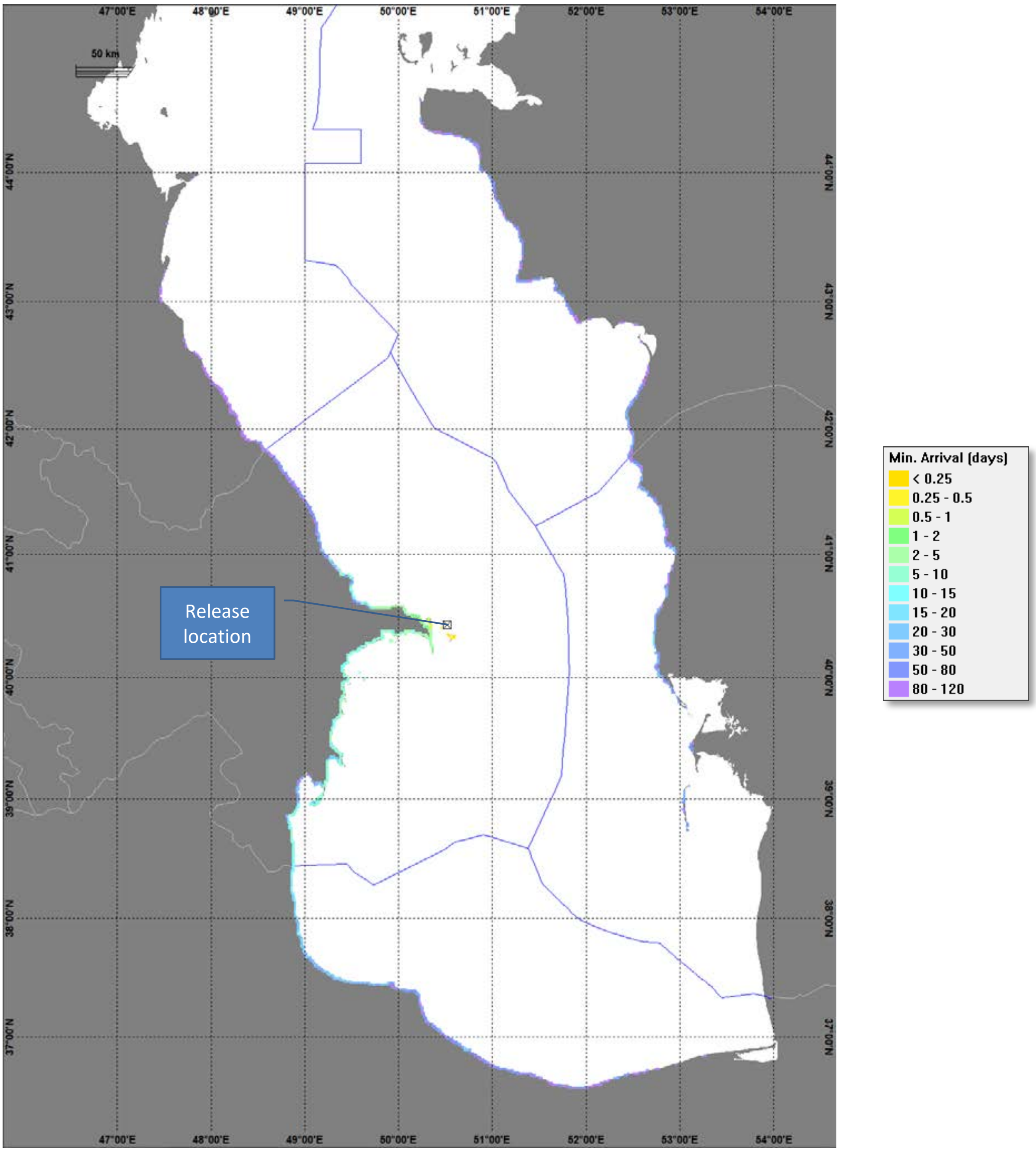


Figure 41: Worst case blowout: Minimum arrival time of oil on shoreline (winter)

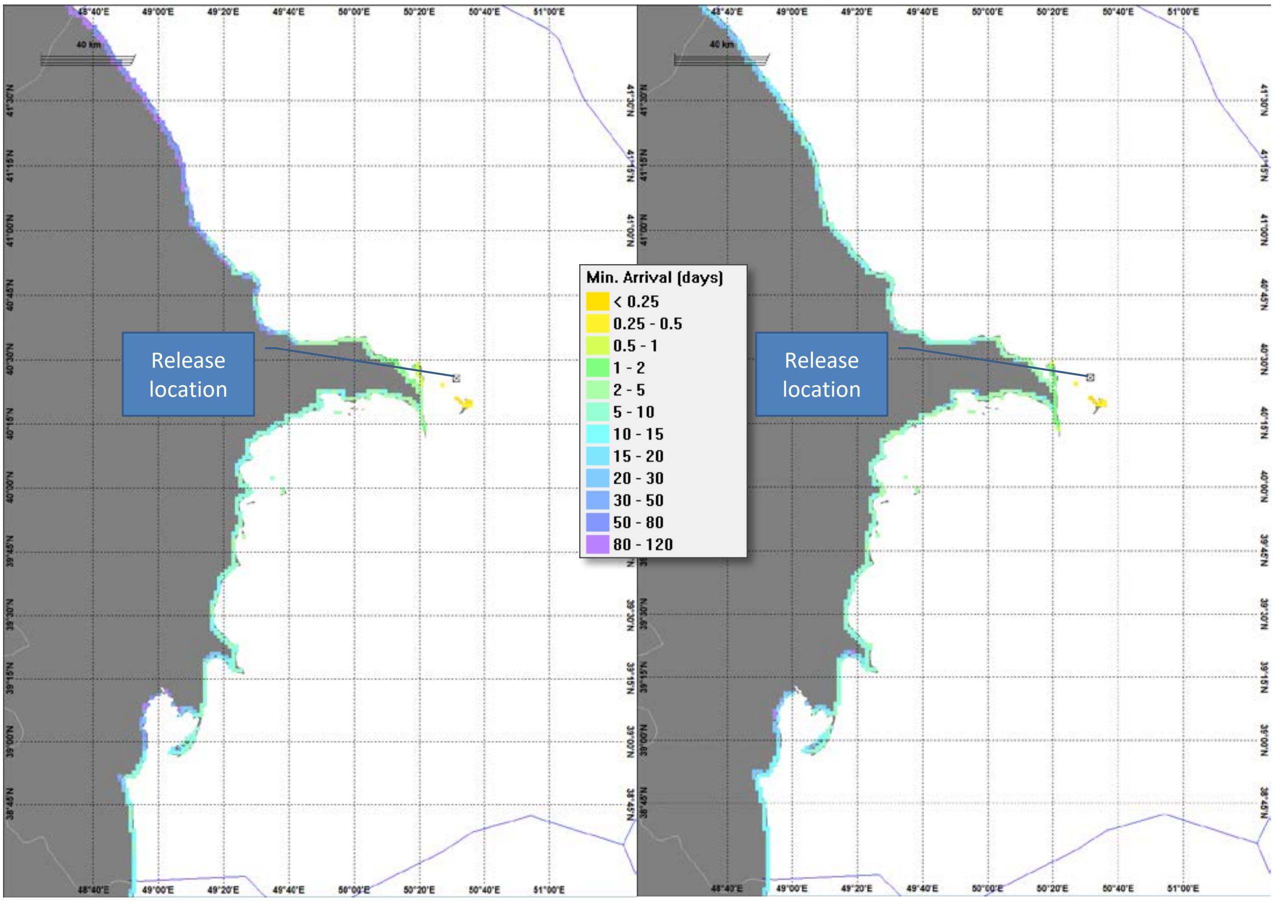


Figure 42: Worst case blowout: Minimum arrival time of oil along shoreline of Azerbaijan (left - summer, right - winter)

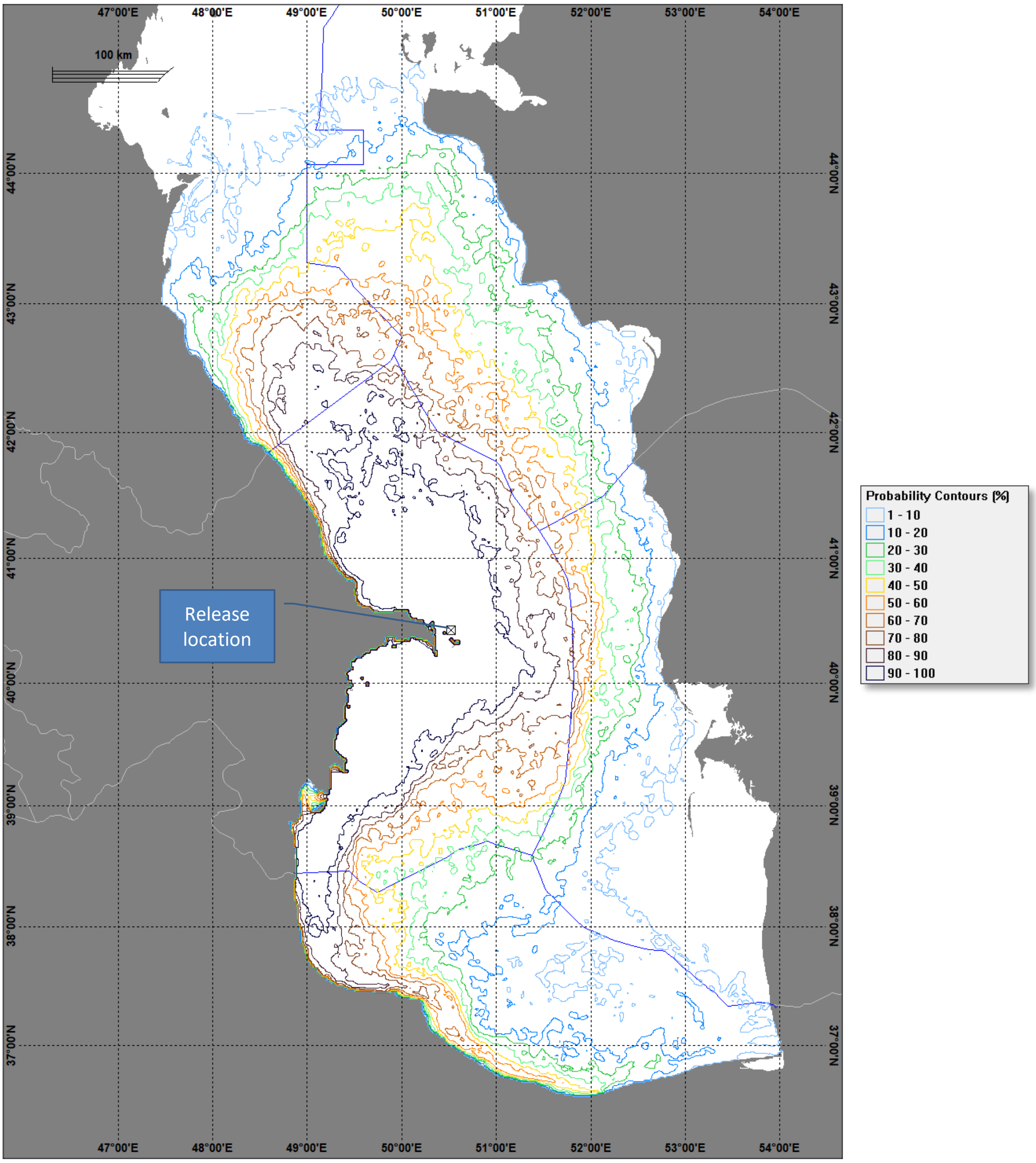


Figure 43: Worst case blowout: Probability of oil in water column above threshold of 58 ppb (summer)

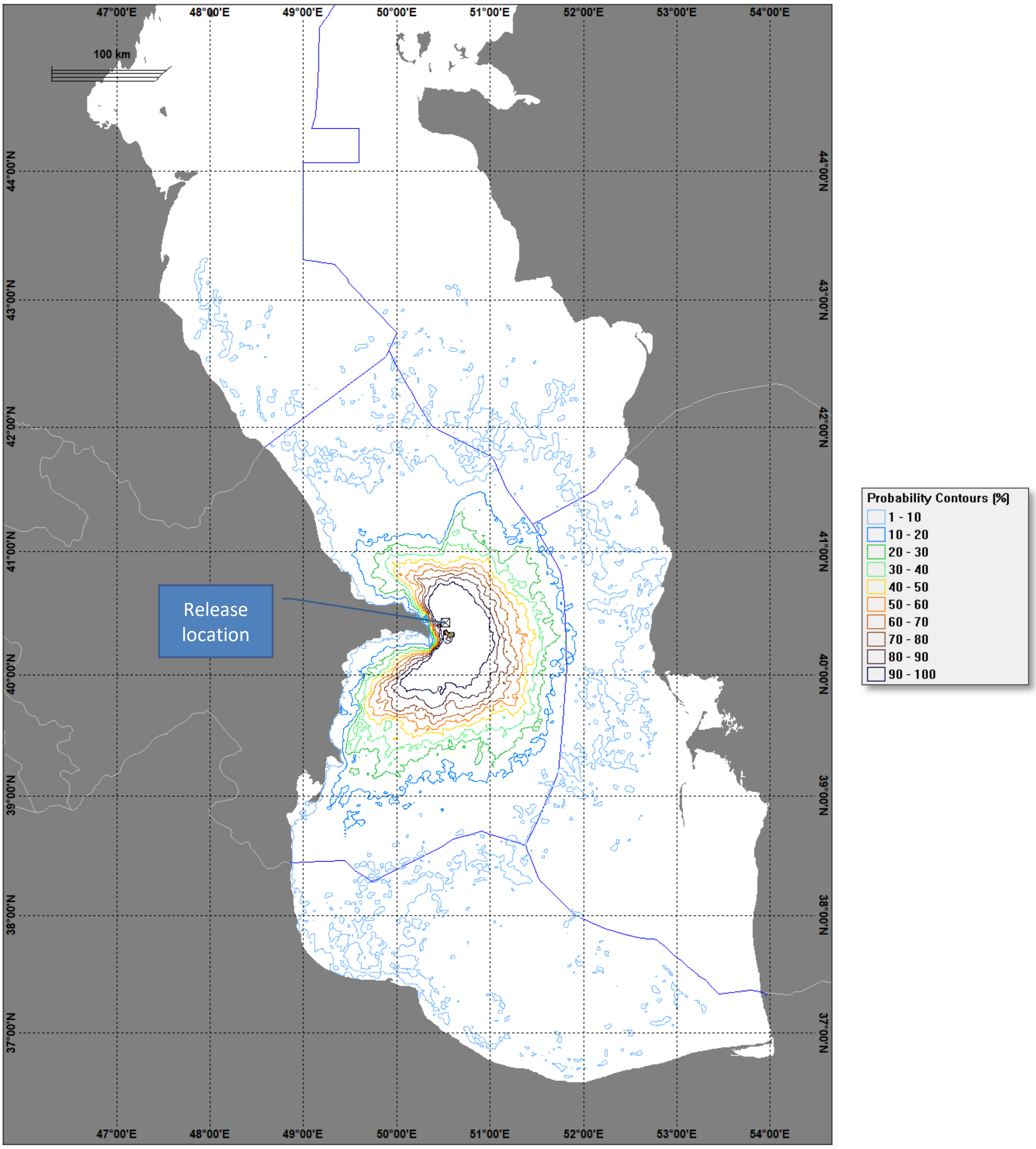


Figure 44: Worst case blowout: Probability of oil in water column above threshold of 58 ppb (winter)

5.2.3 Deterministic modelling

Key outputs from the deterministic modelling are shown in Table 12.

Table 12: Deterministic results summary for worst case blowout

Scenario	Release location	Maximum surface extent of sheen above 0.04 µm (km)		Time until water column concentration[1] <58 ppb (days)[2]	
		Summer	Winter	Summer	Winter
Worst case blowout 810,019 m^3	NKX-1 well	459.7	470.2	> 120	> 120

Notes: 1. Dissolved and dispersed oil in water column.

2. Time from start of release

The timing of the summer and winter deterministic scenarios is chosen to match the cases with the maximum mass of oil reaching shore in each season.

5.2.3.1 Oil on surface

Crude oil on the sea surface is predicted to travel around 400-500 km in these two sets of conditions before it drops below the lowest recognised visible thickness under ideal viewing conditions (Figure 45 and Figure 46). There is a distinct difference in oil movement between summer and winter as shown in the figures. In the summer, oil is more likely to remain closer to the coast, while in the winter it is more likely to spread further distance from the coast.

The thickest areas of oil on the surface (> 0.2 mm) are predicted to cover a greater area during winter than summer. These areas are likely to be associated with the most significant environmental impacts for animals and birds using the sea surface.

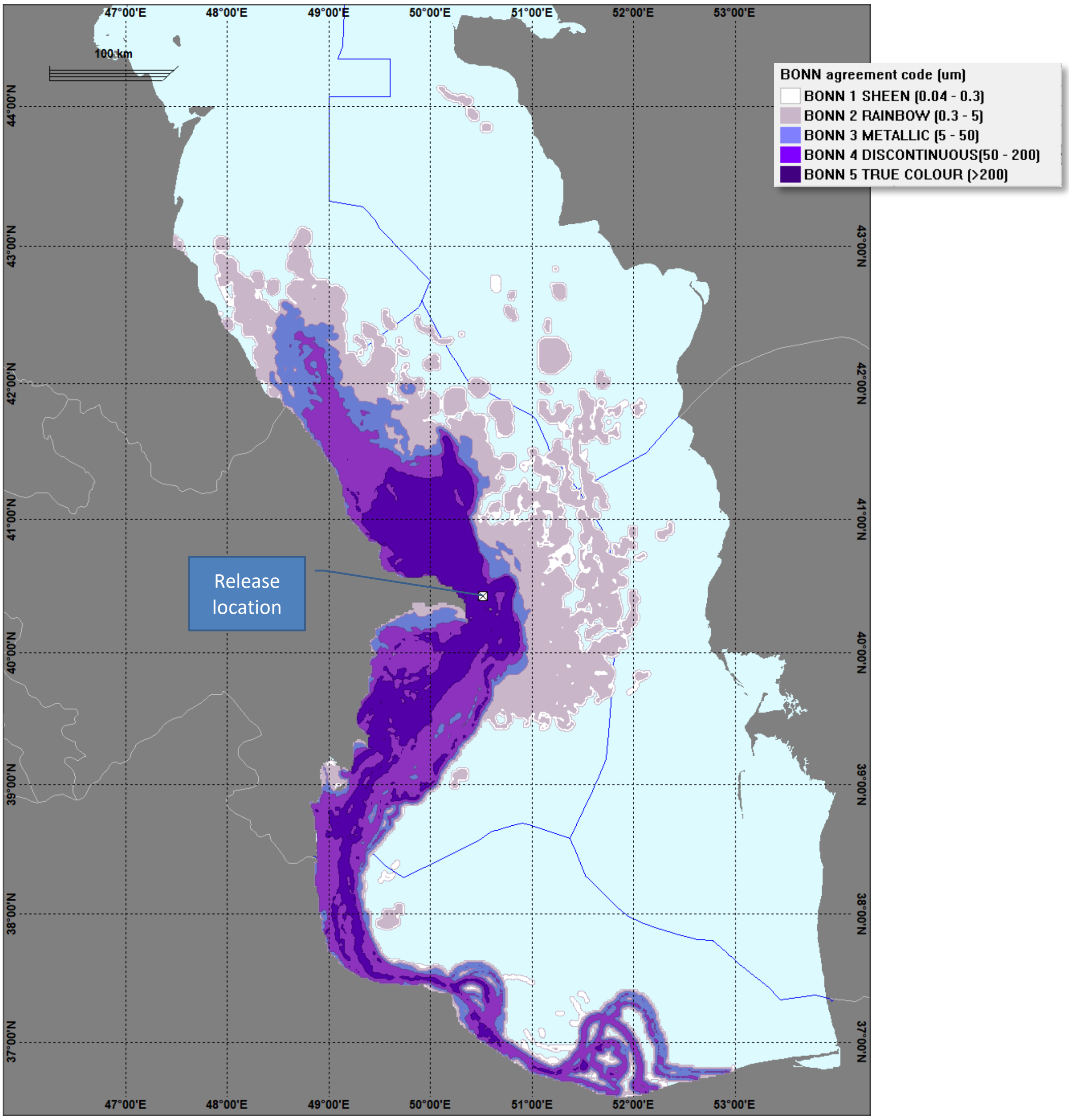


Figure 45: Worst case blowout: Cumulative area of surface sheen - summer

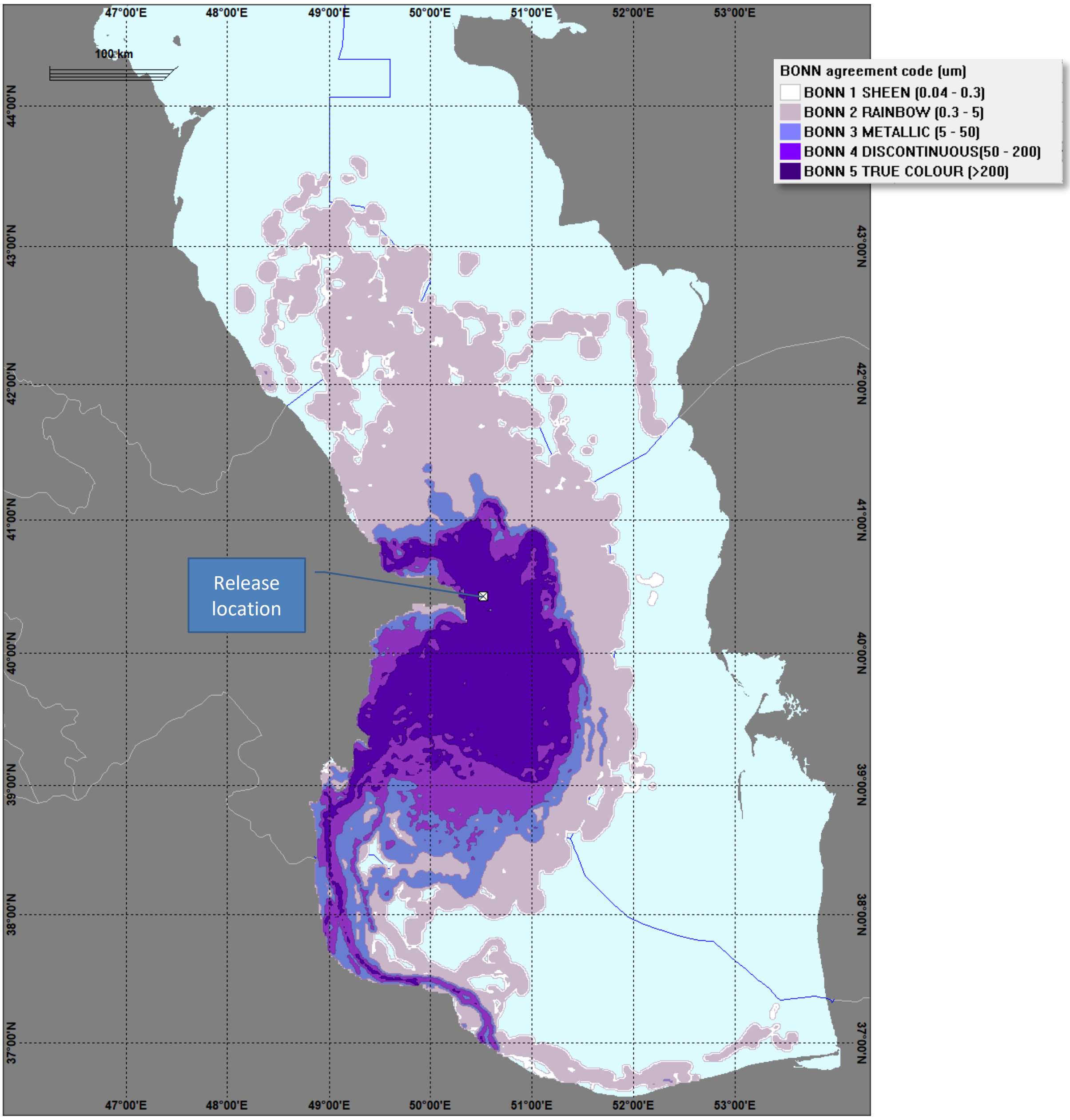


Figure 46: Worst case blowout: Cumulative area of surface sheen - winter

5.2.3.2 Oil on shore

Oil accumulation on shore for the summer deterministic case is shown in Figure 47 and the winter deterministic case is shown in Figure 48. These represent the deposition of oil on the shore at the end of the simulation when the maximum length of coastline is affected. Given the length of the release and the widespread dispersion after 80 days, this distribution is very similar to the distribution at which the maximum mass of shoreline deposition occurs, and so this is not shown in addition. The worst affected areas are shown at a larger scale in Figure 49.

Both cases result in oil reaching southern Azerbaijan, northern Iran and the Absheron peninsula. The summer case presented results in oil also reaching the Russian coast. The eastern coastline of the Caspian Sea is unaffected. A mixture of areas of very light, light, moderate and heavy oil deposition are present.

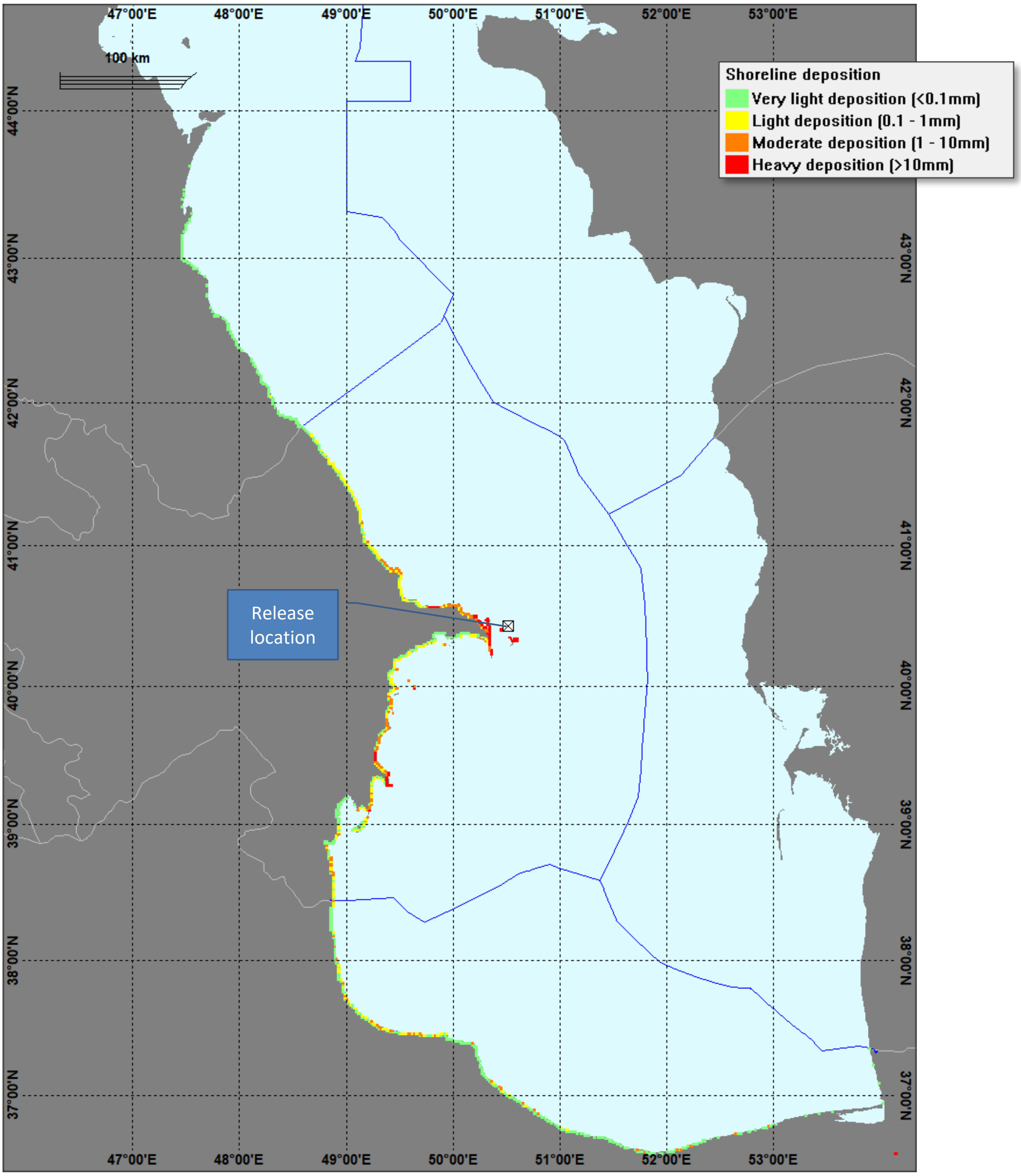


Figure 47: Worst case blowout: Oil on shore - summer

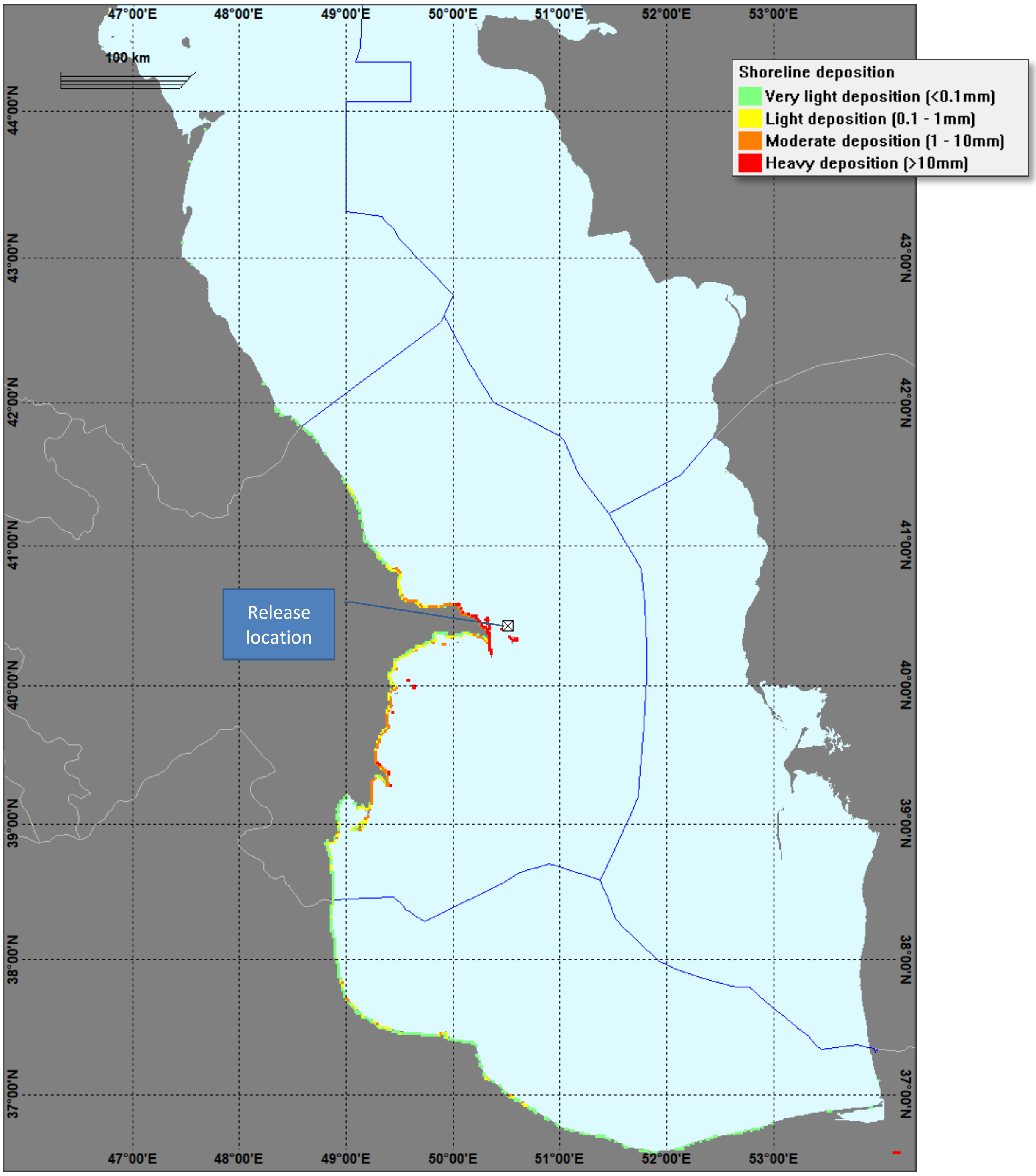


Figure 48: Worst case blowout: Oil on shore - winter

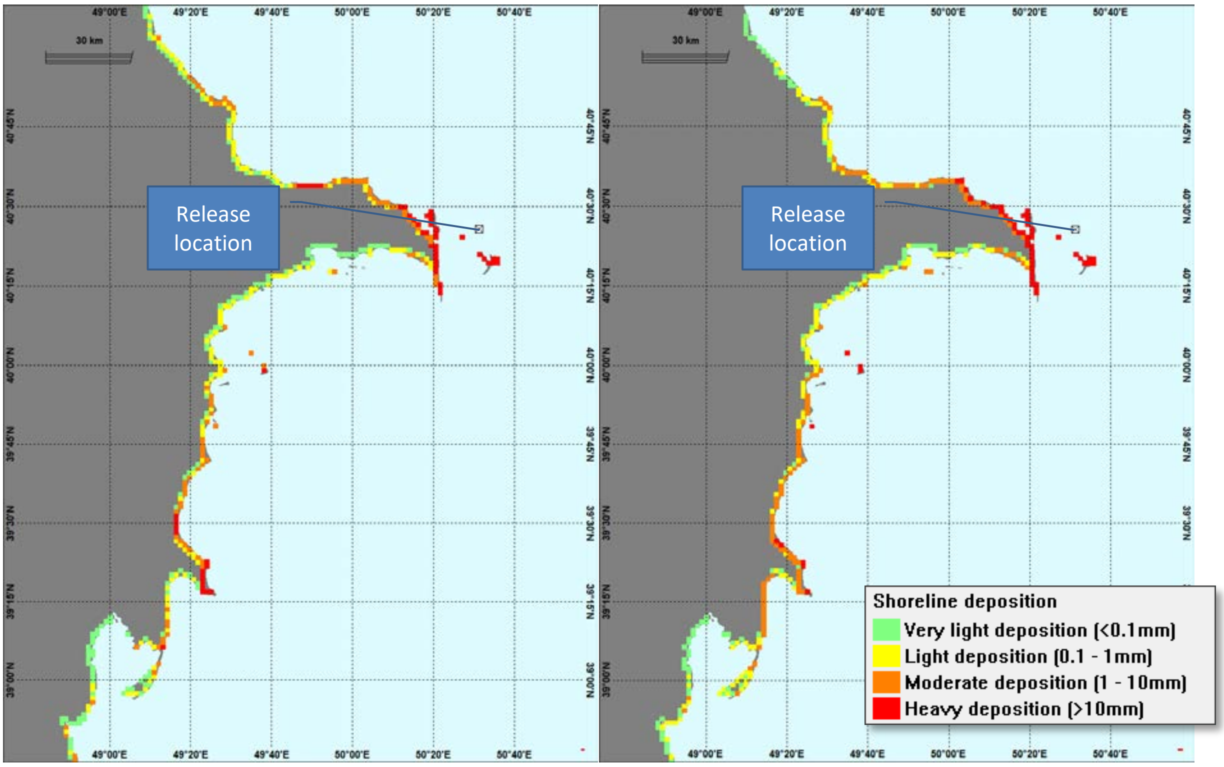


Figure 49: Worst case blowout: Oil on shore in worst affected area - summer (left), winter (right)

5.2.3.3 Oil in the water column

The extent of oil in the water column above the 58 ppb threshold tracks the path of the surface release and can extend 400-500 km from the source as shown in Figure 50 and Figure 51 representing the deterministic cases run in summer and winter, where (for each season respectively) the maximum oil reaches the shore. These outputs represent both dissolved and dispersed oil in the water column. In each figure, the output is the total area the oil has covered as it has moved away from the release location. The cross section through the water column shows that the release remains in the top 70 m of the water column, and remains closer to the surface in the case presented for summer than that for winter.

The oil moves outwards and disperses via the action of circulation currents, winds and waves and its presence in the water column is dominated by the presence of surface slick. Some of the surface oil dissolves into the upper water column and some disperses in droplet form during stronger wind and wave conditions and can then re-appear on the surface in calmer conditions. Wave mixing and diffusion of the dissolved components gives rise to appreciable concentrations in the upper 20 m of the water column, and occasionally deeper to around 50 m depth, although the maximum concentrations remain immediately below the surface oil which is persistent.

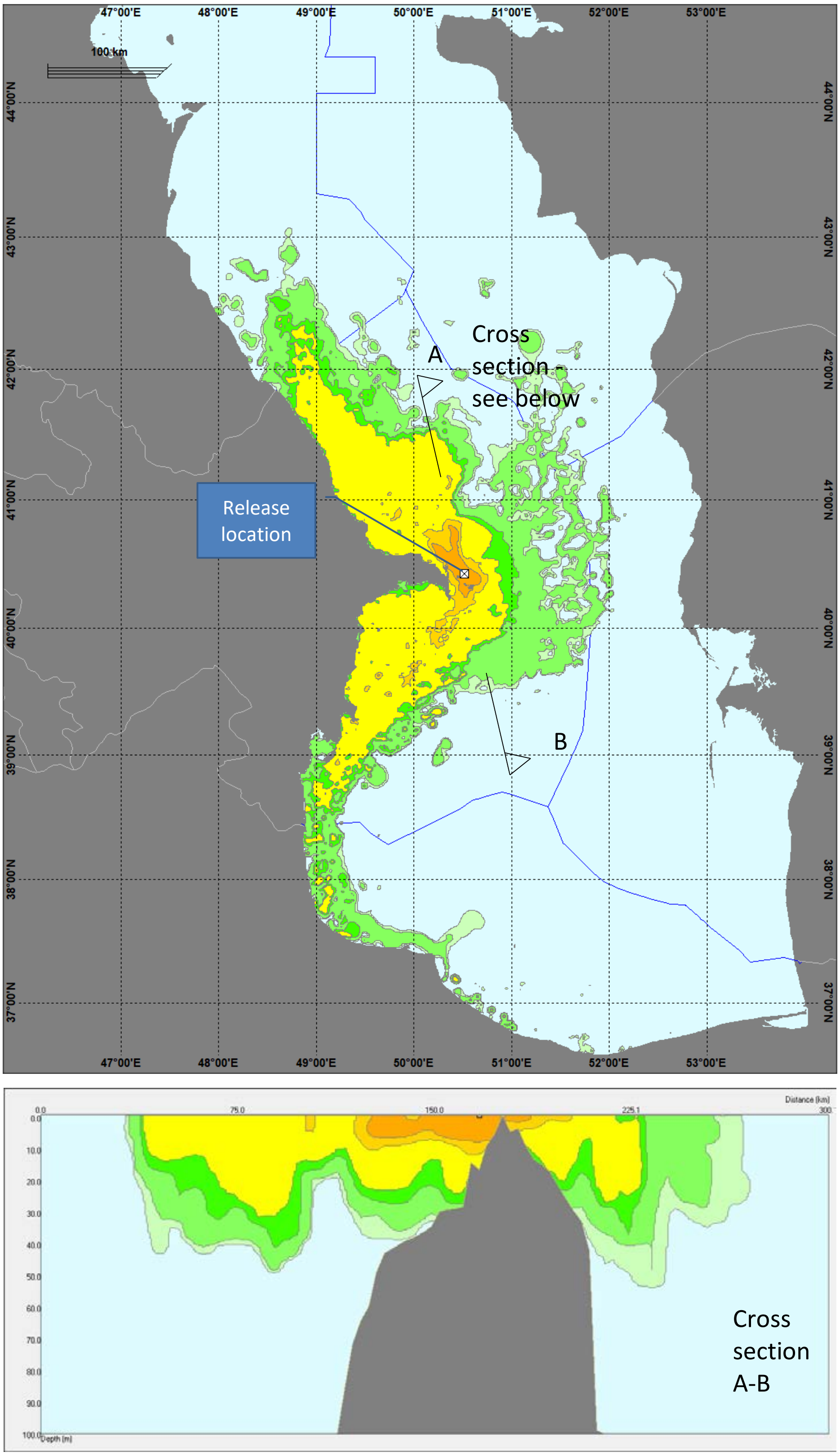


Figure 50: Worst case blowout: maximum affected area of water column during simulation - summer

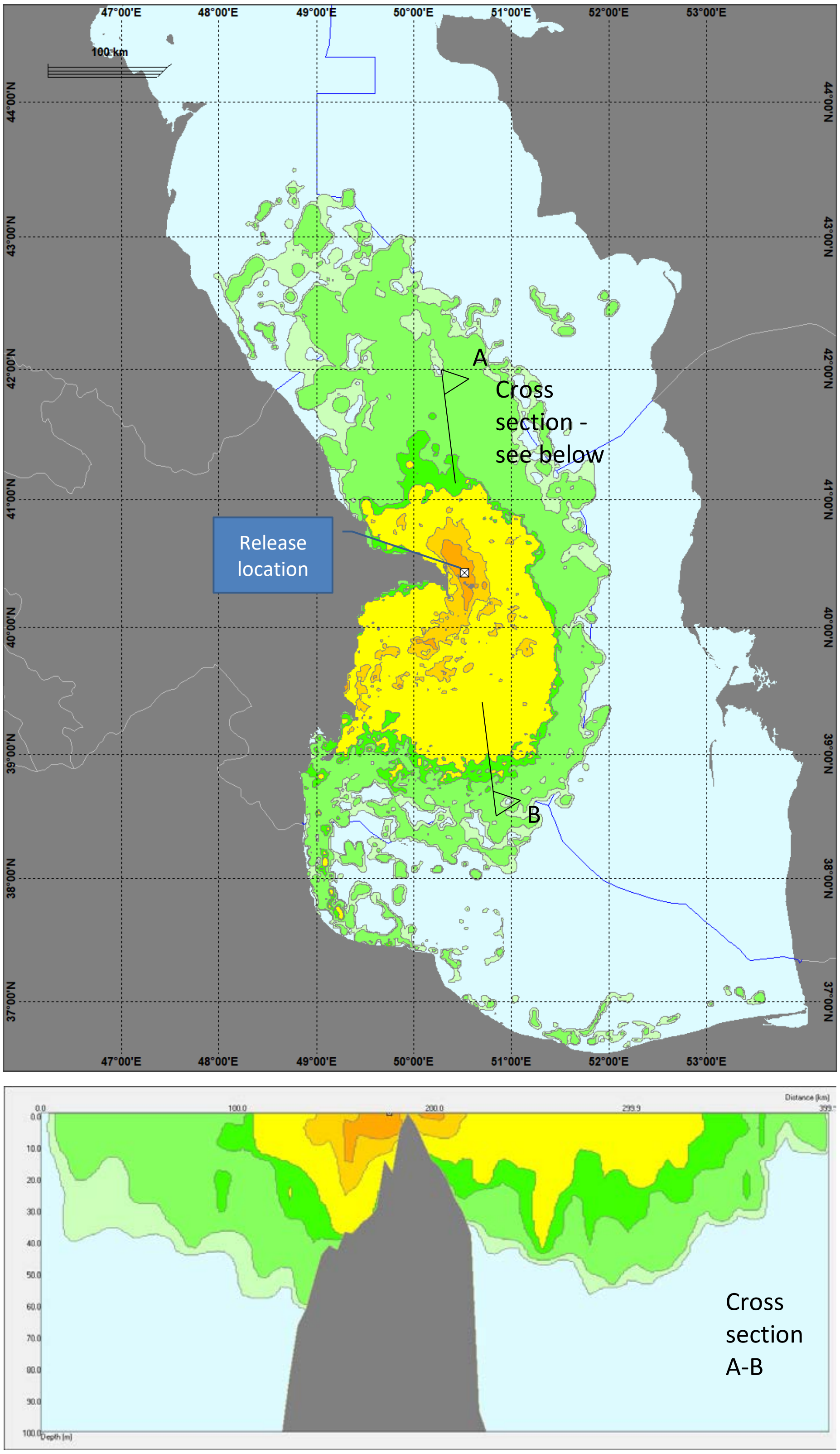


Figure 51: Worst case blowout: maximum affected area of water column during simulation - winter

5.2.3.4 Oil in sediments

By the end of the simulation, around 38% of the oil is predicted to have deposited in sediments, predominantly in the shallow waters east of the Absheron peninsula. The deposition pattern for summer conditions at the end of the simulation (the point of maximum oil in sediments) is shown in Figure 50. This may take a period of months or years to decline substantially. Based on experiences elsewhere in the world, effects on macrofauna are typically greatest amongst mollusc and crustacean communities due to their habitation of the benthos and their limited ability to metabolise oil components. Higher animals are more mobile and typically have wider food sources and greater ability to metabolise oil, although demersal fish could exhibit sub-lethal or toxic effects in the short term and taint in their flesh. Using the thresholds set out, significant effects would be unlikely below the 10 mg/kg contour; between 10-100 mg/kg sub-lethal effects could be expected (such as narcosis and lower reproductive success); while above 1,000 mg/kg acute toxic effects would be expected in multiple species. Given the historic oil-producing nature of the area, background oil levels may already be elevated or tolerated; nevertheless acute toxic effects would be expected mainly within 35 km of the well based on these thresholds and sub-lethal effects potentially at a distance of 170 km.

In winter, the deposition pattern shown in Figure 51 is less concentrated near the coast with a greater level of deposition offshore, reflecting the different metocean conditions.

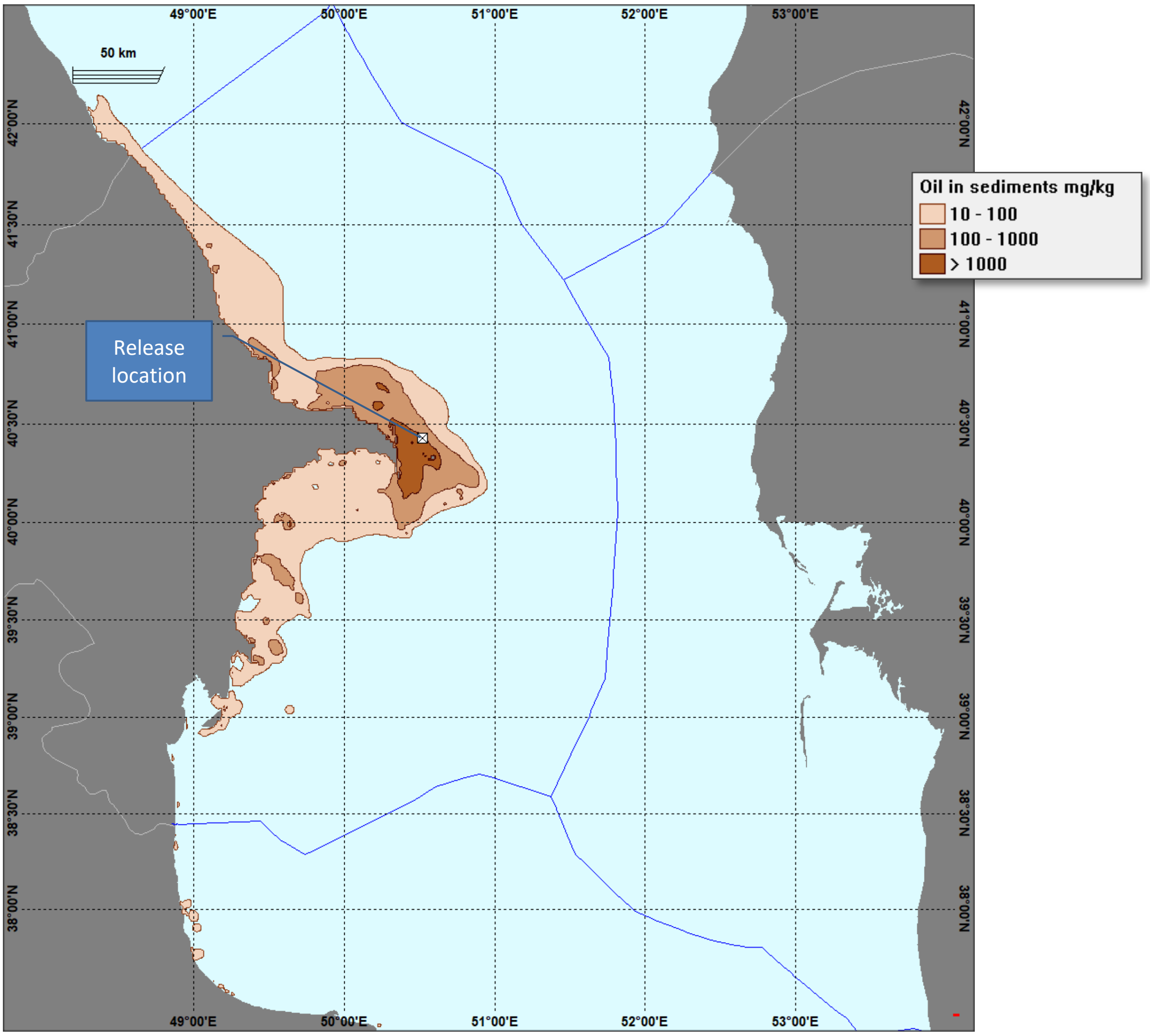


Figure 52: Worst case blowout: maximum mass of oil deposited in sediments (summer)

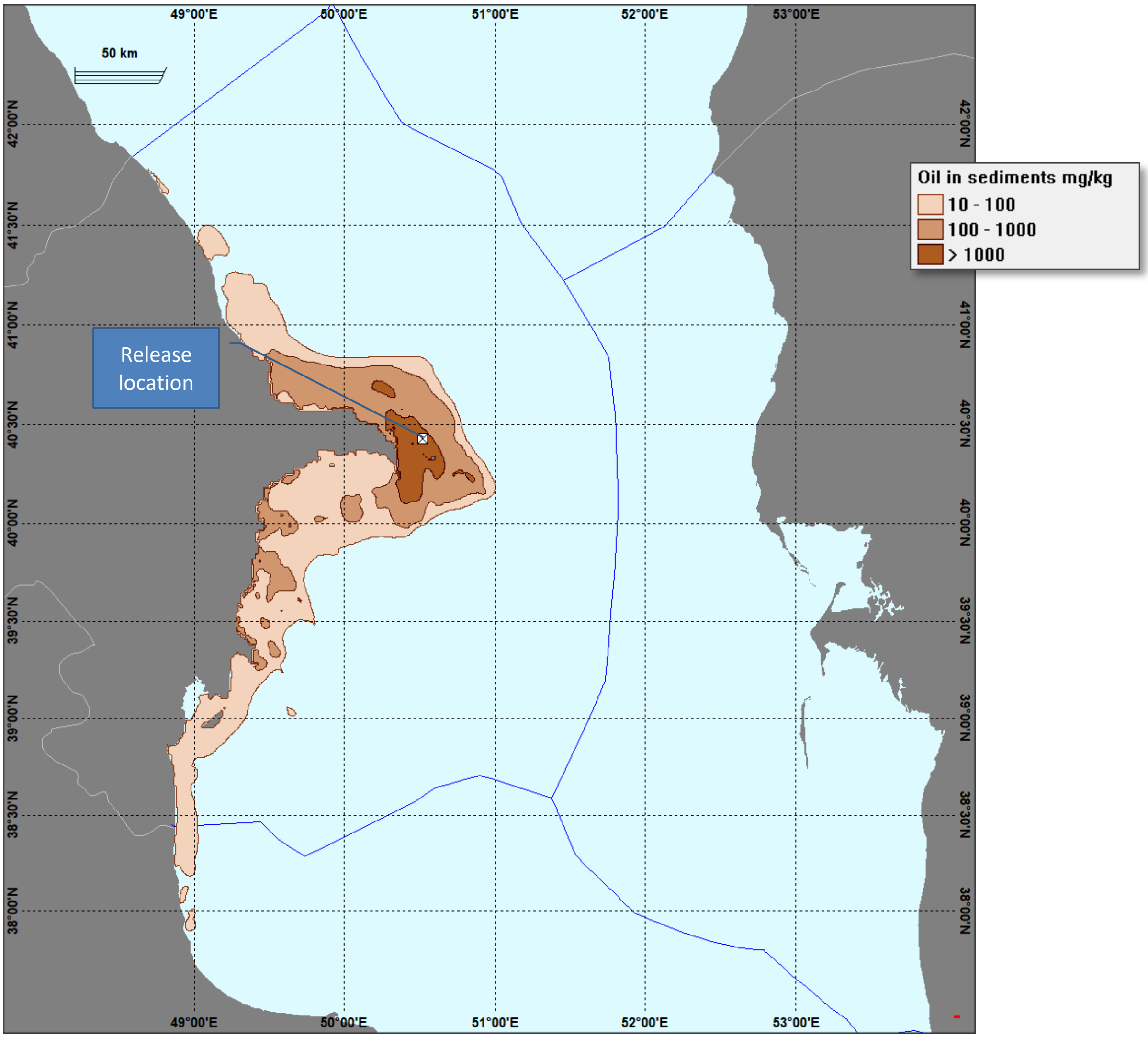


Figure 53: Worst case blowout: maximum mass of oil deposited in sediments (winter)

5.3 Scenario 3 – Cooling water discharge results

As previously described, the prevailing water column temperature profile varies significantly between summer and winter, and circulation currents vary throughout each day, therefore a low and a high current velocity case has been examined for summer and winter conditions, producing four scenarios. For early February and early July (winter and summer respectively), the current data has been examined to find low and high current conditions that are typical of the month. This produces four extremes of plume behaviour, and through each day and season the plume behaviour is expected to vary within the envelope of these scenarios. Under different metocean conditions the orientation of the plume will vary. The depth of the discharge means that wave turbulence has little effect.

The cooling water release results are presented in Figure 54 to Figure 57 which show the plumes after 15 minutes having reached stable conditions in the near field mixing zone. Given the small (8") diameter of the discharge caisson, there is high turbulence and the majority of the heat loss takes place within a few metres of the discharge, often within the initial turbulent plume section. There is some difference between high and low current conditions, which will occur on a daily basis; during slack currents, a stable plume forms which descends downwards through momentum but which then rises upwards slightly due to the residual thermal buoyancy. In higher current conditions, the stable plume does not have a chance to form and both the momentum and thermal advection are overcome by the rapid horizontal current to form an elongated plume at a fairly constant depth.

Although the water depth is relatively shallow, the plume is not predicted to reach the seabed and the benthos in unlikely to be affected.

In all scenarios, the temperature difference between the discharge plume and ambient conditions has returned to 0 within 100 m of the discharge location with differences of 0.5-1°C only occurring within the first few metres of the discharge point in all scenarios modelled. Therefore it is concluded that the 3°C criterion is not exceeded at the edge of a scientifically established mixing zone under any conditions.

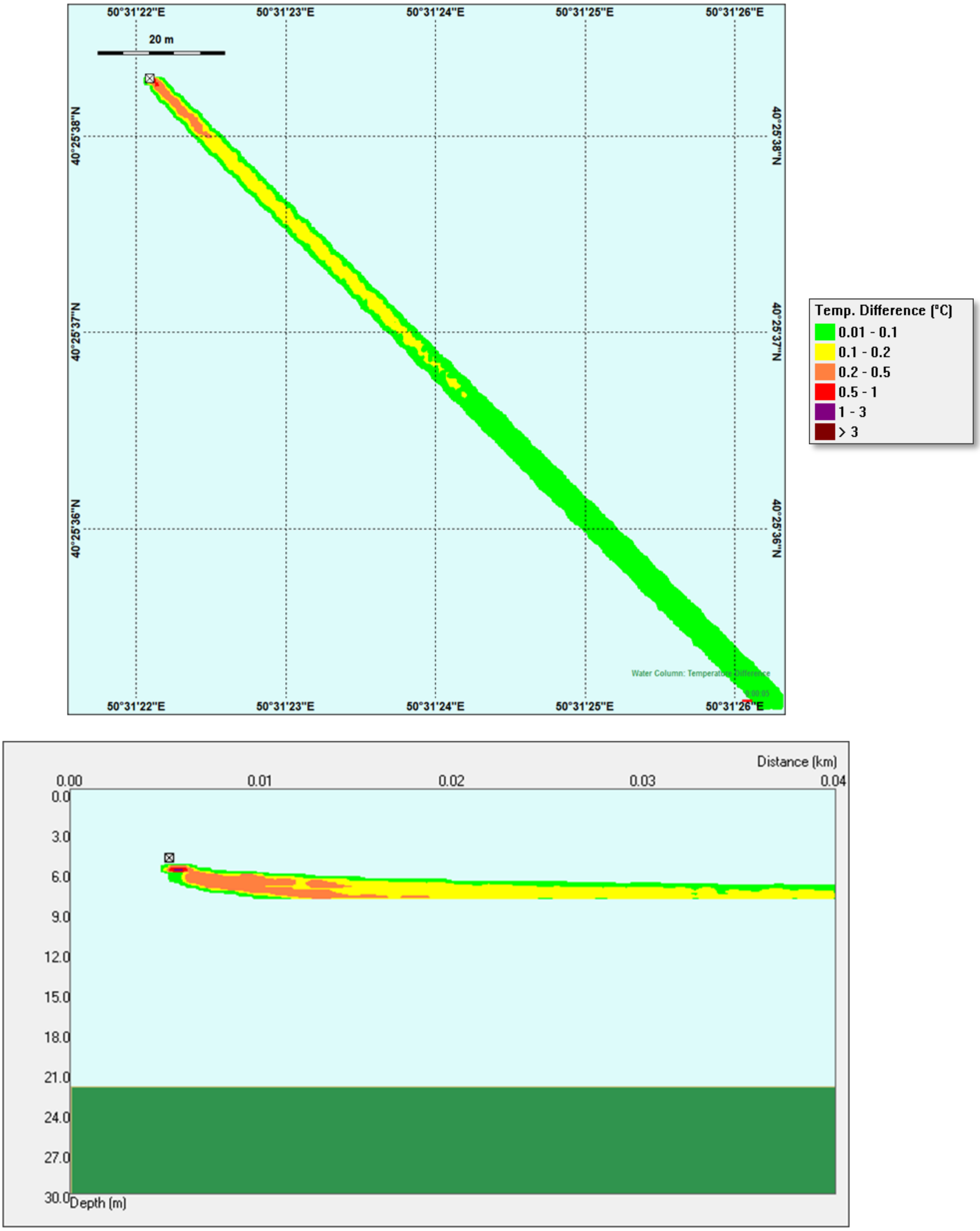
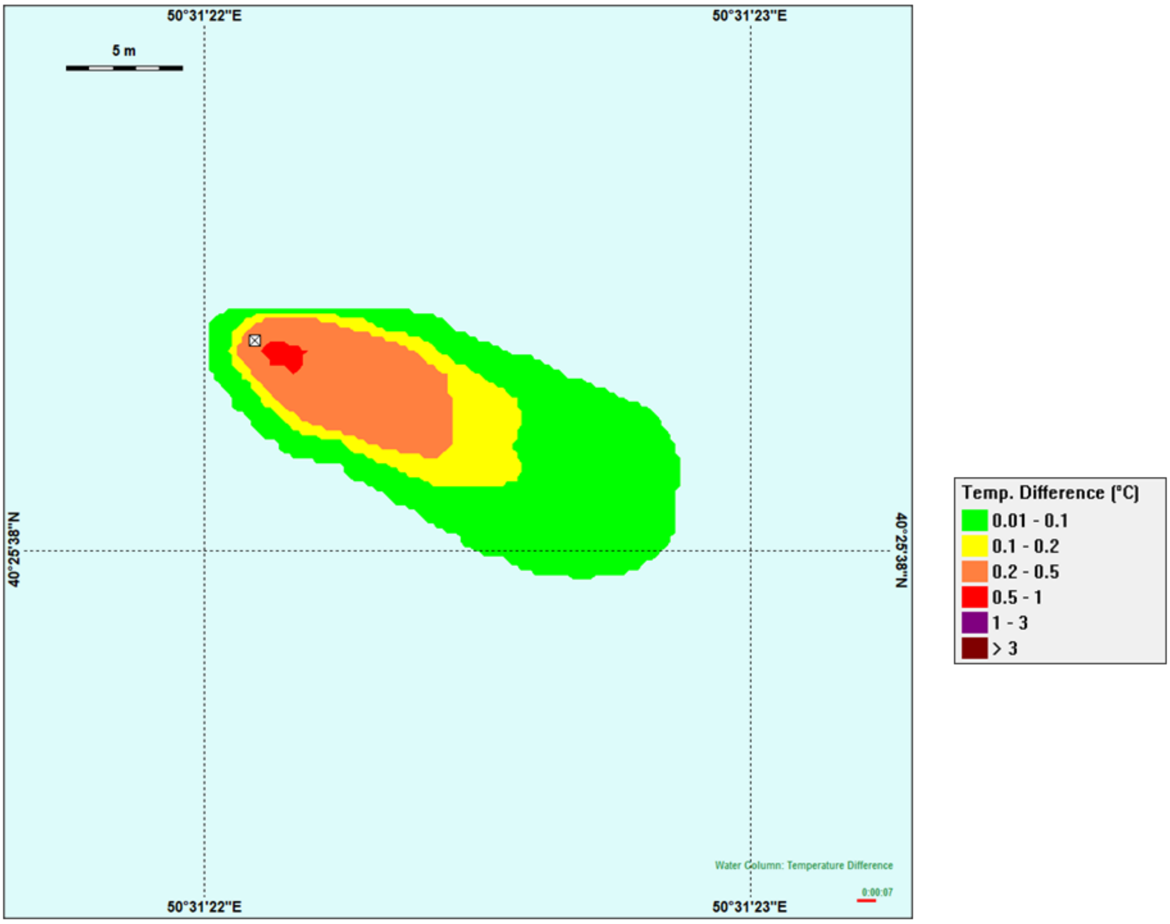


Figure 54: Stable thermal plume, summer, high current conditions (0.68 m/s)



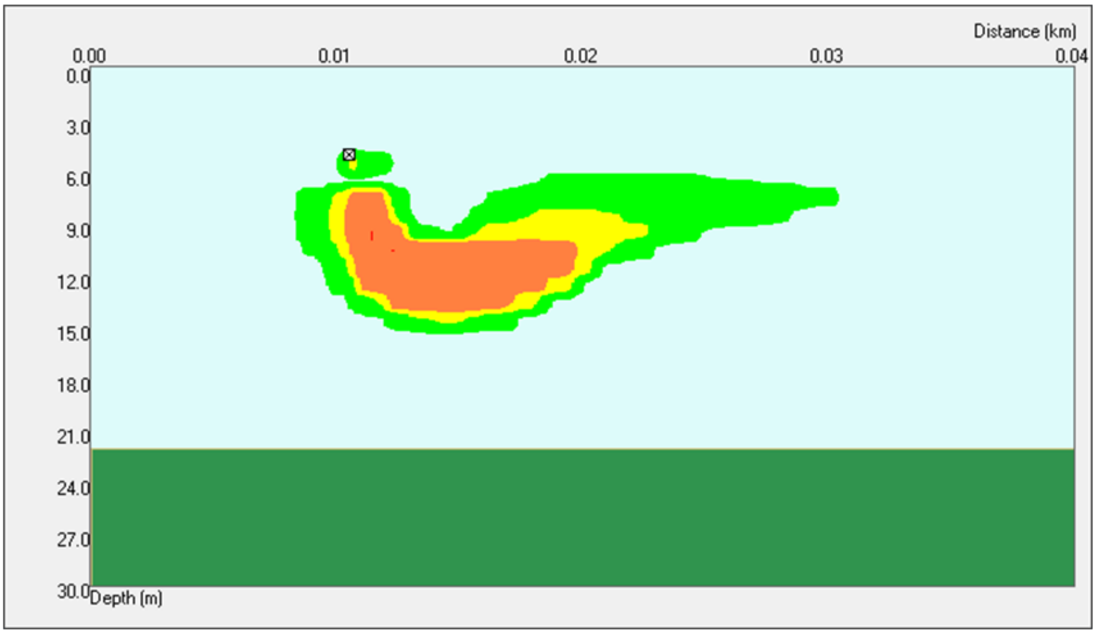


Figure 55: Stable thermal plume, summer, low current conditions (0.12 m/s)

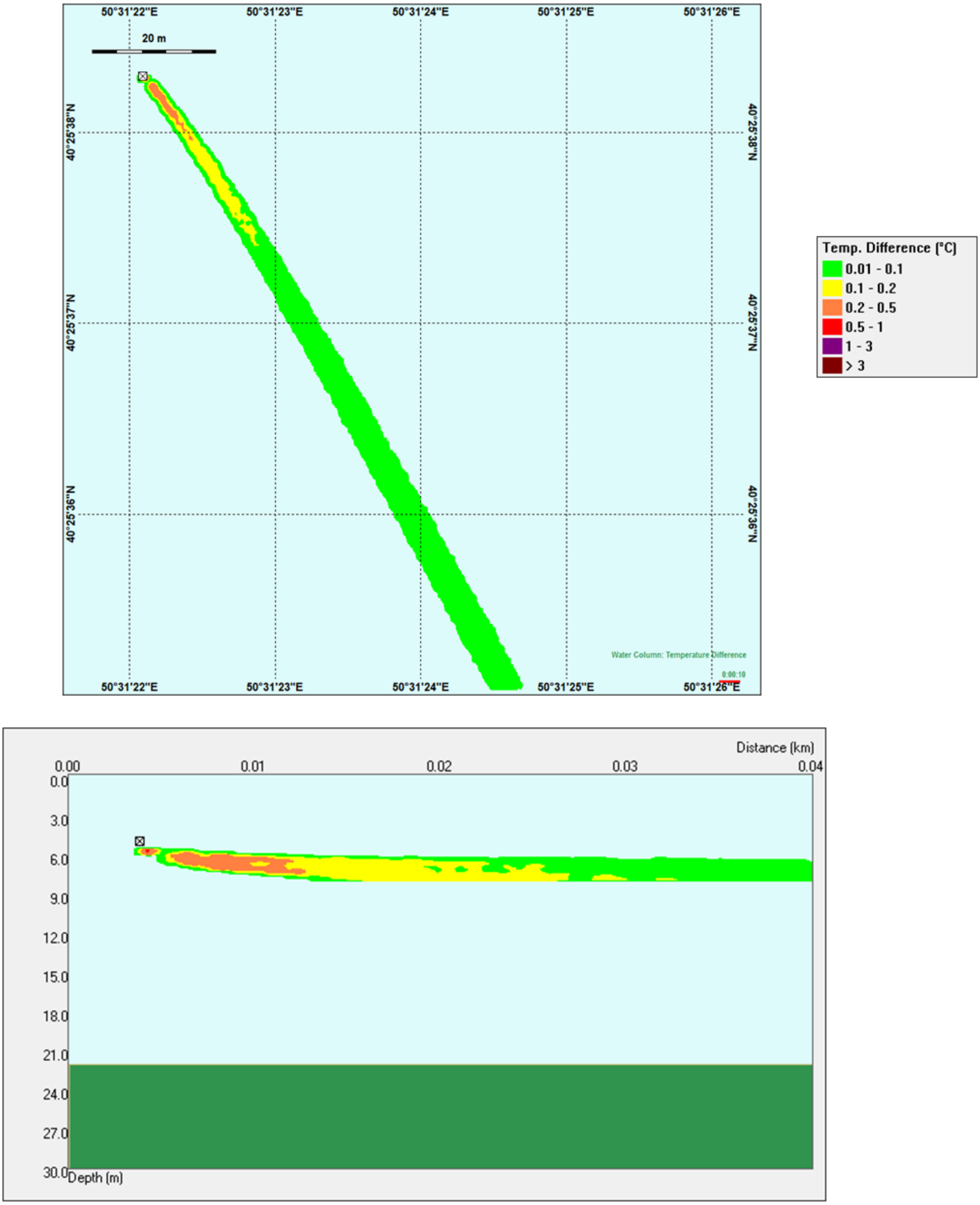


Figure 56: Stable thermal plume, winter, high current conditions (1.10 m/s)

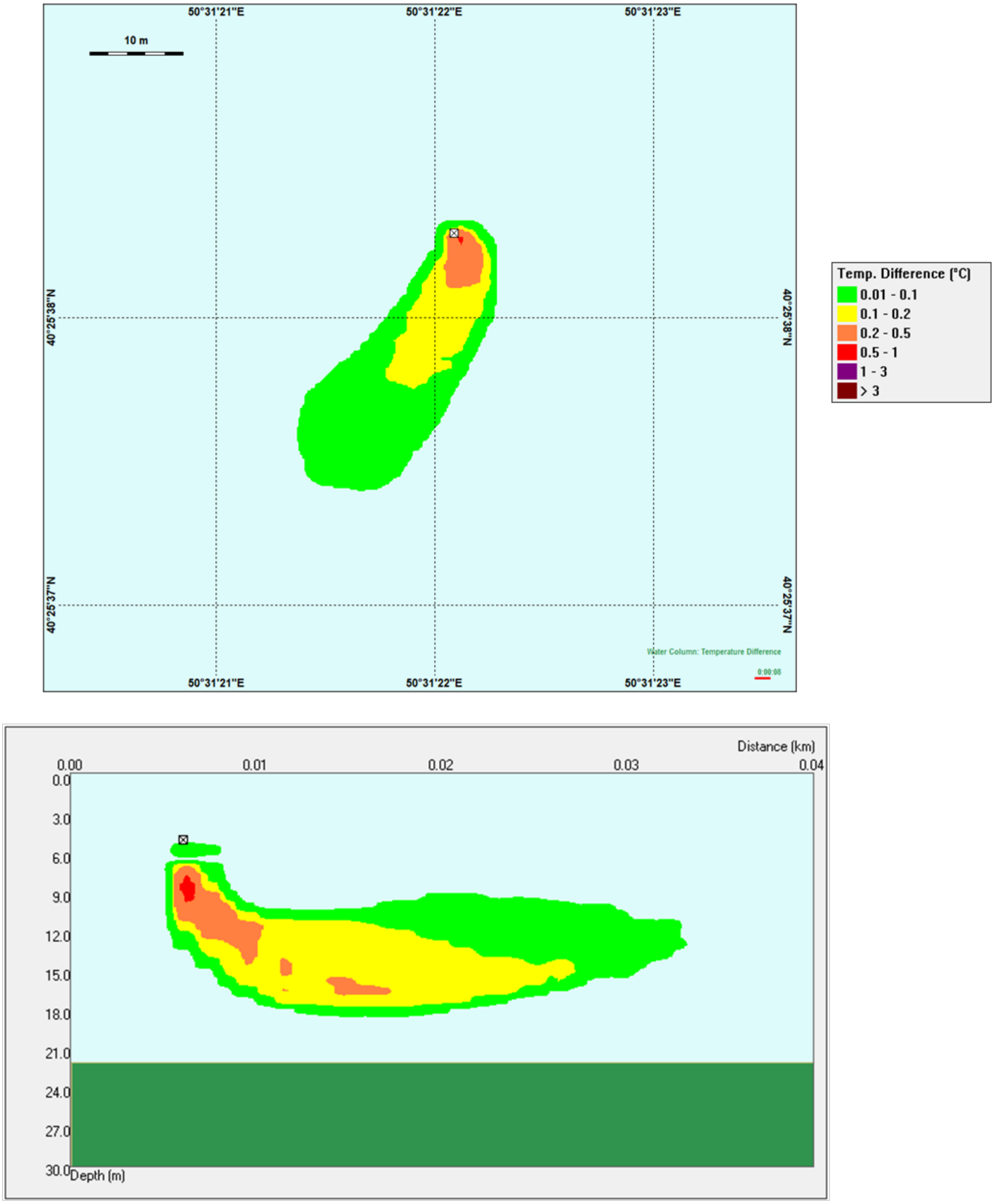


Figure 57: Stable thermal plume, winter, low current conditions (0.16 m/s)

6 Uncertainties

6.1 Characterisation of the release

6.1.1 Release volumes

Diesel volumes are based on known tank sizes and are well defined. Release rates depend on the means of discharge e.g. a perforation. Assuming that this volume leaks in one hour appears a reasonably conservative estimate, and is a small proportion of the time taken for the release to mainly disappear from the surface.

Assumptions provided by BP have been used to determine the declining rate of a blowout from well NKX-1. It is recommended that these are reviewed following well testing.

The duration of blowouts, should they occur, can be very variable and ultimately depend on a maximum realistic time to drill a relief well to arrest the flow. A value of 81 days has been estimated and is within typical timescales for this operation worldwide. Again, data obtained from drilling the exploration well may allow a more accurate estimate to be made.

6.1.2 Spill response

The modelling has been undertaken without applying any oil spill tactical response methods such as surface mechanical recovery or chemical dispersant application. In reality, spill mitigation measures such as oil spill containment, recovery and shoreline protection measures would be implemented in the event of a spill to reduce adverse effects to marine and coastal resources, thereby mitigating the full impact of a spill.

6.1.3 Release geometry

The release geometry for diesel is onto the water surface. An underwater release would reduce the diesel on the surface and increase the diesel in the water column, by a small margin. A smaller release would result in a thinner sheen that would evaporate more quickly.

The release geometry for the worst case blowout has been assumed to be a topsides release given that a fixed jackup rig is being used. There are many other potential geometries of the release, including a subsea blowout, however for this well, sea-surface release from the rig is considered to be the worst case as oil on the surface typically reaches shorelines more quickly and in greater volumes. A subsea release may affect water quality more significantly but reduce surface and shoreline impacts. The time to arrest the blowout by a relief well remains the same, independent of the geometry of the release.

An uncertainty for the cooling water discharge is the phenomenon of air entrainment if there is air inside the caisson, given the flow velocity through the caisson of approximately 1.5 m/s. This is not represented in the modelling, and if air is present then entrainment is very likely and it would tend to make the plume rise and will to some extent counteract or overcome the downward momentum. In this scenario, the modelled plume without gas entrainment descends through the water column but does not reach the seabed. With gas entrainment, it is possible that the plume could rise after first descending due to its momentum. Given that the plume descends to 6 - 18 m depth, it is not thought likely that the plume would rise to the surface and, broadly, the plume would be diluted within the same distance and volume of water as previously, so that the area affected would be no greater than that shown, i.e. the modelled results are indicative of the area affected. The modelled temperature differences are all much less than 3°C and this effect is not believed to alter the conclusions.

6.1.4 Oil properties

The oil properties are not well understood given the exploratory nature of the project and the uncertainties associated with this could be reduced significantly via an oil weathering study on samples of fluid obtained during the exploration drilling. A less common hydrocarbon type was chosen from the OSCAR database to align with the crude oil properties provided by BP for the fluids anticipated from the well. The pour point provided is particularly high and at the extreme range for common oil types. This is probably the largest uncertainty that has a high level of management attached once oil samples have been analysed.

6.2 Metocean data

Seasonal variations in temperature occur, mainly in top tens of metres of the water column. Seasonal variations in salinity are not expected.

The main uncertainty arising is that of differences between actual bathymetry data and that observed through recent surveys, which can be 10-15%. This will have some effect on the hydrodynamic model although it is not expected to be as high as 10-15% as the changes are spread over wide areas. The decision has been taken to retain the GEBCO bathymetry data in the model as the most representative, uniform source, rather than try to load in small patches of new data, which would create anomalies in the seabed and mean that releases were not depth-proportional to the profile of currents. It is unlikely that overall regional circulation is altered by improved bathymetry data, but local effects may be noticeably changed. The effects on oil movement are limited since oil is buoyant and quickly reaches the sea surface layers.

In the vicinity of the Absheron peninsula there are some anomalies in the underlying current data due to the grid size used in the hydrodynamic model leading to some inaccuracy in oil movement very close to the coast. While the impact of this is expected to be limited for a worst case blow out given its scale and the likelihood for all nearby coastlines to be affected, for operational response planning greater model resolution is recommended or specific trajectories could be miscalculated.

6.3 Model capabilities

The OSCAR model has a long pedigree of development coupled with testing that gives confidence in surface and water column outputs. Recent validation by BP has also given confidence to shoreline statistics (de Susanne *et al.,* 2015). Predictions for sediment, however, are based on very simple partitioning calculations, and may have a large margin of variability. Additionally, shoreline types have been mapped as sandy beach, and precise local shorelines will show a greater or lesser affinity for oil.

7 Conclusions

The modelling of hydrocarbon release and rig cooling water discharges associated with the NKX-1 well predicted the following key outcomes. Note that comments are restricted to the behaviour of the modelled fluids rather than interpretation of impacts.

1. Diesel release. A diesel release of 600 m^3 would create a sheen that would occupy a relatively small area of the Caspian Sea for a period of up to 9 days, after which it would be relatively insubstantial. Diesel reaches the shoreline within half a day with up to 275 tonnes predicted to be on the shoreline (12.9 tonnes typically (50^{th} percentile value)). The majority if the diesel would be lost to the atmosphere and/or biodegraded, with a residual component in the water column.

2. Well blowout. A worst case well blowout at the sea surface would create a thick oil slick extending up to 400 - 500 km at its maximum. During the blowout period of 81 days, oil is continually supplied to the sea surface, and oil on the surface remains significant until after the end of the 81 day period. Oil could reach shore within less than a day of the release commencing. The thickest areas of oil on the surface (> 0.2 mm) are predicted to cover a greater area during winter than summer. The most likely locations to receive oil on shore are Azerbaijan, northern Iran and the Russian coast, and up to 64,684 tonnes are predicted to beach on the shoreline (34,675 tonnes typically (50^{th} percentile value)) with the majority deposited in sediments or biodegraded but with a significant proportion remaining on the water surface. The oil emulsifies rapidly and the masses of emulsion at the shoreline are predicted to be 3.3 times the mass of oil reported equating to a maximum value of shoreline emulsion of around 213,458 tonnes (50^{th} percentile value around 114,426 tonnes). In terms of oil spill response, there would be floating, recoverable oil for a long period so booming and recovery may be successful.

3. Rig cooling water discharge. Predictions of the thermal plume from rig cooling water discharges show that temperature changes are reduced to negligible levels within a few metres of the discharge point in a representative range of conditions. As the cooling water is discharged via a submerged caisson, the plume is not predicted to impinge in the seabed or sea surface and remains within the accepted temperature difference at all points.

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