Exploration - Production

TEP SOUTH AFRICA

Block 11B/12B – Discharge Point 2

OIL SPILL DRIFT MODELLING

TECHNICAL REPORT

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DISCLAIMER
Modelling results do not replicate the reality but intend to give an idea of what it could be and are thus to be used for guidance purposes only.

ABSTRACT
This report aims to describes possible fates and trajectories of an oil spill, from a subsea blowout discharge, from exploration drilling in Block 11B/12B. Being the closest points to the shore or to a sensitive area in the drilling area, discharge points selected for the study represent the worst-case locations on the block (not linked to any future well location). Discharge point 2 is approximately 98 km from the nearest shore and at a water depth of 646 m. The fluid scenario selected (crude oil vs. gas condensate) represents a worst case as well since condensate would evaporate within less than a few days. Results detailed in this report are statistical representation of a predefined blowout scenario, and therefore should be used with caution, considering the variability of the environment features, as well as the physical-chemical properties of expected reservoir fluid and model parameters.

In general, for all quarters spill main drift is observed towards the SW/W direction. A secondary drift is possible towards the N/NE direction, in the event of strong winds conditions towards the shore. For the worst-case deterministic scenarios, the maximum distance reached by the oil sick thicker than 5µm (threshold thickness) is between 490 km and 935 km in the SW direction from the discharge point. The seasonality between quarters, seems to influence oil progression at surface, the probability of shoreline oiling, the minimum time for oil to reach the shore, as well as the target areas for mobilization of response means to be considered in the oil spill contingency plan. Model results indicate that shoreline oiling has an annual probability of 83% varying per season (Q1: 72%, Q2: 98%, Q3: 100%, Q4: 63%). The coastal regions most at risk are Port Elizabeth area, Knysna area, Plettenberg Bay area, George area and Tsitsikamma National Park coastline area. The maximum oil mass onshore (from the worst cases scenarios) is as follows:

- Q1: 7937 mt with capping only, 7065 mt with surface response + capping stack, and 4601 mt with surface response + SSDI + capping stack;
- Q2: 14850 mt with capping only, 13620 mt with surface response + capping stack, and 11690 mt with surface response + SSDI + capping stack;
- Q3: 15720 mt with capping only, 13780 mt with surface response + capping stack, and 12860 mt with surface response + SSDI + capping stack;
- Q4: 12750 mt with capping only, 9710 mt with surface response + capping stack, and 8400 mt with surface response + SSDI + capping stack.

The period of the year identified as the worst case in the event of a blowout (i.e. with maximum volume of oil onshore coupled with the maximum probability) is the third quarter (spill starting in August). Depending on the release start date and the observed metocean conditions, the minimum time for oil to reach the shoreline fluctuates from 1 to 60 days, with the average arrival time for all the quarters being around 12 days.

Deterministic modelling results show that surface and subsea responses are essential to limit the extent of the shoreline oiling, however due to the proximity of the discharge point to shore and the occurrence of recurrent strong winds episodes, these responses might have minimum impact on changing the oil arrival time at shore (one should note here that only the worst-case trajectory is being considered, identified for each quarter, which does not reflect each of the 90 iterations performed for each stochastic scenario). For shoreline impacts, a thickness screening threshold of 10 g/m^2 was used, which is conservative.

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1. Introduction

1.1 Preamble

This report presents an assessment of deep-water oil spill scenarios based on best available information and industry-standard numerical modelling methods.

This study describes possible fates and trajectories of an oil spill, from a subsea blowout discharge, from exploration drilling in Block 11B/12B. Discharge point selected for the study scenarios (refer to discharge 2 in Figure 1) represents the worst-case location on the block and is not linked to any future well location.

Discharge point 2 is located approximately 98 km from the nearest shore and at a water depth of 646 m (depth source: MEMW Software Depth Database).

Four periods were considered (i.e. Q1: Jan-Mar; Q2: Apr-Jun; Q3: Jul-Sep; Q4: Oct-Dec) for the study. One should note that each scenario is characterized by the discharge location, a release duration, discharge rate and the selected oil type. The scenarios considered for this study were based on best available input data and are discussed in this report.

In the framework presented in this study, an oil slick is driven by oceanic currents and winds and is treated as many independent particles whose paths and mass are recorded in a defined time-step.

This modelling study considered two approaches, namely:

- Stochastic simulation → which is a statistical calculation/analysis based on results from many sets of similar trajectories under a wide range of weather and/or seasonal conditions; and
- Deterministic simulation → which studies the trajectory and fate of an individual oil slick.

1.2 Context of the study

This study considers the potential effects of a subsea blowout discharge occurring from a discharge point (Point 2) located in Block 11B/12B, in South Africa and forms part of the overall Environmental & Social Impact Assessment (ESIA) study.

To attain this objective, the OSCAR module from MEMW software (v11.0.1) was used. This tool is among the best in class for oil spill modelling, considering its capabilities to determine how the slick will drift and how oil components will interact with the marine environment.

Four periods were covered by the study (i.e. Q1: Jan-Mar; Q2: Apr-Jun; Q3: Jul-Sep; Q4: Oct-Dec) spanning 5 years of metocean data from 01/01/2012 to 31/12/2016. For each period assessed, two (2) types of scenarios were run, namely one stochastic scenario and three deterministic scenarios (more details can be found in Table 2.3).

1.3 Study Area

The exact location of prospects to be drilled within the area of interest in Block 11B/12B in South Africa are not yet known because they are still under assessment by the exploration teams. Therefore, two discharge point were selected to cover the area of interest in the Block after discussion with the Total E&P South Africa (TEPSA) and the company in charge of the ESIA (SLR). Three main criteria were considered for the selection of the discharge points (i.e. release location) inside the area of interest, in order to select worst case scenarios:

- Assess different (rather shallow) water depths,
- Shorter distance from the coast,
- Proximity of sensitive areas.

Figure 1 and Figure 2 present the location of the identified discharge points (refer to Discharge Points 1 & 2).

The two discharge locations (1&2) are located approximately at respectively 89 km and 98km from the nearest shore with a water depth of respectively 1254 m and 690 m (depth source: MEMW Software Depth Database). The locations selected were the closest to the coast and the sensitivity areas (making them worst case) at two different depths.

The closest well which has been drilled and sampled is Brulpadda-1AX. The geological setting and pressure regime of the prospect are expected to be the same as for Brulpadda-1AX, which makes Brulpadda-1AX results good calibration data.

The most recent studies developed have been for the Luiperd-1X well, being drilled in September-October 2020 and using Brulpadda-1AX information.

The remainder of this report considers only Discharge Point 2.

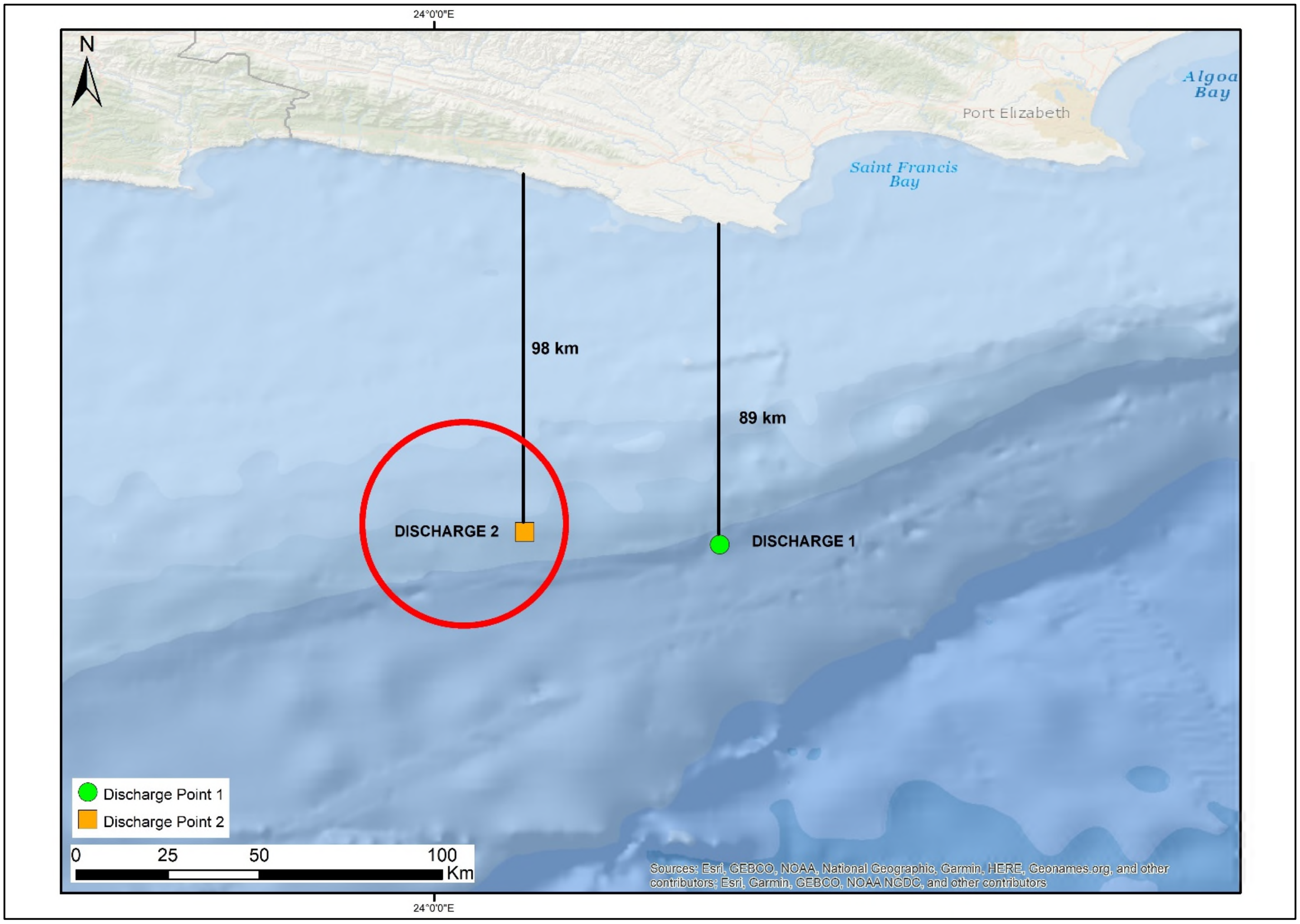

Figure 1 : Project Area Location

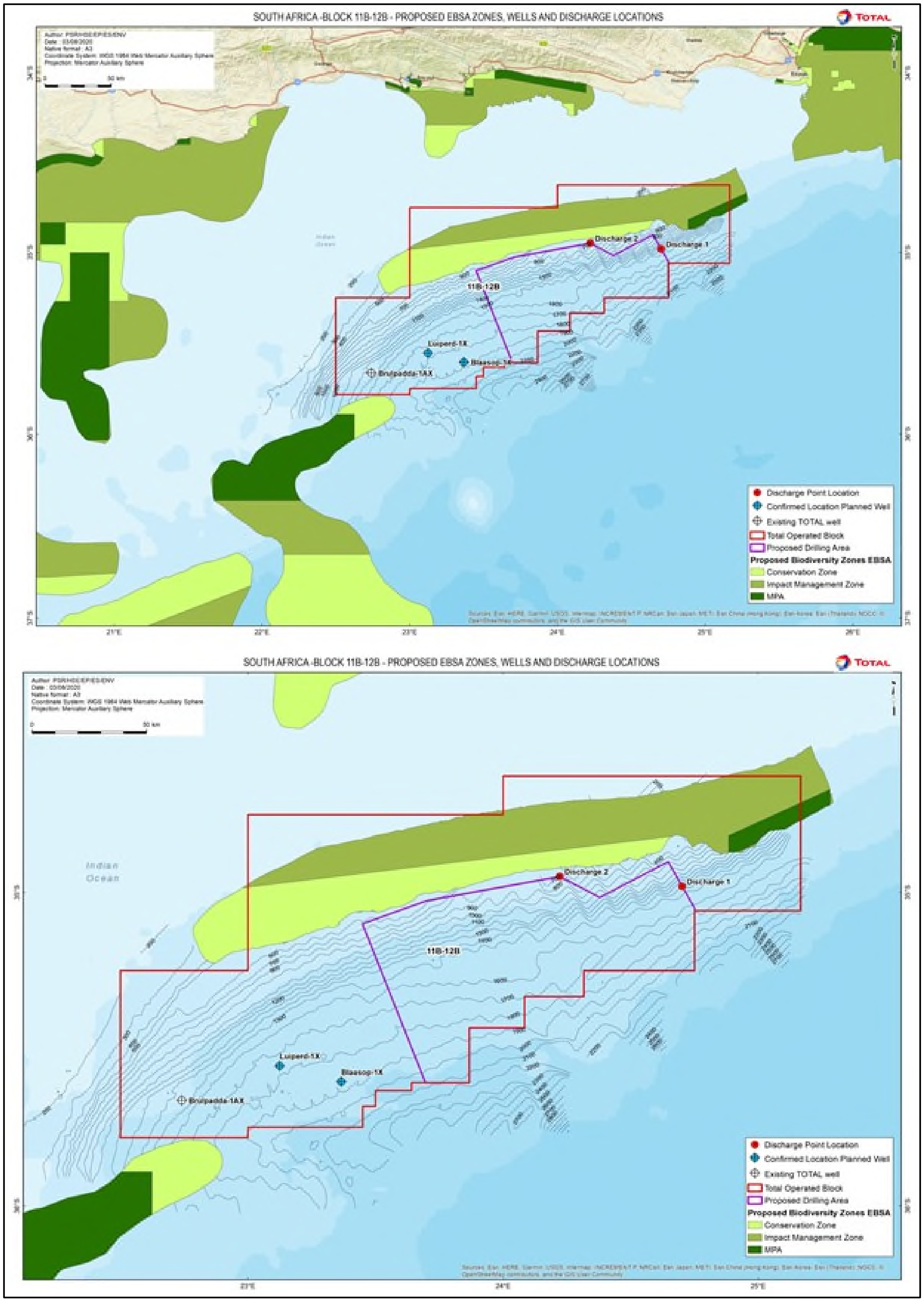

Figure 2 : Study Location and protected areas

2. Material and Method

2.1 OSCAR Modelling Tool

2.1.1 General presentation of the model

The Oil Spill Contingency and Response (OSCAR) application is a modelling tool to support decision making and help estimate oil spills interaction with the marine environment. OSCAR computes the fate and weathering of oil, in order to simulate the oil's drift, concentration and extent, on the sea surface and/or the shoreline. This tool offers the means to quantify potential environmental impacts caused by hydrocarbons spills and to identify the appropriate spill response strategy (dispersants, containment and mechanical recovery).

OSCAR uses surface spreading, advection, entrainment, emulsification, and volatilization algorithms to determine the transport and fate of the oil on the surface (Figure 3). In the water column, horizontal and vertical advection and dispersion of entrained and dissolved hydrocarbons are simulated by random walk procedures. The horizontal and vertical diffusion coefficients are described in Pan, Qingqing, et al, 2020[1]. Partitioning between particulate-adsorbed and dissolved states is calculated based on linear equilibrium theory. The contaminant fraction that is adsorbed to suspended particulate matter settles with the particles. Contaminants at the bottom are mixed into the underlying sediments and may be dissolved back into the water. Degradation in water and sediments is represented as a first order decay process. The algorithms used in the model to simulate these physical processes are described in the literature (Reed et al., 2000, 1995b; Reed and Hetland, 2002). Wind drift coefficient is 3.5% and Coriolis deflection angle is 0.

Near-field blowout model in OSCAR

The near-field blowout model applied in OSCAR is Deepblow, which in the tool itself is referred to as Plume3D. The model is based on a Lagrangian model concept, similar to earlier models developed for aqueous discharges (e.g. JETLAG model), which were later extended to multi-component discharges (sub-sea blowouts with oil and gas) by Zheng and Yapa (2003). In the model, the Lagrangian concept is extended further to include relevant phase transitions in each plume element, e.g., gas dissolved in seawater, and gas converted in hydrate. The calculation of gas hydrates is disabled by default in OSCAR, considering the formation of gas hydrates for deepwater blowouts is still a topic under heavy research. Still, the fraction of gas in hydrate form is given in the output file of the model scenario. The rise velocity of gas bubbles depends on the size of the bubble and the density difference between the gas and ambient water. Since the gas bubbles may contract as well expand, the rise velocity is subjected to changes in the blowout model.

It must be emphasized, that an oil slick may form at the sea surface even in cases where the plume is trapped below surface. The spreading of such slicks will depend on the size distribution of the oil droplets formed in the outlet jet, and the strength and variability of ocean currents in the region of concern. The wide range of possible plume-surface interactions has been reviewed by Jirka and Doneker (1991), but this knowledge has not been implemented in the Lagrangian model concept.

The oil droplet size distribution is given by a modified Weber number model. The size of droplets can be queried manually by clicking on each them, when selecting to visualize droplets in the water column, in MEMW results. Some droplet size distribution information can be also found in output files. This will refer to the distribution at a given timestep. Rise velocity can be obtained by releasing droplets of a determined

[1] Horizontal turbulent diffusion coefficient : $K_x = 0.027t^{1.34}$ - Vertical turbulent diffusion coefficient : $K_z = 0.028\frac{H^2}{T}\exp(-2kz)$ with H, T, k = wave height, wave period and wave number

size from a determined depth in the water-column and running the model to see how long it takes the droplets to rise to the surface. However, it is time-consuming to investigate this alone, because it's not part of the main model output.

The reference validation study where the results from OSCAR are compared to prototype oil spills is the comparison case with the Sanchi oil spill (Pan, Qingqing, *et. al*, 2020).

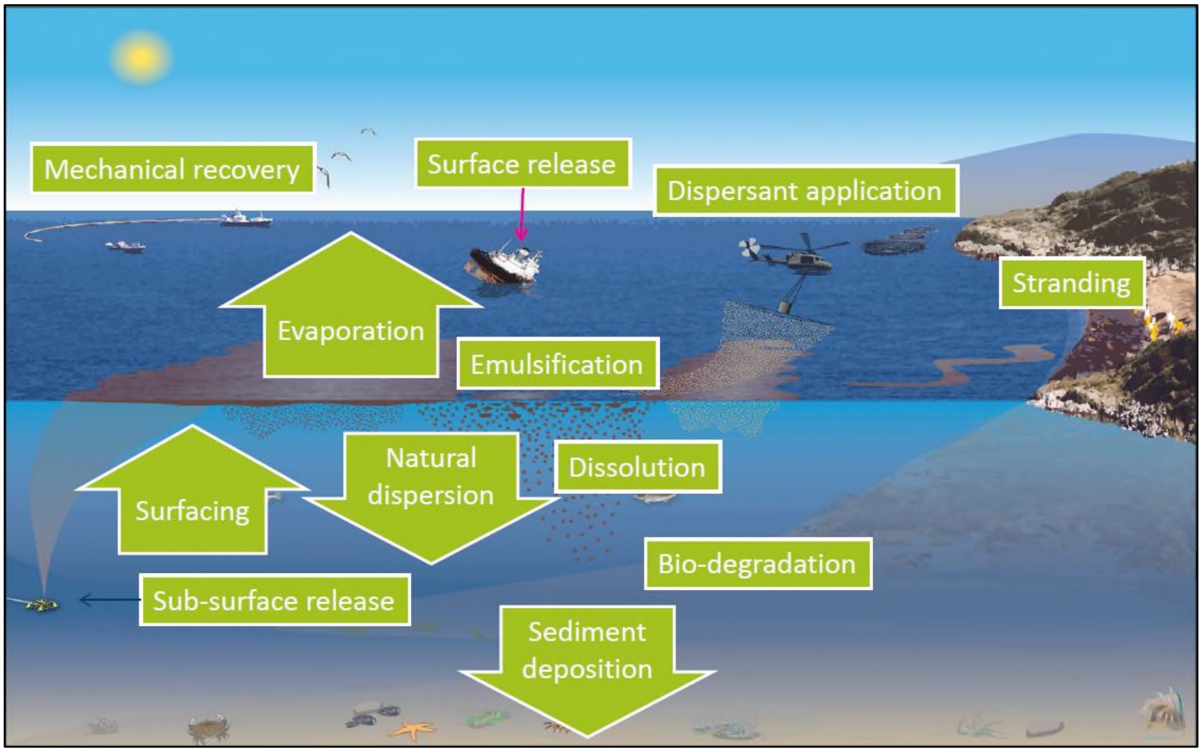

Figure 3: Physical and chemical processes included in the model (OSCAR)

2.1.2 Stochastic approach

OSCAR is a statistical modelling tool that provides insight into how typical oil spill scenarios unfold under a wide range of weather or seasonal conditions. Indeed, the stochastic scenario is a statistical calculation based on results from many sets of similar deterministic simulations (thus using the same weathering model) (Figure 4). The results from each simulation making up the stochastic scenario are combined to produce statistics on oil slick distribution probabilities, in time and space, that are translated on statistical maps. Main result is a map showing the probability of contamination above defined threshold values, for sea surface and shoreline compartments. The probabilities are given as percentages of the total number of simulations (in this study 90 simulations for each stochastic scenario). For example, a probability of 50% implies that an area was impacted during the studied period for half of the number of simulations in the stochastic scenario. One should note that this probability (like other stochastic results) is also interrelated to the threshold value applied to represent model output results.

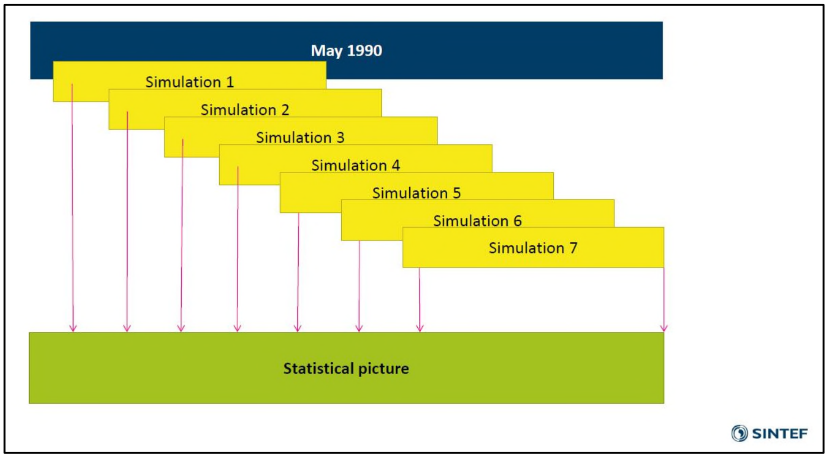

Figure 4: Schematic illustration of stochastic approach

2.1.3 Deterministic approach

Deterministic simulation studies the trajectory and fate of an individual oil slick that starts at a defined moment in the past and uses the associated wind and current data (usually the worst-case trajectory identified in the stochastic simulation). The oil spill behavior is studied for a specific period.

The purpose of this simulation is to better understand how the oil spill progresses in the marine environment, estimate the amount of oil that could reach the coast depending on the weather conditions and oil weathering, as well as the minimum time to observe these impacts.

For this study, the worst-case trajectory selected from the stochastic scenario, represents the trajectory with most quantity of oil reaching the shore.

2.2 Scenarios Parameters

2.2.1 Oil Profile

In Brulpadda-1AX, both gas with condensate and oil were encountered. Due to the likely analogy with Brulpadda-1AX environment, both fluids could be encountered at the discharge location. Nevertheless, for such oil spill modelling study, only the worst case was considered: spill of crude oil.

Indeed, condensates are part of group1 non persistent oils according to ITOPF classification and have a very low solubility in water and are highly volatile. They also have a low density and, if spilled would, typically, float on the sea surface and would begin to evaporate quickly and, as shown in appendix 4, would be removed within less than 2 days after the release having a much lower impact on the marine and coastal environment.

The Table 2.1 details the fluids properties (that is Crude Oil), used for the modelling study. These oil properties have been chosen by similarity to Brulpadda-1AX oil properties. The selected analogue is used in the model to simulate behavior and fate of crude oil in the marine environment. Obtained results are an approximation, of what is expected, considering the assumptions defined for the modelling study (i.e. selected scenarios, release conditions, metocean data used, among other relevant input data).

Table 2.1: Properties of oil profile used in the model (source MEMW/OSCAR Oil Database)

Fluid properties	Crude Oil profile used in the model
°API	36.7
Viscosity (cP)	15
Pour Point (°C)	-6
Wax content (%)	5.13
Asphaltenes (%)	0.07

The Table 2.2 details the release properties used for the modelling study, including the Gas associated to the release.

Table 2.2 : Properties of the release including gas products used in the model

Release properties	
Release Hole Diameter (m)	0.31115 (or 12 ¼ inches)
Gas Rate (Sm^3/day)	$2.2*10^6$ Sm^3/day
Gas Density (kg/Sm^3)	Range 0.67-0.77 kg/m^3
Oil Temperature (°C) at Release Point	70-85°C

2.2.2 Discharged Rate/Volume

The release discharge rate defined for the study scenarios considers the maximum blowout rate from past studies made on the block considering oil from Brulpadda-1AX and similar pressure and geology as what is expected at the discharge point location.

All the Scenarios of this study simulate a continuous blow-out of 69 600 bbls/day.

The total volume of oil released, depending on the release duration and on each scenario properties, is detailed in the "2.2.5 Study scenarios summary" section below.

2.2.3 Oil spill response

The following response means (including associated operational start and end times) were applied to the study scenarios considering spill response strategies (refer to Table 2.3):

I. **Capping Stack deployed at the end of the 20th day** (one day margin compared to the BOCP)**.**

II. **Subsea Dispersant Injection Kit (SSDI) deployed after the 15th day.**

III. **Surface dispersion with the following resources:**

- **2 aircraft for chemical dispersion** operations, deployed respectively 24 h and 72 h after the start of the spill;

- **10 vessels for chemical dispersion** operations with the following deployment times:
  - 3 vessels 24h after the start of the spill;
  - 2 vessels 48h after the start of the spill;
  - 5 vessels 72 h after the start of the spill.
- **5 pairs of vessels for containment and recovery** operations with the following deployment times:
  - 2 pairs 24h after the start of the spill;
  - 1 pair 48 h after the start of the spill;
  - 3 pairs 72 h after the start of the spill.

Above response strategy is in agreement with response strategy outlined in Total E&P South Africa BOCP (Blowout Contingency Plan) and TEPSA OSCP (Oil Spill Contingency Plan). More details can be found in Appendix 2 – Oil Spill Response PPT (BOCP). Vessels for oil spill surface response (chemical dispersion and containment and recovery) can be any vessel, on which equipment from OSRL shipped from abroad will be installed and no issue is foreseen for their mobilization.

2.2.4 Simulation periods

- **Periods considered for the study stochastic scenarios are intended to reproduce the presence of variations (i.e. seasonality) that occur at specific regular intervals normally less than a year, such as quarterly variations. The seasonal fluctuations of this study' time series, is contrasted with recurrent metocean patterns (whenever applicable).**

Scenarios 1 → January to March, i.e. Q1 period, spanning the 5 years of the metocean dataset (i.e. 2012 to 2016).

Scenarios 2 → April to June, i.e. Q2 period, spanning the 5 years of the metocean dataset (i.e. 2012 to 2016).

Scenarios 3 → July to September, i.e. Q3 period, spanning the 5 years of the metocean dataset (i.e. 2012 to 2016).

Scenarios 4 → October to December, i.e. Q4 period, spanning the 5 years of the metocean dataset (i.e. 2012 to 2016).

2.2.5 Study scenarios summary

Study scenarios for discharge point 2 are summarized in Table 2.3.

Table 2.3: Summary of study scenarios for discharge point 2

Scenario	Type of Product	Discharge Rate	Simulation type	Release Duration (days)	Simulation Duration (days)	Nb. of Iterations	Period	Start Time	Spill Response Strategy
1A	Crude Oil	69 600 bbls/day	Stochastic	20	60	90	Q1 2012 to 2016	01/01/2012	Capping only
1B			Deterministic	20		1	Q1 2016 (worst case)	12/03/2016 (worst case)	Capping only
1C			Deterministic	20		1			Surface Reponse +Capping
1D			Deterministic	20		1			SSDI + Surface Response + Capping
2A	Crude Oil	69 600 bbls/day	Stochastic	20	60	90	Q2 2012 to 2016	01/03/2012	Capping only
2B			Deterministic	20		1	Q2 2012 (worst case)	27/06/2012 (worst case)	Capping only
2C			Deterministic	20		1			Surface Reponse +Capping
2D			Deterministic	20		1			SSDI + Surface Response + Capping
3A	Crude Oil	69 600 bbls/day	Stochastic	20	60	90	Q3 2012 to 2016	01/01/2012	Capping only
3B			Deterministic	20		1	Q3 2013 (worst case)	26/08/2013 (worst case)	Capping only
3C			Deterministic	20		1			Surface Reponse +Capping
3D			Deterministic	20		1			SSDI + Surface Response + Capping
4A	Crude Oil	69 600 bbls/day	Stochastic	20	60	90	Q4 2012 to 2016	01/01/2012	Capping only
4B			Deterministic	20		1	Q4 2015 (worst case)	26/10/2015 (worst case)	Capping only
4C			Deterministic	20		1			Surface Reponse +Capping
4D			Deterministic	20		1			SSDI + Surface Response + Capping

2.3 **Modelling Parameters**

2.3.1 OSCAR Model Parameters

Modelling parameters are presented in Table 2.4.

Table 2.4: Modelling Parameters

Product Type	Crude Oil	
Scenario	Stochastic	Deterministic
Grid size (in km)	1635 East x 1150 North	1620 East x 1320 North
Cell size (in m)	1635 m x 1150 m	1620 m x 1320 m
Vertical resolution	10 layers between 0 to 2000 m depth	
Number of liquid/solid particles	10 000	
Number of dissolved particles	10000	
Gas particles	5000	
Lower concentration limit	0.01 ppb	
Calculation parameters	Time step = 20 minutes / Output interval = 3 hours	
Surface film thickness (initial / thick limit / terminal)	4 mm / 0.1 mm / 0.001 mm	
Release depth	At seabed	

2.3.2 Environmental Average Data

Environmental data used for the modelling simulations are detailed in Table 2.5:

Table 2.5: Environmental average data

Upper water column temperature (°C)	22°C (annual mean value)
Lower water column temperature (°C)	3°C (annual mean value)
Air temperature (°C)	21
Salinity (‰)	35
Seawater oxygen content (mg/l)	0m: 7.68 / 250m: 7.36 / 500m: 6.88 / 1000m: 6.08 / 1500m: 5.44 / 2000m: 6.88
Suspended sediment (mg/l)	0

NB: Environmental data detailed in Table 2.5, is a synthesis between EBS survey data and bibliographic research on the study area (as per “OSCAR MODELLING – SERVICE REQUEST FORM”, signed by Affiliate’s HSE Manager, in 15/05/2020).

2.3.3 Metocean Dataset (3D Currents & 2D Wind Data)

A great portion of the 11B/12B block lies on the pathway of the Agulhas Current, a fast and narrow western boundary current flowing along the eastern and southern coasts of South Africa. The core of the current is generally positioned across the block and is occasionally perturbed by shear edge eddies generated upstream south of Port Elizabeth (34° S) and or Natal pulse anomalies generated offshore Durban.

Current direction can change in response to change in winds and or progression of large eddies. The Agulhas Current does not present any seasonality as the anomalies impacting the current flow, in addition to weather, are sporadic and difficult to predict.

- Metocean model selection (model calibration and validation)

The metocean data used for this study were purchased from SAT-OCEAN. SAT-OCEAN have developed innovative and exclusive technologies combining *in-situ data*, satellite sea surface temperature, wind and altimetric data, allowing to generate 3D ocean currents and winds anywhere in the world. In effect, coupled inverse/direct modelling approaches combined with the data allow us to measure these quantities from space with very high spatial (1/32°) and temporal resolutions (3-hour output time step) over the model emprise.

Several studies have shown that upper layer oceanic features can be monitored from satellite measurements over long periods of time. SAT-OCEAN merge up to 9 sensor data sets and produce analyzed SST (sea surface temperature) fields accurate to 0.3°C on average compared to surface drifting buoys' temperature measurements. Monitoring the ocean's surface at such resolutions yields the ability to compute absolute 3-dimensional currents worldwide.

Details about metocean model calibration and validation are provided in Appendix 3 – Metocean Data Memo.

The current data used are based on a 5-year dataset (1st of January 2012 – 31st of December 2016) which comprises 3D currents from the continuous current hindcast at each grid point:

- 3D currents
    - NetCDF format (OSCAR compatible)
    - 5 years of data (1st of January 2012 – 31st of December 2016)
    - Spatial resolution at least 1/32°
    - Vertical resolution: 32 layers
    - Time step: 3 hours

In order to assess the quality and representativity of this dataset, SAT-OCEAN dataset was compared with the results of a previous statistical analysis performed for the period 1999 – 2018 (20 years) based on CMEMS3D, the Operational Mercator global ocean analysis and forecast system at 1/12 degree (resolved on 50 vertical levels form the surface to 5500m) updated daily. The comparison was performed at one location of the Block11/12 where a well is planned (Luiperd).

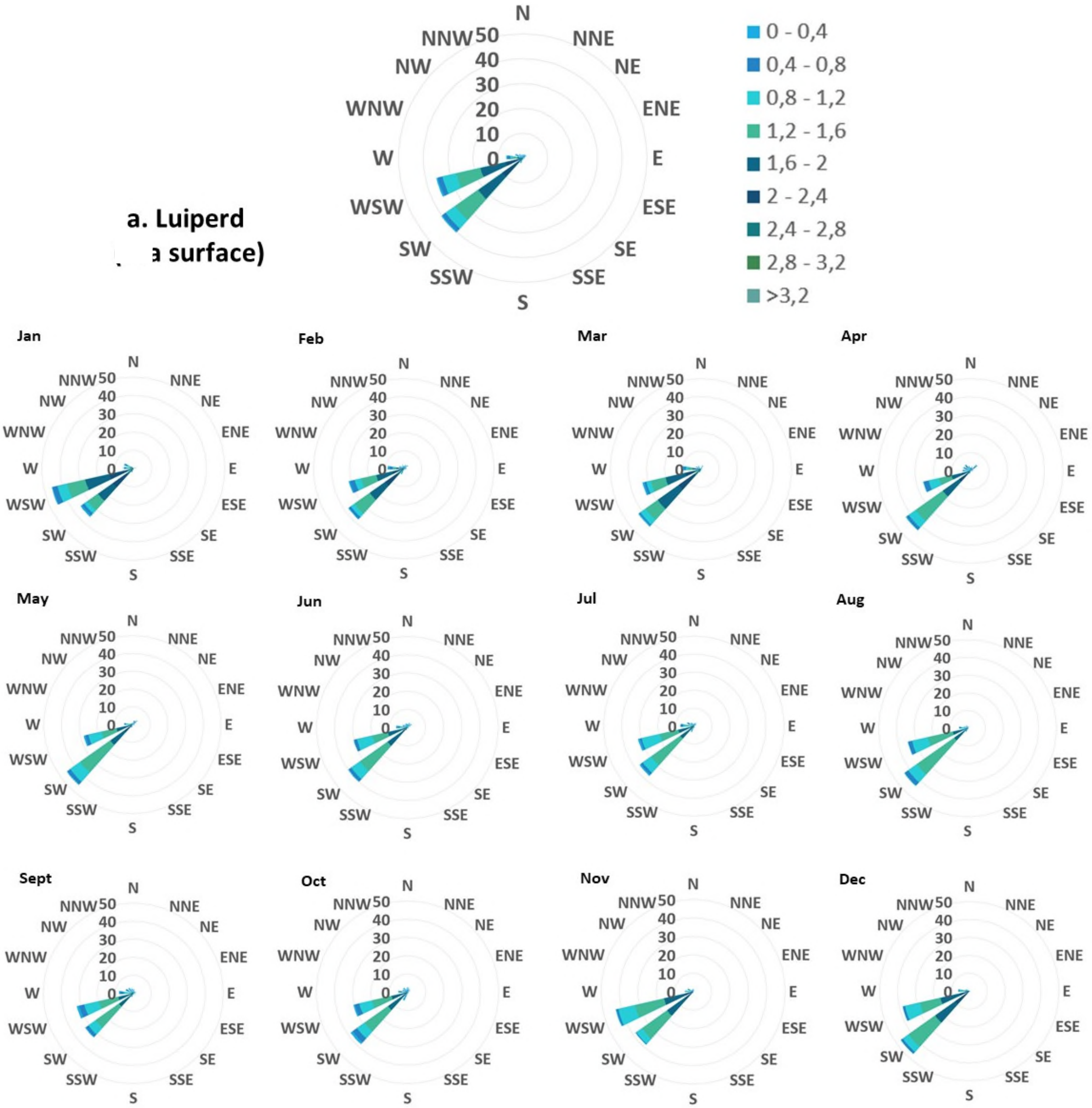

Figure 5- Frequency of surface current magnitude and direction for the entire CMEMS3D hindcast period 1999-2018 at "LUIPERD"

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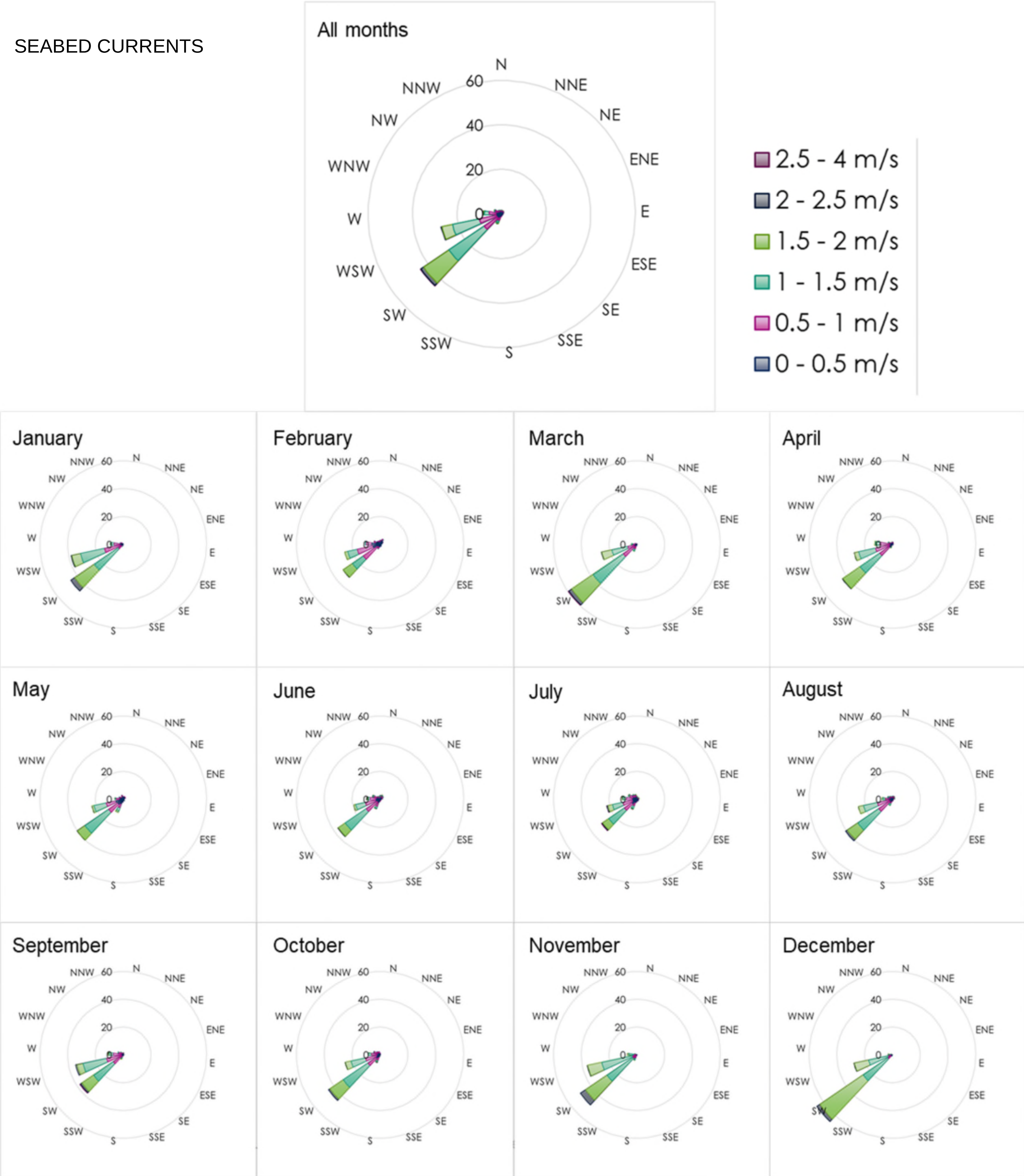

Figure 6 - Frequency of surface current magnitude and direction the 2012-2016 SAT-OCEAN dataset *at "LUIPERD"*

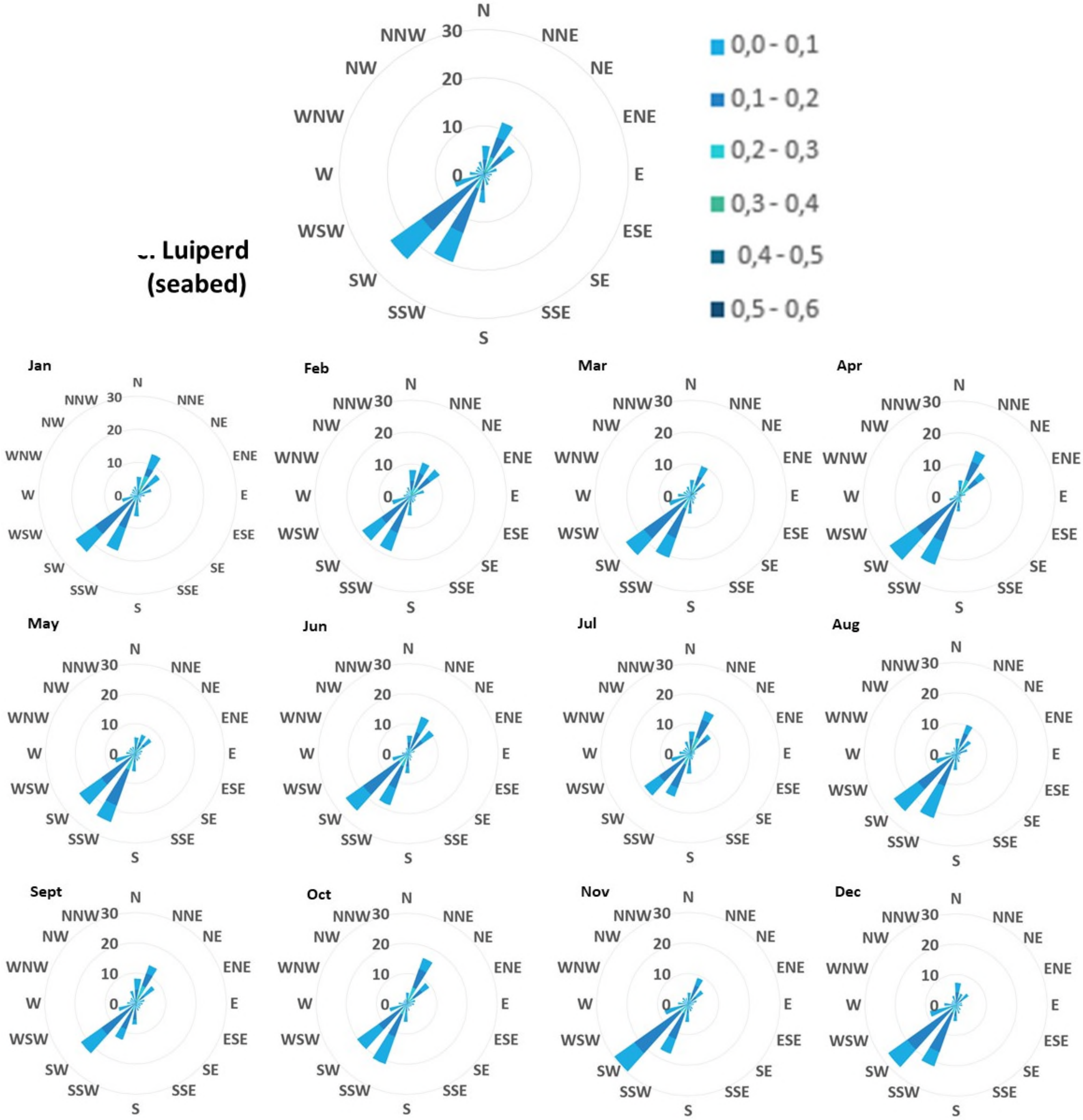

Figure 7 - Frequency of seabed current magnitude and direction the entire CMEMS3D hindcast period 1999-2018 at "LUIPERD"

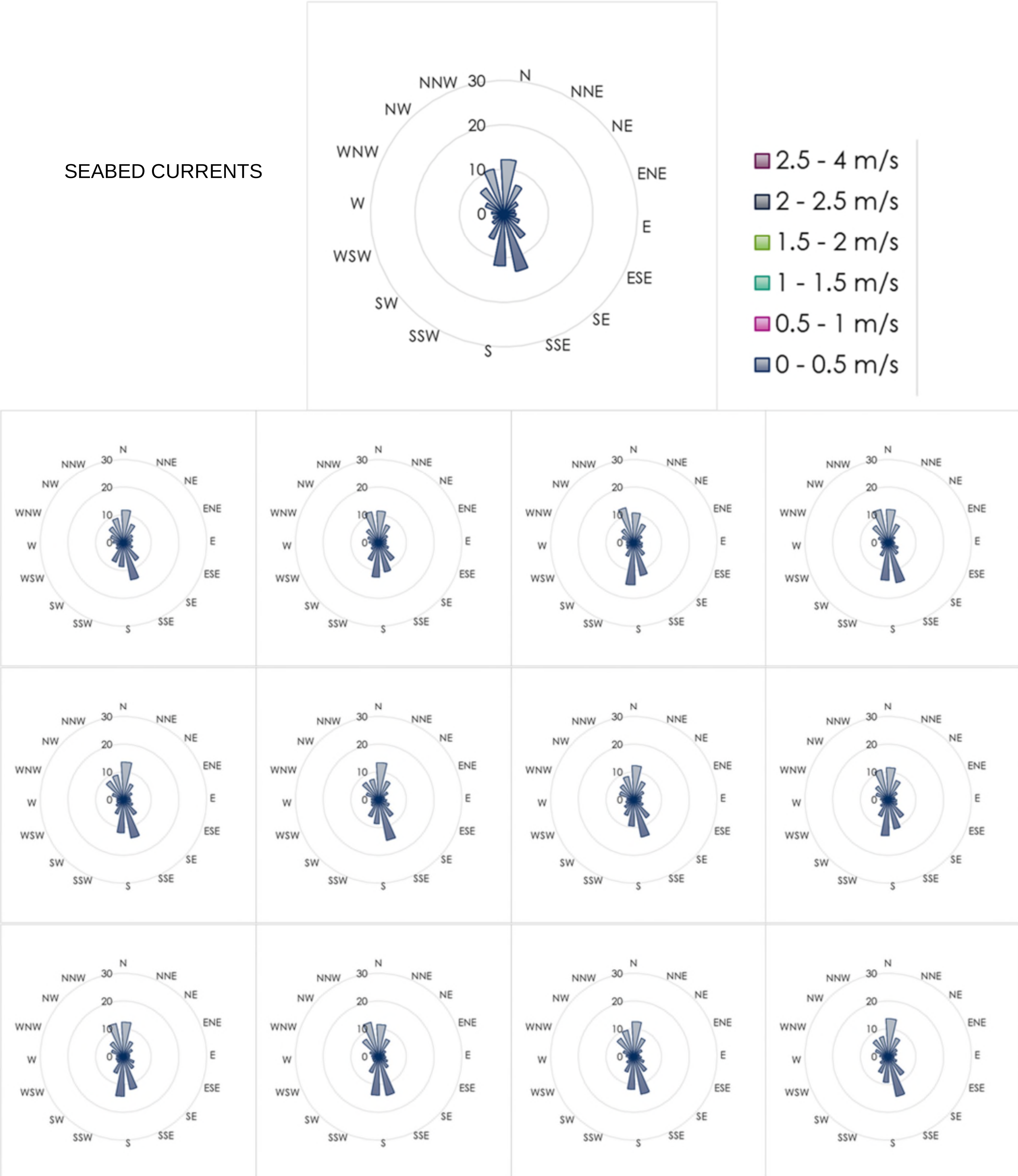

Figure 8 - Frequency of seabed current magnitude and direction for SAT-OCEAN 2012 at “LUIPERD”

Figure 5 and Figure 6 compare the annual surface current statistics at Luiperd for the SAT-OCEAN (2012-2016) dataset and the CMEMS3D dataset (1999 to 2018).

Both roses show a very good correlation of current speed and direction. Predominant directions are toward SW to WSW at Luiperd for the SAT-OCEAN as well as for the CMEMS3D 20 years period hindcast model with occurrence >70% in both cases and towards WSW to SW.

The current roses on Figure 7 and Figure 8 compare the annual seabed current statistics at Luiperd for the 2012-2016 period (SAT-OCEAN) and the entire period of the hindcast model (CMEMS3D 1999 to 2018). Current at seabed from SAT-OCEAN at Luiperd shows a predominate direction toward N-S while directions for the hindcast model are oriented along the zonal axis across the southwestern (55% occurrence) and northeastern (25% occurrence) sectors. But in both cases the current speed remain very low, below 0.5 $m.s^{-1}$.

Figure 9 and Figure 10 below show the surface current and the seabed currents at the second discharge location for 2012-2016. Surface currents at discharge point 1 shows a predominate direction toward WSW (~50% occurrence).
Seabed currents are very low and do not show any predominant direction.

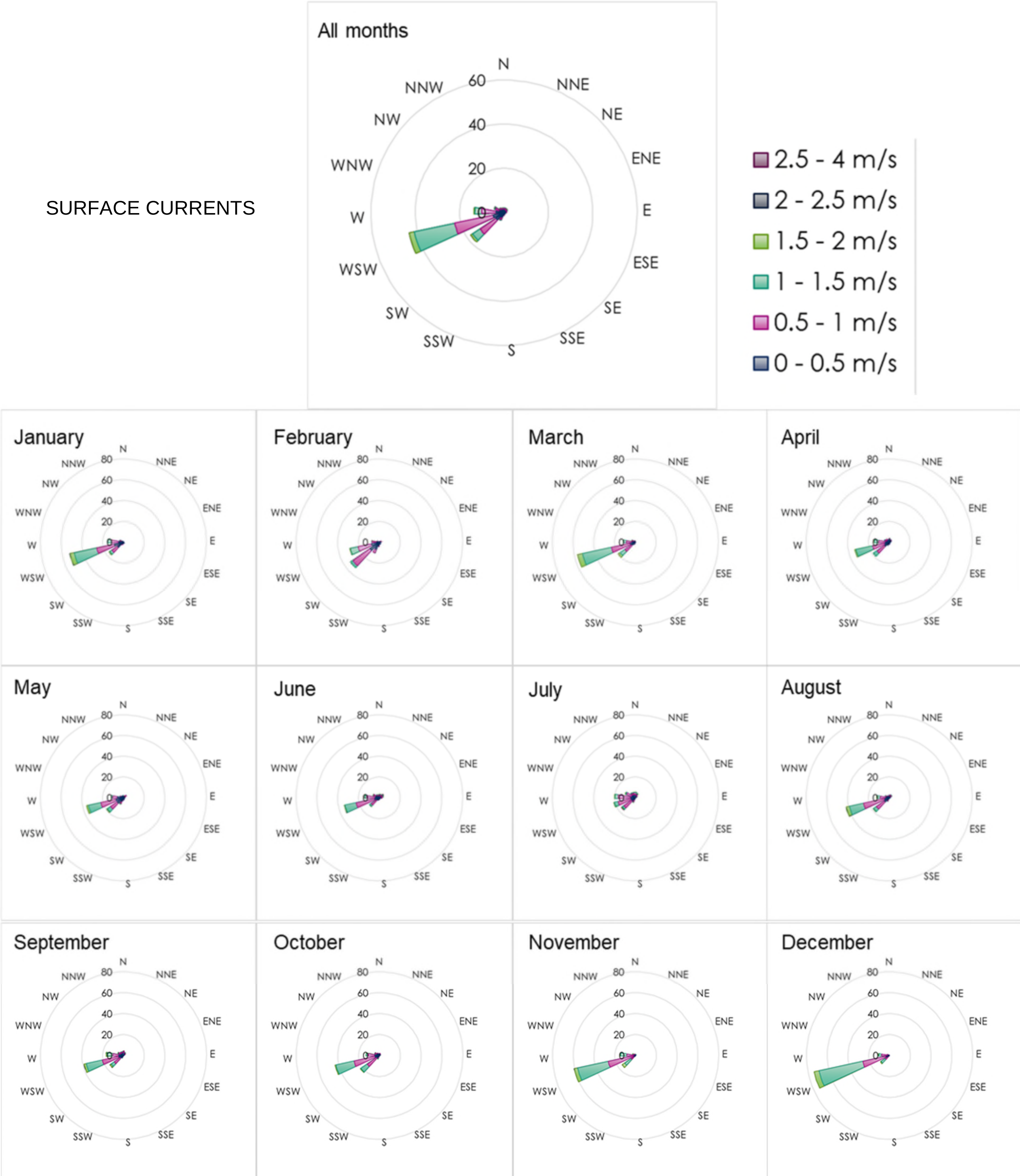

Figure 9 - Frequency of surface current magnitude and direction for SAT-OCEAN 2012-2016 at Discharge point 2.

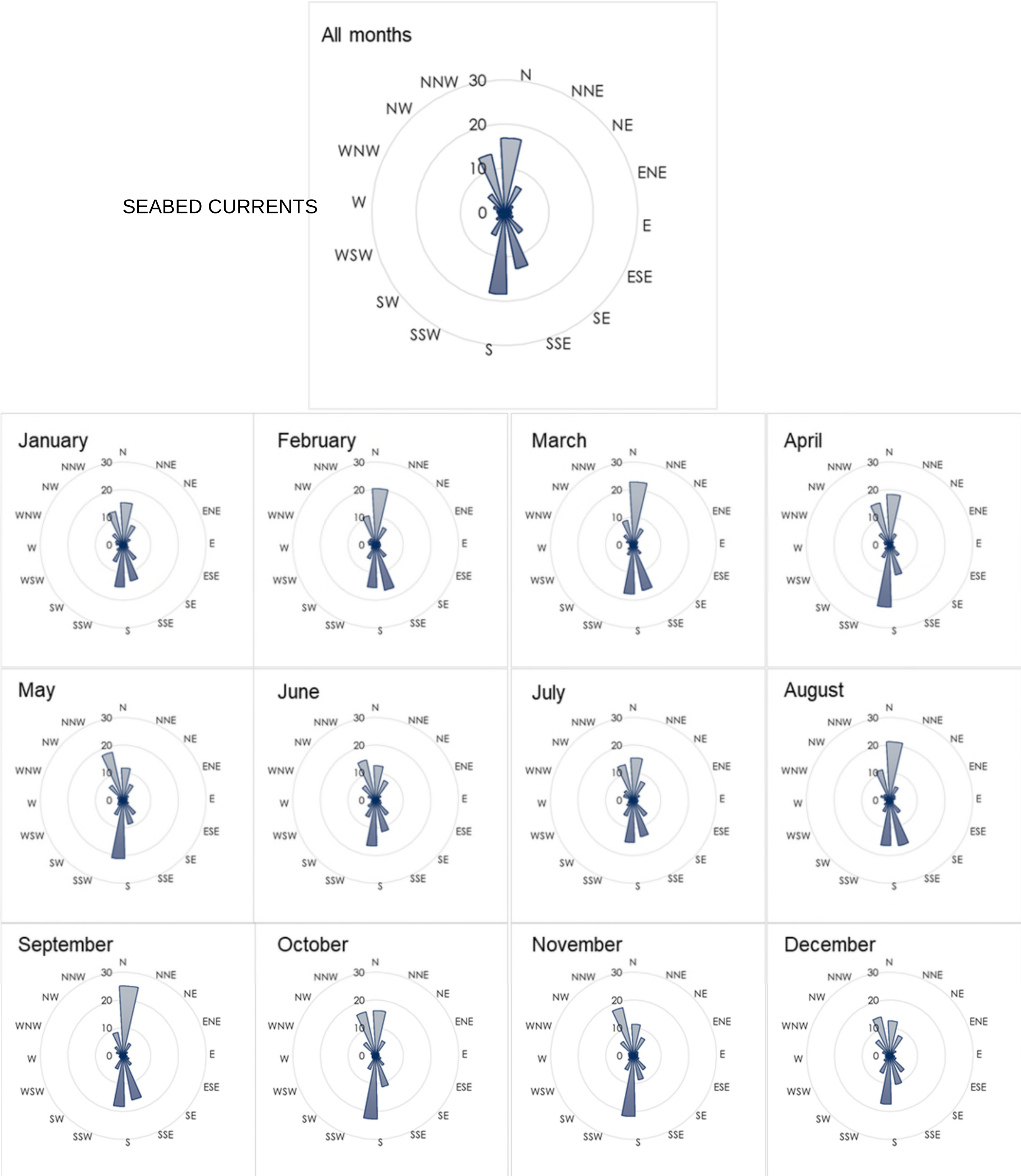

Figure 10 - Frequency of seabed current magnitude and direction for SAT-OCEAN 2012-2016 at Discharge point 2.

The wind data used are based on a 5-year dataset (1st of January 2012 – 31st of December 2016) which comprises 2D winds (associated to the 3D currents) from the continuous wind hindcast at each grid point:

- Associated 2D Winds
  - NetCDF format (OSCAR compatible)
  - 5 years of data (1st of January 2012 – 31st of December 2016)
  - Time step: 3 hours.

In order to assess the quality and representativity of this dataset, a statistical analysis of this dataset was compared with the results of a previous statistical analysis extracted from ERA-interim hindcast model which is a global atmospheric reanalysis available from 1950 to present (70 years) and continuously updated in real time. The spatial resolution of this ERA data set is approximately 31 km on 137 vertical levels from the surface up to 0.01 hPa. The ERA-5 data assimilation and forecast produces hourly analysis fields.

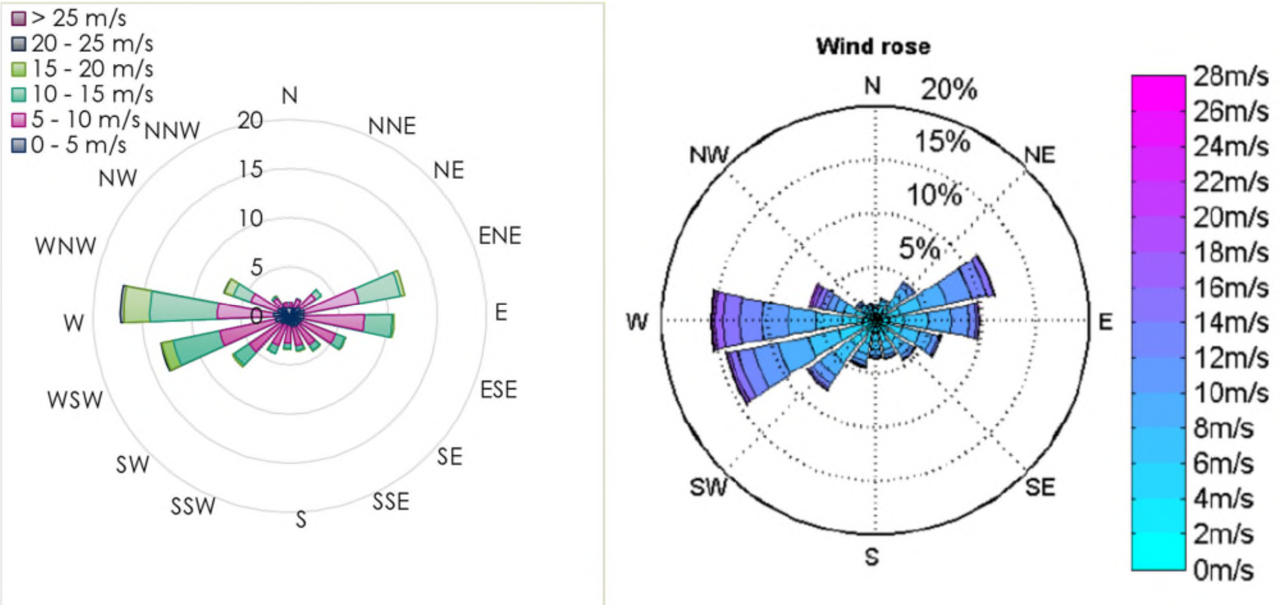

Figure 11: Frequency of wind magnitude and direction: for SAT-OCEAN 2012-2016 (left) and the entire ERA hindcast period 1950 -2019 (right) at "LUIPERD"

The wind roses above compare with the annual wind statistics at Luiperd for 2012-2016 and the entire period of the ERA hindcast model (1950 to 2019). Roses show a very good correlation in terms of frequency of occurrence for wind speed and direction. Both show predominant wind directions between SW and WNW sectors (45% occurrence), and in a lesser extent between NE and ESE sectors (30% occurrence). Lower frequency of occurrence below 10% is observed in both cases for winds flowing from the Southern sector towards the shorelines.
Figure 12 shows that winds at discharge point 2 are very similar to those at Luiperd.

As a conclusion, both datasets show a good correlation for winds and surface currents at Luiperd and further to the East in the block while it is less the case for the seabed current. Overall, the currents in the study area are predominantly driven by the Agulhas Current flowing mainly towards SW although occasionally disturbed by eddy activities inducing recirculation towards the shorelines. Predominant wind directions are oriented along the zonal axis (across the western and eastern sectors). However low occurrences of wind directions directed towards shorelines can be observe in both datasets.

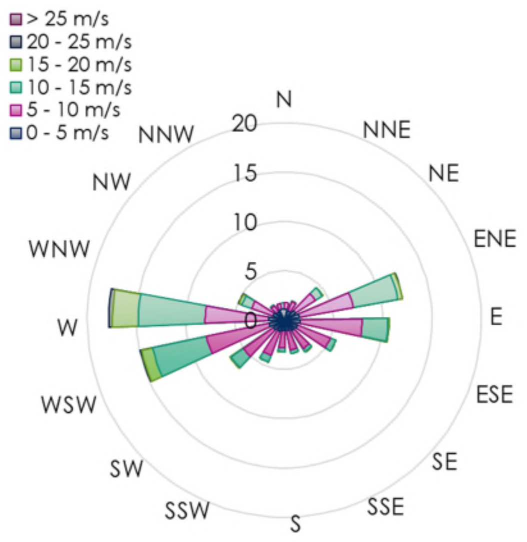

Figure 12 : Frequency of wind magnitude and direction for SAT-OCEAN 2012-2016 at 2nd discharge point

2.3.4 Bathymetry

MEMW database was used for the bathymetry. The bathymetry of the grid used for the modelling study is shown in Figure 13 for discharge point 2.

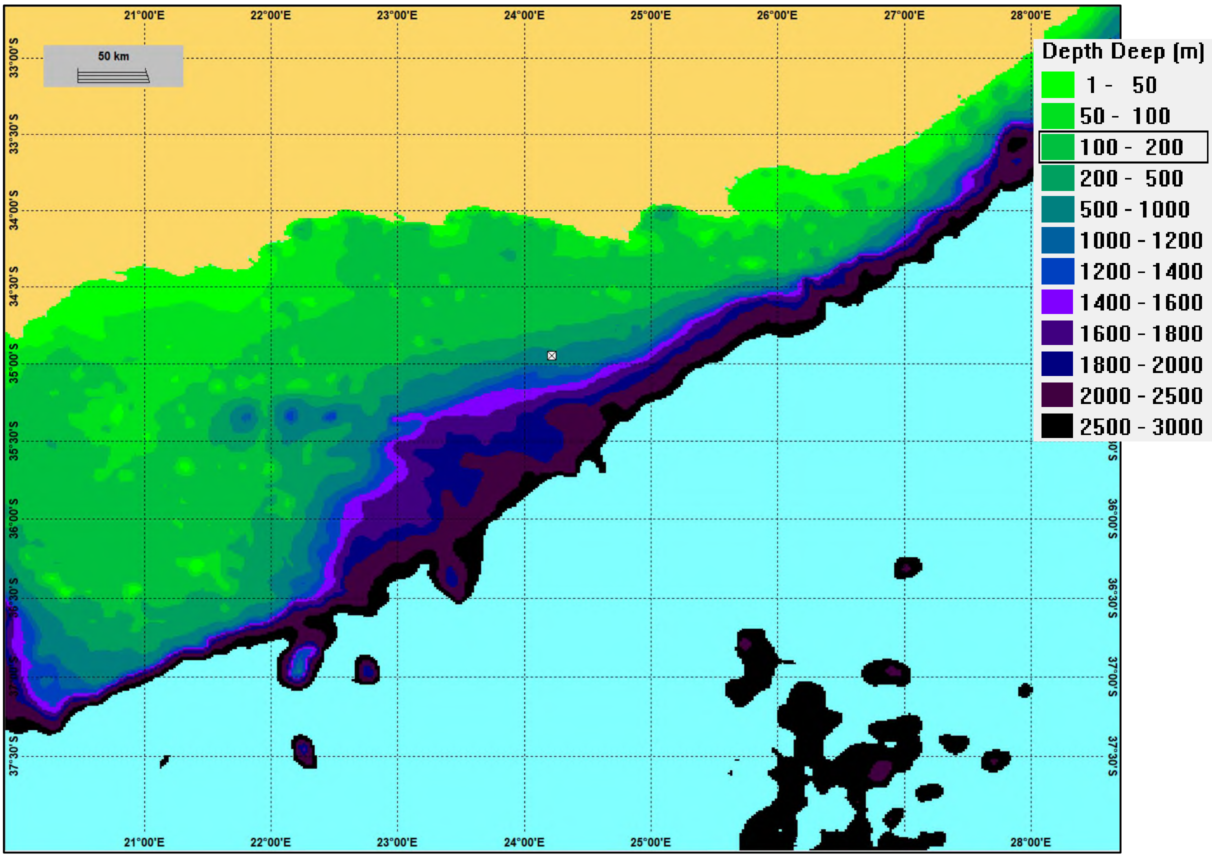

Figure 13: Bathymetry used within the model

2.4 Results Interpretation

2.4.1 Bonn Agreement Oil Appearance Code (BAOAC)

➢ **Concept behind oil slick appearance**

The visible spectrum ranges from 0.40 – 0.75 µm. Any visible colour is a mixture of wavelengths within the visible spectrum. White is a mixture of all wavelengths; black is absence of all light. The colour of an oil film depends on the way the light waves of different lengths are reflected off the oil surface, transmitted through the oil (and reflected off the water surface below the oil) and absorbed by the oil. The observed colour is the result of a combination of these factors; it is also dependent on the type of oil spilled. An important parameter is optical density: the ability to block light. Distillate fuels and lubricant oils consist of the lighter fractions of crude oil and will form very thin layers that are almost transparent. Crude oils vary in their optical density; black oils block all the wavelengths to the same degree but, even then, there are different 'kinds of black', residual fuels can block all light passing through, even in thin layers.

➢ **Bonn Agreement**

Since the colour of the oil itself as well as the optic effects are influenced by meteorological conditions, altitude, angle of observation and colour of the sea water, an appearance cannot be characterised purely in terms of apparent colour and therefore an 'appearance' code, using terms independent of specific colour names, has been developed. The Bonn Agreement Oil Appearance Code (cf. "Bonn Agreement Aerial Operations Handbook, Part 3, Annex A, The Bonn Agreement Oil Appearance Code, Section 11 p - Revision April 2016") has been developed as follows:

- In accordance with scientific literature and previously published scientific papers,
- Its theoretical basis is supported by small scale laboratory experiments,
- It is supported by mesoscale outdoor experiments,
- It is supported by controlled sea trials.

Due to slow changes in the continuum of light, overlaps in the different categories were found. However, for operational reasons, the code has been designed without these overlaps.

Using thickness intervals provides an estimated range of oil volumes that is commonly used both for legal procedures (minimum figure) and for response (maximum figure). Again, for operational reasons, grey and silver have been combined into the generic term 'sheen'.

Bonn Agreement Oil Appearance Codes are detailed in the following Table 2.6:

Table 2.6: Bonn Agreement Oil Appearance Code

Code	Description – Appearance	Thickness Interval (µm)	Litres per km^2
1	Sheen (silvery/grey)	0.04 to 0.3	40 – 300
2	Rainbow	0.3 to 5.0	300 – 5000
3	Metallic	5.0 to 50	5000 – 50000
4	Discontinuous True Oil Colour	50 to 200	50000 – 200000
5	Continuous True Oil Colour	> 200	> 200000

The appearances described above cannot be related to one thickness; they are optic effects (codes 1 – 3) or true colours (codes 4 – 5) that appear over a range of layer thickness.

There is no sharp delineation between the different codes; one effect becomes more diffuse as the other strengthens. Appearance codes here explained, are use as guidance by OSCAR for interpretation of surface thickness results.

2.4.2 Thresholds used in the post-processing of modelling results

Thresholds values used for this study to illustrate modelling output results, are detailed in Table 2.7:

Table 2.7: Threshold used in the post-processing of modelling results

Threshold	Threshold Value	Justification
Surface Oil Thickness	5 µm	10 µm corresponds to the thickness that would impart a lethal dose to an intersecting wildlife individual (French McCay 2009). The value of 5 µm was chosen to keep a margin and because it is as well t he minimum thickness at which response equipment can skim/remove oil from the surface, surface dispersants are effectively applied, or oil can be boomed/collected. Fresh oil at this thickness corresponds to a slick being a dark brown or metallic sheen (refer to Table 2.6 in section 2.4.1).
Water-Column	0.058 ppm	Based on extensive toxicity tests of crude oils and oil components on marine organisms, the OLF (the Norwegian Oil Industry Association) Guideline for risk assessment of effects on fish from acute oil pollution (2008) concluded that the threshold concentration for an expected No Observed Effect Concentration (NOEC) for acute exposure for THC ranges 0.05 to 0.3 ppm. Work undertaken by Neilson et al (2005, as reported in OLF, 2008) proposed a value for acute exposure to dispersed oil of 0.058 ppm, based on the toxicity of chemically dispersed oil to various aquatic species, which showed the 5% effect level is 0.058 ppm.
Shoreline Oiling	10 g/m^2	Shoreline oiling is calculated assuming that a certain surface is affected by kilometre of shoreline, depending on the shoreline type. For various shoreline types, a set of maximum oil “holding capacities” is estimated along with a set of removal rates. The holding capacities are intended to reflect both shoreline slope and permeability. 10g/m^2 provides a more conservative screening threshold used for potential ecological effects on shoreline fauna. Assumed as a sublethal effects threshold for birds on the shoreline (French et al. 1996; French McCay 2009; French McCay 2016).

2.5 Model Limitations

All modelling results, and other information provided in this document are generic and demonstrative, based on the scenarios specifically defined for the present study. Main limitations are intrinsic to the process itself or associated to the use of modelled results.

2.5.1 Limitations of the modelling process

This software is only suitable for the offshore or coastal marine environment. Nevertheless, modelling parameters (grid size and fixed shape, water depth gridding …) are less adapted to shallow waters and shorelines areas, leading to edge effects to be considered when interpreting the raw results.

Models in general cannot precisely predict the changes oil undergoes; they can only indicate whether oil is likely to dissipate naturally or whether it is likely to reach the shoreline.

As with any model, the quality and reliability of the results are dependent on the quantity and accuracy of the input data, such as:

- Resolution of tidal and oceanic metocean dataset (and especially the existence of calibration points that often do not exist for seabed currents), ambient data, depth of release point.
- The properties of the oil in the model's database does not precisely match those expected for the exploration well and even more the real ones recorded further, during the drilling. The properties and behaviour of the oils spilled in a dynamic marine environment may vary slightly to those outputs produced using data held within OSCAR. This is likely with all oils in the database and is intrinsic to all modelling.

2.5.2 Limits of use of the modelling results

There are several limitations to consider when interpreting the outputs, in particular:

- All the results provided in this report are based on past metocean data and can only give indications or trends of drifts at a future time. In case of real event, real data with shore time forecast would prevail.
- The results provided in this report are trends of potential consequences of a subsea blowout, in relation to the analogue oil profile selected for the model, discharge total volume, release location, and specific metocean conditions; they do not represent what will happen in case of a real oil spill.
- Modelling results can be used as a guidance tool to build an oil spill response strategy, nevertheless, oil spill response deployment should not be based and developed solely on modelling results alone but continuously reassessed in case of accidental event.

2.6 Visual Results Representations

Careful consideration needs to be given to the distinction between stochastic and deterministic modelling (see boxed text below, and to understand that **stochastic modelling is not generating a picture of single oil spill)**.

Stochastic modelling is used to predict the probability of sea surface and shoreline oiling that may occur following a spill event.

Stochastic modelling involves running numerous individual spill trajectory simulations (in this study 90 simulations per stochastic scenario) using a range of prevailing wind and current conditions that are historically representative of the season and location of where the spill event may occur. The stochastic model output does not represent the extent of any one oil spill event (which would be substantially smaller) but rather provides a summary of the total individual simulations for a given scenario or oil type.

Deterministic modelling (or single spill trajectory analysis) is used to predict the fate (transport and weathering behavior) of oil spilled over time under predefined hydrodynamic and meteorological conditions.

When carrying out deterministic modelling, the conditions that give rise to the simulation are selected from specific cases to be further studied: it can be either a representative case of the most probable behavior of the spill, or specific cases showing for example the shortest time of impact to the coast, or the biggest quantity of hydrocarbons to the coast. The outcomes of deterministic modelling provide a reasonable approximation of what an oil spill event could look like under certain prevailing conditions, but not the probability of those conditions being prevalent.

Conversely, stochastic modelling provides a probabilistic analysis but not an accurate prediction of what an individual spill could look like.

3. Modelling Results

The following sections presents the results for stochastic and deterministic scenarios for the different period considered for the modelling study.

3.1 Scenario 1A – Stochastic Simulation for Jan-Mar (Capping only)

This scenario simulates a continuous blow-out of 69 600 bbls/day of crude oil for a period of 20 days, through a set of 90 similar trajectories (i.e. 18 trajectories simulated for each quarter, in each of the 5 years covered by the metocean data), under a wide range of metocean conditions and a simulation duration of 60 days, covering the period from January 1st to March 31st for the years 2012 to 2016.

3.1.1 Surface Results

IMPORTANT: Surface results presented in this section do not represent a single spill but the combination of the statistical results of the 90 individual trajectories composing Stochastic Scenario 1. Threshold value applied for the interpretation of surface results is 5 µm, as detailed in Section 2.4.2

The stochastic footprint for the ensemble of trajectories is oriented towards the South-West direction. The highest values for surface oiling probability (i.e. 90% to 100%) are observed for South African offshore waters (Figure 14), along 310 km South-West from discharge point 2.

There is 70% of probability for the drift to go in the North-East direction, meaning that for the 90 trajectories performed for the Scenario 1, 63 trajectories may observe a drift towards the North-East direction (Port Elizabeth area).

As we move away from the release point, the probability values gradually decrease however the main direction of the slick remains towards the South-West, indicating a low variability of the trajectories of the Scenario 1, due to constant metocean conditions in this area.

Offshore waters of Namibia on the West side and Mozambique on the East side are not affected by the blow-out (considering the applied release properties and threshold values applied in the post-processing of modelling results).

The stochastic footprint goes into international waters approximately 500 km South-West from the release location, 4 days after the start of the spill (Figure 15), with a probability of 37% (Figure 14).

The oil slick quickly progresses at sea surface, about 205 km towards South-West and 75 km towards North-East, in 2 days. Three days after the start of the blow-out, the oil slick edge could reach 330 km South-West from the discharge point, or 190 km North-East direction close to the shoreline, due to the strong winds and currents in this area.

Reminder: Surface results characterized in Figure 14 and Figure 15, are considering only hydrocarbons presence at sea surface for a thickness above 5 µm.

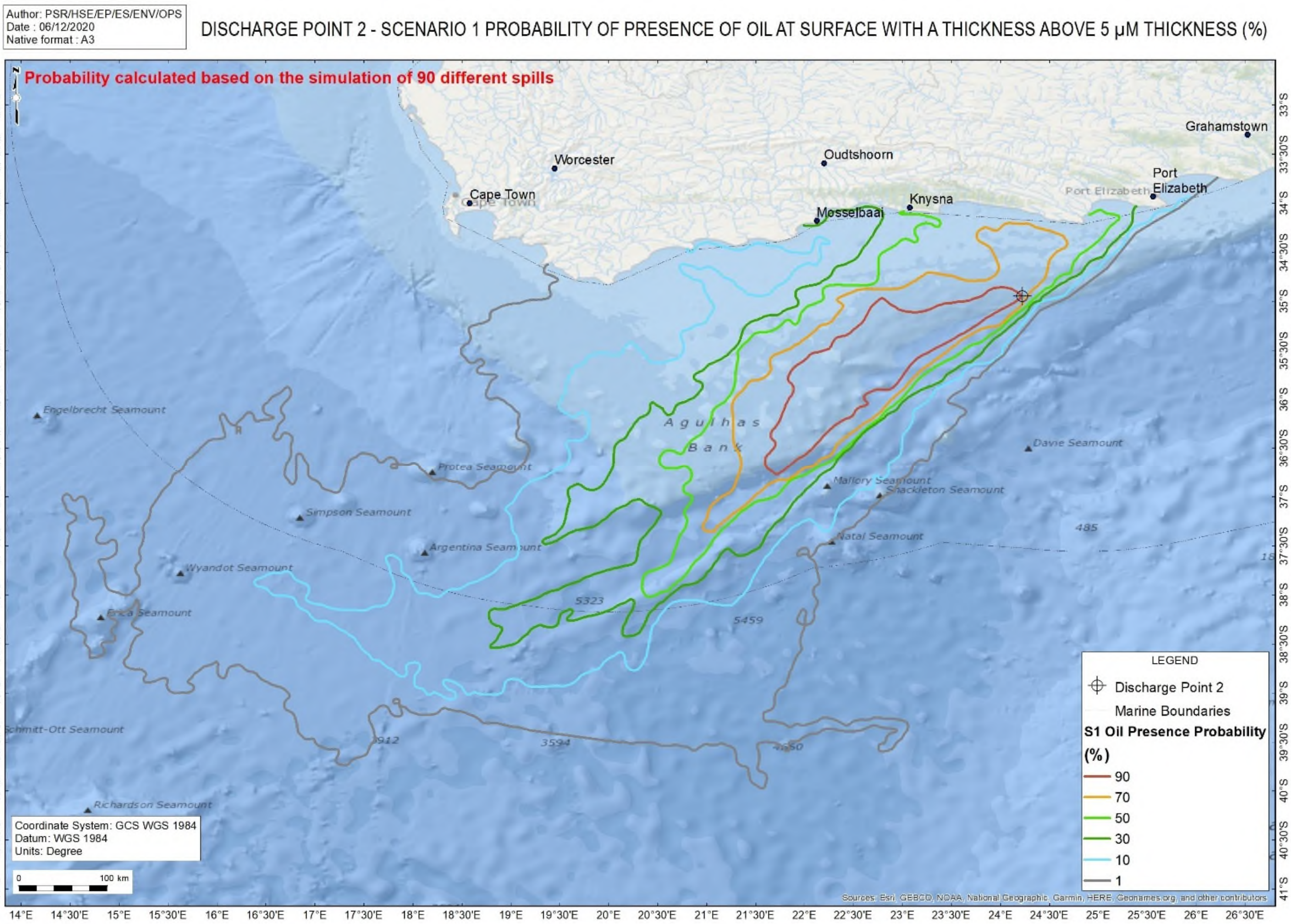

Figure 14: Scenario 1A (Q1) – Surface oiling probability above threshold (i.e. >5 µm)

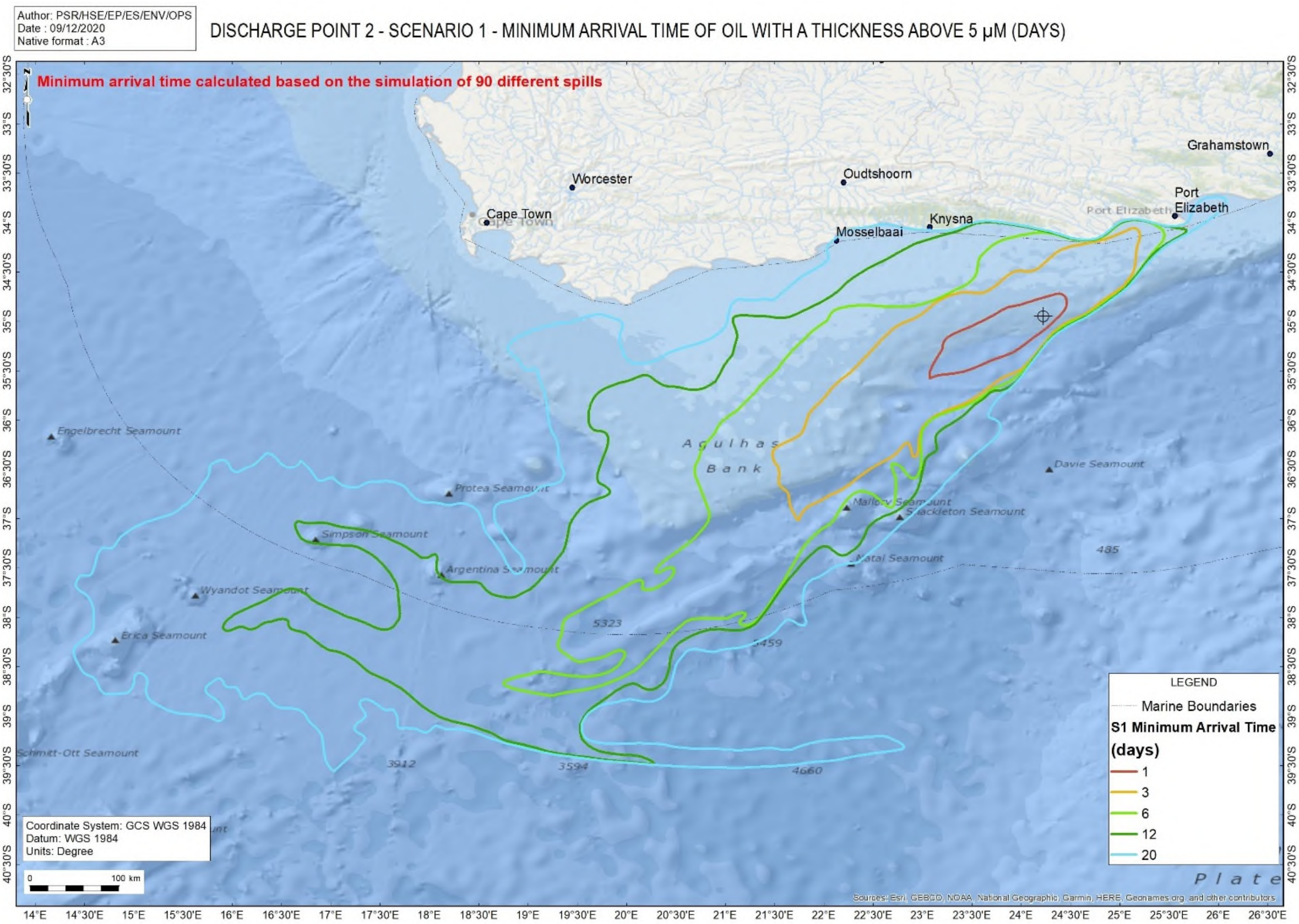

Figure 15: Scenario 1A (Q1) – Surface minimum arrival time (days) above threshold (i.e. >5 µm)

3.1.2 Shoreline Results

IMPORTANT: Shoreline results presented in this section do not represent a single spill but the combination of statistical results of the 90 individual trajectories composing Stochastic Scenario 1. Threshold value applied for the interpretation of shoreline results is 10 g/m^2, as detailed in Section 2.4.2.

Overall, all the shoreline from Cape Town to Port Elizabeth will observe a low to very low probability of shoreline oiling (i.e. from 1 to 20 %). The highest values for shoreline oiling probability (around 72%) are observed on Plettenberg Bay, and high values of 66 % on some spots on the Saint Francis Bay (Figure 16 and Figure 17).

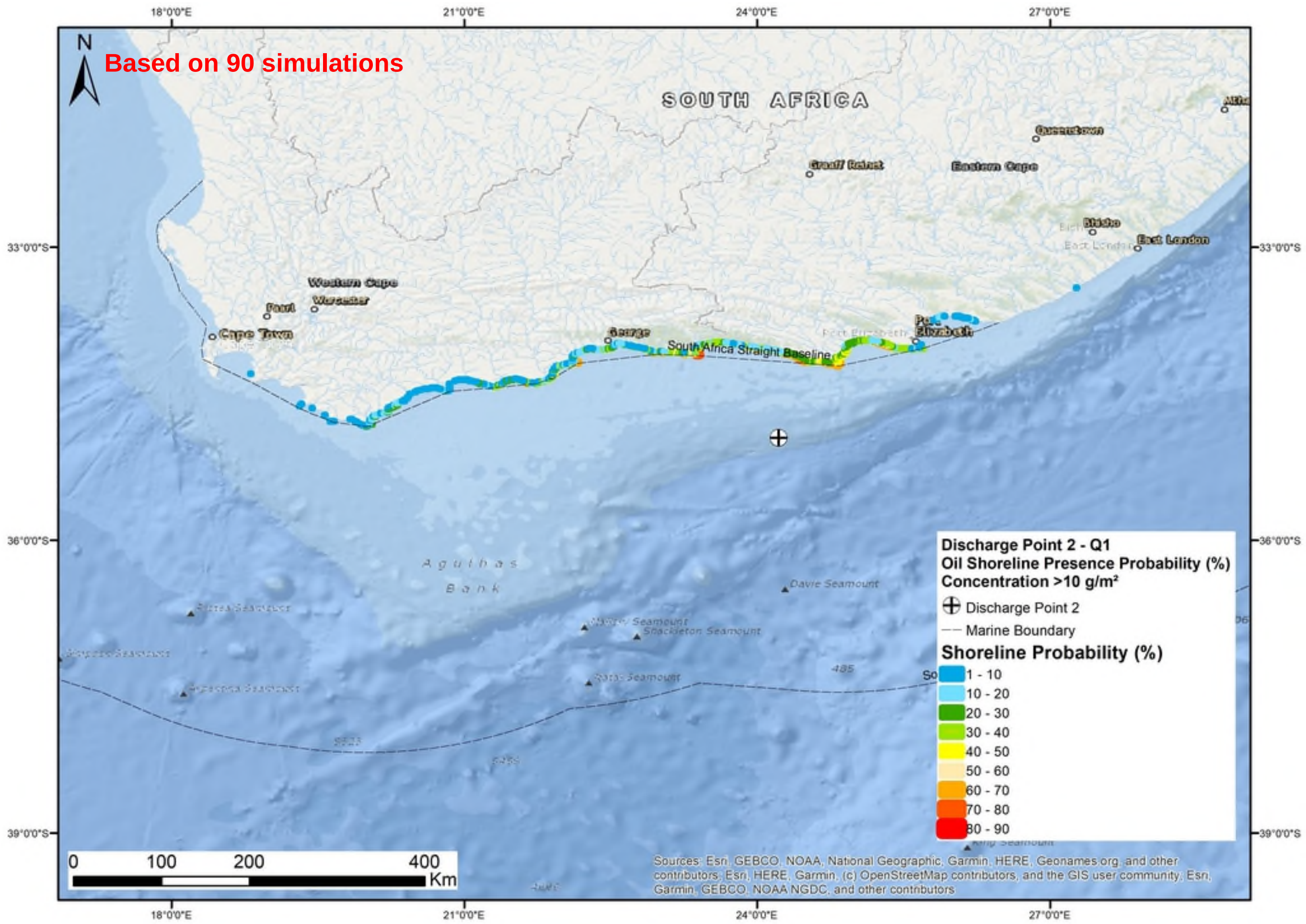

Figure 16: Scenario 1A – Shoreline oiling probability above threshold (i.e. >10 g/m^2)

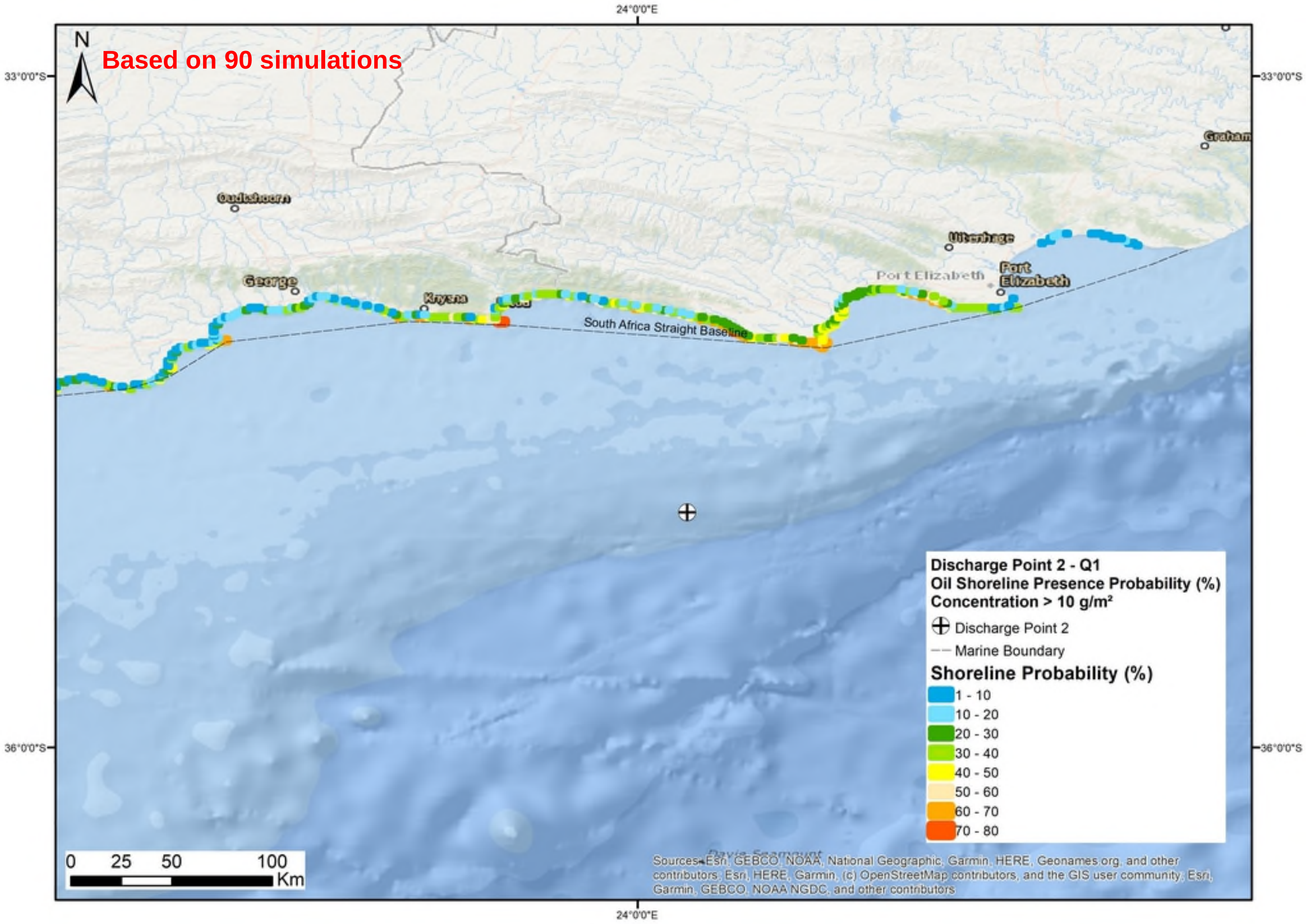

Figure 17 : Scenario 1A – Zoom on Shoreline oiling probability above threshold (i.e. >10 g/m²)

Shoreline minimum arrival time (in days) is observed on the Saint Francis Bay area, approximately between 2 and 3 days after start of the release (Figure 18 and Figure 19). Overall, all the Saint Francis Bay area can observe oil reaching the shore in less than 4 days, with a maximum shoreline oiling probability around 66%.The Port Elizabeth area could observe oil reaching some spots on the shore within 5 days, with low shoreline oiling probabilities (<20%). The rest of the South African shoreline (West to the Saint Francis Bay) presents oil arrival time > 10 days. There is no shoreline transboundary effect in this scenario.

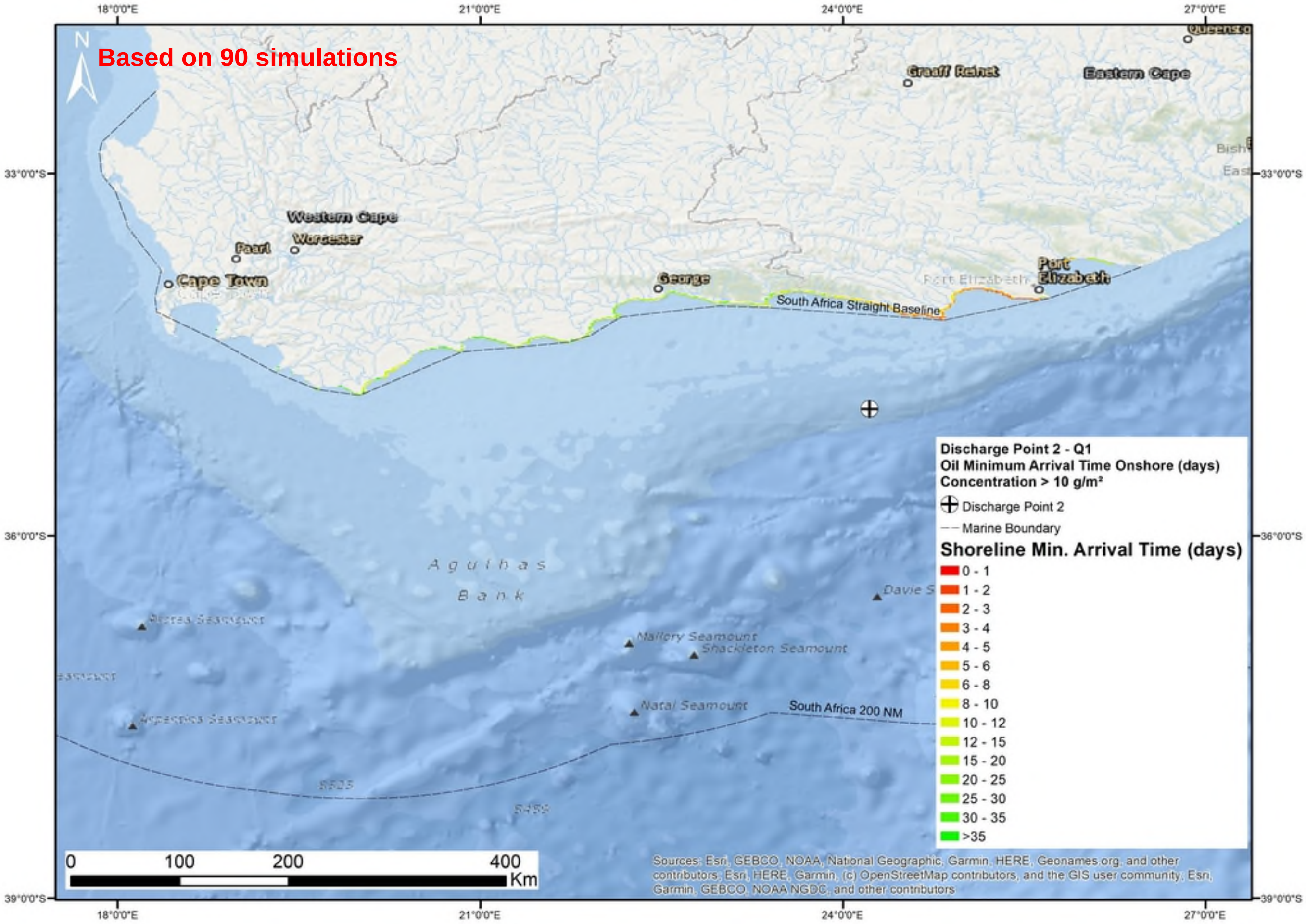

Figure 18: **Scenario 1A – Shoreline minimum arrival time (days) above threshold (i.e. >10 g/m²)**

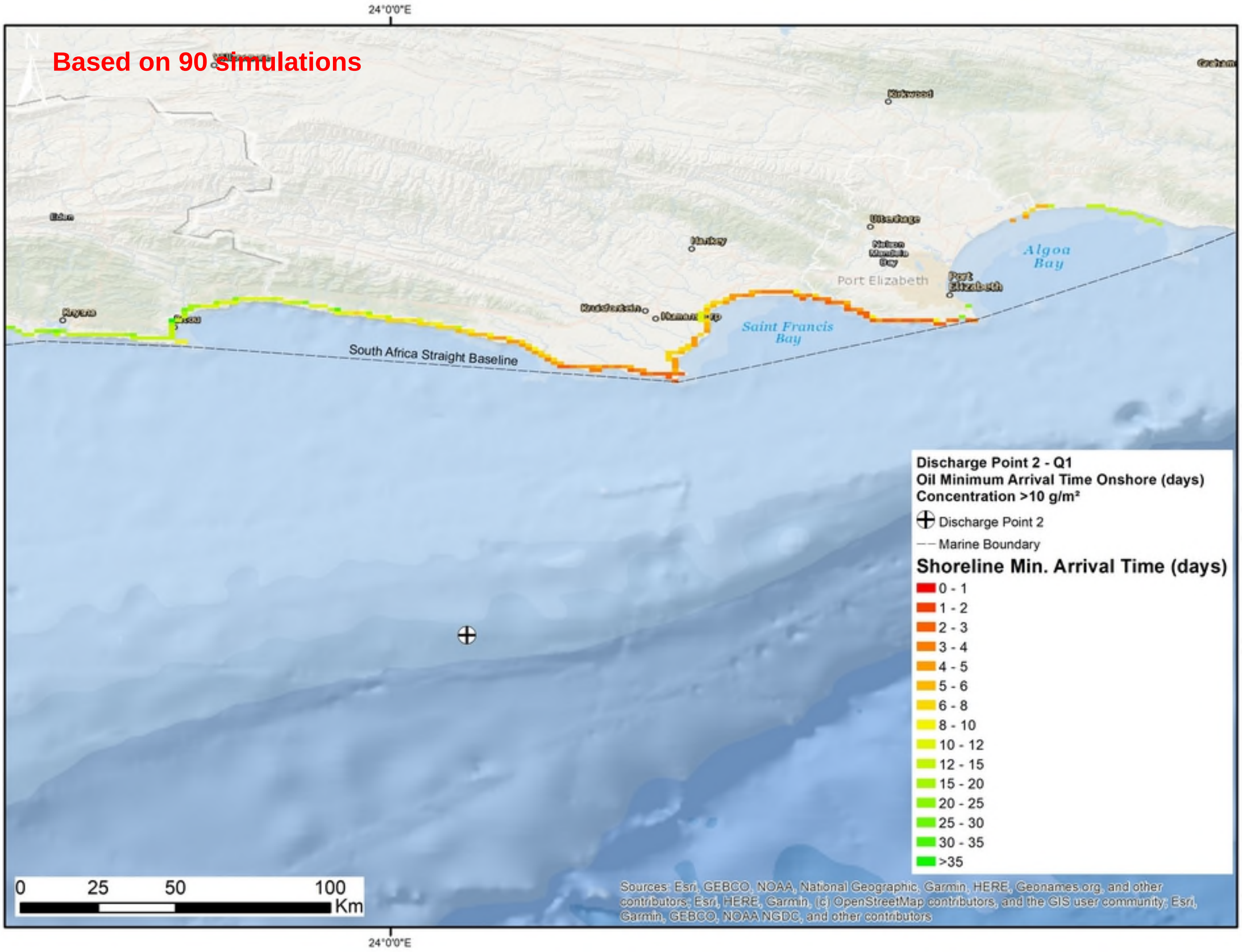

Figure 19 : Scenario 1A – Zoom on the shoreline minimum arrival time most impacted area (days) above threshold (i.e. >10 g/m^2)

Reminder: Shoreline results characterized in Figure 16, Figure 18 and Figure 19, are considering only hydrocarbons presence at shoreline for an oil load threshold >10 g/m^2.

3.2 Scenario 1B – Deterministic Scenario (Capping only) - Spill Drift and Shoreline Impacts

The simulation resulting in the highest hydrocarbon mass reaching the shore for Scenario 1 (i.e. trajectory with start on **March 27th 2016 (22:00 UTC)**), was selected to illustrate the results of the deterministic simulation (i.e. **Scenario 1B**), with a continuous blow-out releasing 69 600 bbls/day for a period of 20 days, and simulation total duration of 60 days.

Note: Figure 20 and Figure 21 have been done with a more precise resolution in order to better analyze the characteristics of the oil in the environment at the beginning of the blow-out.

Figure 20 presents the oil rise in the water column 3 hours after the start of the release, approximately 15 km North from the release location, with a maximum oil thickness at this time of 542 µm. These results will be the same for the Scenarios 1C and 1D considering Capping only Strategy will be implemented before those 3 hours.

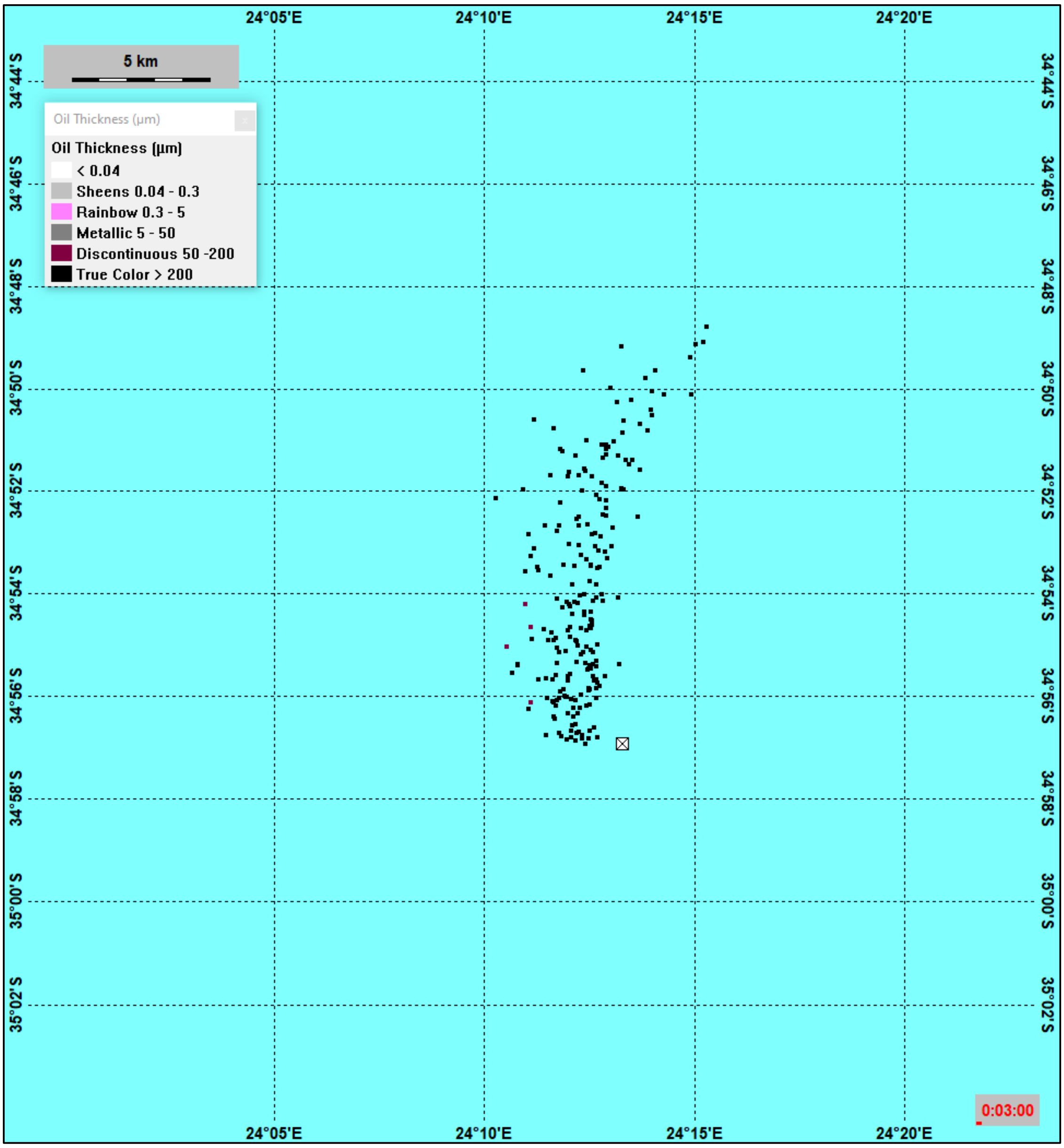

Figure 20: Oil reaching surface for scenarios 1B, 1C and 1D

Figure 21 present the release concentration and the submerged particles in the water column 3 hours after the start of the blow-out.

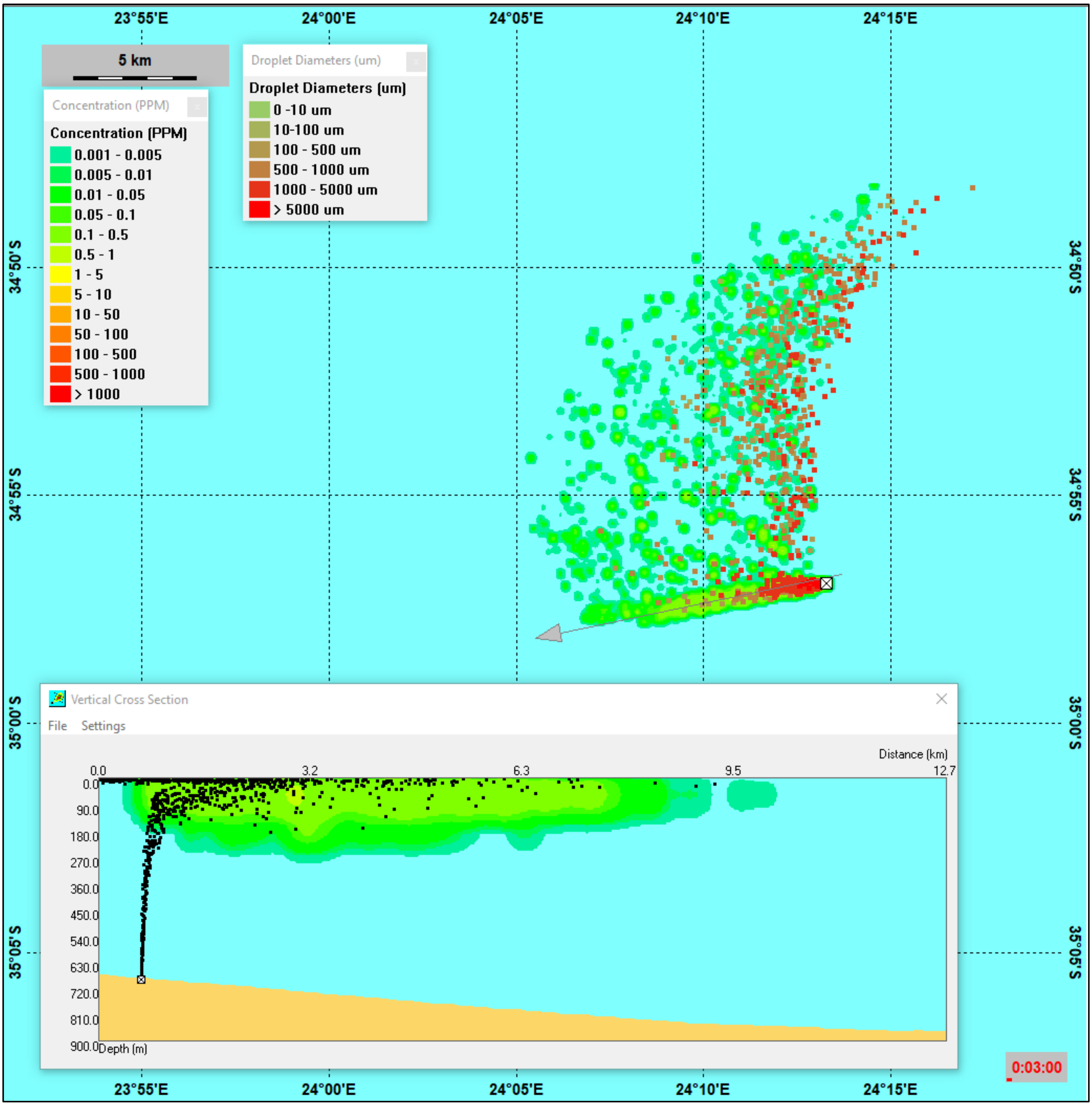

Figure 21 : Release concentration and submerged particles in the water column 3 hours after the start of the blow-out for scenarios 1B, 1C and 1D

The maximum oil concentration in the water column is 4.75 ppm very close to the release point; the maximum oil droplet diameter is 4927 µm on the release point, and the termination depth is around 100 m depth. One should note that Figure 20 is a snapshot of the oil rise within the water-column, and is dependent of the orientation of the vertical cross-section arrow drawn, for the visualization of calculated results (i.e. the profile of the concentrations in the water-column), as well as of the correspondent time-step.

Oil spill initial drift, 24 hours after start of the release, is observed towards the North direction (Figure 22). Slick will then continue its drift towards South-West, progressing in offshore waters, before changing direction to the North/Northeast towards the coastline around release day 5, and finally reaching the shore, on spill 5th day, near the Oyster Bay area.

The maximum distance reached by the surface oil is 935 km South-West from the release point, 13 days ½ after the start of the blow-out.

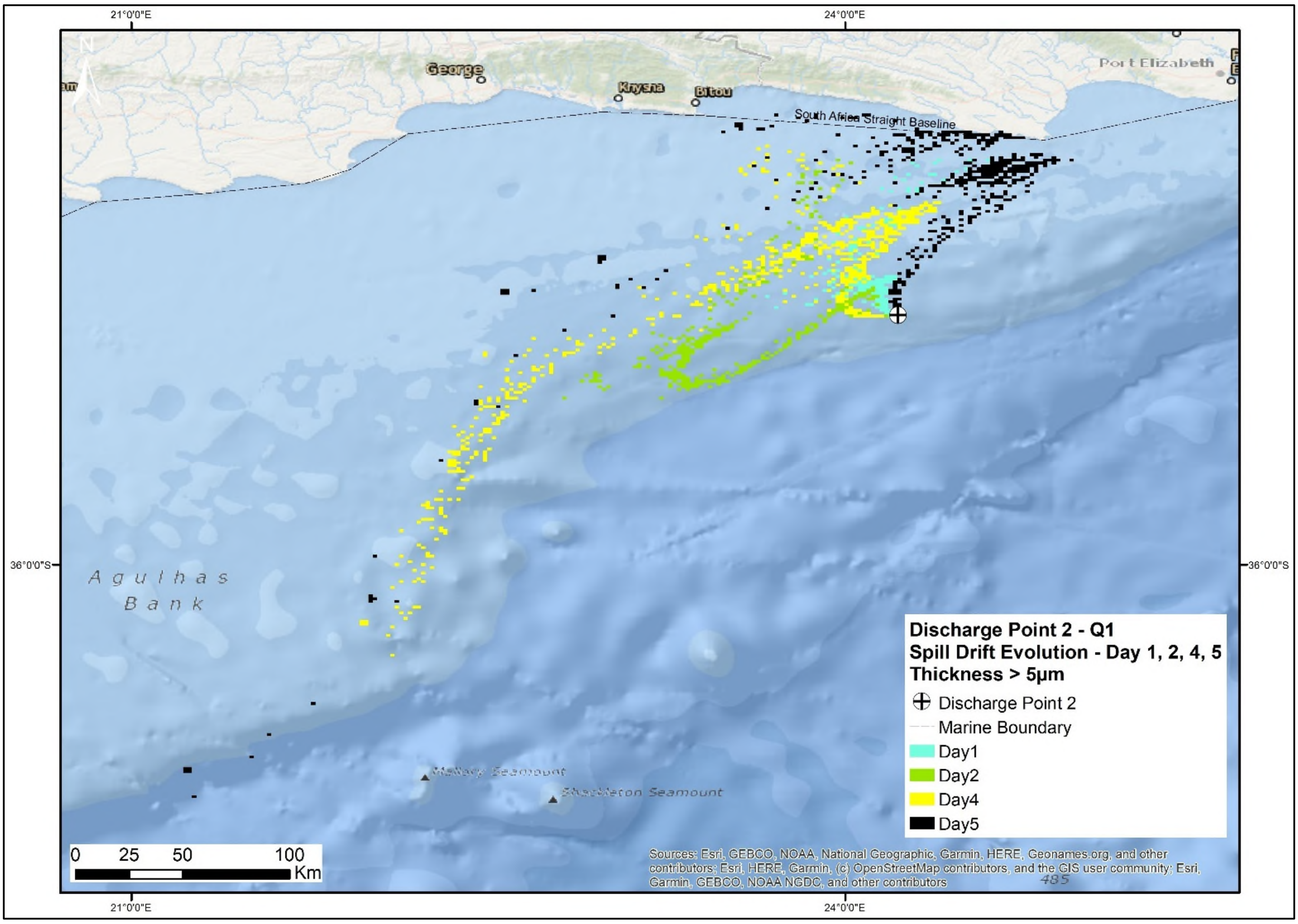

Figure 22: Scenario 1B – Spill drift evolution – Days 1, 2, 4 & 5

Figure 23 and Figure 24, show the impacts over the shoreline at the end of simulation, i.e. 60 days after the start of the blow-out. Impact ashore above threshold (i.e. 10 g/m² or 0.01 kg/m²), is observed from the Blomboschfontein Nature reserve shore to Port Elizabeth area.

Highest value for shoreline oil concentration (around 12000 g/m²) is observed along approximately 230 km between Knysna and Port Elizabeth. The mass reaching the shore at the end of simulation (60 days) would then be 7937 t.

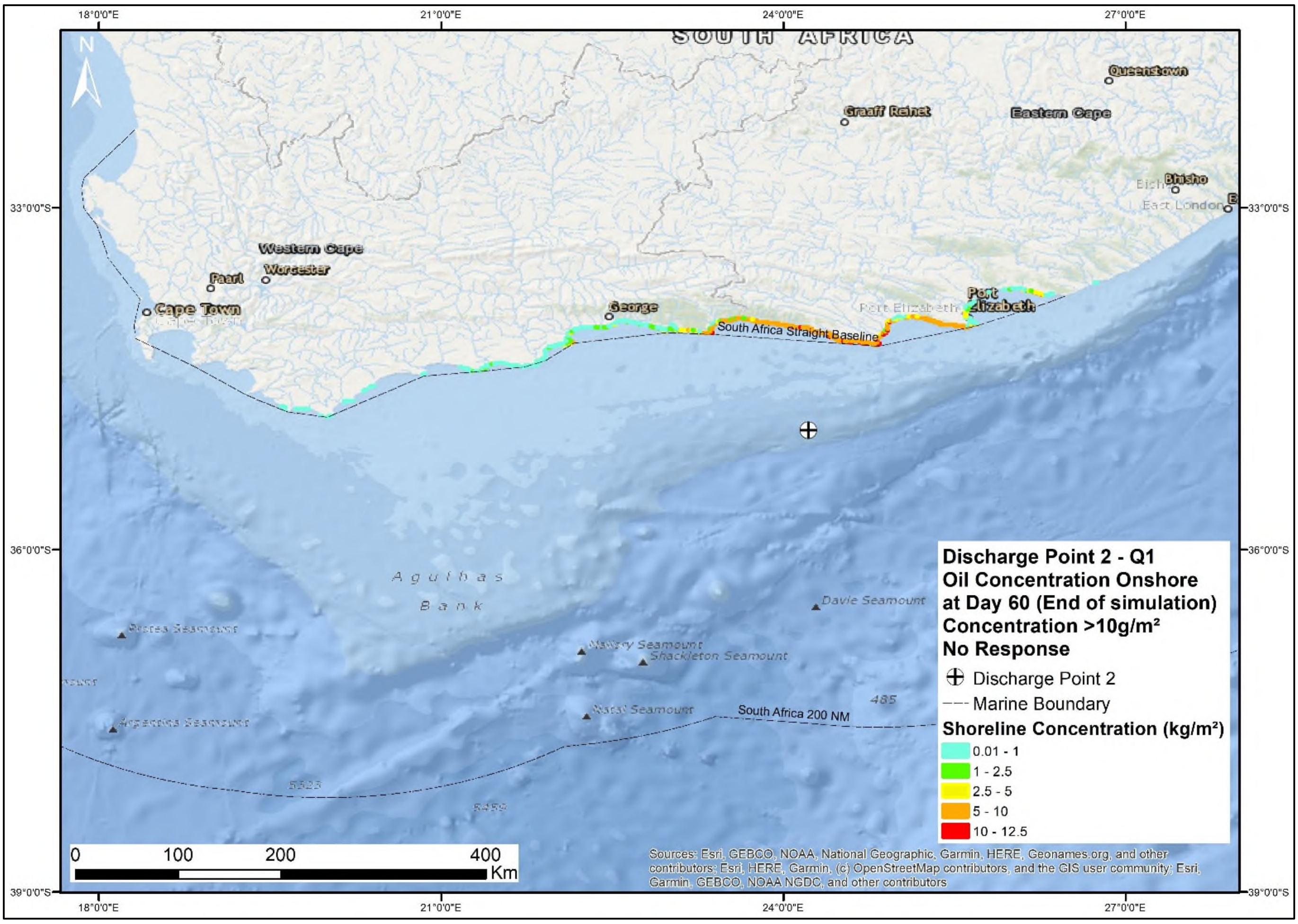

Figure 23: Scenario 1B – Shoreline concentration (>10 g/m²) at the end of simulation

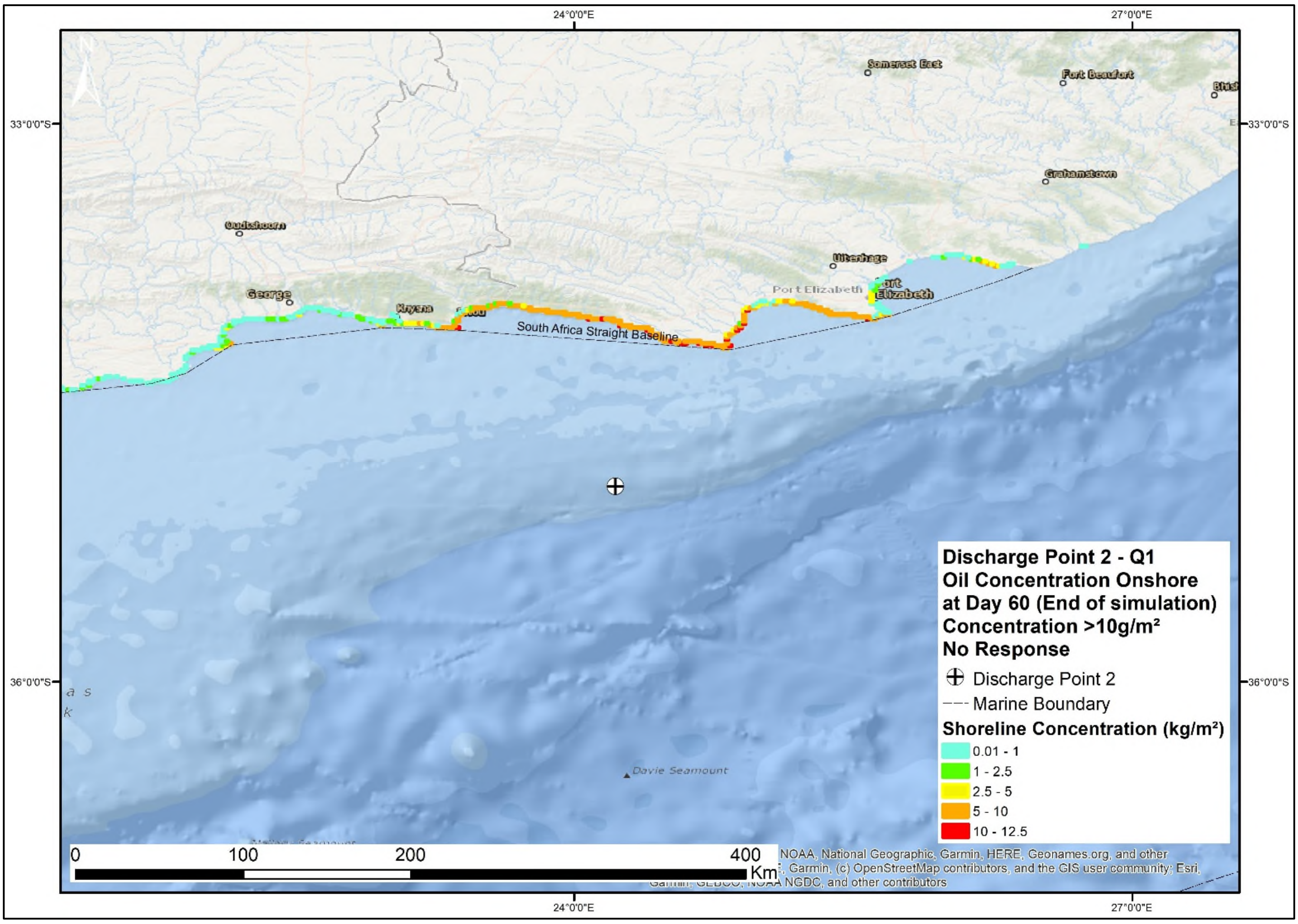

Figure 24 : Scenario 1B – Zoom on the Shoreline concentration most impacted area (>10 g/m^2) at the end of simulation

3.3 Scenario 1C – Deterministic Scenario (Surface Response + Capping) - Spill Drift and Shoreline Impacts

The simulation resulting in the highest hydrocarbon mass reaching the shore for Scenario 1 (i.e. trajectory with start on **March 27th 2016 (22:00 UTC)**), was selected to illustrate the results of the deterministic simulation (i.e. **Scenario 1B**), with a continuous blow-out releasing 69 600 bbls/day for a period of 20 days, and simulation total duration of 60 days.

The following response strategy is deployed and simulated in this scenario (detailed in 2.2.3):

- Surface response with aircrafts and vessels 24 hours after the start of the spill.

Oil spill initial drift, 24 hours after start of the release, is observed towards the North direction (Figure 25). Slick will then continue its drift towards South-West, progressing in offshore waters, before changing direction to the North/Northeast towards the coastline around release day 5, and finally reaching the shore, on spill 5th day, near the Oyster Bay area.

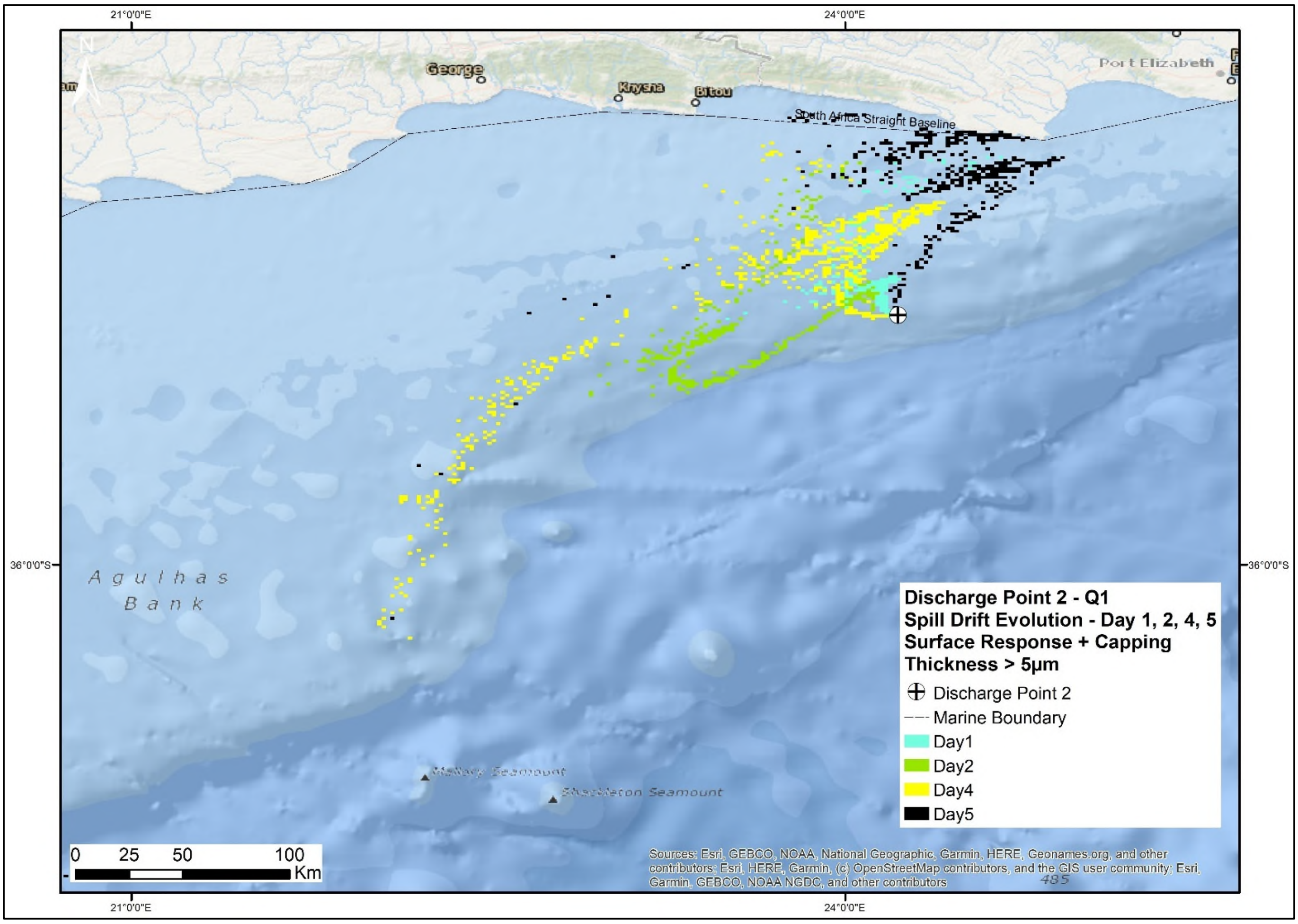

Figure 25: Scenario 1C – Spill drift evolution – Days 1, 2, 4 & 5

Figure 26 and Figure 27 show the impacts over the shoreline at the end of simulation, i.e. 60 days after the start of the blow-out. Impact ashore above threshold (i.e. 10 g/m^2 or 0.01 kg/m^2), is observed from the Buffalo Bay shore to Port Elizabeth area.

Like for the Scenario 1B (Capping only), the highest value for shoreline oil concentration (around 12000 g/m^2) is observed along approximately 230 km between Knysna and Port Elizabeth.

The Surface Response allows to reduce the oil concentration onshore around Knysna area, near Port Elizabeth area, and avoid oil onshore between Agulhas National Park and George.

The mass reaching the shore at the end of simulation (60 days) would then be 7065 t vs. 7937 t with only the capping stack.

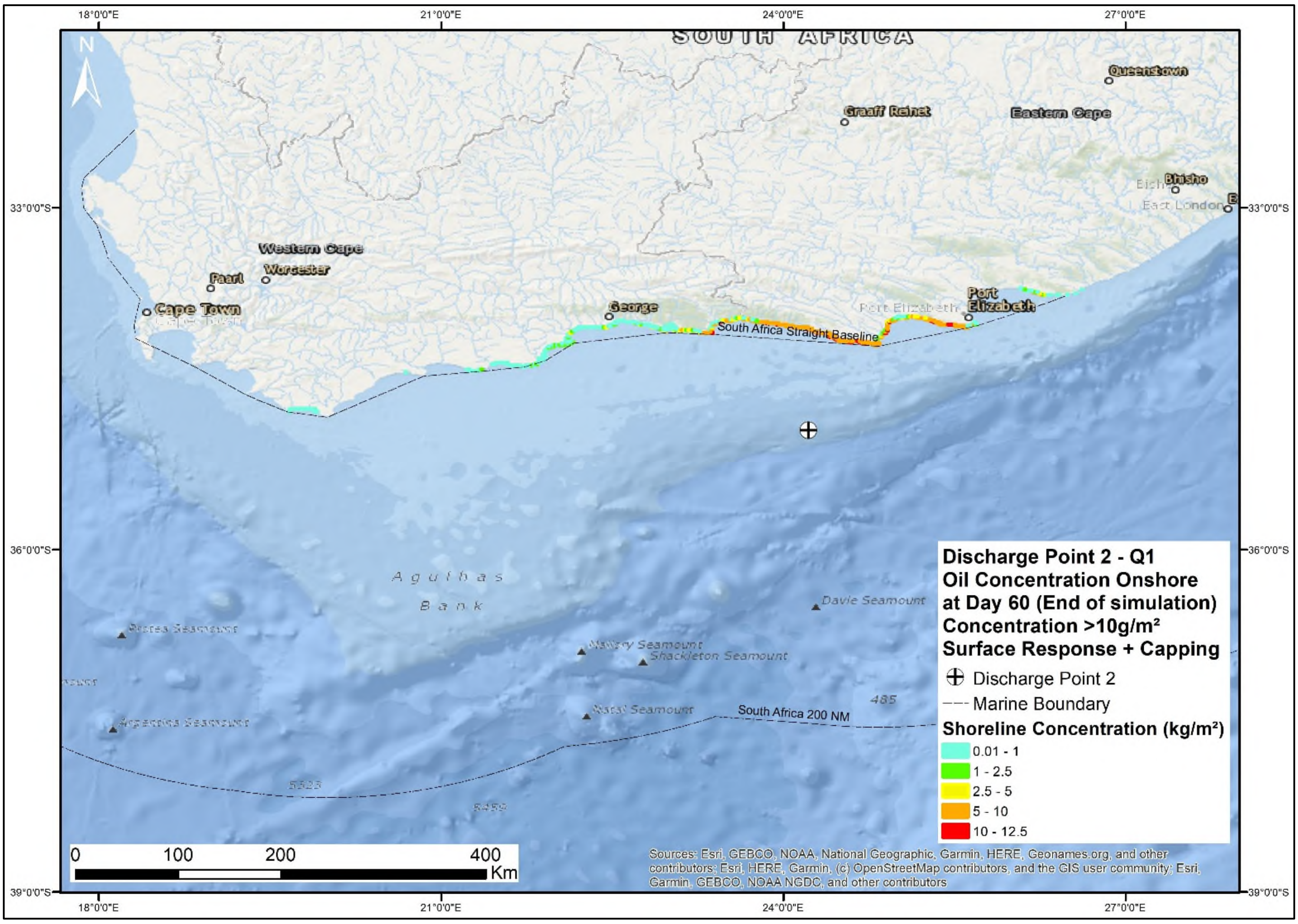

Figure 26: Scenario 1C – Shoreline concentration (>10 g/m²) at the end of simulation

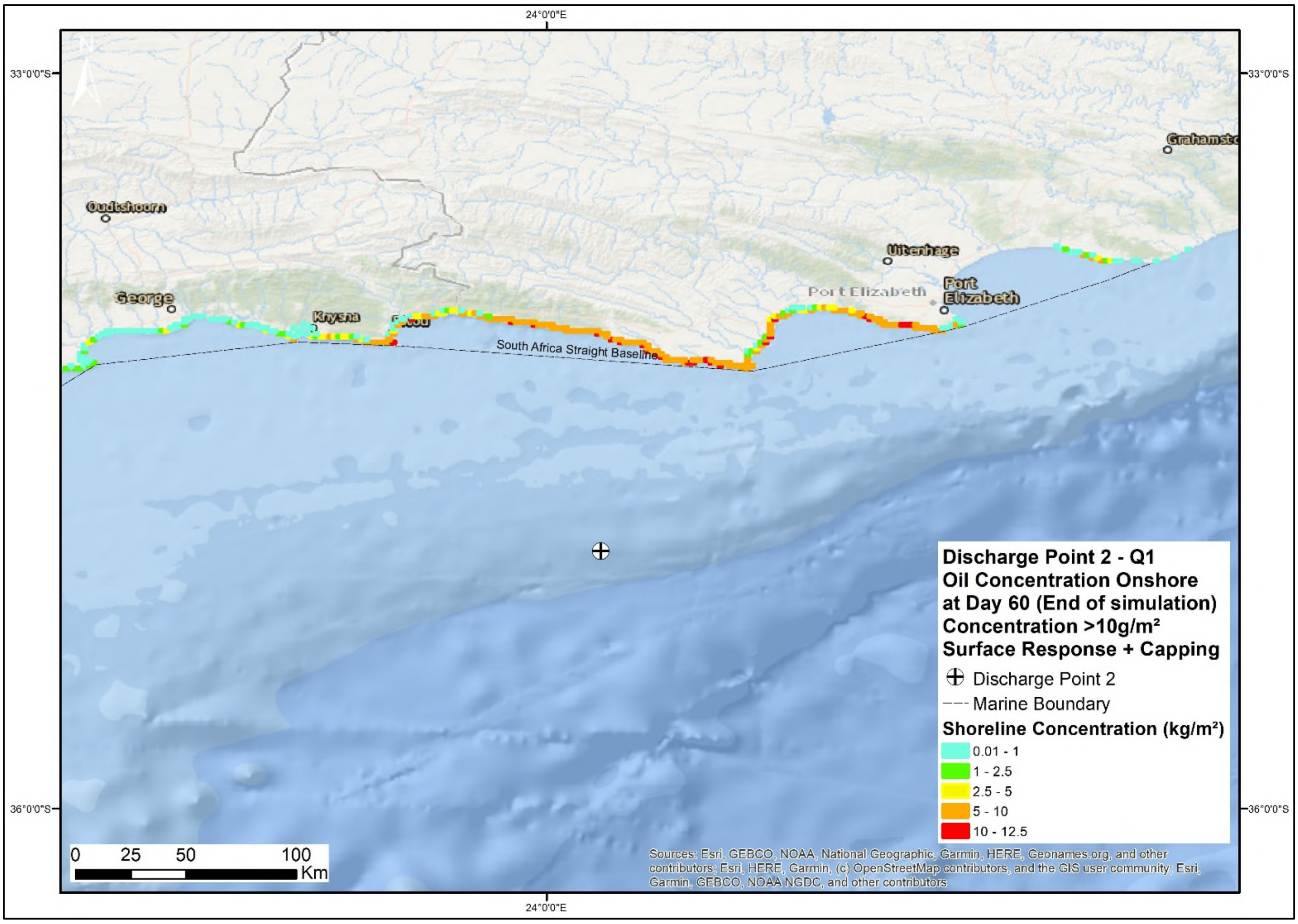

Figure 27 : Scenario 1C – Zoom on the Shoreline concentration most impacted area (>10 g/m^2) at the end of simulation

3.4 Scenario 1D – Deterministic Scenario (Surface Response + SSDI + Capping) - Spill Drift and Shoreline Impacts

The simulation resulting in the highest hydrocarbon mass reaching the shore for Scenario 1 (i.e. trajectory with start on **March 27th 2016 (22:00 UTC)**), was selected to illustrate the results of the deterministic simulation (i.e. **Scenario 1B**), with a continuous blow-out releasing 69 600 bbls/day for a period of 20 days, and simulation total duration of 60 days.

The following response strategy is deployed and simulated in this scenario (detailed in 2.2.3), namely:

- Surface response with aircrafts and vessels 24 hours after the start of the spill;
- SSDI (Subsea Dispersant Injection) 15 days after the start of the blow-out.

Oil spill initial drift, 24 hours after start of the release, is observed towards the North direction (Figure 28). Slick will then continue its drift towards South-West, progressing in offshore waters, before changing direction to the North/Northeast towards the coastline around release day 5, and finally reaching the shore, on spill 5th day, near the Oyster Bay area.

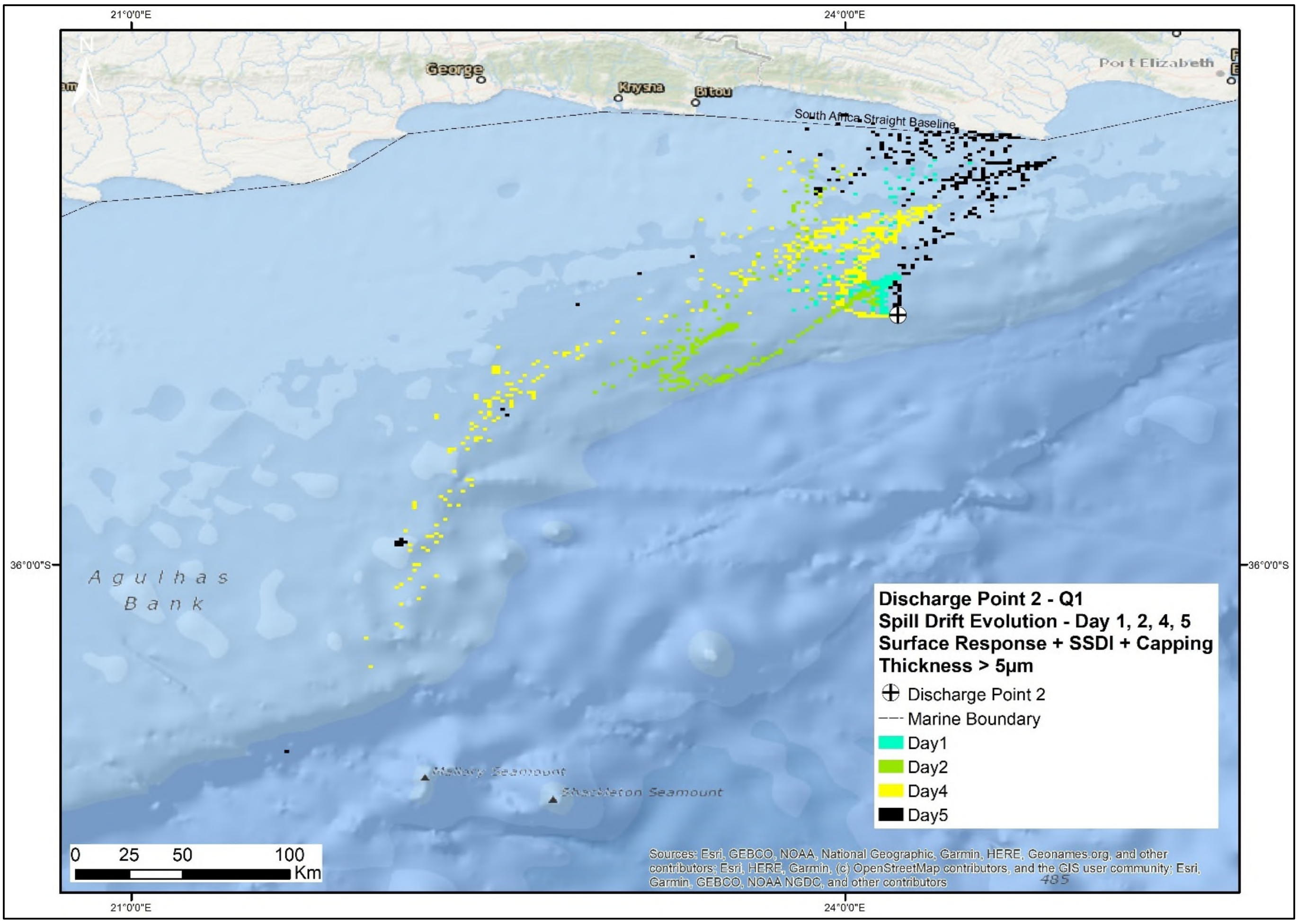

Figure 28: Scenario 1D – Spill drift evolution – Days 1, 2, 4 & 5

Figure 29 and Figure 30 show the impacts over the shoreline at the end of simulation, i.e. 60 days after the start of the blow-out. Impact ashore above threshold (i.e. 10 g/m^2 or 0.01 kg/m^2), is observed from the Buffalo Bay shore to Port Elizabeth area.

Like for the Scenario 1B (Capping only), the highest value for shoreline oil concentration (around 12000 g/m^2) is observed along approximately 180 km between Knysna and Port Elizabeth. The SSDI allows to reduce the high values of oil onshore for 50 km of shoreline in this area.

The Surface Response allows to reduce the oil concentration onshore around Knysna area, near Port Elizabeth area, and avoid oil onshore between Agulhas National Park and George.

The SSDI deployed day 15th allows the reduction considerably the oil concentration onshore and the length of the coastline impacted, especially between Knysna and Port Elizabeth areas, where most of the concentration values are now around 2500 g/m^2 on some spots versus 900 kg/m^2 with only capping.

The mass reaching the shore at the end of simulation (60 days) would then be 4601 t vs. 7937 t with only the capping stack

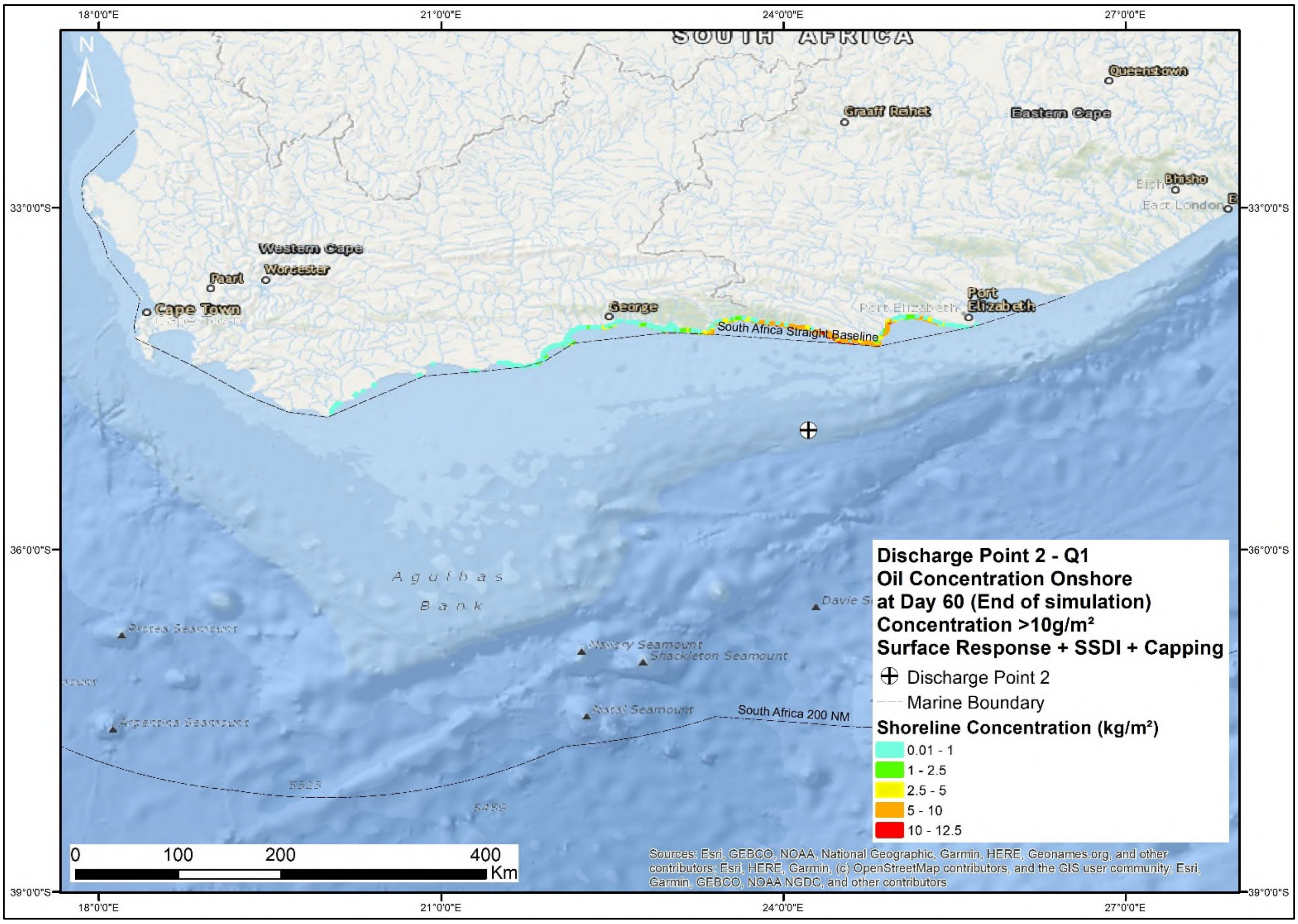

Figure 29: Scenario 1D – Shoreline concentration (>10 g/m²) at the end of simulation

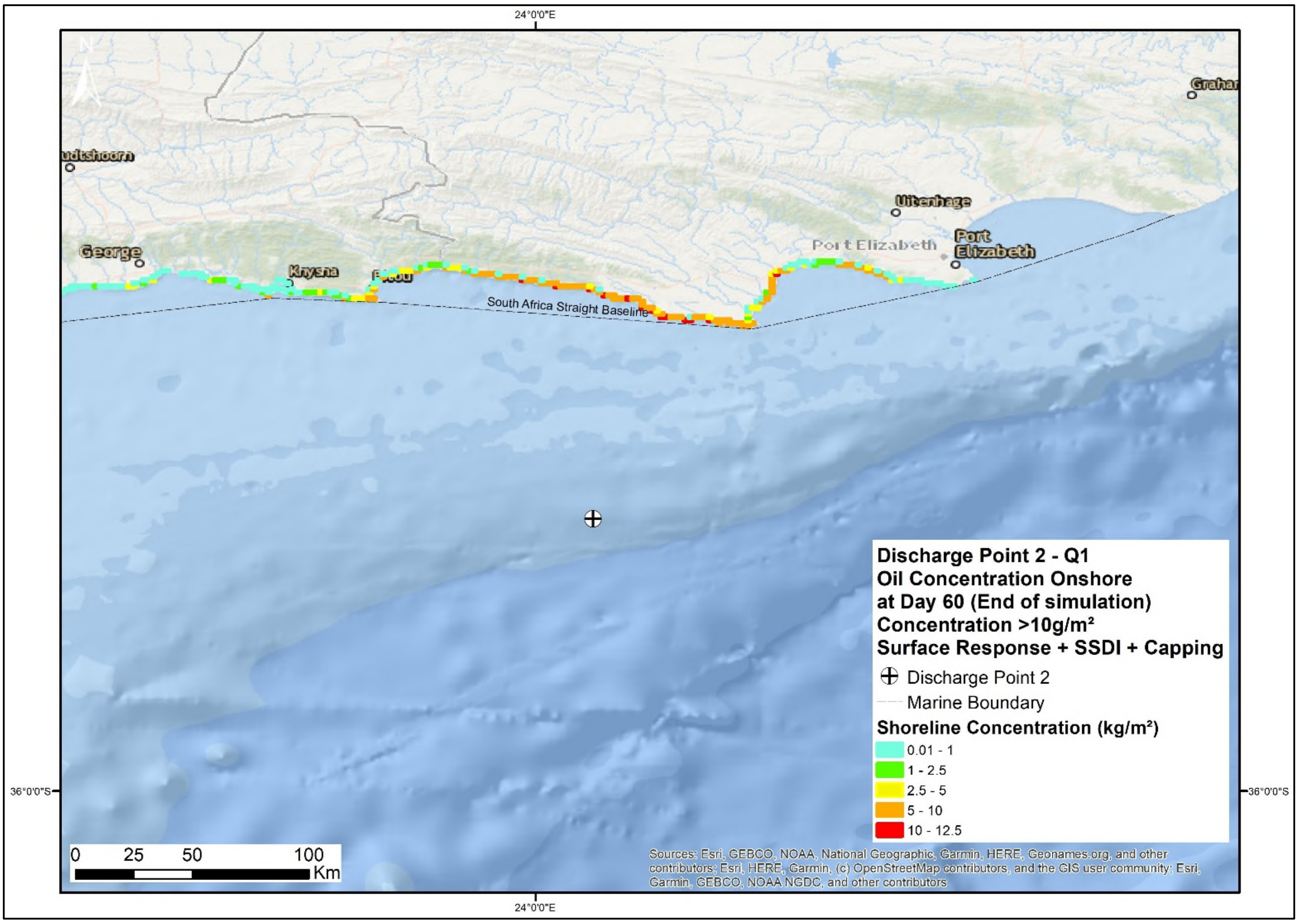

Figure 30 : Scenario 1D – Zoom on the Shoreline concentration most impacted area (>10 g/m^2) at the end of simulation

3.5 Scenario 1 Oil Fate – Capping only Vs. Surface Response + Capping Vs. Surface Response + SSDI + Capping

Figure 31 and Figure 32 present the oil fate comparison between the 3 deterministic scenarios for the Quarter 1, in order to compare the effect of the different oil spill responses.

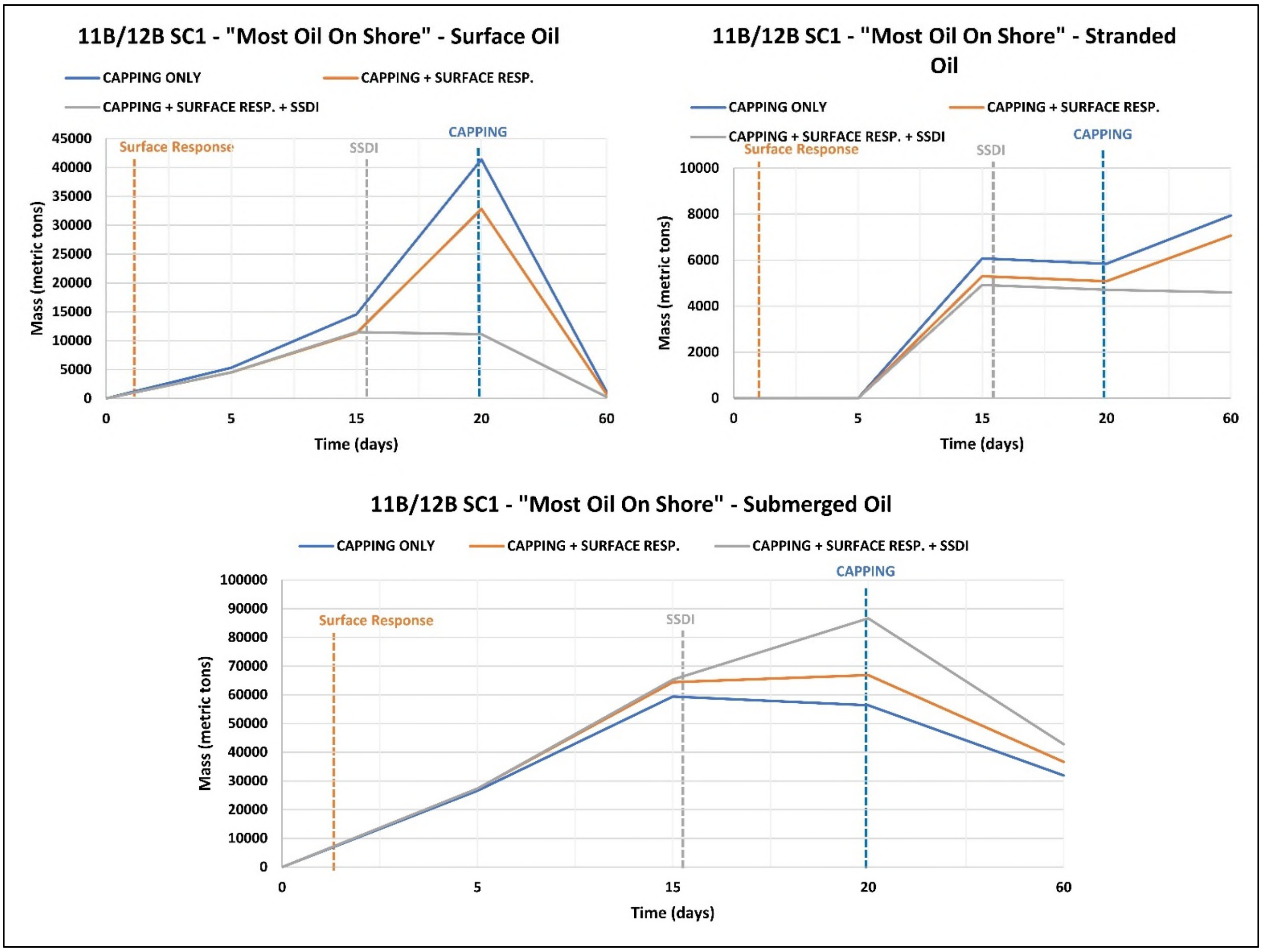

Figure 31: Scenario 1 – "Most Oil Onshore" case's Oil fate comparison (Surface, Stranded and Submerged oil)

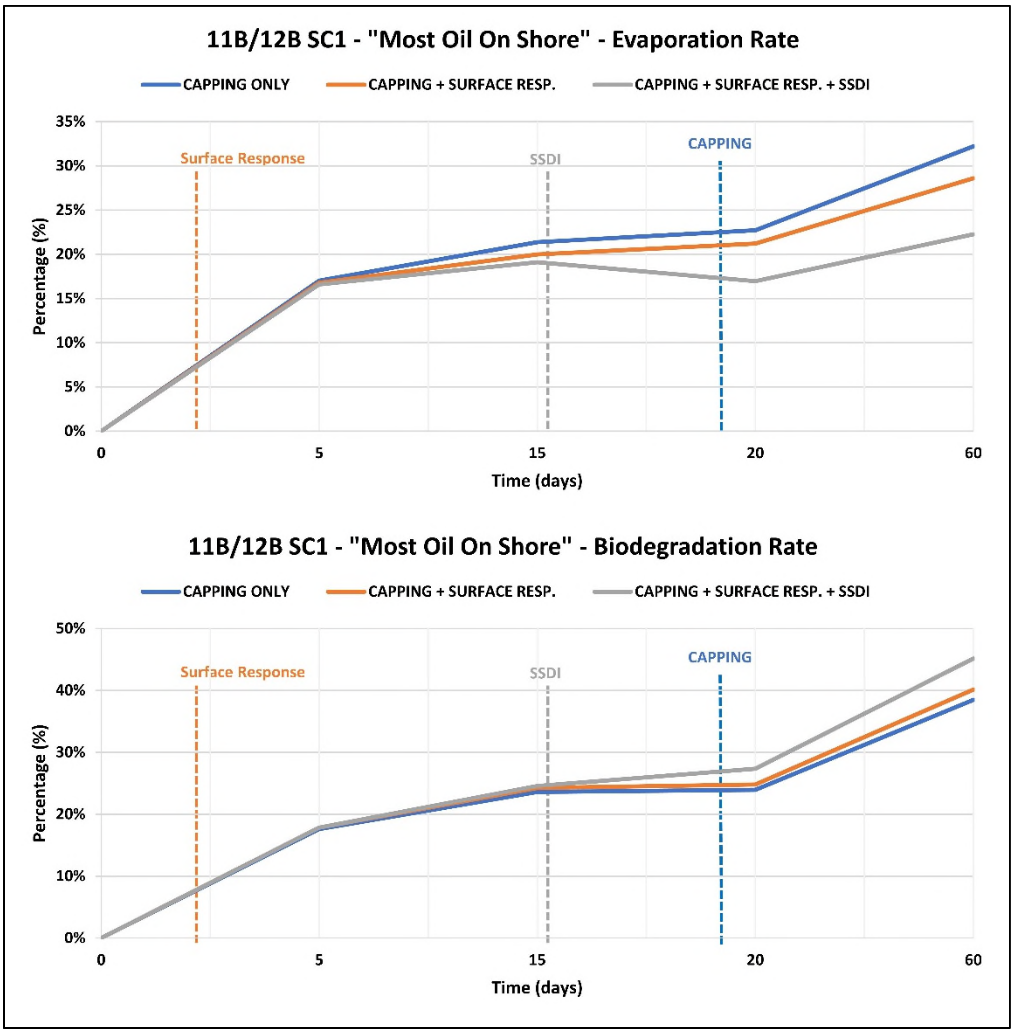

Figure 32: Scenario 1 – "Most Oil Onshore" case's Oil fate comparison (Evaporation & Biodegradation rates)

The **surface response** deployment allows to:

- Reduce the amount of oil remaining on the surface from its deployment;
- Reduce the amount of oil onshore at the end of simulation (i.e. day 60) compared to the Capping only scenario (about 7065 tons with surface response vs. 7940 tons with capping only).

The **SSDI** deployment allows to:

- Reduce greatly the amount of oil reaching the surface on day 20 (approximately 11 130 tons day 20 with SSDI against 41 390 tons with capping only) by reducing considerable the oil droplets size, and consequently their buoyancy capacity, entraining the oil in the water-column, making they more prone for natural biodegrading processes.
- Greatly reduce the amount of oil onshore at the end of simulation (i.e. day 60) compared to the Capping only scenario (about 4600 tons with SSDI vs. 7940 tons with capping only).
- Increase the dispersion and the dissolution of oil in the water column ("submerged oil") and the biodegradation rate (by reducing the droplet size in the water column).

Overall, subsea response has a positive effect on oil mass balance, particularly by decreasing oil reaching the shoreline, evaporated, and increasing the biodegradation (Figure 33).

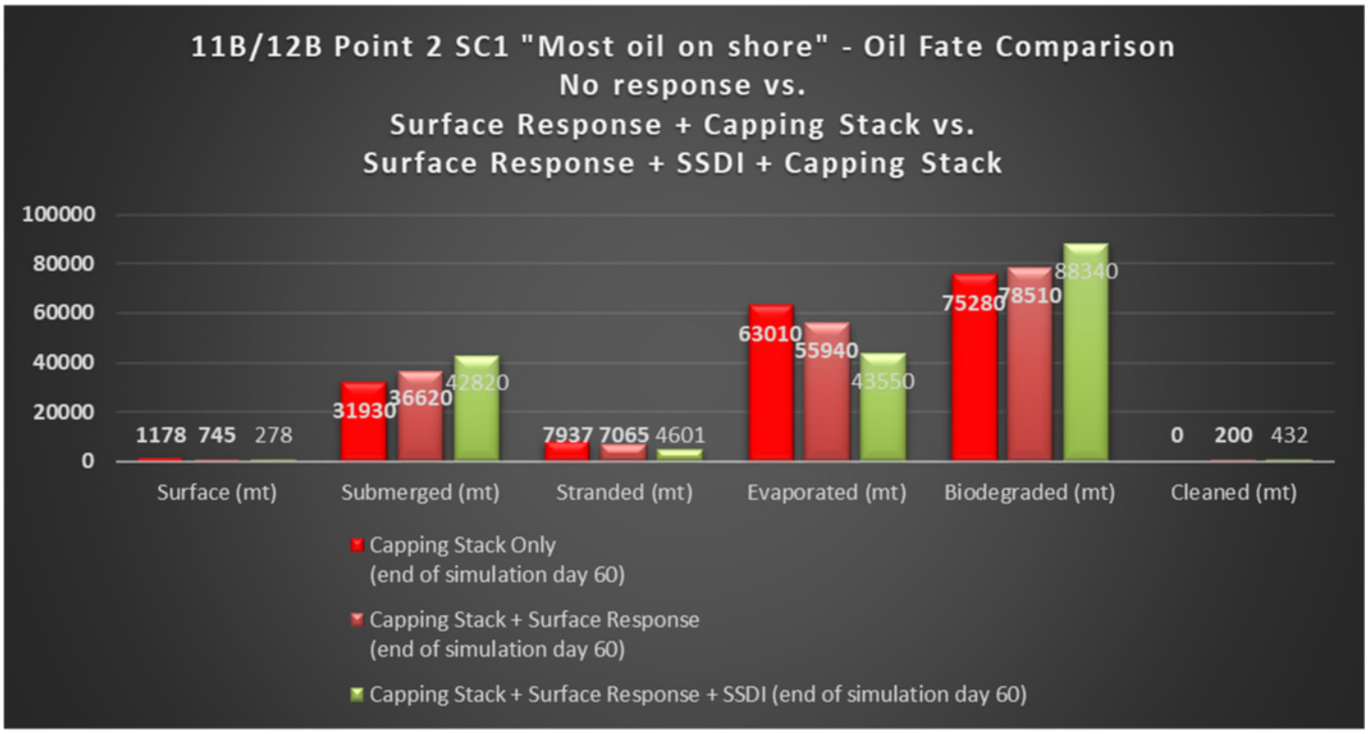

Figure 33 : Scenario 1 Oil Fate Comparison at the end of simulation (day 60)

One should note that SSDI option within OSCAR model, is not part of the response module, and therefore effects are not directly reflected in the oil mass balance. However, its influence is indirectly reflected in the other oil fate compartments such: “surface”, “submerged/dispersed”, “evaporation”, “biodegraded” and “stranded”. Therefore, the results presented here should be considered with caution.

3.6 Scenario 2A – Stochastic Simulation for Apr - Jun (Capping only)

This scenario simulates a continuous blow-out of 69 600 bbls/day of crude oil for a period of 20 days, through a set of 90 similar trajectories (i.e. 18 trajectories simulated for each quarter, in each of the 5 years covered by the metocean data), under a wide range of metocean conditions and a simulation duration of 60 days, covering the period from April 1st to June 30th for the years 2012 to 2016.

3.6.1 Surface Results

IMPORTANT: Surface results presented in this section do not represent a single spill but the combination of the statistical results of the 90 individual trajectories composing Stochastic Scenario 2. Threshold value applied for the interpretation of surface results is 5 µm, as detailed in Section 2.4.2

The stochastic footprint for the ensemble of trajectories is oriented towards the South-West direction. The highest values for surface oiling probability (i.e. 90% to 100%) are observed for South African offshore waters (Figure 34), along 135 km South-West from the discharge point 2.

There is 80% of probability for the drift to travel in the North and North-East directions, meaning that for the 90 trajectories performed for the Scenario 2, 72 trajectories may observe a drift towards the North and North-East directions on South African coastline (Saint Francis Bay and Tsitsikamma National Park areas).

As we move away from the release point, the probability values gradually decrease however the main direction of the slick remains towards the South-West, indicating a low to medium variability of the trajectories of the Scenario 2, due to constant metocean conditions in this area.

Offshore waters of Namibia on the West side and Mozambique on the East side are not affected by the blow-out (considering the applied release properties and threshold values applied in the post-processing of modelling results).

The stochastic footprint goes into international waters approximately 515 km South-West from the release location, about 4 days after the start of the spill (Figure 35), with a maximum probability of 14% (Figure 34).

The oil slick quickly progresses at sea surface, about 260 km towards South-West and 105 km towards North-East, in 2 days. Three days after the start of the blow-out, the oil slick edge could reach 405 km South-West from the discharge point, or 210 km North-East from the discharge point close to the shoreline, due to the strong winds and currents in this area.

Reminder: Surface results characterized in Figure 34 and Figure 35, are considering only hydrocarbons presence at sea surface for a thickness above 5 µm.

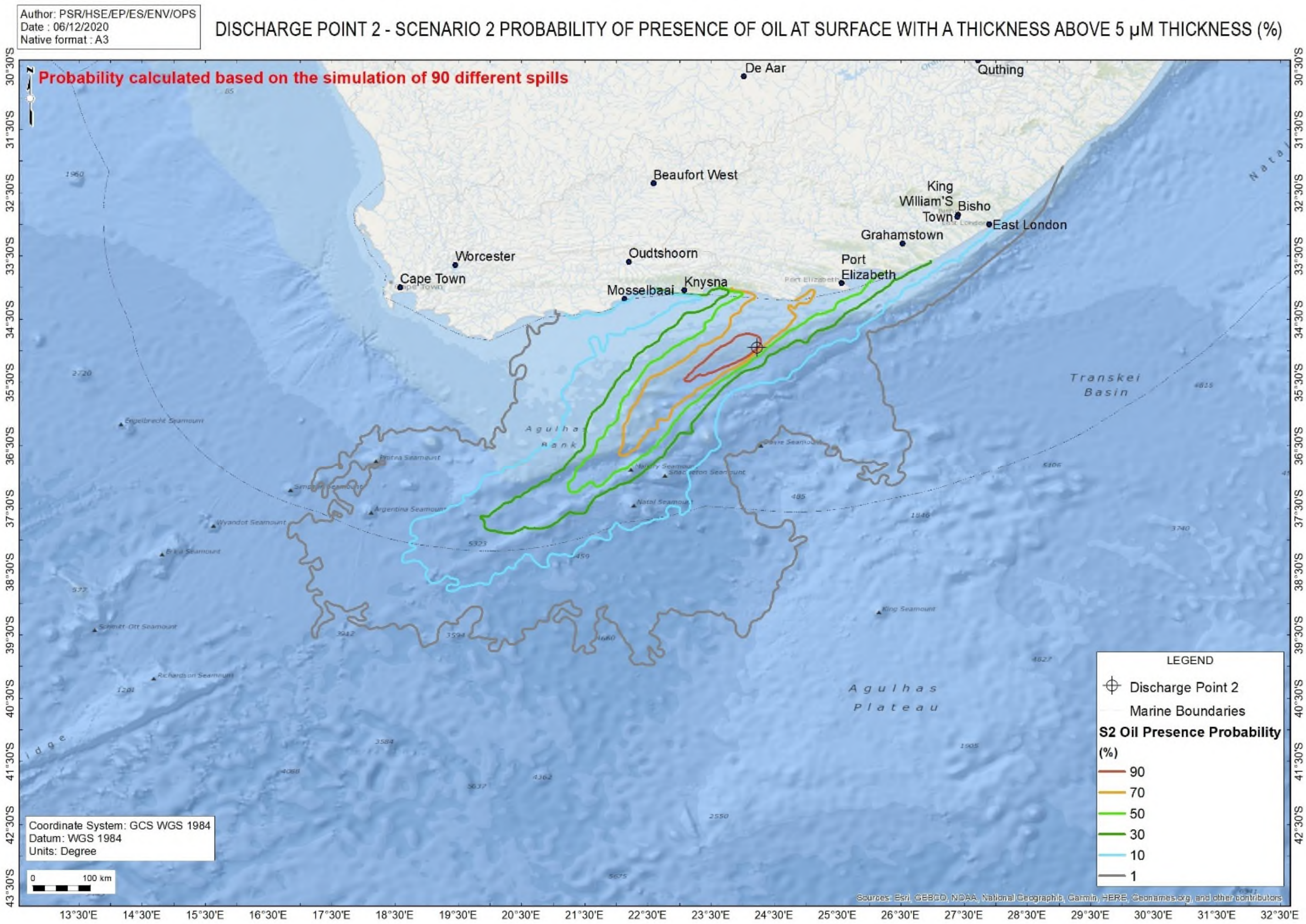

Figure 34: Scenario 2A (Q2)– Surface oiling probability above threshold (i.e. >5 µm)

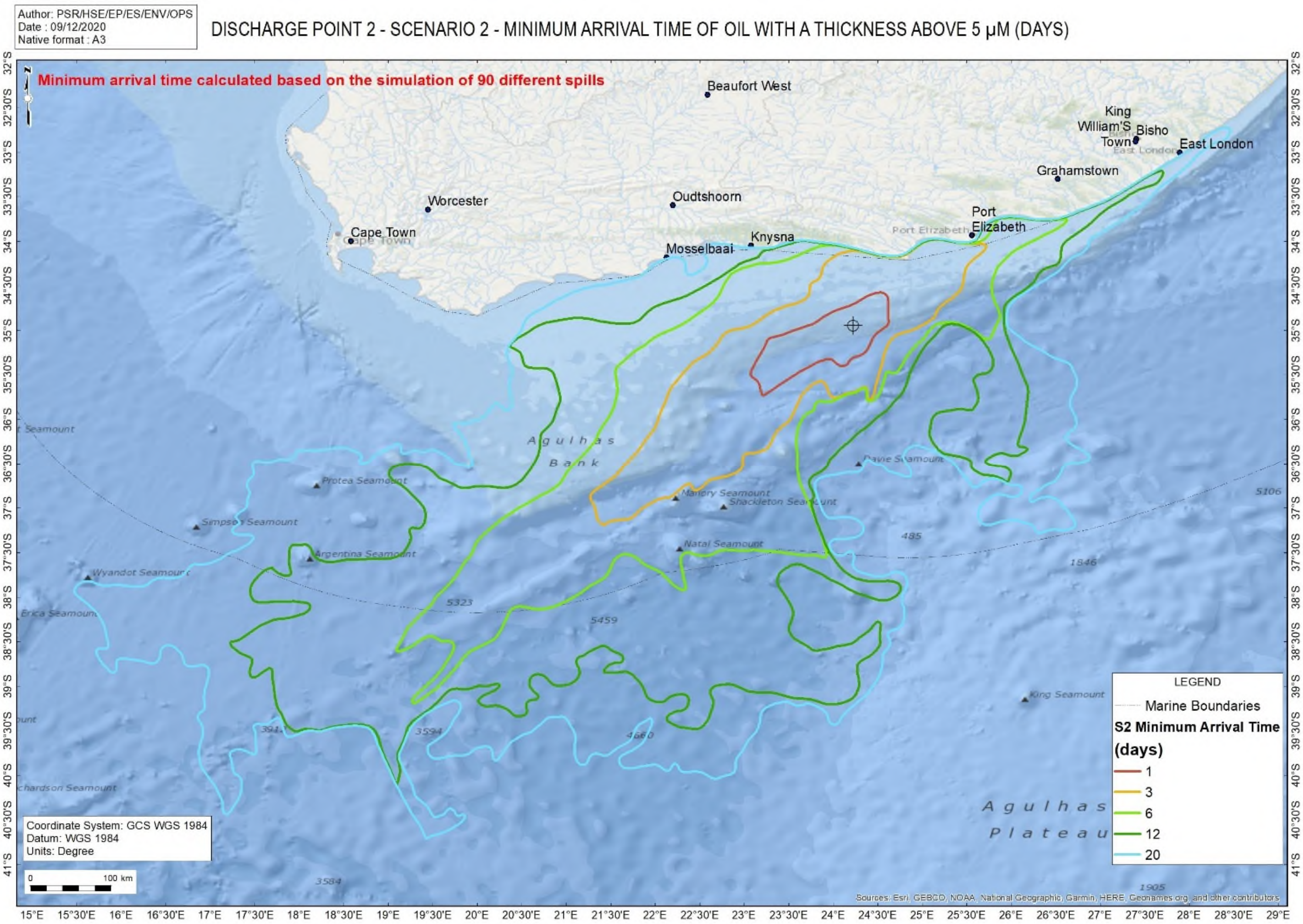

Figure 35: Scenario 2A (Q2)– Surface minimum arrival time (days) above threshold (i.e. >5 µm)

3.6.2 Shoreline Results

IMPORTANT: Shoreline results presented in this section do not represent a single spill but the combination of statistical results of the 90 individual trajectories composing Stochastic Scenario 2. Threshold value applied for the interpretation of shoreline results is 10 g/m^2, as detailed in Section 2.4.2.

Overall, all the shoreline from Cape Town to East London area will observe a very low to high probability for shoreline oiling probability (i.e. from 1 to 98 %). The highest values for shoreline oiling probability (66 to 98%), are observed between Knysna and Port Elizabeth areas (Figure 36 and Figure 37).

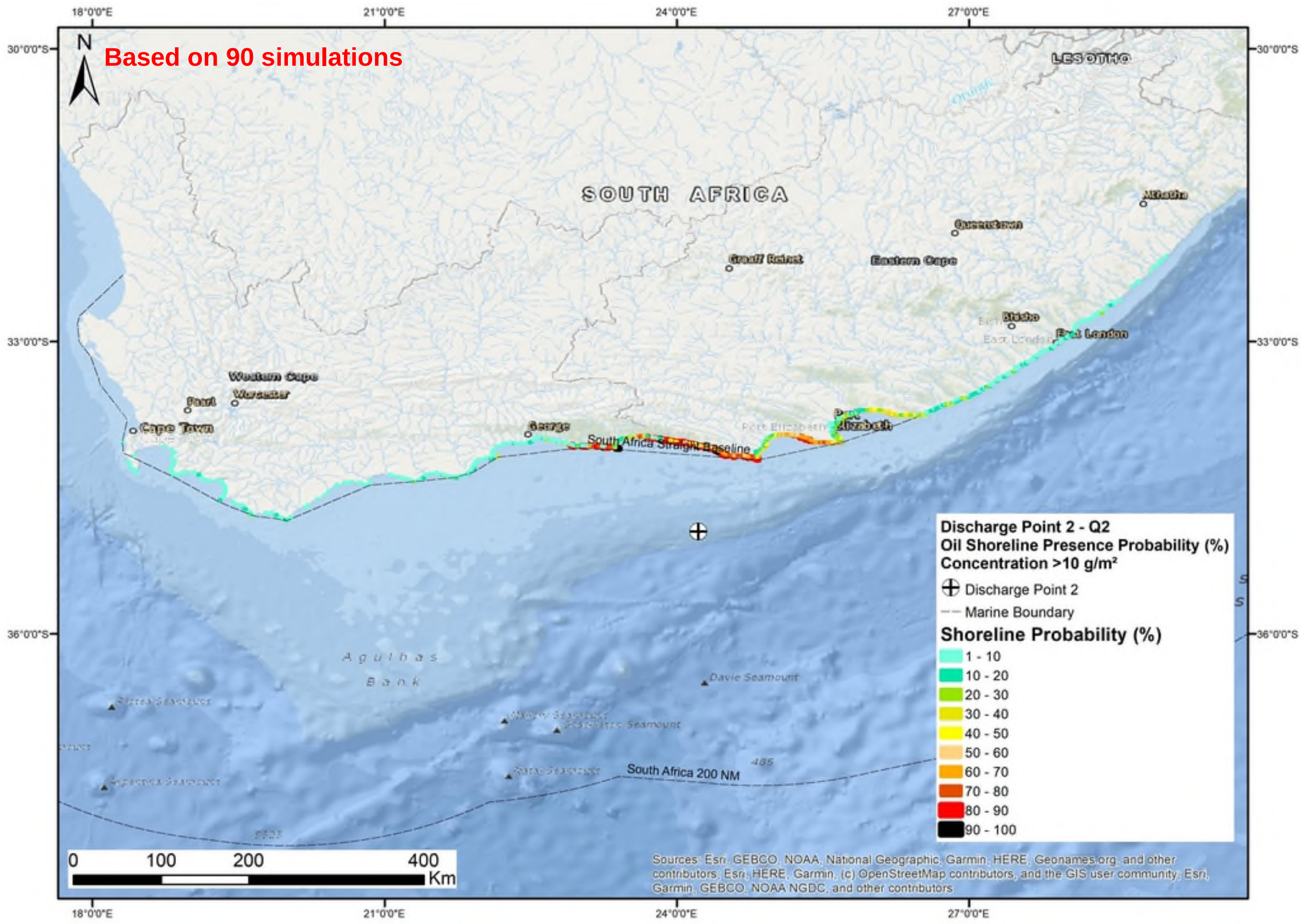

Figure 36: Scenario 2A – Shoreline oiling probability above threshold (i.e. >10 g/m^2)

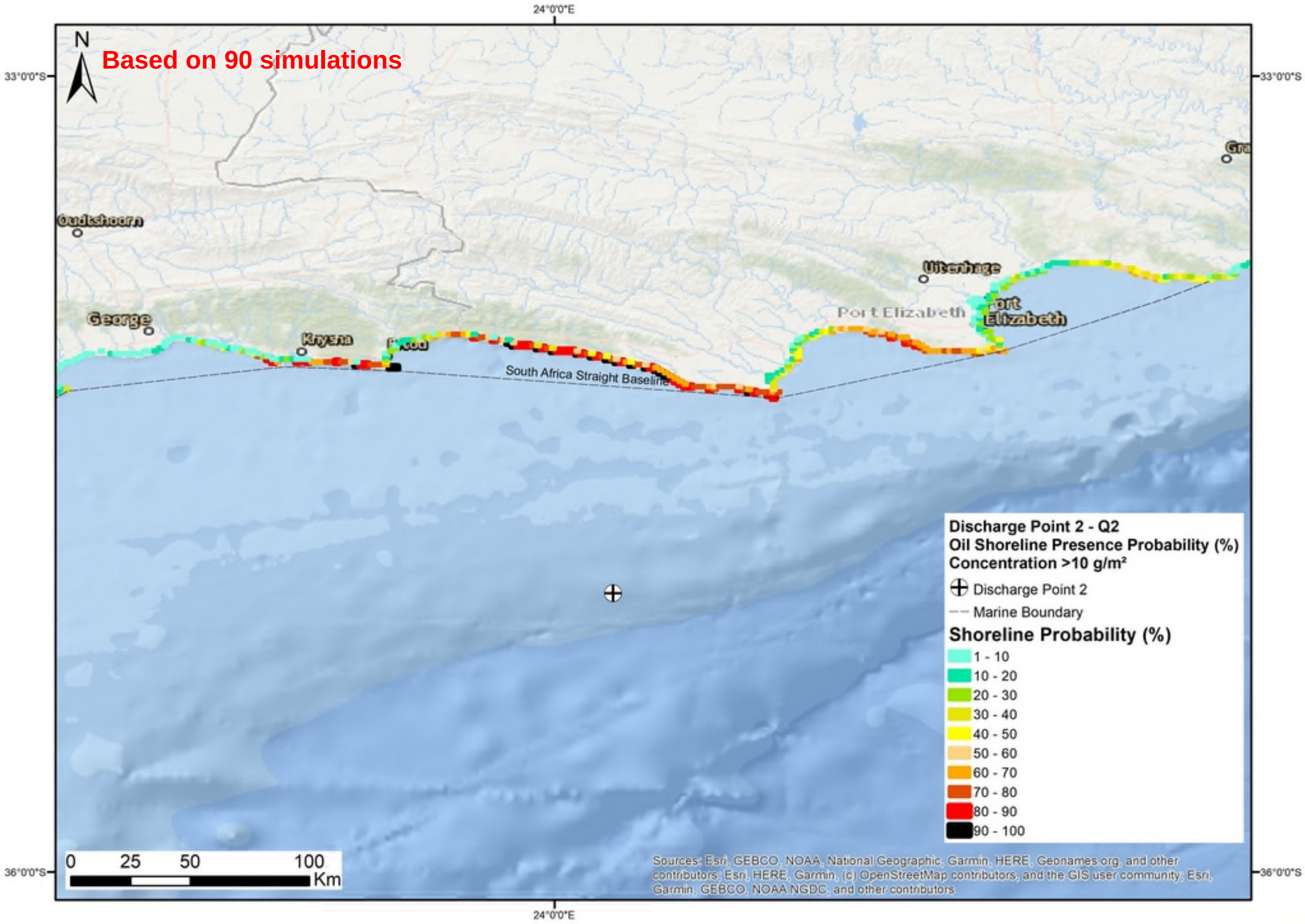

Figure 37 : Scenario 2A – Zoom on Shoreline oiling probability above threshold most impacted area (i.e. >10 g/m²)

Shoreline minimum arrival time (in days) is observed on the Saint Francis Bay area, West to Port Elizabeth, approximately 2 days after start of the release (Figure 38 and Figure 39). Overall, all the Saint Francis Bay area could observe oil reaching the shore in less than 2 days, with a maximum shoreline oiling probability until 90%.The Tsitsikamma National Park area could observe oil reaching the shore within 3 to 5 days, with high shoreline oiling probabilities (until 98%). There is no shoreline transboundary effect in this scenario.

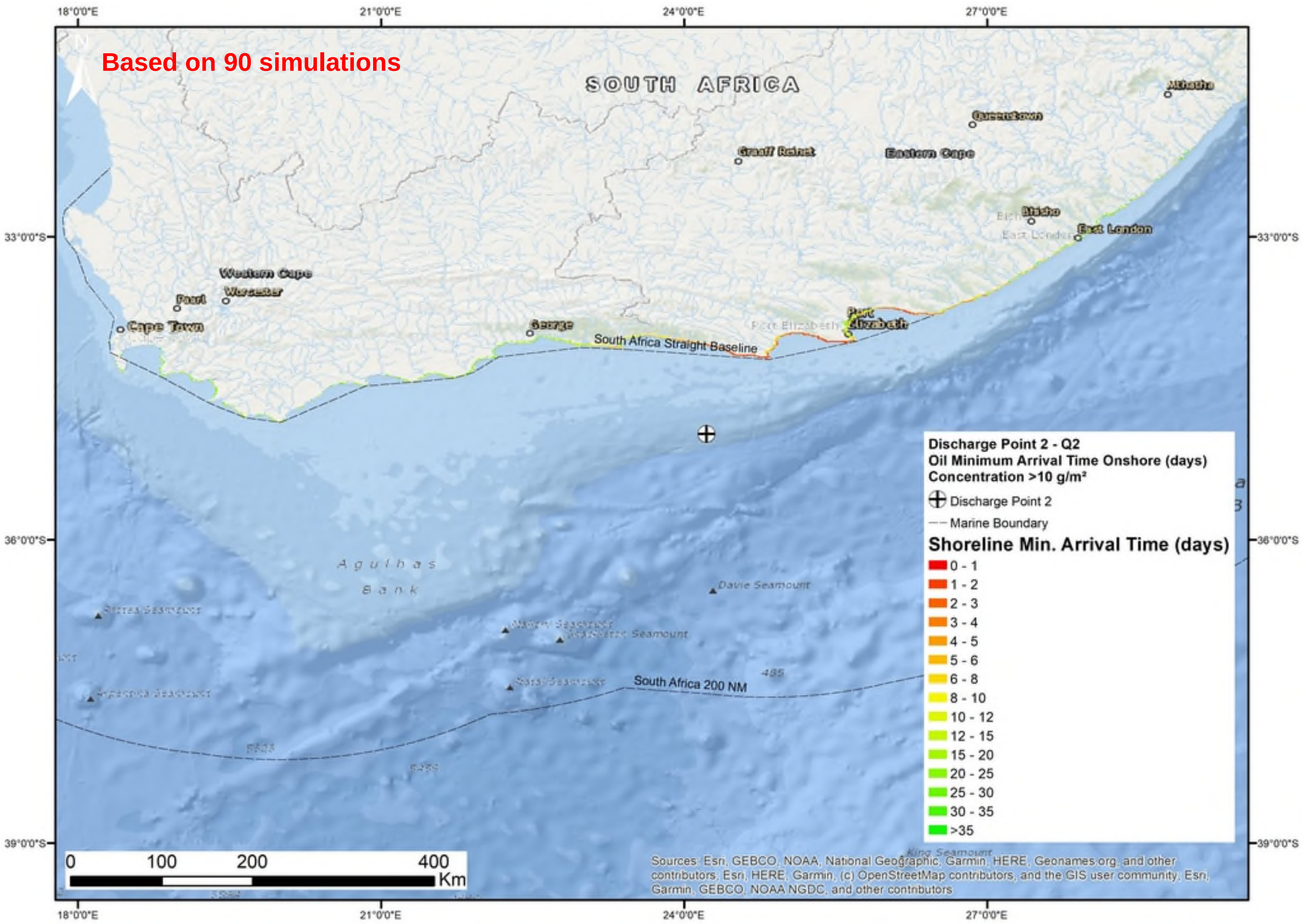

Figure 38: Scenario 2A – Shoreline minimum arrival time (days) above threshold (i.e. >10 g/m^2)

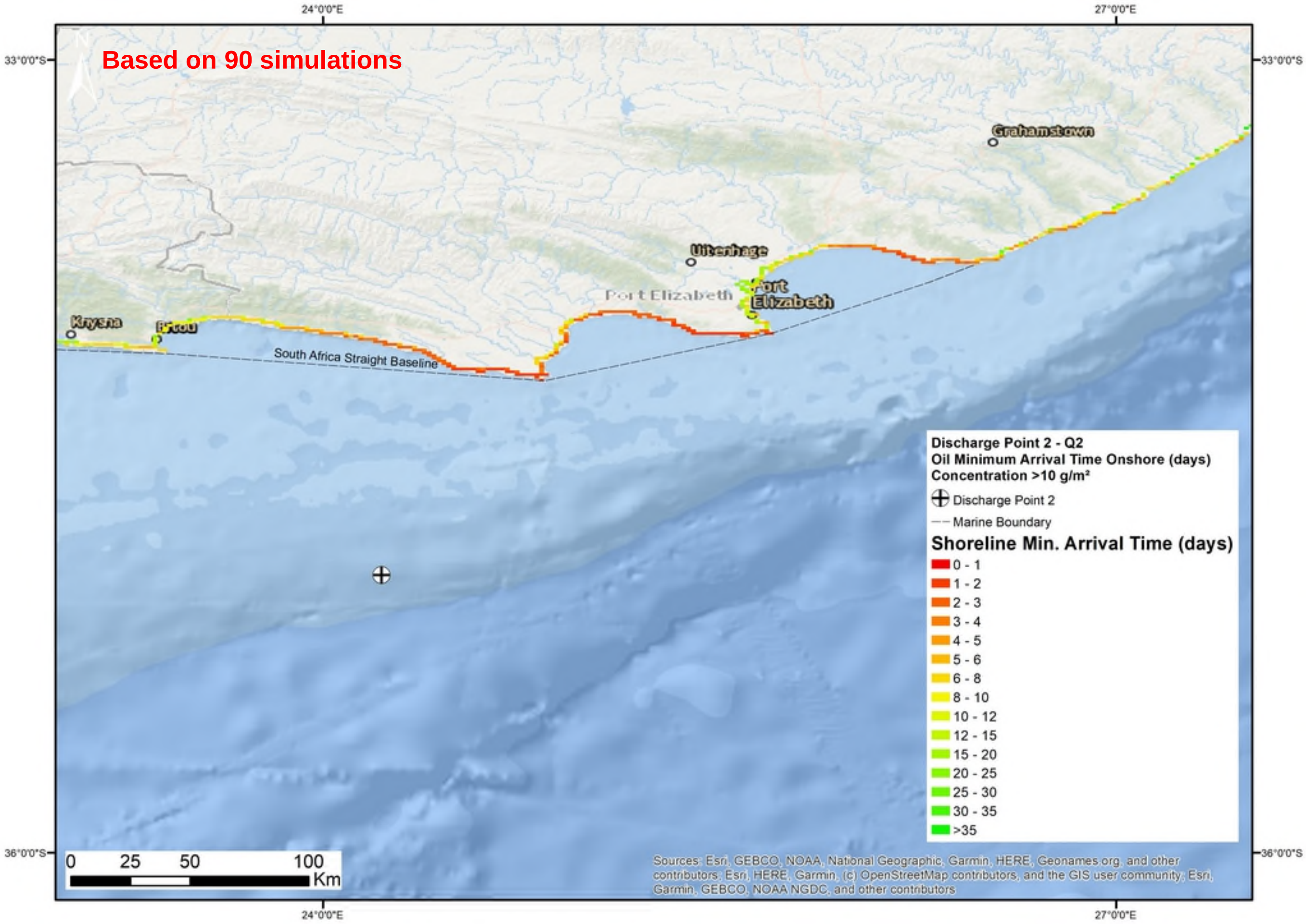

Figure 39 : Scenario 2A – Zoom on the shoreline minimum arrival time most impacted area (days) above threshold (i.e. >10 g/m^2)

Reminder: Shoreline results characterized in Figure 36, Figure 37, Figure 38 and Figure 39, are considering only hydrocarbons presence at shoreline for an oil load threshold >10 g/m^2.

3.7 Scenario 2B – Deterministic Scenario (Capping only) - Spill Drift and Shoreline Impacts

The simulation resulting in the highest hydrocarbon mass reaching the shore for Scenario 2 (i.e. trajectory with start on **June 22th 2012 (15:00 UTC)**), was selected to illustrate the results of the deterministic simulation (i.e. **Scenario 2B**), with a continuous blow-out releasing 69 600 bbls/day for a period of 20 days, and simulation total duration of 60 days.

Note: Figure 40 and Figure 41 have been done with a more precise resolution in order to better analyze the characteristics of the oil in the environment at the beginning of the blow-out.

Figure 40 presents the oil rise in the water column 3 hours after the start of the release, approximately 3 km South-West from the release location with a maximum oil thickness at this time of 828 µm. These results will be the same for the Scenarios 2C and 2D considering no response strategy will be implemented before those 3 hours.

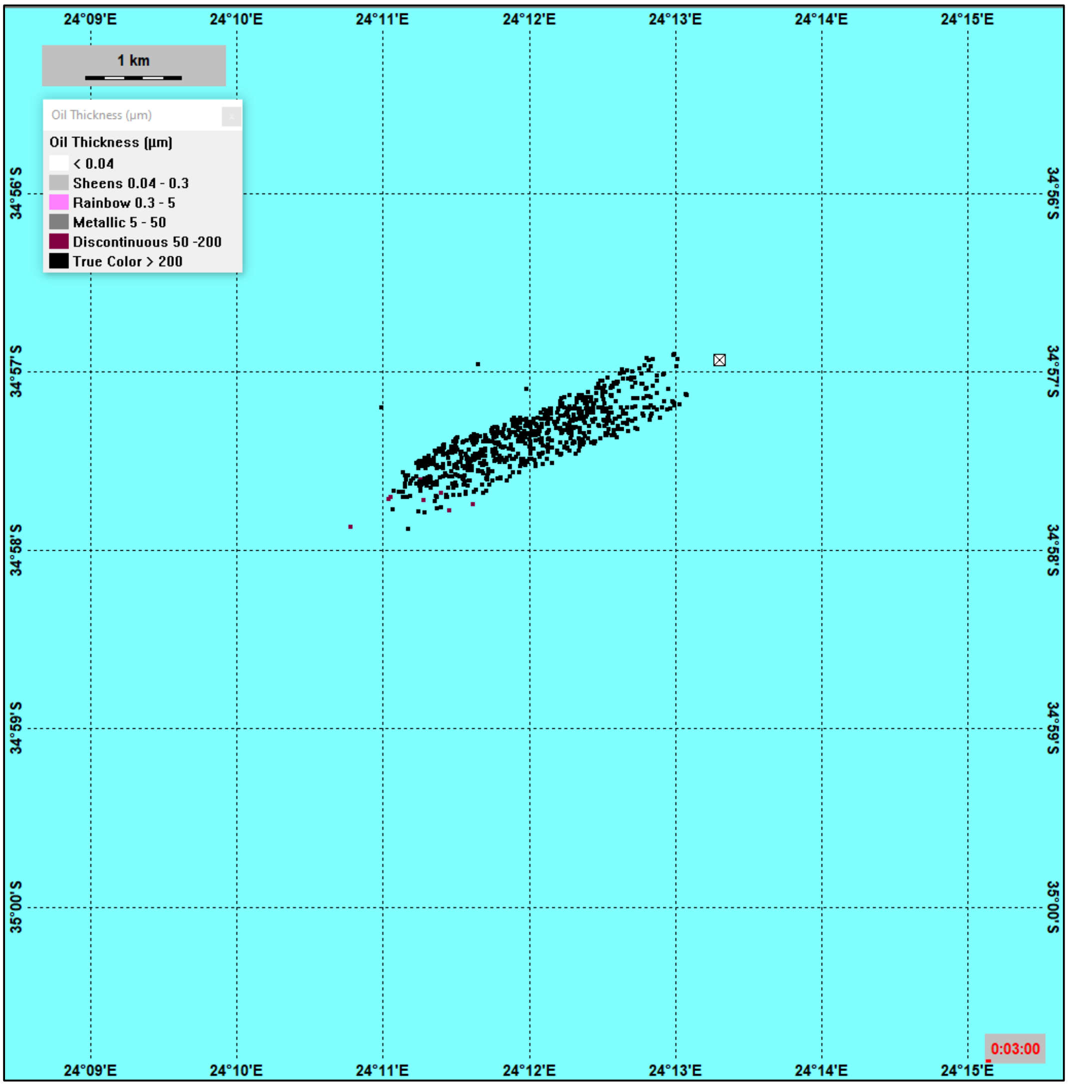

Figure 40: Oil reaching surface for scenarios 2B, 2C and 2D

Figure 41 present the release concentration and the submerged particles in the water column 3 hours after the start of the blow-out.

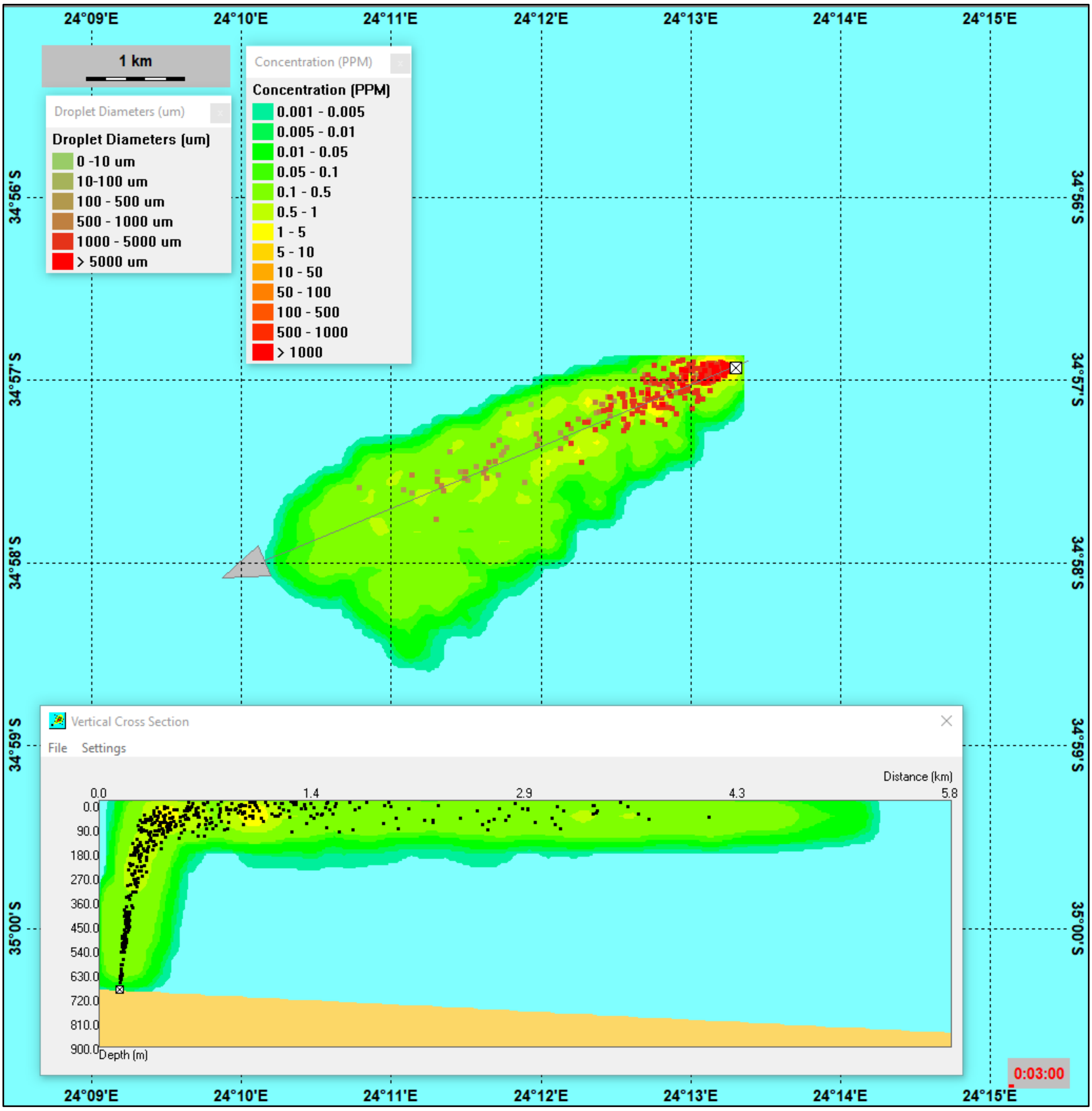

Figure 41 : Release concentration and submerged particles in the water column 3 hours after the start of the blow-out for scenarios 2B, 2C and 2D

The maximum oil concentration in the water column is 5.25 ppm very close to the release point; the maximum oil droplet diameter 3475 µm on the release point, and the termination depth is around 100 m. One should note that Figure 40 is a snapshot of the oil behaviour within the water-column, and is dependent of the orientation of the vertical cross-section arrow drawn, for the visualization of calculated results (i.e. the profile of the concentrations in the water-column), as well as of the correspondent time-step.

Oil spill initial drift, 24 hours after start of the release, is observed towards the West direction (Figure 42). Slick will then drift towards West / South-West on day 2, before changing direction again to North day 4, and finally reaching the shore, on spill 5th day, in Saint Francis Bay area.

The maximum distance reached by the surface oil is 515 km South-West from the release point, 16 days after the start of the blow-out.

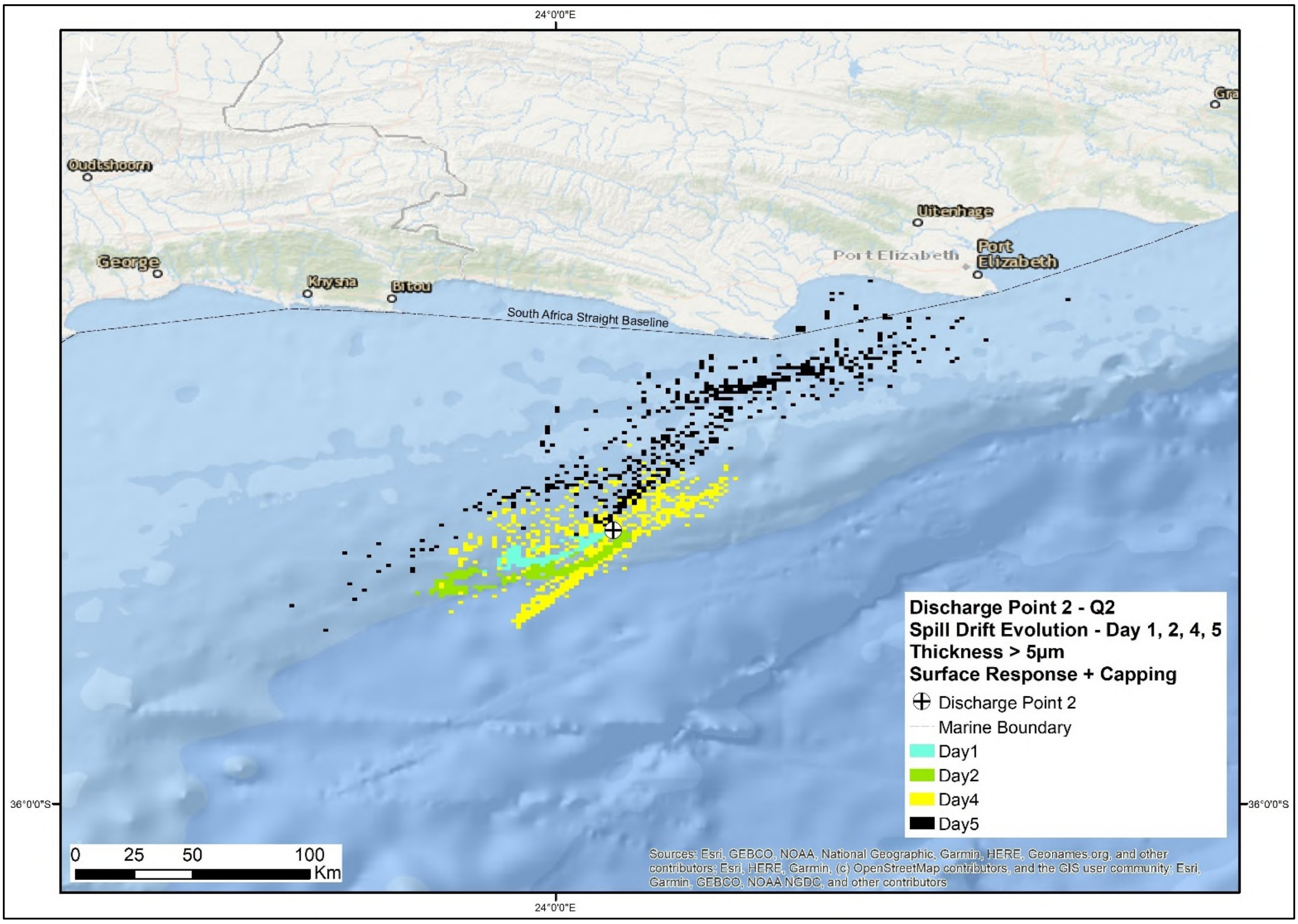

Figure 42: Scenario 2B – Spill drift evolution – Days 1, 2, 4 & 5

Figure 43 and Figure 44, show the impacts over the shoreline at the end of simulation, i.e. 60 days after the start of the blow-out. Impact ashore above threshold (i.e. 10 g/m^2 or 0.01 kg/m^2), is observed from the South of Cape Town to West of East London.

Highest value for shoreline oil concentration (around 12500 g/m^2) is observed along approximately 480 km between George and East of Port Elizabeth. The total mass reaching the shore would be 14 850 t.

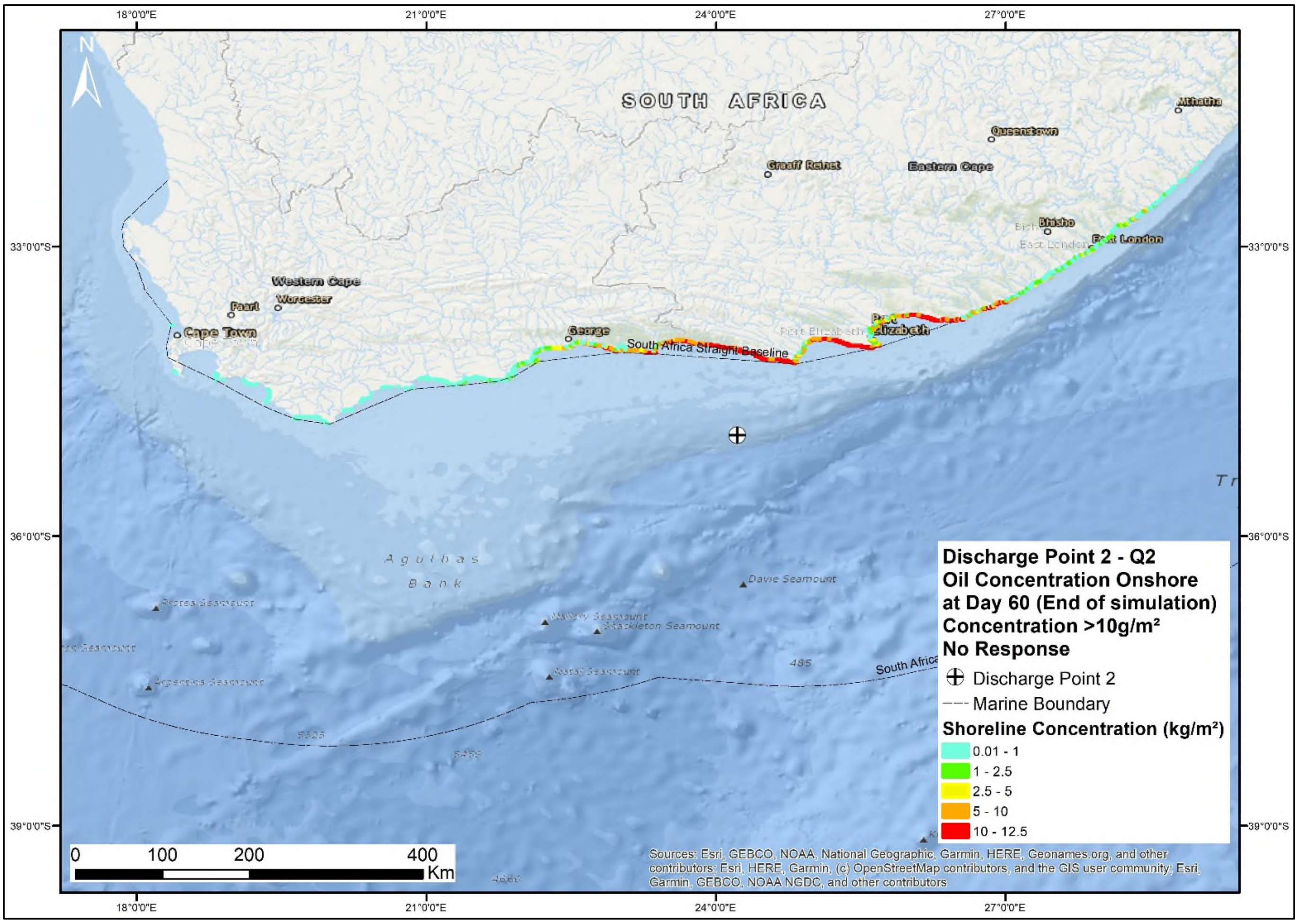

Figure 43: Scenario 2B – Shoreline concentration (>10 g/m²) at the end of simulation

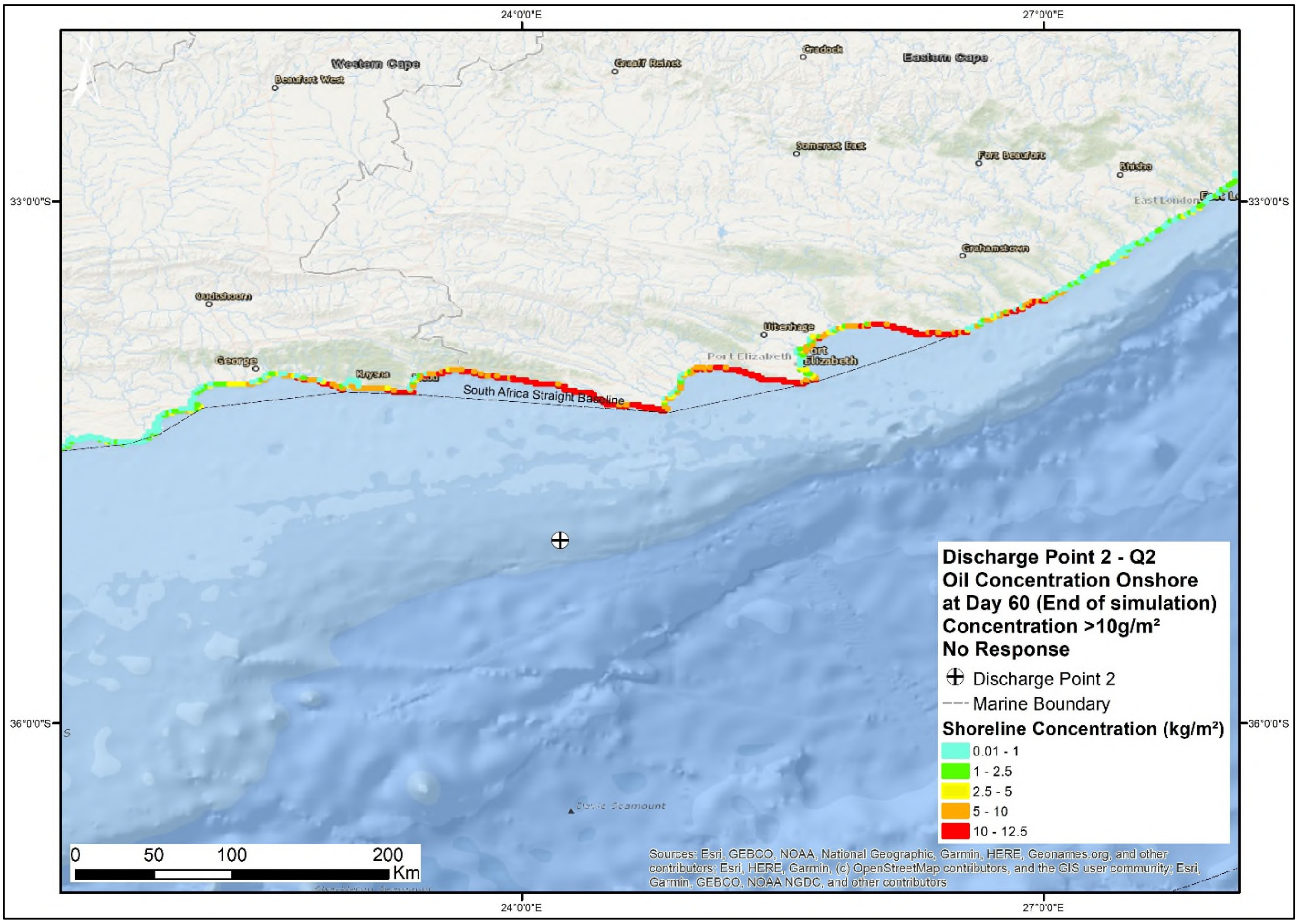

Figure 44 : Scenario 2B – Zoom on the Shoreline concentration most impacted area (>10 g/m^2) at the end of simulation

3.8 Scenario 2C – Deterministic Scenario (Surface Response + Capping) - Spill Drift and Shoreline Impacts

The simulation resulting in the highest hydrocarbon mass reaching the shore for Scenario 2 (i.e. trajectory with start on **June 22th 2012 (15:00 UTC)**), was selected to illustrate the results of the deterministic simulation (i.e. **Scenario 2B**), with a continuous blow-out releasing 69 600 bbls/day for a period of 20 days, and simulation total duration of 60 days.

The following response strategy is deployed and simulated in this scenario (detailed in 2.2.3):

- Surface response with aircrafts and vessels 24 hours after the start of the spill.

Oil spill initial drift, 24 hours after start of the release, is observed towards the West direction (Figure 45). Slick will then drift towards West / South-West on day 2, before changing direction again to North day 4, and finally reaching the shore, on spill 5th day, in Saint Francis Bay area.

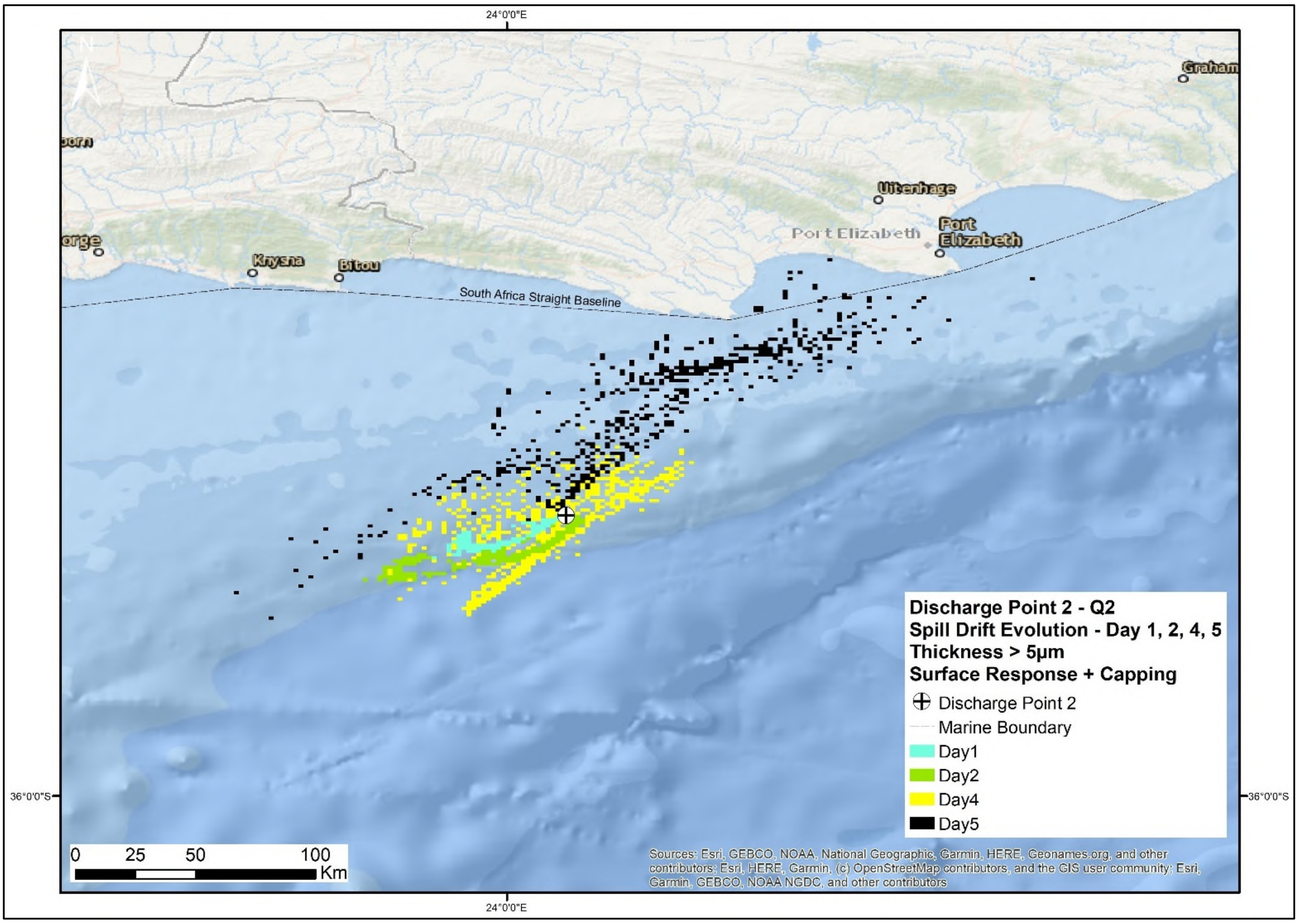

Figure 45: Scenario 2C – Spill drift evolution – Days 1, 2, 4 & 5

Figure 46 and Figure 47, show the impacts over the shoreline at the end of simulation, i.e. 60 days after the start of the blow-out. Impact ashore above threshold (i.e. 10 g/m^2 or 0.01 kg/m^2), is observed from the South of Cape Town to West of East London.

Highest value for shoreline oil concentration (around 12500 g/m^2) is observed along approximately 455 km between George and East of Port Elizabeth.

The Surface Response allows to slightly reduce the oil concentration onshore on George area, and East to Port Elizabeth, where there is less shoreline impacted with high concentration values than with capping only (25 km less).

The mass reaching the shore at the end of simulation (60 days) would then be 13 620 t vs. 14 850 t with only the capping stack.

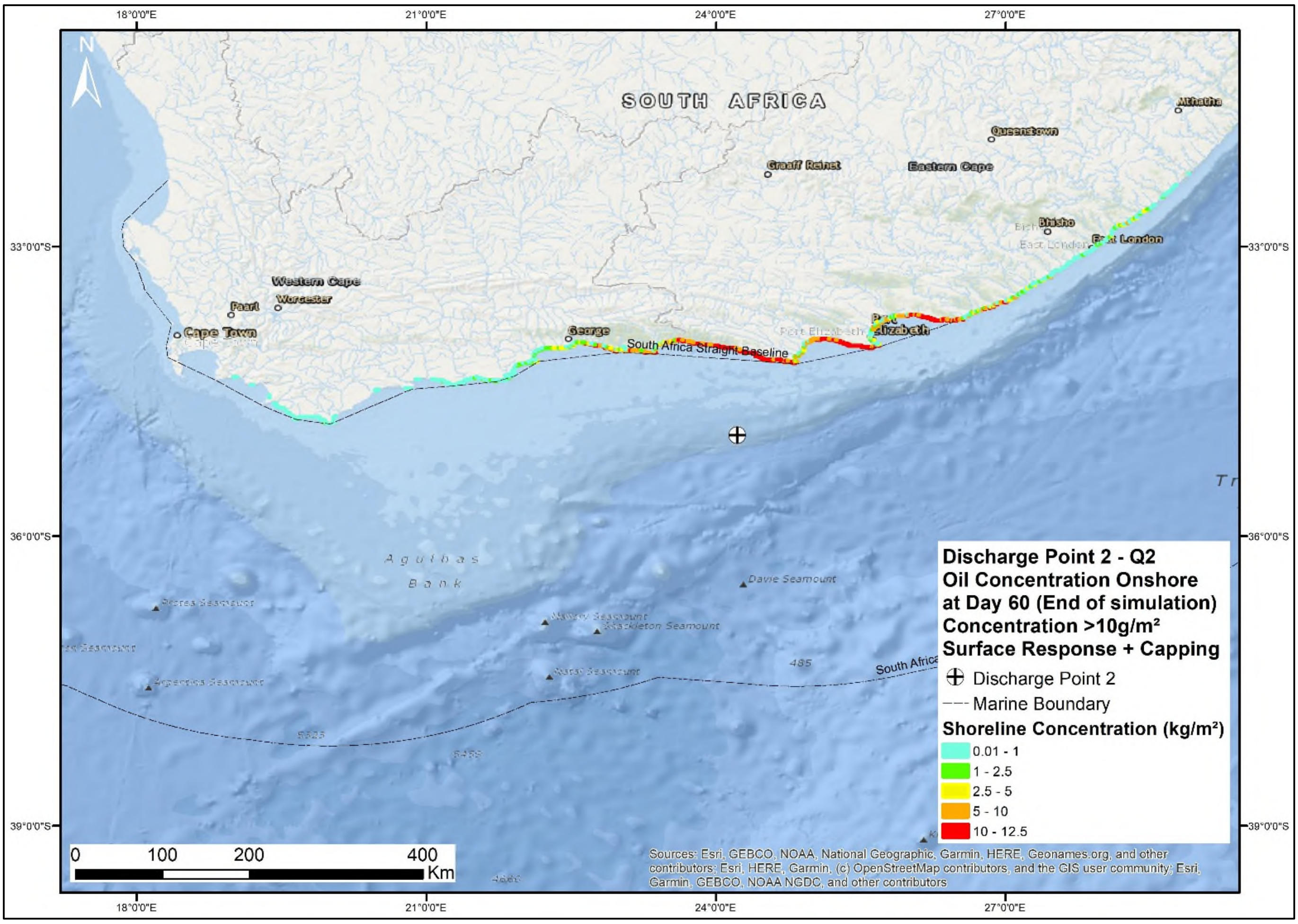

Figure 46: Scenario 2C – Shoreline concentration (>10 g/m²) at the end of simulation

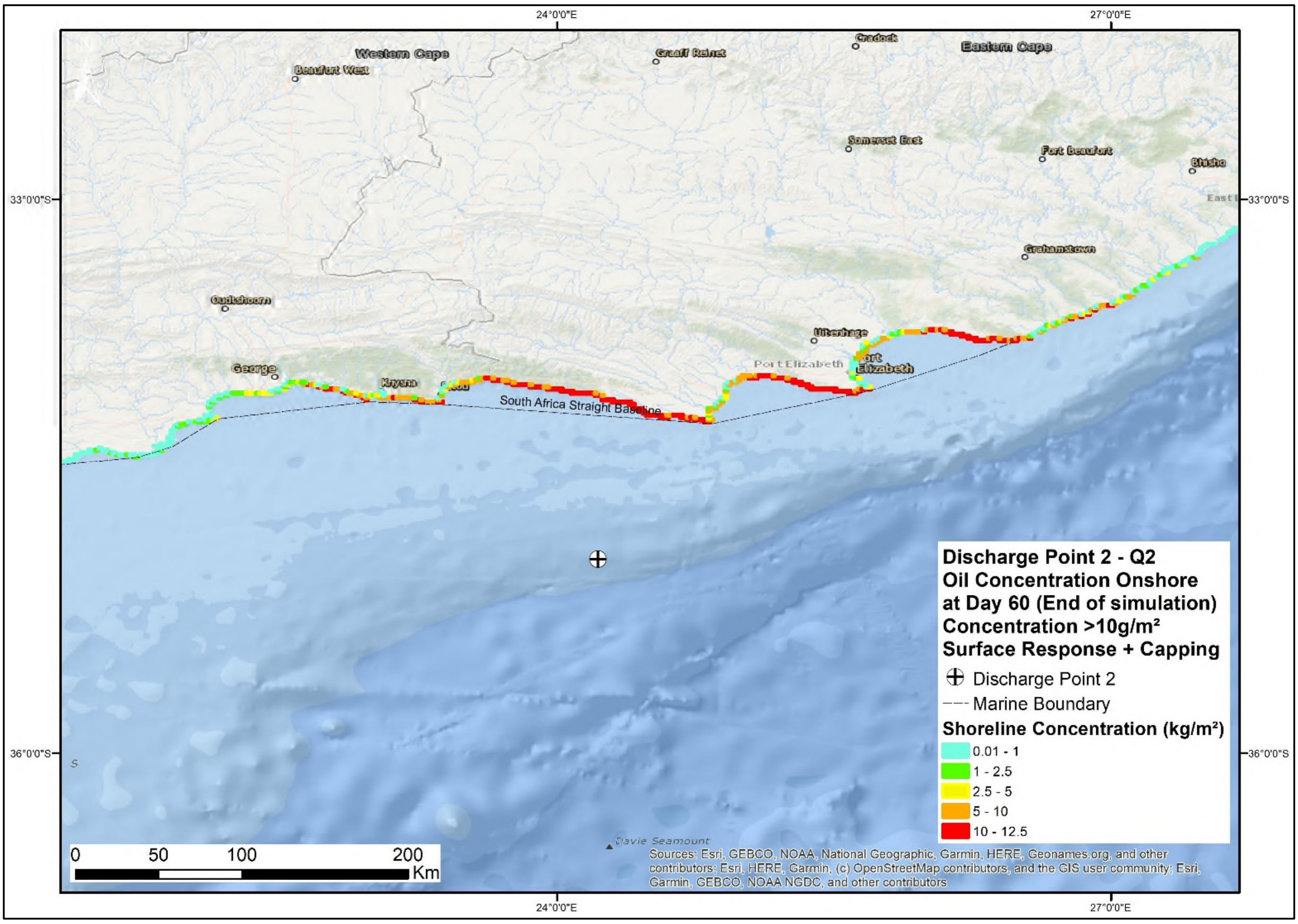

Figure 47 : Scenario 2C – Zoom on the Shoreline concentration most impacted area (>10 g/m^2) at the end of simulation

3.9 Scenario 2D – Deterministic Scenario (Surface Response + SSDI + Capping) - Spill Drift and Shoreline Impacts

The simulation resulting in the highest hydrocarbon mass reaching the shore for Scenario 2 (i.e. trajectory with start on **June 22th 2012 (15:00 UTC)**), was selected to illustrate the results of the deterministic simulation (i.e. **Scenario 2B**), with a continuous blow-out releasing 69 600 bbls/day for a period of 20 days, and simulation total duration of 60 days.

The following response strategy is deployed and simulated in this scenario (detailed in 2.2.3), namely:

- Surface response with aircrafts and vessels 24 hours after the start of the spill;
- SSDI (Subsea Dispersant Injection) 15 days after the start of the blow-out.

Oil spill initial drift, 24 hours after start of the release, is observed towards the West direction (Figure 48). Slick will then drift towards West / South-West on day 2, before changing direction again to North day 4, and finally reaching the shore, on spill 5th day, in Saint Francis Bay area.

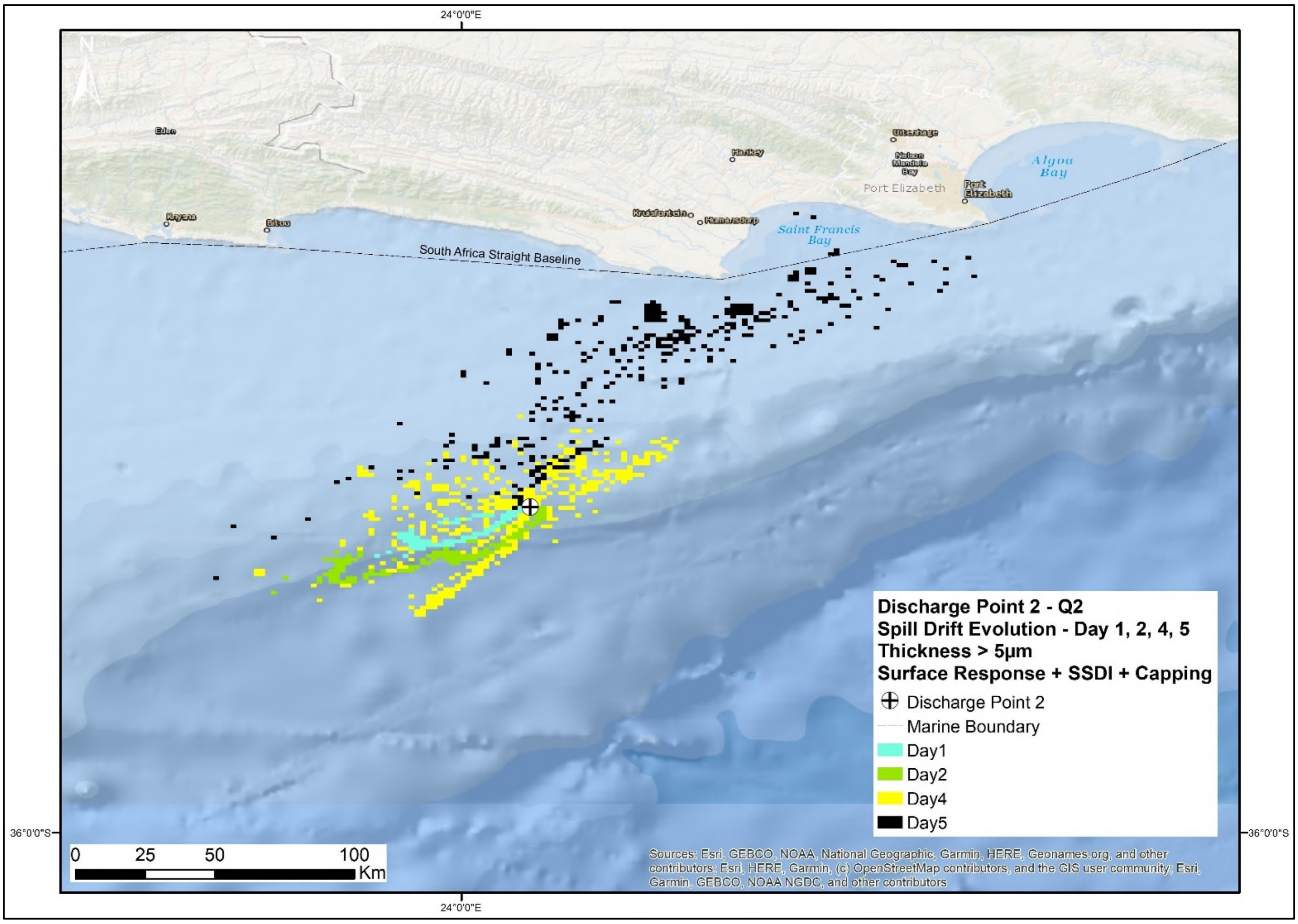

Figure 48: Scenario 2D – Spill drift evolution – Days 1, 2, 4 & 5

Figure 49 and Figure 50 show the impacts over the shoreline at the end of simulation, i.e. 60 days after the start of the blow-out. Impact ashore above threshold (i.e. 10 g/m^2 or 0.01 kg/m^2), is observed from the South of Cape Town to West of East London.

Highest value for shoreline oil concentration (around 12500 g/m^2) is observed along approximately 400 km between Knysna and East of Port Elizabeth. There is a slight reduction of the length of shore with high concentration (approximately 400 km in this case versus 480 km without SSDI).

The SSDI deployed on the 15th day allows the reduction of the oil concentration onshore and the length of the coastline impacted, especially between George and Knysna area, and in the East part of the Port Elizabeth.

The mass reaching the shore at the end of simulation (60 days) would then be 11 690 t vs. 14 850 t with only the capping stack.

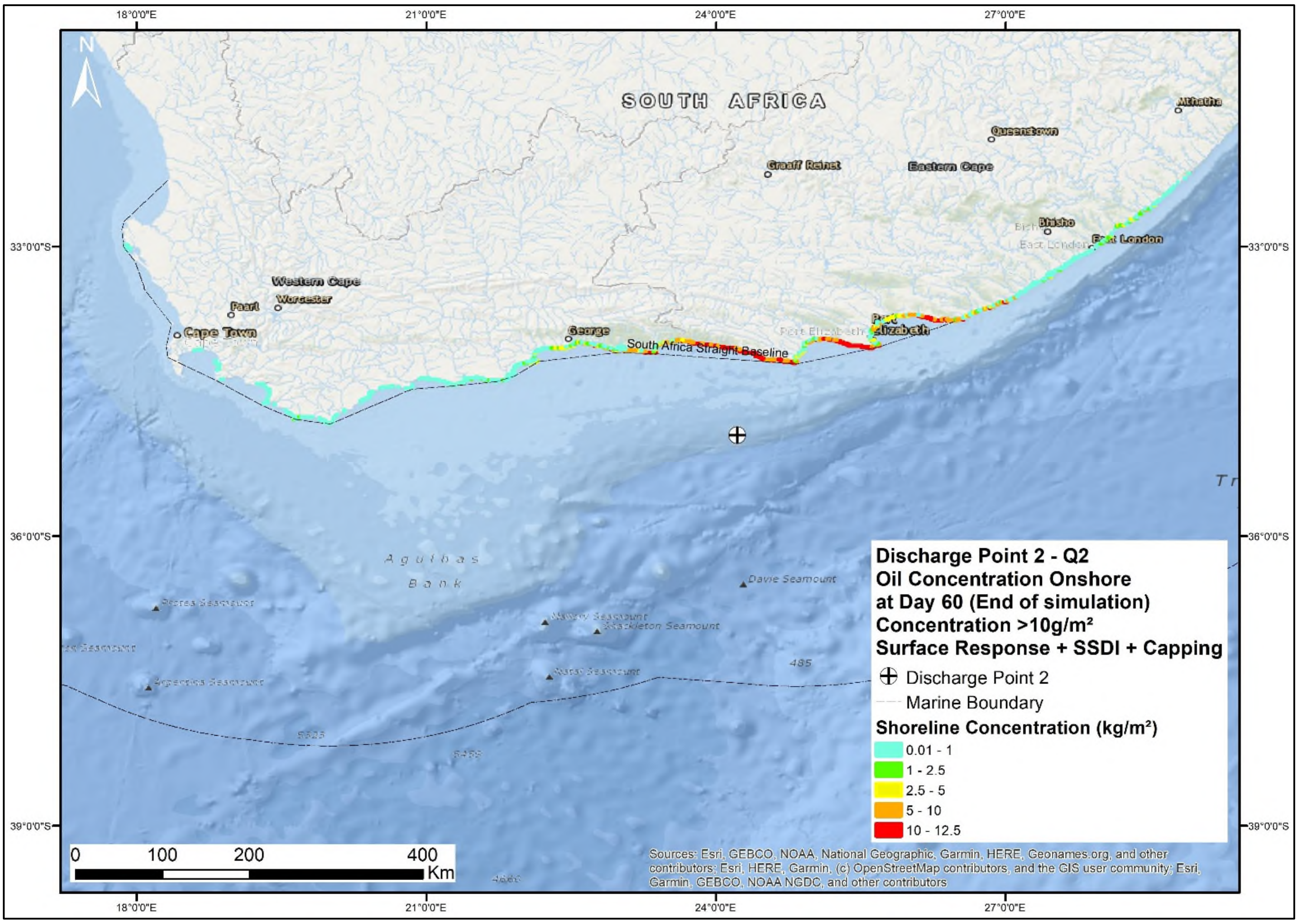

Figure 49: Scenario 2D – Shoreline concentration (>10 g/m^2) at the end of simulation

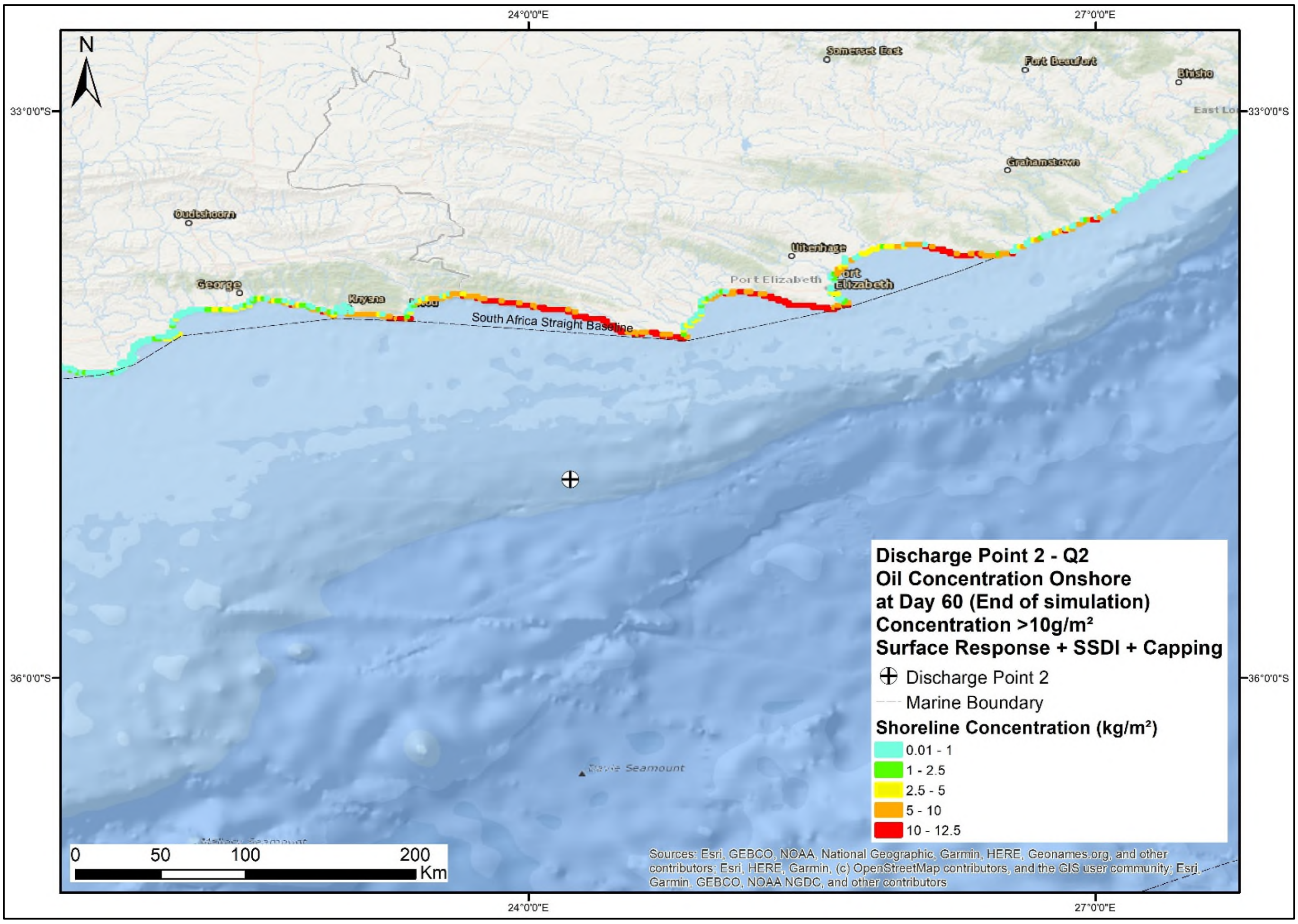

Figure 50 : Scenario 2D – Zoom on the Shoreline concentration most impacted area (>10 g/m²) at the end of simulation

3.10 Scenario 2 Oil Fate – Capping only Vs. Surface Response + Capping Vs. Surface Response + SSDI + Capping

Figure 51 and Figure 52 present the oil fate comparison between the 3 deterministic scenarios for the Quarter 2, in order to compare the effect of the different oil spill responses.

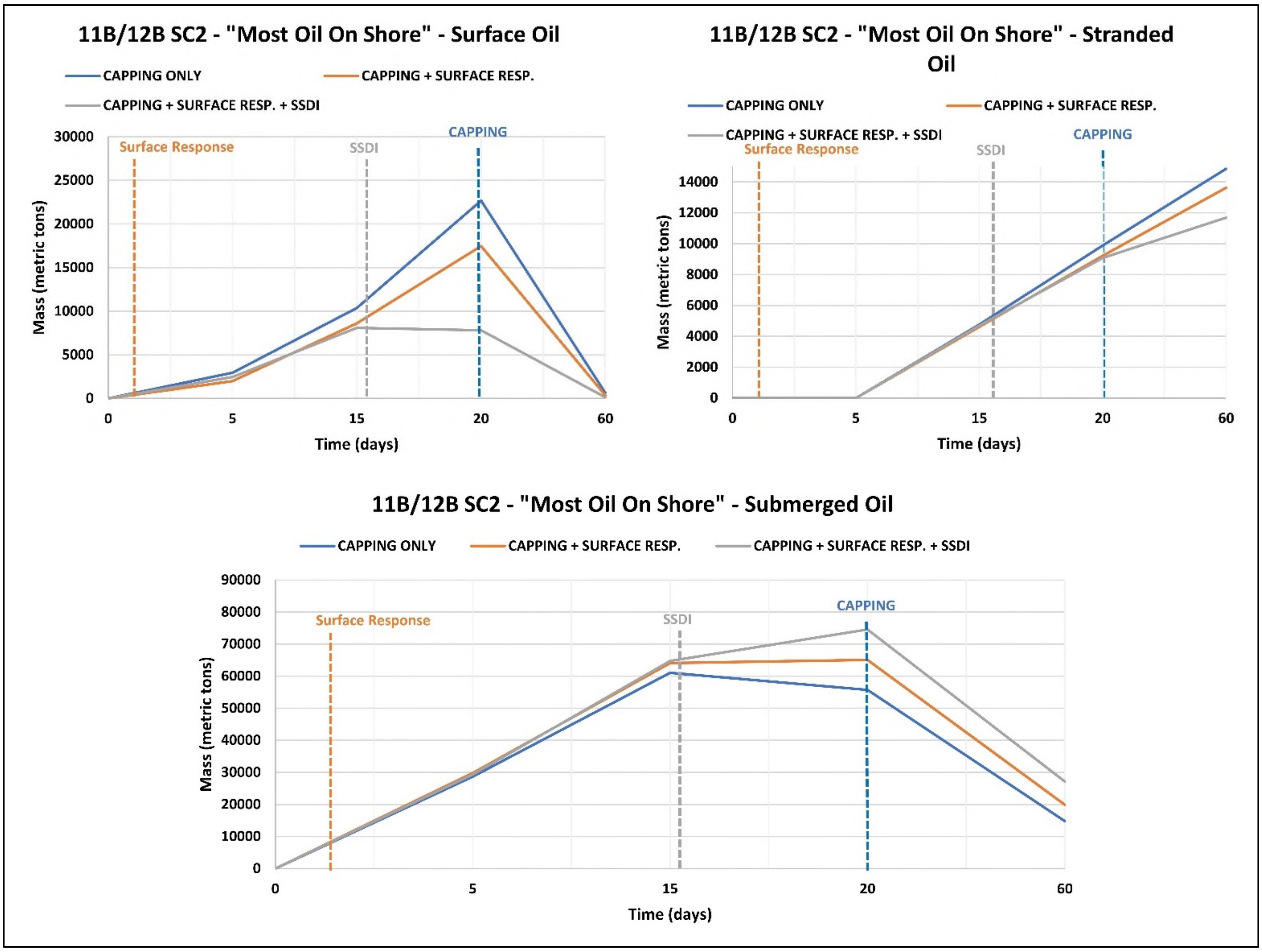

Figure 51: Scenario 2 – "Most Oil Onshore" case's Oil fate comparison (Surface, Stranded and Submerged oil)

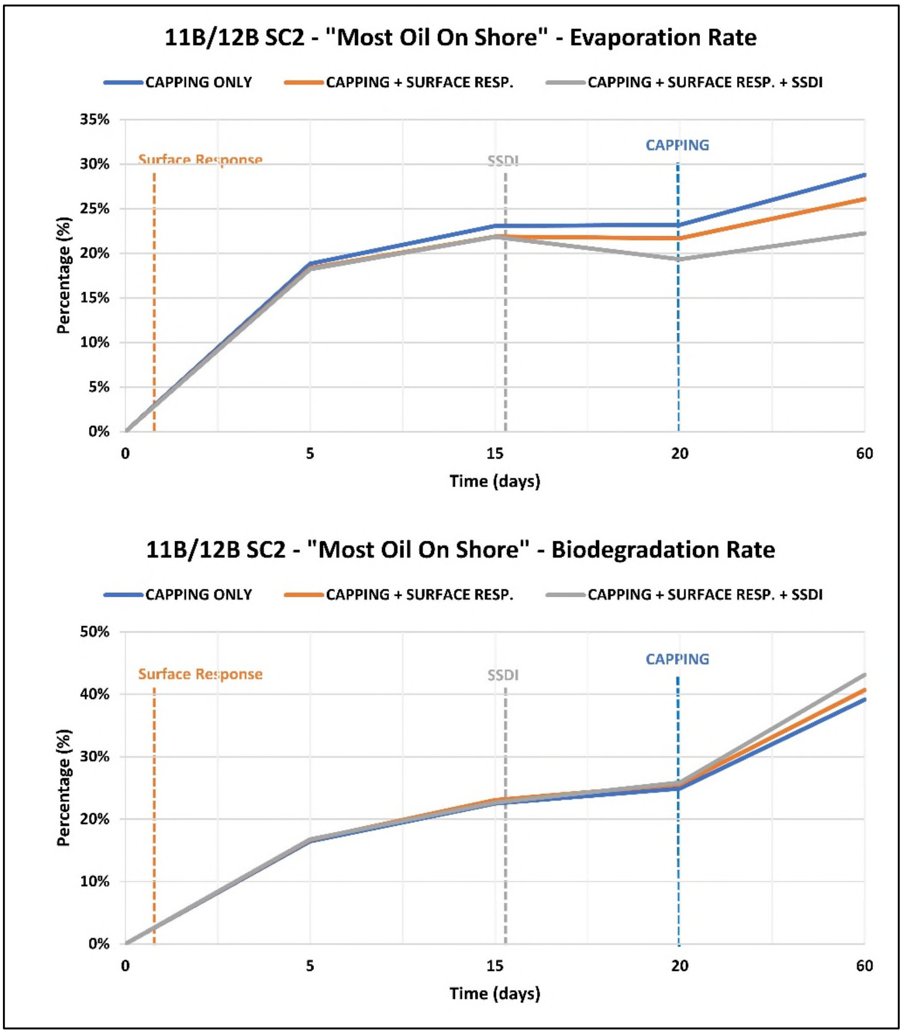

Figure 52: Scenario 2 – “Most Oil Onshore” case’s Oil fate comparison (Evaporation & Biodegradation rates)

The **surface response** deployment allows to:

- Slightly reduce the amount of oil remaining on the surface from its deployment;
- Reduce slightly the amount of oil onshore at 60 days vs. the Capping only scenario (13 620 tons vs. 14 850 tons with capping only).Considering that scenario metocean conditions allows oil to reach the coast swiftly and continue its effects until the end of the release, one should not expect a significant different of the oil fate ashore, against scenario with capping only.

The **SSDI** deployment allows to:

- Reduce greatly the amount of oil reaching the surface on day 20 (approximately 7 820 tons on day 20 with SSDI against 22 670 tons with capping only) by reducing considerable the oil droplets size, and consequently their buoyancy capacity, entraining the oil in the water-column, making the oil more prone for natural biodegrading processes.
- Reduce the amount of oil onshore at the end of simulation (i.e. day 60) compared to the Capping only scenario (about 11 690 tons with SSDI vs. 14 850 tons with capping only).

- Increase the dispersion and the dissolution of oil in the water column (“submerged oil”) and the biodegradation rate (by reducing the droplet size in the water column).

Overall, subsea response has a positive effect on oil mass balance, particularly by decreasing oil reaching the shoreline, evaporated, and increasing the biodegradation (Figure 53).

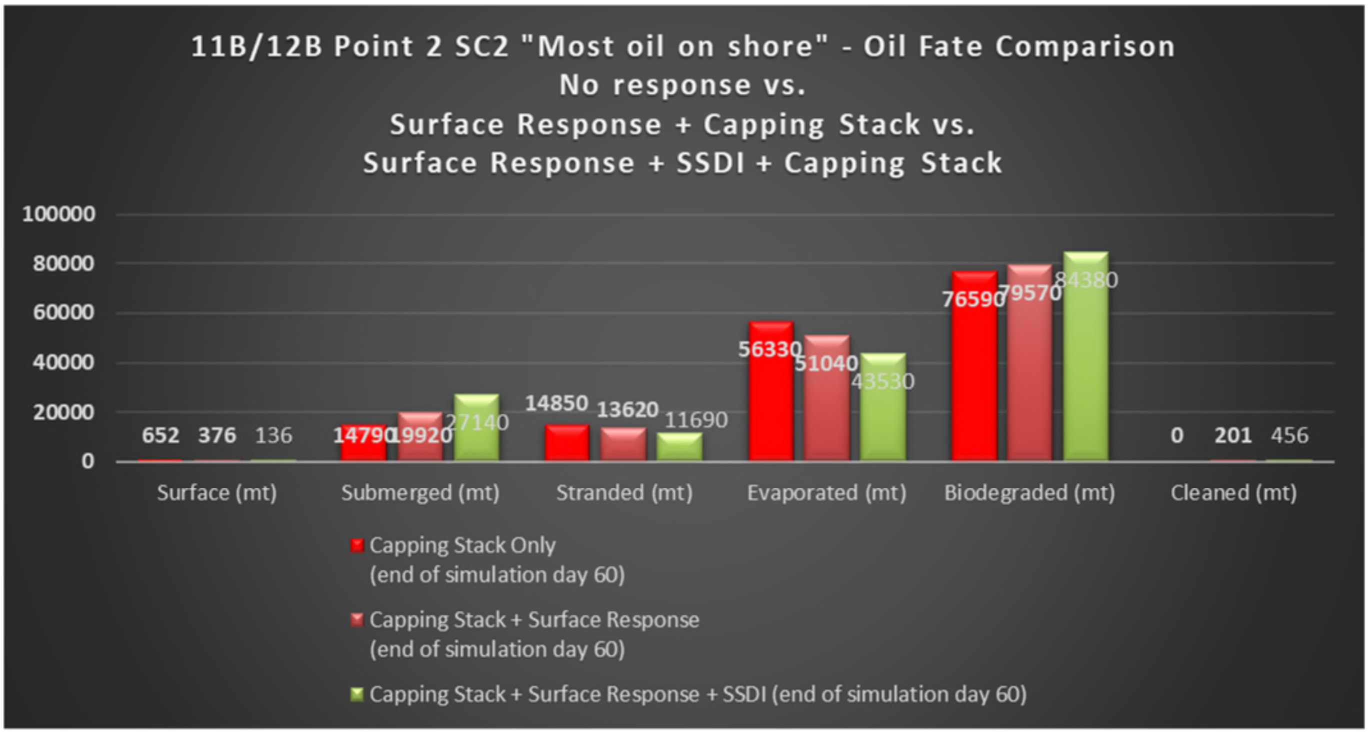

Figure 53 : Scenario 2 Oil Fate Comparison at the end of simulation (day 60)

One should note that SSDI option within OSCAR model, is not part of the response module, and therefore effects are not directly reflected in the “Cleaned” compartment of the oil mass balance. However, its influence is indirectly reflected in the other oil fate compartments such: “surface”, “submerged/dispersed”, “evaporation”, “biodegraded” and “stranded”. Therefore, the results presented here should be considered with caution.

3.11 Scenario 3A – Stochastic Simulation for Jul - Sep (Capping only)

This scenario simulates a continuous blow-out of 69 600 bbls/day of crude oil for a period of 20 days, through a set of 90 similar trajectories (i.e. 18 trajectories simulated for each quarter, in each of the 5 years covered by the metocean data), under a wide range of metocean conditions and a simulation duration of 60 days, covering the period from July 1st to September 30th for the years 2012 to 2016.

3.11.1 Surface Results

IMPORTANT: Surface results presented in this section do not represent a single spill but the combination of the statistical results of the 90 individual trajectories composing Stochastic Scenario 3. Threshold value applied for the interpretation of surface results is 5 µm, as detailed in Section 2.4.2

The stochastic footprint for the ensemble of trajectories is oriented towards the South-West direction. The highest values for surface oiling probability (i.e. 90% to 100%) are observed for South African offshore waters (Figure 54), along 160 km South-West from the discharge point 2, or North / North East until 138 km towards Port Elizabeth area.

As we move away from the release point, the probability values gradually decrease however the main direction of the slick remains towards the South-West or North-East, indicating a low to medium variability of the trajectories of the Scenario 3, due to constant metocean conditions in this area.

Offshore waters of Namibia on the West side and Mozambique on the East side are not affected by the blow-out (considering the applied release properties and threshold values applied in the post-processing of modelling results).

The stochastic footprint goes into international waters approximately 435 km South-West from the release location, 5 days after the start of the spill (Figure 55), with a maximum probability 17% (Figure 54).

The oil slick quickly progresses at sea surface, about 370 km towards South-West and 220 km towards North-East, in 2 days. The oil slick could reach 330 km South-West and 165 km North-East in 2 days. 3 days after the start of the blow-out, the oil slick edge could reach 540 km South-West from the discharge point, or 285 km North-East from the discharge point close to the coastline, due to the strong winds and currents in this area.

Reminder: Surface results characterized in Figure 54 and Figure 55, are considering only hydrocarbons presence at sea surface for a thickness above 5 µm.

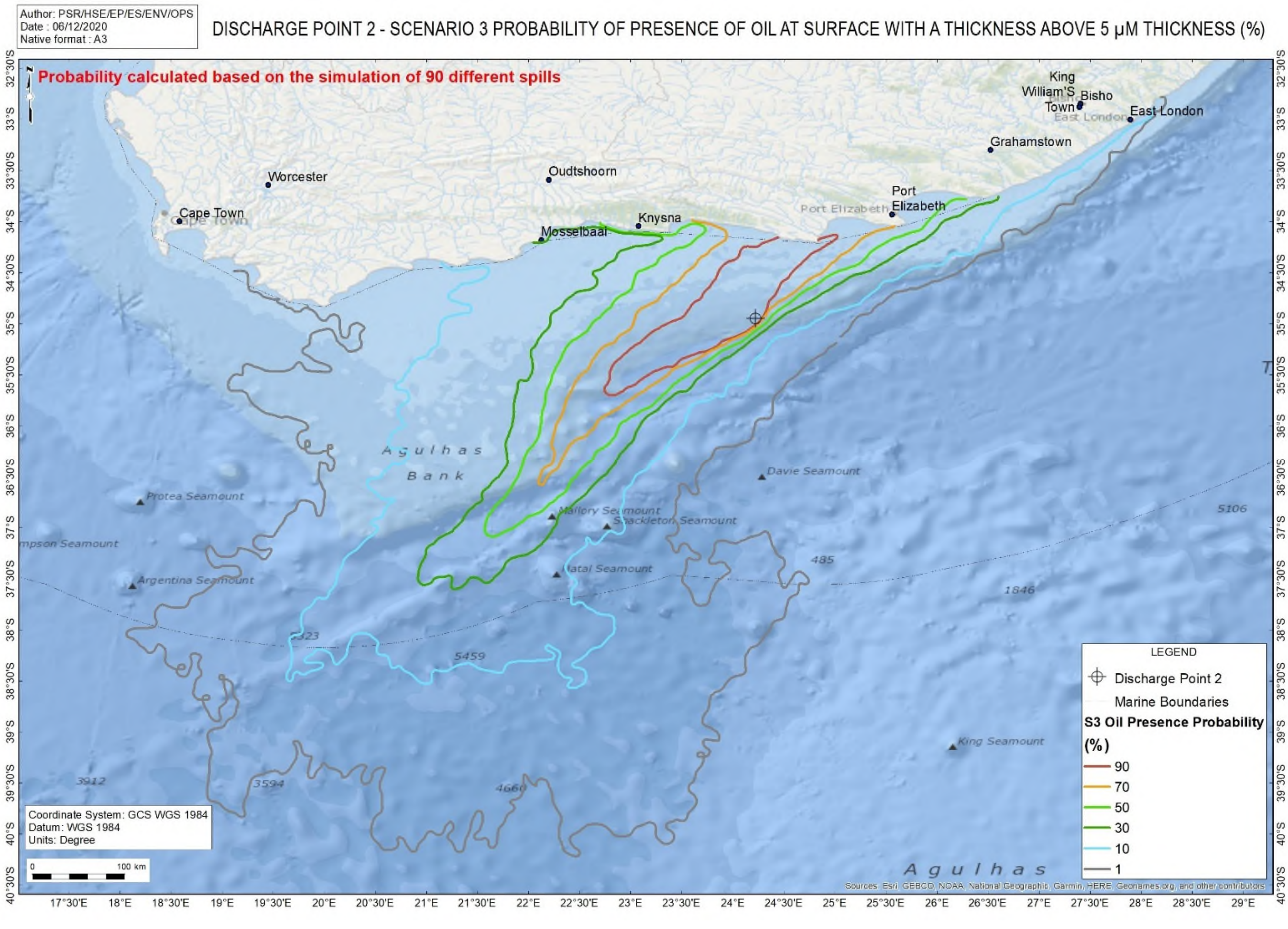

Figure 54: Scenario 3A (Q3) – Surface oiling probability above threshold (i.e. >5 µm)

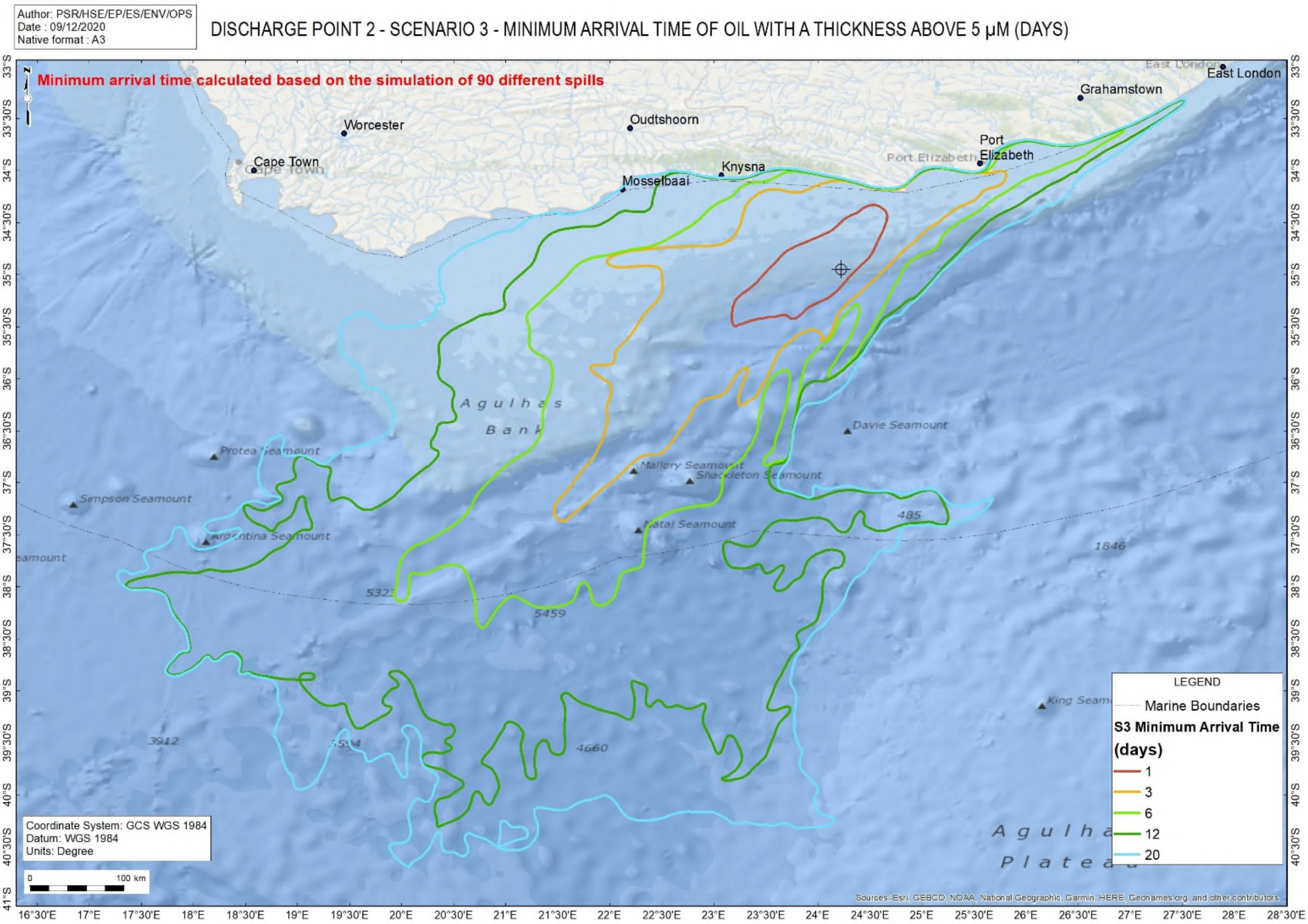

Figure 55: Scenario 3A (Q3) – Surface minimum arrival time (days) above threshold (i.e. >5 µm)

3.11.2 Shoreline Results

IMPORTANT: Shoreline results presented in this section do not represent a single spill but the combination of statistical results of the 90 individual trajectories composing Stochastic Scenario 3. Threshold value applied for the interpretation of shoreline results is 10 g/m^2, as detailed in Section 2.4.2.

Overall, all the shoreline from Cape Town to East London will observe a very low to high probabilityfor shoreline oiling (i.e. from 1 to 100 %). The highest values for shoreline oiling probability (75 to 100%), are observed from George to Port Elizabeth (Figure 56 and Figure 57).

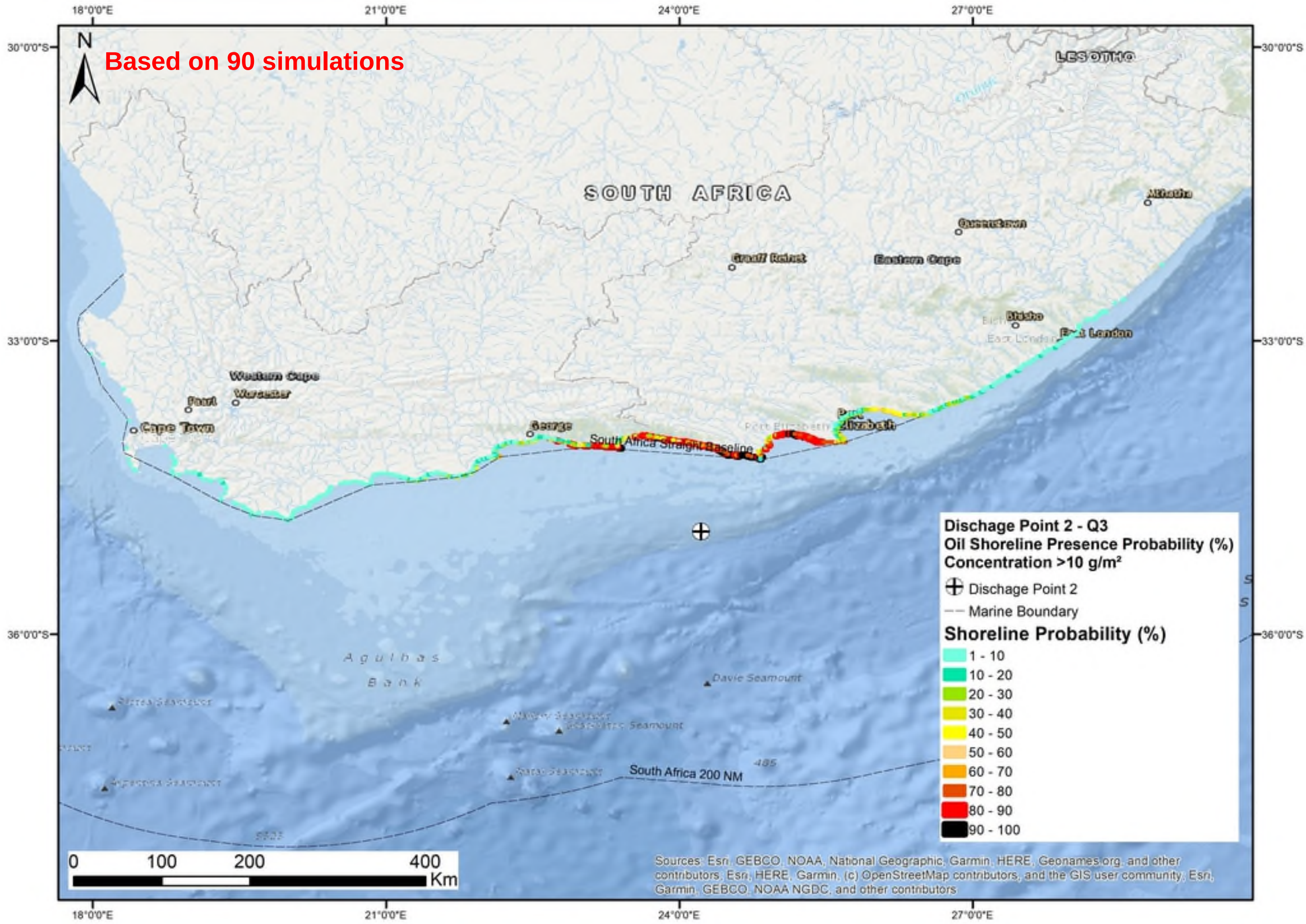

Figure 56: Scenario 3A – Shoreline oiling probability above threshold (i.e. >10 g/m^2)

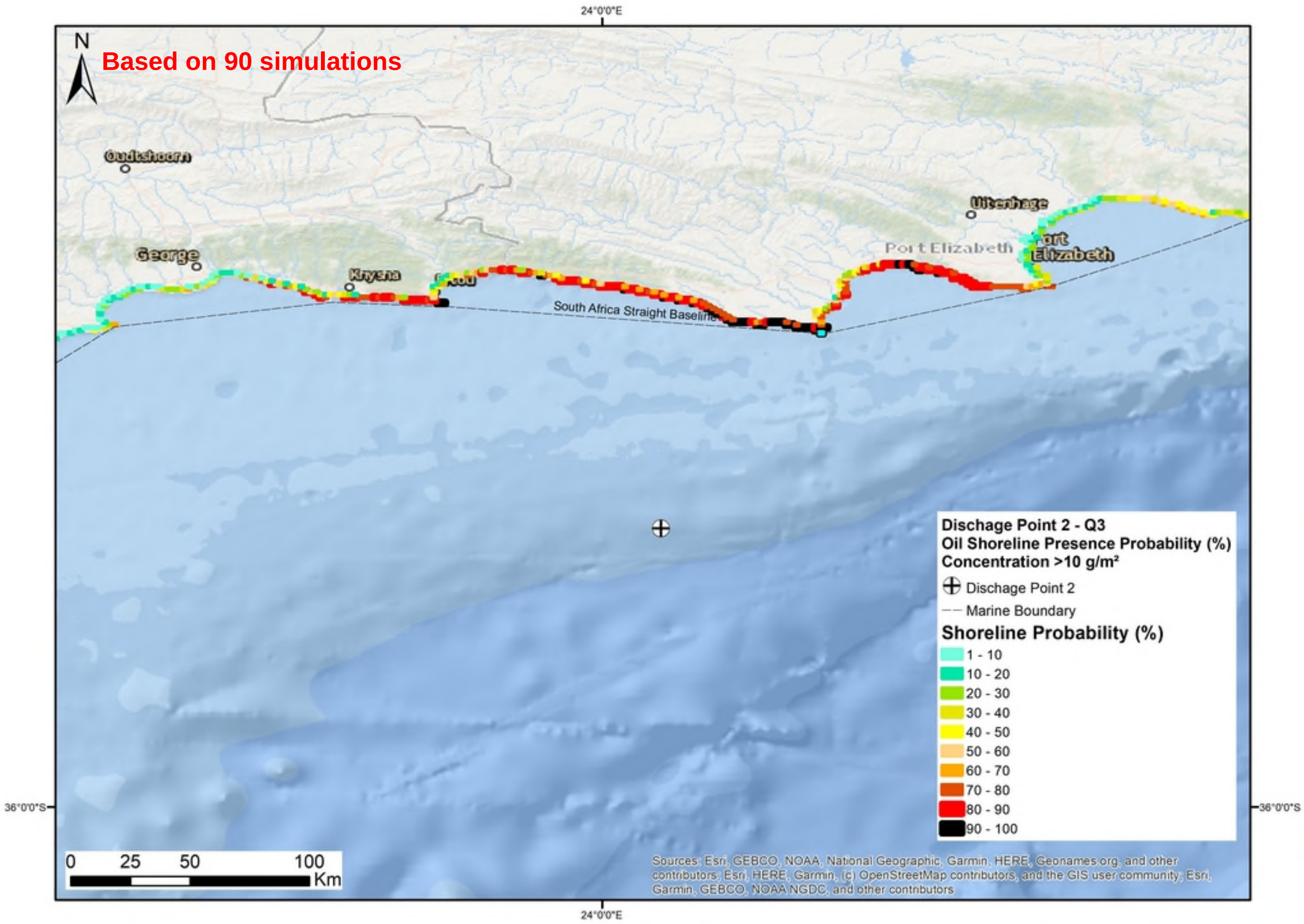

Figure 57 : Scenario 3A – Zoom on Shoreline oiling probability above threshold most impacted area (i.e. >10 g/m^2)

Shoreline minimum arrival time (in days) is observed West of the Saint Francis Bay area, around 12 hours after start of the release (Figure 58 and Figure 59). Overall, all the shoreline between George and Port Alfred area could observe oil reaching the shore in less than 5 days, with a maximum shoreline oiling probability between 80% and 100%. There is no shoreline transboundary effect in this scenario.

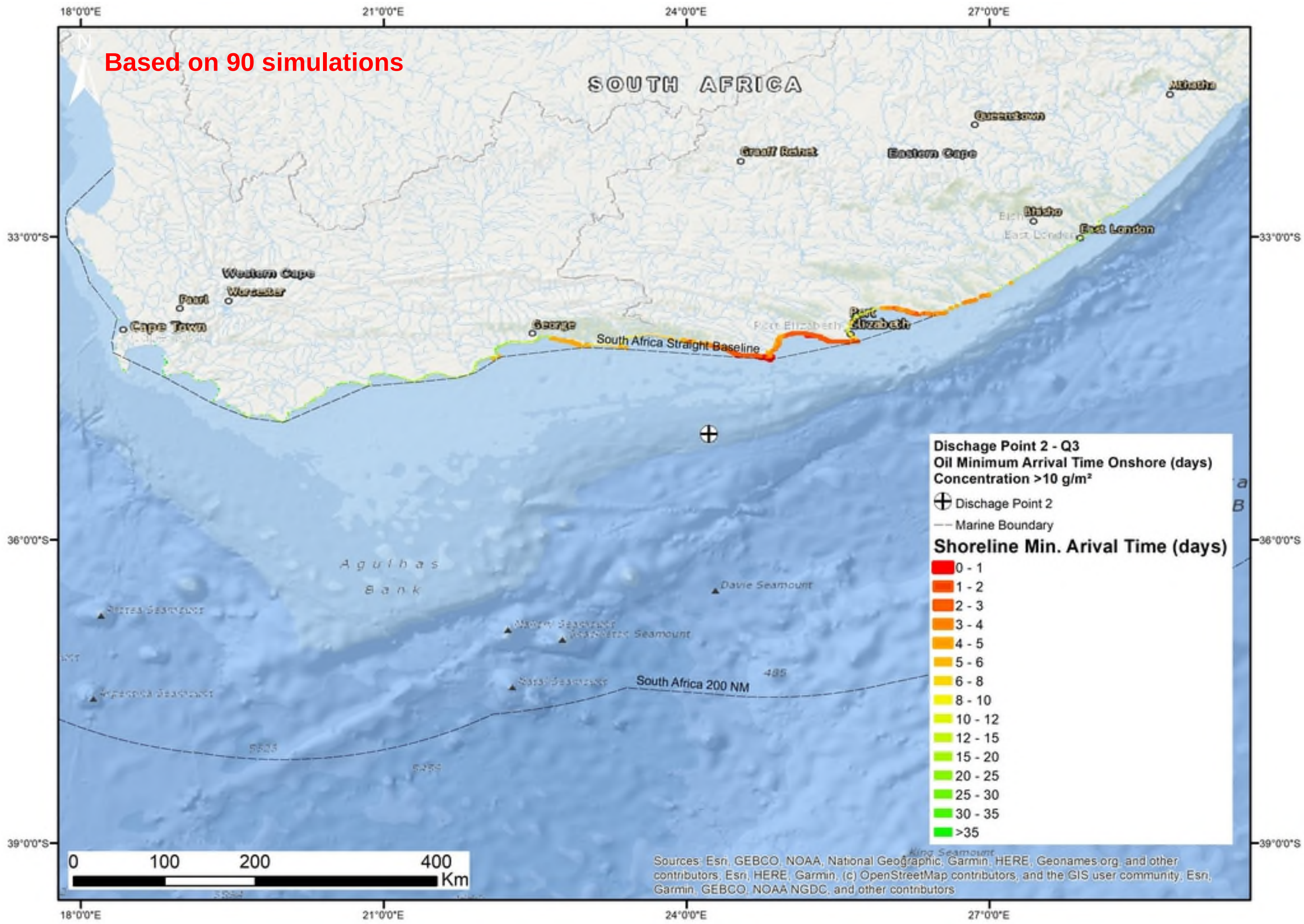

Figure 58: Scenario 3A – Shoreline minimum arrival time (days) above threshold (i.e. >10 g/m²)

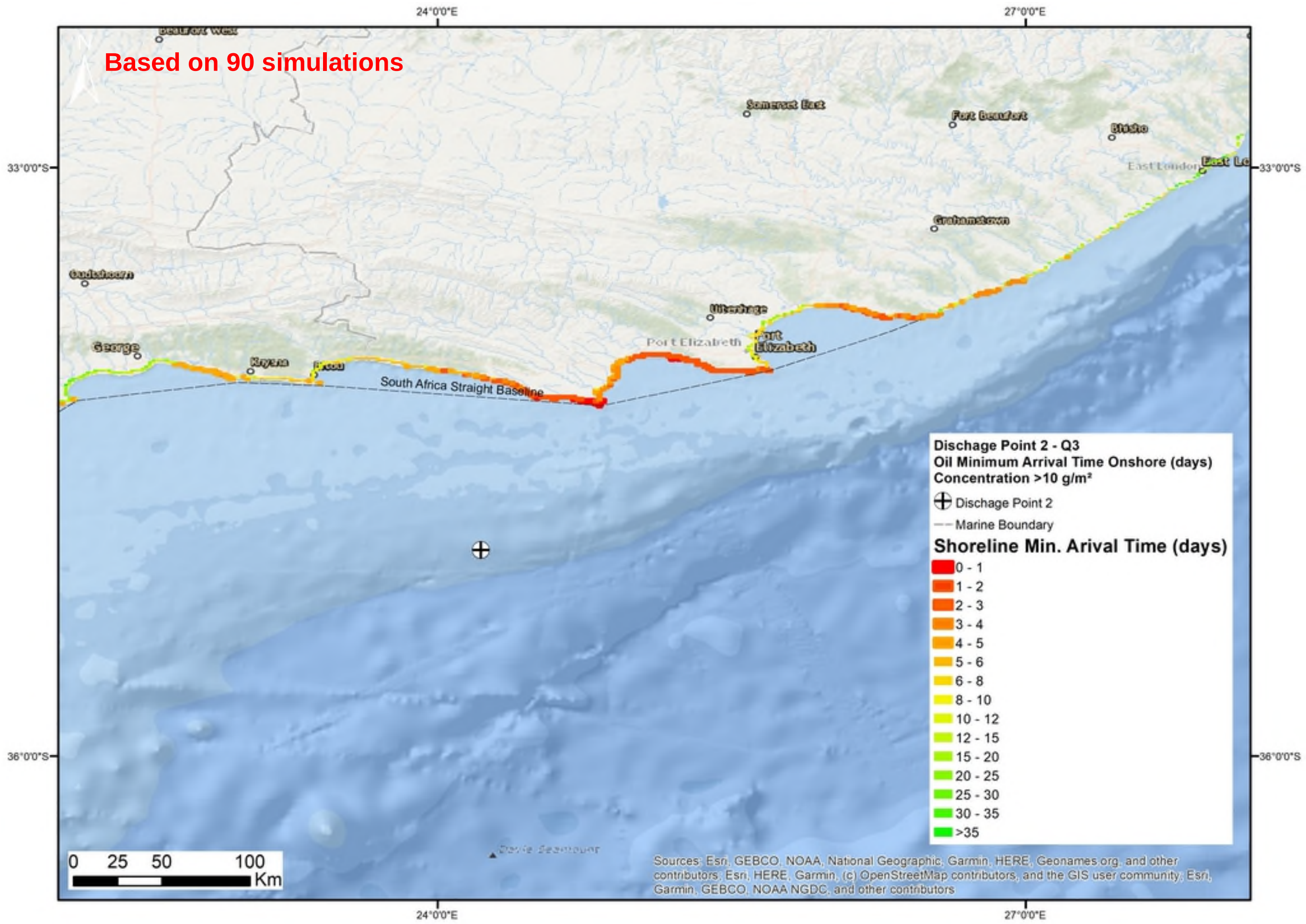

Figure 59 : Scenario 3A – Zoom on the shoreline minimum arrival time most impacted area (days) above threshold (i.e. >10 g/m²)

Reminder: Shoreline results characterized in Figure 56, Figure 57, Figure 58, Figure 59, are considering only hydrocarbons presence at shoreline for an oil load threshold >10 g/m².

3.12 Scenario 3B – Deterministic Scenario (Capping only) - Spill Drift and Shoreline Impacts

The simulation resulting in the highest hydrocarbon mass reaching the shore for Scenario 3 (i.e. trajectory with start on **August 31th 2013 (23:00 UTC)**), was selected to illustrate the results of the deterministic simulation (i.e. **Scenario 3B**), with a continuous blow-out releasing 69 600 bbls/day for a period of 20 days, and simulation total duration of 60 days.

Note: Figure 60 and Figure 61 have been done with a more precise resolution in order to better analyze the characteristics of the oil in the environment at the beginning of the blow-out.

Figure 60 presents the oil rise in the water column 3 hours after the start of the release, approximately 14 km North from the release location with a maximum oil thickness at this time of 739 µm. These results will be the same for the Scenarios 3C and 3D considering Capping only Strategy will be implemented before those 3 hours.

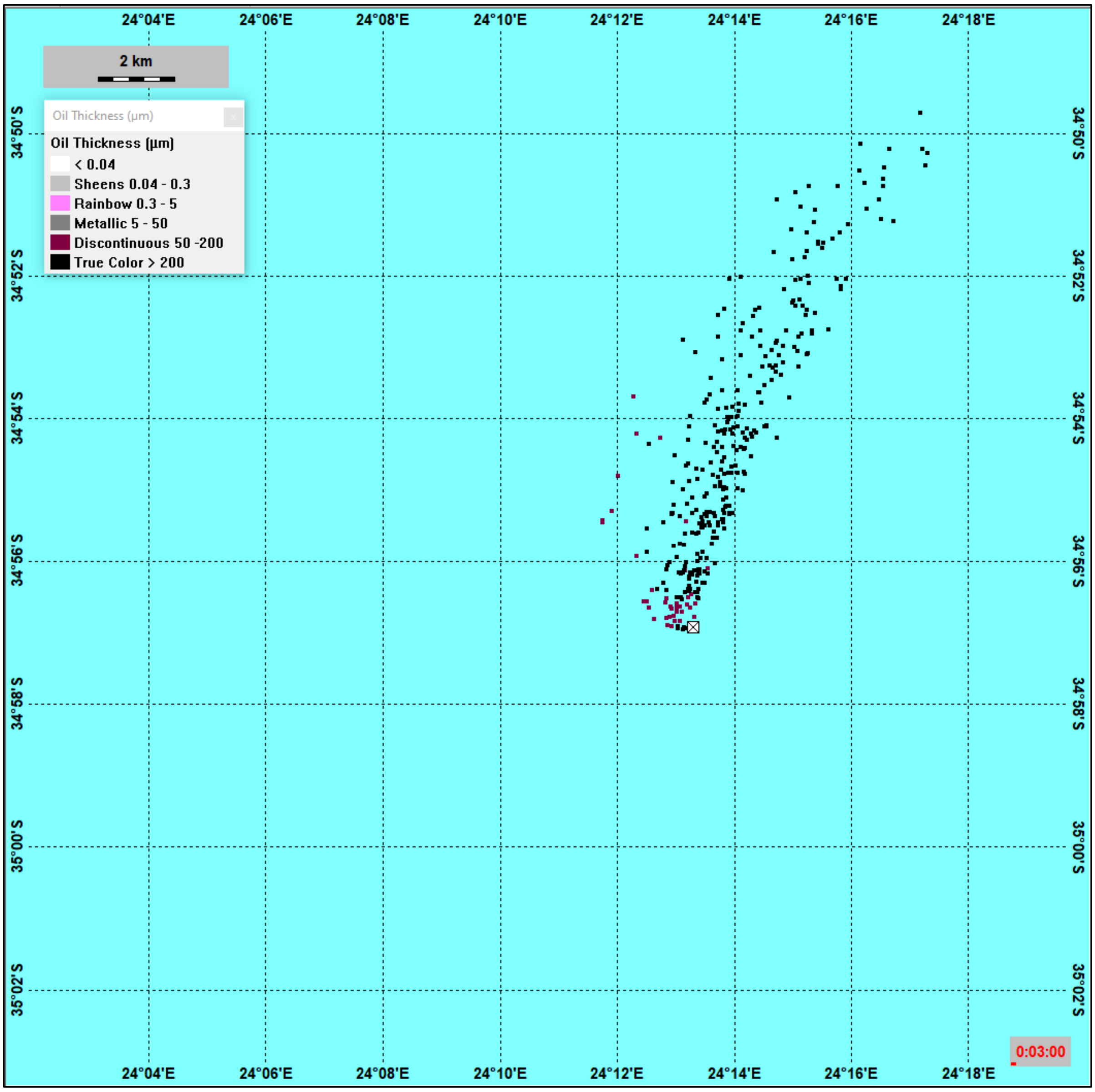

Figure 60: Oil reaching surface for scenarios 3B, 3C and 3D

Figure 61 present the release concentration and the submerged particles in the water column 3 hours after the start of the blow-out.

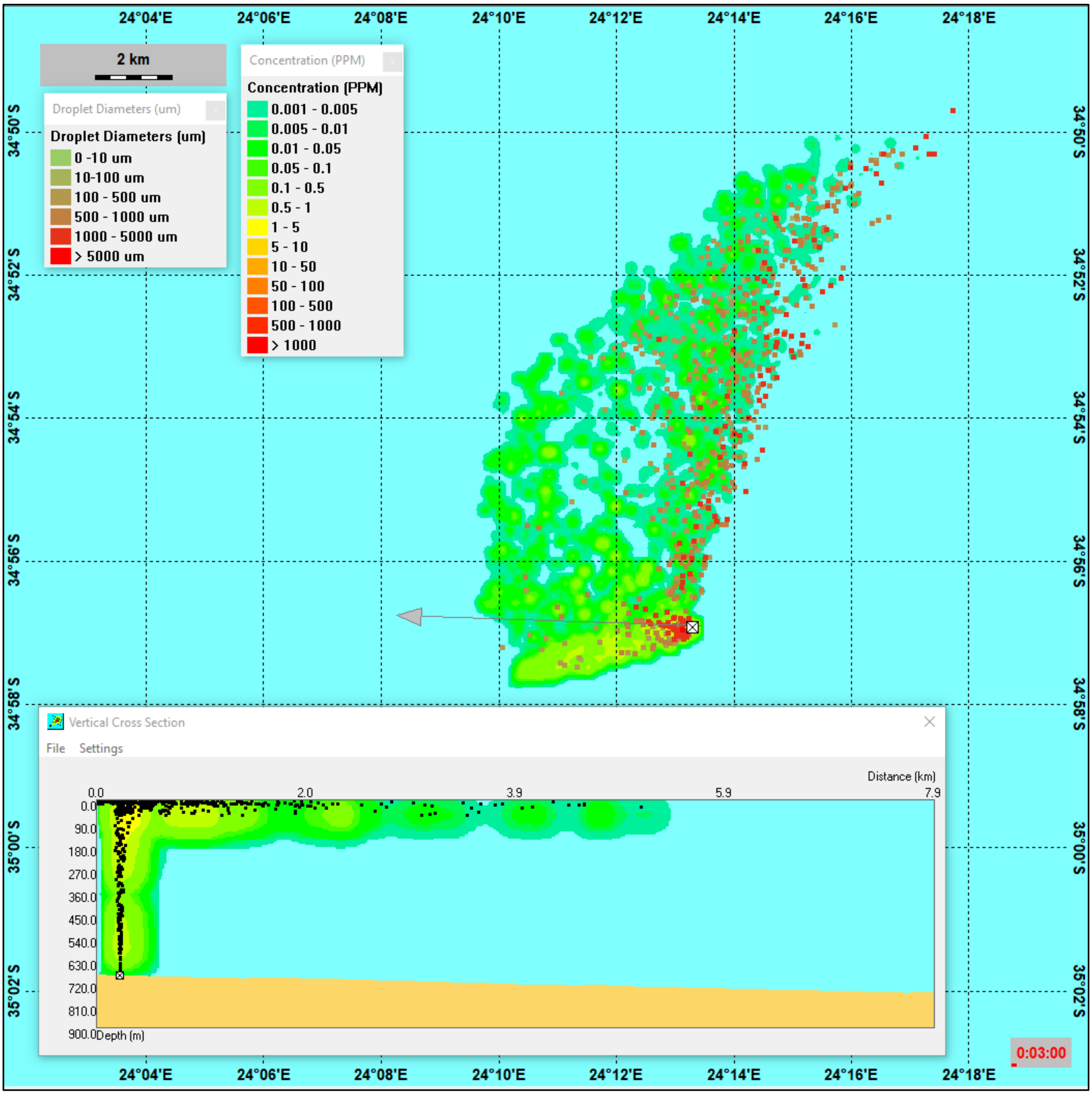

Figure 61 : Release concentration and submerged particles in the water column 3 hours after the start of the blow-out for scenarios 3B, 3C and 3D

The maximum oil concentration in the water column is 4.5 ppm very close to the release point; the maximum oil droplet diameter 4395 µm, on the release point, and the termination depth is around 50 m depth. One should note that Figure 60 is a snapshot of the oil behaviour within the water-column, and is dependent of the orientation of the vertical cross-section arrow drawn, for the visualization of calculated results (i.e. the profile of the concentrations in the water-column), as well as of the correspondent time-step.

Oil spill initial drift, 24 hours after start of the release, is observed towards the North-East direction (Figure 62). Slick will then continue its drift towards North-East, and finally quickly reaches the shore, on spill 2nd day, on the East part of Saint Francis bay area.

The maximum distance reached by the surface oil is 490 km South-West from the release point, 17 days ½ after the start of the blow-out.

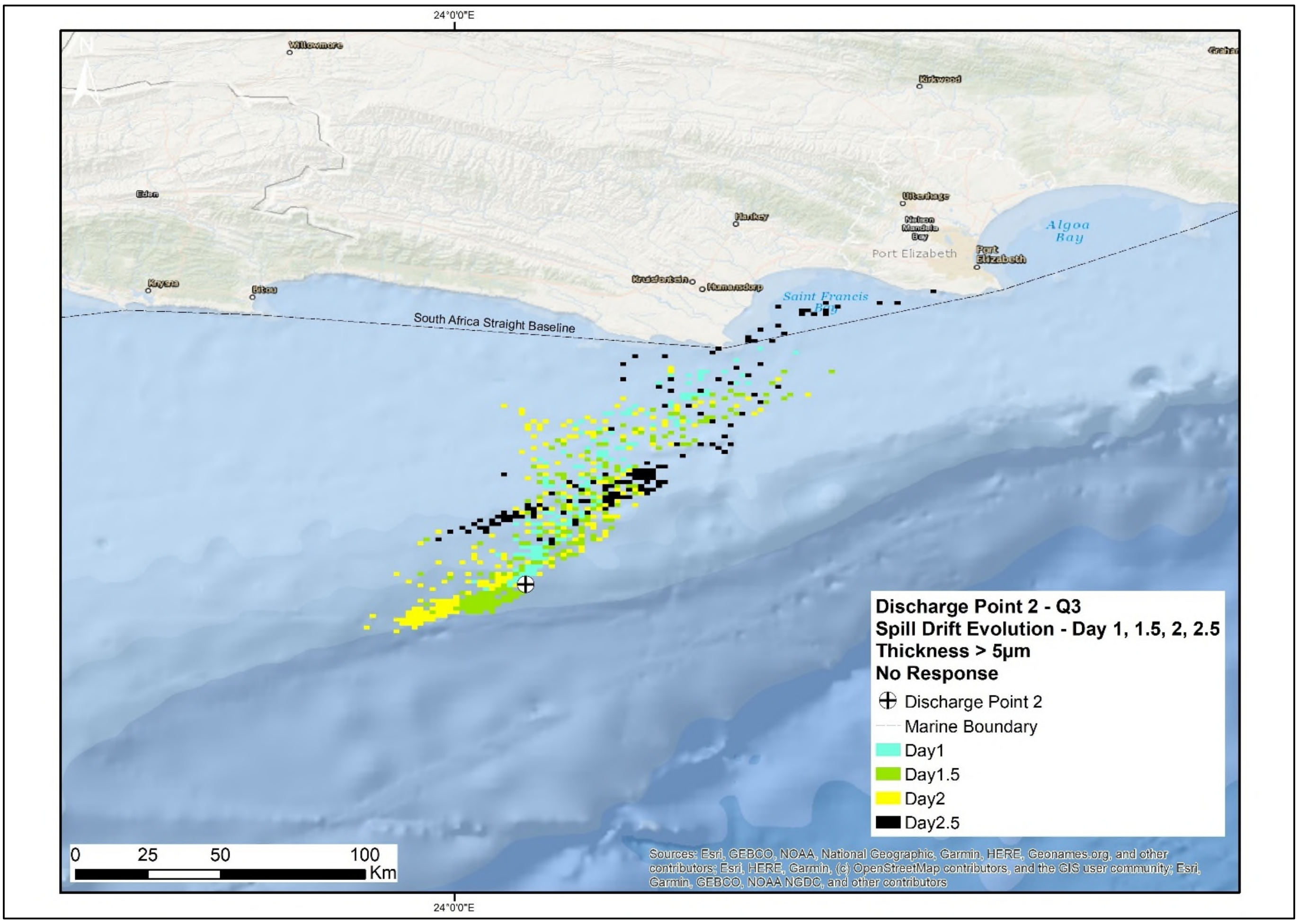

Figure 62: Scenario 3B – Spill drift evolution – Days 1, 1.5, 2 & 2.5

Figure 63 and Figure 64, show the impacts over the shoreline at the end of simulation, i.e. 60 days after the start of the blow-out. Impact ashore above threshold (i.e. 10 g/m^2 or 0.01 kg/m^2), is observed from the South of Cape Town to East London.

Highest value for shoreline oil concentration (around 12000 g/m^2) are observed along approximately 450 km between George city and Algoa Bay.

Medium to low concentration values for shoreline oil concentration (< 5000 g/m^2) are on rest of the South African coastline form Cape Town to the East part of East London town.

The oil mass ashore at end of simulation would be 15 720 t.

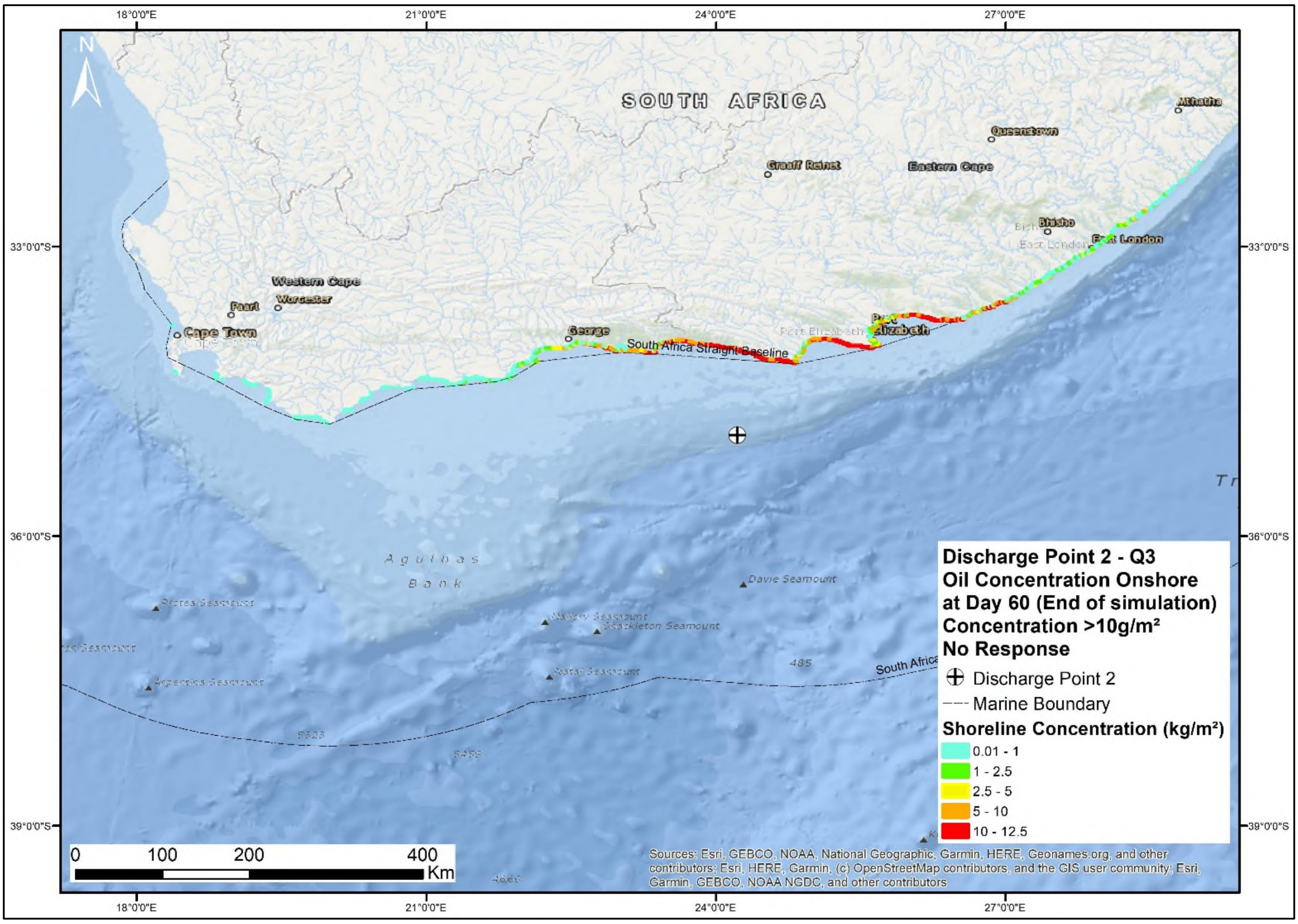

Figure 63: Scenario 3B – Shoreline concentration (>10 g/m^2) at the end of simulation

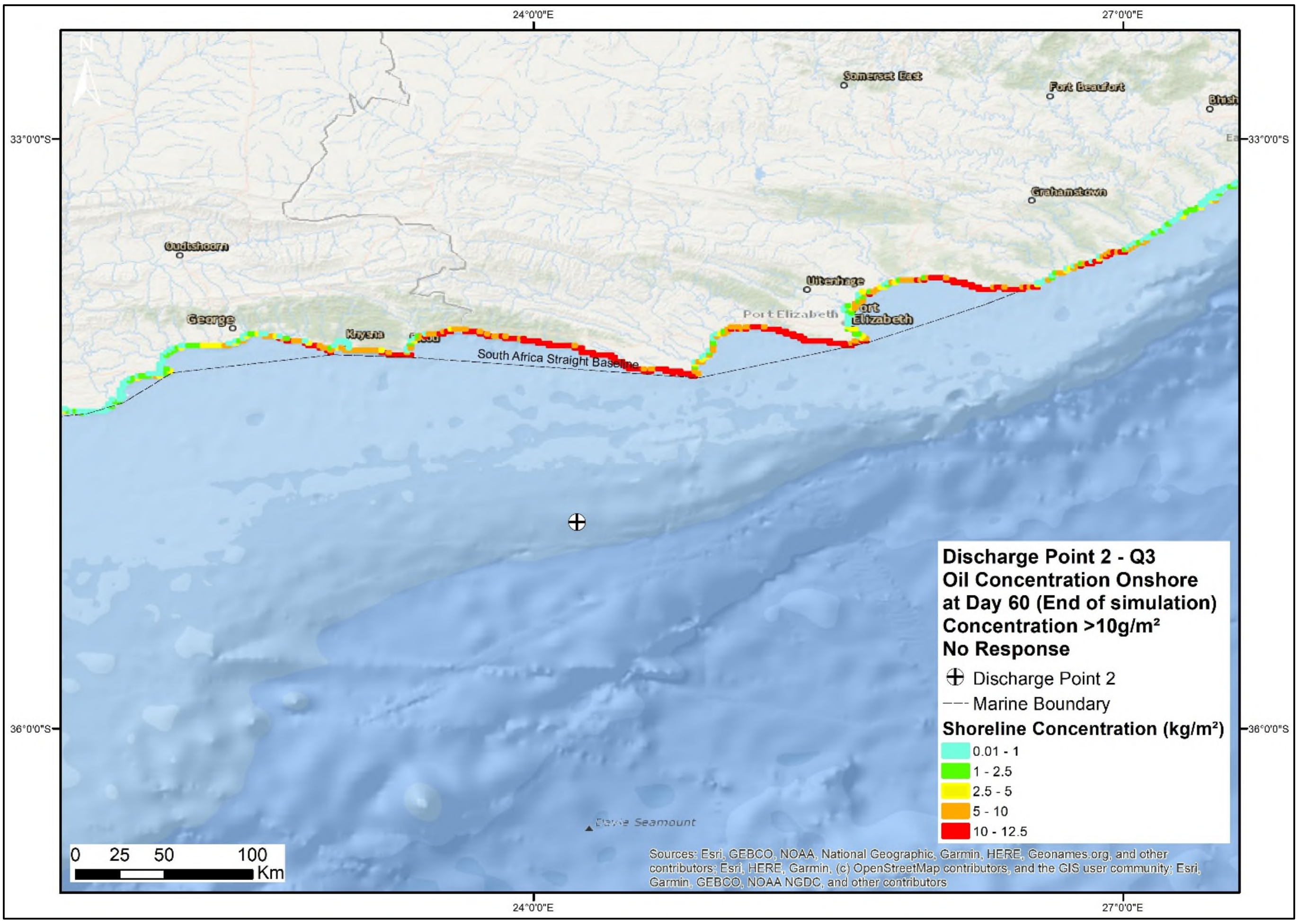

Figure 64 : Scenario 3B – Zoom on the Shoreline concentration most impacted area (>10 g/m^2) at the end of simulation

3.13 Scenario 3C – Deterministic Scenario (Surface Response + Capping) - Spill Drift and Shoreline Impacts

The simulation resulting in the highest hydrocarbon mass reaching the shore for Scenario 3 (i.e. trajectory with start on **August 26th 2013 (19:00 UTC)**), was selected to illustrate the results of the deterministic simulation (i.e. **Scenario 3C**), with a continuous blow-out releasing 69 600 bbls/day for a period of 20 days, and simulation total duration of 60 days.

The following response strategy is deployed and simulated in this scenario (detailed in 2.2.3):

- Surface response with aircrafts and vessels 24 hours after the start of the spill.

Oil spill initial drift, 24 hours after start of the release, is observed towards the North-East direction (Figure 62). Slick will then continue its drift towards North-East, and finally quickly reaches the shore, on spill 2nd day, on the East part of the Saint Francis bay area.

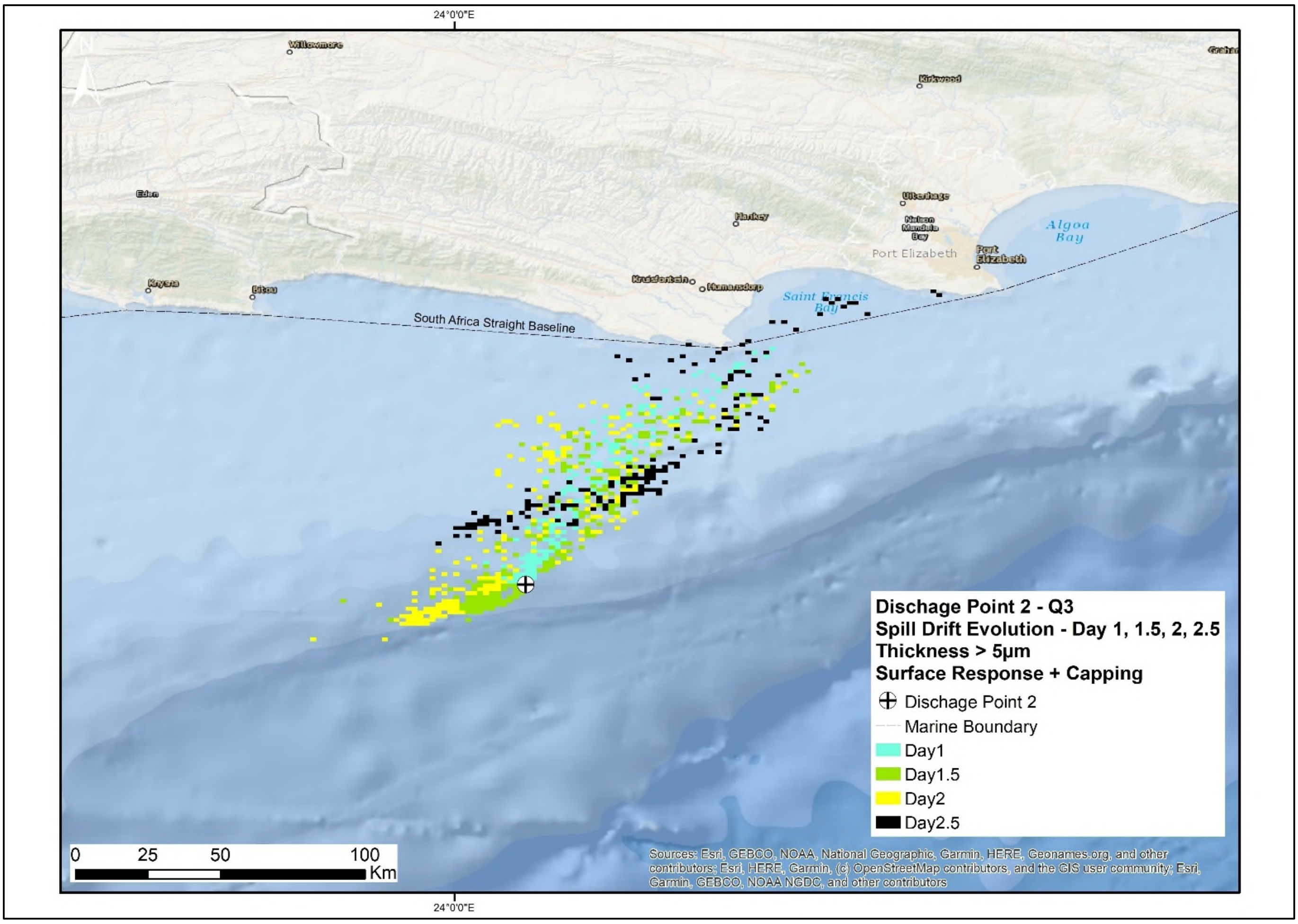

Figure 65: Scenario 3C – Spill drift evolution – Days 1, 1.5, 2 & 2.5

Figure 66 and Figure 67, show the impacts over the shoreline at the end of simulation, i.e. 60 days after the start of the blow-out. Impact ashore above threshold (i.e. 10 g/m^2 or 0.01 kg/m^2), is observed from the South of Cape Town to East London.

Highest value for shoreline oil concentration (around 13000 g/m^2) are observed along approximately 460 km between George and Algoa Bay.

Medium to low concentration values for shoreline oil concentration (< 5000 g/m^2) are on rest of the South African coastline from Bredasdorp to East London.

The mass reaching the shore at the end of simulation (60 days) would then be 13 780 t vs. 15 720 t with only the capping stack.

The surface response deployed in this scenario allow to reduce the length of shoreline impacted, avoiding all the shoreline impact on the East part of East London, and reducing highly the length of the shoreline impacted between Cape Town and West of George.

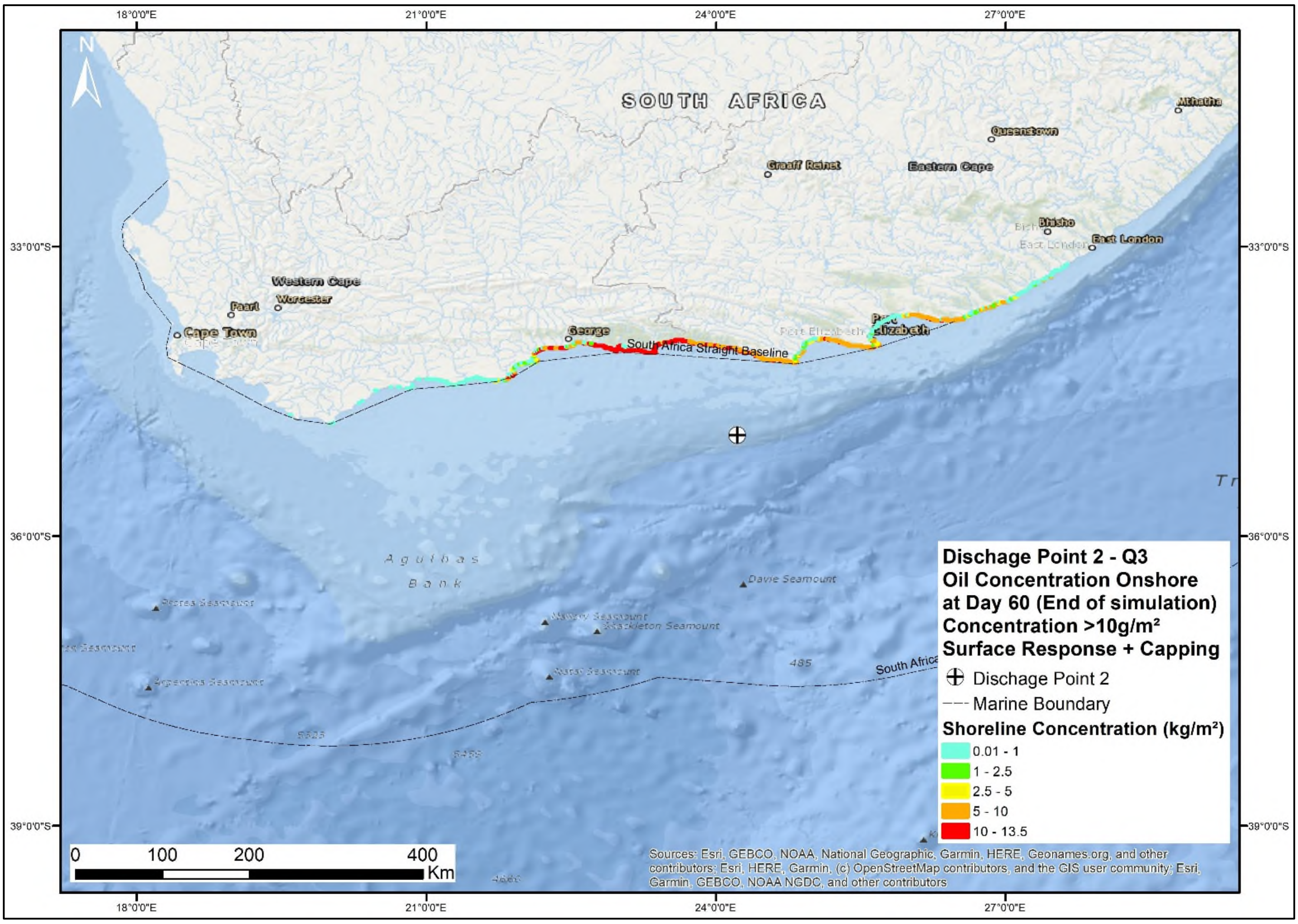

Figure 66: Scenario 3C – Shoreline concentration (>10 g/m^2) at the end of simulation

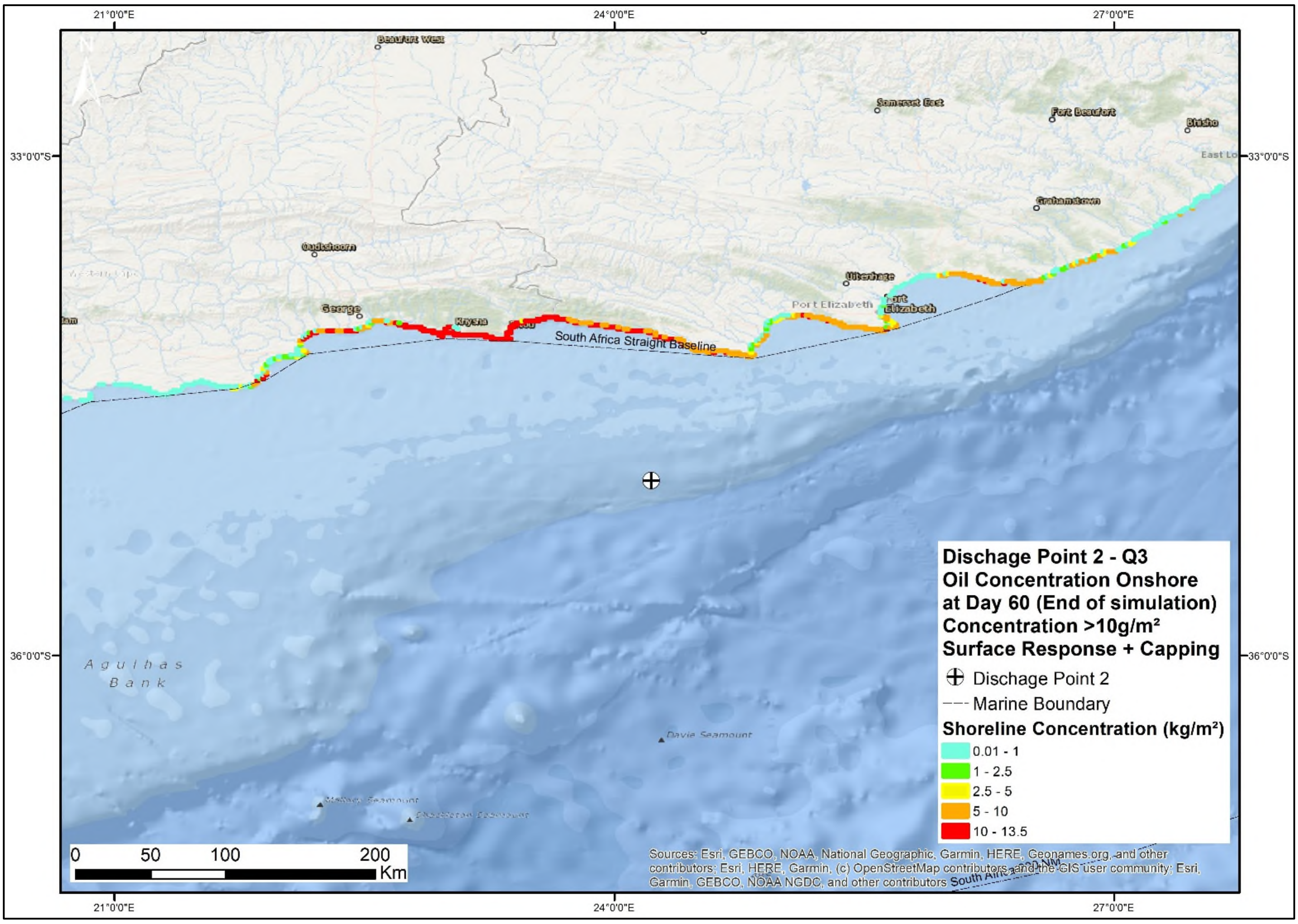

Figure 67 : Scenario 3C – Zoom on the Shoreline concentration most impacted area (>10 g/m²) at the end of simulation

3.14 Scenario 3D – Deterministic Scenario (Surface Response + SSDI + Capping) - Spill Drift and Shoreline Impacts

The simulation resulting in the highest hydrocarbon mass reaching the shore for Scenario 3 (i.e. trajectory with start on **August 26th 2013 (19:00 UTC)**), was selected to illustrate the results of the deterministic simulation (i.e. **Scenario 3D**), with a continuous blow-out releasing 69 600 bbls/day for a period of 20 days, and simulation total duration of 60 days.

The following response strategy is deployed and simulated in this scenario (detailed in 2.2.3), namely:

- Surface response with aircrafts and vessels 24 hours after the start of the spill;
- SSDI (Subsea Dispersant Injection) 15 days after the start of the blow-out.

Oil spill initial drift, 24 hours after start of the release, is observed towards the North-East direction (Figure 62). Slick will then continue its drift towards North-East, and finally quickly reaches the shore, on spill 2nd day, on the East part of the Saint Francis Bay area.

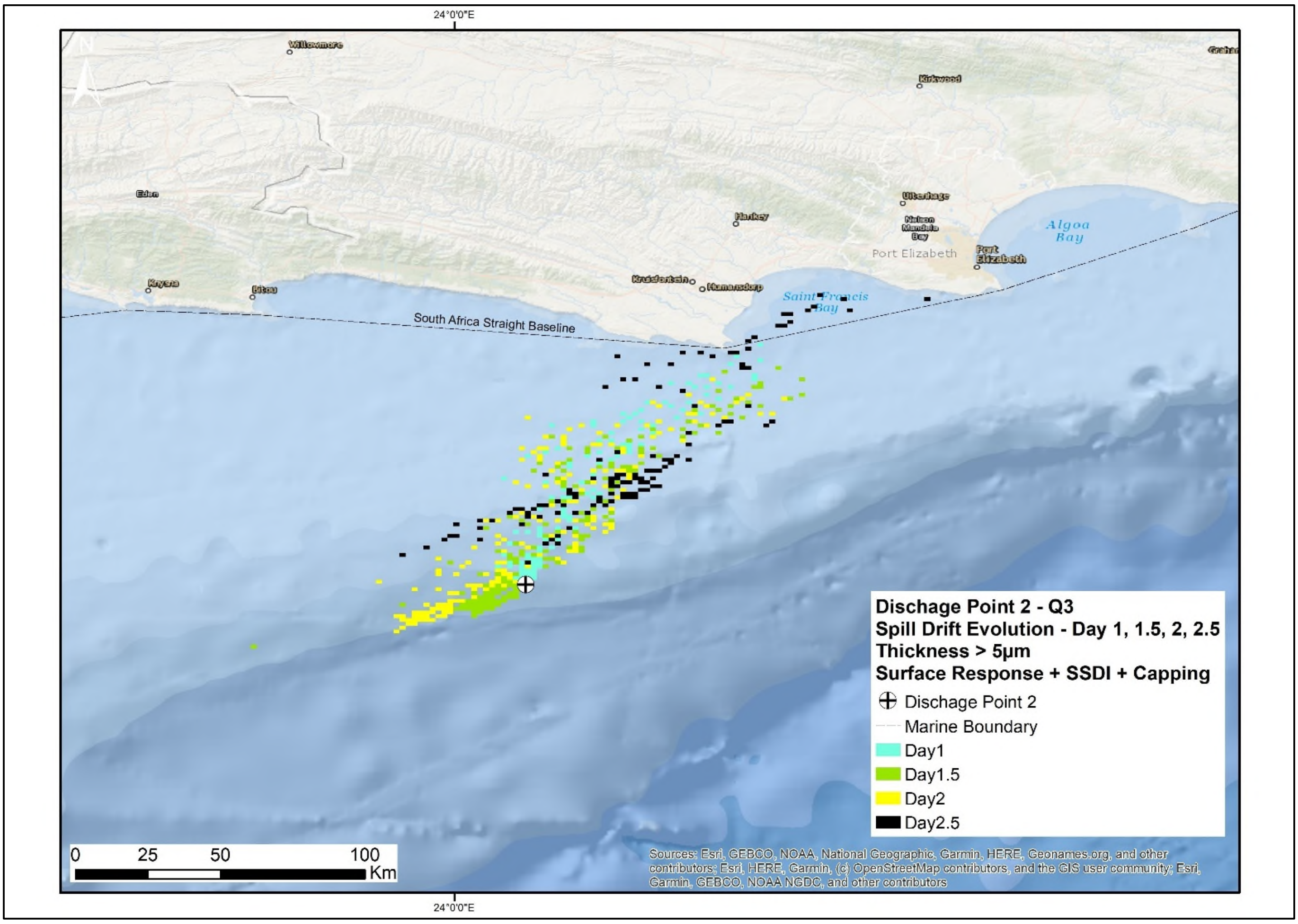

Figure 68: Scenario 3D – Spill drift evolution – Days 1, 1.5, 2 & 2.5

Figure 69 and Figure 70, show the impacts over the shoreline at the end of simulation, i.e. 60 days after the start of the blow-out. Impact ashore above threshold (i.e. 10 g/m^2 or 0.01 kg/m^2), is observed from the South of Cape Town to East London.

Highest value for shoreline oil concentration (around 13000 g/m^2) are observed along approximately 420 km between George and Algoa Bay.

Medium to low concentration values for shoreline oil concentration (< 5000 g/m^2) are on rest of the South African coastline from Bredasdorp coast to East London.

The SSDI deployed day 15th allows to reduce slightly the high oil concentration onshore and the length of the coastline impacted, especially between George and Algoa Bay areas.

The mass reaching the shore at the end of simulation (60 days) would then be 12 860 t vs. 15 720 t with only the capping stack.

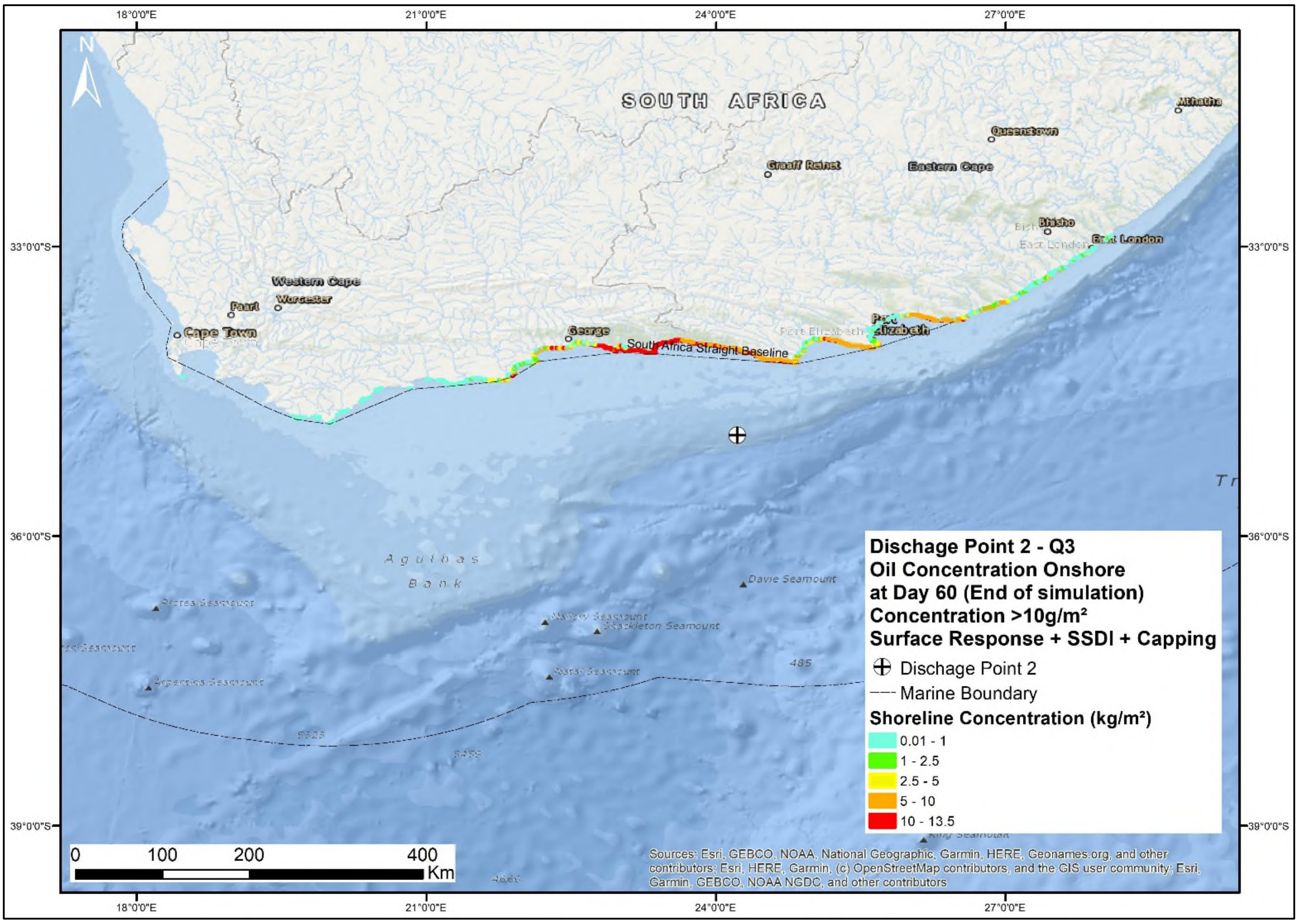

Figure 69: Scenario 3D – Shoreline concentration (>10 g/m^2) at the end of simulation

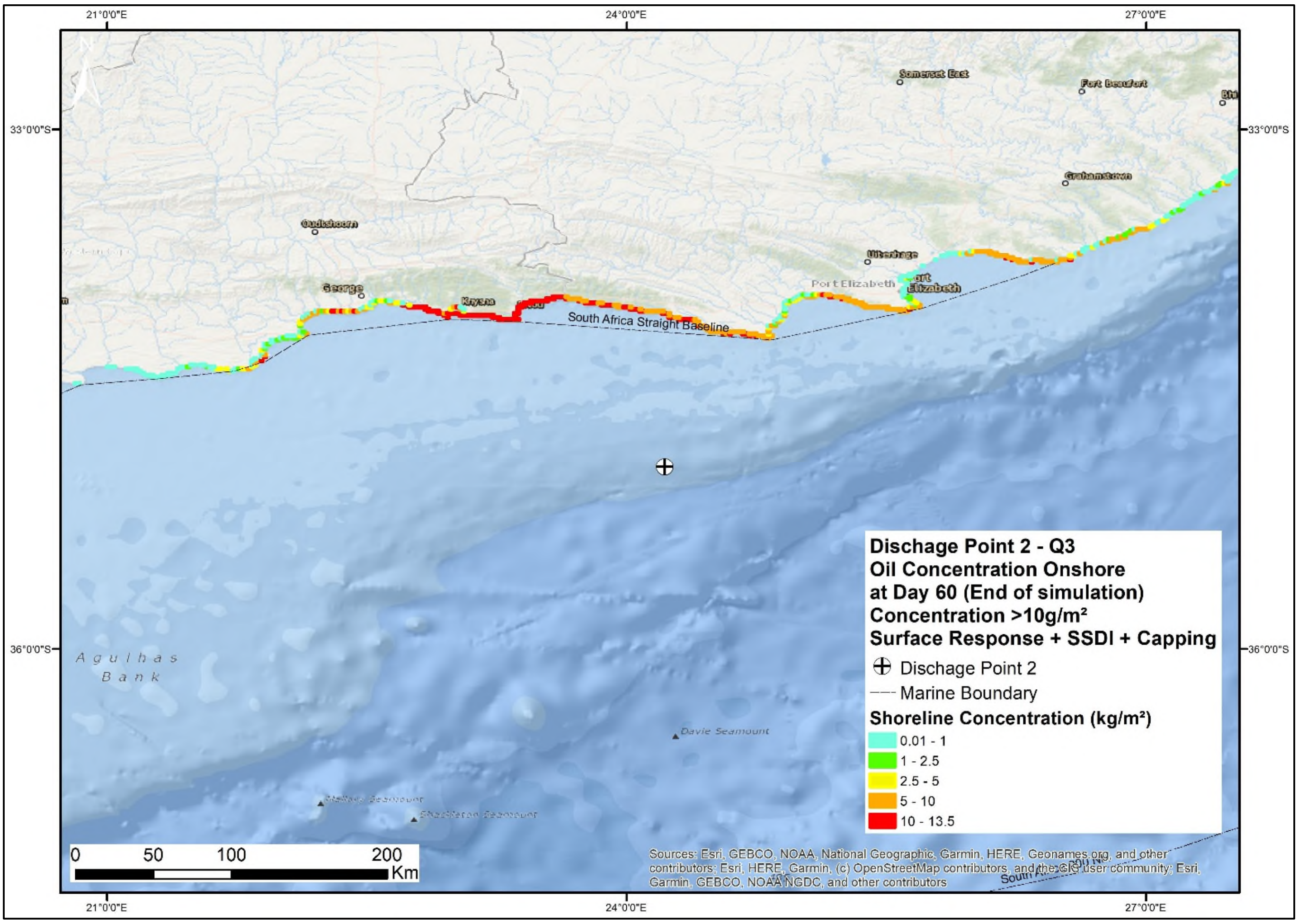

Figure 70 : Scenario 3D – Zoom on the Shoreline concentration most impacted area (>10 g/m^2) at the end of simulation

3.15 Scenario 3 Oil Fate – Capping only Vs. Surface Response + Capping Vs. Surface Response + SSDI + Capping

Figure 71 and Figure 72 present the oil fate comparison between the 3 deterministic scenarios for the Quarter 3, in order to compare the effect of the different oil spill responses.

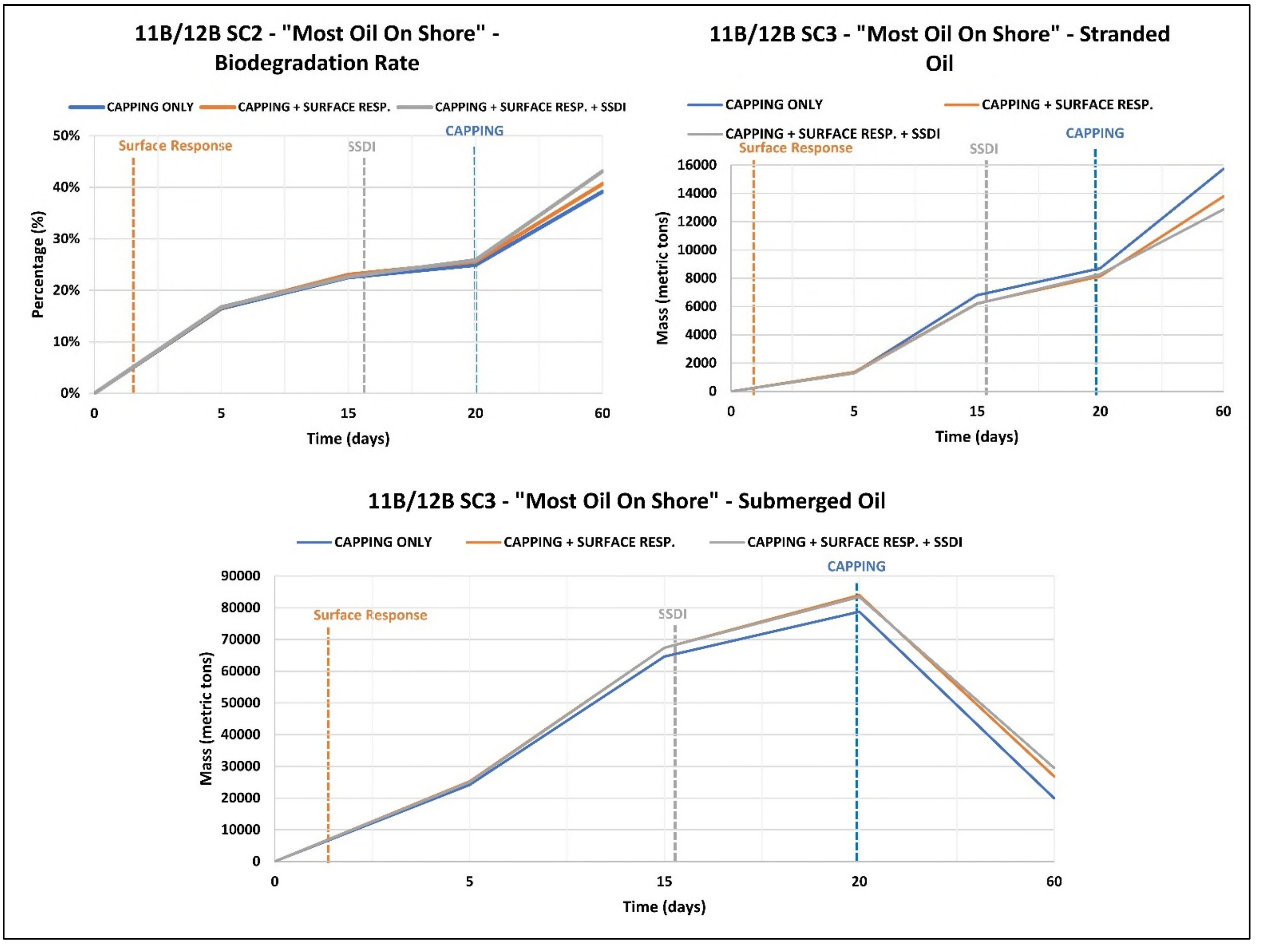

Figure 71: Scenario 3 – "Most Oil Onshore" case's Oil fate comparison (Surface, Stranded and Submerged oil)

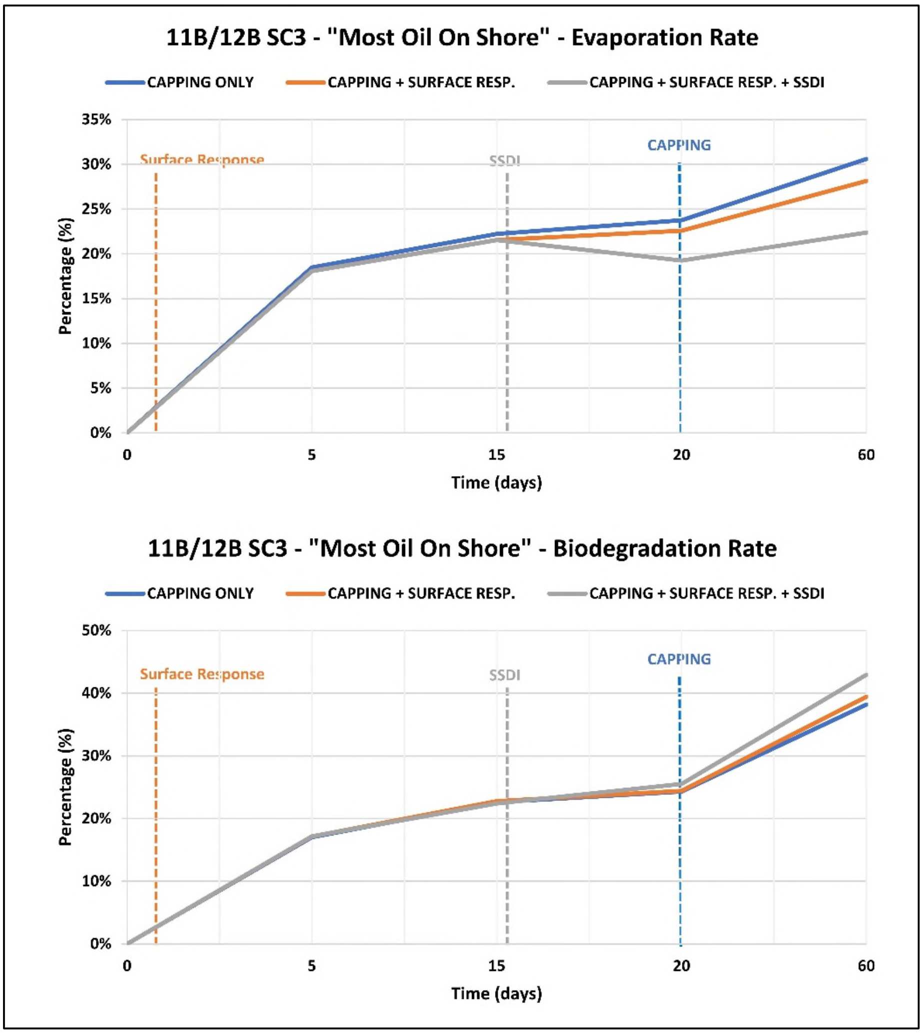

Figure 72: Scenario 3 – "Most Oil Onshore" case's Oil fate comparison (Evaporation & Biodegradation rates)

The **surface response** deployment allows to:

- Reduce the amount of oil remaining on the surface from its deployment;
- Reduce the amount of oil onshore at the end of simulation (i.e. day 60) compared to the Capping only scenario (about 13 780 tons with surface response vs. 15 720 tons with capping only).

The **SSDI** deployment allows to:

- Reduce the amount of oil reaching the surface on day 20 (approximately 6 270 tons day 20 with SSDI against 9 500 tons with capping only) by reducing considerable the oil droplets size, and consequently their buoyancy capacity, entraining the oil in the water-column, making they more prone for natural biodegrading processes.
- Reduce the amount of oil onshore at the end of simulation (i.e. day 60) compared to the Capping only scenario (about 12 860 tons with SSDI vs. 15 720 tons with capping only).
- Increase slightly the dispersion and the dissolution of oil in the water column ("submerged oil") and the biodegradation rate (by reducing the droplet size in the water column).

Note: Regardless of the type of response strategy applied, one observes that amount of the oil at sea surface is being affected by the metocean conditions, from spill day 15 until the end of simulation. This can explain the very close oil fate results for the 3 deterministic runs of Scenario 3 (included the run with Capping only). In fact, the oil amount at sea surface continues to drop throughout the deterministic run, even with capping only.

Overall, subsea response has a positive effect on oil mass balance, particularly by decreasing oil reaching the shoreline, evaporated, and increasing the biodegradation (Figure 73).

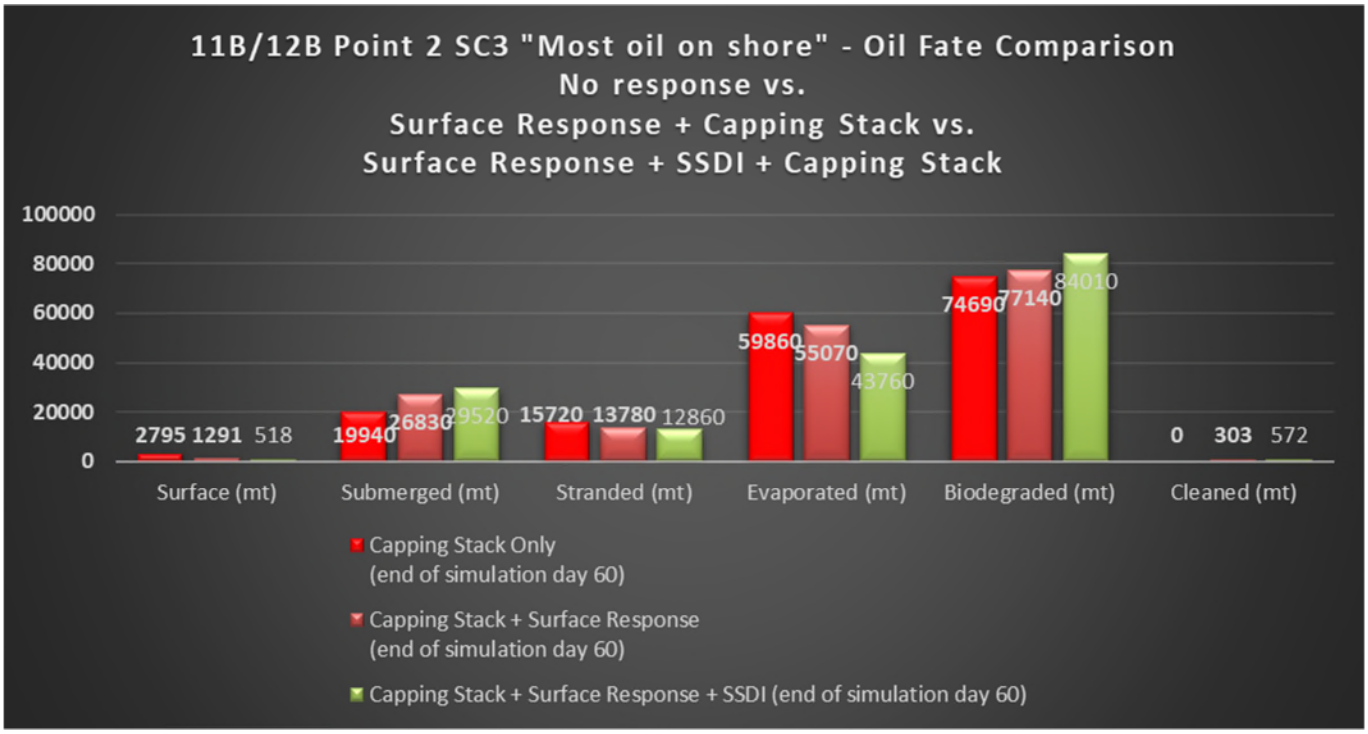

Figure 73 : Scenario 3 Oil Fate Comparison at the end of simulation (day 60)

One should note that SSDI option within OSCAR model, is not part of the response module, and therefore effects are not directly reflected in the "Cleaned" compartment of the oil mass balance. However, its influence is indirectly reflected in the other oil fate compartments such: "surface", "submerged/dispersed", "evaporation", "biodegraded" and "stranded". Therefore, the results presented here should be considered with caution.

3.16 Scenario 4A – Stochastic Simulation for Oct - Dec (Capping only)

This scenario simulates a continuous blow-out of 69 600 bbls/day of crude oil for a period of 20 days, through a set of 90 similar trajectories (i.e. 18 trajectories simulated for each quarter, in each of the 5 years covered by the metocean data), under a wide range of metocean conditions and a simulation duration of 60 days, covering the period from October 1st to December 31st for the years 2012 to 2016.

3.16.1 Surface Results

IMPORTANT: Surface results presented in this section do not represent a single spill but the combination of the statistical results of the 90 individual trajectories composing Stochastic Scenario 4. Threshold value applied for the interpretation of surface results is 5 µm, as detailed in Section 2.4.2

The stochastic footprint for the ensemble of trajectories is oriented towards the South-West direction. The highest values for surface oiling probability (i.e. 90% to 100%) are observed for South African offshore waters (Figure 74), along 290 km South-West from the discharge point 2.

There is a maximum of 48% of probability for the drift to go in the North direction, meaning that for the 90 trajectories performed for the Scenario 4, 43 trajectories may observe a drift towards the North direction on South African coastline (Tsitsikamma National Park coastline areas).

As we move away from the release point, the probability values gradually decrease however the main direction of the slick remains towards the South-West, indicating a low to medium variability of the trajectories of the Scenario 4, due to constant metocean conditions in this area.

Offshore waters of Namibia on the West side and Mozambique on the East side are not affected by the blow-out (considering the applied release properties and threshold values applied in the post-processing of modelling results).

The stochastic footprint goes into international waters approximately 480 km South-West from the release location, 3 days after the start of the spill (Figure 75), with a maximum probability of 26% (Figure 74).

The oil slick quickly progresses at sea surface, about 275 km towards South-West and 100 km towards North-East, in 2 days. Three days after the start of the blow-out, the oil slick edge could reach 475 km South-West from the discharge point, or 175 km North-East from the discharge point close to the Port Elizabeth coastline, due to the strong winds and currents in this area.

Reminder: Surface results characterized in Figure 74 and Figure 75, are considering only hydrocarbons presence at sea surface for a thickness above 5 µm.

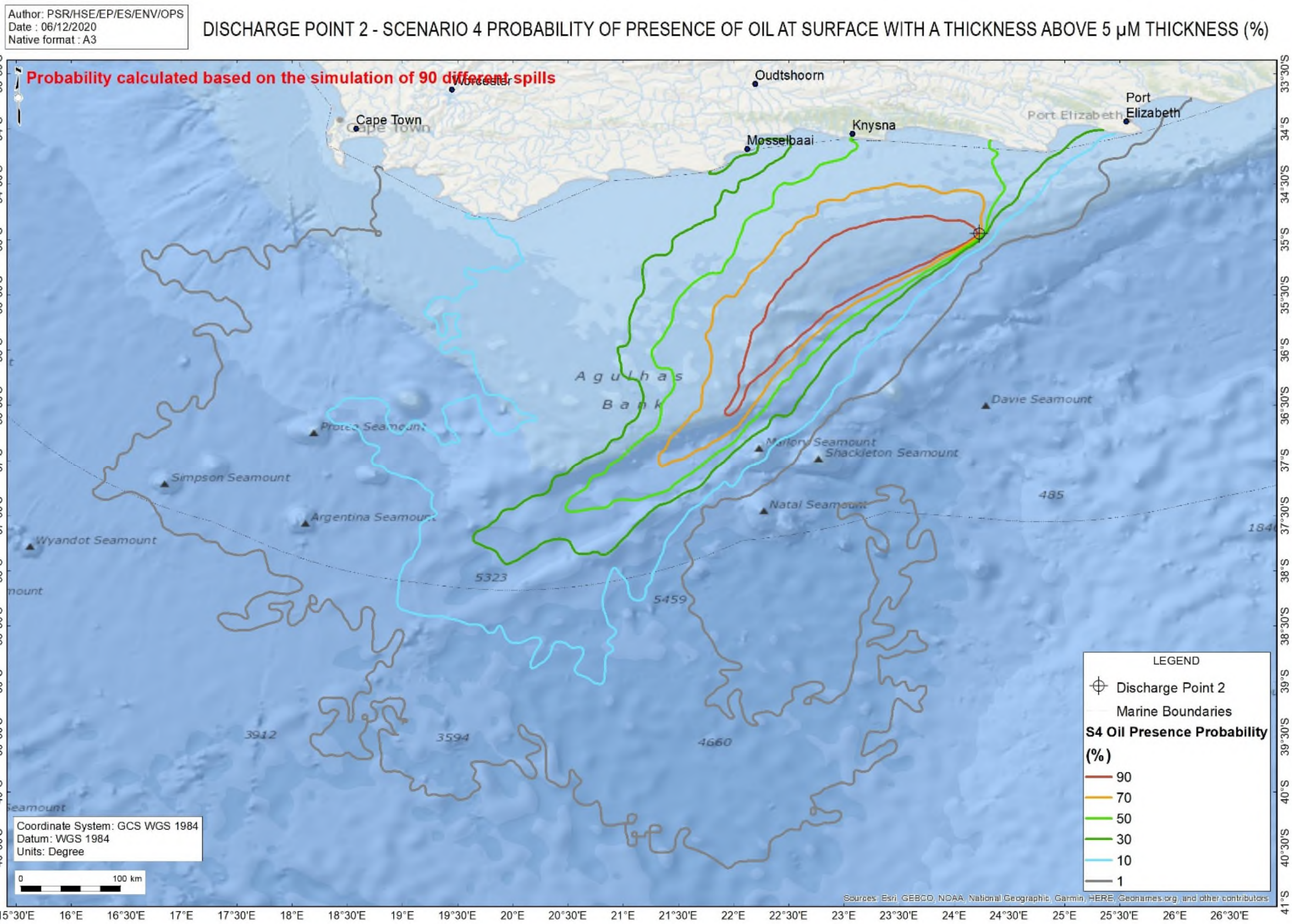

Figure 74: Scenario 4A (Q4)– Surface oiling probability above threshold (i.e. >5 µm)

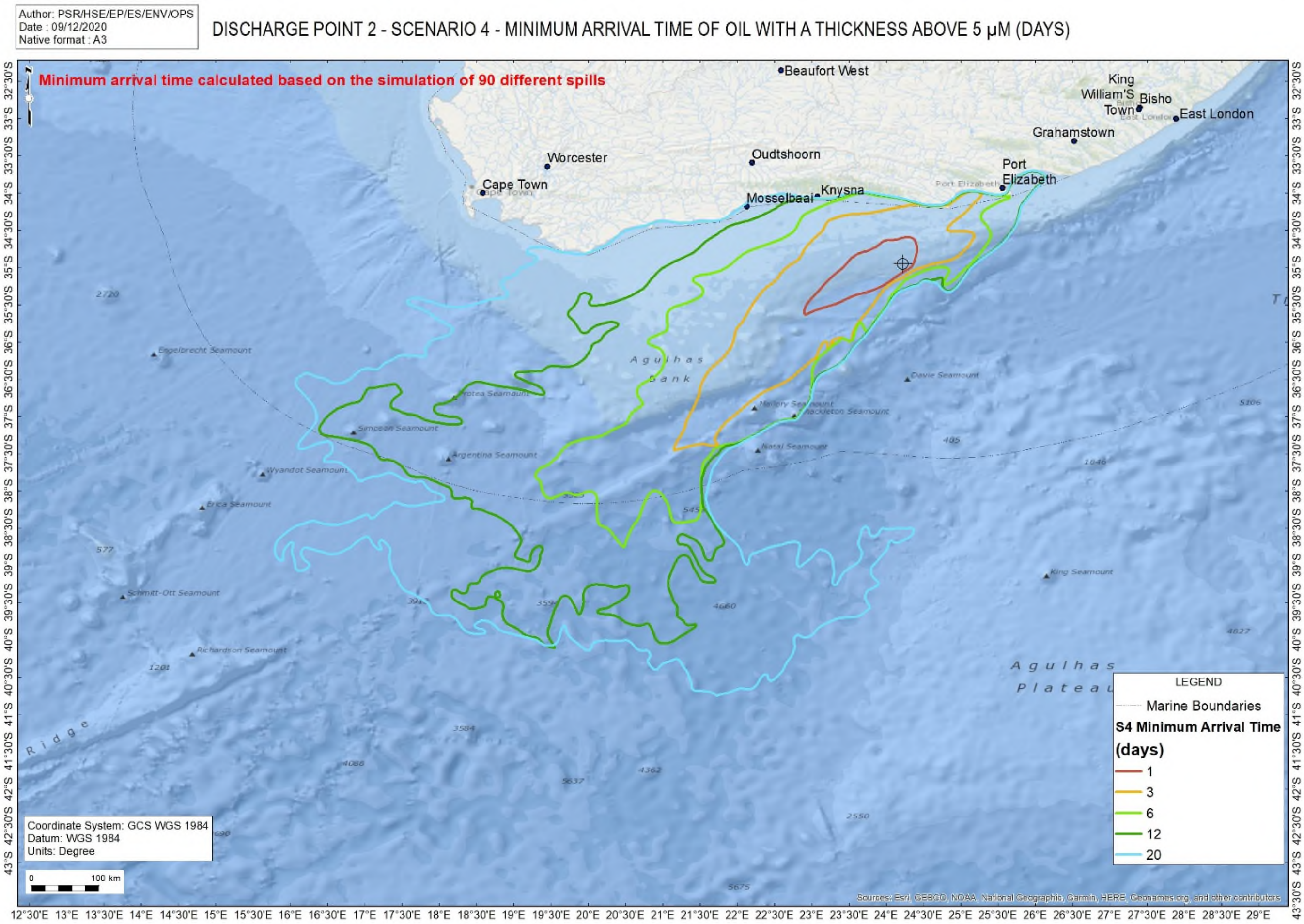

Figure 75: Scenario 4A (Q4)– Surface minimum arrival time (days) above threshold (i.e. >5 µm)

3.16.2 Shoreline Results

IMPORTANT: Shoreline results presented in this section do not represent a single spill but the combination of statistical results of the 90 individual trajectories composing Stochastic Scenario 4. Threshold value applied for the interpretation of shoreline results is 10 g/m^2, as detailed in Section 2.4.2.

Overall, all the shoreline from Cape Town to Port Elizabeth will observe medium a very low probability for shoreline oiling (i.e. from 1 to 63 %). The highest values for shoreline oiling probability (around 63%), are observed on the Tsitsikamma National Park coastline area (Figure 77).

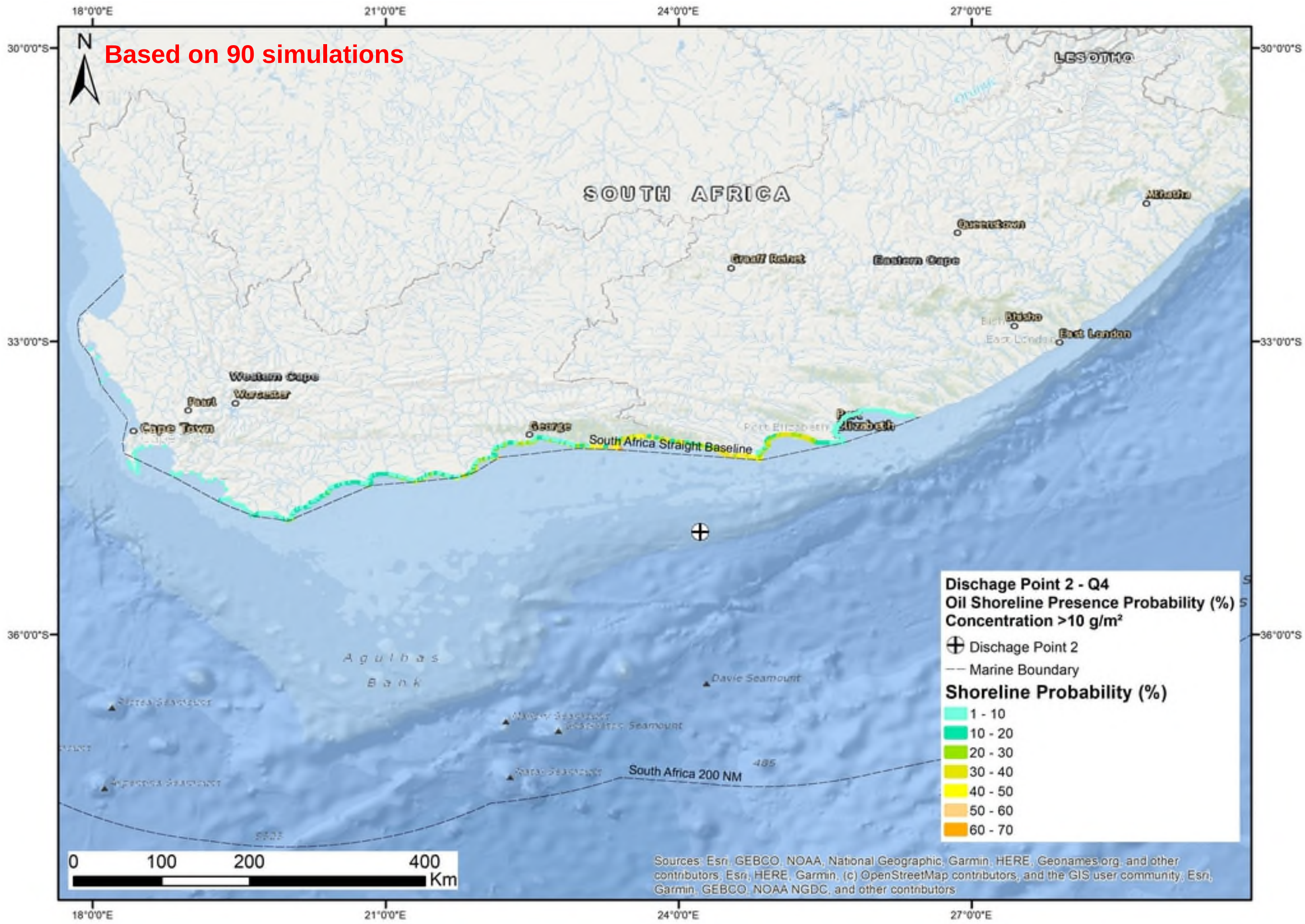

Figure 76: Scenario 4A – Shoreline oiling probability above threshold (i.e. >10 g/m^2)

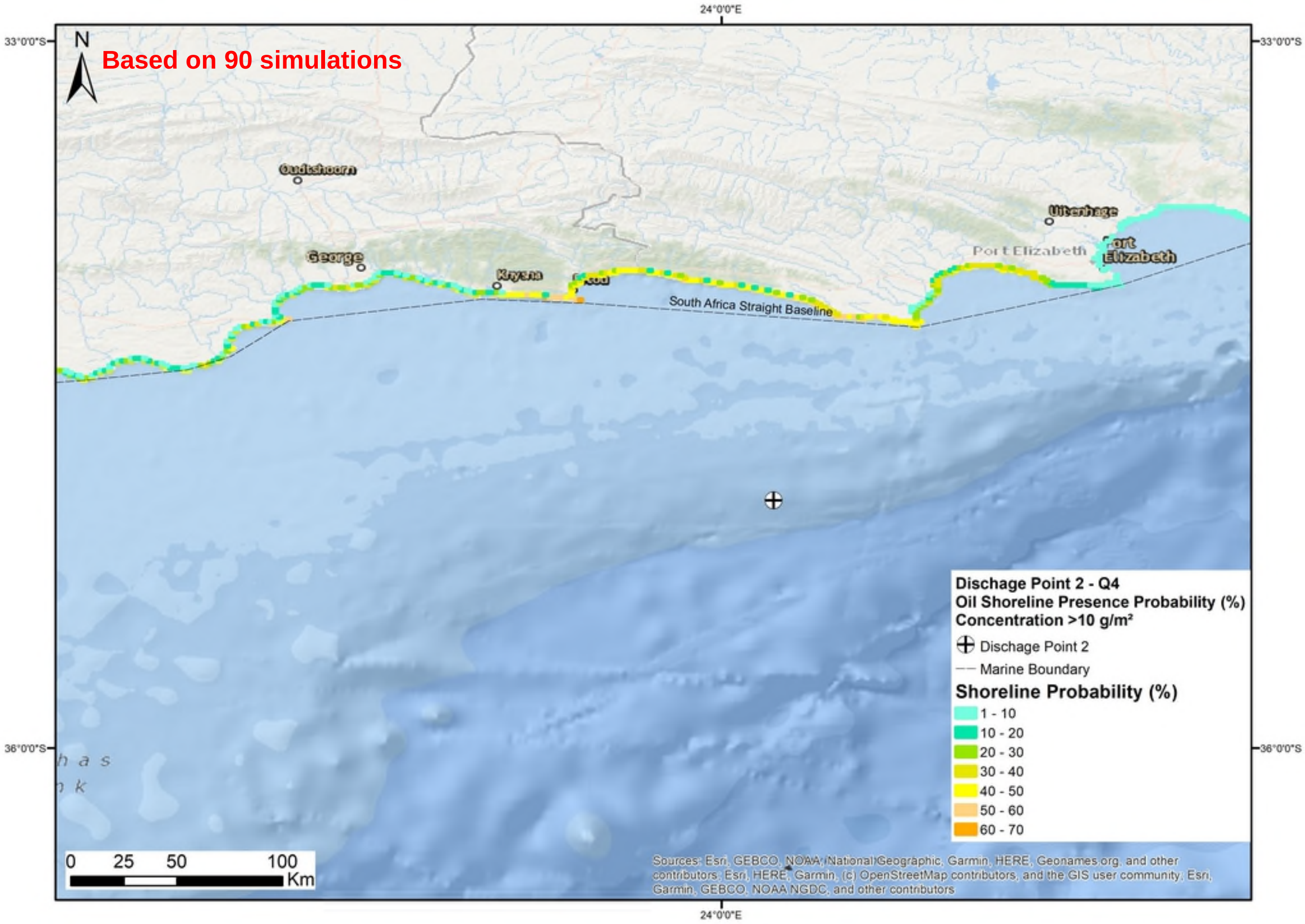

Figure 77 : Scenario 4A – Zoom on Shoreline oiling probability above threshold most impacted area (i.e. >10 g/m^2)

Shoreline minimum arrival time (in days) is observed on the Cape Saint Francis area , approximately 1 day after start of the release (Figure 78 and Figure 79). Overall, all the East area of Tsitsikamma National Park coastline and the Saint Francis Bay could observe oil reaching the shore between 2 and 4 days, with a maximum shoreline oiling probability around 42%.The Saint Francis Bay area could observe oil reaching the shore within 2 to 5 days, with medium shoreline oiling probabilities (until 50%). There is no shoreline transboundary effect in this scenario.

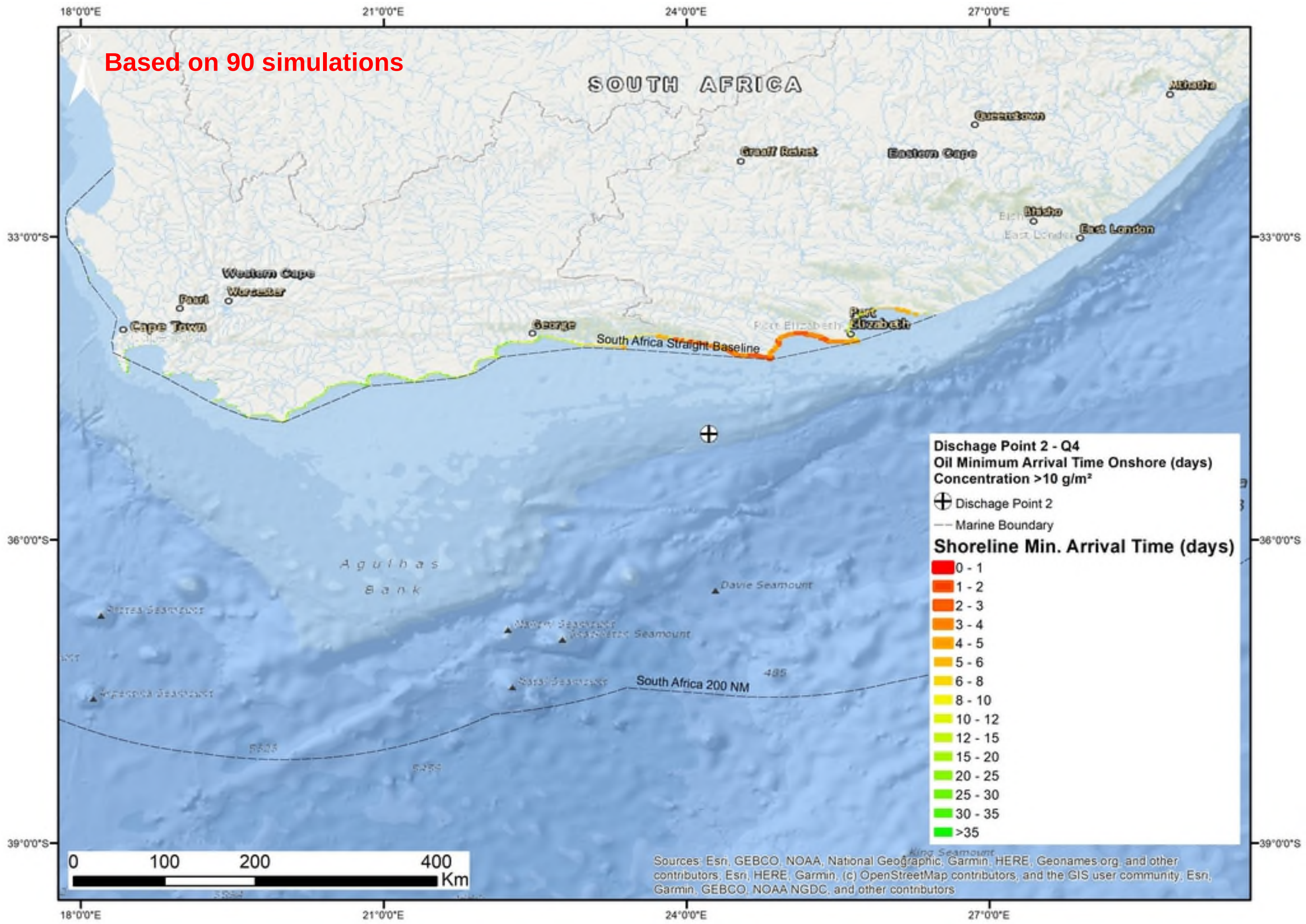

Figure 78: Scenario 4A – Shoreline minimum arrival time (days) above threshold (i.e. >10 g/m^2)

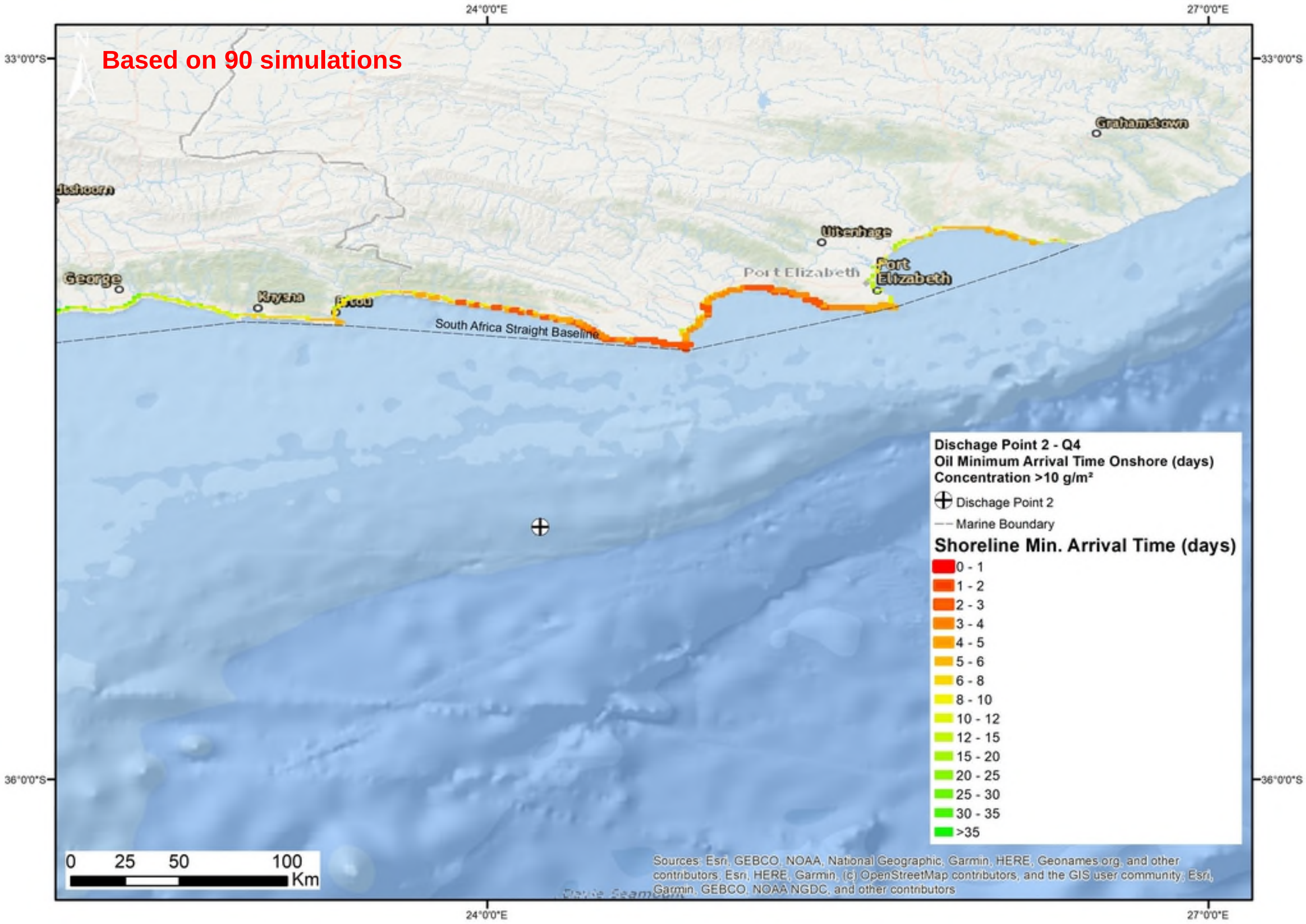

Figure 79 : Scenario 4A – Zoom on the shoreline minimum arrival time most impacted area (days) above threshold (i.e. >10 g/m^2)

Reminder: Shoreline results characterized in Figure 76, Figure 77, Figure 78 and Figure 79, are considering only hydrocarbons presence at shoreline for an oil load threshold >10 g/m^2.

3.17 Scenario 4B – Deterministic Scenario (Capping only) - Spill Drift and Shoreline Impacts

The simulation resulting in the highest hydrocarbon mass reaching the shore for Scenario 4 (i.e. trajectory with start on **October 31st 2015 (14:00 UTC)**), was selected to illustrate the results of the deterministic simulation (i.e. **Scenario 4B**), with a continuous blow-out releasing 69 600 bbls/day for a period of 20 days, and simulation total duration of 60 days.

Note: Figure 80 and Figure 81 have been done with a more precise resolution in order to better analyze the characteristics of the oil in the environment at the beginning of the blow-out.

Figure 80 presents the oil rise in the water column 3 hours after the start of the release, approximately 7.5 km South-West from the release location, with a maximum oil thickness at this time of 636 µm. These results will be the same for the Scenarios 4C and 4D considering Capping only Strategy will be implemented before those 3 hours.

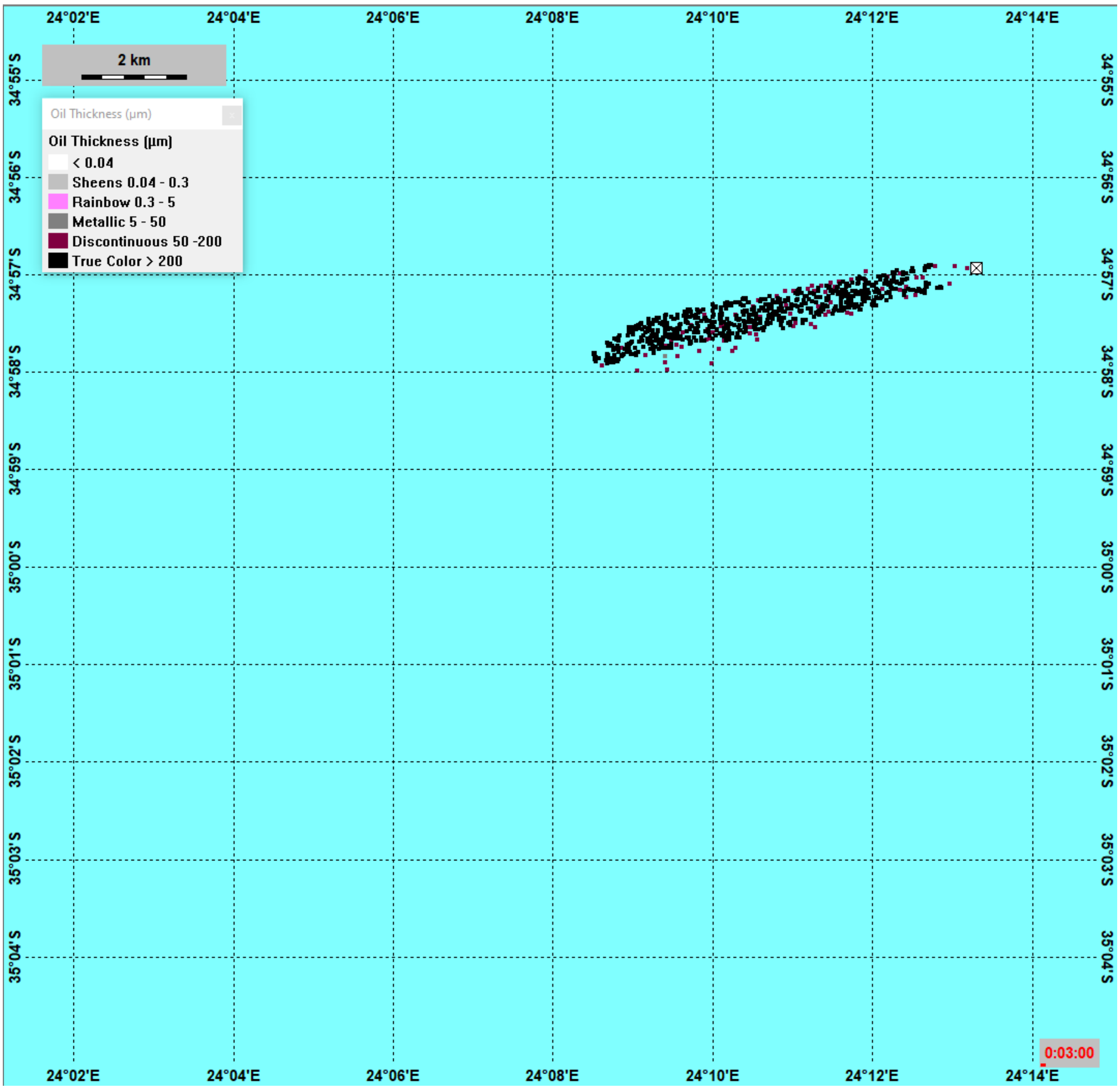

Figure 80: Oil reaching surface for scenarios 4B, 4C and 4D

Figure 81 present the release concentration and the submerged particles in the water column 3 hours after the start of the blow-out.

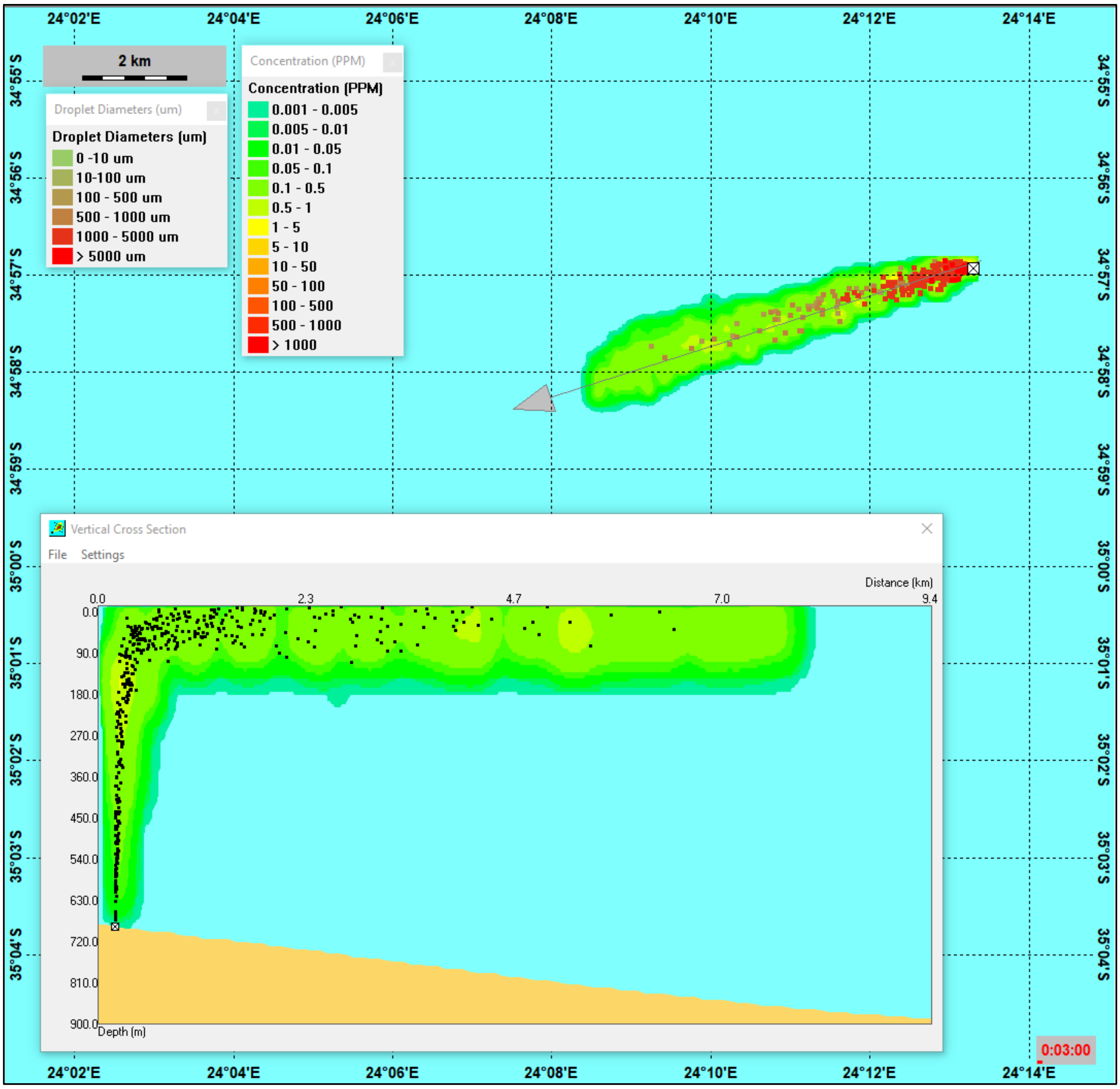

Figure 81 : Release concentration and submerged particles in the water column 3 hours after the start of the blow-out for scenarios 4B, 4C and 4D

The maximum oil concentration in the water column is 5.2 ppm very close to the release point; the maximum oil droplet diameter 4255 µm on the release point, and the termination depth is around 80 m depth. One should note that Figure 80 is a snapshot of the oil behaviour within the water-column, and is dependent of the orientation of the vertical cross-section arrow drawn, for the visualization of calculated results (i.e. the profile of the concentrations in the water-column), as well as of the correspondent time-step.

Oil spill initial drift, 24 hours after start of the release, is observed towards the West direction (Figure 82). Slick will then continue its drift towards North-West, progressing towards coastline, before changing direction to the West / South-West offshore direction around release day 6, and finally go back towards Knysna and Plettenberg Bay coastlines reaching the shore, on spill 11th day.

The maximum distance reached by the surface oil is 695 km South-West from the release point, 12 days after the start of the blow-out.

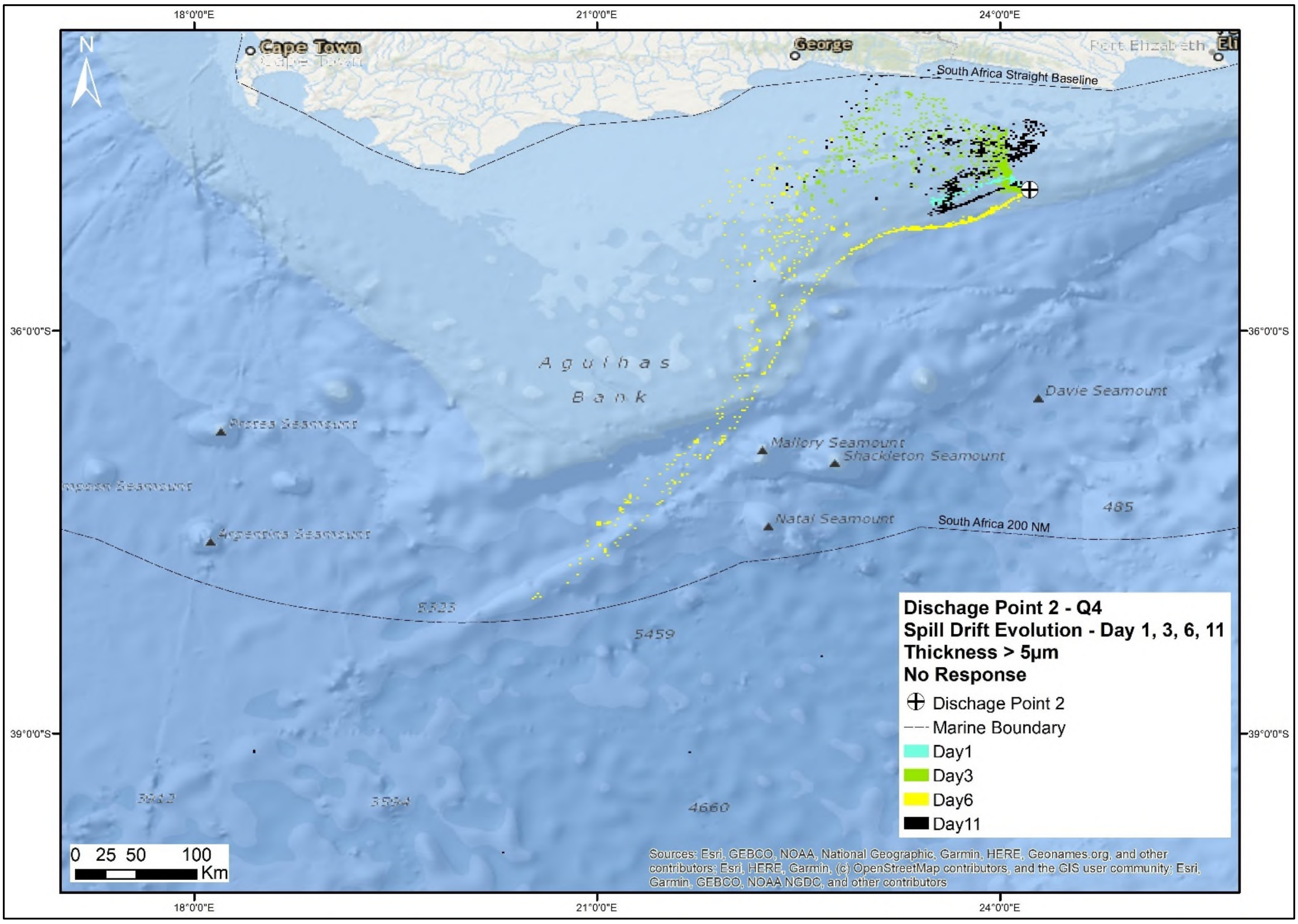

Figure 82: Scenario 4B – Spill drift evolution – Days 1, 3, 6 & 11

Figure 83 and Figure 84, show the impacts over the shoreline at the end of simulation, i.e. 60 days after the start of the blow-out. Impact ashore above threshold (i.e. 10 g/m^2 or 0.01 kg/m^2), is observed from the South of Cape Town to Port Elizabeth.

Highest value for shoreline oil concentration (around 12000 g/m^2) is observed along approximately 460 km between Uiterstepunt coastline and Saint Francis Bay.

Low concentration values for shoreline oil concentration (< 2500 g/m^2) are observed between Cape Town and Uiterstepunt.

The mass reaching the shore at the end of simulation (60 days) would then be 12 750 t.

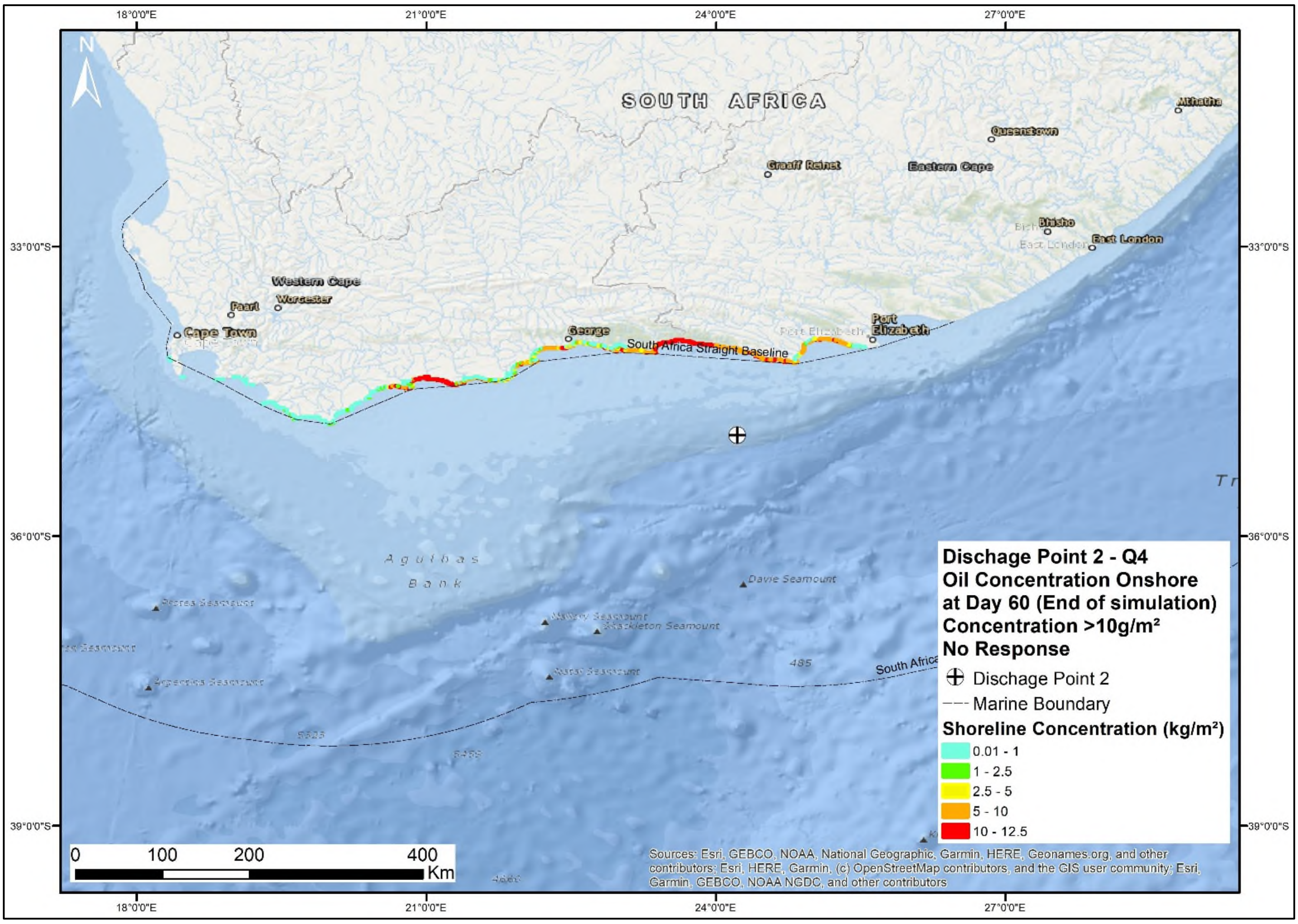

Figure 83: Scenario 4B – Shoreline concentration (>10 g/m^2) at the end of simulation

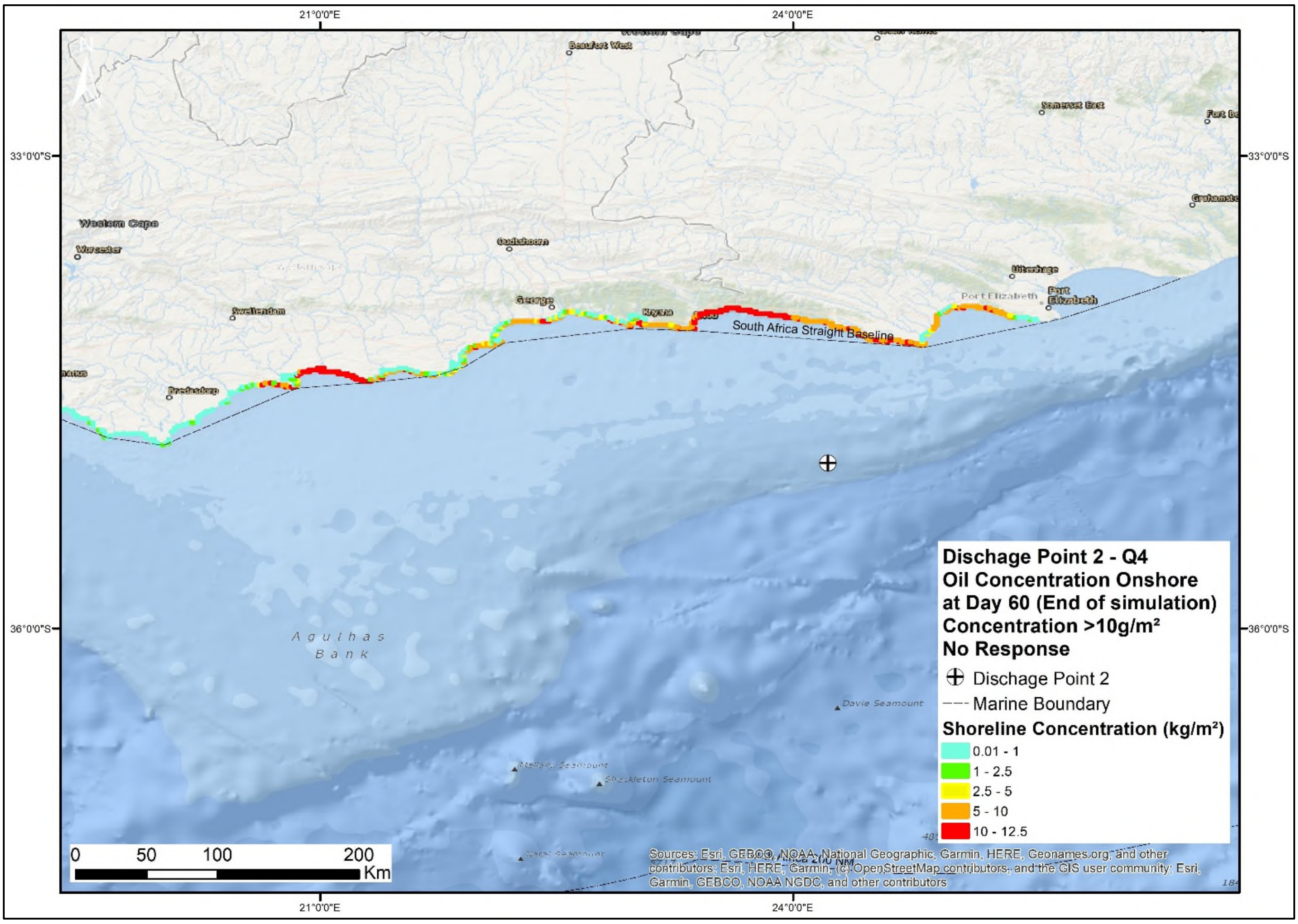

Figure 84 : Scenario 4B – Zoom on the Shoreline concentration most impacted area (>10 g/m²) at the end of simulation

3.18 Scenario 4C – Deterministic Scenario (Surface Response + Capping) - Spill Drift and Shoreline Impacts

The simulation resulting in the highest hydrocarbon mass reaching the shore for Scenario 4 (i.e. trajectory with start on **October 26th 2015 (12:00 UTC)**), was selected to illustrate the results of the deterministic simulation (i.e. **Scenario 4C**), with a continuous blow-out releasing 69 600 bbls/day for a period of 20 days, and simulation total duration of 60 days.

The following response strategy is deployed and simulated in this scenario (detailed in 2.2.3):

- Surface response with aircrafts and vessels 24 hours after the start of the spill.

Oil spill initial drift, 24 hours after start of the release, is observed towards the West direction (Figure 82). Slick will then continue its drift towards North-West, progressing towards coastline, before changing direction to the West / South-West offshore direction around release day 6, and finally go back towards Knysna and Plettenberg Bay coastlines reaching the shore, on spill 11th day.

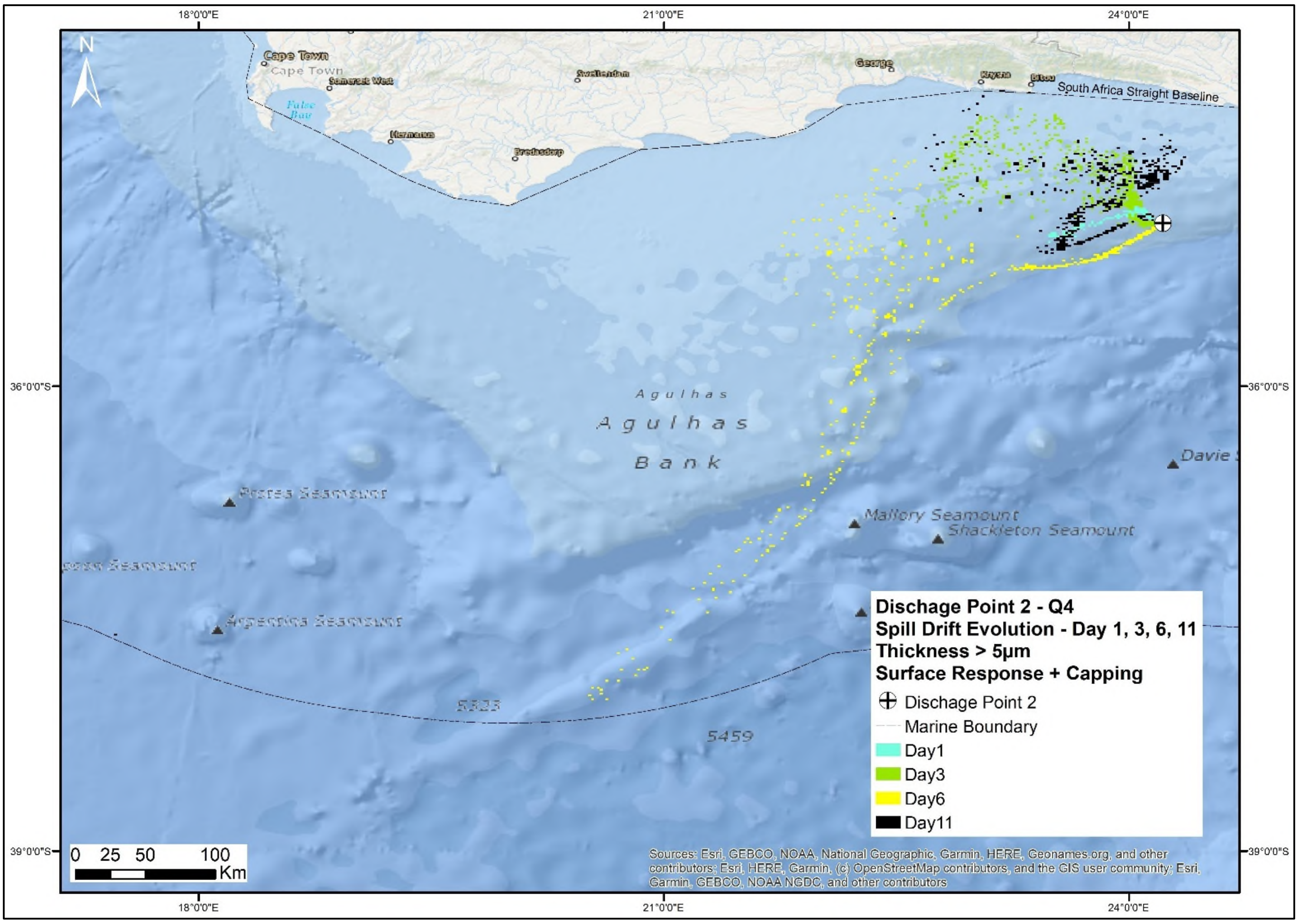

Figure 85: Scenario 4C – Spill drift evolution – Days 1, 3, 6 & 11

Figure 85 and Figure 86, show the impacts over the shoreline at the end of simulation, i.e. 60 days after the start of the blow-out. Impact ashore above threshold (i.e. 10 g/m^2 or 0.01 kg/m^2), is observed from the East of Cape Town to Port Elizabeth.

Highest value for shoreline oil concentration (around 12000 g/m^2) is observed along approximately 60 km around Blomboschfontein Nature Reserve coast area, and on 300 km between George coastline and Saint Francis Bay.

Low concentration values for shoreline oil concentration (< 2500 g/m^2) are observed between Cape Town and Blomboschfontein Nature Reserve coast area.

The mass reaching the shore at the end of simulation (60 days) would then be 9 710 t vs. 12 750 t with only the capping stack.

The surface response deployed allow to reduce the oil concentration onshore in this case especially on the Blomboschfontein Nature Reserve coast and all the Saint Francis Bay area.

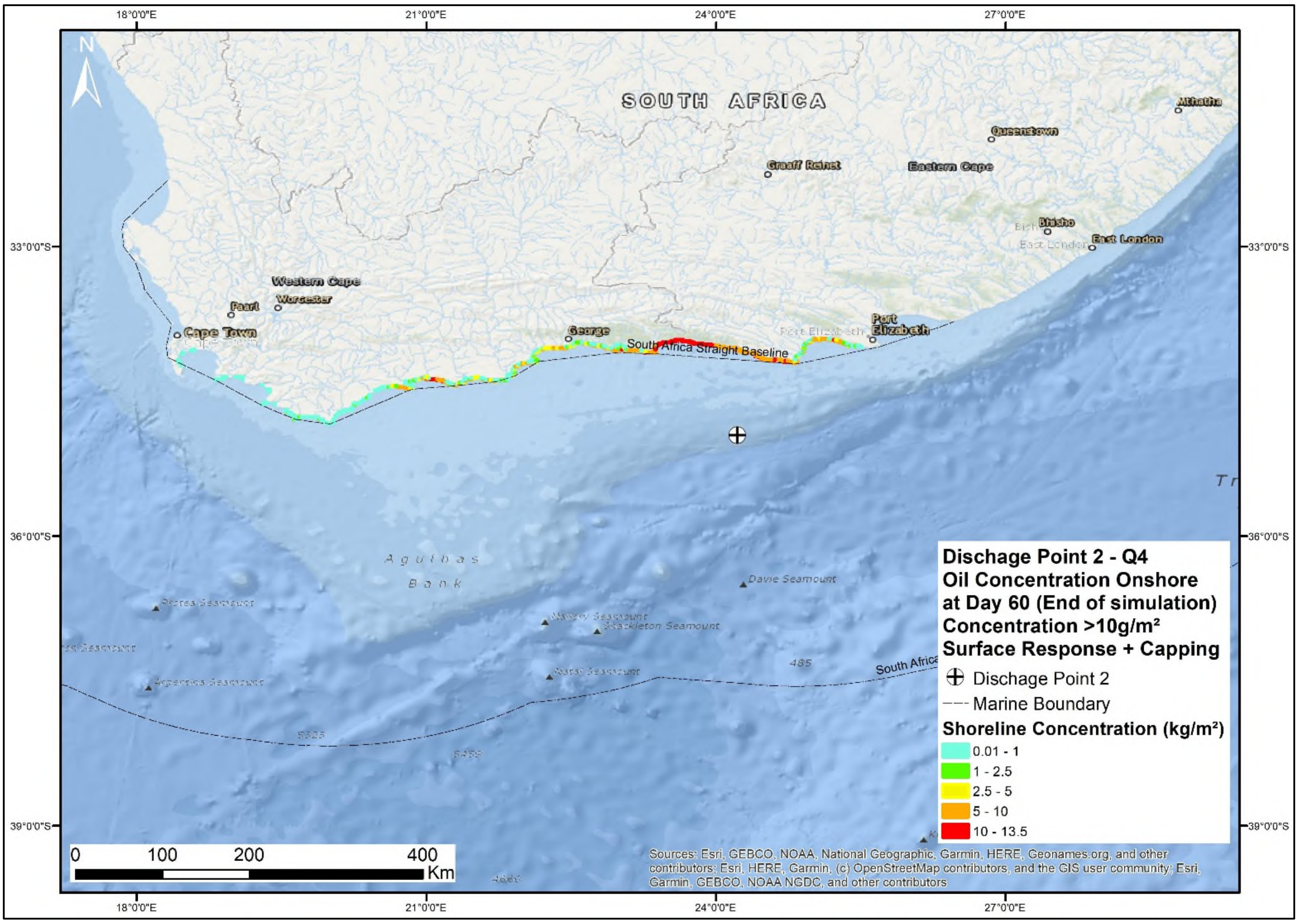

Figure 86: Scenario 4C – Shoreline concentration (>10 g/m^2) at the end of simulation

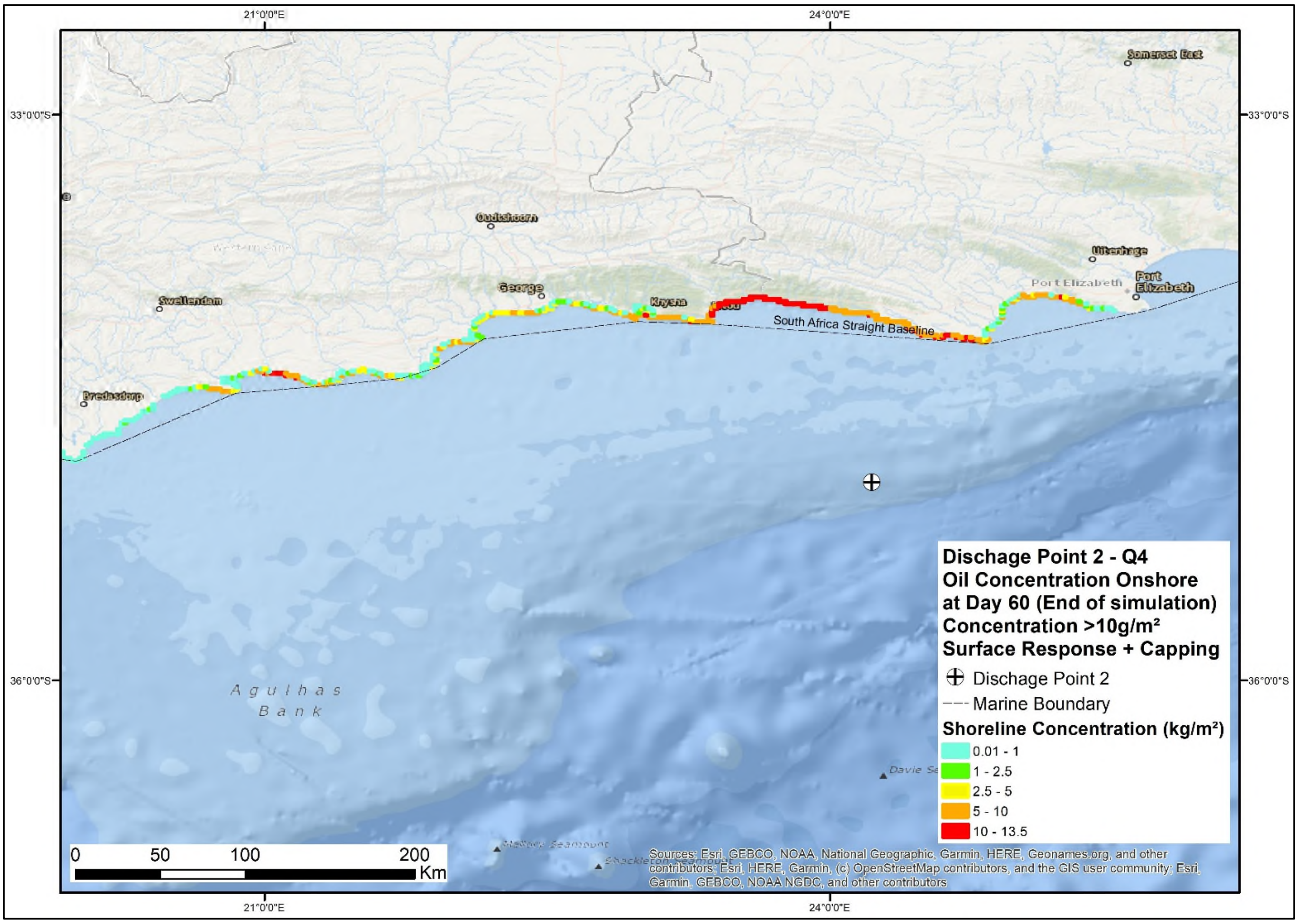

Figure 87 : Scenario 4C – Zoom on the Shoreline concentration most impacted area (>10 g/m²) at the end of simulation

3.19 Scenario 4D – Deterministic Scenario (Surface Response + SSDI + Capping) - Spill Drift and Shoreline Impacts

The simulation resulting in the highest hydrocarbon mass reaching the shore for Scenario 4 (i.e. trajectory with start on **October 26th 2015 (12:00 UTC)**), was selected to illustrate the results of the deterministic simulation (i.e. **Scenario 4D**), with a continuous blow-out releasing 69 600 bbls/day for a period of 20 days, and simulation total duration of 60 days.

The following response strategy is deployed and simulated in this scenario (detailed in 2.2.3), namely:

- Surface response with aircrafts and vessels 24 hours after the start of the spill;
- SSDI (Subsea Dispersant Injection) 15 days after the start of the blow-out.

Oil spill initial drift, 24 hours after start of the release, is observed towards the West direction (Figure 82). Slick will then continue its drift towards North-West, progressing towards coastline, before changing direction to the West / South-West offshore direction around release day 6, and finally go back towards Knysna and Plettenberg Bay coastlines reaching the shore, on spill 11th day.

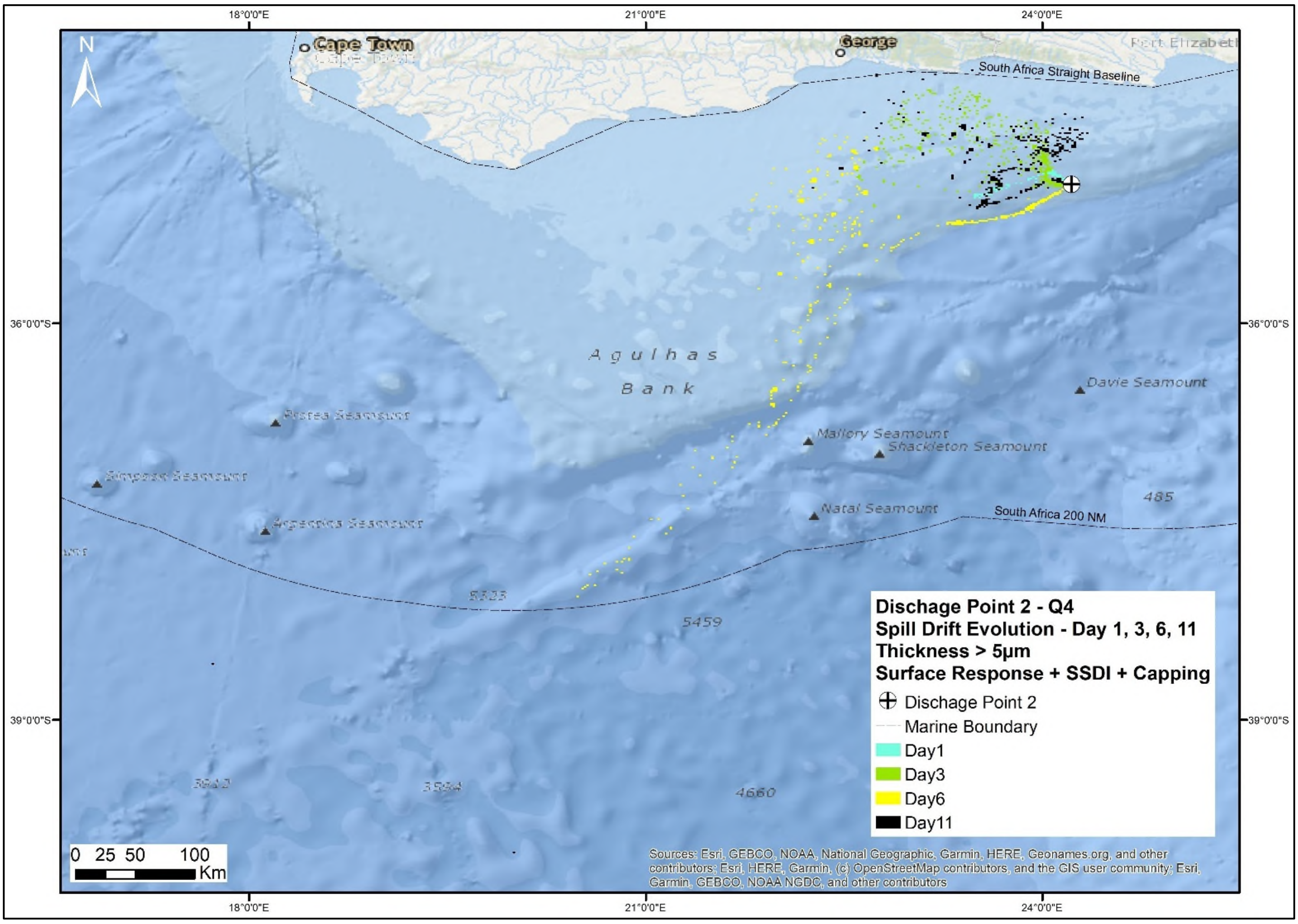

Figure 88: Scenario 4D – Spill drift evolution – Days 1, 3, 6 & 11

Figure 89 and Figure 90 show the impacts over the shoreline at the end of simulation, i.e. 60 days after the start of the blow-out. Impact ashore above threshold (i.e. 10 g/m^2 or 0.01 kg/m^2), is observed from the South of Cape Town to Port Elizabeth.

Highest value for shoreline oil concentration (around 12000 g/m^2) is observed along approximately 205 km between Plettenberg Bay coastline and Saint Francis Bay.

Low concentration values for shoreline oil concentration (< 2500 g/m^2) are mainly observed between Cape Town and George.

The mass reaching the shore at the end of simulation (60 days) would then be 8400 t vs. 12 750 t with only the capping stack.

The SSDI deployed day 15th allows to reduce considerably the oil concentration onshore and the length of the coastline impacted, especially on the Blomboschfontein Nature Reserve coast, where most of the concentration values are now around 3000 g/m² versus 12500 g/m² with only capping.

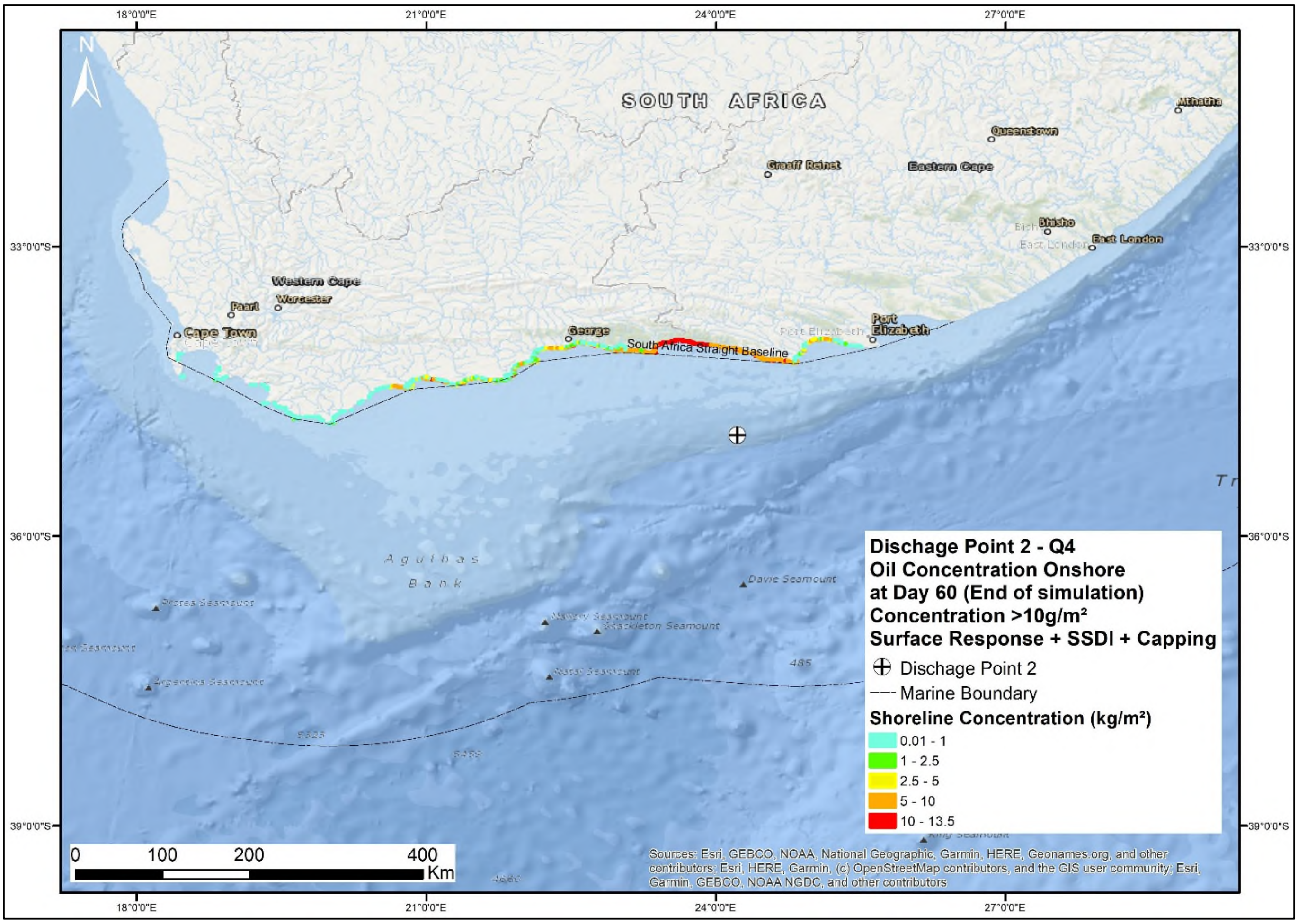

Figure 89: Scenario 4D – Shoreline concentration (>10 g/m²) at the end of simulation

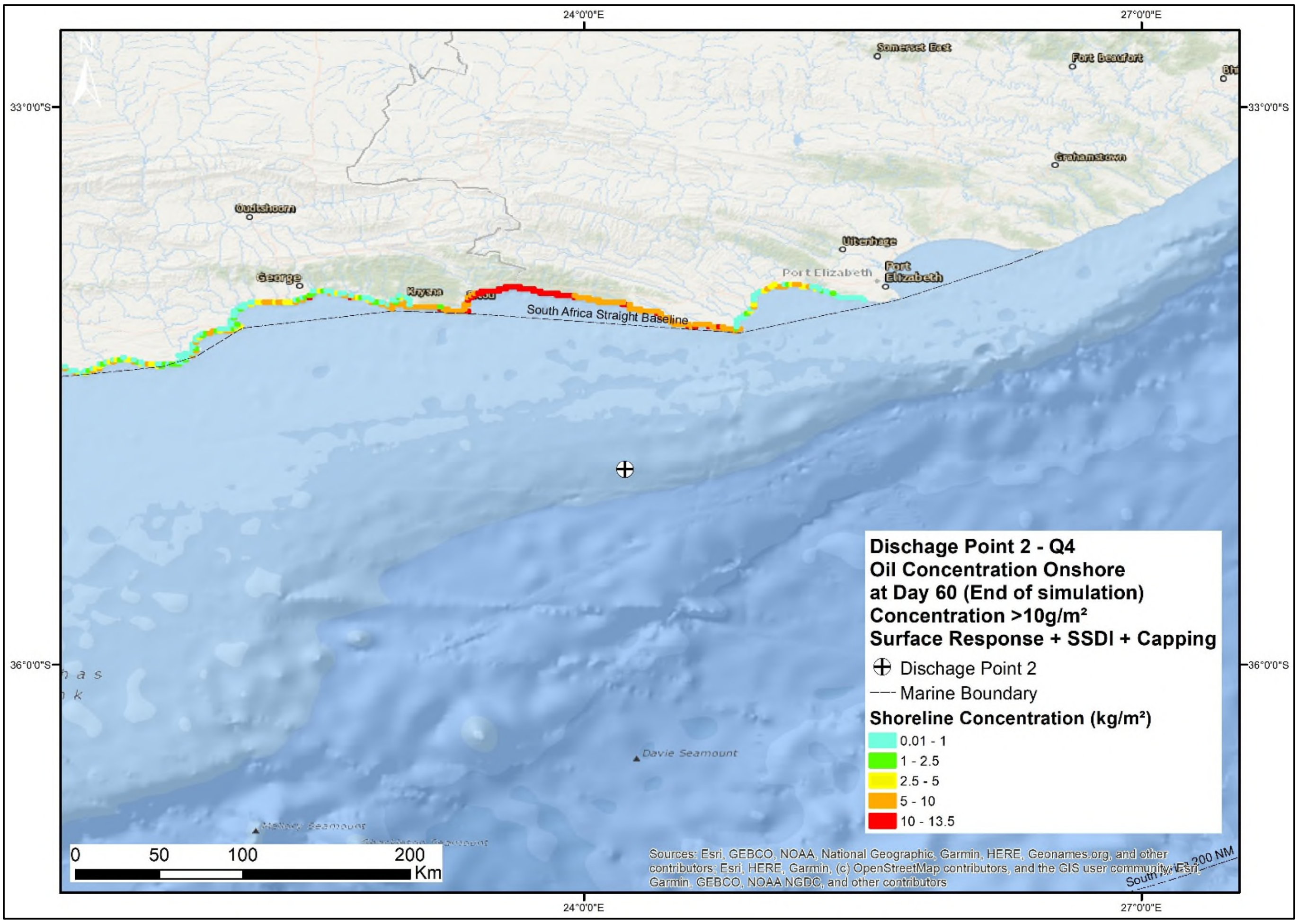

Figure 90 : Scenario 4D – Zoom on the Shoreline concentration most impacted area (>10 g/m^2) at the end of simulation

3.20 **Scenario 4 Oil Fate – Capping only Vs. Surface Response + Capping Vs. Surface Response + SSDI + Capping**

Figure 91 and Figure 92 present the oil fate comparison between the 3 deterministic scenarios for the Quarter 4, in order to compare the effect of the different oil spill responses.

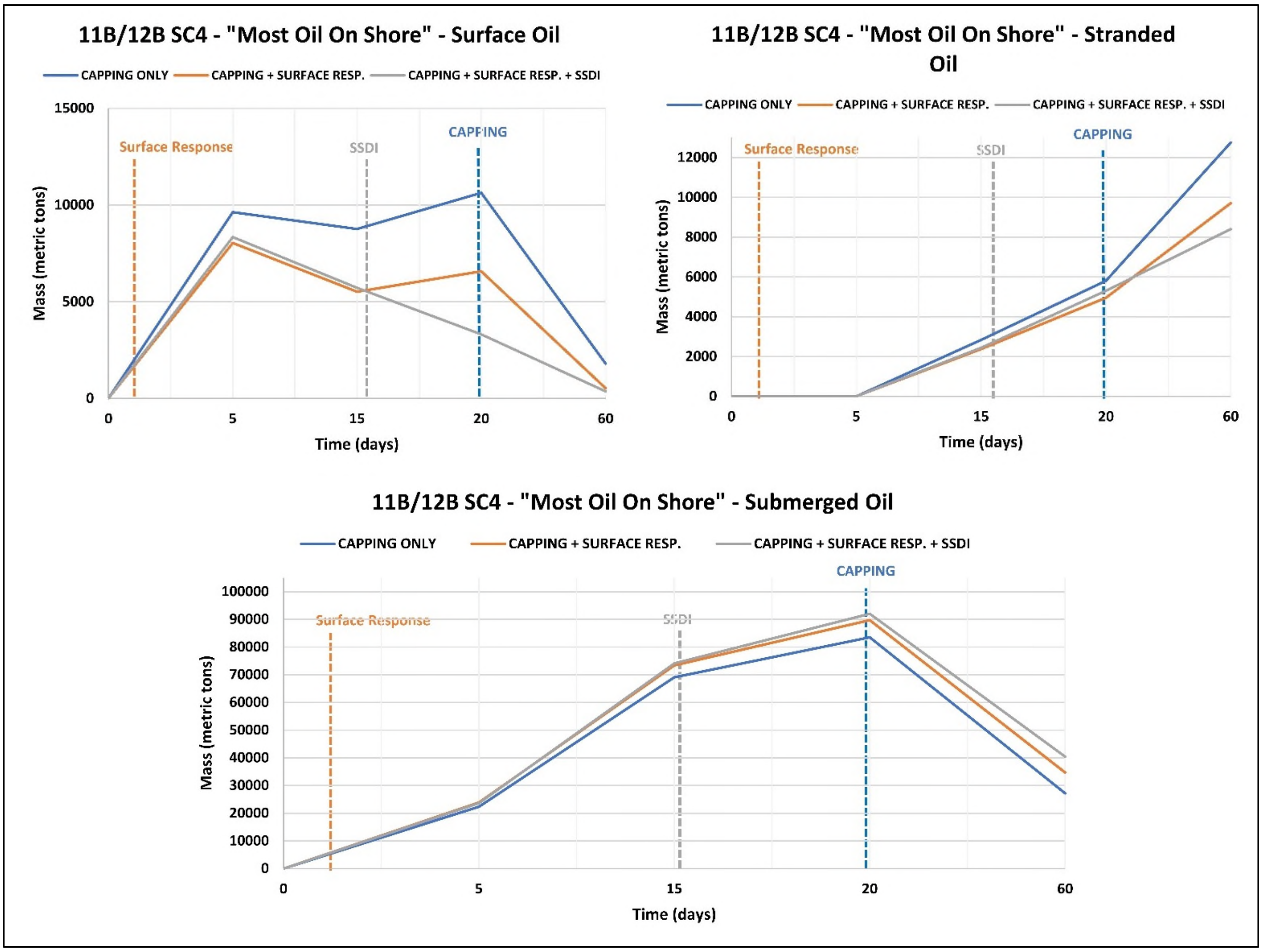

Figure 91: Scenario 4 – "Most Oil Onshore" case's Oil fate comparison (Surface, Stranded and Submerged oil)

Figure 92: Scenario 4 – "Most Oil Onshore" case's Oil fate comparison (Evaporation & Biodegradation rates)

The **surface response** deployment allows to:

- Slightly reduce the amount of oil remaining on the surface from its deployment;
- Reduce the amount of oil onshore at the end of simulation (i.e. at day 60) compared to the Capping only scenario (9 710 tons with surface response vs. 12 750 tons with capping only).

The **SSDI** deployment allows to:

- Reduce greatly the amount of oil reaching the surface on day 20 (approximately 3 320 tons day 20 with SSDI against 10 630 tons with capping only) by reducing considerable the oil droplets size, and consequently their buoyancy capacity, entraining the oil in the water-column, making they more prone for natural biodegrading processes.
- Greatly reduce the amount of oil onshore at the end of simulation (i.e. day 60) compared to the Capping only scenario (about 8 400 tons with SSDI vs. 12 750 tons with capping only).
- Increase slightly the dispersion and the dissolution of oil in the water column ("submerged oil") and the biodegradation rate (by reducing the droplet size in the water column).

Overall, subsea response has a positive effect on oil mass balance, particularly by decreasing oil reaching the shoreline, evaporated, and increasing the biodegradation (Figure 93).

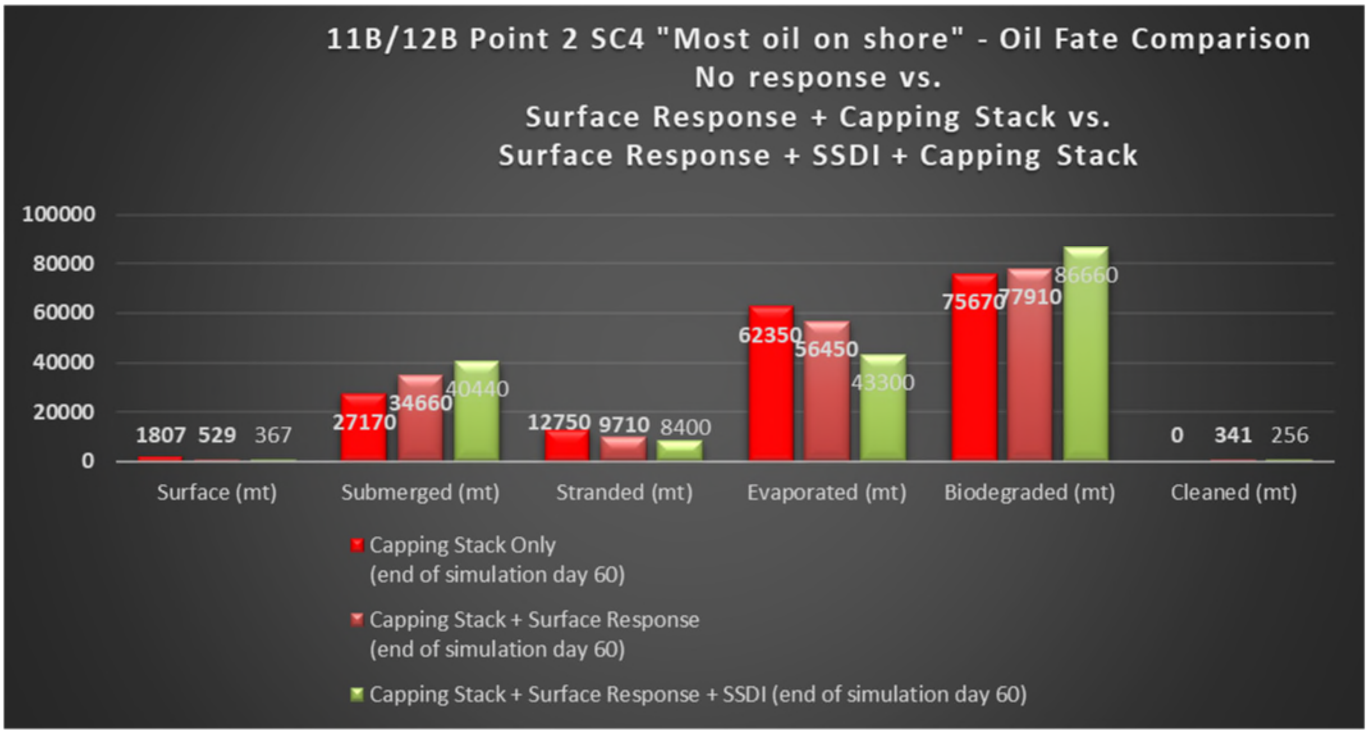

Figure 93: Scenario 4 Oil Fate Comparison at the end of simulation (day 60)

One should note that SSDI option within OSCAR model, is not part of the response module, and therefore effects are not directly reflected in the “Cleaned” compartment of the oil mass balance. However, its influence is indirectly reflected in the other oil fate compartments such: “surface”, “submerged/dispersed”, “evaporation”, “biodegraded” and “stranded”. Therefore, the results presented here should be considered with caution.

4. Conclusions

Results detailed in this report are statistical representation of a predefined blowout scenario, and therefore should be used with caution, considering the variability of the environment features, as well as the physical-chemical properties of expected reservoir fluid and model parameters.

One should note that the stochastic results here described, consider the pre-agreed thresholds for the post-processing of model results, namely, 5 µm for surface oiling and 10 g/m2 for shoreline oil mass.

Stochastic results

In general, for all quarters spill main drift is observed towards the SW/W direction. A secondary drift is possible towards the N/NE direction (especially for Q3), in the event of strong winds conditions towards the shore. Figure 94 presents an overview of the surface presence probability for each quarter.

The seasonality between quarters influences oil progression at surface, the probability of shoreline oiling, the minimum time for oil to come ashore, as well as the target areas for mobilization of response means to be considered in the oil spill contingency plan.

Model results indicate that shoreline oiling annual probability is 83%, however, the likelihood for this to occur varies according to the season. The period of the year identified as the worst in the event of a blowout (i.e. with maximum oil amount onshore coupled with the maximum probability) is the third quarter (spill starting in August).

Depending on the release start date and the observed metocean conditions, minimum time for oil to reach the shoreline can fluctuate from 1 to 60 days, being the average arrival time for all the quarters around 12 days.

Deterministic results

For this study each deterministic run, represents the worst-case trajectory identified from the stochastic scenario (i.e. the trajectory with utmost quantity of oil reaching shore). Each was then tested under different responses strategies (surface response alone and surface response coupled with subsea dispersant injection) to assess its influence over slick drift and oil fate.

Deterministic modelling results show that surface and subsea responses are essential to limit the extent of the shoreline oiling, however due to the proximity of the discharge point to shore and the occurrence of recurrent strong winds episodes, these responses might have limited effect on the oil arrival time at shore (one should note, that here are only being considered the worst-case trajectory identified for each quarter, which does not reflect each of 90 iterations performed for each stochastic scenario).

Furthermore, although essential, the capping stack device alone is not enough to minimize spill effects, for drilling operations occurring during Q3, the rapid impact of the shoreline won't enable a timely response. Therefore, shoreline protection of sensitive sites and/or organization of cleanup plans shall be put in place.

For shoreline impacts, a thickness screening threshold of 10 g/m^2 was used, which is conservative.

The Table 4.1 summarizes the results of the 4 scenarios performed on the four quarters for crude oil cases.

Table 4.1 : Summary of the results for the Block 11B/12B oil spill – Discharge point 2

Scenario	1	2	3	4
Spill	**Blow-out - Crude Oil Release**			
Flow Rate / Amount	Qoil = 69 600 bbl/day Qgas = 2.2 Millions Sm3/day			
Period	**Q1**	**Q2**	**Q3**	**Q4**
Max Oil Presence probability / Drift Direction (Thickness >5µm)	90 to 100 %, 310 km SW 70% on NE towards Port Elizabeth area	90 to 100 %, 135 km SW 80% on N/NE (because of strong winds) towards eastern South-Africa coastlines	90 to 100 %, 160 km SW 90 to 100% N/NE on 138 km (because of strong winds) towards Port Elizabeth coastlines	90 to 100 %, 290 km SW
MAX. % shoreline impact probability	72% observed on Plettenberg Bay area	98% are observed between Knysna and Port Elizabeth	100%, are observed from George to Port Elizabeth	63%, are observed on the Tsitsikamma National Park coastline area
Minimum Shoreline Arrival Time	Saint Francis Bay, approximately 2 days after start of the release	Saint Francis Bay area, West to Port Elizabeth, 2 days after start of the release	West of Saint Francis Bay area approximately 1 days after start of the release	Cape Saint Francis Bay area, approximately 2 days after start of the release
Average Shoreline Arrival Time	14 days	11 days	11 days	12 days
Deterministic Worst Case Oil Onshore with capping only	12000 g/m2 is observed along approximately 230 km between Knysna and Port Elizabeth	12500 g/m2 is observed along approximately 480 km between George and East of Port Elizabeth	12000 g/m2 are observed along approximately from George to Port Elizabeth	12000 g/m2 is observed along approximately 460 km between Uiterstepunt coastline and Saint Francis Bay
Oil ashore at 60 days (mt)	Capping only: 7937 Surface response + capping stack: 7065 Surface response + SSDI _ Capping Stack: 4601	Capping only: 14850 Surface response + capping stack: 13620 Surface response + SSDI _ Capping Stack: 11690	Capping only: 15720 Surface response + capping stack: 13780 Surface response + SSDI _ Capping Stack: 12860	Capping only: 12750 Surface response + capping stack: 9710 Surface response + SSDI _ Capping Stack: 8400

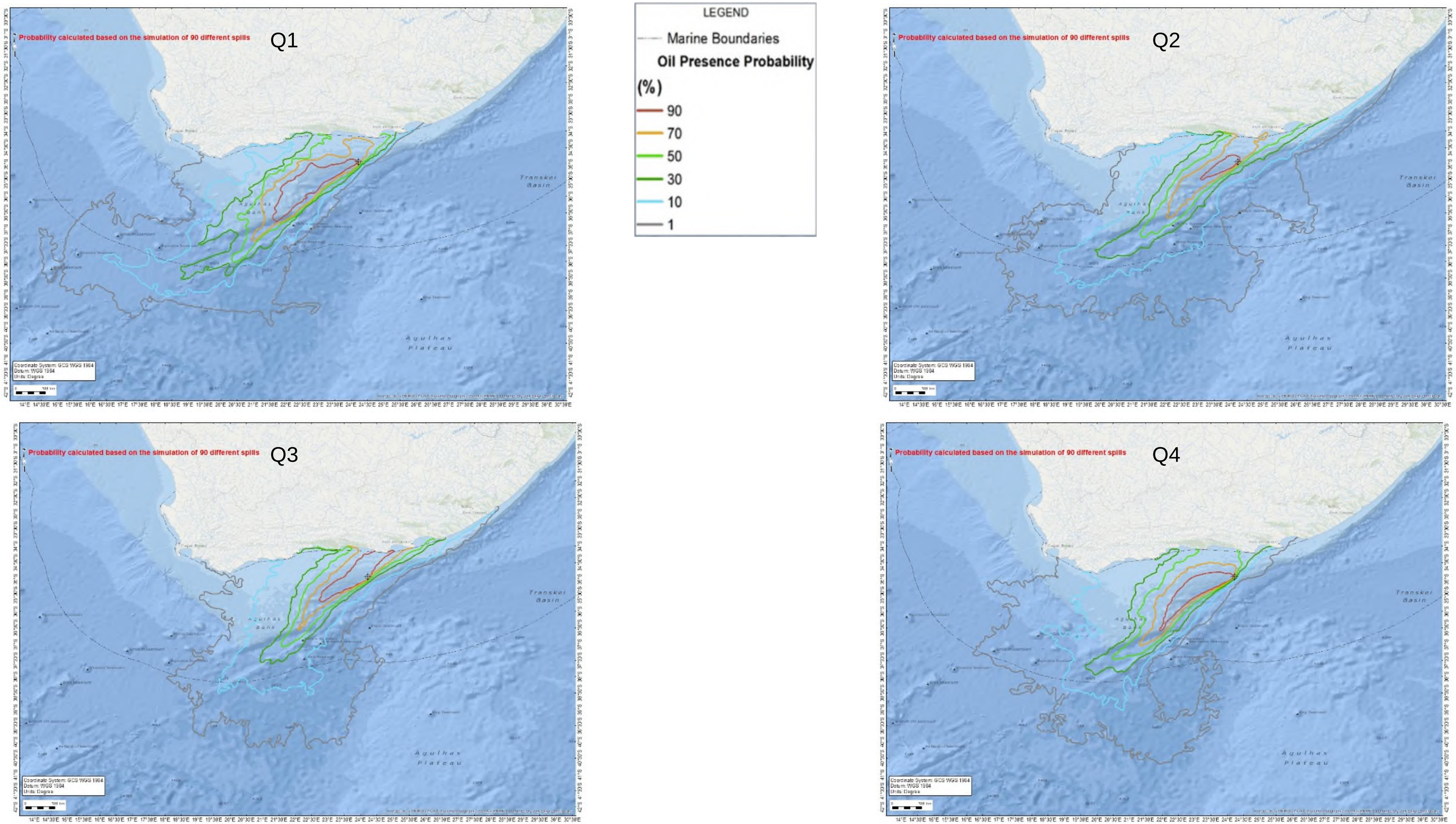

Figure 94 : Overview of the oil surface presence probability for Q1, Q2, Q3 and Q4 for discharge point 2

5. Bibliographic References

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6. Appendices

6.1 Appendix 1 – Service Request Form

OSCAR MODELLING – SERVICE REQUEST FORM

IMPORTANT/ Information detailed here must be agreed and validated (signed) by client before commencement of the study

WARNING 1: Any changes to the information mentioned herein after validation will imply an impact on the delivery time and / or costs associated with the service.

WARNING 2: For studies related with preparation and/or updating of OSCP and/or ESIA, the input data for the study as well as the results, shall be jointly verified by HSE/GCA/SUP or PSR/HSE/EP/ES/ENV/PJT, before disclosure to client.

WARNING 3: Report or results being produced are not absolute values and needs to be interpreted by specialists. Reports are not intended for external use. Any misunderstanding or misleading interpretation of results provided will be client responsibility.

Service Request		
Project	Affiliate Name:	South Africa
	Block:	11B/12B
	Well:	1 Exploration Well for Priority Area 1 1 Exploration well for Priority Area 2
Service Requestor	Name:	Eduard GROENEWALD
	Entity:	TEPSA HSE
	Position:	HSE Manager
	RFS number / date of issuance:	30T20CS730G41
	Support to:	☒ ESIA (Phase 1) ☐ ~~OSCP (Phase 2)~~
Coordination / Execution (In-House / Headquarters)	Name:	Elcio MARTINS
	Entity:	DG/PSR/HSE/EP/ES/ENV/OPS
	Position:	Environmental Engineer Antipollution
Execution (If outsourced)	Contractor Name:	H-Expertise Services S.A.S
	Project Contact Person:	Benjamin LIVAS

Service Deliverables Deadline – Phase 1		
Modelling Phase 1 (ESIA)	Technical Report – Draft Version (for review)	29/05/2020
	Technical Report – Final Version (for validation)	30/06/2020
	PowerPoint – Draft Version (for review)	Once technical report validated
	PowerPoint – Final Version (for validation)	Once technical report validated

Modelling Phase 1 (ESIA) – Scenarios if a Subsea Release	
Stochastic	Well 1 – Priority 1: ☒ 4 scenarios → a scenario for each quarter without response (release duration 20 days and simulation duration 60 days) Well 2 – Priority 2: ☒ 4 scenarios → a scenario for each quarter without response (release duration 20 days and simulation duration 60 days)
Deterministic	Well 1 – Priority 1: ☒ 4 scenarios → a scenario for each quarter without response (release duration 20 days and simulation duration 60 days) ☒ 4 scenarios → a scenario for each quarter with surface response (release duration 20 days and simulation duration 60 days) ☒ 4 scenarios → a scenario for each quarter with subsea response (SSDI at day 15 and Capping stack at day 20) and surface response (simulation duration 60 days) Well 2 – Priority 2:

1

TOTAL Classification: Restricted Distribution

	☒ 4 scenarios → a scenario for each quarter without response (release duration 20 days and simulation duration 60 days) ☒ 4 scenarios → a scenario for each quarter with surface response (release duration 20 days and simulation duration 60 days) ☒ 4scenarios → a scenario for each quarter with subsea response (SSDI at day 15 and Capping stack at day 20) and surface response (simulation duration 60 days)

Release Basic Information	
Release Coordinates (DMS in WGS84)	Priority 1 → LON = 24° 42' 3.649" E / LAT = 34° 58' 49.765'' S Priority 2 → LON = 24° 13' 18.074" E / LAT = 34° 56' 56.043''S
Release Depth (m)	Priority 1 + Priority 2 will use OSCAR bathymetry data
Release Flow Rate	69 600 bbls/day
Release Duration	20 days
Simulation Duration	60 days
SSDI Application	Deployed at release day 15
Capping Stack	Deployed at release day 20
Release Product Properties	
°API	35
Viscosity (cP)	0.19
Pour Point (°C)	<0
Wax Content (%)	8
Asphaltenes (%)	0
Selected Analogue (from model oil database)	VALHALL 2000
Release Properties	
Release Hole Diameter (m)	0.31115 (or 12 ¼ inches)
Gas Rate (Sm³/Day)	2.2 x 10^6 Sm3/day
Gas Density (Kg/Sm³)	Range 0.67 – 0.77 kg/m3
Oil Temperature (°C) at Release Point	70 – 85°C (rounded from WHFT simulation)

Ambient Average Data	
Upper Water Column Temperature (°C)	22°C (annual mean value) source: Actimar-MOC-1769-Report-Part1A_metocean_V2.0)
Lower Water Column Temperature (°C)	3°C (annual mean value) source: Actimar-MOC-1769-Report-Part1A_metocean_V2.0)
Salinity (ppt)	35 source: Actimar-MOC-1769-Report-Part1A_metocean_V2.0)
Air Temperature (°C)	21
Oxygen Content (mg/l)	0m: 7.68 / 250m: 7.36 / 500m: 6.88 / 1000m: 6.08 / 1500m: 5.44 / 2000m: 6.88
Suspended Sediment (mg/l)	0
Important: Above ambient data are a synthesis between EBS survey data and bibliographic data on the study area.	

Metocean Dataset Availability	
☐ No ☒ Yes – If yes, detail period covered: January 2012 to February 2013 (14 months)	
Geographic area covered (*in WGS84*): Latitude → 32°S to 44°S / Longitude → 13,5°E to 32°E	
Is data suitable for the service:	☐ No ☒ Yes ~~– If not, why: ???~~

Modelling Phase 1 – ESIA	
Stochastic Scenario – Visual Representations and Statistical Analysis of Modelling Results	
Surface Results	**Description/Comments**
1 Map → Surface probability of contamination above threshold	Map requiring visual interpretation of results (i.e. contouring and/or removal of possible anomalies required).

2

TOTAL Classification: Restricted Distribution

1 Table → Hydrocarbon presence on surface waters, of the different geographic locations identified in the study area (such as country, or sensitive areas, or other applicable).	Table shall summarize probability and minimum arrival time (MAT) results, of the different geographic locations, identified in the study area (such as country, or sensitive areas, or other applicable).
Shoreline Results	**Description/Comments**
1 Map → Shoreline probability of contamination above threshold	Map does not require visual interpretation of results (no contouring required).
1 Table → Hydrocarbon presence on the shoreline, of the different geographic locations identified in the study area (such as country, or sensitive areas, or other applicable).	Table shall summarize probability and MAT results, of the different geographic locations, identified in the study area (such as country, or sensitive areas, or other applicable).
Modelling Phase 1 – ESIA	
Deterministic Scenario – Visual Representations and Statistical Analysis of Modelling Results	
Surface Results	**Description/Comments**
1 Map → Spill drift evolution at surface (no contour) for the worst-case trajectory identified on the stochastic scenario	Map does not require visual interpretation of results (no contouring required). Spill drift evolution shall be represented in a single map, covering different time-steps of the simulation. Only values above the agreed surface thickness threshold shall be represented.
Shoreline Results	**Description/Comments**
1 Map → Shoreline concentration at end of simulation of the worst-case trajectory identified on the stochastic scenario.	Map does not require visual interpretation of results (no contouring required). Results shall be represented in a single map showing shoreline concentration at the end of simulation. Only values above the agreed shoreline threshold shall be represented.
Masse Balance	**Description/Comments**
1 Table → Oil fate at the end of simulation	Results to be summarized in a table.

Additional Information / Comments	

All additional information not provided in this form, but with potential to significantly affect the study progress (including results), should be here detailed.	Surface Response Strategy:
	The deterministic simulations to be carried out with surface response have considered the following resources:
	• 2 aircraft for chemical dispersion operations, deployed respectively 24 h and 72 h after the start of the spill;
	• 10 vessels for chemical dispersion operations with the following deployment times:
	  o 3 vessels 24h after the start of the spill;
	  o 2 vessels 48h after the start of the spill;
	  o 5 vessels 72 h after the start of the spill.
	• 5 pairs of vessels for containment and recovery operations with the following deployment times:
	  o 2 pairs 24h after the start of the spill;
	  o 1 pair 48 h after the start of the spill;
	3 pairs 72 h after the start of the spill.

Date ..... / ..... / .....

Validated/Approved by ....

Signature

X

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6.2 Appendix 2 – Oil Spill Response PPT (BOCP)

WELL RESPONSE STRATEGY

Total E&P South Africa – Exploration on Block 11B/12B

WELL RESPONSE OUTLINES

- **Capping Stack**
  - Objective: Stop the flowing of hydrocarbons from the well by installing a capping stack
  - Installation of capping stack requires preliminary preparation: debris clearance, ROV survey, etc.
  - TOTAL has set an objective that wells must be capped within a maximum period of 20 days during a blowout
  - Well response strategies are therefore developed and assessed against this objective before their approval

- **Subsea Dispersant Injection Kit (SSDI)**
  - Objective: Subsea dispersion to enhance biodegradation & reduce oil at sea surface
  - The priority would remain the capping stack installation
  - SSDI mobilization would be triggered since the beginning of the event in parallel to the capping stack
  - SSDI deployment will be challenging in this particular harsh environment

- **Surface Dispersion**
  - Objective: Disperse oil on the sea surface to enhance biodegradation & reduce oil impact on shore
  - Surface dispersant will be applied from day 1 of the incident with available resources on site
  - Additional resources will be mobilized from OSRL Global Dispersant Stockpile to ensure a ramp up of the response

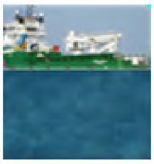
- **Relief Wells (Long-Term Strategy)**
  - Objective: Intercept the flowing well and kill it by injecting mud
  - RIG identified & equipment secured. RIG to be mobilized from North Sea after RIG upgrade.

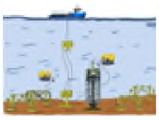
TOTAL Classification: Restricted Distribution

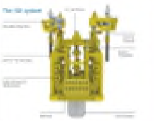
1 TOTAL

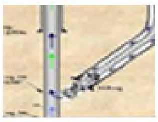
WELL RESPONSE STRATEGY

Action	Strategy	Deployment means		Expected Duration
Site Survey and BOP intervention	Use of ROV available onsite	1. PSV fitted with ROV & intervention skid 2. Rig if available		2 days
Debris Clearance Kit	Primary: WWC (UK) Secondary: OSRL (Norway)	2x MPSV w/ compensated crane 2x ROV	1x PSV fitted with ROV 1x intervention vessel w/ ROV	12 days
Subsea Dispersant Injection Kit (SSDI)	Primary: WWC (UK) Secondary: OSRL (Norway)	Drill pipes from the rig	1- Rig if available 2- Drilling rig (Total E&P affiliate)	12 days
Capping stack	Primary: OSRL (SA) Secondary: WWC (UK or SGP)	1x MPSV w/ compensated crane	1x Intervention vessel + 1x work class ROV	19 days
Dispersant	1. Available on site 2. Stockpile in South Africa 3. Stockpile in France 4. Stockpile in UK	Dispersant used for SSDI or oil spill response – Total available = 2 800 m^3 Dispersant supply ramp-up until 7 days		1. Immediate 2. 7 days
Relief Wells	Top hole with drillship from Total E&P affiliates Riser connected sections to be drilled with Rig sister-ship	1. Drilling rig (Total E&P affiliates) 2. Rig sister-ship		+/- 9 months









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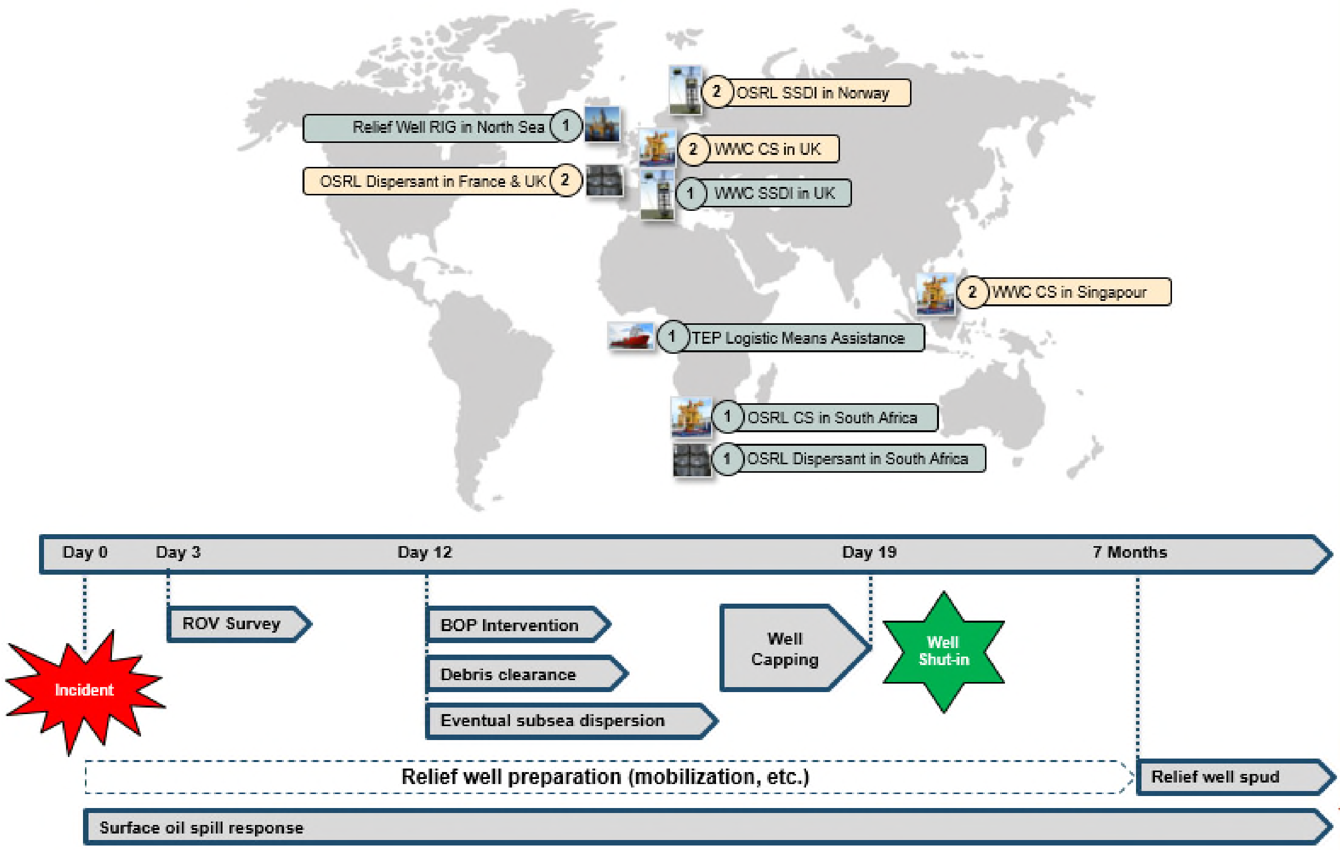
WELL RESPONSE OVERVIEW



6.3 **Appendix 3 – Metocean Data Memo**

TOTAL MEMO

Exploration & Production

TEPSA/OPS – TEPSA/2020-0098/OPS.PL

Destinataire : C. MICHEL (EP/AF/A-FE/ZA-TEP/HSEQ) *To* E. GROENEWALD (EP/AF/A-FE/ZA-TEP/HSEQ)	Expéditeur : P. LATTES (EP/AF/A-FE/ZA-TEP/OPS) T. MAJA (EP/AF/A-FE/ZA-TEP/OPS) *From*
Copie : *Copy*	Date : April 21th 2020
Object : 3D current model calibration and methodology – South Blocks - South Africa. *Subject*	Philippe LATTES Signature numérique de Philippe LATTES Date : 2020.06.09 13:20:38 +02'00'

1 Background

Block 11B/12B is characterized by harsh environmental conditions. Total Hs and surface winds show clear seasonality signals with best conditions occurring during austral summer. Another aspect that affects Block 11B/12B is the core of the Agulhas Current. This warm and saline current is formed by several oceanic currents in the Indian ocean and is the second strongest current in the world.

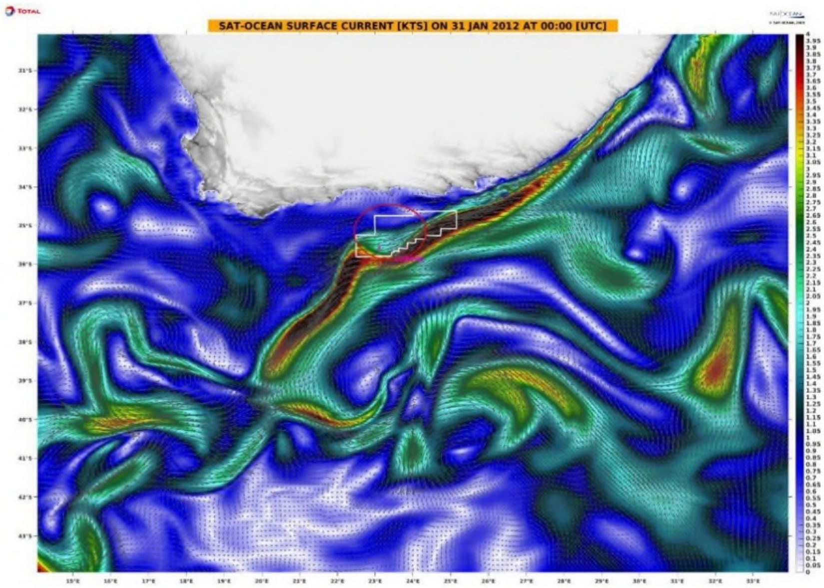


Figure 1: Current speed map of current flow over the southern African region showing the Agulhas Current system for January 2012. A shear edge eddy (red circle) cross the 11B/12B block is demarcated by a white polygon.

MEMO

A great portion of the 11B/12B block lies on the pathway of the Agulhas Current, a fast and narrow western boundary current flowing along the eastern and southern coasts of South Africa. The core of the current is generally positioned across the block and is occasionally perturbed by shear edge eddies (see Figure 1) generated upstream south of Port Elizabeth (34° S) and or Natal pulse anomalies generated offshore Durban. During passage of these anomalies, the current speeds over the block are either weakened or reinforced with an associated change in flow direction and depending on the behavior of the anomaly (see Figure 2).

Current speeds of up to and exceeding 6 knots have been recorded within the core of the current associated with meanders. Current direction can change in response to change in winds and or progression of large eddies. The Agulhas Current does not present any seasonality as the anomalies impacting the current flow, in addition to weather, are sporadic and difficult to predict.

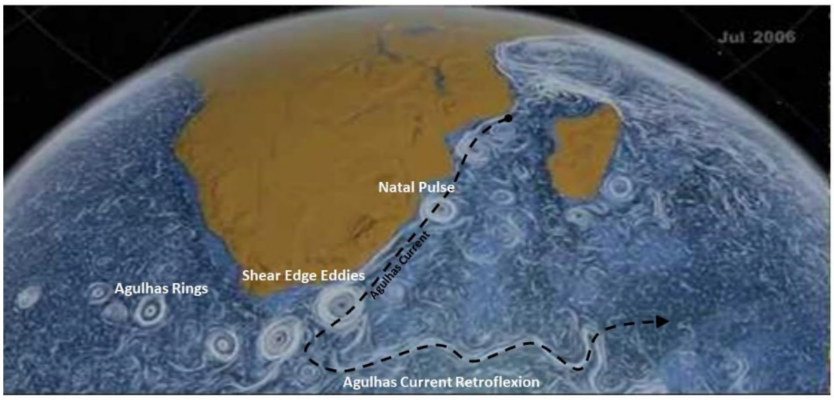


Figure 2 Large current eddies due to shear stress induced by the coast and continental shelf in South Africa

2 SAT-OCEAN Model description

SAT-OCEAN have developed innovative and exclusive technologies based on in-situ, satellite sea surface temperature, wind and altimetric data by which absolute ocean currents and winds are computed, anywhere in the world.

In effect, coupled inverse/direct modeling approaches combined with the data allow us to measure these quantities from space with very high spatial (1/32°) and temporal resolutions (3-hour output time step) over the model emprise (see Figure 1Figure 1: Current speed map of current flow over the southern African region showing the Agulhas Current system for January 2012. A shear edge eddy (red circle) cross the 11B/12B block is demarcated by a white polygon.).

Several studies have shown that upper layer oceanic features can be monitored from satellite measurements over long periods of time. SAT-OCEAN merge up to 9 sensor data sets and produce analyzed SST fields accurate to 0.3°C on average compared to surface drifting buoys' temperature measurements. Monitoring the ocean's surface at such resolutions yields the ability to compute absolute 3-dimensional currents

TOTAL MEMO

worldwide. In addition, SAT-OCEAN model data are cloud free and can be produced up to every 3 hours at a 7-10 km resolution in space from 1998.

SAT-OCEAN inverse/direct model is controlled by very accurate SST analyzed fields, together with wind satellite analyzed data and altimetric data, leading to high resolution current fields. Over several areas of the world including offshore South Africa, this new approach has yielded accurate current estimates with respect to simultaneous on-site measurements (ADCP, HF radars, current meter and buoys' velocities).

SAT-OCEAN also provides high quality analyzed satellite wind data, either in real time or spanning over the past 25 years. The data can be used for design or to assist offshore operations.

3 Satellite observations and Ocean Currents Monitoring

3.1 Satellite data

SAT-OCEAN bases its ocean current computations on several data sets, stemming from scatterometers (for the model forcing winds) as well as from altimeter-based and Sea Surface Temperature satellite observations (to be assimilated in the HYCOM based ocean current model).

3.2 QSCAT and SSMI satellite wind data

Satellite wind scatterometry data are processed for the purpose of forcing the 3D Navier-Stokes direct circulation model.

The data are extracted from the GSFC database (public access), and wind magnitude and direction images are processed (flagged for rainy areas, bad data, projected and calibrated against anemometer data).

The processed data are then merged via objective mapping and spectral fusion. Analyzed wind fields are produced in real time every 3 hours at a 0.125º spatial resolution.

3.3 Geostationary imagery

The geostationary raw data are routinely obtained from the GMS satellite series which cover the area of interest. SAT-OCEAN produces SST images via a methodology analogous to the one described for the AVHRR imagery (section 3.4).

The GOES image series presents a 5 km spatial resolution over the area of concern and 24 to 48 images are available each day, depending on the availability of the data.

3.4 TRMM TMI and AQUA AMSR-E imagery

TOTAL **MEMO**

The TRMM (Tropical Rainfall Measuring Mission), TMI (TRMM Microwave Imager) and AMSR-E AQUA SST image series are extracted in real time from the GSFC (Goddard Space Flight Center) data base (public access). The SSTs are already computed and the projection, geolocation and error correction are already applied. The TMI and AMSR-E measurement technology is such that the ocean is always visible no matter the cloud coverage, except over regions where it is raining. The TMI and AMSR-E image spatial resolution is about 25 km and the area is covered twice a day.

3.5 Polar Orbiting NOAA Satellite AVHRR imagery

Satellite AVHRR (Advanced Very High Resolution Radiometer) Level 1b high resolution imagery is extracted in real time from the NOAA (US National Oceanographic and Atmospheric Agency) Satellite Active Archive server (public access). The level 1b data is very similar to the Level 0 on-board recorded measurement.

The AVHRR image series presents a 1 km (Local Area Coverage) to 4 km (Global Area Coverage) spatial resolution and 10-12 images are available each day, depending on the number of orbiting satellites.

The raw satellite data are processed in real time at SAT-OCEAN including: channels 1 to 5 linear and non-linear calibrations, geolocation, clock drift and satellite attitude (roll, pitch and yaw) error corrections, Lambert Azimuthal Equal Area projection, multi-channel cloud detection and sea surface temperature (SST) will be computed using split, dual or triple window algorithms from the 5 processed channels.

3.6 Satellite altimeter data

Several altimeters are and have been orbiting with a worldwide coverage. Among those, some are performing measurements in spectral bands dedicated to ocean circulation.

SAT-OCEAN will process the data set over the area of concern for the study, calibrate and cross-calibrate all the data to construct an altimeter-based series over the area.

3.7 HF radars and ADCP

ADCP data have been recorded during seismic campaigns and dedicated surveys over the 11B/12B block and have been used for SAT-OCEAN model calibration. In addition, several HF radars installed and operated by TOTAL located along the coast (between Mossel Bay and Port Elizabeth) allowed to monitor surface current since February 2018 over a large offshore area. These data are available every 30 minutes at 6km resolution. This monitoring allows accurate historical and real time monitoring of the surface currents over the block 11B/12B and has been used for model validation/calibration.

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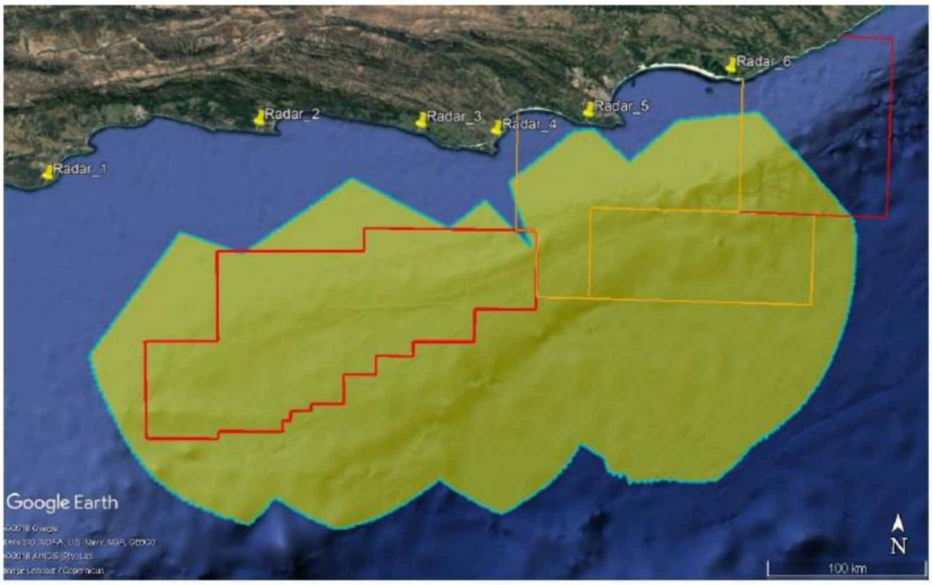

Figure 3 Coverage with 6 radar stations

4 Methodology

4.1 Ocean current computation

SAT-OCEAN ocean current modeling is based on HYCOM (Hybrid Coordinate Ocean Model - Bleck, 2001). HYCOM is a generalized hybrid vertical coordinate model widely recognized as a powerful and efficient tool for ocean modeling. To this state of the art model, SAT-OCEAN brings a significant methodology innovation in using it in an inverse way: the “data” drives the model where the dynamics is fitted onto it to yield 3D absolute ocean currents.

SST cloud-free fields are produced from merged sensor data sets with a very high spatial and temporal resolution and a 0.2°C rms error compared to simultaneous *in situ* measurements. From there, a regression coefficient calculation derived from simultaneous altimetric fields and historical Temperature / Salinity (T/S) profiles yields 3D temperature and salinity, daily: the obtained 3D T/S is called SAT-OCEAN dynamic climatology and represents as closely as possible the 3D state of the ocean over a given region.

The 3D T/S data is then strongly being assimilated in HYCOM/SAT-OCEAN model, strongly in the sense that it is given very little freedom to the model, and are very close to performing an inversion of forcing data, for the ocean circulation (except in the mixed layer which is highly driven by the forcing wind stress). Another way to present this is to say that ocean currents is fitted with high quality 3D satellite data, rather than obtaining current "data" from a model.

TOTAL MEMO

SAT-OCEAN also make a quantitative use of *in situ* data to calibrate the model when available (section 4.2).

A first 1/16° assimilated global model in-house run is used that covers the global ocean domain. Then, a fine resolution 1/32nd degree configuration of the assimilated model will cover a very large target area covering the offshore South Africa area of concern. The run will encompass 34 layers, with an about 10-layer sampling of the thermocline and a 3-hour output time step.

4.2 Calibration

Where TOTAL HF Radar and ADCP *in situ* current measurements are available, SAT-OCEAN performs a calibration and validation of their 3D ocean current model against the field data. Many mooring data as possible are used to perform the model calibration, including previous drilling campaigns and extensive seismic survey-based hull mounted ADCP on site current measurements. However, model calibration and validation at the deeper layers remain always more challenging due to the lack of measurements and are generally less reliable than at the surface where a larger quantity of data measurements are available. For each data set, current speed and direction measurements are extracted at all times and depths from all the provided files, and time-depth arrays are built. Specific procedures are then developed and applied (SVD decomposition, Kalman filtering etc.) to process the data at each measurement site such that it can be used for quantitative comparison and assimilation into the current model.

The pre-processed measurements are then used by SAT-OCEAN to extract the best calibration scheme for obtaining an improved time-depth dataset at each of the mooring sites. The outcome of this approach significantly improves the correlation between the modeled currents and the measurement series. Typically, SAT-OCEAN derive a calibration scheme over a learning data subset and evaluate the result over the remainder set, providing solid ground for the calibration scheme generalization to periods beyond learning periods. The final calibration scheme is applied to the entire ocean current historical/hindcast period to obtain calibrated hindcast datasets at every mooring location.

A calibration of the full South African south blocks dataset is finally performed. Spatial correction fields are derived in order to quantify at all ocean locations the influence of the locally calibrated currents at the mooring sites and of the modeled currents at each grid point of the hindcast domain.

The methodology results in a fully calibrated ocean current data set that takes the best advantage of the HF radar and ADCP on-site data available and of the assimilated model hindcast.

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4.3 Validation: currents and winds

4.3.1 Surface current

The SAT-OCEAN model currents were compared against observational data from HF radar for the purpose of validation. Only currents at the surface could be validated due to limited or no data at the sub-surface and for this exercise, 30 days of surface current observations from a single point were extracted from the HF radar dataset. The comparison of modelled currents with observations offers an opportunity to assess the ability of the SAT-OCEAN model to represent the current variability from the extracted data. Time series data starting from 10/03/2020 and ending on 10/04/2020 is presented in Figure 4 below.

From the visual inspection of the presented time-series in Figure 4 and scatter plots in Figure 5, surface current observations are generally coherent with SAT-OCEAN currents during the 30-day period. The SAT-OCEAN current presents a relative error RMS of 0.32kt. The increasing and decreasing patterns are consistent between the model and observations although there are slight differences in the magnitude of current speeds. The absolute mean bias between the SAT-OCEAN model and HF radar observations generally should not exceed 1 knot and there are occasional and slightly differences in the direction of the surface current flow.

Figure 4: Surface currents time-series from SAT-OCEAN (model) vs HF Radar (observations) for 30 days.

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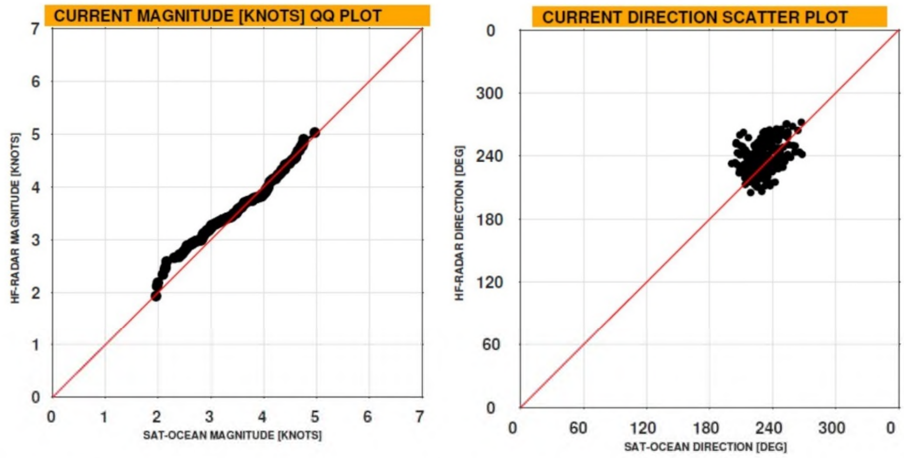

Figure 5 Current speed QQ plot and current direction scatter plot of SATOCEAN model vs observation for the considered period

For the given location, SAT-OCEAN modelled currents performed adequately indicating a reasonably fair representation of the surface current conditions over the 11B/12B block. The performance of the model may vary depending on features impacting the current flow e.g. a meandering core vs jet-regime state. Caution should be exercised when interpreting these results as they only represent validation at a single point within the block area (i.e. the Luiperd well location).

4.3.2 Winds

For the wind model validation, METAR (METeorological Airport Report) wind observations are used as reference to compare with the model output. The comparison is made from a weather station wind dataset from Port Elizabeth which is located north-east outside the11B/12B block along the South African coast. The Port Elizabeth location is within our observation area of interest with HF radars and therefore a relevant position for validation of the wind model. The time series comparison between the dates 10/03/2020 and 10/04/2020 is presented below in Figure 6.

Strong correlation between wind observations and model (see Figure 7) is recorded from the 30-day time series with the model explaining more than 88% of the variability in wind observations (r = 0.94 and rms = 13 kt). The SAT-OCEAN wind model provides coherent and consistent representation of the winds and is accurate in both magnitude and direction. Although the extreme wind conditions at 11B/12B can often exceed that of Port Elizabeth, the SAT-OCEAN model has proven its adequacy in capturing and representing wind conditions over a larger area including the full extent of the 11B/12B block.

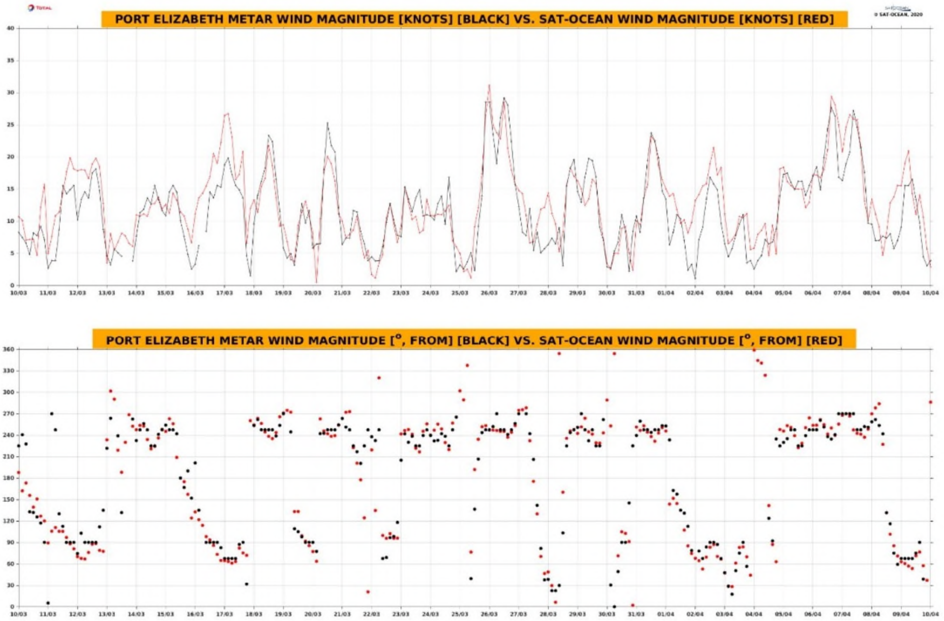

Figure 6 Surface winds time-series from SAT-OCEAN (model) vs METAR (observations) for 30 days.

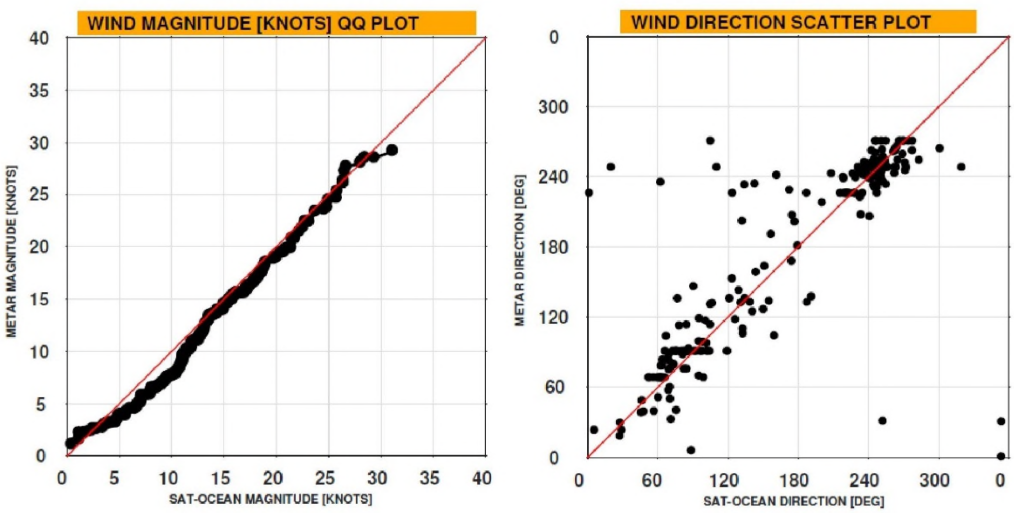

Figure 7 Wind speed QQ plot and wind direction scatter plot of SATOCEAN model vs observation for the considered period

6.1 Appendix 4 – ITOPF rate of removal of oil from the sea

From ITOPF (International Tanker Owners Pollution Federation) website the evolution of oil or condensate at sea over time can be illustrated as follows depending on the oil type.

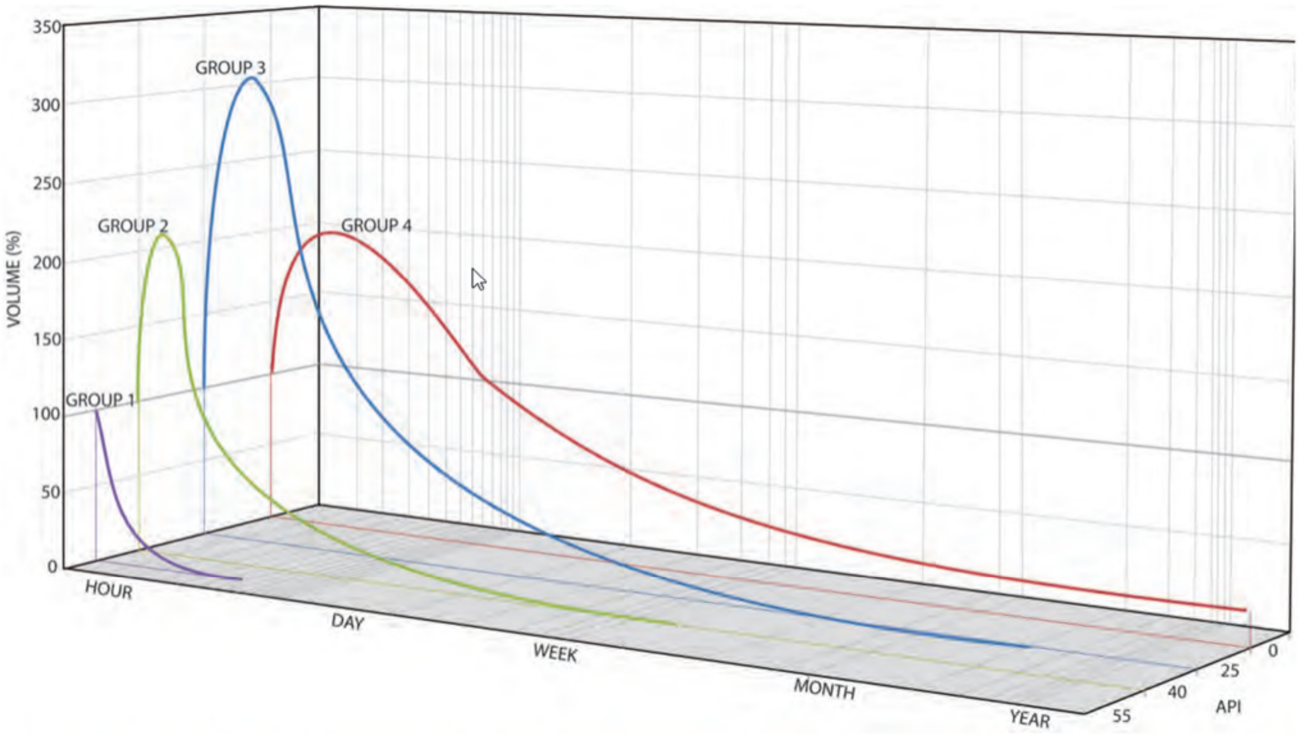

Figure 13: The volume of oil and water-in-oil emulsion remaining on the sea surface shown as a percentage of the original spill volume (100%) for a typical oil from each of the groups shown in Tables 1 and 2. The curves represent an estimated 'average' behaviour for each group. However, the behaviour of a particular crude oil may differ from the general pattern depending on its properties and the environmental conditions at the time of the spill.

Source: ITOPF Technical Information paper 2 : Fate of Marine Oil Spills downloadable from: http://www.itopf.org/knowledge-resources/documents-guides/document/tip-02-fate-of-marine-oil-spills/

Condensates belong to group 1 and would not remain long at surface. The crude oil from the discharge points on bloc 11B/12B would be between group 2 and group 3.

This shows that condensate at sea should disappear within 24h.

Group 1 oils

A: °API > 45 (Specific gravity < 0.8)
B: Pour point °C
C: Viscosity @ 10–20°C: less than 3 CSt
D: % boiling below 200°C: greater than 50%
E: % boiling above 370°C: between 20 and 0%

	A	B	C	D	E
Aasgard	49	-28	2 @ 10°C	58	14
Cossack	48	-18	2 @ 20°C	51	18
Curlew	47	-13	2 @ 20°C	57	17
F3 Condensate	54	<-63	1 @ 10°C	81	0
Gippsland	52	-13	1.5 @ 20°C	63	8
Hidra	52	-62	2.5 @ 10°C	60	11
Terengganu condensate	73	-36	0.5 @ 20°C	>95	0
Wollybutt	49	-53	2@ 20°C	55	4
Gasoline	58		0.5 @ 15°C	100	0
Kerosene	45	-55	2 @ 15°C	50	0
Naptha	55		0.5 @ 15°C	100	0

Group 2 oils

A: °API 35–45 (Specific gravity 0.8–0.85)
B: Pour point °C
C: Viscosity @ 10–20°C: between 4 Cst and semi-solid
D: % boiling below 200°C: between 20 and 50%
E: % boiling above 370°C: between 15 and 50%

Low pour point <6°C

	A	B	C	D	E
Arabian Extra Light	38	-30	3 @ 15°C	26	39
Azeri	37	-3	8 @ 20°C	29	46
Brent	38	-3	7 @ 10°C	37	33
Draugen	40	-15	4 @ 20°C	37	32
Dukhan	41	-49	9 @ 15°C	36	33
Liverpool Bay	45	-21	4 @ 20°C	42	28
Sokol (Sakhalin)	37	-27	4 @ 20°C	45	21
Rio Negro	35	-5	23 @ 10°C	29	41
Umm Shaif	37	-24	10 @ 10°C	34	31
Zakum	40	-24	6@ 10°C	36	33
Marine Gas oil (MGO)	37	-3	5 @ 15°C		

High pour point >5°C

	A	B	C	D	E
Amna	36	19	Semi-solid	25	30
Beatrice	38	18	32 @ 15°C	25	35
Bintulu	37	19	Semi-solid	24	34
Escravos	34	10	9 @ 15°C	35	15
Sarir	38	24	Semi-solid	24	39
Statfjord	40	6	7 @ 10°C	38	32

Note: High pour point oils only behave as Group 2 at ambient temperatures above their pour point. Below this treat as Group 4 oils.

Group 3 oils

A: °API 17.5–35 (Specific gravity 0.85–0.95)
B: Pour point °C
C: Viscosity @ 10–20°C: between 8 CSt and semi solid
D: % boiling below 200°C: between 10 and 35%
E: % boiling above 370°C: between 30 and 65%

Low pour point <6°C

	A	B	C	D	E
Alaska North Slope	28	-18	32 @ 15°C	32	41
Arabian Heavy	28	-40	55 @ 15°C	21	56
Arabian Medium	30	-21	25 @ 15°C	22	51
Arabian Light	33	-40	14 @ 15°C	25	45
Bonny Light	35	-11	25 @ 15°C	26	30
Iranian Heavy	31	-36	25 @ 15°C	24	48
Iranian Light	34	-32	15 @ 15°C	26	43
Khafji	28	-57	80 @ 15°C	21	55
Sirri	33	-12	18 @ 10°C	32	38
Thunder Horse	35	-27	10 @ 10°C	32	39
Tia Juana Light	32	-42	500 @ 15°C	24	45
Troll	33	-9	14 @ 10°C	24	35
IFO 180	18–20	10–30	1,500–3,000 @ 15°C		–

High pour point >5°C

	A	B	C	D	E
Cabinda	33	12	Semi-solid	18	56
Coco	32	21	Semi-solid	21	46
Gamba	31	23	Semi-solid	11	54
Mandji	30	9	70 @ 15°C	21	53
Minas	35	18	Semi-solid	15	58

Note: High pour point oils only behave as Group 3 at ambient temperatures above their pour point. Below this treat as Group 4 oils.

Group 4 oils

A: °API <17.5 (Specific gravity >0.95) or
B: Pour point >30°C
C: Viscosity @ 10–20°C: between 1500 CSt and semi-solid
D: % boiling below 200°C: less than 25%
E: % boiling above 370°C: greater than 30%

	A	B	C	D	E
Bachaquero 17	16	-29	5,000 @ 15°C	10	60
Boscan	10	15	Semi -solid	4	80
Cinta	33	43	Semi -solid	10	54
Handil	33	35	Semi -solid	23	33
Merey	17	-21	7,000 @ 15°C	7	70
Nile Blend	34	33	Semi-solid	13	59
Pilon	14	-3	Semi-solid	2	92
Shengli	24	21	Semi-solid	9	70
Taching	31	35	Semi-solid	12	49
Tia Juana Pesado	12	-1	Semi-solid	3	78
Widuri	33	46	Semi-solid	7	70
IFO 380	11–15	10–30	5,000–30,000 @ 15°C		

Source: ITOPF Technical Information paper 2 : Fate of Marine Oil Spills downloadable from:
http://www.itopf.org/knowledge-resources/documents-guides/document/tip-02-fate-of-marine-oil-spills/