Africa Oil SA Corp SOUTH AFRICA

Well Drilling in
Block 3B-4B

OIL SPILL DRIFT MODELLING

TECHNICAL REPORT
V03

Date: December 5th 2023

Identification page

Title	:	Exploration Well Drilling in Block 3B-4B off the West Coast of South Africa - Oil Spill Drift Modelling
Author(s)	:	Benjamin LIVAS
Location - Date	:	Pau – October 2023

- **Study's reference:** OPP-2023-01-0100
- **Number of volumes**: 1

Keywords: Oil spill modelling, condensate, stochastic, trajectory, oil fate, release point.

Geographical references: South Africa / Offshore / Block 3B-4B

This study, based on best available information and industry-standard numerical modelling methods, describes possible fates and trajectories of an oil spill from a subsea blowout of a well in Block 3B-4B located off the West Coast of South Africa. The Release Point selected for the study scenarios (refer to 1.1) represent the worst-case locations in the block.

Here is a summary of the results with a general conclusion:

- ✓ DRIFT DIRECTION:
  The general direction of the surface oil drift is NW for the all the Quarters in this marine area.
- ✓ DRIFT DISTANCE:
  The maximum distance of the 80 to 100% oil surface probability contour is 42 km NNW from Release Point during the Quarter 1 (January to March).
- ✓ SURFACE PRESENCE PROBABILITIES: there is almost no oil on surface due to large evaporation and dispersion processes on this condensate, but the **Namibian and International Waters could be impacted by surface oil with very low probabilities (3.3%). This means that probabilistically, out of 100 spills that could occur during each quarter period, only 3 cases would have oil on the surface which would cross the Namibian border and international waters.**
- ✓ WATER COLUMN CONTAMINATION: the most contaminated layer is between 725 to 900 m depth for capping only and 775 to 875 m for full response deployed. This is probably due to the large amount of gas contained in the release, making the condensate going up very quickly, and then accumulates in the mid water column before continuing to rise more slowly to the surface.
- ✓ COASTAL IMPACT: there is **no coastal impact** for this type of release for any Quarter of the year, due to the currents in the area making the release always drifting towards NW, opposite to the coastal area.
- ✓ SURFACE RESPONSE: The surface response was only studied for the Quarter 3 (initial planned Drilling period) there is very light effect of the response deployed: the dispersed part is varying very slightly, the atmosphere part is a little reduced, thanks to the very light increase in dispersion. The biodegradation is higher with the response, mainly due to the light increase dispersion in the water column with the SSDI (these two parameters are always positively correlated).

  Because of the properties of the condensate, the SSDI deployment has a very light effect on the dispersion which is already important, and the surface response which consists of dispersing and recovering oil slicks is of no use because all the condensate disperses in the water column or evaporates upon arrival at the surface. In this kind of release, the better choice would be to deploy the capping stack as soon as possible instead of trying to increase the dispersion that is already high for this type of product.

Distribution list of complete report:

EIMS	GP KRIEL

Table of content

Figures

Tables

1. Introduction

This study, based on best available information and industry-standard numerical modelling methods, describes possible fates and trajectories of an oil spill from a subsea blowout of a well in Block 3B-4B located off the West Coast of South Africa. The Release Point selected for the study scenarios (refer to 1.1) represent the worst-case locations in the block.

To perform this project, the Oil Spill Contingency And Response (OSCAR) module from MEMW software (v 14.1) was used to undertake the modelling. This tool is among the best in its class for oil spill modelling, considering its capabilities to determine how a slick will drift and how oil components will interact with the marine environment. An oil slick is represented by many independent particles drifting according to oceanic currents and winds and whose positions and mass are recorded in a defined timeline.

Four modelling period are considered (*i.e.* each quarter of the year) for the study. The release location, release duration, discharge rate, and the selected oil type are the same for all the scenarios. The scenarios considered for this study were based on best available input data at the time of the study and are discussed in this report, developed in 2.2.2).

This modelling study considers two approaches, namely:

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

1.1 Release Points Selection and Location

The exact locations of the wells to be drilled within the area of interest in Block 3B-4B are not yet known.

As several well locations were proposed, the locations were selected for modelling based on:

- Distance from the coast: it will directly influence the travel time and quantities that may be stranded on the shoreline.

- Proximity of marine protected areas (MPAs) and critical biodiversity areas (CBAs) that might be impacted especially by drilling discharges which are more localized than oil spill (refer to separate drilling discharges modelling study) (see Figure 1).

- Winds and Currents directions that could potentially cause the oil slick to drift ashore.

One location is retained, considered as the worst-case locations inside the area of interest, and are presented on Figure 1.

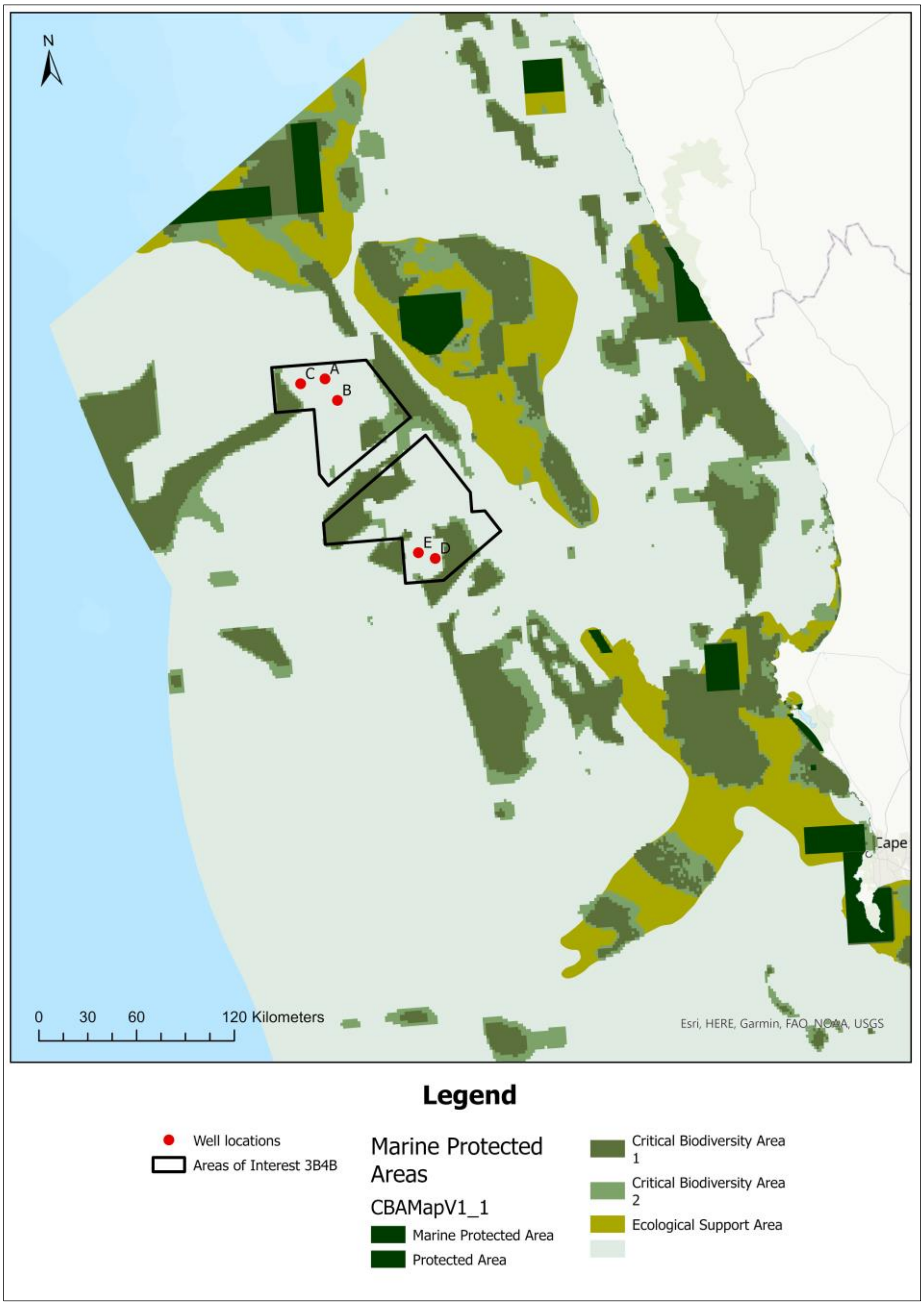

Figure 1: Release points locations, area of interest and sensitivity map

The characteristics of the selected location are presented in Table 1.

Table 1: Release points depth and currents and winds trends

RELEASE POINT	Coordinates (WGS84)	Water Depth (m)	Surface currents main directions (to)	Winds main directions (from)
D	Longitude: 15° 42’ 19.51”E Latitude : 32° 07’ 33.38” S	1499	WSW to NNE	S to SE

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, to simulate the oil's drift, concentration, and extent, on the sea surface and/or water column 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 considers the following processes affecting the oil spill (Figure 2):

- **Spreading**: the fact for the slick to become thinner over a larger area.
- **Emulsification**: water droplets are incorporated to the oil, increasing the density and viscosity of the emulsion.
- **Evaporation**: light components of the oil go to the gas phase.
- **Advection**: the oil slick, dispersed oil droplets and dissolved oil components move according to currents and winds. Some random movements are modelled as well to consider small and local scale phenomena that are not incorporated in the current and wind dataset.
- **Entrainment** (natural dispersion): under the action of waves, the slick is broken in small droplets and entrained into the water column. Depending on the droplet size, the droplet will resurface at different speeds if they resurface at all.
- **Dissolution**: soluble components of the oil will be dissolved in water.
- **Sedimentation**, when oil or emulsion density are high enough, they can sink and lay on the sea bottom.
- **Stranding**: oil can reach the shore and strand.
- **Biodegradation**: the various components of oil can be degraded by bacteria. The biodegradation modelling considers only the first step of biodegradation. Moreover, no lag time for the bacteria colonies activation is considered.

The modelling of these various processes is well described in the Chapter 22 "technical description" in MEMW user guide (SINTEF, 2021). In the water column, horizontal and vertical advection and dispersion of entrained and dissolved hydrocarbons are simulated by random walk procedures. 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), (Reed, French, Rines, & Rye, 1995), (Reed & Hetland, 2002), (Pan *et al*., 2020)).

Wind drift coefficient is 3.5% and Coriolis deflection angle is 0.

Near-field blowout model in OSCAR

The near-field blowout model in OSCAR representing the behaviour of the oil rising with its associated gas in the water column in case of a subsea blowout is Deepblow (Johansen, 2000), referred to as Plume3D in OSCAR. The model is based on a Lagrangian model concept, like 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) (Zheng, Yapa, & Chen, 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. 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 subject 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.

For more details about the OSCAR model and a comparison between a real case refer to Pan, *et al*., 2020.

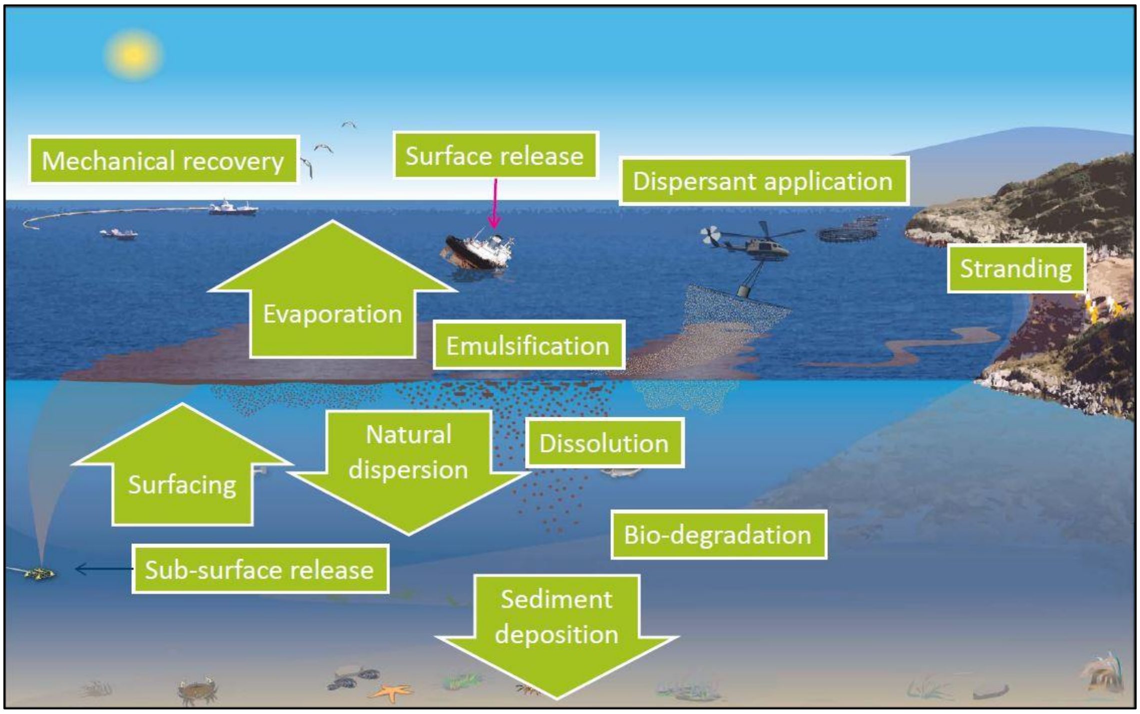

Figure 2: Physical and chemical processes included in the model (OSCAR)

Careful consideration needs to be given to the distinction between stochastic and deterministic modelling (see sections below to understand that **stochastic modelling does not represent a single oil spill)**.

2.1.1 Deterministic approach and visualization

The Deterministic modelling (or single spill trajectory analysis) is the modelling of the trajectory (where the oil travels) and fate (what it becomes: evaporation, biodegradation, stranding) of a **single oil spill at one moment in time** under predefined hydrodynamic and meteorological conditions.

In these types of studies, deterministic simulations are used to provide an example of what could be the evolution of one single spill. Usually a conservative case (worst-case) is chosen, showing for example the shortest time of impact to the coast, or the largest quantity of hydrocarbons to the coast. The outcomes of deterministic modelling provide a reasonable approximation of what a single 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.

Representations: In the maps representing the surface spill drift evolution, oil presence above the threshold value (0.04 µm) per grid cell are represented. The cut-off is applied only to the graphic representation of these quantities: in the model there are cells with a thickness (= a quantity of oil per unit area) less than 0.04 µm, and these hydrocarbons will cause the impacted coast areas to appear larger.

2.1.2 Stochastic approach and visualization

OSCAR allows to perform statistical modelling providing insight into how typical oil spill scenarios unfold under a wide range of weather or seasonal conditions.

- Stochastic oil spill modelling is created by overlaying several individual, computer-simulated, hypothetical oil spills (results of deterministic simulations). **The focus here is not on the quantities of oil, but on the presence of oil on the surface or in the water column at any moment above the threshold.**

- The simulated oil spills for a stochastic model start from the same location (e.g., a drilling location in this study) but each oil spill scenario will have a different release starting date and are thus subject to a different set of metocean (wind and currents) conditions drawn from historical records (which are from 2019 to 2021 for this study). The map below is an example of the stochastic simulation principle, with spill footprint superposition → Depending on the start date, the oil slick will not have the same surface area and/or direction from the release point and potential impacted coastlines, due to the different directions of the winds and currents.

- The principle can be explained in three steps (illustrated in the Figure 3 below):
  - ✓ STEP 1/ Modelling software calculates for a given simulation where, at any time during this simulation, there is oil above the threshold (= spill footprint) for each deterministic run.
  - ✓ STEP 2/ The software then calculates at each point how many simulations have oil above the threshold, and then calculates the associated probability.

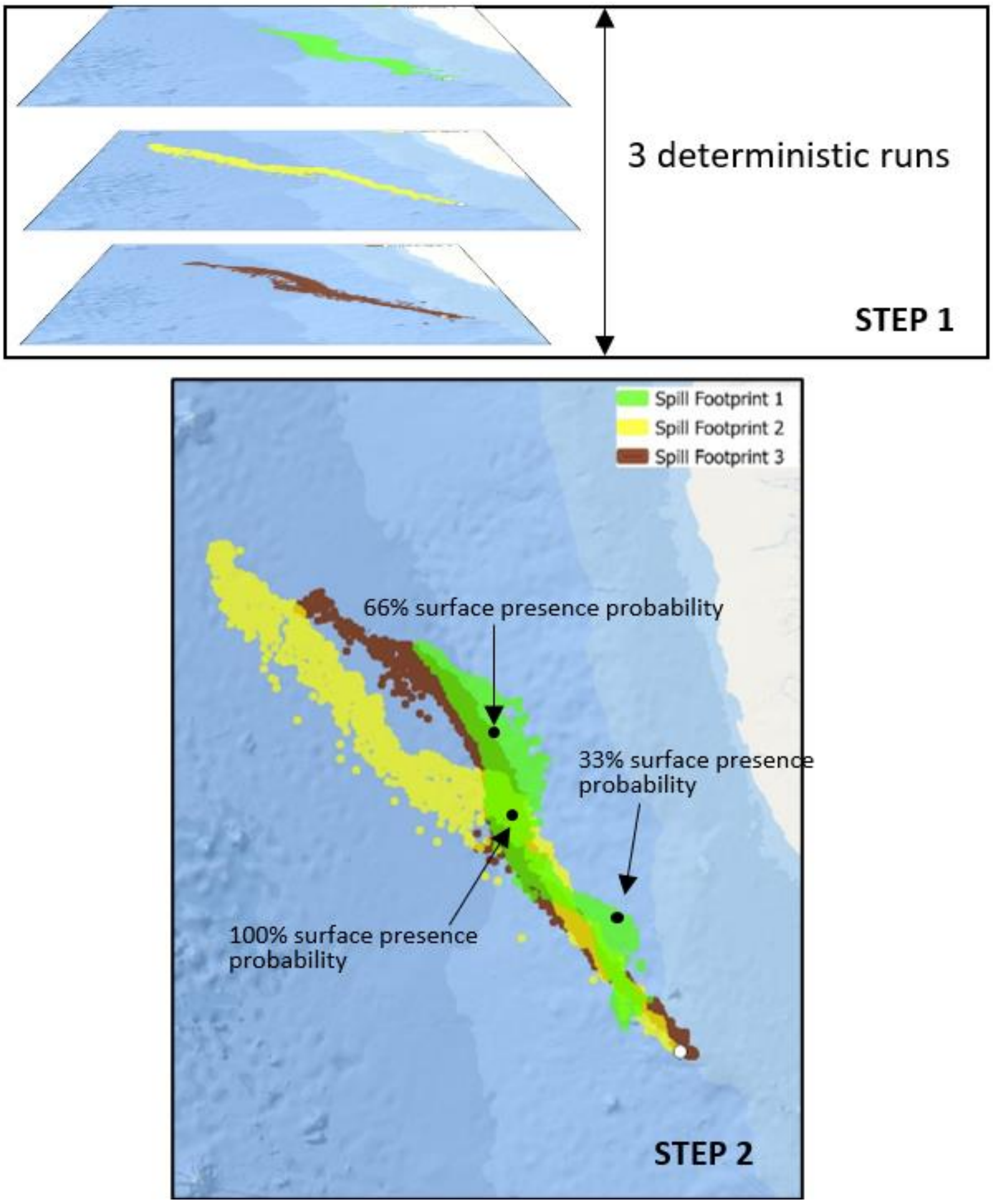

Figure 3: Schematic illustration of stochastic approach

In this study, as onshore oiling never occurs, the focus was made on the Oil Dispersed quantity at the end of the simulations to select the deterministic cases to study. This allows one to see the variability of the impact of the spill in the water column depending on its release date, because there is no oil on surface at the end of the simulations (important evaporation).

This type of results can be useful for informing preparedness and response arrangements as it shows which areas are more or less likely to be impacted in the unlikely event of an oil spill.

2.2 Environmental data

2.2.1 Seasons and Environmental Average Data

The Quarter 3 (July to September) was studied in this project.

Environmental data used for the modelling simulations are detailed in Table 2:

Table 2: Environmental average data.

Upper water column temperature (°C)	Season 1: 20.2 Season 2: 19.2 Season 3: 16.4 Season 4: 16.9
Lower water column temperature (°C)	2.5
Salinity (‰)	35
Seawater oxygen content (mg/l)	5.2
Suspended sediment (mg/l)	4

Temperature and salinity data detailed in the table above are coming from Copernicus global-reanalysis-001-030-monthly dataset over 1993-2020 at the release location. Oxygen content and suspended sediment is a synthesis between data from TEPNA 2913B-Venus EBS (2018) and - TEPSA 567 EMPr update seismic (2013).

2.2.2 **Metocean Dataset (3D Currents & 2D Wind Data)**

The current data used are based on a 3-year dataset (1st of January 2019 – 31st of December 2021) which comprises 3D currents from the continuous current hindcast at each grid point:

- 3D currents
  - NetCDF format (OSCAR compatible)
  - 3 years of data (1st of January 2019 – 31st of December 2021)
  - Spatial resolution at least 1/32°
  - Vertical resolution: 32 layers with different resolutions (5m layers at surface, 500 m layers at 5500 m)
  - Time step: 3 hours.

2.2.3 **Bathymetry**

The Synbap depth database (Figure 4), integrated in the OSCAR Software, was used for the simulations in this study.

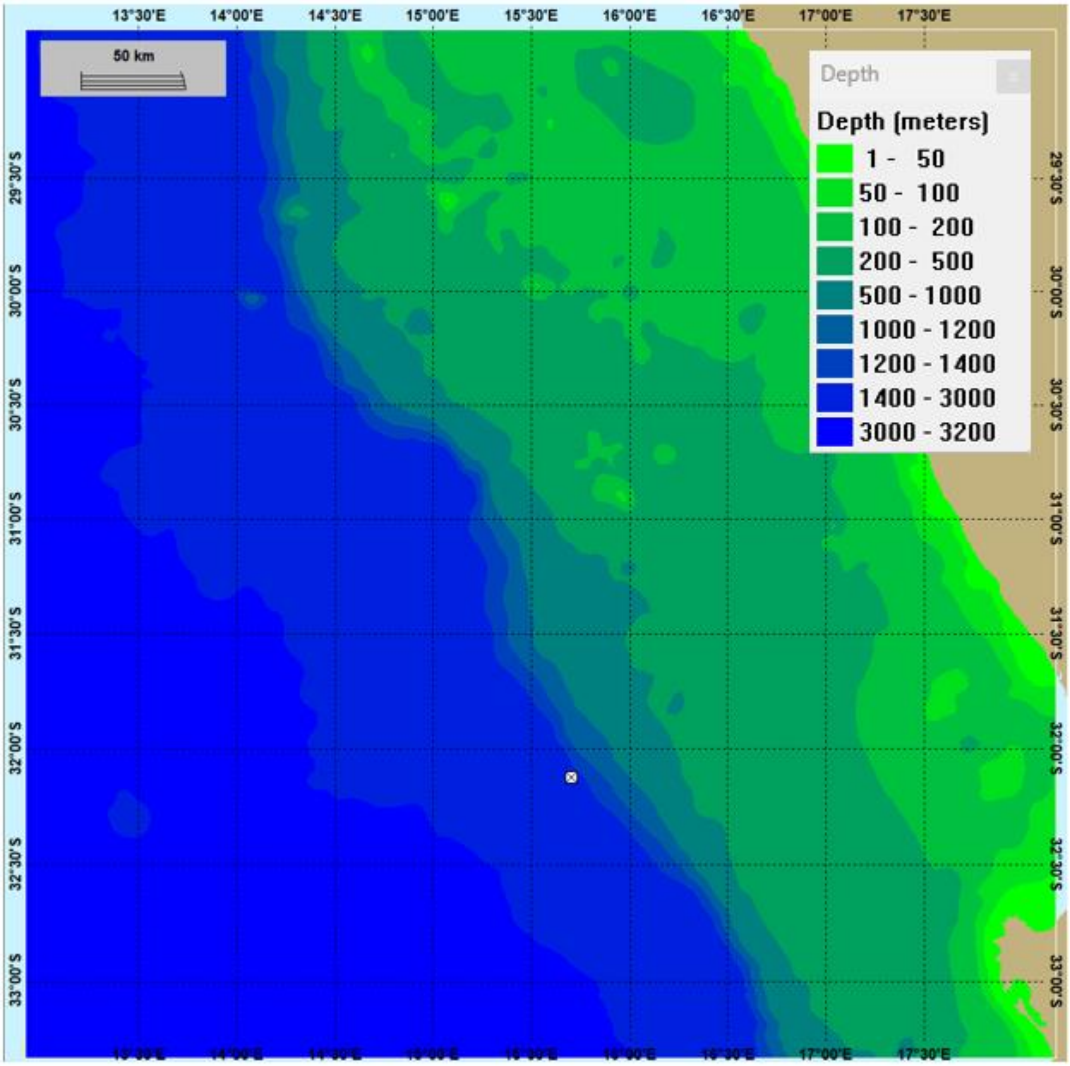

Figure 4: Bathymetry used within the model (*Source: Synbap / MEMW*)

2.3 Scenario Parameters

2.3.1 Hydrocarbon Profiles

A condensate field like Brulpadda and Luiperd on the South Coast of RSA is expected in the Block 3B/4B. For this reason, a condensate with similar properties than the one expected is selected within OSCAR database to perform the modelling as illustrated in Table 3. The condensate selected from SINTEF'S OSCAR Database as an analogue is "Condensate SKARV 13 DEG -2014". This weathering characteristic of this oil (emulsification, evaporation…) were measured in a laboratory and better allow to simulate behaviour and fate of condensate in the marine environment.

Table 3: Properties of condensate profile used in the model (source MEMW/OSCAR Oil Database)

Release Product Properties	
Selected Analogue (from model oil database)	Condensate SKARV 13 DEG -2014
°API	39.2
Viscosity (cP) @13°C	3.0
Pour Point (°C)	6
Wax Content (%)	2.18
Asphaltenes (%)	0.01

Table 4 details the release properties used for the modelling study, including the gas associated to the release.

Table 4: Properties of the release including gas products used in the model

Release Information	
Flow Rate	238.8 cu.m / day
Oil Temperature At Release Point (°C)	70°C
Gas Rate at Release point (sm^3/day)	930000
Gas Density at atmospheric conditions (Kg/Sm^3)	0.7
Release Hole Diameter (m) (equivalent diameter to the	0.31115

area of flow for annulus flow)	

All the scenarios of this study thus simulate a continuous blowout with **238.8 cu.m/day of condensate and 930 000 Sm^3/d of gas.**

2.3.2 Oil spill response

The spill response strategies (including associated operational start and end times) listed below were applied to the study scenarios. These assumptions are based on the Oil Spill Contingency Plan (OSCP) prepared for exploration drilling campaign in Block 11B/12B in 2020 and adjusted for the Block 3B-4B location.

I. **Capping Stack deployed at the end of the 20th day stopping the release.**

Two Blow Out Preventers exist in the region: one for Block 11B/12B and one for Venus well drilling in Namibia. The capping stack would be mobilized from Saldanha Bay in both cases. The capping time would be 13 days and 20 days respectively. Here the most conservative duration was considered.

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

The subsea dispersion consists of injecting a surfactant that reduces the oil droplet size in the water column. The new droplet sizes are calculated for a Dispersant Oil Ratio (DOR) of 1% according to Brandvik *et al.,* 2019. The dispersant efficiency use is the default value of 80%.

III. **Surface dispersion with the following resources (only tested for Quarter 3):**

- **2 aircraft for chemical dispersion** operations, deployed 24 h and 72 h after the start of the spill, respectively.
- **10 vessels for chemical dispersion** operations with the following deployment times:
    - 2 vessels 24 h after the start of the spill.
    - 1 vessel 48 h after the start of the spill.
    - 2 vessel 96 h after the start of the spill.
    - 3 vessels 168 h after the start of the spill.
    - 2 vessels 216 h after the start of the spill.
- **5 pairs of vessels for containment and recovery** operations with the following deployment times:
    - 1 pair 24 h after the start of the spill.
    - 1 pair 48 h after the start of the spill.
    - 3 pairs 96 h after the start of the spill.

2.3.3 Study scenarios summary

Study scenarios for both Release Points are summarized in Table 5.

Table 5: Summary of study scenarios

STOCHASTIC SCENARIOS PER SEASON						
Scenario Number	Simulation duration (days)	Release duration (days)	Cause of the end of release (capping stack, relief well, reservoir depressurisation)	Number of days between start of release and start of SubSea Dispersion (SSDI)	SSDI DOR (dispersant oil ratio: 1% will be used if blank)	Response surface (Y /N)
STO-A	**60**	**20**	**Capping stack**	**-**	**-**	**N**
STO-B	**60**	**20**	**Surface Response + SSDI + Capping stack**	**15**	**1%**	**Y**

ESIA Modelling: DETERMINISTIC SCENARIOS PER SEASON						
Scenario Number	Simulation duration (days)	Release duration (days)	Cause of the end of release (capping stack, relief well, reservoir depressurisation)	Number of days between start of release and start of SubSea Dispersion (SSDI)	SSDI DOR (dispersant oil ratio: 1% will be used if blank)	Response surface (Y /N)
DET-A	**60**	**20**	**Capping stack**	**-**	**-**	**N**
DET-B	**60**	**20**	**Surface Response + SSDI + Capping stack**	**15**	**1%**	**Y**

2.3.4 OSCAR Model Parameters

Modelling parameters for both release points are presented in Table 6.

Table 6: Modelling Parameters

Product Type	Crude Oil	
Scenario	Stochastic	Deterministic
Grid size (in km)	500 East x 500 North 2000 East x 2000 North	
Cell size (in m)	500 m x 500 m 2000 m x 2000 m	
Vertical resolution	1st layer of 2 m (by default in OSCAR) and 19 layers from 2 m to 1600 m depth	
Number of liquid/solid particles	10 000	
Number of dissolved particles	10 000	
Calculation parameters	Time step = 60 minutes / Output interval = 3 hours	
Release depth	At seabed	

The choice of the number of particles is a trade-off between a good representativity and a reasonable calculation time (especially for the stochastic simulations). 10 000 liquid particles ensure that at each calculation time step, 5 particles are released allowing for a certain variability in their trajectories.

2.4 Results Interpretation

2.4.1 Thresholds used in the post-processing of modelling results

Thresholds values used for this study to illustrate modelling output results are detailed in Table 7:

Table 7: Threshold used in the post-processing of modelling results

Threshold	Threshold Value	Justification
Surface Oil Thickness	0.04 µm	10 µm corresponds to the thickness that would impart a lethal dose to an intersecting wildlife individual (French McCay 2009). But as the case studied was condensate, the minimum value of 0.04 µm was chosen to keep a margin and because it is also the minimum thickness visible as rainbow sheens in Bonn Agreement. 5µm is the 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 Appendix 1 - Bonn Agreement Oil Appearance Code (BAOAC)).
Water-Column	58 ppb	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 58 ppb, based on the toxicity of chemically dispersed oil to various aquatic species, which showed the 5% effect level is 58 ppb.
Shoreline Oiling	10 g/m^2	Shoreline oiling calculated for deterministic scenarios 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. 10 g/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 with the use of modelled results.

2.5.1 Limitations of the modelling process

The OSCAR software is only suitable for offshore or coastal marine environments. 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, and depth of release point.
- The properties of the oil in the model’s database might not precisely match those expected for the exploration well of Block 3B-4B. The properties and behaviour of the oil spilled in a dynamic marine environment may vary slightly to those outputs produced using data held within OSCAR. This variation is likely with all oils in the database and is intrinsic to any modelling.

2.5.2 Limits of use of the modelling results

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

- This software is only suitable for the offshore or coastal environment
- The modelling is a simplification of reality, so it is not possible to take into account all the external parameters during the modelling, because of the limitation due to metocean data resolution, the small-scale environmental parameters variations, etc.
- The results provided in this report are trends of potential consequences of a subsea blow-out and does not aim at predicting drifts at a future time but rather give indications where a slick could go linked to:
    - ✓ The selected oil profile used for the study scenarios
    - ✓ The proposed wells coordinates
    - ✓ Past (hindcast) Metocean data from 2019 to 2021
    - ✓ 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
- Careful consideration needs to be given to the distinction between stochastic and deterministic modelling (stochastic modelling is not generating a picture of single oil spill, but an imprint of the passage of several slicks from different spills to determine probability).

.

3. Modelling Results

The following sections present the results for stochastic and deterministic scenarios for one release point (1 499 m depth) for the 4 seasons considered for the modelling study. Some results (Water column concentration and Response deployment testing) are only studied for the Quarter 3 (initial drilling period planned).

Release Point Coordinates (WGS84):

Longitude: 15° 42' 19.51"E

Latitude: 32° 07' 33.38" S

3.1 Capping Only Scenario - Stochastic Simulation – 4 Quarters

These scenarios simulate a continuous blowout of 238.8 m^3 /day of condensate, through a set of 30 individual spill simulations for the 4 Quarters of the year. Each simulation duration is 60 days under a wide range of metocean conditions.

The results of all the scenarios are summarized in the Table 8 at the end of this part.

3.1.1 Surface Probability

IMPORTANT: Surface results presented in this section do not represent a single spill but the combination of the statistical results of the 30 individual trajectories composing the Stochastic Scenario for each season. Threshold values applied for the interpretation results is 0.04 µm for the surface as detailed in Section 2.4.1; there is no shoreline impact for this Release Point.

Figure 5 presents the **probability of presence** of oil above the threshold at sea surface for 4 Quarters.

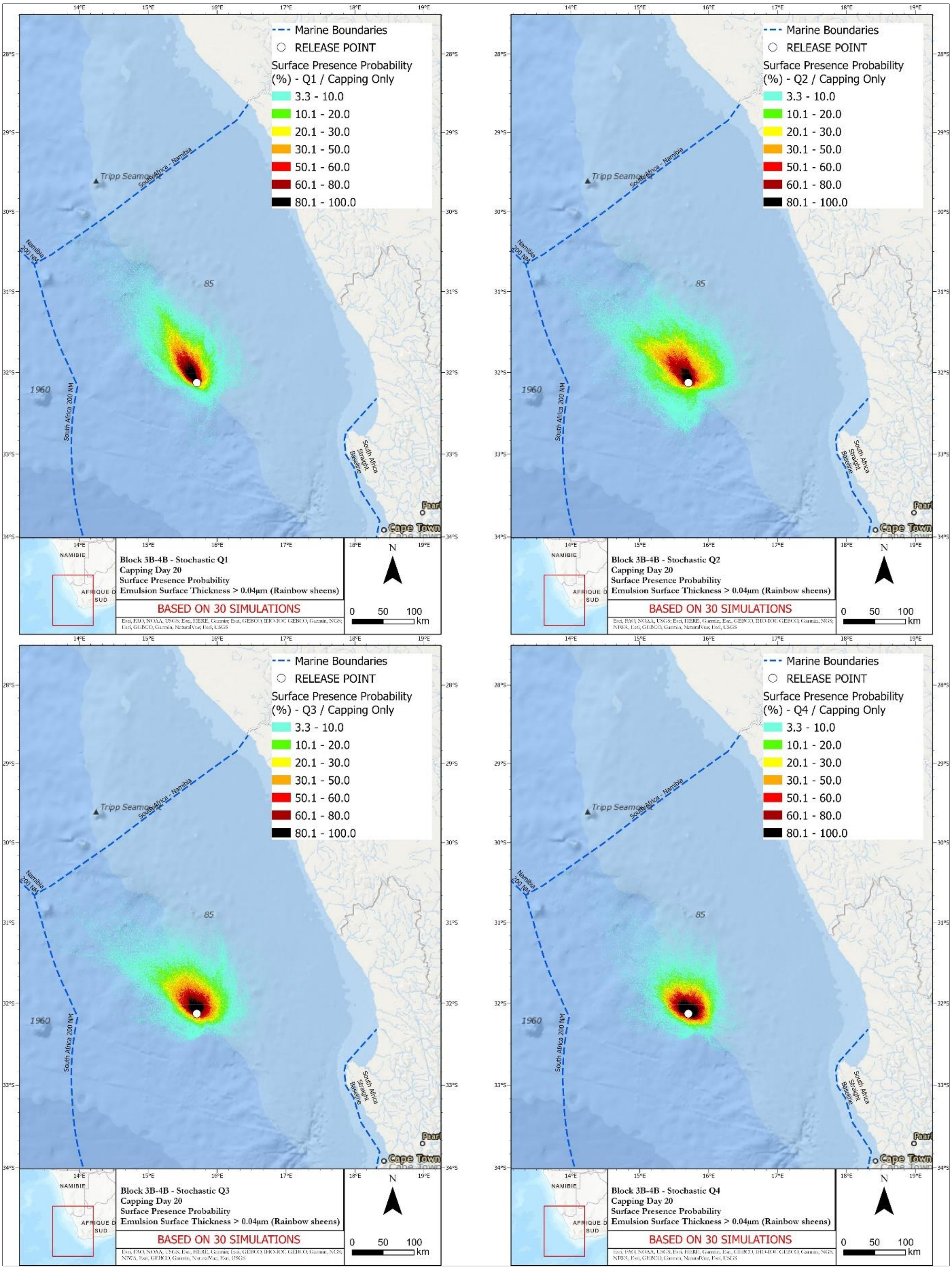

Figure 5: Quarters 1 to 4 - Capping Only – Stochastic Simulation: Surface Presence Results

Based on the Figure above, one can notice that:

- The main drift direction of the spill simulated is towards N to NNW for all quarters. This is due to the main surface currents towards NW and winds from S to SSE in this area.

- In consequence, there is no oil reaching the shore for all these seasons.

- The maximum distance for the 80 to 100% oil surface probability is 42 km N from release point for Quarter 1 (January to March).

To select the deterministic cases to study, the focus was made on the quantity of oil dispersed at the end of the simulations (as there is no oil onshore or on surface because of the condensate release). These results allow one to see the variability of the impact of the spill in the water column depending on its release date.

The Figure 6 below shows the minimum arrival time of oil on surface.

The Main direction of the drift is NNW, with a minimum Surface Arrival Time of 3 hours 45 km SW from release point during Quarter 2 (April to June).

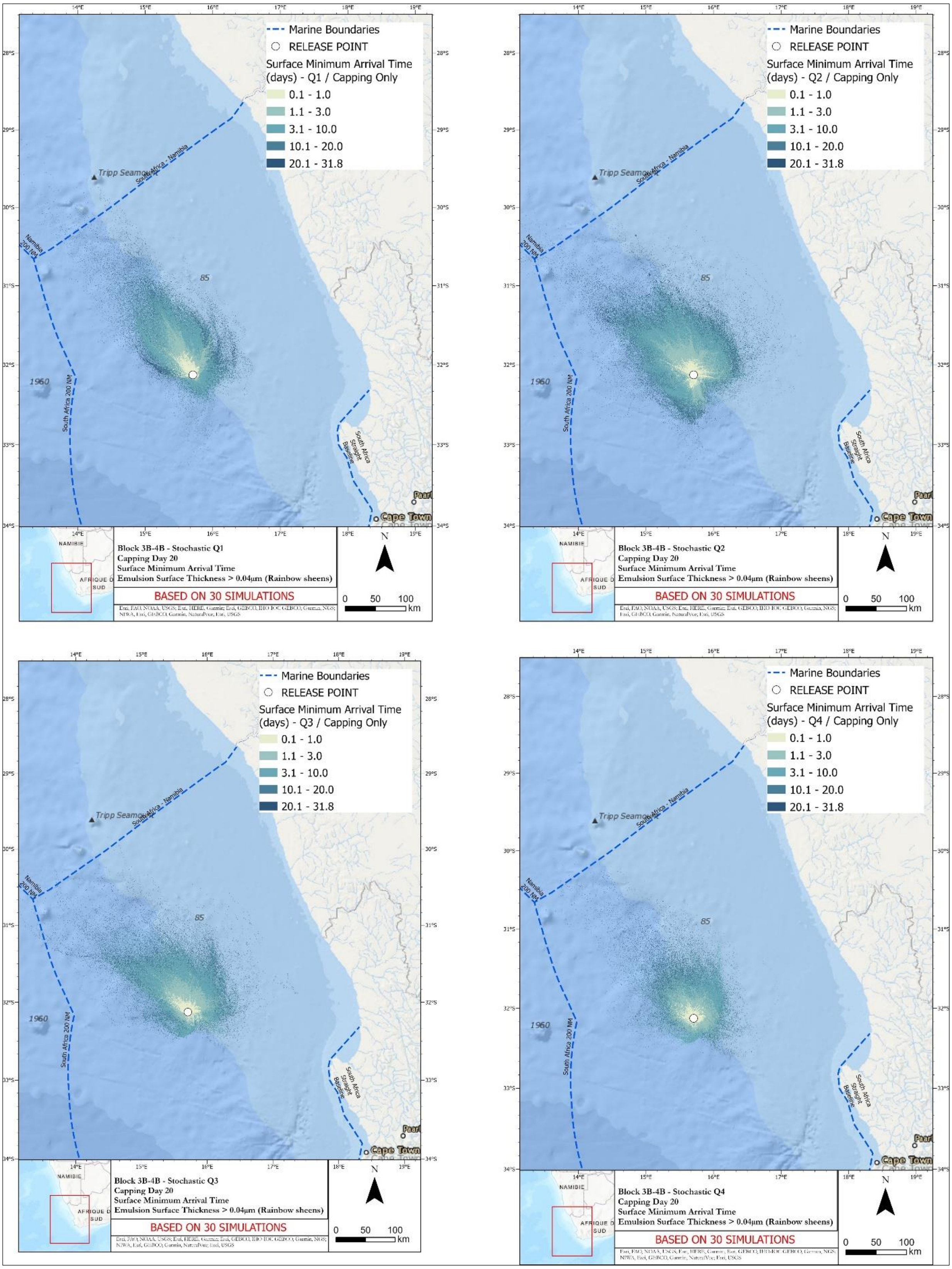

Figure 6: Quarters 1 to 4 – Capping Only – Stochastic Simulation: Surface Arrival Time Results

The Figure 7 below shows the maximum emulsion thickness on surface.

The maximum emulsion thickness reached is 76 µm reached on some spots between precisely above the release point during Quarter 2 (April to June). It represents a discontinuous true oil colour appearance, but most of the slick appears as Sheens and rainbows, due to the high evaporation of the condensate.

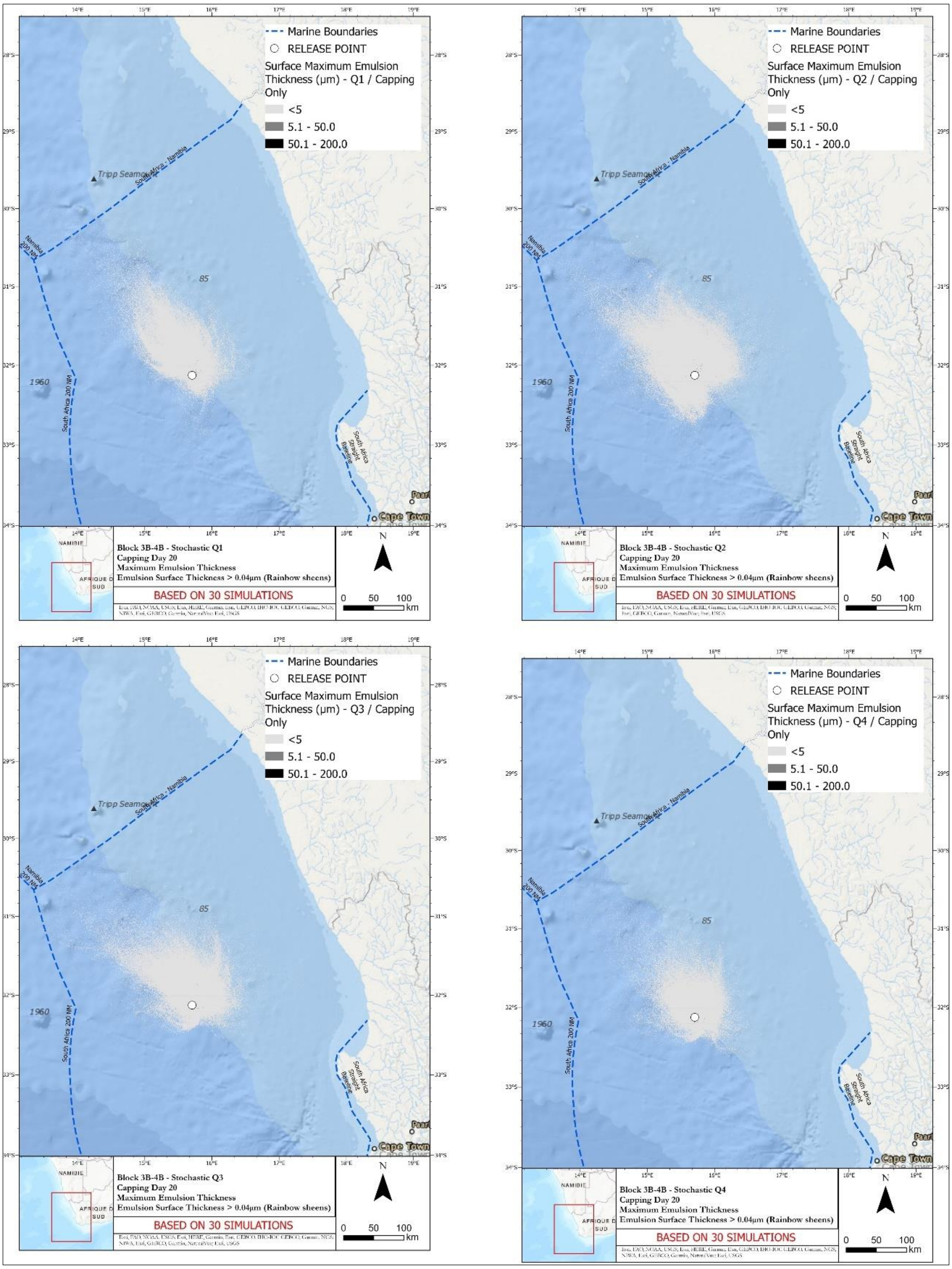

Figure 7: Quarter 1 to 4 – Capping Only – Stochastic Simulation: Emulsion Thickness Results

Figure 8**Error! Reference source not found.** displays the mass balance at the end of the simulations depending on the starting time of the release for the 4 Quarters of the years (for 3 years from 2019 to 2021), to show some correlations between the different compartments.

Some observations can be made:

- The condensate is only evaporated, dispersed and biodegraded. There is no oil onshore or remaining at the surface at the end of the simulations, for all seasons.
- Dispersion and biodegradation are positively correlated, and negatively correlated with the evaporation.
- Evaporation and Biodegradation are clearly negatively correlated, with highest peaks of evaporation during August and September of each year studied.

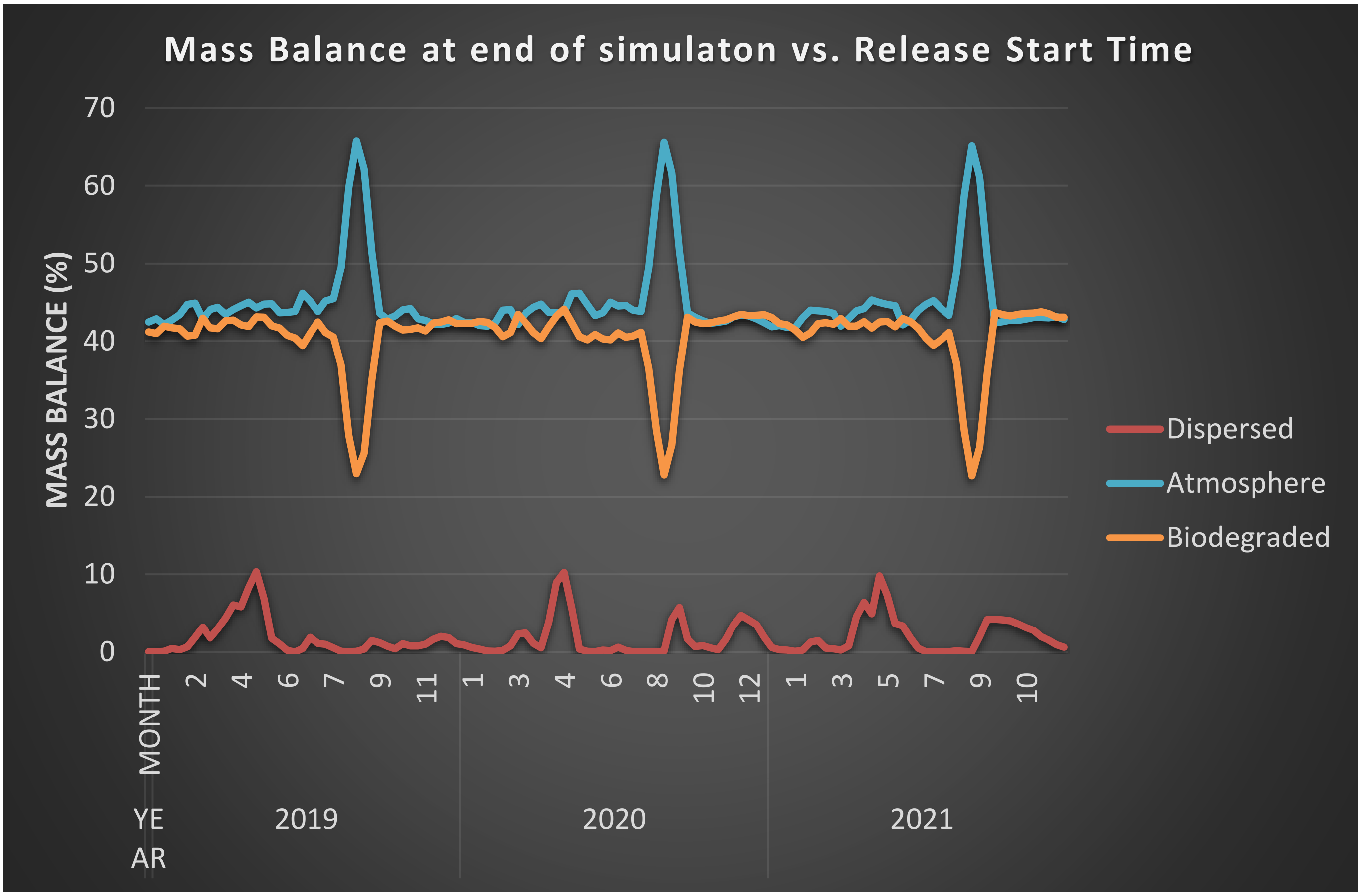

Figure 8: Capping Only: Mass balance at the end of simulation vs. Release start time for 2019 to 2021

3.1.2 Water Column Probability of Contamination – Quarter 3

Only Quarter 3 is presented because the results are similar for all the scenarios.

Figure 9 presents the water column probability of contamination for Quarter 3 studied with the Capping Only case, above the threshold of 58 ppb.

The most contaminated layer is between 725 to 900 m depth. This is probably due to the large amount of gas contained in the release, making the condensate going up very quickly in the first 600 m, and then accumulates in the mid water column before continuing to rise more slowly to the surface. There is no oil presence in the surface of the water column, due to the high dispersion and biodegradation of the condensate before rising the surface.

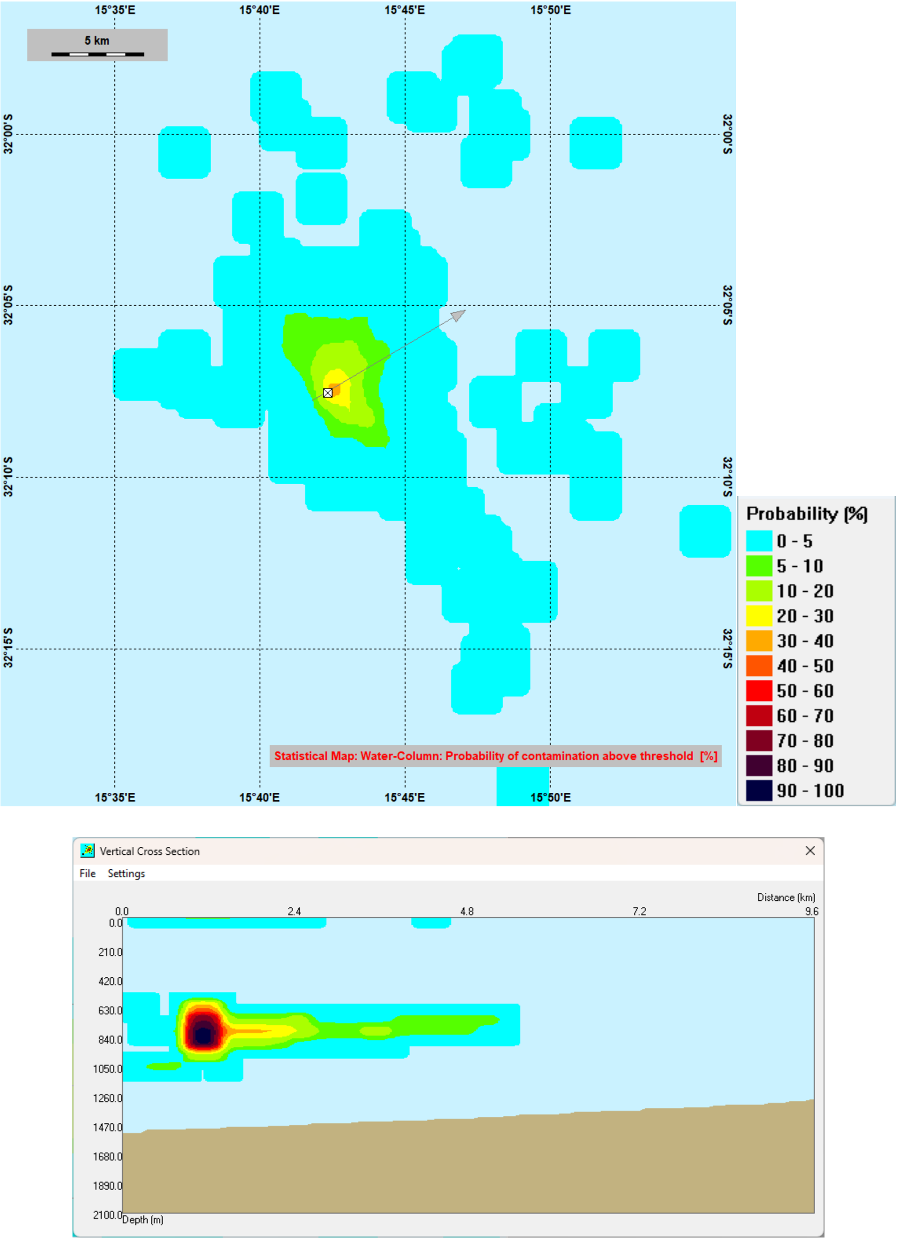

Figure 9: Q3 – Capping only – Water Column Probability of Contamination

3.1.3 Conclusion for Stochastic Simulations for all Quarters

The Table 8 below presents the main results of the Oil Spill stochastic Scenarios for all the Quarters.

Table 8 Summary of the results of the Stochastic simulations for Capping Only / All Quarters

Quarter	Max Distance of Oil Presence Probability 80 to 100% in 60 days / Drift Direction (Thickness >0.04µm)	Minimum Surface Arrival Time	Max. Distance Surface Arrival Time in 1 day	Maximum Emulsion Surface Thickness	MAX. % shoreline impact probability	Offshore surface waters reached by a spill
Q1	42 km NNW	3 hours	32 km NNW	21 mm at 5.7 km NE	NA	**South African Waters for the highest probabilities** **Namibia and International Waters only with 3.3 % of probabilities**
Q2	29 km NNW		71 km NW	76 mm above the release point		
Q3	32 km NNW		69 km NW	8 mm at 6 km NE		
Q4	29 km NNW		51 km NW	10 mm at 17 km E		

3.2 Response Deployment Testing: SSDI + Surface Response + Capping Scenario - Stochastic Simulation – Quarter 3

The following section presents a comparison of the probability of presence of oil on sea surface and in the water column between the Capping only cases compared to the Surface Response + SSDI + Capping cases, for Quarter 3 (initial planned drilling period). The results will be similar for all other Quarters.

Reminder: Time of response deployment after the start of the spill:

- *The surface response: 24h*
- *SSDI: 15 days*
- *Capping Stack: 20 days (end of release)*

3.2.1 Surface Results – Oil Presence Probability – Capping only vs. Surface Response + SSDI + Capping

The Figure 10 present the Surface Oil Presence Probability maps for the Quarter 3, comparing Capping Only cases with the deployment of the Surface Response, SSDI and Capping.

The surface response and SSDI have an unsignificant effect on the surface presence probability. This is because a condensate is naturally well dispersed in the water column and evaporates arriving on the surface, explaining why the SSDI could have a little impact on the dispersion, and the surface response is almost useless compared to a crude oil release. The maximum distance of oil presence probability (80 to 100%) is 33 km N from the release point versus the 30 km of the scenario with capping only, due to the SSDI allowing the oil to drift more far in the water column before rising to the surface.

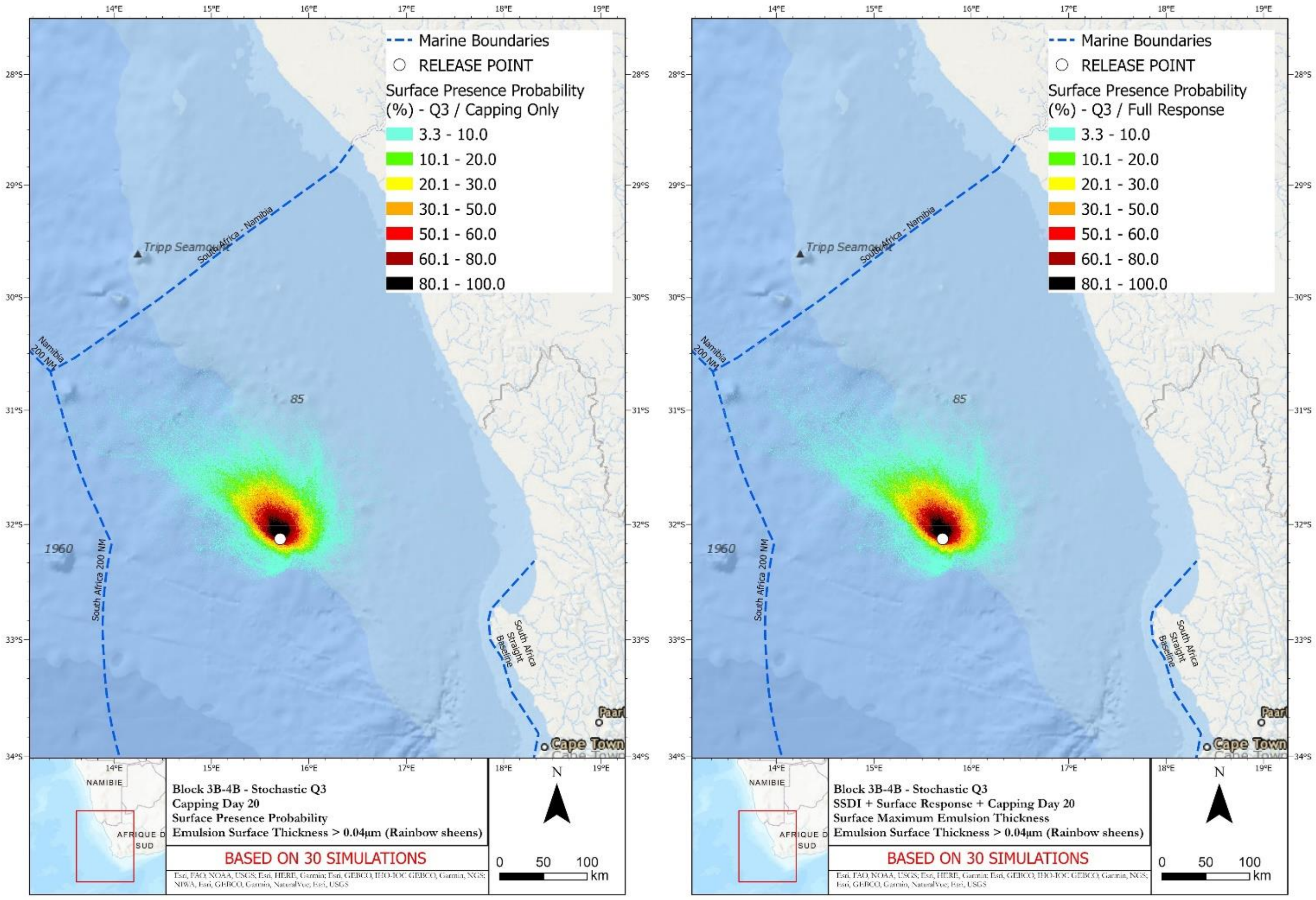

Figure 10: Surface Presence Probabilities - Stochastic Simulation – Capping Only vs. Surface Response + SSDI + Capping

The Figure 11 present the Minimum Surface Arrival Time maps for the Quarter 3, comparing Capping Only cases with the deployment of the Surface Response, SSDI and Capping.

There is no effect of the response deployed on the minimum arrival time on surface, which is 3 hours in both cases.

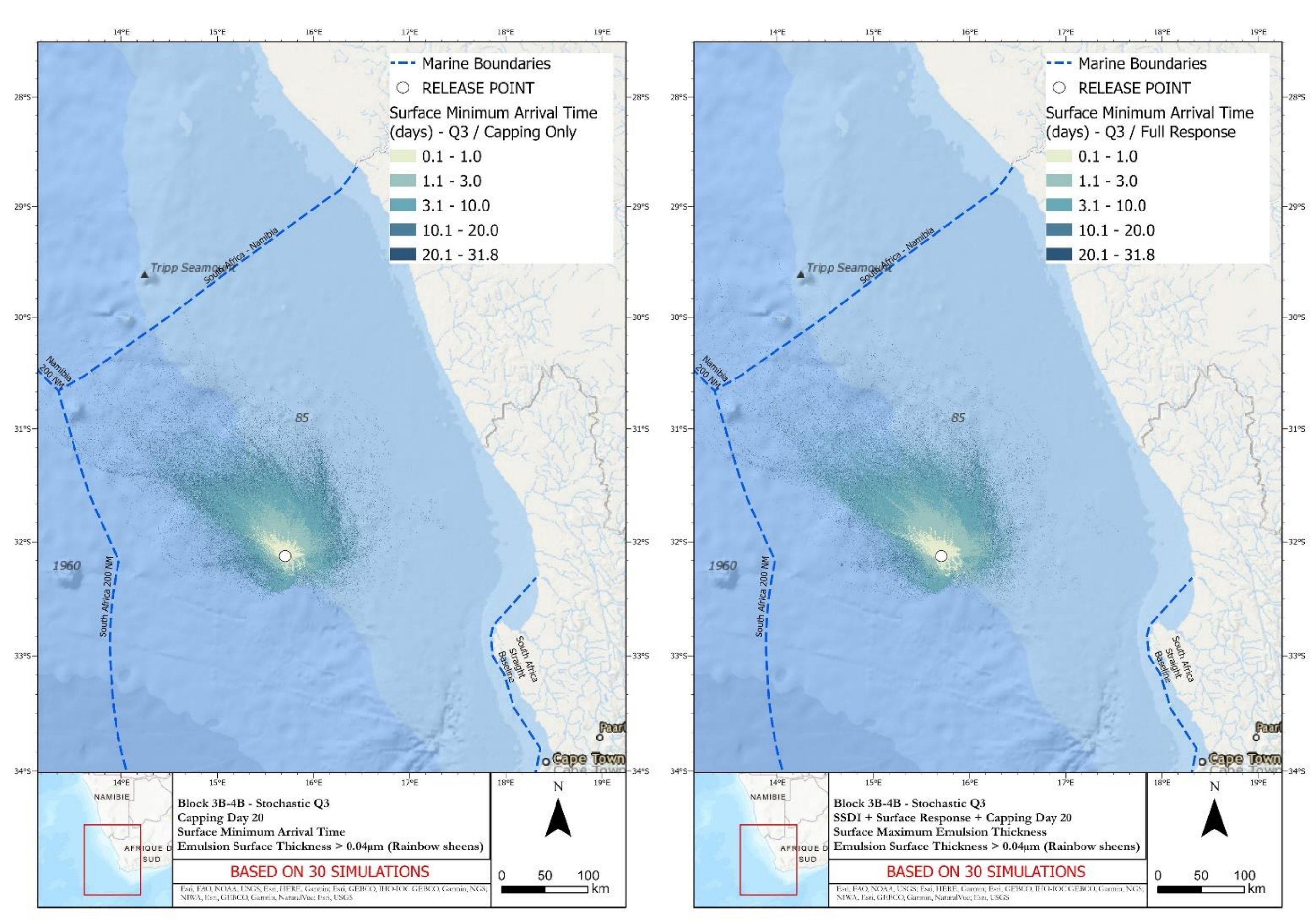

Figure 11: Arrival Time - Stochastic Simulation – Capping Only vs. Surface Response + SSDI + Capping

The Figure 12 present the Maximum Emulsion Thickness maps for the Quarter 3, comparing Capping Only cases with the deployment of the Surface Response, SSDI and Capping.

There is no major effect of the response deployed on the Maximum Emulsion Thickness on surface. There is a light increase of the maximum thickness (consisting only in some spots) with the full response deployed, with 8µm 20 km W from the release point (vs. 7.5 µm with capping only). This difference is negligible and can be attributed to the effects of random software calculations used to represent the variability of actual environmental conditions.

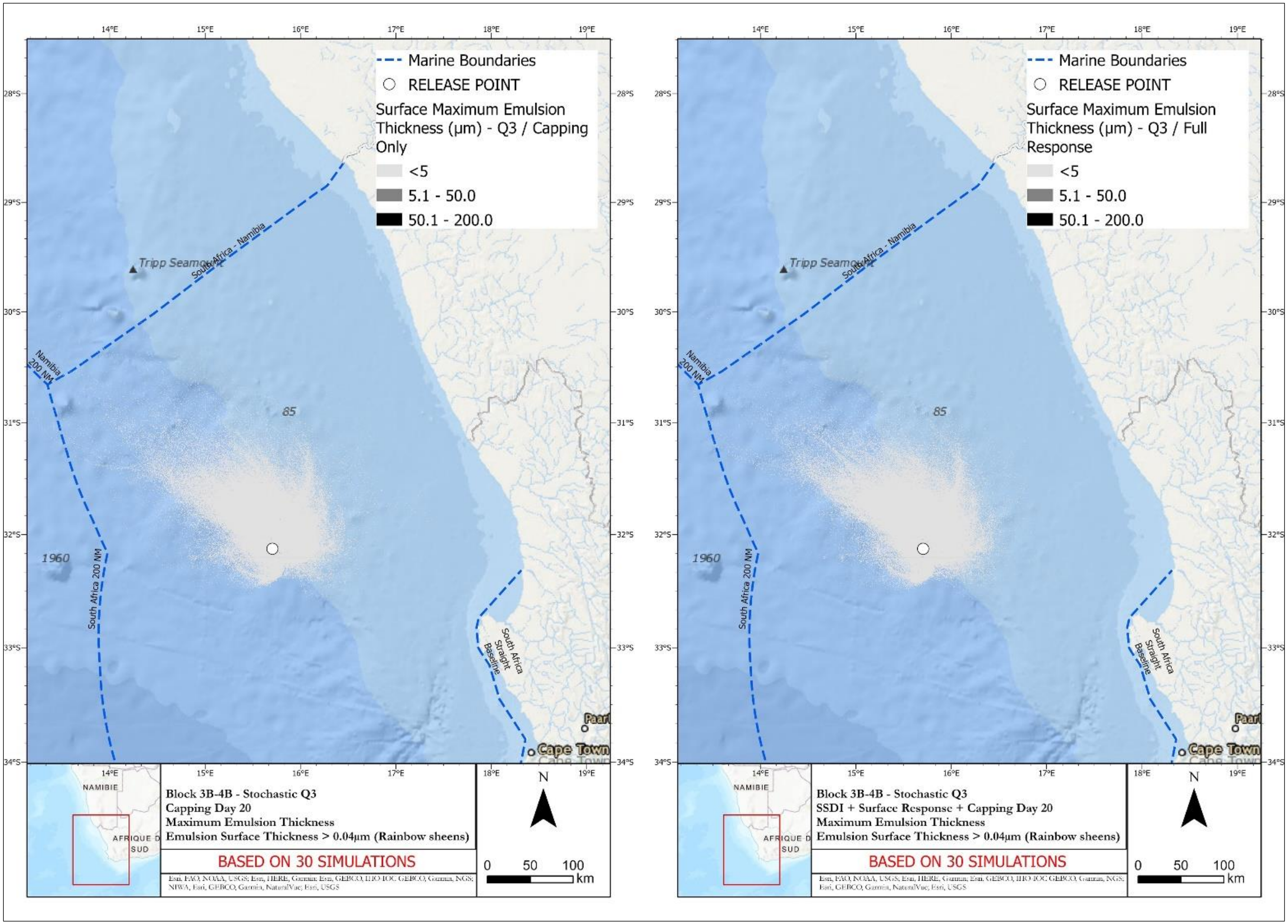

Figure 12: Emulsion Thickness- Stochastic Simulation – Capping Only vs. Surface Response + SSDI + Capping

The Figure 13 displays a comparison of oil quantity on surface vs. the release start time between the Capping only cases and the Surface Response + SSDI + Capping cases.

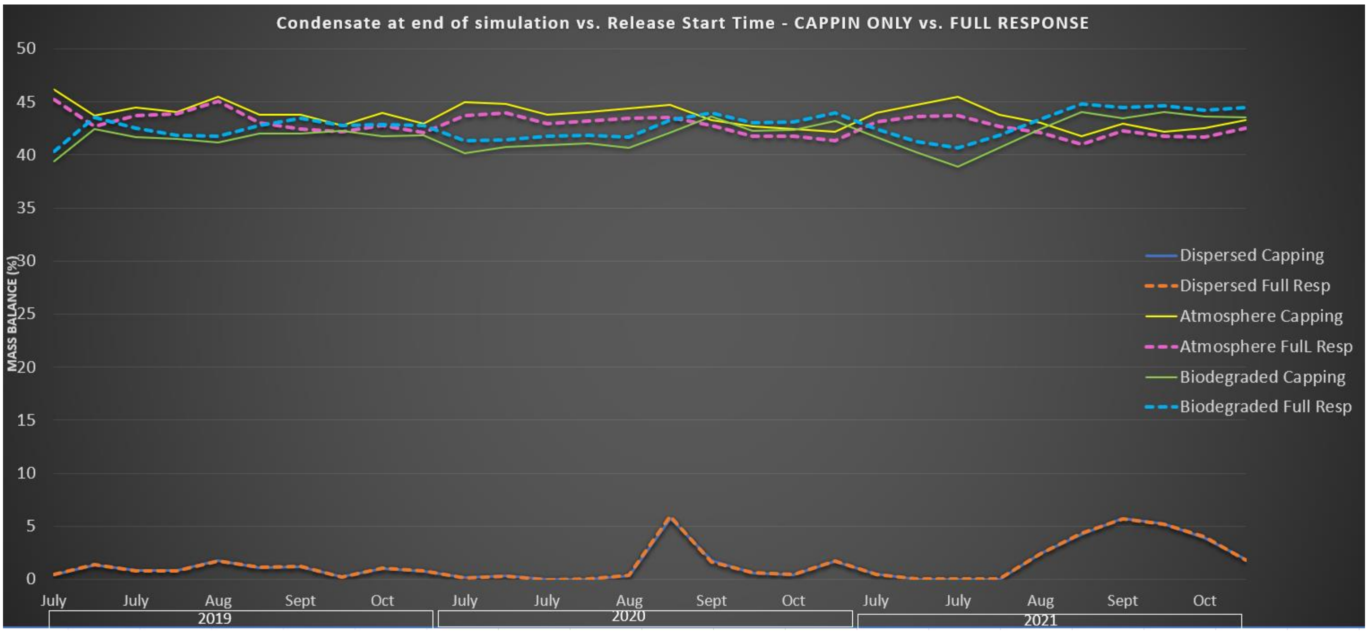

Figure 13 Release Point 1 – Stochastic Simulations - Oil quantity on surface vs. Release Start Time – Capping Only vs. Surface Response + SSDI + Capping

To summarize, for this quarter 3, there is very light effect of the response deployed:

- The dispersed part is varying very slightly but not even visible on the graph. This is because the release consists in condensate with a lot of gas, with a high natural dispersion in the water column.
- The Atmosphere part is a little reduced, thanks to the very light increase in dispersion.
- The biodegraded part is higher with the response, mainly due to the light increase dispersion in the water column with the SSDI (these two parameters are always positively correlated).

3.2.2 Water Column Results – Probability of Oil Contamination - Capping only vs. Surface Response + SSDI + Capping

Figure 14 presents the water column probability of contamination for Quarter 3 studied with the full response deployed, above the threshold of 58 ppb.

The most contaminated layer is between 775 to 875 m depth, compared to 725 to 900 m with capping only. This is probably due to the slight positive effect of the SSDI deployed at the beginning of the blow-out, allowing to disperse quickly the release in the water column, with less accumulation in the mid water column.

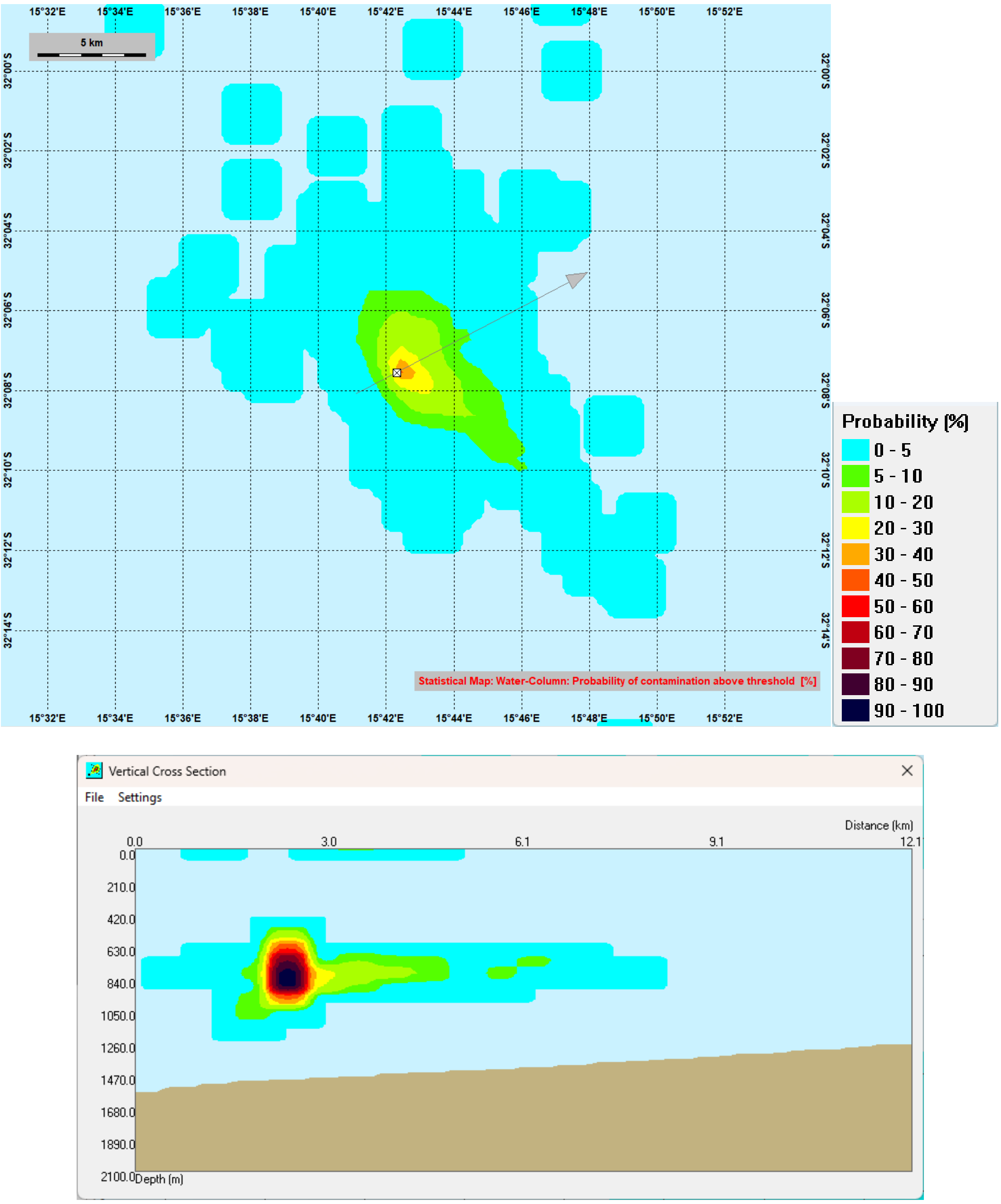

Figure 14: Q3 – Capping only – Water Column Probability of Contamination

The purpose of the response is to disperse the oil into the water column, but despite the Surface Response and SSDI deployment, the oil presence probability seems to be lower in the upper water column at a certain distance from the Release Point. This can be explained by the fact that the SSDI Deployment induces more oil dispersed in the water column directly from the spill point, so less oil reaching the upper layers.

3.2.3 Conclusion – Response Testing - Stochastic Simulation – Quarter 3

Table 9 summarizes the surface results of the stochastic simulations for the Capping Only Scenario and Full Response scenario performed on the Quarter 3.

Table 9: Main Stochastic Simulation Results for Q3 – Comparison Capping only vs. Full Response

Quarter 3	Capping Only	Surface Response + SSDI + Capping
Spill	**Blow-out - Condensate Release**	
Flow Rate / Amount	Qcondensate = 1500 bbl/day or 238.8 m^3/day Qgas = 930 000 Sm3/day	
Max Distance of Oil Presence Probability in 60 days / Drift Direction (Thickness >0.04µm)	30 km N	33 km N
Minimum Surface Arrival Time	3 hours	3 hours
Maximum Emulsion Surface Thickness	7.5 µm / 4 to 9 km around the release points	7 to 8 µm / Until 20 km W from release point
MAX. % shoreline impact probability	0	0
Offshore surface waters reached by a spill	**South Africa** for the highest probabilities Namibia and **International Waters** only with 3.3 % of probabilities	
Water Column Maximum Probabilities contaminated layer	725 m to 900 m depth	775 m to 875 m depth

There is **no oil onshore for the Quarter 3** due to main currents and wind driving the spill toward the NW, away from the coasts. The oil travels further, with only3% probability of crossing the Namibian-South African offshore border (even with surface response and SSDI deployment), and even enters the international waters (with the same very low probabilities around 3.3% for both scenarios). The maximum distance for the 80% to 100% oil surface probability is from 30 to 33 km N from the release point, remaining in the South African Waters.

The most contaminated layer is between 725 to 900 m depth for capping only and 775 to 875 m for full response deployed. This is probably due to the large amount of gas contained in the release, making the condensate going up very quickly, and then accumulates in the mid water column before continuing to rise more slowly to the surface.

There is very light effect of the response deployed: the dispersed part is varying very slightly, the atmosphere part is a little reduced, thanks to the very light increase in dispersion. The biodegradation is higher with the response, mainly due to the light increase dispersion in the water column with the SSDI (these two parameters are always positively correlated).

3.3 Capping Only Scenarios - Deterministic Simulation – 4 Seasons

a. Slick drift

Figure 17 presents the oil slick drift evolution for day 20 (capping stack deployment) for the 4 quarters of the year studied.

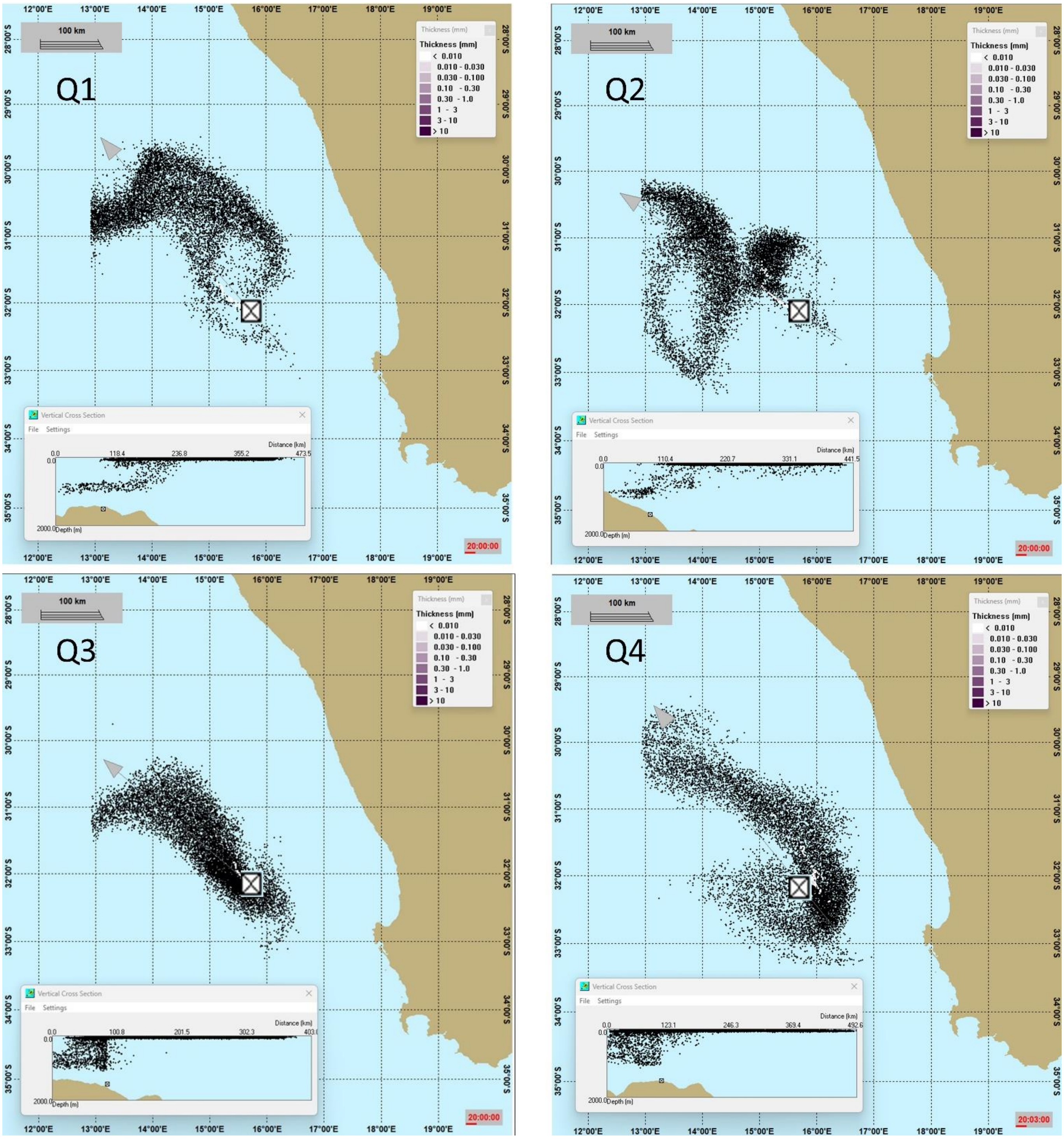

Figure 15: Surface slick drift (in white) and particles inside the water column at day 20 (end of spill) for the 4 quarters (deterministic simulations)

The surface slick and the particles main drift direction is towards NW, avoiding the shoreline located on the East side from the release point.

The main part of oil visible on the maps above **are dissolved in the water column**, because of the properties of the condensate and the natural dispersion.

At the end of simulation, day 60, there is no more oil on surface, but some oil is remaining in the water column, dispersed, present in the International and Namibian Waters.

Here are the time steps after the start of the spill for which the dissolved particles inside the water column crosse the international waters boundary:

- Quarter1: Day 8 and 6 hours;
- Quarter 2: Day 6 and 18 hours;
- Quarter 3: Day 14;
- Quarter 4: Day 11 and 18 hours.

b. **Mass Balance**

The Figure 16 presents the mass balance (each process involved for the oil weathering) for each quarter.

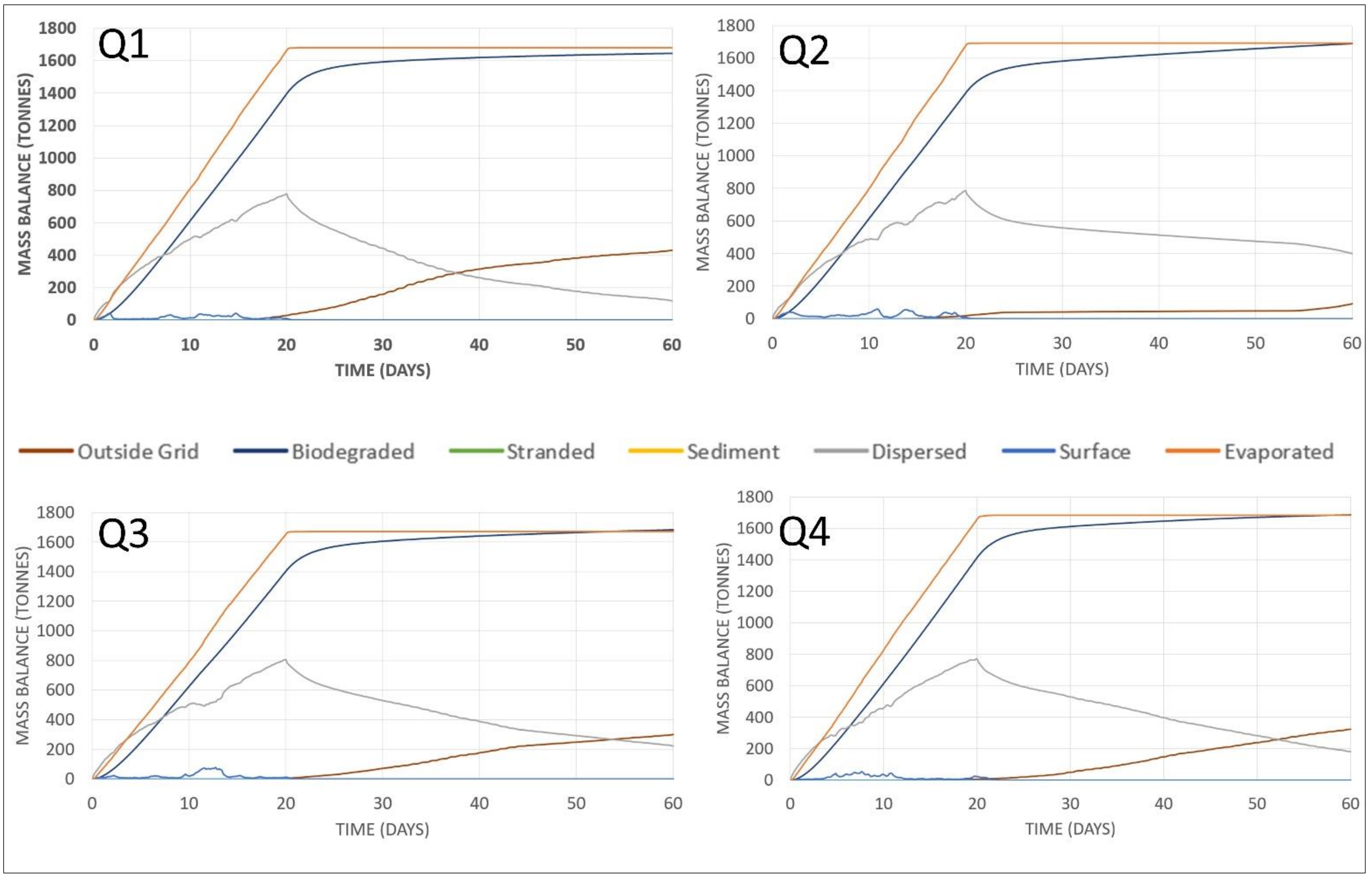

Figure 16: Mass Balance for each quarter – Deterministic simulations

All the graphs show the same trend concerning the oil weathering, no matter the season studied.

Most of the fluid is evaporated, then naturally dispersed and biodegraded in the water column, with very little oil remaining on the surface.

3.4 Response Deployment Testing: Deterministic Simulation – Capping Only vs. Full Response deployment for Quarter 3

The selected scenario starts the 13th of September 2021 (9:00 local time) for 20 days of release on 60 days of simulation.

a. Slick drift

Figure 17 presents the oil slick drift evolution for day 1, day 14 (international waters boundary crossing), day 20 (capping stack deployment) and end of simulation (day 60).

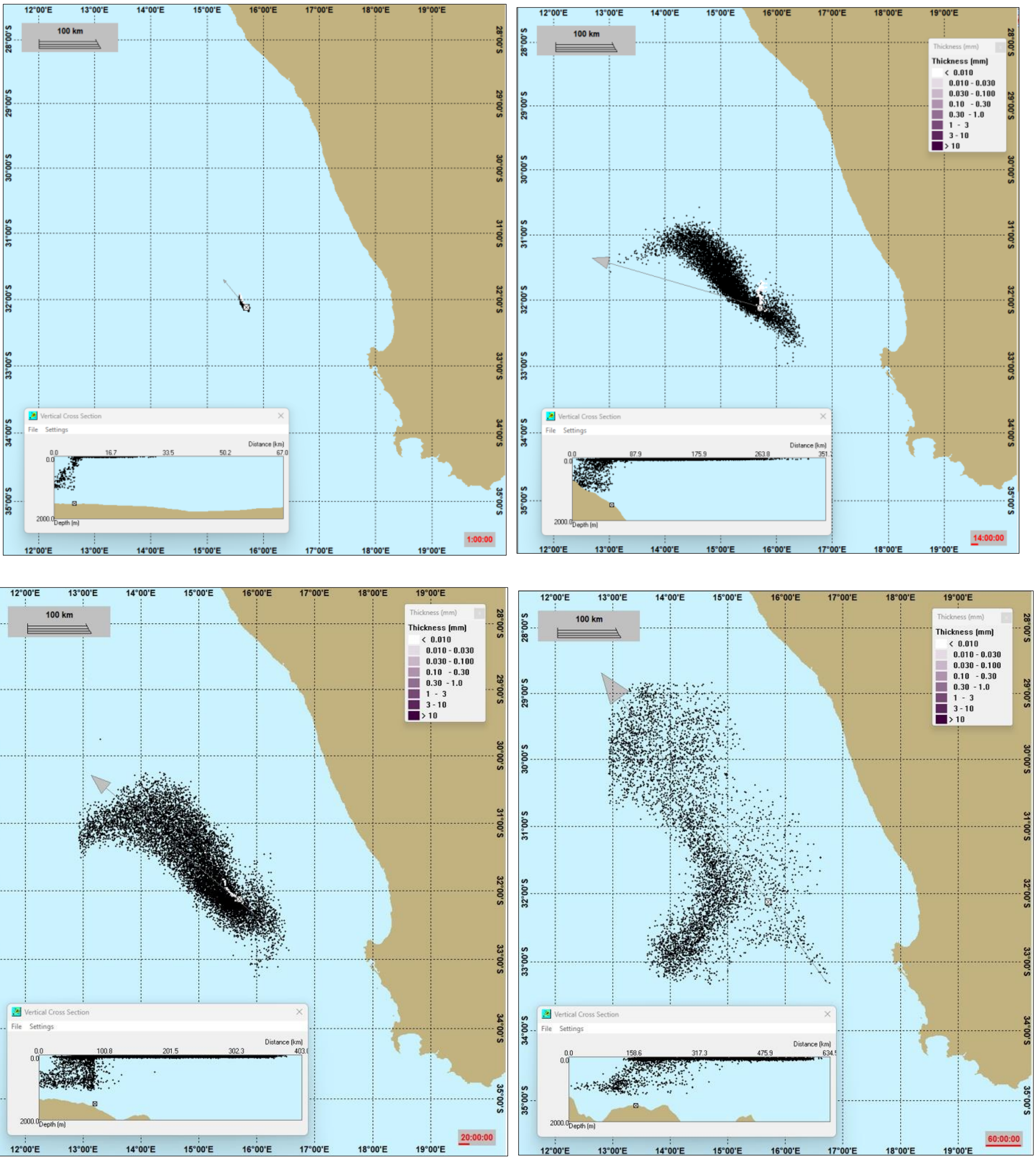

Figure 17: Deterministic Simulation with Surface thickness and dissolved particles for Capping Only

The main drift direction is towards NW and W from the release point, avoiding the impact on the coastline.

The main part of oil visible on the maps above **are dissolved in the water column**, because of the properties of the condensate and the natural dispersion.

At the end of simulation, day 60, there is no more oil on surface, but some oil is remaining in the water column, dispersed, present in the International and Namibian Waters.

The oil is crossing the International Waters boundary **but dissolved inside the water column**, NW from the release point, 14 days after the start of the release.

b. Mass Balance and Correlations with winds

Figure 18 shows that the Surface Response and the SSDI deployment has almost no effect on this scenario. That is because of the properties of the condensate, the SSDI deployment has a very light effect on the dispersion which is already important; the surface response which consists of dispersing and recovering oil slicks is of no use because all the condensate disperses in the water column or evaporates upon arrival at the surface.

In this kind of release, the better choice would be to deploy the capping stack as soon as possible instead of trying to increase the dispersion that is already high for this type of product.

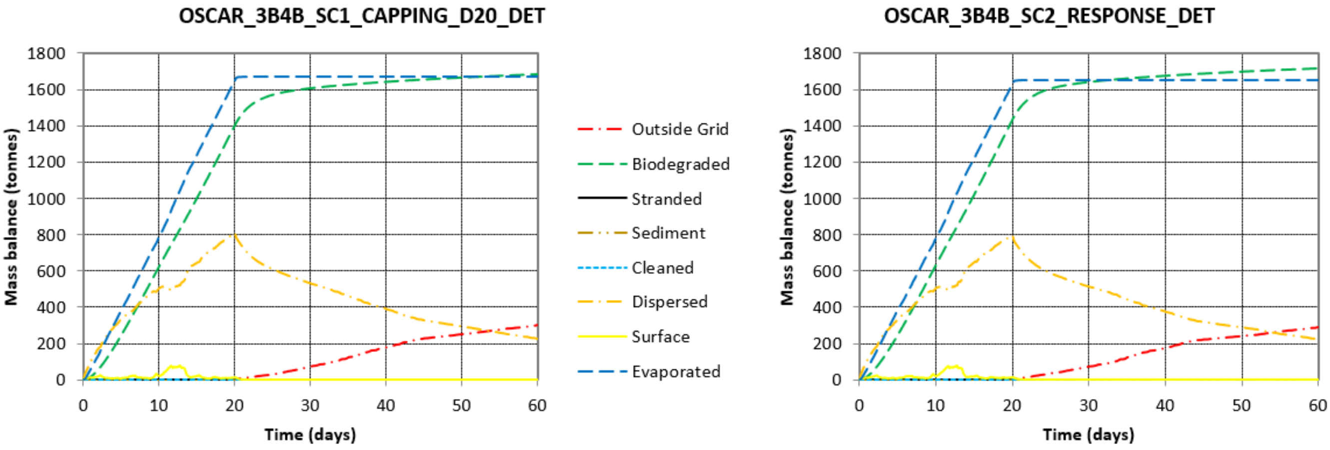

Figure 18: Quarter 3 - Deterministic Simulation – Mass Balance – Capping Only vs. Surface Response + SSDI + Capping

4. Conclusion

Main conclusions of this study are as follows:

- ✓ DRIFT DIRECTION:
  The general direction of the surface oil drift is NW for the all the Quarters in this marine area.

- ✓ DRIFT DISTANCE:
  The maximum distance of the 80 to 100% oil surface probability contour is 42 km NNW from Release Point during the Quarter 1 (January to March).

- ✓ SURFACE PRESENCE PROBABILITIES: there is almost no oil on surface due to large evaporation and dispersion processes on this condensate, but the **Namibian and International Waters could be impacted by surface oil with very low probabilities (3.3%). This means that probabilistically, out of 100 spills that could occur during each quarter period, only 3 cases would have oil on the surface which would cross the Namibian border and international waters.**

- ✓ WATER COLUMN CONTAMINATION: the most contaminated layer is between 725 to 900 m depth for capping only and 775 to 875 m for full response deployed. This is probably due to the large amount of gas contained in the release, making the condensate going up very quickly, and then accumulates in the mid water column before continuing to rise more slowly to the surface.

- ✓ COASTAL IMPACT: there is **no coastal impact** for this type of release for any Quarter of the year, due to the currents in the area making the release always drifting towards NW, opposite to the coastal area.

- ✓ SURFACE RESPONSE: The surface response was only studied for the Quarter 3 (initial planned Drilling period) there is very light effect of the response deployed: the dispersed part is varying very slightly, the atmosphere part is a little reduced, thanks to the very light increase in dispersion. The biodegradation is higher with the response, mainly due to the light increase dispersion in the water column with the SSDI (these two parameters are always positively correlated).

  Because of the properties of the condensate, the SSDI deployment has a very light effect on the dispersion which is already important, and the surface response which consists of dispersing and recovering oil slicks is of no use because all the condensate disperses in the water column or evaporates upon arrival at the surface. In this kind of release, the better choice would be to deploy the capping stack as soon as possible instead of trying to increase the dispersion that is already high for this type of product.

5. Bibliographic References

Aamo, O. M., Reed, M., Daling, P.S, Johansen, Ø. (1993): *A laboratory – based weathering model: PC version for coupling to transport models*. Proceedings of the 1993 Artic and marine Oil spill Program (AMOP) Technical Seminar, pp. 617-626.

Bergstad, O. A.; Høines, ÅS; Sarralde, R.; Campanis, G.; Gil, M.; Ramil, F.; Maletzky, E.; Mostarda, E.; Singh, L.; António, M. A. (2 January 2019). "Bathymetry, substrate and fishing areas of Southeast Atlantic high-seas seamounts". *African Journal of Marine Science*. **41** (1): 11–28

Bonn Agreement Oil Appearance Code (BAOAC): http://www.bonnagreement.org/manuals

Brandvik J., Daling P.S., Leirvik F., Krause D.F., 2019. Interfacial tension between oil and seawater as a function of dispersant dosage. Marine Pollution Bulletin 143, 109-114.

DALING, P. S. LEWIS, A. RAMSTAD, S. 1999. *The Use of Colour as a Guide to Oil Film Thickness – Main Report*. Report Nº STF66 F99082. Trondheim, Norway. 48 pp.

French McCay (2009) – State-of-the-Art and Research Needs for Oil Spill Impact Assessment Modeling

Jirka, G.H., Doneker, R.L., 1991. Hydrodynamic classification of submerged single-port discharges. Journal of Hydraulic Engineering 117, 1095±1112.

Johansen, Ø. (2000). DeepBlow – a Lagrangian Plume Model for Deep Water Blowouts. Spill Science & Technology Bulletin, 6(2), 103–111. https://doi.org/10.1016/S1353-2561(00)00042-6

Johansen, O., Brandvik, P. J., & Farooq, U. (2013). Droplet breakup in subsea oil releases - Part 2: Predictions of droplet size distributions with and without injection of chemical dispersants. Marine Pollution Bulletin, 73(1), 327–335. https://doi.org/10.1016/j.marpolbul.2013.04.012

Pan, Qingqing, et al. "Fate and behavior of Sanchi oil spill transported by the Kuroshio during January–February 2018." Marine Pollution Bulletin 152 (2020): 110917

Scholz D.K. et al. (1999) – *Fate of spilled oil in Marine waters. An information Booklet for decision-Makers*. API publication number 4691

Reed, M., French, D., Rines, H., Rye, H., 1995b. A three-dimensional oil and chemical spill model for environmental impact assessment. In: Presented at the International Oil Spill Conference. American Petroleum Institute, pp. 61–66.

Reed, M., Daling, P.S., Brakstad, O.G., Singsaas, I., Faksness, L.-G., Hetland, B., Ekrol, N., 2000. OSCAR2000: a multi-component 3-dimensional oil spill contingency and response model. In: Presented at the Arctic and Marine Oil Spill Program Technical Seminar, Environment Canada. 1999. pp. 663–680.

Reed, M., & Hetland, B. (2002). DREAM: a Dose-Related Exposure Assessment Model Technical Description of Physical-Chemical Fates Components.

Schwichtenberg, F., Callies, U., Groll, N. et al. Effects of chemical dispersants on oil spill drift paths in the German Bight—probabilistic assessment based on numerical ensemble simulations. Geo-Mar Lett 37, 163–170 (2017)

SINTEF MEMW User's Manual, version 14.0.0, 2022. User guide of the MEMW interface, 223 p.

Vincendet Mathieu, VENUS-2 appraisal well -Initial results PBOR study, 2022.

Yapa, P.D., Zheng, L., 1997. Modelling oil and gas releases from deep water: A review. Spill Science & Technology Bulletin 4, 189-198.

Zheng, L., Yapa, P.D., 1997a. Simulation of oil spills from deep water blow-outs. XXVIIth Congress of the International Association for Hydraulic Research, IAHR and ASCE Conference, San Francisco.

Zheng, L., Yapa, P.D., 1997b. A numerical model for buoyant oil jets and smoke plumes. In: Proceedings of the 20th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Vancouver, Canada, pp. 963-979.

5.1 Appendix 1 - Bonn Agreement Oil Appearance Code (BAOAC)

- **Concept behind oil slick appearance**

The visible spectrum ranges from 0.40 – 0.75 µm. Any visible color is a mixture of wavelengths within the visible spectrum. White is a mixture of all wavelengths; black is absence of all light. The color 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 color 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 color of the oil itself as well as the optic effects are influenced by meteorological conditions, altitude, angle of observation and color of the sea water, an appearance cannot be characterized purely in terms of apparent color and therefore an 'appearance' code, using terms independent of specific color 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 10.

Table 10: Bonn Agreement Oil Appearance Code

Code	Description – Appearance	Thickness Interval (µm)	Liters 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 Color	50 to 200	50000 – 200000
5	Continuous True Oil Color	> 200	> 200000

The appearances described above cannot be related to one thickness; they are optic effects (codes 1 – 3) or true colors (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.

5.2 Appendix 2 – CV of the H-ES Expert

HES EXPERTISE SERVICES

Benjamin LIVAS

Environmental Modelling Expert

Marine Environmental Project Engineer with 10 years of experience in modelling

SINTEF certified user (MEMW Softwares developers)

PROFILE

❑ 12 years of experience in Marine and Coastal Environment

❑ Specialized in Marine Environmental Modelling and GIS

EXPERIENCE

H-Expertise Services S.A.S

❑ **Since February 2019 - Marine Environmental Modelling Expert – PAU (France)**

- Operational marine environmental modelling studies for Oil & Gas Companies (accidental oil leaks, chemical product releases, drilling cuttings, environmental impact of the marine environment, etc.)
- Environmental R&D studies for pollution response research centers and Oil & Gas Companies (comparison of oil slick drift models at sea, supplying databases, etc.)
- Modelling trainer in oil subsidiaries
- Site supervision facilitator (STORENGY)

MODIS

❑ **2010 - 2019 – Project Environmental Engineer – PAU (France)**

- Certified user (SINTEF) in offshore environmental modelling on the MEWM OSCAR & DREAM modules: oil spill, produced waters, chemicals, drill cuttings and particulate discharges (more than 30 studies carried out)
- Assistant for modelling deployment training in the deployment of MEWM software for TotalEnergies's HSE teams (Angola, UK, UAE, Nigeria)
- Team leader on several environmental impact study studies for offshore Oil & Gas installations (Congo, Gabon, Angola): management, HSE, logistics, etc.

CNRS

❑ **2009 - 2010 - Assistant Engineer – DINARD (France)**
Coastal geomorphology, GIS, digital terrain models, spatial statistics, field training

HES EXPERTISE SERVICES

EDUCATION

- **2007 - 2008 Master II Biodiversity and Sustainable Development**

  Université des Sciences de PERPIGNAN via Domitia, FRANCE

- **2006 - 2007 Master I Dynamics of aquatic ecosystems**
  Université de Pau et des Pays de l'Adour, UFR Côte Basque, ANGLET, FRANCE

SKILLS

- MEMW Software – OSCAR, DREAM & ParTrack modules (SINTEF certified user)
- GIS (ArcGIS)
- Microsoft Office Environment

LANGUES

- French (Mother tongue)
- English (Fluent)
- Spanish

MISCELLANEOUS

- BOSIET (Basic Offshore Safety Induction and Emergency Training), HUET (Helicopter Underwater Escape Training)
- Response in case of Accidental Hydrocarbon Pollution at Sea and on the Coast (Cedre, BREST)