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Report

Predictions from a subsea release of Oda crude oil related to oil spill response

Evaluation of response options

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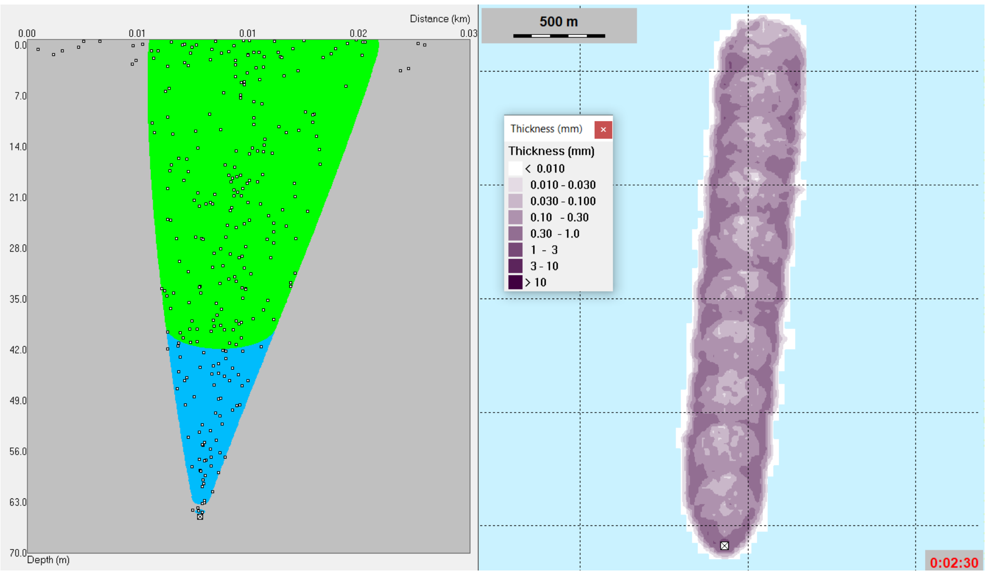

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ABSTRACT

Oil weathering predictions have been performed using the Subsea module integrated in the SINTEF Oil Weathering Model (OWM) of a relevant subsea release from a pipeline rupture (batch release) at the Oda oil field. The OSCAR plume model was run to simulate the buoyancy of the rising plume and initial spreading of the surfaced oil.

Response options were evaluated for this oil spill scenario at the Oda field. Due to the predicted film thickness, the surfacing oil from the batch release (total 433 m^3) is expecting to emulsify at sea and use of mechanical recovery and dispersant application are therefore considered as relevant oil spill strategies for such a spill.

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1 Introduction

Oda is a light to medium paraffinic crude oil (density 0.820 g/mL) with emulsifying properties that may form water-in-oil (w/o) emulsion in cases were the oil film thicknesses are higher than 0.1-0.2 mm (e.g. Melbye et al. 1999). Oil weathering predictions of the properties of Oda crude oil from a standard surface release have been performed by use of the SINTEF Oil Weathering Model (OWM), as described in Sørheim et al. 2019. The results from the surface release scenario showed that Oda crude oil emulsified rapidly and reached a high-water uptake of 80 vol. % and the oil had the potential to form high viscous emulsions with time, if spilled on the sea surface. Moreover, the response options from a surface release indicated that Oda has a potential for both mechanical recovery and use of chemical dispersant within a certain time window based on the oil/emulsion viscosities.

In subsea releases where the oil/gas is penetrating the sea surface, the oil may form oil films that are either too thin to emulsify or films with higher thicknesses that may emulsify based on the release conditions. The fate and behaviour of the oil film from a subsea release is depending on several factors such as the water and release depths, gas-to-oil ratios (GOR), release rates, release diameters (rupture), and weather conditions. The initial film thickness from an underwater oil spill is a crucial factor for evaluating the potential for different response options. A high GOR may e.g. give decreasing initial oil film thickness compared to low GORs, but increased release rates and/or increased release depths may also contribute to higher film thicknesses on the sea surface. All these parameters interact with each other and therefore prediction and simulation of the fate and behaviour of the plume and surfacing oil, based on the relevant hazard and accidental situations (DFU: Definerte Fare- og Ulykkessituasjoner), is recommended. Moreover, it is expected that condensates and light crude oils may form thin oil films that are too thin for emulsification from underwater blowouts (Singsaas et al. 2017), but the ability to form non-emulsifying surface oil films may also apply for emulsifying crude oils as previously shown in a specific subsea release scenario for the Vale light crude oil (Hellstrøm et al. 2018), which in a surface release formed thicker oil films that emulsified, as described in Hellstrøm and Andreassen, 2014.

In this project, a defined subsea batch release from a pipeline rupture at the Oda field has been modelled by use of the integrated "Subsea module" in the SINTEF OWM, and the OSCAR "Deepblow" plume model. The aim was to predict the oil film thickness and the weathering properties of Oda from the relevant scenario. The plume model was run to simulate the buoyancy of the rising plume and initial spreading of the surfaced oil. The input parameters for the modelling work was given by Spirit Energy as described in chapter 2, below.

2 Methodology and input parameters

The model parameters for the defined subsea scenario for Oda crude oil are given in Table 2-1.

Table 2-1 Parameters used for predictions with SINTEF OWM and simulation of the plume with the OSCAR

Parameter	Value
Oil type	Oda crude oil
Temperature (°C)	5 and 15
Wind speed (m/s)	2, 5, 10 and 15
Gas-Oil ratio (GOR) (Sm^3/ Sm^3)	80
Release volume (m^3)	433
Duration of release (hours)	2.75
Water depth (m)	65
Depth of release (m)	65
Release diameter (inch)	10

Traditionally, OWM is used to predict the weathering properties of surface oil/emulsion from surface releases. The OWM Subsea module can also predict the initial film thickness of the surfacing oil after a subsea gas/oil release, in scenarios where the plume reaches the surface. Moreover, the OWM "Subsea module" shares some functionality for predicting the output of underwater blowouts with the SINTEF "Deepblow" plume model, which is integrated in the OSCAR model. With plume modelling in OSCAR it is possible to simulate the 3D blowout plume in the water column and the initial spreading of the oil on the sea surface. Based on the release depth and release rate of oil and gas the model will predict if the momentum and buoyancy of the released plume is sufficient to reach the surface, where the plume will spread the oil out over the sea surface. Alternatively, the oil and gas plume will be trapped in the water column and the oil droplets will rise to the surface through their own buoyancy alone. In this case OSCAR predicts the termination width, depth and the horizontal distance of the oil film from the release.

3 Plume modelling and initial spreading of the oil on sea surface

Figure 3-1 A shows the simulation of the rising plume of an oil-gas release from the Oda pipeline with the OSCAR model based on the input parameters in Table 2-1, at 5 m/s wind. The simulation shows a plume with a diameter of about 20 m a few meters below the sea surface. The large horizontal spreading of the plume at 5-10 m beneath the surface gives a horizontal spreading of the oil droplets, which result in a ~ 400 m wide initial surface oil film. Two and a half hours into the release, right before the release ends, an elongated surface film has formed (Figure 3-1 B). Six hours after release start, the surface film has been transported around 2.5 km away from the spill site (Figure 3-1 C) and the oil has taken up some water, leading to a slightly thicker slick, and a small degree of the surface oil (about 5-10 %) has been naturally dispersed into the water column. A modelled northward current speed varying between 10-17 cm/s (0.19 to 0.33 knots) was used in the simulation, based on modelled ocean currents (Engedahl and Mathisen, 1996) which is a representative current speed for the North Sea under conditions of low wind.

A) Vertical and horizontal spreading of the blowout plume.

B) Birds-eye view spreading of surface oil film 2.5 hours after release

C) Birds-eye view 6 hours after release

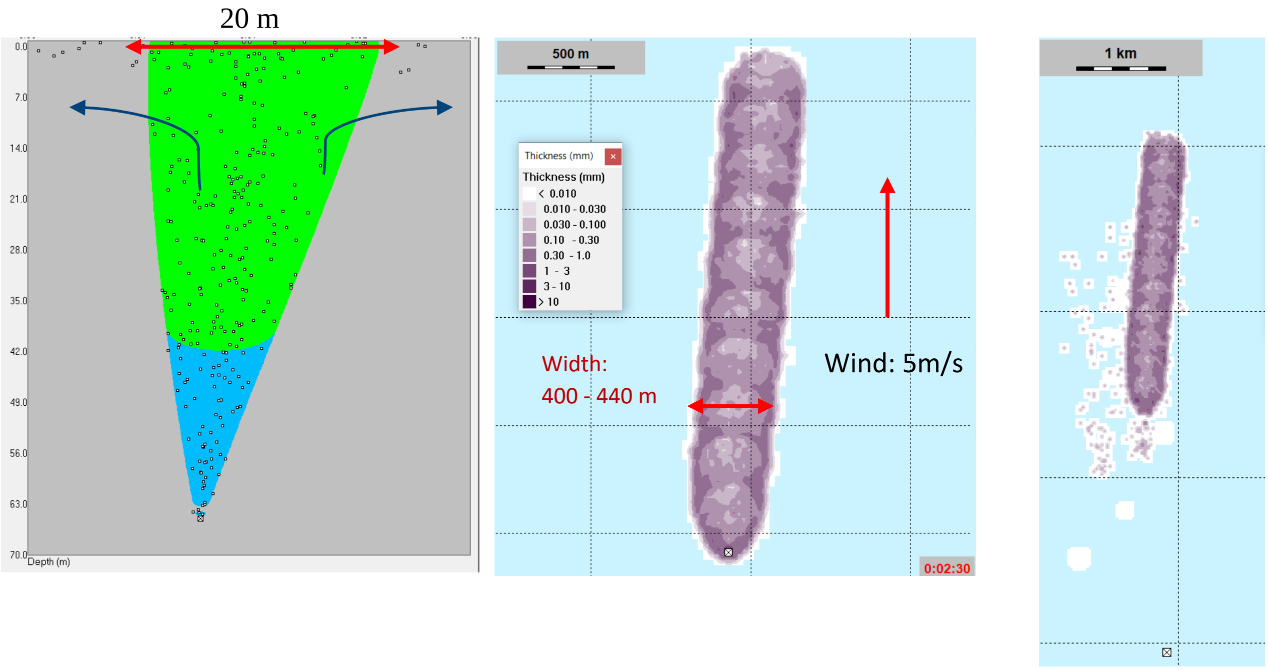

Figure 3-1 ***Blowout simulation and surface spreading of the oil and gas blowout with Oda oil as predicted by OSCAR. (A) The presence of gas in the plume leads to rapid surfacing. Arrows indicate direction of water flow radially from the plume centre as the plume encounters the sea surface. Blue and green plume colours indicate temperature change relative to the release temperature (units not shown) (B) The surfacing plume rapidly spreads the oil out over the surface and winds and currents transport the oil to the north, resulting in a surface plume with a width of around 400 m. (C) Six hours after the end of the release, oil has been transported about 2.5 km to the north and some slight breaking of the surface slick has started to occur.***

4 Weathering properties from the subsea release related to oil spill response

An overview of oil weathering properties (evaporative loss, pour point, flash point, water uptake, viscosities, and mass balances from the defined subsea release of Oda, predicted by the SINTEF OWM, are given in Appendix A. The input data for specific scenario is given in Table 2-1. The predictions of film thicknesses, lifetime of surface oil and surface emulsion are given in the subchapters, below.

4.1 Film thickness

Figure 4-1 shows the predicted film thicknesses at different wind speeds at winter (5 °C) and summer (15 °C) sea temperatures. The film thicknesses are in accordance to the spreading area of the surfaced oil simulated by the "DeepBlow" model as shown in Figure 3-1 B. For this scenario, a pipeline release would cause the surfacing oil to emulsify on the sea surface due to thicknesses above 100 µm.

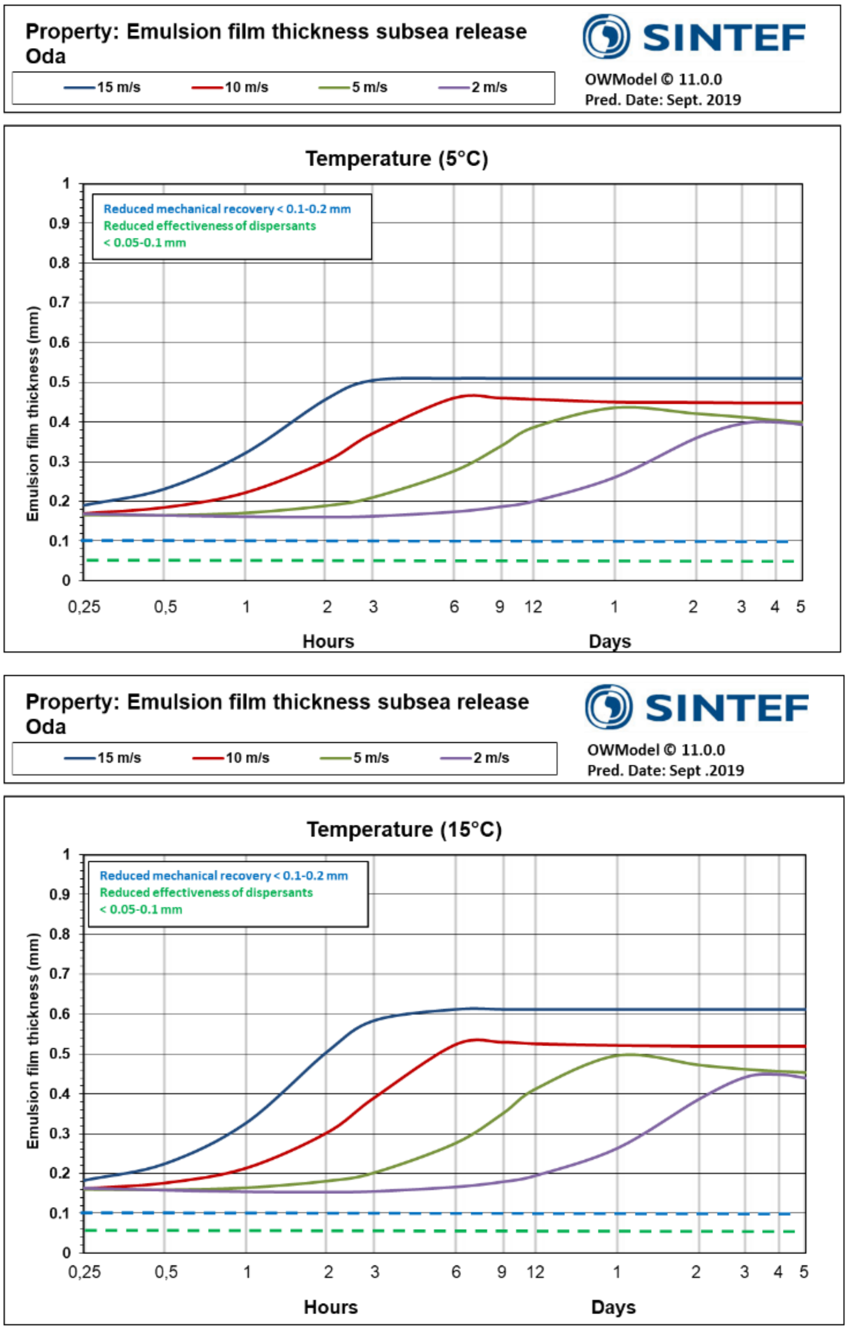

Figure 4-1 ***Predicted emulsion film thickness for Oda at 5 °C (above) and 15 °C (below), given in mm thicknesses***

4.2 Mass balance of surfaced oil and emulsion formation

Natural dispersion and evaporation are the main weathering processes that remove an oil spill form the surface. The predicted remining surface oil as a function of weathering time from the defined subsea release of Oda are shown in Figure 4-2. The predictions of mass balances are also shown in Appendix A.

Figure 4-2 shows that Oda is predicted to have a short lifetime at sea in typical breaking wave conditions (wind speed of 10 and 15 m/s) compared to non-breaking waves (2-5 m/s wind speed). No predicted remaining oil on the sea surface after approx. 6 hours at 15 m/s and 2 days at 10 m/s, at both 5 and 15 °C.

However, the total volume of the surface oil may increase due to emulsification up to 73-76 vol. %, where emulsions are formed by seawater mixed into the oil phase. Figure 4-3 shows the difference in the total volume of the surfaced oil from the subsea release of Oda. The decrease in the total volume is due to the evaporation and natural dispersion of the oil.

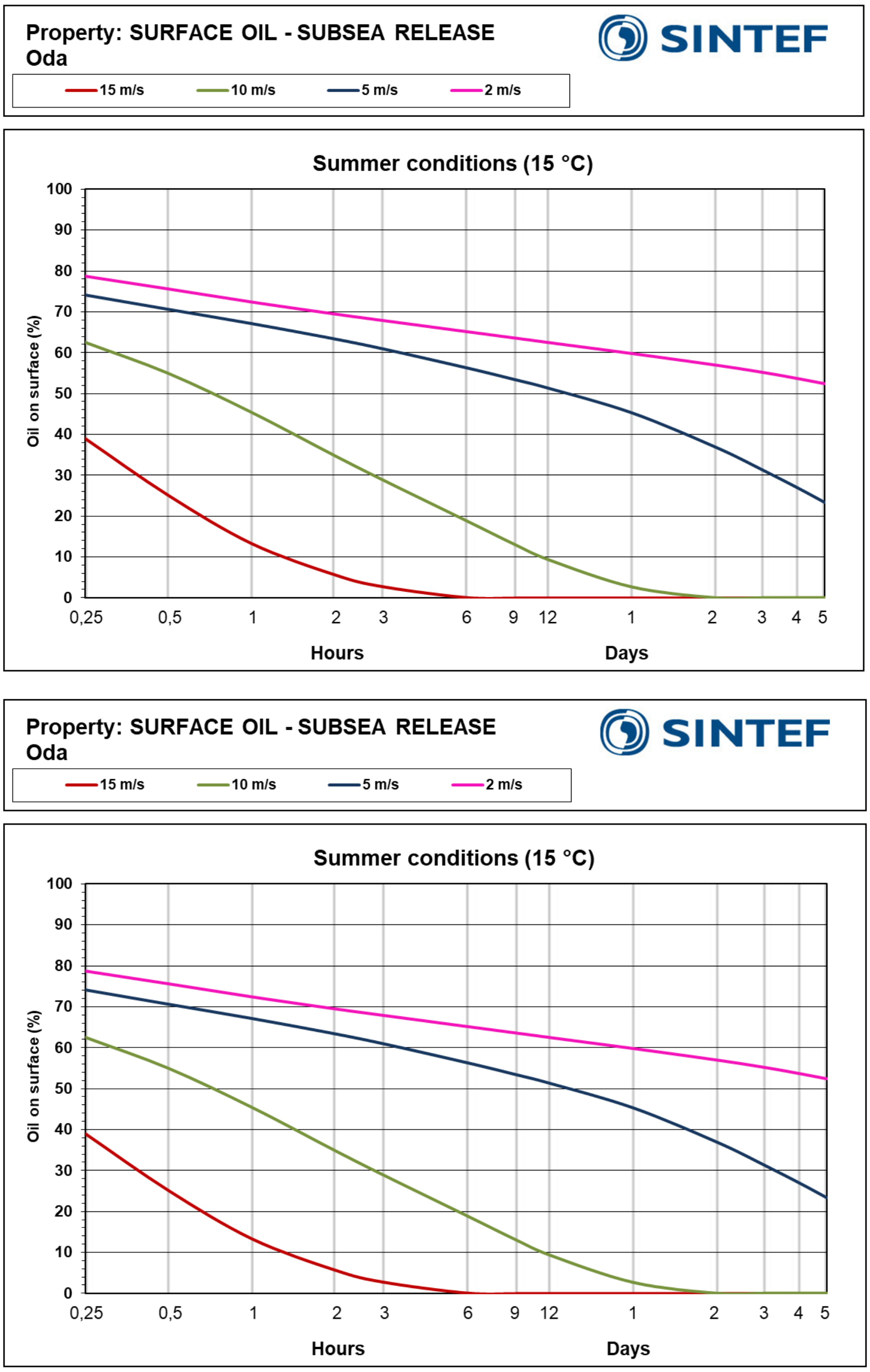

Figure 4-2 *Predicted remaining surface oil from a defined subsea release of Oda at 5 °C (above) and 15 °C (below)*

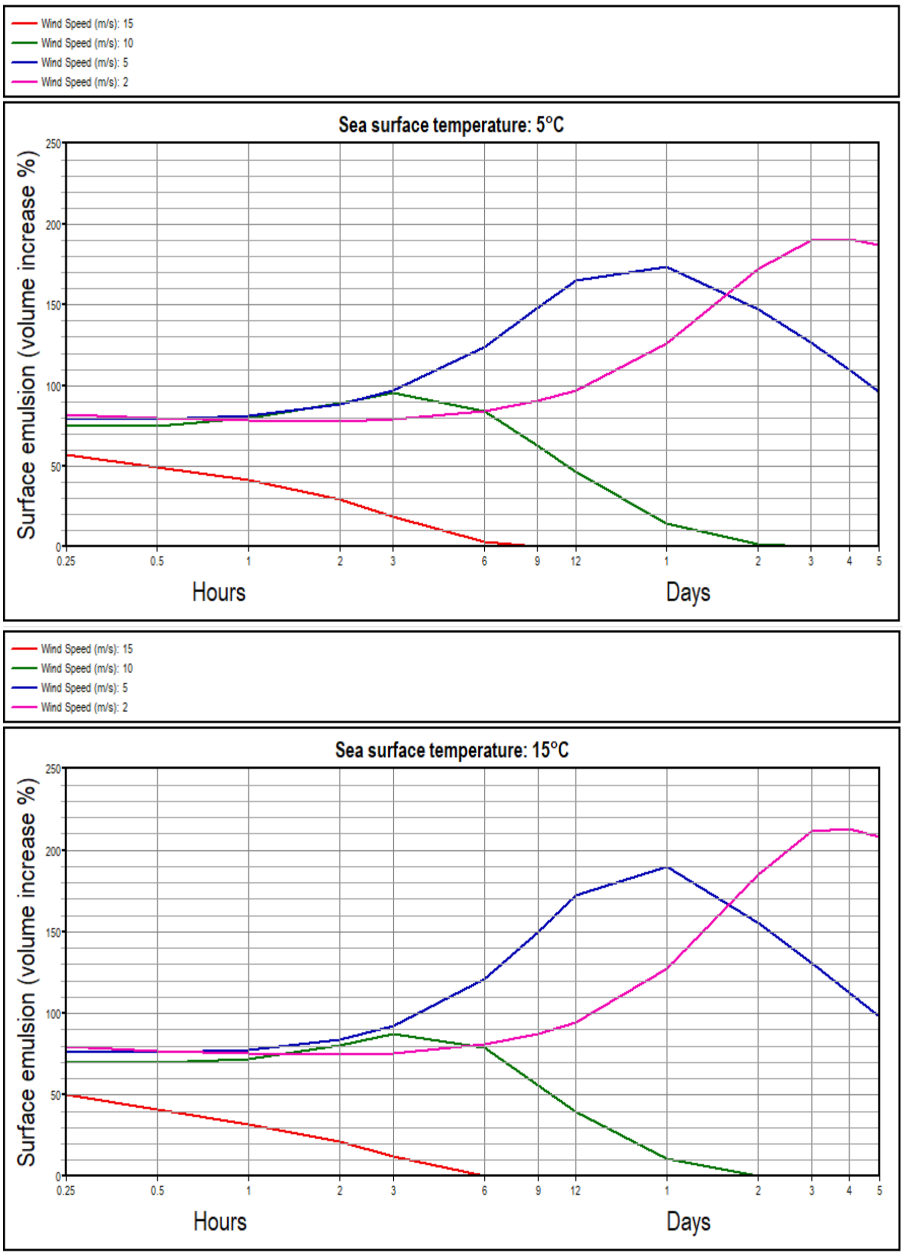

Figure 4-3 ***Total volume due to emulsion formation at different wind speeds from a defined subsea pipeline release of Oda at 5 °C (above) and 15 °C (below)***

5 Evaluation of surface response options

Mechanical recovery, chemical dispersion and mechanical dispersion by high-capacity water flushing are shortly evaluated for the defined subsea release scenario at the Oda field. In case of an oil spill, remote sensing and monitoring should in general be used as support in any response operation and is not evaluated here. In general, a safety zone of 1 hour from the spill site should be considered for all response operations. In this scenario the GOR is relatively low (80 Sm^3/Sm^3), but for larger rate of free gas, a separate model prediction of the atmospheric dilution of the gas plume could be recommended to define a safety zone with respect to explosion hazard for the specific scenario. Furthermore, in any release situation, the oil film that is generated on the sea surface will be subjected to oceanic processes and may form films with varying thicknesses due to wind and wave movement. This can result in fragmentation of the film, and with time, but such oceanographic processes are not considered in the OWM predictions.

A summary of criteria for evaluation of possible response options is given in Table 5-1. These criteria are also described in Singsaas et al. 2017. The response options for Oda based on the OWM predictions at different wind speeds and sea water temperatures of 5 and 15 °C, are given in Figure 5-1 and Figure 5-2, and the more detailed explanation for each response options are given below. Note, the response options are based on the properties of possible available oil on the sea surface.

Table 5-1 Criteria for evaluation response options (Singsaas et al. 2017) from a subsea release of Oda

Response technique	Relevant parametres	Applicable (green)	Reduced efficiency (yellow)	Not applicable (red)
Mechanical recovery	Oil thickness Oil viscosity	> 0.2 mm > 1000 mPa.s	0.1 – 0.2 mm 250 – 1000 mPa.s*	**< 0.1 mm** **< 250 mPas**
Chemical dispersants	Oil thickness Dispersibility efficiency Pour point	> 0.1 mm Oil specific** < 5°C above seawater temp.	0.05 – 0.1 mm Oil specific**	**< 0.05 mm** **Oil specific**** **> 15°C above seawater temp.**
Mechanical dispersing – water flushing	Oil thickness Oil viscosity	< 0.2 mm < 150 mPa.s	150 – 250 mPa.s	**> 0.2 mm** **> 250 mPa.s**

* A lower viscosity limit of 250 mPa.s has been selected for "active booming" in a mechanical recover operation. This is an assumption based on low sea state conditions (wind speed < 5 m/s) and reduced speed on the recovery vessels.

** The dispersibility limits for Oda are found to be < 5000 mPa.s for applicable, 5000-15 000 mPa.s for reduced efficiency, and > 15 000 mPa.s for not dispersible (Sørheim et al. 2019)

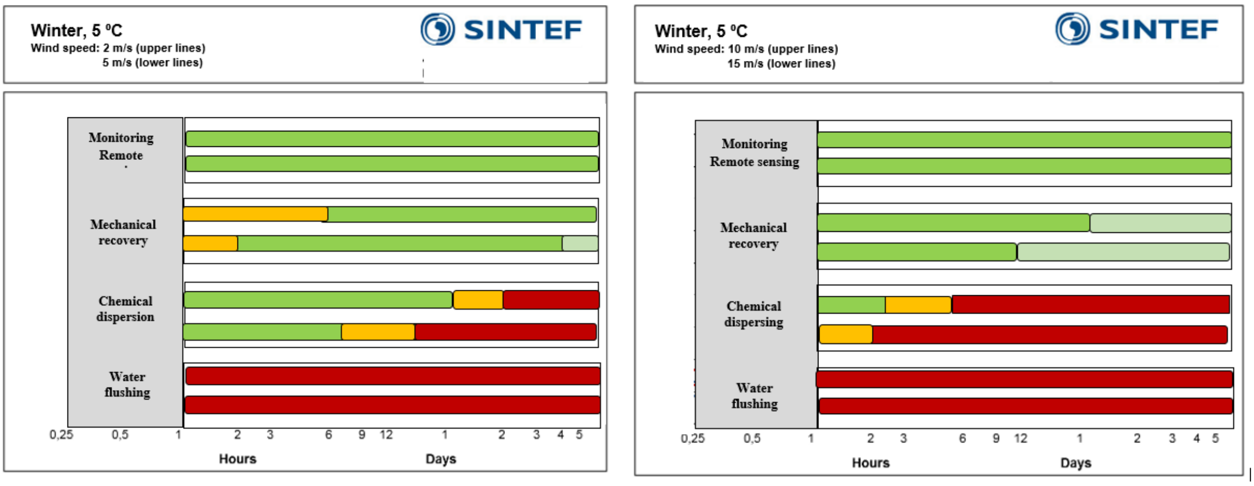

Figure 5-1 ***Response potentials based on the properties of available oil on the sea surface for the batch subsea release of Oda at 2 - 5 m/s (left) and 10 - 15 m/s (right) at 5 °C, predicted by the SINTEF OWM. A delay time for response of 1 hour is here chosen as a safety zone boarder, for explosion hazard and human exposure.***

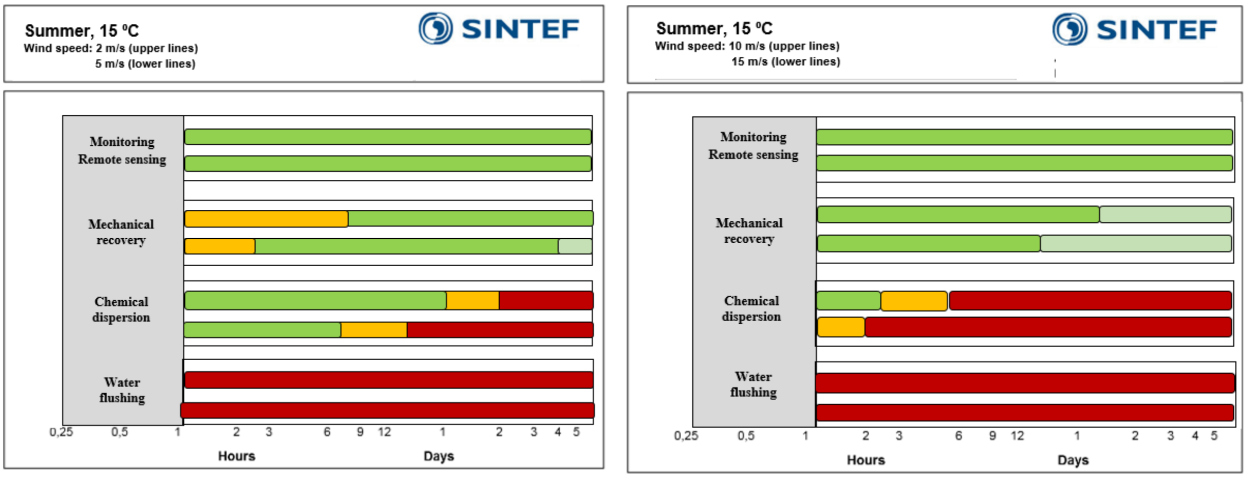

Figure 5-2 ***Response potentials based on the properties of available oil on the sea surface for the batch subsea release of Oda at 2 - 5 m/s (left) and 10 - 15 m/s (right) at 15 °C, predicted by the SINTEF OWM. A delay time for response of 1 hour is here chosen as a safety zone boarder, for explosion hazard and human exposure.***

Mechanical recovery

For mechanical recovery to be efficient, the oil/emulsion film thickness should generally be thicker than 0.1-0.2 mm. For a subsea release relevant for the Oda field, the film thicknesses were thick enough to meet this criterion. Due to emulsification, the oil/emulsion viscosities start at several hundred mPa.s and increases to several thousand by weathering Figure 5-1 illustrates the expected time window for mechanical recovery. At 2 and 5 m/s wind speeds, a reduced recovery is expected for viscosities < 1000 mPa.s due to boom leakage (yellow lines), and applicable (green lines) for viscosities up to 50 000 mPa.s (combination of low visc. and high-visc. skimmers for viscosities > 15-20 000 mPa.s), and lighter green lines for viscosities higher than 50 000 mPa.s when use of high-visc. skimmer, only. Mechanical recovery is thus considered as applicable response option for the given subsea scenario at both summer and winter conditions. In a spill operation, solidification at sea due to high pour points may reduce the skimmers efficacy, and high wind speeds may also reduce the efficacy during confinement of the oil/emulsion by booms, in addition to the potential of increased fragmentation of the slick (patchiness) and entrained oil into water column.

Use of oil spill dispersants

In general, application of chemical dispersant requires a certain oil film thickness (> 50-100 µm) to prevent the dispersant droplets from penetrating the oil film and being diluted in the water beneath. The predicted film thicknesses of the specific subsea release of Oda are above this limit and chemical dispersion can be recommended as a relevant first line response option within certain time-windows. At low wind speed (< 5 m/s) artificial turbulences may be required (e.g. by use of water flushing) to enhance the dispersion efficiency. At 2 and 5 m/s wind speeds (5 °C), the surfaced oil is expected to be dispersible (green lines) up to 6 and 1 day, respectively with for viscosity limits 5000 mPa.s., and reduced dispersible (yellow lines) for viscosities < 15 000 mPa.s, as shown in Figure 5-2. At higher wind speeds the higher viscosities reduce the time window for effective dispersant use. E.g. the oil/emulsion is not considered to be dispersible after 2 hours weathering at sea at both temperatures at 15 m/s wind speed. In addition, increasing weathering also increases the possibility to form solidified lumps at sea. Solidification of the oil/residue is together with the viscosity the limiting factor for effective dispersant use, particularly in winter conditions. Solidification typically arises when the pour point of the oil residue is 5-15 °C above the sea temperature.

Mechanical dispersion with high-capacity water flushing

The most important parameters deciding the effective use of surface water flushing for mechanical dispersion (no dispersant application) are the film thickness, viscosity and pour point. Water flushing may be suitable for oil films with thicknesses < 0.1-0.2 mm and for viscosities typical lower than 150-250 mPa.s. For this specific subsea release scenario, the predicted film thicknesses and viscosities are above these limits and water flushing is therefore not considered as applicable as a main response strategy for Oda, as shown in Figure 5-2 (red lines)

6 Oil weathering properties - subsea release vs. surface release of Oda

The predicted weathering properties from the defined subsea release compared with the standard surface release indicate the main differences. The OWM predictions of the Oda subsea release are given in Appendix A, and the predictions for the standard surface release are given in Appendix B and in the weathering report of Oda (Sørheim et al. 2019).

- Increased evaporative loss, approx. 5-10 % higher for the subsea release compared with the surface release due to an initial thinner oil film when the oil plume reaches the surface (0.1-0.2 mm vs. 2-3 mm)
- Increased flash points for the subsea release due to increased evaporative loss. This means that for the subsea release the flash point is well above the sea temperature at both 5 and 15 °C for all wind speeds
- Increased pour points for the subsea release due to increased evaporative loss. This means that the oil has a potential to solidify within a shorter time at sea compared with the surface release and this may influence on the effective use of dispersant, particularly at winter conditions. E.g. at 5 m/s wind speed, the oil may be poorly dispersible after 6 hours at 5 °C but can be dispersible up to 2 days for a surface release
- The oil reached a slightly lower maximum water uptake (73-76 vol.%) from the subsea release compared with the surface release (80 vol. %). However, the emulsification (kinetic) rates were quite similar between the two scenarios
- Higher oil/emulsion viscosities with weathering time at sea was predicted for the subsea release compared with the surface release. This means that the time-window for dispersant use is somewhat shorter for the subsea release. E.g. at 10 m/s wind speed the viscosity limit (15 000 mPa.s) for when the oil is considered as not/poorly dispersible is about 12 hours, but is 3-6 hours for the subsea release
- The predicted lifetimes (mass balances) from the subsea release show that at high wind speeds (10-15 m/s) the oil is expected to be removed from the surface within considerable shorter time (6 hours)

compared with the surface release (2 days). The overall volume of oil at sea, relative to the volume of oil released, from the subsea release increases about 2-2.5 times due to emulsification. This is somewhat lower than the total volume from the surface release (3 times increase), due to higher degree of natural dispersion, higher evaporative loss and slightly lower water-uptake for the subsea release compared with the surface release

7 Summary

The oil/gas plume from a pipeline rupture will reach the sea surface, as simulated by the OSCAR plume model. The SINTEF OWM was used to predict the oil weathering properties and film thicknesses of the surfacing oil from a subsea release of Oda. The following response recommendations can be made from the defined batch subsea release at the Oda field:

- Oda is predicted to initially form oil films (> 0.1-0.2 mm) that is thick enough to emulsify on the sea surface with the potential to form high viscous emulsions with high water uptake
- Mechanical recovery is expected to be applicable on the surface oil, particularly in combination of low visc. and high visc. skimmers for oil/emulsion viscosities up to 20 000 mPa.s, but for higher viscosities (> 50 000 mPa.s) the high visc. skimmer is recommended by NOFO
- Dispersant application has a potential on Oda, but the time window is dependent on the oil/emulsion viscosity. E.g. at high wind speeds (10-15 m/s), the time window for dispersant use is reduced or considered as not dispersible after 1 hour of weathering but is longer at lower wind speeds (2-5 m/s)
- Consider the relatively small release amount (433 m^3), a rapid response of dispersant application is therefore recommended to enhance the natural dispersion by formation of smaller dispersed oil droplets into the water column
- However, the oil may solidify on the sea surface due to high pour points with time. Solidification may reduce the potential for effective use of dispersants, and reduce the efficacy of mechanical recovery due to the risk of patches of solidified lumps on the sea surface
- In high wind speeds the predicted mass balances indicate that the oil can be removed from the sea surface within 2 days at 10 m/s and 9 hours at 15 m/s
- In low wind speeds (2-5 m/s), the oil/emulsion is predicted to have a prolonged lifetime at sea
- For a continuous blowout e.g. from a pipeline or well, the simulation of the rising plume reaching the surface would be the same as for the batch release assuming identical release conditions. However, a continuous blowout would be in a larger scale with considerable amount of oil released compared to a smaller batch release

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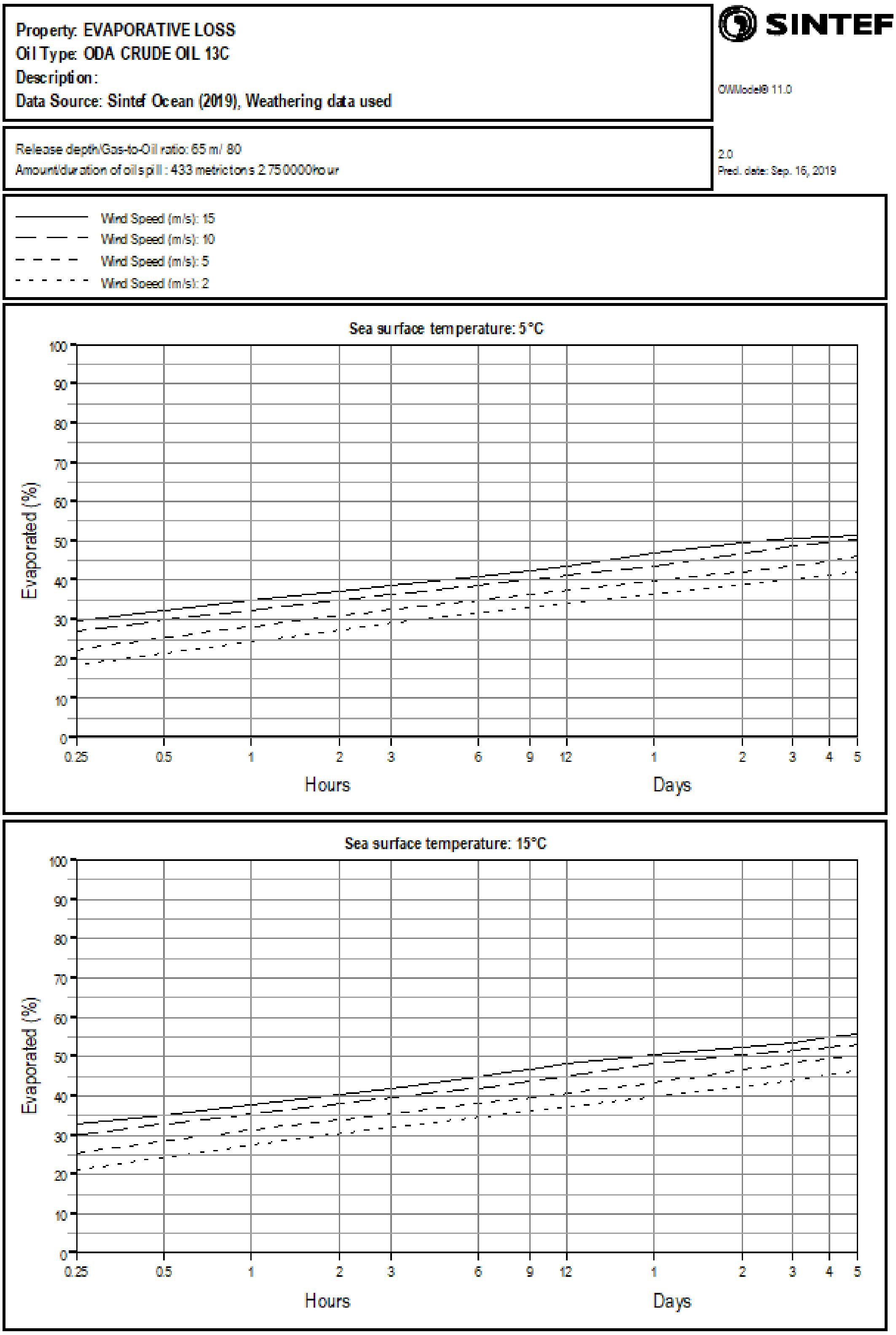
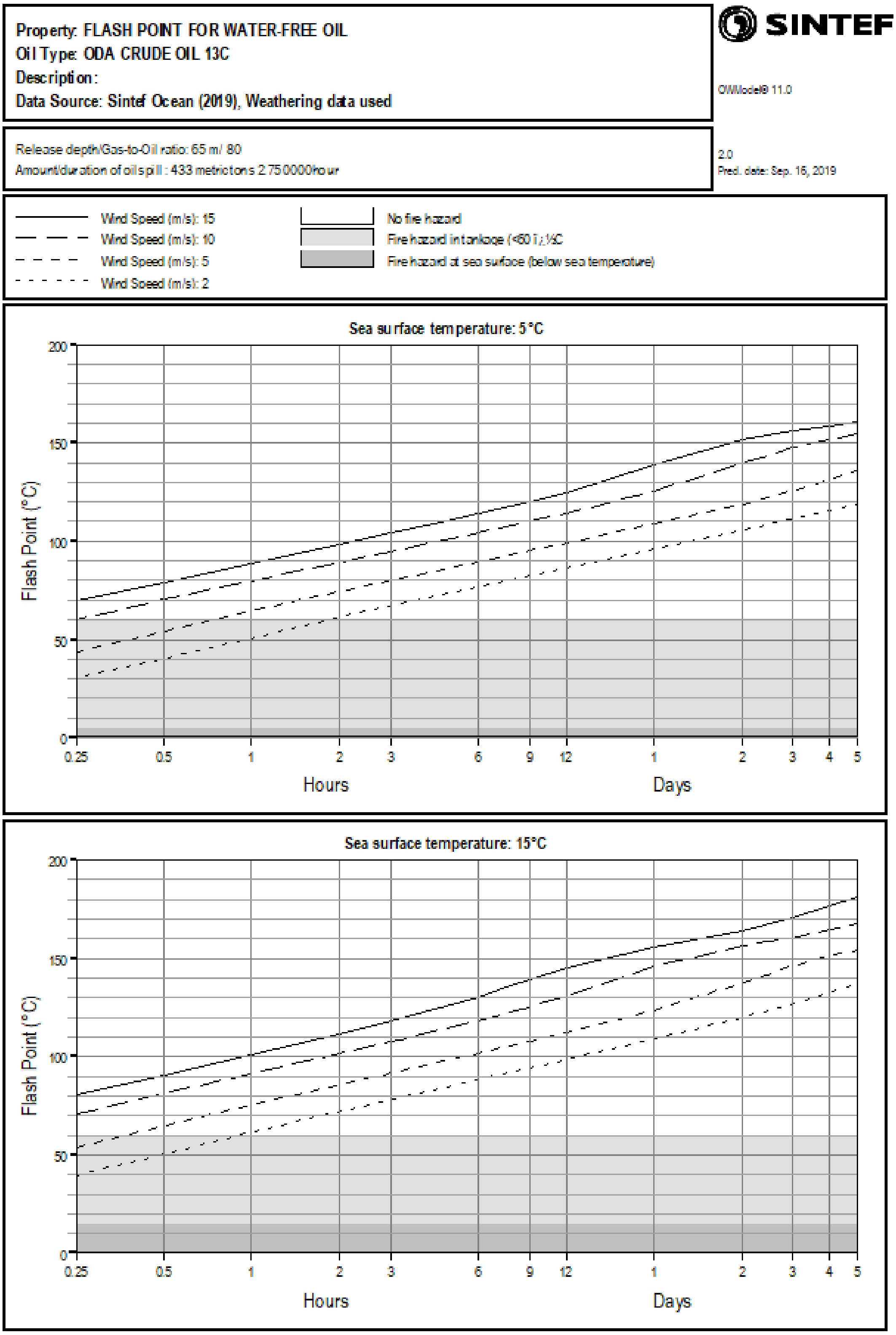
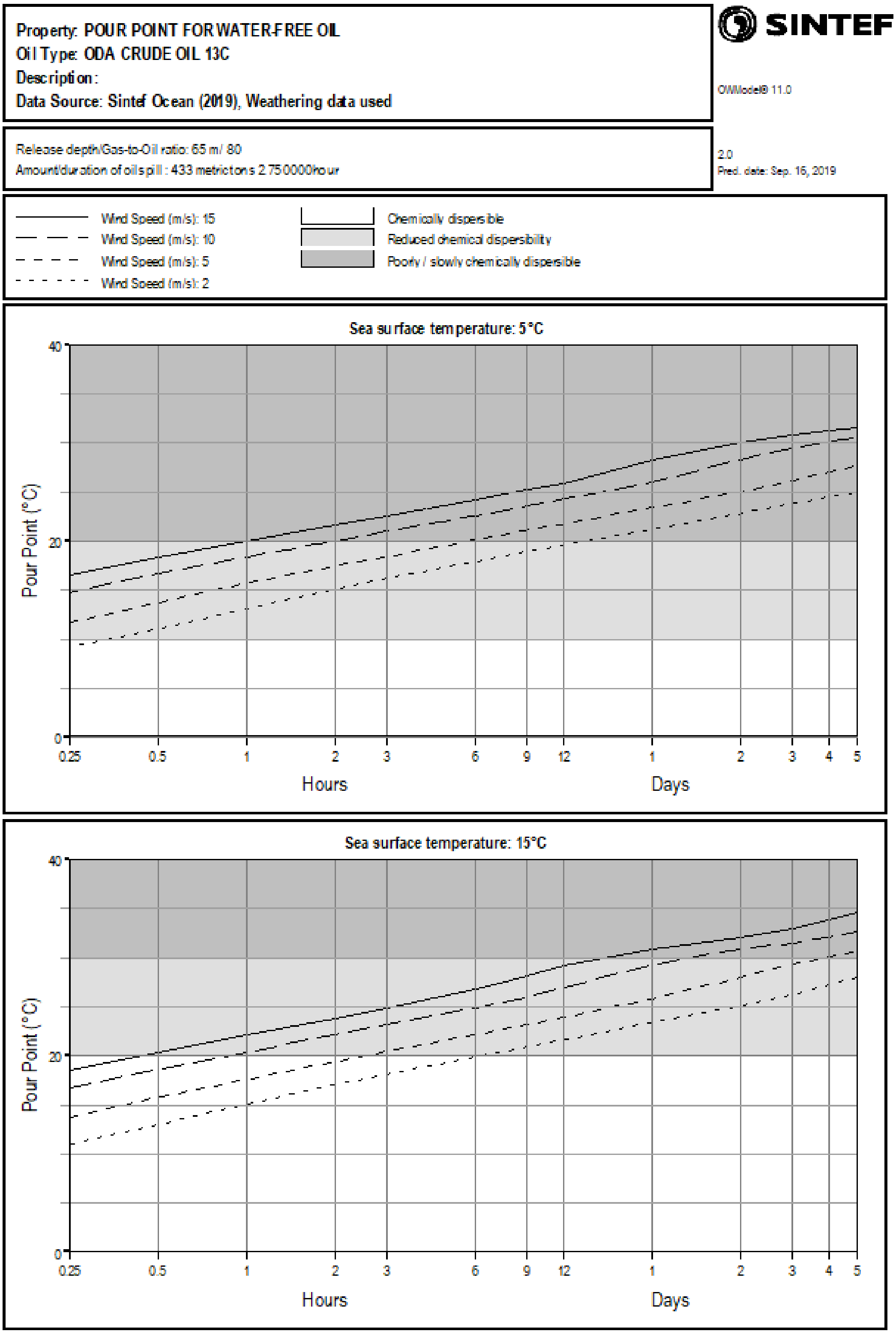
A Prediction of weathering properties from a subsea release of Oda



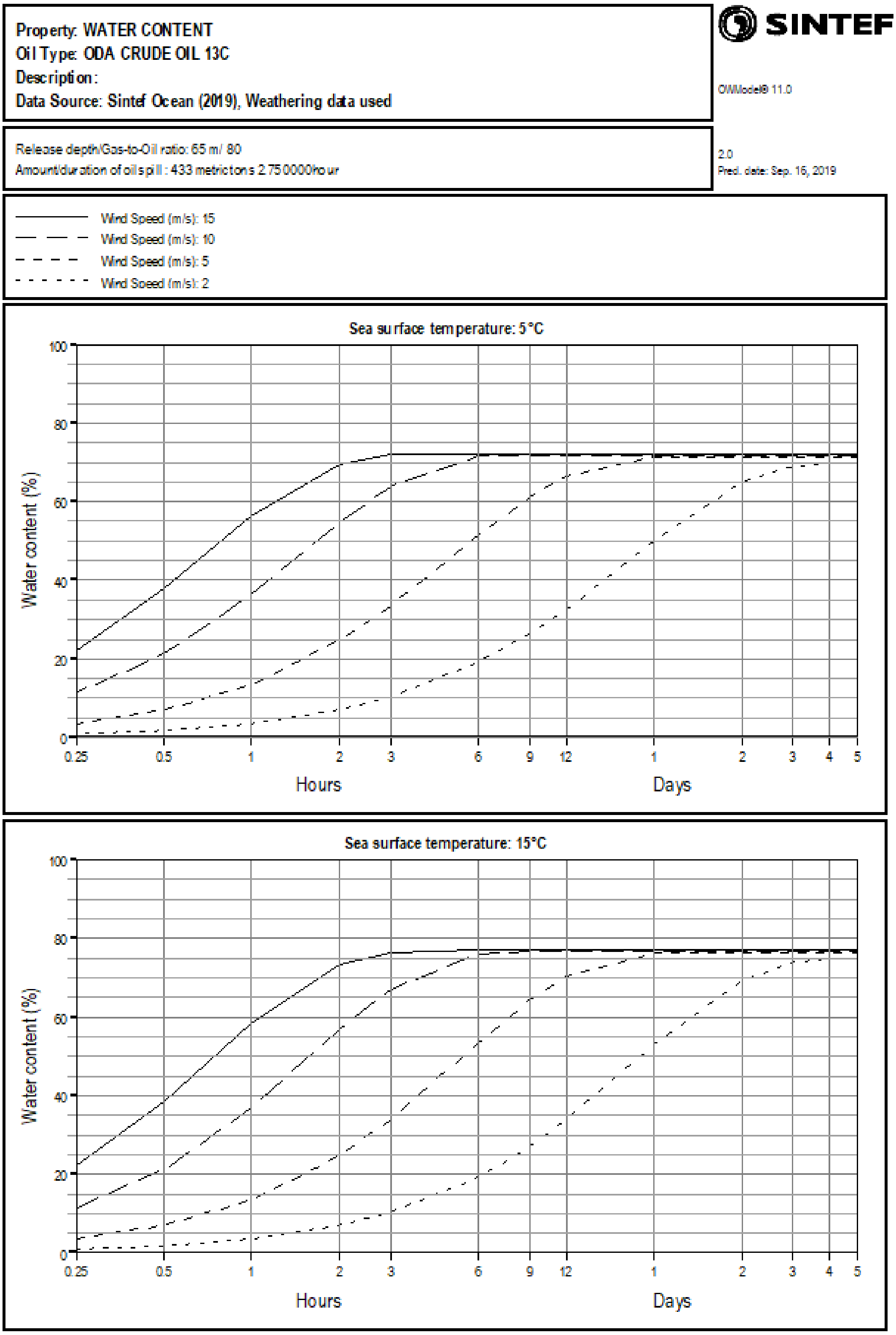
A-1 Evaporative loss of Oda crude oil from a subsea release at sea temperatures of 5 and 15 °C



A-2 Flash point of Oda crude oil from a subsea release at sea temperatures of 5 and 15 °C



A-3 Pour point of Oda crude oil from a subsea release at sea temperatures of 5 and 15 °C



A-4 Water uptake of Oda crude oil from a subsea release at sea temperatures of 5 and 15 °C

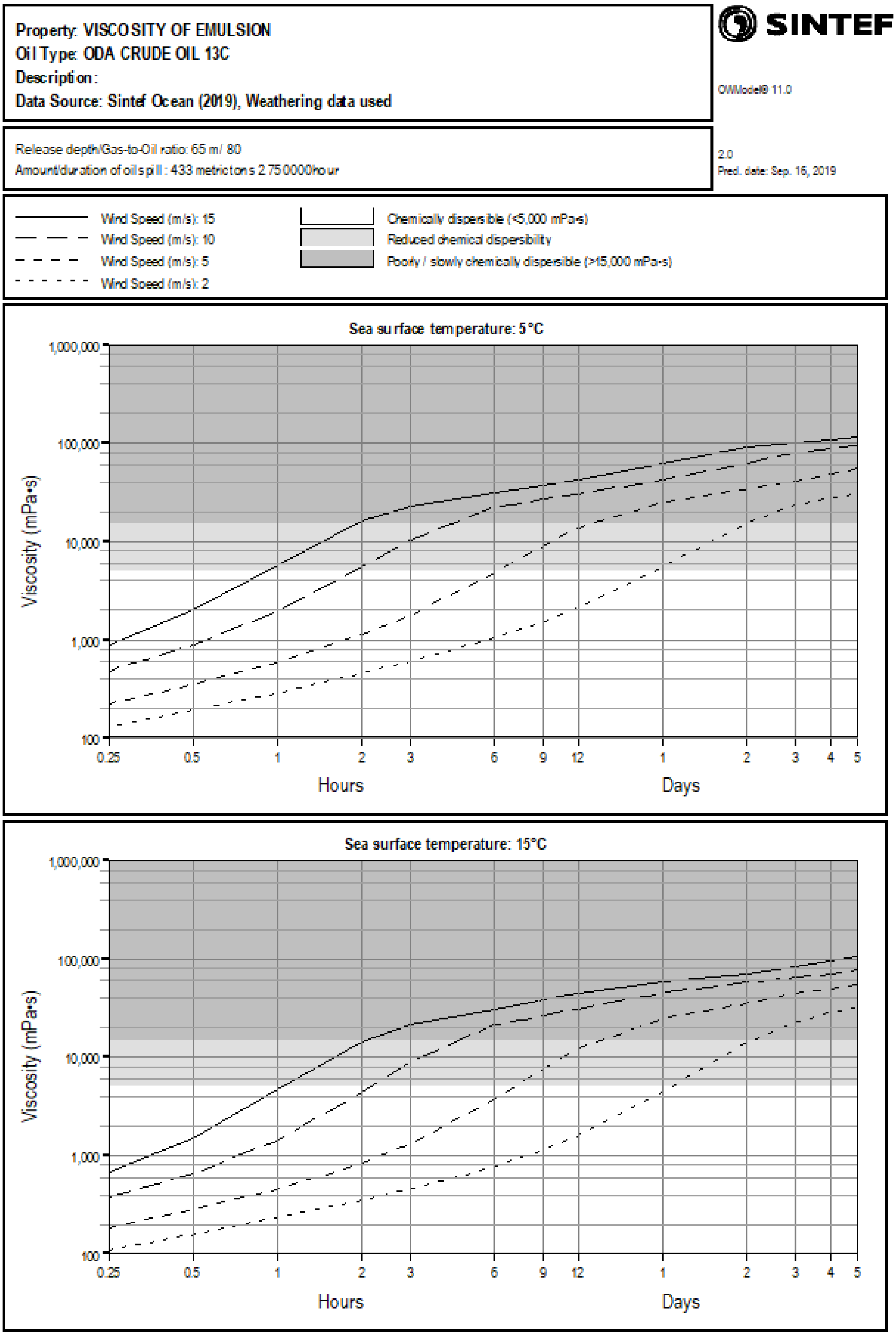


Figure A-5 *Viscosities of Oda crude oil from a subsea release at sea temperatures of 5 and 15 °C Predictions are based on measurements of emulsions performed at a shear rate of 10 s^{-1}*

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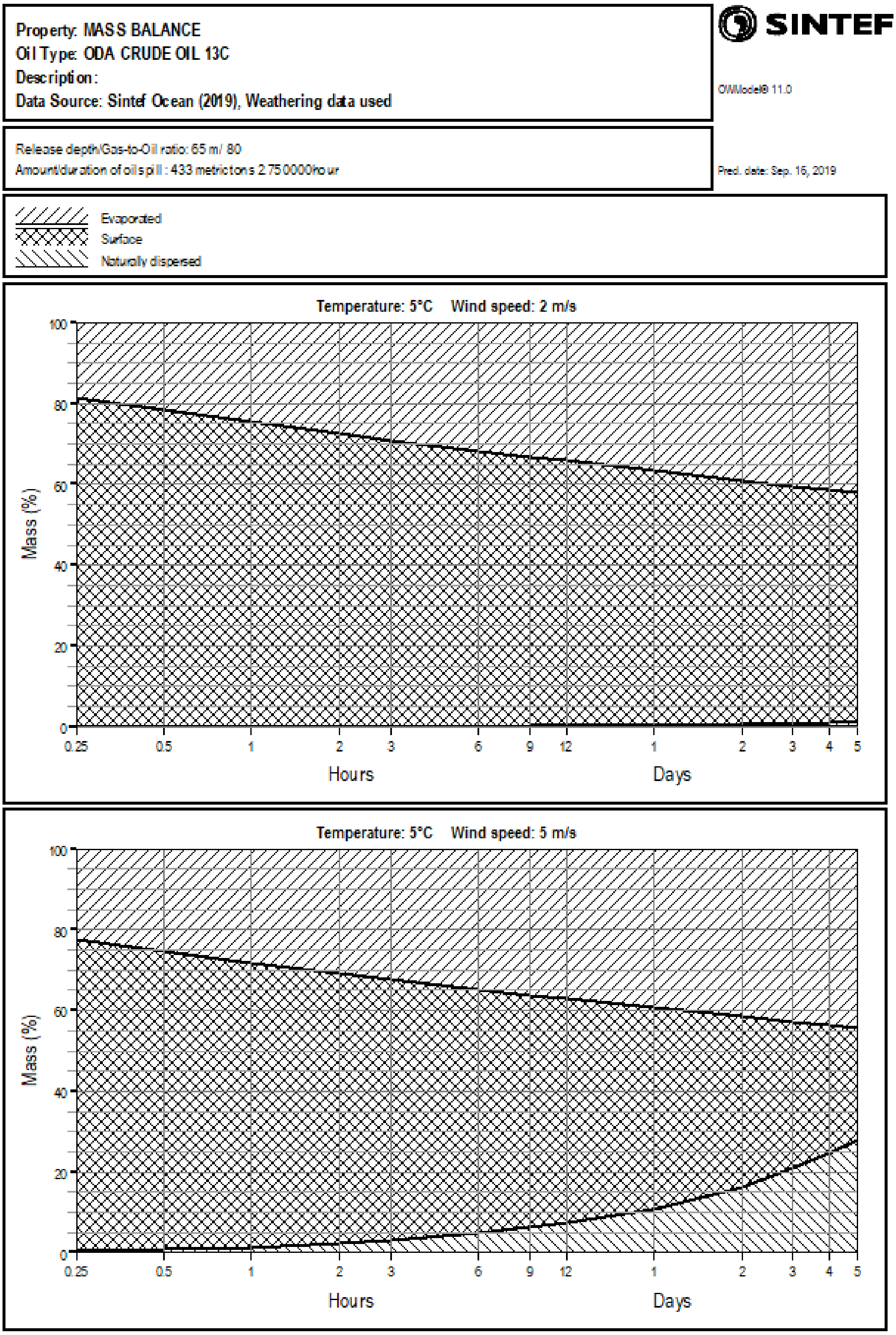
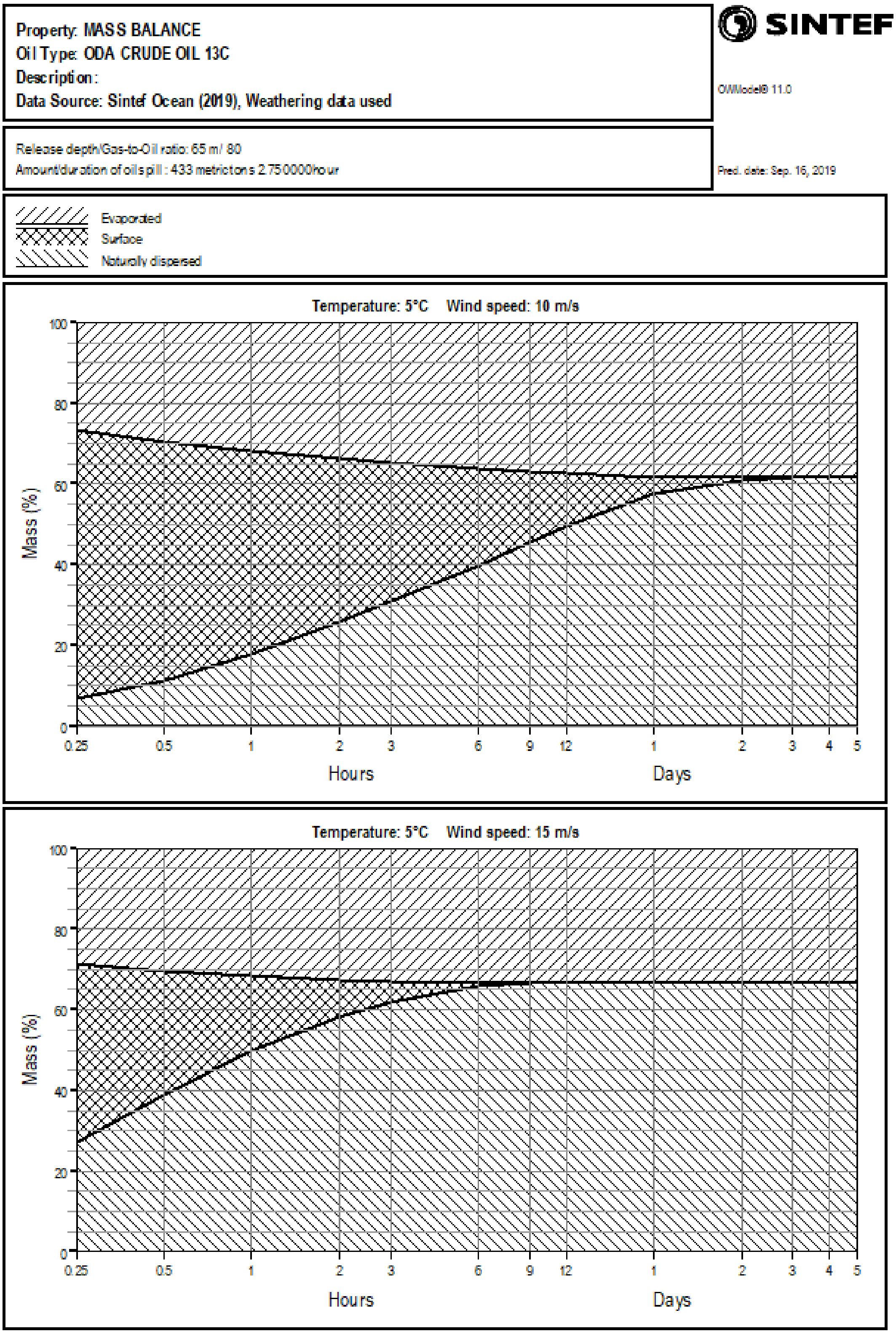
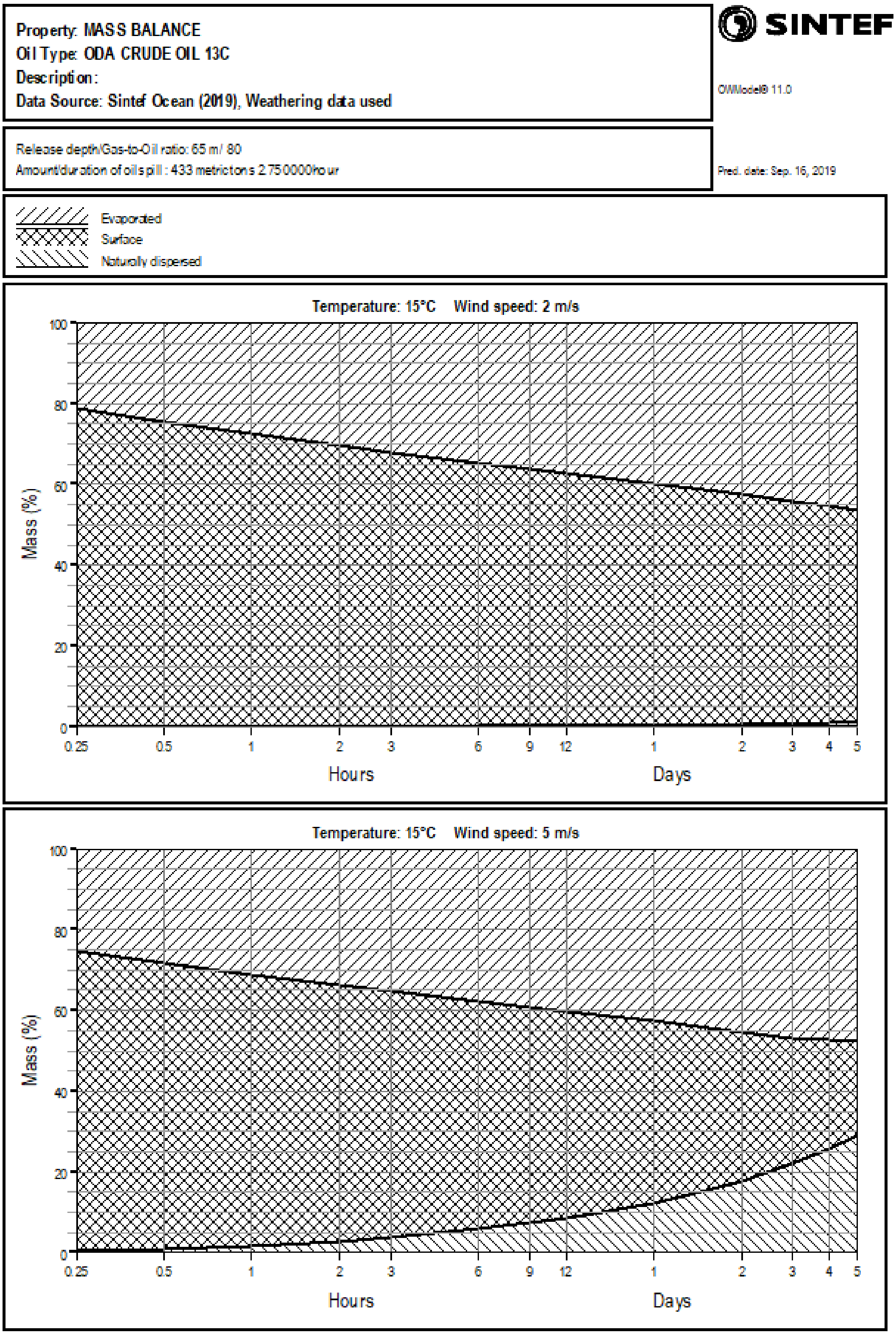


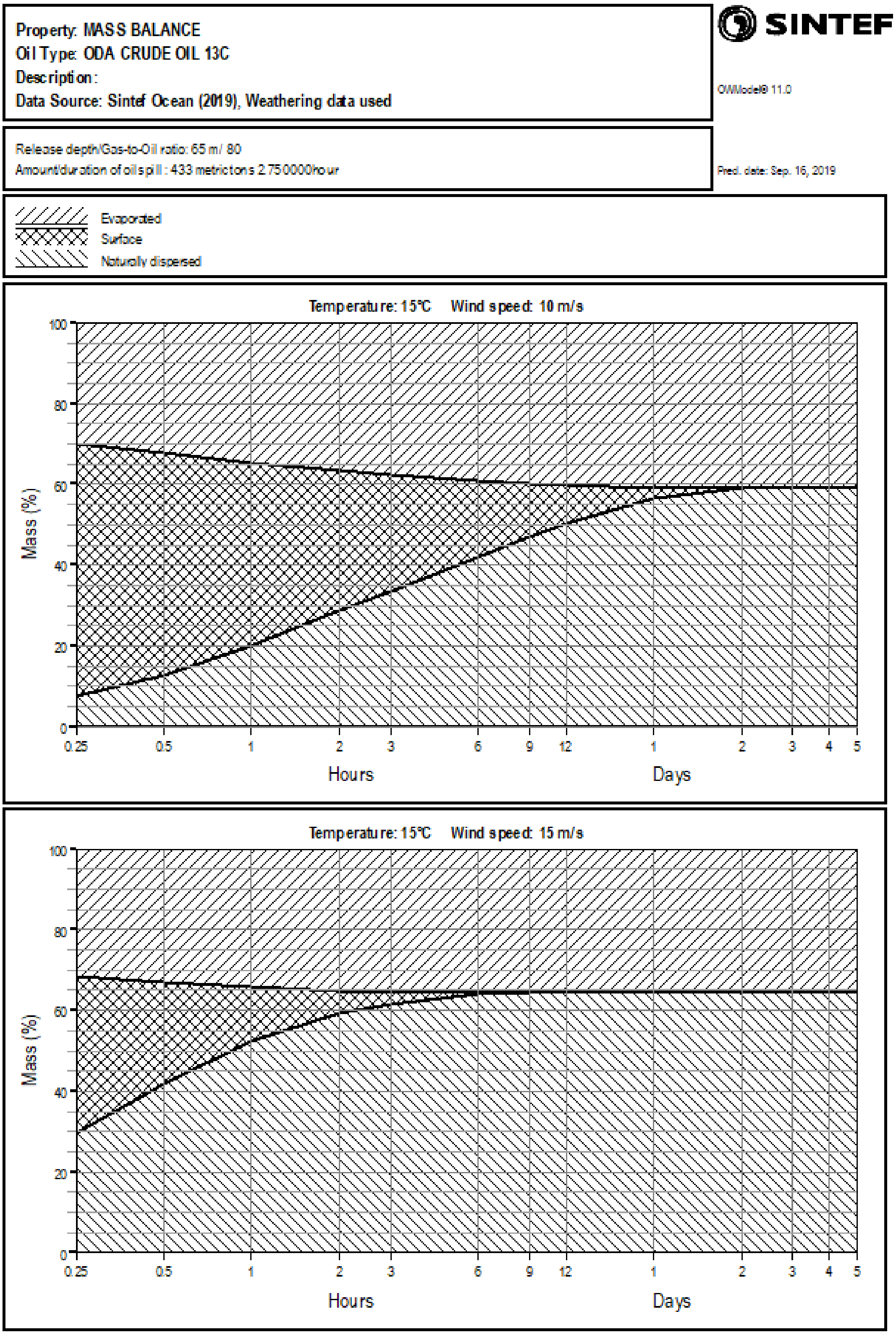
A-6 Mass balance of Oda crude oil from a subsea release at 5 °C and wind speeds of 2 and 5 m/s



A-7 Mass balance of Oda crude oil from a subsea release at 5 °C and wind speeds of 10 and 15 m/s



A-8 Mass balance of Oda crude oil from a subsea release at 15 °C and wind speeds of 2 and 5 m/s



A-9 Mass balance of Oda crude oil from a subsea release at 15 °C and wind speeds of 10 and 15 m/s

B Prediction of weathering properties from a surface release of Oda

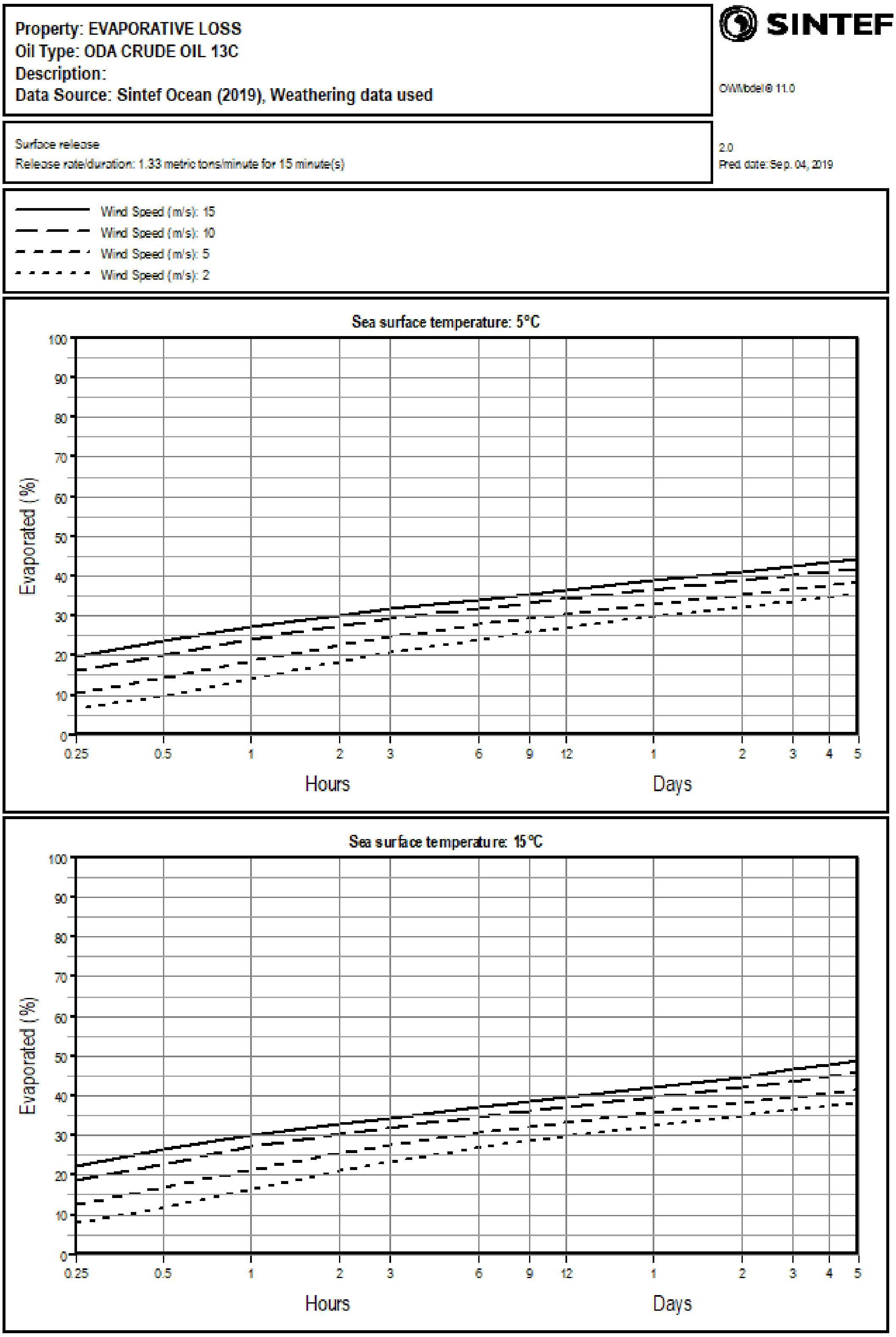


Figure B-1 *Evaporative loss of Oda crude oil predicted from a surface release at sea temperatures of 5 and 15 °C*

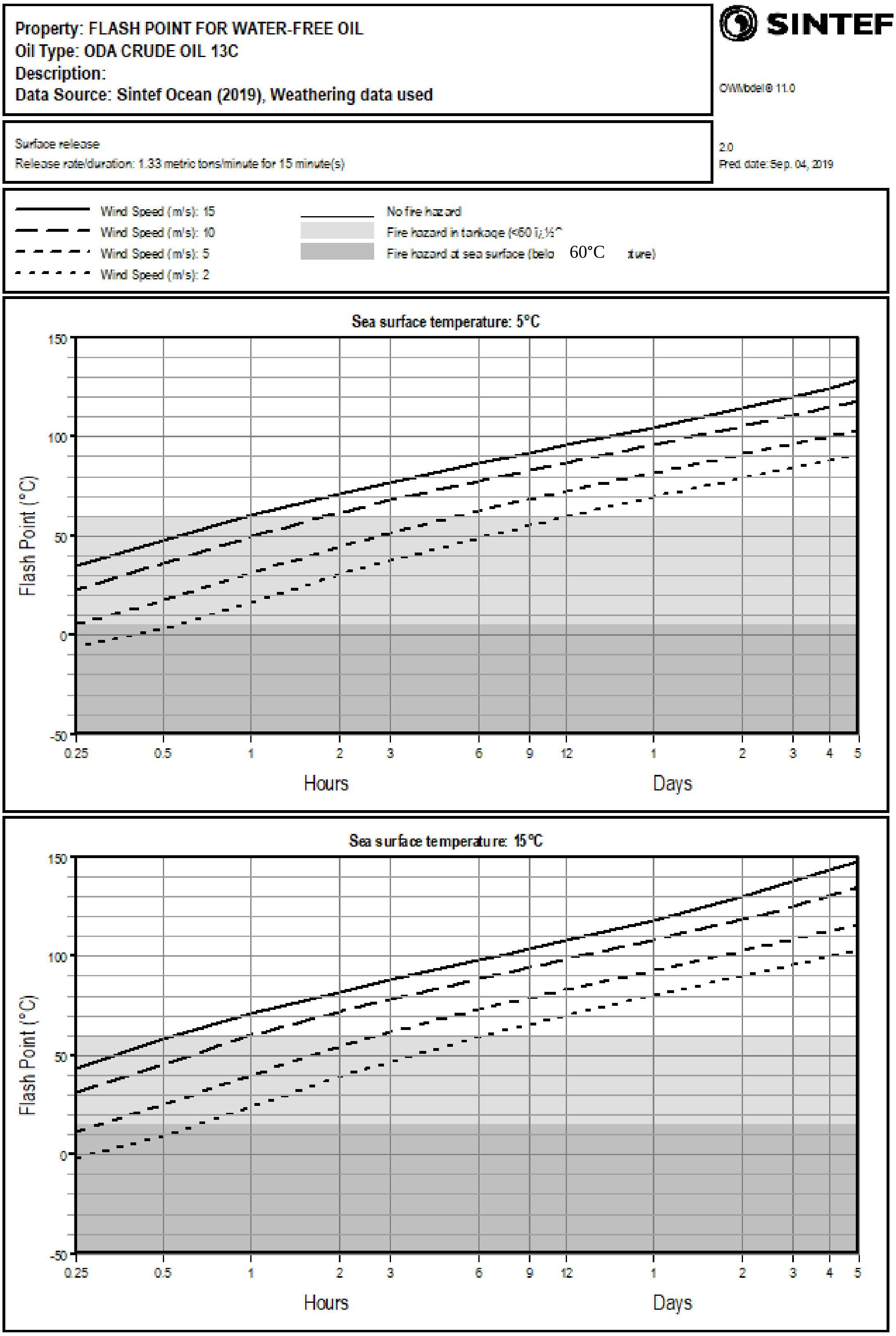


Figure B-2 Flash point of Oda crude oil from a surface release predicted at sea temperatures of 5 and 15 °C

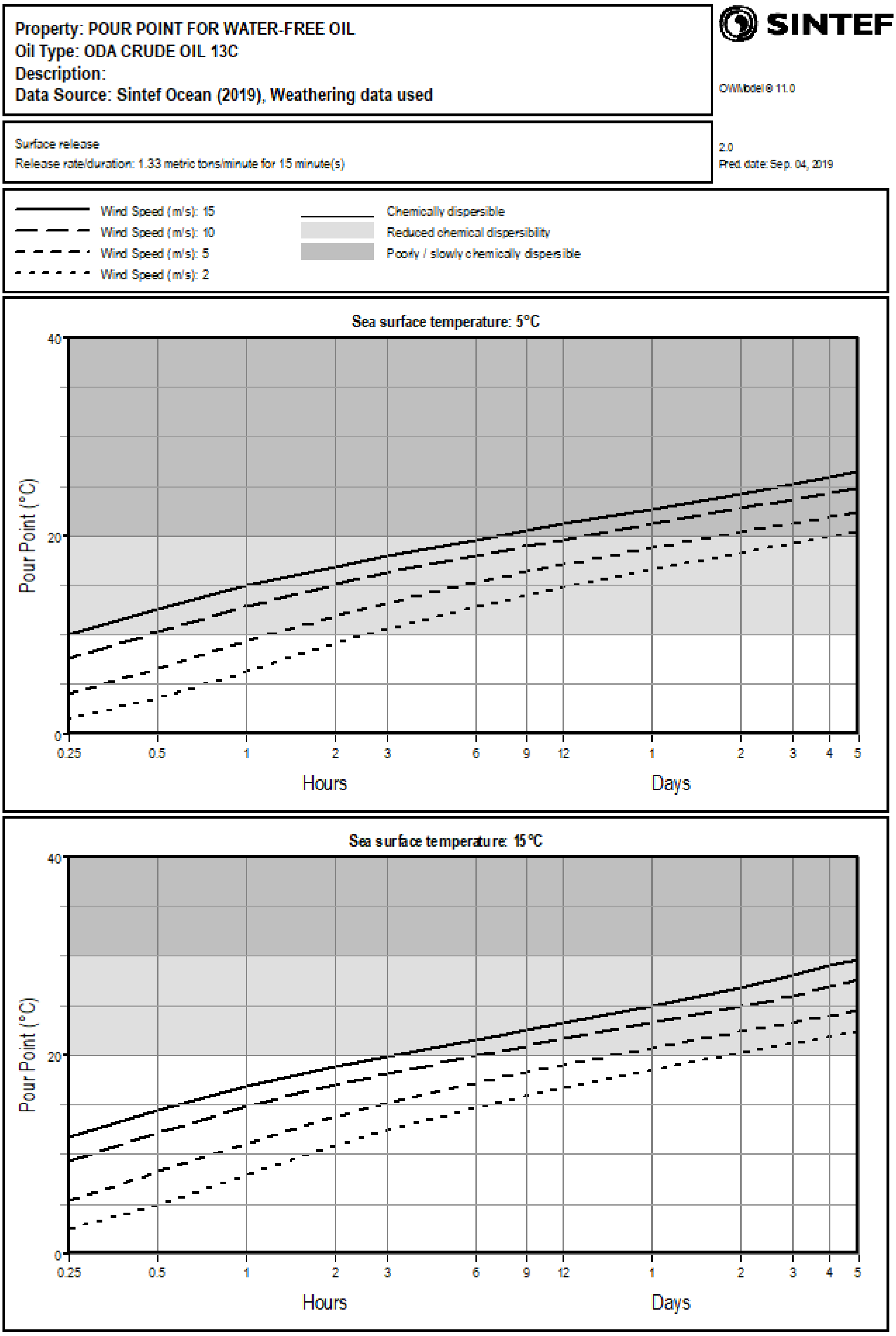


Figure B-3 Pour point of Oda crude oil from a surface release predicted at sea temperatures of 5 and 15 °C

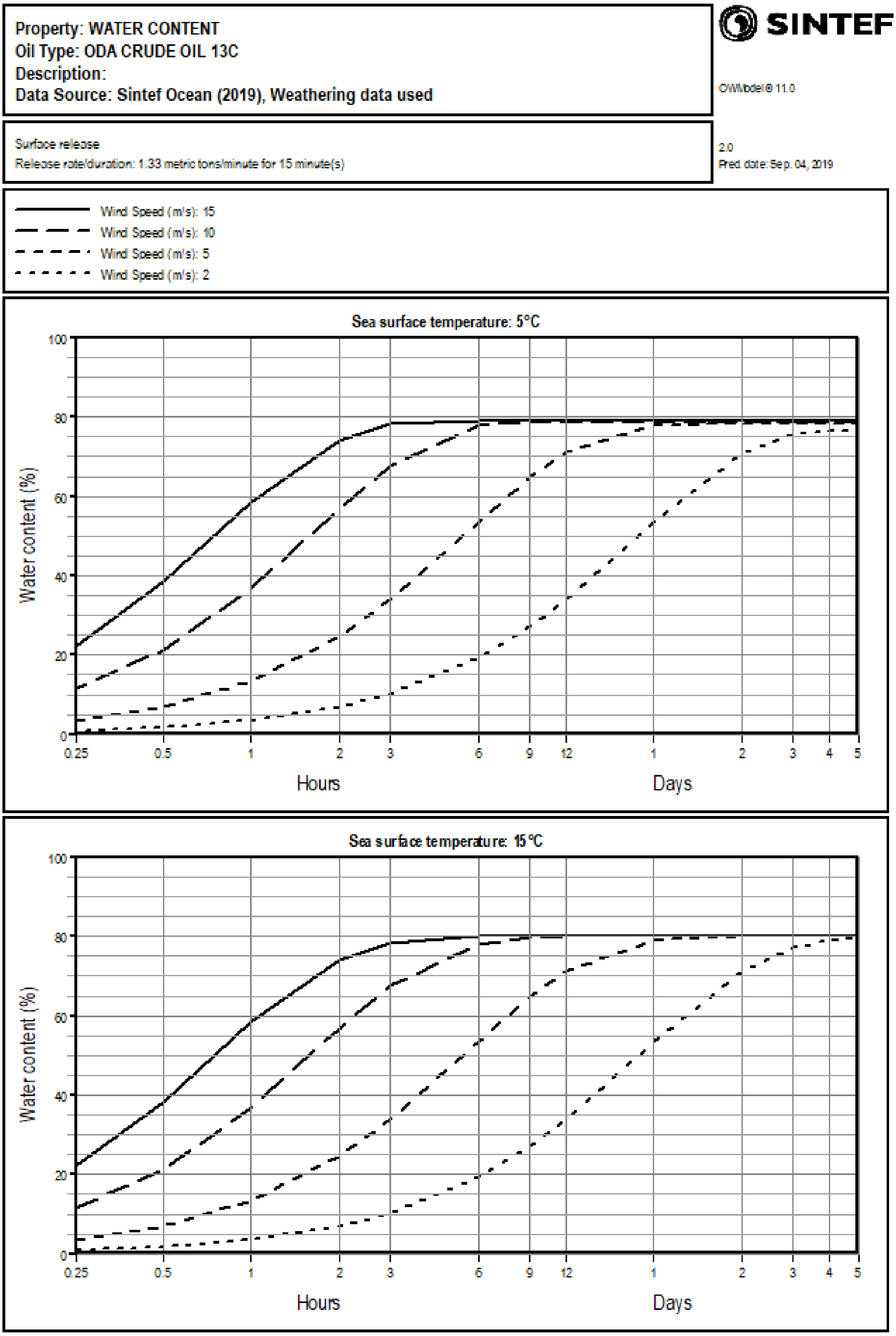


Figure B-4 Water content of Oda crude oil from a surface release predicted at sea temperatures of 5 and 15 °C

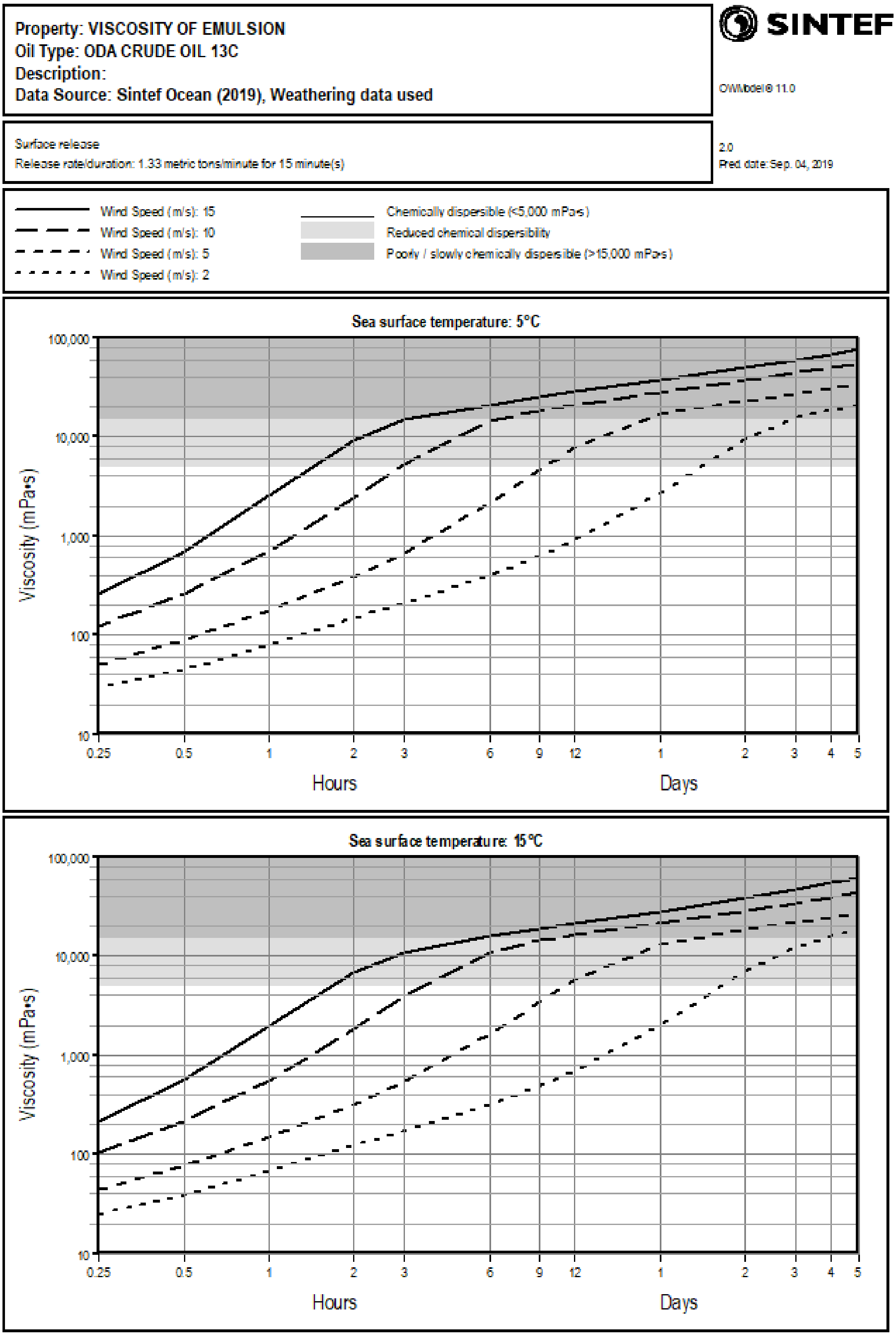


Figure B-5 *Viscosities of Oda crude oil emulsions from a surface release predicted at sea temperatures of 5 and 15°C. Predictions are based on measurements of emulsions performed at a shear rate of 10 s^{-1}*

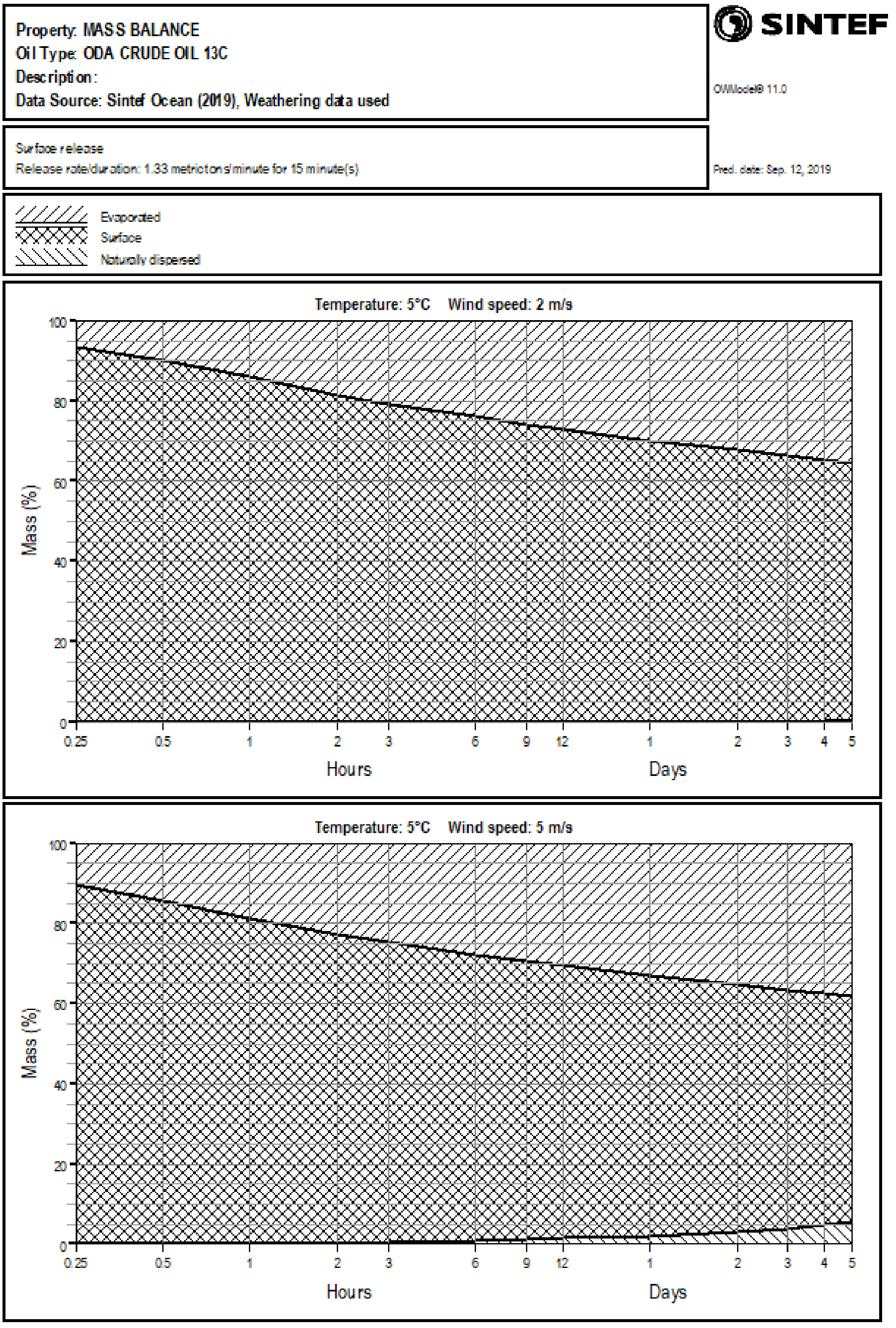


Figure B-6 *Predicted mass balance for Oda crude oil from a surface release at 5 °C and wind speeds of 2 and 5 m/s*

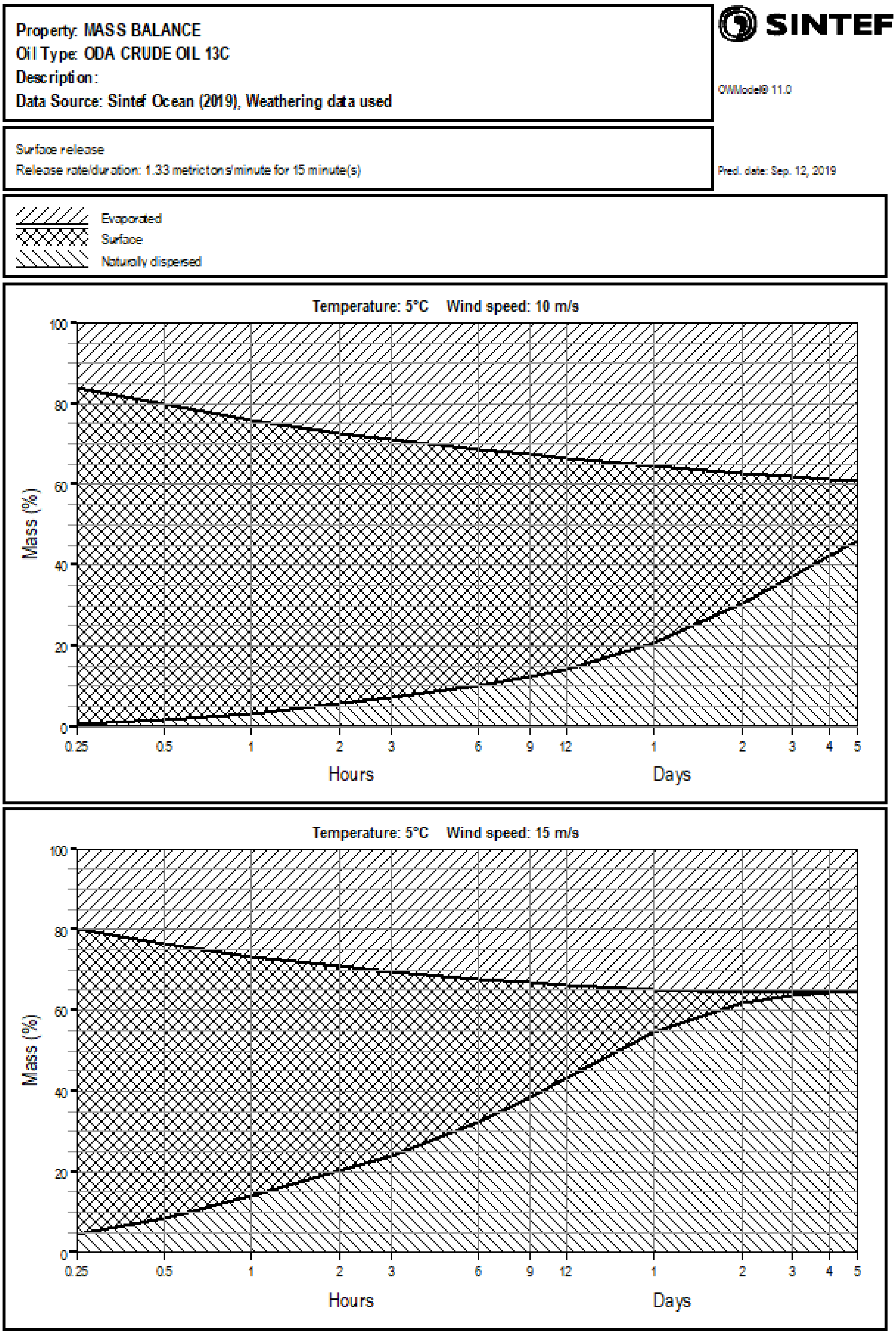


Figure B-7 Predicted mass balance for Oda crude oil from a surface release at 5 °C and wind speeds of 2 and 5 m/s

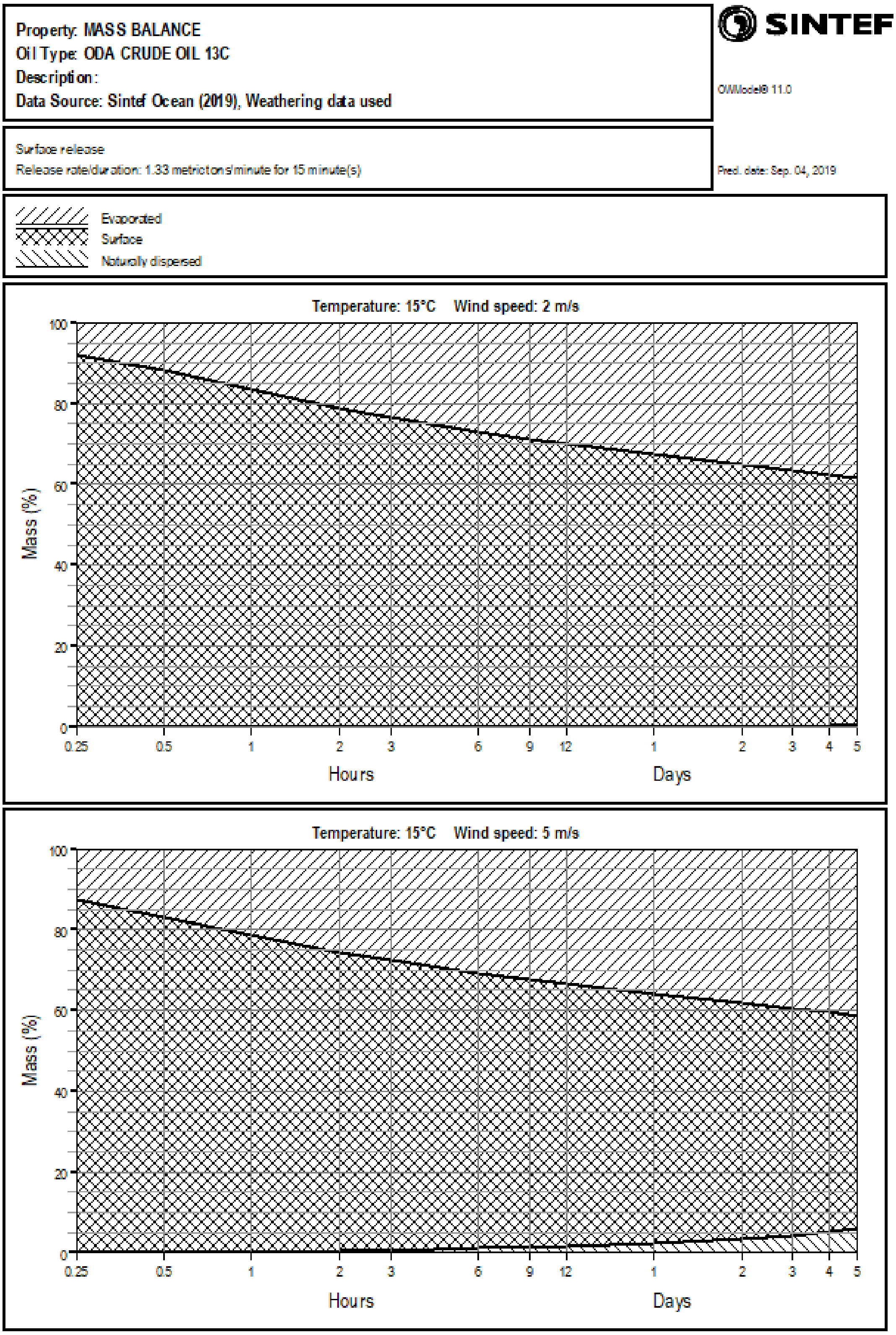


Figure B-8 *Predicted mass balance for Oda crude oil from a surface release at 15 °C and wind speeds of 2 and 5 m/s*

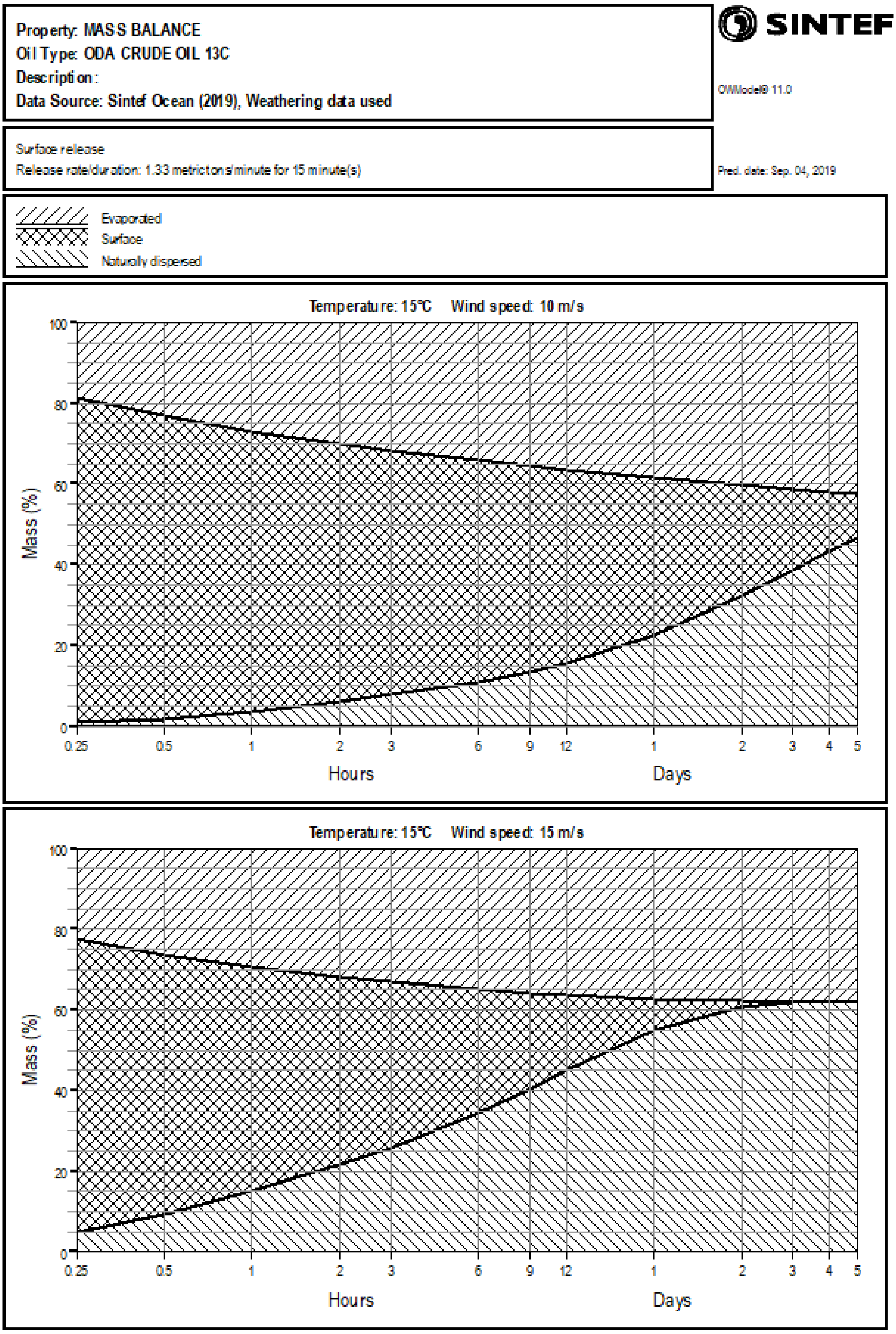


Figure B-9 Predicted mass balance for Oda crude oil from a surface release at 15 °C and wind speeds of 10 and 15 m/s

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