# EIA Disposal dredged sediment from marina Nieuwpoort

## Numerical plume modelling

Consortium Baggerwerken Decloedt en Zoon - DC Industrial
Department

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# 1 Introduction

## 1.1 The assignment

The consortium Baggerwerken Decloedt en Zoon – DC Industrial develop the extension of the marina of Nieuwpoort. During the deepening works a large volume of sediment will be available, consisting of sand and clayey material. Instead of transporting the soil over road, it was decided to dispose of the soil offshore in a designated disposal area in the Belgium part of the North Sea. Therefore an authorization and environmental permit are required. A necessary part to obtain a permit is the writing of an Environmental Impact Assessment (EIA) of the foreseen activities. This task was assigned by the consortium Baggerwerken Decloedt en Zoon – DC Industrial to International Marine and Dredging Consultants nv in June 2018.

In a first step the sedimentological characteristics were defined of the volume of sediment to be disposed (IMDC, 2019).

The disposal works will likely cause turbidity and sediment dispersion. In order to assess the potential impact of this on the background turbidity, the suspended sediment levels and footprint on the seabed, a numerical plume model was set up. The simulated scenarios and parameter settings were chosen in close collaboration with the MUMM (Dries Van den Eynde) in order to fulfil the specific requirements of the EIA.

## 1.2 Scope of the report

In this report, a three-dimensional TELEMAC model is set up in order to study the impact of the disposal of material obtained from dredging works in the future new marina of Nieuwpoort. In order to do so, various scenarios are simulated, each of them for conservative conditions, for which the maximum sediment concentrations and sediment deposition are determined.

## 1.3 Reading guidance

This report represents the analysis of the plumes that are generated when disposing sediment in the disposal zones offshore of Nieuwpoort and Oostende. Thereto, first the model setup of the hydrodynamic and the sediment transport model are discussed in chapter 2. In chapter 3 the five different scenarios are presented. The impact on the sediment concentrations and the deposition are discussed for each of these scenario. Finally some conclusions are given in chapter 4.

# 2 Description of numerical model

## 2.1 Hydrodynamic model

### 2.1.1 Model software

The TELEMAC-3D software (v7p1) is applied for the suspended sediment transport calculations, and solves the three dimensional equations such as the free surface flow equations (without the hydrostatic pressure hypothesis) and the transport diffusion equations of intrinsic quantities (sediment concentration). TELEMAC-3D makes use of the shallow water equations as first derived by Barré de Saint-Venant using a finite element method in the nodes of a mesh consisting of prisms with a triangular base. The main results are, for each point in the 3D mesh, the velocity in all three directions and the concentrations of the transported quantities. On the surface mesh the main result is the water level.

### 2.1.2 Numerical grid and bathymetry

The study area consists of a stretch of the Belgian coastal zone, with a length of 140 km and an offshore extent of approximately 35 km. The mesh consists of 129.862 triangular elements, with a dimension ranging from 20 m to 1800 m (Figure 2-1). Mesh refinements were applied around the current disposal zones offshore Nieuwpoort and Oostende with a typical mesh resolution of 50 m and at the areas with the largest gradients in the bathymetry (typically the edges of the sandbanks).

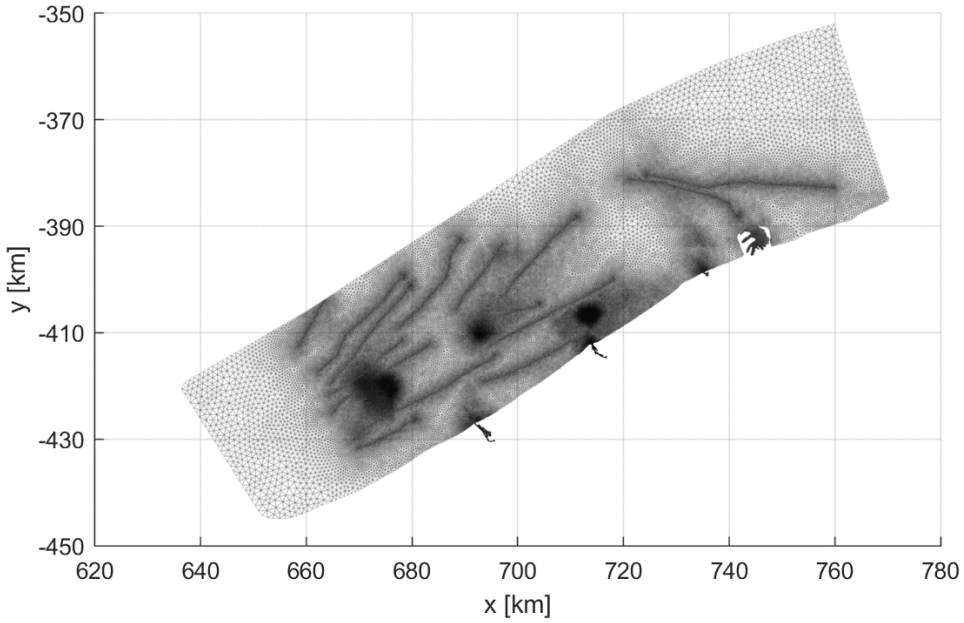



Figure 2-1 Computational mesh

The model bathymetry is shown in Figure 2-2. The model bathymetry was setup using data from three different data sources: the "Bathymetrische databank" of Afdeling Kust for the Belgian coastal zone, SHOM for the French part of the coastal zone and OpenEarth for the Dutch part of the coastal zone. All data were converted to mean sea level (MSL) and then interpolated to the computational mesh.

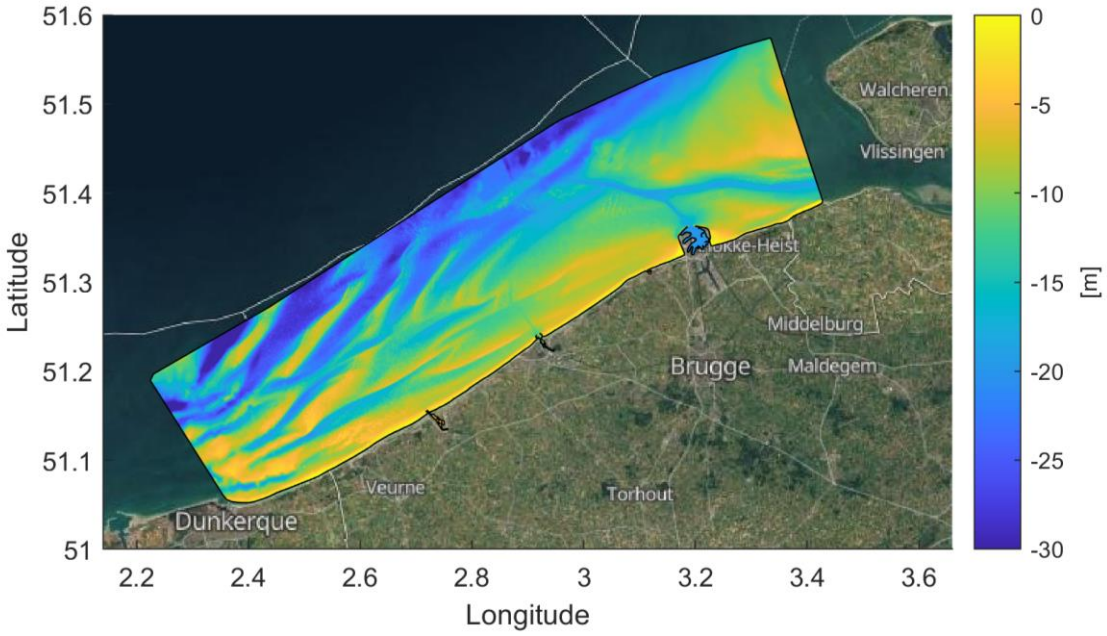



Figure 2-2 Model Bathymetry (in MSL)

### 2.1.3 Vertical layer distribution

The model uses 10 vertical nodes (9 layers) with a sigma coordinate distribution. The thickness of the layers varies according to a hyperbolic tangent distribution, with the smallest mesh size in the upper and lower layer (Table 2-1).

Table 2-1 Distribution of the vertical layers

| Node number | Sigma coordinate of the elevation of the node |
|---|---|
| 1 | 0.000 |
| 2 | 0.031 |
| 3 | 0.095 |
| 4 | 0.214 |
| 5 | 0.394 |
| 6 | 0.606 |
| 7 | 0.786 |
| 8 | 0.905 |
| 9 | 0.969 |
| 10 | 1.000 |

### 2.1.4 Boundary conditions and forcing

The model was forced by water levels and depth averaged velocities from the iCSM model (Breugem *et al.*, 2014). This model was run using tidal boundary conditions from OSU/TPXO (Egbert and Erofeeva, 2002) as well as meteorological data (wind and air pressure) from the ERA-5 meteorological model.




Figure 2-3 Mesh of the iCSM continental shelf model

The data from the iCSM model (water levels and depth averaged velocities) were interpolated to the boundaries of the model (lateral as well as offshore).

### 2.1.5 Settings

A list of the physical and numerical parameters of the hydrodynamic model is shown in Table 2-2.

Table 2-2 Physical and numerical settings of the hydrodynamic model

| Parameter | Value |
|---|---|
| Roughness law | Nikuradse law (constant value of 0.03 m) |
| Horizontal Turbulence model | Smagorinsky |
| Vertical turbulence model | Mixing length model with a Bakhmetev distribution for the mixing length. |
| Coriolis coefficient | Varying in space |
| Wind and meteo effect | Off (but implicitly included in the boundary conditions from the iCSM model)[1] |
| Advection scheme for momentum | Method of characteristics |
| Mass lumping for water depth | 1.0 |
| Matrix solver | Squared conjugate gradient |

[1] No explicit effect of meteorology is applied in the local model. However, meteorological effects are included in the iCSM model that was used to generate the boundary conditions. Changes in the water levels at the boundaries of the local model due to large scale meteorological events are therefore applied to the local model. Changes in the velocities due to these water level changes are therefore also calculated in the local model. Note that the selected model period was meteorologically quiet without strong storms.

### 2.1.6 Model validation

The results of the model were compared with measurement data from "Meetnet Vlaamse Banken" for the period 15th to the 29th of August 2014. The results for the model simulations are shown in Table 2-3 and Table 2-4. In these tables, the bias (average error), root mean square error (RMSE) and the root mean square error corrected for the bias ($RMSE_0$) are shown. A time series of the measured and modelled, water levels and velocities at one location (Scheur Wielingen) is shown in Figure 2-4. The tables and the figure show that the model performs well for calculating the hydrodynamic conditions in the area with a RMSE around 0.2 m for the water levels and around 0.15 m/s for the velocities

Table 2-3 Statistics results for the comparison of the water levels

| Station | Bias Water level [m] | RMSE Water Level [m] | $RMSE_0$ Water level [m] |
|---|---|---|---|
| mn Ostend Harbor | 0.04 | 0.18 | 0.18 |
| mn A2 | 0.05 | 0.19 | 0.18 |
| mn Blankenberge | 0.05 | 0.19 | 0.19 |
| mn Zeebrugge Leopold | -0.03 | 0.19 | 0.19 |
| mn Wandelaar | 0.11 | 0.21 | 0.18 |
| mn Bol van Heist | 0.1 | 0.2 | 0.18 |
| mn Scheur Wielingen | 0.04 | 0.19 | 0.19 |
| mn Nieuwpoort | 0.04 | 0.18 | 0.17 |

Table 2-4 Statistics results for the comparison of the velocities

| | Bias velocity magnitude [m/s] | RMSE velocity magnitude [m/s] | RMSE0 velocity magnitude [m/s] | Bias current direction [deg] | RMSE current direction [deg] | $RMSE_0$ current direction [deg] |
|---|---|---|---|---|---|---|
| mn Bol van Heist | -0.1 | 0.17 | 0.14 | -14.8 | 27.2 | 22.8 |
| mn Scheur Wielingen | -0.01 | 0.13 | 0.13 | -3.0 | 16.0 | 15.7 |

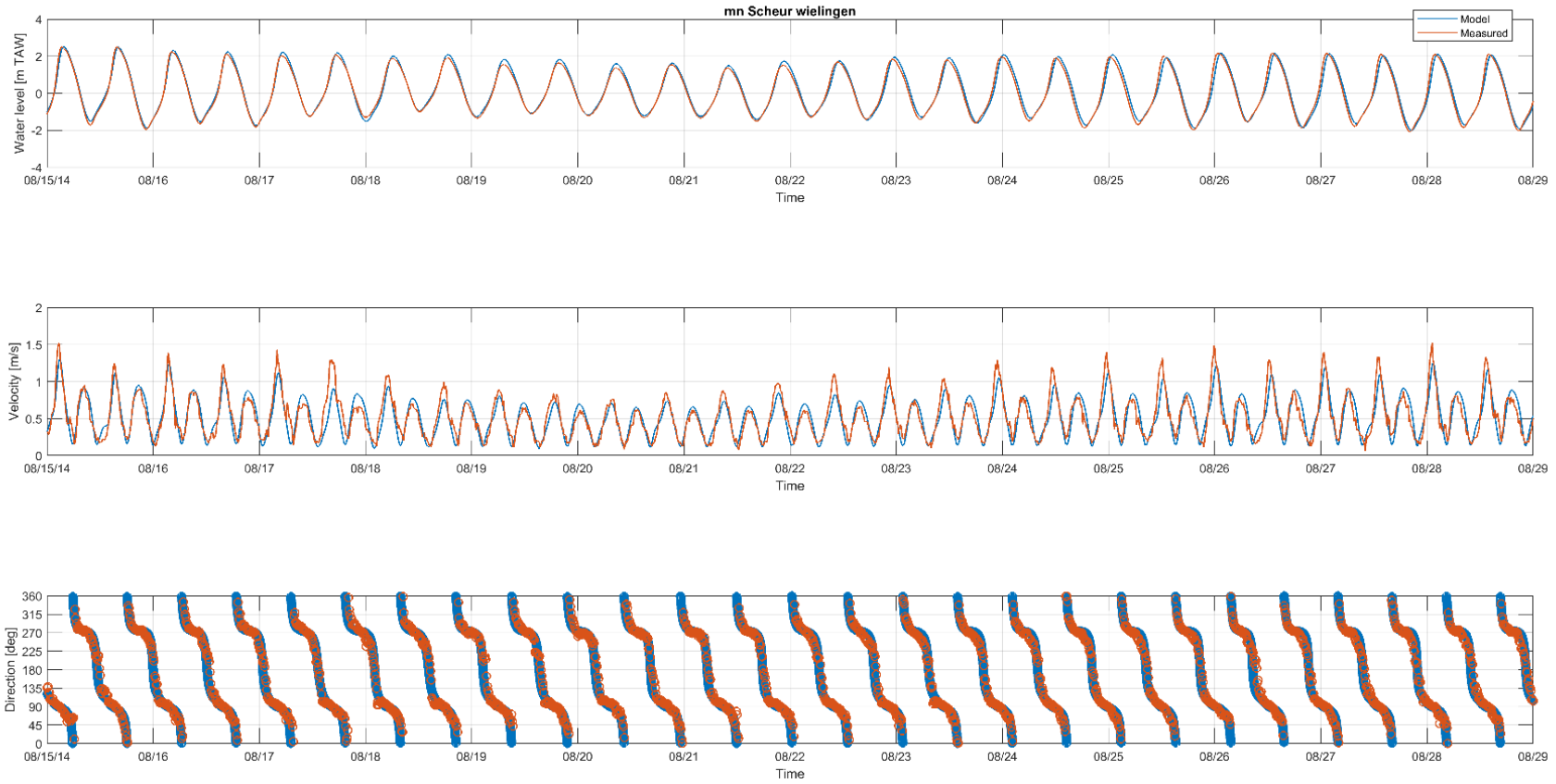



Figure 2-4 Measured and modelled water levels and velocity at Scheur Wielingen

## 2.2 SEDIMENT TRANSPORT MODEL

### 2.2.1 Sediment characterisation

Information from 20 boreholes within the project area and the available geotechnical and sedimentological lab tests were analysed to define the characteristics of the sediment to be disposed. Although the boreholes are described as consisting of sand and clay, the granulometric data show that the sediments consist of layers of slightly organic silty sand and clayey silt and some clay lenses (IMDC, 2019). Of the total volume to be disposed offshore, about 70% consists of silty sand and 30% of clayey silt (containing resp. 22-55% of fines).

It was decided to model a worst-case (conservative) scenario to have the maximum plume formation. It is assumed that only fines (100% cohesive material) are transported to the offshore disposal area and a conservative factor was used to convert the volume of sediment in the barge into 'ton dry matter' in the water column. In addition, also the portion of material that stays in the water column which forms the plume and does not directly sink to the bottom is chosen conservative to come to the biggest plume. The applied settings are described in section 2.2.3.

### 2.2.2 Settings

The motion of the disposed sediment is modelled using an advection-diffusion equation. Naturally occurring sediment is not considered in the model. Instead the disposal plumes are released into an "empty" model. The settings of the sediment transport model are shown in Table 2-5 for modelling the cohesive sediment and Table 2-6 for non-cohesive sediment, which is used in one scenario.

Table 2-5 settings of the cohesive sediment (mud) model

| Parameter | Setting | Remarks |
|---|---|---|
| Settling velocity | Constant in space and time with a value of 0.5 mm/s | This is a characteristic value of slightly flocculated sediment typically found in estuaries or coastal seas. Measurements in the harbour of Zeebrugge (IMDC, 2007) show this as a typical lower limit for the settling velocity. Smaller values may occur in nature, but only during a part of the tidal period and only for a relatively small fraction of the sediment.<br>It is assumed that the flocculation behaviour of the sediment particles dredged in the project site (which mainly consist of silty sand and clayey silt; (IMDC, 2019) is similar as that of the sediment naturally present in the water. However, no data is available to validate this assumption. |
| Erosion law | Off | Used in scenarios without resuspension |
| | Partheniades equation | Used in the scenario with resuspension. Bed shear stresses are calculated from near |

| Parameter | Setting | Remarks |
|---|---|---|
| | Critical shear stress: 0.2 Pa<br>Partheniasdes coefficient: 0.001 kg/m²/s | bed flow velocity. The influence of waves is not taken into account. |
| Threshold for deposition | Not used | The continuous deposition paradigm is used in agreement with the latest scientific insights (Winterwerp and van Kesteren, 2004) |
| Bed density | 1170 kg/m³ | This is a typical value for freshly deposited mud. This parameter is only used to determine the thickness of the deposition layer from the settled mass. |
| Advection scheme | Leo Postma Scheme | |
| Horizontal diffusion | off | Sensitivity tests performed in previous plume modelling studies showed that the difference in the predicted results for simulations with and without horizontal diffusion are very small. The most important horizontal diffusion process is shear induced mixing. As this is an apparent horizontal process, this process needs to be parameterized in a two-dimensional model. In a three-dimensional model, this case, this processes is included in the problem that is resolved. Hence no additional horizontal diffusion is needed to parameterize this. |

Table 2-6 Parameters of the non-cohesive sediment model (sand)

| Parameter | Setting | Remarks |
|---|---|---|
| Sediment diameter | 220 µm | Used to calculate the critical shear stress for erosion in the model. |
| Erosion law | From the near-bed sediment concentration of Van Rijn | Bed sear stresses are calculated from the near bed flow velocity. The influence of waves is not taken into account. |
| Settling velocity | 27.6 mm/s | Calculated from the settling velocity |
| Bed porosity | 0.4 | Used in combination with the sediment density to relate the thickness of the deposition. |
| Sediment density | 2650 kg/m³ | Used in combination with the porosity to relate the thickness of the deposition. |
| Advection scheme | Leo Postma Scheme | |
| Horizontal diffusion | off | Sensitivity tests performed in previous plume modelling studies showed that the difference in the predicted results for simulations with and without horizontal |

| Parameter | Setting | Remarks |
|---|---|---|
| | | diffusion are very small. The most important horizontal diffusion process is shear induced mixing. As this is an apparent horizontal process, this process needs to be parameterized in a two-dimensional model. In a three-dimensional model, this case, this processes is included in the problem that is resolved. Hence no additional horizontal diffusion is needed to parameterize this. |

### 2.2.3 Sediment losses

The disposing was simulated using a source of sediment in the hydrodynamic model, with a constant location in the mid of the current Nieuwpoort disposing area and in the middle of the Oostende disposing area (Marine Spatial Plan 2020-2026). For the calculation of the flux of sediment into the model, the following assumptions were used:

- A barge with a volume of 2000 m3, completely filled with cohesive material (silt and clay) is disposed. This is a conservative approach, as the sedimentological data (IMDC, 2019) show that even in the clayey layers (unit B), 45% of the material consists of sand, which will deposit much more easily than cohesive material.
- In order to determine the mass of the mud in the barge, a porosity of 0.4 and a sediment density of 2650 kg/m3 is used. Hence the wet bulk density of the material is 2000 kg/m3. From a cone penetration test in the area, it can be estimated that the cohesive sediment actually may have a density around 1600 kg/m3. Hence this estimate is conservative: by using a higher density (lower porosity) more mass is disposed in the water column.
- It is assumed that of the total deposited mass 20% will remain suspended. A value between 15 and 20% is typically used for the fraction of sediment that remains suspended, when disposing dredged material. The more conservative value of 20% is chosen to simulate the worst case plume formation, although the plasticity index of the clayey sediment layers implies strong cohesive behaviour (IMDC, 2019). Based on the plasticity index it is expected that in reality a smaller fraction of the disposed mass will become part of the passive plume.
- The sediment that remains suspended is distributed uniformly over the water depth. In reality, it is expected that the concentrations will be higher close to the bed. This is a conservative estimate, because the higher the sediment is put in the water column, the longer it takes before it deposits, and hence the larger the area over which the plume spreads.
- The duration of a disposal is 5 minutes.

In summary, the amount of sediment released in the water is estimated conservatively, and the safety factor applied in the amount of released sediment is estimated at a factor two (based on the conservative assumptions of the porosity of the sediment and the percentage of the cohesive fraction in the dredged sediment).

### 2.2.4 Simulation period

The simulation period that is chosen is a 30-day period from August 7th to September 5th 2014. This period contains the validation period of the hydrodynamic model shown in section 2.1.6. All simulations were begun from hydrodynamic conditions that had a day of spin-up.

# 3 Simulation results

## 3.1 Scenarios

Five different dredging scenarios are simulated:

- **Scenario 1 (base case):** In this case sediment is disposed every 8 hours in the centre of the existing disposing zone in Nieuwpoort (Figure 3-1). No resuspension of sediment is considered, hence all the sediment inserted in the system deposits on the bed. The parameters of the sediment are shown in Table 2-5.
- **Scenario 2 (with resuspension):** In this scenario, the same situation is considered as in scenario 1. However, resuspension of sediment is taken into account, meaning that sediment that deposits temporarily during areas of low flow velocity, can be resuspended when the flow velocity increases later on. The suspension parameters of the sediment are shown in Table 2-5.
- **Scenario 3 (increased disposing):** In this scenario, sand is disposed every 6 hours instead of every 8 hours. Hence, the total amount of sediment brought into system increases with 33% over the same period.
- **Scenario 4 (disposal location Oostende):**
  - **Scenario 4a:** In this scenario, sediment is disposed in the disposal area Bruggen en Wegen Oostende, rather than in the Nieuwpoort disposing area (Figure 3-1).
  - **Scenario 4b:** In this scenario, the same situation is considered as in scenario 4a. However, resuspension of sediment is included.
- **Scenario 5 (sand disposal with resuspension):** In this case, instead of mud, sand is disposed, in order to investigate the resuspension behaviour of the sand. Resuspension is taken into account in this scenario. The sediment parameters for this mode are shown in Table 2-6.

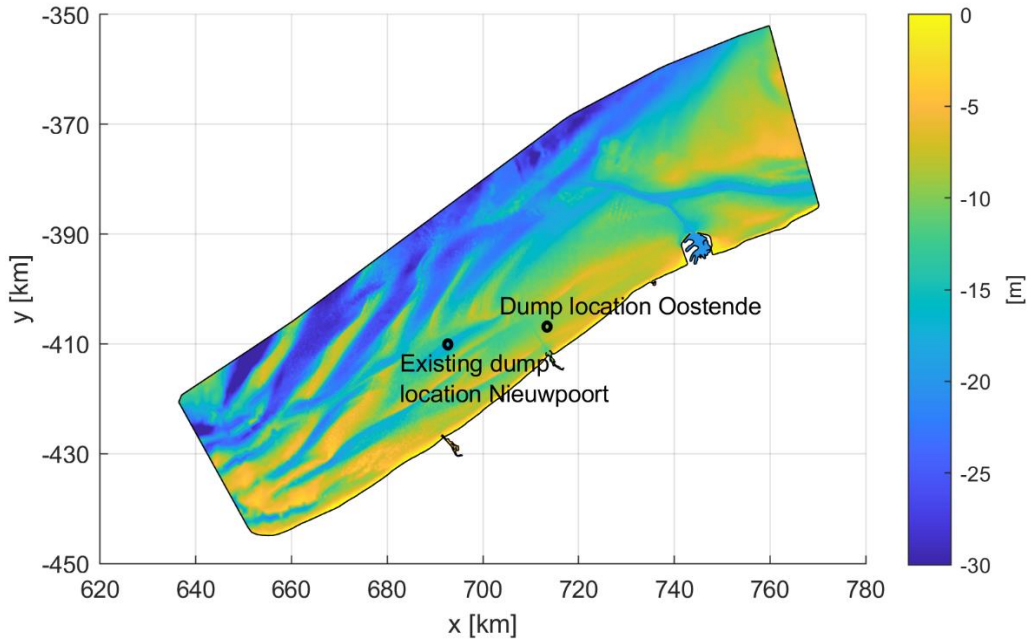



Figure 3-1 Overview of the disposal locations (black circles). Each disposal occurs in the middle of the disposal location.

## 3.2 Plume analysis

### 3.2.1 Temporal behaviour

In Annex B, maps are shown of the depth-averaged sediment concentration (in g/l) with a time interval of 30 minutes during a day for scenarios 1, 2 and 4a. The upper limit of the colour scale is 100 mg/l. These maps show a typical example of the behaviour of a plume. All results are from the end of the simulation period (September 6$^{th}$), after one month of daily disposing (3 times/day). The behaviour of a plume without resuspension is shown in annex B.1. In this annex, one can see that a plume gets generated in a short time and that it has a small spatial extent, when it is generated. It then moves with the tide and while moving, it becomes larger and the sediment concentrations in the plume decrease due to the combined effect of deposition and dilution. It appears that the plume disappears before the next plume is generated.

The behaviour of a plume with resuspension is shown in annex B.2, again at the end of the simulation period, after one month of daily disposing (3 times/day). One immediately notices that in this case, there is already a non-zero concentration present northeast of the disposing zone. The behaviour of the disposal has many similarities with the case without resuspension. Also a small high concentration plume is formed, that moves with the tide. It increases in size and decreases with time since its release. However, the decrease in size is now much slower than in the case without resuspension, because with the used sediment characteristics, the net deposition is lower, because deposition is counterbalanced by erosion. Hence, a larger amount of sediment remains in the water column than in the case without resuspension.

The behaviour of the plume in case of the disposing location in Oostende is shown in annex B.3. As in scenario 1, the plume moves with the tide. Its peak concentration is higher than for scenario 1 and remains visible until the new the next plume is generated.

In order to study the temporal behaviour of the sediment plume in more detail, time series of the maximum depth-averaged sediment concentration (in mg/l) are shown in Figure 3-2 to Figure 3-7 for a duration of 24 hours at the end of the simulation. Here, the maximum sediment concentration is the highest sediment concentration in any node of the mesh. For the cases without resuspension, this can be interpreted as the maximum plume concentration in a frame moving within the plume. The maxima were determined with a time interval of 30 minutes, such that appearance of the time series in these figures is not very smooth and the behaviour on shorter time scales cannot be inferred from the graphs.

#### 3.2.1.1 Base case: disposal location Nieuwpoort without resuspension

In the reference case (Figure 3-2), the sediment concentration suddenly rises when a disposal is executed. Initially, high maximum concentrations are found. The maximum values during the disposal are influenced by the schematization of the plume as a point source. It can be seen that the maximum concentrations differ substantially between consecutive disposals, caused by the hydrodynamic conditions during the disposal. If a disposal occurs during periods of high flow velocity, the sediment concentrations get diluted rapidly and the peaks are lower. Hence, the exact value should not be given too much importance. What is important is the width of the peak. The maximum concentration decreases rapidly with a more or less exponential shape. For all of the visualized disposals, the maximum concentration decreases within five hours to the background values.

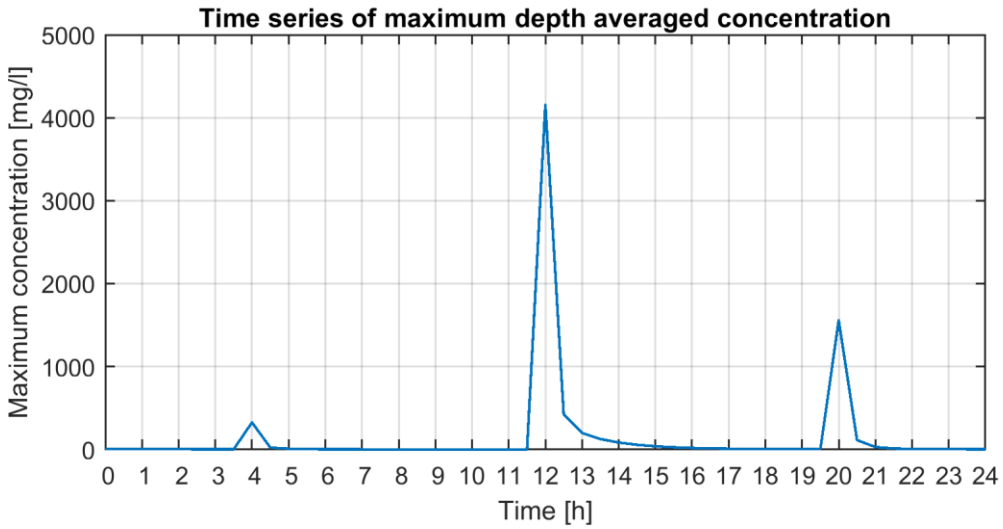



Figure 3-2 Time series of the maximum sediment concentration after 29.5 days of simulation (Scenario 1: base case without resuspension).

#### 3.2.1.2 Scenario 2: disposal location Nieuwpoort with resuspension

The maximum concentrations for the case with resuspension are shown in Figure 3-3. The peaks show a similar behaviour as in the case without resuspension (Figure 3-2), but appear to decrease less rapid and are wider. One can see now that the maximum concentrations are also influence by the tide. During periods of high flow velocity (e.g. at 3h-9h-15h-21h in Figure 3-2), sediment in the system is resuspended, leading to extra peaks in the time series of the maximum sediment concentration.

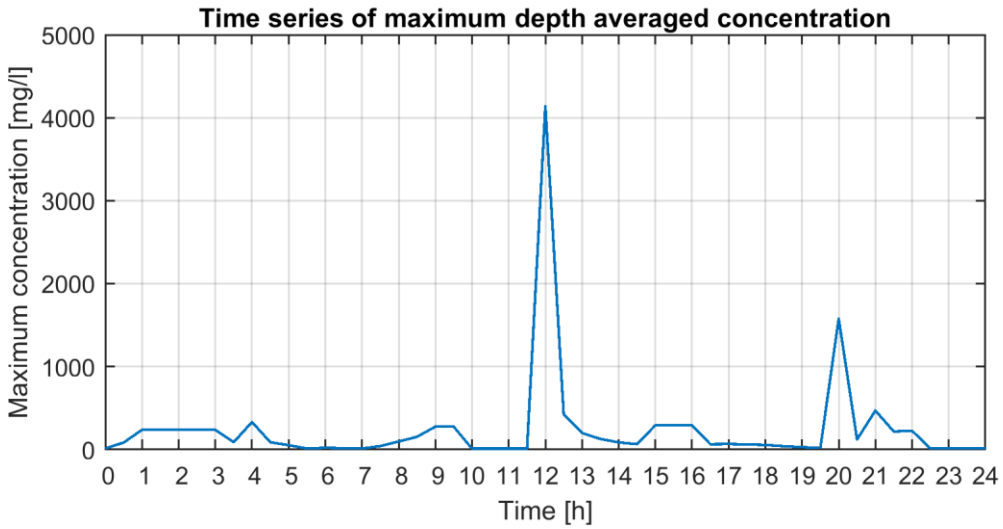



Figure 3-3 Time series of the maximum sediment concentration after 29.5 days of simulation (Scenario 2: with resuspension).

#### 3.2.1.3 Scenario 3: increased disposing every 6h

The results for the simulation with disposals every 6 hour in the disposal zone of Nieuwpoort are shown in Figure 3-4. The behaviour is very similar as in the reference case: a peak forms for every release, which then decreases rapidly. Because the time needed for the decrease of the concentrations (four to five hours) is less than the time interval between the disposals (six hours) the plumes do not interact. For those disposals that happen at the same moment as in the reference case (i.e. during the same hydrodynamic conditions), the maximum concentration peak is the same.

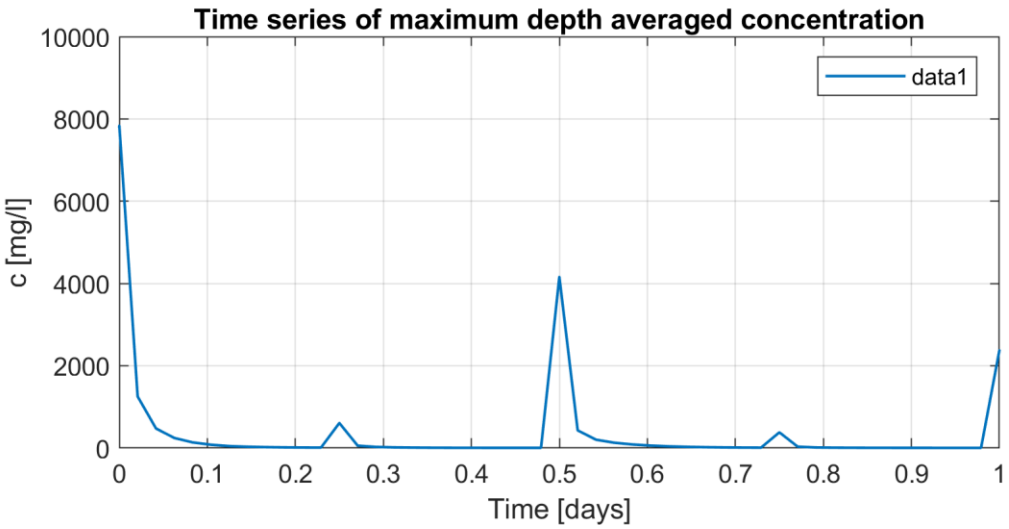



Figure 3-4 Time series of the maximum sediment concentration after 29.5 days of simulation (Scenario 3: disposing with a period of 6 hours); Note that the y-scale is different from the preceding figures.

#### 3.2.1.4 Scenario 4a: disposal location Oostende

The maximum sediment concentrations for the simulation in the disposal area Oostende are shown in Figure 3-5. The behaviour of the sediment plume in time is rather similar to the reference case (Figure 3-2), and also in this location, the maximum concentrations decrease to the background values in four to five hours. However, the maximum sediment concentration are much higher than in the reference case. A possible reason is that the water depth at the Oostende disposal location is shallower (-9.7 m MSL) than in the present Nieuwpoort disposal area (-18.0 m MSL, Figure 3-1), and that the hydrodynamic conditions at this location differ from the conditions at the existing disposal site. Hence the same amount of sediment is concentrated into a smaller vertical space, leading to higher concentrations.

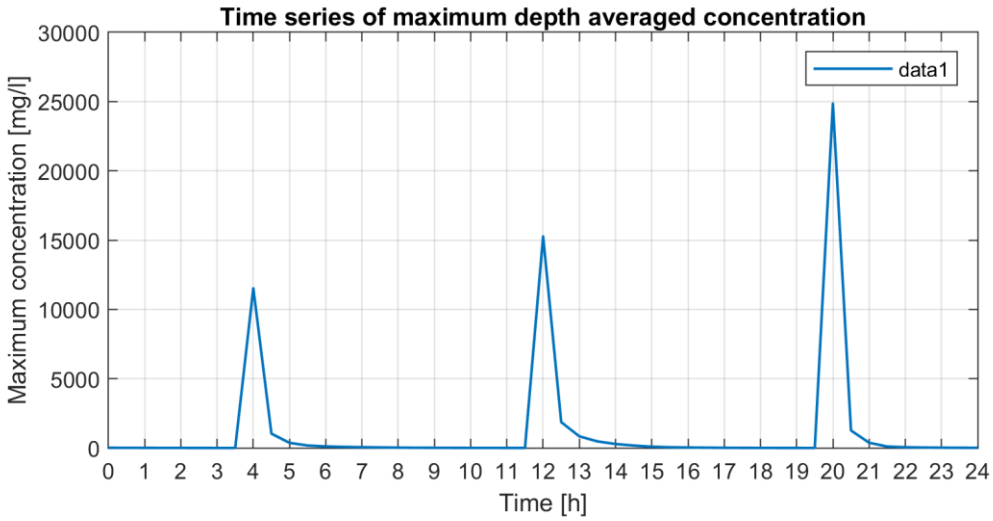



Figure 3-5 Time series of the maximum sediment concentration after 29.5 days of simulation (Scenario 4a: disposal location Oostende). Note that the y-scale is different from the preceding figures.

### 3.2.1.5 Scenario 4b: disposal location Oostende with resuspension

The maximum concentrations for the disposal area Oostende case with resuspension are shown in Figure 3-6. The peaks show a similar behaviour as in the case without resuspension (Figure 3-5), but appear to decrease less rapid and are wider. One can see now that the maximum concentrations are influenced by the tide. During periods of high flow velocity (e.g. at 9h-14h-21h in Figure 3-6), sediment in the system is resuspended, leading to extra peaks in the time series of the maximum sediment concentration.

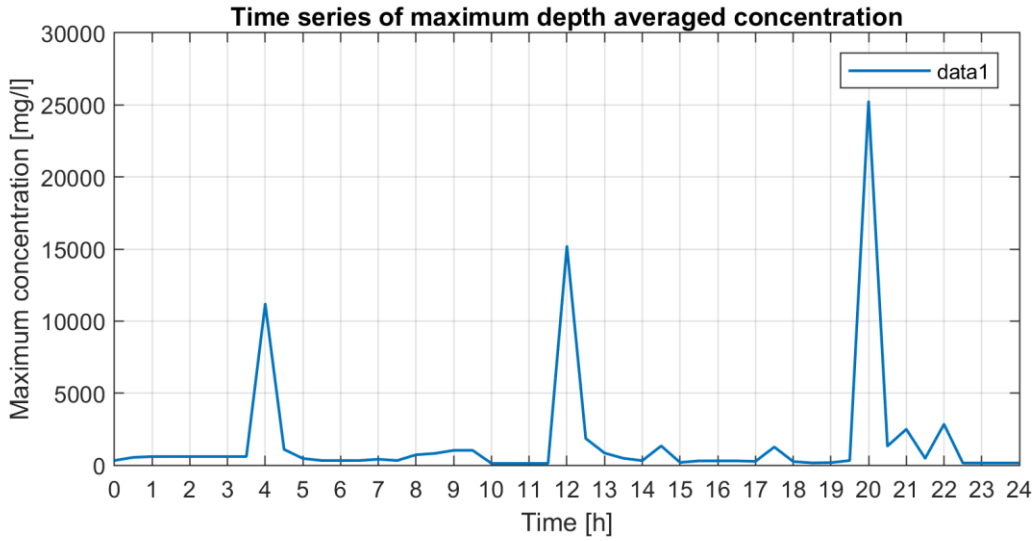



Figure 3-6 Time series of the maximum sediment concentration after 29.5 days of simulation (Scenario 4b: disposal location Oostende with resuspension). Note that the y-scale is different from the preceding figures.

#### 3.2.1.6 Scenario 5: sand disposal with resuspension

The results for scenario 5, in which sand was disposed are shown in Figure 3-7. The larger settling velocity of the sand leads to a more rapid decrease of the sediment concentrations, returning to the background concentration within half an hour. Even though resuspension is on, no peaks are formed during periods of high flow velocity (which was the case in scenario 2; Figure 3-3) which means that all sand that is disposed deposits rapidly and hardly gets suspended afterwards, in contrast to the mud, which does get resuspended (Figure 3-3).

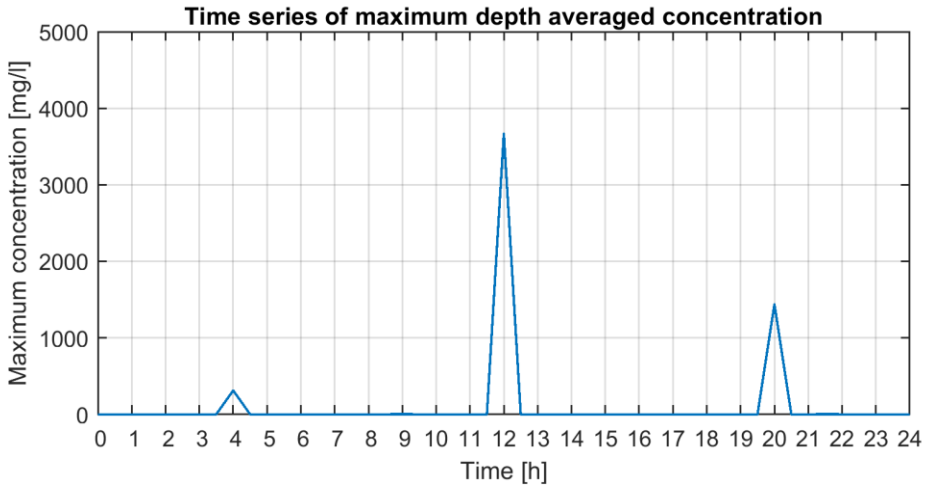



Figure 3-7 Time series of the maximum sediment concentration after 29.5 days of simulation (Scenario 5: disposal of sand); Note that the y-scale is different from the preceding figures.

### 3.2.2 Maximum sediment concentration

Maps with the maximum depth-averaged sediment concentration in the project area are shown in Figure 3-8 to Figure 3-16 for the four different scenarios with cohesive sediment. These maps were created by determining the maximum concentration for any moment in time for each node in the computational mesh. Hence the map does not represent one moment in time. Two points next to each other showing a maximum may not have experienced this maximum at the same moment.

#### 3.2.2.1 Base case: disposal location Nieuwpoort without resuspension

The figures show that the highest sediment concentrations occur close to the disposal area. In the reference case (Figure 3-8), a zone with increased concentrations is found extending more or less parallel to the coast. The area of maximum sediment concentrations does not have its centre at the disposal location. Instead the area extends in northeastern direction, indicating the plumes have a tendency to move offshore. The affected area where concentrations exceed 10 mg/l is 20 km parallel to the coast and its width is approximately 10 km perpendicular to the coast. The area where concentrations exceed the yearly natural background concentration of 25-50 mg/l (Fettweis *et al.*, 2010), is only 7 by 2 km.

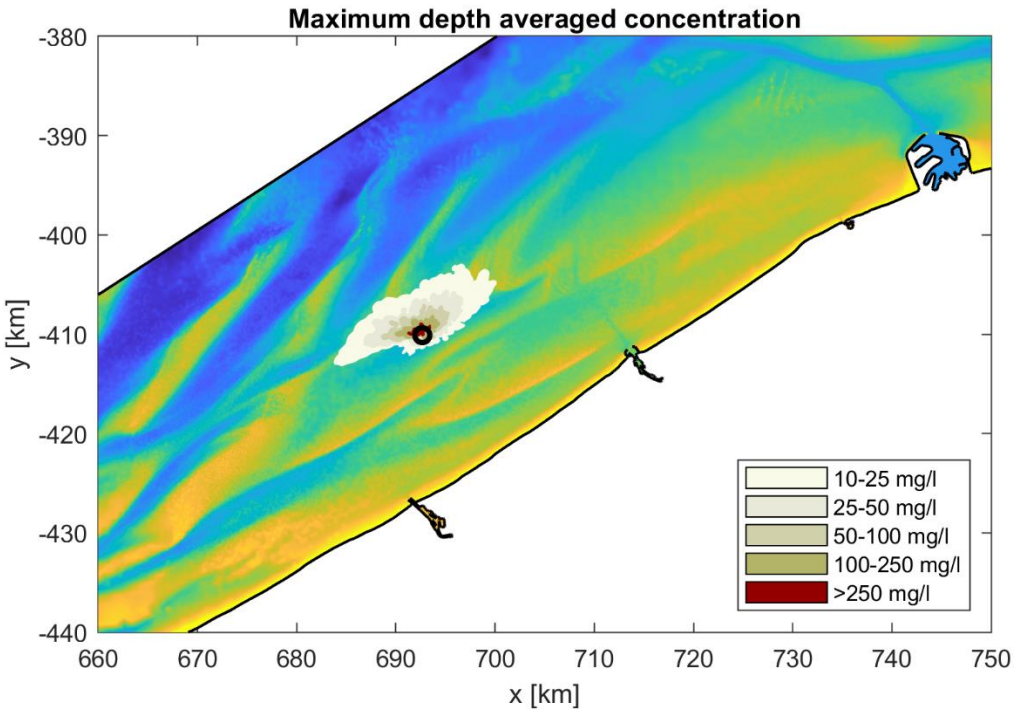



Figure 3-8 Maximum depth-averaged sediment concentration for scenario 1 (reference case).

In this report, the results of the depth averaged sediment concentrations are reported. In order to show the influence of this choice, the maximum concentration in three different model layers are presented in Figure 3-9 to Figure 3-11. The three layers represent respectively the bottom layer, a layer in the middle of the water column and the surface layer. These figures show maximum concentrations that are very comparable to each other, with a slight decrease of the concentrations in the surface layer. The figures are also very comparable to the maximum depth averaged concentrations shown in Figure 3-8. Therefore, it is concluded that it is justified to use the depth averaged concentrations in this report.

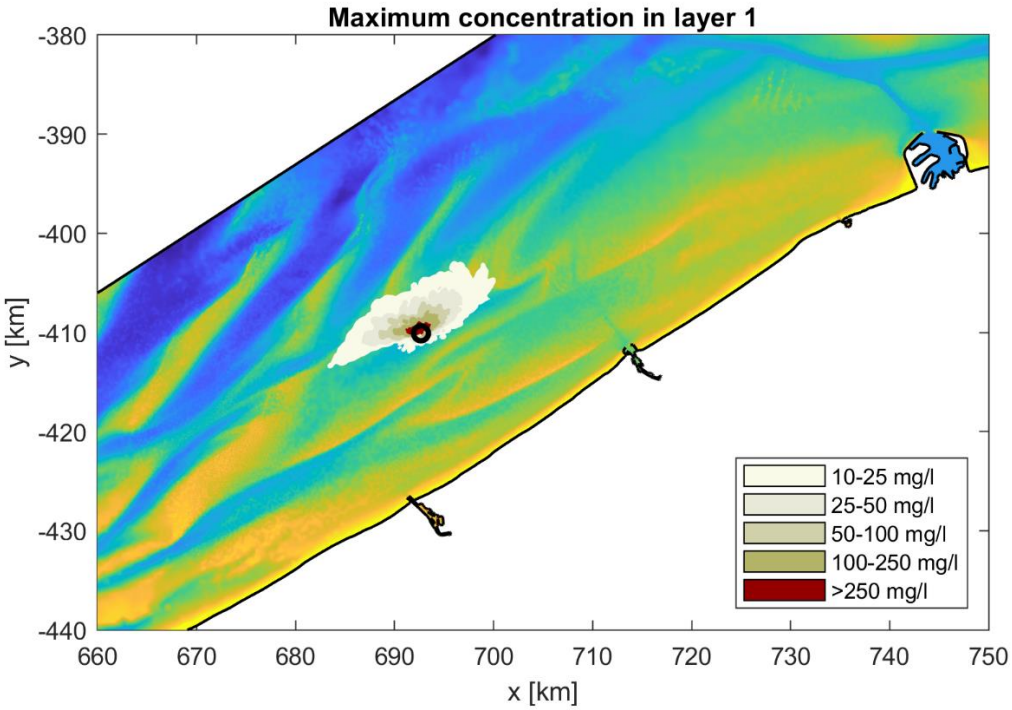



Figure 3-9 Maximum sediment concentration in the bottom layer of the model.

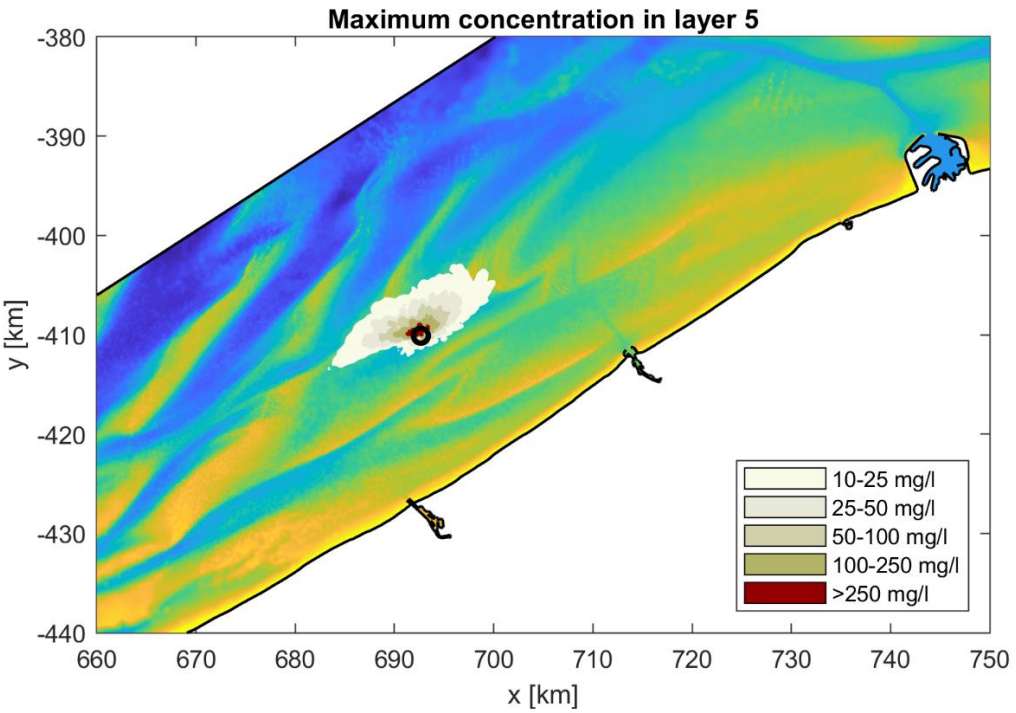



Figure 3-10 Maximum sediment concentration in the fifth layer of the model (at 39% of the water depth).

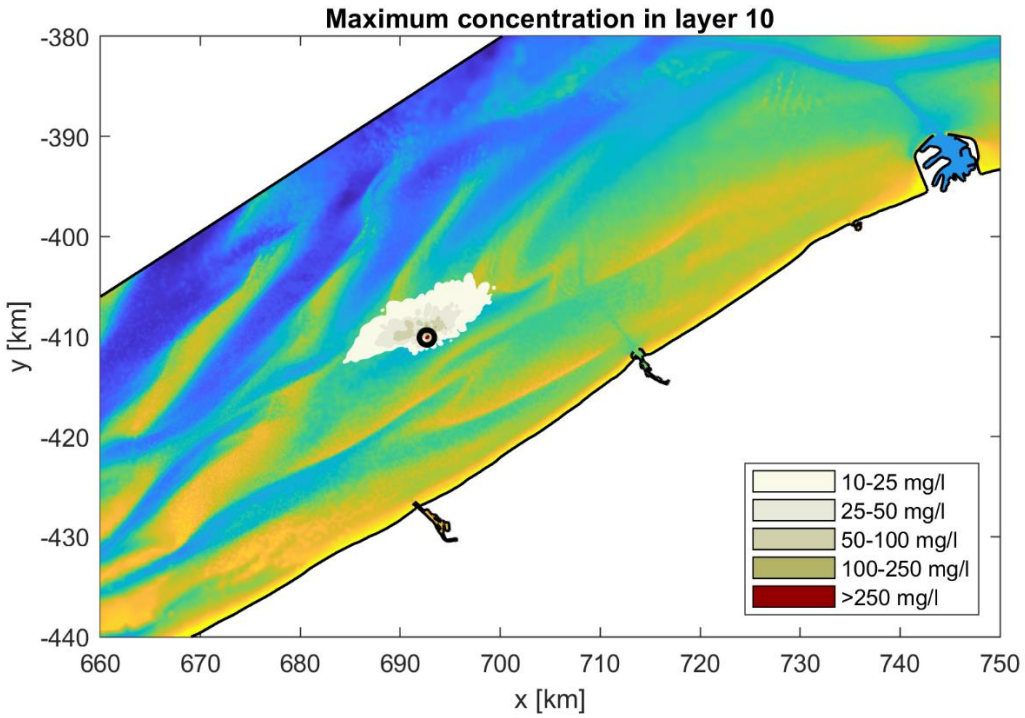



Figure 3-11 Maximum sediment concentration in the top layer of the model

#### 3.2.2.2 Scenario 2: disposal location Nieuwpoort with resuspension

For the case where resuspension was taken into account (Figure 3-12), the area where depth-average concentrations in the water column exceed 10 mg/l is larger (30 km by 10 km). This corroborates with the conclusion in section 3.2.1. Because resuspension and deposition occur simultaneously, the net deposition flux to the bed is less and hence the sediment remains suspended for a longer time, thus leading to larger plumes. Note that the depth-averaged concentrations in areas where substantial resuspension of deposited material occurs remain mostly below 10 mg/l and hence they have a limited influence on the extent of the contours in Figure 3-12 (as can be seen from the probability of exceedance figures in section 3.2.3).

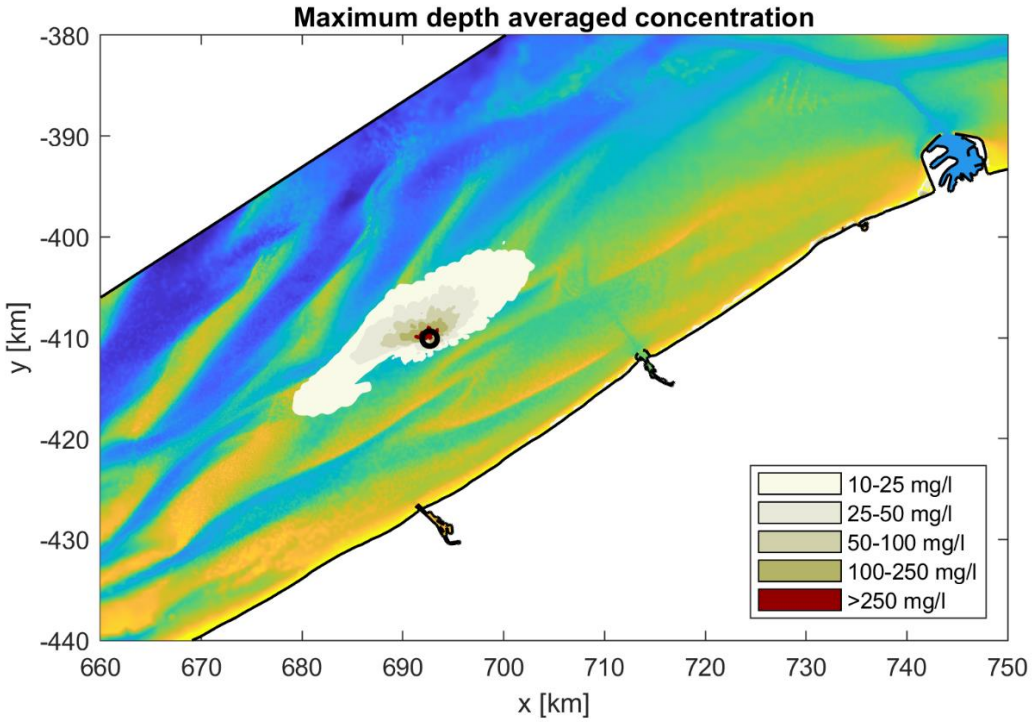



Figure 3-12 Maximum depth-averaged sediment concentration for scenario 2 (with resuspension).

#### 3.2.2.3 Scenario 3: increased disposal every 6h

The maximum sediment concentrations in the scenario with disposal every six hours (Figure 3-13), are very similar to the reference case (Figure 3-8). This is not surprising. The concentrations decrease rapidly, causing a plume to disappear before a second plume is generated. Hence there is also no interaction between two plumes for this case and thus the results for disposals every six hours and every eight hours are expected to be rather similar. Differences in the figures are attributed to the different hydrodynamic conditions during the disposal for the two different cases.

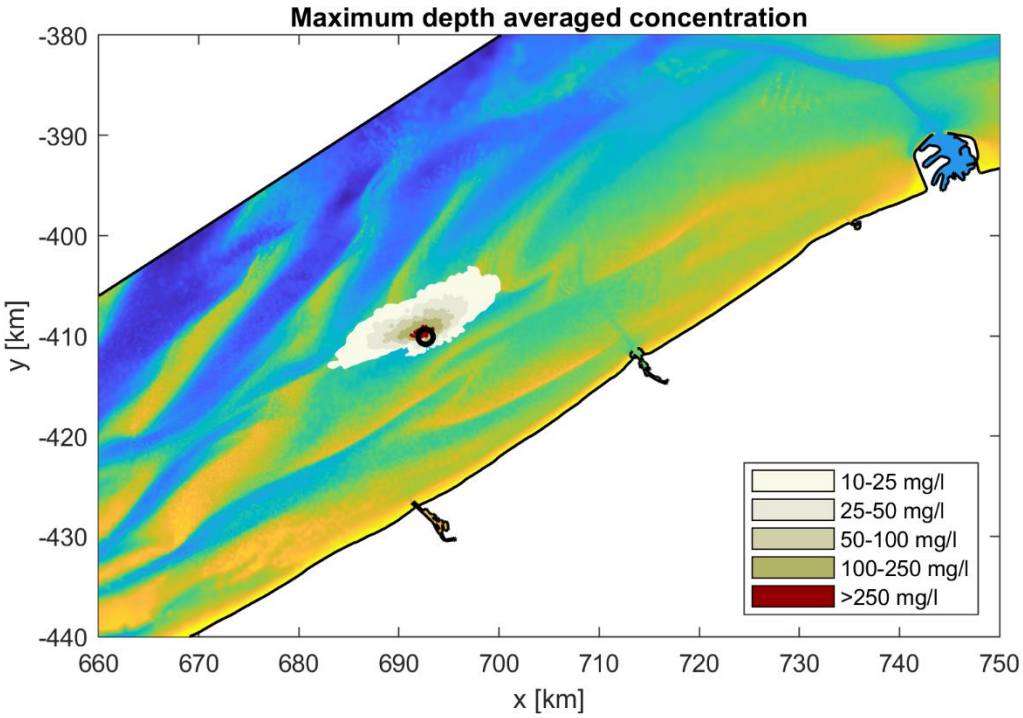



Figure 3-13 Maximum depth-averaged sediment concentration for scenario 3 (disposal every 6 hours).

#### 3.2.2.4 Scenario 4a: disposal location Oostende

In the scenario with the Oostende disposal area, the plume exceeding the 10 mg/l concentration is 35 km x 10 km (Figure 3-14). The plume is somewhat larger and has a more shore parallel elongated shape compared to the reference case, which can be attributed to the more uniform shore parallel directed current velocities at this location. At the Oostende location, also the area in which higher maximum concentrations occur (i.e. concentrations exceeding 100 mg/l) is larger than in the reference case. This corroborates the higher maximum sediment concentrations observed in the time series (Figure 3-5), which were attributed to the shallower water depth at the Oostende disposal location.

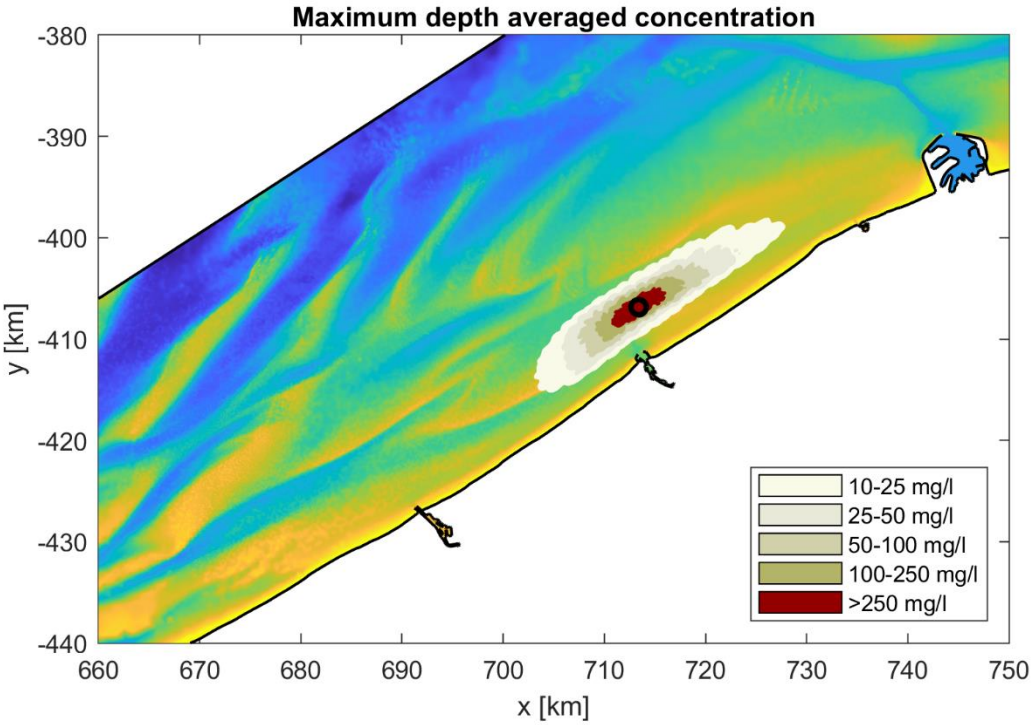



Figure 3-14 Maximum depth-averaged sediment concentration for scenario 4a (disposal location Oostende).

#### 3.2.2.5 Scenario 4b: disposal location Oostende with resuspension

In the scenario with the disposal area Oostende with resuspension, the plume exceeding the 10 mg/l concentration is 50 km x 15 km (Figure 3-14). This is significantly larger than for the reference case of Nieuwpoort with resuspension. At Oostende, also the area in which higher maximum concentrations occur (i.e. concentrations exceeding 100 mg/l) is larger than in the reference case with resuspension. This corroborates the higher maximum sediment concentrations observed in the time series (Figure 3-5 and Figure 3-6), which were attributed to the shallower water depth at the Oostende disposal location.

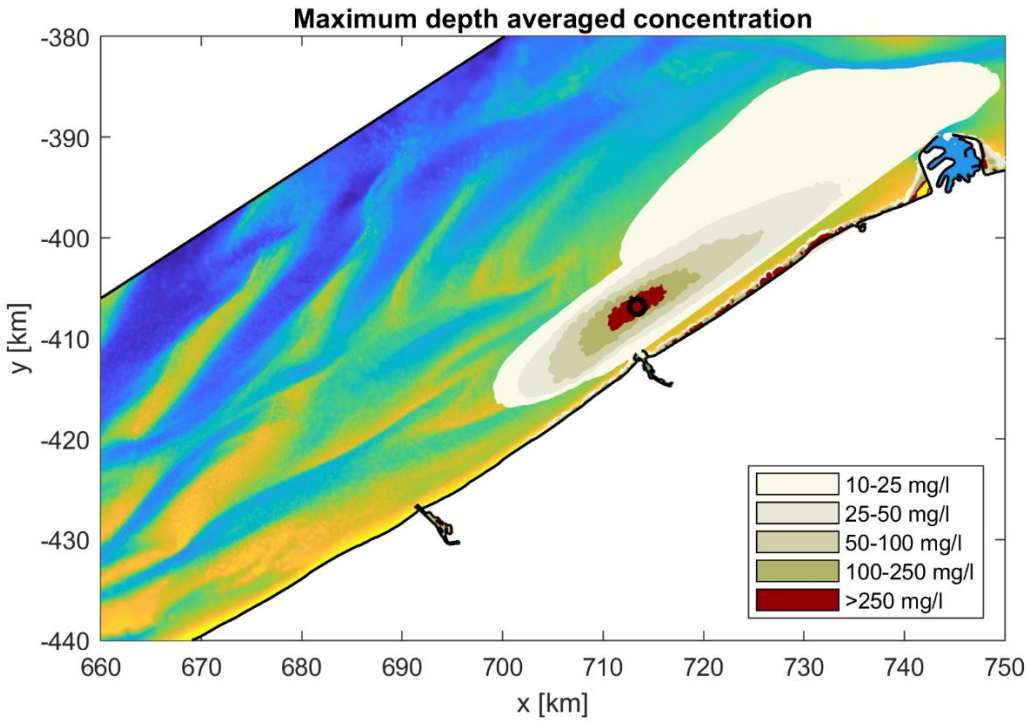



Figure 3-15 Maximum depth-averaged sediment concentration for scenario 4b (disposal location Oostende with resuspension).

#### 3.2.2.6 Scenario 5: sand disposal with resuspension

In case sand is disposed (Figure 3-16), maximum concentrations higher than 10 mg/l occur only within the outline of the disposal zone, showing once again that sand deposits very rapidly and that only a very limited fraction of sand is transported.

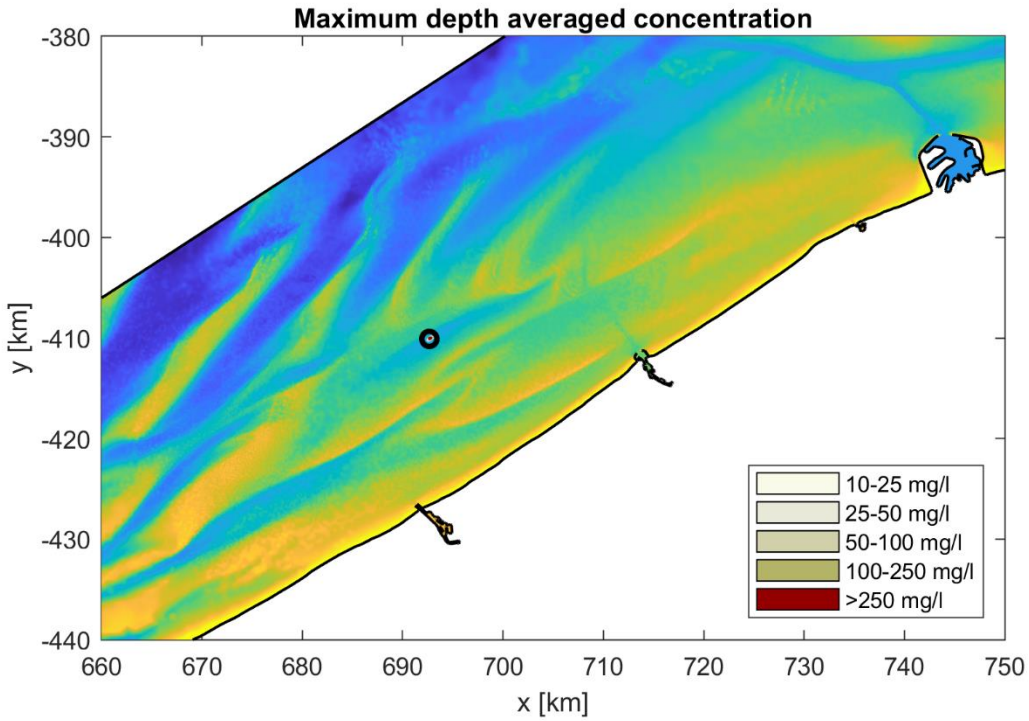



Figure 3-16 Maximum depth-averaged sediment concentration for scenario 5 (disposal of sand).

### 3.2.3 Probability of exceedance

The probability of exceedance for six different sediment concentrations (0.1 mg/l, 1.0 mg/l, 5.0 mg/l, 10.0 mg/l, 50.0 mg/l, and 100.0 mg/l) is visualized in Annex A for the five different scenarios. Some example figures are shown in Figure 3-17. The probability of exceedance was determined by counting at each node the number of times a concentration was exceeded with a half hour time interval and divided by the total number of half our intervals in the simulations.

#### 3.2.3.1 Base case: Nieuwpoort location without resuspension

The figures in Annex A show that in the reference case (scenario 1), concentrations of 1 mg/l (a very low value) occur up to 10% of the total time (30 days) in a limited zone southwest of the disposal zone. However, for most of the area, a value of 1 mg/l is exceeded less than 5% of the time. Exceedances of 10 mg/l occur less than 2% of the time in a limited zone extending 2 km out northeast of the disposal zone (Figure Annex A-1). Exceedances of 50 mg/l are limited to within the disposal zone.

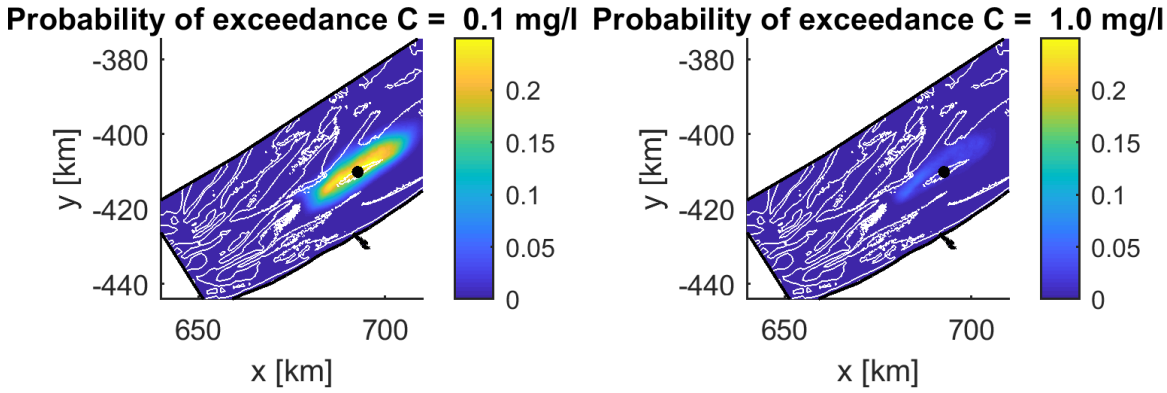



Figure 3-17 Example figures for the probability of exceedance for 0.1 mg/l and 1.0 mg/l for scenario 1 (reference case).

#### 3.2.3.2 Scenario 2: Nieuwpoort location with resuspension

In scenario 2 (with resuspension), the area in which the various threshold concentrations are exceeded is larger than in the reference case. The difference is especially larger for the very low threshold values of 0.1 mg/l and 1.0 mg/l. Concentrations of 1.0 mg/l are exceeded up to 50% of the time for a distance of 20 km northwest of the disposal site and 10 km northeast of the disposal site. However, exceedances of 10 mg/l occur up to 5% of the time in a small zone southwest of the disposal area and are limited to less than 2% of the time in a zone extending a few kilometres from the disposal site. Exceedances of 50 mg/l (natural background concentration is 25-50 mg/l) for more than 1% of the time are almost completely limited to the disposal area. Resuspension leads to increased concentration in a large area, but the depth-averaged concentrations due to resuspension of the disposed sediment are typically low (a few mg/l).

#### 3.2.3.3 Scenario 3: increased disposal every 6h

In scenario 3 (disposal every 6 hours instead of every 8 hours), the probability of exceedance maps have a very similar pattern as in the reference case, but the contours are slightly larger, due to the larger amount of sediment in the water column.

#### 3.2.3.4 Scenario 4a: disposal location Oostende

In scenario 4a, also similar patterns are found as for scenario 1 however the area with exceedances of 10 mg/l for up to 2% of the time is now up to 25 km away in an alongshore direction from the disposal zone. The exceedances of 50 mg/l are mostly limited to the disposal zone with an extension of a only a few kilometres.

#### 3.2.3.5 Scenario 4b: disposal location Oostende with resuspension

In scenario 4b, also similar patterns are found as for scenario 2 in which due to resuspension the areas of threshold concentrations are significantly larger than without resuspension. However, for scenario4b, the area with exceedances of 10 mg/l for up to 25% of the time, extents approximately 30 km from the disposal location in the direction Zeebrugge. The exceedances of 50 mg/l are in this case extending 10 km in an alongshore direction at both the sides of the disposal zone.

#### 3.2.3.6 Scenario 5: sand disposal with resuspension

In case of the disposal of sand, exceedances of 5 mg/l for more than 1% of the time are limited to the dredging zone. However, exceedances of 1 mg/l occur up to 5% of the time

in a zone northeast of the dredging zone. Hence resuspension of sand leads to a small north-eastward transport (which may be underestimated in the model, because bed load is not taken into account) with very low sediment concentrations (order 1 mg/l).

### 3.2.4 Footprint

The visualised footprint is defined as the thickness of the sediment deposition after 30 days (Figure 3-18 to Figure 3-23). The thickness of the mud layer is determined by TELEMAC by first integrating the net erosion/deposition of the sediment in time, in order to calculate the sediment mass on the bed. Then, the sediment mass is converted to a sediment thickness using the prescribed density of the sediment layers at the bed for cohesive sediment (see Table 2-5). For sand, the density of the bed material was calculated using the prescribed material density and porosity (Table 2-6).

#### 3.2.4.1 Base case: Nieuwpoort location without resuspension

In the reference case without resuspension, sediment deposits with a thickness less than one centimetre are observed up to 10 km from the disposal location parallel to the coast (Figure 3-18). Thicker deposits are limited to within the disposal zone.

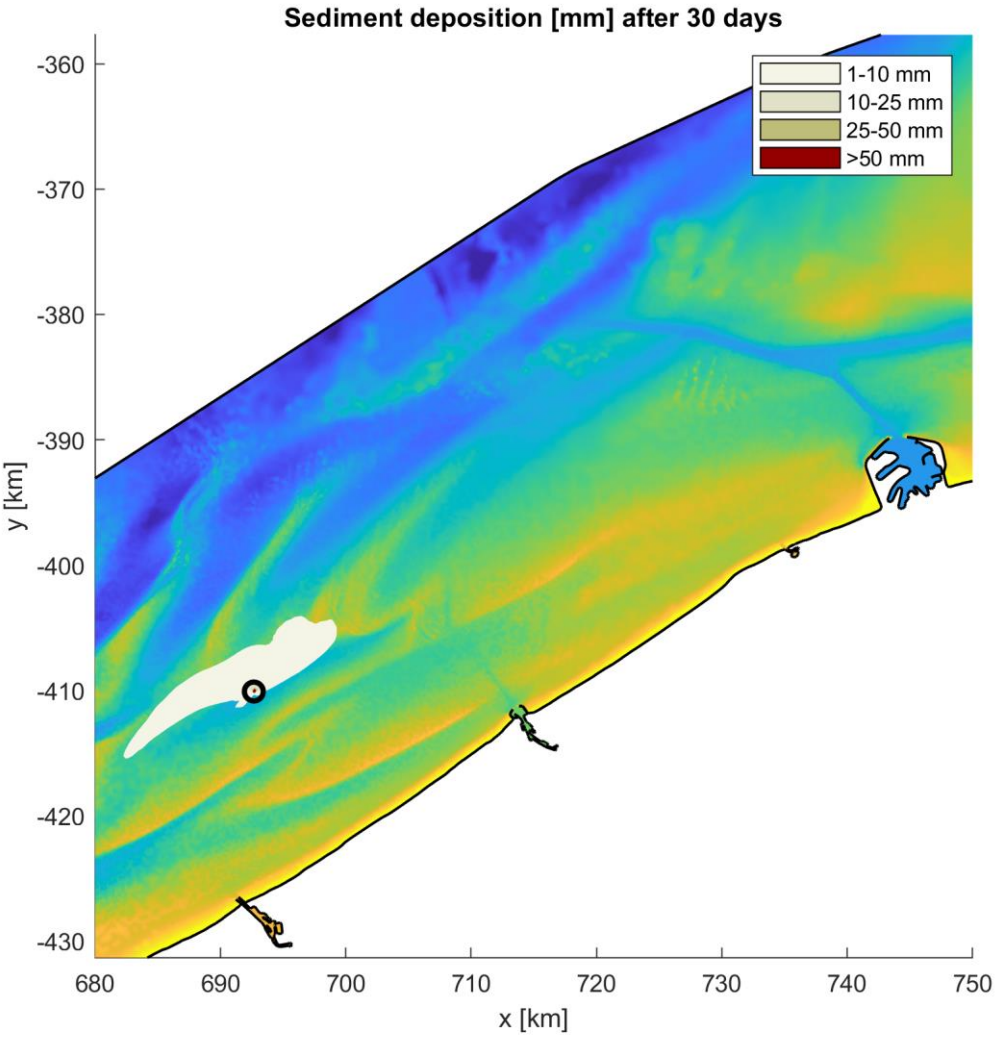



Figure 3-18 Footprint scenario 1 (reference case).

#### 3.2.4.2 Scenario 2: Nieuwpoort location with resuspension

In the case with resuspension (Figure 3-19), in contrast to scenario 1, no deposition on the bed is found in the coastal zone. The only location where some deposition occurs (not visible in Figure 3-19) is the harbour of Ostend. Hence the disposed sediment is that light that it will always get resuspended and no permanent deposition of material will occur in the Belgian coastal zone.

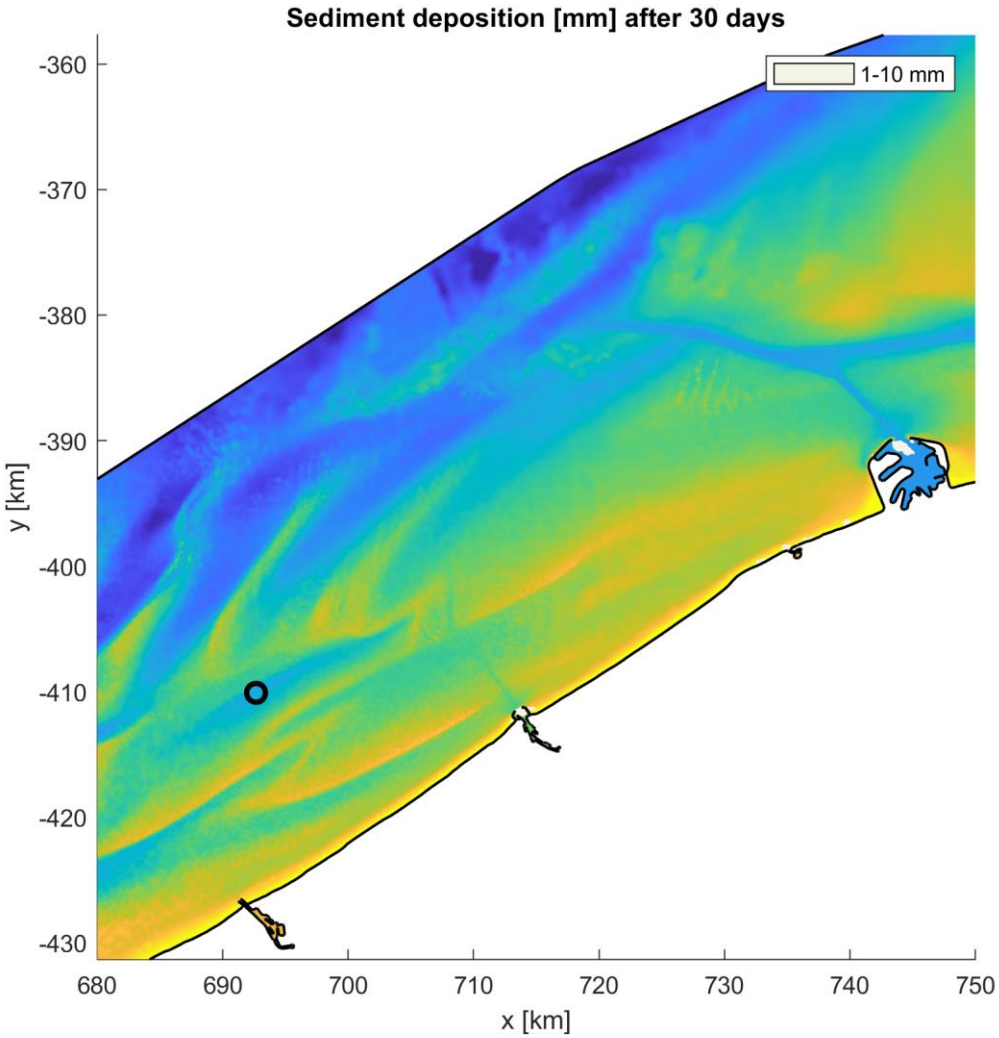



Figure 3-19 Footprint scenario 2 (with resuspension).

#### 3.2.4.3 Scenario 3: increased disposal every 6h

For the case with disposal every 6 hours (Figure 3-20), the deposition pattern is very similar to that in the reference scenario (Figure 3-18), but the area with a deposition between 1 and 10 mm is somewhat larger, because the total amount of sediment that is introduced within the same time period is in this case higher.

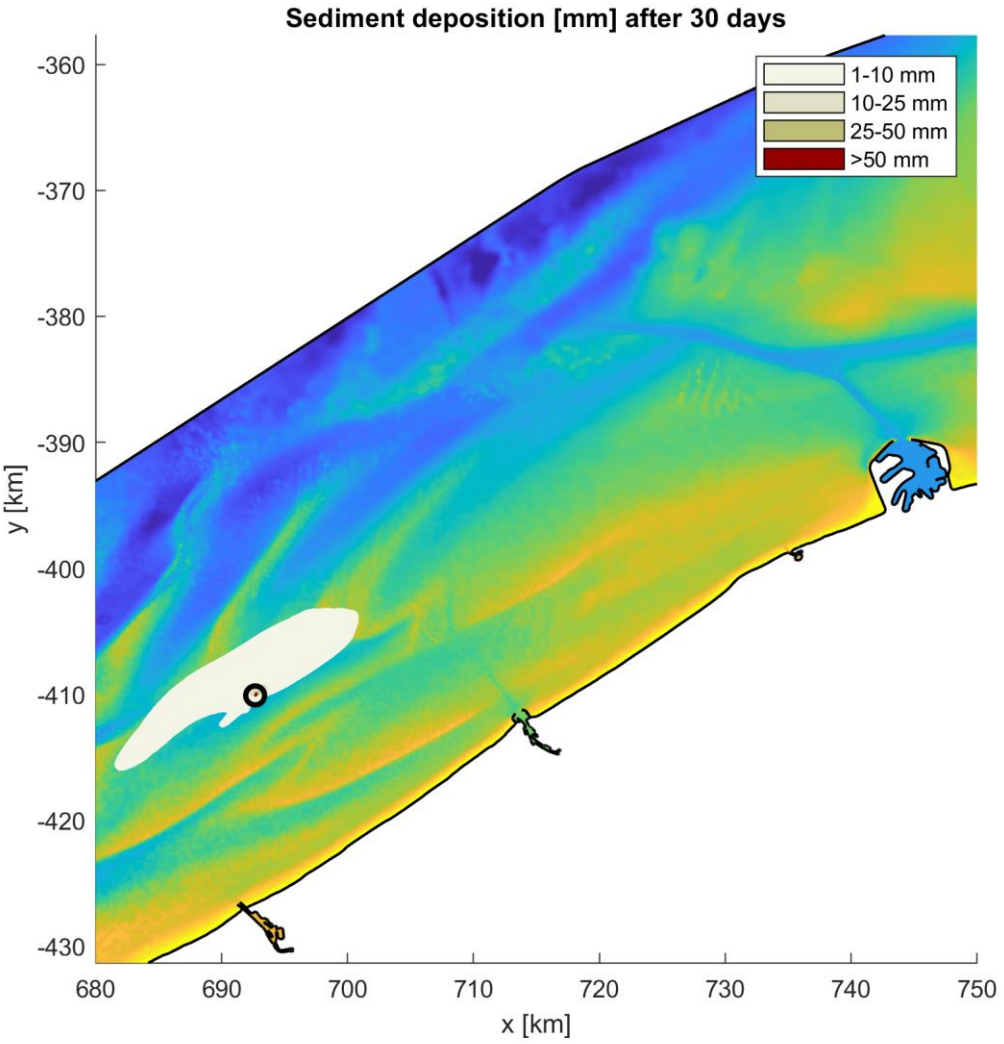



Figure 3-20 Footprint scenario 3 (disposal every six hours).

#### 3.2.4.4 Scenario 4a: disposal location Oostende

In scenario 4, in which the disposal area Oostende is used, (Figure 3-21) the footprint of the disposal is somewhat larger (extending 15 km to the left side and 20 km to the right side parallel to the coast from the disposal site). Also in this case, the area with deposition thicker than a centimetre is larger than in the Nieuwpoort reference case, because of the shallower water depth, but is still confined to the Oostende disposal area.

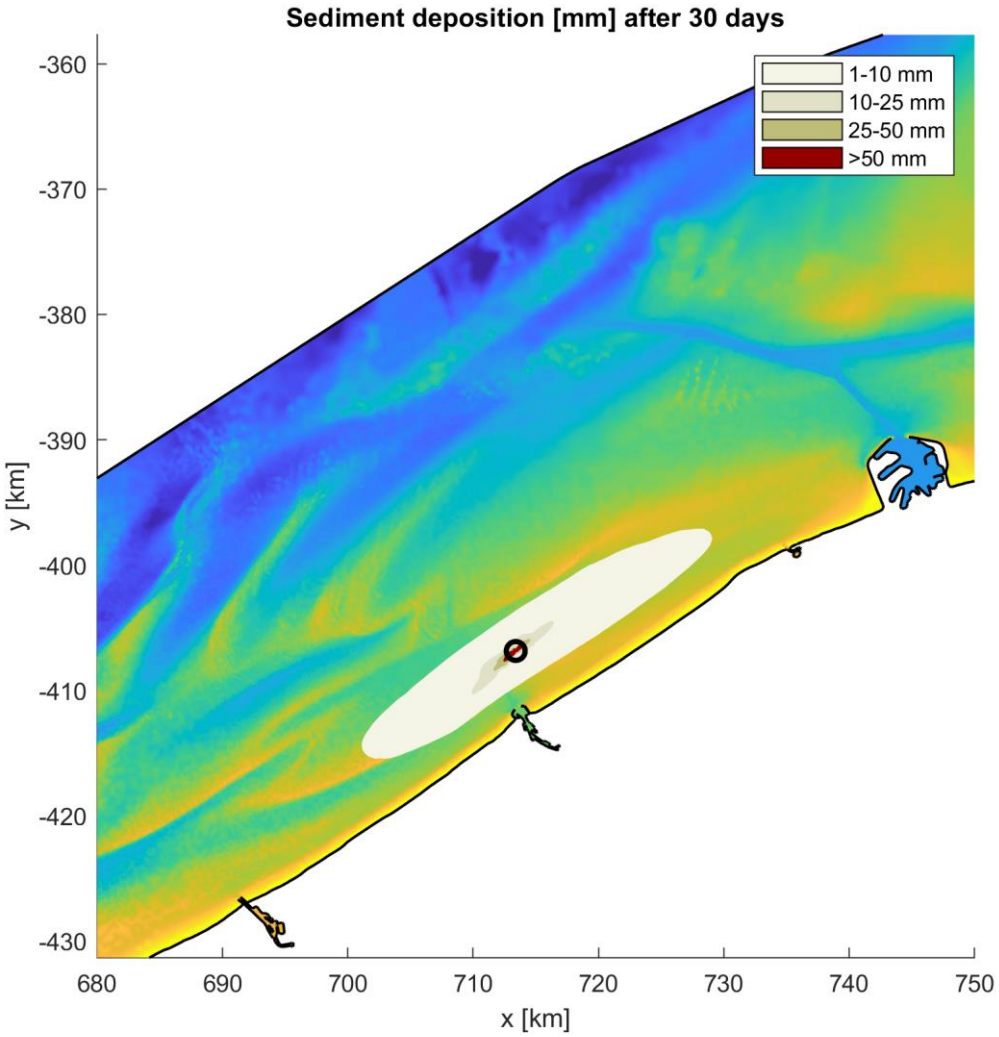



Figure 3-21 Footprint scenario 4a (disposal location Oostende).

### 3.2.4.5 Scenario 4b: disposal location Oostende with resuspension

In scenario 4b, in which the disposal area Oostende is used and resuspension is taken into account (Figure 3-22), no deposition on the bed is found in the coastal zone. The only location where some deposition occurs are the harbours of Oostende and Zeebrugge. Hence the disposed sediment is that light that it will always get resuspended and no permanent deposition of material will occur in the Belgian coastal zone.

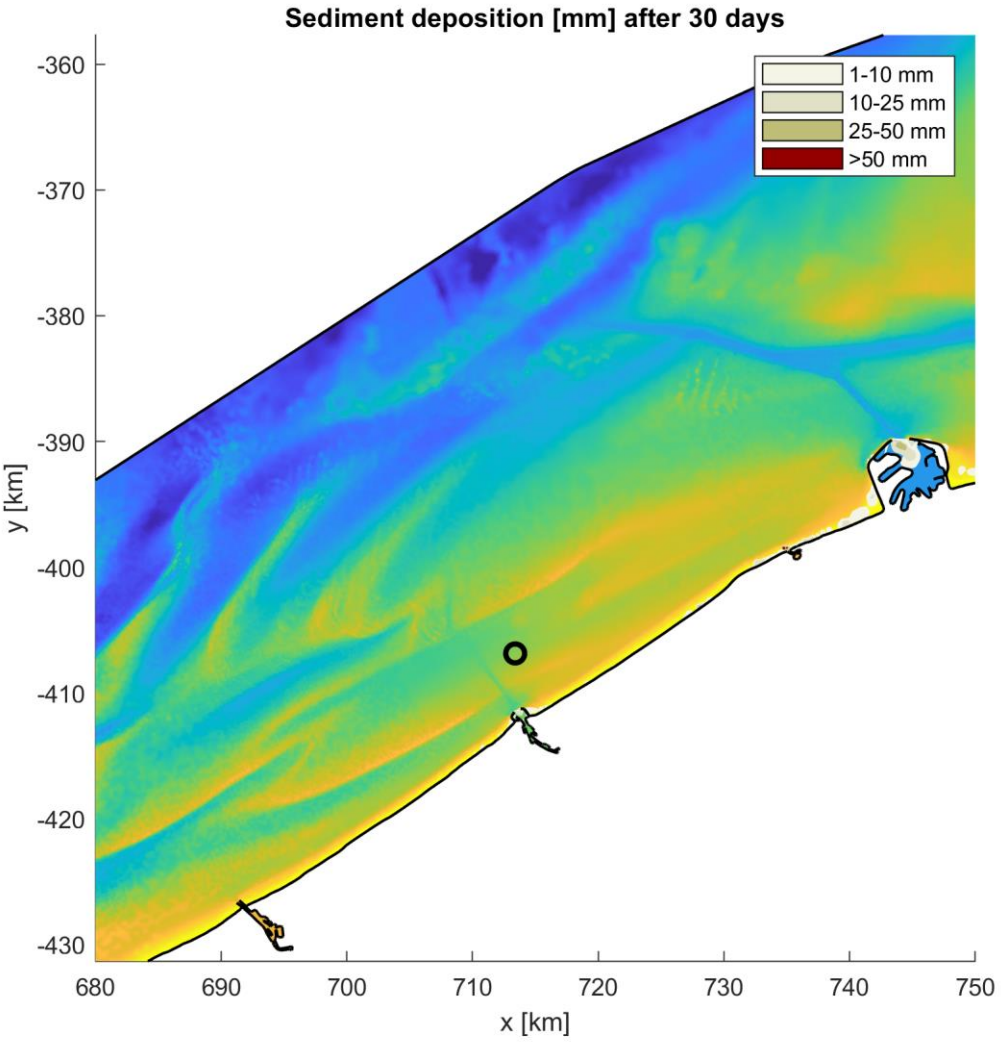



Figure 3-22 Footprint scenario 4b (disposal location Oostende with resuspension).

### 3.2.4.6 Scenario 5: sand disposal with resuspension

In scenario 5, in which sand is used, a very larger part of the sediment deposits rapidly close to the disposal site, because of the higher settling velocity. There is a small deposition area northeast of the disposal site (Figure 3-23), due to a small part of the sediment that gets transported caused by resuspension and which settles again nearby. The amount of sand that gets resuspended is very limited compared to scenario 2 (mud with resuspension), where almost all sediment gets resuspended and remains in the water column resulting in the absence of a footprint. Note that the thickness of the sand layer is much smaller than of a mud layer with the same mass, because the bed density of the sand sediment is much larger.

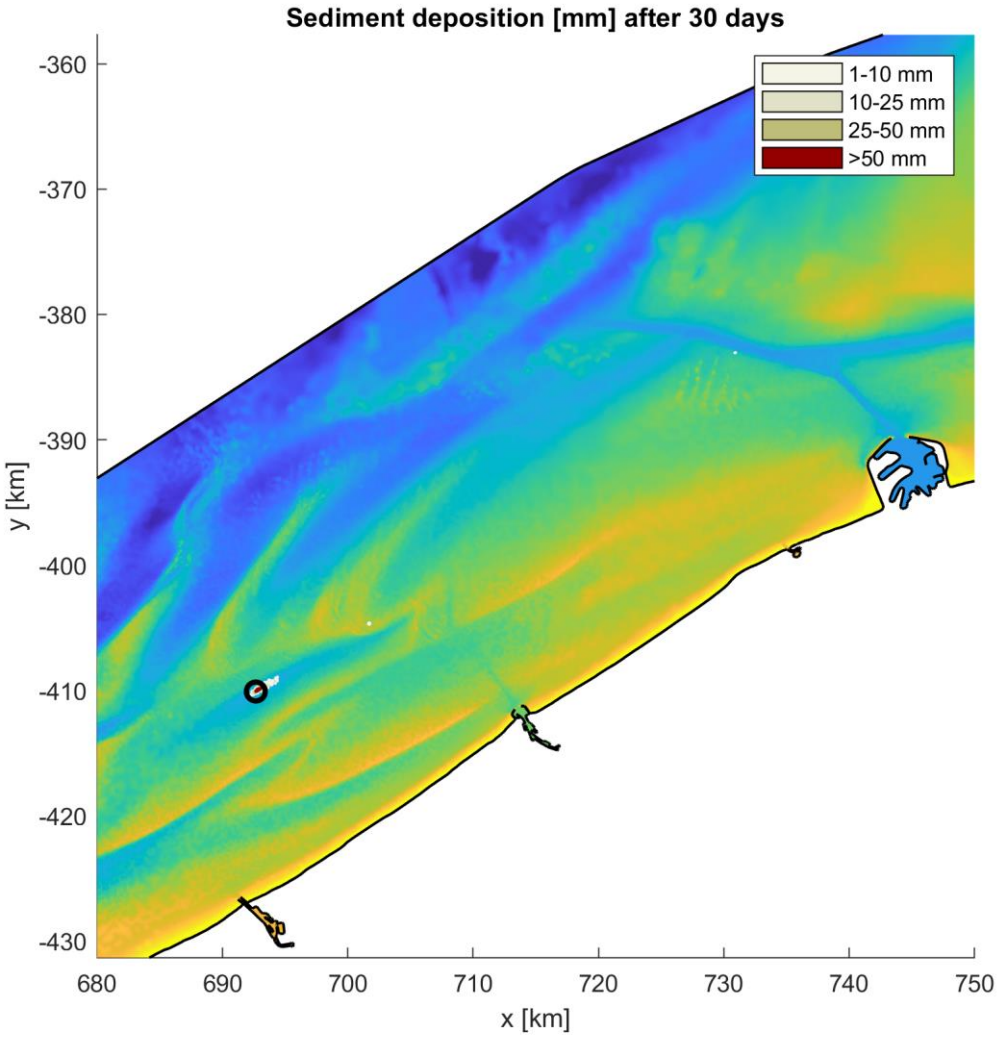



Figure 3-23 Footprint scenario 5 (run with sand).

# 4 Conclusions

In this report, the impact of disposing sediment dredged from the new marina of Nieuwpoort in the disposal zones of Nieuwpoort and Oostende is investigated using a 3D numerical model. Five scenarios were studied, each with a very conservatively estimated amount of fines that is disposed. It was decided to model a worst-case (conservative) scenario with 100% fines, to have the maximum plume formation. In reality, of the total volume to be disposed offshore, about 70% consists of silty sand and 30% of clayey silt (containing resp. 22-55% of fines).

The five scenarios are:

- Scenario 1, the base case, in which sediment is disposed every eight hours in the existing Nieuwpoort disposal zone, without taken into account resuspension of mud from the bed;
- Scenario 2, in which resuspension of mud form the bed was taken into account;
- Scenario 3, in which mud is disposed every six hours instead of every eight hours;
- Scenario 4a, considering disposal of mud in the Oostende disposal zone, which is located southeast of the existing Nieuwpoort disposal zone;
- Scenario 4b, in which same situation is considered as in scenario 4a. However, resuspension of sediment is included.
- Scenario 5, in which sand is disposed, rather than mud (taking into account resuspension).

From the results of the simulations it was found that:

- The impact of the disposal of the dredged sediment is limited:
    - The plume extent (defined as the area with maximum concentrations higher than 10 mg/l) is approximately 20 km x 10 km for the disposal site of Nieuwpoort and 35 km x 10 km for Oostende;
    - Depth-averaged sediment concentrations hardly exceed the natural background concentration of 25-50 mg/l for more than 1% of the time outside the disposal areas;
    - The deposition outside the disposal zone (for scenarios without resuspension) remains below one centimetre.
- The potential impact is somewhat larger when disposals occur every 6 hours rather than every eight hours because the total amount of sediment that is introduced within the same time period is larger;
- When resuspension of mud is considered (scenario 2), it is found that the considered sediment does not deposit on the bed. Instead, it remains suspended and moves through the area and the plume extent increases to 30 km x 10 km for the Nieuwpoort disposal site and to 50 km x 15 km for the Oostende site. Nevertheless, the concentrations due to resuspension are small (order of 1 mg/l);
- The potential impact is higher for disposing sediment in the disposal area Oostende. Because of the shallower water depth, the same amount of sediment is concentrated into a smaller vertical space, leading to higher concentrations over a larger area and a larger footprint on the seabed. The plume extent at this location is larger than for the Nieuwpoort disposal location, especially when resuspension is considered;
- When sand is disposed, the sand deposits very rapidly and concentrations larger than 10 mg/l do not occur outside the disposal zone. There is very limited resuspension of

sand, leading to depth-averaged concentrations of the order of 1 mg/l and a slow transport of sand in north-eastern direction.

It can be concluded that even in the worst case scenario of disposing only fines, the effects of the disposed material are minor and mainly restricted to the official disposal sites. As the dredged material will also comply with the required OSPAR sediment quality regulations, the results of the modelling do not lead to any legal restrictions for the disposal at the sites of Nieuwpoort or Oostende. For a detailed assessment of the effects described above, we refer to chapters 4.1 'Soil and water' and 4.4 'Fauna and flora' in the EIA.

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# Annex A Probability of exceedance

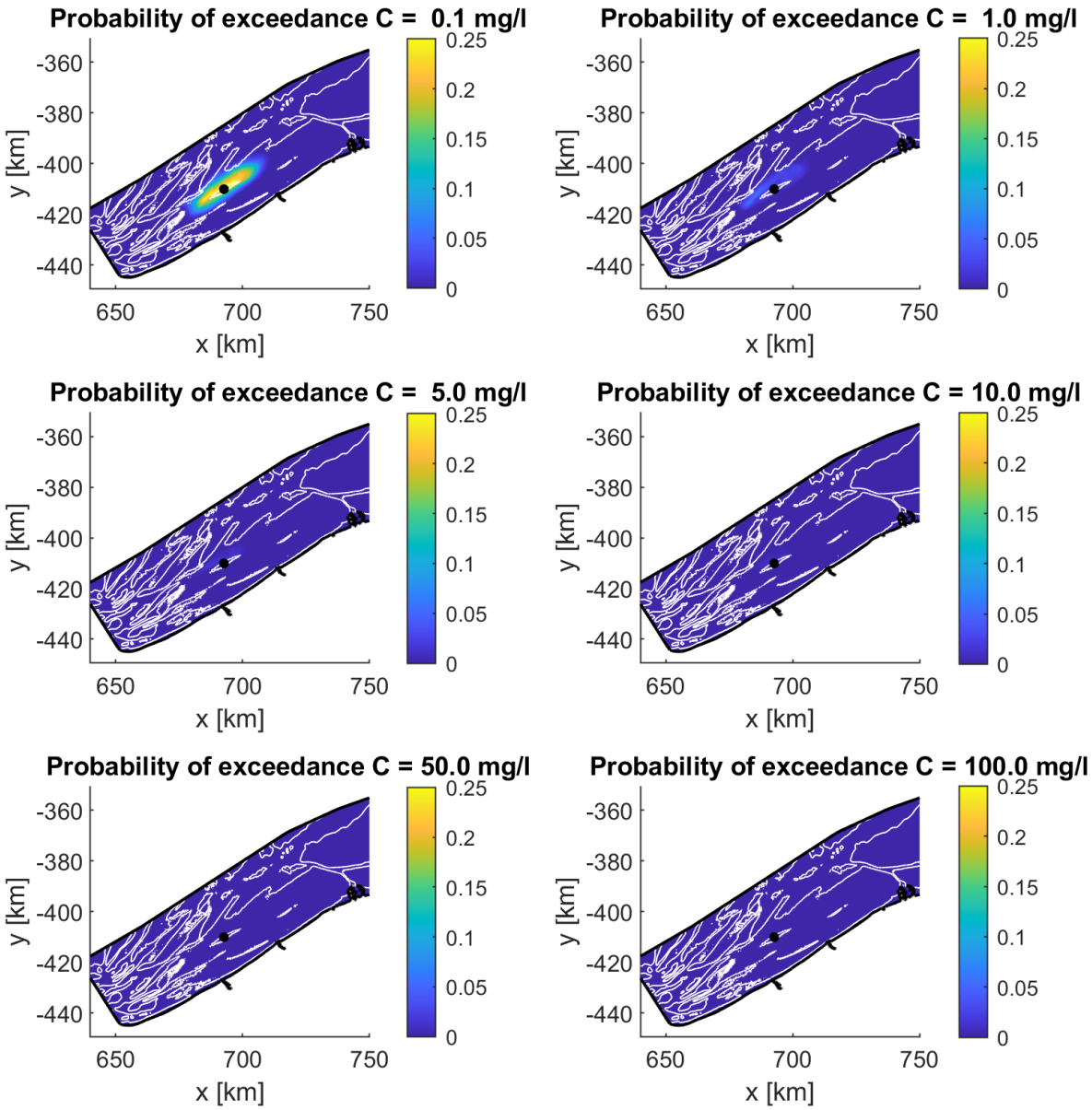



Figure Annex A-1 Maps of the probability of exceedance of different depth-averaged sediment concentrations for scenario 1 (Nieuwpoort reference case).

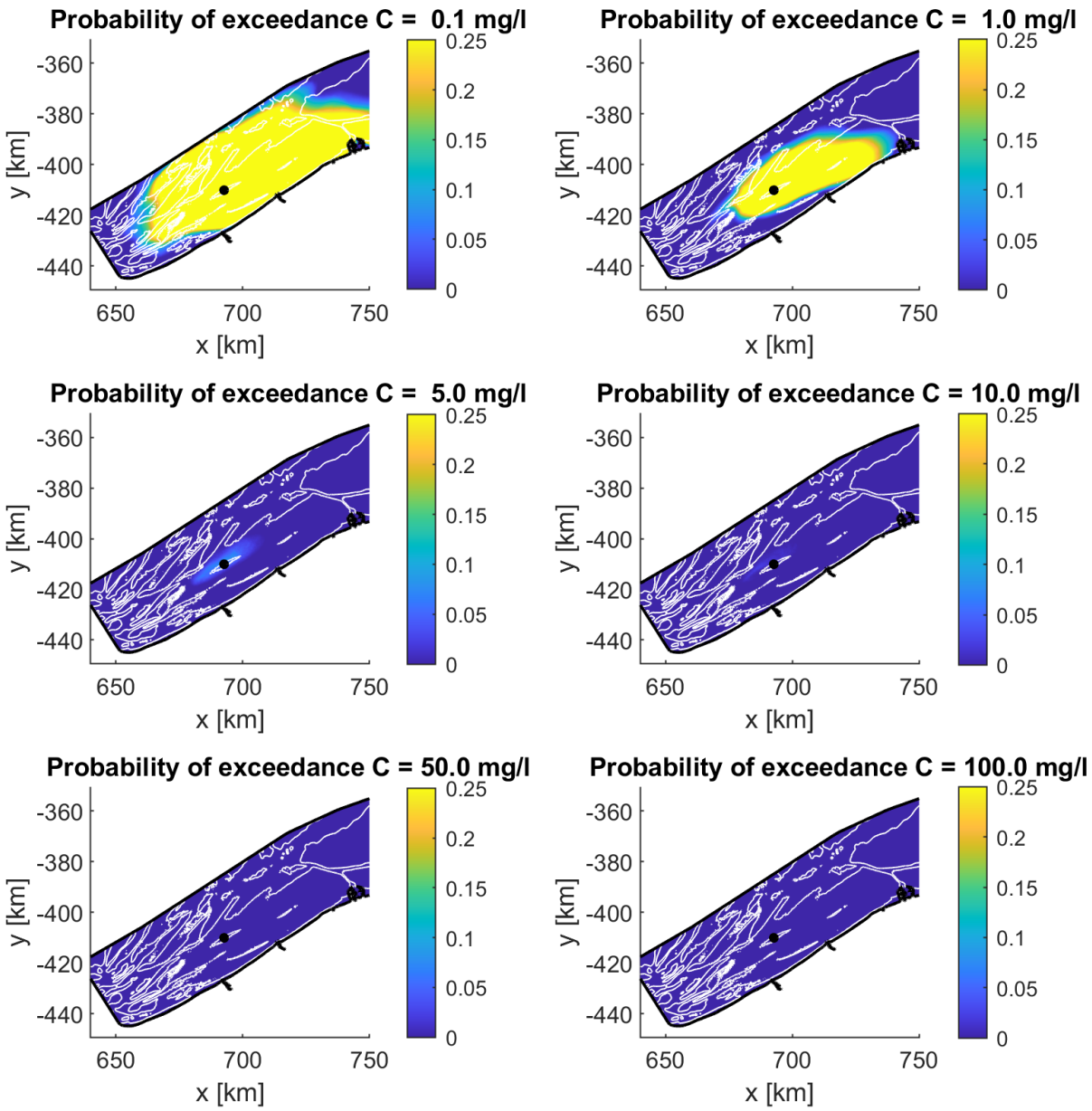



Figure Annex A-2 Maps of the probability of exceedance of different depth-averaged sediment concentrations for scenario 2 (Nieuwpoort with resuspension).

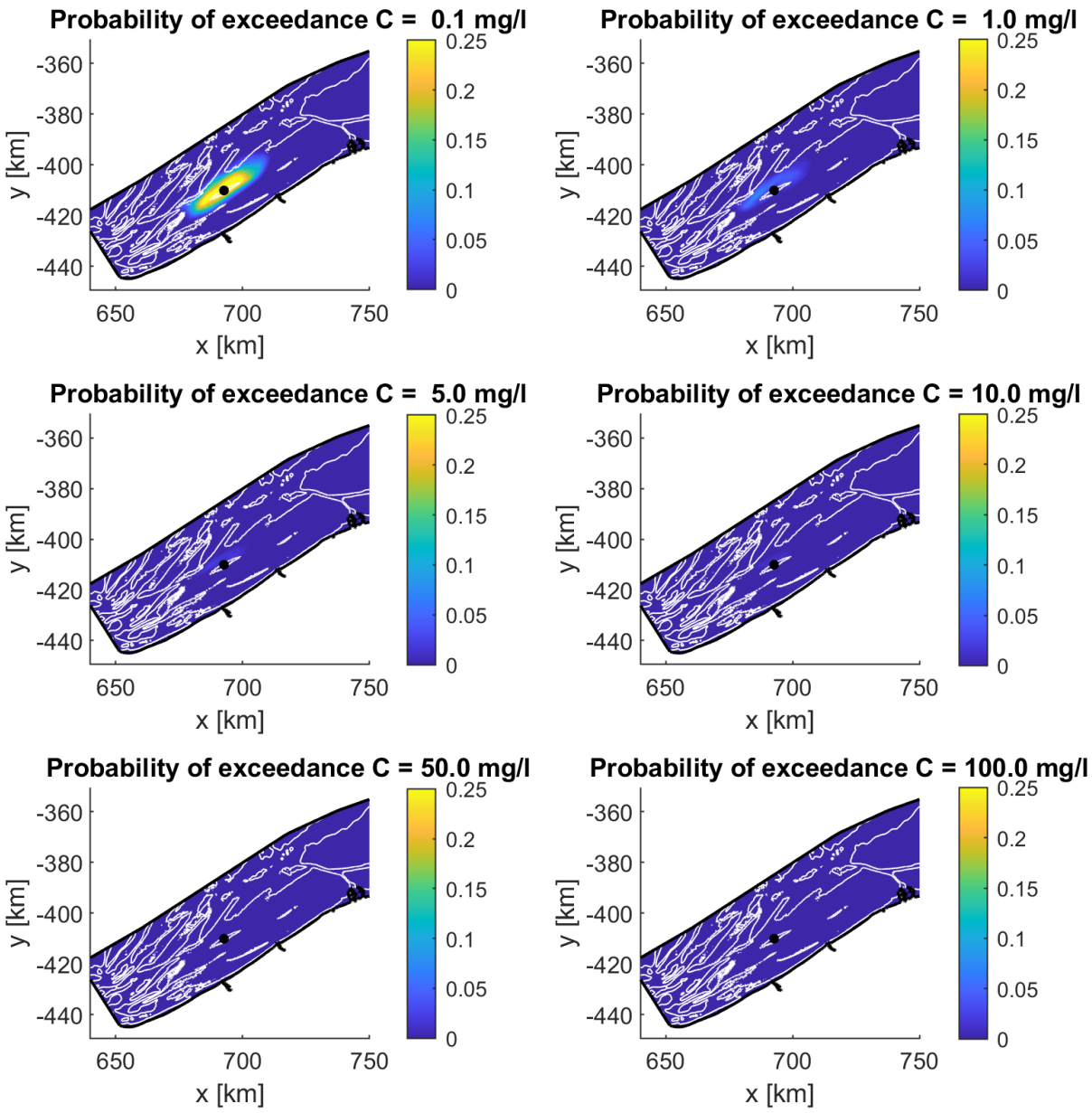



Figure Annex A-3 Maps of the probability of exceedance of different depth-averaged sediment concentrations for scenario 3 (increased disposal frequency).

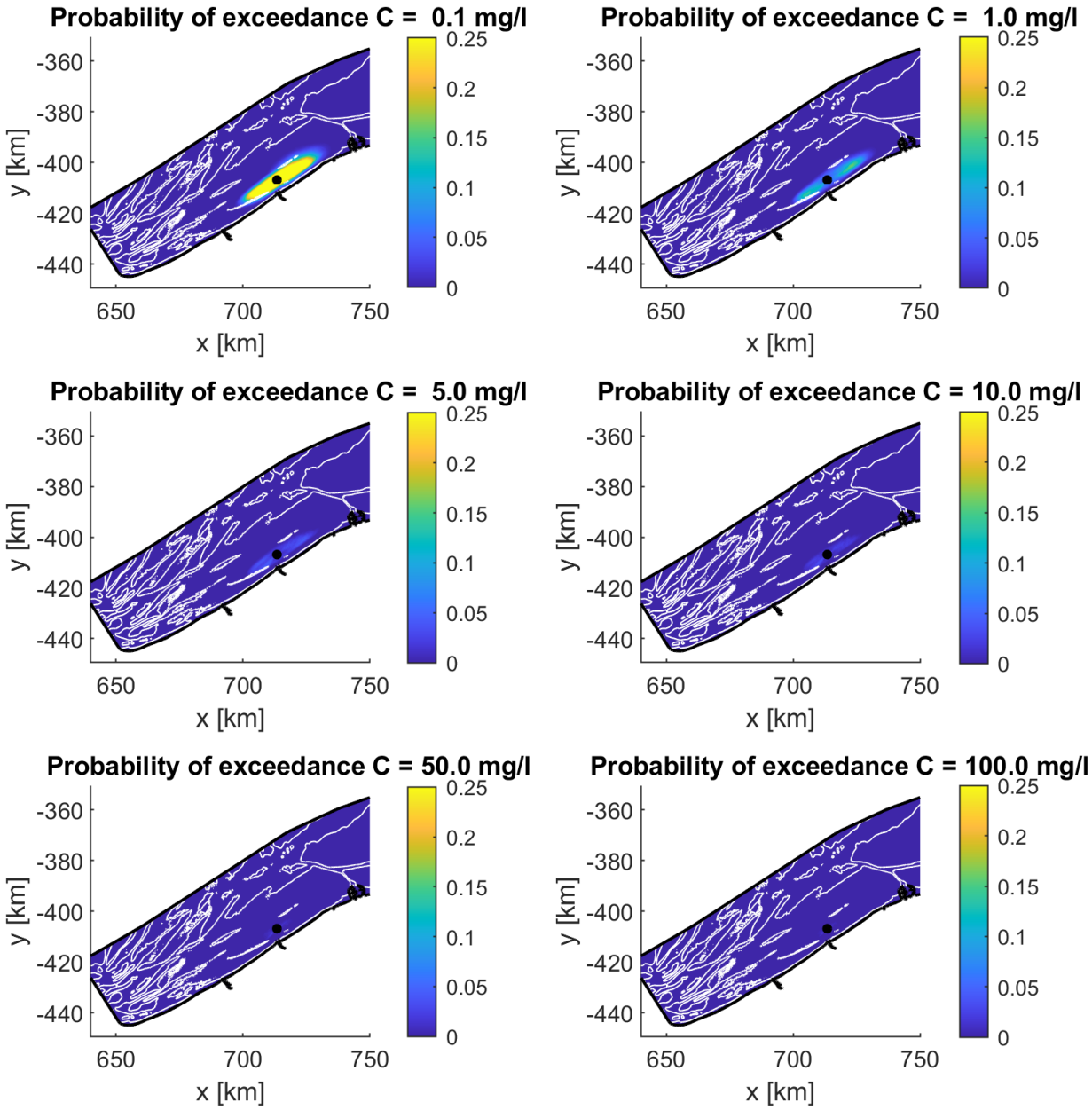



Figure Annex A-4 Maps of the probability of exceedance of different depth-averaged sediment concentrations for scenario 4a (disposal location Oostende).

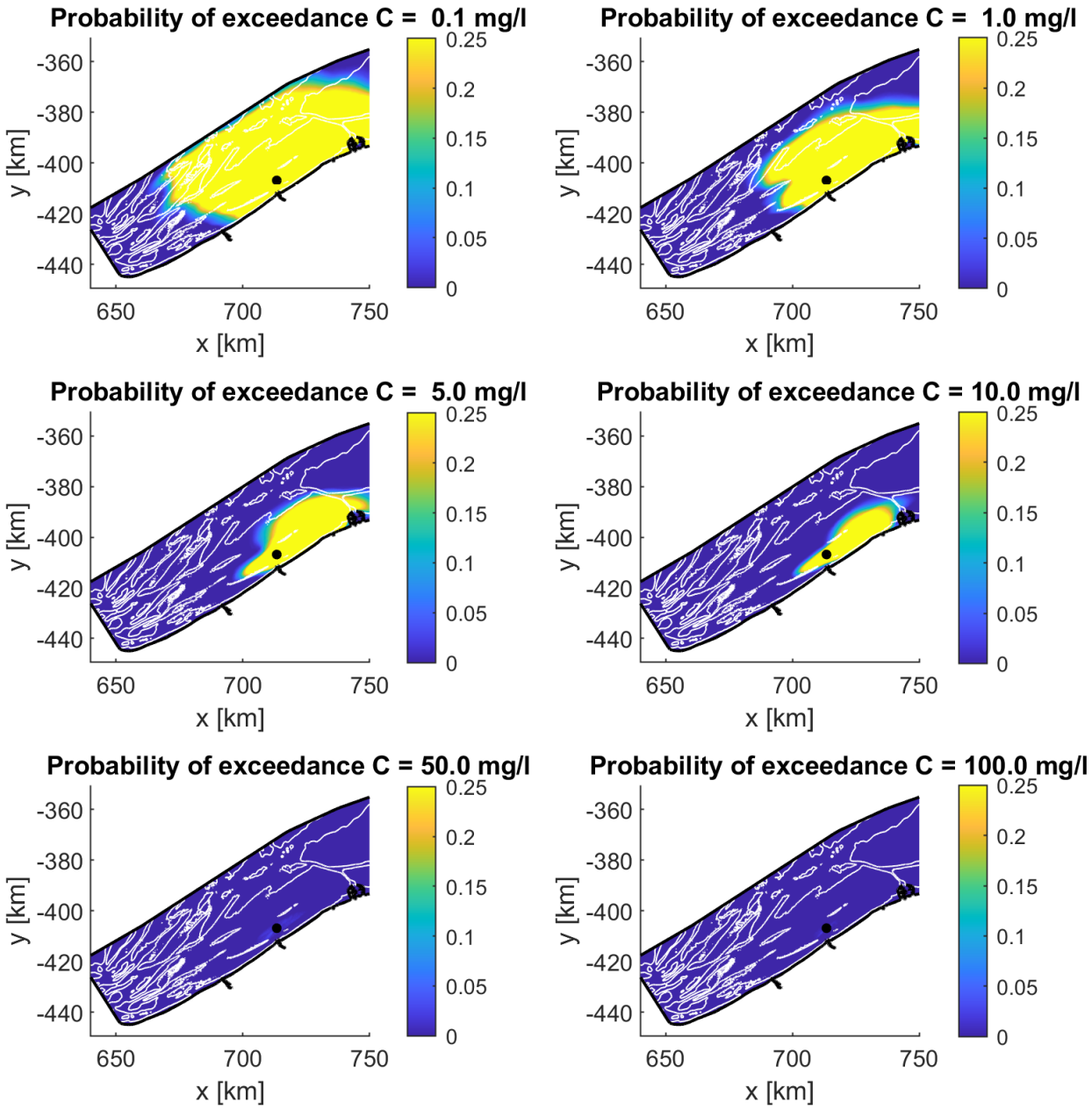



Figure Annex A-5 Maps of the probability of exceedance of different depth-averaged sediment concentrations for scenario 4b (disposal location Oostende with resuspension).

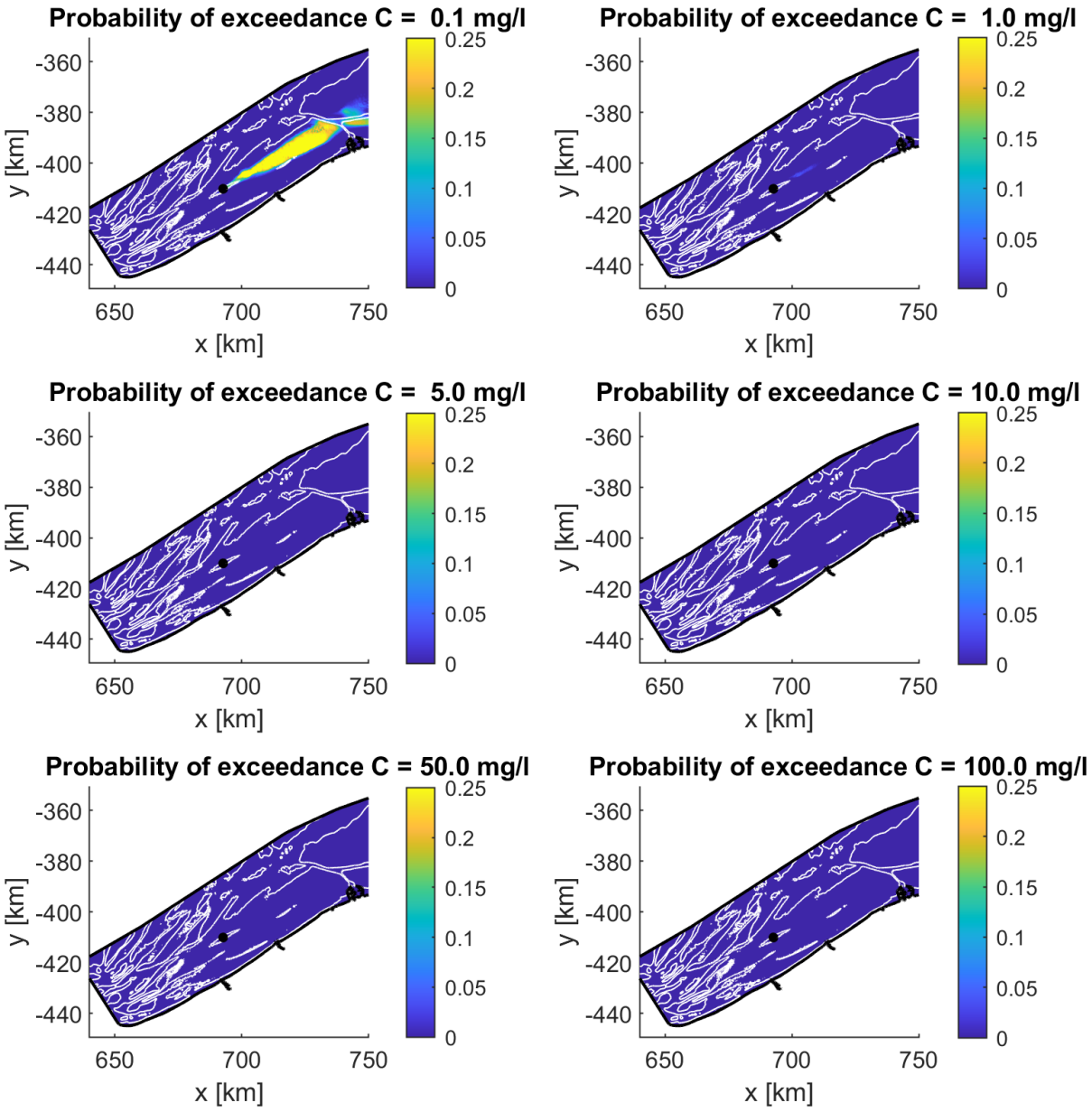
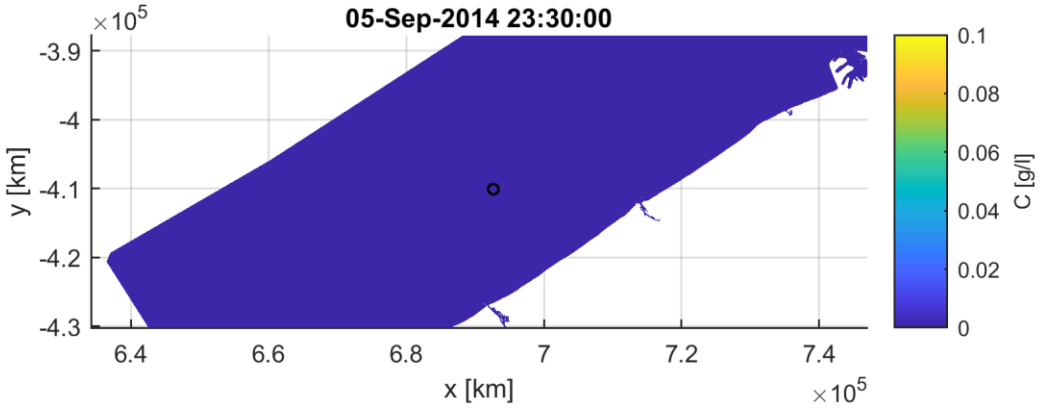
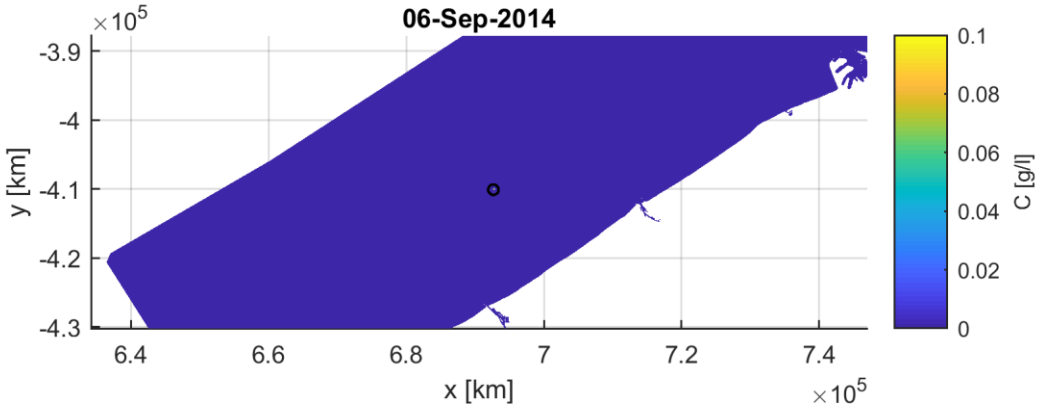


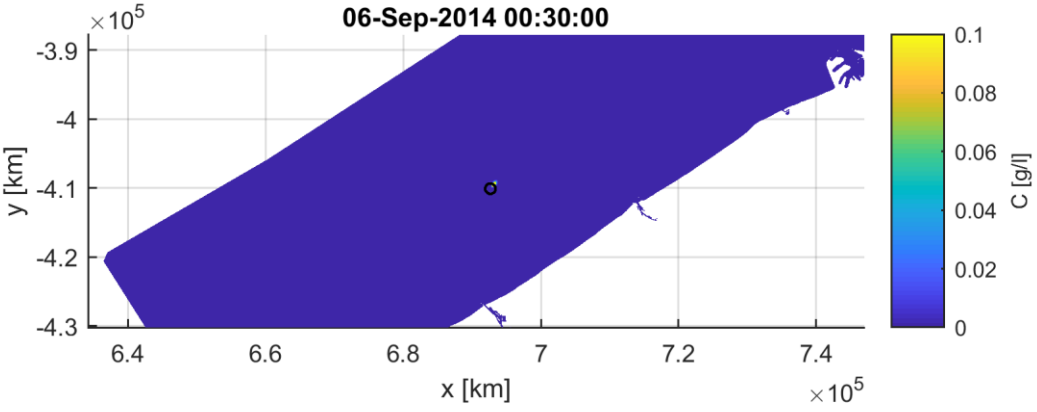

Figure Annex A-6 Maps of the probability of exceedance of different depth-averaged sediment concentrations for scenario 5 (disposal of sand).

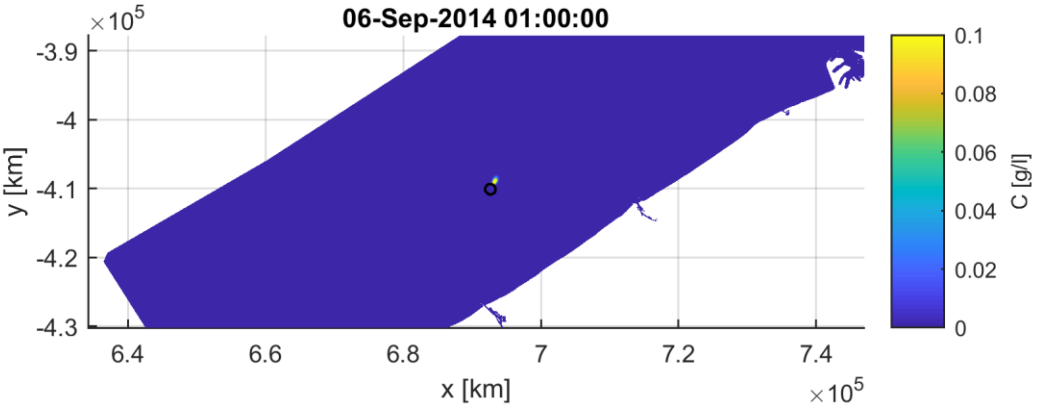
# Annex B Full dredging and disposal cycle

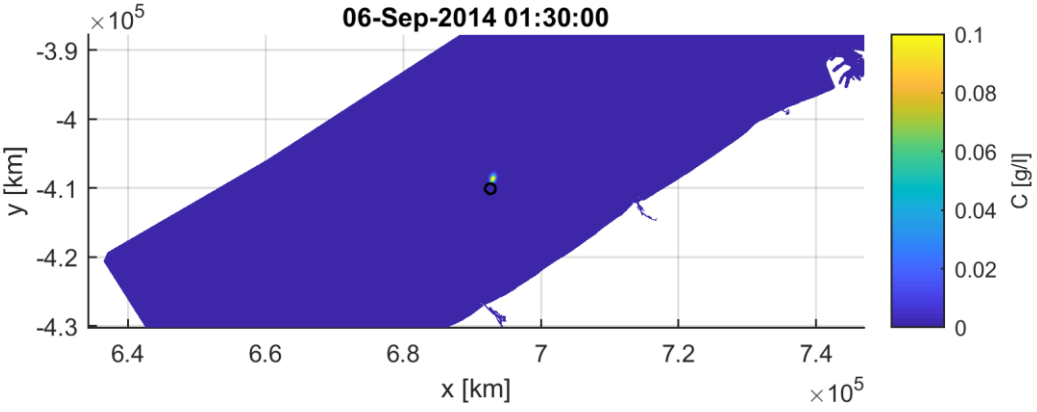
## B.1 Scenario 1 (base case Nieuwpoort without resuspension)

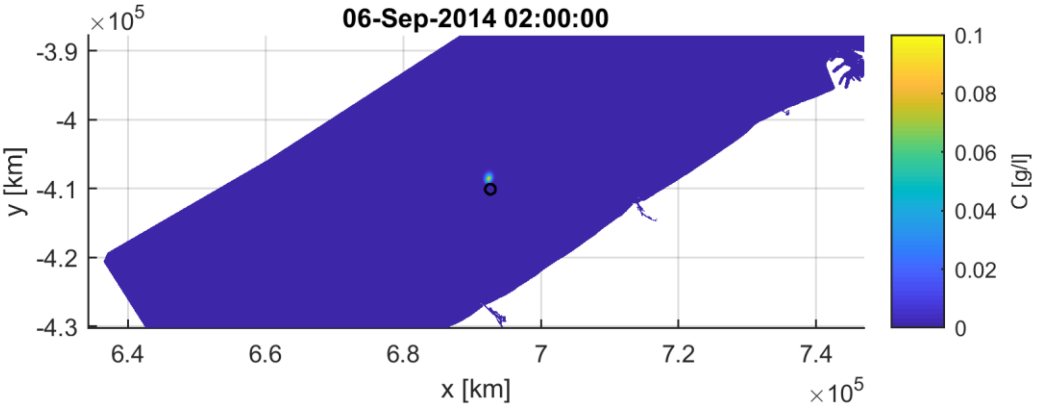


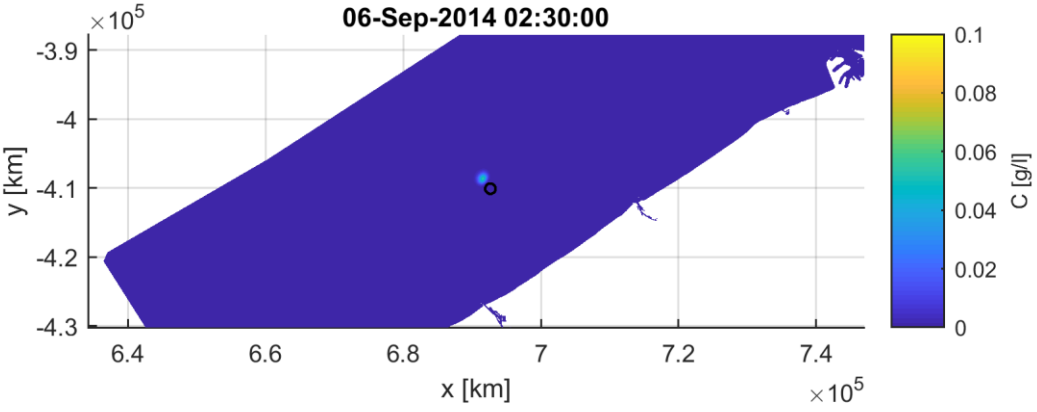



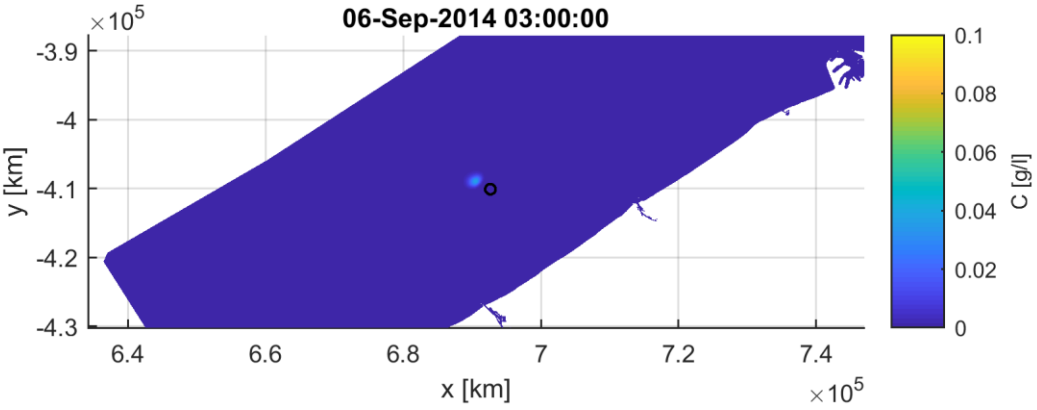

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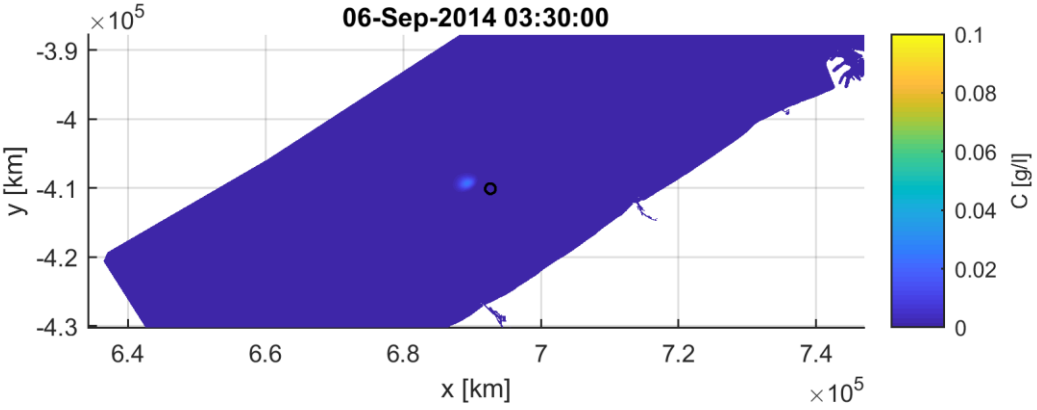

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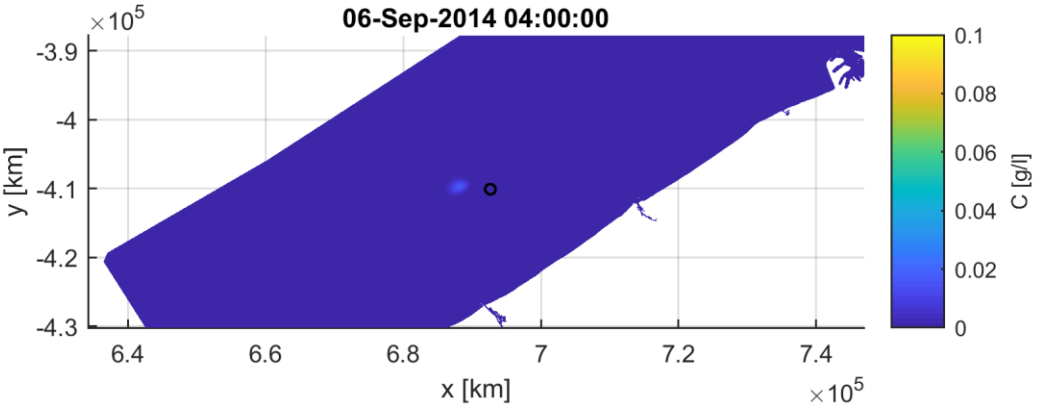

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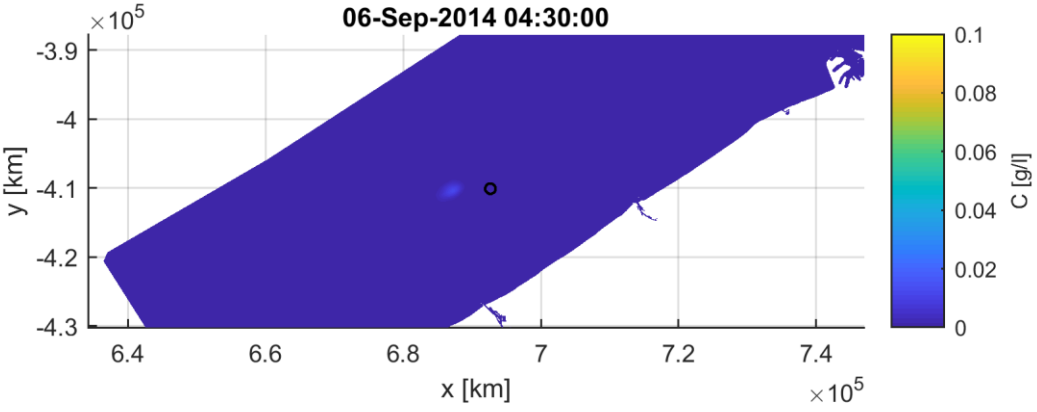

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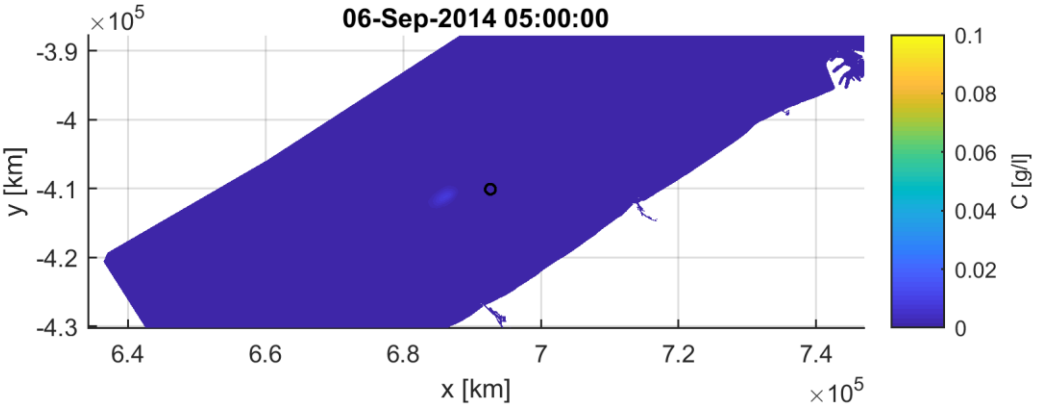

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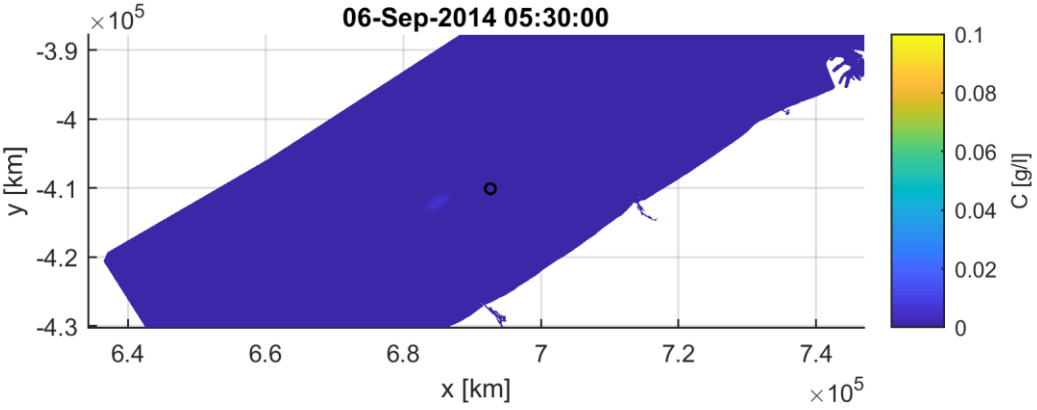

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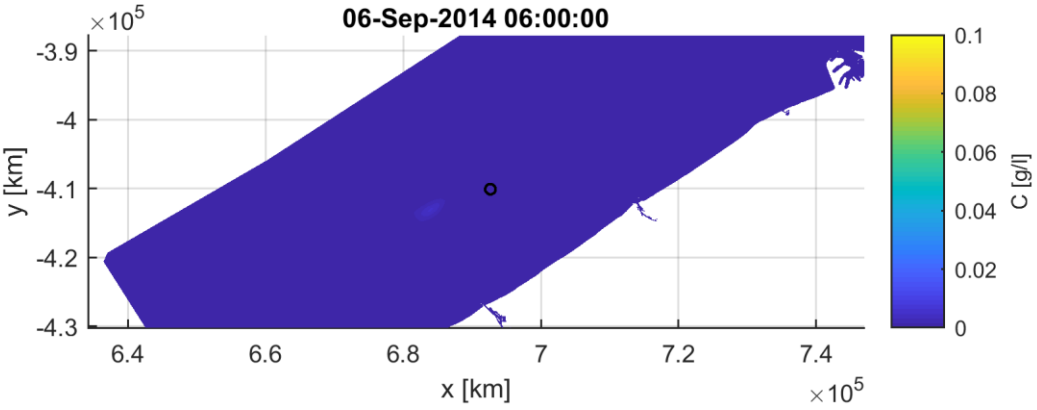

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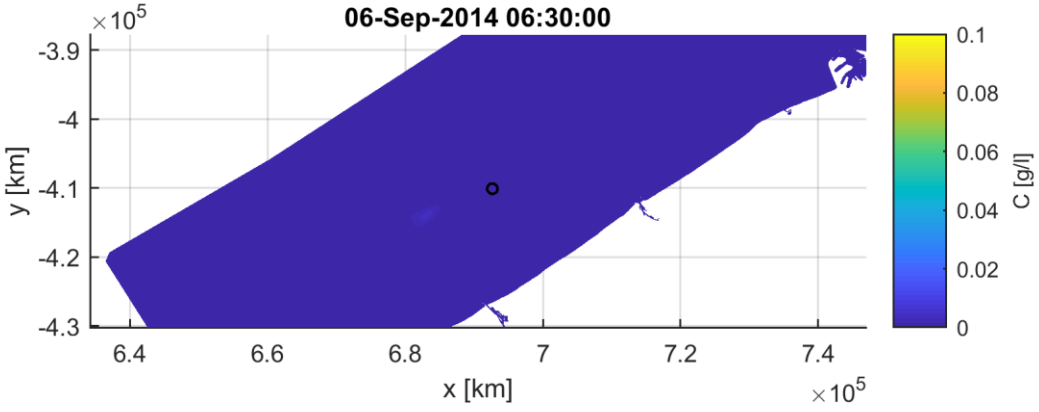

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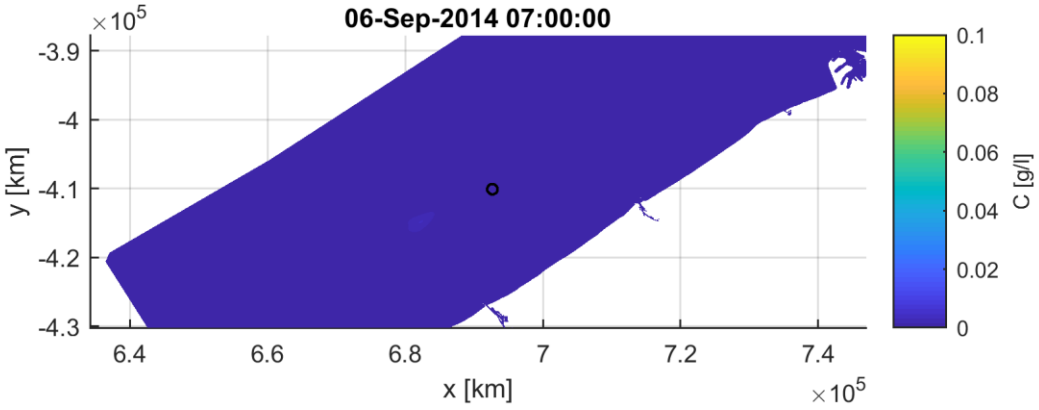

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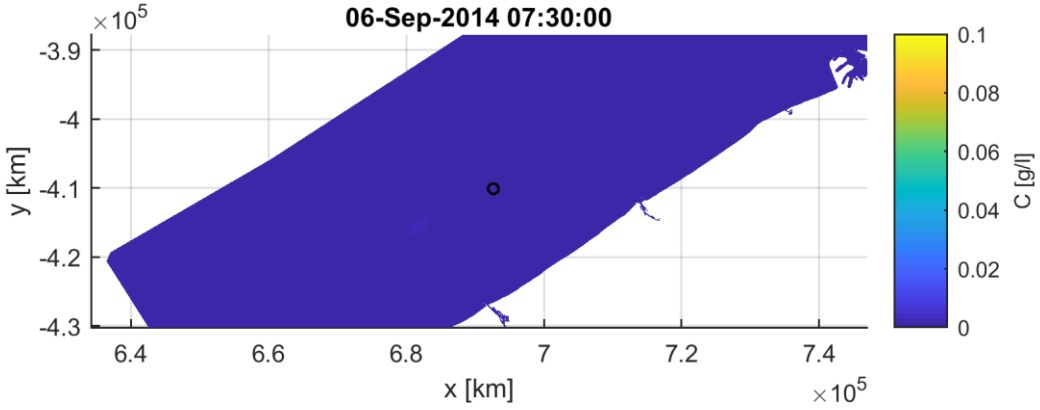

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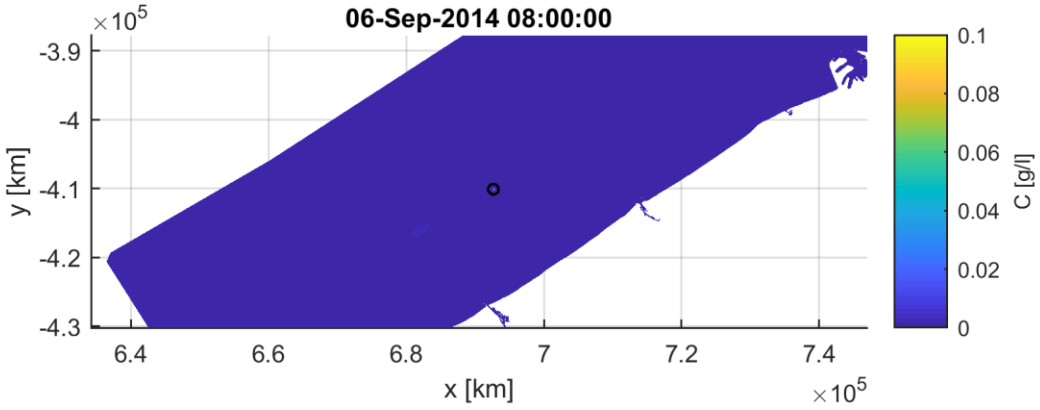

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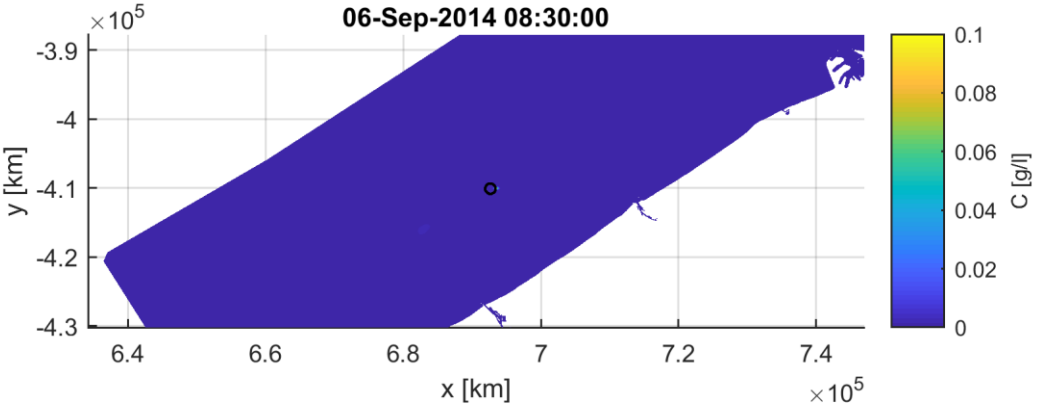

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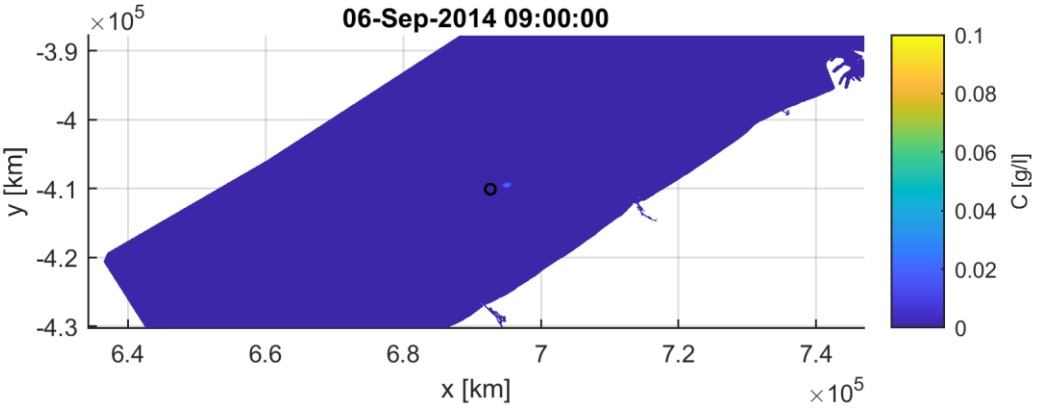

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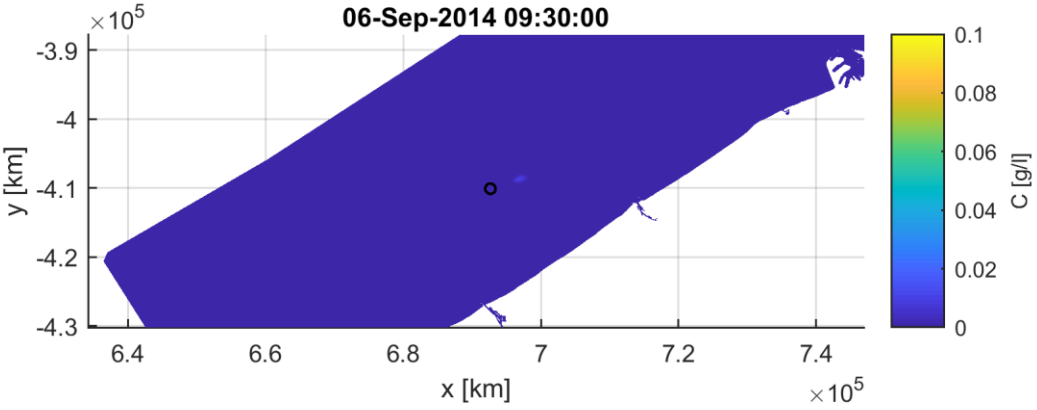

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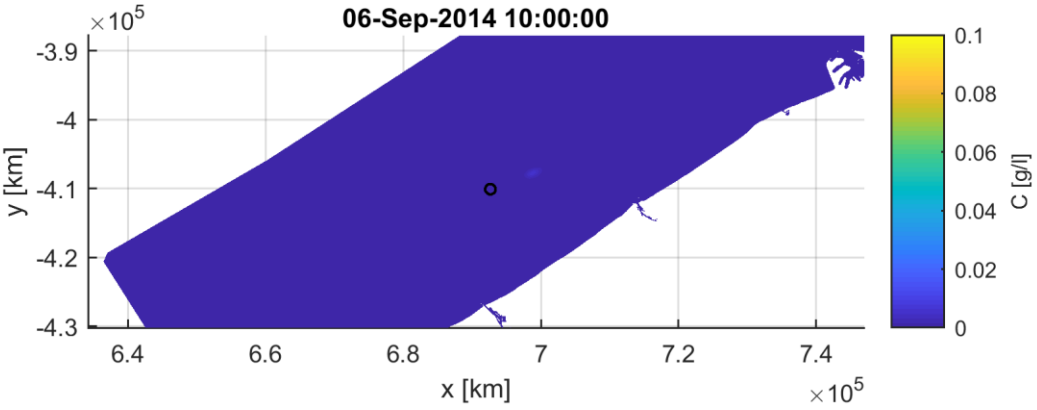

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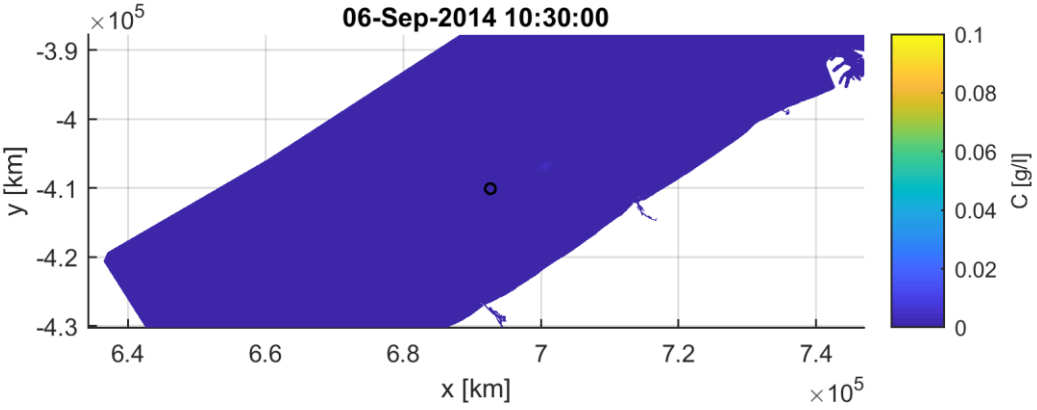

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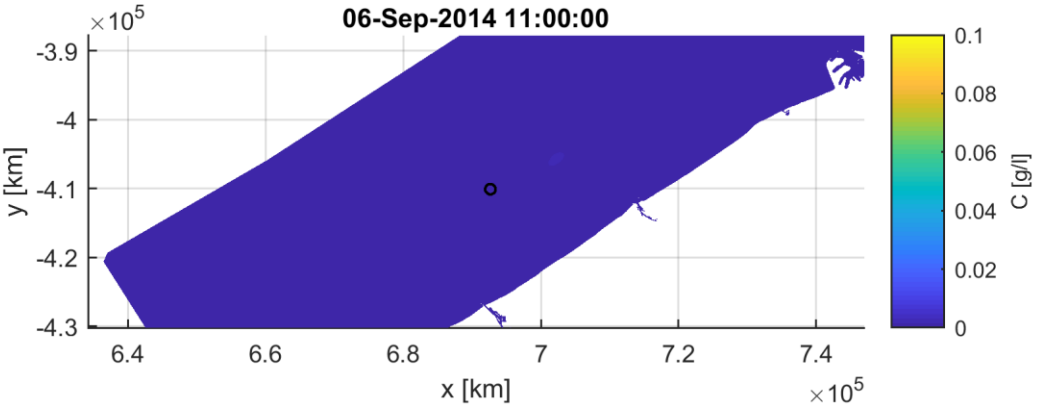

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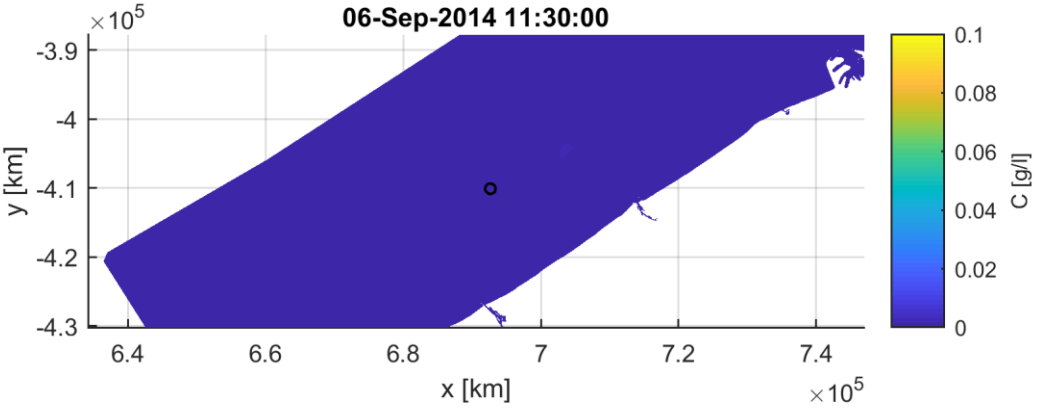

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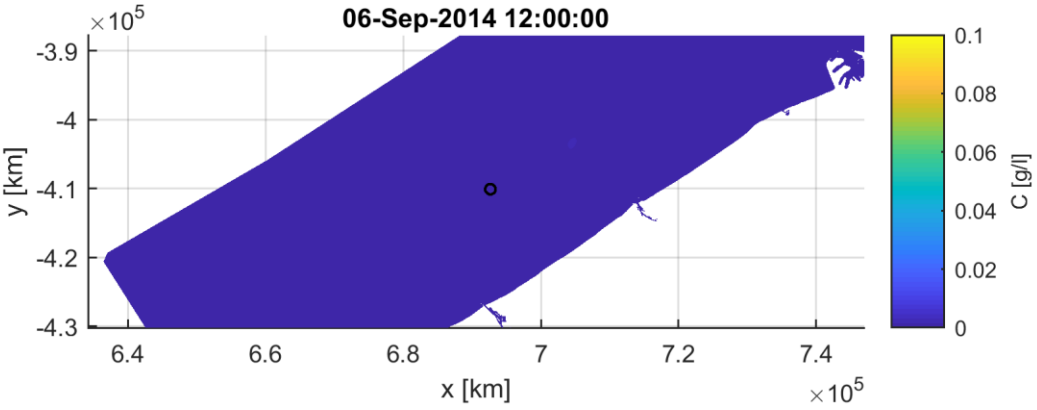

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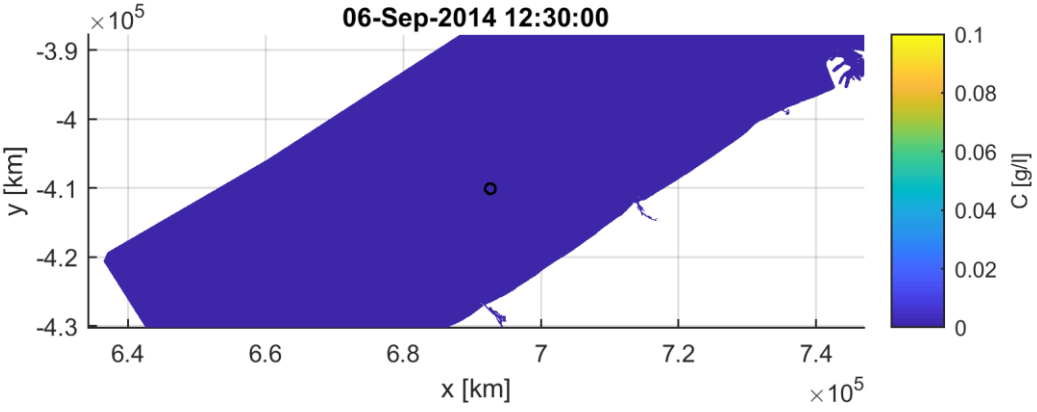

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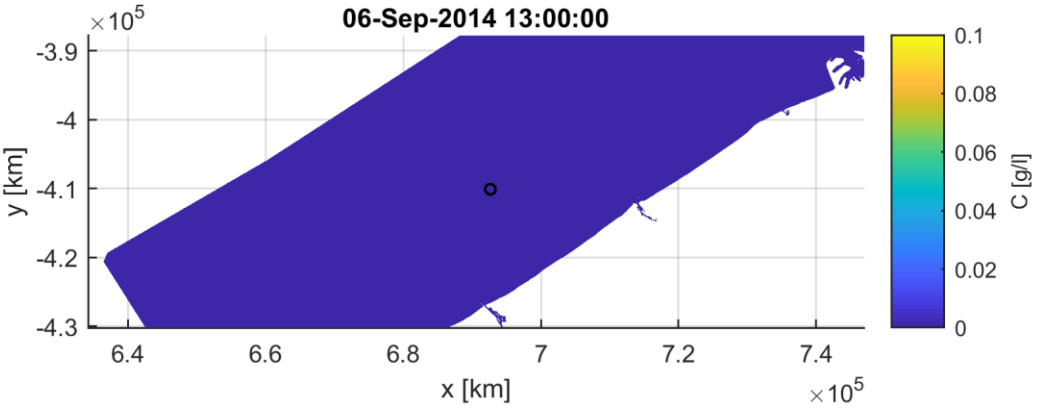

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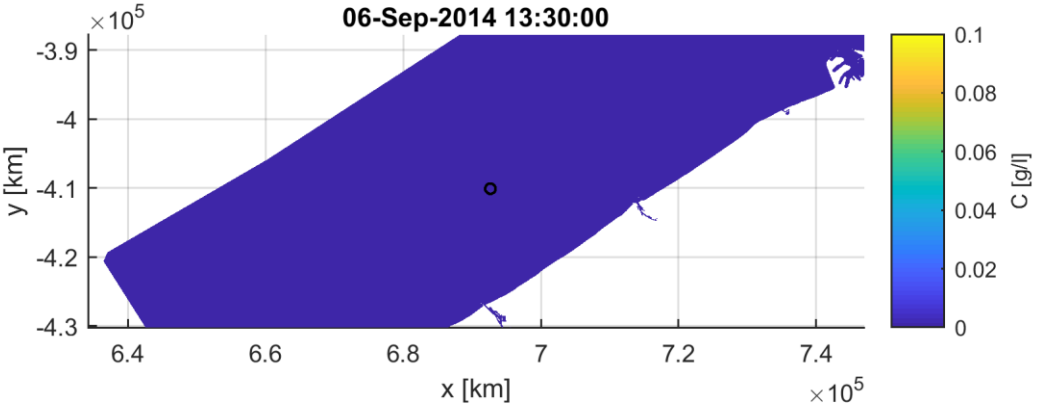

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C [g/l]


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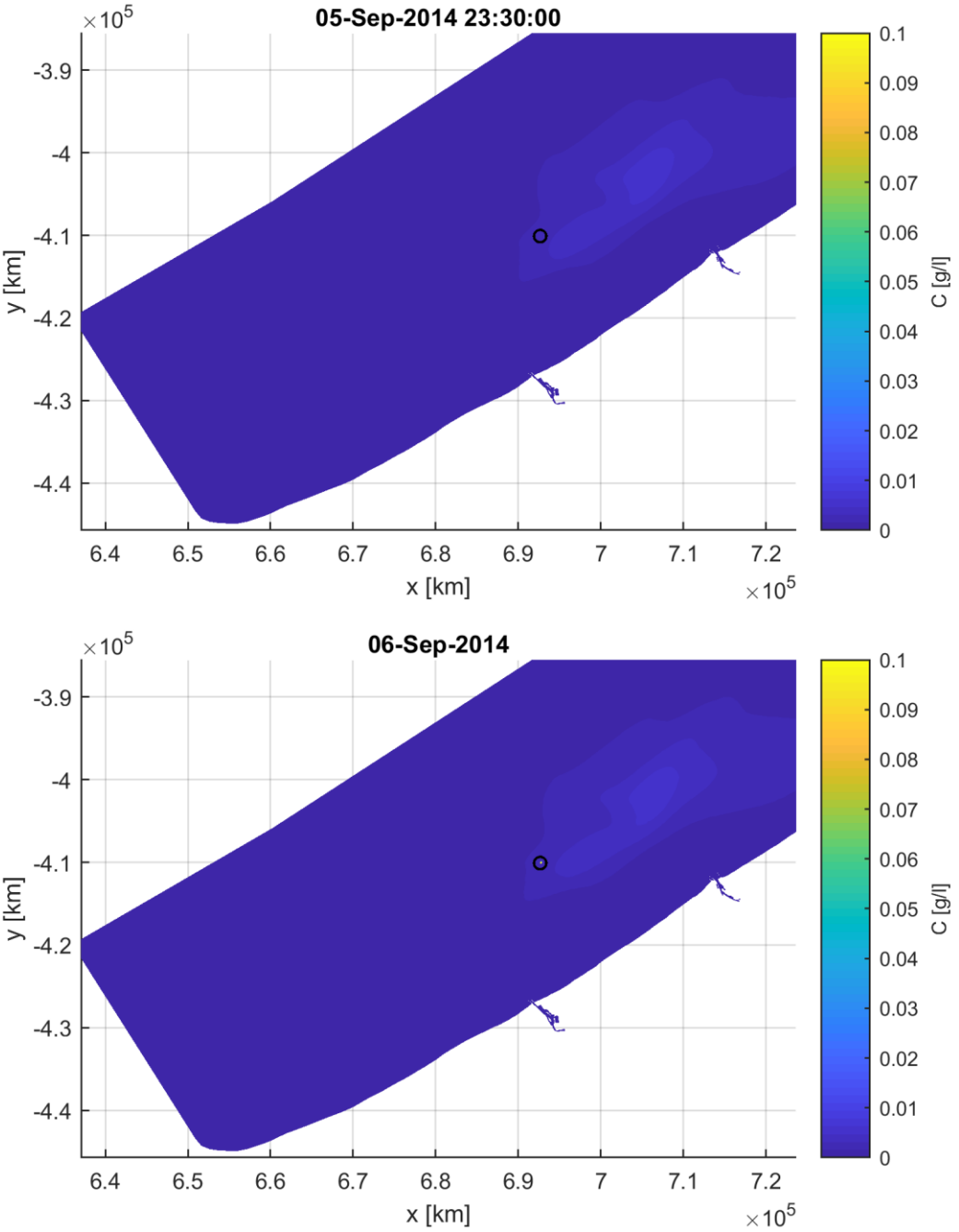

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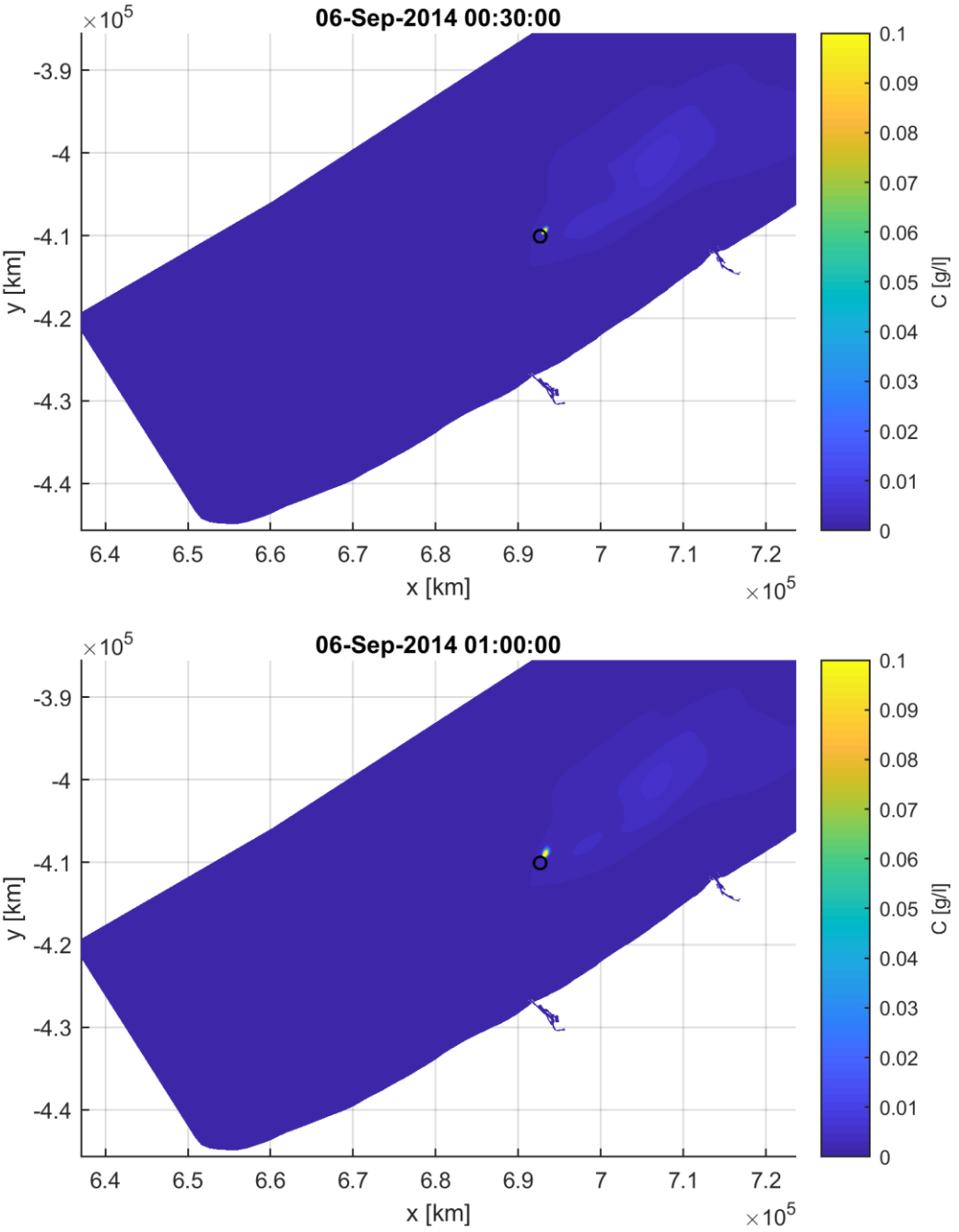

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y [km]
6.4
6.6
6.8
7
7.2
7.4
×10^5
x [km]
0.1
0.08
0.06
0.04
0.02
0
C [g/l]

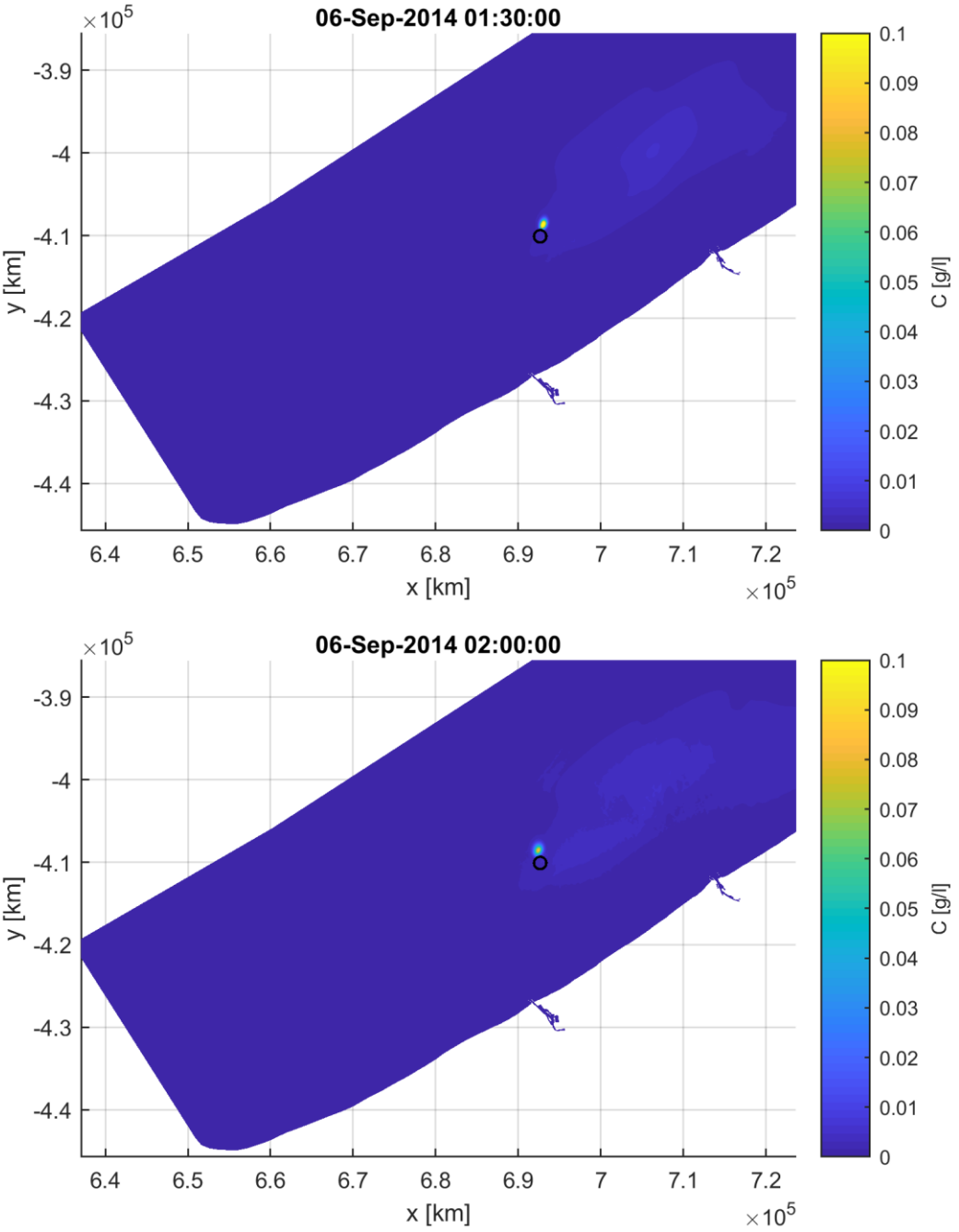

06-Sep-2014 13:00:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
y [km]
6.4
6.6
6.8
7
7.2
7.4
×10^5
x [km]
0.1
0.08
0.06
0.04
0.02
0
C [g/l]

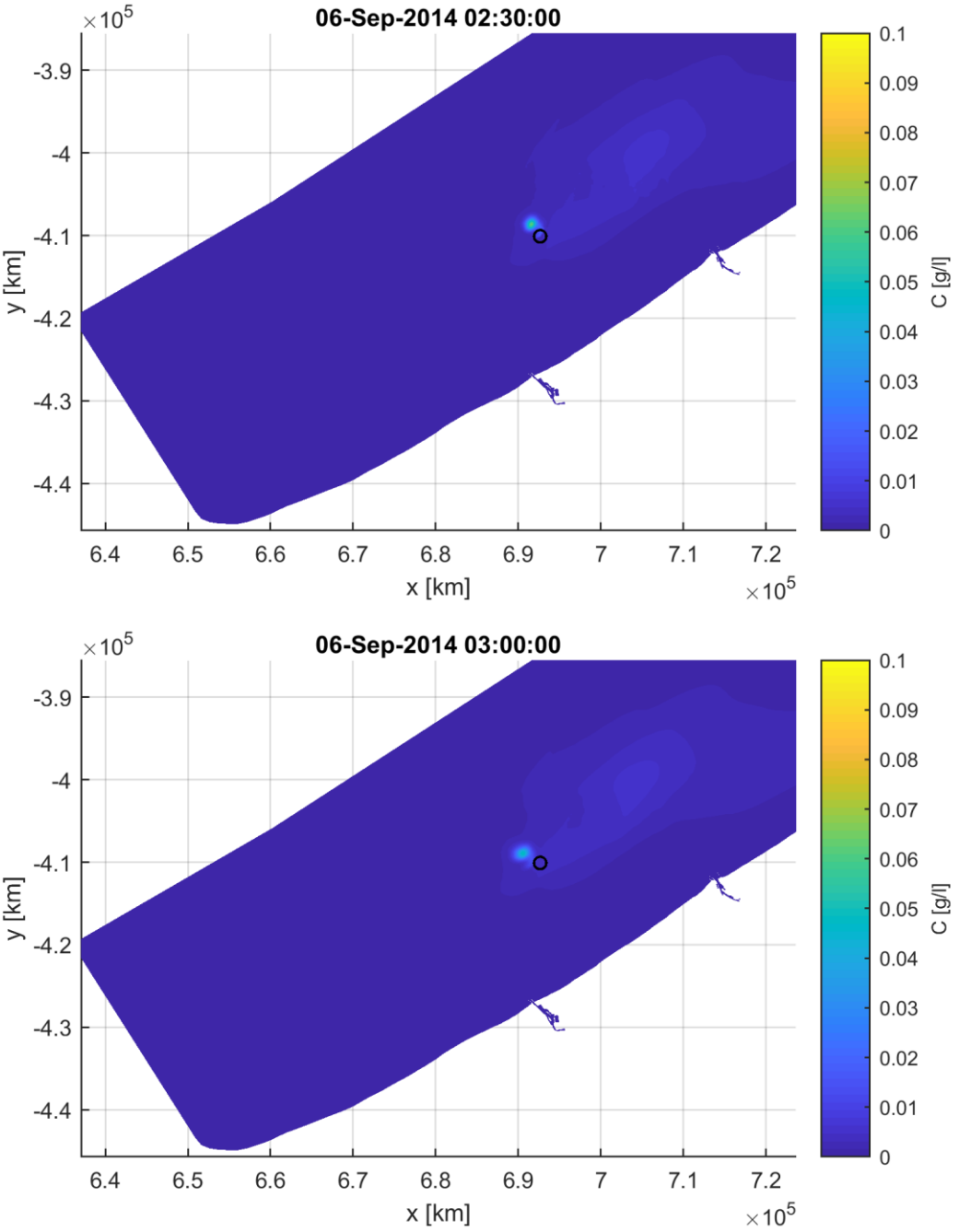

06-Sep-2014 13:30:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
y [km]
6.4
6.6
6.8
7
7.2
7.4
x [km]
×10^5
0.1
0.08
0.06
0.04
0.02
0
C [g/l]

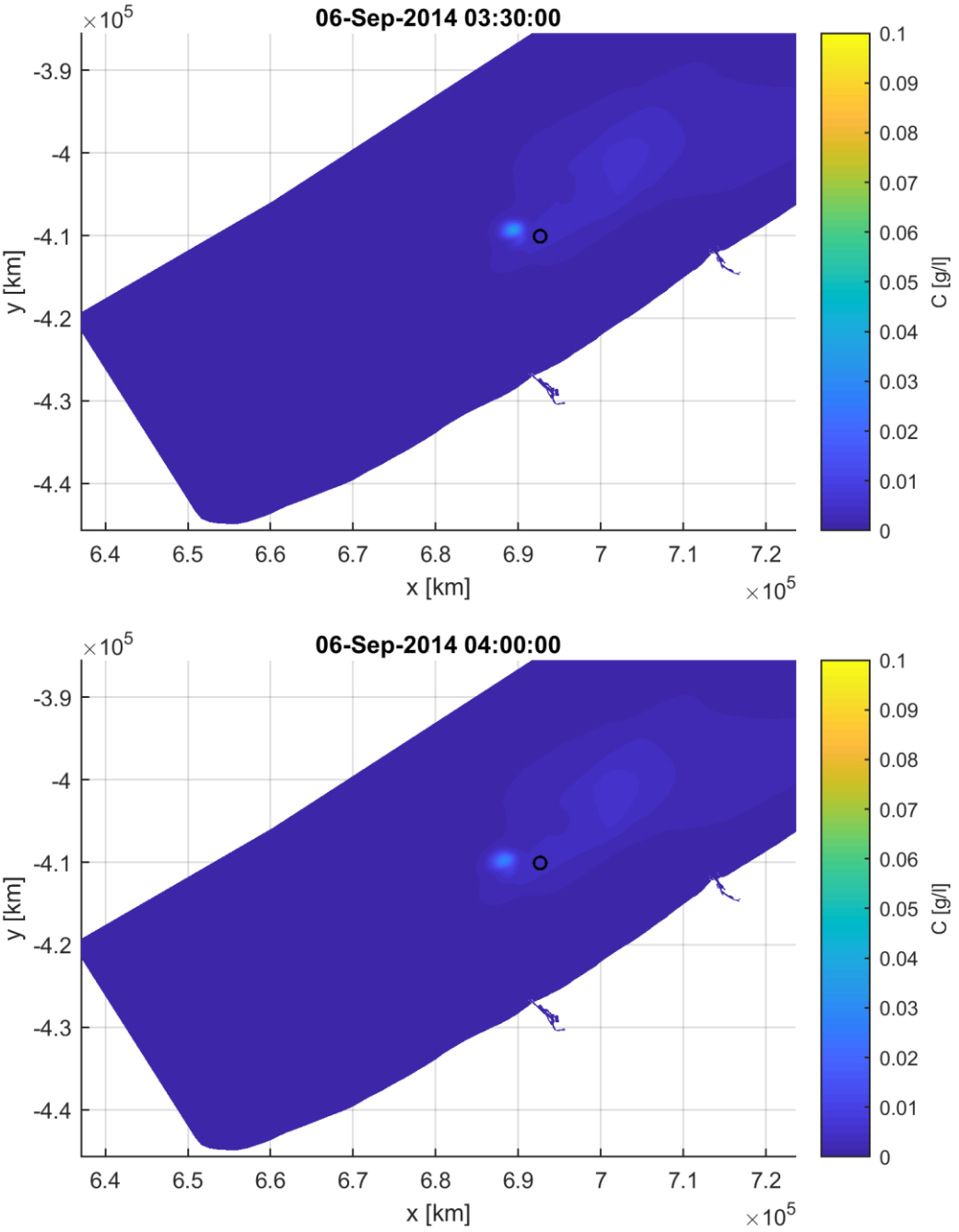
## B.2 Scenario 2 (Nieuwpoort with resuspension)

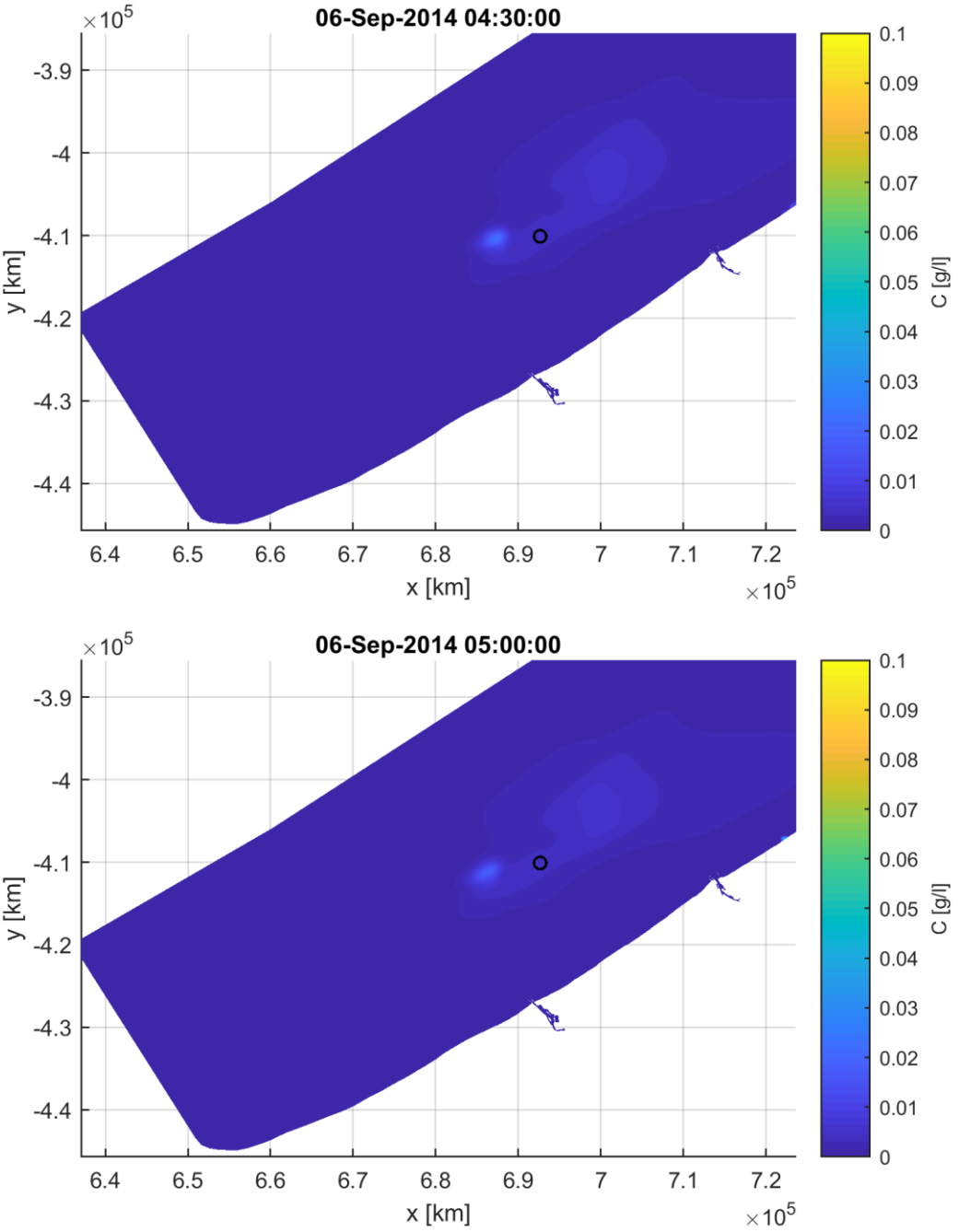


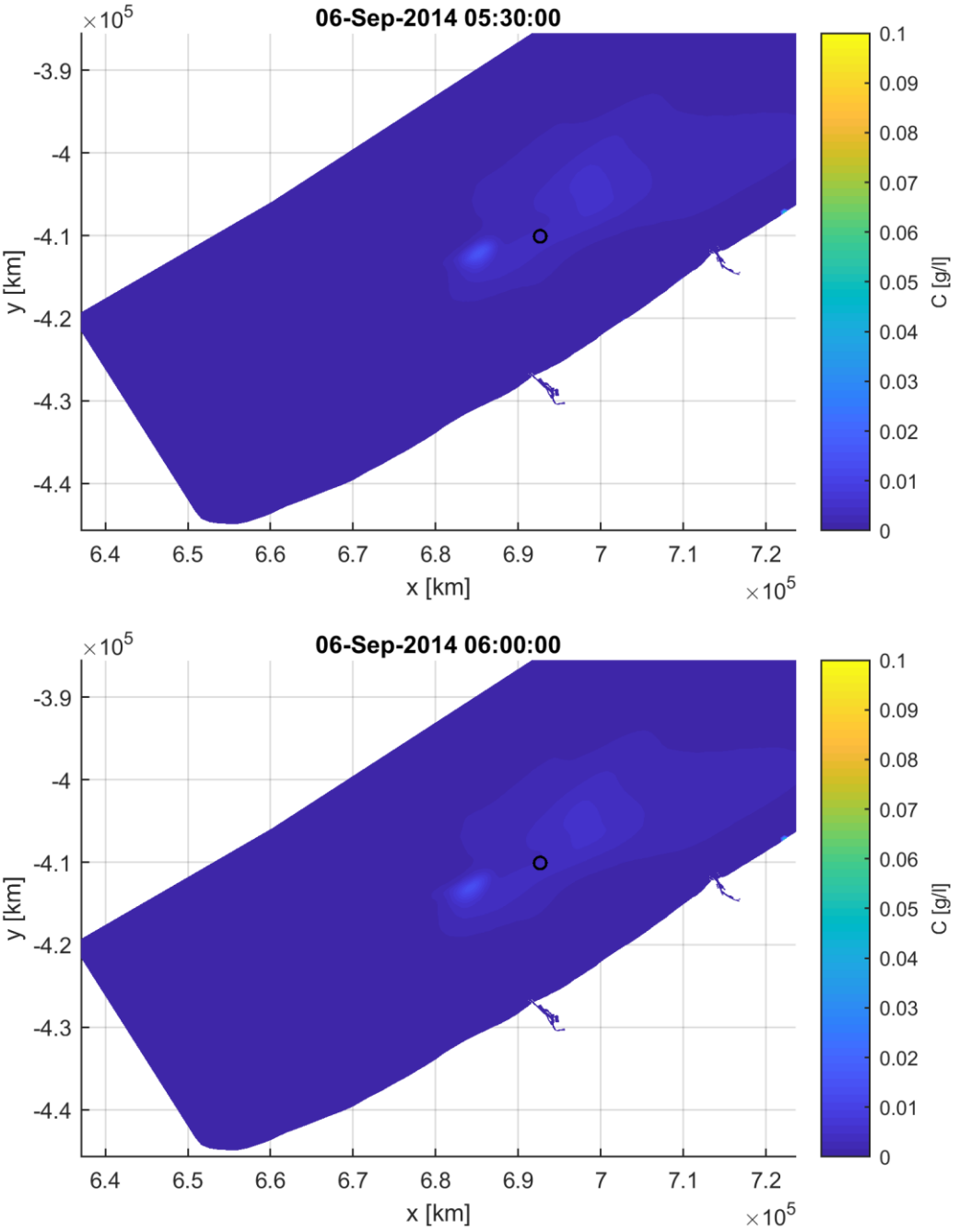

06-Sep-2014 00:30:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]
06-Sep-2014 01:00:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

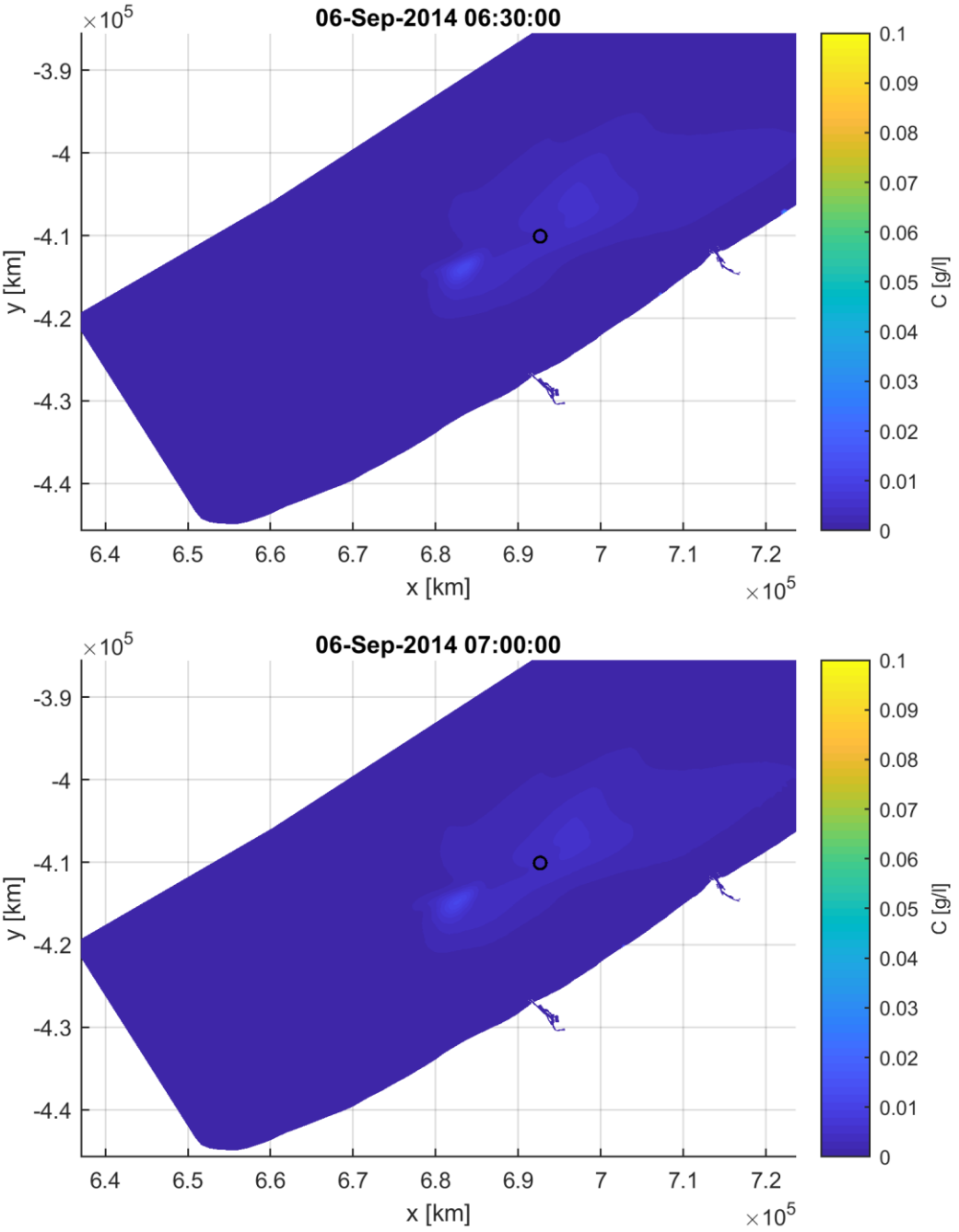

06-Sep-2014 01:30:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]
06-Sep-2014 02:00:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

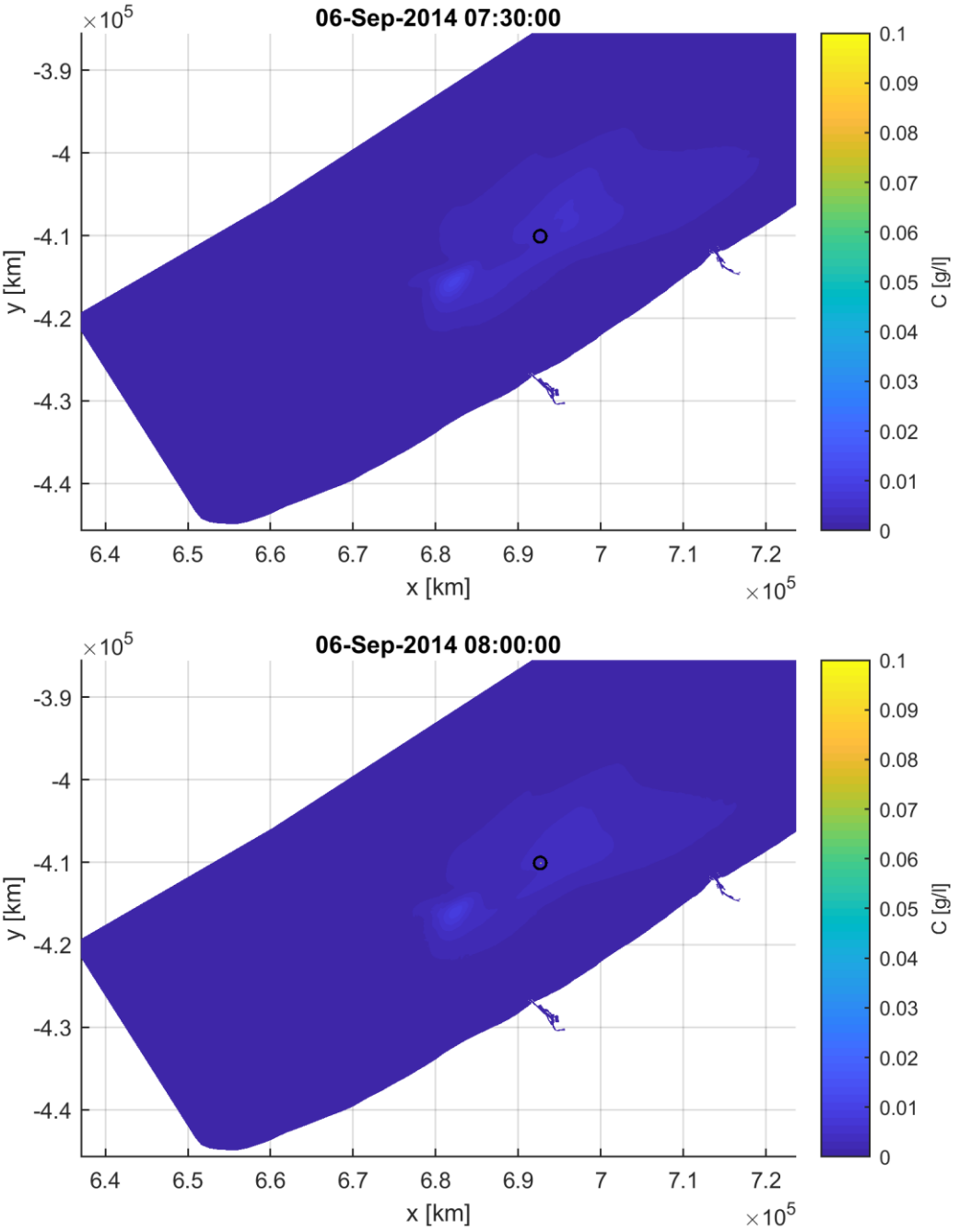

06-Sep-2014 02:30:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]
06-Sep-2014 03:00:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

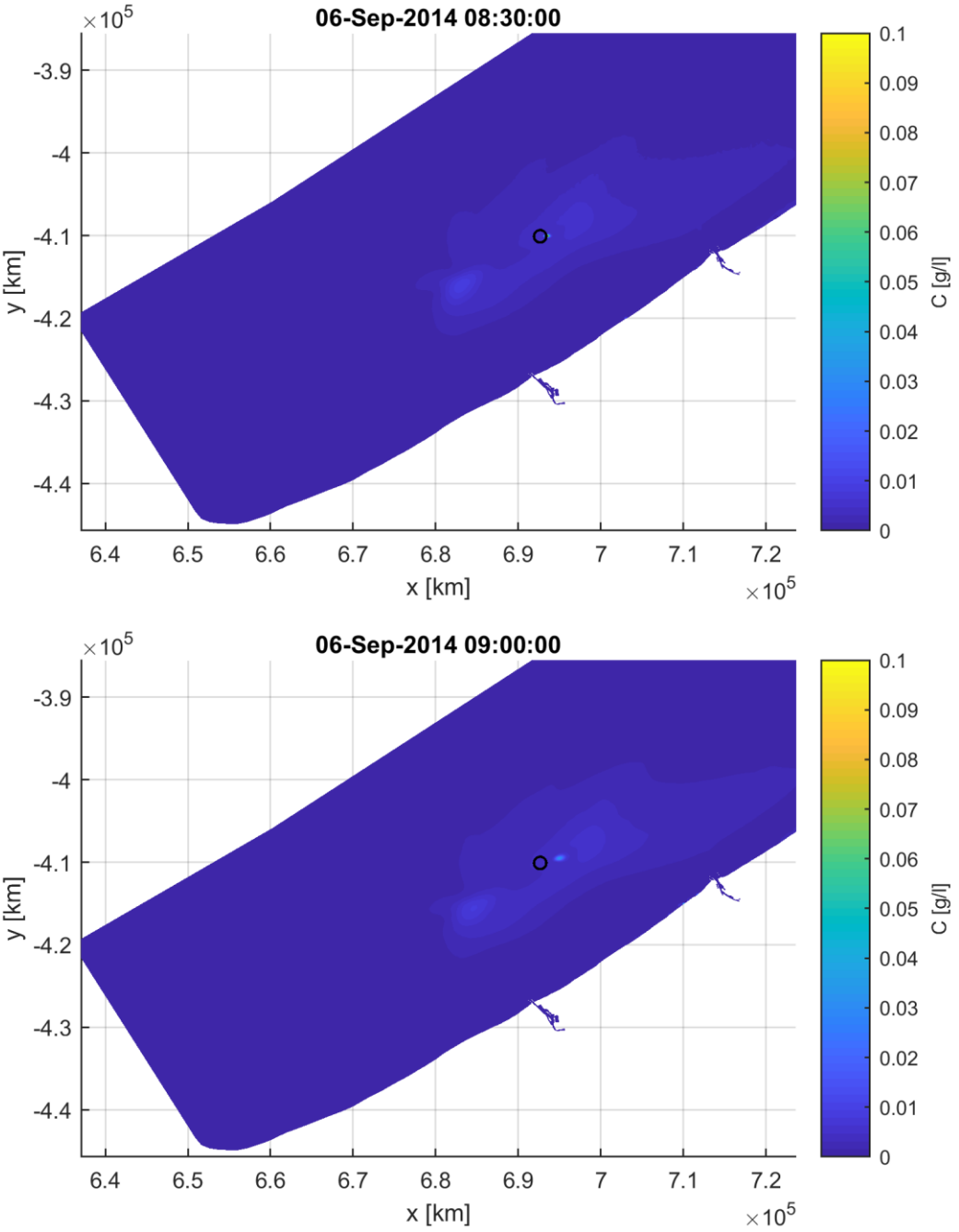

06-Sep-2014 03:30:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]
06-Sep-2014 04:00:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

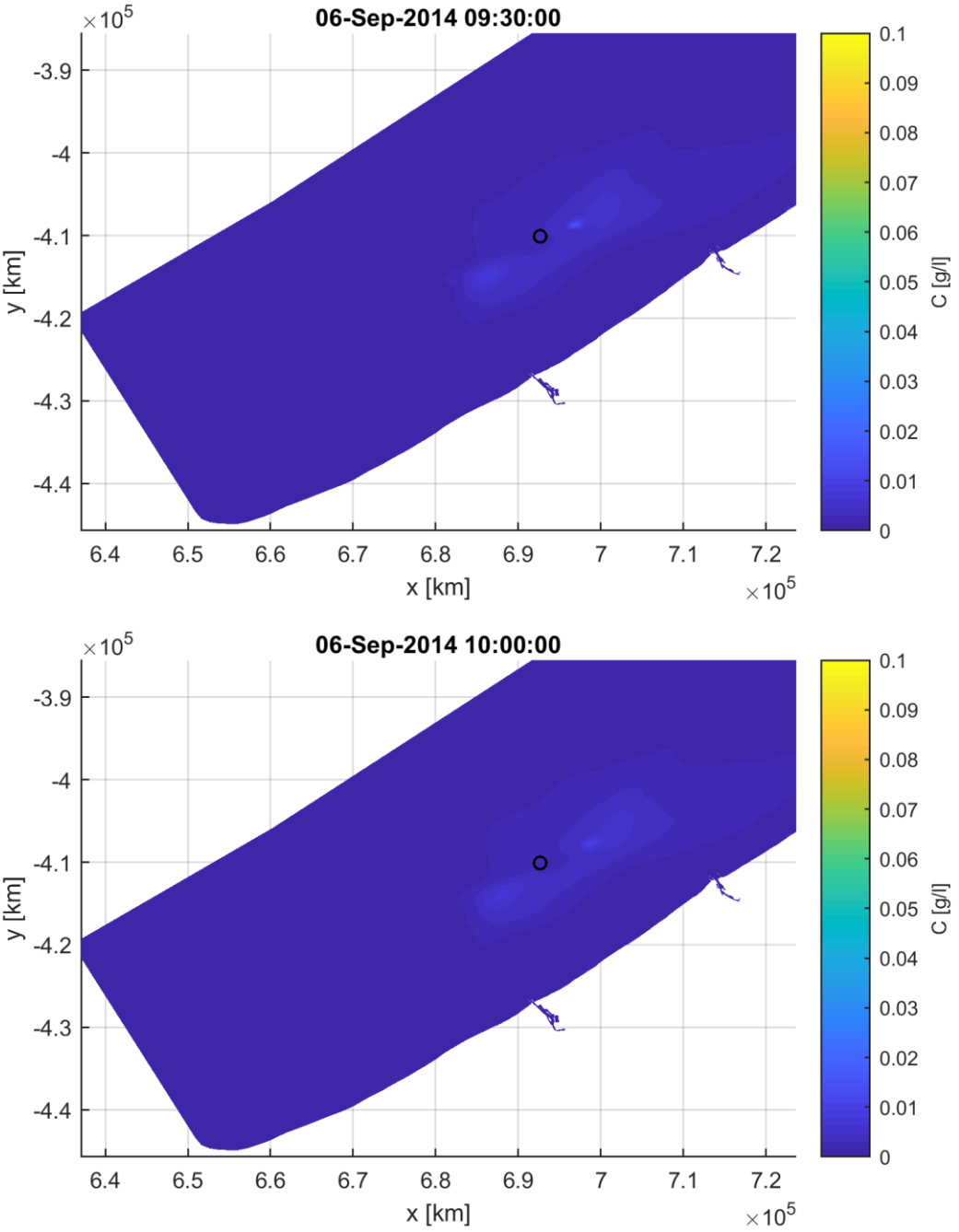

06-Sep-2014 04:30:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]
06-Sep-2014 05:00:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

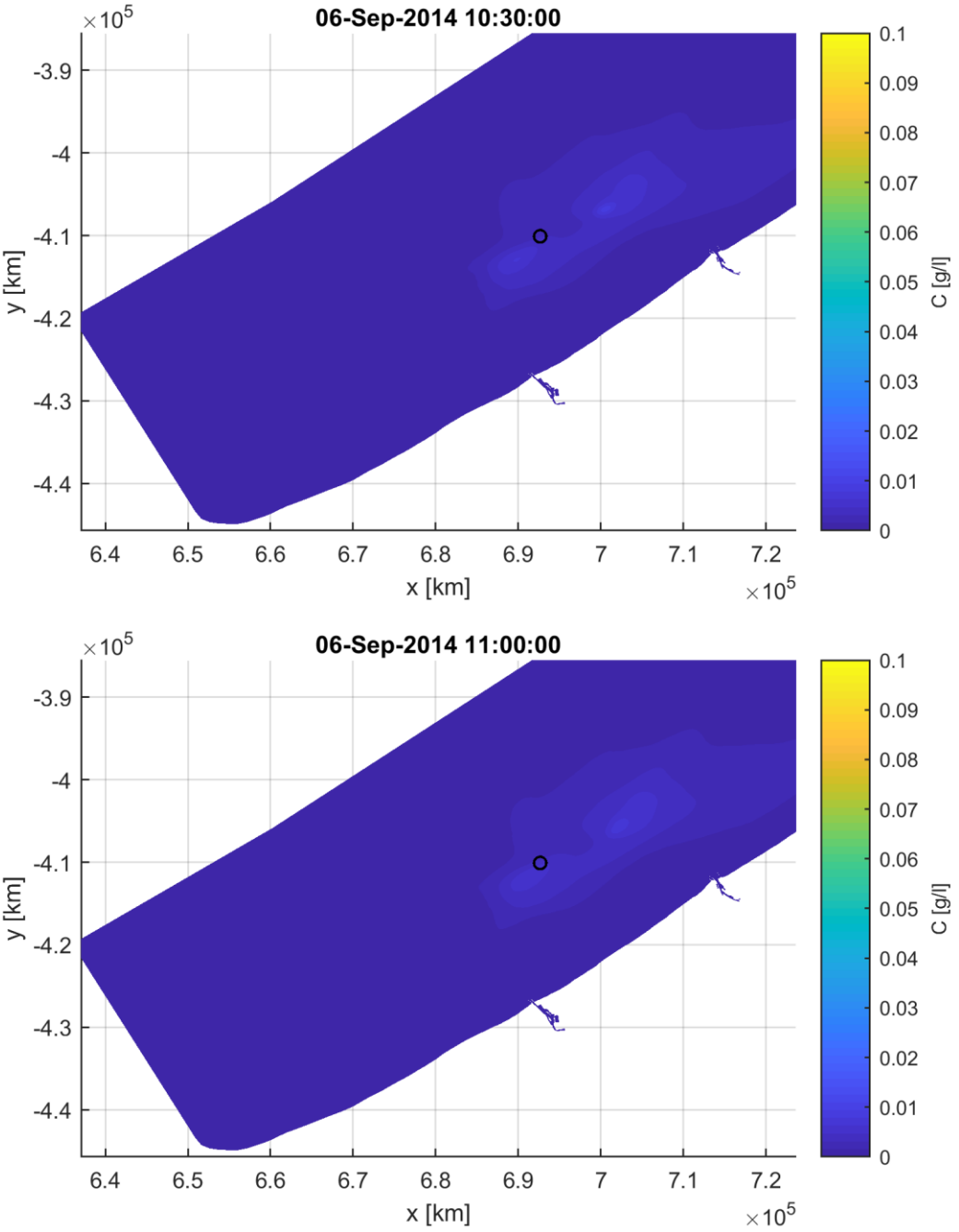

06-Sep-2014 05:30:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]
06-Sep-2014 06:00:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

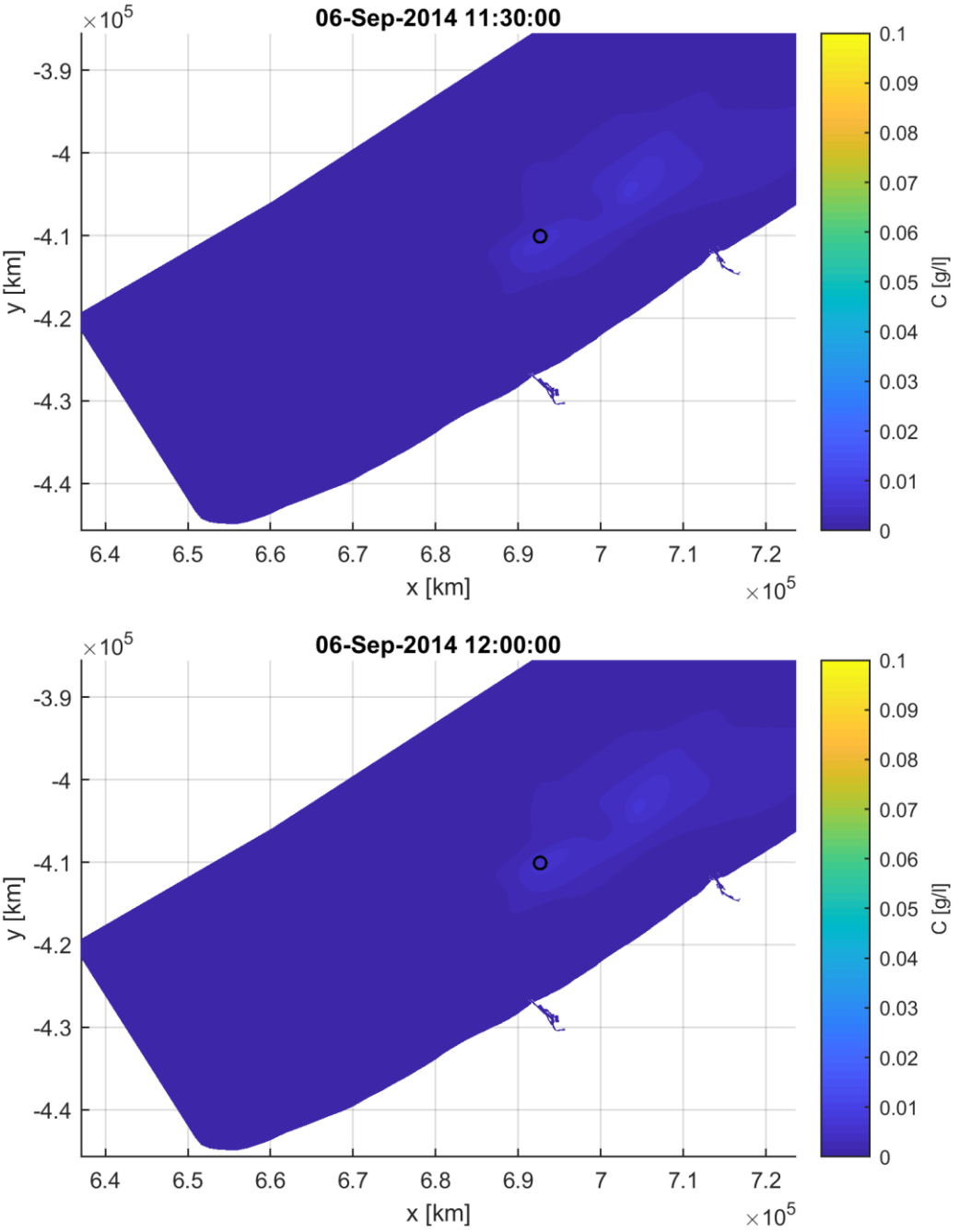

06-Sep-2014 06:30:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]
06-Sep-2014 07:00:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]


06-Sep-2014 07:30:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]
06-Sep-2014 08:00:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

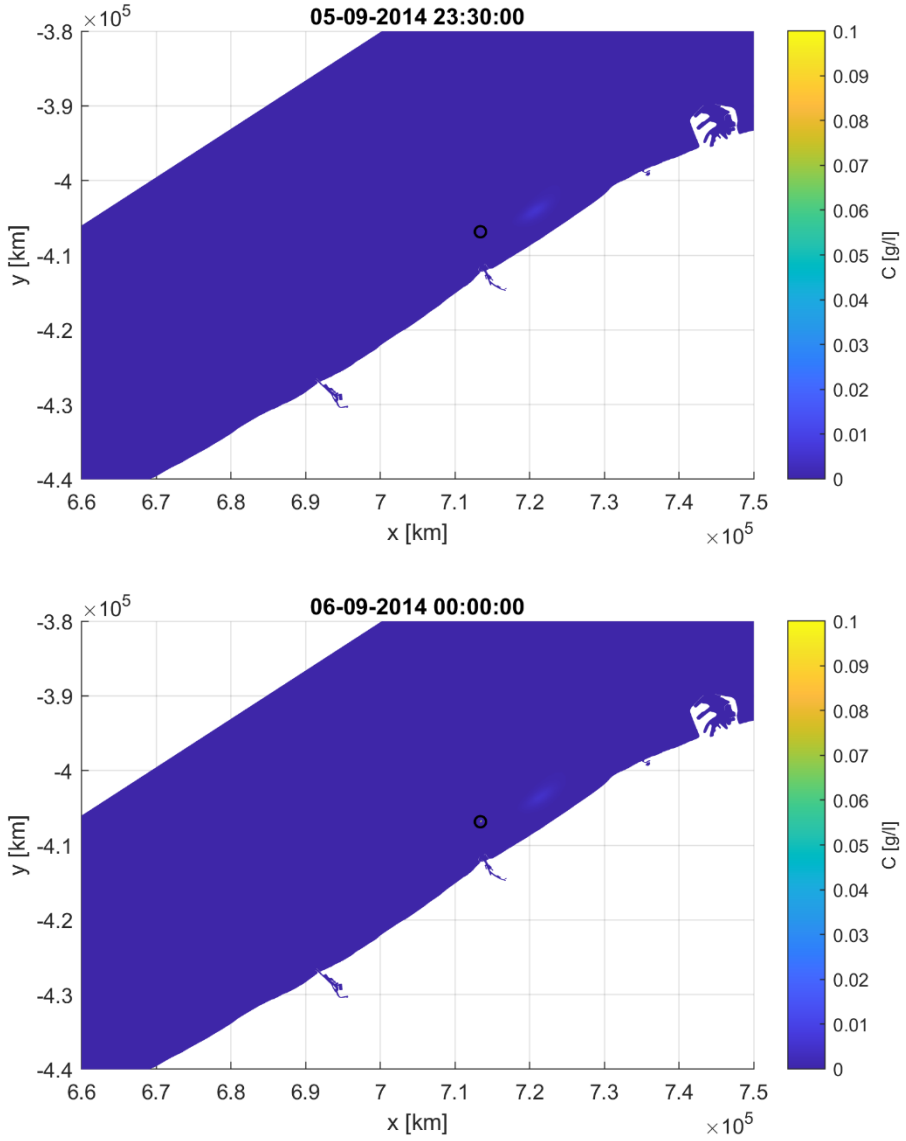

06-Sep-2014 08:30:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
C [g/l]
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
06-Sep-2014 09:00:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
C [g/l]
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0

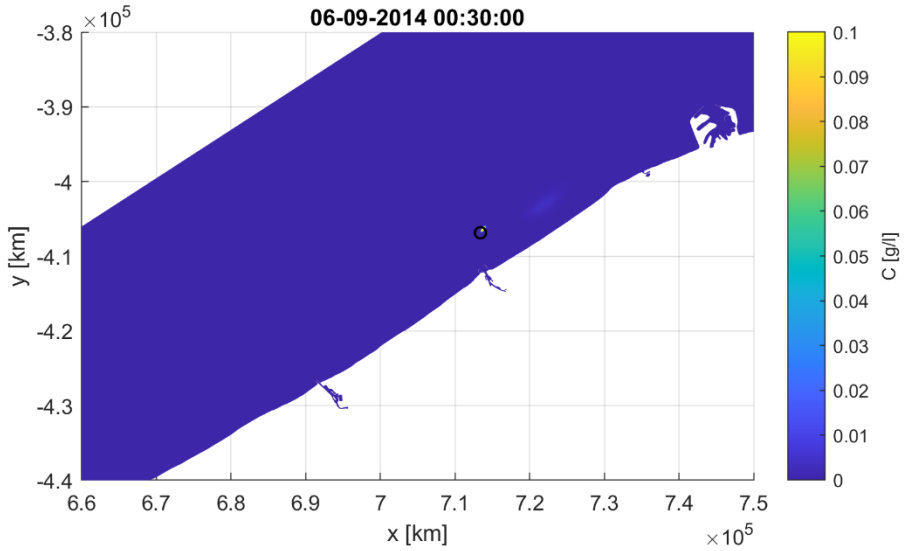

06-Sep-2014 09:30:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]
06-Sep-2014 10:00:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

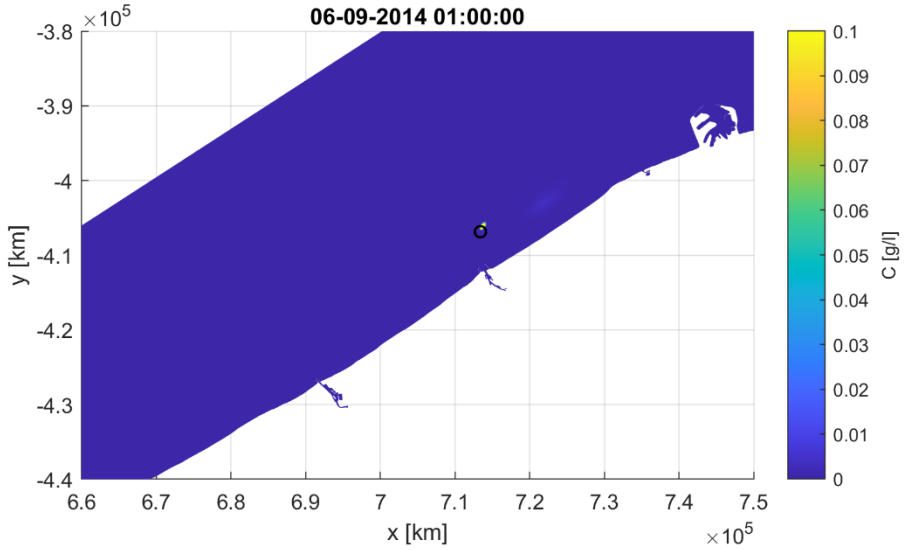

06-Sep-2014 10:30:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
C [g/l]
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
06-Sep-2014 11:00:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
C [g/l]
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0

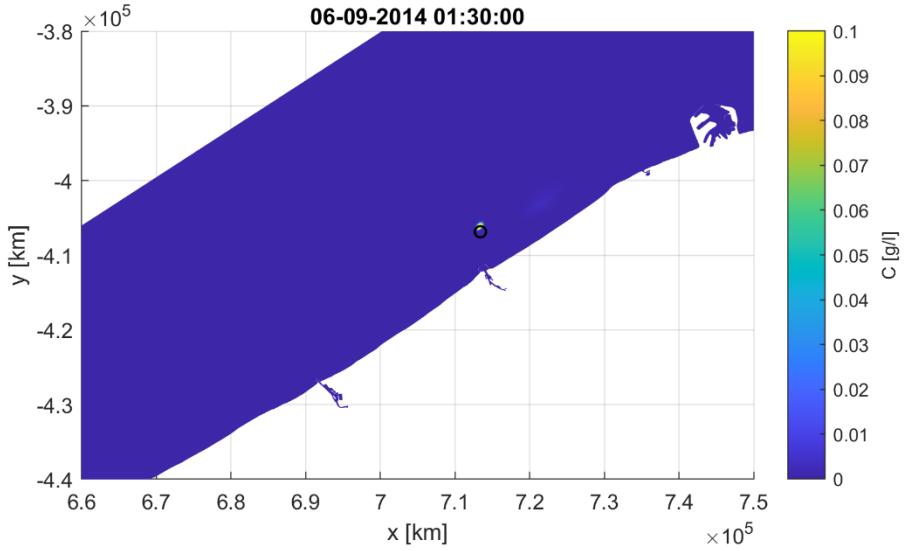

06-Sep-2014 11:30:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]
06-Sep-2014 12:00:00
×10^5
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

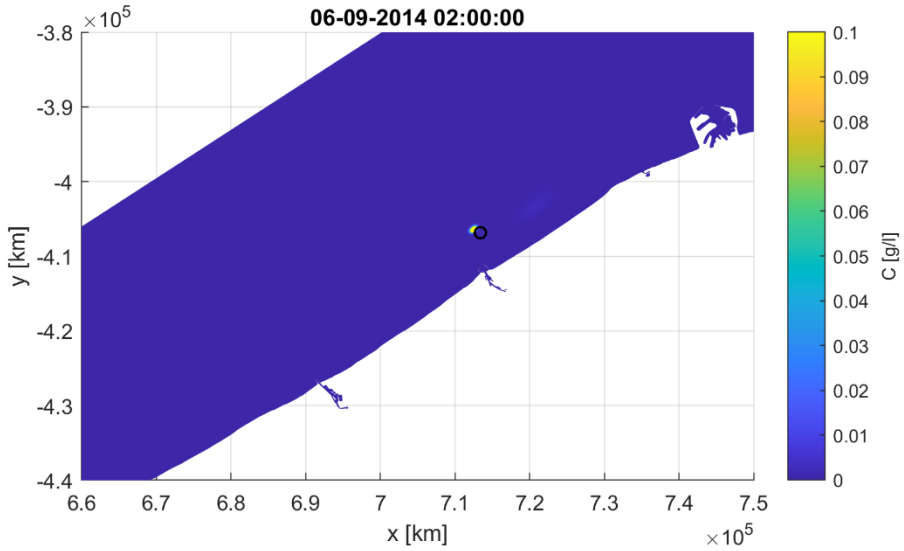
## B.3 Scenario 4a (Oostende without resuspension)

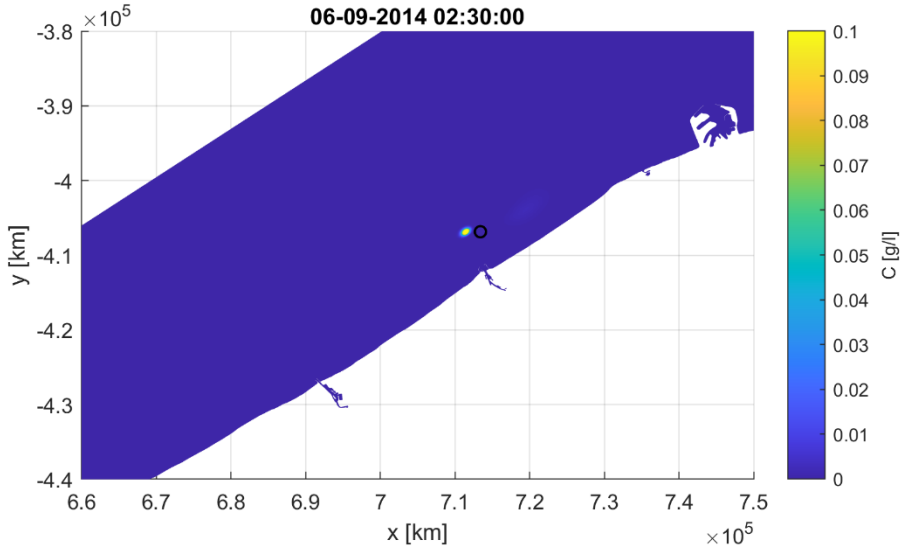


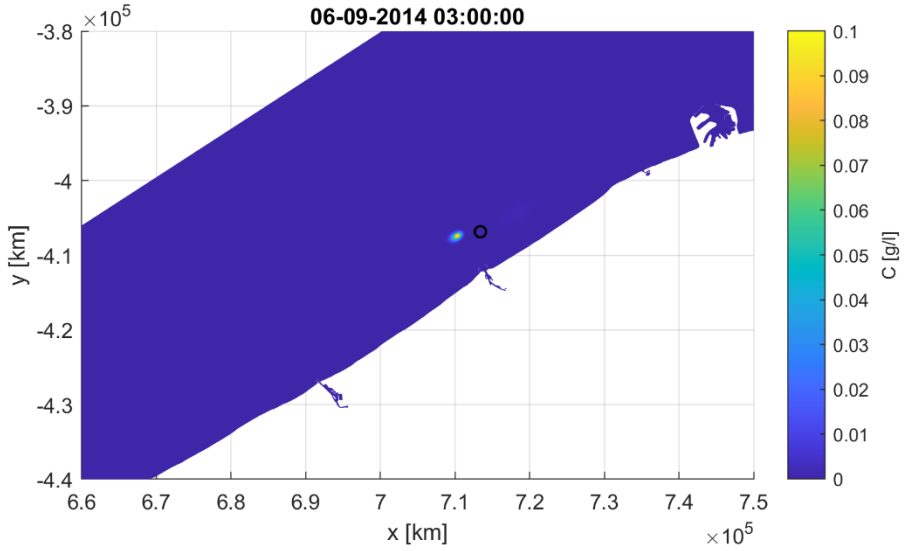

06-09-2014 00:30:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

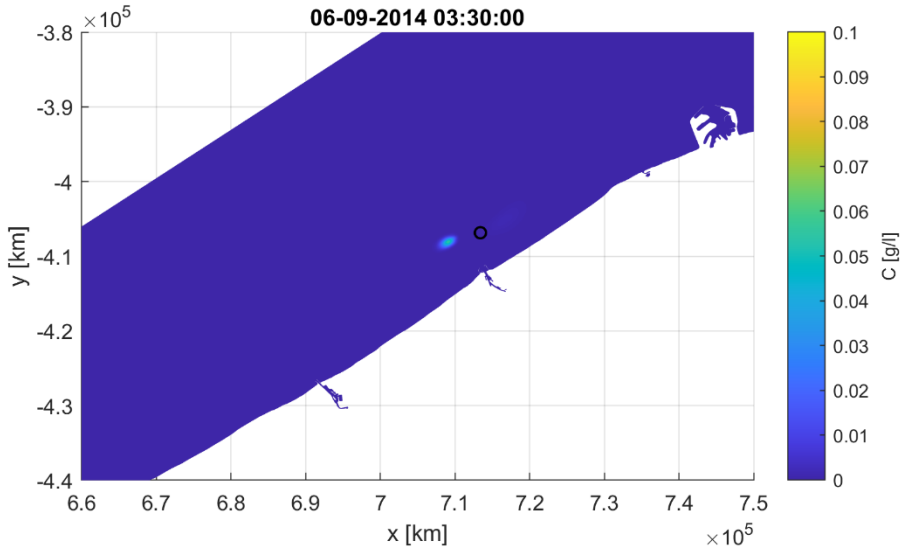

06-09-2014 01:00:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

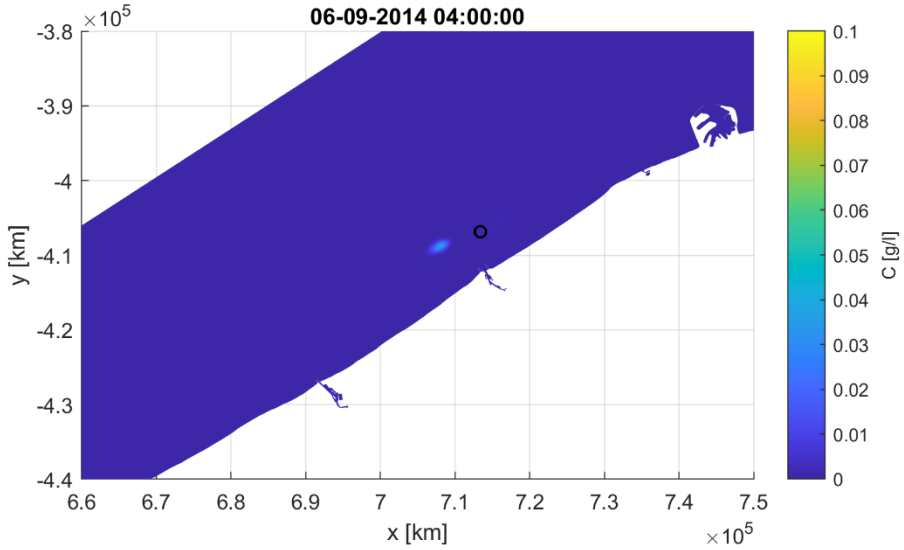

06-09-2014 01:30:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

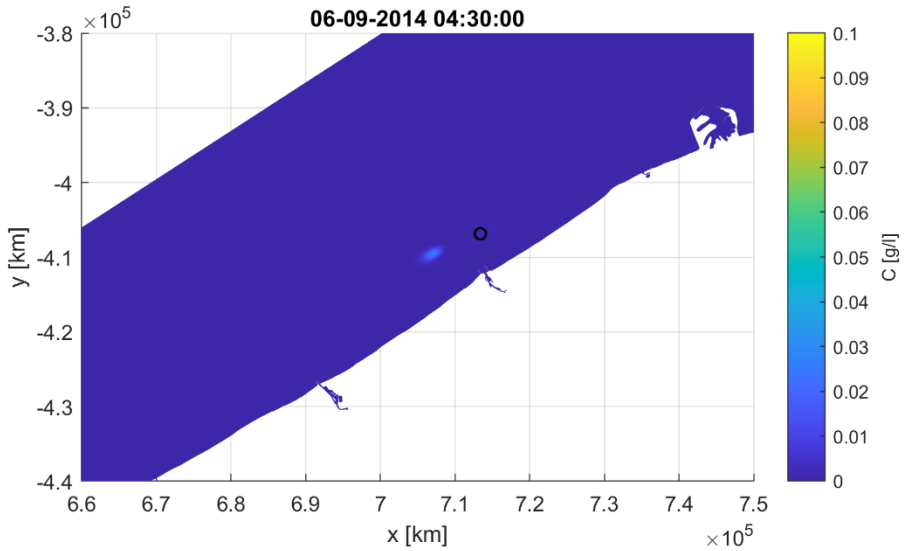

06-09-2014 02:00:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

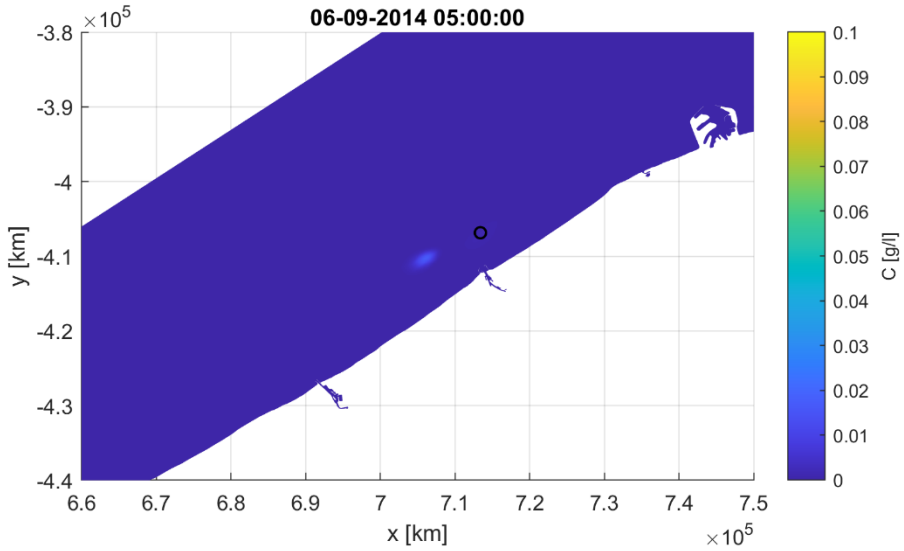

06-09-2014 02:30:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

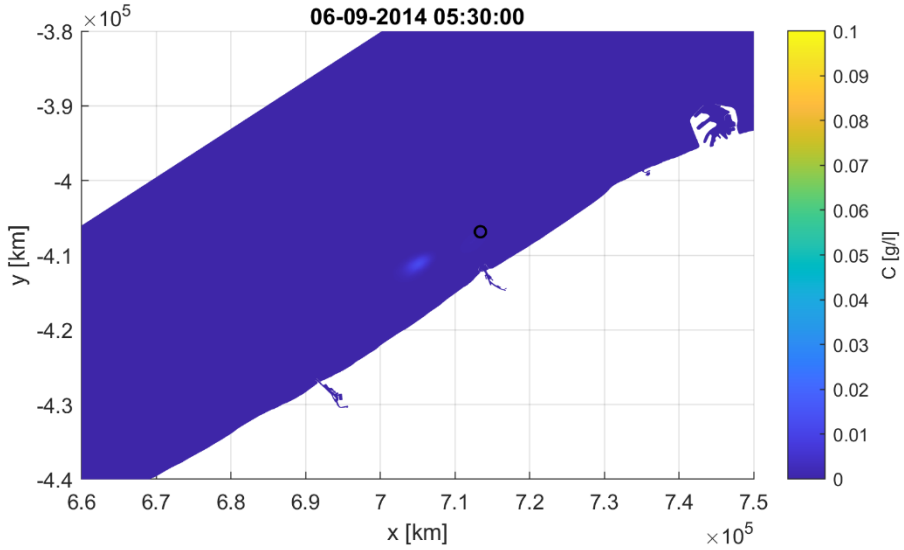

06-09-2014 03:00:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
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0.06
0.05
0.04
0.03
0.02
0.01
0
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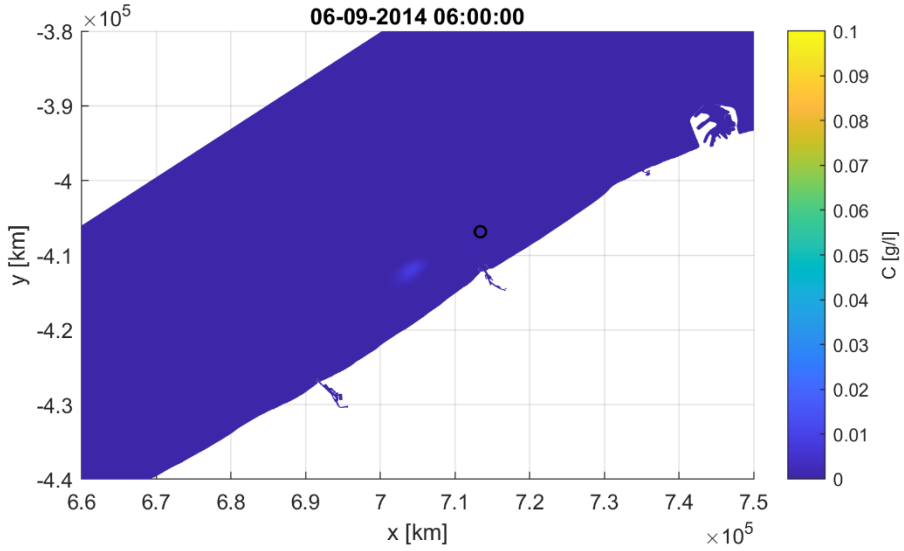

06-09-2014 03:30:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
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0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

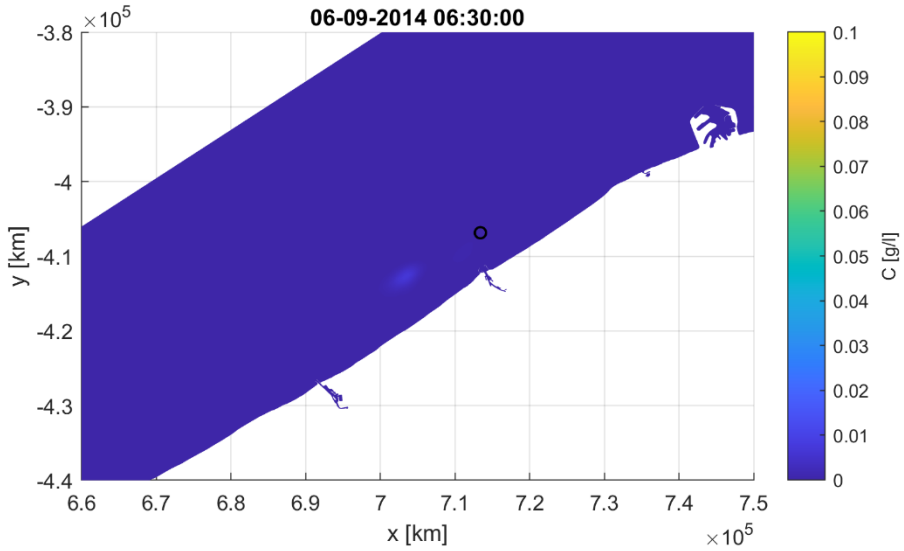

06-09-2014 04:00:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
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0.07
0.06
0.05
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0.03
0.02
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0
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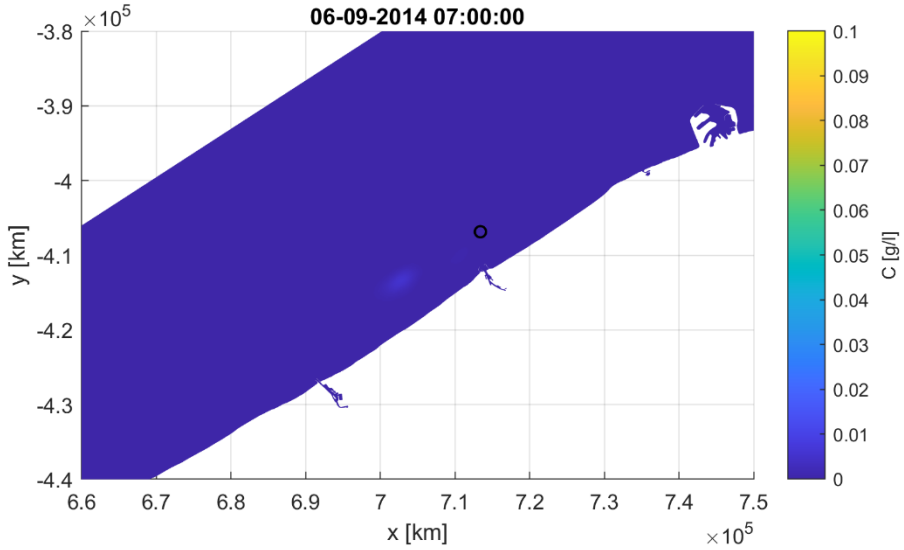

06-09-2014 04:30:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
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7.4
7.5
x [km]
×10^5
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0.07
0.06
0.05
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0.03
0.02
0.01
0
C [g/l]

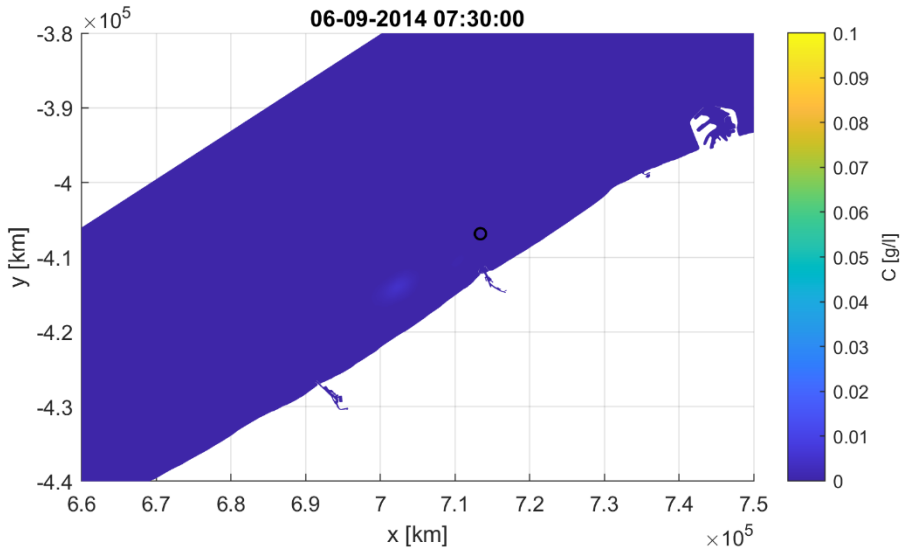

06-09-2014 05:00:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
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0.06
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0.04
0.03
0.02
0.01
0
C [g/l]

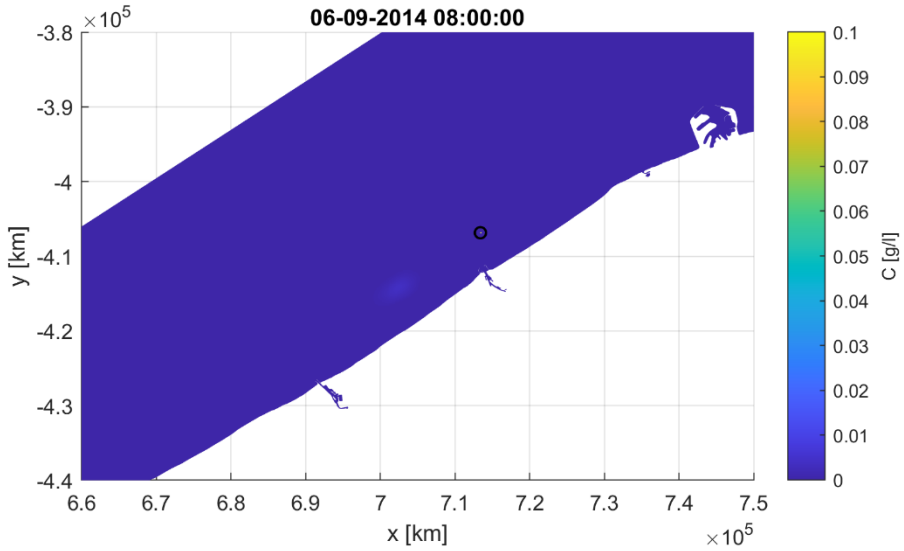

06-09-2014 05:30:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

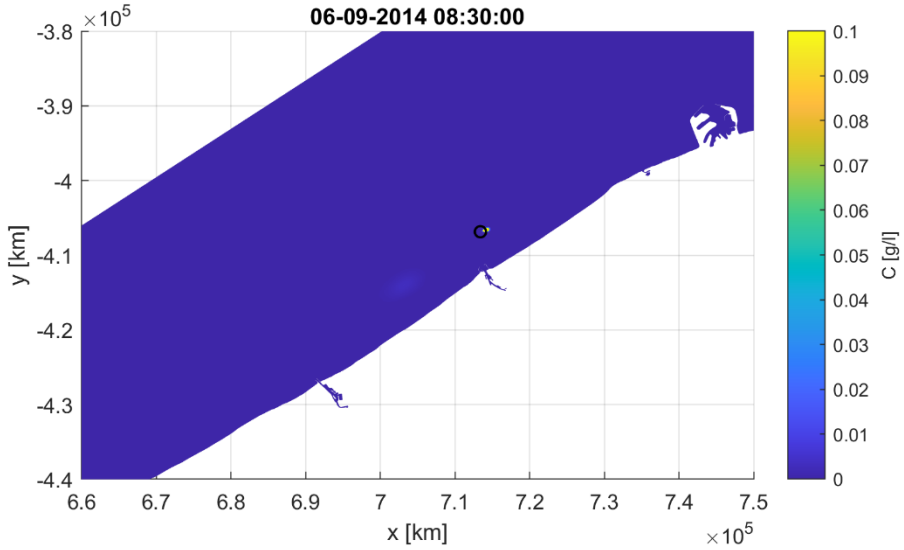

06-09-2014 06:00:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

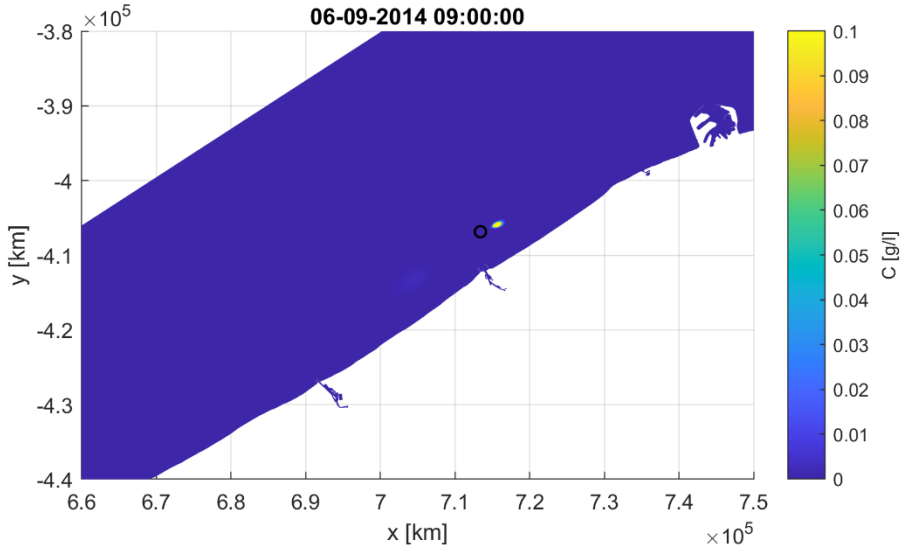

06-09-2014 06:30:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
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0.03
0.02
0.01
0
C [g/l]

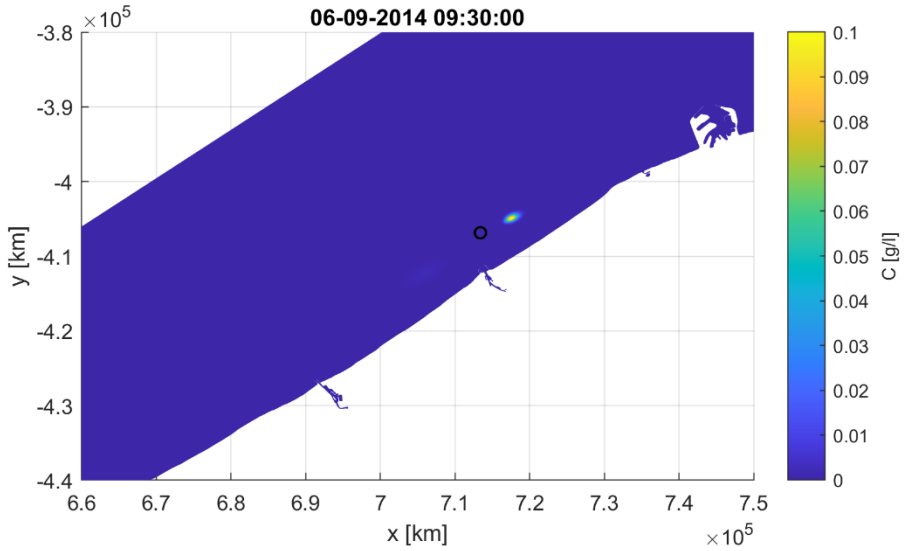

06-09-2014 07:00:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

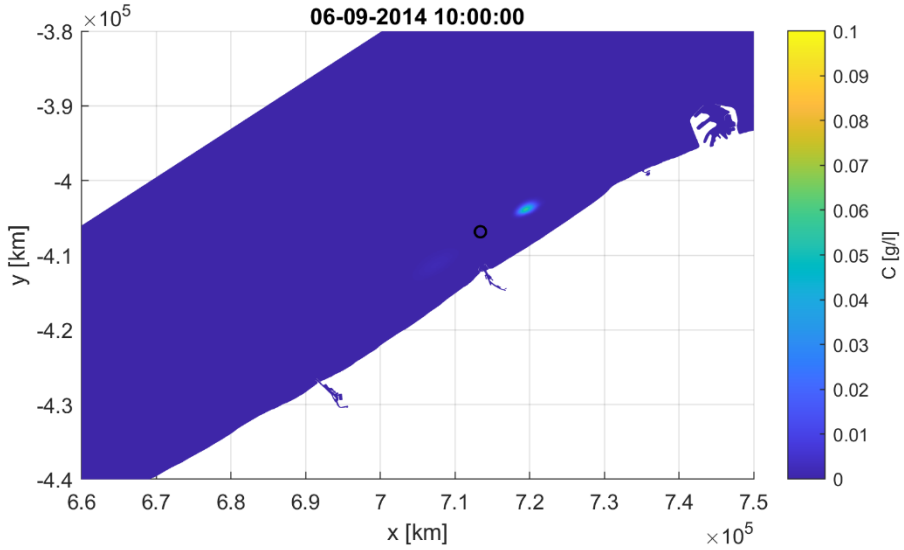

06-09-2014 07:30:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
0.09
0.08
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0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]

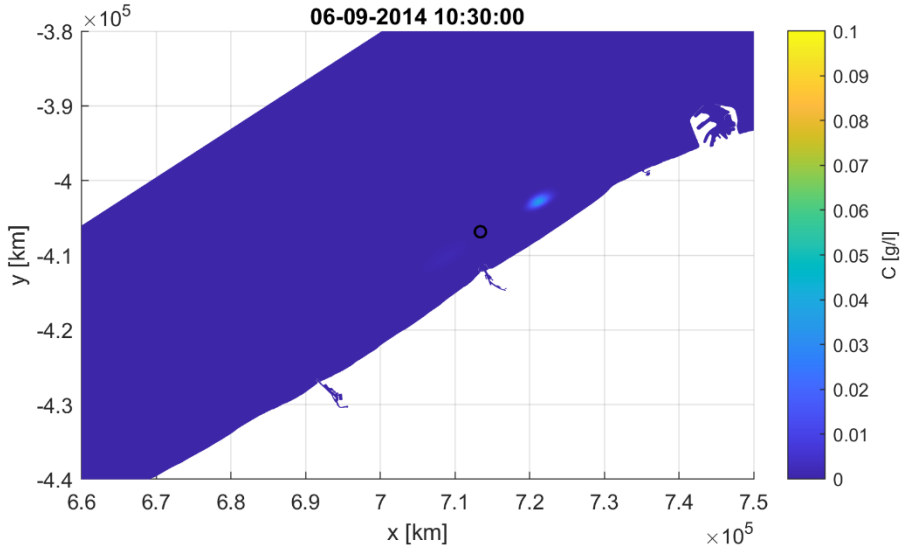

06-09-2014 08:00:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
0.09
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0.07
0.06
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0.04
0.03
0.02
0.01
0
C [g/l]

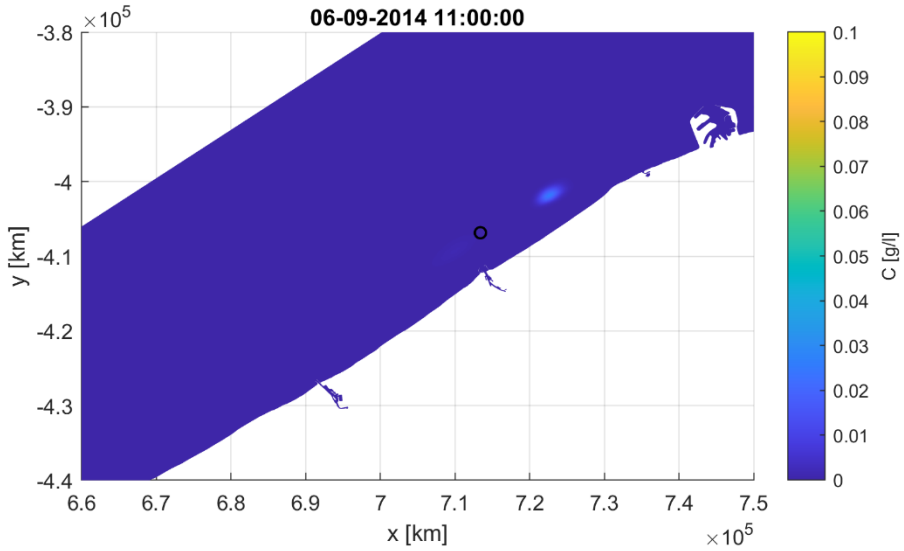

06-09-2014 08:30:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
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6.8
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7.1
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7.4
7.5
x [km]
×10^5
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C [g/l]

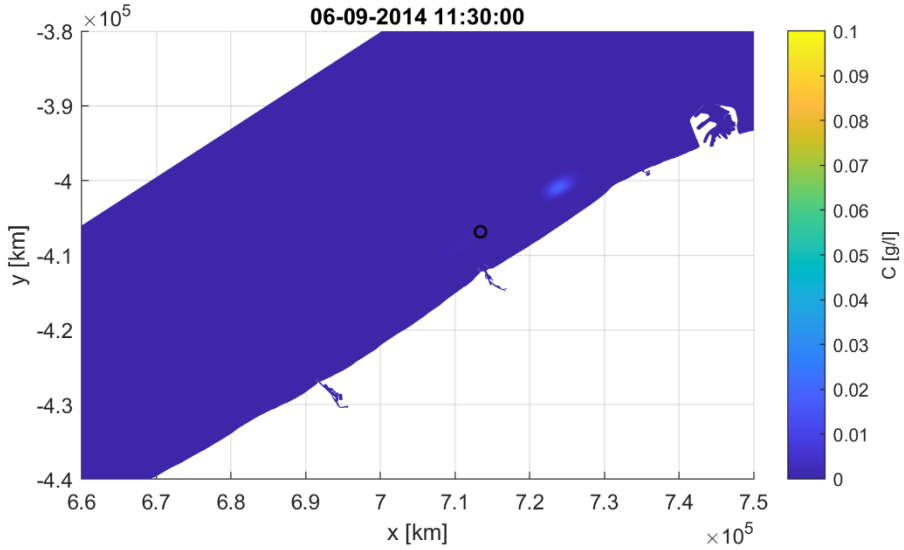

06-09-2014 09:00:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
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-4.4
y [km]
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x [km]
×10^5
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C [g/l]

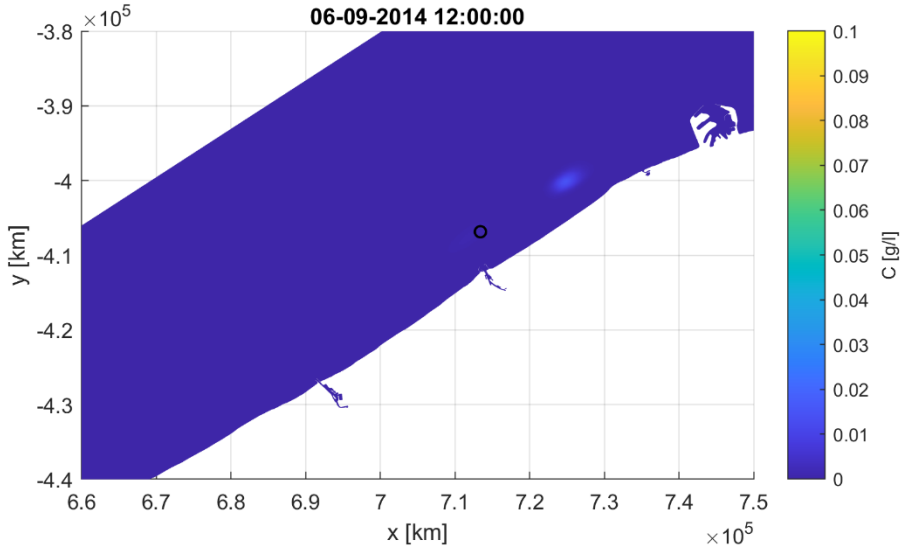

06-09-2014 09:30:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
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x [km]
×10^5
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C [g/l]


06-09-2014 10:00:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
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-4.4
y [km]
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6.8
6.9
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7.1
7.2
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7.5
x [km]
×10^5
0.1
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0.02
0.01
0
C [g/l]


06-09-2014 10:30:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
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7.1
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7.5
x [km]
×10^5
0.1
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0.01
0
C [g/l]


06-09-2014 11:00:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]


06-09-2014 11:30:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
0.09
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0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]


06-09-2014 12:00:00
×10^5
-3.8
-3.9
-4
-4.1
-4.2
-4.3
-4.4
y [km]
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
x [km]
×10^5
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
C [g/l]