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Sub report 10 – Summary of the 2D TELEMAC morphodynamic model ScaldisCoast version 2020 developed for the Complex Projects Coastal Vision and Extra Container Capacity Antwerp

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Subreport 10 – Summary of the 2D TELEMAC morphodynamic model ScaldisCoast: version 2020 developed for the Complex Projects Coastal Vision and Extra Container Capacity Antwerp

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Abstract

In order to analyze the impact of sea level rise on the morphology of the coast and to assess mitigation measures on their efficiency there was a need for a flexible coastal model for the Belgian coast and Scheldt mouth area. In 2015 is was decided to develop a 2D morphodynamic model in the TELEMAC MASCARET model suite. The present report presents a brief description of the model and its parameters as it was used in 2019 for the first scenario runs with the *Complex Project Kustvisie* (CPKV). CPKV is the project initiated by the Flemish Authorities in order the design together with all stakeholders the future coastal defense strategy on the long term.

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1 Introduction

Within the *Complex Project Kustvisie* (CPKV) all involved stakeholders can participate in the process of defining the overall design of the long-term coastal defense of the Belgian Coast. The project was formerly known as project *Vlaamse Baaien* (Flemish Bays). The *Vlaamse Baaien* project was initiated in 2014 by the Flemish Authorities with the goal to protect the Belgian Coast from (extreme) sea level rise and climate change on the horizon 2050 – 2100. The goal of the project is to create an attractive and natural coast that is climate change resilient with economic benefits like estuarine traffic and renewable energy.

In order to analyze the impact of sea level rise on the morphology of the coast and to assess mitigation measures on their efficiency there was a need for a flexible coastal model for the Belgian coast and Scheldt mouth area. In 2015 is was decided to develop a 2D morphodynamic model in the TELEMAC MASCARET model suite.

Efforts are ongoing to improve the model with respect to accuracy, reliability and performance. In 2019 the model was used for a first time for production runs within the CPKV. The model was used to run reference runs with respect to three meter sea level rise (Breugem *et al.*, 2019).

This report aims to give a comprehensive description of the model status as it was used within CPKV.

2 Model description

The following paragraphs give an overview of the model dimensions, grid and settings. The input files of the model are archived on the Flanders Hydraulics Research model repository:

https://wl-subversion.vlaanderen.be/!/#repoSpNumMod/view/head/TELEMAC/Scaldis-Kust/15_068%20Complex%20Model%20Kustvisie%202019

2.1 Domain and grid dimensions

The extent of the computational domain of the so-called 'ScaldisCoast' model is shown in Figure 1. Since TELEMAC is finite element based, the model is based on a triangular mesh. This allows to refine the grid within the zones of interest in order to represent complex geometries like breakwaters and dams, but also sharp gradients like navigation channels or sand banks. For the construction of the grid an advanced grid generator GMSH is used (Geuzaine & Remacle, 2009). GMSH allows to refine automatically near complex features en bathymetries. The flexibility of the mesh allows to incorporate new complex features in an efficient and accurate way. The grid size varies between 750 m offshore to 25 m nearshore, Figure 2. Figure 4 shows a detail of the grid in the surroundings of the port of Zeebrugge. Groins are modelled explicitly in the model. They are represented in the bathymetry as non-erodible layers and the grid is aligned automatically with the crest of the groin, Figure 3. More details on the use of GMSH and the grid generation can be found in Kolokythas *et al.* (2018).

Figure 1 – Model domain and bathymetry of the ScaldisCoast model

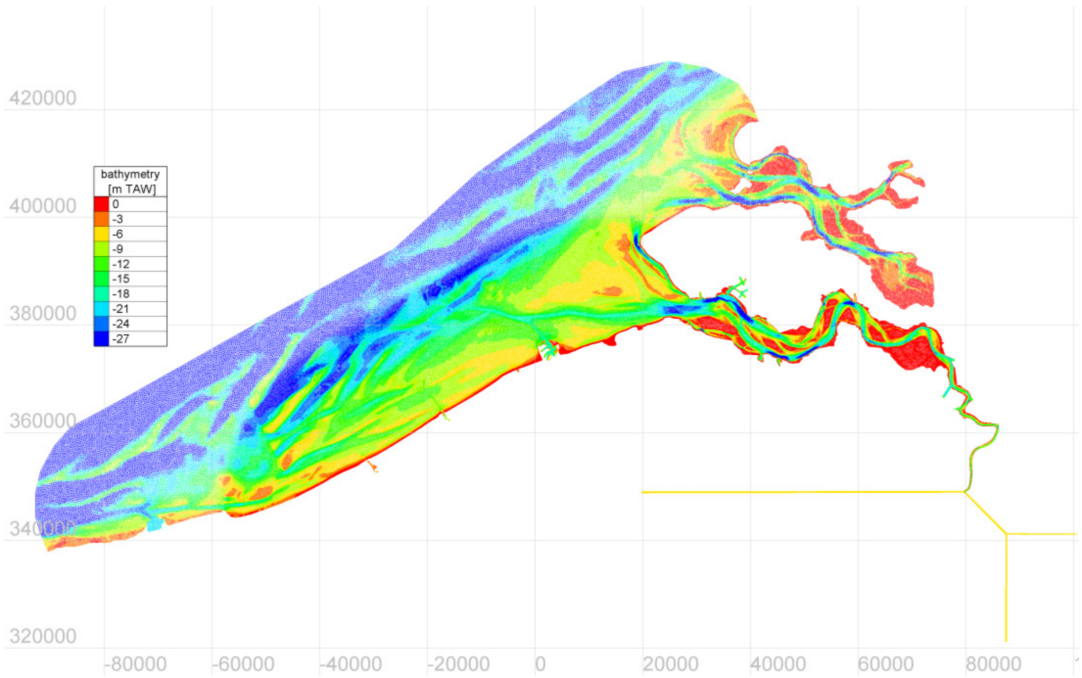


Figure 2 – Characteristic element sizes of the base grid after adaptive mesh refinement using GMSH software.

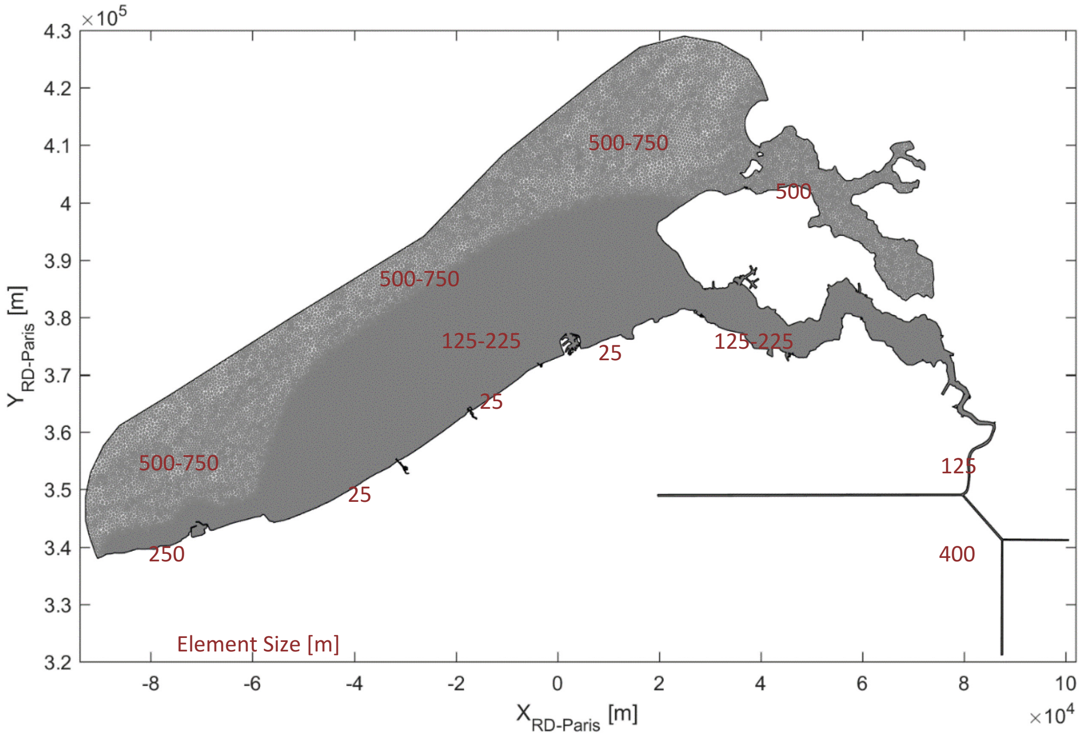


Figure 3 – Typical examples of grid adaptation for the incorporation of non-erodible coastal structures (red-colored groynes) in the computational domain.

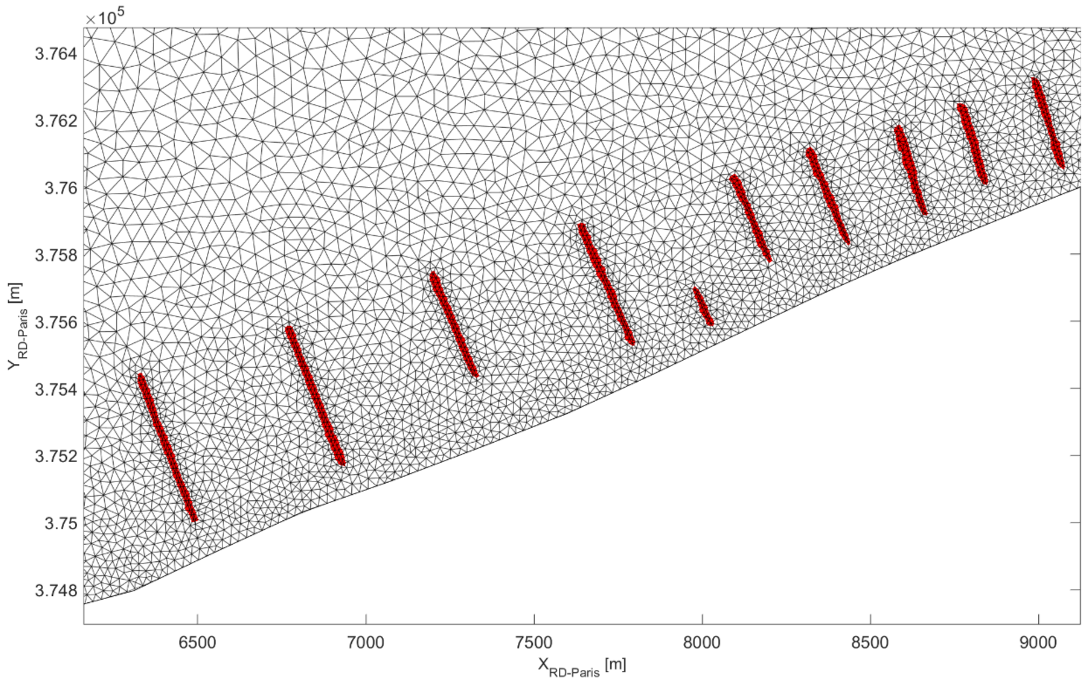


Figure 4 – Detail of the ScaldisCoast grid in the surrounding of Zeebrugge

2.2 Modules

The model suite consists of three coupled submodels (G. K. Kolokythas *et al.*, 2018). The 2D hydrodynamic TELEMAC model, computes water levels and currents, both tidal-, wind and wave-driven currents. Wave propagation is modeled by the TOMAWAC wave model. Both models are online coupled (two-way coupling). The wave model gets the water depths and currents from the HD model and returns radiation stresses and wave-induced bottom shear stresses back to the TELEMAC model. The bed-update is modelled by the sediment transport model SISYPHE. The model gets the currents, water depths and shear stresses from the hydrodynamic and wave model and returns the bathymetric update back. When updating the bed, also bed changes due to dredging and dumping activities are taken into account.

The TOMAWAC wave model was in this approach one of the major bottlenecks with respect to computational time for long-term morphodynamical modelling. Till recently, the TELEMAC software suite did not allow using different grid resolutions or domains for the different modules when fully coupled. Therefore, within the project a new module was developed to allow the coupling between the hydrodynamic model and the wave model, where the two models have their own optimized grid. The wave model can now run on a coarser resolution. Also, the whole Western and Easter Scheldt estuaries, which are important for the tidal propagation, but are limited influenced by waves, are omitted from the wave domain. This way a total speedup of the model of a factor two has been accomplished.

In the next sections the different modules are briefly discussed in a comprehensive way. A list of all parameters is attached to Annex A: Model Setting.

2.3 Hydrodynamic 3D model

Water levels have been validated against the water gauges and current measurements of the *Meetnet Vlaamse Banken*[1] and the Dutch water level gauges of the Western Scheldt (G. K. Kolokythas *et al.*, 2018). In the coastal area the BIAS on the water levels is for most of the stations less than 3 cm and the bias corrected root mean square error ($RMSE_0$) is less than 10 cm. In the Western Scheldt up till Bath, $RMSE_0$ gradually increases till 16 cm, Figure 4, and a bias up till 7 cm. Upstream of Antwerp, the estuary is schematically represented (Figure 1).

Velocities have been validated against available thirteen-hour ADCP transect measurements in the vicinity of the port of Zeebrugge and at different locations in the Western Scheldt (Table 1), and the permanent stations of Meetnet Vlaamse Banken (Figure 6 and Figure 7)

[1] https://meetnetvlaamsebanken.be/

Figure 5 – RMSE0 in the complete water level time-series (16 days) between the modelled by Scaldis-Coast and the modelled by Scaldis-Coast and the measured values at the selected stations in the domain.

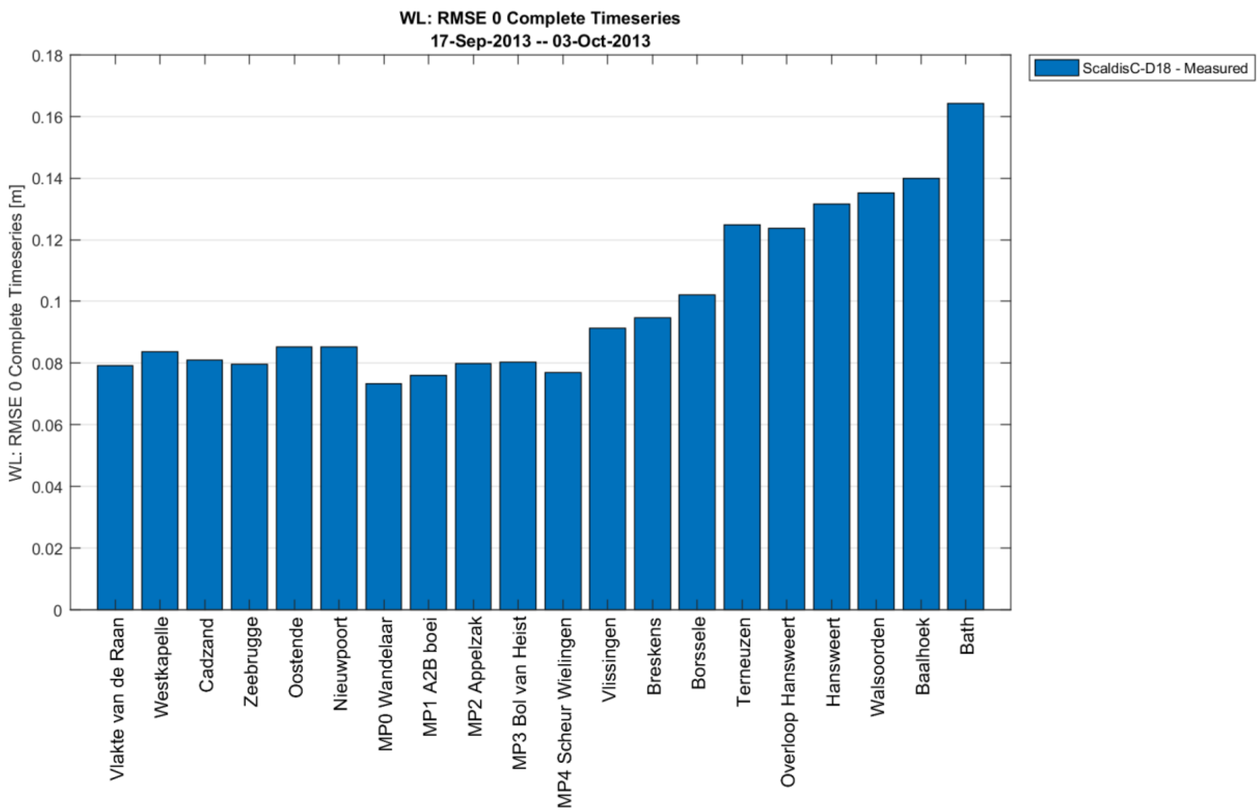


Table 1 – RMSE and RMAE quality parameters for the 13-hour time series of velocities along the considered ADCP sailed transects.

ADCP transect	RMSE Magnitude [m/s]	RMAE [-]
North Sea		
Zeebrugge entrance (Aug)	0.13	0.78
ZB Pas van het Zand	0.18	0.32
ZB Wiel	0.10	0.16
ZB Scheur	0.09	0.19
AVERAGE	**0.13**	**0.36**
Western Scheldt		
R7 Everingen	0.16	0.35
R7 Terneuzen	0.18	0.35
R6 Middelgat	0.19	0.37
R6 Gat van Ossenisse	0.17	0.28
Waarde (Sep)	0.16	0.47
R5 Schaar van Waarde	0.13	0.29
R5 Zuidergat	0.20	0.36
AVERAGE	**0.17**	**0.35**

Figure 6 – Magnitude and direction of the measured and modelled velocity time series at Wandelaar. Measured velocities at both stations come from averaging from 2.5 m to 10 m below water surface.

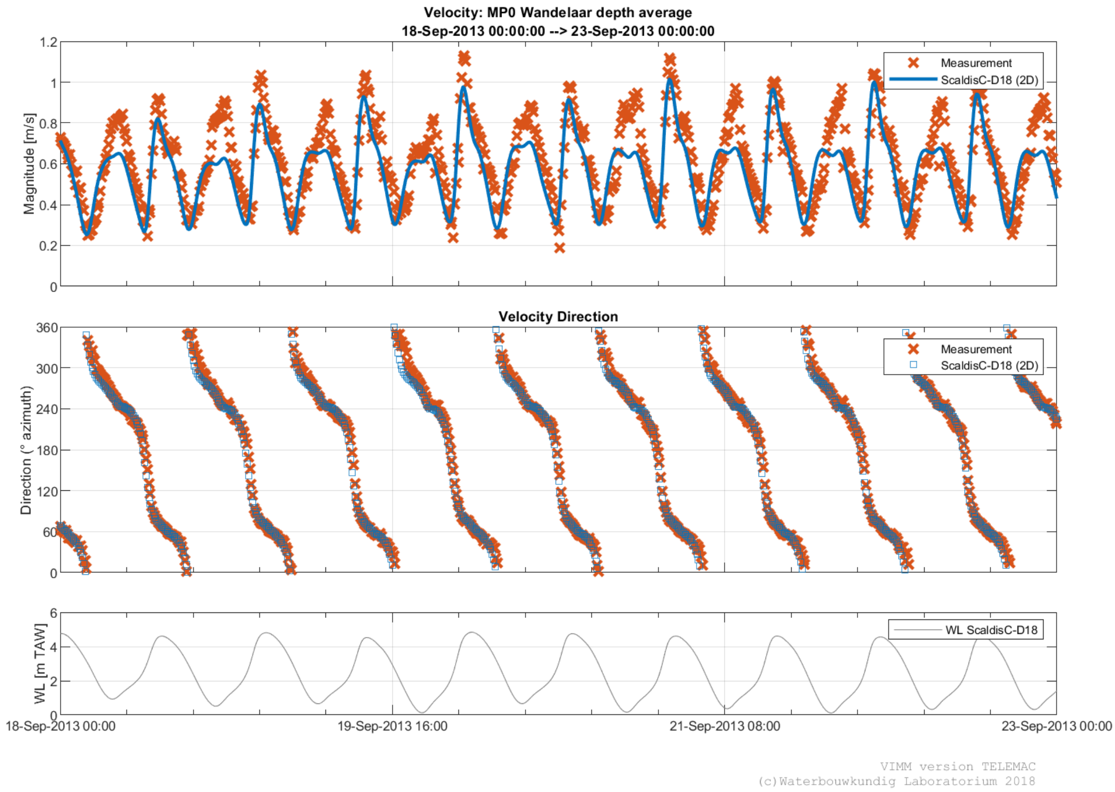
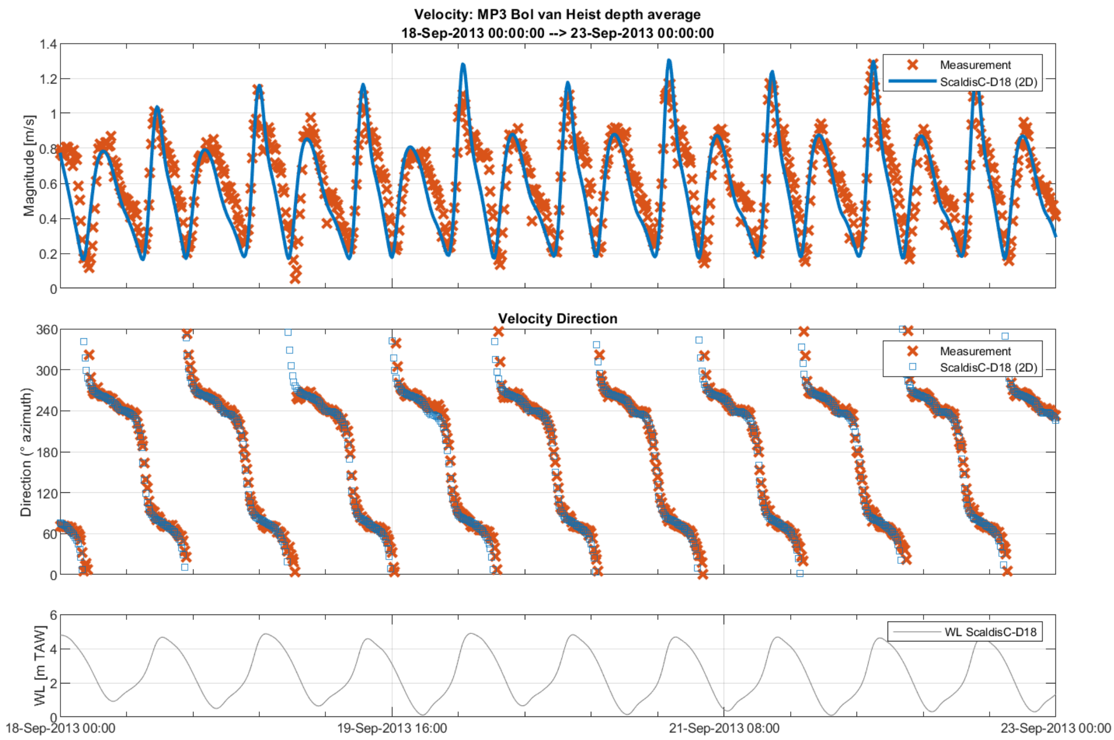


Figure 7 – Magnitude and direction of the measured and modelled velocity time series at Bol van Heist. Measured velocities at both stations come from averaging from 2.5 m to 10 m below water surface.



2.4 Wave model

For the validation of the wave model, data of the Broersbank project has been used (Ortega & Monbaliu, 2015), see Figure 8. Westerhinder lays on the boundary of the ScaldisCoast model and therefore is used as boundary condition to force the wave model. An example of the wave propagation in terms of significant wave height is given in Figure 9.

Figure 8 – Location of the deployed buoys of the Broersbank Project (red circles) and the fixed buoys of MVB: Westhinder and Trapegeer (Ortega & Monbaliu, 2015)

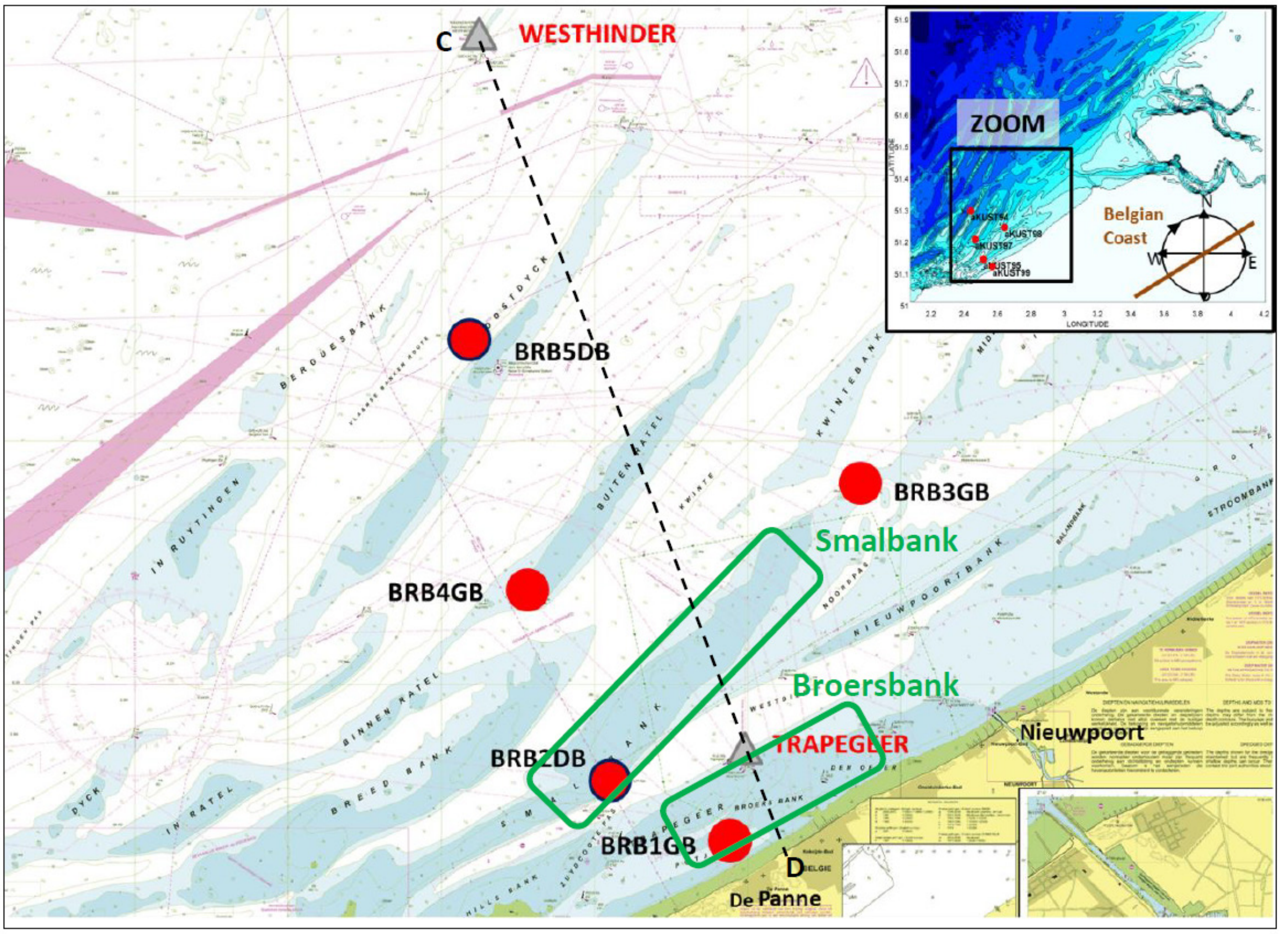
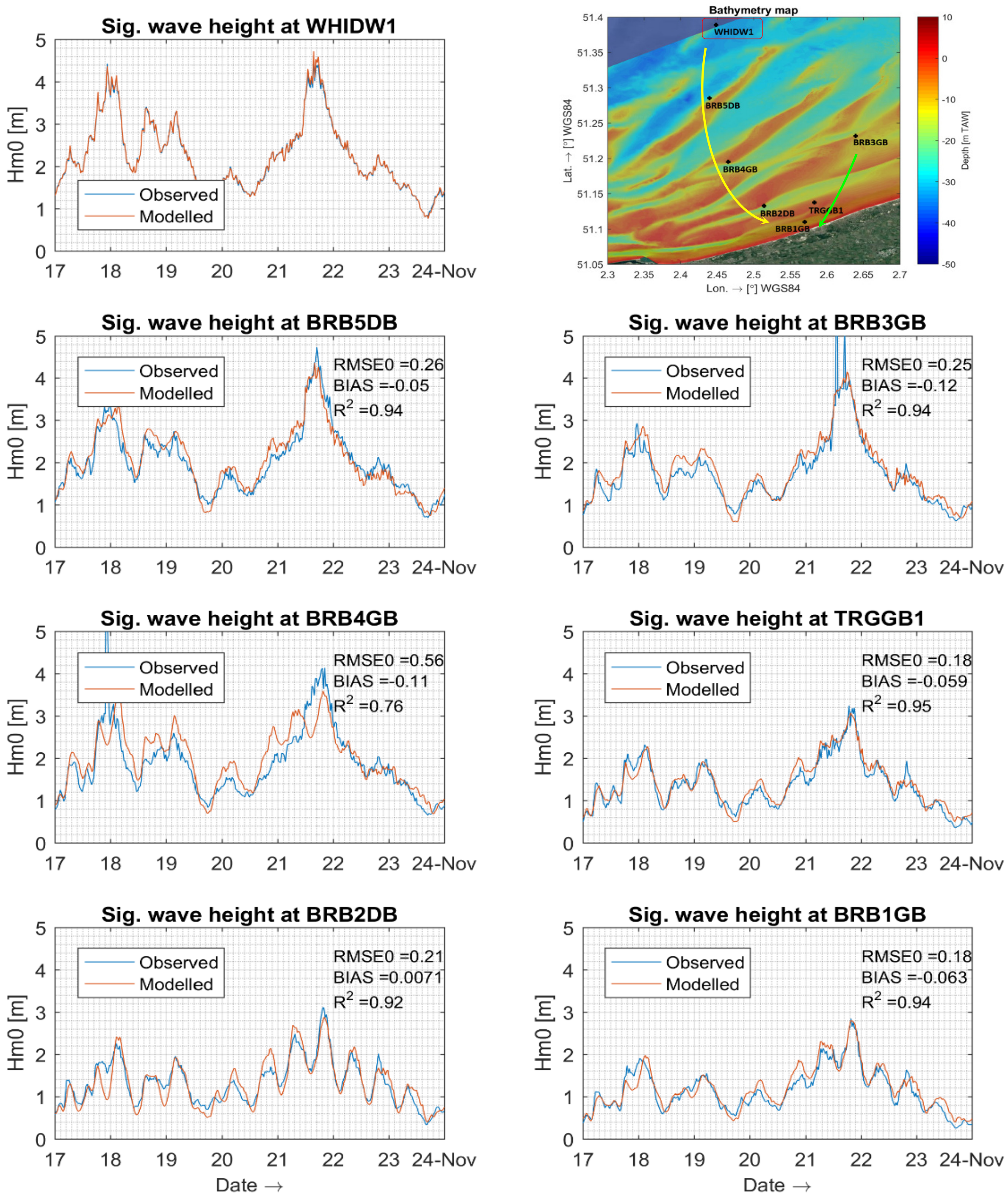


Figure 9 – Modelled wave propagation: significant wave height from Westhinder till Broersbank (G. Kolokythas *et al.*, 2019a)



2.5 Morphodynamic modelling

Finally, the hydrodynamic model and the wave model are coupled to the sediment transport and bed update model. Different transport models have been tested. When comparing the sediment transports, different cases have been tested: 10-years hindcast of the seabed evolution after the extension of the Zeebrugge port in 1986 (G. Kolokythas *et al.*, 2019a). A morfac 10 was used in combination with a representative tide and a schematized wave condition (12 wave conditions).

Figure 10 – Measured (top) and modelled (Engelund-Hansen transport formula) bottom evolution 1986 – 1996 (in this hindcast dredging and dumping was switched off)

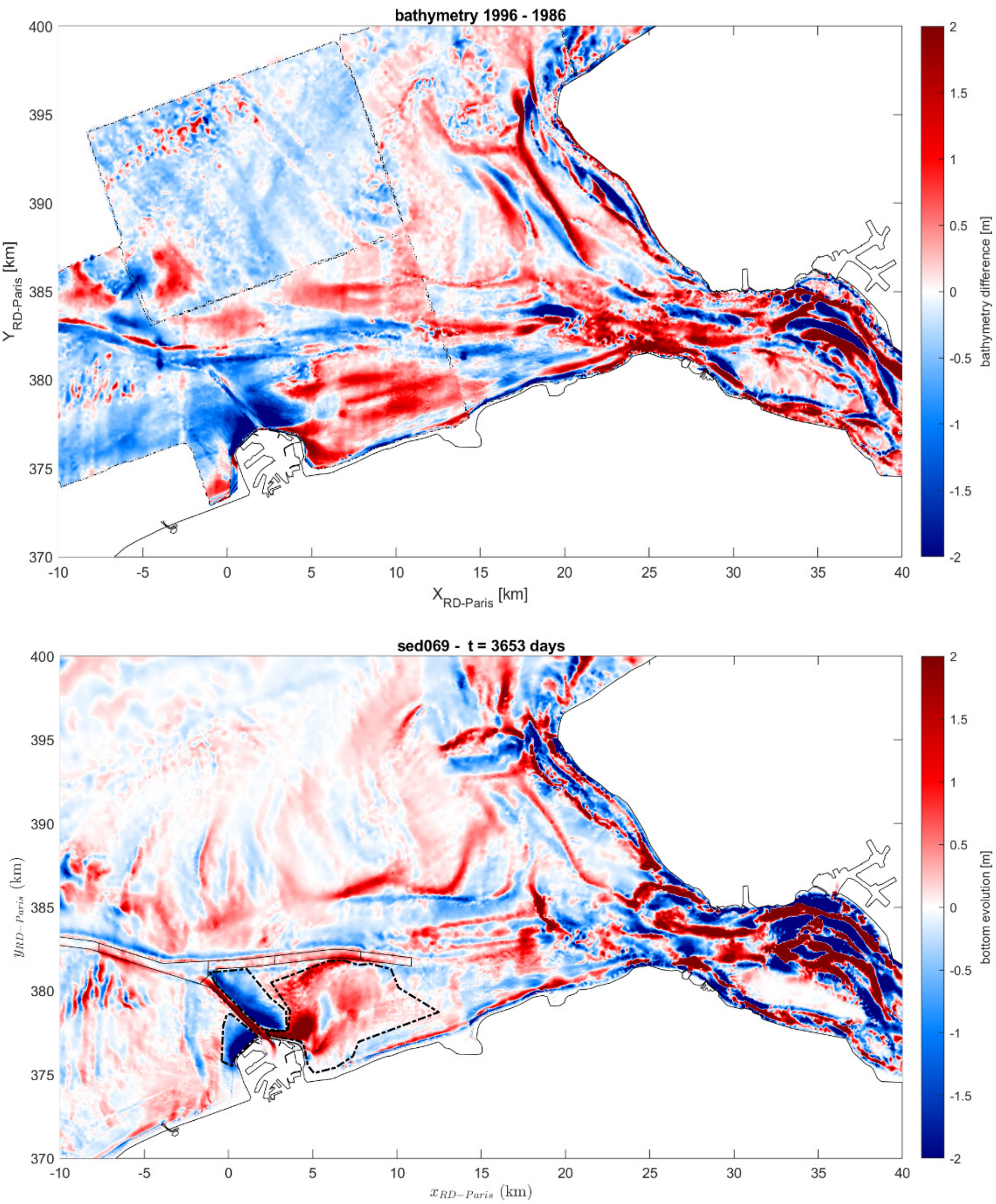
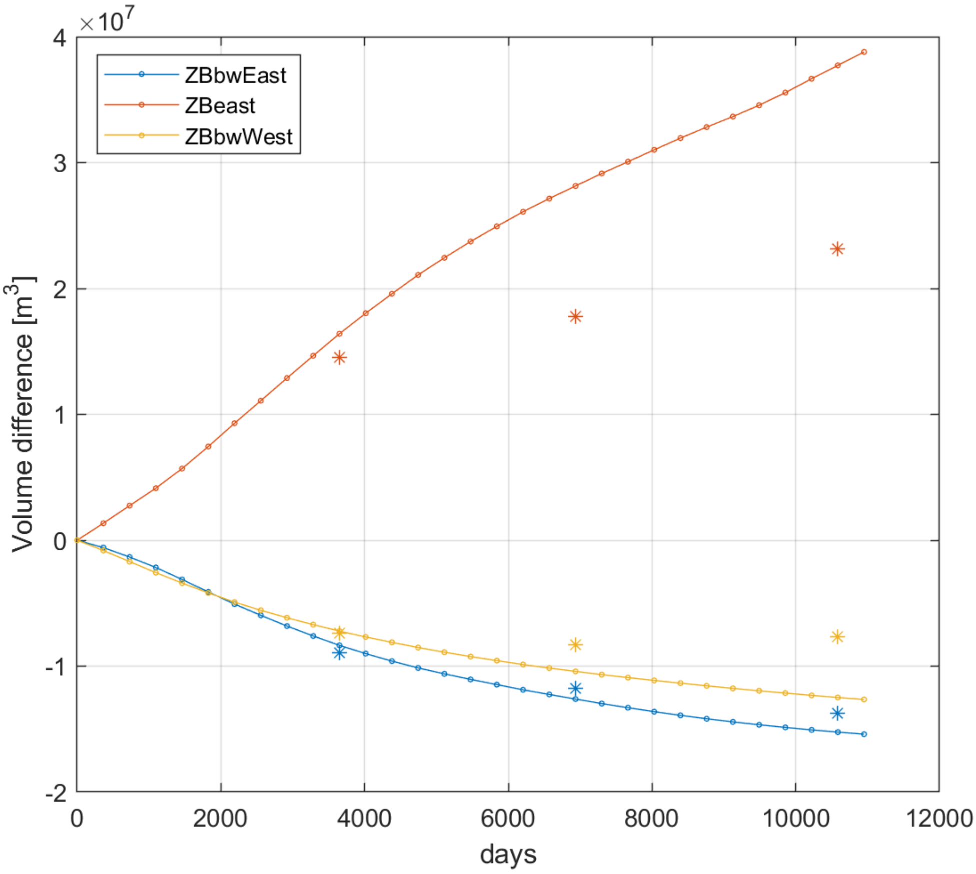


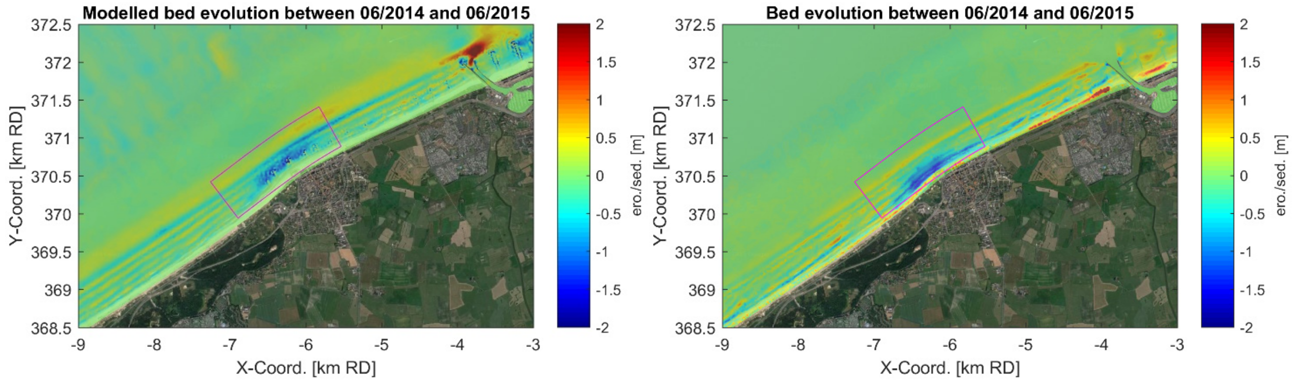
Figure 11 – Measured (asterisks) and numerically predicted (lines) volume change with respect to the year 1986 for the three polygons depicted in Figure 10.
ZBbwEast = Zeebrugge eastern breakwater; ZBbwWest = Zeebrugge western breakwater; ZBeast = Paardenmarkt and surroundings;



But also, on the short term, annual siltation rates of the navigation channels and maintenance dredging volumes, and shoreface/beach evolution at least for longshore dominated sedimentation/erosion have been validated. Figure 12 shows the measured and modelled (Soulsby-Van Rijn transport formula) bed evolution at Wenduine in the year 2014-2015, i.e. in the first year after the nourishments. The measured volume change within the magenta box reaches 145 830 m³, while the model predicts a volume change of 146 600 m³.

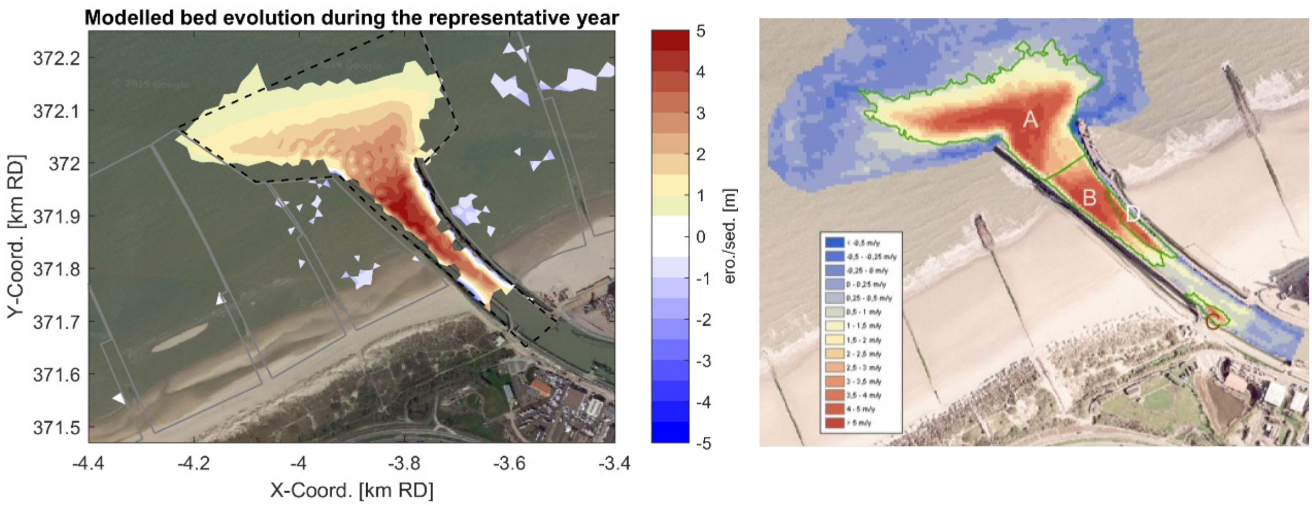
In Figure 13 the annual siltation rates of the Blankenberge marina entrance channel because of long-shore transport are modelled. In this run a morfac 1 was used with a measured timeseries of wave conditions on the boundary condition.

Figure 12 – modelled (left) versus measured (right) evolution of the Wenduine beach and shoreface after the nourishments of 2014



Remarks: In the left plot no sedimentation is noticed in or in front of the Blankenberge navigation channel (upper right corner). Typically, before the touristic season the channel is cleared to ensure access to the Blankeberge marina during the summer season. The sedimentation on the beaches west and east of the channel are sand reserves which were temporally stored before distributing over the beach (sand coming from dredging the channel)

Figure 13 – Modelled (left) versus measured (right, Teurlinck *et al.*, 2009) siltation in the Blankenberge navigation channel



3 Assumptions and limitations of the model

3.1 Hydrodynamic model

The hydrodynamic model is 2D. It is expected that in the coastal zone effects of 3D are limited, except for cross-shore processes which are not considered in the current model suite. For the long-term estimation of the coastal resilience against climate change, it is expected that cross shore processes play an important role. Also on the short term these processes play a role, e.g. beach recovery after a severe storm. It is known that these processes are difficult to model in large scale coastal models. Within the CREST project, strong efforts have been done in building a 3D highly accurate CFD model to investigate in detail the complex physics that are driving these cross-shore transport mechanisms. It is expected that from these so-called *numerical wave flume* experiments new parametrisations will be derived that can be implemented in large scale coastal models.

Salinity is not considered. It is expected that salinity gradients are low in the coastal zone and do not play an important role.

In the long-term morphological simulations there is no meteorological forcing on the hydrodynamic model.

3.2 Wave model

There is no diffraction in the model. Diffraction is important for local effects and inside ports. Wave-driven currents are only driven by radiation stresses. Stokes drift is not modelled. This means that the model misses cross-shore processes. The implementation of cross-shore processes is currently under investigation. The main transport process along the Belgian coast is the longshore transport from west to east.

3.3 Morphology

Only one sand fraction is modelled. No sand-mud interaction or less erosive clay layers are modelled. Mainly in the vicinity of Zeebrugge clay layers are present (Holocene Clay). The extension of the model to sand-mud is under investigation.

As mentioned before, at the moment the model is missing cross-shore processes, i.e. Stokes drift and cross-shore transport due to wave asymmetry.

Only sediment transport in the water is modelled, no aeolian transport nor dune formation is modelled.

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Annex A: Model Setting

TELEMAC version: Cookiecuttershark (v7p2)

Hydrodynamics

Table 2 – Setting of the Hydrodynamic model

Physical processes	Bottom shear stress, Coriolis, tide, wind and wave-current interactions
Bottom roughness	Manning (Variable roughness coefficient between 0.014 and 0.04)
Wind	Off
Turbulence	Smagorinsky (C_s=0.1)
Advection scheme	SUPG(0;1)
Free surface gradient compatibility	0.9
HD-time	1 year (705 tidal cycles + 2 days of warmup period)
Timestep	10 s
Matrix solver	GMRES
Mass lumping H	1.0
Wetting-drying scheme	1

Sediment transport

Table 3 – Setting of the sediment transport model

Sediment transport equation	Bijker (calibration parameter b=2)
D50	Spatially varying (200 to 500 µm) see Figure 14
Morfac	10
Morphologic time	10 years (705 tidal cycles, morfac 10)
Slope effect	Koch en Flokstra (β=1,3)
Secondary Flows	Off
Dredging and dumping	Nestor: dredging activity on maintaining critical depths Pas van het Zand, Scheur, Wielingen and Western Scheldt navigation channel

Waves

Table 4 – Settings of the wave model

Physical processes	Wave propagation, current-wave interaction (2-way coupling), refraction, wind induced wave setup, dissipation by whitecapping, bottom shear and depth induced wave breaking, non)linear wave-interactions
Non-linear frequency transfers	Quadruplets (DIA)
Linear wave growth	Yann
Whitecapping	Van de Westhuysen
Depth-induced wave breaking	Battjes-Jansen
Number of directions	36 (Dθ=10 degrees)
Number of frequencies	24 (min =0.05Hz)
Timestep	120 s
Coupling	TEL2TOM (different grid resolutions for wave and hydrodynamic model. To speed up the model, the resolution of the wave model is about the half of the HD model, parts of the Western and Eastern Scheldt are removed from the wave model)
Current-wave interaction	Transport in frequency domain ignored
Boundary conditions	Schematized wave conditions (36.5 days repeated 10 times) see Figure 15

Figure 14 – Spatial distribution of the mean grain diameter in the computational domain of ScaldisCoast.

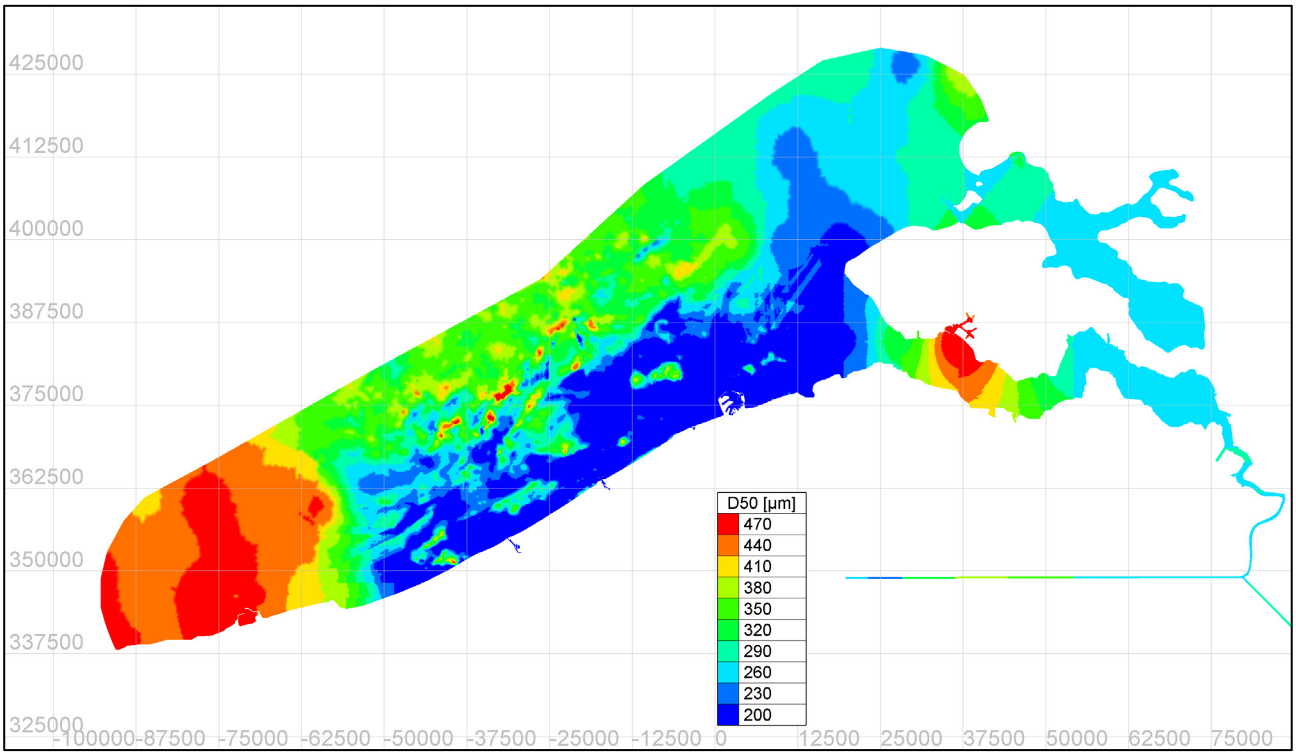
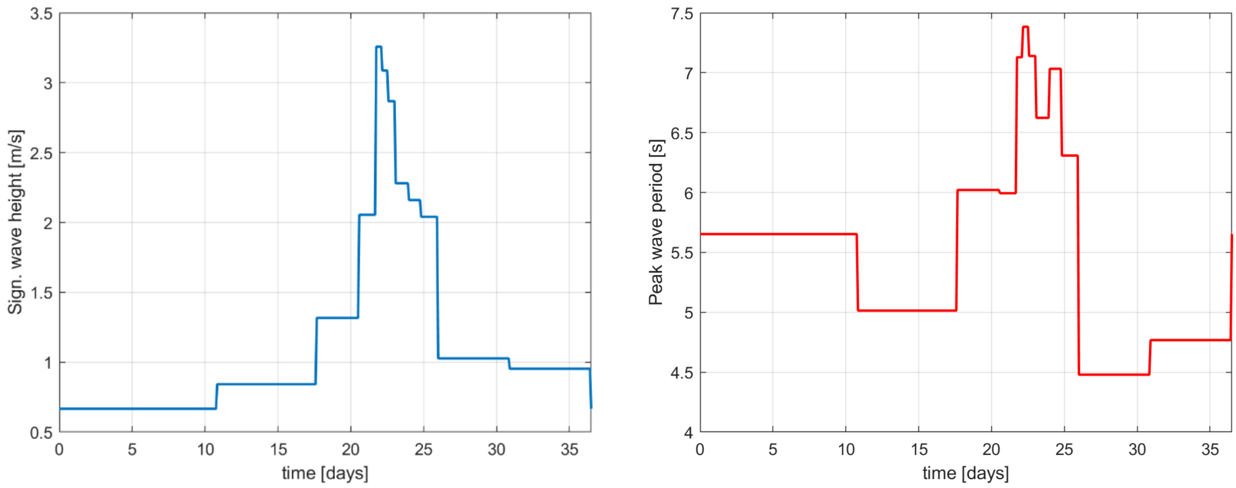


Figure 15 – Schematized wave conditions applied 10 times successively (blue line: Hmo; red line: Tp).



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