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# Set-up of wave model for KustZuid

Robert McCall
Zheng Wang

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**Summary**
A wave model is developed for the South-western Delta that can be coupled with the KustZuid-flow model. The model is validated by comparison of a one-month simulation with measured wave conditions in eight locations in the South-western Delta.

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| | | Zheng Wang | | | | | |
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**State**
draft
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# Contents

# 1 Introduction

## 1.1 Background

The estuary closures carried out in the Delta works, have led to a change in the tidal prism in the Eastern Scheldt. Consequently, the Eastern Scheldt is no longer in equilibrium with the tidal prism and its tidal flats are losing material to channel infilling. This reduction in intertidal area is putting pressure on unique habitats and impacting biodiversity.

As part of the Building with Nature program, the purpose of subprogram “ZW3.2 Morphodynamic coupling between estuary and outer delta” is to investigate large scale interactions between the estuaries and North Sea and to assess methods to increase sediment import into the Eastern Scheldt. Numerical modelling of the estuary system is thought essential in achieving the subprogram goals.

In a previous report (Morphodynamic coupling between estuary and outer delta, Inception note, July 2009), a description was given of the numerical models available to describe tidal hydrodynamics in the South-western Delta. Although large-scale morphodynamics in the Eastern Scheldt are dominated by the tidal component, small to intermediate spatial and temporal scale morphodynamics in the Eastern Scheldt and all scales in the outer delta are influenced by the wave climate.

In order to describe the wave climate in the South-western Delta a numerical wave propagation model has been set up. This report describes the set-up and application of the numerical wave model.

## 1.2 Objective

The objective of this study is to develop and validate a wave model of the South-western Delta which can be coupled with the KustZuid-flow model and can be used as a framework within which other detailed wave models can be set up.

# 2 Model setup

## 2.1 SWAN wave model

The numerical wave propagation model used in this study is SWAN 40.51A, coupled to the KustZuid-flow model by means of Delft3D-wave, Version 3.60. The SWAN wave model is a third-generation wave propagation and generation program that was developed at Delft University of Technology. The model is fully spectral (both in the frequency and directional domain) and can accommodate short-crested random wave fields propagating simultaneously from widely different directions.

Wave propagation in SWAN is based on linear wave theory. The processes of wind generation, dissipation and non-linear wave-wave interactions are represented explicitly with third-generation formulations. The model includes terms for all relevant physical processes of wave propagation, generation and dissipation such as:

- refraction due to variations in depth and currents,
- shoaling,
- wave growth due to wind,
- wave dissipation due to white-capping,
- dissipation due to surf-breaking,
- dissipation due to bottom friction,
- non-linear wave-wave interactions in deep water (quadruplets),
- transmission and reflection at obstacles.

The SWAN model has successfully been validated and verified in several laboratory and (complex) field cases.

## 2.2 Wave model grid

### 2.2.1 Spatial model grid

The wave model developed in this study will be directly coupled to the KustZuid-flow model (described in “Morphodynamic coupling between estuary and outer delta, Inception note, July 2009”). However, the model grid used by the KustZuid-flow model, see Figure 1, is not necessarily suitable for a wave propagation model for three reasons:

- The northern lateral boundary of the flow model is close to the mouths of the Eastern and Western Scheldt, see Figure 1. With no suitable wave boundary conditions on the lateral boundaries of the wave model, the so-called shadow zones would introduce inaccuracies in the areas of interest.
- The offshore boundary of the flow model is not near any wave measurement station, thereby requiring extrapolation or another numerical model to provide suitable offshore wave boundary conditions for the wave model.
- The grid resolution of the flow model is greater than required for the wave model in much of the offshore area, which is almost entirely deep relative to the wave heights and lengths and has limited bathymetric variation. The use of a high-resolution grid in this area leads to unnecessarily large computation times.

For these reasons it is decided not to use the KustZuid-flow model grid for the wave model.

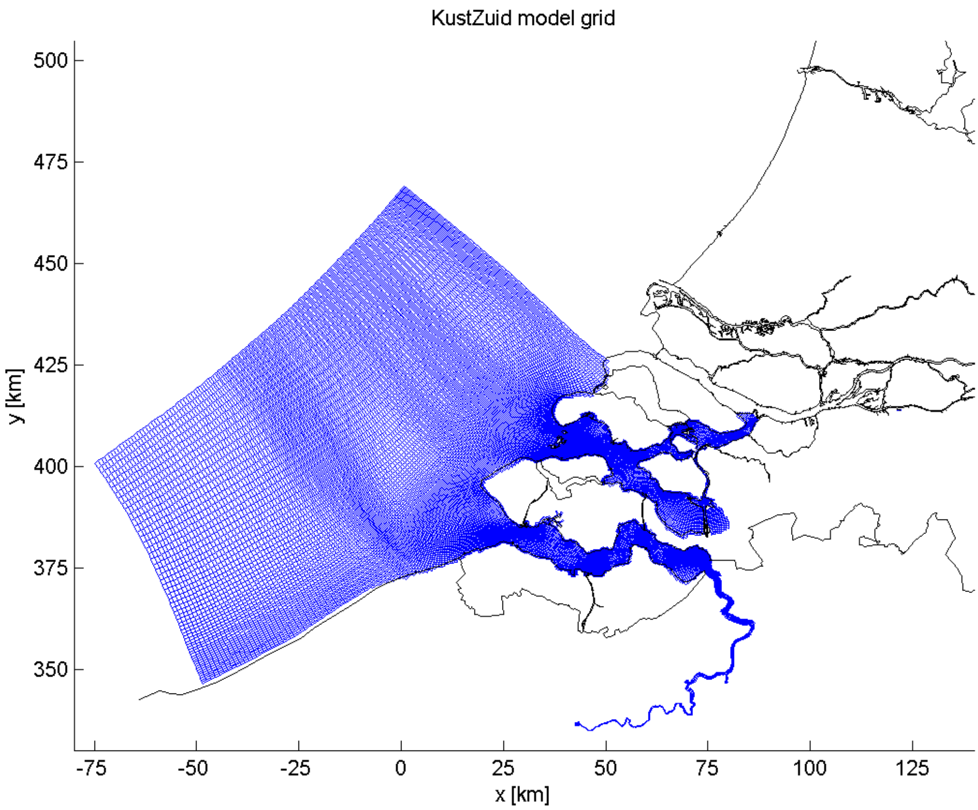


*Figure 1: Model grid of the KustZuid-flow model*

The wave conditions in much of the offshore area of the South-western Delta can be described using coarse spatial resolution, whereas the spatial resolution in the Eastern and Western Scheldt is required to be sufficiently fine to describe the channels and flats. In order to achieve both an accurate, high resolution result in the areas of interest and low computational times in areas that are not of morphological interest, a method of nesting is applied to the wave model. A coarse model grid is set up of the coastal area offshore which is used to provide boundary conditions for two high-resolution models of the Eastern Scheldt and outer delta and Western Scheldt.

The coastal area model grid is based on the Voordelta-model grid (described in “Morphodynamic coupling between estuary and outer delta, Inception note, July 2009”). The coastal model grid is approximately 160 km by 50 km and extends offshore to the Europlatform. The grid cell resolution varies from approximately 5 km offshore to 500 m near the mouths of the Eastern and Western Scheldt estuaries, see Figure 2 and Table 1.

The Eastern and Western Scheldt model grids are based on the KustZuid-flow model grid. The Eastern Scheldt model grid includes the outer delta and the Eastern Scheldt estuary up to the Philipsdam, but not the Veerse Meer, see Figure 3. The Western Scheldt model grid extends from the mouth of the estuary till the start of Antwerp Harbour, see Figure 4. The grid size in both estuaries reduces to approximately 50 m.

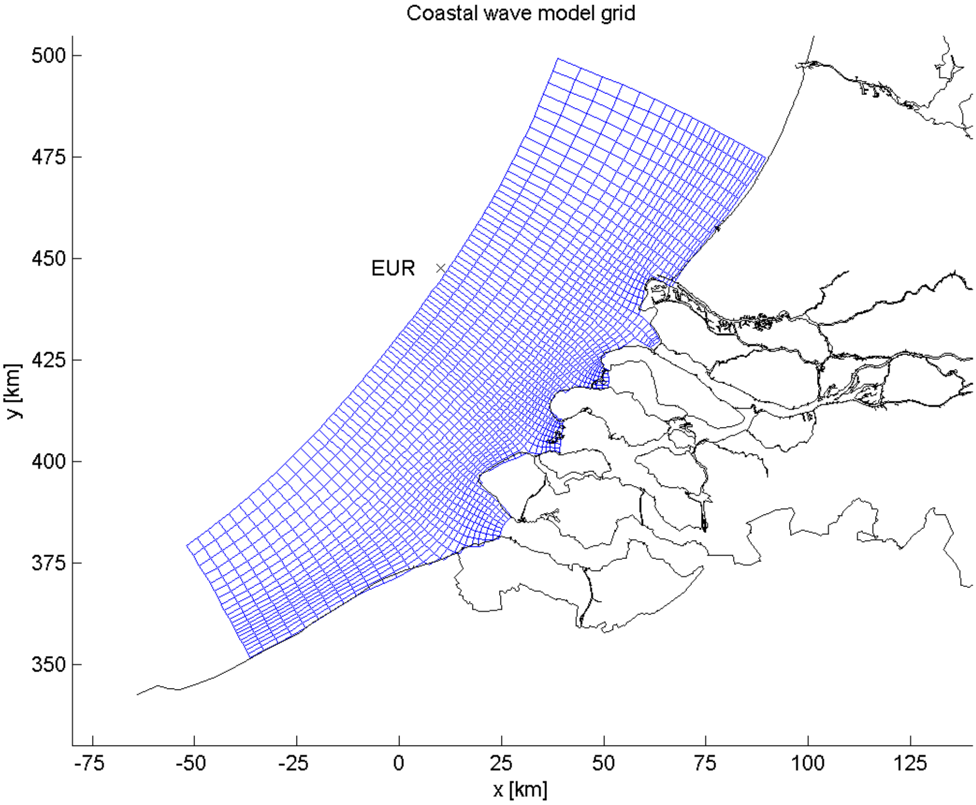


*Figure 2: Model grid of the coastal wave model and the location of the Europlatform (EUR)*

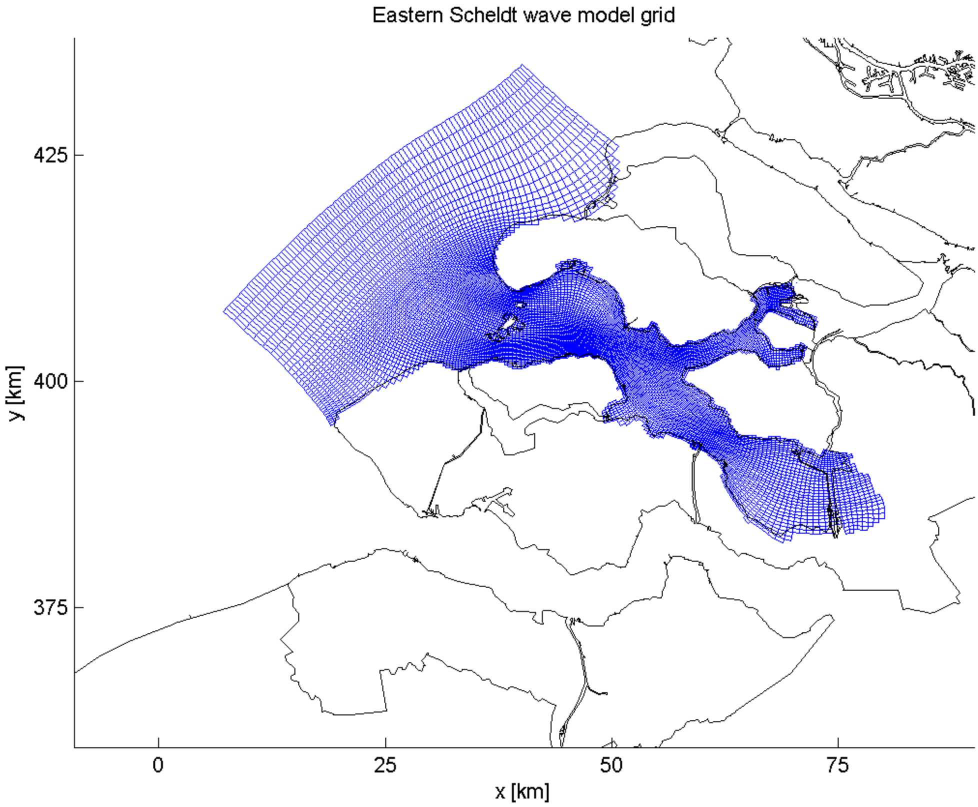


Figure 3: Model grid of the Eastern Scheldt wave model

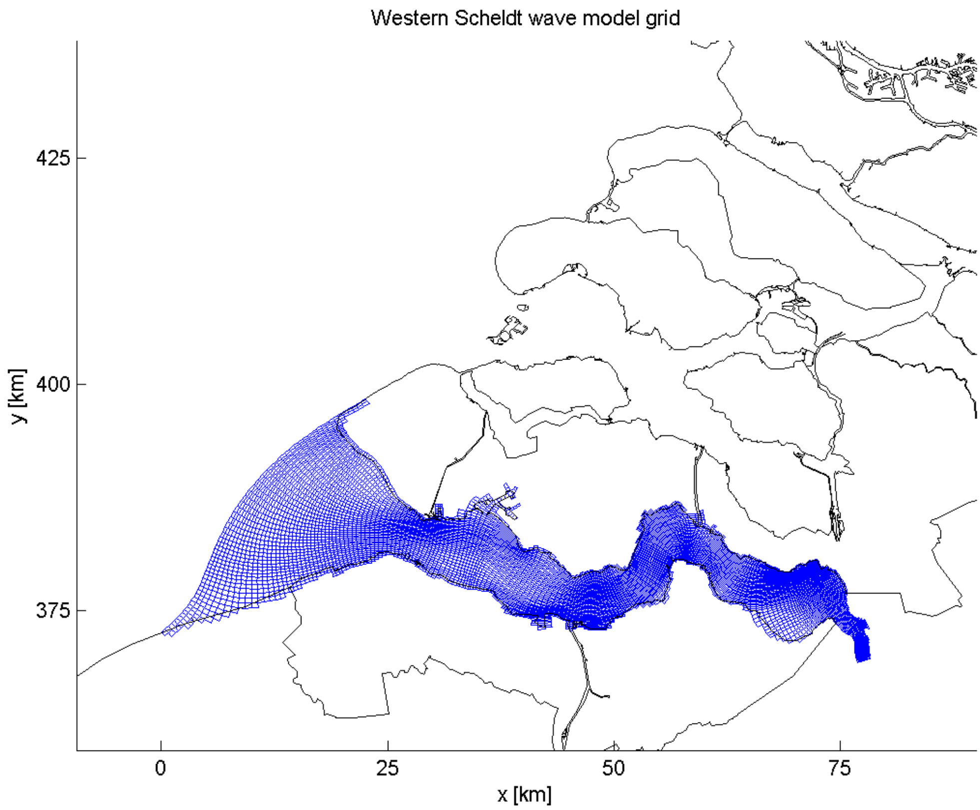


*Figure 4: Model grid of the Western Scheldt wave model*

*Table 1: Three wave model grids*

| | Grid cells | Cross shore grid size | Longshore grid size |
|---|---|---|---|
| Coastal grid | 2400 (30x80) | 340 m – 6000 m | 725 m – 4000 m |
| Eastern Scheldt grid | 21070 (98x215) | 50 m – 1100 m | 50 m – 1800 m |
| Western Scheldt grid | 24743 (109x227) | 46 m – 740 m | 22 m – 980 m |

### 2.2.2 Directional and frequency grid

The directional grids of all three wave models span 360° with a resolution of 10°. The computational wave frequency grids span 0.05 Hz – 1 Hz in 24 frequency grid steps.

## 2.3 Bathymetry data

Accurate bathymetry data, especially in shallow water, are essential for wave models. This section describes the data used to generate the bathymetry for the coastal, Eastern Scheldt and Western Scheldt wave models.

The vakloding database contains measured and interpolated bathymetry data for the entire Dutch coastal zone to a depth of -20 m+NAP at a resolution of 20 m x 20 m in space and one to six years in time. The bathymetric data available for the south-western delta and the years in which the data were measured are shown in Figure 5 and Figure 6 respectively. It can be seen that the majority of the vakloding data in the area of interest were measured last in the year 2000 or later.

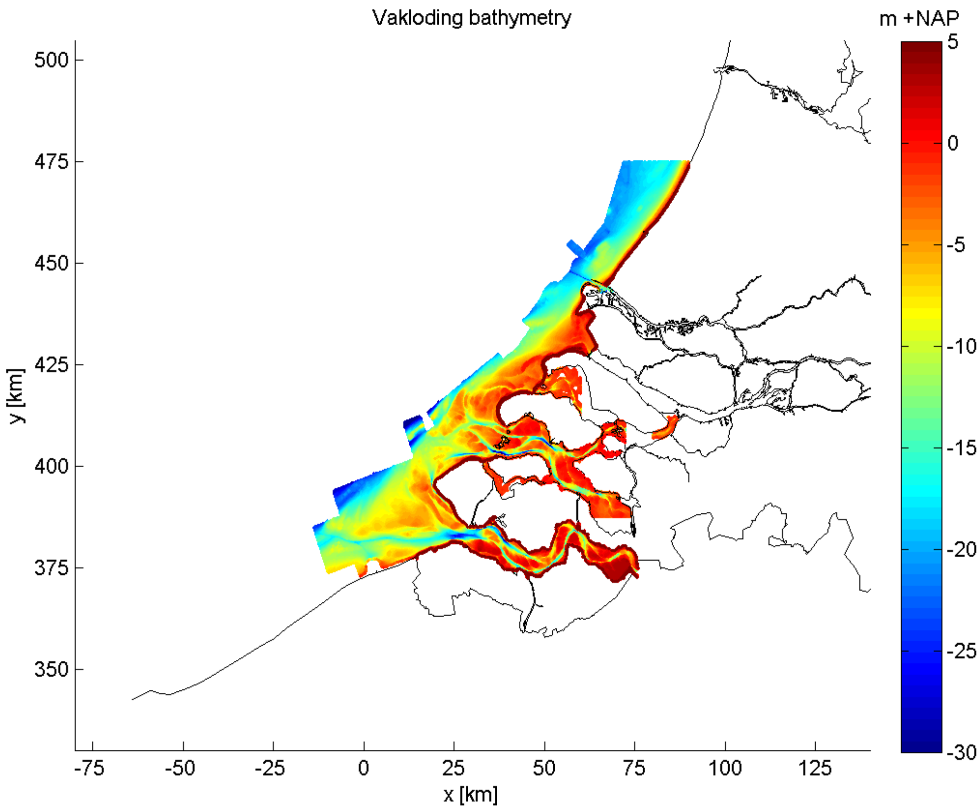


*Figure 5: Vakloding bathymetry data*

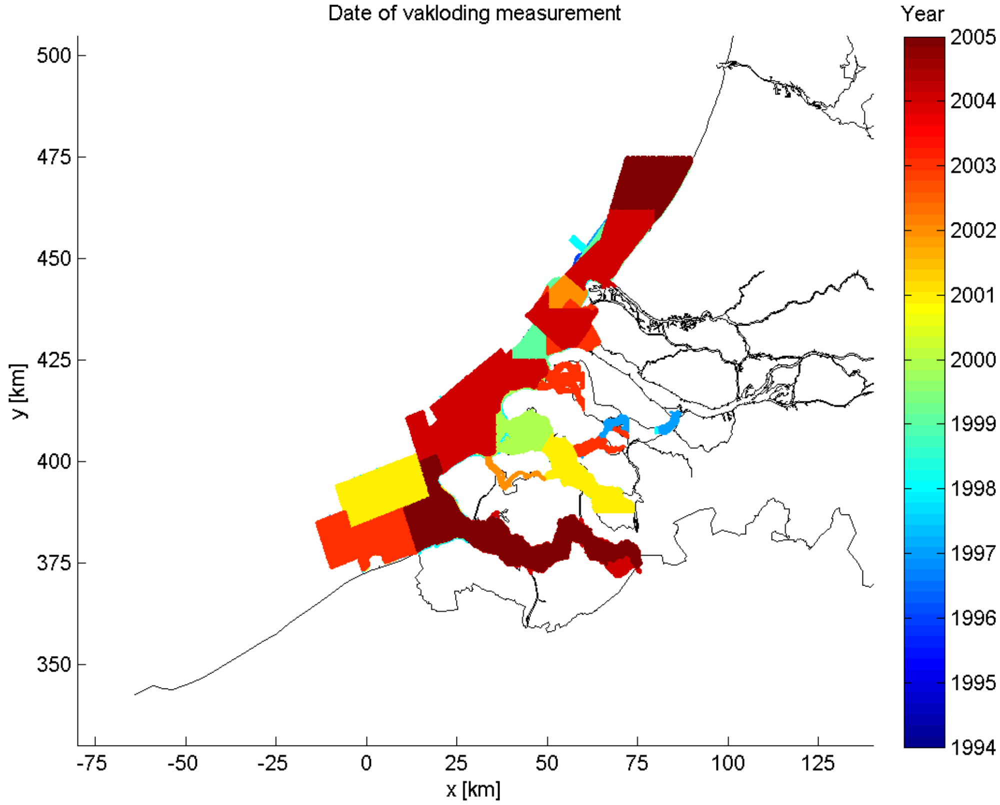


*Figure 6: Dates of vakloding measurements*

In the offshore areas where no vakloding data are available for the coastal wave model, the bathymetry data of the KustZuid-flow model (south-western offshore section of the coastal wave model) and Voordelta model (offshore section to the north of Goeree) are used. The sources of the bathymetry data for the KustZuid-flow model and Voordelta model have been described in “Morphodynamic coupling between estuary and outer delta, Inception note, July 2009”. The combined bathymetry for all three wave models is shown in Figure 7.

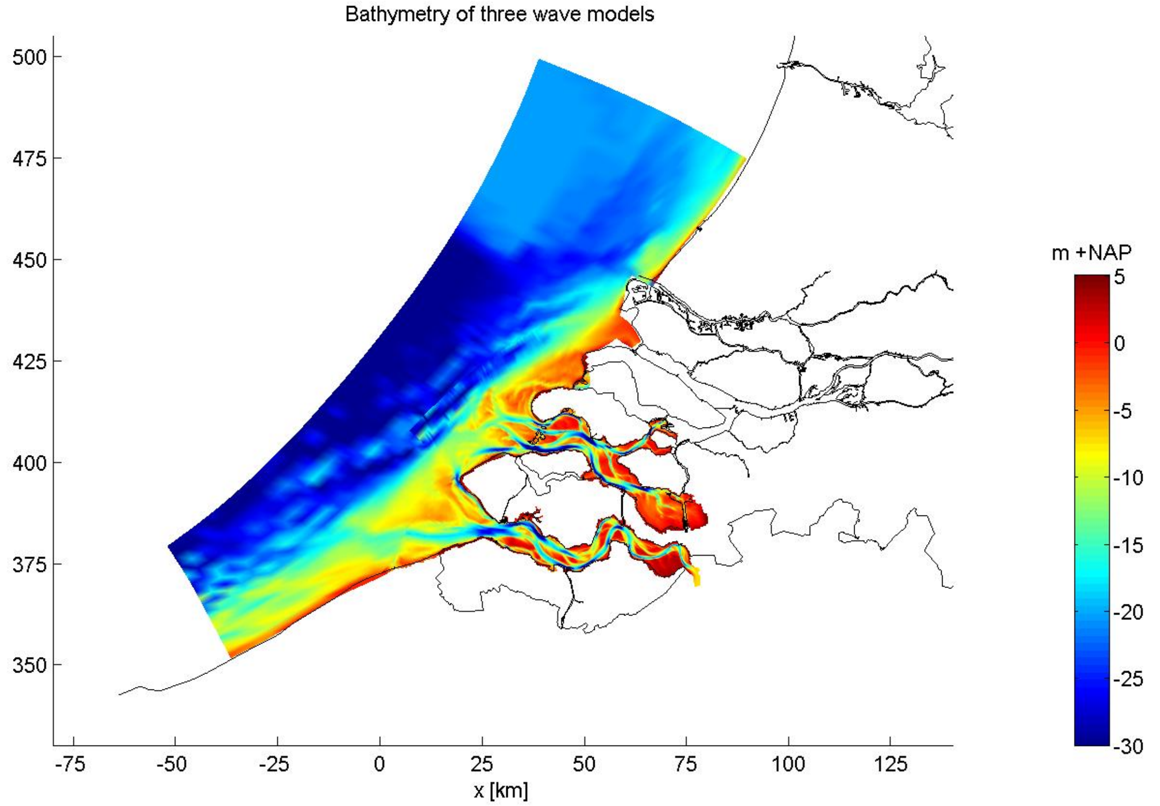


*Figure 7: Bathymetry off all three wave models combined*

# 3 Model validation

In this study the wave models are validated by comparing the results of the wave models to measured wave data time series for January 2000. This year is chosen to correspond with the date of the vakloding bathymetry measurements used in the Eastern Scheldt wave model. During January 2000 the wind conditions measured at Europlatform are variable, with four occurrences of high wind speeds (BF 7 or more) and five occurrences with very low wind speeds (BF 2 or less), see Figure 8.

The wave models are coupled to the KustZuid-flow model by Delft3D-wave, as explained in section 2. In this simulation water levels, flow velocities, wind velocities and wave properties are exchanged between the flow and wave models in order to accurately model wave-current interaction. Wave conditions are updated every four hours, starting from January 3.

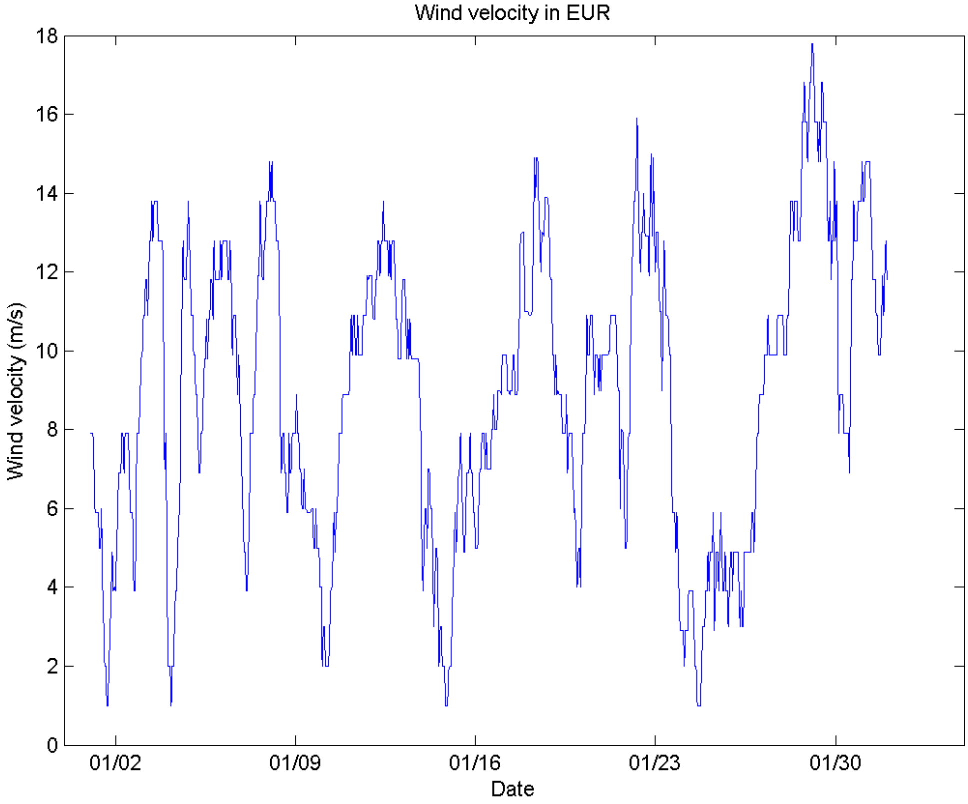


*Figure 8: Measured wind speed time series at Europlatform*

The predicted and measured significant wave height and peak wave period are compared at eight locations:

- LEG, SCHB and DORA l ocated in the coastal wave model, see Figure 9
- OS4, KEET and MRG, located in the Eastern Scheldt wave model, see Figure 10
- HFP1 and BAT2, located in the Western Scheldt wave model, see Figure 11.

Wave data for LEG and SCHB are made available by the Rijkswaterstaat Golfklimaat project and data at the remaining sites are provided by Meetnet ZEGE of HMCZ.

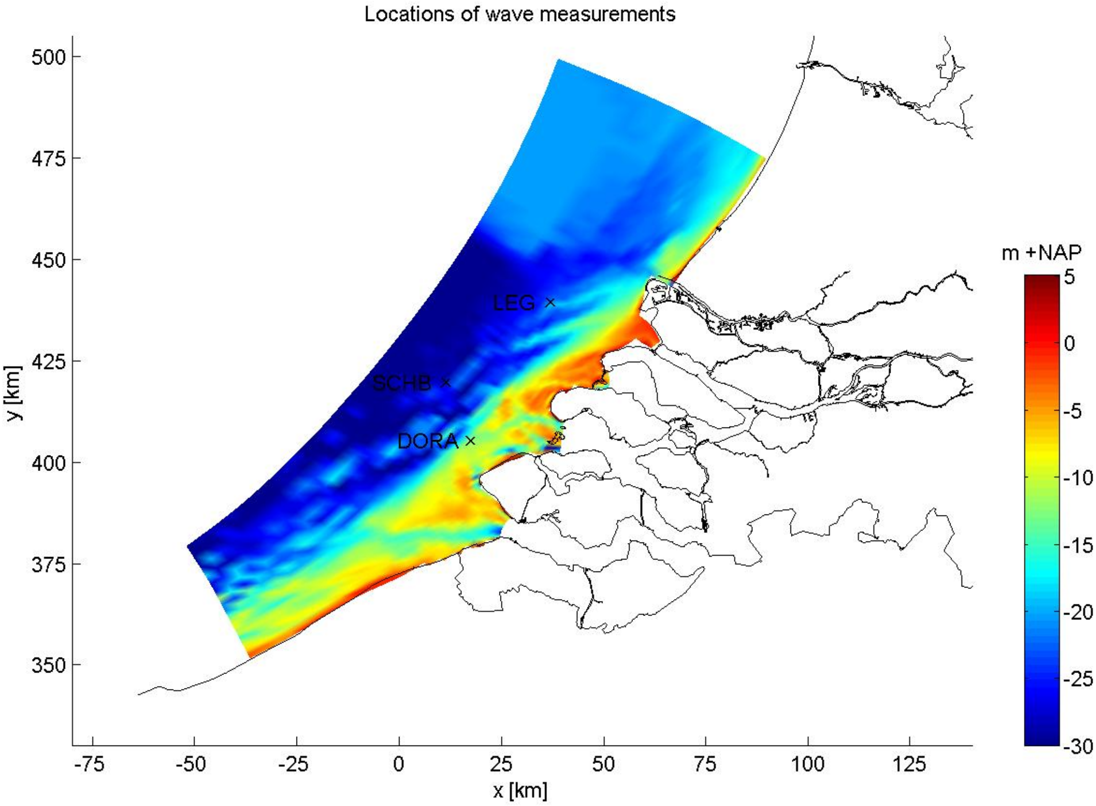


*Figure 9: Wave measurement locations in the coastal wave model*

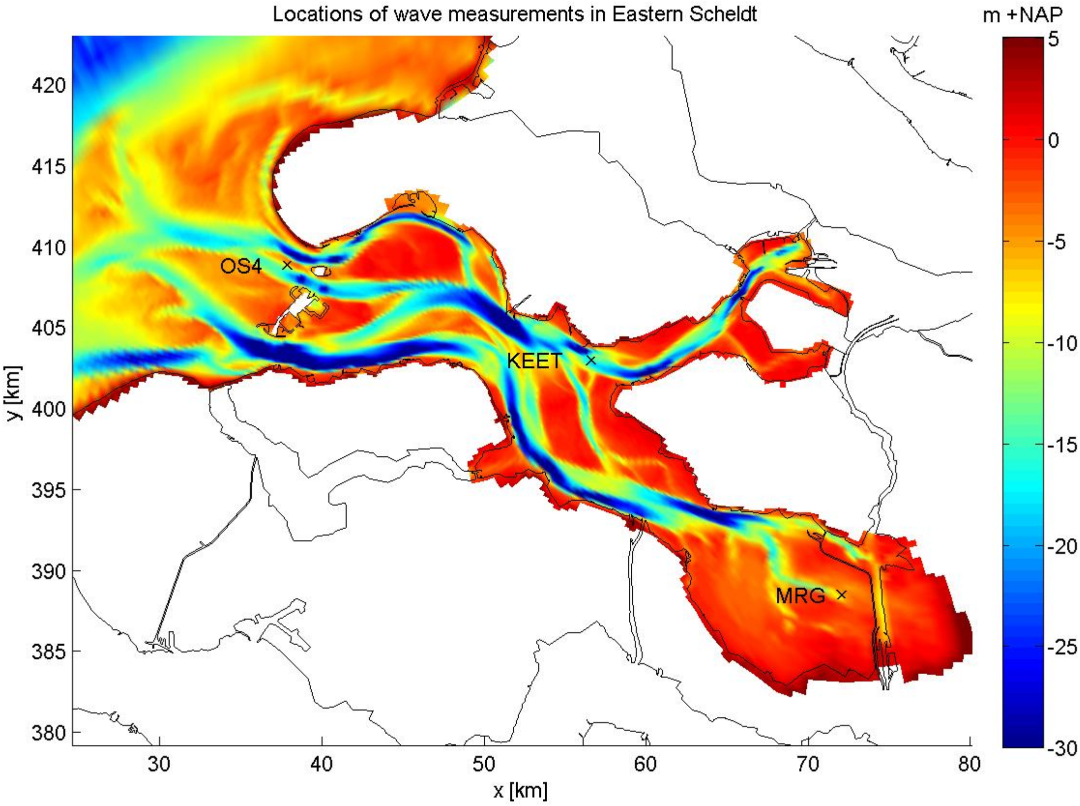


*Figure 10: Wave measurement locations in the Eastern Scheldt wave model*

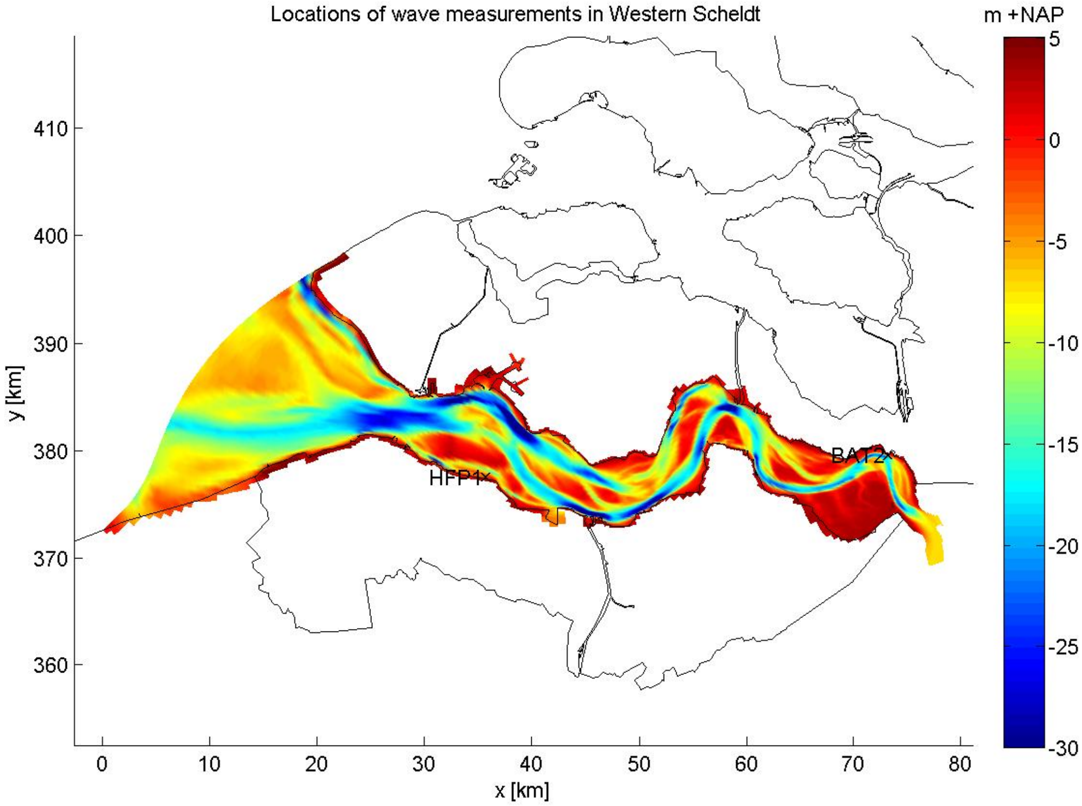


*Figure 11: Wave measurement locations in the Western Scheldt wave model*

## 3.1 Wave input

The wave propagation models require information about wave conditions to be imposed on the offshore, northern and southern boundaries of the coastal wave model. The offshore boundary of the coastal wave model has been chosen to coincide with the Europlatform wave measurement station, for which the Rijkswaterstaat Golfklimaat project publishes wave measurement data. These data can be used to extract time series of measured wave height, wave period and wave direction at Europlatform, which is applied to the entire offshore boundary. In this study a wave measurement time series for January 2000 has been applied. It will be possible to determine a wave climate, based on probability of occurrence or contribution to morphological change, such as longshore transport if required in future studies.

In this study no wave conditions are imposed on the northern and southern boundaries of the coastal wave model. This implies that regions near these boundaries will suffer from shadow-zone affects. For the majority of incident wave angles this will not affect the simulated wave conditions in the Eastern Scheldt. It is possible to impose more realistic wave conditions on the northern and southern boundaries should this be required in future studies.

## 3.2 Wind input

Waves in the South-western Delta are influenced by local wind conditions. The effect of the wind on the wave conditions in the Eastern Scheldt and Western Scheldt estuaries may be equal to or greater than the effect of the offshore wave conditions, as these offshore waves are quickly dissipated on the outer deltas and shoals in the estuaries.

In this study a time series was created of the wind conditions in the South-western Delta for January 2000, based on measured wind time series at eight measurement locations in the area, see Figure 12, published as part of the KNMI-HYDRA project.

Wind velocity data in all eight measurement stations are interpolated to generate a wind velocity field. In order to generate a wind field that extends across the entire domain of all three wave models, wind velocity data are extrapolated outwards from EUR, LEG, VR, CADZ and THOL. The wind direction is assumed to uniform and equal to the wind direction at EUR across the entire model domain. An example of a synthesized wind field is shown in Figure 13.

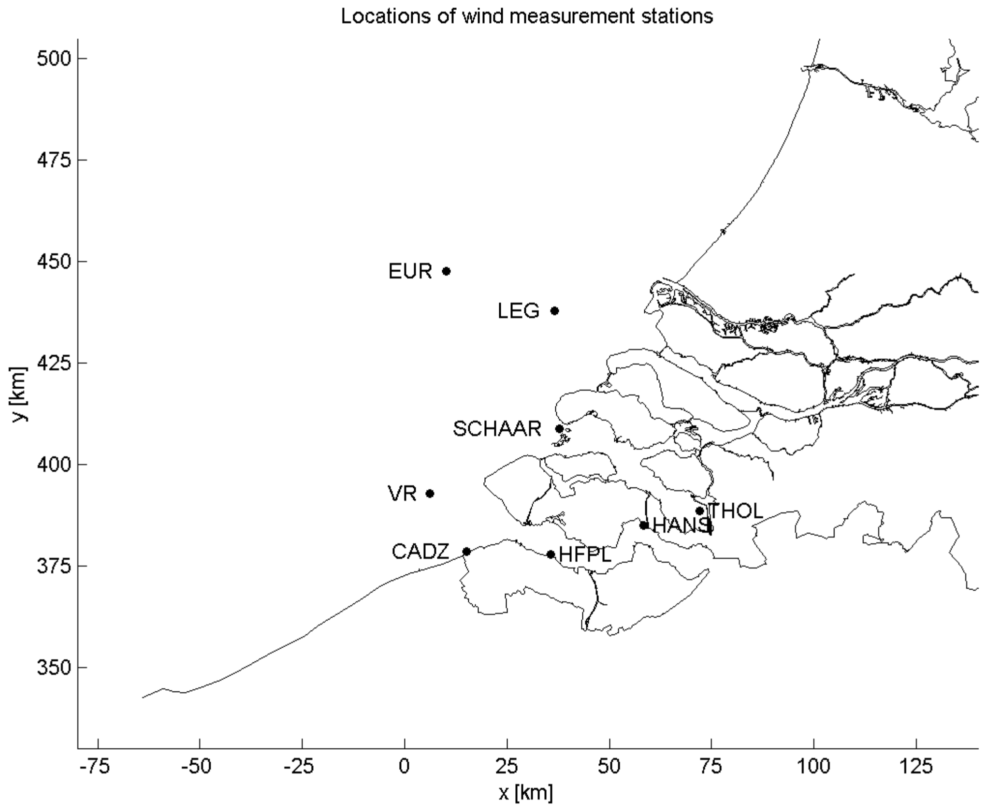


*Figure 12: Locations of wind measurement stations*

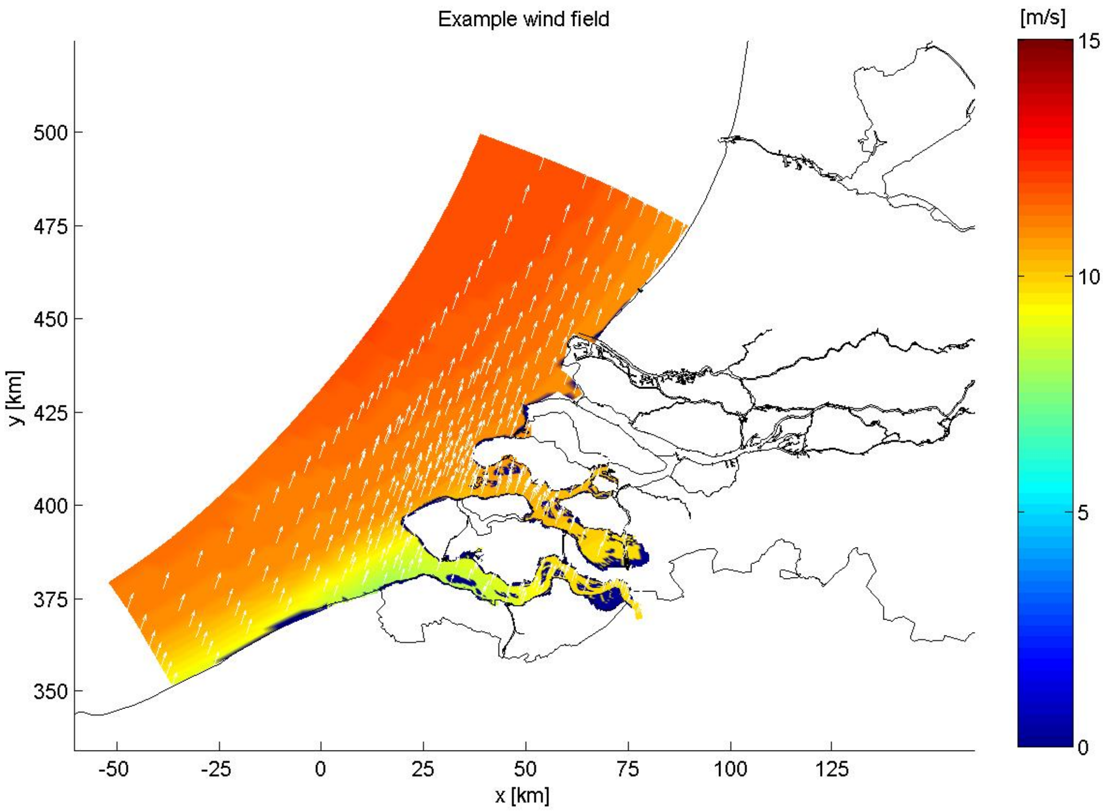


*Figure 13: Example of a wind field used in the wave simulation*

## 3.3 Model comparison

A time series of measured and simulated significant wave height and peak wave period at all eight wave measurement locations are shown in Figure 14 and Figure 15 respectively. The results shown in Figure 14 indicate that the wave models predict the significant wave height in the three offshore locations DORA, LEG and SCHB well, with the exception of two peak events at DORA and LEG. This may be due to a lack of temporal resolution around these two events. The simulated significant wave height in the Eastern Scheldt measurement locations OS4, KEET and MRG correspond well with the measurements, but the simulated values tend towards the maxima of the measurements, rather than the mean. The wave measurement locations in the Western Scheldt, HFP1 and BAT2, are located in shallow water, near the banks of the estuary. No wave measurement locations were found in the centre of the estuary. Despite the fact that the wave model may have an incorrect bathymetry at these locations, the simulated significant wave height corresponds well with the measurements. At BAT2 the simulated wave height consistently tends towards the minima of the measurements, suggesting that the model bathymetry may be too shallow in this point.

The simulated and measured peak wave periods shown in Figure 15 indicate that the wave models generally correspond well with the measurements, but are less accurate than the wave height predictions. It should be noted that the scatter in the measured results include peak wave periods of 30-40 seconds (not shown in Figure 15) and that the wave models may more accurately predict other spectral parameters. The simulated wave periods at the Western Scheldt measurement locations, HFP1 and BAT2 are consistently low and may not be representative for the true conditions.

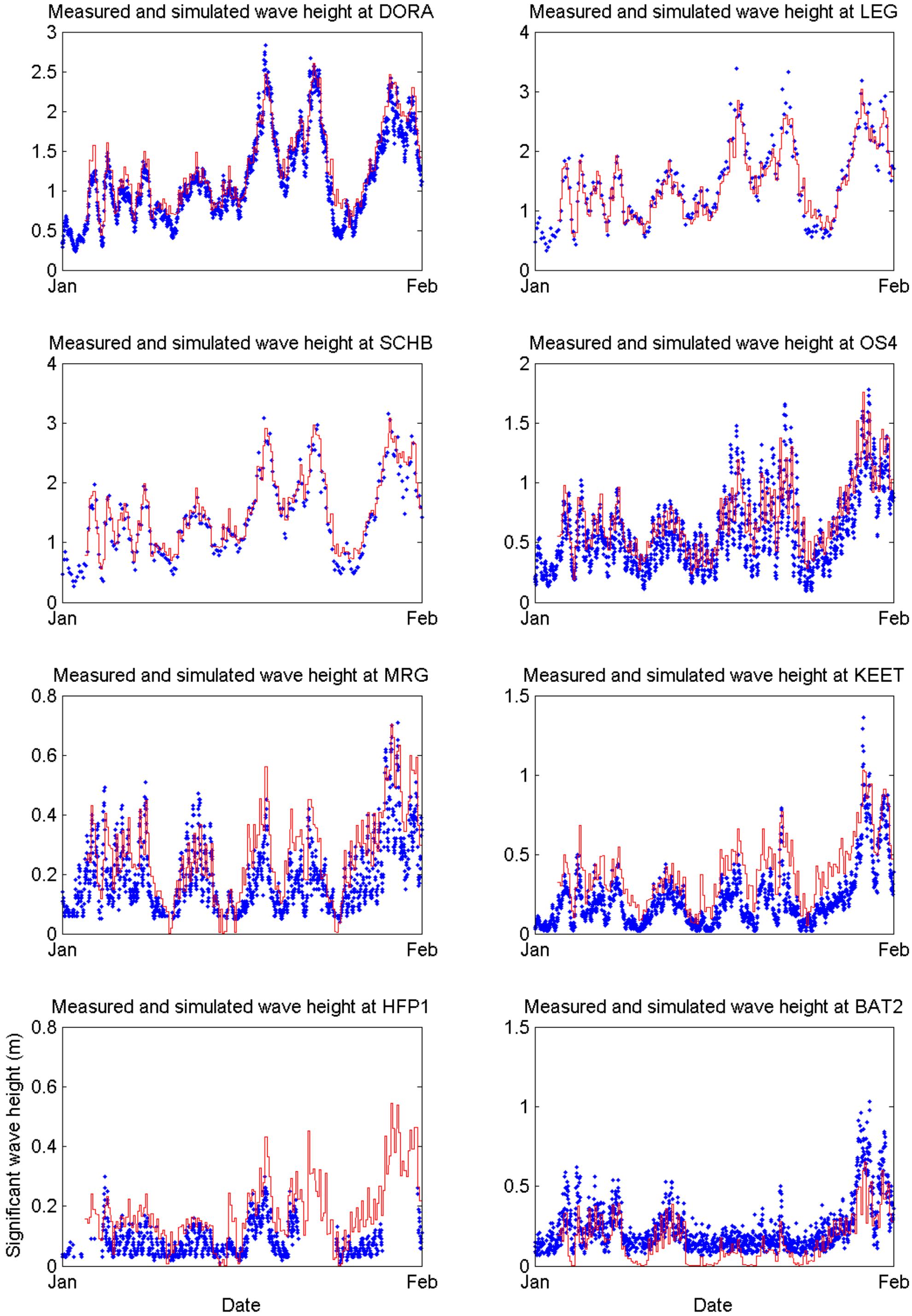


*Figure 14: Measured (blue) and simulated (red) significant wave height at eight locations*

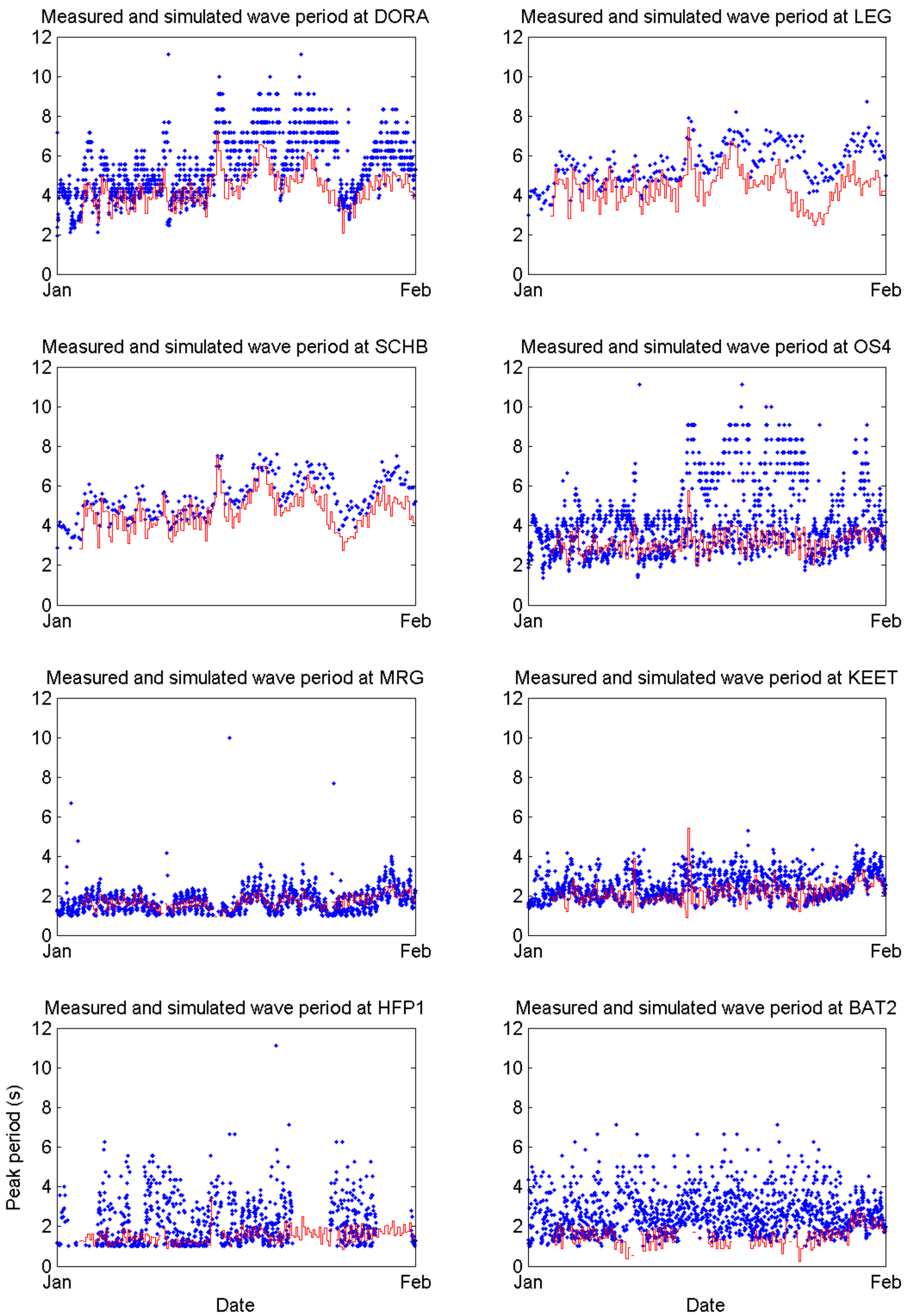


*Figure 15: Measured (blue) and simulated (red) peak wave period at eight locations*

# 4 Model considerations

During the course of this study, several model sensitivities were studied. In this section the wave model sensitivity to two factors will be elaborated.

## 4.1 Storm surge barrier transmission coefficient

The Eastern Scheldt storm surge barrier has been implemented as an obstacle in the wave models. In order to allow wave transmission across the barrier, the barrier is given a transmission coefficient greater than zero. An initial estimate of 0.6 is used based on the ratio between the width of the pillars (10-25 m) and the width of the gates (40 m).

Two sensitivity studies were carried out with a transmission coefficient of 0.2 and 0.8 respectively. Figure 16 shows the relative mean wave height difference between both simulations. It can be seen that although the transmission coefficient has a strong influence on the wave conditions within five to ten kilometres landwards of the barrier, the effect on the rest of the Eastern Scheldt is minimal during normal conditions. Since no wave measurements are available within the area that is affected by the barrier transmission coefficient, no further calibration of the transmission coefficient is possible. In future simulations it will be advisable to couple the transmission coefficient to the predicted surge level, in order to imitate the closure procedure of the Eastern Scheldt storm surge barrier.

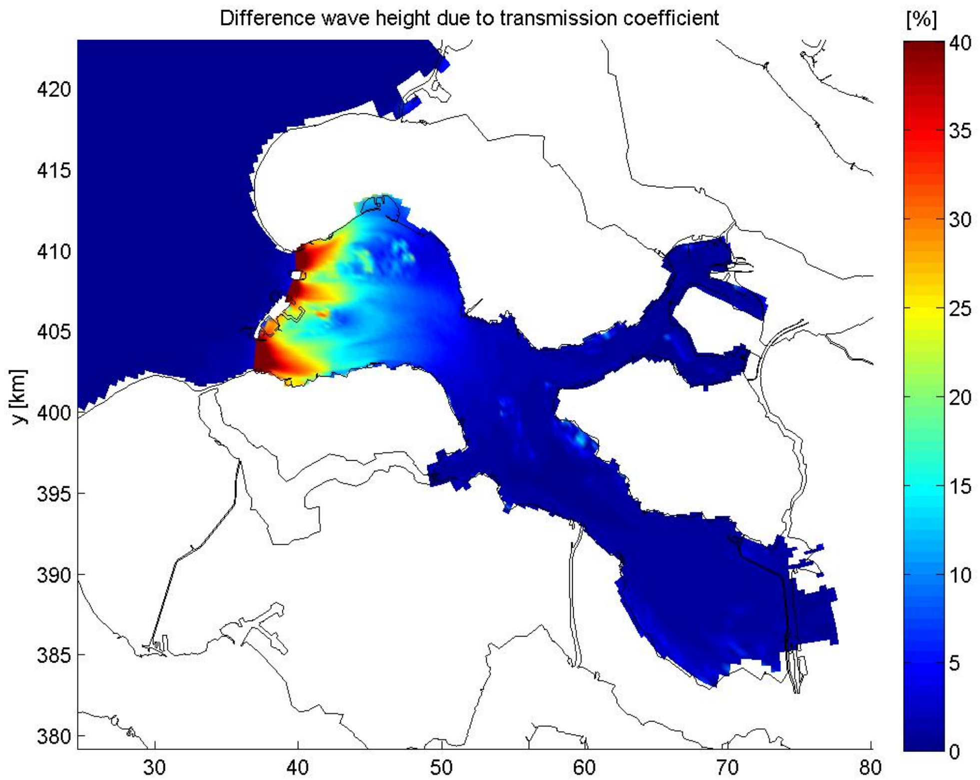


*Figure 16: Difference in mean wave height between a simulation with 0.8 and with 0.2 transmission coefficient in the Eastern Scheldt barrier, relative to the 0.8 transmission simulation*

## 4.2 Wind velocity in the Eastern Scheldt estuary

In order to determine the need for spatially varying wind fields in the wave models, one sensitivity study was carried out with a uniform non-stationary wind field, based on the measured wind conditions at EUR. This sensitivity case will tend to exaggerate the wind speed in the Eastern and Western Scheldt estuaries, as illustrated by Figure 17.

The wave conditions at the offshore locations DORA, LEG and SCHB are not affected greatly by this wind scenario, see Figure 18. However, the significant wave height in all locations in the Eastern Scheldt estuary, KEET and MRG, and Western Scheldt estuary, HPL1 and BAT2, are strongly overestimated, indicating that the local wind conditions are fundamental in predicting the local wave climate.

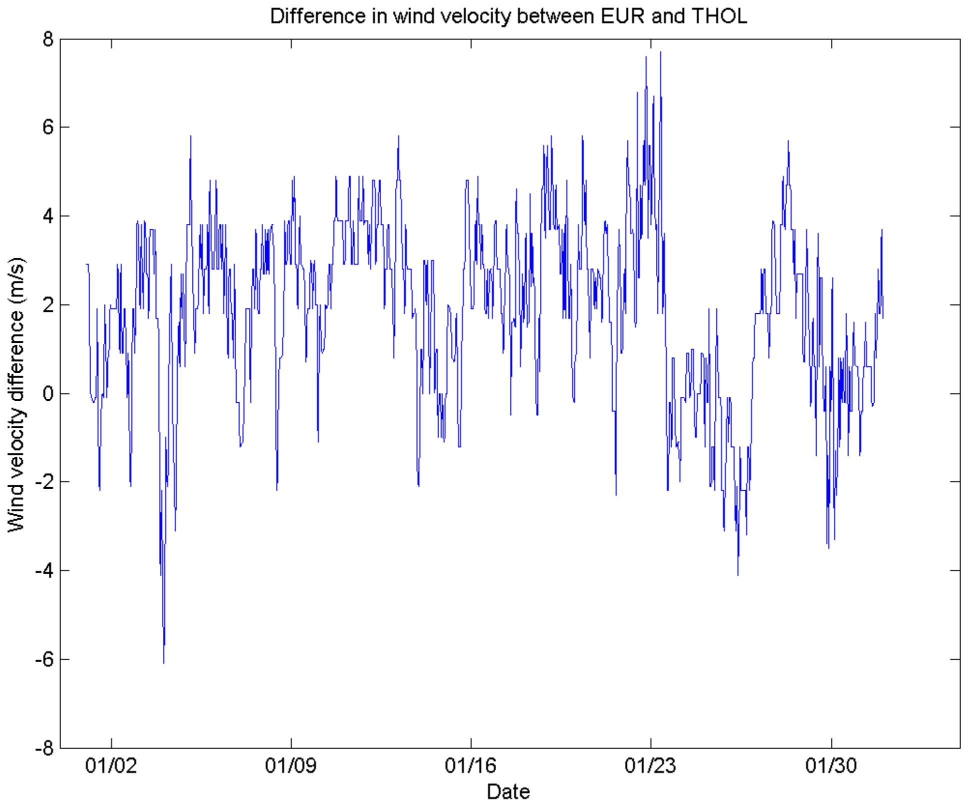


*Figure 17: Measured wind speed difference between EUR and THOL. Positive values indicate the wind speed at EUR is higher than at THOL.*

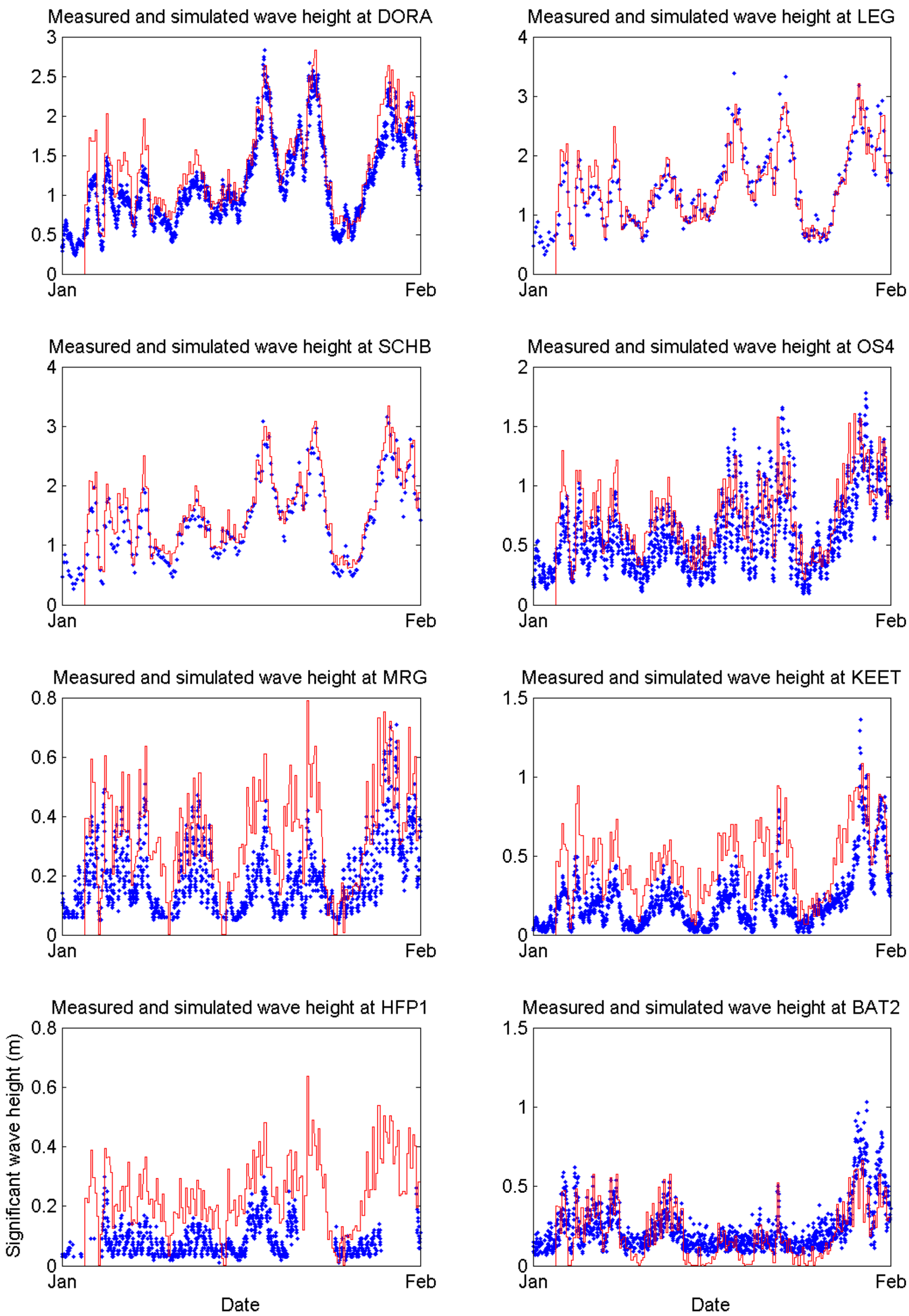


*Figure 18: Measured (blue) and simulated (red) significant wave height at eight locations in the wind speed sensitivity case.*

# 5 Conclusions

In this study a wave model for the South-western Delta has been set up that can be coupled with the KustZuid-flow model. The wave model consists of a coarse wave grid for the offshore section of the South-western Delta and two high resolution wave models of the Eastern Scheldt and Western Scheldt estuaries.

The simulated wave conditions in a hindcast model at eight locations in the South-western Delta have been compared to measurements. The results show that the wave model predicts local wave heights well and that the simulated peak wave period corresponds well with the local peak wave period. In future studies it is recommended to compare to other wave spectral parameters.

Sensitivity studies have shown that the wave height in the Eastern Scheldt and Western Scheldt estuaries are strongly dependent on the local wind conditions. Imposing a uniform wind field based on offshore wind measurements will generally lead to an over prediction of wave heights in the estuaries.

The wave transmission coefficient of the Eastern Scheldt storm surge barrier has significant influence on the wave conditions within approximately five to ten kilometres of the barrier. It is recommended to further investigate the applicability of the value of the transmission coefficient used in this study.