MODELING THE MORPHODYNAMICS OF THE MOUTH OF THE SCHELDT ESTUARY

JEBBE VAN DER WERF[(1)], TOMAS VAN OYEN[(2)], BART DE MAERSCHALCK[(2)], ABDEL NNAFIE[(2)], ARNOLD VAN ROOIJEN[(1)], MARCEL TAAL[(1)], TOON VERWAEST[(2)], LODEWIJK DE VET[(1)], JULIA VROOM[(1)] & MICK VAN DER WEGEN[(1)]

[(1)] *Deltares, Delft, The Netherlands,*
jebbe.vanderwerf@deltares.nl, arnold.vanrooijen@deltares.nl, marcel.taal@deltares.nl, lodewijk.devet@deltares.nl and others
[(2)] *Flanders Hydraulics Research Institution, Antwerp, Belgium,*
tomas.vanoyen@mow.vlaanderen.be, bart.demaerschalck@mow.vlaanderen.be, abdel.nnafie@mow.vlaanderen.be and others

ABSTRACT

Recent research on the Scheldt estuary mainly focused on the Western Scheldt. There is now a renewed interest in the mouth of the estuary as the Flemish government explores the feasibility of large-scale morphological interventions in that area. This paper describes the ongoing development of a process-based numerical model (Delft3D) of the Scheldt estuary. The so-called Delft3D-NeVla model computes morphodynamics forced by waves, tide, wind and river discharge, and affected by sediment dredging and dumping to maintain navigation channels at the desired depth. After further calibration and validation, the Delft3D-NeVla model will become an important tool to understand and predict the morphodynamics of the mouth of the estuary due to natural processes and large-scale morphological interventions such as relocation of navigation channels.

Keywords: Delft3D; hydrodynamics; numerical modeling; morphodynamics; Scheldt estuary

1.   INTRODUCTION

The Scheldt estuary is situated at the border of The Netherlands and Belgium. It consists of a (tidal) river part from Gent to about Antwerp, an inner estuary (Western Scheldt) from Antwerp to Vlissingen and a mouth or ebb-tidal delta (see Figure 1). The average Scheldt river discharge is about 100 m^3/s. The pre-dominantly semi-diurnal tide amplifies in upstream direction to a tidal range exceeding 5 m near Antwerp, making the Scheldt a tide-dominated estuary.
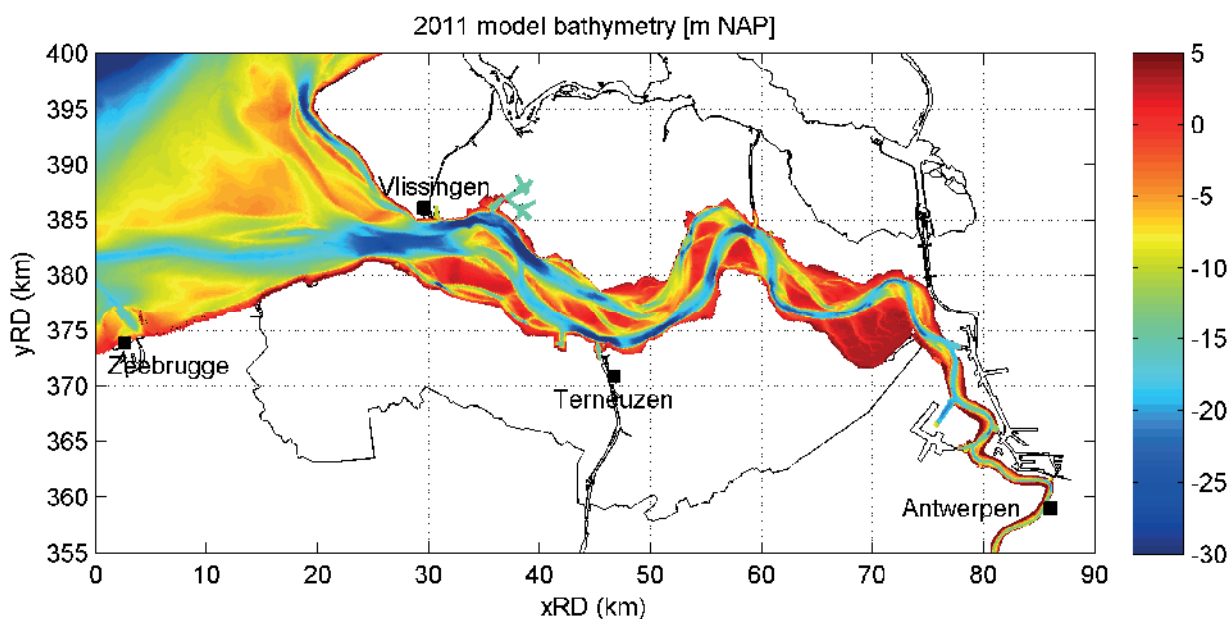

Figure 1. 2011 bathymetry Scheldt estuary.

The Scheldt estuary includes the entire gradient from fresh to salt water providing various habitats for marine flora and fauna. In addition to these ecological values, the estuary is of large economic importance as it provides navigation routes to the ports of Antwerp, Gent, Terneuzen and Vlissingen. Safety against flooding is the third important aspect of the Scheldt estuary.

The morphology of the Western Scheldt displays a regular repetitive pattern of mutually evasive meandering ebb channels and relatively straight flood channels (see Figure 1); also referred to as 'multiple-channel system'. These main channels are separated by intertidal shoals and linked by stable and/or migrating secondary channels. The ebb and flood channels join at dynamic, shallow areas that form sills in the navigation channel, which are dredged regularly. Along the completely embanked shores, intertidal mudflats and salt marshes are found. The mouth or ebb-tidal delta of the Scheldt estuary contains the shallow area called Vlakte van de Raan in the middle and two tidal channels: the Oostgat along the Walcheren coast in the North and the Wielingen, the main entrance to the Western Scheldt, in the South.

Both natural processes and human interferences have influenced the morphological evolution of the estuary over the past two centuries (see e.g. Jeuken & Wang, 2010). Initially, human interferences mainly consisted of reclaiming land that largely silted up by natural processes. This reclamation resulted in a permanent loss of intertidal areas, a rather erratic pattern of embankments and a fixation of the large-scale alignment of the estuary. Since the beginning of the 20th century human interferences shifted from land reclamation to sand extraction and dredging and dumping to deepen and maintain the navigation route to the port of Antwerp. The first deepening took place in the 1970s, the second in 1997/1998 and the last in 2010.

Recent modeling research (e.g. Dam et al., 2007; Van der Wegen & Roelvink, 2012) focused mainly on the Western Scheldt hydro- and morphodynamics. The Flemish government explores large-scale interventions in the mouth in support of safety, navigation and ecology. This requires new knowledge and prediction tools, because the morphodynamics of the mouth and inner part of Scheldt estuary differ. Wave effects are expected to be more important in the mouth, and there is an interaction with coastal morphodynamics. Furthermore, the influence of dredging and dumping activities is probably less pronounced.

This paper describes the set-up of a sophisticated Delft3D numerical model of the entire Scheldt estuary to increase system knowledge and to contribute to estuarine management on the large scale, as well as first model results.

2. DELFT3D MODEL

The Delft3D software solves coupled, wave-averaged equations for waves, currents, sediment transport and bed level change (see Lesser *et al.*, 2004). We have set-up a 2DH (depth-averaged) Delft3D morphodynamic model covering the entire Scheldt estuary including effects of waves, tide, wind and river discharge. Figure 2 shows the computational grid of the so-called Delft3D-NeVla model, since it is based on the NeVla model developed by Flanders Hydraulic Research.
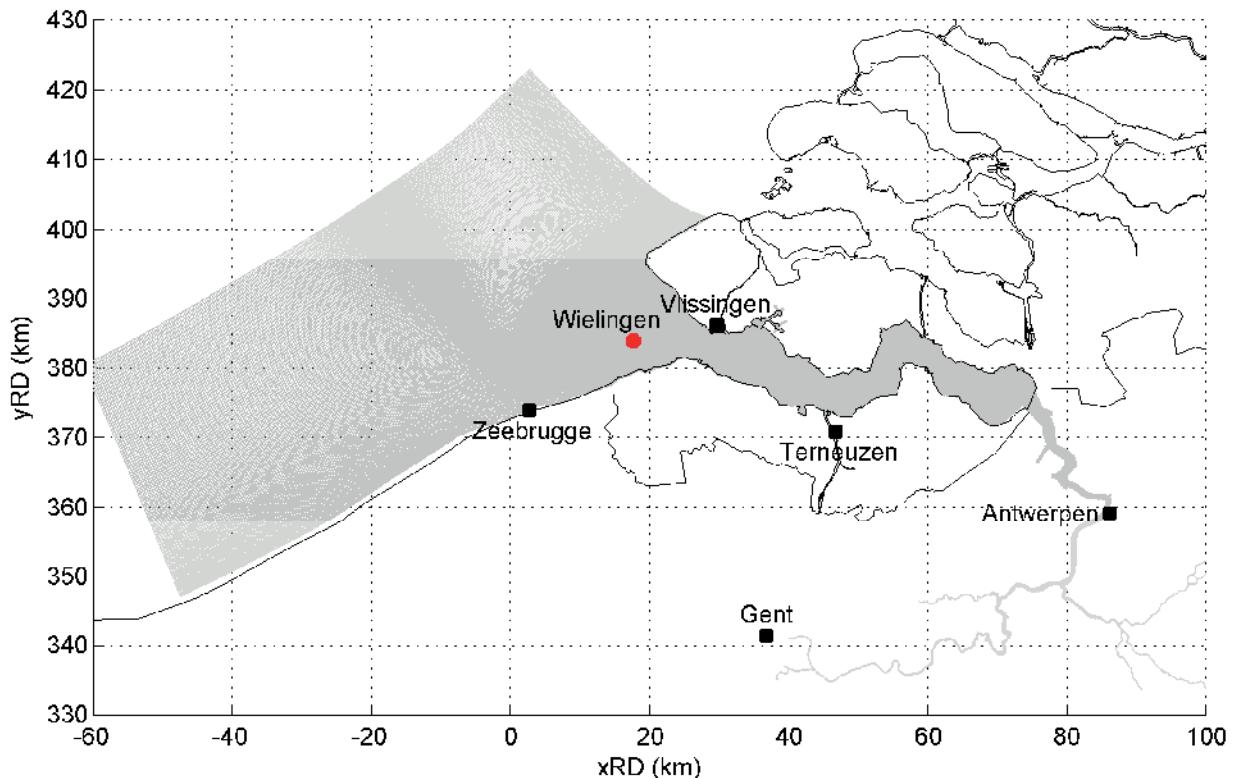

Figure 2. Computational grid Delft3D-NeVla model. The red dot indicates the location of the wave measurement station Wielingen.

The grid resolution varies between ~400 m on the Continental Shelf, to in between 50 and 100 m in the Western Scheldt to ~10 m upstream. The downstream boundary conditions are derived from the DCSM-Zuno model (Zijl *et al.*, 2013; submitted). At the upstream boundary measured discharges are imposed.

The domain of the wave model is smaller; it covers the coastal area and the Western Scheldt up to xRD ≈ 55 km. This was chosen because wave effects become less important further upstream and this study focusses on the mouth of the estuary. The flow and wave field are coupled every 30 minutes.

We apply a single grain size with a D50 of 0.2 mm and use the Van Rijn transport formulation. Furthermore, we account for the existence of hard, non-erodible layers and the sediment dredging and dumping activities related to maintenance of navigation channels and harbors.

3.   FIRST MODEL RESULTS

The original Delft3D-NeVla model was validated earlier using measurements of water levels, discharges, velocities, maintenance dredging volumes and morphological changes in the Western Scheldt (see Consortium Deltares-IMDC-Svasek-Arcadis, 2013). Given the focus of this study we will now focus the model validation on the mouth of the Scheldt estuary, including waves. This section contains the first example results of the model validation, as well as explorative morphological calculations. We will soon be able to present more results.

3.1   Hydrodynamics

Of particular interest is the measurement campaign that was carried in the summer of 2014 (Plancke et al., 2014). Between 8th of August 8 and 5th of September wave, flow velocity and suspended concentration measurements were carried out at 4 fixed locations on the Vlakte van de Raan. Figure 3 shows the location of the measurement frames.

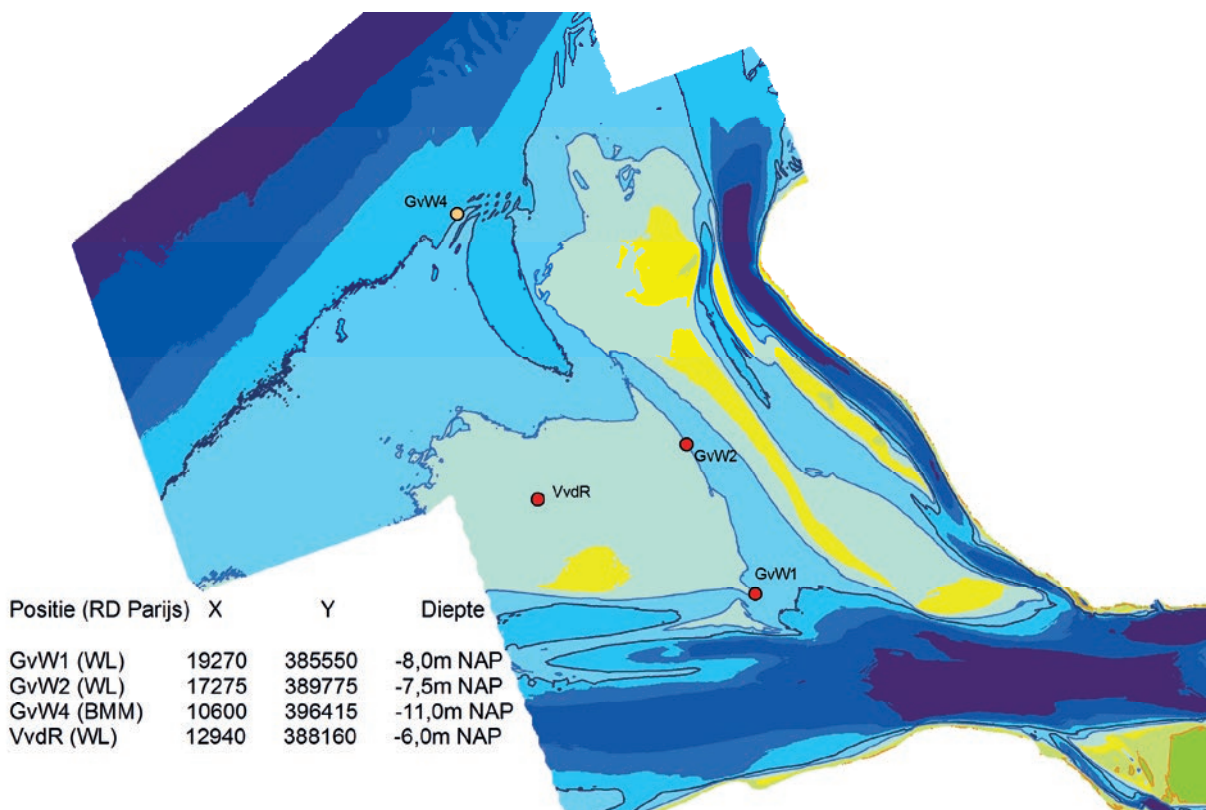| Positie (RD Parijs)	X	Y	Diepte
GvW1 (WL)	19270	385550	-8,0m NAP
GvW2 (WL)	17275	389775	-7,5m NAP
GvW4 (BMM)	10600	396415	-11,0m NAP
VvdR (WL)	12940	388160	-6,0m NAP

Figure 3. Location measurement frames on the Vlakte van de Raan (VvdR) and the channel Geul van de Walvischstaart (GvdW). Figure adapted from Plancke *et al.* (2014). Color scale indicates bathymetry from deep (dark blue) to shallow (bright yellow).

Figure 4 compares measured and computed velocities at the locations VvdR and GvdW2. These are the results of a first run with astronomical boundary conditions and without waves and further tuning. It is shown that the Delft3D-NeVla model can reproduce the measured velocities reasonably well, although the peak values are underestimated. While the model computes the depth-averaged velocity over the entire water column, the observations only covered the upper half the water column. This is supposed to cause the lower peak velocities in the model.

The spring-neap tidal cycle can be observed in the velocity time-series at both locations with higher velocities during spring tide (around 14th of August) and lower during neap tide (around 20th of August). The velocities in the channel (GvdW2) are ebb dominant; compare e.g. the velocity peak that occurs during ebb tide just before 19th of August with the previous one. This is less apparent in the flow velocity measurement on the Vlakte van de Raan. The depth-averaged velocities are generally lower here than in the channel. Furthermore, one can observe that the velocities never drop to 0 m/s at both locations, but remain 0.1-0.2 m/s during high and low water slack.
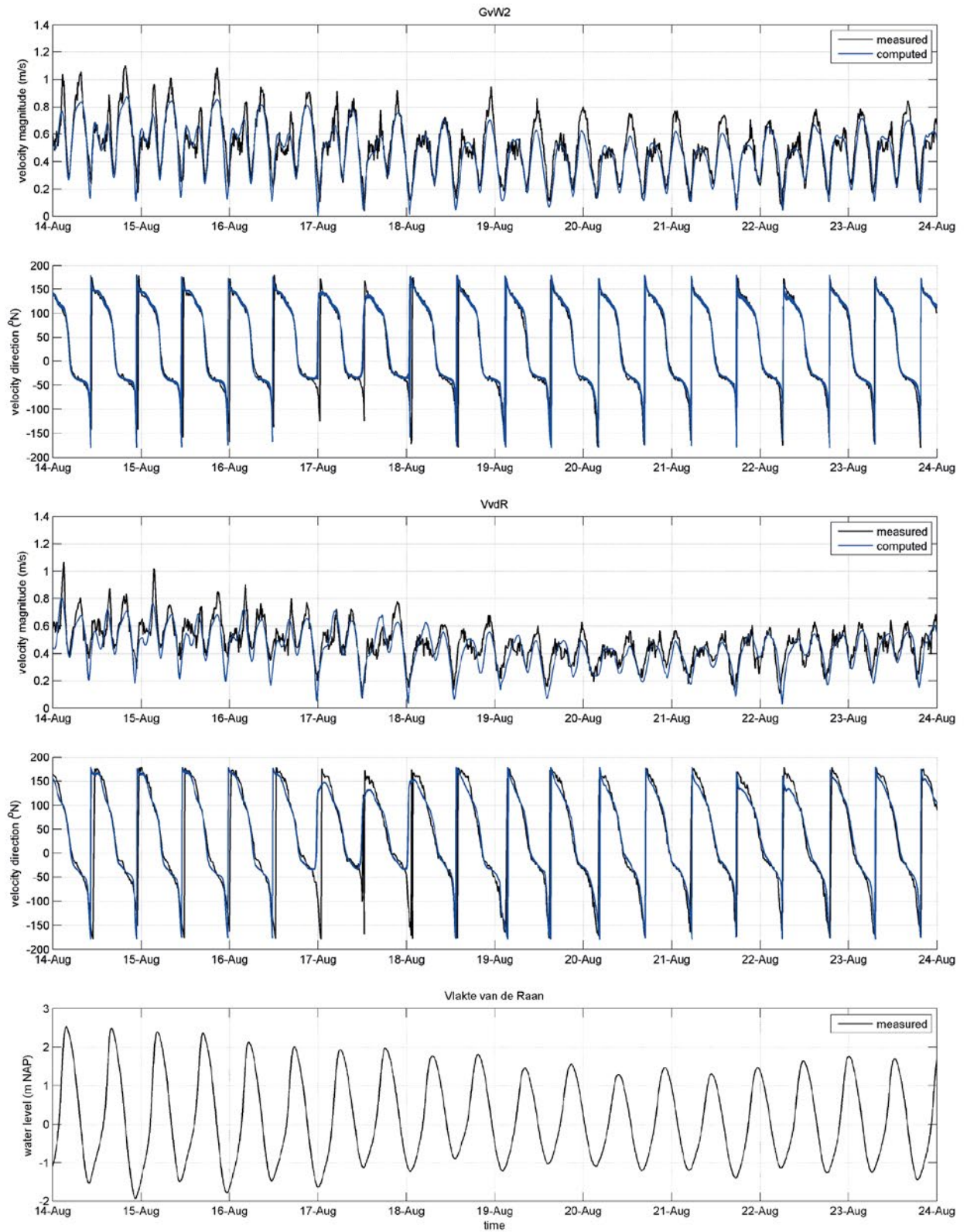
Figure 4. Comparison between measured and computed velocities at the Vlakte van de Raan (VvdR) and in the channel Geul van de Walvischstaart (GvdW2). The lower panel shows the measured water levels at Vlakte van de Raan.

Figure 4 shows that the significant wave height H_{m0} and peak period T_p at Deurloo can be quite well predicted using the Delft3D-NeVla model. Although the model tends to overpredict the wave heights, the increase and decrease during the waxing and waning of the stormy events at 9, 11 and 17 of August is nicely reproduced.
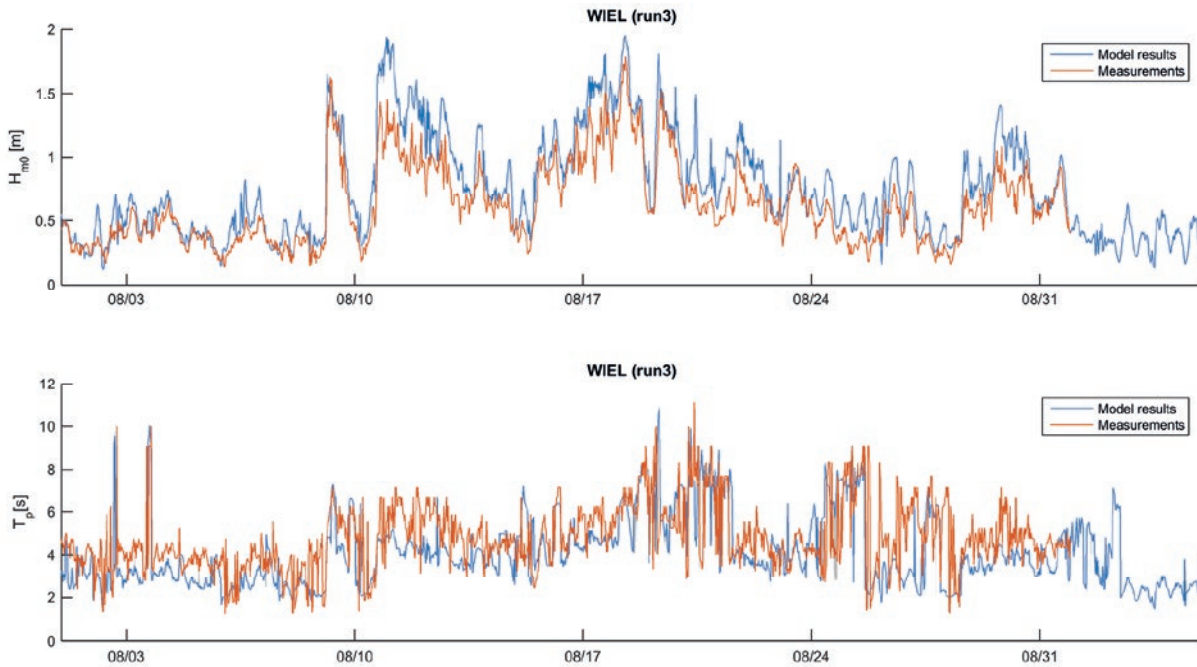

Figure 4. Comparison between measured and computed significant wave height and peak period at Wielingen.

3.2 Morphology

We plan to hindcast the morphological evolution of the mouth and Western Scheldt between 1985 (after the construction of the Zeebrugge harbor) and 2011 to assess the accuracy of the model for long-term morphological simulations. We will compare measured and predicted bed level changes (patterns and magnitude), as well as maintenance dredging volumes. These long-term and large-scale computations are challenging, since they are computationally intensive and the involved physics are very dynamic and complex.

In order to minimize computational time, the model domain is split-up in 5 online-coupled domains using domain decomposition. Flow, sand transport and bed updating are computed every flow time step (online approach). As bed level changes are relatively small during these small time steps, we multiply these with the morphological acceleration factor or morfac (see Roelvink, 2006). We have used morfac = 104, which means that the simulation of one spring-neap flow cycle of ~14 days corresponds to approx. 4 years of morphological change. This saves a lot of computational time.

Under the same assumption we use the parallel online or *mormerge* approach to include wave effects in an efficient way (see Roelvink, 2006). The different wave conditions are run in parallel. They share the same bathymetry that is updated every time step according to the weighted averaged of the bed level changes due to each condition.

Figure 5 compares bed levels computed with a morfac of 104 and 52 (no waves) to analyze the effect of the morfac on the predicted bed level changes. The maximum differences are ±2 m in the Western Scheldt; model results only differ little in the mouth. Compared to the computed bed level changes of around ±10 m, the effect of the morfac is of second order. This is expressed in Figure 6, which show the relative volume changes computed as follows for each time step:

$$\Delta V_{rel} = \frac{\Sigma \left| \Delta V_{i,morfac=104} - \Delta V_{i,morfac=52} \right|}{\Sigma \left| \Delta V_{i,morfac=52} \right|}$$ [1]

with ΔV_i the volume change per grid cell. The variation in the relative volume difference over time is the result of variable wind and tidal forcing. The relative volume differences are larger for the Vlakte van de Raan and Western Scheldt (domain 2) than for the outer domain (domain 1), because domain 2 is morphologically more dynamic than domain 1. Furthermore, we can see that the differences become smaller in time. After 20 years, the relative volume difference is 2-3% which is very small compared to uncertainties due to the physics, numerics and parameter settings of the Delft3D-NeVla model.
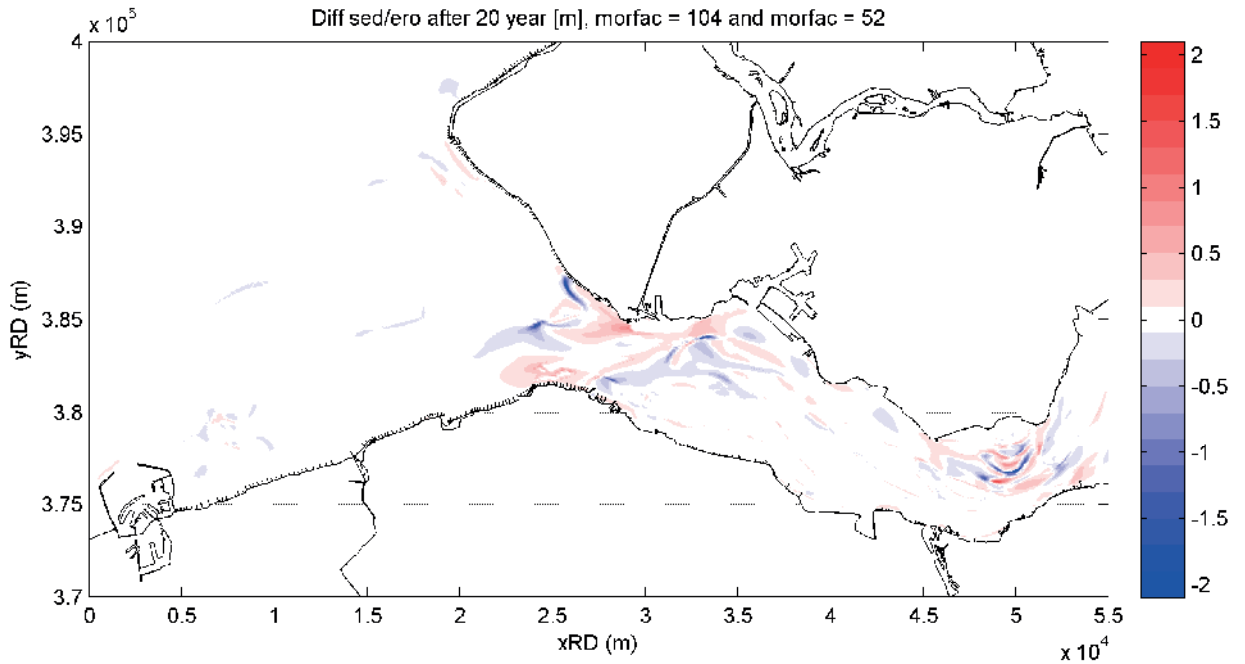
Figure 5. Difference between computed (no waves) sedimentation/erosion after 20 years with morfac = 104 and morfac = 52. Red colors indicate relatively more (less) sedimentation (erosion) with morfac = 104, and blue colors less (more) erosion (sedimentation).
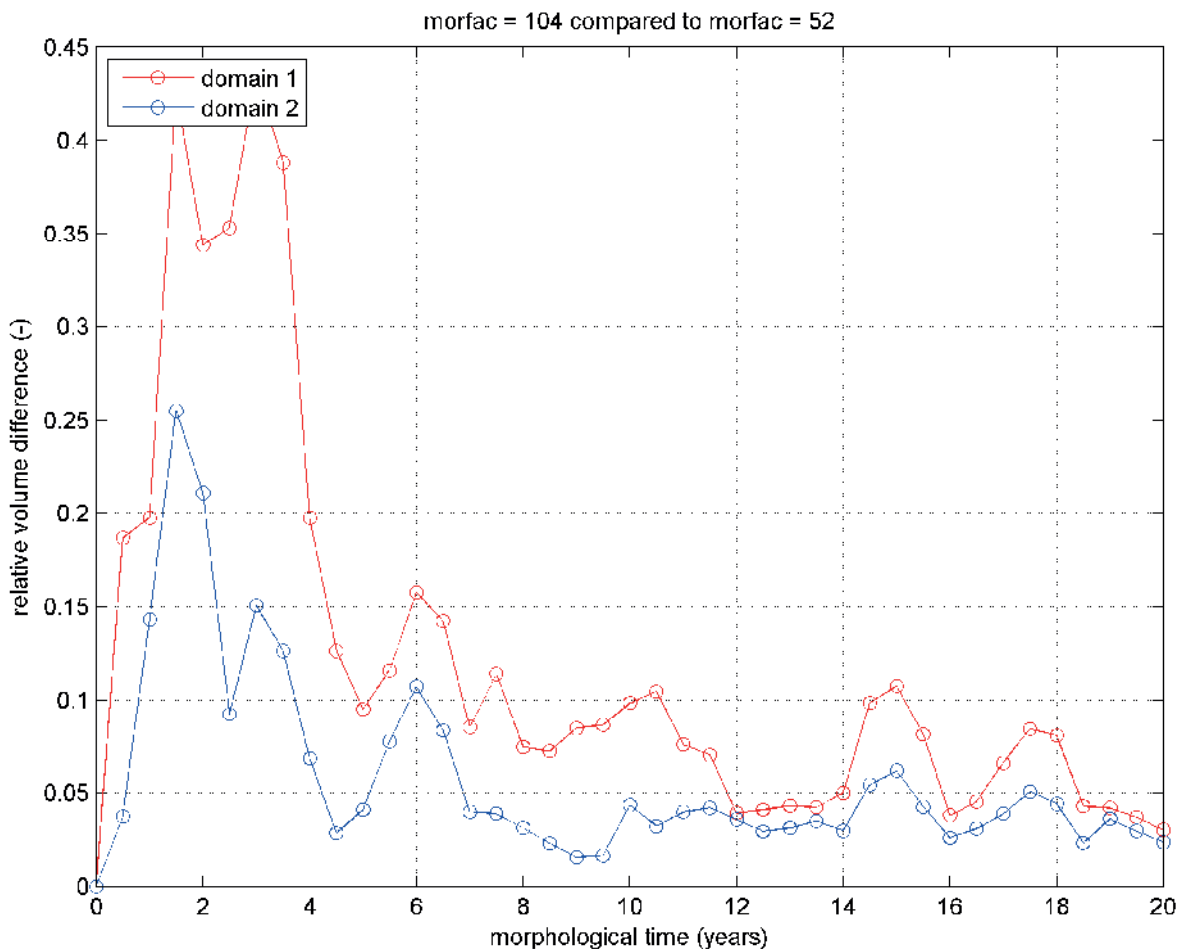

Figure 6. Relative volume difference for a simulation with morfac = 104 compared to a simulation with morfac = 52. Domain 1 refers to the area seaward from the Zeebrugge harbor, and domain 2 to the adjacent domain that extends into the Western Scheldt.

4.   DISCUSSION AND CONCLUSIONS

This paper describes the ongoing development of a process-based numerical model (Delft3D) of the Scheldt estuary. The model will become an important tool to understand and predict the morphodynamics of the mouth of the estuary due to natural processes and human interferences. The main features of this 2DH Delft3D-NeVla model are:

- computational domain covers the entire Scheldt estuary from the North Sea to Gent with a relatively high resolution
- tide, waves, wind and river discharge forcing accounted for
- presence of hard, non-erodible bed layers included
- dredging and dumping activities are accounted for
- simulation of large-scale, long-term morphological development made possible by using advanced techniques (morfac, mormerge)

The first simulations show that the Delft3D-NeVla model reproduces measured velocities and wave heights in the mouth of the Scheldt estuary reasonably well. Future steps are:
1. Further calibration and validation against measured water levels, discharges and velocities.
2. Morphological hindcast for the period 1985-2011.
3. Model simulations to study large-scale morphological interventions in the mouth (e.g. relocation navigation channel)
4. Extension to a fully coupled morphological model for sediment mixtures (incl. mud)

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