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A probabilistic approach to investigate the effect of wave chorology on process-based morphological modelling

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Abstract: This paper demonstrates the sensitivity of morphological process-based models to the chronology of input wave conditions. In this research the effect of an emerged offshore breakwater on the morphology of the beach is investigated. A 30 day long morphological simulation with real time history of the wave (brute force - base case) is compared with 150 different simulations of the same case with schematized wave conditions comprising different chronologies. The comparison between each case and the base case is quantified via the Brier Skill Score. This research shows that the skill score of a simulation largely affected by the sequence of the input wave conditions, and the best result is obtained by averaging all 150 simulations.

Keywords: *wave chronology; wave schematization; morphological modeling; Process-based model*

INTRODUCTION

During the last decade the process-based morphological models have been developed extensively, and now numerical modellers are expected to apply these models to engineering cases such as predicting the effect of the realization of a coastal project (i.e. breakwaters, entrance channels, coastal protection, dredging, etc.) on the morphology of the adjacent coastline in different time scales. However the outcomes of the process-based models are subjected to some degree of uncertainty. This uncertainty is not only due to the schematization of the processes in the models but also can be attributed to the schematization of the inputs of the models. One of the main inputs to a morphological model in the coastal zones is the wave. The common practice to apply wave in such a model is to define a number of wave conditions (significant wave height, Period, and Direction) as the wave input. There are many different suggestions to define these wave conditions; however the effect of chorology of these wave conditions is not investigated in detail. In this paper we have chosen a relatively simple case of the effect of an emerged offshore breakwater on the morphology of the beach, to investigate the effect of the chorology of wave conditions on the outcome of morphological simulations.

MODEL SETUP

The model grid and bathymetry is taken from a study of coastal hydrodynamics as part of the Coast3D program that was developed by Elias et. al (2000), later this model is modified by Roelvink and Reniers (2010). It represents a typical Holland coast profile which is rather uniform in long-shore direction. The grid resolution is in order of 15 by 20 m which gets coarser at the seaward and lateral boundaries. We added an emerged offshore breakwater at the point with 5 meter depth, with the length of approximately 200m at the distance of approximately 500m from the shoreline (Figure 1). Following the procedure of Roelvink and Waltsra (2004), we assigned the water level boundary condition at the sea

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side and the gradient (Neumann) boundary condition at the lateral boundaries. To simplify the model even more we have ignored the tide as well as wind forces and only concentrated on waves.

We have used the depth averaged version of the Delft3D model (2DH) for hydrodynamic, sediment transport and morphological component of the simulations (Lesser et. al 2004). The model uses a finite difference-scheme, which solves the momentum and continuity equations on a curvilinear gird. The velocity field obtained by solving the equation of continuity and the momentum equations is used to calculate the sediment transport field. Every time step, as a consequence of the divergence of the sediment transport field, the bed level is updated. To add the wave forces to the model we coupled Delft3D with the wave propagation and dissipation module of XBeach (Roelvink et. al. 2009). The advantage of this coupling is that the same grid can be used for wave and hydrodynamic solver, without disturbances at the lateral boundaries. All the simulations in this study are carried out for 30 days using different wave conditions.

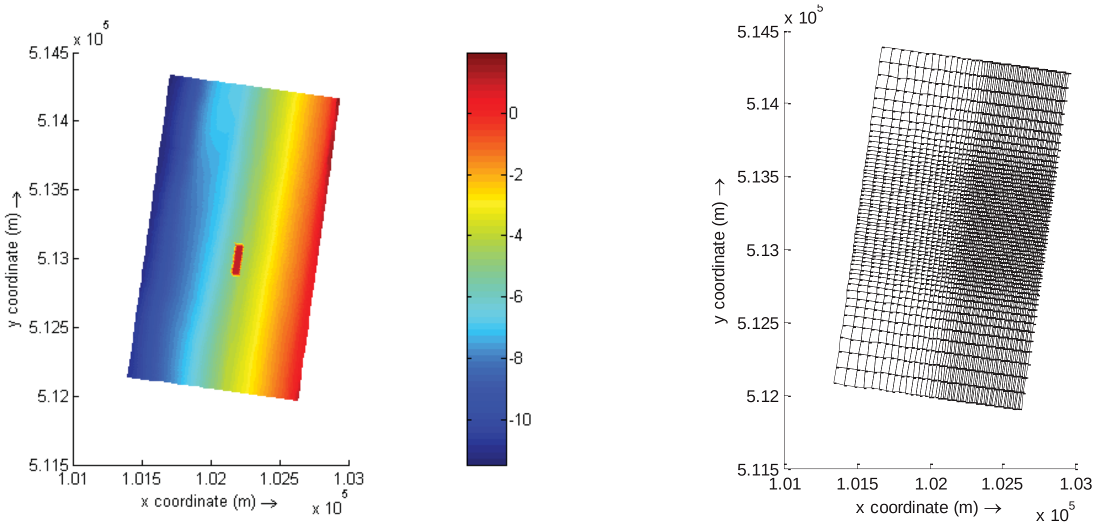

Fig. 1. Grid and bathymetry of the model including an emerged breakwater

WAVE INPUT

A one month time history of wave records (January 2004) is chosen from a wave measurement station in the North Sea (Figure 2).

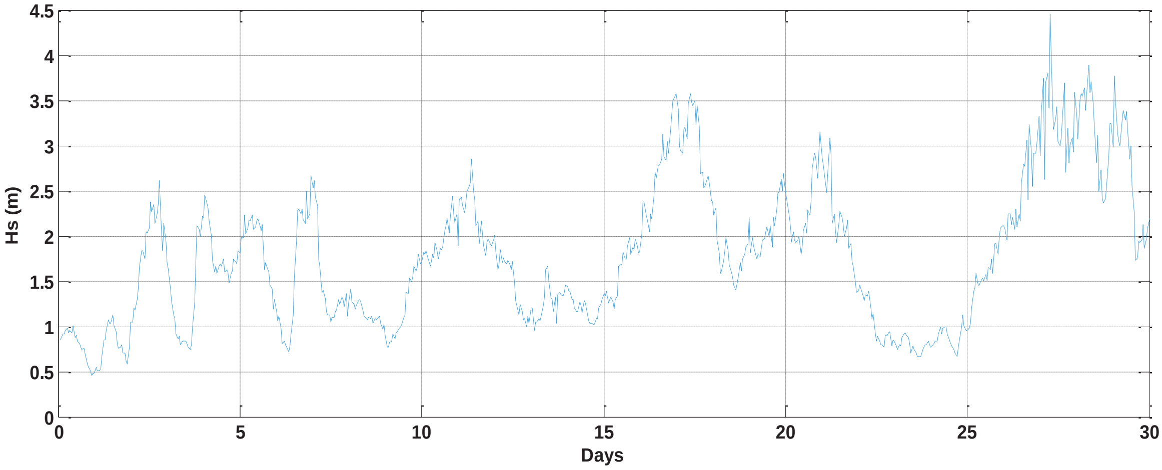

Fig. 2. Time history of wave height in 30 days

We have applied the concept of the wave energy flux to schematize the wave data to 6 wave conditions. In this method first the energy flux of each wave is calculated using the following equation:

$$E_f = (\rho.g.H_s^2/8).C_g \tag{1}$$

In which ρ is the water density, g is the gravitational acceleration, Hs is the significant wave height and Cg is the group wave celerity in deep water.

The directional and wave height bins are determined in a way that the summation of the energy flux of different waves within each bin is the same. For each bin the representative wave is calculated so that the energy flux of the representative wave is equal to average of the energy flux of all the waves in that bin.

$$H_s^{\mathrm{Re}\,p} = \sqrt{\frac{8.\overline{E}_f}{\rho.g.C_g}} \tag{2}$$

Figure 3 shows the procedure of the wave schematization, and 6 schematized wave conditions are presented in Table 1.

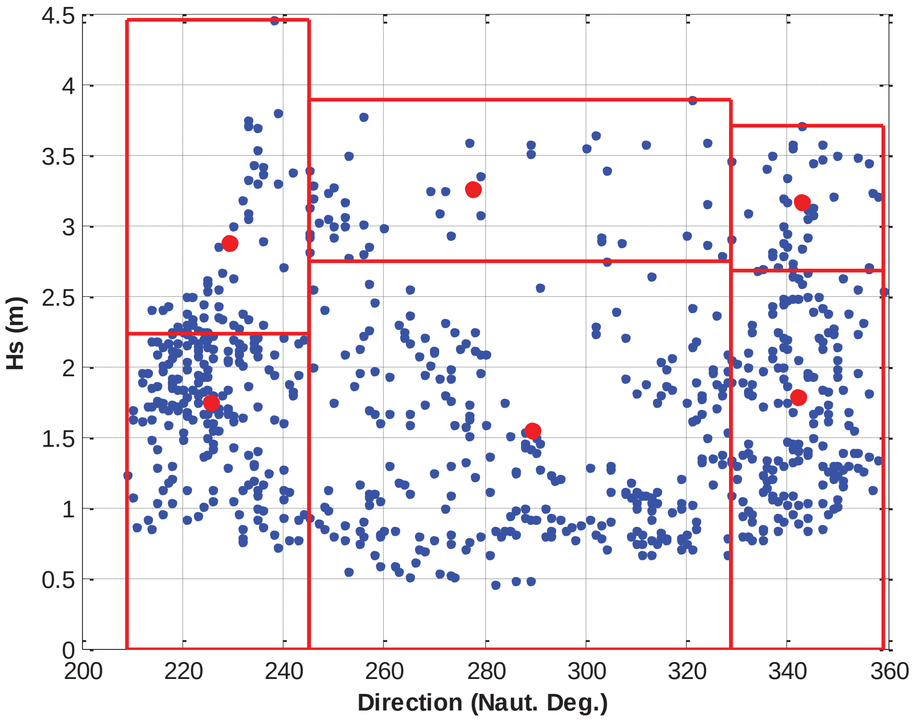

Fig. 3. Representative wave conditions (red lines: boarder of the bins, blue dots: individual waves red dots: representative wave conditions)

Table 1. Schematized wave conditions

	Hs	Dir.	Tp	% of Occ.
1	1.74	225.73	6.16	25.44
2	2.88	229.24	7.37	7.81
3	1.55	289.22	6.20	33.65
4	3.25	277.43	8.13	5.52
5	1.78	342.11	7.07	22.07
6	3.17	342.69	8.52	5.52

SIMULATIONS

Base case scenario

For the base case scenario one 30 days simulation is carried out using the complete time history of wave as the input (Figure 2). The resulting bathymetry of this simulation is considered "Perfect" result and we used this "Perfect" result as the base for comparing the result of different simulations. Figure 4 demonstrates the resulting of the base case after 30 days of simulation.

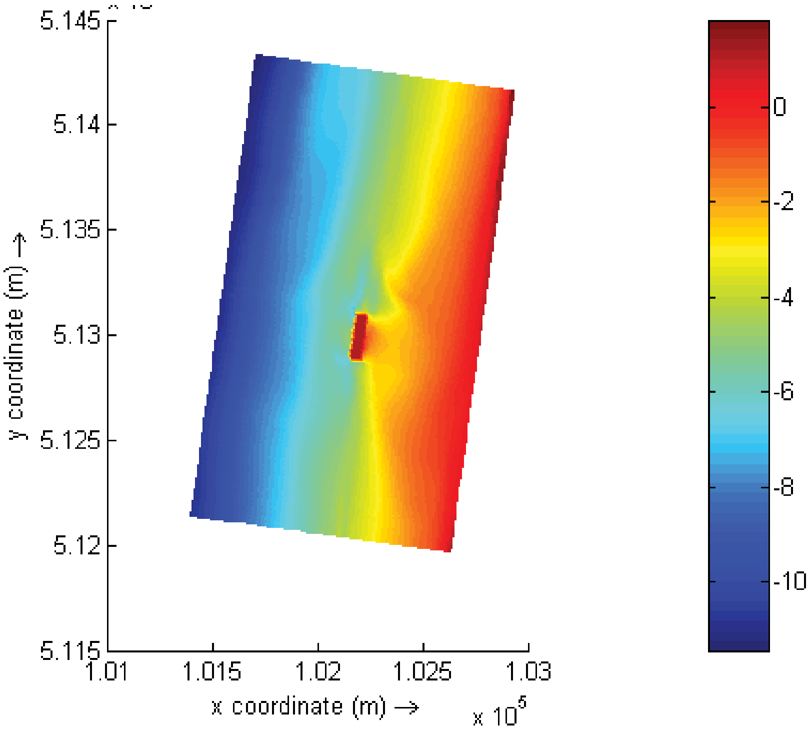

Fig. 4. resulting bathymetry of the base case.

Simulations with different chronology of wave conditions

In total 150 different simulations are carried out with abovementioned 6 schematized wave conditions. In each simulation the chorology of wave conditions is changed randomly and in all of them the morphological changes of the coastline is simulated for 30 days.

RESULTS and DISCUSSIONS

To show the effect of different wave chorology on the outcome of simulations, the results of the base case scenario is considered "perfect" and the results of other simulations are compared with this "perfect" simulation.

First we have used the Brrier Skill Score (BSS) to Compare the result of the simulations. The BSS is one of the indicators that have been used in the evaluation of the coastal morphodynamics models by Brady and Sutherland (2001), Sutherland et al. (2004), Van Rijn et al. (2002), and Van Rijn et al. (2003). In this study the following relation is used to calculate the BSS of the simulations with schematized wave conditions:

$$BSS = 1 - \frac{<(Y-X)^2>}{<(B-X)^2>} \qquad (3)$$

In which Y is the evaluated simulation, X is the perfect simulation (base case), and B is a baseline (initial bathymetry). In this relation, $< >$, means taking an arithmetic average. In other words BSS provides an objective quantification of the skill of a simulation, where skill is defined to be the accuracy of a model prediction relative to a baseline prediction. This skill score has the maximum of 1.0 which means that the evaluated simulation is as good as the perfect simulation. The lower limit of the skill score is not bounded to any number and The BSS can become negative if the simulation result is less accurate than the baseline. The value of zero for BSS indicates that the evaluated simulation is the same as the baseline. In the case that initial bathymetry is considered as the baseline, van Rijn et al. (2003) proposed a qualification of BSS, as repeated in Table 2.

Table 2. Classification of the morphological models based on the BSS Van Rijn et al. (2003)

Qualification	BSS
Excellent	0.8-1.0
Good	0.6-0.8
Reasonable	0.3-0.6
Poor	0-0.3
Bad	<0

For all of 150 different simulations the BSS is calculated. Figure 5 shows the CDF of the resulting BSS for all the simulations. It shows that 23% of the runs give the skill score of less than 0.3 which are considered poor / bad simulations and only 10% of the models considered good (BSS > 0.6) and there is no simulation with BSS of more than 0.8 (Excellent).

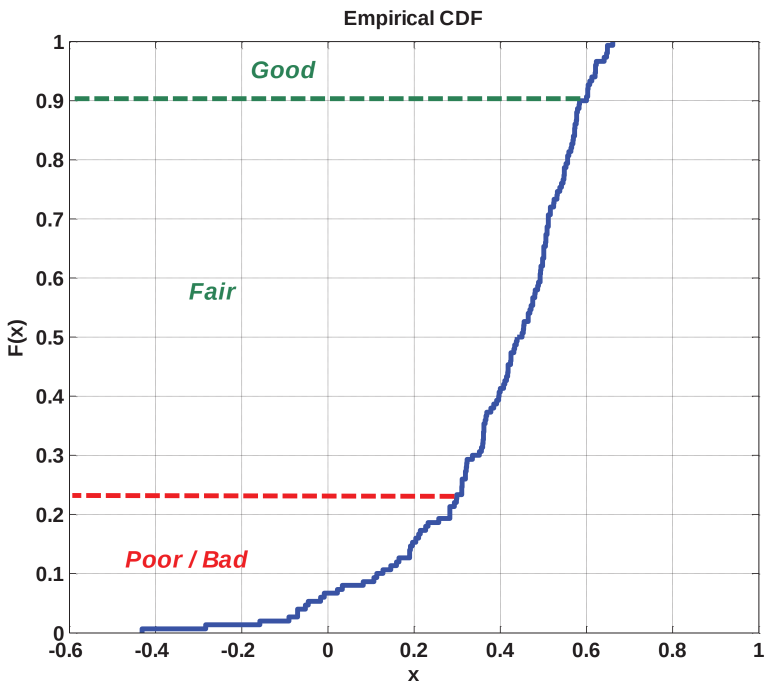

Fig. 5. CDF of the resulting BSS in 150 simulations

The maximum BSS for the best simulation is +0.66, which is indeed a high score for a morphological model, meanwhile the minimum Skill score is -0.43. This very wide range of skill scores demonstrates the effect of wave chronology in the result of the morphological simulation. Figure 6 shows the resulting bathymetry of the best and worst simulation (Based on BSS).

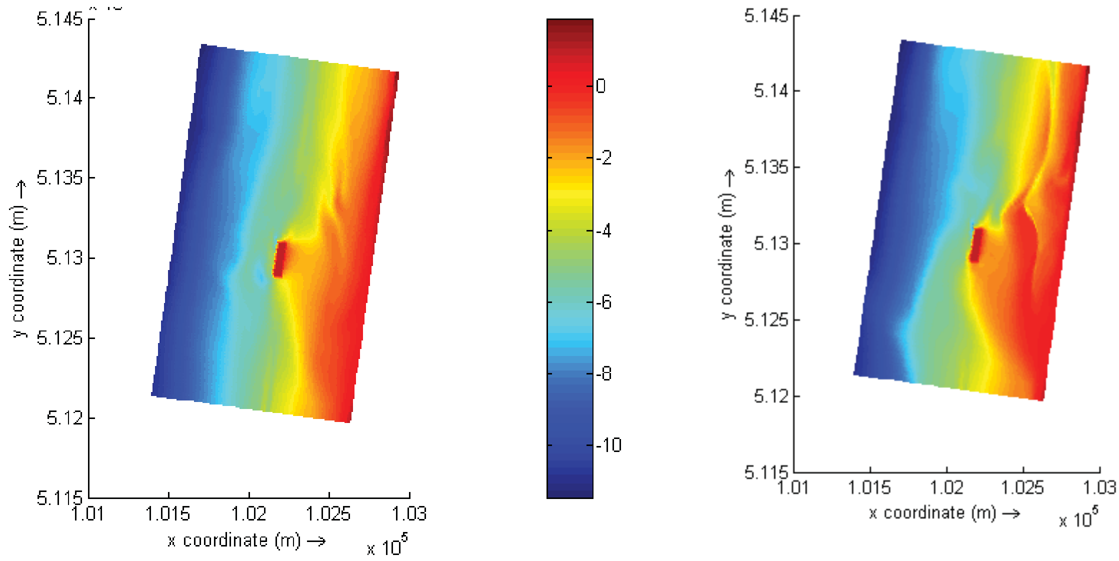

Fig. 6. Resulting bathymetry of the best (left) and worst (right) simulation.

In Figure 7 we have compared the time history of the real wave with the schematized wave conditions applied in the "best" and "worst" simulations. Figure 7 shows that the wave input in the best simulation ends with the wave conditions 6 and 2. These wave conditions are storm wave conditions and the significant wave height of these two wave conditions are reasonably close to the last storm in the time history if the real wave data. Interestingly the wave input in the "worst" simulation is also ends with wave condition 2 but the wave condition which proceed that (No. 1) has relatively low wave height.

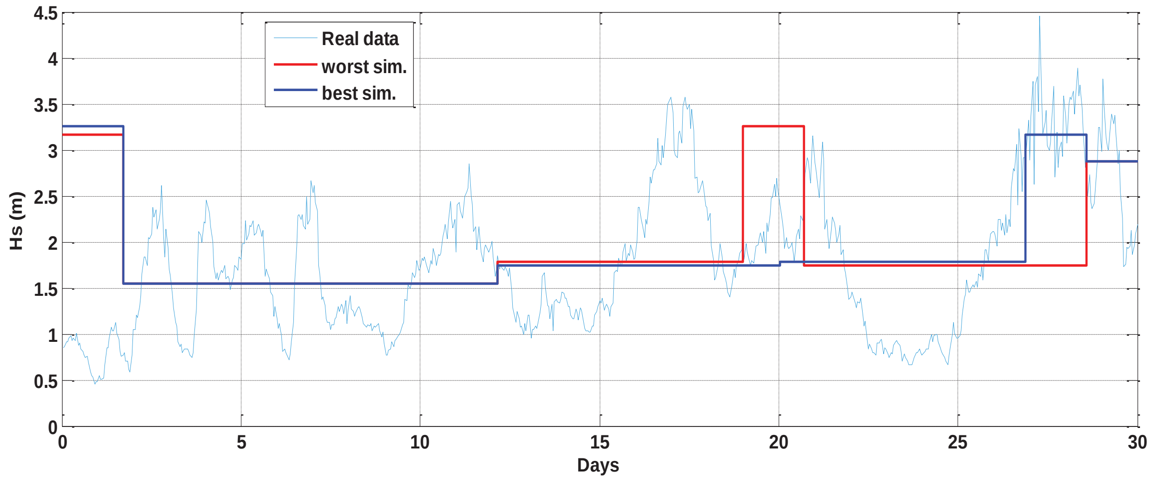

Fig. 7. Time history of real wave and schematized wave for the best and worst simulation

If we average all of the 150 resulting bathymetries (Figure 8 - top panel) and calculate the BSS for this averaged bathymetry, it appears that this solution scores 0.75, which is higher than all the simulations. Figure 8 also shows the sensitivity of different areas in the model to the wave chronology. In the bottom left panel the standard deviation of the resulting depths for all the points in the domain is shown and in the bottom right panel the average sedimentation/erosion values is demonstrated. Comparing these two figures, it can be seen that the area directly in the lee side of the breakwater is a morphologically active area (high sedimentation/erosion) with relatively low sensitivity to the wave chronology (low standard deviation). It appears that the areas on the sides of the breakwater are the relatively active areas with high sensitivity to the chronology of wave conditions.

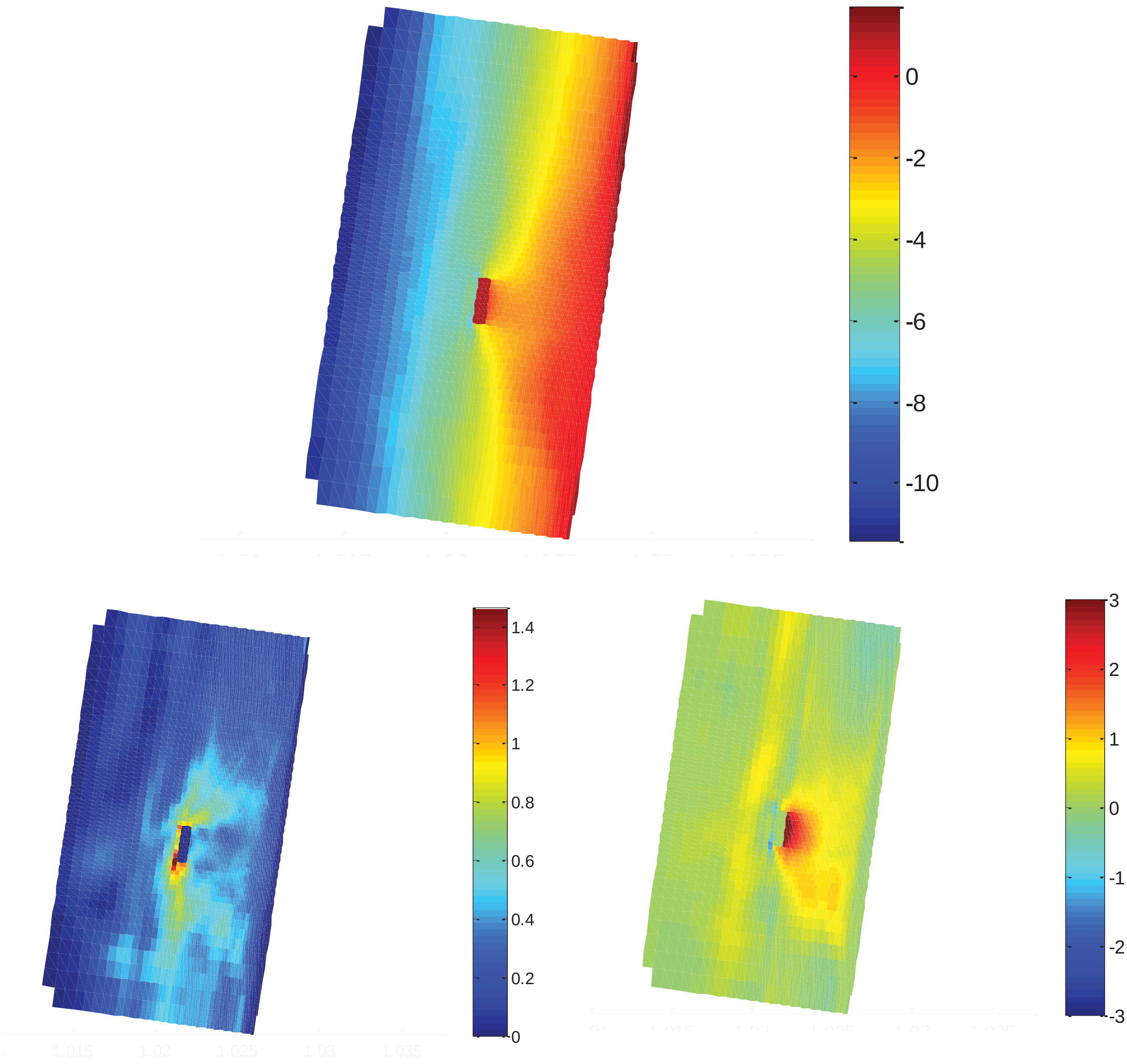

Fig. 7. Average of resulting bathymetries (Top), Standard deviation of the resulting bathymetries (Bottom/left) and Average sedimentation / erosion patterns (Bottom/right)

COCLUSIONS

The effect of wave chronology on morphodynamic predictions made by process based models is investigated by applying Delft3D to an idealised bathymetry containing a single emergent shore parallel breakwater. The results show that the adopted sequence of the wave conditions plays a significant role in defining the final predicted morphology and in some sequences can lead to a non-realistic result. Also it is shown that the last 2-3 storms in the wave sequences mostly determine the main characteristics of the final morphology. The best result is produced when final morphologies predicted forced with various different wave sequences are averaged together. Consequently, this implies that, in forecasting simulations, in which the exact time history of the wave conditions is not known, the best solution may be to average different results obtained by forcing the model with a number of different wave chronologies. This average solution sufficiently captures the main morphological features, which are important in engineering projects.

REFERENCES

Brady, A.J., Sutherland, J. (2001). COSMOS modelling of COAST3D Egmond main experiment. HR Wallingford Report TR 115.

Elias, E., Walstra, D., Roelvink, J. and Stive, M. (2000). The egmond model; calibration, validation and evaluation of delft3d-mor with measurements. in Proc. 27th Int. Conf. on Coastal Engineering (Sydney, Australia).

Lesser, G., Roelvink, J., van Kester, J. and Stelling, G. (2004). Development and validation of a three-dimensional morphological model, Coastal Eng. 51, 8-9, pp. 883-915.

Roelvink, J. and Walstra, D. (2004). Keeping it simple by using complex models, in Advances in Hydro-Science and Engineering (Brisbane, Australia), pp. 1-11

Roelvink, J., Reniers, A., van Dongeren, A., van Thiel de Vries, J., McCall, R. and Lescinski, J. (2009). Modeling storm impacts on beaches, dunes and barrier islands, Coastal Eng. , 56, pp. 1133-1152

Roelvink and Reniers (2010).

Sutherland, J., Peet, A.H. and Soulsby, R.L. (2004). Evaluating the performance of morphological models. Coastal Engineering 51, pp. 917-939.

Van Rijn, L.C., Ruessink, B.G., Mulder, J.P.M. (Eds.), (2002). COAST3D—EGMOND, the Behaviour of Straight Sandy Coast on the Time Scale of Storms and Seasons. Aqua Publications, Amsterdam.

Van Rijn, L.C., Walstra, D.J.R., Grasmeijer, B., Sutherland, J., Pan, S., Sierra, J.P., (2003). The predictability of cross-shore bed evolution of sandy beaches at the time scale of storms and seasons using process-based profile models. Coastal Engineering 47, 295 – 327