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Long-term and large-scale modeling of mega-nourishments

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The Sand Engine, ZM (Zandmotor), is a hook-shaped mega-nourishment (21.5 millions m³) located on the Dutch coast with an alongshore length of 2.4 km and an offshore extension of 1 km. The mega-nourishment project was initiated as a coastal protection measure on decadal time scales to maintain the coastline under predicted sea level rise. It follows the philosophy of working in harmony with the forces of nature by taking advantage of the longshore transport as the main distributor of sand along the adjacent coast (Stive et al., 2013).

In the present contribution we use the Q2Dmorfo model (van den Berg, et al., 2012) to predict the long-term dynamics of the ZM. The Q2Dmorfo lies between the 2DH morphodynamic models and the one-line coastline models. In particular, it computes the longshore transport in a parameterized way (ignoring the surfzone dynamics) and the cross-shore transport by relaxing the bathymetry to an equilibrium, in order to predict non-linear changes in the bathymetry related to the shoreline response. In this way the Q2Dmorfo overcomes the limitations of the 2DH models related to its computational cost, the modeled wave climate can be the real one (it does not need to be schematized) and the wave refraction and shoaling is computed over the changing bathymetry (a more realistic description than the classic one-line approach).

So far, the Q2Dmorfo had been used to understand the main physical mechanisms driving the formation of shoreline sand waves (SSW), which are rhythmic undulations with alongshore scales in the range of 1-10 km that influence the bathymetric contours well beyond de surf zone (van den Berg, et al., 2012). Its validation has been made in a rather qualitative fashion: the model was run in an idealized configuration (i.e. using idealized profiles and perturbations, synthethic or even constant wave climate, etc.) and it was contrasted against nature by looking only at the SSW wavelenghts, in part because data at these large temporal (~years) and spatial (~10km) scales is scarce or unexistent (specially regarding bathymetric data).

The detailed monitoring of the Sand Engine evolution (Figure 1) gives very valuable data and presents a unique opportunity to calibrate/validate the Q2Dmorfo model. Due to the large perturbation in the shoreline and bathymetry we use an updated version in which: a) the 'cross-shore transport' is in the direction of the maximum local bed slope and b) a 'fuzzy shoreline algorithm' is applied to deal essentially in the same way with the submerged and emerged parts of the domain, allowing the modelling of large shoreline angles.

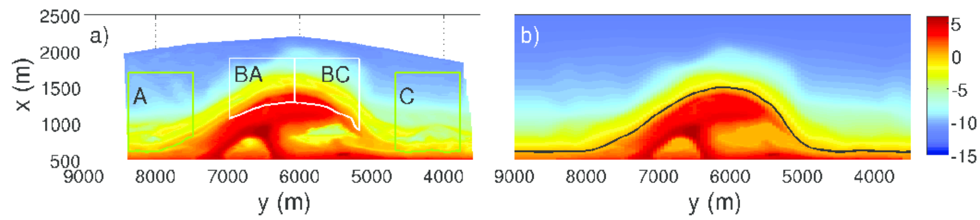

Figure 1 (a) Bathymetric survey from January 2012 with volume control boxes and (b) input bathymetry of the model with the bars filtered out and the lagoons adjusted.

We calibrate the model by optimizing the Brier skill score, BSS, of the modeled bathymetric lines, after 400 d of evolution (Figure 2a), by varying three parameters: a) the coefficient in front of the longshore transport rate, μ (proportional to the K coefficient), b) f_c, related to the dynamic depth of closure, and c), υ, related to the relaxation time towards the equilibrium cross-shore profiles. To validate the model calibration, we first compute the BSS after 1150 d (Figure 2b) for the same range values of the calibration, confirming the validity of the calibrated parameters. The model reproduces the evolution of the shoreline and depth contours until March 2015 with a BSS of about 0.65. Second, by defining control volume boxes (Figure 2a), we confirm the correct diffusion of the ZM tip and the feeding to adjacent beaches. Finally, to compute the effective diffusivity of the simulations and the measurements we use the concept of shoreline diffusivity, which is easily formulated within the framework of the one-line approximation for shoreline dynamics. The modeled coastline diffusivity during the 3-yr period is 0.0021 m^2s^{-1}, close to the observed value of 0.0022 m^2s^{-1}. In contrast, the coefficient of the classical one-line diffusion equation is 0.0052 m^2s^{-1}.

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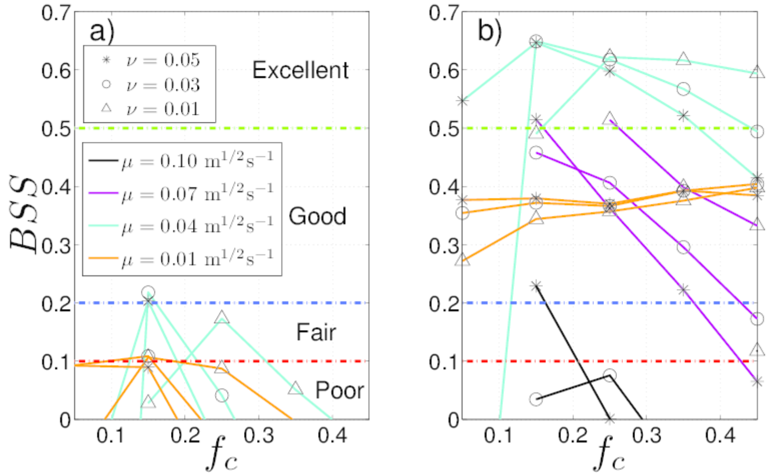

Figure 2 Brier skill score of the bathymetric lines (a) after 400 d and (b) after 1150 d, as a function of μ, υ, f_c

For the long-term analysis, a total simulation time of 30 yr has been chosen which is safely longer than the envisaged time of 15-20 yr (de Schipper et al., 2014, Stive et al., 2013). To account for variability in the future wave climate, WC, five WC were designed based on historical wave data. According to the long-term modeling, for the next 30-yr period, the Zandmotor will display diffusive behavior, asymmetric feeding to the adjacent beaches, and slow migration to the NE. After 30 yr the Zandmotor amplitude will have decayed from 960 m to about 350 m with a scatter of only about 40 m associated to climate variability. The effective diffusivity is reduced in the long-term simulations to 0.0014-0.0019 m^2/s, the variability of the diffusivity (visible in Figure 3) is due to the variability of the different WC. Thus, the lifetime prediction, here defined as the time needed to reduce the initial amplitude by a factor 5, would be ~90 yr instead of the classical diffusivity prediction of ~35 yr. The resulting asymmetric feeding to adjacent beaches produces ~100 m seaward shift at the NE section and ~80 m seaward shift at the SW section. Looking at the variability associated to the different wave climates, the migration rate and the slight shape asymmetry correlate with the wave power asymmetry (W vs N waves) while the coastline diffusivity correlates with the proportion of high-angle waves. Although the measurements and long-term simulations show a diffusive behavior of the ZM, the significant reduction in coastline diffusivity and the observations of sand waves in the Netherlands (Jeunken and Ruessink, 2002), attributable to wave obliquity, confirm the finding of Falques (2006) that the Dutch coast is near the high-angle wave instability. Furthermore, the analysis of the ZM potential to trigger a train of sand waves under climate variability will be shown in the conference.

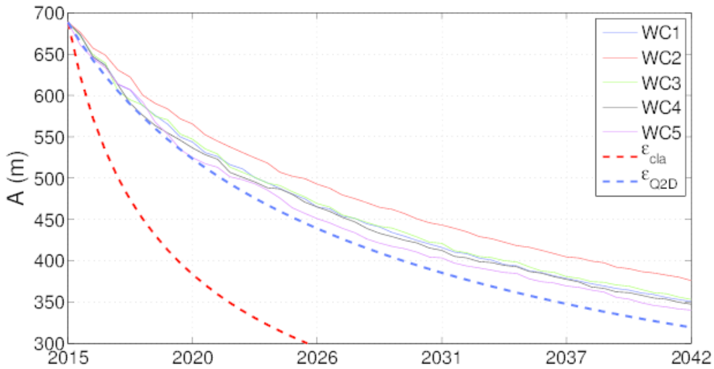

Figure 3 Modeled amplitude of the ZM during 27 yr, starting from March 2015. WC1 to WC5 correspond to model computations with five different wave climate scenarios, ε_{Q2D} and εcla respond to the one-line diffusion equation with the diffusivity inferred from the model computations or with the classical diffusivity evaluation, respectively.

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