LONG-TERM DUNE EVOLUTION UNDER INTERACTING CROSS-SHORE AND LONGSHORE PROCESSES

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INTRODUCTION

Coastal dunes play an important role in flood protection and erosion mitigation along sandy coasts. Still, few models are available that predict long-term dune evolution. Dune processes are typically modeled at shorter time scales, focusing on storm impact. Meanwhile, long-term coastline evolution models typically ignore exchange of sediment between the beach and the dune. Instead, these models often consider a fixed profile that moves seaward or landward if gradients in the longshore transport are negative or positive, respectively. Nevertheless, it is evident from field studies and morphological models that longshore transport gradients provide a relevant contribution to both beach and dune evolution (Psuty, 1988), and that the dune and the beach respond to sediment budget changes at different time scales (Stive et al., 2002). As a step towards bridging the gap between nearshore, beach, and dune modelling, this study investigates the interaction between longshore transport gradients and the beach and dune evolution on decadal time scales. This aim is addressed by combining an analysis of a 22-year long data set at IJmuiden (The Netherlands; see Figure 1) with simulations using a semi-empirical cross-shore model, the CS-model (Larson et al., 2016).

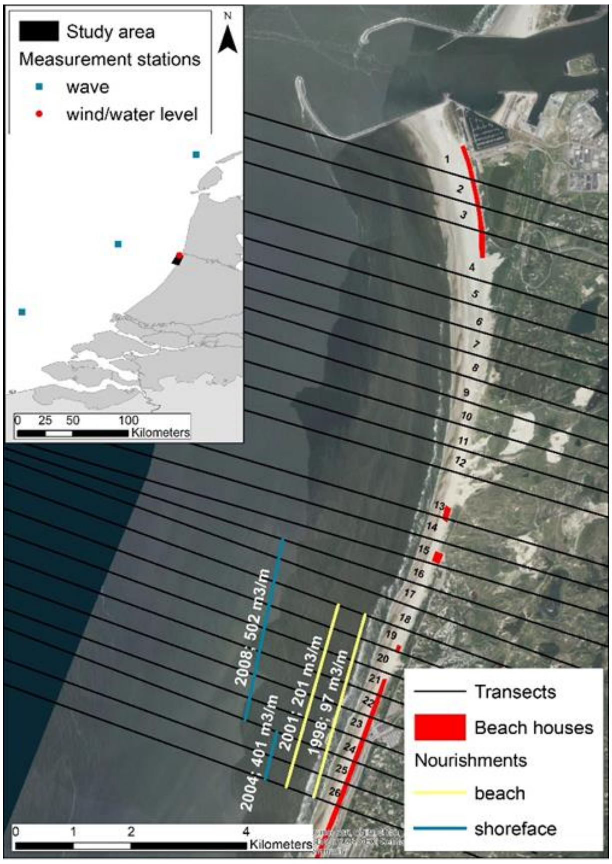

Figure 1 - Study area

MODEL DESCRIPTION

The beach and dune system is described by multiple cross-shore profiles along the studied coastline (Figure 1). The subaqueous part is assumed to follow an equilibrium profile including sand bar deposits. The profile is divided into a dune (V_{dune}), a beach (V_{beach}), and a bar volume (V_{bar}) that exchange sediment in cross-shore direction (Figure 2).

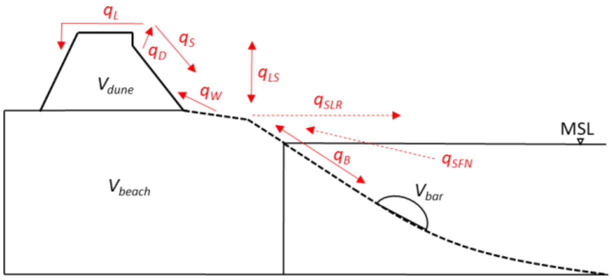

Figure 2 - Profile schematization and included transports

The model is run with a 3-hour time step and is forced with deep-water wave height, wave period, and wave direction, wind speed, wind direction and still water level. The main processes included are aeolian transport (q_W), dune erosion (q_D), which is either deposited at the beach (q_S) or on the landward side of the dune in case of overwash (q_L), exchange between the beach and the bar (q_B), onshore transport from shoreface nourishments (q_{SFN}), and an offshore directed transport to compensate for sea level rise (q_{SLR}). In the CS-model aeolian transport is assumed to be limited by the available sediment volume, V_W, of the proper grain size of dune building sand during each time step i (Fredriksson et al., 2017) according to,

$$V_{W,i} = V_{W,i-1} + (q_{S,i-1} - q_{W,i-1} - A_q(q_{SLR,i-1} - q_{LS,i-1}) + A_s q_{SFN,i-1})\Delta t + A_b V_{nour,i-1}$$

$$V_W \geq 0$$

where Δt is the length of the time step, V_{nour} volume nourished to the beach, and A_q, A_s, and A_b empirical coefficients describing the fraction of sediment that has the proper grain size for aeolian transport with regard to the specified transport rates and volumes. The aeolian transport is limited by the available sediment so that $q_W \Delta t \leq V_W$. Thus, if $V_W = 0$ the aeolian transport, q_W, is set to 0. Impact of beach houses are described by a coefficient, K_{BH}, so that the aeolian transport in transects with beach houses is given by $q_{W,BH} = K_{BH} q_W$.

SELECTED RESULTS AND DISCUSSION

Dune evolution is simulated both with and without gradients in longshore sediment transport rate (q_{LS}), which were derived as an average of observed volume changes in the beach and dune volume in the transects over the period from 1994 to 2016 (JARKUS data).

Figure 3 shows gradients in longshore transport rate from profile 1 just south of the IJmuiden harbor to the southernmost profile 26. If the nourished volumes (specified in Figure 1) are subtracted, profiles 1-15 are long-term accreting, profiles 16-17 are stable, and profiles 18-26 are eroding.

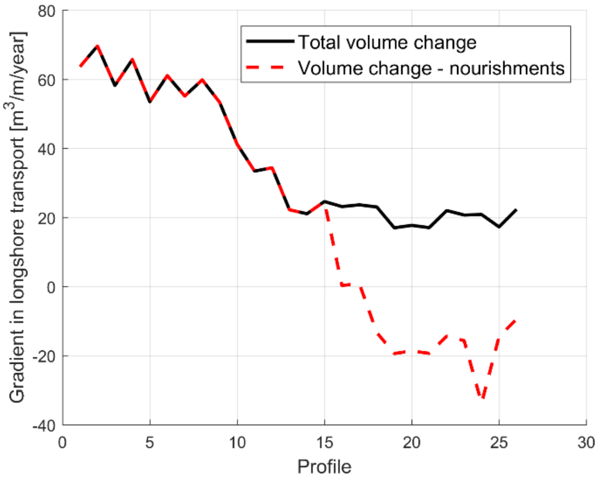

Figure 3 - Gradients in longshore transport rate

Figure 4 shows the results of the simulations for three profiles with different properties. Profile 2 is accreting and has seasonal beach houses in front of the foredune; profile 9 is accreting and the foredune is developing freely; and profile 23 is eroding and impacted by both nourishments and beach houses.

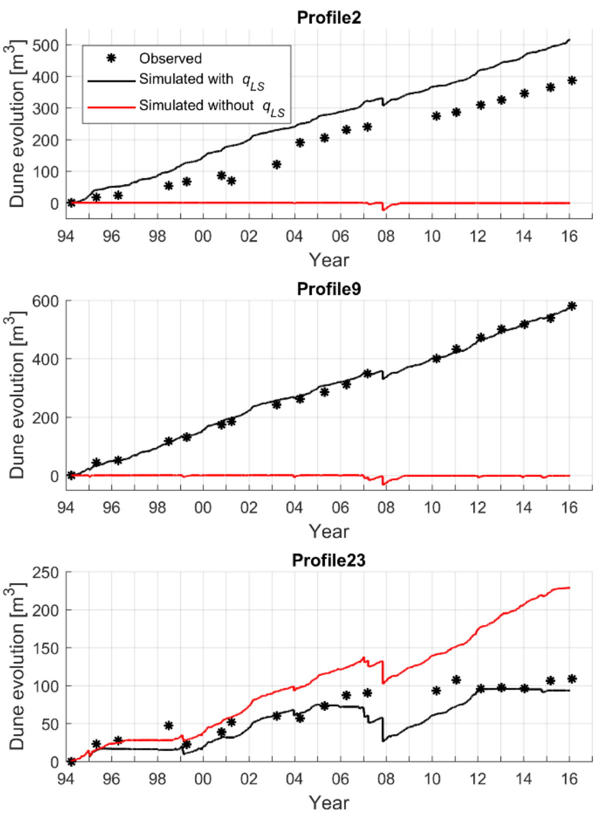

Figure 4 - Observed and simulated dune volume evolution with and without gradients in longshore transport rate

Aeolian transport coefficients were calibrated to fit the most rapidly growing dunes without impact from beach houses in profiles 7-12. In profile 9 the simulation including q_{LS} shows an almost perfect fit to the data. Except for dune erosion during storms (q_S), q_{LS} is the only supply of sediment available for aeolian transport to these profiles. The simulation of profile 9 without q_{LS}, therefore shows zero dune growth.

The same behavior can be seen in the simulation results for profile 2. However, here the simulation including q_{LS} overestimates dune growth by about 25% during the simulation period. An explanation for this could be local differences in beach house management; the beach house coefficient K_{BH} was set to a common value for all profiles assuming that they were present 5 months per year, K_{BH} = 1-5/12 = 0.58. It may also be due to impact on the longshore component of the aeolian transport from the harbor moles or a large gap in the foredune between profiles 3 and 4 that can be seen in Figure 1.

In profile 23, where q_{LS} is negative, beach and shoreface nourishments are the most important sediment supply for aeolian transport. This can be seen in the observations and simulation results through stepwise dune growth after the nourishments in 1998, 2001, and 2008. The initial dune growth is due to a nourishment that was carried out the year before the simulation period. In profile 23, q_{LS} depletes the volume of available sediment (V_W), therefore the simulations without q_{LS} overestimates dune growth.

The results demonstrate that longshore transport gradients are a key factor for long-term dune evolution at the study site. In beach profiles with long-term erosion, nourishments have a significant impact on dune evolution through supplying sediment for aeolian transport. The aeolian transport increased after nourishments, both in simulations and observations, which is in agreement with previous observations along the Dutch coast (Bakker et al. 2012).

Overall, the results are a promising contribution to bridging the gap between nearshore, beach, and dune modelling. As the next step, a coupling between the CS-model and a longshore sediment transport model is envisioned. Such a coupled model can account for the variability in longshore transport rates due to varying forcing conditions, climate change, and evolution of the shoreline shape. The capability to simulate decadal-scale dune evolution will improve long-term risk assessments for flood prone areas protected by dunes, and is a requirement for safe designs of nature-based solutions.

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