Simulating beach and dune evolution due to longshore transport, aeolian transport and dune erosion

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INTRODUCTION

Dune dynamics play an important role in the cross-shore redistribution of sand volume. Though dune erosion during storms is a short-term process on the timescale of days, the effects on the coastal system may be long-term. On the other hand, the recovery or growth of the dune by wind-blown sand originating from the beach and intertidal zone, is on average 10 m3/m per year along the Dutch coast. It is therefore an important source and sink term for coastline evolution. Here we describe the implementation in the ShorelineS code (Roelvink et al, 2020) as a separate module, that can be activated if relevant for the specific coastal zone. Furthermore, this can help to specify practical choices in the set-up of a model, when simulating a coastal zone with both accreting and eroding sections, it is more realistic to be able to separately specify an active height for the underwater profile (depth of closure up to dune foot) and dune profile (dune foot to dune height).

MODELLING APPROACH

The newly implemented dune dynamics module is based on the approach of Larson et al. (2016). The main processes that are considered are dune erosion due to wave attack, and wind-blown sand transport leading to dune growth. The sand transport equations are formulated based on relevant physics in combination with empirical observations and then validated towards laboratory and field data. The modelled features include dune height (from dune foot to crest), the locations of the seaward dune foot, beach width and shoreline position.

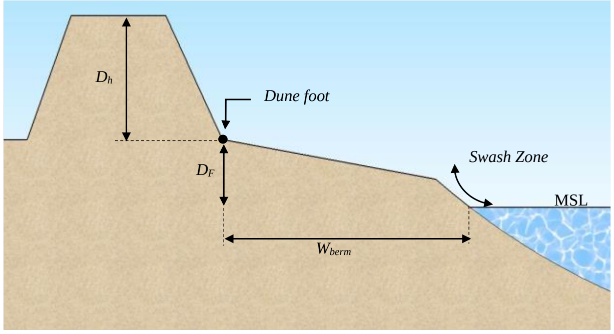

Figure 1. Specifications of the modelled features: dune height (Dh), dune foot height (DF) and berm width (Wberm).

The dune model considers dune growth due to aeolian transport and dune erosion due to wave attack. The beach width plays an important role in both processes, as it controls the aeolian transport through dry beach width and fetch on the one hand, and the runup, which depends on the beach slope, which is defined as dune foot elevation divided by the distance between the dune foot and the MSL contour. By this combination, a wide beach tends to yield dune growth on average, and a narrow beach enhances the probability that dune erosion occurs; in the long run a uniform coast will tend towards a dynamic equilibrium.
In order to add these processes to ShorelineS we defined the beach width, dune foot elevation and dune crest elevation at a number of points alongshore; these properties are interpolated to the coastline points and move along with them. During the simulation, particularly the beach width will change due to longshore transport gradients and the processes just described.

CASE STUDY

The Hondsbossche and Pettemer Zeedijk, near the village of Petten in the Dutch province of Noord-Holland, used to be a 15m high sea dike that was a hard point in an otherwise mostly sandy Holland coast. In 2012 it was decided that this dike no longer met the strict safety criteria for the Dutch coastal defences and a complete beach and dune system were constructed in front of this dike. The 35 Mm^3 of sand required for this was pumped onto the beach and dunes between 2013 and 2015.

Figure 2. Location map (right) and overview of Hondsbossche Dunes project. Source: OpenStreetMap.

An extensive study was carried out by Kroon et al. (2022) following the evolution of the beach and the dune through extensive surveys over the period 2015-2020. In the framework of ShorelineS-TKI, a large joint industry project led by Deltares, Svasek Engineering carried out a thorough calibration of ShorelineS against these data, without considering the fact that the beach profiles were quite far from equilibrium. The top panel of Figure 3 shows a quite reasonable agreement between model and data, though there is a positive bias. In the bottom panel, where the dune processes have been accounted for, we see a much better agreement for the change of the coastline at MSL.

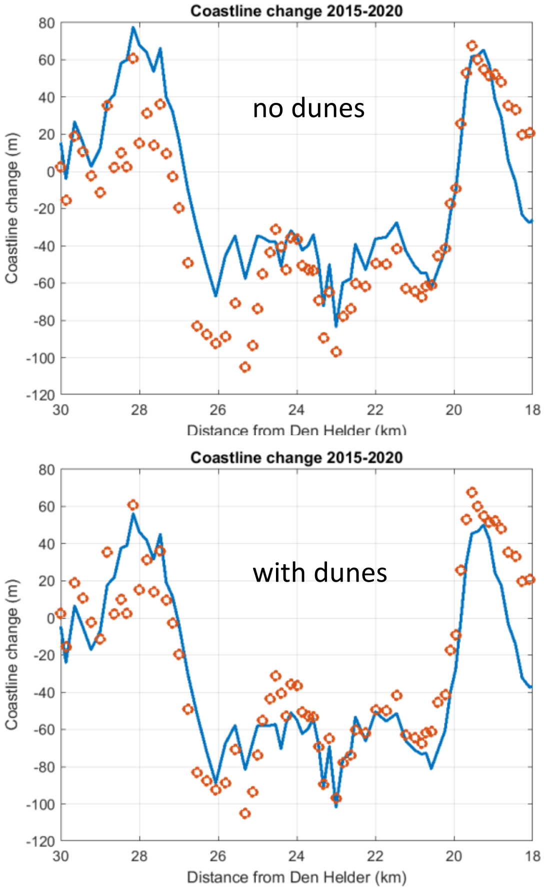

Figure 3. Top panel: optimum calibration result for shoreline change over the period 2015-2020. Bottom panel: simulation result including dune growth and erosion.

The increased erosion of the coastline in the model can mostly be attributed to the aeolian transport on the unnaturally wide initial beach. In Figure 4 the initial beach width and final beach width after 5 years are shown, where we see that at the project location the initial beach width was in the order of 200m, whereas a more natural width, as is seen on either side of the project, is in the order of 80-100m. Clearly, the model approaches this width and the beach width pattern that remains is very similar to the observations. Clearly, there is still a variation in beach width, due to the longshore gradients in beach orientation and hence longshore transport.

In Figure 5 the observed and simulated time series of beach width are shown, again showing good agreement. The dominant process is the aeolian transport, with only in profiles 25 and 26 some signs of dune erosion leading to sudden increases in beach width. This dune erosion is sensitive to the empirical impact factor and to the runup formulation (here, Stockdon 2006 was found the most realistic). We may conclude that this field test of a beach and dune influenced by both longshore and cross-shore processes show a promising extension of ShorelineS. Further work includes the addition of overwash processes.

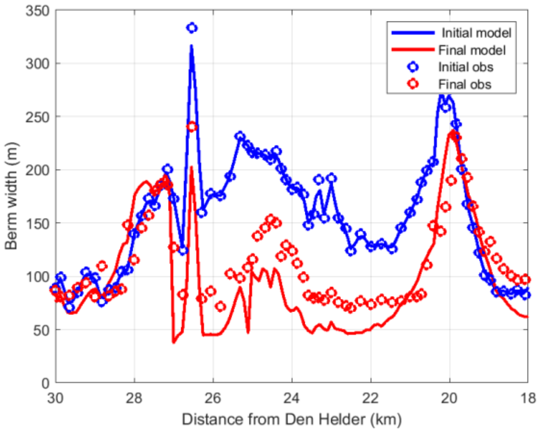

Figure 4. Initial and final beach width as a function of longshore distance; blue: 2015, red: 2020. The circles are the observed values, drawn lines the model.

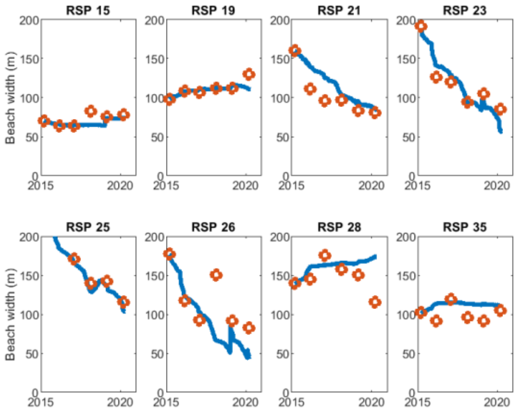

Figure 5. Time series of beach width for different profiles; RSP numbers indicate distance from Den Helder (km).

REFERENCES

Kroon, de Schipper, de Vries,; Aarninkhof. (2022). Subaqueous and Subaerial Beach Changes after Implementation of a Mega Nourishment in Front of a Sea Dike. J. Mar. Sci. Eng. 2022, 10, 1152.

Larson, Palalane, Fredriksson, Hanson (2016). Simulating cross-shore material exchange at decadal scale. Theory and model component validation Coast. Eng., 116 (2016), pp. 57-66, 10.1016/j.coastaleng.2016.05.009

Roelvink, Huisman, Elghandour, Ghonim, Reyns (2020).. Efficient modelling of complex sandy coastal evolution at monthly to century time scales. Frontiers in Marine Science 7, 535.