The influence of cyclic channel-shoal dynamics on waves, currents and sediment transport on the ebb-tidal delta of Ameland Inlet

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Abstract

Ebb-tidal deltas are shallow sandy features located seaward of tidal inlets and are important for coastal safety in barrier systems. They act as a shield for incoming (storm) wave energy and they are a source of sediment for the barrier islands and the back-barrier basin. This 'feeder' function is often related to the observed cyclic behavior of shoal formation, migration and attachment to the downdrift island (Figure 1). Little is known about the underlying physical mechanisms that cause cyclic behavior of ebb-tidal deltas. So far, research on the dynamics of ebb-tidal deltas is strongly biased towards the effects of tides. However, waves are able to transport large quantities of sediment, change and/or strengthen residual flow patterns and therefore affect the morphological evolution of ebb-tidal deltas. The main objective of this study is twofold. (1) to study the waves, flow and sediment transport patterns at an ebb-tidal delta as a function of wave and tide conditions. (2) to study how the cyclic behavior of an ebb-tidal delta influences the wave, tide and sediment transport patterns.

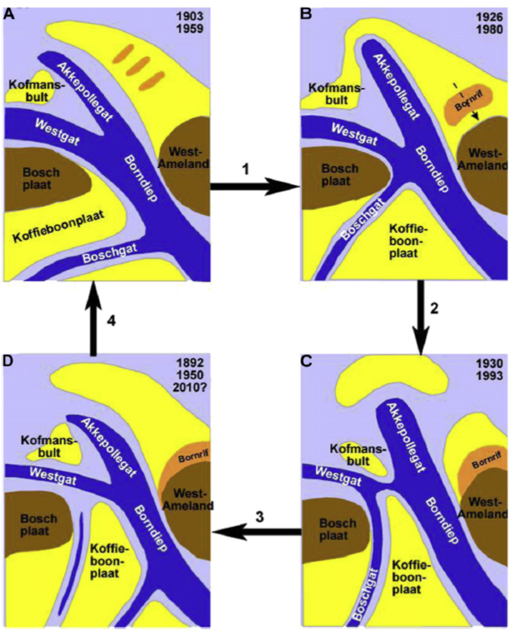

Figure 1: Morphological cycle of the (schematized) Ameland Inlet.

The area of this study is the ebb-tidal delta of the Ameland inlet (Figure 1), which is considered to be the most natural system of the Dutch Wadden Sea. The Delft3D/SWAN model is run with realistic (i.e., measured) bathymetries in a high spatial and temporal resolution. Hydrodynamic forcing either consists of waves (storm/ calm weather) only, tides only or a combination of tides and waves. To test the effect of the shape of the ebb-delta (spatial extent, height, position of channels and shoals), several historic bathymetries have been implemented to the model.

The results indicate that storm waves only (no tides) transport sediment mainly in the vicinity of the outer lobe and the shoals. Bedload sediment transport is dominantly in the landward direction, while suspended transport mainly follows the direction of the wave-induced currents. Storm waves in particular result in erosion of the outer lobe and can cause landward retreat of the ebb-tidal delta (Figure 2). However, the combination of tidal currents and storm waves results in the deposition of sediment at the outer lobe and seaward growth of the ebb-tidal delta (Figure 3). The angle of incidence of the storm waves is shown to be crucial for the magnitude and location of the bed level changes in the vicinity of the outer lobe. Sediment transport and bed level changes during calm weather are several orders of magnitude smaller than during storm conditions. During these conditions, the back-barrier basin is exporting sediment to the outer lobe of the delta. The outcome of simulations with different (historic) bathymetries show that patterns of residual flow and sediment transport varies, yet similar characteristic patterns are recognizable on different locations. The seaward growth of the ebb-tidal delta due to the combination of tidal currents and storm waves is most pronounced when the inlet has a one channel configuration, suggesting that this growth is related to a combination of Stokes return flow and the ebb flow in the channel(s). As a next step, we will determine the sediment exchange rates between ebb-tidal delta and back-barrier basin, between ebb-tidal delta and barrier islands and the sediment bypassing and study this as a function of hydrodynamic forcing and the cyclic evolution of the bathymetry.

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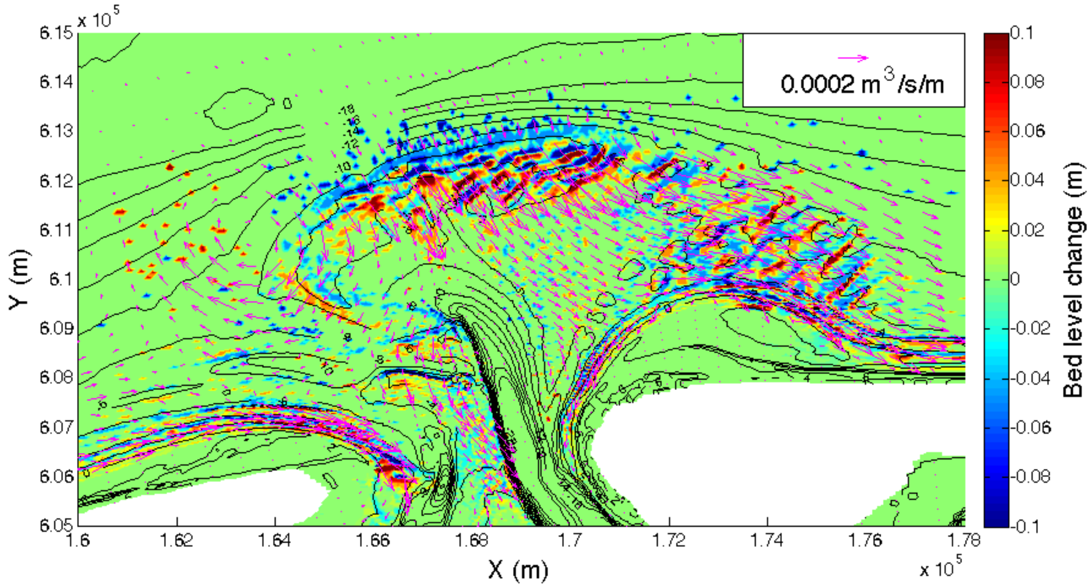

Figure 2: Contour plot of the bed level changes on a semi-diurnal time scale and corresponding total sediment transport (magenta vectors) at the ebb-tidal delta of the Ameland inlet. Bathymetry is indicated with the black contours. The system is forced with storm waves coming from the North West; the tides are omitted in this run. Implemented bathymetry is from 1999.

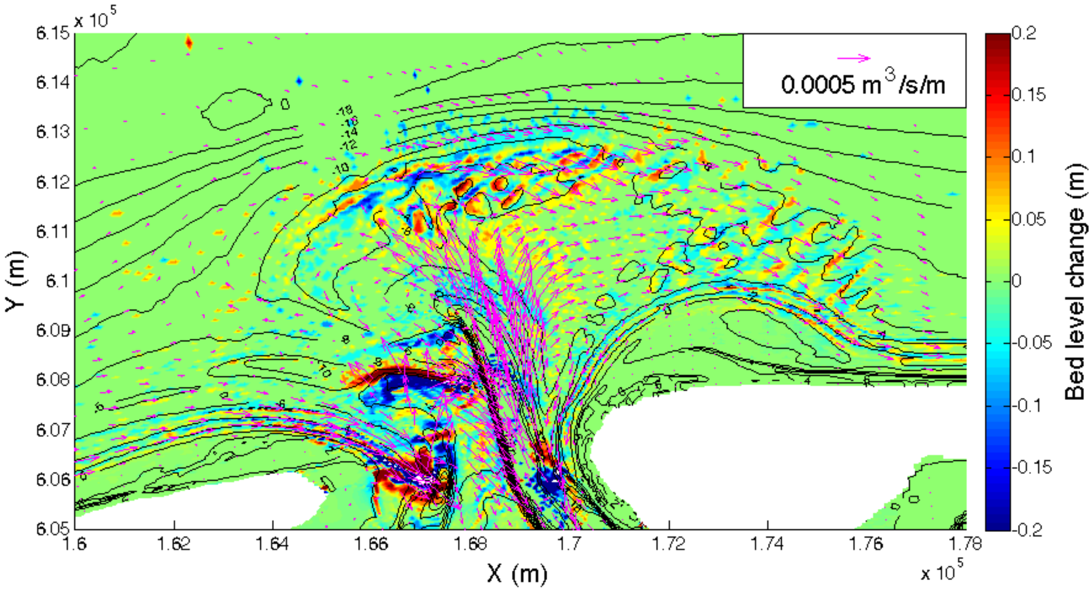

Figure 3: Contour plot of the bed level changes after one tidal cycle and residual total sediment transport (magenta vectors) at the ebb-tidal delta of the Ameland inlet. Bathymetry is indicated with the black contours. The system is forced with both tides and storm waves coming from the North West. Implemented bathymetry is from 1999.