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Physical Processes Driving the Morphological Evolution of the Roggenplaat Tidal Flat

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Abstract

The flow velocities in tidal channels are already rather complex by the presence of various tidal components, wind driven flow and estuarine circulations. An extra level of complexity is introduced when the flow on top of an intertidal flat is considered (Le Hir, 2000). This research aims at understanding the complex flow patterns on top of a large-scale intertidal flat and on assessing the morphological consequences.

The focus of this study is on the Roggenplaat, which is with an intertidal area of 14.6 km^2 the largest intertidal flat fully surrounded by channels of the Eastern Scheldt (The Netherlands, see Figure 1). The flat is subject to a mean tidal range of 2.6 m and is characterized by a typical sediment grain size of 0.25 mm. Two large tidal creeks in the Northwest are the remainder of the merging of separate flats 80-150 years ago. Since the late 1980s, the flats in the Eastern Scheldt have been eroding severely because of the construction of a storm surge barrier and various compartment dams (Louters, 1998). A nourishment of 1.65 million m^3 is planned on this flat for 2017, to compensate for its lowering.

This study combines the results of an Acoustic Doppler Current Profiler (ADCP) measurement campaign with the results of a numerical model. Apart from validation material for the numerical model, the ADCP data is also analysed individually. The focus of this study is on the present-day hydrodynamics and morphodynamics of the Roggenplaat, which is essential knowledge for the design of appropriate nourishment strategies. Furthermore, physical insights achieved in this study are relevant for the understanding of other large-scale intertidal flats around the world.

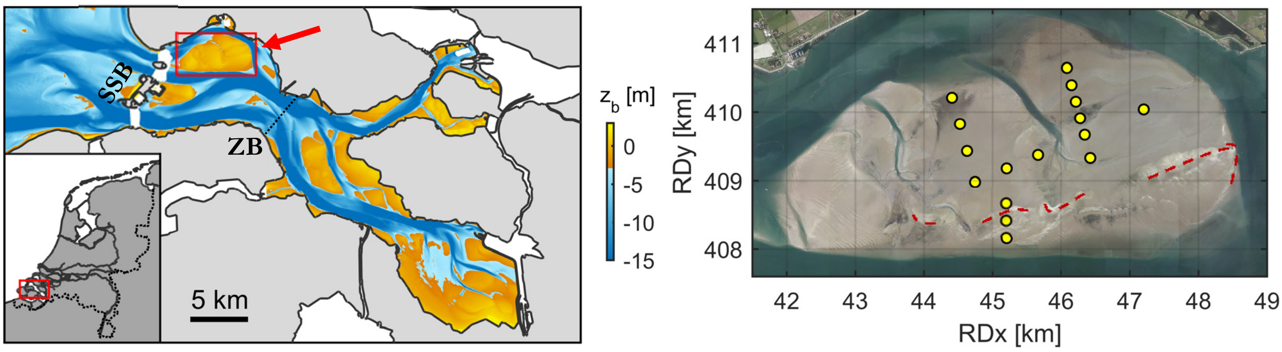

Figure 1 – Left: the location of the Roggenplaat with the storm surge barrier (SSB) and the Zeeland bridge (ZB). Right: an aerial picture of the Roggenplaat (2014, courtesy of Cyclomedia) with the ADCP measurement locations (yellow dots) and some of the major shell ridges (white in picture, marked with red dashes).

The dominant processes driving the hydrodynamics on top of the Roggenplaat are characterized based on an extensive dataset of 16 upward looking ADCPs, which were employed simultaneously for over one month. Substantial temporal variations of the flow velocities were present, see Figure 2. The spring-neap tidal cycle is identified to cause a fluctuation in the average depth-averaged velocities in the order of 50%. Furthermore, during a period of relatively strong winds (15 m/s in the beginning of March) the flow velocities on the flat were substantially amplified, on average also in the order of 50%. The effect of wind is found to be the least substantial for the most southern ADCP, which was located at the lowest bed elevation and at the smallest distance from a channel. As the Eastern Scheldt is a semi-closed basin, stratification is not identified as a dominant driving mechanism for the flow.

To extend the insights achieved from the data, a process-based numerical model (Delft3D) has been set up, of which the domain is bounded between the storm surge barrier and the Zeeland bridge (both indicated in Figure 1). Hydrodynamic boundary conditions are derived from a model which covers the full Eastern Scheldt with its outer delta. The grid sizes of the preliminary model are 30 m on top of the flat, but those will be refined even further. Currently, the model does not account for waves and three-dimensional flow, but the importance of these processes is yet under investigation.

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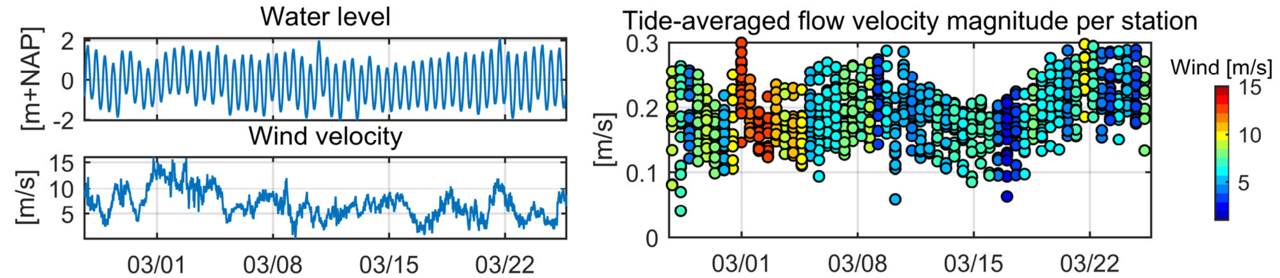

Figure 2 – Left: water level elevation and wind measurements from nearby measurement stations. Right: the magnitude of the tide-averaged velocity for each ADCP with the colours indicating the average wind speed around high water.

The initial model results (Figure 3) indicate the spatial and temporal inhomogeneity of the tidal currents on top of the flat within a typical tidal cycle (halfway between spring and neap tide and during calm wind conditions). Various horizontal circulation currents are modelled, which are already well in agreement with the measurement data. Those horizontal circulation currents are mainly observed around the edges of the flat just before high water. As also visible in Figure 3a, the flow on the flat is mainly in western direction at this moment, whereas the flow in the channels is still in eastern direction (the flood-direction). The shear induced by the opposing flow is an important driver for the horizontal flow structures observed (Jirka, 2001).

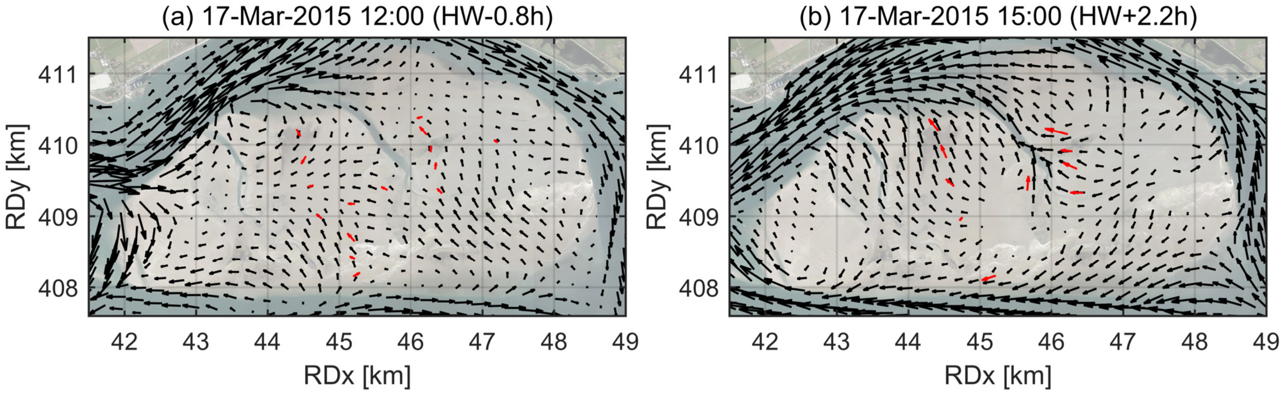

Figure 3 – Modelled depth-averaged flow patterns (black arrows) for a typical tide just before (a) and after (b) high water. Only 1/36th of the arrows are showed to improve readability. Measurements are indicated by red arrows.

Despite the non-uniformity of the flow over time and space, the flow patterns could be decomposed into various distinctive phases during a single tidal cycle, each with different governing spatial scales. With rising water levels, the flat is flooded especially through the two major tidal creeks. Once the water level rises further, the flat is fully underwater and the creeks are much less affecting the flow patterns; the water flows under calm wind conditions simply from SE to NW over the flat. With lowering water levels, the relative importance of those creeks increases again. The morphodynamic processes during each phase will be substantially different.

Importantly, the southern section of the flat is outside the zone which is influenced by the tidal creeks during flooding and drying (i.e., the water flows directly over the southern flat edge). Ridges consisting of dead shells (see Figure 1) are found at the location where the ebb-flow separates between the northward and southward direction (Figure 3b). The presence of those shell ridges is hypothesised to be related to the watershed-like feature, which is also relevant for the morphodynamic evolution of the flat.

Apart from the analyses presented in this abstract, more extensive results will be presented during the conference. Especially, the focus will be more towards the morphological evolution of the flats. Based on bed shear stress distributions and sediment transport patterns, together with initial morphological calculations, the aim is to get grip on the main morphological features. By further improving the model schematization and taking more processes into account, we strive to better asses the physical process driving the morphological evolution of the Roggenplaat.

Based on the initial results, we can already conclude that it is too simplified to consider only astronomical tides for a model of a large-scale flat. The meteorological events are an essential driver for the flow on top of the flat. By the relatively small tidal flow velocities on top of the flat (in the order of 0.2 m/s on average), it is expected that the erosion patterns on these types of flats are mainly event driven. Finally, for a large-scale tidal flat as the Roggenplaat, geometrical features (e.g., tidal creeks) are an essential driver for the resulting flow patterns. Therefore, it is questionable how applicable theories derived from idealised flats are for real-world large-scale intertidal flats.

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