Modelling sediment transport and morphology during overwash and breaching events

by

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Summary

Executive summary

Currently, morphodynamic models as XBeach show substantial overestimations of the erosion rates during breaching and overwash events at barrier islands. The presently used limitations on the Shields parameter and the sediment concentration do hinder erosion, but have undesirable side effects, e.g. the breaching process is suppressed. By implementing additional physics, e.g. the erosion hindering effect of dilatancy and a proper bed slope effect, substantial improvements are achieved for idealised cases. However, two hurricane case studies showed that these model improvements do not hinder erosion sufficiently to achieve reasonable results. A proper description of bed roughness, which is preferably depth dependent and accounts for vegetation, together with calibration of the wave skewness and asymmetry is found to be very important. If this knowledge is applied on a newly introduced case study of Fire Island (hurricane Sandy, 2012), both breaching and overwash are modelled much more in line with reality. However, the complexity of having various morphodynamic processes within one model domain makes calibration a challenging task, requiring a more advanced bed roughness formulation.

Extended summary

During large storm events, barrier islands are subject to substantial erosion causing retreat of the coastline or even lowering of the dunes by overwash and breaching processes. These storm events can have a devastating effect on local topography and ecology, e.g. if a permanent breach channel is generated. As a result, the safety of the mainland can be affected negatively due to inadequate protection against storm surges and waves. To estimate storm impact and the effectiveness of protective measures, a robust modelling tool is required.

The XBeach model is a numerical 2DH morphodynamic model which has a good skill in predicting regular coastal erosion. For overwash and breaching events however, the model needs to be improved as the erosion rates are generally overestimated during these conditions. The main research objective of this thesis is to increase the predictive skill of the XBeach model during overwash and breaching conditions by implementing new model physics. The most important missing processes are implemented and the improved model is validated to several experiments and case studies.
A literature review resulted in an understanding of the morphological processes which are especially important during breaching and overwash events. Dilatancy becomes important at large flow velocities; an inflow of water is required to increase the pore volume which causes an in-bed directed force and consequently an increase of stability of the grains on the bed. Dilatancy can be accounted for by increasing the critical Shields parameter locally. In addition, the fall velocity of suspended sediment is reduced for large concentrations and the quasi-steadiness of the sediment concentration in the sediment-mass balance is reconsidered. Finally, the bed slope effect is improved as it is found to be important for the breaching process during which steep slopes occur. With this study, these physical processes are implemented in the XBeach model.

With the assessment of the XBeach model - on various experiments and field cases - insight is obtained into the importance of various processes. Before the implemented additional physical processes are considered, the sediment transport limitations to the concentration and Shields parameter currently used in the model are researched. A comparison of these results is made to the model with the additional model physics. To test the importance of the individual processes in the improved model, the processes are turned-off, or are modified one-by-one. The model results are compared to measurement data, but it is also verified whether the qualitative description of the dike breach phases by Visser (1998) can be confirmed based on XBeach and how detailed structures like antidunes are modelled.

The models of the considered experiments do show a substantial increase in performance by the improvements, except for the Santa Rosa Island hurricane case study in which still a substantial overestimation of erosion rates is modelled. As the main goal of the XBeach model is to achieve accurate predictions for field cases, this is not satisfying. A new hindcast of an overwash and breaching event by hurricane Sandy on Fire Island is introduced, to get more insight into the overestimations. The Fire Island case is interesting due to the large variety of processes which occurred over a longshore distance of only 2 km. Again, strong overestimations of the erosion rates are observed if the XBeach model is used, even with the suggested model improvements. Since the improvements did show substantial increase of skill in the laboratory and other idealised cases, an analysis is made towards possible reasons of the insufficient prediction of overwash and breaching events in field cases with XBeach.

Several additional physical processes are considered to get to more reasonable model results. By analysing the influence of larger sediment grains, ground water flow, a stronger wave asymmetry and skewness, a Manning roughness instead of a Chézy friction coefficient and the increase of bottom friction to account for vegetation, it is tested which of those processes could explain the large overestimation of the morphological changes. Finally, the morphological changes in the most promising model set-up are analysed to get an understanding of which morphological processes take place during which phase of the storm event.

As a general conclusion, it is stated that the proposed adjustments in model physics do increase the predictive skill of the XBeach model substantially. Especially the dilatancy concept and the bed-slope effect are important processes. However, during storm events in field cases, other factors dominate the results of the model. It is found that a good representation of the bottom friction and the wave skewness and asymmetry is very important to achieve proper model predictions.