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MODELLING FOR ANALYSIS OF REFRACTION EFFECTS ON OVERTOPPING IN A COMPLEX ESTUARY

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INTRODUCTION

One of the flood defences in the Netherlands is the dike in the Eems-Dollard estuary, in the north of the Netherlands, which protects a large part of the area from flooding. The Eems-Dollard estuary is a highly complex estuary of deep channels and shallow plates, which is part of the Wadden Sea. The bathymetry of the estuary is given in Figure 1. A particular aspect for this area is that the design conditions for the dike Eemshaven-Delfzijl are characterized by winds that act in an offshore direction, while predicted wave heights are unexpectedly high (still in the order of H_s = 2 m). Currently, the wind, water levels, currents and waves that occur in the area during (extreme) storms are predicted by models without direct calibration near the shore. This leads to uncertainties in e.g. the required crest level of the dikes.

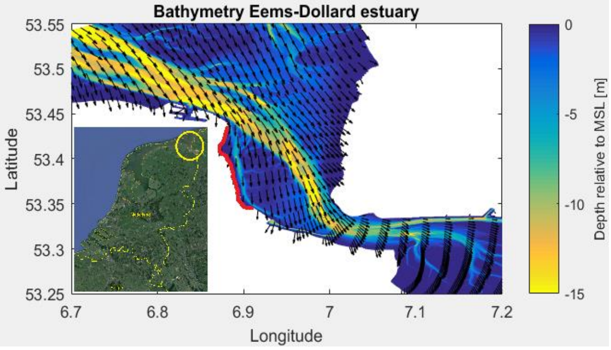

Figure 1 – Complex bathymetry of the Eems-Dollard estuary, with deep channels and shallow plates. Dike location indicated in red. Vectors represent local mean wave direction during extreme storm. The Netherlands is shown in the bottom corner, with the location of interest indicated by the yellow circle.

Therefore, wind, water levels, currents, waves and wave run-up and overtopping are planned to be measured in an extensive field measurement project in this highly complex estuary in the Netherlands, for the coming 20 years. A few potential measurement locations are indicated in Figure 2. The main goal of the field measurements is to reduce the uncertainties in the models which are used to assess the flood defences in the Netherlands, and particularly their height. Hence, to improve the modelling of e.g. the phase-averaged spectral wave model SWAN (Booij et al. 1999) and the EurOtop (2016) wave overtopping equations.

Two important physical mechanisms that influence the wave overtopping in the area are wave refraction effects at transitions from deep channels to shallow flats and towards the dikes, as well as wave overtopping with (very) oblique wave attack at the dikes.

Often an underestimation of wave penetration at the lee side of channels was found with SWAN for similar situations with deep channels and shallow plates (e.g. Magne et al. 2007; Groeneweg et al. 2015). Conflicting explanations were given for the observed refraction effects. In general, it was found that the current phase-averaged models may have difficulties with accounting for strong refraction in these areas of channels and plates.

The present paper is made in preparation for this extensive measurement campaign. It aims to evaluate the most suited locations for wave and overtopping measurements, as well as to gain insight in why such large wave heights are predicted for the dike Eemshaven-Delfzijl.

Figure 2 - Potential wave run-up and wave overtopping measurement locations (yellow circles) and potential water level, current and wave measurement locations (yellow and orange circles).

APPROACH

The research consists of numerical modelling and field measurement aspects. Detailed numerical modelling of the area is performed with SWAN, as well as with more accurate models as the phase-resolving spectral wave model SWASH (Zijlema et al. 2011), in order to gain an understanding of the processes that play a role in the area, as well as to assess the performance of the models in the area. These calculations will also be used to set-up the field measurements in more detail, which will in turn aid in validating the models, as well as in improving the related physical parameterizations.

The paper gives a comparison of results with the newest version of SWAN (version 41.20) and the version that is used to determine the heights of the flood defences in the Netherlands (version 40.72ABCDE, see also http://swanmodel.sourceforge.net), as well as with currently existing measurements in the area.

Furthermore, a source term analysis is given, as well as a quantification of propagation effects, e.g. to highlight the areas where the turning of the waves due to refraction is most induced. A refinement of the required measurement locations is made based on these analyses. It seems that the strongest refraction effects occur at the corner of the Eemshaven, at the transition from the deep major channel towards the shallow plates and minor channel called Bocht van Watum, as well as at the transition from this minor channel towards the shallow areas in front of the dike. Therefore, it was advised to measure around these transitions, with e.g. arrays of wave buoys.

Detailed analyses of the turning of the waves were made with the non-hydrostatic time domain model SWASH. The results are compared to SWAN for these particular areas with large amounts of refraction, to study the prediction of these effects with SWAN, and to determine possible weaknesses in the models.

Presently, two minor aspects (or bugs) were found within SWAN that could be improved. In the version that is used to determine the heights of the Dutch flood defences, after tidal inlets, the model produces oscillations in the bulk wave parameters, which appear the strongest in the $T_{m-1,0}$ wave period, of order ±10% of the average value at the toe of the dike, and roughly 5% on the significant wave height, see Figure 3. This issue seems to be related to the sweep mechanism used for curvilinear grids.

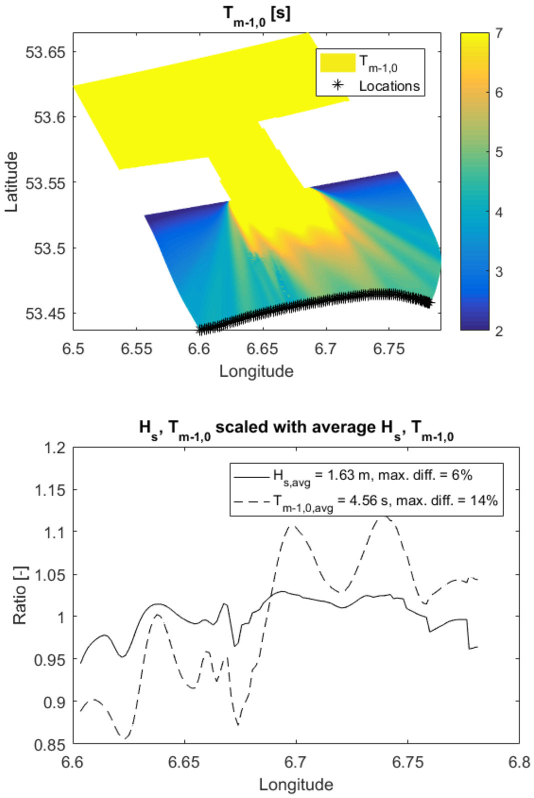

Figure 3 – Simplified curvilinear SWAN-model of tidal inlet at Borkum, with a deep and a shallow area. Oscillations in $T_{m-1,0}$ wave period after inlet, with dike toe locations indicated (top plot). H_s and $T_{m-1,0}$ scaled with their mean value at the dike toe locations (bottom plot). Again the oscillations are visible.

Furthermore, for certain specific conditions and model settings, some numerical issues in the SWAN model were discovered requiring further attention. It seems that for certain conditions and model settings, at transitions from deep to shallow areas, all wave energy is assigned to one directional bin at the first time step, and does not diffuse out of it during subsequent iterations. Hence, it seems to be related to the first guess. At present, this effect can be identified visually, and removed by manually altering the grid or initial settings.

Finally it seems that presently, for extreme storms in the area, the newest version of SWAN predicts up to 40% lower wave heights than the version that is used to determine the heights of the flood defences in the Netherlands, an aspect which is still to be assessed in more detail.

CONCLUSIONS

The origins of the large differences and the observed model effects will be determined in more detail. Furthermore, the performance of SWAN and SWASH in areas with strong refraction and diffraction effects will be determined. With the results of the present paper, the field measurements can be set up in more detail.

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