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The interplay between waves and surges in the Dutch Wadden Sea

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The Dutch Wadden Sea is a shallow shelf sea connected to the North Sea by a number of tidal inlets. The mainland shore consists of dykes protecting the low-lying areas of the northern Netherlands. Tide and extra-tropical storms result in hydraulic loads on dykes through severe surge and wave action. Improved understanding of the physical processes responsible for wave, current and water level conditions is essential for the design of such coastal defenses. This knowledge is required for the 5-year mandatory check to assess the existing level of protection.

Lipari and Adema (2010) address the generating mechanisms of severe surges in the Wadden Sea, whereas the present contribution focuses on the wave conditions in the Wadden Sea and on the interplay with surges. Waves in the Wadden Sea are mainly locally generated and strongly affected by shallow-water and current effects. In addition, some waves generated in the North Sea penetrate into the Wadden Sea through the tidal inlets. Because of the shallowness, accurate water level predictions are essential for the proper computation of the waves, as waves are often depth-limited. In turn, wave set-up significantly affects surge levels in the Wadden Sea.

The modeling of waves in the Wadden Sea is rather complicated due to its geometry consisting of tidal channels and extended tidal flats. Various aspects thereof will be highlighted here.

Firstly, the penetration of North Sea waves into the Wadden Sea is addressed. These waves are strongly affected by the shallow ebb-tidal deltas where severe wave breaking occurs, causing an abrupt drop in wave height. In addition, refraction effects in the tidal channels turn most of the wave energy to the shoulder's sides of these channels where the waves are dissipated. Only in the wider tidal inlets of the eastern Dutch Wadden Sea a relatively large amount of wave energy is able to penetrate farther up to the dykes. The amount of wave penetration is also affected by current effects, and noticeable differences in wave conditions occur for following and opposing currents.

Secondly, the effect of waves on the surge levels was computed and compared with water-level measurements for the storm of 9 Nov 2007. The numerical simulations were performed with the Delft3D flow solver of Deltares in combination with the SWAN model of TU Delft. Various numerical experiments were performed to optimize the coupling of these models. The results of these two-way coupled simulations showed that wave effects could contribute with up to 0.40 m to a peak surge level of about 3 m; but also that inclusion of the wave effect was required to accurately (error less than 0.05 m) predict the water levels, which in turn affect the wave conditions in shallow water.

Thirdly, numerical experiments show that, during severe storms, the wave-current interaction is not limited to the tidal channels, but that it may cover the entire Wadden Sea. Depending on the characteristics of the storm (Lipari and Adema, 2010), this can result in a large-scale flow through the Wadden Sea more or less aligned with the direction of the wind. Then, the waves encounter a large scale following current yielding significantly lower wave heights and periods.

Finally, the hindcast and numerical experiments show that the largest-wave conditions seldom occur simultaneously with the water-level peak. Competing mechanisms are identified that lead to depth-limited high wave conditions.

The results of this study highlight the importance of including current effects in the derivation of Hydraulic Boundary Conditions for the design of the coastal sea defenses. Insights obtained in this study will be explored in further studies.

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Reference:

Lipari and Adema, 2010: The generation of severe surges in the Dutch Wadden Sea: insights from data, hindcasts and numerical experiments. Abstract submitted to this conference.