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Determination of significant waterstage and wave heights of the Elbe estuary in the area of Hamburg using a hydrodynamic 2D model

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As a consequence of climate change the frequency and intensity of storm events, as well as the sea level is expected to rise in coastal zones. This will inevitably increase the risk of flooding for societies living in these regions. The German joint research project XtremRisK aims to improve the understanding of the development of storm surges in dependence on extreme water levels in the North Sea. A deterministic approach has been developed to calculate the flood stages of the Elbe estuary around Hamburg as a consequence of certain storm conditions in the North Sea, the inflow from the catchment at the upstream end of the estuary and local wind conditions.

The hydrodynamic numerical model solves the 2-dimensional shallow water equation with the Finite Element method. The friction is modeled by the physically based approach of Darcy Weisbach. This improves the modeling of extreme roughness conditions and wooden vegetation on the flood-plain and river banks (Pasche 2007). The effect of turbulence is modeled on the basis of the Boussinesq approach in which the eddy viscosity is quantified with an empirical approach which combines the impact of bed shear stress and free shear layer induced turbulence.

For the generation of the Finite Element grid an automatic mesh generator has been applied (Kurzbach et al, 2009). The challenge have been the steep gradients of the river bank and the sharp drop of ground elevation about 20 m. The grid generator has been able to ensure an alignment of the bank elements parallel to the delineation line of the water body, which was found to be crucial for a realistic modeling of the movement of the shoreline during tidal and storm surge fluctuations of the water level. The performance of the grid generator could be considerably improved through the development of a new algorithm, which decompose the flow domain and computes parallel the Finite Element network of the different domains on a multiple compouting resource of a GRID (Kurzbach et al, 2009).

A key question of the research work is the impact of wind on the local water level at storm surge. The surge effect of wind is considered through modelling the shear stress at the water surface in the 2-dimensional shallow water equation. As the numerical model has to give a most realistic evaluation of the water level at the dikes the effect of swell and waves had to be analysed within this research study. Thus the shallow-water-wave model has been coupled with the wave model SWAN (Simulating Waves Nearshore by TU Delft) which calculates the wave parameters on the basis of the balance equation of wave action density. A special user interface called KALYPSO has been developed which integrates both the software code of SWAN and the 2-dimensional flow model RMA KALYPSO (Schrage et al. 2009). Pre- and post-processing are supported for both models through GIS-functionality and interactive graphics to define various boundary and initial conditions and to visualize in a combined way the results of the wave model and the hydrodynamic flow model. Synergies in the generation of the numerical grid have been accomplished through an automatic transfer of the FE-mesh which consists of triangles and quadrilateral elements, to a TIN which is the structure of the numerical network of SWAN.

This paper describes the new accomplishments of integrating 2-dimensional flow modeling and near shore wave modeling to predict the water levels in estuaries as a consequence of extreme storm surges in the open sea and local wind conditions. The model is applied at the complex network of a system of braided water bodies which form the river network of the river Elbe in Hamburg. At the observed flood stages at the storm event of November

2007 the quality of this new instrument will be demonstrated. In a scenario study different local wind conditions and extreme storm conditions of the North Sea are studied and their impact on the flood situation near the dikes is demonstrated.

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