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Evaluation of a shallow water unstructured mesh model for the North Sea–Baltic Sea

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Abstract

A two-dimensional shallow water model is used to simulate tide and storm surges for the North Sea–Baltic Sea. In order to resolve the complex coastline, a finite element model using an unstructured mesh is applied. The resolution varies from 300 m in the shallow and narrow Danish straits to approximately 20 km in the deep parts of the domain. The model is forced by tidal elevations along open boundaries, and by atmospheric wind stress and mean sea level pressure obtained from a high resolution NWP model.

The test consist of three simulations: (1) a 10-days simulation of the M_2 tide only, (2) a one-year full tidal simulation, and (3) a one-year predictive simulation including both tides and atmospheric forcing. The simulations are validated against sea level data from a number of coastal tide gauges, using harmonic analysis and direct time series comparison. The tidal simulations are used to calibrate model bathymetry and bed friction. The last simulation is validated in terms of surface elevation, following procedures applied on the operational storm surge system run at the Danish Meteorological Institute. The model gives reasonable sea level predictions, with the quality matching that of an equivalent finite difference model.

Keywords: Storm surge prediction; Tides; Modelling; Finite element method; North Sea; Baltic Sea

1. Introduction

The operational storm surge system for the North Sea–Baltic Sea currently running at the Danish Meteorological Institute (DMI) is based on a two-dimensional shallow water finite difference model (MIKE21; DHI, 1998) using a number of regular, nested computational grids. The model domain covers the entire North Sea–Baltic Sea area, with two open boundaries; one in the North Sea between Norway and Scotland, and another in the English Channel. The model is forced by specified tidal elevations at the open boundaries, and wind stress and atmospheric pressure at the surface. While the finite difference method has some advantages being simple to program and apply, it also has some limitations, such as representing coastlines. The study area has

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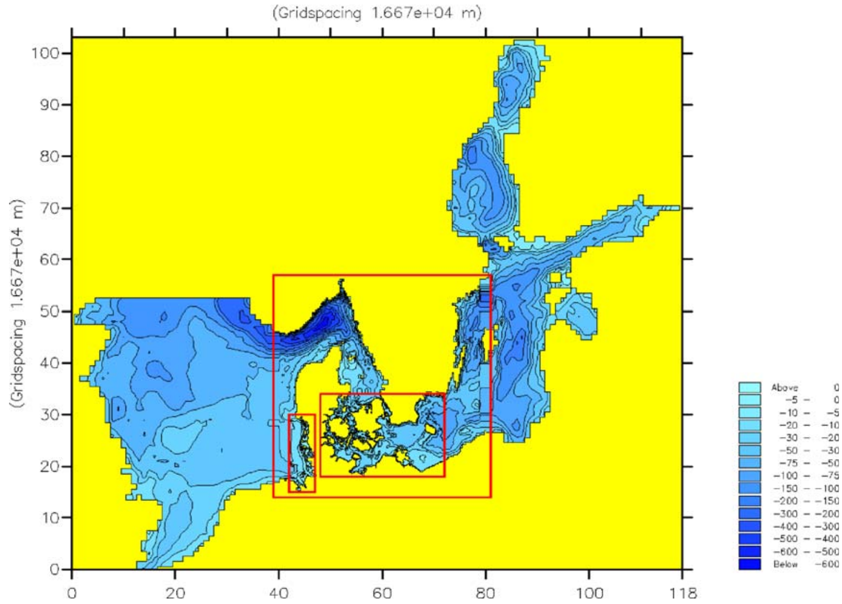

Fig. 1. Nested model domains of the operational finite difference storm surge model.

a complex geometry with a number of narrows and straits, and in order to comply with the different needs for resolution, the model setup has seven domains of different resolution, two-way nested into each other (see Fig. 1). The resolution changes by a factor of 3 between nesting levels, ranging from 9 to 3, 1, 1/3 nautical mile.[1] A fjord model of Limfjorden (see Fig. 2) with a resolution of 750 m is treated using one-way nesting. For a model domain of this complexity, the finite difference method leads to the choice of either having a part of the coastline poorly resolved, or having numerical noise generated at the nesting boundaries. This must then be damped by enhancing the lateral friction or by smoothing procedures.

In order to overcome some of these problems, an alternative model is applied. This model uses the finite element method. The features of finite element and finite difference ocean models have been discussed by for example LeProvost et al. (1994) and Meyers and Weaver (1995). One of the main advantages of the finite element method is that it exploits an irregular mesh and thus nicely handles complex geometry. The setup in this study is similar to the DMI operational storm surge setup with respect to resolution, forcing, and boundary conditions.

Werner (1995) describes a similar shallow water finite element model test. Their purely tidal study covers the English Channel and the southern part of the North Sea. Here, we aim to cover an area of regional scale, and include atmospheric forcing in order to study model performance during storm surges as well.

The test consists of three simulations: (1) a 10-days simulation of the semi-diurnal lunar M_2 tide only, (2) a one-year complete tidal simulation, and (3) a one-year simulation including both tides and atmospheric forcing. The tidal simulations are used to calibrate bathymetry and bed friction. The chosen length of the simulation period is long enough to separate the major tidal constituents, and the validation is done in terms of harmonic analyzed results. The last simulation is a hindcast study of the calendar year 2003, using bathymetry and friction parameters fixed by the tidal simulations. This simulation shows the predictive skill of the model and is validated in terms of actual sea level. Sea level data is obtained from a number of coastal tide gauges, with a time resolution of 10 min. The harmonic analysis has been done by Huess et al. (2002).

The manuscript is organized as follows. Section 2 gives a brief description of the area. In Section 3 the numerical model and the finite element mesh are introduced. The three simulations are discussed in Sections 4–6, and conclusions are given in Section 7.

[1] 1 nautical mile ~ 1852 m.