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ORIGINAL RESEARCH ARTICLE

The impact of surface currents and sea level on the wave field evolution during St. Jude storm in the eastern Baltic Sea☆

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Summary A third generation numerical wave model SWAN (Simulating WAves Nearshore) was applied to study the spatio-temporal effect of surface currents and sea level height on significant wave height; and to describe the mechanisms responsible for wave—current interaction in the eastern Baltic Sea. Simulation results were validated by comparison with in situ wave measurements in deep and shallow water, carried out using the directional wave buoy and RDCP respectively, and with TerraSAR-X imagery. A hindcast period from 23 to 31 October 2013 included both a period of calm to moderate weather conditions and a severe North-European windstorm called St. Jude. The prevailing wind directions were southerly to westerly. Four simulations with SWAN were made: a control run with dynamical forcing by wind only; and simulations with additional inputs of surface currents and sea level, both separately and combined. A clear effect of surface currents and sea level on the wave field evolution was found. It manifested itself as an increase or decrease of significant wave height of up to 20%. The strength of the interaction was

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influenced by the propagation directions of waves and surface currents and the severity of weather conditions. An increase in the wave height was mostly seen in shallower waters and in areas where waves and surface currents were propagating in opposite directions. In deeper parts of the eastern Baltic Sea and in case of waves and surface currents propagating in the same direction a decrease occurred.

1. Introduction

In the event of a storm at sea, rough wave and severe surge conditions may lead to significant coastal and property damage or even to loss of life (e.g. Feser et al., 2015). Correct quantification of met-ocean parameters of a storm using numerical models and forecasting systems helps to reduce the storm related risks and mitigate consequences. Because in nature there is a feedback system between processes, detailed information about different interactions would provide us with a better understanding and improved predictability of hydrodynamic conditions at sea. For instance, an important feedback occurs between slowly-varying currents and highly varying waves. So far, the issue is little studied in the Baltic Sea.

The groundbreaking work of wave—current interaction was done by Longuet-Higgins and Stewart in a series of papers (1960, 1961, 1964). They described the interaction using radiation stress and demonstrated the energy transfer between waves and currents. Bretherton and Garrett (1968) introduced the idea of action conservation. Since then numerous papers have been published on the application of the theory including those by Wolf and Prandle (1999), Guedes Soares and de Pablo (2006) and Van der Westhuysen (2012). Alari (2013) studied the local storm surge effect on wave field in Pärnu Bay, Baltic Sea. He showed that sea level has a significant effect on wave field during extreme weather conditions. However, the effect of surface currents on wave field in the eastern Baltic Sea has had little attention.

The objectives of the present study were firstly, to assess the one-way interaction between waves, surface currents and sea level in almost tideless (up to 10 cm (Feistel et al., 2008)) coastal areas. We tried to find out the mechanisms by which surface currents and sea level rise influence the evolution of significant wave height under stormy conditions. This could help to improve modelling systems and see if it is worth further investigating the coupling of wave and hydrodynamic models in the Baltic Sea. Secondly, we studied the effect of spatial variability of surface currents and sea level on wave field. This would also indicate in which sea areas these interactions might be important during severe storms.

The paper is structured as follows: In Section 2 data and methods are presented including the description of measured and remotely sensed data and the description of numerical models and their set-ups. Section 3 presents the calculation results and discussion. The main conclusions and recommendations for further studies are summed up in Section 4.

2. Data and methods

2.1. Investigation area and measurements

The area of investigation is the eastern Baltic Sea, which is shown in Fig. 1. It includes two large gulfs — the Gulf of Finland and the Gulf of Riga. Water depth varies between 0 and 170 m. The Eastern section of the Baltic Sea, including the Gulf of Finland and Gulf of Riga, are extremely prone to storm surge (e.g. Wolski et al., 2014). The Gulf of Finland is connected with Baltic Proper with no barrier to the propagation of the waves, which allows, under certain meteorological conditions, long and high waves to enter the region (Leppäranta and Myrberg, 2009). According to Kahma and Petterson (1993) the mean significant wave height in spring is 0.5 m with peak period of 3.8 s and in winter 1.3 m with period of 5.3 s. Higher waves are produced in storm conditions (Soomere et al., 2008). In the Gulf of Riga wave propagation and growth are limited by shallow and narrow straits. Annual average wave height is between 0.25 and 0.5 m (Suursaar et al., 2012). According to Raudsepp et al. (2011) the peak period ranges between 2.3 and 8 s.

In Fig. 1 red and black squares show the stations where the measurements were taken for comparison with the simulations. Measurements in the Gulf of Finland (Fig. 1, station A) were conducted by the Finnish Meteorological Institute (FMI) at a site where water depth is 43 m. The device used was the

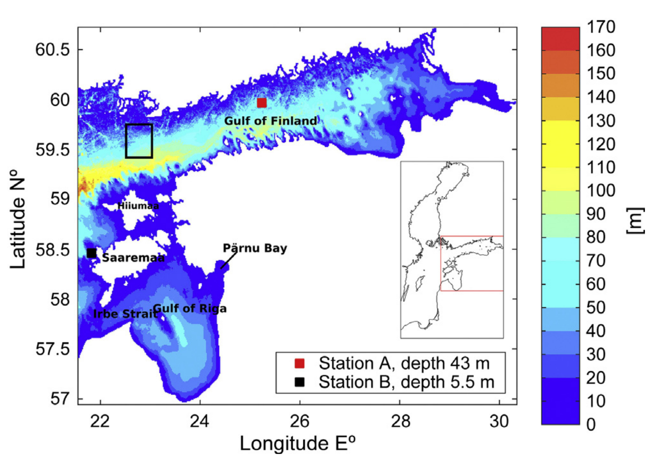

Figure 1 Eastern Baltic Sea bathymetry with grid resolution of 0.5 nautical miles. This area also represents the nested grid area. The black rectangle is the area of SAR measurements.