Coastal Engineering 83 (2014) 205–220

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

Wave modelling in archipelagos

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ARTICLE INFO

Article history:
Received 15 January 2013
Received in revised form 7 October 2013
Accepted 11 October 2013
Available online 14 November 2013

Keywords:
WAM
Wave modelling
Rugged shoreline
Archipelago Sea
Sheltering
Refraction

ABSTRACT

The Archipelago Sea, located in the Baltic Sea between the Gulf of Bothnia and the Baltic Proper, comprises thousands of small islands and shoals. The sheltering effects, depth-induced wave breaking and refraction make the modelling of waves challenging in this area. Ten different high-resolution grids were generated based on coastal nautical charts with horizontal resolutions of 0.1 nmi and 0.5 nmi using two different methods to compile land–sea mask and additional grid obstructions. The wave model WAM was used to model the wave field in the Archipelago Sea. The modelled wave field was compared against measurements made during a research cruise of R/V Aranda in September 2010. The 0.1 nmi grids had the highest accuracy in modelling the local wave field. However, they overestimated the attenuation of the open sea waves propagating into the Archipelago Sea. The 0.5 nmi grids overestimated the energy of the local wind waves and underestimated the attenuation of the open sea waves. When grid obstructions were used in the 0.5 nmi grids, the attenuation of wave energy was modelled with good accuracy, but the energy of the local wind waves was still slightly overestimated. The accuracy of the forcing wind field had significant effect on the accuracy of the locally generated wave field inside the archipelago. The depth-induced wave breaking and wave refraction were shown to have a prominent effect on the modelled wave field at the southern edge of the Archipelago Sea. The 0.5 nmi grids were unable to describe these features in as much detail as the 0.1 nmi grids.

1. Introduction

The Archipelago Sea, located in the Baltic Sea between the Gulf of Bothnia and the Baltic Proper, consists of thousands of small islands and shoals, the smallest islands being just a few metres in diameter (Fig. 1). The Archipelago Sea is a unique type of landscape that is a result of the hard Precambrian bedrock of the Baltic Shield being carved by the continental ice sheet during the last ice age. Similar areas are rare and can be found outside the northern Baltic Sea only in few other places, e.g. in the shorelines of the Canadian Shield and in the Gulf of Maine at the east coast of the USA. Compared to the other archipelagos in the World's Oceans, the surface area of the Archipelago Sea is relatively small, ca. 8300 km^2, but by the number of islands it is one of the world's largest archipelagos. There are over 40,000 islands in this area of which only ca. 250 have a surface area of over 1 km^2. The Archipelago Sea has a complex bathymetry; the estimated mean depth is 23 m (e.g. Suominen et al., 2010). There are some fault lines in this area which are deeper than 100 m but the depth varies typically between 0 and 50 m. At the southern edge of the archipelago the long open sea waves are refracted by the shoals. There are several locations that have potential to generate high concentration of wave energy and even caustics (Kahma et al., 1995).

This type of rugged shoreline is typical for most of Finland's coasts. Of the total length of Finnish shoreline, ca. 6300 km is mainland and 39,000 km is shoreline of small islands (Granö et al., 1999). The total number of islands is over 73,000. In the Baltic Sea a similar type of shoreline and archipelago can be found e.g. in the northern parts of the Swedish coast, and in particular in the Stockholm Archipelago.

The Archipelago Sea has extensive marine traffic in all seasons and therefore there is a demand for reliable wave forecasts. Also, the regional planning in the Archipelago Sea requires information of the wave climate with high spatial resolution. The present wave model implementations in the Baltic Sea are not able to describe the properties of the wave field in the Archipelago Sea due to their coarse resolution. The present operational wave models have resolutions between 2 and 6 nmi (e.g. Soomere et al., 2008). In these implementations the Archipelago Sea is typically handled by setting most of the area as land, thus making the area impassable for waves propagating from the Baltic Proper and the Gulf of Bothnia. Some other applications overestimate the percentage of the sea which usually results in overestimated significant wave heights inside the archipelago.

There are two key issues in wave modelling in archipelagos: how much of the open sea wave energy propagates past the islands and how well the local wave field inside the archipelago is modelled. The highest measured significant wave height outside the Archipelago Sea, in the northern part of the Baltic Proper (location of the Northern Baltic Proper (NBP) wave buoy shown in Fig. 1) is 8.2 m. Wave hindcast

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http://dx.doi.org/10.1016/j.coastaleng.2013.10.011

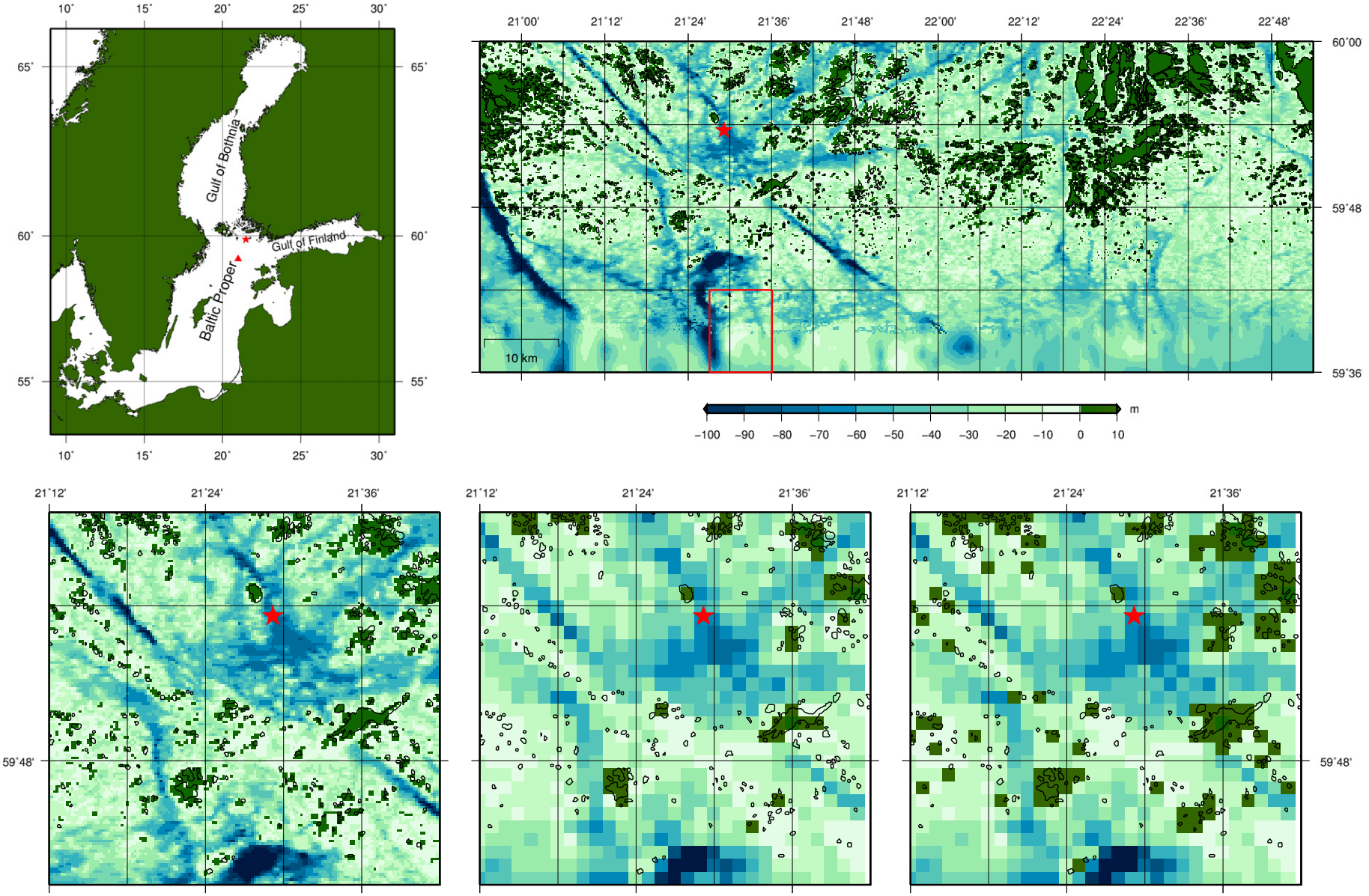

Fig. 1. The Baltic Sea with location of the measurement sites (NBP wave buoy with triangle, R/V Aranda with star) and the bathymetry of the southern part of the Archipelago Sea (with 0.1 nmi resolution) is shown in the upper panels. In the lower panels are shown the land–sea distribution in the 0.1 nmi (on the left) and 0.5 nmi grid with 50% (in the middle) and 30% (on the right) threshold values. In the upper left panel the area presented in Fig. 7 has been outlined with red colour.