The Adriatic Sea wave response to severe *Bura* wind

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Abstract: *Bura* is a strong wind with severe gusts; it occurs suddenly and affects safety of life at sea. It has a large spatial variability and depends on an upstream terrain configuration. The quality of surface winds derived from meteorological models is the key issue (and input) in wave modelling. In this study we are addressing question of storm *Bura* wind and effect on wave field response. Increase in the predicted wind field resolution from 8 to 2 km using Aladin model dynamical adaptation enables high resolution wave forecast as well. There is little information about detailed structure of the wave field (significant height and direction) in the Adriatic Sea produced by severe *Bura* wind. Results for wave response of the Adriatic Sea for 13-18 of November 2004 storm are presented and discussed in detail, as well as differences due to forcing of the wave model with 8 km and 2 km ALADIN wind fields. Comparison of modelled wave response is made with in situ ADCP wave measurements.

Keywords: Wave fields, numerical model, *Bura*, Adriatic Sea.

1. INTRODUCTION

Bura is a strong wind that occurs when there is a pressure gradient across the coastal mountains, usually connected with advection over the mountains towards the sea. Typically there is anticyclone over relatively cold ground and/or cyclone development over the relatively warmer sea. This feature makes *Bura* wind more severe and frequent during the cold part of the year. The flow is blocked or significantly modified by the mountains and characterized by its sudden occurrence, spatial variability and dependence on upstream terrain configuration. Lower resolution meteorological models give overall good results over the oceans, but the results are doubtful in enclosed basins and whenever the surface winds are significantly affected with the surrounding orography. In these areas modeled surface wind fields are almost always underestimated with bias exhibiting strong correlation with land proximity (Cavaleri and Bertotti, 1997). As expected, wave models reflect the same characteristics as input forcing wind fields. Having that in mind we have carried series of numerical experiments with both meteorological and wave model. Modeling effort in the study was made with ALADIN (meteorological model) and SWAN-wave forecast model. Both models are recognized as state of the art in modeling community. Using them with high horizontal resolution (2 km) gives opportunity for reliable wind and wave forecast.

2. METHODS

2.1 METEOROLOGICAL MODEL - ALADIN

One of the reasons why global meteorological models have difficulty in providing high-quality surface winds in enclosed basins is the relatively coarse resolution with which they try to represent the local geometry, in particular the orography that surrounds the basin. Lack of higher resolution in those models acts as a spatial smoothing filter, which removes fine resolution effects (valleys and ridges). Therefore, it is not unreasonable to assume that limited area models, focused on the area of interest with the capability of using much higher resolution, may provide better results (Signell et al., 2004).

The model is run operationally for 00 and 12 UTC in the Croatian Meteorological Service. More details, including comparison of model wind output with observed data for few *Bura* cases can be found in Ivatek-Šahdan and Tudor (2004) and Tudor and Ivatek-Šahdan (2002).

2.2 WAVE MODEL - SWAN

In order to simulate the wave field dynamics using meteorological wind model, a third-generation wave model, SWAN (Simulating WAves Nearshore), has been implemented for the Adriatic Sea. The SWAN model was developed for shallow waters at Delft University of Technology (TU Delft). The basic model used in this study was SWAN version 40.41, which contains important improvements in the advection schemes, which significantly reduce diffusion, extending the application of SWAN from shallow water to basin-scale simulation. The code was enhanced for parallel processing using MPI (Message Passing Interface). Waves are represented with the 2D wave action density spectrum, the balance equation of which, takes into account the local rate of change in time, the propagation in geographical space, the shifting of the relative frequency due to variations in depths and currents and the depth-induced and current-induced refraction. The sink-source terms take into account the generation by wind, dissipation by white-capping, dissipation by depth induced wave breaking, dissipation by bottom friction and redistribution of wave energy over the spectrum by non-linear wave–wave interactions. A full description of the SWAN model is given by Holthuijsen et al. (1989), Booij et al. (1999) and Ris et al. (1999), and http://www.swan.ct.tudelft.nl. A total of 36 uniformly distributed directions were used with 26 frequencies geometrically distributed: $f(n + 1) = 1.1f(n)$, and $f1 = 0.05$ Hz. The model time step was 10 min and the spatial grid had a uniform resolution of about 2 km over the Adriatic. The bathymetry for the 2 km grid was interpolated from the finite element tidal model of Janeković et al. (2003). The wind components from the ALADIN wind model were linearly interpolated onto the 2 km wave model grid prior to running the simulations. Incoming waves at the open southeastern boundary of the Adriatic were assumed to be zero. The model was run in non-stationary mode with wave breaking enabled and Madsen bottom friction with default parameters.

2.3 WAVE DATA OBSERVATIONS

During 'WIsE Summer'[a], 600 kHz RDI ADCP current meters with wave measuring capability have been installed. Wave observations were made from 27th July till 19th November 2004 with 6 hour interval. Wave station was located in the northern Adriatic (indicated as black dot on Fig 1). Obtained data were analyzed and used in comparison with the wave model prediction for significant wave heights (Hs) and directions in time.

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[a] West Istrian Experiment in summer of 2003, carried by GSO, Ruđer Bošković Institute.

3. RESULTS AND DISSCUSION

On the November of 12th *Bura* event started and developed in full featured storm with wind speed exceeding 240 km/h. ALADIN model predicted occurrence and was able to reproduce high variable structure of the jets as well strong horizontal gradients (Fig 1 top left).

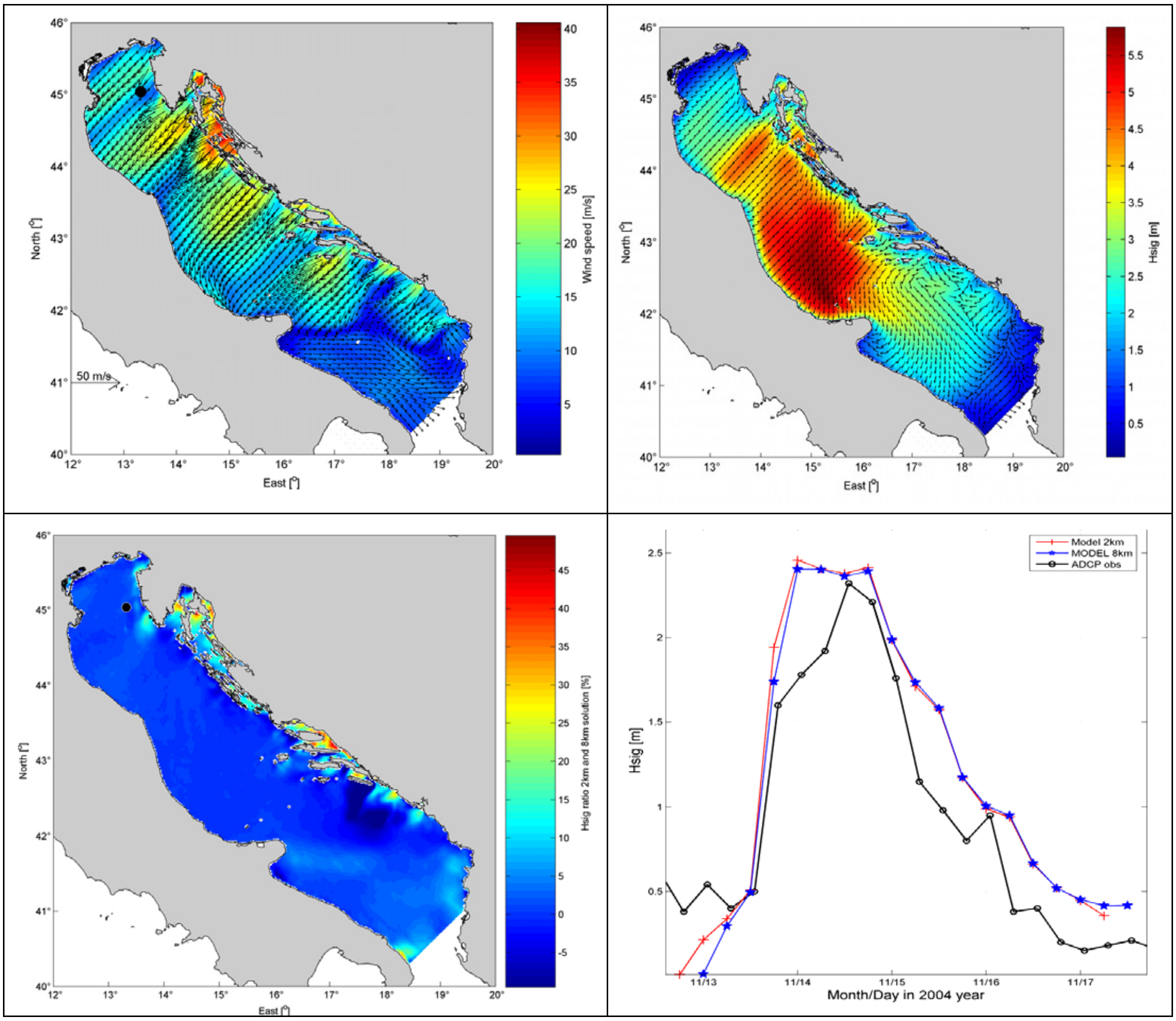

Figure 1. Predicted wind field 10m above sea level [m/s] (top left), model predicted significant wave height [m] (top right), ratio of predicted significant wave height using 2km and 8km forcing (bottom left) and comparison with observations [m] (bottom right). All figures are for 14/11/2004 at 18 UTC.

As the forcing input into wave model, we used continuous ALADIN model wind field outputs at 3 hour intervals, from +12 to +36 hours since model daily run at 00 UTC. In this way we limited the extent of the forecast to avoid large divergences with respect to the analysis, allowing enough time for model to adapt to the initial conditions. Modelled wave fields reflect features of the meteorological model wind field but in smoother way as expected. Moreover wave field exhibits integrated effect (‘have longer memory’), which propagates longer in time and space. Again, wave fields clearly follow structure of wind fields separating northern jet structure of Hs, which originate to Kvarner Bay *Bura* jet and southern - wider structure. Former extend on larger area, without narrow shape (Fig. 1 top right) providing wider source and longer fetch for waves to develop. Maximum values for Hs are found in the central Adriatic, closer to Italian coast, reaching remarkable value of 5,5 meters. Even in the Kvarner Bay, where fetch is relatively short, wave model predicts maximum Hs of 3 meters, mainly due to very strong wind forcing (more than 30 m/s). This region pronounces more clearly difference between forcing wave model with 8 and 2 km ALADIN resolution (Fig.1 bottom left). Lower resolution ALADIN solution underestimates strong *Bura* jets in proximity of land and island simply because of inadequate representation of orography. Consequently, wave response is weaker and difference for Hs can be as much as 1 meter, or about 50% (see Fig. 3 bottom left, for Velebitski channel and Kvarner Bay). Comparison of wave observations with model prediction exhibits generally good correlation. Wave model is capable to accurately predict occurrence, duration and maximal value for Hs (Fig.1 bottom right). Interesting to note is that wave response to 8 km forcing is good as for 2 km. This is probably because of the ADCP wave station position (Fig 1, black dot), located in the region where difference between two model outputs was not pronounced.

4. CONCLUSIONS

The high resolution ALADIN model provides not only more detailed structure, but significantly more accurate wind speeds for storm *Bura* events. In this study we focused on storm *Bura* lasting from 13th to 16th of Nov. 2004. Forcing 2 km resolution wave model of the Adriatic Sea with two different (8 and 2 km) resolution wind model resulted in notable differences, more pronounced in the regions close to land (i.e. Kvarner Bay), where the difference can be as much as 50% for significant wave height. Comparison of modelled and observed waves, at one ADCP station, exhibits accurate prediction of wave storm (within hour), duration and as well maximum peak values. Maximum significant wave height was found for 14/11/2004 at 18 hrs in the middle of the Adriatic, close to Italian coast, where value exceeded 5,5 meters.

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