SEVERE NORTH-EASTERN ADRIATIC BURA EVENTS AND CIRCULATION IN GREATER KVARNER REGION

Milivoj Kuzmić[1], Ivica Janeković[1], Branka Ivančan-Picek[2], Tanja Trošić[1], and Igor Tomažić[1]

[1] Ruđer Bošković Institute, Center for Marine & Environmental Research, Bijenička 54, HR-10000 Zagreb, Croatia
[2] Meteorological and Hydrological Service, Grič 3, HR-10000 Zagreb, Croatia
E-mail: *kuzmic@rudjer.irb.hr*

Abstract: In this paper we explore onset and duration of several severe Bura events, focusing on the circulation that such events impose in the greater Kvarner region. Three periods, better documented meteorologically and/or oceanographically, were selected for modelling and analysis: 5-9 November 1999, 8-15 February 2003, and 12-16 November 2004. In the performed simulations the wind emerged as the dominant driving force with important coastal and bathymetric constrains. The modelled barotropic response to the selected Bura events is characterized by a multitude of cyclonic and anticyclonic circulation cells, strongly controlled by the rich insular topology, lateral geometry, and bottom topography. The high resolution finite-element mesh of the model has allowed for the first time to resolve the intricacies of numerous sub-basins and channels, and to elucidate the interplay of laterally heterogeneous wind stress and bottom topography. The important aspect of the heat loss and surface cooling triggered by Bura episodes has been also addressed to the extent the model and data limitations allowed.

Keywords – *severe Bura, Adriatic, Kvarner, circulation*

1. INTRODUCTION

Bura is one of the two better known local Adriatic winds. This katabatic, orographically controlled, north-easterly wind is often perceived as violent wind storm, with gusts that may exceed 50 m/s. The low and narrow passes in the hinterland play an important part in its development, and exert controlling influence on its along-coast variability. The north-eastern stretch of the Adriatic Sea between the Istrian peninsula and the Zadar Channel (called in this paper greater Kvarner region, GKR) is characterized by numerous islands and channels and water depth not exceeding 100 meters. Elaborate lateral geometry and orography as well as bottom topography of the area profoundly constrain the induced motions, and impose unique response to Bura wind forcing. In this paper we are set to explore onset and duration of several severe Bura events, focusing on the circulation that such events impose in the GKR. To that end the ALADIN/HR (Aire Limitee Adaption Dynamique development INternational/ HRvatska - Croatia) model has been selected to provide the atmospheric forcing, and Quoddy oceanographic circulation model was set up to simulate circulation in the northern Adriatic Sea.

2. DATA

Three periods, better documented meteorologically and/or oceanographically, were selected for the analysis: 5-9 November 1999 (IOP-15), 8-15 February 2003 (ACE/WISE), and 12-16 November 2004. In order to analyze with more confidence the model simulations for those periods several field data sets were collected and processed with a view to validate various aspects of both models. In particular, we have used in the process of validation and analysis the 10m wind, sea surface temperature (buoy measured and satellite detected), air temperature, and current meter data. The location of all data stations is indicated in Fig. 1, together with model bathymetry (Fig. 1, left) and computational grid (Fig. 1, right). Not all is situ data were available for all periods and at all locations.

3. MODELS

ALADIN is a spectral, hydrostatic model that takes initial and boundary conditions from the global Integrated Forecast System/ Action de Recerche Petite Echelle Grande Echelle model. Generalised vertical hybrid pressure co-ordinate is used, with a finite difference horizontal grid in Lambert conformal projection (Gerard, 2001). Dynamic adaptation is used to take into account orographic influence over smaller domains. The Croatian Meteorological Service runs the model operationally for 00 and 12 UTC with horizontal resolution of 8 km (consisting of 169x149 points, with extension zone of 144x120) and 37 vertical levels. The 2 km resolution dynamic adaptation domains consist of 72x72 points (with extension zone 80x80 points) and 15 levels (Tudor and Ivatek-Šahdan, 2002). Out of eight available dynamically adapted domains, two were used in present study (Senj and Maslenica). ALADIN outputs are provided every 3 hours producing 48-hour forecasts.

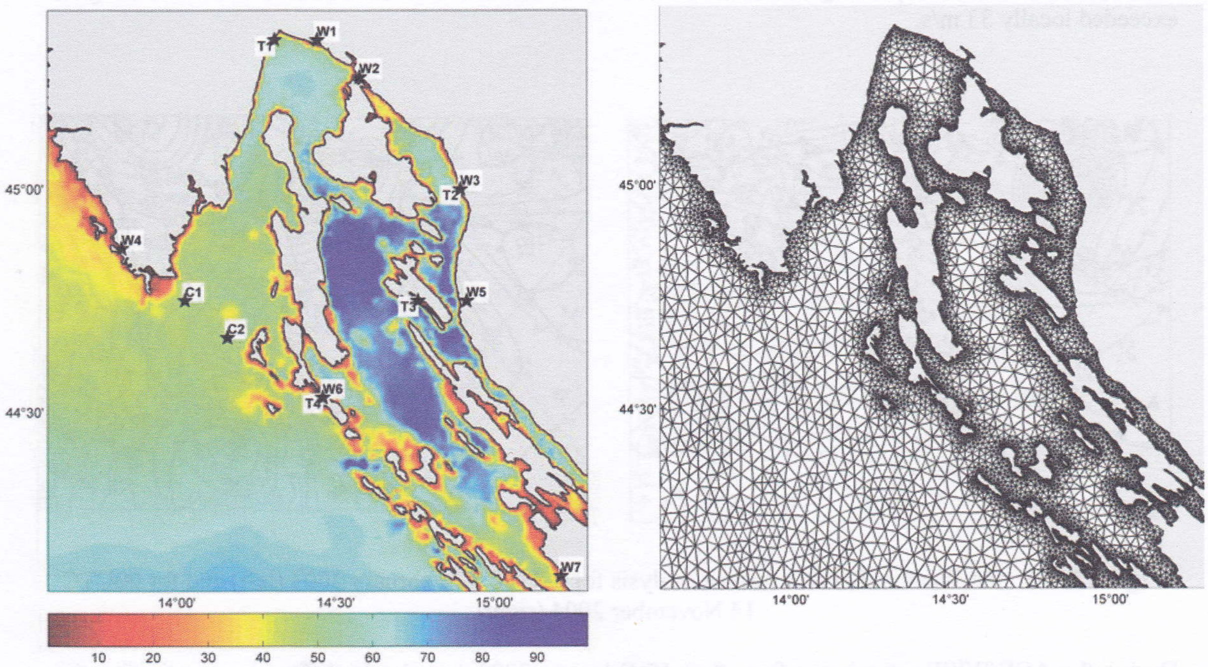

Figure 1. Modelled area with bathymetry and star-marked field data stations (left), and the Northern Adriatic model finite-element mesh, zoomed on the GKR (right). C is for current, T for temperature, and W for wind data.

Quoddy is a three-dimensional, nonlinear finite-element model, with sigma-coordinate transformation in the vertical (Lynch *et al.*, 1996). Details of the finite element solution are given in Lynch and Werner (1991). It has been run on a high-resolution grid (17284 nodes, and 28669 elements over the northern Adriatic – the area above 43°30'N) successfully resolving well-developed eastern Adriatic coast and the GKR in particular (the smallest triangles having sides of only 500m, and area of about 9000 m^2). Well-known sigma coordinate system (x, y, σ) is used in the vertical, with 21 non-uniformly placed nodes, whose sinusoidal vertical spacing provides an increased resolution of the surface and bottom layers.

4. RESULTS AND ANALYSIS

The Bura onset, its longevity and severity are all closely related to larger mesoscale features, in particular to those resulting from the interaction processes of synoptic scale flow with the Alpine massif.

In addition, the speed and direction of Bura are greatly influenced by local topographic features. The synoptic setting of Bura on the northern Adriatic developed during the MAP IOP15 (5 to 9 November 1999) followed an explosive lee cyclogenesis over the Tyrrhenian Sea. The lee cyclogenesis and low-level blocking and deflection of airflow by the Alps was associated with a deep trough extending from the North Sea to France with the cold air advection that had reached the Mediterranean. Simultaneously, there was an increase of the surface anticyclone over the north-western part of Europe resulting with strong pressure gradients developed in the lower levels across the entire Alps and Dinaric massif. In the northern Adriatic, the Bura started developing early on November 7 reaching its maximum strength around 00UTC November 8. Similar weather situation was reported on 12 to 16 November 2004. A moderate to strong Bura started on November 13 as a consequence of a strengthening cyclone over the southern Italy and the Adriatic Sea. Further synoptic development (deepening of the cyclone and a simultaneous strengthening of a middle Europe anticyclone) led to a strengthening of the Bura (Fig. 2, right). There was an increase in the surface pressure gradients over the Dinaric Alps of more than 10 hPa over horizontal distance of 50 km thus pushing the cold air from the inland toward the Adriatic area. Severe gusts exceeded locally 33 m/s.

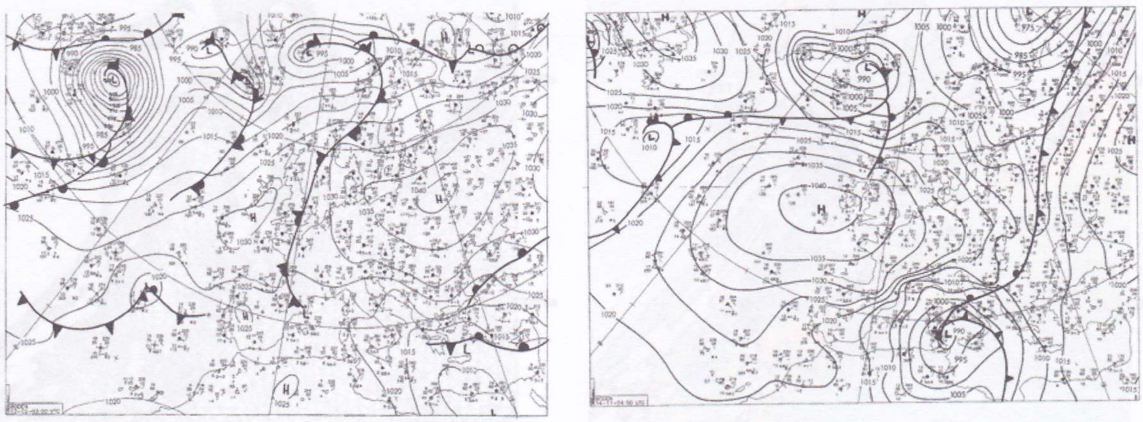

Figure 2. German Weather Service surface analysis for 00UTC 12 February 2003 (left) and for 00UTC 14 November 2004 (right).

During the ACE/WISE experiment from 8 to 15 February 2003 completely different synoptic situation was observed. The synoptic setting leading to severe Bura flow followed a strong anticyclone north and northeast of the Alps, producing strong pressure gradients over the Dinaric Alps (Fig. 2, left).

The impact of the above described situations on the circulation in the GKR was simulated primarily via one way momentum flux, i.e. 10m wind stress. Although the atmospheric model is structured to provide also the fluxes of heat and moisture only the wind stress has been routinely used in the present study, because of technical difficulties, and lacking validation of the modelled heat flux and moisture fields. In order to access the validity of the 10m forcing wind fields the ALADIN/HR data were compared to the wind measurements available at several meteorological stations along the Northern Adriatic coast (Fig. 1). The comparison has shown (Fig. 3, left) variable model-to-data agreement, with modelled and measured vectors more in accord at the stations under more direct influence of Bura.

5. CONCLUSIONS

Throughout the performed simulations the wind emerged as the dominant driving force with coastal control restricting horizontal scales of motion, and bathymetry proving conductive to surface effects penetration through the better part of the water column. The modelled barotropic response to selected Bura events is characterized by a multitude of cyclonic and anticyclonic circulation cells, strongly controlled by the rich insular topology, lateral geometry, and bottom topography (Fig. 3, right).

The high resolution, finite-element mesh of the model has allowed for the first time to resolve the intricacies of numerous sub-basins and channels, and to elucidate the interplay of laterally heterogeneous wind stress and bottom topography. The important aspect of heat loss and surface cooling triggered by Bura episodes has been also addressed to the extent the model formulations and data limitations allowed. This important aspect of the sea response to strong Bura is the subject of our ongoing research and near-future modelling plans.

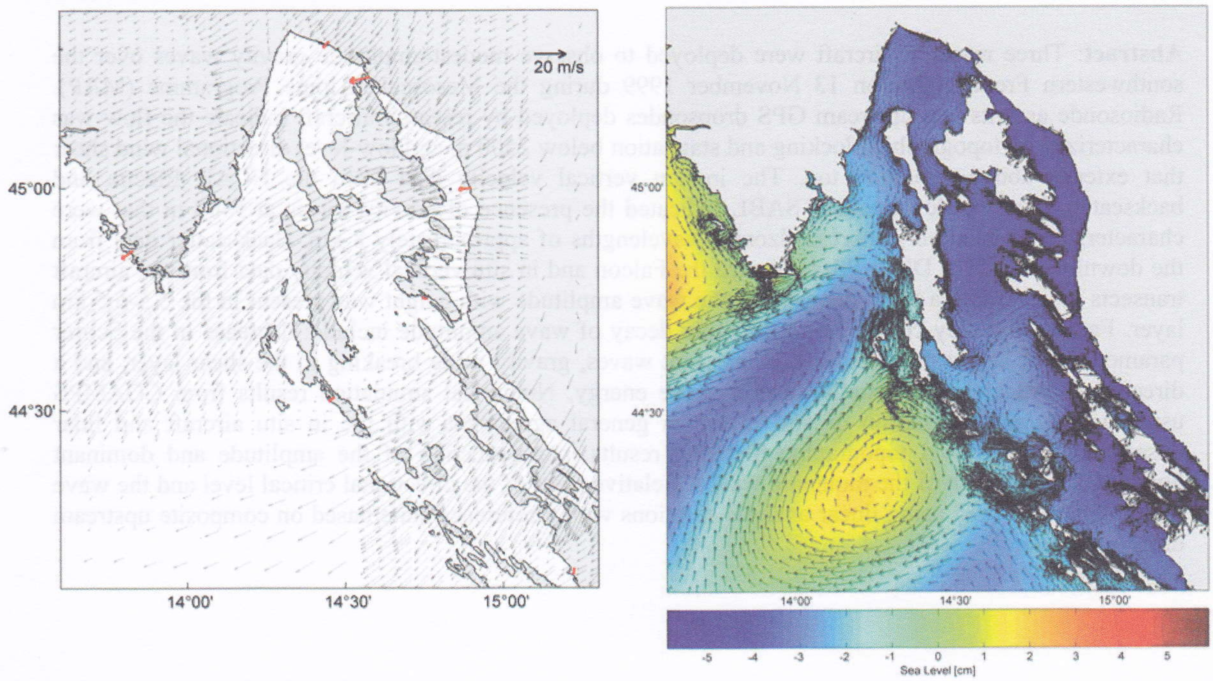

Figure 3. Daily averaged ALADIN-derived (black) and station-measured 10 m winds (red) for the 12 February 2003 (left); model predicted sea level and transports for the 12 February 18:00 UTC (right).

Acknowledgement: This work has been supported by the Croatian Ministry of Science, Education and Sport through the grants 0098113 and 0004001. The US Naval Research Laboratory "ACE" current meter data (C1) were kindly provided by Drs. Henry Perkins and Jeffrey H. Book.

REFERENCES

Gerard, L. 2001: Physical parameterizations in APREGE-ALADIN operational model, ALADIN documentation, Meteo France, 130pp.

Lynch, D. R. and F. E. Werner, 1991: Three-dimensional hydrodynamics on finite elements. Part II: non-linear time-stepping model. *International Journal for Numerical Methods in Fluids*, 12, 507-533.

Lynch, D.R., T.C. Justin, C.E. Naimie, and F. E. Werner, 1996: Comprehensive coastal circulation model with application to the Gulf of Maine, *Continental Shelf Research*, 16, 875 – 906.

Tudor, M. and S. Ivatek-Šahdan, 2002: MAP IOP 15 case study, *Croatian Meteorological Journal,* 37, 1-14.