# VERTICAL STRUCTURE OF THE DINARIC ALPS FLOW DURING MAP IOP 15

Branka Ivančan-Picek[1], Stjepan Ivatek–Šahdan[1] and Vanda Grubišić[2]

[1]Meteorological and Hydrological Service, Zagreb, Croatia
[2]Desert Research Institute, Reno, NV, USA
E-mail: *picek@cirus.dhz.hr*

**Abstract**: In this study, a detailed analysis has been undertaken of the *Bura* flow structure downwind and over the Dinaric Alps on 7 November 1999 during MAP IOP15. Grubišić (2004) used the flight-level data from the coordinated NCAR Electra and NOAA P-3 coast-parallel tracks and cross-mountain tracks by the Electra to document the origin, structure and steadiness of secondary potential vorticity (PV) banners generated by the Dinaric Alps. The observed flow structure is compared here with simulation results from the ALADIN/HR hydrostatic mesoscale model run at the horizontal resolution of 8 km and the 2 km dynamical adaptation. The good agreement between the flight-level data and model simulations provided the basis for the detailed analysis of the evolution and structure of the *Bura* flow along the entire Adriatic during IOP 15.

***Keywords*** *– ALADIN/HR, COAMPS, MAP, IOP 15, Bura, secondary PV banners*

## 1. INTRODUCTION

*Bura* is a strong, gusty, northeasterly downslope wind along the eastern Adriatic coast that is strongly influenced by local processes and orography. Knowledge of the mesoscale flow patterns increases the forecasting skill for surface winds in the region, especially in hazardous situations. The observed maximum *Bura* wind speed during IOP 15 locally at the Maslenica Bridge south of the Velebit Mountain exceeded 40 m/s. The important basic upstream ingredients of a major *Bura* event are strong vertical wind shear, and a typical *Bura* layer covered by a temperature inversion.

The width and maximum height of the Dinaric Alps increase from the northwest to the southeast with the peak heights up to 1.5 km in the north to 2 km in its southern part. Several prominent passes and gaps are important factors determining the along-coast variability of the *Bura* and the attendant PV banners (Grubišić, 2004). In addition, the detailed analysis of the development and structure of the *Bura* flow along the entire Adriatic during IOP 15 is presented. Figure 1 illustrates the cross sections used in the flow analysis. Cross sections AC and AD has a same starting point near Udine.

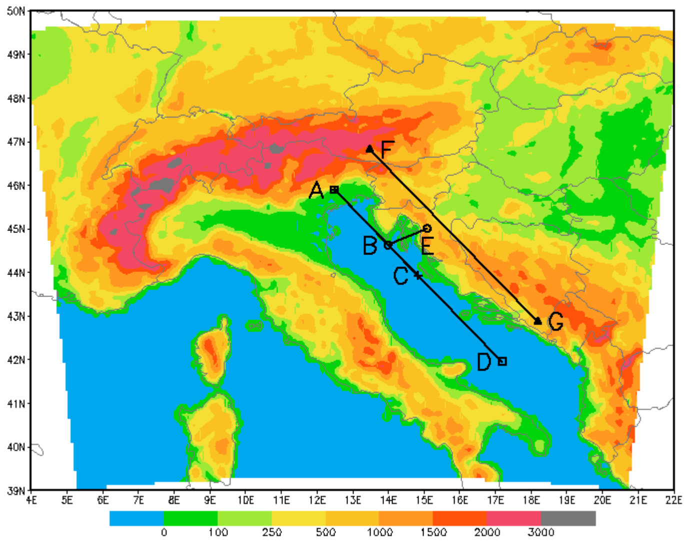


**Figure 1.** ALADIN/HR orography in the 8 km model domain. The thick solid lines mark the cross sections shown in Figs. 2, 3 and 4.

## 2. FLIGHT TIME ANALYSIS

The aircraft mission during MAP IOP 15 was focused on documenting the secondary PV banners in the wake of the Dinaric Alps during the strong *Bura* on November 7. The observed flow structure derived from the NCAR Electra and NOAA P-3 flight-level data from the coordinated coast-parallel tracks and the cross-mountain tracks by the Electra (Grubišić, 2004) is compared here with simulation results from the ALADIN/HR hydrostatic mesoscale model run at the horizontal resolution of 8 km, and the dynamical adaptation run on the 2 km grid. Comparison is also made with the COAMPS non-hydrostatic model runs at the horizontal resolutions of 3 km, used in Grubišić (2004).

All three numerical model results show the wake structure within the *Bura* flow over the Adriatic with several separate low-level jets whose approximate widths are 25 – 50 km (Fig. 2). The high steadiness of the wake structure was found. Steep lowering of isentropic surfaces shows a large amplitude mountain wave on the lee side of the Dinaric Alps and reveals the presence of wave breaking below 3 km. The generation of these flow features (separate low-level jets, hydraulic jump and wave breaking) resulted in the formation of PV anomalies. The models simulated negative and positive PV banners were found to be in good agreement with PV derived from observations (horizontal scale of ~25 km, maximum PV ~ 6 to 10 pvu).

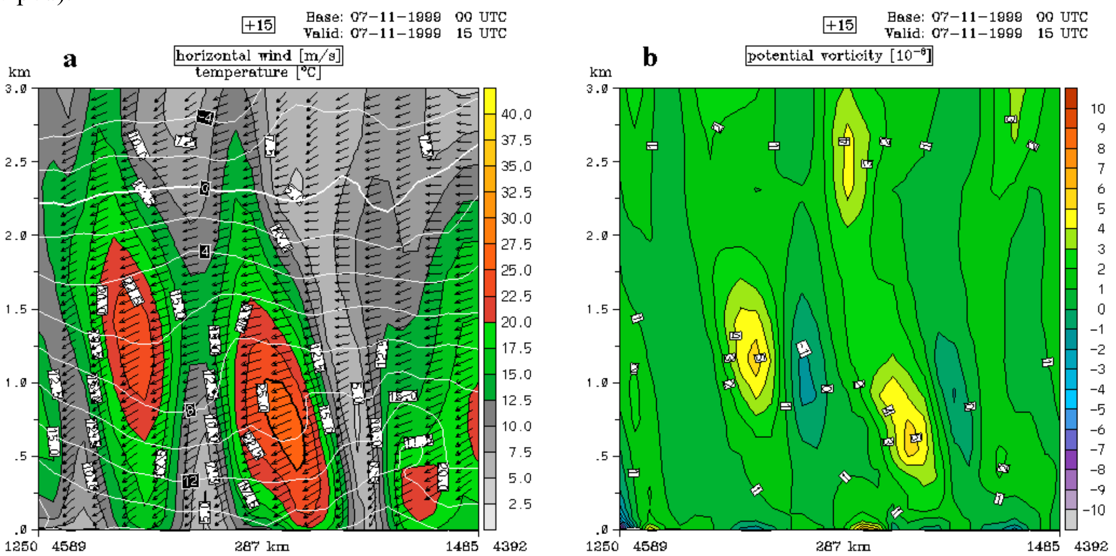


**Figure 2.** ALADIN/HR model (8 km) 15 hours forecast, valid at 15 UTC, 7 November 1999: a) horizontal wind speed (m/s, shaded), wind vectors and temperature (contouring interval 2ºC); b) potential vorticity (pvu), in vertical cross-section AC (the Electra tracks marked by plus sign in Fig.1).

## 3. CROSS - MOUNTAIN FLOW

Vertical cross-section BE across the Dinaric Alps (Fig.3a), show the flow structure simulated by ALADIN/HR 2 km dynamical adaptation. The results indicate a very strong influence of mountain’s configuration on the wind speed and shear layers, particularly in the lower troposphere. A large-amplitude mountain wave on the lee side of the coastal mountains is accompanied by intrusion of potentially much warmer and drier air from aloft. Sharp gradients in high-resolution potential temperature field reveal the presence of wave breaking above the mountain top, and wave flow downstream. The height of the inversion layer reveals that the stable layers are sloping downward in the downstream region. A comparison of the horizontal wind speed and direction for the 8 km (not shown here) and 2 km resolution shows that the wind maximum (more than 35 m/s in the latter) is much closer to the ground and to the mountain slope in the high-resolution model results. In between the coastal range and the Kvarner island of Cres a second wind maximum is located.

Fig. 3b shows the prediction for the *Bura*-driven PV banners in the same vertical cross-section. High-resolution ALADIN/HR simulation suggest the presence of several distinct maxima of PV. The strongest PV maximum at a height of 2.5 km in the jump region is associated with strong wind shear. Several separate PV banners are found within the boundary layer separating individual wind maxima and wakes. These PV anomalies have the characteristic horizontal scale of 10-20 km with the maximum amplitude up to 8 pvu and are in good agreement with PV derived from observations. These results support the thesis that the dissipation in the hydraulic jumps and the wave breaking regions is likely the dominant PV generation mechanism in this case.

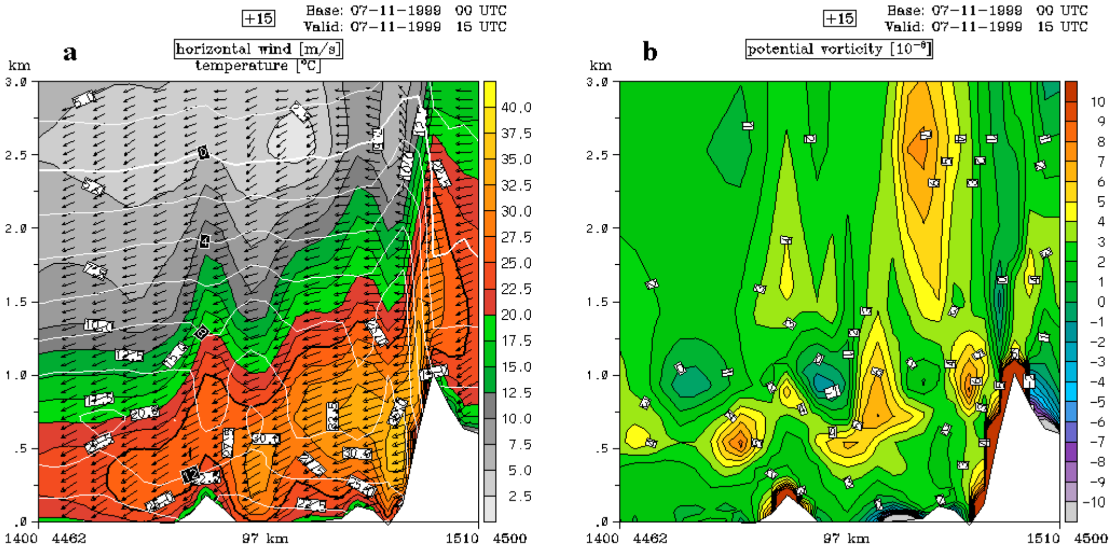


**Figure 3.** Vertical cross-section BE (marked by open circles in Fig.1): a) horizontal wind speed (m/s, shaded), wind vectors and temperature (contouring interval 2ºC); b) potential vorticity (pvu). ALADIN/HR dynamical adaptation model prediction data for 15 UTC, 7 November 1999.

## 4. UPSTREAM AND DOWNSTREAM BURA FLOW STRUCTURE

The good agreement between the flight-level data and model simulations provides the basis for the detailed analysis of the development and structure of the upstream and downstream *Bura* flow along the entire Adriatic and the Dinaric Alps during IOP 15.

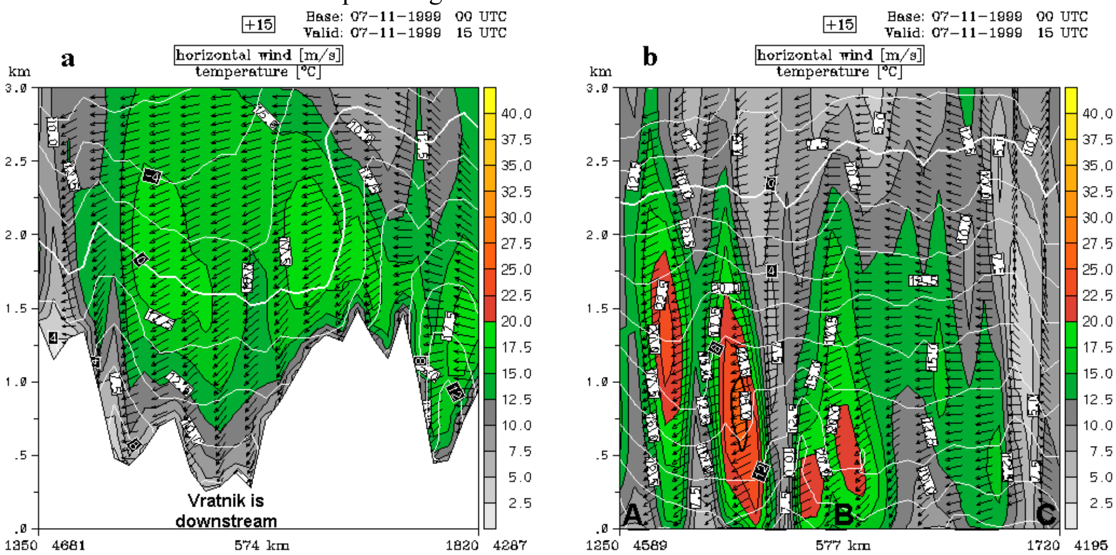


**Figure 4.** Mountain-parallel vertical cross-sections: a) upstream section - FG (marked by open triangles in Fig.1); b) downstream section - AD (marked by open squares in Fig.1) showing horizontal wind speed (m/s, shaded), wind vectors and temperature (contouring interval 2ºC). ALADIN/HR model prediction data for 15 UTC, 7 November 1999.

The appearance of the northeasterly low-level jet over the western part of Croatia close to the 00 UTC on November 7 was associated with the cold air outbreak in the rear of surface front and marks the beginning of this *Bura* event. Many case studies of the Adriatic *Bura* storms indicate the presence of the upstream low-level jet (Ivančan-Picek and Tutiš, 1996).

Numerical model results indicate that the upstream low-level jet position is crucial for the downstream *Bura* flow generation (Fig. 4a). The latter is well correlated with the upwind distribution of mountain passes and peaks along the coastal mountain range of Croatia. Figure 4b shows the wake structure within the *Bura* flow over the northern Adriatic with several separate low-level jets. The main jet, whose approximate width and height are 50 km and 1.5 km, originates as a flow through the Vratnik Pass (cross section BE). The persistence of the upstream northeasterly low-level jet over the western part of Croatia is one of the keys for explaining the strength and localization of this *Bura* event. With a well defined critical level around 2 km (Fig.4b) and the wind turning from north-easterly low-level flow to south-soutwesterly aloft, relatively high and broad Bosnian Dinaric mountains have shielded the southern Adriatic from the strong *Bura* flow observed on the north Adriatic.

## 5. CONCLUSION

A detailed analysis of the *Bura* flow structure across the Dinaric Alps on 7 November 1999 during the MAP IOP 15 has been undertaken. Numerical model results show the wake structure within the *Bura* flow over the Adriatic with several separate low-level jets with approximate widths of 25 – 50 km. The generation of these flow features (separate low-level jets, hydraulic jump and wave breaking) resulted with the formation of PV anomalies. The models simulated negative and positive PV banners were found to be in good agreement with PV derived from observations (horizontal scale of ~25 km, maximum PV ~ 6 to 10 pvu). The model results indicate that the upstream low-level jet position and the upwind distribution of mountain passes and peaks along the coastal mountain range of Croatia are crucial for the downstream *Bura* flow generation. While the ALADIN/HR model is hydrostatic, the results from this model simulations at 8 km resolution successfully captured the essence of the *Bura* dynamics, and produced the PV banner structure over the Adriatic that was in good agreement with the observations and the COAMPS non-hydrostatic model results at 3 km resolution. The evaluation of the model results at different horizontal resolution clearly shows that substantial amount of additional information on the fine-scale structure of the flow is obtained at higher model resolutions.

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## REFERENCES

Grubišić, V., 2004: Bora-driven potential vorticity banners over the Adriatic. *Quart. J. Roy. Metoerol. Soc.,* ***130,*** *2571-2603.*

Ivančan-Picek, B. and V. Tutiš, 1996: Severe Adriatic Bora on 28 December 1992. *Tellus,* **48A**, 357-367.

Ivatek-Šahdan, S. and M. Tudor, 2004: Use of high-resolution dynamical adaptation. *Meteor. Z.*, **13**, 99-108.