P2.14 IS SEVERE ADRIATIC BORA ASSOCIATED WITH A TROPOPAUSE FOLD?

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Keywords: Adriatic, cut-off low, Dinaric Alps, MM5, potential vorticity anomaly, stratospheric intrusion

1. INTRODUCTION

Bora (*bura* locally) is a cold, dry, downslope wind, which blows at the eastern Adriatic coast and in the inland adjacent regions. It is accompanied with the high N-S synoptic-scale pressure gradients and cold air outbreaks from the north (e.g. Bajić, 1987). Due to unexpected violent gusts (e.g. Petkovšek, 1987; Cvitan, 2003; Belušić and Klaić, 2004; Belušić et al., 2004), bora may be hazardous to traffic, buildings and trees. Sometimes it even causes human injuries.

Bora-like flows also occur in other parts of the world, e.g. in Novorossiysk and Caucasus coast of the Black Sea, in the Gulf of Tehuantepec at the Pacific Coast of Mexico (known as *papagayos* or *tehuantepecers*), in the Kanto Plain, Japan (where it is called *oroshi* or *karakkaze*) (Yoshino, 1976), and, at the foothills of Rocky Mountains (Boulder windstorm) (Klemp and Durran, 1987; Smith, 1987).

Bora layer occupies a few lowermost kilometers of the atmosphere. Consequently, synoptic and mesoscale processes within the lower troposphere prior and during bora are well examined and documented. Specifically, a number of recent studies address to the establishment of the low-altitude bora-induced potential vorticity (*PV*) anomalies (*PV* banners) (Grubišić, 2000; Klaić et al., 2003a; Grubišić, 2004; Grubišić et al., 2005; Ivančan-Picek et al., 2005; Belušić and Klaić, 2006), i.e. 'secondary' banners (Grubišić, 2004) that originate from the edges of major massifs along the Dinaric Alps.

Here, we focus on the upper tropospheric conditions during severe bora winds. Specifically, we inspect the upper tropospheric *PV* anomalies which have different origin than the aforementioned orographically generated low-altitude anomalies. For this purpose we select five episodes in which the surface wind speeds up to 200 km h^{-1} (55.6 m s^{-1}) were recorded. All episodes were accompanied with structural damages and major problems with the road and sea traffic, while in two cases even human injuries were reported.

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2. INSPECTED BORA EPISODES

Following bora episodes were selected:

- 7 November 1999 – a major bora event during Mesoscale Alpine Programme Intensive Observation Period 15 (MAP IOP 15). The same episode was also investigated by several authors (Klaić et al., 2003a; Belušić and Klaić, 2004; Grubišić, 2004; Ivatek-Šahdan and Tudor, 2004; Ivančan-Picek et al., 2005).
- 14-15 November 2004 - an extremely strong bora with human injures and severe damages to economy and infrastructure. More about the lower tropospheric conditions for this episode could be find in Klaić and Belušić (2005) and Belušić and Klaić (2006).
- 25-26 January 2005 - at Northern and Middle Adriatic with gusts up to 200 km h^{-1} and 80 km h^{-1}, respectively.
- 22-23 November 2005 – severe bora at whole Adriatic. Human injuries were reported.
- 22-24 January 2006 – severe bora at whole Adriatic.

Analysis of diagnostic synoptic fields for all five episodes revealed the presence of the deep cyclone that extended throughout the whole troposphere. Thus, closed geopotential contours were found up to isobaric surfaces of 300 hPa (Fig. 1), and they were most frequently centered aloft above the central Italy and/or Tyrrhenian Sea.

3. NUMERICAL SIMULATIONS

Numerical simulations were performed with a nonhydrostatic Fifth-Generation Pennsylvania State University – National Center for Atmospheric Research (PSU-NCAR) Mesoscale Model (MM5). It is a three-dimensional, nested-grid, primitive equation meteorological model that uses a terrain-following sigma (nondimensionalized pressure) vertical coordinate (Grell et al., 1995). Here, a version 3.6.3. was employed. Other applications of MM5 to the bora episodes could be find in Beg Paklar et al. (2001) and Belušić and Klaić (2006).

Here, a horizontal domain of 2700 km x 2700 km (Fig. 2) with resolution of 27 km was used. The vertical grid had 36 layers, with a finer spacing at the lower boundary progressively stretching to the domain top (50 hPa). Initial and boundary conditions were obtained from the ECMWF operational analyses that were available every 6 hours.

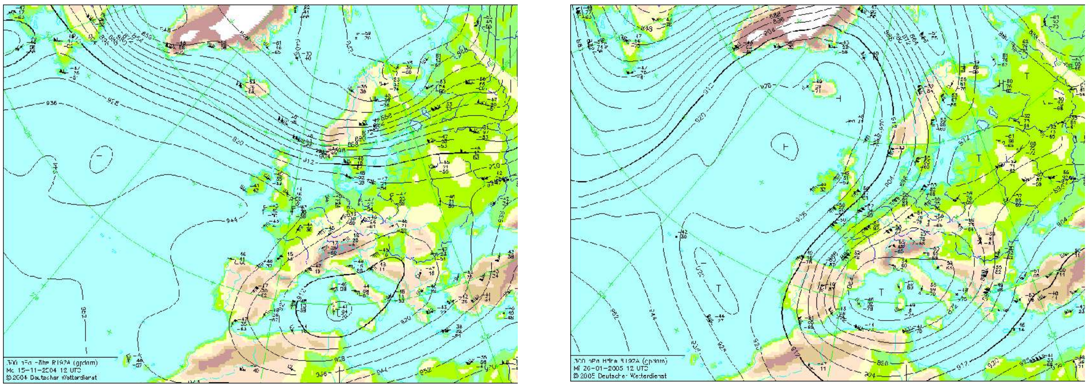

Figure 1: Diagnostic 300 hPa charts for 15 November 2004 (left) and 26 January 2005 (right) at 12 UTC (European Meteorological Bulletin).

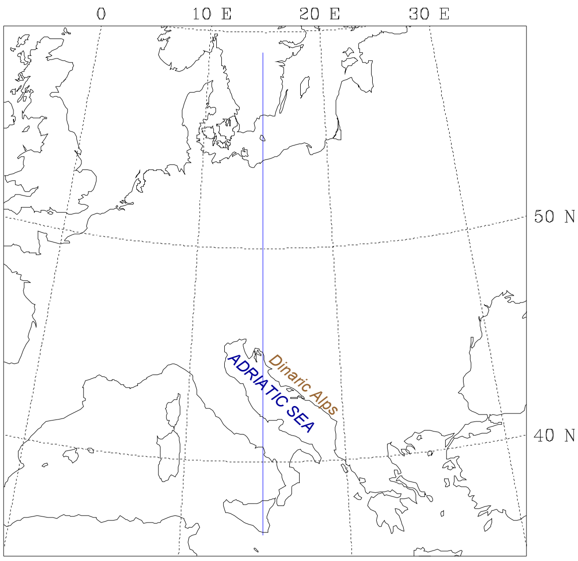

Figure 2: A domain of 2700 x 2700 km^2. Blue line shows the base of the N-S vertical cross-sections shown in Fig. 3.

4. RESULTS

Fig. 3 shows modeled *PV* fields for investigated severe bora cases. Here we give only one ‘snapshot’ per episode. However, regions with the increased, stratospheric *PV* values which indicate the tropopause fold persisted for each episode throughout the whole bora duration. Further, as seen from the vertical cross-sections, *PV* anomalies exhibited tongue-like features, which are typical for stratospheric intrusions. We note, however, that the fine structures of these *PV* streamers are likely more complex (Klaić et al., 2003b), which could not be captured by relatively rough model resolution employed.

On the average, the highest *PV* anomalies (over 4.5 PVU) are found aloft over Tyrrhenian Sea (Fig. 4), i.e. south-westward of the bora region. These roughly coincide with the southern sector of the deep mean cut-off low centered above the central Italy. However, the aforementioned coincidence may be the artifact of the averaging, since individual *PV* anomalies were often found at the western flanks of corresponding deep cut-off lows (c.f. Figs. 2 and 3 for 26 January 2005).

5. SUMMARY AND CONCLUSIONS

Based on the strength of the surface winds, we selected five episodes with the severe bora with wind speeds up to 200 km h^{-1}. Inspection of the upper tropospheric conditions, which were determined from both synoptic diagnostic charts and the mesoscale model (MM5) output, revealed that all episodes were characterized with a deep cut-off low extending throughout the whole troposphere.

Additionally, each episode was accompanied with a prominent tropopause fold penetrating down to the middle troposphere, where *PV* anomaly exhibited surprising duration. It is worth to mention that the stratospheric intrusion during one of investigated bora episodes, namely 7 November 1999, which went along with a north föhn in Alpine region, was also confirmed by other authors (Hoinka et al., 2003; Liniger and Davies, 2003; Keil and Cardinali, 2004). However, present findings give rise to a question if it is just a coincidence, or there is a dynamical link between the bora and the tropopause fold.

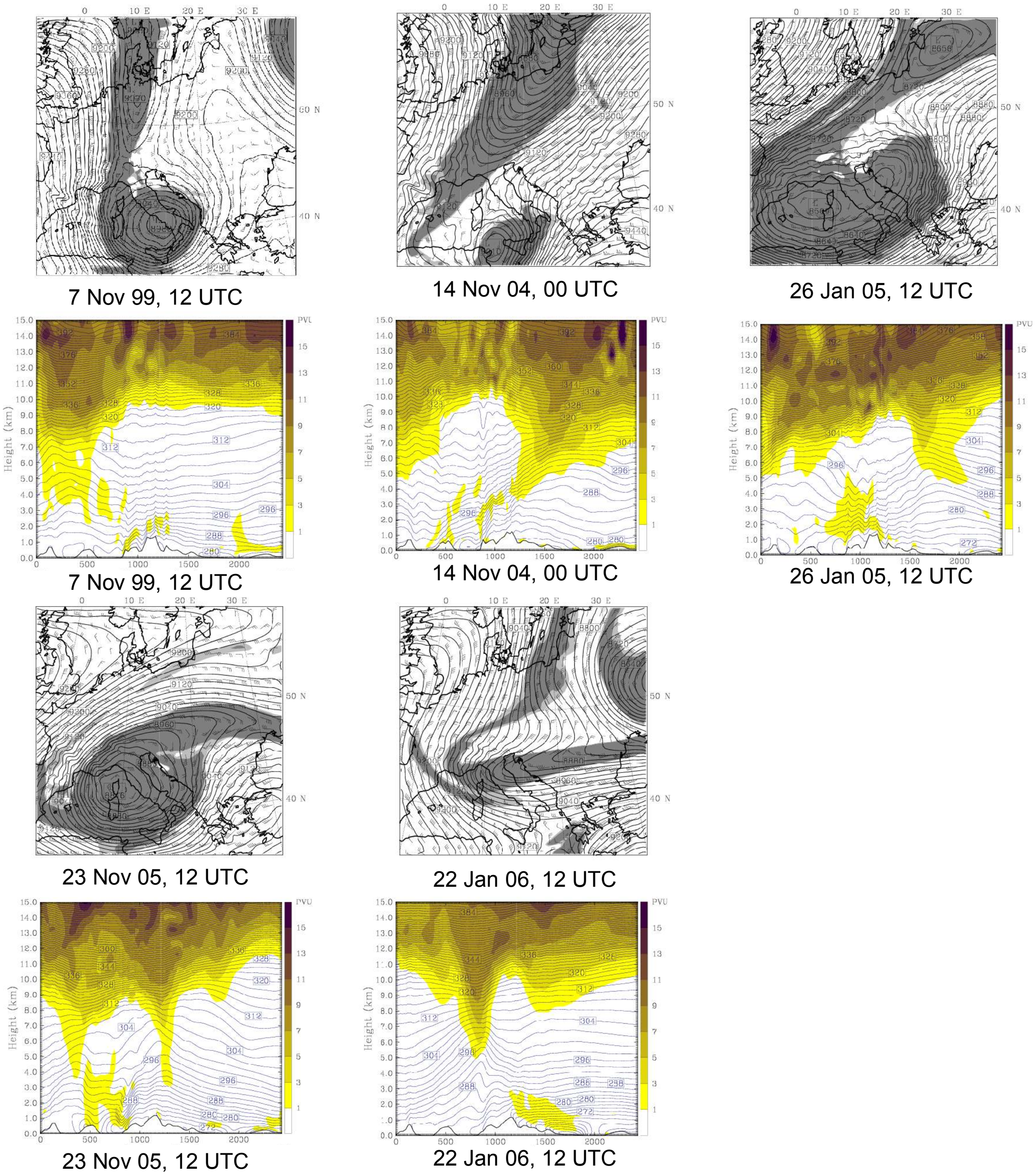

Figure 3: Black/white panels show modeled *PV* fields at 300 hPa isobaric surfaces for investigated bora episodes. Light gray corresponds to region with $PV \geq 1.6$ PVU, while regions with $PV \geq 2.0$ PVU are given in dark gray (1 PVU = 10^{-6} m^2 K kg^{-1} s^{-1}). Horizontal winds and geopotential contours are also shown. Colored panels illustrate N-S vertical cross-sections along the line given in Fig. 2 (N and S correspond to the left- and right-hand side, respectively). Flooded areas show modeled *PV* values. Blue contours represent potential temperature isolines (in °C).

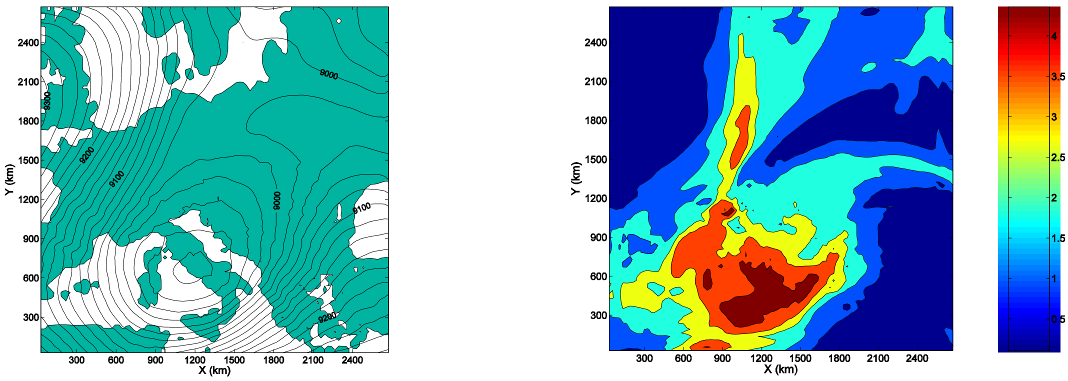

Figure 4: Average modeled geopotential (left) and *PV* (right) fields at 300 hPa isobaric surface for investigated bora episodes.

*Acknowledgements***.** This work was supported by the Ministry of Science, Education and Sports of the Republic of Croatia under project number 0119330.

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