DIFFERENCES IN THE DYNAMICS AND STRUCTURE OF THE NORTHERN AND SOUTHERN ADRIATIC SEVERE BORA

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Abstract: Most of the Bora research to date has been focused on the dynamics and structure of severe Bora in the northern Adriatic. Significantly less studied is the Bora in the southern Adriatic, where the Dinaric Alps are higher and broader and the upwind Bora layer is generally less well defined. Statistical analysis and observations show that a severe Bora with maximum gusts >40 m/s can occur in all parts of the Adriatic, but its duration and frequency decrease from north to south.

The primary aim of this study is to identify main differences in the dynamics and structure of the Bora flow over the northern and southern part of the eastern Adriatic shore based on a comparative analysis of the evolution and structure of two severe Bora events, one “northern” and one “southern” event. The “northern” event is the well-documented MAP IOP15 case from 7-8 November 1999. The “southern” event is the 6-7 May 2005 Bora, which from the outset in the northern Adriatic gradually spread southward and was significantly stronger in the southern Adriatic, causing a significant amount of infrastructural damage there.

Keywords: *Bora flow, differences between northern and southern Adriatic bora, Scorer parameter*

1. INTRODUCTION

Major strides in our knowledge of the Bora phenomenon have been made possible by the data sets collected during the ALPEX SOP with the extended surface and upper air measurements, and particularly by the first aerial observations of this phenomenon (Smith, 1987). Most of the ensuing Bora research has focused on the severe Bora on the northern Adriatic, in particular that at the locus of the climatological maximum near Senj, at the northern end of the Velebit range, where hydraulic theory appears to capture dynamical essence of the Bora phenomenon (e.g. Smith, 1987; Grubišić, 1989; Gohm and Mayr, 2005). Less studied is the Bora in the southern Adriatic, south of the Velebit range, where the Dinaric Alps are higher and broader and the upwind Bora layer tends to be less well-defined, which might be due in part to the lack of upstream data. A few studies that have addressed the Bora on the southern Adriatic (e.g. Jurčec, 1989; Ivančan-Picek and Tutiš, 1996) challenge the traditional view of Bora as a local small-scale phenomenon, and reveal a multi-scale nature of the Bora-related airflow. As the statistical analysis for a 30-year period (1958-1987) shows (Bajić, 1989; Vučetić, 1991), a severe Bora with maximum gusts greater than 40 m s^{-1} may appear along the entire Adriatic coast, but its duration and frequency decrease from north to south. Despite the climatological preference for the northern Adriatic as the locus of strong Boras, events do occur in which Bora reaches higher strength in the southern Adriatic.

The primary aim of this study is to identify key differences in the dynamics and structure of the Bora flow over the northern and the southern part of the eastern Adriatic shore, based on a comparative analysis of the evolution and structure of two severe Bora events, one “northern” and one “southern” event. The analysis is based on the numerical model simulation results obtained with the operational ALADIN/HR hydrostatic model run at 8 km and 2 km horizontal resolutions. The ability of this model to accurately reproduce the observed Bora spatial structure was established using the flight-level data obtained during MAP IOP 15 in the northern Adriatic (Ivančan-Picek et al., 2005).

2. THE “NORTHERN” AND “SOUTHERN” BORA EVENTS

The “northern” event in this study is that documented during MAP IOP 15 (7-8 Nov 1999). An in depth analysis of the MAP IOP 15 Bora case is presented in Grubišić (2004) and Bencetić-Klaić et al. (2003), where the dynamics and structure of the lee-side and cross-mountain flow were investigated using the aircraft and other in situ data. This Bora was stronger in the northern Adriatic (wind gusts of over 45 m s^{-1}), where it started early on November 7, gradually extending to the southern Adriatic later that day, displacing a strong Sirocco (Jugo) and reaching the maximum strength of 26 m s^{-1} there.

The "southern" event occurred on 6-7 May 2005, during which the southern Adriatic maximum of 22 m s^{-1}, measured in Makarska, significantly exceeded the one measured in Senj (7 m s^{-1}). From the outset at the northern Adriatic, this Bora gradually spread southward too, but was significantly stronger in the southern Adriatic, causing a significant amount of infrastructural damage there.

2. SPATIAL STRUCTURE OF THE BORA FLOW

The synoptic situation during MAP IOP 15 (7-8 Nov 1999) was characterized by an explosive lee cyclogenesis over the Tyrrhenian Sea, well captured by the ALADIN model simulations (Tudor and Ivatek-Šahdan, 2002). With a strong anticyclone over north-western Europe, and the cyclone over the Tyrrhenian Sea, the situation was characterized by strong low-level pressure gradients across the Alps. This has led to the onset of Bora on the east coast of the Adriatic, where a strong Sirocco preceded the Bora development (Fig. 1a).

The synoptic situation in the period 6-7 May 2005 was characterized by a cyclone development over the Mediterranean. At 00 UTC 6 May upper-level trough was situated southwest of the Alps, slowly moving towards east. At the same time, centre of the surface cyclone was located in southern Mediterranean moving toward NE. At 18 UTC 6 May 2005, centre of the upper-air cyclone was positioned above the centre of the surface cyclone, which had reached the Ionian Sea. At 00 UTC 7 May 2005, the surface cyclone experienced a rapid deepening above the southern Adriatic and the Balkan Peninsula and the central pressure fell to 996 hPa, as inferred from the ECMWF analysis (not shown). With the upper-level trough SW of the Alps initially, and the centre of the upper-level cyclone over the Ionian and Adriatic Seas subsequently, there was strong NW flow north of the Alps. Pronounced low-level splitting of this NW flow had produced sheltered conditions on the northern Adriatic, whereas on the southern Adriatic the northern branch of this split flow, after turning around the eastern end of the Alps, became perpendicular to the Dinaric Alps.

The ALADIN model simulation captured the essence of this cyclone development reasonably well. Mean sea-level pressure gradient in the north Adriatic was negligible in this case, producing no significant cross-mountain flow (Fig. 1b). On the other hand, in the south Adriatic, the cyclonic forcing had produced a 6 km deep layer impinging on the Dinaric Alps. Inland-seaside mean sea-level pressure gradient near Makarska was 5.4 hPa / 70 km in this case (for comparison, the same gradient in the MAP case was equal to 5.9 hPa / 70km). At 500 hPa, the wind over the Adriatic was NNW, turning clockwise with the pressure to surface NE. Thus, in this case, the synoptic forcing had created a non-uniform pressure gradient across the Dinaric Alps that increased in strength from north to south, contributing to the stronger Bora on the southern Adriatic (Fig. 1b).

While the cross-mountain surface pressure gradient was fairly uniform along the Dinaric Alps in the MAP IOP 15 case, the comparative analysis of the upstream conditions in the northern and southern Adriatic shows overall less favourable conditions for the Bora development in the southern Adriatic (Figs. 2a,c). A shallow upstream NE flow of only 1 to 2 km in depth, upstream of the high and wide southern Dinaric Alps, was in large part blocked by the 1.5 km high mountains, leading to only a shallow layer of the atmosphere involved in the mountain wave dynamics and downslope Bora flow in the southern Adriatic. In contrast, the depth of this NE flow upstream of the lower northern Dinaric Alps (~1 km high) was nearly 3 km. Flow over the mountains of this well defined layer, capped by an inversion and an environmental critical level associated with the synoptic-scale wind turning to SE around 3.5 km MSL, had produced a strong wave response and wave breaking in the northern Adriatic, and strong Bora development there.

In the May 2005 case, the flow upstream of the Dinaric Alps was mostly northerly, turning to the barrier-parallel NW around 6 km. This NW wind was related to the presence of the upper-air cyclone, resulting again in a synoptically induced critical layer as a key decoupling mechanism for the Bora layer. No clear inversion was present. In the northern Adriatic, below this N flow, we find a shallow, about 2 km deep, layer of weak NE flow almost completely blocked by the mountains. With weak surface pressure gradients, there was very little cross-mountain flow there. On the southern Adriatic, where the cross-mountain synoptic pressure gradient was strong, the 4.5 km deep layer of N flow was pulled over the mountains, turning into NE just over and to the lee of the mountain crest. This has led to a very strong wave response, wave breaking, and a strong Bora development there.

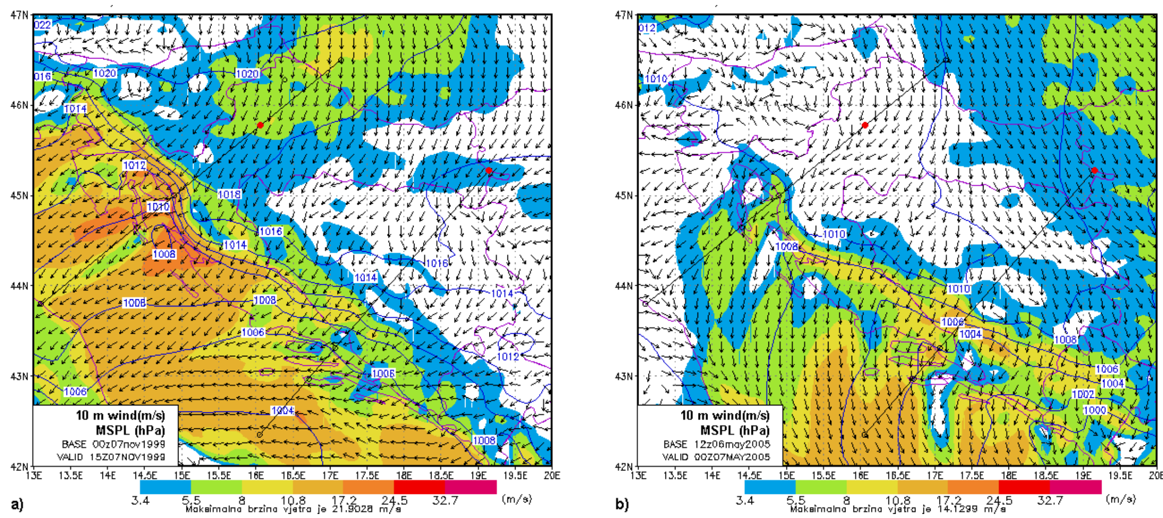


Figure 1: 10-m wind speed (m/s; color shaded) and mean sea-level pressure (hPa, blue isolines): Left: Northern Adriatic severe Bora, forecast valid at 15 UTC 7 November 1999; Right: Southern Adriatic severe event, forecast valid at 12 UTC 6 May 2005. Black solid lines mark bases of the cross-sections shown in Fig. 2., and red dots locations of the soundings shown in Fig. 3.

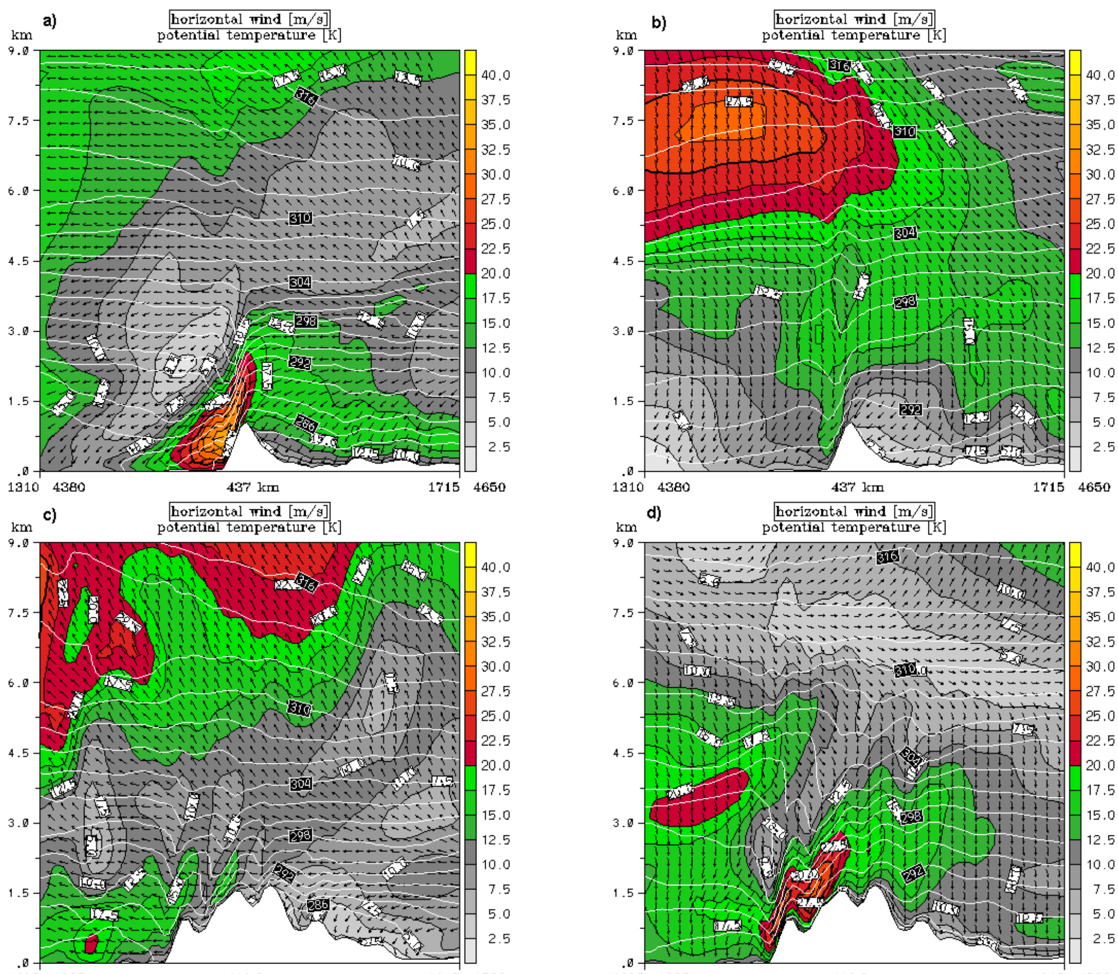
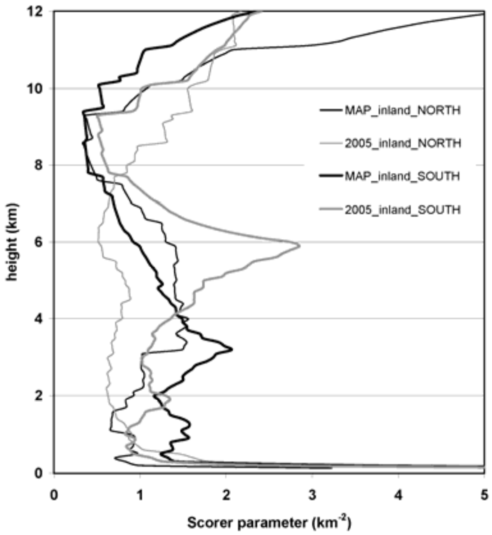


Figure 2: Vertical cross-sections with horizontal wind speed (m/s, color shaded), wind vectors and potential temperature (K; white isolines). Upper row shows the north Adriatic sections and bottom row the south Adriatic cross-sections. Left column: Forecast valid at 15 UTC 7 November 1999. Right column: Forecast valid at 12 UTC 6 May 2005.



Scorer parameter profiles (Fig. 3) for the two upstream locations ("north" and "south") marked in Fig. 1, clearly illustrate different depths of the Bora layer in the two cases in the southern Adriatic (6 km in the May 2005 case vs. 3.5 km in the MAP case). The sharp peaks in the Scorer parameter in these two cases are associated with the environmental critical levels.

Figure 3: Scorer parameter (km^{-2}) calculated from the forecast soundings for the ALADIN 8 km hydrostatic NWP model at two points upstream of the barrier shown in Fig. 1. Thick lines are used for southern points, thin lines for northern points, blue for MAP IOP 15 and red for May 2005 case.

3. SUMMARY

Differences in the Bora at the northern and southern Adriatic in the two cases examined in this study appear to stem mostly from different synoptic situations.

In the MAP IOP 15 case, the severe Bora developed in the northern Adriatic only, due to the presence of a well-defined and deep (~3 km) upstream Bora layer there, capped by both the inversion and the environmental critical level. Weaker upstream flow and stronger low-level stability upstream of the higher and wider southern Dinaric Alps led to the strong blocking there, resulting in a much weaker Bora in the south Adriatic.

The synoptic situation for the May 2005 case was characterized by a rapid development of the Mediterranean cyclone over the southern Adriatic and the Balkan Peninsula. This synoptic-scale forcing had produced a deep layer of upstream flow with the environmental critical level at 6 km that was able to cross the southern Adriatic mountains, resulting in the wave-breaking, creation of the local critical layers and severe Bora development there. The northern Adriatic, on the other hand, was located in the near wake of the Alps in this case, experiencing unfavourable conditions for the Bora development.

Based on the two events examined, the development of the severe Bora in both the southern and northern Adriatic appears critically dependent on the synoptic setting to create an optimal set of conditions in the upstream environment. If an inversion, which might be more readily found in the northern Adriatic, or an environmental critical level are present as the key decoupling mechanism for the upstream Bora layer, severe Bora development on the lee side of the mountains can occur even when the upstream wind direction is not of the optimal barrier perpendicular direction.

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