SENSITIVITY OF BORA TO MEDITERRANEAN CYCLONE PARAMETERS THROUGH AN ENSEMBLE OF NUMERICAL CYCLONE REALIZATIONS

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Abstract: Bora that happened on 14 November 2004 was one of the most severe ever measured, causing significant human, economic and infrastructural losses. Except for its intensity, the particularities of this event were the severe Bora longevity (~24hr) and simultaneous coexistence on Northern and Southern Adriatic. The synoptic setting was characterized with a high over the Eastern Atlantic spreading over the Central Europe and a deep North-west African cyclone in the Southern Adriatic. This created a strong bipolar macroscale pressure environment that resulted in the built-up of the strong pressure gradient across the Dinaric Alps. The numerical analysis illuminates the influence of the cyclone on the pressure build-up through the ensemble of simulations. Overall, the ensemble results showed that the cyclone influence on Bora intensity diminished from south the north. Nevertheless, is seems that the cyclone centre intensity and Bora strength can not be straightforwardly correlated, due to importance of the sub-synoptic tongue of the low-pressure field inside the cyclone, which induced the circulation that superimposed on Bora flow as well as modified the integral background Froude number. It has been proposed that such sub-synoptic processes acted to break-up the upstream inversion and increase the upstream Bora layer depth. In addition, such a pressure distribution contributed to pressure gradient build-up across the mountain as well as changed thermal properties above the sea, what might contribute to the modified Bora behaviour, postponed hydraulic jump and stronger offshore Bora winds, through the influence on the maintenance of the supercritical downstream flow.

Keywords: Bora, Mediterranean Cyclone, Potential Vorticity Inversion, Ensemble

1. INTRODUCTION

The goal of this paper is to analyse the extreme Bora event that took place along the eastern Adriatic coast on 14Nov 2004 through the ensemble of numerical simulations. This extremity of this case is characterized by simultaneous 10-min average wind speeds of gale to hurricane force and wind gusts reaching 50-60m/s all along the eastern Adriatic coast for more then 24 hours. Although forecasted, this event caused a range of human, economic and infrastructural losses.

The synoptic setting was characterized with a high over the Central Europe and Eastern Atlantic and a deep cyclone in the Mediterranean, originally initiated in the lee of High Atlas Mountains (Fig. 1). In subsequent days, the cyclone experienced a NE advection and reached the coasts of Southern Italy and area Southern Adriatic. Such a pressure pattern resulted in the creation of a bipolar macroscale pressure environment conducive to the creation of high pressure gradients over Dinaric Alps.

Ensemble of numerical simulations was designed to shad light on the influence of cyclone position and intensity on pressure build-up across the Dinaric Alps and Bora characteristics over N. and S. Adriatic Sea.

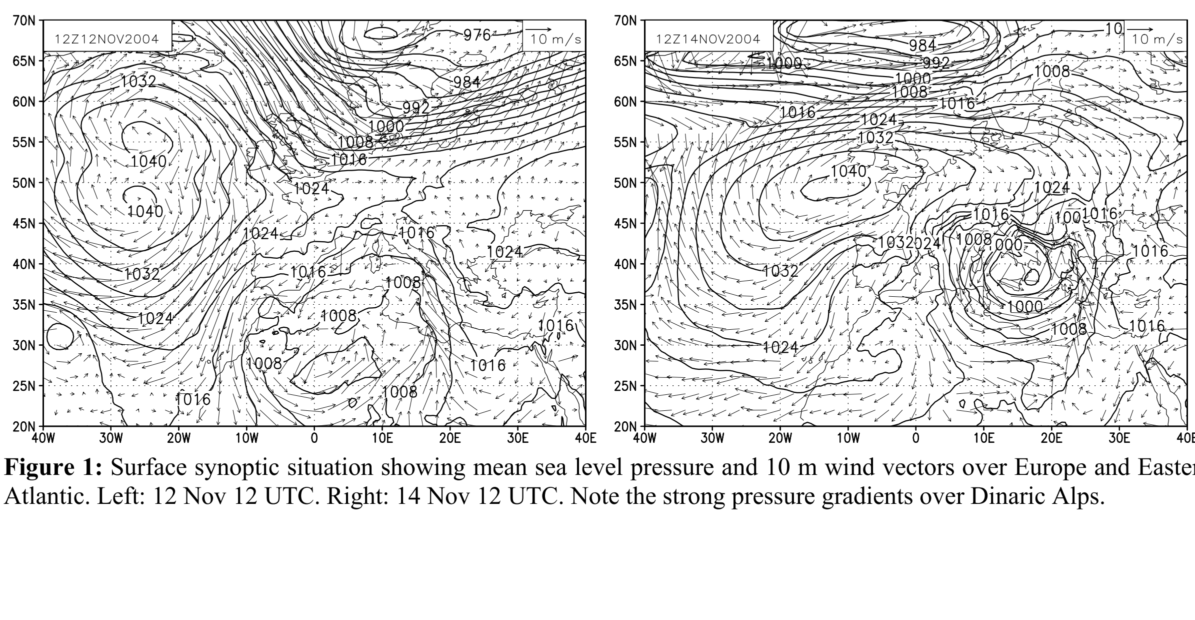

Figure 1: Surface synoptic situation showing mean sea level pressure and 10 m wind vectors over Europe and Eastern Atlantic. Left: 12 Nov 12 UTC. Right: 14 Nov 12 UTC. Note the strong pressure gradients over Dinaric Alps.

2. MODEL AND METHOD DESCRIPTION

The simulations were performed with the non-hydrostatic mesoscale model MM5. For this study one domain was chosen with 23 vertical levels and 21 km resolution. Simulations were initialised on 12 Nov 2004 00 UTC for the 84 hour period. Initial and boundary conditions we provided from the global NCEP/NCAR Final Analysis (FNL).
The planetary boundary layer parameterisation used a modified version of Blackadar parameterisation, while physical parameterizations included Betts and Miller cumulus parameterisation, simple-ice explicit moisture scheme and cloud-radiation scheme.
The strategy of the ensemble production is to use the Potential Vorticity Inversion (PVI, Davis and Emanuel, 1991) with the non-linear balance condition (Charney, 1955) on the Ertel's potential vorticity fields and change the initial conditions to create a set of seven differing simulations (Fig. 2). The simulation start corresponded to the time of the initiation of the cyclone in the lee of the Atlas Mountains (Horvath et al., 2006).

3. RESULTS

The control simulation reasonably well caught the creation of the lee cyclone and its subsequent deepening above the Mediterranean (can be inferred from Fig 4 later on). Figure 3. depicts a time variation of mean sea level pressure in the cyclone centre and wind speed in two points on the eastern Adriatic coast: 1. Krk Bridge on the northern Adriatic and 2. town of Makarska on the southern Adriatic. The result clearly shows that Bora wind speed co-varies with the cyclone intensity more on northern Adriatic then on southern Adriatic. This result is expected since the cyclone located is south of the interest zone. The lowest wind speeds correspond to the least intensive cyclones and the greatest modifications of the upper-level potential vorticity anomaly in the initial conditions (referred to EXP-1p5 and EXP-1p6). This multi-variations is explained

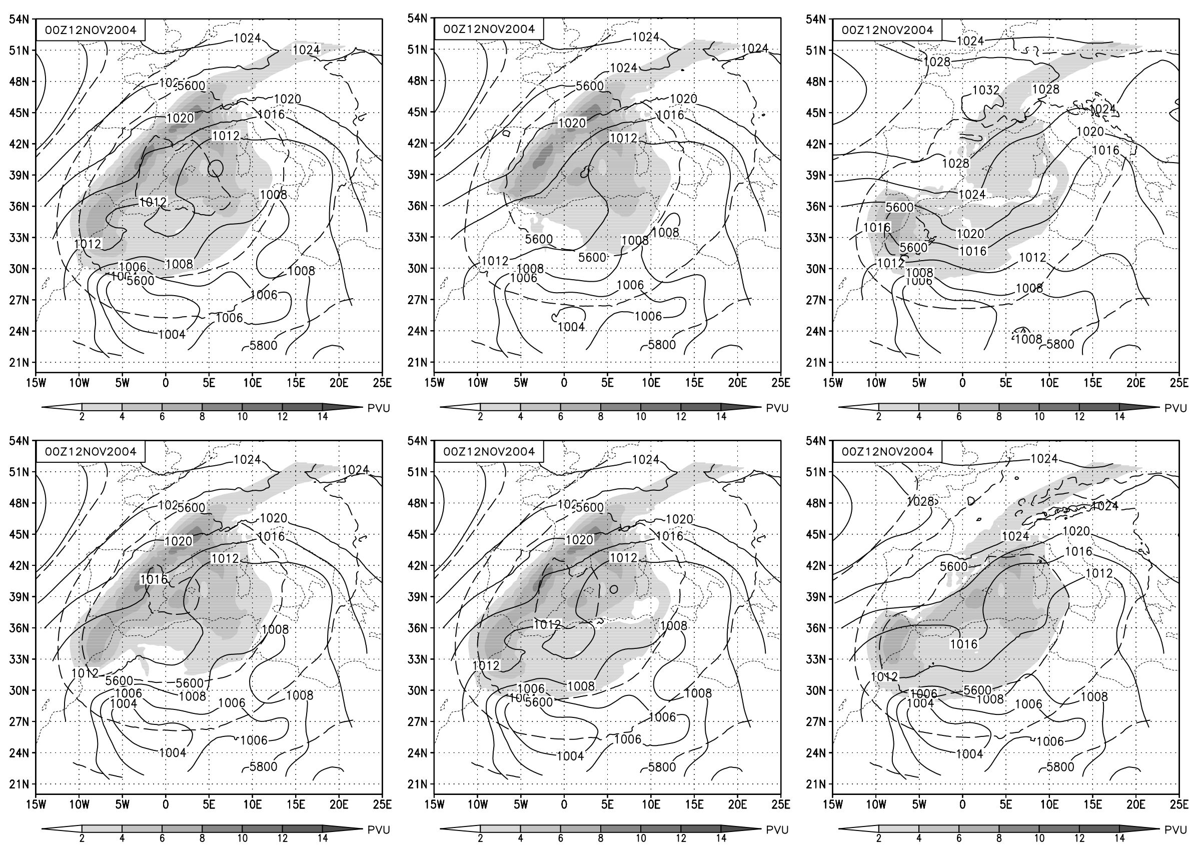

Figure 2: Ensemble initial conditions at 12 Nov 00 UTC showing MSLP, 300 hPa potential vorticity and 500 hPa geopotential. Upper-left: control simulation. From upper-middle to lower-right: experiments -1p1, -1p2, -1p3, -1p4 and -1p5 respectively. The ensemble member with the total upper-level trough removed from the IC (-1p6) is not shown.

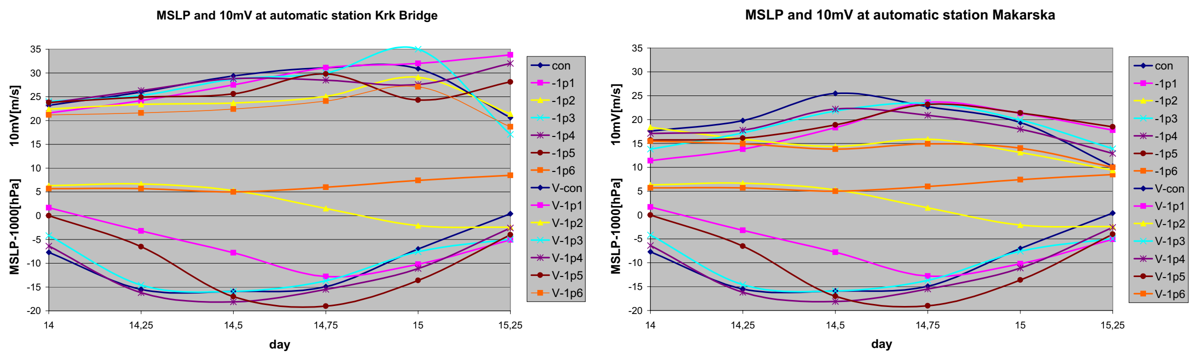

Figure 3: Time series of model predicted MSLP-1000 hPa values and model wind speeds at two chosen locations. Left: Krk bridge on the northern Adriatic. Right: Town of Makarska on the southern Adriatic.

through the cascade of the upper-level energy to lower-levels, to the synoptic scales (cyclone) as well as mesoscales (Bora). However, inspection of the analysed relationship indicates that the correlation is not uniquely determined by the cyclone depth. Further inspection in addition analyses the cyclone positions and sub-synoptic cyclone details in relation with the Bora wind speed along the eastern Adriatic coast in three chosen ensemble experiments (Fig 4.). At 14 Nov 00 UTC means sea level pressure in the cyclone centre in reached 992 hPa the control run, 1000 hPa in EXP-1p5 and 1006 hPa in the EXP-1p6. Comparing the first two, it can be inspected that regardless of the significantly different cyclone intensities and similar positions, maximum Bora wind speed remains the same. In addition, even a much less intensive system significantly closer to the study region does not have a pronounced influence on the Bora distribution and intensity. Thus, it seems that the Adriatic Sea is at this time sequence out of the influence radius of the low pressure zone in the vicinity of the cyclone centre of the control run simulation. Since indeed the actual values could be a result of the small scale processes near the cyclone centre (e.g. strong convection), Bora intensity can not be directly associated with the cyclone depth in case the cyclone is positioned south of the Apennine peninsula. In subsequent hours the cyclone experienced a NE advection and approached the Adriatic Sea. On 12 Nov 12

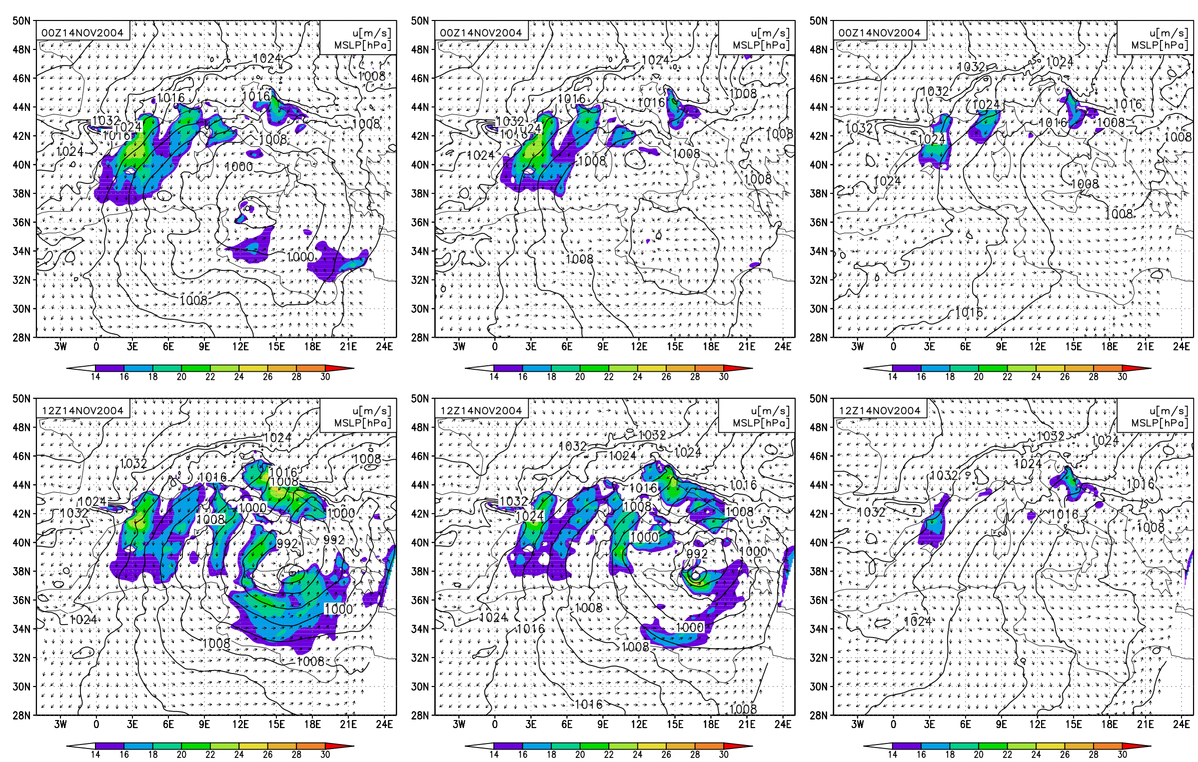

Figure 4: Surface model predicted MSLP and wind fields. Upper row: control run (left), EXP-1p5 (middle) and EXP-1p6 (right) at 14 Nov 00 UTC. Lower row: control run (left), exp-1p5 (middle) and exp-1p6 (right) at 14 Nov 12 UTC.

UTC, cyclone centres in control run and EXP-1p5 were at exactly the same positions reaching 984 hPa (control) and 983 hPa (EXP-1p5), while there was no closed circulation system near the interest zone in EXP-1p6. However, the Bora strength seems to be significantly stronger in the control run, especially in the Middle Adriatic where difference in of the Bora intensity reaches ~25% (EXP-1p5) and ~50% (EXP-1p6). This implies that the tongue of the low pressure extending from the cyclone centre to the southern Adriatic played an important role in Bora severity. Inspection of the background flow showed that in the control run increased background flow was associated with the reduced low-level stability on the upstream side of the mountain. Thus, the integral upstream Froude numbers might significantly differ depending on the cyclone sub-synoptic details. In addition, since the inversion (either upstream of due to wave breaking) is a common ingredient of downslope Bora wind (e.g. Smith, 1987; Bajic, 1989), inversion break-up and deeper Bora layer present in the EXP-1p5 (not shown) might have resulted in a qualitatively different flow response to the background conditions. Nevertheless, a wind-shear induced critical level existed all along the eastern Adriatic coast, supporting the numerical simulations implying that the inversion is not a necessary ingredient of the strong downslope Bora flows (Klemp and Durran, 1987), Finally, the presence of the low pressure tongue in the southern Adriatic strongly affected the downstream conditions. Not only the superposition of the gradient circulation, but also associated warmer lower-tropospheric air and the downstream build-up of the pressure gradients across the mountain, might have changed the local downstream Froude number. More specifically, the discussed conditions might have increased the local Froude number and contributed to the postponed air-stream recovery through the hydraulic jump mechanism, resulting in the significantly stronger offshore Bora winds during the event.

4. CONCLUSION

The study investigates the sensibility of the extreme Bora wind speeds taking place on 14-15 Nov along the eastern Adriatic coast to the Mediterranean cyclone parameters through the ensemble of numerical simulations. Initial conditions of each simulation were modified above the Atlas mountains 2 days before the onset of Bora in order to provide a set of differing lee cyclone realizations in the Mediterranean. The results show that a northern Adriatic Bora is less sensitive to the Mediterranean cyclone intensity then the southern Adriatic Bora, where cyclone influence can account for ~50% of the Bora intensity. However, it seems that the cyclone centre intensity and Bora can not be straightforwardly correlated. The detailed analyses showed that Bora intensity was highly sensitive to the sub-synoptic tongue of low pressure in southern Adriatic, which was coupled to the cyclone centre. While the influence of the increased Bora winds in simulations with the low-pressure tongue presence might be partly explicable in terms of the induced changes in the integral background Froude number, it is proposed that a cyclone induced modification in upstream conditions (inversion break-up, deeper Bora layer) and downstream conditions (increased downstream flow, mountain-cross pressure gradient build-up and changed thermal properties) change the downstream Bora characteristics. These might have in turn resulted in a prolonged supercritical downstream flow and postponed relaxation through the hydraulic jump mechanism, and leaded to significantly stronger offshore Bora winds.

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