DISAPPEARANCE OF PULSATIONS IN SEVERE DOWNSLOPE WINDSTORMS

Danijel Belušić [1], Branko Grisogono [1]

[1] Andrija Mohorovičić Geophysical Institute, Faculty of Science, Horvatovac bb, 10000 Zagreb, Croatia
E-mail: *dbelusic@irb.hr*

Abstract: Idealized numerical simulations of the bora-type flow have been performed. The intention was to find what causes the pulsations in the developed windstorm state to disappear. Four different incident vertical profiles were used and the results showed that the main effect originates from the low-level positive shear, and the upper-tropospheric jet stream acts as a secondary effect.

***Keywords** – quasi-periodic pulsations, wave breaking, wind shear, numerical modeling*

1. INTRODUCTION

The phenomenon of quasi-periodic pulsations in severe downslope windstorms was detected over two decades ago. Spectral analysis of the bora (bura in Croatian) wind speed data measured with small sampling intervals (few seconds) showed that the pulsations appear at periods between 3 and 11 minutes (e.g. Belušić *et al.* 2004). Similar results were obtained in the studies of the Boulder downslope windstorm (e.g. Neiman *et al.* 1988).

It seems that the phenomenon is inherent to downslope windstorms in general. A number of mechanisms responsible for the generation of the pulsations have been proposed during the years. For instance, Peltier and Scinocca (1990) attributed the formation of the pulsations to the Kelvin-Helmholtz instability appearing in the sublayer with high vertical shear located between the lower, stable layer with shooting type flow, and the upper, well mixed layer generated by wave breaking. This seems to be the most accepted explanation so far (e.g. Wang and Lin 1999), and is also confirmed theoretically (Smith 1991). However, only recently a possibility of disappearance of the pulsations, regardless of the mean wind speed values, has been detected in the measured surface wind speed data. It is also noticed that the absence depends mainly on the incident upstream tropospheric profiles in the way that when the upper-tropospheric jet stream (JS) appears, the pulsations disappear.

We investigate how the existence of the pulsations depends upon the upstream profiles, and try to see whether the hypothesis of the JS effect on the pulsations is valid.

2. NUMERICAL SIMULATIONS

The idealized simulations are performed using the atmospheric component of the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) model (Hodur 1997). Two dimensional computational domain was chosen with 300 grid points in the horizontal direction and the resolution of 1 km, and 81 vertical levels with the constant resolution of 0.3 km in the free troposphere and finer resolution near the ground. The model top was at 24 km. The mountain is Gaussian shaped with the eastern half-width of 20 km and western of 10 km. The mountain height is 1100 m, thus idealizing the mountain of Velebit.

The model was initialized using idealized wind and temperature profiles based on the Zagreb soundings taken during several bora episodes. The vertical profiles were chosen that they represent main features of the two distinct groups of cases observed by Belušić *et al.* (2004): one when the pulsations are present during the windstorm and the other when they disappear. The first situation was associated with various vertical profiles, leading to a conclusion that this behavior is a more typical and more frequently occurring property of the bora flow. The second was related to the appearance of the JS.

In all simulations the atmosphere was divided into two stable layers with the buoyancy frequencies of 0.012 s^{-1} in the first 10 km (troposphere), and 0.023 s^{-1} aloft (stratosphere). Also, the wind direction was constant 90°. The wind speed profiles for the four experiments conducted are shown in Fig. 1. Experiment 1 has a constant wind speed of 12 m s^{-1} intending to represent the entire first group. Experiment 2 has JS added, starting at 5 km with the maximum at 9 km. Since the real profiles of the cases with the JS always have positive low-level shear, in Exp. 3 we added positive shear just above the mountain top and below 5 km. Experiment 4 is the same as Exp. 3, only without the JS. Its intention is to test the effect of the JS when the low-level shear is present.

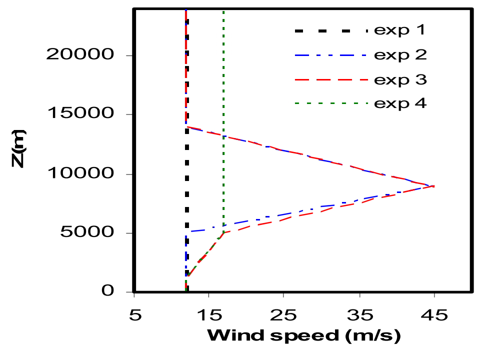

Figure 1. Vertical wind speed profiles for the four experiments conducted.

3. RESULTS

All fields are shown after 8 hours of simulation. Figure 2 shows vertical cross-sections of the potential temperature, TKE, cross-mountain wind component, vertical wind component and Richardson number for Exp. 1. The flow structure in the lee is a pure shooting flow with a propagating hydraulic jump. The pulsation-like behavior in the lower levels in the lee is evident, particularly in the vertical wind where its alternating positive and negative bands interchange every 4–6 km. The pulsations are also seen in the horizontal wind speed.

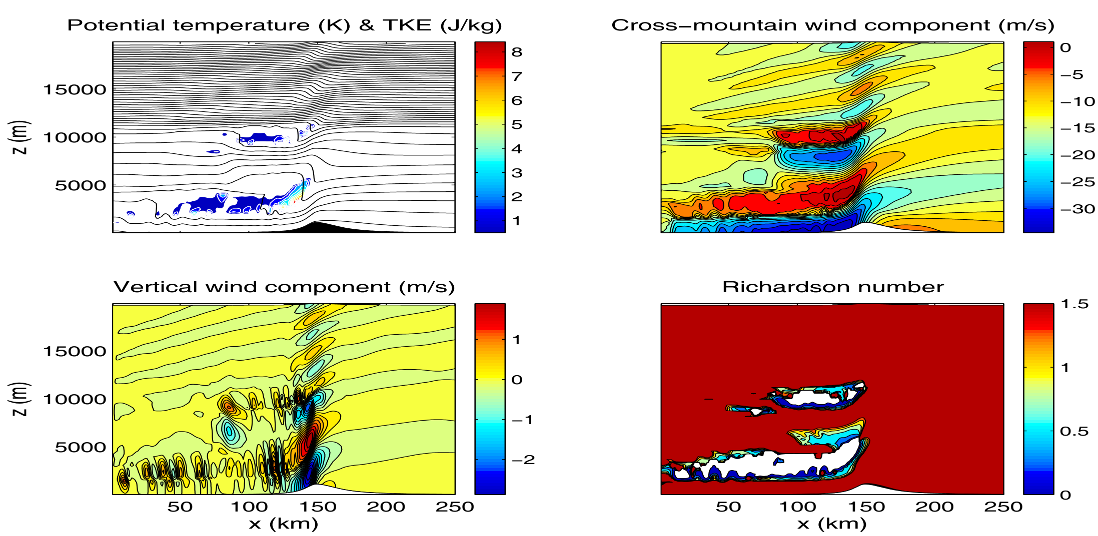

Figure 2. Experiment 1 after 8 hours of simulation. White areas in the Richardson number correspond to negative values, i.e. to convectively unstable layers. The pulsations are present.

The inclusion of the JS (Exp. 2) results in the pulsations weakening but they are still present, as seen in Fig. 3. Again, there is a propagating low-level shooting flow, and also, as in Exp. 1, an area of the low-level convectively unstable layer extending far downstream. The main differences occur in the upper levels where the secondary wave-breaking region is lifted from below the stratosphere (z~10 km) in Exp. 1 to approximately 14 km, thus deeper in the stratosphere.

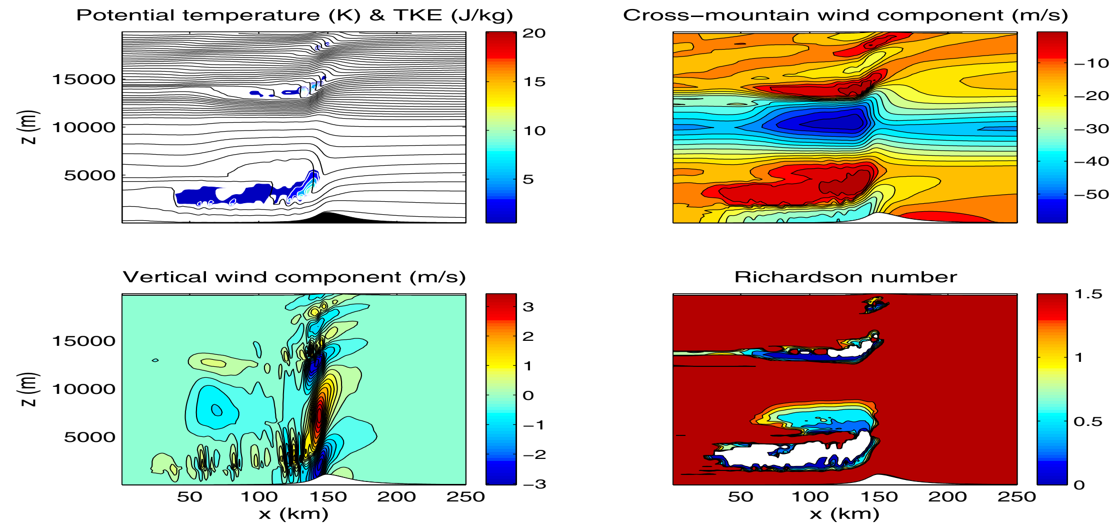

Figure 3. As in Fig. 2, except for Exp. 2. The pulsations still occur.

Figure 4 shows Exp. 3. With the low-level positive shear added, the pulsations disappear completely. The shooting flow is constricted only to the close proximity of the mountain slope, and the structure resembles more a large-amplitude wave than a typical downslope windstorm with a wave-breaking region. This difference is caused by the linearization due to higher wind speed, i.e. the internal froude number gets larger than one when the wind speed exceeds 13 m s^{-1}.

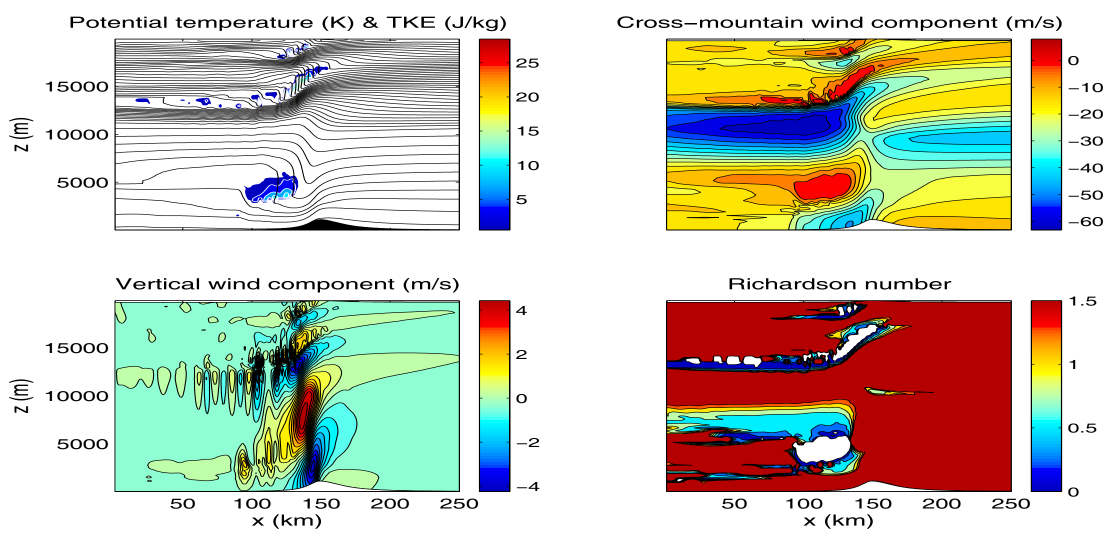

Figure 4. As in Fig. 2, except for Exp. 3. The pulsations disappear in the lee, but appear aloft.

Another issue is that the stratospheric wave breaking is now even more enhanced, resulting in the appearance of the lifted pulsations. Why does the low-level shear affect stratospheric dynamics in such a way is not clear at the moment.

Similarly, but rather unexpectedly, the pulsations are absent also in Exp. 4. Figure 5 shows that the low-level flow resembles that in Exp. 3, only it is a bit more elongated downstream here. In the stratosphere, there is a decrease in nonlinearity, but weak elevated pulsations are still present in Exp. 4.

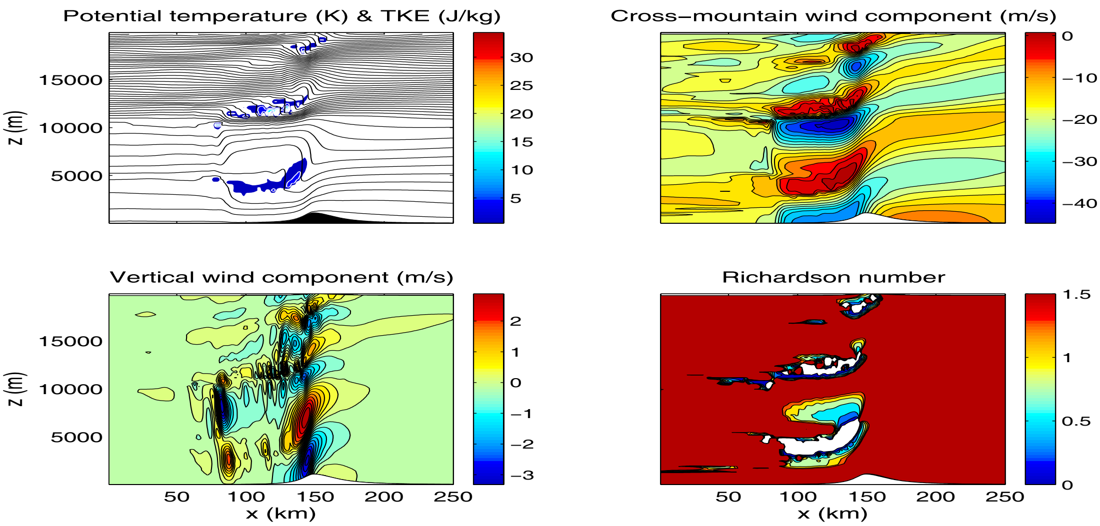

Figure 5. As in Fig. 2, except for Exp. 4.

4. CONCLUSION

We performed idealized simulations of the bora-type flow with four different initial profiles, searching for the mechanisms responsible for the disappearance of the pulsations. The results presented here point to the low-level positive shear (in the layer between the mountain top and 5 km), and to the JS as a secondary effect. Also, the simulations with the low-level inversion were conducted (not shown), but it seems that the inversion does not have a major effect on the phenomenon.

Additional effects occurring in the stratosphere may have an influence on the aviation.

REFERENCES

Belušić, D., M. Pasarić, M. Orlić, 2004: Quasi-periodic bora gusts related to the structure of the troposphere. *Q. J. R. Meteorol. Soc.*, **130**, 1103–1121.

Hodur, R. M., 1997: The Naval Research Laboratory's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). *Mon. Weather Rev.*, **125**, 1414–1430.

Neiman, P. J., R. M. Hardesty, M. A. Shapiro, R. E. Cupp, 1988: Doppler Lidar Observations of a Downslope Windstorm. *Mon. Weather Rev.*, **116**, 2265–2275.

Peltier, W. R., J. F. Scinocca, 1990: The origin of severe downslope windstorm pulsations. *J. Atmos. Sci.*, **47,** 2853–2870.

Smith, R. B., 1991: Kelvin-Helmholtz instability in severe downslope wind flow. *J. Atmos. Sci.*, **48,** 1319–1324.

Wang, T.-A., Y.-L. Lin, 1999: Wave ducting in a stratified shear flow over a two-dimensional mountain. Part II: implications for the development of high-drag states for severe downslope windstorms. *J. Atmos. Sci.*, **56,** 437–452.