FIRST MEASUREMENTS OF BURA WIND AT SENJ WITH A THREE-AXIS ANEMOMETER

Mirko Orlić [1], Danijel Belušić [1], Zoran Pasarić [1]

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

Abstract: Measurements of the bora wind at Senj (east Adriatic) with a three-axis anemometer showed that at the periods smaller than 1 min turbulent eddies propagating downstream prevail, in accordance with conventional wisdom. At the periods of 5–10 min bora pulsations were observed, with rotary spectral analysis pointing to hithertho unsuspected dynamics of these pulsations.

Keywords - *bora, pulsations, rotation, Adriatic*

1. INTRODUCTION

Bora (bura in Croatian) is a cold, dry wind that blows above the Adriatic from the northeast quadrant, most often during winter season. Its average speed is usually not high, but – due to the gustiness – the bora speed maxima may surpass 60 m/s. In a recent paper (Belušić *et al.* 2004) it has been shown that the bora pulsations appear at the periods of about 3–8 min, that they are highly variable in time and that they may disappear and reappear even inside a single bora episode. All previous investigations of the bora wind in the area were based on measurements of horizontal wind components only. In this paper first results of measurements performed with a three-axis anemometer at Senj are considered.

2. DATA DESCRIPTION AND ANALYSIS

We have mounted the WindMaster ultrasonic anemometer produced by Gill Instruments at Senj (44.99°N, 14.90°E, 2 m above MSL) at a height of 13 m above ground, on 18 March 2004. It recorded three wind components with a sampling frequency of 4 Hz. With the aim of illustrating the data collected, we consider here results obtained for the bora episode extending from 24 April (14:02 h LST) to 27 April (16:58 h LST) 2004. The episode was a moderate one, with the horizontal (vertical) wind speeds not surpassing 30 m/s (±10 m/s).

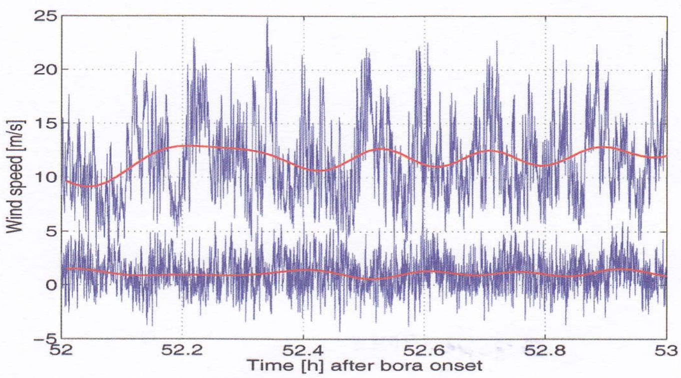

Figure 1. Horizontal (up) and vertical (down) wind components: 1 s and 10 min values.

To simplify the analysis, we have decomposed the wind vector in a coordinate system having the horizontal axis (B) aligned with the direction of maximum wind variance and the vertical axis (z) pointing upwards. Figure 1 shows a subset of B and z time series. Pulsations are clearly visible in both time series, although reduced in the second one.

We have also calculated time-running power spectra (energy density of wind components plotted versus frequency and time) for the episode considered. They were obtained by calculating a series of power spectra over shorter (3.5 h) sliding subintervals, progressing in time with a 30 min time step. Within each subinterval, spectrum was calculated and averaged over 3 Hanning windows (e.g. Papoulis 1977) of 4096 s length. The spectrum thus obtained for B component of the wind is shown in Fig. 2. It reveals that the strongest pulsations occurred between 48th and 60th hour after the onset of the bora episode, at the periods of 5–10 min.

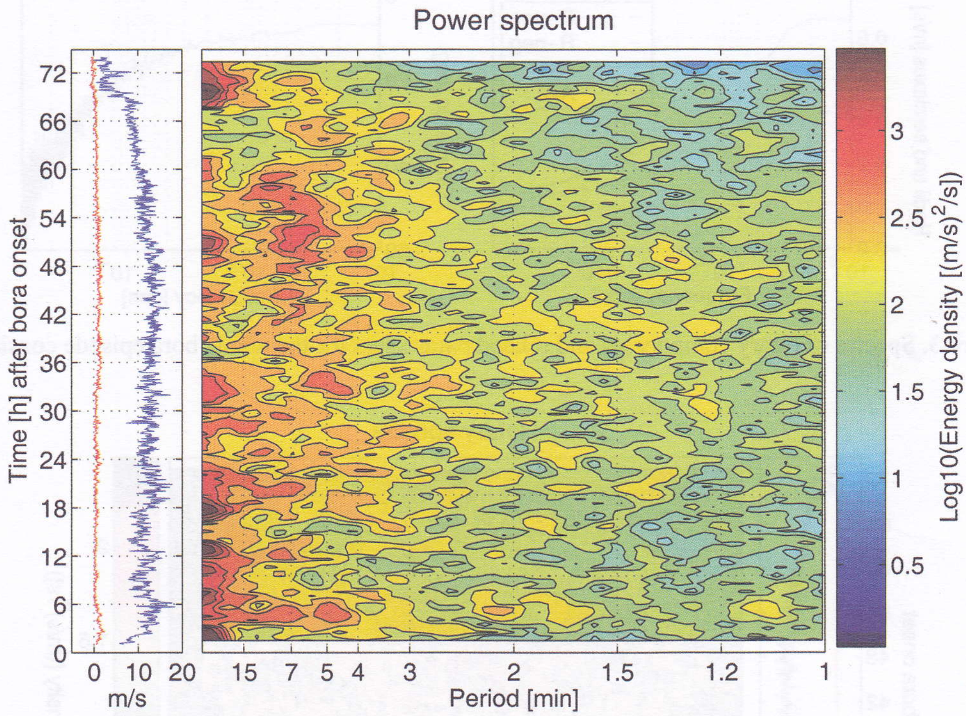

Figure 2. Time-running power spectrum of the horizontal wind component.

In order to document movement of the wind vector in the B-z plane, we have utilized rotary spectra. The main idea behind such an analysis is the decomposition of vector movement at a certain frequency into clockwise and anticlockwise rotary motions. The superposition of these two rotary motions gives the resultant vector whose tip follows a circular, elliptical or linear path – depending on the ratio of the two constituents. The method has been widely used in physical oceanography since its formulation at the beginning of the seventies (Gonella 1972), and it has been introduced to meteorologists by O'Brien and Pillsbury (1974). Rotary spectra and spectra of related parameters, computed for the whole bora episode using 263 windows of 1024 s length, are given in Fig. 3. They show markedly different behavior at periods below and above 1 min. At high frequencies vector tips draw ellipses of high eccentricity, their main axes depart considerably from the horizontal plane and the vectors turn in the negative (clockwise) sense. Low frequencies are dominated by pulsations of the 5–10 min period, with the corresponding ellipses having even higher eccentricity, the main axes being almost horizontal and the vectors turning in the positive (anticlockwise) sense.

Furthermore, we have calculated time-running rotary spectra, using the same approach as utilized in the calculation of power spectra. Figure 4 illustrates the way bora pulsations develop over time and in particular a prevalence of positive over negative rotation at the 5–10 min periods during the second half of the episode.

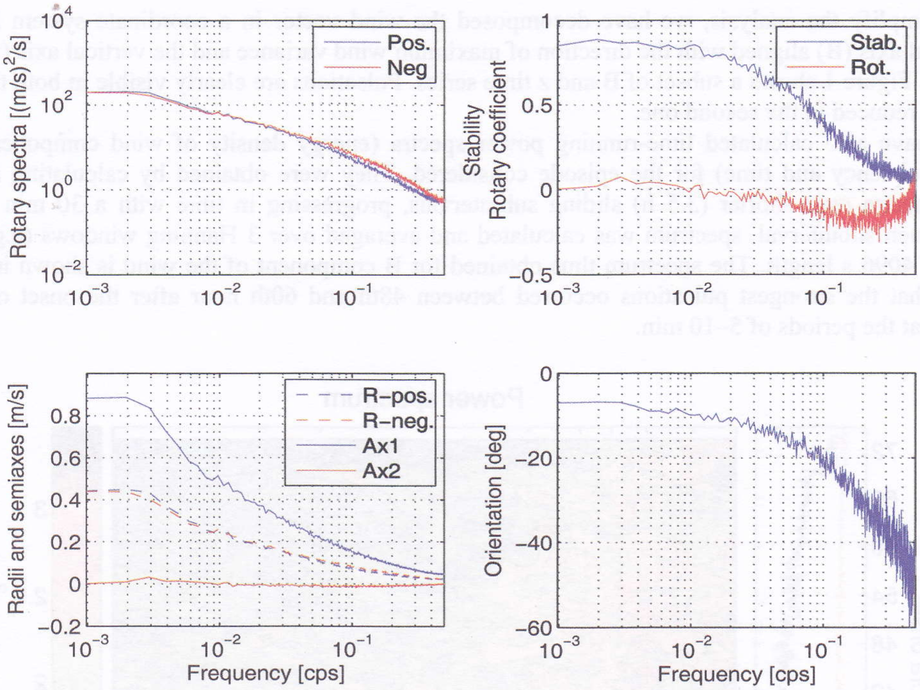

Figure 3. Spectra of rotary components and related parameters for the whole bora episode considered.

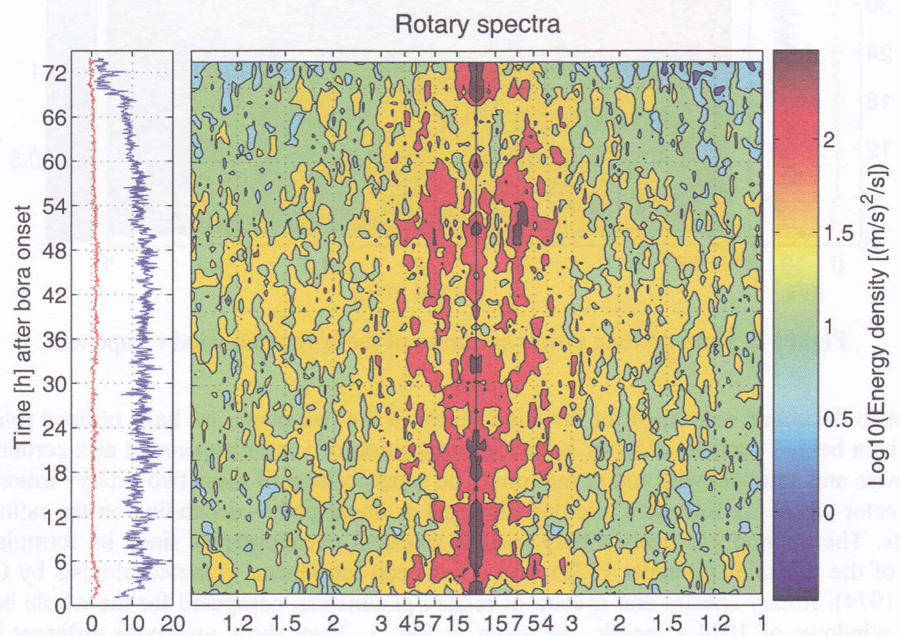

Figure 4. Time-running rotary spectra.

Finally, in Fig. 5 temporal evolution of 5.7 min variability is documented by the amplitude ratio and phase shift between B and z wind components and by the ellipse orientation and rotary coefficient. The bora pulsations in the later part of the episode are characterized by low vertical-to-horizontal amplitude ratio, by phase shift between horizontal and vertical wind components departing from 180°, by the main ellipse axes positioned in the horizontal plane and by the positive turning of the wind vectors.

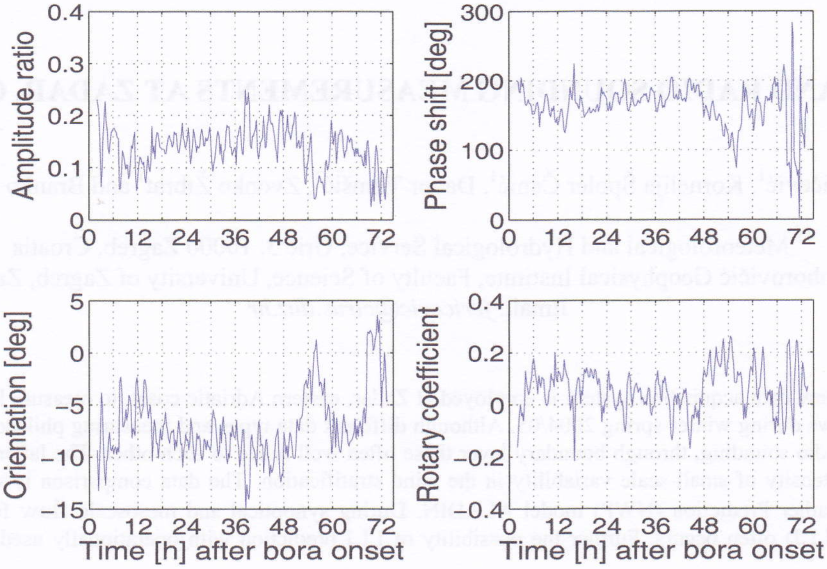

Figure 5. Results of cross-spectral analysis of the horizontal and vertical wind components (up) and of rotary spectral analysis (down), for the 5.7 min period.

3. CONCLUSION

We have seen (Fig. 3) that the bora rotary spectra can be divided into two regions of different behavior divided by the period of 1 min. In the high-frequency part there is prevailing negative turning of the wind vectors, which agrees with the expected dynamical setup wherein turbulent eddies are advected in the direction of the mean wind. On the other hand, in the low-frequency part vectors are turning in a positive sense. This is particularly pronounced when the pulsations are present (Figs. 4 and 5). At those times horizontal amplitude becomes much larger than the vertical one, and the phase difference drops from above 180° to around 100°. This relation between the pulsations and the positive turning, together with the associated phase-shift decrease, is in contrast with the present theories of the pulsation dynamics, which presume downstream propagation of the pulses. A possibility that the bora pulsations are related to hitherto unsuspected dynamical processes opens way to further research which should encompass a large number of bora episodes.

Acknowledgement: *The work was supported by the Ministry of Science, Education and Sports of the Republic of Croatia (grant No. 0119330).*

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.

Gonella, J., 1972: A rotary-component method for analysing meteorological and oceanographic vector time series. *Deep-Sea Res.*, **19**, 833–846.

O'Brien, J. J., R. D. Pillsbury, 1974: Rotary wind spectra in a sea breeze regime. *J. Appl. Meteorol.*, **13**, 820–825.

Papoulis, A., 1977: *Signal Analysis*. McGraw Hill, Auckland, 431 pp.