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Velocity profile of the gusty Bora wind

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Abstract

Vertical velocity profile of the gusty Bora wind blowing on the eastern Adriatic coast is analysed based on the meteorological-tower measurements carried out during summer. Those high-frequency field measurements are taken at three heights up to 40 m. The observed experimental data in this near-ground layer are generally in good agreement with the power-law and the logarithmic-law approximations. However, the most fascinating finding is an increase in the power-law exponent, friction velocity and aerodynamic surface length with decreasing Bora wind velocity that indicates an urban-like velocity profile for smaller wind velocities and a rural-like velocity profile for larger wind velocities.

1 Introduction

Effects of the classical atmospheric boundary layer flow on engineering infrastructure, traffic and human activities are more or less known, but there are some very unique local winds whose characteristics still need to be fully resolved. One example is the gusty Bora wind that blows along the eastern Adriatic coast, and many other dynamically similar places, such as Japan, Russia, Kurdistan, Iceland, Austria, Rocky Mountains in the Northern America, etc. (e.g. Grisogono and Belušić, 2009), significantly influencing local wind energy yield, fatigue of wind energy structures, agriculture and optimal functioning of transportation network (e.g. Kozmar et al., 2012a, 2012b).

Bora is a very strong, usually dry and gusty wind that blows from the northeast across the coastal mountain ranges on the eastern coast of the Adriatic Sea, from Trieste to Dubrovnik and further south (e.g. Belušić and Klaić, 2006). It is spatially and temporally very variable and generally occurs more frequently in winter when it can last up to several days (e.g. Jurčec and Visković, 1994). Bora's mean velocity, 10 to 20 m s^{-1}, is not as substantial as its gusts that can reach velocities up to three or even five times the average value (e.g., Belušić and Klaić, 2006). Bora can be cyclonic, anticyclonic or frontal, depending on the triggering baric system. Cyclonic or 'dark' Bora usually brings clouds with a high possibility for precipitation, while anticyclonic or 'clear' Bora is usually accompanied with clear weather (e.g. Jurčec and Visković, 1994). Frequency of Bora occurrence in the eastern Adriatic decreases from northwest to southeast, and its strength weakens seaward from the shore in a way that it is rarely stormy in the western Adriatic (e.g. Enger and Grisogono, 1998; Grisogono and Belušić, 2009).

2 Methodology

The measurements data discussed in this study were conducted at the meteorological tower on Pometeno brdo in the lee side of the central Dinaric Alps close to the city of Split. Eastern, northern and vertical velocity components and ultrasonic temperature were measured at the sampling frequency of 5 Hz at 10, 20 and 40 m heights. An isolated summer Bora event, which lasted from 24 to 27 July 2010 (Magjarević et al., 2011) is analysed. The Bora velocity profiles are compared against the power- and the logarithmic-law. The power-law is commonly used in wind power assessment where wind at a certain level has to be estimated from wind measurements at another level. Originally, it was suggested by Hellman (1916) as:

$$\frac{\bar{u}_z}{\bar{u}_{\mathrm{ref}}} = \left(\frac{z-d}{z_{\mathrm{ref}}-d} \right)^{\alpha}, \quad (1)$$

with $\bar{u}_z$ as time averaged mean wind velocity in x-direction at the height z, $\bar{u}_{ref}$ as time averaged mean wind velocity in x-direction at the reference height z_{ref}, d as displacement height and α as the power-law coefficient dependent on atmospheric stability, local terrain roughness and the time averaging interval.

The logarithmic-law:

$$\frac{\bar{u}_z}{u_*} = \frac{1}{\kappa} \ln \frac{z-d}{z_0}, \quad (2)$$

where u_* represents shear velocity, κ von Kármán constant with the value of 0.41 and z_0 aerodynamic surface roughness length, can be considered valid within the inertial sublayer (Thuillier and Lappe, 1964). Considering that a potential applicability of the power- and logarithmic-law for Bora wind profiles in the mean wind direction is tested, the appropriate coordinate system is considered to be the one with the x-axis aligned along the mean wind direction. Time averaged wind speed is calculated using moving average with averaging scale of 17 min which represents a suitable turbulence averaging scale for that type of Bora (Magjarević et al., 2011). In order to test the applicability of the power-law, the time averaged mean wind speeds in x-direction at three levels are normalized using the time averaged mean wind speed in x-direction at 40 m height. Therefore, the power-law exponent α is obtained by data fitting where the displacement height equals zero. For the logarithmic-law testing, u_* and z_0 were calculated in two different ways, i.e. (a) by data adjustment to the logarithmic-law, and (b) by directly applying the logarithmic-law to a layer between 10 and 40 m (both with d = 0 m).

3 Results and discussion

In this section applicability of the empirical power-law and the logarithmic-law on the Bora wind velocity profiles, as well as velocity profile characteristics during different wind velocity periods are discussed.

Generally, the results show that both the logarithmic-law and the power-law fit the Bora wind velocity profiles very well, as reported in Fig. 1. For this particular Bora episode, the logarithmic-law and the power-law fit the measured data better when performing the analysis by using the median rather than using the arithmetic mean wind velocity due to a drifting of z_0 values during the recording time.

A decrease in α, u_* and z_0 values with increasing Bora wind velocity can be noticed in Fig. 2 indicating a rural-like velocity profile for larger wind velocities and an urban-like velocity profile for smaller wind velocities. As the time averaged Bora mean wind velocity reaches its local maxima, the corresponding α, u_* and z_0 reach their local minima, and vice versa. In general, the mean value of α for rural terrain is 0.19 and 0.35 for urban terrain, as reported in ESDU 72026 (1972). Moreover, it needs to be mentioned that the reported trends apply to measurements at this specific site only. In addition, more work still needs to be done to fully investigate the applicability of α, u_* and z_0 at other locations, different thermal stability conditions and seasons as well as for the different height ranges of measurement points.

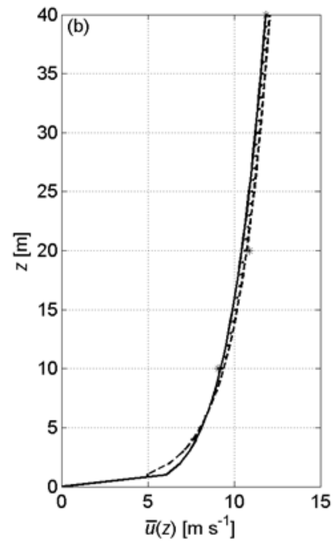

Fig. 1: Vertical velocity profile of the Bora wind; comparison of result measured at the meteorological tower with the empirical logarithmic- and power-law comparison based on calculation using the median value. Legend: star – measured median value, black solid line – power-law, black dotted line – logarithmic-law, black dashed line – logarithmic-law applied to a layer between 10 and 40 m.

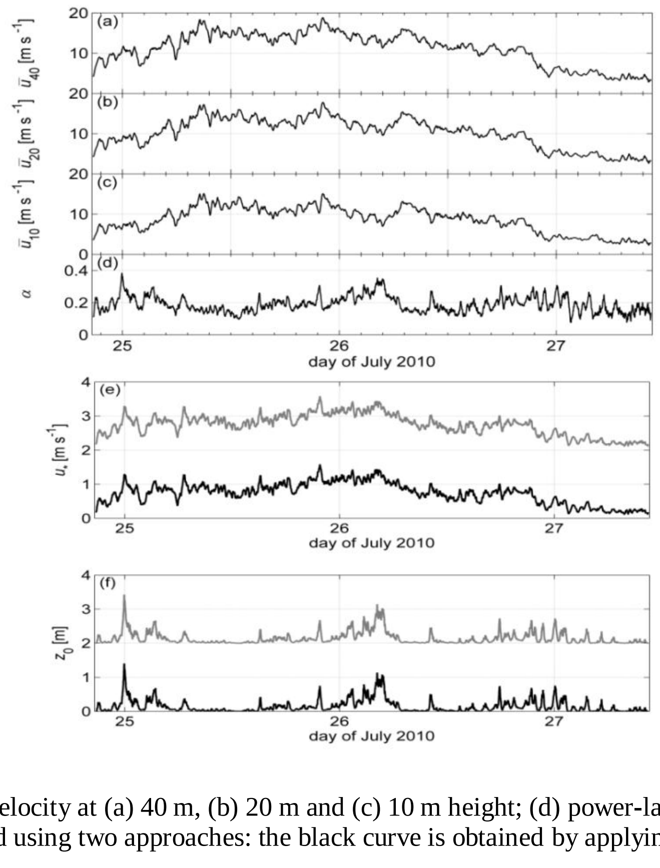

Fig. 2: Mean wind velocity at (a) 40 m, (b) 20 m and (c) 10 m height; (d) power-law exponent α; (e) friction velocity u_* calculated using two approaches: the black curve is obtained by applying the logarithmic-law to a layer between 10 and 40 m and the grey curve is calculated using the logarithmic-law adjustment. The grey curve is artificially shifted upwards for 2 m s^{-1} in order to create a better visual presentation; (f) aerodynamic surface roughness length z_0 calculated using two approaches: the black curve is obtained by applying the logarithmic-law to a layer between 10 and 40 m and the grey curve is obtained using the logarithmic-law. The grey curve is artificially shifted upwards for 2 m in order to create a better visual presentation.

4 Concluding remarks

A summertime vertical velocity profile for the gusty Bora wind was studied. The power-law and the logarithmic-law performance is tested based on 3-level high-frequency velocity measurements carried out on the meteorological tower Pometeno brdo, Croatia. For the first time it is recognized that the observed profiles of the average wind velocity along the dominant Bora wind direction agree well with the power-law and logarithmic-law approximations. An interesting property is an increase in α, u_* and z_0 with decreasing Bora mean wind velocity and vice versa, indicating rural-like velocity profile for larger wind velocities and an urban-like velocity profile for smaller velocities. The logarithmic-law is applied to determine u_* and z_0 by using two different approaches. While both approaches give the same value for u_*, z_0 shows mild discrepancies. The trends mentioned above apply to measurements at the specific site and future work is required to investigate Bora turbulence characteristics at other locations, during potentially different thermal stratifications, seasons and for different elevations of measurement points.

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