ALONG-COAST FEATURES OF THE BORA RELATED TURBULENCE

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Abstract: The mesoscale bora structure in the along-coast direction (normal to the mean bora flow) is featured by an interchange of jets and wakes related to mountain gaps and peaks. Here we examine the along-coast, off-shore turbulence structure of the bora that occurred on 7 November 1999 during the Mesoscale Alpine Program (MAP) Intensive Observation Period 15. We use the aircraft and dropsonde data measured along the lee side of the Dinaric Alps over the Adriatic by the NCAR Electra aircraft. The results are compared with the output from the WRF ARW numerical model.

Keywords: MAP, bora wind, turbulence, turbulence kinetic energy, dissipation rate, WRF ARW model

1 INTRODUCTION

At the Eastern Adriatic coast, there is often blowing a downslope windstorm called bora. It blows from the northeastern quadrant and it is most frequent during winter season. Bora mean wind speed can surpass 20 m s^{-1} and due to its gustiness it reaches speeds greater than 60 m s^{-1} (e.g. Belušić and Klaić, 2006). During such events, the turbulence is strongly developed in the lee of the mountain.

The mesoscale bora structure in the along-coast direction (normal to the mean bora flow) is featured by an interchange of jets and wakes related to mountain gaps and peaks; this has already been studied extensively (e.g. Grubišić, 2004). We present a case study of an early stage of a bora event over the northern Adriatic that occurred on 7 November 1999 during the Mesoscale Alpine Program (MAP) Intensive Observation Period 15. We use the aircraft data measured along the lee side of the Dinaric Alps over the Adriatic by the NCAR Electra aircraft. The study includes two vertically separated flight legs (lower at ~ 370 m, higher at ~ 680 m) and six dropsonde measurements along the legs. The results are compared with the outputs from the WRF ARW numerical model for this event.

2 OBSERVATIONAL DATA ANALYSIS

During IOP 15, two 216 km long flight legs were performed, higher one at approximately 680 m ASL flying SE to NW, and the lower one at 380 m ASL from NW to SE. The data were sampled at the frequency of 25 Hz. The aircraft flew at the mean velocity of 100 m s^{-1}. Two hours prior to IOP 15, nine dropsondes were released by the Electra aircraft at 4200 m above the surface along the flight legs mentioned above. The area of interest, the lower flight leg with the horizontal wind and the coordinates of the dropsondes released are shown in Figure 1.

The coordinate system is rotated counter clockwise in order to lay the x axis across the flight legs pointing SW. The y axis is laid along the legs and points toward SE. The aircraft data crosspectrum and spectrum analysis of the heat and momentum flux respectively, show the energy gap (e.g. Metzger and Holmes, 2008) at the wave number corresponding to the wave length of 120 m for both flight legs. This feature impelled us to filter those data using Moving Average (MA) of 120 m. Consequently we neglect all of the phenomena on scales greater then this MA. The flight legs are divided into 100 segments of 2160 m. For each segment of legs the turbulent kinetic energy (*TKE*) is calculated, and using the inertial dissipation method provided by the Kolmogorov's 1941 (e.g. Večenaj et al., 2007), the *TKE* dissipation rate (ε), is calculated too. The *TKE* values are used as the control parameter for the evaluation of ε (Fig. 2a, 2b and 2c). Bulk Richardson number, R_B, (e.g. Stull, 1988) calculated from the aircraft data is compared with the one calculated from the dropsonde data (Fig. 2d).

3 MEASURED AND MODELED DATA COMPARISON

There is a good agreement between the aircraft and dropsonde data along the flight legs which points out the measurements quality rate. This bora case is simulated using the WRF ARW model. While u wind speed component is reproduced successfully along the flight legs, the agreement with the v component, potential temperature (θ) and *TKE* is poorer (Fig. 3). With respect to the aircraft data, model significantly overestimates v on the entire flight legs while it underestimates θ on the northern part and *TKE* on the southern part of the legs. There is an agreement between aircraft and dropsonde data along the flight legs (Fig. 4). Comparison of the modelled with the dropsonde data shows a good agreement with u and θ, while v shows more deviation both in magnitudes and in vertical structure.

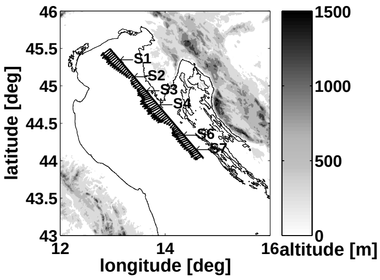

Figure 1. Area of interest together with a lower flight leg (height of 370 m), wind vectors (1600 m means) and positions of dropsondes.

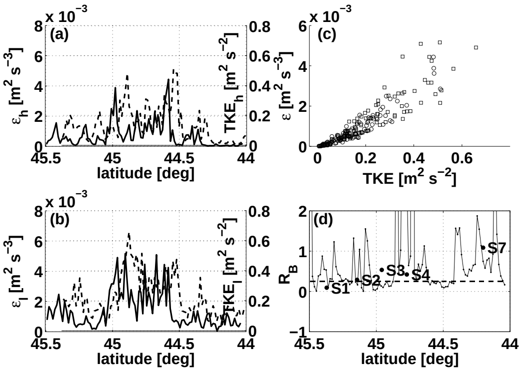

Figure 2. ε (solid line) and *TKE* (dashed line) on (a) higher (b) lower flight leg. (c) ε vs. *TKE* on higher (circles) and lower (squares) flight leg. (d) R_B between flight legs from aircraft data (solid line) and from dropsonde data (diamonds).

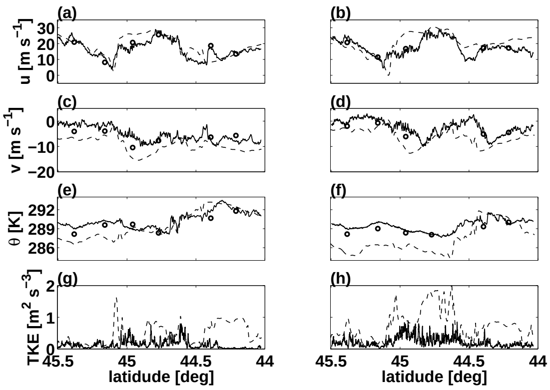

Figure 3. Aircraft (solid line), dropsonde (circles) and modelled data (dashed line) along the higher (a, c, e, and g) and the lower (b, d, f, h) flight leg.

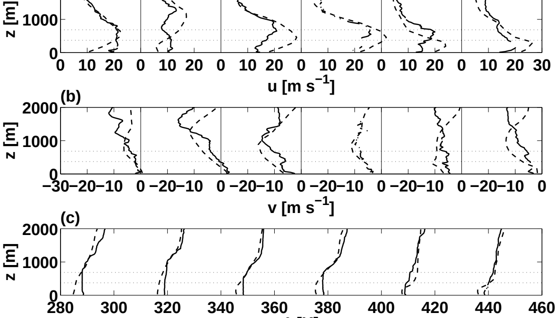

Figure 4. Six dropsonde along flight legs (solid line) and modelled (dashed line) data of (a) u and (b) v. (c) θ is consecutive shifted for 30 K.

4 SUMMARY

A great spatial variability of *TKE* and ε along the flight legs is revealed in this bora case due to the known bora mesoscale features such as mountain waves, wave breaking, jets and wakes, shear zones, etc. Jets, wakes and shear zones are closely related to the terrain complexity which is highly immanent along the eastern Adriatic coast.

Variations of *TKE* time series closely follow those of ε which gives the information about robustness and consistency of the ε estimation. As expected, a scatter plot shows that ε increases with *TKE*. The empirical relation between these two variables is yet to be examined.

In general, aircraft in situ data agree well with dropsonde data which points out the degree of measurements reliability. On the other hand, WRF ARW model reproduces the u wind speed component along the flight legs well, while the v component and θ are overestimated and underestimated, respectively. Also, *TKE* is well simulated at the northern part of the legs, while it is overestimated at the southern part. As for the vertical range, u and θ are reproduced more successful than v.

The main question which we wish to answer is from where does the TKE in the model coming from? Is it a result of the model internal physics, or may it be caused by the effects of boundary conditions?

After we find the answers to the above raised questions, we will look for interpretation of the along-coast features of the bora related turbulence in the model outputs. Also, we will focus on several wakes noticed on horizontal planes (model outputs) both at 370 m and 680 m at the northern part of the flight legs. This will be studied by analysing the models vertical cross sections perpendicular to the legs.

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