Along-coast features of the bora related turbulence

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I. INTRODUCTION

- BORA: a strong downslope windstorm that blows at the E Adriatic coast from the NE quadrant

- most frequent during winter season, T ϵ [~hours, ~days]

- wide spectrum of the mean wind speed, due to the gustiness wind speed maxima my surpass 60 m s^{-1} (e.g. Belušić and Klaić, 2006)

- Smith (1987): Hydraulic nature of the mean bora flow

- bora turbulence:
  - Belušić et al. (2006): bora pulsations, T ϵ [1, 10] min
  - Belušić and Klaić (2006): *TKE* > 30 J kg^{-1}
  - Večenaj et al. (2010): TKE and ε 13 m above the ground

- <u>OBJECTIVE:</u>
  - to describe nature and structure of turbulence along the northern Adriatic coast during the severe bora event by estimating TKE and its dissipation rate ε

II. THEORETICAL BACKGROUND

- TKE per unit mass: $$\bar{e} = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right) \quad (1)$$

- Inertial dissipation method for ε (e.g. Stull, 1988):

$$log\left[S_i(k)\right] = -\frac{5}{3} log\, k + log\left(\alpha_i \varepsilon^{2/3}\right) \quad (2)$$

$$\varepsilon = \left[\frac{k^{5/3} S_i(k)}{\alpha_i}\right]^{3/2} \quad (3)$$

- Parameterization of ε (e.g. Mellor and Yamada, 1974):

$$\varepsilon = \frac{(\bar{e})^{3/2}}{\Lambda} \quad (4)$$

$$\varepsilon = a(\bar{e})^b \quad (5)$$

- Bulk Richardson number: $$R_B = \frac{\Delta\theta_V}{\theta_V} \frac{g\Delta z}{(\Delta U)^2 + (\Delta V)^2} \quad (6)$$

III. DATA

- data were collected during the MAP-IOP 15 on 7 November 1999 – strong bora case (e.g. Grubišić, 2004)

- NCAR Electra aircraft was flying offshore over the N Adriatic coast – two flight legs 216 km long at 130° azimuth (assumption that bora blows at 40° azimuth):

  i) higher ≈0.68 km ASL from SE to NW from 1429 to 1501 UTC
  ii) lower ≈0.37 km ASL from NW to SE from 1504 to 1539 UTC (Fig. 1)

- (aircraft speed ≈ 100 m s^{-1}) + (sampling frequency = 25 Hz) ≈ (dx ≈ 4m)

- nine dropsondes were released by the Electra aircraft along a flight leg from NE to SW at 4200 m ASL between 1347 and 1420 UTC) – the data from six dropsondes that worked properly are used here (Fig. 1)

- the coordinate system is rotated to corespond to the orientation of flight legs and the x axis is pointed downstream (Fig. 1)

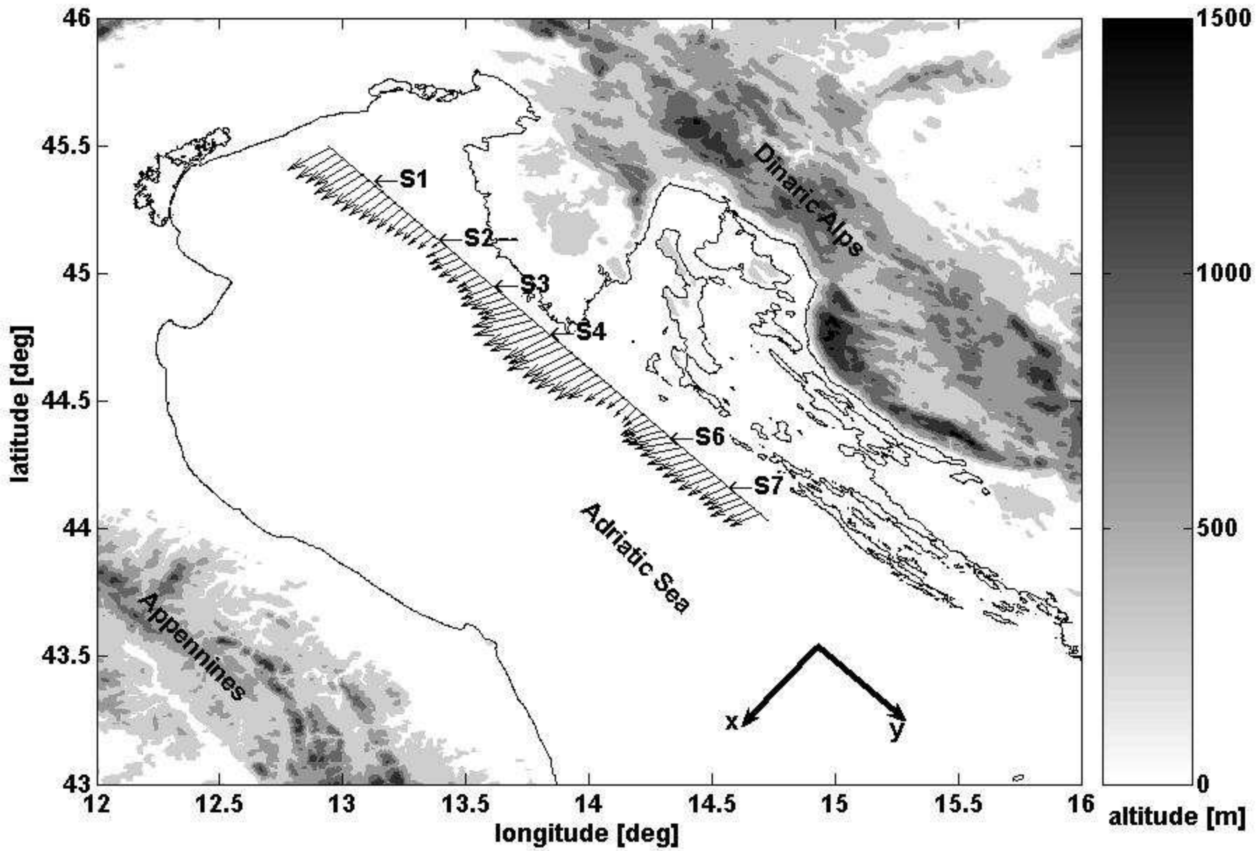

Figure 1: Area of interest, a lower flight leg (height of 370 m) with wind vectors (1600 m means) and positions of dropsondes at the moment they are released. Orientation of the coordinate system is denoted in the bottom of the figure.

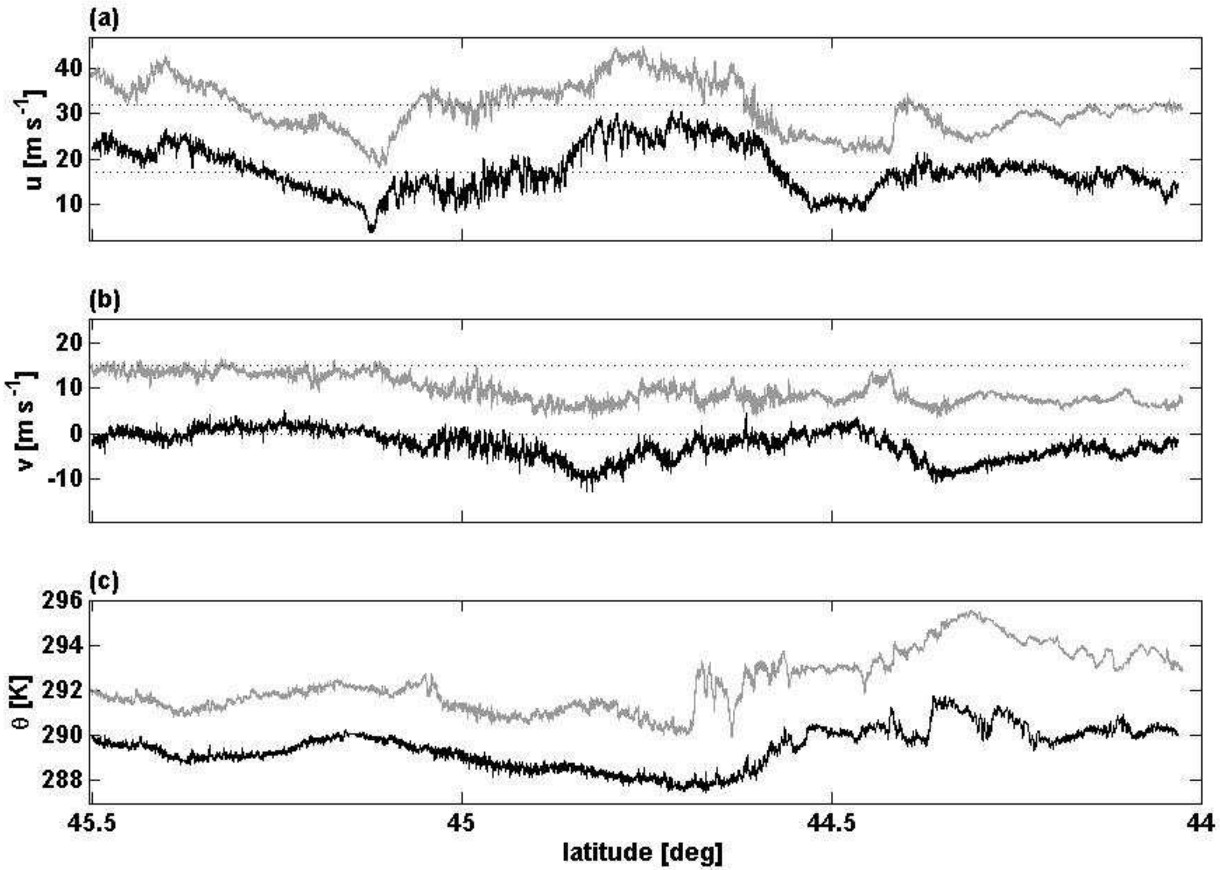

Figure 2. Spatial features of lower (black curve) and higher (gray curve) flight leg: (a) *u* component, (b) *v* component and (c) θ. Values of (u,v) and θ at the higher flight leg are increased for 15 m s^{-1} and 2 K, respectively, for presentation. Horizontal dotted lines in panel (a) and (b) denote 17 and 0 m s^{-1}, respectively.

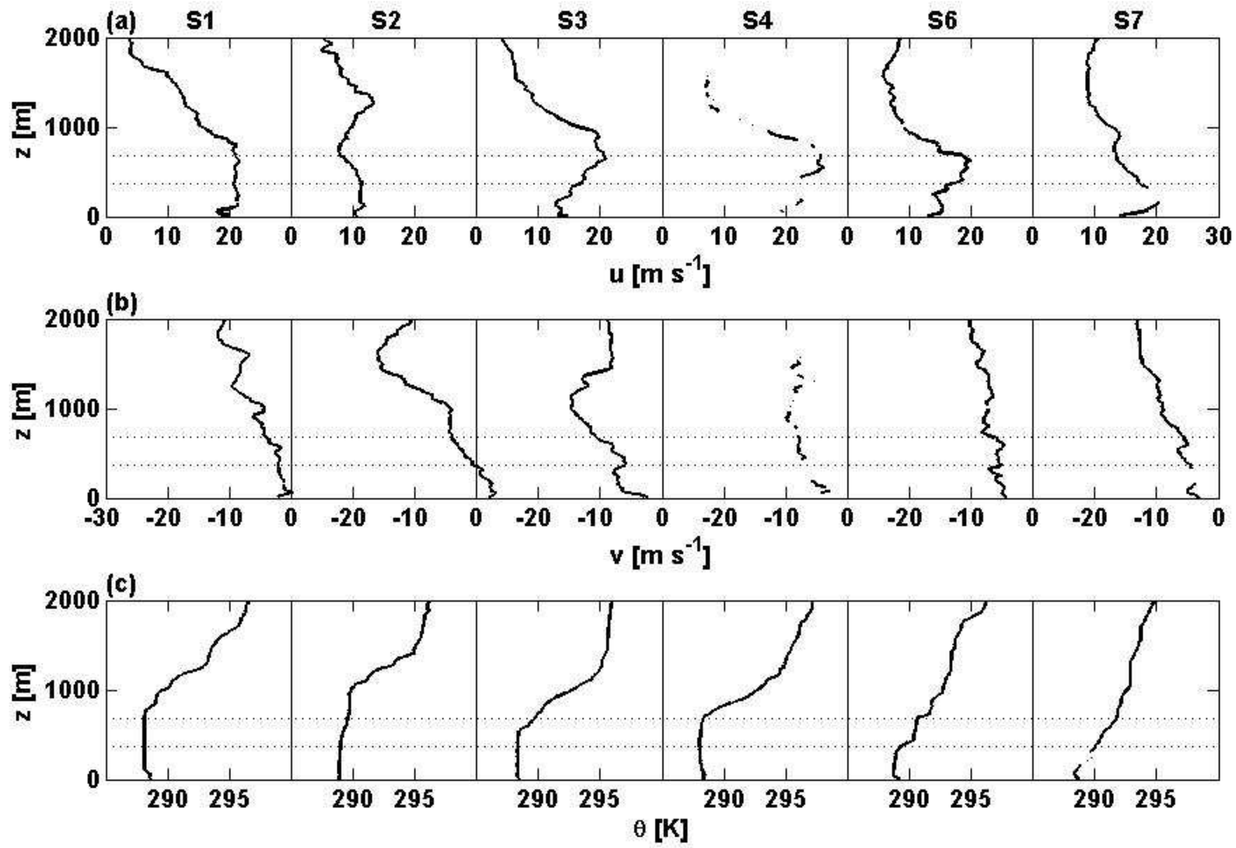

Figure 3. Vertical profiles of the six dropsonde data in the spatial order from left to right as they are released from NW towards SE (see Fig. 1): (a) u component, (b) v component and (c) θ. Horizontal dotted lines represent the flight legs.

IV. MODEL

- WRF-ARW model, version 3.1.1
- three 2-way nested domains; 9, 3 and 1 km horizontal grid spacing; 66x66, 112x112 and 226x229 grid points respectively
- 86 vertical levels
- Initial and boundary conditions from the ECMWF analysis

- 5 different PBL parameterization schemes:

WRF simulation name	**PBL parameterization**
MYJ	Mellor-Yamada-Janjic
QNSE	Quasi-Normal Scale Elimination
MYNN2.5	Mellor-Yamada Nakanishi and Niino Level 2.5
MYNN3	Mellor-Yamada Nakanishi and Niino Level 3
BouLac	Bougeault and Lacarrere

V. RESULTS

V.1. Spectral analysis, TKE and ε

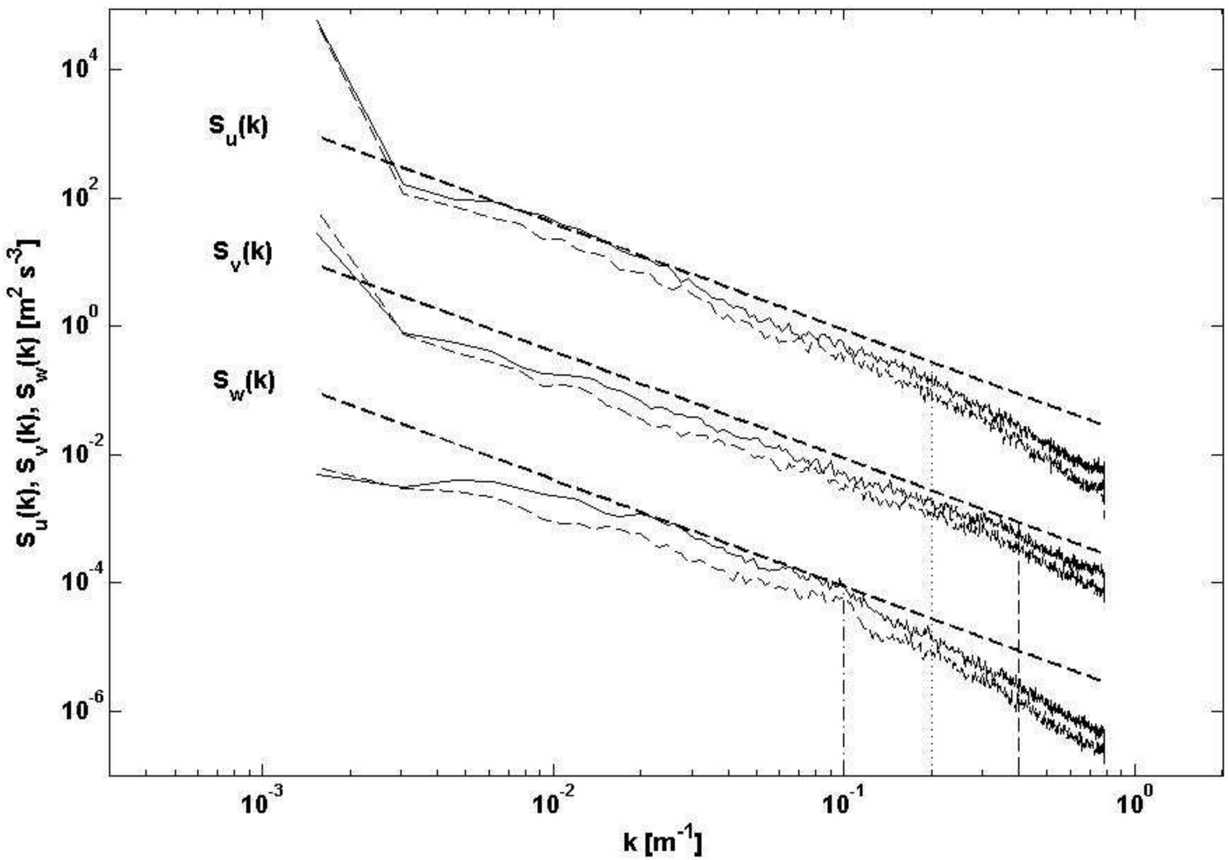

Figure 4. A log-log representation of total *u*, *v* and *w* components power spectrum densities for lower (thin solid line) and higher (thin dashed line) flight legs. The thick dashed lines are the -5/3 slopes. The *v* and *w* spectra have been reduced by a factor of 10^2 and 10^4, respectively, for presentation.

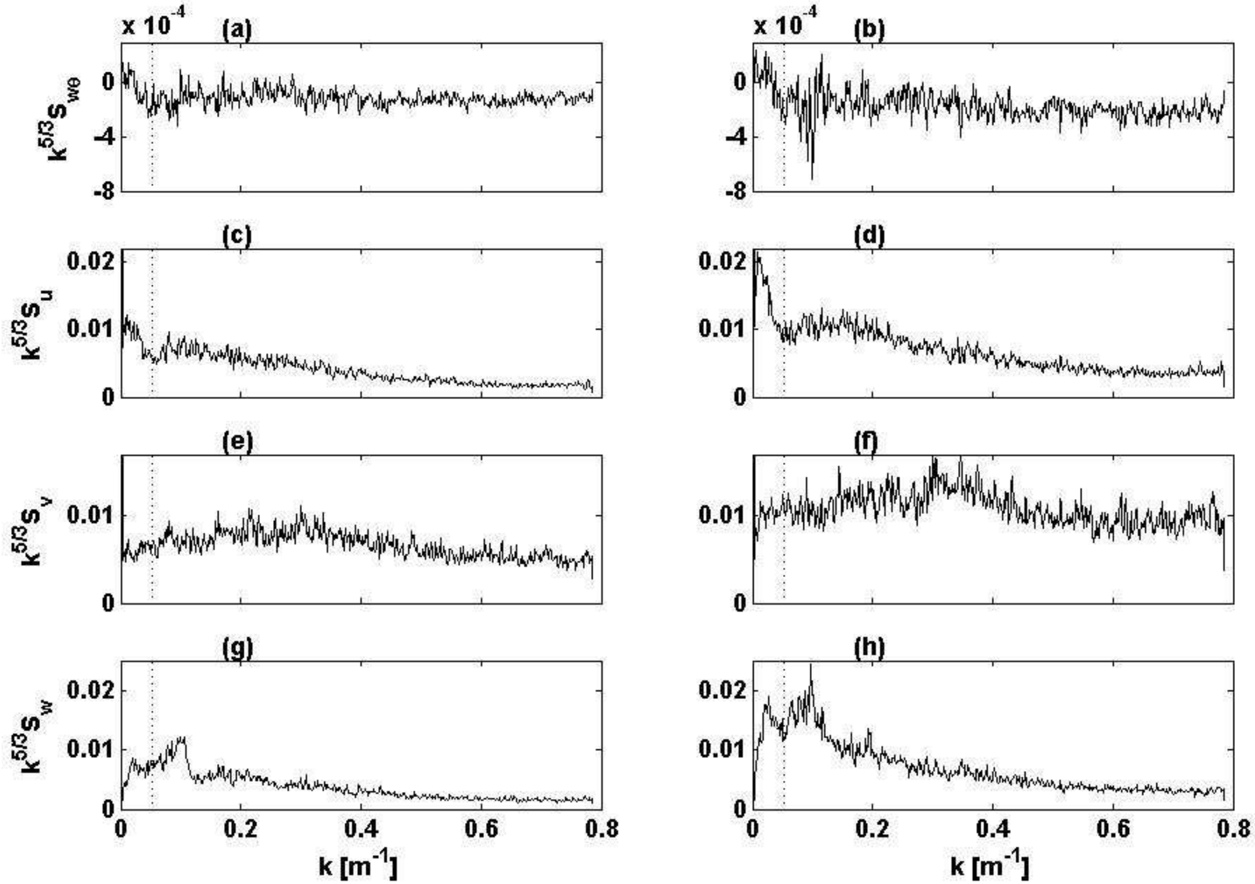

Figure 5. Crosspectra of *wθ* and spectra of all three wind speed components: *u, v* and *w*. Panels (a), (c), (e) and (g) are for higher, whereas (b), (d), (f) and (h) are for the lower flight leg. Position of the 120 m wave length is indicated by the vertical dashed line.

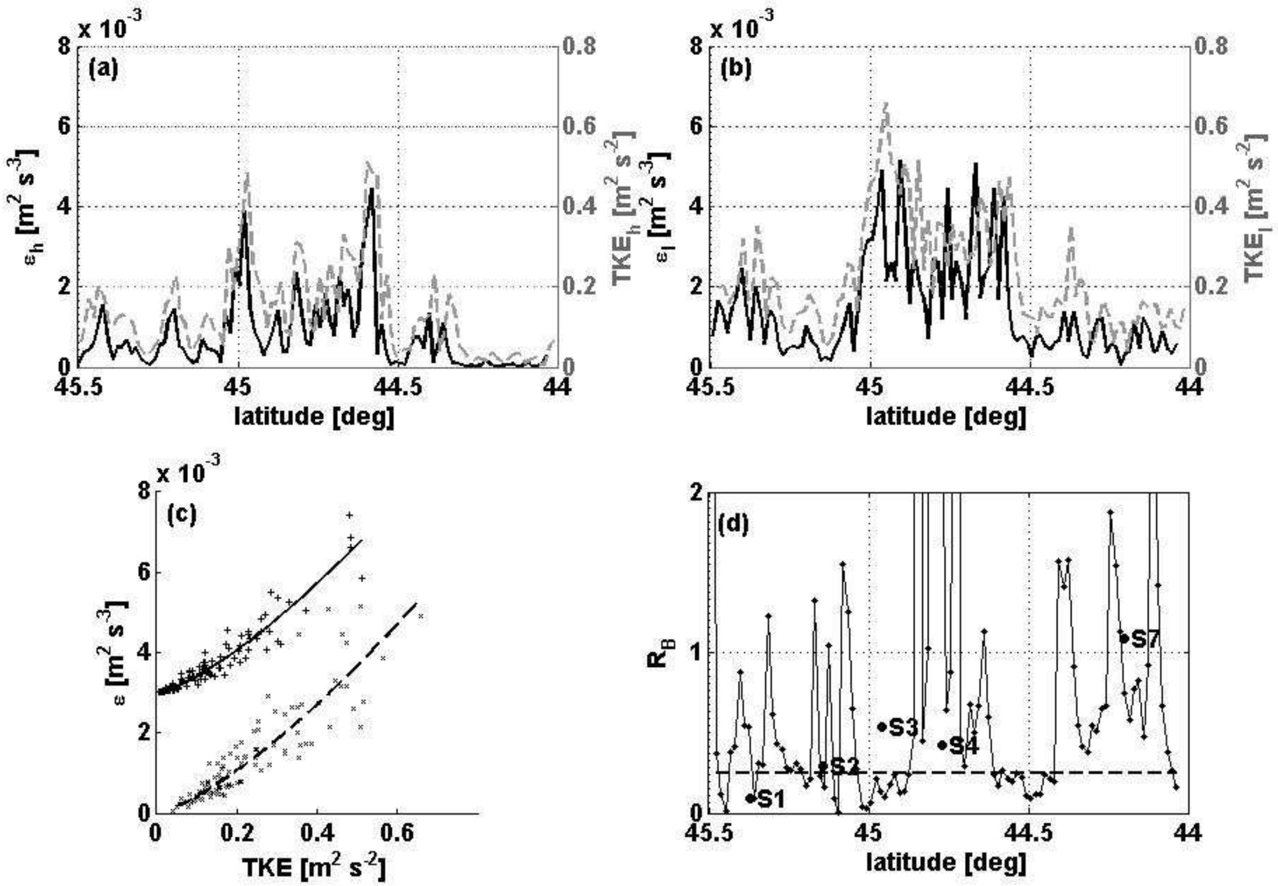

Figure 6. Spatial distributions of TKE (gray dashed curve) and ε (black solid curve) along the (a) higher and (b) lower flight legs. (c) Scatter diagram of ε vs. TKE for higher (plus signs) and lower (crosses) flight legs with the corresponding fits superimposed (solid curve for higher and the dashed curve for lower flight leg). The values of ε for higher flight leg are raised for 0.003 $m^2\ s^{-3}$ for presentation. (d) Bulk Richardson number between the flight legs estimated using the aircraft data (solid curve with dots) and dropsonde data (black circles). Horizontal dashed line denotes the critical value of Richardson number (Rc).

V.2. Comparison of observations with simulated flow

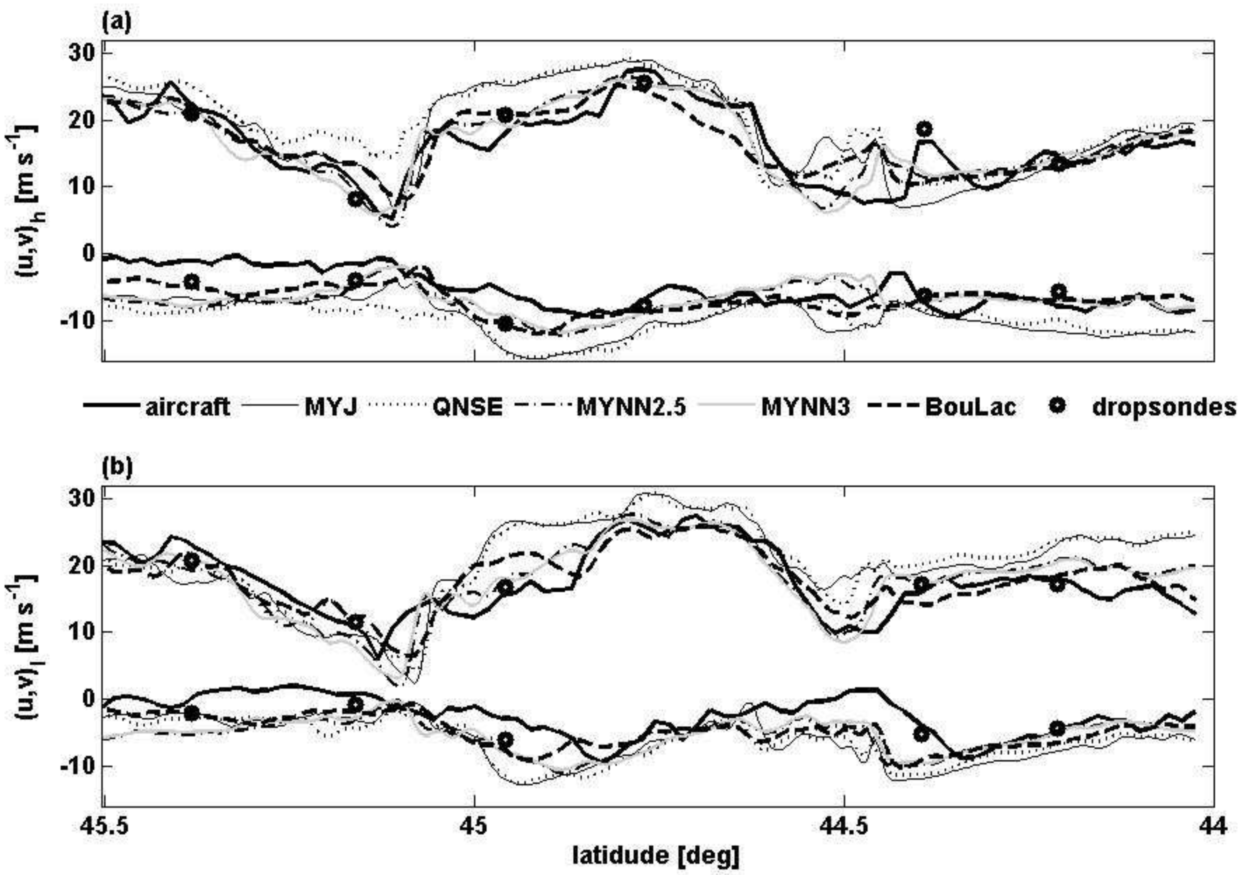

Figure 7. Spatial distribution of *u* and *v* at (a) higher and (b) lower flight leg. Black thick solid curves denote aircraft data. Thin curves, namely black solid, black dotted, black dot-dashed and gray denote MYJ, QNSE; MYNN2.5 and MYNN3 simulations, respectively. Black thick dashed curves denote the BouLac simulation, while black circles denote dropsonde data.

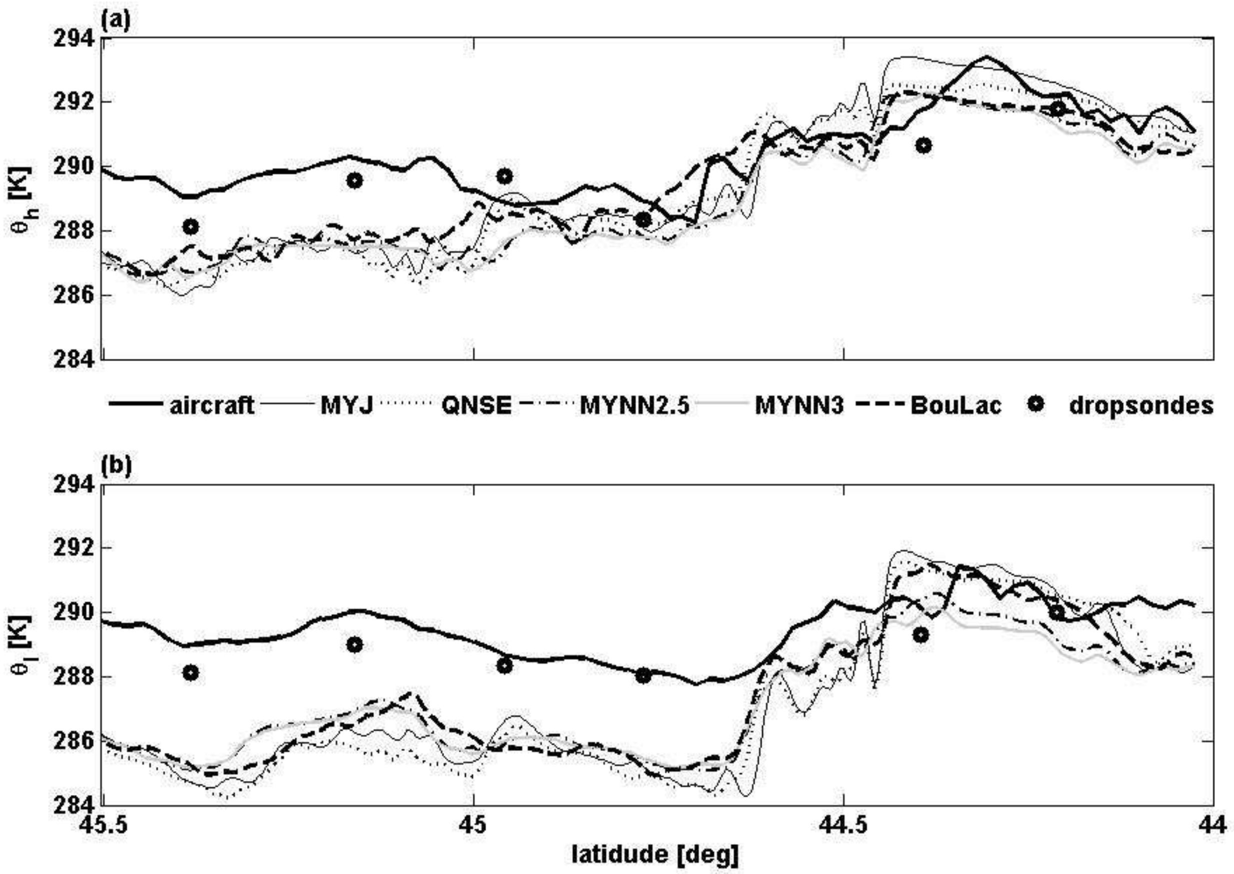

Figure 8. Same as Fig. 7, but for θ.

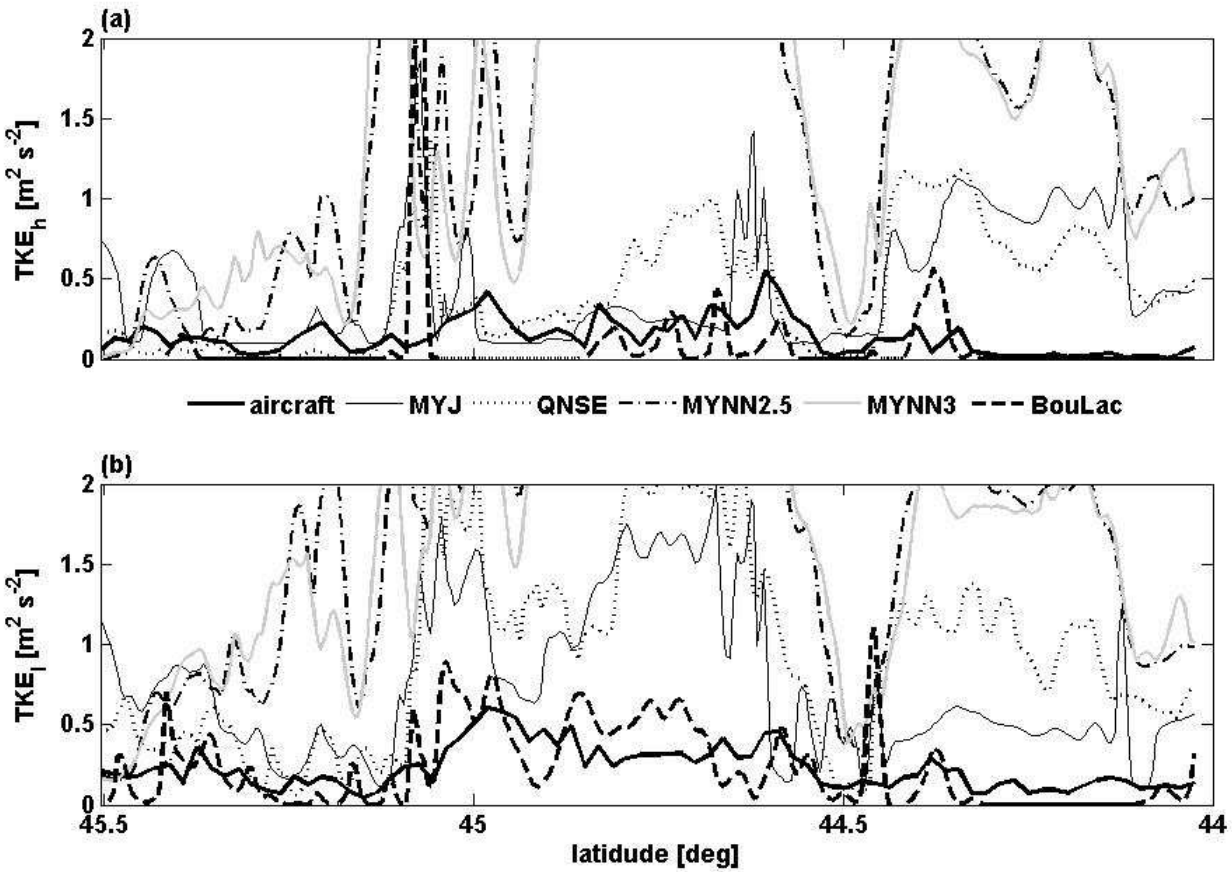

Figure 9. Same as Fig. 7, but for TKE.

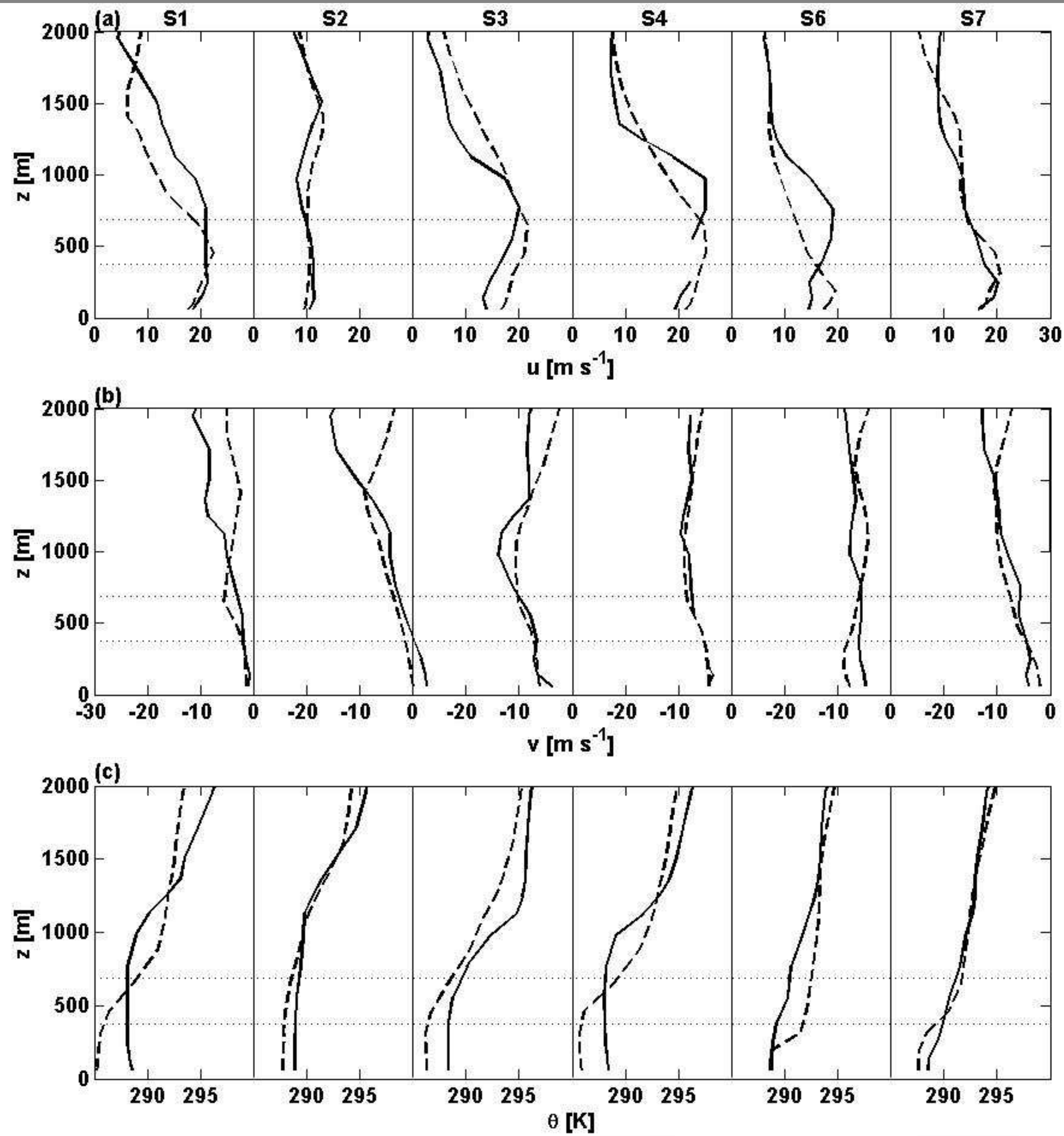

Figure 10. Vert. profiles of the 6 dropsonde data (solid line) and BouLac simulation (dashed lines) in the spatial order from left to right as dropsondes are released from NW towards SE (see Fig. 1): (a) *u* component, (b) *v* component and (c) θ. The dropsonde data are smoothed in order to correspond to the model vert. resolution.

VI. DISCUSSION AND CONCLUSIONS

- Variations of TKE time series closely follow those of ε - robustness and consistency of the ε estimation

- Our data suggest that in this bora episode ε is proportional to $TKE^{1.36}$ for both, lower and higher, flight legs - very similar to the near-surface value (1.3) obtained by Večenaj et al. (2009)

- Parameter Λ, which at higher and lower flight legs amounts ≈ 76 and 84 m, respectively, is also comparable with their near-surface value of 60 m

- In general, aircraft *in situ* data agree well with the dropsonde data which point out to the degree of measurements reliability

- The WRF ARW model reproduces the wind speed along the flight legs well, while θ is underestimated
- TKE is well simulated only for BouLac, while the rest of simulations overestimate the TKE values.
- Vertical profiles of u, v and θ are decently reproduced by BouLac parameterization

Thank you!

Questions?