Some features of near-ground Bora turbulence

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WORKSHOP ON ADVANCES IN MESO- AND MICROMETEOROLOGY
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Presentation outline

- Basic Bora characteristics
- Methodology
- Results
- Concluding remarks

Basic Bora characteristics

- Strong, temporally and spatially very variable wind
- Most prominent feature strong gustiness
- Average wind velocity rarely exceed 17 m/s
- Gusts may reach 69 m/s
- Eastern Adriatic coast and many other dynamically similar places around the world
- Creates significant problems to traffic, infrastructure and human activities in general ....

Bora research

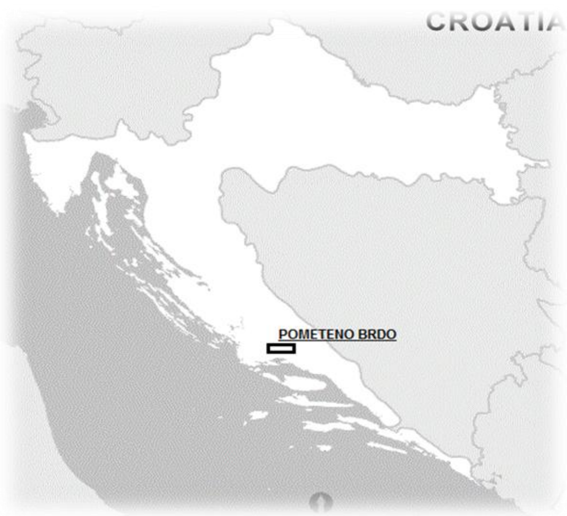
- Previous Bora studies carried out in meteorology and geophysics' communities….

  …. Those results not applicable to structural and wind engineers, as they focus on mesoscale rather than near-ground flow and turbulence!

- Bora analysis needed in a form usable for engineers!

Data collection and analysis

- Meteorological tower (60 m high) on the Pometeno brdo (close to Split, Croatia)
- Measurements in 10, 20 and 40 m height:
  - From April 2010 until June 2011
  - Eastern, northern and vertical wind velocity components; ultrasonic temperature
  - Sampling frequency 5 Hz



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Data collection and analysis

- Analyzed data
  - Isolated summer Bora event from 24 to 27 July 2010 (in total 62 hours)
  - Wind relatively strong and long lasting (mean hourly velocities larger than 15 m/s)
- Coordinate system
  - *x*-axis aligned along the mean wind direction
- Time averaged wind velocity
  - Moving average with averaging scale of 17 min (Magjarević et al., 2011)
  - 17 min represents a suitable turbulence averaging scale (scale which separates turbulence at small scales from the mean flows at large scales) for this Bora episode

Theoretical background

- Applicability test of the power and log-law on 3-level high-frequency Bora measurements (up to 40 m height)

- **Power-law** (Hellman, 1916): $$\frac{\overline{u}_z}{\overline{u}_{ref}} = \left(\frac{z - d}{z_{ref} - d} \right)^{\alpha}$$

$\overline{u}_z$ - time averaged mean wind velocity in the downwind *x*-direction at the height *z*

$\overline{u}_{ref}$ - time averaged mean wind velocity at the reference height z_{ref}

d - displacement height

α - power-law exponent

- **Logarithmic-law** (Thuillier and Lappe,1964): $$\frac{\overline{u}_z}{u_*} = \frac{1}{\kappa} \ln \frac{z - d}{z_0}$$

u_* - friction velocity

κ - von Kármán constant

z_0 - aerodynamic surface roughness length

Theoretical background

Typical values for z_0, d and α :

Terrain description	z_0 [m]	d [m]	α [-]
City centres Forests	0.7	15 to 25	0.23
Small towns Suburbs of large towns and cities Wooded country (many trees)	0.3	5 to 10	0.19
Outskirts of small towns Villages Countryside with many hedges, some trees and some buildings	0.1	0 to 2	0.16
Open level country with few trees and hedges and isolated buildings; typical farmland	0.03	0	0.13
Fairly level grass plains with isolated trees	0.01	0	0.11
Very rough sea in extreme storms (once in every 50 years extreme) Flat areas with short grass and no obstructions Runway area of airports	0.003	0	0.10
Rough sea in annual extreme storms Snow covered farmland Flat desert or arid areas Inland lakes in extreme storms	0.001	0	0.10

→ z_0 and d from ESDU85020 (1985)

→ $\alpha = 0.0961\,(\log z_0) + 0.016\,(\log z_0)^2 + 0.24$ from Counihan (1975)

Data collection and analysis

- Applicability of the power-law:
  - Time averaged mean wind velocity in *x*-direction at three levels normalized using the time averaged mean wind velocity in *x*-direction in 40 m height
  - Power-law exponent α obtained by data fitting

    (displacement height taken to be zero)

- Applicability of the logarithmic-law:
  - u_* and z_0 calculated in two different ways:
    - Data adjustment to the logarithmic-law
    - Directly applying the log-law to a layer between 10 and 40 m (both with d = 0 m)

Data collection and analysis

- Turbulence intensity

$$I_u = \frac{\sqrt{\overline{u'^2(z)}}}{\overline{u}_z} \qquad I_v = \frac{\sqrt{\overline{v'^2(z)}}}{\overline{u}_z}, \qquad I_w = \frac{\sqrt{\overline{w'^2(z)}}}{\overline{u}_z}$$

$$u(t) = \overline{u} + u'(z), \quad v(t) = \overline{v} + v'(z), \quad w(t) = \overline{w} + w'(z),$$

$\overline{u}, \ \overline{v}, \ \overline{w}$ time averaged mean wind velocities in the *x*-, *y*- and *z*- direction

$u', \ v', \ w'$ the respective fluctuating wind velocity components

Turbulent wind velocity components were calculated after subtracting 17-min moving average of the wind velocity from the instantaneous wind velocity

- Reynolds shear stress components:

$$-\rho\,\overline{u'v'}, \quad -\rho\,\overline{v'w'}, \quad -\rho\,\overline{u'w'}$$

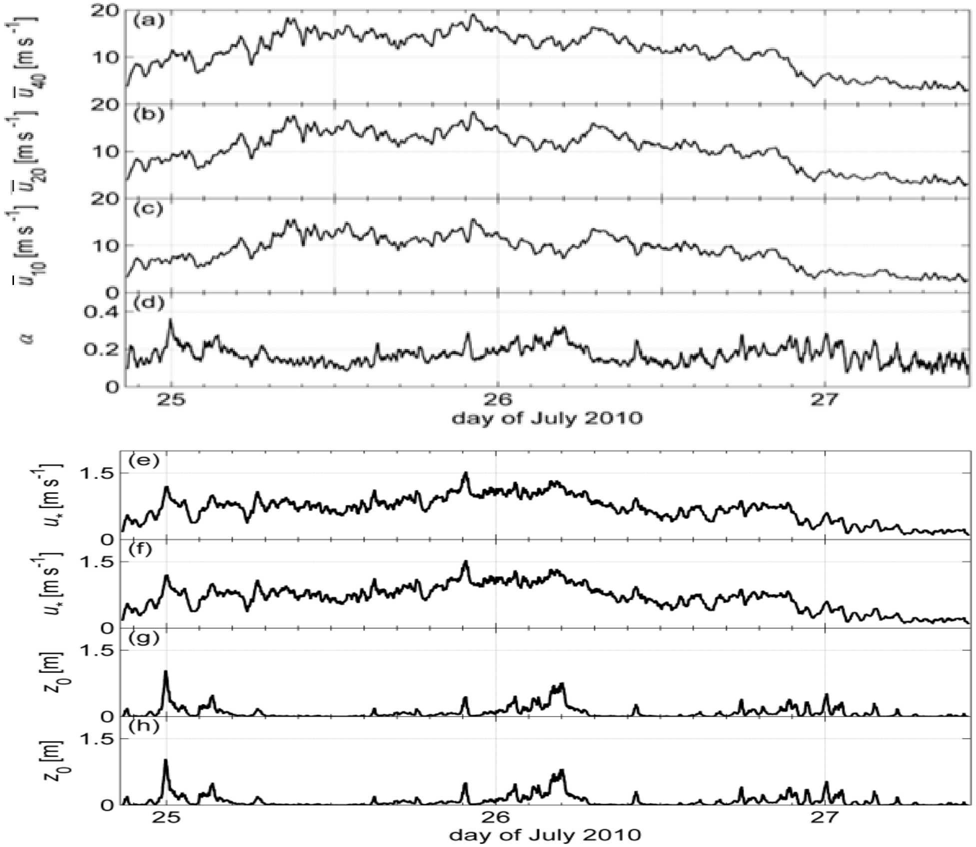
Power-law and logarithmic-law adjustment

$\alpha = 0.169 \pm 0.047$

$u_* = 0.685 \pm 0.292$ m/s

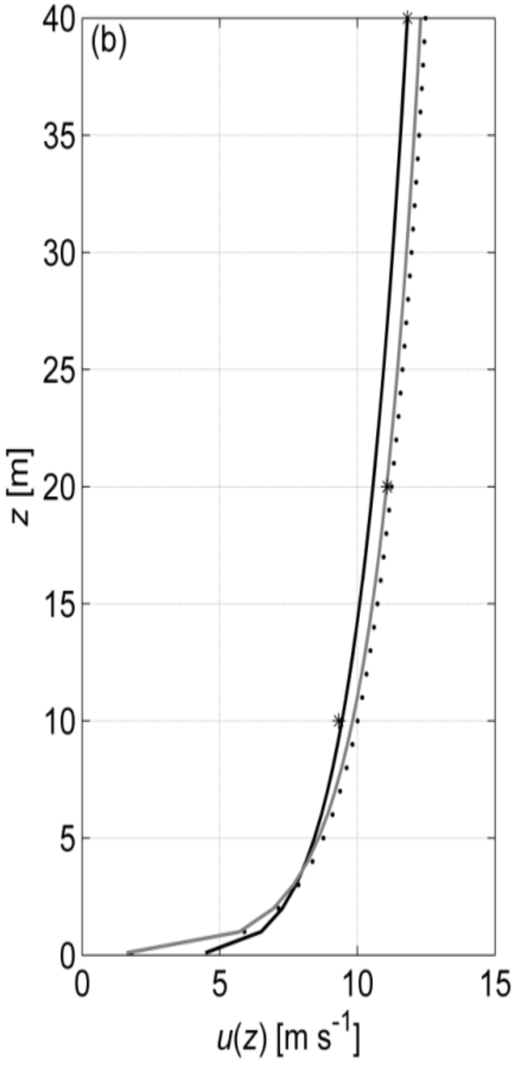
$z_0 = 0.092$ m (Log-law adjustment)

$z_0 = 0.097$ m (Log-law directly)



- Smaller wind velocity ⟶ urban-like velocity profile!
- Larger wind velocity ⟶ rural-like velocity profile!

Velocity profile of the Bora wind compared to the log- and power-law



Star – measured median value

Black solid line – power-law

Black dotted line – logarithmic-law

Grey line – direct adjustment of the log-law

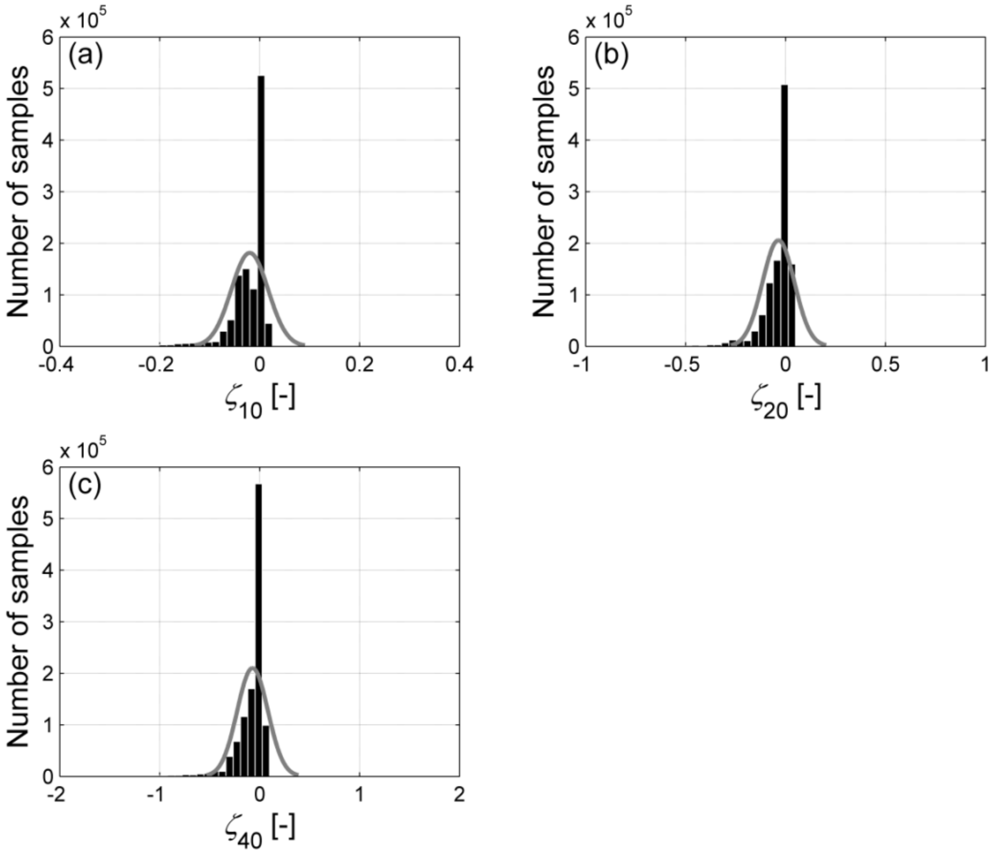
For entire 62 hours of measurement one mean velocity value at every height level is calculated

- Log- and power-law fit the Bora wind velocity profiles very well!
- Better adjustment when performing the analysis by using the median due to a drifting of z_0 values during the recording time!

Thermal stability parameter $\zeta = \frac{z}{L}$

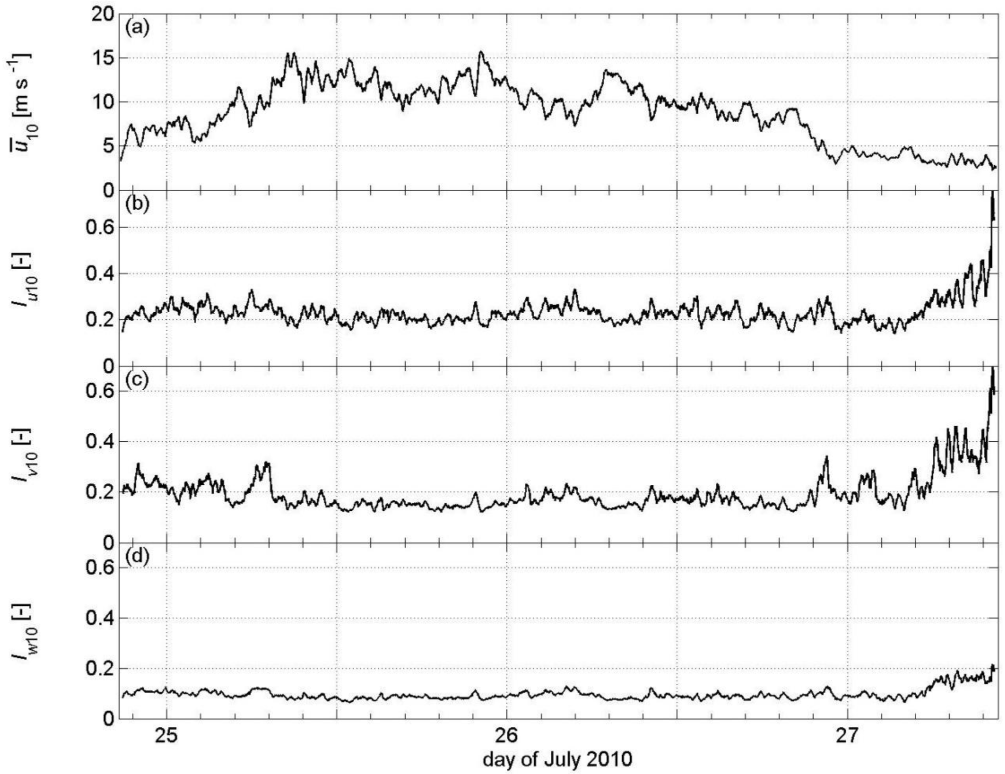
L - Obukhov length

$\zeta \approx \mathbf{0} \longrightarrow$ Bora surface layer nearly neutrally stratified!



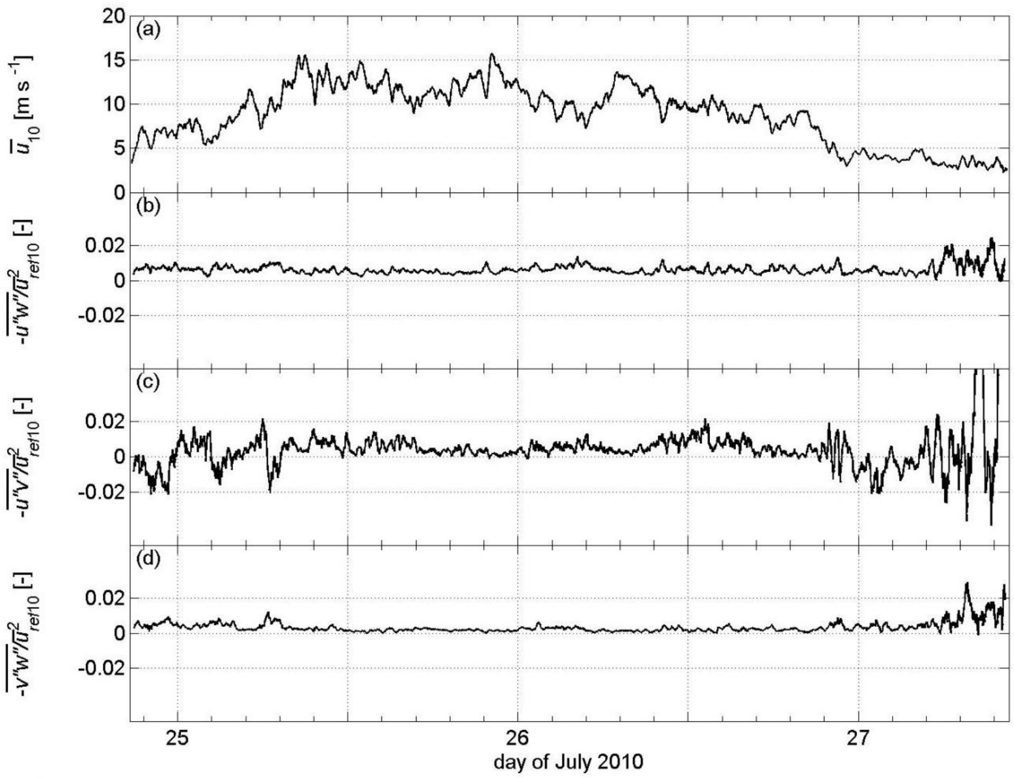
Turbulence intensity in *x*-, *y*- and *z*-direction

- Turbulence intensity in al three directions remain nearly constant for velocities larger than 5 m/s
- 5 m/s– critical velocity for turbulence intensity of the Bora wind?
- Vertical component two times smaller than the other two components
- Same trends for all height levels



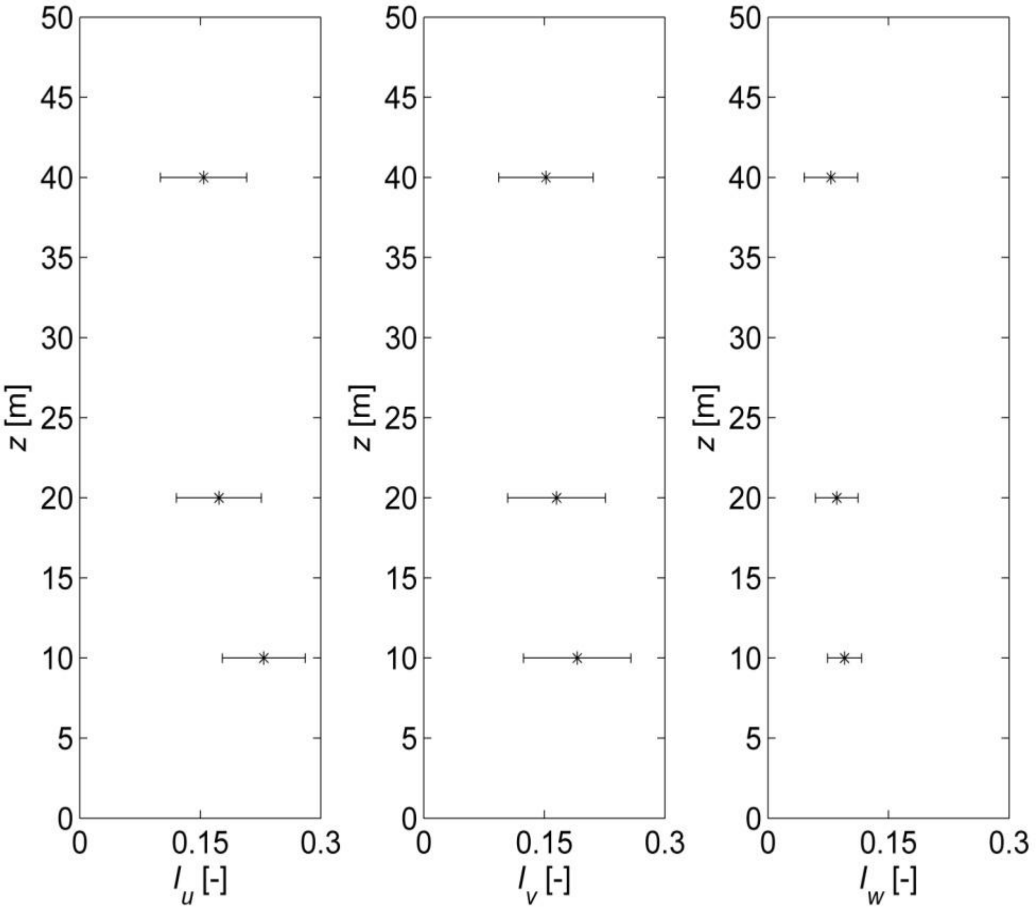
Reynolds shear stress in 10 m height

- Reynolds shear stress in al three directions remain nearly constant for velocities larger than 5 m/s
- 5 m/s– critical velocity for Reynolds shear stress of the Bora wind?
- $-u'v'$ component has the most significant values
- Same trends for all height levels



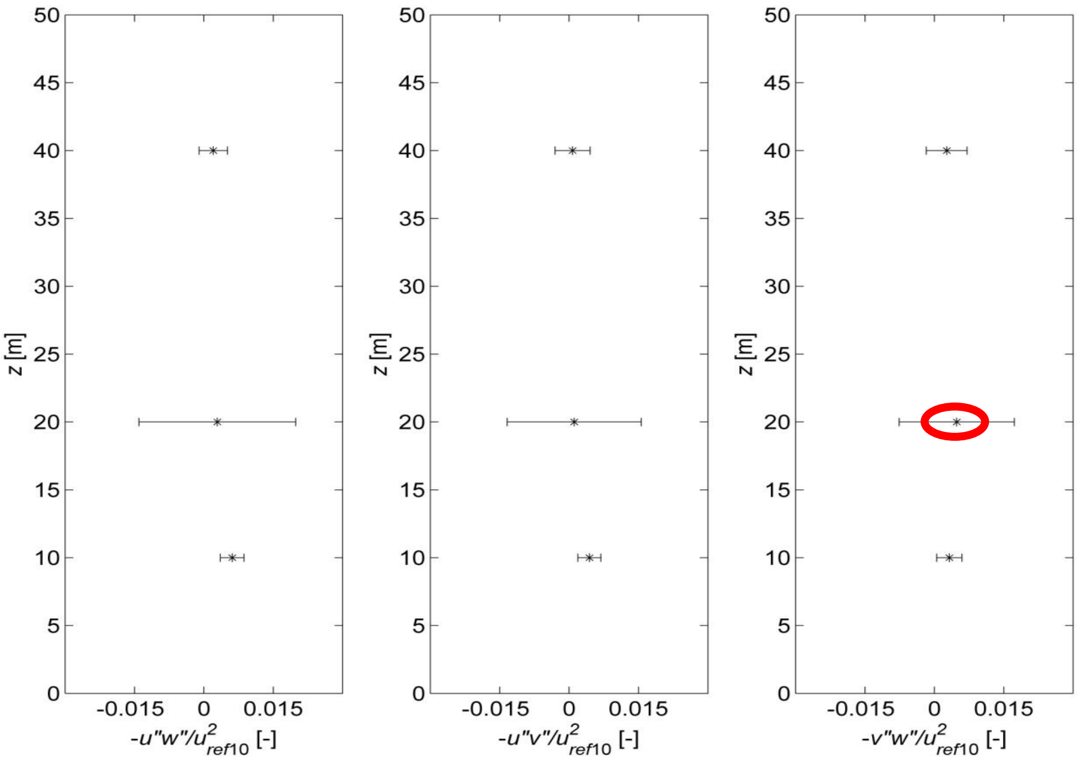
Turbulence intensity vertical profile

- All three components decrease with increasing height
- Vertical component weaker than the other two components
- Larger scattering of the data when higher from the ground



Reynolds shear stress vertical profile

- $-\overline{u'w'}$ $-\overline{u'v'}$ decrease with increasing height
- $-\overline{v'w'}$ on 20 m height larger than the values on other two levels? → at the moment no solid explanation, still working on this!
- Largest scattering on 20 m height level?



Concluding remarks

- Average velocity profiles of the Bora wind agree well with the power- and the logarithmic law
- The power- and the logarithmic law fit the data better when using the median (rather than arithmetic mean)
- Rural-like velocity profile for larger wind velocities, urban-like profile for smaller velocities
- Bora surface layer nearly neutrally stratified
- 5 m/s seems to be a critical velocity for the Bora wind

Concluding remarks

- Variations in velocity profiles at the same site during different wind periods are interesting for itself, as in the engineering community it has been commonly accepted that the aerodynamic characteristics at a particular site remain nearly the same during various wind regimes
- Future work:
- Bora turbulence at other locations, for different thermal stability conditions, seasons, elevations of measurement points….

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