TURBULENCE ANALYSIS OF LIDAR WIND MEASUREMENTS AT A WINDPARK IN LOWER AUSTRIA

Valerie-Marie Kumer[1,2], Vanda Grubišić[1,3], Manfred Dorninger[1], Stefano Serafin[1], Lukas Strauss[1], Rudolf Zauner[4]

[1]Department of Meteorology and Geophysics, University of Vienna. Austria, [2]Geophysical Institute, University of Bergen, Norway, [3]National Center for Atmospheric Research, Boulder, Colorado, [4]Verbund Renewable Power GmbH, Vienna, Austria

LiDAR

An increase in nacelle height and rotor diameter of wind turbines in recent years have made measurements of wind profiles via meteorological masts difficult. In response LIDAR remote sensing has become increasingly important. With this technique, wind information at different heights is easily accessible and enables an analysis of boundary layer processes.

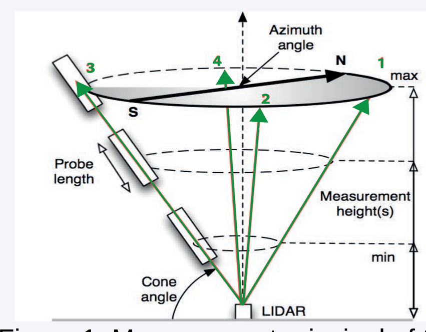

Figure 1: Measurement principal of the Doppler LIDAR WINDCUBE™ V1 [1]

Measurement Campaign

In this study we analyzed Doppler LIDAR measurements conducted in a field campaign at a wind park operated by VERBUND Renewable Power GmbH, near Bruck-an-der-Leitha (Lower Austria). A WINDCUBE™ V1 (WLS7) Doppler LIDAR collected data over a three-month period in summer 2010.

Measurement (analyzed) period	7.7. (25.8.) – 6.10.2010
Scanning technique	VAD
Data availability	70%

The device was located 2.5 rotor diameters (165 m) west of the wind turbine WEA4 (**W**ind**E**nergie**A**nlage) and around 10 rotor diameters (~ 660 m) southeast of the wind turbine WEA5 (figure 2a). As the wind rose in figure 2b shows, the device is capable of capturing the ambient flow, which is influenced by the large and small scale topography.

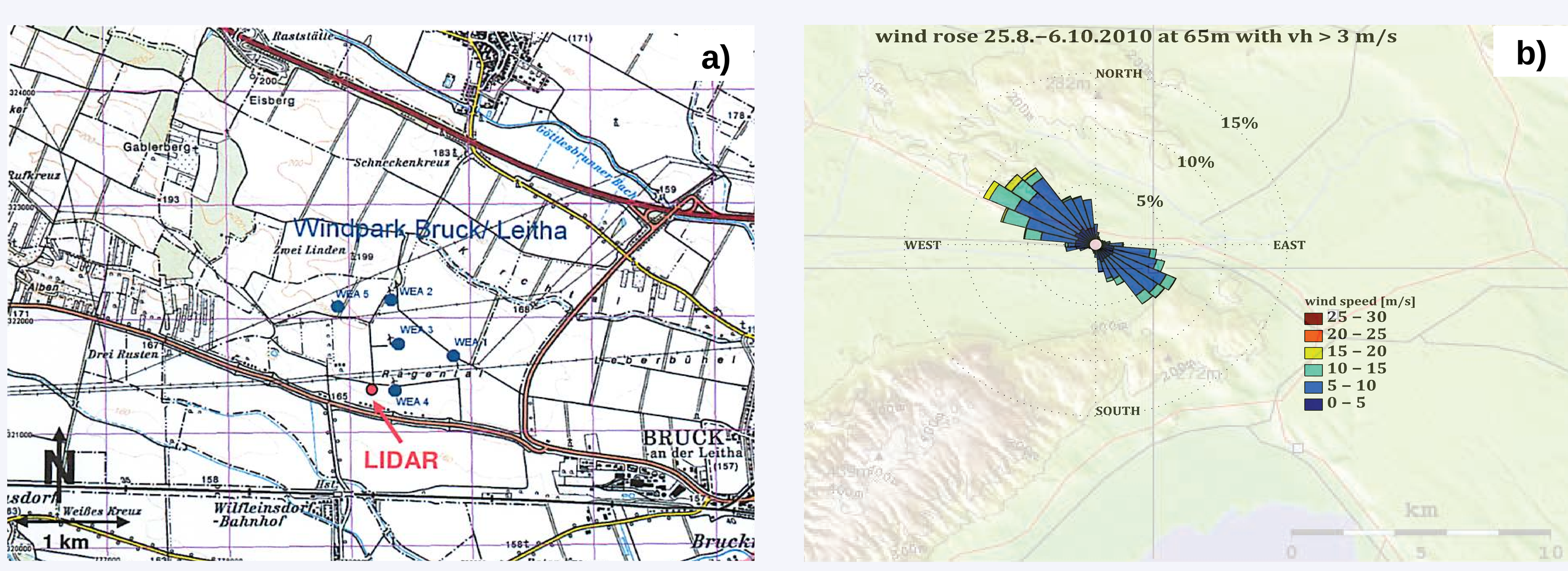

Figure 2: a) Map of the wind farm in Bruck an der Leitha with the location of the WINDCUBE™ in red and the wind turbine sites WEA1-WEA5 in blue [2]. b) Wind rose of horizontal wind speeds greater than 3 m/s collected by the WINDCUBE™, representing the analyzed period at the measurement height of 65 m.

Methods

Due to a high sampling rate of 0.25 Hz, so that calculations of variances and covariances of wind parameters are possible. This allows an analysis of turbulence through derived parameters such as turbulent kinetic energy (TKE) or turbulence intensity (TI), calculated as the following

$$TKE = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right) \qquad TI = \frac{\sigma(v_h)}{\overline{v_h}}$$

where u, v and w are the wind components, v_h is the horizontal wind speed and $\sigma(v_h)$ its standard deviation. The spectral energy gap [3] of u, v and w times series is used for a correct estimation of the turbulence scale (figure 3). On the basis of the momentum equations it is possible to calculate the tendency *T* of TKE [4]

$$T = -AD + B + S + TT + P - D$$

These terms are representing advection *AD*, buoyancy *B*, shear *S*, turbulent transport *TT*, pressure correlations *P* and dispersion *D* as the sources and sinks of TKE.

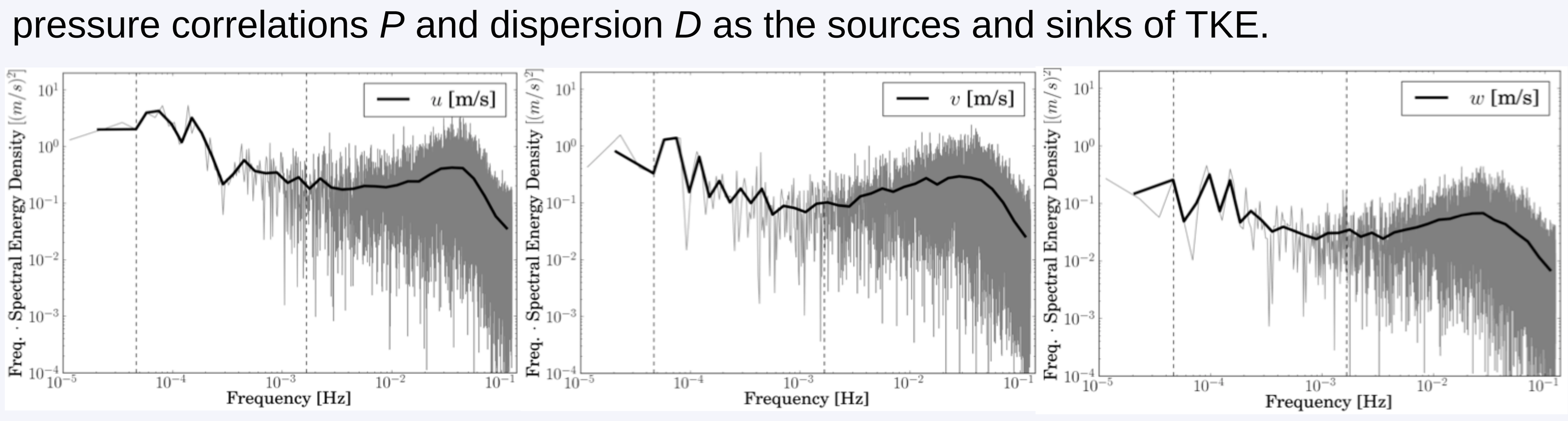

Figure 3: Spectral energy density times frequency plots of the wind components u, v and w on logarithmic axes at 65 m on September 25th 2010. The vertical black lines indicate the frequency of 6 h and 10 min.

Results

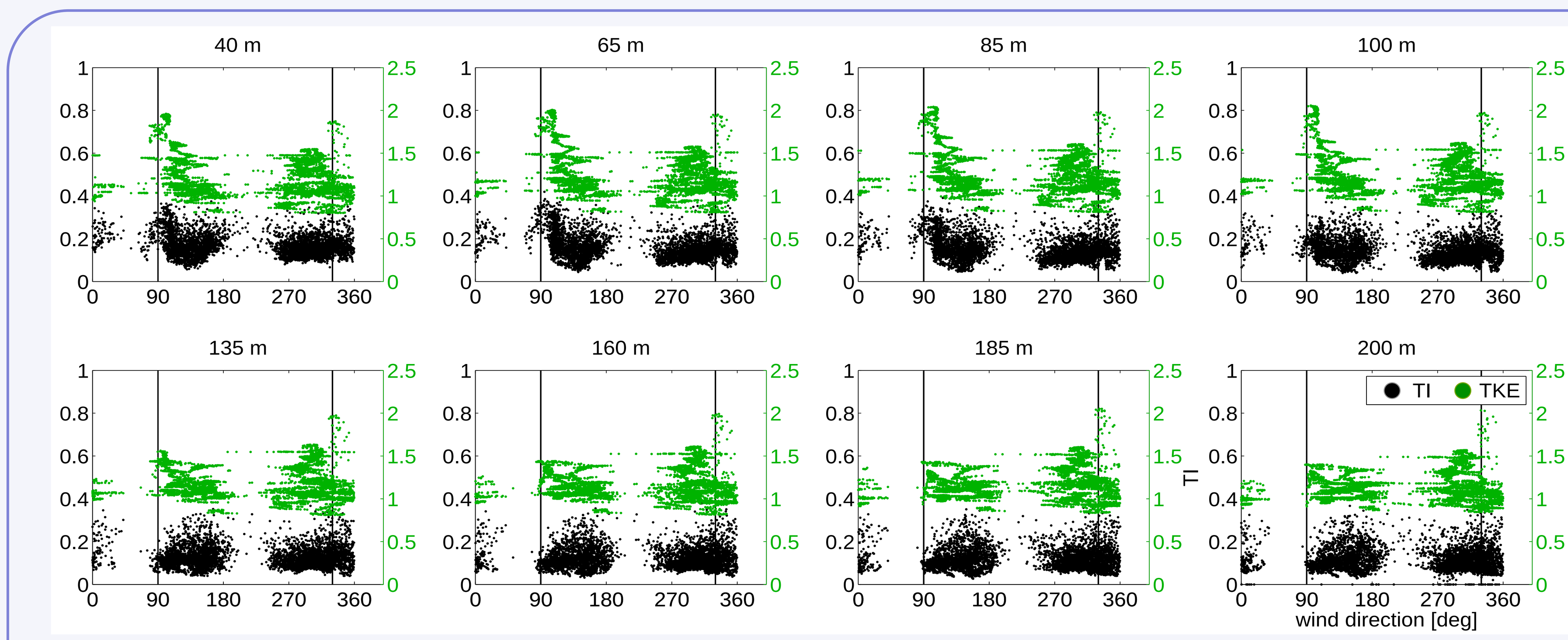

Figure 4: TI and TKE plotted in black and green as a function of wind direction, using the turbulence processed data set for wind speeds > 3 m/s. The vertical black lines at 90° and 330° indicate disturbed winds due to the wakes of WEA4 and WEA5.

- The turbulence distribution shows two wake signals for easterly and northwesterly winds (figure 4). These are consistent with the location of the WINDCUBE™ (figure 2a). The peaks at 90° vanish at measurement altitudes above blade tip height (100 m) in contrast to the ones at 330°. This indicates the wake expansion of WEA5.
- As TKE reproduces the same information as TI, it enables due to its tendency equation a more detailed analysis of turbulence.

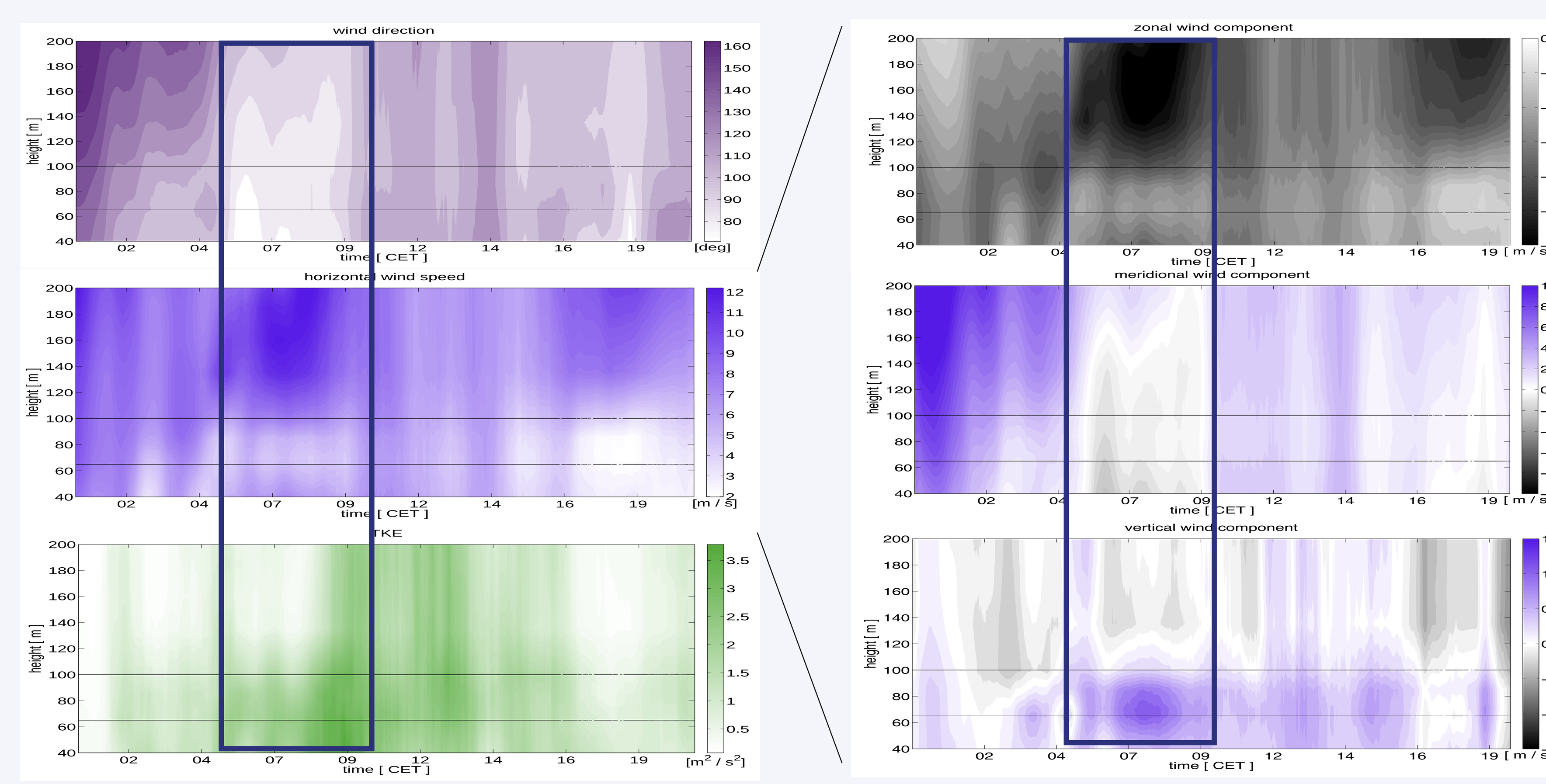

Figure 5: Contour plots of wind direction, horizontal wind speed, TKE (left) and wind components u, v and w (right) profiles during the wake case of September 25th 2010. The purple boxes and black horizontal lines indicate the period during which the device was inside the wake region and hub and blade tip height respectively.

- A case study of September 25th 2010 proofs, LIDAR data is capable of resolving wake effects downstream of the wind turbine WEA4, indicated through a wind speed deficit and increased values of TKE (figure 5). Upwelling motion of the order of 1 m/s, as well as flow reversal in the meridional wind component above the blade tip height support the theoretical approach of helicoidally wake structures [5] and are comparable to results provided by laboratory experiments published by Zhang et al. [6].
- In terms of turbulence generation a maximum in vertical shear generation around the blade tip height shows compared to the other end of the rotor disk irregular loads. This turbulence maximum at blade tip height was also captured by field experiments by Iungo [7].
- The wake represents a high energy loss as TKE takes almost 22% of the whole available kinetic energy in the considered case study [8].

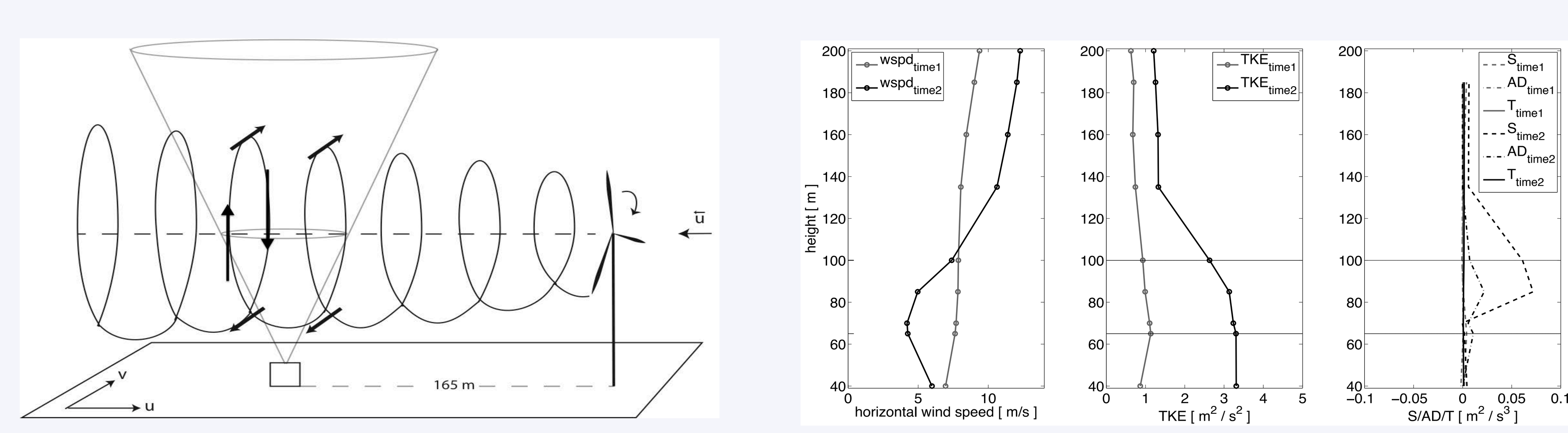

Figure 6: a) Sketch of the wake structure and derived wind pattern captured by the device. b) Vertical profiles of wind speed, TKE and TKE budget terms for time1 = 00 CET and time2 = 09 CET on September 25th 2010. Horizontal heights indicate the blade tip and hub height.

Conclusion & Outlook

A detailed turbulence analysis is possible with LIDAR wind data from a WINDCUBE™ V1, leading to a quantitative description of the wake region. Anisotropic turbulence distribution indicates a dominating shear generation. The maximum shear induced turbulence is located around blade tip height an leads to irregular loads on the rotor blades. Considering this knowledge in the operation of wind parks is crucial for the operators as it could lead to more efficient lifetime power production of wind farms. Moreover the gained information can be used for optimizing layouts of new wind farms as well as for intelligent operation of already existing ones. This work will be continued at the University of Bergen, using a scanning Doppler LIDAR for further investigations.

References

[1] Clifton A. et al (2012), 1. Ground-Based Vertically-Profiling Remote Sensing for Wind Resource Assessment, IEA wind; [2] Koller S. (2010), Technical Report, Meteotest; [3] Van der Hoven I.(1957), Power spectrum of horizontal wind speed in the frequency range from 0.0007 to 9000 cycles per hour, Journal of Meteorology; [4] Markowski P. et al (2010), Mesoscale Meteorology in Midlatitudes, Wiley-Blackwell; [5] Tong W. (2010), Wind Power Generation and Wind Turbine Design., WIT Press; [6] Zhang W. et al (2012), Near-wake flow structure downwind of a wind turbine in a turbulent boundary layer, Experimental Fluids; [7] Iungo G.V. (to be published), Field measurements of wind turbine wakes with LiDARs, Journal of Atmospheric and Oceanic Technology; [8] Kumer V. (2012), Analysis of Lidar Wind Measurements at a Bruck an der Leitha Wind Park, Diploma thesis at Univeristy of Vienna

DeepWind'2013 10th Deep Sea Offshore Wind R&D Conference

DeepWind 2013

24. – 25.1.2013, Trondheim, Norway

Kumer valerie.kumer@gfi.uib.no Grubišić vanda.grubisic@univie.ac.at

Reuder joachim.reuder@gfi.uib.no Zauner rudolf.zauner2@verbund.com