

CFD MODELING OF THE VERTICAL WIND PROFILE AND THE TURBULENCE STRUCTURE ABOVE COMPLEX TERRAIN AND VALIDATION WITH SODAR AND LIDAR MEASUREMENTS

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ABSTRACT

Vertical profiles of wind speed and turbulence intensity were modeled with the CFD model WindSim for two sites in medium complex terrain in Maligrad/Bosnia and Rudine/Croatia. The results were validated against SODAR and ZephIR-LIDAR measurements. At both sites met masts (30 m at Maligrad and 50 m at Rudine) provided anemometer data. Both measurement campaigns were carried out at sites where the winds are known to be sometimes very strong and turbulent, in particular the so called Bora, a gusty wind from north to north-east.

One goal of the campaigns was to examine the performance of SODAR and LIDAR instruments under harsh meteorological conditions. SODAR and LIDAR showed very good performance with high data availability up to 100 m.

For comparison the vertical profiles of WindSim, SODAR and ZephIR-LIDAR were normalised to 30 m/50 m for twelve 30° wind direction sectors. The normalised vertical wind speed profiles of SODAR, LIDAR and WindSim showed good agreement especially for the prevailing wind directions. Vertical profiles of wind speed showed only small increase with height for the prevailing wind directions north north-east and south south-east.

Turbulence intensities calculated from SODAR and LIDAR measurements showed different values as a result of different sampling rates. Furthermore, turbulence intensities calculated by WindSim showed a weak decrease with height in contrary to the almost constant vertical turbulence intensity profiles of the SODAR and LIDAR measurements between 30 m and 100 m. Turbulence intensities remained below class A of the IEC 61400.

1. INTRODUCTION

The South East Europe Wind Energy Exploitation (SEEWIND) project [1], embedded in the 6th framework program of the European Commission, aims to gain experience in wind measurements, site development and operation of wind turbines in complex terrain. In order to get information about the vertical wind profile at two Bora-dominated sites in Bosnia and Croatia, SODAR and LIDAR measurements were carried out. Bora is a strong katabatic wind from north to north-east. Knowledge of the vertical wind profile and the turbulence intensities on Bora dominated sites will provide important information on the impact on a wind turbine operating under such conditions.

This study investigates vertical wind speed profiles and turbulence intensities at Maligrad (Bosnia) and Rudine (Croatia), two Bora dominated site in the West Balkan area and evaluates the performance of the CFD modeling software WindSim [2] regarding the vertical profiles of wind speed and turbulence intensities.

2. SITE DESCRIPTION

2.1 Maligrad/Bosnia

The first measurement site, Maligrad in Bosnia (Figure 1 and Figure 2), was located on the high plateau Podvelez approximately 5 km east of the city of Mostar in Bosnia. The instruments were installed at a height of 730 m asl. To the east there are two other hills reaching up to 880 m asl and 1'060 m asl, respectively. A mountain chain Velez (1'800 m asl) overshadows the site Maligrad further east. To the north north-west, west and south-west, the terrain lowers down to around 50 m asl in Mostar. The prevailing wind direction at Maligrad is north north-east (Bora). Wind speeds are very variable and can easily reach 20 m/s at 30 m height. Figure 3 shows the wind rose and the wind speed distribution including the approximated Weibull distribution at 30 m height for Maligrad.

2.2 Rudine/Croatia

The second measurement site, Rudine in Croatia (Figure 2), was located on a high plateau on the mainland of Croatia, about 35 km north-west of Dubrovnik, approximately 380 m above sea level. The region is dominated by Karst and only low vegetation and the terrain can be described as medium complex. The prevailing wind directions at Rudine are north north-east (Bora) and south south-east (Jugo). Wind speeds are also very variable. Wind speeds above 20 m/s at 50 m height have been observed occasionally. Figure 4 shows the wind rose and the wind speed distribution including the approximated Weibull distribution at 50 m height for Rudine.



Figure 1: The measurement site Maligrad with the SODAR (left) and the ZephIR-LIDAR (right).

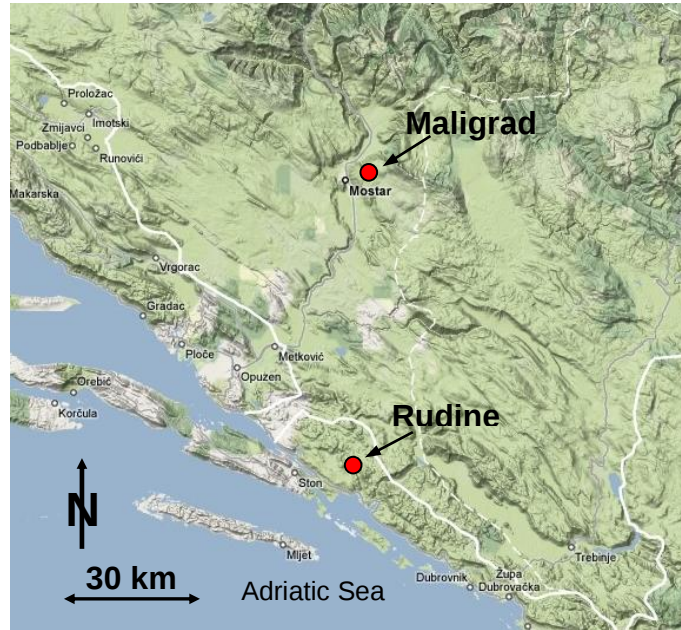


Figure 2: The measurement sites Maligrad in Bosnia and Rudine in Croatia.

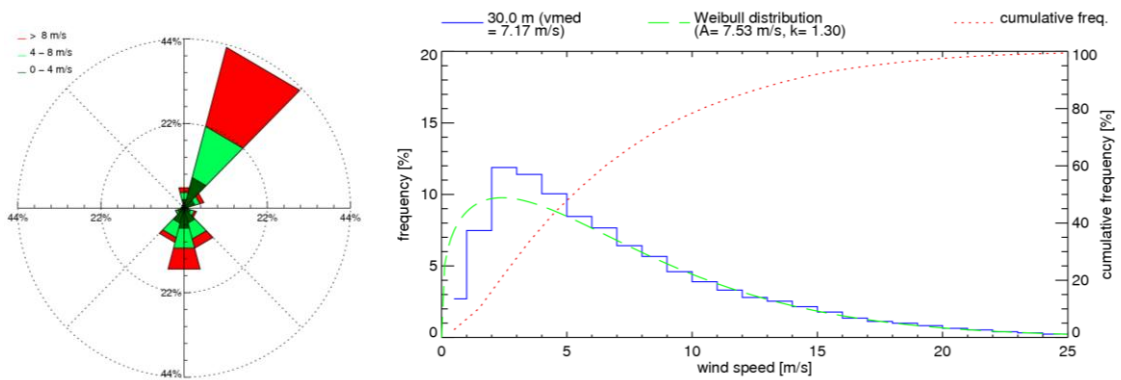


Figure 3: Wind rose and wind speed frequency distribution including approximated Weibull distribution at 30 m height (most measurement) for Maligrad.

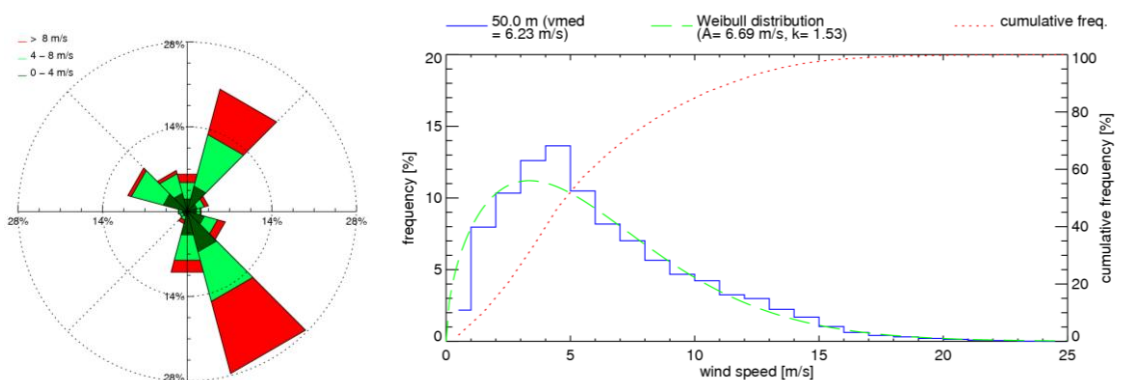


Figure 4: Wind rose and wind speed frequency distribution including approximated Weibull distribution at 50 m height (most measurement) for Rudine.

3. INSTRUMENTATION AND DATA BASE

Wind speed and wind direction data were provided by a 30 m mast at Maligrad and a 50 m mast at Rudine. Mast data were cleaned and corrected for long term conditions by the SEEWIND partner DEWI [3]. The installed SODAR was of type Aerovironment miniSODAR 4000F and the measurement heights ranged from 30 m to 150 m with 10 m intervals. The measuring rate was approximately 0.33 Hz and the averaging interval 10 minutes. The LIDAR was of type ZephIR [4]. The measuring rate was approximately 0.05 Hz and the averaging interval 10 minutes. The instruments' configurations and the measurement periods of masts, SODAR and ZephIR-LIDAR are summarized in Table 1 and 2.

Table 1: Instruments' configuration and measurement period at Maligrad.

	measurement heights of wind speed	measurement heights of wind direction	measurement periods
30 m mast , cup anemometers	12 m; 30 m	30 m	2006 – 2008
SODAR (Aerovironment 4000F miniSODAR, ASC)	30 m to 150 m with 10 m resolution	30 m to 150 m with 10 m resolution	30 Oct '07 – 4 Feb '08
LIDAR (ZephIR, Natural Power)	30 m; 60 m; 80 m; 100 m; 150 m	30 m; 60 m; 80 m; 100 m; 150 m	21 Nov '07 – 10 Dec '07

Table 2: Instruments' configuration and measurement period at Rudine.

	measurement heights of wind speed	measurement heights of wind direction	measurement periods
50 m mast , cup anemometers	30 m; 50 m	30 m	2007 – 2009
SODAR (Aerovironment 4000F miniSODAR, ASC)	30 m to 150 m with 10 m resolution	30 m to 150 m with 10 m resolution	12 Feb '08 – 5 May '08
LIDAR (ZephIR, Natural Power)	30 m; 50 m; 80 m; 100 m; 150 m	30 m; 50 m; 80 m; 100 m; 150 m	9 Apr '08 – 5 May '08

4. CFD MODEL WINDSIM

WindSim [2] is a CFD-package for micrositng based on the CFD solver Phoenixics. The CFD simulations are based on the integration of Reynolds Averaged Navier-Stokes (RANS) equations over a portion of the lower atmosphere. The RANS equations are discretised on a computational grid and integrated with a finite-volume procedure. Turbulence is calculated using the standard k-epsilon turbulence model which allows closing the set of equations. WindSim is able to assess wind resources with a high degree of accuracy. Even terrain with fairly complex features can be processed with WindSim. Three primary inputs are necessary to run WindSim, first a digital elevation model, second a roughness map and third a wind climatology. All these data sets were compiled and provided by the SEEWIND partner DEWI [3] for Maligrad and Rudine. WindSim offers the possibility to extract vertical profiles of various parameters for each modeled height and sector, for example for wind speed and turbulence intensity. The values of the vertical WindSim profiles are only relative values which have to be scaled with a climatology.

5. METHODS

5.1 Vertical Wind Speed Profiles Vertical wind speed profiles of SODAR and LIDAR measurements are only analysed qualitatively in this study, which means that only normalised data sets are compared. Wind speed profiles from both instruments are analysed for twelve 30° wind direction sectors. Furthermore normalised vertical wind speed profiles of the WindSim model output are validated using LIDAR measurements.

5.2 Vertical Turbulence Intensity Profiles

Turbulence intensities (TI) from SODAR and LIDAR measurements are evaluated by calculating the ratio of the standard deviation wind speed (σ_{u_i}) to the mean wind speed (U) according to the following formula: $TI = \sigma_{u_i}/U$. Only wind speeds above 4 m/s are considered. As a

consequence of the different sampling rate of SODAR and LIDAR, standard deviations cannot be compared quantitatively. Finally, vertical profiles of the turbulence intensities calculated by WindSim are verified using LIDAR measurements.

6. RESULTS

6.1 Vertical Wind Speed Profiles

Comparison of SODAR and ZephIR-LIDAR Measurements

Figure 5 shows the vertical wind speed profiles from SODAR and LIDAR measurements for the main wind direction north north-east (Bora) for different wind speed classes for Maligrad and Rudine. The data sets are normalised to 30 m (Maligrad) and 50 m (Rudine) height. The increase of the mean wind speed from 30 to 100 m is in general small for this wind direction. For wind speeds above 4 m/s the profile shape is independent to the wind speed at both studied sites. The outlier in the SODAR profile of Rudine at 40 m height is probably a result of an echo during data collection.

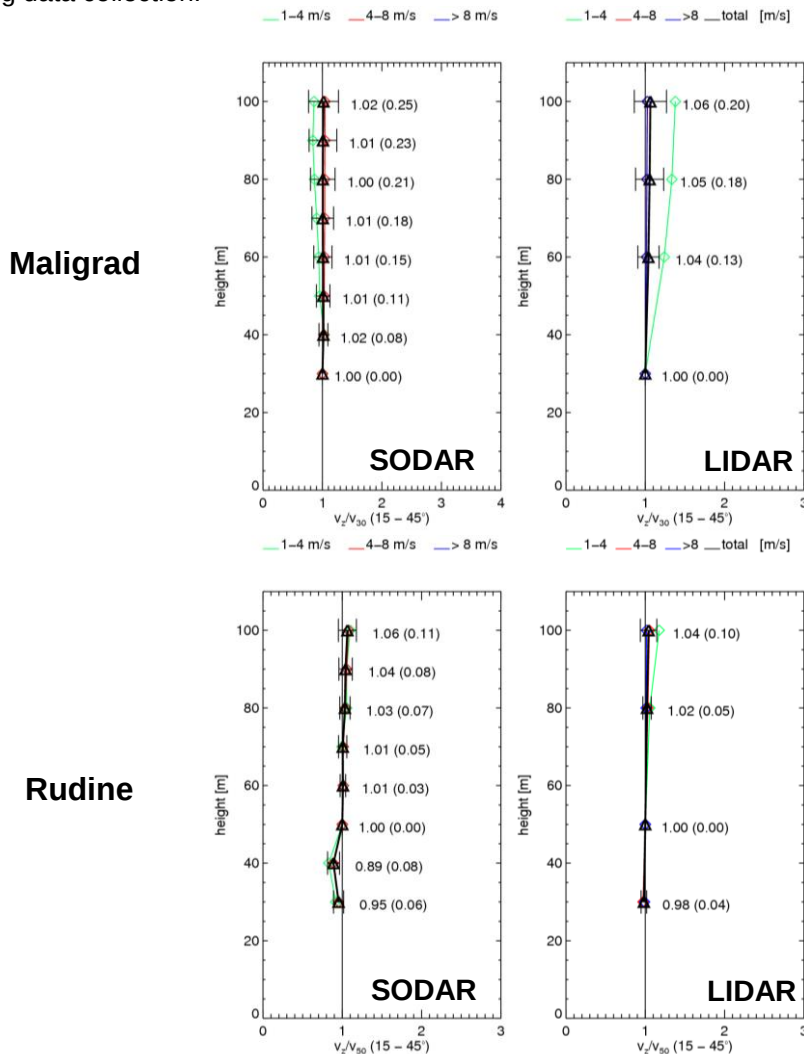


Figure 5: Vertical wind speed profiles from SODAR and ZephIR-LIDAR normalised to 30 m (top, Maligrad) and 50 m (bottom, Rudine) for the wind direction NNE (15°–45°) and for three wind speed classes; in brackets the standard deviation.

Comparison of ZephIR-LIDAR Measurements with WindSim

The vertical levels of the WindSim model output do not agree with the measurement levels of the LIDAR. For comparison reason the wind speed data of the WindSim output level from 25 m was interpolated linearly to 30 m for Maligrad. For Rudine, the 54 m level was interpolated linearly to 50 m. The model output data are normalised to these interpolated values. In Figure 6 the vertical wind speed profiles, normalised to 30 m/50 m, from LIDAR measurements and WindSim model are compared for the main wind direction north north-east (Bora). At Maligrad, the WindSim profile agrees well with the measurement. However at Rudine the WindSim result shows an increase of about 10% from 50 m to 100 m compared to the measured increase of 4% with LIDAR.

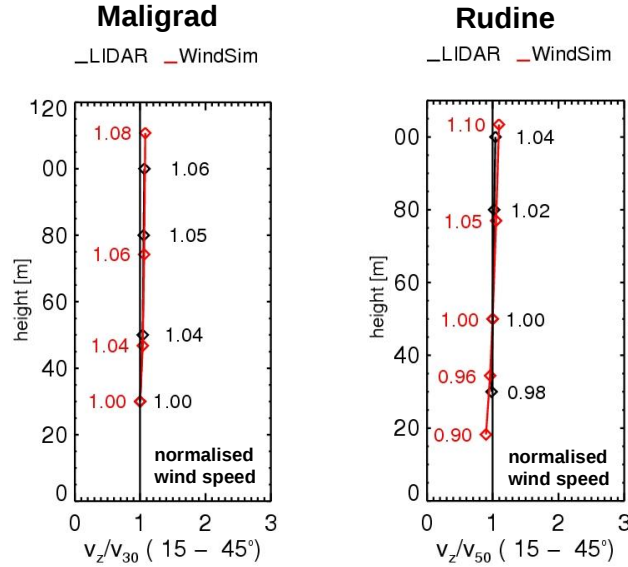


Figure 6: Comparison of vertical wind speed profiles from WindSim (red) and ZephIR-LIDAR (black) normalised to 30 m (left: Maligrad) and 50 m (right: Rudine) for the wind direction NNE (15°–45°).

6.2 Vertical Turbulence Intensity Profiles

Comparison of ZephIR-LIDAR and WindSim Turbulence Intensities

Figure 7 shows the turbulence intensities derived from LIDAR measurements and WindSim calculations for the wind direction north north-east (Bora). LIDAR turbulence intensities are calculated only for wind speeds above 4 m/s. In the WindSim output, a decrease of the turbulence intensity with height is visible while the LIDAR measurements show a constant turbulence intensity profile.

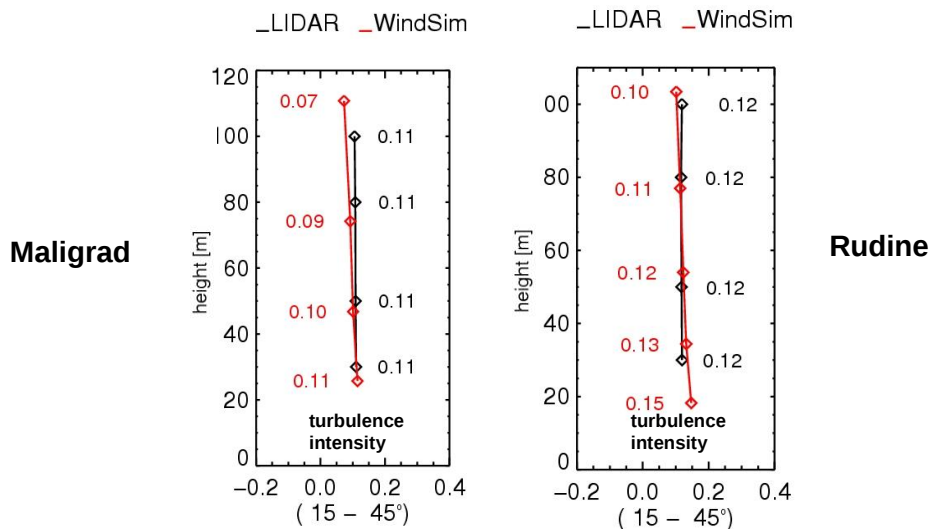


Figure 7: Vertical profiles of turbulence intensities for the wind direction NNE (15°–45°) at Maligrad (left) and Rudine (Rudine) from ZephIR-LIDAR measurements (black) and WindSim calculations (red). Turbulence intensities were calculated only for wind speeds above 4 m/s.

7. CONCLUSIONS

7.1 Bora dominated sites

- Good performance of SODAR and ZephIR-LIDAR in spite of harsh climatic conditions
- Maligrad: only one dominant wind direction
- Rudine: two dominant wind directions
- Maligrad and Rudine: nearly constant vertical wind profile up to 100 m height for sector NNE (Bora!)
- Maligrad and Rudine: nearly constant vertical turbulence intensity profile up to 100 m height for sector NNE (Bora!)
- More investigations of the temporal evolution of Bora events are needed

7.2 SODAR - LIDAR - WindSim:

- Good agreement of SODAR, LIDAR and WindSim normalised vertical wind speed profiles
- Differences in the absolute values of SODAR and LIDAR turbulence intensities (not shown in this study, see [5])
- WindSim calculations show decreasing vertical turbulence intensity profiles in contrast to the constant vertical turbulence profiles measured with SODAR and ZephIR-LIDAR
- Evaluation of turbulence intensity from SODAR and ZephIR-LIDAR data sets needs clarification

ACKNOWLEDGEMENTS

The measurement campaigns at Maligrad and Rudine were financed by the 6th Framework Program of the European Commission and the local project developers Vjetroenergetika BH and Adria Windpower.

REFERENCES

- [1] SEEWIND, <http://www.seewind.org/> (5.3.2009)
- [2] WindSim, <http://www.windsim.com/> (5.3.2009).

- [3] DEWI, GmbH, Deutsches Windenergie-Institut
- [4] LIDAR ZephIR, <http://www.naturalpower.com/zephir-laser-anemometer> (5.3.2009)
- [5] CFD Modeling of the Vertical Wind profile and the Turbulence Structure above Complex Terrain and Validation with SODAR and LIDAR Measurements. DEWEK 2008, S. Bourgeois, R. Cattin, H. Winkelmeier, I. Locker.