COMPARASION OF WIND MEASUREMENTS BY LIDAR AND MEASUREMENT MAST FOR BORA WIND IN BOSNIA AND HERZEGOVINA

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ABSTRACT

Research of wind energy potential with the aim of installing wind turbines was performed on location Hrgud in the southeastern part of Bosnia and Herzegovina. These are complex terrains characterized by specific wind Bora. Measurements were performed by standard procedures using the classical standard instruments, anemometers and wind vanes, mounted at different heights on the measurement mast height of 77.5 m (agl) combined with remote sensing technique such as the LIDAR (LIght Detection And Ranging) during period 23.8. 2013. – 19.12. 2013. The aim of this study was to perform an analysis and comparison of collected measurement data from the measurement mast and the LIDAR (Windcube v2 FCR), as well as the behavior of the equipment itself in the complex terrain and wind Bora conditions in Bosnia. During the comparison the 10-min averaging time for the wind speed and direction is used. It can be concluded from this analysis that the behavior of the LIDAR under harsh local weather conditions was relatively well, except the problems with the power supply. The LIDAR uncorrected wind speed was in general lower than the wind speed measured by the cup anemometer at the same height. The comparison of the data of measurement methods provides reliable information on the wind speed within the considered altitude range.

Keywords: wind energy, LIDAR, wind Bora, Bosnia

1. INTRODUCTION

The first measurements with adequate equipment and technology aimed at determining of the wind energy potential in Bosnia started in 2002 at the location of Podveležje (Mostar). Thanks to analysis of data from different measurements campaigns the area of south Bosnia and Herzegovina has been recognized as an interesting region for wind power production. At the moment, it is impossible to discuss precisely about the real potential for the wind farm construction. Research is still incomplete and limited by the complexity of terrain and by the wind Bora. The Bora is a strong cold katabatic wind which mostly blows from north to north – east, starts suddenly and decelerate slow. There are anti - cyclonal (dry) and cyclonal (with clouds) Bora. Furthermore, there are several conditions needed for Bora (mountain massifs, different values of temperature and pressure in the heights and lowlands, etc.). Also, there has not been enough studies or research conducted on Bora in Bosnia and Herzegovina. According to the rough estimation, the economically feasible potential should be around 1 000 – 1 200 MW (Zlomušica & Behmen, 2003; Ćatović, Behmen, & Zlomušica, 2004; Zlomušica, 2010). In any case, it would be a success to install 50 MW before the year of 2015 (Zlomušica, 2013).

Detailed knowledge of the wind resource is necessary in the developmental and operational stages of a wind farm site (International Standard, IEC 61400-12-1 Ed. 1., 2005). As wind turbines continue to grow in size, measurement masts for mounting cup anemometers (the standard procedure for wind resource assessment) have become much taller, and much more expensive.

The LIDAR is ground-based and can work over one hundred of meters, sufficient for the tall wind turbines. The use of LIDAR in complex terrain is very attractive for wind site assessments since a grinding installation of a high mast can be avoided. The measurement campaigns in some projects showed very promising results (Albers, Janssen, & Mander, 2008; Bingöl, Mann, & Foussekis, 2008; Bourgeois, Cattin, Locker, & Winkelmeier, 2008; Bourgeois, Cattin, Winkelmeier, & Locker, 2009; Krishnamurthy, Boquet, & Machta, 2014). Some strengths of the LIDAR are: relatively easy to deploy, still some fingering with cables and tubes, installed by one or two persons in half a day, withstanding harsh climatic conditions, low power consumption and no noise, while some weaknesses of the LIDAR are: uncertainty of accuracy of wind speed data in complex terrain, very expensive high-tech instrument, affected by rain and low clouds.

However, to the present day it is not recommended to use a LIDAR as a stand alone instrument for accurate wind measurements. More validation studies and comparisons are needed and data retrieval algorithms (vertical wind speed, turbulence) have to be improved. Furthermore, the assumption of a homogeneous flow field used by the LIDAR technology has to be considered in the data analyses, especially in complex terrain. In the next period the standard (IEC 61400-12-1 Ed. 1., 2005) is expected to be changed, and a new standard will include remote sensing techniques like the LIDAR.

The aim of the work is to compare the wind measurements from commercial LIDAR instrument against an instrumented mast, in complex terrain, where many wind farms are now being installed worldwide, as well as equipment behavior under harsh meteorological conditions at the locality of Hrgud (southeast of Bosnia and Herzegovina). This equipment has been used first time in Bosnia and Herzegovina. Measurements performed during the summer-fall period of 2013 in the duration of four months.

2. METHOD AND MATERIALS

A four-months measurement campaign with an LIDAR and 78.5 m mast, which provided also has long term data, for evaluating the remote sensing instruments, was performed. The LIDAR was connected directly to the electrical grid via the local power line. However this power line has been hit by lightings several times during the measurement campaign, which has destroyed the 220V to 24V LIDAR convertor.

2.1 Site description

The measurement site called Hrgud in Bosnia and Hercegovina is situated approximately 35 km southeast of the city of Mostar or 5 km east from the town of Stolac, 10 - 11 km west from the town of Berkovići, 50 km east from the Adriatic sea coast, Figure 1. The area can be categorized as complex, with altitudes varying between 960 to 1110 m asl (above sea level) and is approximately 5 km^2. A southeast – northwest fault delimiting the plateau is characterised with a very steep slope, which have a significant influence at the wind flow at the site. The terrain is characterized by karsts with small meadows, bushes and low forest vegetation.

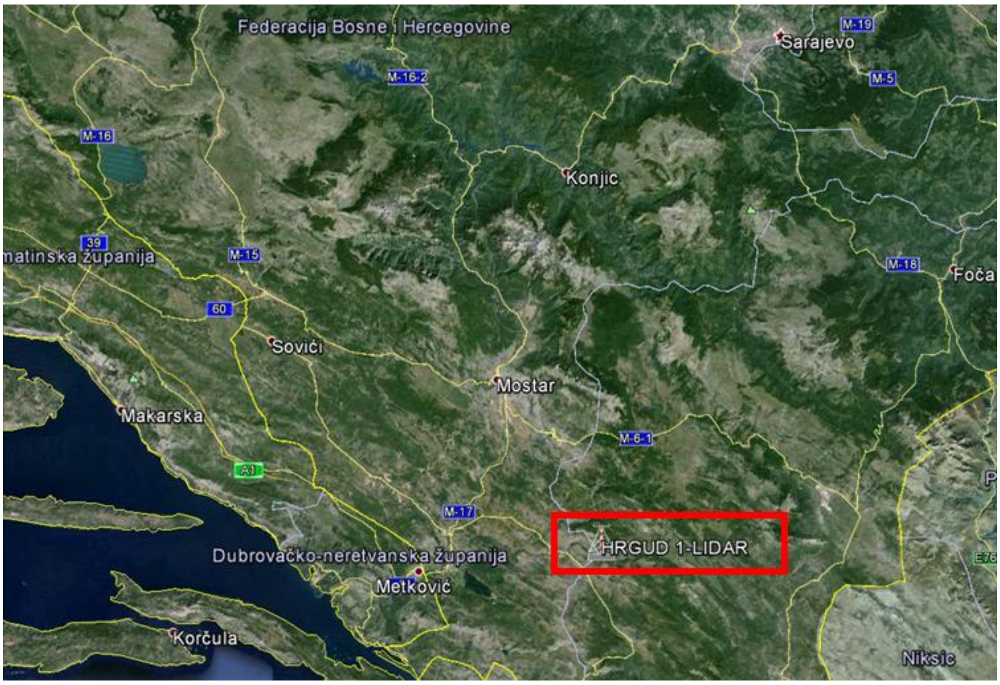

Figure 1. Location of the Hrgud site in Bosnia and Herzegovina

Figure 2 shows the wind rose (frequency) for the Hrgud site of filtered data at 77.5 m agl for the met mast at Hrgud site. The met mast was installed according to the standard IEC 61400-12-1 (IEC 61400-12-1 Ed. 1., 2005) and MEASNET (Measuring Network of Wind Energy Institutes) (Measnet, 2009). It can be seen that the prevailing wind directions are NNE and SSE and consequently the most of the wind energy comes from these directions.

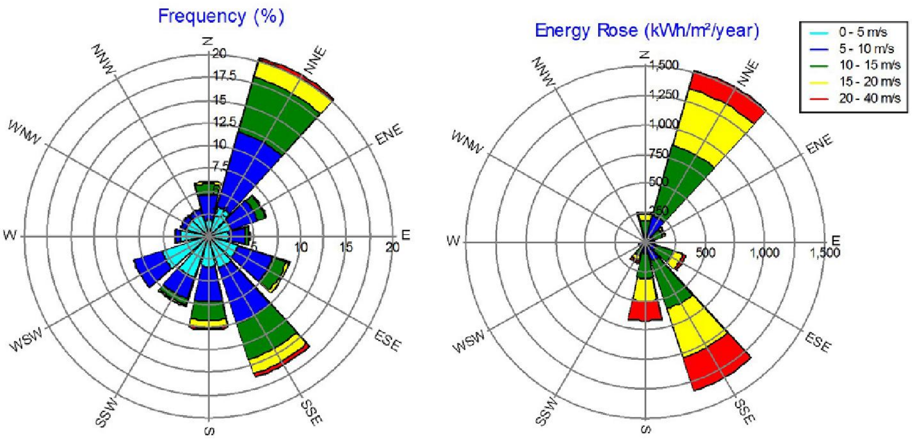

Figure 2. Frequency and energy roses at 77.5 m for the 12 months of wind data at the met mast Hrgud

Site conditions parameters for the met mast height 77.5 m are: max 10-min. measured wind speed is 31.4 m/s, max 3-sec. measured wind speed is 38.7 m/s, annual mean temperature is 10.2 °C, annual min. temperature is –10 °C and annual mean air density is 1.083 kg/m^3 (Impro-Impex & COWI, 2013).

2.2 Measurement configuration

The instruments were installed at a height 1098 m asl. The instruments site coordinates are X: 258 392, Y: 4 776 046 of UTM WGS84 projection, according to the resolution of the GPS device. The instruments were located on 100 m high hill about 1.5 km North of a 1000 m deep and 2 km wide canyon. The hill is about 1 km long and 100 m wide, oriented E-W.

The LIDAR was positioned approximately 1.5 m from measuring mast, Figure 3. The sensor height in the LIDAR is 1 meter above mast ground level. Therefore 1 meter shall be added to the entered heights to get the actual measuring height. The LIDAR measurement started on 23 August 2013. The system consists of a Windcube v2 LIDAR, set up to measure the windspeed at 10 different heights. The LIDAR is powered by 220 V supplied from the commercial grid. Data from the LIDAR shall be used as supplement to data from Hrgud mast (as long term data), in order to give a better assessment of the wind conditions on the site.

Figure 3. The measurement site Hrgud, LIDAR (left) mast (right)

Windcube v2 LIDAR equipped with FCR (Flow Complexity Recognition) for direct wind measurements in complex terrain was used in this campaign. The height range of this instrument is from 40-200 m, data sampling rate is 1 sec.
In Table 1 the measurement configuration and measurement periods of the met mast and the LIDAR are shown.

Table 1. Measurement configuration

	Measurement height of wind speed (m)	Measurement height of wind direction (m)	Measurement period
Mast, cup anemometers, Thies Classic, wind vanes Thies Compact	30; 55; 55; 75; 77.5	53 and 75	30 July 2012 – up to date
LIDAR Windcube v2	44; 54; 64; 74; 77; 79; 89; 119; 129; 159	44; 54; 64; 74; 77; 79; 89; 119; 129; 159	23 August 2013 – 19 December 2013

3. RESULTS

3.1 Analyse of the data availability

The analyzed period for this study started 23 August 2013 and ended 19 Decebmer 2013. The time series of the wind speed measured with the top cup anemometer at 77.5 m and the LIDAR with and without FCR at 78 m are displayed in Figure 4.

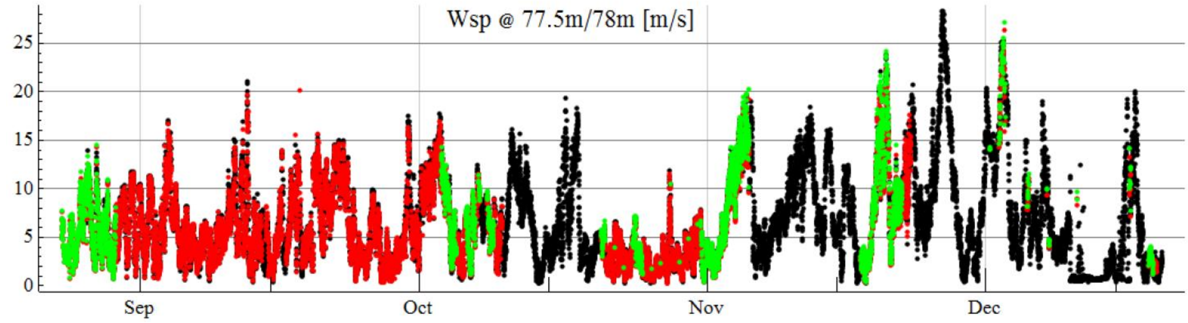

Figure 4. Time series of the wind speed measured with the top cup anemometer (black), the LIDAR without correction (red) and the LIDAR with FCR (green)

The LIDAR measurements were interrupted several times during measuring campaing. The main events causing interruption in the measurements are summarized in Table 2.

Table 2. Periods improper functioning of the LIDAR

Beginning	End	Explanation
29.8.2013	3.10.2013	FCR accidentally turned off
9.10.2013	20.10.2013	Power supply damaged by lighting
20.10.2013	23.10.2013	Complete std data files, but incomplete FCR files (only 1 value/day)
25.10.2013	30.10.2013	Complete std data files, but incomplete FCR files (only 1 value/day)
5.11.2013	17.11.2013	Power supply damaged by lighting
23.11.2013	23.11.2013	End of reliable measurements; LIDAR system damaged by lighting

Much more LIDAR uncorrected wind speed data (non-corrected for the terrain effect) were collected than FCR corrected data.

3.2 Comparison of the measured wind speeds

The comparison of the measured wind speeds between the cup anemometer at 77.5 m and the uncorrected LIDAR measurements and the FCR corrected LIDAR data at 78 m, respectively, for the same dataset is shown in Figure 5 and Figure 6 with scatterplots and the evaluated regression and correlation coefficients.
Dataset including uncorrected LIDAR wind speed data with an availability above 80% (Red: two parametric linear regression; Blue: one parametric linear regression forced through 0).The uncorrected LIDAR wind speed measurements underestimate the cup anemometer by 4.1% on average, Figure 5.

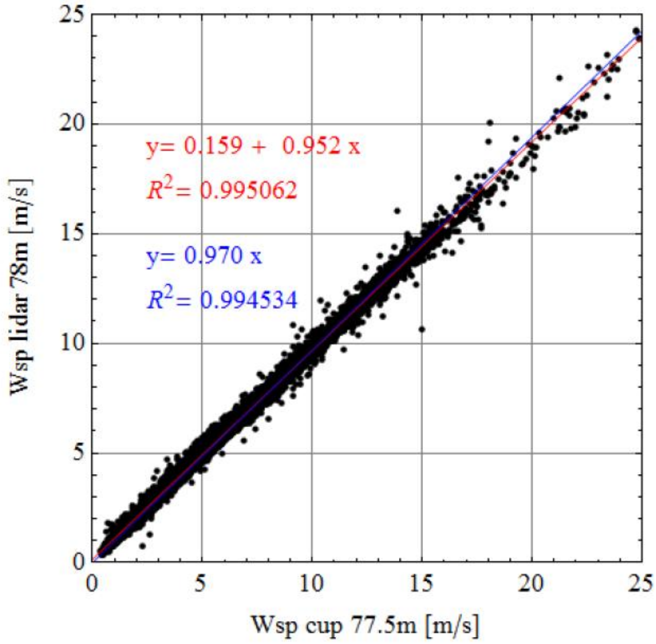

Figure 5. Uncorrected LIDAR wind speed at 78 m vs cup anemometer wind speed at 77.5 m

The FCR corrected LIDAR wind speed measurements overestimate the cup anemometer by 1.5% on average. The correlation coefficient is higher for the FCR corrected data than for the uncorrected measurement. Dataset including FCR LIDAR wind speed data with an availability above 80% (Red: two parametric linear regression; Blue: one parametric linear regression forced through 0), Figure 6.

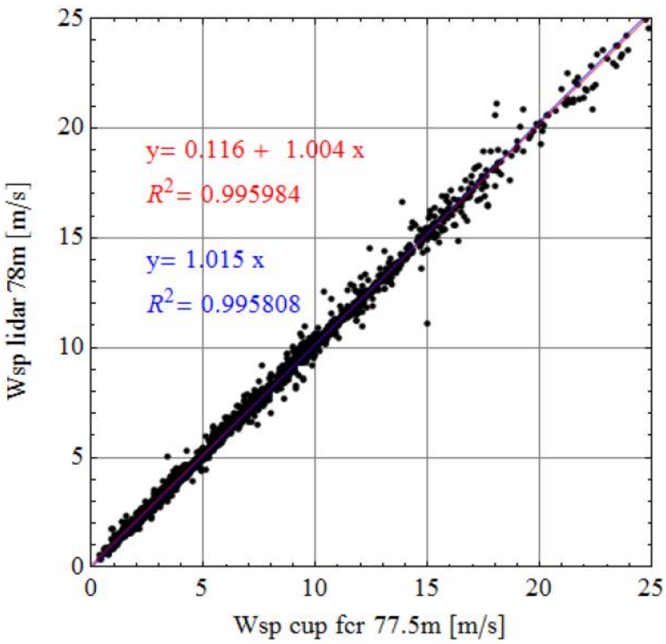

Figure 6. FCR LIDAR wind speed at 78 m vs cup anemometer wind speed at 77.5 m

Similar comparisons between LIDAR wind speeds (uncorrected and FCR corrected) were done at 75 m and 55 m. The comparison results are similar to those at 77.5 m (Wagner & Bejdić, 2014).

3.3 Comparison of the measured wind direction

Direction measurements were taken at 53 m and 75 m with Thies Compact wind vanes, but the wind vane at 75 m got broken during the measurement campaign, therefore the wind vane at 53 m was used in the analysis.

The direction measured by the LIDAR at 55 m was compared to the direction from the wind vane at 53 m. The comparisons of the LIDAR uncorrected direction and the FCR corrected direction are not identical but very similar (Figure 7 and Figure 8). In both cases, the linear regression results in an offset of about 11^0.

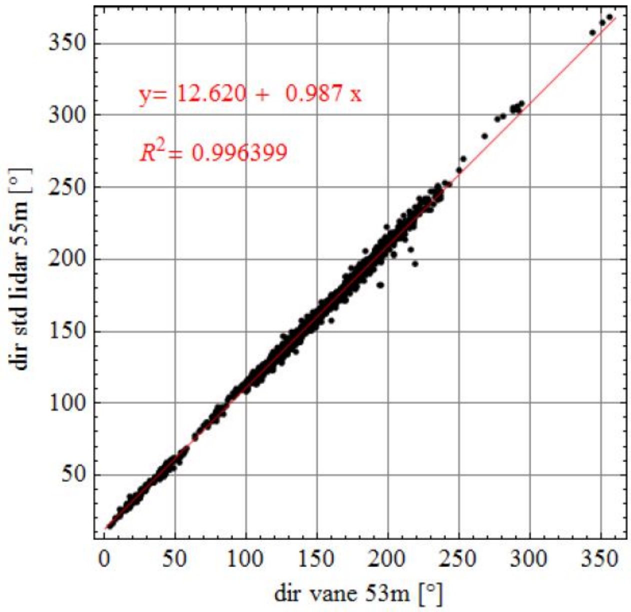

Figure 7. Uncorrected LIDAR wind direction at 55 m vs wind vane at 53 m (Red: two parametric linear regression) – Wind speed below 3 m/s for this comparison

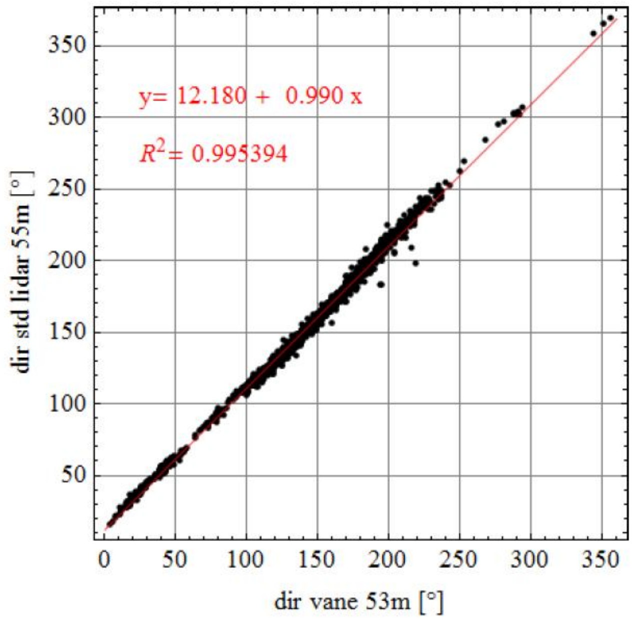

Figure 8. FCR LIDAR wind direction at 55 m vs wind vane at 53 m. (Red: two parametric linear regression) - Wind speed below 3 m/s for this comparison

3.4 Wind Shear

The wind shear or vertical wind speed profile is an important parameter in the choice of the optimal hub height of wind turbine. The wind shear expresses the ratio between the wind speeds at different heights. The wind shear, of course, depends on the topography of the site and is not identical for all directions. The power law wind shear is defined by (International Standard. IEC 61400-1 Ed. 3., 2005):

$$v_2 = v_1 \left(h_2 / h_1\right)^{\alpha} \tag{1}$$

where the shear exponent α is calculated between the respective heights h_1 and h_2 and their corresponding wind speeds v_1 and v_2.
The average wind speed profiles for the four prevailing wind sector measured with the mast between 30 and 77.5 m and with the LIDAR between 45 and 160 m are displayed in Figure 9. The wind sector is indicated at the top of each plot and with the number of data within that sector in parenthesis. The vertical wind speed profiles of LIDAR and mast agree very well for the NE sectors 0°-30°, 30°-60° and SE sectors 120°-150°, 150°-180°. However it was noticed in Figure 9 that the averaged profiles do not typically follow a power law.

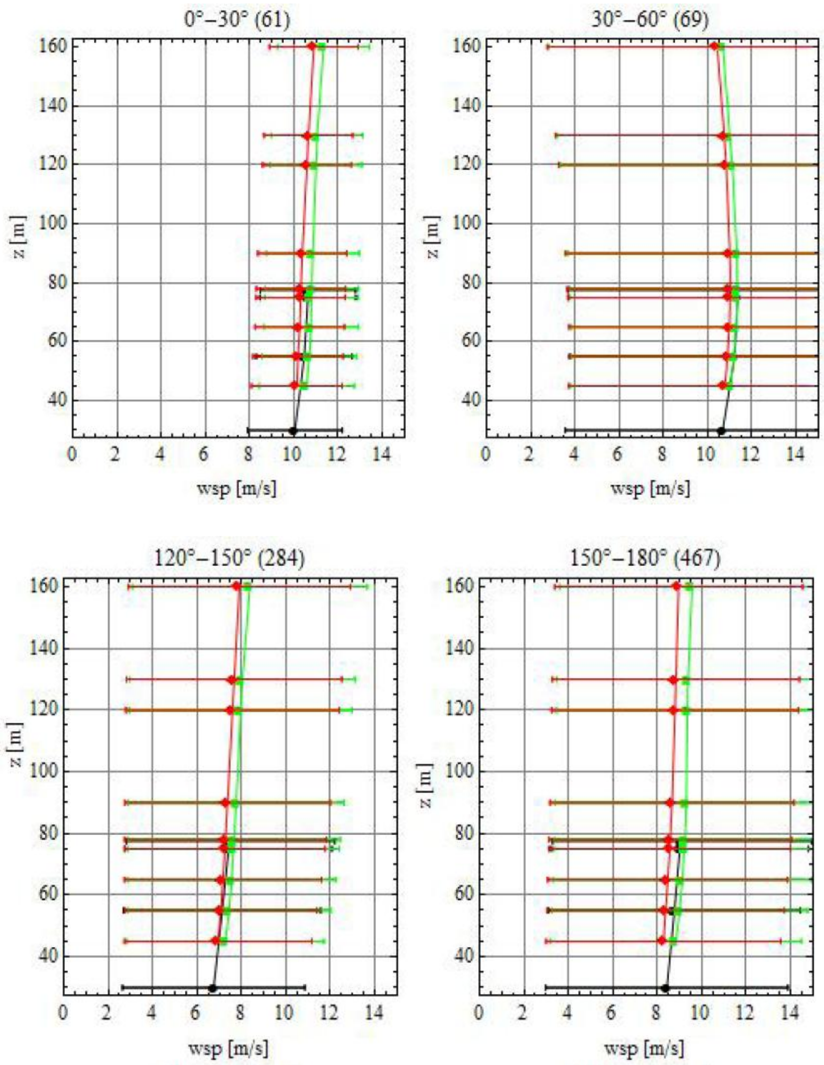

Figure 9. Average wind speed profile for the prevailing wind directions of mast data (black), uncorrected LIDAR (red) and FCR corrected LIDAR (green)

4. CONCLUSIONS

The LIDAR functioned "relatively well" in complex conditions of the terrain and wind characteristics of Bora. Unfortunate events demonstrate the importance of protecting the power supply of the LIDAR from an exposed power line. The LIDAR software also happened to be unstable, since several periods of data were missing although the system had power.
The LIDAR uncorrected wind speed was in general lower than the wind speed measured by the cup anemometer at the same height by about 4%. The FCR corrected wind speeds were higher than the cup anemometer wind speed by about 1.5%.
Based on a rough analysis of the surrounding topography, it seems that the LIDAR deviation is mainly affected by the topography around the LIDAR within a radius of 500 m but the major features of the topography within a larger radius has also some influence. This would need to be further investigated with numerical tools (CFD).
The LIDAR uncorrected wind directions compared well to the wind vane and the FCR correction had no significance influence on this comparison.
The shear exponent derived from the LIDAR wind speeds, both without and with FCR, compared relatively well with the shear exponent form the mast cup anemometers.
For more relevant observance of Bora characteristics and behavior of the equipment in a complex location like this one, it is necessary to carry out measurements in a longer period of time and in different seasons.

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