Comparative analysis between LIDAR technologies and common wind speed meters

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Abstract

An analysis of the feasibility of using new technologies based on remote sensing for measuring wind speed and wind direction at different heights has been performed. A remote sensing equipment, specifically a WindCube Lidar one, and a common cup anemometer have been used. Results over complex terrain are presented of wind speed comparisons at 67 m and wind direction at 64 m above ground level showing excellent correlation between the lidar and the cup anemometer.

I. Introduction

Unlike conventional power plants, the production of wind farms depends on meteorological conditions, particularly the magnitude of the wind speed, which can not be directly influenced by human intervention. Thus, in wind energy systems, as the power is sensitive to the wind speed, good quality anemometers which are sensitive, reliable and properly calibrated must be used for wind measurements. The calibration is done under ideal conditions against a benchmark anemometer, which is considered as the reference one. Even with proper calibration, it has been noticed that some errors may occur in the measurements. One of these important errors is the tower shadow. The nearby obstacles, or even the anemometer tower itself, may shade the instrument, tending to mislead. In order to minimize the risk of tower shadow, guyed towers are preferred than lattice ones.

There are several types of anemometers, [1-2]. The first anemometer appeared as early as in 1450, and was a pressure plate one. Nevertheless, the most commonly used for wind energy resource assessment is the cup anemometer, which is basically a drag device. Though, this anemometer has some limitations. It accelerates quickly with the wind but retards slowly when the wind stops. Thus, cup anemometer does not give reliable measurement in wind gusts. Moreover, the density of the particular location where it is put up affects it.

Another disadvantage is that cup anemometers need met masts for their mounting and the costs associated with the purchase, erection and instrumentation of the met masts increases rapidly with height. The evolution of new multi-MW wind turbines has resulted in increased hub heights and increased rotor diameters, thus making remote sensing an important issue for wind energy applications. Remote sensing techniques offer the ability to determine wind speed and direction at several heights using a ground-based instrument which operates via the transmission and detection of light (LIDAR) or via the transmission and detection of sound (SODAR). Apart from the economic troubles, there is a mounting pressure within the wind energy industry in order to find a new method that takes into account the wind speed over the swept rotor area instead of hub height only, [3].

Although remote sensing for wind energy applications is a recent issue, several approaches have been performed in order to study the behaviour of these instruments versus common wind speed meters. In [4], after solving a problem with the focus of a ZephIR Lidar located in flat terrain, the measurements on a meteorological mast instrumented with several cup anemometers at different heights during a period of three weeks revealed very good correlations at all heights. In [5] measurements with a Lidar and two Sodar in an offshore wind farm during two months showed that remote sensing could be used to supplement met mast measurements for offshore applications. The work developed in [6], points out high correlations between a Lidar and a cup anemometer, both in flat and complex terrain, though it must be noticed that the measurements performed in complex terrain had short duration. In [7], a longer test period over complex terrain shows a good correlation degree. In general, it can be seen that Lidar's results are in good agreement with the classical wind speed meters.

It can be stated that all the works mentioned before used only one type of Lidar, a Zephir one. Whereas in [8] was used by first time a WindCube Lidar for wind energy purposes. It was compared with a Zephir one, a Sodar and a cup anemometer in the power curve performance scope. It was concluded that the WindCube offered good results, very similar to the Zephir ones, and better than the Sodar and cup ones. Since light can be much more precisely focused and spreads in the atmosphere much less than sound, Lidar instruments have higher accuracy than Sodar ones. Moreover, in [9], a depth comparison between the two commercial Lidars present at moment, Zephir and Windcube ones, is performed.

The aim of the present study is to analyse, through measurements performed on a meteorological mast equipped with a cup anemometer and a LIDAR instrument, the similarity degree between both equipment. Thus, in section II a brief description of the test site is shown. Next, section III analyses the measurements performed by both equipment according to wind speed, standard deviation, and wind direction. Finally, section IV summarizes all the ideas found in the work.

II. Test site

A WindCube LIDAR equipment has been used in an experimental test covering a period of three months. The Lidar anemometer is based on the Doppler effect. It measures the Doppler shift of radiation scattered by natural aerosols carried by the wind. It can measure wind speed and direction at several heights using a ground-based instrument.

The test was done in a wind farm located in the south of Spain (due to confidentiality issues it is not allowed to clarify the location more exactly). The LIDAR was installed next to a meteorological mast instrumented with a cup anemometer, at a distance lower than 30 m in the northwest direction. No obstacles were set out between both equipments. Using 10 min averages, wind speed has been measured both in the met mast at 67m above ground, and in a LIDAR system with measurements at 67m. In the same way, wind direction has been measured both in the met mast at 64.3 m above ground, and in a LIDAR system with measurements at 64 m. Figure 1 shows the equipment depicted at test site.

Figure 1. Equipment at test site: Lidar (front) and Met Mast (back)

The first task when a comparative analysis in wind energy measurement technologies is going to be performed is to justify the topographical features of the terrain. According to [9], when the differences in elevation exceeded 60 m within a radius of 11.5 km in the surroundings of the wind turbine, that terrain must be considered as complex terrain. Thus, it can be concluded that the terrain over all the measurements were performed is a complex one. Moreover, it must be pointed out that the topography is a very uncommon one due to its complexity.

III. Experimental Results

All the measurements performed about wind speed, standard deviation of wind speed and wind direction are exposed in this section. Before showing the results achieved, it is important to remark that what it is being made here is a comparison between two different measurement methods, because on the one hand it is being measured over a volume with significant vertical and horizontal extent, and on the other hand it is taken into account essentially a point measurement (the measurement volume of the cup anemometer becomes insignificant in comparison with Lidar one).

III.1 Wind Speed Analysis

Firstly, in order to take an estimation of the similarity degree of both equipments, the root mean square error (RMSE) was calculated, according to the equation (1):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(V_{WindCube} - V_{MM}\right)^2}{N}} \tag{1}$$

Where, $V_{WindCube}$ and V_{MM} are the wind speeds measured by the WindCube and the meteorological mast, respectively. And N is the number of measurements.

By applying equation (1) to the wind speed measured by both equipments during test period, a RMSE equal to 0.5269 m/s is obtained. This result is rather small, considering that the topography of the terrain is a complex one, and no filter has been applied.

In order to understand better the behaviour of both instruments, the RMSE has been calculated according to wind speeds. Thus, 4 m/s wind speed intervals have been chosen, figure 2.

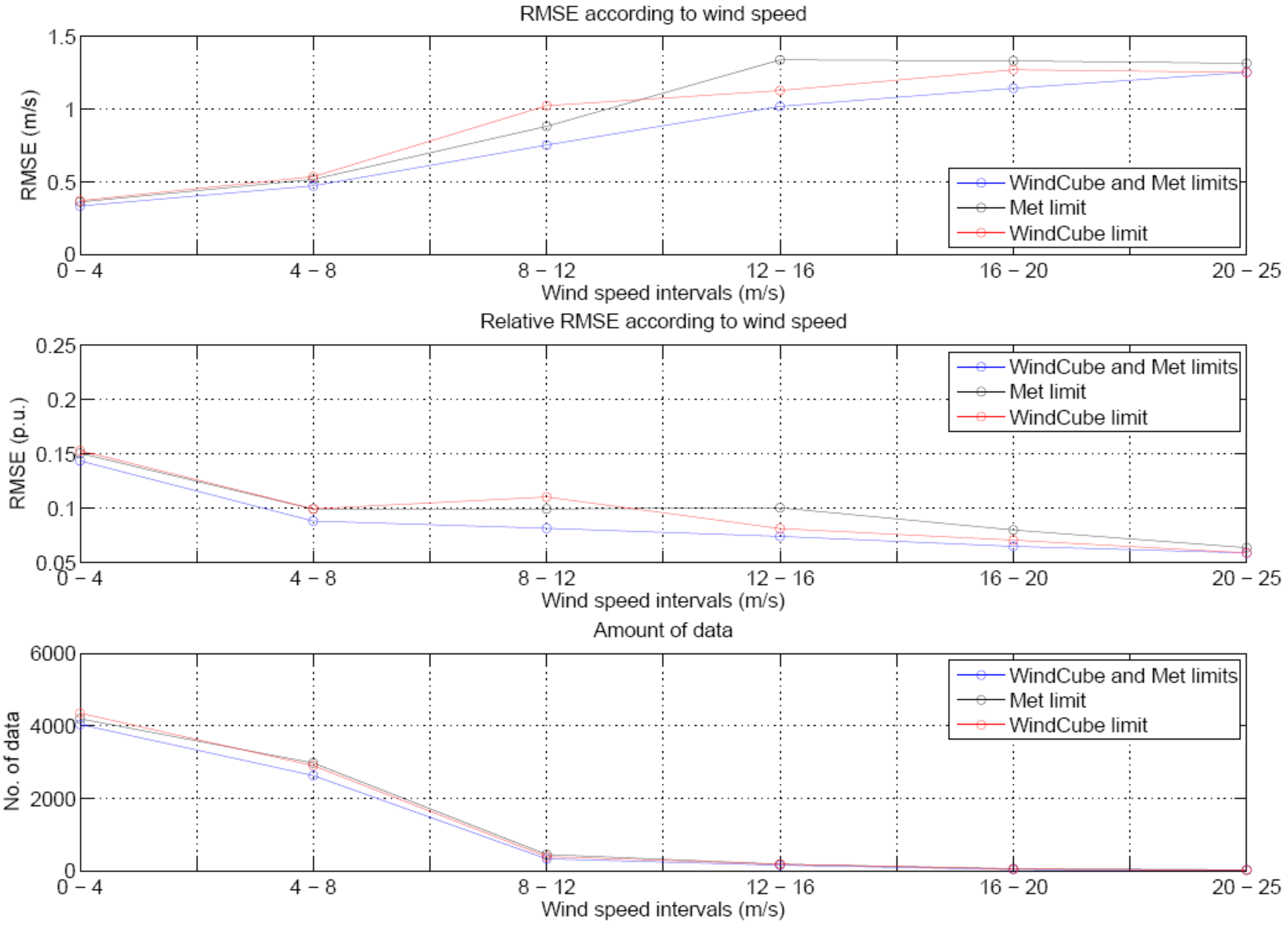


Figure 2. RMSE according to wind speed intervals

There are three different coloured lines in figure 2 showing three different amounts of data chosen. The blue line depicts RMSE calculation taking into account the data both from WindCube and met mast that fits within each interval. Thus, the RMSE obtained with this method is the one which has lower amounts of data. The black line depicts RMSE calculation with the values measured from the met mast fitted within each interval. And the red line shows RMSE calculation with the values measured from the WindCube fitted within each interval. The upper and central part of the figure 2 shows the RMSE in each wind speed interval, in absolute and relative values, respectively. Whereas, the lower part shows the amounts of data used for each calculation.

Looking at the central part of the figure 2, it can be stated that the higher the wind speed, the lower the RMSE. Hence, WindCube measurements reflects at high wind speeds very similar results to cup anemometer measurements. However, in [8] it is said that the WindCube can measure in complete wind still without losing accuracy. Therefore, it must be pointed out that the results shown in the present paper, on the one hand, are based on complex terrain and, on the other hand, the amounts of data for wind speeds higher than 8 m/s fall very quickly.

Another important characteristic for the comparison of both equipments is to analyse the similarity degree according to wind direction sectors. Thus, wind directions measured by both instruments have been divided among six sectors, starting with -30º, and with a width of 60º. Table I depicts the measurement sectors:

1. -30º to 30º	2. 30º to 90º	3. 90º to 150º	4. 150º to 210º	5. 210º to 270º	6. 270º to 330º

Table I. Wind direction sectors

Figure 3 shows the RMSE calculation according to the wind direction sectors depicted in table I. Two wind direction sectors where the RMSE is bigger than the other ones are noticed. This result may be caused on the one hand, because in sector 3 the tower is shadowing the Windcube and, on the other hand, because in both sectors 2 and 3 the amounts of data measured is the lowest.

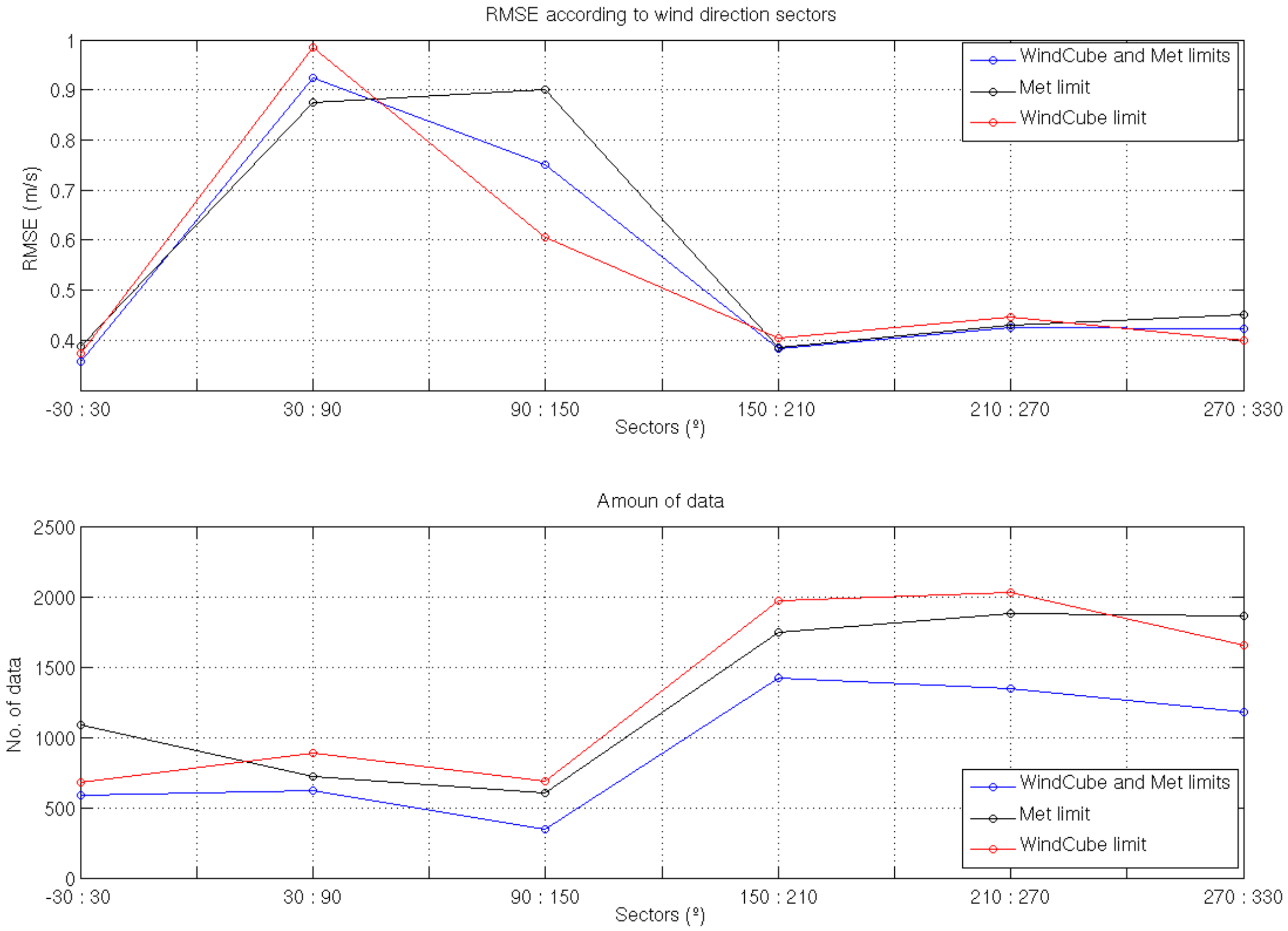


Figure 3. RMSE according to wind direction sectors.

Once studied the RMSE both according to wind speed and wind direction, it is going to be performed a correlation analysis. Thus, Figure 4 shows the measurements performed by the WindCube and the cup anemometer related to the wind direction sectors depicted in table I, together with the linear regression adjustment. Good results are noticed from this figure. Apart from sector 3 where the WindCube is found in met tower shadow, high values for the slopes are achieved. The results are in line with the work developed in [7] over complex terrain, although in [7] the instruments used were a ZephIR Lidar and a cup anemometer, and there was used a filter in order not to use wind speed lower than 4 m/s. Whereas, the results shown in figure 4 have no filter, and even so, a high correlation degree is proven.

Even being good results, they are far from the excellent ones achieved by [4 - 6]. The main differences lie in that on the one hand, the measurements performed by them are located over flat terrain, whereas the work presented here is influenced by a very complex terrain and, on the other hand, meteorological parameters like rain, which could disturb the measurements, [8], has not been taken into account.

III.2 Standard Deviation Analysis

The correlation of the standard deviation of the wind speeds measured by both instruments has been analysed in the same way than the wind speed. Thus, during the test period, the next equation is found: $y = 1.008 \cdot x + 0.159$, figure 5. Due to the proximity of the slope to the value 1, a good correlation between the standard deviations is achieved.

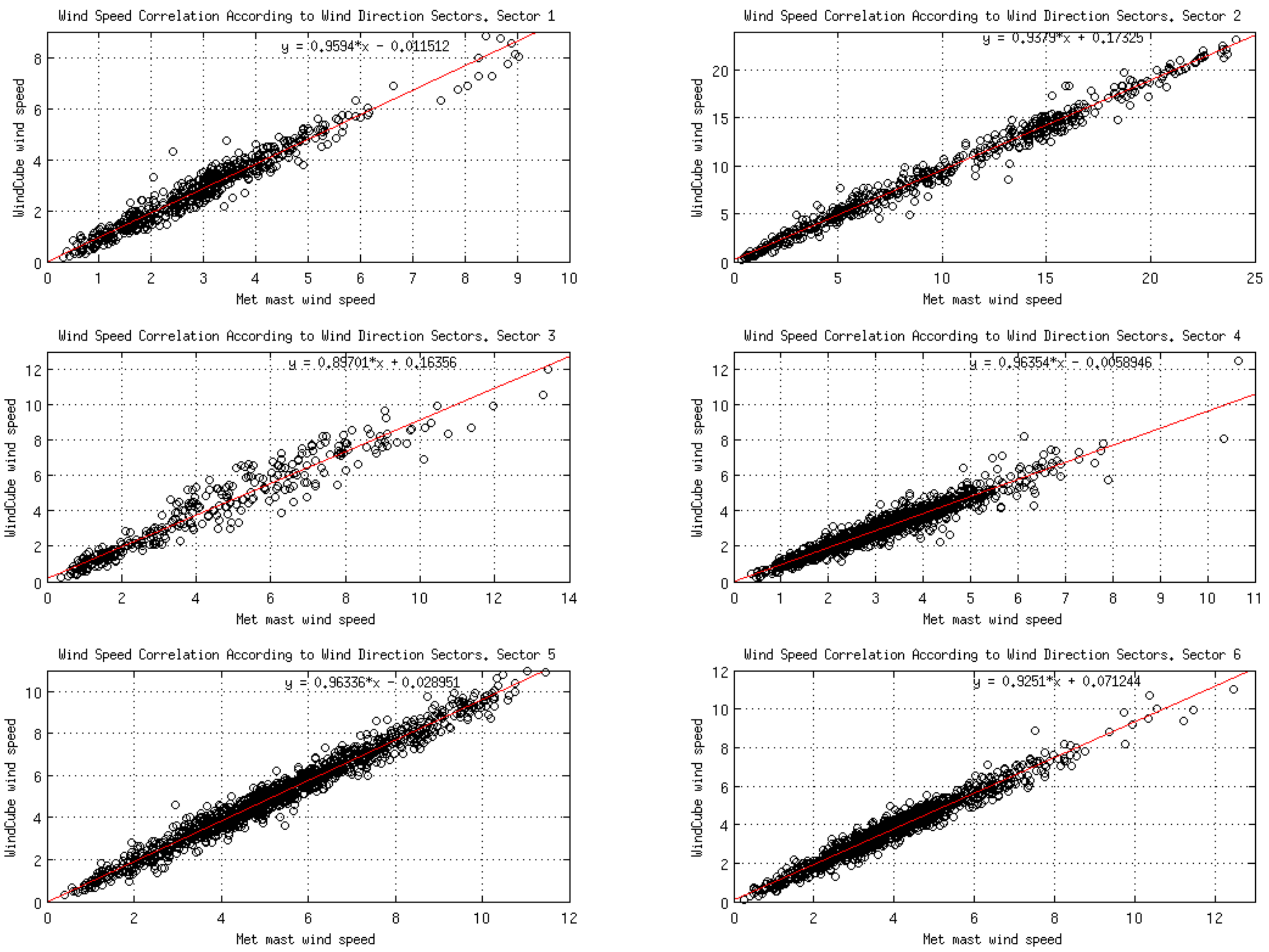


Figure 4. Wind speed correlation according to wind direction.

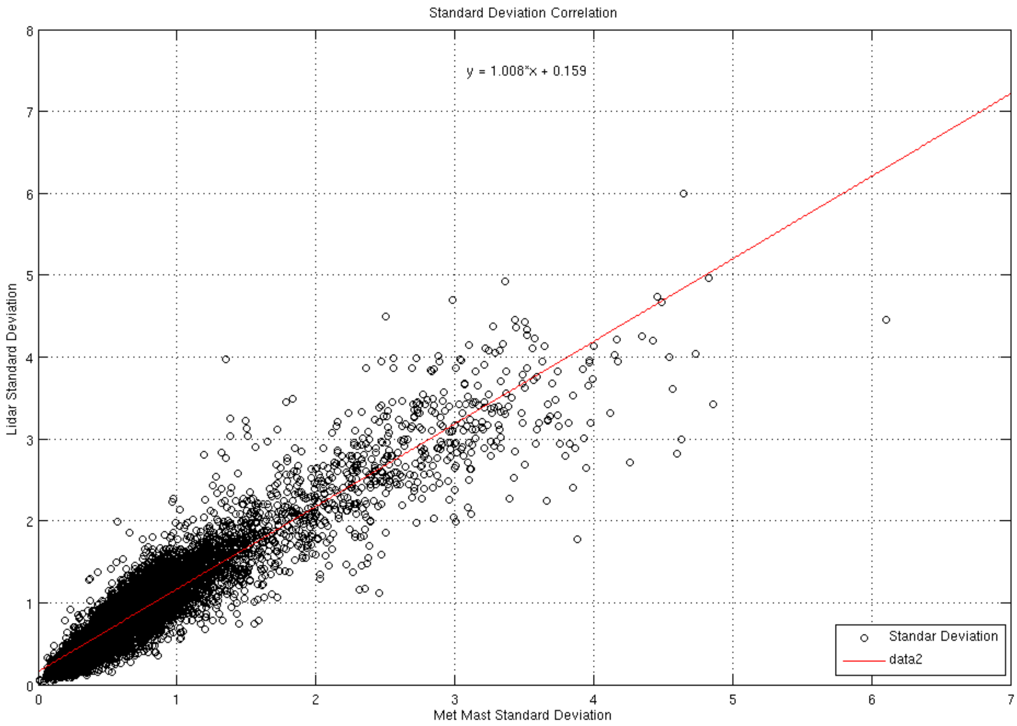


Figure 5. Standard deviation of wind speed correlation.

III.3 Wind Direction Analysis

In figure 6, the wind direction measured by the WindCube at 64 m and by the cup anemometer at 64.3 m above ground is shown. A big spread of data is depicted and could mislead. But, in fact, the spread is not significant because when one instrument measures value closeness to 360º at one moment and the other instrument a closeness to 0º one at the same moment, really the correlation performed by the instruments is good although appears some spread in the figure (for example, all the points located in the left upper corner depicts this characteristic).

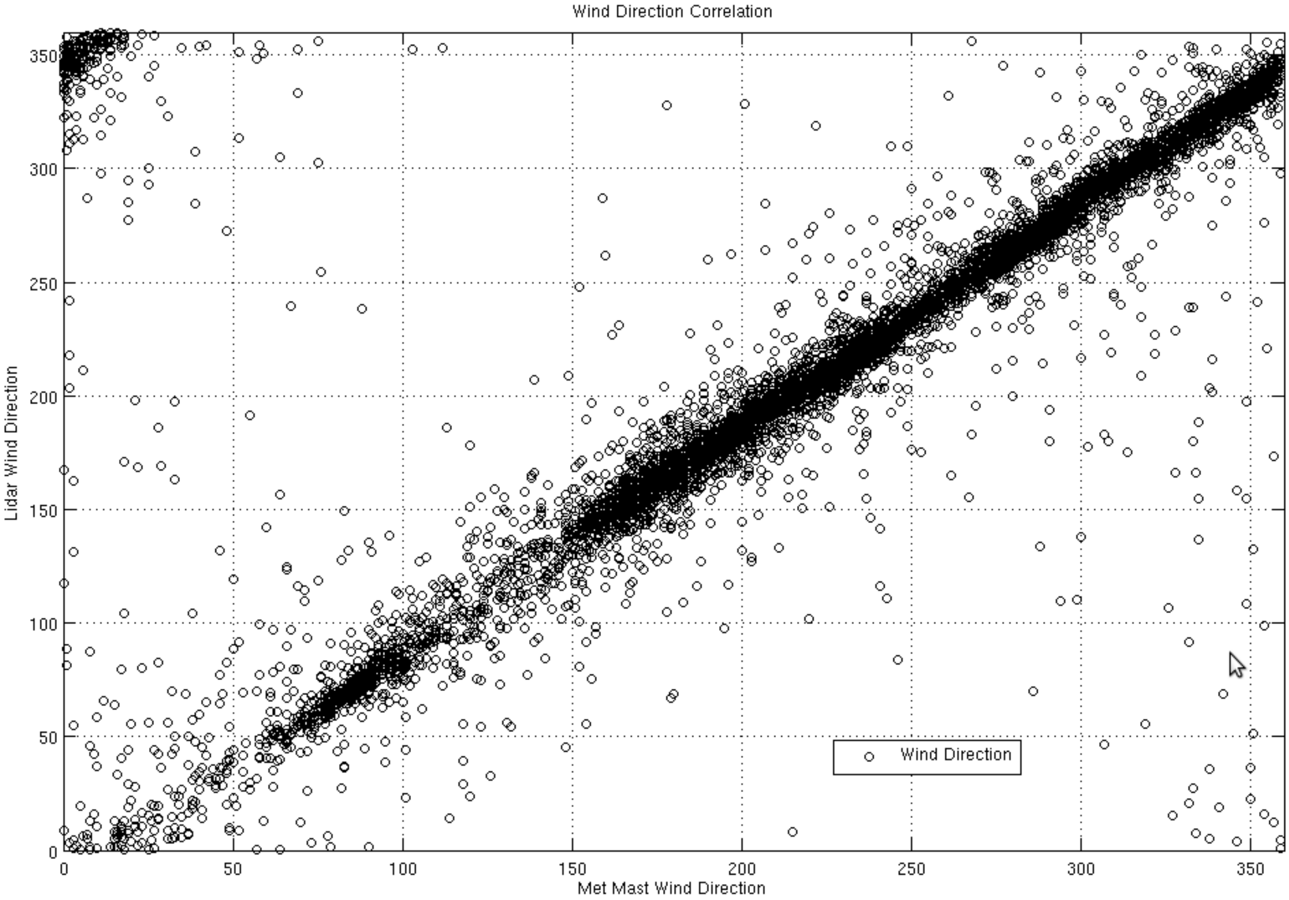
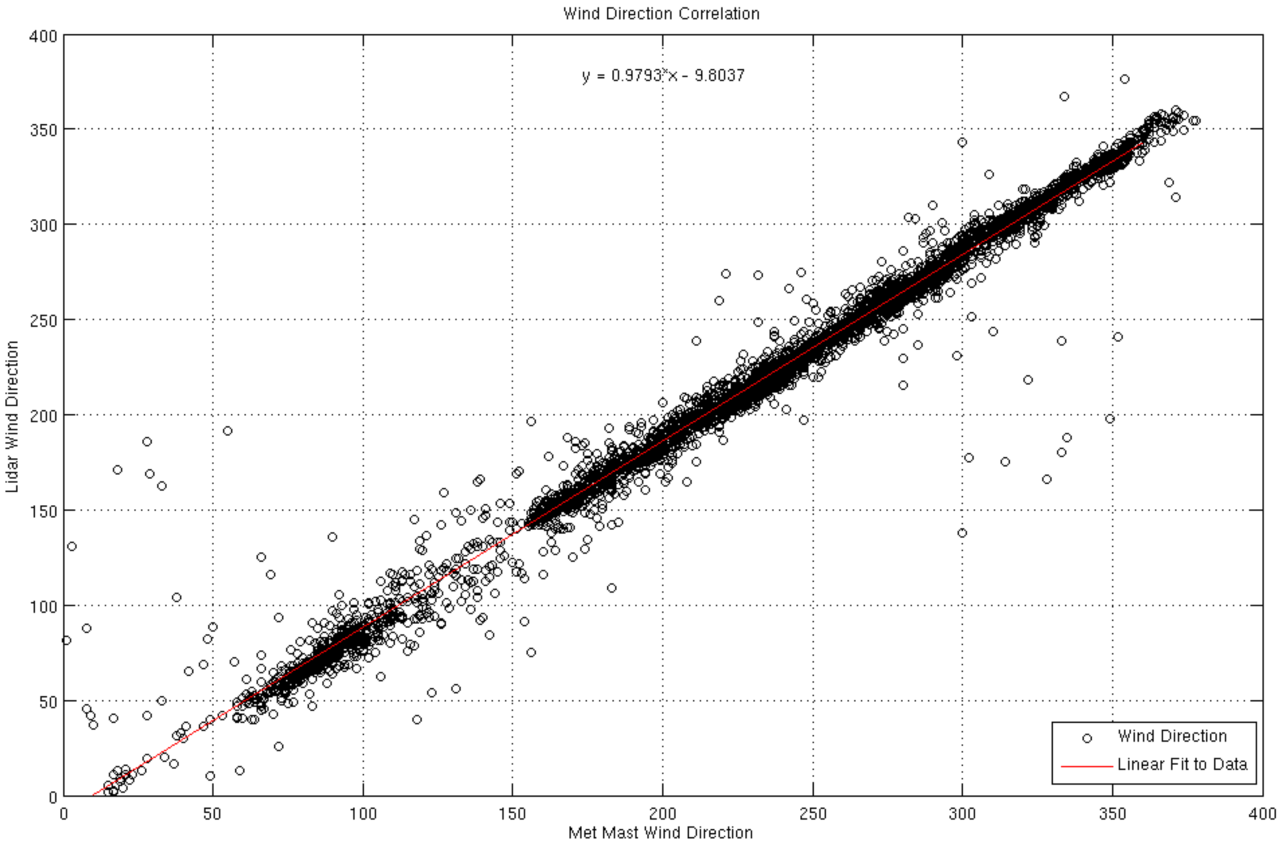


Figure 6. Wind direction correlation.

Therefore, in order to improve the wind direction correlation, in figure 7 two filters have been applied. On the one hand, a filter that adds 360º to the lower measurement when the difference between each pair of wind directions is higher than 180º has been improved. On the other hand, all the wind speeds lower than 3 m/s have been filtered in order to avoid the great variances in wind direction that occurs at low wind speeds.

Besides, a linear fit to the data has been calculated, obtaining a slope of 0.9793, which can be understood like a tolerable value. However, further attention is needed for a relevant offset of -9.8037º that appears in the calculations. Apart from the complexity of the terrain, the small difference between the measurement heights (WindCube measures wind direction at 64 m, and met mast at 64.3 m) could be leading this offset error.



IV. Conclusions

Generally, remote sensing results based on Lidar instruments are intended to be very good and promising. One of the major advantages of these systems is their easy and quick deployment, which can make this equipment a relevant tool for use in wind energy issues, like wind resource assessment and power curve performance. However, due to its recent application in the wind energy scope, further research is needed.

A WindCube Lidar system and a cup anemometer have been deployed in a wind farm in order to analyse their correlation degree in a very uncommon terrain, a very complex one. Wind speed, standard deviation, and wind direction have been assessed.

The WindCube show high correlations to the common cup anemometer mounted on a meteorological mast. Apart from those sectors affected by tower shadow, wind speed correlation shows grateful results. In the same way, the wind direction registered by the WindCube shows good agreement with the cup anemometer, although some variation on the dispersion between both devices has been found, and this matter needs further attention. A possible reason lies on the measuring method (volume versus point measurements). Thus how to interpret the difference between these two methods of measurements is not fully understood.

In spite of the previous trouble, the work developed in the present paper states that WindCube instruments can be used in the same way than cup anemometers.

V. Acknowledgment

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Biographies

Andrés Honrubia-Escribano was born in 1984. He received the Electrical Industrial Engineer degree in the Polytechnic University of Madrid (UPM), Madrid, Spain, in 2008. Since then, he has been employed at the Renewable Energy Research Institute in Albacete, Spain, as a Ph.D fellow. His main interest is wind energy measurements based on remote sensing.

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Emilio Gómez-Lázaro was born in 1969. He received the Electrical Engineering and Ph.D degrees in the Technical University of Valencia (UPV), Valencia, Spain, in 1995 and 2000, respectively. Currently, he is Associate Professor in the University of Castilla-La Mancha, being the header of the Renewable Energy Research Institute. His main interest is design and modelling of wind farms and wind turbines and power system operation with large amounts of wind power.