TITLE

Validation of LIDAR measurements in extremely complex terrain

AUTHORS

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Abbreviations

LIDAR: Light Detection and Ranging

Abstract Content

The aim of this study is to analyse the adequacy of using ground base continuous wave LIDAR technologies in very complex sites, for reproducing critical wind variables in wind resource analysis and site assessment. As a test, an extremely complex site was selected, with a mean altitude of 1100 m and slopes that can reach 30 deg. near the LIDAR device.

Comparisons between horizontal wind speed, wind direction, turbulence intensity, and vertical wind speed and inflow angle measured values in the LIDAR and in a nearby mast were carried out.

Due to the existing extreme climatic and topographic conditions, a LIDAR detailed data treatment and validation, directional analysis of wind speed and significant variables, and in-depth study of correction factors to apply (using a CFD model in this case) was required. Detailed results of the data analysis carried out and magnitude and behaviour of correction factors are presented.

Relevant and positive conclusions concerning the accuracy of LIDAR measurements when reproducing the mean and directional behaviour of wind speed were obtained. However, the wind speed distribution obtained with the LIDAR device presented discrepancies from the one obtained at mast that can lead to different annual energy production results.

Relative deviations between LIDAR and mast measurements were significant in the case of turbulence intensity and maximum wind speed values, therefore the validity of the analysed LIDAR technology for site assessment studies in very complex sites could not be confirmed.

A considerable decrease of LIDAR data availability with height was detected, probably due to the low aerosol presence at such altitude and the unfavourable climatic conditions present at site (fog and others).

Approach

The current work presents the study performed by the Wind Resource Department of Iberdrola Engineering, with the aim of analysing the suitability of using ground base continuous wave LIDAR technologies for wind resource analysis and site assessment in very complex terrain.

The particularity of this study is that, as a test, an extremely complex Spanish site was selected, with a mean altitude of 1100 m and slopes that can reach almost 30 deg. near the LIDAR device. Also climatic conditions at site are harsh, with frequent extreme or ice events during winter months.

A meteorological mast is available at site from October of 2014. The analysed LIDAR device was installed next to this mast in May of 2015. Therefore, a significant common period of almost 8 months would be available for the comparison.

Figures {1}, {2}

In complex terrain the problem of a ground base continuous wave LIDAR, is that non-uniform flow across the LIDAR scan cone (30 deg.) may result in a breakdown of the model assumptions and lead to a different measurement when compared to single point cup anemometers located in a traditional meteorological mast. However, the LIDAR error in complex terrain depends mainly on the curvature of the flow, therefore an analysis with a CFD model can be performed with the aim of applying a correction factor to LIDAR measurements which could reduce the existing bias. A commercial CFD model and its LIDAR conversion module were used for the present study.

Main Body

The first analysis of LIDAR data availability (filtered by LIDAR’s internal processor) showed a significant decrease with height, with 54% of valid data for LIDAR top height of 200 m, increasing with the height decrease until a value of about 86 % at the lowest analysed height (20-25 metres). As a result, at the nearest hub height common mast-LIDAR level of 45m, the availability was reduced to 71%, resulting in about 27,000 common mast-LIDAR data available, still adequate for the comparison.

As it was explained previously, the presence of sharp topography in main wind directions makes necessary a precise parametrization of the CFD model in order to avoid steady state solutions. Also mesh size and number of cells were selected in order to have an acceptable number of nodes into LIDAR scan cone. A set of suitable dynamic conversion factors by wind direction sector (10º) for each LIDAR measurement height were finally obtained and applied to LIDAR wind speed measurements for the comparatives carried out.

Figures {3}, {4}

As a first result, after applying the calculated correction factors to LIDAR wind speed data, the horizontal wind speed at highest LIDAR-mast common height of 45m showed a relative deviation of 0.6% (LIDAR wind speed was slightly lower) considering wind speeds higher than 2m/s. The consideration of more restricted wind speed ranges does not affect significantly the relative deviation and degree of correlation obtained. Disturbed sectors by nearby turbines were not considered (IEC 61400-12-1 calculation methodology was applied).

Figure {5}

It is important to emphasize that relative deviation between mast and LIDAR wind speed data was reduced in an almost 10% at 45m level with the application of the correction factors.

Maximum wind speed values were not correctly reproduced by LIDAR device, with LIDAR maximum wind speed values 4m/s below the ones registered by the mast.

On the other hand the LIDAR and mast wind speed distribution presented considerable differences in significant wind speed bins that lead to discrepancies in the calculated annual energy production results.

Furthermore, turbulence intensity results showed a significant directional behaviour, which was characterized analysing in a separate way north and southern directions. Northern sectors showed higher turbulence intensity values and relative deviations of about 13% at 45m. However southern sectors showed significantly lower turbulence intensity values with relative deviations about 5% at the same level. This result confirms the importance of considering a directional analysis in order to validate LIDAR measurements in complex terrains. However in spite of the directional treatment, deviations in turbulence intensity global mean values were significant. Also turbulence intensity analysis by wind speed bins showed differences in the obtained curves that would be crucial for site assessment purposes.

Figures {6}, {7}

In the case of vertical wind speed values, an ultrasonic 3D anemometer installed in the meteorological mast was used for the comparison. The behaviour is also very directional and surprisingly well reproduced by LIDAR device. Northern vertical wind speeds were positive and southern negatives, with deviations almost null in both cases. The same behaviour can be observed when analysing inflow angle values.

Conclusion

Results showed good correlations and acceptable values of relative deviations between LIDAR and mast horizontal and vertical wind speed measurements in the analysed extremely complex site.

An important result is that obtaining a set of dynamic factors with an adequate model parametrization can reduce the relative deviation between LIDAR and mast measurements in an almost 10%.

However, a significant decrease in data availability (filtered by LIDAR's internal processor) with height was found, with about 30% LIDAR data missed from 20 to 200m height. This can provide indication of the expected percentage of LIDAR data available in harsh climate sites, probably due to the low aerosol presence at such altitude and the unfavourable climatic conditions present at site (fog and others).

Site assessment variables as turbulence intensity or maximum wind speed values obtained in LIDAR and mast presented significant deviations; therefore the validity of the analysed LIDAR technology for site assessment studies in very complex sites could not be confirmed.

Learning Objectives

- Indication of LIDAR behaviour in very complex terrain.
- Analysis of LIDAR data availability and quality in a harsh climate site that could provide guidance in the design of LIDAR measurement campaigns.
- Analysis of magnitude and behaviour of correction factors obtained with ground base continuous wave LIDAR.

References

[1] IEC 61400-12-1 "Power performance measurements of electricity producing wind turbines", Ed1 (2005).

[2] IEC 61400-12-1 "Power performance measurements of electricity producing wind turbines", Final Draft Ed2 (2011).

[3] IEC 61400-1 Edition 3.0 2010-10 Amendment 1 Wind turbines-Part 1: Design requirements

[4] MEASNET "Power Performance Measurement Procedure" Version 5-December2009.

[5] ISO 2533 *"Standard atmosphere"* Addendum 2 (1997).

Figures

Figure {1}: Slopes at site in degrees. Blue points represent the projected wind turbines and green cross marks the LIDAR position.

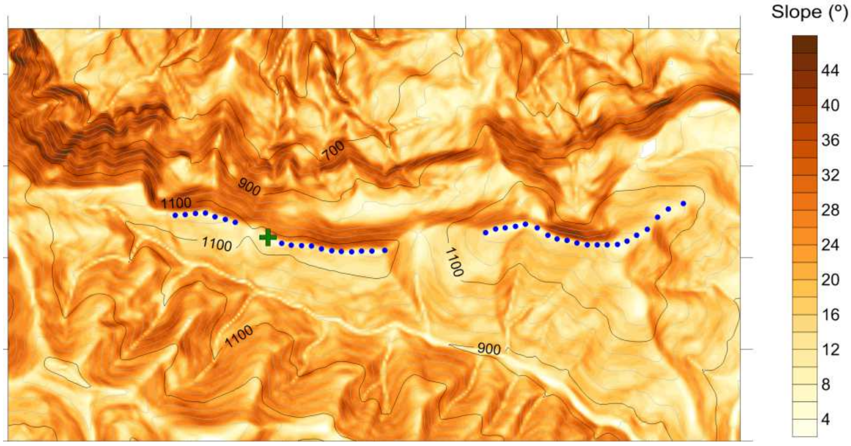

Figure {2}: Relative position of LIDAR and meteorological mast

Figure {3}: Wind rose at the analyzed meteorological mast

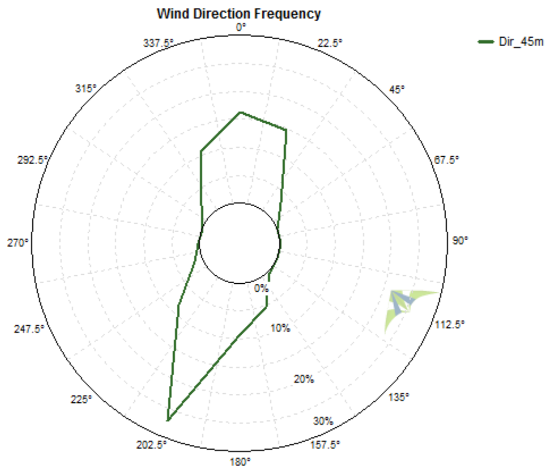

Figure {4}: Directional dynamics correction factors at different heights (36 sectors from 20 to 200m)

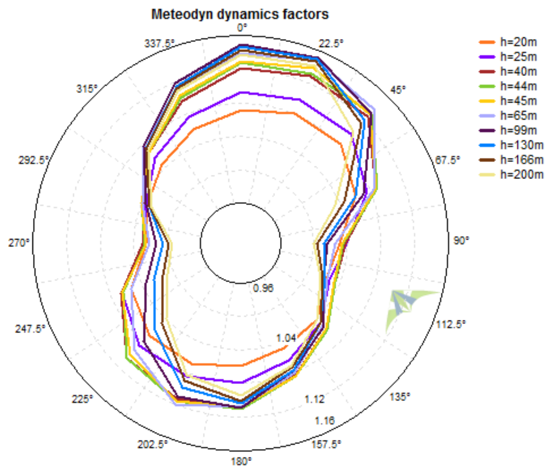

Figure {5}: Correlation of LIDAR and mast measurements at 45m height

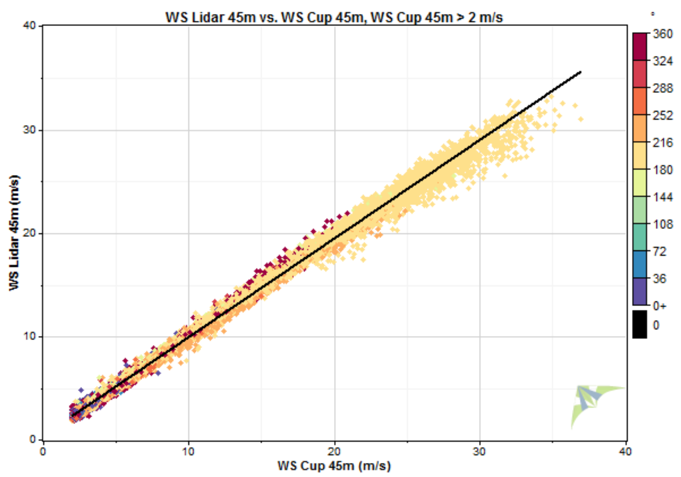

Figure {6}: Correlation of LIDAR and mast turbulence intensity measurements at 45m height considering wind directions between 135-225º

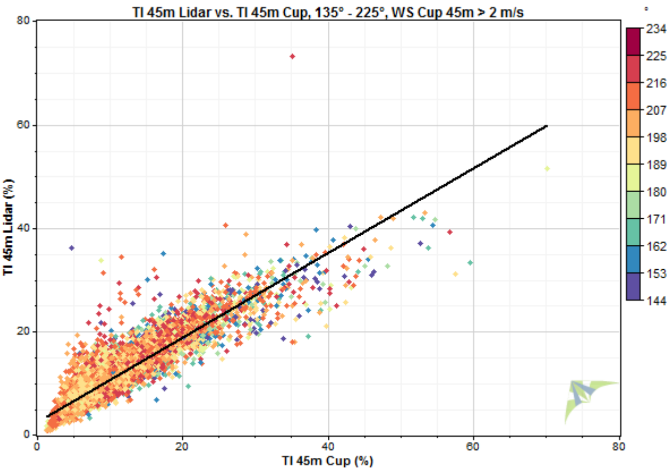

Figure {7}: Correlation of LIDAR and mast turbulence intensity measurements at 45m height considering wind directions between 315-45º