Authors: A. Sarthe, J. Mann, R. Wagner, M S. Courtney

Technical University of Denmark

Risø Campus Frederiksborgvej 399, P.O. Box 49

4000 Roskilde Denmark

Tel +45 23672894

amsat@dtu.dk

Highlight results

- **Gust analysis using lidar and met-mast data**
- **Turbulence spectra analysis using a pulsed lidar**

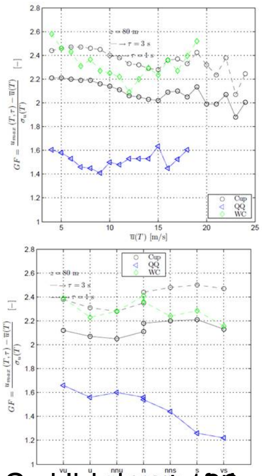
Background :

Wind turbines are designed for fatigue and extreme loads. Turbulence is one of the main driving factors for the fatigue loads, whereas extreme winds result in extreme loading. The IEC design requirement standard quantifies extreme winds in different ways, e.g. a 50 year extreme wind, wind gusts, extreme turbulence etc. In an ideal world, we would like to have long term measurements of these extremes so that wind turbines could be designed with a fair degree of confidence to sustain extreme loads. However, we live in a real world, and hence, long term measurements of extreme winds are scarce, particularly at the site of interest where the wind turbines operate.

Nevertheless, rapid expansion of wind energy in the last decade has led to some dedicated measurement campaigns for wind energy, both onshore and offshore. These sites have tall meteorological masts (>100 m height) and are equipped with cup and sonic anemometers to measure wind speeds. Tall meteorological masts are very expensive, and offshore, the costs increase significantly. The advent of remote sensing devices like lidars gives a further boost to the development of wind energy. In this work we attempt to find out if lidars can measure extreme winds. We divide the work into two parts.

Part I – Gust Analysis

In part I we focus our analysis on the measurements of the maximum wind speed in a 10-min period and the gust factor. We perform data analysis on the measurements carried out by the commercially available ZephIR and Windcube lidars, and compare it with the results from the cup anemometer.



Comparison of the gust factor against mean wind speed and atmospheric stability between cups and lidars at 100 m

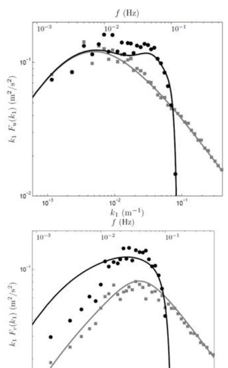
Part II – Turbulence spectra

Turbulent velocity spectra, as measured by a scanning pulsed wind lidar (WindCube), are analyzed. It is known that the gust factor is proportional to the moments of turbulence spectra. Thus, the model of turbulence spectra is also a prerequisite for obtaining a theoretical model of the gust factors measured by lidars. The relationship between ordinary velocity spectra and lidar derived spectra is mathematically very complex, and deployment of the three-dimensional spectral velocity tensor is necessary. The resulting scanning lidar spectra depend on beam angles, line-of-sight averaging, sampling rate, and the full three-dimensional structure of the turbulence being measured, in a convoluted way. The model captures the attenuation and redistribution of the spectral energy at high and low wave numbers very well. The model and measured spectra are in good agreement for all components of the wind field. The theoretical understanding of the shape of turbulent velocity spectra measured by scanning pulsed wind lidar is given a firm foundation.

Conclusions

Windcube measures gust factors that are comparable to that of the cup anemometers but the ZephIR always underestimates it. A primary reason is that the ZephIR updates the velocity vector at one height quite infrequently (about every 20 s), whereas the Windcube updates every 2 s. A good comparison between the Windcube and the cups could be due to the systematic errors arising from the contribution of the all components of the Reynolds stress tensor. This has to be further verified.

A theoretical explanation of the interaction of the spectral tensors that cause redistribution of the spectral energy, and thus measurement of turbulence spectra using pulsed wind lidars is given. This study is particularly relevant for further understanding of how a pulsed wind lidar measures turbulent gusts. Given the complications displayed in this study, it might be advantageous to abandon the VAD technique for spectral analysis of lidar data, and instead analyze time series of individual beams.



Comparison of the lidar and sonic turbulence spectra for the u and v components. The solid lines are models and the markers are measurements

Bibliography

[1] A.Sathe, M S. Courtney, R. Wagner, J.Mann. How good are remote sensors at measuring extreme winds? In proceedings of EWEC, 2011, Brussels, Belgium.

[2] A.Sathe and J.Mann. Measurement of turbulence spectra using scanning pulsed wind lidars. Journal of Geophysical Research, 2012, 117, D01201, 11 pp.