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Validation of Measurements from a ZephIR Lidar

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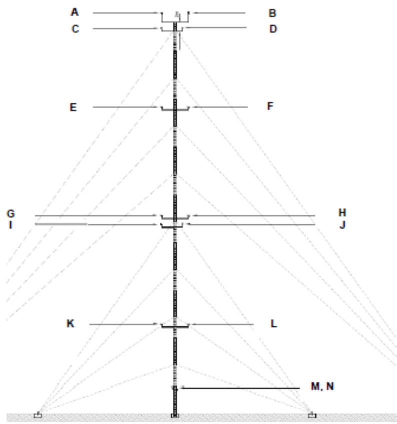
Abstract

Historically wind speed measurements for wind resource assessment have been made using tall meteorological masts. The development of remote sensing techniques, in particular Doppler lidar (light detection and ranging) now enables these measurements to be made from the ground, without the costs of erecting a met mast. This work compares measurements from a ZephIR 300 continuous wave lidar against measurements from an IEC compliant 91m mast, concluding the lidar data to be at least as good as the mast data and with a higher availability rate.

Objectives

The primary objective of this work is to show that wind measurement data from lidar are at least as good as wind measurements from meteorological masts. This is demonstrated through a number of plots of mean and standard deviations of wind speed.

A secondary objective is to investigate the potential for using lidar data to be the basis of calculating atmospheric stability throughout the ABL as a source of validation data for complex wind farm simulations and to see if lidar measurements are affected by stability



Right: Figure 1: Diagram of the UKRSTS meteorological mast
Below: Table 1: Description of the instrumentation used on the mast

Label	Height (m)	Orientation (°)	Type	Manufacturer/Model	Instrument to mast centre (mm)
A	91.5	300	Cup Anemometer	Riso P2546A	1025
B	91.5	120	3D Sonic Anemometer	Metek USA1	1025
C	88	300	Direction Vane	Vector W200P	3700
D	88	120	Temperature / Humidity	Campbell Scientific CS215	-
E	70.5	300	Cup Anemometer	Riso P2546A	3700
F	70.5	120	Cup Anemometer	Vector A100LM	3700
G	45.5	300	Cup Anemometer	Riso P2546A	3700
H	45.5	120	Cup Anemometer	Vector A100LM	3700
I	43.5	300	Direction Vane	Vector W200P	3700
J	43.5	120	Temperature / Humidity	Campbell Scientific CS215	-
K	20.5	300	Cup Anemometer	Riso P2546A	3700
L	20.5	120	Cup Anemometer	Vector A100LM	3700
M	6	-	Pressure	Campbell Scientific CS1000	-
N	6	-	Data Logger	Campbell Scientific CR1000	-

Measurement data of atmospheric conditions have been made available by the lidar manufacture ZephIR Lidar. The measurements were collected using a ZephIR 300 wind lidar (finance grade measurements up to 200m) over a period of one year from November 2012 to October 2013 at their UK Remote Sensor Test Site (UKRSTS). For the purposes of validation, concurrent measurements from the site's IEC compliant 91m mast, located less than 10m from the Lidar were also made available. The dataset was cleaned to remove events where shadow effects from the mast structure were observable.

Results

Measurements from the mast's two wind vanes at heights 88m and 43m were found to be strongly correlated, although Figure 2 suggests a systematic variation between the heights. By comparison, the lidar data show less variation between heights and a good agreement with the mast's lower wind vane. The lidar only needs to be oriented once at ground level to ensure every measurement height is correctly aligned. A met mast by comparison requires the installer to identically orientate multiple instruments whilst working at height. It is therefore reasonable to conclude the lidar directional measurements are more reliable.

Due to rotational inertia, cup anemometers can be slow to respond to and subsequently under-report rapid changes in wind speeds. Figures 3 and 4 compare wind speeds measured by both the mast anemometers and the lidar, across all directions. Figure 3 shows a classic Weibull wind speed distribution is measured at each of the four cup anemometer heights, and is matched by the lidar results. The mast consistently reports slightly higher velocities though this is within measurement error.

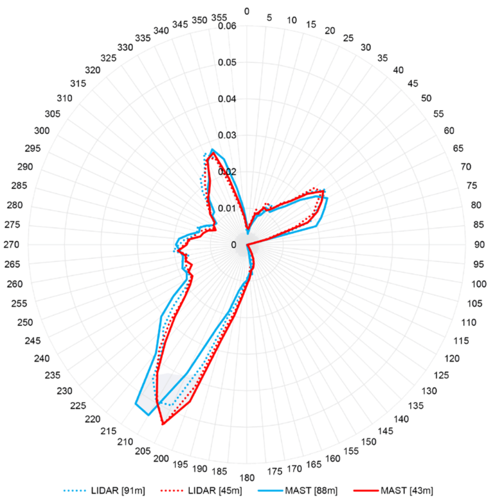


Figure 2: Wind rose at two heights from both mast and lidar

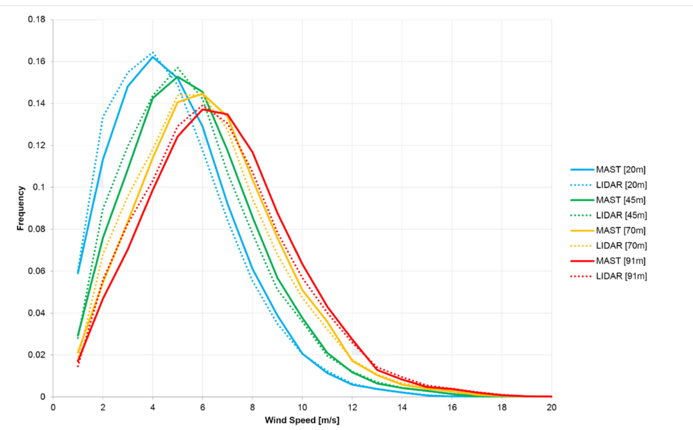


Figure 3: Wind speed frequencies measured by mast and lidar

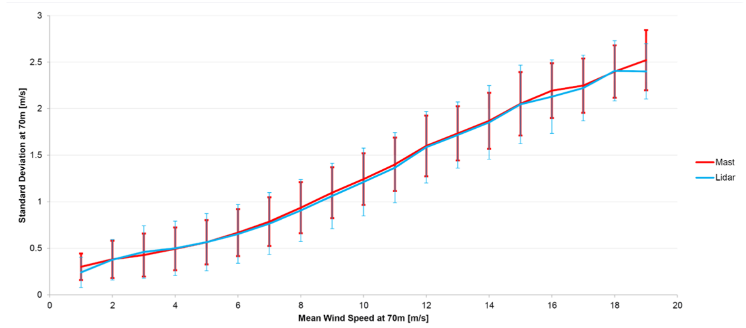


Figure 5: Comparison of the measurement standard deviation within each ten-minute event with wind speed at 70m height

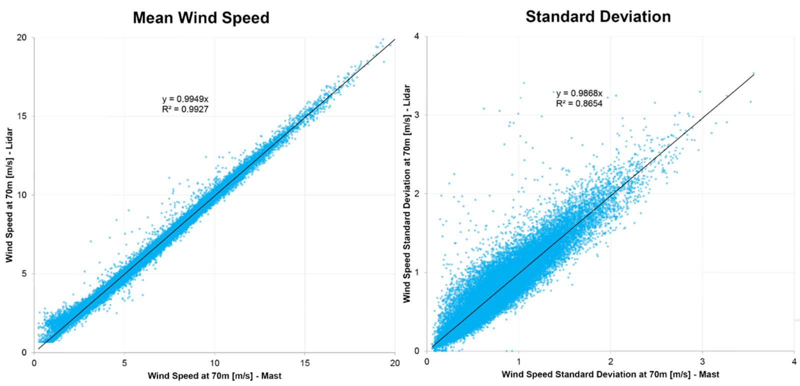


Figure 4: Comparison of 70m mean wind speed (left) and standard deviation (right) measured by mast and lidar

Figure 5 compares how the standard deviation of wind speed measurements changes with mean wind speed at 70m above the ground. The vertical axis shows the mean value of measurement standard deviation across events where the mean wind speed occurs within the bin on the horizontal axis. The error bars indicate the standard deviation of the standard deviation values shown on the vertical axis. The figure clearly shows that statistically, the measurements of mean wind speed are the same whether measured by cup anemometers or by lidar. It is also of note that the mean value of measured standard deviation increases linearly with wind speed and that the variance of lidar standard deviation is larger than for the mast data.

Atmospheric stability is calculated using the gradient Richardson number (RiG) according to Equation 1 and Table 2 where T is temperature, g is gravity, z is height and u is wind speed. Events with RiG values outside the ranges shown in Table 2 (54%) was discarded for stability analysis. Figure 6 shows there is some stability dependence on the agreement between mast and lidar measurements. On average, the lidar records lower wind speed values than the mast for more stable conditions, though the difference is small and height dependent.

Equation 1:

$$Ri_G = \frac{\frac{g}{T}\left(\frac{dT}{dz}\right)}{\left(\frac{du}{dz}\right)^2}$$

Table 2: Definition of atmospheric stability classes

Stability Class	Acronym	Range of Ri_G Values	Frequency
Very Unstable	VU	$-1.28<Ri_G<-0.64$	3%
Unstable	U	$-0.64<Ri_G<-0.32$	3%
Near Unstable	NU	$-0.32<Ri_G<-0.13$	3%
Neutral	N	$-0.13<Ri_G<0.08$	15%
Near Stable	NS	$0.08<Ri_G<0.12$	8%
Stable	S	$0.12<Ri_G<0.17$	10%
Very Stable	VS	$0.17<Ri_G<0.19$	3%

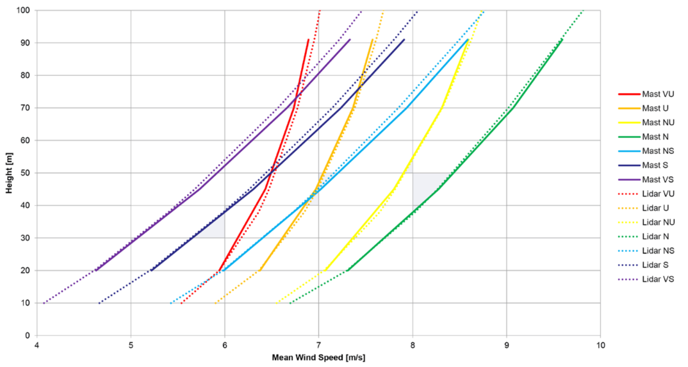


Figure 6: Wind speed profiles measured, filtered by stability

Conclusion

From the results presented in this work, it is clear that a ZephIR 300 wind Lidar is capable of measuring the wind resource to at least the same standard as a met mast, with very comparable values of wind speed (both mean and standard deviation) and wind direction. Furthermore, the Lidar data set had greater availability than the mast and more measurement heights – both within the mast's height range and also extending to over twice the mast height. The Lidar wind direction measurements are more reliable than mast mounted wind vanes due to aligning multiple vanes and mast shadow effects. Lidar directional measurements throughout the ABL atmospheric boundary layer are also useful for validation purposes when computing the Ekman spiral, both for wind resource assessment and forecasting. Although a lidar is unable to measure temperature with height to directly calculate RiG, the relationship of stability with wind shear that can be determined more accurately over a greater range of heights than can be provided by an average mast suggests it may provide a suitable substitute. There is some evidence that the lidar records lower wind speeds higher up during stable conditions than a cup anemometer and higher wind speeds in unstable conditions, though the difference is small.