PO.ID 206

Measurement of Secondary Wind Characteristics by the WINDCUBE® v2 LIDAR

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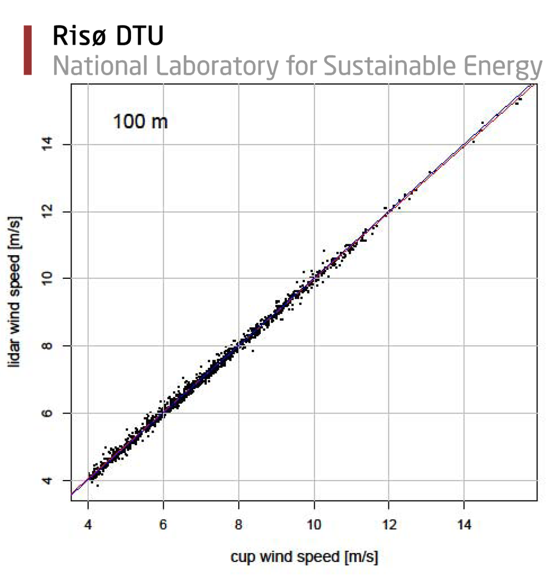
Abstract

Assessment of climatic conditions for a wind farm project includes the study of the wind characteristics on a particular site. It concerns not only mean wind speed and direction statistics but also other wind parameters like shear values over the whole rotor area, flow-inclination and turbulence intensities. If long considered as secondary parameters, these values are now becoming more and more critical to develop and optimize a wind farm project.

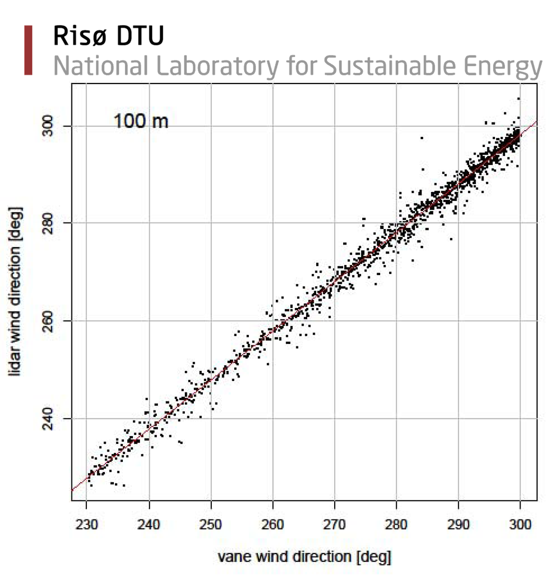
Lidar remote sensing devices are powerful instruments to assess the primary and secondary wind characteristics. They measure wind speed and direction vertical profiles, and lidars like the WINDCUBE® can also measure inflow-angle and turbulence intensities with a fair agreement with cup and sonic anemometers.

In this paper, we propose to analyse the level of agreement of these secondary wind parameters measured by the WINDCUBE® lidar in comparison with traditional anemometry. We also briefly show the consequences of the “volume measurement” principle on the results when compared to mast-mounted “point measurement” anemometers. New innovative solutions are proposed to reach a better correlation on the turbulence intensities and thus increase the range of application possibilities of the WINDCUBE® lidar.

Measurement of the 3 wind vector components



Horizontal wind speed

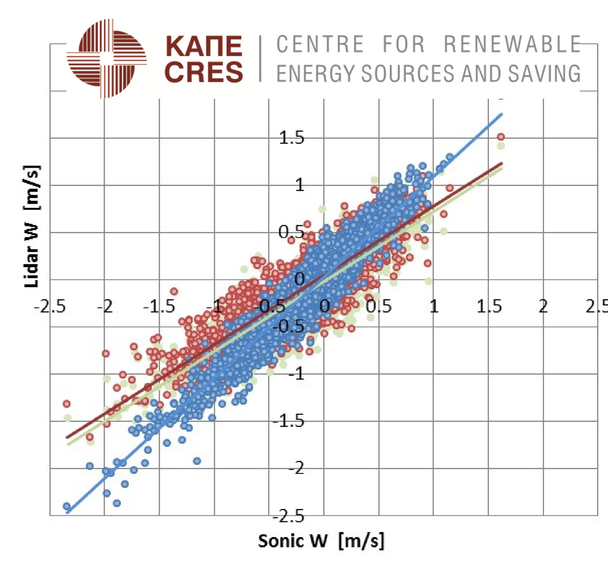


Wind direction

Standard Regression for 10min mean wind speeds @100m (left plot is horizontal wind speed HWS and right plot is wind direction DIR)

- $HWS_{windcube}=0.989*HWS_{cup}+0.09m/s$
- $R^2=0.9968$

- $DIR_{windcube}=1.005*DIR_{vane}-3.5°$
- $R^2=0.989$

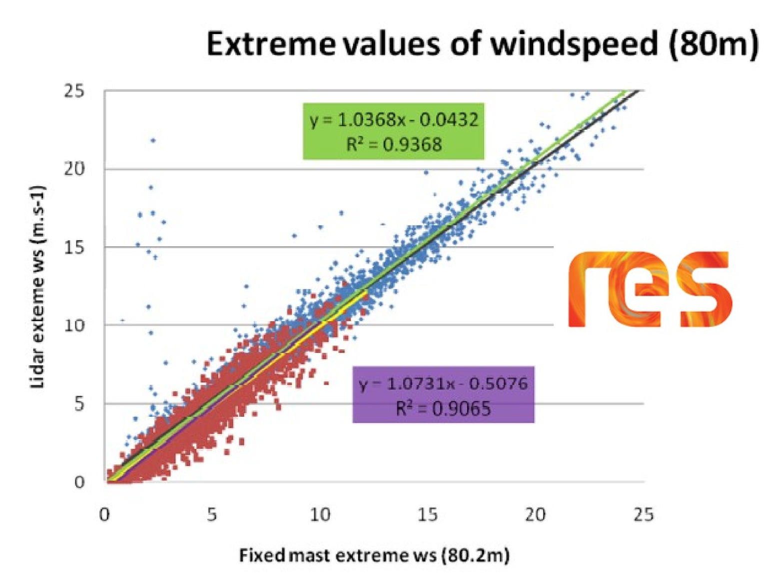


Vertical wind speed

Standard Regression for 1min mean vertical wind speeds @100m on CRES test facility in Lavrio (moderately complex terrain) (red scatter plot is WINDCUBE® v1 lidar and blue scatter plot is WINDCUBE® v2 lidar)

- $W_{windcube\ v1}=0.73*W_{sonic}+0.05m/s$
- $R^2=0.74$

- $W_{windcube\ v2}=1.07*W_{sonic}+0.03m/s$
- $R^2=0.91$



1s Extreme horizontal wind speed values

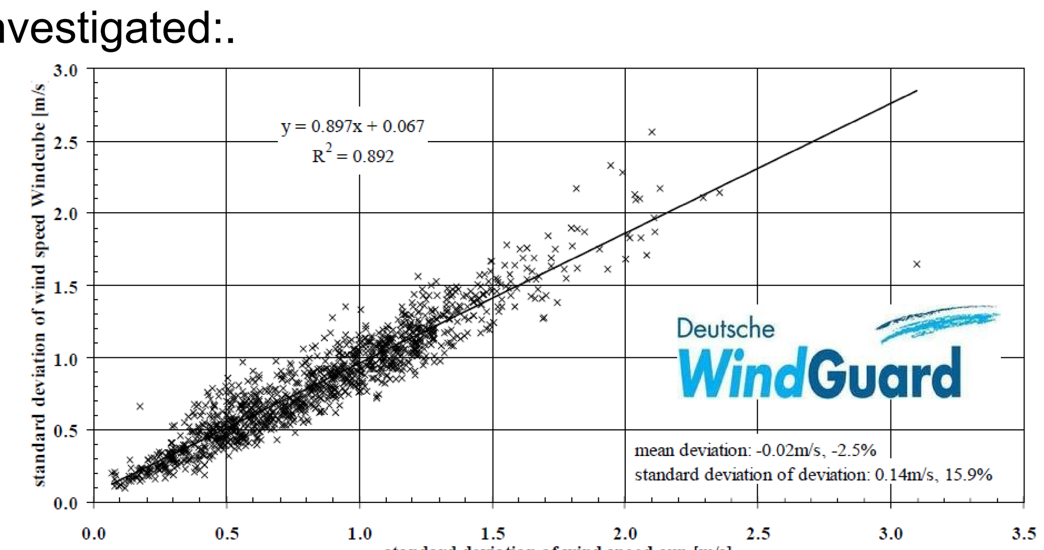
WINDCUBE® v2 lidar provides high quality horizontal wind speed and wind direction measurements. Retrieval of vertical wind speed has improved in order to get inflow-angle measurement with fair accuracy in comparison to sonic anemometry.

Measurement of standard deviations components

Turbulent diffusion is generally characterized by its second order moments. In the wind energy industry, one wants more specifically to study the wind regimes with the Turbulence Intensity (TI) parameters, given by the standard deviation over the mean value of the wind speed:

$$TI_U=\frac{\sqrt{\acute{u}^2}}{U} \qquad TI_W=\frac{\sqrt{\acute{w}^2}}{W}$$

Therefore accurate measurement of standard deviation is necessary, mainly for site suitability analysis. Several lidar to cup comparisons have however shown a deficit in the ability to accurately retrieve this parameter (see scatter plot below) and the reasons of that are being closely investigated:.



Every second, the WINDCUBE calculates two horizontal wind speed components u and v. The retrieval process mixes two opposite radial wind speeds S (from the four measured) for each of the u and v components. Example below for one sample i of u:

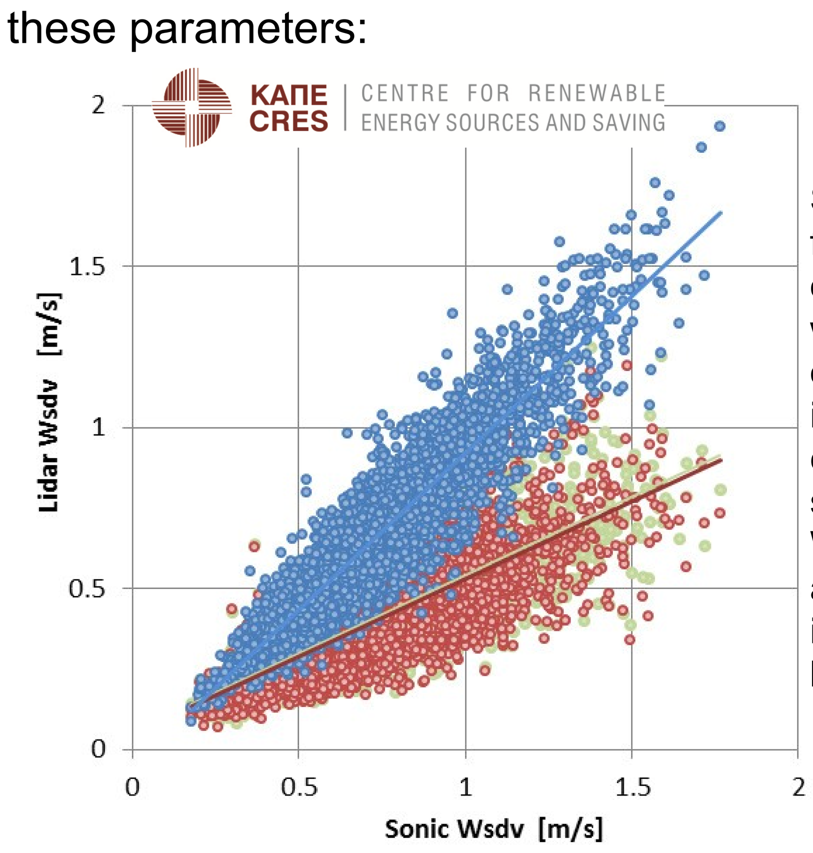
$$u_{lidar}(i)\begin{aligned}&=\frac{S_{\varphi=0}-S_{\varphi=\pi}}{2*sin\theta}\\&=\frac{u_{\varphi=0}+u_{\varphi=\pi}}{2}+\frac{w_{\varphi=0}-w_{\varphi=\pi}}{2*tan\theta}\end{aligned}$$

Therefore, the standard deviation estimated by the WINDCUBE on the *x-axis* for example is given by:

$$std(u_{lidar})^2=\frac{std(u_{true})^2+<\acute{u}_0\mid\acute{u}_\pi>}{2}+\frac{std(w_{true})^2-<\acute{w}_0\mid\acute{w}_\pi>}{2*(tan\theta)^2}+\frac{<\acute{u}_0+\acute{u}_\pi\mid\acute{w}_0-\acute{w}_\pi>}{2*tan\theta}$$

While the correct parameter to retrieve is $std(u_{true})$, on the above expression it is seen that the vertical component influences the turbulence intensity measured by the lidar through its second order moments: variance and covariance.

The study of turbulence intensities with lidars thus requires (at least) a good estimation of the vertical wind speed and standard deviation of it. For this reason the configuration of WINDCUBE® v2 lidar has been improved to better retrieve these parameters:



Standard Regression for standard deviation of 1min mean vertical wind speeds @100m on CRES test facility in Lavrio (moderately complex terrain) (red scatter plot is WINDCUBE® v1 lidar and blue scatter plot is WINDCUBE® v2 lidar)

- $Std(W_{windcube\ v1})=0.48*std(W_{sonic})+0.05m/s$
- $R^2=0.58$

- $Std(W_{windcube\ v2})=0.97*std(W_{sonic})+0.05m/s$
- $R^2=0.85$

On-going work

Today’s work concentrates on the study of the lidar raw data: the measured radial wind speed, which is the projection of the wind speed components on the lidar axis (described by the zenithal angle θ and the azimutal angle φ); and on the temporal variance and of the radial wind speed:

$$s(\theta,\varphi)=u*\sin(\theta)*\cos(\varphi)+v*\sin(\theta)*\sin(\varphi)+w*\cos(\theta)$$

and

$$\sigma_S^2(\theta,\varphi)=\overline{\left(S(\theta,\varphi)-\overline{S}(\theta,\varphi)\right)^2}=\overline{\acute{u}sin\theta cos\varphi+\acute{v}sin\theta sin\varphi+\acute{w}cos\theta}$$

Which can be developed into:

$$\sigma_S^2(\theta,\varphi)=\overline{\acute{u}^2}sin\theta^2cos\varphi^2\overline{\acute{v}^2}sin\theta^2sin\varphi^2\overline{\acute{w}^2}cos\theta^2+2\overline{\acute{u}\acute{v}}sin\theta^2cos\varphi sin\varphi+2\overline{\acute{u}\acute{w}}sin\theta cos\theta cos\varphi+2\overline{\acute{v}\acute{w}}sin\theta cos\theta sin\varphi$$

This expression can be derived for every line of sight measurement and recombinations can be done to retrieve variances and co-variances of the wind speed components.

Conclusions

WINDCUBE® v2 lidar shows very high performances in terms of measurement of horizontal wind speed, wind direction and inflow-angle. These parameters are retrieved with high fidelity toward the measurement of cup, vane and sonic anemometry. Though standard deviation of vertical wind speed has been encouraging for the WINDCUBE® v2 lidar, further improvement remain to be done on the retrieval of the standard deviation of horizontal wind speed.

Acknowledgement

The authors want to sincerely acknowledge Julia Gottschall from Risø DTU, Dimitri Foussekis from CRES, Iain Campbell from RES Group and Axel Albers from Deutsche Windguard for their cooperation in providing wind data and analysis.

References

1. M. Courtney, R. Wagner and P. Lindelöw, 2008, “Commercial LIDAR profilers for wind energy. A comparative guide”, Risø DTU
2. A. Albers & al., 2008, “Comparison of Lidars, German Test Station For Remote Wind Sensing Devices”, Deutsche Windguard GmbH
3. D. Foussekis, 2009, “CRES activities for WP6”, UpWind 6th meeting – WP6 Remote Sensing
4. I Campbell & al., 2010, “A Comparison of Remote Sensing Device Performance at Rotsea site”, RES Group