Seasonal Correction of Short-term Sodar and Lidar Measurements for Use in Energy Yield Assessments of Wind Farms

Karin Görner (DEWI GmbH), Annette Westerhellweg (DEWI GmbH), Simon Brillet (VALOREM)
DEWI GmbH, Ebertstraße 96, D-26382 Wilhelmshaven, Germany
Phone: +49 (0)4421 4808-846
Fax: +49 (0)4421 4808-843
Email: k.goerner@dewi.de

Summary

Sodar and Lidar measurements have become more and more important in the field of wind energy assessment. At planned wind farms with high hub heights they can evaluate the wind profile in addition to 1 year mast measurements. Wind profiles gained from short-term Sodar and Lidar measurement campaigns need a correction to consider seasonal variation in the atmospheric stratification before they can be applied. DEWI developed two methods following different approaches, which will be presented on data measured during a Sodar, Lidar and mast comparison campaign realised by VALOREM in the south west of France.

1 Motivation

Energy yield or site assessment reports are usually based on minimum one year measurement periods, to gain a representative wind direction and wind speed distribution, which is independent from seasonal variations [1]. Information from short-term Sodar and Lidar measurements can be used in addition to determine the wind profile up to great hub heights, which are exceeding the measurement mast height, to verify the wind and energy yield prediction model (e.g. WASP) to reduce the uncertainty of the calculation.

Periods of Sodar and Lidar measurements usually cover only a few weeks. For this reason special care needs to be given to seasonal changes of the wind profile (see Figure 1). DEWI developed two different methods for a seasonal correction of short-term measured wind profiles: the Solar Zenith Angle Correlation (section 3) and the Wind Gradient Correlation (section 4).

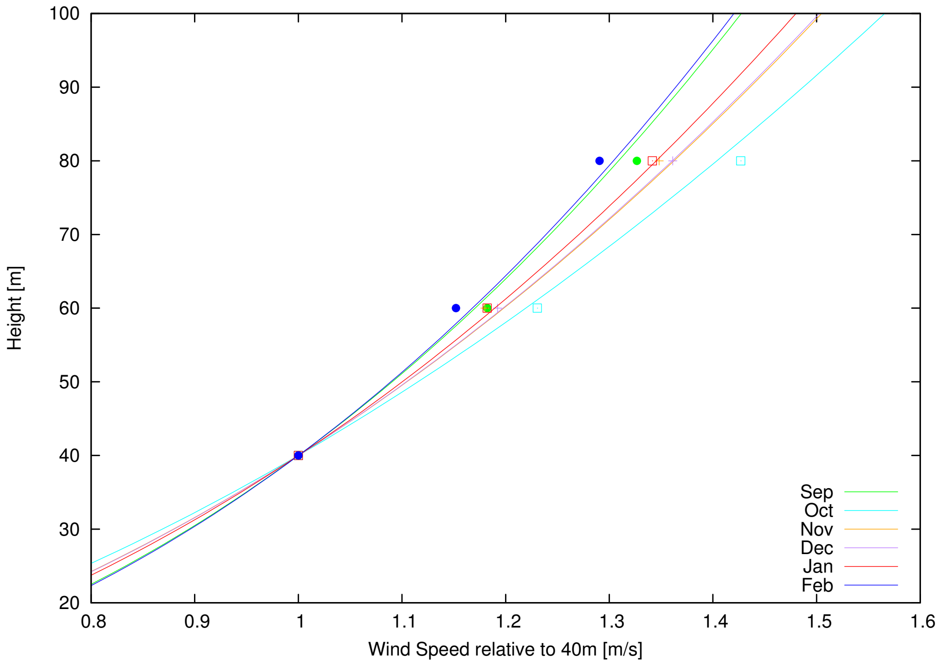


Figure 1: Monthly evolution of wind profile measured with a mast on a site in France, calculated on basis of the wind power law. Wind speeds are relative to 40m of each month.

2 Measurement Campaign

The French developer VALOREM started a measurement campaign in July 2009 at a site in the south-west of France for a comparison study between a mast, Sodar and Lidar. The study was prepared by DEWI. Main properties of the setup are summarised in Table 1.

The met mast is located on a field with a distance of about 500 m east from a pine forest. Lidar and Sodar were set up in a distance of about 55 m east to the mast. About 180 m east of the remote sensing instruments a 30 m wide pine forest band ranging from north-east to south-west defines the border of the site. In the north and in the south the site is quite free of any influence up to 1.5 km. Numerous forested areas determine the further surrounding.

The measurement mast (met mast) is equipped with Second Wind C3 and Thies First Class (T1) anemometer. Wind direction is measured with NRG 200P wind vanes, double boom-mounted in 45m and 65m height. The mast is still in use. All wind speed data from the met mast presented in the following refer to a Thies First Class anemometer. Mast shading effects were filtered out.

The remote sensing instruments used were a WindCube Lidar from Leosphere and a Triton Sodar from Second Wind. Both manufacturers have supported the set-up of their remote sensing instrument at the site. The system availability of the Lidar is low due to maintenance problems at the beginning of the measurement campaign (Figure 2). The Sodar and Lidar data were filtered with standard filtering methods based on delivered quality criteria from the instruments software. Table 2 presents the availability of valid Sodar and Lidar data for common measurement heights up to 120m.

Only wind speed values greater 2 m/s were considered in the following. Predominant wind directions at the site are west and east south east. Figure 3 shows the correlation between mast data and Sodar/Lidar data for the period 2009-07-17 to 2009-11-19 (common data sets).

Instrument	**Measurement Mast**		**Lidar (WindCube)**	**Sodar (Triton)**
Measurement period start stop	2009-07-10 2010-03-15		2009-07-10 2009-11-19	2009-07-17 2009-12-04
System Availability	100.0%		69.6%	100.0%
measuring heights	boom North	boom South	**40m**, 50m, **60m**, 70m, 75m, **80m**, 100m, 120m, 145m, 170m	**40m**, 50m, **60m**, **80m**, 100m, 120m, 140m, 160m, 180m, 200m
	80m (T1), 75m, 70m, **60m (T1)**, **40m* (T1)**, 15m	80m, 75m, 60m, 50m, 40m, 25m		

Table 1: Overview on Measurements (T1 = Thies First Class)
*The Thies First Class was only installed at 25th of August 2009.

Height [m]	Valid Lidar Data	Valid Sodar Data
40	99.6%	94.4%
60	99.3%	93.4%
80	98.7%	89.7%
100	97.4%	84.2%
120	95.9%	77.9%

Table 2: Data availability after application of filter procedures at Lidar and Sodar (100% = individual period of raw data).

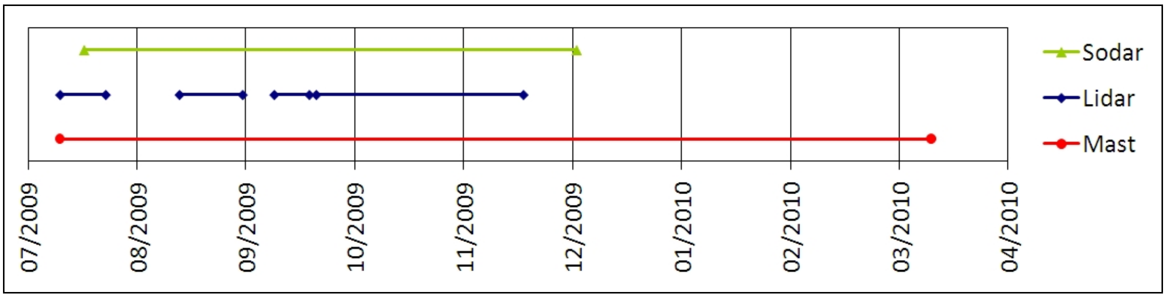
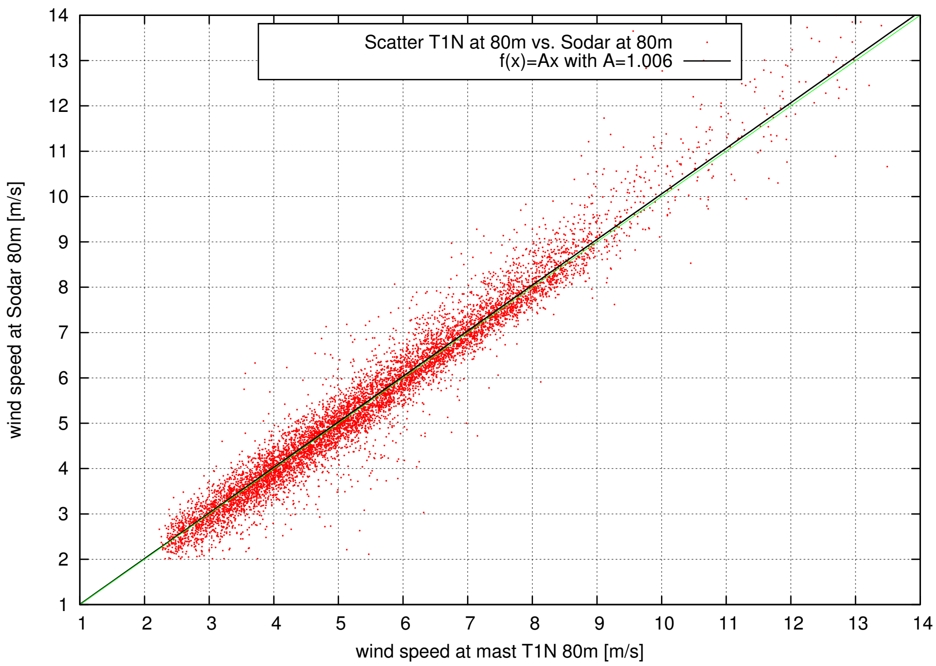


Figure 2: System availability of the measurements.



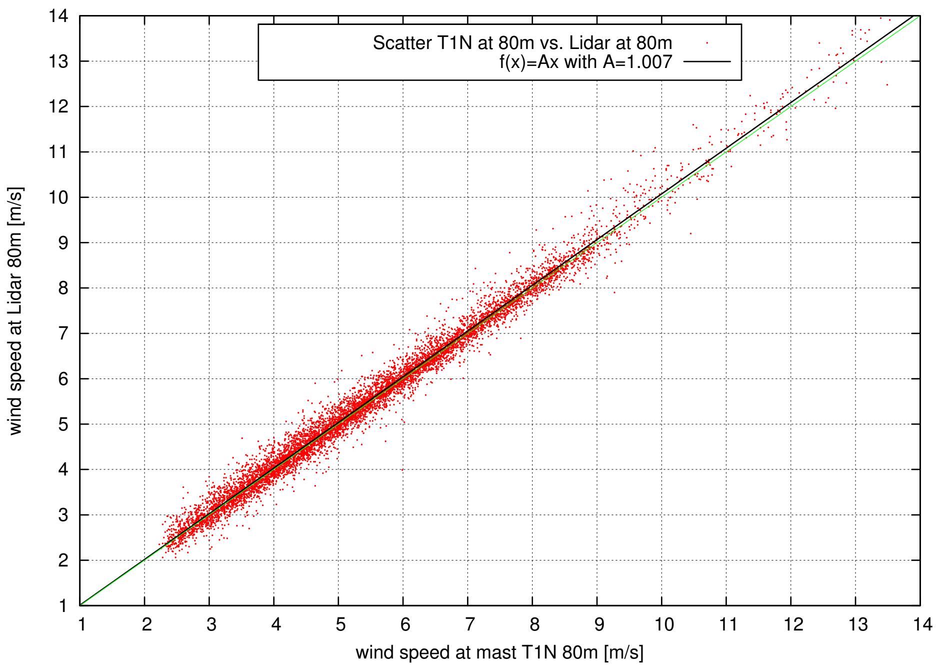


Figure 3: Wind speed scatter plots in 80m height for mast with Sodar (above) and mast with Lidar (below). Black line: linear regression function. Green line: identity.

3 Method I - Solar Zenith Angle Correlation

The method utilizes a dependence of the wind profile on the solar altitude. The approach is based on the fact, that the development of the daily wind profile is connected to the thermal driven development of the stratification, which again underlies a seasonal variation.

The solar altitude is represented by the cosine of the solar zenith angle (calculated after [2]), ranging from -1 to +1 the lowest and highest possible solar altitude (zenith position). The value Zero marks the sun rise and sun set. For each time step of the measurement this value is calculated under consideration of the geographical position of the site. The wind profile is represented by the wind speed ratio of two different heights, which are usually the met mast top height and the height of interest (considered hub height).

Figure 4 and 5 show scatter plots of the wind speed ratio (100m/80m) measured with the Sodar and the Lidar versus the cosine of the solar zenith angle. The average ratio for cosine zenith angle bins with a width of 0.05 is displayed by black marks with error bars. The blue line indicates the bin count during the short-term measurement period. An average wind speed ratio closer to one can be observed during day, when the stratification is rather unstable. During night, when the stratification is rather stable, usually higher ratios occur. Less scatter can be observed during day compared to night.

An overall wind speed ratio representative for 1 year can be calculated by weighting each bin-wise wind speed ratio (black marks with error bars) gained from the short-term measurement with the according bin frequency of one year (green line).

The scatter in Figure 4 and 5 is determined by following factors:

- all atmospheric situations are considered, also those where the development of the wind profile is not primarily driven by the thermal heating/cooling of the ground,
- direction dependent influences due to topography,
- situations at night with a stable boundary layer height lower than hub height (the flow above the layer is decoupled from the flow near the ground),
- measurement accuracy and therefore the measurement principle of the used instrument (volume measurement in case of Sodar and Lidar).

The short-term Sodar/Lidar measurement period should be representative with respect to measured wind speed, wind direction and coverage of different stratification situations (stable, neutral, unstable), when applying this procedure.

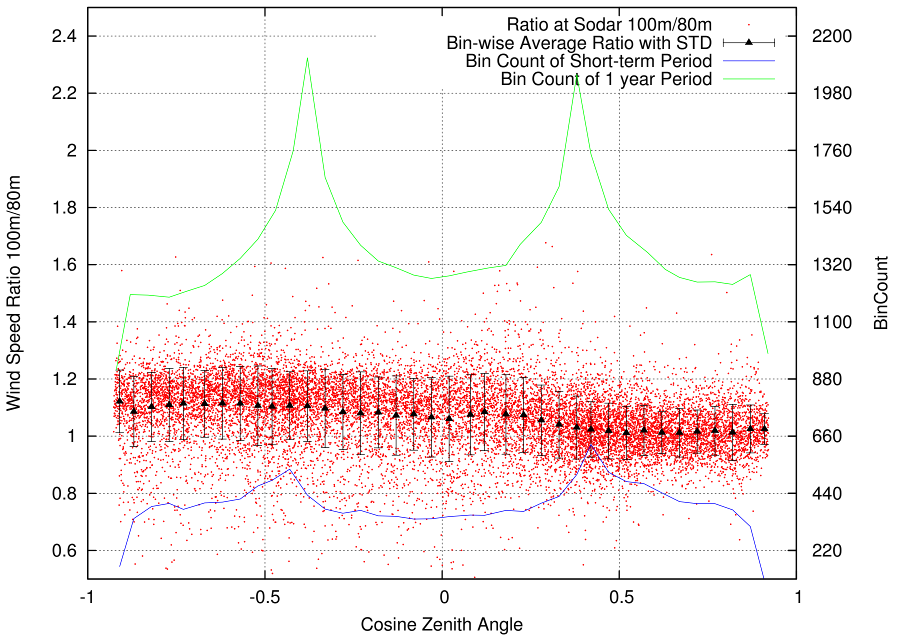


Figure 4: Measured wind speed ratio 100m/80m with Sodar versus cosine zenith angle.

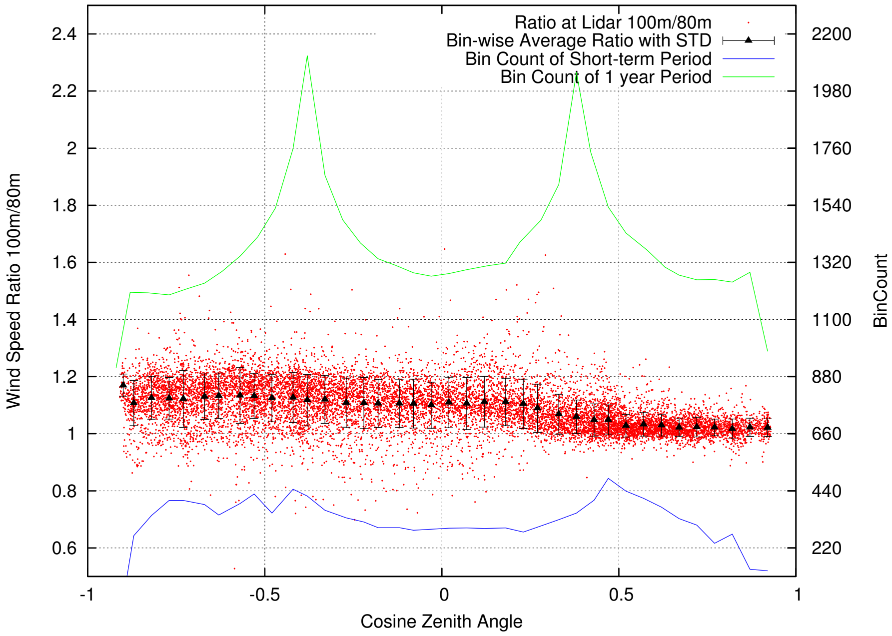


Figure 5: Measured wind speed ratio 100m/80m with Lidar versus cosine zenith angle.

4 Method II - Wind Gradient Correlation

DEWI is following another approach to realise the correction of short-term measured wind profiles without knowledge about the stratification situation. By correlating relative wind speed gradients measured with met mast at lower heights and measured with Sodar/Lidar at larger heights during the common measurement period, a relation between the gradients can be found. Strong or low gradients at the met mast go along with strong or low gradients at the Sodar/Lidar. It is assumed that the relation of wind speed gradients is independent from the season.

A parameter study using the Monin-Obukhov-theory for calculation of the wind profile under different stratification situations by variation of the stability parameter L shows that the relation between relative wind speed gradients in different heights can be fitted quite well by a linear approximation [3]. The method is based on the assumption that the logarithmic wind profile and the Monin-Obukhov-theory are valid up to hub height.

Figure 6 and 7 show scatter plots for relative wind speed gradients measured with the met mast (v80-v60)/v80 and with Sodar/Lidar (v100-v80)/v80. The wind speed measured in the height of the met mast top is always used as reference wind speed. A high accuracy of the measurements is needed as the measurement error sums up within the calculation of the relative wind speed gradients, which is affecting the scatter.

The linear fit considering all wind direction sectors (green line) shows a correlation of 0.47 with the Sodar data and 0.76 with the Lidar data. Higher correlation can be gained considering wind direction sectors of 30° or smaller (blue lines). Applying the gained direction-dependent relations to the one-year mast data, allows the extrapolation of the measured wind speed at met mast top (here 80m) to hub height, e.g. 100m.

5 Results

Both methods have been applied on the short-term Sodar and Lidar data to predict the wind speed ratio between 80m and 60m for the met mast period 2009-07-10 to 2010-03-15 (Table 3). Method I scales the measured ratios gained from Sodar/Lidar up and method II scales the ratios down.

The measured ratio gained from the met mast during period 2009-07-10 to 2010-03-15 is 1.134. Method I is very close to the result. The applied correction factor is only small compared to the uncertainty of the methods, which is defined by the scatter (Figure 4 to 7).

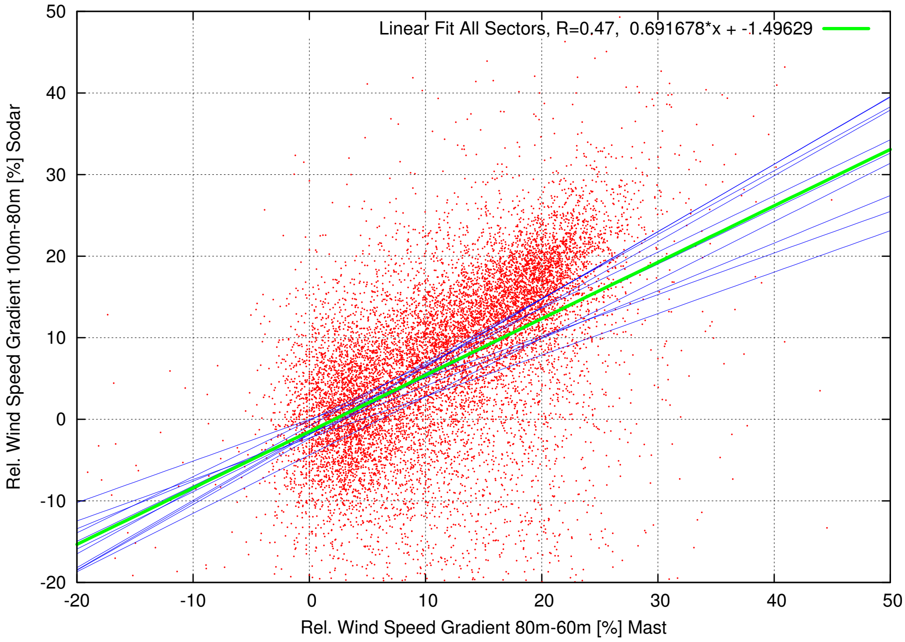


Figure 6: Scatter plot of relative wind speed gradients measured at met mast and Sodar with best fit linear regression function.

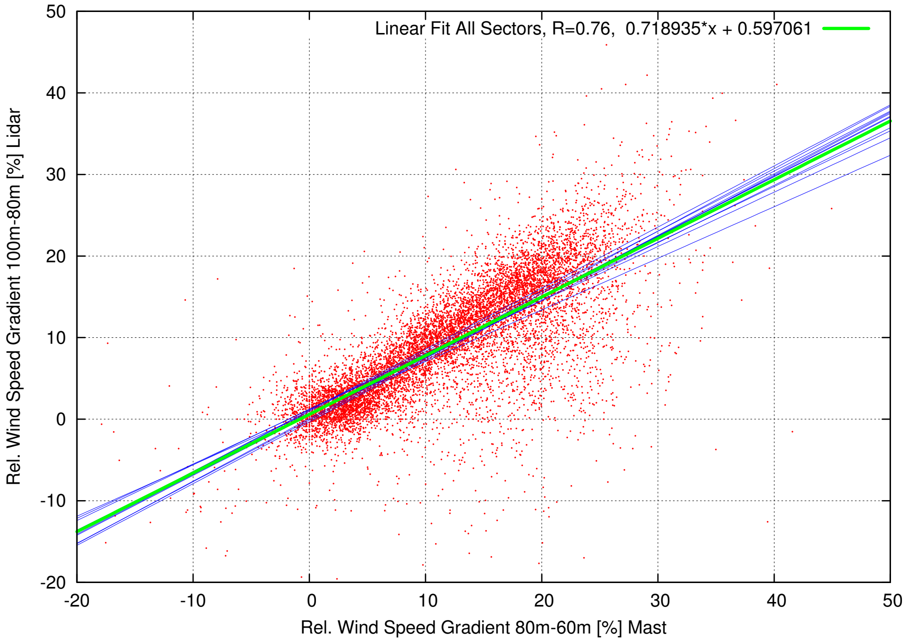


Figure 7: Scatter plot of relative wind speed gradients measured at met mast and Lidar with best fit linear regression function.

Wind Speed Ratio 80m/60m	**Lidar**	**Sodar**
measured during short-term period	1.130	1.128
pred. with Method I	1.135	1.134
pred. with Method II	1.123	1.122

Table 3: Wind speed ratio measured with Sodar and Lidar and predicted for the period 2009-07-10 - 2010-03-15 for comparison with mast data.

6 Conclusion

DEWI developed two methods for a seasonal correction of short-term measured wind profiles, which are following different approaches - both with assets and drawbacks.

The solar zenith angle correlation is based on the approach that the wind profile development is connected to the development of the stratification, which is on the other hand partly related to the solar altitude. Due to the complexity of this relationship, influenced also by other atmospheric parameters, there is quite large scatter. Still a significant relation can be found. The method can be improved by direction-dependent consideration, which is recommended at sites with strong roughness variation in the near surrounding. The method does not work at sites that expect to have a change in albedo during the year (e.g. due to snow coverage).

The wind gradient correlation works without knowledge about the stratification situation. The results are only reliable, if a high correlation between the wind speed gradients at mast and Sodar/Lidar is visible. According to DEWI's experience this is rarely the case due to the scatter. The scatter is mainly defined by the accuracy of the measurement instruments. The difference in the measurement principle between mast (punctual measurement) and Sodar/Lidar (volume measurement) plays an important role. A validation of the method only with mast data has been performed by DEWI and showed only 2-3% deviation comparing the correlated with the measured results [3].

For both methods it is necessary to check if the short-term Sodar/Lidar measurement period is representative with respect to measured wind speed / wind direction and coverage of different stratification situations (stable, neutral, unstable). This is more likely the case, if the measurement has been performed during the transition time between summer and winter [4].

Furthermore both methods rely on the validity of the logarithmic wind profile up to the considered hub height. Situations when this does not apply occur rather during night, when the height of the stable boundary layer is low. It increases the uncertainty of both methods, due to outliers in the scatter plots (larger scatter).

References

[1] MEASNET. Evaluation of Site-Specific Wind Conditions. Vers.1, Nov. 2009

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[3] Mellinghoff H, Strack M. Erfahrungen aus dem Messbetrieb mit SODAR. *DEWEK 2002*.

[4] Pietschmann K, Dr. Mönnich K, Priv.-Doz. Dr. Emeis S. Application of Sodar Measurements for Energy Yield Assessment. *DEWI Magazin Nr.31*, Aug. 2007.