Operational Characteristics of SODARs – External Meteorological Influences

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Abstract

For wind measurements in the area of wind energy applications SODARs are supposed to be a potential alternative to classical cup anemometer and wind vane measurements at meteorological masts, especially when wind speed and direction measurements at higher altitudes (above 80 to 100 m) are required. In the European funded WISE-project (Wind Energy Sodar Evaluation) SODAR and other meteorological measurements were performed in order to investigate the capabilities and operational characteristics of available SODAR systems under different atmospheric conditions. Analysis of the data availability of a SODAR system in conjunction with the atmospheric stability revealed a remarkable loss of data during near neutral stratification conditions, and it appears to be more pronounced above measuring heights of about 100 m.

1. Introduction

In the field of wind energy, measuring the wind speed for purposes like site assessment or wind turbine power curve verification is usually performed using cup anemometers mounted on top of met towers, preferably at the turbine hub height. With the ongoing enlargement of wind turbines their hub height increases and hence the necessary measurement height, leading to rising costs associated with wind measurements. This gave birth to the idea to use wind speed remote sensing techniques for higher altitude wind detection. A monostatic phased array SODAR, measuring wind speed profiles over vertical ranges of up to 200 m and more (e.g. over a wind turbine's rotor disk) seems to be the appropriate technique. Though, the ability of SODARs to deliver correct measurements is influenced by atmospheric conditions such as precipitation, atmospheric stability, wind speed, and other parameters.

As one part of the European funded WISE-project (Wind Energy Sodar Evaluation) the influence of various external meteorological parameters on the operational characteristics of different types of SODARs – e.g. with respect to the reliability and yield of the received data – were investigated. The main purpose of the still ongoing WISE project has been, to evaluate the suitability and applicability of SODAR measurements for standardized wind energy measurements like power performance test. For that reason SODARs were operated on different flat terrain test sites in the vicinity of meteorological met masts, being equipped with a variety of meteorological sensors.

A couple of meteorological parameters like wind speed, temperature, vertical gradients of wind speed and temperature (and others) were investigated regarding their influence on operational characteristics of SODARs. The emphasis of the results presented here lies on the data availability (or data yield) as being dependent on the stability of the atmosphere

2. Measurements

The SODAR measurements were simultaneously performed in conjunction with meteorological mast measurements on the WINDTEST test site in Kaiser-Wilhelm-Koog, located in Northern Germany close to the North Sea. A monostatic multi-frequency phased array SODAR of the type Scintec SFAS was used. The device's parameters were set to reach maximum measuring heights of 200 m and to produce profiles of the 3D-wind-field with a vertical resolution of 5 m. The averaging period for the recording of the vertical profiles was set to 10 minutes. The distance between SODAR and the met mast amounted to about 150 m. Meteorological parameters like wind speed and direction as well as temperature, pressure, relative humidity and others were taken on various levels between ground level and the top of the met mast at 60 m. Temperature and wind speed gradients – as an input for the stability calculations – were taken from differences between two met mast sensor levels, i.e. from 60 and 10 m for wind speed and from 55 and 5 m for temperature.

3. The Richardson Number

The non-dimensional Richardson Number, which is directly connected to the vertical temperature gradient and the vertical wind speed gradient (wind shear),

$$Ri = \frac{g}{\theta}\frac{d\theta}{dz} / \left(\frac{dU}{dz}\right)^2 \qquad (1)$$

represents a non-dimensional measure for the stability of the atmosphere (g: gravity, θ: potential temperature, U: wind speed). Since the gradients as taken from the met mast measurements could only be calculated as differences between two measuring levels (some 50 m apart) the Ri- number becomes a bulk number.

4. Results

To calculate the Ri-number temperature and wind speed differences (i.e. vertical gradients) had to be calculated and were taken from 10-minute-averages of an explicit temperature difference device (with PT500 sensor on 55 and 5 m) and from two cup anemometers mounted on 60 and 10 m, respectively. Figure 1 shows in the upper panel the distribution (histogram) of 10-minute-averages of potential temperature differences (converted from the in-situ difference temperature measurements) as recorded over a period of almost 2 months between 2003-05-23 and 2003-07-23. The distribution reveals a clear majority of smaller positive and negative difference values.

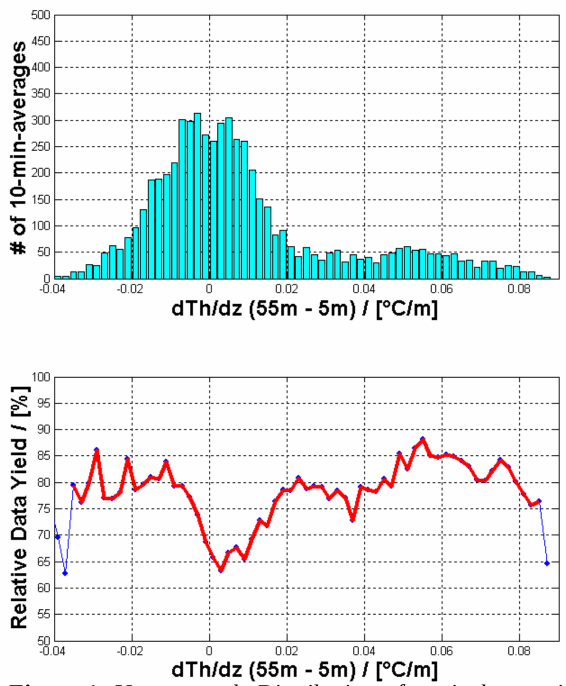

Figure 1. *Upper panel: Distribution of vertical potential temperature gradient as observed from 2003-05-23 to 2003-07-23. Lower Panel: Percentage of relative data yield of SODAR receptions for the same period, plotted versus pot. temperature gradient.*

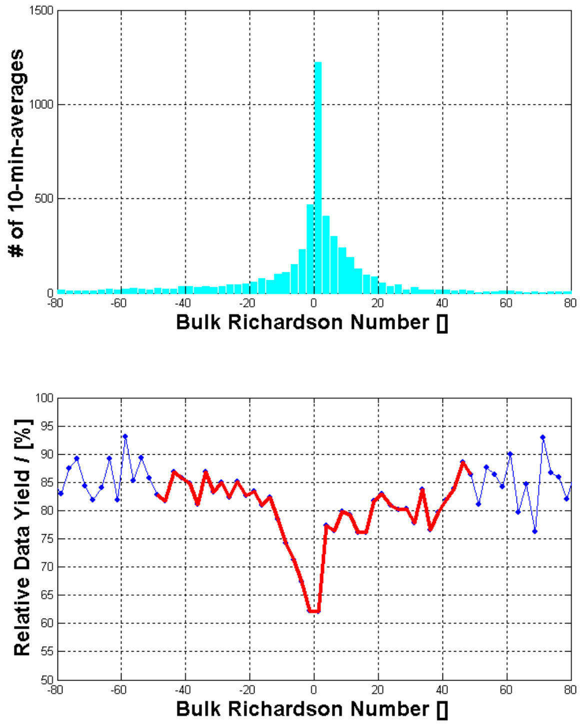

Figure 2. *Upper panel: Distribution of Bulk Richardson number as observed from 2003-05-23 to 2003-07-23. Lower panel: Percentage of relative data yield of SODAR receptions for the same period, plotted versus the Bulk Richardson number.*

The lower panel in figure 1 shows the relative data yield (as a percentage relative to the maximal possible data yield) of the deployed SODAR for the same measuring period, plotted against the potential temperature difference. The relative data yield of the SODAR was calculated by taking the number of “good” height cells (i.e. usable receptions of the back scattered acoustic SODAR signal) for each 10-minute averaged profile. Then the profiles were binned within temperature difference classes according to their respective temperature difference value, as simultaneously recorded. Within those temperature classes the numbers of “good” height cells of the binned profile were then summed up, and finally this result was divided by the possible maximum number of height cells of all binned profiles. This resulted in a kind of vertically integrated or averaged data yield, that was plotted against the binning parameter, which in figure 1 (lower panel) is the vertical gradient of the potential temperature. The heavily plotted curve shows a clear drop in the data yield to below 70 % for values slightly above vanishing potential temperature differences, i.e. at values between 0 and 0.02 °C/m.

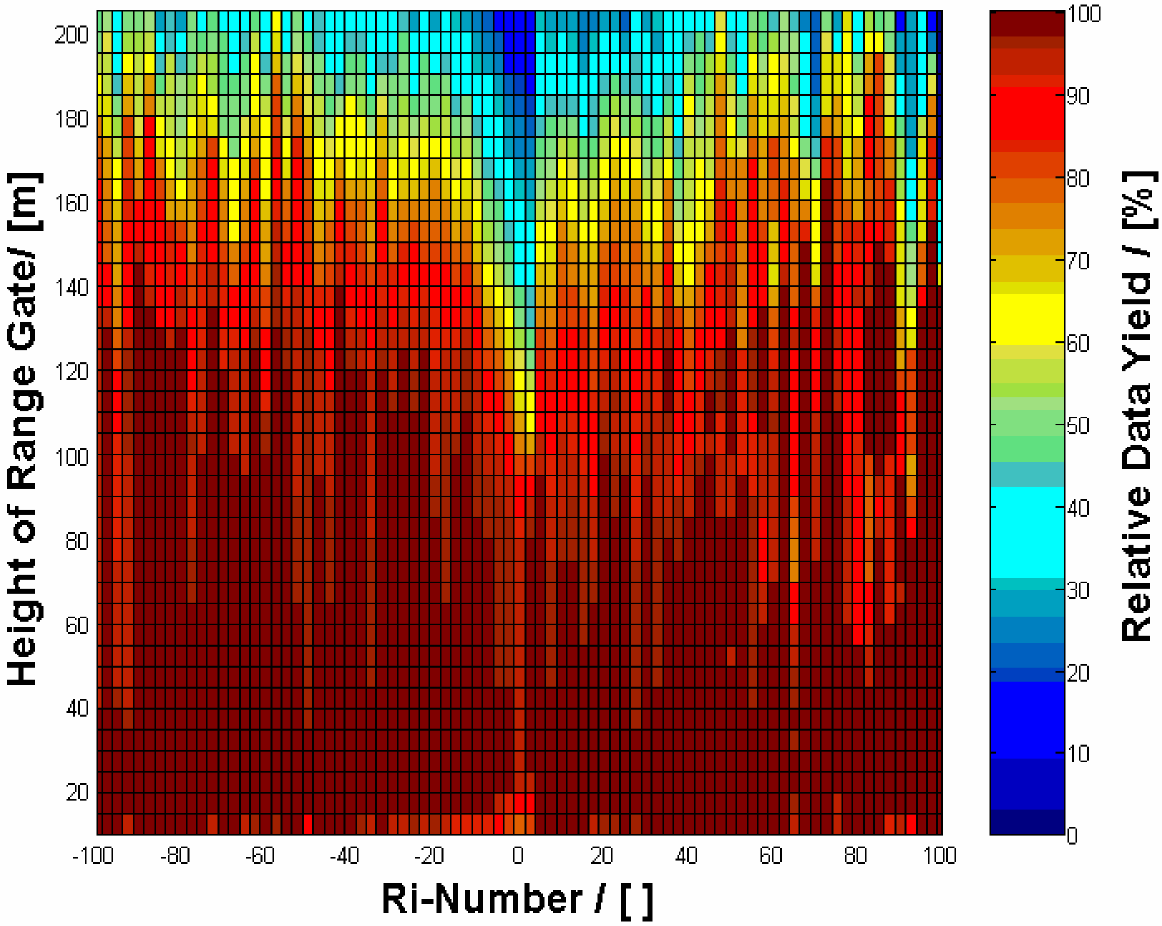

***Figure 3**. Percentage of relative data yield of SODAR receptions as colour map, plotted against height of the SODAR range gates and against the Bulk Richardson number, as calculated from vertical temperature and wind speed gradients, taken from meteorological met mast measurements.*

Combining temperature gradients and wind speed gradients to the Ri-Number, according to equation (1), resulted in figure 2. Its lower panel shows a sharp drop of the vertically averages data availability to below 65 % at Richardson numbers near zero, i.e. at near neutral atmospheric stratification conditions. The vertical wind speed gradient (not shown here) didn't seem to contribute much to the break down of data availability, so it's more related to the temperature gradient. Taking into account that in most cases there are neutral conditions present (as can be seen in the Ri-number distribution in upper panel fig. 2) the lack of data is even more important.

To resolve the data availability vertically, the same relative data yield derivation was performed for each individual height cell (between 15 and 205 m, 5 m cell width), resulting in a colour map as shown in figure 3. Here the colour scales the percentage of the data yield (as of the colour bar on the right), the horizontal axis represents the Ri-Number and the vertical axis the height above ground level of each SODAR back scattering cell. The drop of the data yield at near neutral conditions (Ri-number near zero) can clearly be seen. It is most pronounced at heights above 100 m, rapidly falling to below 40 % at about 140 m.

5. Concluding Remarks

In a field experiment comparing classical wind measurements with soundings of an acoustic Doppler wind profiler a remarkable loss of usable SODAR receptions of almost 40 % was observed during near neutral atmospheric stratification conditions. A significant amount of data loss seems to happen at heights of above 100 m. Below that the back scattered SODAR signal might be strong enough to ensure good quality receptions

For power performance tests – to be carried out by SODARs on larger wind turbines in the future – such data loss will generally result in longer measuring campaigns in order to get a sufficient number of usable wind soundings, compared to classical cup anemometer (met mast) measurements. Furthermore a reduced data availability of SODAR measurements will create problems when employed for wind speed and direction assessments on potential wind farm sites. Here generally a 100 % temporal data coverage is demanded, in order to produce a complete wind statistics over a full seasonal cycle to allow for a reliable prognosis of the long term wind energy production.

Acknowledgments

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