Calibration of SODARs for wind energy applications

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Abstract

Traditionally SODAR wind profilers have been assumed to be largely self-calibrated, with measurement errors mostly random. However, increasing demand for accuracy in applications such as wind energy demand robust calibration and intercomparison procedures. Comparisons of three commercial SODARs show that performance can be optimised when care is taken with siting, parameter settings during the measurements and data filtering. Instrument design changes can give additional improvements. Recommendations for generic calibration procedures are presented. An outlook on a new standalone calibration method is given.

1 Introduction

As part of a larger EU project on use of SODARs for wind energy, the Profiler Intercomparison Experiment (PIE) developed and tested calibration procedures and formulated guidelines for manufacturers to optimise SODAR wind results. The primary goal was to compare SODAR measurements with a cup measurement on an inexpensive low mast (40 m) and extrapolate the calibration to the remaining range gates of the SODAR.
Three commercial SODARs from different manufacturers were operated at non-overlapping frequency bands about 70 m from a 118m meteorological mast at the Risø - Høvsøre Meteorological Station, DK from March to June 2004. The mast was instrumented with cup anemometers at six levels, 6 sonic anemometers and 2 vanes giving a detailed wind profile (Bradley et al., 2005, Antoniou et al., 2004 and Kindler et al., 2004). Data quality was assured by real time filtering and post processing of the SODAR data sets. Filtering of cup anemometer data excluded sectors affected by the mast construction and low wind speed data.

2 Sources of inaccuracy

While comparisons between meteorological masts and SODARs have a long history, a systematic tracking of error sources seems not to have been attempted.
The sources of error in SODAR data can broadly be classified into three categories: (1) Geometrical errors due to inaccurate height estimation tilt angle and scattering angle; (2) Bias in wind estimation due to problems with calibration, incomplete data, volume separation and averaging; and (3) Low signal-to-noise ratio (SNR) created by background noise or driven by atmospheric stability (Kindler et al. 2004). These errors may be combined to provide an error budget for SODAR measurements of wind speed (Table 1).
The first 3 errors are due to poor setting up of the SODAR and can usually be avoided. Rain data can be filtered out using a sensitive rain gauge. Beam spread, drift, separation and averaging (Antoniou et al., 2003) are fixed through SODAR design. A narrow beam SODAR with a moderate tilt angle will generally have small beam and beam separation error. Beam drift error is inescapable, but generally also negligible over common wind ranges. Some of the errors are larger for beams having a greater tilt angle, but the peak detection resolution is improved if the Doppler spectrum is more spread, which occurs for larger tilt angles.
All except for the peak position error can be systematic (rain and fixed echo errors vary with conditions, but when present can lead to persistent errors which are non-random).

Table 1. Error sources and estimates for SODAR derived wind speed

Source	Parameter	Slope error $\frac{\hat{u}}{u}-1$	Parameter range	Error range
Temperature	ΔT [K]	$+\frac{\Delta T}{2T}$	±20 K	± 3 %
Out of level	$\Delta\varphi$ [radian]	$-\frac{1}{2}(\Delta\varphi)^2$	±15° (±0.3 rad)	-3.5 % to 0 %
Fixed echoes	Δx [m]		0 to 500 m	0 to -100%
Rain	R [mm/h]		0 to 50 mm/h	20 - 30 m s^{-1}
Beam spread	σ_φ [radian] φ [radian]	$+2\frac{\sigma_\varphi^2}{\sin^2\varphi}$	4°-8° (0.07-0.14 rad) 15°-24° (0.26-0.42 rad)	+6 % to +25 %
Beam drift	u/c	$\pm\sqrt{2}\frac{u}{c}$	0 to ±0.06	0 % to ±8.5 %
Beam separation	$\rho(\Delta x)$	$-(1-\rho)$	0.8? to 1	-20 % to 0 %
Vector averaging	z_0 [m] z [m]	$\frac{1}{2\left(\ln\frac{z}{z_0}\right)^2}$	0.01 to 2 m 10 to 1000 m	0 to 10 ?
Peak position	$\sigma_{\Delta f}$ [Hz] φ [radian] f_T [Hz]	$\pm\frac{c}{\sqrt{2}\sin\varphi}\frac{\sigma_{\Delta f}}{f_T}$	±0.5 Hz 15°-24° (0.26-0.42 rad) 1000 to 6000 Hz	0 to 10

3 Results of regressions

One important question is how representative comparisons between a SODAR and a cup are, given that one is a spatially averaging and one an in-situ device. Figure 1 compares the RMS residual error of the Aerovironment-cup regression at 60m to that of the cups at 60 m and 80m for wind speeds between 0 and 20 m/s. Systematic differences between SODAR-cup and cup-cup comparisons are not evident.

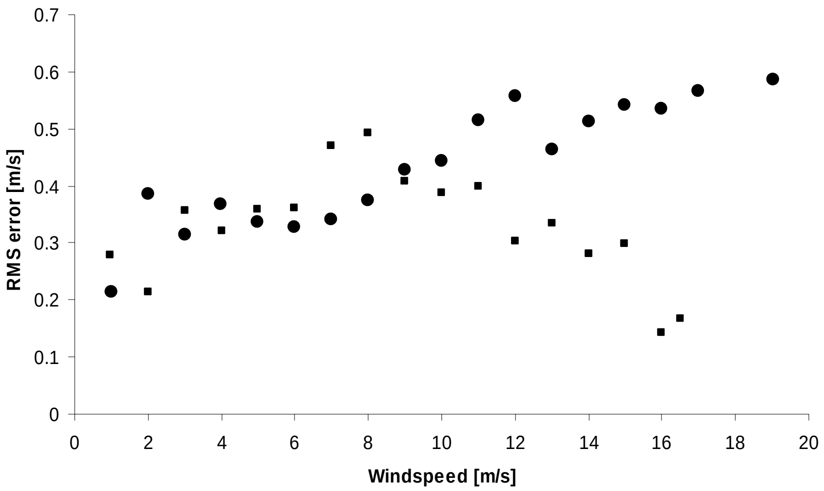

Figure 1. RMS residual error (i. e. uncertainty in least-squares fitted windspeed) vs windspeed. Circles: Aerovironment 4000 vs cups at 60 m; squares: cups at 80 m vs cups at 60 m.

Whereas a systematic bias between the SODAR and Cup measurements can easily be removed by the calibration method, care needs to be taken to avoid systematic changes in the regression slope with height to optimise the extrapolation procedure (Figure 2).

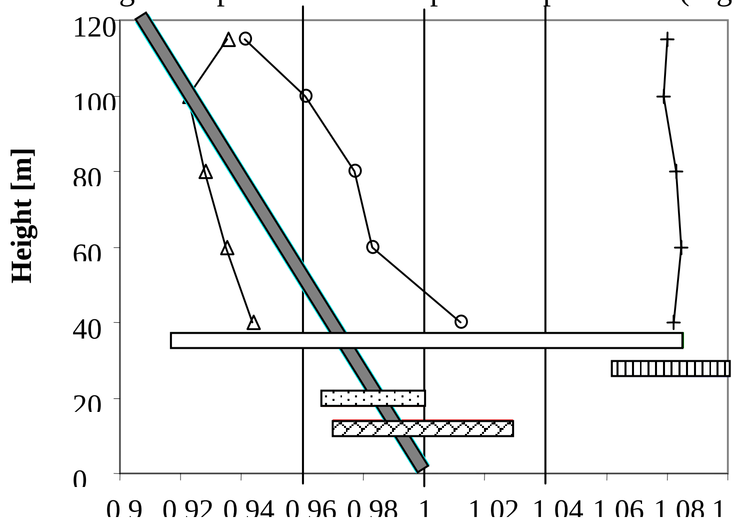

Figure 2. Variation in regression slope with height (+= Aerovironment, △= Metek, ○ = Scintec) and regions of applicability of various errors, compared with calibrations. Temperature (diagonal filling); out of level (dotted filling); beam spread (vertical filling); beam drift (white filling); beam separation (grey filling).

Temperature, out of level, beam spread and beam drift errors introduce a constant slope error, whereas slope introduced by the beam separation decreases with height.

4 Conclusions, and Outlook

The PIE experiment has shown that SODAR performance can be improved by comparison with a meteorological mast. There is further scope for enhancement through the implementation of design changes for SODARs such as fixed echo detection algorithms and rain detection algorithms. In addition, the need for stand-alone calibration techniques which are independent of costly mast installations has become apparent. The European Framework 6 UpWind programme aims to develop such a standalone method utilising methods similar to those proposed by Baxter (1994). The aim is to use an acoustic transmitter/receiver device recording the emitted SODAR pulse or pulse sequence, simulating a wind-profile giving a pseudo-atmospheric response and feeding this response back into the SODAR in real time.

Literature

Antoniou, I., H. E. Jørgensen, F. Ormel, S. G. Bradley, S. von Hünerbein, S. Emeis, G. Warmbier, 2003: On the Theory of SODAR Measurement Techniques (final reporting on WP1, EU WISE project NNE5-2001-297). Ioannis Antoniou (ed.), Hans E. Jørgensen (ed.), Risø National Laboratory, Roskilde, Denmark.

Antoniou, I., H. E. Jørgensen, S. von Hünerbein, S. G. Bradley, D. Kindler, 2004: Inter-comparison of commercially available SODARs for wind energy applications. Proc. 12th International Symposium on Acoustic Remote Sensing and Associated Techniques of the Atmosphere and Oceans, 12 - 16 July 2004, Cambridge, UK.

Baxter, R. A., 1994: Development of a universal acoustic pulse transponding system for performance auditing of SODARs. Proc. 7th International Symposium on Acoustic Remote Sensing and Associated Techniques of the Atmosphere and Oceans, 3 – 7 October 1994, Boulder, US

Bradley, S. G., I. Antoniou, S. von Hünerbein, D. Kindler, H. Jørgensen, M. de Noord, 2005: SODAR calibration for wind energy applications, final reporting on WP3, EU WISE project NNE5-2001-297, Salford

Kindler, D., I. Antoniou, H. E. Jørgensen, S. von Hünerbein, S. G. Bradley, , 2004: Operational Characteristics of SODARs - External Meteorological Influences. Proc. 12th International Symposium on Acoustic Remote Sensing and Associated Techniques of the Atmosphere and Oceans, 12 - 16 July 2004, Cambridge, UK.