Long-Time Comparison of Remtech PA2 Sodar Wind and Turbulence Measurements with Cabauw Tower Data

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1. Introduction and motivation

A considerable number of sodar - tower comparisons have been published in the past. A recent review was given by Crescenti (1997). While these studies agree that the mean horizontal wind measured by the sodars is reliable, the results concerning turbulent parameters – the foremost one being the standard deviation of the vertical wind component, σ_w – are not conclusive. Seibert and Langer (1996) had found a marked bias in the σ_w data of the Remtech A0 sodar and attributed it to a systematic difference in valid echos from updrafts and downdrafts under convective conditions. The aim of the present study was to obtain results for the Remtech PA2 system, a widely used, commercial sodar, during a period long enough for reliable statistics under different states of the boundary layer.

The study was conducted at the Cabauw field site of the Royal Netherlands Meteorological Institute (KNMI) with its 200 m instrumented tower. KNMI operates a boundary-layer wind profiler with RASS option there, too. During the year 1996, the Department of Meteorology at the Agricultural University Wageningen operated fast-response propeller anemometers (so-called K-vanes) on this tower so that turbulence data were also available. A detailed description of the site and the routine measurements is given by Monna and van der Vliet (1987). The site is located between the villages of Lopik and Cabauw in the Netherlands at 51°58'N and 4°55.5'E. The surroundings are flat within 25 km. The site is not completely homogenous. While there is a good fetch in the SW, there are trees a few hundred metres E of the site.

2. Measurement set-up

2.1 Sodar measurements

The PA2 is a phased-array system with 196 individual speakers/receivers, manufactured by Remtech S.A. It uses 5 different frequencies around 2250 Hz and a pulse length of 200 ms for each frequency. The tilted beams have an angle of 30°to the vertical. The system had been delivered in 1993 and version V6.06 of the operating system, delivered in July 1996, was used. Values were obtained from 30 atmospheric layers, the minimum height being 20 m and the height increment 20 m. In order to minimise nuisance to the neighbours, the signal power was reduce by 5 dB from 20 UTC to 3 UTC (22 to 5 CEST). Measured quantitities were recorded as 30 min averages. In addition, single-pulse raw velocity data (not subjected to consensus quality control) have been recorded but not yet evaluated.

The system was installed about 20 m to the east of the wind profiler site, about 300 m away from the tower and 100 m from a regional road with some traffic. First experience showed strong fixed echoes during the night, originating probably from the tower and/or the little forest to the east. Therefore the sodar was re-oriented so that the tilted beams pointed towards NW and SW. Regular operation was started on 2 Sep 1996 15.00 UTC and stopped on 15 Jan 1997 12.00 UTC. The data have one gap of 4 days (cable cut by a farmer) and two gaps of 1.5 days (disk full).

2.1 Tower data

Wind speed and direction were measured routinely with Gill propeller vanes at 20 m, 40 m, 80 m, 140 m and 200 m. At each level, there are three booms at different angles and the least disturbed one was selected automatically. K-vanes consist of a wind vane with the tip branching into two ends pointing 45° above and below the horizontal, respectively, each carrying a propeller anemometer (resembling the shape of the letter K, therefore the name). They were mounted on the booms at 20 m, 100 m and 180 m above ground. Only two of the three booms at each level could be equipped with K-vanes. Thus results for some wind directions might be slightly affected by wakes. Data were supplied as 30 min averages of the three wind vector components u, v, w, the wind direction, and the moments $\overline{u'u'}$, $\overline{v'v'}$, $\overline{w'w'} = \sigma_w^2$, $\overline{u'v'}$, $\overline{u'w'}$, $\overline{v'w'}$. Some cases in which one of the propellers had stalled completely due to week wind had to be excluded from the analysis.

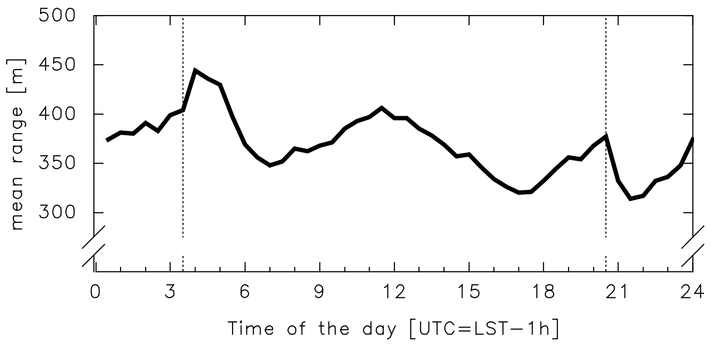

Figure 1: Average range of the sodar as a function of the time of the day. The switching times for the acoustic power reductions are indicated by dotted lines.

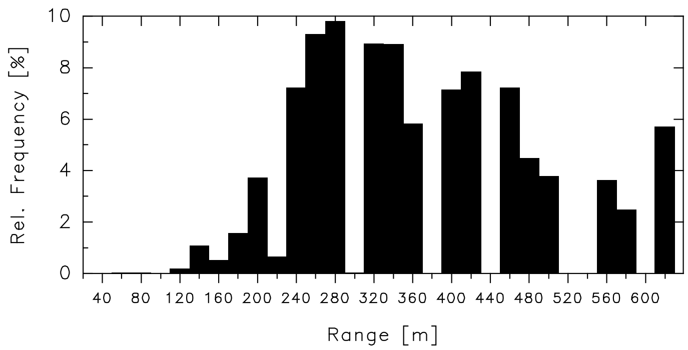

Figure 2: Frequency distribution of the range (highest valid level) of the sodar.

3. Results

3.1 Range

The average range of the sodar is depicted in Figure 1 as a function of the time of the day, varying between 250 m and 400 m for the wind speed and (not shown) 200 m to 350 m for σ_w. The effect of the power reduction in the night is clearly visible. This range is less than what was expected from previous sodar measurements; it is unclear whether it can be ascribed solely to the traffic noise which was only moderate.

The frequency distribution of the range of the wind speed (Figure 2) is very strange. Instead of forming a steady distribution, some range gates never appear as the topmost valid one and others do so only very rarely. Roughly speaking, every third range gate is missing in the histogram. A similarly strange behaviour is found in the frequency distribution of the range of σ_w (not shown).

3.2 Wind speed and direction

Scatter plots for the comparison of wind speed and direction between sodar and routine mast instruments at 200 m are shown in Figure 3. The correlation coefficients for the wind speed are very high at all levels, between 0.94 and 0.97. However, at the lowest level (40 m) high wind speeds are overestimated by the sodar as compared to the mast. This leads to a bias of 0.97 m/s and a root-mean-square error (rmse) of 1.4 m/s. This effect is present also at 80 m but less pronounced. At 140 m and 200 m, there is instead a slight underestimation of the wind speed by the sodar, with a bias of 0.4 m/s. In contrast to the systematic deviation at lower levels, the error does not appear to be correlated with wind speed. The rmse is about 1.0 m/s.

The direction scatter plot (Fig. 3) shows data points densely packed along the diagonal with a few outliers, the latter being probably due to light wind conditions. At different levels, biases between 1° and 4° are revealed in comparison with the routine instruments. There is no systematic trend with height. These biases most likely indicate the difficulty to determine exactly the azimuth of the instruments. The sodar is probably the most reliable instrument here, because the azimuth can be measured on the ground instead of on a boom of the tower. The rmse of the wind direction is caused to a good extent by the systematic deviations. If this effect is corrected for, the rmse values range between 9° and 14°, again without systematic height dependence.

3.3 Mean vertical wind

The mean value of the vertical wind component w is a parameter that does not normally receive a lot of attention, because its physical significance is often not clear. The correlation between the 30 min means of w measured by the sodar and the K-vanes is very small (0.27).

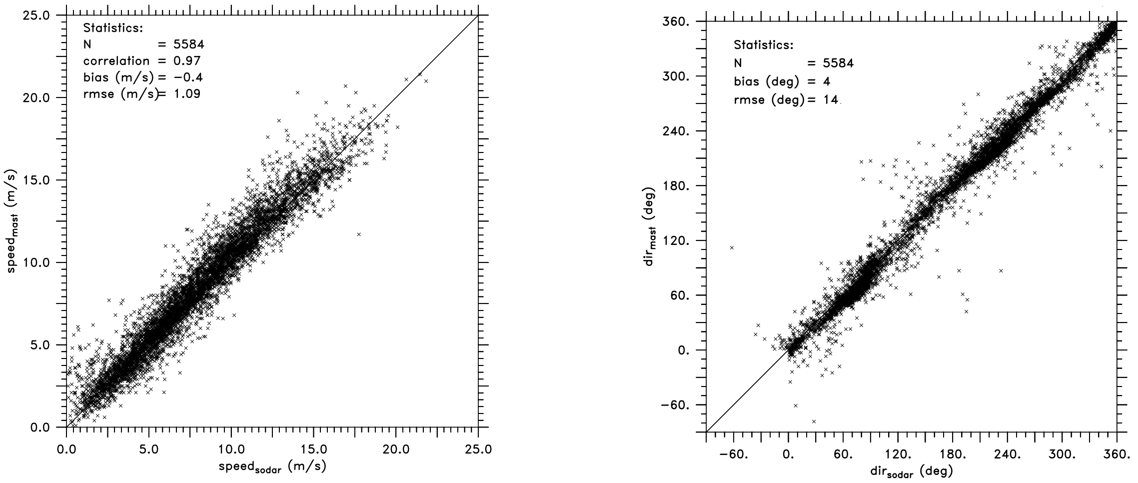

Figure 3: Scatter plot of horizontal wind speed (left) and direction (right) at 200 m, as measured by the sodar (abscissa) and the standard tower instrumentation (ordinate).

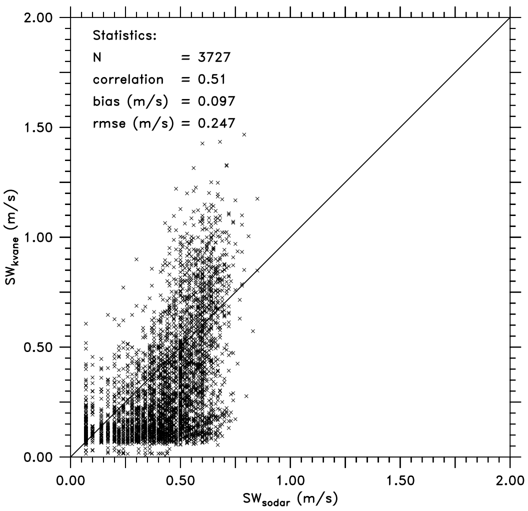

Figure 4: Scatter plot of σ_w at 180 m, as measured by the sodar (abscissa) and the K-vane.

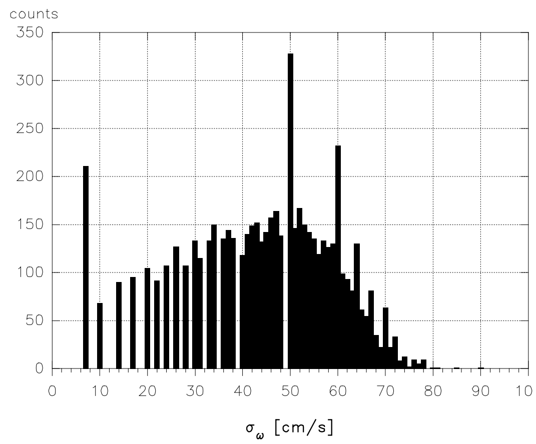

Figure 5: Frequency distribution of all σ_w values measured by the sodar at 180 m.

3.3 Standard deviation of the vertical wind component

A scatter plot for comparison of the standard deviation σ_w measured by the sodar and the K-vanes at 180 m is shown in Figure 4; the results at 100 m are very similar. The bad correlation (correlation coefficient around 0.5) and a virtual cut-off of the sodar data at 0.75 m/s are immediately apparent. In addition to this effect, a considerable overestimation of σ_w by the sodar is visible for low turbulence situations. These results are much worse than most other published results of such comparisons, especially if considering the more recent literature. As Figure 8 of Crescenti (1997) shows, the worst previously reported correlation coefficient for σ_w is about 0.65 at the near-200-m-level.

A hypothesis underlying the present study had been that the underestimation of high values of σ_w is related to selective sampling of updrafts under strongly convective situations (Seibert and Langer, 1996). However, due to the season (September to January) and unfavourable weather conditions, strongly convective conditions were not found in the data set. At least moderately convective situations, characterised by $z/L < -1$ (where z is the measurement level and L the Monin-Obukhov length) have been looked at separately. At 180 m, they make up about 12% of the full data set. Cases with high σ_w values are missing in the subset. Obviously, they were caused by mechanical turbulence associated with high wind speeds rather than strong convection. It is thus interesting to note that underestimation of high σ_w is not limited to convective situations. Low turbulence under unstable conditions was massively overestimated. The correlation coefficient is very low (0.37).

Figure 5 shows the frequency distribution of all σ_w values. These values are recorded by the system with a numeric accuracy of 0.01 m/s and this is also the resolution of the histogram. The frequency distribution is not, as one would expect, continuous, but has gaps as well as peaks. All the gaps occur at values below 0.50 m/s while the all the peaks are found at 0.50 m/s or more. The peak at 0.07 m/s is an exception; it is caused by setting all smaller values to a minimum of 0.07 m/s. This figure was submitted to Remtech S.A., asking for an explanation. Remtech S.A. suspected that the unexpected frequency distribution have been caused by 50 Hz disturbances. We think, however, that a software problem is more likely as an explanation, and that this might also explain the bad results in the σ_w comparison.

4. Conclusions

It has been confirmed that the mean horizontal wind can be reliably measured by the Remtech PA2 sodar. A moderate overestimation of the wind speed by the sodar at the lowest level deserves further attention. However, the accuracy of the σ_w measurements turned out to be unsatisfactory and much worse than what was found in other studies. It was not possible to test the hypothesis that systematic underestimation of σ_w especially at higher levels will occur in convective situations, due to lack of such situations during the measurement period. Interestingly, a systematic underestimation of σ_w was found with cases where strong mechanically generated turbulence was present. In addition, the frequency distribution of σ_w as recorded by the sodar exhibits strange gaps and peaks which might have been caused by a problem in Remtechs software. This shall be studied on the basis of the single beep raw data in the future.

The most important statement to be made is that in spite of a number of favourable comparisons for σ_w measured by sodars which have been published in the literature, there is no guarantee that a specific system performs well. It must therefore be highly recommended that users have their systems compared with reliable measurements before using any second moment data from sodars. In the case of the Remtech PA2 system together with software V6.06, usage of the σ_w as input for pollution dispersion modelling or other applications should be avoided. Though not yet investigated, other turbulence parameters are also suspect because they are even more difficult to determine and more uncertain than σ_w.

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