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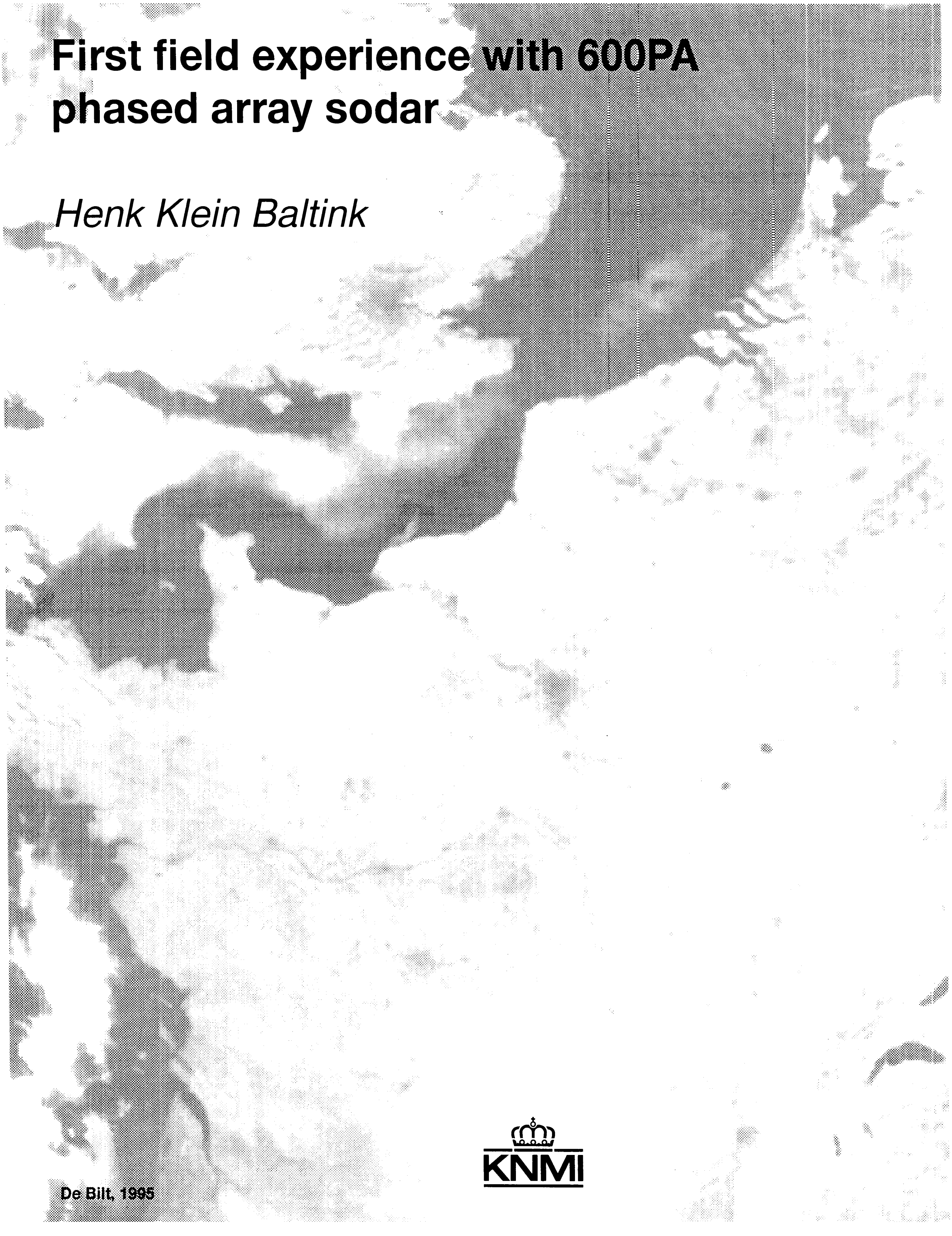

First field experience with 600PA phased array sodar

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FIRST FIELD EXPERIENCE WITH THE RADIAN 600PA PHASED ARRAY SODAR

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Contents.

1. Introduction

This report deals with the first field experience with a Radian 600PA Doppler sodar system. The 600PA sodar is a three beam phased array Doppler sodar manufactured by the Radian Corporation, Austin, Texas, USA. The 600PA sodar has been purchased in 1993 by the Aeronautica Division of the KNMI. This sodar has replaced a single beam acoustic sounder at the Schiphol Airport in october 1994. Before installing the system at the airport the 600PA sodar was operated for a field test at the experimental research site of the KNMI at Cabauw. During a two month period from mid March till mid May 1994 data were collected from the 600PA sodar, the 200 m high meteorological tower and a second Doppler sodar, which was almost collocated with the 600PA.

The analysis presented in this report is focused on mean horizontal wind speed and wind direction. Other output parameters like the standard deviations of wind speed, wind direction, vertical speed and backscatter strength are only briefly discussed. The mean wind speed, wind direction and vertical speed are the only parameters which are presented in real time at the meteorological office at the Airport. In chapter 2 of this report the instruments are described. Chapter 3 deals with the field program and the data acquisition and processing. Results of the intercomparison are presented and discussed in chapter 4. Chapter 5 presents the conclusions and recommendations.

2. Description of the instruments.

2.1 The Radian 600PA Doppler sodar.

The 600PA is a three beam phased array sodar recently developed by Radian Corporation. The phased array antenna consists of an array of 120 small acoustic speakers. The beams are electronical steered by proper phase shifting of the transmit signals to the acoustic speakers. The two oblique beams point at an angle of 15° from zenith. The transmit frequency is centred at 2125 Hz. The program for system control, data acquisition, processing and display called "Echosonde", runs on a 486PC under Windows. Some of the system parameters can be adjusted by the operator using the 600PA Echosonde graphical user interface. During this field experiment a fixed set of parameters was selected.

Radian implemented a spectral processing method which is different from what is commonly used in Doppler sodar systems. The spectra for each ping and range gate within a measuring period are stored. At the end of the measuring period the time series of the data for each spectral bin in the frequency domain are checked for outliers. The remaining data points are averaged per bin and the result is an averaged spectrum. Next a narrow band line filter is applied to the spectrum to suppress groundclutter echoes. The next step is to calculate the first three moments of the largest peak in the averaged spectrum. These three moments are related to the power in the spectral peak (backscatter strength), mean frequency (radial velocity) and the width of the peak (radial velocity variance and turbulence).

The velocities and variances measured along the three beams axis are transformed to the u,v,w coordinates. The mean wind speed, wind direction and the variances are only calculated if the signal-to-noise ratio (SNR) of the largest spectral peak for a particular gate of all three beams is equal or larger than the SNR-threshold set by the operator. Beside σ_u, σ_v and σ_w the program also calculates σ_θ and σ_ψ the standard deviation of wind direction θ and vertical wind direction ψ respectively. ψ is defined as $\arctan(w/\sqrt{(u^2+v^2)})$. Finally a shear check is applied on the vertical profiles of horizontal wind speed and wind direction. For a description of the calculation of the backscatter strength, the mixing layer height and the stability class we refer to the system manuals.

The processed data are written to three different types of datafiles: Common Data Format files (CDF-files), wind report files and backscatter report files. The CDF files are ASCII files which start with a header and subsequently present vertical profiles of wind and SNR data per averaging period. For each range gate the following parameters are stored: quality index (QC), height, wind speed, wind direction, u, v, w, 3 consensus values and 3 SNR values. The consensus values are a remains of a previous implementation and it is not clear what the meaning and relevance is for the present processing.

The wind report files contain all the data present in the CDF-file except for the header but include all the standard deviations of the wind components, the mixing layer height and stability class. The wind report files contain some printer specific characters, but the data itself are stored as ASCII characters. The backscatter files are printer specific. When printed on an Epson compatible printer a grey tone image of the backscatter strength is created (see fig. 1 for an example).

Beside the report files the Echosonde program can also store binary data files for wind, backscatter and mixing height. These files are used when the Echosonde program is run in playback mode. In the playback mode it is possible to reprocess the original data with different settings of the system parameters, e.g. a longer averaging period or a different SNR-threshold.

2.2 The Remtech Doppler sodar.

The second Doppler sodar used in this field experiment is a three antenna system originally developed by Bertin, now Remtech. This system is used for atmospheric research at KNMI (Beljaars 1983). The Remtech sodar transmits a dual frequency pulse centred around 1600 Hz. This technique is also used in the more recent Remtech AO sodar. The Remtech sodar also applies spectral techniques for processing of the Doppler shifted echo-signals. The mean frequency of the spectral peak is calculated once every 60 sec. The three radial velocities are transformed to horizontal wind speed, wind direction and vertical speed. The time series of these 60 sec. values are used to calculate the mean wind speed, wind direction, w, σ_θ and σ_w within the averaging period. These data are stored as ASCII characters in a data file on diskette. Parameters stored are echo intensity, wind speed, wind direction, σ_θ, w, σ_w and the standard deviation of echo intensity.

2.3 The meteorological tower.

The 213 m. high meteorological tower is equipped with instruments for measuring wind, temperature, humidity and visibility (Monna and Van der Vliet, 1987). Wind speed and direction are measured by Gill propeller vanes type 8002DX. Mean values and standard deviations are calculated in real time once every 10 minutes. In the post-processing these 10 min. values are averaged to the 30 min. values which have been used in this experiment for comparison with the values measured by the sodars. Wind data are measured at 10, 20, 40, 80, 140 and 200 m. above ground level (agl). The wind speed and direction data are based on the 3 sec. sampling interval. Instruments for measuring vertical wind speed are not installed in the tower.

3. Field program and data description.

3.1 Location and weather conditions.

The sodar systems were located approximately 250 m. to the north-east of the Cabauw tower. The distance between both sodars was appr. 40 m with the Remtech being located to the east of the 600PA sodar. The research site and its surroundings are almost flat within a radius of approximately 20 km. The land type nearby the tower is mainly grassland with some scattered trees, orchards and some houses. To the north and east of the sodar location some houses and trees were present at relative short distance.

The data used for the intercomparison were collected from 14th of March to 18th of May 1994. In the first half of this period the weather conditions were unfavourable for sodar measurements, a lot of rain and relative high winds. In the second half conditions improved considerably. An overview of wind speed, wind direction, temperature and precipitation is presented in figure 2. Consequently data availability for both sodars varied strongly from the first half period compared to the second half period of the field experiment.

Due to some problems with the postprocessing the data availability for the tower was not as high as usual during this experiment.

3.2 Data preprocessing.

In the analysis we used 30 min. averaged values for the comparison of the data from the different instruments. The 30 min. averaged values for wind speed and wind direction are standard output for the tower measurements. However, the sodar systems collected the data at different averaging periods. Therefore the sodar output data had to be processed to get 30 min. averaged values as well. The typical system parameters and settings for

	Remtech	Radian	
frequency	1600	2125	Hz
pulse length	150	150	ms
acoustic power	30	?	Watt
min range height	50	50	m
max range height	525	700	m
gate height	25	25	m
receiver gain	-	40	dB
pulse ampl.	-	18	dB
vertical wind correction	?	on	-
oblique beam angle	18°	15°	(from zenith)

Table I. Sodar system parameters.

both sodars used during the experiment are summarized in table I. The processing of the 600PA data is described first.

The averaging period for the 600PA sodar was set initially at 15 min. During the data acquisition the vertical velocity correction was always on. In the analysis only data stored in the CDF files were used. The 15 min. values of the u, v and w components were averaged to obtain 30 min. values. The mean wind speed and wind direction were calculated using the 30 min. averaged u and v values.

The 600PA 15-min. values for SNR and QC were processed as follows. The lowest of the three SNR values for each gate for the first and the second 15 min. period within each halfhour were both stored separately. The two lowest SNR values are used to study the effect of the SNR-threshold on 600PA data availibility and quality. These two SNR-values are also used to select valid data from the database. The 15 min. QC-value has either the value 0 (valid) or 8 (invalid). This QC-value can have been set either by the SNR-threshold check (set at 0 dB during data-acquisition) or by the shear-check applied to the vertical profiles of wind speed and wind direction. The 30 min. QC-value was stored as 0 (QC1=QC2=0), as 1 (QC1=8, QC2=0), as 2 (QC1=0, QC2=8) or as 8 (QC1=QC2=8).

Unfortunately the operator of the 600PA system set the averaging period (unintentional) to 5 min. after 18th of April. It was decided to linear average all the 5 min. data to 15 min. values (including the SNR-data) and process these 15 min. averaged values as described before.

The Echosonde playback program for reprocessing of the 600PA data has the option of performing the averaging as well. However, this program was not available at the time of the field experiment.

The 600PA wind speed and direction data are vectorial averaged values. This should be kept in mind when comparing the results with the tower data which are scalar averaged values. Data from the 600PA sodar which were stored in the database for intercomparison are mean wind speed, mean wind direction, mean vertical component w, QC and the two lowest SNR values.

The Remtech sodar collected data at 15 min. periods as well. Except for a short period when only a 20 min. period could be used. The Remtech system does perform some internal quality controls on the data and will only output data which have passed all these checks. These quality control procedures are not exactly known. A 30 min. average Remtech data was only calculated and stored in the database when both 15 min. values were available. The wind speed, wind direction, echo intensity, w and σ_w were all scalar averaged to get the 30 min. values. The averaged data were stored in the database for further analysis.

Vectorial or scalar averaging of the sodar and tower measurements can lead to different results. Beside one has to realize that sodar measurements are volume averaged while tower measurements are point-values. Also the sodar has to scan three beams in sequence which implies that data are collected with a rather poor temporal resolution and that the three samples which are combined to one wind vector are also spatial separated. In general this should not have too much influence on the mean values, but for the value of the standard deviations this may have significant effect which can not always be neglected in unstable, convective conditions.

4. Data intercomparison.

Although a fixed SNR-threshold of 0 dB was used for the 600PA sodar during the data acquisition, the way the data are stored allows to evaluate the effect of different threshold values in post processing. Therefore we first tried to find the optimum SNR-threshold to be used in the intercomparison of the data. This is described in section 4.1. Section 4.2 describes the data availability of the sodars and section 4.3 deals with the intercomparison of wind speed and wind direction. These two parameters are of main interest for the operational use. Section 4.4 deals with the vertical wind speed and section 4.5 with the standard deviation of the wind direction.

4.1 SNR-threshold 600PA sodar.

One of the first issue to address is the SNR-threshold value for processing of the 600PA sodar data. According to the manufacturer's experience a value of -3 dB should give reliable results. Evaluating some data recorded before the start of this field experiment gave us at first a different impression. Further analysis showed that the 600PA data were at times severely contaminated by groundclutter. These fixed echoes can have large SNR-values and are not rejected by the SNR-threshold. The clutter suppression band filter in the spectral domain and the physical protection of the antenna by the clutter screen were obviously not able to reduce always the groundclutter efficiently. As will be shown in section 4.3 applying the wind shear check may eliminate some of the groundclutter contaminated data which do have SNR-values above the SNR-threshold.

After comparing the 600PA data with the tower data to analyze the effect of SNR-threshold we set the SNR-threshold to be used in the intercomparison at -2 dB. In figure 3 the effect of the SNR-threshold on the comparability of the 600PA wind speed data with tower data at the 200 m. level is illustrated in scatter plots 3A to 3E. The sodar data at low windspeeds (lower left corner of fig. 3A), which have a large negative relative wind speed error compared to the tower data are probably contaminated by groundclutter. It is clear from figure 3F that at high windspeed the SNR of the sodar return signal is always low (high background noise level). If the SNR-threshold is set at -2 dB for example, no measurements seem to be valid anymore for wind speeds above 20 m/s at 200 m. agl.

The valid 600PA sodar wind data (SNR $\geq$ -2) with a relative wind speed error $\leq$ -20 % were analyzed to see if any relation with atmospheric conditions could be detected. The results are presented in fig. 4. Large relative errors occur only at night time between 18:00 and 06:00 UTC (fig. 4A). The standard deviation of the wind direction for these cases is low (fig. 4B). This indicates that turbulence is low and the atmospheric backscatter strength is reduced. These conditions increase the chance of groundclutter problems as the atmospheric peak may become smaller than groundclutter peaks. Fig. 4C shows that SNR-values of the data with a large negative relative wind speed error have no relation with the magnitude of this error. Therefore it is not possible to discriminate between valid and suspect/invalid data by the SNR-threshold alone in case of low atmospheric backscatter.

4.2 Data availability.

In general sodar data availability depends on atmospheric conditions, site characterictics and the system parameters. The dependence on atmospheric conditions and system parameters is described by the sodar equation for the power of the sodar echo signal P_r:

$$P_r = E . e^{-2.\alpha.R} . \sigma(R, f) . \frac{A}{R^2} . G . \frac{c.\tau}{2} . P_e$$

where:
- P_e = the emitted power (Watt)
- E = efficiency of emission and reception
- R = height of scattering volume (m)
- α = average sound attenuation (m^{-1})
- σ = scattering cross section per unit volume (m^{-1})
- f = sound frequency (Hz)
- A = antenna surface area (m^2)
- G = correction for antenna directivity
- c = speed of sound in air (m/s)
- τ = pulse lenght (s)

The attenuation α depends on the sound frequency, humidity and temperature. In general we have no absolute calibration of the sodar systems. Therefore the efficiency E is unknown. The sodar systems used in this experiment operate both in backscatter mode. In this case the scattering cross section σ reads:

$$\sigma = 0.0039 . k^{(1/3)} . \frac{C_T^2}{T_0^2}$$

where:
- k = the wave number (m^{-1})
- C_T^2 = the structure parameter for temperature ($K^2 m^{-2/3}$)
- T_0 = the absolute air temperature (K)

From these two equations is it clear that atmospheric condition does influence the echo power by the absorption of the sound waves, the structure constant (temperature fluctuations, stability) and to a lesser extent by the air temperature itself. The structure parameter C_T^2 depends on turbulence and the (vertical) gradient of the acoustic refractive index.

For both sodars the data availability is calculated as a function of height. The overall availability is given in fig. 5A. The 600PA curve shows an unusual increase near the 300 m level. This is due to groundclutter most likely originating from the tower. The curve should show a continuous decrease with height.

The availability is also calculated separately for day and night time (fig. 5B). As expected there is an increase in availability for daytime at the higher levels although the increase is rather small. The difference between the first and second half period of the field experiment is much more pronounced (fig. 5C, 5D). This is due to the difference in weather pattern as explained before. Comparing availability in this experiment with data presented in literature can only be done in a qualitative sense as conditions and systems parameters may vary largely. A 50% value in the range of 400 to 600 m is typically value found for sodar systems operating in this frequency range. The Remtech sodar seems to perform not so well. We do not have an explanation for this rather poor data availability. The 600PA sodar seems to perform in agreement with reports on other sodar systems (Piringer 1994, Seibert 1992, Vogt 1994).

4.3 Comparison of wind speed and wind direction.

One of the most important parameters for the operational use at the airport is the accuracy of the wind speed and wind direction. During the last 15 years numerous experiments have been performed to compare sodar with tower data (Finkelstein and Kaimal 1986, Kurzeja 1994, Piringer 1994, Vogt and Thomas 1994). In general a good agreement has been found for the mean wind speed and wind direction. The 600PA sodar is a new product of the Radian Corporation and comparisons for this specific sodar were not available yet.

We have compared the 600PA sodar, the Remtech sodar and tower measurements at 200, 150 and 75 m. agl. respectively. The tower levels 80 and 140 m. do not coincide exactly with the centre of the sodar gate at 75 and 150 m. respectively. No attempt is made to correct for this difference in observation height. The statistical analysis is limited to the bias and standard deviation of the difference between data from the sodars and the tower. The linear regression is also computed for the data sets at these three levels. In addition we present in scatter plots also the relative wind speed difference and the wind direction difference as a function of the tower wind speed.

As mentioned before applying only the SNR-threshold to the Radian wind data is not sufficient as a quality check in case of groundclutter contaminated data. Therefore we also analyzed the data originally recorded with SNR-threshold equal to 0 dB and subjected to a wind speed shear threshold of 3.1 m/s and a wind direction shear threshold of 50°. These thresholds are the default 600PA values. There is some note of caution as in the first half period these thresholds have been applied to 15 min. averaged values where in the second half of the field experiment these have been applied to 5 min. averaged values. In

level (m)	bias (m/s)	σ (m/s)	X -	Y (m/s)	R^2 -	N -
		Radian vs. tower (SNR ≥ -2 dB)				
200	-0.95	1.55	1.07	-1.60	.87	1941
150	-0.37	0.95	1.09	-1.15	.94	2095
75	-1.48	2.46	0.85	-0.31	.56	2232
		Remtech vs. tower				
200	-0.64	1.40	0.85	0.74	.86	1214
150	-0.52	1.12	0.92	0.14	.88	1638
75	-0.80	1.23	0.81	0.67	.86	2330
		Radian vs. tower (SNR ≥ 0 dB and QC = 0)				
200	-0.79	1.27	1.06	-1.34	.90	1621
150	-0.31	0.78	1.08	-1.03	.96	1874
75	-1.36	1.10	0.99	-1.24	.86	1632
		Radian vs. Remtech (SNR ≥ -2 dB)				
200	0.12	1.59	1.07	-0.44	.84	1070

Table II. Intercomparison results for wind speed.

fact we were not aware of that the shear threshold check was applied at all as it was not mentioned in the manuals nor is it operator controlled in the graphical user interface. It was afterwards during data analysis that it became clear that data were rejected otherwise than by SNR-threshold.

The shear threshold values are set in the "echo.ini" file which will be read when the Echosonde program is started. The shear threshold is not applied to the u,v,w components and did not interfere with the analysis based on the SNR-threshold alone. The 600PA data on which shear threshold check is applied are only plotted for the 75 m. level. The regression and statistical analysis is performed for all three levels.

The results of the analysis are summarized for wind speed and wind direction in table II and table III respectively. In these tables X is the slope of the regression line and Y is the intercept value. R^2 is the squared correlation coefficient and N the number of data points.

4.3.1 The 600PA sodar tower intercomparison.

First we discuss the results for the 600PA-tower analysis for sodar data with SNR $\geq$ -2 dB. The scatterplots for this data set are presented in fig. 6, 10 and 12 respectively.

The relative wind speed difference and the wind direction difference both show a dependence on the (tower) wind speed. This is expected as at low wind speed, in unstable conditions, wind speed and direction show larger variations. The relative wind speed difference scatter plots (fig. 6C, 10C, 12C) show that for all three levels at low wind speed quite some 600PA sodar data are probably contaminated by ground clutter.

The results for wind direction show for all three levels a high correlation and the slope of the regression line is almost equal to one. The intercept shows a small dependence on height. The bias in the wind direction difference is small but positive for all levels.

A remarkable aspect of the 600PA wind speed scatter plots (fig. 6A, 10A, 12A) is the relative sharp cut-off at the top side of the scatter band. This is not observed in the scatter plots for the Remtech wind speed data. It is most likely to be a consequence of vectorial versus scalar wind data averaging. This may also have an effect on the slope of the regression line for the wind speed. The difference of vectorial versus scalar is expected to be more pronounced at lower wind speed when the variation in wind direction is larger (unstable conditions). Therefore, the slope of the regression line is expected to be larger than one in case of a comparison between vectorial and scalar averaged data.

The standard deviation for wind speed difference is large for the 75 and rather large for the 200 m level (table II). Again this seems to be mainly caused by the ground clutter contaminated data at low wind speed. The value for 150 m level is in better agreement with values found in literature for comparable field experiments. The data at 150 m seem to be the least influenced by ground clutter.

If we look at the data on which the shear check has been applied at least a part of the ground clutter contaminated data have been flagged as invalid. Fig. 8 and 9 show the valid and invalid data at 75 m level with QC = 0 and QC > 0 respectively. It is obvious that the shear check is able to remove a substantial amount of data contaminated by ground clutter. How well the shear check performs can not be concluded from this data set. The

level (m)	bias (deg)	σ (deg)	X -	Y (deg)	R^2 -	N -
		Radian vs. tower (SNR ≥ -2 dB) level				
200	8.2	19.2	0.987	10.6	.97	1936
150	9.2	11.7	0.990	9.62	.99	2094
75	4.4	22.7	1.010	2.49	.94	2094
		Remtech vs. tower				
200	4.6	18.3	0.985	7.22	.96	1209
150	4.4	14.4	0.995	5.28	.98	1631
75	-.1	17.1	0.992	1.79	.97	2330
		Radian vs. tower (SNR ≥ 0 dB and QC = 0)				
200	7.2	13.0	0.987	10.9	.98	1621
150	8.9	8.6	0.997	9.87	.99	1874
75	4.2	11.1	1.000	5.12	.99	1632
		Radian vs. Remtech (SNR ≥ -2 dB)				
200	5.6	22.7	1.010	3.99	.94	1070

Tabel III. Intercomparison results for wind direction.

standard deviation of the wind speed and wind direction difference are smaller than without the shear check applied (table II and III). Especially the standard deviation for wind speed is now in better agreement with values found in literature. The bias shows only a marginal improvement.

4.3.2. The Remtech sodar tower intercomparison.

The data of the Remtech tower intercomparison show similarity to those of the Radian tower intercomparison. Remind that the processing of the Remtech data produces a result more similar to scalar averaging. The main difference is the slope of the regression line for windspeed which is at all levels lower than found for the 600PA data. It seems that the Remtech sodar underestimates the wind speed at higher wind speed. In section 4.4 the vertical wind speed is analyzed. A dependence of the vertical wind speed on the horizontal wind speed is found for the Remtech data. This indicates that wind component w measured by the vertical beam is not corrected for the beam tilt induced by the horizontal wind. The effect of this correction for vertical beam tilt is larger at higher wind speed. Perhaps this may induce some underestimation of the sodar measured wind at higher wind speeds.

We find also that the intercept of the regression line for wind direction and the bias changes with height and has the same sign and magnitude as found for the 600PA data. It is not clear whether the bias is caused only by a misalignment of the sodars or that it is also due to the measuring method as well.

The 600PA sodar and the Remtech sodar have been compared for the 200 m level for reference only. It does not show any unexpected results as compared to the sodar tower intercomparison (fig. 14).

4.4 Analysis of the vertical windspeed.

A valuable parameter for turbulence measurement is the standard deviation of the vertical wind speed σ_w. This parameter is measured by both sodar systems. Unfortunately the tower is not equipped with instruments for measuring the vertical speed w or σ_w. Instead we just compare the vertical wind speed w measured by the sodars with the horizontal wind speed measured by the tower. If the sodar systems measure the vertical wind speed w correctly we do not expect any dependence of w on the magnitude of the tower wind speed. The results are plotted in fig. 15, only 600PA data with QC=0 are presented.

For the 600PA data we do not see any correlation between w and horizontal wind speed. There seems to be a bias towards positive w for all three levels. This might reflect that the backscatter in updrafts is stronger than average. To investigate this in more detail some independent measurement of the vertical wind speed w would be needed. This is not performed and is also beyond the scope of this project.

The data from the Remtech sodar do show a clear dependence on the horizontal wind speed. As the vertical beam is deflected by the wind it will induce an apparent vertical wind. The first order approximation of this effect is indicated in fig. 15 by the solid line. The magnitude of the apparent speed w is approximated by $w = .85\ U^2/c_a$, where U is the horizontal windspeed and c_a the acoustic sound speed (340 m/s). We do not known whether Remtech applies a correction to the vertical speed to compensate for the dependence on horizontal wind speed, it seems they do not.

The 600PA data were corrected for vertical wind speed at acquisition. In post processing we calculated the influence of the vertical wind speed correction for 600PA wind speed at the 200 m. level and QC=0. The uncorrected wind speed data were calculated using the u,v and w components stored in the 30-min. database. The uncorrected windspeed was also compared with the tower data at 200 m. The bias in the difference was -0.94 m/s compared to -0.79 m/s for the corrected sodar windspeed. The standard deviation was 1.40 m/s for the uncorrected data compared to 1.27 m/s for the corrected data. So a small improvement is achieved by applying the vertical windspeed correction.

4.5 Analysis of the standard deviation of the wind direction.

The standard deviation of the wind direction σ_θ is measured by both sodars as well as by the tower. The standard deviation of the wind direction can also be a valuable parameter for dispersion models and for turbulence studies. Comparison of sodar measured σ_θ with tower data shows in general large scatter. Probably too large to be of any value as input parameter for dispersion models (Gaynor 1994). Moreover, in unstable conditions one has to apply a correction on the sodar measured σ_θ which depends on the integral length scale of the turbulence (Kristensen and Gaynor 1986). This parameter is not easily determined at operational measuring sites.

We did not analyze σ_θ for all the 600PA data available. After just analyzing some days of 600PA data it was obvious that the σ_θ data were either not correctly measured or processed. This is shown in fig. 16. In this figure the wind components are presented for

8th of august 1994. This day is chosen for a marked variation during the day in σ_θ measured by the tower. In the fig. 16A we see again some problems with groundclutter when turbulence is low at the first few hours.

The most interesting feature is presented in fig. 16E. In this figure the standard deviation of the u and v components are plotted along with the standard deviation of the wind speed measured by the tower. The difference is very large and it seems as if σ_u and σ_v are almost equal in value to the u and v components itself. This seems to point in an error in the calculation of the standard deviation. It is unlikely that the width of the spectral peak should show such a speed dependence. It seems almost that the second moment of the spectrum is calculated as $\sigma^2 \propto \sum f^2S(f)$ instead of $\sigma^2 \propto \sum (f-f_o)^2S(f)$ where f is the frequency and f_o is the frequency of the peak. The check of this assumption is left to the manufacturer. As the standard deviation of the wind direction is calculated using σ_u and σ_v it is not surprising that this value is too large as well. We also expect that the value of σ_w is not reliable in the present output of 600PA system.

5. Conclusions and recommendations.

The analysis of the data collected at the field experiment leads to some conclusions about the capabilities of the Radian 600PA phased array sodar. These conclusion are:

- The measurement of the mean wind speed and mean wind direction compare well with the tower measurements for conditions where backscatter strength and ground clutter are not limiting factors.
- In conditions with low turbulence too many data that are contaminated by ground clutter are considered valid if one relies only on the SNR-threshold for data quality control.
- The shear check on the average wind profile measured by the sodar does improve the data quality as it removes at least a part of the ground clutter contaminated data.
- The standard deviation of wind direction and wind speed components measured or calculated by the 600PA sodar are unreliable if not useless.

It will depend on the characteristics of actual site how severe this ground clutter problem will be at for example Schiphol Airport. In this respect it is interesting to note some results published for the Remtech PA2 phased array sodar. The PA2 sodar is operated without any clutter screen. Data presented in literature from a field test do not show as much problems with ground clutter as with the 600PA sodar (Vogt 1994). The test of the PA2 was also performed next to a tower. Quality control and beamshaping by controlling the amplitude of the transmit signals to the speakers of antenna array might have contributed to reduction of ground clutter.

In the meanwhile Radian started in 1994 to redesign their antenna in order to improve data quality. One option to consider might be the use of a more elaborated data quality control instead of the present simple shear check. We suggest that the Weber-Wuertz time-height algorithm might be a good alternative. Some sodar data users have already implemented this algorithm for quality control in post processing (Hines et al 1994). Recent experiments by NOAA show also that it can be succesfully applied in real time data quality control (Miller et al 1994).

The reason for the unreliable data for standard deviation of wind speed components and wind direction might be due to an error in the program code. Radian has stated that the measurement and processing of the standard deviation will be reviewed.

Based on the experiences in this field experiment we have the following recommendations for the use of the present 600PA sodar system at Schiphol Airport:

- the selected site should have as few as possible ground clutter sources
- a SNR-threshold of -2 dB can be applied
- use the shear check for wind speed and wind direction with the default system values
- the presentation of echo strength (backscatter) should be considered as this can give useful information about the atmospheric condition (eg. inversion layers)
- try different setting of the shear thresholds to find the optimum values. This can be performed on data already recorded.

- other values of system parameters (like pulse length, receiver gain) should be tried to gain more insight in the optimum values for operational use of the 600PA sodar. This parameter set may be different from the parameter set used in this field experiment.

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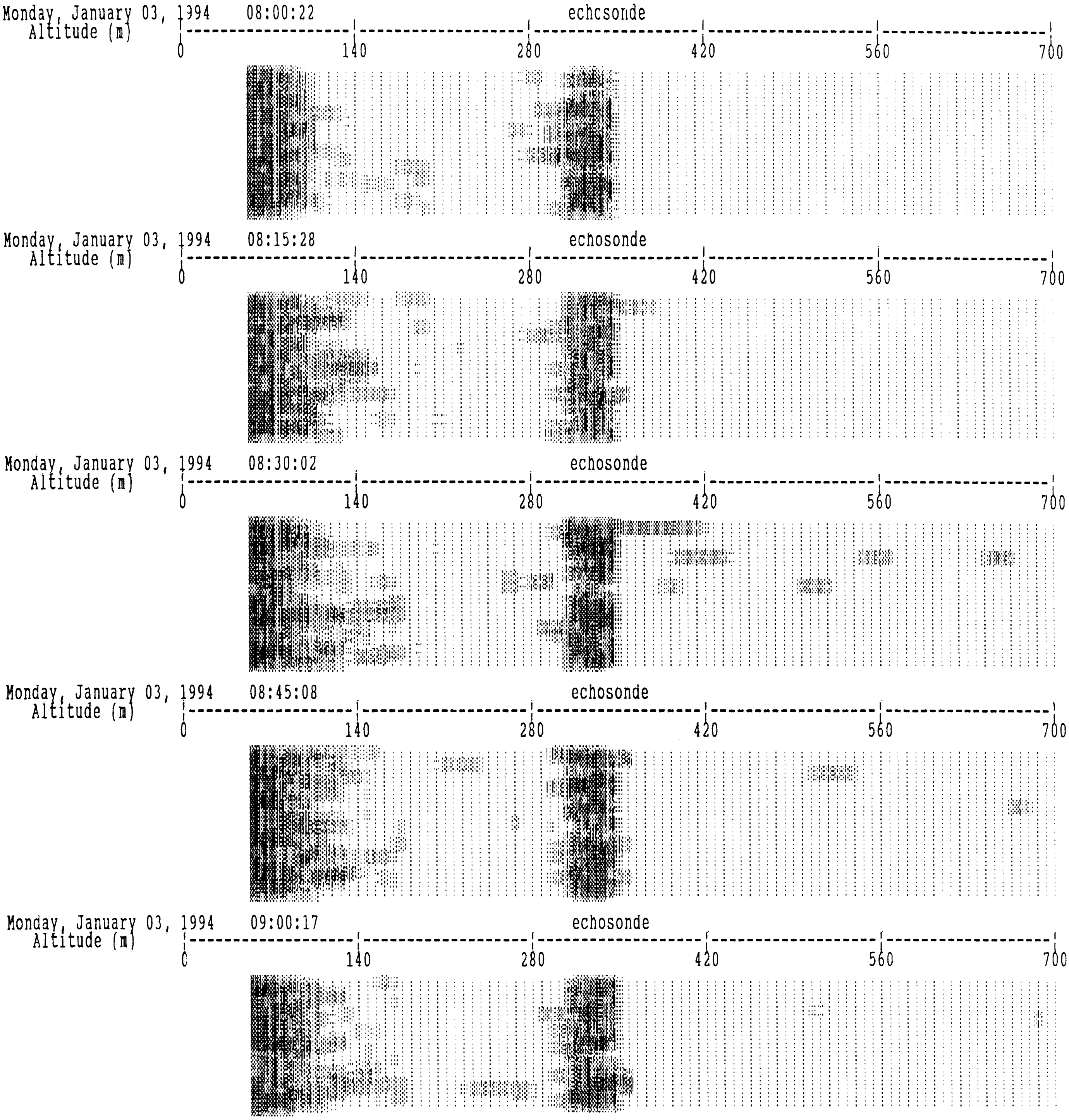


Fig. 1 An example of printout of a 600PA sodar backscatter report.

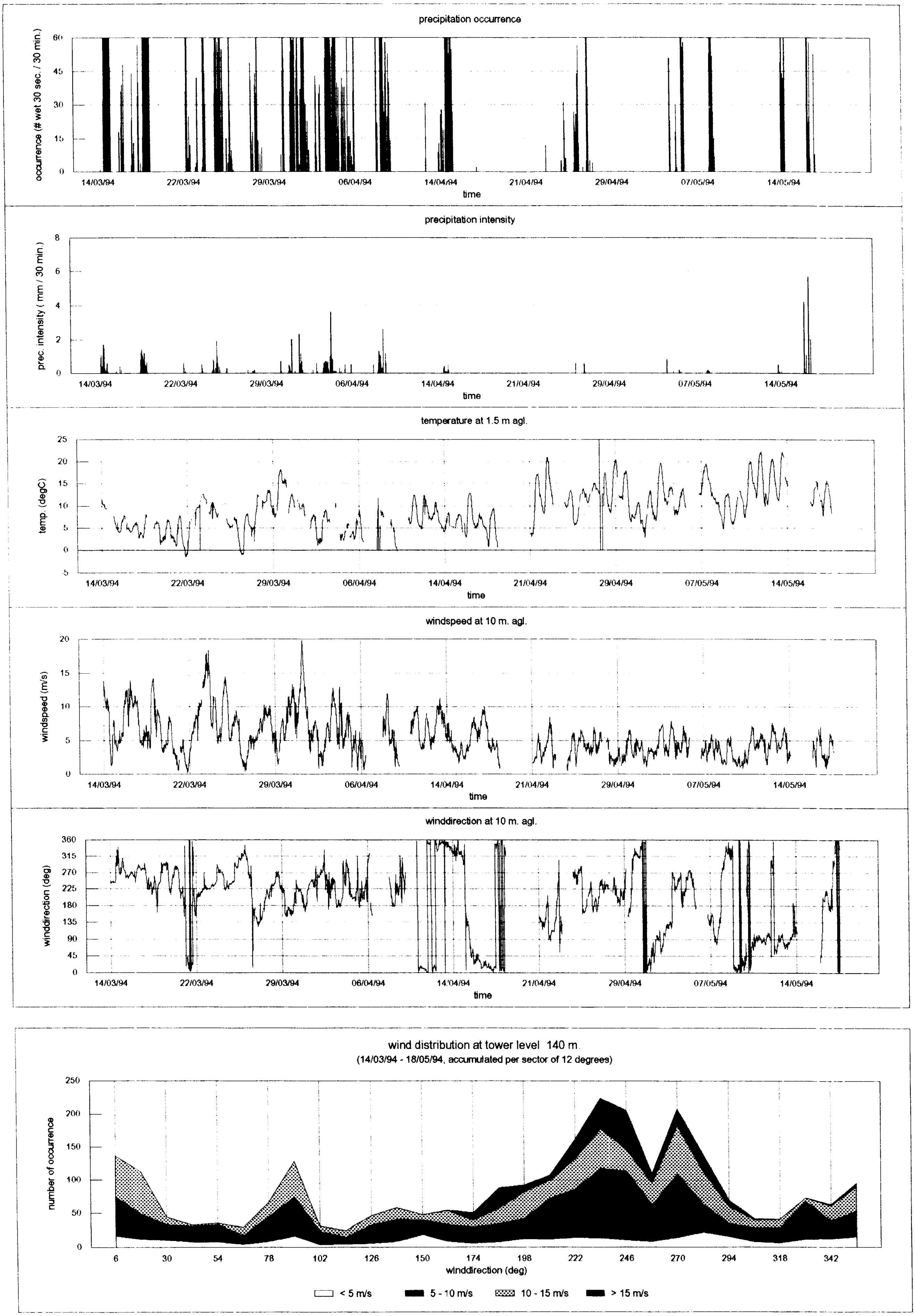


Fig. 2 Overview of precipitation, temperature and wind during the field experiment.

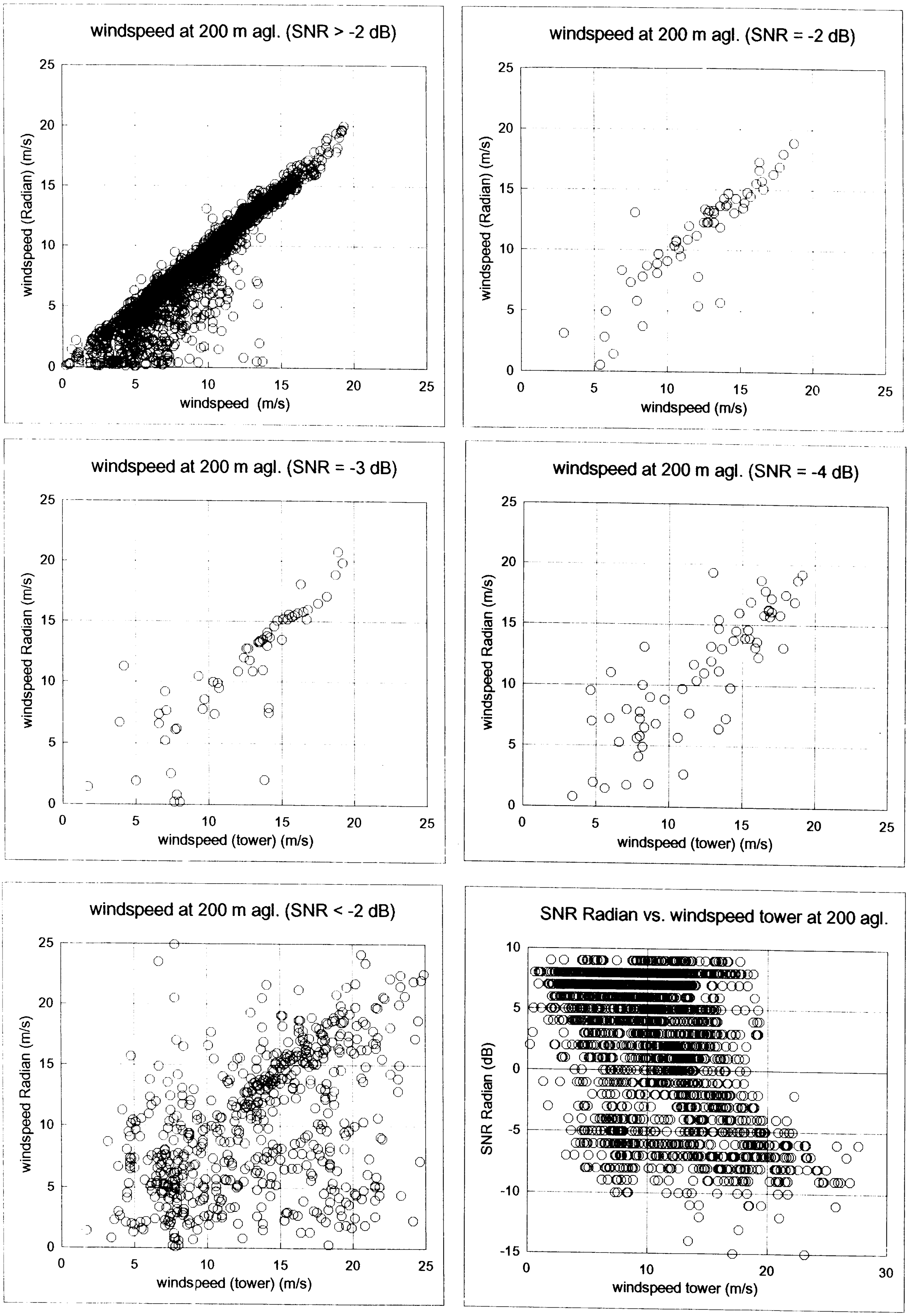


Fig. 3 Effect of the SNR-threshold on the 600PA sodar data quality and availability.

3A top-left	: SNR > -2 dB	3D mid-right	: SNR = -4 dB
3B top-right	: SNR = -2 dB	3E bottom-left	: SNR < -2 dB
3C mid-left	: SNR = -3 dB	3F bottom-right	: SNR vs. windspeed

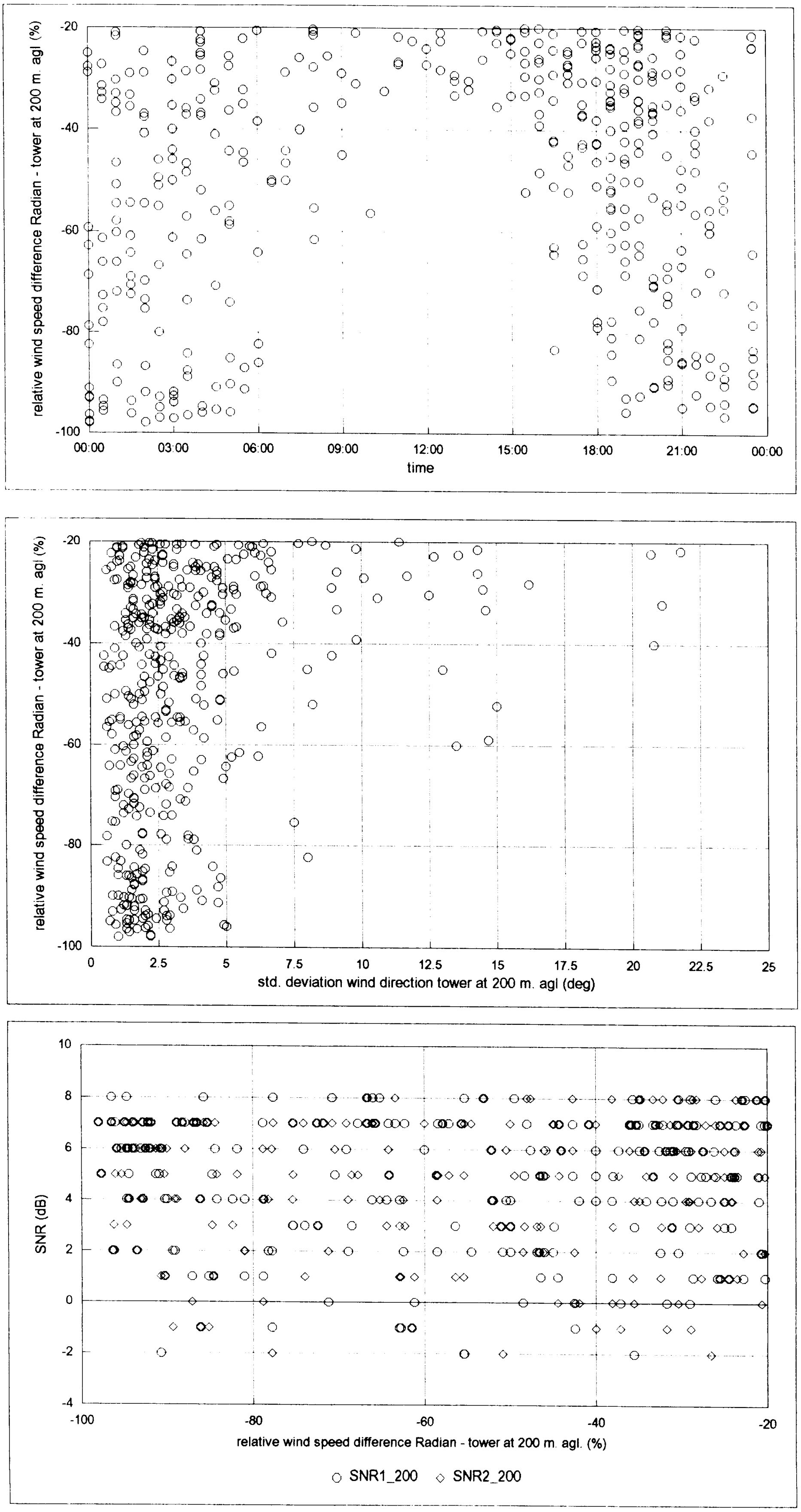


Fig. 4 600PA wind data with large negative relative wind speed error.

4A top : relative error vs. time of day
4B mid : relative error vs. σ_θ
4C bottom : SNR vs. relative error

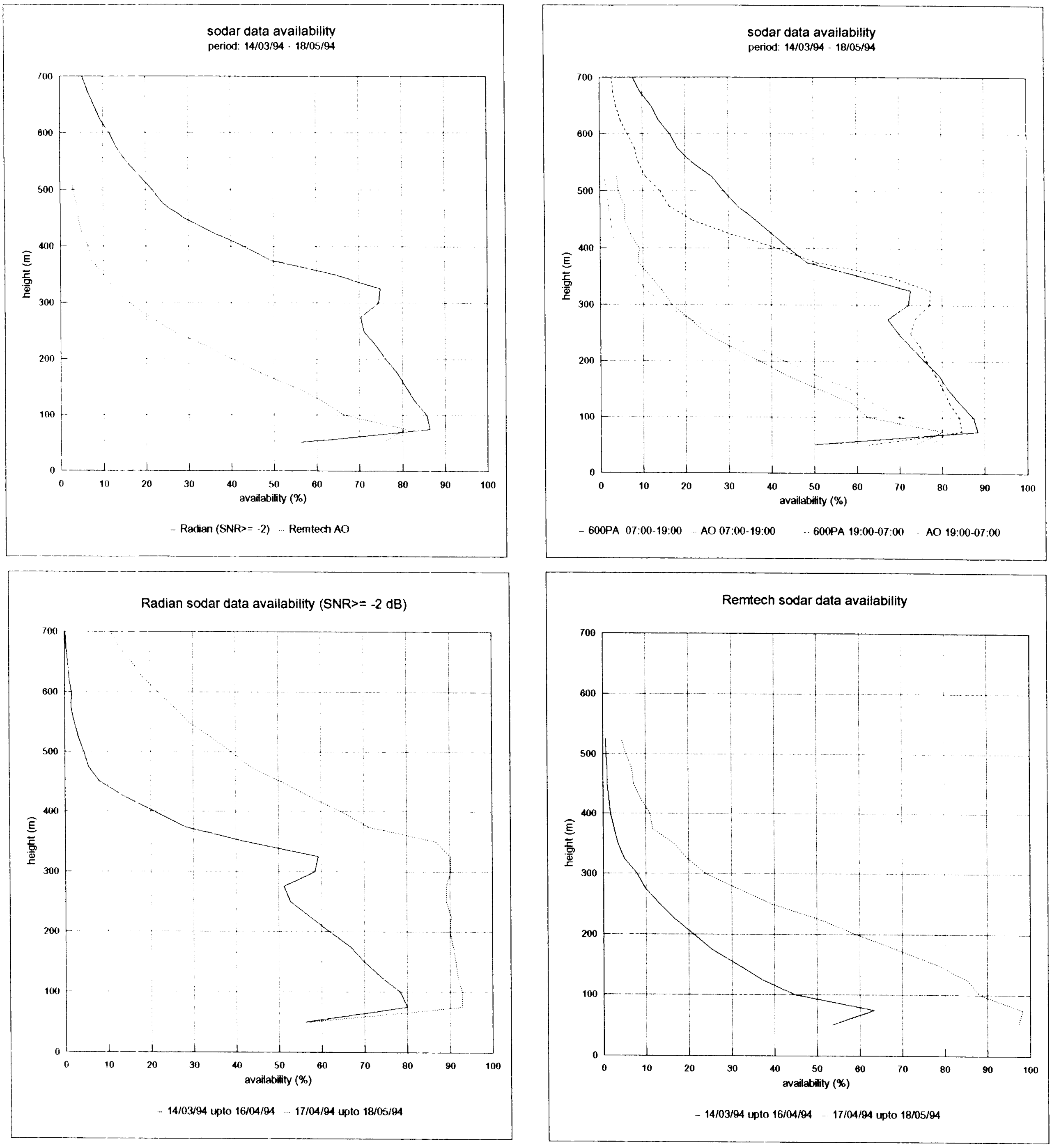
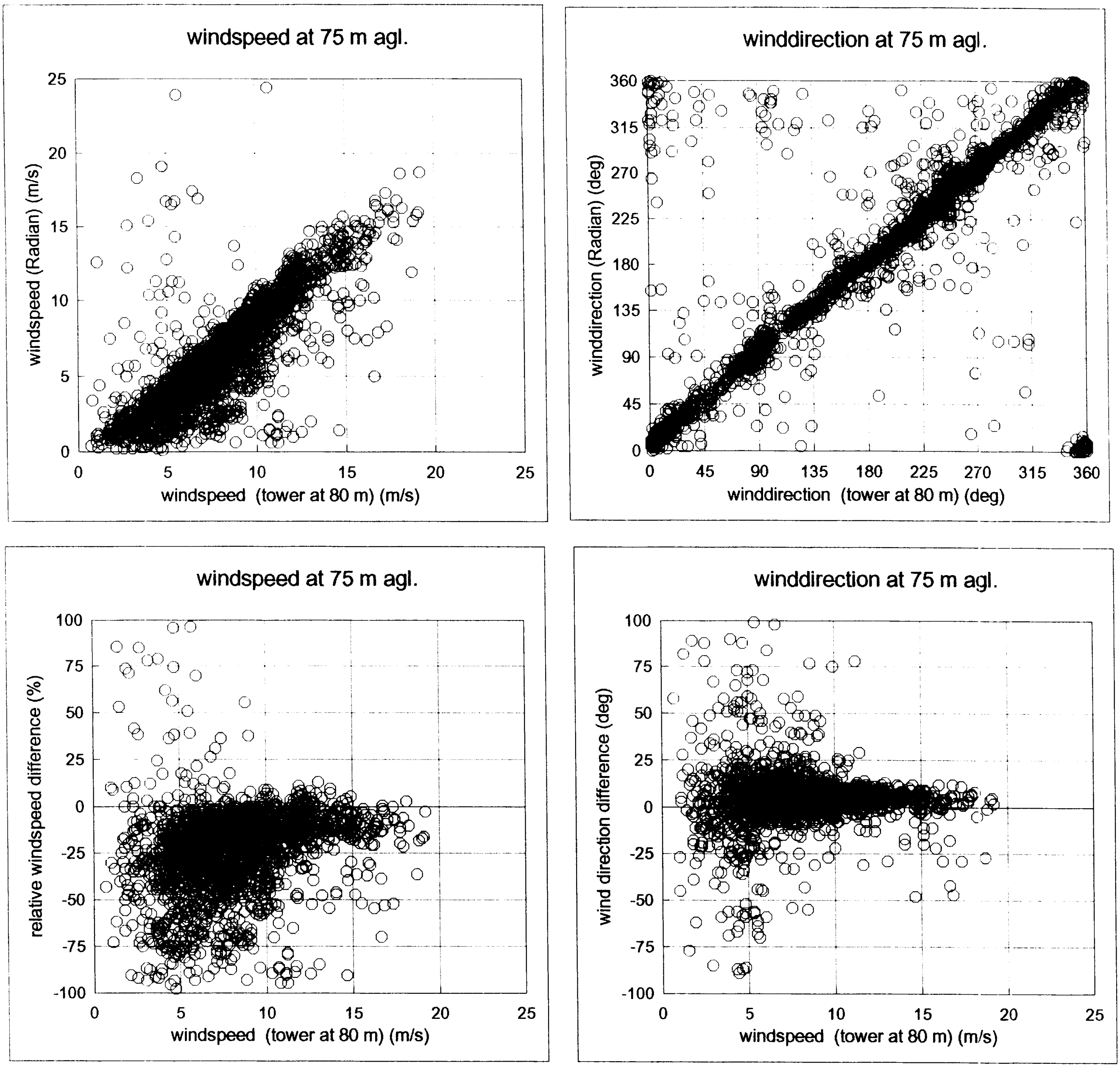


Fig. 5 Sodar data availability.

5A top-left	:	all data
5B top-right	:	day and nighttime data
5C bottom-left	:	600PA data 1st and 2nd half period
5D bottom-right	:	Remtech data 1st and 2nd half period



Regression Output for windspeed:

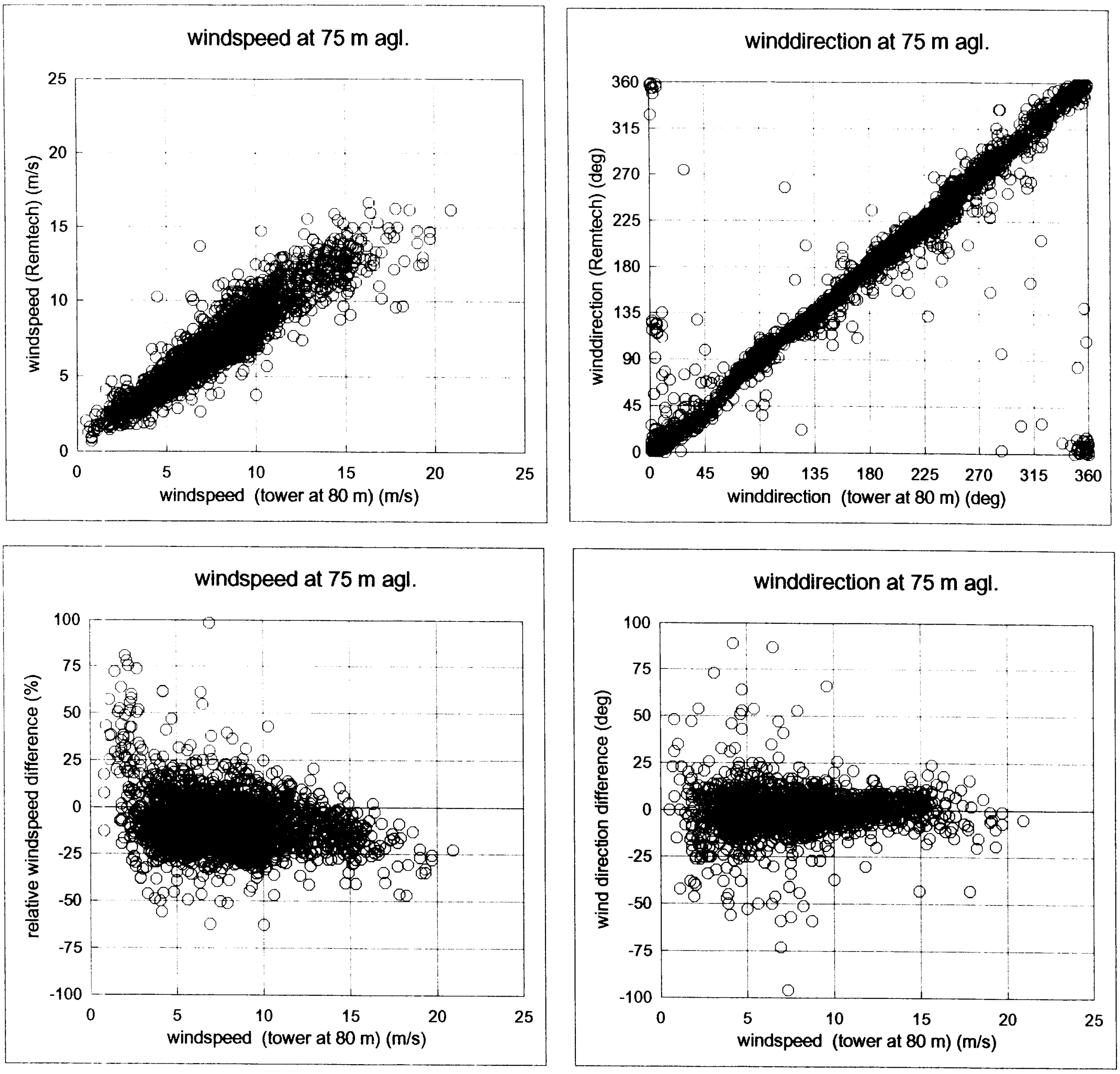
X Coefficient	0.85
Std Err of Coef.	0.02
Constant	-0.31
R Squared	0.56
No. of Observations	2232
Bias:	-1.48
Std. dev.:	2.46

Regression Output for winddirection:

X Coefficient	1.010
Std Err of Coef.	0.005
Constant	2.49
R Squared	0.94
No. of Observations	2094
Bias:	4.4
Std. dev.:	22.7

Fig. 6 Radian 600PA wind data vs. tower data at 75 m. agl.

6A top-left : windspeed
6B top-right : wind direction
6C bottom-left : relative wind speed error vs. tower wind speed
6D bottom-right : wind direction difference vs. tower wind speed



Regression Output for windspeed:

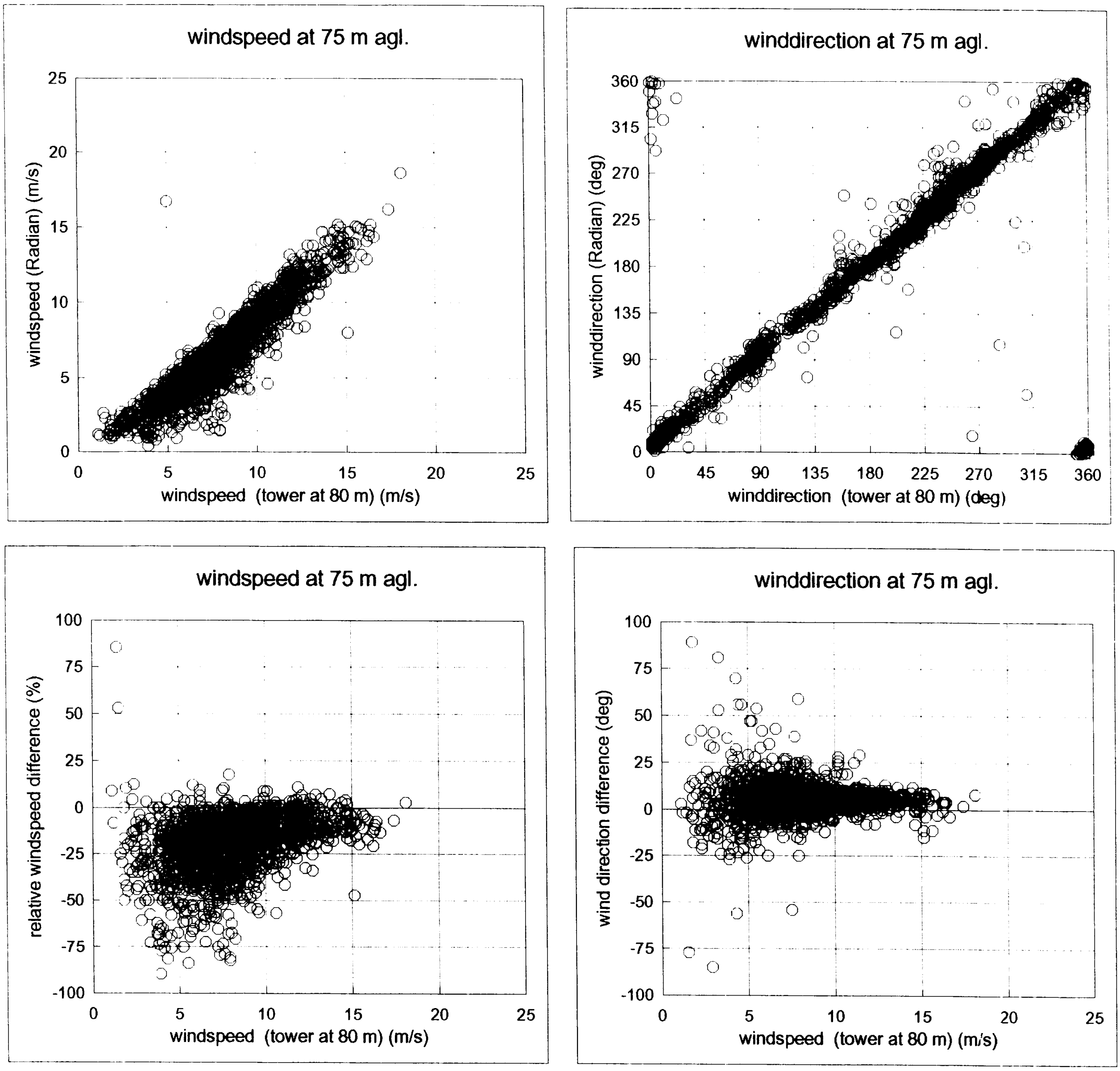
X Coefficient	0.81
Std Err of Coef.	0.01
Constant	0.67
R Squared	0.86
No. of Observations	2330
Bias:	-0.80
Std. dev.:	1.23

Regression Output for winddirection:

X Coefficient	0.992
Std Err of Coef.	0.003
Constant	1.79
R Squared	0.97
No. of Observations	2330
Bias:	-0.1
Std. dev.:	17.1

Fig. 7 Remtech wind data vs. tower data at 75 m. agl.

7A top-left : windspeed
7B top-right : wind direction
7C bottom-left : relative wind speed error vs. tower wind speed
7D bottom-right : wind direction difference vs. tower wind speed



Regression Output for windspeed:

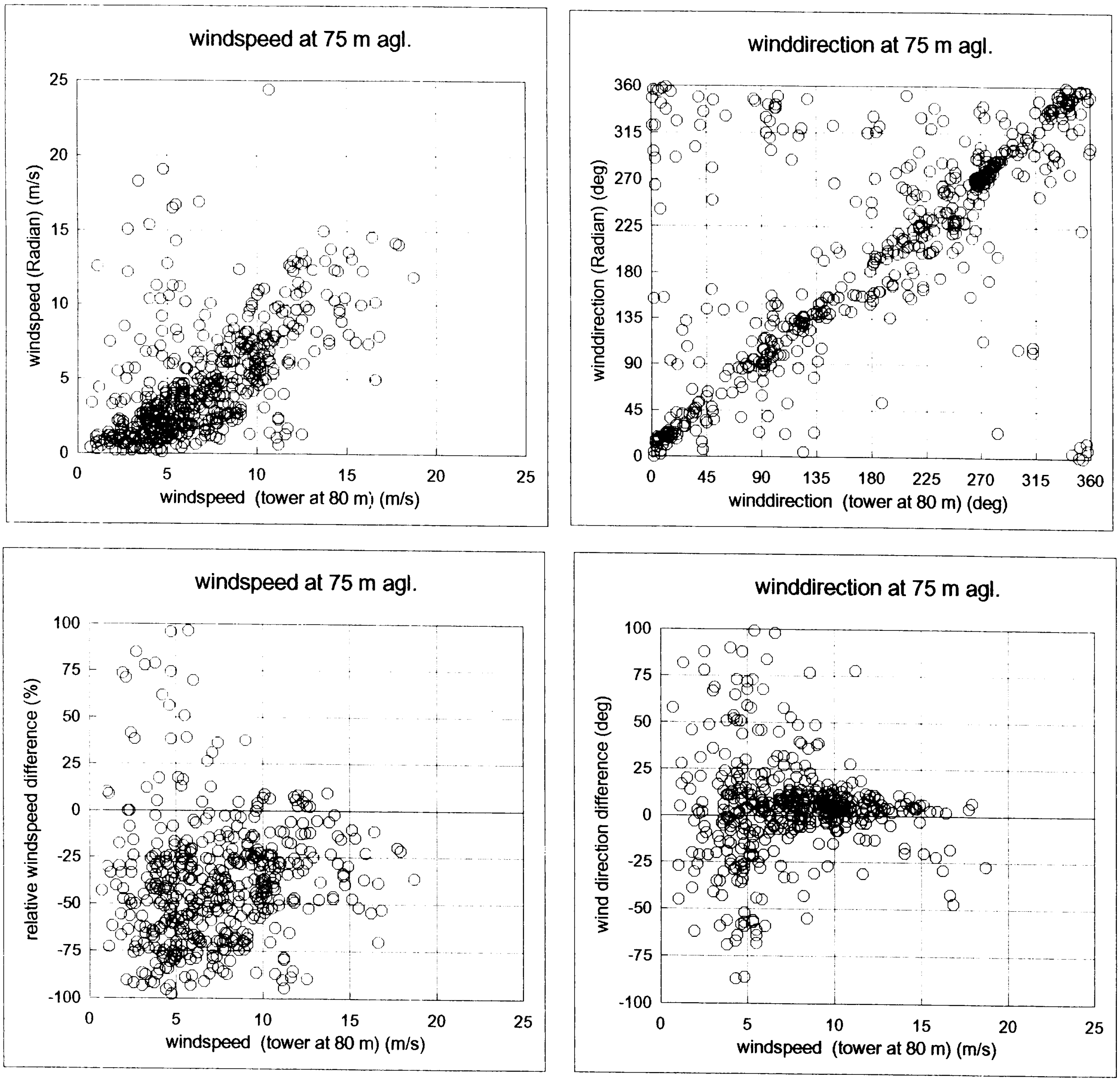
X Coefficient	0.99
Std Err of Coef.	0.01
Constant	-1.24
R Squared	0.86
No. of Observations	1632
Bias:	-1.36
Std. dev.:	1.10

Regression Output for winddirection:

X Coefficient	1.000
Std Err of Coef.	0.003
Constant	5.12
R Squared	0.99
No. of Observations	1632
Bias:	4.2
Std. dev.:	11.1

Fig. 8 Radian 600PA wind data vs. tower data at 75 m. agl.
SNR ≥ 0 dB and QC = 0

8A top-left : windspeed
8B top-right : wind direction
8C bottom-left : relative wind speed error vs. tower wind speed
8D bottom-right : wind direction difference vs. tower wind speed



Regression Output for windspeed:

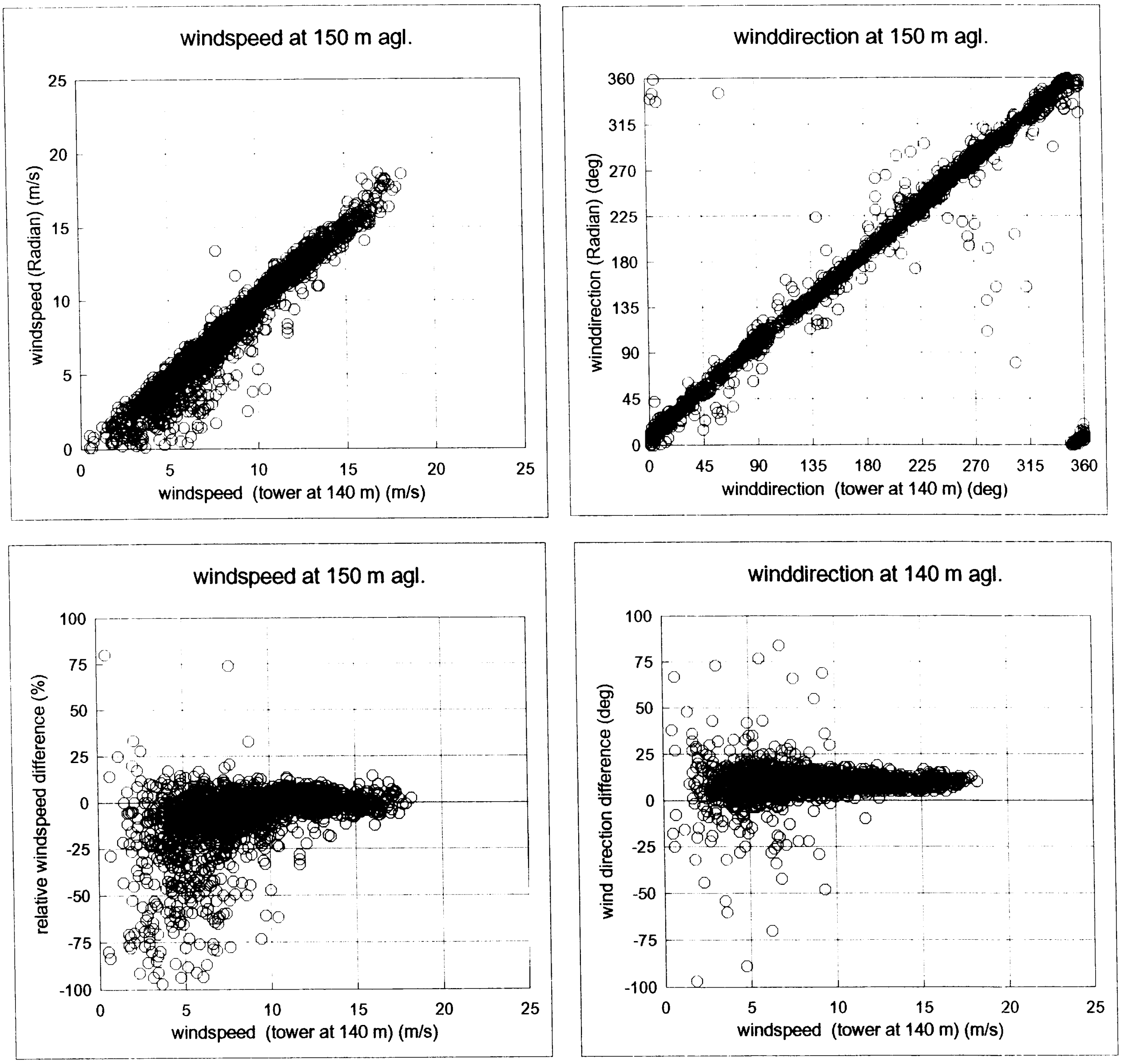
X Coefficient	
Std Err of Coef.	
Constant	
R Squared	
No. of Observations	503
Bias:	-1.98
Std. dev.:	4.18

Regression Output for winddirection:

X Coefficient	
Std Err of Coef.	
Constant	
R Squared	
No. of Observations	503
Bias:	7.3
Std. dev.:	43.6

Fig. 9 Radian 600PA wind data vs. tower data at 75 m. agl.
SNR $\geq$ 0 dB and QC > 0

9A top-left	:	windspeed
9B top-right	:	wind direction
9C bottom-left	:	relative wind speed error vs. tower wind speed
9D bottom-right	:	wind direction difference vs. tower wind speed



Regression Output for windspeed:

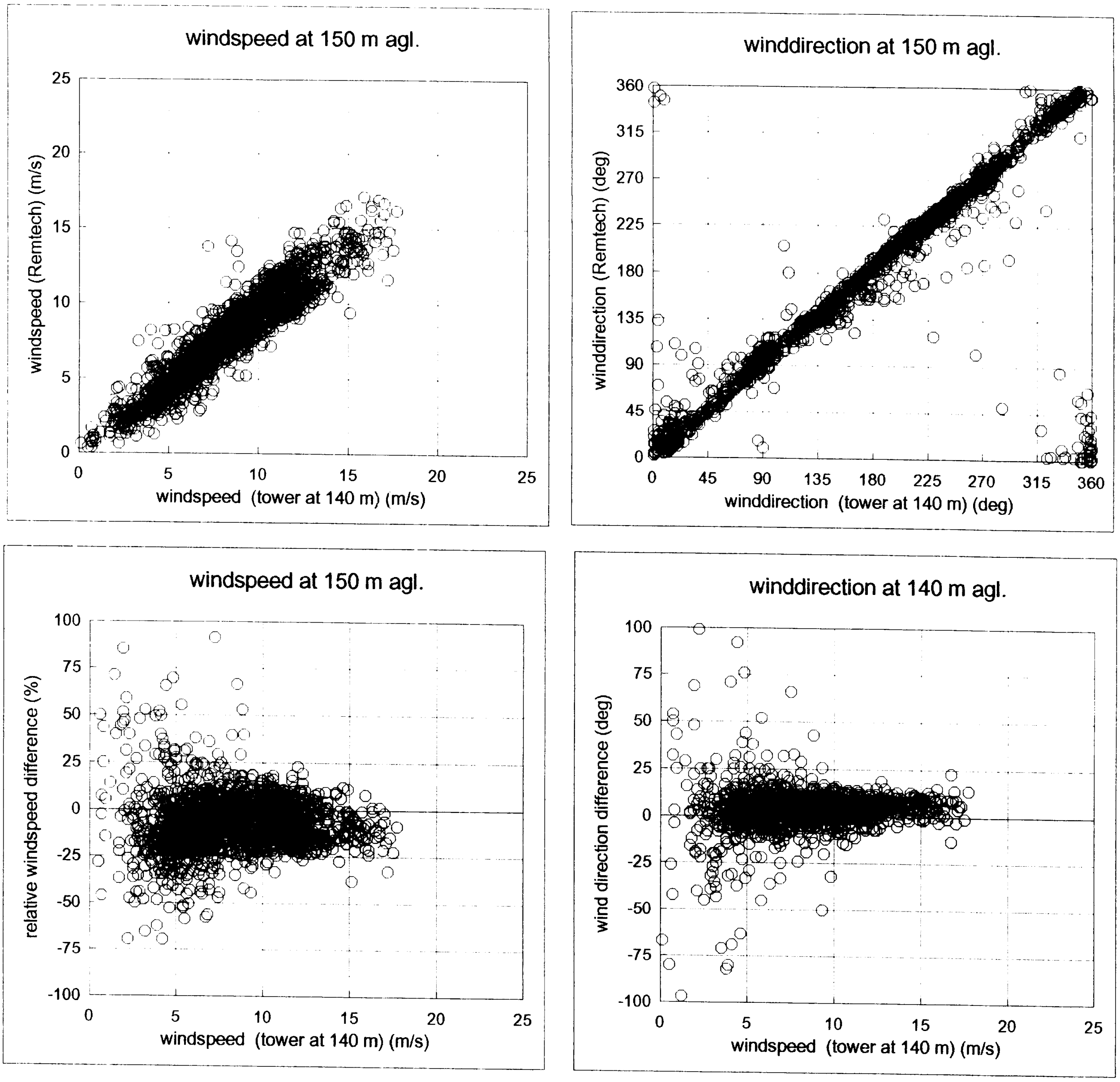
X Coefficient	1.09
Std Err of Coef.	0.01
Constant	-1.15
R Squared	0.94
No. of Observations	2095
Bias:	-0.37
Std. dev.:	0.95

Regression Output for winddirection:

X Coefficient	0.990
Std Err of Coef.	0.002
Constant	9.62
R Squared	0.99
No. of Observations	2094
Bias:	9.2
Std. dev.:	11.7

Fig. 10 Radian 600PA wind data vs. tower data at 150 m. agl.

10A top-left : windspeed
10B top-right : wind direction
10C bottom-left : relative wind speed error vs. tower wind speed
10D bottom-right : wind direction difference vs. tower wind speed



Regression Output for windspeed:

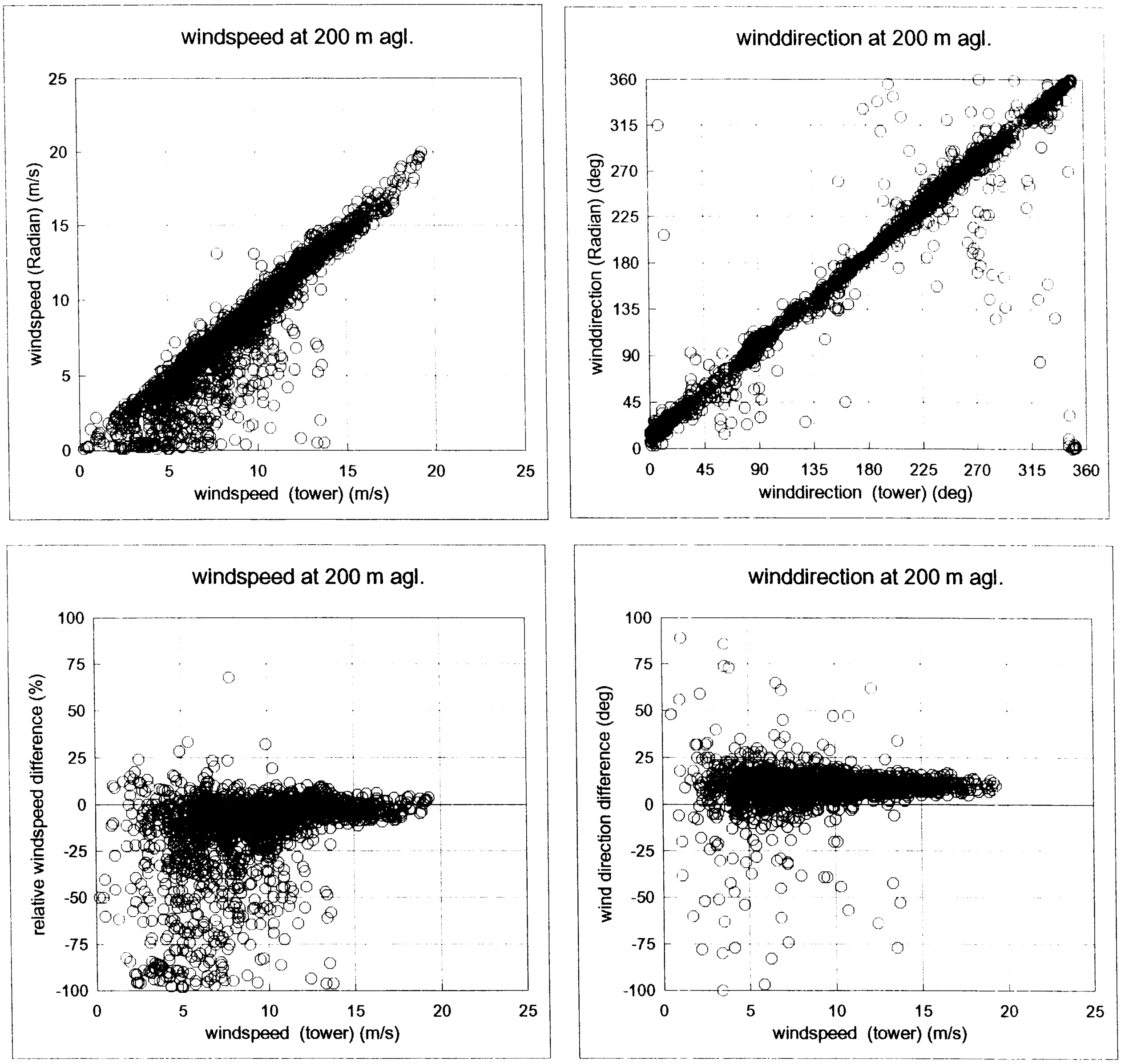
X Coefficient	0.92
Std Err of Coef.	0.01
Constant	0.14
R Squared	0.88
No. of Observations	1638
Bias:	-0.52
Std. dev.:	1.12

Regression Output for winddirection:

X Coefficient	0.995
Std Err of Coef.	0.004
Constant	5.28
R Squared	0.98
No. of Observations	1631
Bias:	4.4
Std. dev.:	14.4

Fig. 11 Remtech wind data vs. tower data at 150 m. agl.

11A top-left	:	windspeed
11B top-right	:	wind direction
11C bottom-left	:	relative wind speed error vs. tower wind speed
11D bottom-right	:	wind direction difference vs. tower wind speed

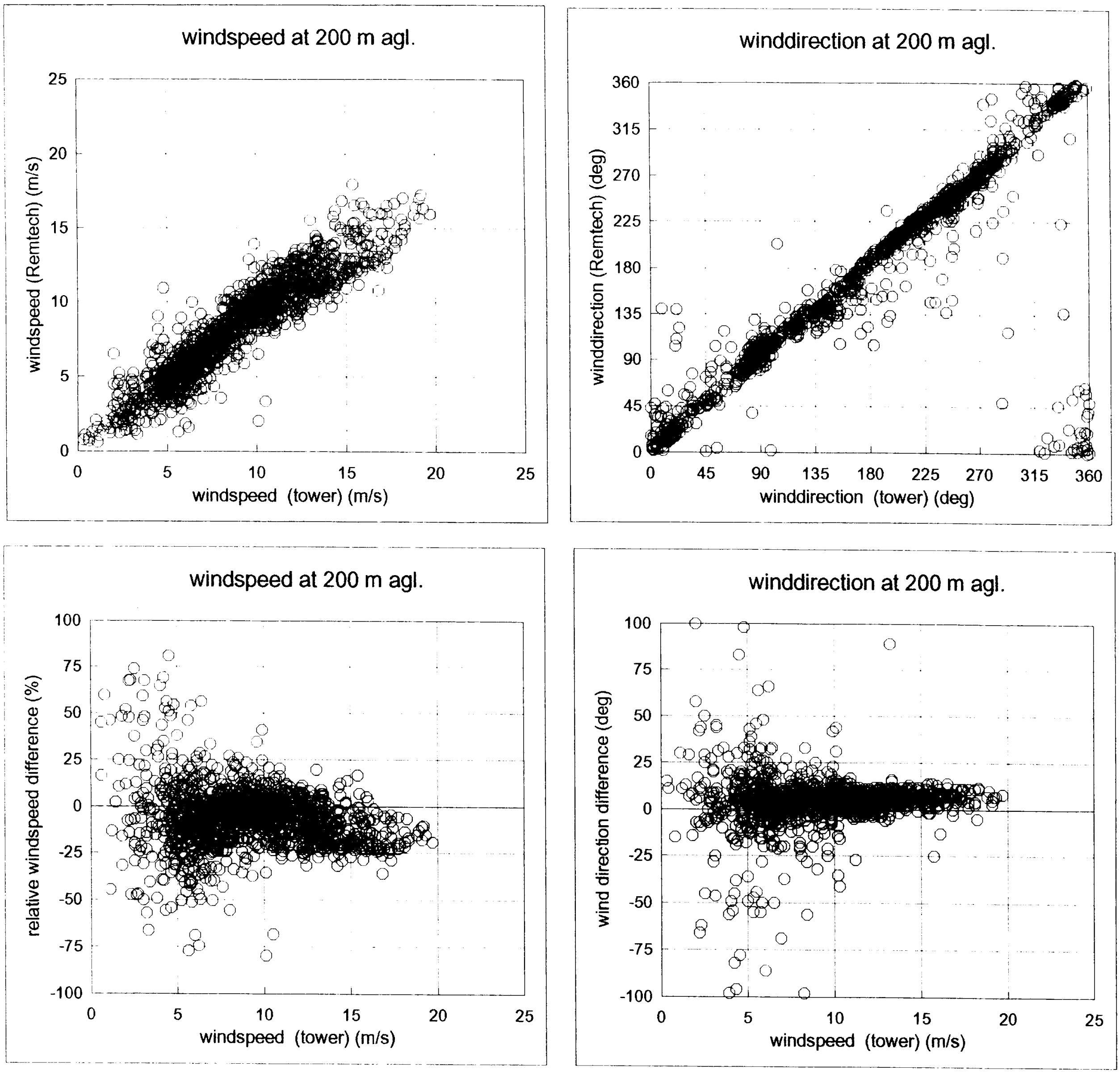


Regression Output for windspeed:	
X Coefficient	1.07
Std Err of Coef.	0.01
Constant	-1.6
R Squared	0.87
No. of Observations	1941
Bias:	-0.95
Std. dev.:	1.55

Regression Output for winddirection:	
X Coefficient	0.987
Std Err of Coef.	0.004
Constant	10.6
R Squared	0.97
No. of Observations	1936
Bias:	8.2
Std. dev.:	19.2

Fig. 12 Radian 600PA wind data vs. tower data at 200 m. agl.

12A top-left : windspeed
12B top-right : wind direction
12C bottom-left : relative wind speed error vs. tower wind speed
12D bottom-right : wind direction difference vs. tower wind speed



Regression Output for windspeed:

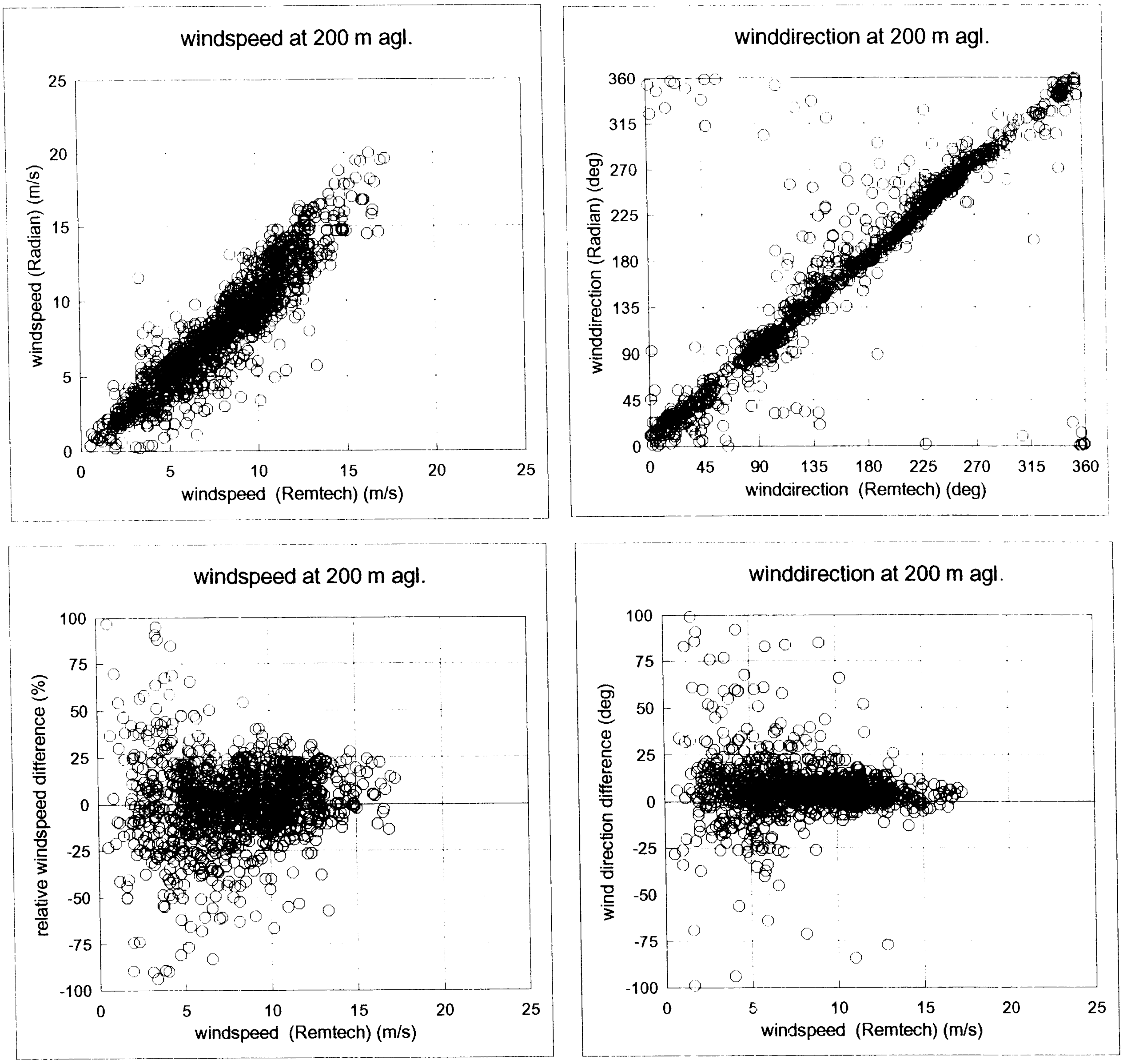
X Coefficient	0.85
Std Err of Coef.	0.01
Constant	0.74
R Squared	0.86
No. of Observations	1214
Bias:	-0.64
Std. dev.:	1.40

Regression Output for winddirection:

X Coefficient	0.985
Std Err of Coef.	0.006
Constant	7.22
R Squared	0.96
No. of Observations	1209
Bias:	4.6
Std. dev.:	18.3

Fig. 13 Remtech wind data vs. tower data at 200 m. agl.

13A top-left : windspeed
13B top-right : wind direction
13C bottom-left : relative wind speed error vs. tower wind speed
13D bottom-right : wind direction difference vs. tower wind speed



Regression Output for windspeed:		Regression Output for winddirection:	
X Coefficient	1.07	X Coefficient	1.010
Std Err of Coef.	0.01	Std Err of Coef.	0.007
Constant	-0.44	Constant	3.99
R Squared	0.84	R Squared	0.94
No. of Observations	1070	No. of Observations	1070
Bias:	0.12	Bias:	5.6
Std. dev.:	1.59	Std. dev.:	22.7

Fig. 14 Radian 600PA wind data vs. Remtech wind data at 200 m. agl.

14A top-left : windspeed
14B top-right : wind direction
14C bottom-left : relative wind speed error vs. tower wind speed
14D bottom-right : wind direction difference vs. tower wind speed

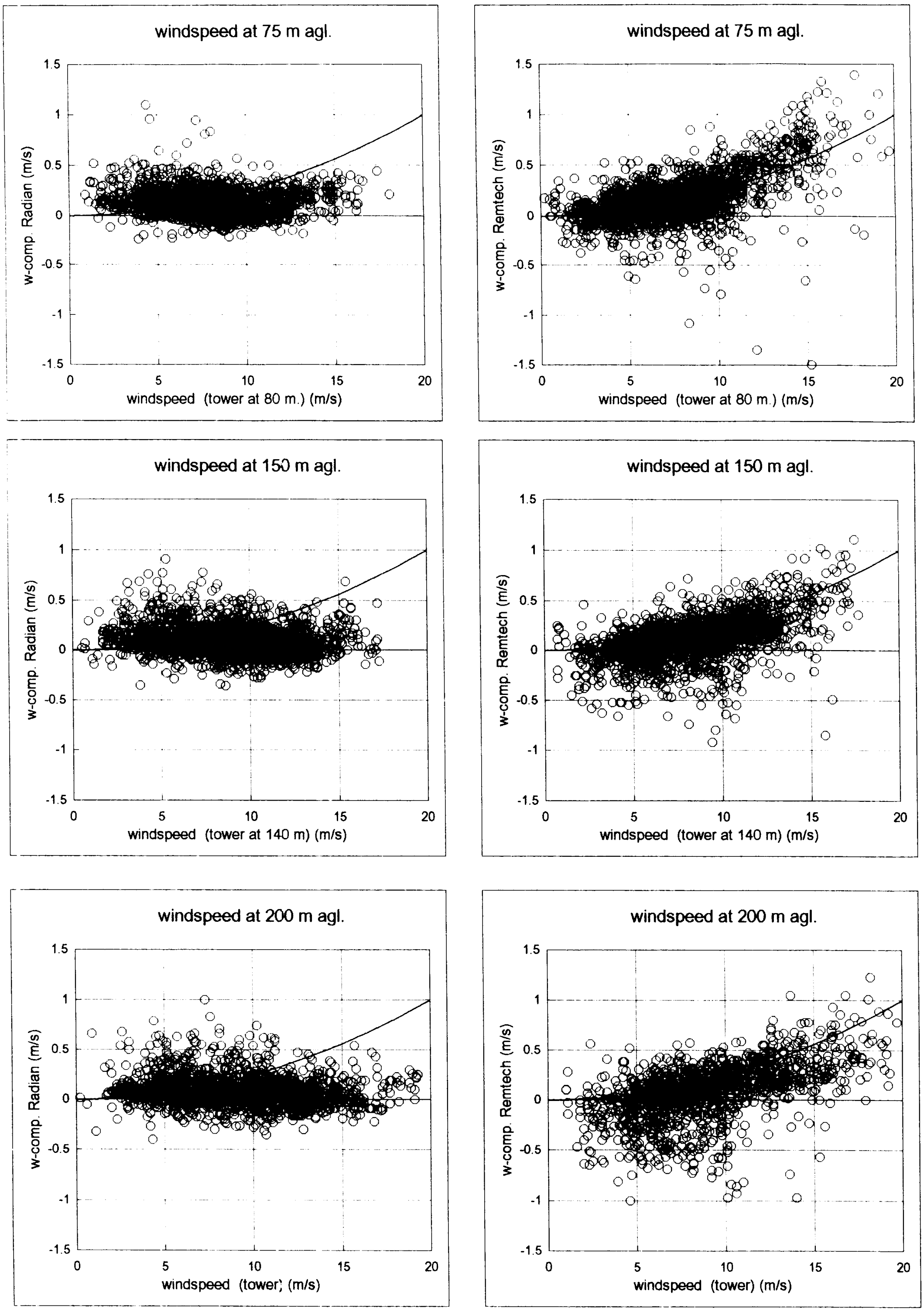


Fig. 15 Sodar vertical wind speed vs. tower wind speed.

15A top-left	:	Radian 200 m.	15D mid-right	:	Remtech 150 m.
15B top-right	:	Remtech 200 m.	15E bottom-left	:	Radian 75 m.
15C mid-left	:	Radian 150 m.	15F bottom-right	:	Remtech 75 m.

Solid line is first order approximation of apparent vertical wind speed induced by the tilt of the vertical beam by the horizontal wind.

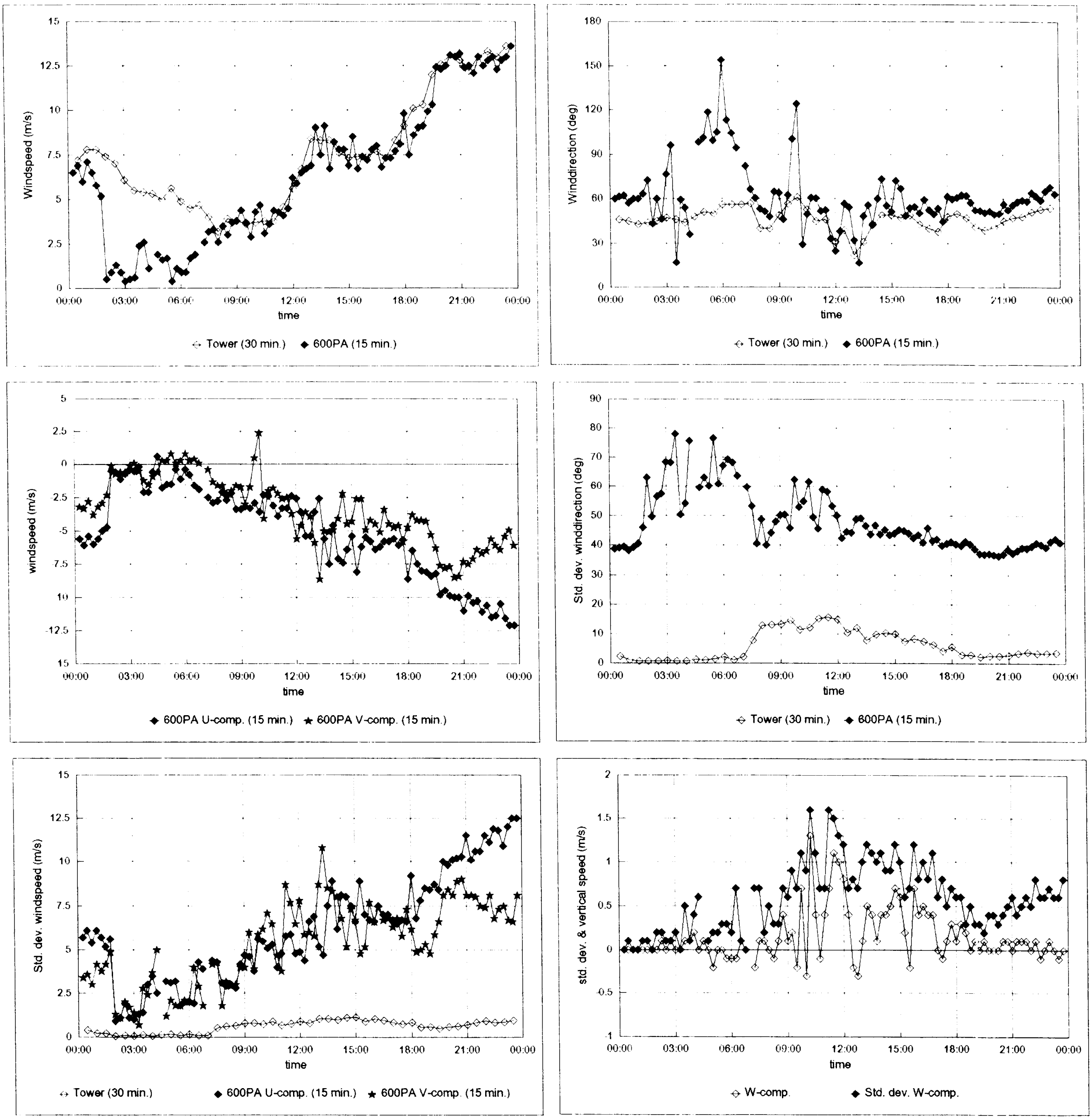


Fig. 16 Wind mean values and standard deviations for Radian and tower.
8-august-1994, 200 m. agl.
Radian : 15 min. averaged values, SNR ≥ -2 dB.
Tower : 30 min. averaged values.

16A top-left	: windspeed	16D mid-right	: σ_θ
16B top-right	: winddirection	16E bottom-left	: σ_u , σ_v
16C mid-left	: u and v components	16F bottom-right	: w , σ_w