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CONTENTS

RESULTS OF THE SODAR INTERCOMPARISON EXPERIMENT AT DÜRNROHR, AUSTRIA

Abstract. A statistical and meteorological intercomparison of the three-axis monostatic A0-Doppler Sodar and the monostatic PA2 phased array Sodar is presented, both produced by the french manufacturer REMTECH. The comparison was undertaken on the grounds of the power plant Dürnrohr northwest of Vienna, Austria, in the beginning of 1993. It was intended to test, whether the interpretation skill, gained with the A0-Sodar at different sites in Austria during some years, could be transferred to the new PA2-Sodar. The results of the intercomparison are discussed thoroughly, but not all the discrepancies can be explained fully. After a careful survey of the literature it turned out, however, that the results are within those of other intercomparisons. The comparison presented here comprises, for the first time, all parameters measured by both instruments.

Zusammenfassung. Gegenstand des vorliegenden Vergleichs sind das A0-Doppler Sodar und das PA2 phased array-Sodar, beide von der französischen Herstellerfirma REMTECH produziert. Der Vergleich wurde am Gelände des Kraftwerks Dürnrohr im Tullnerfeld zu Beginn des Jahres 1993 durchgeführt, um zu prüfen, ob die mit dem A0-Sodar seit 1986 aus Messungen an mehreren Standorten gewonnenen Interpretationsmuster auf das neu einzusetzende PA2-Sodar übertragbar sind. Die Ergebnisse des Vergleichs werden eingehend statistisch und meteorologisch diskutiert. Nicht alle aufgetretenen Diskrepanzen können befriedigend erklärt werden, doch stand nach eingehendem Literaturstudium fest, daß die Ergebnisse durchaus im Rahmen anderer Vergleichsexperimente liegen. Bei dem hier präsentierten Vergleich werden zum ersten Mal in der Literatur alle Parameter, die von beiden Instrumenten gemessen werden, diskutiert.

1. INTRODUCTION

Between December 23, 1992 and March 2, 1993, a series of comparative measurements with two acoustic sounders were undertaken on the grounds of the power plant Dürnrohr (48°19' N, 15°55' E), Austria. The site was made available by the Austrian electricity companies „Verbundkraft“ and „EVN“. The instruments compared were the A0 Doppler Sodar, purchased in 1986 by the Austrian electricity company „Verbundkraft“ and one of the newly bought phased-array Sodars PA2, both manufactured by the French company REMTECH. The A0-Sodar was run by the Central Institute of Meteorology and Geodynamics at different inner- and outer-alpine locations to study local circulation and turbulence patterns (Piringer, 1992). After some tests and experiments, the PA2 Sodars will be positioned at selected sites near the Austrian border to provide continuous information on the wind field and turbulence, which is intended to be used explicitly in cases of severe nuclear accidents abroad with radioactive clouds approaching Austria affording rapid decision-making. Because of the longterm experience with the A0 Sodar, a comparison between the two types of acoustic sounders was of primary interest. This report contains a detailed discussion of the results of the intercomparison. Partly during the experiment, partly afterwards in the course of the statistical evaluation of the data it turned out that the performance of the A0-Sodar was steadily declining most probably due to defective membranes generating the acoüstic power, and the PA2-Sodar, whose software still being in a stage of development at this time, showed some software defects. In this report, therefore, data for the first month when the two systems operated at their full acoustic powers, will be discussed. The evaluation of the full dataset is available from Piringer (1995).

Vogt and Thomas (1994) published a comparison between PA2 Sodar and Karlsruhe tower data using 10 minutes averages. Comparisons of the A0 Sodar and the tower were undertaken earlier (Thomas and Vogt, 1993; Thomas and Vogt, 1990). A direct intercomparison of A0- and PA2-Sodar data concerning data availability, wind direction and windspeed was published by Piringer (1994); these results are included and extended here, together with those of the other parameters: vertical velocity, the standard deviations of wind direction and vertical velocity, and the echo intensity. The results will be compared with other investigations obtainable from the literature, all of which include at least one Remtech Sodar of type A0 and the comparison with other Sodars or towers.

The next chapter contains a technical description of the Sodars. In chapter 3, the methodology and the problems of the intercomparison will be explained. This is followed by a description of the location and the measurement programme. Chapters 5 and 6 contain the results of the intercomparison: first, the availability of data as a function of height is discussed, then the agreement of the parameters is investigated. Chapter 7 contains two meteorological case studies. Summary and conclusions are given in chapter 8.

2. TECHNICAL DESCRIPTION OF THE TWO SODARS

The A0 Doppler Sodar (REMTECH, 1985; Sodar is an abbreviation for „sound detection and ranging", Neff and Coulter, 1986) consists of three funnel-shaped antennas (upper diameter approx. 2 m, about 2 m high) which alternately transmit sound pulses; each of the antennas also serves as a receiving unit for the backscattered signal (monostatic Sodar). One antenna points in the vertical, the other two are tilted from the vertical at an angle of 18°; the angle between them is 90°.

The new PA2-Sodar (REMTECH, 1991; the abbreviation stands for „phased array", the number 2 describing the size of the system) consists of a single flat „antenna" of 14 x 14, in sum196 small loudspeakers mounted on a 1,3 x 1,3 m horizontal platform. The PA2-Sodar, too, is a monostatic Sodar. The loudspeakers are electronically controlled in such a way that the sound waves generated by them show the intended direction via interference: emitting in phase, the sound wave propagates vertically; tilted signals are produced by internally steered phase shifts. The system parameters of the two instruments are listed in Table 1.

Table 1: System parameters of Sodars A0 and PA2

Parameter	A0	PA2
Centered frequency (Hz)	1600	2100
Pulse length (ms)	50 - 400	5 x 200
Time of reception (ms)	200	200
Number of elements	3	196
Angle-tilted antenna	18°	30°
Number of range gates (max.)	20	30
Min. height of first gate (m)	40	50 - 60
Mean distance of range gates (m)	20 - 50	20 - 50
Max, height range (m)	1000	900
Averaging period (min)	10 - 60	10 - 60

Atmospheric stability is deduced from the vertical distribution of the backscattered signal intensity („echo“), and the components of the three-dimensional wind are derived from the frequency shifts due to the Doppler effect. These principles are examined in more detail in the following.

The sound pulse transmitted by a Sodar is backscattered continuously from the atmosphere, the time of reception indicating the height at which backscatter occurred (approx. 6 seconds for a height range of about 1000 m). Usually, the echo intensity varies for one signal: higher intenities are received from layers of strong thermal turbulence (daytime convection) or enhanced mechanical turbulence (windshear, mainly in connection with night-time temperature inversions), lower intensities are associated with weak turbulence or near-neutral lapse rates. Because the speed of sound is well-known, vertical profiles of the echo intensity can be constructed.

The turbulence elements responsible for the echo intensity move at the speed of the wind, thus a double Doppler effect results (REMTECH, 1985): the first is realized when the acoustic beam reaches the moving turbulence elements, the second, when these cells rebroadcast by backscattering a part of the sound energy, while the antenna, now receiving, is still fixed.

Transmission and reception times are almost equal for the A0-Sodar and exactly equal for the PA2-Sodar. The radial windspeed along the beam axis v_r is responsible for the frequency shift. In order to sample air volumes not too much apart (with each antenna at each time step) and to reduce the influence of air temperature on the sound propagation $c + 2v_r$ (REMTECH, 1985), the „horizontal" antennas are tilted at a rather narrow angle (Table 1), thus reducing v_r for a given horizontal windspeed. On the other hand, the horizontal wind is measured more precisely if the inclination of the antennas from the vertical is larger. as it is the case for the PA2-Sodar (Table 1). The antenna tilt is therefore to be seen as a compromise between different demands.

The horizontal wind components are calculated from the frequency shifts of the signals of the tilted antennas, the vertical velocity from that of the vertical antenna (each including the standard deviations). In order to compensate for the temperature dependance of the speed of sound, the emission frequencies of the Sodars are automatically adjusted to temperature changes.

The information from Sodars is averaged both in space and time. In Tables 2 and 3, typical data displays for the A0- and the PA2-Sodars are reproduced. All in all, six quantities are available for comparison: Wind direction and its standard deviation, windspeed, vertical velocity and its standard deviation, and the echo intensity.

Table 2: Typical data display for one half-hour, A0-Sodar (after REMTECH, 1985)

DAY	MONTH	YEAR	HOUR	MIN	SEC	VAL1	VAL2	VAL3	NSLICE
23	2	88	3	59	59	295	312	379	20

VAL	RANGE	ECHO	S ECHO	SPEED	TETA	S TETA	W	S W
0	700	80	23					
0	660	95	38					
1	620	96	41	552	188	-9999	-29	19
1	580	90	31	805	193	-9999	-36	27
1	540	136	37	826	190	-9999	-28	34
1	500	221	40	709	188	1	-12	37
1	460	264	22	557	185	2	-12	33
1	420	228	33	500	186	3	-21	24
1	380	227	44	341	203	4	-10	19
1	340	229	41	203	194	22	-9	14
1	300	335	47	136	182	45	-16	11
1	260	637	32	74	24	36	0	19
1	220	377	52	220	41	14	1	23
1	180	208	31	211	79	16	3	23
1	140	318	41	156	80	35	0	24
1	100	299	46	64	53	60	5	24
1	60	349	17	35	89	85	-7	19

Legend:

VAL1, VAL2, VAL3	Number of valid returns of each antenna in the averaging period
NSLICE	Number of layers
VAL	= 1: layer values valid
	= 0: layer values invalid
RANGE	Height above ground (m)
ECHO	dimensionless value of the echo intensity
S ECHO	Standard deviation of the echo intensity
SPEED	Windspeed in cm/s
TETA	Wind direction in degrees
S TETA	Standard deviation of the wind direction in degrees
W	Vertical velocity in cm/s
S W	Standard deviation of the vertical velocity in cm/s

The example of Table 2 is characteristic for night-time temperature inversions. The inversion top is expected to lie at the height of the echo maximum in about 260 m. Downwards and in the inversion layer winds are variable: changing values for the wind direction, low windspeeds and high values of S TETA are present there. Vertical velocites inside the inversion are low. At the inversion top and above, the values of some parameters change significantly: wind velocity increases with height, wind direction is from the south at all layers, the values of S TETA are small. Furthermore, downward motion dominates, values of W being negative. The standard deviation of the vertical velocity is, however, not changed, the variability of W remaining equal throughout the layer.

Table 3: Typical data display for one half-hour, PA2-Sodar (after REMTECH; 1991)

BL	MONTH	DAY	YEAR	HOUR	MIN	SEC	VAL1	VAL2	VAL3
256	2	4	91	20	14	57	240	218	252

FREQ1	FREQ2	FRASS	DOPP1	DOPP2	VAL.4	NOIS1	NOIS2	NOIS3
2045	2045	2143	-9	-29	0	20	15	18

ALT	CT**2	SPEED	DIR	S DIR	W	S W	S U	S V
500	800	980	139	-9999	-9999	-9999	-9999	-9999
450	940	952	139	-9999	10	5	-9999	-9999
400	1028	924	136	1	20	6	-9999	-9999
350	1233	925	138	0	16	6	-9999	-9999
300	1147	855	136	1	9	5	-9999	-9999
250	1144	730	129	0	-1	4	61	18
200	1150	624	118	1	-7	4	53	21
150	574	586	109	1	0	4	36	26
100	286	588	108	2	11	4	26	30
50	322	599	109	2	18	4	24	32

Legend:

BL	Number of block in the data file
VAL1, VAL2, VAL3	Number of valid returns for each antenna during the averanging period
FREQ1, FREQ2, FRASS	Operational frequencies
DOPP1, DOPP2	mean Doppler shift in Hz
NOIS1, NOIS2, NOIS3	Environmental noise for each beam
ALT	Height above ground in meters
CT**2	dimensionless value of the echo intensity
SPEED	Windspeed in cm/s
DIR	Wind direction in degrees
S DIR	Standard deviation of the wind direction in degrees
W	Vertical velocity in cm/s
S W	Standard deviation of the vertical velocity in cm/s
S U	Standard deviation of the u-component of the horizontal wind in cm/s
S V	Standard deviation of the v-component of the horizontal wind in cm/s

Table 3 shows a nighttime profile as measured by a PA2 Sodar, but the echo maximum in 350 m above ground is not very strong. Therefore, no strong inversion is assumed to be present. This is supported by other parameters: Wind speed increases continuously with height, in accordance with a slight shift in the wind direction. The parameters W and S W show small values, typical for a stable lapse rate. Most probably, the vertical temperature profile was characterized by a stable gradient, including small layers of inversions.

More extended information, both theoretically and with respect to data interpretation, can be found e. g. in Brown and Hall Jr. (1978), Neff and Coulter (1986), and Neff (1990). Some more literature will be discussed in section 3.2.

3. METHODOLOGY OF THE DATA INTERCOMPARISON

3.1 Statistical criteria

The Sodar data to be compared here are half-hour mean values in height intervals of 50 m, starting 50 m above ground. Qualitatively, the agreement of the data is discussed based on mean vertical profiles of the measured quantities and on windroses for the wind direction. For a quantitative comparison, a statistical analysis was carried out. For this comparison, three basic criteria, adopted by Kaimal et al. (1984) and since then applied by many authors, are used:

1.) Sample bias:

$$\text{Bias} = 1/N \sum_{i=1}^{N} (Y_i - X_i) \tag{1}$$

2.) Root-mean-square difference or comparability:

$$\text{RMSD} = [1/N \sum_{i=1}^{N} (Y_i - X_i)^2]^{1/2} \tag{2}$$

3.) Precision or standard deviation of the differences:

$$\text{Prec} = (\text{RMSD}^2 - \text{Bias}^2)^{1/2} \tag{3}$$

Here, N is the total number of data pairs, X_i is the i-th value of the A0-Sodar (reference instrument) and Y_i the i-th value of the PA2-Sodar (test instrument).

Whereas the bias indicates the systematic difference between the data measured by the two instruments, the precision describes the scattering or the statistically distributed difference of simultaneously measured data, after being corrected for the systematic difference (Thomas and Vogt, 1993). All the statistical parameters can be calculated as absolute or relative (divided by the mean of X) values.

If the data agree perfectly, all these parameters assume the value of 0. Low values of RMSD and precision usually coincide with a high correlation of the data. In the comparison following, except for the wind direction, values of the linear correlation coefficient are also given, which would be 1 for perfect correlation. The comparison with the literature is conducted mainly by using these basic criteria together with the linear correlation coefficient.

3.2 Problems and limits of the data intercomparison

Many investigators (e. g. Piringer, 1994; Vogt and Thomas, 1994; Thomas and Vogt, 1993; Chintawongvanich et al., 1989; Finkelstein et al., 1986; Beljaars, 1985) conclude from Sodar - tower and Sodar - Sodar intercomparisons that wind direction and horizontal windspeed can be derived from Sodars with reasonable accuracy. This means that the analysis of the horizontal Doppler shift of Sodars (see chapter 2) works well. This is less true for the echo intensity of the vertical beam, for the vertical Doppler shift, and for the derivation of the horizontal and vertical velocity variances. These deficiencies will be discussed in more detail.

According to Vogt and Thomas (1994), limitations of turbulence measurements with a Sodar result from volume averaging, spatial and temporal separation of sampling volumes, and the relatively slow propagation of the speed of sound. A thorough discussion of these basic limitations is available from Kaimal and Gaynor (1990) and Gaynor (1994). Earlier, Beljaars (1985) discussed extensively the effects of volume averaging on the standard deviation of the vertical velocity, σ_w. Kaimal et al. (1984) and Finkelstein et al. (1986), showed a tendency of Sodars to over-estimate σ_w in the stable nocturnal boundary layer and to under-estimate it during daytime convection. These authors find larger scatter in the σ_w-data among different instruments during nighttime, while Chintawongvanich et al. (1989) and Thomas and Vogt (1993) report on a better coincidence of Sodar- and tower-derived σ_w at night. Finkelstein et al. (1986) suggested that contributions from sources other than the true vertical velocity fluctuations occur, such as uncertainties in the Doppler tracking of the wind. Recently, Seibert and Langer (1996) found a systematic bias in Sodar-measured σ_W which they explain by a lower percentage of valid returns from the regions of subsidence as compared to the higher backscatter cross-section within thermal plumes, resulting in a loss in the variance of the vertical velocity. Despite these findings, numerous investigators (e. g. Vogt and Thomas, 1994; Kaimal et al., 1984; Beljaars, 1985; Gaynor, 1994; Piringer, 1989) have shown that σ_w can be measured sufficiently reliably with Sodars to allow for a useful estimation of the turbulence state of the boundary layer.

From results of the International Sodar Intercomparison Experiment ISIE at Boulder in September 1988 (Gaynor et al., 1990), which included an A0-Sodar, Gaynor (1994) concluded that the accuracy of Sodar-derived standard deviation of the horizontal wind direction, σ_θ, „is not adequate for any useful purpose". Similar results were derived by Thomas and Vogt (1993). According to Neff et al. (1991), beam wander and tilt is the major cause for the very poor horizontal wind variance measurements. Gaynor (1994) expects improved σ_w measurements from Sodars with a high-frequency, narrow beam and fast repetition rate.

The intensity of the backscattered signal is simply given as an indicative number with no physical background to the values as such. Its height dependance is used to estimate inversions and mixing heights (see chapter 2 for details). Looking at the data displays of Tables 2 and 3 it becomes clear that the numbers as such differ much for the Sodars, resulting e. g. in a large systematic bias. Because only the locations of the echo maxima in the vertical profile are relevant for inversion detection, a high correlation between A0 and PA2 echo values is important rather than the agreement of absolute values. The statistical analysis of the echoes (chapter 6.6) is therefore restricted to the calculation of the linear correlation coefficient.

4. SITE AND MEASUREMENT PROGRAMME

As mentioned, the Sodars were positioned on the grounds of the power plant of Dürnrohr, approx. 36 km northwest of Vienna (Fig. 1). The surrounding area is flat, but approx. 15 km southeast of the location, the pre-Alpine sandstone ridge of the „Wienerwald" rises approximately 300 m above the level terrain. The ridge, in its steepest part, is oriented from northeast to southwest. This ridge and some affluents to the Danube coming from the southwest influence the near-surface windfield, as will be shown in chapter 6.

The intercomparison between the A0-Sodar and the PA2-Sodar took place between December 23, 1992, and March 2, 1993. Until January 25, 1993, both instruments operated at their full acoustic powers. After this date, acoustic power had to be reduced by 12 dB (from approx. 100 dB near the instruments) between 22:00 and 6.00 local time due to complaints by neighbours. This reduction should coincide with a considerable loss in the available height

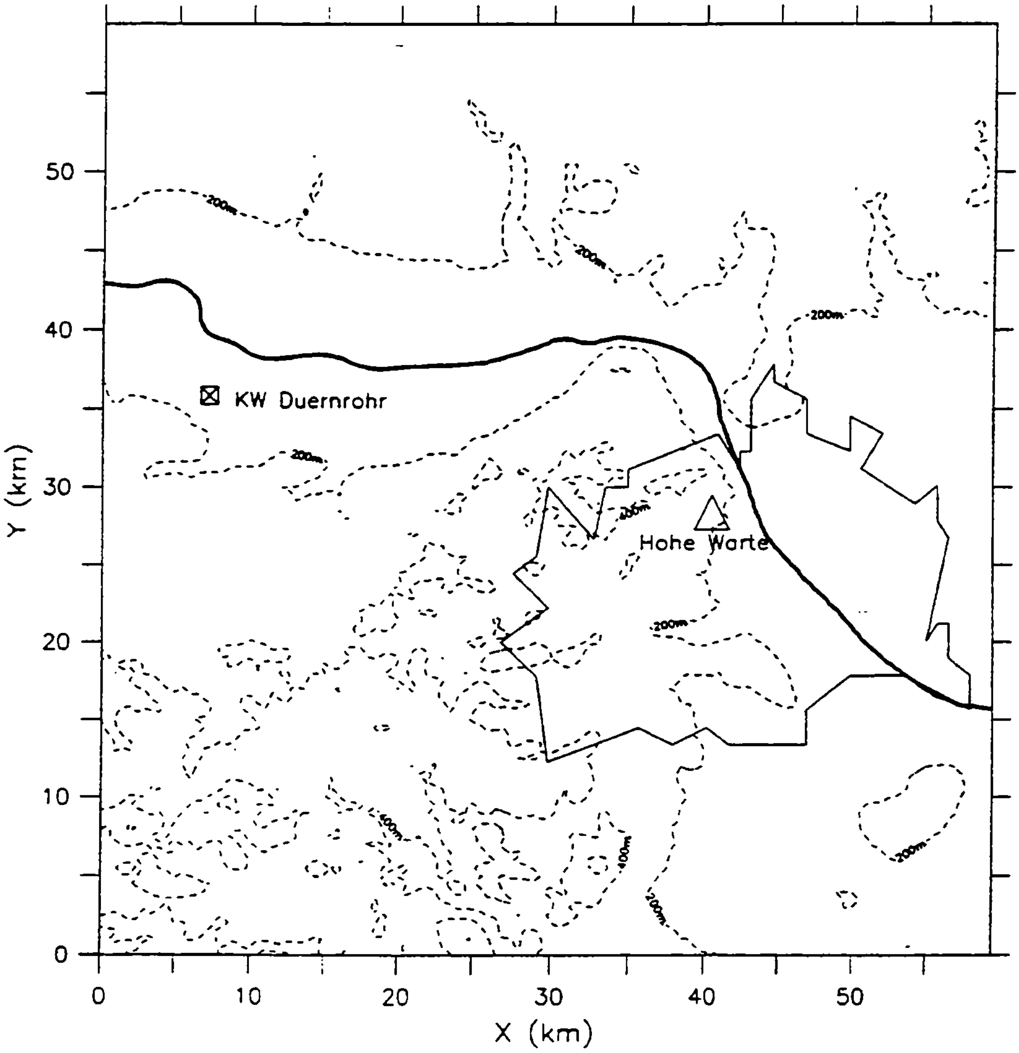


Fig.1: Topographic map of Vienna and surroundings including Dürnrohr

range. Therefore, the period of investigation is split into two parts, the first between December 23, 1992 and January 25, 1993 (henceforth called „January case“), the second between January 26 and March 2, 1993 („February case“).

The height range of the comparison extends up to 600 m. Up to this height, more than 100 data pairs (half-hour mean values) are available. As discussed by Piringer (1994) and shown in chapter 5, the second period was characterized by a strong reduction in data availability for the A0-Sodar. These large data losses are due to technical problems. The data comparison in chapter 6 is therefore presented for the „January case“ only. The full intercomparison is presented in Piringer (1995).

5. DATA AVAILABILITY

Because Duernrohr is a quiet site, it was expected that a relatively large vertical data range would be attained, the PA2-Sodar performing somewhat better than the A0-Sodar. For this analysis, data availability of windspeed for different heights is compared in detail, and results for the other parameters are summarized.

The results on data availability are presented in Fig. 2a (daytime) and Fig. 2b (nighttime). Height above ground is displayed along the abscissa, the frequency of valid data along the ordinate. The solid lines represent the A0-Sodar, the dashed lines the PA2-Sodar. Generally and as expected, the percentage of valid data is higher for the phased-array acoustic sounder. During January, the data gain by the PA2-Sodar compared to the A0-Sodar is about 20 % at daytime and about 10 % at night, except at very high altitudes.

For echo intensity, more data are available from the PA2-Sodar only for heights above 350 m. The data available for all the other parameters, esp. the standard deviations, is less. At large heights, data availability is poor for both instruments.

The percentage of valid data at daytime (Fig. 2a) is larger during the „January case“. For the PA2-Sodar, a maximum reduction of 10 % is noted during the second period as compared to the first. This might be caused by different weather patterns during both periods: January 1993 had above-normal temperatures, February 1993 below-normal temperatures (resulting in 15 days with temperature averages below 0 °C); rainfall rates were about normal during both months.

The strong reduction in the data amount for the A0-Sodar (Fig. 2a; it concerns all parameters measured) in February, however, probably cannot be explained by the lower ambient

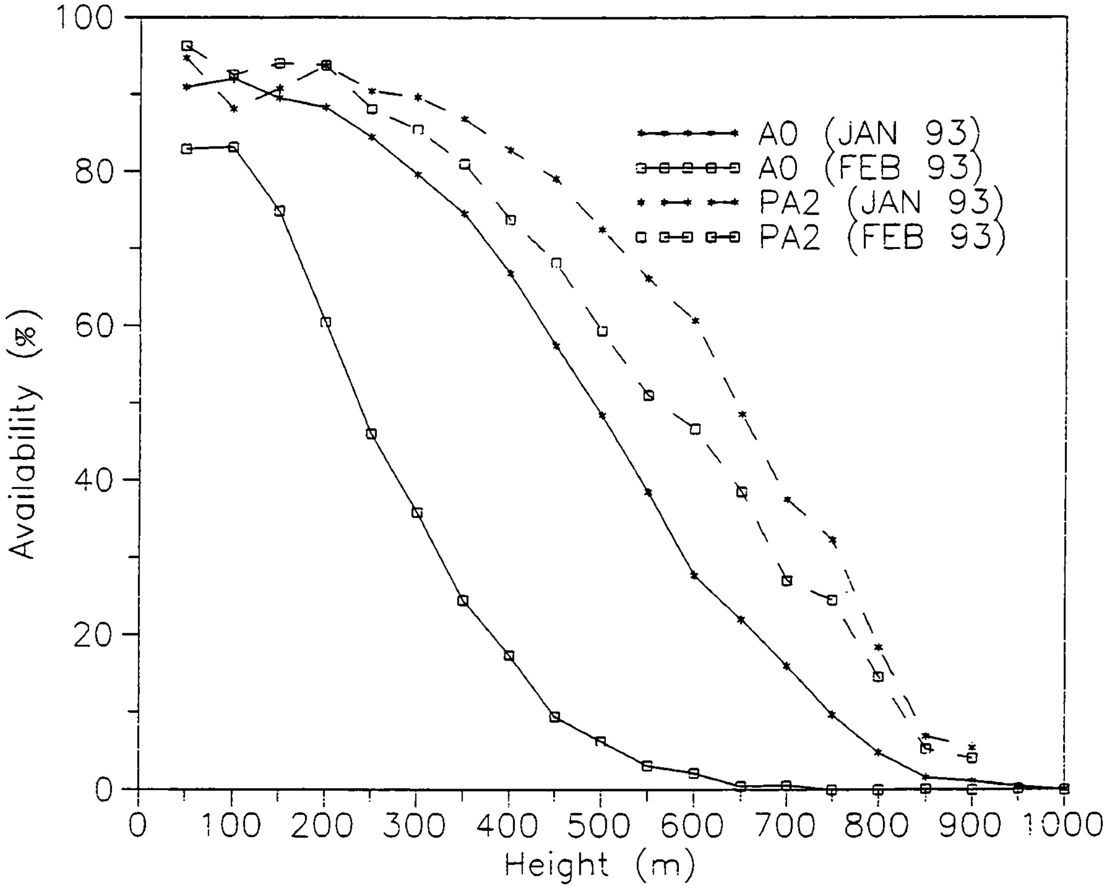


Fig. 2a: Availability of windspeed data at Duernrohr
Daytime (6 – 22 hours local time)

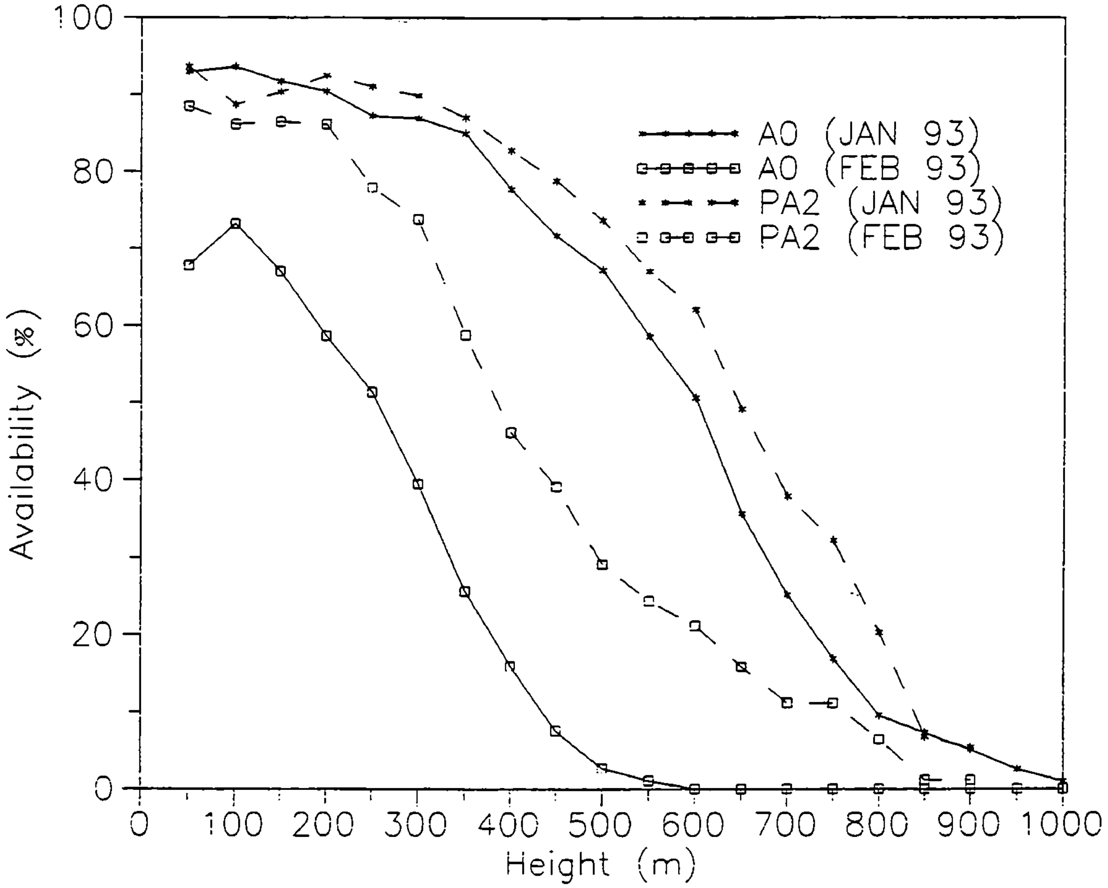


Fig. 2b: Availability of windspeed data at Duernrohr
Nighttime (22 – 6 hours local time)

temperatures during February alone. The large data losses were caused by technical problems. Possible reasons could have been insufficiencies in the antenna heating systems prohibiting snowmelt inside the antennas or defects of the membranes generating the acoustic power (a failure which occurred frequently before). Afterwards, the very reason cannot be determined. By statistical analysis it was shown (Piringer, 1994) that these data losses had no effect on data quality, but the sample available for comparison was reduced very much for the „February case".

As can be seen from Fig. 2b, reduction of acoustic power during February resulted in considerable height losses, especially for the A0-Sodar. This is true for all the measured quantities. The software of the PA2-Sodar allows for power reduction in steps of 6 dB, whereas for the A0-Sodar, acoustic power can be reduced in steps of 0.1; it is not exactly clear if a power reduction of 10 % corresponds to this value. This was however assumed, and the A0-Sodar was operated at 10 % power reduction at night. A reduction of 12 dB for the PA2-Sodar is equivalent to about 15 %. Comparing the nighttime curves for the „January" (full acoustic power) and „February" (power reduction) periods (Fig. 2b), the data losses are mostly large for both systems. For the PA2-Sodar, they start above 200 m height and approach approximately 50% at 500 m. The situation is even worse for the A0-Sodar. At 50 % availability, the height loss for the PA2-Sodar is 250 m (from 650 to 400 m) due to 12 dB power reduction, and 350 m (from 600 to 250 m) for the A0-Sodar. Vogt and Thomas (1994), for the PA2-Sodar, found only 100 m reduction (from 400 to 300 m) at the 50 % level when acoustic power was decreased by 12 dB. The large reductions found here also affected the quality of windspeed data (Piringer, 1994). Because of the technical problems and the data losses reducing the available data sample, the „February" period was omitted from the statistical data comparison discussed in chapter 6.

6. STATISTICAL COMPARISON OF THE MEASURED QUANTITIES

6.1 Overview of experiments conducted earlier

The number of Sodar intercomparison experiments, whose results are available in the literature, is limited. In the following, those whose results were taken to be compared to our own experiment, will be described briefly, especially with respect to date and location, Sodar types involved, and quantities available.

Beljaars (1985) reported about several field studies necessary from the decision to buy a three dimensional Remtech Sodar in 1980 to finally purchase a Remtech Sodar with spectral analysis in February 1983. In this last version, the spectral distribution of the signal is calculated by means of the Fourier transformation to determine the Doppler shift as this is handled by the A0-Sodar and described in section 2 of this report. For this FFT Sodar, comparisons were done in April and May 1983 during the COAST experiment, where the measurements were compared to an anemometer at a tower at a height of 70 m, giving horizonatal windspeed and wind direction and the standard deviation of the latter. Additionally, in the summer of 1983, a comparison with data from the Cabauw meteorological tower was undertaken, when the Sodar was equipped with a new antenna foam. This time, the comparison comprised, besides the former parameters at levels 40, 80, 120 and 200 m with respect to the Monin-Obukhov length as a stability parameter, also σ_w and a comparison of the scattering intensity C_T with the surface heat flux, both without statistics.

In September 1982, a three-week field experiment was conducted at the Boulder Atmospheric Observatory (BAO), where four Doppler Sodar manufacturers had been invited to have their measurements compared to those of the BAO 300 m meteorological tower. The results were first published in a BAO report (Kaimal et al., 1984) and later on, mostly identical, but somewhat shortened, in an international journal (Finkelstein et al., 1986). Gaynor and Kristensen (1986) used part of these data for their comparison of second moments derived from monostatic Doppler Sodar winds to those of the tower sonic anemometers. The Sodars involved in this field experiment were a three-axis monostatic system by AeroVironment, the Remtech A0-Sodar, a colocated monostatic/bistatic system by Radian Corporation, and the Xontech three-axis bistatic system. The averaging period for the intercomparison was 20 minutes. The three comparison levels were 100, 200 and 300 m. The comparison comprised horizontal windspeed and wind direction and σ_w values.

Chintawongvanich et al. (1989) report on another field test program which took place at the BAO observatory during 15 - 20 September 1986 to test and evaluate the remote sensors that would be deployed in supporting the U.S. army programs and missions. The instruments involved in the program were two Remtech three-axis monostatic systems, one provided by the U.S. Army Atmospheric Sciences Laboratory (ASL), th other by the U.S. Army Dugway Proving Ground (Dugway). The ASL supplied also a laser Doppler Lidar. The ASL Sodar's horizontal wind sensing antennas tilted 18°. The operating frequency centered at 1600 Hz, and it was set to operate in the range 50 tö 525 m. The corresponding data for the Dugway Sodar were 15,5°, 2400 Hz, and 50 to 325 m. Comparisons on horizontal windspeed and wind direction, σ_θ and σ_w, all except σ_θ also split into day- and nighttime, were provided. The averaging period was again 20 minutes; height levels were 100, 200 and 300 m.

Gaynor (1994) investigated the accuracy of Sodar wind variance measurements, using data gained at the BAO observatory during the International Sodar Intercomparison Experiment ISIE from September 6 to 22, 1988 (Gaynor et al., 1990). Three commercial Sodars were compared with the BAO sonic anemometers and with each other: again the three-axis monostatic systems of AeroVironment and Remtech were used, together with the three-beam phased-array Sodar from Xontech. Data averaging time was 20 minutes. Heights above ground used were 50, 150 and 200 m.

The Institute for Meteorology and Climate Research at the University of Karlsruhe, Germany, gained a lot of experience in comparing Sodars of different types with instrumentation at their meteorological tower at the „Kernforschungszentrum Karlsruhe". Thomas and Vogt (1990) report on a comparison of a Remtech three-axis monostatic Sodar with tower data. The Sodar was operated for almost one year, from October 1, 1984 to September 5, 1985. Half-hour mean values from 20 levels between 40 and 420 m AGL were sampled. Horizontal windspeed and wind direction were compared to the tower cup anemometers and wind vanes at 40, 60, 80, 100, 160 and 200 m AGL. The standard deviation σ_φ of the angle of elevation φ of the wind vector and σ_w not available from tower measurements but approximated using σ_φ were compared at 40, 100 and 160 m AGL. Thomas and Vogt (1993) add results of direct measurements of σ_θ (wind vane) and σ_w (vector vane) at the tower to be compard to the Sodar using the same long period as above and σ_w data gained by a sonic anemometer at 100 m height during June 1 and July 31, 1990. This time they used the statistical criteria given in section 3.1 of this report.

Vogt and Thomas (1994) tested the Remtech PA2-Sodar by intercomparison with the Karlsruhe tower data. Besides the report presented here, this paper by Vogt and Thomas is the only comparison available up to now known to the author where a PA2-Sodar was involved. The intercomparison took place between October 4 and 19, 1990. The Sodar operated at 20 levels from 60 to 440 m AGL with a level distance of 20 m. Horizontal windspeed and wind direction were compared at 80, 100, 160 and 200 m AGL, σ_θ at 100 and 160 m, at the tower measured by wind vanes and vector vanes. Mean values of 10 minutes were used.

In all of the field programs mentioned above, a Remtech Sodar was involved; thus, some comparative data are available, especially for the three-axis monostatic Sodar and for the parameters horizontal windspeed and wind direction as well as the standard deviations σ_θ and σ_w. The comparison presented in the next chapters is the most comprehensive with respect to a PA2-Sodar available in the literature. Furthermore, because it is a direct Sodar-Sodar comparison, it extends to larger heights than any other study. Finally, it comprises all the quantities which can be compared between an A0- and a PA2-Sodar.

6.2 Wind direction

In Figs. 3a - f, the windroses of the Sodars from 100 to 600 m (at 100 m intervals) are displayed. The solid lines represent the A0-Sodar, the dashed lines the PA2-Sodar. The radius corresponds to the percentage of all data (values are given along the northern axis). Moreover, the number N of data pairs available is given.

The main wind directions in eastern Austria are from the west and the south-east. The wind field at Duernrohr is supposed to be influenced by the surrounding topography (Fig. 1). Because of the orientation of the Wienerwald ridge from northeast to southwest, the south-easterly winds in the Vienna basin - characteristic for anticyclonic conditions - are supposed to be deflected to more easterly or northeasterly directions below crest height in the area of investigation. Local near-surface southwesterly winds, the outflow of southwest - northeast oriented affluents to the Danube river, should shift to the west - which is the dominant wind direction in the area - as height increases.

From Fig. 3, the distribution of wind directions with height largely confirms the above assumptions. Wind direction WSW is the predominant direction for the A0-Sodar at all heights up to 500 m, but decreasingly so with height, while westerly airflow increases until, at 600 m, the frequency of WSW winds and W winds is equal. The PA2-Sodar measures more westerly directions at all levels. WSW dominates until 300 m, is equal to West at 400 m, and W winds

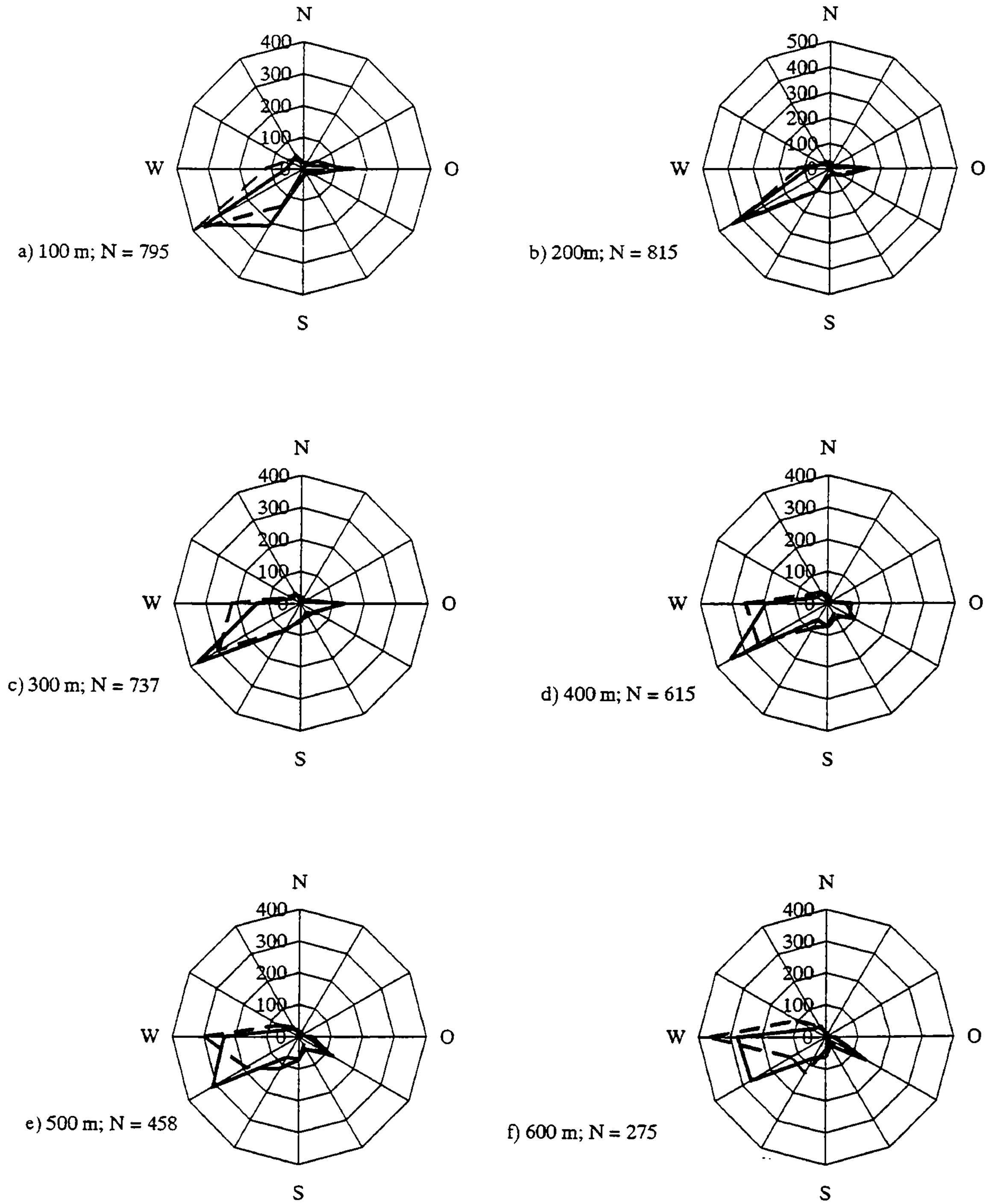


Fig. 3: Windroses at Dürnrohr

Solid: A0-Sodar

Dashed: PA2-Sodar

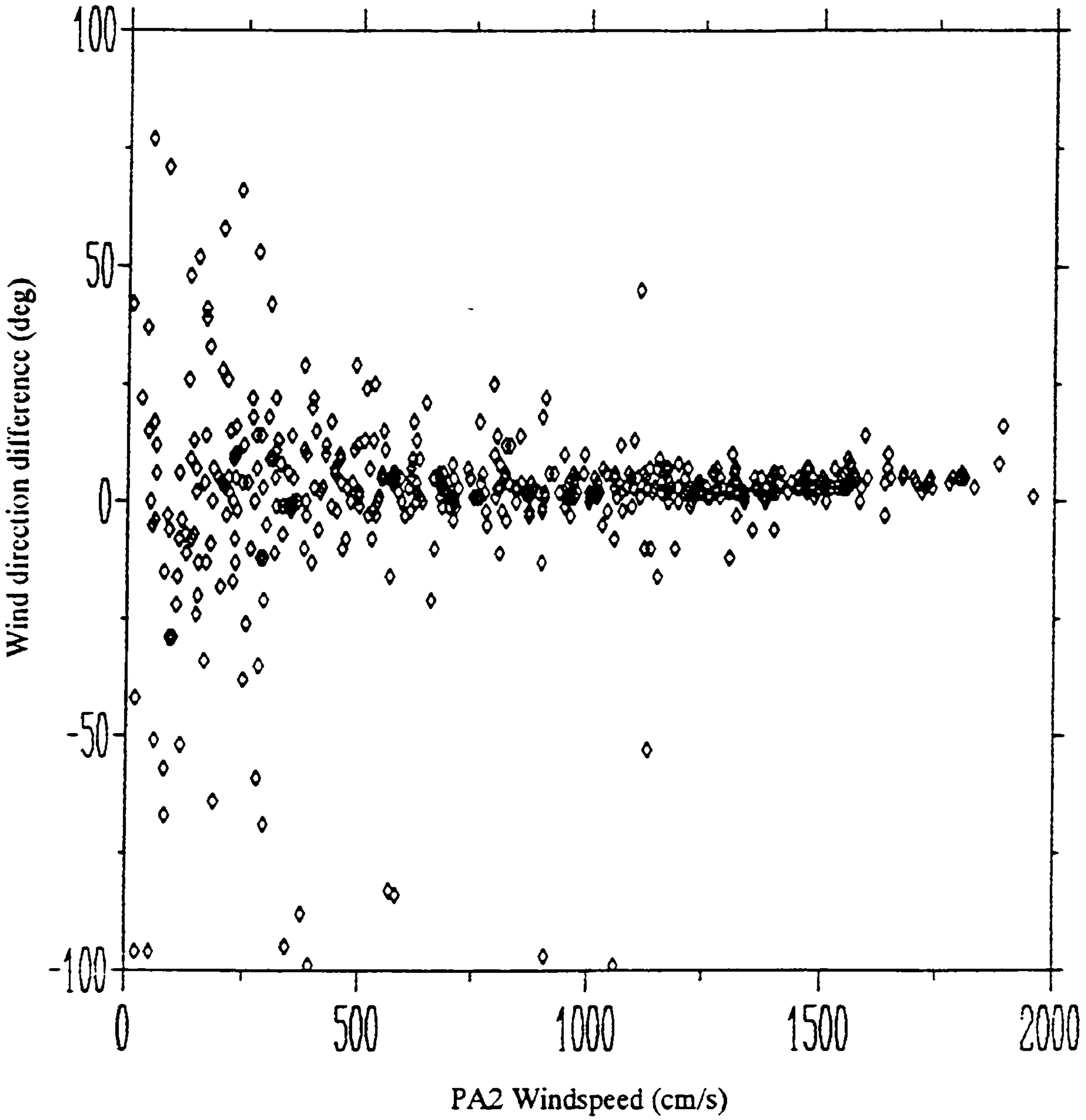


Fig.4: Wind direction difference between Sodars PA2 and A0
depending on PA2 windspeed
Height: 200 m above ground

exceed WSW winds above this level. The proposed shift from south-westerly to westerly winds with height is thus somewhat retarded for the A0-Sodar compared to the PA2-Sodar. This retardation cannot be explained, but considering crest heights along the south-westerly affluents to the Danube being only 100 to 150 m above level terrain, the wind shift detected by the PA2-Sodar seems to better represent reality.

The proposed turning of easterly winds to southeasterly ones with height is described in a similar manner by the two Sodars. From below crest height up to 300 m above ground, among all easterly winds, those from the pure east are most common for both Sodars. However, at the 100 m level, the frequency of winds from the east is 50 % larger for the PA2-Sodar compared to the A0-Sodar. Above this level, the discrepancies are much smaller. Above 400 m, well above crest height of the Wienerwald, ESE becomes the predominant wind direction among easterly winds; thus, the proposed deflection of south-easterly main flows due to the topography is well confirmed by the measurements.

In Fig. 4, wind direction differences between the Sodars, depending on windspeed, are displayed. As would be expected, the differences of wind directions decrease with increasing windspeed. Similar results have also been reported by Vogt and Thomas (1994).

The results of the statistical analysis for the wind direction are displayed in Table 4, for daytime (6:00 to 22:00 local time) and nighttime (22:00 to 6:00 local time). The calculation of the statistical properties of the wind direction was done such that the smaller of the two possible wind direction differences was taken, thus restricting the maximum difference to 180°.

Table 4: Wind direction comparison between A0-Sodar and PA2-Sodar

a) daytime

Height (m)	100	200	300	400	500	600
N	528	539	480	397	273	144
Bias (deg)	6,0	5,6	6,6	6,2	6,1	11,6
RMSD (deg)	27,7	25,4	15,7	15,6	14,9	34,5
Precision (deg)	27,1	24,8	14,3	14,3	13,6	32,5

b) nighttime

Height (m)	100	200	300	400	500	600
N	267	276	257	218	185	131
Bias (deg)	8,2	6,7	2,9	5,0	4,4	2,8
RMSD (deg)	28,1	21,0	20,5	16,6	22,2	21,6
Precision (deg)	26,9	19,9	20,3	15,8	21,7	21,4

The results of Table 4 can be interpreted as follows:

- The agreement of the wind direction data of both Sodars is generally good. The statistical properties are worst at the lowest, and during daytime, at the uppermost level. The comparably bad performance at the first level is probably due to the PA2-Sodars inability to resolve backscattered signals from these heights correctly; this will also be discussed when comparing the windspeed data.

- The bias ranges from about 3 to about 11 degrees. It is always positive, resulting from the slight shift to the right for westerly winds for the A0-Sodar as compared to the PA2-Sodar, which can be seen from Figs. 3. At night, there is a tendency of the bias to decrease with height. Beljaars (1985), from the Cabauw field experiment, found biases comparable to the Duernrohr data. Finkelstein et al. (1986) found mostly negative biases, turning positive at 300 m, of the same range as in this report for the Remtech A0-Sodar and the other Sodars. They slightly decreased with height and, at 100 and 200 m, were smaller at night than during daytime. Also from Chintawongvanich et al. (1989), biases started negative at 100 m and turned positive at 300 m, but nighttime biases were larger than those at daytime, especially at 200 and 300 m. Positive biases in the same range, decreasing between 80 and 200 m, were found by Vogt and Thomas (1994).

- RMSD and precision show values between below 15° and 35°; their values are rather similar due to the low bias. They decrease with height as long as mean windspeeds increase (chapter 6.2); the higher the windspeed, the more conform are the wind directions. The values are comparable to those reported in the literature. A decrease of RMSD and precision with height was also found by Vogt and Thomas (1994), whereas no systematic height dependance could be deduced from the experiments of Beljaars (1985) and Finkelstein et al. (1986). Contrary to the findings here, Chintawongvanich et al. (1989) reported an increase in RMSD and precision with height especially at daytime and twice as high values during daytime compared to night. They attributed the better values during nighttime to the absence of convection, which is not important here because the data were collected during mid-winter.

6.3 Windspeed

The mean vertical profiles of windspeed are shown in Fig. 5. The agreement of the data is good except at the first layer (50 m height). The discrepancies there are probably due to the fact that the software release of the PA2-Sodar available during this experiment could not evaluate correctly the backscattered signal at this level. From tests and experiments conducted later and also from Vogt and Thomas (1994), the minimum height for the PA2-Sodar to receive correct data should be chosen to be 60 m.

As can be seen from Fig. 5, there are only minor deviations in mean windspeeds between the Sodars, except above 550 m at daytime. Day-night - differences increase above 200 m, the higher windspeeds experienced at night. The reversal of the daytime maximum at lower levels to the minimum at higher levels of the PBL, as observed here, is a characteristic and well-known feature of vertical windspeed profiles (see e. g. Arya, 1988). This can be explained by good vertical mixing conditions during daytime causing vertical exchange of momentum, heat, and moisture; vertical changes of physical quantities under such conditions are small. Contrary to daytime conditions, the vertical exchange at night is mostly small, esp. when temperature inversions occur. This includes vertical change of momentum, which is prohibited in case of inversions and gives rise to higher velocities above inversions at night compared to daytime. This phenomenon can even produce so-called “low-level jets“.

In Fig. 6, relative windspeed differences (ordinate) at 200 m above ground between PA2- and A0-Sodar are presented depending on the windspeed, measured by the PA2-Sodar (abscissa). Data pairs showing more than 100 % difference are omitted from the comparison. Windspeed differences decrease with increasing windspeed, as expected. Between windspeeds of 5 to 12 m/s, higher values are recorded by the A0-Sodar. The result displayed in Fig. 6 is somewhat disappointing, compared to the dependance of PA2-Sodar and Karlsruhe tower data differences on windspeed, published by Vogt and Thomas (1994). In the mean, the sometimes

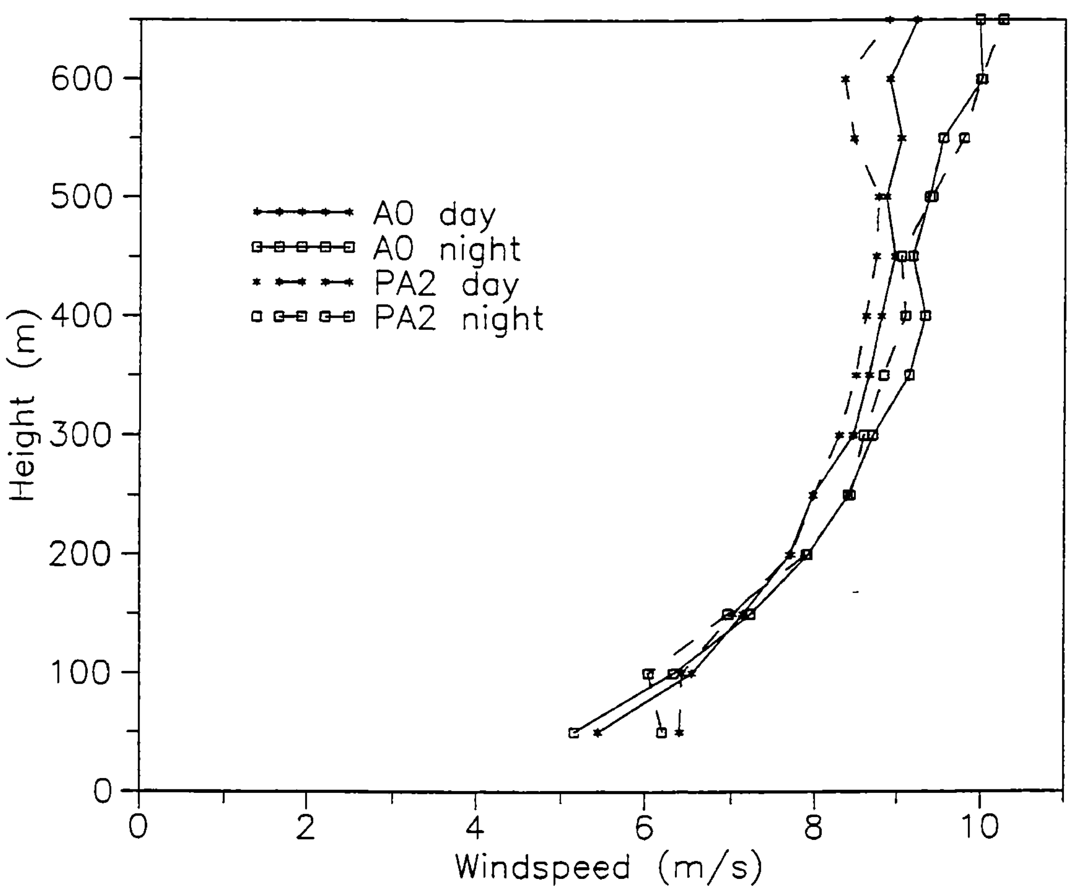


Fig. 5: Mean vertical profiles of horizontal windspeed
at Duernrohr

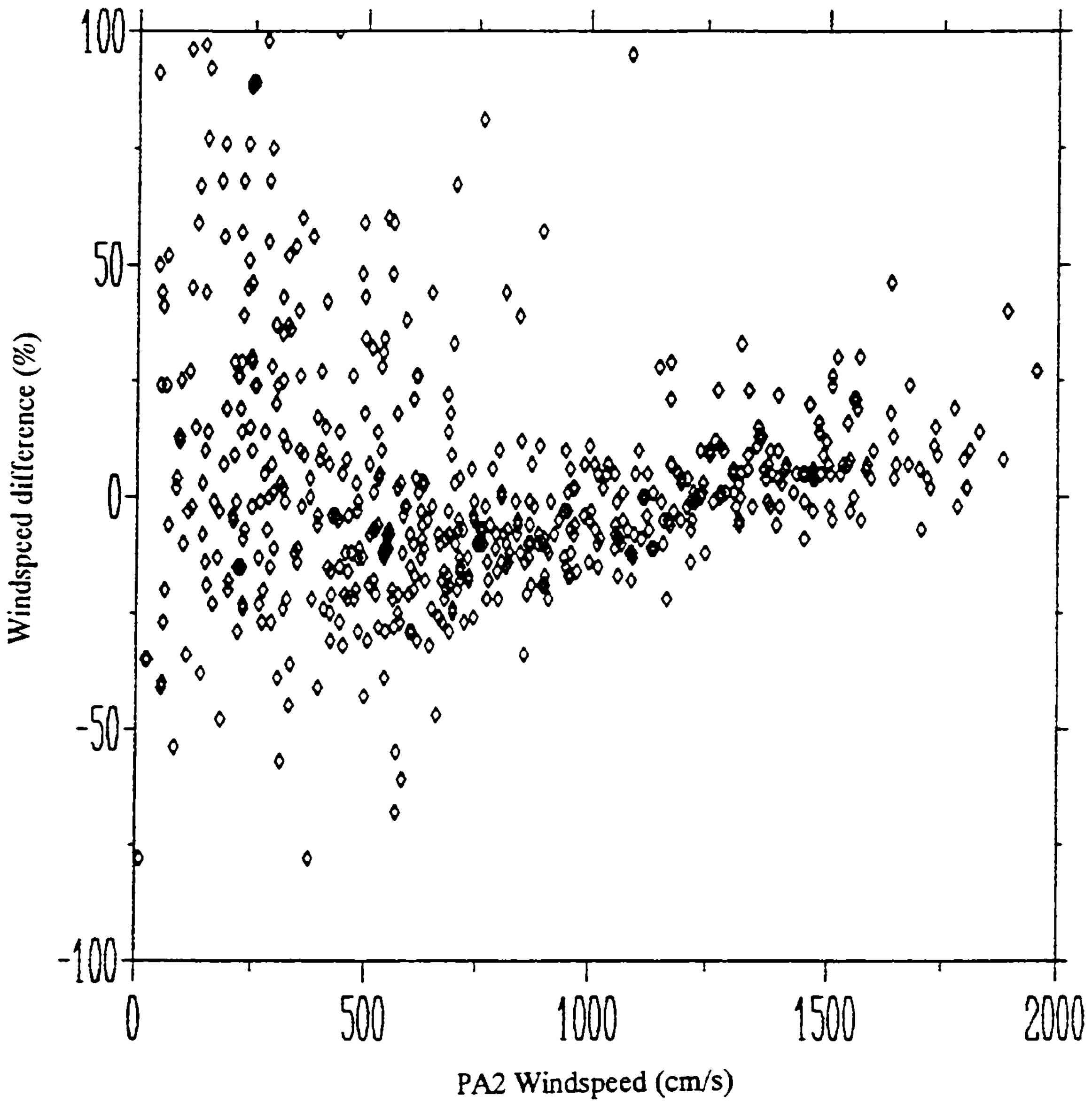


Fig. 6: Relative windspeed difference between Sodars PA2 and A0 depending on PA2 windspeed
Height: 200 m above ground

large single windspeed differences as displayed in Fig. 6 apparently cancel each other, as seen from the good agreement of mean windspeeds in Fig. 5.

In Table 5, the statistical results for the windspeed comparison are shown. In contrast to the wind direction, mean values, relative bias and precision, and the correlation coefficient R can also be calculated.

Table 5: Windspeed comparison between A0-Sodar and PA2-Sodar

a) daytime

Height (m)	100	200	300	400	500	600
N	528	539	480	397	273	144
A0 mean (m/s)	6,54	7,69	8,46	8,80	8,86	8,90
PA2 mean (m/s)	6,42	7,70	8,29	8,61	8,76	8,35
Bias (m/s)	-0,12	0,01	-0,17	-0,19	-0,10	-0,55
Rel. Bias (%)	2	0,1	2	2	1	6
RMSD (m/s)	1,42	1,76	1,44	1,50	1,94	2,53
Precision (m/s)	1,42	1,76	1,43	1,49	1,93	2,47
Rel. Prec. (%)	22	23	17	17	22	28
R	0,94	0,92	0,94	0,92	0,87	0,76

b) nighttime

Height (m)	100	200	300	400	500	600
N	267	276	257	218	185	131
A0 mean (m/s)	6,33	7,91	8,70	9,33	9,38	10,01
PA2 mean (m/s)	6,04	7,89	8,59	9,09	9,41	9,99
Bias (m/s)	-0,29	-0,02	-0,11	-0,24	0,03	-0,02
Rel. Bias (%)	5	0,3	1	3	0,3	0,2
RMSD (m/s)	1,56	1,59	1,33	1,41	2,13	2,56
Precision (m/s)	1,53	1,59	1,33	1,39	2,13	2,56
Rel. Prec. (%)	24	20	15	15	23	26
R	0,93	0,93	0,95	0,93	0,83	0,77

The interpretation of the results of Table 5 is as follows:

- Generally, the agreement of the windspeed data is very good, except for the last two levels displayed. The bias is mostly small and does not show any systematic dependance with height; day-night - differences are also absent. The sign of the bias is frequently negative, meaning that the PA2-Sodar is measuring lower windspeeds in the mean. The relative bias is, however, nowhere exceeding 6 %. According to Vogt and Thomas (1994), the signal-to-noise ratio of the PA2-Sodar is increased due to the improved antenna diagram, and it is therefore able to better measure small Doppler shifts associated with low windspeeds than the A0-Sodar. This results in a tendency to overestimate windspeeds by the A0-Sodar.

- Windspeed biases reported in the literature are of comparable range as in Table 5. Beljaars (1985) found the largest values under very stable conditions and in 200 m AGL, but they did not exceed -0,5 m/s. Sodar mean values were generally lower than mast values. Finkelstein et al. (1986) reported a slight underestimation of windspeed at 100 m and mostly a slight overestimation at 200 and 300 m by all Sodars compared to the BAO tower. Chintawongvanich et al. (1989) also found an overestimation of windspeed by the Sodars except at 100 m for the ASL Sodar. The over-estimation increased with height and was larger for the Dugway Sodar than for the ASL Sodar. Thomas and Vogt (1993) reported about the A0-Sodar under-estimating windspeed during unstable situations and over-estimating it during all other cases; over-estimation increased with height. The PA2-Sodar (Vogt and Thomas, 1994) under-estimated windspeed at all levels, increasing with height.

- RMSD and precision increase from about 1,5 m/s at 100 m to about 2,5 m/s at 600 m. There is also no day-night - difference. Due to the small bias, these quantities do not differ much. The relative precision shows a minimum at 300 and 400 m. At lower levels, the larger scatter could be due to topographical effects, whereas at higher levels, beam separation might be a reason. RMSD and precision are somewhat higher than reported by Vogt and Thomas (1994), Thomas and Vogt (1993), Chintawongvanich et al. (1989) or Finkelstein et al. (1986). The most probable reason for that are the higher wind velocities experienced here, esp. at elevated levels. Beljaars (1985) reported about an increase in the RMSD with height from below 1 m/s at 40 m to almost 2 m/s at 200 m. An increase with height, but less pronounced, was also found by Finkelstein et al. (1986) and Chintawongvanich et al. (1989), the latter reporting on lower values at night. An increase of the precision with height resulted from the A0-Sodar investigations of Thomas and Vogt (1993) for unstable situations, but a decrease for stable cases. Vogt and Thomas (1994), for the PA2-Sodar, found a slight increase in RMSD with height, but no height dependance for the precision.

- Up to 400 m height, the linear correlation coefficient is above 0,9 and thus comparable to findings in the literature. Values of R are decreasing where the absolute error increases; at 600 m, the explained variance is only about 50 %. Contrary to these results showing no day-night - differences, Thomas and Vogt (1993) found worse correlations to occur under convective conditions in their summertime comparison.

6.4 Vertical velocity

The mean vertical profiles of the vertical velocity are shown in Fig. 7. The differences between the two Sodars are large. The A0-Sodar, near the surface, shows large negative mean values. Above 100 m, the values are nearer to zero, but still mostly negative, experiencing larger downdrafts at night. Contrary to these findings, the PA2-Sodar's mean values near ground are slightly positive and are decreasing with height during daytime. Also contrary to the A0-Sodar, the mean values are smaller or more negative during daytime: from 150 m upwards, they are negative and mostly parallel to the A0-Sodars daytime values. At night, the vertical velocity measured by the PA2-Sodar is mostly near zero in the mean. There is no parallelism to the A0-Sodar at night, which shows large differences in the mean values from layer to layer. The vertical profiles of the PA2-Sodar are more steady and especially at night show mean values near zero, as would be expected; the negative values during daytime might reflect the absence of convective conditions in winter. Thus, the PA2 values seem to be more reliable.

Results of the statistical analysis are given in Table 6.

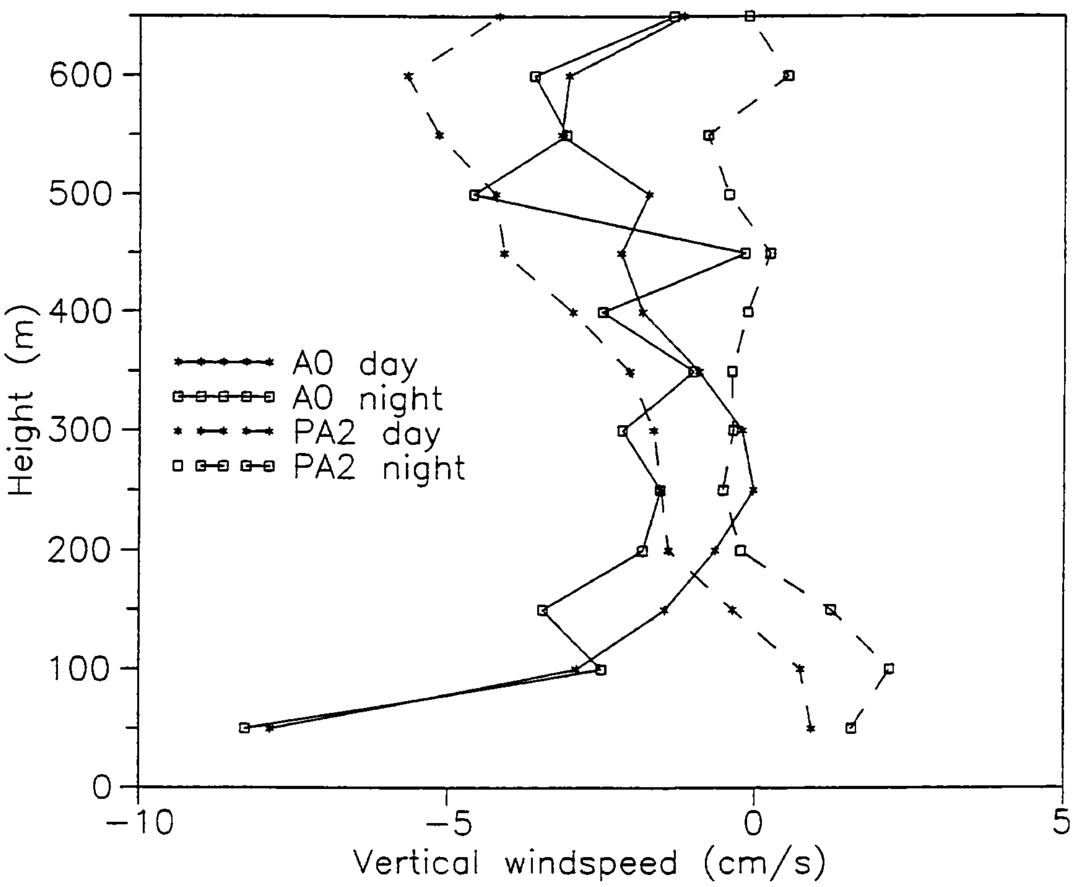


Fig. 7: Mean vertical profiles of vertical windspeed at Duernrohr

Table 6: Vertical velocity comparison between A0-Sodar and PA2-Sodar

a) daytime

Height (m)	100	200	300	400	500	600
N	536	550	487	402	283	155
A0 mean (cm/s)	-2,90	-0,66	-0,22	-1,85	-1,75	-3,03
PA2 mean (cm/s)	0,74	-1,42	-1,67	-2,97	-4,22	-5,65
Bias (cm/s)	3,64	-0,76	-1,45	-1,12	-2,47	-2,62
Rel. Bias (%)	126	115	659	61	141	86
RMSD (cm/s)	18,65	18,71	18,25	18,02	20,53	22,74
Precision (cm/s)	18,29	18,70	18,20	17,98	20,38	22,59
Rel. Prec. (%)	631	2833	8272	972	1165	746
R	0,25	0,45	0,52	0,67	0,66	0,77

b) nighttime

Height (m)	100	200	300	400	500	600
N	270	283	261	220	190	140
A0 mean (cm/s)	-2,50	-1,84	-2,17	-2,49	-4,58	-3,59
PA2 mean (cm/s)	2,17	-0,24	-0,37	-0,13	-0,44	0,53
Bias (cm/s)	4,67	1,60	1,80	2,36	4,14	4,12
Rel. Bias (%)	187	87	83	95	90	115
RMSD (cm/s)	19,33	21,12	23,92	23,58	22,24	21,35
Precision (cm/s)	18,75	21,06	23,85	23,46	21,85	20,95
Rel. Prec. (%)	750	1145	1099	942	477	584
R	0,26	0,45	0,49	0,50	0,57	0,68

A comparison like that shown in Table 6 is not available in the literature. Instead, Thomas and Vogt (1993) and Finkelstein et al. (1986) investigated the spectra of the vertical windspeed deduced from instantaneous measurements and compared them to those derived by sonic anemometers. From these investigations, the poor performance of Sodars to detect the vertical windspeed becomes clear and is explained by the Sodar's inability to cover the whole spectrum compared to a sonic anemometer due to the lower sampling rate and the poor confidence level of Sodars at higher frequencies. The implications for σ_w will be discussed in the next chapter. With this respect, the bad results of Table 6 are not surprising and can be explained as follows:

- At daytime, the bias is often negative except at the first level, indicating the test instrument to measure lower vertical velocities in the mean. At night, there is a systematic positive bias, which probably results from w values too negative of the A0-Sodar. Instead, the PA2-Sodar shows plausible near-zero mean values. The relative bias most often is around 100 %, showing the large systematic difference in the data.

- The scatter in the data is extremely large. During daytime, it increases somewhat with height, but there is no clear height-dependance at night. The relative precision fluctuates from level to level at daytime and slightly decreases with height at night.

- The correlation coefficient increases with height. This is in agreement with Finkelstein et al. (1986), who state that in the convective boundary layer, uncertainties in the observed spectra and the measured variances decrease with height. In the investigation presented here this trend is also shown for the nighttime data.

6.5 The standard deviation of the vertical velocity

The results of the comparison of the standard deviations of the vertical velocity σ_w are more unfavourable than expected. This is mainly due to the surprisingly low values of the PA2-Sodar. During experiments with PA2-Sodars carried out later, especially during a measuring campaign in Vienna in the summer of 1994, using a new software release, the σ_w values were again as high as expected. Reasons for the low values of the PA2-Sodar at Dürnrohr, which are also poorly correlated to those of the A0-Sodar, could not be found in retrospect.

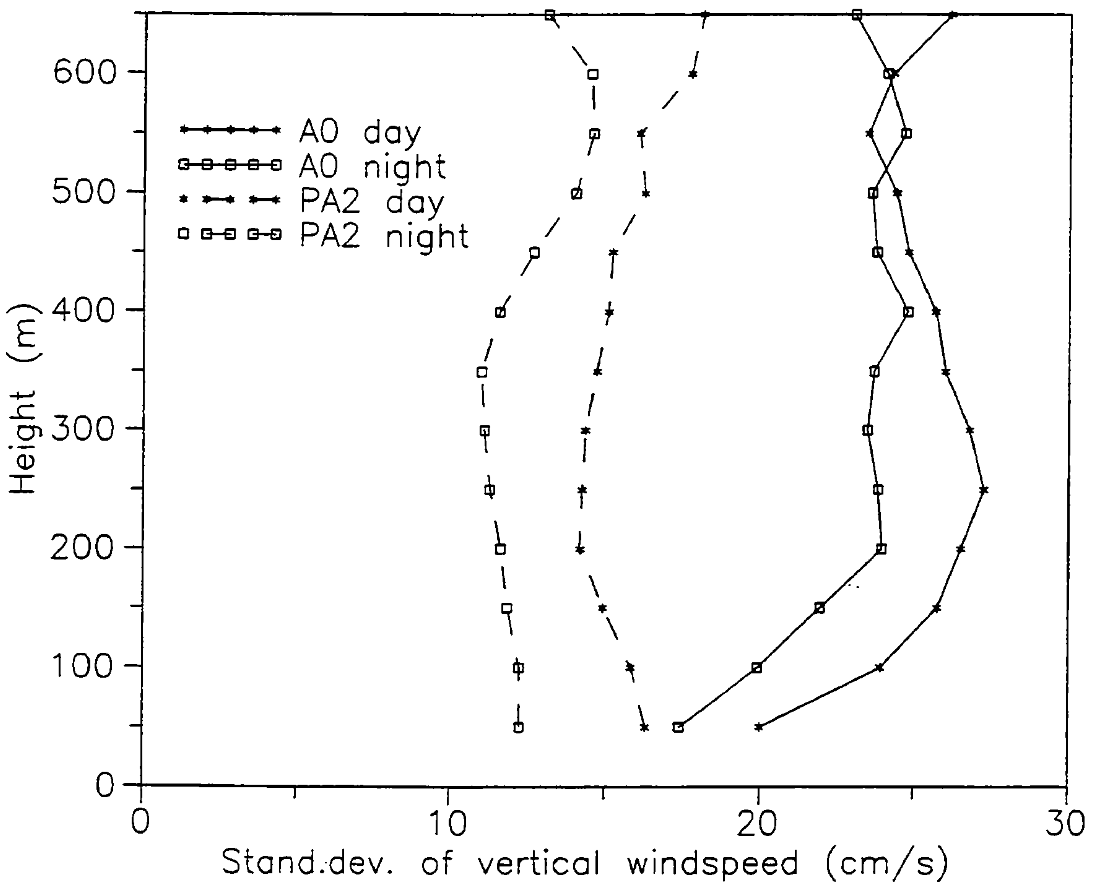


Fig. 8: Mean vertical profiles of sigma w at Duernrohr

The mean vertical profiles of σ_w are displayed in Fig. 8. At all levels, the values of the PA2-Sodar are lower than those of the A0-Sodar. Additionally, also changes of σ_w with height are different: whereas the mean profiles of the A0-Sodar show maxima at 250 m during daytime and 200 m during night characterizing the levels of highest thermal or mechanical turbulence, the PA2-Sodar does not show these maxima. To the contrary, the PA2 profiles even show minima at these heights. The low day-night - differences are also somewhat unexpected, but probably attributable to the wintertime conditions with low convective activity during daytime and a limited amount of inversions at night due to frequent fog. The higher daytime values are the only common feature of the profiles.

Beljaars (1985) published a comparison of single profiles of σ_w measured with the A0-Sodar on the one hand and calculated from w-measurements of sonic anemometers at the Cabauw tower on the other. He examined convective and stable cases and found both agreement and disagreement. During stable conditions, σ_w was under-estimated by the A0-Sodar.

The statistical analysis is shown in Table 7.

Table 7: σ_w comparison between A0-Sodar and PA2-Sodar

a) daytime

Height (m)	100	200	300	400	500	600
N	544	543	485	397	271	148
A0 mean (cm/s)	23,93	26,48	26,75	25,69	24,41	24,30
PA2 mean (cm/s)	15,83	14,21	14,38	15,10	16,25	17,73
Bias (cm/s)	-8,10	-12,27	-12,37	-10,59	-8,16	-6,57
Rel. Bias (%)	34	46	46	41	33	27
RMSD (cm/s)	15,65	16,90	16,79	15,77	15,42	15,91
Precision (cm/s)	13,39	11,63	11,34	11,69	13,08	14,50
Rel. Prec. (%)	56	44	42	46	54	60
R	0,61	0,67	0,69	0,67	0,60	0,56

b) nighttime

Height (m)	100	200	300	400	500	600
N	281	284	258	212	186	138
A0 mean (cm/s)	19,92	23,97	23,49	24,79	23,62	24,10
PA2 mean (cm/s)	12,27	11,66	11,11	11,61	14,07	14,54
Bias (cm/s)	-7,65	-12,31	-12,38	-13,18	-9,55	-9,56
Rel. Bias (%)	38	51	53	53	40	40
RMSD (cm/s)	15,66	17,73	16,61	17,52	15,51	18,55
Precision (cm/s)	13,66	12,76	10,75	11,54	12,22	15,90
Rel. Prec. (%)	69	53	46	47	52	66
R	0,43	0,46	0,55	0,53	0,51	0,27

A lot of literature on σ_w comparisons exists. This makes it easier to interpret the results of Table 7:

- The bias is systematically negative by -6 to -13 cm/s, meaning that the mean σ_w values of the PA2-Sodar are lower by these values. Absolute and relative biases are highest at mean heights. The results are slightly worse at night. Finkelstein et al. (1986), from their comparisons of different Sodars and the Boulder Atmospheric Observatory (BAO) tower, conclude that Sodars over-estimated σ_w, esp. at night; the A0-Sodar and the AeroVironment Sodar under-estimated σ_w during daytime at 100 and 200 m. Chintawongvanich et al. (1989), on the contrary, found larger negative biases during daytime ranging up to -24 cm/s and smaller negative biases at night for their comparison of two different US army Sodars and the BAO tower, meaning an overall under-estimation of σ_w by the Sodars. A slight systematic under-estimation of σ_w by the A0-Sodar compared to the BAO tower was also found by Gaynor (1994). Thomas and Vogt (1993), too, found a systematic under-estimation of σ_w by the A0-Sodar by as much as 70 % under convective conditions at low levels; the relative bias decreased with height and increasing stability. Their results were better at night, according to Chintawongvanich et al. (1989), but in contrast to Finkelstein et al. (1986).

- The values of the RMSD are generally between 15 and 18 cm/s, showing a tendency to higher values at night. Finkelstein et al. (1986) and Gaynor (1994) found similar or slightly higher values not depending on height. Finkelstein et al. (1986) did not observe systematic day-night differences. Chintawongvanich et al. (1989) found higher values during daytime than at night; RMSDs were higher between the Sodars and the BAO tower (up to 36 cm/s) than among Sodars (only up to 13 cm/s). The comparison of the A0-Sodar and measurements from the Cabauw tower gave RMSDs between 12 and 23 cm/s (Beljaars, 1985) without any systematic height dependance.

- The precision is lowest at mean levels, relative values ranging from 42 to 60 % during daytime and 46 to 69 % at night. Gaynor's (1994) values of the precision increase with height from 20 to 40 cm/s, both for the comparison with the BAO tower and among Sodars. Thomas and Vogt (1993) found values up to 37 cm/s (70 %) for neutral stability and low heights. The values improved with increasing stability and increasing height, giving only 7 cm/s (around 15 %) for stable stratification and higher levels. Due to Chintawongvanich et al. (1989), the scatter was larger during daytime and between Sodars and tower and increased with height, but was low at night (only 7 to 10 cm/s). The relative precision did not show any systematic dependance on height or daytime. Values between 20 and 50 % were found. Again contrary to these findings, Finkelstein et al. (1986) found two to three times larger relative precisions at night, implying a larger scatter in the night-time measurements of σ_w.

- The values of the correlation coefficient are 0,7 at a maximum; they are worst at high levels. They are partly below those of the other authors. Thomas and Vogt (1993) reported an increase with increasing stability and increasing height from about 0,5 at 40 m and unstable conditions to above 0,7 for neutral to stable stratification at 160 m. Chintawongvanich et al. (1989) do not find any systematic height dependance, but most of the values were above 0,8.

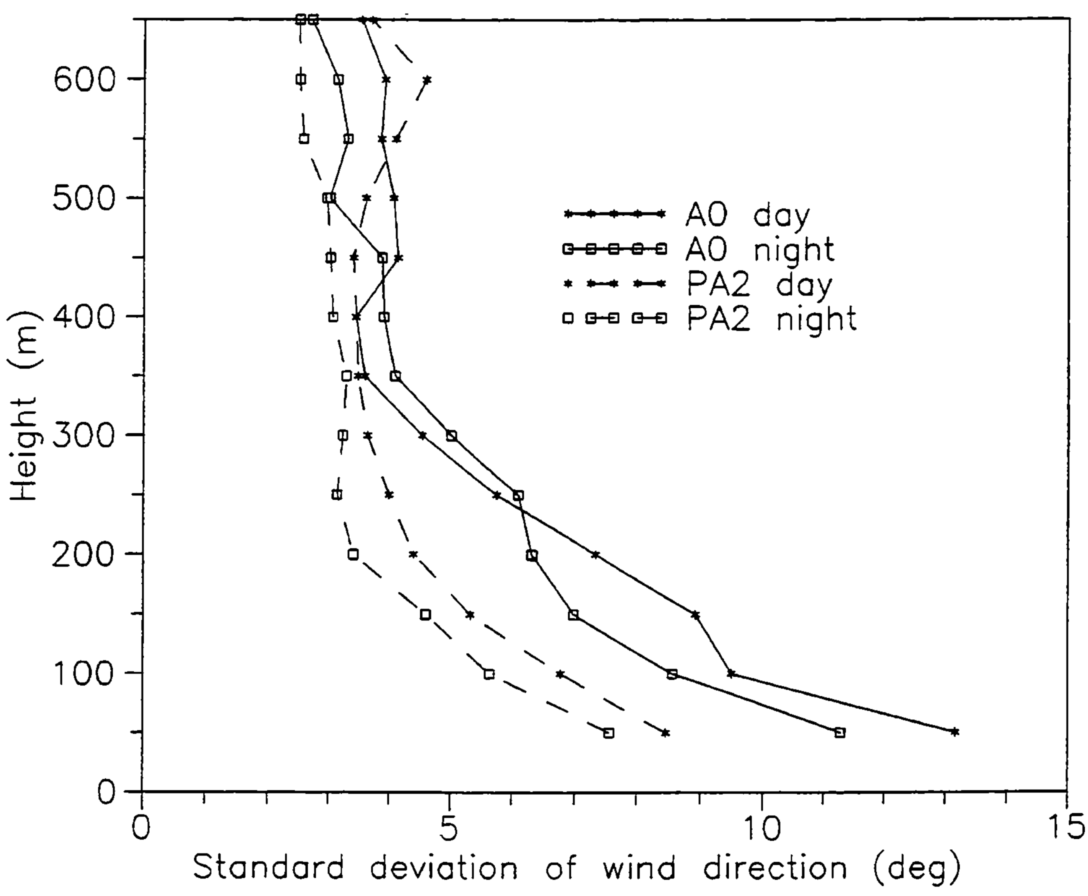


Fig. 9: Mean vertical profiles of sigma theta at Duernrohr

6.6 The standard deviation of the wind direction

The mean vertical profiles of the standard deviation of the wind direction σ_θ are shown in Fig. 9. For both instruments, σ_θ decreases with height up to 350 m; above, σ_θ values remain more or less constant. In the height range of decreasing mean values, the PA2-Sodar measures lower σ_θ, above, the values are comparable to those of the A0-Sodar. At all levels, PA2-Sodar's σ_θ is larger during daytime than at night. This is to be expected, because fluctuations in the wind direction are supposed to be larger during daytime convection than during nighttime stable stratification. However, the day-night - differences are not very large. The A0-Sodar does not show higher daytime mean values at all levels; between 250 and 400 m, the higher means are calculated for nighttime conditions.

Whereas the mean σ_θ profiles between the Sodars are more similar than the σ_w profiles, the statistical analysis delivers results even more unfavourable. These are summarized in Table 8.

Table 8: σ_θ comparison between A0-Sodar and PA2-Sodar

a) daytime

Height (m)	100	200	300	400	500	600
N	449	448	364	245	123	54
A0 mean (deg)	9,49	7,33	4,53	3,45	4,08	3,93
PA2 mean (deg)	6,76	4,39	3,64	3,45	3,62	4,59
Bias (deg)	-2,73	-2,94	-0,89	0,00	-0,46	0,66
Rel. Bias (%)	29	40	20	0	11	17
RMSD (deg)	10,14	8,80	5,57	4,48	4,12	5,85
Precision (deg)	9,76	8,29	5,50	4,48	4,10	5,81
Rel. Prec. (%)	103	113	121	130	101	148
R	0,49	0,54	0,56	0,17	0,20	-0,06

b) nighttime

Height (m)	100	200	300	400	500	600
N	228	241	209	149	109	62
A0 mean (deg)	8,57	6,31	5,01	3,92	3,02	3,15
PA2 mean (deg)	5,65	3,41	3,22	3,07	2,97	2,52
Bias (deg)	-2,92	-2,90	-1,79	-0,85	-0,05	-0,63
Rel. Bias (%)	34	46	36	22	2	20
RMSD (deg)	9,21	8,70	5,40	3,48	4,12	4,59
Precision (deg)	8,73	8,20	5,09	3,38	4,12	4,55
Rel. Prec. (%)	102	130	102	86	136	144
R	0,49	0,48	0,59	0,62	0,32	0,10

The results of Table 8 can be interpreted and compared to those in the literature as follows:

- In general, the bias is mostly negative and decreases with height, which means that the PA2-Sodar measures the smaller values. At lower levels, the relative bias ranges up to 40 %; very low values are calculated at higher levels. This behaviour occurs both at day and at night. Decreasing mean values of σ_θ with height have also been found by Thomas and Vogt (1993). They also found decreasing values with increasing horizontal windspeed. A systematic over-estimation compared to tower values was reported by Vogt and Thomas (1994) for the PA2-Sodar and by Chintawongvanich et al. (1989) for the Dugway Sodar, whereas the ASL Sodar under-estimated σ_θ systematically. Over-estimations were also found by Beljaars (1985) and by Gaynor et al. (1990), esp. for the Aerovironment and REMTECH A0-Sodars. Thomas and Vogt (1993), on the other hand, found a small systematic under-estimation of σ_θ by the A0-Sodar compared to Karlsruhe tower data that declined with increasing windspeed, but was independant of height.

- There is also a decrease for RMSD and precision with height. For the precision, this is in agreement with Thomas and Vogt (1993), who also found a decrease with increasing windspeed. Chintawongvanich et al. (1989) found an increase with height, from about 8° at 100 m to about 15° at 300 m. Their relative precisions showed values around 100 to 120 %, comparable to those presented in Table 8. They attributed this very large scatter to spatial and temporal separations of the acoustic beams, like other authors. RMSDs and precisions reported by Vogt and Thomas (1994) were above 10° for light winds and decreased with increasing windspeed, but did not show any height dependance.

- The maximum value for the linear correlation coefficient is about 0,6. It is slightly better at night than during daytime. At heights above 400 m, the correlation vanishes. This corresponds to the range of small biases. From the other statistical parameters one has to conclude that the small biases occur by chance and that the similar mean values are composed by irregular fluctuations of small singular values. Beljaars (1985) found correlation coefficients from 0,6 to 0,8 for his comparisons with the Cabauw tower. Vogt and Thomas (1994), in their two weeks intercomparison between the PA2-Sodar and the Karlsruhe meteorological tower, found no height dependance, but a dependance on the horizontal windspeed: for light winds, values about 0,5 occur, increasing to 0,8 for high windspeeds. On the contrary, Thomas and Vogt (1993), for their long-time comparison with the A0-Sodar, found no dependance on windspeed, but a strong increase of R with height (from 0,42 at 60 m to 0,7 at 200 m). Chintawongvanich et al. (1989) found also values between 0,4 and 0,7, but no height dependance.

6.7 Echo intensity

Some hints for the interpretation of vertical profiles of the echo intensity have been given when explaining Tables 2 and 3. Peaks in the vertical profiles are of special interest, because they are associated with layers of enhanced convection at daytime (spiky echoes on facsimile charts) and inversions at night (layer echoes). It is interesting to investigate whether these peaks also occur in the mean vertical profiles discussed here.

For the PA2-Sodar, a quantity C_T^2 is given in the data display for the echo, and the values are much higher (but not to the square) than those for the A0-Sodar. A systematic positive bias when compared to the test instrument is therefore inevitable. The statistical intercomparison following the discussion of the mean vertical profiles is therefore restricted to the correlation coefficient, which is supposed to be high when both instruments are able to detect the same

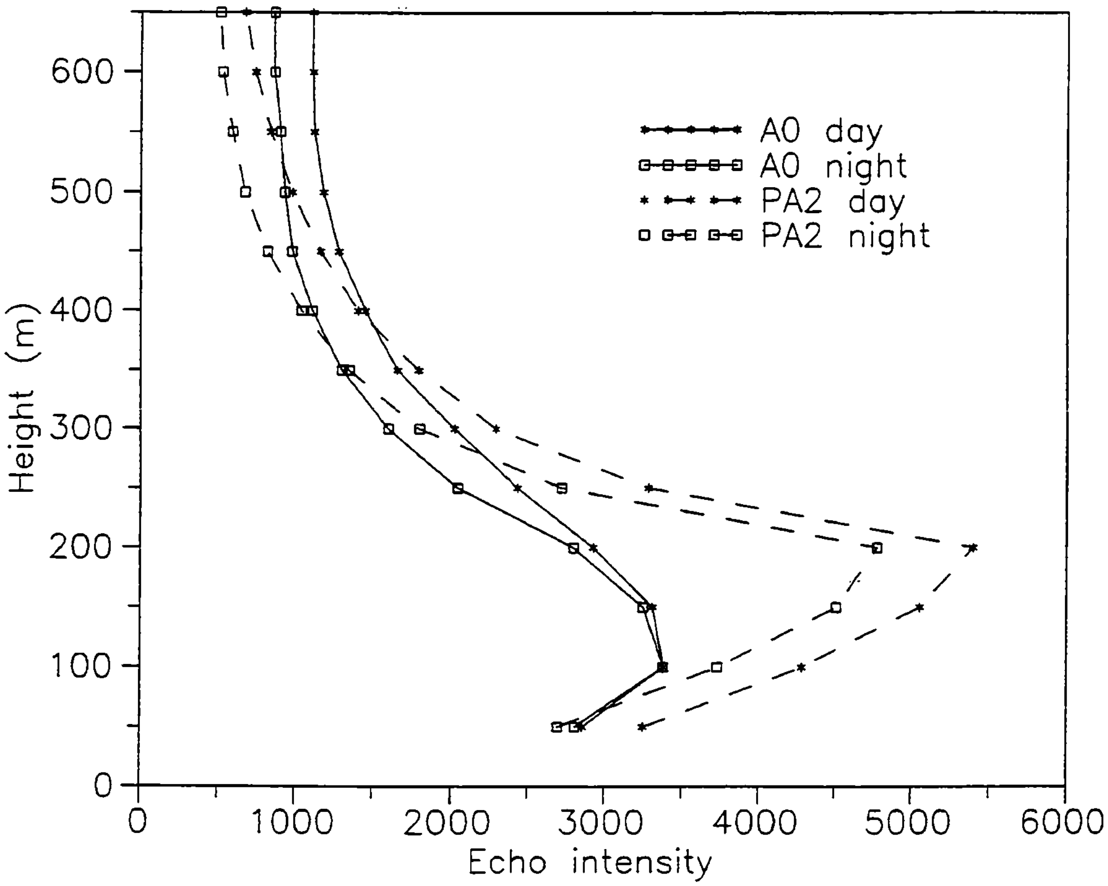


Fig. 10: Mean vertical profiles of echo intensity at Duernrohr

layer-specific phenomena. It should be pointed out, however, that C_T^2 of REMTECH is not identical to the C_T^2 of the theory (e. g. Neff and Coulter, 1986).

The mean vertical profiles of the echo intensity are shown in Fig. 10. The values of the A0-Sodar have been multiplied by the factor of 10 to make the structure of the vertical profile visible. The structures of the vertical profiles are rather similar. Starting at the ground, the values increase with height and show a maximum at 100 to 150 m for the A0-Sodar, for the PA2-Sodar very marked at 200 m. Above, the values decrease with height, again much sharper for the PA2-Sodar. From tethersonde measurements carried out at Dürnrohr before, temperature inversions are mainly restricted to a layer of about 100 to 150 m, corresponding to the mean echo profiles of the Sodars at night. On the other hand, the maximum of convective activity is restricted to the lowest 200 m of the atmosphere, especially in winter; this would also correspond to the Sodar echo profiles.

The very strong damping of echo values above the fourth level for the PA2-Sodar was, however, also observed during a comparative experiment of four PA2-Sodars at a military site in Northern Austria during April 1994 (see also Chapter 8). The four Sodars were positioned inside an area of only a few kilometers radius in undulating terrain, with maximum level differences not exceeding 80 m. The first Sodar level was 60 m above ground, level distance was 40 m. Independant of the absolute heights of the sites, mean echo values showed only small variations up to the fourth level, but decreased rapidly above. The same behaviour was observed if data were split into day- or night-time. Possibly, this inherent damping overlies or even dominates the vertical course of the echo intensity resulting from purely meteorological processes. Nevertheless, a rather good, meteorologically plausible agreement between the vertical echo profiles can be derived from the statistical analysis presented in Table 9.

Table 9: Echo comparison between A0-Sodar and PA2-Sodar

a) daytime

Height (m)	100	200	300	400	500	600
N	548	573	524	468	395	248
A0 mean (deg)	338	293	202	145	118	111
PA2 mean (deg)	4283	5395	2287	1402	977	738
R	0,86	0,80	0,78	0,75	0,61	0,53

b) nighttime

Height (m)	100	200	300	400	500	600
N	271	284	269	226	202	165
A0 mean (deg)	338	281	160	111	93	86
PA2 mean (deg)	3730	4777	1800	1040	671	526
R	0,88	0,80	0,71	0,71	0,54	0,65

No such statistical comparisons exist in the literature. A preliminary interpretation of the results of Table 9 would be as follows:

- The mean values of the PA2-Sodar are smaller at night at all levels. The values of the A0-Sodar decrease mor rapidly at night.

- The linear correlation coefficient decreases with height and does not show remarkable day-night - differences. Up to 400 m, the values are relatively high (above 0,7) meaning that convective activity and inversions are resolved similarly by the Sodars. Upwards, the correlation gets worse. The decrease of correlation with height is probably due to the decrease of signal-to-noise ratio.

7. TWO METEOROLOGICAL CASE STUDIES

In the following, a possible dependance of the comparison of Sodar data on the weather situation will be investigated. Two 48 hour periods have been chosen: December 25/26, 1992 was characterized by a high pressure system with continental air over Austria; January 15/16, 1993 was dominated by westwinds and maritime air. Another criterion was a high Sodar data coverage, which made it impossible to select „ideal“ weather conditions. It will be shown, however, that weather has no or only a limited influence on the quality of the data comparison. More interesting than that is the additional information gained by Sodars compared to routine surface-based observations.

The weather situations have been chosen by looking through the daily weather reports of the Central Institute for Meteorology and Geodynamics. The course of the weather will be described using this kind of material only. The data will be presented as time-height cross-sections, the statistical analysis will be carried out analogous to chapter 6, but no splitting into layers will be undertaken due to the shortness of the comparison periods. The standard deviation of the wind direction σ_θ is omitted from the analysis because of its poor performance (see chapter 6.6).

7.1 The anticyclonic situation of December 25/26, 1992

The 1000 hPa centre of the anticyclone was situated east of Austria on both days, wandering slowly southwards from Poland to the Carpathian mountains during this period. At 500 hPa, it was rather weak, centered north of Austria. Caused by this pressure distribution, easterly currents dominated near ground, north-easterly ones above 1500 m. A summary of the meteorological conditions observed by routine measurements is given in Table 10.

Table 10: Summary of meteorological conditions on December 25/26, 1992, Vienna

Parameter	Mean	Range
Air pressure (hPa)	1041,5	1040 to 1045
Air temperature (°C)	-4,8	-8 to -2
Wind direction (deg)		20 to 110
Windspeed (m/s)	3,9	2 to 7
Inversions	**Height range (m)**	**Temperature increase (°C)**
26. 12., 1:00 LST	500 to 1500	+7
26. 12., 13:00 LST	500 to 1000	+6

Except local fog on the first morning, skies were clear, and there was no precipitation.

Vector plots of the A0-Sodar and the PA2-Sodar are presented in Figs. 11a and 11b, respectively. They show the maintenance of the easterly current throughout the period and only minor differences between the Sodars. As an example, the speed minima near ground at the beginning and near the end of period detected by the A0-Sodar are less pronounced looking at the PA2 data. The height coverage is slightly better for the PA2-Sodar. Both Sodars detect the turning of the wind with height from easterly or north-easterly directions to south-easterly ones for most of the time. The strongest shift occurs above crest height, that is around 300 m. The statistical analysis (Table 11 at the end of this chapter) confirms again the good performance of Sodar horizontal wind measurements.

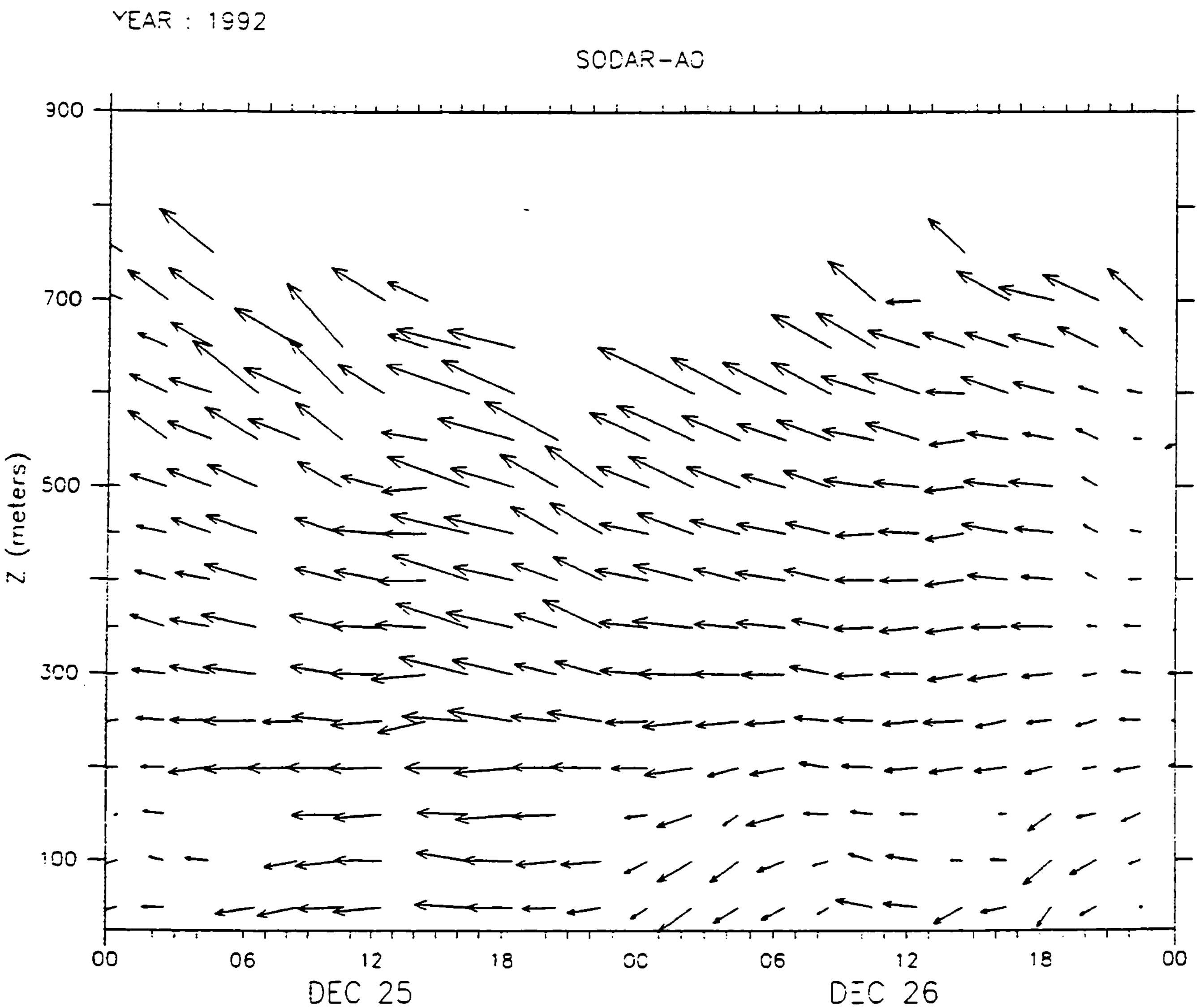


Fig. 11a: A0-Sodar wind vectors

⟶ 10 m/s

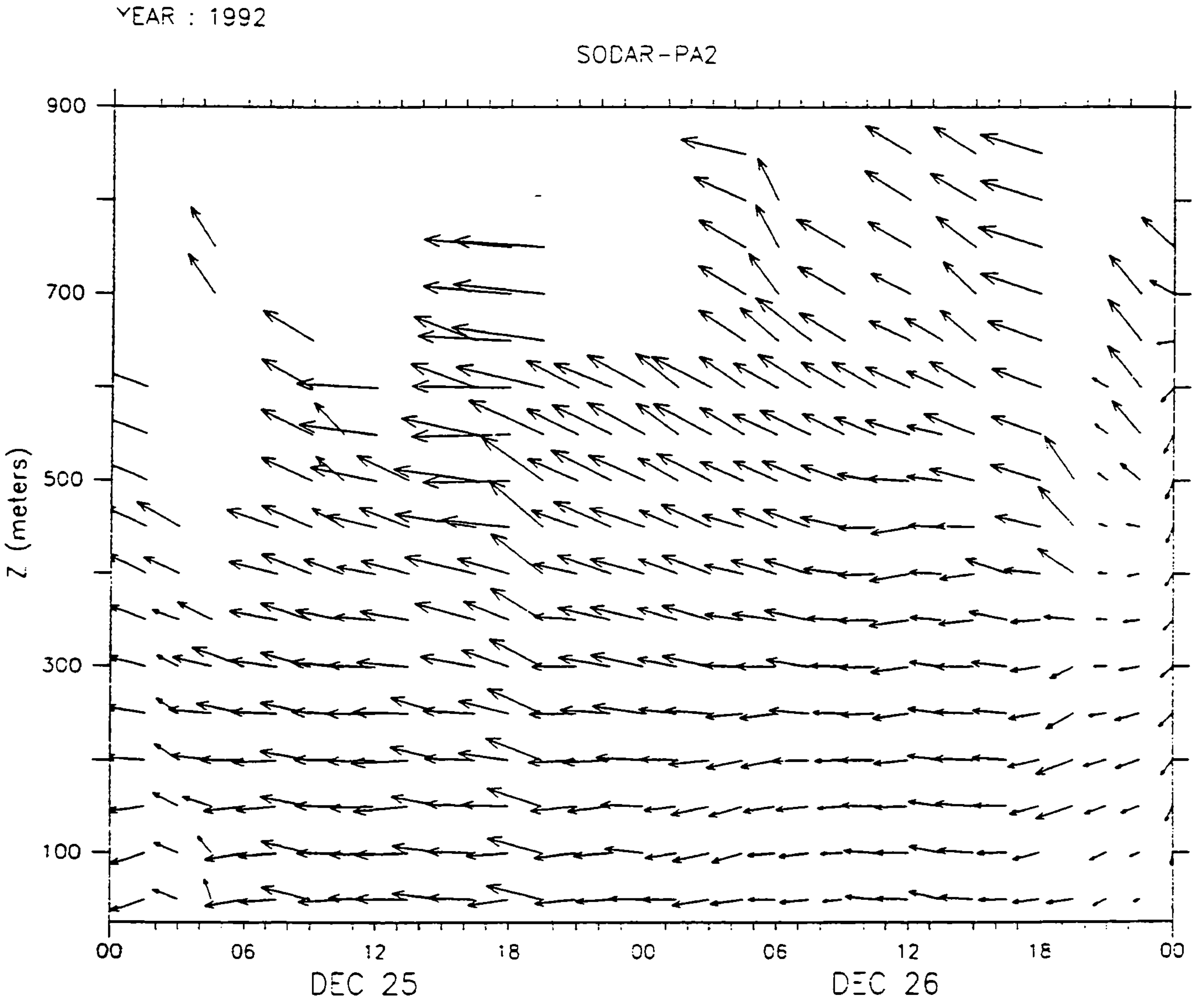
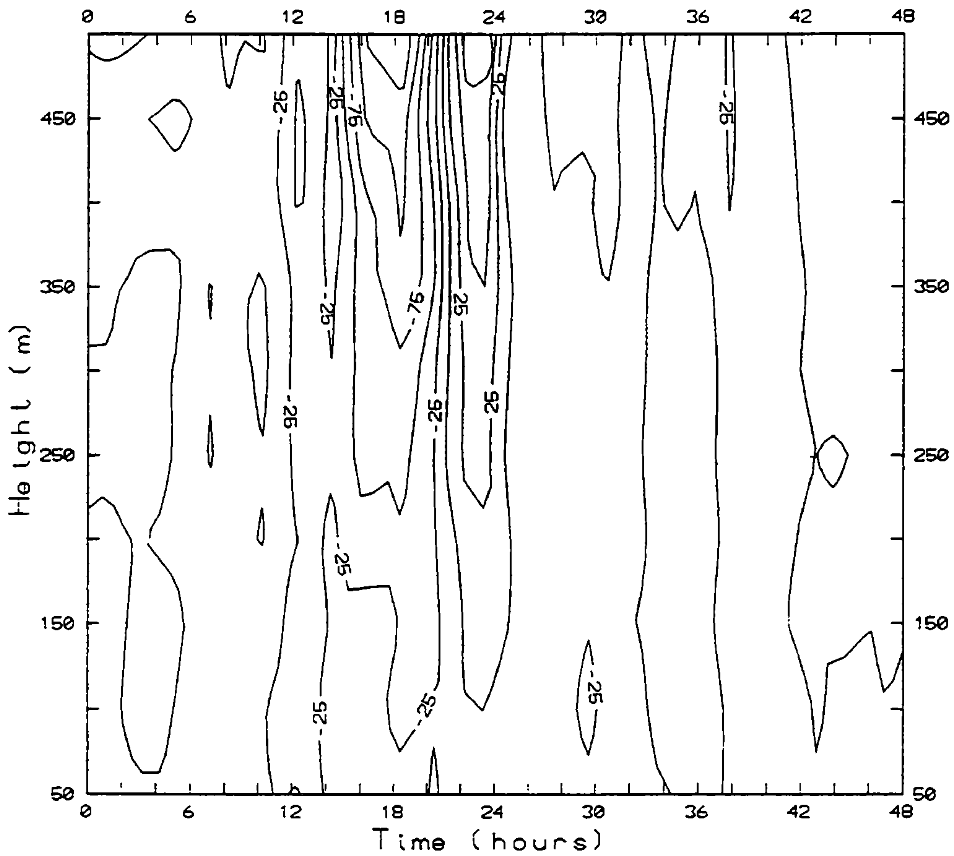


Fig.11b: PA2-Sodar wind vectors

⟶ 10 m/s

Fig. 12a: A0 Vert. Speed 25./26. 12. 92



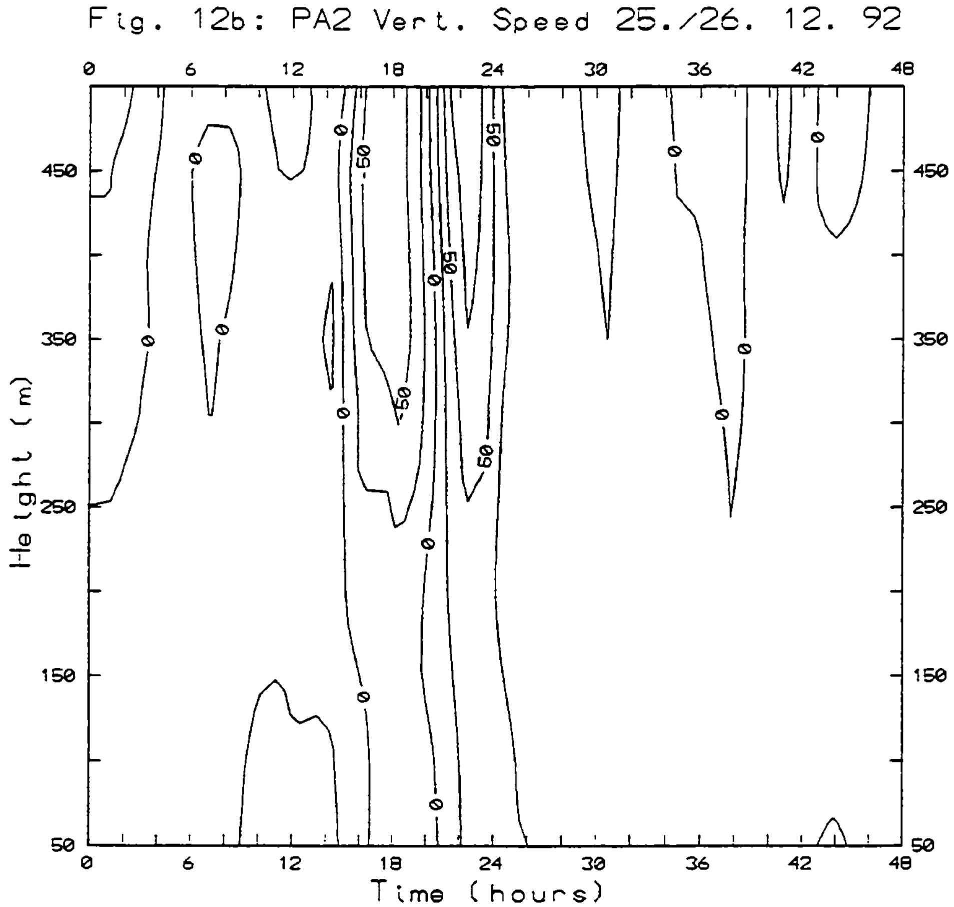


Fig. 12b: PA2 Vert. Speed 25./26. 12. 92
Height (m)
Time (hours)
0
6
12
18
24
30
36
42
48
50
150
250
350
450
-50
50

Fig. 13a: A0 Sigma w 25./26. 12. 92

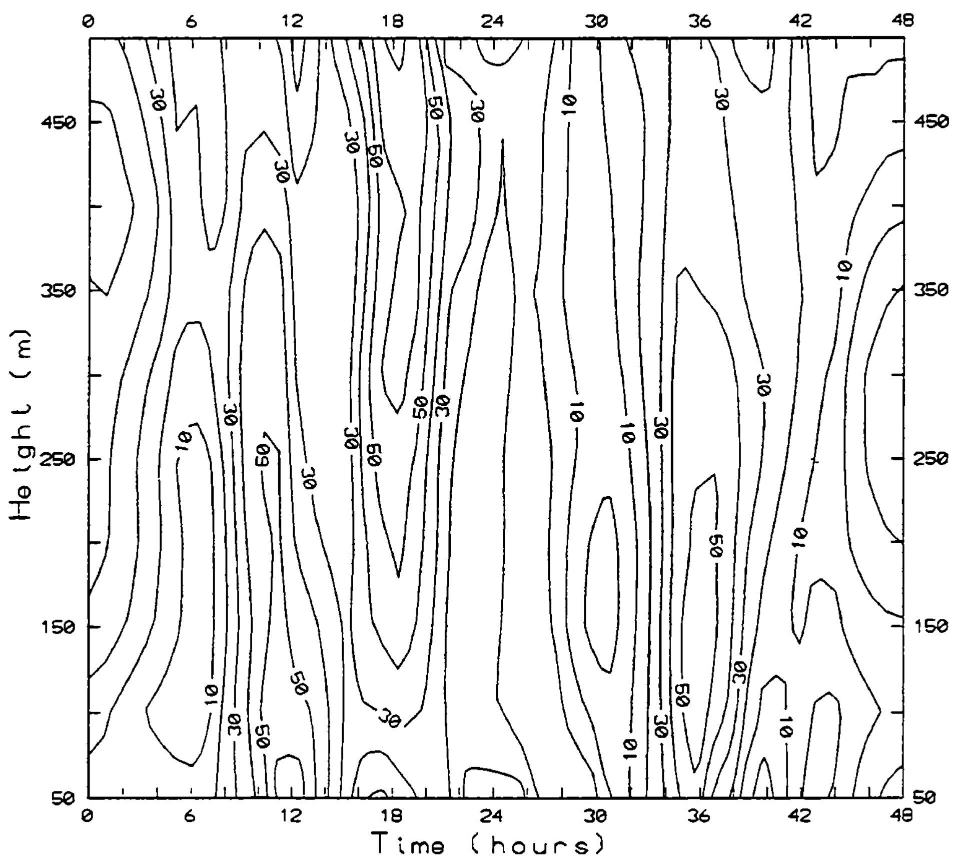


Fig. 13b: PA2 Sigma w 25./26. 12. 92

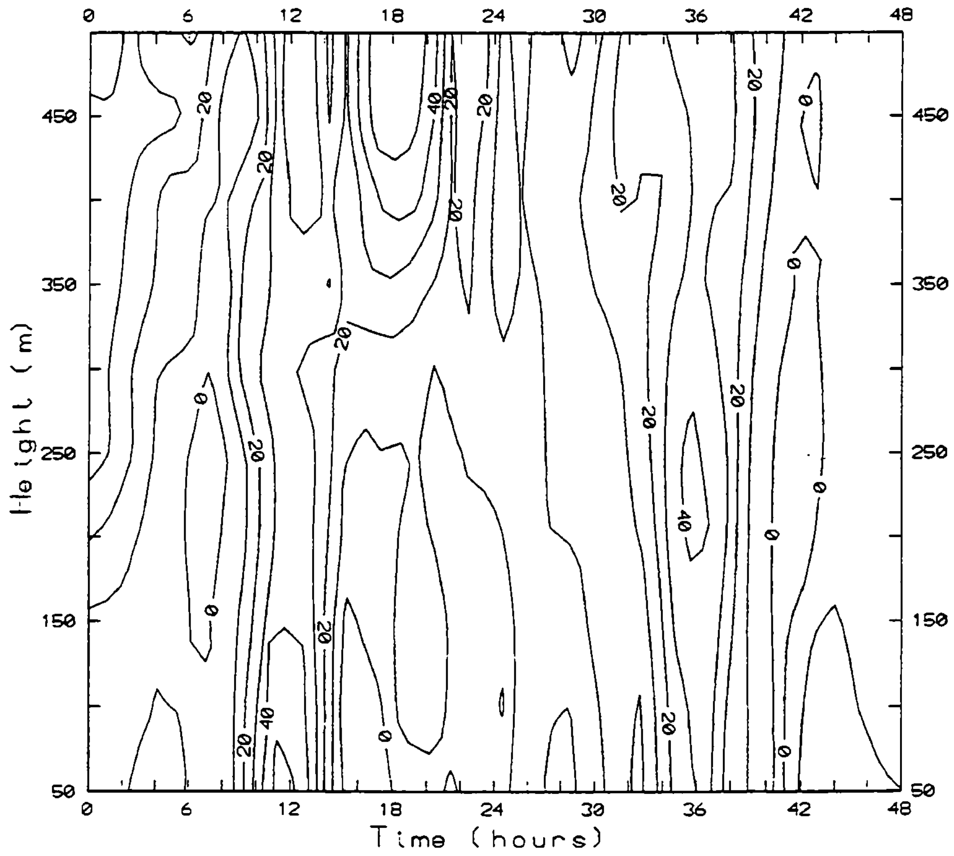


Fig. 14a: A0 Echo 25./26. 12. 92

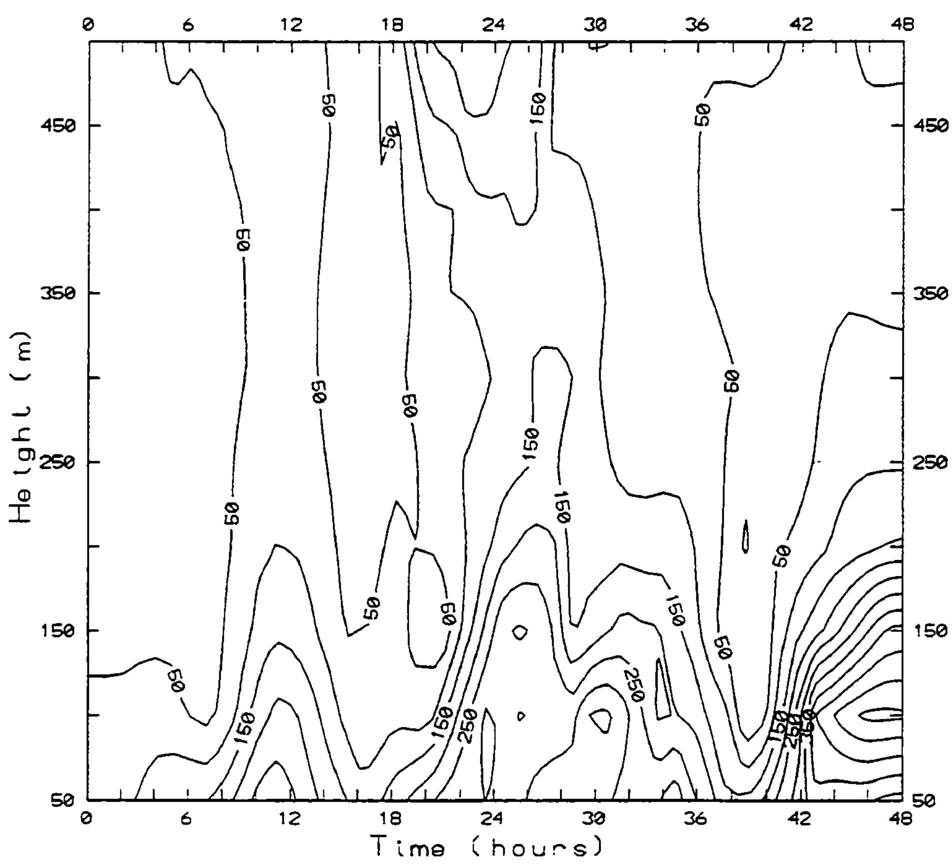
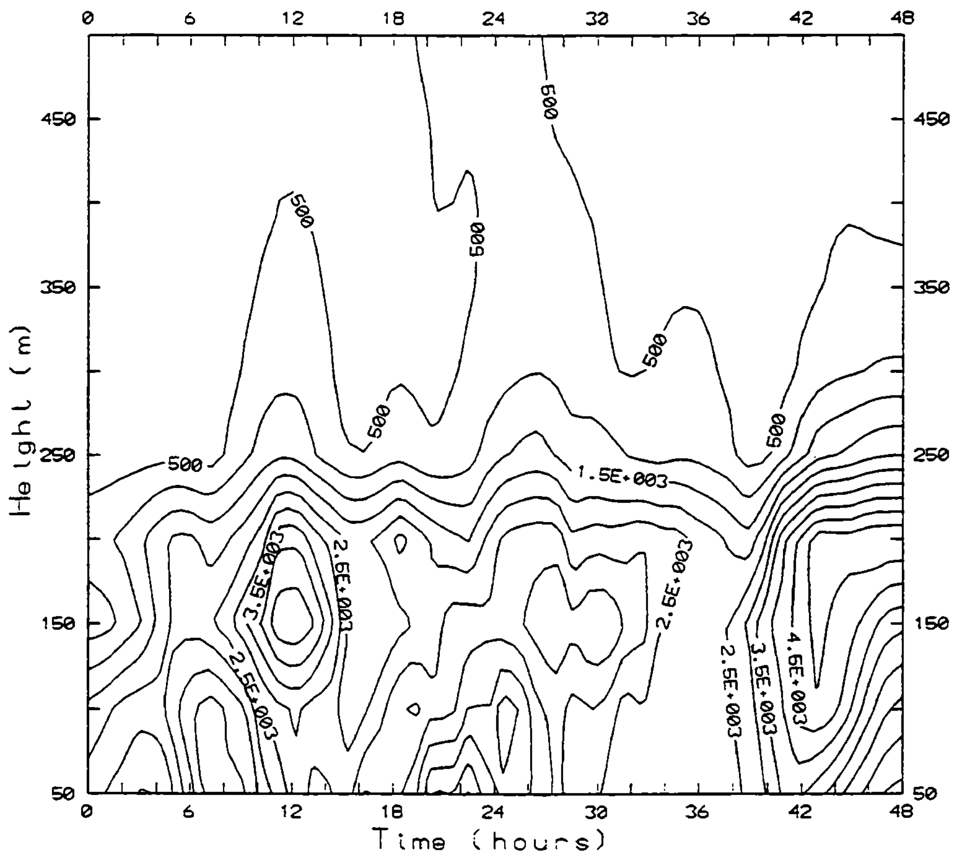


Fig. 14b: PA2 Echo 25./26. 12. 92



Time-height cross-sections of the vertical velocity are shown in Figs. 12a and 12b. For most of the time, the PA2-Sodar measures smaller vertical velocities. They are generally weak, except on December 25 during the second half of the day, when above 250 m until 20:00 LST strong downward movements, afterwards until midnight, strong upward movements occur. The PA2-Sodar's negative values are smaller, but the positive values are as large as those of the A0-Sodar. Strong vertical motions are detected in a similar way by both instruments. The maximum of negative vertical speed coincides with a maximum in the horizontal windspeed (Figs. 11a, 11b). These strong motions are not easy to interpret, because there are no routine observations available to verify them. The midnight radiosounding in Vienna on December 25 shows warming between 1000 m and 2500 m by 5 °C compared to the sounding 12 hours before, possibly the only hint of frontal processes occuring during this time. The statistical analysis (Table 11) shows a large positive bias, which is much higher than observed for the whole period (Table 6). The RMSD is higher than in Table 6, the absolute precision in the range of values presented there, but the relative precision is much smaller. The value of the linear correlation coefficient of 0,79, too, demonstrates the rather good quality of this dataset of vertical velocities.

A comparison of the standard deviations of the vertical velocity of both Sodars can be taken from Figs. 13a and 13b. As for the vertical speed, the main structures are revealed by both Sodars in a similar way. This is true for the maxima at lower levels, created by weak convection at noon on both days, and for the maximum at higher levels around 18:00 LST on December 25 in connection with the high horizontal windspeeds. The values for the A0-Sodar are generally higher. For the rest of the period, both instruments measure low σ_w values. The statistical results (Table 11) are comparable to those of Table 7. Again it has to be kept in mind that, during experiments conducted later, PA2 σ_w values were in the expected higher range.

Time-height cross-sections of the echo intensity are shown in Figs. 14a and 14b. As explained in chapter 6.7 (Fig. 10), the PA2-Sodar shows a strong damping of echo values above the fourth level, which superposes other reasons for enhanced returns, like temperature inversions. The strong gradient at this height can also be seen from Fig. 14b, which is missing for the A0-Sodar (Fig. 14a). This is why the turbulence structure near ground is detected more clearly by the PA2-Sodar (e. g. the convective activity at noon on December 25), phenomena occurring at higher levels by the A0-Sodar (e. g. probable advection of warm air in the evening of December 25 by an increase of echo values with height). From the statistical analysis of Table 11, a rather low correspondance of echo values in this case follows.

Table 11: Statistics of the Sodar comparison for Dec. 25/26, 1992

Quantity	Speed	Direction	Vert. speed	Sigma w	Echo
N	420	420	437	422	437
A0 Mean	6,37		-10,7	26,1	107
PA2 Mean	6,06		9,3	15,5	1423
Bias	-0,31	-- 5,0	20,0	-10,6	
Rel. Bias (%)	5		187	41	
RMSD	1,31	12,9	26,6	16,7	
Precision	1,27	11,9	17,6	12,9	
Rel. Prec. (%)	20		165	49	
R	0,87		0,79	0,58	0,49

7.2 The westerly current on January 15/16, 1993

This period was embedded into a longer-lasting westerly flow regime which was dominant mainly at upper air levels, whereas near ground, westwinds were not observed all the time. Between January 15 and 16, the high pressure system at ground weakened, and the second day of the chosen period was more windy than the first. Frontal systems crossed the northern and eastern parts of Austria. There was, however, no precipitation at the Sodar site. Cloudiness increased during the period. The meteorological conditions observed by routine measurements are summarized in Table 12.

Table 12: Summary of meteorological conditions on Jan. 15/16, 1993, Vienna

Parameter	**Mean**	**Range**
Air pressure (hPa)	1033	1030 to 1038
Air temperature (°C)	6,7	0 to 13
Wind direction (deg)		30 to 60, 240 to 300
Windspeed (m/s)	3,7	2 to 7
Inversions	**Height range (m)**	**Temperature increase (°C)**
16. 1., 1:00 LST	Ground to 1000	+9

Vector plots for this period are shown in Figs. 15a (A0-Sodar) and 15b (PA2-Sodar). Again, the agreement is remarkable. The westerly current is interrupted between the morning and the late evening on January 15. The change from south-westerly to south-easterly directions occurred suddenly at all levels. From the data of the PA2-Sodar, however, one gets the impression that above approx. 600 m, the westwind was never really interrupted except for a very short period of southerly flow on the evening of January 15. The discrepancy to the A0-Sodar is partly due to the lower height range of the latter, but at noon on January 15, a remarkable difference in wind directions between the Sodars at around 700 m occurred, the A0-Sodar measuring south-easterly winds, the PA2-Sodar north-westerly ones (not really simultaneously, because PA2 did not reach that height at 12:00 LST; but south-easterly winds at that time would not fit into the picture for the PA2-Sodar). But all the other features, the speed minimum at low levels in the afternoon and evening on January 15, the gradual shift in directions from southeast over south, southwest to west above 200 m and the strong westerlies on January 16 (with a shift from southwest to west with height most of the time) were observed by both systems. The good agreement is also revealed in the statistical results presented in Table 13 at the end of this chapter. The quantities for speed and direction are in the expected range.

The time-height cross-sections of the vertical velocity are shown in Fig. 16a and 16b for the A0-Sodar and the PA2-Sodar, respectively. They show plenty of details without much agreement. On January 15, vertical speeds are relatively weak. Positive and negative values are observed by the A0-Sodar, whereas the PA2-Sodar mostly measures weak negative velocities. On January 16, the vertical exchange is larger. After midnight, downward motions dominate, the larger values observed by the A0-Sodar. Before noon, upward motions are measured, again more pronounced for the A0-Sodar. In the evening, however, large negative values lower than -60 cm/s are observed by the PA2-Sodar, corresponding to only -40 cm/s in a small area by the A0-Sodar. The statistical results presented in Table 13 show only a relatively small negative bias, but a lower correlation than in Table 11; RMSD and precision again confirm the large scatter in the data.

The comparison of the standard deviation of the vertical velocity σ_w is given in Figs. 17a and 17b. In general, high windspeeds are connected with high σ_w values and vice-versa; this is more pronounced for the A0-Sodar. Especially during the early morning wind minimum on January 15, σ_w values are also low; relatively low values are also observed at low levels in the evening hours on January 15. For both Sodars, the σ_w maximum occurs at noon on January 15. Only the A0-Sodar shows an expected increase in σ_w values parallel to the increase in windspeed after midnight on January 16. In the course of January 16, however, σ_w values for both Sodars are changing irregularly, despite a rather homogeneous windfield (Figs. 15a, 15b).

The observed parallelism of the increase of σ_w and windspeed after midnight on January 16 led to an investigation of the possible dependance of σ_w on windspeed statistically. Results are shown in Fig. 18. The agreement for the whole period is however rather weak; for the PA2-Sodar not shown here, it is non-existent. The statistical results presented in Table 13 are even slightly worse than those from Table 11. Once again it has to be remembered that σ_w performed much better for the PA2-Sodars during the following measuring campaigns.

From Figs. 19a and 19b, the period under discussion is characterized by high values of the echo intensity for both instruments. These high values have no apparent foundation in the observed weather conditions. This time, the structure revealed by the time-height cross-sections is more similar than during the period observed previously (chapter 7.1). The high values near ground at the beginning of the observing period are probably in connection with an inversion: windspeeds were low in the morning, skies were clear. During the radiosounding in Vienna on January 15, 1:00 LST, however, no inversion was present. The high values around noon on January 15 are not easy to interpret because skies were cloudy, thus inhibiting strong convection; mechanical turbulence caused by windshear (Figs. 15a and 15b) might offer an explanation. During the night to January 16, the values are again high, especially during the phase of high windspeeds. Before the windspeed increase a strong inversion was discovered during the radiosounding in Vienna (Table 12). Possibly the high values are again caused by

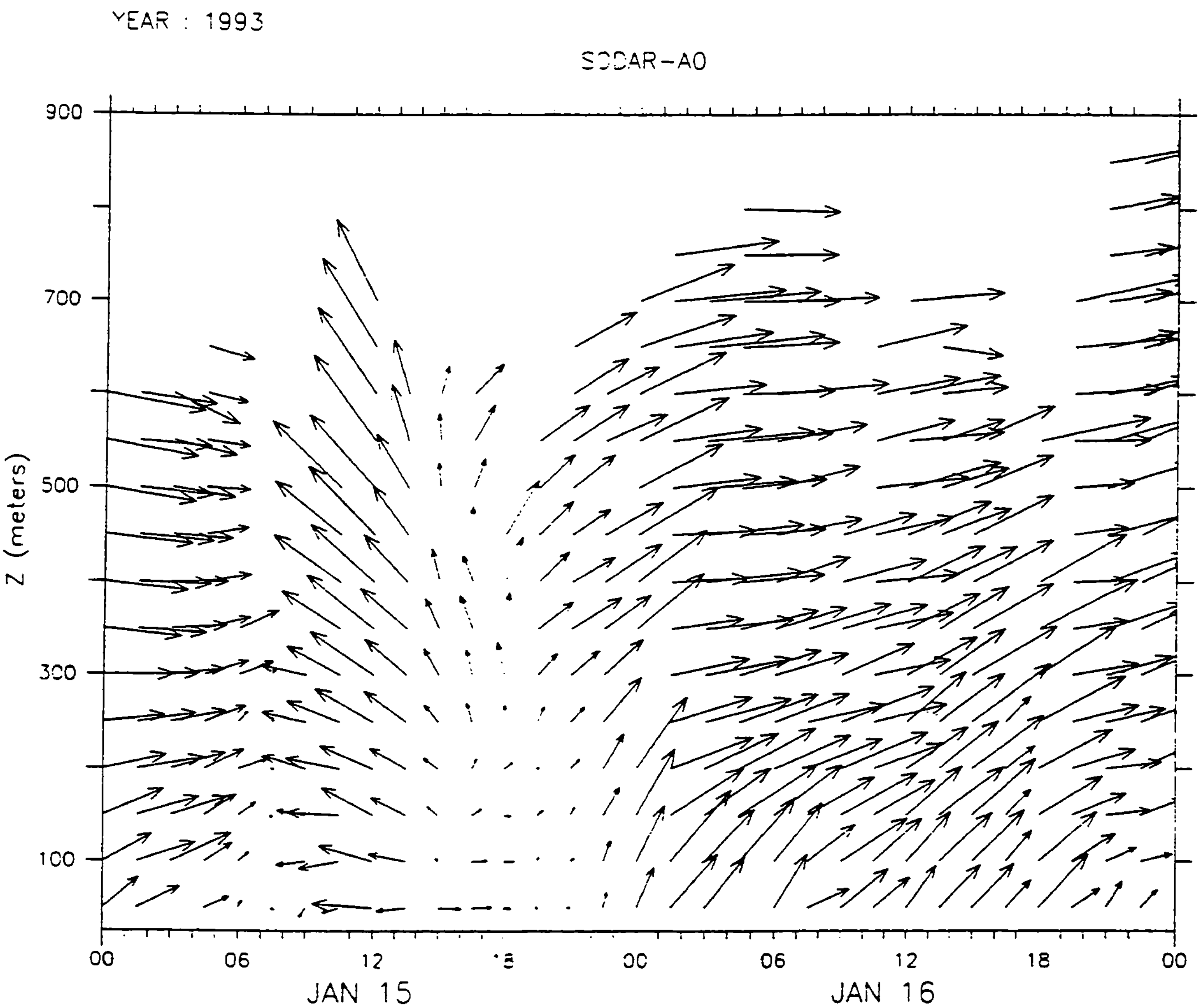


Fig. 15a: A0-Sodar wind vectors

⟶ 10 m/s

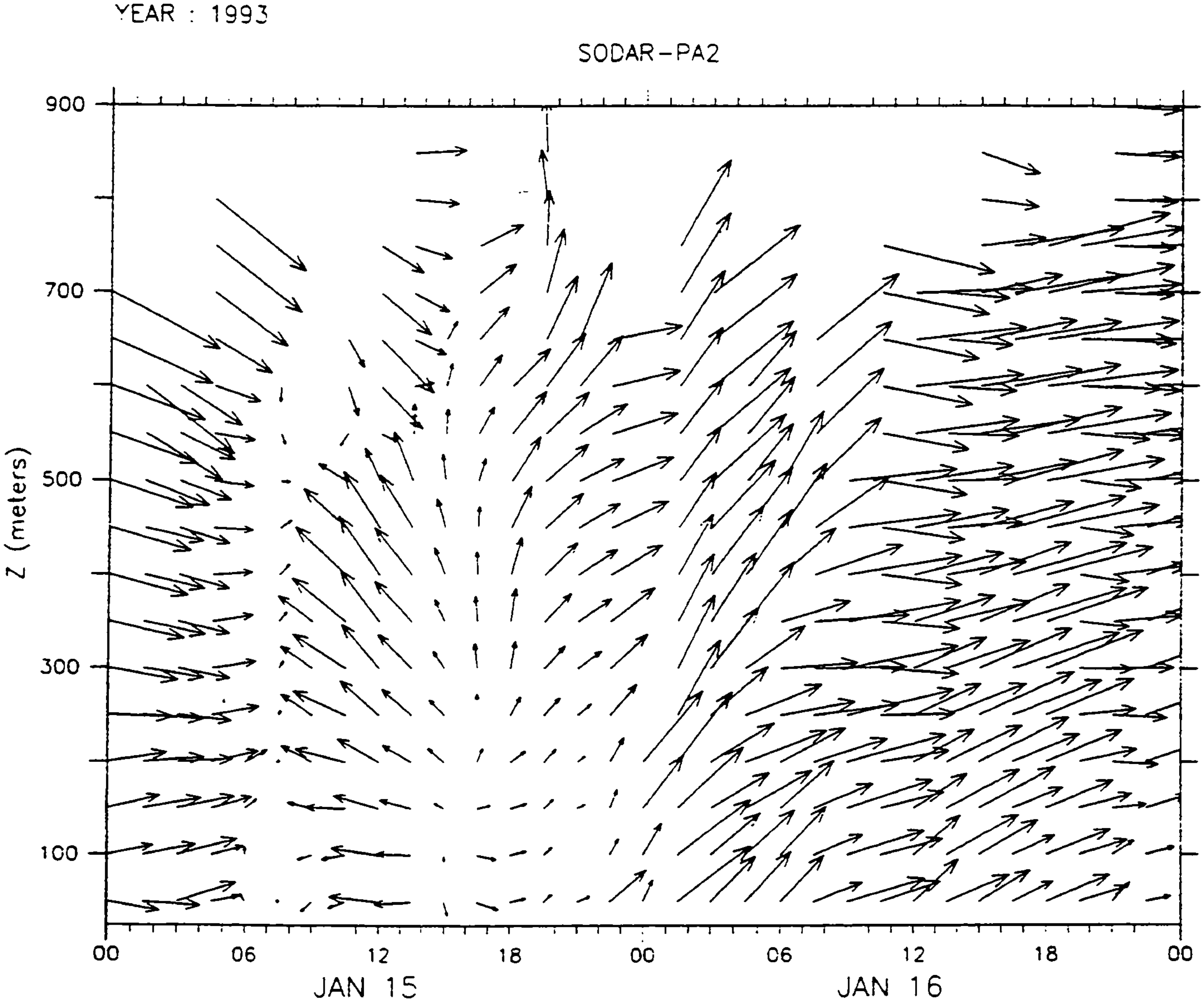


Fig.15b: PA2-Sodar wind vectors

⟶ 10 m/s

Fig. 16e: A0 Vert. Speed 15./16. 1. 93

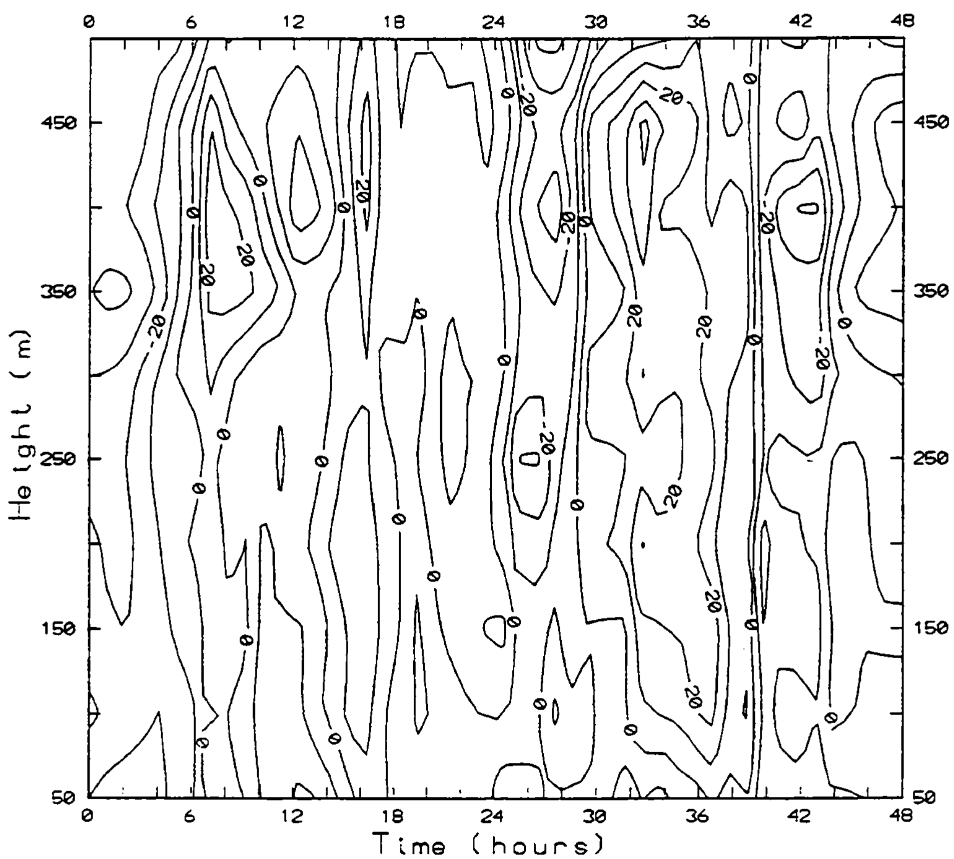


Fig. 16b: PA2 Vert. Speed 15./16. 1. 93

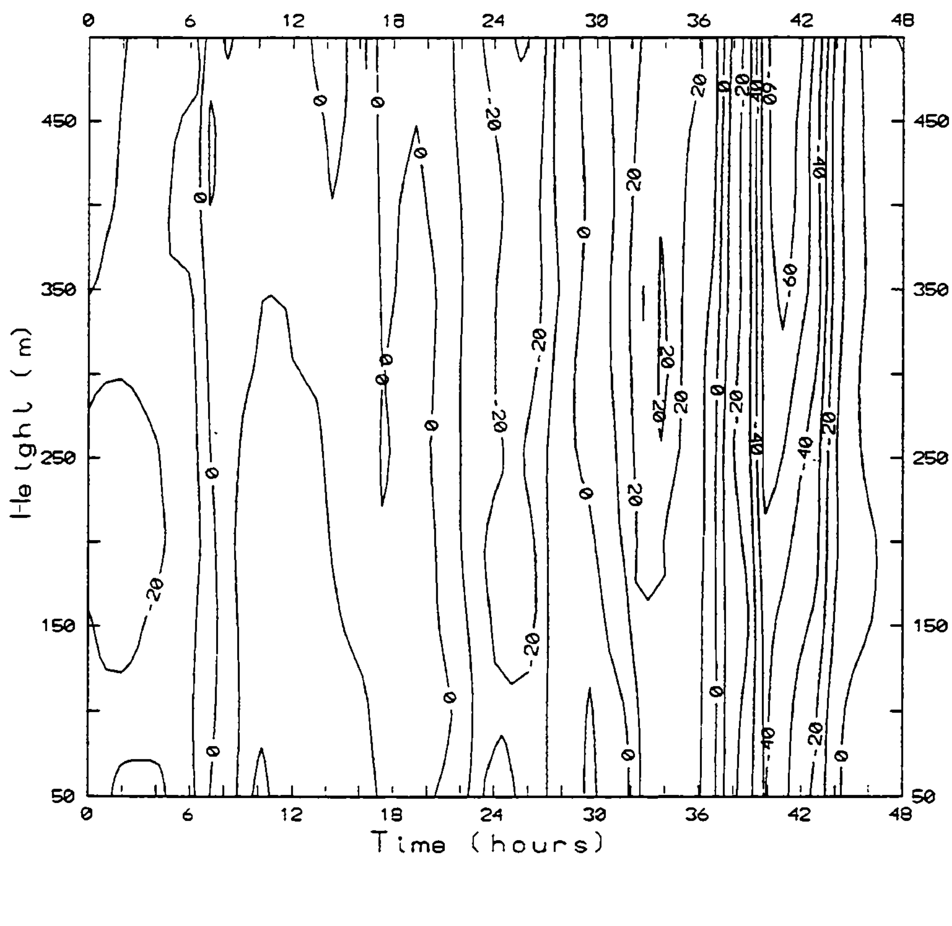


Fig. 17a: A0 Sigma w 15./16. 1. 93

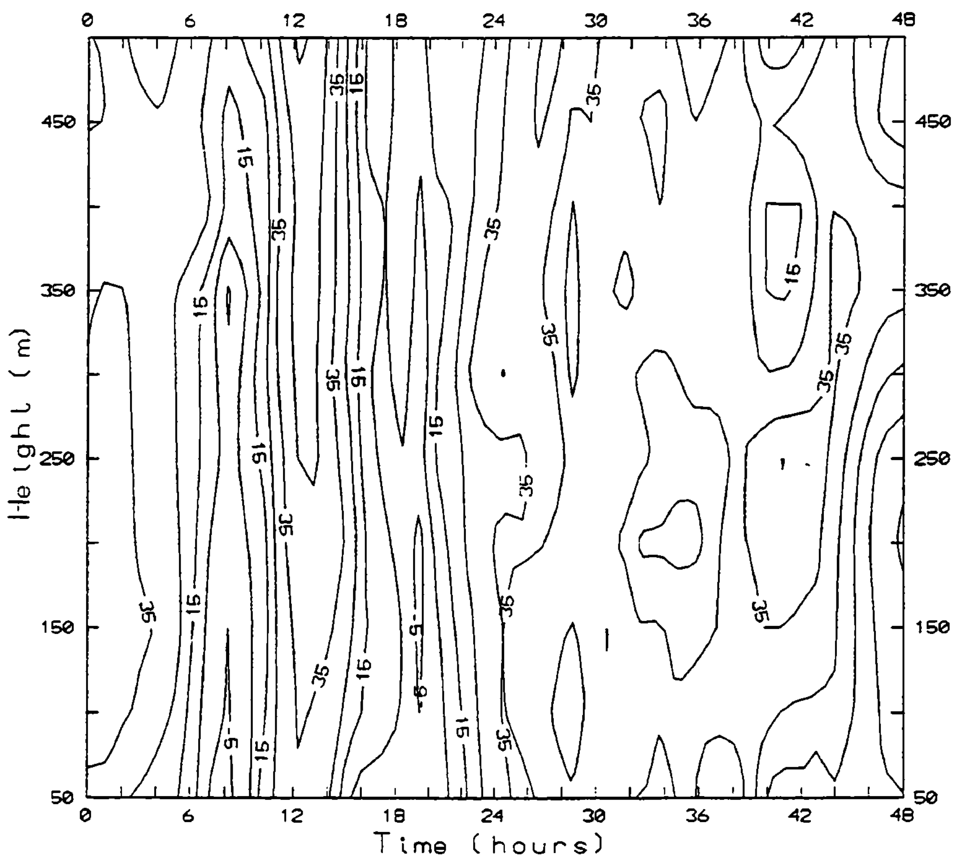
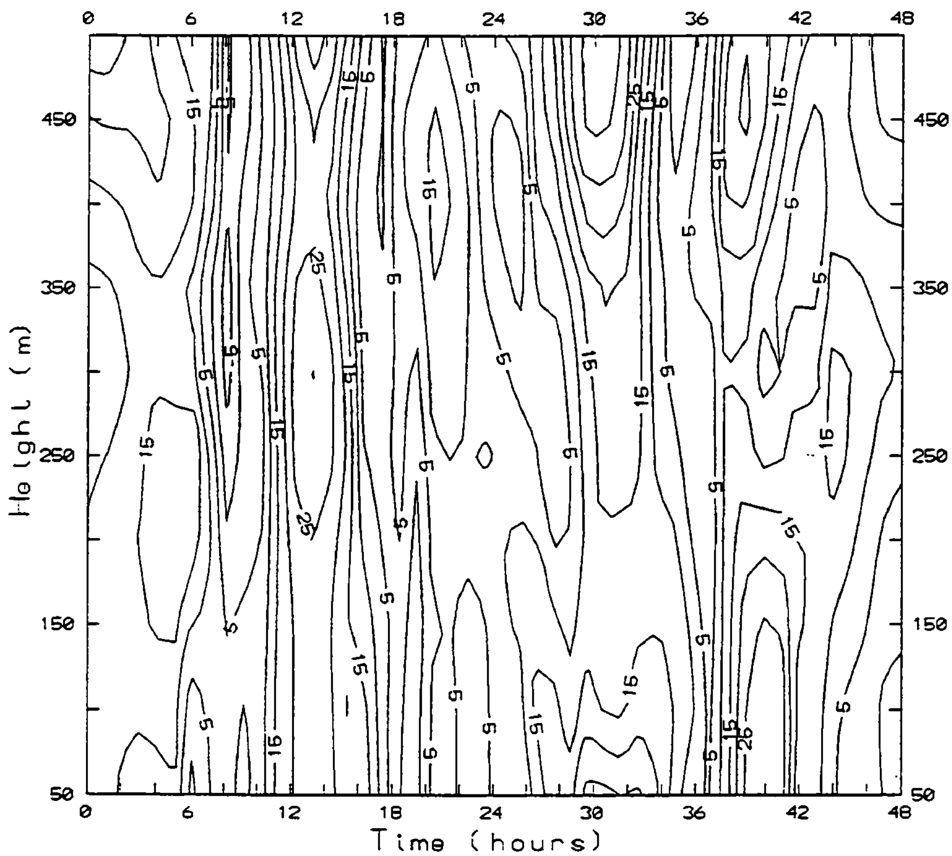


Fig. 17b: PA2 Sigma w 15./16. 1. 93



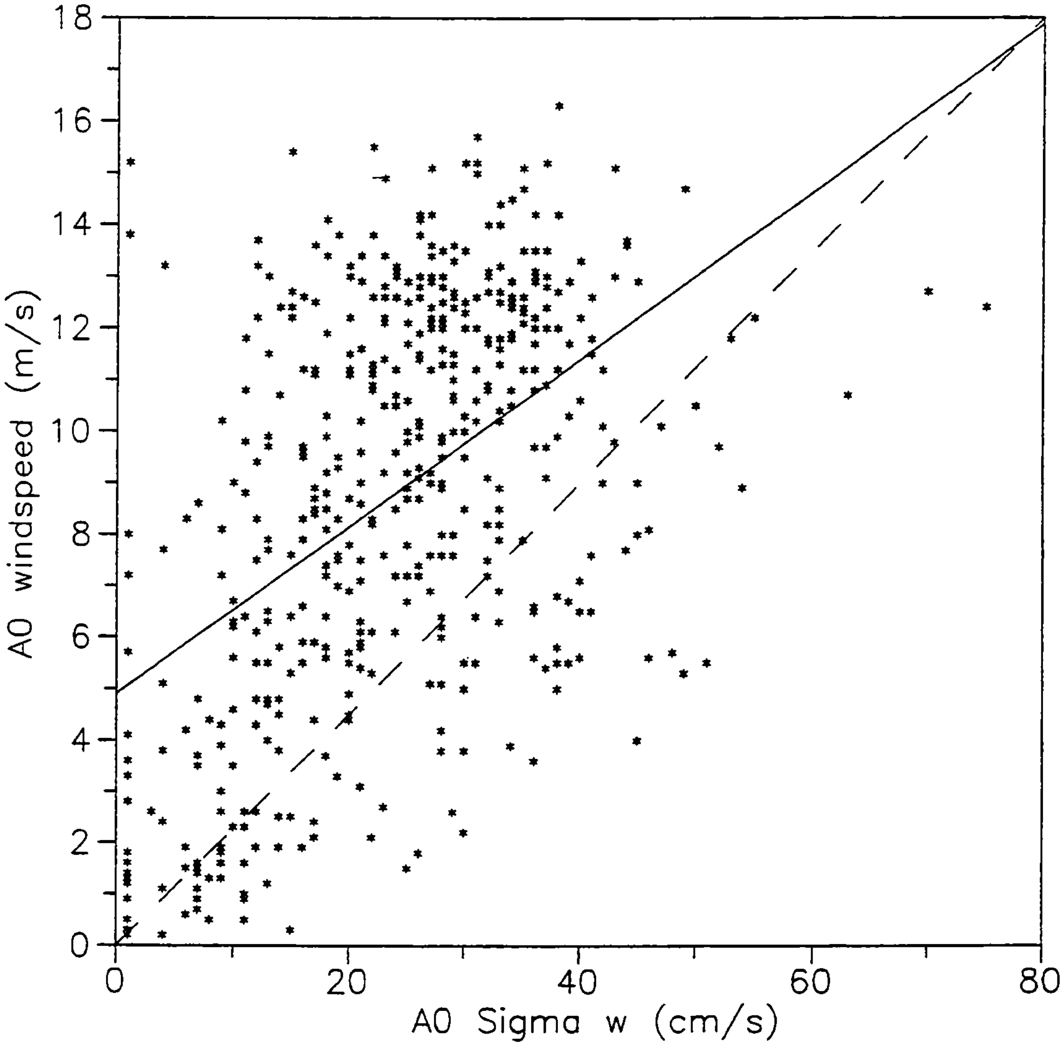


Fig. 18: Sodar comparison 15./16. 1. 93

Best-fit line: y = 0,16x +¨ 4,9

mechanical turbulence. The high values at the beginning of the night to January 17 could be caused by an inversion associated with decreasing windspeeds. Because of missing data there is no proof by the midnight Viennese radiosounding. From Table 13, the correlation coefficient for the echo comparison is rather high, especially compared to chapter 7.1.

Table 13: Statistics of the Sodar comparison for Jan. 15/16, 1993

Quantity	Speed	Direction	Vert. speed	Sigma w	Echo
N	816	816	830	839	876
A0 Mean	8,91		-0,4	23,8	271
PA2 Mean	8,79		-1,8	11,7	3584
Bias	-0,12	3,8	-1,4	-12,1	
Rel. Bias (%)	4		350	51	
RMSD	1,51	21,5	14,7	16,8	
Precision	1,50	21,1	14,6	11,5	
Rel. Prec. (%)	17		3650	48	
R	0,93		0,64	0,44	0,77

8. SUMMARY AND CONCLUSIONS

Results of an intercomparison between two different Remtech Sodars, the three-axis monostatic Sodar A0 and the phased-array Sodar PA2, were presented. The experiment was undertaken at the grounds of the power plant Duernrohr (48°19' N, 15°55' E), Austria, between December 23, 1992 and March 2, 1993. It was conducted because after several years of experience with the A0-Sodar, four PA2-Sodars had been purchased from the Remtech company in 1992, and it was of great interest to test the compatibility of the two systems prior to the further use of the PA2-Sodars. Partly during the experiment, partly afterwards in the course of the statistical evaluation of the data it turned out that the intercomparison revealed a momentary picture, because on the one hand the performance of the A0-Sodar was steadily declining most probably due to defective membranes generating the acoustic power, and the PA2-Sodar, on the other hand, whose software still being in a stage of development at this

Fig. 19a: AØ Echo 15./16. 1. 93

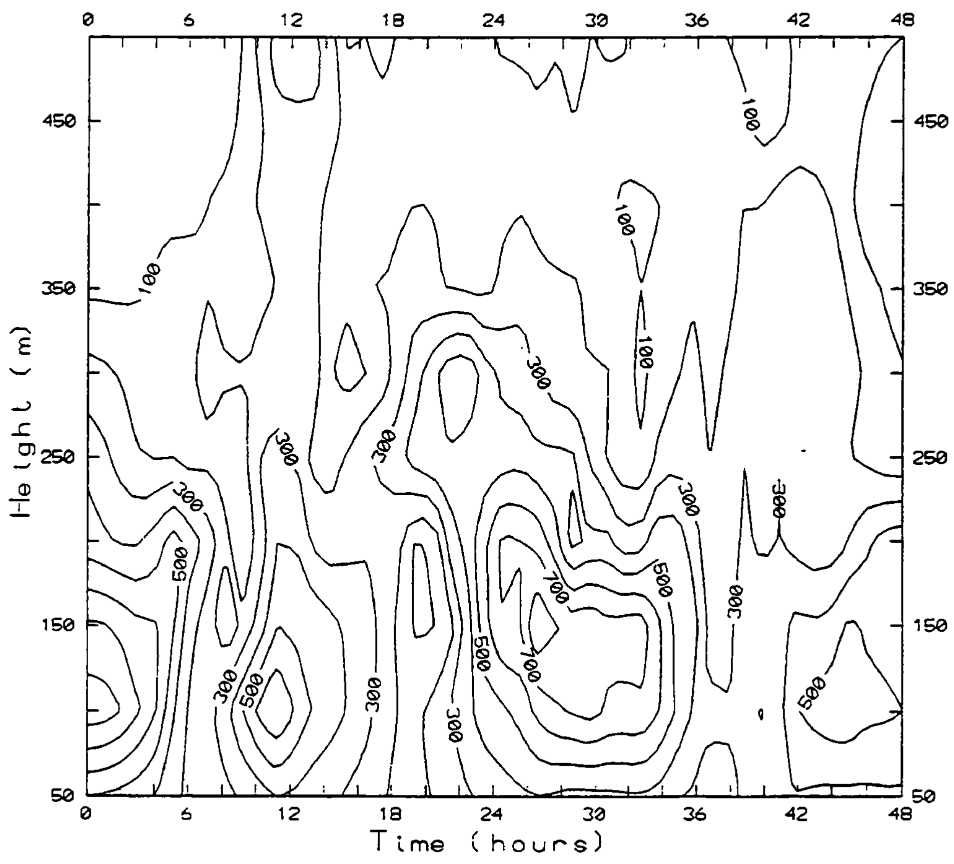
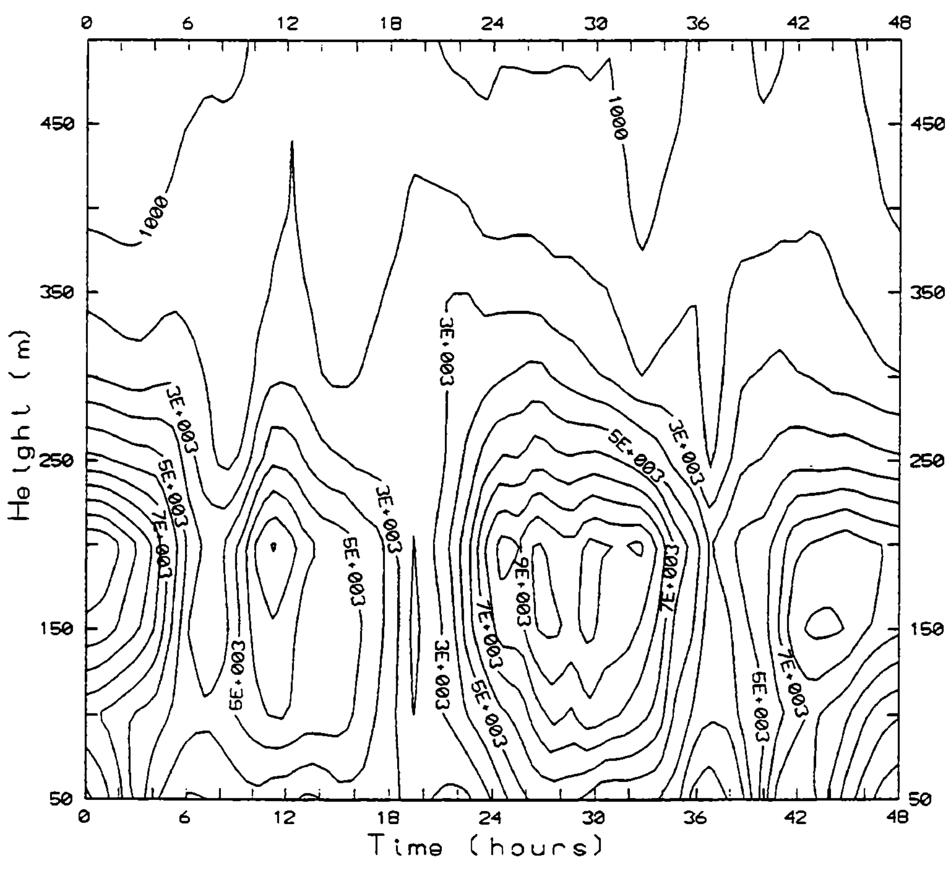


Fig. 19b: PA2 Echo 15./16. 1. 93



time, showed software defects resulting in too low estimates of σ_w and in a too strong damping of the vertical profile of the echo intensity above the fourth level.

Nevertheless, the comparison presented was the most comprehensive one and the only one after that of Vogt and Thomas (1994) so far undertaken with a PA2-Sodar. The Duernrohr experiment comprised all comparable data up to heights of 600 m. The results of the statistical investigation were compared to those available in the literature. In all of these comparisons, conducted at Cabauw, The Netherlands (Beljaars, 1985), Boulder, Colorado (e. g. Finkelstein et al., 1986; Chintawongvanich et al., 1989), and Karlsruhe, Germany (Thomas and Vogt, 1993; Vogt and Thomas, 1994), at least one Remtech Sodar of three-axis monostatic configuration except for Vogt and Thomas (1994), who used the PA2-Sodar, was involved. Comparative data exist for the horizontal windspeed and wind direction as well as for σ_w and σ_θ.

The Duernrohr comparison included data availability (chapter 5), a statistical (chapter 6) and a meteorological (chapter 7) evaluation of the Sodar data. In general, data availability was slightly better for the PA2-Sodar. The measurement period was divided into two sections. During the first until January 25, both systems operated at their full acoustic powers. After that date until the end of the measurements, power was reduced at night due to complaints by neighbours. This second period coincided with large data losses for the A0-Sodar, independant of acoustic power reduction (Figs. 2). With reduced acoustic power, data losses for the PA2-Sodar were larger than reported by Vogt and Thomas (1994). The statistical comparison was therefore restricted to the first period with full acoustic power.

The statistical results for wind direction and windspeed agree well with those of other investigators (Chapters 6.2 and 6.3). These are the quantities which Sodars measure most correctly. However, the height dependance of the statistical quantities as well as the sign of the bias differ among different experiments. For the standard deviations, the agreement is less. For σ_θ, this is explained primarily by the spatial and temporal separation of the sampling volumes of the tilted beams for a given layer (e. g. Chintawongvanich et al., 1989). For σ_w, the main reason is that Sodars are not capable of detecting the whole spectrum of vertical velocity; instead, at least under convective condititons, they are more sensitive to strong updrafts covering less time and volume than the weak downdrafts (Seibert and Langer, 1996). Some other publications deal with these problems (e. g. Gaynor, 1994; Neff and Gaynor, 1991;

Kaimal and Gaynor, 1990). Moreover, there is a lot of uncertainty if Sodars over- or underestimate σ_θ and σ_w (see Chapters 6.5 and 6.6 for details).

The vertical velocity and the echo intensity had not been treated statistically in the same manner as here by other investigators. The scatter in the vertical velocity data was extremely large. The mean values of the vertical velocity were nearer to zero for the PA2-Sodar (Fig. 7), especially at night. Thus, the PA2-Sodar values of the vertical velocity seemed to be more reliable. The echo intensity is not the same for the two systems compared. In the PA2-Sodar output, it is called C_T^2, which is not the C_T^2 of the theory (e. g. Neff and Coulter, 1986). Because the PA2-Sodar echo values were much larger than those of the A0-Sodar and thus a large systematic positive bias had to be expected, the echo comparison was restricted to the correlation coefficient (Chapter 6.7). It decreased with height and did not show remarkable day-night differences.

The Sodar performances were furthermore investigated for two two-day meteorological episodes, an anticyclonic one during December 25/26 and a westerly current during January 15/16 (Chapter 7). Among all the meteorological parameters, air temperature showed the most significant differences between the two periods (Tables 10, 12). The aim of this investigation was to see if different meteorological conditions affected the Sodar intercomparison. Data availability during the second period doubled compared to the first (Tables 11, 13). The statistics for windspeed were equally good for both periods, the wind direction data, surprisingly, showed more scatter during the westerly flow despite higher windspeeds. The statistics for the vertical velocity were somewhat better than for the whole dataset analyzed in Chapter 6.4. During the anticyclonic period, a large systematic positive bias occurred, when the A0-Sodar measured large negative values. σ_w statistics was worse during westerly airflow, while the correlation of the echo intensities was much better. During the second period, especially the PA2-Sodar measured very high echo intensities. To summarize, the performance of the parameters investigated did not show a unique tendency with respect to the two different weather regimes; therefore it was concluded that these weather regimes did not systematically affect the performance of the Sodars.

After the end of the Sodar intercomparison period described in this report, the PA2-Sodars were used a lot at different places for testing and later on for scientific purposes. As a next step, it was decided to test all the four instruments together at the extended facilities of the Vienna International Airport. The test, conducted in the summer of 1993, however failed because of many hard- and software defects, which led the Remtech company to check the

Sodars in the following autumn and winter and finally returning more reliable systems. In April 1994, the test was repeated successfully - except of the large damping of the echo intensities described in Chapter 6.7 - at a military site in Northern Austria. In the summers of 1994 and 1995, the PA2-Sodars were used for field experiments in the Vienna area (Piringer et al., 1995; Piringer et al., 1996). In the 1994 experiment, the vertical structure of the boundary layer during ozone episodes was analyzed; in 1995, convective situations were examined, partly making use of small averaging times down to two minutes. Results were discussed at international conferences (Piringer, 1996a and b), papers to appear in scientific journals are in preparation. Although Remtech provides us with a new update of their Sodar software approximately once a year, up to now the main inherent problems of Sodar operation, addressed in this report, concerning echo intensity, vertical speed, and the standard deviations, have not been solved satisfactorily.

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