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AIR RADIOTHEODOLITE WINDFINDING TRIAL CRAWLEY 1991

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1. INTRODUCTION.

An AIR radiotheodolite was installed at Crawley (Sussex, WMO station number 03774) radiosonde station in 1990 in order to test the system prior to its deployment by British Antarctic Survey at Halley Bay (WMO station number 89022) in the Antarctic during late 1991. The radiotheodolite system was required to replace an old Vaisala Microcora groundstation which had been using Omega windfinding. Monitoring had shown that the Omega wind measurements were difficult to obtain and of poor quality because absorption of Omega signals propagating across the ice cap prevented adequate Navaid geometry for windfinding at Halley Bay.

This report presents an evaluation of the AIR radiotheodolite windfinding expressed in terms of its accuracy and operational viability. Most of the analysis within this report relates to the comparison flights made during a 5 week period in 1991 at Crawley. This trial obtained detailed wind measurements under varying conditions which were compared simultaneously with both primary (Cossor) radar and operational Loran measurements . Information is additionally included from 5 other sources as follows:-

(i) Prior to its deployment in Antarctica, the same radiotheodolite had also been tested at Dzhambul (Khazakstan) in 1989 during Phase III of the WMO Radiosonde Intercomparison Trial where a Russian secondary radar provided the reference for simultaneous comparisons. (Ivanov et al ,1991 [1])
(ii) The system was tested again at Crawley during September 1990 when a series of 12 simultaneous triple ascents was made with the newly operational Vaisala RS80 and the previously operational UK RS3 radiosonde.
(iii) In spring 1994 a similar AIR radiotheodolite system took part in Phase IV of the WMO Radiosonde Intercomparison Trial in Japan. (Yagi, et al 1993 [2])
(iv) A similar system was subsequently tested at Larkhill (Salisbury Plain, WMO station number 03743) during the Army "BMETS" test in 1994. (Elms, et al [3].)
(v) At the time of writing (June 1997) the AIR radiotheodolite system tested at Crawley is still in use , providing daily aerological soundings from Halley Bay. Additional information on the practical experience of the system to date is provided by extracts from annual reports written by members of the British Antarctic Survey.

2. THE AIR RADIOTHEODOLITE SYSTEM.

The groundstation tested at Crawley consisted of a radiotheodolite (see photograph Annexe 1) coupled via a receiver and signal demodulator unit to a Hewlett Packard Vectra ES/12 computer. This computer ran a suite of programs to display, archive and encode the data received via the radiotheodolite from the radiosonde. The radiosondes used were AIR "Intellisondes" with a nominal transmission frequency of 1680 MHz.

Two types of AIR radiosondes were used:-
Model IS-4A-1680 (calibrated April 1989) were flown on 15GMT and midnight flights.
Model IS-4A-1680X (calibrated June 1990) were flown on midday flights.

The only design difference apparent to the user of these radiosondes was that 1680X radiosondes had metal rod thermistor outriggers whereas nearly all the older (1680) radiosondes used plastic outrigger supports. A further difference between the two types was that the 1680X radiosonde pressure elements had been calibrated to produce "split" coefficients in order to improve the accuracy of the pressure measurements.
Neither of these differences significantly affected the windfinding performance of this system which forms the main subject of this report.

3. TRIAL PROGRAM AND DATA ACQUISITION

3.1 The Crawley Trial Program (February/March 1991)

The Trial took place in two separate periods:-
(i) 28/1/91 12 GMT to 8/2/91 00GMT (Flights 4 to 47)
(ii)19/2/91 00GMTto 2/3/91 00GMT (Flights 51 to 72).
These 2 periods had appreciably different weather conditions and enabled the AIR radiotheodolite tracking to be assessed at varying elevation angles. (See Annexe B for midday surface analyses and summaries of weather conditions during the Trial).

Evaluation of the AIR system was one part of this Trial. The main aim was to evaluate the newly developed PC-CORA Loran windfinding system (Nash,Oakley 1991,[4]) and provide reference comparisons between the sensors of the UK RS3 and Vaisala RS80 radiosondes. AIR radiosondes were flown on 39 of the 72 comparison flights. They were flown on a rig with an RS80 Loran radiosonde and AIR Intellisonde at the same level 30m below a radar reflector. On some flights an additional RS80 PTU radiosonde and/or an RS3 radiosonde was also attached at the same level. Data from the radar, Loran and AIR soundings have been analysed from all these flights.

The flight log and main features of these ascents is given in Annexe C, including burst pressures, flight duration , plus the availability of other measurements for comparison with the radiotheodolite measurements.

3.2 Data Synchronisation.

Radar and Loran winds were derived from 2 independent Vaisala PC-CORA groundstation systems . (Nash ,1991 [5]). These two systems were synchronised from a pulse initiated by a remote button press on launch. The AIR system timing was synchronised with PC-CORA using its "auto" start facility based on reducing pressure measurements at launch. Comparison of the temperature and humidity profiles of the AIR and RS80 sensors enabled small adjustments to the timing to be applied. These corrections are tabled in Annexe C, but are insignificantly small (generally less than 5 seconds) to impact on the wind comparisons.

3.3 Wind Data Acquisition and Quality Control.

Vaisala RS80 and AIR radiosondes sample pressure, temperature and relative humidity approximately every 1 to 2 seconds. The AIR radiotheodolite winds were evaluated for each PTU cycle. Loran phase derivatives were recorded every 10 seconds. The Cossor radar slant range, azimuth and elevation were recorded every 1 second by the PC-CORA groundstation. These raw radar data were also used as input to a Met Office wind computation program "UAWNDS" which provided independent wind calculations. In order to supplement the low level radar windfinding information, an optical tracker was interfaced with the radar and groundstation computer at Crawley to provide balloon bearing and elevation data for the period from launch to radar target acquisition. Optical tracker data were used by the UAWNDS program to provide low level winds closer to the surface than with the standard PC-CORA software.

In order to compare fine structure in the measurements the Vaisala and AIR data were interpolated at 1 minute intervals from launch time and archived in a Minute Database. "RSKOMP" software devised by Kurnosenko [6] for use in WMO Radiosonde Comparisons was used to display and analyse the archived data. The amount of data excluded from statistical analyses of the results was kept to a minimum. Reasons for all excluded data are given in the Remarks column of Annexe C.

4. WIND REFERENCE MEASUREMENTS

4.1 Quality of Radar Winds.

The Cossor radar providing the reference wind measurements at Crawley was one of a network of similar radars used for more than 30 years for windfinding in the UK. Tests in 1984 of the windfinding performance of this type of radar showed that the RMS vector errors in the wind varied from about 0.4 $m.s^{-1}$ at 20km range to 1.5$m.s^{-1}$ at 80km, Edge et al., [7] .These results were derived by tracking the same balloons with Cossor radars separated by 50 km at Bracknell and Crawley (West Sussex) .At that time operational RS3 radiosonde software was used to compute winds and this used a lower sample rate for the raw radar data than the PC-CORA or UAWNDS software.

In the last 2 years winds from the Aberporth (West Wales) Cossor radar have been compared with winds from a high precision tracking radar at the same site. 4 comparison flights have been made. The results showed that RMS errors in the Cossor winds computed using UAWNDS software were significantly smaller than those found in 1984. These results are presented in Figures 1(a) and (b) as the standard deviation of the differences between Cossor and high precision radar wind for wind components resolved parallel (along) and perpendicular (across) the radar beam. The errors in the Cossor winds across the radar beam are expected to be linearly related to slant range if errors in azimuth tracking are independent of elevation (see Nash [8]). The results in 1(b) would be produced by an effective random error of 0.02° in Cossor azimuth measurements. For winds measured along the radar beam , errors in Cossor elevation cause the wind errors to increase as the height of the target increases , (see Nash [8]) and the results in Figure 1(a) correspond to short term random errors in elevation of less than 0.1° .
Thus, the comparisons with the High Precision Radar show that the RMS vector errors attributed to Cossor winds can be reduced from the original 1984 estimates to about 0.2 $m.s^{-1}$ at 20km range to 0.9 $m.s^{-1}$ at 90km, for measurements using PC-CORA data sampling.

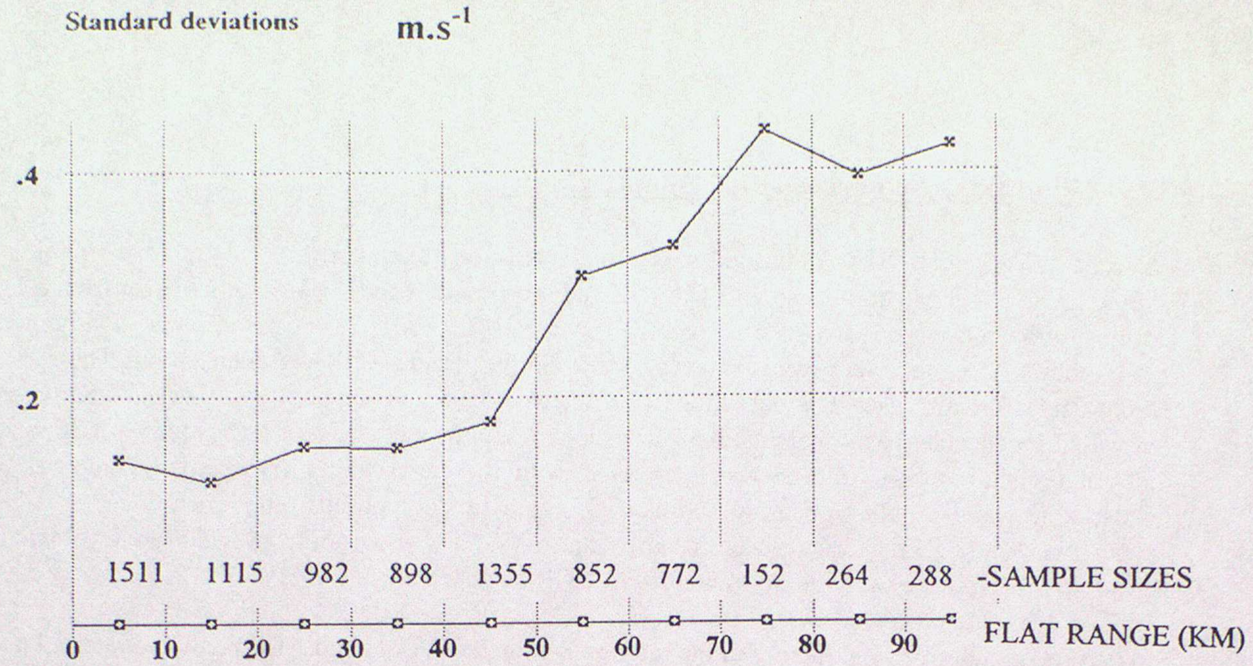


FIGURE 1 (a)

HIGH PRECISION RADAR TRIAL -
STANDARD DEVIATION OF (COSSOR - HIGH PRECISION) RADAR WIND COMPONENTS MEASURED ALONG THE RADAR BEAM

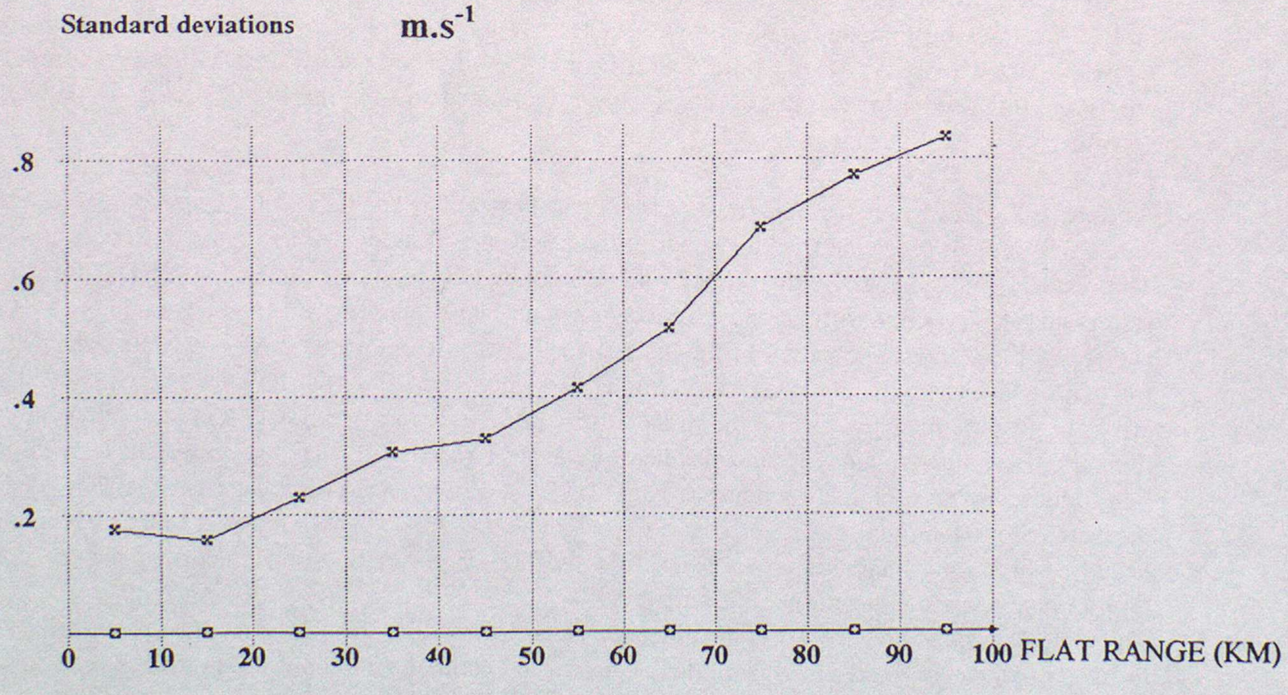


FIGURE 1 (b)

HIGH PRECISION RADAR TRIAL -
STANDARD DEVIATION OF (COSSOR-HIGH PRECISION) RADAR WIND COMPONENTS MEASURED ACROSS THE RADAR BEAM

During the AIR radiotheodolite test the mean flat range was only about 30 km from 100 hPa to 10 hPa. Maximum flat ranges on individual flights varied between 12 km and 170 km and minimum elevations varied between 10 and 58 degrees. Estimates of the errors in radar winds appropriate to the mean flat ranges obtained with increasing altitude during the Crawley trial are shown on the statistical analyses in Figures 14(a) and 14(b).

4.2 Quality of Loran Winds.

The Loran windfinding used transmissions from the following 2 chains:-
FRENCH CHAIN GRI 8940
Lessay (Master) , Soustons (1st slave)
NORWEGIAN CHAIN GRI 7970
Ejde (Faeroes) (Master), Bo (Norway) (1st slave), Sylt (Germany) (2nd slave), Sandur (Iceland) (3rd slave), Jan Mayen (4th slave).

The RS80-L Loran radiosondes (all calibrations March or May 1990) performed well measuring reliable winds to burst throughout both phases of the Trial apart from on Flight 34 where data at pressures below 200 hPa were lost due to poor signal transmission from the radiosonde. (Loran data from 3 ascents (Flights 14, 37 and 63) were recorded to burst ,but rejected from the data analysis as the Loran tracker timing was not synchronised with the radar and timing errors could not be accurately established.)
The Loran line fitting length was set to 30 seconds at all flight levels throughout the Trial.
The RMS vector error in the Loran wind components would be expected to be in the range 0.5 $m.s^{-1}$ in the troposphere and up to 1 $m.s^{-1}$ at long ranges in the stratosphere. (Nash ,Oakley [4]).

5. AIR. RADIOTHEODOLITE WINDFINDING COMPARISON EXAMPLES.

5.1 Data Designations used by Display and Comparison Software

The designations listed below appear on the key to the various diagrams in sections 5 and 6 :-

LOR PC-CORA (Loran system) ,Loran wind and altitude data transcribed directly from the Vaisala ".EDT" 2 second files obtained from a Vaisala RS80-L radiosonde.

RAD PC-CORA (Radar system) Radar winds computed by a second PC-CORA groundstation from the 1 second slant range, elevation and azimuth data.

AIR AIR Radiotheodolite system winds.

UAW60 Independently calculated radar winds using the Met Office "UAWNDS" software which also incorporated optical tracker data in its lowest level wind calculations.

UAW240 As above but calculated using a 240 second line fit.

5.2 Examples of Simultaneous Windfinding Comparisons .

Figures 2 to 9 show examples of simultaneous wind measurements made by the 3 independent windfinding systems during the Trials. The examples illustrate the main features of performance of the various systems. To enable an overview of the flights from launch to burst, most of the graphs display data at 1 minute intervals. The standard level pressures are indicated on the right hand edge of each graph. Wind components are in $m.s^{-1}$ using the convention that northerly winds have a negative N-S component and westerly winds have a positive E-W component.

5.2.1 Examples of Reliable AIR Radiotheodolite Windfinding.

Figures 2 to 4 display simultaneous samples of wind components at one minute intervals by AIR, RADar and LORan systems from launch to burst during flights 5,10 and 30 respectively. These 3 ascents gave typical results for flights when the minimum balloon elevation was greater than 20 degrees. Note that on all 3 flights the wind component measurements of all 3 systems in the troposphere were generally within about 1 $m.s^{-1}$ of each other . In these cases the radiotheodolite tracked well from the surface. In the stratosphere the longer line fitting length (240 seconds) used by the AIR software produced less structure in the vertical than on the other systems. This produced differences of up to 3 $m.s^{-1}$ in one or more components when compared with the radar and Loran measurements.

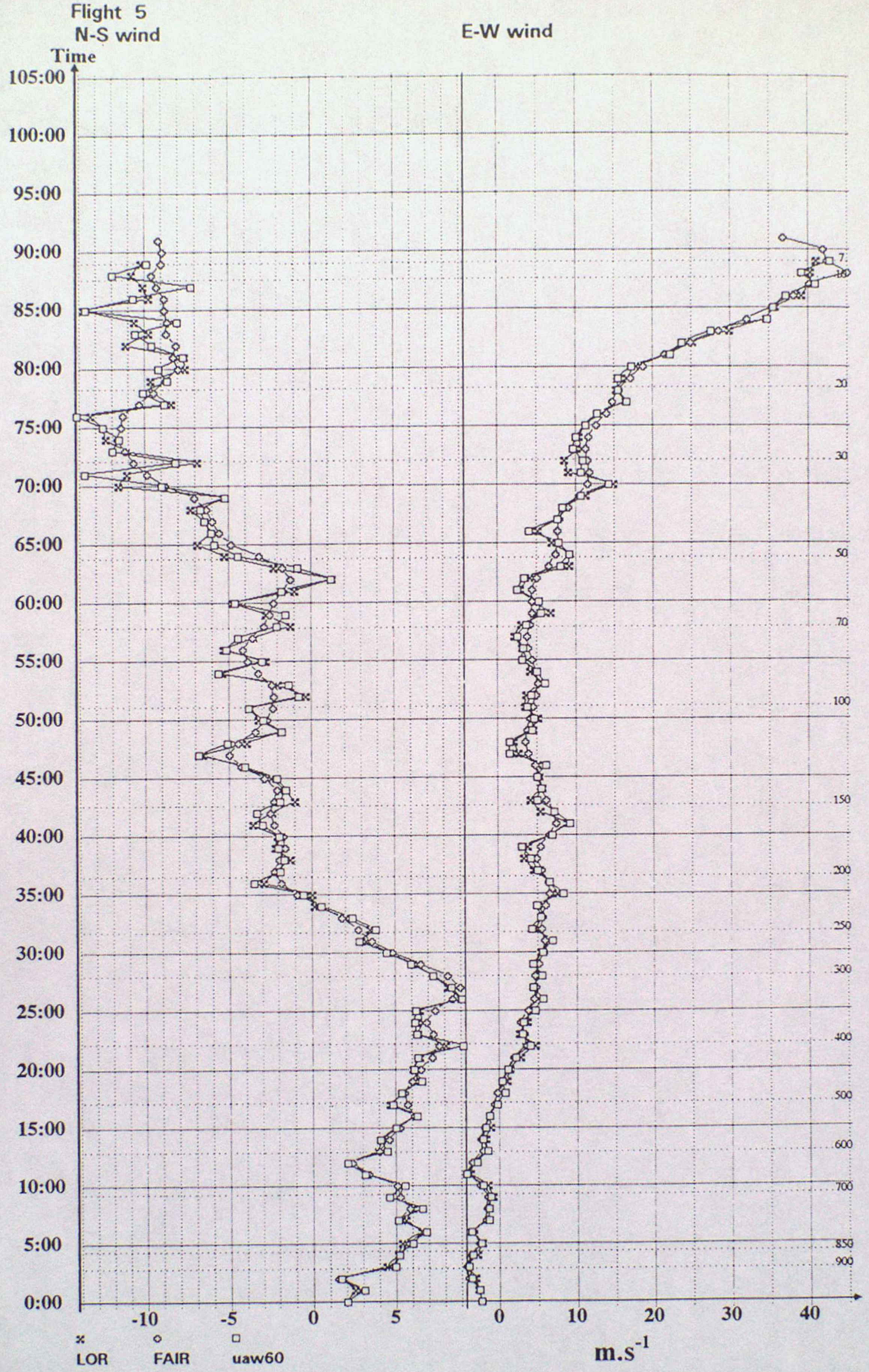
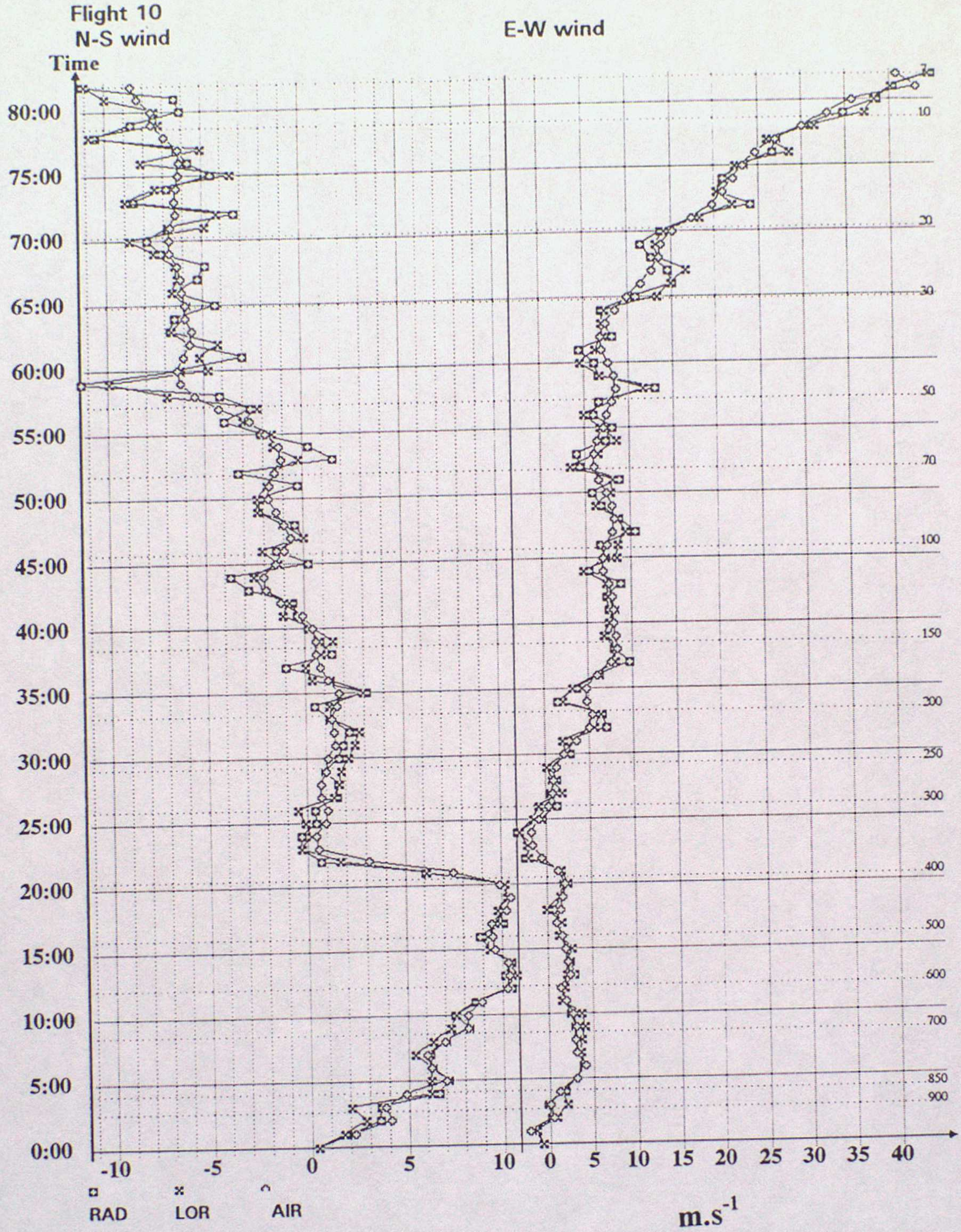


FIGURE 2

RELIABLE AIR RADIOTHEODOLITE TRACKING FROM LAUNCH TO BURST.



Flight 10
N-S wind
E-W wind
Time
80:00
75:00
70:00
65:00
60:00
55:00
50:00
45:00
40:00
35:00
30:00
25:00
20:00
15:00
10:00
5:00
0:00
-10
-5
0
5
10
0
5
10
15
20
25
30
35
40
RAD
LOR
AIR
m.s-1
10
20
30
50
70
100
150
200
250
300
400
500
600
700
850
900

FIGURE 3

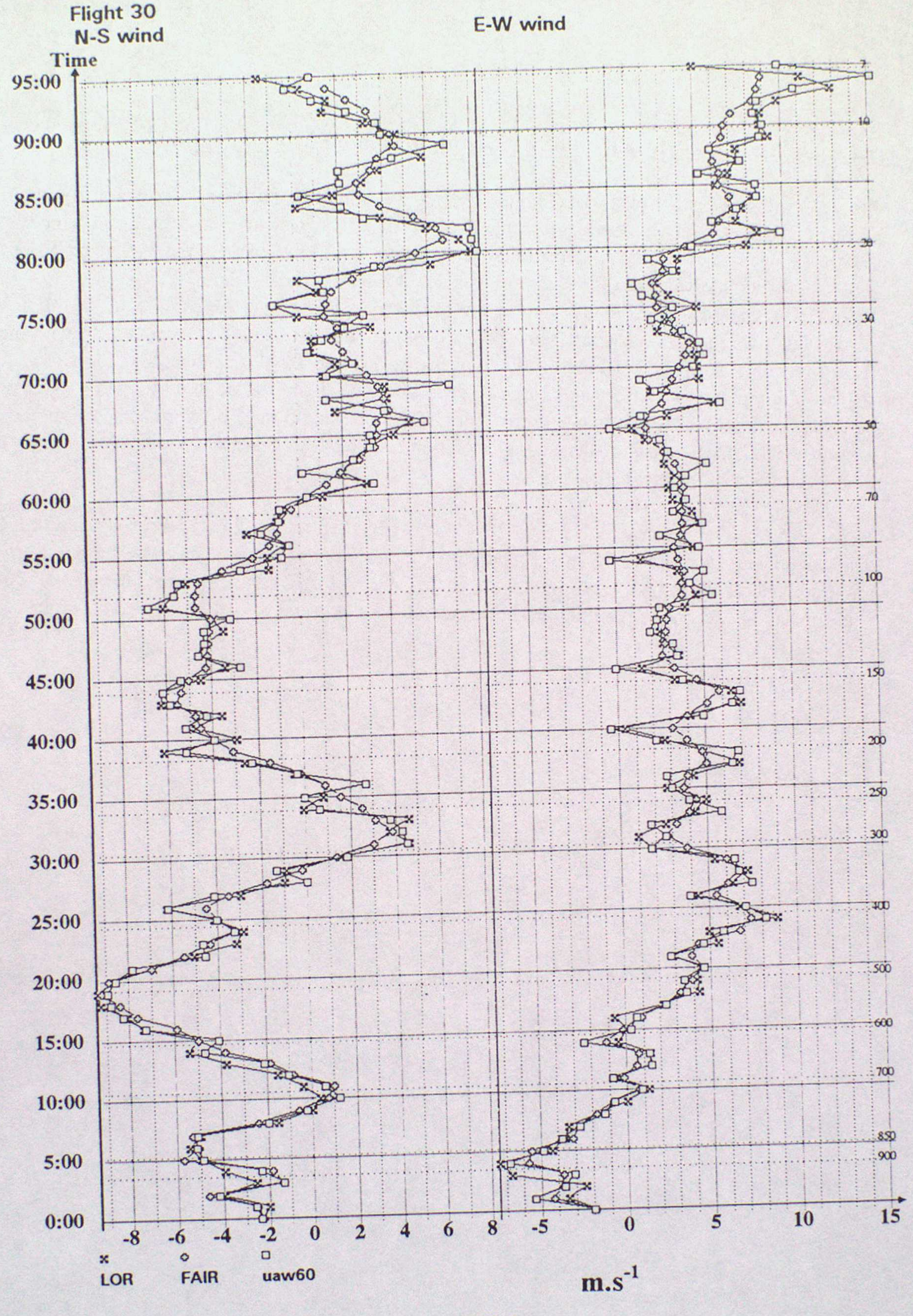


FIGURE 4

RELIABLE AIR RADIOTHEODOLITE TRACKING FROM LAUNCH TO BURST

5.2.2 Examples of the Effect of Changing the Line Fitting Length

Figure 5 shows a further example (Flight 4) of reliable radiotheodolite measurements from launch to burst. The detail in wind measurements shortly after launch, shown at 10 second intervals in Figure 5A again shows good agreement between the wind measurements of the 3 systems. Here the AIR line fitting interval set in the software was about 60 seconds.
Figure 5B compares the radiotheodolite winds with radar winds from the same data , using a 240 second line fit. The radiotheodolite wind components are now in much better agreement with those from the radar at pressures below 300 hPa. However, use of a 4 minute line fit causes fine structure in the stratospheric winds to be less well defined. Note for example the good agreement between the radar and Loran winds (both using 60 second line fitting) between minutes 50 and 70 in Figure 5. The AIR measurements in this section produce a representative mean layer wind, but do not represent the vertical structure as well.

When working at elevations higher than 20° it is possible that the use of a 240 second line fit has a detrimental impact on the AIR winds, but further work is necessary to identify the appropriate optimum smoothing to be used in the stratosphere. When observing at elevations lower than 20° it is clear that 240 seconds smoothing in the stratosphere is essential for the AIR radiotheodolite.

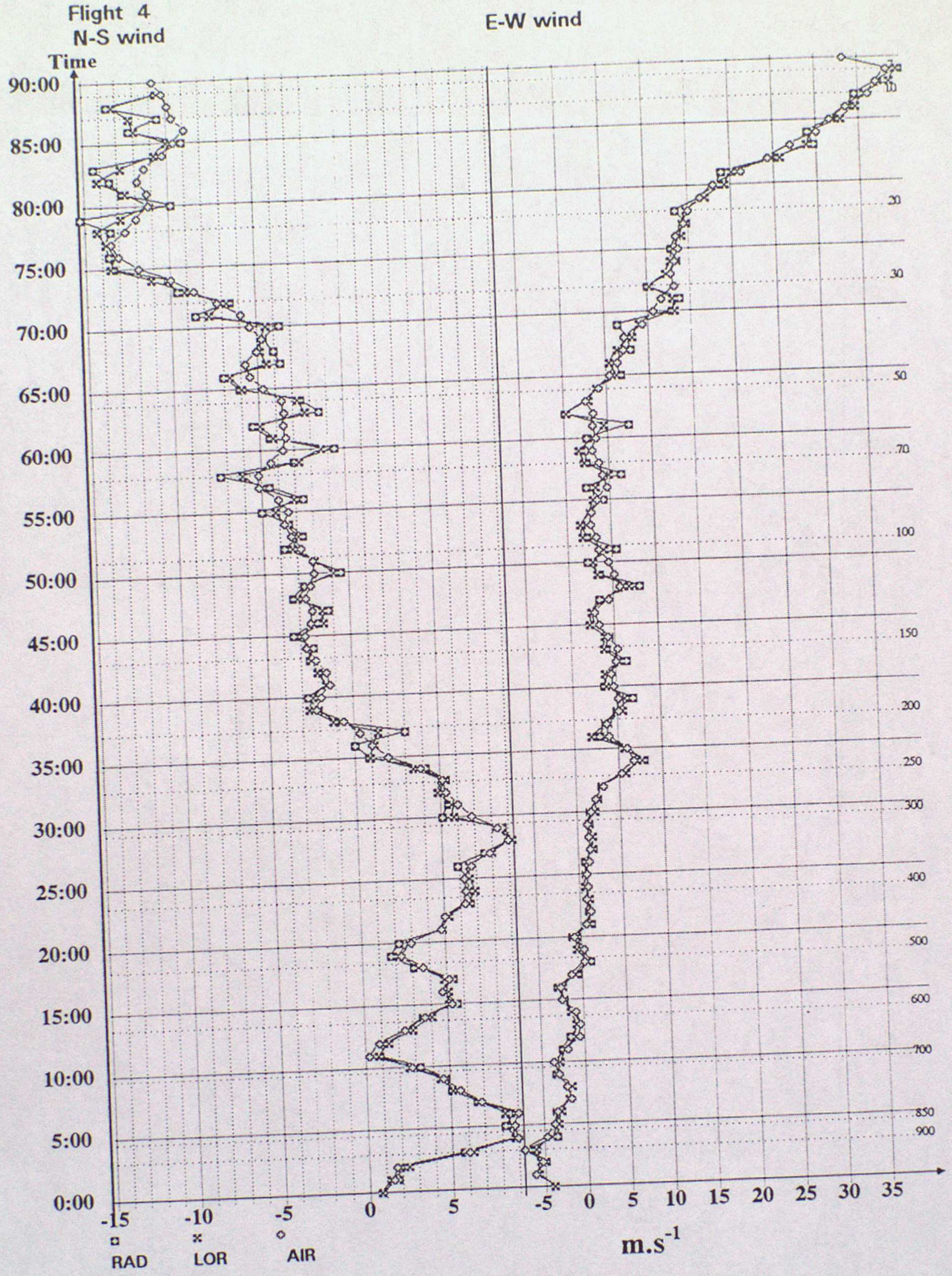


FIGURE 5

GOOD AIR THEODOLITE TRACKING FROM LAUNCH TO 7 HPA

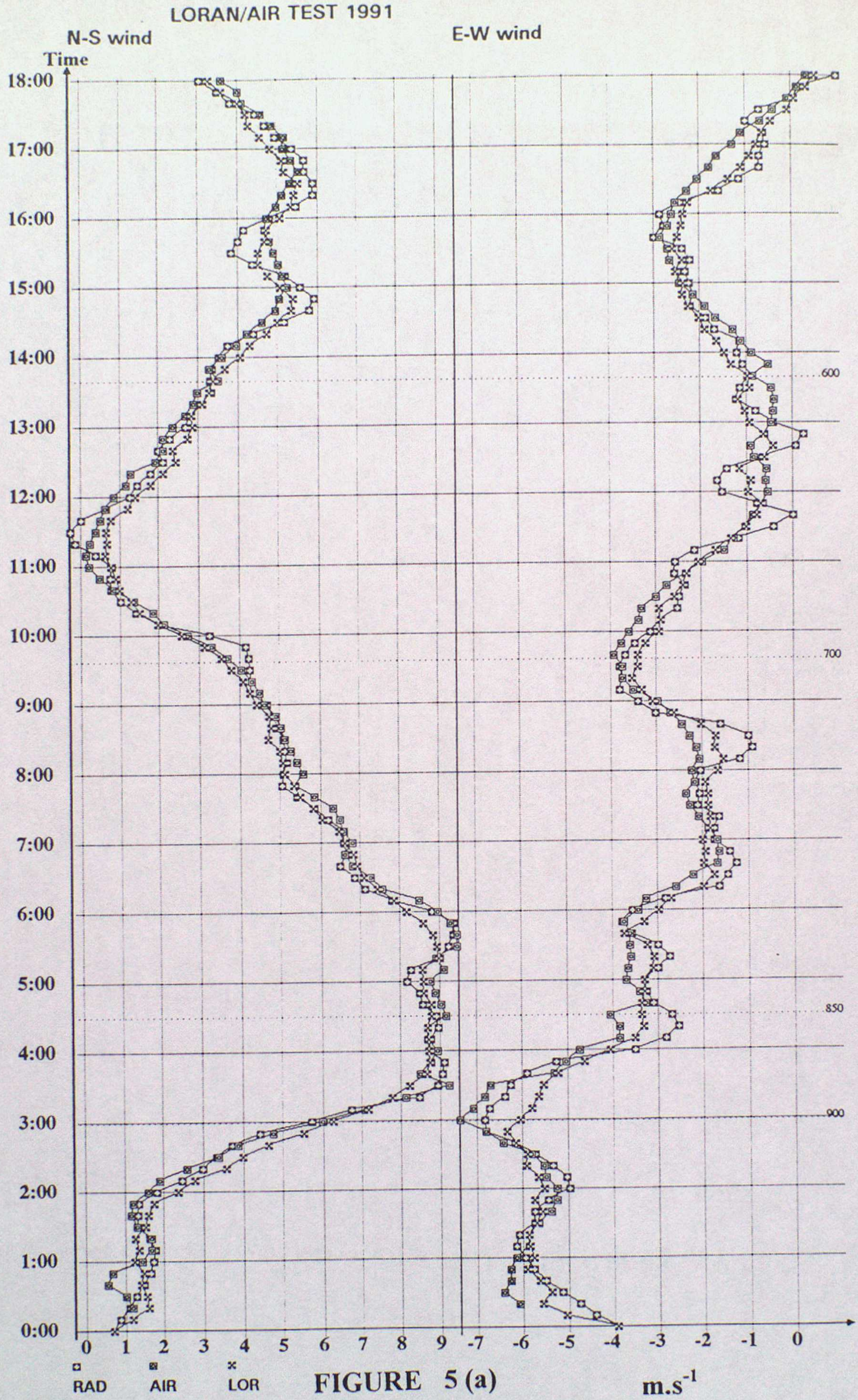


FIGURE 5 (a)

EXAMPLE OF GOOD AIR THEODOLITE WIND MEASUREMENTS

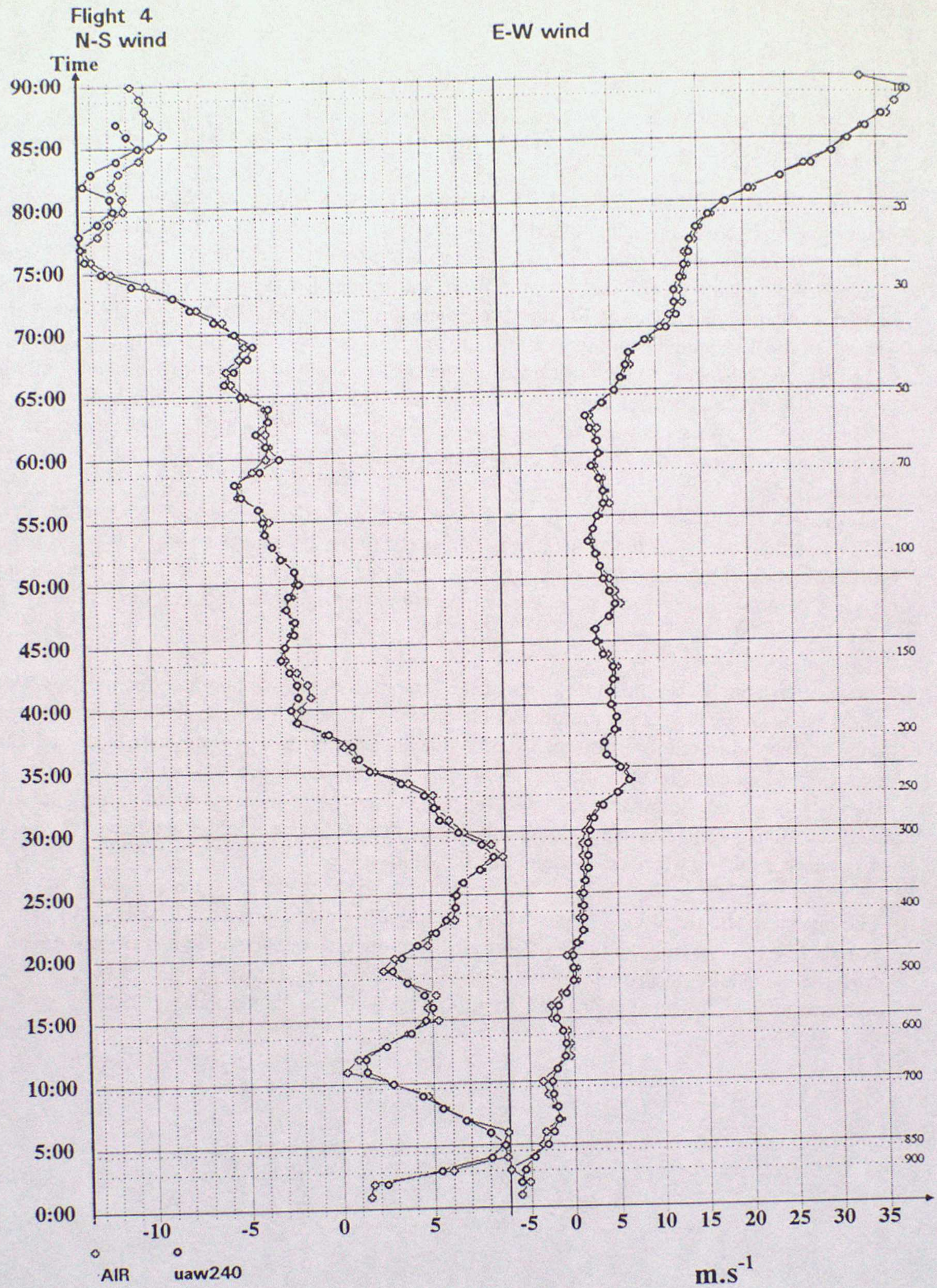


FIGURE 5 (b)

AIR WINDS COMPARED WITH RADAR WINDS COMPUTED WITH 240 SECOND LINE FITTING

5.2.3 Example of Erroneous AIR Winds at Low Levels- SIDELOBES.

Figures 6 and 7 (Flights 27 and 25 respectively) show significant errors in the AIR wind measurements between minutes 0 and 4 . These errors were caused by the radiotheodolite antenna tracking the radiosonde signal on a side lobe with the Intellisonde at close range. This caused the radiotheodolite antenna to point away from the true position of the radiosonde resulting in incorrect bearing and elevation for the wind calculations. Similar cases to those shown occurred on 13 out of the 39 soundings in this trial. (These are all noted in the remarks column of Annexe C).
The AIR radiotheodolite was positioned on the southern end of the roof of the main building at Crawley ,with a higher roof to its north (see photograph Annexe A). From the launch area it was difficult to visually assess whether the radiotheodolite was aligned with the radiosonde immediately after launch. (For safety reasons an operator could not go on the roof whilst the radar was transmitting).
Furthermore, the radiotheodolite did not track well on 3 consecutive ascents (Flights 14,15 and 17) when the bearing to the balloon was due north (over the adjacent roof) . It is probable that different siting of the radiotheodolite may have reduced the number of occasions when the antenna tracked on a side lobe. However, sidelobe tracking is still a problem operationally in the Antarctic (see section 7.2.2 .)

Soon after launch, the operators checked the radiotheodolite elevation and bearings against those of the radar and realigned the radiotheodolite once it was clear that the radiotheodolite was tracking on a sidelobe. In both figures 6 and 7 the AIR winds are erroneous from launch. In each case the effect of realignment of the radiotheodolite may be seen in the profiles between minutes 2 to 4. During this period the 60 second line fitting to the raw data included rapidly changing bearings and elevations whilst the tracking was adjusted and so large errors in the winds would be expected for at least 1 minute when a 60 second line fit was being used.

The operator should always be aware of the potential problem of sidelobe tracking and make visual checks from the radiotheodolite position once the radiosonde has been launched. The AIR radiotheodolite is provided with a siting telescope and a local manual drive facility which responds to elevation and bearing data input to a keypad. (see photograph Annexe A)

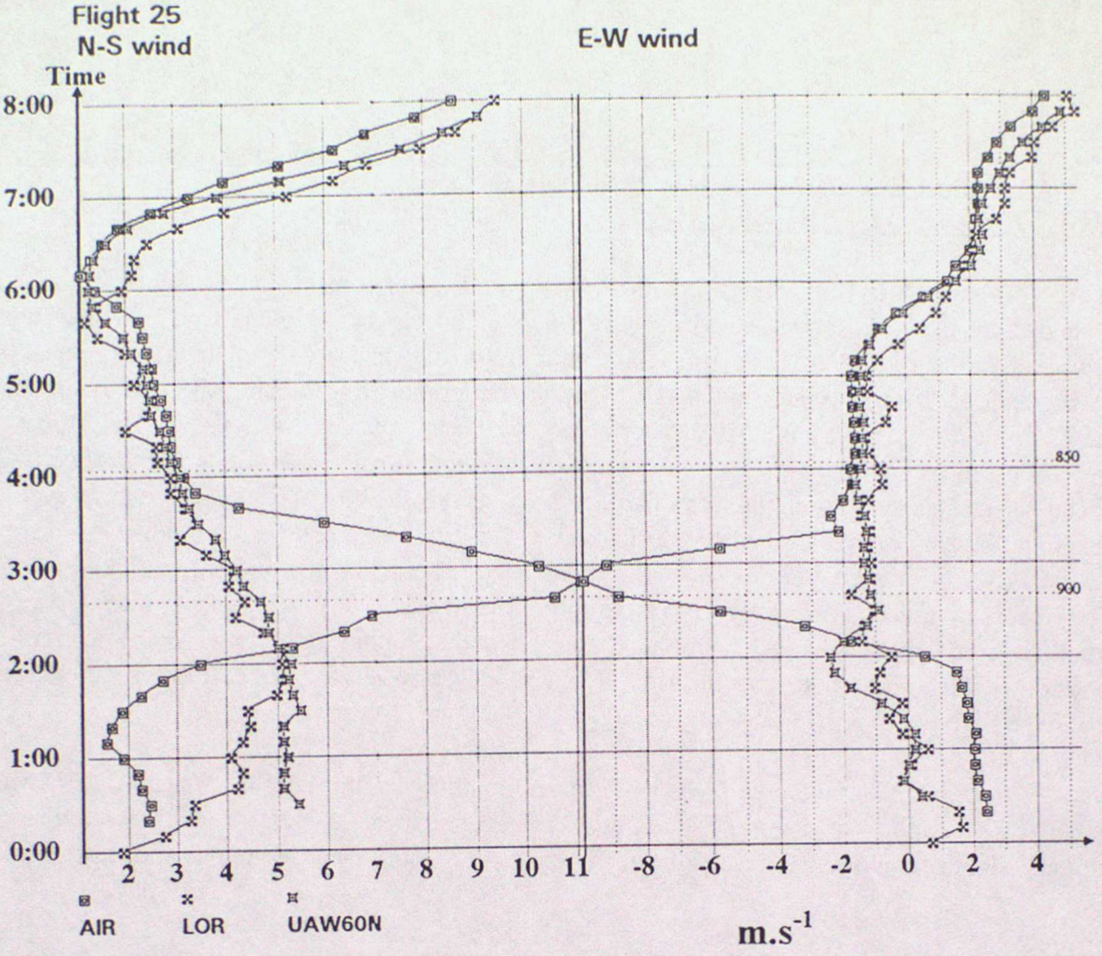


FIGURE 6

AIR RADIOTHEODOLITE TRACKING USING A SIDELOBE EARLY IN FLIGHT.

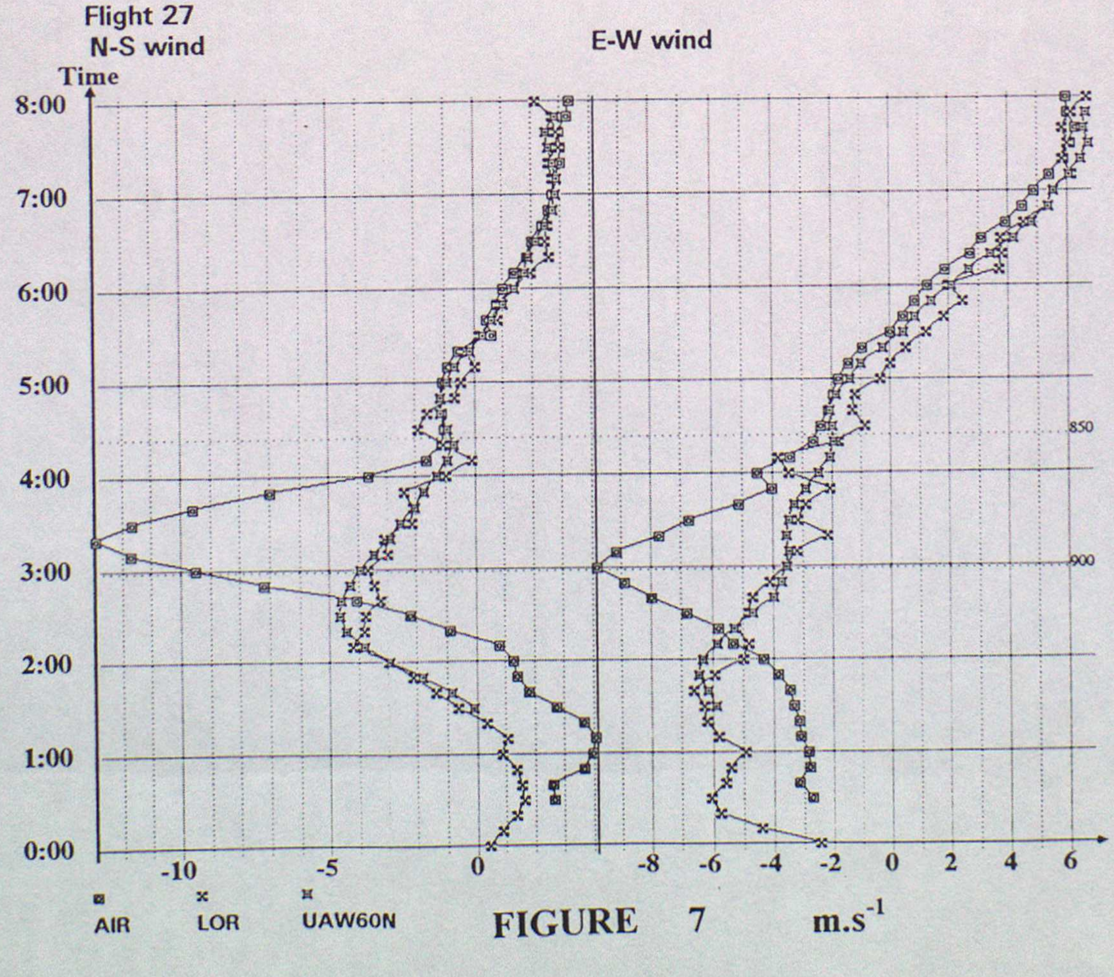


FIGURE 7

5.2.4 Examples of Erroneous AIR Winds at Low Elevations - MULTIPATH INTERFERENCE.

Figures 8(a) and 8(b) show large errors in AIR wind measurements when the elevation angle subtended by the radiosonde decreased below about 20 degrees. Comparison of the 2 figures between minutes 10 and 30 shows that the errors are greater in the N-S component (aligned with the direction of strongest winds and hence along the balloon bearing) than in the E-W component . The errors were caused by multipath interference between radiosonde signals received directly in the main beam and radiosonde signals received via the antenna sidelobes from ground reflections or reflections from nearby buildings or other suitable surfaces. With this type of interference, the maximum signal strength is often detected by the radiotheodolite at an elevation differing significantly from the true elevation of the radiosonde. The actual magnitude and stability of the wind error obtained in any given test flight will depend on the precise location of the radiotheodolite (e.g. height above ground, distance from neighbouring buildings, etc.), azimuth and elevation of the radiosonde, and the rate at which elevation changes once low elevations occur during the flight.

Figure 9 shows another example (Flight 63) of multipathing errors. On this occasion the elevation decreased to about 15 degrees by minute 4 and remained below 15 degrees until burst. Radiotheodolite windfinding errors of up to 15 $m.s^{-1}$ in each wind component occurred in this case.

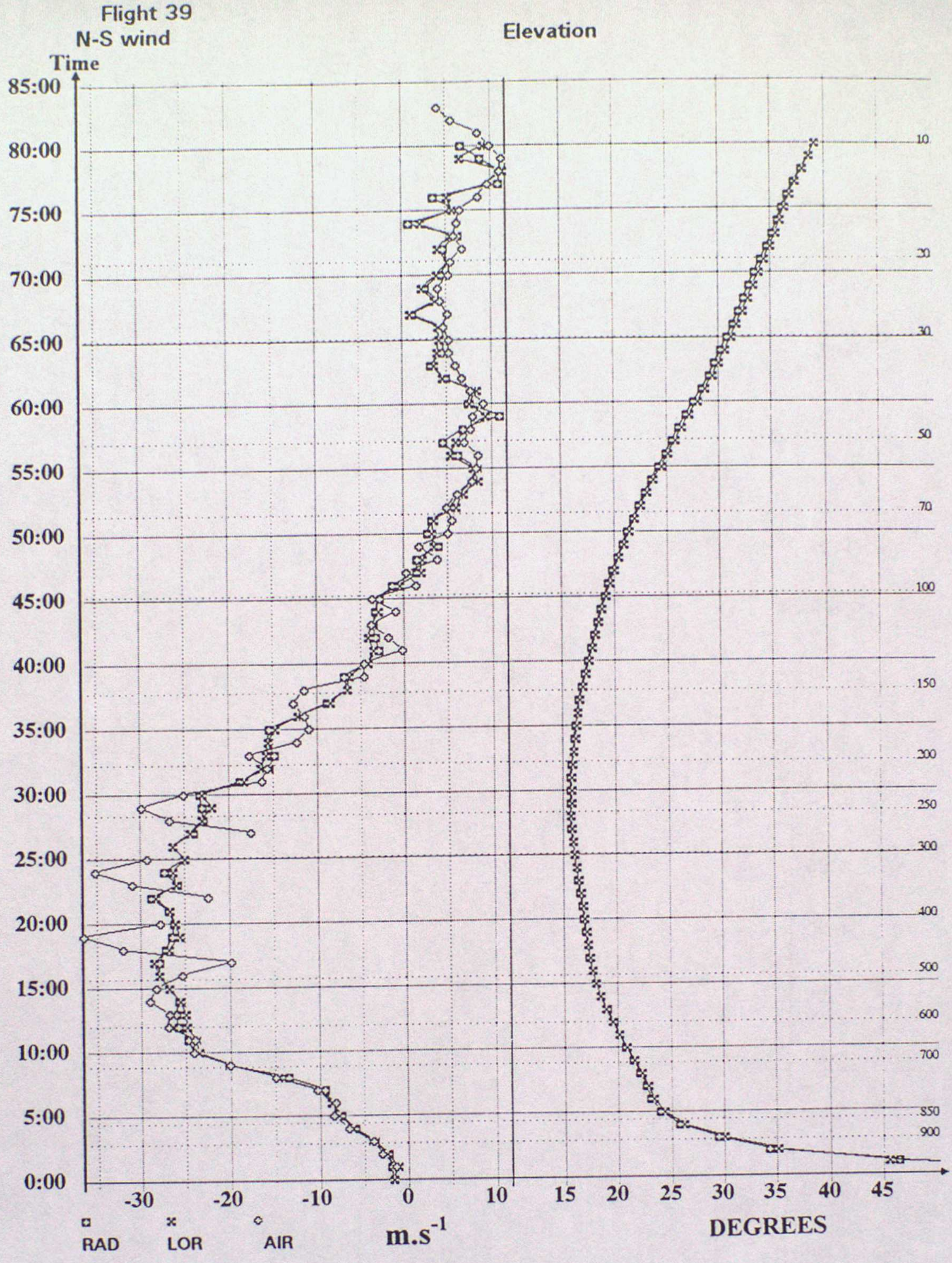
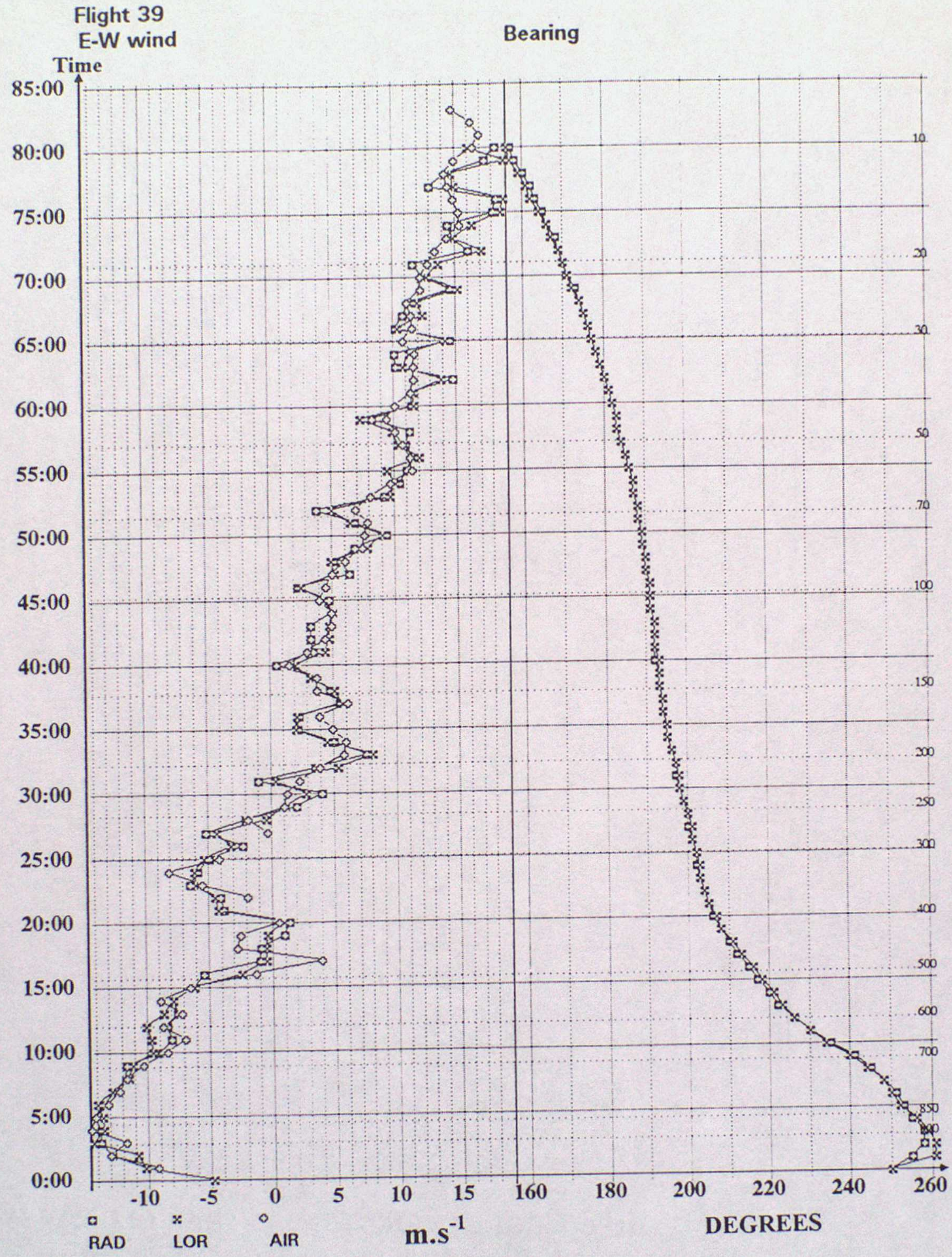


FIGURE 8 (a)

MULTIPATHING - MORE EVIDENT IN N-S THAN IN E-W WIND COMP



Flight 39
E-W wind
Time
Bearing
85:00
80:00
75:00
70:00
65:00
60:00
55:00
50:00
45:00
40:00
35:00
30:00
25:00
20:00
15:00
10:00
5:00
0:00
-10
-5
0
5
10
15
160
180
200
220
240
260
RAD
LOR
AIR
m.s-1
DEGREES

FIGURE 8 (b)

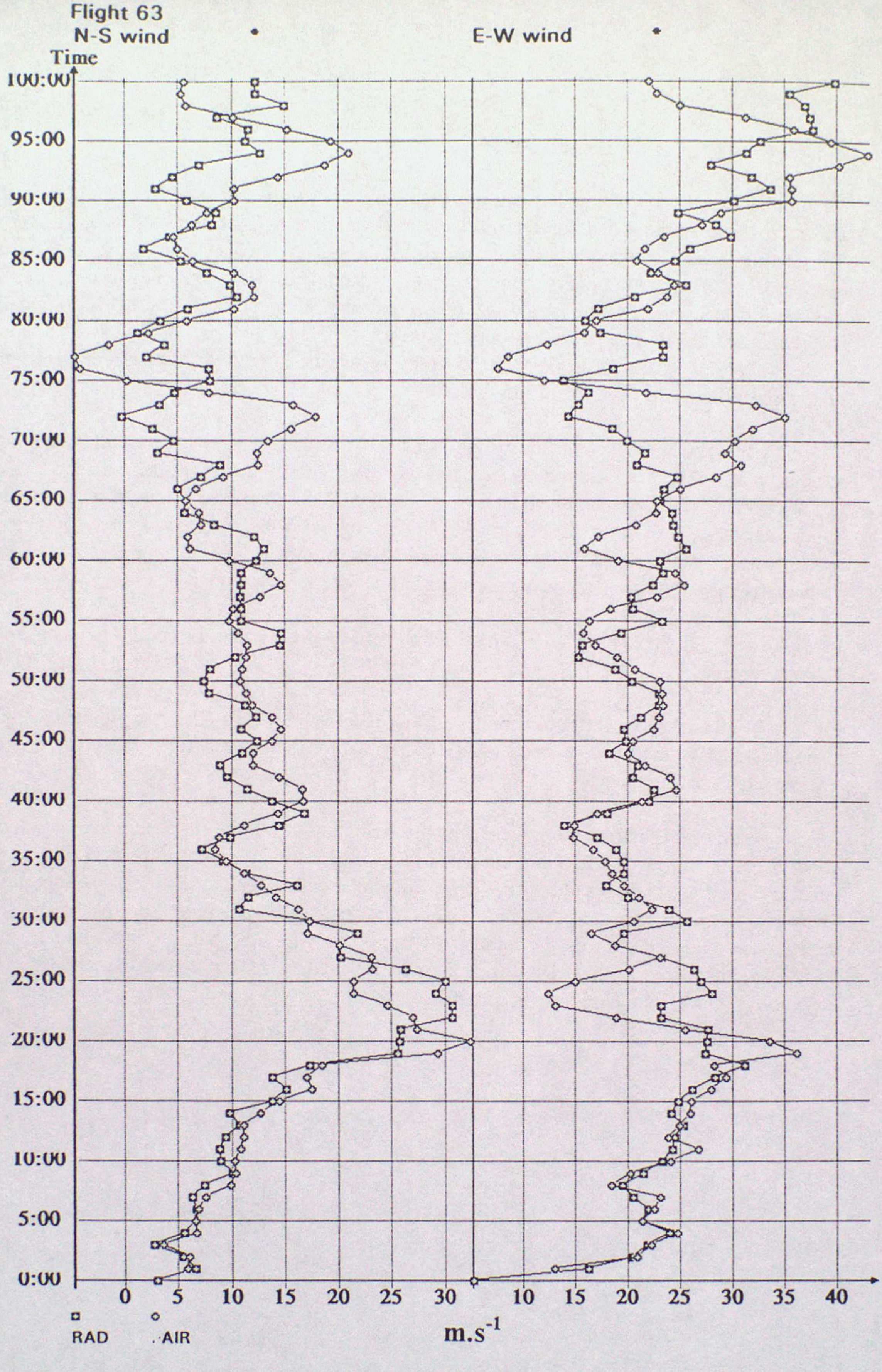


FIGURE 9

MULTIPATH INTERFERENCE ERRORS OCCURRING FOR MOST OF THE ASCENT. (Elevation decreased to 15 degrees by minute 4 . Maximum flat range was 170 km.)

5.3 Low Level Windfinding.

Accurate determination of wind structure in the boundary layer is important for forecasting at some UK radiosonde stations and for Defence applications such as ballistics and acoustic forecasts. Cossor radar winds are not usually measured until about 90 seconds into flight. One minute on average is required for the radar to locate the target and a further 30 seconds to obtain sufficient positional data prior to the midpoint of a 60 second line fit to determine the balloon's movement. However, additional data from an optical tracker (operated by staff following the launch at Crawley) were used by the UAWNDS program to provide low level winds closer to the surface than with the standard PC-CORA software.

Figures 10 to 12 show examples of comparisons between wind component measurements made on ascents when the AIR radiotheodolite tracked the radiosonde from the surface. The AIR radiotheodolite winds are compared at 10 second intervals for the first 8 minutes of ascent with the winds computed by the Met Office UAWNDS program using both radar and supplementary optical tracker data. The 10 minute mean surface wind from a 10m anemometer mast measured immediately after launch is marked as X at zero time for each component.

In Figure 10 (Flight 19) the AIR radiotheodolite wind profile was in good agreement with the UAW60 profile.

Figures 11 and 12 show further examples of low level wind measurements computed by the AIR radiotheodolite which were in good agreement with those computed from the combined optical tracker/radar measurements.

These 3 examples illustrate the potential of the AIR radiotheodolite to obtain accurate low level winds from the surface. For optimum performance at lowest levels the radiotheodolite should be sited in a position which would normally be upwind from the balloon launch position and as far away from obstructions as possible. This decreases the potential for MULTIPATHING interference and also reduces the number of occasions when the balloon flies directly over the radiotheodolite early in the flight when it may be unable to respond to the rapidly changing elevation angles. (See later notes from British Antarctic Survey operational reports, section 7.2.2).

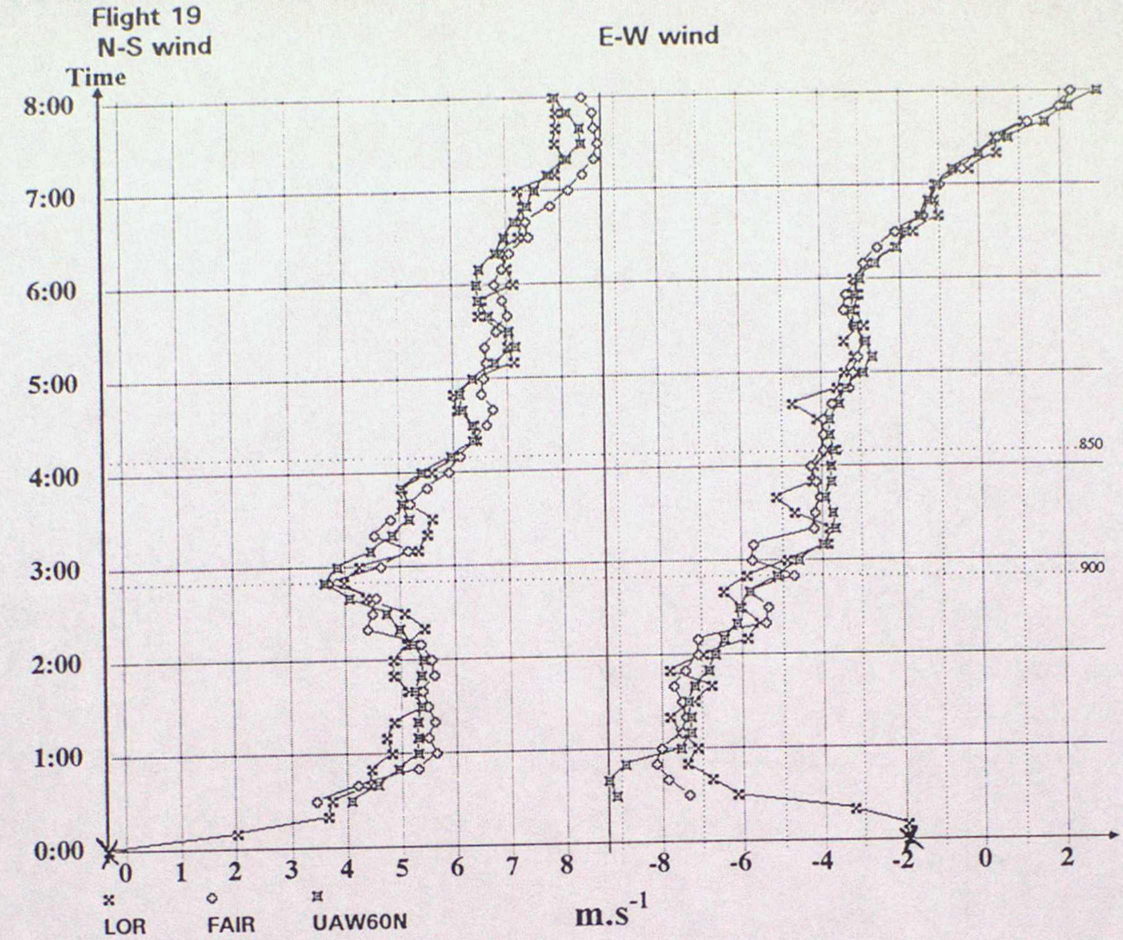


FIGURE 10

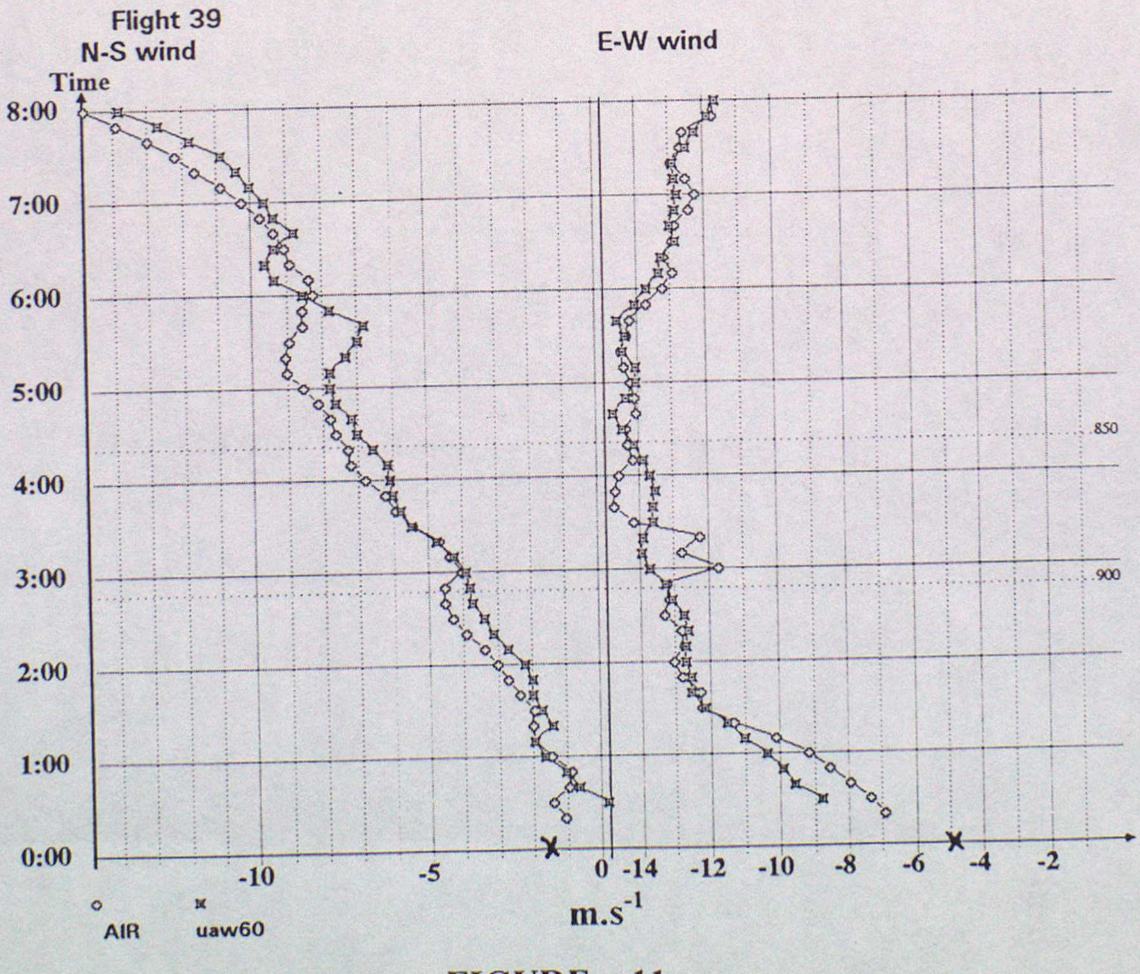


FIGURE 11

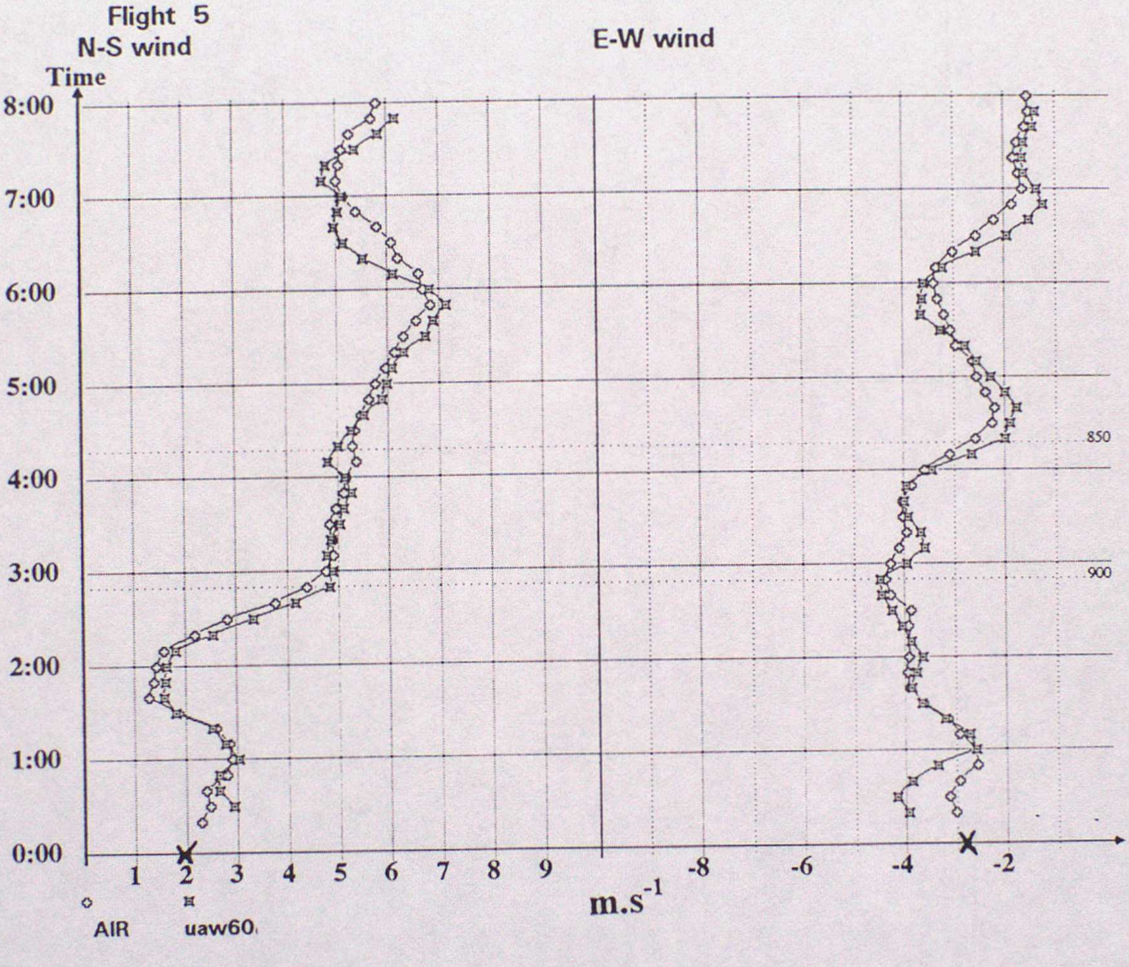


FIGURE 12

AIR THEODOLITE LOW LEVEL WINDS COMPARED WITH RADAR/OPTICAL TRACKER WINDS (UAW60)

6. WIND COMPARISON STATISTICS

6.1 AIR Radiotheodolite and Loran Windfinding System Bias

Figures 13(a) and 13(b) show the "Flight by Flight" differences between the winds for the westerly and northerly components respectively. These differences have been calculated by averaging all available minute (AIR -radar) differences banded within pressure bands corresponding to approximately 2 km height intervals.

For pressures higher than 30 hPa, the mean AIR-radar wind E-W wind component differences were generally less than +-0.2 $m.s^{-1}$ with negligible overall bias . At pressures lower than 30 hPa the systematic errors increased to about 0.5$m.s^{-1}$ The AIR N-S wind component differences within most zones showed a slight positive bias in the stratosphere (averaging about 0.2 $m.s^{-1}$). Figure 13(c) shows the Flight by Flight wind direction differences (computed for all winds greater than 10 $m.s^{-1}$) and reveals an average 2 degree bias between the wind direction measurements of the radiotheodolite and those of the radar. (This 2 degree bias was still present after having removed the flights affected by signal multipathing from the analysis.) The cause of this 2 degree bias is difficult to explain as regular pre-flight optical checks were made of the radiotheodolite alignment . It is possible that ,although the optical axis was correct, there was still a small error in the radiotheodolite tracking. A small reference modulator (test source) is now provided by AIR as part of the radiotheodolite system. This was not available during the Crawley trial, but has been used effectively by British Antarctic Survey at Halley Bay since 1991 to verify the radio axis of the radiotheodolite.
This 2 degree negative bias would be expected to have a greater effect on winds measured across the beam than on those parallel to it. During the latter part of the Crawley trial the axis of the radiotheodolite was usually aligned in a W-E direction which may explain the greater bias observed perpendicular to the antenna axis in the AIR N-S wind component differences at this time.

The mean Loran -Radar windfinding bias was also generally less than +-0.2 $m.s^{-1}$ in each component except in the E-W component at pressures below 30 hPa.

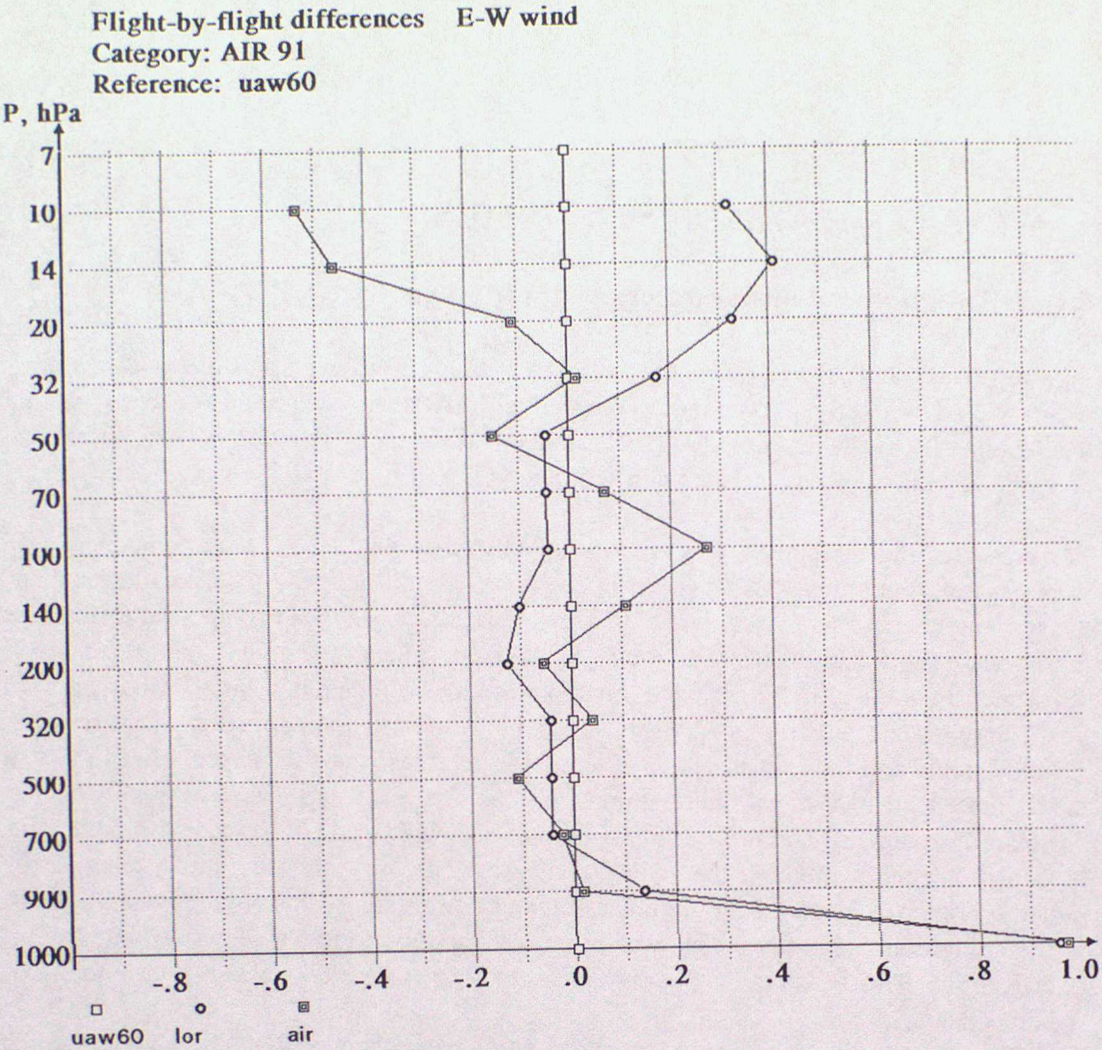


FIGURE 13 (a)

FLIGHT BY FLIGHT DIFFERENCES OF E-W WIND COMPONENT (m.s-1)

Flights: 1 3 4 5 7 9 10 12 14 15 17 19
20 22 25 27 29 30 32 34 35 37 39 40
42 44 45 47 51 55 59 63 67 68 69 70
71 72

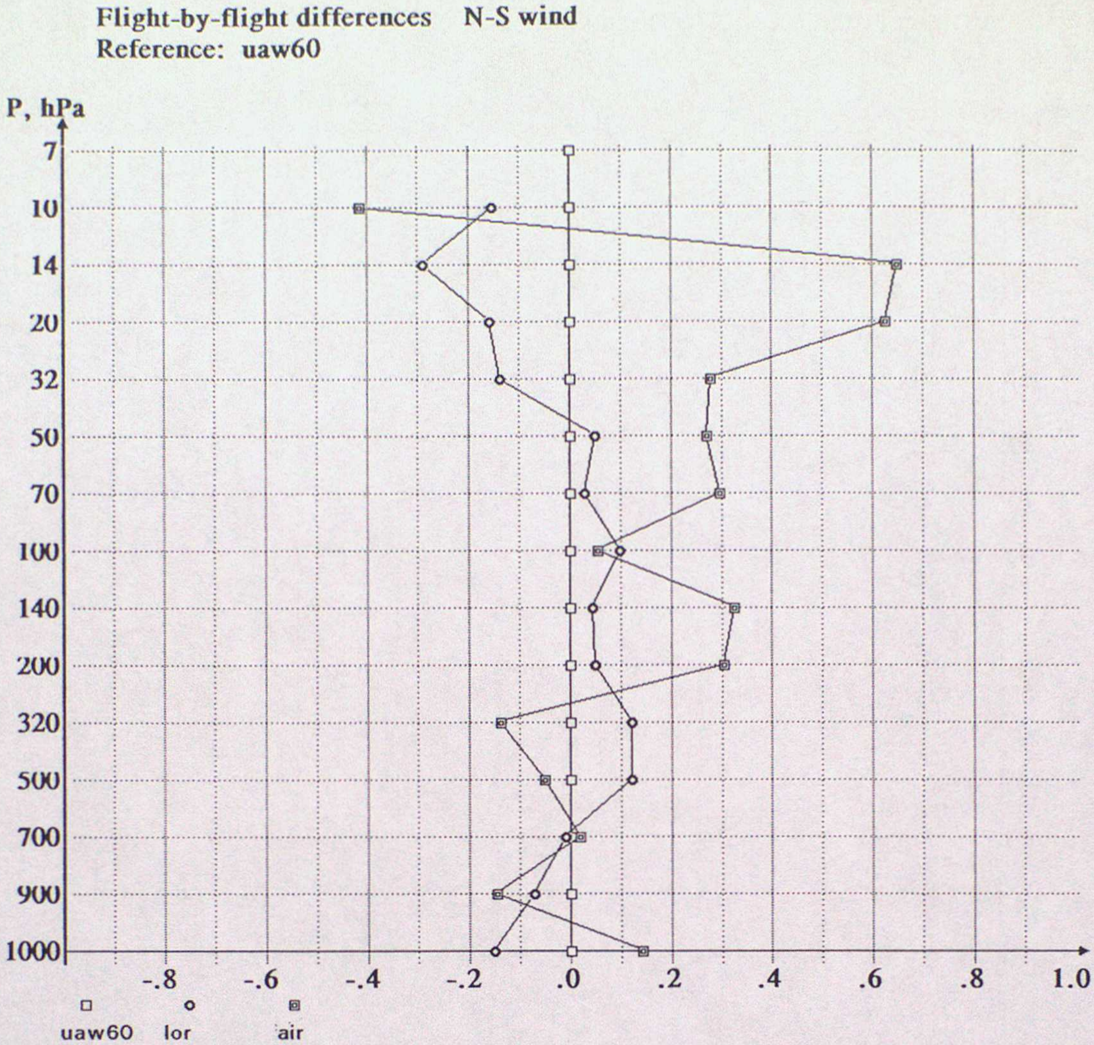


FIGURE 13 (b)

FLIGHT BY FLIGHT DIFFERENCES OF N-S WIND COMPONENT (m.s-1)

Flights: 1 3 4 5 7 9 10 12 14 15 17 19
20 22 24 25 27 29 30 32 34 35 37 39
40 42 44 45 47 51 55 59 63 67 68 69
70 71 72

Direct differences Direction

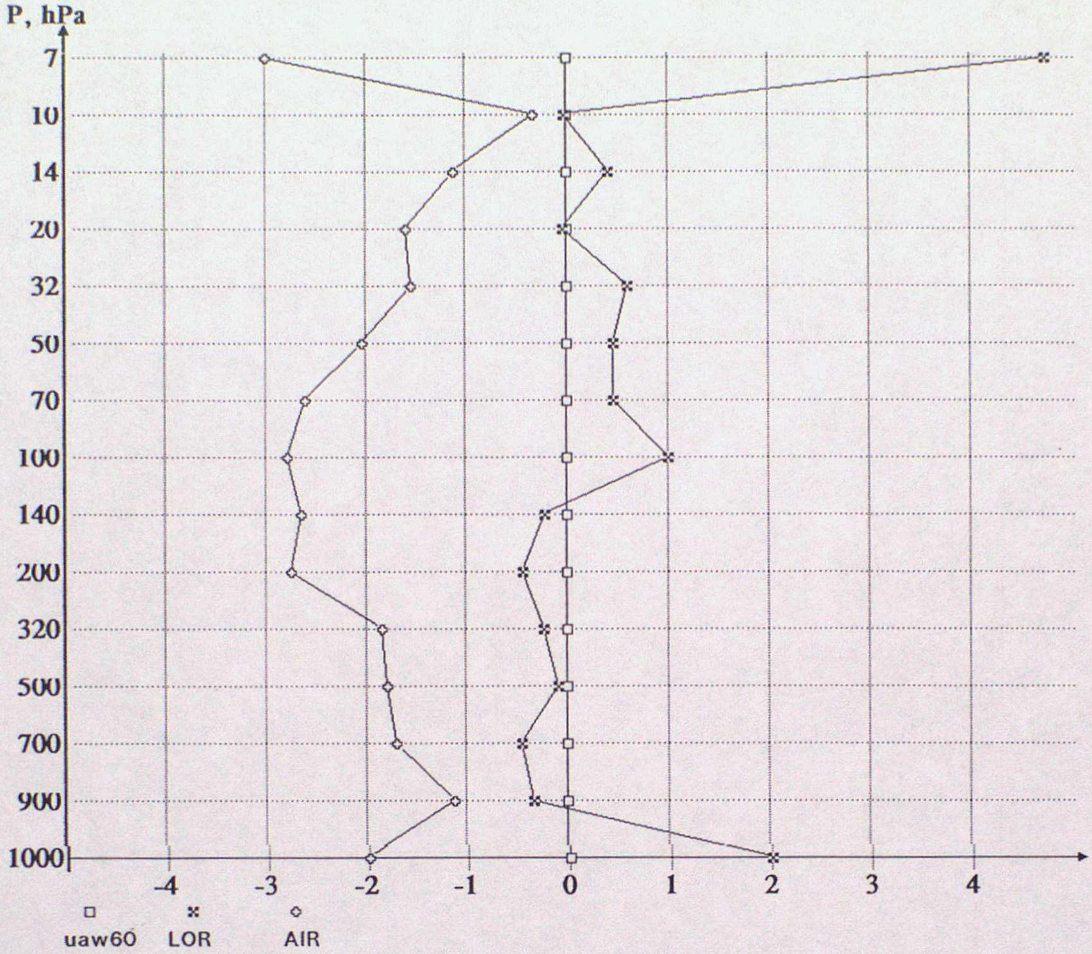


FIGURE 13 (c)

DIRECT DIFFERENCES OF WIND DIRECTION (FOR ALL WINDS > 10 m.s-1)

6.2 AIR Radiotheodolite and Loran Windfinding System Standard Deviations

Interpretation of the standard deviations between the various wind measurements must take into account that if there is no correlation between the errors of the two sets of winds being computed:-

$$(\text{s.d. of } \Delta u)^2 = Eu_1^{\ 2} + Eu_2^{\ 2}$$

where E_{u1} and E_{u2} are the rms errors of wind components measured by systems 1 and 2 respectively.

6.2.1 Radar Error Assessment.

Estimates of the errors in the radar tracking for each wind component are shown as dashed lines in Figures 14(a) and 14(b). These were derived from simultaneous comparisons of wind measurements made between Cossor and High Precision radars at Aberporth in the past 3 years. The source of these error estimates is discussed in section 4.1.

6.2.2 Standard Deviation of the AIR Radiotheodolite Wind Component Differences.

Figures 14(a) and 14(b) display the standard deviations of the wind component differences for the westerly and northerly components respectively . These analyses include all flights in the Trial. The standard deviations rapidly increase for pressure bands above 700 hPa to values of approximately 2 $m.s^{-1}$ in the stratosphere.

Figures 14(c) and 14(d) show similar analyses excluding 10 ascents which were affected by multipathing interference. These give a more realistic determination of the magnitude of the radiotheodolite windfinding errors to be expected in periods when elevation angles do not fall below about 20 degrees. These can be compared with the results from an Omega windfinding Trial at Gibraltar in 1993 (Elms, [10] shown as dotted lines on Figures 14 (c) and 14(d)) .

The standard deviations of the Loran winds compared with those from the radar were generally less than 1 $m.s^{-1}$ in each component. These results are consistent with Cossor radar/RS80-L wind comparison results obtained in various locations in the UK within the last 5 years, see Nash and Oakley [4].

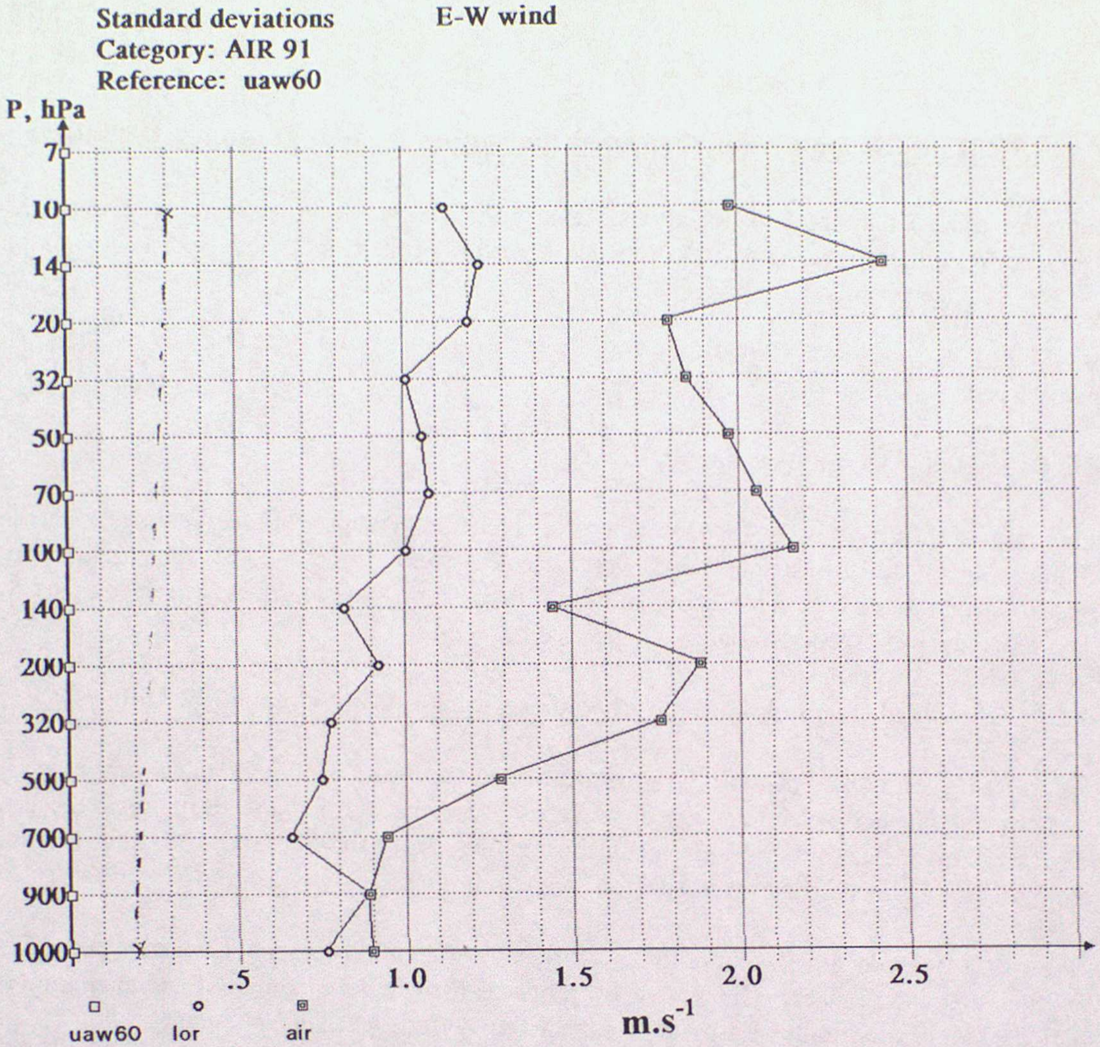
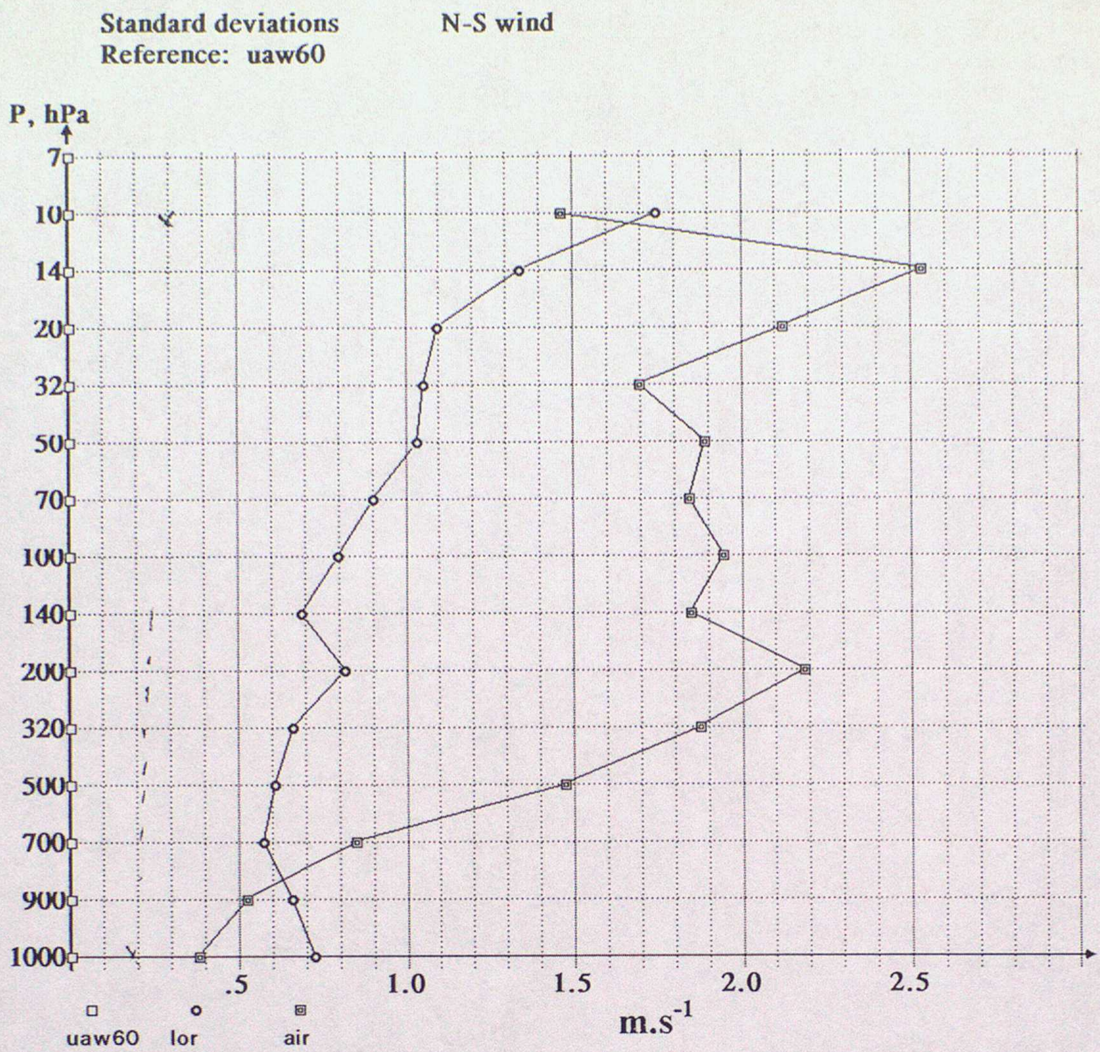


FIGURE 14 (a)

STANDARD DEVIATION OF E-W WIND COMPONENT (m.s-1)

Flights: 1 3 4 5 7 9 10 12 14 15 17 19
20 22 25 27 29 30 32 34 35 37 39 40
42 44 45 47 51 55 59 63 67 68 69 70
71 72

(ESTIMATED COSSOR RADAR ERROR X--------X)



.00	—	—
0	0	0
.00	1.75	1.47
15	15	7
.00	1.34	2.53
70	70	69
.00	1.10	2.12
145	134	145
.00	1.05	1.70
250	225	250
.00	1.03	1.89
187	164	187
.00	.90	1.84
201	177	200
.00	.80	1.94
227	202	227
.00	.69	1.85
222	198	222
.00	.82	2.18
271	246	267
.00	.66	1.87
362	331	354
.00	.61	1.47
259	245	259
.00	.57	.85
294	284	288
.00	.66	.52
128	124	82
.00	.72	.38
9	9	6

FIGURE 14 (b)

STANDARD DEVIATION OF N-S WIND COMPONENT DIFFERENCES m.s-1

(ESTIMATED COSSOR RADAR ERROR X - - - - - - - -X)

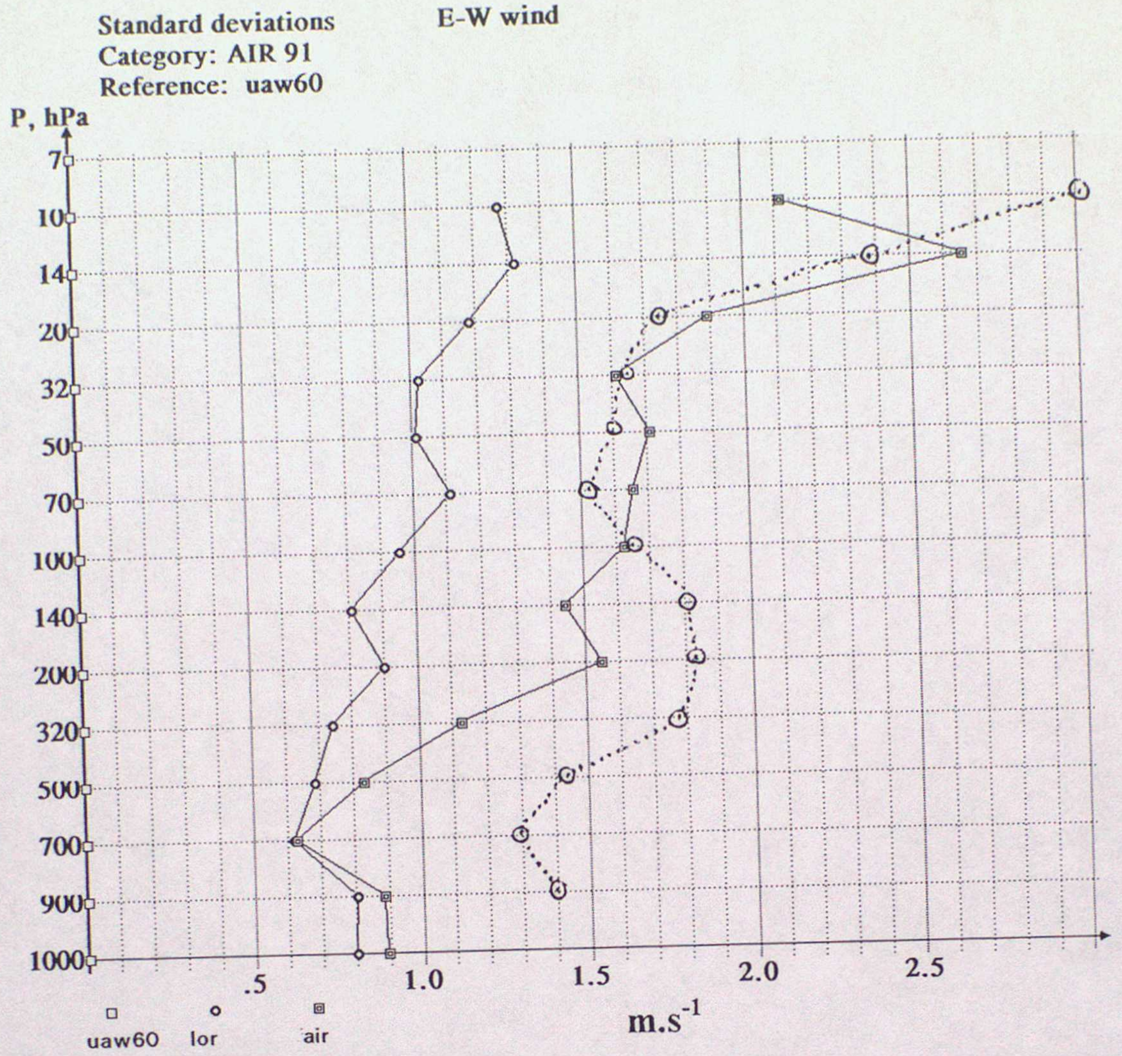


FIGURE 14 (c)

STANDARD DEVIATIONS OF E-W WIND COMPONENT DIFFERENCES (m.s-1)
EXCLUDING 10 FLIGHTS AFFECTED BY SIGNAL MULTIPATHING

Flights: 1 3 4 5 7 9 10 12 19 20 22 25
27 29 30 32 34 35 37 42 47 51 55 59
68 70 71 72

(GIBRALTAR OMEGA TEST ⚬······⚬)

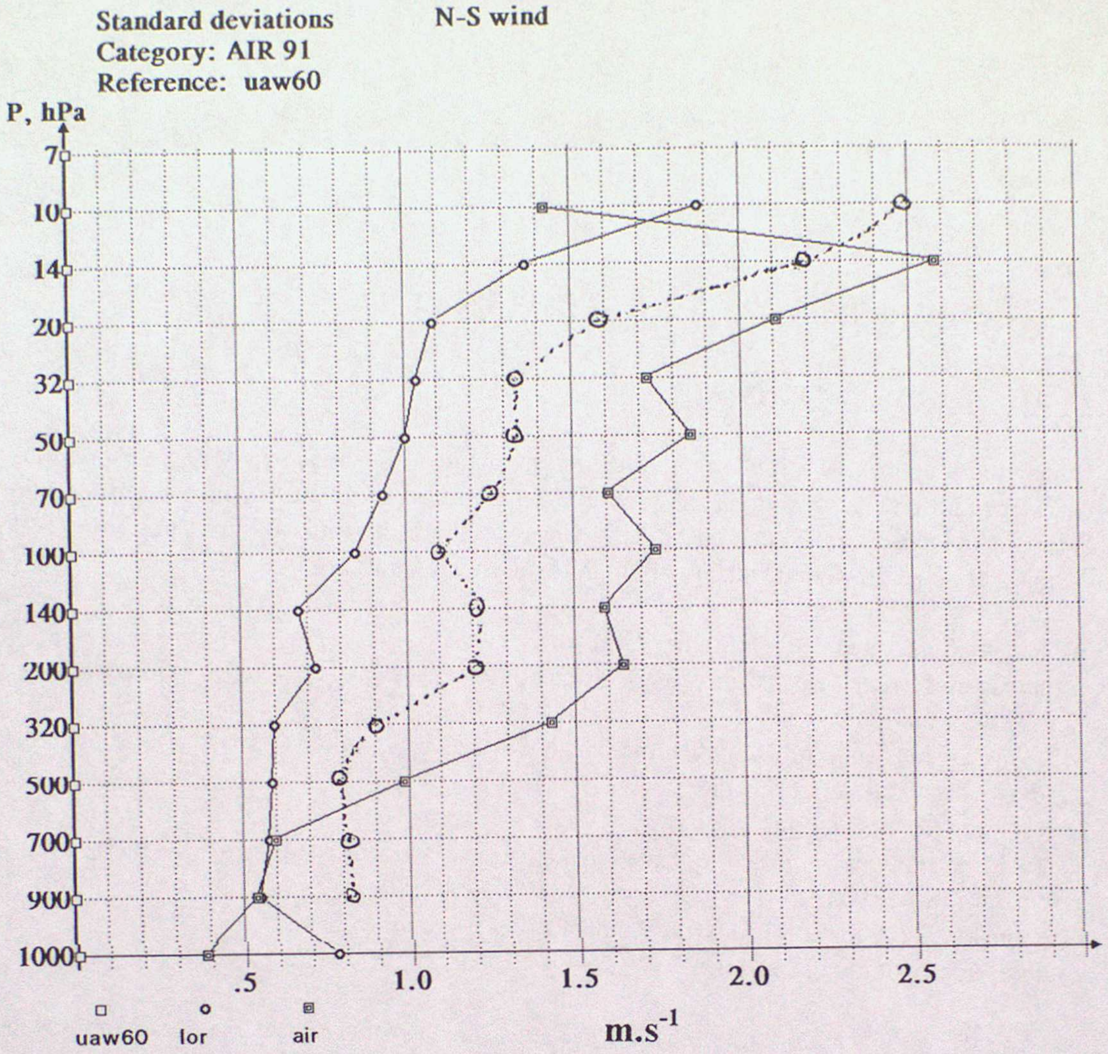


FIGURE 14 (d)

STANDARD DEVIATIONS OF N-S WIND COMPONENT DIFFERENCES (m.s-1) EXCLUDING FLIGHTS AFFFECTED BY SIGNAL MULTIPATHING

Flights: 1 3 4 5 7 9 10 12 19 20 22 25
27 29 30 32 34 35 37 42 47 51 55 59
68 70 71 72

(GIBRALTAR OMEGA TEST o·······o)

7. OPERATIONAL PERFORMANCE.

7.1 AIR "Intellisonde" Performance.

During the 1991 trial at Crawley and the 12 tests made at the same site during the previous year, the AIR radiosondes transmitted the pressure, temperature and humidity measurements with very few data outages from launch to burst. However, the radiosonde failure rates prior to launch during these 2 trials were unacceptably high for normal operations:-

3rd to 19th September 1990 Crawley Trial
6 radiosondes were rejected because of excessive pressure errors (> +-5 hPa from check barometer measurement).
1 thermistor was found broken when the packaging was removed.
2 radiosondes would not transmit.
28th January to 1st March 1991 Crawley Trial
10 radiosondes were rejected because of excessive pressure errors (> +-5hPa from check barometer measurement).
1 thermistor was found broken when the packaging was removed.
2 radiosondes would not transmit.

The overall preflight failure rate for the Crawley Trials was therefore 22 out of 73 radiosondes or 30%.

AIR Intellisondes have been flown from Halley Bay normally at 12 GMT each day since installation of the system at the end of 1991. The operational radiosonde failure rates have not been as high as at Crawley, but the majority of failures have also occurred on the ground. (Refer to BAS Reports, [9]) .It should also be noted that the number of radiosonde failures has decreased since the first full year of operations (1992) when the overall failure rate was about 10% . 26 of the radiosondes flown in 1992 were rejected prior to launch, either failing groundchecks (pressure > +-5 hPa from check barometer) or failing to transmit any signals. All ground failures were returned to AIR for replacement. A further 14 failed during flight.

The combined experience of the UK Met Office and British Antarctic Survey from 1990 to 1992 showed that too many radiosondes failed during preflight tests. Most of the preflight rejections were caused by excessive pressure errors. More recently , BAS have noted that the type of battery used to power the Intellisondes has affected their performance especially in terms of premature in flight signal failures. In the most recent (1996) report they have advocated using Lithium PP3 cells which give a much more reliable performance than the normally supplied alkaline PP3 cells. From the most up to date information received from B.A.S. for the first quarter of 1997, 90 flights were attempted and only 2 of these failed to reach 150 hPa.

7.2 AIR Radiotheodolite Operational Performance.

7.2.1 Dzhambul 1989

During Phase III of the WMO International Comparison Trial a fault in the 110v to 240v power converter for the AIR radiotheodolite rendered the system inoperable. A back up system of similar design was used for this trial. Statistical results from this trial are given in Annexe D.

7.2.2 Crawley 1990-1991

During the year that the AIR radiotheodolite was at Crawley, very few mechanical or electrical problems were encountered with the system. The only serious fault was that the power cables to the radiotheodolite could get wrapped round the pedestal on occasions of light winds. This problem continued to occur occasionally at Halley Bay. (see 7.2.2)
During the Crawley tests prior to each flight the radiotheodolite was inspected and ,if necessary, the cables were repositioned to preclude any damage.

7.2.3 Halley Bay 1992-1997.

The radiotheodolite is in a radome on the roof of one the buildings. It is positioned east of the launch area . Thus ,following launch the balloon often travels over the radiotheodolite too fast for the azimuth motor to track. This almost inevitably results in the radiotheodolite locking on to track on a side lobe and causing erroneous winds. Operators reduce the probability of this occurrence, when the winds are light enough, by walking northwards with the radiosonde before launching. The radome provides good protection from the elements, but was found to be insufficiently heated until 1995. (The manufacturer's specification states a minimum working temperature of -25°C) . The low temperatures encountered by the radiotheodolite in the early years may have contributed to some of the main equipment failures listed below:-

In 1993 the digital electronics and receiver boards needed replacing in the radiotheodolite antenna and a suspect contact was resoldered. The phasing array board was also replaced.
The small test source (known as the "reference modulator" mounted on top of a nearby mast to provide an azimuth and elevation check for the radiotheodolite before launch) failed to transmit . BAS scientists managed to repair this test source using a radiosonde transistor for the purpose.
It was noted that a spare reference modulator would have been useful.

During 1994 the radiotheodolite power supply failed due to a faulty azimuth drive motor. The engineers were able to utilise a power supply from another equipment. Having replaced the power supply, a short circuit across the terminals of the azimuth motor was diagnosed. The replacement azimuth drive motor was therefore fitted and backlash tension on the drive was adjusted to minimise noise in the drive motor. This replacement azimuth motor failed after 11 days requiring the motor casing to be opened on advice from AIR. One of the electronics boards was then replaced and this board was connected to the remaining serviceable motor.

In September 1995 B.A.S. reported that tracking an overhead radiosonde had caused a large change in elevation from 30 to 130 degrees resulting in strain on the cable which caused the drive motor socket to be broken and an open circuit in the main cable itself. The spare cable was installed whilst the original was repaired.
The BAS report for 1995 states that the system hardware ran without many major problems for most of the year, although some use was made of a number of spares.

The only radiotheodolite problem in 1996 was remedied by a small cabling repair resulting from damage during radiotheodolite movement. The radiotheodolite seemed to benefit from the higher temperatures now provided by thermostatically controlled heaters in the radome and required no attention for the whole year. A poor connection in the DC supply to the test source needed repair during the year.

The AIR. radiotheodolite system is supported in Antarctica with a "Hostile Environment Spares Kit", but this does not include spares for all contingencies. As recounted above, the operations were maintained at the Base often due to the inventiveness of the scientists in cannibalising other equipment.

7.3 Software

7.3.1 Crawley Trial Experience

The software version used during the trial did not enable preflight gain of the radiosonde signal. Operators had to use separate "testcard" software for preliminary tuning and directing the radiotheodolite prior to loading the main "V18B AIR" program for the preflight ground controls sequence.

Except in moderately strong surface wind conditions when a 1.2 hPa tolerance was used ,the pressure test limit used for automatic launch detection was set to 0.8 hPa and these limits were sufficient to detect launch time throughout the trial.

The facilities provided for editing the message are user friendly, but the Met Office would suggest a further intermediate scale to be provided within the graphics. Operators also found that care was needed to ensure that "SIGW" was invoked when editing the wind profile, otherwise PTU selections may be altered. This possibility needs to be inhibited by the software.

7.3.2 Halley Bay

Several revisions to the software have been made since the trial. B.A.S. experience of upgrades has shown that the software is not always fully tested before release by the manufacturer. A recent example occurred in January 1996 when attempts to upgrade the software from version 2.03 to version 2.05 were unsuccessful due to a number of apparent bugs, so the operators reverted to 2.03 with very few further problems.

8. SUMMARY

8.1 Wind Measurements During Medium and High Balloon Elevations

1. The AIR Radiotheodolite windfinding accuracy was similar to that of Omega windfinding when the signal to the radiotheodolite was not subject to multipathing. The accuracy is generally better than that of Omega windfinding at levels below 500 hPa.

2. Once launched ,the radiosondes usually transmitted reliably to burst. 2 per cent of the total wind data were lost during the Crawley trial, mainly due to the radiotheodolite tracking on sidelobes near the surface.

3. When the radiotheodolite followed the primary main radiosonde signal from launch , the low level winds obtained were usually more accurate in the first 300m than those from either Loran or radar data.

8.2 Wind Measurements During Low Balloon Elevations.

The results from the Crawley Trials, and from the BMETS Trial (Elms, 1994 [3]) and (especially) those in Phase IV of the WMO Comparison Trial in Japan (Yagi et al, 1993 [2]) show that whenever elevations become lower than about 18 degrees the radiotheodolite tracking is likely to be degraded by multipathing errors. The analyses given in Annexes D5 to D8 show the magnitude of the errors obtained when using the radiotheodolite was used to track at very low elevations (< 10º) during the WMO Phase IV Trial. Under different siting and range conditions the critical angle when multipathing commences may be slightly higher or lower than 18 degrees ,but the likelihood of encountering winds strong enough to require low elevation observations is fundamental to upper air observations especially from temperate latitudes. Nash [8] has shown for example that in January to March 1993 ,30% of winds measured at 11kms in the British Isles were made with the angle to the balloon less than 10 degrees. (see Table 1 below):-

TABLE 1

Percentage of Operational Wind Observations at 11km Produced at Low Elevations for the first 6 months of 1993

	EUROPE	UK	USA	JAPAN	INDIA
Jan-Mar $\theta < 10^\circ$	19	30	10	40	3
Apr-Jun $\theta < 10^\circ$	3	5	3	12	0
Jan-Mar $15^\circ > \theta > 10^\circ$	25	25	20	39	8
Apr-Jun $15^\circ > \theta > 10^\circ$	17	21	18	34	1

8.3 General .

The Met Office would consider the use of the AIR radiotheodolite system at an operational radiosonde station under the following conditions:-

1. The station using the system should be in a region where low elevations were uncommon . (e.g. in the Tropics).

2. Some evidence as to the improved reliability of the AIR "Intellisonde" since these early tests in 1991 would need to be offered by the manufacturer.

3. A complete set of system spares should be available at the sounding station and regular preventative maintenance should be carried out.

4. Although soundings may be made by one person, the Met Office would advise using at least 2 people at launch time so that one could validate the tracking soon after launch .

9. ACKNOWLEDGEMENTS.

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The display and analysis software was developed by Mr S Kurnosenko (Central Aerological Observatory, Dolgoprudny) for WMO Radiosonde Intercomparisons .

Special thanks also to Mr Jonathan Shanklin and the B.A.S. team for providing very useful information from their annual reports.

10. REFERENCES.

1. **Ivanov,A.,Kats,Kurnosenko,Nash,Zaitseva**, WMO International Radiosonde Intercomparison Phase III (Dzhambul, USSR, 1989) Final report. *WMO/TD-No. 451*. Instruments and Observing Methods Rep. No 40 ,1991.

2. **Yagi, S., A. Mita, N Inoue** - WMO International Radiosonde Comparison - Phase IV; Final Report (Tsukaba, Japan) , *WMO/TD No. 742*, Instruments and Observing Methods Report No. 59, 1993.

3. **Elms J.,Glennie and Nash** .BMETS Trial - Larkhill February 1994. (Met Office Report for DRA)

4. **Nash, J., and T. Oakley,** Experience in the use of Loran -C Windfinding in the UK , *Proc. 21st Annu. Technical Sympos., Wild Goose Association, Birmingham, England.*, P.O. Box 556, Bedford, MA 01730, USA, 81-88, 1992.

5. **Nash, J.**, Implementation of the Vaisala PC-CORA Upper Air Sounding System at Operational Radiosonde Stations and Test Ranges in the United Kingdom. (American Met. Society .7th Symposium on Meteorological Observations and Instrumentation . New Orleans Jan 1991)

6. **Kurnosenko, S., and T. Oakley.** Description and User Guide for the Radiosonde Comparison and Evaluation Software Package. (RSKOMP - Version 3/Version 4). WMO Instruments and Observing Methods Report No. 60 . *WMO/TD - No. 771*, 1996

7. **Edge, P., M Kitchen, J Harding, J Stancombe**, The reproducibility of RS3 radiosonde and Cossor Mk IV radar measurements, *O.S.M. No 35*, Meteorological Office, Bracknell, 1986.

8. **Nash, J.,** Upper wind observing systems used for meteorological operations. Annales Geophysicae 12, pp 691-710 ,1994

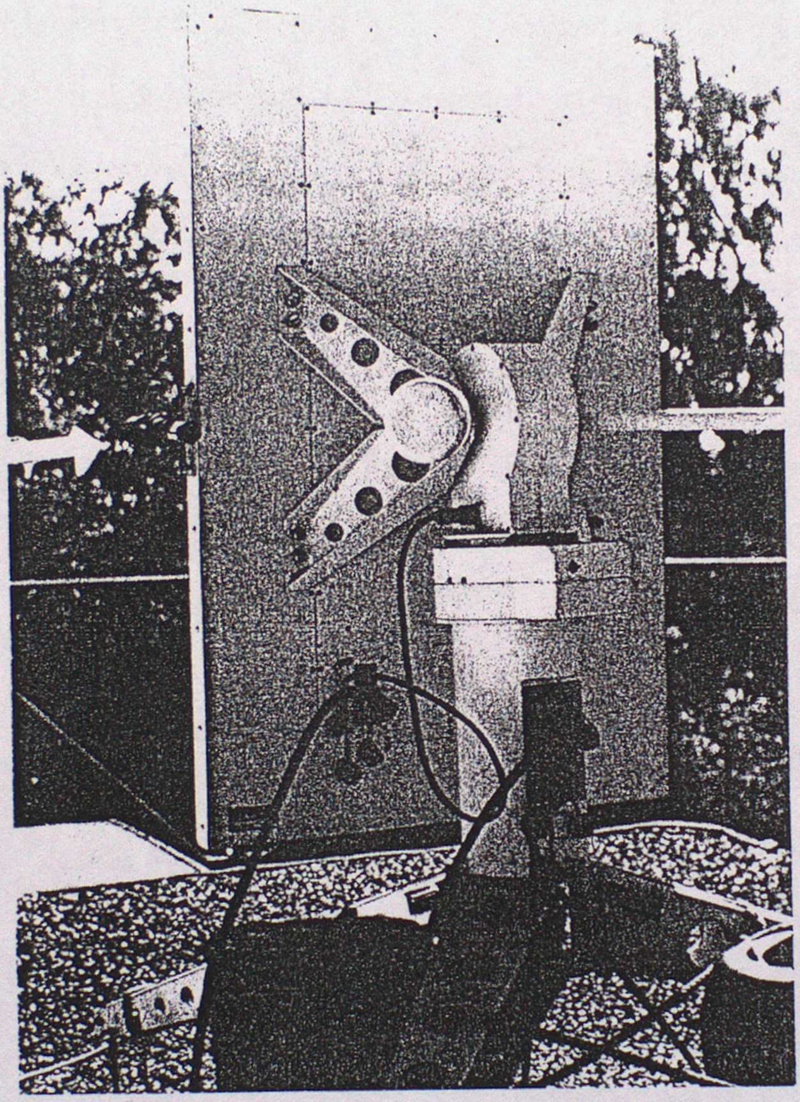
9. **Various authors** - Meteorological Reports Halley V 1992 to 1996 Bay (B.A.S. internal reports. British Antarctic Survey Archives, High Cross, Madingley Road, Cambridge CB3 0ET).

10. **Elms,J.,** Gibraltar Omega Windfinding Trial March/April 1993 (Met Office internal report, 1994)

ANNEXE A (i)

AIR RADIOTHEODOLITE ANTENNA (BACK)

SITING
TELESCOPE

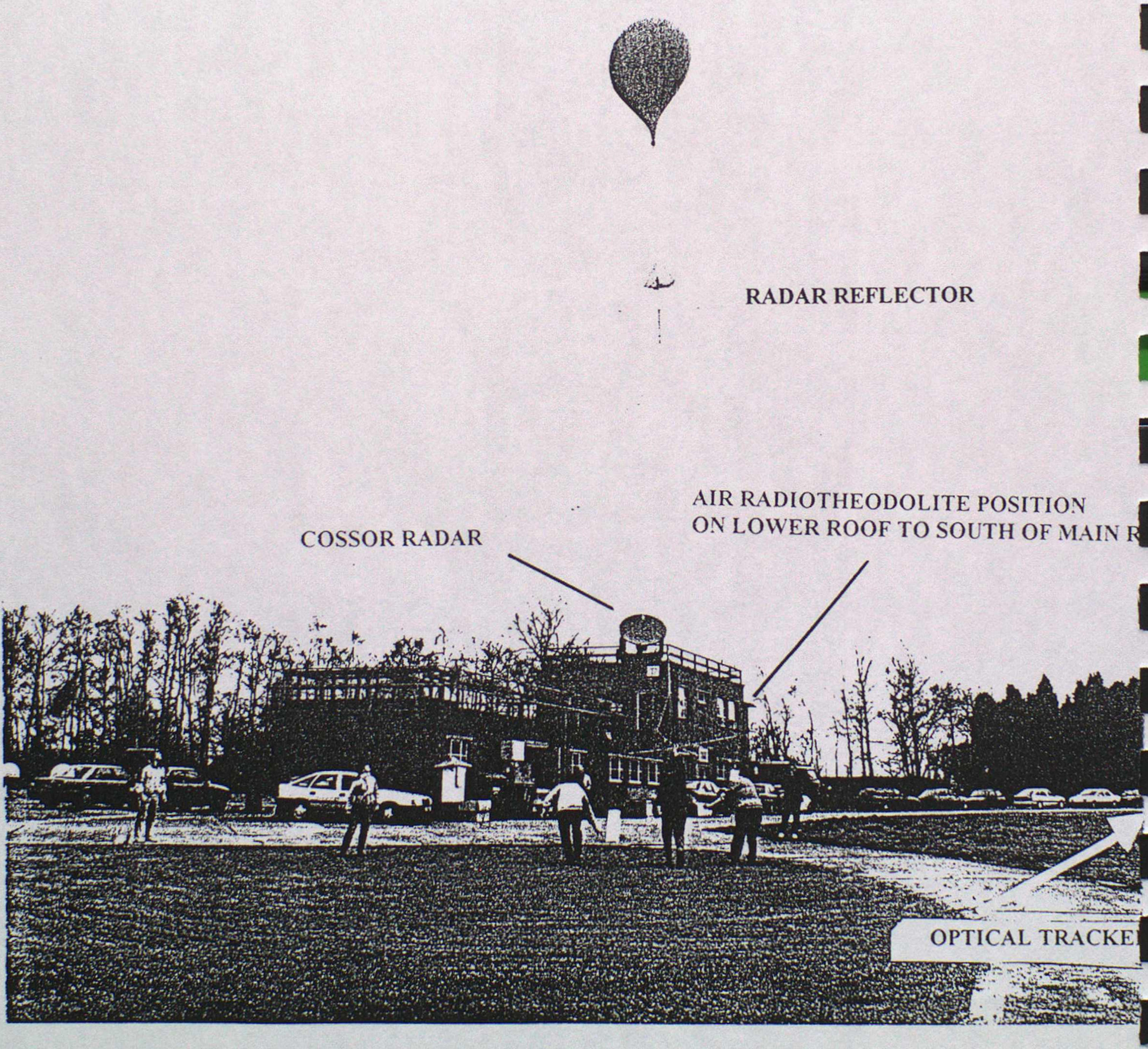


ANNEXE A (ii)

AIR RADIOTHEODOLITE ANTENNA (FRONT)

ANNEXE A (iii)

CRAWLEY RADIOSONDE STATION LAUNCH SITE



ANNEXE B

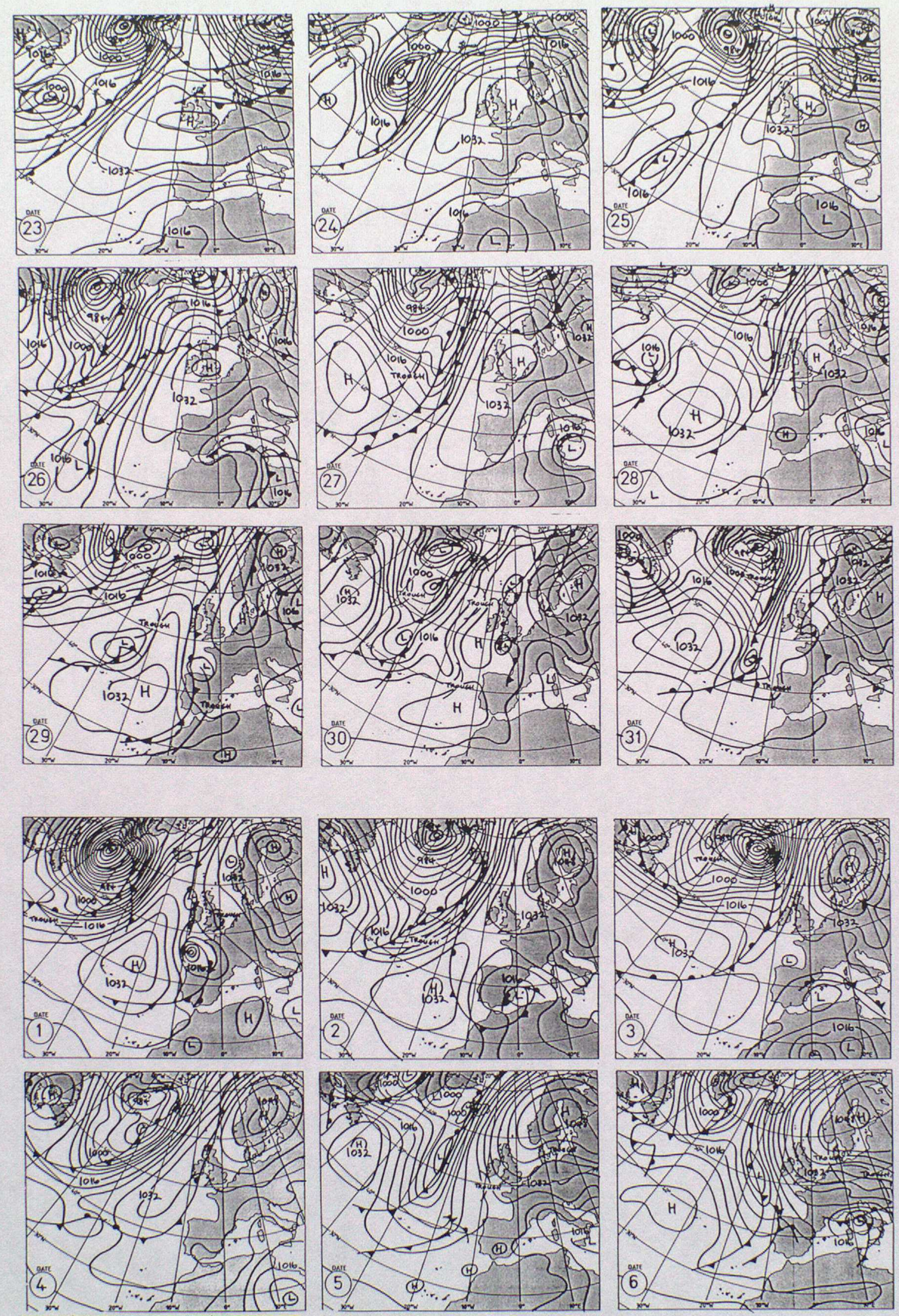
Prevailing Weather and Upper Air Conditions.

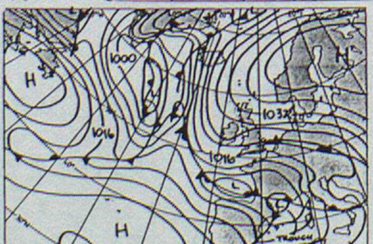
The Crawley 1991 AIR system trials took place in 2 periods:-
1. 28/2/91 12 GMT to 8/2/91 00 GMT. (Flights 4 to 47)
2. 19/2/91 00 GMT to 2/3/91 00 GMT (Flights 51 to 72)

During the first period the surface and lower tropospheric air flow was generally from an easterly direction. Cold, dry anticyclonic conditions gradually gave way to a depression moving northwards from France which produced moderate snowfalls during the last 3 days. 3 to 6 inches of lying snow resulted in the premature abandonment of the Trial during the daytime of the 8th. Upper stratospheric air temperatures were unusually cold (-82°C on Flight 1) for the first 2 A.I.R. ascents. Generally maximum wind speeds were less than 30m.s-1 .

The second period was generally influenced by a more mobile SW to W flow and correspondingly milder surface conditions. Maximum winds exceeded 30 m.s-1 more frequently.

The 12 GMT surface analyses for each of the 2 periods are shown on the next 2 pages:-

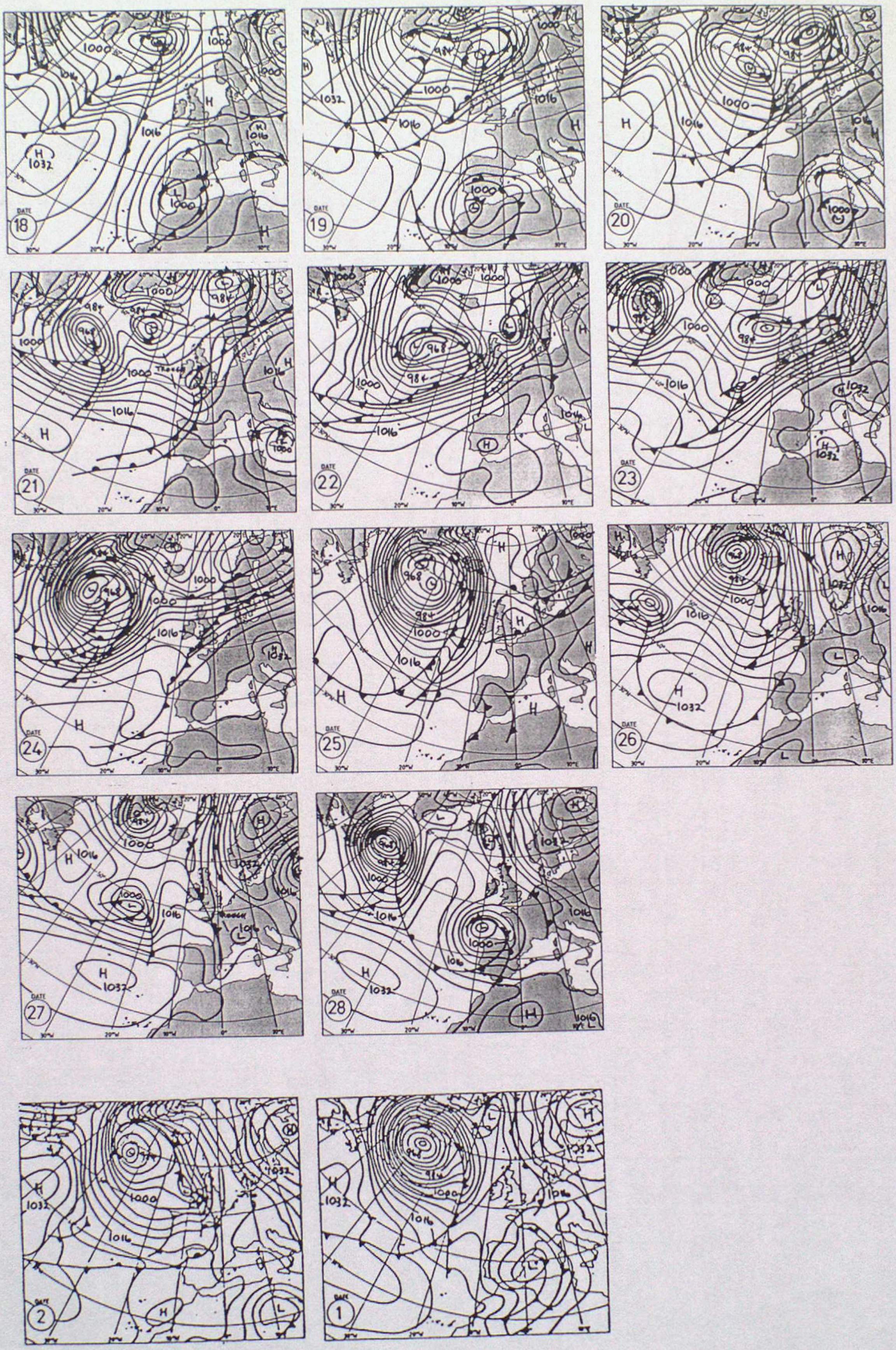




DAILY WEATHER MAPS
12 GMT

JAN / FEB 1991

Dates are ringed at
lower left-hand corner
of each map



DAILY WEATHER MAPS
12 GMT

FEB / MAR 1991

Dates are ringed at
lower left-hand corner
of each map

ANNEXE C. FLIGHT LOG OF AIR COMPARISON FLIGHTS CRAWLEY 1991

FL	LAUNCH	MINS	BST hPA	LOR miss min	RAD miss min	AIR miss min	AIR tcor secs	RA kms	MIN EL	WX	SURF WIND	FLAG MINS	REMARKS
1	23/1/ 1511	84	10	2	3	5	6	40	35	-	350/1	AIR 0-5,RAD 53,54. LOR 7,8	SIDELOBE
3	24/1 1131	85	9	0	0	0	0	30	23	-	100/2		
4	28/1/ 1142	89	9	0	0	0	0	33	37	02	100/4		
5	28/1/ 1508	89	9	0	0	0	3	38	38	02	130/3		
7	28/1 2319	95	11	11	0	0	0	35	30	02	140/3		
9	29/1 1121	78	10	0	0	3	0	23	25	--	130/4	AIR 0-2	SIDELOBE
10	29/1 1500	83	7	0	0	0	0	40	37	02	110/1		
12	29/1 2316	83	16	0	0	4	0	25	40	02	000/0		
14	30/1 1115	86	8	---	0	0	0	35	25	-	360/1		* LORAN TIME ERRORS BEARING 360
15	30/1 1500	92	7	0	0	13	0	38	20	-	030/3	AIR 0-9	SIDELOBE . BEARING 360
17	30/1 2326	83	11	0	0	6	0	34	18	02	040/2	AIR 0-4	SIDELOBE .BEARING 360
19	31/1 1117	82	10	0	0	0	0	33	18	71	080/2		BEARING 360
20	31/1 1503	93	6	-	2	2	0	31	18	-	130/3	RDR 0-2	POOR RADAR DATA 0-2 NO LORAN
22	1/2 0048	88	11	0	0	3	0	27	20	68	130/4		
24	1/2 1117	67	37	0	-	0	0	23	26	02	160/4		NO RADAR DATA AVAIL
25	1/2 1454	83	7	0	0	7	0	19	30	01	200/2	AIR 0-4	SIDELOBE
27	1/2 2316	91	12	0	0	6	0	12	45	10	100/2	AIR 0-4	SIDELOBE
29	4/2 1120	84	12	0	0	4	3	18	43	-	050/3	AIR 0-4	SIDELOBE
30	4/2 1514	99	5	0	0	4	0	24	42	--	040/3		
32	4/2 2333	94	10	0	16*	2	0	10	38	--	030/2	RAD 79-94	*EL>85BAD RADAR TRCK
34	5/2 1116	69	25	36*	0	0	0	18	31	03	060/5		*LOR SIG POOR < 200 hPa
35	5/2 1523	91	6	0	10*	3	0	19	28	70	030/3	RAD 82-91	*EL>85mins82-91POORTRK
37	5/2 2315	74	15	0	0	3	0	27	25	02	070/2		LORAN TIMING ERROR
39	6/2 1116	80	10	0	0	0	0	45	16	85	070/5		MULTIPATHING.
40	6/2 1508	88	7	0	0	4	0	52	13	85	030/7	AIR 0-4	SIDELOBE. MULTIPATH.
42	6/2 2317	79	18	0	0	0	0	30	19	85	050/4		
44	7/2 1122	82	9	0	0	4	3	21	18	02	040/4	AIR 0-4	SIDELOBE. MULTIPATH
45	7/2 1511	85	9	0	0	4	2	23	17	02	050/4	AIR 0-4	SIDELOBE. MULTIPATH
47	7/2 2332	77	12	0	0	0	0	21	23	70	050/1		
51	18/2 2316	74	13	0	0	1	0	58	21	-	050/2	RAD 13-14	EL >85 MIN 13-14
55	19/2 2318	119	9	0	0	2	4	50	23	-	230/2		
59	20/2 2318	86	10	0	0	4	0	95	18	20	180/4		
63	21/2 2317	109	7	-*	0	0	0	173	11	--	240/6		MULTPATH.*LORTIME ERR
67	22/2 2319	83	16	0	0	7	3	110	10	63	230/10	AIR 0-5	SIDELOBE. MULTPATH
68	25/2 2318	95	10	0	0	4	0	49	22	45	120/4	AIR 0-4	SIDELOBE
69	26/2 2318	82	19	0	0	0	0	58	17	45	160/1		MULTIPATH @ 200 hPa
70	27/2 2340	78	15	0	0	4	0	32	25	60	310/1	AIR 0-4	SIDELOBE
71	28/2 2324	95	8	0	6	9	0	20	58	-	000/0	*AIR 22-31	*VPOOR AIR SIGNAL 22-31
72	1/3 2323	112	7	0	53*	4	0	--	--	02	120/2		*RADARDATALOGPROBS

ANNEXE D

ADDITIONAL EXPERIENCE OF THE A.I.R RADIOTHEODOLITE SYSTEM.

During Phase III WMO Radiosonde Intercomparison Trial (Dzhambul ,USSR 1989) the AIR Radiotheodolite system was tested. The radiotheodolite was positioned too close to buildings in line of sight of the balloon when elevations went below 17 degrees. All such data was therefore flagged and not used in the statistics given in Figs (D1 to D4).

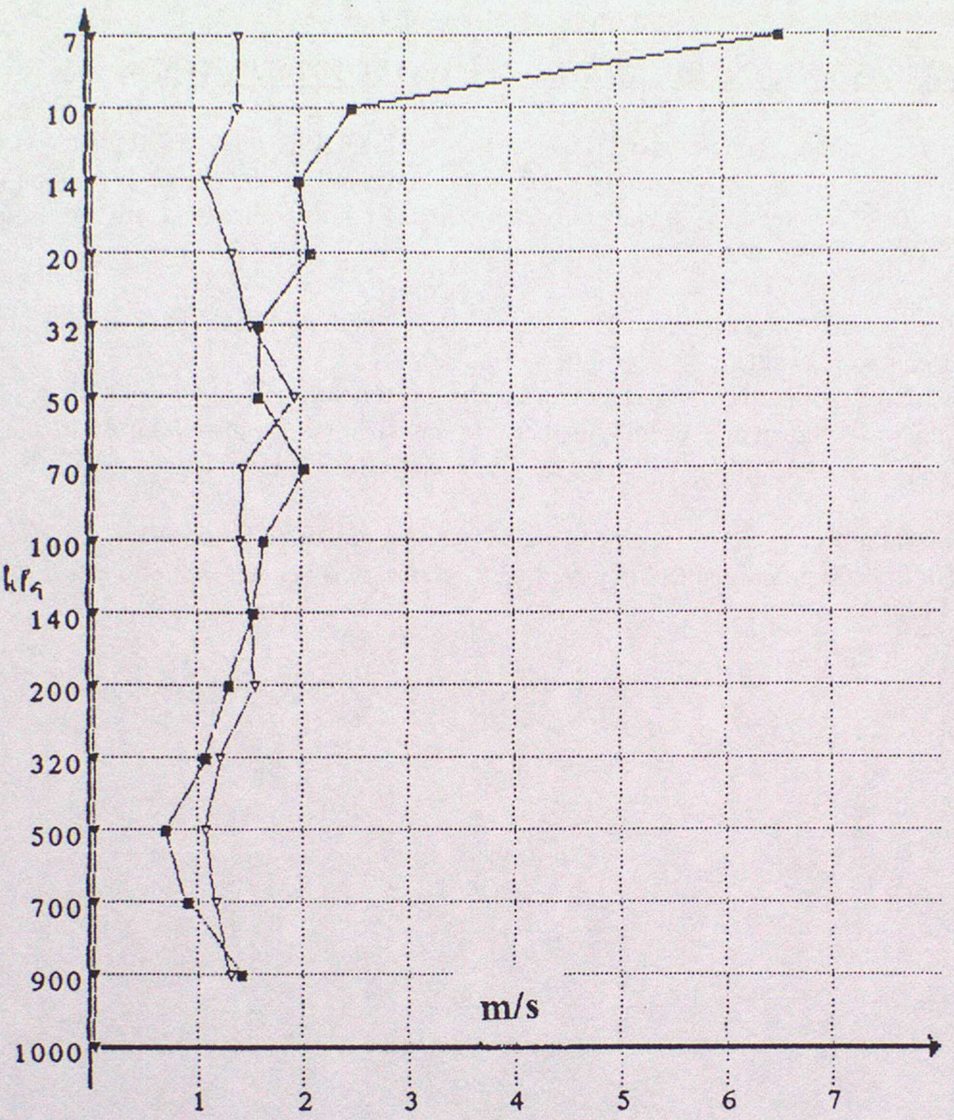
During Phase IV WMO Radiosonde Intercomparison Trial (Japan, 1994) both the AIR Radiotheodolite and the Meisei Radiotheodolite systems were evaluated.
These systems were roof mounted to minimise degradation of results due to multi-pathing or signal obstruction.
Upper wind strengths in winter over Japan are generally higher than anywhere else in the world. All ascents during this Trial were tracked at wind elevations falling below 10 degrees with the lowest elevations occurring between 100 and 70 hPa.
Figs (D5 to D8) show the results from this Trial where errors at 100 hPa measured for the AIR radiotheodolite as compared with Vaisala LORAN system gave standard deviation for the westerly component of 6 m/sec.

Standard deviations E-W wind [m.s-1]

Category: 00Z + 06Z + 12Z + 18umoist

+ 18udry + 06udry + 12udry + 00udry

Reference: MRZ



FIN	AIR
1.4	6.5
71	9
1.4	2.5
236	128
1.1	2.0
286	159
1.4	2.1
368	208
1.5	1.6
530	227
1.9	1.6
337	94
1.4	2.0
376	91
1.4	1.6
376	92
1.5	1.5
363	120
1.5	1.3
470	215
1.2	1.1
569	316
1.1	.7
390	254
1.2	.9
440	284
1.3	1.4
106	72
0	0

▼ - MRZ ▽ - FIN ■ - AIR

SECONDARY RADAR,RUSSIA **OMEGA VAISALA** **RADIOTHEODOLITE**

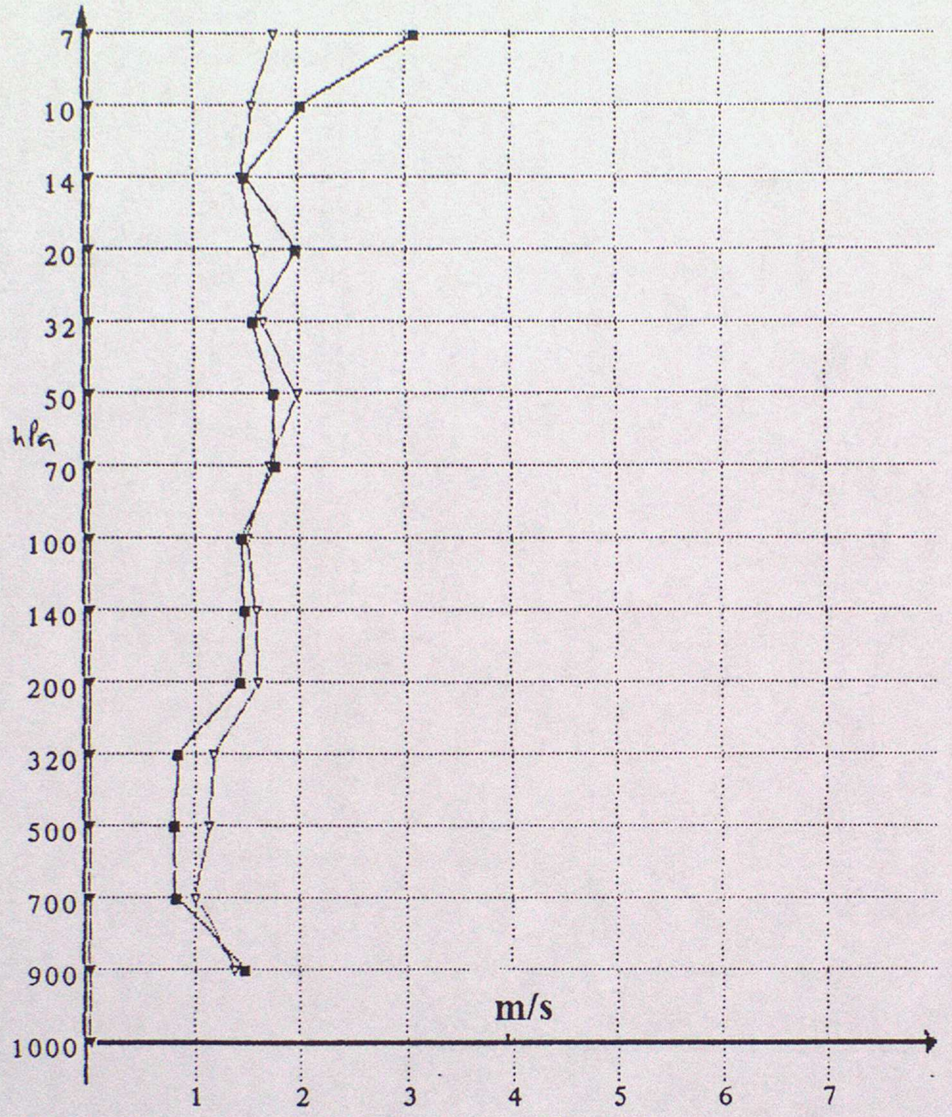
Flights processed:									
1	2	3	4	6	7	8	9	10	
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	27	28	29	30	
32	33	34	35	37	38	39	40		
41	42	43	44	45	46	47	48	50	
51	52	53	54	55	57	58	59	60	
61	62	63	64	65	66				

PHASE III WMO RADIOSONDE COMPARISON

ANNEXE D1

Standard deviations N-S wind
Category: 00Z + 06Z + 12Z + 18umoist
+ 18udry + 06udry + 12udry + 00udry
Reference: MRZ

ANNEXE D2



FIN	AIR
1.8	3.1
71	9
1.5	2.0
236	128
1.5	1.5
286	159
1.6	2.0
368	208
1.6	1.5
530	227
2.0	1.8
337	94
1.7	1.8
376	91
1.5	1.4
376	92
1.6	1.5
363	120
1.6	1.4
470	215
1.2	.8
569	316
1.1	.8
390	254
1.0	.8
440	284
1.4	1.5
106	72
---	---
0	0

▾ - MRZ ▿ - FIN ▪ - AIR

SECONDARY RADAR,RUSSIA **OMEGA VAISALA** **RADIOTHEODOLITE AIR**

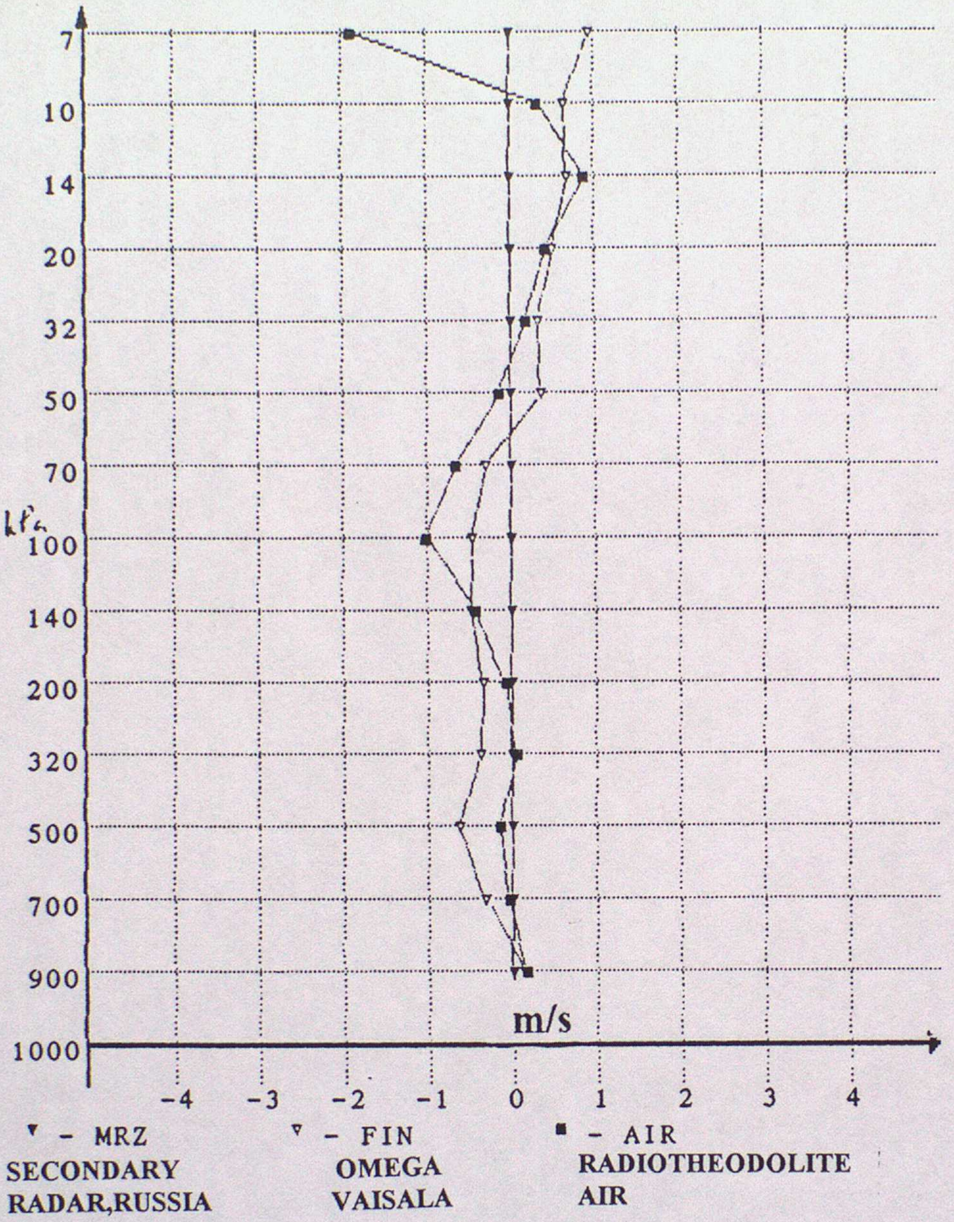
Flights processed: 1 2 3 4 6 7 8 9 10
11 12 13 14 15 16 17 18 19 20
21 22 23 24 25 27 28 29 30
32 33 34 35 37 38 39 40
41 42 43 44 45 46 47 48 50
51 52 53 54 55 57 58 59 60
61 62 63 64 65 66

PHASE III WMO RADIOSONDE COMPARISON

ALL AIR DATA AT ELEVATIONS > 17 °
LOCATION OF ANTENNA UNSUITABLE FOR LOW ELEVATION
WORK SINCE TOO CLOSE TO BUILDINGS IN LINE OF SIGHT TO BALLOON

ANNEXE D

Consistent differences E-W wind
Category: 00Z + 06Z + 12Z + 18umoist
+ 18udry + 06udry + 12udry + 00udry
Reference: MRZ



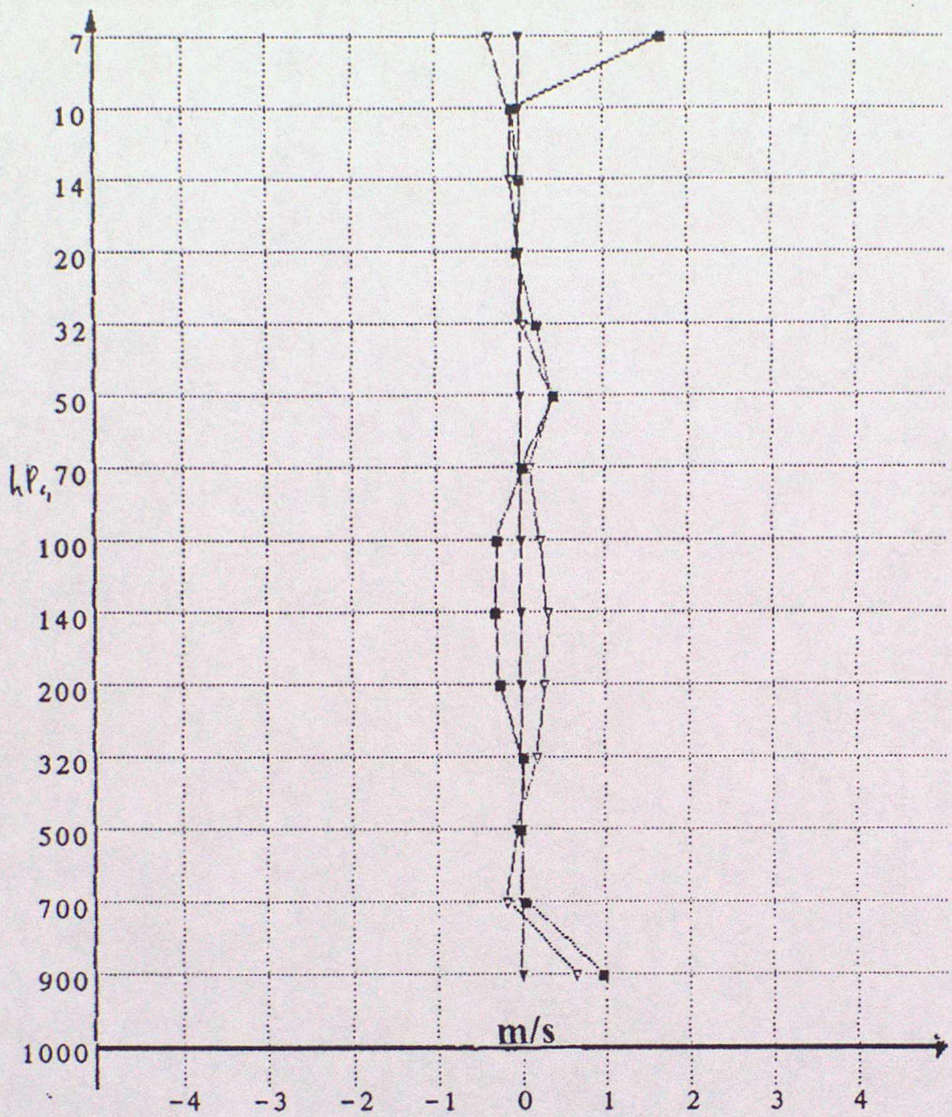
FIN	AIR
.9 78	-1.9 16
.6 245	.3 137
.7 295	.9 168
.5 378	.4 218
.3 540	.2 237
.3 358	-.2 115
-.3 382	-.7 97
-.5 379	-1.0 95
-.5 363	-.4 120
-.4 472	-.1 217
-.4 579	.0 326
-.6 393	-.1 257
-.3 459	.0 303
.1 117	.2 83
--- 0	--- 0

Flights processed:	1	2	3	4	6	7	8	9	10	
	11	12	13	14	15	16	17	18	19	20
	21	22	23	24	25	27	28	29	30	
	32	33	34	35	37	38	39	40		
	41	42	43	44	45	46	47	48	50	
	51	52	53	54	55	57	58	59	60	
	61	62	63	64	65	66				

PHASE III WMO RADIOSONDE COMPARISON

Consistent differences N-S wind [m.s⁻¹]
Category: 00Z + 06Z + 12Z + 18umoist
+ 18udry + 06udry + 12udry + 00udry
Reference: MRZ

ANNEXE D.



Level	FIN		AIR	
7	-.4	78	1.7	16
10	-.1	245	-.1	137
14	-.1	295	.0	168
20	.0	378	.0	218
32	.0	540	.2	237
50	.4	358	.4	115
70	.1	382	.0	97
100	.2	379	-.3	95
140	.3	363	-.3	120
200	.3	472	-.3	217
320	.2	579	.0	326
500	-.1	393	.0	257
700	-.2	459	.0	303
900	.6	117	1.0	83
1000	---	0	---	0

▾ - MRZ SECONDARY RADAR,RUSSIA
▿ - FIN OMEGA VAISALA
▪ - AIR RADIOTHEOD. AIR

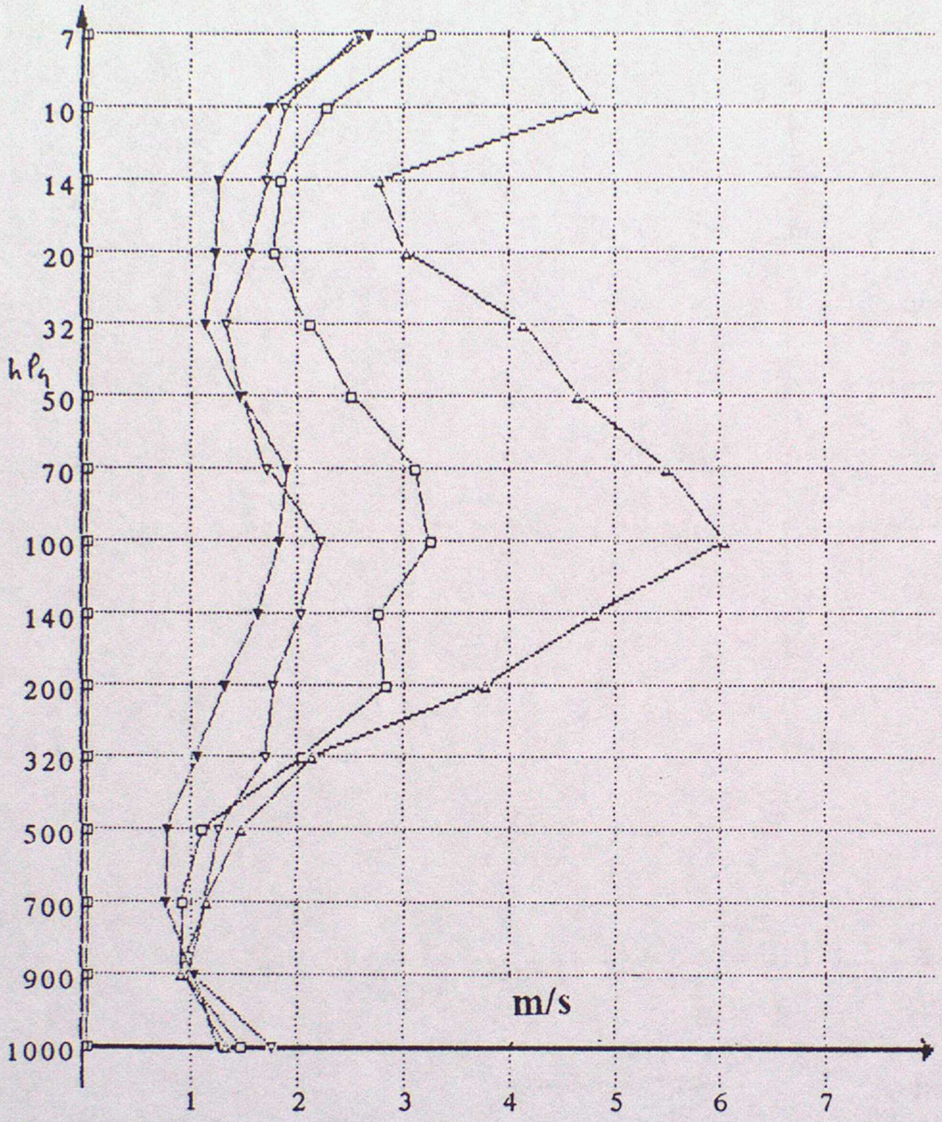
Flights processed: 1 2 3 4 6 7 8 9 10
11 12 13 14 15 16 17 18 19 20
21 22 23 24 25 27 28 29 30
32 33 34 35 37 38 39 40
41 42 43 44 45 46 47 48 50
51 52 53 54 55 57 58 59 60
61 62 63 64 65 66

PHASE III WMO RADIOSONDE COMPARISON

ALL AIR DATA AT ELEVATIONS > 17 °

Standard deviations E-W wind [m.s⁻¹]
Category: 08J + 11J + 14J + 20J
+ 20ICED + 20CIRRUS
Reference: FN2MIN

ANNEXE D5



FN1M	VZ3M	JP2M	AR1M
2.6	2.7	3.2	4.3
199	127	198	198
1.9	1.7	2.3	4.8
242	154	265	254
1.7	1.3	1.8	2.8
215	136	241	234
1.5	1.2	1.8	3.0
297	187	339	325
1.3	1.1	2.1	4.1
422	241	447	425
1.5	1.5	2.5	4.6
295	163	301	288
1.7	1.9	3.1	5.5
298	168	304	292
2.2	1.8	3.2	6.0
272	159	282	273
2.0	1.6	2.8	4.8
245	148	245	238
1.8	1.3	2.8	3.8
302	175	308	289
1.7	1.0	2.0	2.1
426	244	436	416
1.2	.8	1.1	1.5
352	190	360	346
1.1	.8	.9	1.1
434	237	442	418
1.0	1.0	.9	.9
215	116	219	209
1.7	1.3	1.5	1.3
38	22	39	38

▫ - FN2MIN ▿ - FN1MIN ▾ - VZ3MIN ▫ - JP2MIN ▵ - AR1MIN

LORAN VAISALA **OMEGA VAISALA** **LORAN VIZ** **RADIOTHEOD. MESEI** **RADIOTHEOD. AIR**

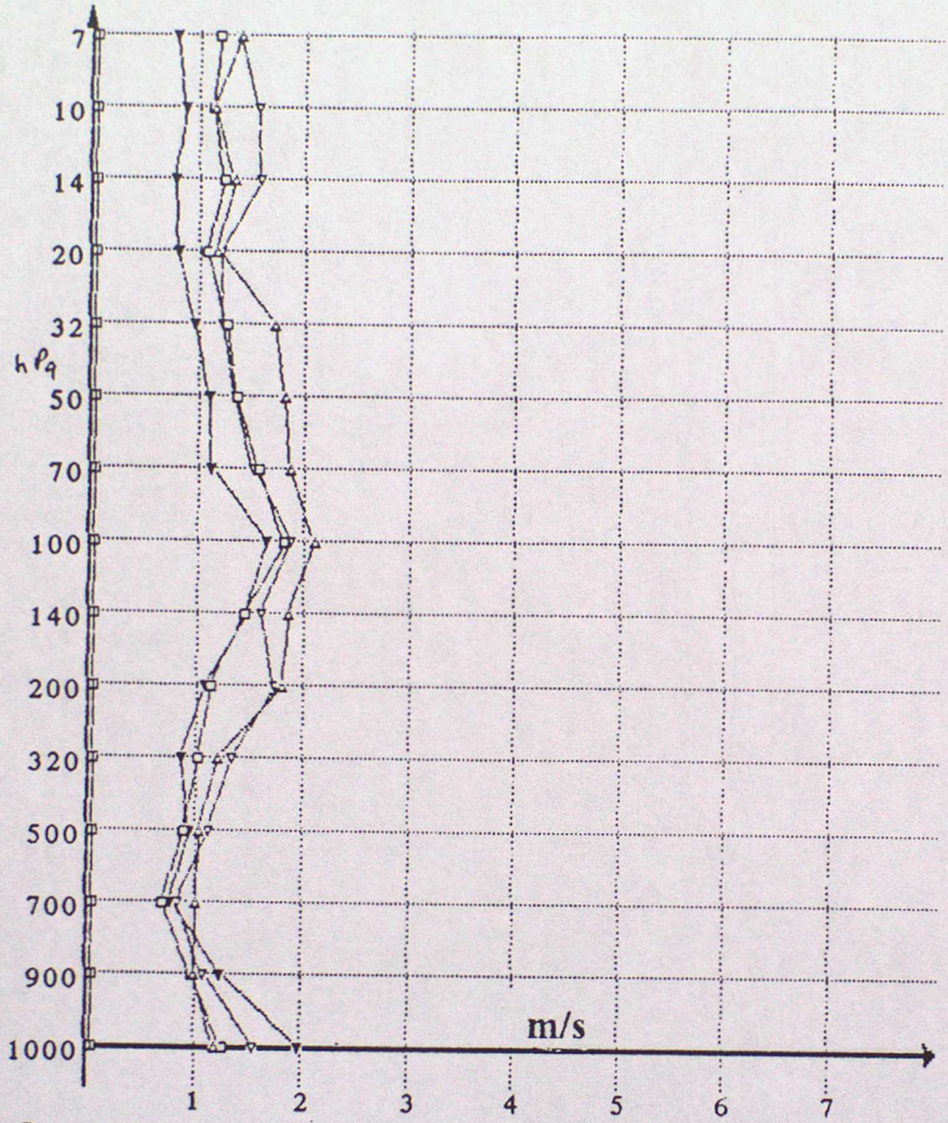
Flights processed: 1 2 3 4 5 6 7 8 9 10
11 12 13 14 15 16 18 19 20
21 22 23 24 25 26 27 28 29 30
31 32 33 34 35 36 37 38 39 40
41 42 43 44 45 46 47 48 49 50
51 52 53 54 55 56 57 58 59 60
61

PHASE IV WMO RADIOSONDE COMPARISON

ALL FLIGHTS TO LOW ELEVATIONS < or = 10 °
LOWEST ELEVATIONS BETWEEN 100 AND 70 hPA.

Standard deviations N-S wind [m.s⁻¹]
Category: 08J + 11J + 14J + 20J
+ 20ICED + 20CIRRUS
Reference: FN2MIN

ANNEXE D6



FN1M	VZ3M	JP2M	AR1M
1.4	.8	1.2	1.4
199	127	198	198
1.5	.9	1.1	1.1
242	154	265	254
1.6	.8	1.2	1.3
215	136	241	234
1.2	.8	1.1	1.2
297	187	339	325
1.2	.9	1.3	1.7
422	241	447	425
1.3	1.1	1.4	1.8
295	163	301	288
1.5	1.1	1.6	1.9
298	168	304	292
1.9	1.6	1.8	2.1
272	159	282	273
1.6	1.5	1.4	1.8
245	148	245	238
1.7	1.1	1.1	1.8
302	175	308	289
1.3	.8	1.0	1.2
426	244	436	416
1.1	.9	.9	1.0
352	190	360	346
.8	.7	.7	1.0
434	237	442	418
1.1	1.2	1.0	1.0
215	116	219	209
1.5	2.0	1.2	1.2
38	22	39	38

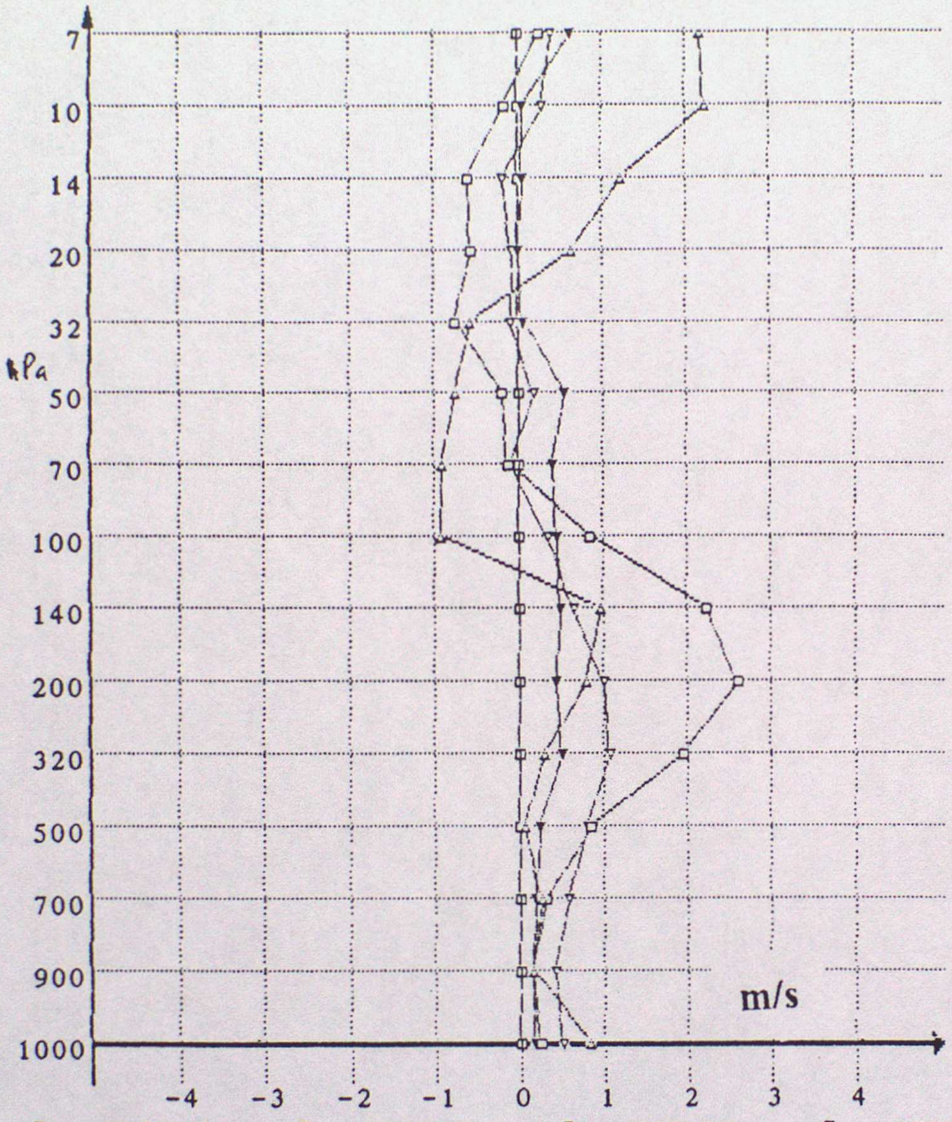
▫ - FN2MIN **LORAN VAISALA** ▿ - FN1MIN **OMEGA VAISALA** ▾ - VZ3MIN **LORAN VIZ** ▫ - JP2MIN **RADIOTHEOD. MESEI** ▵ - AR1MIN **RADIOTHEOD. AIR**

Consistent differences E-W wind
Category: 08J + 11J + 14J + 20J
+ 20ICED + 20CIRRUS
Reference: FN2MIN

Flights processed: 1 2 3 4 5 6 7 8 9 10
11 12 13 14 15 16 18 19 20
21 22 23 24 25 26 27 28 29 30
31 32 33 34 35 36 37 38 39 40
41 42 43 44 45 46 47 48 49 50
51 52 53 54 55 56 57 58 59 60
61

Consistent differences E-W wind [m.s⁻¹]
Category: 08J + 11J + 14J + 20J
+ 20ICED + 20CIRRUS
Reference: FN2MIN

ANNEXE D7



hPa	FN1M	VZ3M	JP2M	AR1M
7	.4	.6	.2	2.2
	256	135	254	253
10	.3	.1	-.2	2.2
	318	179	341	330
14	-.2	.0	-.6	1.2
	279	159	308	301
20	-.1	.0	-.6	.6
	378	215	423	409
32	-.1	.0	-.8	-.6
	550	300	581	559
50	.2	.5	-.2	-.8
	386	203	392	379
70	-.1	.4	-.1	-.9
	385	207	391	379
100	.3	.4	.8	-.9
	353	195	363	354
140	.6	.5	2.2	1.0
	322	181	322	315
200	1.0	.4	2.6	.8
	399	217	405	386
320	1.1	.5	1.9	.3
	562	299	572	552
500	.8	.2	.8	.0
	441	229	449	435
700	.6	.2	.3	.2
	526	282	546	522
900	.4	.1	.1	.1
	260	139	268	258
1000	.5	.2	.2	.8
	45	25	47	46

▫ - FN2MIN	▿ - FN1MIN	▾ - VZ3MIN	▫ - JP2MIN	▵ - AR1MIN
LORAN VAISALA	OMEGA VAISALA	LORAN VIZ	RADIOTHEOD. MESEI	RADIOTHEOD. AIR

Flights processed: 1 2 3 4 5 6 7 8 9 10
11 12 13 14 15 16 18 19 20
21 22 23 24 25 26 27 28 29 30
31 32 33 34 35 36 37 38 39 40
41 42 43 44 45 46 47 48 49 50
51 52 53 54 55 56 57 58 59 60
61

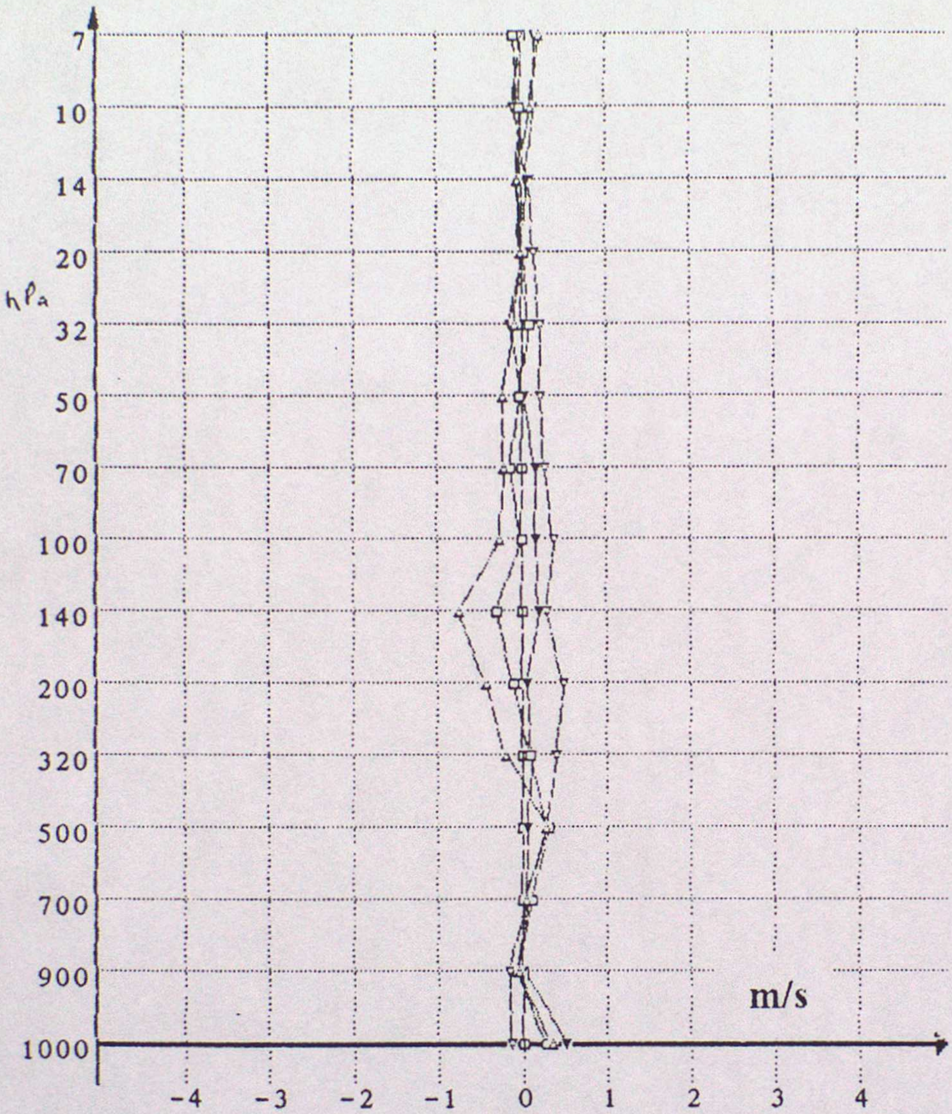
PHASE IV WMO RADIOSONDE COMPARISON

Consistent differences N-S wind [m.s⁻¹]

Category: 08J + 11J + 14J + 20J
+ 20ICED + 20CIRRUS

Reference: FN2MIN

ANNEXE D8



FN1M	VZ3M	JP2M	AR1M
.0	.1	-.1	.2
256	135	254	253
-.1	.1	.0	.1
318	179	341	330
.1	.0	-.1	-.1
279	159	308	301
.1	.0	.0	.0
378	215	423	409
.2	-.2	.1	-.1
550	300	581	559
.2	.0	.0	-.2
386	203	392	379
.3	.1	-.2	-.2
385	207	391	379
.4	.2	.0	-.3
353	195	363	354
.3	.2	-.3	-.8
322	181	322	315
.5	.0	-.1	-.4
399	217	405	386
.4	.1	.1	-.2
562	299	572	552
.3	.1	.3	.3
441	229	449	435
.0	.0	.1	.0
526	282	546	522
-.2	.0	-.1	-.1
260	139	268	258
-.2	.5	.3	.3
45	25	47	46

▫ - FN2MIN	▿ - FN1MIN	▾ - VZ3MIN	▫ - JP2MIN	▵ - AR1MIN
LORAN	**OMEGA**	**LORAN**	**RADIOTHEOD.**	**RADIOTHEOD.**
VAISALA	**VAISALA**	**VIZ**	**MESEI**	**AIR**

Flights processed:

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	18	19	20	
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61									

PHASE IV WMO RADIOSONDE COMPARISON