METEOROLOGICAL OFFICE BRACKNELL

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G.P.S RADIOSONDE SYSTEM TRIAL CAMBORNE, 15 to 19 JANUARY 1996.

[EVALUATION OF AIR SYSTEM and SUMMARY OF VAISALA SYSTEM]

J B Elms, Met Office Bracknell, Berks, RG12 2SZ

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1. INTRODUCTION

The primary purpose of this test was to evaluate and compare the windfinding accuracy of radiosonde systems using GPS (Global Positioning Systems). The network of worldwide Omega navigation transmissions is likely to cease in 1997 which will necessitate urgent replacement of the windfinding systems at some of the UK overseas radiosonde stations. In the short term, the need to replace the obsolete groundstation in the Falklands is becoming urgent.

The test was arranged between A.I.R (Atmospheric Instrumentation Research ,Inc) ,Vaisala Oy,and the UK Met Office. Each company provided the groundstations, 20 GPS radiosondes and representatives to demonstrate its system. (A previous test of the AIR GPS system had been carried out in the week of 6th to 10th February 1995. Following this test various improvements were made to the AIR system.)

In both systems the radiosondes received satellite GPS transmissions in the digitally modulated spread spectrum signal on 2 carrier frequencies (1.226 GHz and 1.575 GHz). The 1.575 Ghz carrier is modulated by a satellite-specific pseudo random noise (PRN) code which effectively spreads the spectrum to 2 Mhz. The satellites are identified through the individual PRN code.

The radiosonde pressure ,temperature and humidity measurements were also compared both during flight and against independent surface sensors in field checks prior to launch.. During this test there were no opportunities to evaluate the systems' performances in continuous precipitation. (The weather conditions for the week are given in Annexe 3).

A previous draft of this Report was sent to A.I.R . in May 1996. Since this Trial , A.I.R have modified the radiosonde design . In particular, the temperature sensor position and humidity sensor have been changed. The UK Met. Office have not yet retested the modified radiosonde.

2. THE AIR GPS RADIOSONDE SYSTEM.

2.1 The AIR GPSonde

The AIR GPSonde measures wind by tracking its motion through analysis of Global Positioning System (GPS) signals received,compressed, and re-transmitted by the radiosonde. The radiosonde differs completely from the AIR radiosondes deployed in Phases III and IV of the WMO Radiosonde Comparisons. The GPSonde is crystal-controlled to maintain RF frequency stability and powered by dry cell batteries. Measurement of temperature is performed using a low mass white coated bead thermistor. Pressure is measured using an aneriod capacitive sensor whose small temperature dependence is compensated by a temperature-sensitive capacitor mounted near the sensor. Relative humidity is measured by a capacitive sensor constructed from a 2 micron thick polymer film. The size and weight of the radiosonde would make it suitable for launching in strong winds if used in the Falklands.

2.2 The AIR GPS Ground Station.

The AIR GPS system determines the displacement of the radiosonde by measuring changes in the differences between satellite information received simultaneously at the groundstation and the radiosonde. Two groundstation antennae are required to receive the data. A Base GPS Antenna receives data from as many of the 24 satellites simultaneously available above the horizon.The UHF Antenna receives the radiosonde transmissions including the re-transmitted GPS information. The groundstation computer then evaluates the winds using differential computations which compare the GPS signals received at the radiosonde with those received through the base channel. A diagram (Annexe 1) shows the main components of the system.

3. TRIAL PROGRAM AND DATA ACQUISITION

3.1. The Trial Program

Annexe 6 gives an overview of the ascents made and data obtained from the Trial. 32 soundings were evaluated during the period from 1130 on 15th to 1720 on 19th January. The tests comprised the following combinations of radiosonde comparisons:-

(I) 9 ascents were made using Vaisala GPS,Vaisala Loran and AIR Gpsondes.

(ii) 10 ascents were made using Vaisala GPS in comparison with radar and/or Loran measurements.

(iii) 7 ascents were made using AIR GPS in comparison with radar measurenents.

(iv) 6 additional radar or loran ascents were launched at intervals close to the GPS comparison launches.

3.2 Comparison Rigs.

On all ascents tracked by radar, a large reflector was suspended about 5m below the balloon from which a bamboo cane (originally intended to accommodate the 3 radiosondes) was suspended from a Graw unwinder. It became apparent from tests early on in the Trial that the 2 Vaisala RS80 radiosonde transmissions interfered with those from the AIR Gpsonde. During field comparisons, for example, it was found necessary to move the GPSonde to a position about 20m from the bamboo support on which the 2 Vaisala radiosondes were being checked . The decision was made to fly the GPSonde 30m below the cane containing the 2 Vaisala radiosondes. Thus, during all comparison flights between Vaisala and AIR GPS radiosondes, the Vaisala GPS radiosonde was suspended 30m and the AIR GPSonde 60m below the reflector. The 2 Vaisala radiosondes were suspended from opposite ends of the same bamboo cane. On most flights the Vaisala GPS radiosonde was taped to the bamboo to avoid any possible high frequency pendulum effect which might have degraded reception of satellite data. At other times during the Trial various other rig arrangements were used according to requirements. The alternative arrangements are given later in Annexe 6 .

3.3 Wind Data Acquisition and Quality Control.

Meteorological parameters were measured at 1 to 2 second intervals by the Vaisala RS80 radiosondes and the AIR Gpsonde. In order to compare the fine structure , the data transmitted by the 3 radiosondes were interpolated at simultaneous 2 second intervals from launch time and archived in a 2 Second Database.The RS80 2 second data were obtained directly from an ASCII conversion of the Vaisala "EDT" files. The AIR data were interpolated from the binary files within the groundstation and then output using AIR programs developed for use with Kurnosenko's "RSKOMP" inter-comparison software .

Annexe 5 details the amount of minute wind data missing or flagged as erroneous. Only these gross anomalies in the data have been excluded from within the minute data analyses presented in section 6.

3.4 Data Synchronisation.

Timing of the Radar, Vaisala Loran and Vaisala GPS systems was synchronised with the button press on launch . Timing adjustments were applied mainly to the AIR system data. The AIR groundstation "launch " was initiated by an auto start facility within its program which relied on decreasing pressure. The timing corrections for PTU measurements incorporated the delay in time when the GPSonde flew 30m below the Vaisala radiosondes.

3.5. Data Designations

The following designations were applied to both the 2 Second and Minute data bases.:-

UAWNDS Met Office independent (Trials Reference) wind computations produced by 60 second radar line fitting program UAWNDS to verify Vaisala PC-CORA winds.

LORMK4 PC-CORA pressure,temperature,humidity ,Loran wind and altitude data transcribed directly from the Vaisala ".EDT" 2 second files."Altitude" (above mean sea level) was calculated from the hydrostatic equation.

AIRGPS The AIR data converted to ASCII at the end of the flight.

AIRAUTO The AIR system belonging to the Navy was used to evaluate the sounding in autonomous" mode.

VAISGPS The Vaisala GPS radiosonde data transcribed directly from the Vaisala "EDT" 2 second files.

4. WIND REFERENCE MEASUREMENTS

4.1 Radar Performance.

The Cossor radar used to provide the reference wind measurements at Camborne is one of the few remaining radars currently used in the UK for windfinding. Tests in 1984 of the windfinding performance of this type of radar showed that the RMS vector errors in the wind vary from about 0.4 $m.s^{-1}$ at 20km range to 1.5$m.s^{-1}$ at 80km, Edge et al.,[3] .These results were derived by tracking the same balloons with Cossor radars separated by 50 km at Bracknell and Crawley (West Sussex) . 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 Annexe 2 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. These comparisons with the High Precision Radar show that the RMS vector errors using UAWNDS can be reduced from the original 1984 estimates to about 0.2 $m.s^{-1}$ at 20km range to 0.8 $m.s-^{1}$ at 90km. The Cossor radar at Camborne has been regularly checked and maintained and its tracking accuracy is regarded as at least as good as the radars of the same type used in these earlier tests.

During the GPS test the mean flat range was about 20 km at 100 hPa increasing to about 80km at 10 hPa. Throughout the Trial week the Cossor radar tracked all ascents very successfully.The details given in the flightlog summaries (Annexe 7) show that maximum ranges were generally below 100 km and minimum elevations were greater than 20 degrees on half of the ascents. These were ideal tracking conditions and the radar did not once fail to track the target.However ,the EHT had to be switched off until at least 5 minutes into flight on all comparison ascents using th Vaisala GPS sonde. This was necessary as the radar transmissions impeded GPS reception by the Vaisala radiosonde when the radiosonde was relatively close to the radar. The AIR system was not susceptible to the radar EHT transmissions so that the radar could be used from launch on soundings not involving the Vaisala GPS radiosonde.

A Data Processing Unit (DPU) fault affected 2 consecutive flights (Flights 21 and 22) causing an indeterminate shift in the bearing data recorded. Although the 1 second data in the respective PC-CORA RDR files was corrupted , the minute records of range,bearing and elevation output to a (Kienzle) printer were unaffected and were therefore used to evaluate minute winds for comparison on these 2 ascents. The radar line fitting length was set to 60 seconds throughout the Trial.

4.2 Loran Performance.

The Rs80-L Loran radiosondes (all from identical calibration batch December 1995) performed very well throughout the Trial. Loran wind data was obtained to burst on all ascents except Flight 11 when poor signals from the RS80L caused an early termination of the PTU signals which also caused the 1 second radar data to cease recording in the RDR file. The associated signal "chatter" on this flight was believed to be caused by overmodulation of the loran radiosonde's transmitted signals.

The Loran windfinding receiver used transmissions from the following 2 chains:-
FRENCH CHAIN GRI 8940
Lessay (Master) , Soustons (1st slave) , Sylt (2nd slave)
NORWEGIAN CHAIN GRI 9007
Ejde (Faeroes) (Master), Jan Mayen (1st slave),Bo (Norway) (2nd slave), Vaerlandet (Norway)(3rd slave).
The flightlog report (Annexe 7) gives details of the overall percentage of time during each ascent for which transmissions from these stations were received by the radiosondes.
Experience has shown that radiosonde windfinding degrades slightly when transmissions from Sylt are not received.This is especially true if there are few other transmissions available. During the Trial, timing signals from all 7 stations in the 2 chains were received for most of the ascents and **transmissions from Sylt were received on all flights.**
The Loran line fitting length was set to 60 seconds throughout the Trial.

5 GPS WINDFINDING COMPARISONS.

5.1 Wind Profile Examples

Figures 1 to 7 show examples of simultaneous wind measurements made at similar intervals from launch by the 4 independent windfinding systems on each of the 5 days of the Trial. They illustrate the main features of performance of the various systems.

Figure 1 (Flight 5) shows good agreement between computed winds of all 4 systems,except between minutes 20 and 25 on the Vaisala GPS system. These Vaisala GPS winds coincided with switching on the radar EHT which possibly interfered with the satellite reception causing a gap in the data for several minutes. Some of the data within this gap were subsequently interpolated by the Vaisala software. This was the most extreme example observed during the trial of anomalous winds computed by the Vaisala GPS system. The AIR winds did not correlate as well with those of the other 3 systems in the last 20 minutes of flight. This may have resulted from low battery voltage (measured at 6.9 v at 115 minutes after the sonde had ceased to transmit wind data) leading to lower signal to noise in the radiosonde signal received at the ground.

Figures 2(a), 2(b) and 2(c) all display evidence of a slight time displacement in the AIR winds (between 10 and 20 seconds) from the structure in the radar and Vaisala winds . This may have been caused by the line fitting technique used in the AIR software. All sections illustrated are from the early stages of each flight when best signal reception would have been expected. Note that in Figures 2(a) and 2(b) (Flights 9 and 11 respectively) a correction has already been applied to allow for the AIR radiosonde being 30m below the 2 Vaisala radiosondes. Furthermore , Figure 2C still shows the time displacement on Flight 16 when the AIR GPSonde was flown on its own below the radar.

Figure 3(a) (Flight 8) displays generally good agreement between all 4 wind measurements. The tendency of the Loran system to smooth the wind fine structure relative to that of the radar may be seen between minutes 50 and 65. Note also above 50 hPa the Vaisala wind structure correlates less well with those of the other 3 systems due to interpolations caused by loss of satellite data. An enlargement of the data from minutes 52 to 88 (Figure 3(b)) illustrates this point. The AIR GPS radiosonde ceased transmitting wind and PTU data at minute 74.

Figure 3(b) highlights the gaps in the wind data caused by outages in the satellite data reception . Between minutes 70 and 72 and between minutes 80 and 82 winds have been interpolated by the Vaisala processing software. The interpolated winds (VGINT in Figure 4) are computed using a cubic spline line fitting technique. (Similar problems occur when this technique is used to interpolate missing data in PC-CORA radar or loran windfinding.) (Further examples of spurious interpolated Vaisala GPS winds may be seen in previous Figure 2(b) (between minutes 17 and 19 , 21 and 23)

On 17th January several solo radiosonde ascents were made comparing individually the Vaisala and AIR GPS radiosonde winds with radar winds. Figures 4 to 6 show ascents launched all launched within a 3.5 hour period.:-

Figure 4(a) displays good agrreement between radar and AIR GPS winds to 10hPa. Figure 4(b) shows that the differences between AIR GPS and radar wind component measurements sampled at 1 minute intervals were generally less than 1 m/s in each component.

Figure 5(a) (Flight 15) shows the very good agreement between Vaisala GPS and radar wind components measured at minute intervals from launch.. Figure 5(b) shows the wind component differences were generally less than 0.5 m./s for levels up to 50 hPa.

Figure 6(a) (Flight 16) also shows good agreement between radar and AIR GPS winds during an ascent launched 100 minutes after Flight 15. Figure 6(b) shows that the component differences were generally less than 1 m/s in each component.

Figure 7 (Flight 18) shows winds evaluated from all 4 groundstations. On this occasion the AIR groundstation had a computer problem so a spare system acquired by the Navy was used to calculate the winds in autonomous mode . Winds in the last 10 minutes of AIRAUTO ascent were clearly anomalous and have been omitted from the comparison statistics. Low signal to noise ratios from about minute 75 onwards were observed on the display of satellite information available on the AIR groundstation. In this case it would have been better for the software to have used this satellite status data to reject the winds as errors exceeding 20m/s occurred during this latter part of the AIR ascent.

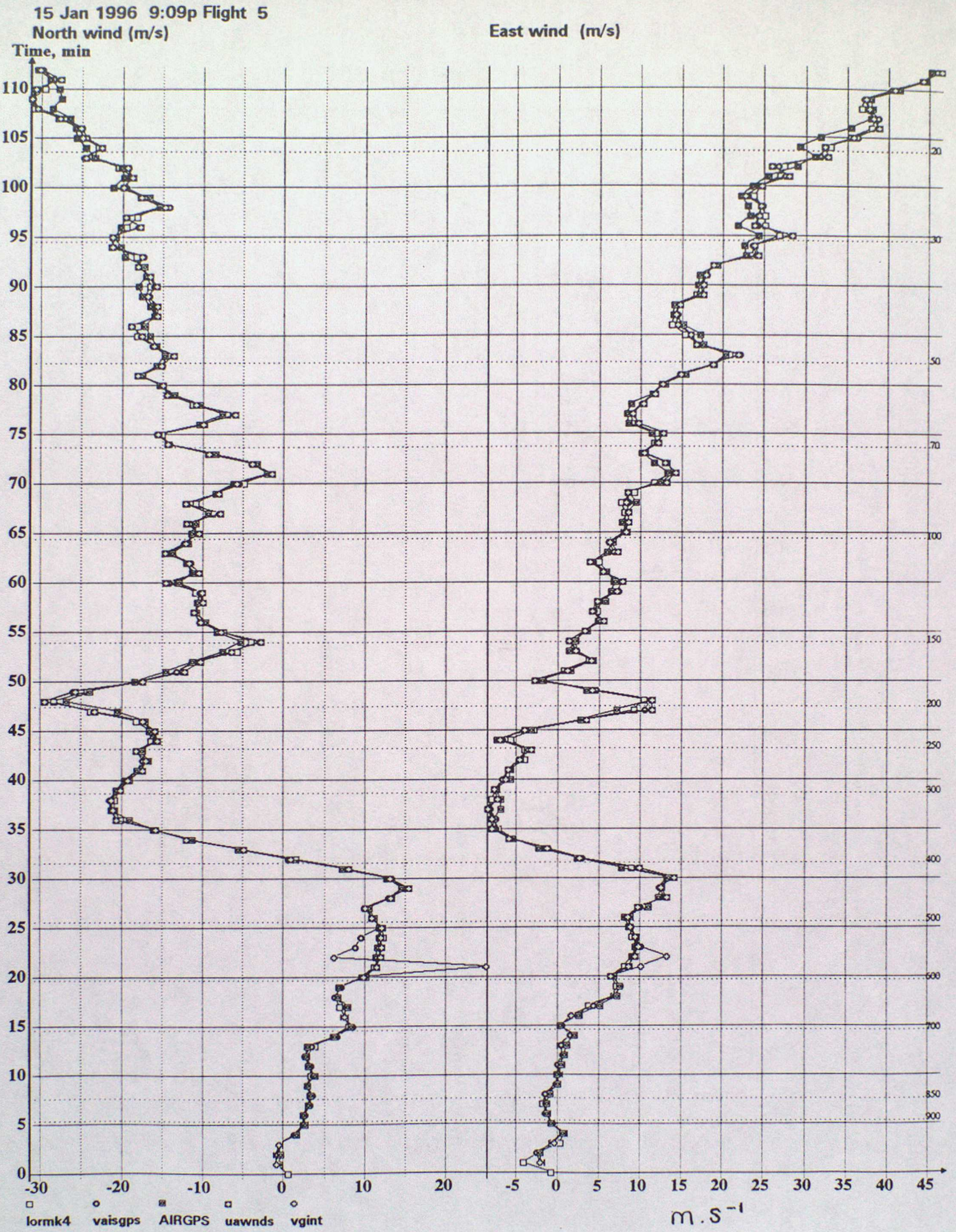


FIGURE 1
Example showing Erroneous Data Interpolations in Vaisala GPS Winds

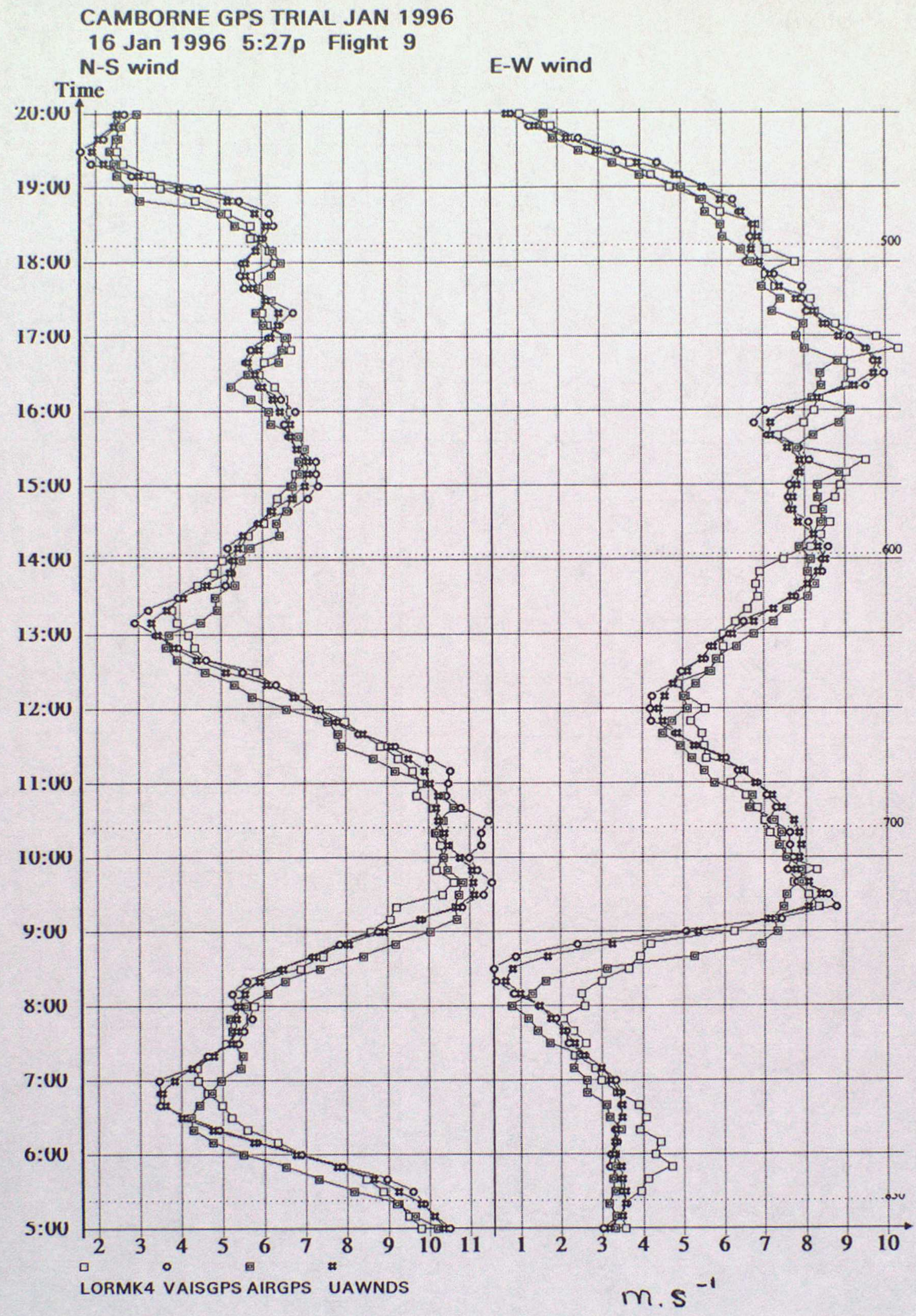
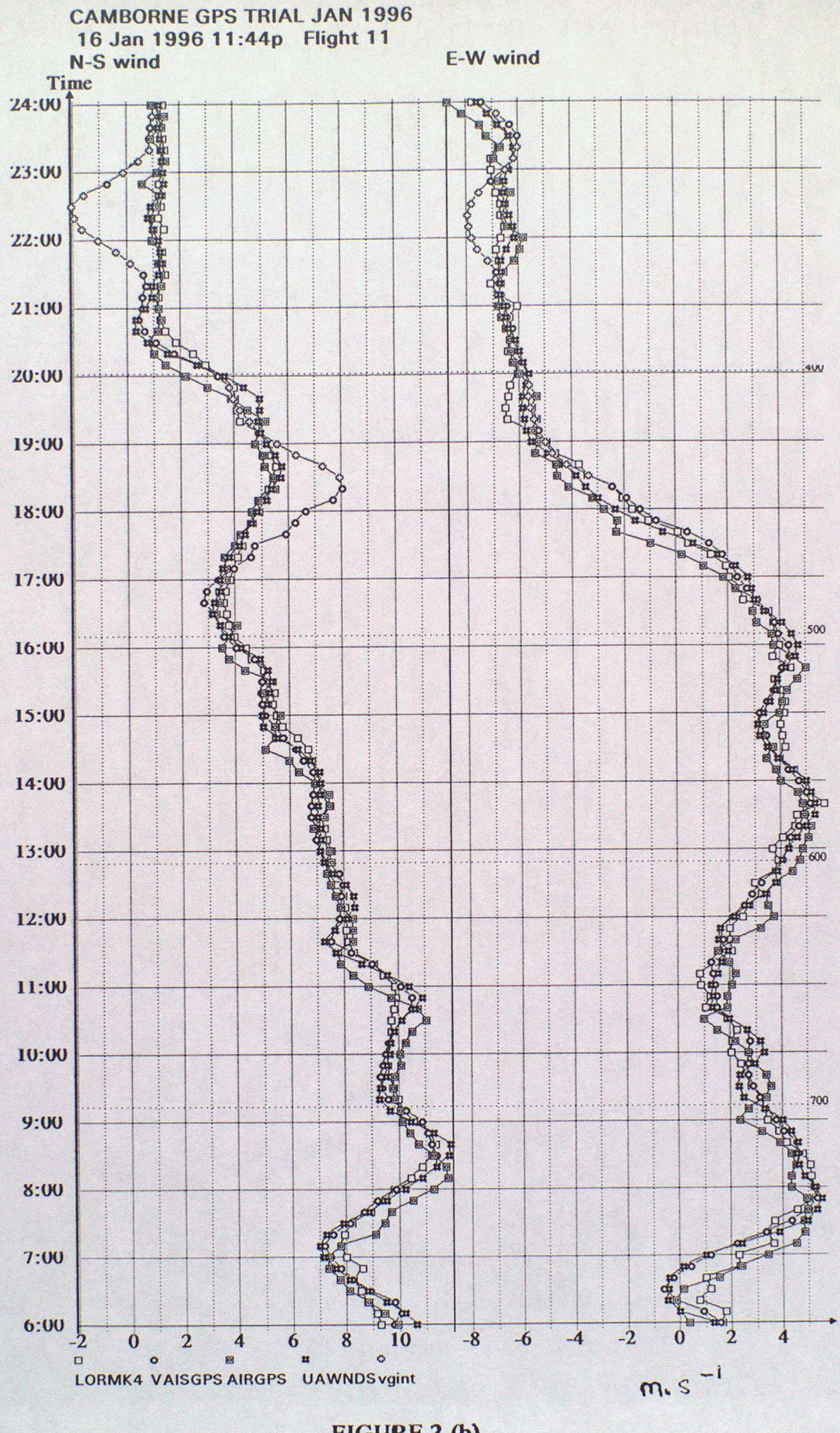

CAMBORNE GPS TRIAL JAN 1996
16 Jan 1996 5:27p Flight 9
N-S wind
E-W wind
Time
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
9:00
8:00
7:00
6:00
5:00
2 3 4 5 6 7 8 9 10 11
1 2 3 4 5 6 7 8 9 10
500
600
700
LORMK4 VAISGPS AIRGPS UAWNDS
m.s⁻¹

FIGURE 2(a)



CAMBORNE GPS TRIAL JAN 1996
16 Jan 1996 11:44p Flight 11
N-S wind
E-W wind
Time
24:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
9:00
8:00
7:00
6:00
-2
0
2
4
6
8
10
-8
-6
-4
-2
0
2
4
500
600
700
LORMK4 VAISGPS AIRGPS UAWNDSvgint
m. s -1

FIGURE 2 (b)

CAMBORNE GPS TRIAL JAN 1996
17 Jan 1996 7:06p Flight 16

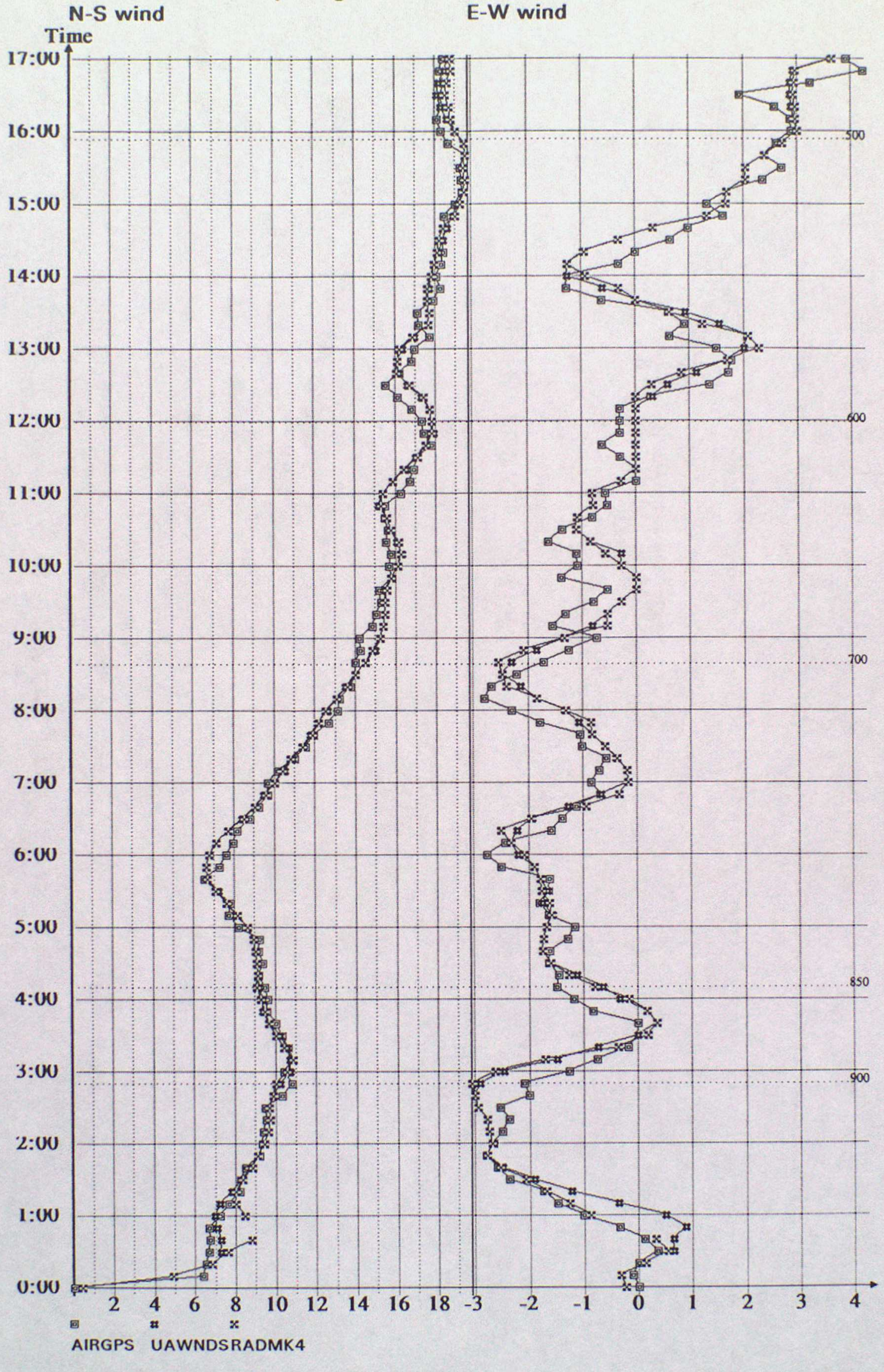


FIGURE 2 (c)

m.s^{-1}

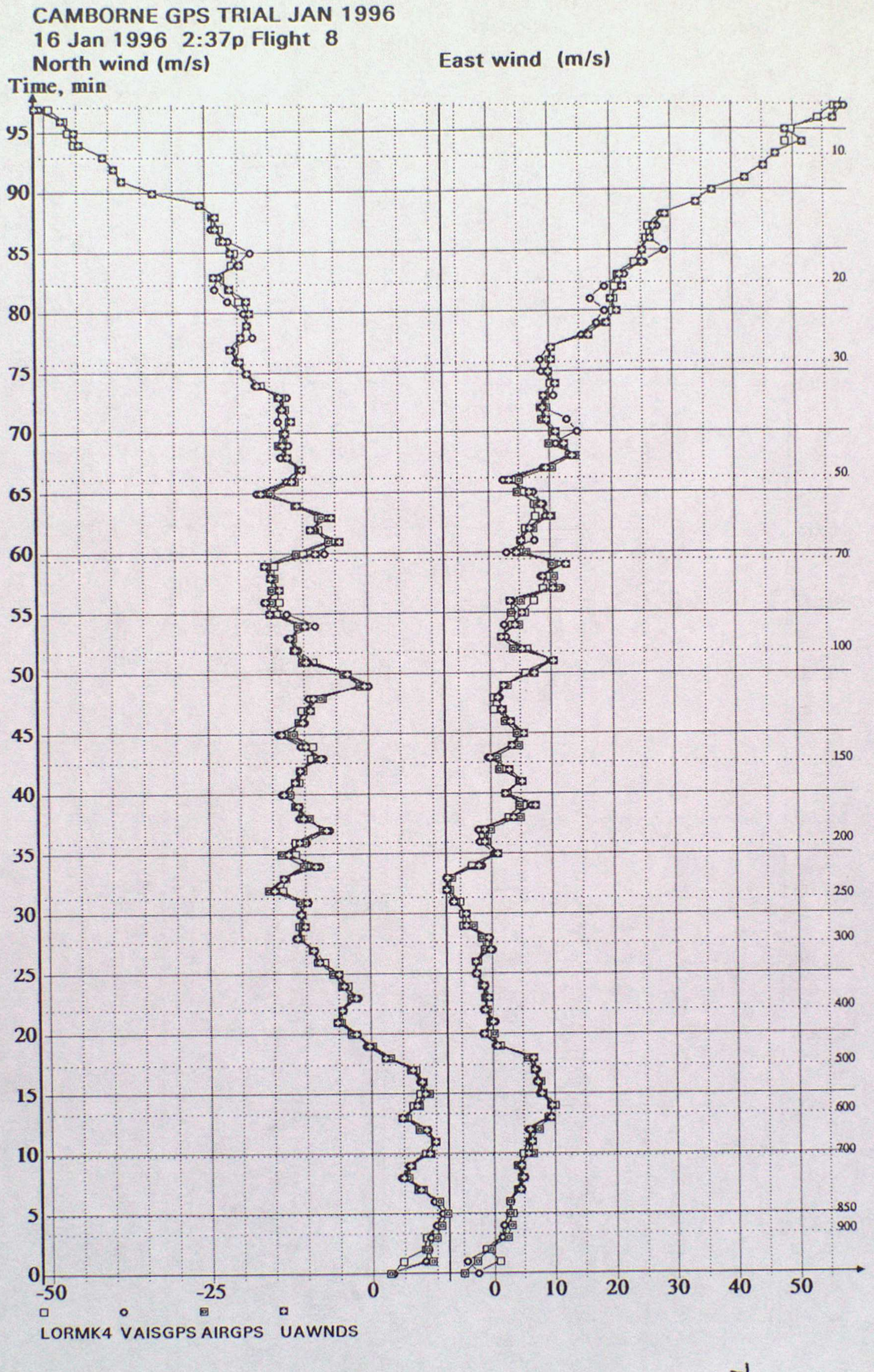

CAMBORNE GPS TRIAL JAN 1996
16 Jan 1996 2:37p Flight 8
North wind (m/s)
East wind (m/s)
Time, min
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-50
-25
0
0
10
20
30
40
50
10
20
30
50
70
100
150
200
250
300
400
500
600
700
850
900
LORMK4 VAISGPS AIRGPS UAWNDS
m.s⁻¹

FIGURE 3 (a)

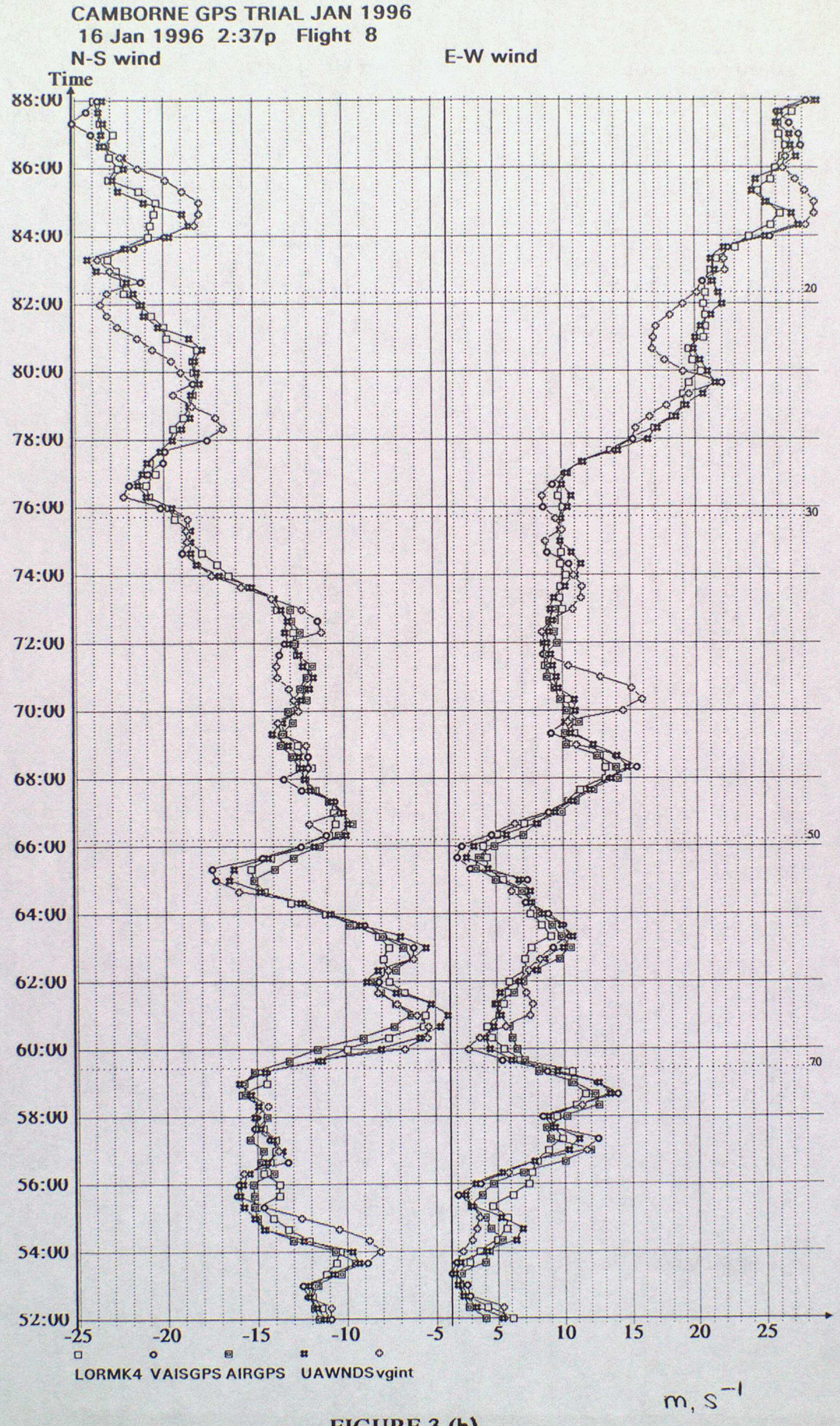

CAMBORNE GPS TRIAL JAN 1996
16 Jan 1996 2:37p Flight 8
N-S wind
E-W wind
Time
88:00
86:00
84:00
82:00
80:00
78:00
76:00
74:00
72:00
70:00
68:00
66:00
64:00
62:00
60:00
58:00
56:00
54:00
52:00
-25 -20 -15 -10 -5 5 10 15 20 25
20
30
50
70
LORMK4 VAISGPS AIRGPS UAWNDS vgint
m, s⁻¹

FIGURE 3 (b)

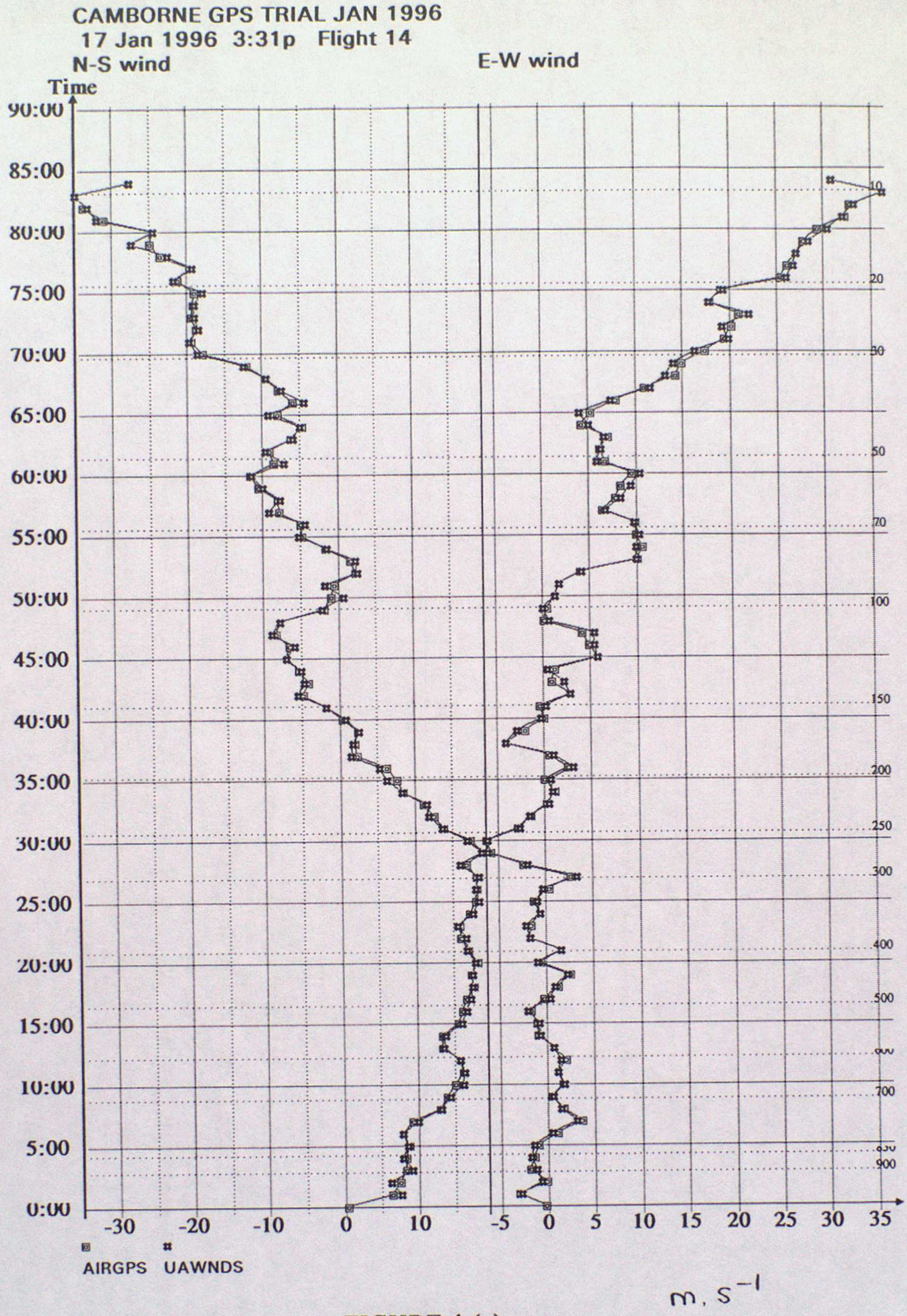
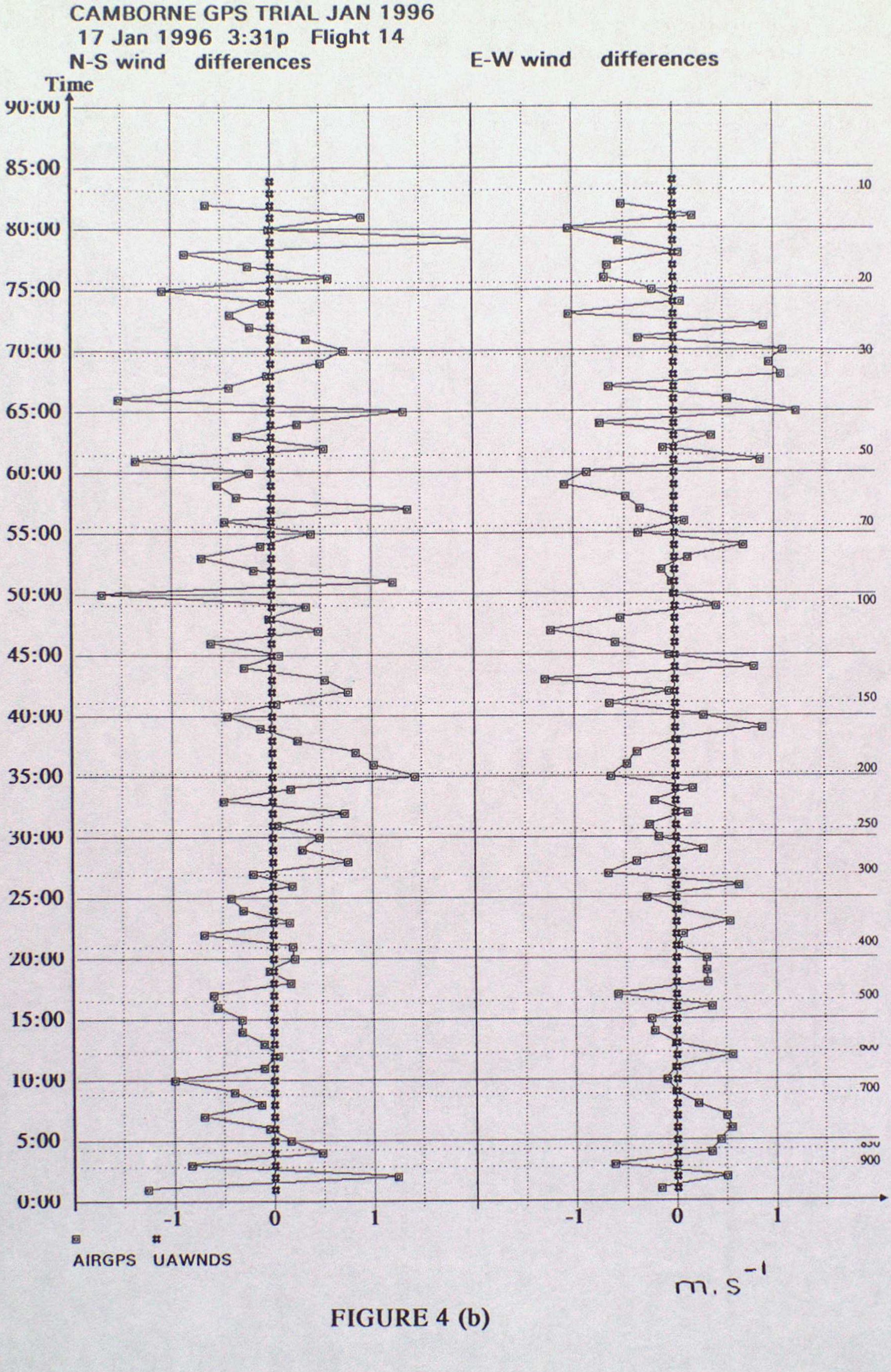

CAMBORNE GPS TRIAL JAN 1996
17 Jan 1996 3:31p Flight 14
N-S wind
E-W wind
Time
90:00
85:00
80:00
75:00
70:00
65:00
60:00
55:00
50:00
45:00
40:00
35:00
30:00
25:00
20:00
15:00
10:00
5:00
0:00
-30 -20 -10 0 10
-5 0 5 10 15 20 25 30 35
10
20
30
50
70
100
150
200
250
300
400
500
700
900
AIRGPS
UAWNDS
m.s-1

FIGURE 4 (a)



CAMBORNE GPS TRIAL JAN 1996
17 Jan 1996 3:31p Flight 14
N-S wind differences
E-W wind differences
Time
90:00
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
-1
0
1
-1
0
1
10
20
30
50
70
100
150
200
250
300
400
500
700
900
AIRGPS UAWNDS
m.s^-1

FIGURE 4 (b)

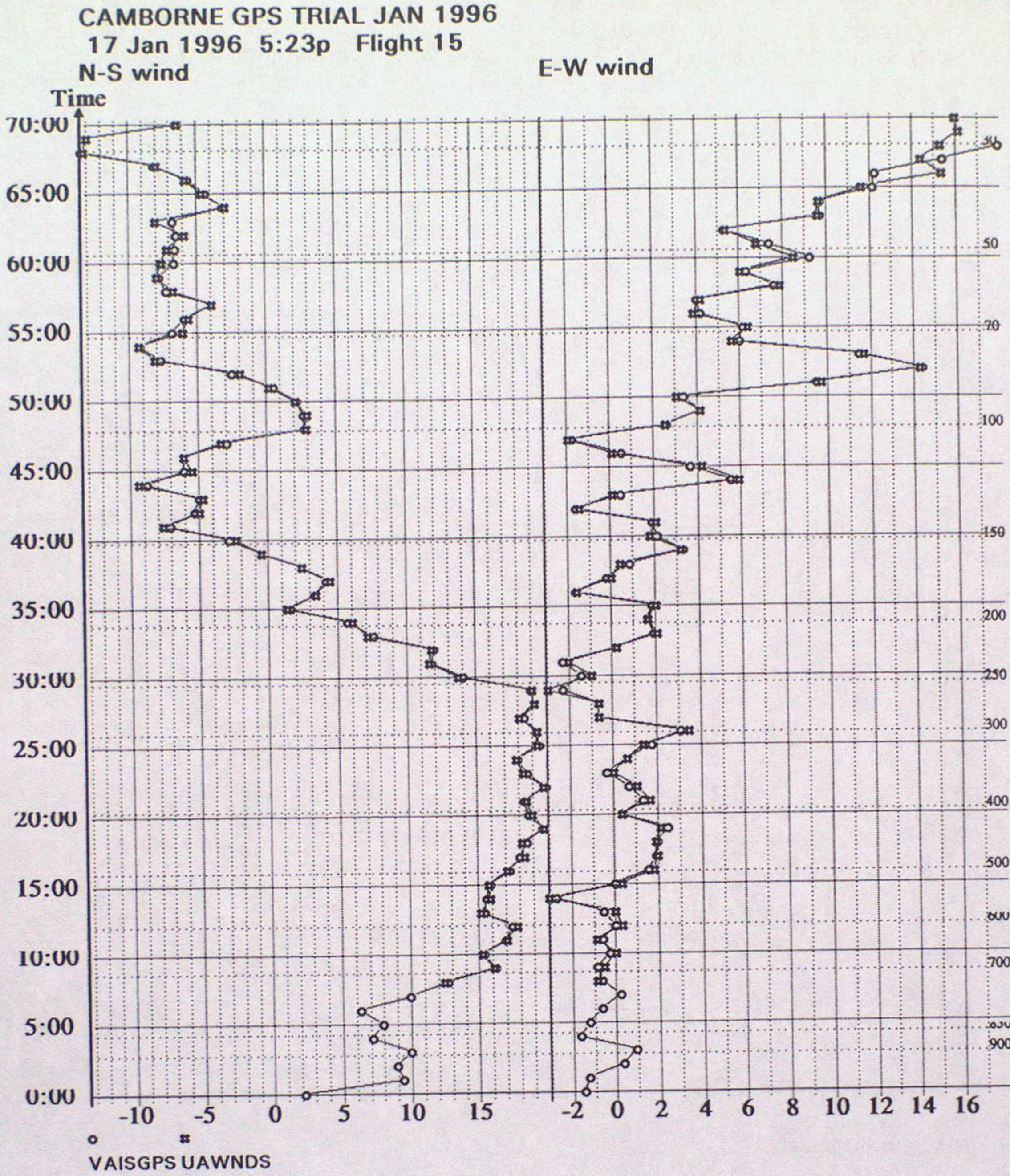


FIGURE 5 (a)

m.s⁻¹

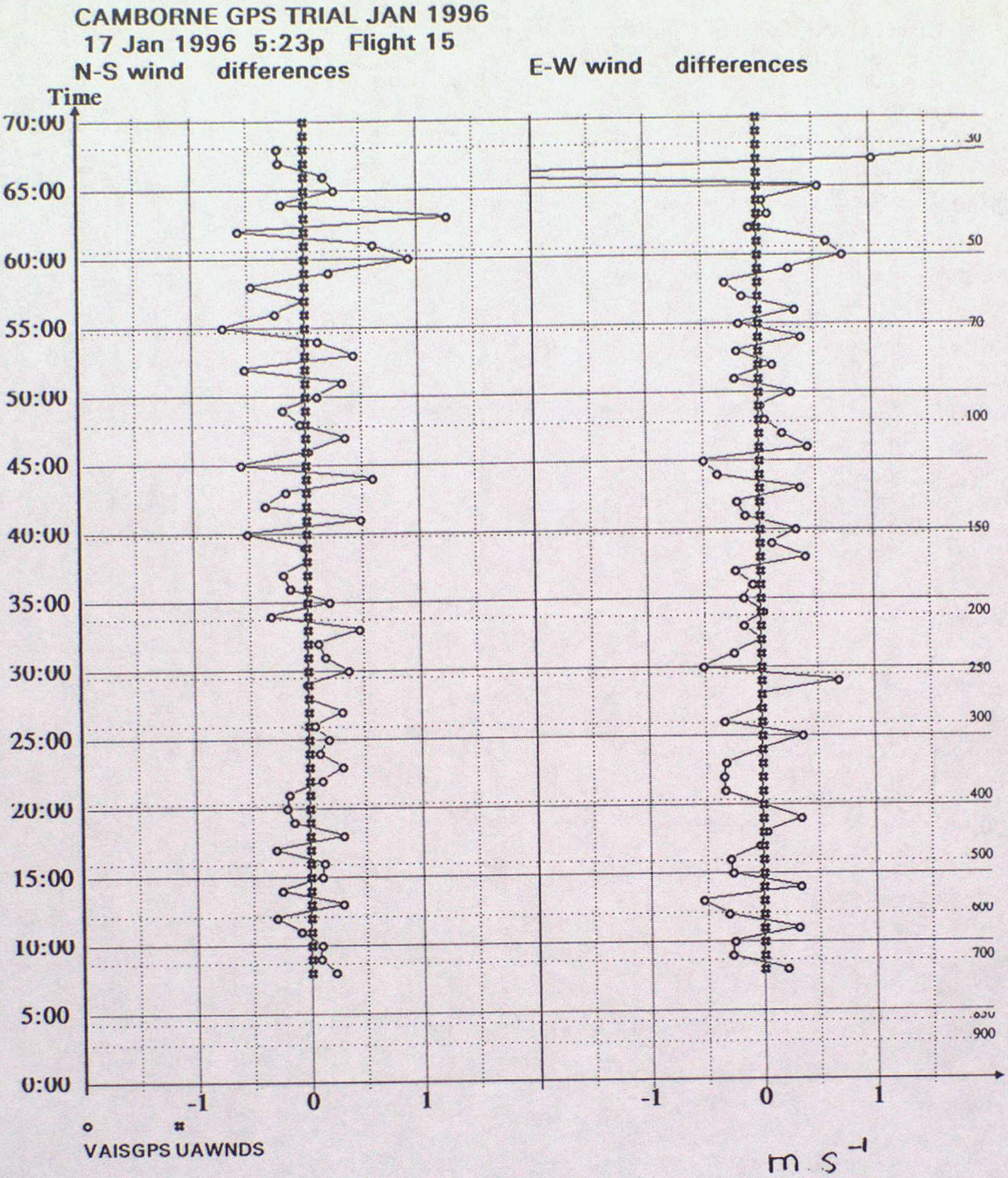
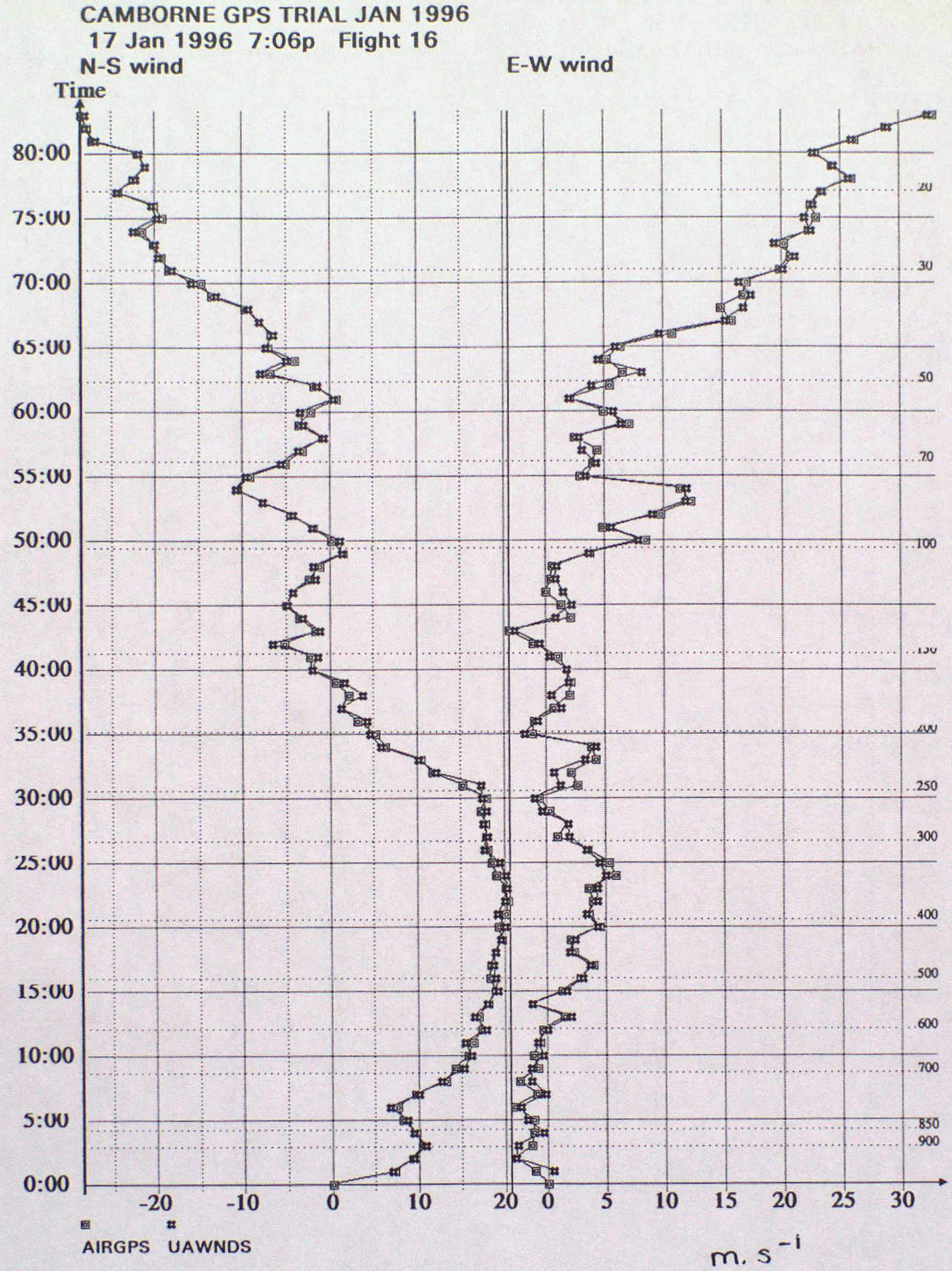
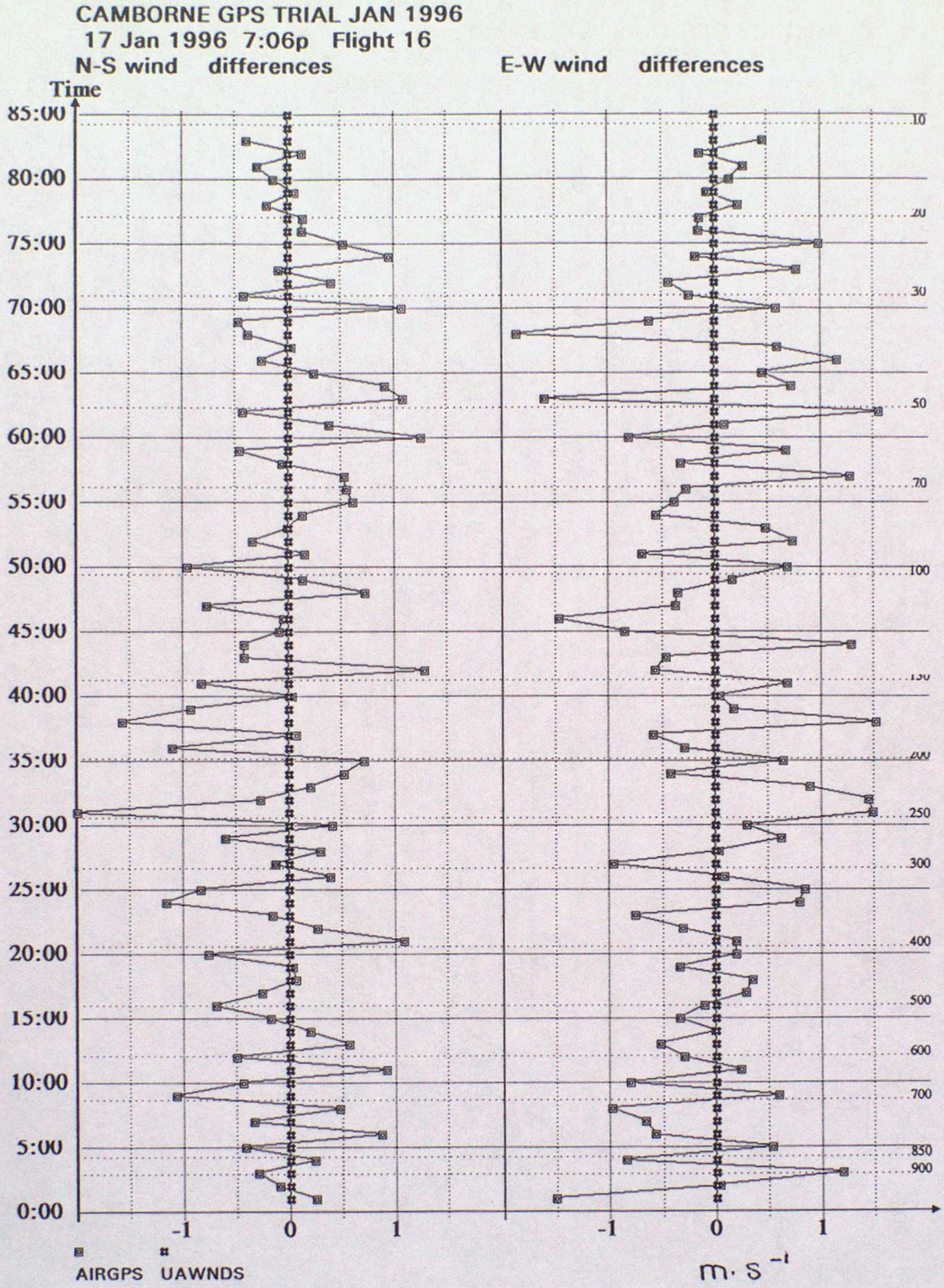

CAMBORNE GPS TRIAL JAN 1996
17 Jan 1996 5:23p Flight 15
N-S wind differences
E-W wind differences
Time
70:00
65:00
60:00
55:00
50:00
45:00
40:00
35:00
30:00
25:00
20:00
15:00
10:00
5:00
0:00
-1
0
1
-1
0
1
50
70
100
150
200
250
300
400
500
600
700
900
VAISGPS UAWNDS
m s⁻¹

FIGURE 5 (b)



CAMBORNE GPS TRIAL JAN 1996
17 Jan 1996 7:06p Flight 16
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
-20 -10 0 10 20
0 5 10 15 20 25 30
.20
.30
.50
.70
.100
.150
.200
.250
.300
.400
.500
.600
.700
.850
.900
AIRGPS
UAWNDS
m. s⁻¹

FIGURE 6 (a)



CAMBORNE GPS TRIAL JAN 1996
17 Jan 1996 7:06p Flight 16
N-S wind differences
E-W wind differences
Time
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
-1
0
1
AIRGPS
UAWNDS
m·s⁻¹
10
20
30
50
70
100
150
200
250
300
400
500
600
700
850
900

FIGURE 6 (b)

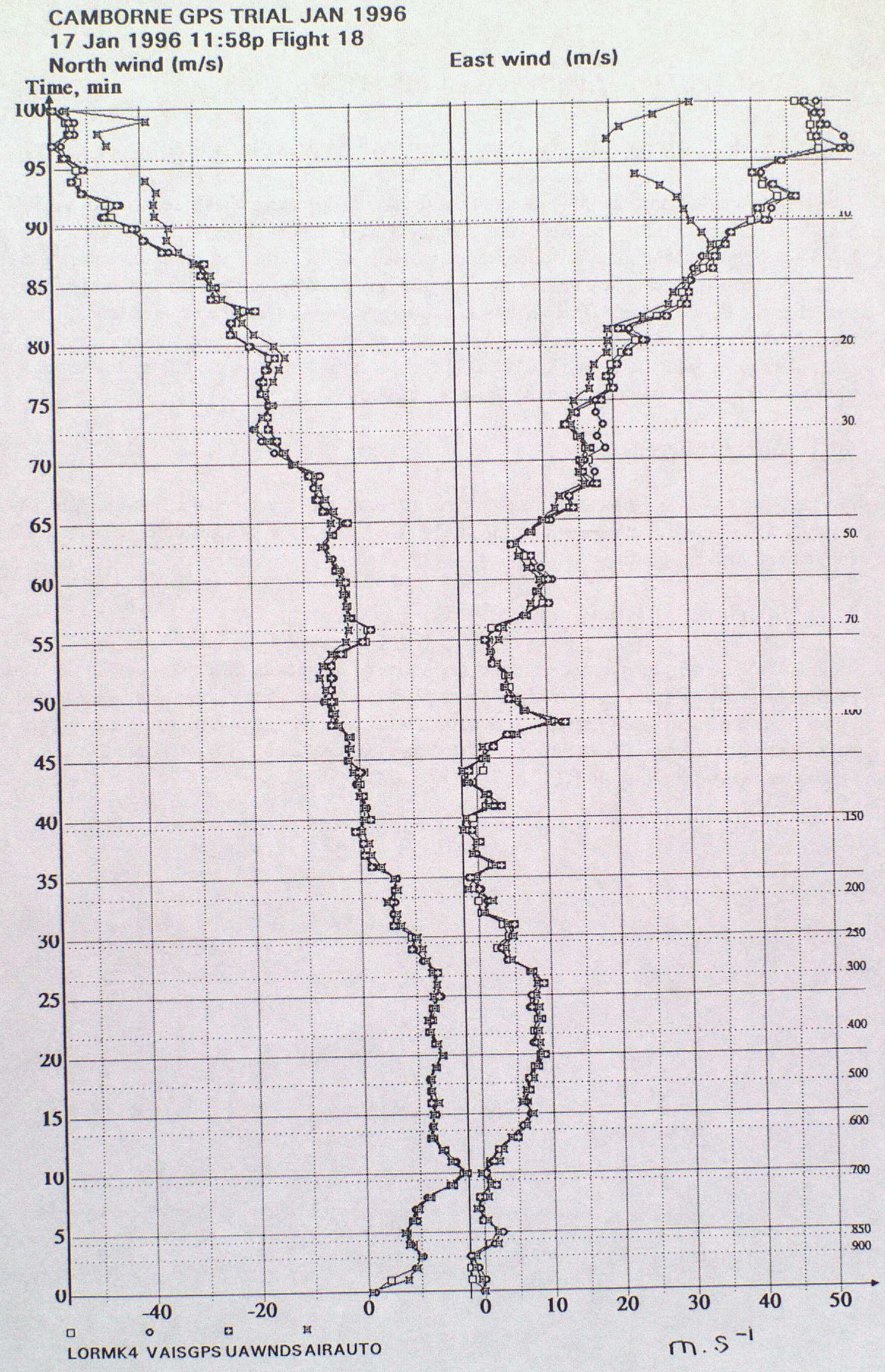

CAMBORNE GPS TRIAL JAN 1996
17 Jan 1996 11:58p Flight 18
North wind (m/s)
East wind (m/s)
Time, min
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-40
-20
0
0
10
20
30
40
50
10
20
30
50
70
100
150
200
250
300
400
500
600
700
850
900
LORMK4 VAISGPS UAWNDS AIRAUTO
m.s⁻¹

FIGURE 7

6. WIND COMPARISON STATISTICS

6.1 Wind Comparison Results From All Available Ascents.

The results in this section are presented in terms of differences with respect to UAWNDS. Simultaneous wind measurements were compared at 1 minute intervals. The radar reference UAWNDS components computed independently using a Met Office program are subtracted from simultaneous component measurements of each of the systems. UAWNDS evaluations are very similar to the PC-CORA RADMK4 winds as they are derived from the same radar data ,however the UAWNDS computations have been used as the reference as they apply no cubic spline fit to interpolate for missing data. The UAWNDS program also evaluates the information from optical tracker readings more reliably than the Vaisala program.

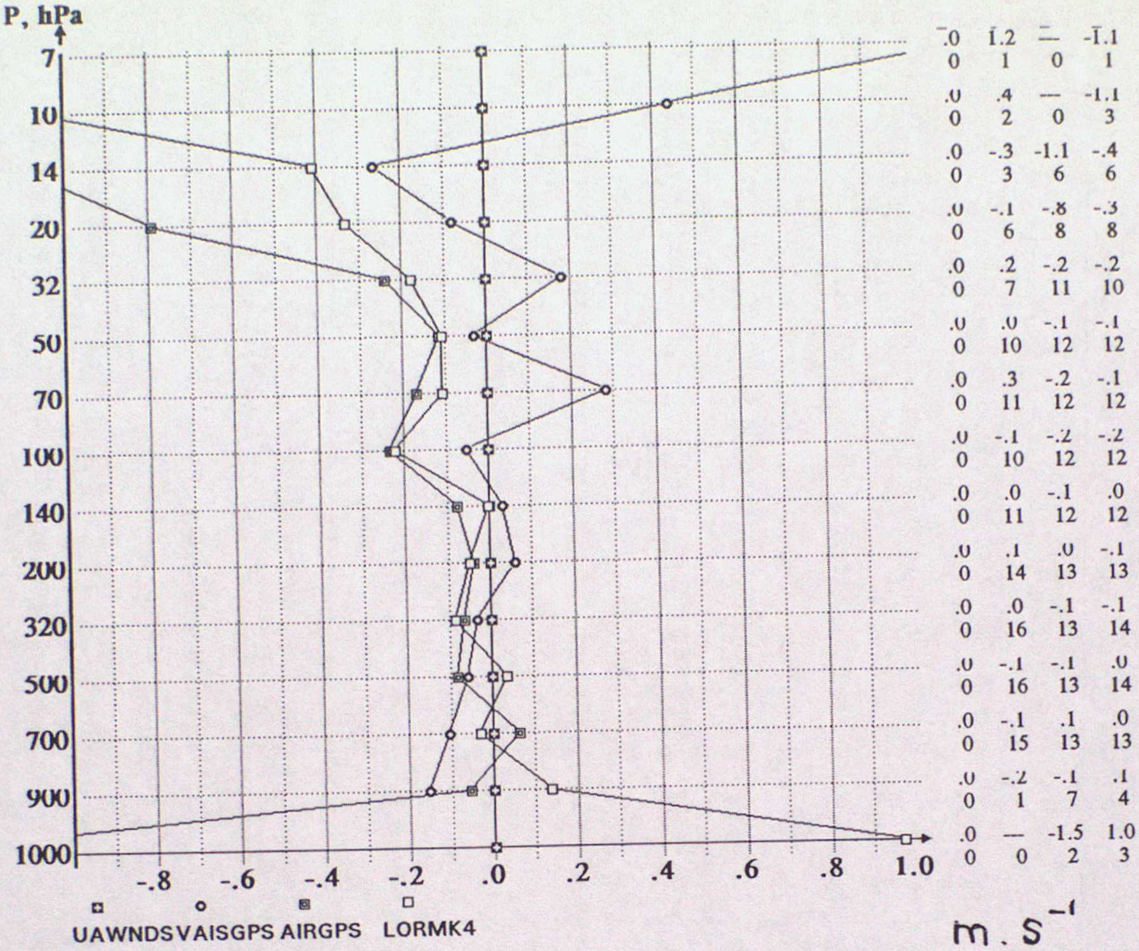
6.1.1 Direct Differences

Figures 8(a) and 8(b) show the mean differences between the computed minute winds in the westerly and northerly components respectively. The differences are generally less than 0.2 m/s and not regarded as significant .

6.1.2 Standard Deviations

Figures 9(a) and 9(b) display the standard deviations of the minute differences within the westerly and northerly components respectively. The standard deviations of the Loran winds compared with those from the radar are generally less than 1 m/s in each component.These results are very consistent with Cossor radar/RS80-L wind comparison results obtained in various locations in the UK within the last 5 years. [Ref 2].

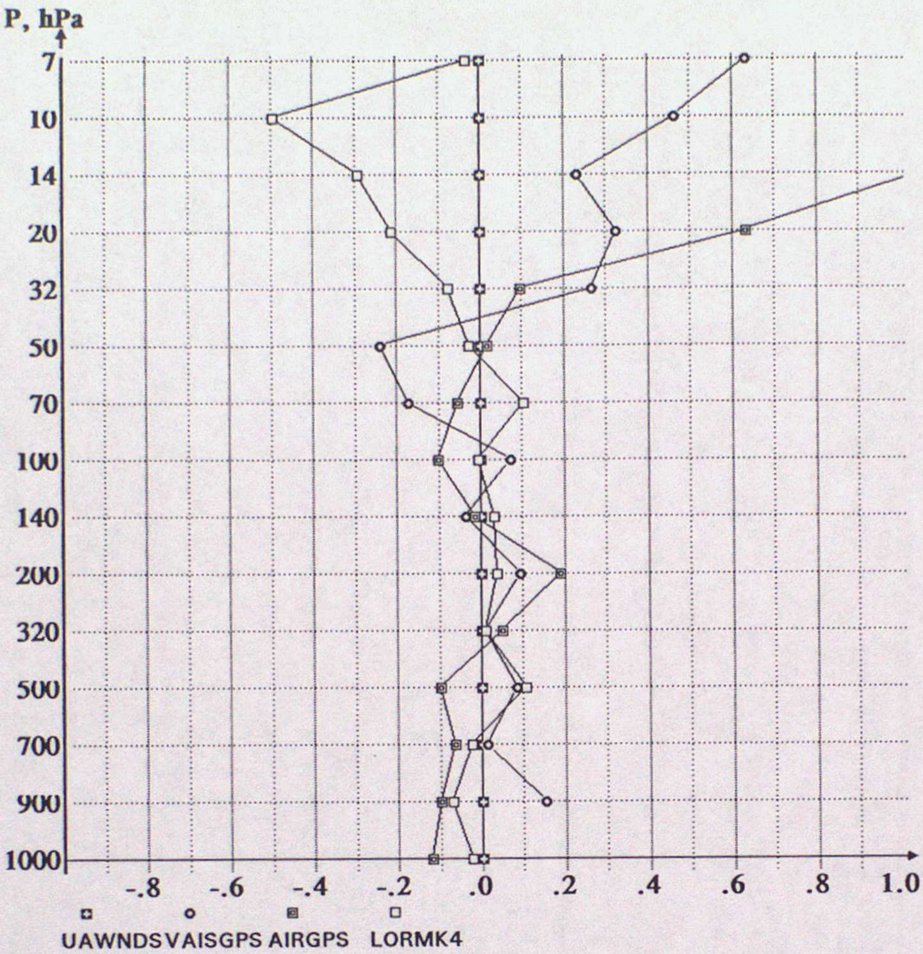
Flight-by-flight differences E-W wind
Reference: UAWNDS



Flights: 1 2 3 5 7 8 9 10 11 12 13 14
15 16 17 18 19 20 21 22 23 24 25 26
29

FIGURE 8 (a)

Flight-by-flight differences N-S wind
Reference: UAWNDS

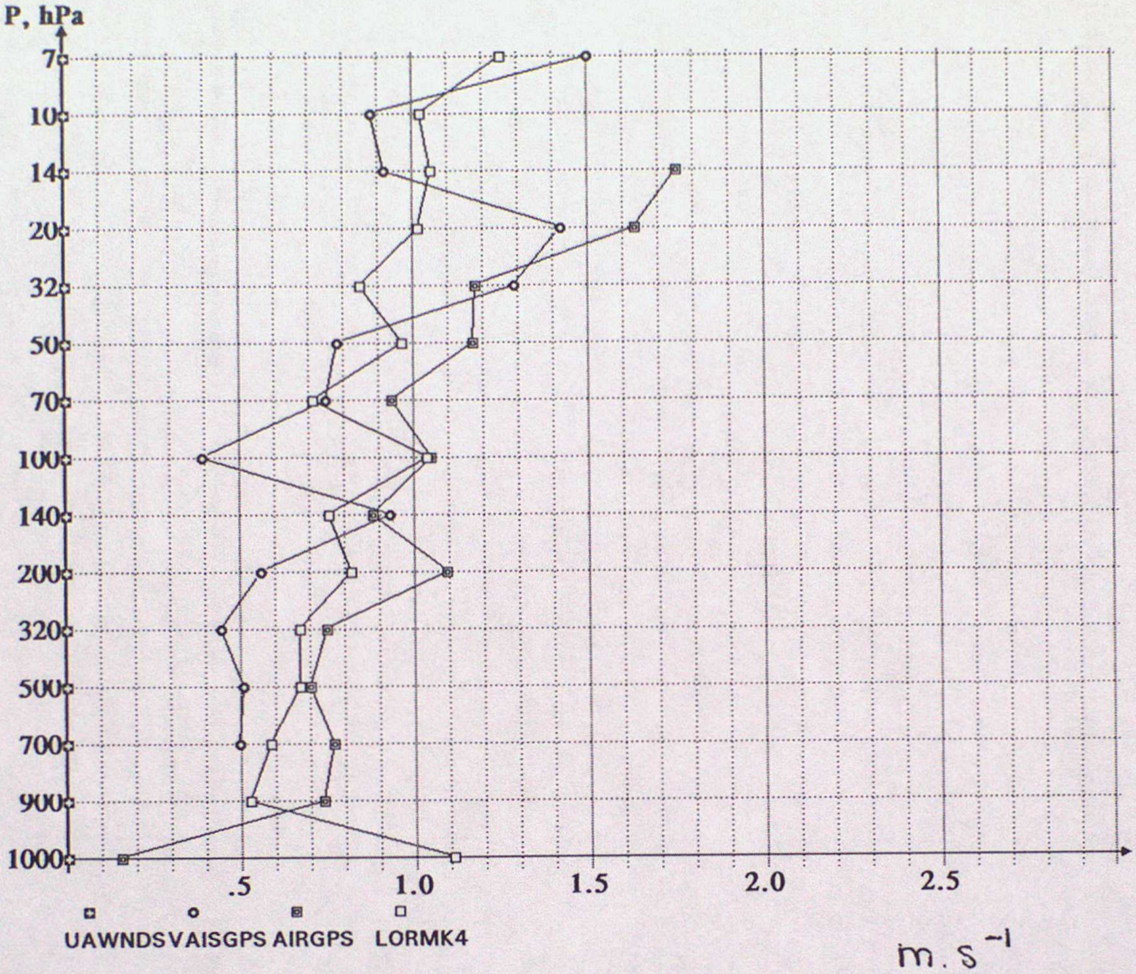


.0	.6	—	.0
0	1	0	1
.0	.5	—	-.5
0	2	0	3
.0	.2	1.1	-.3
0	3	6	6
.0	.3	.6	-.2
0	6	8	8
.0	.3	.1	-.1
0	7	11	10
.0	-.2	.0	.0
0	10	12	12
.0	-.2	-.1	.1
0	11	12	12
.0	.1	-.1	.0
0	10	12	12
.0	.0	.0	.0
0	11	12	12
.0	.1	.2	.0
0	14	13	13
.0	.0	.0	.0
0	16	13	14
.0	.1	-.1	.1
0	16	13	14
.0	.0	-.1	.0
0	15	13	13
.0	.1	-.1	-.1
0	1	7	4
.0	—	-.1	.0
0	0	2	3

m.s⁻¹

FIGURE 8(b)

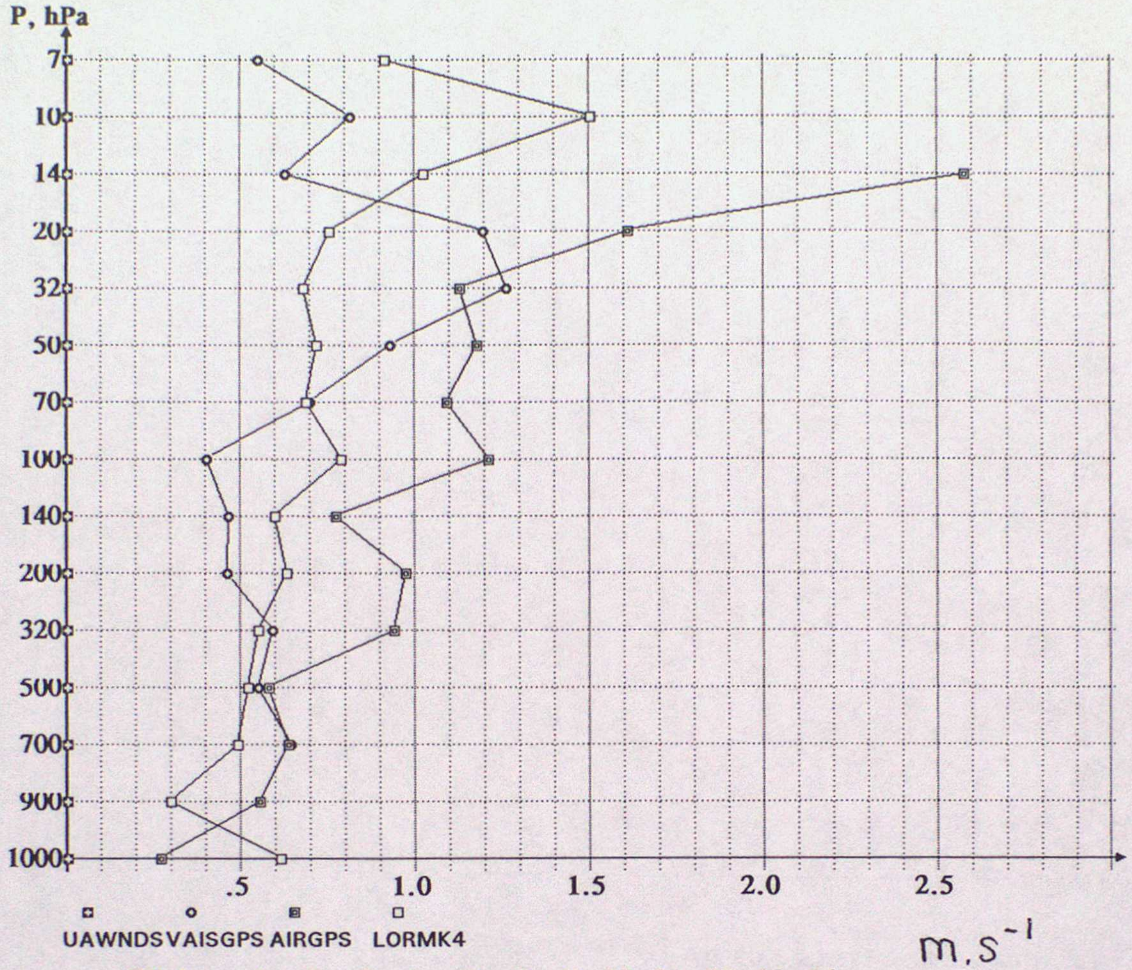
Standard deviations E-W wind
Reference: UAWNDS



Flights: 1 2 3 5 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 29

FIGURE 9 (a)

Standard deviations N-S wind
Reference: UAWNDS



Flights: 1 2 3 5 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 29

FIGURE 9 (b)

7. TEMPERATURE COMPARISONS.

7.1 Introduction.

The purpose of the Camborne test was mainly to examine the capability of the GPS windfinding system. A thorough examination of PTU performance would have required larger comparison samples, particularly at night. However, the performance of the temperature, pressure and relative humidity sensors on the GPS radiosondes was checked to identify any potential anomalies caused by the modified body design.

7.2 Trial Record of Minute PTU Data Acquisition.

The complete record of ascents in which simultaneous PTU comparisons were made is given in Table 3 of Annexe 6 which gives details of the amount of data flagged from the statistics and all timing corrections applied

7.3 Temperature Comparison Examples.

The following examples from both the 2 second and 1 minute data files displayed by the VIEWRS software highlight the main features of the upper air temperature measurements during the Trial.
As the Vaisala GPS radiosonde incorporated the same RS80 pressure ,temperature and (A-humicap) humidity sensors as in the Loran RS80L the examples highlight mainly the differences between the measurements from the AIR bead thermistor and those of the Vaisala "thermocap".

7.3.1 Scatter in the AIR Temperature Data.

Figures 10 to 12 (Flights 7, 12 and 19) show examples of the scatter in the high altitude GPS temperature measurements when compared with the RS80 profiles during the daytime.
Figures 13 to 15 (nighttime ascents 5,9 and 11 at similar levels between 30 and 10 hPa) show much less scatter in the AIRGPS temperature data than the daytime profiles. This would be expected if the proximity of the thermistor to the radiosonde body was occasionally causing it to gain heat from the radiosonde body that was already above ambient temperature. The heating effects would be greater by day than at night due to the greater effect of solar insolation compared with infrared radiation.

Thus the scatter in the temperature measurements in the high stratosphere during the daytime suggests that the proximity of the sensor boom to the radiosonde body has a significant effect and should be reduced by repositioning the sensor boom above the top of the radiosonde body.

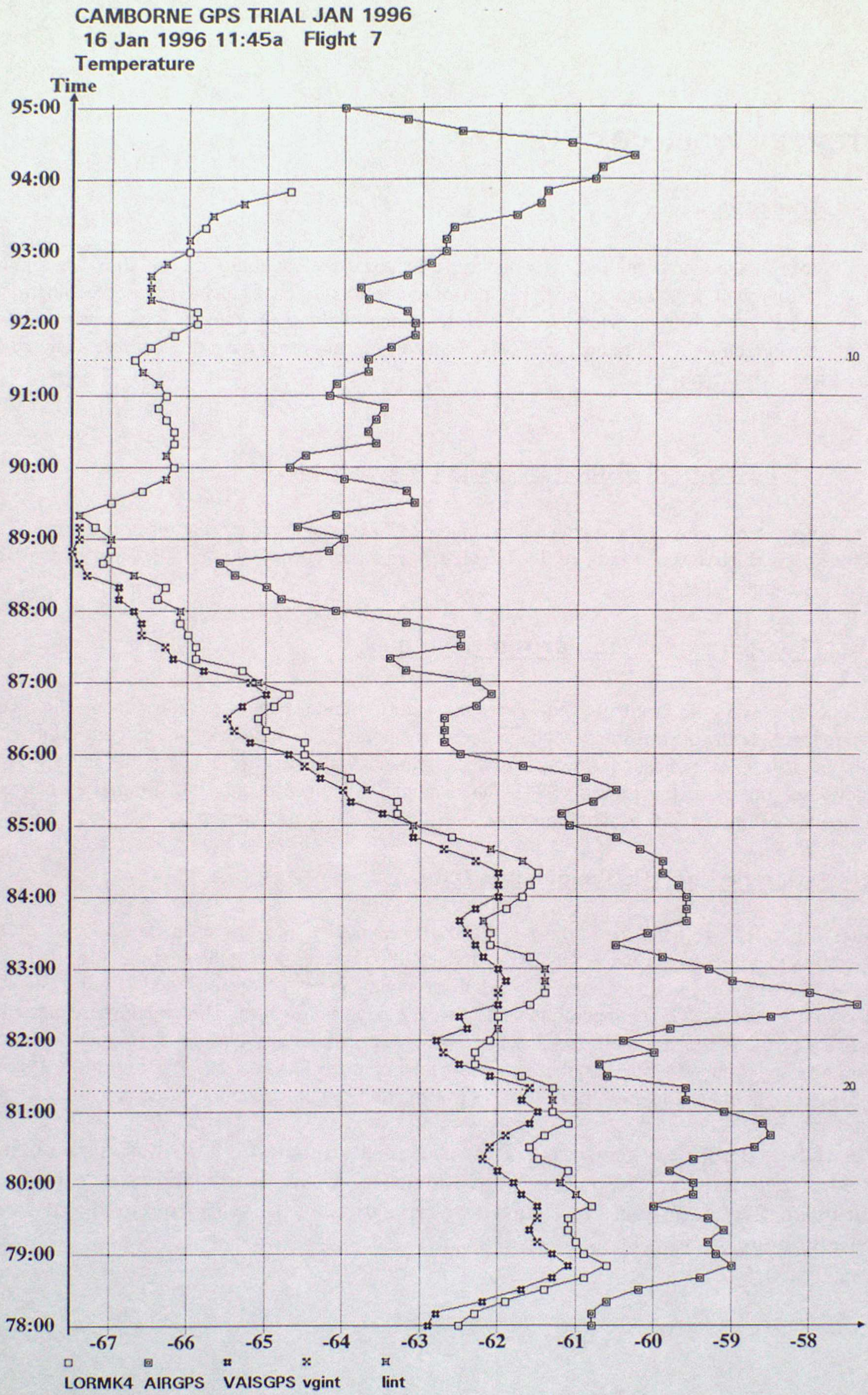
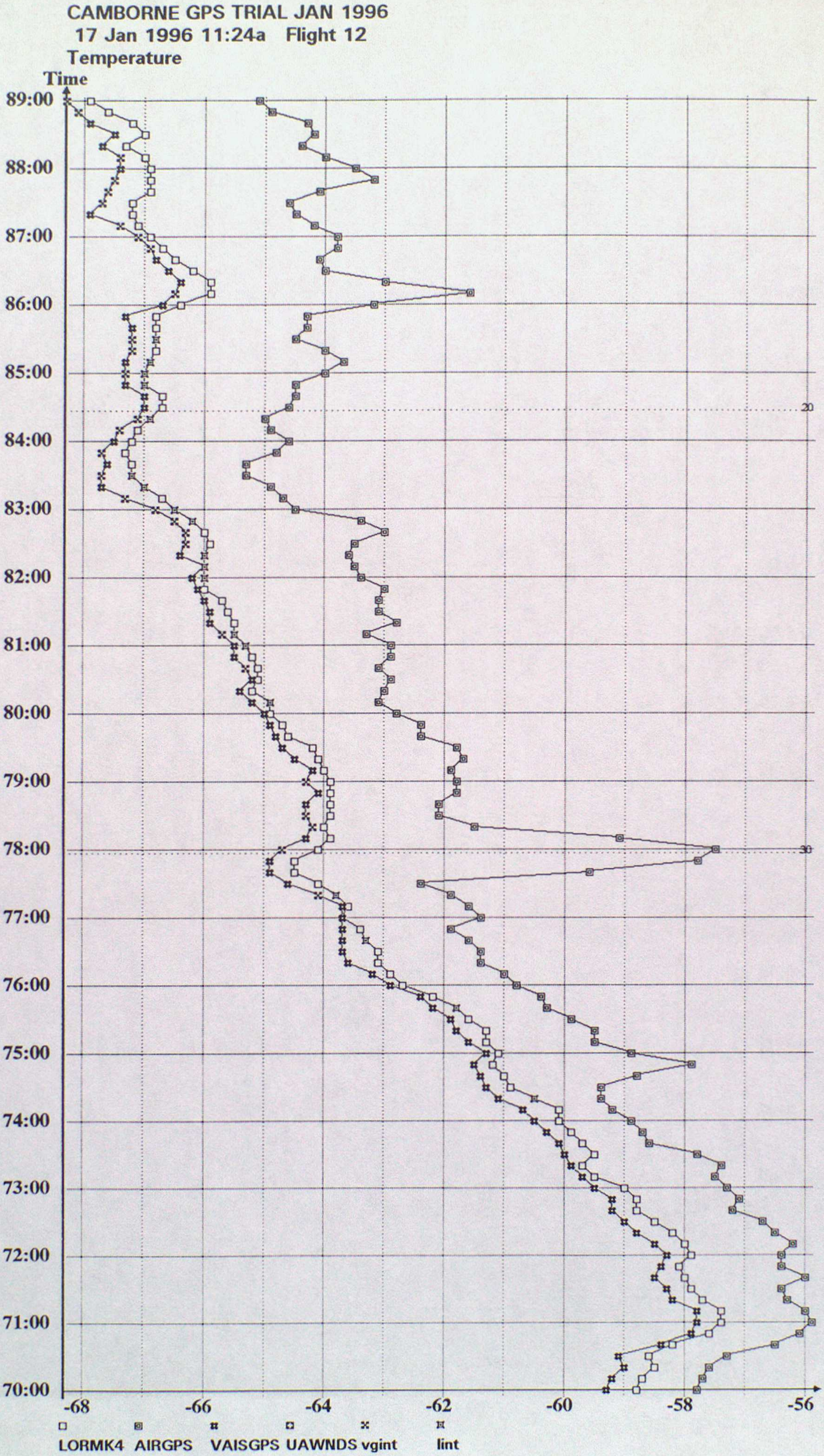

CAMBORNE GPS TRIAL JAN 1996
16 Jan 1996 11:45a Flight 7
Temperature
Time
95:00
94:00
93:00
92:00
91:00
90:00
89:00
88:00
87:00
86:00
85:00
84:00
83:00
82:00
81:00
80:00
79:00
78:00
10
20
-67
-66
-65
-64
-63
-62
-61
-60
-59
-58
LORMK4 AIRGPS VAISGPS vgint lint

FIGURE 10



CAMBORNE GPS TRIAL JAN 1996
17 Jan 1996 11:24a Flight 12
Temperature
Time
89:00
88:00
87:00
86:00
85:00
84:00
83:00
82:00
81:00
80:00
79:00
78:00
77:00
76:00
75:00
74:00
73:00
72:00
71:00
70:00
-68
-66
-64
-62
-60
-58
-56
20
30
LORMK4 AIRGPS VAISGPS UAWNDS vgint lint

FIGURE 11

CAMBORNE GPS TRIAL JAN 1996
18 Jan 1996 11:27a Flight 19
Temperature

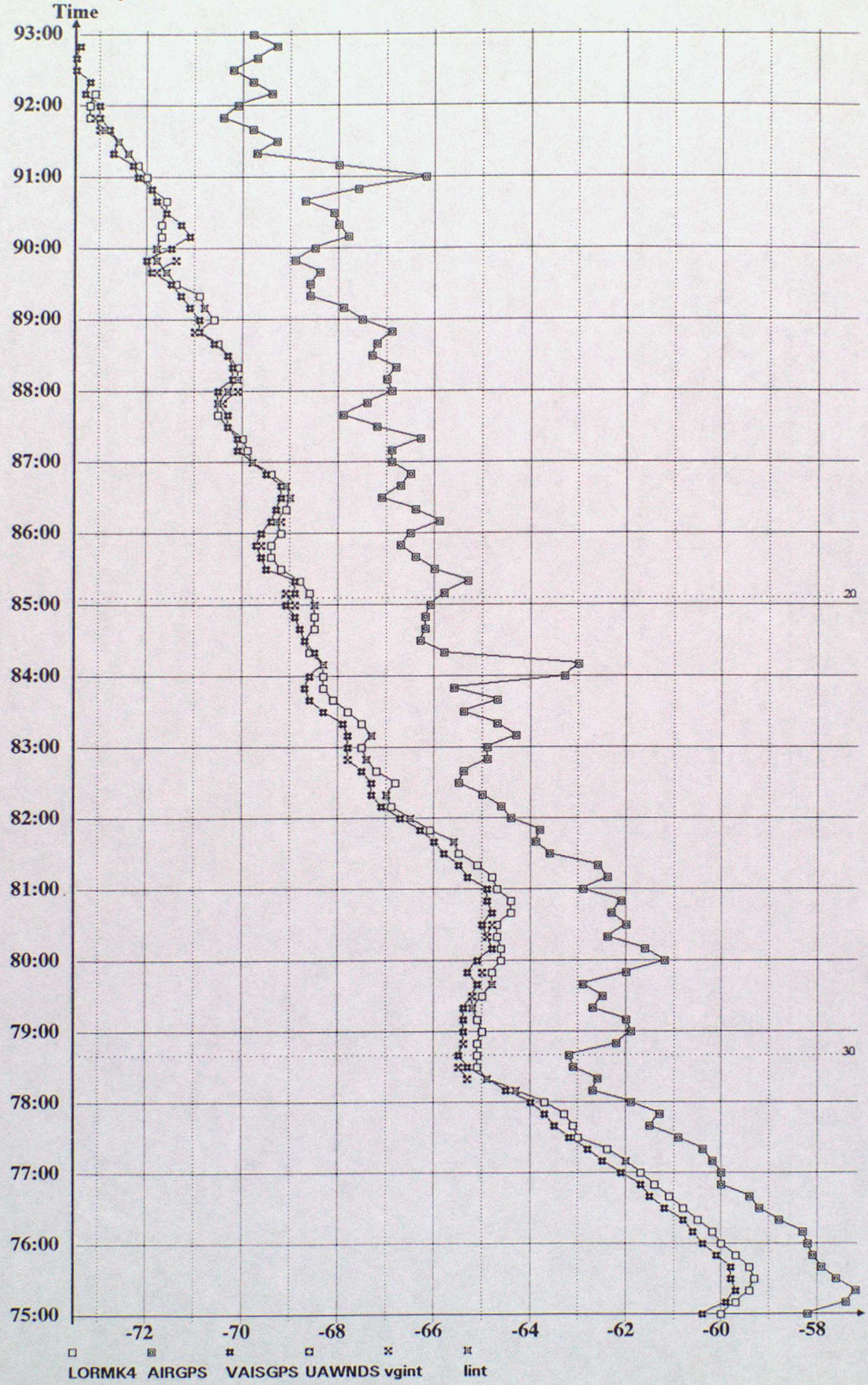
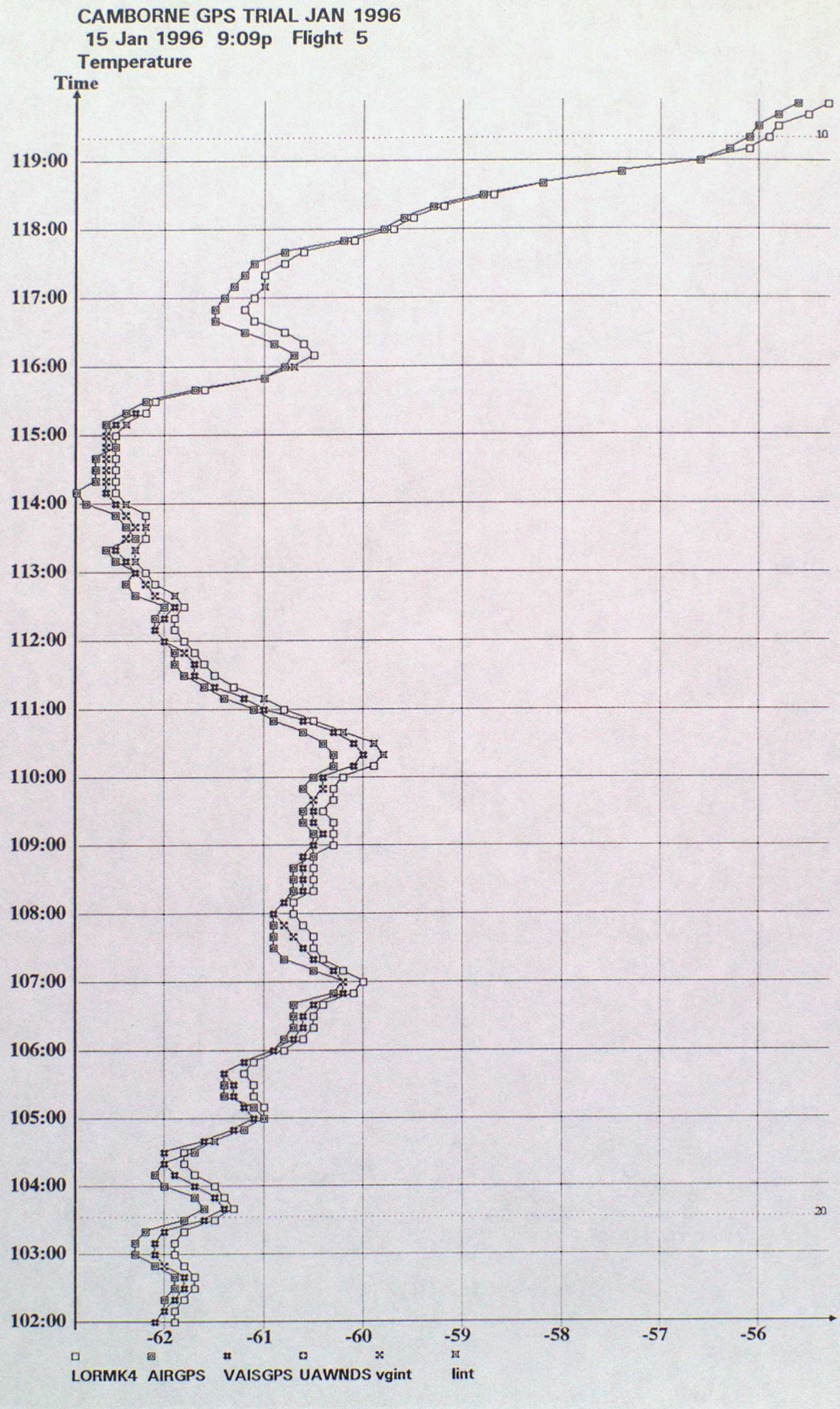


FIGURE 12



CAMBORNE GPS TRIAL JAN 1996
15 Jan 1996 9:09p Flight 5
Temperature
Time
119:00
118:00
117:00
116:00
115:00
114:00
113:00
112:00
111:00
110:00
109:00
108:00
107:00
106:00
105:00
104:00
103:00
102:00
-62
-61
-60
-59
-58
-57
-56
10
20
LORMK4
AIRGPS
VAISGPS
UAWNDS
vgint
lint

FIGURE 13

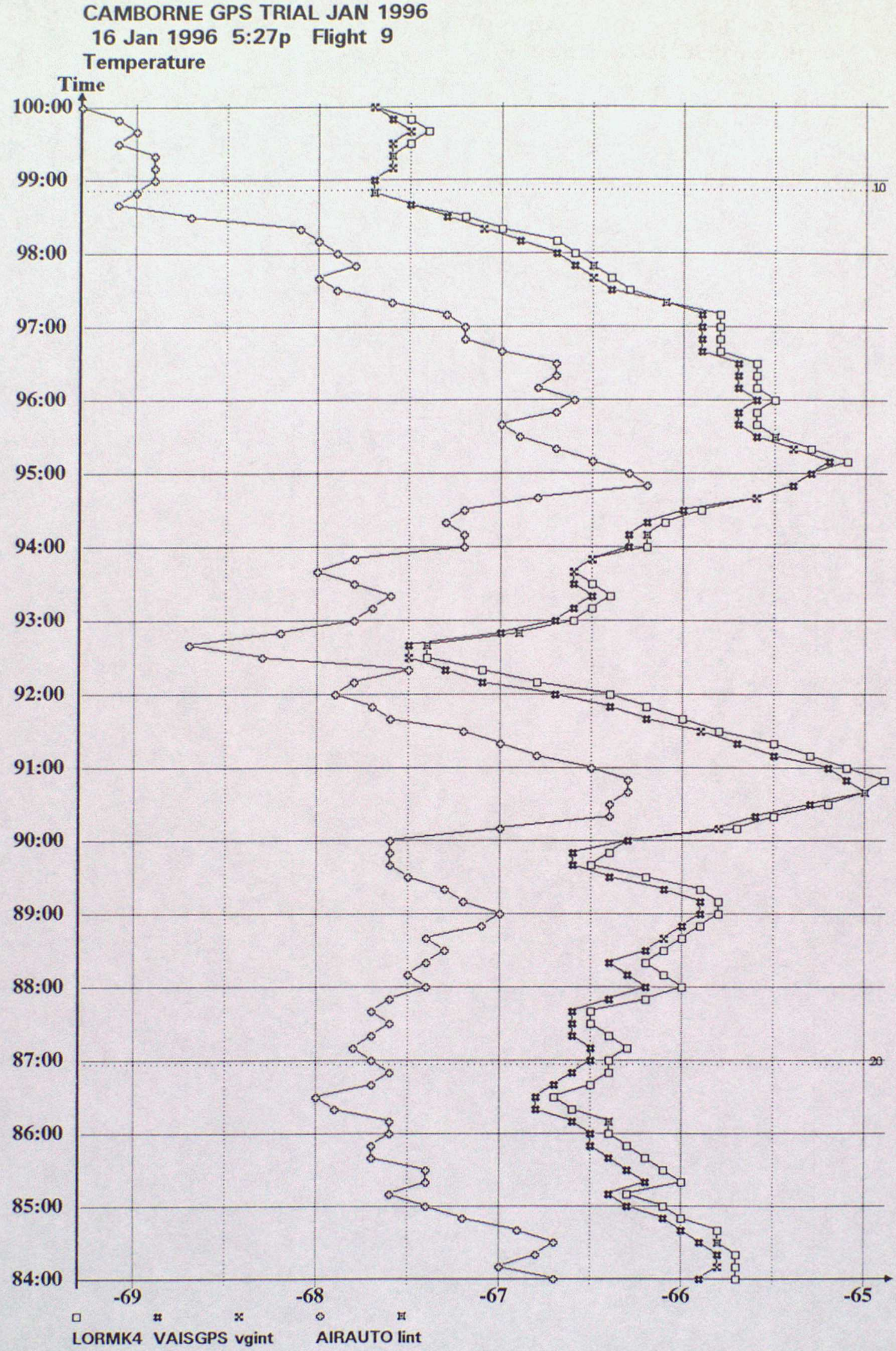
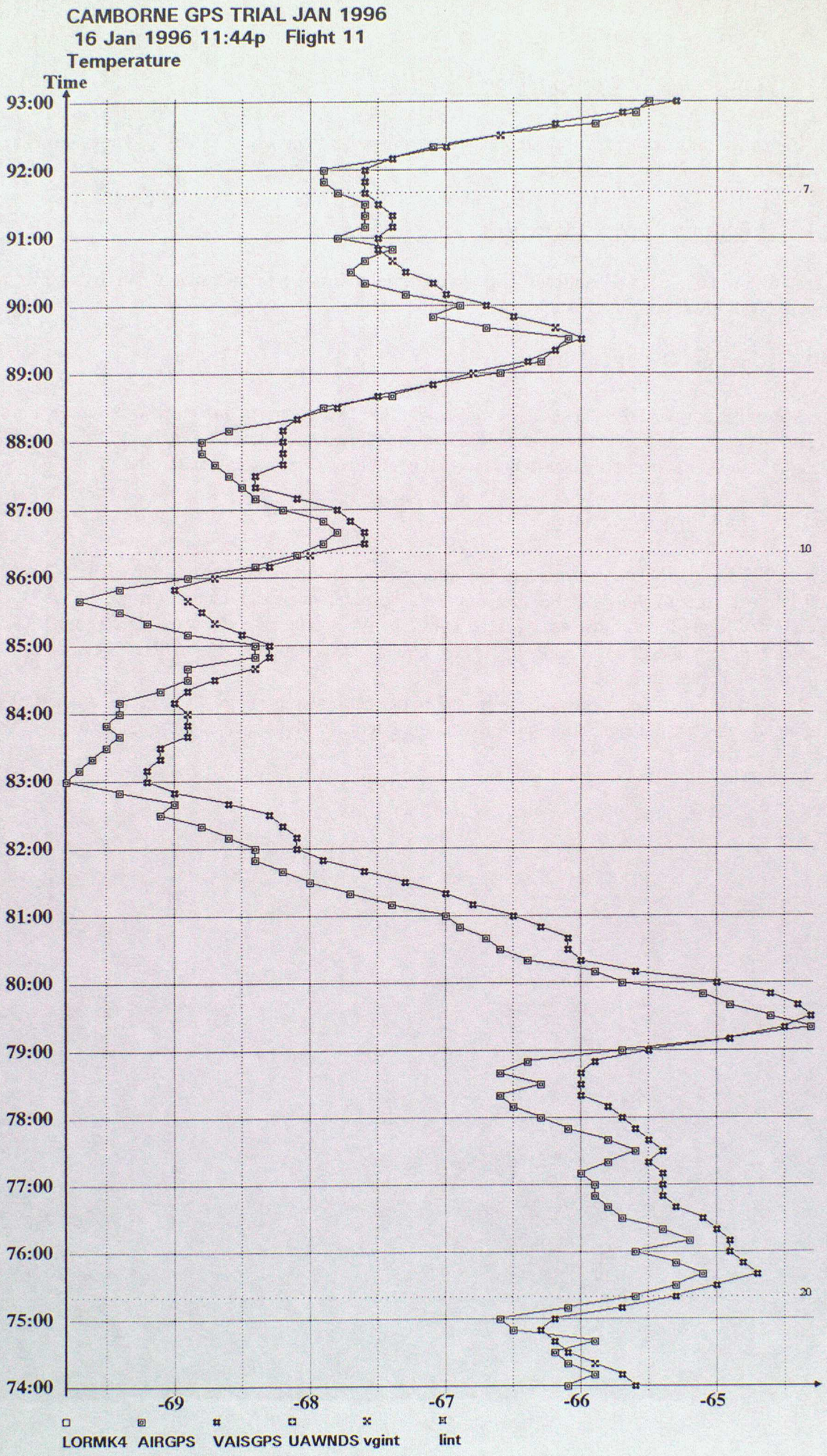

CAMBORNE GPS TRIAL JAN 1996
16 Jan 1996 5:27p Flight 9
Temperature
Time
100:00
99:00
98:00
97:00
96:00
95:00
94:00
93:00
92:00
91:00
90:00
89:00
88:00
87:00
86:00
85:00
84:00
-69
-68
-67
-66
-65
10
20
LORMK4 VAISGPS vgint AIRAUTO lint

FIGURE 14



CAMBORNE GPS TRIAL JAN 1996
16 Jan 1996 11:44p Flight 11
Temperature
Time
93:00
92:00
91:00
90:00
89:00
88:00
87:00
86:00
85:00
84:00
83:00
82:00
81:00
80:00
79:00
78:00
77:00
76:00
75:00
74:00
7
10
20
-69
-68
-67
-66
-65
LORMK4 AIRGPS VAISGPS UAWNDS vgint lint

FIGURE 15

7.4 Temperature Comparison Results.

Only the small amount of data from the Database shown as flagged in Table 3 (Annexe 6) has been excluded from the following analyses :-

7.4.1 Nighttime Direct Differences.

Figure 16 shows the mean (Flight by flight) temperature differences for the minute data banded within the pressure zones given in Table 1 Annexe 4.

7.4.2 Daytime Direct Differences.

The AIR GPS software does not apply any radiation corrections to the measured temperatures.The increase in the relative bias betwen the AIRGPS temperature measurements and those of the Loran RS80 shown in Figure 17 is primarily due to the increasing effect of solar insolation with height.

7.4.3 Standard Deviations.

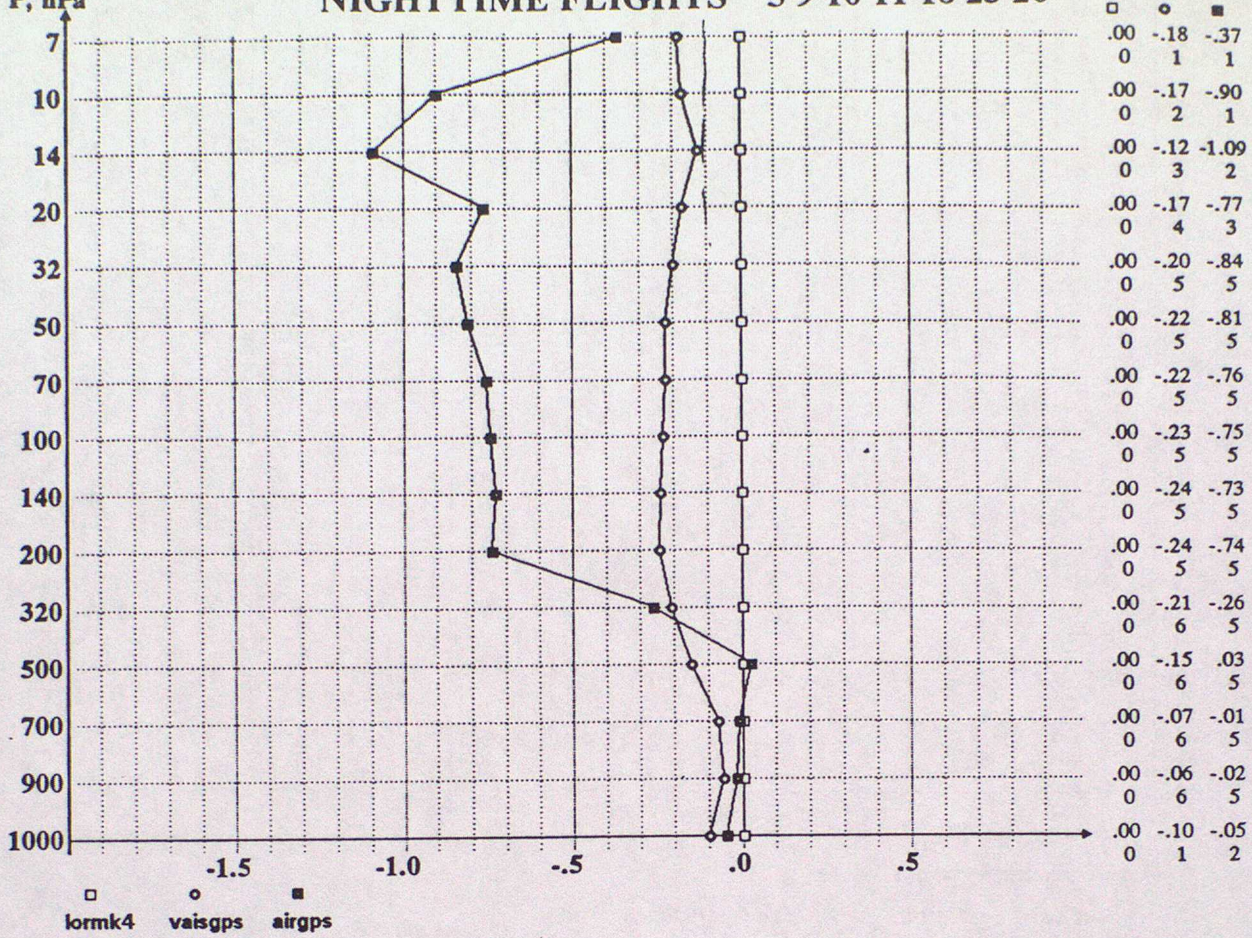
Figure 19 shows the Nighttime standard deviation of the minute temperature biases.The 0.3 to 0.4 °C standard deviations of the AIRGPS measurements do not reduce significantly in the Flight By Flight standard deviations for differences averaged over layers computed for the same data (Figure 18). This indicates that that the there is appreciable flight to flight variation in the AIRGPS errors caused by calibration and other differences .

The standard deviations of the daytime temperature biases shown in Figure 21 increase to about 0.7°C at 30 hPa and again are not significantly reduced in the Flight By Flight analysis of Figure 20.

Flight-by-flight differences Temperatur(
Reference: lormk4

FIGURE 16

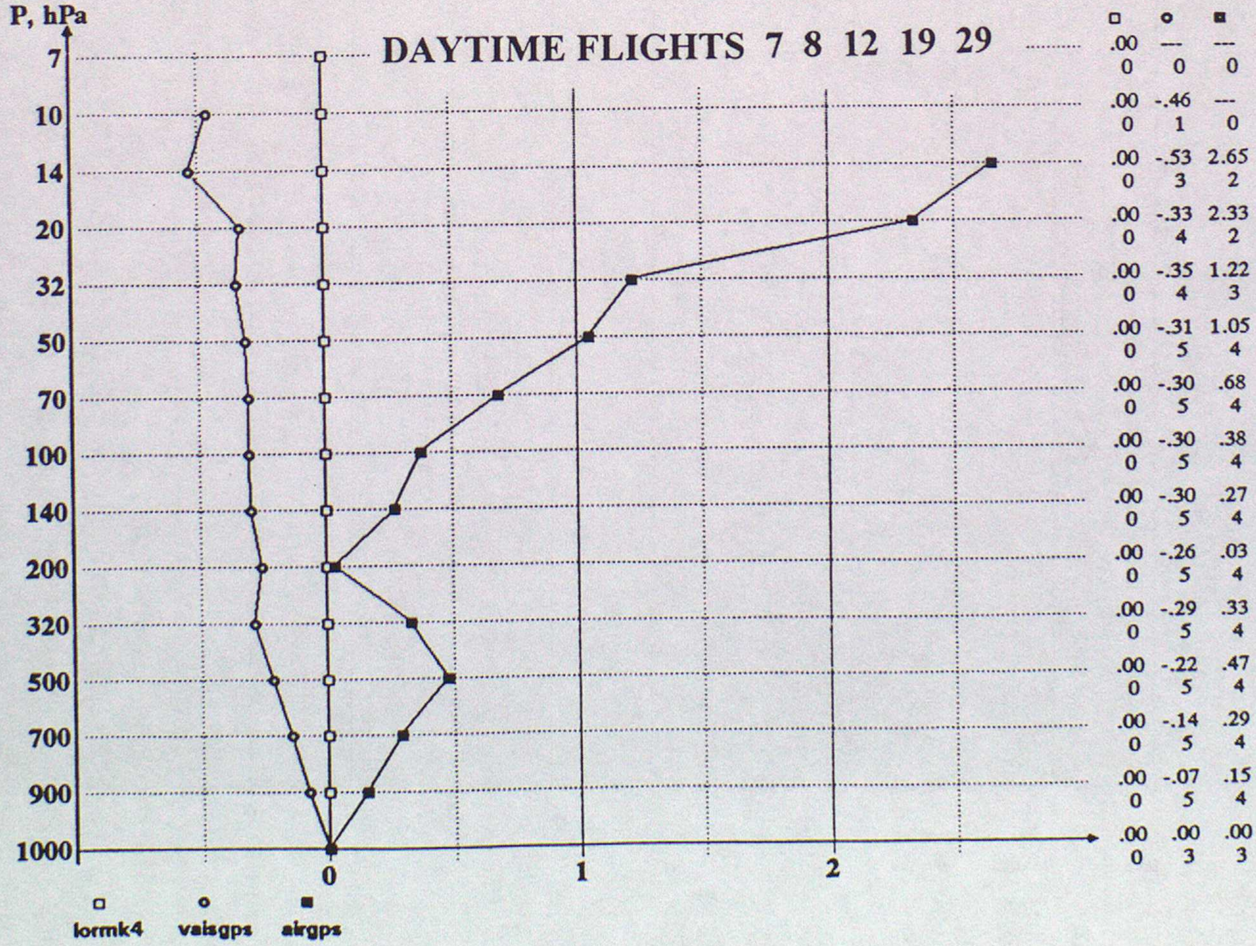
NIGHTTIME FLIGHTS 5 9 10 11 18 23 26



Flight-by-flight differences Temperature
Reference: lormk4

FIGURE 17

DAYTIME FLIGHTS 7 8 12 19 29

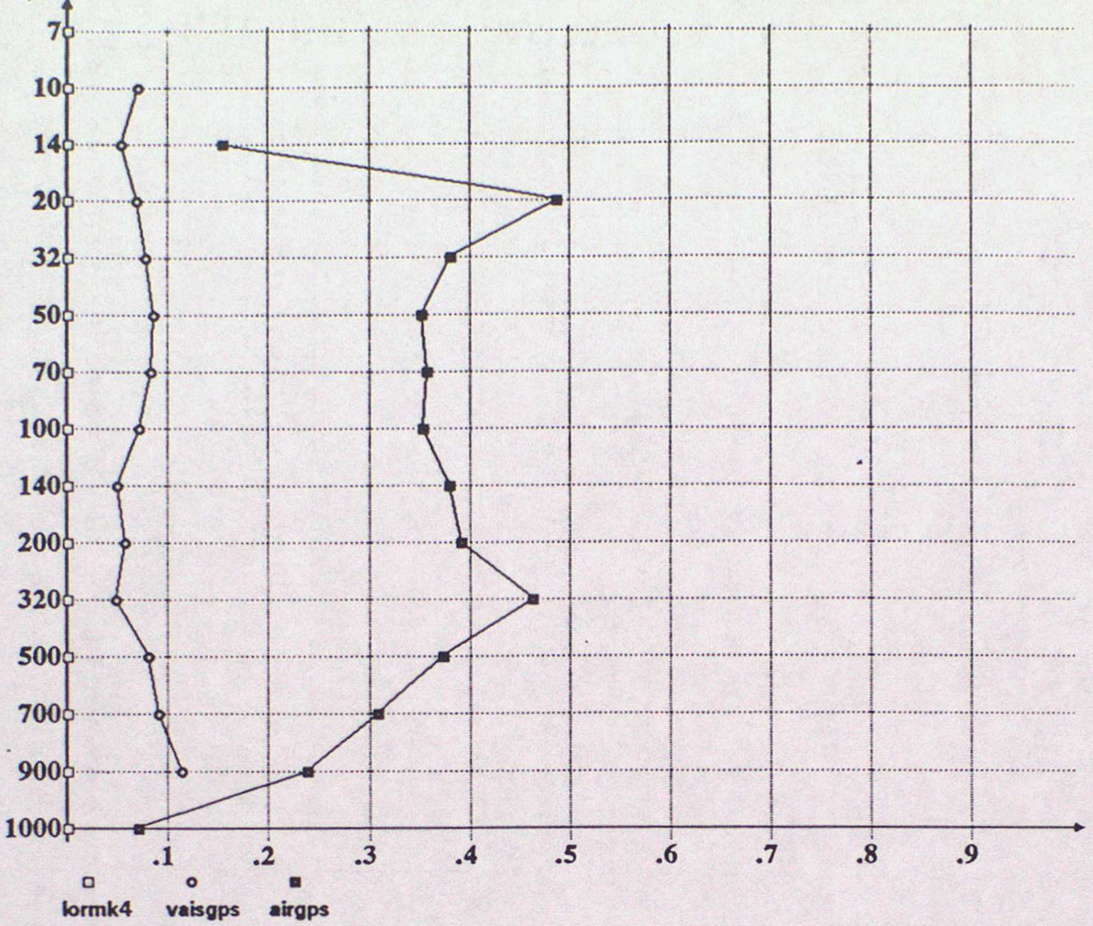


1

Flight-by-flight st. deviations Temperature
Reference: lormk4

FIGURE 18

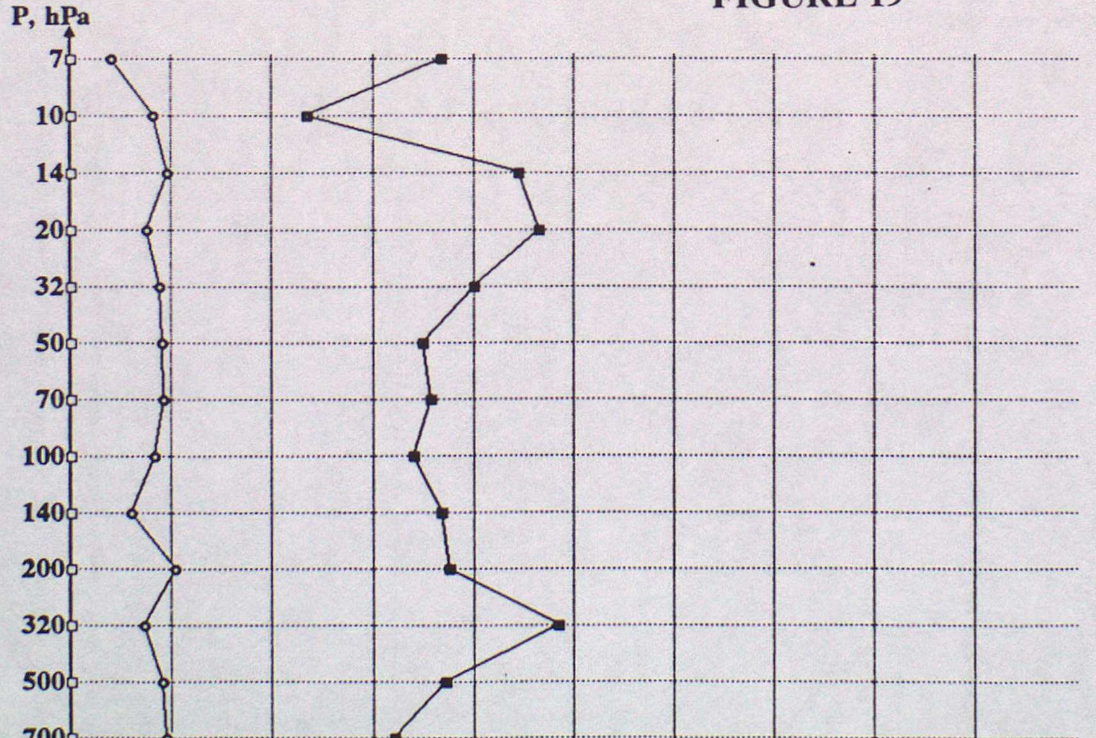
NIGHTTIME FLIGHTS 5 9 10 11 18 23 26



□	○	■
.00	---	---
0	1	1
.00	.07	---
0	2	1
.00	.05	.16
0	3	2
.00	.07	.49
0	4	3
.00	.08	.38
0	5	5
.00	.09	.35
0	5	5
.00	.08	.36
0	5	5
.00	.07	.35
0	5	5
.00	.05	.38
0	5	5
.00	.06	.39
0	5	5
.00	.05	.46
0	6	5
.00	.08	.37
0	6	5
.00	.09	.31
0	6	5
.00	.11	.24
0	6	5
.00	---	.07
0	1	2

Standard deviations Temperature
Reference: lormk4

FIGURE 19



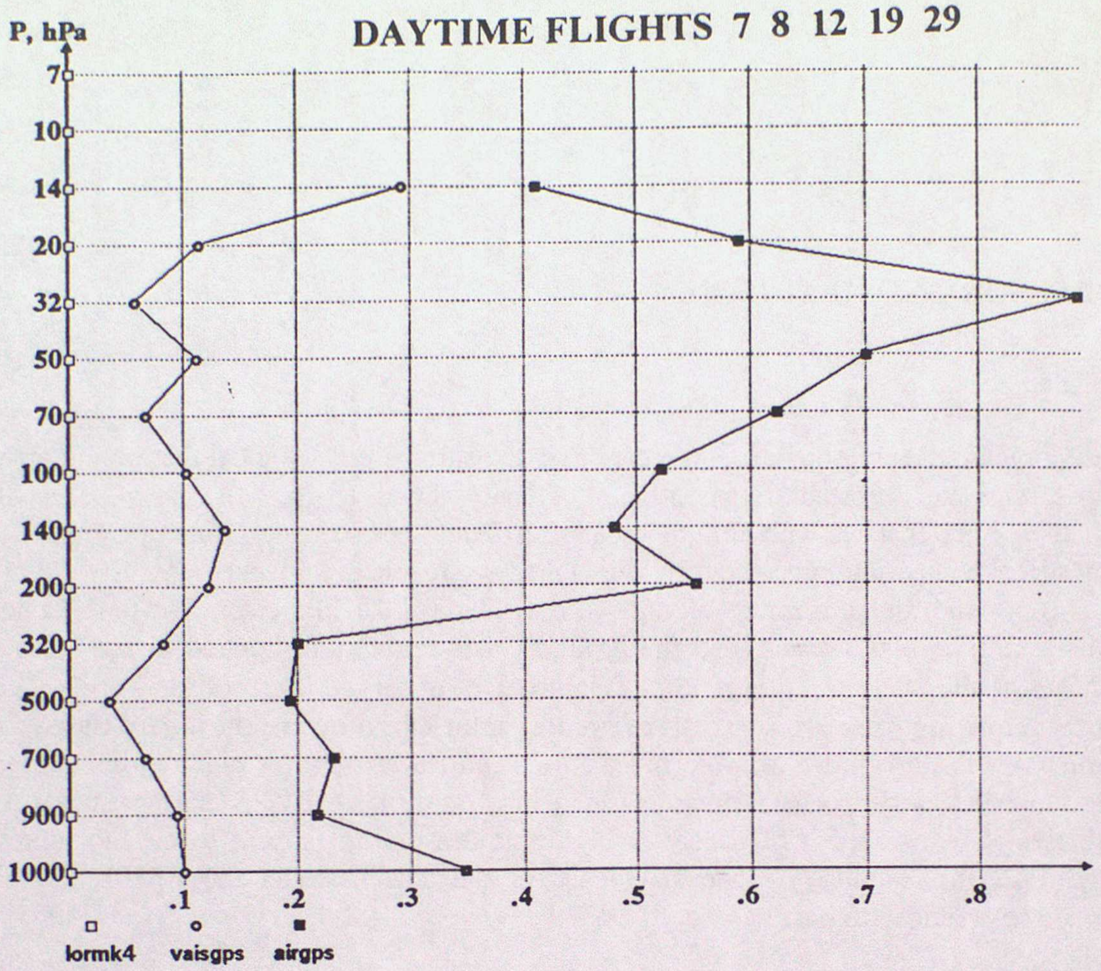
□	○	■
.00	.04	.37
6	6	6
.00	.08	.23
10	10	5
.00	.10	.44
15	15	11
.00	.08	.47
29	29	23
.00	.09	.40
57	47	49
.00	.09	.35
43	36	37
.00	.09	.36
44	37	38
.00	.08	.34
47	40	40
.00	.06	.37
41	34	35
.00	.10	.37
48	40	40
.00	.07	.48
74	61	54
.00	.09	.37
55	47	39
.00	.09	.32
56	47	41
.00	.12	.25
29	25	21
.00	---	.07
2	1	2

printed 6/2/96
Flights: 5 9 10 11 18 23 26

Flight-by-flight st. deviations Temperature
Reference: lormk4

FIGURE 20

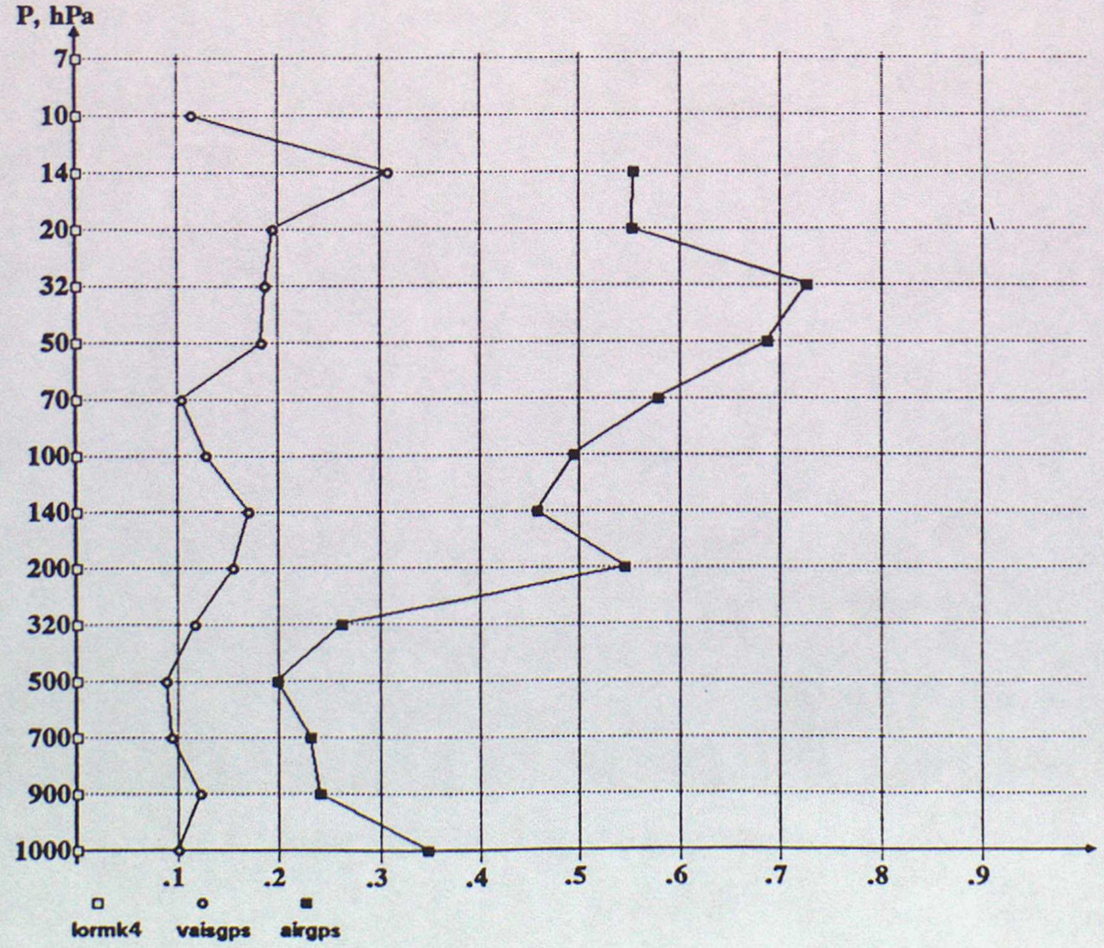
DAYTIME FLIGHTS 7 8 12 19 29



P, hPa	□	○	■
7	.00	---	---
	0	0	0
10	.00	---	---
	0	1	0
14	.00	.29	.41
	0	3	2
20	.00	.11	.59
	0	4	2
32	.00	.06	.89
	0	4	3
50	.00	.11	.70
	0	5	4
70	.00	.07	.62
	0	5	4
100	.00	.10	.52
	0	5	4
140	.00	.14	.48
	0	5	4
200	.00	.12	.55
	0	5	4
320	.00	.08	.20
	0	5	4
500	.00	.04	.19
	0	5	4
700	.00	.07	.23
	0	5	4
900	.00	.09	.22
	0	5	4
1000	.00	.10	.35
	0	3	3

Standard deviations Temperature
Reference: lormk4

FIGURE 21



P, hPa	□	○	■
7	.00	---	---
	0	0	0
10	.00	.11	---
	5	5	0
14	.00	.31	.55
	15	15	10
20	.00	.19	.55
	24	24	12
32	.00	.19	.72
	38	38	22
50	.00	.18	.69
	34	34	27
70	.00	.10	.58
	37	37	30
100	.00	.13	.50
	35	35	28
140	.00	.17	.46
	37	34	30
200	.00	.15	.55
	44	40	35
320	.00	.12	.26
	55	55	45
500	.00	.09	.20
	42	42	33
700	.00	.09	.23
	43	43	31
900	.00	.12	.24
	22	19	14
1000	.00	.10	.35
	3	3	3

printed 6/2/96

DAYTIME FLIGHTS Flights: 7 8 12 19 29

8. PRESSURE COMPARISONS.

8.1 General

In order to compare the pressure measurements near the surface it is essential that timing errors on comparison ascents are accurate to within about one second. (At 6 ms^{-1} rate of ascent the near-surface pressure changes with altitude by about 0.7 hPa per second). Timing is much less significant when comparing pressures in the higher stratosphere however. At 10 hPa, for example, a 10 second timing error would induce only about a 0.1 hPa error. Previous Table 3 records the timing corrections and also the ground check corrections applied to the pressure measurements at the surface. **During the Trial it was observed that there were 4 AIR radiosondes requiring pressure corrections greater than 2 hPa before they were flown . At least 2 other AIR radiosondes ,unable to be flown ,had even greater corrections**. Despite sometimes applying large surface pressure corrections to the AIRGPS measurements the pressure biases shown by the AIR sensor at high altitudes did not appear to be anomalously large. Figure 22 (a) (Flight 7) for example shows the bias between the RS80L and the AIRGpSonde has reduced to near zero at 10hPa.

An overall analysis of the differences in pressure measurements was produced using minute data within the same bands as used for the temperature comparisons. All the following comparison analyses use the RS80 Loran pressure measurements as the reference.

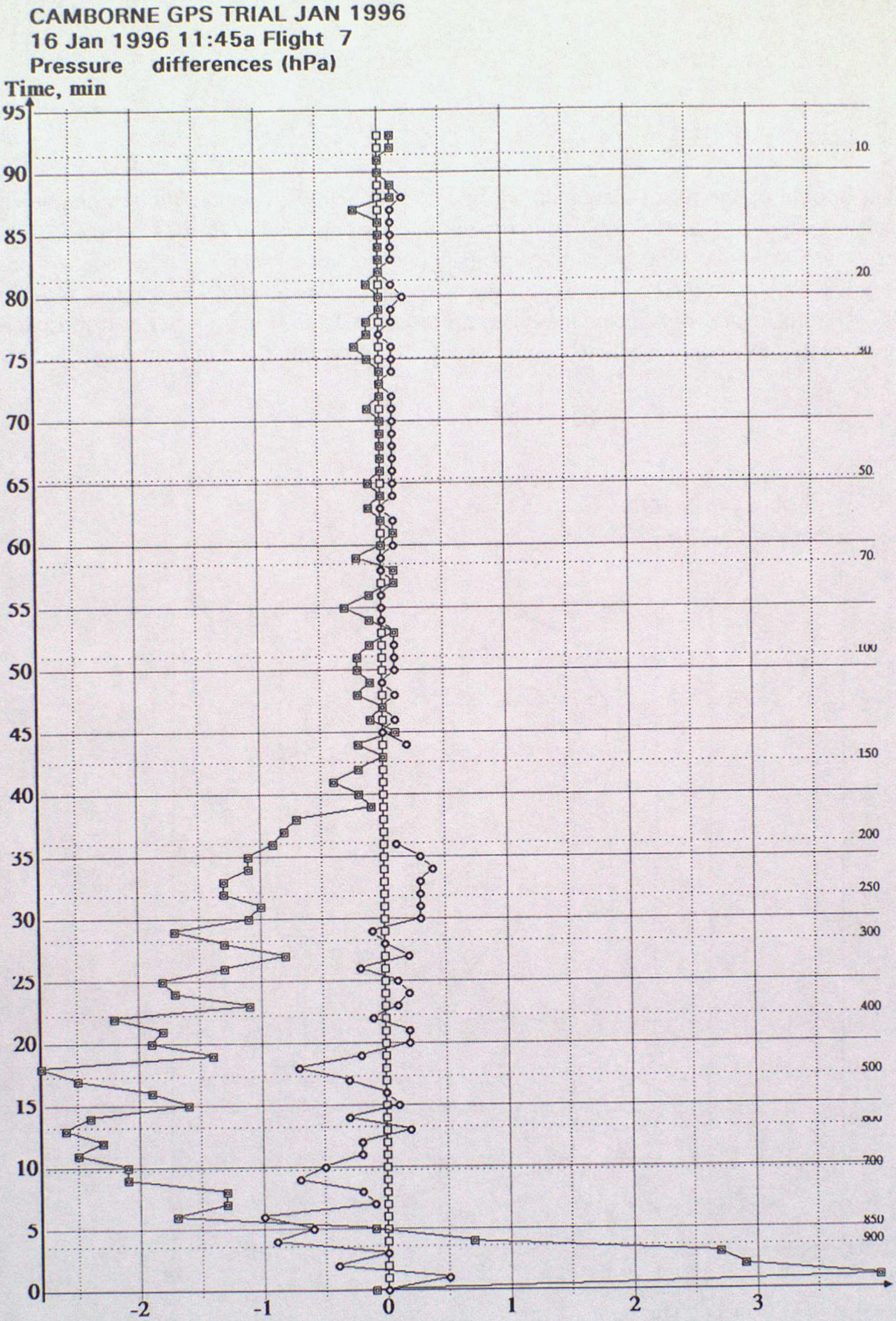


FIGURE 22 (a)

LARGE AIRGPS PRESSURE BIAS NEAR SURFACE (Ground corection -4.3 hPa

8.2 Pressure Bias

The profile of the mean biases shown in Fig 22B below ,from the limited number of flights available, suggest that the GPSonde pressure readings are similar to those of the RS80 at levels between 50 and 10 hPa. (Previous comparisons between radar and radiosonde geopotential heights have shown the RS80 to report pressures approximately 0.4 hPa too low at 10 hPa .) The RS80 pressure transducer may read up to about 1 hPa too high in the troposphere due to the inability of its components to compensate fully for rapid temperature changes .

FIGURE 22B

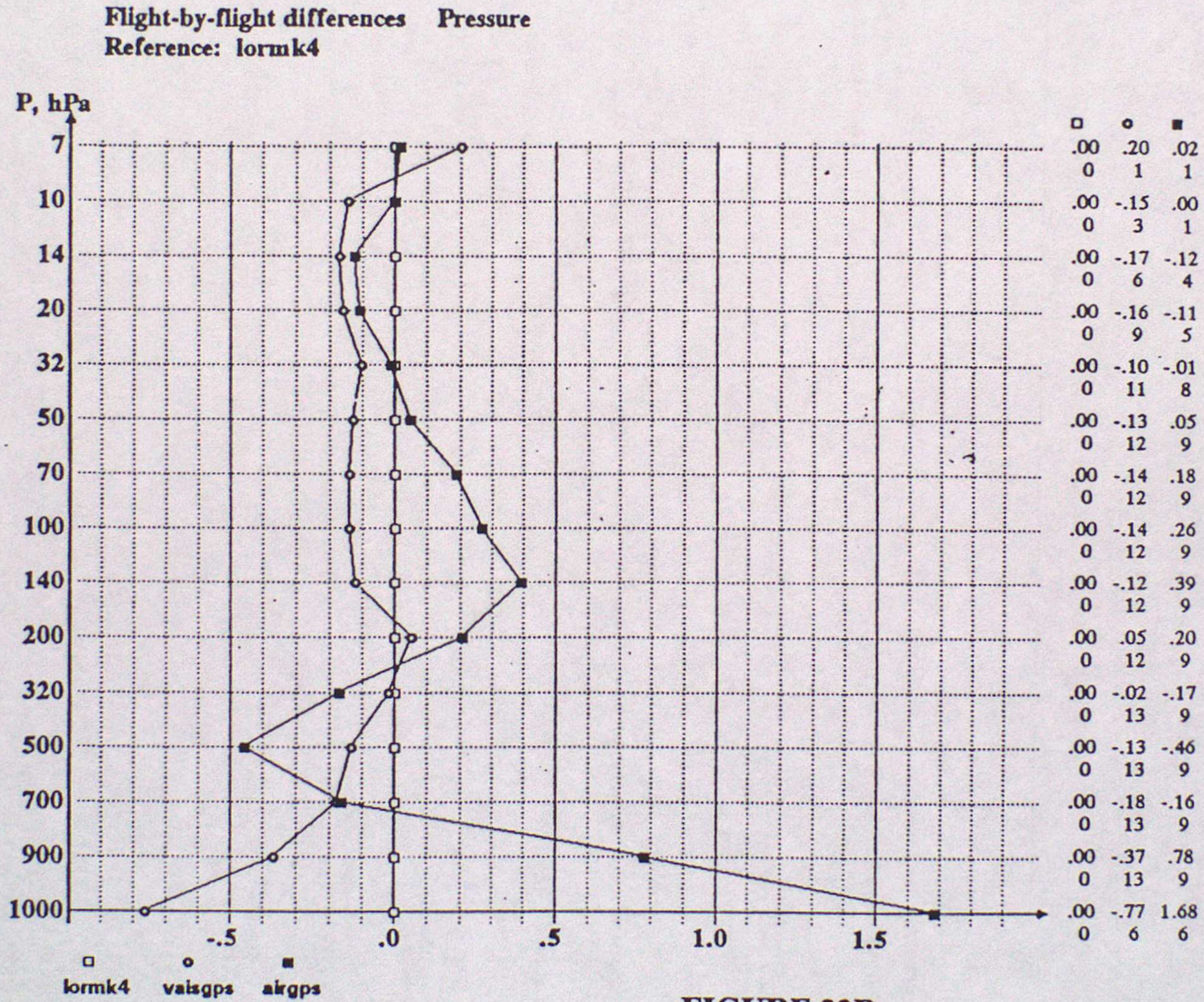


FIGURE 22B

printed 7/2/96

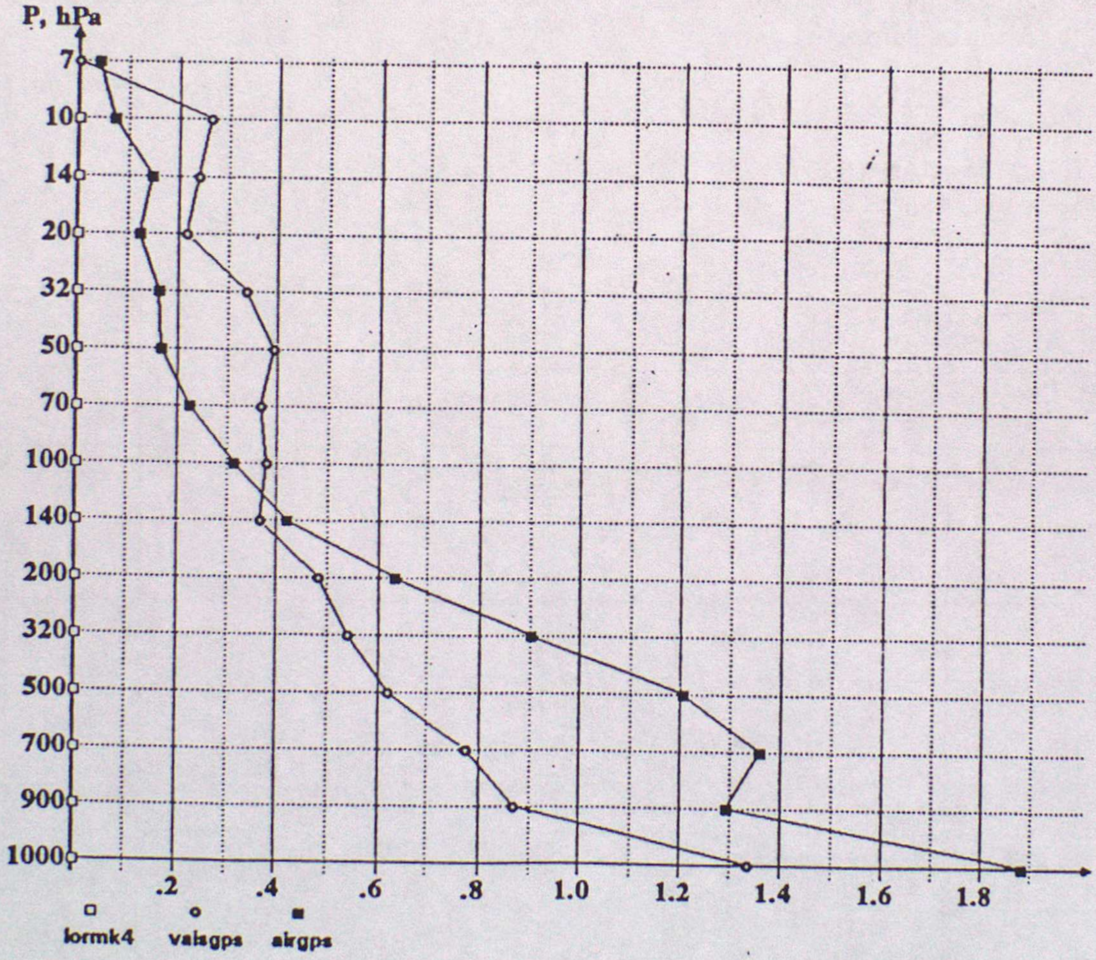
Flights: 3 5 7 8 9 10 11 12 18 19 23 25 26 29

8.3 Pressure Standard Deviation.

Figure 22 (c) shows the standard deviation of the pressure measurements of the 2 GPS sensors compared against those of the RS80L. Some of the variability in the AIRGPS biases at low levels is probably due to the difficulty in correcting for the timing errors to better than 1 second accuracy.

FIGURE 22 (c)

Standard deviations **Pressure**
Reference: lormk4



□	○	■
.00	.00	.04
6	6	6
.00	.26	.07
15	15	5
.00	.24	.15
30	30	21
.00	.22	.12
59	59	35
.00	.34	.16
114	104	72
.00	.39	.17
90	83	64
.00	.37	.22
96	89	68
.00	.38	.31
96	89	68
.00	.37	.42
92	85	65
.00	.48	.63
110	102	75
.00	.54	.90
152	139	99
.00	.62	1.21
113	105	72
.00	.77	1.36
127	119	82
.00	.87	1.29
61	57	40
.00	1.33	1.88
7	6	6

printed 7/2/96
Flights: 3 5 7 8 9 10 11 12 18 19 23 25
26 29

9 HUMIDITY COMPARISONS.

9.1 Humidity Comparisons at 2 Second Resolution.

All comparisons used the operational RS80L humidity mesurements as reference.

9.1.1 AIR Gpsonde Humidity Measurements.

Although none of the ascents was flown in continuous rain , most comparison flights traversed through low cloud and temperature sensors often displayed varying degrees of psychrometric cooling on emerging from the cloud. The occurrence of these conditions was used to designate the flights "wet" or "dry" .Only 2 of the comparison ascents incorporating the AIR GPSonde (Flights 7 and 8 flown in the daytime were likely to have avoided saturated air.

Figures 23 (a) and 23 (b) show that during these 2 "dry" flights the GPSonde humidity measurements in the boundary layer appear to be anomalously low (by up to about 25%. on Flight 7) These anomalies can be confirmed in the preflight field checks made for these ascents suggesting erroneous humiditty calibrations for these radiosondes at the moist end of the scale or perhaps inaccuracies caused by solar heating of the sensor and protective cover.

FIGURE 23 (a)

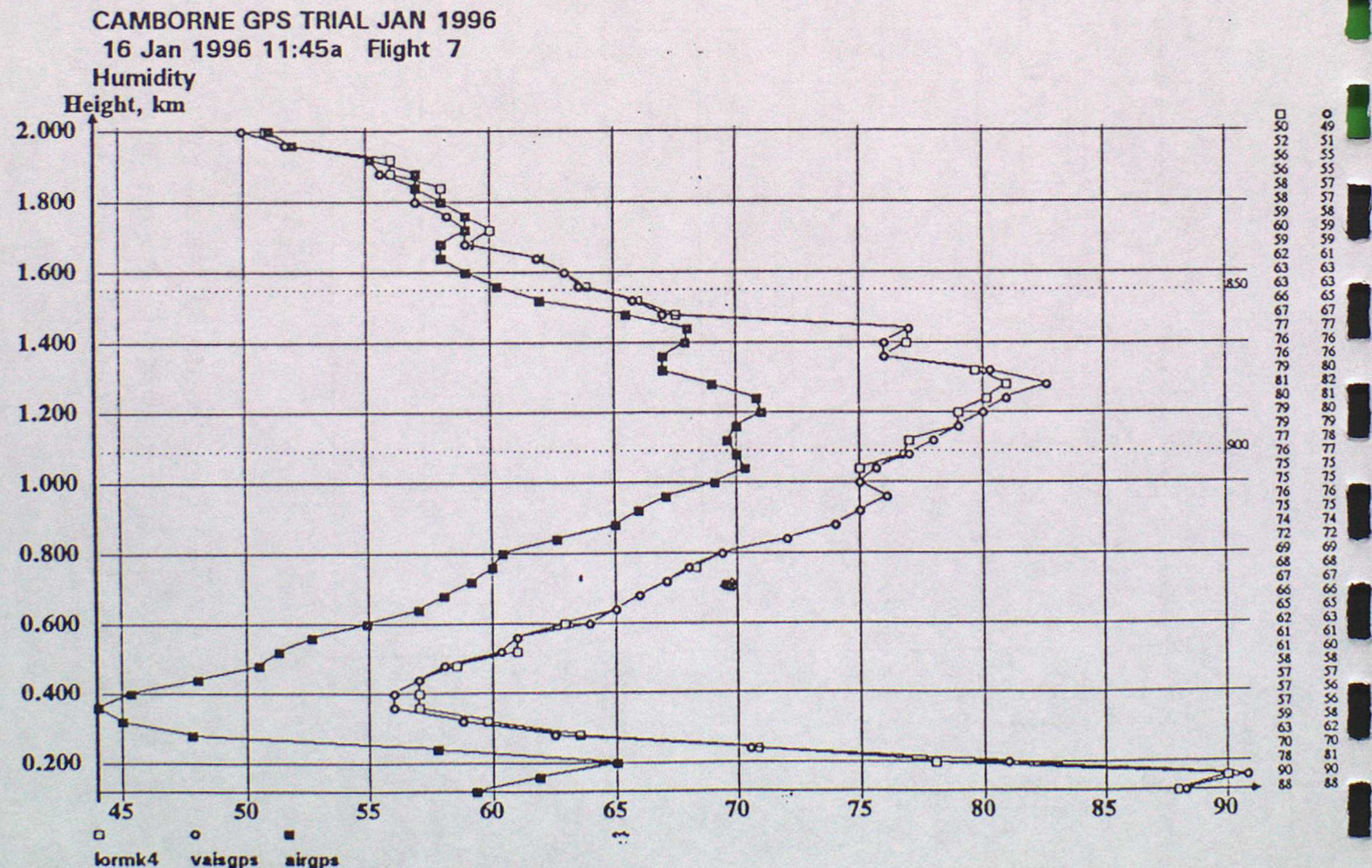


FIGURE 23A ANOMALOUSLY LOW AIR HUMIDITIES IN THE BOUNDARY LAYER

CAMBORNE GPS TRIAL JAN 1996

16 Jan 1996 2:37p Flight 8

Humidity

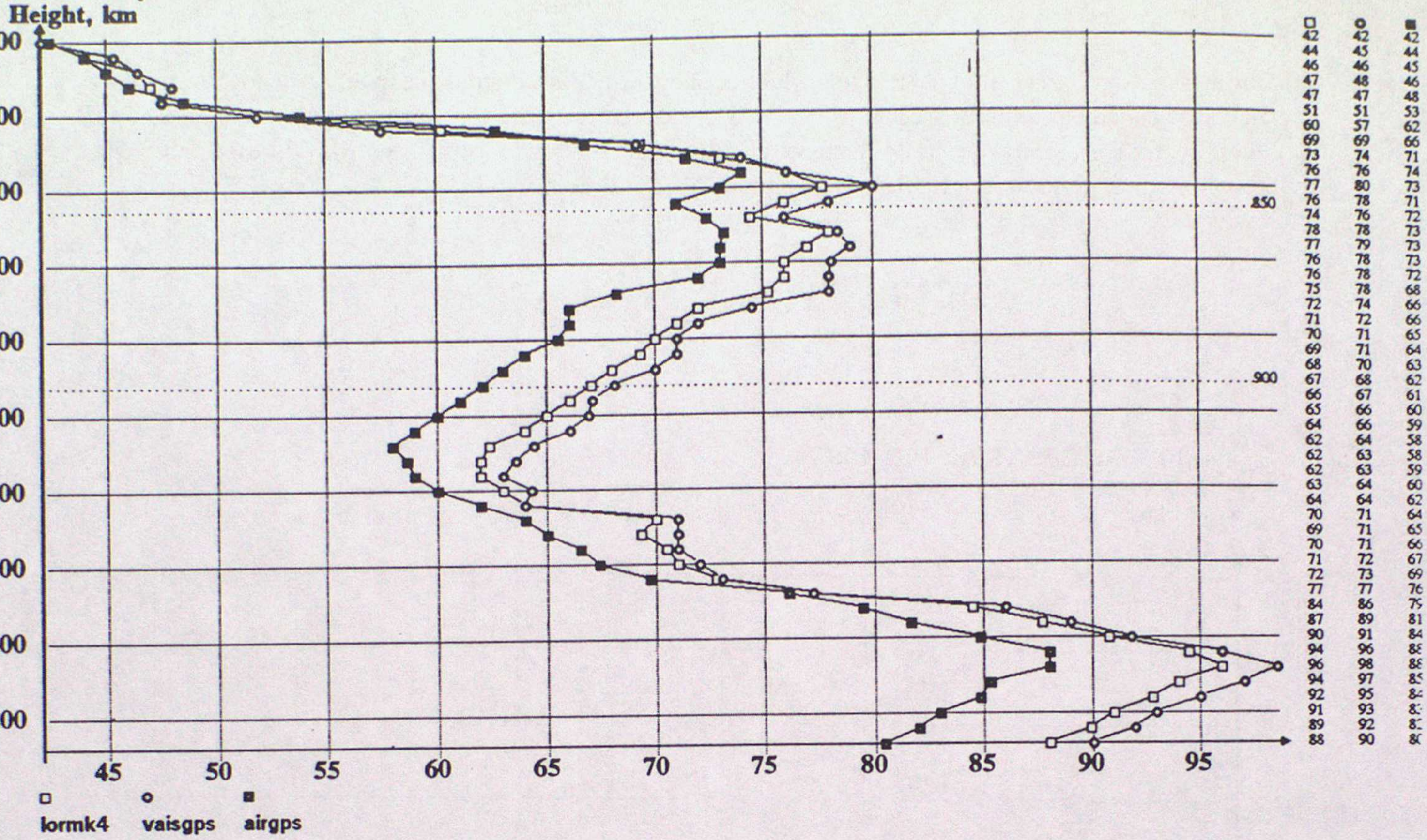
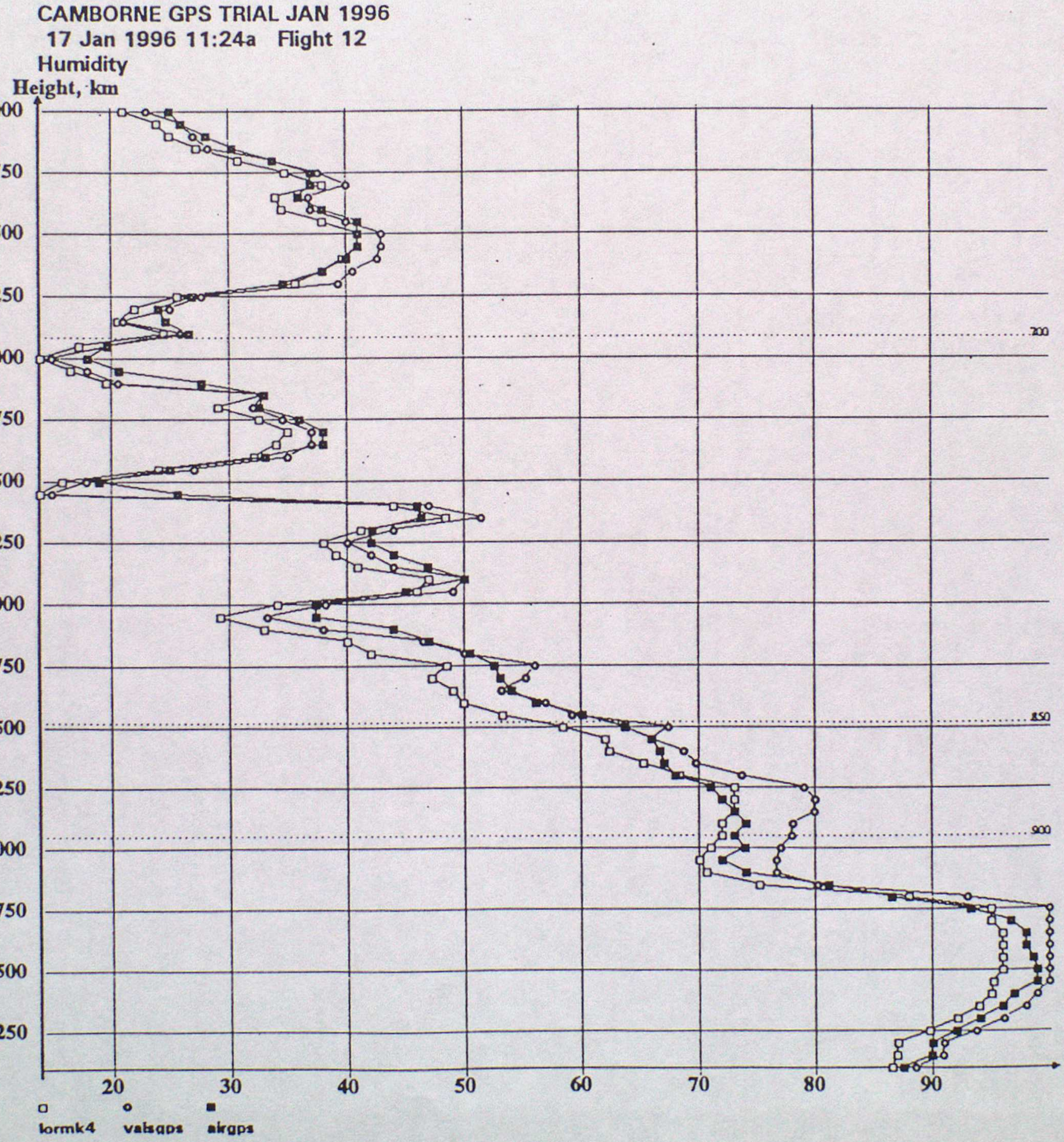


FIGURE 23B

During the "wet" ascents the AIR sensor did not show such large anomalies and responded to humidity changes adequately. These ascents show better agreement between the radiosondes,with the AIR humidity measurements generally reading slightly higher than those of the RS80L especially when traversing through low cloud.. Refer to example 23 (c) below (Flight 12)

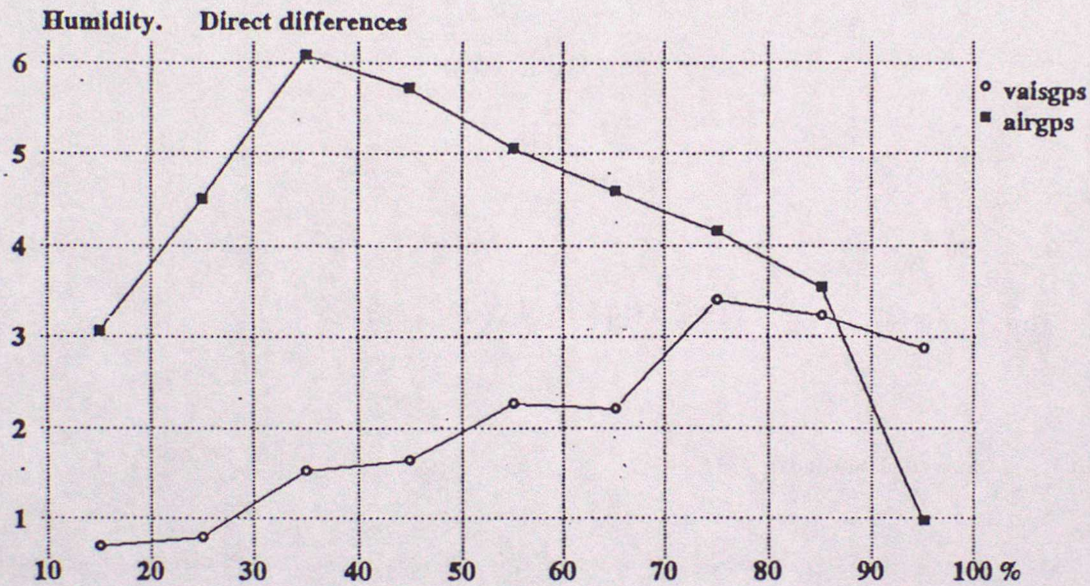
FIGURE 23 (c)



9.3 Humidity Comparison Statistics.

Analyses of the humidity measurements were performed by the HUMRS program which computes the bias and Standard Deviation for measurements grouped in 10 humidity bands from 0 to 100 percent in increments of 10%. The analyses are separated for measurements relating to temperature data above and below -20°C. in Figures 24 (a) and 24 (b) respectively.
The 2 second data from all the following flights where comparisons could be made with the operational RS80-Loran humidity measurements in "wet" low level conditionswere used to compile these stsatistics:-
Flights 3,5,9,10,11,12,18,19,23,25,26,29.
This included 7 AIR flight comparisons and 10 VAIS GPS comparisons.

FIGURE 24 (a)
HUMIDITY COMPARISONS - LOWER TROPOSPHERE- "WET"



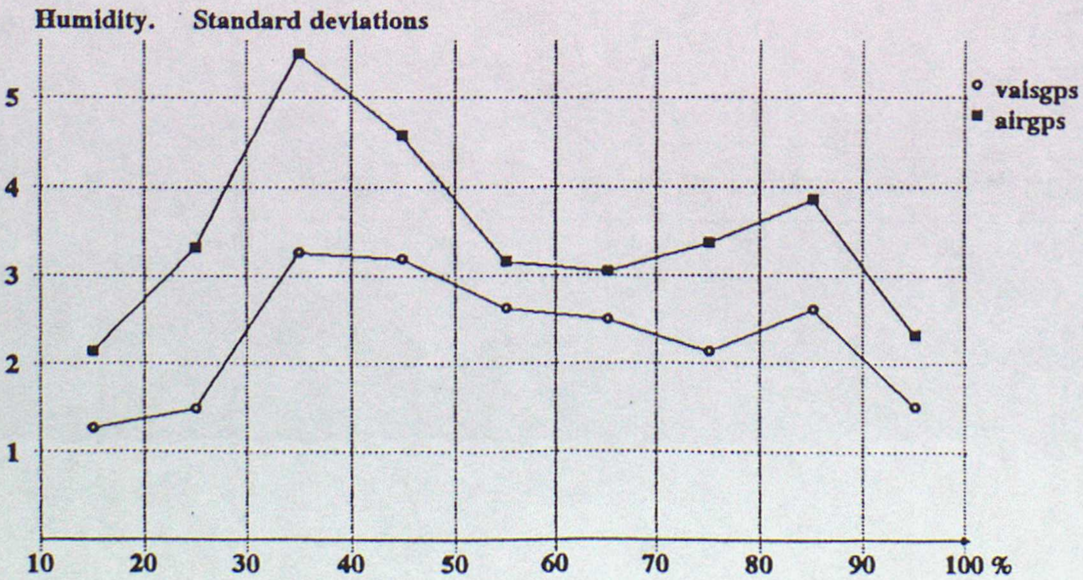


Figure 24B below shows the mean bias of the AIR GPS humidity measurements during 2 "dry" ascents 7 and 8

FIGURE 24B
HUMIDITY COMPARISONS - LOWER TROPOSPHERE- "DRY"

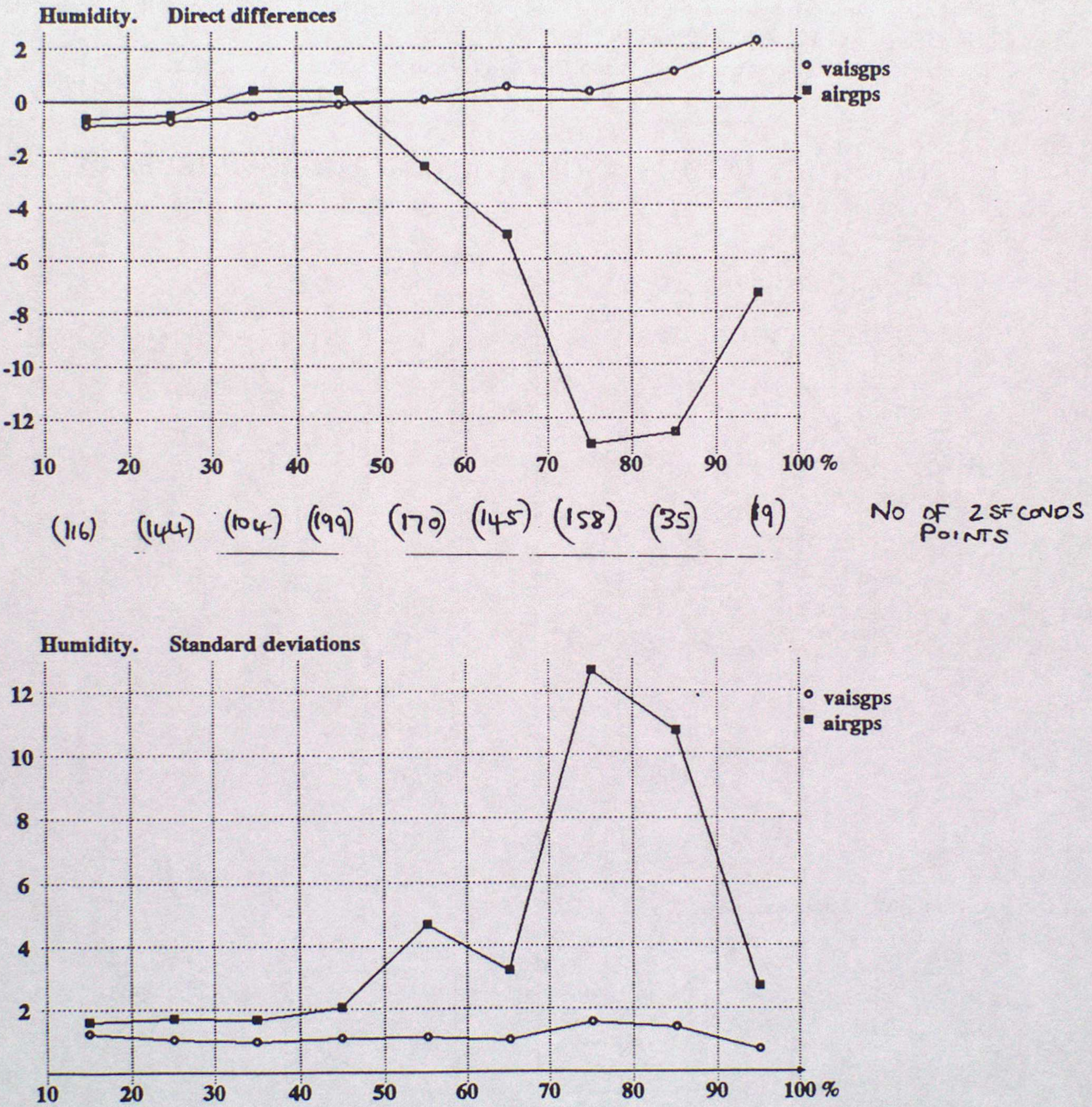
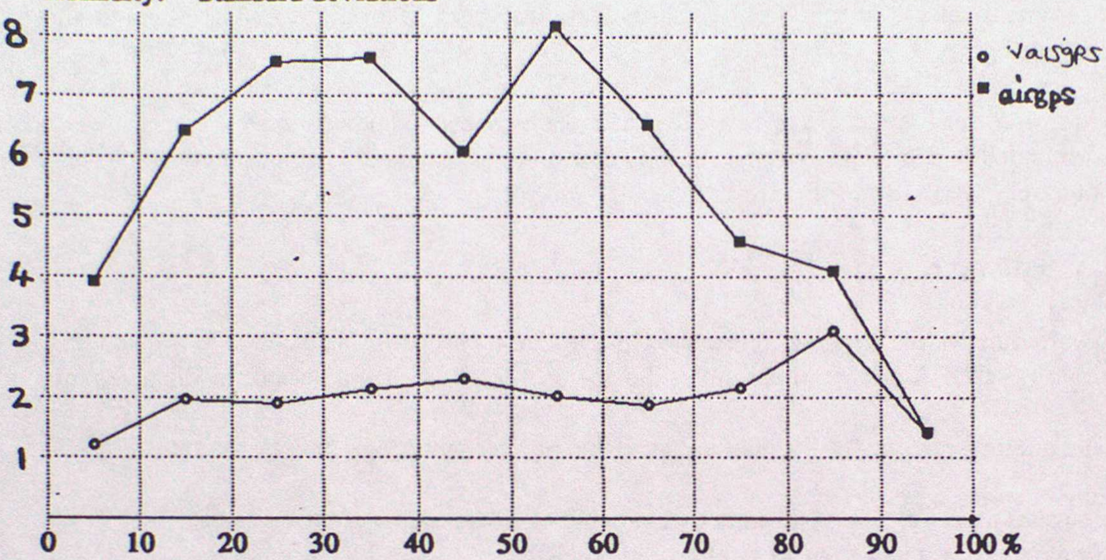


FIGURE 24 (c)

HUMIDITY COMPARISONS (Temperature < -20° C)

Humidity. Standard deviations

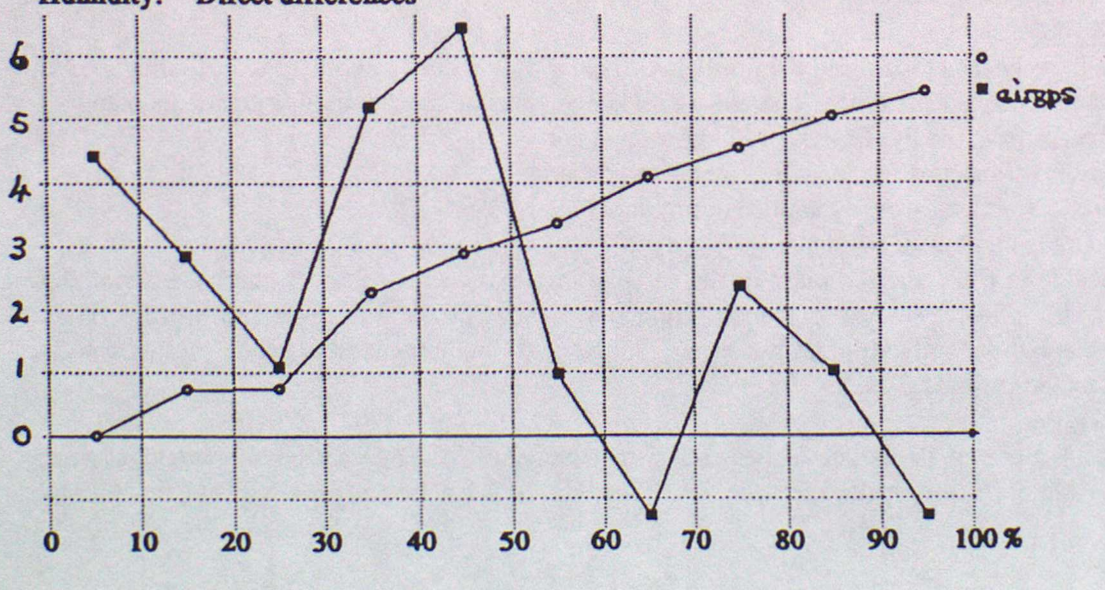


(10961) (1702) (1060) (465) (435) (278) (194) (35) (22) (21) SAMPLE SIZE } AIR GPS

(18428) (1886) (1280) (745) (621) (673) (506) (232) (120) (89) } VAISALA GPS

Flights 3, 5, 9, 10, 11, 12, 18, 19, 23, 25, 26, 29

Humidity. Direct differences



10. SOFTWARE .

10.1 Quality Control Problems.

AIRGPS Problems.

Evidence of large errors in the wind data shows the need for more stringent quality control of the satellite data. The most striking example of this occurred in the data above 15 hPa on the AIR (Navy system) ascent Flight 18 .(see figure 7).

VAISGPS Problems.

The quality control used for the wind data is unable to detect erroneous winds computed in cases where there is insufficient satellite data. The existing interpolation routines using cubic splines may not be very reliable in this situation . (see ascent 5 Figure 1).

10.2 Display Software.

AIRGPS SYSTEM

The system software runs within Windows under the OS/2 operating system.

As with the Vaisala PC-CORA system ,this enables the operator to choose from various in flight displays available.

Plotted values and numeric displays of the data are available as the flight progresses.

The system has several useful displays not curently available in the Vaisala system:-

1. The status of both the Local and Remote satellite data available.
2. A circumzenithal plot of the various satellites available above the horizon.
3. An overview of transmissions within the entire 400 to 410 spectrum.
4. A plan position of the balloon trajectory .

During the Trial the message editing and production facilities were not available for testing in the software.

VAISGPS SYSTEM

The system display uses MetGraph to renable the operator to view the data and profiles using similar facilities to those in PC-CORA systems. Curently however the satellite status data is not made available in the standard software.

10.3 Operational Considerations.

AIRGPS SYSTEM

The system is relatively easy to run and the preflight sequence only requires about 10 to 15 minutes from boot up . One of the first tasks is for the operator to select the almanac for the satellite positional data.

The main differences from the PC-CORA preflight routine are:-

1. The calibration coefficients are transmitted by the radiosonde.
2. Ground control corrections are only applied to pressure data.
3. The surface data is input prior to launch.

The operator is able to check the reception of the satellite information both through the Base aerial and from the radiosonde prior to launch and also during the flight. Currently there are no profile editing facilities available and the software does not generate messages.Simulations of previous ascents can be run from the recorded rawdata files.

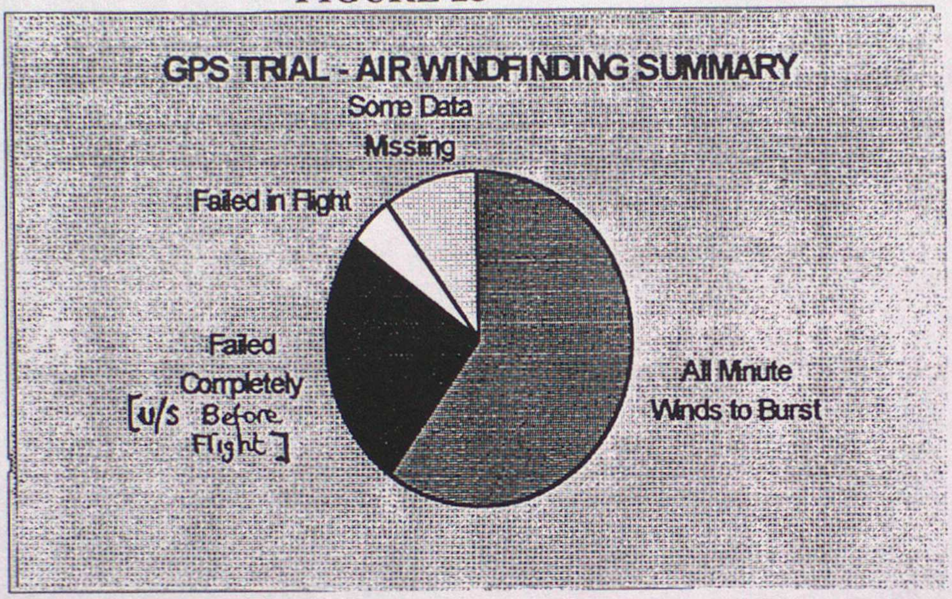
VAISGPS SYSTEM

The system is very similar in operation to the existing opersational PC-CORA loran windfinding system. The operator is similarly informed when the local satellite receiver is synchronised and the ground checking (using touchpads on the main MW15 unit) and in flight editing (using the attached MetGraph facility) progress in the same way.

11. SUMMARY & RECOMMENDATIONS - The AIR GPS SYSTEM.

The AIR GPS system has demonstrated its capability of determining sufficiently accurate winds from launch to burst when the transmitter is functioning. Before consideration of any contractual agreement,the manufacturers would need to demonstrate to the Meteorological Office a much greater reliability in the radiosonde than was attained during the Trial.Figure 25 below shows an overview of the windfinding success rate during the Trial.

FIGURE 25



Once the transmitter was launched the system's windfinding was reliable. Only 1 flight failed completely after launch and under operational procedures would have required a repeat sounding.

The measured winds were generally of sufficient accuracy to satisfy requirements for the Falklands,but on one occasion erroneous winds were produced from limited satellite data. The quality control needs improvement in this area.

The temperature measurements had random errors that were larger than on other modern radiosondes .

2 modifications to the temperature sensor design are recommended:-

1. The sensor boom should deploy to be clear of the top of the GPSonde case.

2. The thermistor coating should be modified to reduce its emissivity in the infrared and its susceptibility to psychrometric cooling after passing through lowcloud.

The humidity measurements obtained on ascents in clear daytime conditions appeared to be erroneously low in the 80 to 100% range. Further tests would be required to prove whether or not these were symptoms of a batch problem or whether the humidity element has a design or fundamental calibration fault. (This type of error was also found with the AIR radiosondes during the WMO Relative Humidity Sensor Comparison).

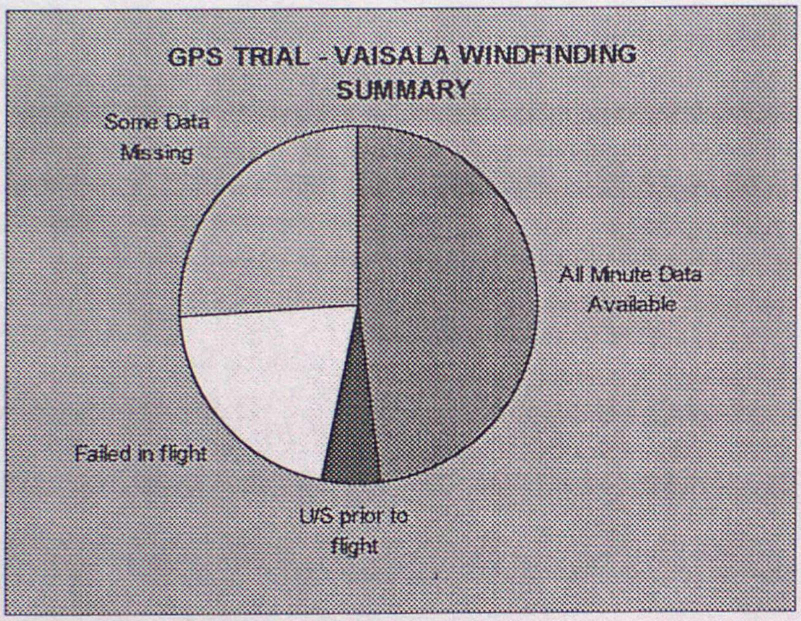
The TEMP Message selection and coding software (for example as available in AIR radiotheodolite software) needs to be incorporated within this GPS software.

The unacceptably high number of radiosondes (5 out of 20) either rejected (4) completely or failing at launch (1) shows that the manufacturer needs to make much more stringent batch quality checks before supplying the radiosondes to the customer.

11. SUMMARY & RECOMMENDATIONS - The VAISALA GPS SYSTEM.

The VAISALA GPS system has demostrated its capability of determining very accurate winds from launch to burst when the transmitter is functioning. Before consideration of any contractual agreement,the manufacturers would need to demonstrate to the Meteorological Office a much greater reliability in the radiosonde than was attained during the Trial.
Figure below shows an overview of the windfinding success rate during the Trial.

FIGURE 26



The VAISALA GPS windfinding proved to be very accurate when there were data from at least 4 satellites available .

During the trial there were however too many occasions when wind computation either ceased completely before the 200 hPa standard level was reached or else data outages caused erroneous winds to be interpolated.

Three problems need to be remedied:-

1. **The reliability of the satellite receiver module interface with the RS80 needs to be improved.** It is believed by Vaisala Oy that the likely reason for sudden irretrievable loss of all wind data during flight was caused by poor soldering joints on the ribbon cable connection between the 2 modules.

2. **The method of search to regain satellite information after an outage needs improvement to reduce the length of time during which winds need to be interpolated.**

3. **The susceptibility of the Vaisala GPS radiosonde system to interference from radar transmissions needs to addressed. Before accepting the system for use in the Falklands the Met Office would need to be guaranteed that radar transmissions from sites at Mount Pleasant would not interfere with the system**

12. ACKNOWLEDGEMENTS.

The author gratefully acknowledges the support given by Mr D G Drew (Station Manager ,Camborne Meteorological Office), Mr J Stancombe (Senior Manager UK Radiosonde Network) , scientific staff based at Camborne and the Trials team from Bracknell who made the comparison soundings.
The support from Mr K Gibson (ATO) and technical staff is also much appreciated.
The display and analysis software was developed by Mr S Kurnosenko (Moscow Institute of Meteorology) for WMO Radiosonde Intercomparisons .

13. REFERENCES.

1. **Edge,P., M Kitchen, J Harding, J Stancombe**,1986, O.S.M No 35, available Meteorological Office Bracknell.

2. **Nash,J., T. Oakley** . Experience in the use of Loran -C Windfinding in the UK . (Proceedings of 21st Annual Technical Symposium August 1992 (Wild Goose Association)

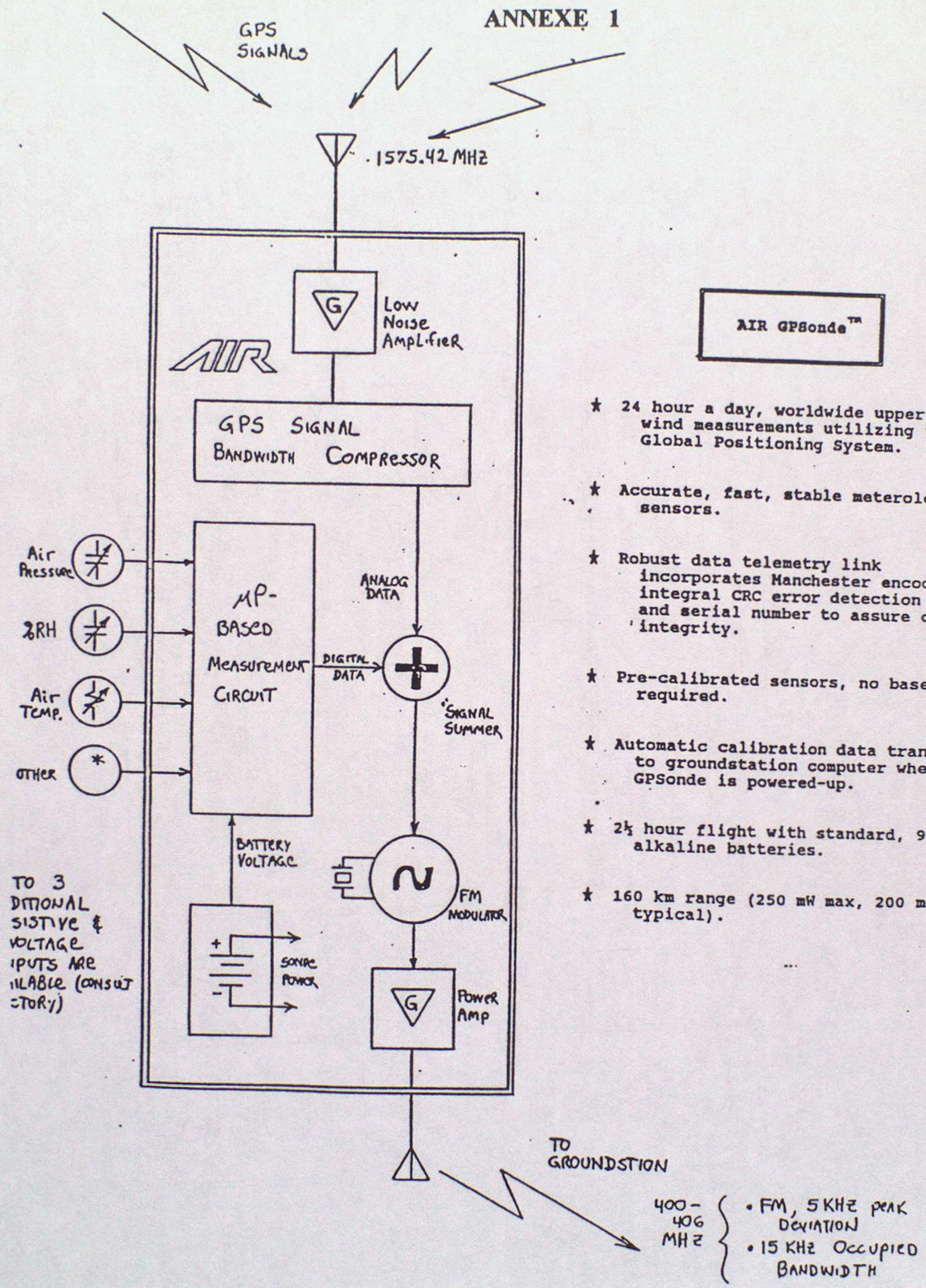
3. **Elms J.,** Gibraltar Omega Windfinding Trial March/April 1993 (Met Office internal report) .

4. **Ivanov ,A., A Kats, S. Kurnosenko, J Nash ,N Zaitseva, 1991** , WMO , Instruments and Observing Methods Report No 40.

5. **Nash J., and F.J.Schmidlin, 1987** ,WMO ,Instruments and Observing Methods Report No.30.

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

ANNEXE 1



AIR GPSonde™

- 24 hour a day, worldwide upper air wind measurements utilizing the Global Positioning System.
- Accurate, fast, stable meterological sensors.
- Robust data telemetry link incorporates Manchester encoding, integral CRC error detection code, and serial number to assure data integrity.
- Pre-calibrated sensors, no baseline required.
- Automatic calibration data transfer to groundstation computer when GPSonde is powered-up.
- 2½ hour flight with standard, 9 V alkaline batteries.
- 160 km range (250 mW max, 200 mW typical).

A I R GPS RADIOSONDE SYSTEM BLOCK DIAGRAMS

(Information from Manufacturer)

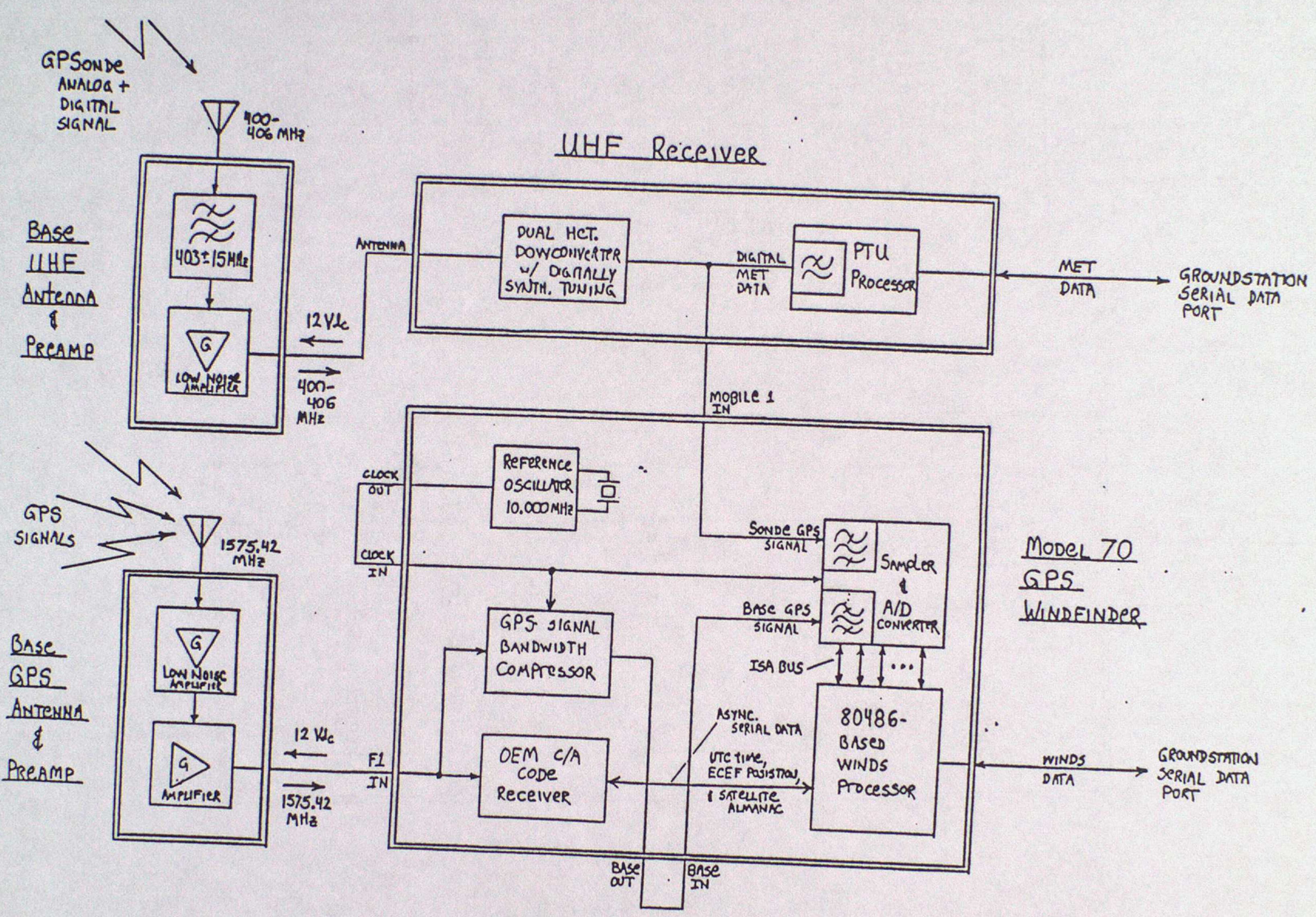
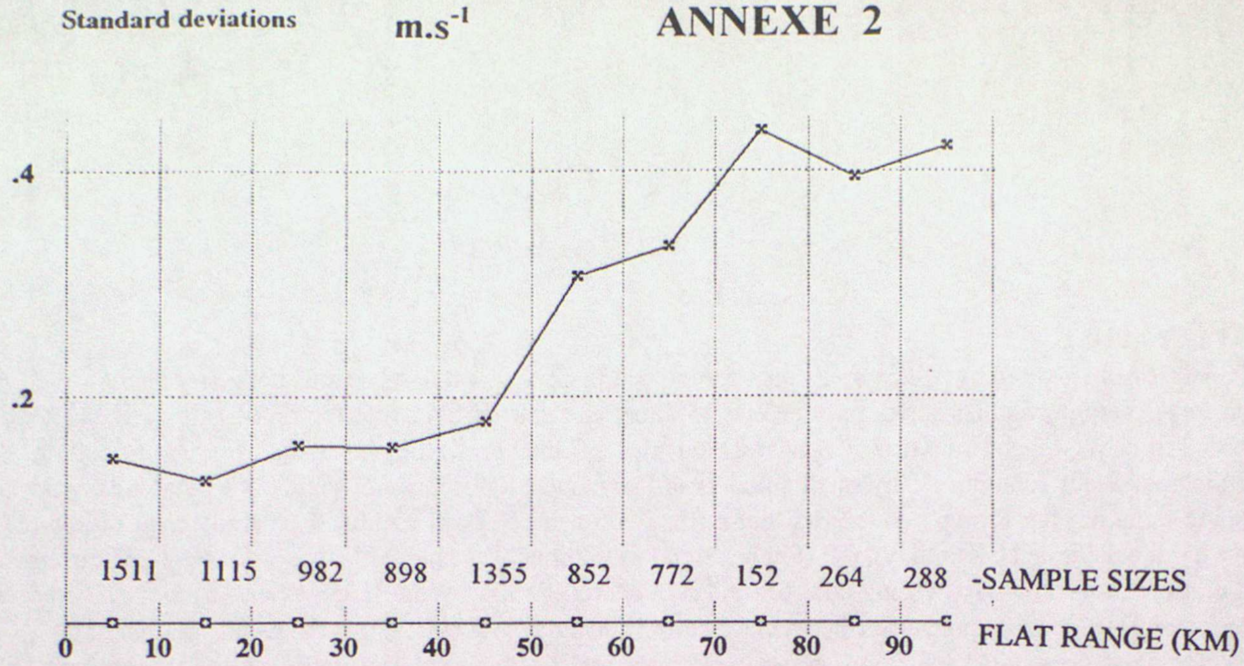
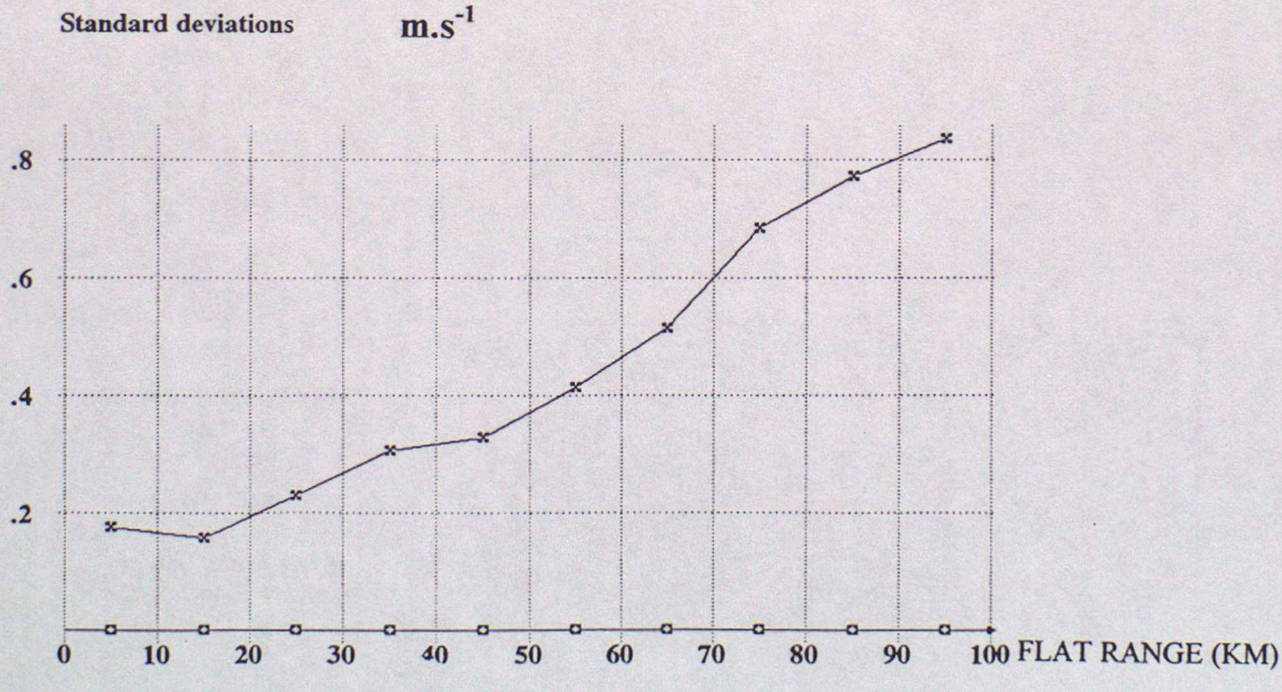


Figure 1-3 : Ground-based Signal Processing Block Diagram

ANNEXE 2



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



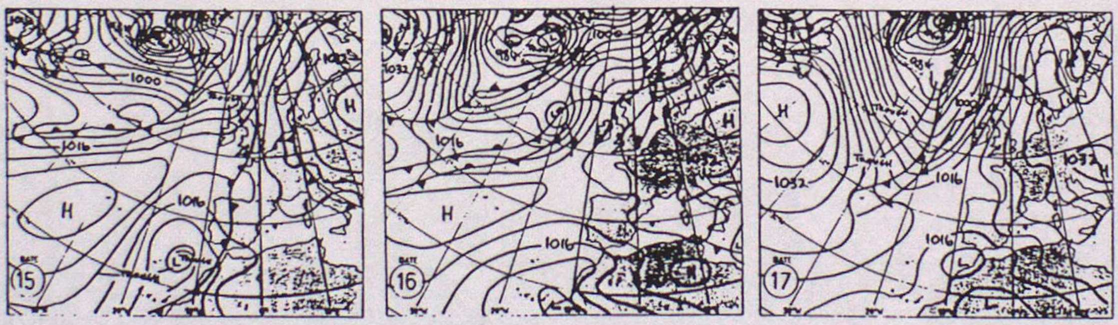
HIGH PRECISION RADAR TRIAL -
STANDARD DEVIATION OF (COSSOR-HIGH PRECISION) RADAR WIND COMPONENTS MEASURED ACROSS THE RADAR BEAM

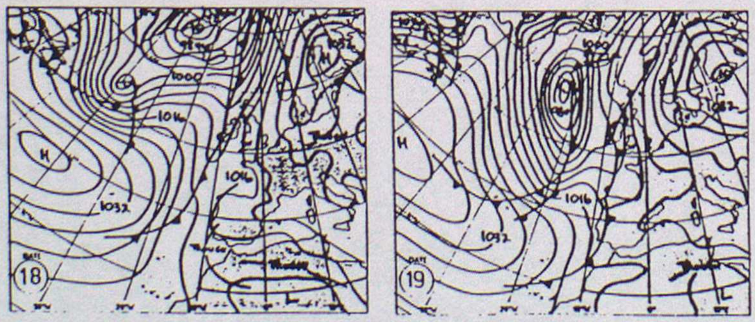
ANNEXE 3

WEATHER

High pressure centred over Eastern Europe for the whole week maintained a weak southerly air flow near the surface.Average wind speeds did not exceed 15 knots and apart from some fog on Monday night and some occasional very light rain/drizzle towards the end of the Trial the soundings were launched in dry conditions.Skies containing only small amounts of low cloud produced sunny conditions on Monday 15th but led to radiation fog forming on the first night (Flights 5 and 6) .Skies remained generally clear of low cloud during the daytime on Tuesday 16th (Flights 7 and 8) ,although patches of cirrus were observed throughout Tuesday. From Tuesday evening until the end of the Trial on Friday the skies remained mostly cloudy with low stratus or stratocumulus. Surface temperatures remained close to10°C for the whole period.

Winds were generally light from between southeast and southwest during much of the troposphere , but above the tropopause the wind direction veered to the north west and increased with height to give maximum winds close to 80 m/s at heights above 32 km. These wind reversals persisted for the whole week and generally caused ideal tracking conditions with radar elevations remaining above 15 degrees for the period .The balloons tracked to the southeast in the latter part of the ascents which enabled good reception from the AIR local satellite aerials placed to the east of the main building.(The maximum recorded stratospheric wind was 310 ° 80 m/s on flight 8). Further details of the surface weather conditions are shown in the Flight log





DAILY WEATHER MAPS
12 GMT

JANUARY 1996

Dates are ringed at lower left-hand corner

ANNEXE 4

Display and Comparison Software

A suite of programs ("RSKOMP") devised by Kurnosenko for use in WMO Radiosonde Comparisons is used in this Report both to display and analyse the archived data. The main programs used to display and analyse the data were :-

"VIEWRS" which displays the comparison data at 2 second intervals or multiples to 1 minute.
"DIFFRS" which calculates the bias and mean deviation of the data within certain time bands.
"HUMRS" which calculates and displays the mean humidity bias and standard deviations banded within selected humidity ranges.

Statistical processing of the full range of meteorological variables was performed using the DIFFRS program. The principles of the statistical processing are briefly described in Nash and Schmidlin (1 and also Ivanov et.al ( ). Differences between the measurements of a given variable by each system were computed for the samples available each minute throughout the flight. The difference data were subdivided into the pressure bands indicated in Table 1 below. For each pressure band , the mean differences between two given system types and the associated standard deviation of the data set was computed. For wind observations the differences were computed for southerly and westerly components, rather than for wind speed and direction, since the component statistics are easier to interpret when upper winds are relatively weak.

TABLE 1
PRESSURE BANDS FOR COMPARISON DATA

NOMINAL PRESSURE hPa	ACTUAL LAYER hPa
1000	SURFACE to 975
900	975 to 840
700	840 to 589
500	589 to 415
320	415 to 245
200	245 to 164
140	164 to 119
100	119 to 84
70	84 to 58.9
50	58.9 to 41.5
32	41.5 to 24.5
20	24.5 to 16.4
14	16.4 to 11.9
10	11.9 to 8.4
7	8.4 to 5.9

ANNEXE 5

The following notes give the key to the various columns:-

COLUMN 3 The various rigs used during the trial are coded as follows:-

CODE	RIG
1	2 Vaisala sondes below cane. RS80GPS sonde taped. AIR GPSonde 30m below
2	" " " " " " " swinging " "
3	2 Vaisala radiosondes only below cane.
4	Single Radiosonde 30 m below radar reflector.
5	Single Radiosonde NO RADAR TARGET.
6	GPS R/S 30m below balloon .Loran R/S 60m below balloon. NO RDR TARGET.
7	As 6 above ,but with radar target
8	Radar Pilot Only.

COLUMN 4 contains the burst preesure.
COLUMN 5 " Number of minutes to burst.
COLUMN 6 " Number of LORAN data minutes missed or flagged.
COLUMN 7 " Time (MINS into flight) when Radar target located after EHT switched on..
COLUMN 8 " Number of RADAR data minutes missed or flagged.
COLUMN 9 " Number of VAISGPS data minutes missed or flagged.
COLUMN 10 " Vaisala GPS LINEFITTING LENGTH (seconds)
COLUMN 11 " Number of AIRGPS data minutes missed or flagged.

ANNEXE 5 - MINUTE WIND DATA ACQUISITION

1	2	3	4	5	6	7	8	9	10	11	
FLT	TIME	RI	BURST	MINS	LOR miss	EHT ON	RDR miss	VAIS miss	V LINE	AIR miss	REMARKS
1	15/1130	4	7	104	0		0				LOR/RAD TEST
2	15/1333	4	18	74			0			0	GOOD AIR WINDS TO BURST
3	15/1547	3	14	91	0	19	42 *	0	60		GOOD VAISALA WINDS TO BST. Eht on min 19 .radar off for oper flt min 68
4	15/1724	8	25	87			0				Oper Radar Pilot Only
5	15/2108	1	9	119	0	20	20	10	60	5	eht on min 19 . BOTH GPS GOOD. VAISGPS MINS 21-24 FLAGGED.MINS 113-119 MISS
6	16/0001	5	30	78	0						Oper Loran Ascent Only
7	16/1145	1	8	94	0	6	6	66	30	0	VAISGPS WIND FAILED MIN28
8	16/1436	2	7	97	0	6	6	6	30	24	AIR SONDE FAILED MIN 74 (+ptu fail) VAISGPS miss 89-94 (swinging rig?)
9	16/1726	1	9	101	0	5	5	0	30	17	Air miss 85-101(+ptu fail BUT OK ON NAVY SYSTEM,suspect computer ram problem?)
10	16/2100	1 *	21	82	0		0			0	AIR voltage down to 7.2v at bst. VAISGPS NOT FLOWN DUE TO GROUNDSTATION
11	16/2343	1	5	96	27	6	6*	0	60	0	LOR SONDE "CHATTER CAUSED PTU.& RDR fail min69.* RADAR MINWINDS from KIENZLE
12	17/1124	1	10	95	0		0	**	60	0	** NO VAISGPS from launch . experimented using EHT from launch
13	17/1400	4	18	76		8	8	10	60		VAISGPS SONDE PTU & WINDS LOST min 67
14	17/1531	4	13	82			0			0	GOOD AIR WINDS TO BURST
15	17/1723	4	32	68		8	8	0	60		GOOD VAISALA WINDS TO BURST
16	17/1906	4	14	83			0			0	GOOD AIR WINDS TO BURST
17	17/2118	4	16	82		8	8	0	60		GOOD VAISALA WINDS TO BURST
18	17/2357	1	7	101	0	6	6	0	60	13	AIR DATA FROM NAVY SYSTEM .last 13 mins of winds erroneous (FLAGGED)
19	18/1126	1	13	93	0	7	7	22	60	0	VAISGPS FAILED MIN 72
20	18/1330	4	17	77		9	9	0	60		
21	18/1500	4	32	74			0		60	0	GOOD AIR WINDS TO BURST. NAVY AUTONOMOUS.(E-W BIAS) .RDR DPU PROBLEMS. SOME WINDS FRM KIENZLE.
22	18/1623	4	90	50		10	10	19	60		VAISGPS FAIL MIN 32 (ptu ok). RDR DPU PROBS. FLT TERMINATED BEFORE BST.
23	18/1755	1	9	100	8	9	9	5	60	***	VAISGPS FAIL MIN 95. LOR FAIL MIN 92. *** AIR data awaited
24	18/2033	4	113	44			44			44	AIRGPS FAILED FROM LAUNCH. OPER ENDS
25	18/2150	6	19	80	0			10			VAISGPS WINDS MISSING mins 65-69,72-76
26	18/2352	7	8	87	0	10	16 *	40	60		VAISGPS WINDS MISS mins 34-37,46-53,56-81,86-7 *EHT purposely off mins 41-6.RDR MIN 61 ANOM SPIKE
27	19/0945	5	10	.83				0	60		VAISGPS WINDS TO BST BUT 25mins INTERPOLATION !! winds appear ano,malous at 500 hPa (cw pilot flight 28)
28	19/1002	8	35	68			0				RADAR PILOT TO COMPARE FLT 27
29	19/1205	1	13	89	0	6	6	20	60		AIR SONDE FELL OFF ON LAUNCH! VAISGPS mISS WINDS 31-35,68-71,80-89 . 52 MINS of VAISGPS WIND DATA INTERPOLATED
30	19/1413	5	13	82						0	GOOD AIR WINDS TO BURST
31	19/1426	8	31	71			0				RADAR PILOT TO COMPARE FLT 30
32	19/1720	5	30	74	0						OPERATIONAL LORAN FLT ONLY

ANNEXE 6 - PTU DATA ACQUISITION

1	2	3	4	5	6	7	8	9	10	11	TABLE 3
FLT	TIME	RIG	BURST	MINS	LOR MISS	VAI MISS	VAI PCOR	AIR PCOR	TIME COR	AIR MISS	REMARKS
1	15/1130	4	7	104	0						LOR/RAD TEST
2	15/1333	4	18	74				-2.7		0	
3	15/1547	3	14	91	0	0	-0.1				
4	15/1724	8	25	87							Oper Radar Pilot Only
5	15/2108	1	9	119	2	4	0.4	-0.9	A-2	0	VAISALA GPS PTU MISSING MINS 116-119. LORMK4 MINS 1,2 WET BULB
6	16/0001	5	30	78	0						Oper Loran Ascent Only
7	16/1145	1	8	94	0	11	0.5	-4.3	A+8	0	VAISALA GPS PTU MISSING MINS 90-94, VAIS TEMP INTERPOLATION MINS 37-43
8	16/1436	2	7	97		0	0.3	-2.9	A+4	24	AIR SONDE FAILED MIN 74
9	16/1726	1	9	101	0	0	-1.5	-1.3	A+4	17	Air miss 85-101(+ptu fail BUT OK ON NAVY SYSTEM,suspect computer ram problem?)
10	16/2100	1 *	21	82	0			-0.3	A+5	0	AIR voltage down to 7.2v at bst. VAISGPS NOT FLOWN DUE TO OPERATIONAL PROBLEMS
11	16/2343	1	5	96	28	0	-1.3	-0.2	A+5 V-32	1	LOR SONDE "CHATTER CAUSED PTU fail min69.LOR,AIR WET BULB MIN 2
12	17/1124	1	10	95	0	3	0.8	-0.8	A+2	7	AIR ERRONEOUS TEMP FLAGGED MIN 78,.VAISGPS WETBULB MINS 3-5,AIR WB 3-8
13	17/1400	4	18	76		10	0.8				VAISGPS SONDE PTU LOST min 67
14	17/1531	4	13	82				-0.3		0	
15	17/1723	4	32	68		0	-0.3				
16	17/1906	4	14	83				+0.1		0	
17	17/2118	4	16	82		0	0.7				
18	17/2357	1	7	101	2	1	0.5	??		7	AIR DATA FROM NAVY SYSTEM ..LORMK4 5-6 FLAGGED WB. AIR MINS 5-11 FLAGGED WB,VAISGPS WETBULB Min 7
19	18/1126	1	13	93	0	0	1.0	-2.4	A+4 V-12	0	
20	18/1330	4	17	77		0	0.8				
21	18/1500	4	32	74			0.1	-0.7		0	.
22	18/1623	4	90	50		0					FLT TERMINATED BEFORE BST.
23	18/1755	1	9	100	6	0	0.1	-0.5		***	..***BIG WET BULB EFFECT LORAN SONDE DATA MINS 8-13 FLAGGED..*** AIR data awaited.
24	18/2033	4	113	44				??		44	AIRGPS FAILED FROM LAUNCH. OPER ENDS
25	18/2150	6	19	80	1	0	0.8		V-8		LORMK4 MIN 6 WET BULB
26	18/2352	7	8	87	2	0					LOR MINS 7-8 WET BULB
27	19/0945	5	10	83		0	1.2				
28	19/1002	8	35	68							RADAR PILOT TO COMPARE FLT 27
29	19/1205	1	13	89	0	0	0.1		V-15		AIR SONDE FELL OFF ON LAUNCH!
30	19/1413	5	13	82				-0.4		0	ALL AIRGPS HUMIDITIES (100%) FLAGGED
31	19/1426	8	31	71							RADAR PILOT TO COMPARE FLT 30
32	19/1720	5	30	74	0						OPERATIONAL LORAN FLT ONLY

ANNEXE 7

PC-CORA FLIGHT LOGS FOR VAISALA LORAN & GPS ASCENTS

The information tabulated in the following pages was obtained from the PC-CORA 2 second "EDT" file output.

Key:-

Actl = Launch Time GMT
P,T U CORRECTIONS are PREFLIGHT CONTROLS CORRECTIONS in hPa X 10 , °C X 10 and percentage humidity respectively.
DD = Surface Wind Direction
FF = Surface Wind speed (m/s) from 10m anemometer.
CLOUD GROUP . WMO Cloud report at launch time
Wr WMO Weather code " "
Max Rge = Maximum flat range in kms.
Asct Rate = Ascent Rate (mean m/s)

MAXWIND
FF = Wind Speed (m/s)
DRN = Direction
TEM Min = Mininmum Temperature of ascent (°C)
ELEV Mn = Minimum Elevation During ascent

BURST
Azi = Balloon azimuth at burst
t = End of flight code (5= burst)
Tim = Burst Time (mins from launch)

TRO,PAUSE
Tmp = Tropopause Temp (°C)
Hgt = " Height (dkm)

WIND INTERP
Tot = Total no. of seconds wind data "interpolated" by PC-CORA software.
Lt4 = " " " " " " in first 4 minutes only.
fgv = First good value (as perceived by PC-CORA quality control)

LORAN INFORMATION:-
Station Identifiers:-
Mast = Master station
1 = Slave 1
2 = Slave 2 (etc)
The values quoted in columns headed by the Loran Station Identifiers are percentages of the total flight time when Loran data was received from that Station.

ANNEXE 7 A

VAISALA LORAN RADIOSONDE FLIGHT LOG DETAILS

GPS LORAN COMPARISON FLTS

Flt	DDHH	Actl	SondeNum	CORRECTION P	T	U	SURFACE Pres	TmpL	Hum	DD	FF	GROUP Cloud	Wr
1	1511	1130	542504115	-3	1	0	1010	11M	92	0	0	25632	10
3	1516	1605	542504110	5	1	-2	1012	10M	93	0	0	15132	05
5	1521	2108	542504105	8	-1	0	1014	7M	100	13	1	15600	46
6	1600	1	542504100	3	1	-1	1014	9A	98	0	0	860//	44
7	1611	1145	542504206	8	1	0	1015	10M	91	12	6	16302	05
8	1614	1436	542504201	5	1	0	1014	10M	90	14	4	31302	05
9	1617	1726	542504312	11	0	0	1014	10M	93	16	5	762//	10
10	1621	2100	542504010	6	3	-1	1014	9M	96	16	4	67401	10
11	1623	2343	542504005	0	-1	0	1014	9M	93	18	2	853//	05
12	1711	1124	542504111	1	0	-1	1012	10M	88	17	4	853//	05
18	1723	2358	542504106	6	2	-1	1008	9M	92	17	1	851//	05
19	1811	1127	542504212	7	-1	0	1005	10M	89	14	5	854//	05
23	1817	1756	542504207	11	0	0	1003	10M	93	14	2	873//	50
25	1821	2150	542504202	7	1	0	1003	10M	93	14	2	863//	10
26	1823	2352	542504313	1	2	-1	1003	10M	94	15	2	55400	21
29	1912	1206	542504001	3	0	0	998	10M	86	16	8	784/2	05
32	1917	1720	542504006	10	0	-1	994	10A	96	19	5	6832/	61

Flt		MAXWIND FF	DRN	HGT	Max Rge	HUM Min	Max	TEM Min	ELEV 80+	Mn	hPa Heights 100	50	30	Asct Rate
1	96011511	73t	293	32824	36f	1	91	-65	0	16	16097	20410	23545	5.2
3	96011516	56	297u	27997	75	1	93	-65	0	21	16116	20430	23568	5.1
5	96011521	67	303	30469	117	1	100	-65	0	15	16148	20484	23619	4.3
6	96011600	28	307	23308	39	1	97	-65	0	31	16172	20509	23636	5.0
7	96011611	70	312	31469	75	1	90	-68	0	23	16207	20543	23697	5.6
8	96011614	80	310	32273	87	1	97	-69	0	20	16201	20536	23703	5.5
9	96011617	64	312	30990	77	1	99	-68	446	22	16205	20544	23723	5.1
10	96011621	27	315	25743	25	1	100	-66	218	26	16208	20560	23723	5.2
11	96011623	18	317	17905	13	1	98	-66	518	30	16215	20573	23738	5.8
12	96011711	59	318	30273	31	1	96	-73	0	21	16200	20559	23741	5.3
18	96011723	75	321	34115	89	1	100	-77	0	21	16164	20545	23724	5.6
19	96011811	53	327	28903	42	1	99	-73	0	22	16132	20518	23700	5.2
23	96011817	39s	316	27878	42	1	100	-76	0	25	16089	20481	23658	5.1
25	96011821	30	308	26528	36	1	100	-67	0	23	16096	20499	23704	5.5
26	96011823	74	324	31460	50	1	100	-76	0	24	16087	20488	23684	6.0
29	96011912	47	306	28830i	69	1	97	-70	0	16	16026	20446	23668	5.4
32	96011917	30	193	9739	70	3	98	-61	0	14	15975	20400	23630	5.3

Flt		Norwegian Chain Mast	1	2	3	4	5	French Chain Mast	1	2	3	4
1	96011511	98	98	98	0	0	0	90	0	77	80	0
3	96011516	100	100	100	0	0	0	100	93	99	100	0
5	96011521	100	100	100	0	0	0	99	98	66	100	0
6	96011600	100	100	100	0	0	0	98	42	100	100	0
7	96011611	100	100	100	0	0	0	93	14	0	91	0
8	96011614	100	100	100	0	0	0	89	24	33	86	0
9	96011617	100	100	100	0	0	0	96	91	0	93	0
10	96011621	100	100	100	0	0	0	100	98	100	83	0
11	96011623	100	100	100	0	0	0	100	99	100	94	0
12	96011711	100	100	99	0	0	0	100	0	71	96	0
18	96011723	100	100	99	0	0	0	100	95	95	98	0
19	96011811	99	99	97	0	0	0	98	39	65	99	0
23	96011817	92	92	92	0	0	0	92	92	92	92	0
25	96011821	100	100	100	0	0	0	100	99	100	100	0
26	96011823	100	100	100	0	0	0	99	98	73	55	0
29	96011912	100	100	100	0	0	0	99	53	69	100	0
32	96011917	100	99	99	0	0	0	99	72	100	100	0

VAISALA GPS TRIAL CAMBORNE 1996

ANNEXE 7 B

VAISALA GPS RADIOSONDE

FLIGHT LOG DETAILS

FLT	DDHH	Act	SondeNum	CORRECTION P	T	U	SURFACE Pres	Tmp	Hum	DD	FF	GROUP Cloud
3	1516	1605	602102305	-1	3	-5	1012+	10M	95	0	0	/////
5	1521	2109	602102301	4	0	-2	1014+	7M	100	0	0	/////
7	1611	1145	602102402	5	1	-4	1015+	10M	92	12	6	16302
8	1614	1437	602102311	3	1	-2	1014+	10M	90	14	4	31302
9	1617	1727	602102313	-15	-1	-2	1014+	10M	94	16	5	762//
11	1623	2344	602102413	-13	0	-3	1014+	9M	94	18	2	853//
12	1711	1125	602102105	8	1	-2	1012+	10M	88	17	4	853//
13	1714	1401	602102407	8	0	-3	1010+	10M	87	16	5	/////
15	1717	1724	602102115	-3	1	-3	1009+	10M	90	15	3	853//
17	1721	2119	602102102	7	0	0	1009+	9M	87	16	7	864//
18	1723	2358	602102403	5	1	-2	1076+	9M	92	17	1	/////
19	1811	1127	602102307	10	1	-2	1005+	10M	90	14	5	854//
20	1813	1331	602102101	8	0	-2	1004+	10M	94	15	5	861//
22	1816	1624	602102306	1	0	1	1003+	10M	95	15	3	862//
23	1817	1756	602102312	1	1	-1	1003+	10M	94	14	2	873//
25	1821	2151	602102106	8	1	-1	1003+	10M	93	14	2	863//
26	1823	2352	602102111	8	0	-1	1003+	10M	95	15	2	/////
27	1909	945	602102408	12	0	-3	999+	10M	91	15	7	/////
29	1912	1206	602102302	1	1	-2	998+	10M	86	16	8	/////

SURFACE PRESSURE INCORRECTLY INSERTED BY OPERATOR

FLT	Date	MAXWIND FF	DRN	HGT	Max Rge	HUM Min	Max	TEM Min	ELEV 80+	Mn	hPa Heights 100	50	30	Asct Rate	BURST Azi	Rge	hPA	t	Tim	HGT	TRO,PAUSE Tmp	HGT	WIND Tot
3	96011516	55	295	28172	75	1	94	-65	14	21	16110	20420	23556	5.1	112	75	14	5	91	2825	-61	1157	368
5	96011521	55	302	28507	94	1	100	-65	0	17	16137	20468	23600	4.3	133f	94	12	6	115	2943	-64	1159	212
7	96011611	15h	225	4682	10f	1	91	-68	0	27	16198	20529	23677	5.5	-99f	-99	12	1	89	2940	-65	1152	90
8	96011614	81t	309	32193	53	1	99	-70	0	28	16190	20520	23683	5.5	-99f	-99	7	5	97	3219	-64	1126	1066
9	96011617	66	309	31337	78	1	100	-68	454	22	16199	20536	23711	5.2	139	78	9	5	101	3133	-65	1166	772
11	96011623	90	314u	33622	92	1	100	-69	518	20	16200	20551	23708	5.9	134t	92	5	5	96	3405	-65	1159	834
12	96011711	87q	137	416	20n	1	100	-73	0	4	16180	20530	23707	5.4	-99f	-99	10	5	95	3060	-59	1078	1164
13	96011714	20h	154	9764	25f	1	100	-65	0	24	16176	20538	23716+	5.9	-99f	-99	32	*	66	2337	-59	1095	10
15	96011717	25	307	23491i	30	1	100	-63	0	21	16163	20535	23709+	5.7	28t	24	31	5	68	2350	-56	1019	298
17	96011721	39s	314	27945i	-99n	1	100	-72	0	-9	16166	20534	23721	5.7	-99f	-99	13	5	83	2866	-57	1032	1338
18	96011723	79	315	33042i	91	1	100	-77	20	21	16691	21066	24240	5.7	118	91	5	5	100	3447	-57	1070	884
19	96011811	17e	202	7646	35t	1	100	-74	0	22	16121	20501	23680	5.2	-99f	-99	12	5	92	2912	-61	1048	16
20	96011813	33	318u	27352	36	1	100	-72	0	25	16116	20511	23696	5.9	61t	36	16	5	78	2756	-62	1073	782
22	96011816	14q	196	6408	20T	1	100	-63	0	28	16098	-99	-99	5.5	-99f	-99	90	0	50	1676	-63	1074	64
23	96011817	51t	314u	29176	47	1	100	-76	0	25	16093	20481	23654	5.1	-99f	-99	9	5	100	3088	-63	1076	590
25	96011821	26e	304	26092	35t	1	100	-67	0	23	16088	20487	23689	5.5	-99f	-99	19	5	80	2659	-62	1066	578 1
26	96011823	67q	320u	30940	25f	1	100	-76	0	24	16080	20478	23676	6.1	-99f	-99	7	5	87	3216	-63	1076	1596 1
27	96011909	55	310u	29982i	55	1	98	-75	0	20	16020	20435	23640	6.0	64t	55	10	5	83	3013	-61	1071	1594 2
29	96011912	30e	297	24985	30f	1	100	-71	0	17	16012	20427	23644	5.4	-99f	-99	13	5	89	2867	-62	1022	3150

Note especially the excessive amount of interpolated winds (seconds) during each flight in "Tot " colu

FLT	Date	Acc. Data	Track On	100hPa P-R	Ev	Azi	Cot	30hPa P-R	Ev	Azi	Cot
3	96011516	59	92	-99	44	85	1.0	-99	28	107	1.9
5	96011521	81	97	-99	41	150	1.2	-99	24	139	2.2
7	96011611	82	94	-99	-9	-99	-9.9	-99	-9	-99	-9.9
8	96011614	48	76	-99	58	145	.6	-99	37	146	1.3
9	96011617	75	87	-99	65	158	.5	-99	38	152	1.3
11	96011623	40	84	-99	84	283	.1	-99	60	149	.6
12	96011711	35	37	-99	-9	-99	-9.9	-99	-9	-99	-9.9
13	96011714	89	98	-99	-9	-99	-9.9	-99	-9	-99	-9.9
15	96011717	84	91	-99	30	2	1.7	-99	-9	-99	-9.9
17	96011721	38	65	-99	-9	-99	-9.9	-99	-9	-99	-9.9
18	96011723	41	84	-99	34	20	1.5	-99	41	56	1.1
19	96011811	95	100	-99	26	14	2.0	-99	-9	-99	-9.9
20	96011813	70	82	-99	28	16	1.8	-99	35	39	1.4
22	96011816	70	82	-99	-9	-99	-9.9	-99	-9	-99	-9.9
23	96011817	59	88	-99	27	12	2.0	-99	32	41	1.6
25	96011821	51	74	-99	26	8	2.1	-99	-9	-99	-9.9
26	96011823	5	27	-99	-9	-99	-9.9	-99	-9	-99	-9.9
27	96011909	43	66	-99	21	11	2.6	-99	26	29	2.1
29	96011912	8	28	-99	-9	-99	-9.9	-99	-9	-99	-9.9