Results of the RS92 Acceptance Test performed by the Met Office (UK)

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Abstract

During summer 2004 the Met Office conducted an extended acceptance test of the Vaisala RS92 GPS radiosonde. This test was the culmination of three year collaboration with Vaisala in improving the relative humidity measurements of Vaisala radiosondes. The acceptance test was conducted in three distinct sections; Relative humidity tested against the Meteolabor Snow White sensor, Temperature tested against Sippican 3 thermistor Radiosonde, and with geopotential height and winds checked against measurements from the Graw DFM97 radiosonde. The results of this test are presented here.

Introduction

The Met Office has considered upgrading from the RS80 radiosonde since 2001, when the DigiCORA III ground system was introduced into use in the UK upper air network. However, the RS90 radiosonde did not meet the UK specification for relative humidity measurements when it was tested in 2000. Subsequently, Vaisala agreed to co-operate with the Met Office in developing solutions to the problems encountered. This has led to a series of tests at regular intervals of various possible solutions to the problems in the last three years.

In the case of the relative humidity sensor a variety of changes have been introduced since the test in 2000, for instance:-

- Relative humidity sensors were regenerated to eliminate contamination. Both in the factory, before calibration, and also before the radiosonde was used in flight.
- The pulse heating cycle was speeded up to provide more regular heating to minimise errors in clouds with high liquid water content in the early parts of the measurement.
- The pulse heating has also now been continued to temperatures as low as -60°C to minimise contamination in upper cloud.
- Production problems with the manufacturing of the pulse heating drives have been rectified.
- The thickness of the relative humidity sensor was adjusted to improve the stability of the sensors during flight.
- Revised calibrations were introduced to improve accuracy at lower temperatures.

With the announcement from Vaisala that the production of the RS80 will stop in 2005, the time came to perform a detailed acceptance test on the Vaisala RS92.

Test facilities

For this test, Vaisala loaned the Met Office a SPS311 processing board, a PC running DigiCORA III version 3.12 and a pre-amp to upgrade the RB21 antenna at Camborne. The radiosondes to be tested were a mixture of Vaisala RS92- SGP and Vaisala RS92-AGP, supplied by Vaisala.

High quality relative humidity measurements were to be provided by Snow White chilled mirror hygrometers (see Fig 1) flown with the Meteolabor SRS C34 radiosonde and Argus37 ground station. One of the main benefits of the Argus ground station was the provision of additional 'house keeping channels' allowing performance of the Snow White systems to be monitored. The upgrade with additional channels required the Snow White hygrometers to be returned to Meteolabor. Problems were encountered with damage during the shipping of the Snow Whites from Switzerland, and this led to considerable delay in the completion of the test. This had the advantage that test flights were performed in a variety of conditions over several months, so that the results are more likely to be generally applicable than if the test was completed in two weeks.

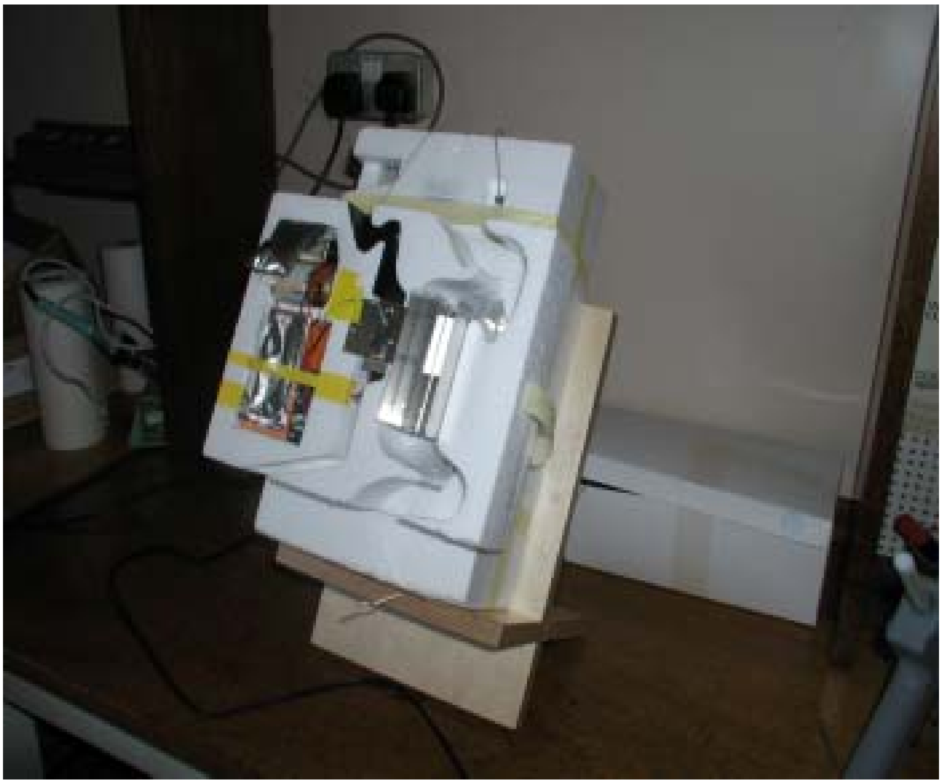


Figure 1- Snow White undergoing flight preparation at Camborne.

The Graw GK90C ground station has been used at Camborne since 2001 as a height reference for testing other radiosondes but within a short time of starting the test the ground system developed a fault. On repair by the manufacturer the interface between the ground station and radiosonde was upgraded to take into account advances in GPS technology that had recently been introduced by Graw. The DFM97 GPS radiosondes stored at Camborne since 2002 were replaced by the manufacturer with radiosondes incorporating the GPS upgrade.

A Sippican ground station is also used at Camborne for referencing height measurements. This required a software upgrade to allow processing measurements for the 3 thermistor radiosonde. The software allowed processing of 4 additional temperature channels plus the standard channel.

Relative Humidity Results

Fig 2 shows an example of a comparison between simultaneous measurements of dewpoint measured by the Snow White and values derived from temperature and relative humidity measurements from the Vaisala RS92. The correct value of dewpoint in the stratosphere [after minute 40] for the time of year in the UK was probably between -75 and -80°C [relative humidity between 8 and 3 per cent.)

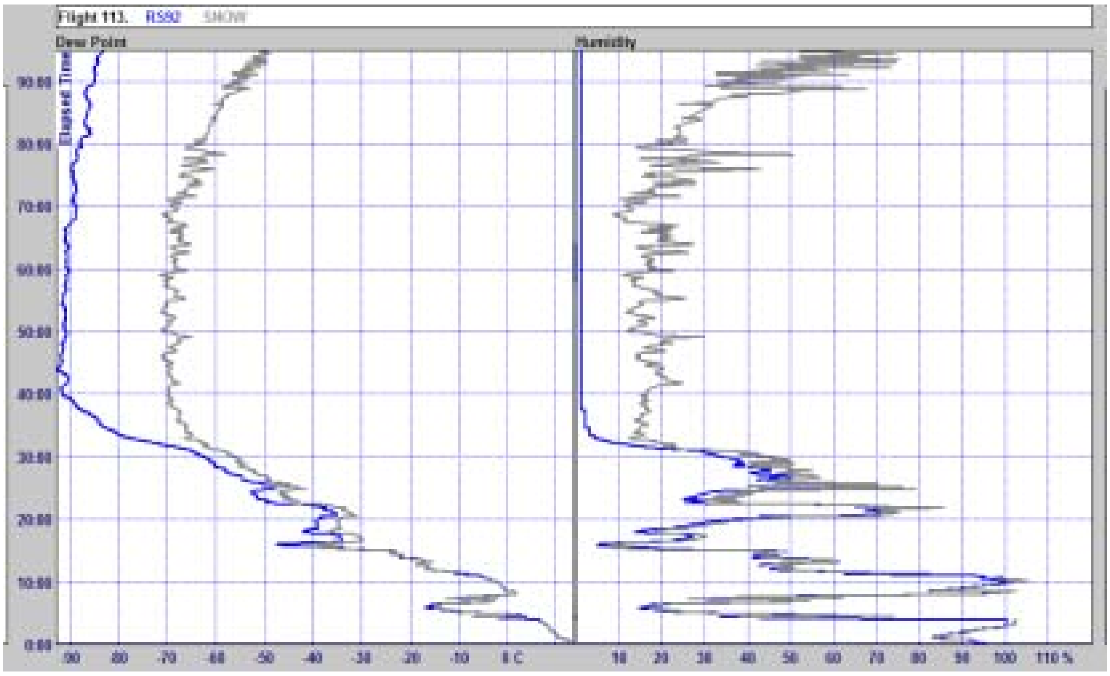


Figure 2- Simultaneous comparison between Snow White and Vaisala RS92 dewpoint, left hand pane and relative humidity right hand pane.

The increase in dewpoint with height after minute 70 was related to the build up of water vapour contamination around the cold mirror in the Snow White [P.Ruppert[1], personal communication] and would mostly disappear once the balloon burst and ventilation of the Snow White improved. On many flights the Snow White dewpoint did not fall lower than -60°C in the stratosphere because of contamination in the ducts. Thus, in order to minimise the build up of this contamination, an open-ended metal cylinder was inserted immediately above the Snow White sampling chamber, and the entry to the ducts at the top of the radiosonde was blocked off, see Fig. 3. The measurement in Fig.2 is made with this arrangement, and although it did not solve the contamination problem entirely, the speed of response of Snow White and the level of contamination after passing through several layers of high relative humidity was better than in some of the early test flights.

Figure3 - Snow White showing the ventilation modification. With a normal Snow White, ice crystals can enter through the top vent and accumulate in the ventilation duct and around the sensor housing. Side ventilation should limit this ingress by extending the duct well away from the body of the radiosonde.

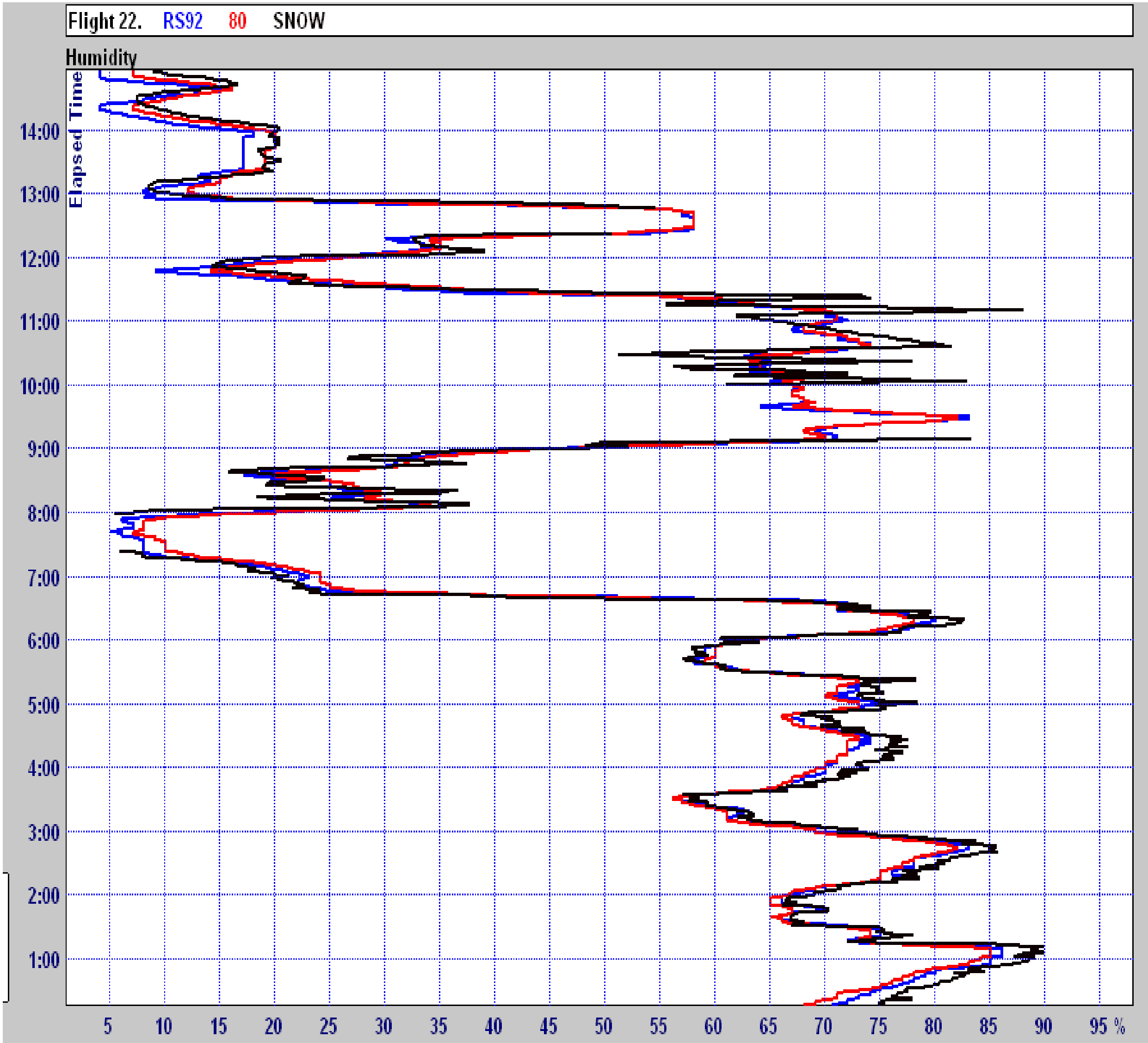


Figure 4(a), Simultaneous relative humidity measurements of RS92 (blue), RS80 (red) and Snow White (black). The Y axis is time from 0 to 15 minutes and the X axis is relative humidity (%)

Figure 4 shows a detailed comparison between Snow White and Vaisala in the lower troposphere. It takes about 20s into flight before the RS80 and Snow White sensors begin to ventilate correctly. Snow White data have been edited out for about 40s before minute 8, because the air was so dry that the film of water on the mirror disappeared and dewpoints were invalid. Snow White data were also edited out between minute 9 and 10 because it tended to be unstable, with the dewpoint temperature oscillating after the rapid increase in relative humidity [dewpoint] at minute 9.

The full extent of the instability in dewpoint control of this particular sensor is seen later in the flight after minute 23, see Fig.4b. In some flights, the dewpoint oscillations were much larger in upper cloud and all the Snow White data were edited out. Data from at least one comparison in rain were excluded from the data set, since all the sensors were heavily contaminated and iced, with the results not representative of normal measurement conditions.

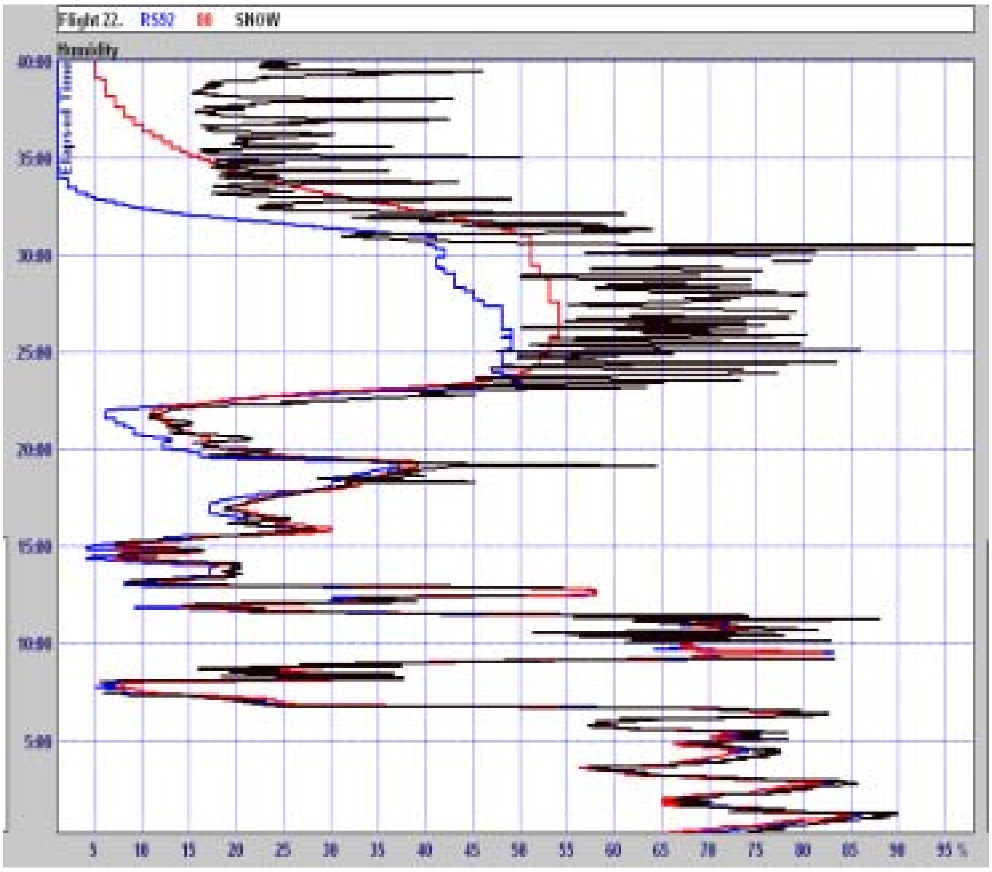


Figure 4. (b), Simultaneous relative humidity measurements of RS92 (blue), RS80 (red) and Snow White (black). The Y axis is time from 0 to 40 minutes and the X axis is humidity (%)

By the end of the test, the number of successful Snow White, Vaisala RS92 comparisons was 18 in the day and 15 at night. Here, the results have been processed using RSKOMP software [S. Kurnosenko[2], personal communication] for 3 temperature bands, greater than 0, 0 to -30, and -30 to -60. The systematic difference in Relative Humidity between RS92 and Snow White, and the standard deviation of the comparison are presented for day and night in Figs 5 to 7.

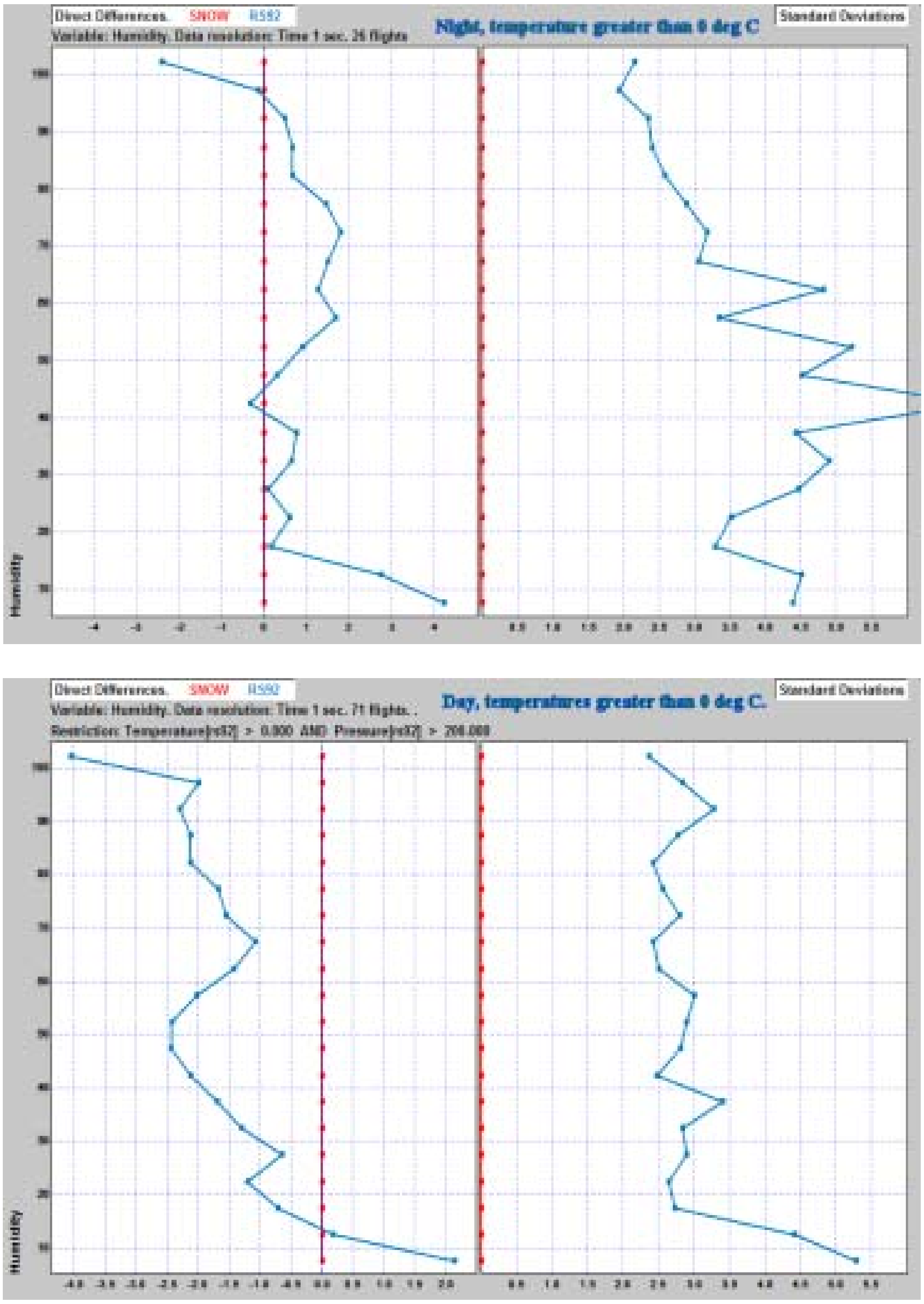


Figure 5- Left hand pane is direct differences in relative humidity [Snow White-RS92] as a function of relative humidity for temperatures greater than 0°C. RS92 trace is blue, and Snow White (red, reference). The standard deviations of the differences are shown in the right hand pane. Upper plots are for night time measurements, lower plots for daytime.

In Fig.5, the typical day-night difference between Vaisala and the reference was -3 per cent at high relative humidity. On average at night the two sensors agreed to better than 2 per cent. The standard deviations between the measurements are consistent with the random error in each of the two sensors in the range 2 to 4 per cent.

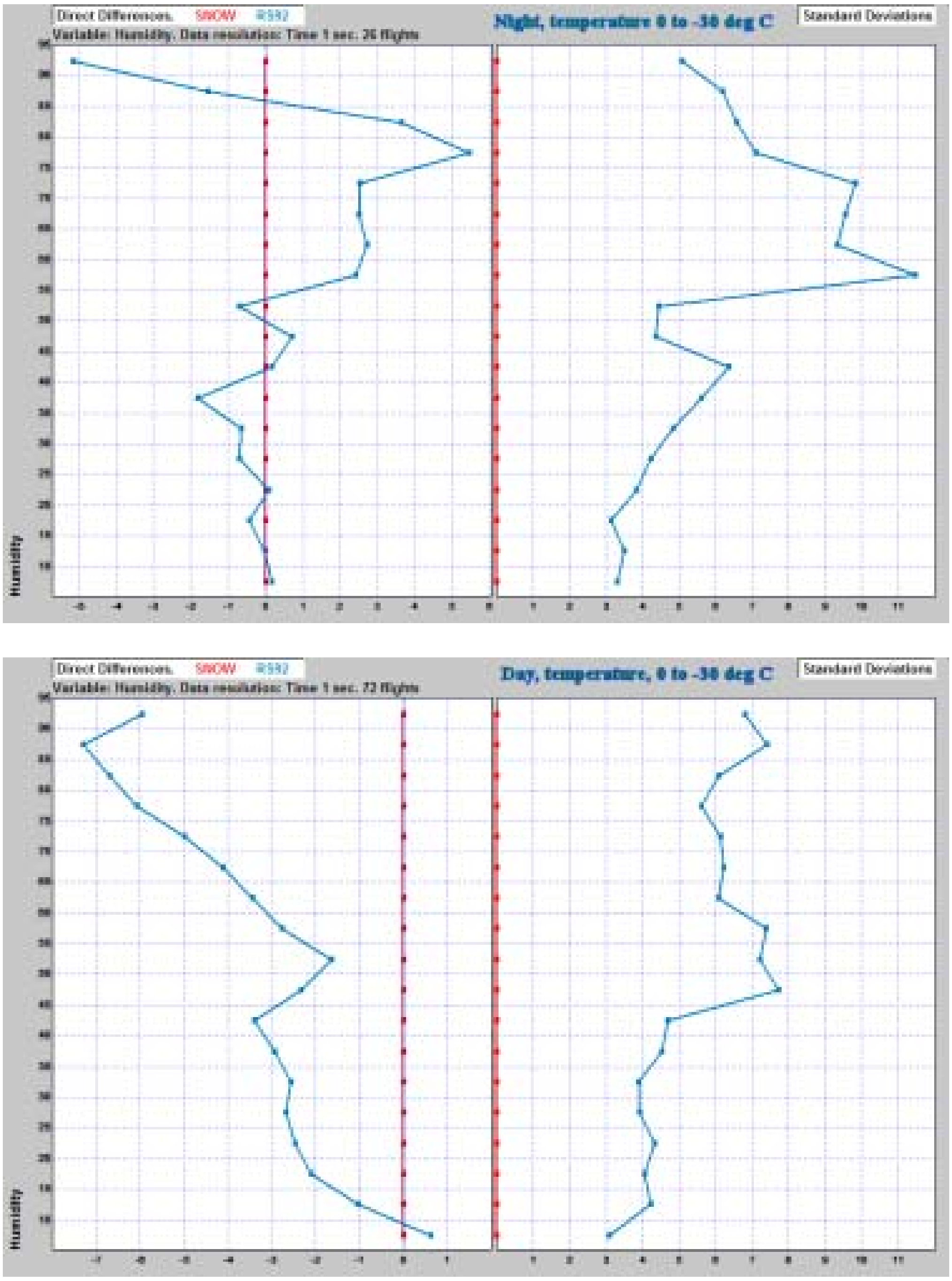
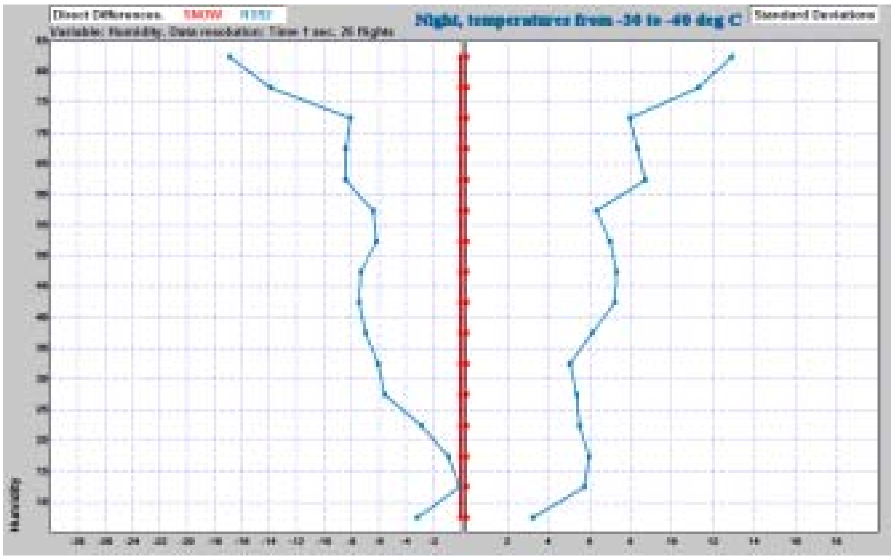


Figure 6- Similar plots to Fig.5 but for the temperature range 0 to -30 °C

In Fig.6 the typical day–night difference for this temperature range, centred at about 70 per cent was about -6 per cent relative humidity. At night both sensors agreed on average to better than 2 per cent. The standard deviations between the measurements were consistent with random errors in individual sensor of between 3 and 7 per cent. Some of this may have been due to oscillations in Snow White dewpoint, but some of the variation will be induced by the response to changes from wet to dry layers [contamination in the Snow white ducts, hysteresis in the capacitative sensors].



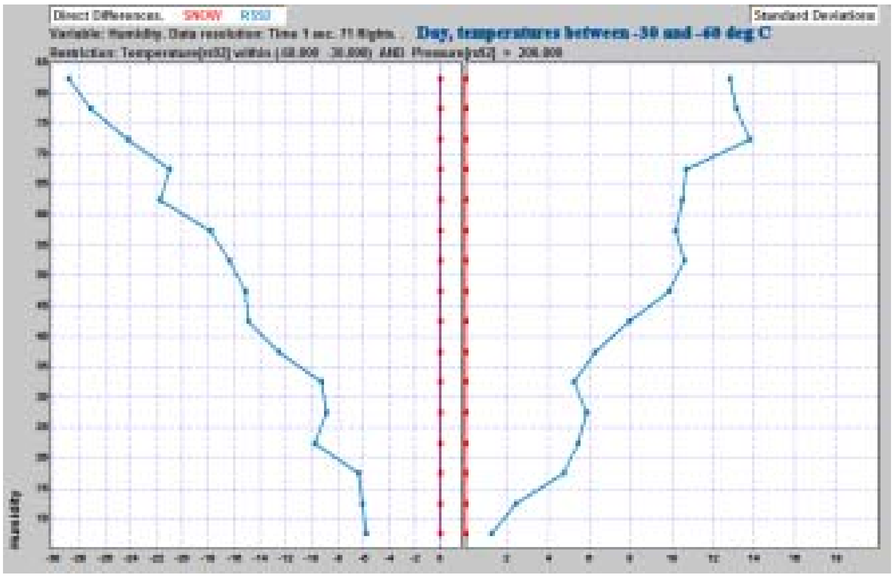


Figure 7- Similar plots to Fig.5 but for the temperature range -30 to -60 °C

In Fig.7 the typical day–night difference for this temperature range, centred at about 60 per cent was about -12 per cent relative humidity. At night both sensors agreed on average to better than 2 per cent at low relative humidity, but differed by about 7 per cent at 70 per cent relative humidity. In the daytime the differences at 70 per cent had increased to about 20 per cent. The standard deviations between the measurements at all but the highest relative humidity were consistent with random errors in individual sensor of between 3 per cent at low relative humidity to up to 8 per cent at high relative humidity. Some of the higher random errors may have been due to oscillations in Snow White dewpoint, but not all.

Throughout the test GPS water vapour measurements and microwave radiometer measurements of integrated water vapour were available both at night see Fig. 8 and during the day see Fig.9

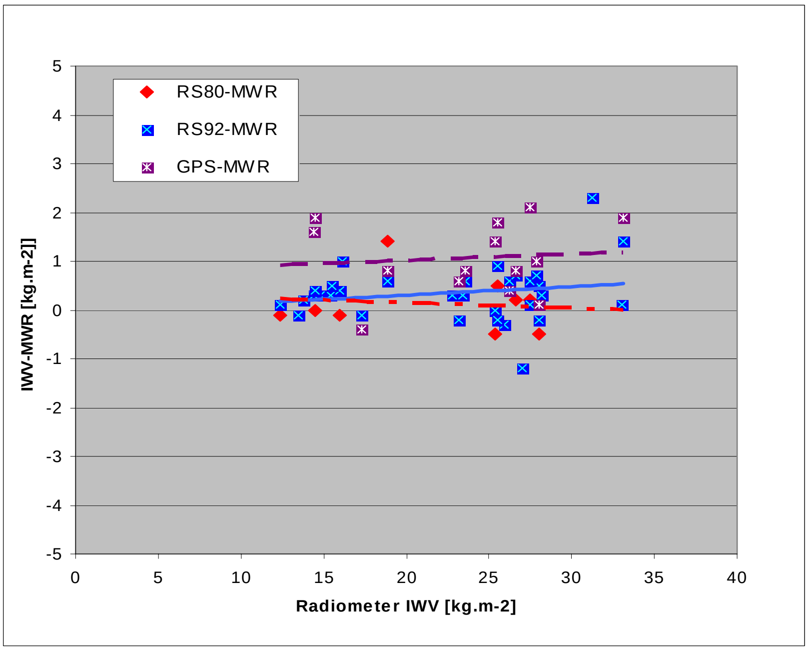


Figure 8- Night time differences between radiosonde and GPS integrated water vapour measurements from simultaneous Radiometrics microwave radiometer measurements when it was not raining, RS92 Acceptance Test, Camborne.

In Fig 8 the night time radiosonde measurements were in close agreement with the microwave radiometer measurements, whereas the GPS water vapour measurements had a positive bias of about 1 kg.m^{-2}.

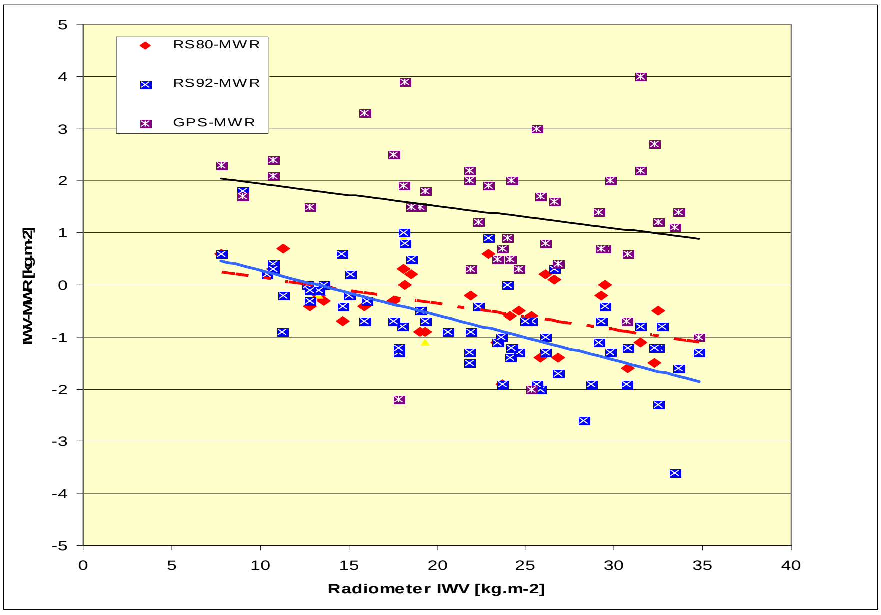


Figure 9- Daytime differences between radiosonde and GPS integrated water vapour measurements from simultaneous Radiometrics microwave radiometer measurements when it was not raining, RS92 Acceptance Test, Camborne.

In the daytime, Fig.9, the RS92 radiosonde measurements show a negative bias of about -1.3 kg.m^{-2} for IWV of 30 kg.m^{-2}. This would be equivalent to a negative bias of about 4 per cent relative humidity on average through the lowest 4 km of the troposphere. The temperature at 4 km during the test was normally in the range 0 to -10 °C. This value appears consistent with the day-night biases in RS92-Snow White comparisons, if nearly all the day-night difference in Fig. 5 and 6 were originating in a change in the RS92 humidity sensor performance.

A 78GHz cloud radar was operated during the test flights for most of the test. This allowed the presence of upper cloud to be monitored.

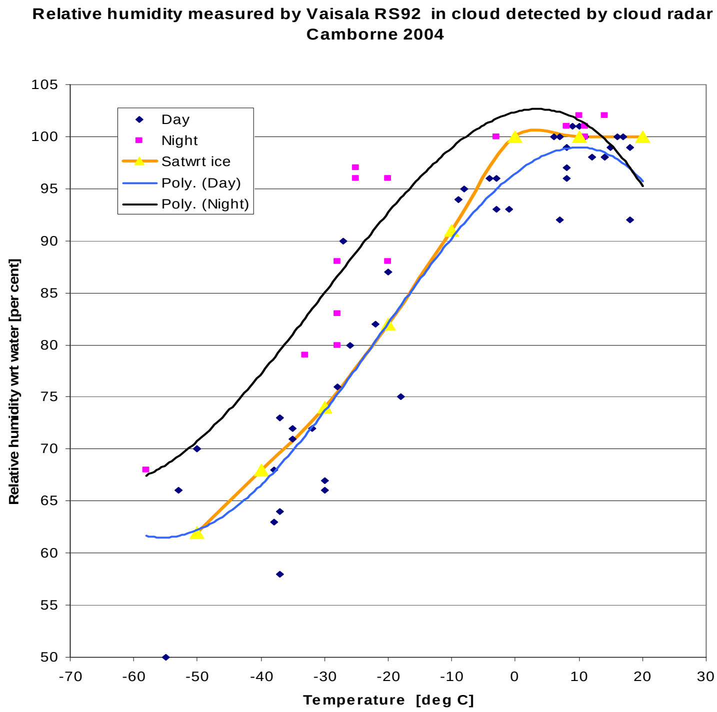


Figure 10- Maximum relative humidity observed at level of cloud detected by cloud radar, RS92 Acceptance Test, Camborne

Fig 10 shows the maximum values observed in layers of cloud or fog identified by the cloud radar. The results above 0°C are again consistent with a day-night difference of about 3 per cent in Vaisala measurements. Most of the mid-level cloud was observed at temperatures around -30°C. Fig.10 shows a clear day-night difference in the relative humidity measurements of about 10 per cent. This was again consistent with most of the day-night difference in Figs 6 and 7 originating from a day-night difference in the Vaisala measurements. Fig.10 shows that at -35°C the daytime relative humidity measurements were about 5 per cent lower than saturation with respect to ice. The night time relative humidity in cloud centred at -20°C was about 10 per cent higher than saturation with respect to ice, but this may be correct because of supercooling in some of the clouds.

Height and wind analysis.

Figure 11 shows the direct differences and standard deviation for simultaneous comparisons of geopotential height including the Graw DFM97 GPS (reference, blue), the RS92 GPS (green) and the RS80 (black). The GPS height reported by the Graw radiosonde was converted from geometric to geopotential height before comparing against the two Vaisala radiosondes. As can be seen from the left hand plot the RS92 geopotential height is within 5 meters of the Graw GPS height from the surface to burst.

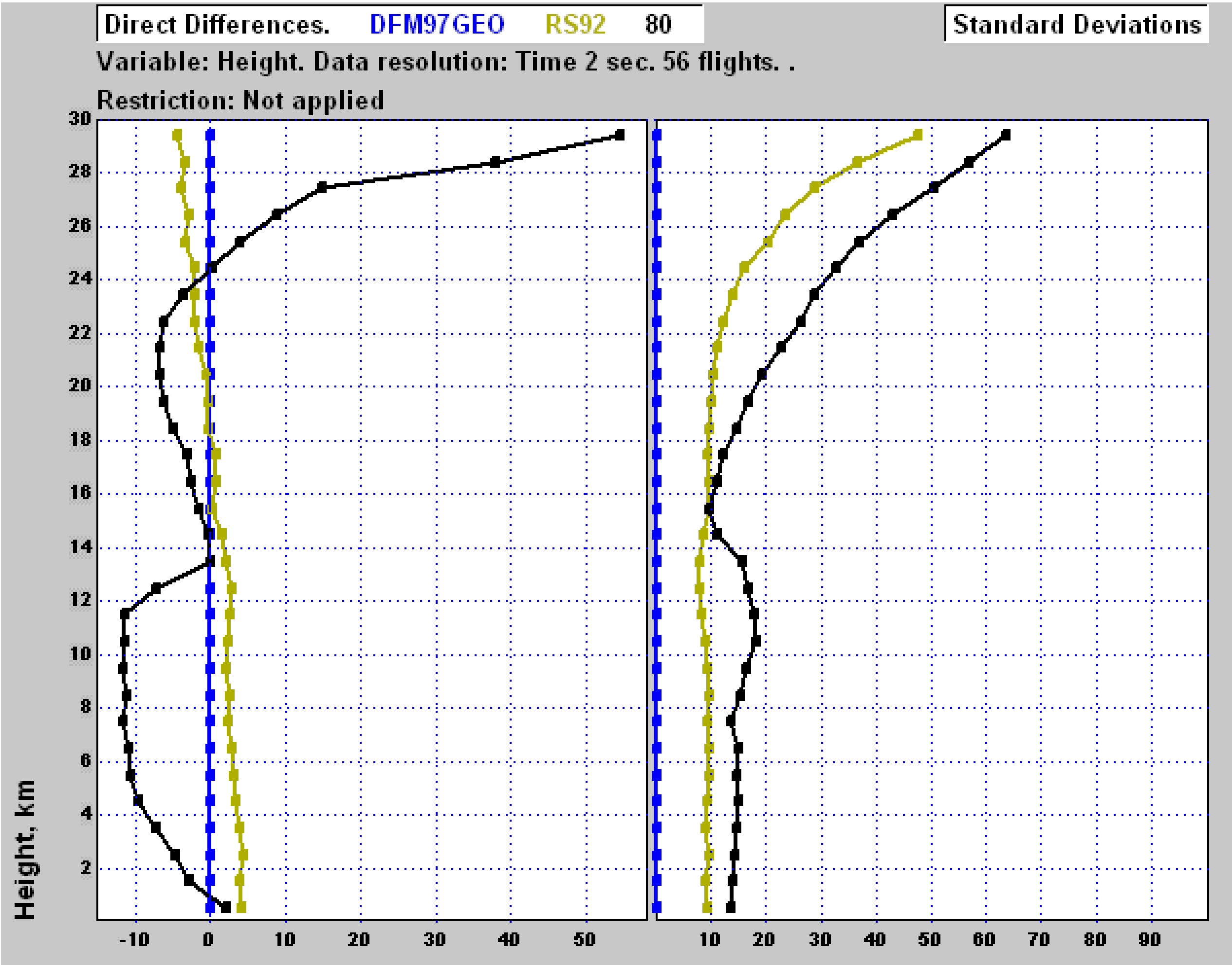
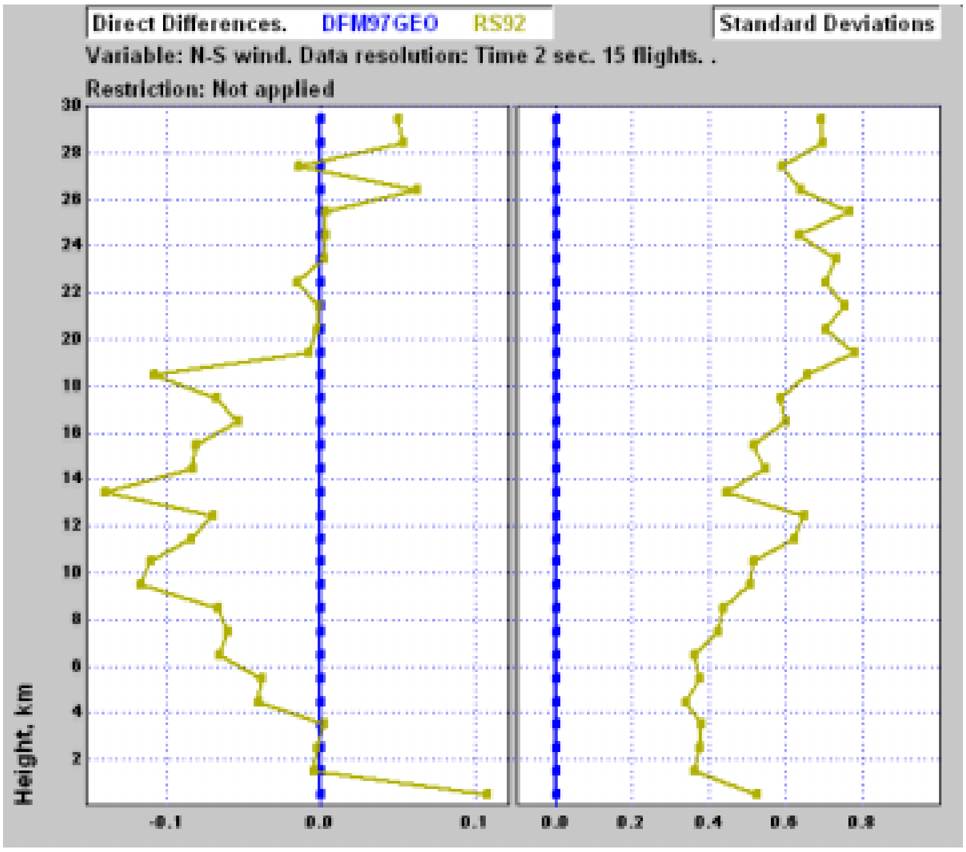


Figure11- Simultaneous comparison of geopotential height, RS92 acceptance test, Camborne, Left hand pane direct differences, right hand pane standard deviations

The accuracy of the GPS heights is not expected to vary significantly with height, so the rapid increase in the standard deviations at heights above 24 km for the RS92 was caused by the random errors in the RS92 pressure sensor. This suggests that the random errors in Vaisala RS92 pressures near 10 hPa were less than 0.1 hPa.

Figure 12, shows the direct differences in the North- South and East-West wind components between the Graw DFM97 (reference, blue) and the RS92 GPS (green).
These results show larger standard deviations than in previous trials. It is probable that the basic smooting of the Graw winds has changed, since if the winds are averaged in the vertical the standard deviations in the comparison have values around 0.1 ms^{-1}.



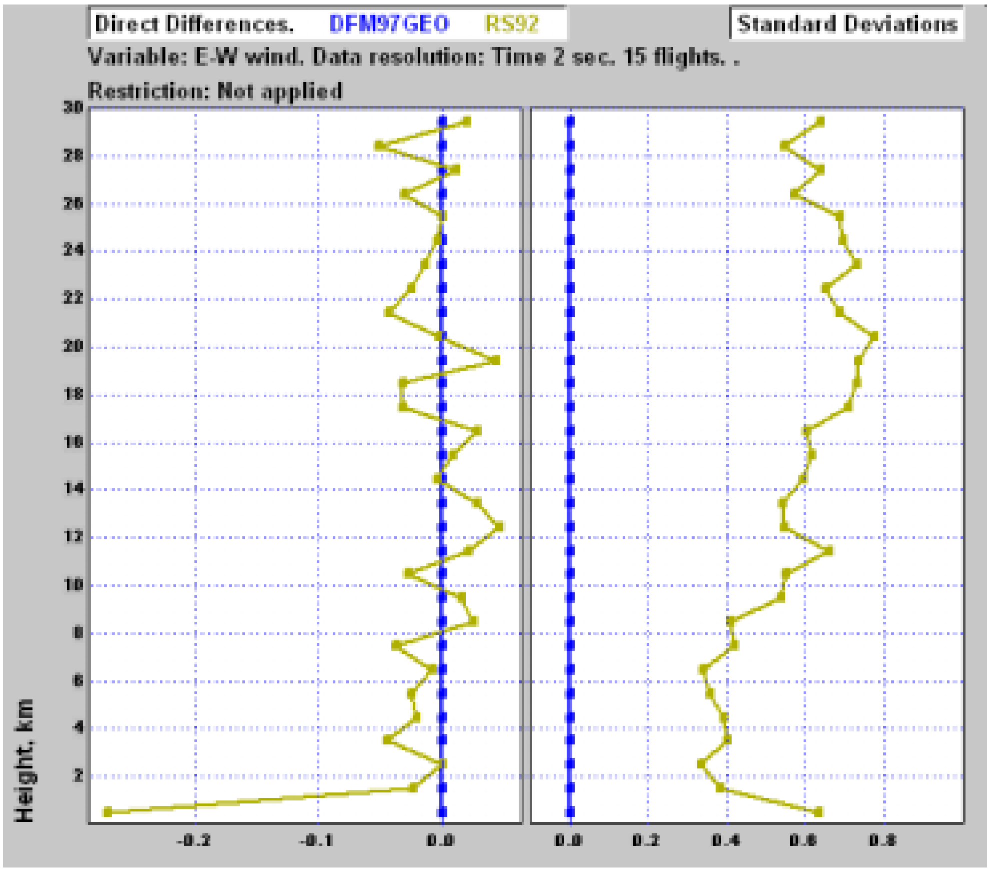


Figure12- Simultaneous comparison between wind components as a function of height, presented as systematic difference, left hand pane and standard deviations, right hand pane.

Temperature measurement

The main purpose of the temperature comparisons was to check the correction of Vaisala RS92 daytime measurements against a reference provided by Sippican 3 thermistor measurements. The thermistors used were Sippican chip thermistors, much smaller than the rod thermistors, so that errors to be corrected were smaller than with the rod thermistor.

Although the five thermistors supplied would usually agree well before launch, once in flight significant discrepancies occurred that were clearly not related to differences in the thermistor coatings. The origin of these differences could have been faulty calibration or variations in radiofrequency pickup between the signal channels on the radiosonde. Thus, in order to produce consistent results the thermistor readings of some sensors were adjusted to values that gave consistent results in the stratosphere. The aluminium sensors required adjustment most often and were most often in error by 0.5 and sometimes 1°C. The adjustment procedure employed relied on knowing the uncorrected temperatures of the Vaisala RS92 and was estimated to limit the reliability of the final multi-thermistor output to an optimum accuracy of 0.2°C at best.

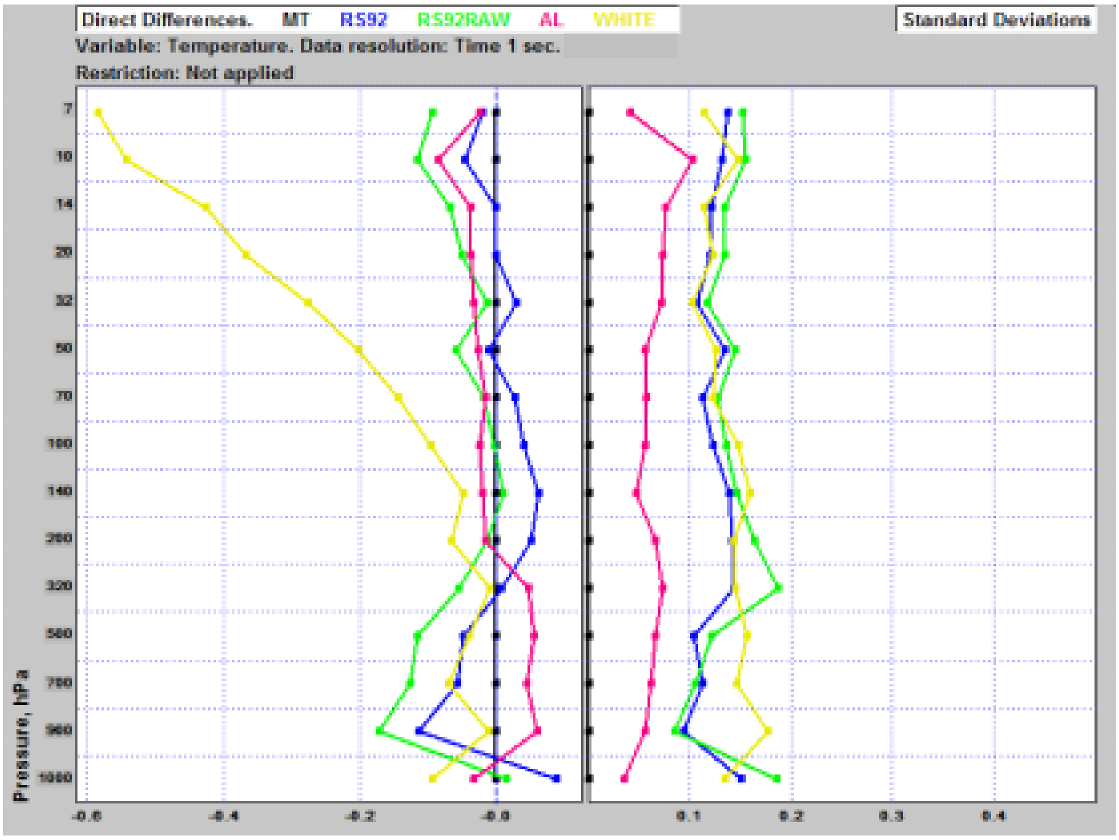


Figure13- Result of simultaneous night time comparisons between multi-thermistor output [black, reference], Vaisala RS92 [blue], Vaisala RS92 raw [green], multi-thermistor aluminium sensor [red] and multi-thermistor white sensor [yellow]. 5 comparison flights. Direct differences as a function of pressure, left hand pane, standard deviations, right hand pane.

The 5 night time comparison flights confirmed close agreement between the multi-thermistor and Vaisala RS92 measurements. The white paint used was relatively black at night so infrared cooling lowered the temperature of this thermistor by about 0.5 °C at night.

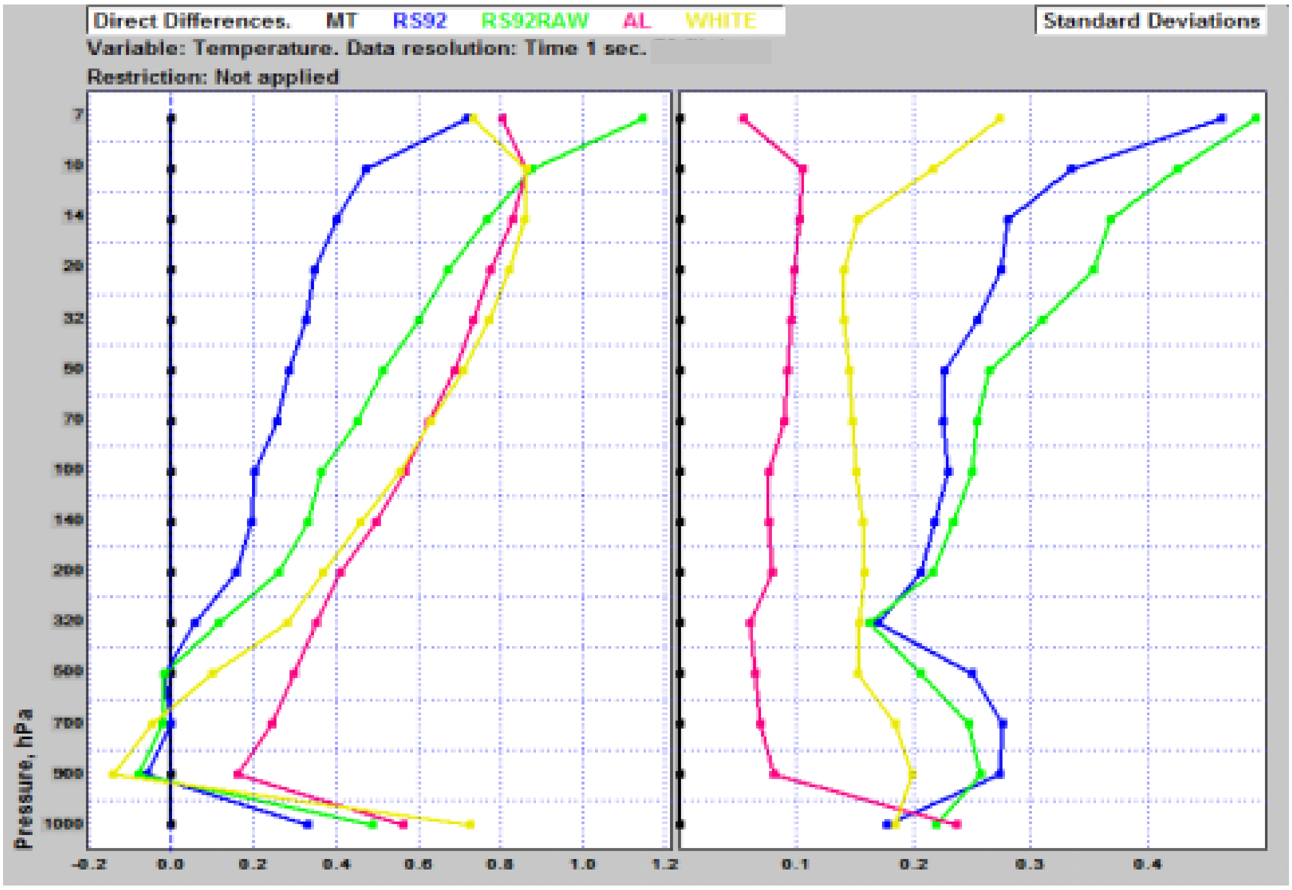


Figure14- Result of simultaneous daytime comparison between multi-thermistor output [black, reference], Vaisala RS92 [blue], Vaisala RS92 raw [green], multi-thermistor aluminium sensor [red] and multi-thermistor white sensor [yellow]. 14 comparison flights. Direct differences as a function of pressure, left hand pane: standard deviations, right hand pane.

In the daytime, the uncorrected 3 thermistor measurements were close to the Vaisala RS92 uncorrected measurements. In the stratosphere, the Vaisala measurements showed heating spikes of up to 1 °C [probably air heated by the sensor support frame passing onto the sensor] as the radiosondes rotated. The Sippican chip thermistors, deployed pointing upwards above the supports, did not show temperature variations correlated with radiosonde rotation. The Vaisala editing process removed most of the heating spikes, and this is probably the main reason why the standard deviations associated with the Vaisala RS92 in Fig.14 are lower than for the Vaisala raw in the stratosphere. If the Sippican 3 thermistor computation is correct then the Vaisala RS92 needs larger temperature corrections than are currently applied, with the correction twice that currently applied at 10 hPa.

Frequency Drift

One of the factors influencing the version of the Vaisala RS92 radiosonde in the long term is the radiofrequency characteristics of the transmitter.

	RS80	RS92-SGP	RS92-AGP
Number of Flights :	46	77	45
Total drift (MHz) :	5.911	0.291	0.020
Maximum drift (MHz) :	0.700	0.270	0.003
Mean drift (MHz) :	0.1285	0.0038	0.0004
Flights with drifting :	40	13	11
Flights with no drifting :	6	64	34

Table 1- Summary of the stability of radiosonde transmissions, RS92 Acceptance test

Conclusions

During the UK RS92 radiosonde acceptance test, not only was the new Vaisala radiosonde exercised but also new versions of systems from Graw, Meteolabor and Sippican. It is hoped that this will lead to improved performance of all these systems.

In particular, a diurnal heating problem with the relative humidity sensor of the Vaisala RS92 was quantified. It has subsequently been identified that the heating of the humidity sensors in daytime was exacerbated by the coatings on some of the surfaces close to the sensors. Vaisala will change these coatings for the WMO Radiosonde Comparison in Mauritius and for future operational versions of the RS92 radiosonde.

Similarly, the Vaisala day time temperature correction software will be modified for the Mauritius test.

References

[1]Paul Ruppert, Manager, Meteolabor AG , Hofstrasse 92, CH-8620 Wetzikon, Switzerland; email: paul.ruppert@meteolabor.ch
[2]Sergey Kurnosenko, Scientific software consultant; email: skurnosenko@cox.net