Review of test results on the accuracy of radiosonde relative humidity sensors

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1. Introduction

The data used to generate the picture of radiosonde relative humidity sensor performance presented here were mainly obtained in the WMO Radiosonde Comparisons. These tests contained large numbers of comparison flights where radiosondes of different types were flown together under the same balloons. The total number of test flights varied from 40 to over 100, depending on the particular test plan. Tests were performed in UK (1984), USA (1985), Kazakhstan (1989), Japan (1993), USA (1995) and Brazil (2001). The respective project leaders for the tests were J. Nash (UK), F. Schmidlin (USA), A. Ivanov (Russia), S. Yagi (Japan) and R. da Silveira (Brazil). An additional international test of similar scale to the WMO comparisons was hosted in the UK in 1992, testing potential reference radiosondes (PREFRS) with participants from USA, Switzerland and Russia. The results in this paper were generated with software provided by S. Kurnosenko formerly of the Central Aerological Observatory, Dolgoprudny, and Russia.

2. Relative humidity sensors in use

The latest edition of the WMO Guide to Instruments and Methods of Observation (WMO, 1996), provides a basic introduction to modern radiosonde relative humidity measurements in section 12.5 and a review of sources of measurement error in section12.8. In this paper, the sensor types considered will be:-

- Goldbeaters skin (mainly used in China and Russia, but also formerly used by the UK in many of the test reviewed here).
- Carbon Hygristor (manufactured in the USA but also used under license by many national radiosonde designs , e.g. Switzerland)
- Capacitative sensor (thin polymer film) originally used extensively by Vaisala (Finland) the dominant manufacturer world-wide, but now also implemented by other national radiosonde designs such as in Japan and France.

It will be seen that the different types of sensor offer quite different measurement capability and should not be treated as equivalent “radiosonde” measurements.

3. Referencing relative humidity measurements

In recent years a chilled mirror hygrometer (Snow White) has been introduced in Switzerland by Meteolabor, providing measurements of dewpoint at high temporal resolution during test flights that can be used as an independent check on the radiosonde sensors. The Met Office has used this system together with the latest capacitative sensor from Vaisala (on RS90-G radiosonde) to examine the performance of two of the other widely used types of radiosonde relative humidity sensor. Results from some of these tests were reported in Smout et. al. (2002). Standard deviations between RS90 and Snow White measurements at night at temperatures between 15 and 0 ºC were typically between 2 and 3 per cent, much lower than were obtained between the different types of older radiosonde sensors. The systematic bias between the Snow White and RS90 (twin sensors, heated in turn to remove contamination in flight) were as shown in Fig.1 from two tests, one in Brazil and the other at Ascension Island. The negative bias of the Vaisala measurements in daytime seems mostly due to solar heating of the Vaisala humidity sensors.

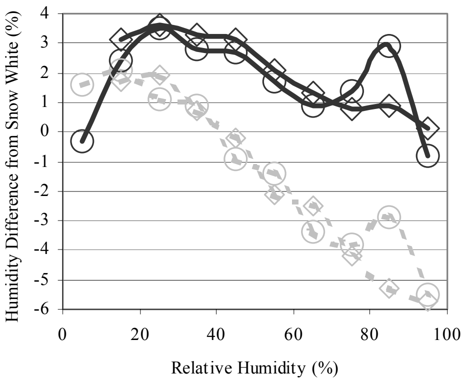


Fig.1 Daytime (grey) and nighttime (dark) comparisons between RS90 relative humdity and Snow White, circles results from WMO Radiosonde Comparison Brazil, 2001 diamonds from a UK/Vaisala test on Ascension island in 1999 for the temperature band 0 to 15 ºC

In estimating systematic errors from the different radiosonde comparison tests it is assumed that the Vaisala sensors have a slight positive bias at low humidity as shown in Fig. 1 at night because of hysteresis in the sensor. The relative humidity indicated in cloud is used to estimate the error at high humidity. It is then assumed that the bias in Vaisala relative humidity usually runs out smoothly between high and low humidity as indicated against Snow white in Fig.1. In daytime measurements it is assumed that solar heating introduces a negative bias relative to nighttime Vaisala measurements at high humidity in mid-latitudes. This is of smaller magnitude than shown in Fig. 1 (about 3 per cent in the lower troposphere). The magnitude is consistent with day- night differences recently found in comparison with microwave radiometer and GPS measurements of Integrated Water Vapour.

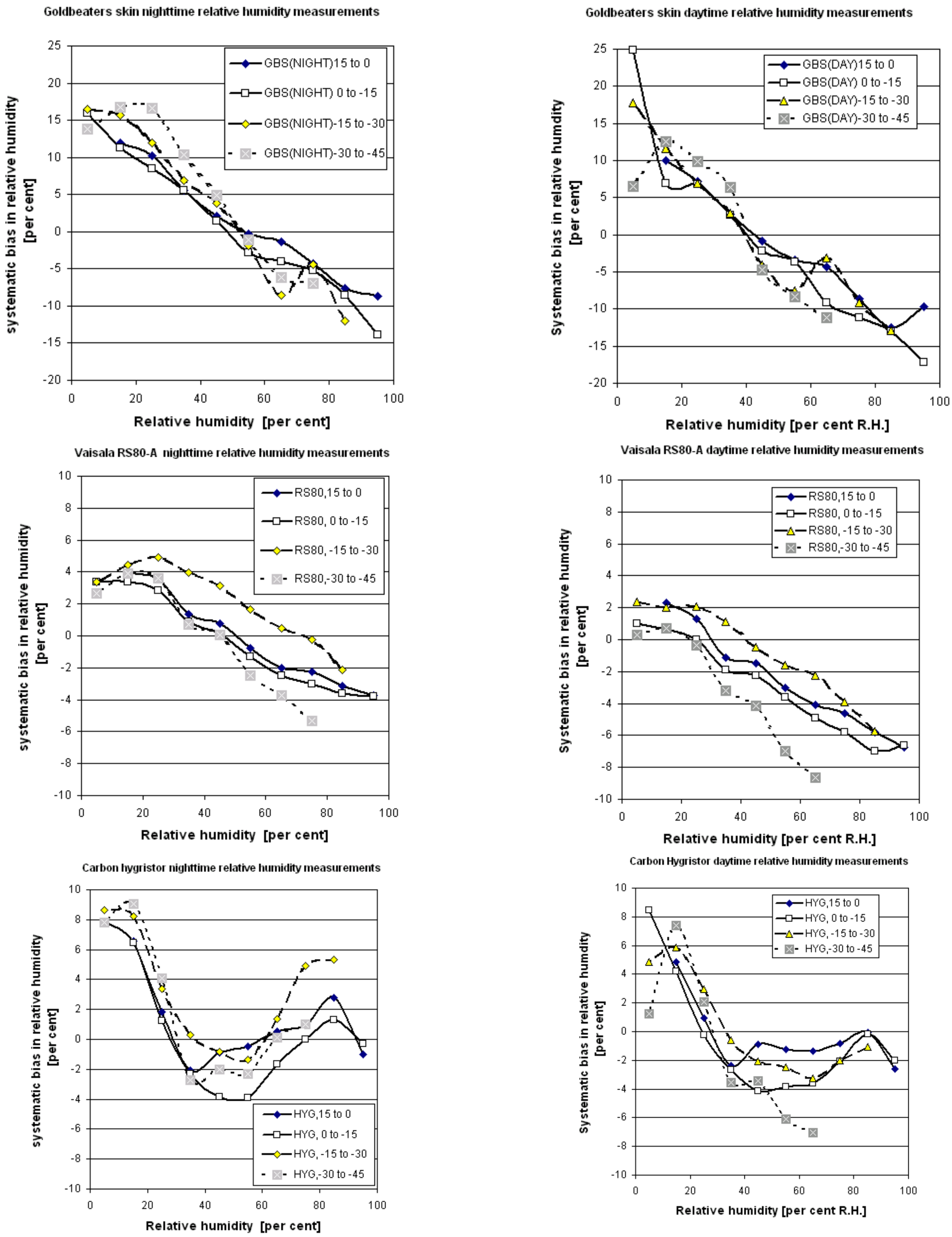
4. Summary of test results

The test results presented here are derived from the differences between the different types of radiosonde sensor measured in the comparisons, given that flights where the sensors have become wet in ascending through low cloud and rain have been omitted. The comparisons are divided into 15 degree temperature bands. The sensor performance has a complex dependence on both temperature and pressure, but temperature is probably the more dominant influence. The absolute error is derived from an estimate of the Vaisala performance based on the Snow white comparisons indicated in section 3, and the performance of the Vaisala sensors in cloud in individual tests.

If the systematic errors presented for the carbon hygristors were differenced from the systematic errors from the Vaisala sensors, the resultant value would be the difference actually measured in the comparisons. The accuracy to which the systematic error of the individual system could be estimated is about 2 to 3 per cent at high temperatures and less than this at the lowest temperatures.

4.1. Goldbeaters skin

Fig.2 contains estimates of systematic errors for gold beaters skin sensors, obtained from UK radiosondes but also those from China and Russia. The sensors have relatively small errors at about 50 per cent R.H., but the systematic errors are large at both high and low humidity. This is not the result of poor sensor calibration, because these sensors exercised in a laboratory chamber with twenty to thirty minutes to settle would give values close to truth. In flight the sensors will respond rapidly to a sudden change of humidity, see Fig.3 at low levels, but there are parts of the sensor that do not respond at the higher rate. Thus, the whole sensor underestimates the magnitude of the transition and it takes many minutes at high or low humidity before the sensor gets close to the true relative humidity. In Fig.3, it probably took 7 minutes to ascend 2 km.


Goldbeaters skin nighttime relative humidity measurements

Goldbeaters skin daytime relative humidity measurements

Vaisala RS80-A nighttime relative humidity measurements

Vaisala RS80-A daytime relative humidity measurements

Carbon hygristor nighttime relative humidity measurements

Carbon Hygristor daytime relative humidity measurements

Fig. 2 Estimates of systematic error in night-time and daytime measurements for goldbeaters skin, carbon hygristor and Vaisala A Humicap sensors from the WMO Radiosonde Comparisons + PREFRS

The time constant of response of goldbeaters skin drops rapidly with temperature .It is unwise to use the e measurements at temperatures below –40 ºC. The random errors in the measurements are at best 6 to 9 per cent R.H. (1 s.d.) and worse than this at the lower temperatures. Thus, goldbeaters skin sensors do well to deliver measurements at high and low humidity of about 15 per cent R.H. accuracy. The sensors do identify the positions of significant hydrolapses with relatively good accuracy. It is to be expected that the use of these sensors will be phased out within a few years in China, but the plans for future radiosonde use are not so clear in Russia. The gold beaters skin sensors function reasonably well in rain and contamination errors is usually not larger than some of the other errors.

4.2. Carbon Hygristor

Fig.2 contains estimates of carbon hygristor measurements spanning nearly 20 years, both in VIZ radiosondes (later Sippican) (USA) and in other manufacturers purchased from VIZ, such as the Phillips radiosonde in Australia, Meteolabor in Switzerland and AIR Intellisondes (USA).

Recent results from two tropical tests with Snow White are summarised in Fig. 4. In this case the consistency relative to the Snow whites is much poorer than for the Vaisala RS90 Humicap, and at relative humidity lower than 25 per cent the systematic errors show a large variation between the four test categories considered. The standard deviation of the differences with respect to Snow white is about 5 per cent. The large variation between tests at low relative humidity has been found for many years. Although the carbon hygristor is more consistent than goldbeaters skin at high humidity, at low humidity below 30 per cent it is more inconsistent from batch to batch than the goldbeaters skin. Historically, relative humidity lower than 20 per cent was not reported in the USA when carbon hygristors were in use.

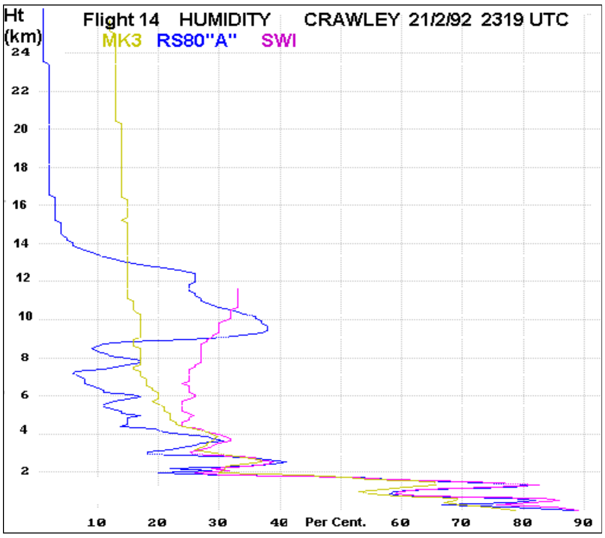


Fig. 3 Relative humidity measurements compared at 1 minute intervals from a test flight during PREFRS (1992) in southern England. The MK3 sensor was goldbeaters skin; the SWI sensor was a carbon hygristor mounted in an internal duct on the radiosonde, the RS80 "A" sensor was the A Humicap sensor in operational use in the UK at the time. Temperature at 8 km was -40ºC and at 12 km was -70ºC.

Carbon hygristor calibration in the factory is set up at about 30 per cent R.H. and it can be seen that the systematic error in this region is low. There have been a significant number of variants in processing algorithms for the sensor, as issued by the manufacturer, and it would be unwise to assume stability to much better than 5 per cent in R.H. systematic error even at higher humidity.

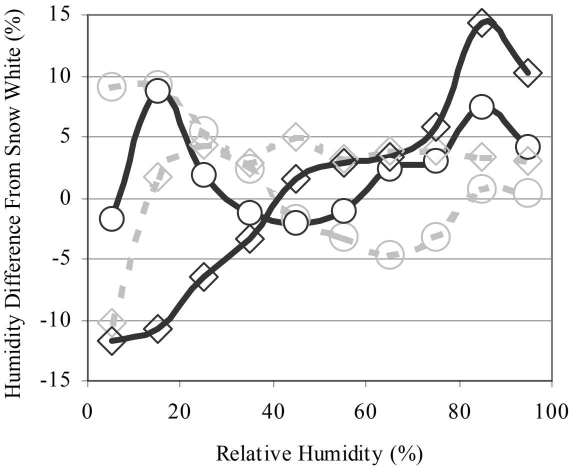


Fig.4 Daytime (grey) and nighttime (dark) comparisons between Sippican carbond hygristor relative humdity and Snow White, circles results from WMO Radiosonde Comparison Brazil, 2001 diamonds from a UK/Vaisala test on Ascension island in 1999 for the temperature band 0 to 15 ºC

The sensor is quite inconsistent in performance at temperatures lower than about –40 ºC. On some test flights it appears to work reasonably well down to temperatures of –50 ºC, but on other occasions it appears to become insensitive at temperatures around –40 ºC. Thus, measurements by carbon hygristors at temperatures lower than –40 ºC should be treated with caution.

One of the main drawbacks with the carbon hygristor sensor is that it may not be stable in calibration if exposed to wetting conditions (humidity near saturation) for a relatively short time during the ascent or in the laboratory. Often the calibration changes and subsequent measurements are too low by around 20 per cent R.H. This is the main reason why flights through low cloud have been excluded from the main comparison database here. As this is the case it is unwise to assign a typical measurement accuracy of much better than 10 per cent R.H. to the carbon hygristor, although it may be better than this at middle and high humidity in the lower troposphere, and worse than this in dry layers.

4.3. Capacitative sensor

Fig.2 contains results from testing with the Vaisala RS80-A capacitative sensor, used widely in the operational networks for more than fifteen years. This sensor responds to humidity changes at much lower temperatures than -40ºC, and can be used down to between –60 and -70ºC, although the newer RS90 sensor is more reliable at the lower temperatures and works down to at least -80ºC. In the early 1990s a second sensor known as the H-Humicap was also introduced into operation with the RS80 radiosonde, e.g. in the USA operational network. This has been used in the UK for more than 6 years. The polymer film of this sensor is more stable at high humdity than the A-Humicap but requires a higher order ploynomial calibration than the A-Humicap. Random errors for these types of sensor are about 3 per cent (1 s.d.), about half those of the carbon hygristor.

Test results from the A and H Humicap sensors are almost identical at temperatures higher than -40ºC, but at lower temperatures than -40ºC, the H-Humicap is slower in response than the A-Humicap but more accurate in calibration. The problem with the A- Humicap calibration can be seen to be starting at temperatures between –30 and -45ºC in Fig. 2 , where the systematic error is getting larger at high humidity. Most of the published test results from the USA imply larger negative systematic errors for this sensor in cirrus, but most of the test flights were performed in the day, and the solar heating then makes a significant contribution to the low bias.

In situations where the sensor is contaminated in passing through low level cloud there is often a positive bias in the reported humidity. It is relatively simple to identify flights that have been contaminated for long periods by checking the magnitude of the relative humdity reported in the stratopsphere. A positive bias of 20 per cent on an individual flight is not uncommon at upper levels in moderate rain .

Another problem studied by the sceintific community in recent years was the effect of chemical contamination of capacitative sensors during storage before use. It was found that the H-Humicap could read low at high humidity by at least 10 per cent after 1 years' storage, with the sensor contaminated by styrene gas from the radiosonde body. It is believed that some of the radioosnde sensors in the tests reported here were contamintaed to some extent. Operational experience within the UK indicated that individual batches of sensors from the factory varied in performance with some clearly correct in cloud and others reading as much as 6 per cent low in cloud even after short term storage. In later years sensors were supplied that reported values up to 10 per cent too high. This suggests that on some occasions sensors were contaminated before calibration in the factory and in this case the dessicant in the radiosonde pacakage was able to clean the sensors up in short term storage causing a high bias on use.

The packaging used with the RS80 has now been changed to minimise the probability of contamination, so operational RS80 radiosondes in use should have a much lower chance of significant contamination and associated low bias.

Thus, although the capacitative sensors can work to much lower temperatures than the other types, the full benefit of this has yet to be achieved because of the limitations imposed by chemical contamination , the effects of water contamination in flight and solar heating of the senors. It would thus be unwise to claim that the accuracy achieved by the RS80 sensors was better than 5 per cent even though the reproducibility of the measurements in a given radiosonde batch is probably about 3 per cent. Under most circumstances in the UK the accuracy achieved with the H-Humicap has probably been in the range 5 to 7 per cent.

The RS80 radiosonde is expected to be replaced worlwide by the RS92 radiosonde in 2005. This radiosonde will have a similar sensor package to the RS90 but an improved heating cycle to drive off contamination more efficiently. The effects of chemical contamination will be minimised by ensuring sensors are clean before calibration at the factory and the sensors are then regenerated by heating before the radiosonde is launched. With this radiosonde system it should be possible to produce measurements with an accuracy better than 5 per cent at all levels in the troposphere.

5. Summary

The newer capacitative radiosonde relative humdity sensors have the capability to meet the stated WMO user requirement of 5 per cent accuracy . In order to achieve this it is necessary to be very careful in storing and preparing the sensors for flight (removing contaminants from the sensors). The procedures necessary to achieve the accuracy have now been identified and it is expected that the practices will spread into the operational radiosonde networks within a few years. Information from these types of sensors can be used in all of the tropopause (even in the tropics) without excessive error, but the sensing systems will not be of suitable accuracy or speed of response for use in the stratosphere.

About 40 per cent of the global radiosonde network is not capable of meauring with an accuracy better than 10 per cent at any height in the atmosphere, and does not provide useful measurements at temperatures lower than -40ºC.

Simple constant bias corrections , independent of the relative humdity measured, are not appropriate for the error characteristics of the radiosonde relative humdity sensors. For instance a simple positive bias correction of + 3 per cent for Vaisala RS80 measurements will lead to even higher positive error at low humdity at night.

6. References:

Guide to Meteorological Instruments and Methods of Observation, Sixth Edition, (1996) WMO-No. 8

Smout, Richard , J. Nash, D. Lyth, and J.Elms: Comparisons between the Vaisala RS90 and snow-white relative humidity measurements obtained from the WMO GPS radiosonde comparison in Brazil (2002). Proceedings of TECO-2002, Bratislava: WMO Instr. And Obs. Methods Report No. 75, WMO/TD No. 1123.