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COMPARISONS OF 7-YEAR RADIOSONDE DATA FROM TWO NEIGHBORING STATIONS AND ESTIMATION OF RANDOM ERROR VARIANCES FOR FOUR TYPES OF RADIOSONDES

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1. ABSTRACT

It has always been a challenge to assess the accuracy and precision of radiosonde instrumentation due to the lack of transfer standards for comparisons. One of ways for such assessment is to compare data collected from neighboring stations. The U.S. National Weather Service radiosonde station at Norman, OK is 25 km away from a research station located at Purcell, OK operated by the Atmospheric Radiation Measurement (ARM) program. During 1996-2002, four types of radiosonde, VIZ-B, VIZ-B2, Vaisala RS80-H and Vaisala RS90, were launched at the two stations. A total of 490 pairs of sondes were launched within a half hour and based on visual examination, sampled the same air mass. These co-incident soundings enabled four types of inter-comparisons, VIZ-B vs. RS80-H, VIZ-B2 vs. RS80-H, RS80-H vs. RS80-H, and RS80-H vs. RS90. The comparisons confirm the previous finding that the Sippican (formally VIZ) carbon hygristor fails to respond to humidity changes in the upper troposphere (UT), sometimes even in the middle troposphere. This lack of response produced significant and artificial relative humidity (RH) changes in the UT when a transition occurred and resulted in the inability of the carbon hygristor to measure RH vertical and seasonal variations. The comparisons between Vaisala RS80-H and RS90 data consistently show unexplained, significantly drier (~5% in RH) RS90 data in the UT. When RS80-H was launched at both stations, the temperatures in the middle and upper troposphere at Norman were colder than those at ARM-B6. Such a cold bias is associated with a known coding error in the post processing software in the U.S. operational radiosonde ground system. Random instrumentation error variances for four types of radiosondes, which are critical for the data assimilation, are estimated based on these paired soundings and will be presented.

2. INTRODUCTION

Global radiosonde datasets still represent one of the important resources for initializing Numeric Weather Prediction, monitoring and understanding climate changes, and validating satellite data. Their application, especially in climate studies, are limited by their accuracy and their temporal/spatial inhomogeneity which is a result of constant changes in instrumentation, observational procedures and other factors. It has always been a challenge to assess the quality of radiosonde data due to the lack of transfer standards for comparisons. There have been four common approaches for monitoring the quality of global radiosonde data:

(1) Studying the compatibility of radiosonde geopotential measurements by comparing them with the first guess fields of ECMWF (Elms 2003),
(2) Conducting WMO radiosonde inter-comparison projects and other intercomparison field projects, during which two or more sondes were launched on the same balloons (e.g., Richner and Phillips 1982; Wang et al. 2003),
(3) Comparing data collected at neighboring stations (Elliott et al. 2002),
(4) Comparing data with other independent observations.

In this study, we use the third approach, comparing 7-year (1996-2002) radiosonde data collected at two stations, which are 25 km apart. It provides a unique opportunity to inter-compare four types of radiosondes, VIZ-B, VIZ-B2, Vaisala RS80-H and Vaisala RS90, and characterize their accuracy of both temperature and humidity. Section 3 describes the data. Temperature and relative humidity (RH) comparisons are presented in Section 4 and 5, respectively. In order to take advantage of the 490 pairs of soundings collected, we also use the dataset to estimate the random instrumentation error variances in Section 6. The conclusions are made in Section 7.

3. DATA

This study uses the data collected at two U.S. neighboring radiosonde stations, an operational radiosonde station at Norman, OK (97.4°W, 35.2°N, 357 m) operated by the US National Weather Service (NWS) and a research station at Purcell, OK (97.42°W, 34.97°N, 344 m) operated by the Atmospheric Radiation Measurement (ARM) program (referred to as the ARM-B6 station). The two stations are 25 km

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apart. The ARM-B6 station is one of the boundary facility stations at the ARM Southern Great Plains (SGP) site. The data are available from 1996 to 2002 at both stations (see Fig. 1). Radiosondes at Norman were launched at 11 and 23 UTC, resulting in ~60 soundings per month shown in Fig. 1. Note that the anomaly of over 90 soundings in June 2002 is due to extra sondes launched for the International H_2O Project (IHOP_2002) (Weckwerth et al. 2004). Sondes were not launched regularly at ARM-B6 except during ARM intensive observation periods when there were 3-hourly (from 02:30 UTC to 23:30 UTC) (see Fig. 1). The number of soundings per month at ARM-B6 ranged from 2 to 236 (Fig. 1). The vertical resolution of the data at Norman and ARM-B6 is 6 second and 2 second, respectively, corresponding to about 30 m and 10 m. Note that the data at Norman is the high-resolution (6s) operational data archived by the ARM external data center. Four types of radiosondes, VIZ-B, VIZ-B2, Vaisala RS80-H and Vaisala RS90, were launched at the two stations during 1996-2002 (Fig. 1). At Norman, the radiosonde type was changed from VIZ-B to VIZ-B2 on 1 June 1997 and from VIZ-B2 to Vaisala RS80-H on 1 June 1998. At ARM-B6, Vaisala RS80-H had been launched since the start of the operation in October 1994 and was switched to Vaisala RS90 on 1 May 2001. Since 1988, there have been five types of radiosondes used in U. S. radiosonde network (total 96 stations), VIZ-B, VIZ-B2, Vaisala RS80-H, SDD and Microsonde. The SDD and Microsonde radiosonde were only used at 13 stations during 1989 to 1995 and at 5 stations from 1998 to present, respectively. This study focuses on three main radiosonde types (VIZ-B, VIZ-B2 and RS80-H) used in U.S upper-air network from 1988 to present.

A total of 593 pairs of soundings were launched within a half hour at two stations. They were then visually examined to assure that the pairs sampled approximately the same air mass based on the likelihood of T and RH profiles. As a result, a total of 490 pairs were kept for four types of inter-comparisons;, VIZ-B vs. RS80-H, VIZ-B2 vs. RS80-H, RS80-H vs. RS80-H, and RS80-H vs. RS90 (Fig. 1). The number of samplings for each type of comparison is from 97 to 158 (Fig. 1).

4. TEMPERATURE COMPARISONS

Figure 2 shows the frequency distribution of temperature differences between ARM-B6 and Norman for four types of comparisons along with mean difference profiles. The differences between RS80-H and VIZ-B sondes are wide spread with standard deviations from ~0.6°C at the surface to ~1.4°C above 12 km. VIZ-B data have good agreement with RS80-H near the surface, but become warmer aloft by ~0.5°C above 11 km. The comparison between RS80-H and VIZ-B2 shows similar structures, but with a more narrow spread and smaller mean difference. The cold bias in the VIZ soundings in the UT is likely due to no radiation adjustment being applied to the data. The VIZ radiation error below 15 km is insignificant at night, but is positive (warm bias) at daytime (Luers and Eskridge 1998). The warm bias in the UT at 23 UTC (16.5 LST) is larger than that at 11 UTC (4.5 LST) (Fig. 3), suggesting that the warm bias is mainly due to solar radiation heating. The difference between RS80-H and VIZ shown in Fig. 2 is also consistent with the results from various WMO inter-comparison experiments (cf., Eskridge et al. 2003).

When Vaisala RS80-H was launched at both stations, the comparison revealed a systematically colder temperature (~0.5ºC) in the middle and upper troposphere at Norman than at ARM-B6 (Fig. 2). Although the sonde was the same, ARM-B6 used the standard Vaisala ground system with the radiation correction software, while NWS integrated Vaisala's radiation correction scheme into their Microcomputer Automatic Radio-Theodolite (Micro-ART) system. The version of the Vaisala radiation correction scheme in use after 1993 is called as RSN93. Eskridge et al. (2003) and Redder et al. (2004) have found that a coding error in the U.S. RS80/RSN93 post-processing software introduced colder biases into both daytime and nighttime data in the troposphere, but with larger magnitudes at daytime. This is consistent with the comparisons at 11 UTC and 23 UTC in Fig. 3. The comparison between RS80-H at Norman and RS90 at ARM-B6 again shows this cold bias (~0.2-0.5ºC) in the middle and upper troposphere in RS80-H temperature data at Norman (Fig. 2 and 3).

5. HUMIDITY COMPARISONS

The frequency distribution of RH differences between ARM-B6 and Norman is presented in Fig. 4. The striking feature found in Fig. 4 is the large disagreement between Vaisala and VIZ sondes, but good agreement between Vaisala sondes. The larger VIZ RH measurements in the UT and lower stratosphere (LS) (> ~10 km) are mainly due to a lack of response of VIZ's carbon hygristor there (e.g., Wang et al. 2003). The known dry bias in RS80-H data (Wang et al. 2002) is also evident in the comparisons between RS80-H and VIZ sondes. The excellent agreement (~0%±8%) of RS80-H data collected at two stations further assures us that soundings from two stations sampled the same air mass. The consistent, significantly drier RS90 data (~5%) in the UT/LS cannot be explained (Fig. 4). The solar heating error of the RS90 humidity sensor boom could result in a dry bias because the twin-Humicap design of the RS90 prevents it from having the alumni cap to shield it from solar heating or rain/ice. However, a similar pattern is found for both day and night soundings (Fig. 5).

The lack of response of carbon hygristor in VIZ sondes has significant climate impacts. Time series of monthly mean RH profiles from January 1996 to December 2002 at Norman show that VIZ data cannot capture the seasonal and vertical RH variations in UT/LS in comparison to Vaisala data after June 1, 1998 (Fig. 6). Time series of the monthly mean RH anomaly at 5, 10, 15 km at Norman show artificial drops of RH associated with the transition from VIZ-B2 to Vaisala RS80-H at all three altitudes (Fig. 7). The ~18% drop at 15 km primarily originates from no response of the carbon hygristor explained above. The drop at 5 km is mainly a result of the contamination dry bias found in Vaisala RS80 data (Wang et al. 2002).

6. ESTIMATION OF RADOM INSTRUMENTATION ERROR VARIANCES

For any instrumentation, the observation error variance is critical for the data assimilation to define the relative weight each observation is given, although it is very difficult to quantify. In this study, we estimate random instrumentation error variances using 490 pairs of soundings and the alagorithm presented in Richner and Phillips (1982):

$$\sigma^2_{ik} = (n_{ik} - 1)(\sigma^2_i + \sigma^2_k) / (2n_{ik} - 1) \qquad (1)$$

where σ_{ik} is the standard deviation (SD) of the differences in T or RH between sonde i and k, n_{ik} is the number of samplings, and σ_i and σ_k are the SD of the random error for the sonde i and k, respectively. For the RS80-H comparison between ARM-B6 and Norman, σ_i equals to σ_k, so RS80-H random error SD can be derived using (1). Then, the random error SD of other three types of sondes can be derived using (1). VIZ sondes have much larger RH random error SDs (6-20%) than Vaisala sondes (4-8%) (Fig. 8). VIZ-B temperature random error SD increases almost linearly with height, and is much larger than others above 2 km (Fig. 8). The data assimilation researchers use the observation error variance of radiosonde data from NCEP, which is a very rough estimation and is independent of radiosonde types (Parrish and Derber 1992). Therefore, more accurate and detailed estimation in radiosonde error variance would be very useful for the data assimilation. Note that the observation error includes both instrumentation error (both systematic and random) and the error of the representativeness. This study only deals with the random error.

7. CONCLUSIONS

The systematic errors/biases of radiosonde data are essential for the climate community because the radiosonde data are often used to detect small climate variability. However, they are very difficult to quantify because of the lack of references and standards for comparisons. The 7 years of radiosonde data collected at the two neighboring stations was carefully examined to produce 490 pairs of soundings for four types of radiosonde inter-comparisons. The comparisons confirm, and more importantly quantify, some known errors including the radiation errors in the UT/LS in VIZ T data, the cold bias in the MT/UT in U.S. operational RS80-H T data, the lack of response of the VIZ carbon hygristor in the UT/LS, and the dry bias in the Vaisala RS80-H data. We also found that RS90 RH data are significantly and consistently drier than RS80-H by ~5% in the UT/LS, which cannot be explained by any known problems associate with RS80-H or RS90.

The errors/biases presented in this study can introduce artificial climate shifts associated with the transition from one type of sonde to another one. Our results suggest that Vaisala RS80-H and RS90 T data at ARM-B6 can serve as a transfer standard for correcting the shifts in the twice-daily radiosonde T data record at Norman. Such application will be studied in more detail in the future, including developing better statistical techniques to show the discontinuity at the change points and to apply the corrections. Time series of monthly mean RH profiles at Norman clearly show the impacts of the change from VIZ to Vaisala sondes in June 1998. However, due to the uncertainties in Vaisala data, the correction cannot be made.

The 490 pairs of soundings were also utilized to compute T and RH random error variances of four types of radiosondes. Such information can be very beneficial to the data assimilation, which will be explored in the future by collaborating researchers working on the data assimilation.

8. ACKNOWLEDGMENTS

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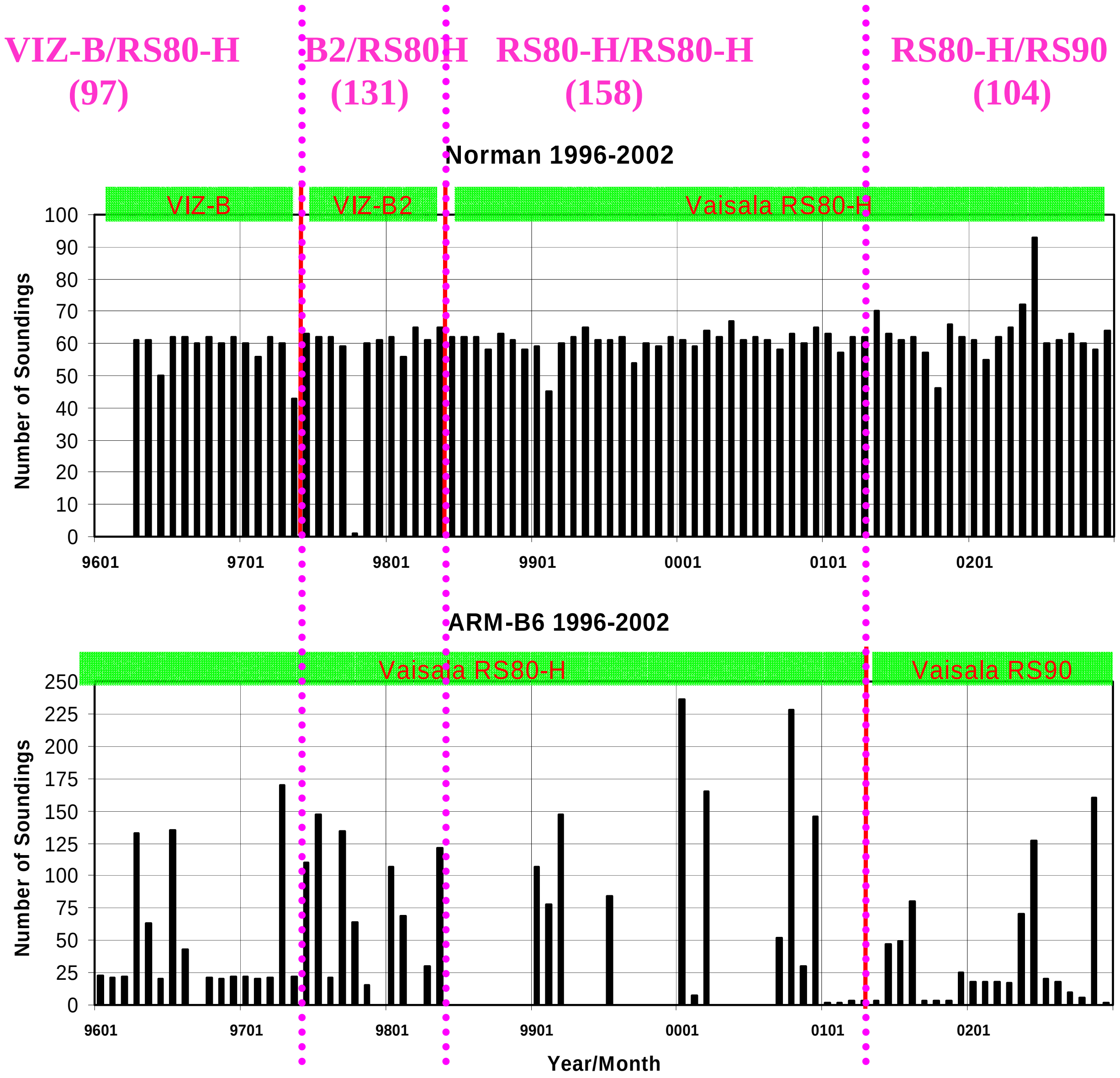

Figure 1 Number of soundings for each month from January 1996 to December 2002 at Norman (upper panel) and ARM-B6 (lower panel). Solid vertical magenta lines separate different radiosonde types with green-shaded labels at the top of each panel, and dotted vertical magenta lines separate different types of comparisons with labels at the top of the plot and number of matched soundings in the parentheses.

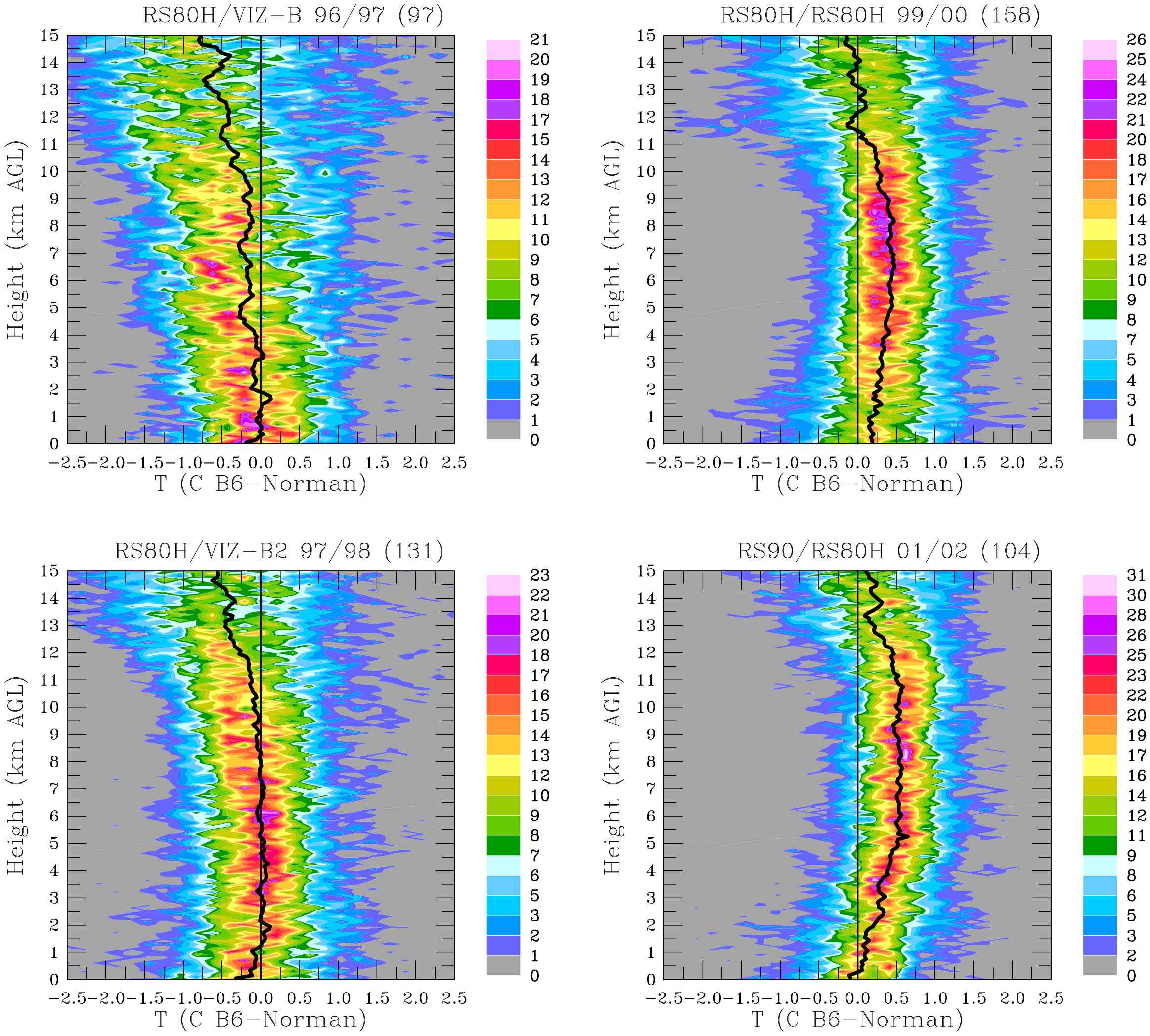

Figure 2 Frequency distributions of temperature differences (ARM-B6 - Norman) as a function of heights (km AGL). The frequency is calculated in 0.2°C and 1 km intervals and sums up to 100% for each 1 km layer. The thick solid black lines are mean difference profiles. The sonde types used at ARM-B6 and Norman are given in the titles and are separated by "/". Years of data and number of matched pairs are also given in the titles.

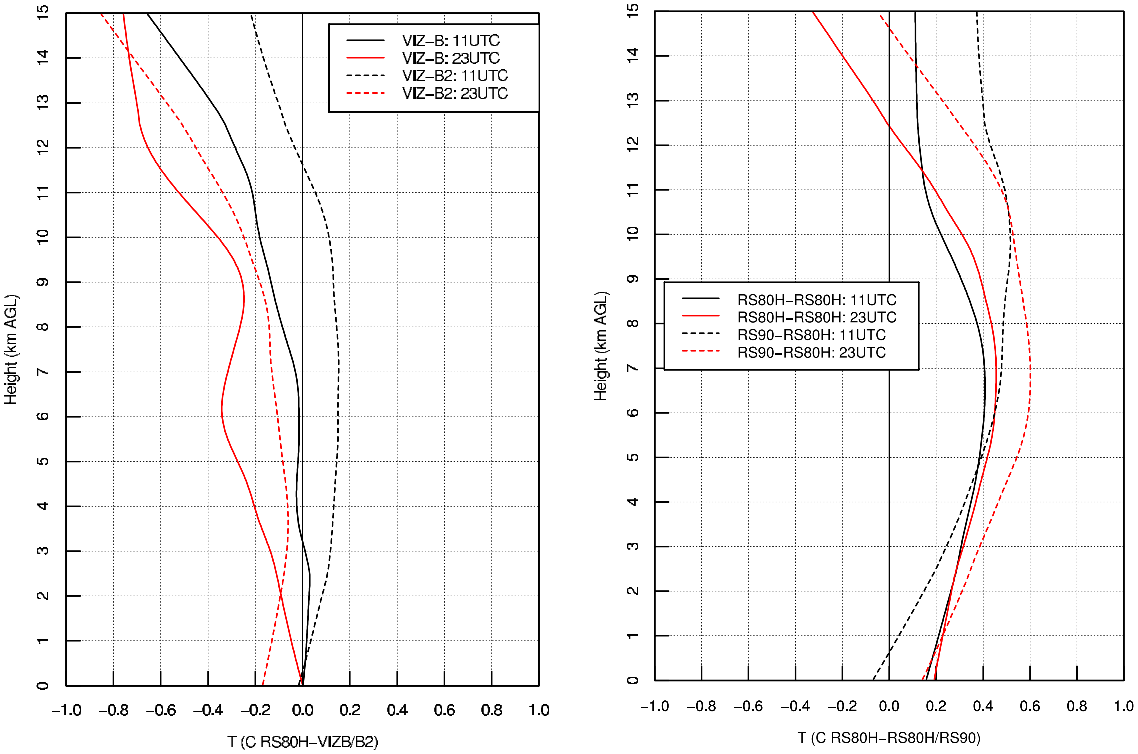

Figure 3 Mean temperature difference profiles between RS80-H at ARM-B6 and VIZ-B/VIZ-B2 at Norman (left panel) and between RS80-H/RS90 at ARM-B6 and RS80-H at Norman (right panel) at 11 UTC (black lines) and 23 UTC (red lines).

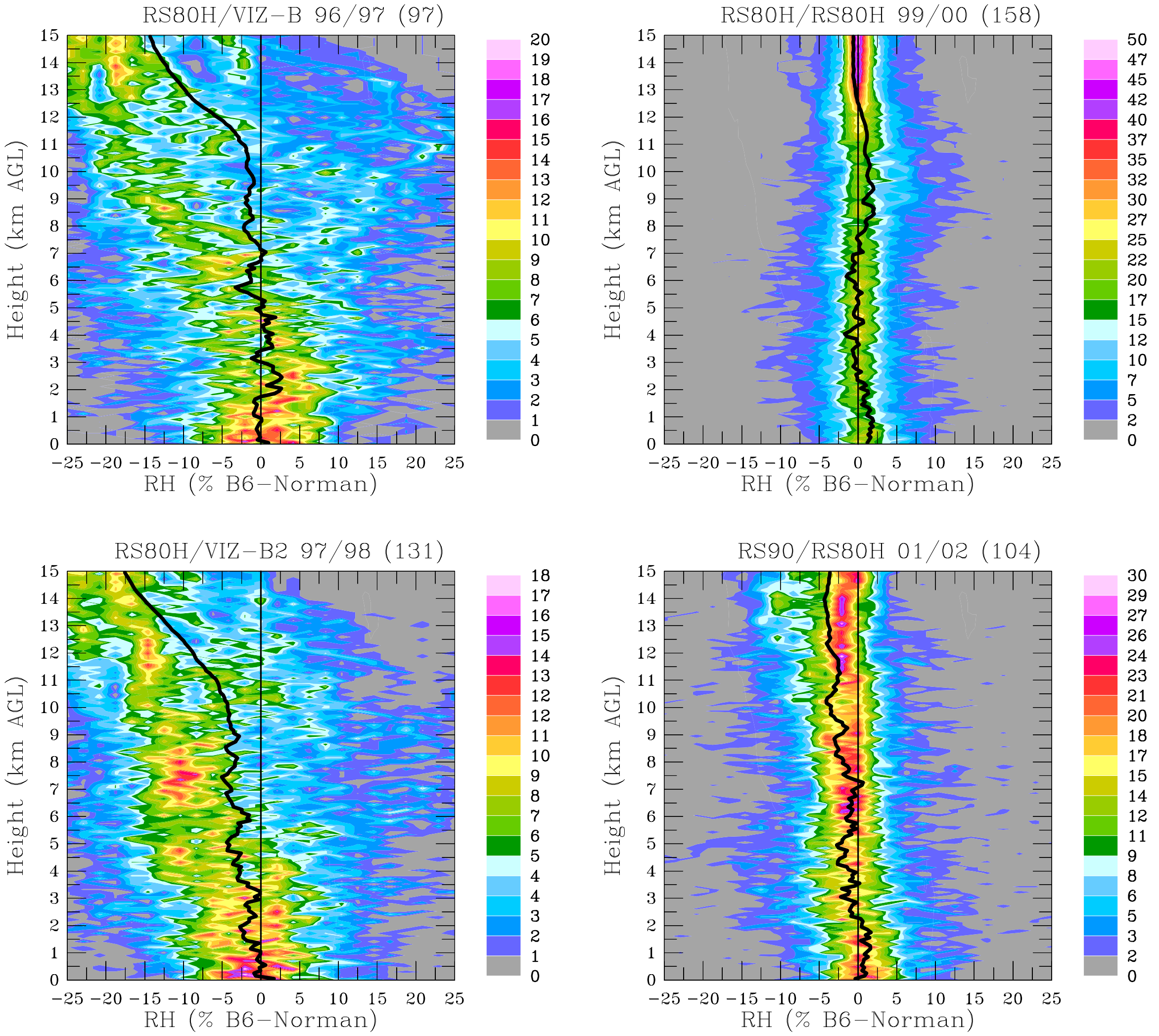

Figure 4 Frequency distributions of RH differences (ARM-B6 - Norman) as a function of heights (km AGL). The frequency is calculated in 2.5% and 1 km intervals and sums up to 100% for each 1 km layer. The thick solid black lines are mean difference profiles. The sonde types used at ARM-B6 and Norman are given in the titles and are separated by "/". Years of data and number of matched pairs are also given in the titles.

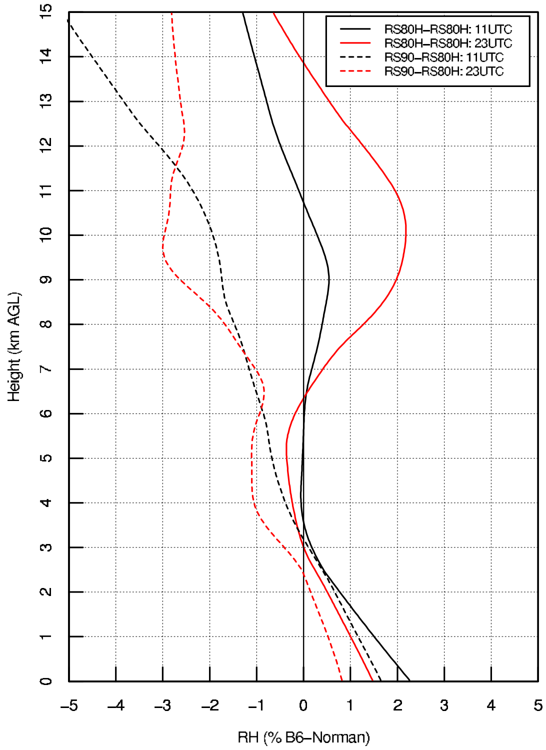

Figure 5 Mean RH difference profiles between RS80-H/RS90 at ARM-B6 and RS80-H at Norman at 11 UTC (black lines) and 23 UTC (red lines).

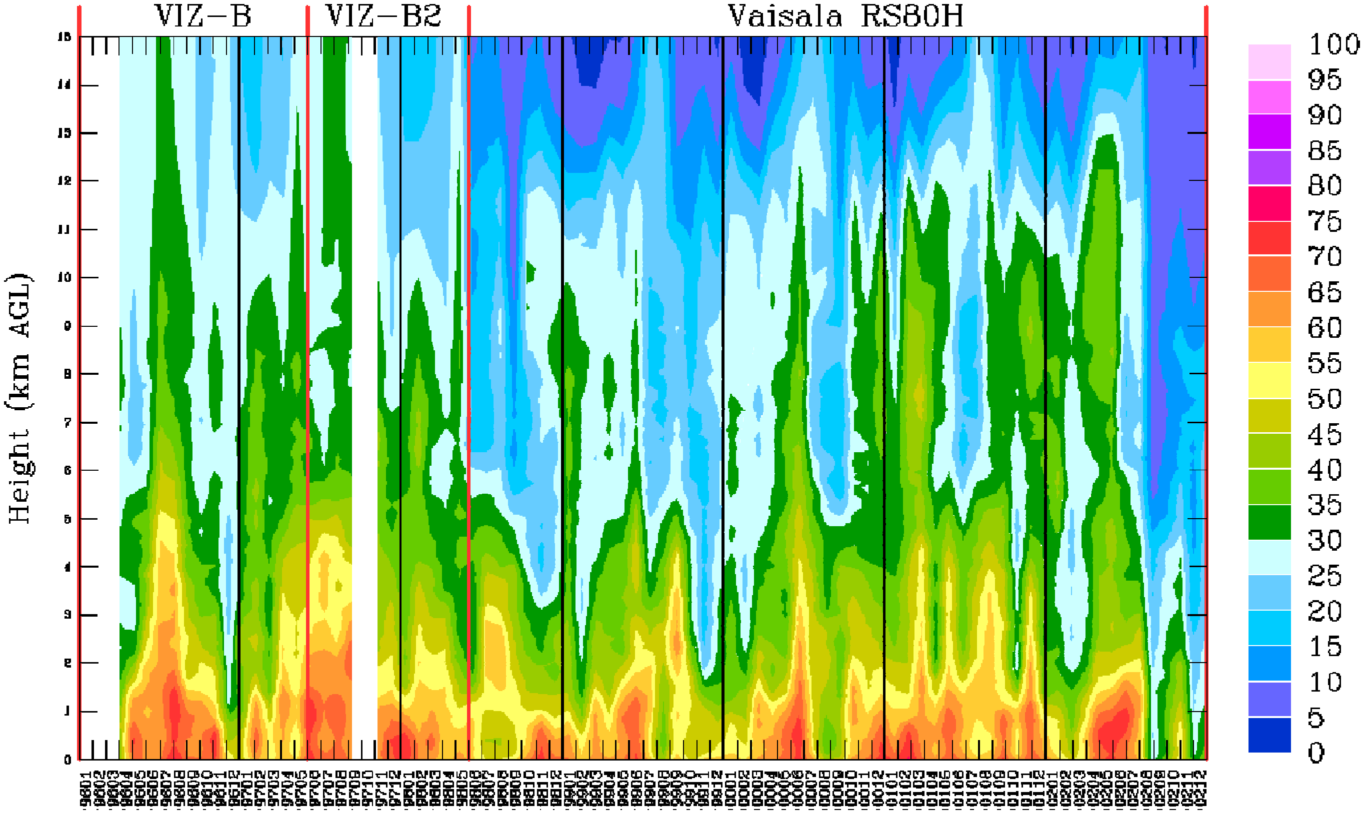

Figure 6 Time series of monthly mean RH profiles at Norman from January 1996 to December 2002.

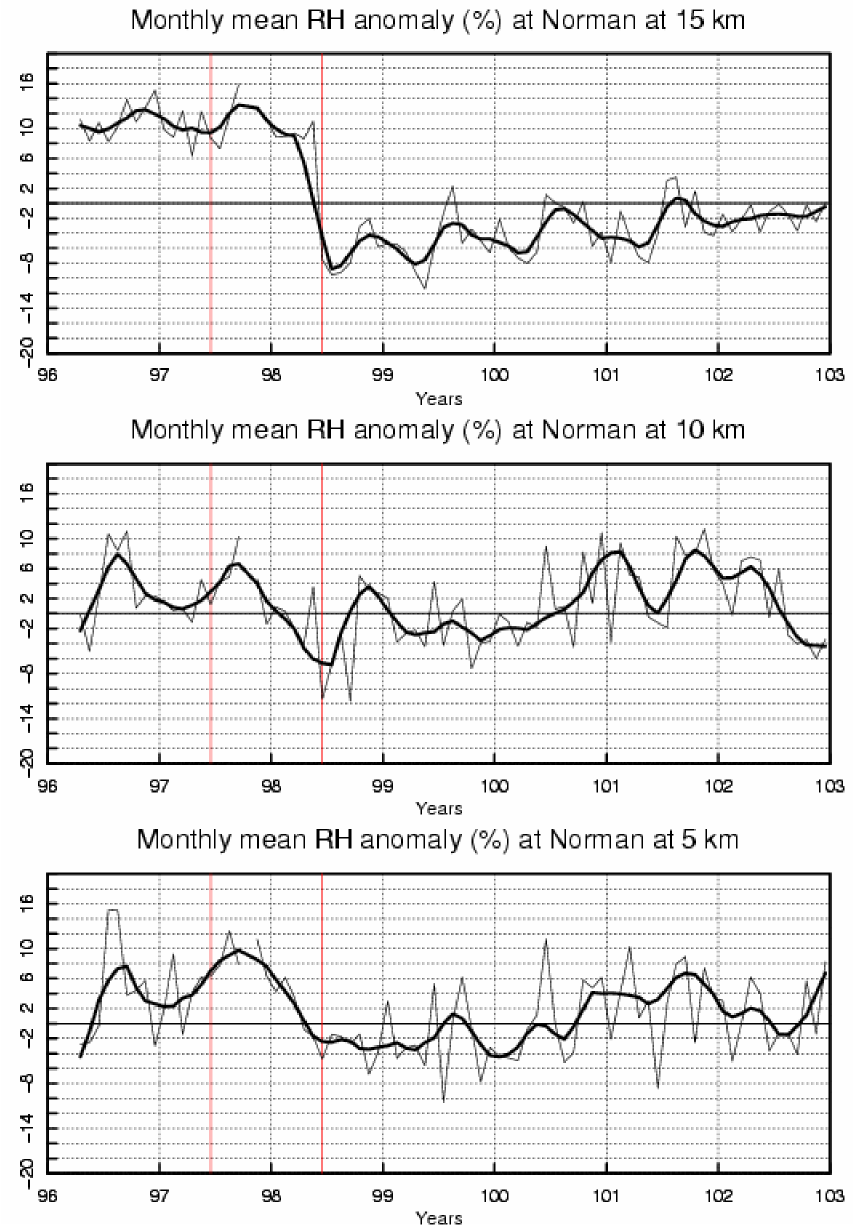

Figure 7 Time series of monthly mean RH anomaly (in %) at 5, 10, and 15 km AGL at Norman. Thin and thick lines show original and smoothed data, respectively. 100, 101, 102 and 103 at x-axis labels represent 2000, 2001, 2002 and 2003, respectively.

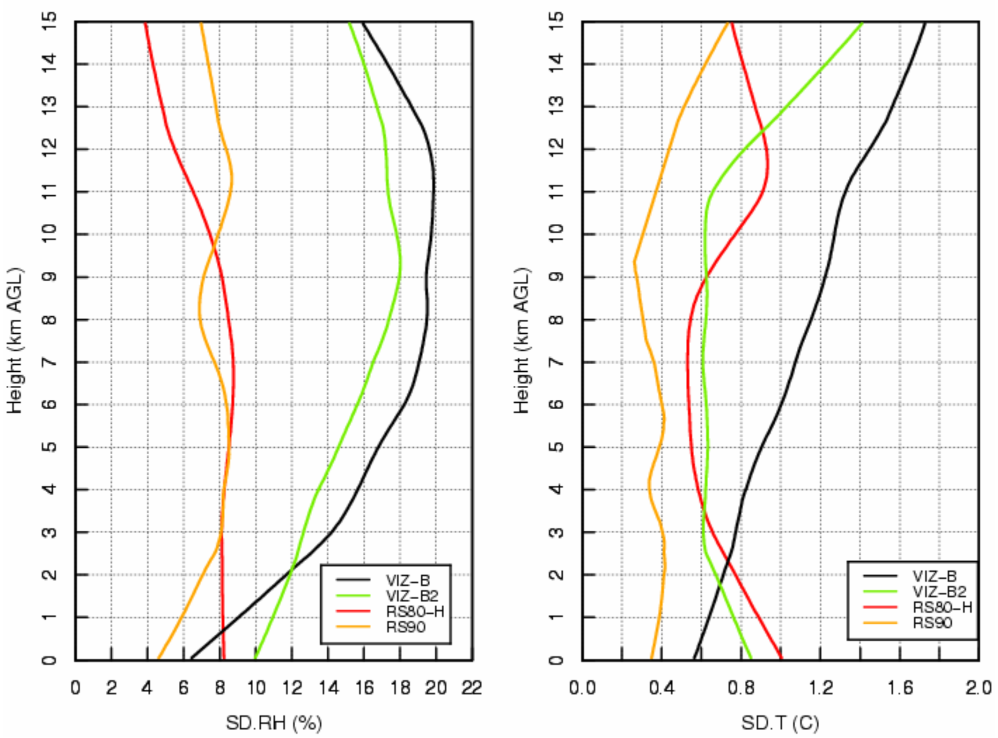

Figure 8 Profiles of random error standard deviation for RH (left panel) and T (right panel) for four types of radiosondes.