SHEBA GLASS SOUNDING DATA

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Considerable speculation has been brought to bear as to whether there is a dry bias in the SHEBA radiosonde data. Two independent comparisons, one between the NCAR C-130 aircraft and the GLASS soundings from the SHEBA site, and the other between a microwave radiometer and radiosonde soundings taken at the SHEBA Ice Station have led to the speculation by some of the SHEBA investigators that the soundings are dry biased.

A closer look at these two comparisons coupled with evaluation of the SHEBA soundings themselves casts a different light. Indeed, the evidence to follow supports the assertion that the soundings are NOT dry biased and that there is no need to apply the dry bias correction.

Aircraft Sounding – GLASS Sounding Comparisons

Five flights, RF11 through RF15, contain aircraft soundings that were made near the radiosonde launch point. In general, both the aircraft and the radiosonde traversed through nearly the same air mass separated in time by less than thirty minutes. Typically, the aircraft would start a descent from about 450mb as the sonde was launched. About 30 minutes later, the sonde would reach that 450mb level while the aircraft would have finished its descent sounding. On several of the flights the aircraft did more than one sounding near the radiosonde site.

Initial comparison of plots of mixing ratio data from both the aircraft sounding [General Eastern (GE) chilled mirror hygrometer] and the radiosonde sounding [“H”-type “humicap” measuring relative humidity (RH)] might lead one to believe that the radiosonde moisture measurement is dry with respect to that of the aircraft. However, closer inspection reveals that this is likely not the case. Evidence shows that the frost point measurement on the aircraft, at least during the comparison times, may be the cause of the discrepancy.

In SHEBA, two GE hygrometers were flown on the NCAR C-130. The analysis presented herein uses data from the GE hygrometer which was deemed by the Aviation Facility’s Data Quality Report to be the more reliable (producing the better data quality) of the two. For reference to that data quality report see http://raf.atd.ucar.edu/Projects/SHEBA/.

Data from the aircraft Ultra-Violet (UV) hygrometer are also available on some flights. Analysis of the UV hygrometer mixing ratio data shows reasonable agreement with mixing ratio data derived from the radiosonde.

RF11

An aircraft descent sounding traversing the same vertical extent as the radiosonde (launched at 2315) was started at 2325. In that sounding, shown in Fig. 1, the aircraft mixing ratio derived from the GE hygrometer is a few tenths of a gram per kilogram more moist than the radiosonde mixing ratio. In the following ascent sounding, Fig. 2, the difference is more pronounced, the aircraft mixing ratio profile from the GE hygrometer shows mixing ratio values of one gram per kilogram greater than those derived from the radiosonde RH measurement. Closer examination of this data will show that the aircraft mixing ratio data derived from the GE hygrometer are clearly suspect and the radiosonde data are more likely to be closer to the truth. The GE hygrometer measurements at times provide results that are unrealistic – dew point temperature values warmer than temperature values and super saturated conditions that would not exist in the conditions encountered.

Figure 3 shows the temperature and dew point (from GE hygrometer) from the aircraft through both the descent and ascent soundings. (The dew point presented is the measured frost point converted to dew point with respect to water using Goff Gratch – See RAF Bulletin 9.) Figure 3 shows some significant problems in the behavior of the GE hygrometer dew point. Most notably, a sinusoidal response is clearly evident in the dew point trace. This is an indication that the chilled mirror temperature control circuitry is not performing optimally– the instrument overshoots and then corrects and overshoots the other way. (The chilled mirror operates by altering the mirror temperature to maintain a constant build up of ice on that mirror – that temperature is the frost point temperature.) Another problem demonstrated in Fig. 3 is that the dew point is often warmer than the temperature, especially on the ascent. This is physically unreasonable.

With regard to the relationship between the aircraft dew point and temperature, it is possible that the temperature sensor could be “wetted” and reading erroneously low, especially in this case where there is some liquid water present. However, three different temperature sensors all agree within less than half a degree. One of the temperature sensors is heated and thus unlikely to be effected by “wetting”. In addition, all C130 temperatures agree well with the radiosonde temperatures. In this case, “wetting” is unlikely as more liquid water and/or icing would be required to have a significant effect.

Initially, before the aircraft descent sounding begins, the aircraft data at approximately 440mb agree, on average, with the sounding at that same pressure (the radiosonde hits that pressure about 30 minutes later). The average dew point from the aircraft GE hygrometer between 2320 and 2323 is –33.6 C, the radiosonde dew point temperature (radiosonde RH is measured with respect to water by virtue of how it was calibrated) at 440mb is -32.9 C. An aircraft average was used to account for the oscillation in the aircraft dew point data at this level.

Several short level legs were flown during the descent sounding. The oscillation is clearly apparent in the data trace during these periods. In addition, much of the dew point data are warmer than the temperature data from the aircraft. Given the temperature sensor performance (no likely wetting) this is indicative of a problem with the GE hygrometer data. The GE hygrometer also shows some periods of super saturation in the descent sounding as well as in the subsequent ascent sounding. Such super saturation is not reasonable in these conditions. (The red triangles on some of the figures show the saturation value with respect to water, the orange triangles show saturation with respect to ice.)

Both FSSP and Rosemount icing probe data indicate liquid water present at various times in the aircraft soundings, even at temperatures below zero degrees Celsius. It is possible that due to liquid water present that the GE hygrometer is having trouble maintaining a constant thickness of ice (or condensate) on its mirror, possibly heating the mirror too much to compensate for liquid water that might be depositing on it. It is also possible that the hygrometer performance is impaired by liquid water obstructing normal flow through the instrument.

Regardless of the cause, it appears that at the freezing level, the GE hygrometer has extreme difficulty, producing clearly erroneous data after the aircraft goes through zero degrees Celsius on its descent. The combination of ice on the mirror melting and additional liquid water present seemingly causes the mirror to be heated too much, resulting in an erroneously high dew point value. The GE hygrometer indicates a mixing ratio more than a gram per kilogram greater than that for saturation with respect to water at zero degrees Celsius.

In the subsequent ascent, these problems persist until nearly 600mb. Up until that point, the mixing ratio continues to be too high and the aircraft dew point temperature is warmer than the aircraft temperature. The aircraft ascent sounding (GE hygrometer data) shows significant super saturation. Such super saturation and, of course, a dew point temperature warmer than the temperature are not realistic.

Note the correlation in Fig. 3 between the liquid water and periods where the aircraft dew point is greater than the aircraft temperature. It appears that the liquid water is having an effect on the GE hygrometer. The FSSP liquid water data are also shown in Fig. 4.

RF13

In the descent sounding shown in Fig. 5, two things are evident. There is a clear oscillation in the hygrometer data throughout the sounding with a significant lag. Also, the aircraft hygrometer mixing ratio is slightly more moist than that of the radiosonde at pressures less than 600mb. In the lower part of the sounding comparison, the radiosonde mixing ratio and aircraft mixing ratio agree reasonably well. The oscillation and slowed response relative to the radiosonde may indicate that there is a problem with the mirror temperature control in the GE hygrometer.

In flight 13, the UV hygrometer was functioning and its mixing ratio data are plotted along with the radiosonde mixing ratio data in Fig. 6. Their agreement is for the most part reasonable. The UV hygrometer mixing ratio is slightly more moist higher in the sounding. Otherwise, the two mixing ratio values agree with the exception that the two measurements may be a little out of phase at times.

Figure 6B shows a scatter plot of radiosonde mixing ratio versus UV hygrometer mixing ratio through a vertical extent from 500mb to 900mb. The black line is the best-fit regression line. The red line is the one-to-one line (radiosonde mixing ratio equals UV hygrometer mixing ratio). The scatter relative to both lines is quantified by use of a root mean square error for both lines. This plot shows an average agreement in both values, although there is quite a bit of scatter. The plot does not show any clear, significant bias in the radiosonde data, dry or moist.

RF14

In the higher portion of the sounding comparison in flight RF14, the radiosonde and aircraft mixing ratio values agree (Fig. 7). Below 500mb the aircraft values are more moist with a superimposed oscillation. In this segment of the aircraft sounding, the GE hygrometer sensor shows some super saturation. At 700mb, the aircraft sensor indicates a relatively dry layer that the radiosonde sensor does not detect. It is possible here that the radiosonde RH sensor has a frozen ice film on it. Below this the two sensors agree, except near 900mb, where the radiosonde reports a dry layer (this may simply be questionable radiosonde data, and not a dry layer).

Again the UV hygrometer was working on this flight. There is agreement between the UV hygrometer mixing ratio and the radiosonde mixing ratio through the entire comparison with the exception of the two dry layers (Fig. 8). Again, there is some noise in the UV hygrometer mixing ratio data. Figure 8B shows a scatter plot of radiosonde mixing ratio versus UV hygrometer mixing ratio through a vertical extent from 450mb to 675mb. The vertical extent in this presentation is limited to this segment to avoid including the dry layer that the radiosonde does not detect. This plot shows good agreement between the two measurements through this pressure range and again, offers no indication of a significant bias in the radiosonde measurement.

RF15

In flight 15, there is agreement among all three sensors during a descent sounding. The GE hygrometer data output exhibits the oscillations symptomatic of poor mirror temperature control, but in the average that data agree with the sonde data (Fig. 9). Again, the UV hygrometer is noisy but agrees, on average, with the radiosonde data (Fig. 10). The scatter plot in Fig. 10B verifies the agreement between the radiosonde and the UV hygrometer. No indication of a significant bias in the radiosonde measurement is present. Both aircraft sensors detect a dry layer that the radiosonde does not. Perhaps the radiosonde RH sensor in frozen.

Conclusions: Aircraft – Radiosonde Sounding Comparison

At times, data from the C130 GE hygrometer and radiosonde RH sensor agree reasonably well. When they don't agree, there is usually some question with respect to the output of the GE hygrometer. In many instances, even when the data agree, the GE hygrometer output exhibits an obvious oscillation suggesting sub-par performance of the mirror temperature control circuitry. In other cases, the GE hygrometer is reporting unrealistic super-saturations or dew point temperature values that are warmer than the temperature values, or both.

When the UV hygrometer on the aircraft is functioning (flights 13 through 15), there is reasonable agreement between its data and that from the radiosonde RH sensor. Although it is acknowledged that at times the UV hygrometer data are somewhat noisy.

Given the preceding evaluation of comparisons of sounding moisture data between the aircraft and the radiosonde, there is no clear reason to suspect that the radiosonde RH measurement is biased dry. At times there is good agreement, at other times when there is not good agreement, the aircraft sensor is exhibiting suspect behavior.

Independent Evaluation of the Radiosonde Data

Saturation in the Sounding Profile

Evaluation of many radiosonde moisture profiles provides evidence that there is no dry bias problem associated with the SHEBA radiosondes. There are numerous soundings, from all times of the year, which do indeed show saturation, i.e. 100% relative humidity readings through a significant extent of the sounding (at temperatures greater than 0 degrees Celsius). This is prima fascia evidence of a lack of a dry bias in those soundings.

Ice Saturation

In addition to occurrences at temperatures above freezing, saturation is seen at colder temperatures as well. The radiosonde RH sensor is calibrated with respect to water. In saturated conditions at temperatures below freezing, the radiosonde RH sensor will read an RH value equivalent to saturation with respect to ice for any given temperature.

Several scatter plots of radiosonde temperature vs. RH data are attached to this document (Figures 11, 12, 13, and 14). Each plot presents radiosonde data from an entire month. The red triangles on these scatter plots correspond to the RH value for ice saturation at that temperature. Radiosonde RH data from all months show clear saturation with respect to ice at temperatures below freezing.

If all the points on the scatter plots were plotted to the left of, and above the red triangles, that would be a good indicator of a dry bias in that RH data. This is not the case. The data show saturation and even some apparent super saturation (could be inherent, normal calibration uncertainty or possibly be physically realistic) and thus, no indication of a dry bias present.

Radiosonde - Microwave Radiometer Column Water Comparisons

Comparisons of integrated column water determined from the radiosonde profile and a microwave radiometer at the SHEBA Ice Station showed a significant difference. The radiosonde data were considerably drier than that from the microwave radiometer, perhaps leading one to believe that the radiosonde RH data were dry biased.

Comparisons were also made at the ARM North Slope of Alaska (NSA) test site. Here an additional instrument, the atmospheric emitted radiance interferometer (AERI) was included. In these results the microwave radiometer produced results more moist than both the AERI and the radiosondes. The AERI data were more moist than the radiosonde but not by a significant amount.

Given the NSA results, some investigators have questioned the accuracy of the microwave radiometer results at SHEBA, postulating that they are too moist. The microwave radiometer is considered by many to be the best reference for column water vapor measurement (clear sky days). However, for the microwave radiometer to provide accurate information, it needs to be properly calibrated (“tip cals” on clear sky days, coupled to a black body reference). Some feel that the calibration for these Artic comparisons was not adequate. The reasons for this being two fold – the general lack of moisture in the Artic atmosphere and the uncertainty associated with the calibration technique.

Obviously, this information is qualitative at best, bordering on anecdote, however, it does cast doubt on the microwave radiometer reference, if only in this case.

Conclusions

All the evidence presented supports the conclusion that there is no obvious dry bias associated with the SHEBA radiosonde moisture measurement. The radiosonde data show saturation both at temperatures above zero degrees Celsius and below. (At saturation below zero degrees Celsius, the radiosonde reports an RH value equivalent to the ratio of ice saturation to water saturation at any given temperature, i.e. it reports the RH at ice saturation as its RH sensor is calibrated with respect to water.)

Saturation is seen in the radiosonde data throughout the entire year of the SHEBA project. In other projects, TOGA COARE comes to mind, where there is a dry bias in the radiosonde data, saturation was not observed at all. In TOGA COARE, a project with an obvious dry bias, there were no RH values greater than 95 or 96% RH through the entire year (TOGA COARE took place in the tropical Western Pacific). This is not the case in SHEBA where values of 100% RH are frequently seen.

Comparisons of radiosonde data with aircraft sounding data indicate that the aircraft data are suspect and that the radiosonde data are likely reasonable. Comparisons of total column water between the radiosonde and the microwave radiometer would indicate that the radiosonde data might be dry, at least upon first inspection. However, given other evidence and the questionable veracity of the microwave radiometer data, this is not likely the case.

The final conclusion from this evidence is that there is not a clear, unquestionable indication of dry bias in the SHEBA radiosonde data set. Having come to that conclusion there is no need to correct the SHEBA data set for dry bias.

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