# 8.3 FLIGHT TEMPERATURE COMPARISONS BETWEEN THE NASA THREE THERMISTOR REFERENCE RADIOSONDE AND THE NATIONAL WEATHER SERVICE QUALIFIED GPS RADIOSONDES

**C. A. Bower, Jr and J. J. Fitzgibbon**
National Weather Service

## 1. INTRODUCTION

Two radiosonde vendors Sippican, Inc. and InterMet qualified 1680 MHz GPS radiosondes with the National Weather Service (NWS) for use with the Radiosonde Replacement System. A pre-production contract will provide production-line radiosondes for extensive follow-on testing including sensor suite testing. Testing will include accuracy, response time, resolution, and availability over a range of environmental conditions. This paper will be limited to in-situ temperature sensor performance.

NWS field sites have not applied radiation corrections to the radiosonde flight data because of computer limitations. The NWS policy was for corrections to be applied to data by the National Centers for Environmental Prediction (NCEP) based on flight comparison results with operational radiosondes and NASA Three Thermistor results as adjusted by NCEP observations minus first guess fields. Vaisala RS-80 radiosondes were the exception. The Vaisala RSN93 radiation corrections on the Vaisala RS80-57H were to be applied by field sites via the Vaisala SPU-11.

## 2. ACCURACY REQUIREMENTS

The NWS requirements are based on user needs, vendors technical data, and what is feasible. Current quality radiosondes can measure tropospheric temperatures with standard errors ranging from 0.2 to 0.3 $^{O}$C. In the stratosphere, accuracy can be equal to that found in the troposphere but at pressures lower than 30 hPa, accuracy generally decreases. The NWS requires temperature error to not exceed 0.3 $^{O}$C. The temperature measurement shall be corrected for the effects of solar and infrared radiation encountered during flight (NWS 2002).

Within the accuracy requirements, performance limits have been agreed on (WMO No.8) for synoptic use. Performance limits have been set for which improved temperature performance is not required (denoted by (A)) and the limit of error beyond which data obtained will have limited value (denoted by (B)). Performance limits can vary significantly from location to location and even seasonally for the same location. Table 1 lists performance limits where the values are standard errors in $^{O}$C

## 3. IN-SITU TESTING

Successful factory tests are not good indicators of how temperature sensors will perform in the environment. Small errors over a flight can lead to large errors in geopotential heights. The inclusion of these errors and height calculations in the WMO coded message for use by the NCEP as well as other International centers can lead to data rejection. Height calculations are determined from pressure, temperature and relative humidity so the total height error is comprised of three parts. The temperature contribution to geopotential height errors can be significant. A temperature error of 0.25 $^{O}$C can lead to significant errors. Table 2 (WMO No.8) shows geopotential height errors for Standard Pressure Levels.

Table 1. Radiosonde Temperature Performance Limits

| Region | Pressure level (hPa) | Synoptic Use | | Temperature Range $^{O}$C |
|---|---|---|---|---|
| | | (A) | (B) | |
| Extratropical Troposphere | | 0.15 | 2.0 | -80 to +40 |
| Equatorial Troposphere | Upper<br>Lower | 0.15<br>0.15 | 0.7<br>0.7 | -100 to +40<br>-100 to +40 |
| Extratropical Stratosphere | 200<br>100<br>50<br>5 | 0.3<br>0.3<br>0.3<br>0.3 | 3.8<br>1.4<br>0.7<br>0.9 | -100 to +50 |
| Equatorial Stratosphere | 100<br>50<br>10<br>5 | 0.3<br>0.3<br>0.3<br>0.3 | 2<br>2<br>3<br>3.5 | -100 to +20 |

Table 2. Errors in Geopotential Heights

| Temperature Error 0.25 $^{O}$C | Standard and Significant Level (hPa) | | | |
|---|---|---|---|---|
| | 300 | 100 | 30 | 10 |
| Geopotential Height Error (GPM) | 9 | 17 | 26 | 34 |

Flight testing against the NASA Three Thermistor Reference Radiosonde (Schmidlin et. al., 1986) helps determine in situ accuracy of the radiosonde temperature sensor in day and night environments under the influence of long and short wave radiation. It is further used to verify the radiation correction algorithms employed by the vendors to remove biases from their radiosondes measurements.

Radiation effects can be minimized through sensor design, through the proper selection of sensor coating materials, and proper boom design. Coating materials highly reflective in the short wave and with low emissivity values in the infrared spectrum should be used.

An example of same sensor technology, same coating material, different physical dimensions of the rod thermistors, and different atmospheric readings is depicted in Figure 1. The sensors are Sippican Rod

Corresponding author address: Carl A. Bower,Jr, National Weather Service, W/OS7, 1325 East-West #4312, Silver Spring, MD 20910, e-mail: Carl.Bower@NOAA.GOV

Thermistors (one the large rod and the other the small rod). The variation in the lower atmosphere between the large and small rods is not great although it is different. Above 30 hPa, the curve on the upper right (small rod minus large rod) the sensors depart from each other significantly. Radiation corrections have not been supplied to these sensors. Until recently, radiation corrections were not available for the small rod thermistor. The NCEP has generated corrections for application to these sensors.

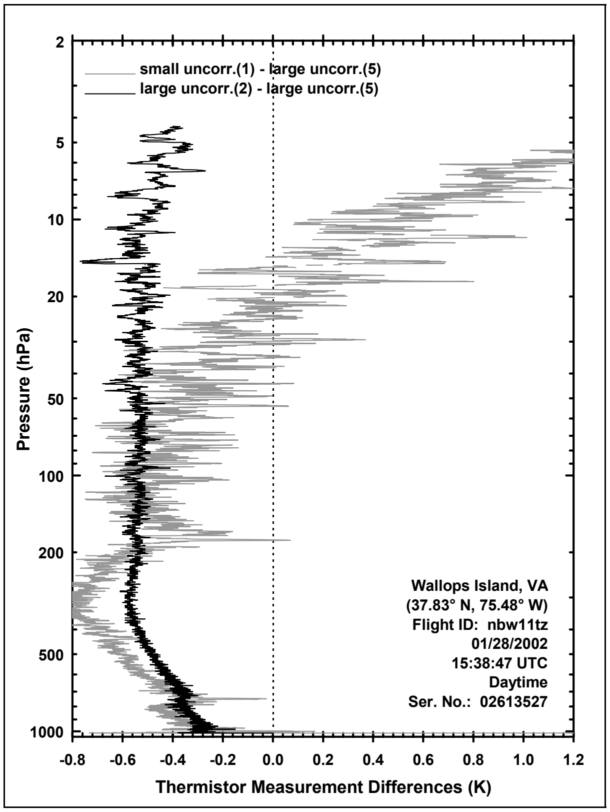


Figure 1. Daytime Difference of Sippican Large Rod vs Large Rod and Large Rod vs Small Rod Thermistor.

Figure 2 shows performance following replacement of a VIZ B2 radiosonde with a Mark II radiosonde at an NWS site. The temperature data were rejected from the surface to 400 hPa and from 99 hPa to flight termination. In order to determine the correction required for a mid day flight at the Sterling, Virginia, NWS upper air test site, (Solar Angle about 50 degrees) for a Vaisala RS80-57H, one radiosonde was tracked with one ground system and through the use of a signal splitter, one set of data was processed as mid-day and the other as mid-night. Figure 3 shows the normal correction difference between day and night for the Vaisala radiosonde using the RSN93 correction algorithm. The daytime data if uncorrected for temperature from the flight would have caused geopotential height errors as high as 170 meters as shown in Figure 4.

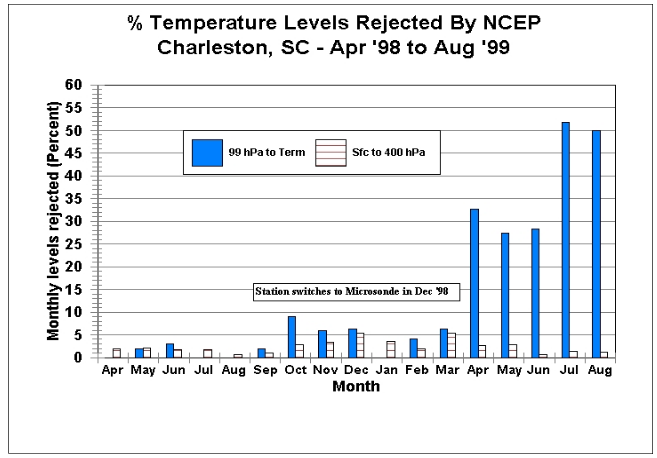


Figure 2. Charleston Temperature levels rejected.

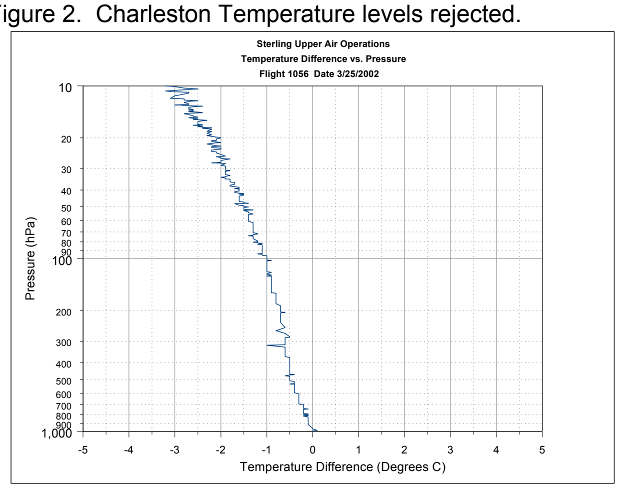


Figure 3. Radiation Correction for RS80-57H mid-day flight

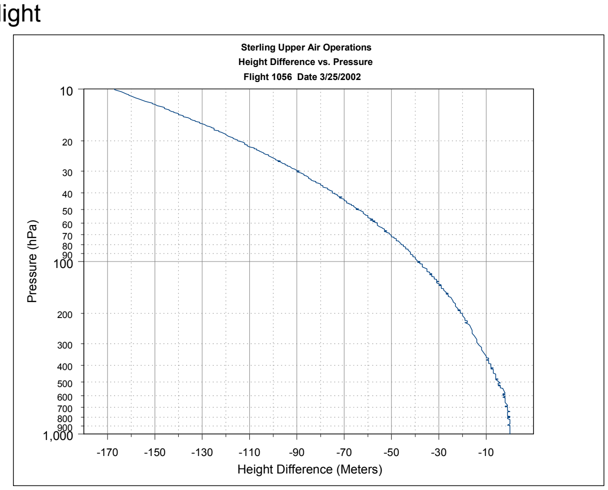


Figure 4. Height Error without Radiation Correction for RS80-57H mid-day flight

While radiation corrections to thermistors are necessary, they are based on averages and as such shift a bias in a given temperature reading. They may often make reasonable data worse. For this reason, every effort should be made to minimize the radiation offset required for a temperature sensor. This can be accomplished through sensor and boom designs and with better coatings to mitigate radiation impacts. An example of this is shown in Figure 5 contrasting the radiation correction required for a Vaisala RS90 versus a Vaisala RS80 radiosonde. Through marked improvements in the RS90, the radiation correction is quite small.

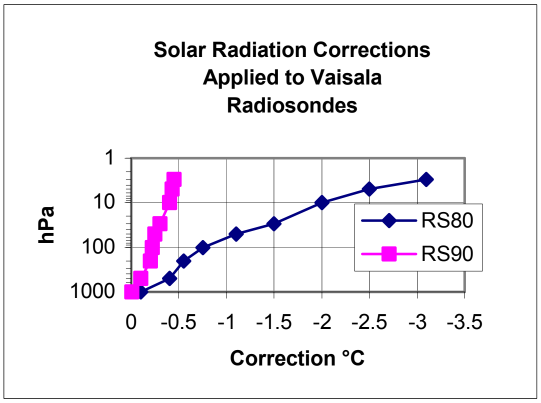


Figure 5. Radiation Correction by Pressure Level for RS80 and RS90 Mid-day Radiosonde Flight

4. TEST RESULTS

The NWS flew six and five NASA Three Thermistor comparison flights of InterMet and Sippican GPS radiosondes respectively. The purpose of this evaluation was to compare how well the vendor's sensors compared with a reference standard and to evaluate the Sippican and InterMet radiation correction routines under development. Results from several flights are depicted. The flight results do not incorporate the radiation corrections. The temperature sensors are (small chips or beads) coated. Sippican uses an aluminumized coating and InterMet a white barium sulfate coating. In general, the deviations from the NASA three thermistor system are small.

Intermet Flights

A composite of InterMet flights is shown in Figure 6. With the exception of the night flight, the tropospheric temperatures are cooler than the three thermistor solution by 0.3 to 0.7 $^{O}$C. This appears to be rather large. At this point since we have a composite agreement on the day flights and the same characteristic curve exists for the night flight, it is possible that the white coating material is radiating in the short wave. The curves have the same basic curve except for the night flight with a profile showing a positive difference (cooler than three thermistor) through the entire flight. The day flights have three distinct regions. The surface to 500 hPa is characterized by cloudy conditions and high relative humidity, 600 to 100 hPa is the upper troposphere in the absence of clouds and above 100 hPa is in the stratosphere. This uncorrected sensor is highly influenced by atmospheric conditions that may relate to the long wave characteristics of the white coating material. In Figure7 the InterMet night flight shows the radiosonde sensor to be cooler than the three thermistor with the exception of the first 600 hPa. From 600 to 30 hPa, the difference is relatively constant and from 30 hPa to termination, the difference increases. Figure 8 is an InterMet day flight. This flight is actually cooler than the three-thermistor flight up to 400 hPa and becomes warmer than the three thermistor radiosonde above 200 hPa.

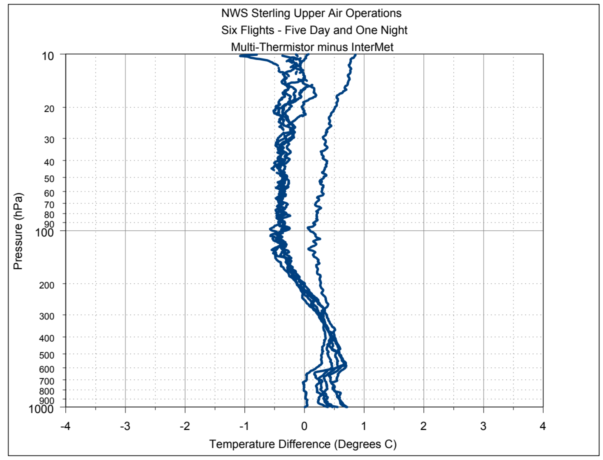


Figure 6. Three Thermistor minus InterMet Flight series

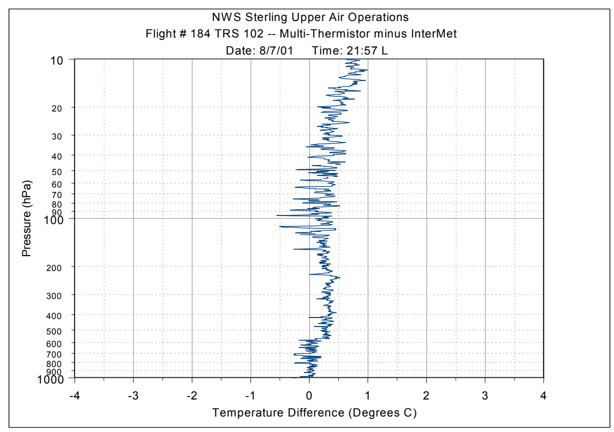


Figure 7. Three Thermistor minus InterMet Night Flight

Sippican Flights

Figure 9 is a composite of three day and two night flights. The five flights have shown uniform consistency in both the troposphere and the stratosphere. The three day flights are consistent with each other as are the night flights. The aluminized coatings are providing a fairly uniform day/night profile. Weather conditions during the flight series were humid with cloudy conditions from 700 to 500 hPa over the period. Figure 10 is a Sippican night flight. The difference of the temperature from the three-thermistor solution indicates that the performance is consistent with night flights. The difference never exceeded 0.3 $^{O}$C. The infrared is not impacting the night flight. Figure 11 is a Sippican day flight. The agreement is reasonable with the three thermistor solution but once again, it is cooler than the three thermistor sonde for the entire flight. This may be a long-wave emission issue. Until we have the Sippican radiation correction algorithm we will not be able to fully assess the performance of the sensor.

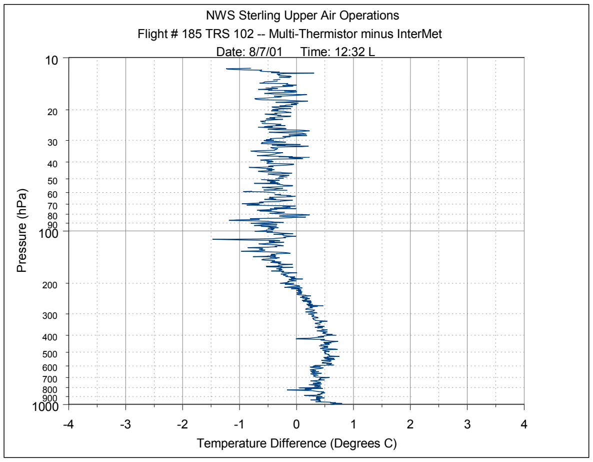


Figure 8. Three Thermistor minus Intermet Day Flight

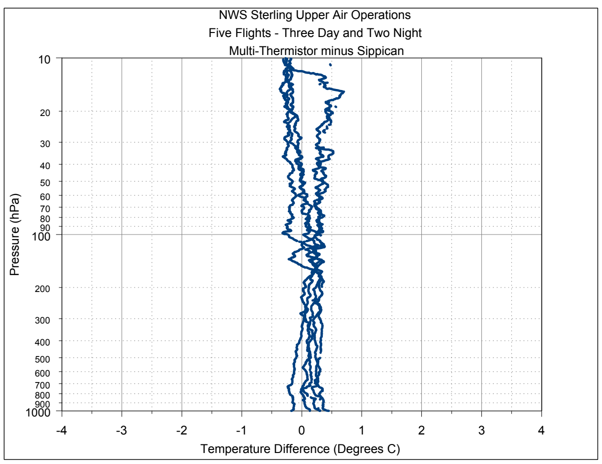


Figure 9. Three Thermistor minus Sippican Composite Flights

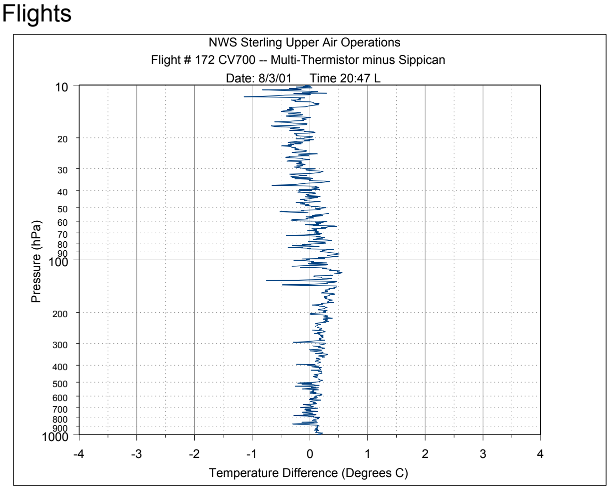


Figure 10. Three Thermistor minus Sippican Night Flight

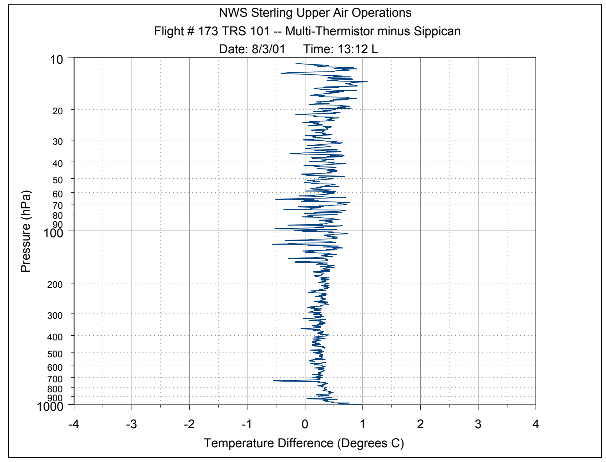


Figure 11. Three Thermistor minus Sippican Day Flight

## 5. CONCLUSIONS

Radiosonde radiation schemes are not all- weather.

Three-thermistor in-situ testing is critical for determining accuracy, bias, and required radiation algorithm assessment for operational radiosondes.

Preliminary results from flights of the InterMet and Sippican radiosondes against the NASA three thermistor system are promising. The agreement is quite good throughout the entire radiosonde flight.

The IntermMet sensor coating appears to be more susceptible to lower tropospheric conditions. The results from mid-summer flights may not be representative of flights under different weather conditions.

Follow-on testing of the pre-production radiosondes against the NASA three-thermistor reference will be required to assess the radiation correction algorithms the vendors are developing.

The new temperature sensors and coatings mitigate radiation impacts. With vendor refinements to the radiation correction schemes we anticipate improved results

## 6. REFERENCES

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