# Recent Application of The Accurate Temperature Measuring (ATM) Radiosonde

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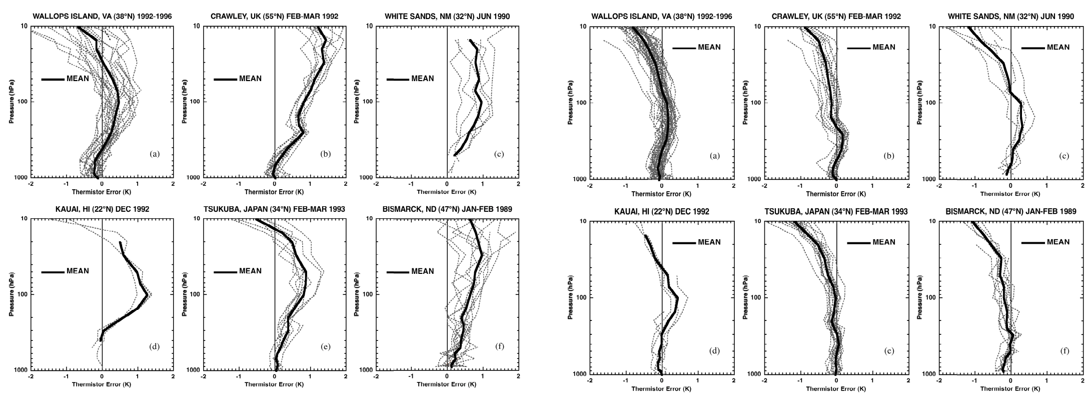
*Abstract*

The Accurate Temperature Measuring ATM radiosonde developed at NASA's Wallops Flight Facility is being used in more applications then originally intended. A description of the method in use and results of new small bead (2.5 mm diameter) fast response thermistors are presented. Results of recent comparisons of the small chip thermistor used on the Sippican LMS-5 radiosonde and the small bead thermistor of the Intermet IMET radiosonde and Vaisala RS-92. As time permits reference will be made to results of comparisons with other radiosondes. Unexplained variations appearing in the profiles requiring explanation will be discussed. However, temperature profile mean differences between the ATM radiosonde and other radiosondes, while smaller than in the past, are not yet consistent between different radiosonde instruments.

*Introduction*

The development of the Accurate Temperature Measuring (ATM) radiosonde was initiated by the National Aeronautics and Space Administration (NASA) at Wallops Flight Facility in the mid-1980's as a method for correcting the white rod thermistor used in the United States and elsewhere. The ATM radiosonde method was developed using the resistive rod thermistor of Sippican, Inc. (formally VIZ Manufacturing Co., and now Lockheed Martin Sippican, Inc.). It was cost-efficient to use Sippican components because Sippican is the major radiosonde system used at NASA Wallops Island. This also provided a method to determine the error of the rod thermistor without resorting to other more sophisticated or expensive test methods. Currently, the white rod thermistor is used only with the Sippican VIZ-B radiosonde.

As Figure 1 illustrates, daytime measurements obtained at NASA's Wallops Flight Facility, Wallops Island, Virginia, are quite variable. Although the figure represents just four years of data it elucidates quite vividly that the error accompanying the white thermistor is generally negative in the lower troposphere, positive in the upper troposphere, maximizes near 100 hPa, and finally decreases, even becoming negative near 10 hPa. The figure shows that the error varies considerably; the profiles cover most of the months during the four-year period. Furthermore, the measurements for the remaining test sites in Figure 1 indicate the error is different from site to site. The explanation for this variation is the background environment at each location. The nighttime examples for the same daytime sites indicate similar behavior except there is less variability, probably because the modulating effect of sunlight is missing.




Daytime Nighttime

Figure 1. Daytime and nighttime rod thermistor errors obtained during the development of the ATM radiosonde. Daytime profiles have greater variability; this is expected from solar radiation modulating the sensor response. The heavy solid profile characterizes the mean error profile at each location. The dataset is limited in time as suggested by the locations and dates, nonetheless, the resulting profiles illustrate quite clearly the role radiation plays in determining thermistor errors.

World Meteorological Organization sponsored international radiosonde comparisons conducted between 1984 and 1993 identified temperature error as the major source of radiosonde measurement discrepancy (Hooper, 1986; Nash and Schmidlin, 1987; Schmidlin, 1988; Ivanov etal, 1991; Yagi etal, 1997). Differences ranged from ±1.0°C at 100 hPa to ±2.0°C to ±4.0°C at 10 hPa. Other comparisons in the United States and United Kingdom found similar results. The early literature contains numerous reports about thermistor accuracy (Badgley, 1957; Teweles and Finger, 1960; Ballard and Rubio, 1968; Daniels, 1968; Talbot, 1972; and McInturff etal, 1979). It should be noted that there was considerable interest and effort expended to improve thermistor accuracy, however, the problem still exists to some extent. Modern radiosondes have shown great improvement whereby the differences between radiosonde measurements are now smaller than given by earlier radiosondes (Nash et al, 2005). Nonetheless, in spite of the improvements there are significant errors still present needing to be addressed. The sections that follow examine thermistor errors of new radiosonde types determined by comparison with the true ambient temperatures derived with the ATM radiosonde.

*ATM Radiosonde Method*

The ATM radiosonde technique requires three thermistors during daytime and two at night, although three can also be used at night, if desired. The thermistors are three different colors whose emissivities and absorptivities were measured in the laboratory. The area of each thermistor also is measured. These parameters are used in a matrix of three heat balance equations, one equation for each thermistor, to solve for $T_{air}$ defined by $(T - \Delta T)$, where T is the thermistor temperature and $\Delta T$ its ereror. The heat balance equation effectively accounts for the long- and short-wave radiation impinging on the thermistors. The heat balance equation relating the rod thermistor and true air temperature has been discussed previously (Talbot, 1972: Luers, 1992; McMillin, 1992; Ranganayakamma, 1994).

The ATM multi-thermistor radiosonde technique uses uniquely calibrated thermistors mounted in an identical configuration. The incident long- and short-wave fluxes impinging on the thermistors are the same, but the radiative energy absorbed differs due to the different emissivity and absorptivity values, i.e., the thermistors' temperatures are different. Simultaneous solution using a matrix of three heat balance equations is carried out to determine $\Delta T$ and subsequently $T_{air}$. It would be ideal if each thermistor were identical in size; unfortunately measurements at Wallops revealed that lengths and diameters of a few hundred thermistors are not uniform. To overcome this variation each thermistor flown on the ATM radiosonde is measured. Thermal lag of the thermistors is also considered in the calculation since occasionally it can lead to relatively large errors; its effect on routine measurements usually is not considered. At times, thermal lag leads to measurement errors of ~0.5°C (Huovila and Tuominen, 1990). Errors due to heat conduction also are considered in Wallops solution of the heat balance equations.

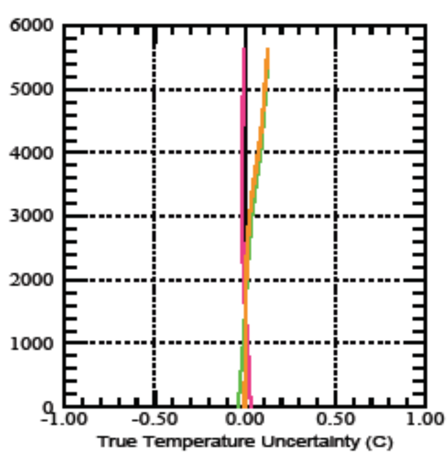


Figure 2. Five thermistors provide four solutions of the true temperature. Results of testing show that the ATM radiosonde can provide accuracy to less than 0.2°C.

The ATM radiosonde incorporates five thermistors (two white, two aluminum, and 1 black) to provide four solutions of $T_{air}$. Although four solutions may seem redundant, imperfection in coatings, calibration, mounting, and several other minor sources of error cause uncertainty and limit the ATM radiosonde accuracy to about 0.2°C. Efforts to reduce this uncertainty are in progress using small bead thermistors. Figure 2 illustrates the spread of the differences from the four solutions. As noted in the figure, two solutions from two thermistors are very near perfect while the other combination of two thermistors has differences of less than 0.2°C.

*Recent Comparisons*

The NASA ATM radiosonde has been used to judge the accuracy of different radiosonde types. Comparison with the Meteolabor SRS-400, the UK MK-3 and MK-4 (Vaisala RS-80 adopted by the UK for some sites), VIZ 1392, AIR Intellisonde, Meisei RS2-80 and RS2-91, and Vaisala RS-80 were compared between 1984 and 1993. Results of these tests can be found in the WMO papers mentioned earlier. It is important that accuracy of the newer radiosonde types be compared against the ATM radiosonde. Some of these have corrections applied for daytime observations; nighttime corrections usually are not available. Recent comparisons were conducted in November 2005 between the Intermet and Modem GL-98 radiosondes, in February 2006 with the Vaisala RS-92, in March with the Sippican AMPS (LMS-5) radiosonde, and in July 2006 with the Intermet, Vaisala RS-92, and Sippican MK IIa radiosondes.

Figure 3 shows a nighttime example of thermistor difference between the Intermet and the ATM radiosondes. Daytime profiles are not available for a comparison during this series. The curve represents the raw, or uncorrected temperatures. Nighttime differences to about 30 km, are generally less than ~0.5°C. The apparent reversal occurs near 15 km, or near the altitude of the tropopause, indicating long-wave radiation most likely is seriously affecting the bead sensor in the stratosphere.

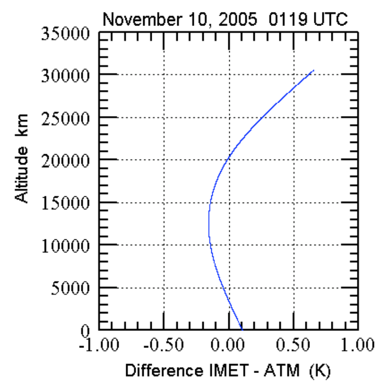



Figure 3. Nighttime comparison between IMET and ATM radiosondes. IMET temperatures are uncorrected.

Comparison between the ATM radiosonde and Vaisala RS-92 was possible at the Southern Great Plains Atmospheric Radiation Measurement site (SGP-ARM) during February 2006. Figure 4 shows differences for a daytime flight that increases nearly monotonically to 0.3ºC at 30 km. Some of the flights did not have as small a difference; some differences exceeded 0.5°C. The analysis showed no discrepancy in either the ATM or RS-92 radiosondes' measurements. Other daytime comparisons also revealed this increase with altitude. The nighttime comparison, on the right panel of Figure

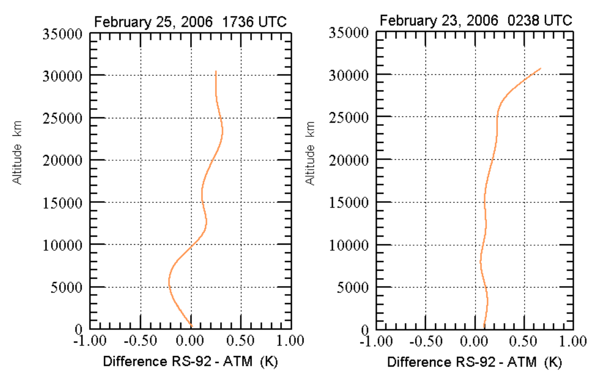



Figure 4. Differences between RS-92 and ATM radiosondes. Daytime comparison is shown on left.

4, indicates a difference similar to the daytime. However, the negative difference from the surface to 28 km suggests the nighttime RS-92 temperature sensor is probably affected by long-wave radiation.

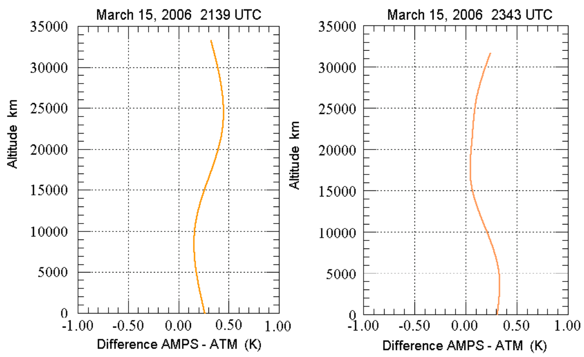



Figure 5. AMPS (LMS-5) and ATM radiosonde comparison. Daytime observation is on right. Although the time is misleading, this was a late afternoon test.

Comparison of the AMPS radiosonde (Automated Meteorological Profiling System) with the ATM radiosonde is illustrated in Figure 5. The AMPS radiosonde is provided by Lockheed Martin Sippican, Inc to the US Air Force and, except for a modification made to the relative humidity sensor is the same instrument type manufactured by Sippican and known as the LMS-5 radiosonde. The difference between the two instruments, AMPS and LMS-5, is that the AMPS has been modified with a capacitance relative humidity sensor located in the duct replacing Sippican's ubiquitous resistive carbon sensor. The daytime temperature example shown in Figure 5 indicates the AMPS correction may not be adequate to recover the true atmospheric temperature. Review of other AMPS and ATM measurements comparisons indicate similar and larger differences. The nighttime difference between AMPS and ATM shown in the right panel is less than 0.5ºC, although AMPS reports slightly higher nighttime temperatures, there are no corrections applied to the measurements.

*Planned Improvement*

The ATM radiosonde technique has depended on rod thermistors since the development of the ATM instrument began. Using rod thermistors in the complex of the multi-thermistors has been valuable during development since it also provided important information on the errors of this thermistor. Rod thermistors will no longer be available

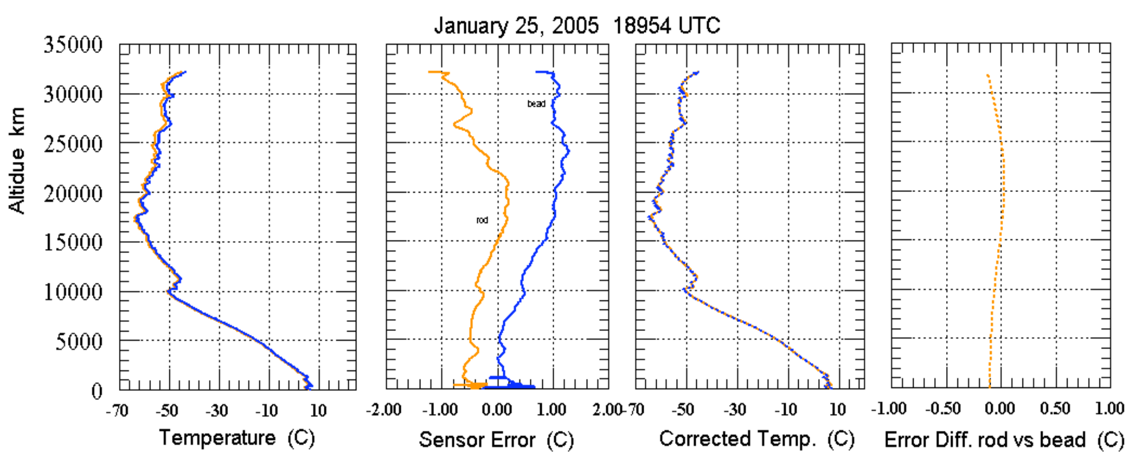



Figure 6. Dual measurements using rod and bead thermistors show that while the different sensors will usually give a different atmospheric measurement the thermistor errors are different, After correction is made to the measurements both measurements are identical within the error of the system. The panel on the right shows the size of the error between the two different thermistors when flown on the same platform.

in the future. For this reason as well as our desire to improve the ATM method we are investigating bead thermistors. Our desire is not to use very small chips or very small beads, simple because it is important that the thermistors used be identically mounted. Spherical beads will enable this to happen, are large enough to allow their dimensions to be measured and still be mounted in any orientation. Figure 6 examines a comparison of rod and bead thermistors mounted on the same radiosonde. The test data shown involves two sets of thermistors, each consisting of three rods and three beads, both sets use the same color combinations. The error of the white rod and white bead shown in the figure is not the same. Clearly, the magnitude and shape of the curves above 20 km is quite different. The altitude used here applies to both sets of thermistors since these were on the same platform. After applying the corresponding errors to their respective temperature profiles, shown in the second from right panel, we find that the resulting ambient temperature profiles are virtually identical. The corrected rod is in orange and the corrected bead is over the orange curve in blue dots. The far right panel illustrates the difference between the two corrected temperature profiles. The difference is less than 0.2ºC, the limit of the technique as mentioned earlier in this paper.

## *Summary*

The major parameter realized from the ATM radiosonde development is its ability to obtain the true ambient temperature. During development of the ATM it was apparent that thermistor error varied with the background environment. Because of this, we realized that the actual error of any given thermistor continually varies, therefore, fixed mean corrections typically those that may be provided in a table of look up values usually introduces bias to the measurements. The ATM radiosonde, regardless of the environment, always provides the true temperature. Simultaneous comparison of thermistor measurements against the ATM indicates that the error of different operational radiosondes is not consistent, and as shown in the figures, can be as large as 0.5°C.

The ATM radiosonde currently is used at NASA Wallops Flight Facility for upper air research studies, by the National Weather Service to certify temperature measurement reliability of radiosondes considered operational radiosonde replacements. Others include the US Army to determine the thermistor error of the MSS radiosonde's bead thermistor used at the Kwajalein Atoll, by the WMO during the Phase 4 of the international radiosonde comparison, during the PREFRS test in 1992, and for remote measurement validation. The ATM radiosonde is an especially important tool for validating remote measurements from satellite instruments. Adoption of the ATM radiosonde at operational observing stations would make available true temperature reports over the GTS for the meteorological and climatological communities, and is strongly recommended.

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