Recent Application of the Accurate Temperature Measuring (ATM) Radiosonde

F. J. Schmidlin
NASA/Goddard Space Flight Center/Wallops Flight Facility
Wallops Island, Virginia 23337 USA
Tel: 1 757 824 1618; Fax: 1 757 824 1036
E-mail: fjs@osb.wff.nasa.gov

Abstract

The Accurate Temperature Measuring (ATM) radiosonde developed at NASA's Wallops Flight Facility is now being in more applications then originally intended. A description of the method and results of new, small bead thermistors (2.5 mm diameter) fast response thermistors are presented. Results are given of recent comparisons with extremely small chip thermistors now used with the Sippican, Inc., MK-IIa and with thermistors used with the Modem, Inc. radiosonde. Comparisons indicate unexplained variations in temperature profiles that require explanation. 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

In this day of improved radiosonde instruments the question often asked is: have upper air instrument measurements (accuracy) really improved? The National Aeronautics and Space Administration (NASA) emphasizes measurement quality for all of its satellite data. This is especially true for *in situ* measurements since, for upper air, radiosondes often are the standard used for validation. Considerable resources are expended for validation of data related to different disciplines, yet, questions continue to be raised about radiosonde accuracy, precision, and reproducibility, especially for temperature measurements. Thermistor accuracy suffers from many influences: sensor exposure on the radiosonde; sensor calibration; sensor time constant; cloud cover; albedo; surface (earth) temperature; vertical temperature structure; processing method; and method of reporting. These influences will lead to measurement error.

World Meteorological Organization sponsored radiosonde comparisons conducted during the last two decades have identified temperature errors as the major source of radiosonde inaccuracy (Hooper, 1986; Nash and Schmidlin, 1987; Schmidlin, 1988: Ivanov et al, 1991; and Yagi et al, 1997; da Silveira, to be published). These, and other comparisons carried out in the United States (US) and United Kingdom, showed that measurement differences ranged from ±1ºC at 100 hPa to approximately ±2ºC to ±4ºC at 10 hPa. The scientific literature contains many citations pertaining to the evaluation of temperature measurement accuracy. Badgley, (1957) reported that at 11 hPa the radiative error of the rod thermistor, used extensively in the US, was negative during both day (-0.9ºC) and night (-2.0ºC). According to Ballard and Rubio (1968), the daytime error would reach 1.8ºC at 10 hPa. Teweles and Finger (1960) in an effort to improve the consistency of upper air charts, examined many sets of day-night radiosonde temperatures resulting in adjustments to global radiosonde temperatures (McInturff et al, 1979). Obviously, there was considerable concern about radiosonde errors over 50 years ago. Hence, these early reports were very important catalysts for initiating radiosonde comparisons.

Other US laboratories and agencies that expend a considerable part of their budgets to obtain reliable measurements share NASA's concern about measurement quality. In particular, the US National Weather Service, US Department of Energy, US Air Force, and others, have in place programs to evaluate radiosonde temperature measurement. Data quality is a concern of weather services of all nations and, in particular, the continual carrying out of radiosonde comparisons sponsored by the World Meteorological Organization (WMO) testifies to their importance. Recognizing the lack of suitable temperature measurement standards, NASA introduced the Accurate Temperature Measuring ATM radiosonde (Schmidlin et al, 1986) and demonstrated its accuracy of 0.2ºC-0.3ºC.

Descriptive Examples

Thermistors continuously try to reach equilibrium with their surroundings. Consequently, the temperature of the thermistor is reported, not the ambient temperature. The sources of radiation impinging on the thermistor include direct and indirect solar radiation; long-wave emission from the ground, clouds, the atmosphere from below and from above the thermistor. As the thermistor absorbs long-wave radiation from its surrounding environment it simultaneously emits long-wave radiation from its surface. Solar radiation reaches the thermistor directly, from reflection, and from scattering by the atmosphere. In order to overcome the radiative influence and other thermal forces, corrections are necessary.

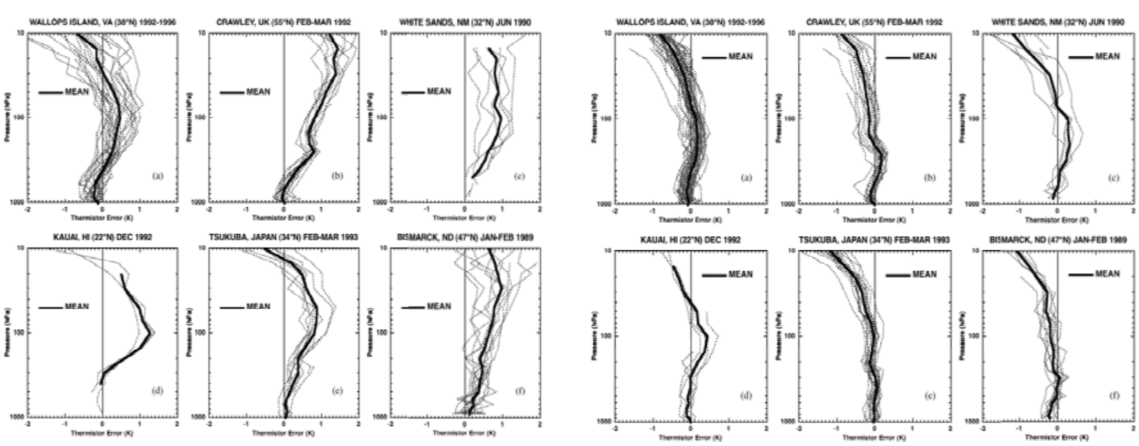
Using three thermistors each of a different color is necessary to characterize the emissivity and absorptivity of each, three heat balance equations are simultaneously solved. Such as

$$-HA(\Delta T) + \varepsilon R + \alpha S - \varepsilon\sigma AT^4 + 2\pi r_{wi}^2 k_{wi}(dT_{wi}/dl)_{l=0} = CdT/dt \qquad [1]$$

Where,

H	=	convective heat transfer coefficient
A	=	thermistor surface area
ΔT	=	thermistor error ($T - T_{air}$)
ε	=	emissivity of thermistor coating
R	=	long-wave radiation impinging on the thermistor
α	=	absorptivity of thermistor coating
S	=	short-wave radiation impinging on the thermistor
σ	=	Stefan-Boltzmann constant
T	=	thermistor temperature (K)
T_{air}	=	ambient temperature (K)
l	=	length of lead wires
r_{wi}	=	radius of lead wires
k_{wi}	=	thermal conductivity of lead wires
C	=	conduction
DT_{wi}/dl	=	temperature gradients of lead wires at thermistor junction, and
dT/dt	=	thermistor temperature time/rate of change.

The two terms on the right of Eq [1], provide adjustments for conduction and thermal lag. The long- and short-wave incident radiation R and S irradiating the thermistor equals the radiative energy absorbed by the thermistor as if it were a perfect black body. When only a single thermistor is used the thermistor error ΔT is difficult to determine unless the parameters ε α, R and S in Eq [1] are known. Laboratory measurements of ε and α usually are available but accurate estimates of R and S are not possible. During day and night, the incident long-wave radiation actually absorbed is proportional to the term εR and during daytime, the short-wave incident radiation absorbed is proportional to the term αS. The thermistor's long-wave emission $\varepsilon\sigma AT^4$ maintains the thermistor temperature at a value lower than the ambient temperature at night while tending to reduce the size of the error during the day. The result is mostly negative thermistor errors during nighttime and at high altitudes during the day. The figures below of daytime and nighttime thermistor errors show that the radiation effect is not constant for any given thermistor but differs with the environmental background. Thermistors, other than the Sippican rod thermistor, will experience different radiative exchange, conduction, and lag; but all will have errors. This implies that a single correction (adjustment) will not be adequate under all conditions.



DAYTIME NIGHTTIME

Figure 1. Describes thermistor errors resulting from different environmental backgrounds at six sites during both day and night. Nighttime results appear more stable. These examples are for the rod thermistor of early VIZ radiosondes; different radiosondes with different thermistors will experience different radiative error.

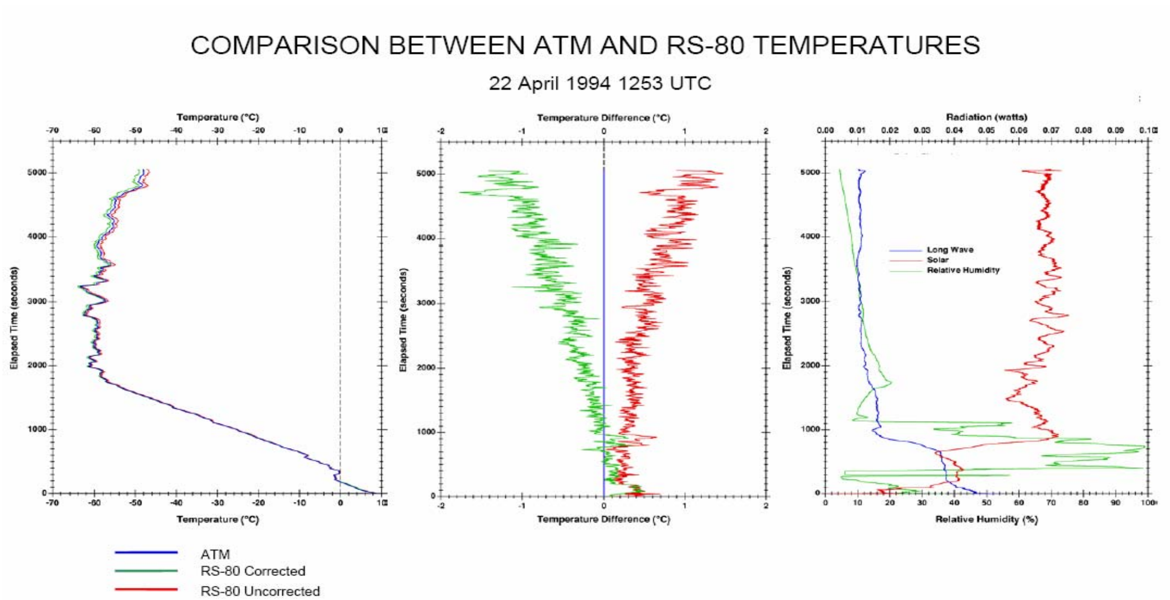


Figure 2. Comparison is shown between ATM radiosonde temperatures with the Vaisala RS-80 temperatures. This comparison was conducted at the US National Weather Service Test and Evaluation Facility, Sterling Virginia. Both instruments flew on the same balloon. Time is used as the common parameter since the pressure measurements disagreed. The Vaisala correction Table RSN-86 indicates a radiation correction at 10 hPa (in the figure at about 5100 seconds after release of the instruments) of -2.1ºC, the sun angle is approximately 35 degrees. At 100 hPa (~2700 seconds) the Vaisala radiation correction is given in the Table as -0.8ºC. The study suggests that the Vaisala correction is about 1ºC too large at 10 hPa and 0.4ºC at 100 hPa. The red curve compares the measured RS-80 temperature vs the ATM temperature and the green curve after the standard RS-80 correction is applied. The ATM radiosonde method also permits backward calculation to determine the long- and short-wave heat flux, R and S respectively. The right hand panel shows a significant increase in the short-wave flux at the top of the cloud indicated by the RH profile; long-wave decreases, and the figure also suggests that the long-wave flux in clouds is relatively constant.

Figure 3. Illustrates comparison between ATM temperature (green line) and uncorrected chip temperature (light red line) and corrected chip temperature (dark red line). The correction applied to the chip thermistor is in the proper direction, but in this example the amount of the correction is not considered to be large enough.

It has been suggested many times that radiosonde thermistors should be smaller and respond faster. Experience with the multi-thermistor ATM radiosonde indicates that the ATM method of determining the true temperature will work regardless of the thermistor size. In fact, the rod thermistor will perform as well as the new chip thermistors now adopted by Sippican. In Figure 3 an example of the ATM radiosonde temperature with the uncorrected “raw”chip temperature and the corrected chip temperature. This example is courtesy of the US National Weather Service. The Weather Service uses ATM radiosonde results to qualify the chip thermistor for use in the radiosonde network. The example shown indicates reasonably good agreement after correction, but should not be considered a final result since many comparison observations are still needed. The use of rod thermistors should not be discounted since the atmospheric structure given by the chip thermistor is comparable to that given by the rod, as Figure 3 indicates. The time of response of the chip thermistor allows significant 'noise' to appear in the profile, nonetheless, the major atmospheric features are present in both measurements.

Summary

The ATM radiosonde method has been used by NASA for a number of years. Because of its ability to provide the true atmospheric temperature it also has been used in WMO radiosonde intercomparisons, for special satellite validation requirements, more recently by the US National Weather Service, and it is proposed for use in other national tests. In this poster we have given three examples (of many available) to demonstrate the usefulness of the ATM radiosonde as a measurement standard. Work is continuing to provide a more promising radiosonde tool. New analysis methods are under investigation; one is the use of bead thermistors.

References

Badgley, F. I., 1957: Response of radiosonde thermistors. Rev. Sci. Instr., 28, pp 1079-1084.

Ballard, H. N. and R. Rubio, 1968: Corrections to observed rocketsonde and balloonsonde temperatures. J. Appl. Meteor., 7, pp 919-928.

da Silveira, R. B., G. F. Fisch, L. Machado, A. M. Dall'Antonia Jr, LK. F. Supucci, D. Fernandes, R. Marques, 200?: Report of the WMO RSO Intercomparison Experiment – Brazil. In Draft, to be published.

McInturff, R. M., F. G. Finger, K. W. Johnson, and J. D. Laver. 1979: Day-night differences in radiosonde observations of the stratosphere and troposphere. NOAA Tech. Memo. NWS NMC 63. 47 pp.

Hooper, A. H., 1986: WMO international radiosonde comparison Phase I, Beaufort Park, UK, 1984, WMO Instruments and Observing Methods Report No. 28, 118 pp.

Nash, J. and F. J. Schmidlin, 1987: Final report of the WMO International Radiosonde Intercomparison. WMO Report No. 30, 123 pp.

Schmidlin, F. J., 1988: WMO International Radiosonde Intercomparison, Phase II, 1985: Wallops Island, Virginia USA. WMO Instruments and Observing Methods Report No. 29. 113 pages.

Ivanov, A., A. Kats, S. Kurnosenko, J. Nash, and N. Zeitseva, 1991: WMO international radiosonde comparison, Phase 3. Instruments and Observing Methods Report No. 40, WMO/TD-No. 451, 135 pp.

Schmidlin, F. J., J. K. Luers, and P. D. Hoffman, 1986: Preliminary estimates of radiosonde thermistor errors. NASA Tech. Paper 2637. 15pp.

Yagi, S., A. Mita, and N. Inoue, 1996: WMO International Radiosonde Comparison - Phase IV - Tsukuba, Japan, 15 February - 12 March 1993, Final Report, Instruments and Observing Methods Report No. 59, 130 pages.

Teweles, S. and F. G. Finger, 1960: Reduction of diurnal variation in the reported temperatures and heights of stratospheric constant-pressure surfaces. J. Meteor., 17, 177-193.