THE UNITED STATES NATIONAL WEATHER SERVICE (NWS) IN-SITU RADIATION TEMPERATURE CORRECTION FOR RADIOSONDE REPLACEMENT SYSTEM (RRS) GPS RADIOSONDES

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ABSTRACT

The National Weather Service will require individual field sites to apply in-situ radiation corrections to temperature measurements from radiosondes used with the RRS. The radiation corrections will be more dynamic than current correction algorithms in use by radiosonde vendors today. Current radiation correction algorithms use solar elevation angle, balloon ascent rate, and empirical bias corrections such as differences derived from paired radiosonde flights using reference radiosonde technology such as the National Aeronautics and Space Administration (NASA) accurate temperature measurement (ATM) reference radiosonde, differences between day and night flights, and Numerical Weather Center's observation minus first guess-field differences. Improved physics and empirically-based dynamic correction techniques are being developed by NWS radiosonde providers to include the impacts of observed cloud conditions on the correction. Cloud amount, 27 cloud types, cloud base, and cloud thickness are to be considered in the in-situ radiation corrections. The required cloud information is derived from the World Meteorological Organization (WMO) coded cloud group message included with the transmission of each upper air sounding's coded message. The magnitude of the cloud impacts on the temperature correction will be shown for various cloudiness conditions. Results from NASA ATM reference radiosonde flight comparisons for corrected and uncorrected radiosonde temperature profiles will be presented. The results from the comparison flights support the determination of the radiosonde temperature sensor accuracy without correction and the assessment of the dynamic radiation correction algorithm

1. INTRODUCTION

The National Weather Service requires in-situ radiation corrections to be applied to radiosonde temperature measurements by individual field sites. Current radiation correction algorithms are based on solar elevation angle, balloon ascent rate, and empirical bias corrections derived from paired radiosonde flights with the National Aeronautics and Space Administration (NASA) accurate temperature measurement (ATM) three-thermistor reference radiosonde. Improved dynamic correction techniques are being developed by NWS radiosonde providers to include the impacts of 27 cloud types, cloud amount, cloud base, and cloud thickness on the in-situ radiation corrections. The cloud information is derived from the World Meteorological Organization (WMO) coded cloud group message included with the transmission of each upper air sounding. The magnitude of the cloud impacts on the temperature correction will be shown for various cloudiness conditions. Results from preliminary flight comparisons of corrected and uncorrected radiosonde temperature profiles against the NASA reference radiosonde will be presented

2. THERMISTOR IN-SITU BIAS EVALUATION

Successful factory tests are not good indicators of how temperature sensors will perform in the environment. Small in-situ 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 used by the National Centers for Environmental Prediction (NCEP) and 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.

3. IN-SITU COMPARISONS AGAINST A STANDARD

Primary contributions to the bias error of radiosonde temperature measurements are thought to come from short and long wave radiation. A technique to determine the contribution of these biases uses three temperature sensors with different coatings. The different spectral characteristics of coatings selected provide a spread of absorptivity and emissivity values. By knowing the differences in the spectral response of the coatings, it is possible to solve a series of simultaneous equations to determine the overall radiation error. Thermistors flown at night are selected such that one is coated with a material with a low emissivity and the other with a high emissivity. The simultaneous equations solved provide the long-wave correction. The coatings used on these sensors are white and aluminum. Daytime measurements require reference sensors, one with high solar absorptivity and the other with a low solar absorptivity. These are white coated and black coated respectively (Schmidlin 1986). The above technique can be used under various cloudiness conditions and solar elevation angles to determine the temperature bias. The results from comparison measurements have been aggregated and are the basis for correction algorithms in use today. Correction tables have been generated for various solar elevation angles by the NCEP using the NASA ATM results and inclusion of data from first guess fields. 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 on the thermistor as a function of the environment.

4. PHYSICS BASED ENERGY BALANCE MODELS

Luers (1990) through the use of empirical data from three thermistor flights worked to model radiation corrections by using the heat transfer process for a rod thermistor shown Figure 1.

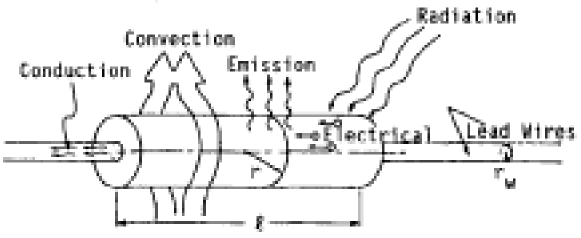

FIG. 1. Thermistor geometry and heat transfer processes.

The time rate of change of the temperature sensor of the radiosonde is shown in Equation 1 for the Figure 1 example:

$$mC(dT/dt) = q_{abs} - q_{emit} + q_{conv} + q_{elec} + q_{cond} \quad (1)$$

Equation 2 is the equation for estimating the temperature error of the radiosonde rod thermistor under different environments

$$q_{abs} = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} \bar{A}_p(\theta) \int_{\lambda} \alpha(\lambda) I(\theta, \phi, \lambda) d\lambda \sin\theta d\theta d\phi \quad (2)$$

Luers (1996) in work with the National Climatic Data Center developed radiosonde correction models for enhancing historical data records. As part of the work on correction models was the use of the Air Force LOWTRAN 7 atmospheric radiance and transmission model to model the radiative fluxes a function of the environment. The model was used to generate environmental input to accommodate atmospheric conditions in the data correction solution. This included incorporating cloud information.

5. NWS REQUIREMENT FOR RADIATION CORRECTION

The new GPS radiosondes that the NWS is procuring need vendor-provided radiation correction algorithms for correction of the temperature measurements before data transmission from the field sites. The algorithms are to physics-based in considering the energy balance equations. They are to be dynamic in that they will consider direct radiation under clear sky conditions as well as reflected and scattered long and short wave radiation, radiosonde ascent rate/atmospheric density, solar angle, and cloud observations (Sky cover, cloud amount, cloud height and cloud type). The cloud information was to be extracted and derived from the WMO cloud code group.

The WMO (1995) code group used as part of the Upper Air Coded message is: N_h C_L h C_M C_H

N_h	Amount of all the C_L cloud present, or if no C_L is present, the amount of all the C_M cloud present.
C_L	Clouds of the genera Stratocumulus, Stratus, Cumulus, and Cumulonimbus.
h	Height above surface of the base of the lowest cloud seen. If there are no low clouds reported but middle clouds are reported, the height value is ascribed to the middle cloud.
C_M	Clouds of the genera Altocumulus Altostratus, and Nimbostratus.
C_H	Clouds of the genera Cirrus, Cirrocumulus and Cirrostratus.

Limitations:

If a low cloud, middle cloud, and high cloud are reported, the cloud cover is only reported for the first layer. If the low cloud is absent (0 cloud type reported), a middle cloud (if reported with other than a 0 cloud type) is assigned the cloud cover okta amount.

Cloud cover is not ascribed to a high cloud report, even if low and middle clouds are not reported (code field populated with 0 for each cloud type).

Cloud base height information in the WMO Code Table not reported beyond 2500 meters for the low or middle cloud.

Cloud-base height information is not supplied for middle clouds above 2500 meters or for high clouds.

Cloud-layer thickness is not available from the Cloud Code Group.

Because of limitations in the WMO Cloud Code Group cloud reporting for the Low, Middle, and High clouds, empirical climatological information from work by Poore et.al.,. (1995) on cloud bases, thickness for various cloud types were used to complete a cloud table for all 27 types of clouds. Poore’s work compiled for 10 cloud types and had to be expanded to the 27 cloud types reported in WMO code tables. Rules were also established for summing okta cover for each cloud type so that total sky cover would not exceed 8 oktas. Table 1 is the table used by the radiosonde vendors to make

Table 1. Reported and estimated cloud cover bases and thickness from WMO Cloud Code Group

Low Cloud				Middle Cloud				High Cloud			
Cloud Code	Okta Cover	Cloud Base	Cloud Depth	Cloud Code	Okta Cover	Cloud Base	Cloud depth	Cloud Code	Okta Cover	Cloud base	Cloud depth
0	0rpd			0	0	Rpd/3300 if code 9	1300	0	0	7252	1000
1	Rpd	Rpd	1000	1	Rpd/8	Rpd/3300 if code 9	1500	1	4	7572	1000
2	Rpd	Rpd	1200	2	Rpd/8	Rpd/3300 if code 9	2500	2	4	7572	1000
3	Rpd	Rpd	2000	3	Rpd/2	Rpd/3300 if code 9	1200	3	1	7252	1000
4	Rpd	Rpd	1200	4	Rpd/3	Rpd/3300 if code 9	1200	4	4	7252	1000
5	Rpd	Rpd	1200	5	Rpd/5	Rpd/3300 if code 9	1200	5	1	7252	1000
6	Rpd	Rpd	1500	6	Rpd/1	Rpd/3300 if code 9	1200	6	4	7252	1000
7	Rpd	Rpd	1500	7	Rpd/3	Rpd/3300 if code 9	1200	7	8	7252	1000
8	Rpd	Rpd	1200	8	Rpd/2	Rpd/3300 if code 9	2500	8	4	7252	1000
9	Rpd	Rpd	2000	9	Rpd/5	Rpd/3300 if code 9	1500	9	2	7252	1000
/	9			/	9			/	9		
	/				/						

transformations from the WMO Cloud code group transmitted message into a form for inclusion in a thermistor radiation correction model. Data not reported in the WMO cloud message are estimated.

6. PRELIMINARY NWS FLIGHT TESTING

The National Weather Service uses the ATM reference radiosonde (Schmidlin et. al., 1986) to assess 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 as an evaluation standard for vendor radiosonde thermistor performance. The standard is accurate to 0.2^o C in the troposphere and 0.3^o C in the stratosphere (WMO, 1996). The standard is used for live radiosonde flights during daytime and nighttime. The three thermistor system enables the NWS to evaluate vendor sensor performance, including the effectiveness of the sensor coating material for both long and short wave radiation and the radiation correction algorithm the vendor is required to provide.

7. TEST RESULTS

The NWS flew 7-day and 4-night NASA ATM three thermistor comparison flights respectively with the Sippican MARK IIA GPS radiosonde. The purpose of this preliminary flight series was to compare how well the vendor's sensors compared with a reference standard and to evaluate the MARK IIA radiation correction routine under development. Results from the flights are depicted. The MARK IIA temperature sensors are (small chips) aluminized.

Part of the evaluation of the prototype radiation correction model was to determine the sensitivity to cloud information on the correction to be applied to the thermistor. Figure 2 has flight information from a live flight flown under overcast conditions. The difference in temperature is shown as the difference between the NASA ATM three thermistor measurements and the vendor corrected MARK IIA temperature (MARK IIA warmer than NASA ATM). The NASA ATM is an all weather system and is not impacted by weather on measurements unless it is precipitating. As such it provides an accurate measurement in cloudy and cloud free situations. A second curve on the figure is for clear conditions. In the upper atmosphere, the difference between the correction for a clear day and an overcast day is 0.3^o C. That is, an overcast day needs a greater correction to temperature values because of reflections off the cloud tops. These values are consistent with the values of 0.5 K found in measurements in the United Kingdom (WMO 1996). Basically, the cloud cover should attenuate the short wave emissions in-cloud, diminish the correction below-cloud. Results below the cloud deck are under review and minor adjustments have been incorporated.

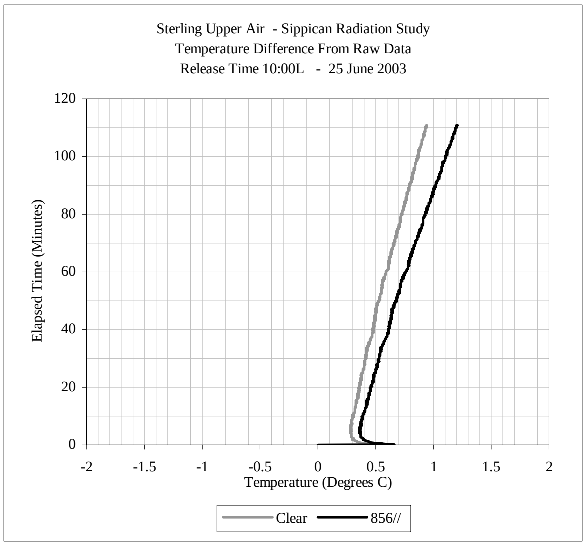

Figure 2. Temperature difference of MARK IIA minus the NASA ATM for overcast and clear conditions.

Composite corrected mean differences between the NASA ATM and the MARK IIA radiosonde for the 7 day flights are shown in Figure 3. The flights were generally during cloudy conditions and consisted of different flight times. It appears that we are over correcting near the surface and under correcting aloft. However, the values are within the worst case tolerance on the accuracy of the NASA ATM and the MARK IIA. The differences for a NASA ATM flight and corrected and uncorrected Mark IIA radiosonde data are shown in Figure 4. There is good agreement between the ATM and the corrected radiosonde data.

Means and standard deviations of the four Sippican night flights are shown in Figure 5. The night flights do not have short or long wave corrections applied by the vendor's correction model. Although there are some long wave influences on the sensor, they are deemed small and do not receive a correction.

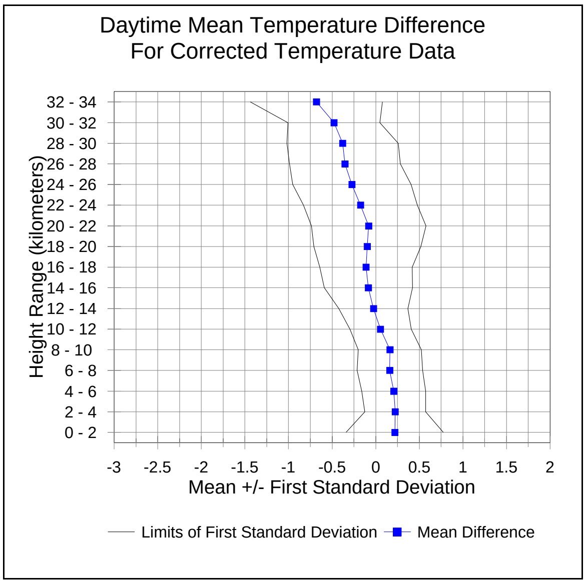

Figure 3. Composite day flight corrected difference and standard deviation NASA ATM minus MARK IIA.

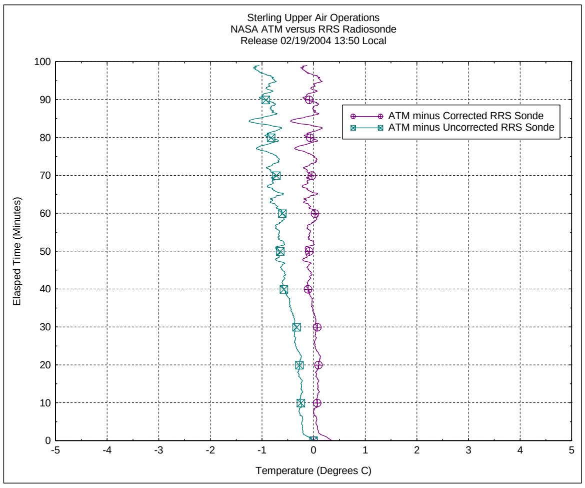

Figure 4. The difference between the ATM and Mark IIA corrected and uncorrected for radiation.

8. CONCLUSIONS

The NASA ATM reference radiosonde dual flight in-situ testing with standard radiosondes is critical for Determining temperature accuracy, bias, and required radiation algorithm assessment for operational radiosondes.

Preliminary results from flights of the Sippican MARK IIA radiosondes against the NASA three thermistor system are promising. The uncorrected errors are less than for previous thermistors on older radiosondes and qualitatively, the dynamic radiation correction is functioning properly. More flight testing under different solar angles and weather conditions is required.

Follow-on assessment of the radiation model and possible adjustments to more accurately account for differences between the NASA ATM all weather reference radiosonde and the MARK IIA radiosonde need to be undertaken.

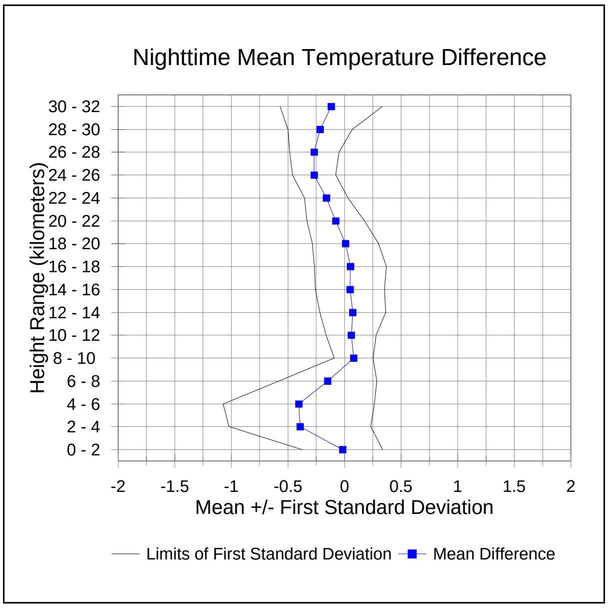

Figure 5. Night flights means and standard deviations of the difference of the NASA ATM minus the MARK IIA radiosonde.

9. REFERENCES

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