245 ASSESSMENT OF MULTI-THERMISTOR RADIOSONDE AIR TEMPERATURE AND SENSOR UNCERTAINTY

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1.0 INTRODUCTION

The National Weather Service (NWS) has a mixed upper air network of radiosonde types used for conducting soundings in support of weather prediction. These radiosondes have unique error characteristics and to better quantify their temperature error, the NWS is considering the use of multi-thermistor radiosonde (MTR) technology as an independent reference. The MTR, originally developed by NASA Wallops scientist, Frank Schmidlin, consists of three sensors with unique radiative properties which are used to instantaneously correct raw temperature sounding measurements of radiative effects. The NWS has developed a correction process for the MTR called the Advanced Multi-thermistor (AMT) and it is evaluated in this study.

2.0 PURPOSE

The study assesses the precision of the MTR sensors and the precision of the AMT air temperature solution. The MTR system has five thermistors: three thermistors deposited with aluminum; one thermistor coated with black paint; and one thermistor coated with white paint. The precision of the aluminum thermistor sensor is easily ascertained since there are three of them on an MTR, but not the black and white thermistor sensors. To assess their precision, this study utilizes “specialty” MTR systems, with all five thermistor sensors coated either black or white, in tandem with the “traditional” MTR system.

3.0 AMT SOLUTION

Air temperature determined by a radiosonde is dependent on the thermistor sensor’s mass, radiative properties, and thermal conductivity. Mathematically, it can be expressed as

$$H \cdot A \cdot (T_{sen} - T_{air}) = S \cdot A_S + R \cdot A_R \,, \qquad (3.1)$$

where H is thermal conductivity, A is area, T_{sen} is sensor temperature, T_{air} is air temperature, S and R is short- and long-wave intensity, and A_S and A_R is the sensor short- and long-wave absorptivity coefficient. The unknown in this equation includes H, T_{air}, S and R. The coefficients A_S and A_R are prescribed to a sensor based on lab assays.

In this assessment, only the MTR’s daytime characteristics are evaluated since large air temperature correction is normally not required for the system at night. Therefore, to solve equation (3.1) for daytime MTR flights, the AMT solution first makes an educated guess at air temperature. The first guess is determined with only the black and white MTR sensors. With these two sensors, it is assumed that above 32 km the shortwave radiation component is more important than the longwave, especially since the black and white longwave absorptivity coefficients are similar in magnitude. Next, the profile of S is approximated with a solar model dependent on solar angle and cloud cover. After the aforementioned substitutions, equation 3.1 now has two unknowns in the two sensor system of equations which can be solved with linear algebra. Next, the solutions of the previous process are substituted into the aluminum equation while neglecting the longwave component, as following

$$F = H \cdot A \cdot \frac{T_{AL} - T_{air}}{S \cdot A_S}, \qquad (3.2)$$

and F represent any inaccuracies in assigned absoptivity coefficients (ex., due to poor sensor workmanship) or thermal conductivity values. Finally, the three sensors are equated into a system of three equations with three unknowns (T_{air}, S and R). The H profile is substituted into these equations and so is the F corrective term as following,

$$H \cdot A \cdot (T_{AL} - T_{air}) = F \cdot S \cdot A_S + R \cdot A_R. \qquad (3.3)$$

Linear algebra techniques are then used to solve for air temperature.

4.0 METHODOLOGY

Soundings of specialty and traditional MTR systems attached to a single balloon, in a dual bar configuration, were conducted to assess the precision of the raw sensor measurements and AMT solution simultaneously. These soundings were conducted during daytime periods at the NWS Sterling Field Support Center (SFSC) in Sterling, VA. There were six dual bar soundings conducted for both specialty MTR systems. Each dual bar sounding offered either six white or six black thermistor observations

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(depending on which specialty sonde was used) which allowed 18 possible AMT air temperature solutions. To evaluate the many temperature solutions, WMO significant pressure levels were used to average the flight data into pressure bins.

5.0 RESULTS

5.1 PRECISION FLIGHTS

Figure 1 shows the precision of the black and white sensor measurements for each dual bar sounding conducted. It shows that on average the white sensor consisted of less error than the black sensor. In addition, it illustrates that the black sensor error increased with cloud cover totals. There is one specialty white flight that exhibits an equivalent magnitude of error to that of the black sensors, identified by the green profile, and its error is due to poor workmanship, as shown in Figure 2. One of the six white sensors consisted of a badly chipped white coating.

Figure 3 displays the precision of the AMT air temperature solution for the aforementioned dual bar soundings. On average, the error of the AMT solution is significantly lesser than that of the sensors. The magnitude of the AMT solution error for the white sensor is equivalent to that for the black sensor, which implies that the white sensor propagates a larger air temperature error in the MTR's set of energy equations. It can be seen that the error induced by the poor workmanship of the white specialty flight propagated a large error into the AMT air temperature solution. Nevertheless, the absolute mean error for the AMT solution is well within the NWS's ± 0.3° requirement for its operational radiosondes.

5.2 SENSITIVITY ANALYSIS

The 12 dual bar soundings were artificially perturbed to assess the sensitivity of the white, black and aluminum sensor components in the AMT solution. Table 1 shows the average difference in air temperature above 32 km for the respective sensors after varying them by the amount indicated in the top row of Table 1. It can be seen that changing the black sensor very slightly ($\Delta 10^{-5}$), either by warming or cooling, produces a significance cooling effect of almost 1° on the AMT solution. This result is very unusual and unexpected. It indicates that at minimum an error in the black sensor measurement can propagate an air temperature error of about -1°, which error is not consistent with the precision results of section 5.1. As the absolute perturbations increase, Table 1 shows the aluminum sensor and the white sensor exhibiting more sensitivity than the black sensor, with the aluminum sensor exhibiting the most.

6.0 SUMMARY

The black coated thermistor sensor produced more uncertainty than the white coated thermistor sensor. The sensors produced an average error of the following for the 12 dual bar specialty flights: the black sensor an error of 0.27 ± 0.69; the white sensor an error of 0.14 ± 0.41; and the aluminum sensor an error of 0.17 ± 0.50. The AMT air temperature error for both the white and black specialty flights was negligible relative to their sensor error. The black sensor specialty flights displayed an average error of 0.04 ± 0.10 and the white sensor specialty flights an average error of 0.06 ± 0.14. The sensitivity analysis supported the fact that error with the white sensor observations was more detrimental to the AMT solution than error with the black sensor. In addition, the sensitivity analysis uncovered the sensitivity of the black sensor to very small perturbations. The extent of the impact of this result on the AMT solution is still under review.

The MTR system offers a robust upper air system for accurate measurement of air temperature. The results of this analysis show the AMT solution to be very precise at the SFSC mid-latitude region, but before this system can be recommended as a reference more testing in other climate regimes are required, along with further assessment of the sensitivity of the AMT solution to sensor error.

7.0 TABLES AND ILLUSTRATIONS

Tables

Table 1. This table provides results from a sensitivity analysis conducted with the measurements above 32 km from the specialty dual bar soundings.

ΔT_{sen}	-10^{-5}	-10^{-4}	-10^{-3}
WHI	0.01	-0.94	-10.01
BLK	-0.92	-0.56	3.98
ALU	-0.02	-2.01	-19.85

ΔT_{sen}	10^{-5}	10^{-4}	10^{-3}
WHI	0.2	1.11	7.80
BLK	-0.99	-1.33	-5.45
ALU	0.03	1.99	17.64

Figures

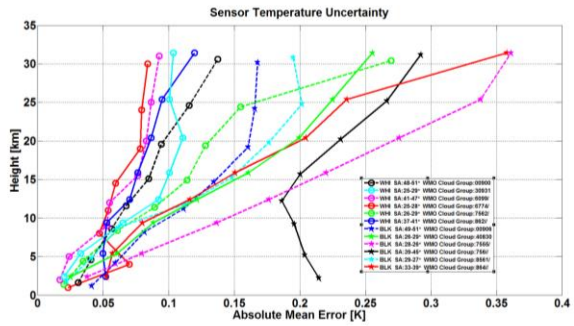

FIG. 1 displays the error of the 12 specialty dual bar soundings conducted at the National Weather Service Sterling Field Support Center.

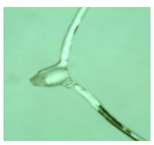

FIG 2 displays a white thermistor sensor with poor workmanship. The lead wires and sensor are exposed through the white coating.

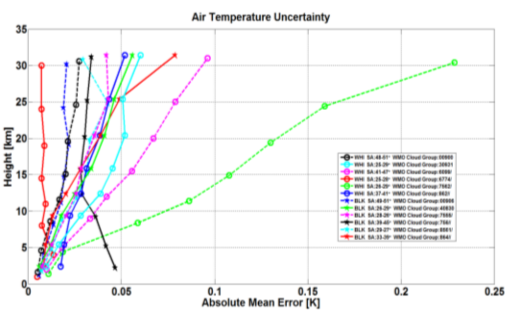

FIG. 3 displays the error of the AMT air temperature solution for the 12 specialty dual bar soundings. Relative to the sensor error the air temperature errors are minuscule.