1.4 Update on the Consensus Reference Concept for Testing Radiosondes

Joe Facundo, Carl Bower, and Ming Liu, Office of Operational Systems,

Silver Spring, Maryland and Sterling, Virginia

1. INTRODUCTION

The National Weather Service (NWS) has been testing radiosonde manufacturer's radiosondes for many decades at test facilities around the country and has developed a number of test techniques for verifying performance. Recent advances in measuring the upper air atmosphere utilizing state-of-the-art referencing technologies and the development of new test techniques within the U.S. are now available for evaluating radiosonde performance to meet the more stringent climate monitoring requirements. Examples of these reference technologies include: NWS's Advanced Temperature Measuring system, Snow White, high-precision GPS measurements of height, the Integrated Precipitable Water sensor using GPS techniques, and ground-based surface instrumentation to measure clouds and weather. Each reference technology can play an important role in the *Consensus Reference System;* whereby, data are integrated into information data bases from which statistical techniques can be applied to the time-based and pressure/height candidate instrument measurements of say, pressure/heights, temperature, moisture variables, cloud bases, and winds as compared to the various references in use. This extended abstract will focus on recent developments with use of a temperature referencing system used by the NWS to validate candidate radiosondes' temperature measurements and their associated correction schemes.

2. MULTI-THERMISTOR SYSTEM

The Lockheed Martin LMG6 Ground System receives in situ meteorological and Global Positioning System (GPS) data transmitted from in-flight Lockheed Martin LMS6 series radiosondes. There are two LMG6 based ground system configuration: the single antenna configuration, and the dual antenna configuration. Both configurations contain two digital RF receivers operating in the 400 – 406 MHz band. The single antenna configuration connects to a single antenna, and can tracks two radiosondes simultaneously. The dual antenna configuration connects to two separate antennas, and tracks a single radiosonde. Both LMG6 configurations can include, as necessary, a GPS receiver for accurate differential GPS (DGPS) radiosonde tracking and wind speed, wind direction, height, and barometric pressure calculations. All data are output to a Windows XP-based computer over a 10/100BaseT Ethernet connection. Multiple LMG6-based ground systems can be connected over a local area network (LAN).

The main components of the LMG6 Ground System are illustrated in Figure 1. They include an LMG6 rack mount chassis, a high angle RF antenna, a low angle RF antenna and a GPS antenna. The antennas connect directly to the LMG6 chassis using RF coax cables up to 200 feet in length. In addition, the system includes the Win9000 Processing and Display software which runs on any computer with the Microsoft Windows XP or Windows Server 2003 operating system and provides a user friendly means of configuring the LMG6 and acquiring, processing, viewing, analyzing, and archiving the data. The computer requires a network adapter and, if more than one system will be connected to the same computer over a LAN, an Ethernet switch. Win9000 can communicate with up to eight LMG6 chassis over a LAN, and multiple systems can also share the same antennas using optionally supplied signal splitters.

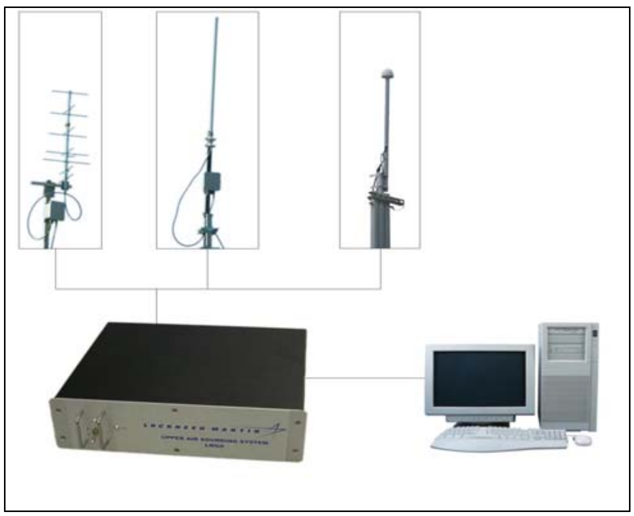

Figure 1. LMG6 system configuration.

As a key step in the verification of a radiosonde's radiation correction algorithm, the NWS will fly the test radiosonde against the LMS-AMT (advanced multi-thermistor) reference radiosonde. The multi-thermistor temperature solution is then compared against the test radiosonde temperatures throughout a flight. This test is conducted to evaluate the accuracy of the upper air temperature measurements from the test instruments and to validate any new or modified solar radiation correction algorithms being provided for that particular radiosonde.

The LMS-AMT reference radiosonde has 5 temperature sensors; one white, three silver and one black. For each of the three different colored sensors the emissivity and absorptivity of the coatings have been pre-determined in a laboratory by the vendor of the system. This information is then used to solve a set of equations to determine a “true” temperature solution. The true temperature solution is composed of one white, one black, and the average of the silver sensors. This process eliminates the effects of the solar and infra-red radiation. This true temperature is then compared against the test radiosonde’s corrected temperature that was flown on the same balloon.

3. NWS TEST PROCESS

The sections below describe test locations and the general process used to evaluate temperature measurements from a test instrument using this consensus technique.

3.1 Test Locations

Meteorological and climatological data play a major factor in test site selection. In order to fully ensure that a radiosonde is qualified, it must be tested in all atmospheric conditions present in the NWS network. Along with meteorological conditions, the types of operational equipment at a site were considered in the selection process. Figure 2 illustrates the relationship between meteorological zones and prospective test locations.

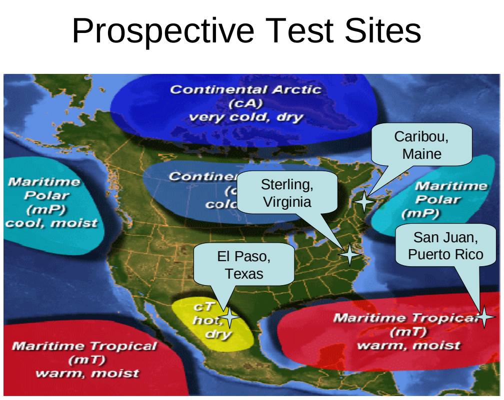

Figure 2. Select Test Sites.

3.1.1 Sterling, Virginia.

The mission of the Sterling Field Support Center (SFSC) in Sterling, Virginia, is to test sensor technologies for both meteorological and climatological applications using a wide range of techniques and technologies at a mid-latitude site. Testing in the mid-latitudes covers the vast majority of environmental conditions to be found within operational networks and can provide a wealth of data from just a few well-chosen locations around 35-45 degrees of latitude. These cover all types of temperature and precipitation types as well as high-altitude locations. However, some more extreme types of environments require specific locations and times of year as discussed in the following sections.

3.1.2 Caribou, Maine

Caribou, Maine, was chosen as a test site because it is classified as a Continental Polar climate. This type of climate requires cold ground surface temperatures (less than -10°C) and dry humidity. Along with the temperature and relative humidity requirements, Caribou, ME accumulates large quantities of snow during the winter months which could contaminate the radiosonde sensors as it ascends through the atmosphere.

3.1.3 El Paso, Texas

El Paso, Texas, was selected as a test site because of the desert (hot and dry) weather conditions present during the spring months. Desert conditions can challenge instrumentation especially during very dry surface conditions and blowing contaminants. Very dry biases can occur if the moisture sensors are not well calibrated for the areas of the country that observe this type of weather.

3.1.4 San Juan, Puerto Rico

In the Maritime Tropical climate, San Juan, Puerto Rico, was selected as the test site. This site was selected in order to test the radiosonde in high moisture, heat and high solar angles. Also, since San Juan is the southernmost test location, the radiosonde was observed on how it handled the extreme low temperatures (often less than -80°C) of the upper troposphere that are seen closer to the equator.

3.2 General Process

The multi-thermistor temperature solution is compared against the test radiosonde temperatures both for the uncorrected difference and then again after the vendor-provided solar correction scheme had been applied. For the purposes of this paper, NWS used one of the silver-coated channels (T1) to illustrate the process and techniques used.

3.2.1 Data Collection

The technique in general was as follows:

1. The purpose of this test is to test the performance of the radiation correction algorithm apart from the radiosonde. If the LMS-AMT or the test radiosonde were determined to be defective post-flight, the comparison flight data would not be used.

2. Flights should be divided between night (dark, moonless conditions are ideal) and daytime conditions over a range of solar angles. The flights should also be conducted in sky conditions ranging from clear to varying amounts of clouds (scattered to overcast). Note, the literature recommends not performing the tests during precipitation since it will have a negative effect on the reference to ascertain the true temperature. The WMO cloud code group is noted for each flight.

3. For the purpose of compliance determination, all paired data for each flight are analyzed for a compliance/non-compliance determination from the surface to flight termination. The following excerpt from the NWS specification describes the performance criteria:

"The temperature measurement error, after correcting for the effects of solar and infrared radiation encountered during flight, shall be within the allowable temperature measurement error for 98.5 percent of the time-paired, corrected temperature measurements during Government flight tests…"

3.2.2 Analysis Conducted

Testing is then conducted and the data analyzed in the following manner:

1. Inter-comparison flights are generally conducted at night, first, to ascertain the degree of difference without shortwave radiation present. The premise being that the test temperature sensor should not be producing any bias at night or a small amount due to a possible long-wave component. Figure 3 illustrates this concept using the T1 channel of the LMS-AMT as the test sensor and +/-0.3 consensus reference thresholds to illustrate the general process for meeting the compliance criteria.

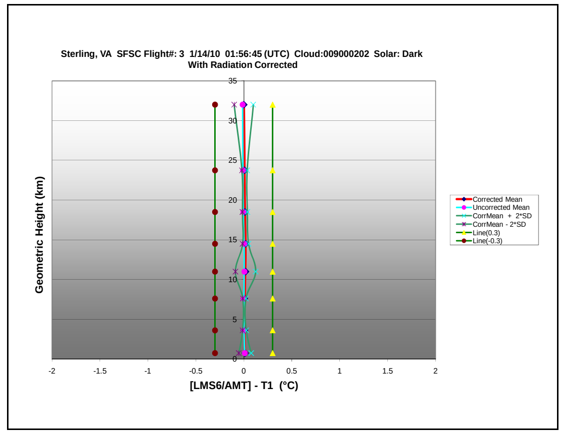

Figure 3. Example of Nighttime results

2. The next process step is centered on collecting data from daytime flights under clear conditions (<1/8th cloud cover of the celestial dome). Here, one would expect the uncorrected temperature data to be out of consensus with the reference and then be within the consensus thresholds after corrections are applied. Figure 4 delineates the uncorrected and corrected profiles with 98.5% lines in green denoting the dispersion of the data around the mean.

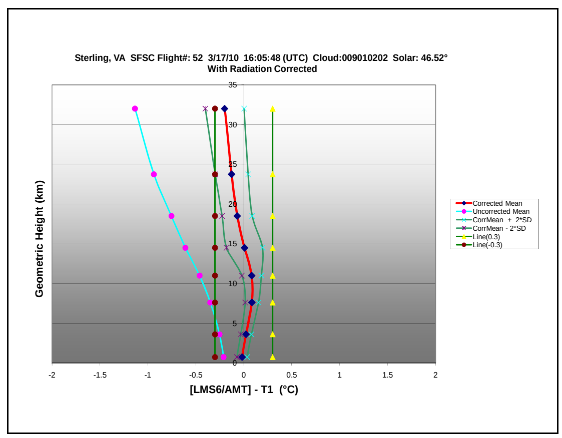

Figure 4. Clear daytime case.

3. The final set of flights conducted relate to varying amounts of cloud cover from scattered (>1/8th sky cover) to overcast (total sky). Data are also collected over varying solar angles; in this case (Figure 5), note the 77.72° solar angle obtained at San Juan.

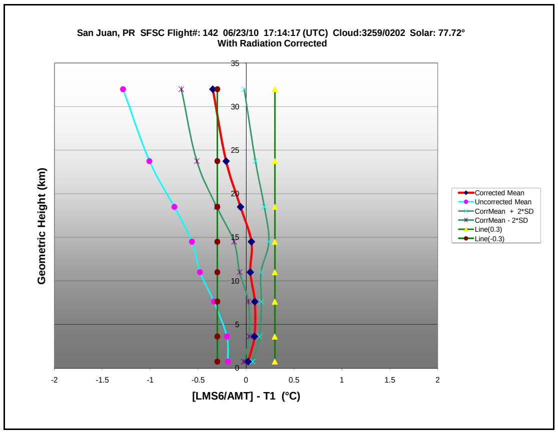

Figure 5. Cloudy, daytime case.

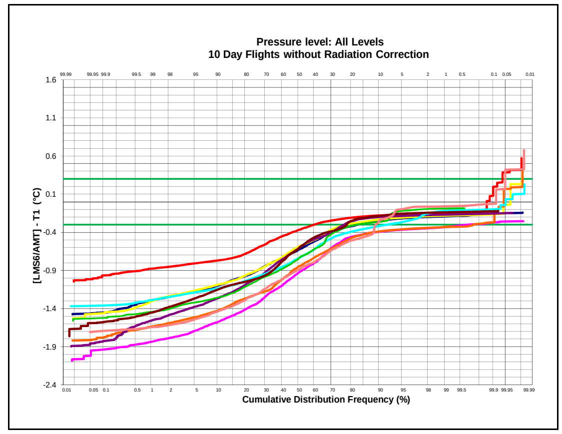

Figure 6. Display of the uncorrected data.

3.3.3 Consensus Reference Composites

The next step in the process is to compute the Consensus Reference Composites (CRC) for each temperature sensor under test as follows:

1. Compute a solution for each sensor under test using the above defined technique. Then display the Uncorrected (raw) data using the Cumulative Distribution Frequency (CDF) format to discern a pattern for these differences being depicted over the range of meteorological and solar conditions experienced. Refer to Figure 6 for an example of this type of CDF profiles for 10 Day flights.
2. The green horizontal lines depict the specification or consensus reference threshold lines and one could also add, say, red lines to include the uncertainty of the reference system. For each flight the differences are accounted for and displayed roughly as "S-shaped" profiles. Where they intersect the outer lines indicate what percentage of these differences exceeds the specification requirement plus any uncertainty value.
3. Next, compare the LMS-AMT data to the corrected test instrument temperatures.
4. Bifurcate the results into a) day and night composites and then b) further bifurcate the daytime results into clear and cloudy conditions. In this way the results may begin to indicate the true performance of the test sensor under these varying meteorological and solar conditions.
5. By combining like results into CDFs for each category (Figure 7), a pattern begins to emerge with the expected outcome of the test radiosonde in "consensus" – meaning the data are within allowable tolerances in a statistically significant percentage of the time with the results from the reference. It also allows NWS to link the results directly to specifications.
6. Varying results may also be expected as a function of solar angle, since data are collected over different times of the year at different locations inferring different latitudes. One way to display results is by separating the data into four subsets as follows:
   a. Dark, i.e., no solar angle: 0°
   b. Low solar angles: 1 - 30°
   c. Mid-range: 31 - 60°
   d. High angles: 61 - 90°

   By using the CDF format, one can determine if biases exist after corrections are applied within any of these solar angle ranges.

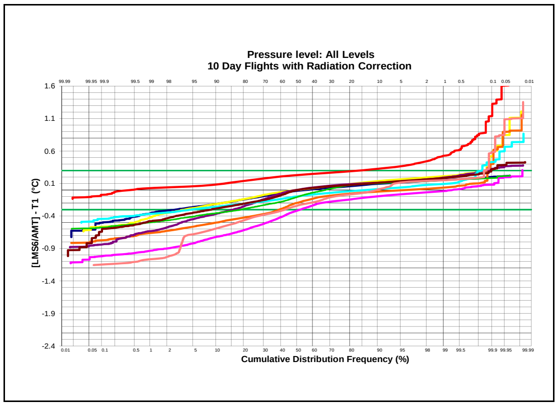

Figure 7. Composite set of Day flights over a series of solar angles.

4. CONCLUSIONS

The purpose of this paper is to inform the meteorological and climate communities about the use of the LMS-AMT as a consensus reference system, whereby an ensemble of tests are conducted and the results standardized to formulate a consistent pattern for evaluating upper air instrumentation and systems.

The use of the LMS-AMT has important attributes for assessing the atmospheric temperature distribution:

- Verifying the temperature correction schemes provided by a potential vendor are consistent with NWS Radiosonde Specifications
- Test radiosondes can perform over a wide range of meteorological and even climate regimes
- Tests can be repeated with consistent results over time as changes are introduced into later models of radiosondes.
- Could be of great benefit to NWP and climate modeling through a clear understanding of the error characteristics of the radiosonde temperature measurement.

Once the methods discussed in this paper are further developed and proven, the plan is to document it into a catalogue for use by the wider community. Other techniques can also be developed by others who wish to contribute their knowledge and expertise to this concept.

5. Acknowledgements

The NWS wishes to acknowledge the outstanding efforts of those involved with radiosonde testing at the Sterling Field Support Center in Sterling, Virginia. Special appreciation goes to Ashby Hawse, Ryan Brown and the rest of the CyberData support team. Finally, special thanks are in order for Tom Curran and Dr. Rich Scarlett from LMS, who have provided a deeper understanding of their LMS-AMT in the process of developing these concepts.

6. References

World Meteorological Organization 2008: Guide to Meteorological Instruments and Methods of Observation, Seventh Edition, WMO-No. 8, Geneva.

NOAA Technical Report, NWS 44: Functional Precision of National Weather Service Upper-Air Measurements using VIZ Manufacturing Co. “A” radiosonde (Model 1492-510)

ASTM Standard, E 177, Standard Practice for Use of the Terms Precision and Bias in Test Methods.

ASTM Standard, D 4430, Standard practice for Determining the Operational Comparability of Meteorological Measurements.

AMS Extended Abstract, Testing Radiosonde Replacement System (RRS) Radiosondes – Part 1, Jim Fitzgibbon, and Joe Facundo, Office of Operational Systems, Silver Spring, Maryland

AMS Extended Abstract, Testing Radiosonde Replacement System (RRS) Radiosondes – Part 2, Jim Fitzgibbon, and Joe Facundo, Office of Operational Systems, Silver Spring, Maryland

AMS Extended Abstract, Use of the Consensus Reference Concept for Testing Radiosondes, Joe Facundo and Jim Fitzgibbon, Office of Operational Systems, Silver Spring, Maryland and Sterling, Virginia

AMS Extended Abstract, The Consensus Reference Methodology as it Applies to a Radiosonde under Test, Ryan Brown, Joe Facundo and Jim Fitzgibbon, Office of Operational Systems, Silver Spring, Maryland and Sterling, Virginia

AMS Extended Abstract, Update on the Consensus Reference Concept for Testing Radiosondes, Joe Facundo, Carl Bower, and Jim Fitzgibbon, Office of Operational Systems, Silver Spring, Maryland and Sterling, Virginia