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7.8 AN UNUSUAL OKLAHOMA MESONET TEMPERATURE SENSOR PROBLEM (NEARLY) SLIPS BY *INSITU*, REAL-TIME, SHORT TERM AND LONG TERM QA EFFORTS...AND WHY THIS COULD HAPPEN TO YOU.

OR, IF EVERYTHING CHECKS OUT SO WELL HOW CAN THE DATA STILL BE BAD!?

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1. INTRODUCTION

The Oklahoma Mesonet consists of 114 fully instrumented and automated meteorological stations covering the entire state of Oklahoma (Figure 1). Station spacing is about 35 km. Data consist primarily of 3 second sensor samples averaged over a 5 minute period (Brock et al., 1995). The Mesonet expends considerable effort in trying to maintain data quality in a variety of ways. Such efforts include complete new instrument predeployment calibration checks periodic on-site intercomparisons, extensive real-time, short and long term Quality Assessment (QA) programs looking at spatial, temporal and seasonal factors, and periodic sensor rotation to reverify sensor calibration quality (Brock and Fredrickson, 1993; Schafer and Hughes, 1996; Arndt, Fredrickson, and Schafer, 1998).

Among the suite of sensors at each Mesonet station, each site has an air temperature/relative humidity probe at the 1.5 m level. Roughly half the sites also have a second air temperature sensor (of different design) at 9 m by request of the agricultural community. A series of tests were conducted evaluating the use of these two sensors at these two levels for

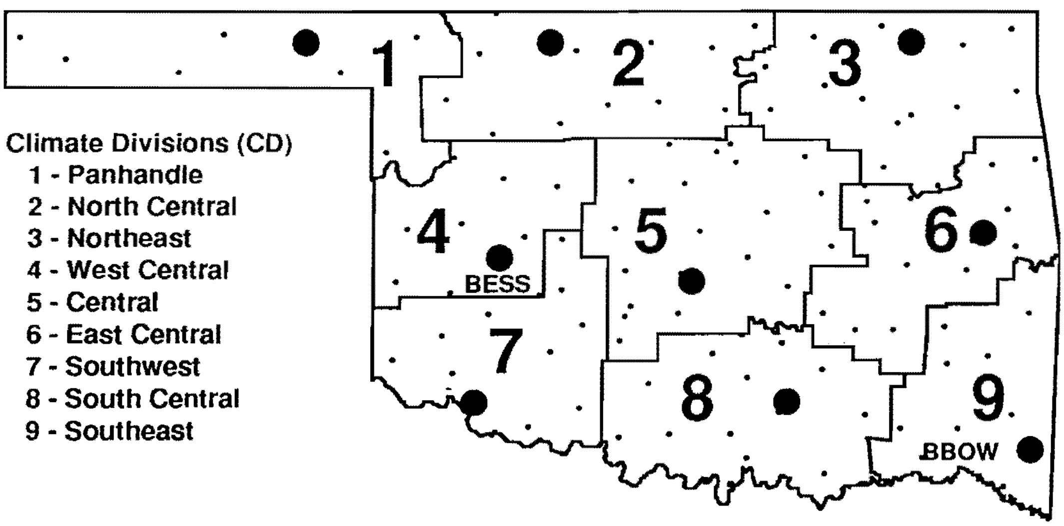

Figure 1: Site locations in the Oklahoma Mesonet relative to the nine Climate Divisions of Oklahoma. The nine enhanced sites, with additional Thermometrics (TMM) at 1.5 m, are in bold.

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sensible heat flux estimates. The results of these tests indicated the need for including another sensor at 1.5 m that was the same type as that at 9 m. Evaluating the results of adding this third sensor revealed an unexpected problem for the original 1.5 m temperature measurement at 8 out of the 9 test sites. Temperature errors were found, ranging from 0.5 to nearly 2°C, and seemed to be related to sensor calibration. Previous pre-calibrations, on-site inter-comparisons and other QA efforts had indicated all was working fine. The source of the problem was very difficult to track down. Once found, however, we realized that the most well thought-out plans of checks and cross checks could still have a few "holes" where problems could slip through undetected. The calibration quality of all probes (both good and seemingly bad) was verified as being all good. The problem lay in an area completely unsuspected and involved a unique combination of probe type, modifications to the probe, calibration software, datalogger and logger software. We present the results of this "chase" in the hopes that it will help others prevent a similar situation happening to their data collection system.

2. BACKGROUND

All Oklahoma Mesonet sites have a modified Vaisala HMP35 air temperature/relative humidity sensor at the 1.5 m level. Fifty-three sites also have an air temperature sensor at 9 m supplying data to the agricultural community: a Thermometrics (TMM) thermistor. The two temperture sensors have significantly different time constants (Scott et al., 1998). Each sensor is housed in a similar solar radiation shield, a Coastal Environmental Systems multiplate, naturally aspirated shield (resembling a set of stacked, inverted pieplates). Each sensor is mounted vertically and axially within this shield. Sensor sampling at each Mesonet site is done by a Campbell Scientific CR10T Measurement and Control System (data logger).

The Thermometrics temperature sensor at 9 m is a TMM type DC95 thermistor. This is factory epoxied to the tip of a TMM type T5503 stainless steel housing 4" long. When installed in the Mesonet radiation shield, virtually none of this probe body is exposed to direct sunlight. Its small size and exposure also gives it a short time constant in light air of about 10 seconds.

Calibration of the TMM probe is done by immersing the probe in a well stirred antifreeze bath while varying the temperature from -20°C to +45°C. Although the original Mesonet specification for the 9m temperature is +/- 0.4°C, a probe is typically within +/- 0.2°C.

The 1.5 m temperature probe is part of a Campbell/Vaisala HMP35C temperature/relative humidity sensor. For the Vaisala probe both temperature and RH sensors are located within a volume surrounded by a microporous membrane designed to protect the RH sensor from particulate contamination. This results in a fairly long temperature time constant (Richardson et al., 1998).

Campbell Scientific makes two modifications to the standard Vaisala HMP35A temperature/relative humidity sensor. One modification to the Vaisala probe is the substitution of a Fenwal thermistor (type 192-104QET) for the normal Vaisala platinum RTD. The other modification is a solid state switch which allows the RH portion of the probe to be turned off between measurement times, reducing total power consumption.

The radiation characteristics of the Vaisala probe are different from the TMM. About half of the body of the HMP35C (approximately 12 cm) protrudes from the bottom of the radiation shield. This contributes to a small radiation temperature error at low sun angles and low wind speeds (Brock and Richardson, 1995).

Calibration of the HMP35C temperature sensor is not straightforward. The temperature sensor is hardwired to the probe and located directly next to the RH sensor, precluding any fluid immersion calibration tests. However, present day thermistor manufacturing processes are usually of high quality. As such, it was felt that the characteristics of one specific thermistor type was uniform enough to allow the quality of that thermistor to be determined from measurements at a single temperature. Thus, during the course of a normal RH sensor calibration, temperature measurements are also made and an RMS temperature error is determined for the temperature sensor. Values are typically 0.2°C RMS.

3. HEAT FLUX STUDY

One investigator was interested in using the data from these two levels for heat flux studies (Brotzge, 1997; Brotzge et al., 1998). To evaluate this possibility a test site was set up with several arrangements of sensors at the two levels. At the 1.5 m level were three sensors and three shields: 1) a TMM set up in a naturally aspirated shield. 2) another TMM in a naturally aspirated shield with a small fan attached, and 3) an HMP35C and TMM both mounted together in one naturally aspirated shield. At the 9 m level

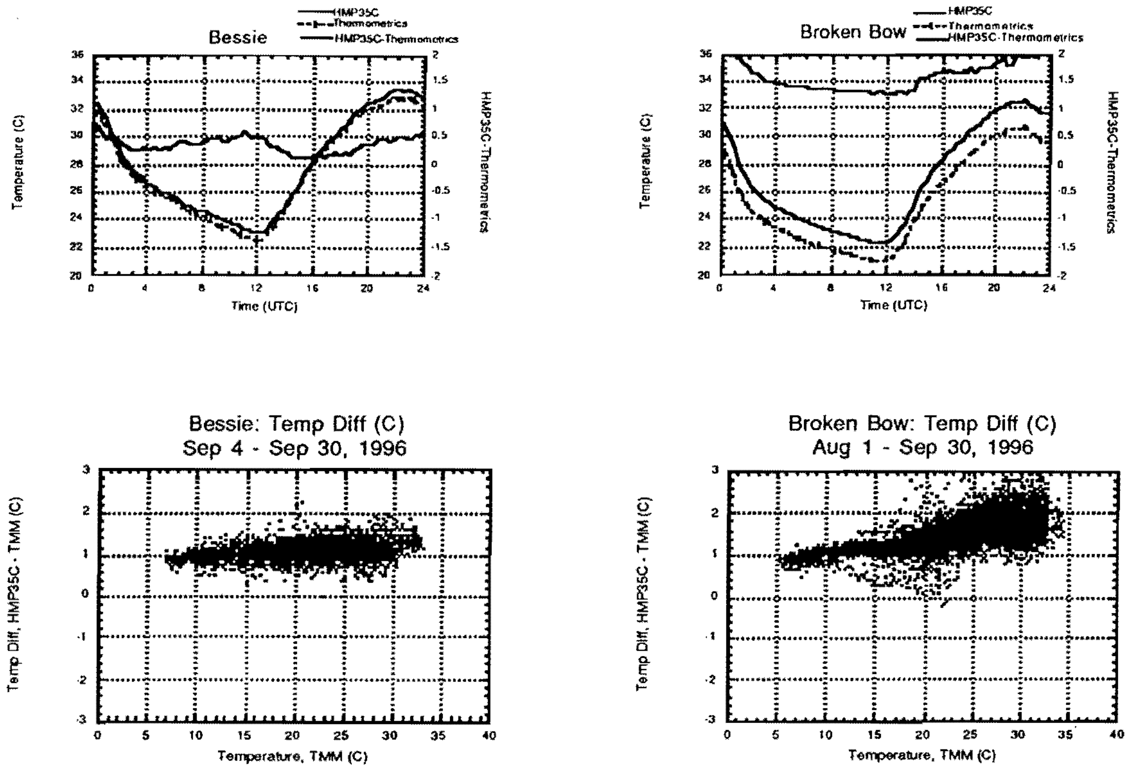

Figure 2: Temperature measured using the HMP35C and Thermometrics (TMM) at 1.5 m.
a) (Top): The difference between the HMP35C and TMM as a function of time of day.
b) (Bottom): The difference between the HMP35C and TMM as a function of air temperature (as measured by the TMM).

there two sensors and two shields: 1) one TMM in another fan-asprirated shield and 2) one TMM in a naturally aspirated shield.

Results from this test indicated that sensible heat flux measurements could be estimated under certain conditions. The shield with the HMP35C and TMM together indicatedthere was a slight difference between the two due to solar radiation. Although not large, this difference plus the inclusion of the time constant difference was enough to preclude using the standard Mesonet site configuration of only the TMM at 9 m and the HMP35C at 1.5 m. However, the naturally aspirated but matched TMMs at 9 m and 1.5 m did work well enough to measure useful vertical gradients in temperature. This arrangement (adding a second naturally aspirated TMM at the 1.5 m level) was thus implemented at 9 Mesonet sites across Oklahoma in roughly 9 different climate regions. (Figure 1). Calibrated and well matched TMM pairs were then used at these two levels.

4. NATURE OF PROBLEM

In evaluating the sensible heat flux estimation data from the 9 m and 1.5 m TMM sensors an unexpected problem was discovered. When incidently comparing the TMM and HMP35C at the same 1.5 m level, there seemed to be a much larger than expected (and variable) temperature difference at some sites, seemingly related to solar radiation (Figure 2a). Replotting these differences as a function of air temperature (from either of the two probes) instead of time of day, a different pattern appeared. We found a persistent 0.5 to nearly 2°C temperature difference between the TMM and the HMP35C at the 1.5 m level at 8 out of 9 sites (Figure 2b). These were much larger differences than had been previously observed with HMP35Cs based upon historical on-site intercomparisons and realtime QA spacial analysis routines. And this difference appeared to be a function of temperature; not of solar radiation nor wind speed

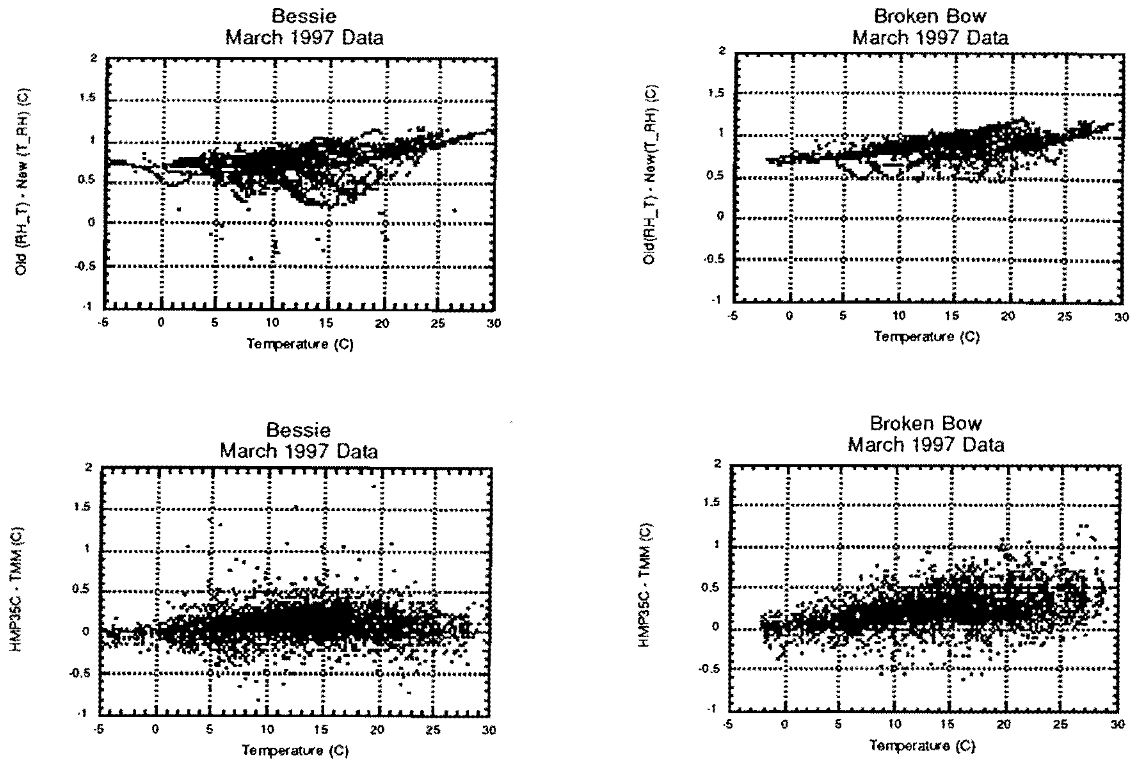

Figure 3: a) (Top): The temperature difference between the old (RH_T) and new (T_RH) methods of measuring the HMP35C air temperature.

b) (Bottom): The improved temperature difference between the HMP35C (T_RH) and TMM as a function of air temperature.

as first expected. This was symptomatic of a severe sensor calibration problem. Additionally, the indication of problems at 8 out of 9 sites did not speak well of what we might find at the remaining 105 Mesonet sites.

As the TMM sensors had only recently been calibrated and installed, we removed the HMP35C T/RH sensors at several sites and brought them in for calibration checks. These sensors had had site residence times of about a year. Previous "postcalibrations" of other HMP35Cs showed temperature problems to be rare. More puzzling, these units just brought in also tested as being well within temperature specifications (certainly no where near 0.5 to 2°C). Reference temperature sensors were rechecked. Calibration records were reviewed and the possibility eliminated that some procedure or hardware was changed. Data loggers used in the calibration laboratory, at the field sites and in the intercomparison kits were the same type.

A further study involved placing the program instruction sampling of the temperaturesensor at different locations in the "flow" of logger program code. Under certain circumstances it is always possible that some sensors can interfere with others. In this case we found that the HMP35C temperature could be sampled at any point in the program without error with but one exception. Sampling the temperature sensor immediately after the RH sensor produced apparent temperature errors of 0.5 to 1.5°C. For our HMP35C calibration process temperature was always sampled before RH. All on-site programs and intercomparison test kits, however, sampled RH before T. In the program sequence for sampling the sensors, the following occurred. The RH sensor was sampled by first instructing it to be powered on, making the RH measurement, then powering it off. The next logger instruction sampled the temperature. Not realized by us, the RH supply voltage had a fall time long enough to still be significantly present when the logger started this next instruction. The temperature sensor, then, was being sampled too soon and thus had an extraneous signal superimposed on it. By some twist of fate, somewhere early in the design of the Mesonet when parameters were listed to be measured, someone wrote "RH, temperature, ...etc" instead of "Temperature, RH...etc".

We attempted to quantify the extent of the problem, both in magnitude (°C) and extent (how many sites had this problem). At all Mesonet sites, program code was modified to sample the HMP35C temperature twice; once the "old" way, RH before T (RH_T), and then a second time later in the program code; the "new" way, T before RH (T_RH). Differences in temperature would then be solely a function of the datalogger software. Roughly 80% of the Mesonet sites had this problem to some degree, and errors were typically within the 0.5 to 1.5°C range. Although the error initially seemed to be only a function of temperature, it also appeared to be a function of several other variables that either were not deteminable or not measured. Plots of the difference between RH_T and T_RH are illustrated in Figure 3a. No correction to old data at this time is possible; the error seems to be unique to each probe/datalogger combination.

The solution to the problem, however, was simple; measure temperature first, then RH. Plots of current temperature differences between the two different sensors at the same 1.5 m level are shown in Figure 3b. Generally, the two probes are within 0.4°C of each other. Excursions from this range are due to radiation error and differences in sensor time constant.

5. CONCLUSION

How did we miss this problem? We took great care to require proof of sensor quality at many places along the way. We followed a concept of not believing the manufacturer's claims of quality unless we could verify it ourselves. To do this we designed calibration laboratory tests to check as much of the sensor's characteristics as possible. We did "pre-deployment" calibration checks before the instruments went to the field and "post-field" calibrations when they came back.

We also did periodic on-site intercomparisons with like-sensors and site-similar software. By doing this we reasoned that any differences between sensors were due to site-specific sensor or exposure problems. This should have been a sufficiently adequate test. A better approach would have been to use a third "type" sensor in our intercomparisons, accomplishing two things. First we would have noticed a difference between the site-similar temperature sensors with their algorithm and the other type temperature sensor with its different algorithm and programming code. Second, we would avoid a dilemma found with some intercomparisons. That is, if a difference is detected between two sensors, it is not always a certainty which one might be bad. We have encountered occasions where the field reference has failed and good site sensors were replaced.

We followed a procedure of periodically rotating field sensors back to the calibration laboratory. We felt this helped catch any unusual wear or signs of drift before they became failures. Unfortunately for our temperature sensors, the calibration software was slightly different from the field software and allowed a problem to slip through undetected.

We developed an extensive set of mainframe computer based QA programs. These routines have detected a great many sensor problems that were corrected in a very short period of time. However, their sensitivity threshold was high enough that there were still a number of field problems of a low level or spacial nature that could slip through. But the nature of meteorological data is that there will probably always be some catagories of problems that will always elude detection.

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