Calibration of Temperature Sensors in Preparation for the 2017 Total Solar Eclipse

Erick Agrimson, Kaye Smith, Rachel DuBose, Vina Onyongo-Robshaw, Ana Taylor, Alynie Walter, Peace Sinyigaya, Grace Maki, Rachel Lang | Department of Physics, St. Catherine University, St. Paul, MN 55105

Brittany Craig | General Dynamics, Bloomington, MN 55341

Gordon McIntosh | Division of Science and Mathematics, University of Minnesota, Morris, MN, 56267

James Flaten | Department of Aerospace Engineering and Mechanics, University of Minnesota, Minneapolis, MN 55455

Abstract

In preparation for the 2017 total solar eclipse, St. Catherine University developed a calibration protocol for the temperature sensors flown during thermal wake boom experiments. The calibration method used a standard two-point technique that corrected each individual sensor for both slope and offset errors using a high quality NIST certified thermocouple as the temperature standard. Our method is not absolute but corrects each sensor relative to the NIST standard so that we feel some confidence that individual sensor variations are mitigated. In preparation for the eclipse, calibration curves were generated for over 200 individual digital and thermistor temperature sensors.

Background

The sensors used in this process are digital Dallas DS18B20 temperature sensors. Each sensor is manufactured with a unique 64-bit serial code address allowing for multiple sensors to be arranged in a 1-wire multi-bus configuration. The GT probes used are NIST certified thermocouples. The Dallas sensors are calibrated against the GT probes, which serve as the gold standard for all calibration work. An Arduino Mega is used in conjunction with the Dallas sensors. The code utilized generates a record on an SD card which includes a timestamp along with the temperature of the particular sensor queried.

Sensors	Accuracy	Range
GT-1	± 0.1º C at 0º C to 50º C	- 200º C to 200º C
DS18B20	± 0.5º C at - 10º C to 85 ºC	- 55º C to 85º C

1. GT probes next to meter stick

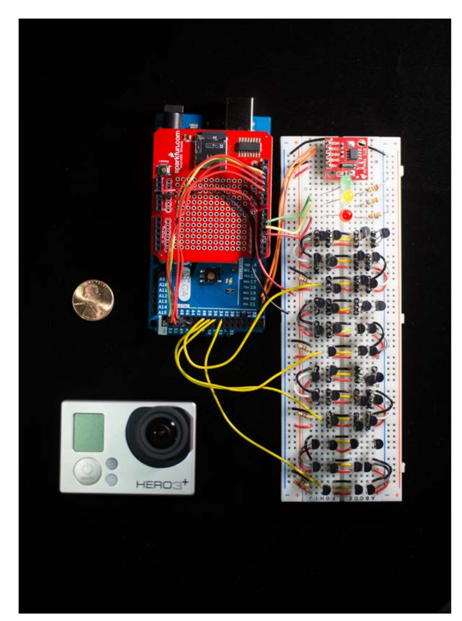
Motivation

St. Catherine University began measuring the thermal wake of ascending HABs in 2011 – see (Ref 1-3). Early in the process HOBO thermistors were primarily used. As we needed to fly more and more sensors but keep the weight down, we moved to using Dallas 18B20 digital sensors as they work using one-wire technology, meaning many sensors may be read using one input/output port.

The manufacturer accuracy of these sensors is listed as ±0.5º C but at low temperatures and pressures we were seeing much larger sensor-to-sensor variability. Because of this, we started to calibrate each sensor used utilizing our low pressure and temperature chamber. Through this calibration process, we mitigate sensor-to-sensor variability and increase confidence in the accuracy and precision of our temperature measurements – see Ref 4.

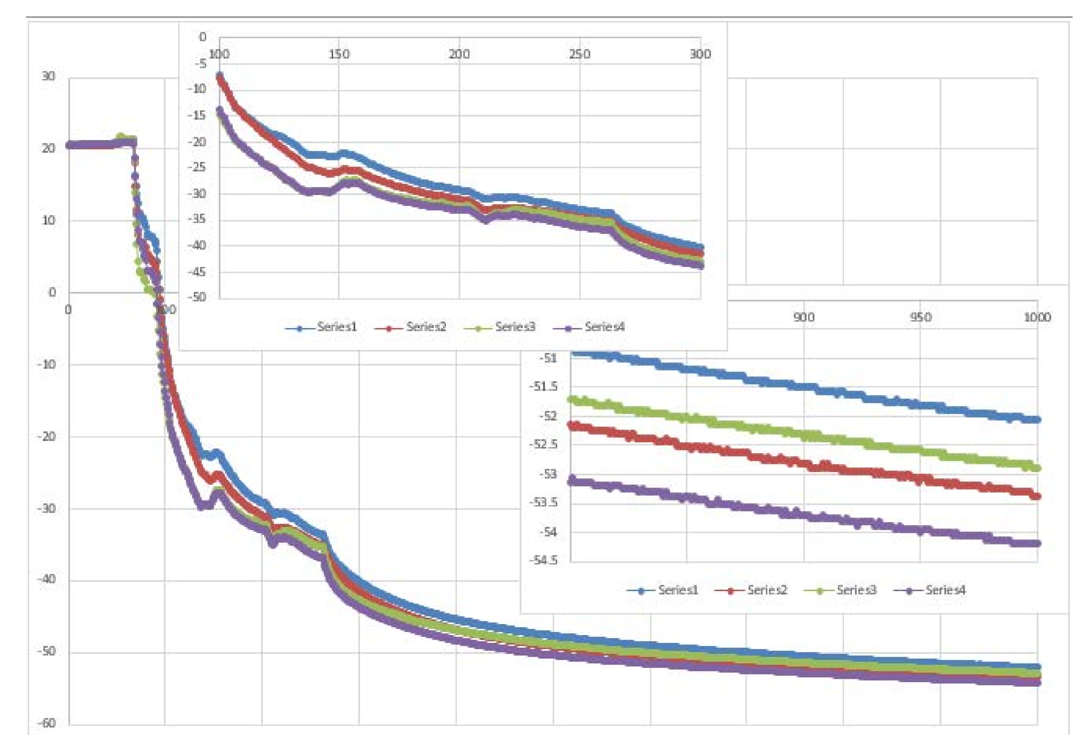
Methodology and Equipment

It was essential that the sensors be ordered sequentially before calibration because each sensor was manufactured with a unique address. The sensors were placed on a bus in sequence from smallest to largest registration number. Once the sensors had been ordered, they were connected to an Arduino Mega fitted with an SD shield which recorded data. To perform the calibrations, the Dallas temperature sensors and GT probes were put through four tests. The tests being room temperature room pressure (RTRP), low temperature room pressure (LTRP), low temperature low pressure (LTLP) room temperature low pressure (PRLP). At low temperatures we used dry ice which allowed us to obtain temperatures as low as - 54º C. To obtain a vacuum we used a rough pump which pulled pressure down to fractions of an atmosphere. As indicated in Fig. 4 the temperature profile levels off near - 55º C which indicated that we had reached near equilibrium conditions.



2. Arrangement of sensors in breadboard in preparation for calibration.

3. Cold soak and vacuum chamber used to calibrate sensors.



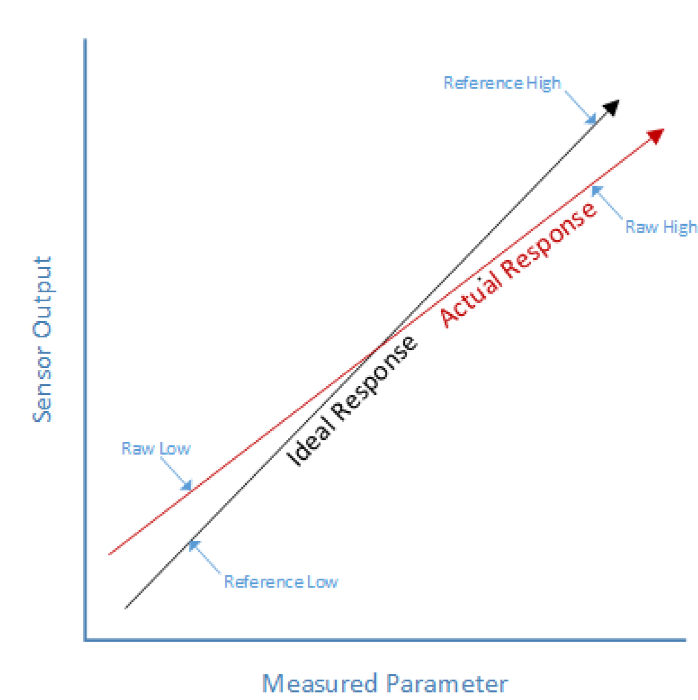
4. The graph is of four temperature sensors as they cool to equilibrium in the pressure chamber. Once they reach equilibrium, bottom right, you can see that they are reading very similarly, but are offset from each other. The offset can be corrected with a one-point calibration, but data from before equilibrium, top left, shows that the slopes of the lines sometimes crossed, indicating that we needed to correct for not only an offset, but also a slope difference. This is why the two-point calibration is ideal.

Two-Point Calibration

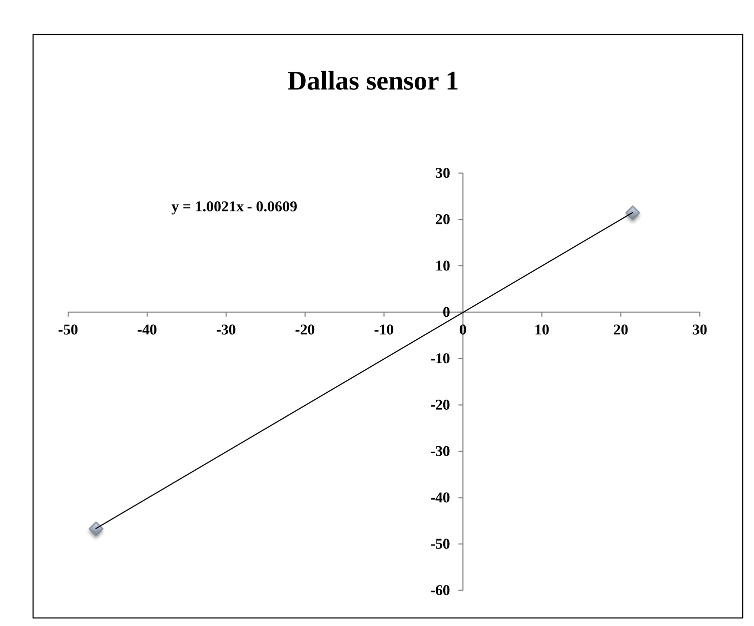
Once the four data points were collected for each sensor, the near equilibrium temperature conditions were averaged and used as data points for calibration curves. For each individual sensor, a calibration curve was made using GT probe data as the input, and Dallas sensors temperatures as the output. A calibration equation was then extrapolated from the curve and used as the correction factor for all temperature collected by that unique sensor.

The DS18B20 reads with an accuracy of ±0.5º C from - 10º C to + 85º C and ±2º C accuracy from - 55º C to + 125º C … see Ref 5.

- Each Dallas sensor produced a slightly different calibration curve: thus the need for calibration corrections.
- It was assumed that GT probes produce the ideal response because they are high resolution and NIST certified – making them ideal for use as a control.



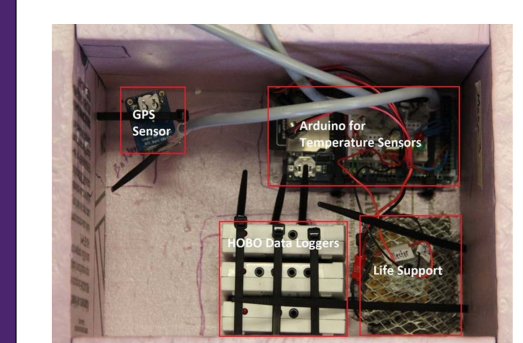
5. Two point calibration – see Ref 6



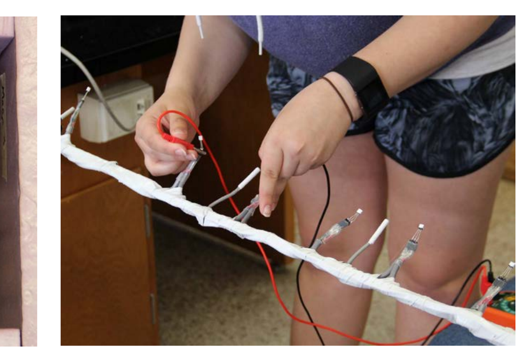
6. Two point calibration curve for Dallas sensor number one.

Implementation

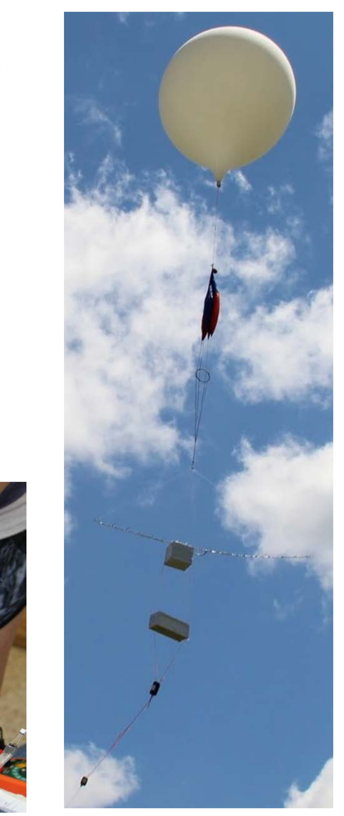
The Dallas sensors were flown on a 10ft wake boom with 22 sensors total on a single 1-D wake arm. Prior to a flight, the sensors were painted with a light coat of whiteout and the wires that run the length of the wake arms were wrapped using white tape. The white color helps reduce heating due to absorption of thermal energy. The Dallas sensors were used in conjunction with Onset corporation thermistor sensors.



7. Picture of payload box with components.



8. Checking continuity of installed sensors on wake arm bus.



9. Wake boom in flight on balloon stack.

Future Steps

To improve the accuracy of calibrated data, future efforts will focus on:

- Multi-variable calibration curves
- Calibration curves using more than two points
- Executing advances in machine learning to find trends and patterns in the calibration data

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