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Tornado Probe Deployments into Tornado Vortices by Drones

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Abstract
The purpose of our research project, TILTTING, is to further understand why tornadoes only develop in specific environments and under certain circumstances. Inspired by the tornado research studies conducted by Dr. Wurman and his VORTEX teams (Cobb, n.d.), Dr. Timmer and his private research team (Timmer et al, 2022) along with Tim Samaras and his TWISTEX crew (Samaras, 2004), Project TILTTING sets out to travel to and from the Great Plains and the Northeast regions of the United States to gather data from in and around tornadoes, investigating parameters and environmental conditions through our own measurements and data collection. Our first approach to observe these environmental parameters is using our own prototyped tornado probes, called the TILTTING-23 probes. To test this instrumentation, two tests were conducted to observe its representativeness. After observing the results from both tests, significant differences in biases were found in the data sets.

Introduction

Undergraduate students at Millersville University created the tornado research project, the Thermodynamic Investigation of LCL Thresholds during Tornadogenesis and its Influence in the Northeast and Great Plains regions (TILTTING). TILTTING sets out to gather data from severe thunderstorm setups, specifically from tornado cores and their surrounding thunderstorm environments, in efforts to improve severe weather forecasting and help save lives and property. Among the instrumentation used in this project is the TILTTING-23 Probe, a prototype designed by one of the students' authors. To ensure dependability and accuracy of the probes, the students performed multiple tests that examine intercomparisons of three parameters: temperature, humidity, and pressure. These observations from the Probe will be tested against other reference instruments and review each parameter's static characteristics. While conducting these tests, the authors consider the following research questions: What kind of biases might exist between the sensors? How reproducible are the measurements? Does the TILTTING-23 Probe have adequate and accurate representativeness of boundary layer phenomenon?

Probe Testing

The TILTTING-23 Tornado Probe features the MKR Zero microcontroller board from Arduino, along with high-resolution precision sensors that gather temperature, pressure, relative humidity, wind speed and direction (see Figure 1.1). The importance of measuring temperature and humidity with the probe is to examine any perturbations that could help us to make conclusions in our research. To determine this instrument's capabilities and representativeness of its environment, two tests were conducted to measure the accuracy and potential biases the instrument may have. If the testing reveals biases, then either bias correction or calibration should be implemented. Our first test was the use of a kite, graciously provided by NASA's AEROKATS program, to evaluate the temperature and relative humidity measurements.

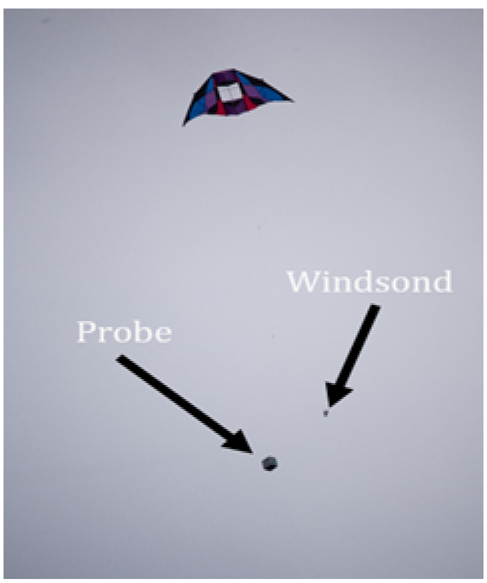


Figure 1.2 - The TILTTING-23 Probe and a Windsond are used during the kite flight, observing temperature and relative humidity profiles.

With the Windsond serving as the reference instrument, a Windsond and a TILTTING-23 Probe were used for the kite test on November 16, 2022, starting at 20:26 UTC and ending at 21:20 UTC that same day. About an hour's worth of data was observed for analysis.

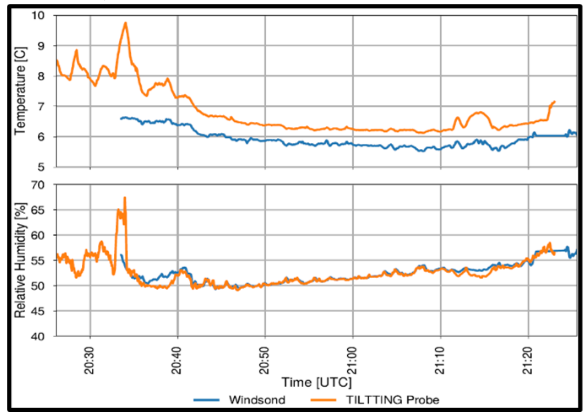


Figure 1.5a - Depicted above is a graphical representation of the biases that exist between the Probe and Windsond's sensors.

Probe vs Windsond Kite Data

Using Bias/MAE equation

$$\bar{\varepsilon} = \frac{1}{N}\sum_{i=1}^{N} \varepsilon_i$$

Temperature Bias:	*0.79°C*
RH Bias:	*0.78%*

Figure 1.5b- Biases from the kite flight are expressed here, values are showing to be.

Results of Kite Test

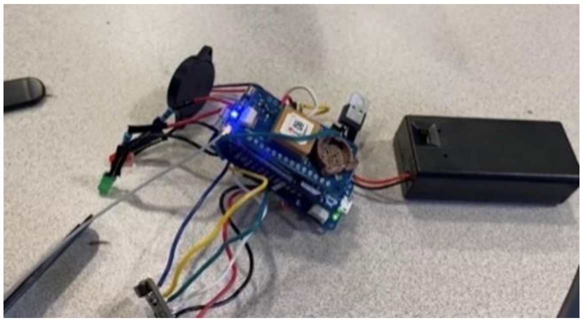


Figure 1.1 - The TILTTING-23 Probe in its wired construct before PCB development.

Depicted in Figures 1.5a and 1.5b, the results of the kite test identified low biases, which is ideal for meteorological research. Figure 1.5a shows the deviation of observations to be very small between the Probe and the Windsond. Figure 1.5b shows the Mean Absolute Error (MAE) calculations used to find the biases of the measurements. The temperature bias between the Windsond and the Probe show to be about 0.79 °C while the relative humidity bias shows to be about 0.78% above the expected value. With these results considered, due to its close to zero bias, the Probe showed to be representative of its environment and can be used for tornado vortex deployments.

Results of Static Test

Our second test involved the same instrumentation, the Windsond and TILTTING-23 Probe, to gather temperature and relative humidity observations in a static environment without wind consideration.

Figure 1.6- The TILTTING-23 Probe (far right) and a Windsond (far left) are used during the static test, observing temperature and relative humidity profiles outdoors and indoors.

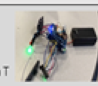
INSTRUMENT	WEIGHT (g)	VARIABLES	SAMPLING ACCURACY/RATE (PER DOCUMENTATION) AND PICTURE
Kestrel 5200 Meter	121	T, P, RH, Dewpt T, Wind Speed	T: ±0.5°C P: ±1.5 hPa RH: ±2% Dewpt T: ±1.9°C Wind Speed: ±0.1 m/s Rate: 1 sec 
Windsond	12	T, P, RH, Dewpt T, Wind Speed, Wind Direction	T: ±0.2°C P: ±1 hPa RH: ±1.8% Dewpt T: (depends on T and RH readings) Wind Speed: ca 5% m/s Wind Direction: (depending on GPS coordinates) Rate: 6 sec 
TILTTING-23 Probe (pre-PCB form)	210 (with casing)	T, P, RH, Dewpt T, Wind Speed, Wind Direction	T: ±0.5°C P: ±1.7 hPa RH: ±3% Dewpt T: depends on T and RH readings) Wind Speed: ±0.05 m/s* Wind Direction: ±0.3°* Rate: 1 sec  *Based off of the SAM-M8Q GPS module from the Arduino MKR GPS Shield

Figure 1.4- For reference purposes, this displays and lists the meteorological instrumentation, also used as reference instruments, to be used for TILTTING. The names, weight, measured variables, and sampling accuracies/rates are included with a picture of their respective instrument.

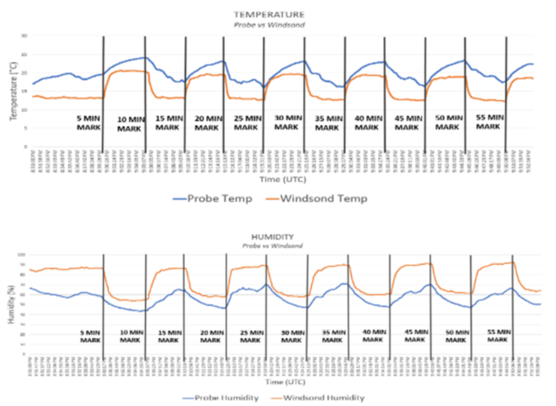


Figure 1.7a- This chart displays the acquired data during the static test. This also shows the biases between the data.

During data analysis, calculations, and visualization of our data, the static test showed staggering results. Figure 1.7a highlights the visual representation of the acquired observations and Figure 1.7b shows the numerical results after using the MAE equation. The temperature bias between the Windsond and the Probe show to be about 4.17 °C while the relative humidity bias shows to be about 18.21% above the expected value. With only these results considered, we can conclude that the Probe demonstrates the need for bias correction or calibration before being used for research purposes. It is uncertain what may have caused the biases to be greater in the static test compared to the kite test, but a hypothesis has been made that the insulation box surrounding the TILTTING-23 Probe (Figure 1.6) may have influenced this drastic difference. The Probe's BME280 sensor is found to be on the side of the insulation box. As the Probe is doing work inside of the insulation box, it creates heat, which is then developed and trapped inside of the insulation box. The insulation box may be absorbing the heat from the Probe and emitting some of that heat outside of the box, causing the BME280 sensor to pick up the increase of temperatures. Contributing to the biases in the second test could also be that because there is no wind involved with the static test, the warmer air molecules emitting from the box are not being blown away. The kite test had a constant 10 knot (7-10 mph) wind involved during the experiment, in this case the warmer air molecules were being blown away from the insulation box, causing the Probe's BME280 to not record the warmer air molecules and report a lower temperature bias. The findings prompt the next question to be explored further: Is the TILTTING-23 Probe's sensor wind dependent?

Probe vs Windsond Static Test Data

Using Bias/MAE equation

$$\bar{\varepsilon} = \frac{1}{N}\sum_{i=1}^{N} \varepsilon_i$$

Temperature Bias:	*4.17°C*
RH Bias:	*18.21%*

Figure 1.7b- Biases from the static test are expressed here, values are showing to be drastically different from the kite flight.

Conclusions

Significant variability in the temperature and humidity biases are present in our tests. Two options we can pursue to correct these differences in bias are 1) hard code the Probe to have adjusted bias corrections to the temperature and relative humidity lines of code and 2) implement two different sensors that are designed to measure both properties separately. As stated, a second version of the probe is undergoing its research and development (R&D) phase. Part of this phase was observing the results from this experiment.

Figure 1.3- The location of the kite flight is shown in an open field, ideal for an observation kite experiment.

Future Work

Testing will take place to see if the accuracy of the BME280 sensor on the Probe is wind dependent, along with new sensors that will be integrated to measure temperature and humidity. The Probe will be customized to a printed circuit board (PCB) because the current wired connections are problematic when deployed into the core of a tornado vortex. The LTE/GNSS BG95 Shield, which supports cellular communication/technology, will be switched out for radio link technology because cellular connection/connectivity was interrupted at around 2,000-2,500 feet during a previous balloon test in 2022. The Probe's battery package will be reduced to allow for lightweight operation, as well as making the probe more power efficient.

Acknowledgements

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Please visit www.tiltting.com for a list of our sponsors and supporters. The kite equipment was provided by the NASA AEROKATS program and ROVER Education Network (AREN).

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