TILTTING 2024
Tornado Research Proposal

Title

TILTTING (**T**hermodynamic **I**nvestigation into **L**CL **T**hresholds during **T**ornado-genesis and its **I**nfluence in the **N**ortheast and **G**reat Plains)

Abstract

Each year, tornadoes are one of the leading, weather-related phenomena responsible for loss of life and property in the United States (Fricker and Friesenhahn 2021). Although tornado lead times have increased in recent years, research shows that tornadogenesis, along with track and intensity, remains a primary forecasting challenge (Brotzge & Donner 2013). A better understanding of how various lifting mechanisms impact the Lifting Condensation Level (LCL) height at tornadogenesis will help mitigate these challenges. This proposed research project will investigate differences in height threshold of the LCL at tornadogenesis between the Great Plains and Northeast through observations of shear, lift, instability, and moisture (SLIM) parameters.

Historical Background

After chasing the EF-3 Mullica Hill, NJ tornado in September 2021, a group of students from Millersville University decided to study, investigate, and observe possible atmospheric differences between tornadoes in the Great Plains and those in the Northeastern United States. To study these potential differences, specific instrumentation will be designed and developed to withstand the force of tornadic winds. We have built an instrumentation probe that will be sent into the core of a tornado. The idea was inspired by the scientific research done by Dr. Josh Wurman and the VORTEX research teams (Cobb, n.d.), Dr. Reed Timmer and his Team Dominator research group (Timmer et al., 2022), as well as Tim Samaras and his TWISTEX crew (Samaras 2004). These previous studies have greatly improved tornado forecasting and lead times, resulting in protecting and saving more lives and property (Dowell, Romine, Snyder 2010)(Supinie et al. 2016). However, research specific to LCL height threshold at tornadogenesis remains sparse (Brown and Nowotarski 2019), thus this study will focus on this component.

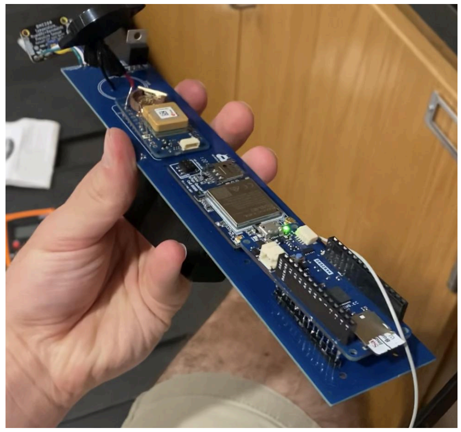
Technical Description

The purpose of this research project is to further understand why tornadoes only develop in specific environments and under which certain circumstances. Tornadogenesis is especially dependent on several parameters and factors, all of which are equally important in tornado formation within mesocyclones. Without these parameters, tornado formation is unlikely – owing to the fact that well below half of all mesocyclones actually produce a tornado (Trapp et. al. 2005). Among these parameters is the Lifting Condensation Level (LCL). The Rasmussen and Blanchard (1998) climatology investigating the 1992 tornado season found LCLs on past tornado soundings to be significantly lower than that of typical mesocyclones/supercells without tornado formation due to weaker potential outflows from rain-cooled air. This creates less opportunity for vertical vorticity and localized cyclone rotation to be undercut and dissipated (Rasmussen and Blanchard 1998; Brown and Nowotarski 2019). Davies (2006)[1] found that tornadoes typically form in environments of high shear and low LCLs (<1300 m above ground). Out of 44 tornadoes sampled in the study, no significant tornadoes developed when LCL heights were greater than 2000 meters.

Despite there being ample knowledge of the importance of lower LCLs within mesocyclones that lead to tornadogenesis, not all tornadoes tend to form in this specified manner; tornadoes do not require low LCL heights to develop (Davies 2006)[2]. Regional and seasonal variations are also found when studying the differences in LCLs and tornado formation, specifically across the Great Plains and Southeastern United States (Grams et al. 2012). However, research from numerous tornado outbreaks and events is most typically conducted in these regions of the United States. Grams et al. (2012) highlights these regions of the country, dismissing tornadoes that may have formed in the Mid-Atlantic or Northeastern parts of the country. Therefore, tornadogenesis research across these regions of the United States is less common and an area that requires further investigation.

Two technical barriers that we will encounter will be the high degree of unpredictability of these events and limited opportunities to intercept a tornado. Even if numerical model guidance suggests that environmental factors will be favorable for tornado development, there is always a chance that severe convective initiation fails (Markowski et al. 2006). In addition, tornadoes are generally between 300 and 500 yards in diameter and travel at an average speed of 10-20 mph (NSSL, n.d.), making a successful intercept challenging. To mitigate these challenges, our team will consist of eight members with an extensive background in operational forecasting, including a Millersville University faculty member who has been in the field for 12 years and has over five years of operational forecasting experience. Each member will be observing the surrounding area of our target location in order to understand the complexities of the synoptic and mesoscale environments. In addition, we will be utilizing dual-pol Doppler radar products and use GR2Analyst viewing and analysis tools for a three-dimensional view of convective initiation and updraft rotation. The details of the experimental design will be discussed in the next section.

Statement of Work (or Technical Approach)



To investigate the desired parameters and environmental conditions through our own measurements and data collection, we will travel to and gather data from tornadoes in the Great Plains. We have built our own prototype, the TILTTING-23 Tornado Probes, to collect data described hereafter. 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. To collect temperature, pressure, and relative humidity, we have incorporated the BME280 sensor from Bosch Technologies. The BME280 features a ±3% accuracy for humidity measurements, ±1 hPa for barometric pressure readings, and ±1 degree Celsius for temperature readings (Ada, 2015). The probe will also feature the MKR GPS Shield, powered by the SAM-M8Q GPS module from ublox. This will have three-dimensional axes of position, offering the ability to gather wind speed, wind direction, and altitude based on the probe's coordinates. The GPS shield offers a horizontal position accuracy of ±2.5 meters, a heading accuracy of ±0.3 degrees, and a velocity accuracy of ±0.05 meters per second (Ublox, 2019). An 8GB SD card will be included onboard the probe to print and store hard copies of data retrieved within the tornado. In addition, the Arduino MKR Compatible LTE/GNSS BG95 Shield (iot-bots.com, 2021), which will transmit data wirelessly from the probe to a receiver for convenient data and status monitoring from the vehicles. The probe will also feature two status LEDs, as well as a piezo transducer that will emit simultaneous, one-second interval beeps used for probe retrievals.

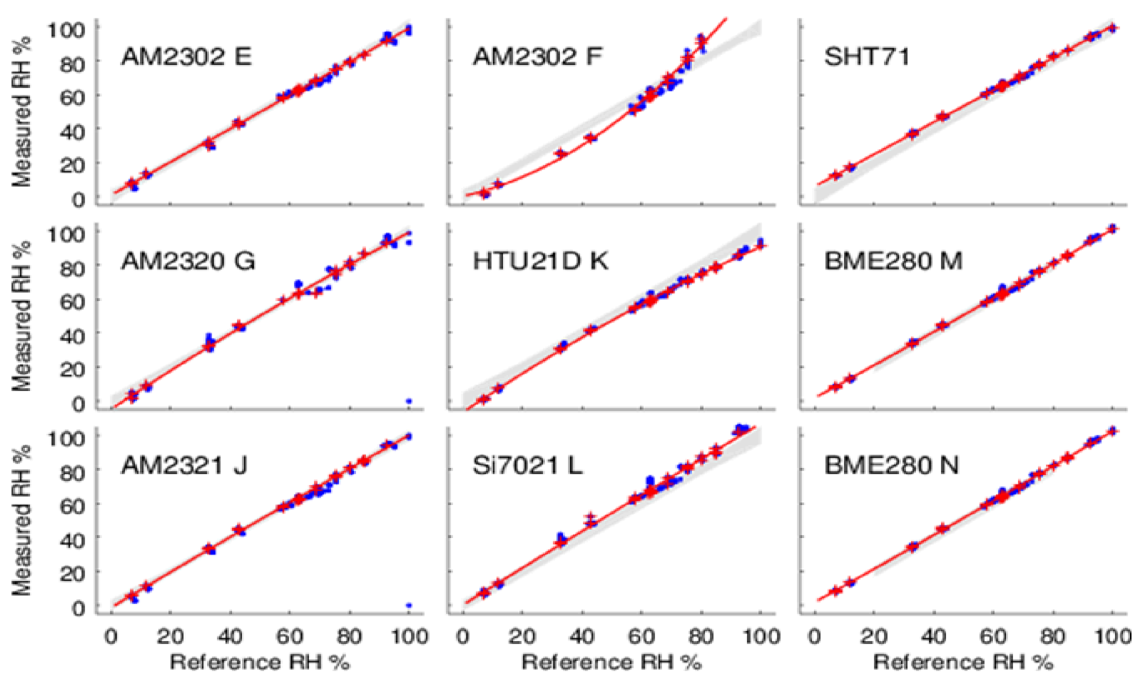
To show the accuracy of each sensor for the probe, we found datasheets of experiments done, relating the accuracy, tolerances, voltages, and operating ranges between the BME280, and several other sensors. The report was conducted and written by Robert Smith, and he goes on to show his investigations and results.

Manufacturers' Specification						
	AM2302	AM2320/AM2321	SHT71	HTU21D	Si7021	BME280
Operating Range	0–100	0–100	0–100	0–100	0–100	0–100
Absolute accuracy (%RH, 25ºC)	±3% (10-90%) ±5% (<10, >90%)	±3% (10-90%) ±5% (<10, >90%)	±3% (20-80%) ±5% (<20, >80%)	±3% (20-80%) ±5% (<20, >80%)	±3% (0-80%) ±5% (>80%)	±3% (20-80%)
Repeatability (%)	±0.3	±0.1	±0.1	-	±0.025	-
Long term stability (% per year)	0.5	0.5	0.5	0.5	0.25	0.5
1/e Response (sec)	5	5	8	5	18 (with cover) 17 (without)	1
Voltage supply (V)	3.3–5.5	3.1–5.5(AM2320) 2.6–5.5(AM2321)	2.4–5.5	1.5–3.6	1.9–3.6	1.71–3.6

"The table lists values taken from datasheets. The Aosong data sheets do not specify maximum tolerances for most parameters, just 'typical' values. It would therefore seem that any particular device is not guaranteed to meet these specifications. For all the other devices the numbers above are the maximum tolerances and most also offer better 'typical' specifications" (Smith, 2018).

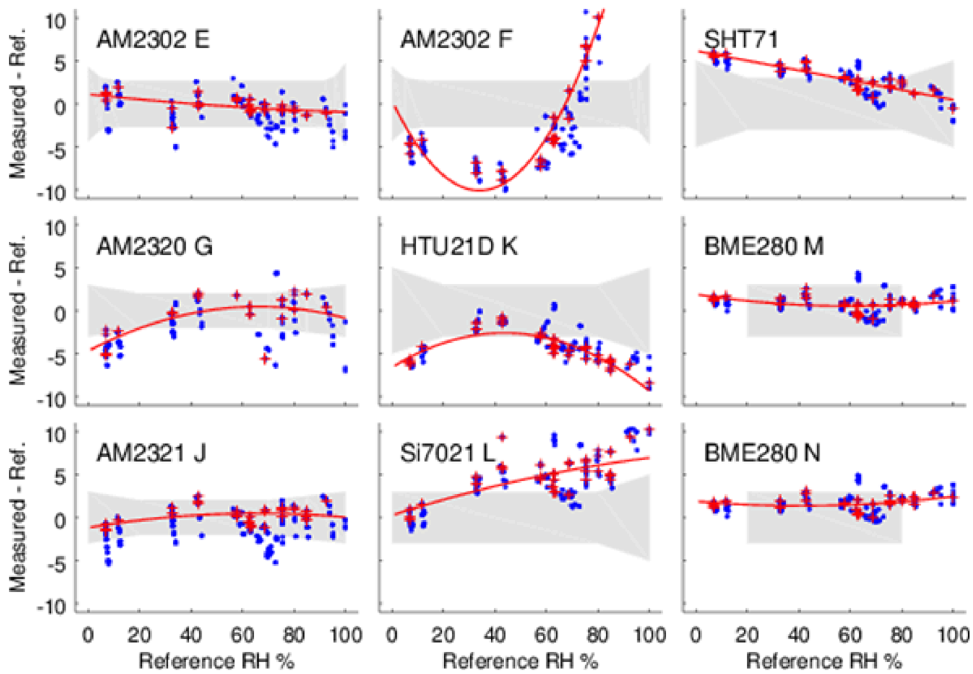
Smith makes a note in his report that he will only be observing the temperature and humidity values for his experiment (Smith, 2018).

To begin, Smith plots his data as a function of humidity with his humidity measurement comparisons (Smith, 2018). You can clearly see the variation of data input and results from other sensors compared to the BME280. The other readings are inaccurate according to the actual humidity measurement in the following figure:



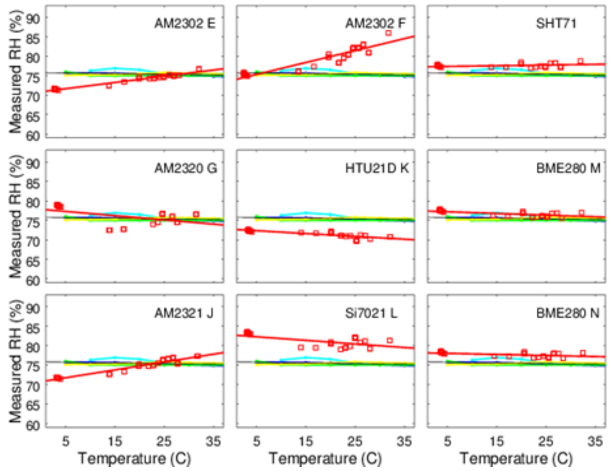
“Plots of the humidity values from each sensor plotted against the expected humidity for each reference solution. The shaded gray region is the specified tolerance from the manufactuers' data sheets. All data collected, irrespective of temperature, are shown as blue dots. Red crosses are just those data obtained at 25±1°C, so any that lie outside the shaded region fail to meet the specification” (Smith, 2018).

The next figure shows the same data set but also shows the deviations from a perfect calibration (Smith, 2018).

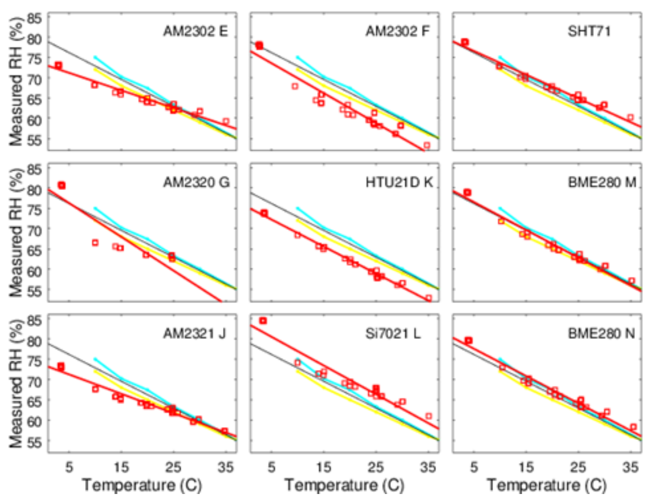


“Plots showing the deviation of humidity values from the known reference value. These plots show the error of each sensor as a function of humidity. The shaded gray region is the specified tolerance from the manufacturers' data sheets. All data collected, irrespective of temperature, are shown as blue dots. Red crosses are just those obtained at 25±1°C, so any that lie above or below the shaded region fail to meet the advertised specification. Where blue dots scatter outside the shaded region it indicates a drift in the calibration as a function of temperature. Red lines are quadratic fits to the 25±1°C data.” (Smith, 2018).

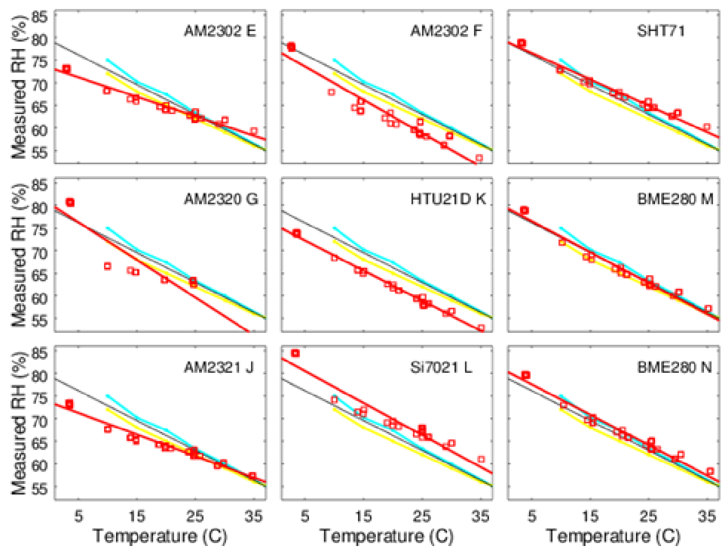
Next, Smith begins his investigation into the temperature readings of each sensor by plotting his data as a function of temperature now (Smith, 2018). Although now, his method of approach for measuring the temperature values of each sensor is by using three chemical compounds: Sodium chloride, Ammonium nitrate, and Magnesium chloride (Smith, 2018). See the following figures for his data sets:



“Shown as red boxes and a linear fit are measurements for all sensors with saturated **sodium chloride** over the temperature range 5–35°C. Plotted for comparison are values taken from the published literature. Blue data are from Greenspan (1977), cyan data from O'Brien (1948), green from Rockland (1960) and yellow, Wexler (1954). The thin black line is an ensemble fit to them all, weighting all equally” (Smith, 2018).

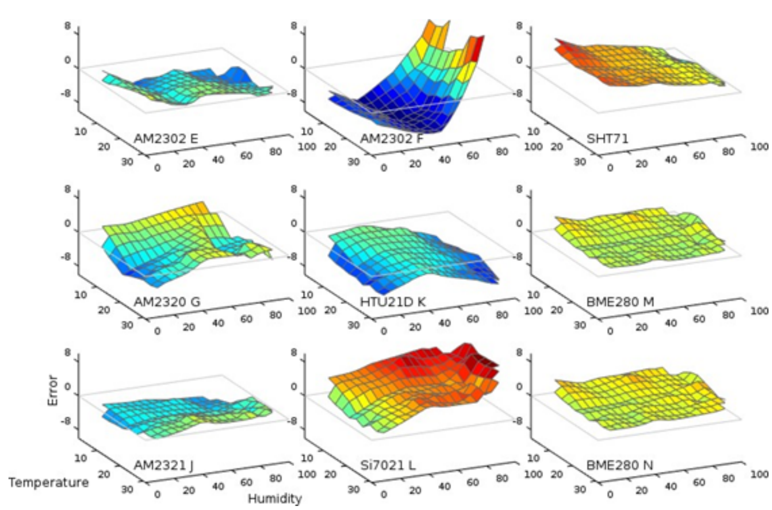


“Shown in red boxes and a linear fit line are measurements for all sensors with saturated **ammonium nitrate** over the temperature range 5– 35°C. Plotted for comparison are values taken from the published literature. Cyan data from O'Brien (1948) and yellow from Wexler (1954). The thin black line is an equally weighted fit to both.” (Smith, 2018).



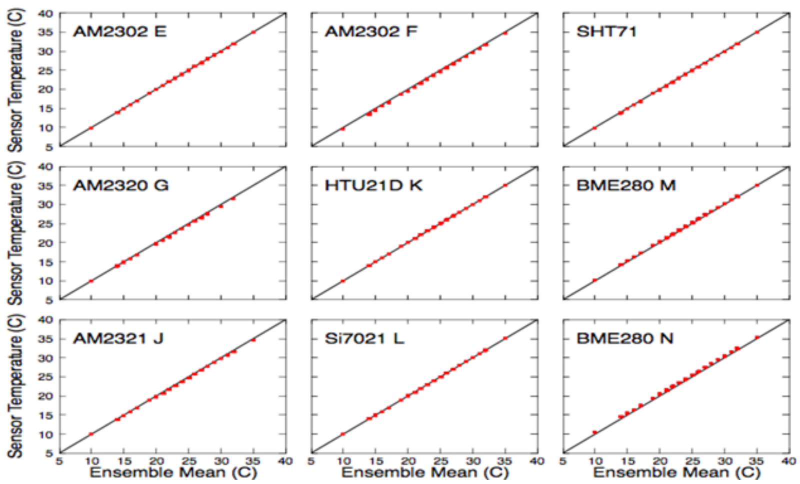
“Shown as red boxes and a linear fit are measurements for all sensors with saturated **magnesium chloride** over the temperature range 5–35°C. Plotted for comparison are values taken from the published literature. Blue data are from Greenspan (1977), cyan data from O'Brien (1948), green from Rockland (1960), magenta are the CRC Handbook (1977) and yellow, Wexler (1954). The thin black line is an ensemble fit to them all, weighting all equally...” (Smith, 2018).

Smith additionally points out the possibility of the sensor undergoing a test of measuring multiple values of humidity while also measuring varying temperatures at the same time (Smith, 2018). So, a full bivariate calibration is required for the sensor. In our case of building a tornado probe, what we understand so far about the nature of tornadoes is that their temperatures and humidity levels are constantly and rapidly changing, so our tornado probe will need to undergo the same calibration that Smith describes. He continues with conducting a test with all the sensors and observing their temperature outputs from 5 < °C < 35 (Smith, 2018).

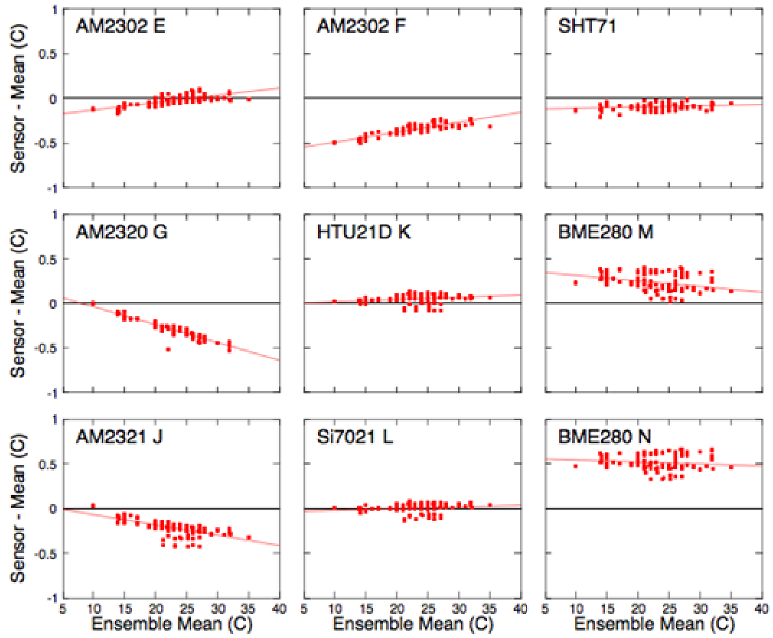


“It has been moved out into a separate document since rendering nine surfaces simultaneously proved an excessive load for some web browsers.] Surfaces showing deviation of each sensor from the true relative humidity as a function of temperature and humidity. A 'perfect' sensor would be a featureless green-yellow plane at zero. Blue shows low readings and red are high. The fits in Figure 4 are cross sections through these surfaces at T=25°C” (Smith, 2018).

Smith continues with another brief comparison of temperature in the next figure.



“Plots show temperature returned by each device compared to the average of all nine. The black line is just 'sensor ensemble mean' as a visual guide, not a fit” (Smith, 2018).



"Plots showing deviation of each device's own temperature from the average of all nine, plotted as a function of temperature" (Smith, 2018).

In another chart, Smith shows how the BME280's thermometer is slightly humidity sensitive, but not to the point where data is completely misconstrued and unrepresentative of the environment the sensor is placed in (Smith, 2018). Overall, Smith concludes that the best sensor out of the pool of sensors experimented on is in fact the BME280 (Smith, 2018). A contributor from Bosch added in a forum post about the measuring principle for it to report its surroundings. The Bosch Sensor Technologies contributor says the temperature sensor is diode voltage based, the pressure sensor is resistive, and the humidity sensor is capacitive (Bosch Sensor Technologies, 2019).

As we can see from reading the experimental charts from Robert Smith, as well as reading the information from the marketplace website publisher Lady Ada, it is a vital decision to choose the BME280 as the leading front of acquiring reliable and accurate data for tornado research (Smith, 2018; Ada, 2015).

The TILTTING-23 probe will be assisting us in answering a multitude of questions regarding the correlation between LCL height and parameters within the core of the tornado. What type of correlation is there in the data set when comparing temperature fluctuation, within the vortex tube, with LCL height? What correlation is there between dew point temperature and LCL height? What do the pressure perturbations look like within the tornado at certain LCL heights? To understand the purpose of the probe further, let there be an example data set of 200 tornadoes over the course of a few years. After conducting statistical analyses of those 200 tornadoes (including Gaussian/Poisson distributions), 40 of those tornadoes had LCL heights between 500 and 600 meters. The data set shows a 95% confidence of consistent correlation between air temperature, dew point temperature, pressure perturbations, and LCL height. After post-damage investigations made by the National Weather Service, those 40 tornadoes have been rated as EF-3 and EF-4 tornadoes. With those facts in mind, we can confidently conclude that tornadoes with LCL heights between 500 and 600 meters, with the measured perturbations, have a 50-55% chance of having EF-3 or EF-4 rated damage. How can meteorologists use this information further? When forecasters observe soundings, such as point-and-click products provided by Pivotal Weather, and see these similar parameters in the future, forecasters can confidently warn communities that there is a high potential for tornadoes to have EF-3 or even EF-4 damage associated with them. With this provided information, forecasters have the potential to evacuate heavily urbanized communities hours in advance.

The probe will be customized into a shape designed for airborne usage. The airborne probe is set to undergo its testing phase, which involves being fastened to a drone, called the TILTTING-23 drone, and flown at high speeds for data collection. The probe will be used to penetrate the core of the condensation funnel to record data within the suction vortex. Since the probe will be moving in LaGrangian with the tornado, the probe will have the capability of tracking tornado wind direction and speed using latitude and longitude. In order to maintain a safe distance while deploying our probe, there will be a secondary drone that will follow the TILTTING-23 drone to ensure it penetrates the tornado. FAA regulations mandate that drones cannot fly higher than 400 feet without clearance from an airport. To carry out the project's methodology and experimental design , the team will complete a Part 107 Operational Waiver Application. While conducting field research in the Great Plains, the DJI Phantom 4 drone should not have to observe the TILTTING-23 drone since the terrain is relatively flat. However, the drone will be used in tandem with the TILTTING-23 drone in the Northeast to mitigate the effects of complex terrain across the region, allowing us to see the TILTTING-23 drone's path into the tornado.

Aside from using our tornado probes, we will be utilizing the R.M. Young Wind Monitor system (Wind Monitor, n.d.), which will record and provide data on the conditions occurring outside of the vehicle. The Kestrel 5200 Weather Meter (Kestrel Meters, n.d.), a handheld anemometer that sends wind speed data directly to a smartphone, will be on-board the lead vehicle. The lead vehicle will get into position to launch the probe into the tornado, while the Kestrel Meter collects wind speed and direction data. The trailing secondary vehicle will be using the R.M. Young Wind Monitor system, which will be mounted on the roof of the secondary car and connected to a data logger. The secondary vehicle will be in a different location to observe wind speed and direction and compare it to the lead vehicle's data. Along with the probes and wind monitoring systems, we will utilize Windsonds, which are smaller versions of radiosondes. Data gathered by Windsonds will be used to plot a Skew-T Log-P diagram, which is a thermodynamic profile of upper-air observations (Blumberg et. al. 2017). This will allow us to calculate various thermodynamic parameters by using the Skew-T Log-P diagram, including height of the LCL. We will launch three Windsonds per tornadic event: one thirty-to-sixty minutes prior to the storm, one during the storm, and one thirty-to-sixty minutes after the storm. Thus, we will be able to obtain and analyze changes in thermodynamic parameters and LCL height. The balloons will be launched from the trailing second vehicle while the lead vehicle deploys the drone-based probes. After collecting data from the Great Plains, we will archive that data and repeat these same procedures in the Northeastern United States.

After collecting a substantial set of SLIM and LCL data from tornadoes in both regions, we will use Python and Microsoft Excel to analyze and draw conclusions and comparisons between both regions of the United States. Following are several questions that our research will attempt to answer. Does a certain pressure reading at a certain temperature or altitude prompt correspond with an increase in a SLIM parameter(s)? Is there a correlation between dewpoint temperature and instability at the LCL? Is there an optimal range of wind speeds that either inhibit or encourage the development of adequate rotational velocity and azimuthal shear? How much higher does 0-3 km and 0-6 km wind shear have to be in high-LCL environments at tornadogenesis in comparison to low-LCL environments?

Broader Impacts

Further reasoning for conducting this tornado research project is so that the students involved are given the opportunity to gain hands-on research experience in the field, while acquiring skills not obtainable in the classroom. Some specific skills that each student will expand upon through the research include, but are not limited to, tornado forecasting abilities, interpretation of numerical model data, analyzing Skew-T Log-P diagrams and hodographs, proper training on equipment and software such as our own TILTTING-23 tornado probe and the Windsond interface, weather balloon filling and launching techniques, observing cloud type and structural changes to predict supercell growth and tornadogenesis locations. Additionally, any thermodynamic analyses and data acquired in the field will be sent to local NWS offices. Along with the completion of this project, we will be documenting the trip and contributing video documentation to show our research procedures while in the field. Beyond improving upon meteorological skill sets, students will learn and improve upon team building and leadership skills vital for the workforce. Therefore, the project will better prepare undergraduate students for graduate-level research and a career in meteorology. In addition, the potential outcomes of this research can contribute to the field of tornadogenesis research which can impact the understanding and forecasting of these systems.

Budget for Research (or Monetary Reasoning of Instrumentation)

To accomplish the goals of our project, funding for the travel and equipment expenses will be needed. Each item will be listed, along with a thorough breakdown of the costs. The total cost will then be listed underneath each item. A chart summarizing these items and their costs is provided at the end of the budget.

Budgeting for Travel Expenses

Food

Allocating funds for basic human necessities such as food and water is essential for any trip. Assuming each meal is approximately $10 for breakfast, $10 for lunch, and $10 for dinner, this leaves each student with $30 per day to spend on food. When taking eight people into account, that would be $240 per day on food, which will equal $3,360 for two weeks. This only covers food while the field research is being conducted in the Great Plains region of the United States. This does not cover any food expenses while conducting field research in the Northeast region of the United States. For a trip in the Northeast, if we were to spend two days, using the same initial meal amounts, an additional $480 would be needed. The grand total would be $3,840.

Cost: $3,840.00

Gas

Prices for gasoline constantly fluctuate nationally and states in the Northeast region have the highest gas prices compared to other states in the U.S. (AAA 2024)[1]. Gas in Pennsylvania is $3.35 (AAA 2024) compared to the national average of $3.27 (US Energy Information Administration 2024).

As of December 1, 2023, TILTTING has inquired about obtaining a decommissioned police interceptor for the Millersville University Earth Sciences Department to be used as a research instrumentation vehicle, or better known as a mobile mesonet. The team awaits a response from the University regarding whether or not the acquisition will be feasible. In preparation for any turn of event, the team has prepared two gas budgets entailing two scenarios: If the team does not acquire a decommissioned police interceptor before the time of the Great Plains deployment, and if the team does acquire the vehicle by that time.

In the event we do NOT obtain the decommissioned police vehicle (we will name this Scenario 1), we will be using two vehicles: a Dodge Caravan and a Ford F-350. The Dodge Caravan has a tank capacity of 20 gallons at approximately 25 miles per gallon (mpg), yielding a 500-mile trip per tank of gas. Assuming an 8,000-mile trek, with 500 miles per tank of gas, we will need roughly 16 tanks of gas for the Dodge Caravan for the whole trip. Since the national average is $3.27 per gallon, and the Caravan has a 20 gallon tank, we will need roughly $65.40 for a full tank of gas. Finally, since we will need about 16 tanks of gas for a whole trip, at a cost of $65.40 per tank, the total cost for gas will roughly be $1,046.40. In addition, the Dodge Caravan has a charge of $0.66 per mile to use. Assuming an 8,000-mile trek at $0.66/mile, we will need to add $5,280 to the cost of gas travel for the Caravan. The total for the Caravan will be $6,326.40. The next vehicle is the Ford F-350, which has a tank capacity of roughly 30 gallons at roughly 13 mpg, yielding a 390-mile trip per tank of gas. Assuming an 8,000-mile trek, with 390 miles per tank of gas, we will need roughly 21 tanks of gas for the F-350 for the whole trip. As mentioned, the national average is $3.27 per gallon, and since the F-350 has a 30 gallon tank, we will need roughly $98.10 for a full tank of gas. Finally, since we will need about 21 tanks of gas for a whole trip, at a cost of $98.10 per tank, the total cost for gas will roughly be $2,060.10. So, the total amount of money needed for both vehicles would be $8,386.50, each vehicle fueling up at the national average of $3.27 per gallon. Now please note, the previous calculations are for a trip in the Great Plains only. For an IOP mission in the Northeast, it is a possibility that an additional few extra tanks of gas per vehicle are required. Using similar figures, for a Northeast mission, assume a 1,000-mile trek for both vehicles and three tanks of gas for both vehicles. The Dodge Caravan would yield another $196.20 and the Ford F-350 would yield another $294.30, requiring roughly an additional $500 for one Northeast IOP mission. Assuming we have at least three Northeast missions, we will need $1,500 for Northeast deployments. Include an extra $1,000 to account for any unforeseen increases to the national average of gas. The total gas costs for the Northeast would be $2,500. Therefore, the grand total cost for gas would be $10,886.50

[1]Gas prices as of January 11, 2024.

Cost for Scenario 1: $10,886.50

In the event that our team does obtain the decommissioned police vehicle (we will name this Scenario 2), we will be using two vehicles: a Ford Explorer and a Ford F-350. The Ford Explorer has a tank capacity of 19 gallons at approximately 23 miles per gallon (mpg), yielding a 437-mile trip per tank of gas. Assuming an 8,000-mile trek, with 437 miles per tank of gas, we will need roughly 18 tanks of gas for the Ford Explorer for the entire trip. Since the national average is $3.27 per gallon, and the Explorer has a 19 gallon tank, we will need roughly $62.13 for a full tank of gas. Finally, since we will need about 18 tanks of gas for a whole trip, at a cost of $62.13 per tank, the total cost for gas will roughly be $1,118.34. Unlike the Dodge Caravan's additional mileage fee, if the decommissioned police vehicle becomes an Earth Sciences department vehicle, no additional mileage fee would be applied. Therefore, the total for the Ford Explorer will be $1,118.34. The next vehicle is the Ford F-350, which its details have been thoroughly covered in the previous scenario. Referencing the last scenario's calculations, the total cost of gas for the Ford F-350 would be roughly $2,060.10. Again, please note that the previous calculations are for a trip in the Great Plains only. For an IOP mission in the Northeast, it is a possibility that an additional few extra tanks of gas per vehicle are required. Using similar figures, for a Northeast mission, assume a 1,000-mile trek for both vehicles and three tanks of gas for both vehicles. The Ford Explorer would yield another $186.39 and the Ford F-350 would yield another $294.30. Similarly to the last scenario, we will need roughly an additional $500 for one Northeast IOP mission. Assuming we have at least three Northeast missions, we will need $1,500 for Northeast deployments. Include an extra $1,000 dollars to account for any unforeseen increases to the national average of gas. The total gas costs for the Northeast would be $2,500. Therefore, the grand total cost for gas would be $5,678.44

[1]Gas prices as of January 11, 2024.

Cost for Scenario 2: $5,678.44

For maximum preparation, we will be using the total gas cost figure from Scenario 1 ($10,886.50)

<u>Lodging</u>

The field research is entirely dependent on where convective initiation and tornadic supercells develop. Thus, lodging must be booked on a last-minute basis. According to Platas (2023), $151.23 was the reported national average for a hotel room. Using that figure and considering that we will need 2 rooms per night, that would yield a nightly total of $302.46. For two weeks of field research in the Plains, lodging for the entire trip would total $4,234.44. For a two-night trip in the Northeast region, there would be an additional amount of $605. In the case we have at least a few Northeast missions, the total lodging costs would be $1,815 for the Northeast. The grand total for lodging would then equal $6,049.44

Cost: $6,049.44

Total cost for Travel Expenses (Food, Gas, and Lodging): <u>$20,775.94</u>

Budgeting for Equipment Expenses

Decommissioned Police Interceptor(1):

A decommissioned police interceptor will serve as a mobile mesonet for the project, as previously mentioned earlier in this proposal . This will allow us to mount meteorological instrumentation to the roof of the SUV (see example pictured below. Image courtesy from the Public Broadcasting Service (PBS)) to gather surface-level observations in the environment of a tornadic thunderstorm. Having this additional resource to use for our project will allow us to 1) dedicate a vehicle for obtaining surface level data, 2) mitigate the risk of using student vehicles that are unreliable in the field, 3) use a vehicle with four-wheel drive, 4) allow enough interior space to carry research equipment while transporting student personnel during field/storm chasing campaigns, and 5) use a vehicle that is gas efficient. A decommissioned police vehicle is expected to cost around $5,000.

Cost: $5,000.00

New drone (1):

During practice flights with one of the original plane drones, the plane sustained significant damage during practice flights and will need to be replaced with a plane of the same make and model. The cost for the plane itself is $249.99, a battery for the plane costs $70, and a battery charger for the battery is $35.99. This totals to $356.

Cost: $356.00

Quadcopter drones (2):

After watching previously documented tornadic environments online, team members have communicated with one another that it would be wise to have a secondary plan of action, in the event the original methodology of the fixed-wing planes do not succeed in the field due to extreme turbulence that the plane will encounter. We have allotted for $1,000 to use towards purchasing two quadcopter drones

Cost: $1,000.00

Helium tank costs

A previous quote for helium and helium tank costs totaled to $700. Assuming helium costs have stayed the same, we have allotted $700 to cover the cost of helium.

Cost: $700.00

Tornado probe costs:

The TILTTING-23 probes will have an outer carbon fiber composite shell to protect the inner electronics from any outside elements, excluding the sensor element. The cost for the probe casing materials and Internet of Things (IoT) based cell phone services on the probe total to $279

Cost: $279.00

First Aid Kit (2):

In the event of a first aid emergency, we will need first aid kits available in each vehicle. The selected first aid kits are comprehensive and will allow the team to be prepared for any minor injuries, if any are sustained, during the research missions.

Cost: $92.00

Website maintenance costs

We are currently using Squarespace as our website's server host. The website will allow us to keep the public up-to-date with latest project updates, project details, team member biographies, sponsor descriptions, along with a location to store data from past deployments. Squarespace's monthly cost totals to $292.56. We also will be paying a biannual fee to keep the TILTTING.com domain, which is $26.50. For now, our season's budget will only account for the monthly website costs of $292.56.

Cost: $292.56

Total cost for Equipment: $7,720.00

Budgeting for Meteorological Instrumentation Expenses

Since we have a full inventory on radiosondes and have tornado probes prepared for deployment, no additional instrumentation will be needed for this season.

Budget Summary

Travel Expenses	Equipment Expenses	Meteorological Instrumentation Expenses
Food: $3,840.00	Police Interceptor: $5,000.00	NONE THIS SEASON
Gas: $10,886.50	New plane drone: $356.00	
Lodging: $6,049.44	Quadcopter drones: $1,000.00	
	Helium: $700.00	
	Probe costs: $279.00	
	First Aid Kits: $92.00	
	Website: $292.56	
Total: $20,775.94	Total: $7,720.00	Total: $0.00

GRAND TOTAL: $28,495.50

Concluding Remarks

While we do want to investigate various lifting mechanisms to determine potential differences in LCL height threshold, we also hope to contribute our research and findings to the greater meteorology community, in efforts to not only help improve weather forecasts and severe weather alerts, but to ultimately help save lives and property.

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