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Lagrangian Drift Sensor for Tornado Research: Thermodynamic Investigation of LCL Thresholds during Tornadogenesis and its Influence in the Northeast and Great Plains (TILTTING)

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Abstract

This paper focuses on the mathematical development for the proposed methodology, and the physics encountered prior to and inside the torus flow surrounding the vortex tube of a tornado. We describe an instrument designed and built by undergraduate students, and the experimental design that will allow us to investigate differences in height thresholds of the Lifted Condensation Level (LCL) at tornadogenesis between the Northeast and Great Plains. The instrument is a lightweight and durable suite of sensors that will obtain measurements of conventional meteorological variables when carried into a thunderstorm with the potential for tornadogenesis on an expendable drone. The mathematical underpinning shows the conditions encountered along the flight path of an expendable drone, carrying the Lagrangian Drift Sensor (LDS), from the launch point to the tornado. Sufficient Convective Available Potential Energy (CAPE), speed and directional shear, storm-relative helicity, and moisture are required for severe thunderstorm initiation and conditions that support tornadogenesis. Once the drone enters the updraft, we expect the sensors to be carried aloft by buoyancy to provide in-cloud vertical profiles, which will be supported by in-situ balloon-borne vertical profiles using rawinsondes in the near thunderstorm environment. We hypothesize that LCL heights need to be lower in the Northeast for successful tornadogenesis.

Introduction

The Thermodynamic Investigation of LCL Thresholds during Tornadogenesis in the Northeast and Great-Plains (TILTTING) project, is an undergraduate-led research project at Millersville University. Simply put, Tornadogenesis is the process in which a tornado forms (going from a rotating mesocyclone, to producing a funnel cloud/tornado). The project is looking at the

LCL of the mesocyclone and parent supercell, and how it can influence tornadogenesis across two geographic regions in the United States. Tornado Alley is traditionally the stretch of the central United States from North Dakota to Texas and is seen as the hot spot for tornado activity. However in recent years, there has been a notable eastward shift within Tornado Alley (Agee et al., 2016) with speculation that Dixie Alley, a region in the deep south of the United States, may become more active in certain El Niño Southern Oscillation (ENSO) years (Gagan et al., 2010). After storm chasing and witnessing the devastation left behind from the EF-3 tornado in Mullica Hill, NJ from the tornado outbreak spawned from Hurricane Ida's remnants, the leads of the TILTTING project speculated a northeast branch in tornado activity within the Northeast region of the United States.

The purpose of this research project is to further understand why tornadoes only develop in specific environments and under 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 rotating updrafts, or vorticity, and localized cyclone rotation to be undercut and dissipated (Rasmussen and Blanchard 1998; Brown and Nowotarski 2019). Davies (2006) 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.

Instrumentation

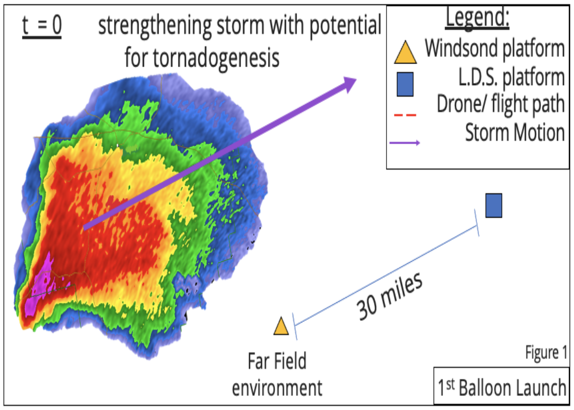
The project consists of two main instrumentations, with a variety of other instrumentations for surface layer observations within the convective boundary layer. The project relies on the Lagrangian Drift Sensor (L.D.S.), an instrument designed and built by undergraduate students. The L.D.S. is a lightweight and durable suite of sensors that will obtain measurements of conventional meteorological variables when carried into a thunderstorm with the potential for tornadogenesis on an expendable drone. The other mobile platform is the Windsond platform, a miniature radiosonde instrument which provides in-situ balloon borne atmospheric profiles. Both platforms together will sample the Far Field, Near Field, and "Close" Field.

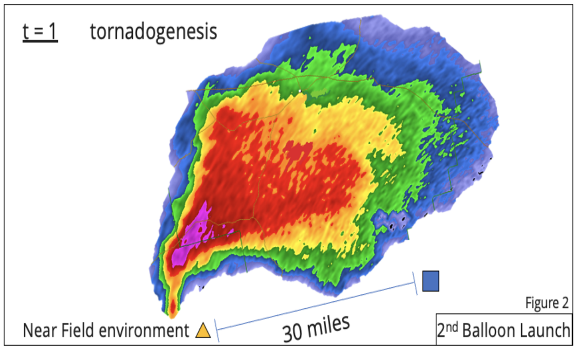
Additionally, the project relies on instrumentation like the R.M. Young Wind Monitor mounted on the roof of the second mobile vehicle, to determine the tornado inflow speed and optimal direction for drone and L.D.S. deployment. Furthermore, the Kestrel 5200 provides similar information for the first mobile vehicle launching the Windsonds, to determine wind speed and direction at the time of launch.

The drone uses a first person view camera set up, placed in the cockpit, used in conjunction with a headset to fly the aircraft. There is a second monitor that can be used for a second set of eyes while the pilot is flying the aircraft. The drone always remains within the line of sight of the second mobile vehicle at all times prior to penetrating the tornado.

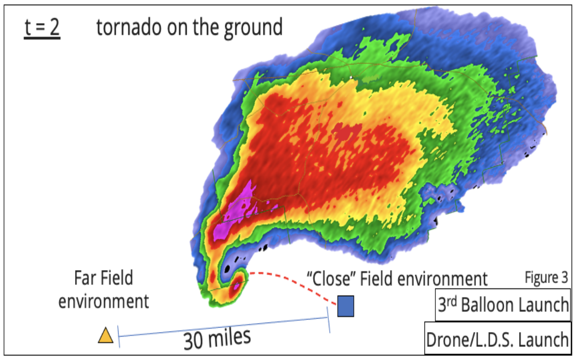
Methodology

To investigate differences in height thresholds of the LCL at tornadogenesis, two mobile platforms are used, separated by a distance of 30+ miles, to deploy in-situ balloon-borne rawinsondes (Windsonds) for vertical profiles in the near thunderstorm environment at tornadogenesis (t = 0 to 2). The balloon launches are approximately thirty minutes to an hour prior to the storm, during the storm, and thirty minutes to an hour after the storm. Additionally, the L.D.S. is carried on an expendable drone into the core of a developed tornado during (t=2). The diagram below shows a visual representation of deployments.





Tornadic supercells have been observed in both the near and far fields (Wade et al., 2018). The Windsonds sample the environment in the far fields and the mesocyclone in the near field. The L.D.S. samples from the launch point into the tornado, this is what we call the "close" field observation. As the L.D.S. samples along the flight path, pressure gradients become apparent from the near field observation to the tornado, while also measuring pressure perturbations once inside the tornado.



Uncertainty in the U and V components

In this hypothetical scenario, radar products, such as spectrum width, can identify areas of turbulent motion in the inflow to correct the flight path in real time. An assumption for the methodology is laminar flow for one smooth flight path without needing to correct. However once in the field, unexpected turbulence can be encountered which begs the question: What is the optimal sampling path into the tornado?

The mathematical approach shows the conditions encountered along a flight path of an expendable drone, carrying the Lagrangian drift sensor, sampling the atmosphere from the launch point into the tornado. In the idealized case, the drone flies in the laminar inflow to the tornado. For the full U and V component mathematical breakdown see the link below: https://drive.google.com/file/d/1oH_cmjjUc95Bkg-KqnGDRCEnsfKhrAaE/view?usp=sharing.

The mathematics show the wind direction along the flight path in section 1 blowing due east at 30 knots. In order to stay on the desired flight path, the heading must be changed which is indicated by the blue arrows stemming off the desired flight path. Similarly in section 2., the heading is corrected to remain on the desired flight path.

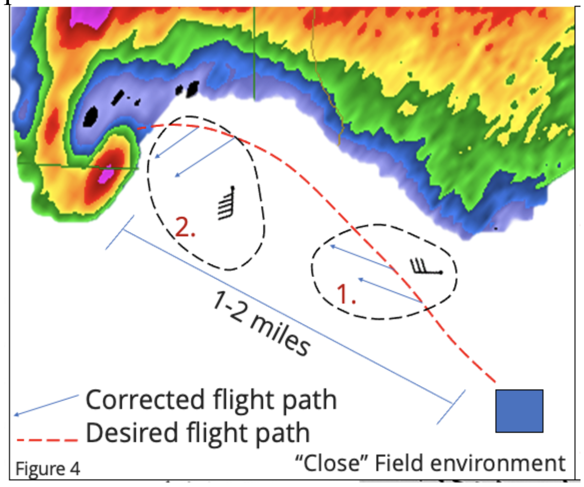


Figure 4

Expanding this into the third dimension approaching the vortex, the drone flying at approximately thirty feet veers with the inflow wind vectors until it reaches the core of the tornado. Once inside the tornado, the strongest pressure drop the L.D.S. would be able to record is from the L.D.S. getting hit by one of the vortices within the core. Below is the three dimensional drone approach, showing multiple vortices in purple within the tornadoes core. These vortices are the most destructive within a tornado, as they spin faster than the tornado as a whole.

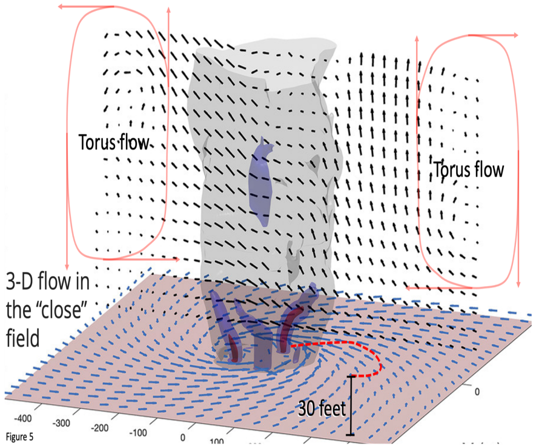


Figure 5

The Third Dimension

Third dimension considers the vertical component of the drone's flight path. The drone ascends to 400 feet prior to the first pocket of turbulent flow in figure 4. Due to the wind field around the torus flow (horizontally rotating region outside of the tornado), the drone must enter the tornado at the surface.

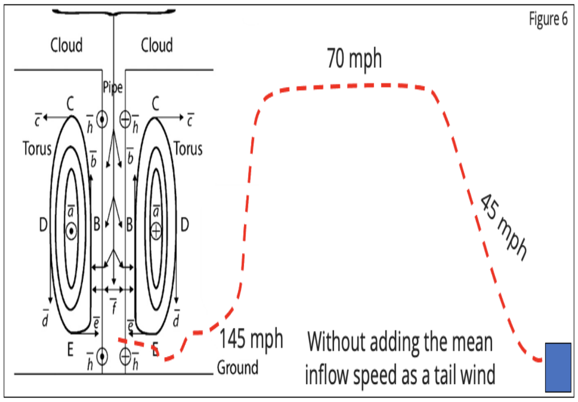
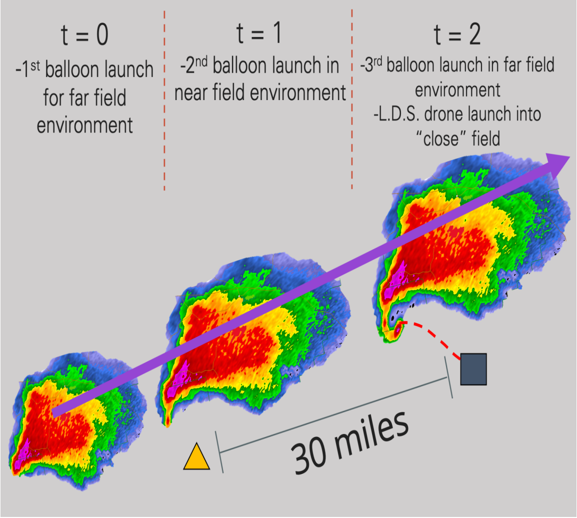


Figure 6

Therefore, the drone must dive from its cruising altitude, converting potential energy into kinetic energy, increasing the drones overall speed as it enters the tornado's core. The drone will level off around 30 feet above the surface so it can maintain its speed without being pushed into the ground prior to the tornado.



Putting it all together, we have t = 0 through t = 2 to fully capture the tornadoes and our research methodology progression in tandem. At t = 0, it is our first balloon launch observing the far field ambient thunderstorm environment. Going forward in time, t = 1 is the second balloon launch in the near field environment, observing the present conditions at tornadogenesis. Lastly, t = 2 is the final balloon launch once again observing the far field ambient thunderstorm environment after the storm has moved through, while also launching the Lagrangian Drift Sensor and observing both the near field and what has determined the close field by getting the sensor into the core of a tornado.

Future Work

Another season of field deployments is needed in order to further test the hypotheses and proposed methodology. The project was able to generate four poster presentations and an oral presentation from the 2022 field campaign, including a case study of a strengthening QLCS with data collected from the rear flank downdraft. For the 2023 campaign, the methodology can be reproduced using Cloud Model 1 (CM1), to further test the capability and feasibility proposed in this document. Furthermore, a more robust data set from both geographical regions will be required to incorporate Windsond data in the CM1 simulations, to use the Far and Near field observations as the initial conditions when simulating tornadic supercells. A successful deployment of the L.D.S. into the core of a tornado can also be used within CM1 to compare the pressure gradient from the launch point to the tornado within the “Close” Field while also comparing pressure perturbations inside the tornado.

References

Agee, J. (2005). Literacy, aliteracy, and lifelong learning. *New Library World, 106*(5/6), 244 252. doi:10.1108/03074800510595850

Chong, S. L. (2016). Re-thinking aliteracy: When undergraduates surrender their reading choices. *Literacy*, *50*(1), 14-22. doi:10.1111/lit.12063

Little, C. A., McCoach, D. B., & Reis, S. M. (2014). Effects of differentiated reading instruction on student achievement in middle school. *Journal Of Advanced Academics*, 25(4), 384-402. doi:10.1177/1932202X14549250

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