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EXAMINING RIGHT-MOVING SUPERCELL ENVIRONMENTS WITH DOPPLER WIND LIDAR OBSERVATIONS

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EXAMINING RIGHT-MOVING SUPERCELL ENVIRONMENTS WITH DOPPLER WIND LIDAR OBSERVATIONS

A THESIS APPROVED FOR THE
SCHOOL OF METEOROLOGY

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Abstract

While immense enhancements to meteorological observations and simulations have been made over the last several decades, two lingering questions continue to plague the community: (1) Why do some storms produce tornadoes while others do not, and (2) why do storms in seemingly identical environments go on to produce different hazards? Developing robust answers to these questions are critical as tornadoes continue to be a top cause for weather-related fatalities. Storm environment research through simulated storms, reanalysis products, and limited observations have guided the current understanding and have identified differences between environments supportive of tornadic and non-tornadic supercells. This work aims to use more detailed observations through Doppler wind lidars to capture the storm environment evolution in both time and space.

Since 2016, the National Severe Storms Laboratory has operated mobile scanning Doppler wind lidars within the inflow of supercell thunderstorms as part of collaborative field projects (mini-MPEX, TORUS, PERiLS, TORUS-LiTE, and LIFT). The research goal of this instrument is to observe the evolution of storm inflow properties to gain a better understanding of the storm environment surrounding an evolving supercell. Various scanning and post-processing techniques to capture the wind profile evolution via DWL observations have been used. Prior to 2022, a velocity azimuth display technique was used to retrieve a vertical wind profile every 3-5 minutes using 8 points 20 degrees off zenith. In 2022-23, a continuous scanning mode was implemented to retrieve wind profiles as frequent as every 5 seconds. Both of these scanning strategies yielded vertical profiles of derived horizontal winds about every 18 meters with the first usable data point around 75 meters AGL after filtering based on a signal-to-noise ratio

threshold. A new optimal estimation technique was designed to incorporate co-located rawinsonde and surface observations into the wind retrievals that provide data between the surface and 75 meters. These observations are used to validate the post processing techniques and output will be compared to previously used methods.

Focus will be placed on the evolution of the near-ground kinematic characteristics and the storm induced environmental modification in both tornadic and non-tornadic storms. To remove background trends from the environmental evolution, Rapid Refresh model-based analysis profiles are used. Full, surface-based wind profiles will allow for the quantification and time evolution of severe weather forecasting parameters, such as storm-relative helicity, storm-relative winds, etc. Implications of these results on recent studies discussing the relative importance of streamwise vorticity versus storm-relative winds on supercell properties and tornado production will be discussed.

Results show that differences in mesocyclone intensity between tornadic and non-tornadic supercells cause the downstream spatial variability of their environments. This is particularly true when quantifying storm-induced accelerations, which can lead to the length scales at which mesocyclone induced perturbations can be observed. Furthermore, low-level ground-relative winds tend to provide greater differences in the storm environment whereas storm-relative winds contain greater composite differences above 1 kilometer. Also explored are the vorticity trends in these storm environments in time and space, and the horizontal vorticity components (and associated differences) will be shown.

Chapter 1

Introduction

A better understanding of supercell thunderstorms and their hazards is critical towards saving a disproportionate number of lives lost compared to other weather-related events (Brotzge et al., 2013). Efforts continue in both modeling and observational research to decipher differences between various supercell environments and the downstream hazards associated with storms within them (e.g., Nowotarski and Jensen, 2013; Parker, 2014; Coffer et al., 2020; Coniglio and Parker, 2020). Of note, predicting tornadic versus non-tornadic supercells has been particularly difficult (Brooks and Correia Jr, 2018). These difficulties highlight the importance of storm environment research and developing a better understanding of storm environment variability.

1.1 Supercell Thunderstorms

The term 'supercell' is used to describe a thunderstorm with a rotating updraft, or mesocyclone (Browning, 1962). An early distinction found between supercells and ordinary thunderstorms was their movement separate from the mean wind. Browning (1964) created a formal model of the now coined, 'right moving supercell'. As time and research progressed, a supercell was used to describe an anti-cyclonically rotating storm moving to the left or a cyclonically rotating storm moving right of the mean wind. In this study, only right-moving supercells are analyzed. Schematics for these storms were developed by Lemon and Doswell III (1979) who posed a two dimensional view of supercell structure and it's governing features (Fig. 1.1) as well as an evolutionary diagram of the supercell and its associated updraft and downdraft evolution (Fig. 1.2).

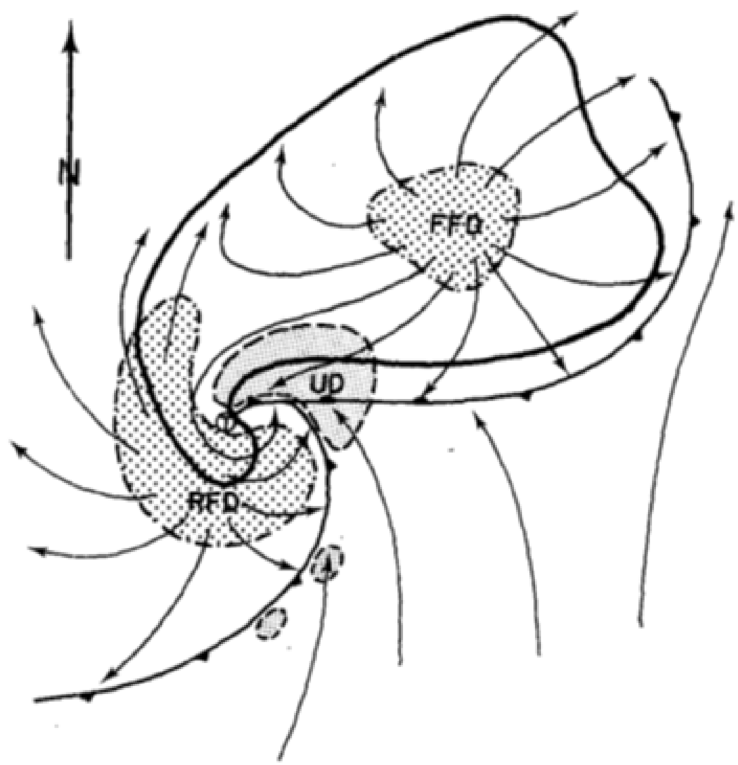

Figure 1.1: One of the first two dimensional views of a supercell and its primary regions. Regions include the forward and rear flank downdraft (FFD/RFD), updraft (UD), and a generalized flow pattern. Figure from Lemon and Doswell III (1979). Their figure 7.

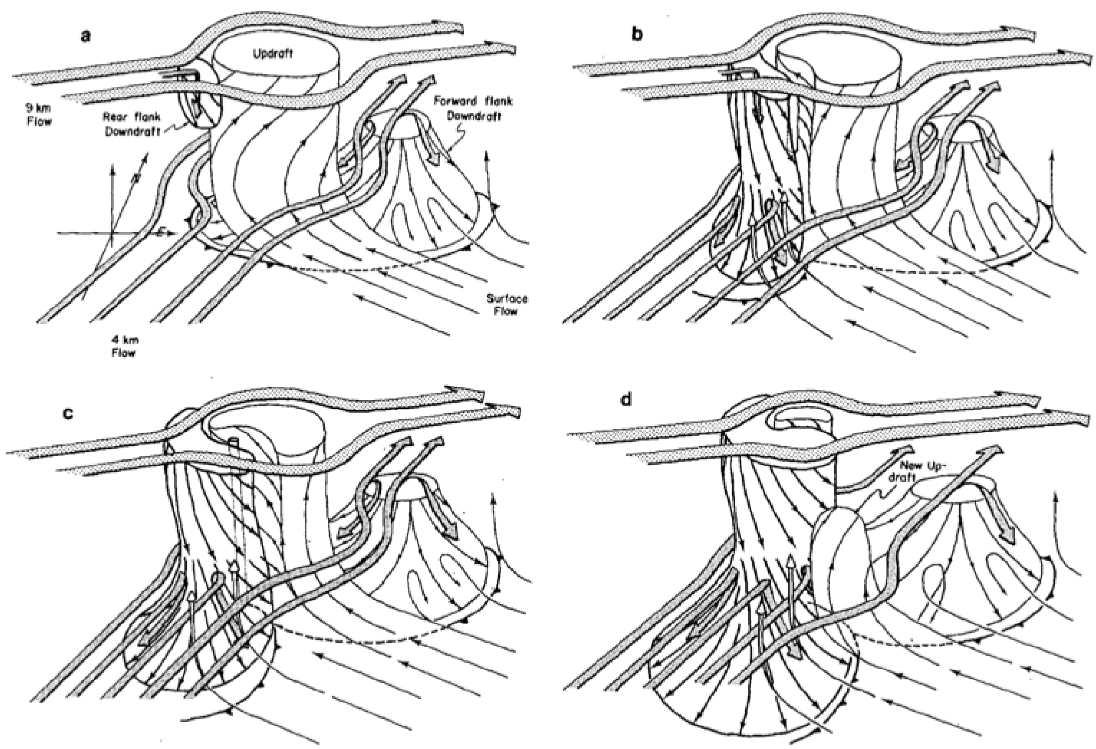

Figure 1.2: Updraft and downdraft evolution during the lifetime of a supercell thunderstorm including mid and upper level flow patters and previously identified storm features. Figure from Lemon and Doswell III (1979). Their figure 9.

Chapter 2

Data and Methods

This research analyzes mobile scanning DWL data from various deployments from 2017 through 2023. Instrumentation details, data collection strategies, and quality-control and post processing techniques will be provided in this section. In total, 36 supercells were observed over 50 deployments with co-located radiosondes launched throughout operating periods (Fig. 2.1).

2.1 Surface Observations

In 2017, the National Severe Storms Laboratory (NSSL) deployed a DWL as part of their Collaborative Lower Atmospheric Mobile Profiling System - CLAMPS. This system was outfitted with a Vaisala met station which collected surface observations valid approximately 1 meter above the trailer (approximately 5 meters above ground level). Surface observations were logged every 5 seconds with an accuracy of $\pm 0.1 m\, s^{-1}$ in wind speed observations and $\pm 2^{\circ}$ in wind direction (WIN, 2022).

From 2019 to 2023, the NSSL operated a DWL (two DWLs in 2022) from the bed of a Ford pickup truck. Mounted on this truck was a mobile mesonet rack where an RM Young 05103 Wind Monitor was used to collect surface horizontal wind speed and direction information every 1 second. These observations have wind speed accuracy within $\pm 0.3 m\, s^{-1}$ and wind direction accuracy within $\pm 3^{\circ}$ (Waugh, 2021). Collected surface observations were used to subjectively determine the passage of various bound-

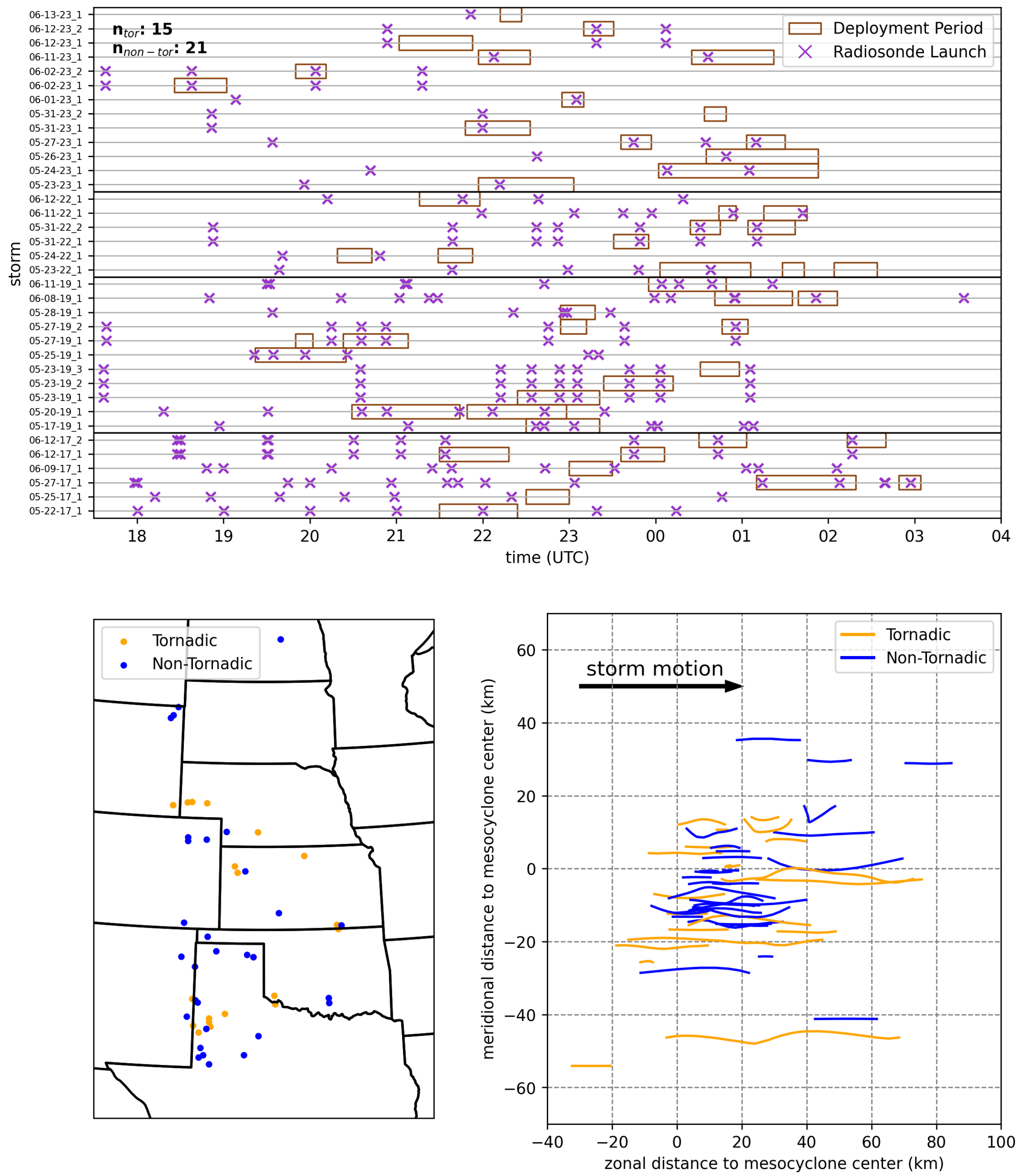

Figure 2.1: Timing of DWL deployments (blue rectangles) and co-located radiosonde launches (red marker) for each storm analyzed in this study (left). Deployment locations separated by tornadic (red) and non-tornadic (blue) storms (right).

aries indicative of no longer sampling inflow air (e.g., a gust front passage).

Chapter 3

Results

This chapter addresses the results from this study as they relate to each of the hypotheses in chapter 1. Additional results as they were made apparent in the data will be discussed thereafter.

3.1 Hypothesis Driven Results

3.1.1 Environmental Spatial Variabilities

Previous observational based efforts have found greater spatial variability in non-tornadic inflow environments compared to tornadic storm environments (Parker, 2014). Given their dataset of rawinsonde launches, these variances were displayed through SRH and composite wind profiles (Fig. 3.1). Using similar methodology, we can assess this dataset in a near and far-field perspective. First, an assessment of the number of profiles making up each spatial bin must be addressed (Fig. 3.2). Composite profiles can then be created showing near and far-field hodographs in tornadic and non-tornadic storms (Fig. 3.3). In this work, the near-field will be used to describe the inflow environment up to 30 kilometers away in the x-direction. Far-field will consist of data beyond the 30 kilometer threshold.

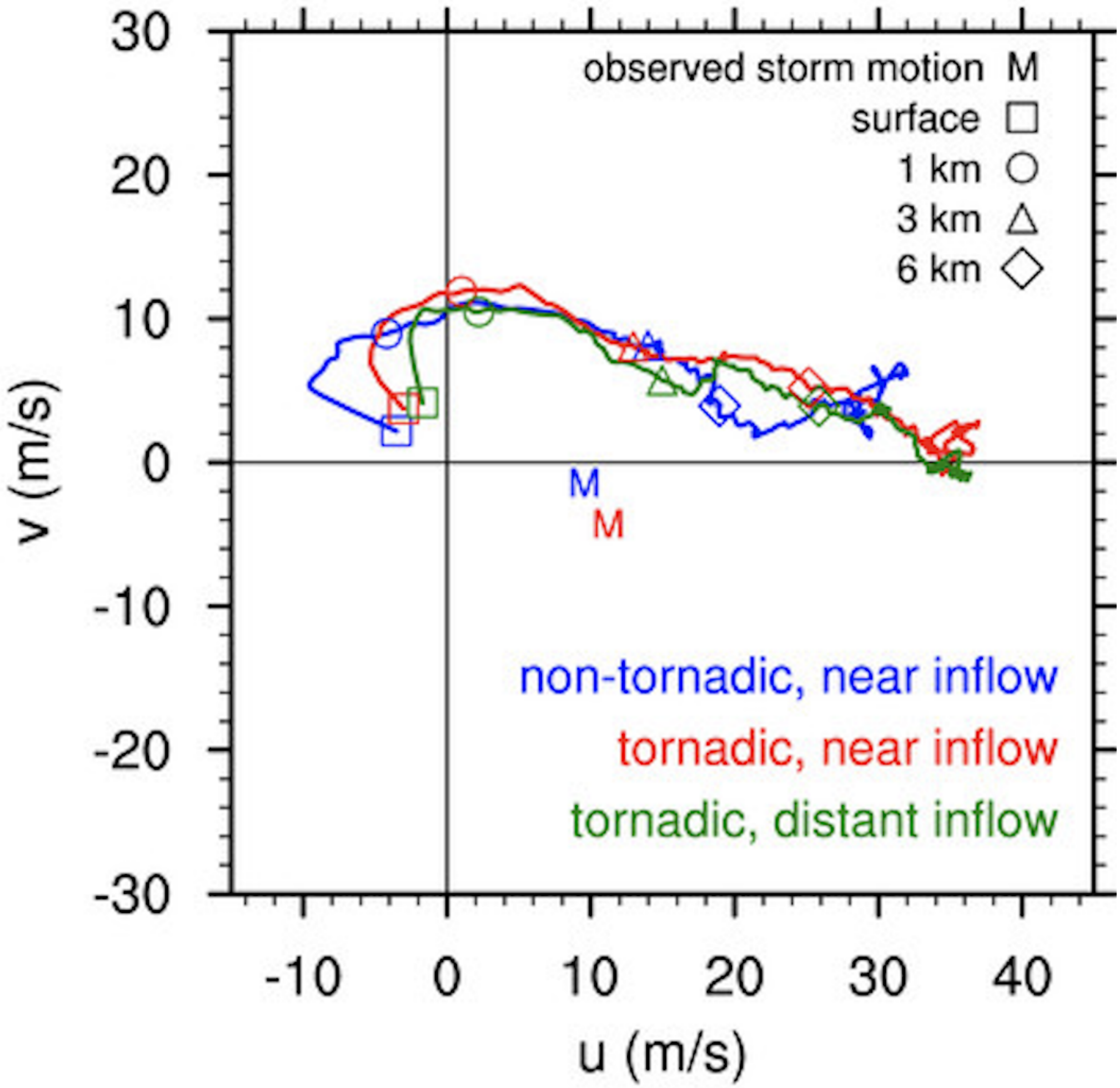

Figure 3.1: VORTEX-2 composite wind profiles, drawn from rawinsonde launches. From Parker (2014); their figure 12.

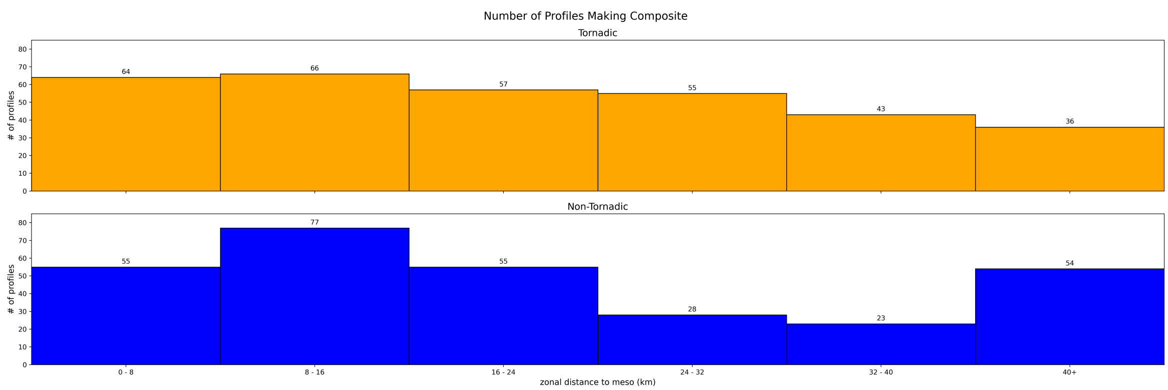

Figure 3.2: Histogram of the number of WINDoe profiles making up the spatial composites used in this section. Counts for tornadic (top, orange) and non-tornadic (bottom, blue) composites are shown.

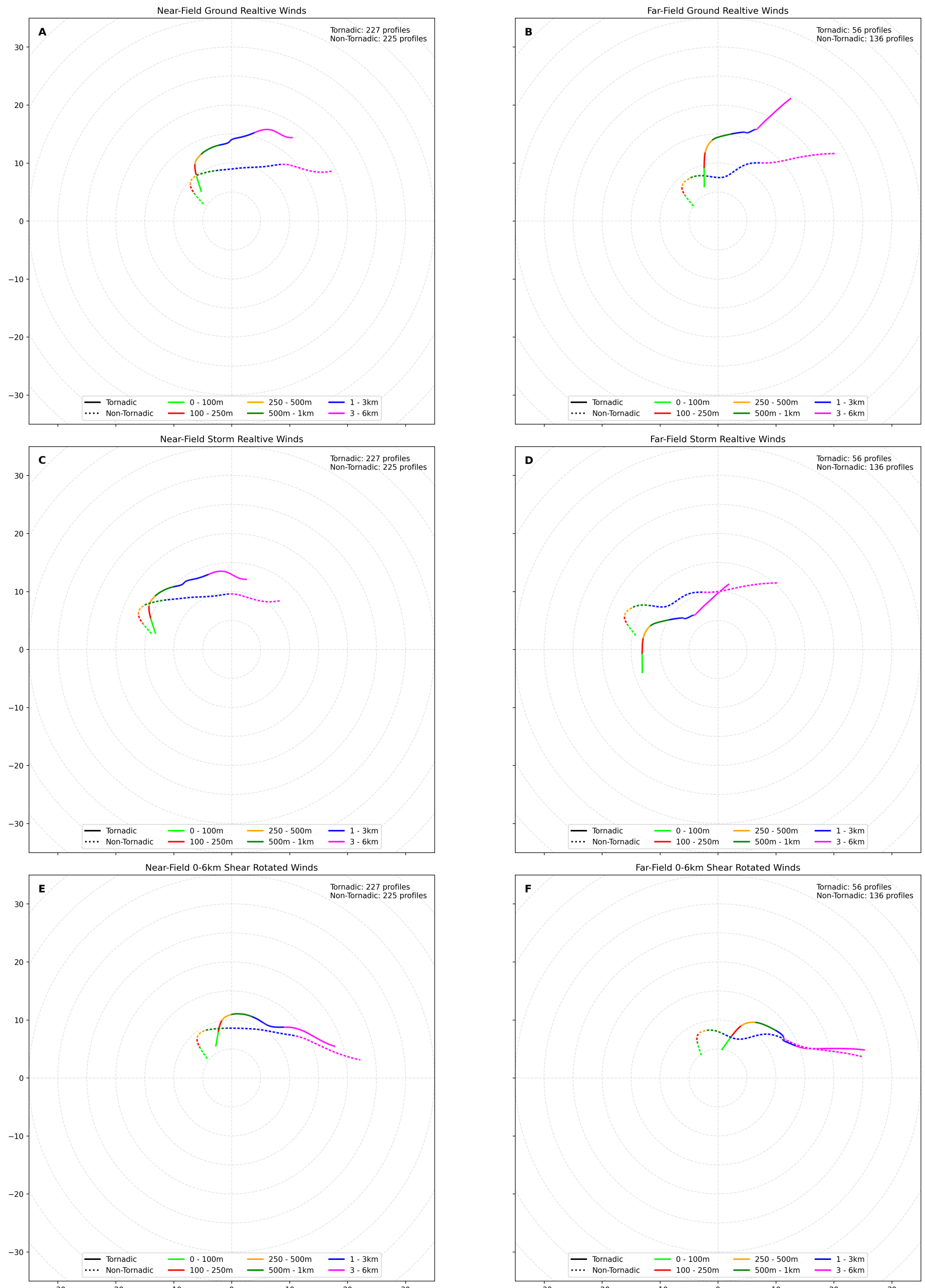

Figure 3.3: Composite ground relative (A,B; ms^{-1}), storm relative (C,D; ms^{-1}), and 0-6km shear vector rotated (E,F; ms^{-1}) hodographs for near-field and far-field inflow regions. Tornadic (solid) and non-tornadic (dashed) profiles are shown with the number of profiles comprising each composite shown in the respective panel.

Chapter 4

Summary and Conclusions

To this point in severe storms research, the use of DWL data in convective environments has been minimal. This work provides an atypical use case for the instrument and displays the benefits of using an instrument of this nature to observe severe convective storm environments, particularly in detailing the near-ground wind profiles. Although the main drawback of using DWLs for this purpose lies in their blind spot below about 60 to 80 meters, improvements to post-processing techniques have aided in alleviating this problem. In this study, we have explored the use of DWL wind retrievals and a wind estimation method (WINDoe) to quantify the evolution and variability of the low-level wind profile in storm environments. Specifically using the prior dataset created for use in this analysis, WINDoe provides an opportunity to combine DWL wind retrievals with other observational data sets to create a unified analysis of the wind profile over the lower troposphere in severe storm environments. Furthermore, WINDoe quantifies uncertainty in the retrievals, something missing from many observational based studies to this point in the science. Overall, the ability for this instrument to be nimble in operational settings, tied together with strides in data-analysis techniques should highlight the possibilities of utilizing DWLs in severe storms research.

This research provides an in-depth observation-based analysis into how supercell storm environment wind profiles evolve in time and space exploiting the ability of DWLs to retrieve wind profiles as frequently as every 5-10 seconds with high vertical resolution (about 18 meters). This includes the environmental differences between tornadic and non-tornadic storm environments, building on a lengthy literature of storm environment research rooted in observations, reanalysis, and simulated storms. Many previous efforts have yielded conflicting results, so this work seeks to provide clarity through the use of real-world datasets while targeting the most intense non-tornadic storms, findings that could further inform the forecasting community. Based on previous efforts this work addressed the following hypotheses:

1. Kinematics vary more in non-tornadic storms in space, with drastic changes in SRH from the far-field to near-field not seen in tornadic composites (Parker, 2014).

2. Low-level, inflow winds in non-tornadic supercell environments contain more crosswise vorticity compared to their tornadic supercell counterparts (Parker, 2014).

3. SRW plays an insignificant role in tornado dynamics and thus, there are minimal differences in low-level SRW profiles in tornadic and non-tornadic environments (Peters et al., 2023).

4. Streamwise vorticity drives changes in SRH in the storm environment and provides the skill between SRH and tornado prediction (Peters et al., 2023).

5. Low-level parameters such as SRH_{500m} provide better discriminatory skill compared to deeper-layer parameters such as SRH_{1km} or SRH_{3km} (**?**Coniglio and Parker, 2020).

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