Dual-Doppler Analysis of Two Tropical Cyclone Tornado Cases

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I. Introduction

As a Tropical Cyclone (TC) approaches a coast line, land-surface roughness contributes to surface friction, increasing vertical motion, and tornadoes can form within the TC rainband as a result. **The research conducted in this study looks at all landfalling TCs that produced tornadoes between 2008 and 2015** and compares it to the existing database of TC tornadoes between 1950 and 2007. **This study also compares tornadic (Tropical Storm Fay) and non-tornadic (Hurricane Isaac) cases of TCs with differing orientations of the rainband to the coastline upon landfall.**

II. Background

Schultz et al. (2009) created a database of all tropical cyclone tornadoes between 1950 and 2007. This study focused on the spatial distribution, azimuthal distribution, time of day, cyclone speed and direction, and the time from landfall at which these tornadoes occurred to see what factors triggered tornadogenesis. Novlan and Gray (1974) and Gentry (1983) discussed the importance of the water-to-land transition, which increases friction, in-turn decreasing wind speeds, and results in increased shear. This is very important in the formation of rotating supercells. McCaul conducted multiple studies on tropical cyclone tornadoes (1986, 1991, 1995). These include a study on the buoyancy and shear characteristics of hurricane-tornado environments, doppler radar and lightning network observations, and a simulation on shallow supercells within landfalling hurricane environments. Other studies, including McCaul (2003) and Eastin (2009), conducted case studies on supercells within specific tropical cyclones.

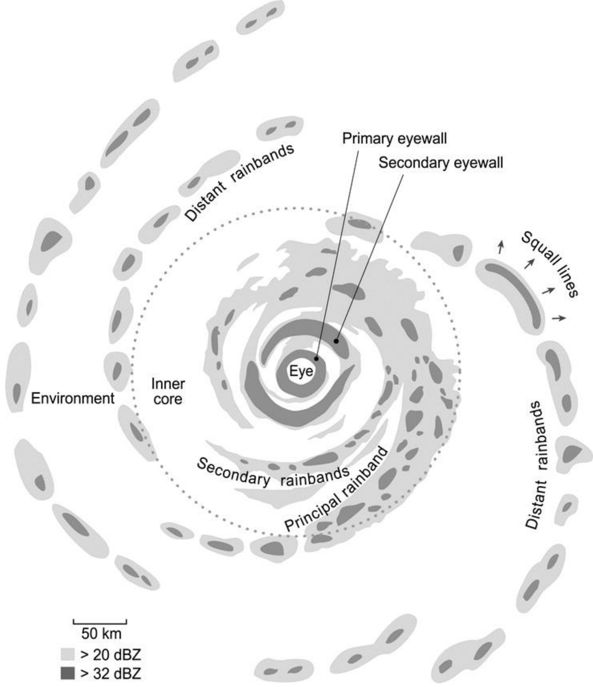
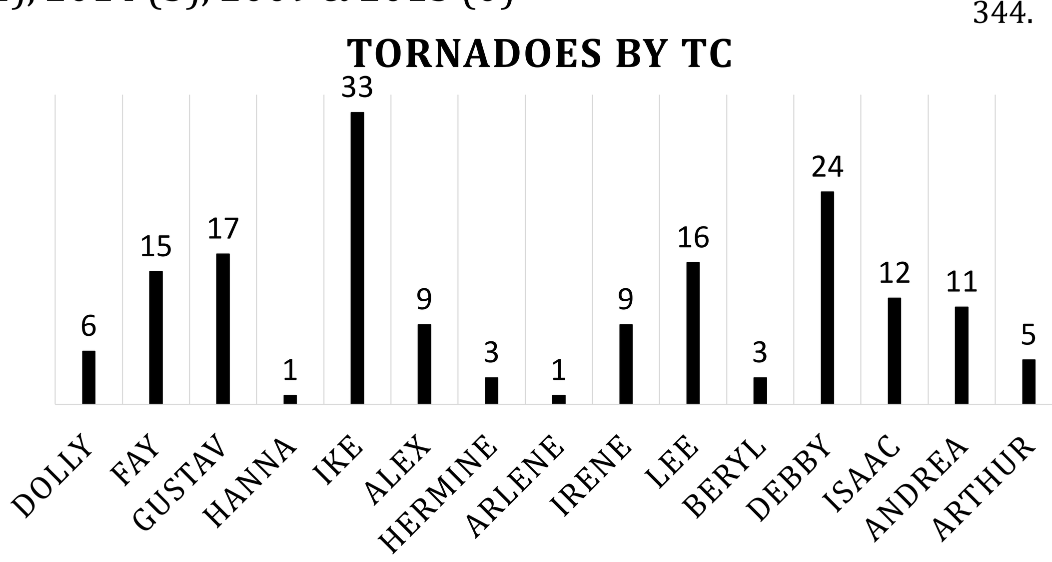


Fig. 1. Schematic showing principal (primary), secondary, and distant rainbands within a TC. Houze, R. (2010). Clouds in Tropical Cyclones. *Monthly Weather Review,138*(2), 293–344.

III. Key Findings

- Between 2008 and 2015, 26 TCs made landfall in the continental US
- Fifteen TCs produced tornadoes (9 tropical storms, 6 hurricanes) - 165 total TC tornadoes (EF0 – 124, EF1 – 36, EF2 – 5)
- Tornado distribution by year: 2008 (72), 2012 (39), 2011 (26), 2010 (12), 2013 (11), 2014 (5), 2009 & 2015 (0)
- Tornado distribution by state: FL (64), MS (24), LA (23), TX (19), AR (10), NC (8), AL (6), VA (4), NY (2), DE, GA, NJ, PA, & SC (1)
- 2 fatal tornadoes, 6 causing injuries – 10 total injured



A. Spatial Distribution

- It is hypothesized that the majority of tropical cyclone tornadoes will occur within the first 200 km of the coast (Schulz et al. hypothesized the first 150 km of the coast)
- The results conclude that 83% of tornadoes occurred within the first 200 km of the coast (the major outlier being Ike who produced most of its tornadoes after the first 200 km of the coast in LA & AR)

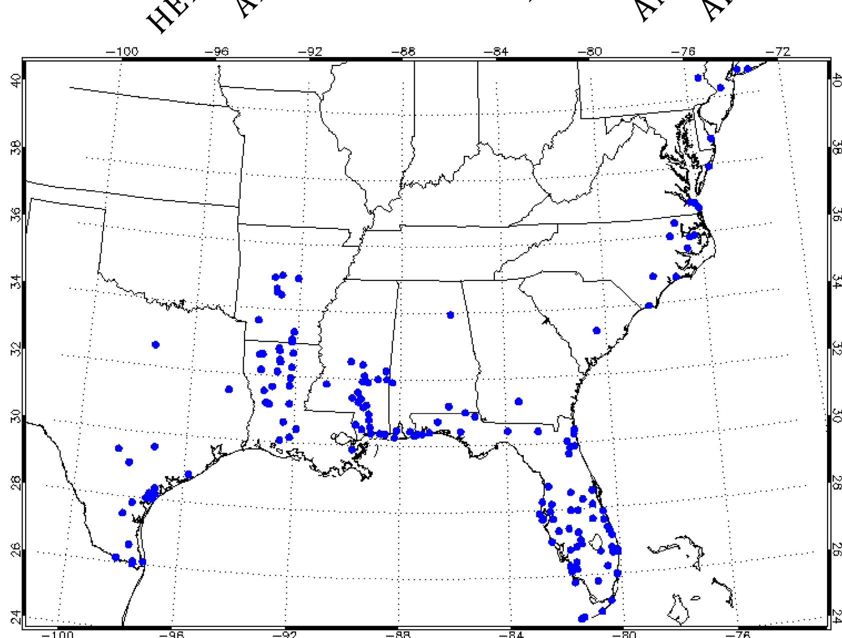


Fig. 2. Tropical cyclone tornadoes plotted relative to their location in the continental US.

B. Azimuthal Distribution

- Mapping the azimuthal distribution will help determine if there is a specific quadrant that tornadoes form in
- It is hypothesized that the majority of tornadoes will form in the right-front quadrant (RFQ) because that is where the maximum wind speeds occur

B. Azimuthal Distribution (cont.)

- However, it is important to note that even though the RFQ would be the most ideal, several of the tropical cyclone tornadoes were spawned from tropical storms, where wind speed comes into question
- It is apparent that the majority of tropical cyclone tornadoes occurred in the RFQ region of the true north graph. In the storm motion graph, only 48% of tornadoes occur in the RFQ.
- After further investigation, this issue seems to be resolved when eliminating distant rainband tornadoes

	Storm Motion (A)	Primary Rainband Only (A)	True North (B)
Right-Front Quadrant (RFQ)	48%	68%	67%
Left-Front Quadrant (LFQ)	15%	12%	10%
Right-Rear Quadrant (RRQ)	29%	21%	20%
Left-Rear Quadrant (LRQ)	8%	0%	3%

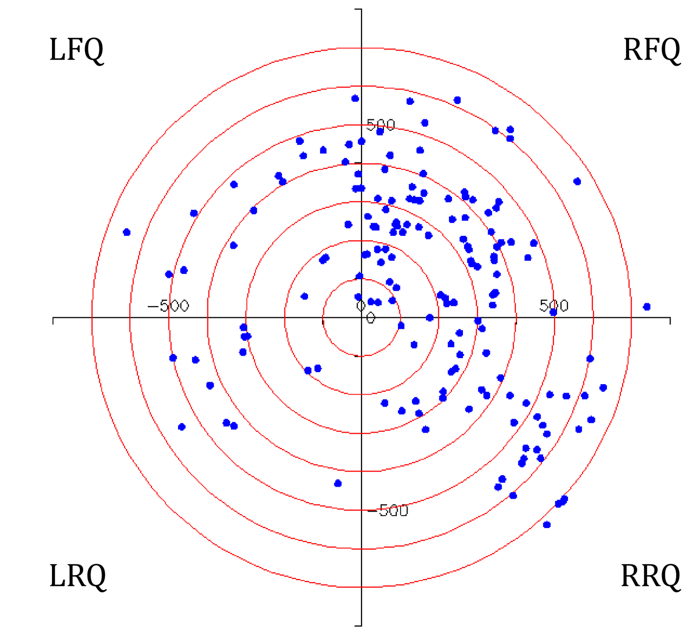


Fig. 3a. TC tornadoes plotted azimuthally in Cartesian coordinates **with respect to storm motion**. Range rings are in 100 km increments.

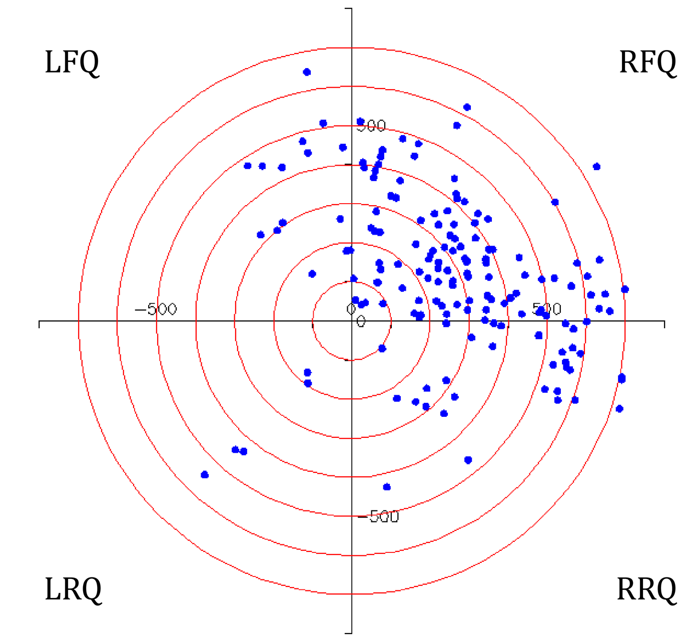
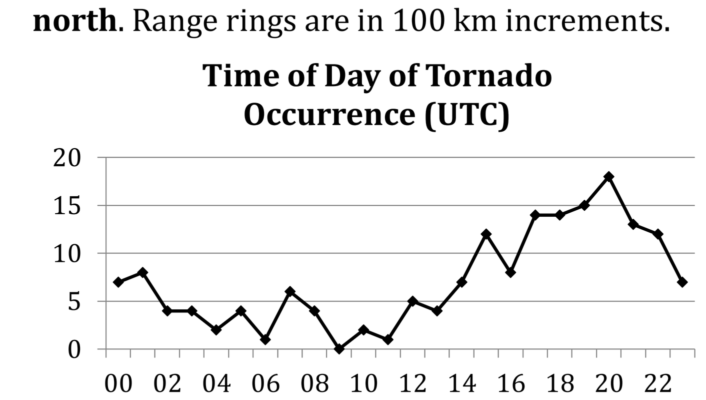


Fig. 3b. TC tornadoes plotted azimuthally in Cartesian coordinates **with respect to true north**. Range rings are in 100 km increments.

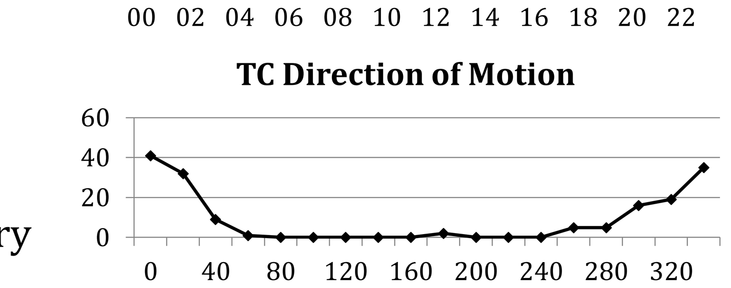
C. Time of Day

- It is hypothesized that the majority of tornadoes will occur in the afternoon, due to the effects of daytime heating and maximized CAPE during this time frame
- The results conclude that the hypothesis holds, however, the peak in tornado occurrence occurred a few hours after the Schultz et al. maximum



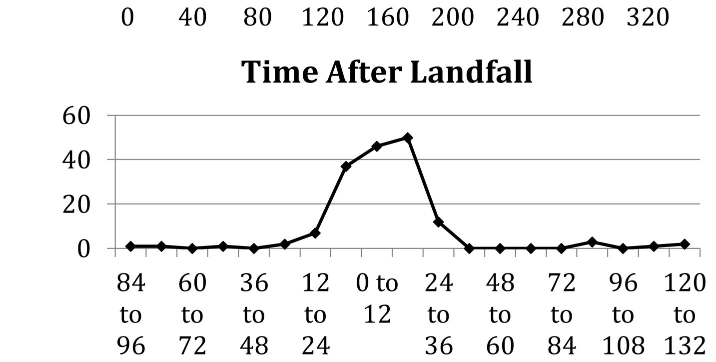
D. TC Direction

- The majority of tornadoes are hypothesized to occur when the TC is moving between 270 and 90 degrees (due to the fact that this study studies only TCs in the northern hemisphere)
- The hypothesis holds in this case



E. Time from Landfall

- The majority of tornadoes are hypothesized to occur between 12 hours before and 12 hours after landfall, as this is the time that the primary rainband would also be making landfall
- The results conclude that although the majority of tornadoes occurred within the hypothesized time frame, the peak occurred 12 to 24 hours after landfall



IV. Case Studies

Tornadogenesis within tropical cyclones is an area of large uncertainty within tropical meteorology. Dual-Doppler Analysis is an excellent tool that can be used to help address this issue and was performed on a tornado-warned distant rainband supercell of Hurricane Isaac and the primary rainband of Tropical Storm Fay as it went through the dual-Doppler lobes and spawned a tornado. Isaac and Fay were ideal case studies chosen for a few different reasons: (1) they are cases in which the University of Alabama in Huntsville (UAH) Mobile X-Band (MAX) Radar deployed, (2) the rainbands of the storms were of differing orientations to the coast upon landfall, and (3) the majority of tornadoes spawned in Isaac were out of the distant rainbands and the majority of tornadoes spawned in Fay were out of the primary rainband.

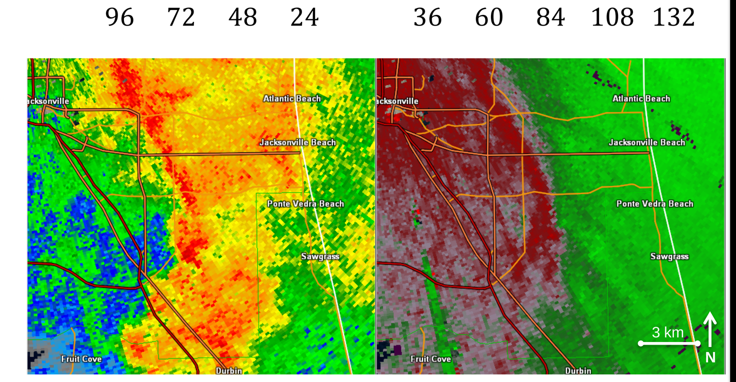


Fig. 4. Tropical Storm Fay tornado warned system (EF0 tornado confirmed), 23 August 2008, 2203z

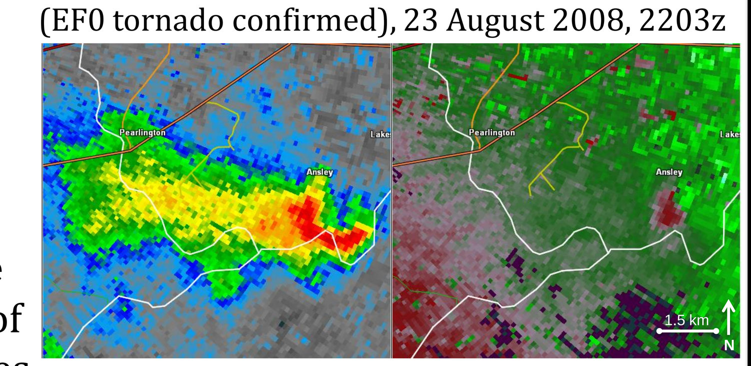


Fig. 5. Hurricane Isaac tornado warned supercell, 28 August 2012, 1650z

A. Tropical Storm Fay

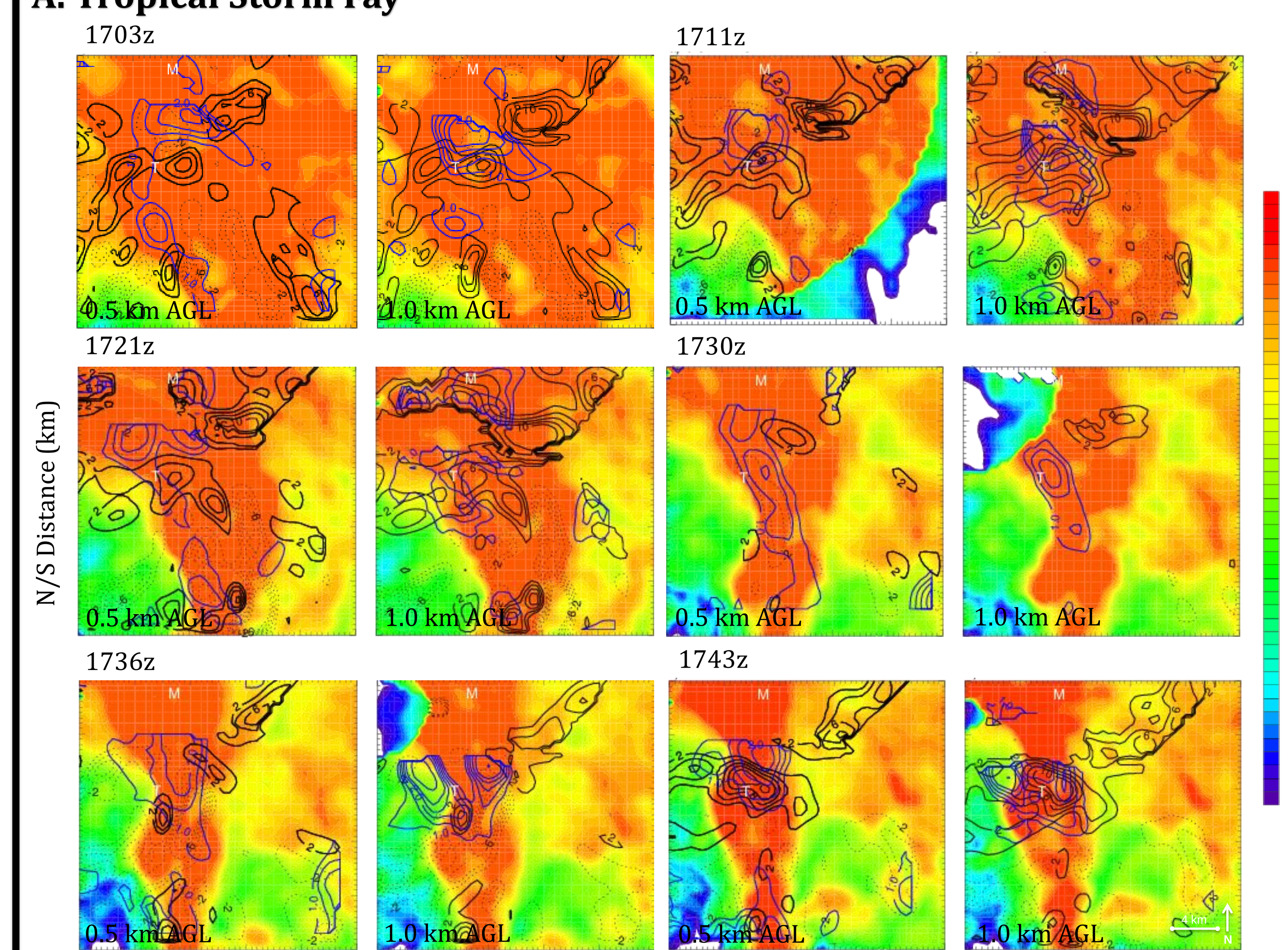


Fig. 6. Time series of Tropical Storm Fay reflectivity (dBZ), vertical motion (black contours, m/s) and vertical vorticity (blue contours, 10^{-2} s^{-1}). Tornado reported at 1740z.

B. Hurricane Isaac

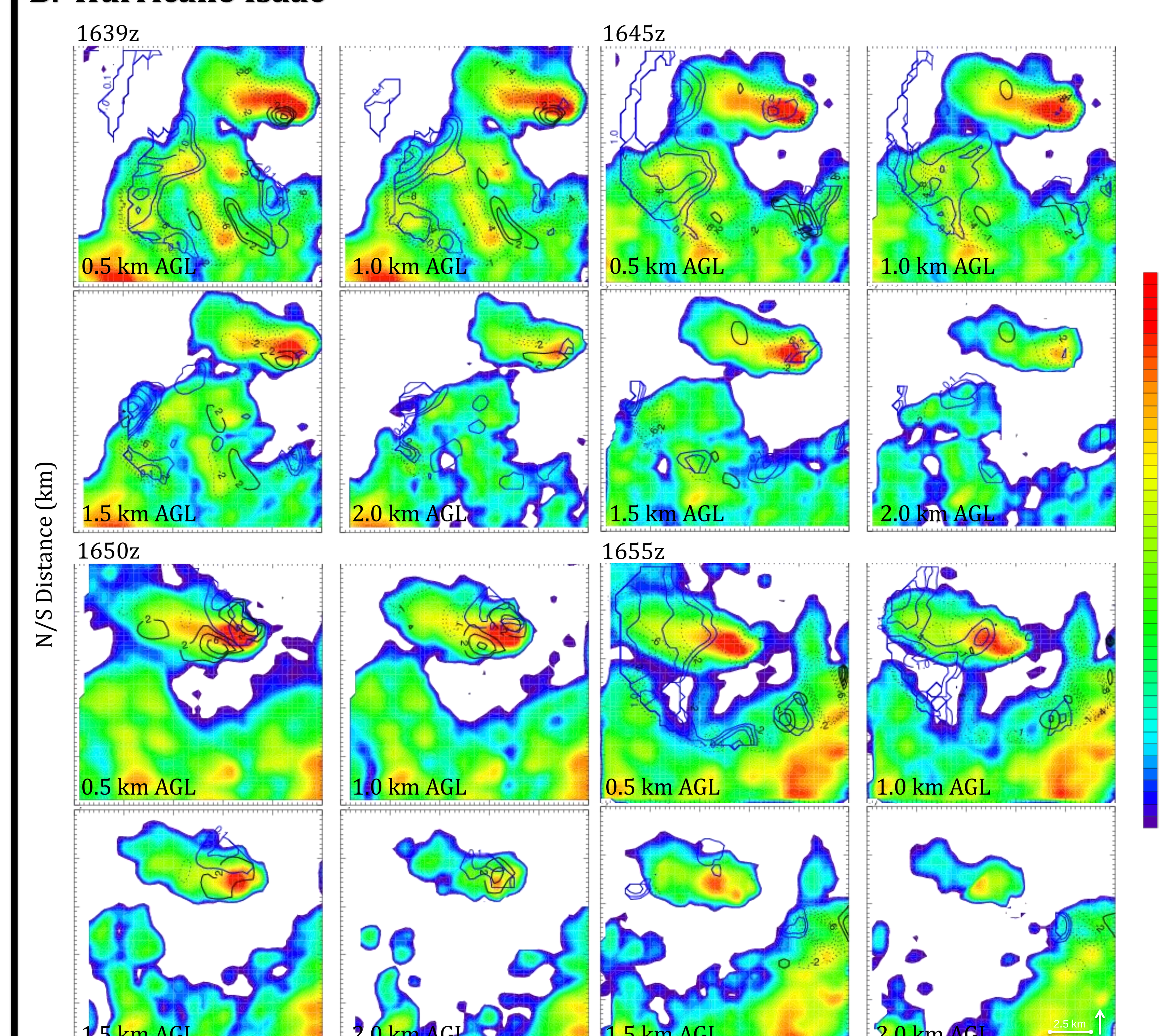


Fig. 7. Time series of Hurricane Isaac reflectivity (dBZ), vertical motion (black contours, m/s) and vertical vorticity (blue contours, 10^{-2} s^{-1}). Supercell warned at 1655z.

V. Conclusions & Future Work

The Schultz et al. database is consistent with the expanded one here. The only major difference was in the azimuthal distribution, storm motion plot, but the discrepancy is resolved when eliminating distant rainband tornadoes. No formal conclusion can be formed from the dual-Doppler analysis results. Future work includes quality checking the dual-Doppler work and performing dual-Doppler analysis on a longer time series to see how the vorticity evolves over time.