A Climatological Perspective on Tornado Outbreaks Spawned by Landfalling Tropical Cyclones Across the Eastern U.S.

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Background

- Upon making landfall, tropical cyclones (TCs) typically spawn tornadoes within their right-forward quadrant, but the strength and frequency of these tornadoes can be quite variable on a case-by-case basis. For example, Hurricane Ivan (2004) generated an extraordinary 3-day outbreak of 118 tornadoes across 9 states, while Hurricane Dennis (2005), despite a remarkably similar surface strength and landfall location, produced a mere 10 tornadoes, with all but one occurring in the state of Florida (Fig. 1).
- Previous studies (e.g. Curtis (2004) and Baker et. al (2009)) have associated TC tornado outbreaks with strong mid-level vorticity, high convective available potential energy (CAPE), and the presence of a dry air intrusion.
- In order to determine how the most prolific tornado outbreaks are generated, this poster examines 33 landfalling TCs along the Gulf Coast of the United States (excluding Texas). They are analyzed through a synoptic conceptual framework that distinguishes the TC in terms of its location with respect to the mid-latitude westerlies.

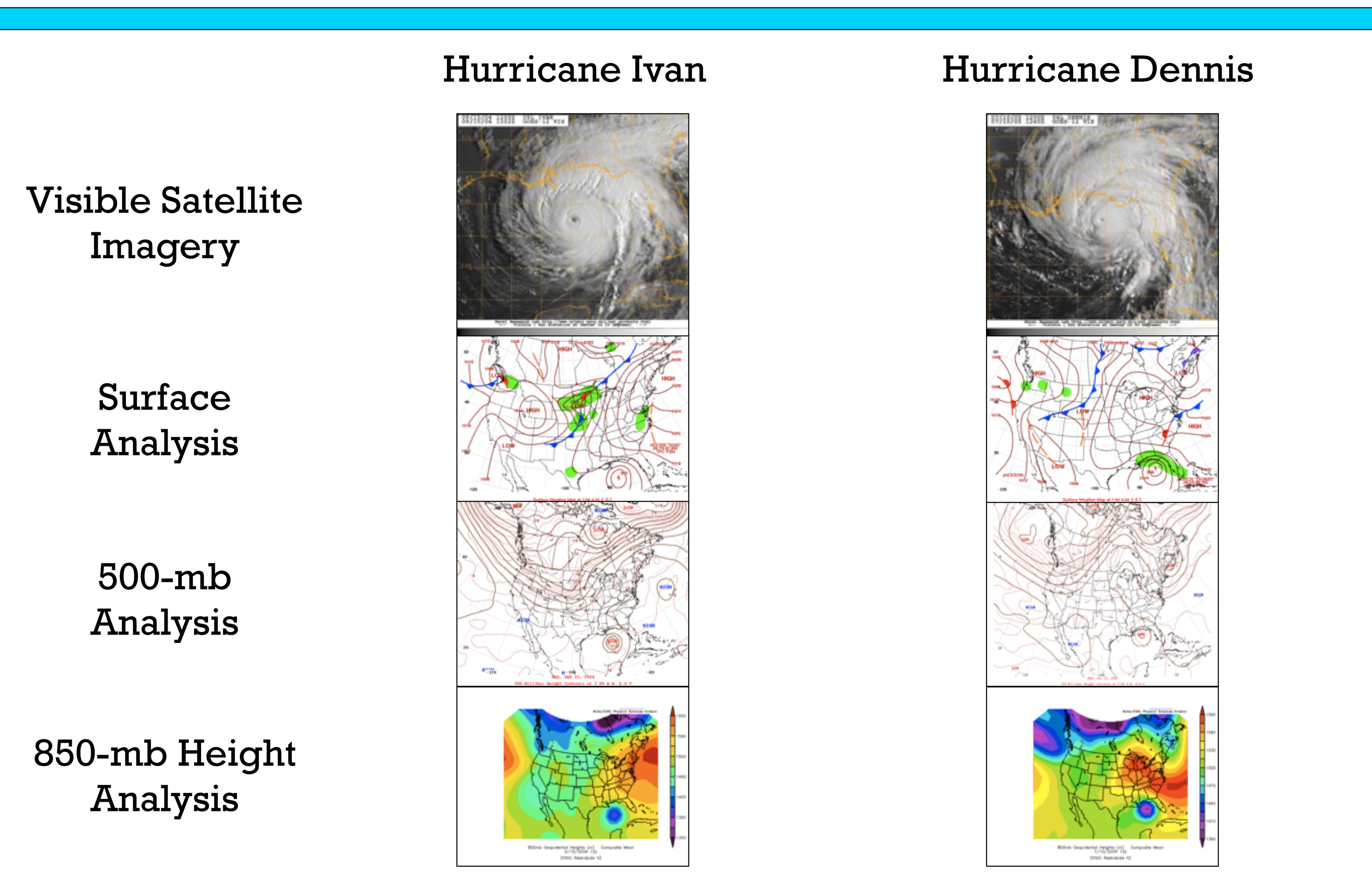

Fig. 1: Comparison near landfall of the prolific tornado-spawning Hurricane Ivan (12Z on September 15, 2004) and the exceptionally non-tornadic Hurricane Dennis (12Z on July 10, 2005)

Research Questions

- What sort of atmospheric environment encourages TC tornadogenesis (e.g. weak vs. strong vertical wind shear, presence vs. absence of dry air)?
- How does this favorable tornadogenesis environment relate to the location of the TC relative to the mid-latitude circulation?

Methodology

- This study examined all tornadoes associated with TCs that made landfall along the Gulf Coast from 1995-2009. Atlantic landfalling TCs were not included in this study as 88% of TC tornadoes in the U.S. are associated with Gulf landfalling systems.
- For this analysis, the total tornado production for each Gulf TC was segregated into daily "mini-outbreaks" (days with ≥6 tornadoes) or "non-outbreaks" (days with <6 but >0 tornadoes) using Roger Edwards's *TCTOR* database.
- Each tornado day (i.e. mini-outbreak or non-outbreak) was assigned to one of four synoptic stages on the basis of the location of the TC relative to the mid-latitude circulation (Fig. 2).
- The aggregate power or destructive potential of the tornadoes observed on each day was estimated through the calculation of "Fujita miles" (Box 1).
- Using daily synoptic charts, archived tropospheric map analyses, atmospheric soundings, and HYSPLIT back trajectories, the values of the following circulation variables were estimated in the vicinity of the TC: 500-mb height and wind speed, 850-mb height and wind speed, and the horizontal speed and direction of motion.
- The tornado day destructiveness (i.e. Fujita miles) was correlated with circulation variables across the four synoptic stages (Fig. 3). Additionally, T-tests were computed to determine which circulation variables effectively distinguished days with no Fujita miles (i.e. bottom tercile of tornado destructiveness) versus those with many Fujita miles (top tercile of tornado destructiveness). These tests were computed across each stage of the TC life cycle.
- Lastly, the size of each TC was estimated at landfall and associated with circulation variables that effectively distinguish tornado destructive potential across the four TC synoptic stages.

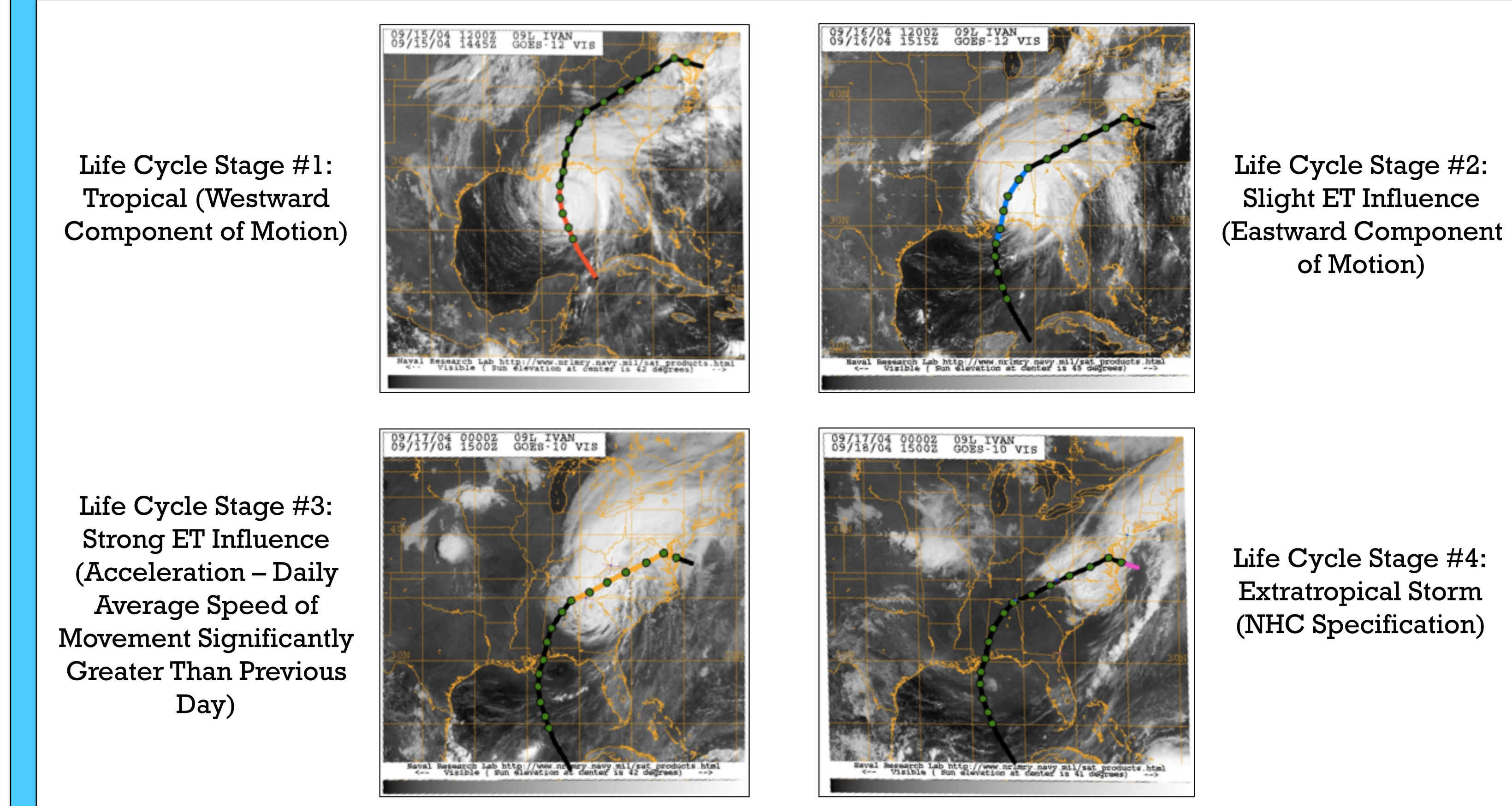

Fig. 2: The four life cycle stages of Hurricane Ivan from September 15-18, 2004

Box 1: The "Fujita Miles" Concept

Fujita miles is defined as the F/EF level of a tornado multiplied by its track length.
Mathematically, this translates into the following formula:
F/EF level (0-5) * track length (miles) = Fujita miles

Because the reported F/EF level represents the *maximum* level assigned along the tornado track, this metric overestimates the true intensity of a tornado. However, this overestimation bias should be minimal as most TC tornadoes are weak (i.e. F/EF-0 or F/EF-1).

Sample Correlations between Fujita Miles of a TC Tornado Mini-Outbreak/Non-Outbreak and TC Attributes (n = 91)	
TC Attribute	Correlation
Highest 850-mb Wind Speed over Approximated Centroid of Tornado Mini-Outbreak/Non-Outbreak Region	0.29
Lowest 500-mb Height	-0.28
Highest 500-mb Wind Speed in RF Quadrant	0.25
Lowest 850-mb Height	-0.16
Horizontal Speed of Motion	0.08
Horizontal Direction of Motion	0.00

Fig. 3: Pearson's correlation coefficients between the Fujita miles of TC tornado outbreak days and various TC attributes (n = 91)

TC Fujita Miles by Life Cycle Stage

- The tercile analysis (Fig. 4) reveals that the first life cycle stage ("Tropical") contains the greatest proportion (relative to the other three life cycle stages) of TC tornado days with low tornado production (1st tercile or 0 EF-miles).
- The third life cycle stage ("Strong ET Influence") contains the greatest proportion of TC tornado days with high tornado production (3rd tercile or 10.1-294 EF-miles).
- TC Fujita miles per tornado day is greatest (~34 EF-miles) in the third stage (Fig. 5).

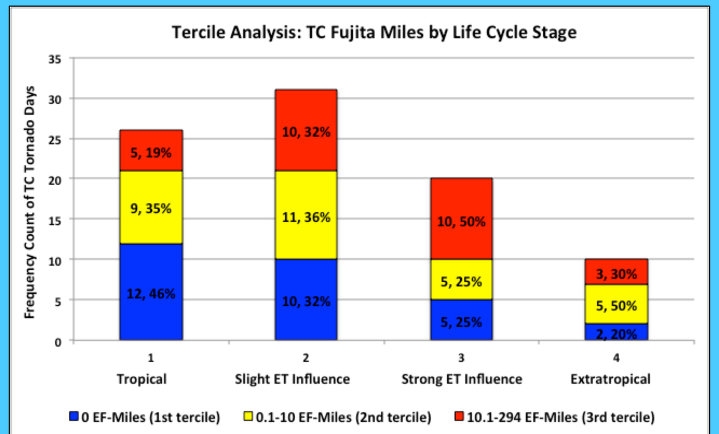

Fig. 4: Tercile analysis tracing the frequency distribution of TC tornado day magnitudes (measured in Fujita miles) across four TC life cycle stages

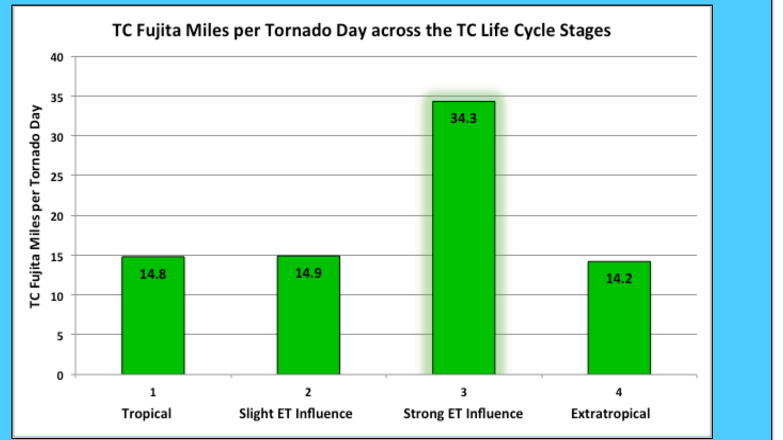

Fig. 5: TC Fujita miles per tornado day across the TC life cycle stages

TC Circulation Strength by Life Cycle Stage

- The 850-mb circulation strength variables, particularly the wind speed, show a positive relationship with TC tornado production across the first three life cycle stages.
- Based on the results of the tercile analysis and Student's t-tests presented (Fig. 6), the 500-mb height and wind speed variables are not statistically significant indicators of prolific TC tornadogenesis, with the exception of 500-mb wind speeds in the second life cycle stage.
- The statistically insignificant results associated with the fourth life cycle stage may be tied to an insufficient sample size.

Tercile Analysis and Student's T-tests: TC Circulation Strength by Life Cycle Stage				
TC Circulation Parameters	TC Life Cycle			
	Stage #1	Stage #2	Stage #3	Stage #4
500-mb Height	NSS	NSS	NSS	NSS
500-mb Wind Speed (m/s)	NSS	SS (p-val < 0.005)	NSS	NSS
850-mb Height	NSS	NSS	SS (p-val < 0.05)	NSS
850-mb Wind Speed (m/s)	SS (p-val < 0.05)	SS (p-val < 0.05)	SS (p-val < 0.005)	NSS

Fig. 6: Student's t-tests comparing mean TC circulation strength variables by terciles of TC Fujita miles [Red coloration indicates statistically significant values]

TC Size by Life Cycle Stage

Is there a viable physical relationship that can explain why TCs with strong upper-level circulations tend to spawn the most prolific tornado outbreaks? What about the size (the area within the outermost closed isobar) of TCs?

- Based on a tercile analysis that traces the Fujita mile production associated with large and small TCs across all four life cycle stages, large TCs are associated with a disproportionate number of moderate-to-extreme tornado outbreaks, particularly within the third life cycle stage. In stark contrast, small TCs are tied to a disproportionate number of minor-to-moderate tornado outbreaks (Figs. 7-8).
- Student's t-tests confirm that the mean 850-mb circulation strength of the largest (3rd tercile) Gulf TCs is statistically stronger than that of the smaller (1st and 2nd tercile) TCs.
- The results (Fig. 9) indicate a positive relationship between TC size and circulation strength verifies across all four life cycle stages (with the sole exception of 850-mb wind speeds in the fourth stage).

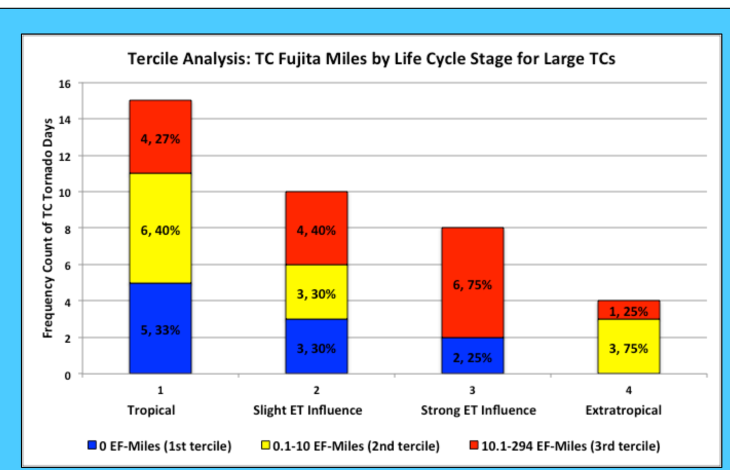

Fig. 7: Frequency distribution of TC Fujita miles associated with large TCs across the four TC life cycle stages

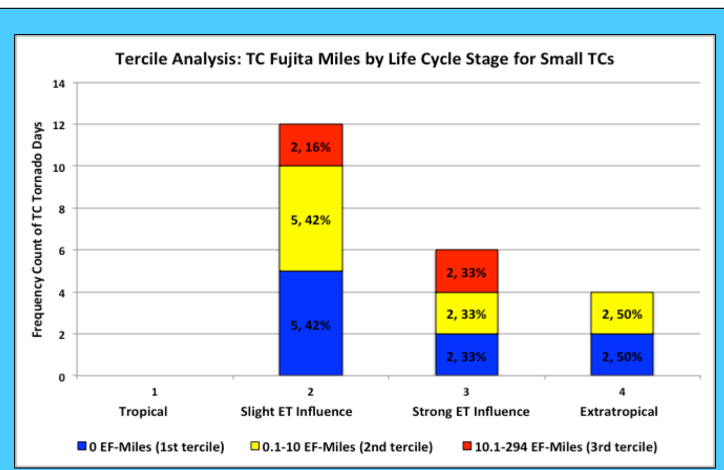

Fig. 8: Frequency distribution of TC Fujita miles associated with small TCs across the four TC life cycle stages

Tercile Analysis and Student's T-tests: TC Circulation Strength by Life Cycle Stage				
TC Circulation Parameters	TC Life Cycle			
	Stage #1	Stage #2	Stage #3	Stage #4
850-mb Height	SS (p-val < 0.05)	SS (p-val < 0.001)	SS (p-val < 0.01)	SS (p-val < 0.001)
850-mb Wind Speed (m/s)	SS (p-val < 0.01)	SS (p-val < 0.05)	SS (p-val < 0.001)	NSS

Fig. 9: Student's t-tests comparing mean TC circulation strength variables at the 850-mb level by terciles of TC size [Red coloration indicates statistically significant values]

Conclusions and Future Work

- Significant tornado outbreaks can occur within any of the four TC life cycle stages, but the greatest frequency are by far associated with the third stage, when the TC accelerates with an eastward component of motion.
- The most prolific tornado-spawning TCs tend to be large in size and possess strong circulations at the 850-mb level, particularly during the third life cycle stage. This suggests that strong shear (i.e. rapid increase in wind speed with height) is associated with large TCs and increases the threat for land-based tornadogenesis.
- This suggests that the size and 850-mb strength of a Gulf-landfalling TC can serve as useful predictors of the potential for enhanced tornadogenesis.