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Cool Season Tornadoes in the Southeast United States: A Climatological and Case Study Perspective

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1. Introduction

Previous research has shown that there is a relatively high frequency of tornadoes in the overnight-to-early-morning hours during the cool season in the southeastern United States (US), particularly in areas close to the Gulf of Mexico. For example, most strong and violent tornadoes (F2 or greater) in Florida occur during the cool season, and are associated with extratropical cyclones. Previous research has also documented the importance of the return flow of warm, moist tropical air across the Gulf region (e.g., after the passage of cold fronts through the Gulf) in the development of potential severe weather scenarios along the Gulf coast. The warm Loop Current in the Gulf also can increase fluxes of heat and moisture into this return flow air, which can lead to rapid air mass destabilization. It has also been shown, however, that forecasting the trajectories of return flow air is difficult, and that operational numerical prediction models are not able to accurately forecast the modification of the boundary layer (partially due to lack of data over the Gulf), which can be important in determining the severe weather potential over the Southeast.

The purpose of this study is to examine the climatology of cool season tornadoes in the Southeast, and to investigate the synoptic scale forcing mechanisms that are often responsible for initiating these events.

2. Data and Methodology

Storm Data was used to create a climatology of tornado reports in the southeast US. Only reports of F2 or greater magnitude were considered, as reporting of strong tornadoes has not increased during the time period considered, 1950-2001. The number of F0 and F1 tornado reports across the Southeast increased dramatically during this time period, and thus are not considered in the climatology. The cool season was defined as November through March.

NCEP/NCAR Reanalysis data (2.5° x 2.5°) was used to create a tornado-relative composite of all tornado episodes which began between 0000 and 0600 UTC. The grids were translated so that the grid point closest to the first tornado of each episode lay at 32° N, 90° W.

3. Climatology

Although there is a relatively small number of cool season tornadoes (greater than or equal F2) in the southeast US, some useful signals can be extracted from the reports when the climatology is stratified according to the topography of the Southeast. Figure 1a shows the area of the southeast US used in this study. The area south of 36.5° N was divided into sub-regions which were loosely based on the topography. In each of the sub-areas (as well as in the Southeast as a whole), cool season tornadoes (greater than or equal F2) account for approximately half of all F2 or greater tornadoes. In all regions of the southeast US, a primary (springtime) and secondary (cool season) peak of tornado occurrence is present in the monthly distribution (Fig. 2a). The Florida peninsula (FL) differs from other regions of the Southeast in that the secondary peak occurs during the months of January and February rather than November and December (Fig. 2a).

Previous research has shown that cool season tornadoes can occur at any time of day, especially during the overnight hours (Anthony 1988; Fike 1993). However, the diurnal distribution of cool season tornadoes depends greatly on the area defined as the southeast US. Mountainous regions such as the Ozarks (OZ) and Appalachians (AP) exhibit a strong diurnal signal in cool season tornadoes, with a large fraction of tornadoes occurring during the peak diurnal heating time near 0000 UTC (Fig. 2b). Regions near the Gulf coast, as well as the Mississippi River valley (CO, MR) have a strongly damped diurnal signal, as well as a weak secondary peak of tornadoes during the overnight or early morning hours near 1200 UTC (Fig. 2b). The diurnal distribution of tornadoes in FL differs from other regions of the southeast US, as does the monthly distribution. The tornadoes exhibit a trimodal peak,

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with one peak during the peak diurnal heating (1800-0000 UTC), and two nocturnal peaks (0300-0600 UTC, and 0900-1200 UTC).

4. Composite Analysis

Episode-relative composites of tornado episodes in the southeast US lend insight into the dominant large-scale forcing mechanisms which are present during these events. The composites were created based on the closest 6 h synoptic time in the NCEP/NCAR Reanalysis data, in order to determine whether tornado episodes which begin during the overnight hours look similar or dissimilar to those which occur begin during the peak diurnal heating time. Only the 0000-0600 UTC start time will be discussed in this preprint. Events which began during this time were composited using NCEP/NCAR reanalysis data from 0000 UTC in order to obtain picture of the synoptic scale environment just prior to the first tornado. Geography shown in the composite figures is for scale reference only, as the grids have been translated so that the first tornado occurs at the point marked with an X in the figure (Fig. 3). The composite is made up of 393 members, which encompasses all tornado episodes from 1950 to 2001 that began between 0000 and 0600 UTC.

The location of the first tornado in the composite occurs downstream of a 500 hPa trough on the southern edge of the area of cyclonic vorticity advection (Fig. 3a). More striking is the presence of a greater than 44 m s^{-1} jet core at 200 hPa. The first tornado occurs directly underneath the equatorward entrance region of the upper-level jet. There is the suggestion of the presence of an upstream jet core at 200 hPa as well, with the 40 m s^{-1} contour extending back to the south and west of the first tornado. North-south cross sections taken through the tornado show strong upper-level divergence in the equatorward entrance region of the upper level jet, which is strongest between 200 and 250 hPa (not shown). The first tornado also occurs underneath a region of warm air advection at 850 hPa (Fig. 3c), in the southerly flow out ahead of the surface low (Fig. 3d). There is a southwesterly low-level jet of greater than 14 m s^{-1} in the composite (not shown), a feature which operational forecasters have often observed to be present during cool season tornado episodes in the southeast US (Bob Johns and Steve Weiss, personal communication). The strong low-level flow helps to created a ridge of warm moist air which noses northward towards the first tornado. This is evidenced by the ridge of high equivalent potential temperature (θ_e) air present at 850 hPa in the composite (Fig. 3f). A composite sounding taken at the location of the first tornado indicates the presence of a veering wind profile with warm air advection in the low levels, convective available potential energy (CAPE) of 347 J kg^{-1}, and a low lifting condensation level (LCL) of 972 hPa (not shown). The net result of the cyclonic vorticity advection at 500 hPa, warm air advection at 850 hPa and presence of a favorably positioned upper level jet is quasi-geostrophic forcing for ascent, as indicated by the vertical motion maximum at 700 hPa (Fig. 3e). The large-scale forcing for ascent, combined with instability, low-level moisture, and strong vertical wind shear (speed and directional) result in a favorable setup for severe weather in the composite sense.

5. Conclusions

A secondary peak of tornado occurrence is present during the cool season in the southeast US. The time of the cool season in which this secondary peak occurs varies depending on location, as does the diurnal timing of cool season tornadoes. A tornado-relative composite of 393 members encompassing all tornado episodes beginning between 0000 and 0600 UTC shows strong large-scale forcing for ascent, as well as the presence of instability, low-level moisture, and vertical wind shear. Future work will include the creation of tornado relative composites of tornado events which began at different times of day to determine whether there is something inherently different about the large-scale forcing of nocturnal tornado events which begin after 0600 UTC. Additionally, future work will include examination of individual tornado events for the presence of mesoscale features (e.g.; outflow boundaries, baroclinic zones) to determine their role in the evolution of these tornado episodes.

6. Acknowledgement

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7. References

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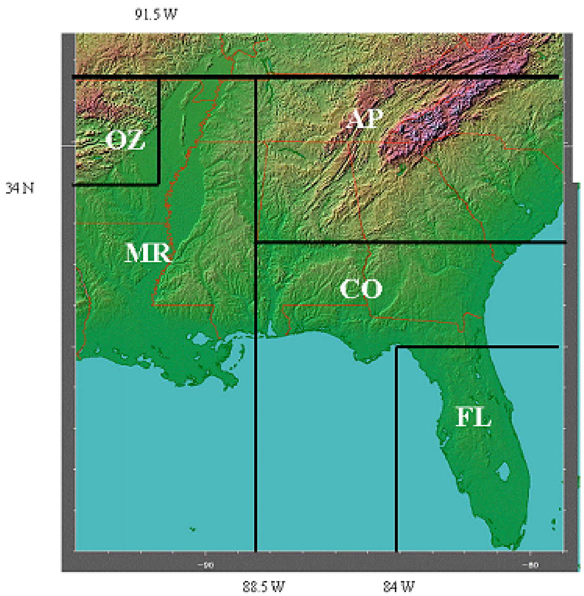

a)

	Number >=F2 Tornadoes	Number Cool Season >=F2 Tornadoes
FL	228	115
CO	396	210
AP	976	460
M R	1071	560
OZ	250	142

b)

Fig. 1: a) Area of study and sub-regions of southeast US, b) table of number of greater than or equal F2 tornadoes for whole year and cool season for each sub-region.

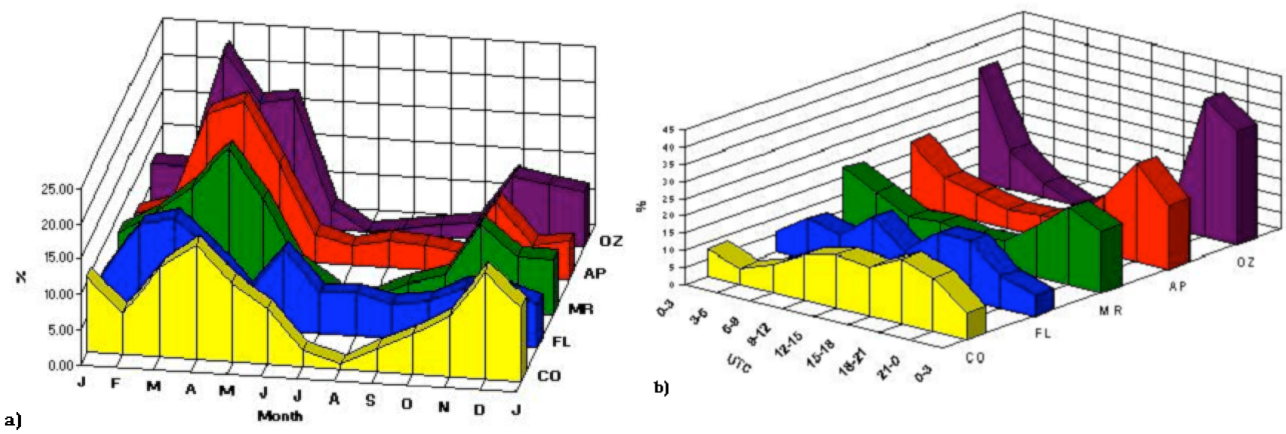

Fig. 2: Percent F2 or greater tornadoes a) per month and b) per hour (UTC) for each sub-region of southeast US.

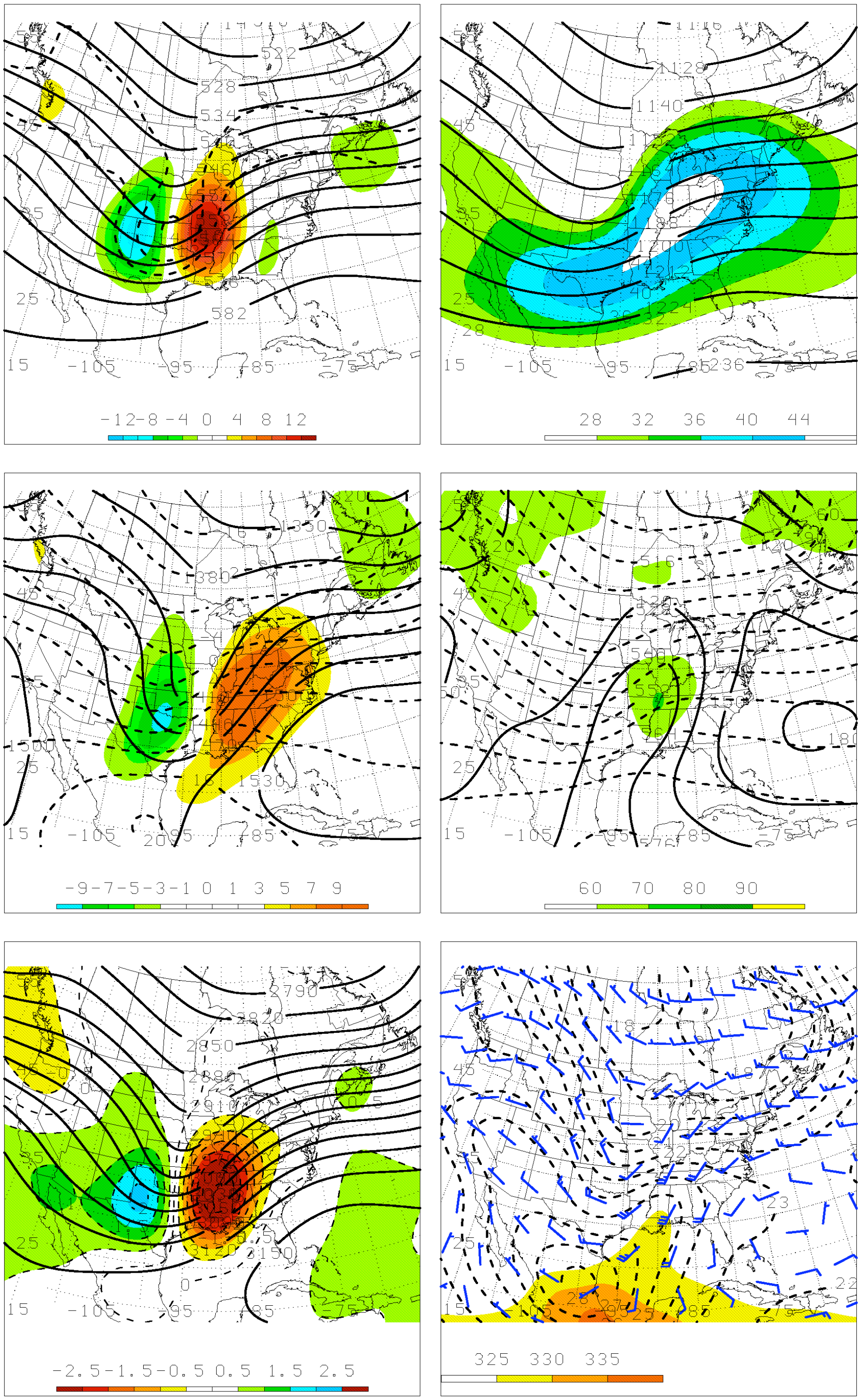

Fig. 3: 0000-0600 UTC tornado-relative composite a) 500 hPa height (dam, solid), absolute vorticity (x 10^{-5} s^{-1}, dashed), and vorticity advection (x 10^{-10} s^{-2}, shaded), b) 200 hPa height (dam, solid) and isotachs (m s^{-1}, shaded), c) 850 hPa height (m, solid), temperature (°C, dashed) and temperature advection (x 10^{-5} °C s^{-1}, shaded), d) 1000 hPa height (m, solid), 1000-500 hPa thickness (dam, shaded), and 700 hPa relative humidity (%, shaded), e) 700 hPa height (m, solid) and vertical motion (x 10^{-3} hPa s^{-1}, shaded), and f) 850 hPa θ_e (K, shaded), winds (barbs, kt), and 850-500 hPa lapse rate (°C, dashed).