AN EXAMINATION OF THE CONTRASTING EVOLUTION OF TWO SOUTHEAST UNITED STATES COOL-SEASON SEVERE WEATHER EPISODES

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1. Introduction:

On 22-23 February 1998, a violent tornado outbreak struck central Florida after sunset, and extended into the early morning hours of 23 February. The tornadoes resulted in 42 deaths and 259 injuries. In addition, significant property damage occurred across a wide area of central Florida. In total there were three F3 tornadoes reported, 2 F2 tornadoes, and 5 F1 and F0 tornadoes. On 2-3 February 1998, severe weather, including seven tornadoes and many high wind reports, occurred across south Florida. While eventually this project will compare these two Florida tornado outbreaks, the primary focus of this paper is to compare and contrast the contributions of the large-scale and the mesoscale forcing to focusing and intensifying the convection which moved through central Florida on 22-23 February 1998.

As can occur with many cool season tornado outbreaks in the southeast United States, the 22-23 February 1998 outbreak occurred after dark (Anothony 1988, Fike 1993). Large scale forcing was present as a potent 500 hPa trough moved eastward towards the area. Central Florida lay roughly in the right entrance region of the subtropical jet (a favorable region for enhanced upward motion) for the twenty-four hour period preceding the outbreak. Strong thermal advection in the lower troposphere was occurring during the hours preceding the event as the low-level low pressure system moved towards the area. During the twenty-four hour time period preceding the outbreak, a remarkably strong low-level baroclinic zone developed across central Florida and moved slowly northward with time. As the convection initiated and intensified, the baroclinic zone appeared to become associated with the southward moving, east-west oriented line of convection out of which the tornadoes developed.

The purpose of this investigation is to examine the role of mesoscale forcing mechanisms (e.g., pre-existing surface boundaries; frontogenesis) in the intensification of the line of convection which eventually resulted in tornadogenesis. A synoptic scale analysis will be presented, and the role of the large-scale forcing in the development of this event will be analyzed.

2. Synoptic Scale Evolution:

Forty eight hours before the tornadoes occurred, split flow was in place across the western US. A potent 500 hPa trough was swinging through the desert Southwest. In the northern stream, a highly amplified ridge was in place. Winds at the 200 hPa level across the Southeast exceeded 80 m s^{-1} as the southern and northern streams merged. A strong baroclinic zone was present in the lower troposphere over southern Florida as cold air from a previous cold surge encountered warm, moist tropical air. This baroclinic zone was persistent throughout the duration of the event. Between 48 and 24 hours before the event, the upper level jet above the southeast US intensified rapidly to over 90 m s^{-1}, but the core of the jet had begun to move offshore by 22/1200 UTC. Warm air advection was beginning at the surface and 850 hPa as the wave moved towards the region of strong thermal gradient. Flow over Florida at 500 hPa was beginning to amplify in the southern stream with the approach of the trough.

By 12 hours before the event (22/1200 UTC), the main vorticity maximum at 500 hPa was located over southern Louisiana. At 850 hPa, the thermal gradient had sharpened around the 850 hPa low, and a 23 m s^{-1} southwesterly jet developed ahead of the low. This jet, located in the central Gulf at 1200 UTC, moved eastward during the day on 22 February with the system, and by 23/0000 UTC was located over the region where the tornado outbreak occurred. The large thermal gradient at 850 hPa was still present across north Florida. Soundings across central Florida for 22/1200 UTC indicated a strong veering wind profile, with large directional shear concentrated at low levels and large speed shear aloft, as well as the potential for surface-based CAPE to increase to over 1000 J kg^{-1} given daytime heating and destabilization of the boundary layer (not shown).

By 23/0000 UTC, the baroclinic zone at 850 hPa had moved north into Georgia, but warm air advection was still occurring across central Florida. By 23/0600 UTC, central Florida was under anticyclonic vorticity advection at 500 hPa and cold air advection at low levels. Hence, this tornado outbreak was not long-lived, as the main forcing and destabilization came together for less than a six hour window between 23/0000 UTC and 23/0600 UTC.

Figure 1 shows a north-south cross section of frontogenesis, equivalent potential temperature, vertical motion, winds, and ageostrophic circulation from 41°N, 88°W to 21°N, 78°W for 22/1800 UTC and 23/0000 UTC. This cross section was chosen so as to approximately cut through the upper-level jet as well as the low-level baroclinic zone near the area where the strongest tornadoes occurred. The weakening of the subtropical jet is apparent, and by 22/1800 UTC a strong low-level frontogenesis maximum had

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developed. The strong ascent in the plane of the cross section had not been present at 1200 UTC when no low-level frontogenesis was present. Although vorticity and thermal advection were present to force large-scale ascent at this time, it would appear the rapid increase in frontogenesis is responsible for part of the enhanced vertical motion (via secondary frontal circulation) that occurs by 22/1800 UTC. At this time, a loosely organized, wide band of moderately intense convection was moving southward towards the Florida panhandle, and its intensification as it moved southward appeared to be closely associated with the frontogenesis maximum which appeared by 22/1800 UTC. By 23/0000 UTC, the continued eastward motion of the core of the upper-level jet east of the cross section is implied as the core of maximum winds in the cross section continues to decrease. At 23/0000 UTC, there is still a frontogenesis maximum in roughly the same area as at 22/1800 UTC. While the magnitude of the frontogenesis has weakened somewhat, it also has become more concentrated at low levels.

3. Role of Surface Features:

Figure 2 shows frontogenesis interpolated from the surface observations on 23 February between 0200 and 0500 UTC. Sustained strong frontogenesis was occurring across north-central Florida before and up to the time the strong tornadoes occurred. At 22/2200 UTC (Fig. 2a), the surface boundary is draped across the northern Florida peninsula, and is associated with the main band of convection. Confluent winds associated with this boundary result in a maximum of surface frontogenesis which remains draped across central Florida. The maximum in frontogenesis does not weaken until 23/0500 UTC. Another factor which likely helped develop the strong frontogenesis was the trajectory of the surface winds across the ocean before converging at the thermal boundary. Off the southern tip of Florida, the Gulf Stream waters are approximately 3 °C warmer than normal (not shown), which likely enhanced the θ_e values of the air advected into south Florida by the 10 to 20 kt southerly surface winds. In addition, the waters west of the Gulf Stream just off the northeastern Florida coastline were more than 4 °C below normal (not shown). Surface winds to the south (north) of the boundary were blowing across anomalously warm (cool) sea surface temperatures off the Florida coast, which likely helped enhance the baroclinicity across the Florida peninsula.

Figure 3 shows the surface vorticity interpolated from the surface winds from 0200 to 0500 UTC on 23 February. As the northeasterly winds north of the boundary turned more easterly with time and a wind shift line approached central Florida from the west, surface vorticity increased rapidly, and by 23/0400 UTC a band of relatively high surface vorticity was draped across central Florida. As the squall line moved into this region of high vorticity, it began to break apart into a line of supercell storms, and rapidly became tornadic. All of the strongest (F3) tornadoes in this outbreak occurred within an hour of 23/0500 UTC.

4. Conclusions

Figure 4 shows a timeline of the evolution of this cool-season tornado outbreak. Surface parameters were examined each hour from the hourly surface observations, while upper level parameters were examined at 6-hourly synoptic times for which NCEP Eta model analyses were available. Lift, instability and moisture were determined by examining Eta fields of 700 hPa vertical motion, 850-500 hPa lapse rate, and 1000-850 hPa average θ_e, respectively. The type of squall line was determined by examination of 5-minute base reflectivity radar composites. Tornado times were determined from Storm Data. Strong tornadoes included all tornadoes F2 and greater. Squall line arrows on the timeline indicate when there was a squall line present across the Florida peninsula, and the other arrows on the timeline indicate periods when the parameters exceeded specified thresholds (e.g.: surface vorticity greater than 9×10^{-5} s^{-1}, etc.).

A synoptic-scale environment favorable for convective development existed over the Florida peninsula from 22/1800 UTC through 23/0600 UTC. As the core of the upper level jet had already moved offshore by this time, secondary jet circulations were becoming less important in enhancing ascent than was the appearance of strong low-level frontogenesis from 22/1800 UTC onwards. As the squall line encountered this region of strong frontogenesis, it underwent rapid strengthening, and even produced some weak tornadoes. However, the line did not break into supercells until it encountered the narrow band of rapidly intensifying cyclonic surface vorticity across central Florida. As the line encountered this band of vorticity, the squall line broke apart, and soon after, strong tornadoes developed across central Florida. All the strong tornadoes in this outbreak occurred in a narrow two-hour time span, in a concentrated geographical area. Not long after this occurred, the squall line redeveloped once again into a single intense line of convection. By 23/0600 UTC, most of the synoptic and mesoscale lifting mechanisms had moved away from the Florida peninsula, and thus the event was a very short-lived, intense tornado outbreak.

5. Acknowledgement:

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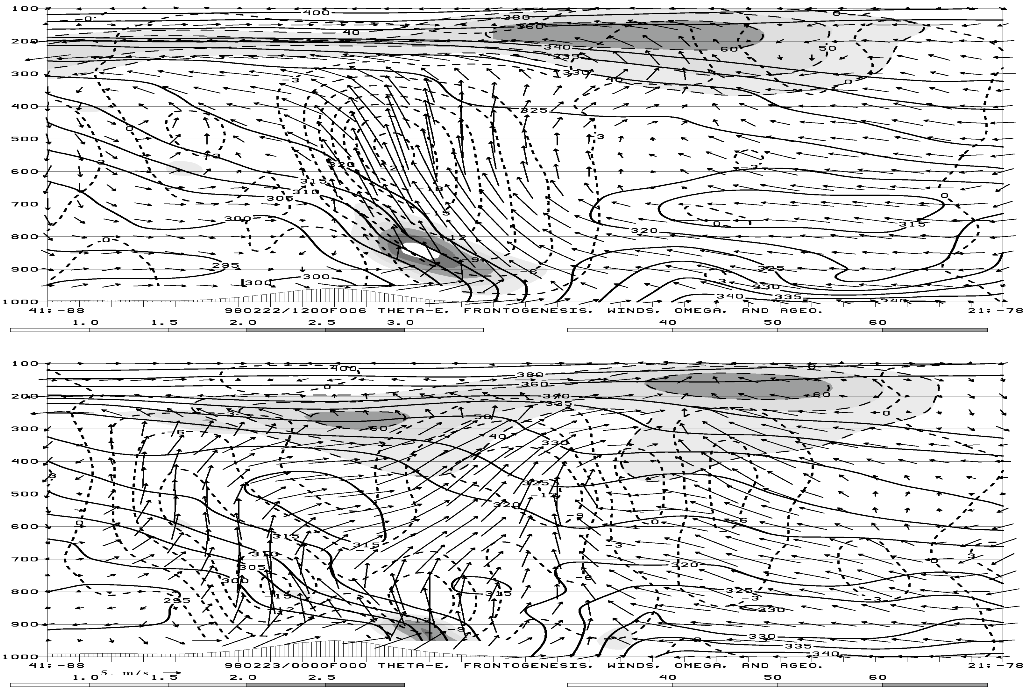

Fig. 1: Cross section of isotachs (shaded, m s^{-1}), frontogenesis (shaded, °C 100 km^{-1} 3 h^{-1}), equivalent potential temperature (solid, K), vertical motion (dashed, x 10^{-3} hPa s^{-1}), and ageostrophic wind (arrows, m s^{-1})for a) 22 February 1998 at 1800 UTC, and b) 23 February 1998 at 0000 UTC.

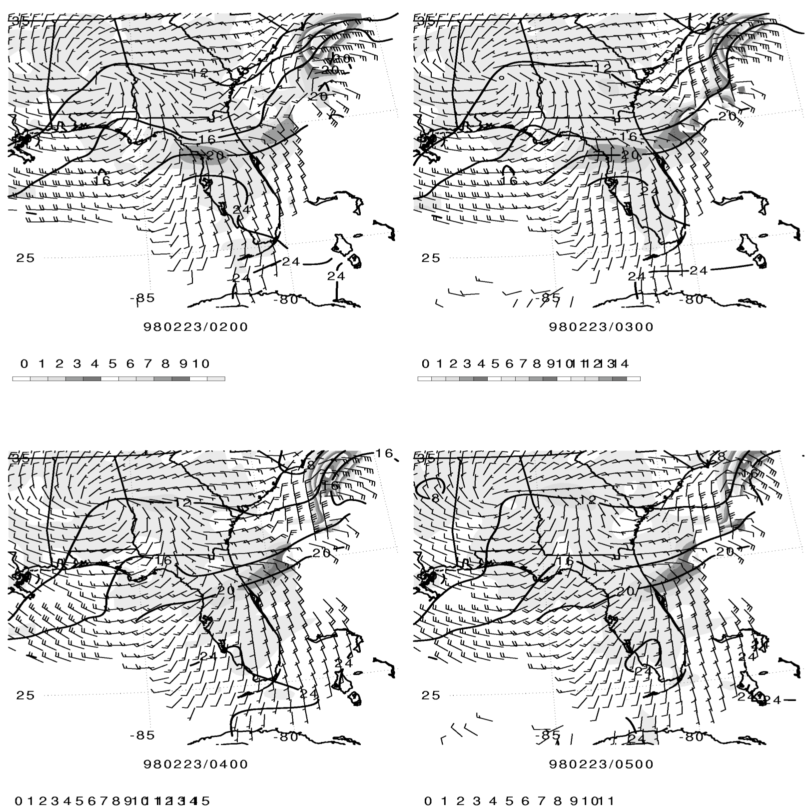

Fig. 2: Surface winds (kt), potential temperature (contoured every 4 °C), and frontogenesis (° C 100 km^{-1} 3 h^{-1} , shaded for positive values) for 23 February 1998 at a) 0200 UTC, b) 0300 UTC, c) 0400 UTC and d) 0500 UTC.

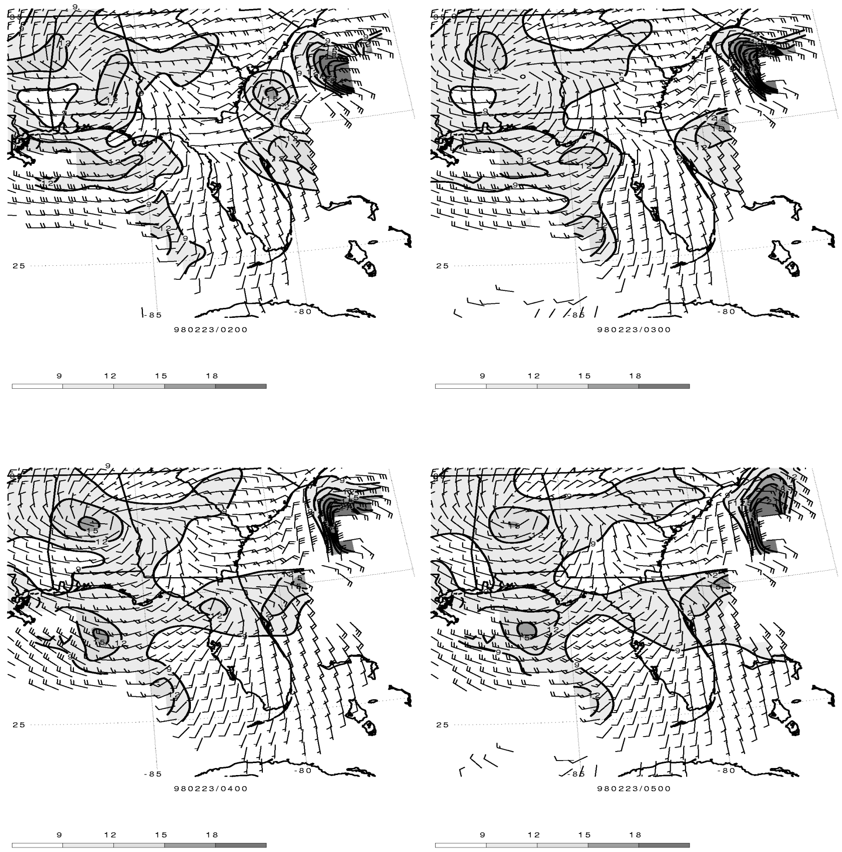

Fig. 3: Surface winds (kt) and vorticity (contoured and shaded greater than 9×10^{-5} s^{-1}) for 23 February 1998 at a) 0200 UTC, and b) 0300 UTC, c) 0400 UTC and d) 0500 UTC.

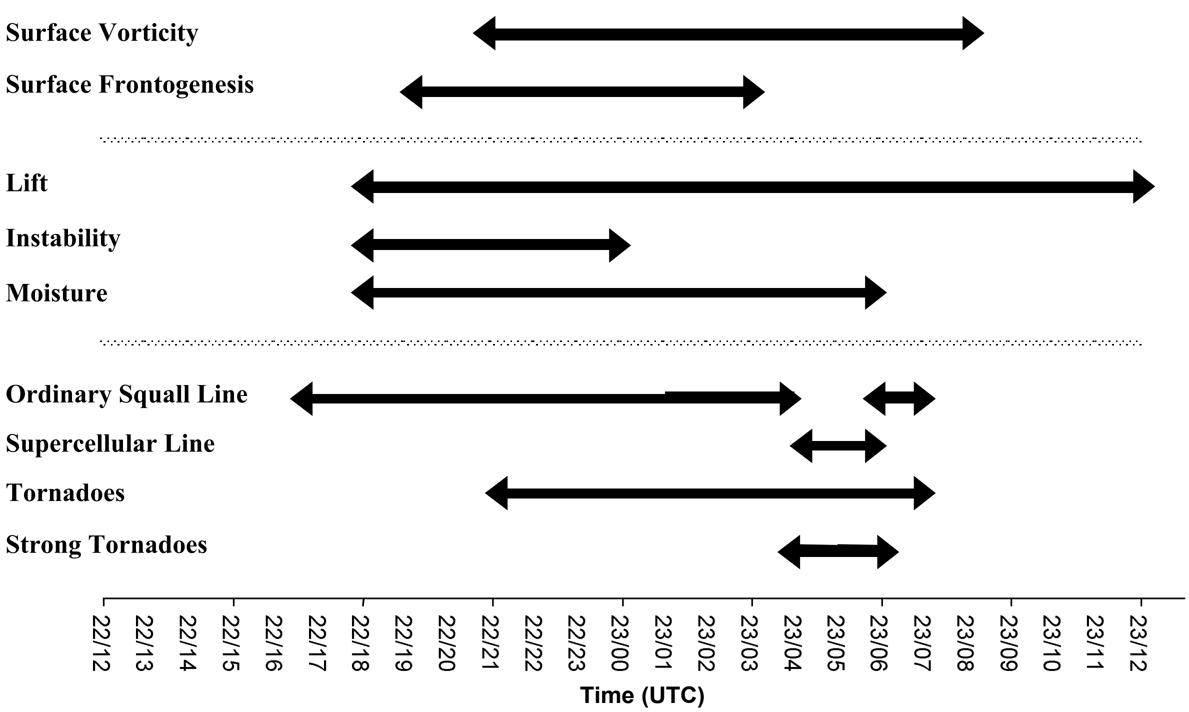

Fig. 4: Timeline depicting when lift, moisture, instability, and surface parameters met or exceeded threshold values in relation to evolution of event.