MESOSCALE ASPECTS OF THE RAPID INTENSIFICATION OF A TORNADIC SQUALL LINE ACROSS CENTRAL FLORIDA: 22-23 FEBRUARY 1998

Alicia C. Wasula* and Lance F. Bosart
University at Albany, State University of New York, Albany, New York

Russell Schneider, Steven J. Weiss and Robert H. Johns
Storm Prediction Center, Norman, Oklahoma

1. Introduction

On 22 February 1998, a significant 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. The tornado reports across central Florida occurred roughly on 23 February between 0200 and 0700 UTC (23/0200 UTC-23/0700 UTC).

As can occur with many cool season tornado outbreaks in the southeast United States, the 22-23 February 1998 outbreak occurred after dark (Anthony 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 a 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. A squall line moving eastward across the Gulf of Mexico underwent rapid intensification and became supercellular as it made landfall and encountered the baroclinic zone.

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.

2. Case Overview

Forty-eight hours before the tornadoes occurred, a split flow pattern was in place across the western US. A potent 500 hPa trough was swinging through the desert Southwest. Winds in the 200 hPa jet across the southeast US exceeded 80 m s^{-1} as the southern and northern streams merged. A strong east-west oriented baroclinic zone was in place across central Florida, and would remain there throughout the duration of the event. Between 48 and 24 hours prior to the tornado event, the upper-level jet core present across the Southeast began to move offshore, and warm air advection in the lower levels was beginning as the 850 hPa low encountered the baroclinic zone. By 22/1200 UTC, about 12 h prior to the event, a 500 hPa vorticity maximum was located over southern Louisiana, and the thermal gradient associated with the 850 hPa low had sharpened considerably. A 25 m s^{-1} low-level southwesterly jet had developed ahead of the 850 hPa low, and progressed eastward with time so that it was situated over the Florida peninsula by 23/0000 UTC. Soundings from across central Florida for 22/1200 UTC indicated a strong veering wind profile and the potential for CAPE to increase to over 1000 J kg^{-1} as daytime heating destabilized the boundary layer.

At 23/0000 UTC, there was still low-level warm air advection occurring over central Florida, providing synoptic-scale forcing for ascent. However, the main vorticity maximum at 500 hPa had begun to shift to the northeast, and thus there was some suggestion that differential vorticity advection would not provide large-scale forcing for ascent over the Florida peninsula. By 23/0600 UTC, central Florida was under the influence of cold air advection and anticyclonic vorticity advection at 500 hPa, and the synoptic-scale forcing for ascent was no longer present. Thus, this tornado episode across central Florida occurred within a very short time span (6 h), and the line of storms appeared to intensify at a time in which the synoptic-scale forcing was weakening across central Florida (personal communication, Steve Weiss & Bob Johns, 2002).

A tornado watch had been posted for northern Florida at 22/1400 UTC due to an intense bow echo embedded in a region of moderate to intense precipitation that was moving across the Florida panhandle. As this system moved eastward with time, the broad area of precipitation expanded across northern Florida northward into Georgia. The system made little southward progress into the Florida peninsula, and helped to set up a strong baroclinic zone across the peninsula which persisted through the afternoon hours of 22 February.

A tornado watch valid through 23/0200 UTC for central Florida was issued on 22/2000 UTC, based on vertical wind shear profiles and moderate instability on the Florida peninsula. The decision to reissue the tornado watch at 23/0200 UTC was decidedly difficult for SPC forecasters (personal communication, Steve Weiss & Bob Johns, 2002). The convective line over the eastern Gulf had weakened throughout the afternoon as it moved toward the Florida peninsula. In addition, the convection within the east-west band over central Florida had diminished. However, the decision was made to reissue a tornado watch for central Florida based largely on the high CAPE and strong vertical wind shear in the 23/0000 UTC Tampa Bay (TBW) sounding. Less than 6 h later, an intense line of tornadic supercells moved across the Florida peninsula.

3. Mesoscale Influences

An important issue unique to southeast US tornado events is the relationship of the sea surface temperature (SST) anomalies in the Gulf of Mexico to the intensity of the convection as it crosses the Gulf. Figure 1a shows the SST anomalies for 22 February 1998. The Loop Current (LC) appears as a warm eddy in the eastern Gulf. In fact, SSTs in

Corresponding author address: Alicia C. Wasula, Dept. of Earth and Atmos. Science, Univ. at Albany/SUNY, Albany NY, 12222. E-mail: alicia@atmos.albany.edu

the LC were anomalously warm (+3°C), while the normally cooler waters on the northeast and west coasts of the Florida peninsula were anomalously cold (-3°C). By examining cloud-to-ground (CG) lightning flash rate data, it appears that the SST anomalies are directly correlated to the frequency of CG lightning strikes, which can be used to get a general idea of the intensity of the convection (Fig. 1b). Fifteen minute flash totals are at their highest when the system is over the warm waters of the LC. Flash rates rapidly decline as the squall line moves over the anomalously cool waters off the west coast of Florida. Rapid intensification occurs between 23/0200 UTC and 23/0300 UTC as the system encounters the moist, unstable air present over the Florida peninsula, and lightning flash rates increase to nearly the level they had when the system was over the warm LC. An issue to be investigated further is what role the relatively stable planetary boundary layer over the anomalously cool ocean waters off the western Florida coast played in enhancing the low-level jet (and thus the low-level vertical wind shear) over this region.

Another issue to be investigated is what role the anomalously cold SSTs along the northeast Florida coast played in enhancing the low-level baroclinic zone present across central Florida. Figure 2 shows frontogenesis interpolated from surface observations from 22/1800 UTC to 23/0600 UTC. Surface frontogenesis and absolute vorticity calculations (discussed in the following paragraph) were computed using surface, ship and buoy observations interpolated to a 0.5° x 0.5° grid via a Barnes interpolation scheme. Frontogenesis was computed using the two-dimensional Miller (1948) equation, and absolute vorticity was computed from the gridded surface wind field.

The baroclinic zone draped across the north central Florida Peninsula maintained itself due to persistent frontogenesis across the region during the day on 22 February and into 23 February (Fig. 2). It was likely that diabatic effects were enhancing the baroclinic zone during this time as well, as evaporative cooling was occurring in the air to the north of the boundary (where the precipitation was falling), and daytime heating was occurring in the clear air to the south of the boundary (diurnal heating was limited on the north side of the boundary due to the thick cloud cover and precipitation). Additionally, the northerlies to the north of the boundary and off the northeast coast of Florida near 23/0000 UTC (Fig. 14) contributed to the advection of relatively cool air southward, while the southerlies and southeasterlies to the south of the boundary were advecting warm moist air northward. The advection of air over anomalously warm (cool) SSTs to the south of Florida northwards towards the boundary (off the northeast coast of Florida southward towards the Florida peninsula) also likely helped sustain the strength of the baroclinic zone for such a long period of time. The frontogenesis maximum in the vicinity of the surface boundary persisted through 23/0600 UTC.

A vertical cross section from Illinois to Cuba (along the length of Florida) valid at 22/1800 UTC shows a distinct ascent maximum directly over the surface baroclinic zone extending southward toward the warm side of the boundary (Fig. 3). While much of the ascent maximum is likely due to synoptic scale forcing, it is also likely that upward motion to the south of the baroclinic zone was enhanced by the secondary circulations associated with the strong frontogenesis. This assertion is based on the finding that the ascent rapidly increased in intensity at approximately the same time the frontogenesis began to strengthen (not shown).

Figure 4 shows the surface absolute vorticity during the period that the squall line rapidly intensified and broke into a line of tornadic supercells. By 22/0200 UTC, the winds to the north of the surface baroclinic zone had veered from northerly to a more easterly direction, which is shortly followed by a rapid increase of surface vorticity across central Florida by 23/0400 UTC. This region of increased vorticity sustained itself through 23/0600 UTC, when the most intense tornadoes were occurring across the region.

It appears that as the squall line encountered this region of relatively high surface vorticity and frontogenesis, it was able to rapidly intensify and become supercellular in a matter of a few hours. Thus one could infer that mesoscale effects became much more important relative to the synoptic scale forcing as the time of the tornadoes approached, although more detailed analysis is necessary to substantiate this result.

4. Conclusions

A synoptic-scale environment favorable for convective development existed over the Florida peninsula during the day on 22 February 1998. Diabatic contributors to frontogenesis appeared to be important factors in the persistent strong baroclinic zone across central Florida, and strong frontogenetical circulations likely enhanced synoptically forced ascent on the warm side of the boundary. At the same time, daytime heating acted to destabilize the air on the warm side of the boundary. The SST anomalies (both warm and cold) in the Gulf of Mexico seem to have a direct effect on the intensity of the convection as it moved across the water. The relationship of the relatively stable boundary layer over the anomalously cool Gulf waters north of TBW and the strong low-level jet over the Florida peninsula on 23 February 1998 has not yet been established. As the squall line made landfall over central Florida it rapidly intensified and broke into a line of tornadic supercells. It is believed that this evolution may have been aided by the subtle shift in wind direction on the north side of the baroclinic zone to a more northeasterly or easterly component. This wind shift led to an increase in the vorticity near the surface just prior to and during the time the squall line became supercellular.

It appears that while the synoptic scale forcing (i.e., differential cyclonic vorticity advection, jet circulations) was favorable for the creation of a broad region of ascent over Florida in the twelve to twenty four hours before the event, it rapidly became less favorable in the six to twelve hours prior to the first tornado touchdown. There appeared to be a transition in the six hours before the event from forcing primarily on the synoptic scale to forcing on the mesoscale as the upper-level system moved northeast away from Florida. What is suggested by this event is that the structure of the lowest layer of the atmosphere (from the surface to 850 hPa) plays a very important role in the evolution of cool-season tornado events in the Southeast. It appears that both the thermodynamics and the vertical wind shear in the surface-to-850 hPa layer can mean the difference between a null event and a tornado episode, and that subtle variations of these properties on small geographic scales are important.

5. Acknowledgement

This research grew out of COMET-supported research at the University at Albany/SUNY through grant #S99-19133.

6. References

Anthony, R., 1988: Tornado/severe thunderstorm climatology for the southeastern United States. *Preprints, 15th Conference on Severe Local Storms*, American Meteorological Society, 22-26 February 1988, Baltimore, MD, pp. 511-516.

Fike, P. C., 1993: A climatology of nocturnal severe local storm outbreaks. *Preprints, 17th Conference on Severe Local Storms*, American Meteorological Society, St. Louis, MO, 4-8 October 1993, pp. 10-14.

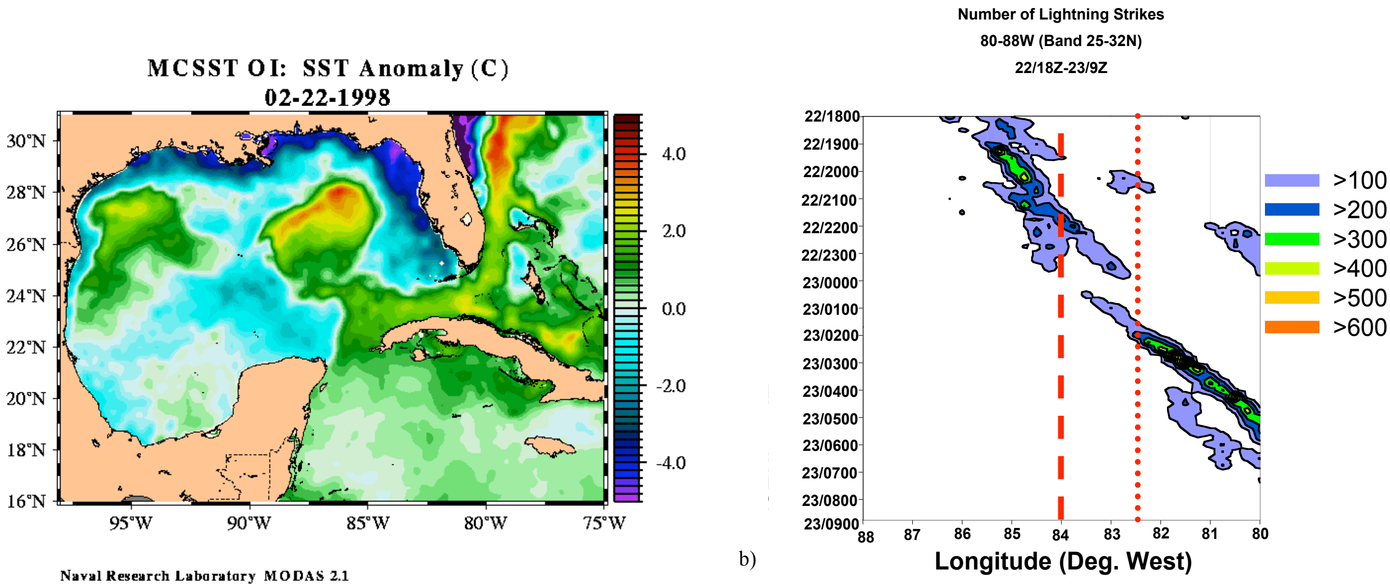

Fig. 1: a) sea surface temperature anomalies for 22 February 1998 (°C), and b) Hovmoller diagram of number of lightning flashes (15 minute intervals) from 22/1800 UTC to 23/0900 UTC. Dotted line represents longitude where SST anomaly changes sign from positive to negative. Dashed line represents roughly the longitude of the Florida west coast.

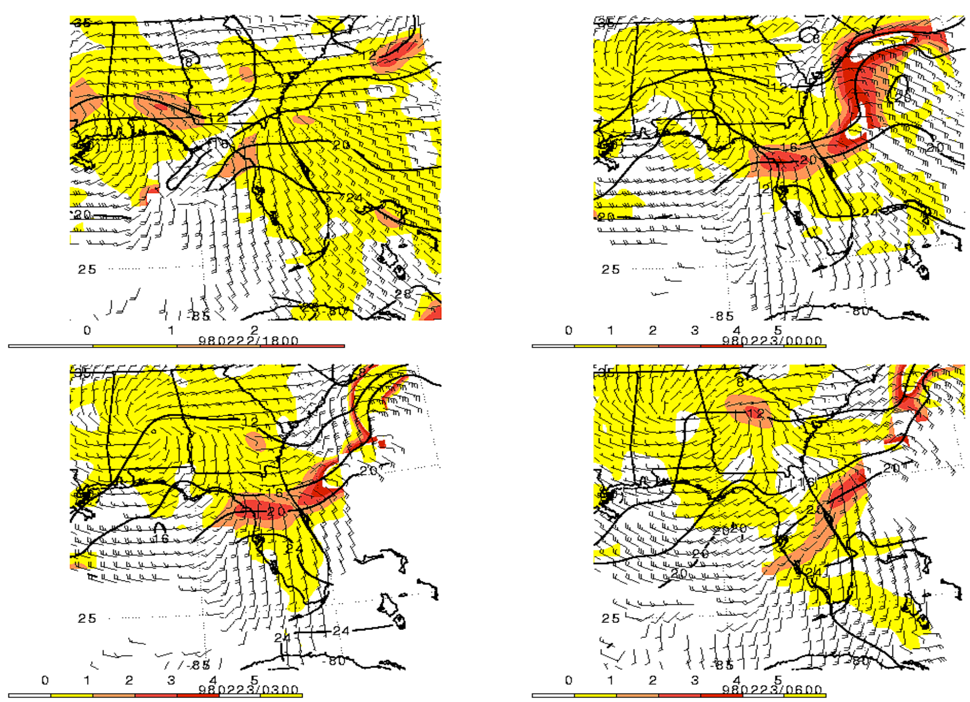

Fig. 2: Surface frontogenesis (°C 100 km^{-1} 3 h^{-1}) for 22/1800 UTC, 23/0000, 0300, 0600 UTC.

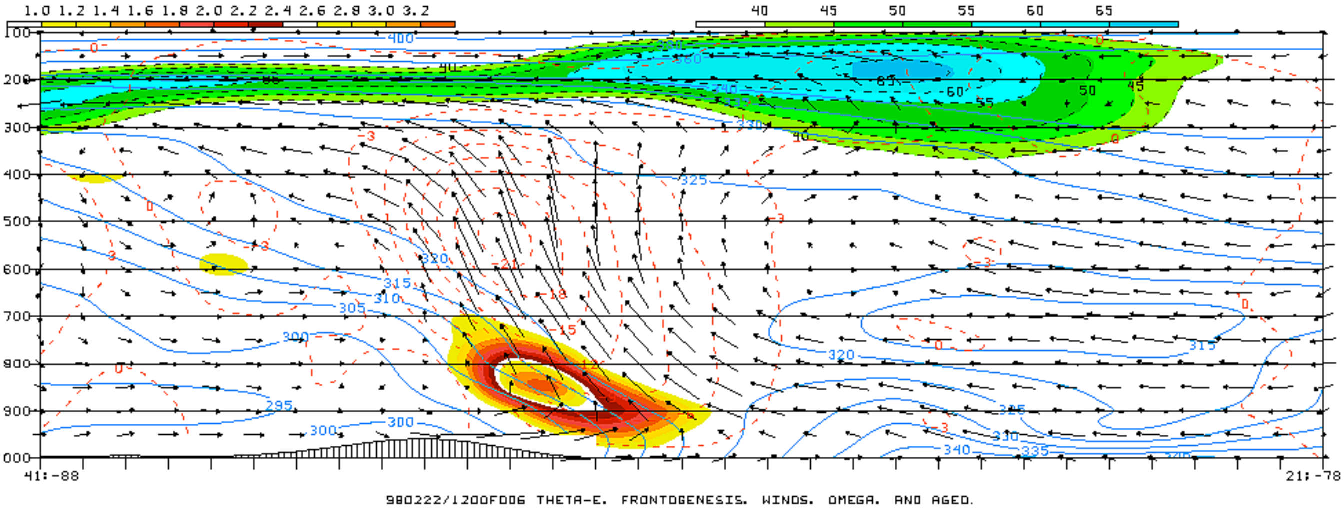

Fig. 3: Cross section from Illinois (left) to Cuba (right)of equivalent potential temperature (K,solid), vertical motion (x 10^{-3} hPa s^{-1}, dashed), isotachs (m s^{-1}, shaded with dashed outline), and frontogenesis (°C 100 km^{-1} 3 h^{-1},shaded only) for 22/1800 UTC.

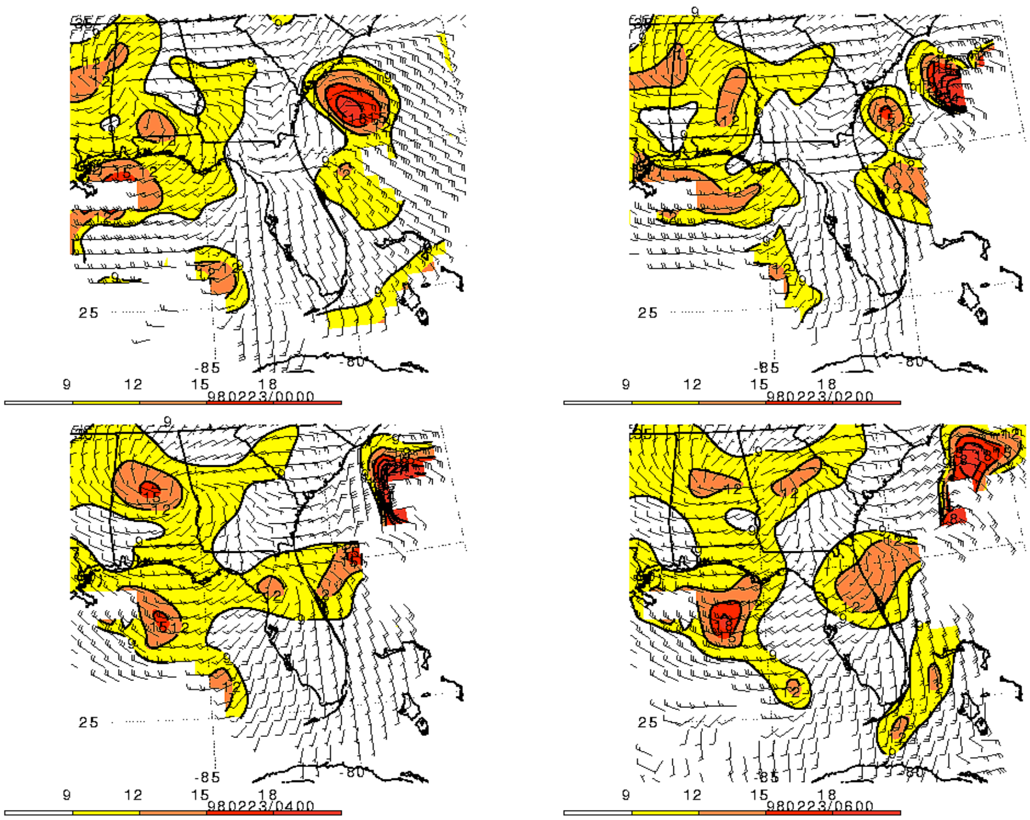

Fig. 4: Absolute surface vorticity (x 10^{-5} s^{-1}) every 2 h from 23/0000 UTC to 23/0600 UTC.