THE 2 MAY 1997 SEVERE WEATHER EPISODE OVER NORTHEAST LOUISIANA AND CENTRAL MISSISSIPPI: THE APPARENT INFLUENCE OF FRONTOGENETIC FORCING ALONG A NEWLY FORMED MESOSCALE BAROCLINIC ZONE

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Abstract

On 2 May 1997, an outbreak of severe thunderstorms and tornadoes occurred over northern Louisiana and central Mississippi. While the overall synoptic pattern suggested the development of a progressive squall line along an advancing cold front, a locally developing mesoscale boundary appeared to focus a lesser-anticipated, but more significant area of severe weather well downstream from the cold frontal position. Differential diabatic heating across a residual outflow boundary led to the formation of a rather intense low-level mesoscale baroclinic zone over northern Louisiana and central Mississippi. By mid afternoon, this baroclinic zone became the focus for severe thunderstorm development, including three supercells that produced large hail, damaging straight-line winds, and tornadoes. This case study documents the evolution of this mesoscale baroclinic zone and investigates frontogenetical forcing as one of the contributing factors to the development of severe convection during the afternoon and evening of 2 May 1997. Additionally, factors that may have enhanced the supercell and tornado potential along this newly developed baroclinic zone will be discussed.

1. Introduction

During the afternoon and evening of 2 May 1997, an outbreak of severe thunderstorms and tornadoes affected parts of northern Louisiana and central Mississippi. A composite of the synoptic scale pattern for this event, valid 0000 UTC 3 May 1998, is shown in Fig. 1. This overall synoptic pattern lead forecasters to anticipate the development of a progressive mesoscale convective system oriented along or ahead of an advancing surface cold front. However, during the 2 May 1997 event, a large number of the severe weather reports were confined to a narrow corridor that stretched from near Monroe, Louisiana (MLU) to near Columbus, Mississippi (CBM) (Fig. 2). Most of these reports were associated with three supercell thunderstorms that developed over northern Louisiana and moved eastward across central Mississippi during the afternoon and early evening hours.

This paper will present the synoptic and mesoscale features that made severe thunderstorm development, including supercells, especially favorable over northeast Louisiana and central Mississippi. The objective of this paper is to document the evolution of a mesoscale baroclinic zone and investigate the possible role of frontogenetical forcing as one of the causative factors in the initiation of deep convection. Other factors, possibly enhancing the supercell and tornado potential along this newly developed baroclinic zone, will also be discussed.

2. Synoptic Background

Several parameters for severe thunderstorm development were in place over the Lower Mississippi Valley on 2 May 1997, as shown in Fig. 1. A progressive upper-level trough moved from the Western High Plains at 1200 UTC 2 May to the Middle Mississippi Valley region by 0000 UTC 3 May. A strong polar jet stream in excess of 50 m s^{-1} stretched from northwest Texas to Illinois with a mostly zonal subtropical jet stream extending across the northern Gulf of Mexico. A surface low pressure center was located over southern Illinois with trailing cold front that stretched southwestward into northeast Texas. Also shown (Fig. 1), is the location of a mesoscale baroclinic zone that developed during the afternoon across northeast Louisiana and central Mississippi. This mesoscale boundary will be discussed in detail in section 3.

The 1200 UTC soundings from Jackson, MS (Fig. 3) and Shreveport, LA (Fig. 4) showed the presence of a moist low-level air mass and steep (~8.2 °C km^{-1}) 700-500 hPa lapse rates in the warm sector, contributing to surface-based Convective Available Potential Energy (CAPE) values of 1300-1500 J kg^{-1}. By late afternoon, daytime heating and moisture advection, enhanced by a 28 m s^{-1} low-level jet, led to further air mass destabilization with CAPE values increasing to 2135 J kg^{-1} (Fig. 5).

The hodograph for Jackson, MS (JAN), valid 0000 UTC 3 May (Fig. 6), showed clockwise turning of the low-level shear vectors with increasing mid- to upper-tropospheric winds with height. The 0-3 km storm-relative helicity values were 392 m^2 s^{-2}, suggesting the potential

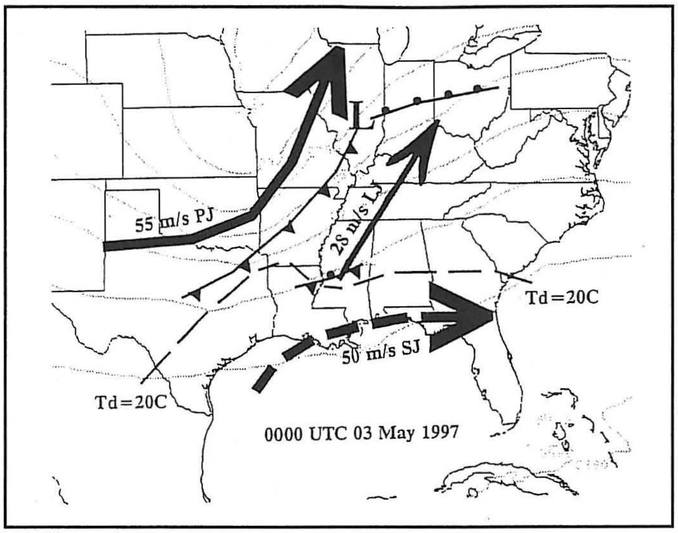

Fig. 1. Composite chart valid at 0000 UTC 3 May 1997 of the 500 hPa geopotential height contours (solid thin), the polar jet (PJ), the subtropical jet (SJ), and the low-level jet (LJ). The surface frontal boundaries are shown using conventional symbols. A dashed line denotes the northward extent of surface dewpoints of 20 °C or higher.

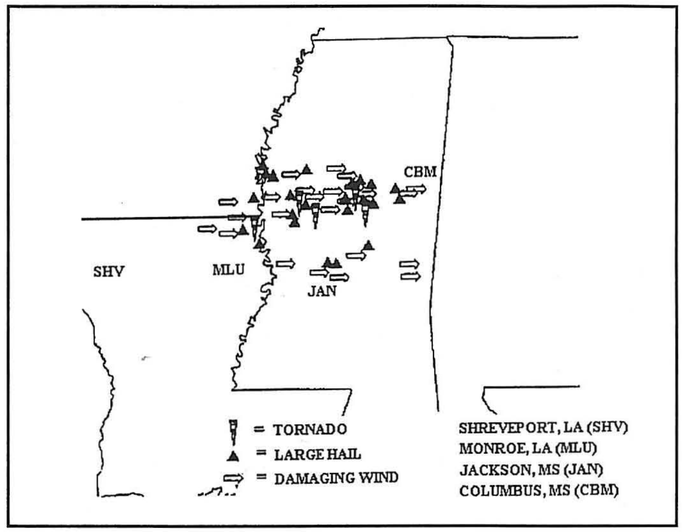

Fig. 2. Reports of large hail, damaging winds, and tornadoes across Mississippi and northeast Louisiana on 2 May 1997. The first severe weather reports were received around 2200 UTC over northeastern Louisiana. The final reports were received from east-central Mississippi around 0600 UTC 3 May 1997.

for supercells and tornadoes (Davies-Jones 1990). The mid-level storm-relative winds (Thompson 1998) and the Bulk Richardson Number (BRN) shear values of 10.3 m s^{-1} and 139 m^2 s^{-2}, respectively, also confirmed the potential for tornadic supercells.

This combination of decreasing static stability and increasingly favorable vertical wind shear created a large-scale environment supportive of severe thunderstorm development, including supercells, across the central Gulf Coast states. The next section will discuss the evolution of a mesoscale boundary that served to focus convective development in this favorable large-scale environment.

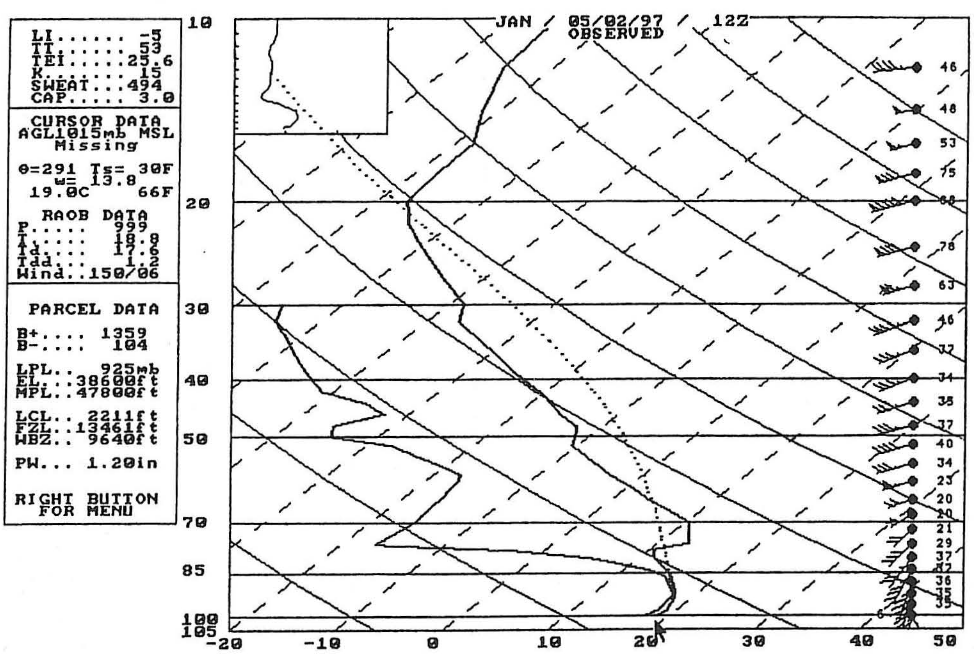

Fig. 3. Observed Jackson, MS (JAN) sounding at 1200 UTC 2 May 1997.

3. Mesoscale Boundary Evolution and Convection Initiation

By 1400 UTC on 2 May, elevated convection had developed along the low-level jet axis in an area of enhanced warm advection from southeastern Arkansas to northern Mississippi (not shown). Thunderstorms increased in coverage and intensity during the morning, with several thunderstorms producing hail and straight-line winds exceeding severe criteria by noon.

During the early afternoon, an outflow boundary emanating from this elevated convective complex had become stationary from northern Louisiana to east central Mississippi. At 2100 UTC, differential diabatic heating across this outflow boundary had led to the development of an intense low-level thermal gradient (approximately 8 °C 10^{-2} km^{-1}). Temperatures ranged from 19 °C in the cloudy, rain-cooled air mass over northern Mississippi to near 30 °C south of the boundary (Fig. 7). This temperature gradient focused a new area of convective development over northern Louisiana, near Monroe (Fig. 8). This new convective development rapidly became supercellular in nature, exhibiting persistent, deep mesocyclones (Burgess 1976) as it moved across extreme northeast Louisiana and into west central Mississippi (Fig. 9).

In all, three radar-identified supercells tracked eastward

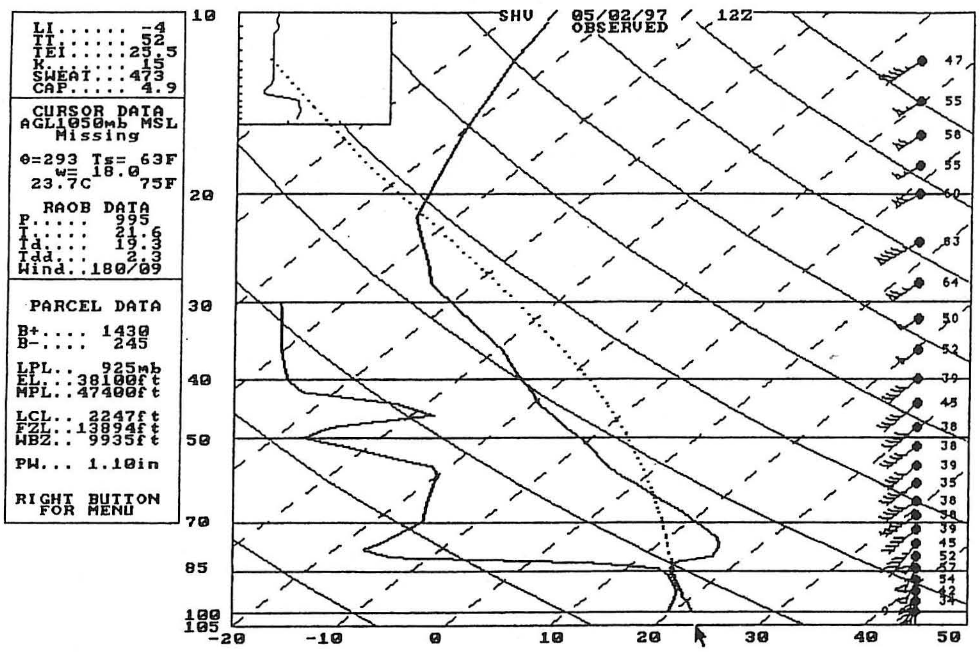

Fig. 4. Observed Shreveport, LA (SHV) sounding at 1200 UTC 2 May 1997.

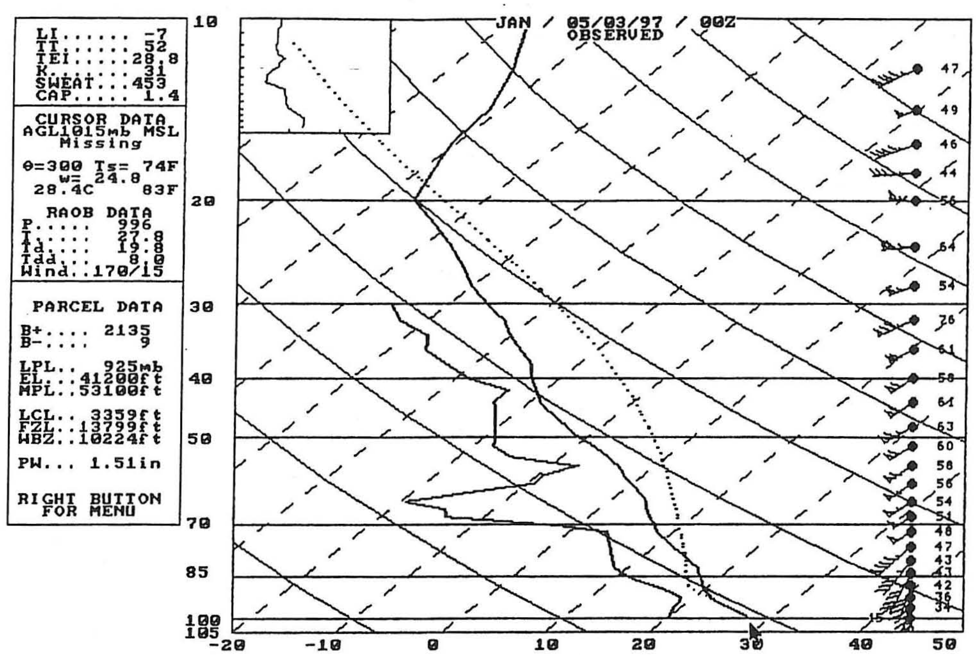

Fig. 5. Observed Jackson, MS (JAN) sounding at 0000 UTC 3 May 1997.

along this mesoscale thermal boundary from northern Louisiana to east central Mississippi. These supercells were responsible for the majority of severe weather reports shown in Fig. 2, including hail up to baseball size and five tornadoes, one of which reached F3 intensity.

4. Frontogenetical Forcing

Severe thunderstorm and tornado outbreaks focused along similar, shallow moisture and thermal boundaries have been documented by Korotky (1990), Businger et al. (1991), and Vescio et al. (1993). More recently, Langmaid et al. (1996), Koch et al. (1996), Langmaid and Riordan (1998) and Koch et al.(1998) investigated frontogenetical forcing along a shallow frontal boundary as one of the contributing factors leading to the 1994 Palm Sunday outbreak in the southeastern U.S.. Specifically, they investigated several mesoscale processes, including a frontogenetically forced direct thermal circulation developing transverse to this shallow frontal boundary, and the potential effects on convection initiation and maintenance. Langmaid and Riordan (1998) concluded that although this frontogenetical forcing did not directly trigger the deep convection, it may have contributed to it's rapid development through local destabilization associated with the ageostrophic adjustment processes.

Bluestein (1993) describes in detail this atmospheric adjustment that occurs when geostrophic deformation increases the temperature gradient (frontogenesis). Essentially, the atmosphere responds to the geostrophic and hydrostatic imbalance due to a tightening low-level temperature gradient by developing mesoscale vertical and ageostrophic motions. This direct thermal circulation helps restore the thermal wind balance by decreasing the horizontal temperature gradient and increasing the vertical wind shear.

To determine whether or not frontogenetic forcing was a causative factor in the development of deep convection along the mesoscale boundary, objective surface analyses of the Petterssen (1956) two-dimensional frontogenesis function were constructed using the GEMPAK software package for workstations (desJardins et al. 1991). Although this function ignores cross-frontal gradients of diabatic heating, it has proven to be a useful tool in the diagnosis of frontogenesis in other cases (Sanders and Bosart 1985; Dorian et al. 1988).

Figure 10a shows the initial stages of frontogenesis occurring over north central Louisiana. By 2000 UTC, the frontogenesis had increased in intensity and expanded along the entire length of the low-level baroclinic zone (Fig. 10b). It was at this time convection initiated within

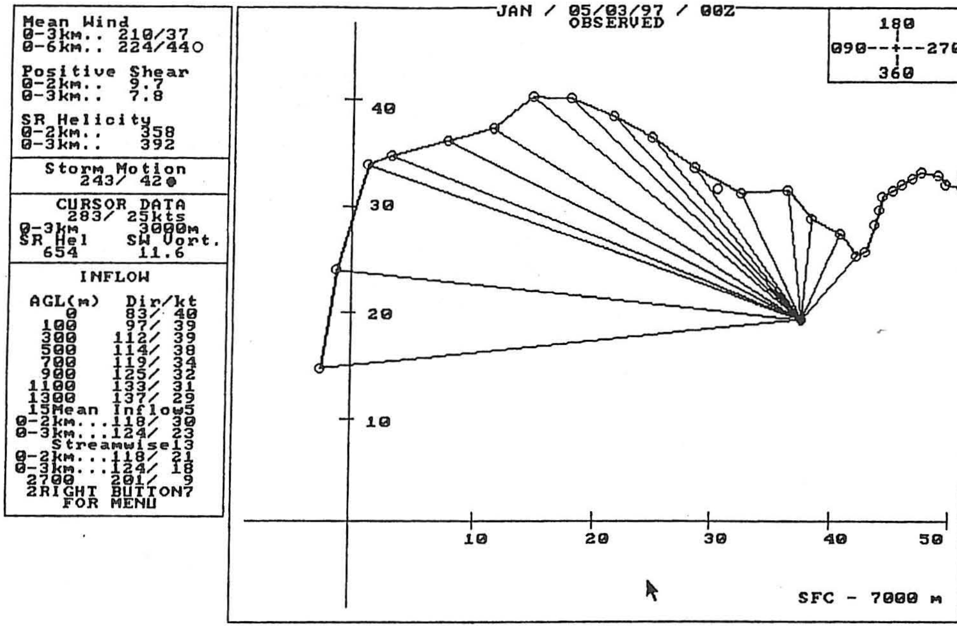

Fig. 6. Observed Jackson, MS (JAN) hodograph at 0000 UTC 3 May 1997.

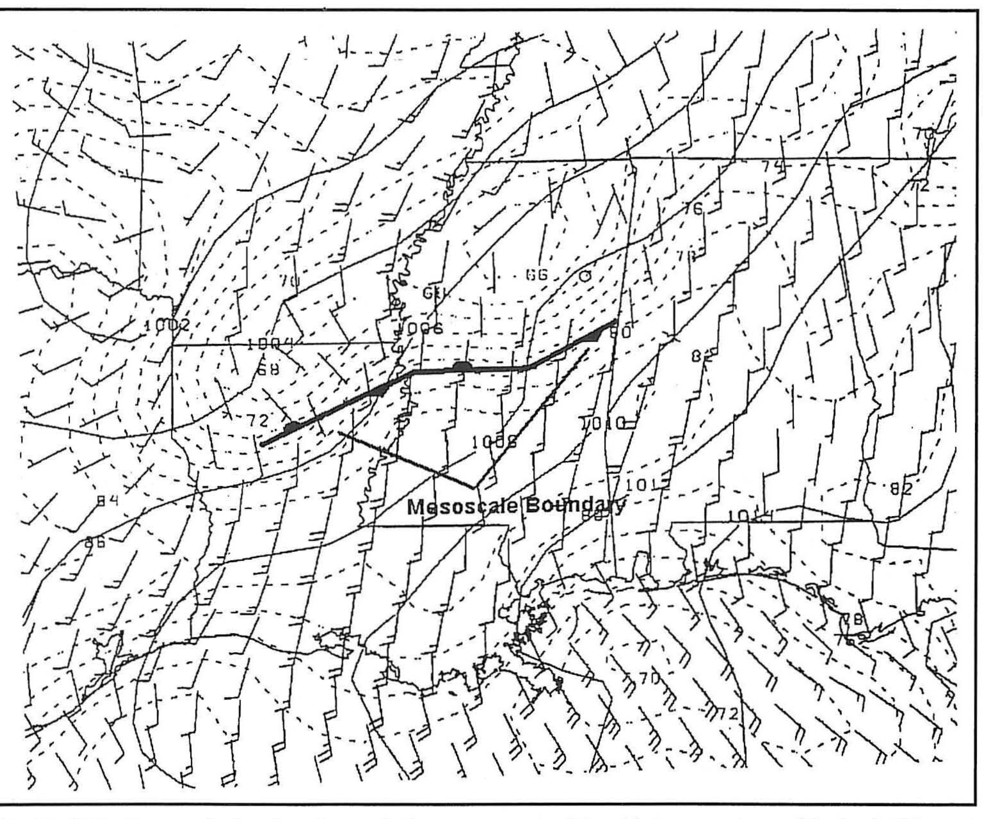

Fig. 7. Objective analysis of surface winds, pressure (solid, mb), temperatures (dashed, °F), and mesoscale boundary location at 2100 UTC 2 May 1997.

the most intense zone of frontogenesis, located over northeast Louisiana. By 2100 UTC, the most intense frontogenesis had "shifted" eastward to central Mississippi (Fig. 10c). Although the baroclinicity of the mesoscale thermal boundary changed little over northern Louisiana from 2000 to 2100 UTC, convection continued to develop in this area. This thunderstorm development was occurring along a band of 3-h surface pressure falls of at least 4 mb that were observed on the warm side of the thermal boundary[1] (Fig. 11). According to the adjustment process described in Bluestein (1993), these pressure falls over northeast Louisiana and central Mississippi were likely related to the location of the upward branch of the thermally-direct circulation. If this is the case, mesoscale vertical motions associated with the thermally-direct circulation, combined with low-level convergence along the thermal boundary, would have been sufficient to lift parcels to their level of free convection. Once the thunderstorms developed, thermal and kinematic properties inherent to these mesoscale boundaries may have influenced the eventual convective mode and resultant type of severe weather. This is discussed in the next section.

5. Factors Affecting Convective Mode and Resultant Severe Weather

Several studies have documented cases where thunderstorms have rapidly intensified and produced tornadoes upon interacting with thermal boundaries. Maddox et al. (1980) examined four cases where thunderstorms produced tornadoes upon interacting with pre-existing thermal boundaries. From these cases, a physical model of boundary-layer winds was developed, explaining how thunderstorms intensify as they move along and across thermal boundaries. The intensification was attributed, in part, to the maximized convergence and cyclonic vertical vorticity of the sub-cloud wind fields in these areas. More recently, Vescio and Thompson (1998) and

[1]Even when factoring out diurnal fluctuations, the observed pressure falls that occurred along and just south of the baroclinic zone are still considered significant with respect to surrounding areas.

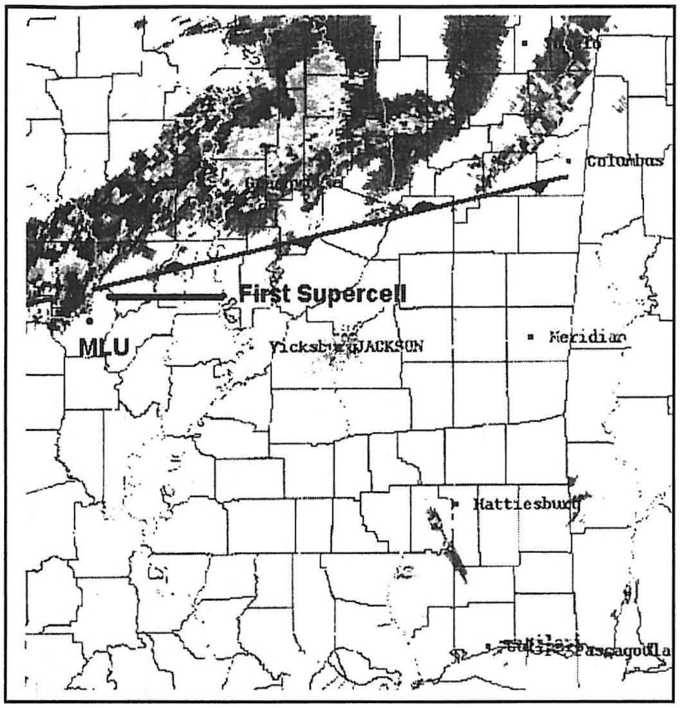

Fig. 8. 0.5 degree reflectivity image from the Jackson, MS, WSR-88D at 2054 UTC 2 May 1997. The first supercell is noted along the mesoscale boundary over northeast Louisiana, just to the south of the widespread rainfall occurring over southeast Arkansas and northern Mississippi.

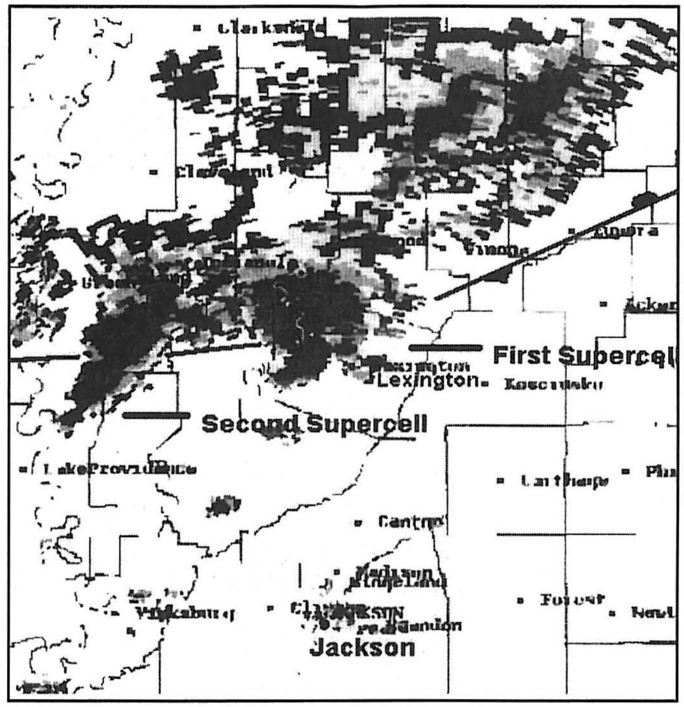

Fig. 9. 0.5 degree reflectivity image from the Jackson, MS, WSR-88D at 2331 UTC 2 May 1997. The first supercell, just north of Lexington, was producing an F3 tornado at this time. A second supercell was located immediately to the west of the first supercell and had just crossed the Mississippi river into west-central Mississippi.

Pence et al. (1998) have examined cases where thermal boundaries provided the focus for convective development and created a mesoscale wind shear environment, exhibiting areas of enhanced low-level streamwise vorticity (Davies-Jones 1984), to support tornadic supercells. Furthermore, Rasmussen and Blanchard (1998) suggest that while large-scale environments characterized by optimal instability and wind shear may be sufficient to support supercells, local augmentation of these variables on the meso-beta and -gamma scales may determine whether or not the supercell becomes tornadic. Indeed, Markowski et al. (1998a, 1998b) have shown that mesoscale storm-relative helicity in close proximity to tornadic supercells may double, and in some instances quadruple, the ambient, large-scale values.

From the sounding and hodograph structures shown previously, it appears that the large-scale environment had a sufficient amount of instability and wind shear to support supercells regardless of the mesoscale boundary. However, evidence elucidated from the research work cited above suggests that it may well have been the mesoscale enhancement of thermodynamic and kinematic properties along this newly developed mesoscale boundary on 2 May, that allowed the supercells to become tornadic.

6. Conclusion

On 2 May 1997, an outbreak of severe thunderstorms and tornadoes occurred over northeast Louisiana and central Mississippi. During the afternoon hours, differential diabatic heating across a residual outflow boundary led to the formation of an intense low-level baroclinic zone. Frontogenetical forcing occurring along this low-level boundary may have been one of the causative factors in the initiation and intensification of three supercells that moved along this boundary, producing a significant amount of severe weather, including large hail, damaging straight line winds, and tornadoes.

Operational forecasters need to use all available data, including radar and satellite imagery, surface analyses, and wind profilers to identify the development and/or movement of any synoptic and mesoscale boundaries. Once identified, forecasters should be aware of specific processes occurring along these boundaries, such as frontogenesis and the associated direct thermal circulation, which create a more favorable environment for the initiation and maintenance of deep convection. Once convection has been initiated, knowledge of mesoscale enhancements of instability and wind shear along these boundaries, will allow forecasters to better anticipate the most likely severe weather threats with any storm-boundary interactions that may occur.

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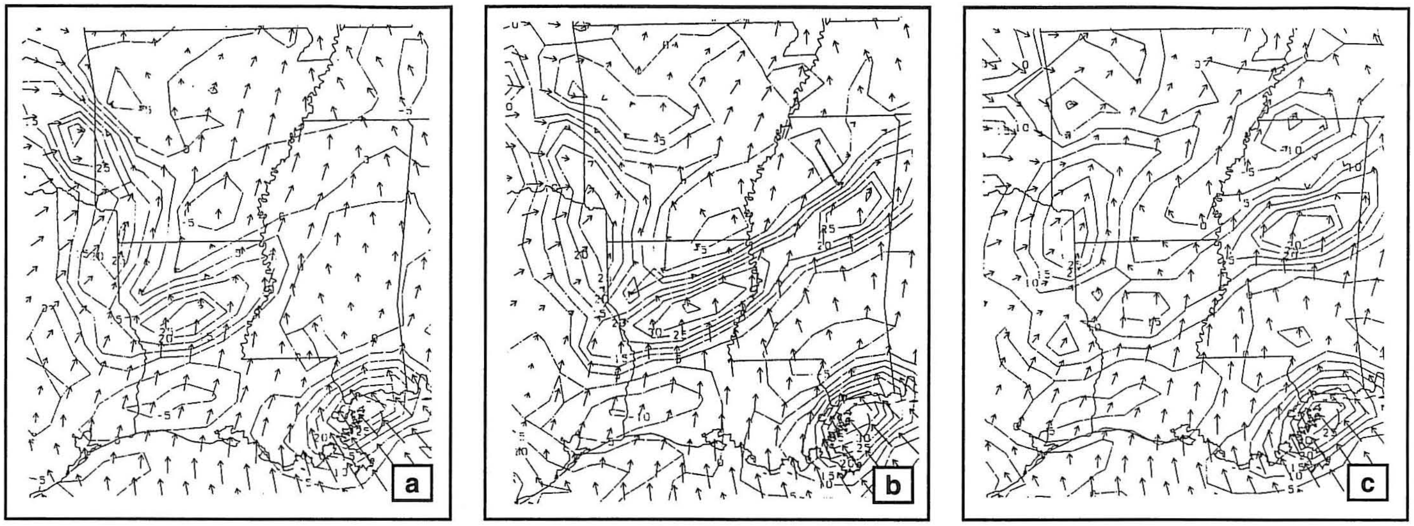

Fig. 10. Objective analyses of the Petterssen two-dimensional frontogenesis function (°K/100 km/3 h) and the observed wind (m s^{-1}) valid at: a) 1900 UTC 2 May 1997, b) 2000 UTC 2 May 1997, and c) 2100 UTC 2 May 1997.

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Both authors have a strong interest in the observations and forecasting of severe convective storms.

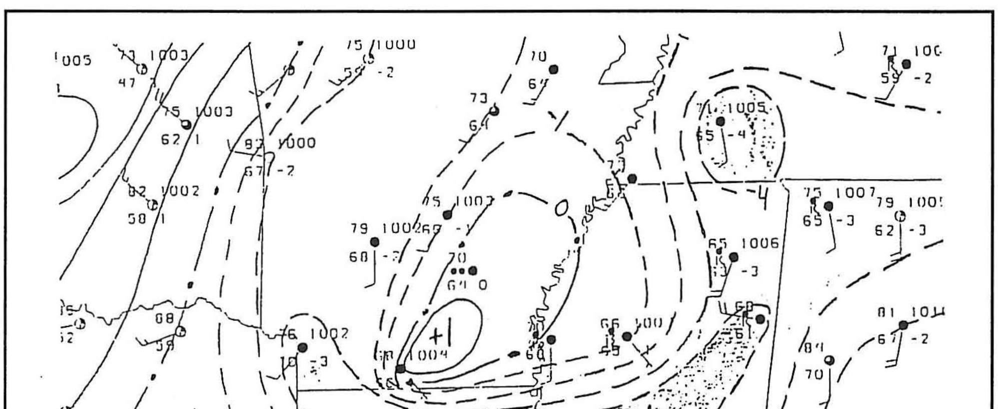

Fig. 11. Subjective isallobaric analysis contoured in mb h^{-1}, valid at 2100 UTC 2 May 1997. Areas observing 4 mb pressure falls or greater in 3 hours are shaded.

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