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PRESSURE AND TEMPERATURE PERTURBATIONS DURING THE 4 APRIL 1977 SEVERE STORMS OUTBREAK OVER SOUTHEAST U.S.

L.R. Hoxit, R.A. Maddox, J.M. Fritsch and C.F. Chappell
National Oceanic and Atmospheric Administration
Atmospheric Physics and Chemistry Laboratory
Boulder, CO 80303

ABSTRACT

Detailed surface analyses of the 4 April 1977 severe storms outbreak over the Southeast U.S. are presented. Mesoscale pressure perturbations which accompanied the severe weather are compared to thermodynamic changes which occurred through the troposphere and lower stratosphere. It is hypothesized that a significant portion of the pressure and thermodynamic changes occur as a result of the organized thunderstorm activity. The relevance of mesoscale perturbations to the forecast problem is discussed.

1. INTRODUCTION

We have known for some time that severe weather, especially intense and long-lived tornadoes, is often associated with mesolows at the surface (1,2). Most of these mesolows are large enough to be in approximate hydrostatic equilibrium and therefore result from mean temperature changes and associated mass divergence in the atmospheric column (3). Feteris (4) was one of the earliest investigators to focus on the effects of circulations in the environment around convective clouds. Ninomiya (5, 6) was able to supplement standard rawinsonde data with satellite imagery to document significant changes in the upper level flow regime in the vicinity of organized, intense thunderstorms. Recent studies by Fritsch (7), Fritsch et al (8) and Maddox et al (9) have revealed some important details of cloud-environment interactions which produce meso-high and low pressure systems not only at the surface but in the vicinity of the tropopause.

To further document and understand the cloud-environment interactions leading to mesolows, a major severe weather event which occurred over the southeastern United States on 4 April 1977 was analyzed. Twenty-two tornadoes were reported including one of F5 intensity at Birmingham, Alabama, that killed 22 people while inflicting tremendous damage. An intense storm, with associated large hail and tornadic activity, was partly responsible for the crash of Southern Airways Flight 242 in northern Georgia and the deaths of 71 persons.

During the severe weather period, special rawinsonde data (1800 GMT) were taken over the southeast U.S. as part of a SESAME '77 experiment (10). These soundings were used in conjunction with surface observations, radar data, and GOES imagery to prepare detailed surface analyses of the event and to relate the surface pressure perturbations to changes in the mean temperature fields aloft. Miller (11) has also analyzed this particular severe storm situation.

2. SURFACE MESOANALYSES

Mesoanalyses of surface conditions over the Southeast are presented for the period 1200 GMT 4 April to 0000 GMT 5 April 1977, along with selected satellite images, in Figs. 1 and 2. Analyses of mesoscale pressure perturbations (large-scale pressure subjectively estimated from time series of surface analyses then subtracted from the observed pressure) are on the 1200, 1500, 1800, 2100, and 0000 GMT charts.

At 1200 GMT a mesoscale area of low pressure was located over northern Mississippi with several separate but weak smaller scale centers. A squall line trailed southwestward into eastern Louisiana. Moist southerly flow with dewpoints of at least 65F was present from the Gulf Coast northward to Tennessee. Considerable thunderstorm activity, occurring well to the east of the synoptic scale cold front in Arkansas, was already

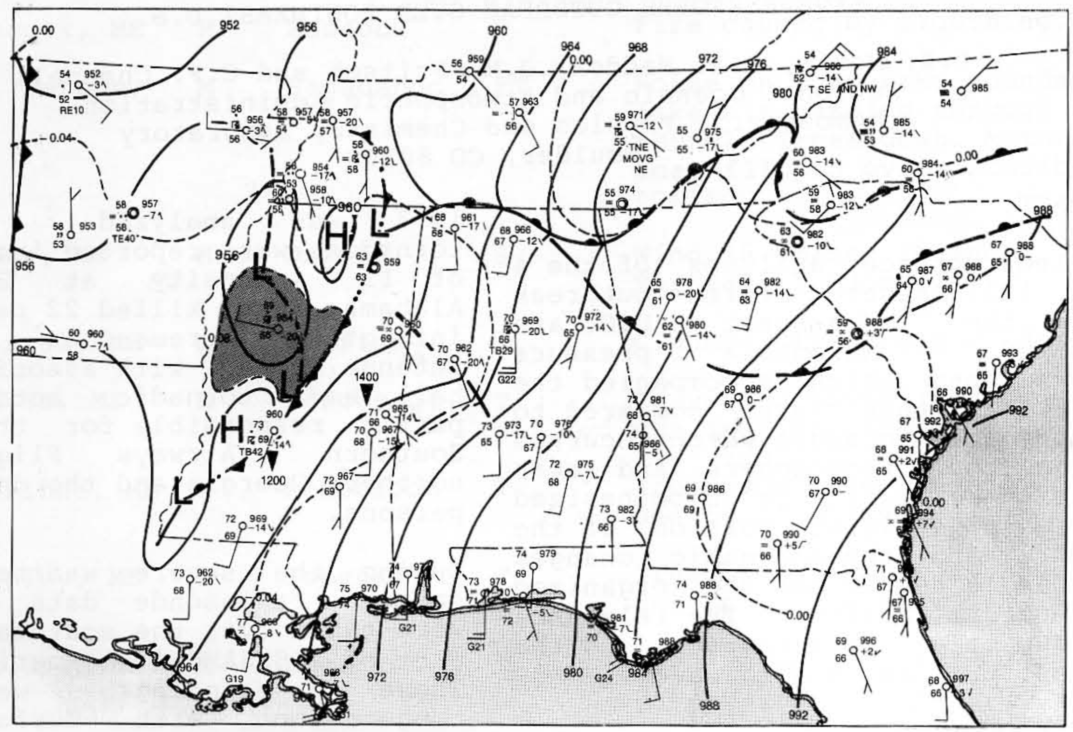

Fig. 1a. Surface mesoanalysis for 1200 GMT, 4 April 1977. Pressure analysis (of altimeter settings), fronts, trough lines, and thunderstorm outflow boundaries are solid black lines. Analyses of mesoscale pressure perturbations (dashed lines) are shown with areas of -0.08 inches or less shaded, and areas of +0.04 inches or more cross-hatched. Tornado events logged at the National Severe Storms Forecast Center are indicated (triangles) along with the GMT time of occurrence.

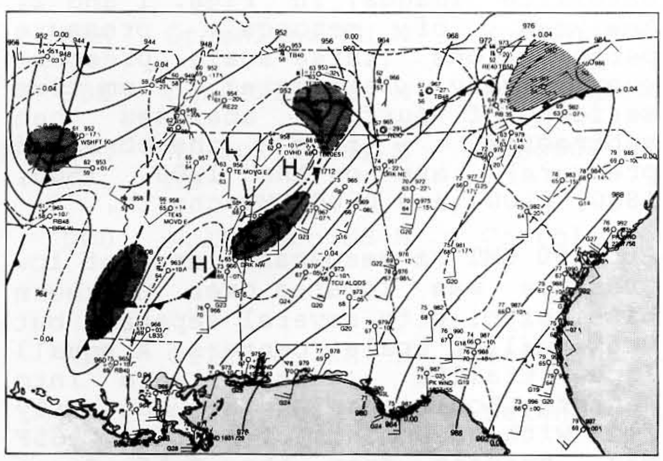

Fig. 1b. Surface mesoanalysis for 1500 GMT, 4 April 1977. Details as in Fig. 1a.

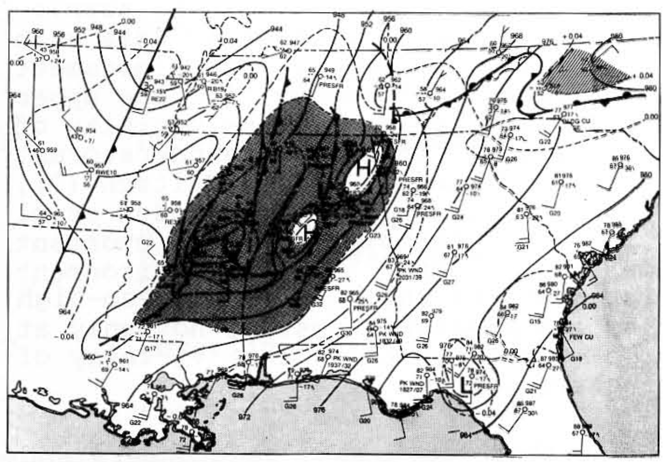

Fig. 1c. Surface mesoanalysis for 1800 GMT, 4 April 1977. Details as in Fig. 1a.

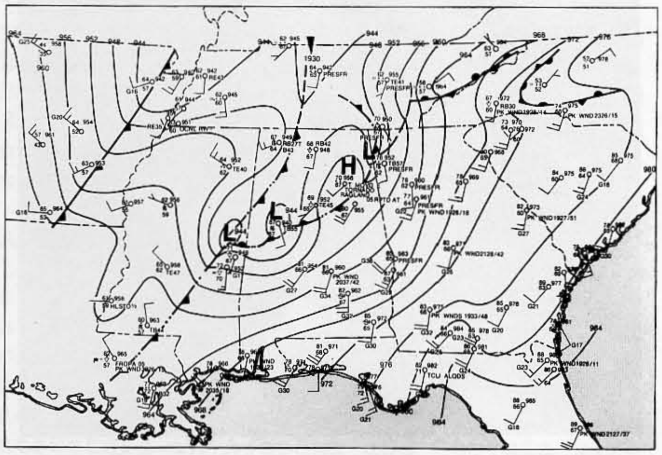

Fig. 1d. Surface mesoanalysis for 1900 GMT, 4 April 1977. Details (except for pressure perturbations) as in Fig. 1a.

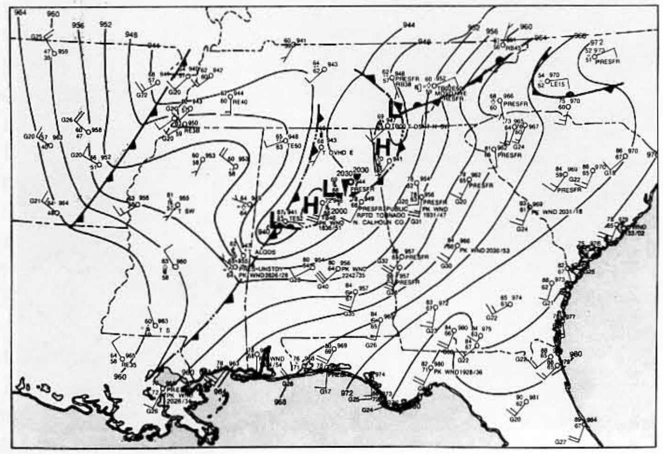

Fig. 1e. Surface mesoanalysis for 2000 GMT, 4 April 1977. Details (except for pressure perturbations) as in Fig. 1a.

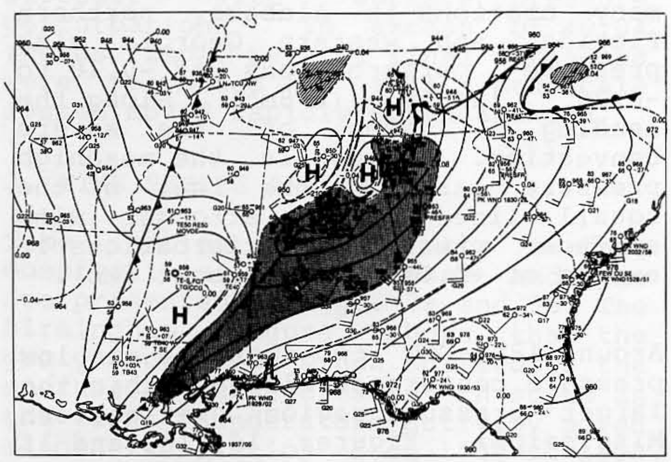

Fig. 1f. Surface mesoanalysis for 2100 GMT, 4 April 1977. Details as in Fig. 1a.

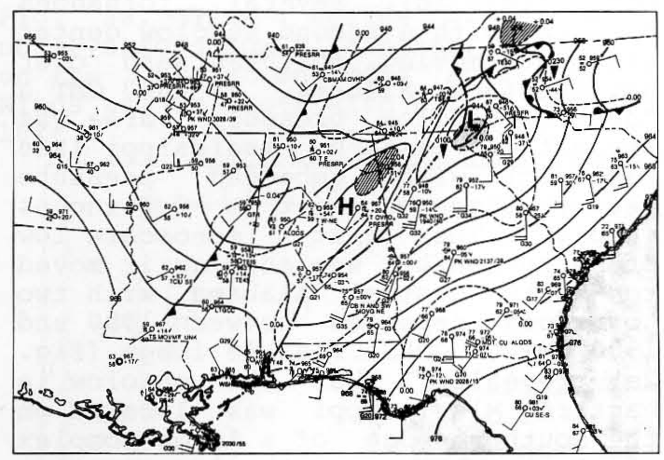

Fig. 1g. Surface mesoanalysis for 0000 GMT, 5 April 1977. Details as in Fig. 1a.

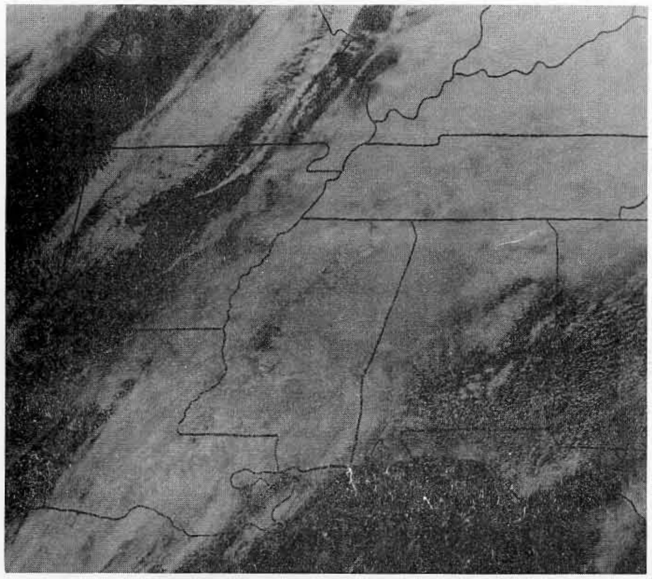

Fig. 2a. Full resolution GOES visible image for 1800 GMT, 4 April 1977.

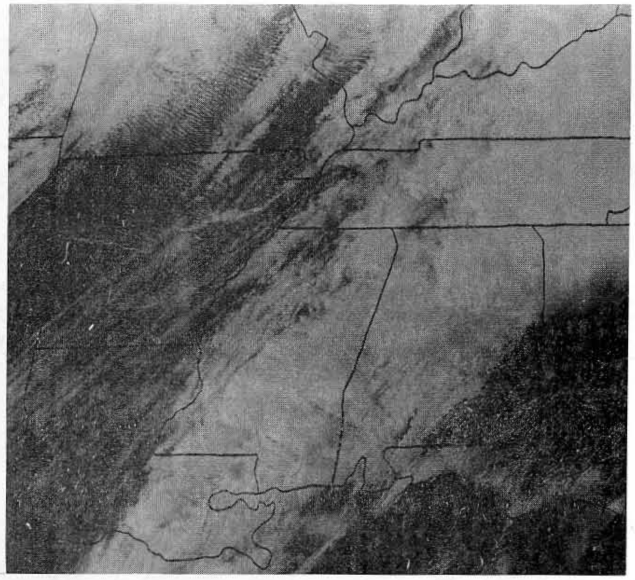

Fig. 2b. Full resolution GOES visible image for 2100 GMT, 4 April 1977.

in progress in Tennessee and Mississippi. As the day progressed the thunderstorm activity and its associated outflow boundary moved slowly eastward. A series of mesoscale pressure systems, accompanied by severe storms, developed along the outflow boundary and moved rapidly northeastward. The first of the series moved out of northeast Mississippi to an area just south of Nashville, Tennessee by 1500 GMT (Fig. 1b). Several tornadoes occurred with a second mesolow center that was moving northeastward over northwestern Alabama. At 1800 GMT a "deep" mesolow pressure area was present in eastern Mississippi (see Fig. 1c) with embedded pressure perturbations as great as -0.2 inches (8mb). The first mesoscale low pressure center weakened as it moved to north central Alabama with two tornadoes reported between 1800 and 1900 GMT. A GOES visible image (Fig. 2a) revealed that the mesolow in eastern Mississippi was located on the southern edge of a large complex of storms; however, the low pressure perturbations over northern Alabama appeared to be located in a region of suppressed convection beneath thin cirrus anvil cloud.

As the convection intensified, strong and gusty southerly winds increased over Mississippi, Alabama and Georgia to the south and east of the squall line. The temperature contrast across the squall line also intensified with mid-eighties (F) reported over southeastern Alabama compared to upper-sixties over northeastern Alabama. All of the significant convective storms continued to occur well in advance of the synoptic scale cold front. Pressures fell rapidly at many stations in Alabama, northern Florida and western Georgia with pressure perturbations of -0.10 to -0.20 inches (4-8mb) along the leading edges of the severe convection. Meanwhile the mesohigh pressure area to the rear of the squall line became stronger with surface pressure perturbations in excess of +0.04 inches (about 2mb).

Around 1800 GMT two separate mesolow pressure centers developed within the larger pressure region over eastern Mississippi. Figures 1d, 1e, and 1f indicate that both of these mesoscale pressure systems moved northeastward at 60-65kt. Indeed, Miller (11) reported that radar cell motions for the severe storms on this afternoon averaged about 63kt. The leading center became the second mesolow pressure system to cross north-central Alabama. This center was located near Tuscaloosa, Alabama, at 1900 GMT; just northeast of Birmingham by 2000 GMT; and slightly southwest of Rome, Georgia, by 2100 GMT. (Tuscaloosa is about 100km west-southwest of Birmingham and Rome is about 100km northwest of Atlanta.) The trailing system moved along a similar path about one hour later. Both mesolows were tornadic around 2100 GMT (Fig. 1f) with one located near Birmingham and the other just southwest of Rome.

A concurrent satellite photograph of the thunderstorm activity (Fig. 2b) shows that the mesolows were associated with intense storms characterized by multiple overshooting tops. The overshooting domes seem to indicate a double wave structure in Alabama and Georgia with one wave crest located just west of Birmingham and the other just southwest of Rome, Georgia.

By 0000 GMT (Fig. 1g) the major squall line had moved across most of northern and western Alabama and northern Georgia. The second and third mesolows that had crossed northern Alabama apparently merged as they continued to move northeastward to western North Carolina. The magnitude of the low pressure perturbation had decreased markedly while the mesohigh pressure area to the rear of the squall line became stronger with surface pressure perturbations in excess of +0.04 inches (2mb). Several final tornadoes were reported as this mesoscale system moved rapidly northeastward.

3. TIME SERIES ANALYSES

Time series showing the surface observations at Birmingham and Rome are presented in Figs. 3a and 3b. The Birmingham figure shows that the gusty southerly winds shifted to the southwest and decreased in speed as the first thunderstorm activity moved across the station from 1700 to 1800 GMT. The pressure then fell rapidly during the next two hours as the second mesolow moved out of western Alabama and approached the station (see Figs. 1d, 1e). During this time the winds backed to a southerly direction and became very strong just before the mesolow passed the station. The pressure rose rapidly as thunderstorms with the mesosystem affected the station and then fell rapidly as the trailing (third) mesolow approached from the southwest. An F5 tornado was embedded in this third mesosystem. After it passed at about 2100 GMT surface winds remained west to northwest and pressures gradually rose as continuing thunderstorm activity affected the Birmingham area. Notice that during the entire period of extreme pressure fluctuations the surface temperatures and dewpoints remained relatively constant. This was also the case in the Omaha and Neosho tornadoes analyzed by Maddox et al (9) and indicates that thermodynamic features and circulations associated with the important mesopressure systems were primarily aloft.

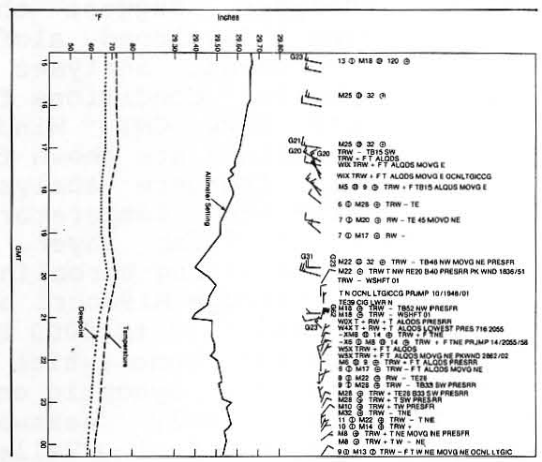

Fig. 3a. Time series of surface observations for Birmingham, Alabama, on the afternoon of 4 April 1977. Winds are in knots with a full barb = 10kt.

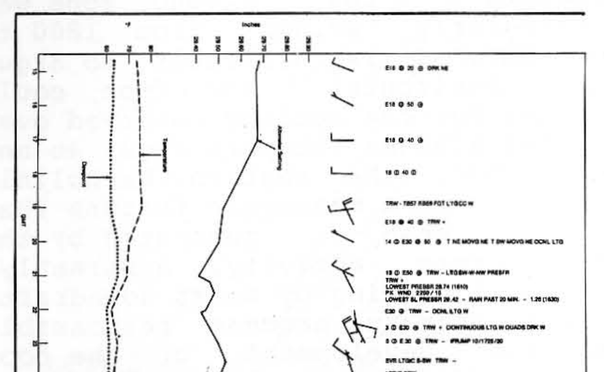

Fig. 3b. Time series of surface observations for Rome, Georgia, on the afternoon of 4 April 1977. Winds are in knots with a full barb = 10kt.

At Rome, thunderstorms moved over the station around 1900 GMT in conjunction with the first mesolow and the wind shifted to the southwest. Temperatures dropped sharply as the dewpoint increased. Surface pressures leveled off for about an hour and then fell rapidly as a second mesolow approached. The second center passed the station shortly after 2100 GMT as the sea level pressure tumbled to 29.42 inches. Southwesterly wind gusts to 50kt indicate that a tornado cyclone may have passed very near the observation site. The third mesolow passed between 2200 and 2300 GMT, after spawning the Birmingham tornado.

4. UPPER LEVEL ANALYSES

Along with the large and fast-moving changes that occurred at the surface, upper-air analyses suggest that similar changes developed aloft. Figures 4a-c present analyses of lower tropospheric conditions for 1200, 1800, and 0000 GMT. Winds, heights and streamlines are shown for the 850mb level; isotherm analyses are shown for the mean temperatures in the surface to 700mb layer. In Fig. 4a, notice the strong baroclinic zone stretching through Missouri and Arkansas. During the 1200 to 0000 GMT period this baroclinic zone (which is associated with the synoptic cold front) advanced slowly eastward across the Mississippi Valley. However, as the region of deep convection grew and intensified, a cool pocket and second baroclinic zone developed in the vicinity of the squall line. The strong cooling which produced the second zone was particularly evident from 1800 to 0000 GMT. It is difficult to argue that horizontal advection could account for the cooling observed over central Alabama (compare Figs. 4b and 4c). Thus, the eastern baroclinic zone must be a mesoscale feature that has been generated by the thunderstorm activity. Apparently, low-level cooling by moist downdrafts is the primary process responsible for the development of the cool pocket and new baroclinic zone.

Looking somewhat higher in the troposphere, in the 700 to 250mb layer, additional thermal changes are

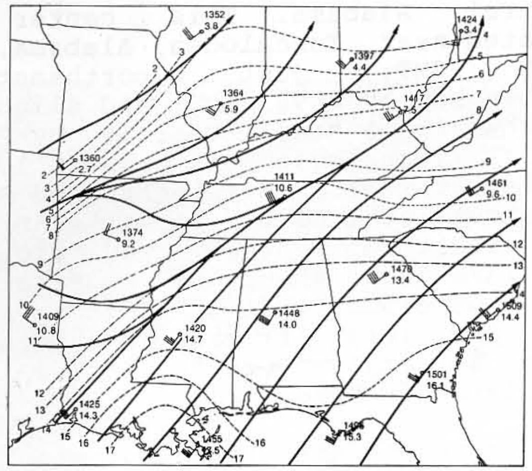

Fig. 4a. Lower tropospheric conditions for 1200 GMT, 4 April 1977. Heights, winds, and streamlines are for 850mb. Isotherms are shown for the mean surface to 700mb temperature (plotted below the height).

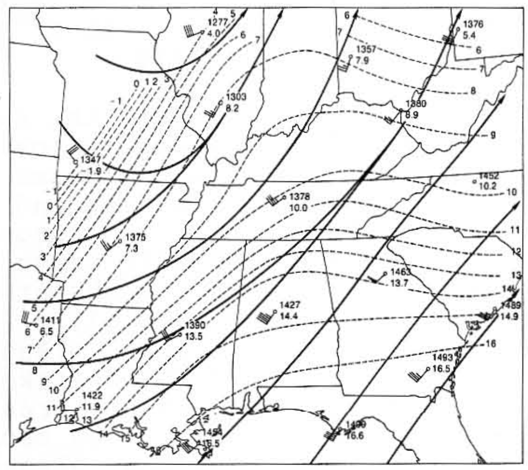

Fig. 4b. Lower tropospheric conditions for 1800 GMT, 4 April 1977. Details as in Fig. 4a.

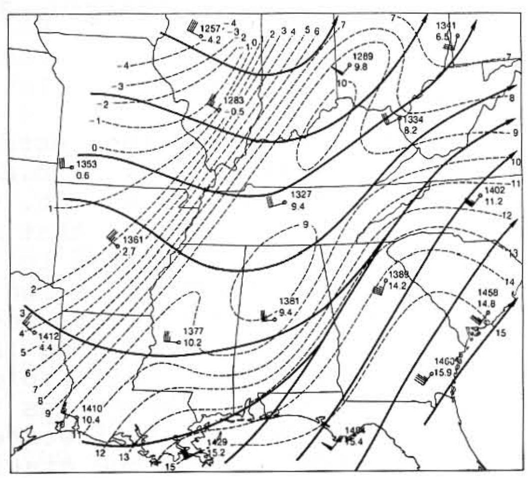

Fig. 4c. Lower tropospheric conditions for 0000 GMT, 5 April 1977. Details as in Fig. 4a.

readily apparent. Figs. 5a-c show heights, winds and streamlines for the 500mb level along with isotherm analyses of the mass weighted mean temperature in the 700 to 250mb layer. From 1200 to 1800 GMT strong middle-level warming occurs in the region of the severe squall line. Mean temperatures in the layer increase 3-5C over portions of northern Mississippi, northern Alabama, and central Tennessee. Part of the increase is due to warm advection; however, once again it is difficult to argue that horizontal advection alone produced such strong warming. It is possible that the convection itself generates a significant portion of the warming. Specifically, the deep convective clouds force subsidence and compressional warming in their near environment. In response to this "local-scale" area of subsidence warming the atmosphere may generate a region of mean mesoscale ascent in the thunderstorm region with a corresponding area of mesoscale descent over a somewhat broader scale environment. Evidence for the development of a mesoscale circulation comes from many sources. For example, Fankhauser (12, 13), Sanders and Emanuel (14), and Ogura and Chen (15) have diagnosed such a circulation for squall lines passing through the National Severe Storms Laboratory's upper-air sounding network in Oklahoma. Broad areas of steady rain, persisting for several hours, frequently develop following the maturation of large convective complexes. Note steady rain regions in Fig. 1; see also Houze (16), Zipser (17), Leary and Houze (18). Kreitzberg and Perkey (19), Fritsch (7) and Brown (20) found mesoscale vertical circulations developed in response to the convection in mesoscale numerical models.

The exact role of such a circulation in the development of mesoscale weather systems is unclear at this time. However, this type of circulation may be a mechanism by which convection interacts "up-scale" with its environment to organize and enhance future convective growth.

Finally, upper tropospheric and lower stratospheric conditions are illustrated in Figs. 6a-c. These charts

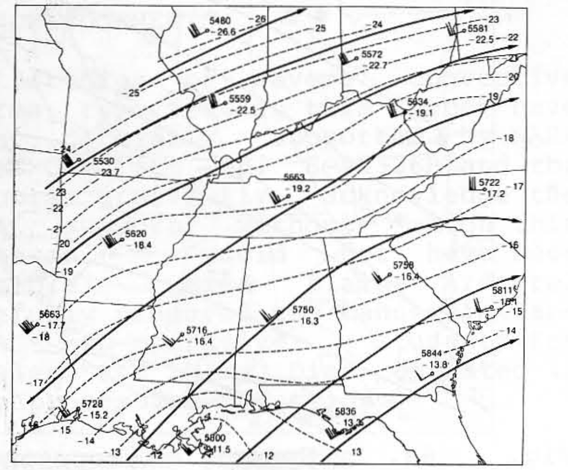

Fig. 5a. Middle tropospheric conditions for 1200 GMT, 4 April 1977. Heights, winds, and streamlines are for 500mb. Isotherms are shown for the mean 700 to 250mb temperature (plotted below the height).

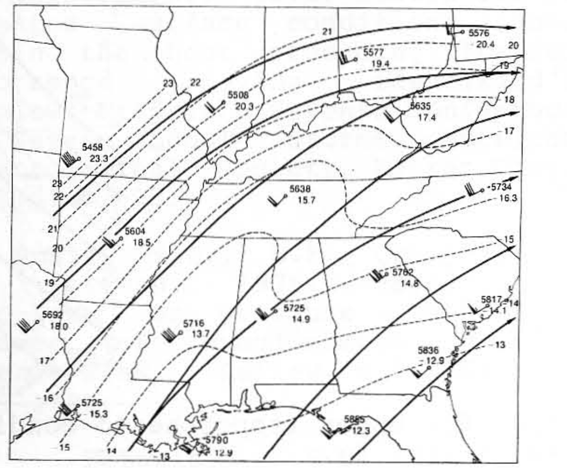

Fig. 5b. Middle tropospheric conditions for 1800 GMT, 4 April 1977. Details as in Fig. 5a.

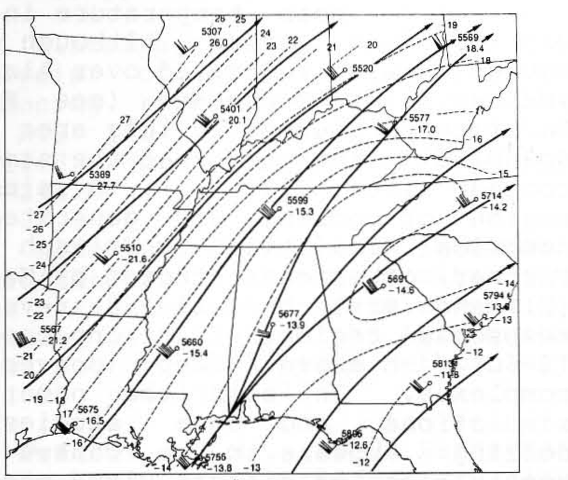

Fig. 5c. Middle tropospheric conditions for 0000 GMT, 5 April 1977. Details as in Fig. 5a.

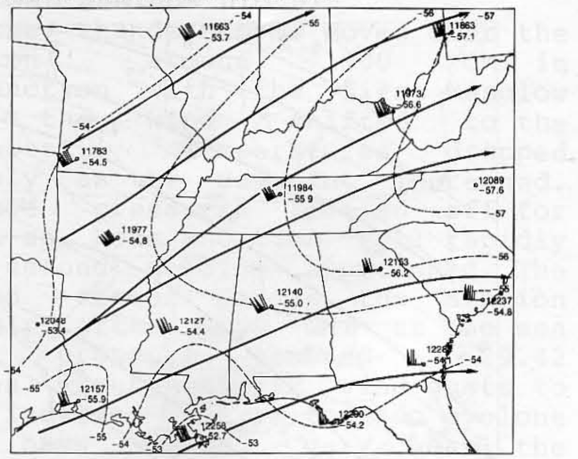

Fig. 6a. Upper tropospheric conditions for 1200 GMT, 4 April 1977. Heights, winds and streamlines are for 200mb. Isotherms are shown for the mean 225-175mb temperature (plotted below the height).

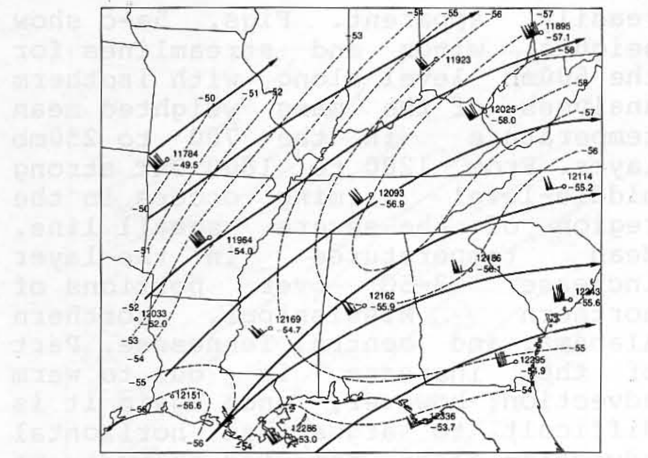

Fig. 6b. Upper tropospheric conditions for 1800 GMT, 4 April 1977. Details as in Fig. 6a.

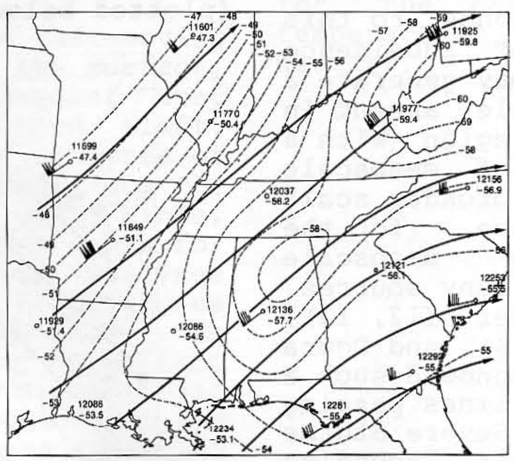

Fig. 6c. Upper tropospheric conditions for 0000 GMT, 5 April 1977. Details as in Fig. 6a.

show heights, winds, and streamlines for the 200mb level and thermal analyses for mean temperature in the 225 to 175mb layer. Although warm advection was indicated over Alabama and eastern Tennessee (see Figs. 6a-b) temperatures in this area (and downwind) either remained the same or cooled (see Fig. 6c). A similar region of cooling was generated in numerical simulations by Fritsch (7). Further, other case studies by Maddox (21) and Fritsch et al (8) revealed mesoscale regions of strong cooling (2-6C) above deep convective complexes. In both the numerical simulations and case studies the cooling appears to be caused by a combination of direct cloud cooling (overshooting, mixing and evaporation) and by adiabatic expansion in the region of mean mesoscale ascent.

5. SUMMARY

Modification of the environment by deep convective clouds can be easily detected at the surface where observations are fairly dense and the convective changes dramatic. At middle and high levels convectively forced changes are more difficult to detect because of large data separations and strong background flow fields. However, the analyses presented above, along with several others cited in the references, suggest that mesoscale convective complexes can affect and modify the environment on scales large enough to be detected in the synoptic sounding network. The likelihood that the observed upper-air changes found in the thunderstorm regions are due in large part to the thunderstorms themselves is enhanced in the 4 April case because the convective activity occurred well ahead of the synoptic scale front and its associated upper-level baroclinic zone.

This case study demonstrates once again the strong association between severe weather and surface mesoscale pressure systems; most of the reported tornadoes were associated with mesolows. The exact mechanisms responsible for the series of mesolows, however, were not resolved by the coarse-resolution, upper-air data. Small mesolows appeared to be closely linked to active storm complexes while the general region of low pressure along the squall line probably resulted from a combination of mesoscale effects that would include low-level warm advection and upper level subsidence warming. For a more detailed discussion of mesocyclogenesis see Hoxit et al (3) and Fritsch and Chappell (22).

If indeed cloud to environment feedbacks are present, they may have a significant influence on how a given potential severe weather situation evolves. Unfortunately much of the atmospheric physics associated with these feedback processes are not included in present operational forecast models. Thus, while the forecaster would be aware of these processes, the present state of the art will not provide reliable objective guidance on if, where or how thunderstorm induced mesoscale perturbations will form.

It is interesting that many of the most detailed studies of surface pressure perturbations associated with thunderstorm activity were accomplished in the late 1940's and 1950's. See, for example, Brunk (23), Williams (24), Fujita et al (25) or the extensive analysis and list of references in Pedgley (26). Though the early papers did not focus on the upper level perturbations, the reader is encouraged to compare the qualitative aspects of their findings with those presented in this paper.

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