NOAA Technical Memorandum ERL ESG-17

SUB-SYNOPTIC WEATHER ANALYSIS AND THE FORECASTING OF CONVECTIVE WEATHER EVENTS IN THE SOUTHEASTERN UNITED STATES

Charlie A. Liles

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NATIONAL OCEANIC AND
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ABSTRACT

Conventionally analyzed surface and upper-air data are reanalyzed, employing sub-synoptic analysis and enhancement techniques and discussed in detail. The potential of these procedures for improving short-range weather forecasts is shown through numerous examples that compare conventional and sub-synoptic analysis techniques. Some of these cases use analyses actually done in real time; others were analyzed after the fact, using techniques that are feasible for real-time situtations.

Sub-synoptic analysis has been an integral part of my forecasting routine for several years, and I am firmly convinced that detailed diagnosis of the structure of the atmosphere can pay high dividends to both the forecaster and the user public. This Technical Memorandum is not a complete answer to operational problems posed by significant convective storms, but the case studies considered substantiate the value of intensive analysis procedures.

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1.0 INTRODUCTION

Most forecasters have been diverted from their once prime role as meteorological analyst and have gradually built their forecasting routine around the National Meteorological Center's (NMC) analyses and a plethora of guidance products. During the 1970s, emphasis at the forecast office shifted from weather analysis and forecasting to interpretation of the numerical model runs and resulting guidance. For a number of years forecasters have been playing the game of forecaster vs. Model Output Statistics (MOS) guidance. The "selling" of MOS and subsequent reliance on the guidance and numerical models have apparently led to a decline in our ability to apply basic knowledge of physical laws that govern the atmosphere in the forecasting process. In his paper on meteorological cancer, Snellman (1977) warned National Weather Service (NWS) forecasters of this danger. It's obvious why we subject the forecaster to MOS war games. Objective evaluation of temperatures is relatively easy, but measuring the actual worth of forecasts is nearly impossible.

The NWS exists primarily to help protect lives and/or property. Indeed, the NWS mission statement (National Weather Service Operations Manual, 1970; sec. 70-45) states that priorities for service to the nation are (1) Protection of life, (2) Protection of property, and (3) Promotion of the nation's welfare and economy. With this in mind, I define a significant weather event as one that threatens life and/or property. Although a 20-inch rainfall in the central Gulf of Mexico is an important meteorological event, it is not significant to NWS operations unless it poses a threat to boating or shipping interests. In this report I deal specifically with significant weather events of the convective kind. This brings me to perhaps the greatest problem forecasters are faced with today. Heavy reliance on numerical models leaves the most important aspect of the NWS mission doomed to failure. Why? Because virtually all significant convective weather is created by sub-synoptic features or is a consequence of interactions between sub-synoptic and synoptic-scale features. Not all forecasters will agree with this statement. I certainly cannot rigorously prove it. However, meteorologists who have studied significant weather events would probably testify to the validity of my statement.

Fortunately during the past several years, there has been a movement (perhaps a result of Snellman's paper) to reassess the role of the forecaster in the NWS. There are growing numbers of NWS meteorologists who are not satisfied playing the role of model interpreter. They realize that a forecaster performing in that mode is not equipped to cope with the most important part of our mission. These forecasters know that to keep the NWS ability to handle significant weather events from deteriorating further, the basic philosophy of the role of the forecaster must be changed.

I hope to provide encouragement to these meteorologists. Rather than teaching specific techniques of sub-synoptic analysis, my intent is to make more forecasters aware of what can be accomplished with conventional data. Since the trend is to allow further deterioration of our data network, sub-synoptic analysis will not get any easier! However, it is only through sub-synoptic analysis that we may detect important relationships between features with various scales. Although my emphasis will be on hand analysis, AFOS application programs should gradually assume a greater share of the load during the remainder of this decade. A wealth of programs to compute a variety of derived fields ranging from vorticity analyses at different mandatory levels to surface divergence and moisture divergence have already been developed. In addition, NMC computers may someday be used to delineate sub-synoptic features using conventional data and appropriate objective analysis techniques.

Although I concentrate on anticipating significant convective weather events through analysis, it should be obvious that my "back-to-basics" approach applies to everyday forecasting as well. Sub-synoptic analysis should be part of the everyday routine. The reader should also realize that the solution of specific forecast problems at individual stations is certainly beyond the scope of this effort. This must be accomplished at the local level, by individuals much more attuned to their forecast problems than I. In fact, localized efforts have already been established at some Southern Region forecast offices. Since I am an operational forecaster who has had the luxury of spending several months away from the forecast office, and not an "ivory-tower hermit", I am well aware of the problems forecasters have to deal with in the real world of the Weather Service Forecast Office (WSFO). My hope is to inspire one or two enthusiastic leaders (enthusiasm is the main requirement) to take the lead in attacking local forecast problems at each WSFO.

2.0 PHILOSOPHY OF WEATHER FORECASTING

Figure 1 illustrates a measure of precipitation forecast skill for the years 1966-1977 (Ramage, 1982). In another look at forecast skill, Sanders (1979) concluded that there was some evidence of forecast skill improvement for the day-two and-three forecasts, but no improvement for day one. Proponents of MOS argue that statistics show that there is little difference between guidance and actual forecaster errors in terms of temperatures and precipitation probabilities. Indeed, long-term averages show very little difference (again see Fig. 1). Perhaps 90 to 95 percent of the time adhering strictly to MOS guidance allows the forecaster to get by. However, 95 percent is not good enough! If, as I rather arbitrarily suggest, MOS guidance allows us to get by 90 to 95 percent of the time, why is this not good enough? Consider the kind of weather that constitutes the remaining five of ten percent. It is probably weather that may endanger lives and/or property,--the kind of weather that is most important to mankind. But this is exactly the kind of weather event that MOS and the numerical models cannot handle accurately!

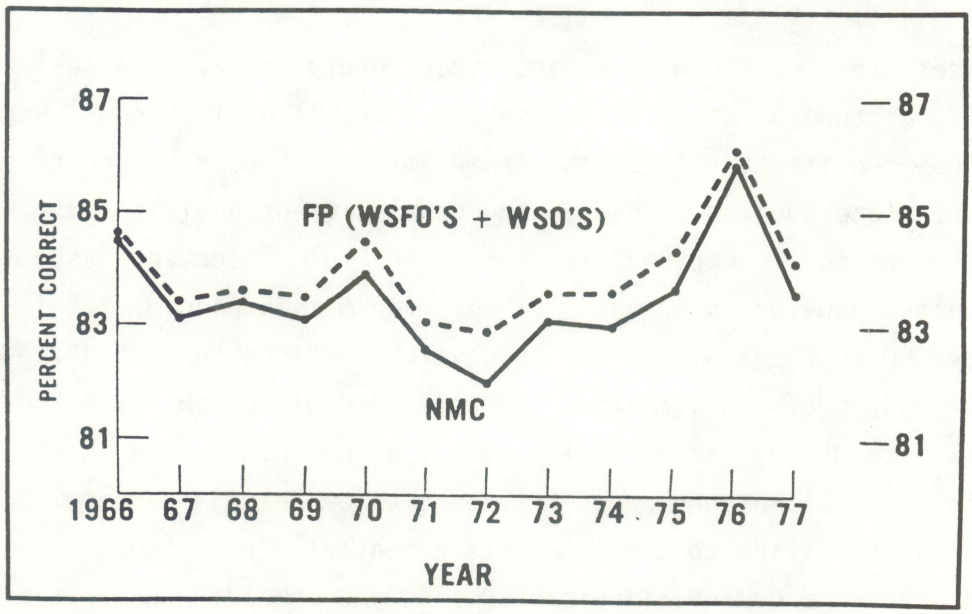


Figure 1 Measure of precipitation forecast skill for the years 1966-1977 (Ramage, 1982).

In the words of Schaefer (1973), "Because moisture is carried in only three layers of the present version of the LFM (Limited-Area Fine-Mesh Model) the scheme for the parameterization of convection can only crudely approximate atmospheric convective processes." [My emphasis on crudely!] Thus, some of the most important types of weather events in the southern United States can only be crudely handled by the numerical guidance. Similarly, the LFM cannot accurately predict the development and movement of sub-synoptic features (e.g., low-level jetstreams, mesoscale outflows from widespread convection, squall lines, etc.). An obvious conclusion is that the forecaster cannot rely upon guidance products when dealing with significant mesoscale weather events.

As far as I am concerned, there is only one meteorologically sound method of weather forecasting. Before any thought can be given to the forecast, the forecaster must develop an accurate picture of current atmospheric structure. This first step should be obvious to most forecasters. However, it is surprising how many forecasters "jump" to the forecast and skip this essential first step. To be successful, forecasters must be able to visualize the fluid atmosphere, with its various complexities of structure. Detailed analysis is one way that we can develop this picture in our minds. Indeed, the act of analysis should make the forecaster more aware of what is currently happening.

A forecaster must be willing and eager to dig out all available data to construct a picture of what the atmosphere looks like right now! Naturally, this process requires the forecaster to examine past data to understand how the current state evolved. This is why continuity of analyses must be carefully maintained. Fortunately, Automated Field Observing System (AFOS) hardcopy plots provide an adequate vehicle for maintaining regional continuity. Once a mental picture is developed of the current state, the forecaster must begin to visualize how the fluid might behave in the future. The only way to do this is by employing solid reasoning based on the fundamental laws of meteorology. I suspect that one major problem forecasters have today is a failing to complete this essential first step. Indeed, many forecasters spend abundant time interpreting the LFM 12-48 hour panels without even looking at the initial analysis panel.

Although individual philosophies differ, we would probably all agree that meteorology remains an inexact science. For this reason, "rules of thumb" can never represent anything more than guidelines. Indeed, statistics, rules of thumb, and climatology are merely different types of guidance. This is not to say they are not important. Pattern recognition and knowing what usually happens in certain situations is certainly an asset in forecasting. However, the negative aspect of rules of thumb and pattern recognition is that they generate complacent forecasting by discouraging thinking. Forecasters should apply such tools with extreme caution; nothing can take the place of sound, physical reasoning and meteorological understanding.

> "The philosophy of analysis is to use the computer to do the basic work of drawing and redrawing isobars and to have the human analyst monitor, correct, augment, and delete data as necessary to provide the computer with sufficient information to accurately depict the sea level pressure field, especially in regard to depth and position of storms. The analyst's intervention is based on continuity, persistence, vertical consistency and the evidence of satellite pictures, particularly as to locations of storm centers at sea. The analyst decides on the location of fronts based on these principles as well as the reported data and digitizes the fronts in one of the ways described in Section 2.4, North American Surface Analysis." (National Meteorological Center, 1979)

You have just read NMC's philosophy of analysis for the North American surface chart. I have underlined several words for emphasis. It should be clear to the forecaster that the primary purpose for NMC analysis procedures (surface and upper-air) is numerical model initialization. Unfortunately, these large-scale, smoothed analyses do not provide forecasters with the necessary detail to deal with significant weather events. In fact, these charts/analyses frequently do not provide the details necessary for everyday forecasting! My reason for saying this should be obvious. NMC analyses are meant to provide an overview of synoptic features over the United States and Canada. But forecasters must do their forecasting on the sub-synoptic scale; breaking the forecast down by zones is an exercise in sub-synoptic meteorology.

However, besides providing the computer with the necessary information to depict the sea level pressure accurately, NMC analyses are valuable to the field forecaster. It is certainly not feasible for forecasters to analyze the synoptic setting over the entire country or hemisphere. The NMC analyses do provide a general picture of the large-scale flow over extended areas.

Therefore, the role of the NMC analyses (as far as the forecaster is concerned) should be to provide a foundation upon which to build a sub-synoptic analysis. The forecaster can then proceed to focus on understanding the current state of the weather over some regionalized area. Naturally, this area will vary depending upon the particular situation at hand. At times during the cold season, it may cover a large section of the country. During the summer "doldrums" the area of interest may be only a four-or five-state area (especially for the first-period forecast).

Analyzing maps does not imply a simple process of drawing isolines. The whole purpose of the analysis routine is construction of a picture of the multidimensional structure of the atmosphere. That is, as I mentioned before, the final result of analyzing the structure of the fluid from the earth's surface to the lower stratosphere should be a detailed visualization (i.e., mental picture) of the multidimensional atmosphere. The forecaster must make use of all available tools. A meaningful analysis must draw upon satellite imagery (if available), Satellite Interpretation Messeges (SIMS), radar (if applicable), pilot reports, and any other data that may contribute to a comprehensive analysis.

If there is any one area that forecasters should concentrate on (this is especially true in diagnosing convective potential), it is the vertical motion field. Since convection occurs where moist, unstably stratified air is lifted, forecasters should concentrate on vertical motion while building a mental picture of atmospheric structure. A forecaster who has finished analyzing a set of maps should feel confident about where the air is rising and sinking and, qualitatively, to what degree. Further, this should include an intuitive notion of how that vertical motion field is changing with time. Only then can the forecasting process really begin.

Unfortunately, many forecasters who are convinced of the worth of sub-synoptic analysis view it as a tool that should be saved for the heat of battle. However, sub-synoptic analysis must be a part of the everyday routine, clear skies or not. The reason for this is at least twofold. First, the forecaster can't possibly know for certain that "nothing is going on" unless the situation has been analyzed in detail. Very subtle features that have been smoothed away in large-scale products can often ruin a fair-weather forecast. Second, practice is required to develop or maintain analysis skills. For those who are not believers, my purpose is to demonstrate what can be accomplished using conventional data.

3.0 THE NATURE OF SUB-SYNOPTIC WEATHER

Before I proceed any farther, I should discuss the term "sub-synoptic," since I have already used it several times. A perusal of current meteorological literature reveals a wealth of terms such as mesoscale, microscale, meso-alpha scale, meso-beta scale, meso-gamma scale, and, yes, even sub-synoptic. Figure 2 shows a variety of scale "definitions" and beautifully illustrates how confusing terminology can become. I will define a sub-synoptic feature as one too small to be completely resolved by the conventional upper-air network and will use the terms sub-synoptic and mesoscale interchangeably. Unfortunately, very little is known about sub-synoptic weather features, or the relationships between them and the larger-scale features we can readily identify with our present-day observational network. Whether you're looking at an extratropical cyclone, a synoptic cold front, or even a hurricane, the weather is not homogeneous within the system. The most significant weather will be controlled by sub-synoptic influences embedded within the larger-scale system. Some of the lack of understanding is the result of the sparse data network meteorologists have to work with. Radar and satellite data certainly have made meteorologists aware of how important mesoscale processes really are. However, an in-depth understanding of the nature of sub-synoptic features awaits further research. One very basic question that is still being studied is whether mesoscale features cause convective development or convection produces mesoscale features.

Some modeling studies suggest that low-level convergence may increase by an order of magnitude after convection develops. However, observations support the viewpoint that mesoscale features can affect the initiation of thunderstorms. For example, mesoscale boundaries are frequently detected well before convective development. One dominant peculiarity of mesoscale phenomena is that mesoscale features produce much of the weather of most significance to mankind. While synoptic-scale systems contain vast amounts of energy and produce weather over large areas, the embedded mesoscale phenomena are often those that endanger life and property. Mesoscale systems can be described in two broad categories: (1) those that are produced by forcing from inhomogeneities near the earth's surface, and (2) those produced by internal modifications of large-scale flow patterns that lead to small-scale

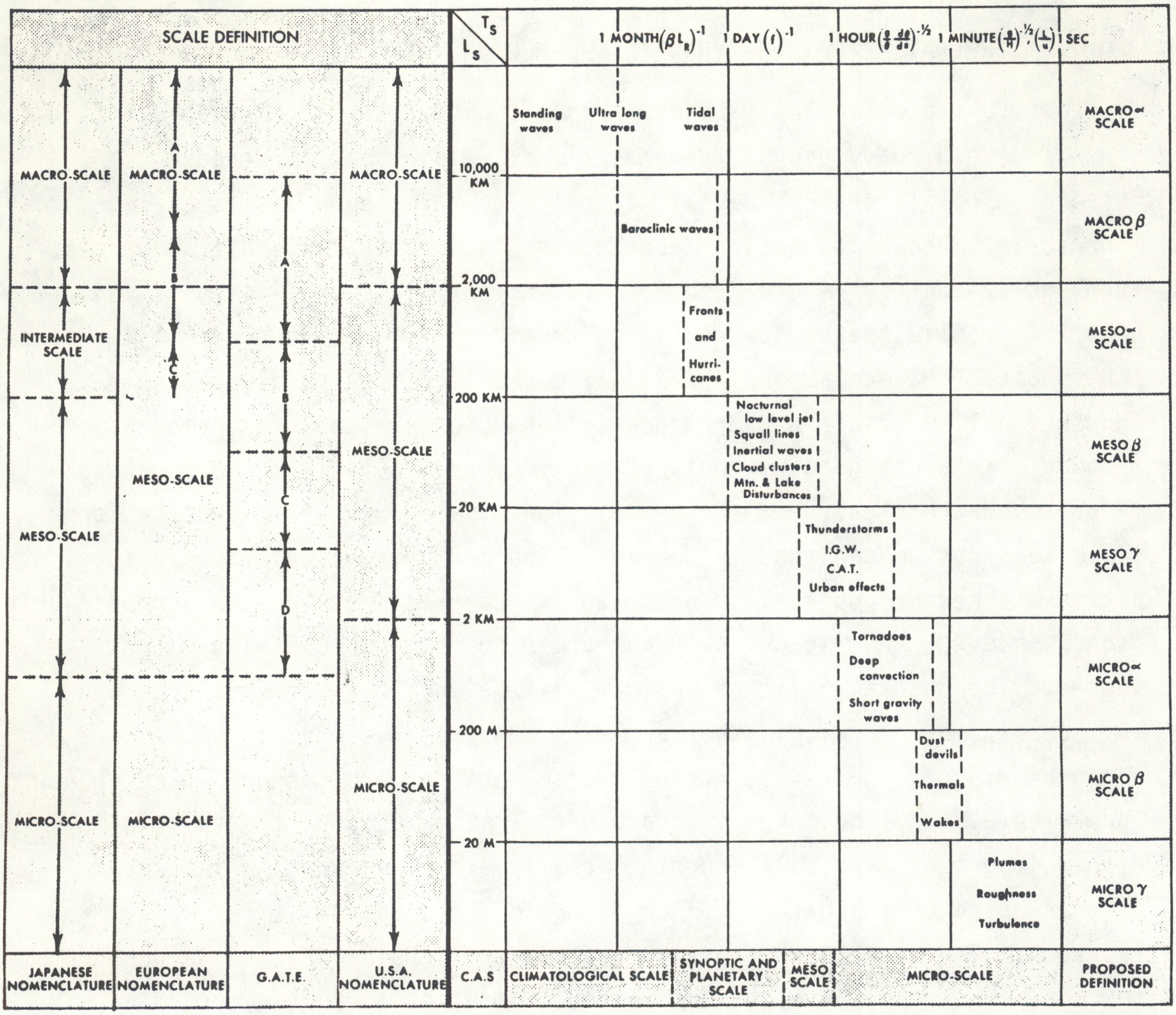


Fig. 2 Scale definitions and meteorological example (Orlanski, 1975).

circulations. It should be pointed out that a particular mesoscale feature may be the product of either or both of the general processes.

Thermally driven mesoscale flows include the familiar land and sea breezes. Inhomogeneities in the surface terrain frequently induce mesoscale features mechanically. For example, meteorologists are very familiar with frontal waves that develop in the western Gulf of Mexico because of differences in the way cold air flows from Texas and Louisiana into the Gulf. New Orleans forecasters are especially familiar with these waves, because of Belville and Stewart's (1983) finding that they frequently play a role in producing heavy rainfall over southern Louisiana. Weak surface troughs and wind shift lines are frequently generated by subtle variations in orography. Hills, variations in vegetation, soil and moisture characteristics, etc., can all produce mesoscale features through differential heating. It is up to the forecaster to determine which mesoscale features are significant. Once again, nothing can replace sound meteorological reasoning in evaluating the features that have been detected.

For example, let's say that one summer afternoon, widespread convection dumped 1 to 2 inches of rainfall over a 10-county area of your state, while adjacent counties remained dry. Differential heating the next morning produces a weak low-pressure trough that might be significant. Weak, low-level convergence combined with diabatic heating of moist unstably-stratified air could produce strong convection along the surface trough. Add a transient middle-level trough that cools the mid-troposphere by 2°C, and you may be dealing with golfball-sized hail and severe wind gusts instead of "typical" summertime thundershowers.

Generation of mesoscale systems can at times be accomplished by internal modification of the large-scale flow. Situations in which the flow possesses a large degree of baroclinity favor development of mesoscale circulations (Staley and Gall, 1977). However, development of mesoscale systems from instability within the large-scale flow generally requires release of latent heat. Convective bands in tropical storms as well as other extra-tropical mesoscale convective patterns may be the result of processes set in motion by release of latent heat. These mesoscale circulations may not be a necessary ingredient for fueling massive convective systems, but certainly could be instrumental in focusing large amounts of energy into small areas to maintain these systems (and at the same time, producing significant weather events). Just as large-scale shearing and stretching may lead to frontogenesis, convergent zones between synoptic-scale air masses may produce mesoscale systems through convective development (Zipser, 1983). The possible growth of mesoscale systems should never be overlooked once convection is initiated through large-scale forcing.

Detecting, tracking, and determining the significance of existing mesoscale features is obviously a challenging task. If this is so, then what chance do forecasters have of actually predicting the development and evolution of mesoscale features? The first step should be building an understanding of the nature of sub-synoptic features. Just using the basic ideas that have been mentioned in this chapter, within the everyday forecast routine , should allow the forecaster to anticipate situations in which convective instability will be produced or available on the mesoscale. We know that there are regions within synoptic-scale systems in which development of mesoscale systems is favored. For example, the northeast quadrant of an extra-tropical cyclone seems to be a favored region for a variety of mesoscale systems. The intersection of a low-level jet stream with a warm front frequently leads to meso-low development (Miller, 1972). Once mesoscale features have been detected, there is nothing magical about predicting their evolution. Admittedly, it can be very difficult! Forecasters should try to deal with these systems in the same manner as with synoptic-scale systems (e.g., in dealing with large-scale storms, we frequently employ the conceptual life-cycle model of the Norwegian Cyclone).

Just as with synoptic-scale systems, the process must involve sound meteorological reasoning. For example, monitoring hour to hour (or more frequently with "special" observations) changes in observations as well as continuity, is essential if one is to follow the evolution of temperature and wind fields. Admittedly, this is often more difficult than synoptic-scale analysis, but what choice is there? Naturally, this analysis process depends on reliable data. Unfortunately, even this is not a given, especially during bad weather (one of the corollaries to Murphy's laws). Of course, the problem is compounded at night. Significant weather doesn't keep bankers' hours; in fact, there is a high incidence of flash flood events during the nighttime hours (Maddox, 1979).

4.0 USING THE NUMERICAL MODELS

4.1 General Discussion

This chapter is another one of those "good news, bad news" stories we've all heard. The good news is that numerical models to simulate mesoscale processes have been developed during the past 5 years and considerable progress has been made in modeling frontal convection (see Anthes' [1983] review). Even without representation of mesoscale circulations in the initial data, some numerical models can predict future mesoscale developments (e.g., Kaplan et al., 1984). Zipser (1983) states that "an accurate specification of large-scale thermodynamics and momentum fields, together with realistic physical forcing at the surface, adequate representation of diabatic effects in the free atmosphere, and the appropriate resolution, may be sufficient to predict the evolution of some mesoscale systems for hours or even a few days, in advance of their development." Indeed, successful severe thunderstorm forecasting procedures used at the National severe Storms Forecast Center (NSSFC) substantiate the validity of this statement.

As one might suspect, the bad news is that there are important limiting factors that affect both the prospects for real-time mesoscale models and in the practical use of current operational forecast models. Even if suitable numerical techniques are employed to approximate the nonlinear partial differential equations to an accurate enough degree, poor horizontal and vertical resolution of available data seriously restricts the utility of operational mesoscale models. Newer computers can speed the running of models, but real improvement in resolution is impossible without an increase in the data-gathering network. Unless high-resolution, reliable, remote sensing becomes a reality (don't hold your breath!), mesoscale modeling probably will develop primarily as a research tool. Additionally, a mesoscale model would have to depend heavily on surface data, and current trends certainly do not favor development of improved surface observations in the near future. Indeed, the present-day surface network is often inadequate. Thus, the obvious conclusion is that for the 1980s, and probably well beyond, the forecaster must make optimum use of hand-drawn analyses, AFOS, and our operational forecast models.

Since the characteristics of the LFM model are adequately described in NMC Technical Notes, I won't go into detailed specifics concerning the LFM.

However, it is important to remember that the current LFM resolves poorly any features whose length scale is smaller than about 1000 km. In spite of its inherent limitations, there is evidence that the LFM does forecast some sub-synoptic features of nonconvective origin. In a very detailed look at an LFM forecast, Brown and Marroquin (personal communication, 1983) found that the model output apparently described a standing mountain wave. However, the manner in which they examined this forecast is not possible in the real-time world of the forecaster.

Note $\approx 5 \Delta x$ or 600 miles or Washington to Chicago

The LFM occasionally does well in forecasting the development and position of drylines and pre-frontal troughs over the southern United States. These features can be readily inferred by forecasters, in real time, through detailed analysis of the LFM output. If the LFM forecasts other sub-synoptic features, it's debatable whether forecasters can actually recognize these features and be able to deal with them in real time. More documentation is needed that details exactly what the numerical models can and cannot tell us.

Numerical models go through an adjustment period early in each forecast cycle. The variables oscillate (sometimes rather wildly) during the first 3-12 hours as they gradually approach a state of balance dictated by the model's equations. Therefore, even for the LFM, the 12-hour forecast may not be completely reliable, even if the initialization was accurate. In spite of their inability to handle most types of significant weather events, numerical models must play an integral part in the scheme of day-to-day weather forecasting. However, they should be used intelligently and certainly with caution.

Precisely where does the numerical model belong in the forecast scheme? The numerical models represent the best source of information on how atmospheric structure is going to evolve after the initial 6 to 12 hours of the forecast. Through mesoanalysis, the forecaster's "visualization" of the atmosphere should provide the best source of short-term detail. This is important since the forecaster's ability to visualize atmospheric evolution probably decreases rapidly after the first 6 to 12 hours. It is after 12 hours that model output should begin playing a greater role in the forecast process. The models have demonstrated considerable skill in forecasting the evolution of scale features in the 24-to 48-hour range. This is the task that models perform best, and forecasters should put heavy emphasis on models for their second-and third-period forecasts.

4.2 Using the LFM Initial Analyses

One of the first steps in developing a sound forecast is to study the LFM initial analyses. There is no reason to examine the forecast panels in detail until the forecaster has first considered the representativeness of the initial panels. Compare the model's initial fields with the satellite photographs, making use of the Satellite Field Service Station's (SFSS's) discussions. Unless local management strongly objects, drawing troughs, ridges, vorticity maxima, etc., on the satellite imagery with grease pencils can greatly facilitate this task. The SFSSs are constantly evaluating what they see in animated imagery to determine which models (if any) are handling features best and if there are errors in the initialized data. Which SFSS's SIMS to read naturally depends on one's location and the situation at hand.

Forecasters in the southern United States frequently have to deal with short waves traveling in strong flow over the data-sparse region of Mexico during the cool season. Forecasters should compare the initial vorticity field over Mexico with the vapor channel imagery (if available) to help pinpoint weak mid-tropospheric impulses (although features may not be detectable in enhanced infrared [EIR] or visible imagery they are often captured by the vapor channel imagery). This is important because weak short waves not captured in the model analysis can lead directly to a busted winter forecast over the southern United States. This is especially true when a short wave moves across a shallow layer of cool air that doesn't extend far into the Gulf of Mexico.

Figures 3 through 11 show a situation in which a short wave trough is evident in the vapor channel imagery, but not in the EIR (or the visible). The short wave had moved inland from the Pacific to western Mexico by 0530 GMT on 9 November 1983. Notice that the wave moved rapidly into central Mexico by 1130 GMT (Fig. 5), but was not obvious in the 1100 GMT EIR (Fig. 6). However, use of the vapor channel imagery provides the answer to the question of whether the initial LFM 500-mb analysis over Mexico is reasonable. In this particular case the LFM initialization over Mexico (Fig. 7) seems reasonable.

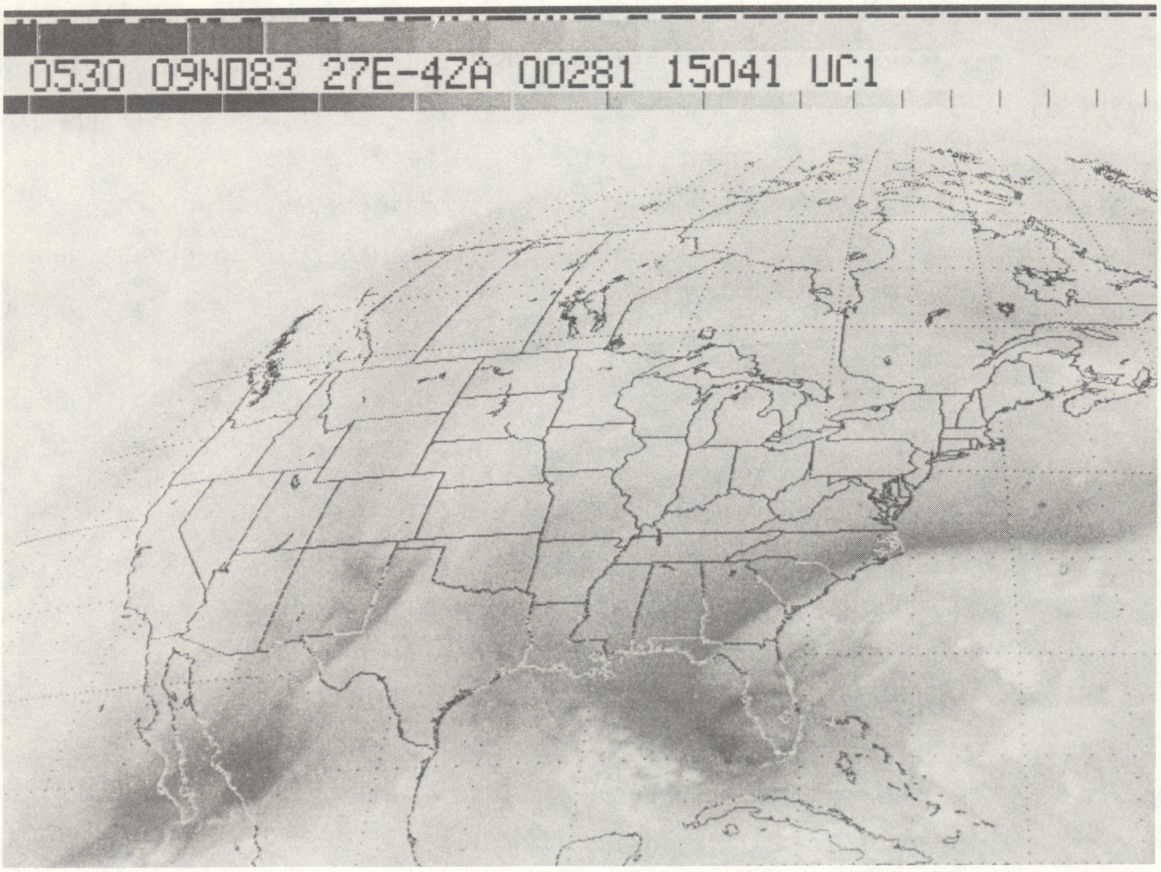


Fig. 3 *Middle-level water vapor channel (6.7 um, darker regions are dryer) satellite image for 0530 GMT 9 November 1983.*

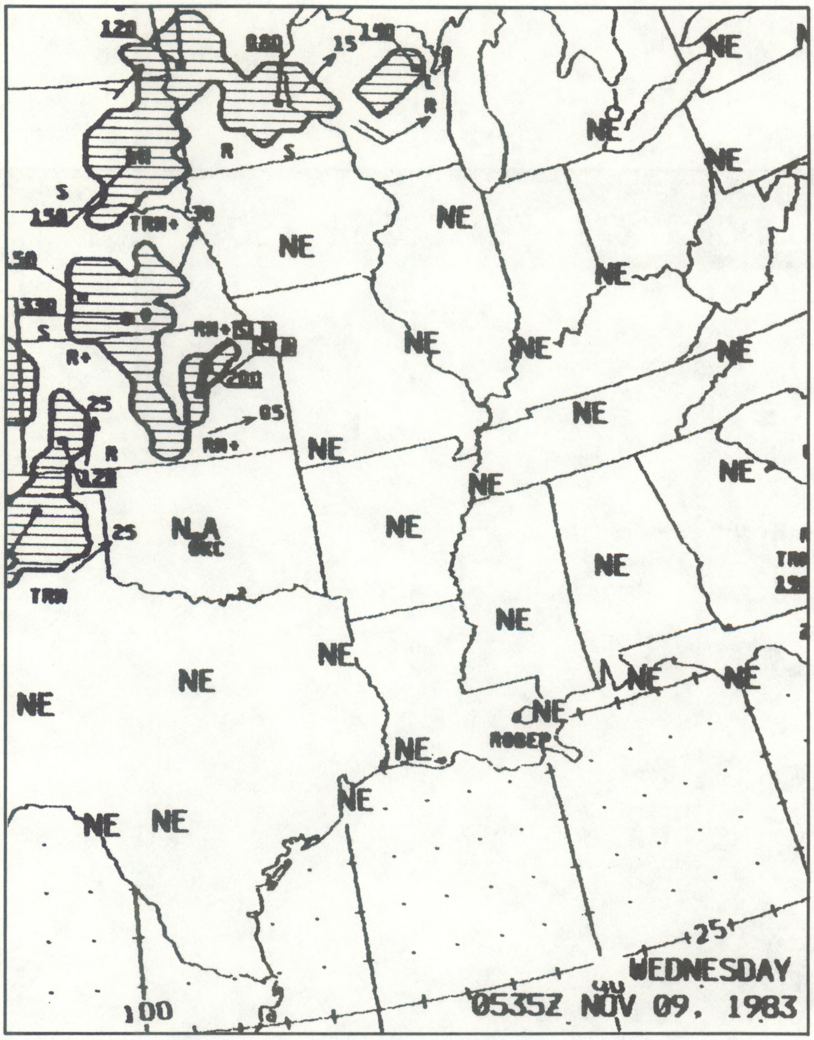


Fig. 4 *Radar summary chart for 0535 GMT 9 November 1983. Interior hatched areas indicate regions of stronger echo. Echo tops are shown in hundreds of feet above sea level.*

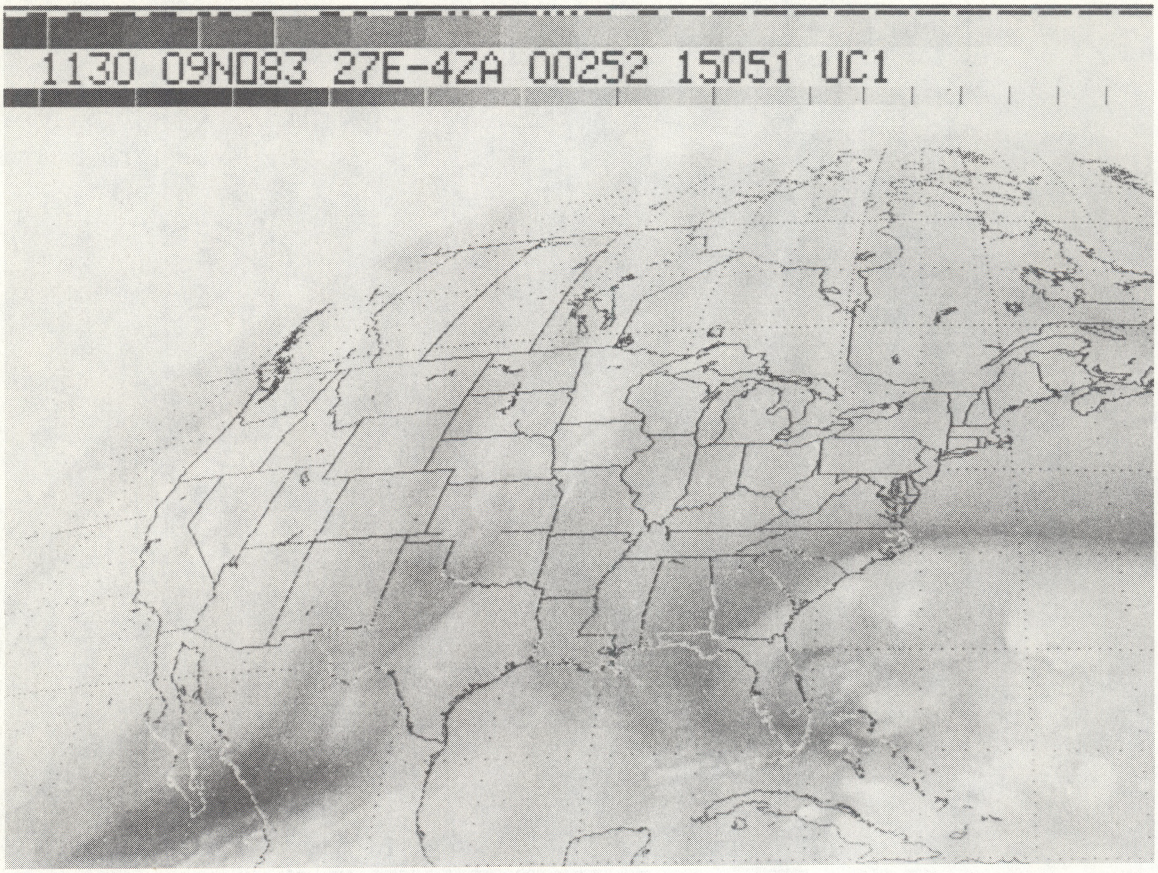


Fig. 5 Water vapor channel satellite image for 1130 GMT 9 November 1983.

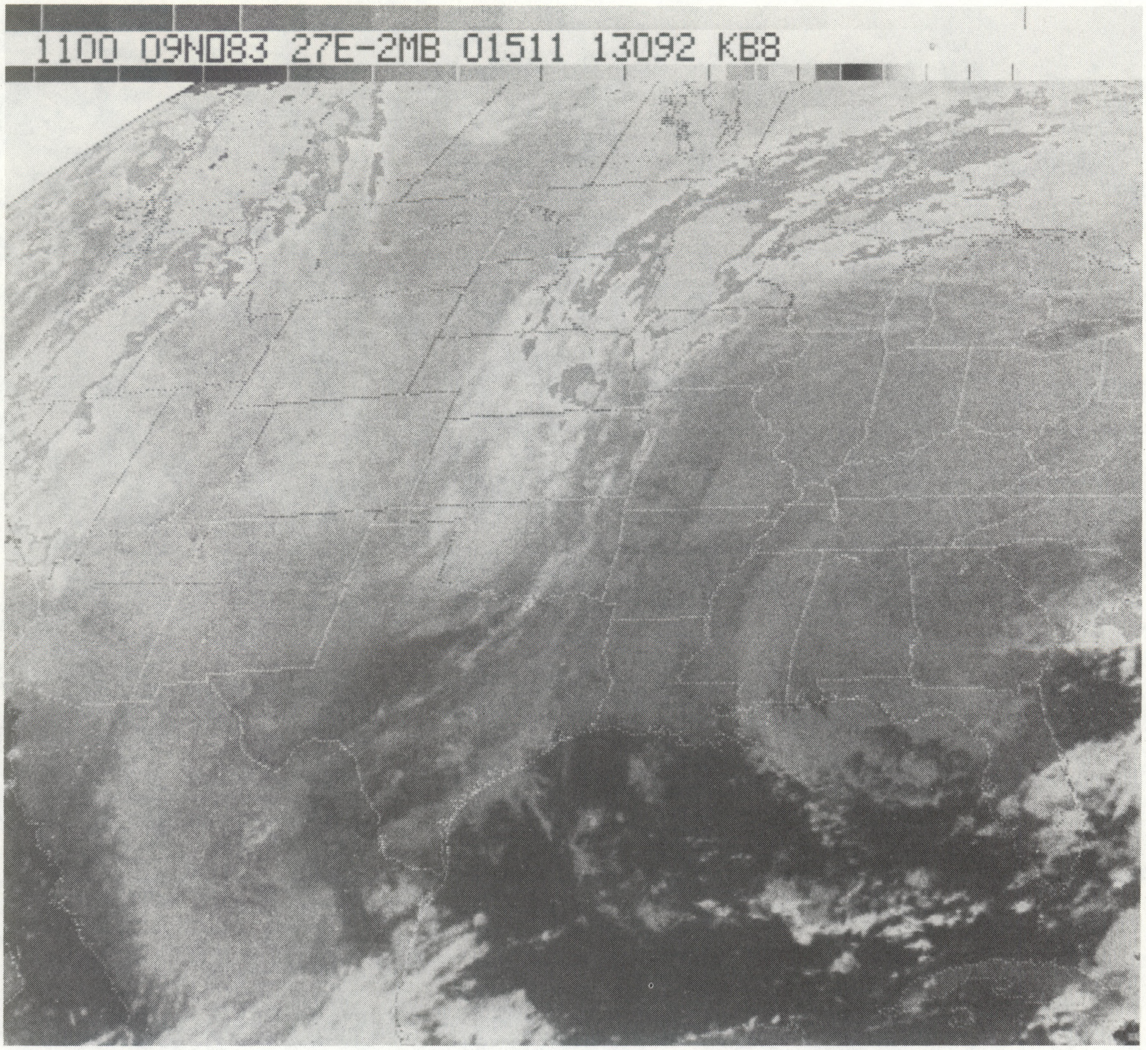


Fig. 6 *Enhanced infrared satellite image (interior gray and black shades indicate colder cloud-top temperatures) for 1100 GMT 9 November 1983.*

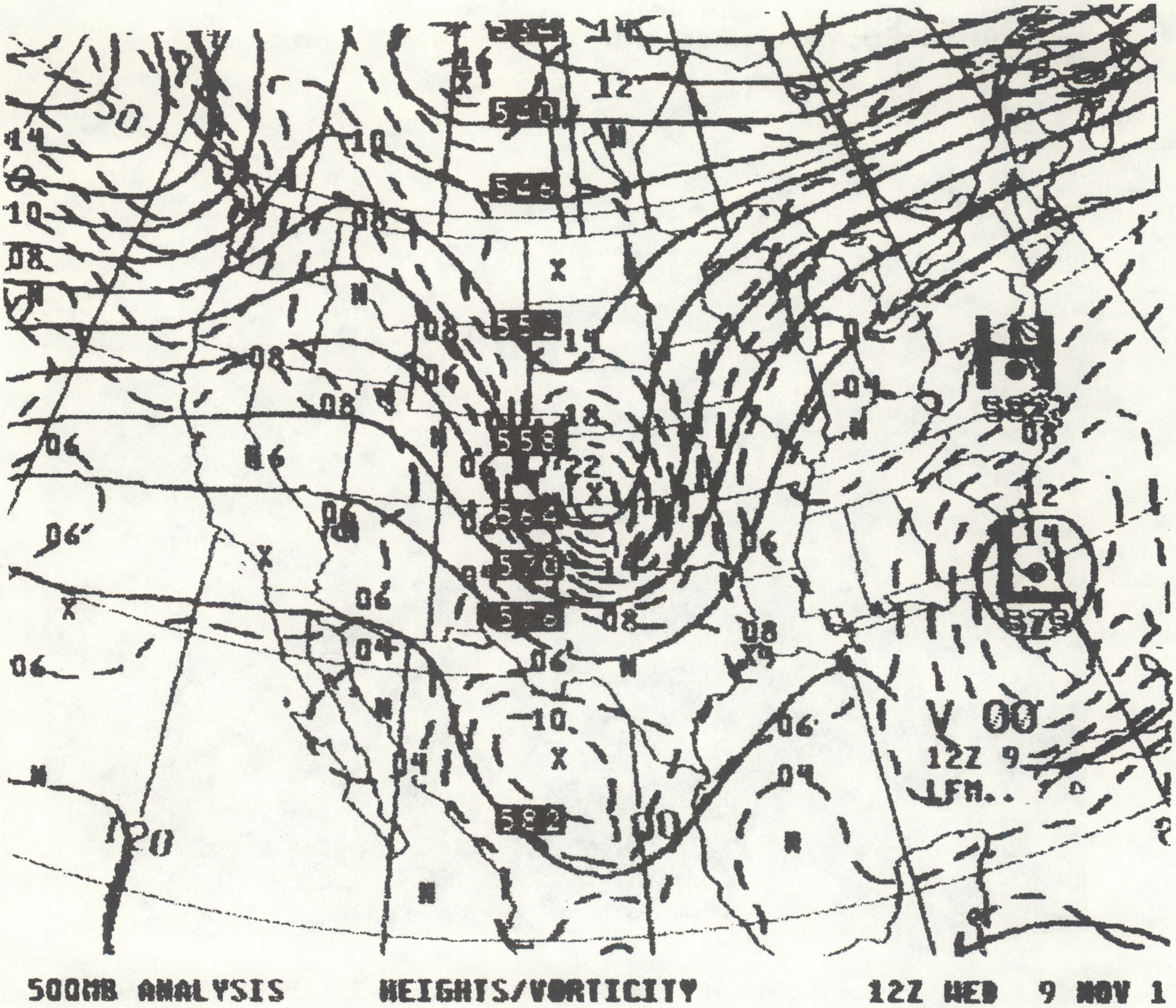


Fig. 7 *Limited Fine Mesh (LFM) initial analysis for 1200 GMT 09 November 1983. Shown are 500 mb heights (solid) and vorticity contours (dashed).*

Figure 8 shows that the LFM forecast predicts this wave to be shunted southeastward by the intense circulation over the central United States. The result is basically a "no precipitation" forecast over southeast Texas, although the model somehow wrings out a token 0.04 inch over the western Gulf of Mexico (Fig. 9). However, the vapor channel seems to indicate southwesterly high-level flow from the Pacific to the northern United States, indicating that the LFM's forecast movement of the short wave may be unreliable. Figures 10 and 11 illustrate thunderstorm activity that occurred in the vicinity of a frontal system along the Texas coast as this short-wave trough approached late in the day. For this event, the vapor channel provided valuable clues as to whether the model initialized the 500-mb data over Mexico properly. The vapor channel also provided hints as to whether the LFM was handling the wave properly.

The mandatory-level charts should be reanalyzed by the forecaster so that any needed adjustments can be made to the initial positions of features (see Maddox, 1979). It is important that all features be represented accurately on the initial panels, not just the ones in and near the southern section of the country. For example, if the LFM's positioning of a short wave over the eastern Pacific is in error by 250 km, it may affect the forecast movement of a downstream wave and lead a forecaster in the southern section of the country astray. In addition, in rapidly evolving situations, features initialized on the edge of the model's grid boundary in the Pacific may be affecting Texas and Oklahoma within 36 to 48 hours. Therefore, it is doubly important that these features be detected and followed (note that frequently they are not captured in the automated analysis when located close to the model's grid boundaries). Unfortunately, obviously bad data can also affect the initialization and thereby contaminate the entire forecast run. Sometimes bad input data may create a feature that can be readily discounted (although the entire model run may still be contaminated). At other times, the ramifications of bad data are more subtle. Figure 12 shows a vorticity maximum over southwest Arkansas that was produced by faulty wind data from the Jackson, Miss., sounding. In this case, the winds from 700 mb to 500 mb were entered into the model with a direction approximately 30 degrees in error. Satellite imagery, SIMS, and reanalyzed mandatory-level charts can be used to make sure the initialized features really exist, and also to make sure that their intensity seems reasonable.

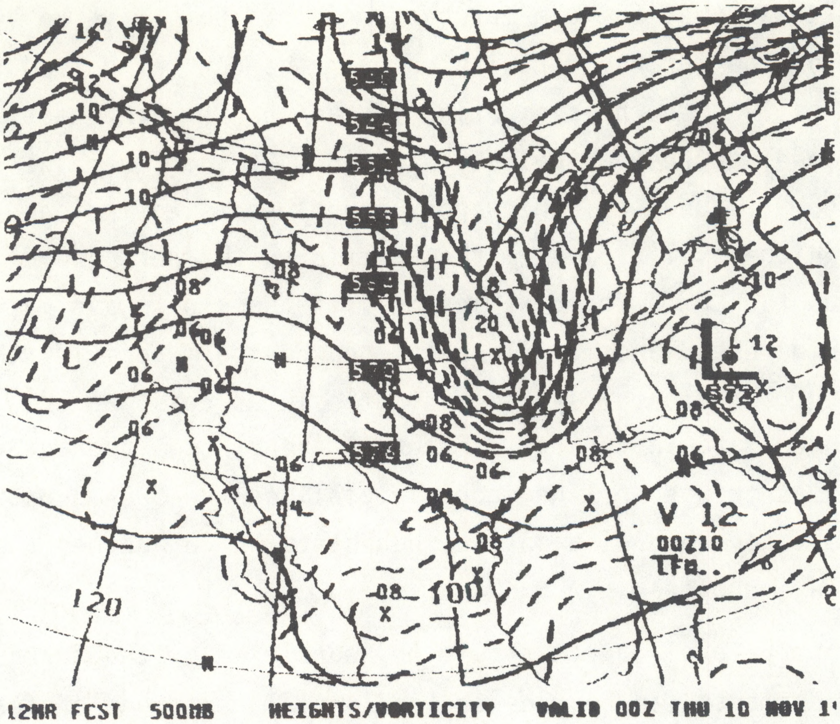


Fig. 8 *LFM 12-hour forecast of 500 mb heights (solid lines) and vorticity (dashed lines) valid 0000 GMT 10 November 1983.*

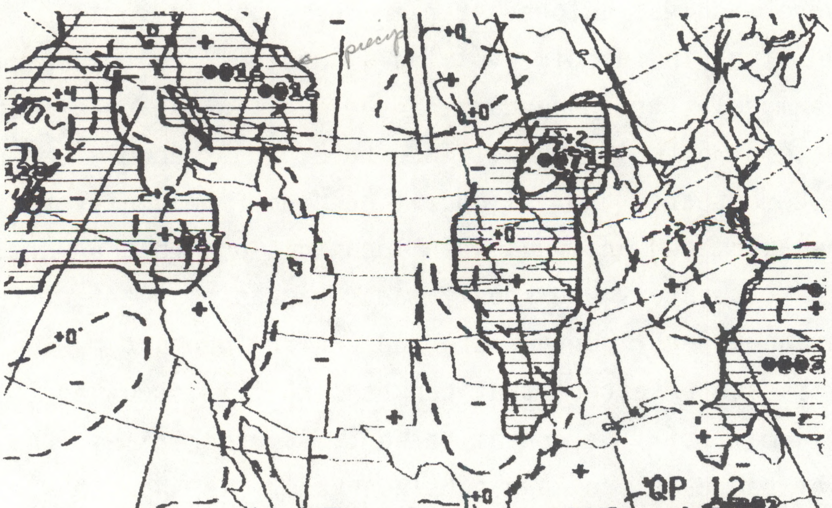


Fig. 9 *LFM 12-hour forecast of 12-hour accumulated precipitation (solid lines and hatched area) and 700 mb vertical velocity (dashed lines) valid 0000 GMT 10 November 1983.*

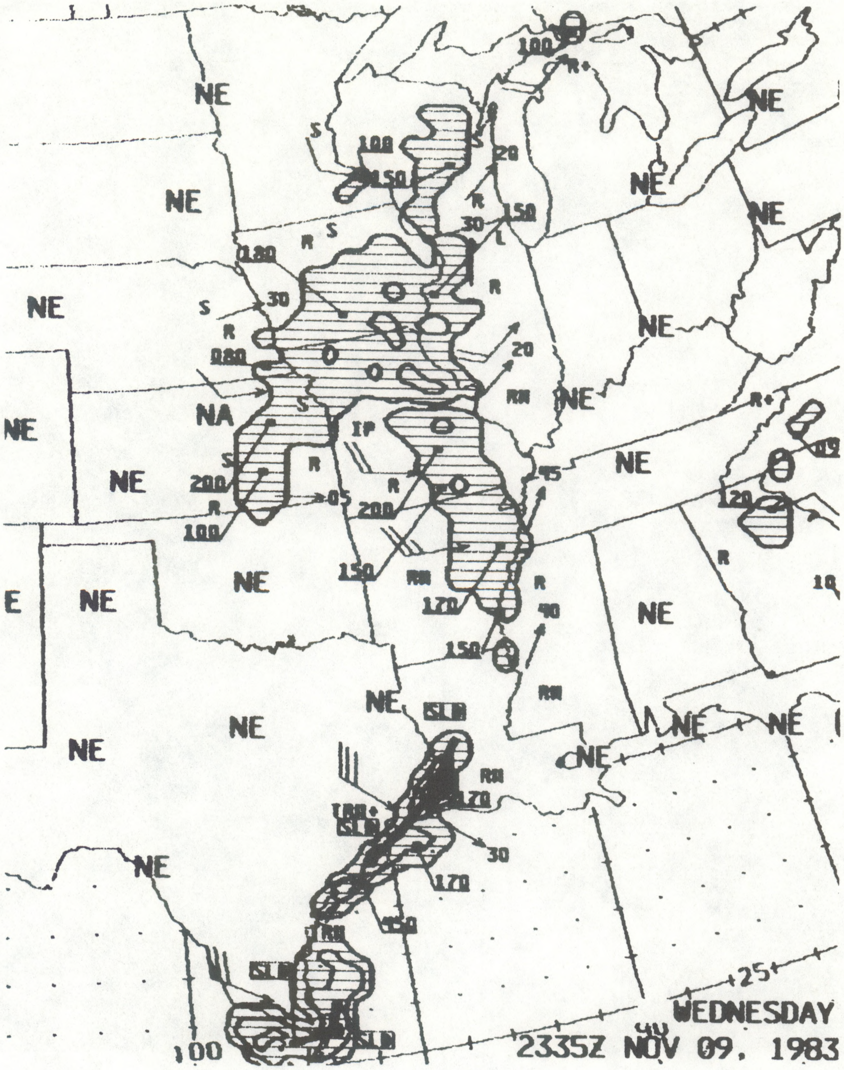


Fig. 10 Radar summary chart for 2335 GMT 9 November 1983.

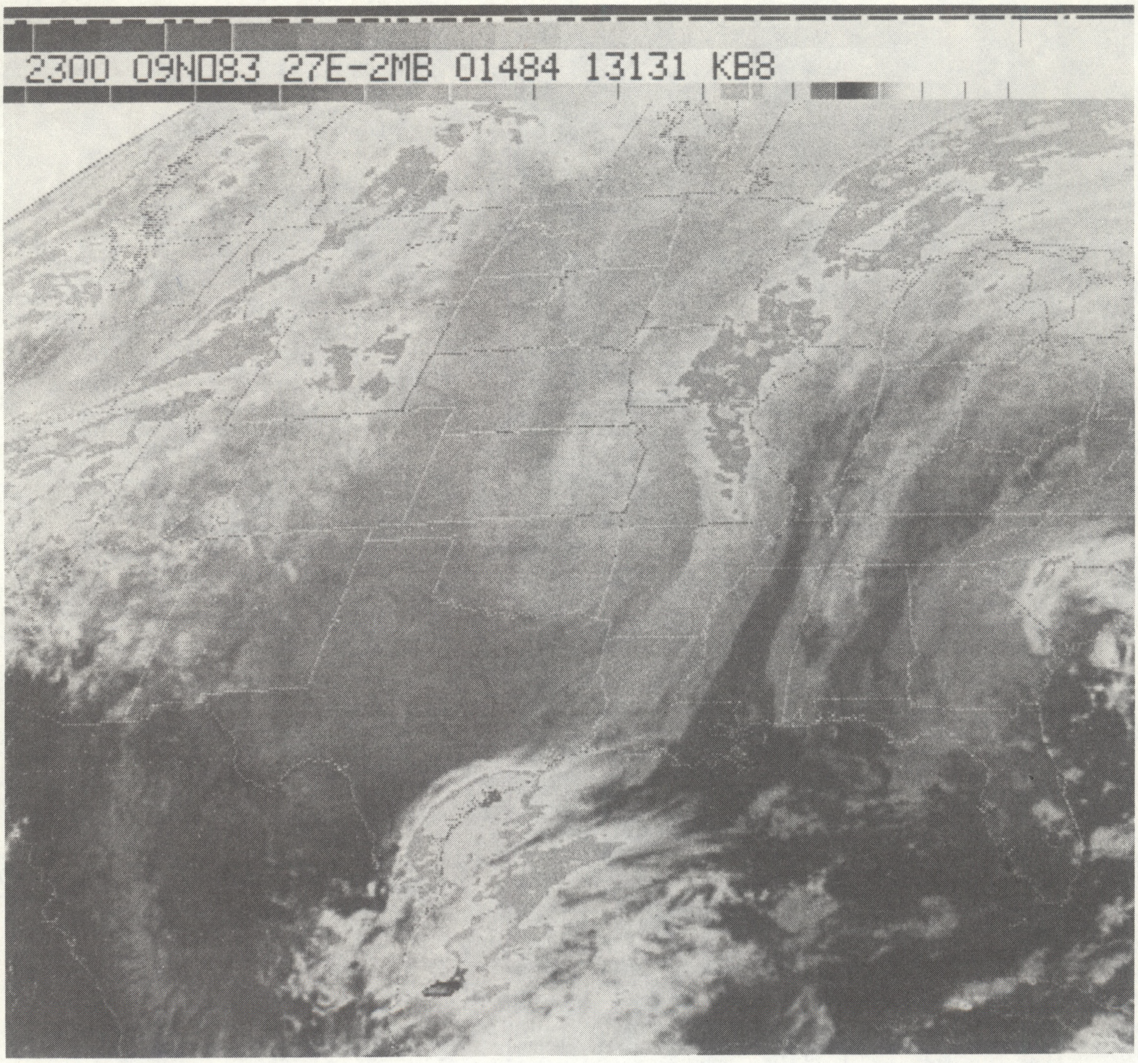


Fig. 11 Enhanced infrared satellite image for 2300 GMT 9 November 1983.

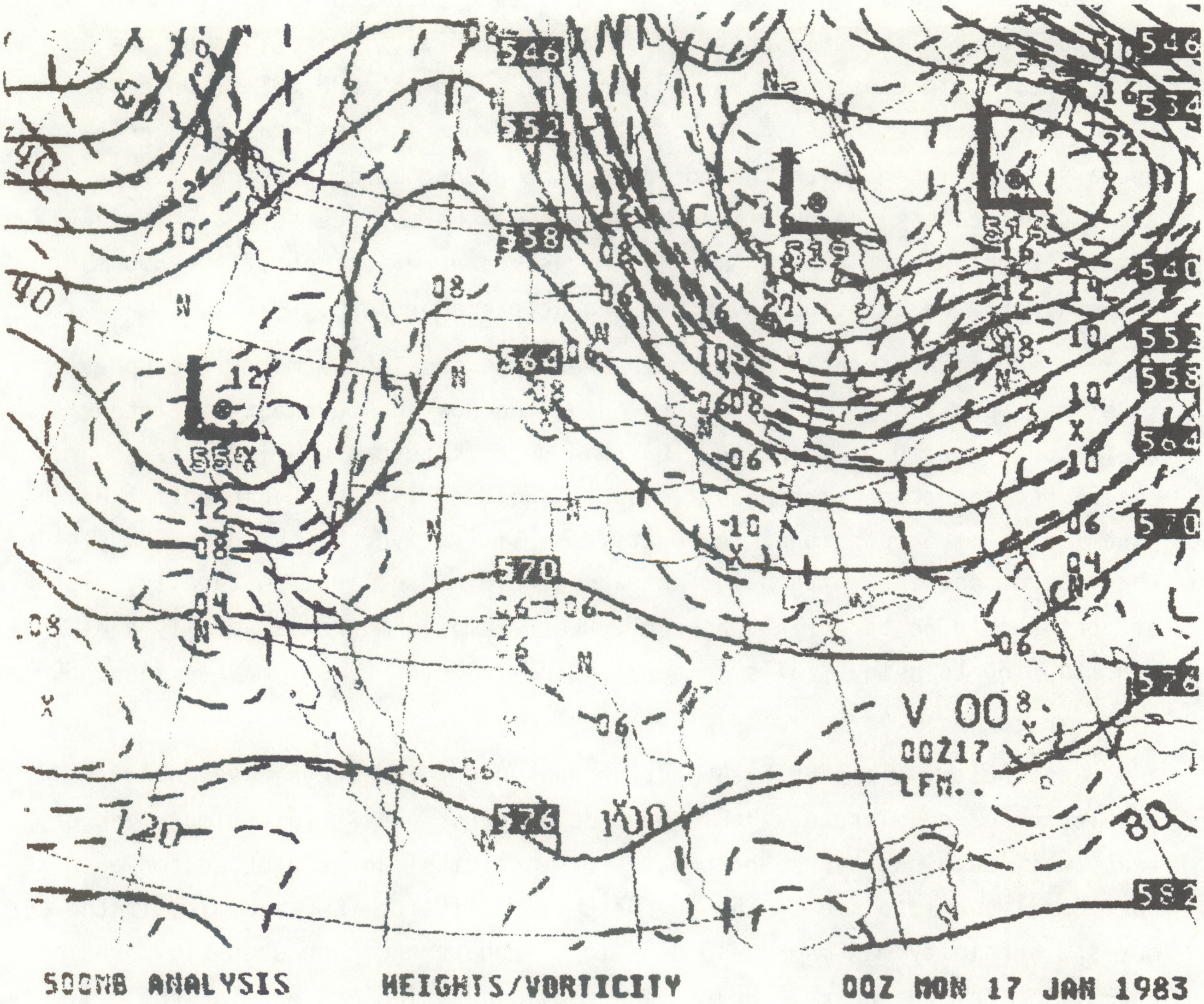


Fig. 12 Initial LFM analysis for 0000 GMT 17 January 1983.

Once it has been established that the initial panels accurately depict the structure of the atmosphere, the forecaster should ensure that forecast movement and changes in intensity of features appear consistent with the basic laws that govern the atmosphere. For example, Figs. 13 and 14 show the 48 hour spectral forecast (500 mb and surface) valid at 1200 GMT 21 December 1983. The surface forecast of an intense cyclone in the Texas panhandle appears inconsistent with the forecast concurrent 500 mb pattern. If the forecaster accepts the 500-mb prognosis, then the surface forecast is very difficult to accept. A much more likely surface reflection of the 500 mb pattern would be a cyclone over eastern Nebraska or Iowa.

In addition, forecasters should reanalyze the isotherms on the upper-level maps and study the pattern to determine how the movement and intensity of features should be changing. One can go back to basic principles and make use of the geopotential tendency equation(Holton, 1975). Geopotential height rise (fall) is proportional to negative (positive) vorticity advection plus the rate of decrease with height of warm (cold) advection. Naturally, diurnal effects should be taken into account. For example, there is usually a diurnal contribution to height falls (rises) on the 1200 (0000) GMT maps even at 500 mb.

Continuity, along with subjective reasoning of whether waves will accelerate or decelerate, should provide a "first guess" to the movement of features. Wave positions and centers of vorticity can be plotted for each 12-hour model panel to see if the movement is realistic. For example, if the LFM moves a vorticity maximum at 15 ms^{-1} for 24 hours and then suddenly moves it at 25 ms^{-1} for the next 12 hours, one should question and examine the validity of the forecast acceleration.

Figure 15 shows the 12-hour LFM forecast 500 mb height/vorticity panel valid for 1200 GMT 19 March 1983. Compare Fig. 15 with the 500 mb analysis for the same time (Fig. 16). Other than the fact that the vorticity maximum forecast over the Oklahoma-Kansas-Colorado border appears to be stronger and farther east, the LFM's forecast of a rather complex pattern appears quite accurate. However, Figs. 17 and 18 (the 24-hour LFM and concurrent analysis) show that smoothing has caused a loss of definition of the individual short waves and the LFM begins to blend them all together into a wave. Although the LFM usually displays this smoothing characteristic between 36 and 48 hours,

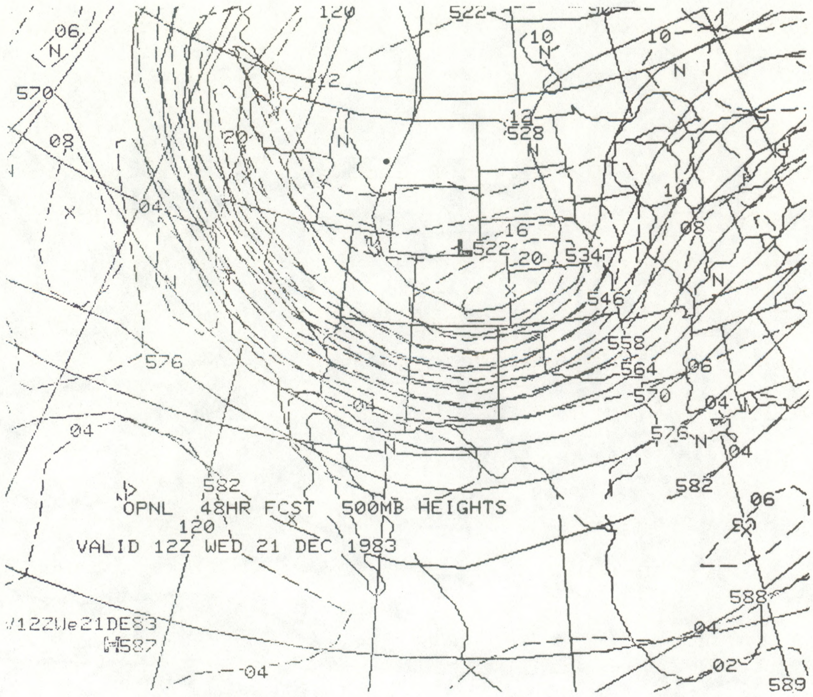


Fig. 13 *Spectral 48-hour forecast of 500 mb heights and vorticity contours valid 1200 GMT 21 December 1983.*

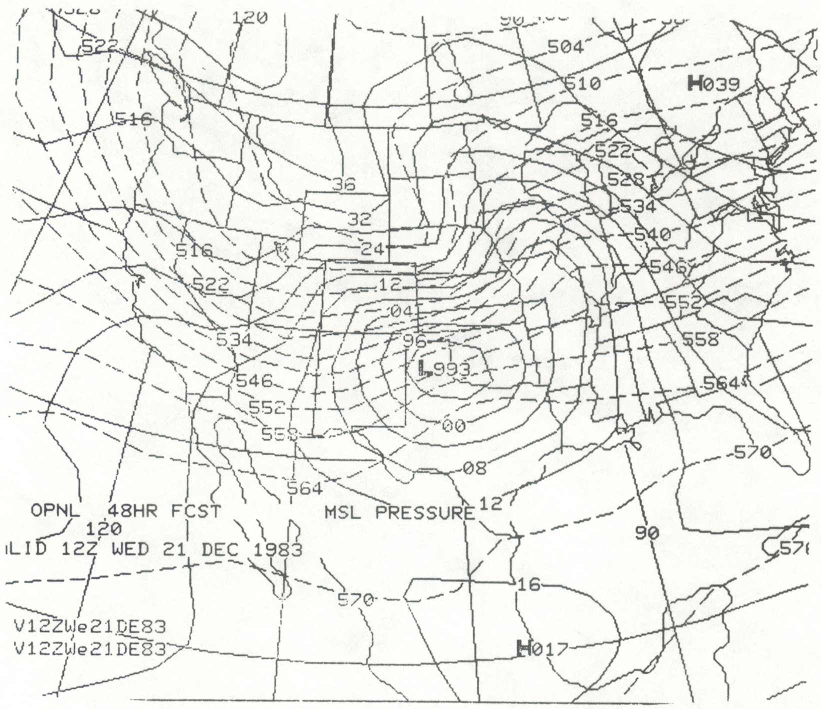


Fig. 14 *Spectral 48-hour forecast of MSL pressure (solid lines) and 1000-500 mb thickness (dashed lines) valid 1200 GMT 21 December 1983.*

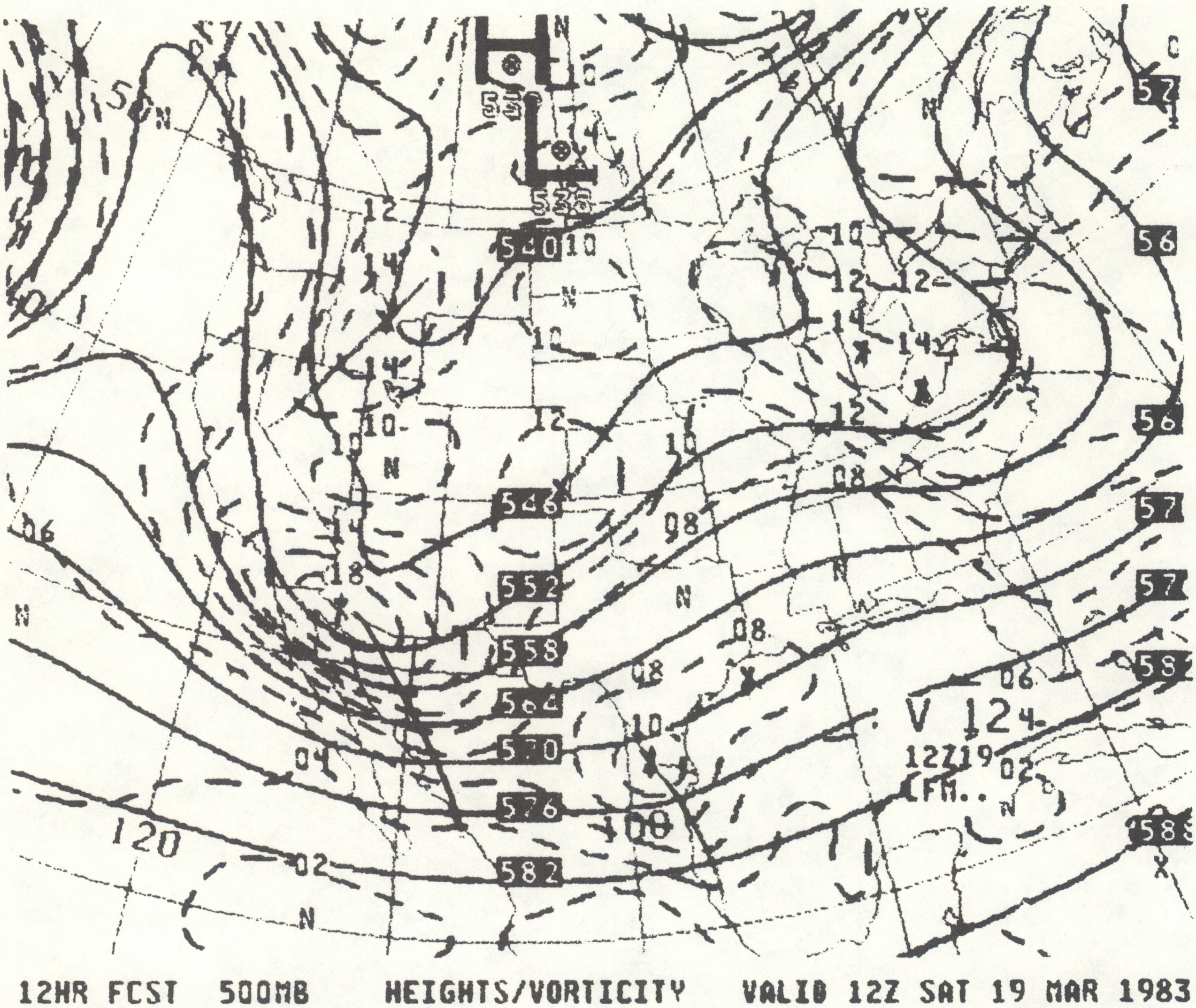


Fig. 15 *LFM 12-hour forecast of 500 mb heights and vorticity valid 1200 GMT 19 March 1983.*

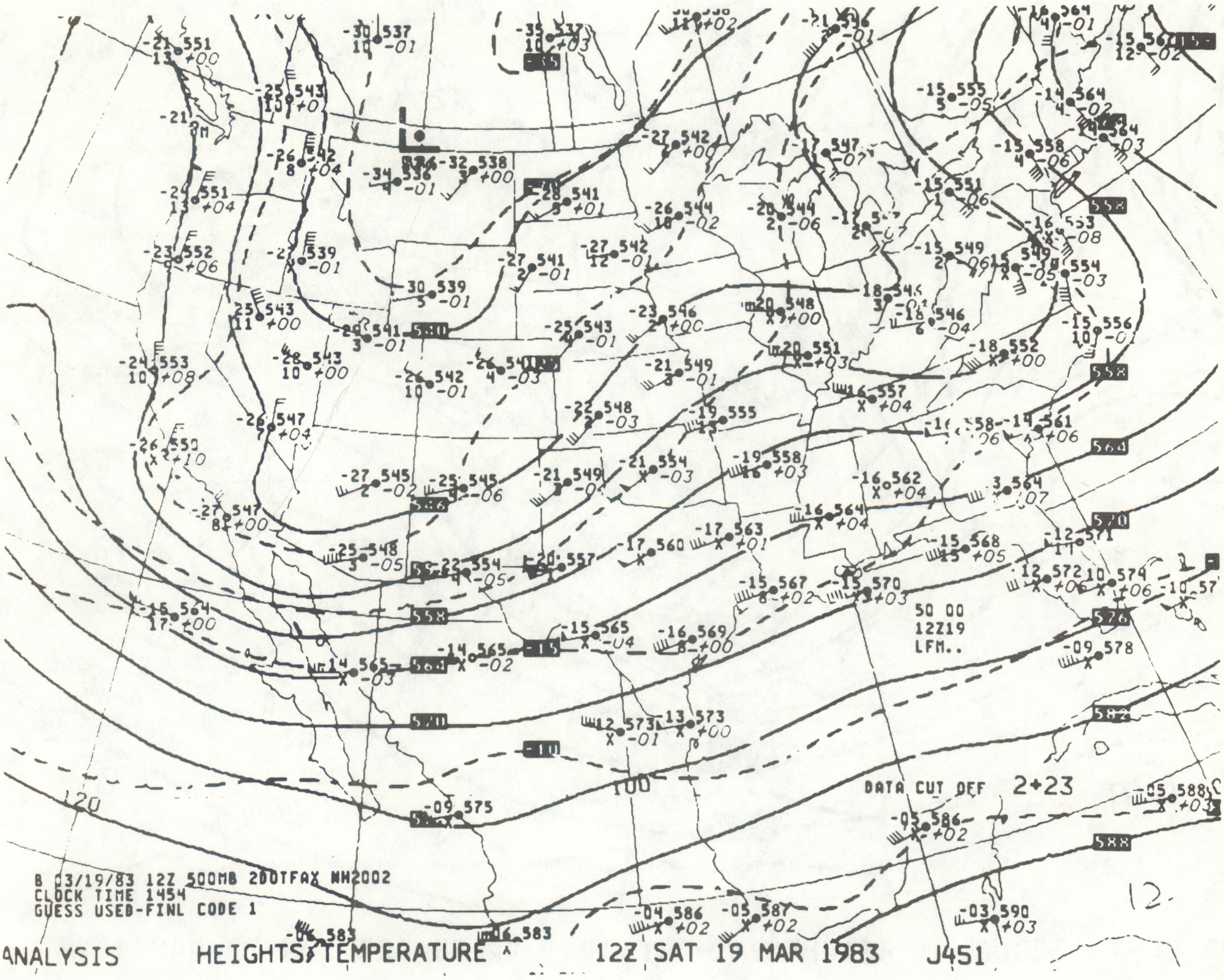


Fig. 16 *NMC 500 mb analysis for 1200 GMT 19 March 1983. Height contours are solid lines, isotherms (°C) dashed and 12 hr height changes (dam) are plotted. Winds are in knots; full barb=10 kt* $(\sim 25\ ms^{-1})$.

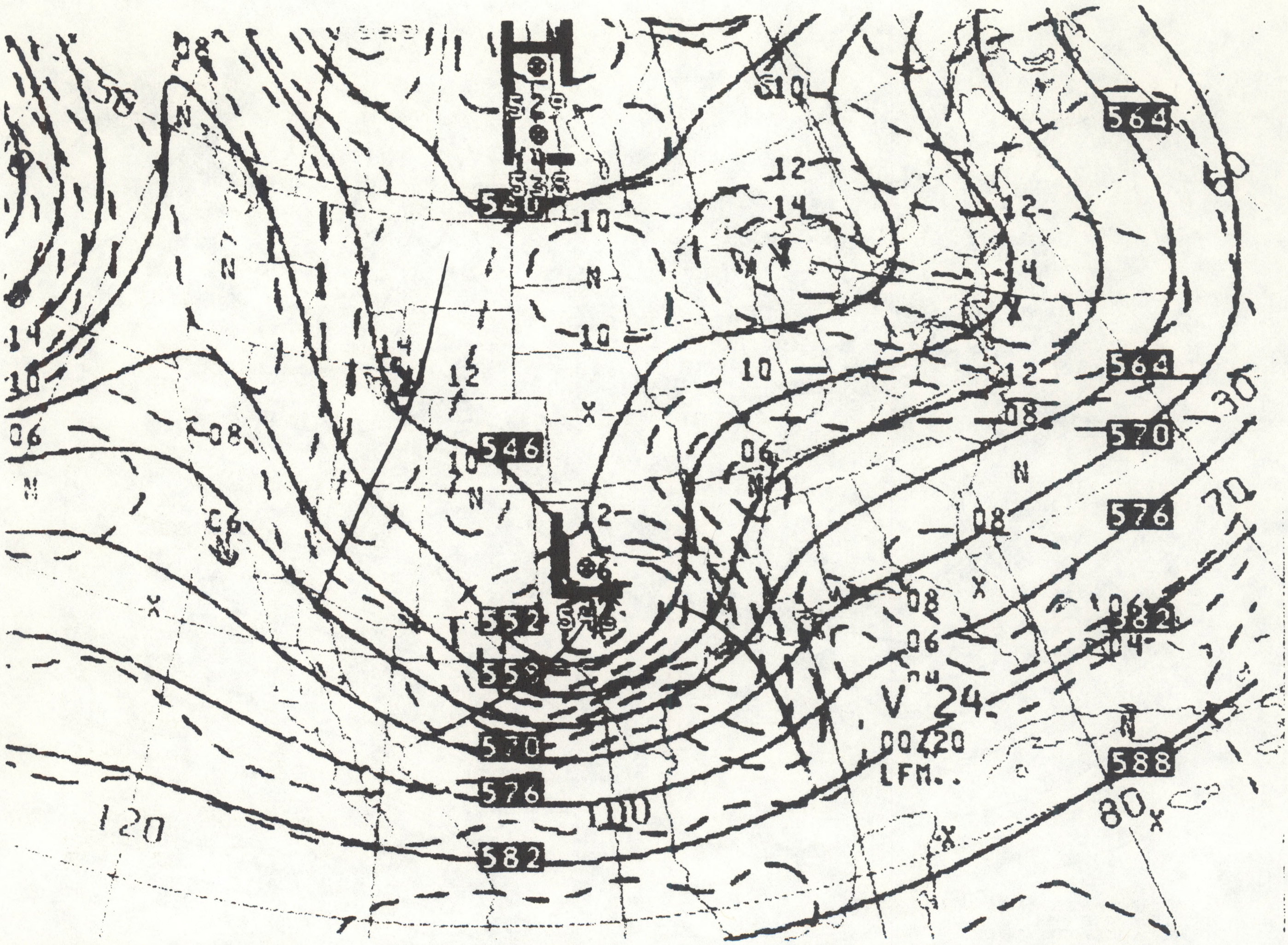


Fig. 17 LFM 24-hour forecast of 500 mb heights and vorticity valid 0000 GMT 20 March 1983.

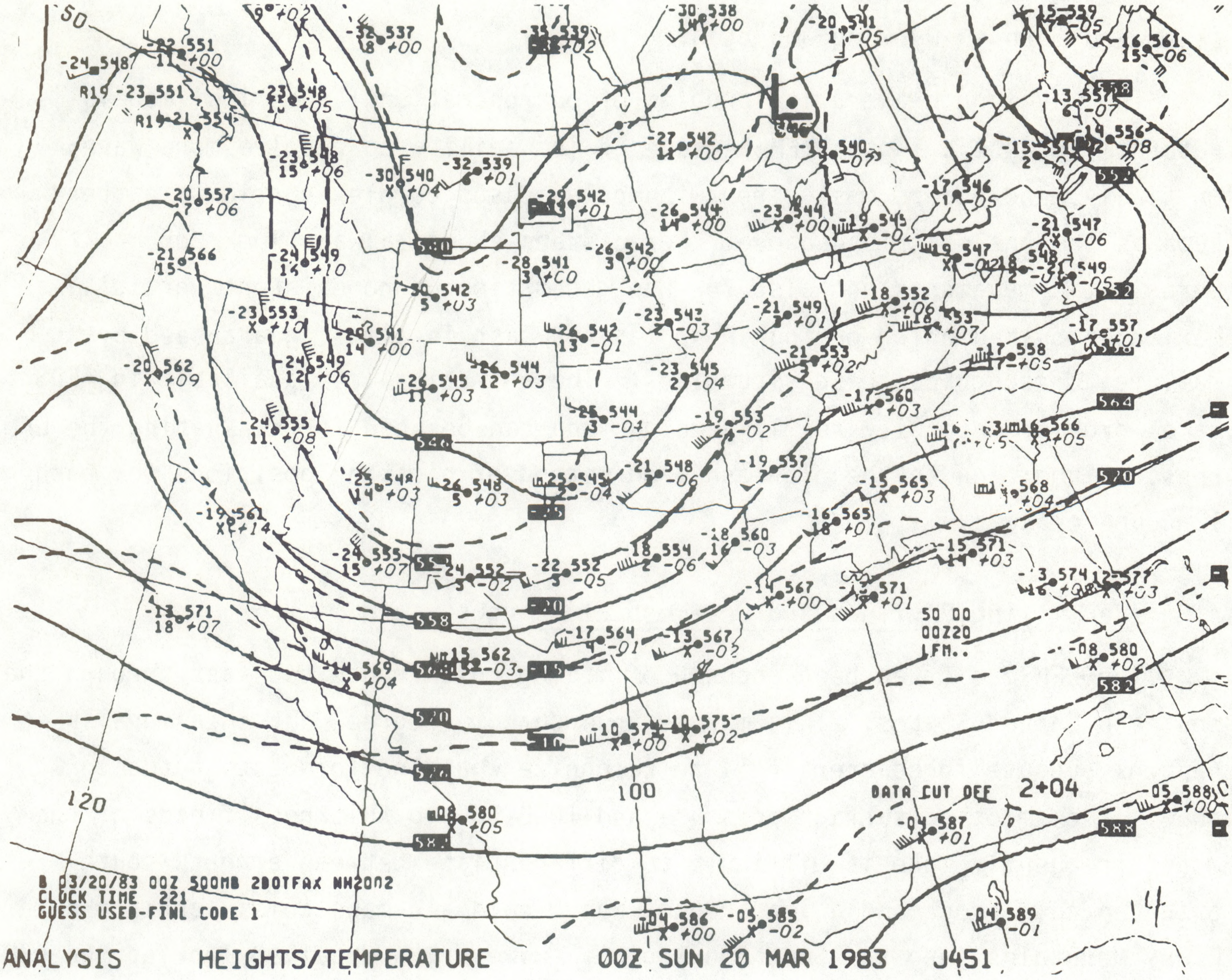


Fig. 18 NMC 500 mb analysis for 0000 GMT 20 March 1983.

the effect is more pronounced in this case because of the presence of several short waves within a small region. The LFM does maintain several short waves, but consider the difference between the LFM forecast and the 500-mb analysis along the Mexico-Arizona-New Mexico borders! Meanwhile, farther west, the LFM still has a good "handle" on the short-wave trough that extends from Montana southward through Wyoming and Utah.

The wavelength-averaging problem of our operational numerical models is naturally greatest in the LFM because of its ability to resolve more waves initially, and occurs most often with cold-season complex vorticity patterns such as the one described above. Forecasters should always look for unrealistic movements and also for the generation of nonexistent vorticity maxima; a busted third-or fourth-period forecast is almost guaranteed by failure to recognize these situations. The animation loop available in AFOS makes broken continuity really jump out and can be used for evaluating the LFM runs, in addition to the old-fashioned method of plotting positions for each 12-hour forecast.

4.3 Identifying Drylines and Pre-Frontal Troughs

The LFM has often been accused of moving cold fronts too fast through the southern United States. This may be true to some degree, but occasionally it happens because forecasters fail to recognize what the forecasts actually show. The smoothed surface pressure and 1000-500 mb thickness fields of the model frequently make it difficult to differentiate between a north/south-oriented cold front and a lee trough when a cold air mass comes across the Rocky Mountains into the Southern Region. However, a detailed look at the LFM boundary layer winds usually allows accurate identification of both the real front and the lee trough.

The LFM sometimes develops a surface trough ahead of a cold front and then moves both features across the southern United States. The leading trough may represent a dryline forecast by the LFM. If so, the LFM will have developed the trough in association with forecast strong downward vertical velocities (usually from -4 to -8 microbars per second). Normally the surface dryline becomes diffuse as it moves eastward, but frequently the surface trough remains. Regardless of whether the LFM is forecasting development and eastward movement of a dryline, or a pre-frontal trough, the result is frequently the same: significant convection develops along the trough, while the cold front remains inactive or characterized by weaker convection.

Figures 19 through 25 show a typical situation in which the LFM develops a pre-frontal trough over Texas. The very broad trough shown in Figs. 19 and 20 most likely represents a lee trough and a developing pre-frontal trough. However, at 36 hours and even at 48 hours (Figs. 21 and 22), the LFM still forecasts a distinct surface trough preceding the cold front. The vertical motion forecast (Figs. 23 and 24) allows better resolution of the two features. In Fig. 24, the vertical motion field associated with the pre-frontal trough has a distinctive north-south axis that extends into the Gulf of Mexico, while the cold front, apparently forecast as a less significant feature, appears as a weak lobe of upward vertical motion over south Texas between two small regions of downward motion.

Satellite imagery (Fig. 25) shows convection occurring along the pre-frontal trough while the only visual evidence of the cold front is a broken line of much weaker thundershowers stretching from the Louisiana-Texas border north of Lake Charles across the Gulf to the south of Galveston. Notice the sub-synoptic region of apparent subsidence between the trough and cold front (Figs. 24 and 25). This feature was forecast by the LFM 48 hours in advance! Unfortunately, it is difficult for the forecaster to know in advance when the LFM is going to have such an exceptional handle on the situation. Usually in these situations the detail goes unnoticed, and NMC (including the man/machine-mix forecast charts) interprets the trough as the cold front.

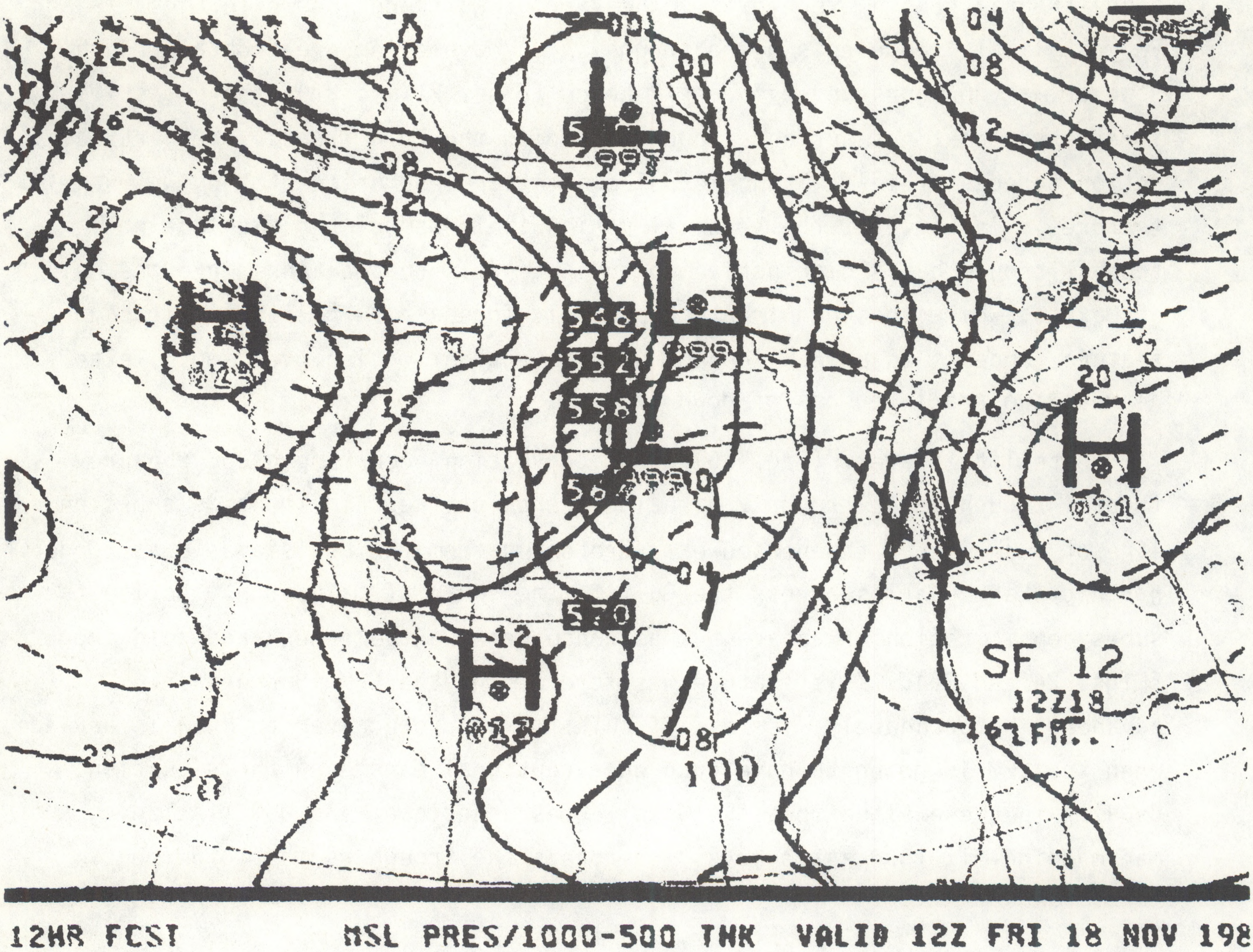


Fig. 19 *LFM 12-hour forecast of MSL pressure (solid lines) and 1000-500 mb thickness (dashed lines) valid 1200 GMT 18 November 1983.*

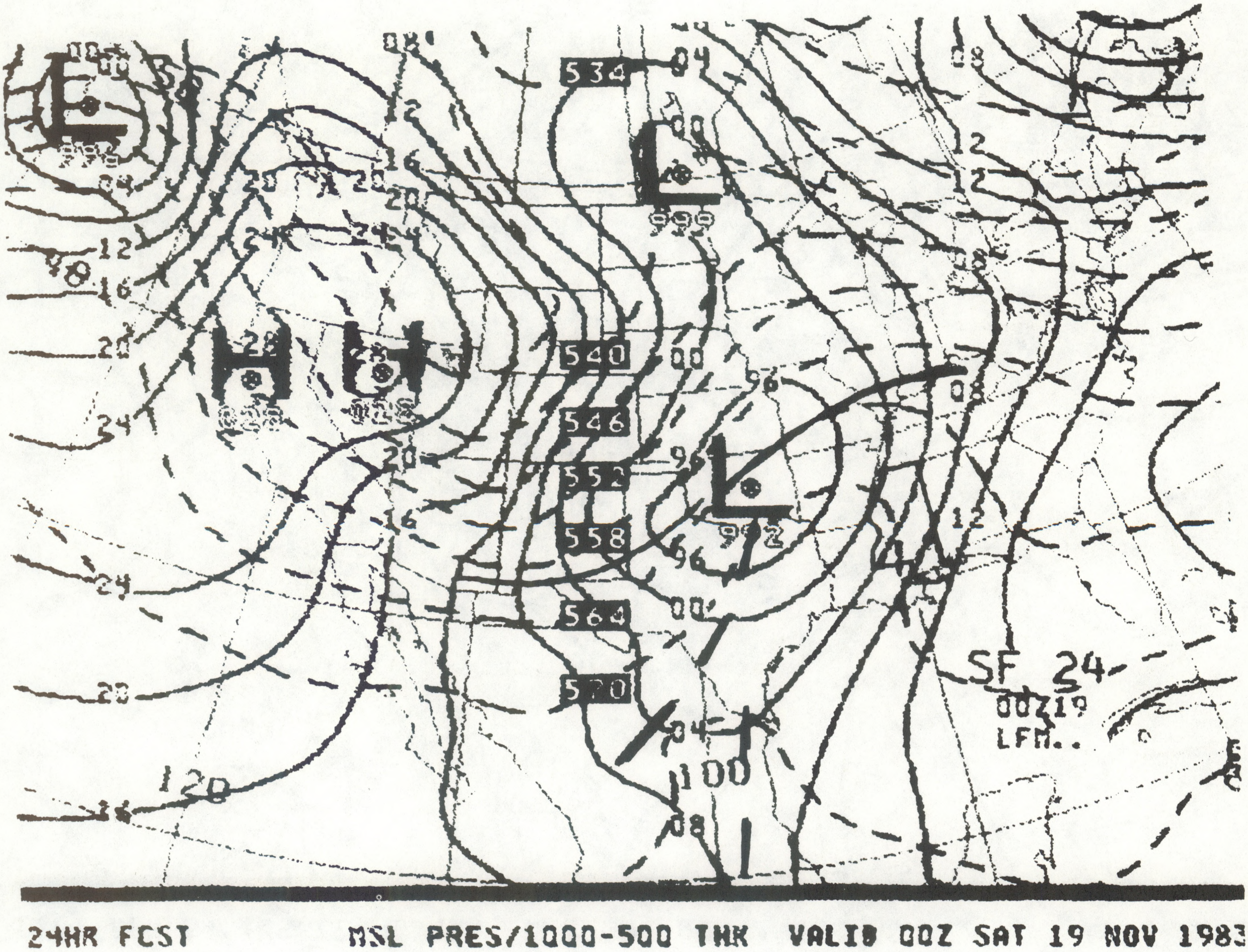


Fig. 20 *LFM 24-hour forecast of MSL pressure and 1000-500 mb thickness valid 0000 GMT 19 November 1983.*

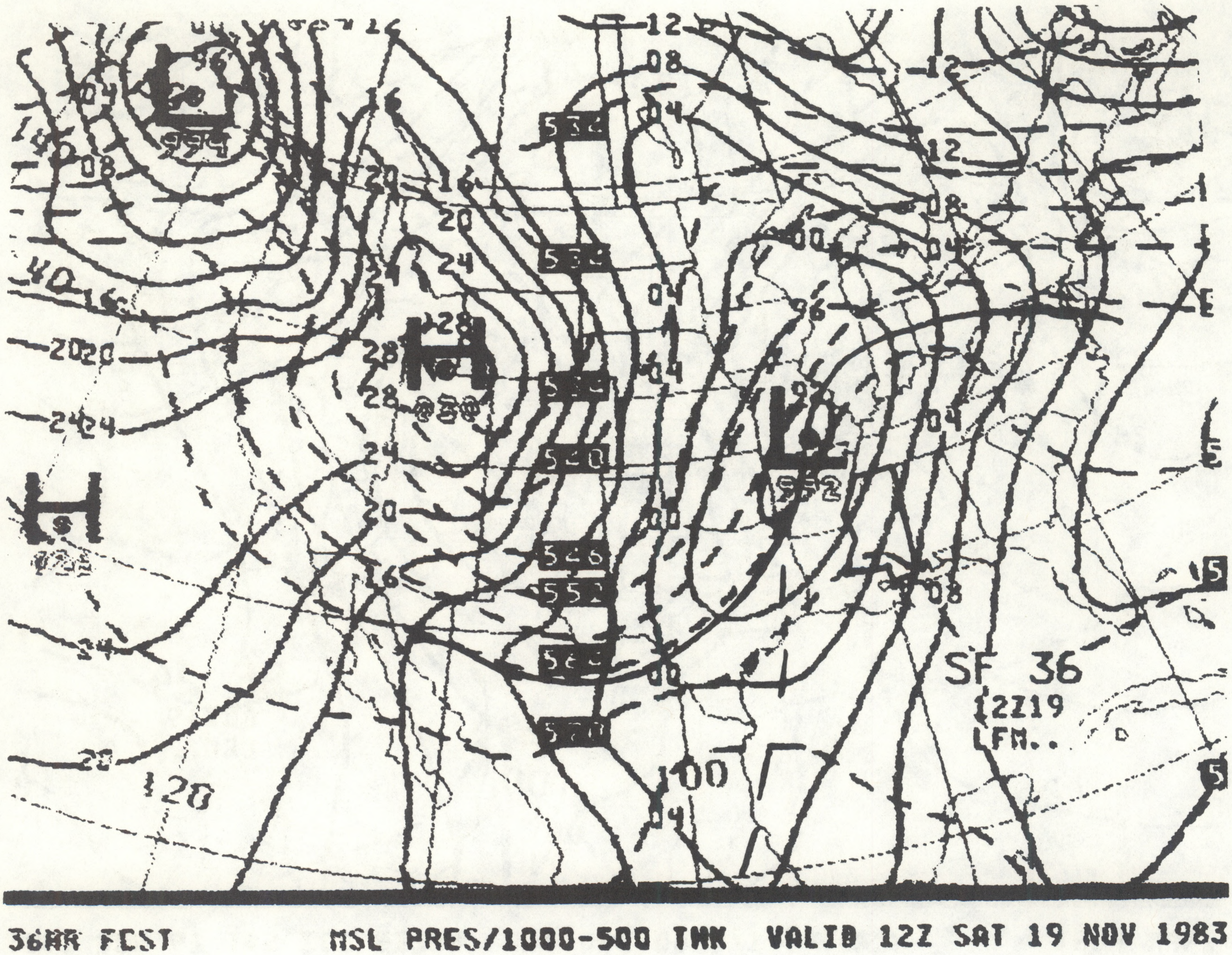


Fig. 21 *LFM 36-hour forecast of MSL pressure and 1000-500 mb thickness valid 1200 GMT 19 November 1983.*

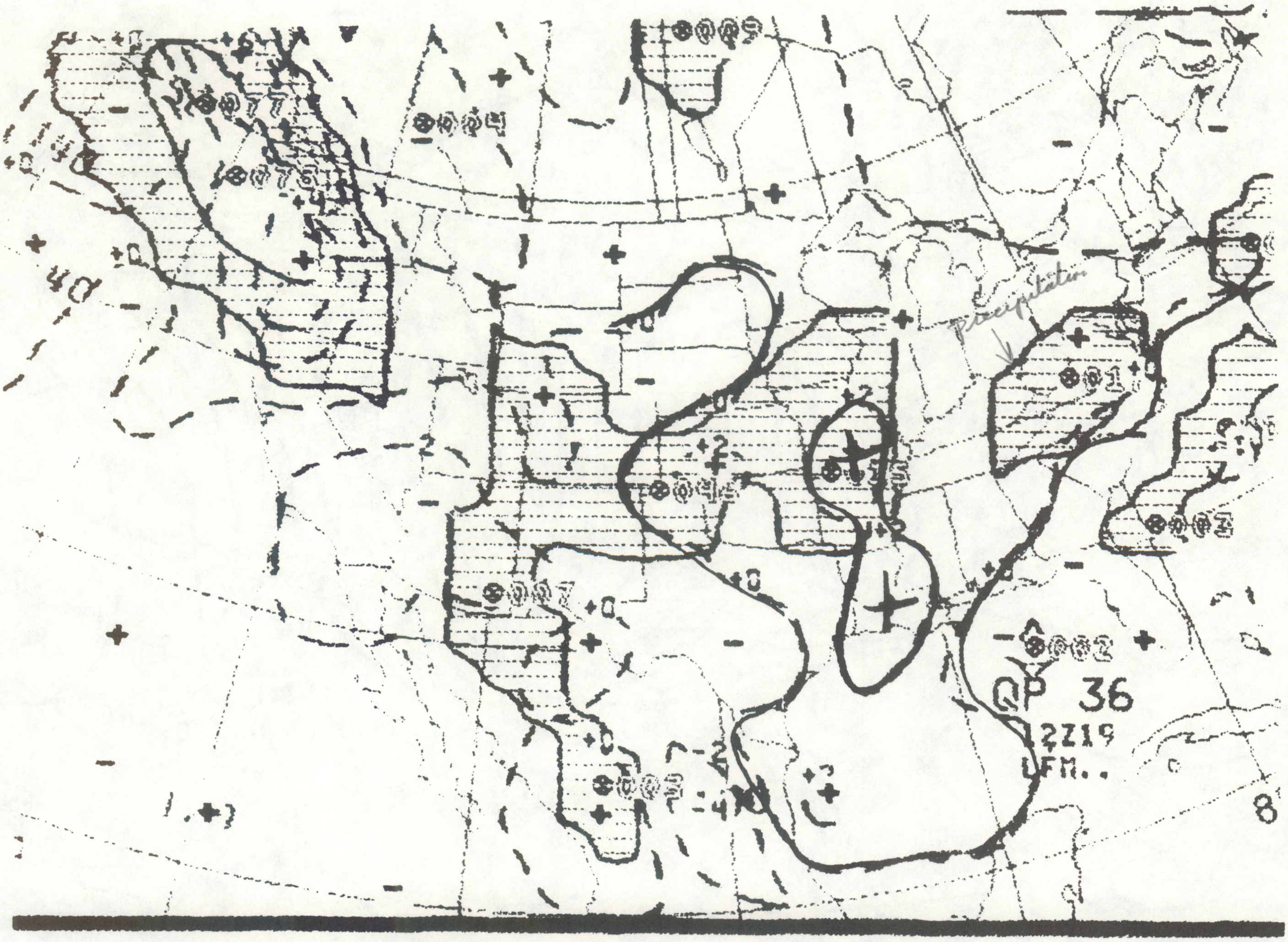


Fig. 22 *LFM 36-hour forecast of accumulated precipitation and 700 mb vertical velocity valid 1200 GMT 19 November 1983.*

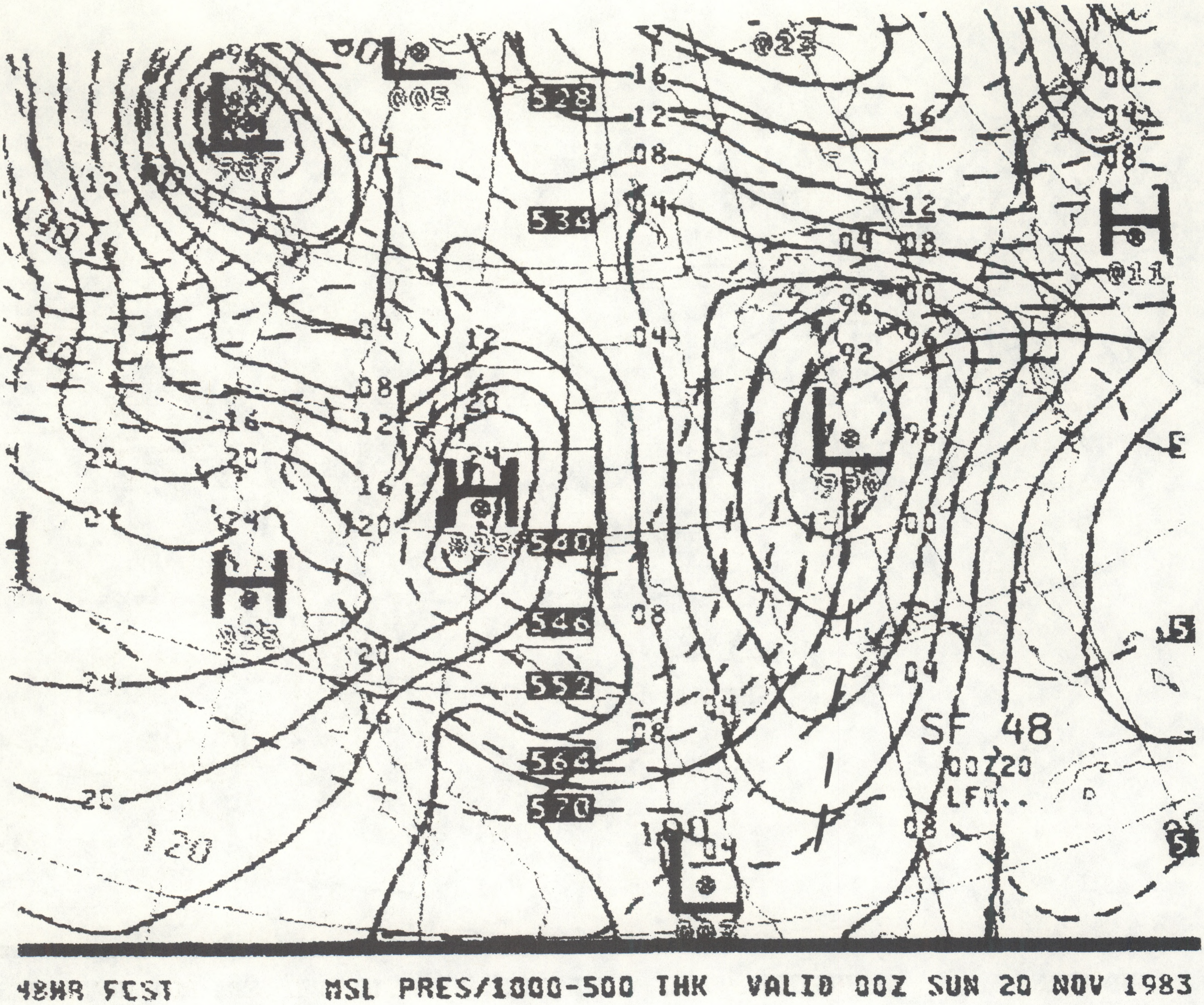


Fig. 23 *LFM 48 -hour forecast of accumulated precipitation and 700 mb vertical velocity valid 0000 GMT 20 November 1983.*

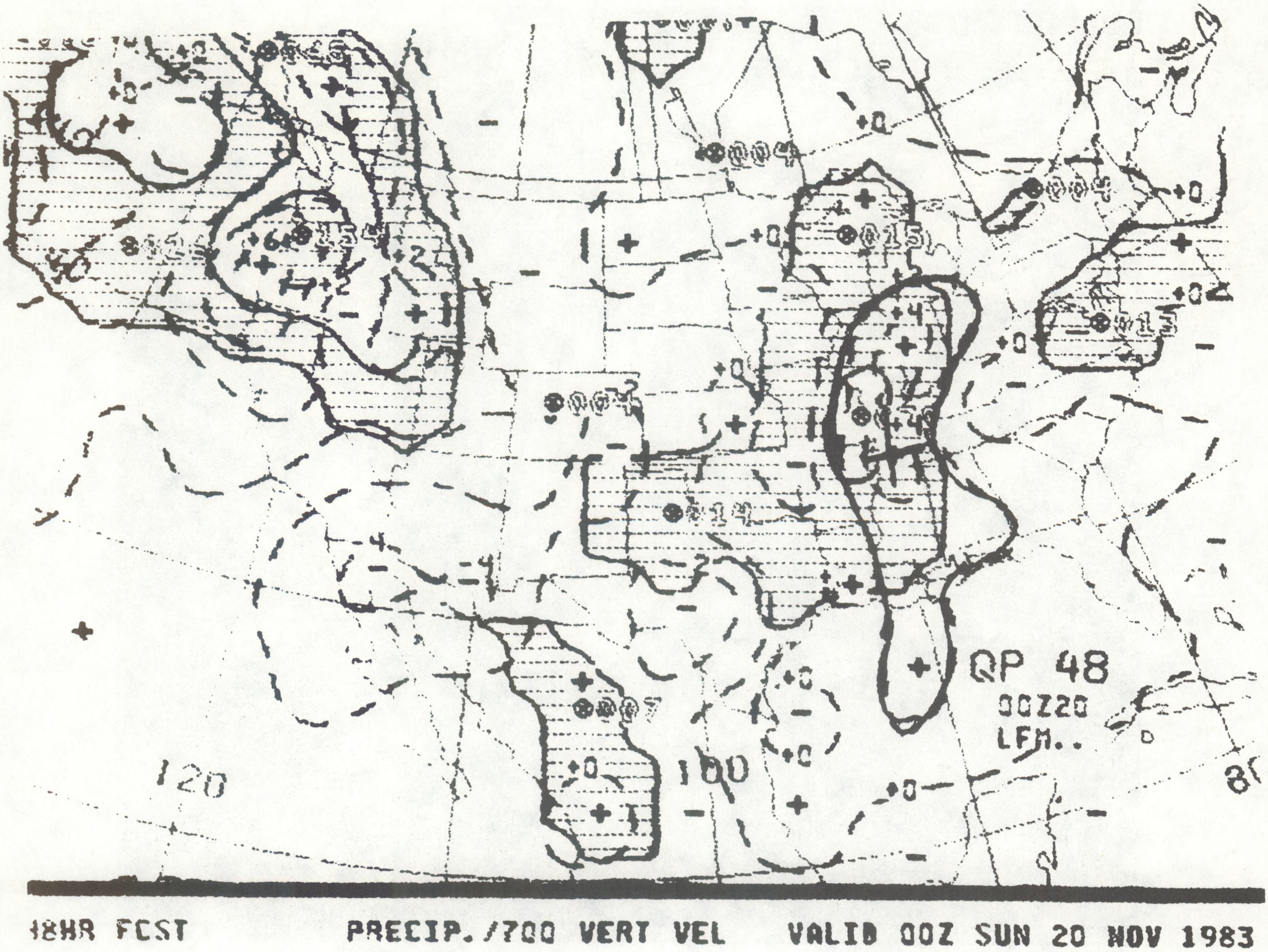


Fig. 24 *LFM 48-hour forecast of MSL pressure and 1000-500 mb thickness valid 0000 GMT 20 November 1983.*

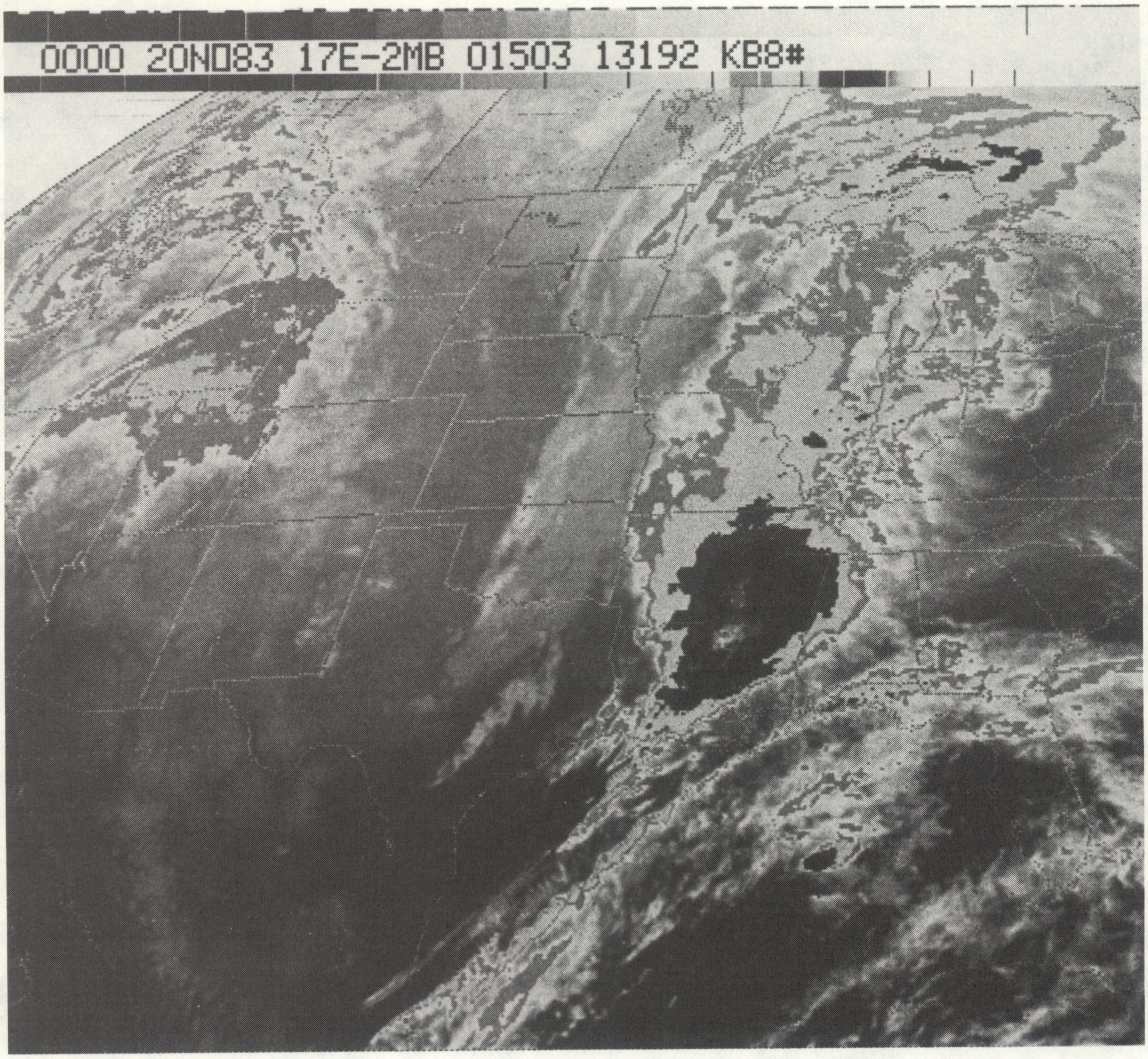


Fig. 25 Enhanced infrared satellite image for 0000 GMT 20 November 1983.

4.4 Using the Models to Diagnose and Forecast Vertical Motion

Solving the puzzle of where the air is rising and sinking in the atmosphere requires a concentrated effort of combining analysis with the fundamental laws that govern the atmosphere. For example, just diagnosing divergence and convergence can be very difficult at times. The numerical models can be helpful in this effort, but only to acquire the large-scale picture. Diagnosing sub-synoptic vertical motion patterns can be accomplished only through mesoanalysis. Rather than accepting the vertical motion forecast of the models, the forecaster should determine what the model is trying to "say." Knowing how the models calculate vertical motion can enable the forecaster to anticipate events by knowing what to look for.

Studying the LFM, Spectral or Barotropic 500-mb vorticity/height panels to determine what is going on in the atmosphere really caught on in the 1970s. In fact, use of vorticity advection to assess the vertical motion field has become an accepted practice during the past 15 years. Forecasters routinely shade in areas of positive and negative vorticity advection (PVA and NVA) on the LFM and then proceed to explain what is going to happen in terms of vorticity advection. Anyone who has listened to a map discussion in a forecast office has certainly heard a forecaster state that "nothing big is going to happen because there's not enough PVA", or "we're in for a wild day because of the strong PVA". Such discussions might leave one wondering how it ever rained before PVA was invented. Numerical models use the continuity equation and forecast wind fields to calculate the vertical motion field. The numerical models actually use the sum of an initial, nondivergent wind field and the previous 12-hour divergence forecast to obtain the new initial wind field. Therefore, if the previous 12-hour forecast was significantly in error, the current model run will proceed from a flawed initialization.

It's easy for forecasters to get into the habit of assuming that vorticity advection implies upward (downward) vertical motion with PVA (NVA) at 500 mb. However, vorticity advection [again see Holton's (1975) discussion of the omega equation] implies upward (downward) vertical motion where the rate of positive (negative) vorticity advection increases with height. It's important to remember that if we examine only vorticity advection at 500 mb we assume that the vertical derivative is in the sense discussed above and that the vorticity advection term is the prime cause of vertical motion.

However, the simplified omega equation illustrates that vertical motion (upward, downward) is directly proportional to the rate of increase with height of (positive, negative) vorticity advection and (positive, negative) thermal advection. Thus, warm advection generates upward vertical motion, and cold advection produces downward motion. Unfortunately, the effect of thermal advection on the vertical motion field is frequently neglected (or not emphasized enough) by forecasters. No doubt, many bad forecasts could be traced back to situations in which the effects of thermal advection were as great as (or greater than) the effects of differential vorticity advection. For example, in southern United States heavy rainfall events the effects of thermal advection often appear to dominate differential vorticity advection.

The problem of differentiating the often opposing effects of vorticity advection and thermal advection provided the incentive for Trenberth (1978) to combine the two terms into one. This essentially rearranges the omega equation so that the forecaster may directly relate vorticity advection by the thermal wind to vertical motion. (Meteorologists who have used Q-vectors are already familiar with the concept.) Forecasters look for regions of positive isothermal vorticity advection (PIVA), and negative isothermal vorticity advection (NIVA)--see Sangster (1980). PIVA produces upward vertical motion; NIVA produces downward vertical motion. Instead of making assumptions by "eyeballing" the 500 mb height/vorticity panels, forecasters who want to use the numerical models to diagnose and/or forecast the vertical motion field should be employing AFOS tools that are readily available. (That is, by overlaying the 1000-500 mb thickness field with the 500 mb vorticity field the forecaster can determine approximately where PIVA and NIVA are occurring.) Thus, if strong PVA by the geostrophic wind is accompanied by equally strong cold advection, the isothermal vorticity advection may be neutral. On the other hand, when weak PVA by the geostrophic wind is accompanied by strong warm advection (as in most heavy rainfall events in the southern United States), the PIVA should be significant.

↑ PVA + warming
↓ NVA + cooling

Figures 26-32 illustrate a rather typical situation in which the contribution of thermal advection apparently overwhelms the contribution of differential vorticity advection. On the 24-hour LFM 500-mb panel (shown in Fig. 26), notice the weak PVA apparent over Texas, Oklahoma, Louisiana, and extreme western Arkansas. Considering Fig. 27, it is obvious that cool air at the surface extends into the Gulf of Mexico. The forecast warm advection, implied by the large angle of intersection of the isobars and thickness lines, from Mississippi westward is obvious. Figure 28 further illustrates warm advection forecast by the LFM, with the 700 mb flow superposed on the 1000-500 mb thickness field.

The thermal wind, overlaid on the map of Fig. 26, is shown in Fig. 29. The width of the arrows represents the relative strength of the thermal wind. The difference between the geostrophic vorticity advection and the vorticity advection by the thermal wind is tremendous. Owing to the combined effects of thermal advection and vorticity advection, one would expect the LFM to indicate maximum upward motion in the vicinity of San Antonio where the PIVA is strongest (notice the strength of the thermal wind). However, Fig. 30 shows more moisture to the north, and the LFM forecast the heaviest precipitation in this region as well. Apparently, the contribution of latent heat release shifted the maximum vertical motion (+4 microbars per second) northward to the Dallas-Fort Worth area (see Fig. 31). (Note that with southerly low-level flow, terrain-induced lifting may have played a small part in the result as well.)

How well did the forecast verify? At initial time there was no precipitation anywhere in the region; however, within 24 hours, precipitation spread across Texas and Louisiana into Mississippi and Alabama. The use of PIVA could have helped in forecasting the development and rapid spread of precipitation eastward. However, as you can see from Fig. 32 (satellite imagery at the time the 24-hour LFM was valid) something went wrong. The location of the upper low near El Paso was forecast quite well by the LFM, and the vorticity maximum south of the Louisiana-Texas coast seems close to the LFM's forecast of a weak vorticity maximum over the Gulf of Mexico. However, as is typically the case, moisture and warm advection combined for maximum sensible weather effects well ahead of the upper low, which was spinning away in drier air to the west. One other aspect of this event should be noted. The heaviest precipitation spread along the thickness lines where the strongest thermal wind was forecast by the LFM. Although rainfall was not heavy rainfall for this case, patterns like this often produce heavy precipitation in the south.

Using this approach instead of geostrophic vorticity advection is not a panacea. For one thing, the difference between geostrophic and isothermal vorticity advection may still be difficult to distinguish on the synoptic-

Figures backwards

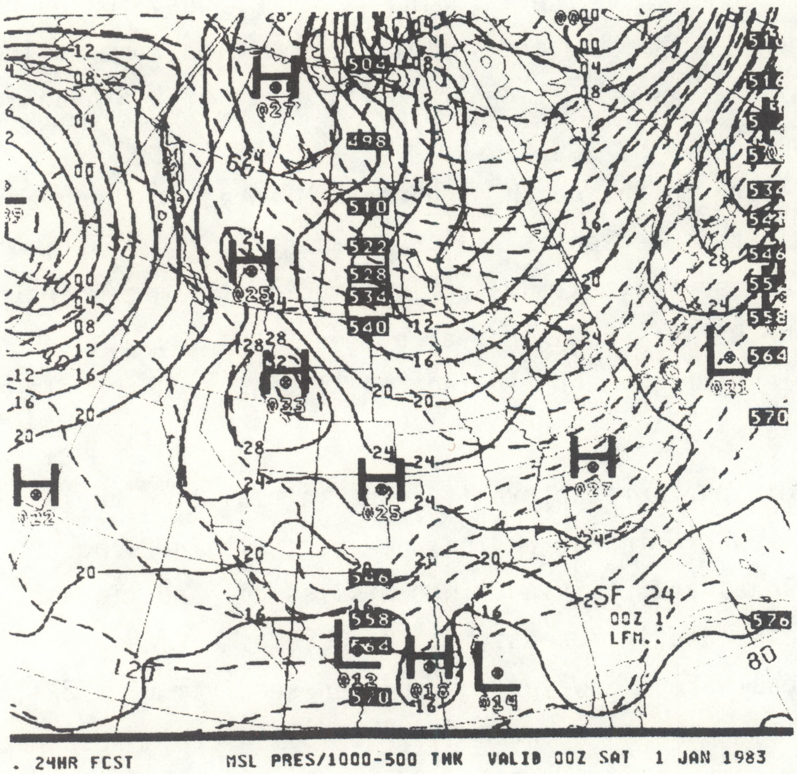
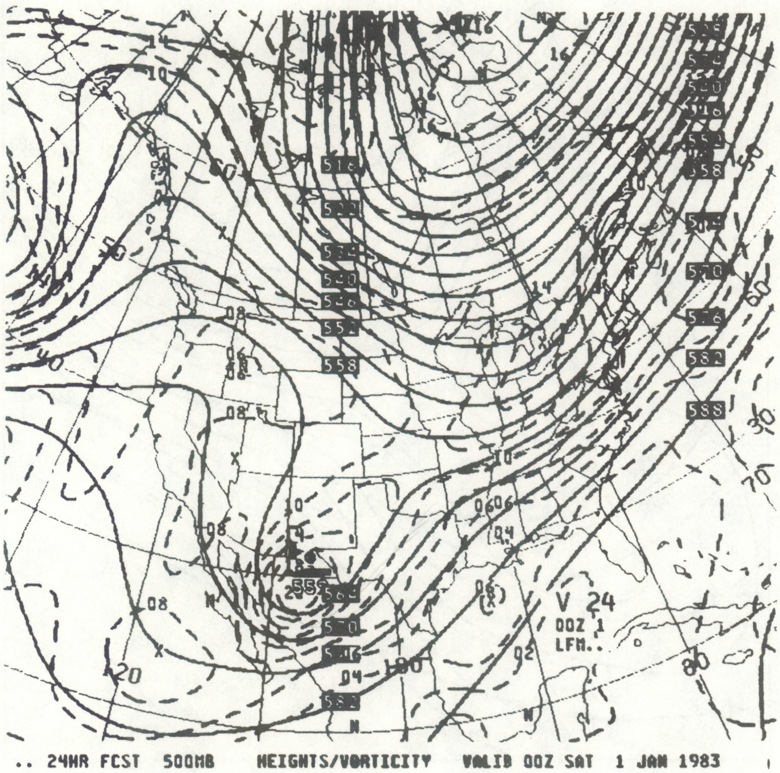


Fig. 26 *LFM 24-hour forecast of 500 mb heights and vorticity valid 0000 GMT 1 January 1983.*



Reason for heights (500 mb) + Vorticity together

advect $\nabla \cdot \mathbb{V}$ with Z_{500} for PVA or NVA

or

why one did not want to drop barotropic model.

Fig. 27 LFM 24-hour forecast of MSL pressure and 1000-500 mb thickness valid 0000 GMT 1 January 1983.

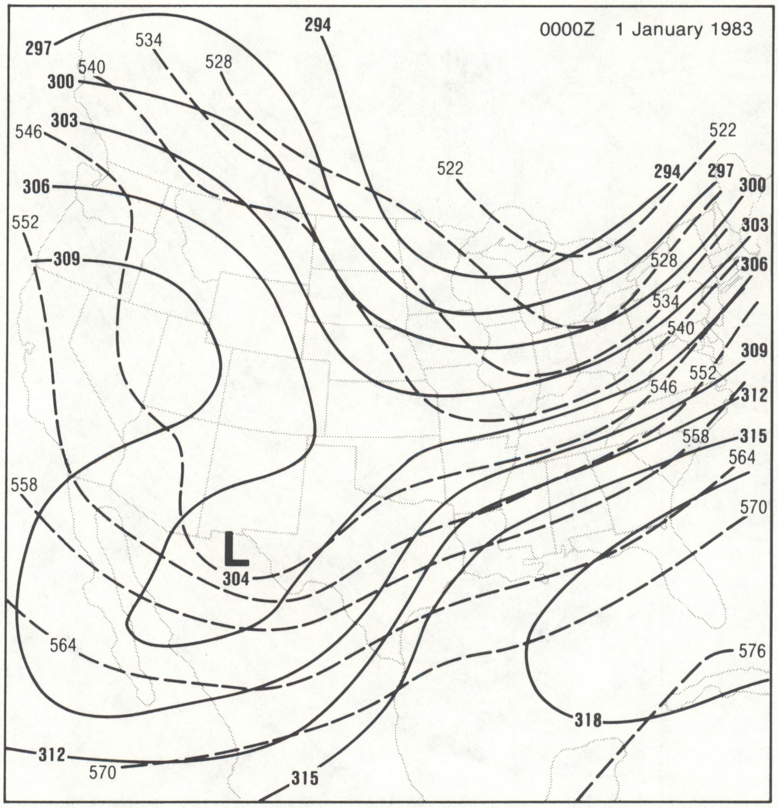
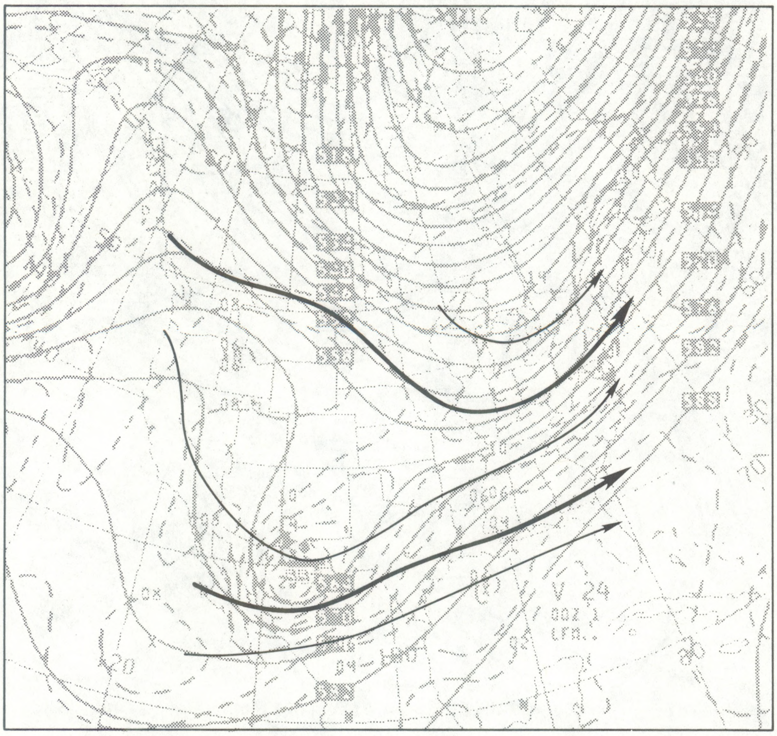


Fig. 28 *LFM 24-hour forecast of 700 mb heights (solid lines) overlaid on the LFM 24-hour forecasted 1000-500 mb thickness (dashed lines) valid 0000 GMT 1 January 1983.*



Thermal advection
∇ · V advected
by Thickness (1000-500mb)
fields

Fig. 29 *Streamline of the thermal wind (1000-500 mb) are shown on the LFM 24-hour 500 mb heights and vorticity panel valid for 0000 GMT 1 January 1983. Width of arrows illustrates the subjective relative strength of the thermal wind.*

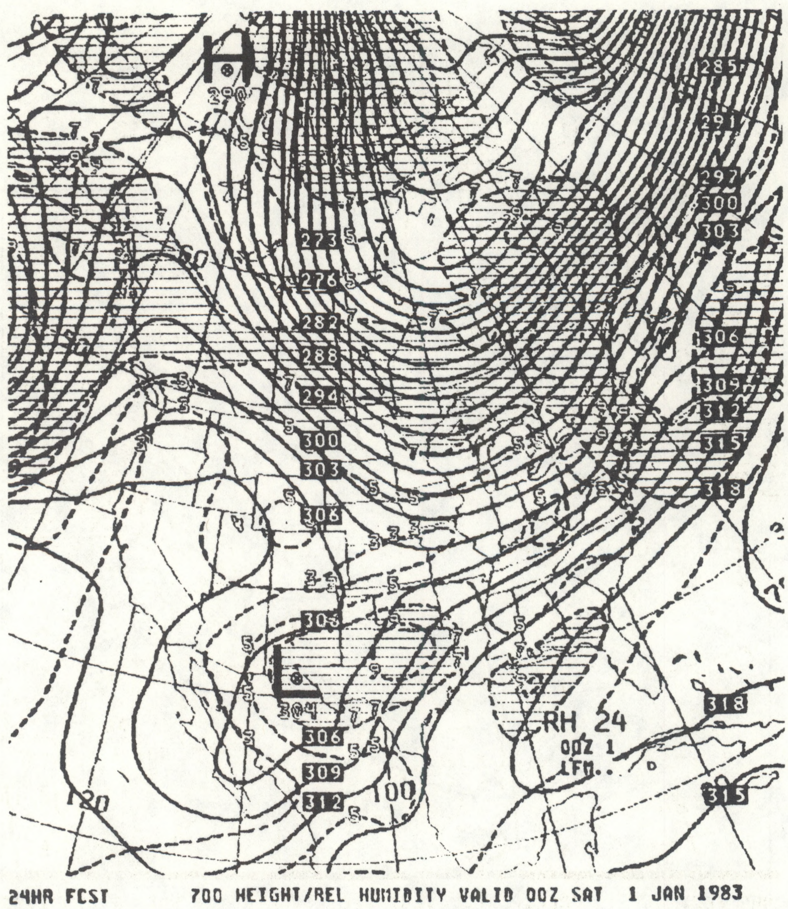


Fig. 30 *LFM 24-hour forecast of 700 mb heights (solid lines) and relative humidity (dashed lines and hatched areas) valid 0000 GMT 1 January 1983.*

Fig. 31 *LFM 24-hour forecast of accumulated precipitation and 700 mb vertical velocity valid 0000 GMT 1 January 1983.*

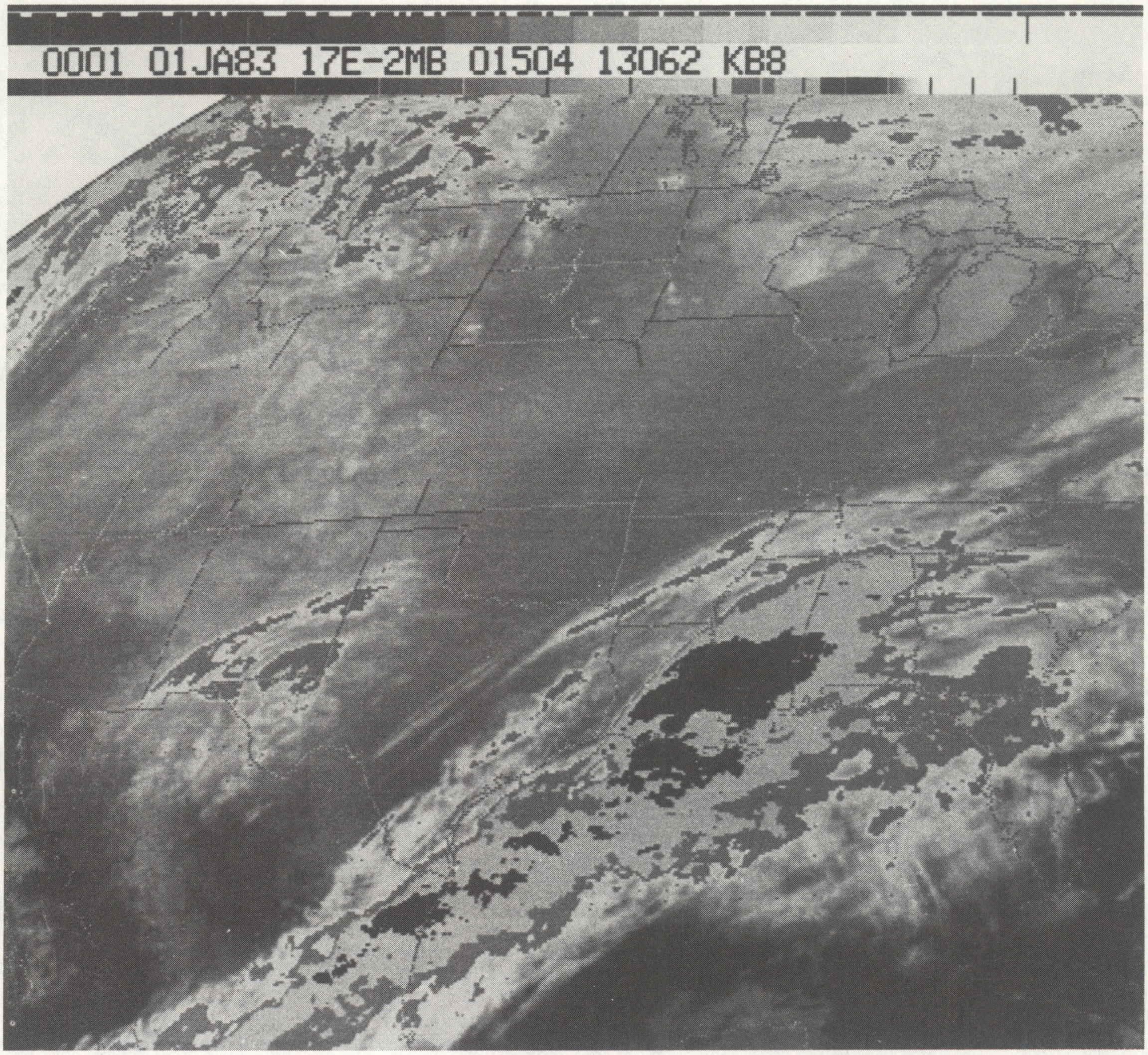


Fig. 32 Enhanced infrared satellite image for 0001 GMT 1 January 1983.

scale models unless the region being studied possesses a large degree of baroclinity. That is, in many cases, the isothermal and geostrophic vorticity advection fields will appear similar. However, a look at a small sample of events during 1982 and 1983 (over the Southern Region) indicated that widespread and/or significant convection developed almost every time PIVA was more pronounced than PVA. I have mentioned the use of the 1000-500 mb thickness because it is so readily available; however, use of low-level thickness fields (e.g., 1000-850 mb or 850-700 mb) should help in better diagnosing and forecasting the vertical motion field.

When we are diagnosing a vertical motion field using synoptic-scale numerical models (or any other method for that matter), we must consider the contributions of both thermal advection and vorticity advection, as well as other terms such as latent heat release and terrain effects. Figure 33 shows LFM surface terrain over the United States and southern Canada. By comparing the LFM's terrain with a topographical map of the United States, one can see how heavily smoothed is the model's terrain. Some topographical features (e.g., Rocky Mountains, Sierras) that interact significantly with synoptic-scale phenomena are poorly represented in the LFM terrain. However, the LFM's surface terrain certainly possesses much greater resolution of these features than does the spectral model (see Fig. 34).

The forecaster can achieve considerable insight by studying the 500 mb vorticity/height prognoses along with the 700 mb vertical velocity forecasts. For example, if the LFM indicates weak PVA (or neutral or even NVA) over a region while the vertical velocity panel shows strong upward motion over the same area, you can be sure that either warm advection or latent heating is the main contributor to the vertical motion. The amount of precipitation the model generates will usually allow the forecaster to determine if the main component of vertical velocity is being generated by warm advection or latent heat. In cases in which neither warm advection nor vorticity advection appears to be significant, forecasters should remember that latent heat release may contribute greatly to the vertical motion field. Although in most cool season heavy-rainfall events, the LFM forecasts weak PVA, it often does forecast upward vertical velocities of 4 to 8 microbars per second. This is a strong vertical motion forecast from a synoptic-scale model.

We shall examine several LFM vertical motion forecasts to determine what the LFM was really trying to say about the vertical motion field. In this manner we can see how specific effects within the model can combine to produce various results. Figures 35-37 show a 24-hour LFM forecast of the 500-mb height and vorticity fields, 1000-500 mb thickness, and precipitation. The LFM's vertical motion forecast for this time is presented in Fig. 38.

Obviously, PVA and PIVA both are occurring in the upward vertical motion region centered over Kentucky, and indeed, the LFM forecast a rather strong (+4 microbars per second) synoptic-scale vertical velocity over the region. However, maximum vertical velocity is centered over the Florida panhandle. Although the PVA and PIVA ahead of the impulse over the eastern Gulf of Mexico are not nearly as impressive as those over Kentucky, the LFM forecasts heavy precipitation over Alabama, Georgia, and the Florida panhandle and virtually none over Kentucky. Thus, latent heat must be a significant contributor to the LFM's vertical motion forecast over the Florida panhandle.

again reliance upon the model.

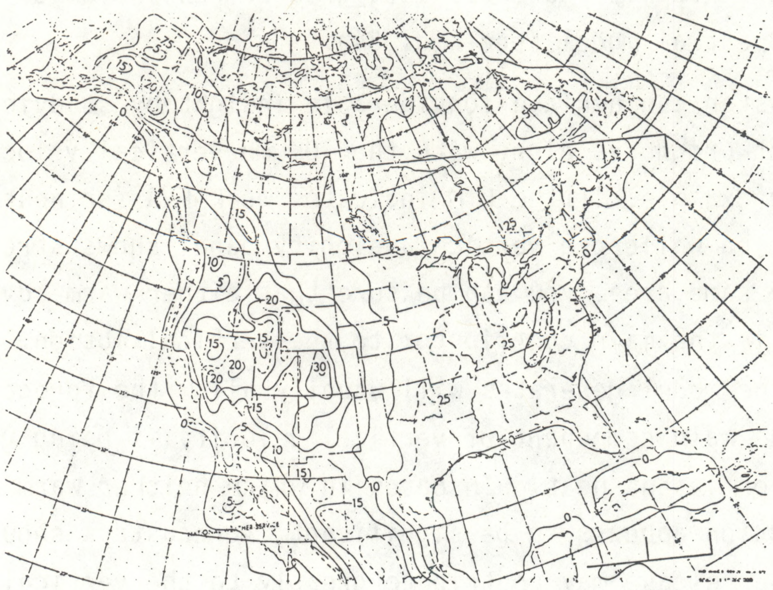


Fig. 33 Limited Fine Mesh-II model surface terrain over the United States and southern Canada in hundreds' of meters.

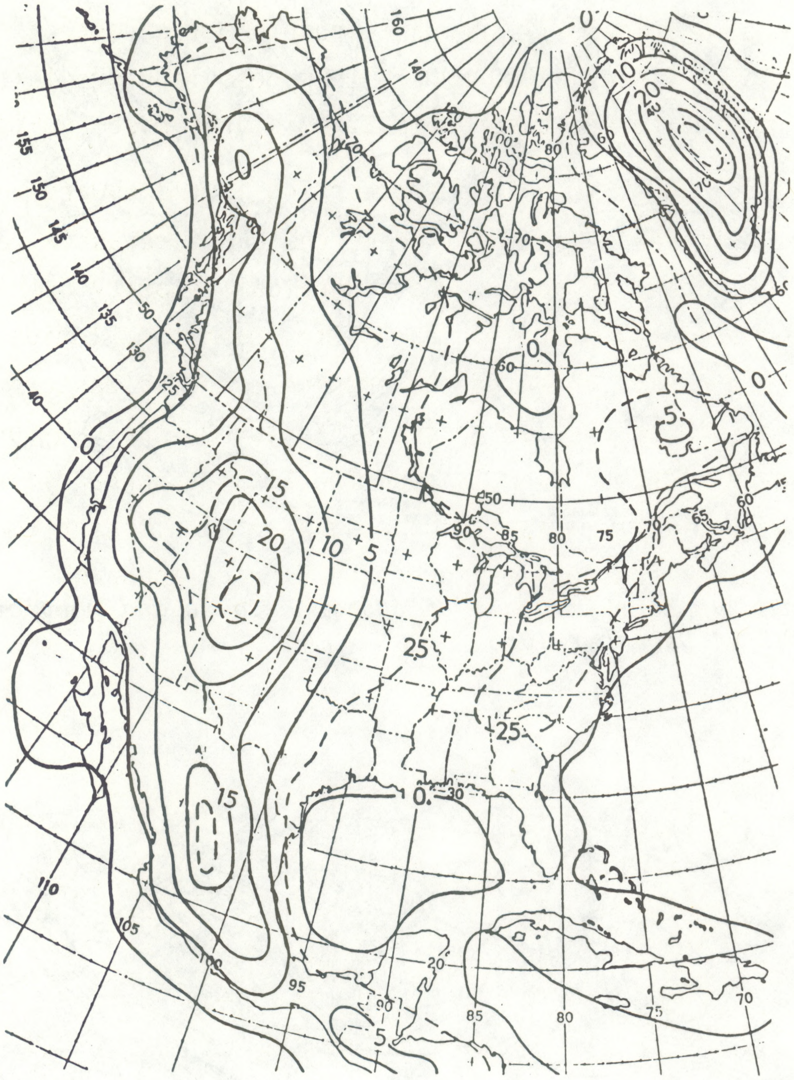


Fig. 34 *Spectral model surface terrain over the United States and southern Canada in hundred's of meters.*

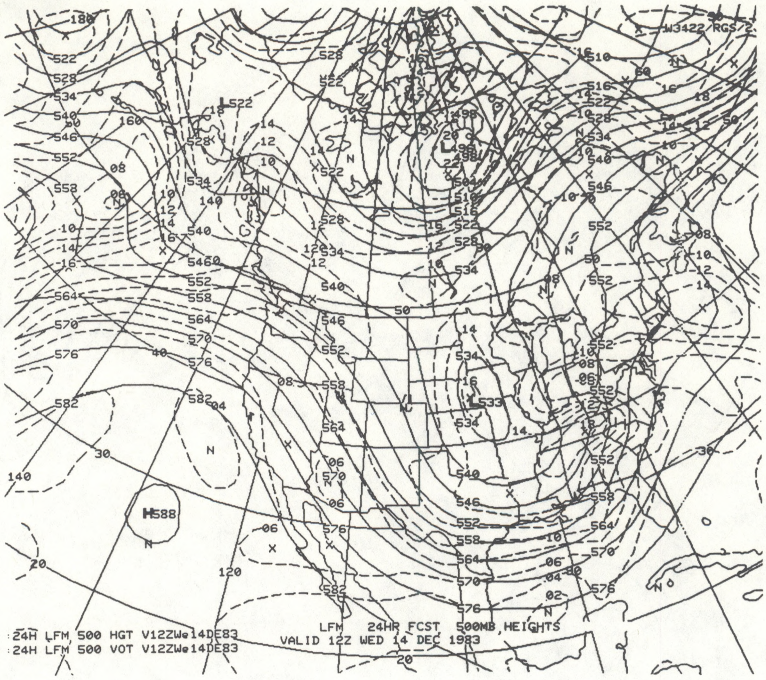


Fig. 35 *LFM 24 -hour forecast of 500 mb heights and vorticity valid 1200 GMT 14 December 1983.*

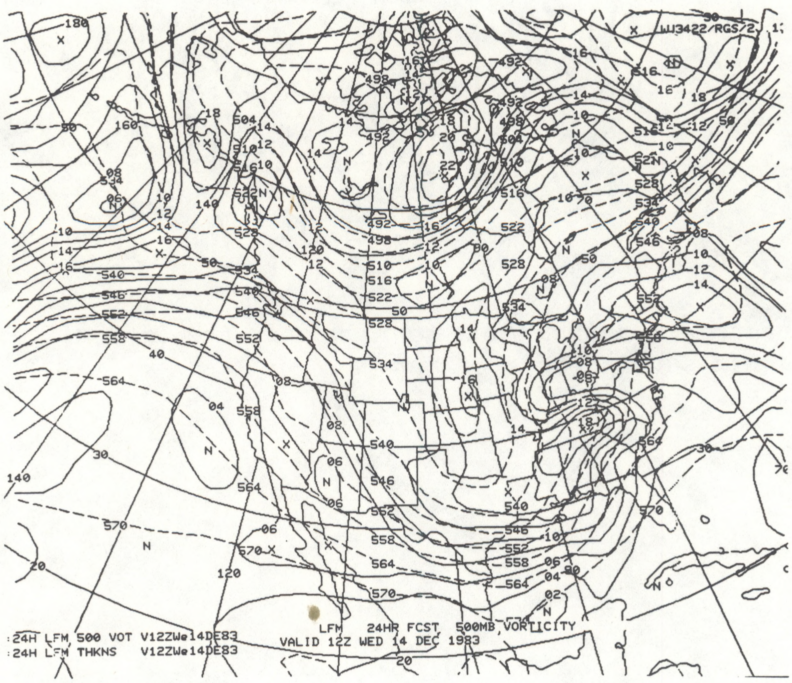


Fig. 36 *LFM 24 -hour forecast of 500 mb vorticity and 1000-500 mb thickness valid 1200 GMT 14 December 1983.*

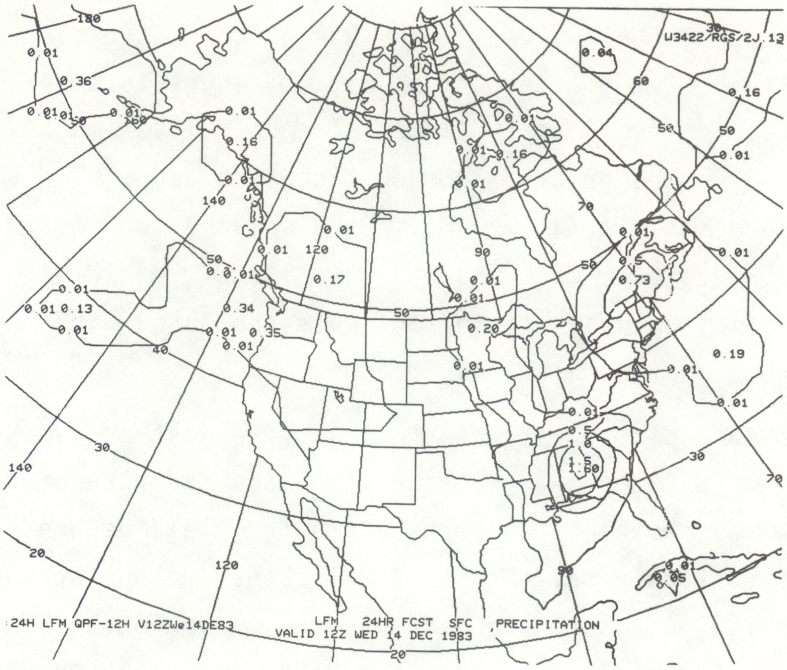


Fig. 37 LFM 24-hour forecast of 12-hour accumulated precipitation (in inches) valid 1200 GMT 14 December 1983.

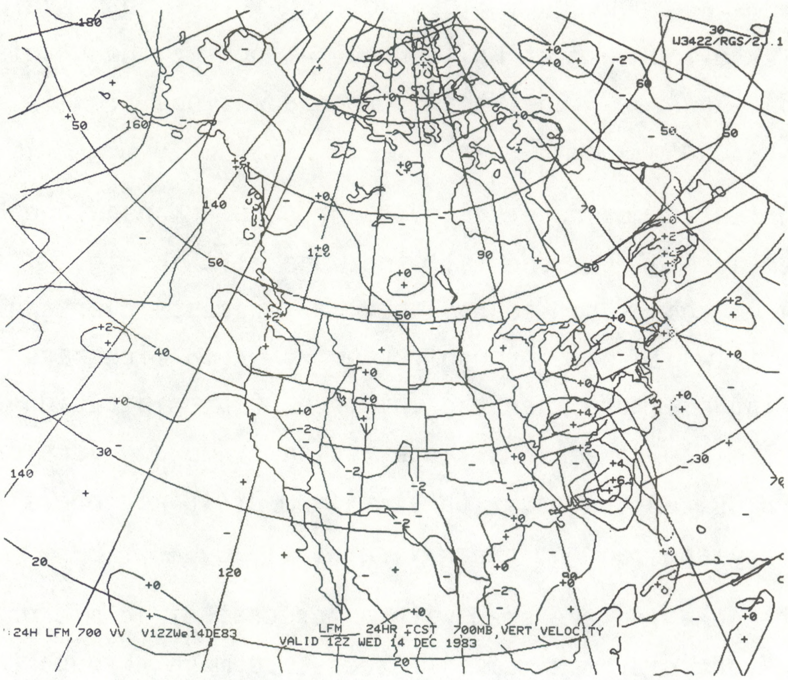


Fig. 38 LFM 24-hour forecast of 700 mb vertical velocity valid 1200 GMT 14 December 1983.

Figure 38 also shows that the LFM forecasts a region of sinking air from southwest Texas to southern Nevada. Any NVA or cold advection in this region is certainly weak, but a glance back at Fig. 33 suggests that the downward motion is probably due to terrain slope. The satellite imagery (Fig. 39) shows that the LFM did a pretty good job with this case. The vertical motion pattern appears reasonable, although it is displaced 100 to 200 miles for the eastern United States system. Notice how well the LFM did with the small region of upward motion over southeast Texas associated with the weak short wave rotating through the relatively dry air.

Figures 40-43 depict a situation with active weather over large portions of the country. You might want to study the maps and attempt to translate what the LFM is saying about the vertical motion field before reading my discussion. If not, read on. First of all, consider the strong downward vertical motion (-4 microbars per second) over north Texas (Fig. 43) extending into New Mexico. It is obvious (from the difference between Figs. 40 and 41) that cold advection is playing a significant role, since the NIVA is significantly stronger than the NVA. The combination of NVA and cold advection obviously should produce the strongest downward vertical motion over the Fort Worth vicinity. Why is there another maximum forecast over northeast New Mexico? It is apparent from Figs. 40 and 41 that both NVA and NIVA diminish rapidly to the west of Ft. Worth. A look at the gradient of terrain height (Fig. 33), however, shows that strong downslope flow is probably producing this second maximum.

The LFM indicates moderate PVA over northern Arkansas and Missouri, but owing to the strength of the thermal wind, the PIVA in Fig. 41 appears quite strong. The +4 microbars per second the LFM forecasts over the area is indeed impressive, but it would have probably been +6 or +8 microbars if the LFM had been able to wring out more than the .01 inch of precipitation forecast (Fig. 42). The LFM also has forecast a large region of upward vertical motion over the northeastern United States, with a maximum of +8 microbars per second over Pennsylvania, Maryland, and northern Virginia.

First, let's examine the area with a forecast of +8 microbar per second. A weak vorticity maximum is forecast to move through the area, but the PVA is definitely weak. However, there is an obvious difference in the orientation of the contours and thickness lines in Figs. 40 and 41, indicating that the PIVA is more pronounced than the PVA. Additionally, the air will be

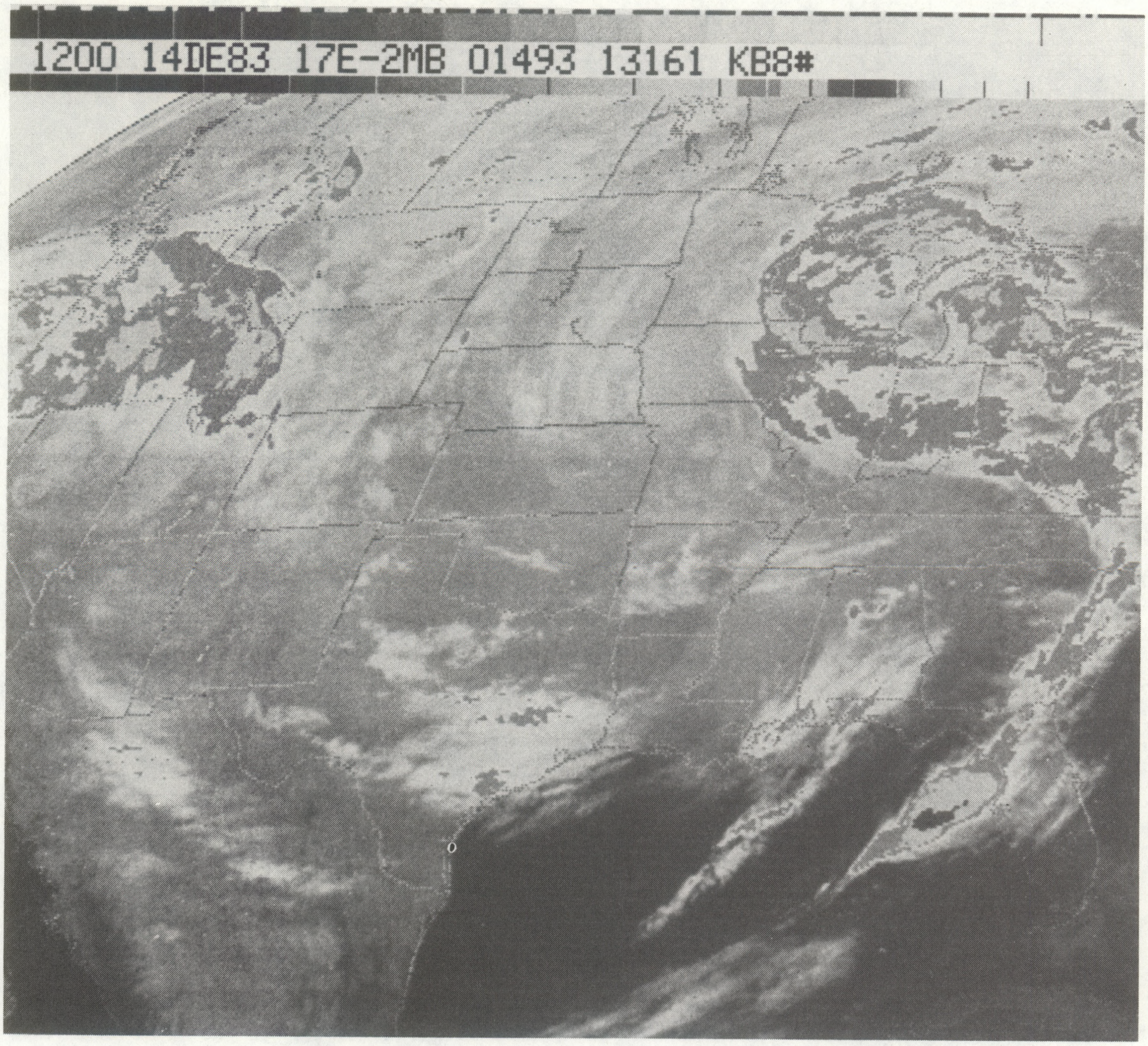


Fig. 39 Enhanced infrared satellite image for 1200 GMT 14 December 1983.

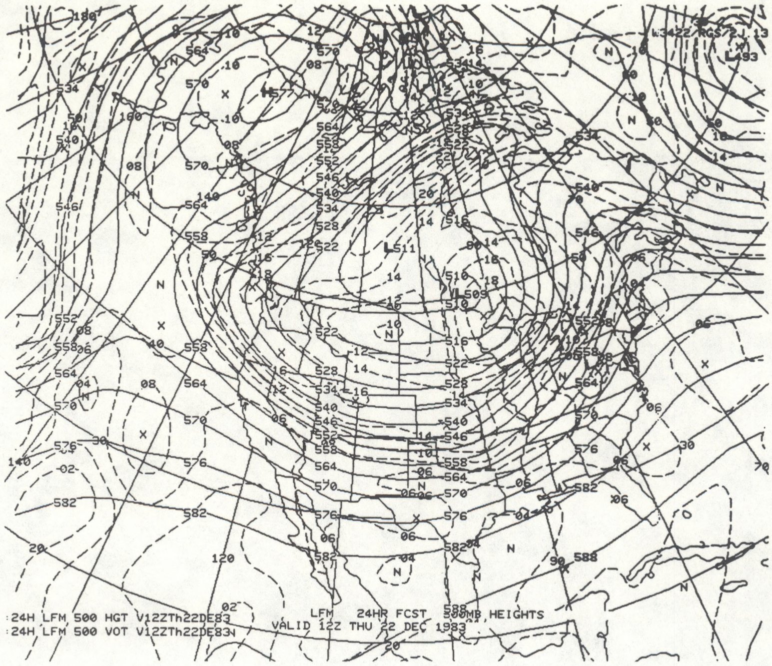


Fig. 40 *LFM 24-hour forecast of 500 mb heights and vorticity valid 1200 GMT 22 December 1983.*

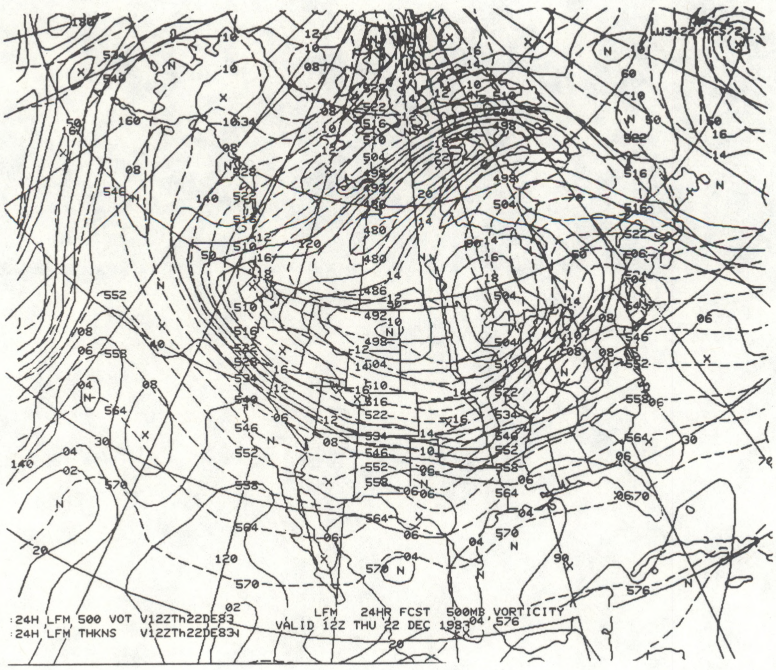


Fig. 41 *LFM 24-hour forecast of 500 mb vorticity (solid lines and 1000-500 mb thickness valid 1200 GMT 22 December 1983.*

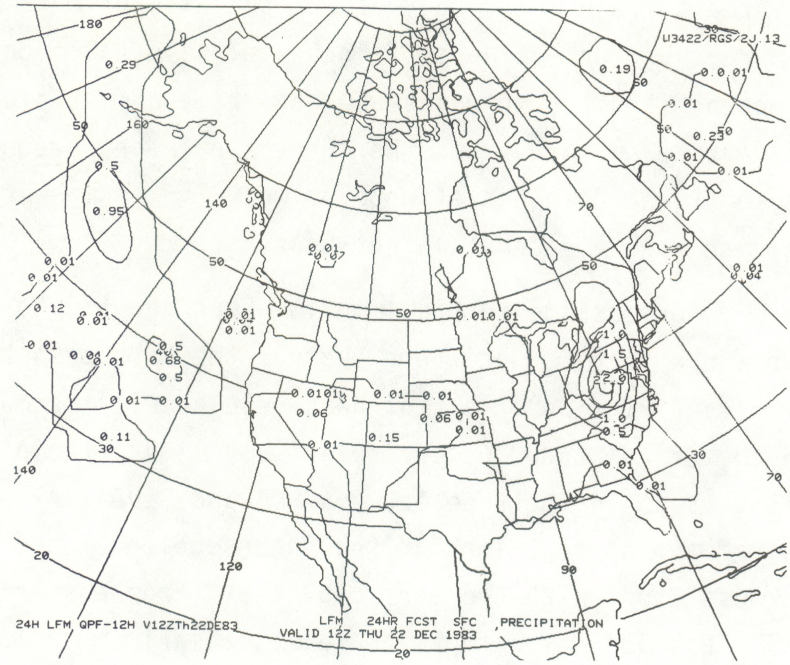


Fig. 42 *LFM 24-hour forecast of 12-hour accumulated precipitation valid 1200 GMT 22 December 1984.*

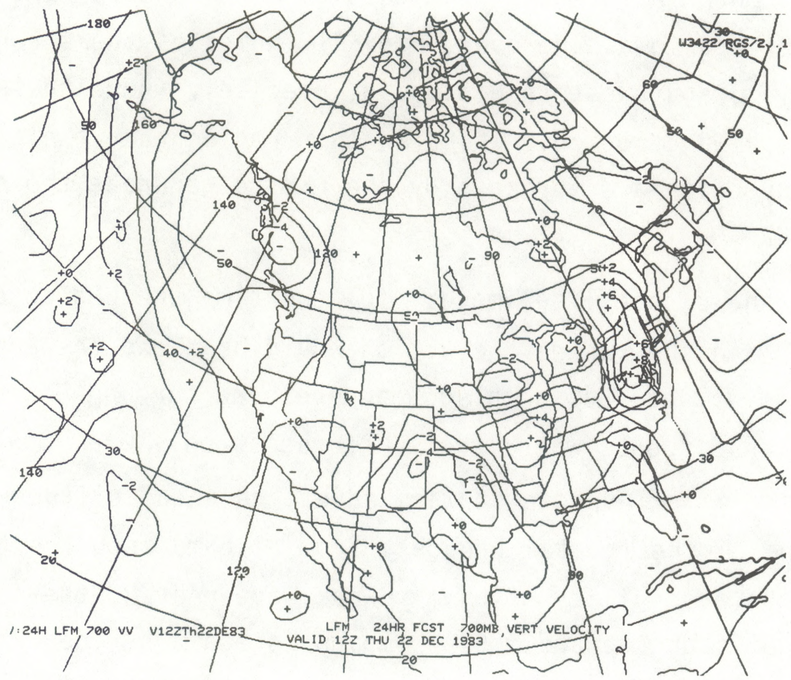


Fig. 43 *LFM 24-hour forecast of 700 mb vertical velocity valid 1200 GMT 22 December 1983.*

forced upward by the terrain (Fig. 33) west of the axis of maximum vertical motion. The LFM does produce at least 2 inches of rainfall along the windward slopes of the Appalachians, so that latent heat release must play a big part in the forecast vertical motion. So, the +8 microbars per second is forecast by the LFM because of the combined effects of weak PVA, some warm advection, terrain lifting, and the release of latent heat.

Why is the LFM forecasting vertical motion near the New York-Canada border? The terrain effect is not there because the LFM doesn't know that the Adirondacks exist (see Fig. 33). Latent heat release will be much less here than farther south, as evidenced by the relatively light precipitation forecast, but look at the difference between PVA and PIVA! Although the thermal wind is not too strong, look at the intersection of the 5340- and 5400-meter thickness lines with the vorticity field from eastern Canada to the New York border. This indicates that the relative maximum is mainly the result of the LFM's forecast of warm advection perhaps coupled with latent heat release.

One final detail should be discussed before leaving this case: the minimum (-2 microbars per second) centered over northeast Iowa. Figure 40 shows fairly strong NVA forecast from eastern North Dakota through Minnesota and extreme northern Iowa. However, Fig. 41 indicates the strongest NIVA over northern Iowa into southwestern Wisconsin, precisely where the LFM forecasts the strongest downward motion. It is in this region that the contributions of NVA and cold advection are forecast by the LFM to generate the strongest downward motion.

Figure 44 shows satellite imagery for the time the LFM forecast was valid. The LFM did show where the action would be along the Appalachian Mountains. However, convection also has developed through Georgia and Alabama along the weak cold front, where the LFM forecast only weak upward motion. This is most likely in response to warm advection ahead of the weak short wave. The shape of the frontal boundary from Alabama into the Gulf of Mexico also suggests the possibility of a very weak wave near Bootheville. What is happening in the strong upward motion region forecast by the LFM over southern Missouri and northern Arkansas? Not very much. Although the vertical motion forecast may well be accurate, the much weaker short wave has triggered the convective releases and the main system has little moisture left to work with. The LFM did accurately forecast the weak upward motion field over south

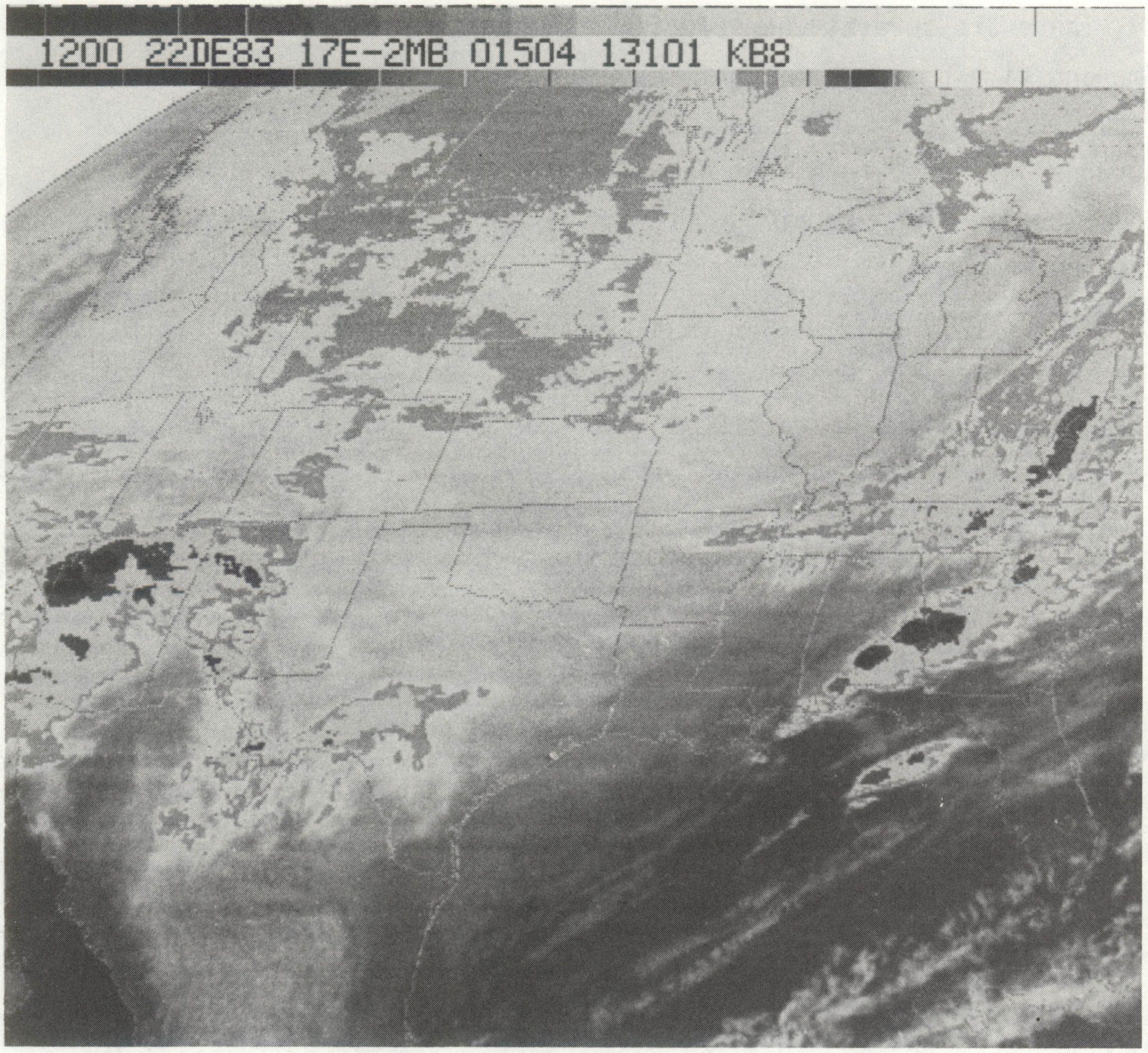


Fig. 44 Enhanced infrared satellite image for 1200 GMT 22 December 1983.

Texas ahead of the vorticity maximum in the dry air, and the forecast vertical motion field (upward motion) over western Colorado and Arizona looks good too, although the LFM appeared to move these eastward a little too fast.

There are several characteristic patterns that seem to repeat themselves time and time again when significant convective weather occurs. A brief discussion and example of each is offered (only as "rules of thumb"). These patterns are indicators that detailed digging into other meteorological parameters (besides vorticity) is called for. Tropical storms are excluded from the discussion.

Forecasters always seem to be looking for impressive vorticity on the numerical forecasts but the strong middle-level waves that often cross the United States with a nice "18" or "20" center do not always create significant weather in the Southern Region. The effect of cold advection compensates for the contribution of differential PVA to the vertical motion field in many cases. The most significant weather (as far as the Southern Region is concerned) usually occurs well ahead of such a system, where the effects of weak PVA with a leading short wave, warm advection, and return of Gulf moisture (convective destabilization) often act in concert. The result is frequently a significant mesoscale convective system (MCS). Figure 45 depicts a typical case illustrating this particular pattern. The MCS that developed across the Gulf states (see Fig. 46) produced more than 6 inches of rain at many locations, and the second 24-hour rainfall exceeding 8 inches at Jackson, Miss. during this century.

The author has examined Mississippi's heavy rain events from 1977 to 1982 and found that 500-mb vorticity advection was weak in all cases. The pronounced vertical lifting needed to support convection for a long period of time was manifested by low-level advection of warm, moist air, and release of latent heat. A similar study of significant rainfall events in Louisiana (Belville and Stewart, 1983) revealed a common 500-mb pattern characterized by a closed low near the Texas-New Mexico border, and weak short waves embedded in the flow around the low. Belville and Stewart attributed the Louisiana vertical motion to advection of warm, moist air and release of latent heat.

The greatest threat with these situations is almost always heavy rainfall and flash flooding. In many cases, Gulf moisture has been absent for more than 24 hours, owing to a shallow layer of dry, relatively cool air that has penetrated a short way into the Gulf of Mexico. The return of moisture from the Gulf can be rapid, changing a rather dry sounding to something that resembles Miller's (1972) Type II sounding in less than 12 hours. Severe weather in such cases is usually not widespread, although numerous "short-lived" marginally severe storms may develop. (Note that the severe weather potential increases when an MCS develops over the western portion of the Southern Region.) Severe storms usually develop near the intersection of maximum moist low-level inflow with a boundary (often a warm front). This type of severe thunderstorm activity usually occurs toward the south side of the MCS. One special word of caution is called for here. Weak boundaries over the Gulf of Mexico usually are not shown on NMC analyses. Therefore, it is up to the forecaster to find the boundaries using all the tools available. This job can be made much easier by maintaining continuity on fronts that move southward into the Gulf.

emphasis only for synoptic scale

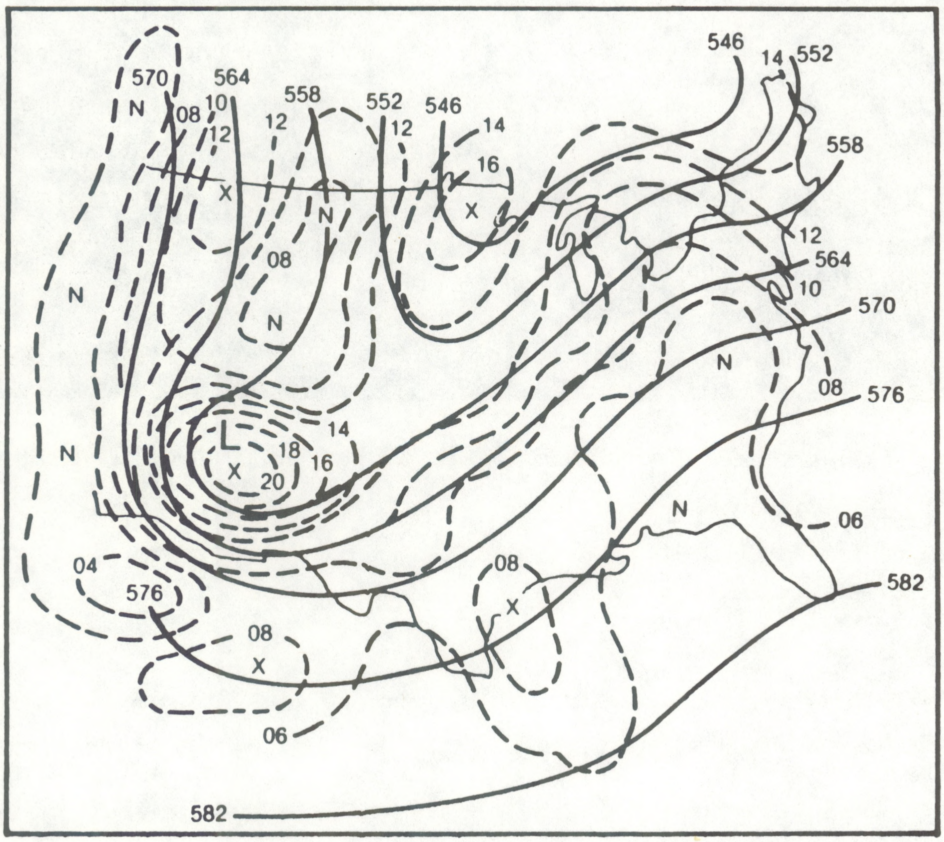


Fig. 45 *LFM 12-hour forecast of 500 mb heights and vorticity valid at 0000 GMT 12 April 1980.*

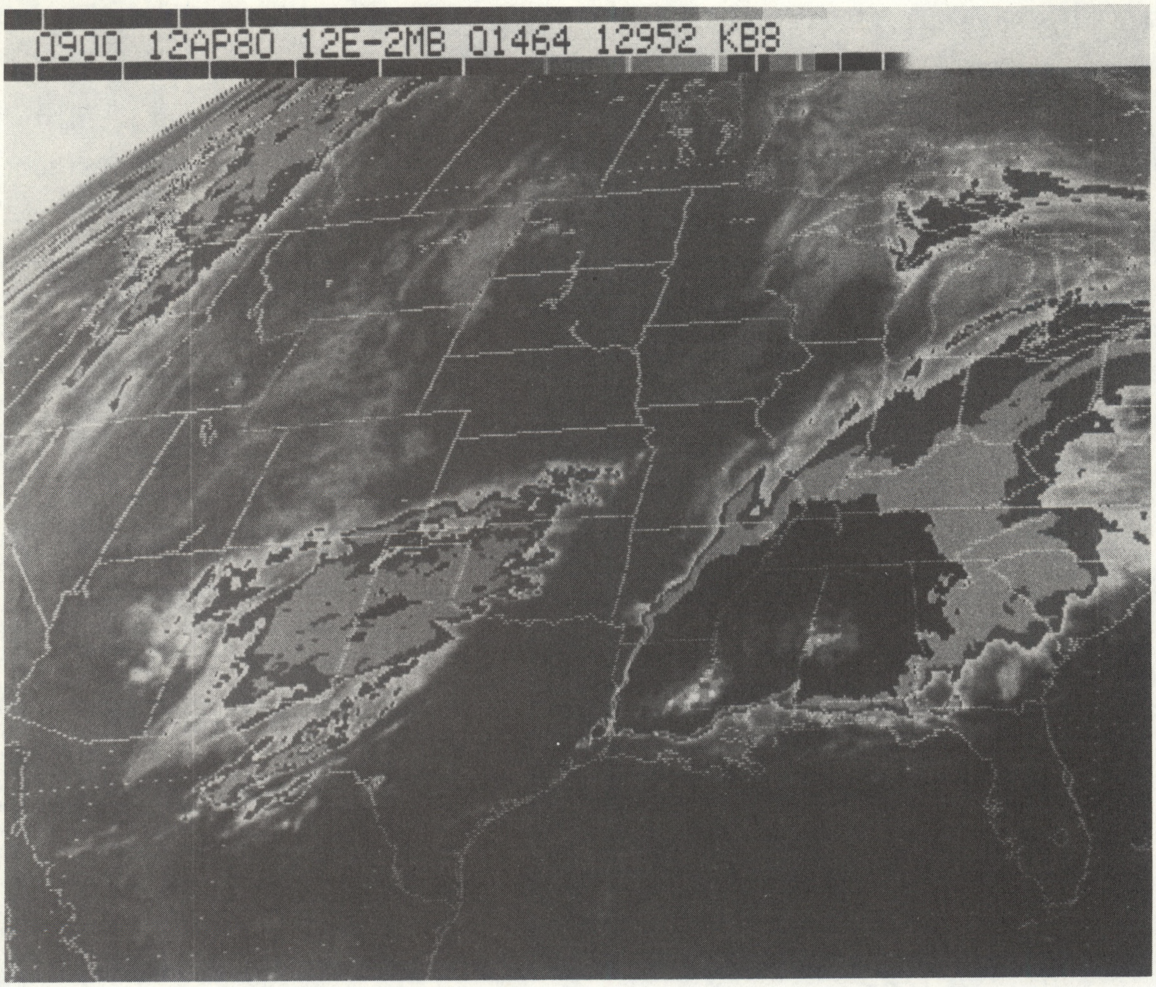


Fig. 46 Enhanced infrared satellite image for 0900 GMT 12 April 1980.

Now, let's consider the impressive vorticity maximum farther west (refer to Fig. 45). By the time this main system reaches the southern United States (if it tracks that far south), the weak short wave that initiated convection has moved well to the east, taking most of the moisture with it. However, the lack of amplitude in the initial impulse leaves abundant Gulf moisture close at hand, so that its rapid return may be triggered by the approaching system. If significant weather develops with the main system, it is more likely to be severe because of intense destabilization resulting from differential temperature and moisture advection.

Flash flooding is also a possibility, although prolonged rainfall is not likely. Most of the convective activity with these systems is concentrated in lines that produce severe thunderstorms and/or heavy downpours for brief periods at any one location. Of course, if the middle-level system "cuts off", becoming stationary or moving slowly, you may be left with a slow-moving front that provides a perfect setup for a synoptic-type flash flood event as described by Maddox (1979). This possibility is most likely in late fall and again in early spring. The nearly stationary front allows convective storms to occur over localized regions for long periods of time. Figures 47-53 illustrate a typical "double shot" situation for the Gulf Coast States. Rainfall with the weak short wave totaled 6 to 10 inches across northern Mississippi and northern Alabama, while the main system produced severe thunderstorms and tornadoes across the same two states.

You have probably noticed that these illustrations have involved cool-season situations. Using the model's vertical velocity forecasts during the warm season is a bit more difficult. During the summer, an LFM-forecast vertical velocity in excess of 2 microbars per second over the southern United States is rare. Use of detailed LFM data can provide the forecaster better resolution of the field, but the scarcity of strong baroclinic weather systems makes summertime numerical model forecasts of limited use. Warm-season heavy-rainfall events, other than those associated with tropical systems, are frequently the result of just the right combination of subtle features.

Massive MCSs often develop over the central United States during the warm season. Kansas, Missouri, Texas, Arkansas, and Oklahoma are prime development areas from April through June. Figures 54 and 55 show typical 850-mb and 500-mb patterns that lead to MCS development. This particular situation led to

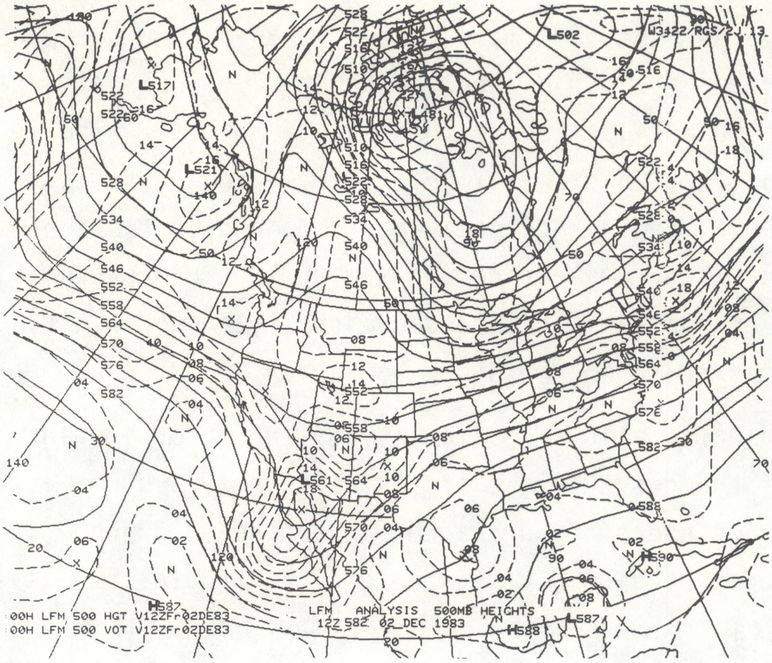


Fig. 47 *LFM initial numerical analysis of 500 mb heights and vorticity for 1200 GMT 2 December 1983.*

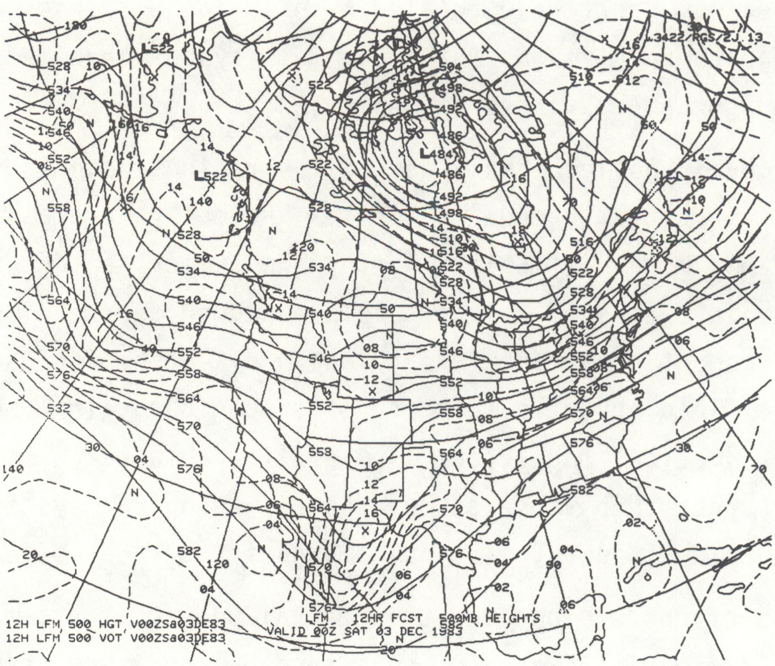


Fig. 48 *LFM 12-hour forecast of 500 mb heights and vorticity valid 0000 GMT for 1200 GMT 3 December 1983.*

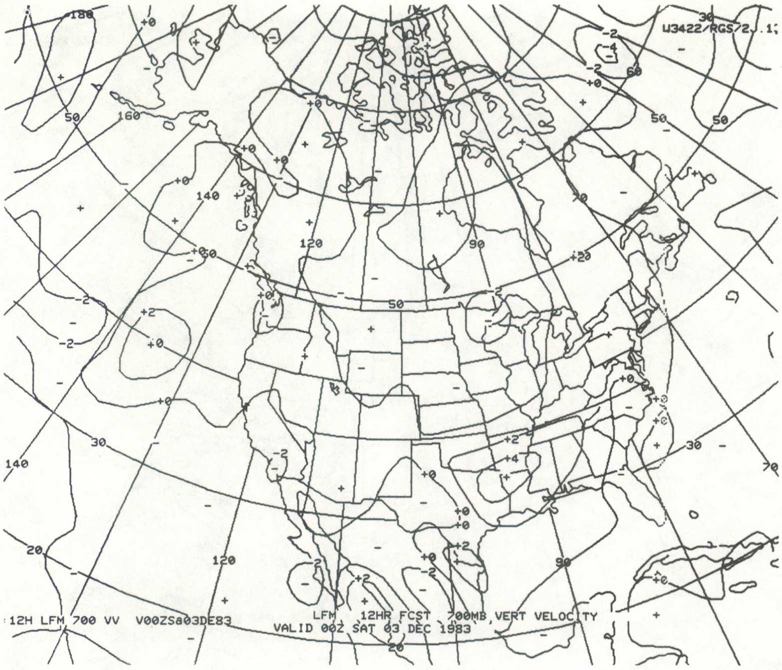


Fig. 49 *LFM 12-hour forecast of 700 mb vertical velocity valid 0000 GMT 03 December 1983.*

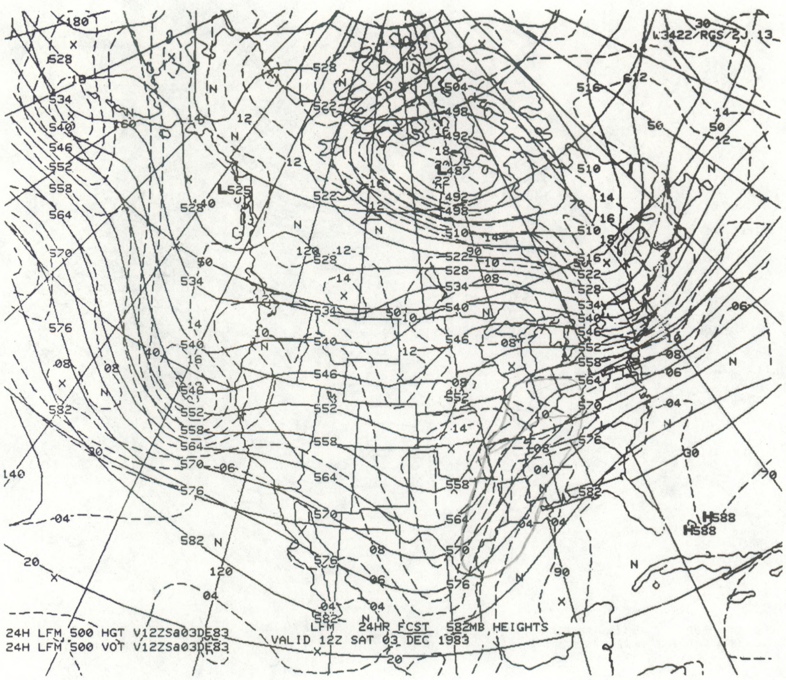


Fig. 50 *LFM 24-hour forecast of 500 mb heights and vorticity valid 1200 GMT 3 December.*

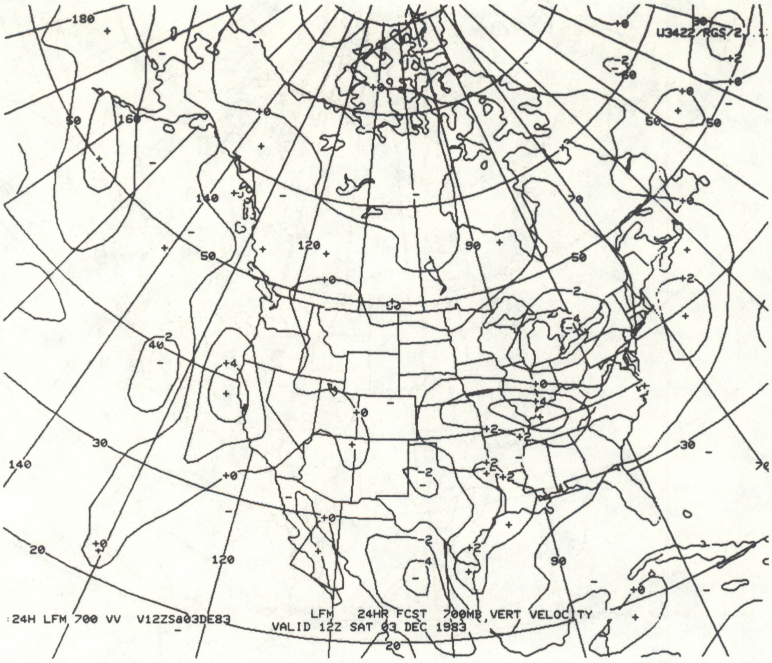


Fig. 51 *LFM 24-hour forecast of 700 mb vertical velocity valid 1200 GMT 3 December 1983.*

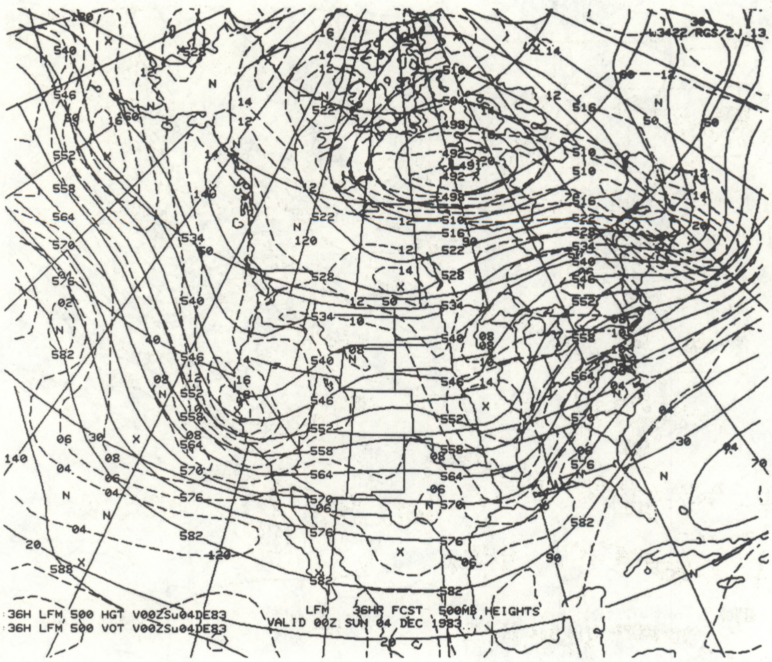


Fig. 52 *LFM 36-hour forecast of 500 mb heights and vorticity valid 0000 GMT 4 December 1983.*

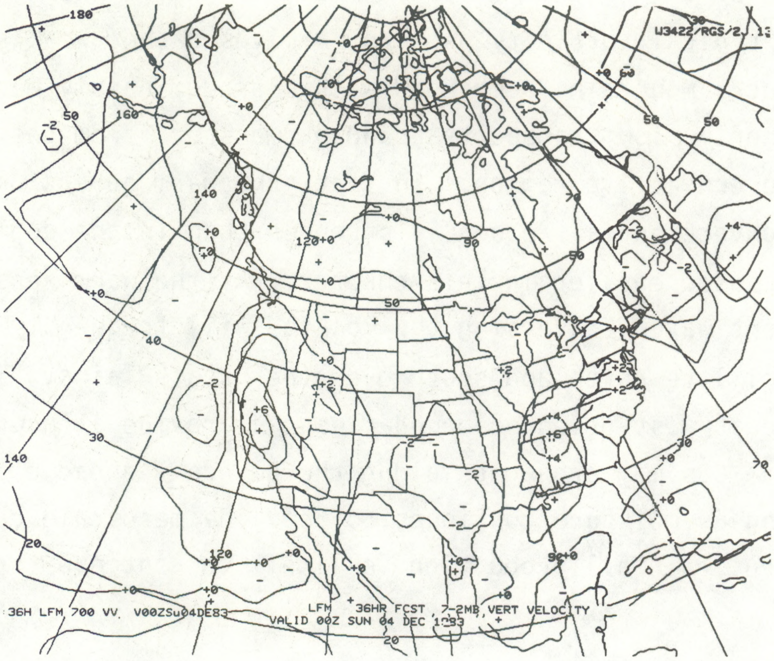


Fig. 53 *LFM 36-hour forecast of 700 mb vertical velocity valid 0000 GMT 4 December 1983.*

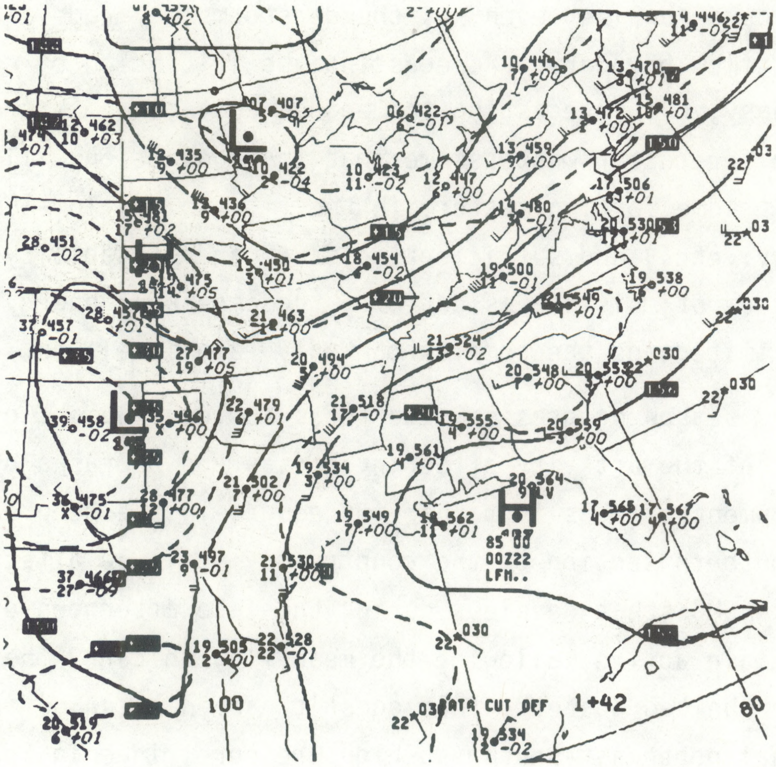


Fig. 54 *NMC 850 mb analysis for 0000 GMT 22 June 1981.*

the development of an MCS that affected Missouri and northern Arkansas (see Fig. 56). The typical vorticity pattern involves rather weak short waves that traverse the Rocky Mountains, embedded within predominantly westerly flow. Low-level southerly flow transports abundant moisture from the western Gulf of Mexico into the convective region. In fact, the warm advection that helps initiate the convection is frequently stronger than in the cool season situations discussed earlier in this chapter. As the warm season progresses, a series of short waves traversing the Rockies will frequently allow a frontal boundary to oscillate north and south over the Great Plains. These predominantly east/west-oriented boundaries can provide a focus for convection, and MCSs may propagate along the boundary ahead of a short-wave trough. As long as moisture continues to feed the mesoscale convective region, efficient rainfall production is likely to continue throughout the night.

Forecasters downstream (usually east and south) of the favored development region must try to determine what effects (if any) these convective systems will have in their area of responsibility. Will heavy rains require flash flood watches/warnings or will strong, mesoscale outflows pose a problem for aviation? One cannot assume that these storm systems will always decay around sunrise; even so, thunderstorms may redevelop along the system's old outflow boundary. Forecasting the initiation of convection is certainly not easy, but forecasting the end of convection is frequently more difficult. The forecaster must assume that the convection will continue as long as there is some forcing feature in the flow (e.g., low-level jet, outflow boundary, etc.) and sufficient moisture and instability to maintain it. Once the flow of moisture is cut off, the amount of energy available to the system is limited and the complex can only rain itself out.

As the warm season progresses, the focus for development of MCSs shifts northward, most of the activity affecting Kansas and Nebraska by mid-July. Although development of MCSs is rather infrequent in the deep south with this pattern, the southern section of the country may still be affected by MCSs in several ways. An MCS that develops during the late afternoon over western Nebraska may remain active, allowing the mean flow to carry the complex into the southeastern United States. This doesn't happen often during the summer because the usual northeast-southwest high pressure ridge in low levels shuts off the inflow of moisture to the complex. However, each weather situation

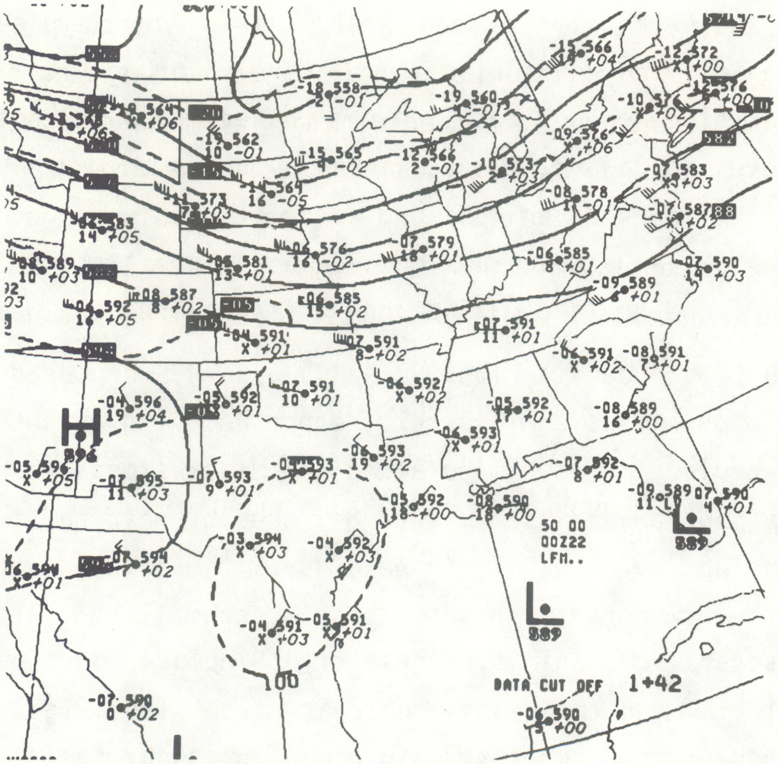


Fig. 55 NMC 500 mb analysis for 0000 GMT 22 June 1981.

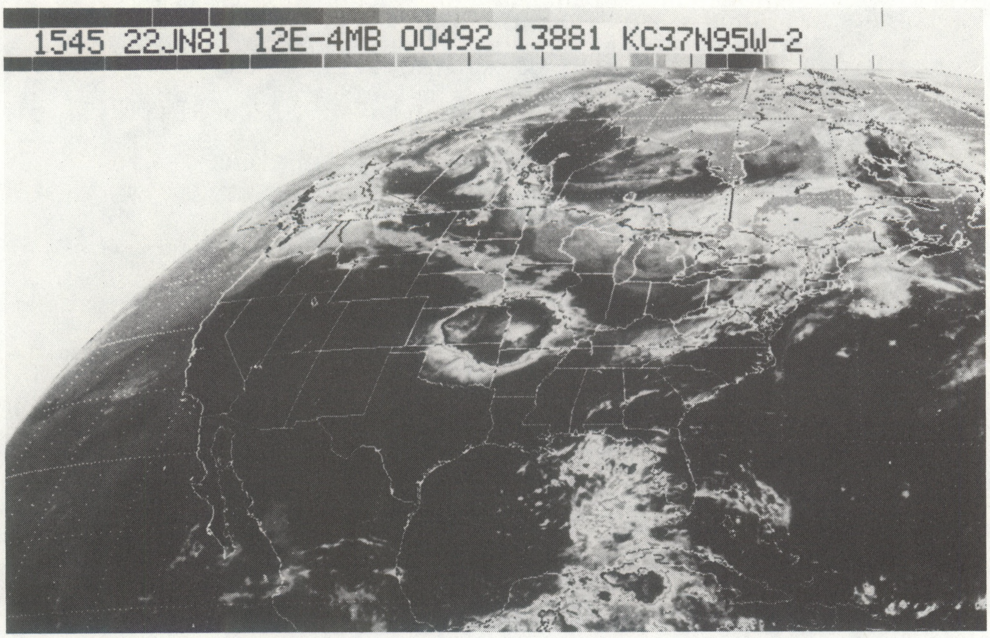


Fig. 56 Enhanced infrared satellite image for 1545 GMT 22 June 1981.

must be treated as the individual case that it is. For example, if the short wave that helped initiate convection is relatively strong, it may also erode the high-pressure ridge enough to allow the western Gulf to continue feeding the MCS as it moves southward. Forecasters in the south may also have to deal with the indirect effects of an MCS long after its demise. Johnston (1982) has shown how an MCS can produce a middle-level (approximately 700 mb) vorticity maximum, and how the maximum can affect subsequent weather events.

In the situation shown in Figs. 57 and 58, an MCS produced copious amounts of rain over Kansas and Missouri before decaying at about 1800 GMT on 13 August. New convection developed along the Mississippi-Arkansas border later in the day, and an additional 7 to 8 inches of rain had fallen over northwest Mississippi by 1200 GMT the next day. The development and maintenance of the new convection was probably accomplished through the combination of several mechanisms. These might include the intersection of moist, low-level flow and the quasi-stationary front (see Figs. 59 and 60); increased difluence in the upper troposphere produced by the original MCS; and possibly middle-level vorticity produced by the original MCS.

Thus, it is important to monitor the regions of decaying MCSs (upstream from your area of responsibility) and to look closely at any vorticity maximum that shows up in the next model run's initial panels for those regions. Vorticity analysis at 700 mb should be performed if possible (AFOS applications programs should soon be available for this), or at least the cyclonic curvature at 700 mb should be subjectively analyzed. The SFSSs routinely look for vorticity maxima produced by MCSs, so SIMS will often discuss these if they are identifiable in satellite cloud motion.

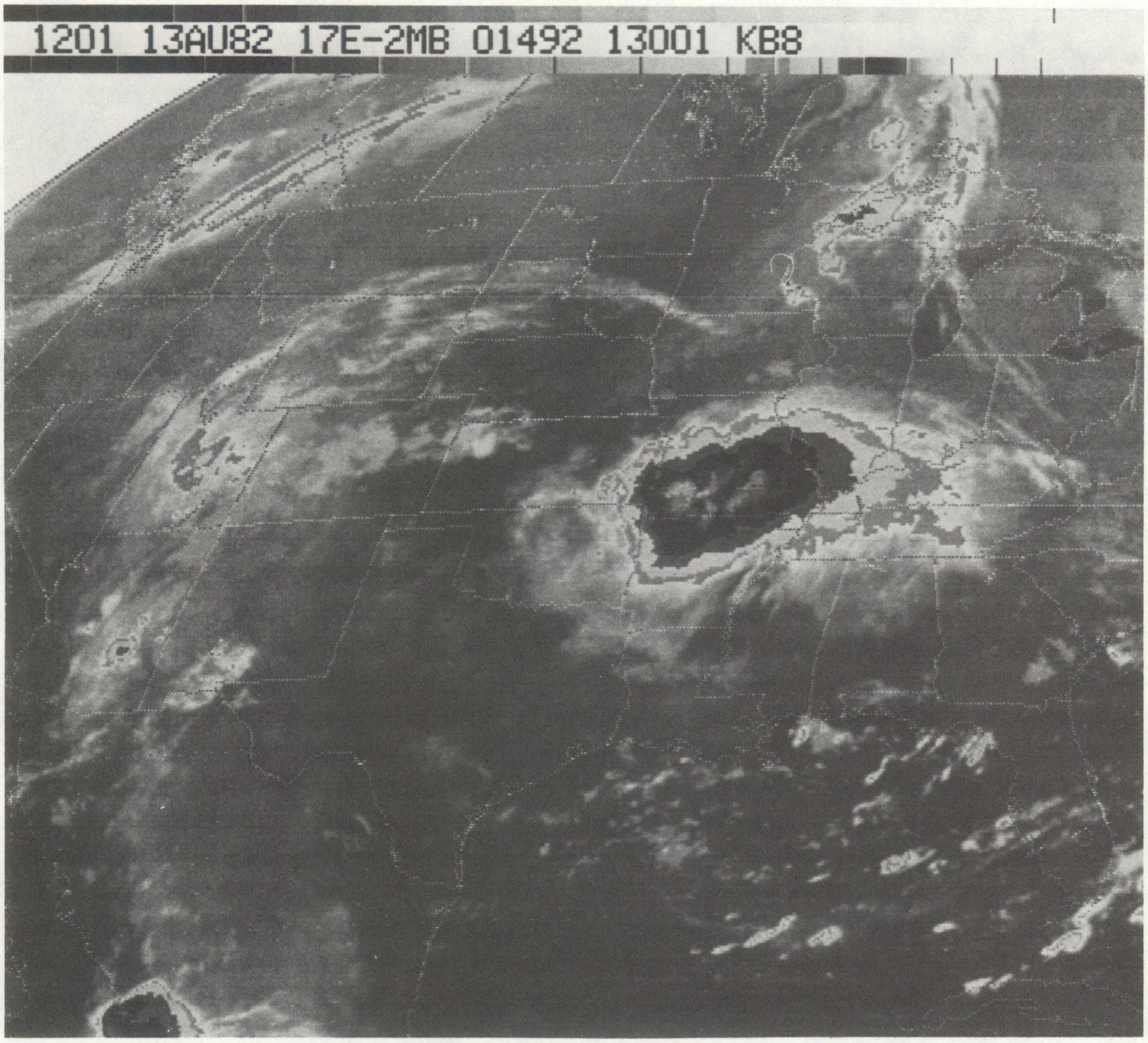


Fig. 57 Enhanced infrared satellite image for 1201 GMT 13 August 1982.

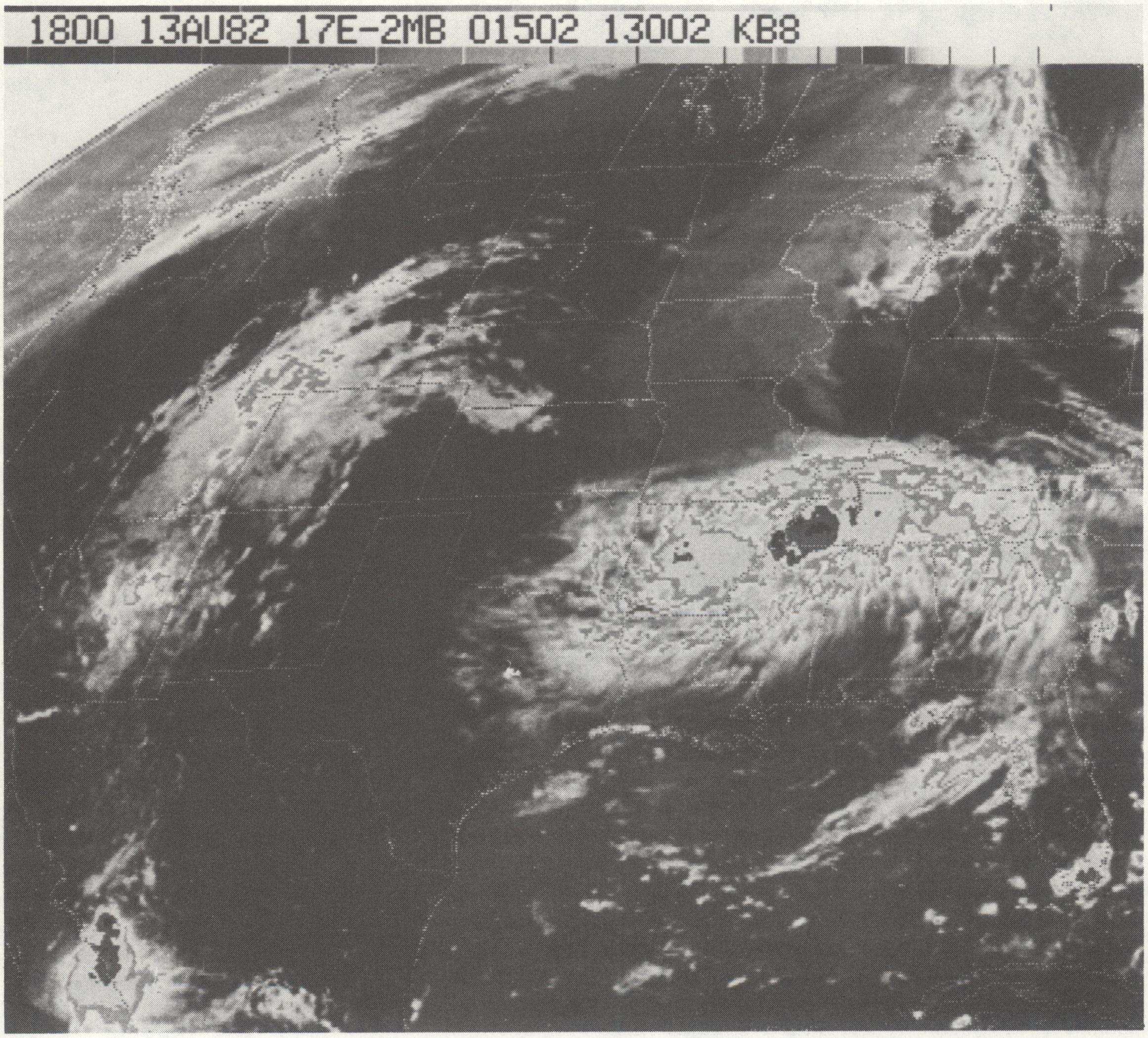


Fig. 58 Enhanced infrared satellite image for 1800 GMT 13 August 1982.

Note Hess p 79 $\Delta\psi$ (geopotential ht) $= -29.29\,\Delta \overline{T_K^*} \ln \frac{P_2}{P_1}$

if $P_2/P_1 = .85$ $\ln P_2/P_1 = -.1625$ then $\Delta\psi_{850-1000} = 4.76\,\Delta\overline{T^*}$

or approx 20 m change for 4 °C change

or " 30 m " " 6 °C "

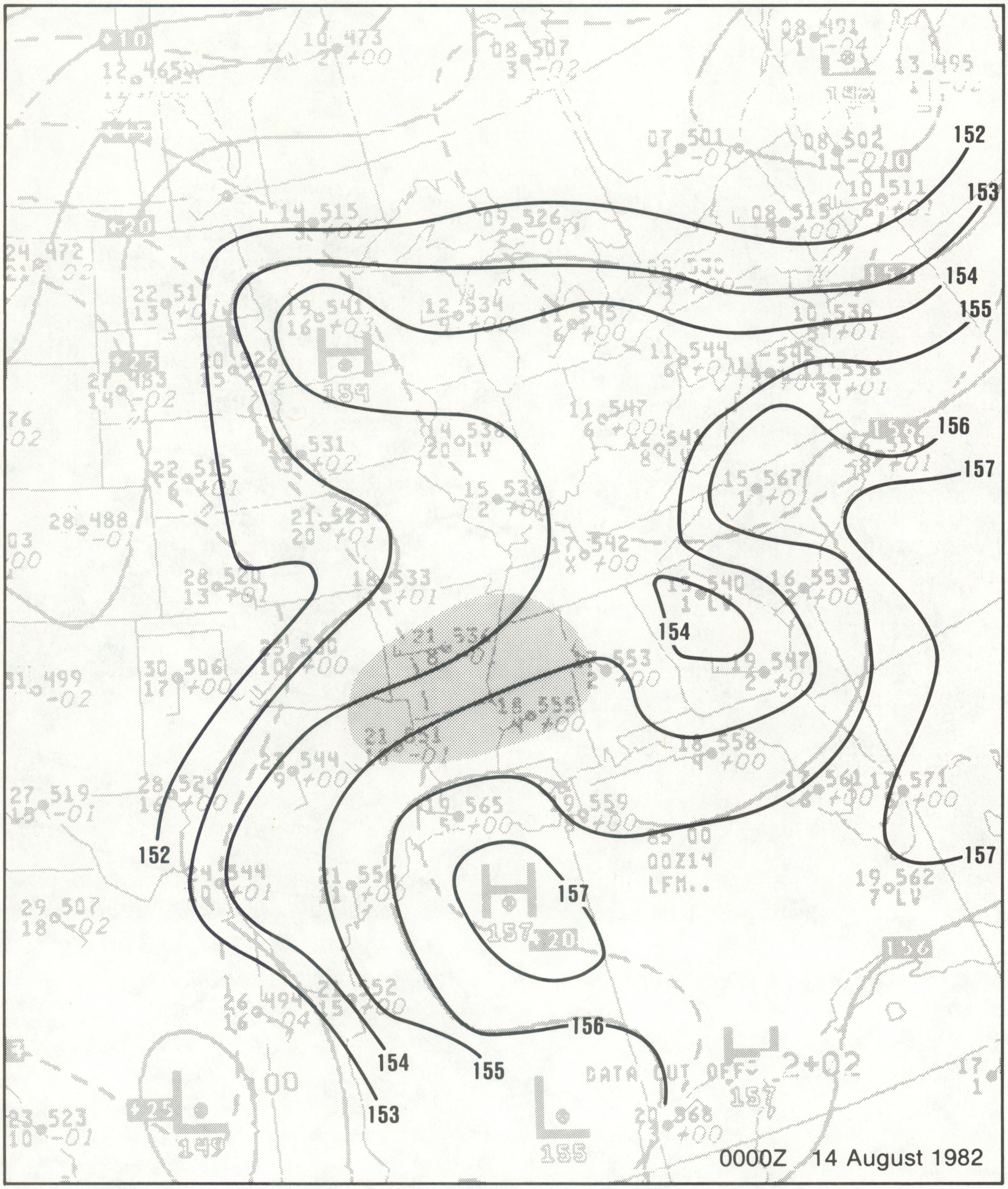


Fig. 59   *Reanalyzed 850 mb height field shown on NMC analysis for 0000 GMT 14 August 1982.*

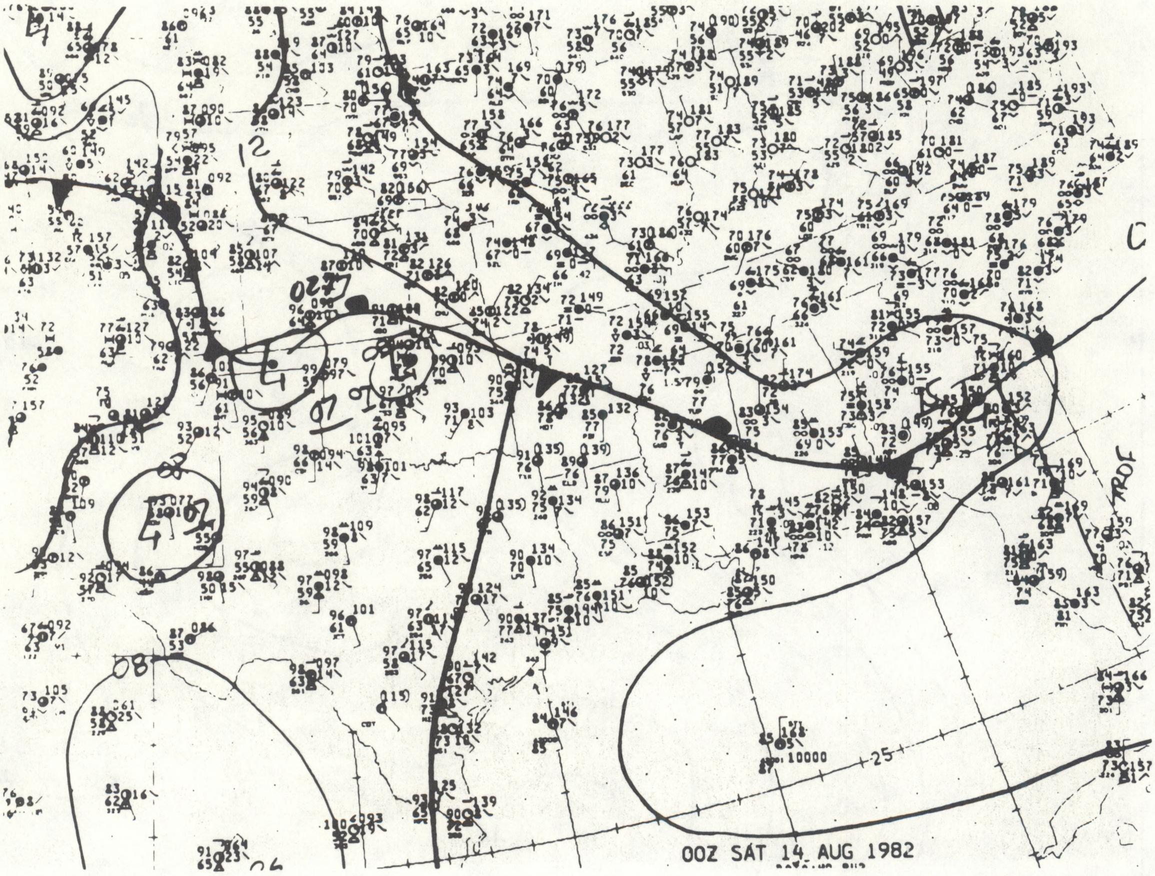


Fig. 60 NMC surface analysis for 0000 GMT 14 August 1982.

5.0 UTILIZING THE STANDARD UPPER-LEVEL CHARTS

Some forecasters undoubtedly consider reanalyzing upper-level charts a redundant and wasteful exercise. However, I believe that reanalyzing the charts is absolutely necessary for several reasons. Since the main use of NMC's analysis of the upper levels is for running the numerical models, the charts could be considered a "by-product" of model initialization. Additionally, the charts are synoptic-scale analyses, and very important details are frequently not depicted on NMC analyses. This is especially true during the warm season, when synoptic-scale features are especially weak over the southern United States.

Ideally, forecasters should use AFOS to plot maps and the analyses should be performed from scratch. However, if time doesn't allow, the NMC maps can be reanalyzed, or at least enhanced using appropriate contour intervals. A professional meteorologist should be able to determine, for any given situation, what contour intervals will depict the degree of detail wanted. If forecasters need help in determining proper intervals (rigid schemes ultimately lead to "going through the motions"), flexible guidelines should be determined locally by station management or an appointed technical advisor. Developing one set of guidelines for an entire country (or region) seems an absurd idea. For example, try to establish guidelines for drawing isodrosotherms that would serve the meteorological needs of both New Orleans and Lubbock. However, there is rarely any reason to analyze with the same contour intervals as those shown on the NMC maps. If you want to see the general synoptic-scale flow pattern, use the NMC products.

The first step in any analysis is to identify bad data. For example, a 500-mb height 30 geopotential meters (gpm) lower than surrounding stations may be an obvious "bad" report in one case and an important "good" report (i.e., when associated with a sub-synoptic short wave) in another. Use basic meteorological concepts; make sure there is a physical feature that supports the observation. Satellite imagery, SIMS, radar, and anything else at your disposal should be used to evaluate dubious observations. Forecasters should always read the relevant SIMS. If you suspect the presence of a feature but cannot verify it (or are not certain), call one of the SFSSs. Their looping capability frequently reveals features that are hinted at in static images.

Upper-level charts should always be analyzed to fit the situation. This is extremely important! There will indeed be times in the winter when 30- to 60-gpm contour intervals at 500 mb will satisfy the meteorologist's needs. However, during the warm season, 10-gpm intervals are frequently necessary (especially in the southern United States). If you have never drawn contours at 10-gpm intervals at 500 mb (or even 5-gpm intervals at 850 mb) you will be amazed at the detail that can be revealed. Figure 61 shows an NMC 850-mb analysis for 1200 GMT 19 June 1982. The same map analyzed at 10-gpm intervals over the area of interest is shown in Fig. 62. In addition to the weak troughs that now show up, a sharp frontal trough over southwest Texas is emphasized by a truer rendition of the 1500-gpm contour than was produced by NMC smoothing. A satellite image for 2300 GMT (Fig. 63) shows intense thunderstorms in the vicinity of this pronounced trough.

In another example, Fig. 64 shows an NMC 850-mb analysis for 1200 GMT 1 July 1982; the same data analyzed at 10-gpm intervals are shown in Fig. 65. The trough that extends from the Atlantic Coast into the Central Plains might be a significant feature if it interacts with moist, unstably-stratified air during the period of afternoon heating. Another simple analysis tool, detailed examination of the stability, that can be very useful for warm-season forecasting (when used with caution) is illustrated in Fig. 66. Notice the strip of relatively unstable air along the trough, with another region of unstable air extending north-south along the lee of the Rocky Mountains. As one can see (in the 2300 GMT satellite image--Fig. 67), scattered convection developed along the trough through Missouri and Arkansas. Although the convection was weak over Alabama and Georgia, much stronger convection developed west of the ridge line, where southerly flow of moist, Gulf air was intersecting the trough. Strong convection also developed in the unstable region from southwest Texas to South Dakota. These cases are not unusual; rather they typify what can be gained through detailed analysis of the situation at hand. Rarely is warm-season convection truly random; it is often concentrated along features that are readily detected with detailed analysis.

As with contours, isotherms should be drawn to fit the situation. If 500-mb temperatures range from -10° to -25°C across Georgia, it is certainly not necessary to draw 2° isotherms. In such cases, 4° or 5°C intervals should suffice. However, during the warm season, 2°C intervals are necessary most of

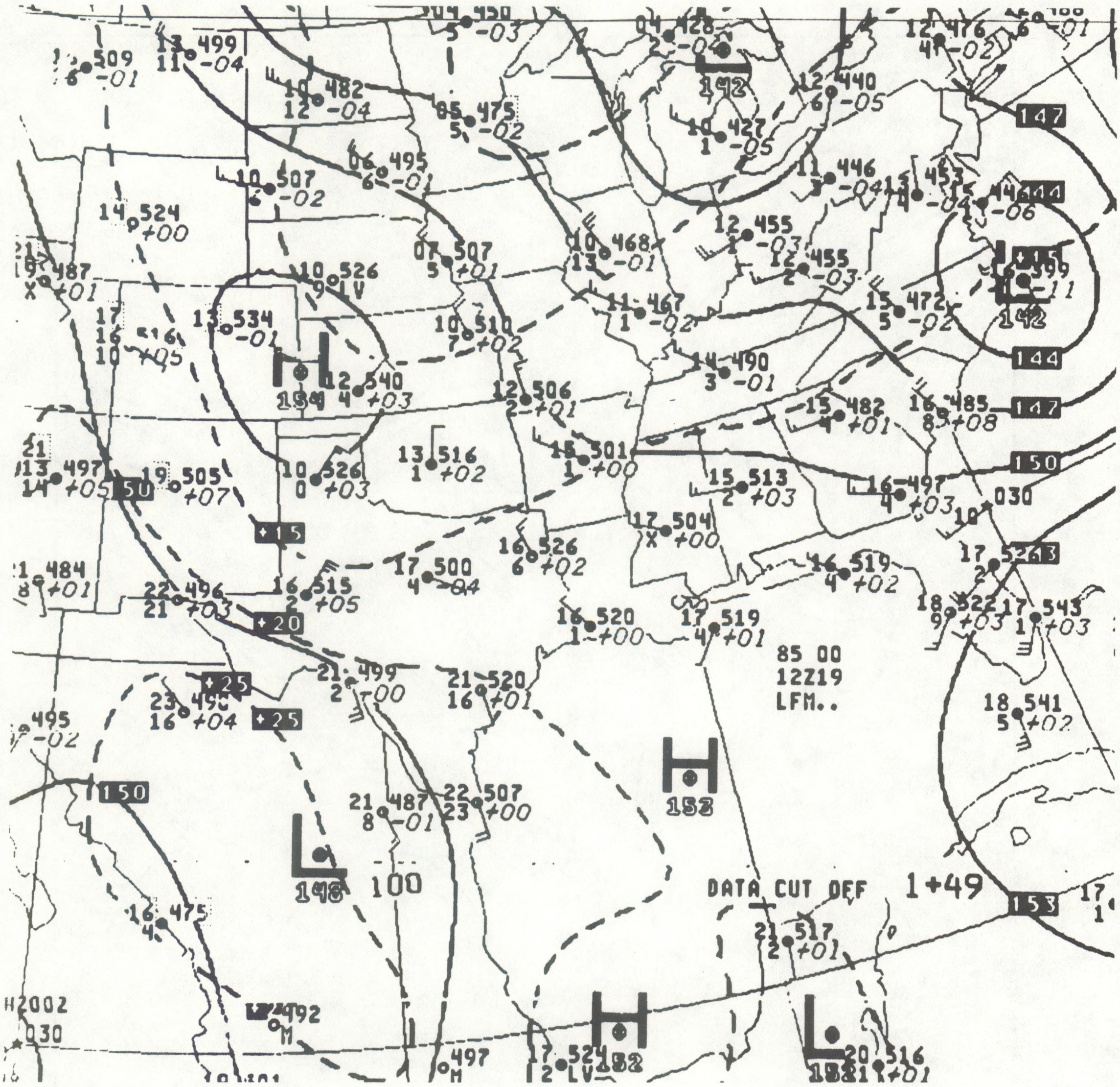


Fig. 61 NMC 850 mb analysis for 1200 GMT 19 June 1982.

see p75

$\Delta\psi$ (geopotential ht in meters) ~ 4.76 $\Delta T^*_{850-1000\ mb}$

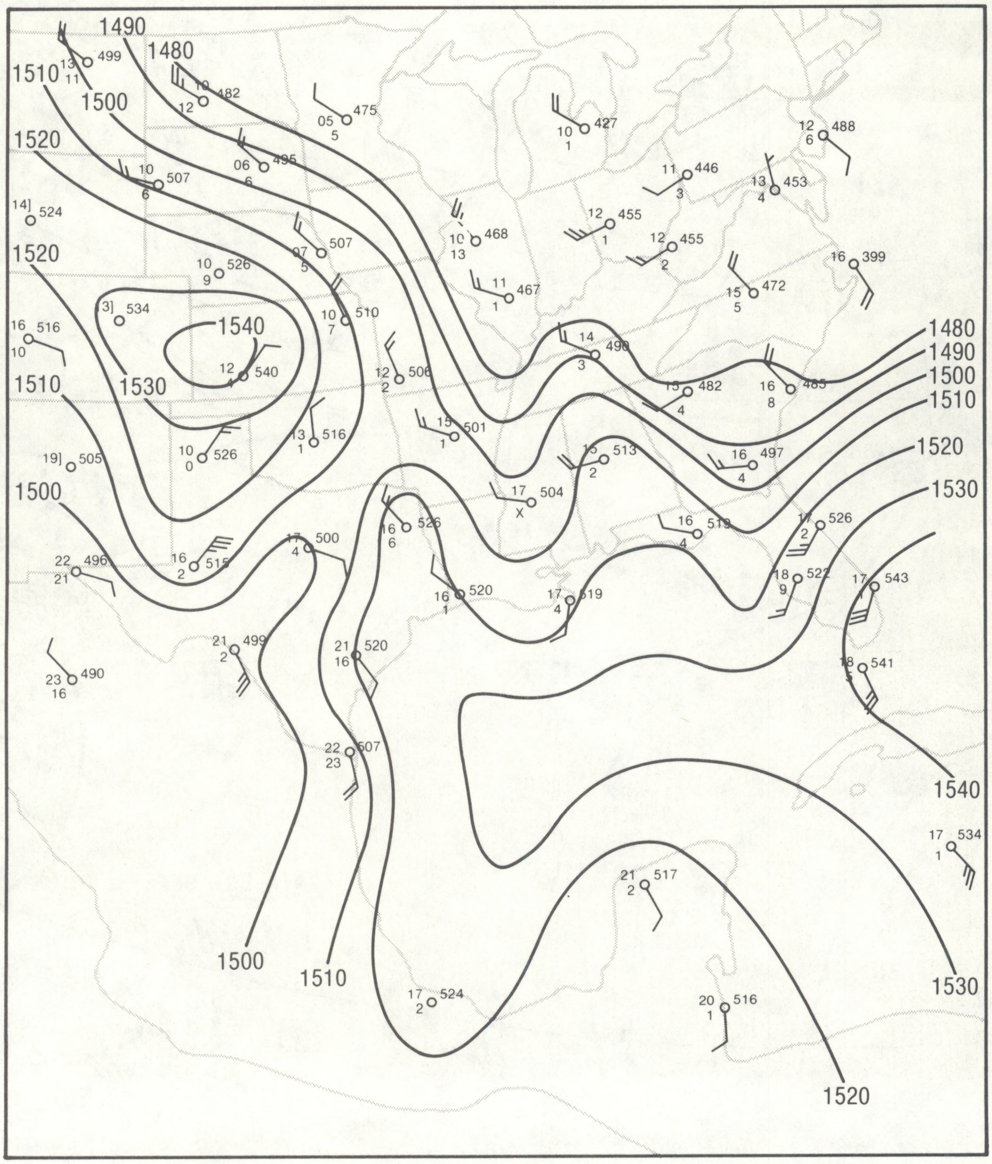


Fig. 62 *Heights at 850 mb for 1200 GMT 19 June 1982, reanalyzed at 10 gpm intervals.*

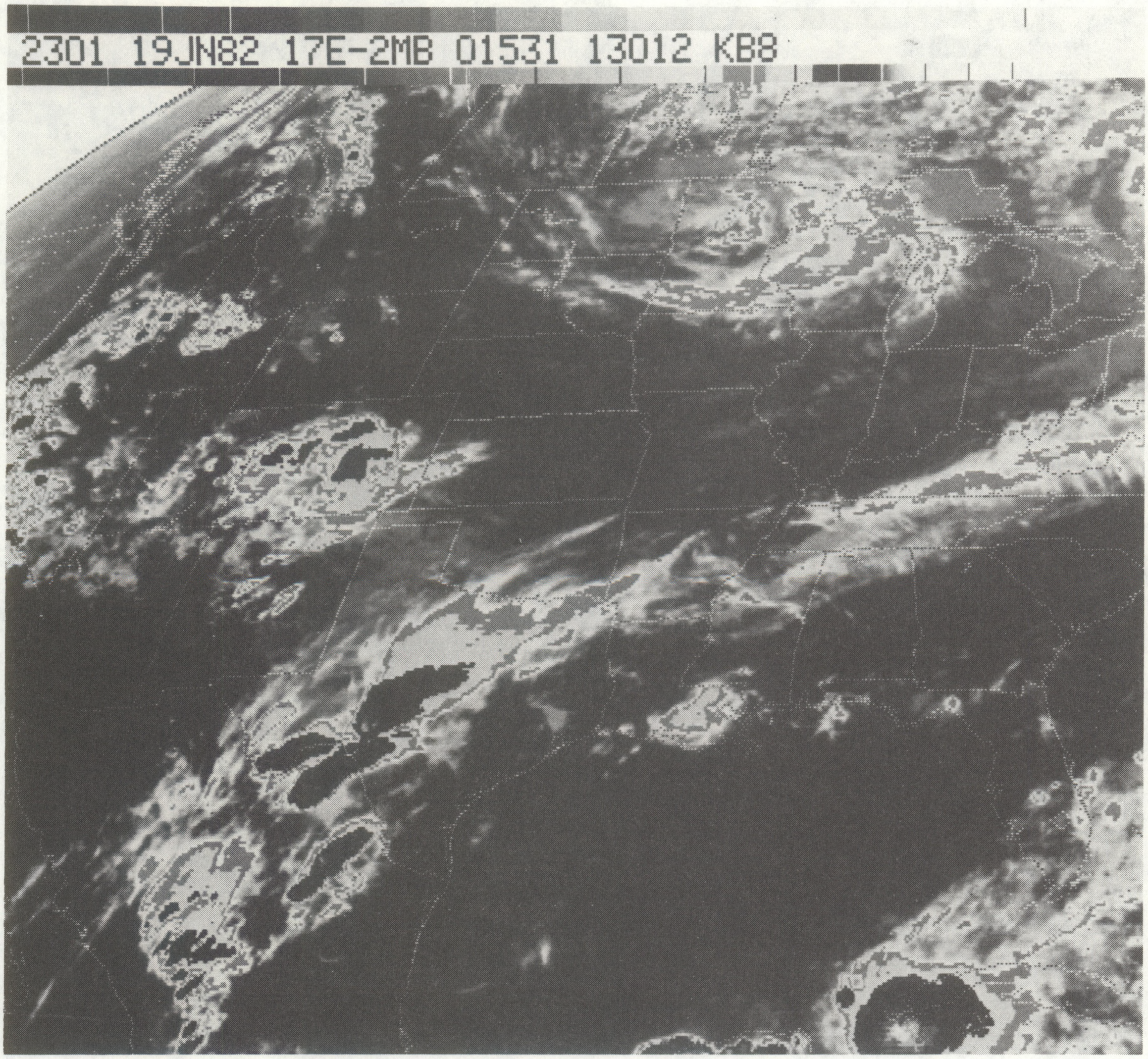


Fig. 63 Enhanced infrared satellite image for 2301 GMT 19 June 1982.

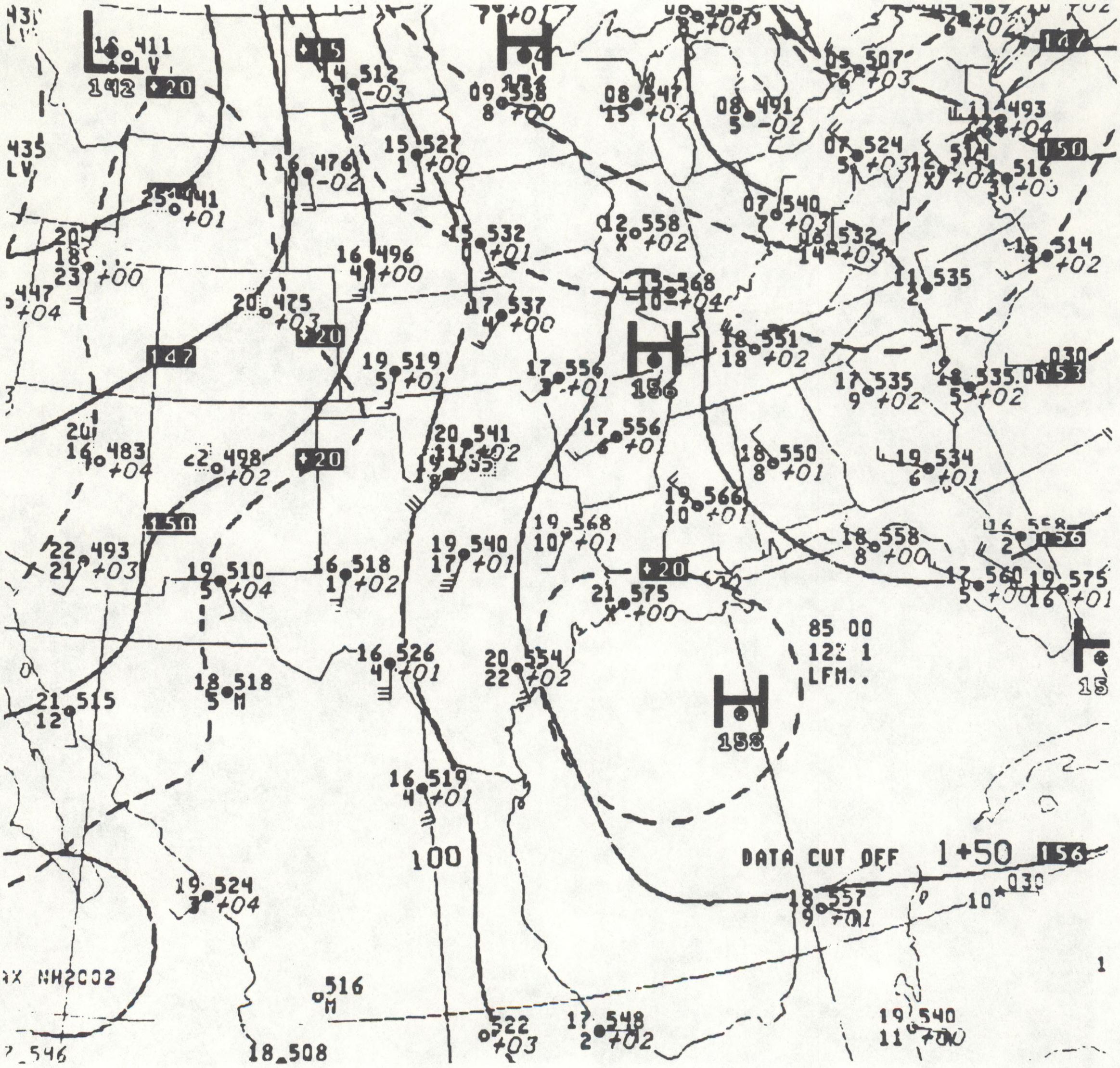


Fig. 64 NMC 850 mb analysis for 1200 GMT 1 July 1982.

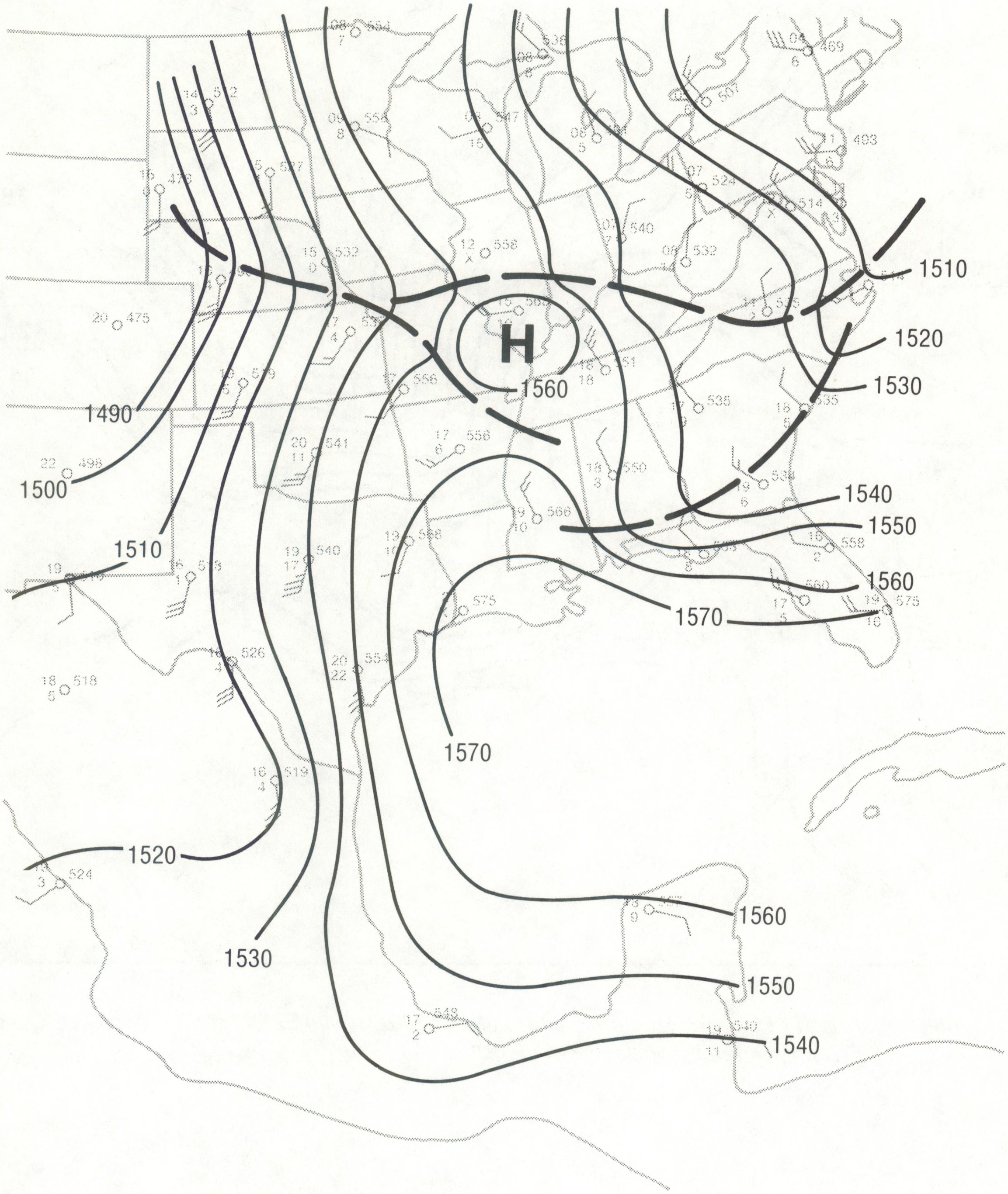


Fig. 65 Heights at 850 mb for 1200 GMT 1 July 1982, reanalyzed at 10-gpm intervals. Trough position in Southeast in shown by heavy dashed lines.

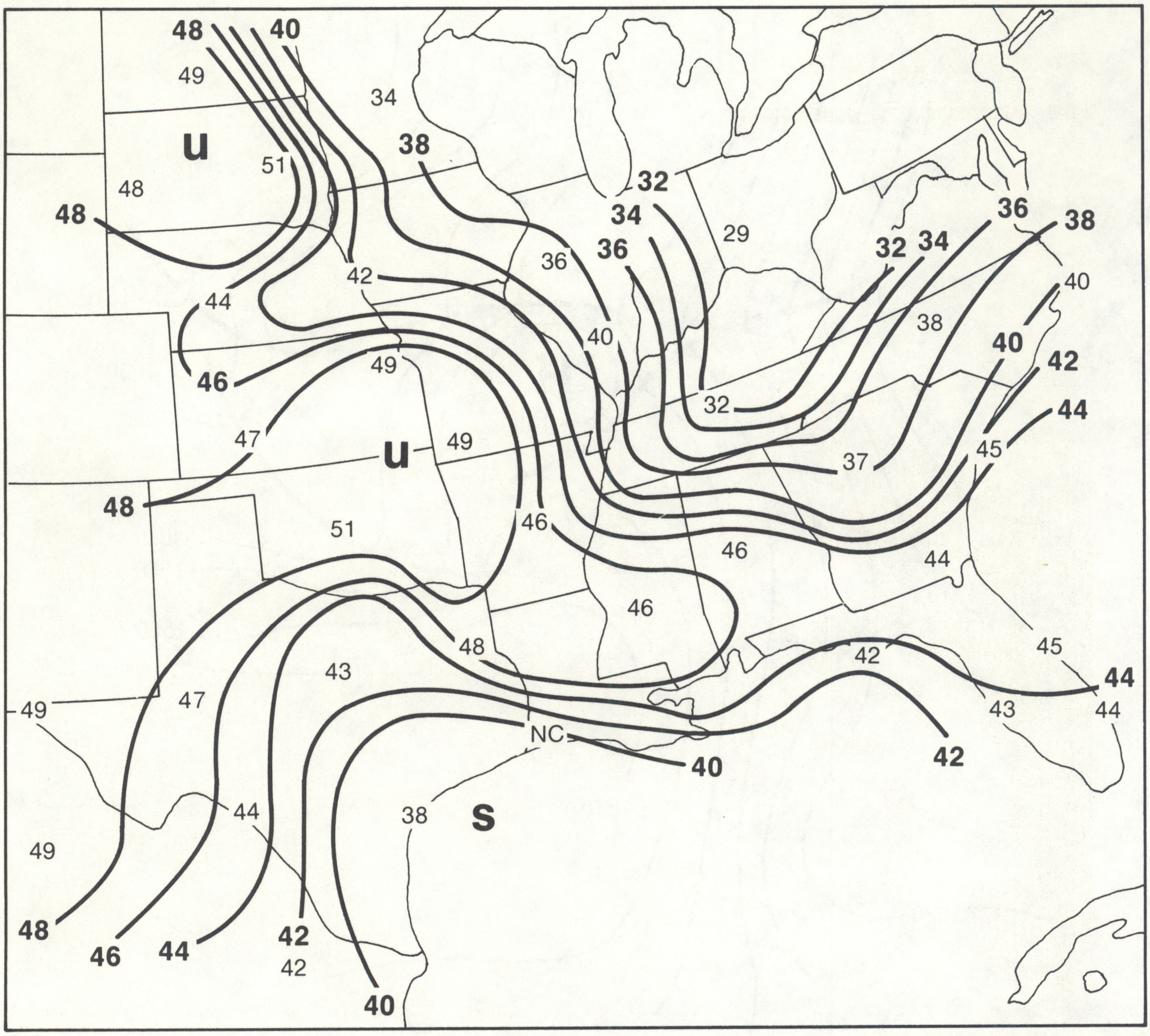


Fig. 66 *Stability chart for 1200 GMT 1 July 1982. Total Totals index is in contoured intervals of 2°C.*

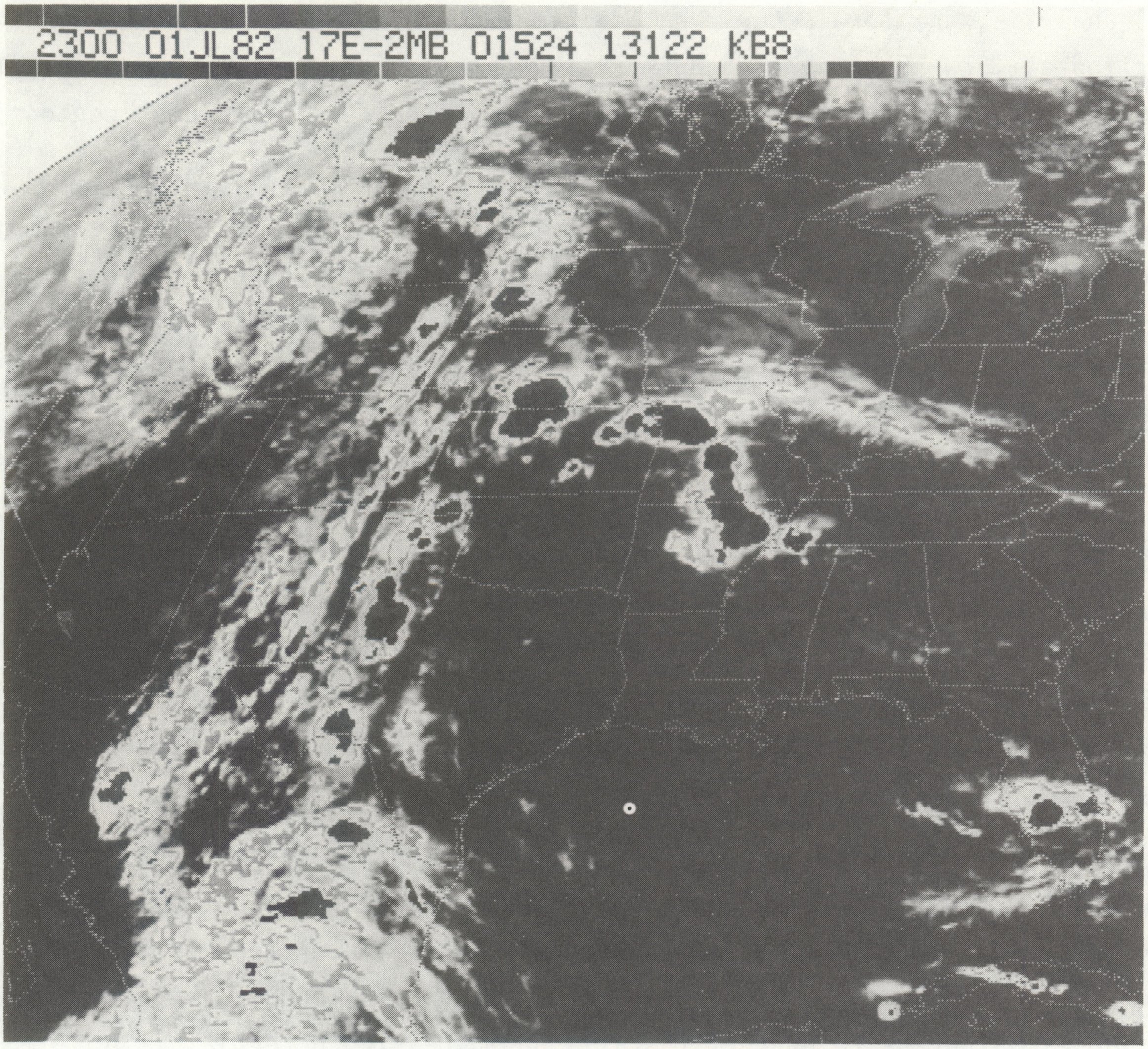


Fig. 67 Enhanced infrared satellite image for 2300 GMT 1 July 1982.

the time, and even 1°C intervals may be required to resolve very weak (but potentially important) features. A slight increase in instability during the summer may be all that is needed to allow convection to become severe. During the analysis, the forecaster should be concentrating not only on the quasi-horizontal flow shown by the contours, but also on the vertical motion implied by characteristics of the flow (e.g., jets, difluent and confluent regions).

Radar data can also be a great aid during the upper-air analysis routine. The existence of weak troughs can frequently be verified by simply monitoring radar echo movement for clues to the mid-tropospheric flow. The radar observations (for the approximate time of the mandatory-level maps) can sometimes reveal differing precipitation movements, thereby helping the analyst locate troughs. Trends in the velocity of cells and precipitation areas can indicate how the flow pattern is changing. Another tool that must be utilized for analyzing the upper-level charts is continuity. Part of the analysis routine should always include the review of previous analyses to study the progression and trends of features. Map-to-map differences in contour intervals might seem to make this difficult. However, one should remember that contouring is done to reveal features in the pattern. Once identified, continuity of the features is the goal of subseguent analyses.

Zones, ribbons, and tongues of cold and warm advection should be analyzed in detail and monitored. During the analysis, the forecaster should be especially aware of the influence these features will have on the vertical motion field. This is especially important in the lower and middle troposphere. Detecting and monitoring warm and cold tongues can also provide valuable insight as to whether there is an increasing potential (i.e., decreasing stability due to differential temperature advection) for heavy rainfall or severe thunderstorms. If time is a restricting factor, I recommend starting in the lower troposphere and working up. If possible, the 850-, 700-, and 500-mb charts should be reanalyzed in detail, since they provide the most insight into stability fields.

Upper-air analyses have typically included shading of station circles where dew point depressions are 5°C or lower. One problem with this approach is that it doesn't explicitly depict absolute moisture content or advective patterns very well. At least one or two isodrosotherms should be drawn, at a value or interval appropriate for the level of analysis. If the pattern of moist or dry advection (or those infamous moist or dry tongues) starts to become apparent, more detail is certainly called for. Figure 68 shows the NMC 850-mb analysis for 1200 GMT 5 July 1982; Fig. 69 shows the same data analyzed with isodrosotherms at 2°C intervals where dew point temperatures are at least 14°C. Several pockets and tongues of high moisture content are readily apparent. Satellite imagery for 2131 GMT is shown in Fig. 70. A solid line of convection developed in the moist air along the trough from the Mississippi River to Georgia, while extensive convection also developed over Florida ahead of a north-south oriented trough. (The sea breeze probably interacted with these troughs, playing a role in the evolution of convection.) Notice the western boundary of the convection, where drier air and subsidence seem to prevail over Texas, Louisiana, Arkansas, and Missouri (the thundershowers over southeast Texas are probably the result of land/lake and sea breezes). Convection over Tennessee and Kentucky is probably the result of solar heating, occurring in conjunction with advection of the low-level moisture that was centered over southern Illinois early in the day. Widespread convection also developed northward from west Texas in the moist unstable air.

In spite of the shortcomings of our upper-air data collection system, jet streams can usually be detected on the upper-level maps, if use is made of satellite imagery and the SIMS. Unfortunately, simply knowing where the jet streams are located doesn't necessarily mean that one will be able to forecast a significant weather event. More important than the locations of jet stream axes, are subtle variations in jet stream structure (i.e., jet streaks). A jet streak that just happens to be in the right place at raob time will be detected. But more often than not, detailed analysis of the satellite imagery (EIR) is required to help locate jet streaks. SIMS messages usually mention identifiable streaks. If a forecaster even suspects the existence of a jet streak, he should call the appropriate SFSS for corroboration.

Locating jet streams in the lower troposphere is not as easy. However, there are many clues that help reveal their existence. For example, rapid changes in moisture and/or temperature at the 850- or 700-mb level should be considered in detail. The forecaster must identify the cause of these changes. For example, consider a case in which low-level moisture exists from 960 mb to 860 mb over an area from Louisiana to Missouri, with dry air above. The 850 mb chart will not reveal the presence of the moisture.

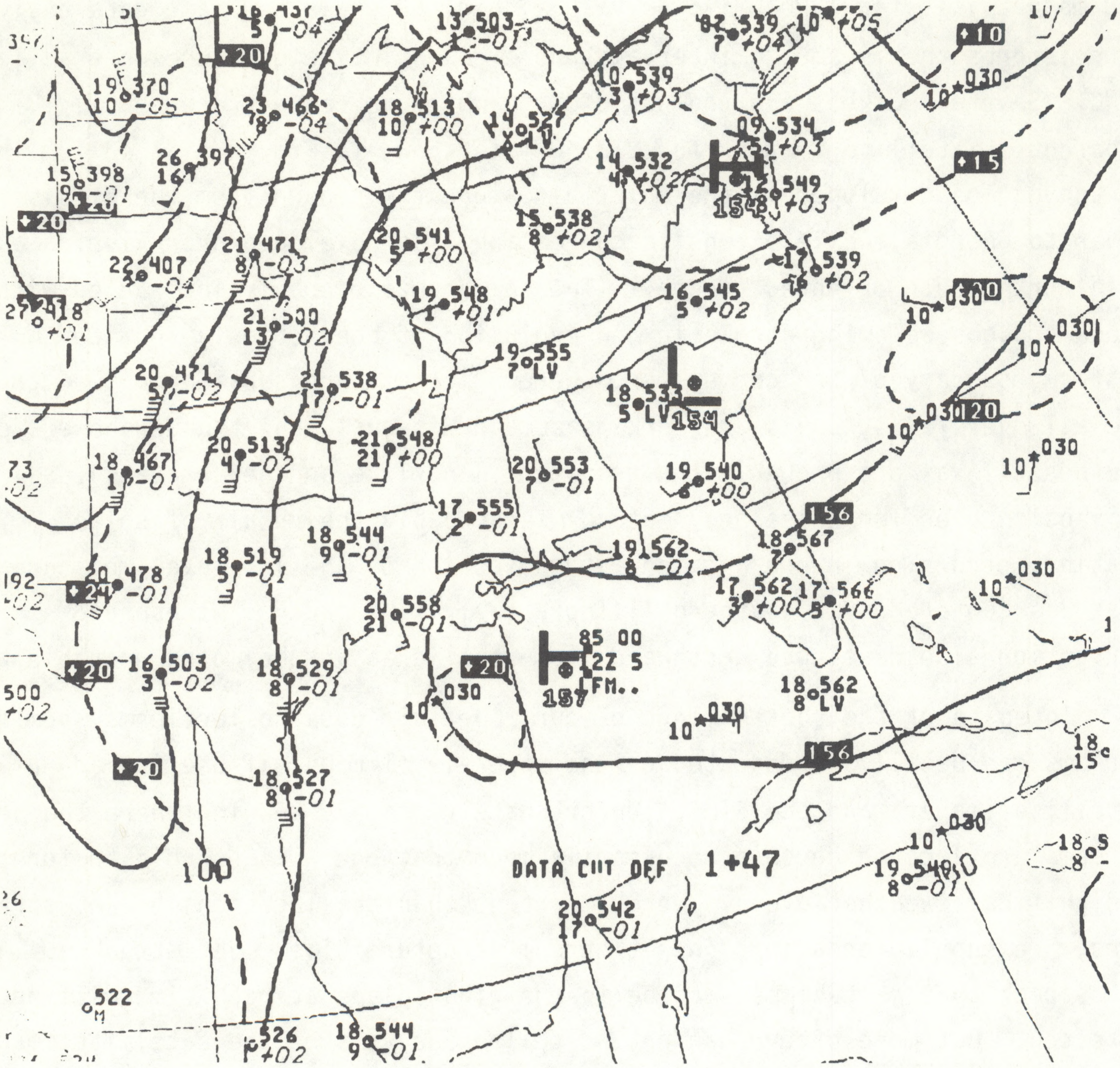


Fig. 68   NMC 850 mb analysis for 1200 GMT 5 July 1982.

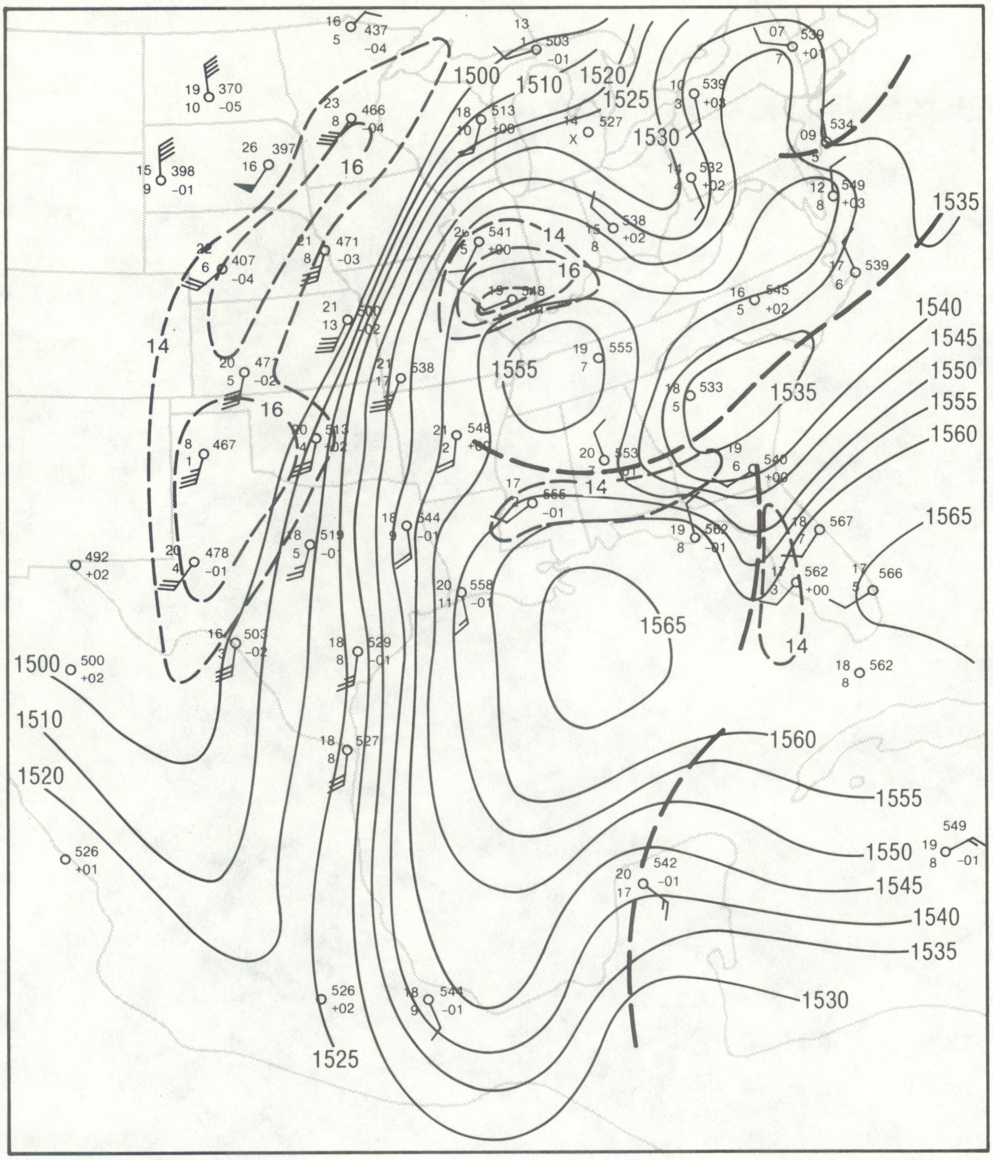


Fig. 69 *Height at 850 mb for 1200 GMT 5 July 1982, reanalyzed at 10 gpm heights (solid lines) and 2°C isodrosotherms (dashed lines) where dew point temperatures are 14°C. Trough positions are shown by heavy dashed lines.*

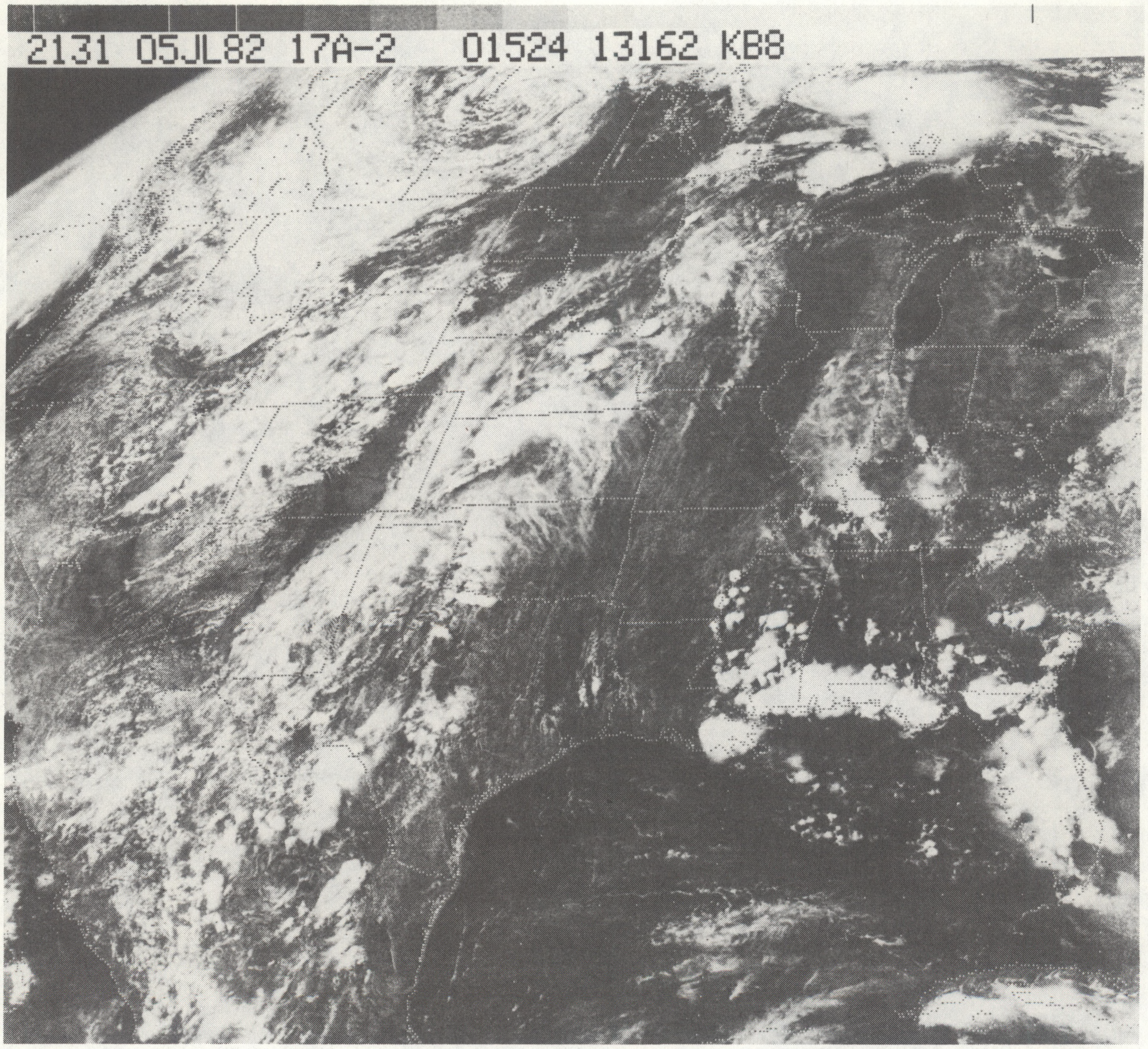


Fig. 70 Visible 2 km resolution satellite image for 2131 GMT 5 July 1982.

However, suppose the next 850 mb chart (12 hours later) shows only slight dew point depressions over the region. The forecaster must decide whether this drastic change was due to vertical motion or to advection by strong low-level winds. Warm, cold, moist and dry tongues are usually the result of strong deformation associated with jet streams.

Low-level jets may also be located with satellite imagery (read the SIMS) if higher-level cloudiness does not obscure them. In fact, satellite imagery is frequently the best tool for detecting developing low-level jet streams over Texas and Oklahoma. When the low-level jet develops on the western edge of an eastward-moving anticyclone, the increasing moisture gradient will indirectly reveal the jet in both the visible and EIR imagery. The first indication of the low-level jet may be the appearance of "black stratus" on the EIR between 0000 GMT and 1200 GMT. During the daytime, changes in the low-level jet can be monitored by following the evolution of stratus, strato-cumulus, or cumulus fields in the visible imagery. Additionally, the dry, middle-level jet stream that acts to increase convective instability often escapes detection in synoptic-scale upper-air data. However, blowing dust on visible (sometimes EIR) satellite images or a "dry" intrusion on EIR can be used to infer the location of this jet at the 850- and 700-mb levels.

Jet streams don't have to be unusually strong dynamic features to help produce significant convection. Besides trying to locate any jet streams during the analysis routine, forecasters should note subtle changes in the flow, in the lower as well as the upper troposphere. The forecaster should integrate regions of speed and directional confluence and difluence at the different levels into a mental picture of atmospheric structure, keeping in mind the vertical motion field implied by differing combinations. This part of the analysis routine really represents a visualization of the law of mass continuity.

Analysis of chart-to-chart height changes in combination with movement of jet streams can provide good clues to the forecaster to how atmospheric structure is currently changing, leading to an impression of how it will behave in the future. Naturally, when evaluating height changes, the forecaster must try to understand why the changes took place. First of all, the forecaster must make adjustments for normal diurnal variations (e.g., approximately 20-gpm 500-mb changes between raob runs). Twenty-four-hour height change analyses do tend to eliminate diurnal contributions. Not only should the analyst be aware of "convective contamination" by a single thunderstorm, but also of changes (especially in the upper half of the troposphere) that can take place as a result of widespread convection. For example, the effects of weak large-scale cold advection at 500 mb may be overwhelmed by meso-alpha-scale latent heat release from a large convective complex. Thus, where the analyst was expecting temperatures to decrease from chart to chart, they may have increased instead. Other upper-tropospheric changes should be anticipated downstream from where convection has been widespread,--changes such as increased anticyclonic curvature, development of speed maxima, and cooling of temperatures between 200 and 100mb (where the troposphere has been raised). Although the magnitude of absolute changes may be important, relative changes are usually more significant. When the upper-level charts have been analyzed to their fullest extent by use of every bit of information available, the forecaster should have a clear visualization of atmospheric structure.[1]

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[1] One additional tool in detecting upper-level features is certainly the surface map. The surface map should not be viewed as a collection of data that are independent of the upper-level maps, but instead as an integral part of the analysis. Since surface features are often a reflection of ongoing processes above, a detailed surface analysis can greatly aid the detection and enhancement of the upper-level features. Since the surface network is so much more dense than the upper-air network, and the observations are hourly (at least), not only can the surface analysis help "fill in the gaps" of the upper-level maps, but continuity of surface features can provide important clues to changes above, occurring between 12-hour upper-air collections.

6.0 THE ANALYSIS OF SURFACE DATA

Ideally, it would be best for forecasters to plot their own surface maps. The act of direct involvement with the data increases awareness of the situation. Even more importantly, reading the observations brings the analyst in touch with remarks--still one of our own best tools for identifying and tracking sub-synoptic features. Automation has unfortunately made observational remarks less and less accessible to forecasters, which only serves to hurt the forecast effort. However, on the plus side, AFOS has made the job of plotting surface data much easier when time is at a premium. Each forecast office can run one (or more) regional plot routines in just a few minutes. The meteorologist should always subjectively analyze these plots instead of using the smooth AFOS pressure analysis. A wealth of applications programs for AFOS, many of which plot and analyze surface data, are in varying stages of development. For example, an AFOS-produced surface convergence analysis could prove useful in making 3- to 6-hour forecasts of convection. This might be especially true during the warm season when only weak convergence in conjunction with solar heating of moist, unstable air is required to initiate impressive convection.

As with the upper-level maps, analyzing at predetermined, fixed intervals can be a worthless endeavor. However, there are a few rules that should be followed. First of all, the analysis should be sub-synoptic, and second, altimeter settings should be used for the pressure field. There is rarely a reason to perform synoptic-scale analysis on a regional surface plot. Again, if you want to see the generalized surface pattern over the region (or the entire country), use the NMC analysis.

6.1 Pressure Field

Anyone who has tried to analyze a surface map (especially at night) knows that station closings of the past few years have made the job of identifying and tracking sub-synoptic (sometimes even synoptic) features a most difficult task. This is the primary reason altimeter settings should be used for analysis of the pressure field. Use of altimeter settings instead of sea level pressure increases the data field by approximately one-third. In addition, since altimeter settings are part of special observations, they provide an essential help for detecting and tracking mesoscale pressure perturbations. Using altimeter settings is especially suited to the southern United States, where terrain-induced biases are minimal.

An essential part of analysis is to be objective and draw for the data. First of all, realize that a model is a model--is a model! The Norwegian cyclone model represents a simplistic composite of storms over the North Atlantic. When you took synoptic laboratory, you probably analyzed such a system that was carefully picked out by your instructor. Sometimes, these nearly perfect storms actually occur (after all, your lab instructor found a case), but usually you'll be dealing with cyclones that bear only a superficial resemblance to the simplified model.

Be objective and draw for the data, even if it would get you in trouble in most universities' synoptic laboratories. Just be certain your analysis makes physical sense! If you've maintained continuity and visualized mesoscale atmospheric structure, then you're going to have a good idea of what the next analysis should look like. Being on top of the situation allows the forecaster to perform the analysis quickly and efficiently. Since small differences in the pressure field may reveal sub-synoptic features, it is extremely important that forecasters know which stations have persistent biases in their observations. Station elevations and surrounding terrain can produce variations in pressure and wind that are nonrepresentative of the situation. (For example, AVL and CSV observations will seldom fit surface analyses: Asheville is subject to cold air drainage, and Crossville sits high on the Cumberland Plateau.) Such characteristics should be taken into account during the analysis.

Forecasters should also know that not every station is going to have properly calibarated equipment all the time. Identifying bad data is mostly a matter of practice. When you have analyzed a certain region of the country over and over again, you will know to add .02 inches Hg to station XXX and subtract .03 inches Hg from station YYY. (I hope you'll teach this to your new troops and inform the stations of their problems!) Some meteorologists may feel uneasy about such a keen awareness, but those who routinely analyze surface plots know that this is not only possible, but essential in differentiating truth from noise or error.

Each forecaster should be able to compile a mental fudge sheet after awhile. Better yet, forecasters should independently develop their own fudge sheet for a month or two, and then compare notes to develop a fudge sheets for the station. However, the sheet should be updated frequently. (After nearly 6 months of adding my fudge factor to a WSFO's observations, all of a sudden I started analyzing a meso-high over the station. This prompted me to call the station in question, and I found that its barometer had recently been calibrated.)

In addition to systematic problems that are easy to deal with (through practical familiarity) forecasters have to deal with other errors. It is a rare AFOS surface plot on which there are no observations missing or adulterated. AFOS plot routines must delete an observation with a missing character, incorrect time, etc. Observers should realize that not transmitting computer-compatible observations has important consequences. Hourly soundings and other programs are also affected when observations are not coded correctly. Most of the time, the forecaster can call the missing observations out of AFOS and hand plot them. However, sometimes this can take almost as much time as the analysis of the pressure field itself.

Figure 71 shows the NMC surface analysis for 1800 GMT 15 June 1983. The pressure gradient, typical for the warm season, shows no isobars from Cape Hatteras to Little Rock. A forecaster's real-time analysis of 1800 GMT data, using altimeter settings (plotting courtesy of AFOS), is shown in Fig. 72. The three-hundredths (inches of mercury) contour interval reveals several troughs of low pressure. The most pronounced extends east-west across northern Louisiana and central Mississippi, and a weak low pressure center is located along the Louisiana-Mississippi border.

Convection had already developed by 1800 GMT; the satellite image for 2100 GMT (Fig. 73) illustrates the activity a few hours later. Several clusters of thunderstorms were in progress along the trough, and coldest tops were over western Mississippi in the vicinity of the weak low-pressure center. Apparently, the most significant feature on the surface map was revealed only by the forecaster's mesoanalysis!

At times the AFOS plots are not available, and simply enhancing the NMC analyses can provide the detail the forecaster needs to visualize atmospheric structure. Figure 74 shows the NMC analysis for 1800 GMT 25 May 1980. This Memorial Day weekend was forecast to be sunny and hot across the southeastern section of the country. However, the surface pattern was not as bland as the

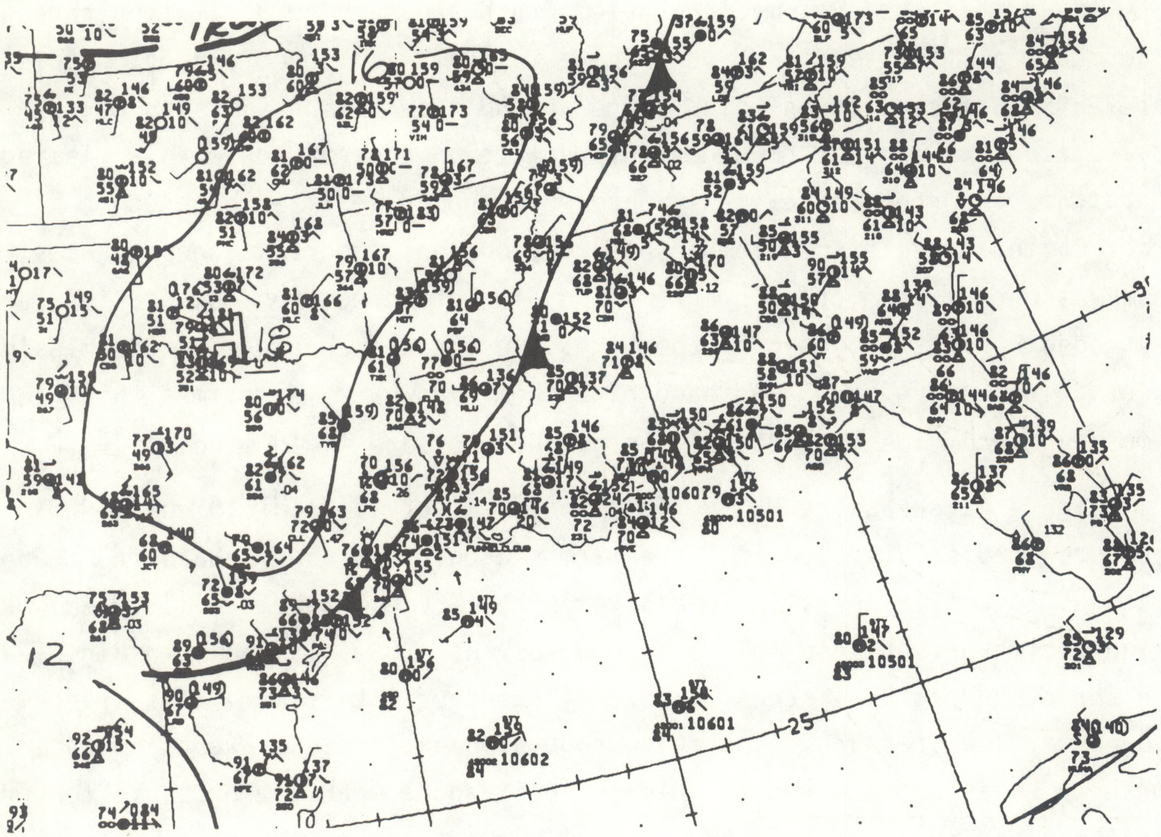

Fig. 71 NMC surface analysis for 1800 GMT 15 June 1983.

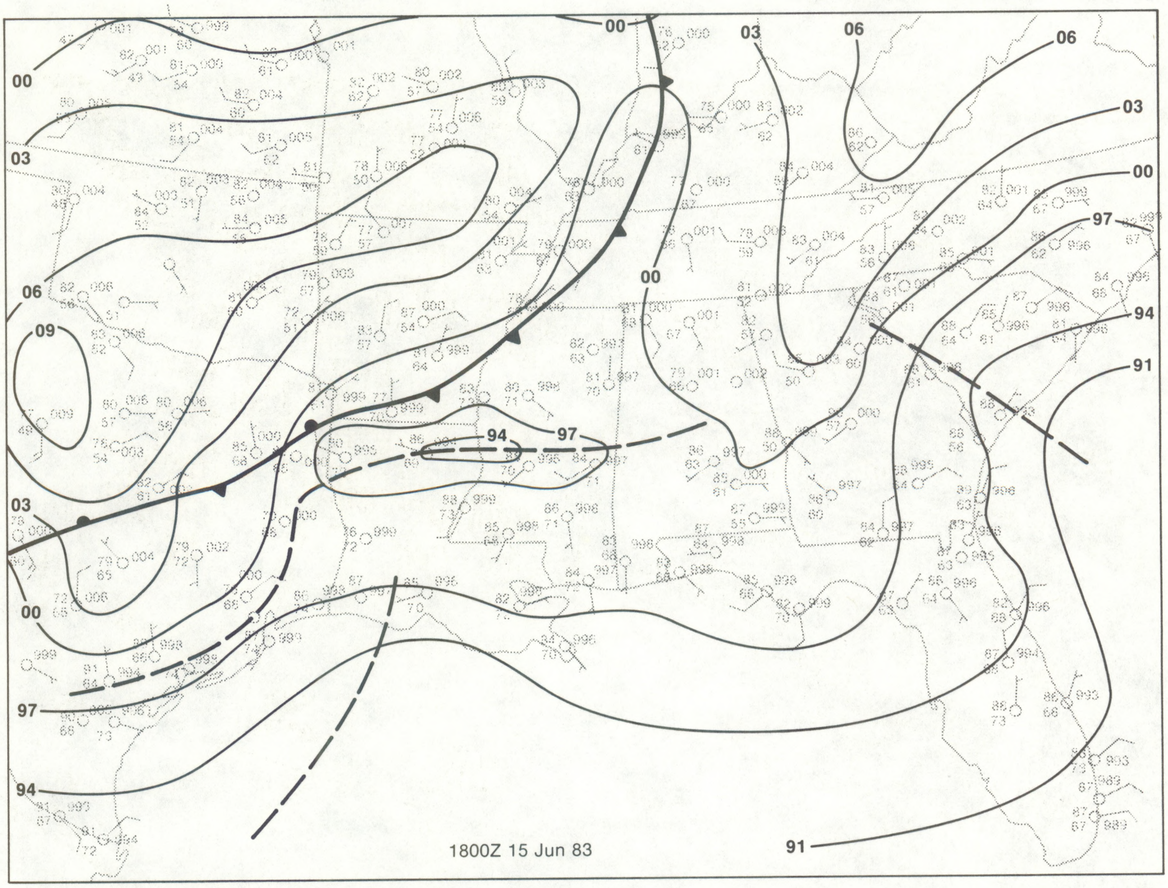

Fig. 72 *Surface chart for 1800 GMT 15 June 1983, reanalyzed using altimeter settings at three-hundredths inchof mercury (1 mb) intervals. Frontal and trough positions are shown.*

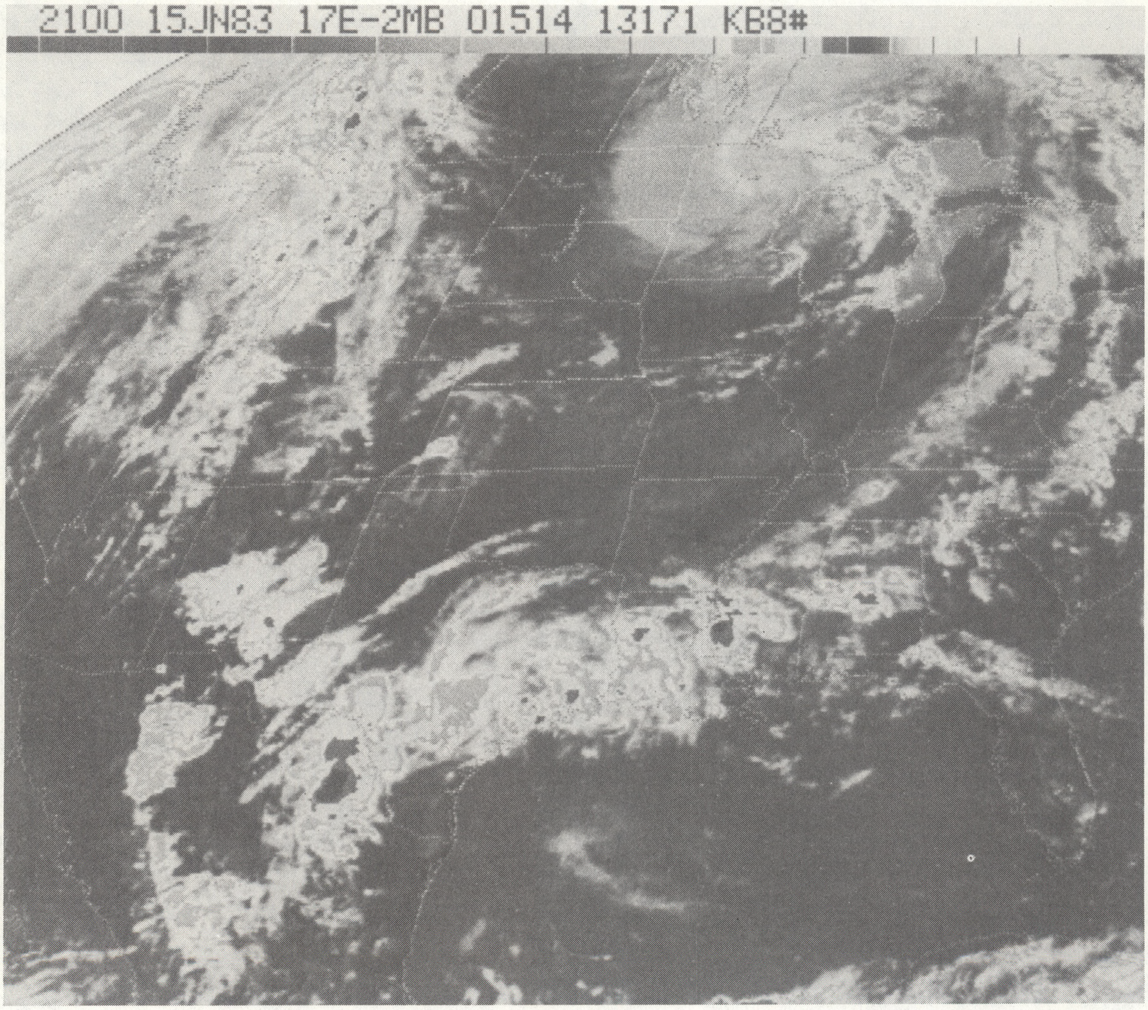

Fig. 73 Enhanced infrared satellite image for 2100 GMT 15 June 1983.

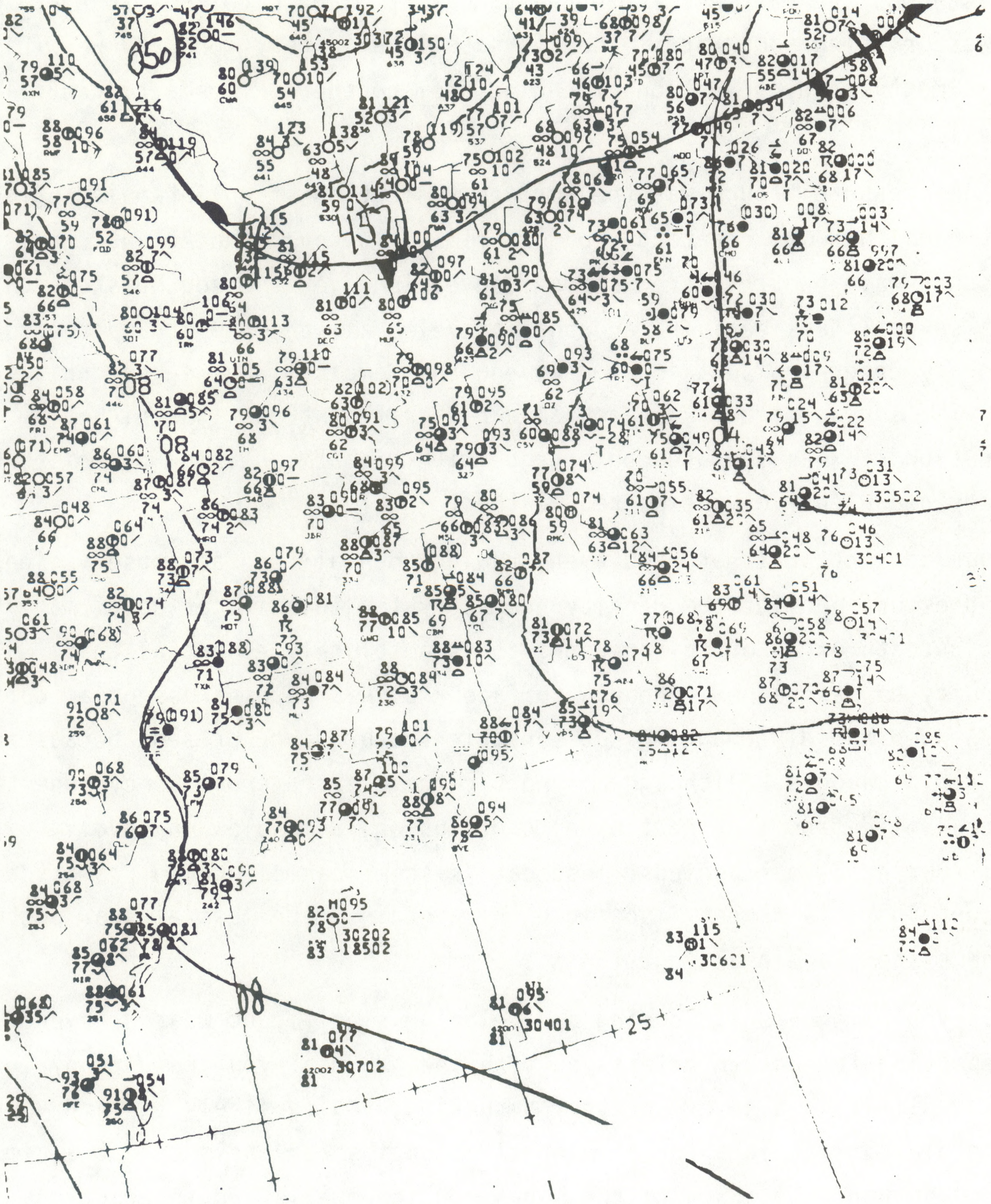

Fig. 74 NMC surface analysis for 1800 GMT 25 May 1980.

NMC analyses would lead one to believe. An enhanced analysis of the same data is shown in Fig. 75. The main culprit in putting a damper on the day (and the forecast) was the east/west-oriented trough from the Carolinas to Arkansas that was drifting southward. The EIR satellite imagery for 2230 GMT (Fig. 76) shows almost solid convection extending from northern Florida to central Arkansas.

The pressure trough was the surface reflection of an intensifying short-wave trough that was rotating around a closed low over the Atlantic Coast. This short wave had triggered strong convection over the southeastern United States several days earlier, and then traveled all the way around the quasi-stationary upper-low just in time to end the Memorial Day weekend on a wet note. The surface trough may not appear significant, but the right combination of weak surface convergence with diabatic heating of moist, Gulf air provided plenty of unexpected weather.

Our conventional network, even drawing upon all surface observations, still does not provide the density necessary for identification of many sub-synoptic features. For this reason, it is absolutely essential that continuity be maintained. Hourly surface analysis becomes essential during periods when rapidly changing sub-synoptic features are present because of their rapid changes. Although a synoptic-scale extra-tropical cyclone takes days to evolve from a nascent wave to occlusion, a mesolow may evolve within hours. During 3-hour periods, mesoscale systems can change so dramatically that continuity is almost impossible to maintain, much less a clear picture of how the systems are changing.

If you come on shift during a developing significant weather event and the departing forecaster briefs you with the NMC map, you are already in trouble. If it is a severe weather situation, you're likely to find yourself issuing blanket warnings for five or six counties (or parishes) at a time because you won't be aware of the sub-synoptic details and interactions that are taking place. Indeed, it is a rare event when all the thunderstorms in a line or cluster are severe at the same time. A thunderstorm's becoming severe is certainly not a matter of coincidence; there is always a reason. Although there are certainly times when we are unable to determine the reason, a forecaster following the situation (by means of mesoanalysis), and working with a competent radar operator, may be able to make that all-important decision at the right time.

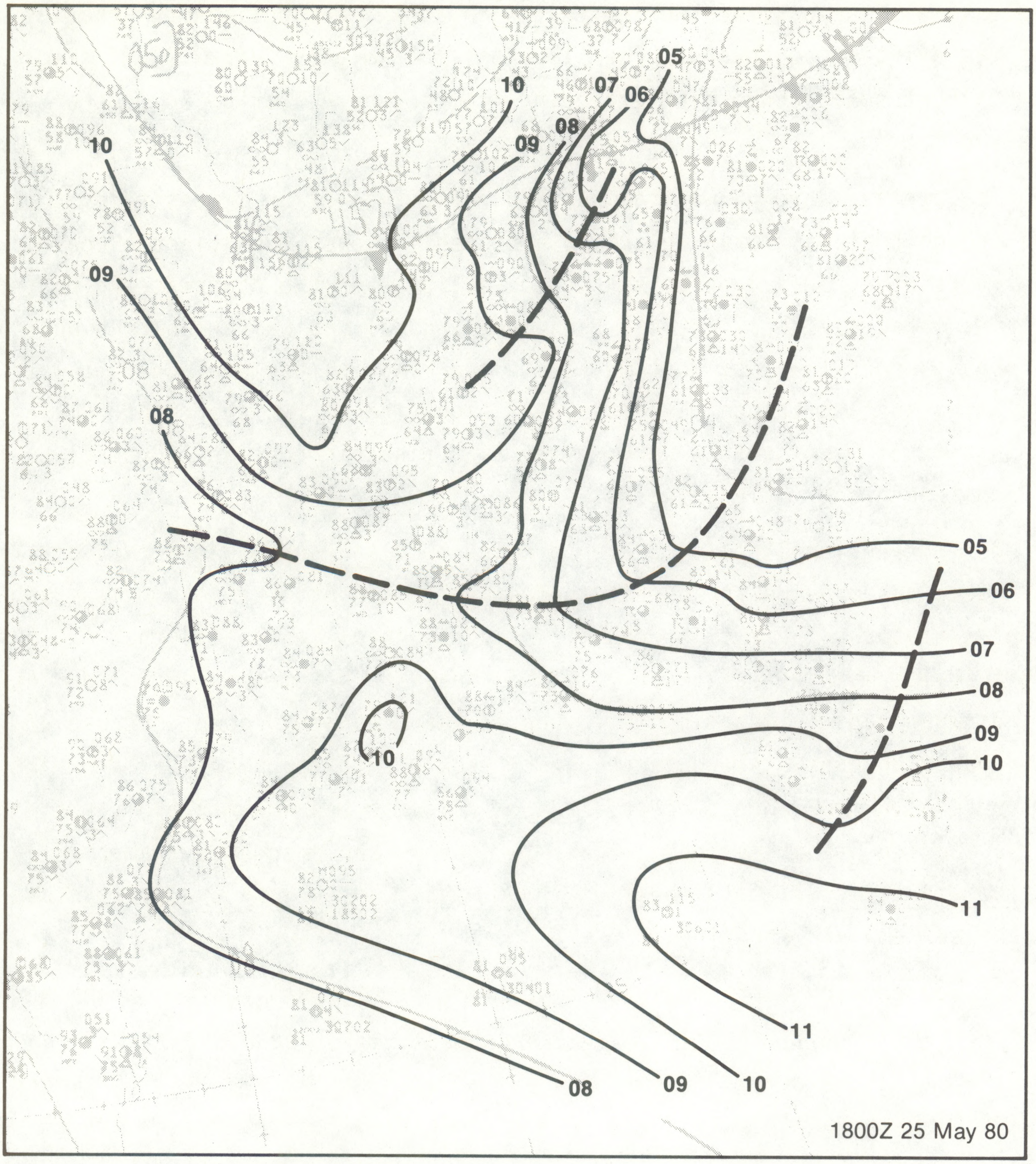

Fig. 75 Surface reanalyzed, as in Fig. 73, for 1800 GMT 25 May 1980.

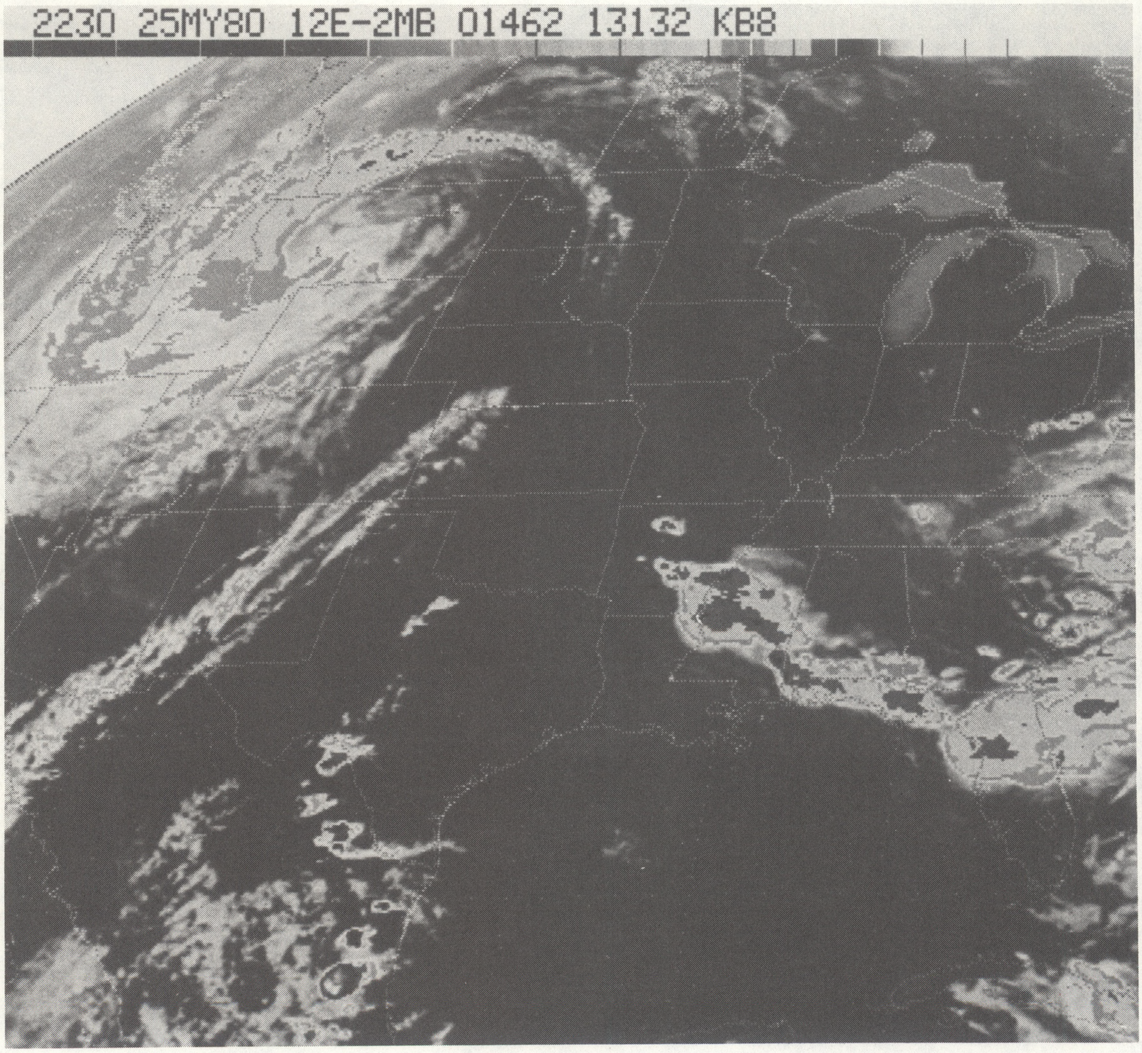

Fig. 76 Enhanced infrared satellite image for 2230 GMT 25 May 1980.

6.2 Isallobaric Fields

The pressure tendency equation states that local pressure change is a function of (a) the vertically integrated horizontal mass divergence, (b) the vertically integrated horizontal mass advection, and (c) the vertical accelerations, over the point where pressure is being measured. Unfortunately, synoptic-scale vertical motion primarily represents the small difference between the advection and divergence terms, neither or which can be accurately measured with conventional data collection systems. However, pressure changes can provide some clues to the vertical motion field at times.

Regardless, isallobaric analysis is one of the best tools for identifying and tracking sub-synoptic features (Magor, 1959). Unfortunately, this valuable tool seems rarely used anymore. Hourly surface analysis can be very difficult during significant weather events, so the additional task of isallobaric analysis is considered an impossibility by many forecasters. Nevertheless, some forecasters manage to perform isallobaric analysis during the heat of battle. It doesn't require much time for a practiced analyst who knows what to look for. Altimeter settings should be used, and the area monitored should fit the situation at hand. For example, if all the action is occurring along an east-west boundary near the Gulf coast, drawing isallobars over northern Arkansas may be a waste of time. The forecaster should be concentrating on the action area, i.e. where the important weather is and where it is expected to move. Of course, the forecaster must be cautious, since there may be two or more areas of significant convection.

Sub-synoptic features are usually characterized by significant ageostrophic wind components. A certain proportion (it varies) of the ageostrophic component is caused by the isallobaric acceleration. This acceleration is produced by changes in the pressure field, so that the stronger the gradient of isallobars, the stronger the acceleration. Furthermore, the stronger the isallobaric acceleration, the more the wind field will adjust directly toward pressure fall centers. For this reason, the isallobaric analysis should include a plot of observed winds. Changes in wind velocity from hour to hour, coupled with isallobars, can ease detection of many sub-synoptic features. For example, one's suspicion that a weak sub-synoptic low pressure system is approaching a station can frequently be verified by a backing wind if the pre-existing flow is reasonably strong.

Continuity is essential to detect and track the sub-synoptic system(s) involved. Although rules of thumb can be used as guidelines (e.g., the northeast quadrant of a sub-synoptic low is usually the region of strongest upward vertical motion), as always, the meteorologist must employ basic physical concepts, acknowledging the fact that the combination of variables at any one place and time is unique. A pressure fall (net loss of mass above a point) may not be imminently important if it is occurring in a region of very dry, stable air. However, the implications may be entirely different if the pressure fall center is moving into a moist region beneath a low-level jet stream.

Figures 77 and 78 show NMC surface analyses for 1200 GMT 5 February 1983 and 0000 GMT 6 February 1983. The smoothed analyses illustrate the synoptic situation very well, i.e., one or two waves tracking eastward along a frontal boundary in the northwestern Gulf of Mexico. Working in real time and alternating the task, two forecasters at Jackson, Miss., performed hourly isallobaric analyses, which revealed several rise and fall centers. This was done for seven consecutive hours, beginning at 2100 GMT, in conjunction with hourly surface analyses using data plotted on AFOS. Figures 79, 80, and 81 show the first three isallobaric analyses. (By the way, these meteorologists were not extra or overtime workers, but were the routinely scheduled forecasters.)

Sea level pressures were used, since AFOS plots using altimeter settings were not available in the Southern Region at that time. Several pressure fall centers and lobes do reveal themselves. One fall center can be easily tracked from northeast Louisiana to northeast Mississippi during the 3-hour period, while a rise center moves northward from southern Louisiana to northern Mississippi. Another substantial pressure fall center moves into extreme southeast Louisiana (Fig. 80). Note in Fig. 79 the region of relatively weak pressure falls in southeast Texas. These pressure falls were associated with a north/south-oriented trough west of the active thunderstorms; however, this region of falls tracked eastward, merging with the northward-moving fall center over the southern tip of Louisiana (Fig. 80) to produce the center over southwestern Mississippi (Fig. 81). Figure 82 shows how the 0000 GMT surface map was analyzed (in real time) by the forecasters. The mesolows are quite apparent. (Consider the lack of detail that would be available in the 2- or

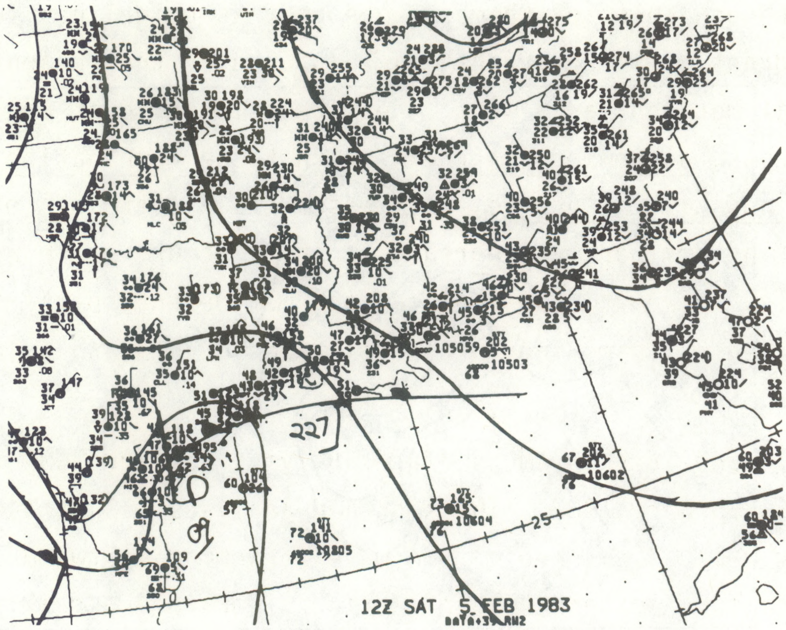

Fig. 77 *NMC surface analysis for 1200 GMT 5 February 1983.*

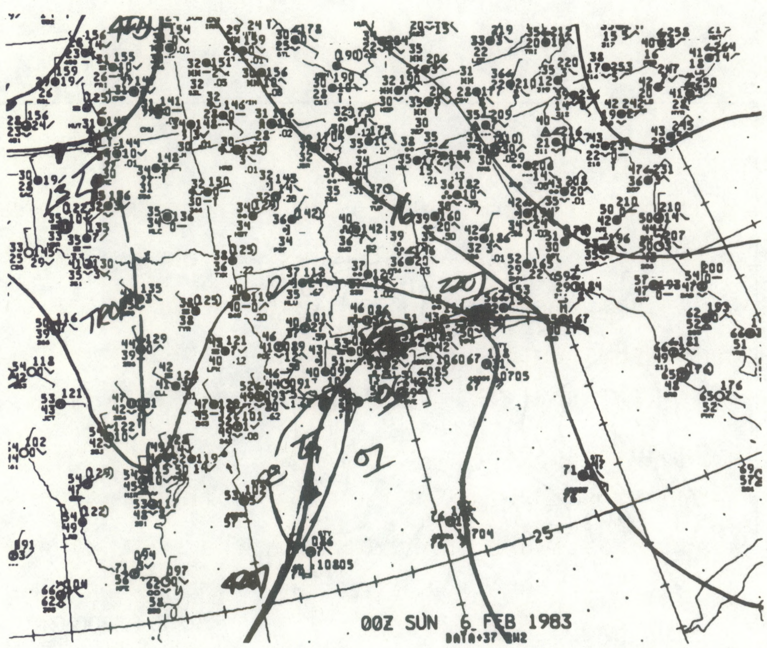

Fig. 78 *NMC surface analysis for 0000 GMT 6 February 1983.*

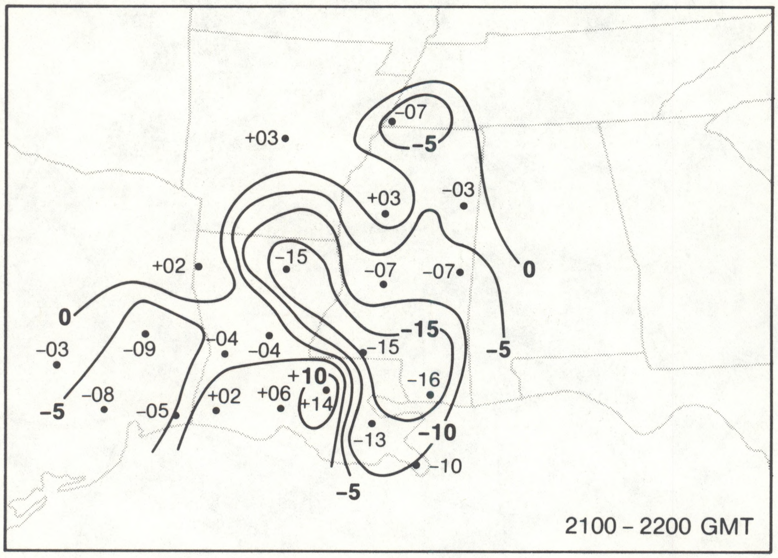

Fig. 79 *Analysis of surface pressure change in tenths of millibars for 2100-2200 GMT 6 February 1983.*

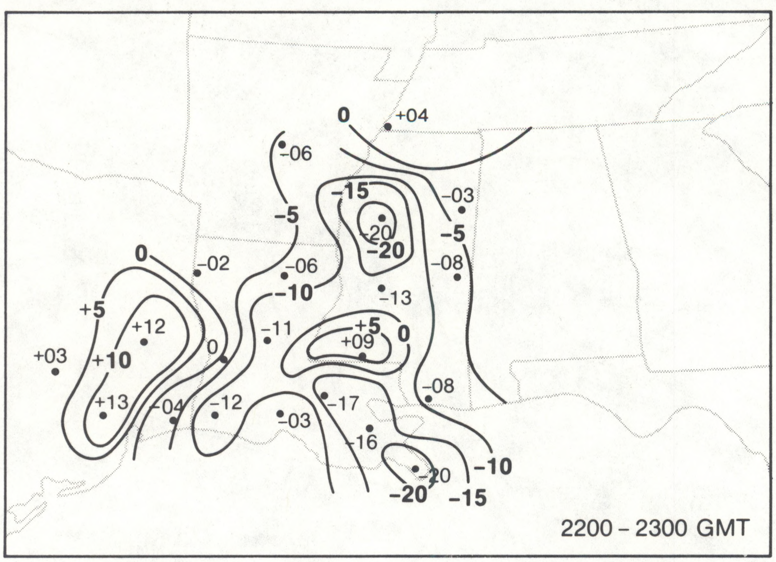

Fig. 80 *Analysis of surface pressure change in tenths of millibars for 2200-2300 GMT 6 February 1983.*

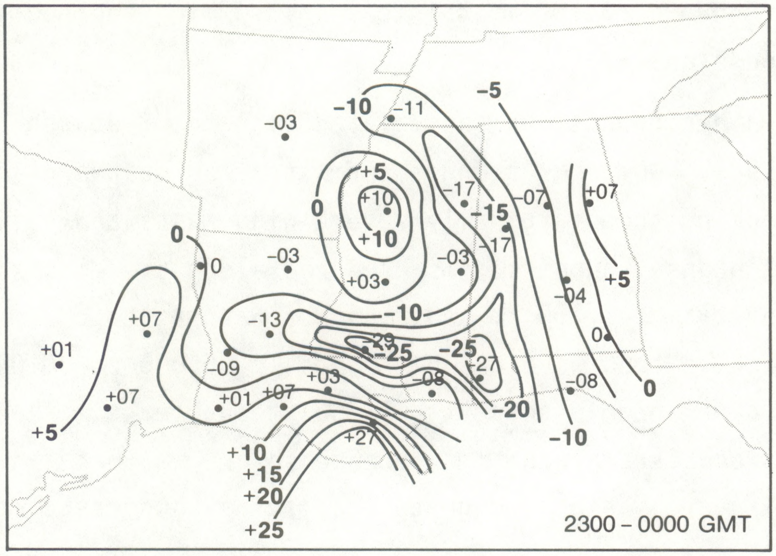

Fig. 81 *Analysis of surface pressure change in tenths of millibars for 2300-0000 GMT 6 February 1983.*

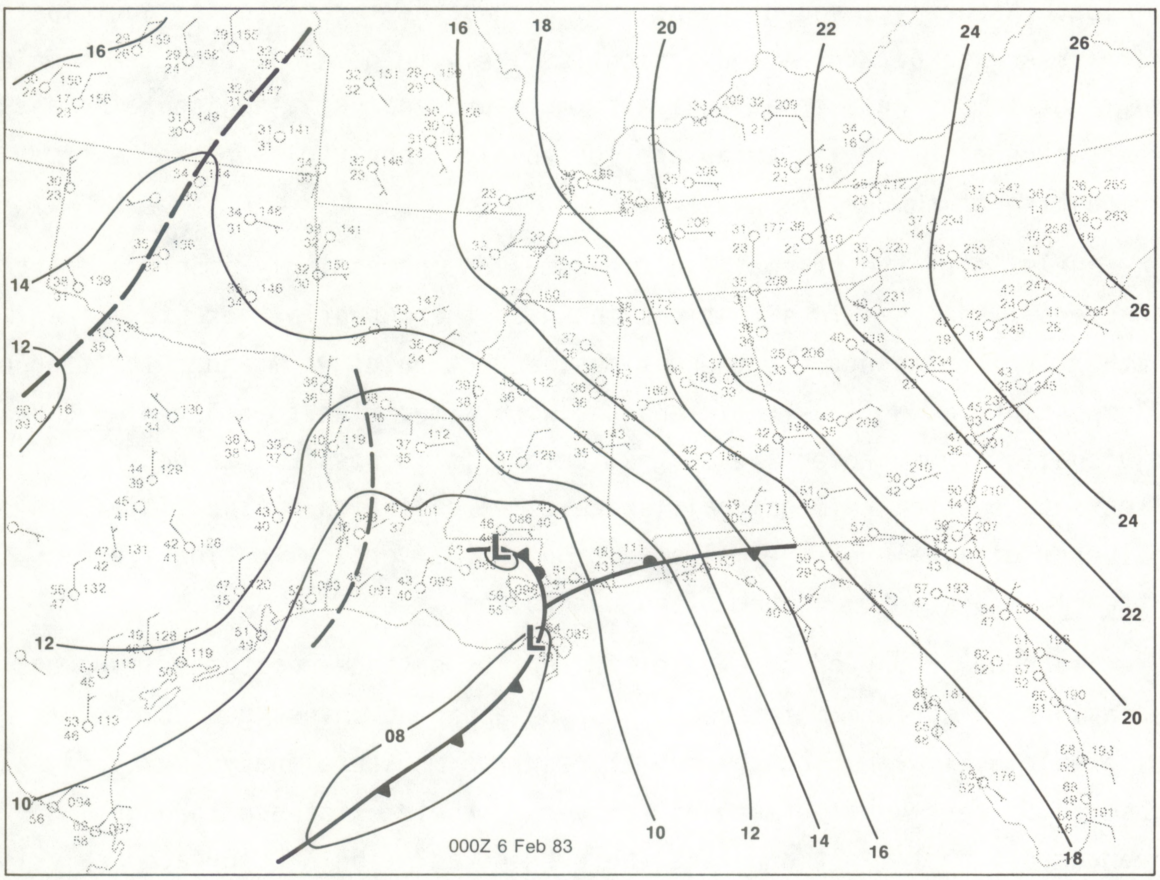

Fig. 82 *Standard surface data reanalyzed for 0000 GMT 6 February 1983.*

3-hour pressure change fields in this case by summing the hourly changes over southeastern Louisiana.)

So what weather events were associated with the features on the evening of 5 February 1983? Numerous thunderstorms tracked eastward across southern Louisiana, producing some marginally severe wind gusts and hail (see Fig. 83). The most intense thunderstorms occurred along the Mississippi-Louisiana border, from approximately 50 km southwest of Natchez to 60 km north of New Orleans. Convective tops were not high (mostly 25,000 to 30,000 ft), which is frequently the case in cold season, Gulf Coast outbreaks. These outbreaks usually give forecasters a bad time because severe weather can be produced by convective cells barely high enough to qualify as thunderstorms.

6.3 Temperature and Moisture Fields

At times during the warm season when solar heating plays a primary role in initiating convection, isotherm analysis during the pre-convective hours can greatly aid in preparing a 3- to 6-hour forecast of where convection will develop. Naturally, sounding analysis allows the forecaster to anticipate at what surface temperatures convection is likely to develop. Thus, a simple scheme of combining thermal analysis, moisture analysis, and sounding analysis from surrounding raob data can provide an excellent tool for short-term forecasting of summertime convection.

Analysis of the thermal field becomes an increasingly important part of the overall analysis in situations in which the potential for significant weather is increasing. At these times, detection of warm and cold "tongues" is important, as well as their changes with time. The forecaster must be able to visualize these advective surges, before it is possible to determine their effects on the four-dimensional (space-time) evolution of the fluid. The influence of low-level thermal advection on the vertical motion field is extremely important, and too often overlooked.

Since no AFOS product explicitly depicts surface moisture, important variations in surface moisture may not be apparent unless dew points are followed closely. During the summer, surface moisture analysis may reveal the presence of very subtle features (or verify their existence through enhancement) that might otherwise be overlooked. The NMC surface analysis for 1500 GMT, 6 September 1982 is shown in Fig. 84. Although little is

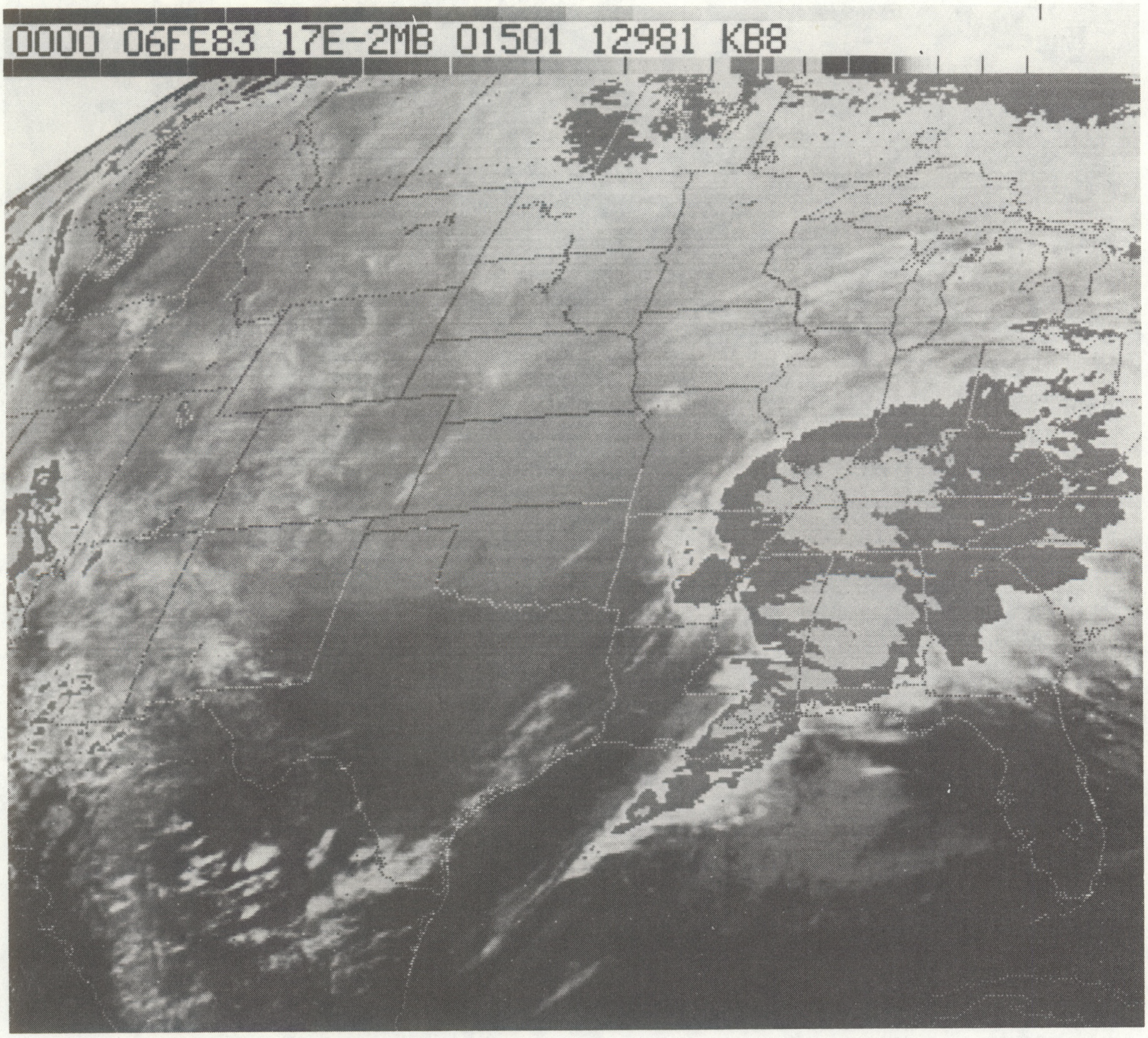

Fig. 83 Enhanced infrared satellite image for 0000 GMT 6 February 1983.

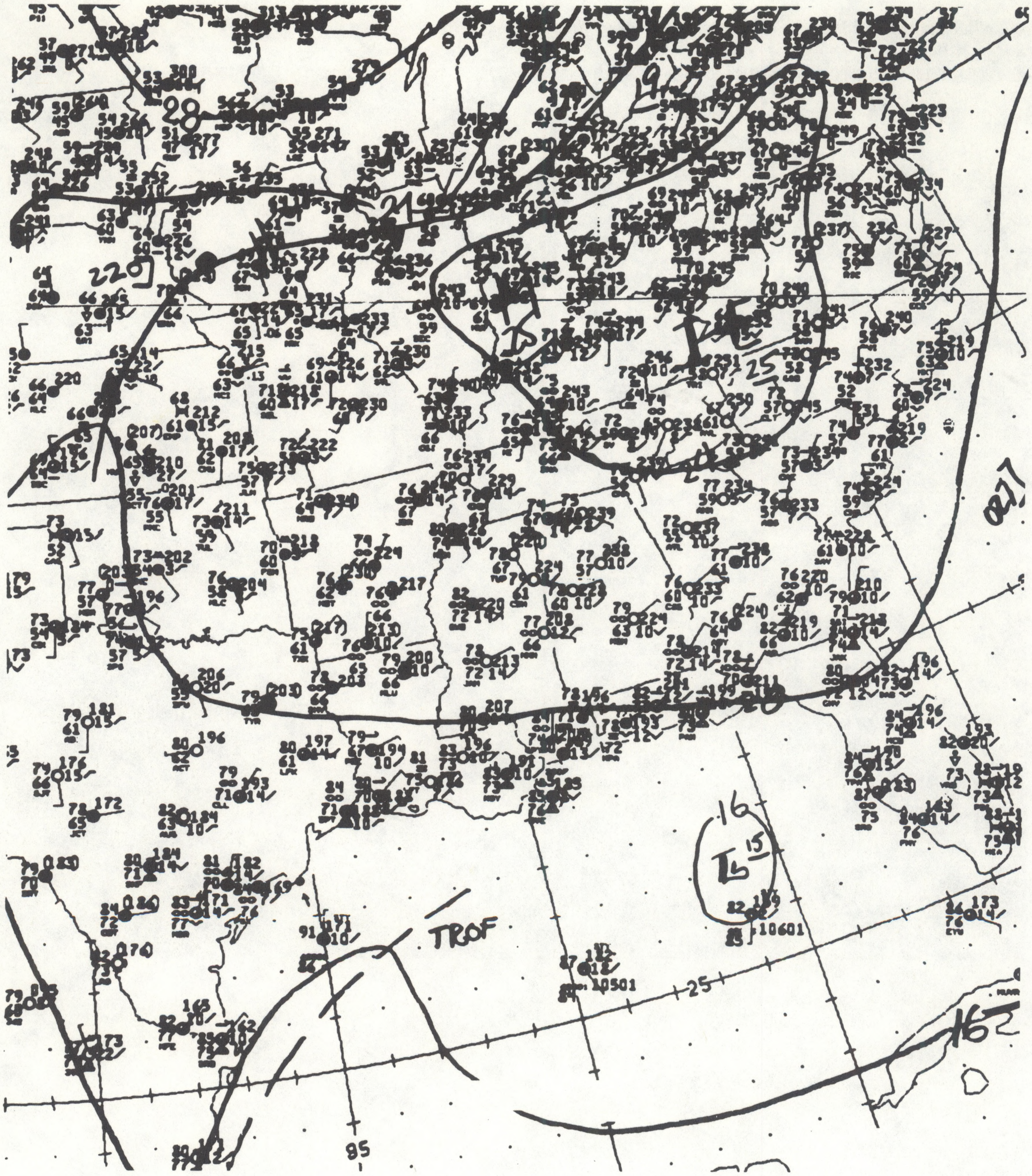

Fig. 84 NMC surface analysis for 1500 GMT 6 September 1982.

immediately apparent, forecasters should recognize this pattern as one often affected by waves moving westward along the Gulf Coast. In Fig. 85, I have added the 70°F isodrosotherm, along with isobars at 1-mb intervals, over the area of interest. The satellite imagery for 1631 GMT (Fig. 86) shows the cumulus field that began developing along the troughs, apparently supported by weak convergence and higher dew points.

Patterns of moisture advection, revealed by the combined pattern of isobars and isodrosotherms, can be quite impressive during the cool season, especially when the low-level jet stream is present over Texas and Oklahoma. Any moist or dry tongue (no matter how weak) should be analyzed in detail, with the thought in mind of how these features may affect or be affected by the vertical motion field. Much of the effect of these features on the forecast will be determined by answering the question: "What is required for convection to develop?" The answer comes from the forecaster's sounding analysis, which should naturally include anticipated changes.

Figure 87 shows an AFOS-type surface plot (with sea level pressure). In this situation, only 10-degree contour intervals are required to reveal the moist tongue surging northward through east Texas and Arkansas. By considering the motion field in the dry air west of the dryline, one can visualize where dry air is likely to be surging eastward into and over the developing moist ridge. Thus, without any other maps to study, one would expect a potential for severe thunderstorms to spread across the middle Mississippi Valley. It is in this region that the strongest flow of dry air is intersecting the moist ridge at the greatest angle. Farther south, the dryline has obviously lost any eastward push. In this case, the dryline moved farther east before it produced severe thunderstorms and several communities in Illinois and Indiana were damaged by tornadoes and high winds.

Moisture convergence is simply the rate of increase of atmospheric moisture content due to action of the wind field on existing moisture and moisture gradients. Like all other tools in meteorology, moisture convergence means little by itself. However, when integrated with other analyzed fields it can help provide a clearer picture of the structure of the atmosphere. An analysis of the 8 June 1974 severe storms in Oklahoma (Liles, 1976) showed that moisture convergence clearly preceded tornado development. However, the detailed data for the analysis were not those routinely available to

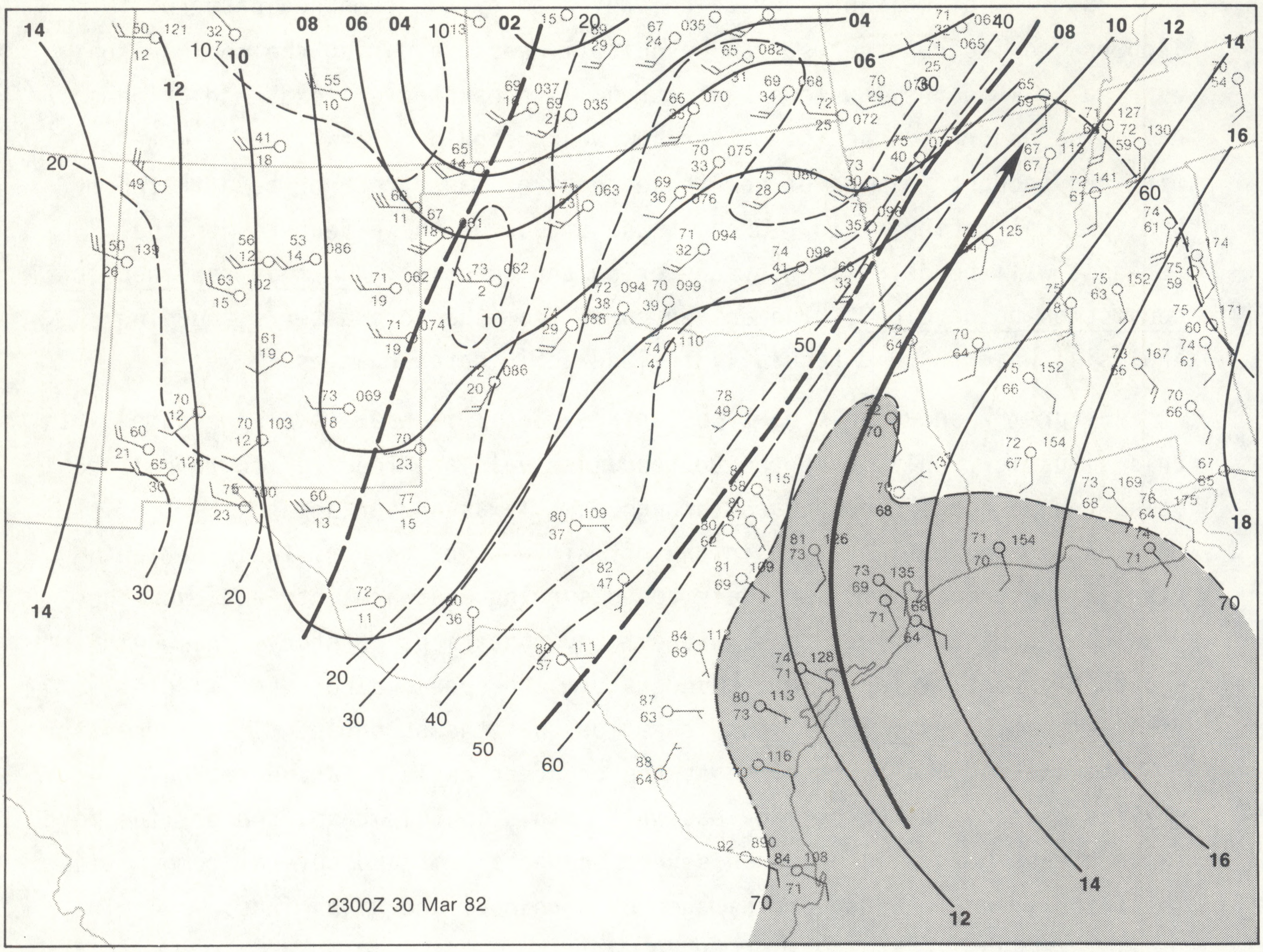

Fig. 87 *Surface data for 2300 GMT 30 March 1982 reanalyzed using 2 mb (solid lines) and 10°F-isodrosotherm contours (dashed lines). Shaded area denotes region where dew-points are ⩾ 70°F. Heavy solid line shows dry line position. Streamline illustrates flow of moist surface air into lower Mississippi Valley.*

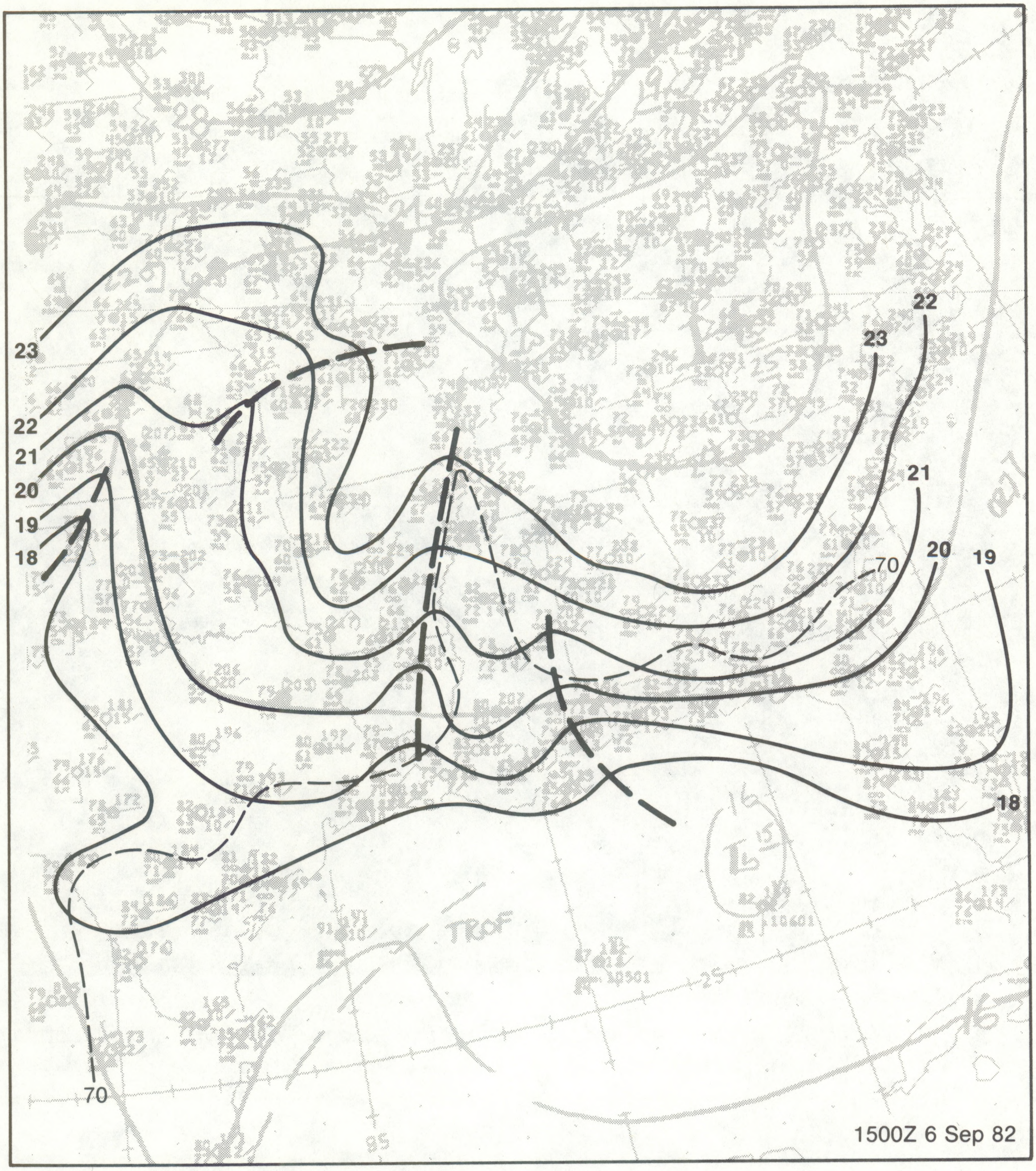

Fig. 85 *Standard surface data reanalyzed(1 mb pressure contours) for 1500 GMT 6 September 1982. The 70° surface dewpoint isopleth is shown as a dashed line.*

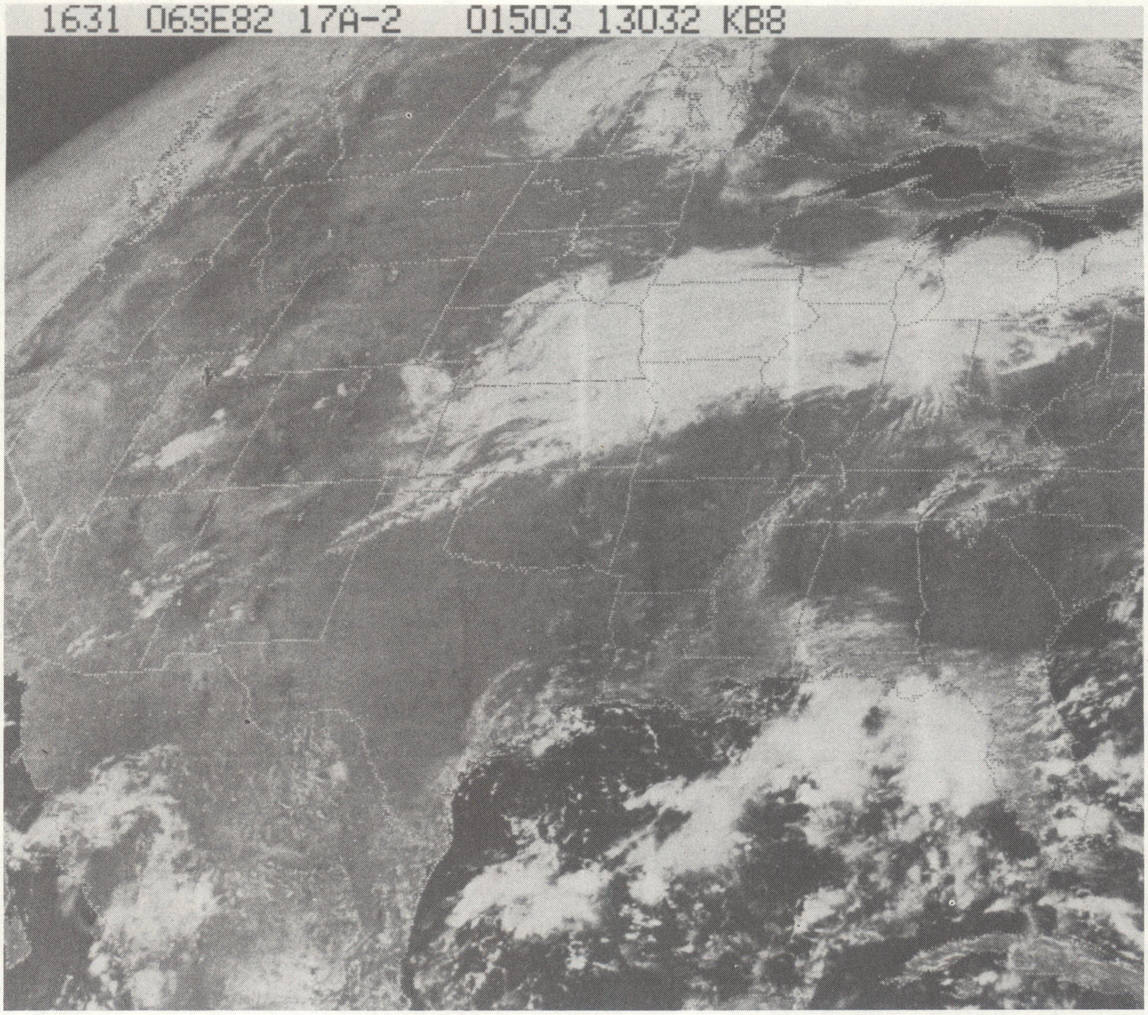

Fig. 86 *Visible, 2 km resolution, satellite image for 1631 GMT 6 September 1982.*

forecasters but were provided by the National Severe Storm Laboratory's mesonetwork.

In spite of obvious shortcomings (at least as far as severe weather is concerned), the 3-hour AFOS analyses can delineate areas where storms are more likely, before convection actually develops. Low-level convergence in an unstably stratified environment is an important mechanism for initiating convection. However, in severe weather situations in which the dryline is instrumental, it is likely that maximum mass convergence occurs in the dry air where wind speed variations contribute greatly. Meanwhile, maximum moisture convergence occurs on the moist side of the dryline, often where a mesolow acts as a focusing mechanism. During development of significant weather events, besides looking for highest absolute values, look for strong gradients of moisture convergence, especially where the strongest gradient is moving along a discontinuity.

6.4 Other Aspects of the Surface Analysis

Drawing streamlines on surface maps is often an exercise in futility in the southern United States. A detailed analysis of the pressure field usually gives the forecaster a better picture of the structure of the atmosphere, but there are times when surface streamlines can be an aid. When the flow is relatively strong, streamlines can provide good clues to where air is confluent and difluent. Variations in velocity can reveal regions where speed divergence or convergence is probably occurring. These subtleties are often instrumental in convective weather events in the South. Just as significant (if not more so) as hourly surface winds are the hour to hour changes in the flow. As previously mentioned, these changes can be used to aid in the detection of weak sub-synoptic features. However, extreme caution is required. For example, veering and backing of the flow may be meaningless with wind speeds of 5 knots; on the other hand, an hourly wind change from 180/15 to 130/14 may be the result of an approaching and/or intensifying mesolow. Naturally, forecasters should also be aware of diurnal changes in direction (especially with upslope or downslope flow), and take them into account.

Although varying terrain and surface characteristics (forested, cultivated, etc.) may confuse the streamline analysis, we should realize that they are real influences and try to consider their effects. Admittedly, on the smallest of scales, we will always be at the mercy of the farmer who has recently plowed his field, and the added lift that the hill along his property gives the tropical, summer air when the flow happens to hit it perpendicularly. However, we can deal with larger-scale terrain variations such as the Caprock escarpment, the Quachita Valley sandwiched between the Boston and Quachita Mountains of Arkansas, the terrain slope across Oklahoma and Texas, etc. All forecasters should be intimately familiar with the influences of terrain features such as these on the low-level flow. These topographical variations should be fixed in the mind so that their effects on the surface flow can be visualized at any time, for any particular situation.

Some forecasters tend to laugh at the insistence by "locals" that some nearby hills or other features have an effect on their weather. We all know how very small terrain influences can make the difference between a clear sunrise and one obscured by fog. It could also be true that a small hill could provide the needed boost to the vertical motion field to produce convection under the right circumstances. Careful observations of such local effects over a period of time could lead to better short-range (or nowcasting) prediction techniques.

Forecasters in the southern United States should take special care in maintaining continuity for fronts. This is especially true for fronts that have moved southward into the Gulf of Mexico. NMC will frequently drop these from their analyses. It is important to realize that the significance of these discontinuities is not fixed, but varies with the particular situation. Long after these fronts reach the Gulf they may still provide a good situation for "overrunning" precipitation to develop with the approach of a weak short-wave trough. The combination of warm-air advection and lifting across the frontal surface can develop widespread precipitation from Texas to Georgia in less than 24 hours at times when a front isn't even analyzed on the NMC maps.

Fortunately, a lot of tools are available to forecasters who want to maintain continuity of old Gulf baroclinic zones. Satellite imagery generally makes accurate location of Gulf fronts possible as long as the fronts are active (i.e., characterized by significant low-level cloudiness). However, once the fronts become inactive, identification by means of satellite imagery becomes more difficult. Remnant cumulus lines can sometimes pinpoint frontal locations. However, care must be taken to distinguish short-duration cumulus lines from true frontal boundaries. These cold air masses can become shallow enough that even warm, moist Gulf air can flow well north of the surface frontal position before condensation takes place. Thus, the satellite imagery gives the impression that the front lies farther north than it does. Even though the surface boundary may not be significant at that point, it may become significant under favorable circumstances. For example, as a short-wave trough approaches from the west, the boundary may move northward and focus significant convective development.

Forecasters using satellite imagery to locate Gulf fronts should also take special care not to confuse fronts with convergence lines that sometimes abound in the Gulf. These convergence lines frequently have lifespans of less than 24 hours, but a frontal boundary may remain as a significant feature after 48 or 72 hours. Forecasters should refer to the New Orleans SIMS for help. The loop capability that the SFSSs have can reveal a tremendous amount of information. A particularly valuable tool for getting a good handle on the low-level Gulf flow is the low-level wind vectors derived from the satellite imagery (described in the SIMS). Additional helpful data include the oil rig and buoy observations available on AFOS. These data points can be added to AFOS surface plots to avoid hand plotting. Although the pressures (and sometimes temperatures) are frequently unreliable, the wind data can be very helpful in locating and maintaining continuity of Gulf fronts.

Since a front in the Gulf will usually return northward through the western Gulf first, a weak frontal inversion will lower through the south Texas soundings as the cool air mass gets shallower. Although inspection of surrounding raobs should be routine, forecasters should take special care in studying south Texas soundings during times when they anticipate the northward movement of Gulf fronts. If time doesn't permit detailed analysis of surrounding raob data, AFOS plots can be run in less than a minute.

The NMC surface analysis for 2100 GMT 15 May 1981 is shown in Fig. 88. The analysis shows a cold front extending into the eastern Gulf of Mexico, but west of 90° longitude the "front" apparently doesn't meet NMC's frontal criteria. However, the boundary actually extends westward into south Texas. Although the boundary appears insignificant on the 2100 GMT analysis, by 0300

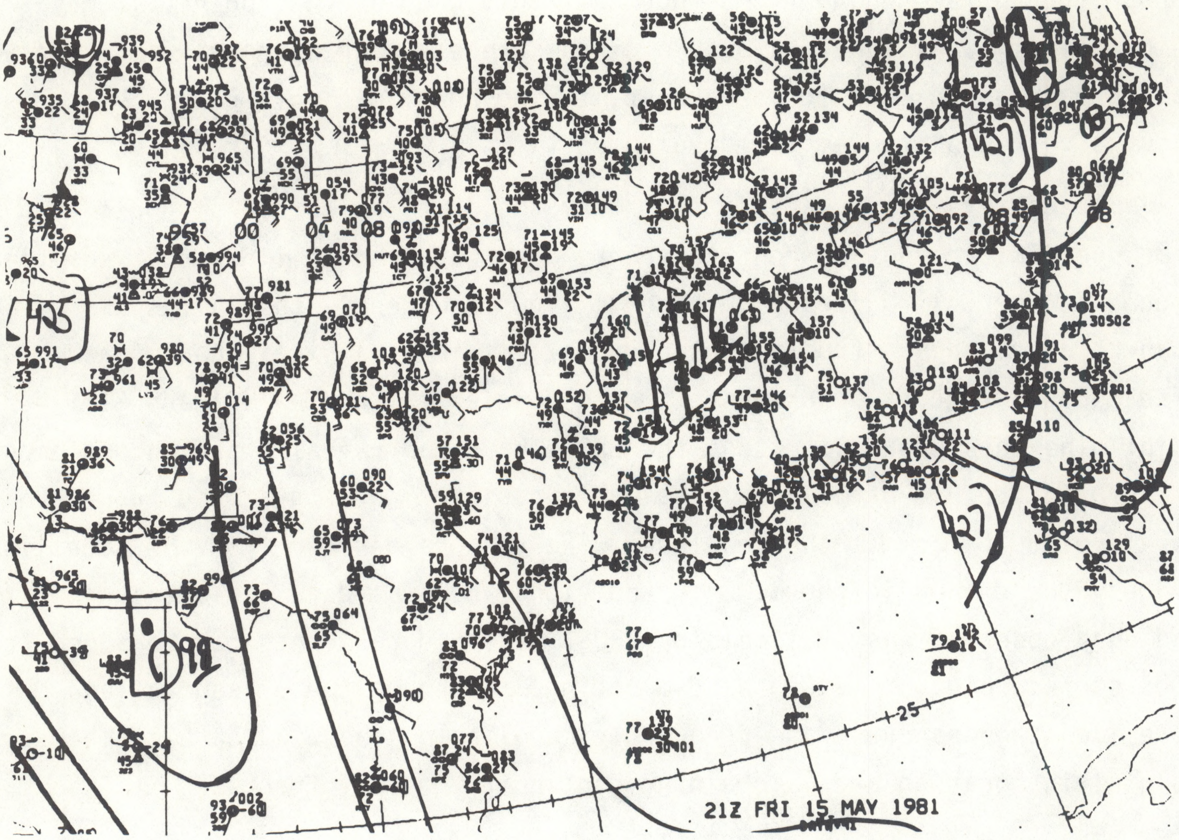

Fig. 88 NMC surface analysis for 2100 GMT 15 May 1981.

GMT on 16 May the boundary had strengthened and moved northward over Texas. However, it still was not indicated on the NMC analysis (Fig. 89). Analyzing the same data (Fig. 90) with 2-mb intervals reveals not only the frontal boundary, but another east-west oriented boundary farther north. Rapid development of convection ensued as a low-level (850 mb) flow of warm, moist air overran these boundaries at about a 90-degree angle.

The 850 mb analysis for 1200 GMT on 16 May (Fig. 91) shows a well-developed jet stream that splits over Texas. I have added isotherms at 2°C intervals to enhance the analysis. One branch of the jet stream intersects the frontal boundary near Lake Charles. The other branch intersects both boundaries (i.e., over north Texas and along the Oklahoma-Texas border). Note the strong speed convergence apparent ahead of both jets. Satellite imagery for 1200 GMT (Fig. 92) shows that the low-level jet is feeding two mesoscale convective systems in these areas. The convective development that took place in this situation produced hail and a few tornadoes. In addition, the rapid spread of convection eastward with the Louisiana segment of the jet caught both the numerical models and MOS off guard completely. However, this is an extremely simple case in which significant convection was generated by the low-level jet advecting moist, warm air across boundaries easily detected by mesoscale analysis.

Identifying thunderstorm outflows with surface data can be easy on a summer afternoon. (For a detailed discussion of outflow boundaries, the reader should refer to Doswell, 1982, Sec. III-7.) The evaporative cooling that takes place frequently drops surface temperatures by 15°F or more. Satellite imagery and radar detection of these boundaries can be great aids as well, and can in fact frequently pinpoint the boundaries much more accurately than surface data alone. However, if condensation hasn't occurred along the boundary, satellite imagery will not reveal its presence. But in these cases, if the density gradient is significant, radar may detect a "fine line".

As boundaries age, their identification usually becomes increasingly difficult. The boundary can spread out well ahead of precipitation, and modification by heating and advection causes temperature contrast to decrease across the boundary. Although the outflow boundary spreads out in all directions, the expansion is normally faster in the direction of thunderstorm motion. Observations reveal that outflow boundaries generated one afternoon

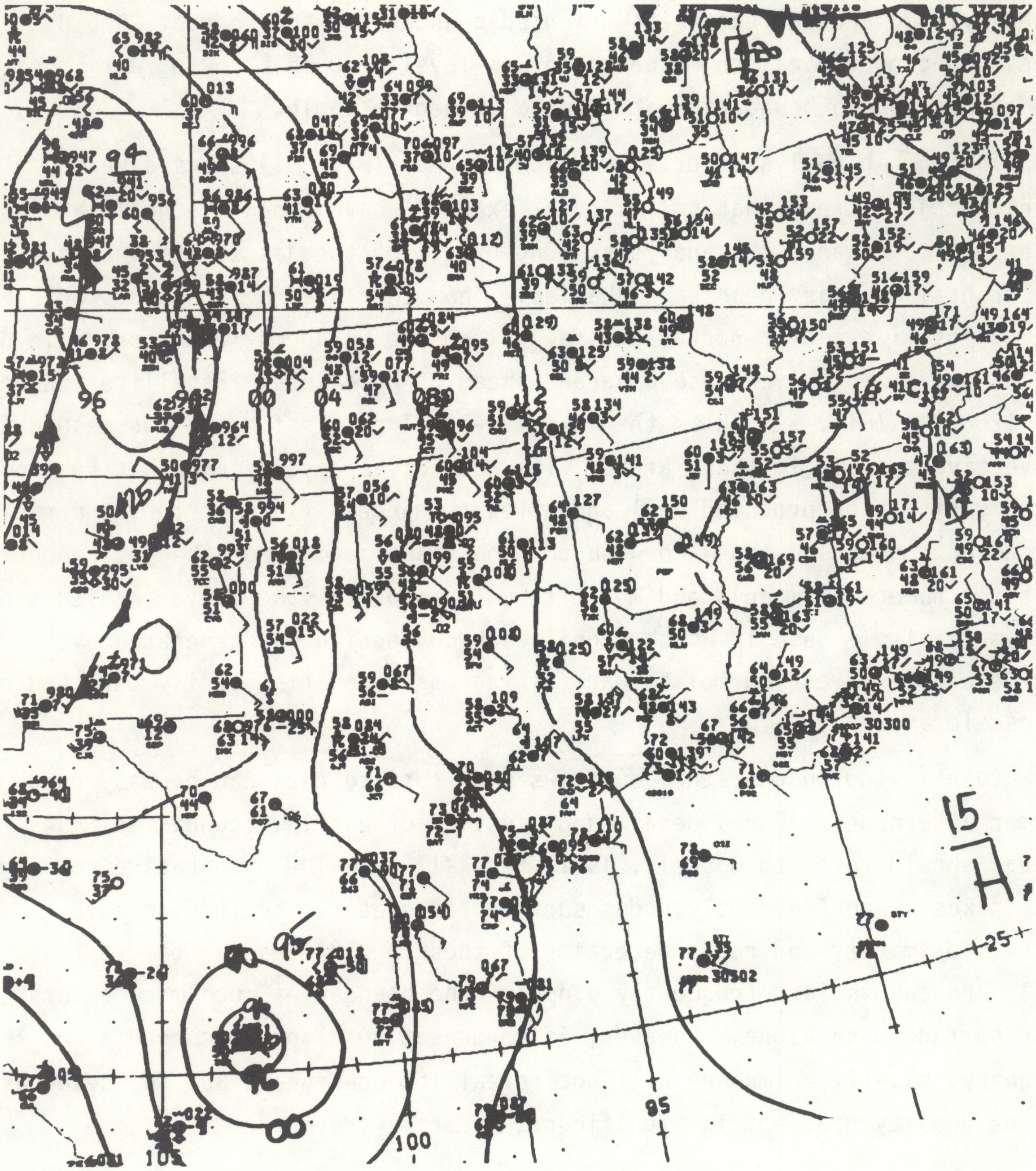

Fig. 89 NMC surface analysis for 0300 GMT 16 May 1981.

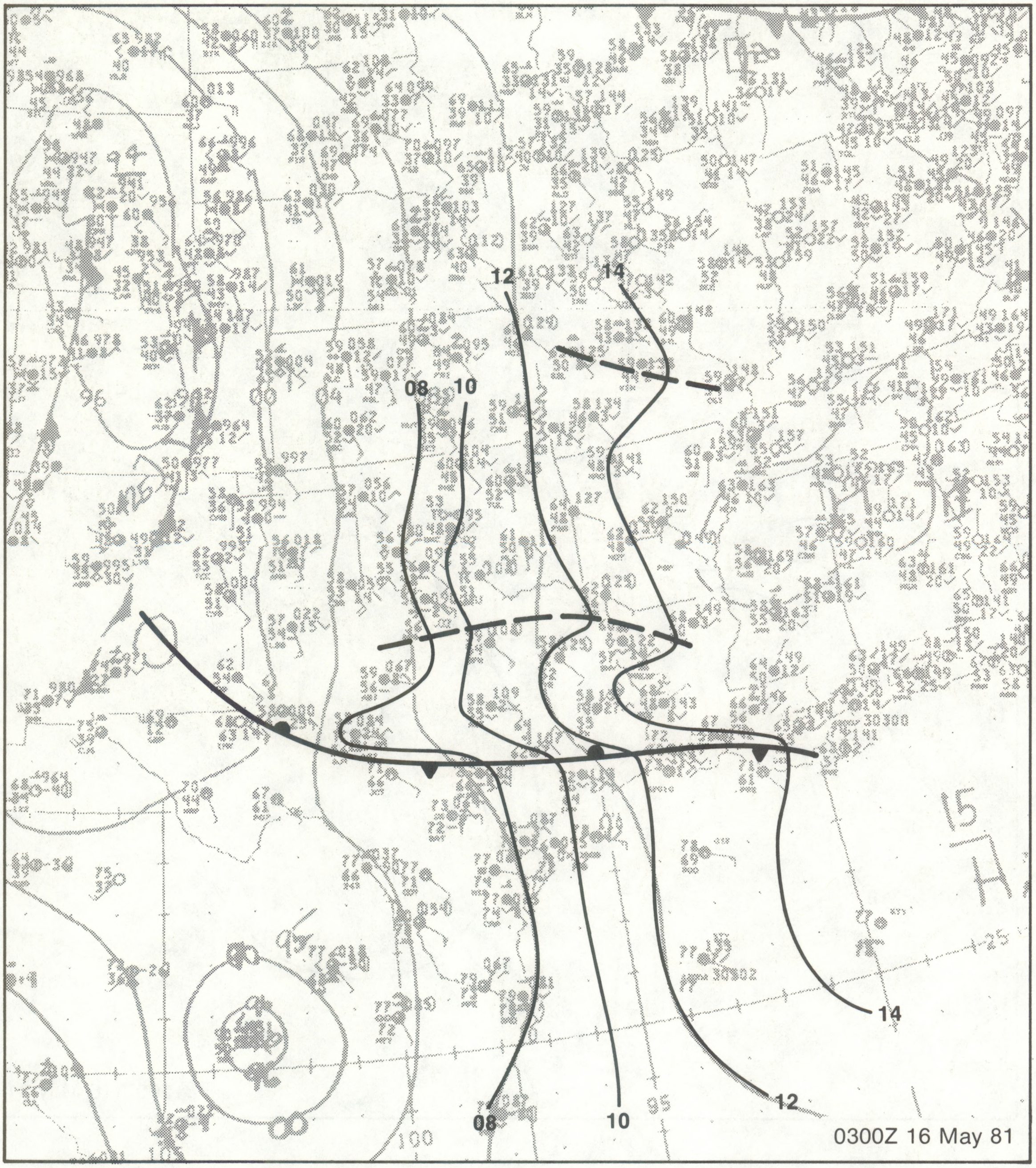

Fig. 90 *Surface reanalysis with 2 mb contours (solid lines) for 0300 GMT 16 May 1981.*

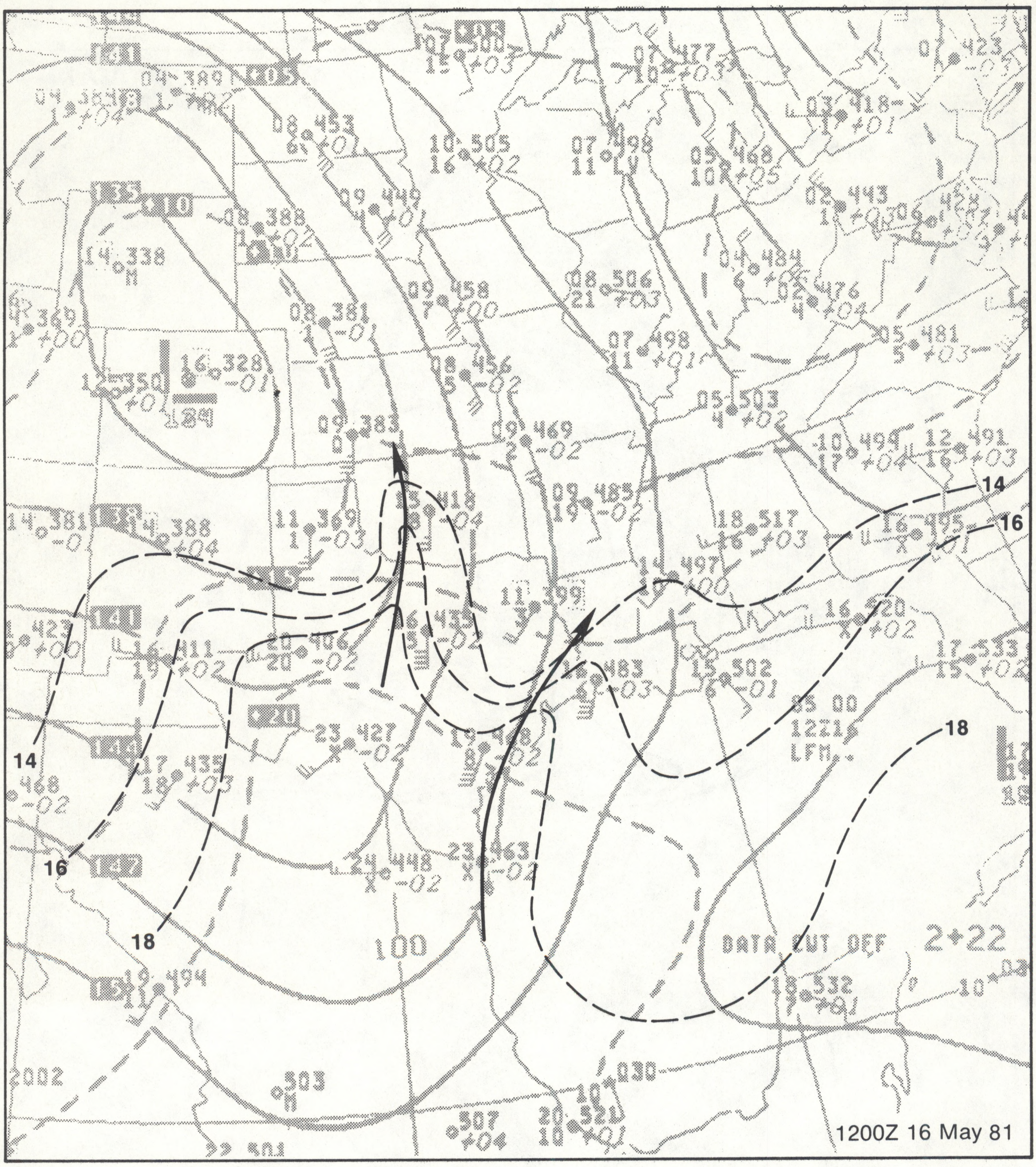

Fig. 91 *Analysis of 850 mb temperatures 2°C intervals (dashed lines). Heavy arrows show low-level jet streams.*

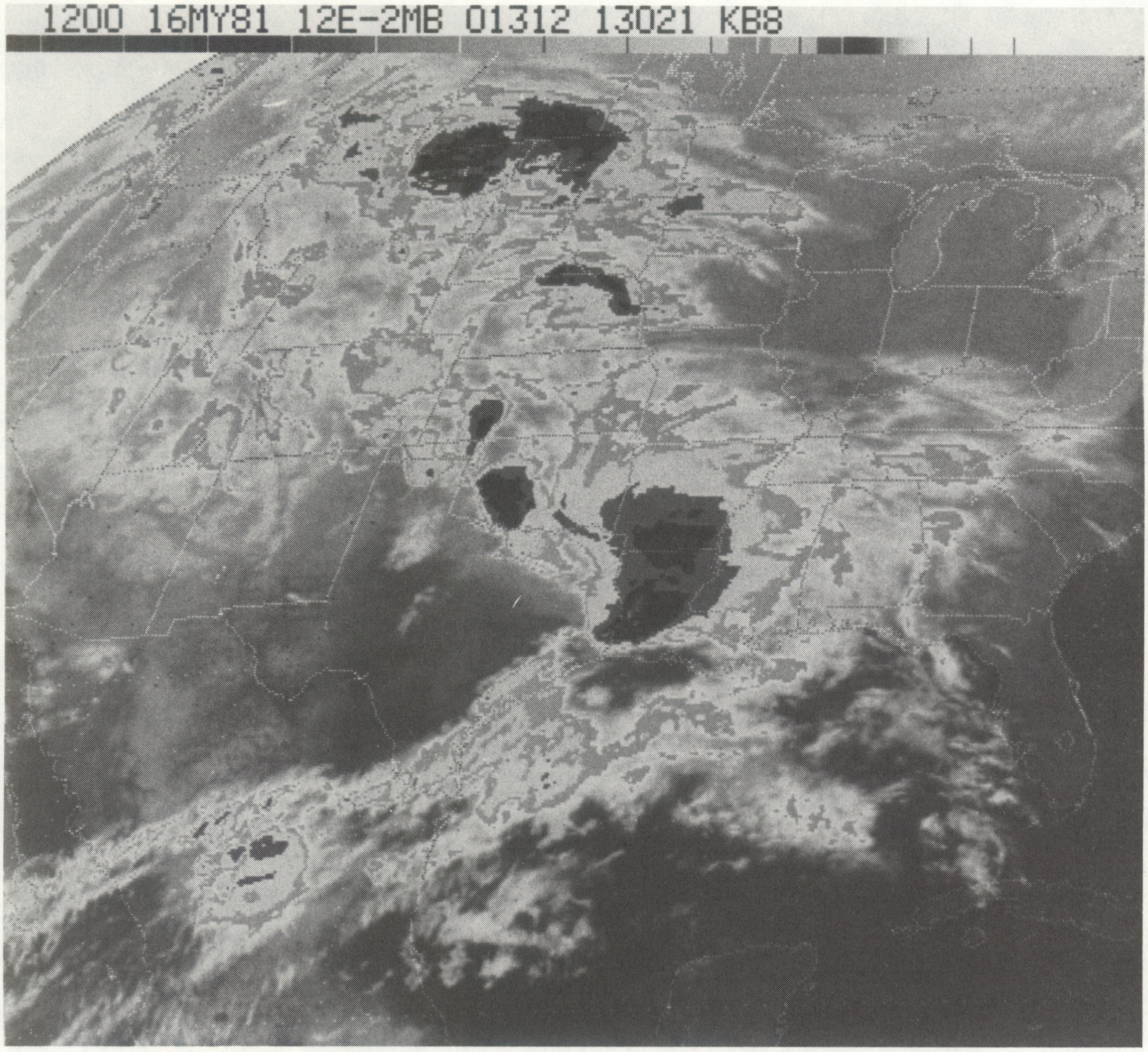

Fig. 92 Enhanced infrared satellite image for 1200 GMT 16 May 1981.

can persist throughout the night into the next day, helping to initiate new convection 24 hours after their inception. For these reasons, it is essential that forecasters maintain continuity of these features. Detection and continuity both require a thorough sub-synoptic analysis of the surface data. Some warm-season, weak troughs of unknown origin could probably be traced back to a beginning as outflow boundaries.

Another important surface feature has often been referred to as the dryline, dew point front, dryline front, or Marfa front, among other terms. I shall refer to this feature as the dryline, because of the familiarity of the term and my desire not to invent new terminology. The dryline is an air mass boundary, although it usually does not meet classical definitions of a front. Once more, the reader should see Doswell (1982) which provides an excellent extended discussion of the dryline in Sec. III-5.

Although a dryline frequently exists over west Texas, the intensification of the feature is manifested by the low-level surge of moisture north and northwest from the western Gulf as a high pressure system over the central and eastern United States moves eastward. The increasing terrain elevation doesn't allow the moisture to spread all the way across Texas (most of the time), so that a north/south-oriented moisture discontinuity results. The position of the dryline reflects the surface boundary between the moist and dry air masses. Accurate identification of the dryline on a surface map is quite easy, although some analysts persist in diagnosing the dryline as a cold front. At times the dryline can move eastward through Louisiana and Arkansas, although movement east of the Mississippi River is rare. Forecasters east of the Mississippi River should realize that even though the surface dryline may never pass their station, the dryline aloft may still be instrumental in producing severe convection across the southern United States. Figure 93 shows an analysis of mixing ratio in the vicinity of a dryline that helped produce numerous tornadoes over Oklahoma and Kansas on 8 June 1974. The slope of the dryline may vary considerably, but it is usually almost vertical from the surface up to between 800- and 700-mb, where it may extend almost horizontally eastward for hundreds of kilometers. Indeed, "subsidence" inversions to the east of the surface position of the dryline may reflect this.

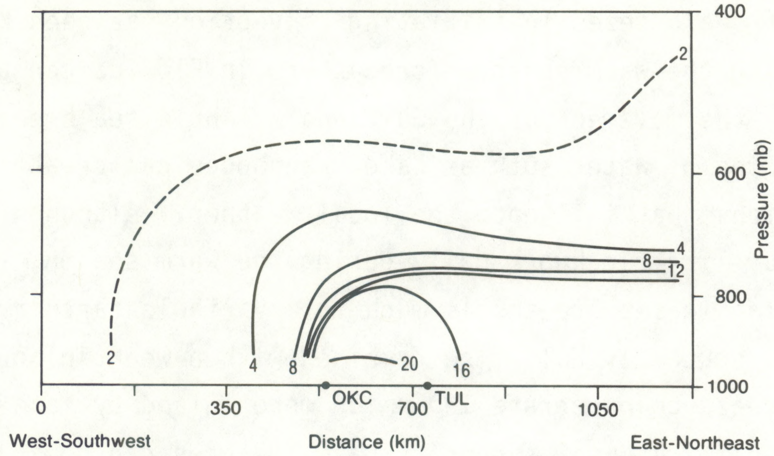

Fig. 93 *Cross-section through dryline of 0000 GMT 9 June 1974. Countours are of mixing ratio at 4 g/kg intervals. Heavy line shows positions of dry line.*

Schaefer (1973) shows that movement of the dryline can occur through vertical mixing in the boundary layer that acts to disperse the moisture. Thus, if moisture is shallow (just east of the surface dryline), the moisture can be dispersed rapidly, while farther east, the moisture is too deep to allow "passage" of the surface dryline. This may accurately describe the behavior of the dryline when it is inactive, but movement of the dryline is a more complex process when the dryline is active. The processes that aid the eastward movement probably include not only the synoptic-scale vertical motion field, but also the added vertical velocity manifested by sub-synoptic waves propagating along the dryline, as well as differential thermal advection. Strong downward motion on the dry side of the dryline is often instrumental in moving the discontinuity eastward.

As explained previously, the LFM may do a good job of forecasting the development and movement of the dryline that accompanies most southern United States severe storm outbreaks. This is especially true in late winter and spring situations in which cyclogenesis is forecast in the lee of the Rocky Mountains. An LFM vertical velocity forecast of -4, -6 or -8 microbars per second over the western sections of Texas, eastern Colorado, eastern New Mexico, Oklahoma, or Kansas is a good indication that a strong dryline will develop. The LFM usually also forecasts development of a pronounced RH gradient at 700 mb in these situations in association with the strong downward vertical motion field. Forecasters should use the boundary layer relative humidity forecast to pinpoint the LFM forecast dry-line position.

The role of sea breezes in initiating convection has been known for a long time. During the warm season, forecasters in Florida can almost set their watches by the movement of the Gulf and Atlantic sea breezes. Even large inland bodies of water such as Lake Okeechobee can create thermally driven circulations that influence the local weather. Although the Florida sea breezes occur like clockwork daily during the warm season, the movement of the Gulf and Atlantic sea breezes is much more variable farther north and west. A strong, southerly Gulf flow combined with a weak inland gradient can allow the sea breeze to penetrate 150 km or more inland by late afternoon; at other times, even fairly weak synoptic-scale features can dominate the mesoscale sea breeze influence, so that little or no inland movement occurs.

Detection of the sea breeze using conventional surface data is usually difficult, although it is easiest during the fall and spring when land/sea thermal contrasts are greatest and the sea breeze is least subtle. For example, during the late spring, passage of a weak cold front will provide light northerly flow to the Gulf coast, allowing temperatures to rise to the highest levels of the spring. However, weak north or northeast flow may easily be overcome by a sea breeze circulation driven by the strong thermal land/sea contrast by late morning or early afternoon. These sea breeze passages are most noticeable as they shift the wind to the south, increase the dew point by 5 or 10 degrees, and subsequently drop the temperature by 5 or 10 degrees. However, owing to the subtlety of the sea breeze in most cases, by far the best tool for locating and maintaining continuity of sea breezes is satellite imagery. Even weak convergence along the sea breeze will usually produce a line of cumulus clouds in the moist air that persists near the coasts.

Although severe convection along a sea breeze is rare, the monitoring of these features can greatly boost the accuracy of the 6- to 12-hour forecast, and be a great aid in nowcasting. Also, the movements should be monitored closely for potential mergers with other boundaries. Radar can also be a useful tool at times for pinpointing the location of sea breezes. A sea breeze initiated by a strong thermal land/sea contrast or the influence of convection along the sea breeze sometimes allows identification of the sea breeze on radar as a fine line. Naturally, when this is the case, much more accurate monitoring is possible using radar rather than satellite imagery.

Detailed analysis of surface maps almost always reveals a number of features other than the ones mentioned. Weak pressure troughs, moisture gradients, pockets of dry air, moist air, and wind shifts become apparent. Some of these features can be traced (using continuity) to previously mentioned discontinuities. For example, a weak wind shift may be the remnant of a once-sharp outflow boundary. Some wind-shift lines may have been induced by small-scale terrain variations or soil moisture variations. These wind-shift lines influence the weather under the right circumstances. Indeed, convection in the southern United States is not random, but is instead related to small scale features (also see: Mogil, 1978 and 1983; Moller, 1980; and Grice and Ely, 1983). It is up to the meteorologist to both detect and assess the significance of small-scale features resolved by the surface data.

7.0 DIAGNOSING CONVECTIVE POTENTIAL THROUGH SOUNDING ANALYSIS

At one time, part of the forecast routine involved detailed examination of raob data. However, during the past decade many forecasters have become accustomed to writing forecasts (even for aviation terminals) without even looking at upper-air soundings! Several AFOS application programs are available that plot soundings and compute various parameters. These programs should be run not only for the nearest raob station but for surrounding upstream locations as well. It should be obvious that upstream stations may be in different directions for different levels of the atmosphere. For example, low-level easterly flow with middle- or high-level westerly flow results in upstream stations whose azimuths are 180 degrees apart. Since sounding-to-sounding changes are important and should be examined for both local and surrounding stations, hard copies should be produced and saved for several days. This obviously requires that all forecasters participate in the endeavor.

Several manuals already exist that explain basic sounding analysis techniques (e.g., Air Weather Service [1969] and Reed and Grice [1983]). I will not review them, but will instead concentrate on determining convective potential through sounding analysis. Just as sub-synoptic analysis of surface and upper-level maps should be part of the everyday routine and not just for the heat of battle, the same is true for sounding analysis.

Using the sounding data, the raob minicomputer determines the Showalter Stability Index (SSI), which is a simple expression of the conditional instability of air at 850 mb. Unfortunately, this is where the evaluation of thermodynamic stratification frequently ends. Other indices that also provide clues to the instability include the Totals, Lifted, and Best Lifted, and K index. One major difference between these indices is in the method of evaluating ambient moisture. For example, if low-level moisture doesn't reach to the 850 mb level, the Totals and SSI will not be representative. This is not to say that the SSI or Totals Index is useless, but forecasters must be aware of inherent pitfalls and take them into consideration. Evaluation of convective instability should involve examination of the entire sounding and not key on the use of a single number, or even a set of numbers (indices).

No matter how unstably stratified the atmosphere may be in any area, evaluation of both positive and negative buoyancy must be performed to determine if the instability is likely to be released. There is no fixed way to evaluate positive and negative areas. The analyst must choose the parcel to be evaluated, on the basis of the atmospheric processes expected during the next 12 hours. During the summer, solar heating will frequently be the dominant effect acting to alter 1200 GMT conditions in the southern United States; however, effects of vertical motion, temperature, and moisture advection, etc., must all be considered. Consecutive soundings should be carefully monitored for changes as well. Sometimes, very subtle changes can make the difference between fair weather cumulus and severe thunderstorms.

Figures 94-97 represent soundings taken on two consecutive mornings in July at Jackson, Miss. The 6 July morning sounding has a Totals Index of 47; a Lifted Index of -5 (at 500 mb) was computed using a mixing ratio of 16 g kg^{-1} as representative of the lowest 100 mb along with a forecast maximum temperature of 100°F. The K Index is approximately 38. This sounding is clearly taken in an unstable atmosphere; so, what are the chances for thunderstorm development?

Although weak cold advection is implied through a deep layer (approximately 750 to 150 mb), the important changes that will take place during the 0-12 hour forecast period primarily involve solar heating of the low levels. What will happen if the temperature reaches 100°F? If we still have an average mixing ratio of 16 g kg^{-1}, nothing will happen! The surface temperature would have to reach approximately 105°F for cumulus with a base near 760 mb level to develop (see Fig. 95). However, the resulting cumulus would grow and accelerate upward, reaching the equilibrium level at 145 mb (approximately 46,000 ft) with substantial momentum. If we rule out the possibility of surface temperatures reaching 105°F, what else might happen? If the mixing ratio increased to 17 g kg^{-1}, cumuli would form once the surface temperature reached 96 or 97°F. But the sounding indicates that these cumuli would be very flat, with a base at approximately the 840-mb level (4600 ft) and tops near 820mb. A more significant increase in moisture would be required to overcome the negative area below the stable layer between 850mb and 700mb.

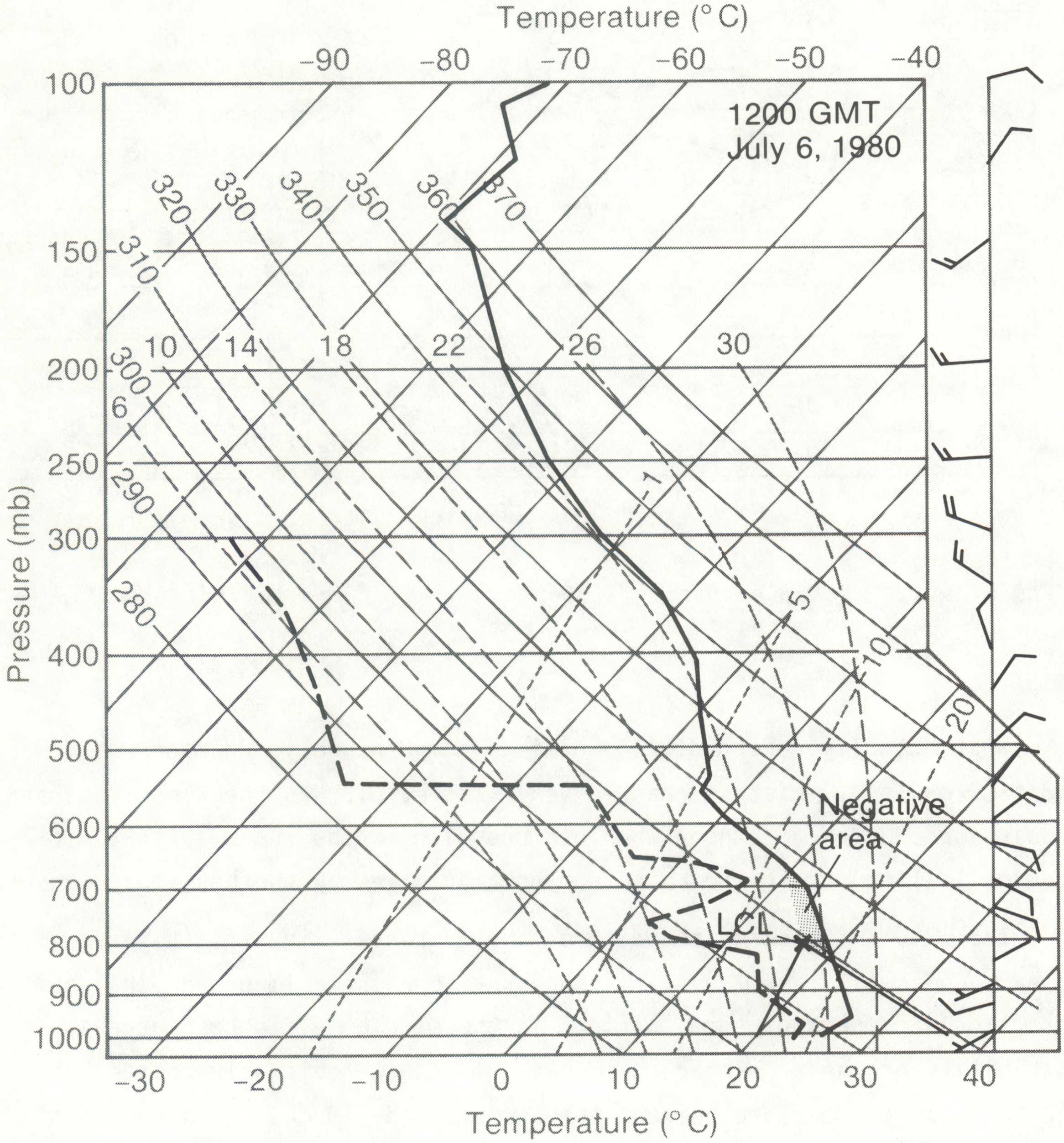

Fig. 94 Skew T/log-P plot of Jackson, Mississippi (JAN) rawinsonde data on 1200 GMT 6 July 1980.

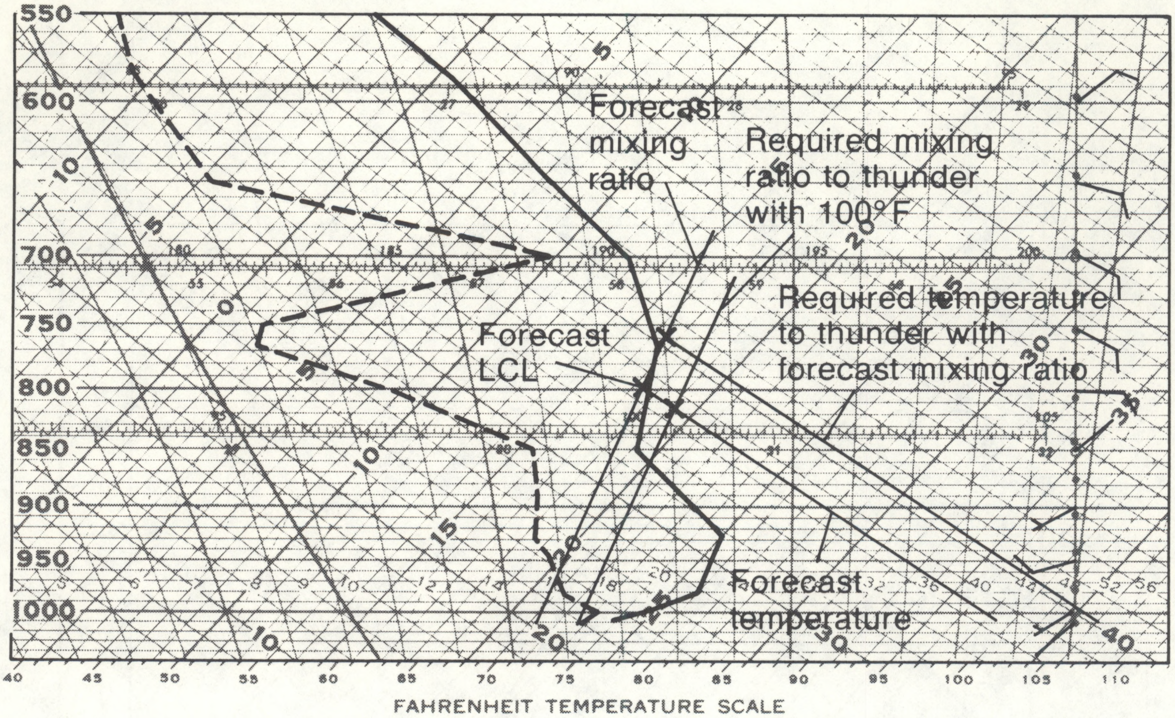

Fig. 95 Detailed plot of lower portions of Fig. 94. if the 1200 GMT sounding on 6 July.

What actually happened? The maximum temperature in Jackson was 100°F, and the low-level moisture changed very little. It was the kind of central Mississippi Sunday afternoon when old dogs lie in the shade (with their tongues lolling) trying to keep from getting baked by the hot, hazy sunshine.

The 1200 GMT Jackson sounding on the next day (Fig. 96) at first glance appears quite similar. However, there have been some important changes. Cold advection (and perhaps some lifting) in the middle levels has increased the instability of the atmosphere somewhat. The most noticeable change has been the increase in moisture between the surface and 770 mb. This sounding exhibits a Totals Index of 57. Using a mean mixing ratio of 18 g kg^{-1} for the lowest 100 mb produces a Lifted Index of -10 (at 500 mb). In contrast the K Index is only 32, owing to the dry air at 700 mb. If the surface temperatures again reached 100°F nothing would inhibit convective development unless enough drying occurred in the low-levels to decrease the average sub-cloud mixing ratio to below 17 g kg^{-1}. Without drying, cumuli would develop when the surface temperature reached about 96°F (see Fig. 97). Initially, these cumuli would have a base near 850 mb and might be inhibited from further growth by

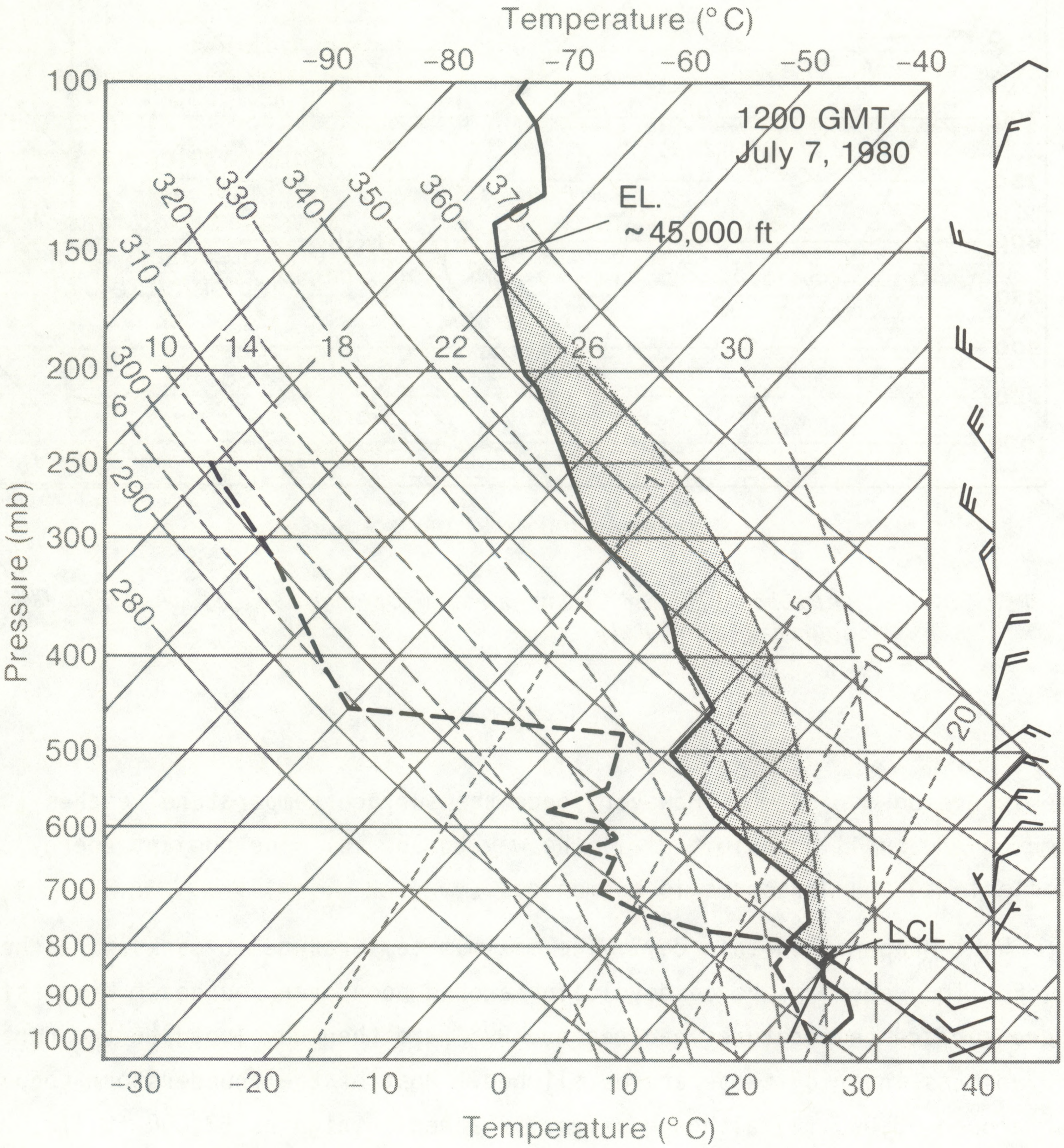

Fig. 96 *Skew T/log-P plot of Jackson, Mississippi (JAN) sounding for 1200 GMT 7 July 1980.*

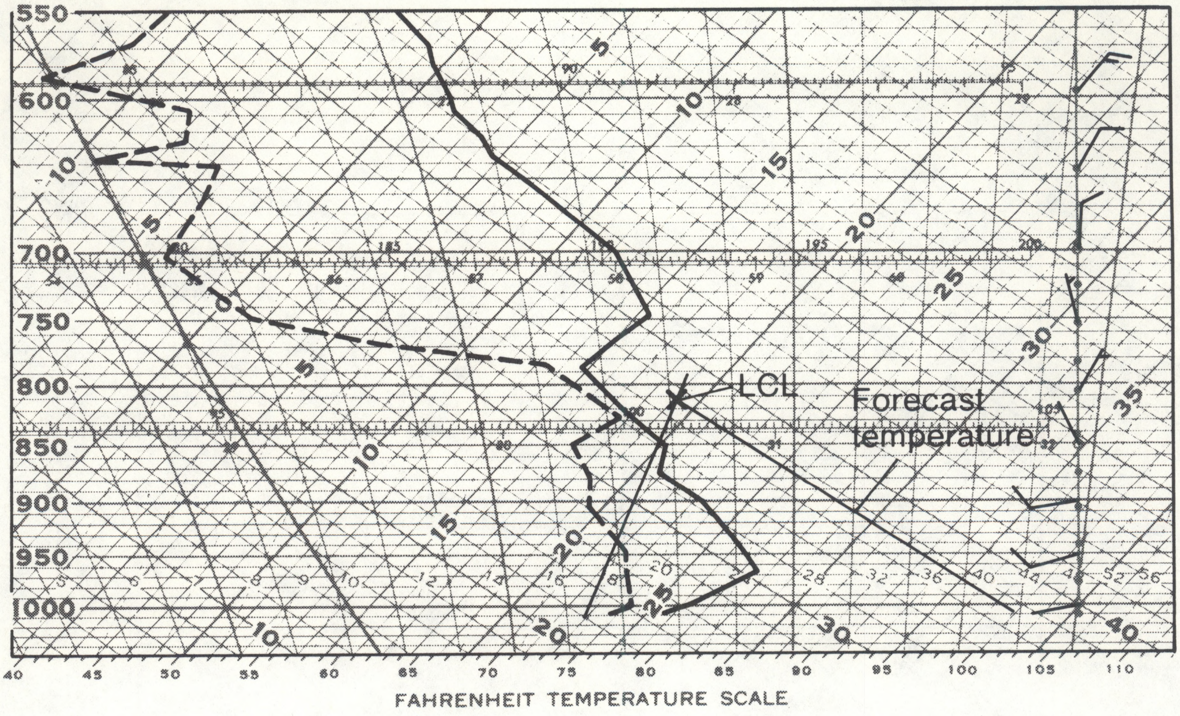

Fig. 97 *Detailed plot of lower portion of Fig. 96. if the 1200 GMT sounding on 7 July.*

the inversion at 750 mb. However, once the surface temperature reaches 100°F, cumulus growth is uninhibited all the way to 150 mb. The buoyant energy then available to thunderstorms is tremendous.

What happened on this day? The maximum temperature at Jackson reached 101°F. Thunderstorms began developing around noon over southeast Mississippi where surface temperatures had reached 99°F and then developed to the north and west as interior temperatures climbed. Most of the thunderstorm topped out around 55,000 ft, although several reached as high as 63,000 ft (18,000 ft above the equilibrium level). Severe thunderstorm warnings were issued throughout the afternoon, as hail fell, trees were uprooted, and strong wind gusts unroofed buildings and caused power outages. In addition, a small plane crashed near Jackson during the thunderstorm activity, killing one passenger and seriously injuring the pilot(see Pfost, 1982, for a detailed description of this event). Diagnosing convective potential using only these soundings provided substantial information about the instability of the atmosphere and the chances that thunderstorms would occur. These are not unusual cases!

The depths of moist layers (ambient and anticipated) can give valuable clues as to whether convection is likely, and if so, whether the main threat is severe thunderstorms or heavy rainfall (or both). In the southern United States, forecasters are well aware that some storms become severe (usually for short periods of time as opposed to long-lived supercells) when shear is weak. However, these storms are the hardest for the forecaster to deal with, and forecasters cannot afford to downplay their importance.

Although strong winds and vertical shear are impressive indicators of severe weather outbreak potential, directional shear should also be examined closely, even when wind speeds are moderate to weak. No matter what the wind speeds, directional shear is apparently very important in many southern United States significant convective weather events. This is true not only of severe thunderstorm outbreaks, but of heavy rainfall events as well. Directional shear can be instrumental in helping thunderstorms become severe by producing large relative wind speeds, especially when storm motion is slow, with weak to moderate environmental flow (Doswell, 1982).

Detailed examination of the directional shear must be accomplished through sounding analysis. Forecasters in the southern section of the country are becoming more aware (through study of significant convective events) that warm air advection (strong veering) in the lowest 100 to 200 mb of atmosphere is probably the most important contributor to the vertical motion field that generates heavy rainfall and/or severe thunderstorms. Directional shear can also be important in generating (by means of differential temperature and moisture advection) the convective instability necessary for storms to become severe. The low-level southeast or southerly flow veers to the southwest or west in the mid-troposphere, allowing dry air from Mexico or west Texas to intrude above the moisture. Without this veering, a deeper layer of moisture is likely, increasing the heavy rainfall potential.

Of the four "air mass types" associated with severe storms (Miller, 1972), two apply most often to storms in the southern section of the country. Figures 98 and 99 show Miller's typical 1200 GMT Type I and Type II severe weather air mass soundings. Forecasters should keep in mind that these are typical pre-storm soundings, and that particularly in the case of Type I, significant changes must take place before the instability can be released.

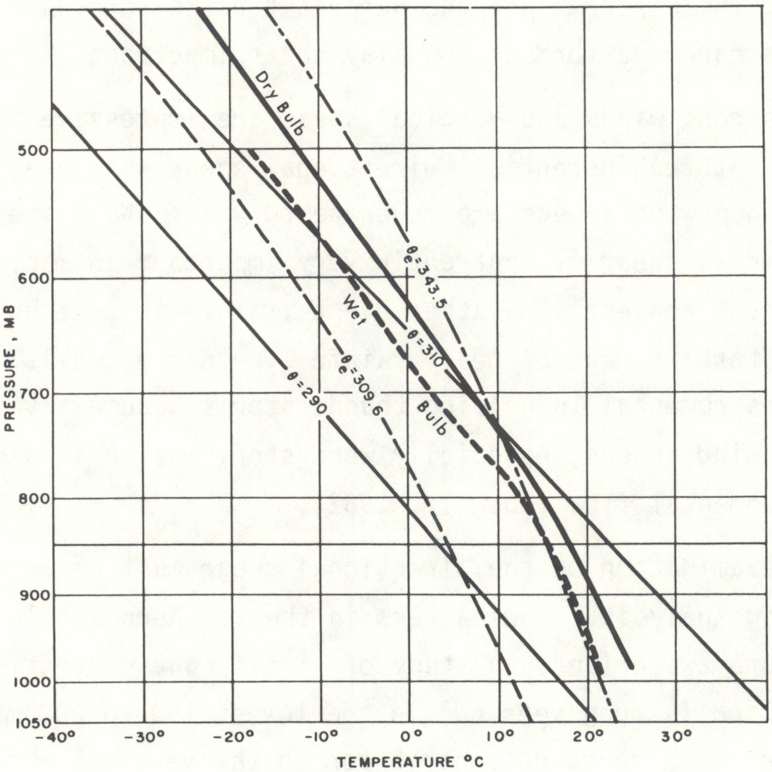

Fig. 98 Mean sounding of Type I Tornado Air Mass (Miller, 1972).

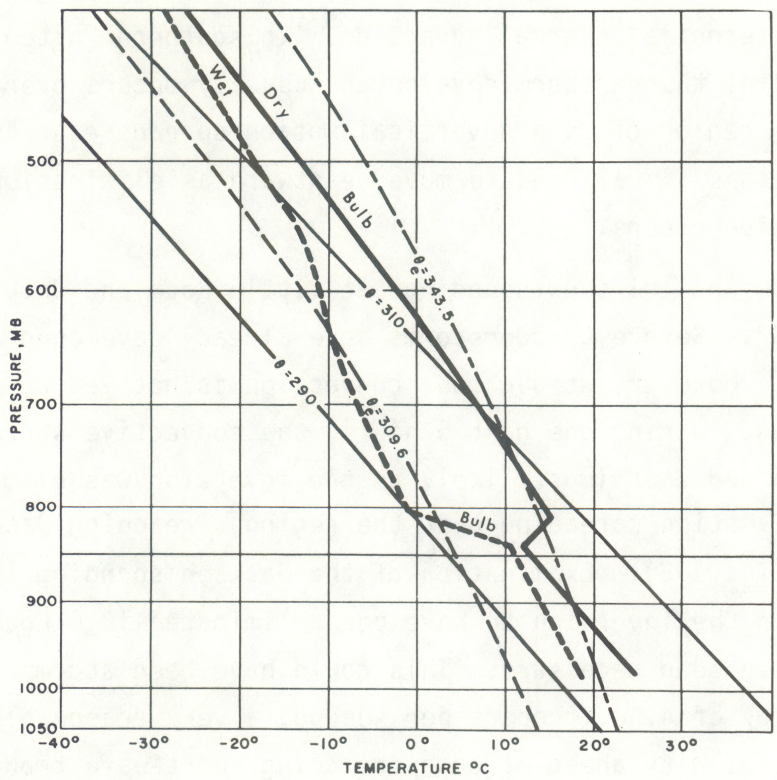

Fig. 99 Mean sounding of Type II Tornado Air Mass (Miller, 1972).

Once these typical soundings are recognized, the forecaster should examine them in detail, concentrating on what is required to release the instability. Elimination of the inversion of the Type I sounding almost always requires more than just afternoon heating. The modifications are usually accomplished by the combined efforts of solar heating, vertical motion, and differential thermal advection. In southern United States severe outbreaks, initial thunderstorm development usually occurs over Texas or Oklahoma. As a region of upward vertical motion spreads eastward, the convection develops (is allowed to move) eastward as elimination of the elevated inversion occurs.

Figures 100 and 101 show soundings at Little Rock and Jackson for 0000 GMT 3 April 1982. Severe thunderstorms have already developed across Arkansas (see Fig. 102). However, at Jackson, convection is not yet possible because of the inversion. During the next 6 hours, the convective storms spread gradually south and east (most likely as the inversion was eliminated by upward vertical motion spreading over the region), reaching Jackson around 0600 GMT (see Fig. 103). Examination of the Jackson sounding (Fig. 101) reveals that for the inversion to have been eliminated in 6 hours, lifting of 100 mb would have been necessary. This could have been accomplished by a vertical velocity of 4.6 microbars per second, a very reasonable synoptic-scale vertical velocity ahead of an approaching short-wave trough. Thus, in this particular case, the steady ascent of atmosphere ahead of an approaching synoptic-scale system could have allowed the release of instability.

Beside computing the vertical motion field required to release the instability of Miller's type I air mass locally, forecasters should study surrounding soundings. For example, suppose examination of the sounding at an upstream station reveals that cumulus development will occur only if specific changes take place in the environment. Through observing the surface temperature and dew point temperature at which cumulus clouds actually develop, the forecaster can estimate the low-level changes since the sounding was taken. Furthermore, observing cumulus growth (using pilot reports for cloud tops) can allow the forecaster to determine how the atmosphere has changed above the cloud bases. Thus, observations at upstream stations can help forecasters anticipate changes in their own area of responsibility.

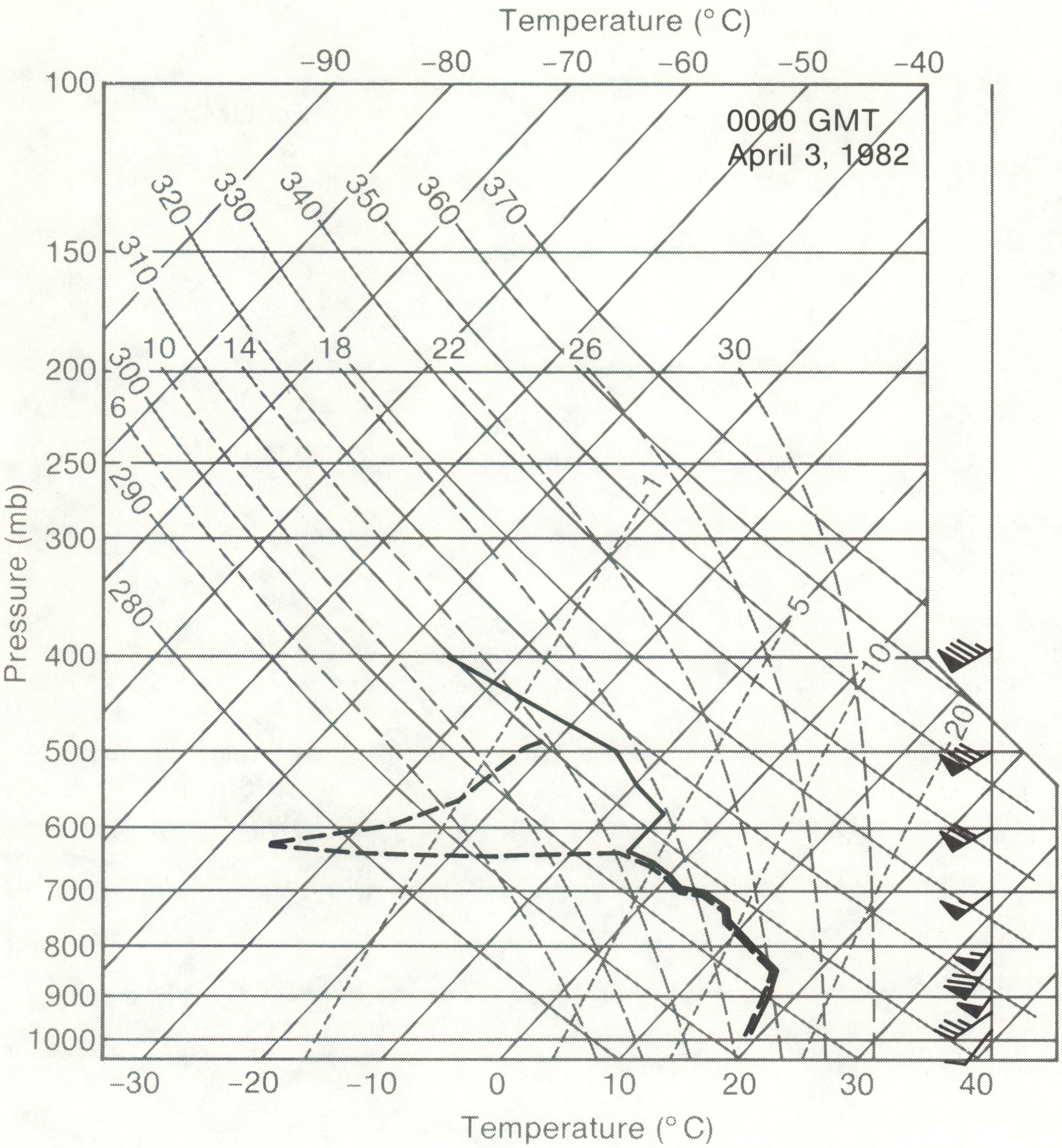

Fig. 100 *Skew T/Log-P plot of Little Rock, Arkansas (LIT) sounding for 0000 GMT 03 April 1982.*

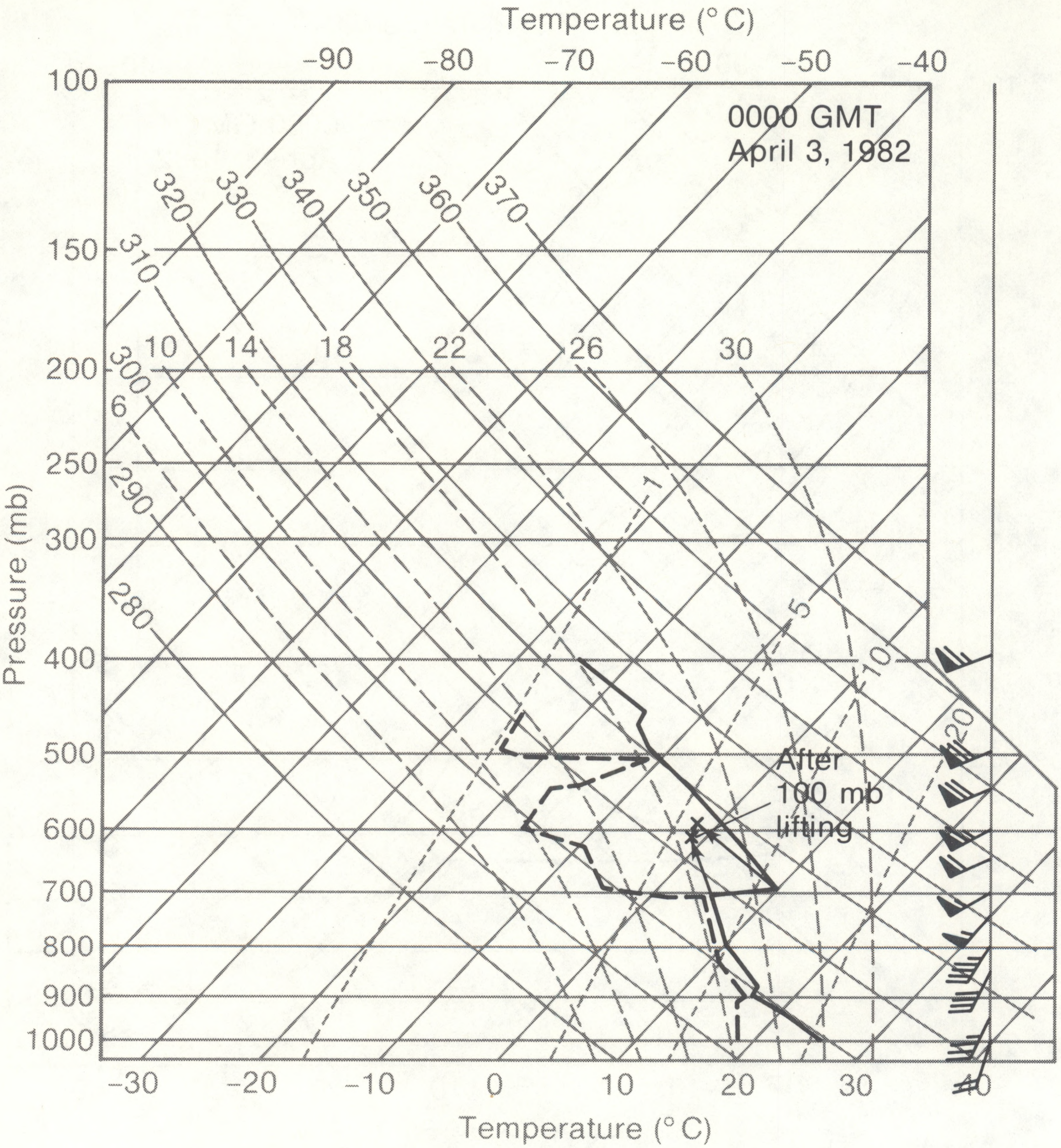

Fig. 101 Skew T/log-P plot portion of Jackson, Mississippi (JAN) sounding for 0000 GMT 03 April 1982.

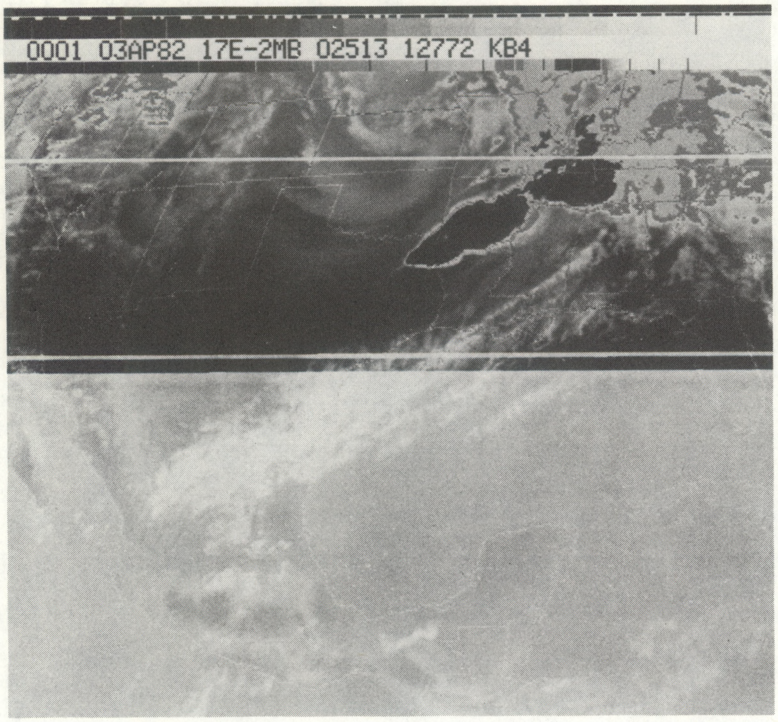

Fig. 102 *Enhanced infrared satellite image for 0001 GMT 3 April 1982.*

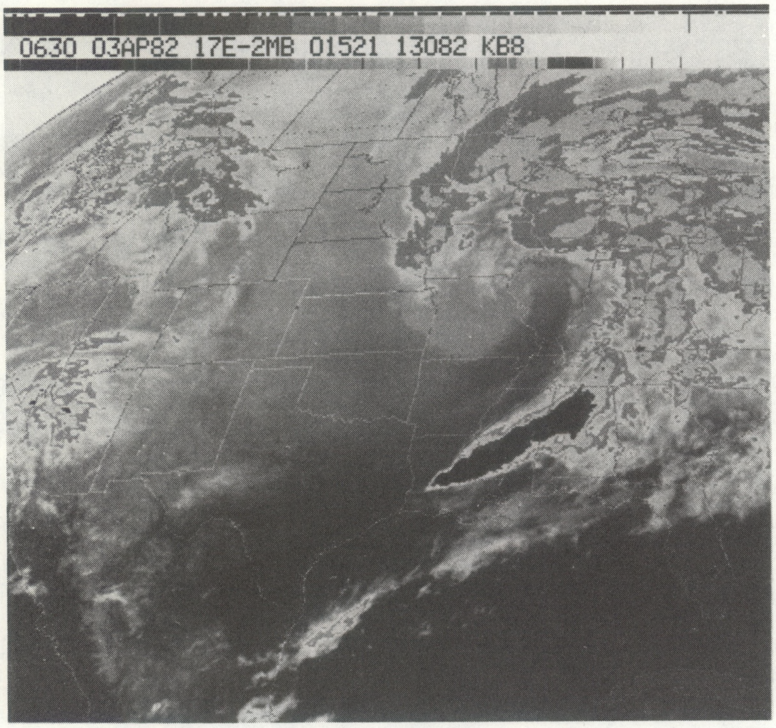

Fig. 103 *Enhanced infrared satellite image for 0630 GMT 3 April 1982.*

Generally, in severe thunderstorm outbreaks of Miller's Type I in the southern United States, the strongest PVA occurs to the north of the region. Low-level warm advection most likely makes a greater contribution in forcing vertical motion. Therefore, monitoring the directional shear associated with strong warm advection is essential, and forecasters should pay particular attention to the veering in the lowest 100 to 200 mb. It is likely that directional shear above 600 mb becomes less important, and cold advection may actually overspread the region in the middle troposphere by the time a severe weather outbreak gets under way. In fact, differential advection is probably a contribution to elimination of the elevated dryline inversion in some cases.

Heavy rainfall events, and minor severe weather outbreaks in the southern United States are often associated with environments characterized by a sounding similar to Miller's Type II. The sometimes frustrating role of the severe weather coordinator is complicated by these outbreaks because many of the storms are severe for only short periods of time. These storms may not appear (on radar) to have the classic severe structure associated with Type I storms. Whether they actually do have the same structure is a matter for debate, but storms produced in the Type II environment usually do not attract the attention of research meteorologists.

Obstacles to overcome for the release of instability may be in the form of a frontal inversion (from an old Gulf baroclinic zone), or a radiation, surface-based inversion (or both). However, in either case, far less lift is required to remove the inversion than is needed for the Type I sounding. One exception may be a winter outbreak in which strong southerly flow of warm, moist air may be overrunning a cold, shallow layer still being reinforced by northeasterly to easterly flow from an east coast anticyclone. Strong thunderstorms may still develop in the warm air above the front, but chances that severe weather phenomena will reach the surface are usually not good. Caution is advised, since there are exceptions (e.g., the Altus, Okla., tornado of February 1975).

Elimination of any inversion is usually accomplished easily by low-level warm advection, and/or solar, boundary-layer heating. Reliance on typical PVA approaches will usually result in failure to recognize the severe weather potential. In Type II situations, it is becoming increasing apparent that the most important influence on the vertical motion field that initiates the convection is low-level warm advection. However, the southern section of the country also experiences significant convective weather events in which both the vorticity advection and thermal advection appear to be weak. Part of the problem here is that the strongest warm advection sometimes occurs below the 850-mb level, thus escaping detection on mandatory level maps. This is why examination of the sub-cloud or boundary-layer thermal advection is so important!

Except for significant low-level veering, the wind profile for Type II severe storm events will usually not be impressive. Although directional shear accompanying this type of sounding will usually show substantial veering up through the middle troposphere (approximately 500 mb), wind speeds will not necessarily be strong, and may decrease with height. A low-level jet may frequently provide the strongest wind flow of the entire sounding below the 400-mb level.

For a number of years, NWS procedures have attached great importance to the tropopause height, with little or no attention toward other high-level stable layers or physically important heights. To make matters worse, the raob minicomputer routinely computes the tropopause height using a constraining definition that may not always truly reflect the situation. In the meantime, sounding data are typically plotted up to the 400-mb level, so that the forecaster knows nothing of the local environment in the vicinity of the computed tropopause. As far as a thunderstorm is concerned, the tropopause has no inherent physical significance. It is the <u>equilibrium level</u> that is significant.

The equilibrium level is the level at which the temperature of an ascending parcel of air would once again be equal to the environmental temperature. It is at this point that the parcel would stop accelerating upward. The upper limit of the parcel's trajectory is naturally above the equilibrium point, the distance depending on the momentum generated by the parcel's buoyancy below the equilibrium level. This can be determined by the positive area on the skew-T/log P diagram, but not on the NWS version of the Stuve diagram.

Tropopause heights and the equilibrium level can be very far apart. Reliance on tropopause heights instead of the equilibrium level can cause serious problems in detecting severe storms. For example, if the tropopause height is 54,000 ft, and the equilibrium level is 36,000 ft, a 42,000-ft thunderstorm may be quite significant even though it does not warrant a special radar observation (for example, see the October 1983 case study by Pfost [1984]). This is not to say that forecasters should base their assumptions on storm severity only by comparing storm tops with the equilibrium level. What is important is realization (by the forecaster and the radar operator) that a storm may be significant because it has developed above the equilibrium level. Then the forecaster may proceed to dissect the storm's structure and determine what action should be taken.

Figure 104 shows the sounding for 1200 GMT 22 December 1982 at Jackson, Mississippi (JAN). This sounding illustrates the pitfalls of correlating tropopause heights with storm severity. It also shows the necessity of anticipating changes in the atmospheric structure. Examining the sounding for stability reveals a SSI of +4, and a LI of +5 (using 7.9 g kg^{-1} to represent the mean mixing ratio in the lowest 100 mb). It is obvious that unless the atmospheric structure changes significantly, there is no chance for thunderstorm development in this environment.

The raob minicomputer computed a tropopause at the 110-mb level (51,700 ft) on this sounding. The existence of the stable layer near 220 mb (35,500 ft) will remain elusive if the forecaster uses a sounding plotted only to 400 mb. Computing the equilibrium level in this case is not easy, and is quite subjective. In spite of this, the importance of the equilibrium level (located at about 440 mb) will be obvious (see Fig. 105).

Examining the wind profile, we can see that warm advection is occurring from the surface to around the 750-mb level, with cold advection between 750 and 500 mb. Therefore, we know that differential thermal advection is probably going to destabilize the atmosphere further with time. By anticipating the effects of advection (considering upstream air at the surface and upper-level maps), and solar heating, I would forecast a mid-afternoon surface temperature of approximately 70°F with a dew point of 60°F. Using these values, we can see that cumulus clouds with bases near the 950-mb level could develop once the temperature reached approximately 68°F. Cumulus growth would be inhibited above the 780-mb inversion unless the inversion had been lifted. In that case, growth still would reach only approximately the 670-mb level (11,000 ft). However, once the temperature reached 70°F, on the basis

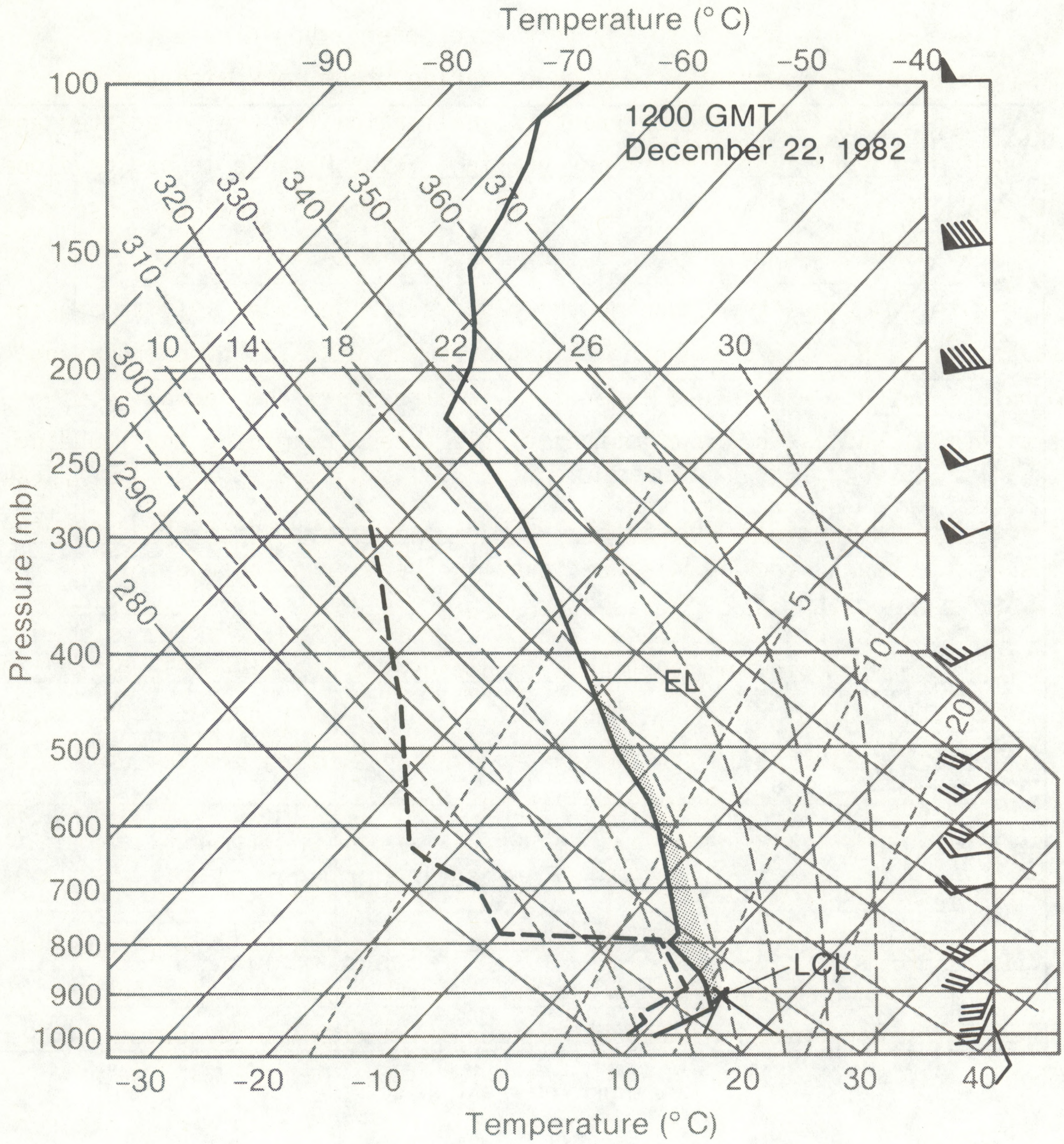

Fig. 104 *Skew T/log-P plot of Jackson, Mississippi (JAN) sounding for data on 1200 GMT 22 December 1982.*

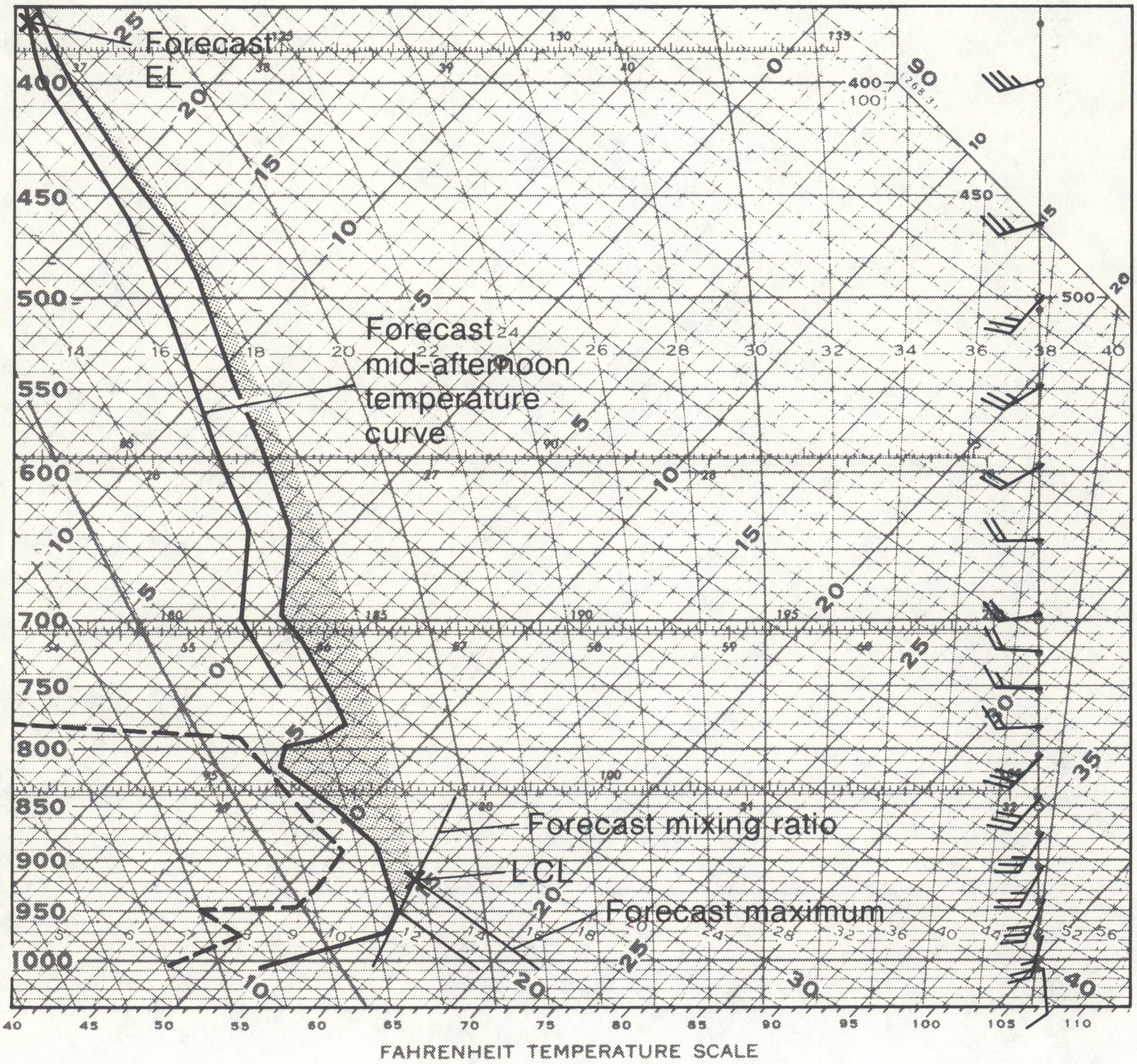

Fig. 105 Detailed plot of lower portion of Fig. 104.

of anticipated low-level changes the new equilibrium level would be near the 420-mb level (22,000 ft). Accurate computation is difficult because of the pseudo-adiabatic lapse rate of the actual sounding between 600 mb and 400 mb.

Now, if we take into account middle-level changes from cold advection, the equilibrium level will be higher. How much higher is greatly a function of our subjective view of the situation. Considering the fact that the 1200 GMT Jackson 500-mb temperature was -13.5°C, while upstream soundings exhibited 500-mb temperatures of -16°C, I would forecast a 500-mb temperature of -15°C for my mid-afternoon sounding. Allowing the whole layer (from 750 to 400 mb) to cool by 1.5°C, we now compute the equilibrium level to be around the 375-mb level (25,000 ft). Different meteorologists would probably compute equilibrium levels for this situation that varied by several thousand feet. But the important point is that the 110-mb (51,700 ft) tropopause found by the raob minicomputer is meaningless in this situation!

Thunderstorms did develop during the mid-afternoon across central Mississippi, and one of them produced a weak tornado. The thunderstorm tops reached maximum heights between 235 and 170 mb (35,000 to 41,000 ft), seemingly insignificant for forecasters who base storm severity on relationships with tropopause heights. Figure 106 shows the EIR satellite imagery for 2200 GMT 22 December. This is approximately the time the tornado was in progress. The satellite imagery shows the temperature of the convective cluster over central Mississippi to be between -41° and -52°C. This certainly does not seem impressive. However, a convective top with a temperature between -41° and -52°C is impressive when the equilibrium level temperature is somewhere between -20° and -28°C.

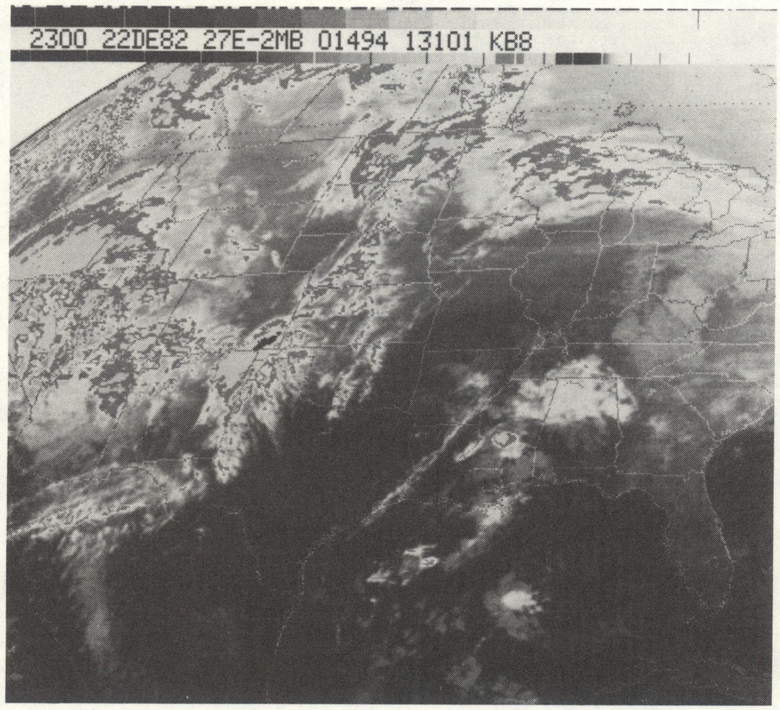

Fig. 106 Enhanced infrared satellite image for 2300 GMT 22 December 1982.

8.0 CONCLUSIONS AND RECOMMENDATIONS

For years I have believed that the key to dealing with significant weather (as well as everyday forecast problems) lies in detailed analysis. Mesoanalysis has been an integral part of my forecast routine for several years, and I am convinced that visualization of the detailed structure of the atmosphere can pay high dividends both to the forecaster and the public. This is especially true for the first- and second-period forecasts.

During the several months I worked with the Weather Research Program of the Environmental Research Laboratories, I hoped (a) to find cases to illustrate the importance of combining detailed analysis with basic meteorology, and (b) to document what can be accomplished with this approach. I didn't think that finding cases would be a problem because I've seen so many cases during my everyday forecast routine. Indeed, one problem was limiting the cases to keep the length of this work from getting totally out of hand. I hope to incorporate some of the cases that didn't make it into this report into a separate workbook and other training packages that Southern Region Scientific Services Division plans to prepare. Ideally, I would have liked to have used AFOS products for all the cases, but this was not possible because of the limited archiving of AFOS data. Nevertheless, the Weather Research Program's extensive archives of NMC maps proved valuable, and the clarity of data was much greater than with facsimile products.

I certainly don't expect this report to be accepted as a definitive answer to the operational problems generated by significant convection, but the case studies support the points that I have made. My hope is to help provide incentive and a foundation for individual weather service offices to use in addressing their own local forecast problems. As I have pointed out in this document, some forecast offices have already begun studying their local climatologies to help deal with a significant convection.

Although I'm convinced that a commitment to detailed analysis and basic meteorology is necessary for the adequate handling of significant weather events (and the first-period forecast in general), I'm equally convinced that the effort requires the cooperation of everyone on the team--both forecasters and managers! If the team's commitment is not genuine and substantial the team will fail. Finally, I make two recommendations:

1. Each WSFO and WSO should appoint one or two individuals "mesoscale focal points". These focal points should be assigned the task of solving local and/or regional forecast problems through mesoanalysis, and could also use their expertise to help other meteorologists on station with their local studies.

2. Station management (or mesoscale focal points) should develop rough outlines for a mesoscale routine. I believe this has already been done at one or two WSFOs. The outline should allow considerable flexibility to repond to the situation at hand.

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REFERENCES

Air Weather Service Manual 105-124: "Use of the Skew T, Log P diagram in analysis and forecasting," July 1969.

Anthes, R.A., 1983: Regional models of the atmosphere in middle latitudes. Mon. Wea. Rev., 111, 1306-1335.

Belville, J.D. and N.O. Stewart, 1983: Extreme rainfall events in Louisiana: The New Orleans type. Preprints, Fifth Conference on Hydrometeorology. Tulsa, Oklahoma, American Meteorological Society, Boston, 284-290.

Doswell, C.A. III, 1982: The Operational Meteorology of Convective Weather, Volume I: Operational Mesoanalysis, NOAA Technical Memorandum NWS NSSFC-5, NOAA/NWS National Severe Storm Forecast Center, Kansas City Missouri, 19, 23.

Grice, G.K. and G.E. Ely, 1983: Surface subsynoptic and upper analysis: An Intergral Part of the Shift Routine, Fifth Conference on Hydrometeorology, Tulsa, OK, 252-258.

Holton, J.R., 1975: An Introduction to Dynamic Meteorology. Academic Press, New York.

Johnston, E.C., 1982: Mesoscale vorticity centers induced by mesoscale convective complexes. Preprints, Ninth Conference on Weather Forecasting and Analysis, Seattle, Washington, American Meteorological Society, Boston, 196-200.

Kaplan, M.L., J.W. Zack, V.C. Wong and G.D. Coats, 1984: The interactive role of subsynoptic scale jet streak and planetary boundary layer processes in organizing an isolated convective complex. Mon. Wea. Rev., 112, 2212-2238.

Liles, C.A., 1976: Variational Optimization Analysis of the 8 June 1974 Severe Storms in Oklahoma. M.S. Master's Thesis, Texas A&M University, 85 pp.

Maddox, R.A., 1979: A methodology for forecasting heavy convective precipitation and flash flooding. Nat. Wea. Digest, No. 4, 32-42.

__________, 1980: Mesoscale convective complexes. Bull. Amer. Meteorol. Soc., 61, 1374-1387.

Magor, B.W., 1959: Mesoanalysis: Some operational analysis techniques utilized in tornado forecasting. Bull. Amer. Meteorol. Soc., 40, 499-511

Means, L.L., 1952: On thunderstorm forecasting in the central United States. Mon. Wea. Rev., 80, 165-189.

Miller, R.C., 1972: Notes on Analysis and Severe-Storm Forecasting Procedures of the Air Force Global Weather Central. Air Weather Service Technical Report 200 (Rev.), Air Weather Service, Scott Air Force Base, Ill., 190 pp.

Mogil, H.M., 1978: Meso-Scale Analysis--An Important But Overlooked Diagnostic Tool, Conference on Weather Forecasting and Analysis and Aviation Meteorology, Silver Spring, MD, 58-70.

__________, 1983: Subsynoptic and mesoscale analysis and Hydro-Meterologoical Forecasting: Can It Be done Without Data? Fifth Conference on Hydrometeorology, Tulsa, OK, 80-87.

Moller, Alan, R., 1980: Mesoscale Surface Analysis of the 10 April 1979 Tornadoes in Texas and Oklahoma, Preprints, Eighth Conference on Weather Forecasting and Analysis, Denver, CO, 36-43.

National Meteorological Center, 1979: North American Surface Analysis, Washington, D.C., Section 2.4.

National Weather Service Operations Manual, 1970: Section A-02.

Nuemann, J., 1951: Land breezes and nocturnal thunderstorms. J. Meteorol., 7, 21--22.

Newell, J.E. and D.G. Deaven, 1981: The LFM-II Model--1980. NOAA Technical Memorandum NWS NMC 66, NOAA/NWS National Meteorological Center, Washington, D.C.

Orlanski, I., 1975: A rational subdivision of scales for atmospheric processes. Bull. Amer. Meteorol. Soc., 56, 527-530.

Pfost, R.L., 1982: Heavy Thunderstorms over South and Central Mississippi, Monday July 7, 1980. Nat. Wea. Digest, 7, (2): 19-25.

__________, 1984: A Very Small Scale Heavy Rainfall Event-Part I, Southern Region Technical Attachment, 28 August 1984, 6 pp.

Purdom, J.F.W., 1976: Some uses of high-resolution GOES imagery in the mesoscale forecasting of convection and its behavior. Mon. Wea. Rev., 104, 1474-1483.

Ramage, C.S., 1982: Have precipitation forecasts improved? Bull. Amer. Meteorol. Soc., 63, 739-745.

Reed, R.O. and G.K. Grice, 1983: A Review of the use of the Thermodynamic Diagram and its Functions. NOAA Technical Memorandum NWS SR-109, NOAA/NWS Southern Regions, Ft. Worth, TX.

Sanders, F., 1979: Trends in skill of daily forecasts of temperature and precipitation, 1966-78. Bull. Amer. Meteorol. Soc., 60, 763-769.

Sangster, W., 1980: A New Concept in Diagnosing Large-Scale Vertical Motion. Central Region Technical Attachment 80-20, National Weather Service, Washington, D.C.

Schaefer, J.T., 1973: The Motion and Morphology of the Dryline. NOAA Technical Memorandum ERL NSSL-66, NOAA/ERL National Severe Storms Laboratory, Norman, Oklahoma, 81 pp.

Snellman, L.W., 1977: Operational forecasting using automated guidance. Bull. Amer. Meteorol. Soc., 58, 1036-1044.

Trenberth, K.E., 1978: On the interpretation of the diagnostic quasi-geostrophic omega equation. Mon. Wea. Rev., 106, 131-137.

Zipser, E., 1983: The National Storm Program.

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