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DIAGNOSING THUNDERSTORM POTENTIAL
USING AFOS

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DIAGNOSING THUNDERSTORM POTENTIAL USING AFOS

The following set of guidelines can be used as a guide for thunderstorm forecasting and will focus on the three necessary ingredients for thunderstorm development. They are

1. LOW LEVEL MOISTURE
2. INSTABILITY
3. LIFTING MECHANISM

All three of these ingredients are important for convection. The presence of each on a given day can be used to subjectively analyze the potential for thunderstorms. The forecaster must look at the relative strengths of each of the three to come up with a potential. For example, a very strong lifting mechanism, such as a strong cold front or vigorous short wave, might help overcome a lack of rich, deep low level moisture. Or the presence of extreme instability will help negate the lack of a strong lifting mechanism. This discussion, although not meant to be comprehensive, will give the reader a good start with regard to how to predict thunderstorm location and severity. Sounding analysis is a very important starting point for thunderstorm prediction and will be stressed throughout the paper.

I. LOW LEVEL MOISTURE

A. INTRODUCTION

The presence of low level moisture is one of the primary things to look for in predicting thunderstorms. Increasing low level moisture leads to an increase in atmospheric instability. The primary source of low level moisture for much of the southern United States is, of course, the Gulf of Mexico. South to southeasterly low level flow can advect moisture from the Gulf into many areas east of the Rockies, especially when a strong low level jet exists. "Low level" in this case refers to that part of the atmosphere from the surface to around 4 or 5 thousand feet above the surface. The ideal situation is to have a deep (5000') layer of moisture capped by much drier air aloft, say at 700 mb. This maximizes the potential instability.

B. GRAPHIC PRODUCTS

All AFOS graphics have the 9 letter identifier NMCGPHxxx which can be displayed by simply entering xxx at an AFOS ADM. All AFOS graphic products will be referenced by only the 3 letter identifier xxx throughout this paper.

1. The first chart to look at to get a broad picture of available surface moisture is an AFOS surface chart. It would be a good idea to draw isodrosotherms (lines of equal dew point) to get a picture of surface moisture distribution in the area of concern. If strong (>25 kts) or moderate (15-25 kts) south to southeasterly flow exists from the gulf coast to Oklahoma, with dew points increasing to the south, then it is obvious

that higher dew points are advecting into Oklahoma. Sometimes in summer, dew points along the gulf coast can be over 80 degrees with 70s reaching north into most of the southern United States.

Other charts for examining surface moisture are generated by the AFOS Data Analysis Programs (ADAP) (Bothwell, 1988). Values of objectively analyzed surface mixing ratio in grams per kilogram are displayed by SMR, shown in Figure 1. This chart focuses on a smaller region than that of a regular AFOS chart and allows the user to monitor the surface moisture in the area on an hourly basis. Surface streamlines (SSW) can be overlayed with SMR to detect regions experiencing the maximum surface moisture advection. Another ADAP product, SQC, which shows mixing ratio changes with units of g kg-1 hr-1, is shown in Figure 1. The user can change the time interval analyzed to between a 1 and 23 hour change. Two hour changes are usually recommended as a balance between reducing noise and retaining the mesoscale signal. Increasing surface dew points/mixing ratios can lead to a rapid destabilization of the atmosphere since surface air parcels with higher moisture content are more buoyant and also require less lifting to reach saturation.

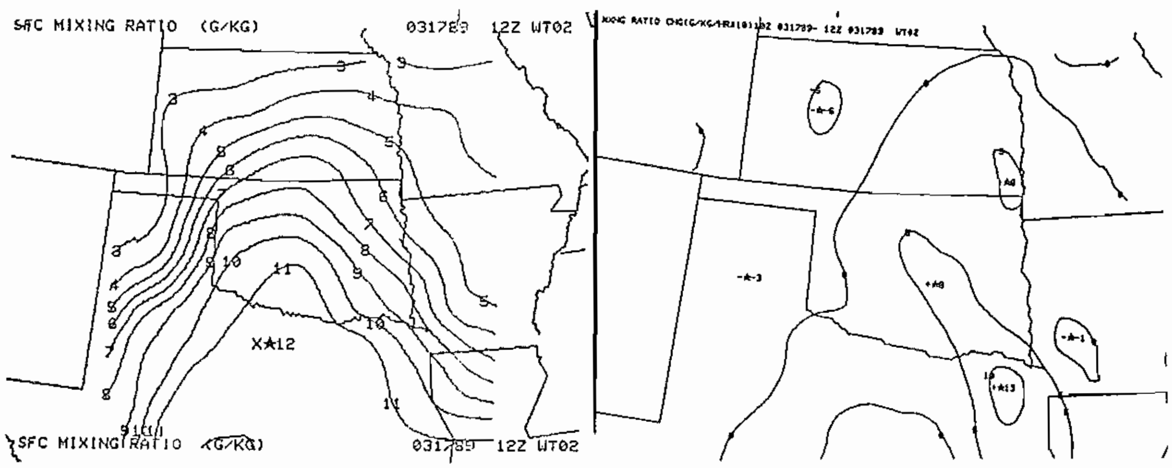


Figure 1: Examples of ADAP graphics SMR (left) and SQC (right). The highest moisture values are pushing into south central Oklahoma, while the best two hour increase is across eastern Texas.

2. So far, the discussion of moisture maps has dealt with surface moisture. For severe convection to develop, a deep (4-5 kft) layer of moisture is typically present. The 850 mb plot, 80A, gives a moisture distribution at the 850 mb level (approx. 5 kft above mean sea level). Temperatures and dew point depressions are plotted. The best way to view the moisture distribution is to obtain dew points by subtracting the depression from the temperature and drawing isodrosotherms. Again, notice whether or not the area of concern has high dew points at 850 mb or if higher dew points will be advected into the area. It might even be useful to look at the previous version of 80A to see how much the 850

dew points have changed during the past 12 hours.

An alternative is to use Michael Foster's Upper Air Diagnostics program (UA) on an AFOS ABT computer. This program objectively analyzes mandatory level upper air data and calculates derived fields. Examples of two of these UA graphics, 850 mb dew points (80P) and 850 mb mixing ratios (80R), are shown in Figure 2. Table 1 provides guidance with respect to what is considered to be a "high" moisture content at 850 mb as well as in the low levels as a whole. Some of the numbers in Table 1 were taken from Miller (1972), others are from the author's experience. The values given in the table are meant to be used in the southern states east of the Rockies. For an area in say North Dakota, farther from a source of moisture, lower values of moisture will be considered "HIGH". The same holds true for elevations higher than about 2000 feet. For example, a surface dew point of 55 degrees F is only "GOOD" in northern Texas, while the same 55 degree dew point might be considered "HIGH" in North Dakota.

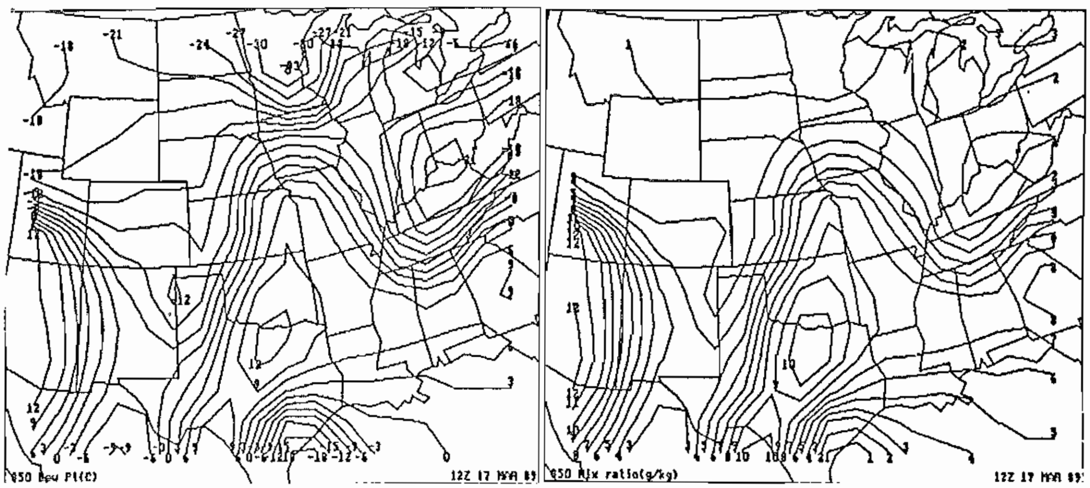


Figure 2: Examples of UA graphics 80P (left) and 80R (right) showing 850 mb dew points and mixing ratios. Notice the maximum values in south central Oklahoma and north central Texas.

3. To best determine location and depth of moisture, examine the local soundings. A sounding can show moisture below 850 mb, if it exists, which otherwise may be overlooked if only the 850 mb plot is examined. For example, a forecaster interested in thunderstorms in northeast Oklahoma would look at the soundings from Norman, OK (OUN) and Monett, MO (UMN). If OUN or UMN has little in the way of low level moisture in their soundings, look at the soundings from Stephenville, TX (SEP) or Longview, TX (GGG). Is the moisture more abundant and deeper? Are southerly winds going to advect the moisture northward in time to give northeast Oklahoma a deep layer of low level moisture and form thunderstorms? Are winds likely to back or veer in the next 12 hours to create a flow more favorable or less favorable for moisture return?

Isentropic surfaces from AFOS program ISENT (Little, 1985) are also excellent for finding low level moisture. These plots on a constant potential temperature "surface" are like material surfaces and are usually better than the constant pressure charts for tracking moisture.

Table 1: Values of moisture for convection

	LOW	MODERATE	HIGH
sfc dew point (F)	55 F	56-65 F	>65 F
sfc mixing ratio	10 g/kg	11-15 g/kg	>15 g/kg
850 dew point (C)	8 C	9-14 C	>14 C
850 mixing ratio (or mean mixing ratio sfc to 5 kft)	8 g/kg	9-12 g/kg	>12 g/kg

4. Look for low cloudiness on satellite imagery. Stratus or stratocumulus clouds will often form in the late night to early morning period when abundant, low-level gulf moisture is advected northward and saturation is reached. Many times, moderate to strong southerly winds will develop ahead of an approaching storm system. The southerly winds can tap moisture from the gulf and low clouds can form in the region of rising motion associated with low level warm advection. Look at surface observations upwind from the area of interest or any available satellite imagery to find the low clouds. Kansas City will often issue special satellite interpretation messages (SIMMKC) denoting the northern edge of a northward advancing area of low cloudiness, appearing as "dark stratus" on nighttime infrared imagery, which marks the edge of the deeper low level moisture (Gurka, 1980).

II. INSTABILITY

A. INTRODUCTION

Thunderstorms usually do not form in areas with no vertical instability. An exception is slantwise convection which will not be covered here; instead the reader is referred to Lussky (1987). Severe thunderstorm formation usually requires a high degree of instability. This section tells how to measure stability by using various charts and indices. A brief look at how to tell if instability will significantly change is also presented.

B. AFOS GRAPHICS

1. The first and most important duty a forecaster of convection should perform is inspecting the soundings in order to determine atmospheric instability. The Skew-T format available from program RP.SV on AFOS plots soundings using mandatory and significant level data. Looking at the soundings will enable the forecaster

to get an idea of the actual temperature and moisture profile. AFOS soundings also give a number of indices on the chart, which can be used for reference. Refer to Miller (1972) or Sadowski and Rieck (1977) for a detailed discussion of stability indices. In addition, winds are plotted on the soundings. Winds that veer and increase in velocity with height, starting at the surface up to 3 or 4 kilometers, are favorable for the formation of organized thunderstorm updrafts and tornadoes (see IV.A.1). A good way to thoroughly examine the wind profile is to inspect a hodograph, which is discussed in section IV.B.

A very good idea of how much positive area will be available in the afternoon can be obtained by using a morning sounding and estimating the afternoon temperature and dew point. The positive area in a sounding is that area bounded by the moist adiabat of the surface parcel and the actual sounding temperature trace above the Level of Free Convection and below the Equilibrium Level (Air Weather Service, 1961). The amount of positive area is proportional to potential energy, which is theoretically proportional to the updraft speed and storm top (Weisman and Klemp, 1986). Another AFOS applications program, CONVECTA, calculates positive area. CONVECTA will be discussed in section IV.

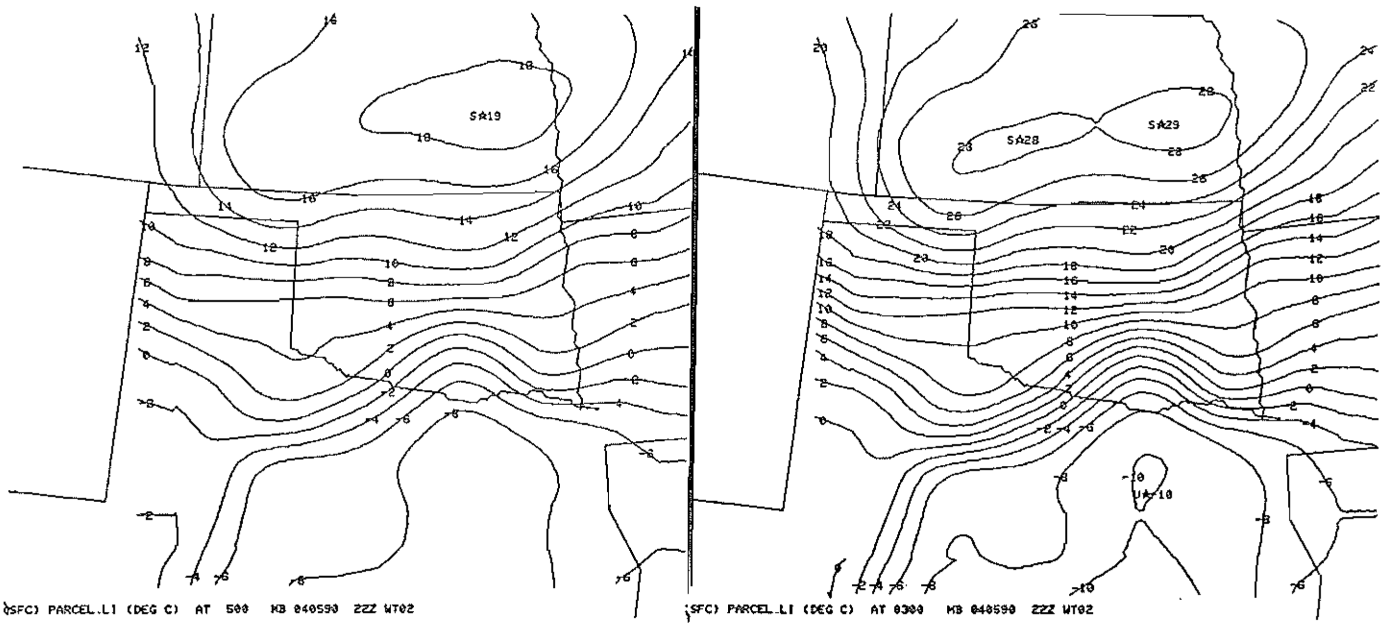


Figure 3: ADAP lifted index graphics SSL (left) and SSU (right). Maximum instability is in northcentral and northeast Texas. Very stable air is over northern Oklahoma and Kansas to the north of a front.

2. ADAP Graphics

a. Each hour, ADAP generates two Lifted Index graphics. The first, SSL, is the LI at 500 mb and is found by lifting a surface parcel. The second, SSU, is an LI at 300 mb using the same surface parcel. The only difference is that the parcel is lifted to 300 mb before the temperature difference is taken. When the numbers in SSU are more unstable than those in SSL in a given area, as in Figure 3, a large amount of positive area exists. Be aware that these two graphics lift a SURFACE parcel for the index calculation. The numbers that they give may not be very representative of actual instability if moisture is very shallow. Also be aware of changes occurring aloft that could affect the stability. Specifically, look at 500 mb temperature advection on AFOS chart 50A or UA products 50T or 50A. Other things being equal, mid-tropospheric cold advection, at 500 mb for example, will destabilize the atmosphere. Also keep in mind that synoptic scale upward vertical motion leads to destabilization while synoptic scale sinking motion leads to atmospheric stabilization.

b. Two other ADAP graphics can be used to help determine instability. Instead of using a surface parcel to calculate the LI, these two graphics (SXL and SXU) use that parcel in the lowest 300 mb of a sounding which has the maximum wet bulb potential temperature (Theta W). Examples of SXL and SXU are given in Figure 4. Basically what ADAP does is search each sounding, using significant and mandatory upper level data, and finds that parcel in the lowest 300 mb which gives the maximum instability if that parcel were lifted to 500 mb (SXL) or 300 mb (SXU). These two charts use only upper air data and therefore are generated only twice a day and have poorer spatial resolution than the hourly products. These charts can be used when the surface conditions are not representative of what is going on just above the

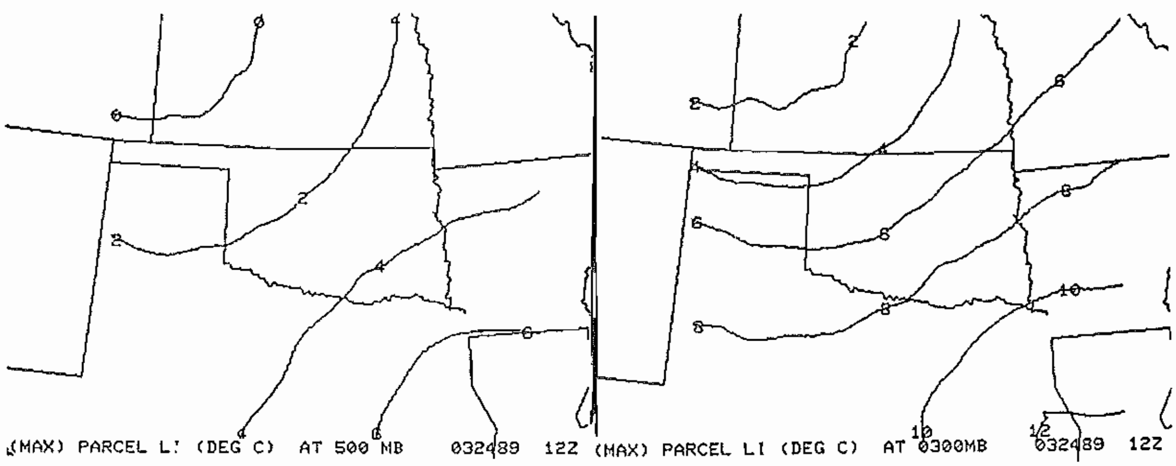


Figure 4: ADAP graphics SXL (left) and SXU (right) are generated only twice a day and use the maximum theta W in the lowest 300 mb of the sounding for the LI calculation. Note the word "MAX" in parentheses on the lower left of each chart.

surface. For example, a look at SXL and SXU would be beneficial at night or when a warm front is to the south with cool, stable air at the surface and much warmer and more moist air several thousand feet above the surface. The surface-based LIs may give very large positive numbers while the Theta W max LI may show some instability. In this particular case, thunderstorms may be a good possibility. Their likelihood and severity depends on the temperature profile aloft, the strength of the warm advection, and upper air support.

3. NGM Products

a. Four-layer Best LI progs
This prog is a graphic of forecast 500 mb LI available at 12 hour increments out to 48 hours. The commands for these are I2L, I4L, I6L, and I8L. The numbers are obtained by lifting a parcel from each of the NGMs four lowest layers and plotting the lowest of the four numbers (Phillips, 1985). The author's experience with this graphic has shown that it does a pretty good job of finding those areas of maximum instability, especially out to 24 hours. Weiss (1987) found that the NGM often overforecasts areas of extreme instability (LI less than or equal to -8).

As an example of using the NGM LIs, let's say I6L shows an area in central Kansas where instability exists with minimum LIs at or below -4. The significance of the chart in this case is not necessarily the value of the index itself, but rather the AREA, in this case central Kansas, which has the lowest LIs. The NGM is predicting the best combination of warm, moist low level air and cool mid level temperatures in central Kansas in its 36 hour prog. For forecasting less than 12 hours in advance, it is a good idea to look at the initial graphic I0L and compare the numbers with those from the soundings or ADAP to see how well the NGM is doing. Examples of the NGM four layer LI will be shown and discussed in the case study in Section V.

b. "Raw" NGM output
Forecast numbers of 4-layer LI are available at several particular stations by looking at tabulated FOUS data from the NGM. The AFOS identifiers for these products are in the form FRHTxx where xx is a number between 60 and 78 (National Weather Service, 1985). The LIs on the tabulated data are the same ones plotted on the graphics, except the tabulated data gives values every 6 hours out to 48 hours. Keep in mind that the forecast numbers from the NGM are susceptible to the same errors that occur every day with the models, such as being too warm or too cold, too fast or not fast enough with fronts, bad initialization, too weak or too strong with low level

flow and corresponding return of moisture, etc. The tabulated NGM FOUS data has other uses; examples will be shown and discussed in Section V.

C. ADDITIONAL NOTES

One graphic on Foster's UA program, 70S, gives a measure of instability. This product is a graphic of 700 mb to 500 mb temperature difference; an example is shown in Figure 5. This number, which is easily calculated, gives the steepness of the lapse rate between 700 and 500 mb. A steep lapse rate for this layer is around 22-24 degrees C. The temperature difference for a dry adiabatic lapse rate through this layer varies some with temperature but is right around 26 degrees C in the usual temperature range for convection.

The trajectory model gives a 24 hour forecast of surface, 850 mb, and 700 mb temperature and dew point, as well as forecast K-index and trajectory forecasts (Reap, 1978). The AFOS command for the message is FTJxx where xx is a number between 50 and 57. Graphic products depicting parcel trajectories are also available from the trajectory model. The trajectory output can be used to plot part of a forecast sounding up to 700 mb. Other uses of the trajectory forecast output and graphics will be given in Section III and examples will be given in Section V.

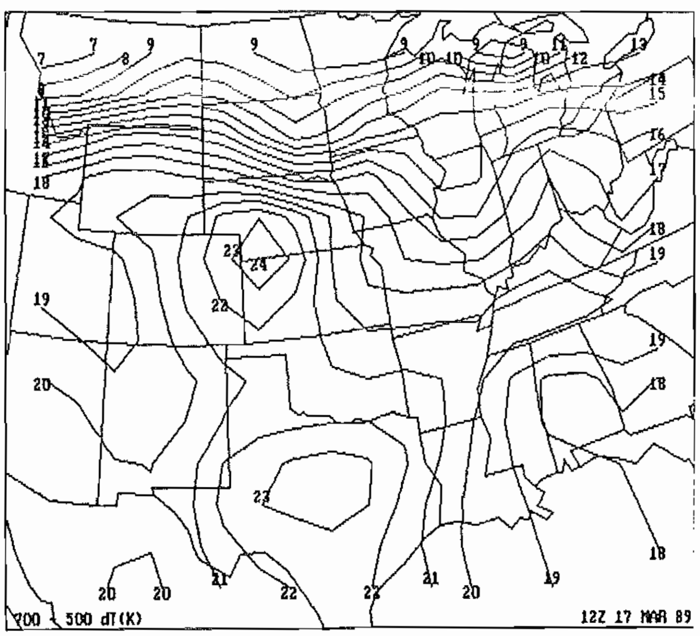


Figure 5: UA graphic 70S which is a map of 700 mb to 500 mb temperature change. In this example, the steepest lapse rates are in central Texas and northwest Kansas/southwest Nebraska.

The forecast temperature at 500 mb, as well as the forecast temperature and winds at other levels, can be obtained from the forecast temperature and winds aloft product (FD) issued by NMC (National Weather Service, 1979). The forecaster can examine the current and forecast temperatures at 500 mb to assess the changes occurring aloft which might affect the atmospheric stability. Other uses of the FD products are discussed in Section IV.A.1.

IT SHOULD BE EMPHASIZED THAT NOTHING IS MORE IMPORTANT THAN EXAMINING THE SOUNDINGS. After examining the morning soundings, the hourly ADAP products can be inspected each hour to keep track of the increasing instability that takes place with daytime heating or an increasing moisture supply. Keep in mind that the ADAP products during the day are only using 12Z upper air data to obtain the grid point temperatures at 500 mb and 300 mb. ADAP does not and cannot take into account changes occurring above the surface, unless the user manually edits the upper air files and reruns the upper air objective analysis (Bothwell, 1988). At night, look at ADAP graphics SXL and SXU which will likely be more representative of instability when a boundary layer inversion exists. Look at other guidance products to monitor changes that may be occurring above the surface, e.g. 500 mb temperature advection. If all available tools are used, including soundings, ADAP, and the NGM progs, an excellent picture of instability and its areal distribution can be determined.

III. LIFTING MECHANISMS

A. INTRODUCTION- LIST OF TRIGGERS

With moisture and instability in place, a "trigger" mechanism is needed to release the instability and form the thunderstorm. The trigger provides the necessary initial vertical velocity necessary for thunderstorm formation. Upper level forcing often leads to low-level adjustments in the temperature, dew point, wind, and pressure fields. Below is a list of lifting mechanisms which can act as "triggers".

1. Convergence along fronts, troughs, outflow boundaries, or drylines.
2. Convergence associated with mesolows.
3. Synoptic scale rising motion associated with differential positive vorticity advection.
4. Synoptic scale rising motion associated with low level warm advection.
5. Rising motion below right rear or left front quadrants of upper level jet streaks.
6. Solar heating (differential solar heating).
7. Orographic lifting (upslope).
8. Gravity waves.
9. Sea breeze fronts.

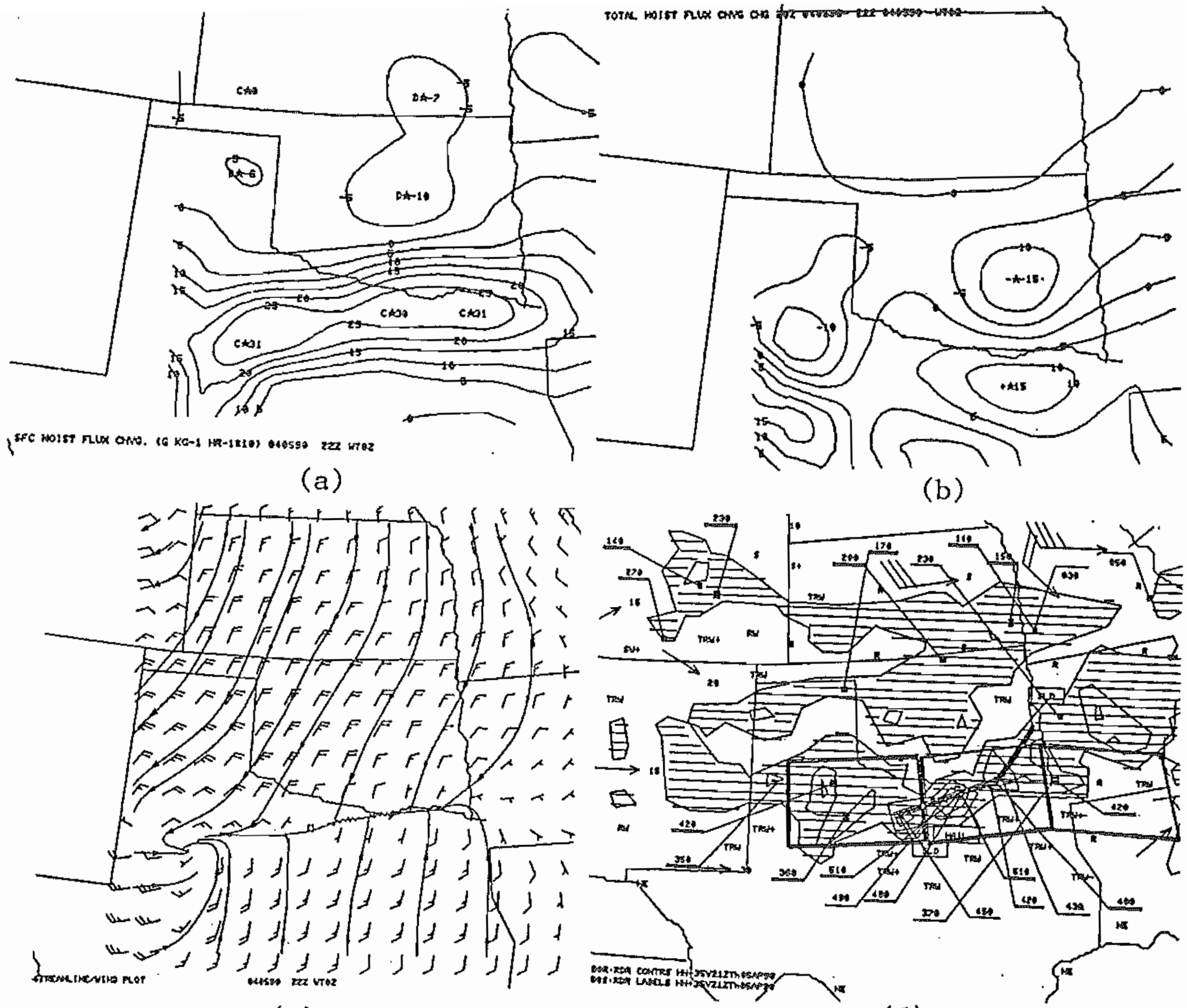
B. AFOS AND UA GRAPHICS

1. Four ADAP products are generated every hour to help locate those areas where a good trigger exists. They are:
   a. SMC- moisture flux convergence. Look for areas of positive moisture flux convergence associated with fronts, dry lines, troughs, etc. The pattern of moisture flux convergence can hint at the type of convection which might form; i.e. an east-west or north-south axis of moisture flux convergence might lead to a squall line while a small, round center might lead to an isolated cell. Be aware that thunderstorms don't always form right in the area of strongest moisture convergence, but may sometimes form in areas where the convergence is much weaker. This can be explained by realizing that the region of moisture convergence is frequently underneath a capping inversion. Moisture may build up under the inversion and thunderstorms may form in an area where relatively weak moisture convergence exists but a weakness in the cap also exists (Bothwell, 1988).

   b. SCC- two hour change in moisture flux convergence. Look for areas of increasing moisture convergence- it means either low level forcing is increasing, or moisture is increasing or moisture advection is increasing, and thunderstorms become more likely there. Sometimes, the moisture convergence maps, as well as the other ADAP graphics, will show maximum or minimum centers. These centers are often authentic maxima or minima in the field being analyzed. Other times, the centers may be an artifact of the objective analysis, especially when there are weak gradients. Examples of SMC and SCC are shown in Figure 6.

   c. STA and SAA- surface theta advection and two hour average theta advection. Look for areas of sustained warm advection. Low level warm advection is associated with synoptic scale rising motion (Holton, 1979). More obvious is the fact that warm advection can act to bring in warmer and therefore more unstable air. Intense warm advection sustained over a period of several hours can enhance geostrophic wind veering in the lower levels of the atmosphere which increases the potential for severe thunderstorms or tornadoes. Examples of theta advection graphics are shown in Figure 7.

2. There are numerous graphics generated by the three numerical models, the NGM, AVN and LFM, to help determine the areas where lifting will occur. All the graphics can't be listed here, but instead the discussion will focus on the products generated by all three models. First, though, the availability and



(a) (b) (c) (d)

Figure 6: (a) Example of moisture flux convergence SMC and (b) moisture flux convergence change SCC. A well-defined moisture flux convergence axis is across north Texas with increasing moisture flux convergence across northeast Texas. (c) shows the surface streamlines & wind plot (SSW). (d) shows the radar summary chart for approximately the same time as the ADAP graphics. These graphics are from the same date/time as those in Figure 3. A severe thunderstorm outbreak occurred on this day in northern Texas with several tornadoes reported west of Abilene, TX and northwest of Waco, TX. Figure 8 shows the respective cap strength and altimeter change graphics.

importance of the mandatory level plot maps will be emphasized. Each of these, 80A, 70A, 50A, 30A, 20A, and 20B, are available twice a day in AFOS. A hand analysis of these maps, as opposed to a smoothed computer analysis, will allow the analyst to better locate boundaries or short waves, areas of warm and cold advection, and jet maxima.

Getting back to the models, each of NMC's current models generates surface charts and 500 mb height and vorticity charts. Overlaying 500 mb heights and 500 mb vorticity gives the frequently used 500 mb vorticity advection which is used to infer rising motion for positive vorticity advection. A better alternative is to overlay the 500 mb vorticity with the appropriate 1000-500 mb thickness chart to detect vorticity advection by the thermal wind (Doswell, 1982). This alternative method automatically includes both the vorticity advection and temperature advection contributions to assess vertical motion (Trenberth, 1978). Rising motion is inferred from positive isothermal vorticity advection (PIVA) and synoptic scale sinking motion is inferred from negative isothermal vorticity advection (NIVA).

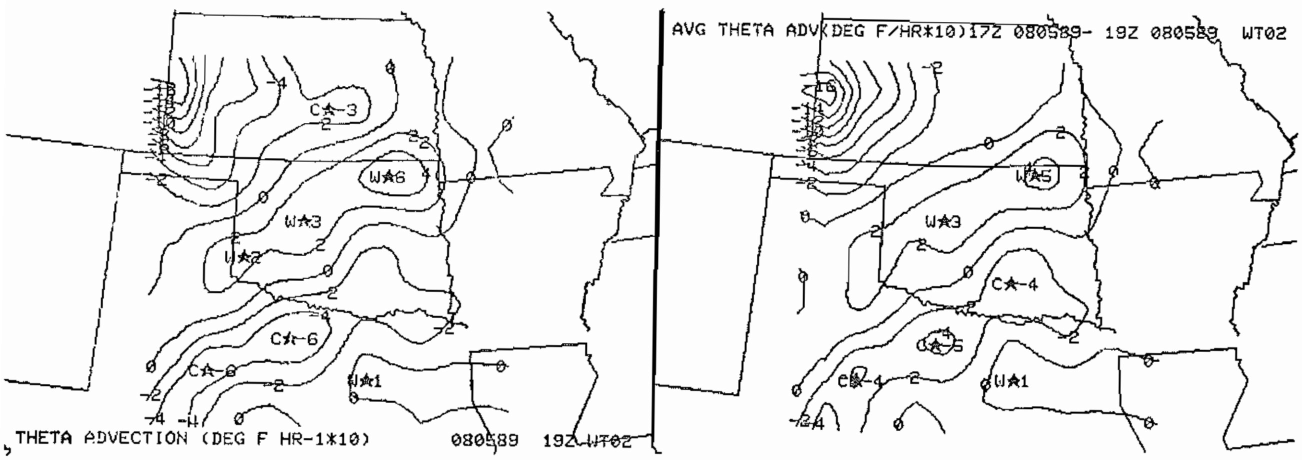


Figure 7: Examples of ADAP surface Theta advection STA (left) and 2 hour average Theta advection SAA. Note axis of weak warm advection from west central to northeast Oklahoma. Theta advection is analyzed instead of temperature advection to help alleviate spurious warm and cold advection centers caused by elevation differences (Bothwell, 1988).

All three model solutions should be considered because many times one has a more reasonable solution than another on location of surface features and short waves. Prognostic map discussions from NMC (e.g. PMDSPD) or state forecast discussions (cccSFDccc) will often mention a preferred "model of the day." In addition to the standard 12 hour forecast charts, 6 and 18 hour forecast charts of surface and thickness, (01I,K1K) and (03I,K3K), and 500 heights/vorticity, (51H,51V) and (53H,53V), are available from the NGM runs. The NGM also has a moisture convergence product for 6 hr, 12 hr, and 18 hr forecast times. L1Z, L2Z, L3Z can be useful in determining where the best surface based lifting will occur. The NGM also has boundary layer wind graphics, L0M, L1M, L2M, L3M, etc., which are useful in finding the forecast positions of some of the weaker boundaries. The 700 mb vertical velocity progs available on the NGM and AVN can help locate those areas where the best synoptic scale lift will occur. Examples of the NGM moisture convergence graphic, the boundary layer wind graphic, and 700 mb vertical velocity graphic will be shown in Section V.

3. The NMC-analyzed surface charts 90I and 90F give locations of major large scale boundaries. These products are only available every three hours and should not replace a hand analysis. The analysis may not detect or show mesoscale boundaries such as outflow boundaries. The hourly radar chart 90R when used with the latest surface plot may help in locating these smaller scale boundaries.

4. The UA program gives a representation of the current patterns of rising/sinking motion with Q-vectors. The idea of Q-vectors is to combine both forcing mechanisms in the quasi-geostrophic omega equation, differential positive vorticity advection and low level warm advection, into one "term" or vector. Rising motion can be inferred where Q-vectors are converging, and sinking motion where Q-vectors are diverging. For example, 700 mb Q-vector convergence implies large scale rising motion between 850 and 500 mb. Refer to Barnes (1985) or Prater (1990) for more information on Q-vectors. Also available on the UA package are temperature advection graphics for each of the mandatory levels as well as moisture convergence graphics. The UA programs are also useful for finding areas of divergence aloft, which will be discussed in section IV.A.3.

5. Isentropic charts can be plotted by AFOS programs and hand analyzed to examine horizontal and vertical motions with potential temperature conserved. These charts can be generated twice a day after each model run and are especially useful in warm advection or "overrunning" situations. Moore (1988) discusses the application of isentropic charts. AFOS program documentation is given by Little (1985).

6. The trajectory model generates graphic representations of 24 hour trajectories terminating at 700 mb, 850 mb, and the surface. The AFOS identifiers for these products are 7W1 (Western U.S.) and 7WJ (Eastern U.S.) for 700 mb trajectories, 8W1 and 8WJ for 850 mb, and 0W1 and 0WJ for parcels terminating at the surface. One of the possible uses of these charts is to look for parcel trajectories (esp. the surface and 850 mb) that converge or have cyclonic curvature; both can be used to infer low level convergence and thus rising motion (Reap, 1978).

C. THE CAP-INHIBITOR OF CONVECTION

Many times, an area can have instability and moisture, but convection fails to develop. A capping inversion often will prohibit thunderstorm formation since the low level inversion acts as a lid to suppress parcels of rising air. The best way to look at a capping inversion and determine its strength is by inspecting soundings. You can monitor the cap strength hourly with ADAP graphic SSC, shown in Figure 8, which gives cap strength in degrees Celsius. Researchers have found that the edge of the "lid" is near the 2 degree C isopleth of cap strength (Bothwell, 1988). Deep convection becomes less likely as cap strength increases. However, a strong lifting mechanism such as a strong cold front or vigorous short wave will often "lift out" a 5 or 6 degree cap over a period of several hours. The cap is gradually eroded with time until it is weak enough for convection to form. A look at the individual soundings and the relative strength of the lifting mechanism will allow the forecaster to make a judgment. There is also a need to look for possible ways the cap can be strengthened or weakened during the day...i.e. look at 850 or 700 mb temperature advection or an isentropic analysis on AFOS. Lanicci (1985) discusses specific procedures, using 850 and 700 mb charts, to assess and predict the lid as it affects severe storm outbreaks.

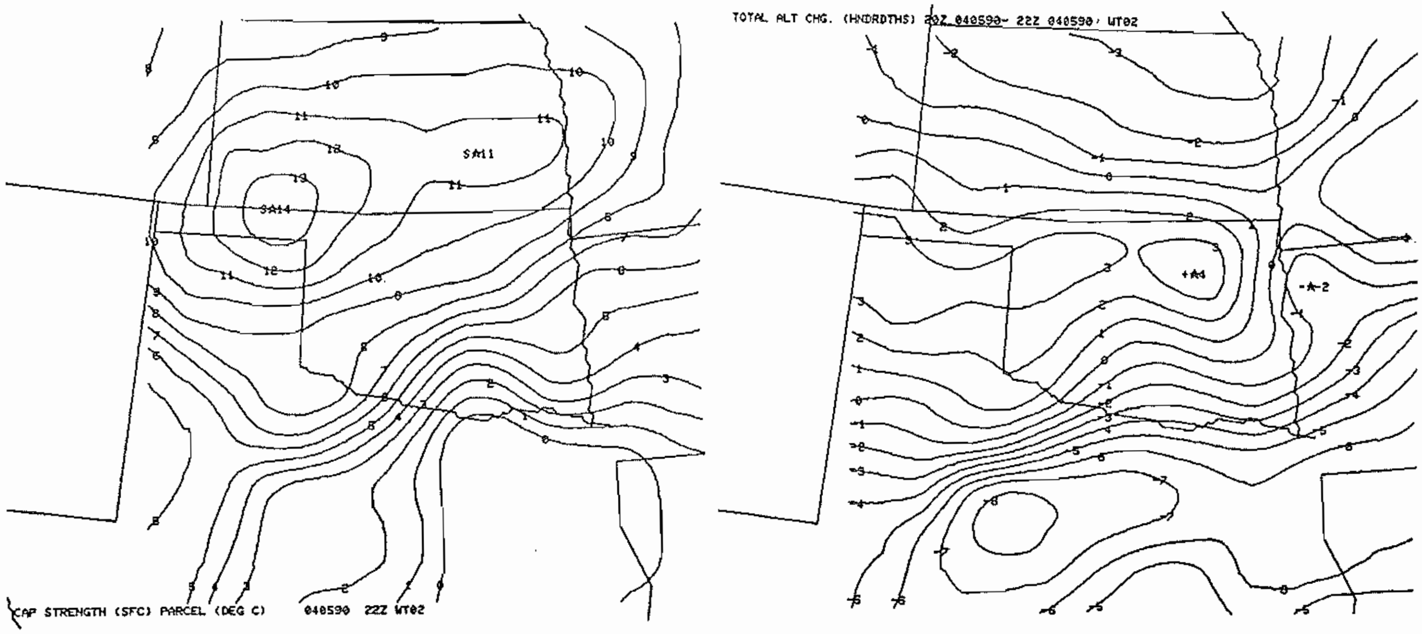


Figure 8: Example of ADAP cap strength SSC (left) and 2 hour altimeter change SAC (right). In SSC, the area to the east and south of the 2 degree C isopleth of lid strength (northeast Texas) is relatively uncapped. The SAC graphic shows a pressure fall center in western Texas. The stability and moisture flux convergence charts for this same date/time are shown in Figures 3 and 6.

The ideal case for severe convection is to have a warm, moist air mass capped by hot and dry air. The inversion or "lid" acts to keep convection from forming until late afternoon when solar heating or some other trigger mechanism erodes the cap until it is sufficiently weak to allow thunderstorm updrafts to form. The instability "builds up" during the day and is suddenly released as explosive convection forms.

There are several "rules of thumb" governing whether or not convection can overcome a cap or layer of warm air aloft. One such rule states that thunderstorm formation is unlikely with 700 mb temperatures above 14 degrees C. Another says that an atmosphere with a 1000-500 mb thickness greater than 5790 meters is not conducive to significant severe thunderstorm episodes (Johns, et al., 1988). Both of these rules work best at elevations below 3500 feet MSL. Keep in mind that these are only rules of thumb; each thunderstorm case should be examined for physical processes that lead to or inhibit convection.

IV. SEVERE WEATHER PREDICTION

A. INGREDIENTS/PRECURSORS

Once areas favorable for thunderstorm formation have been located, the next problem is determining if and where severe thunderstorms will occur. A few hints on locating favorable areas for severe weather have been mentioned in the preceding discussion. For significant outbreaks of severe weather, many variables need to come together at the right place and time. The greatest potential for severe weather or tornadoes will be in those areas with greatest potential instability, "best" vertical wind shear, and best lifting. Instability and lifting have already been covered, so now vertical wind shear will be discussed.

1. Strong vertical wind shear

This is an important ingredient in the formation of SEVERE thunderstorms. Strong shear infers good baroclinicity (thermal contrast) associated with the presence of frontal boundaries (Holton, 1979). Strong shear also provides "ventilation" of the upper parts of thunderstorms and can help take precipitation out of the updraft. Also, an environment in which the winds veer and increase in speed with height is important for the formation of thunderstorms with rotating updrafts (Browning, 1983).

There are many ways to look for vertical wind shear. One way is by looking at the plotted winds on the soundings. Others include looking at the mandatory level plots or looking at UA programs such as 30I, 20I, 50I, etc. "Strong" speed shear is present if the magnitude of the vector difference between the 500 mb wind and the 850 mb wind exceeds 35 knots (National Weather Service Training Center, 1988). "Strong" directional shear exists if the directional change in wind shows more than 60 degrees of veering between 850 mb and 500 mb (NWSTC, 1988).

Forecast wind information for particular stations can be obtained from the wind and temperature aloft forecasts from NMC. These products give 6, 12, and 24 hour forecasts of winds and temperatures aloft for 9 levels ranging from 3,000 to 39,000 feet (NWS, 1979). The AFOS identifier for the products are in the form FDxFAn, where x=1, 2, or 3 for a 6, 12, or 24 hour forecast and n=1 through 6 for different parts of the country. For example, FD3FA4 gives the 24 hour wind and temperature aloft forecasts for the south central U.S. These forecasts can be used to get an idea of a forecast wind profile up to 24 hours in advance.

While looking at wind graphics, keep an eye out for jet streaks or speed maxima which can enhance wind shear and vertical velocity as well as upper-level divergence. Isotach analyses are available on AFOS as 30Y and 203 and isotach progs are available from the models as 24Y, 3EY, and 3GY. Certain jet stream configurations (low level jet position with respect to upper level jet position(s)) are favorable for severe weather when other parameters, such as dry air intrusion and moist axes, are in place. For details on such configurations, refer to Maddox and Doswell (1982a, 1982b), Doswell (1982) or Uccellini and Johnson (1979).

A recently developed set of programs by Woodall (1990) can be used to analyze and qualitatively forecast the extent of tornado occurrence associated with thunderstorms. The programs use observed or forecast winds aloft to calculate storm relative helicity; an environment with high helicity is favorable for the development of cyclonically rotating updrafts and tornadoes.

2. Pressure tendencies
The presence of a pressure fall center in an area of strong or potentially strong convection can enhance the potential for severe weather and tornadoes (Doswell, 1982). A detailed discussion of how and why pressure fall centers form is beyond the scope of this paper. Bothwell (1988) has a well-referenced discussion of pressure fall centers.

An hourly graphic of altimeter change is generated by ADAP and is called SAC; an example is shown in Figure 8. SAC is usually a 2 hour change chart, although the user can change the time interval. Look for pressure fall centers or fall/rise couplets as possible precursors to severe weather or tornadoes. Once again, hand analyses of pressure tendencies are useful since even ADAP may not be able to distinguish small scale pressure pulses partly because of the smoothing inherent in the objective analysis program (Branick, 1989). The ADAP graphics SC2, SC1, and SPC may help fine-tune hand analyses.

Large pressure rises appearing behind a squall line are often associated with an increased threat of damaging thunderstorm winds (Bothwell, 1988). The pressure rise center as well as the fall/rise couplet can exist for several hours, making both a valuable prognostic tool if they are extrapolated ahead in space and time.

3. Upper level divergence
   By finding areas of divergence in the upper levels, the forecaster will find those areas where good lifting may be occurring and, if other parameters are favorable, where an increased potential of severe weather exists. As discussed by Doswell (1982), upper level divergence is often hard to infer at any given area on a map. Difluence may be an indicator of divergence and is often an important ingredient for significant outbreaks of severe weather. McNulty (1978) related divergence to the right rear and left front quadrants of upper speed maxima. Foster's UA program calculates divergence at all of the upper levels from mandatory level data.

B. HODOGRAPHS

A hodograph is simply a plot of a curve connecting the end points of wind vectors of a sounding drawn from a common origin. A hodograph gives the forecaster a way to inspect the vertical shear profile, which can be used to predict thunderstorm type (supercell, multicell, etc.) (Weisman and Klemp, 1986). An example of a hodograph available on AFOS is shown in Figure 9. Although the 12Z soundings have prediction value, the forecaster should keep in mind changes which may occur in the wind field during the day (Rasmussen and Wilhelmson, 1983). For example, the presence of a low level jet can drastically change hodograph shape and make the hodograph more favorable for supercell formation (Doswell, 1988). The low level jet will often back (turn counterclockwise) and decrease after sunrise as mixing brings more friction into the flow. A look at the 3,000 foot or 6,000 foot winds on the forecast wind and temperature aloft product (FD) might help in assessing the forecast strength and location of the low level jet.

Thunderstorms that form in weakly-sheared environments tend to be multicellular, while those that form in strongly-sheared environments can be supercellular (Weisman and Klemp, 1986). A measure of shear, a Bulk Richardson number, will be discussed in the next section. Doswell (1988), in cooperation with the Southern Region Scientific Services Division, published a set of notes on the use of hodographs in severe storms forecasting.

C. INDICES-CONVECTIVE PARAMETERS

1. Traditional indices can be found on individual soundings or can be collected by various programs (ex:EISTAB). The stability indices will not be discussed here. Refer to

Miller (1972) or Sadowski and Rieck (1977) for information on the various stability indices.

2. CONVECTA parameters and hodograph
In this section, some of the parameters on the hodograph graphics available on AFOS through the locally run CONVECT programs will be discussed. The AFOS identifier for the product is usually the Raob station name plus the letters "HO". For example, the Topeka, Kansas hodograph is stored under TOPHO. Each hodograph has various indices and derived quantities as well as the winds plotted on U-V coordinates. The hodograph itself has already been discussed, but some of the numbers on the hodograph product deserve attention. An example of a hodograph is Figure 9. More detailed information on the programs as well as descriptions of all the parameters available from the programs are found in Stone (1988).

LCL = lifting condensation level

LFC = level of free convection

CCL = convective condensation level

EL = equilibrium level

MPL = maximum parcel level

TROP = tropopause height

WMAX = calculated maximum vertical velocity of a non-entraining parcel at the EL

WAVG = average mixing ratio in lowest 100 mbs of sounding

B+ = amount of positive area in the sounding assuming a non-entraining parcel. Units given are (m/sec)**2 which is equivalent to Joules/kg. For severe convection, this number is typically large. On moderately unstable convective days, B+ ranges from 1500 to 2500 J/kg, although it can be as large as 4500 J/KG in extreme cases (Weisman and Klemp, 1986).

B- = amount of negative energy that a non-entraining parcel encounters during lifting

C TMP = convective temperature-indicates temperature at which convection is likely to be initiated by afternoon heating

SHR = a measure of wind shear over the lowest six km of the atmosphere. Units of (m/sec)**2.

BRN = Bulk Richardson number. This is a number that takes into account the amount of positive area AND the amount of shear; BRN=B+/SHR. The BRN may be useful in determining the type of convection that may develop. As a general rule, the smaller the BRN, the greater the shear and subsequent chances for supercell thunderstorm development. Weisman and Klemp (1986) came up with this set of guidelines for use in predicting thunderstorm type:

BRN	Convection type
>30	MULTICELLS
10-40	SUPERCELLS

The numbers outside the box represent values of a parcel assuming no entrainment while parameters enclosed in the boxed area are all computed with entrainment that increases the mass of the parcel by 60 percent over a 500 mb parcel ascent.

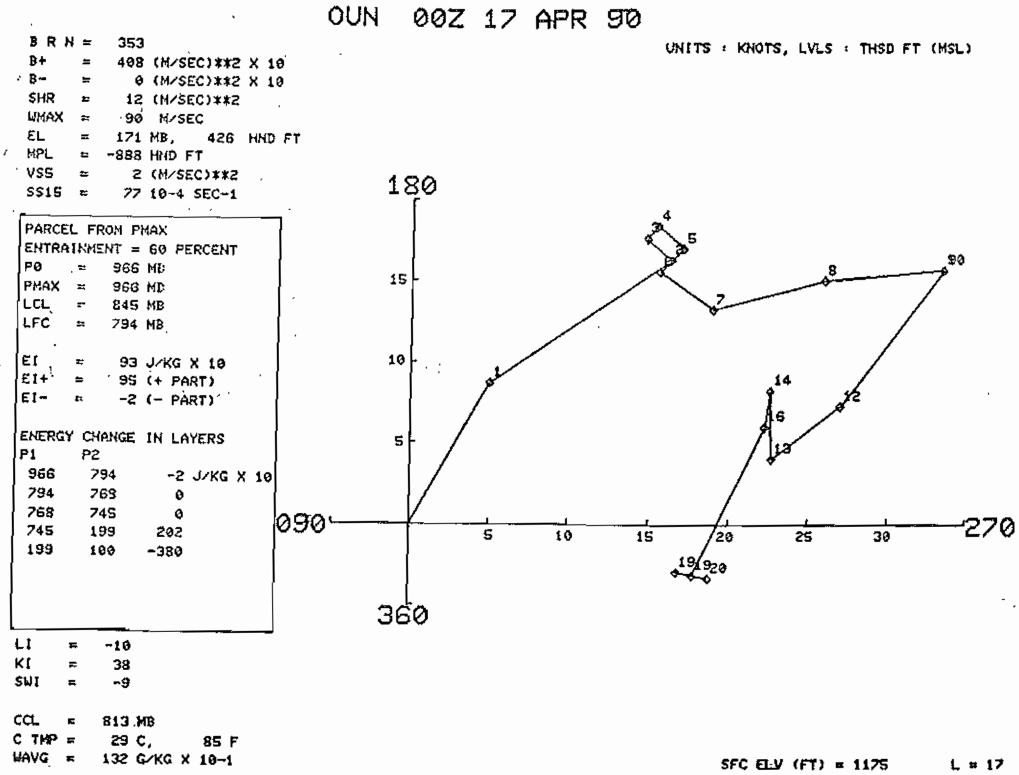


Figure 9: An example of a hodograph from Norman, OK as available on AFOS from CONVECTA program. This hodograph showed the rather substantial positive area (4080 J/kg) that was present in Oklahoma on 16/17APR90. Although no tornadoes were reported, a severe thunderstorm outbreak occurred in Oklahoma with baseball sized hail reported 42 miles northeast of OKC at 0130Z 17APR90. The Totals Totals index from the OUN sounding from 00Z 17APR90 was 62 with a Sweat Index of 621.

CONCLUSION TO SECTIONS I THROUGH IV

By now, it should be apparent that many fields and many products need to be analyzed to predict thunderstorms and their intensity. This was not meant to be a comprehensive report, but was meant to be a review of how to use the available tools in thunderstorm forecasting. For a more thorough discussion of severe weather forecasting and dynamics, consult Doswell's two volume set "The Operational Meteorology of Convective Weather" (1982, 1985). For a detailed discussion of the ADAP products see Bothwell's Southern Region Technical Memorandum #122 (1988). Other references are listed at the end of section V.

V. A SUMMERTIME FORECAST CASE

In this section, an actual case is presented which shows the steps that a forecaster might take in diagnosing the potential for thunderstorms. The illustrations presented in this section vary from 36 hour graphic progs from the NMC forecast models to ADAP graphics with times several hours before predicted thunderstorm formation. The dates of the illustrations are August 4 and 5, 1989. The synoptic pattern was progressive with a longwave trough forecast to form over the eastern United States with a ridge over the west. A cold front was forecast to move south from the northern United States into northern Oklahoma and eventually all the way into south Texas. The first set of graphics will present part of a forecaster's point of view beginning with forecast maps from the day before, using 36 hour progs. Many of the charts and ideas discussed in previous sections will be presented to illustrate the applicability, at least in this particular case, of the AFOS graphics and guidance products to thunderstorm forecasting.

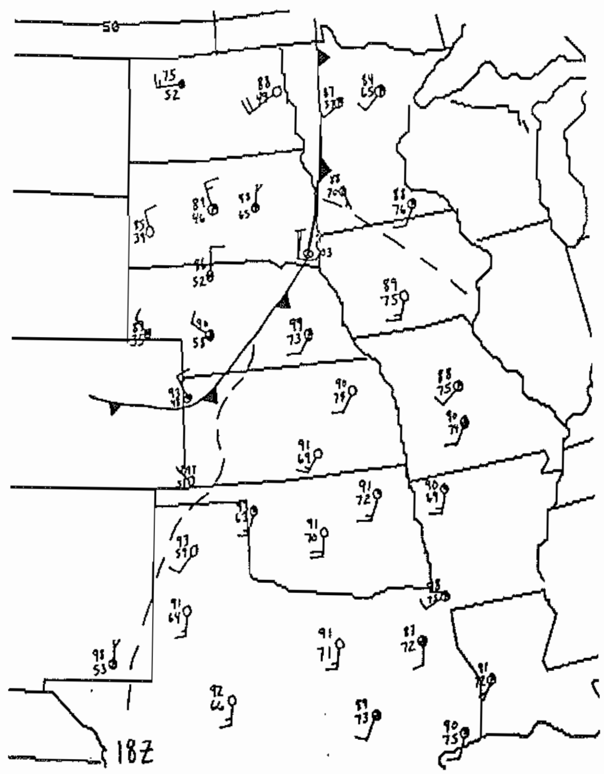


Figure 10: Hand analyzed surface chart from 18Z Friday, August 4, 1989.

This case is presented using a forecaster's point of view beginning the morning of Friday, August 4, 1989. The forecast problem is determining whether or not thunderstorms will develop in northern Oklahoma the following afternoon or evening, Saturday, August 5, 1989.

A. 36 HOUR PRODUCTS

The first graphic shown is a hand analyzed surface chart from 18Z (100 pm CDT) Friday, August 4, 1989 and is shown in Figure 10. A cold front stretched from western Minnesota to a surface low in extreme southeast South Dakota; the front then continued into extreme northwest Kansas and central Colorado. A weak trough intersected the front in south central Nebraska and extended across western Kansas into the southeast corner of New Mexico. The temperature contrast across the front was not pronounced since fronts in this part of the country are not typically associated with large low level temperature gradients in the summer. Nonetheless, the front can easily be located from its rather distinct windshift and dew point contrast. The area of interest, northern Oklahoma, is characterized by moderate southerly surface winds with temperatures in the lower 90s and dew points mostly in the lower 70s.

Instead of trying to show a lot of graphic products from the models, the NGM FOUS data and a few selected graphics from the 12Z run on Friday 8/4/89 will be shown. The left side of Figure 11 shows FRHT68 and FRHT69. An examination of the DDFF column shows a windshift from west to northeast at Dodge City, Kansas (DDC) between 24 and 30 hours and from west to north at Topeka, KS (TOP) between 24 and 30 hours. From these two stations alone, it is apparent that the NGM brings the cold front southeastward with time and gives a frontal position somewhere southwest of Dodge City to around Topeka by 30 hours which is 1 pm Saturday afternoon or 18Z Saturday 8/5/89. 20 knot north winds are shown by 48 hours in the DDFF column at TOP and DDC. Inspection of the T1 column, which gives the model layer 1 (lowest 35 mb) temperature in degrees Celsius, shows that low level cooling is well pronounced behind the front at BFF (Scottsbluff, Nebraska), LBF (North Platte, Nebraska) and OMA (Omaha, Nebraska). Fairly significant thickness cooling (HH column) is also evident at the stations north of the front. For example, OMA has an initial thickness of 583 geopotential dekameters with a 48-hour value of 569 dkm! This may not seem like much of a change, but for a mid-summer cold front it is very substantial. Similar changes can be seen at DSM (Des Moines, Iowa), DDC, LBF and BFF. We can therefore see that the NGM brings a strong cold front, and thus a potentially strong lifting mechanism, from the north into central and eastern Kansas by Saturday evening.

The approximate forecast frontal position and strength has been determined from only the NGM FOUS data. Many times, a forecaster can recognize significant changes occurring at individual stations by inspecting the NGM or LFM FOUS data. Of course, looking at the forecast graphics would be superior to looking at just the grid point data. The NGM FOUS data was chosen to illustrate the determination of the forecast frontal position for several reasons. The most important was to show those readers not familiar with using the product how much useful data it contains. All parts of the NGM FOUS data were not discussed and some could be critical, especially the vertical velocity and lifted index forecasts. Attention was focused on the forecast frontal position with the NGM FOUS product. Other products will be used to determine moisture and instability fields. The right side of Figure 11 shows the LFM FOUS data, FRH68 and FRH69, valid for the same stations and the same time period as the NGM FOUS. This is presented to give "another opinion"; a forecaster often wants to see how the models compare with one another. In this case, the LFM and NGM are similar in bringing the front southeastward, so the LFM FOUS will not be discussed in detail.

```
NMCFRHT69
FOUM69 KWBC 041200
OUTPUT FROM NGM 12Z AUG 04 89
TTPTTR1R2R3 VVLI PSDDFF HHT1T3T5    TTPTTR1R2R3 VVLI PSDDFF HHT1T3T5
OKC//655319 -0598 102027 82272317   DFW//824116 00496 141920 80252216
06000454929 -1297 082014 84322410   06000493719 00890 111911 82302217
12000395041 00497 061920 85332617   12000303725 -2499 091017 83322416
18000515149 00198 082023 84282517   18000544236 -0299 111924 82272417
24000675443 00798 002121 82232417   24000735234 00399 112121 79232316
30000445129 -1198 072010 84312317   30000514535 -1090 101908 82302217
36019465753 03695 052012 84332515   36000364945 -0799 071916 83332515
42032526881 01096 002119 82302515   42000515153 00199 092022 82282415
48005576854 01997 072808 82272414   48000735553 01999 092220 80232315
SAT//944133 -0696 141616 80242116   IAH//934624 -1194 161911 70252016
06000584947 -1095 131509 79302216   06000645149 -1795 151808 79292116
12000435050 -2098 091415 82322415   12000594938 -2096 121714 80292217
18000695756 -0498 131722 79252116   18000384232 01395 141918 79252118
24000955343 -1193 131914 77222015   24000984138 -1095 142215 78242016
30000594533 00090 111769 80282016   30000584137 -1297 131908 79292117
36000434533 -2198 081713 81312315   36000534341 -1598 101915 80302217
42000704436 00598 111723 80252117   42000793936 00398 122018 80252318
48000924625 00199 121915 77222016   48000904335 00498 122216 78232217
BRO//814523 00594 131719 79272316   DRT//794437 00996 131517 00242115
06000654739 00794 141515 79292216   06000525248 -0595 111406 81292114
12000664029 -0795 111420 80282218   12001375345 -0798 081412 83312413
18000844439 -0295 141721 78262116   18005576152 00099 121524 80252112
24000095045 -0395 131014 78252016   24004806142 -1099 121814 78212012
30002685451 -0496 131608 78282115   30000545438 00798 101508 80282013
36000645355 -1297 101417 80282116   36000405333 -1599 071514 82302213
42000795365 -0196 111617 79262216   42000595341 -0199 101621 80252013
48009935783 -1795 111615 78242115   48000005429 -0399 111814 78201912
NMCFRHT68
FOUM68 KWBC 041200
OUTPUT FROM NGM 12Z AUG 04 89
TTPTTR1R2R3 VVLI PSDDFF HHT1T3T5    TTPTTR1R2R3 VVLI PSDDFF HHT1T3T5
DSM//794717 00293 052315 81262417   TOP//754515 01396 072222 83262519
06000504634 -1990 031910 84332519   06000454433 -0693 052112 85332519
12000305052 03291 002219 86362010   12000354750 -1394 032119 86362810
18000445533 01593 012715 84322818   18004545257 01995 052225 84292719
24000514814 -0697 033319 80262517   24007615025 -0195 052612 82272618
30000314210 -1599 063510 77302216   30006435337 03195 060203 82322418
36000285012 -1400 073312 76302212   36015377154 -1195 060312 81332515
42000424107 -3701 093421 72251910   42000366415 -0297 080319 79302414
48000693907 00704 123519 68181509   48009514904 02401 110321 74222012
DDC//523410 -0295 052227 86292710   OMA//783911 00192 042219 83262719
06000344045 01093 031905 86352716   06000444645 00389 022010 95342620
12000235233 -0797 021600 87362817   12000255234 00794 002415 86372918
18000345719 -0497 052020 85312617   18000345117 02596 033418 83322718
24000335511 00897 042504 84302717   24000444516 -1099 063622 78252417
30000346023 01498 060504 84312317   30000294810 -0400 083609 77292215
36000376627 01096 060513 82312315   36000295412 -0400 083409 76302211
42000446707 -1194 103619 79282214   42000414406 -2900 113619 72251909
48000534912 00196 110420 70242114   48000634208 -1603 133521 69191508
LBF//353815 00196 032718 84292617   BFF//243018 -1299 083117 78222010
06000233031 -1297 043310 83312316   06000223020 -2000 093106 77251709
12000194413 -1999 043609 82322414   12000204918 -0499 071202 79272009
18000244412 -1199 062011 81302414   18000215409 04197 092401 78271909
24000355707 00098 080718 77242612   24000425308 03098 130318 73101508
30000385503 01098 110207 75251012   30000414507 -0198 140105 73211307
36000325007 -0598 100209 76271909   36000325310 -0198 120508 75241605
42000395411 00599 143615 73241707   42001485011 03098 160913 72191405
48000526025 -2299 163513 70201006   48016606816 03198 171011 69161204
```

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HMCFRH69
FOUS69 KWBC 041200
OUTPUT FROM LFM 12Z AUG 04 89
STA RH R1R2R3 VVLI HHDDFF TBPSPTT STA RH R1R2R3 VVLI HHDDFF TBPSPTT
OKC 59 986730 ///97 812426 0110/// DFW 54 995132 ///96 792319 0813///
 06 46 884620 -0297 622019 0209000  06 47 934527 -1096 801910 0112000
 12 44 844126 -0796 031919 0307000  12 49 874731 -0296 801915 0210000
 18 44 834128 -0596 032019 0307000  18 49 814929 -0796 811920 0210000
 24 49 834635 00797 022115 0309000  24 50 775230 -0296 802010 0311000
 30 51 764746 00096 022210 0310000  30 48 704930 -0396 812114 0412000
 36 49 674547 -0295 022006 0509000  36 47 614932 00895 812112 0609000
 42 49 664547 00295 812104 0610000  42 49 625036 00295 802112 0611000
 48 49 664743 00695 803602 0511000  48 49 654938 -0195 802218 0511000
SAT 62 996240 ///94 781715 0114/// IAH 62 996146 ///95 771609 9816///
 06 56 895535 -1095 781613 0113000  06 58 855841 -1095 771712 0015000
 12 53 855430 00495 791708 0211000  12 55 783833 -0295 781612 0212000
 18 54 795029 -0496 791612 0212000  18 57 726233 -0495 781813 0214000
 24 54 765027 -0596 781711 0312000  24 55 656330 -0395 771913 0314000
 30 49 725322 -0596 791711 0413000  30 50 605727 -0595 781913 0514000
 36 48 675222 00296 801810 0511000  36 48 565327 -0195 791915 0612000
 42 46 674323 -0296 791811 0512000  42 47 585129 -0195 792014 0514000
 48 45 664722 -0496 791710 0411000  48 44 584628 -0596 782111 0513000
BRO 66 996039 ///92 771616 0014/// DRT 59 986235 ///96 791715 0312///
 06 61 786343 -0995 771511 0114000  06 54 085431 -0397 801708 0312000
 12 57 736134 -0296 791511 0212000  12 52 855232 00097 801705 0410000
 18 58 716240 -0195 771310 0214000  18 52 835327 -0297 801610 0411000
 24 54 705737 -0595 761511 0313000  24 52 835327 -0697 791708 0411000
 30 51 695239 -0596 781409 0314000  30 53 795224 -0297 801706 0412000
 36 49 664330 -0196 791411 0311000  36 40 725225 -0197 801607 0510000
 42 48 664740 -0296 791510 0313000  42 49 714925 -0296 801609 0611000
 48 47 664639 -0396 791408 0312000  48 47 724924 -0297 801606 0510000
HMCFRH68
FOUS68 KWBC 041200
OUTPUT FROM LFM 12Z AUG 04 89
STA RH R1R2R3 VVLI HHDDFF TBPSPTT STA RH R1R2R3 VVLI HHDDFF TBPSPTT
DSM 59 985737 ///95 802519 0206/// TOP 59 895446 ///95 822425 0207///
 06 53 984750 00495 812413 0205000  06 53 655044 00697 822317 0206000
 12 50 894297 -0495 822215 0203000  12 43 774344 -0796 832120 0304000
 18 52 834461 01296 802612 0105000  18 47 814148 01096 822317 0306000
 24 50 724457 -0497 703109 0207000  24 50 794354 00697 812608 0208000
 30 45 564345 00499 763209 0303000  30 49 684252 00297 792806 0310000
 36 38 384325 -0700 743412 0603000  36 49 513937 -0397 703405 0710000
 42 37 414321 -0403 713615 0212000  42 34 433525 -0698 763606 0711000
 48 42 524524 -1006 623616 9714000  48 37 403830 -0301 730313 0414000
DDC 44 654325 ///00 842517 0505/// OMA 50 884339 ///95 822513 0304///
 06 42 574137 00799 931607 0705000  06 43 794063 00896 812610 0304000
 12 43 543352 -0498 831912 0905000  12 45 703757 -0397 82221A 0302000
 18 41 543551 -0297 832409 0906000  18 47 654059 01197 802911 0306000
 24 41 523749 00497 819403 0909000  24 44 544053 -0699 773411 0308000
 30 41 473342 00697 806505 0911000  30 39 403934 00101 753503 0511000
 36 37 393834 00197 790807 1211000  36 33 293924 -1102 733612 0711000
 42 36 423729 -0497 761106 1112000  42 36 354223 -0603 710113 0413000
 48 39 453925 00496 760908 1014000  48 43 484928 -0806 680214 5916000
LBF 45 543560 ///02 813012 0505/// BFF 43 414059 ///03 763414 0808///
 06 39 383268 -0701 023212 0705000  06 37 313359 -1001 762804 1107000
 12 35 323156 00601 790405 1005000  12 33 263441 00700 750402 1408000
 18 34 313402 -0501 763506 0912000  18 36 284035 -0200 730803 1313000
 24 32 293332 -1002 740310 0812000  24 37 314233 -0501 710804 1114000
 30 33 273631 -0802 730505 0914000  30 37 324328 -0400 721306 1216000
 36 35 254934 -0501 730807 1014000  36 49 344533 00760 711309 1215000
 42 38 314430 -0601 720306 0815000  42 41 374030 -0300 701405 1017000
 48 43 424033 00201 700911 0517000  48 42 434727 03000 701109 0910000
```

Figure 11: AFOS products FRHT69 and FRHT68 (left) and FRH69 and FRH68 (right) from 12Z 04AUG89.

More 36 hour products will now be shown to determine the thunderstorm potential in northern Oklahoma late Saturday afternoon or evening (around 00Z Sunday the 6th). The triggering mechanism will be discussed some more, since this is easily the most important ingredient for convection in this case, as well as in many summertime cases. To explain this, one must first realize that solar radiation is more direct in the summer and this results in warmer surface temperatures.

Temperatures in the mid levels of the atmosphere are also warmer in the summer for various reasons, but the low level warming combined with typically higher moisture values often overcome the mid level warmth to produce atmospheric instability sufficient for thunderstorms. The typically high values of low level moisture in the summer can be attributed to several "causes": warmer ocean surface temperatures provide a more favorable source of moisture, warmer low level temperatures allow the air to hold more water vapor, and relatively weak low level winds make advection of drier air (and conversely more moist air) a slow process. In other words, the missing ingredient for summer thunderstorms is often the triggering mechanism since moisture and instability are usually present to some degree. Significant short waves in the westerlies are usually too far north to provide sufficient forcing, and daytime heating sometimes does not provide enough "lift" on its own.

With the above ideas in mind, we turn our attention to the forecast frontal position for Saturday evening. Figure 12 shows the 36-hour NGM surface and thickness prog as well as the corresponding boundary layer wind graphic from the 12Z Friday run. These products show the front nearly east to west across central Missouri, into extreme southern Kansas and extreme northwest Oklahoma by Saturday evening. Northeast boundary layer winds behind the front in northern Kansas and southerly boundary layer winds south of the front indicate convergence along the front, perhaps strongest in extreme south central or southeast Kansas.

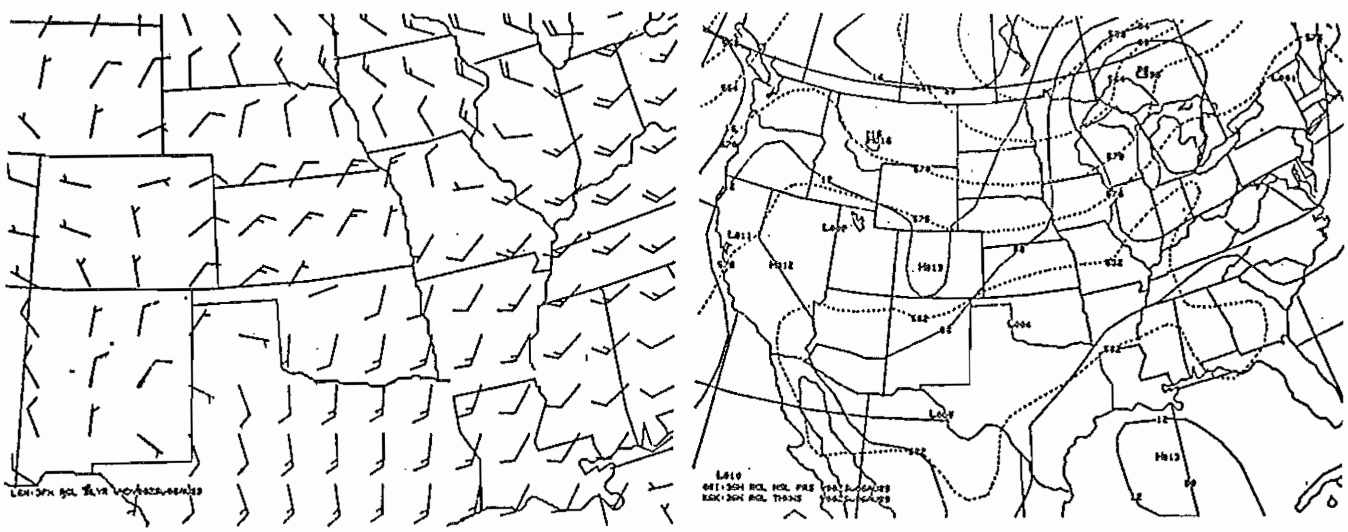


Figure 12: 36 hour NGM graphics. On the left is L6M, which is forecast boundary layer wind plot. The 36 hour forecast MSL pressure and 1000-500 mb thickness (06I,K6K) are on the right. Both graphics are valid 7 pm CDT Saturday, August 5, 1989.

Figure 13 shows the 36-hour NGM 500 mb height and vorticity graphic and the NGM 36-hour 700 mb vertical velocity graphic both valid Saturday evening at 7 pm CDT. The 500 mb chart shows the main short wave centered over northern Lake Superior with a high centered in Arizona. Relatively weak and slightly cyclonically curved flow covers the area of interest with a weak short wave or shear zone evident across extreme southeast Missouri and northeast Oklahoma. Of more significance is the vertical velocity chart. It shows a large area of +3 (units of ub/s, rising motion) extending from southwest Missouri to west central Oklahoma. Inside this broad area of rising motion is an area of even more substantial vertical velocity with +6 covering parts of northeast Oklahoma and extreme southeast Kansas. This vertical velocity forecast can be attributed to convergence near the front since other forcing, specifically differential positive vorticity advection and low level warm advection, appears weak. Weak dynamics, at best, are forecast to act on the unstable air in the vicinity of the front. This idea is also supported by the orientation of the axis of maximum positive vertical velocity; it is parallel to the front. Therefore, with relatively weak flow aloft forecast for northern Oklahoma, and no major short wave forecast by the NGM to affect the area, thunderstorm formation, if any, will depend mostly on surface heating and convergence near the front.

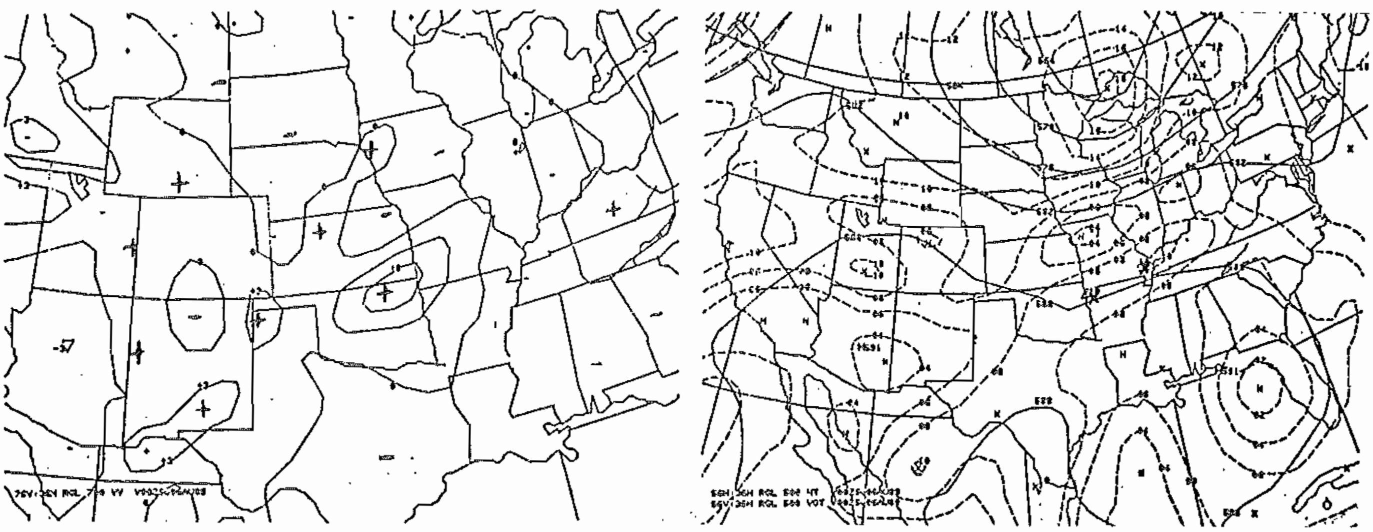


Figure 13: 36 hour NGM progs for 7 pm August 5, 1989. The 700 mb vertical velocity forecast (76V) is on the left; forecast 500 mb height and vorticity (56H,56V) is on the right.

Figure 14 shows I6L which is the NGM 36-hour lifted index graphic and 86H and 86T which is the 36-hour NGM 850 mb height and temperature graphic. The NGM has LI values below -4 across the area of interest with a local minimum in extreme southeast Kansas. The 850 mb prog shows a weak trough associated with the front across Kansas. Light south south-west flow at 850 mb covers most of Oklahoma, which could act to bring slightly drier air in ahead of the front. Perhaps a more important feature of the 850 mb prog is the large temperature gradient and strong cold advection behind the main

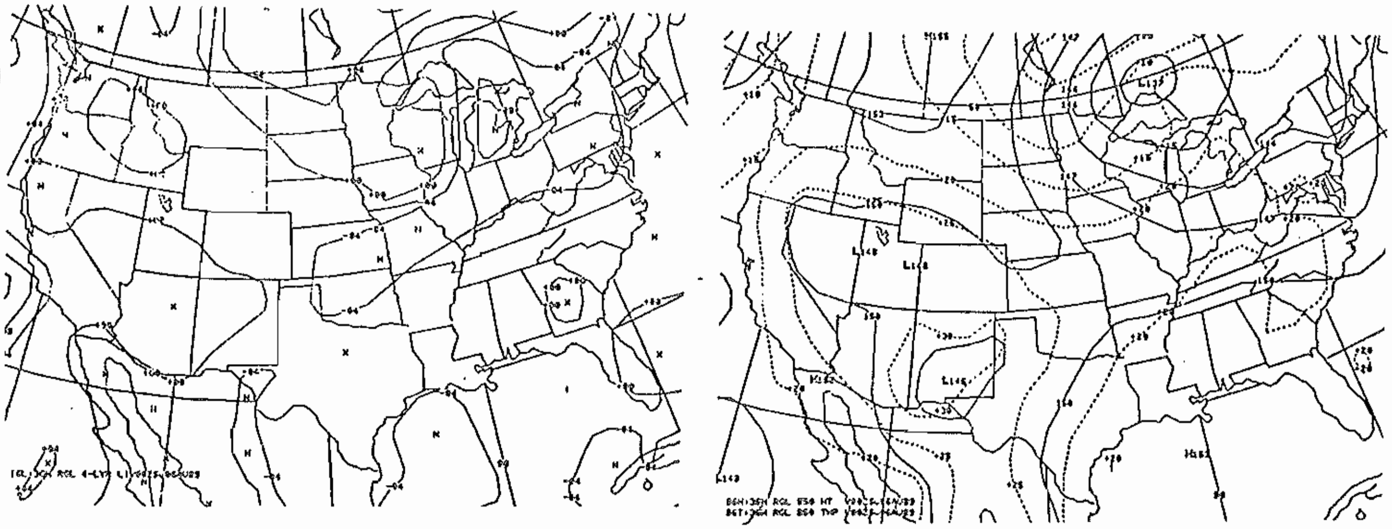


Figure 14: 36 hour NGM progs valid 7 pm August 5, 1989. 4-layer Lifted Index (I6L) is on the left with forecast 850 mb height and temperature on the right.

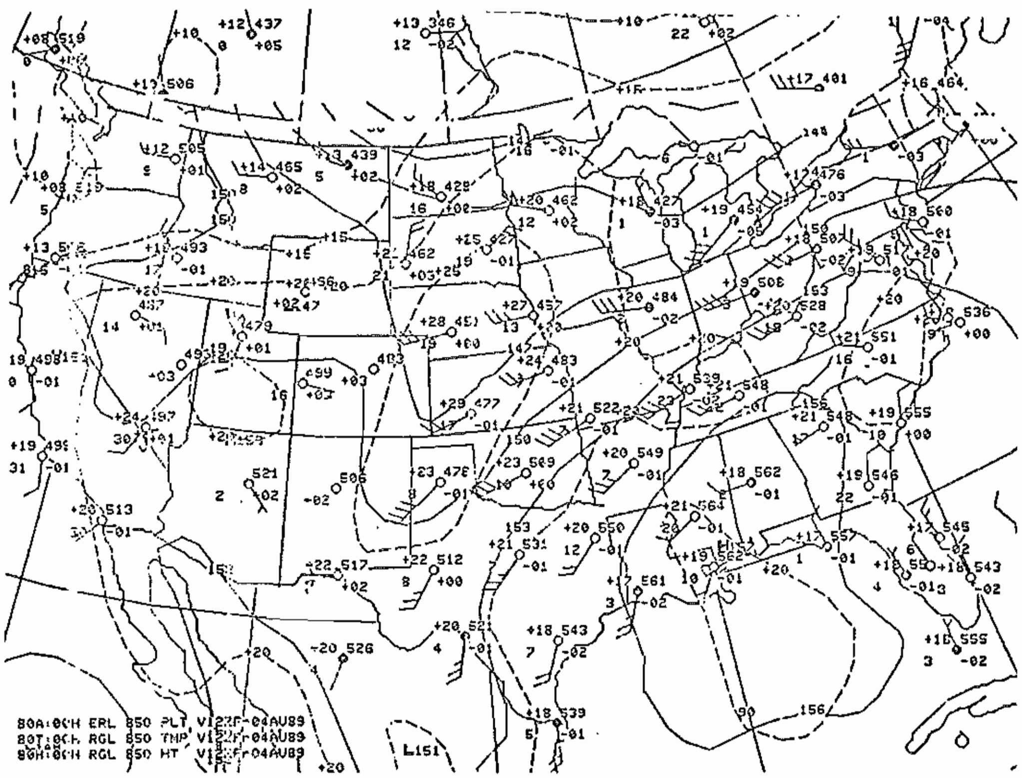


Figure 15: 850 mb plot and NGM initial analysis for 12Z Friday, August 4, 1989.

850 mb low north of Lake Superior. The temperatures forecast for northern North Dakota and northern Minnesota are less than +10 Celsius with the +5 degree C isotherm not far upstream in Manitoba.

The forecast products discussed thus far have dealt mostly with the triggering mechanism and instability. The third thunderstorm ingredient, low level moisture, will now be diagnosed. Figure 15 shows an AFOS graphic with the 850 mb plot and the initial NGM 850 mb height and temperature chart all overlayed on a single chart. These charts are valid 12Z Friday, which is 36 hours before the target time. Dewpoints at 850 mb in the area are mostly in the mid teens; Norman, OK (OUN) has 13 degrees Celsius and Monett, Missouri (UMN) 14 degrees C, which places them in the "MODERATE" category in Table 1 on page 4. The winds are fairly strong southwesterly at both OUN and UMN and this is normally a dry advection pattern for Oklahoma. But dewpoints upstream at Midland, Texas (MAF), Amarillo, Texas (AMA), and even El Paso, Texas (ELP) are not any lower. With this moisture distribution and the fact that the 36 hour NGM 850 mb prog in Figure 14 showed relatively light south southwesterly flow across the area, the moisture at 850 mb is not likely to change significantly by Saturday evening. Surface moisture should also be no problem since Figure 10 showed 70 degree dewpoints across the area and the NGM boundary layer wind forecast from Figure 12 showed moderate southerly winds across most of Oklahoma and eastern Texas.

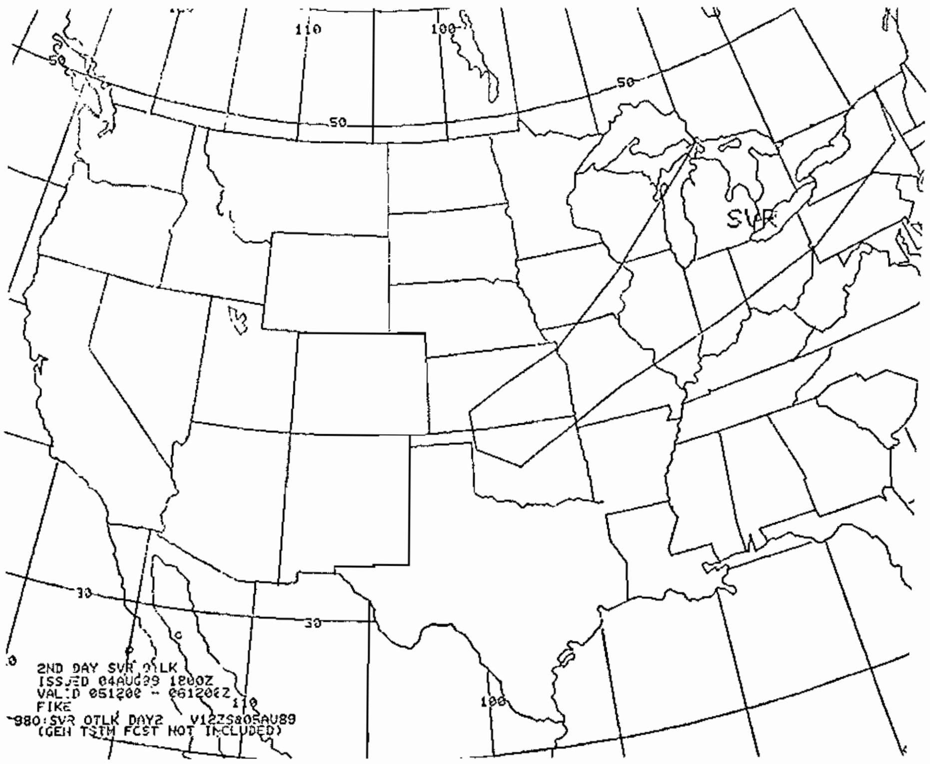


Figure 16: AFOS product 98o, the SELS day 2 severe weather outlook graphic, for Saturday, August 5, 1989.

With abundant moisture and instability forecast for Saturday evening, it is not hard to see the possibility of thunderstorms as the cold front approaches northern Oklahoma. One negative factor that could act to suppress thunderstorm development is the large 1000-500 mb thickness values forecast for Saturday evening. Figure 12 showed thickness values in excess of 5820 m across the area of interest. The NGM FOUS data in Figure 11 showed a thickness of 5840 m at OKC Saturday evening. The high thickness values represent warm air aloft which could act to cap thunderstorm development. This is not to say that thunderstorms will not form in the area, but the large thickness values could suppress thunderstorm development by reducing the amount of potential energy available. If a strong short wave were forecast to move over southern Kansas and northern Oklahoma, then the cooling aloft might help counteract the high thicknesses. However, no significant short wave is forecast in the area by the NGM, so thunderstorm formation will have to be initiated by strong convergence near the front and fueled by hot surface temperatures.

Another point that deserves consideration is whether or not there is a potential for severe thunderstorms Saturday evening. Figure 16 shows the SELS day 2 severe weather outlook for the period 12Z Saturday to 12Z Sunday. Northern Oklahoma and southeastern Kansas are near the southern end of the risk area. The actual forecast for northeast Oklahoma called for mostly clear skies Saturday with a high near 100 and a 30 percent chance of afternoon thunderstorms. Temperatures near 100, combined with dewpoints around 70 degrees should sufficiently destabilize the atmosphere to support thunderstorm development in spite of the relatively high thicknesses forecast for the area. It looks as though vertical wind shear will be weak in northern Oklahoma, but the high degree of instability expected should help overcome the less-than-favorable wind shear profile. With surface dew point depressions forecast to approach 30 degrees Saturday afternoon, there would be a potential for damaging winds with any strong thunderstorms that form (Sohl, et al., 1987).

B. 24 HOUR PRODUCTS

Now we progress twelve hours and look at some data from the Friday evening (August 5, 00Z) model runs. Figure 17 shows the NGM FOUS data with an initial time of Friday evening. An inspection of the DDFF column at TOP and DDC shows the front passing through DDC by 18 hours (1 pm CDT Saturday) and TOP by 24 hours. From the NGM FOUS wind forecasts for these two stations alone, it looks like the NGM is forecasting the front to have more of a northeast to southwest orientation than the previous NGM run. It looks as though the front will still be close enough to northern Oklahoma to act as a possible triggering mechanism sometime Saturday evening. The front is forecast by the NGM to pass through Oklahoma City (OKC) by 42 hours which is 1 pm Sunday. The best vertical velocity at OKC is forecast at 30 hours with a +3.9. Thicknesses show a drastic drop again on this run with the biggest thickness decrease over the 48 hour period at OMA with a 200 meter drop.

Another product from the Friday evening run is also shown in Figure 17. The forecast at 850 mb for OKC Saturday evening is a temperature of 24 degrees C and a dew point of 13 degrees.

```
NMCFRHT69
FOUM69 KWBC 050000
OUTPUT FROM NGM 00Z AUG 05 89
TTPTTR1R2R3 VVVLI PSDDFF HHT1T3T5   TTPTTR1R2R3 VVVLI PSDDFF HHT1T3T5
OKC//453013 -3095 001725 05332617   DFW//453414 -1796 111717 04322516
06000603319 -1098 091924 03272410   06000703410 00297 111023 02262317
12000703627 -0299 102120 02232319   12000893412 01198 122119 01222317
18000513045 00796 091910 04302219   18000523736 -2698 122009 02292117
24000425055 00297 071908 03322516   24000303041 01398 071914 04332510
30007495562 03996 002117 02302515   30000504149 00699 092023 03202410
36030616470 01296 002709 00262414   36000704950 -0299 102319 00242317
42010456945 01096 090410 00302313   42000475260 00698 092207 01312315
48000305114 -0598 100516 79312312   48000306290 00190 071902 02332514
SAT//463021 -2095 111521 03322416   IAH//694020 -1495 141716 00292216
06000773016 01496 121622 01252217   06000863116 -0697 141718 01252310
12000944220 00698 141913 79222117   12000963440 -0497 142213 79232317
18000594637 -0596 131600 00292117   18000534645 -1390 142009 79302217
24000414735 -1199 091715 02312416   24000504543 -1500 111015 02302317
30000674427 -0499 111720 00262217   30000864131 00198 131917 00252410
36000914320 -0100 112013 70222215   36000994036 02190 122313 79232417
42000404227 -0203 101006 01302215   42000474139 -1301 112105 01302217
48000334732 -1002 001510 02322414   48000464536 -1100 091910 01312416
BRO//634512 -1094 121426 01302418   DRT//304019 -1697 001322 05342615
06000754016 -0596 111426 00272410   06000554020 00190 111523 02252215
12000844747 00596 131710 78252317   12014735734 00790 141015 70212015
18000655154 -1397 131512 79202216   18000525036 00297 111400 01282015
24000655060 -1798 101415 79282316   24002425332 -1097 001515 02302214
30001815371 01297 121516 79252315   30000604735 00690 111620 01262015
36007905404 -1097 101613 78242216   36000814425 -0500 111714 70211915
42012675970 -0898 121200 78272115   42000414033 -0602 101406 01282015
48000674962 -1198 091314 60272117   48000324542 00102 001311 02302312
NMCFRHT68
FOUM68 KWBC 050000
OUTPUT FROM NGM 00Z AUG 05 89
TTPTTR1R2R3 VVVLI PSDDFF HHT1T3T5   TTPTTR1R2R3 VVVLI PSDDFF HHT1T3T5
DSM//504621 00580 032015 04322719   TOP//554320 -0191 051919 05332719
06006705338 -1009 032321 03292710   06000614053 -0494 062225 04292719
12008725435 00591 052011 00262610   12000745747 02694 072320 02252710
18000414936 01294 063307 00312317   18010406050 01193 072403 03322410
24000314522 -1198 073415 77302214   24045366065 -2194 063600 02332315
30000433403 00503 103521 73231912   30000436445 01198 100221 79272315
36000733900 -1103 123518 68181409   36000515516 00802 120220 74211913
42000554013 -0003 133410 66211307   42000304310 -0902 130109 72251009
48000534719 -1404 143515 64211306   48000305123 -2602 133614 71261007
DDC//274023 04494 031917 08362919   OMA//455027 03789 022111 05342019
06000394735 -0796 051027 06312018   06002535025 -0298 032315 04312710
12000494320 01197 062121 05252019   12000545041 00993 063313 00262510
18000345023 02098 060704 05312516   18000355032 01297 003510 79292117
24011466230 03195 070509 02302314   24000304716 -0400 093514 76292113
30007466614 -3295 110421 00282213   30000383900 -1402 123619 73241911
36000555506 00797 130521 76222012   36000694516 -1502 140119 60181500
42000394711 -0399 143610 75261911   42000525210 -1603 153511 66211307
48000356333 -2599 130711 75272009   48000404919 -1204 163614 65211305
LBF//103520 -1698 043506 04332616   BFF//104315 02097 050107 02302211
06000204220 02098 051109 02322514   06000196624 03200 090511 79262000
12000395026 -0790 100323 70222213   12000575115 01500 150310 72131609
18000395617 01000 130112 76241612   18000415011 00699 160106 73201300
24000315013 -1499 120310 75261910   24000335622 00699 130000 74231506
30000355423 -0399 150510 73241700   30000415015 01698 161312 72211406
36000405919 -0499 160413 70201600   36012546623 03398 171504 70171303
42009497034 00299 109400 69211406   42007497010 02298 100610 70191204
48004497425 00399 170313 69221404   48007536915 00698 100614 70191202
```

```
TRAJECTORY FCST

            050000Z   050600Z   051200Z   051800Z           060000Z
           LATLONPPP LATLONPPP LATLONPPP LATLONPPP        TEMP DEWPT   K

ALS 700 320072704 384065694 380057700 376056710       14.0  -2.4  31
    SFC 320260738 384062734 380055751 376055757 748 19.7   2.1

ABQ 700 356076681 359069687 355062699 352062707       15.2   1.2  30
    SFC 352001754 358075754 355067763 352064774 776 24.3   5.3

ELP 700 323655712 321055703 321055705 319057704       14.9   5.0  30
    SFC 327005010 323070013 320069820 310065037 840 25.3  15.9

DDC 700 392022676 331010600 307002696 302000698       15.0  -2.7  31
    850 372032955 375996861 303992864 302992863       29.0  11.5
    SFC 351999942 358994345 381992945 382991946 934 32.7  16.4

LBB 700 337027692 339023696 341016703 339015705       15.4   1.7  32
    850 312010862 313021053 323021049 331019850       20.0  12.4

OKC 700 332002701 342995704 350986705 353979707       14.7  -2.1  26
    850 297990651 317990856 334996050 346979957       24.0  13.1
    SFC 281977000 304990903 322982975 340979975 974 31.0  20.4

FTW 700 285986662 299986679 312981691 321975699       13.5  -3.0  23
    850 262975036 202979044 330979050 314575052       22.6  11.9
    SFC 240954013 276961000 291969997 309571590 990 28.1  22.7

SAT 700 243972666 258980676 273982690 285983690       12.3    .4  27
    850 232964842 246972843 265979047 281982050       22.0  12.4
    SFC 243947007 255959002 257970993 281978900 986 27.6  22.7

BRO 700 230942672 220954679 240963690 249968698       12.8    .2  27
    850 215941031 223951036 234960842 245968848       22.4  11.5
    SFC 221939981 230940984 236957999 247966002 889 28.5  21.6

DRT 700 257000609 272005695 283006781 289006704       13.3   4.4  37
    850 241986076 259394866 273004060 234007056       25.7  15.7
    SFC 242979970 260998900 272001960 285006953 942 28.1  21.3
```

Figure 17: AFOS products FRHT69 and FRHT68 (left) and FTJ55. All 3 products were created from the 00Z Saturday, August 5, 1989 model runs.

The trajectory forecast for an air parcel terminating at 850 mb at OKC is from the south southwest, similar to what the previous NGM run had forecast. An inspection of the stations to the south southwest of OKC shows dew points of 12 at both Lubbock, Texas (LBB) and Fort Worth, Texas (FTW), so the 850 mb air is not considerably different to the south or southwest of the target area.

Another important part of Figure 17 is the set of forecast 700 mb temperatures for the area Saturday evening. OKC has 14.7, DDC 15.0, and FTW 13.5 degrees C. These warm 700 mb temperatures represent the forecast warm air aloft that could act as a cap to suppress thunderstorm development. However, the numbers are only forecast values and even if they verify, the forecaster must still inspect the latest soundings to analyze the thunderstorm potential.

The scene is now set for possible thunderstorm formation

Saturday evening. Forecast maps for 36 and 24 hours in advance of the target time have been shown and discussed. This brings us to Saturday morning, August 5, 1989, approximately 12 hours before the target time. The focus now will be on diagnostic charts rather than prognostic charts. However, most of the diagnostic charts have some prognostic value.

C. 12 HOUR PRODUCTS

The first products a forecaster might look at Saturday morning are the regional soundings since they are often the first products available. Figures 18 and 19 show Skew-T soundings from Norman, Oklahoma (OUN) and Monett, Missouri (UMN) from 12Z Saturday, August 5, 1989. Both of the soundings are from AFOS program RP.SV on a skew-T background. Figures 18 and 19 have the dry bulb temperature, wet bulb temperature, and the dew point plotted on the chart. The winds are plotted conventionally on the right side of the chart.

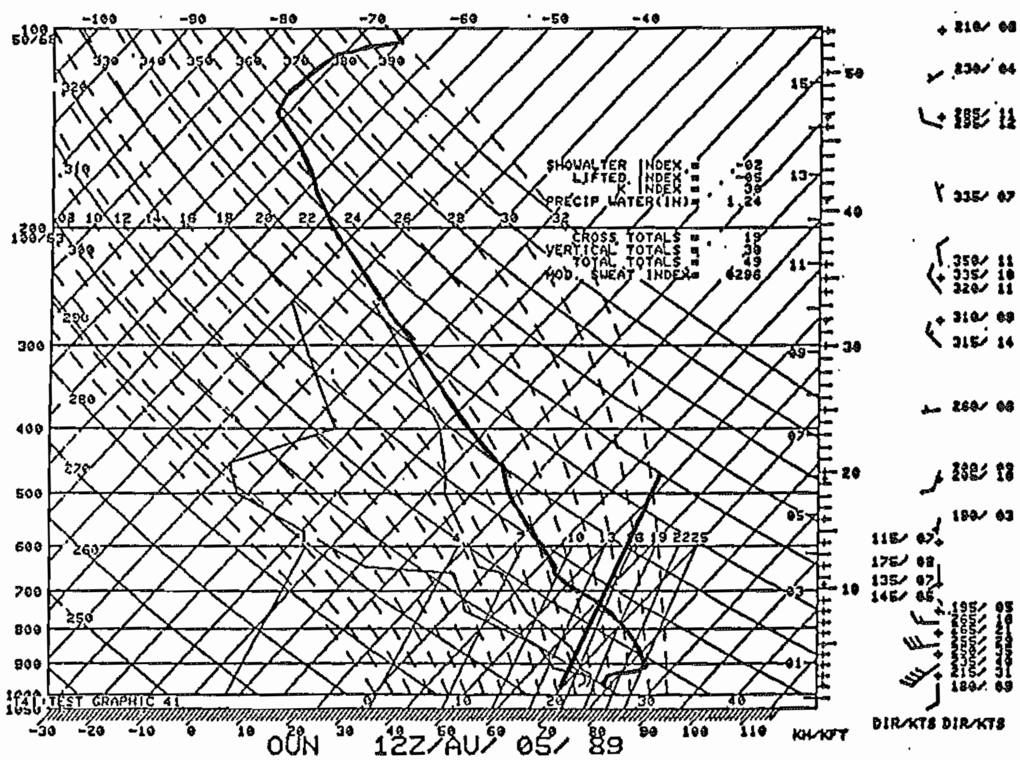


Figure 18: Sounding taken at Norman, OK 12Z Saturday, August 5, 1989.

An examination of the OUN sounding in Figure 18 reveals a mean mixing ratio in the lowest 100 mb of the sounding of 15 g/kg with the best moisture near the surface and slightly drier air above. A mean mixing ratio of 15 g/kg falls in the "HIGH" category in Table 1. A radiation inversion is present and noticeably drier air is present above the inversion. A fairly deep potentially unstable layer exists between 930 mb and 650 mb, with the freezing level above 15,000 feet. The winds in the Norman sounding are fairly strong southwest to west above the surface and below 8,000 feet, but are much lighter above.

The winds veer from southerly to northerly between 10,000 and 35,000 feet, although the greatest speed on the chart in this layer is only around 15 knots. This type of wind profile is not atypical for this part of the country in early August. The lack of strong vertical wind shear will act to limit the organizational potential of storms which might form in the afternoon or evening, unless the wind profile is drastically changed during the day.

The UMN sounding in Figure 19 is similar to the OUN sounding with a few important exceptions. Although the moisture and wind profiles are similar, the temperature plots show major differences. The first is the depth of the low level stable layer; for OUN it is around 3,000 feet ASL, and for UMN approximately 7,000 feet. The temperatures in the stable layer

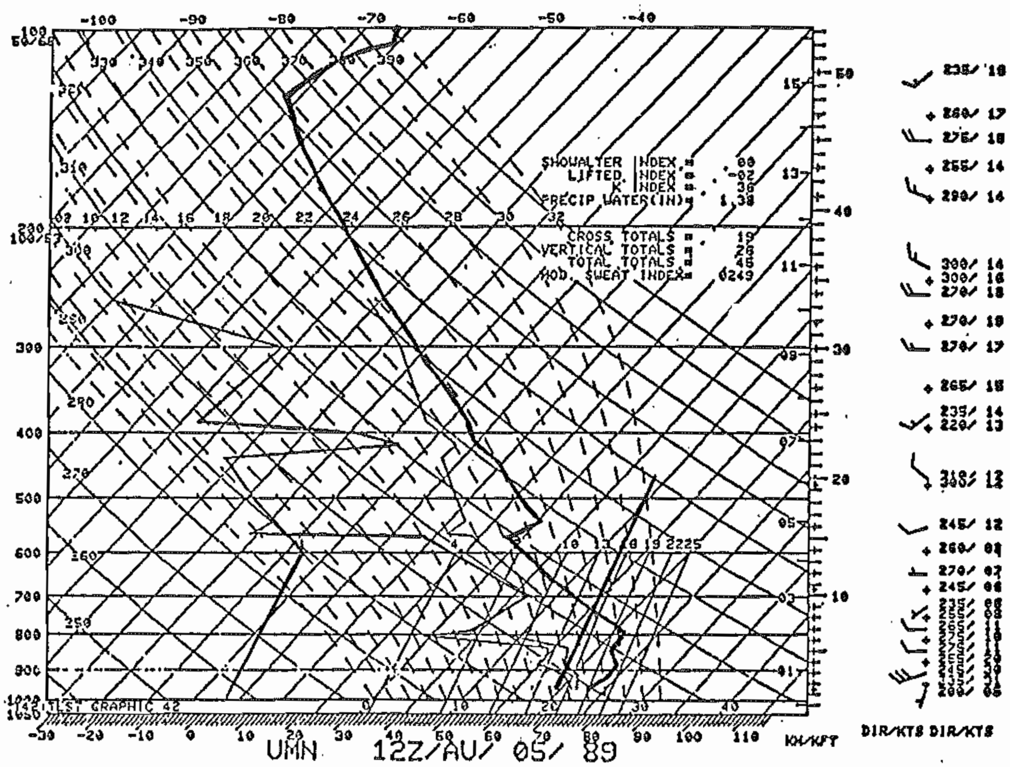


Figure 19: Sounding taken at Monett, MO 12Z Saturday, August 5, 1989.

are warmer in the OUN sounding than in the UMN sounding. The effect may be that stations in the vicinity of the UMN sounding do not have the potential for getting as hot at the surface as those areas in the vicinity of OUN. This can be attributed to warmer temperatures aloft at OUN and the idea that the air, as it is heated from solar insolation, must be mixed through a deeper layer in the Monett area than in the Norman area if solar heating is equal. The net result will probably be a hotter surface temperature at Norman and a cooler surface temperature at UMN, which is normally expected anyway. The cooler surface temperatures will not only lead to less instability, but also not allow the stable layer to be completely erased and thus a low level cap might still come into play. At OUN, the shallow inversion will allow temperatures to rise quickly with daytime heating and will likely erase nearly all of the low level cap. Of course, the possible effect of the southwest winds above the surface at both UMN and OUN must be considered; warm advection just above the surface may change the above scenario by strengthening the cap. Possible modifications to the soundings will be considered later.

The second major difference in the OUN and UMN soundings is found in the temperature profile around 15 thousand feet. The UMN sounding shows a distinct temperature inversion between 580 and 540 mb, whereas the OUN sounding shows no such layer. This inversion, likely caused by subsidence near an upper ridge, could act to suppress thunderstorm updrafts that encounter the warm air aloft. Consideration must be given to the processes that could change the sounding during the day. For example, cold advection at 500 mb at UMN will act to erode the elevated inversion.

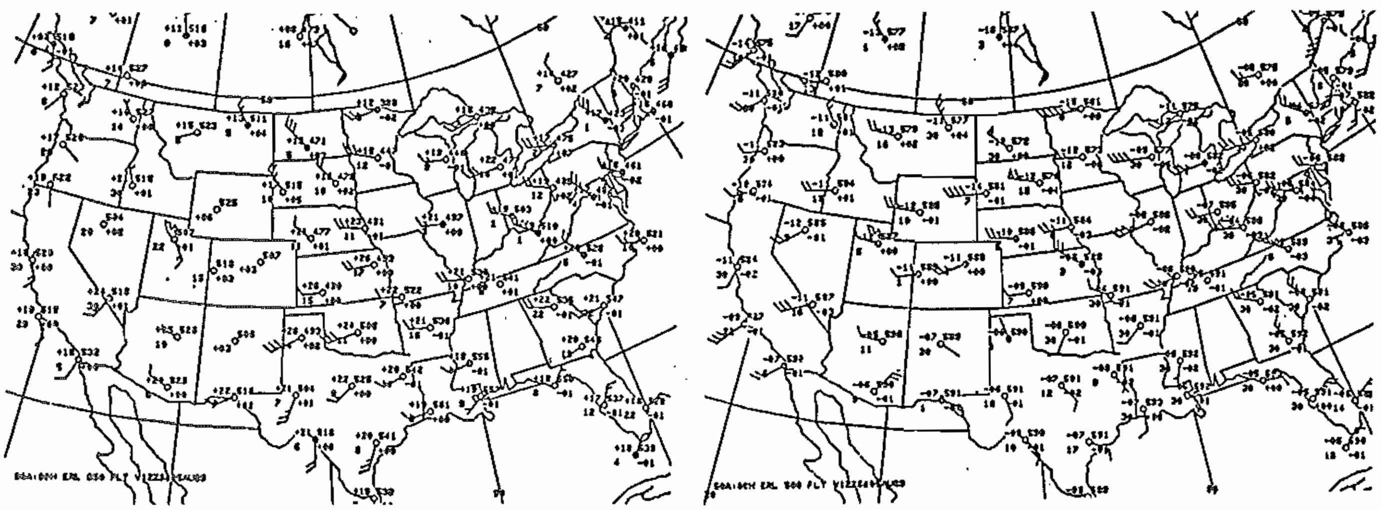


Figure 20: 850 mb plot (80a)(left) and 500 mb plot (50a) for 12Z Saturday, August 5, 1989.

Figure 20 shows the 850 mb and 500 mb plot from 12Z Saturday. The 850 mb chart shows warm advection at 850 mb with west-southwesterly winds in the area of concern, which again is northern Oklahoma. The warm advection is also occurring at UMN where the cap may be strengthened by the warmer 850 mb air. The west to southwest winds at 850 mb at OUN, AMA, and DDC are usually not favorable for severe thunderstorms in this situation for two reasons: the westerly component of the wind will (1) tend to generate less convergence along an east-west boundary than the convergence which would be realized with an 850 mb wind with more southerly component and (2) usually act to bring down drier air from higher terrain. The 500 mb plot in Figure 20 shows light flow across the area of interest. Temperatures at 500 mb are -6 degrees C at AMA and OUN and -4 at UMN. However, upstream from UMN, TOP has a temperature of -8 C with west northwest winds advecting cooler air into southwest Missouri. This cold advection will help to destroy the previously mentioned elevated inversion on the UMN sounding in Figure 19. Temperature advection at 500 mb in northern Oklahoma is nearly neutral with southwest winds around 10 kts. Another look at 500 mb temperature advection is presented in Figure 25.

Figure 21(a) shows a surface analysis from 15Z Saturday. The cold front extends from southwestern Iowa across north central Kansas and dips southward to a weak low pressure area along the Oklahoma-Kansas border northwest of Gage, Oklahoma (GAG) and then continues westward across the Oklahoma panhandle. A weak surface boundary (dashed line) is ahead of the front across east central Kansas and northwest Missouri. The observations in Oklahoma showed scattered or clear skies at 15Z (10 AM CDT) across most of Oklahoma with temperatures already in the mid 80s. Dewpoints are in the 70s over the eastern half of Oklahoma with light to moderate southerly flow between eastern Oklahoma and the gulf coast.

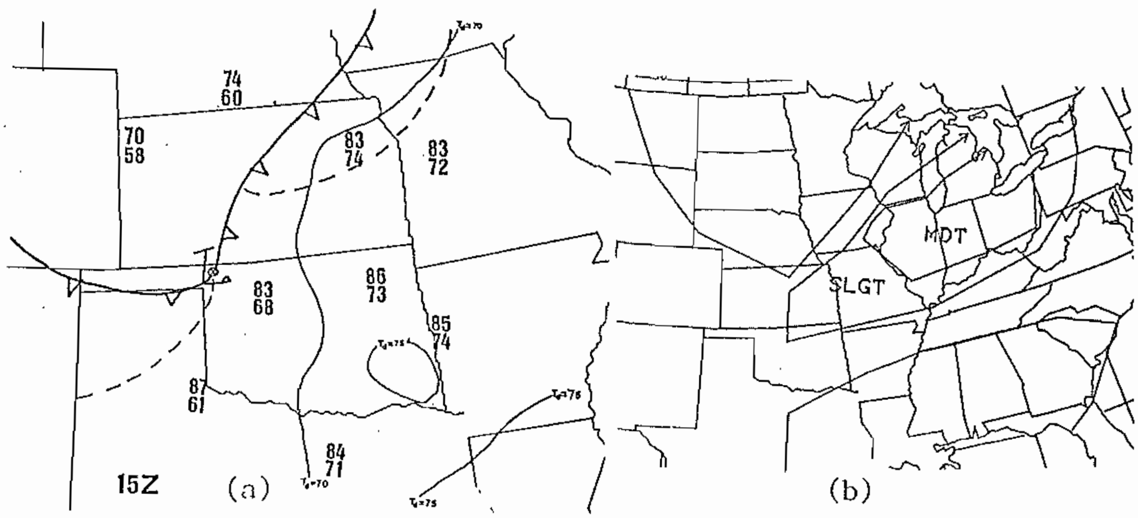


Figure 21: (a) Surface analysis for 15Z Saturday. The 70 and 75 degree isodrosotherms are drawn with temperatures and dew points from selected stations shown. (b) 94o, the day 1 severe weather outlook issued at 15Z Saturday, August 5, 1989.

Now that surface conditions have been analyzed, the morning sounding will once again be used. Figure 22 shows the 12Z Norman sounding with a surface temperature of 100 degrees and a mean mixing ratio equal to the 12Z mean mixing ratio that is already on the Skew-T. A large positive area exists on the sounding with a 500 mb LI around -8. Given the amount of energy that will be available to updrafts that originate near the surface boundary and the good influx of surface moisture on moderate southerly winds, the potential for severe thunderstorms is evident. The vertical wind profile is not especially favorable for long-lived thunderstorms or tornadoes, but the degree of instability should allow some thunderstorms to exceed severe limits. Figure 21(b) shows the day 1 severe weather outlook graphic issued by SELS at

15Z August 5, 1989.

The last prognostic map to be shown is Figure 23, which is the 12-hour NGM moisture convergence graphic valid Saturday evening at 7 pm CDT. The graphic shows an axis of moisture convergence extending from central Illinois into east central Kansas and into northwest Oklahoma. The NGM moisture convergence graphics often do a very good job of locating important areas of convergence and are usually worthy of inspection.

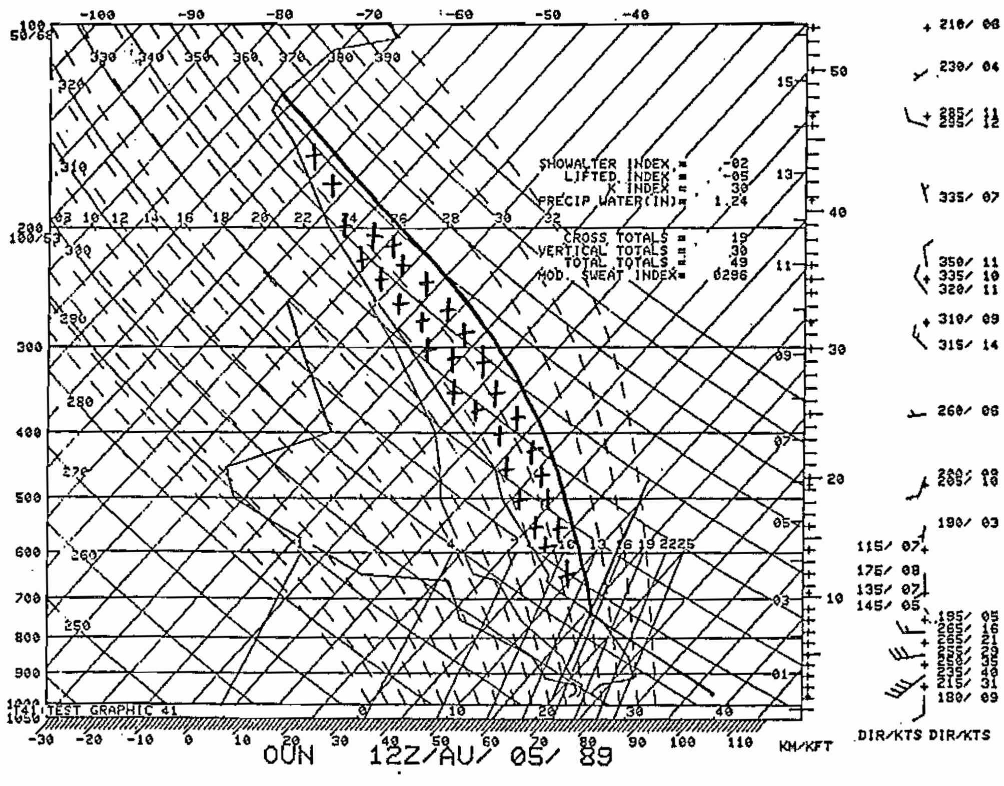


Figure 22: Same as Figure 18 except with a forecast afternoon temperature of 100 degrees used for positive energy determination. The plus signs denote positive energy available if surface temperature reaches 100 degrees and the mean mixing ratio is 15 g/kg.

D. DIAGNOSTIC CHARTS

Figures 24 and 25 show several products from the Upper Air Analyses and Quasi-Geostrophic Diagnostics Program from 12Z Saturday, August 5, 1989. Figure 24 shows the steepest lapse rates between 700 mb and 500 mb across Nebraska and western Kansas. In the area of concern, the steepest lapse rates on this chart are found in northwest Oklahoma. Also in Figure 24 is the 700 mb Q vector divergence product. It shows the synoptic scale forcing well to the north of Oklahoma. Figure 25 shows 300 mb isotachs and 500 mb temperature advection.

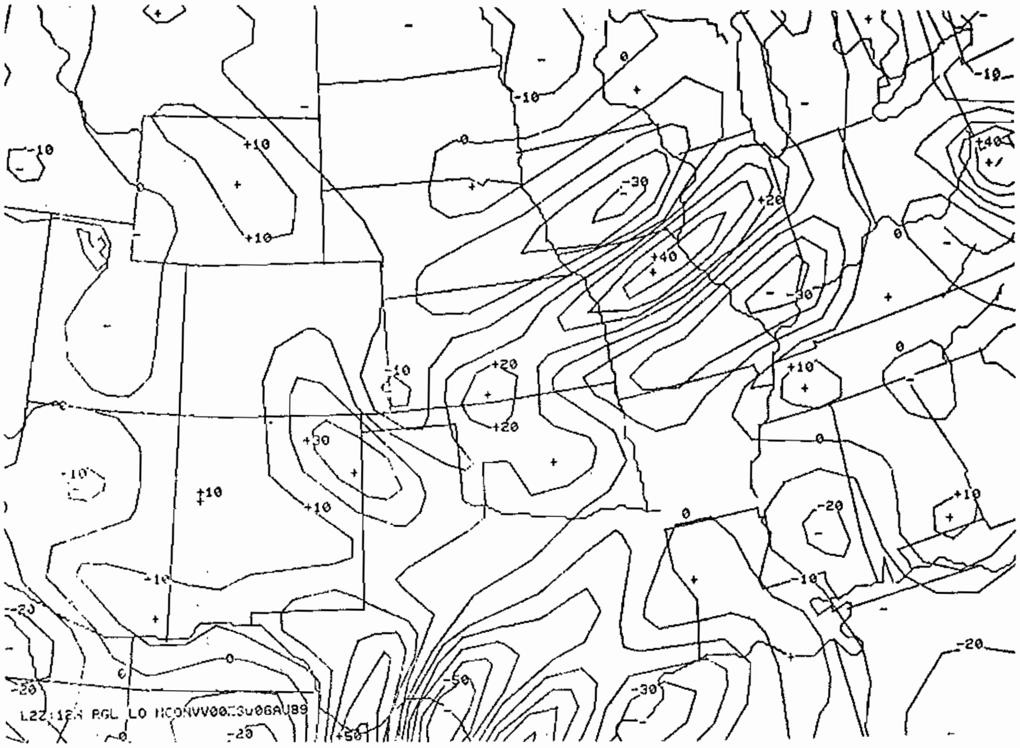


Figure 23: L2Z, the 12 hour NGM moisture convergence graphic
valid 00Z Sunday, August 6, 1989.

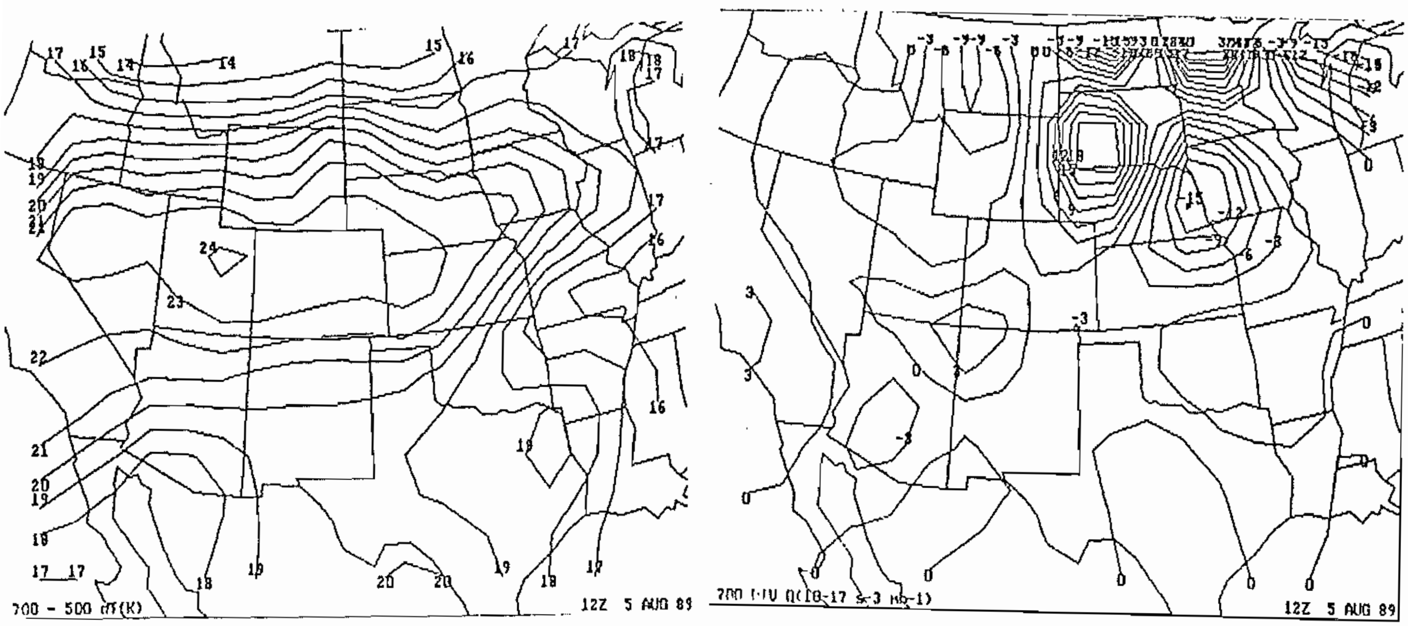


Figure 24: UA products from 12Z Saturday, August 5, 1989.
On the left, 70S shows 700-500 mb lapse rates greater than 20 degrees C across northwest OK and western Kansas. 7QD on the right shows Q vector convergence centered in eastern Nebraska.

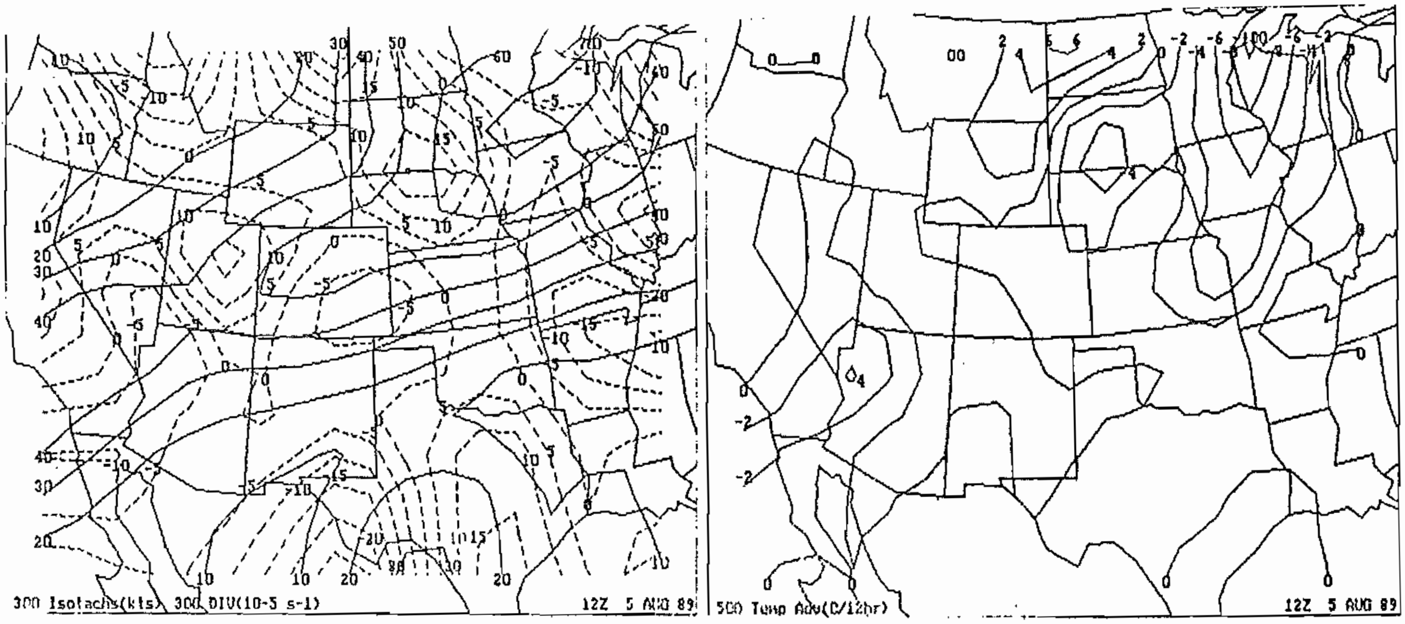


Figure 25: UA products 30I and 30D (left) and 50A (right) from 12Z Saturday, August 5, 1989. On the left, the highest wind speeds are across central Nebraska and southern Minnesota with 300 mb convergence indicated over northeast OK. On the right, 500 mb cold advection is occurring over eastern Kansas.

Attention will now be concentrated on ADAP graphics. Figure 26 shows six products from the 14Z Saturday ADAP run. The moisture flux convergence graphic in Figure 26(a) shows a center of moisture flux convergence in the eastern Oklahoma panhandle associated with the surface low in that area. An axis of convergence extends across central Oklahoma associated with speed convergence of the surface winds. The SCC graphic in Figure 26(b), which is total moisture flux convergence change over a two hour period, shows increasing moisture flux convergence in the same area.

Figures 26(c) and (d) show 14Z ADAP 500 and 300 mb LI. The 500 mb LI values, which are computed using a surface parcel, are around -4 or -5 across northern Oklahoma. The 300 mb values range from -3 to -6 across northern Oklahoma. For northwest Oklahoma, the values at 300 mb and 500 mb are very nearly the same, but in northeast Oklahoma the 300 mb value is lower than the 500 mb value. This observation allows the conclusion that at 14Z more potential buoyant energy is available in northeast Oklahoma than in northwest Oklahoma.

The cap strength graphic in Figure 26(f) shows cap strength based on surface wet bulb potential temperature (calculated from surface temperature, dew point, and pressure) at 14Z. The cap is 5 to 6 degrees Celsius with the strongest cap in the northwest. Surface mixing ratio is shown in Figure 26(e). A distinct west-east surface moisture gradient exists with the highest values in the east.

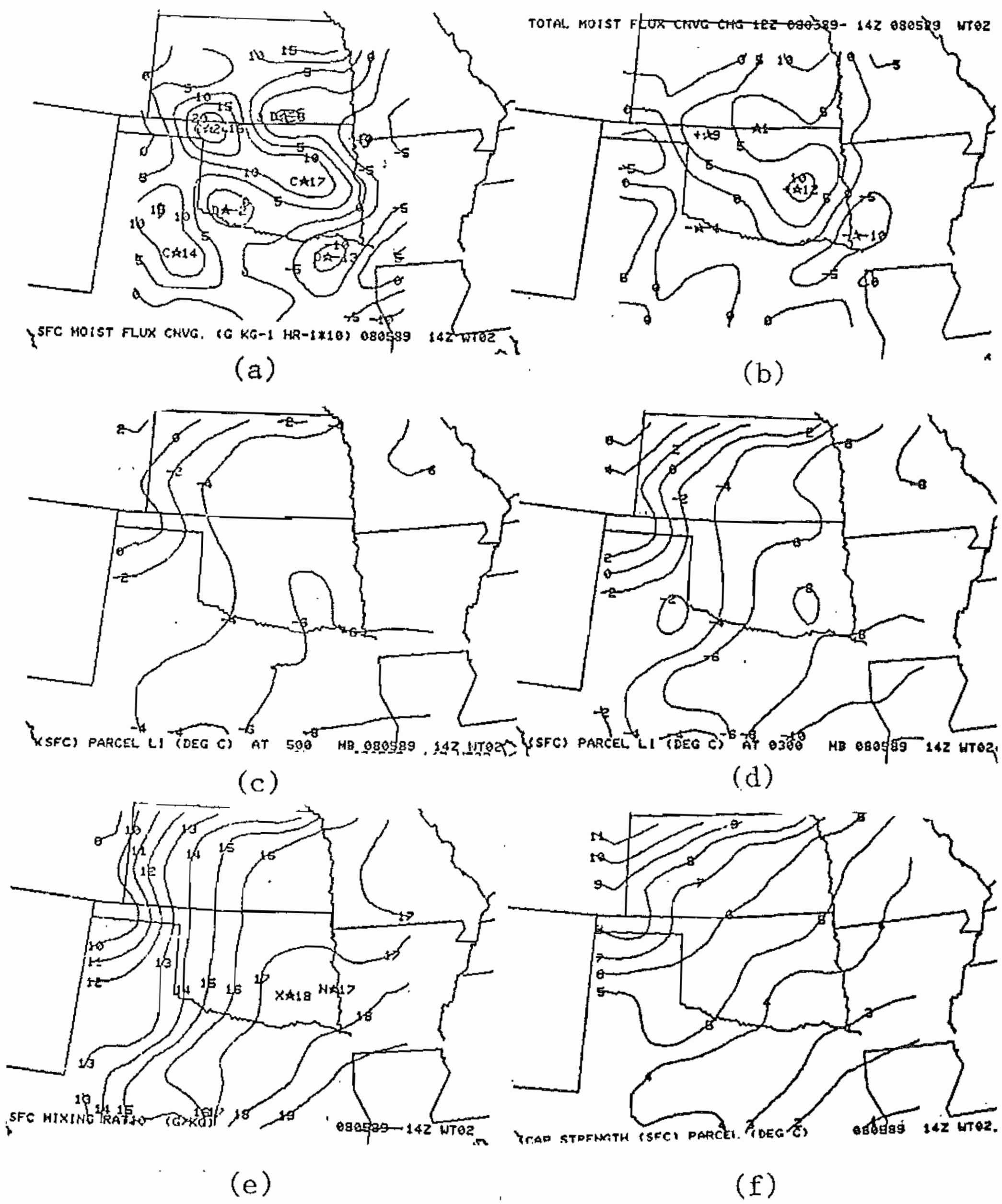


Figure 26: ADAP graphics from 14Z Saturday, August 5, 1989. From the upper left, (a) is surface moisture flux convergence (SMC); (b) is 2 hour moisture flux convergence change (SCC); (c) is 500 mb Lifted Index (SSL); (d) is 300 mb LI (SSU); (e) is surface mixing ratio (SMR); and (f) is cap strength (SSC).

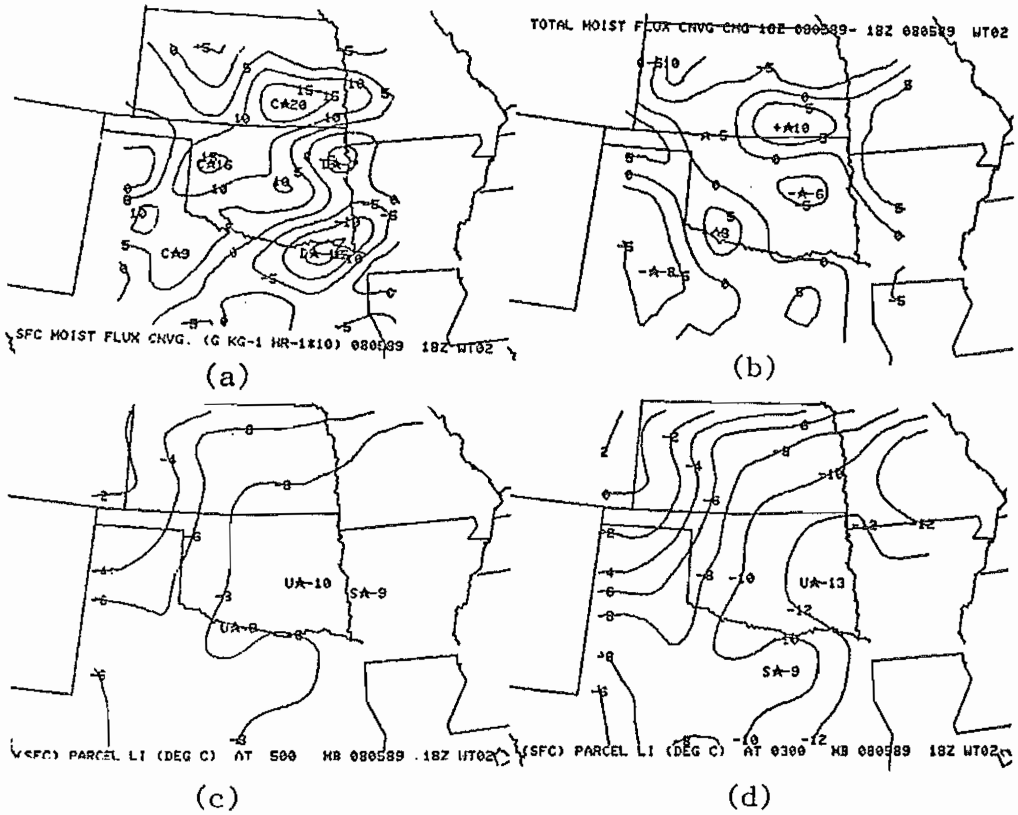


Figure 27: 18Z ADAP graphics. (a) SMC, (b) SCC, (c) SSL, and (d) SSU.

Several 18Z ADAP graphics will now be discussed. Figures 27(a) and (b) shows surface moisture flux convergence and 2 hour total moisture flux convergence change, SMC and SCC. The SMC graphic is similar to that of 14Z with an axis of moisture convergence across central Oklahoma. Of greater significance is the area of moisture flux convergence showing up in south central and southeast Kansas. This area is associated with the southward moving surface boundary that was previously analyzed over east central Kansas on the 15Z surface chart in Figure 21. SCC in Figure 27(b) shows that the moisture flux convergence has increased across south central and southeast Kansas between 16Z and 18Z. Daytime heating has destabilized the atmosphere with LI values at 500 mb between -6 and -9 across northern Oklahoma on Figure 27(c). The 300 mb values have decreased to -12 in northeast Oklahoma, as shown in Figure 27(d).

Figure 28 shows four more ADAP graphics from 18Z. SMR and SSC which are surface mixing ratio and cap strength, respectively, are shown in (a) and (b). Mixing ratios have increased slightly across northeast Oklahoma and remained nearly constant across northwest Oklahoma since 14Z. Cap strength has decreased about 2 degrees Celsius since 14Z with the 2 degree isoline across southeast Oklahoma and higher values to the northwest.

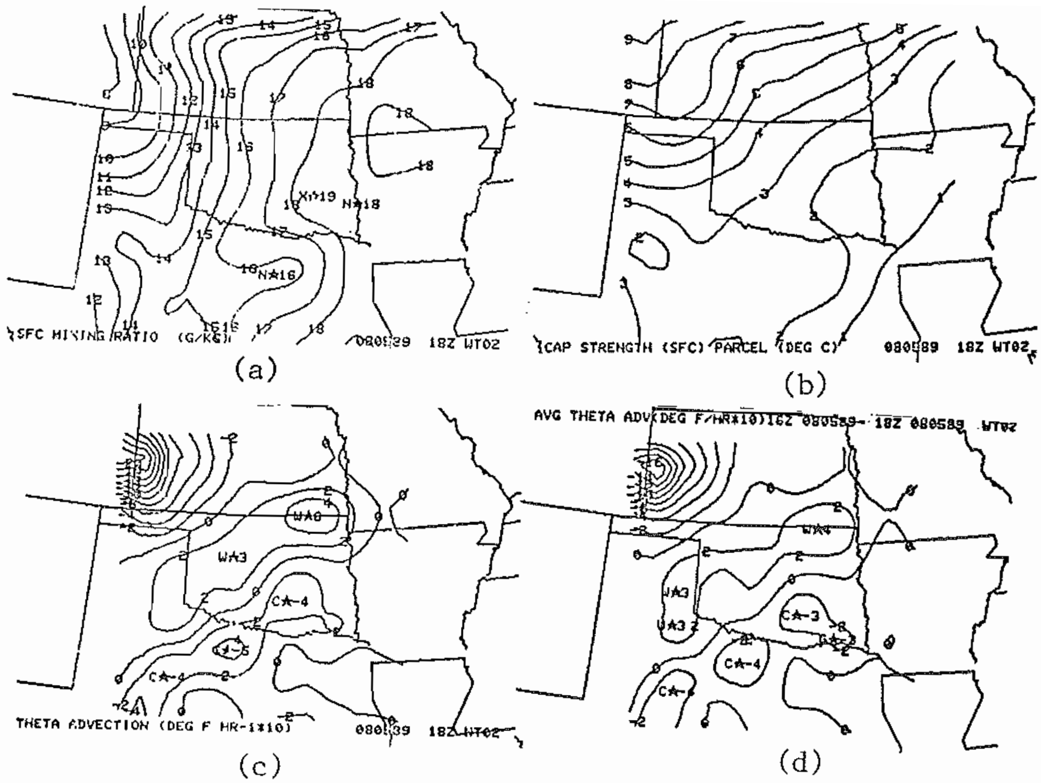
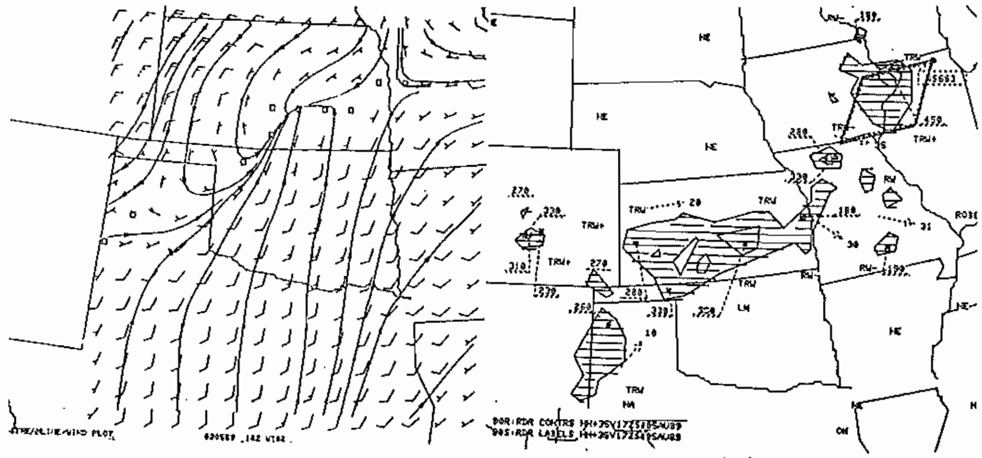


Figure 28: 18Z ADAP graphics. (a) SMR, (b) SSC, (c) STA, and (d) SAA.

Surface theta advection and 2 hour average surface theta advection at 18Z are shown in Figures 28 (c) and (d). Weak warm theta advection is indicated from west central Oklahoma into northeast Oklahoma and southeast Kansas. Fairly strong cold theta advection was present across southwest Kansas behind the cold front. The 18Z surface streamlines in Figure 29(a) indicate a weak deformation zone in east central Kansas and west central Missouri. Elsewhere, the surface streamlines at 18Z show north to northeasterly flow across most of Kansas with southerly flow across most of Oklahoma and southeast Kansas ahead of the surface boundaries.

Figure 29(b) shows the radar summary chart valid at 1735Z or 1235 pm CDT. The chart shows an area of showers and thunderstorms near the front in Kansas and the Oklahoma panhandle. The highest tops in this area on the chart are only 35,000 feet in the Wichita area. Most of the echoes in Kansas are shown on the charts as VIP levels 1 and 2 with movement to the east at 20 knots.

At 21Z, the moisture flux convergence graphic, Figure 30(a), shows a moisture convergence center in west central Oklahoma with several axes of convergence from the center. One axis runs west-east across central Oklahoma and into northwest Arkansas. Also note the divergent center in southeast Kansas. It appears that perhaps a weak mesohigh has formed in the rain cooled air in southeast Kansas. The moisture flux convergence



(a) (b)

Figure 29: (a) 18Z ADAP graphic SSW, surface streamlines and winds. (b) AFOS product 9ØR (radar contours) overlayed with 9ØS (radar labels) for 1735Z, August 5, 1989.

change graphic from 21Z is shown in Figure 3Ø(b) and shows large decreases in moisture flux convergence in south central and southeast Kansas. Figure 3Ø(c) shows the surface streamline graphic from 21Z. The streamlines indicate southerly flow across most of Oklahoma except in the Oklahoma panhandle and extreme northwest Oklahoma with light north winds behind the cold front and in the extreme north central part of the state where light east winds are shown. The convergence axis across central Oklahoma in Figure 3Ø(a) is still associated with speed convergence of the winds. The divergence in the surface winds in southeast Kansas is shown nicely in the wind plot and streamline analysis. Although there does not appear to be a well-defined clockwise circulation in the analysis, the divergence indicated in southeast Kansas in Figures 3Ø(a) and (c) gives evidence of an important surface boundary in southeast Kansas ahead of the cold front. The actual cold front extended from northeast Kansas to northwest Oklahoma at 21Z.

Figure 3Ø(d) shows the cap strength graphic from 21Z. The values in northern Oklahoma range from 4 in the northwest to around 2 degrees C in the northeast. With the relatively weak cap, high degree of instability, and surface boundaries in the area, thunderstorm formation seems likely in northern Oklahoma. In northwest Oklahoma where the cap is "strongest", the convergence values are highest. In northeast Oklahoma where the cap strength is around 2 degrees, it appears that only a small amount of convergence is necessary to release the instability that has built up.

The LI graphics from 21Z are shown in Figures 31(a) and (b). 5ØØ mb LIs are now generally between -8 and -1Ø in northern Oklahoma with 3ØØ mb LIs between -8 and -14. The greatest available potential energy in our area of concern is in northeast Oklahoma. At 21Z, the temperature at Tulsa was 98, which was the high for the day, with a dewpoint of 75 and a

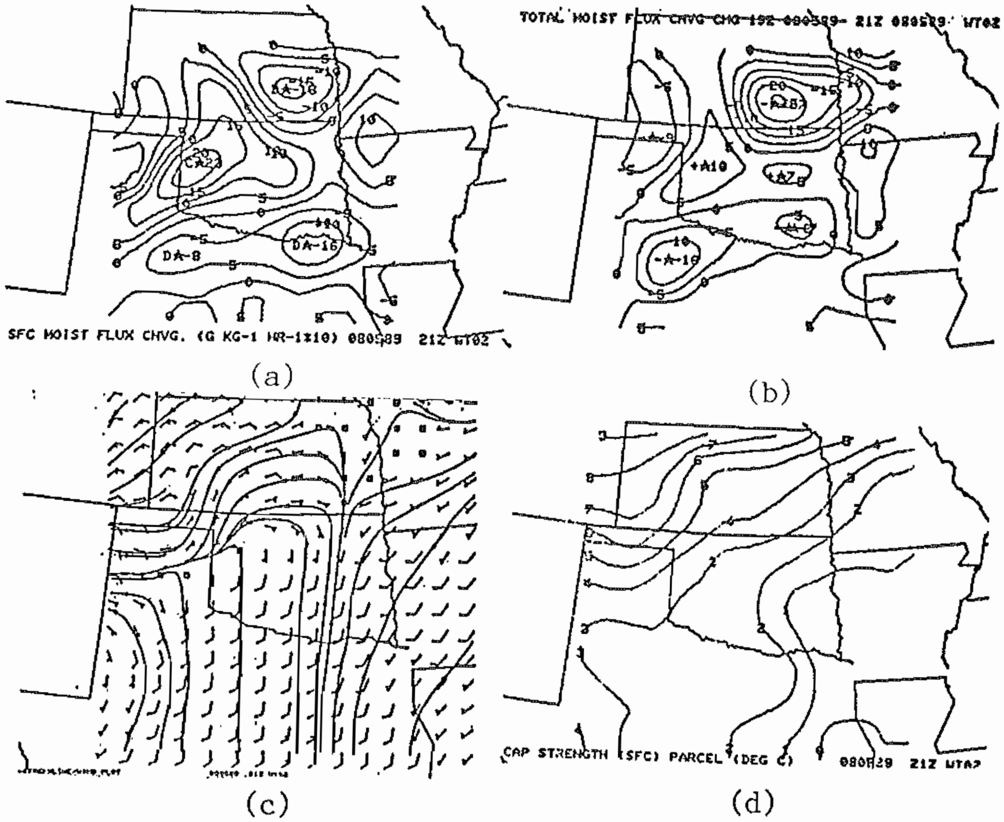


Figure 30: 21Z ADAP graphics: (a) SMC, (b) SCC, (c) SSW, and (d) SSC.

190 degree wind at 11 kts. With this hot, humid air, it is not hard to imagine the possibility of strong thunderstorms. The proximity of a surface convergence boundary gives support to the possibility of severe thunderstorms.

Figure 32 shows the 2135Z radar summary chart. A very strong thunderstorm had formed in south central Kansas along the surface boundary in this area as mentioned above. Golf ball sized hail was reported near Sedan, Kansas (65 miles north of Tulsa, OK) at 2205Z and was associated with this thunderstorm. Other strong thunderstorms were in the Texas Panhandle and southern Missouri. Notice that there are no significant storms

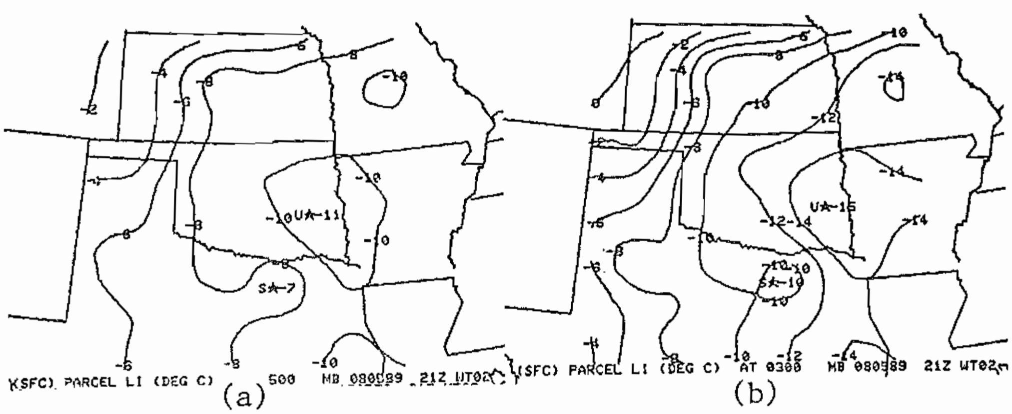


Figure 31: 21Z ADAP graphics SSL (left) and SSU.

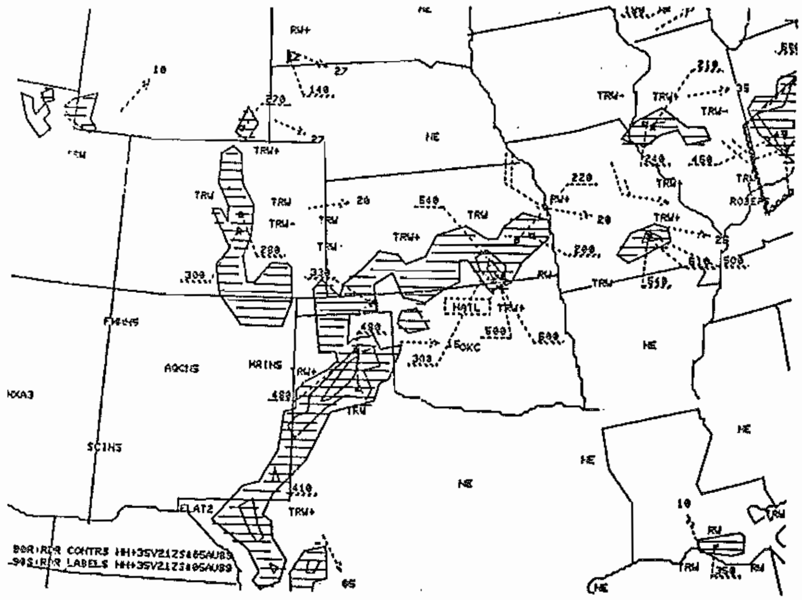


Figure 32: Radar summary chart (AFOS products 9Ør and 9Øs) for 2135Z, August 5, 1989.

in northwest Oklahoma yet, only level 1 and 2 echoes. However, the moisture convergence in that area (see Figure 3Øa) suggests that rapid thunderstorm development is possible.

A severe thunderstorm watch was issued at 224ØZ for a large part of northern and central Oklahoma from 2315Z Saturday until Ø4ØØZ Sunday August 6. The text of the watch bulletin stated that severe thunderstorms were expected to develop along the surface boundary in the northern part of the state and sag southward.

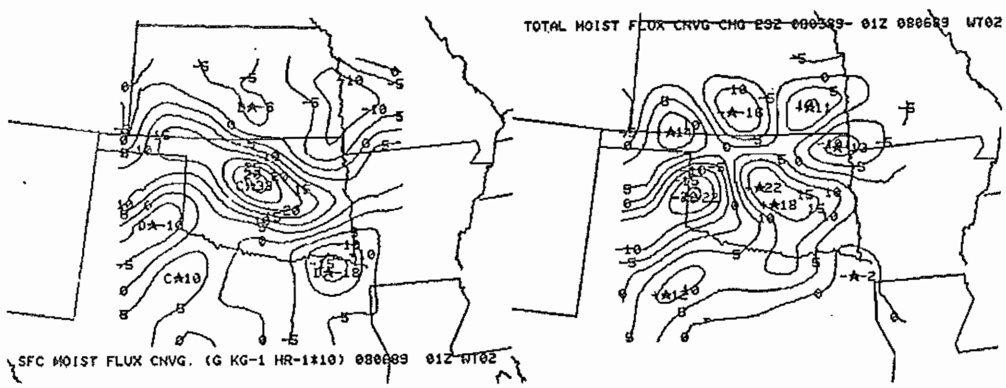


Figure 33: ADAP graphics SMC and SCC for Ø1Z, August 6, 1989.

Figure 33 shows the moisture flux convergence graphics at Ø1Z Sunday, August 6, 1989. The axis of convergence had become very well defined from northwest Oklahoma across the middle of the state. The pre-frontal surface boundary had just passed through Tulsa and strong to severe thunderstorms were occurring over parts of northern Oklahoma. Figure 34 shows the radar summary chart for 0035Z. Thunderstorms with VIP level 4 or higher intensity are occurring across a large part of northern Oklahoma. There are also two separate tops at 62,000 feet reported in northern Oklahoma.

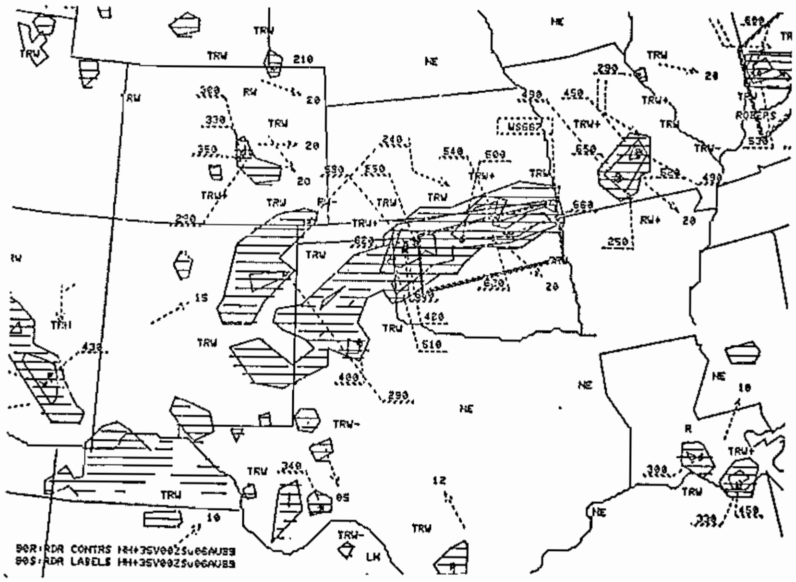


Figure 34: Radar summary chart from 0035Z August 6, 1989.

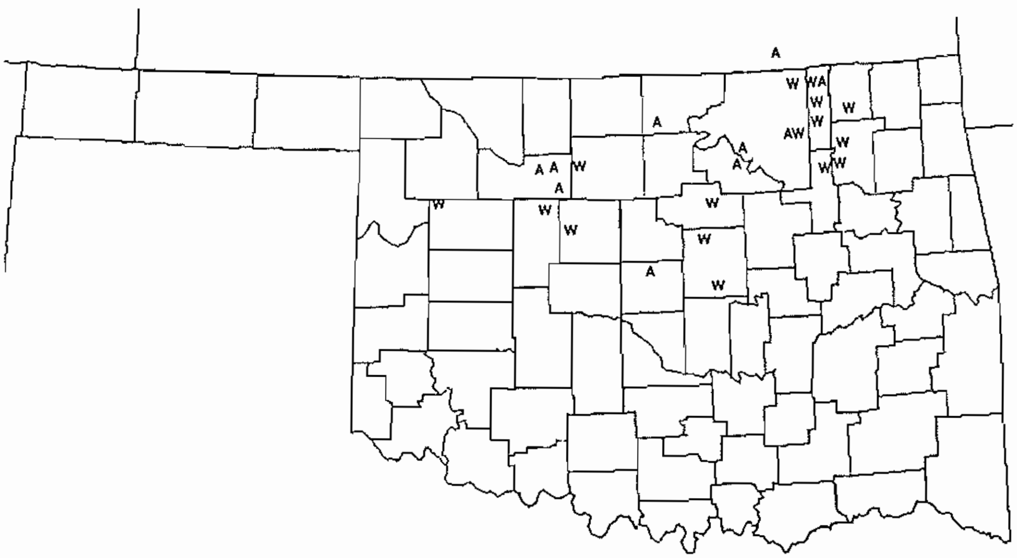


Figure 35: Plot of severe weather events for the period 2205Z Saturday, August 5, 1989 through 0345Z Sunday, August 6, 1989."W" denotes a thunderstorm wind gust of 50 knots or greater and "A" indicates where 3/4" or greater diameter hail fell.

The reports of severe weather are plotted in Figure 35. The reports were taken from local storm reports (LSRs), data given in the body of warnings, and Storm Data. The majority of the reports are damaging winds although there are several reports of large hail. The cluster of reports north of Tulsa was associated with the severe thunderstorms that developed southeastward from southeast Kansas and occurred mostly between 23Z and Ø130Z. The other cluster of reports was associated with thunderstorms that formed near the moisture convergence center in Figure 33 and occurred generally between 23Z and Ø1Z. No tornadoes were reported in Kansas or Oklahoma with this episode. The time of the last report was Ø345Z in central Oklahoma near Edmond. Instability decreased with loss of daytime heating and the storms gradually decreased as they moved southeast into central and southern Oklahoma.

E. CONCLUSION

Numerous graphics and the resulting weather have been shown for this particular case. Even though significant dynamics were lacking, strong and severe thunderstorms still formed as a result of high instability and a sufficient triggering mechanism. The possibility of thunderstorms was evident from 36 hours previous to the time they occurred, thanks to NMC guidance products. The mesoscale developments were important in this particular example; Doswell (1984) and Maddox and Doswell (1981) stressed the importance of looking at subtle mesoscale features that are often very important in ascertaining the severe weather event.

Although the cold front was really not the focus as originally thought, the thunderstorms that did form were along an outflow or rain-cooled boundary that moved southward ahead of the front. The rain and thunderstorms responsible for the boundary in Kansas originally formed as a result of the cold front. Thus, the cold front was ultimately the key ingredient for the thunderstorms on this day. The potential for more widespread severe weather was greater to the northeast of Oklahoma where dynamics and wind shear were better. However, some thunderstorms were severe in northern Oklahoma due mainly to favorable thermodynamics. This case illustrates that strong dynamics are not necessary with the unstable air masses of summer.

Although real-time satellite imagery could not be used in this example, visible and infrared imagery can help the forecaster pinpoint important boundaries or other features that can aid in the short term forecast of convection. Purdom (1979) and Xiang and Beckman (1985) discuss the use of satellite imagery applied to the short range convective forecast.

This case has proven that there are plenty of AFOS graphics available for diagnosing the potential for thunderstorms. Products which are useful in Oklahoma and surrounding states were discussed. The reader is encouraged to use these products or perhaps discover others that may be useful in his part of the country.

ACKNOWLEDGEMENTS

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APPENDIX: LIST OF GUIDANCE PRODUCTS

ADAP PRODUCTS CREATED TWICE A DAY USING MAXIMUM WET BULB THETA IN LOWEST 300 MB OF SOUNDINGS

COMMAND	DESCRIPTION
SXC	Cap strength
SXL	500 mb Lifted Index
SXU	300 mb Lifted Index
SS4	3 panel map of SXC, SXL, and SXU

ADAP PRODUCTS CREATED HOURLY USING LATEST UPPER AIR DATA AND HOURLY SURFACE DATA

SSL	500 mb Lifted Index
SSU	300 mb Lifted Index
SSC	Cap strength
SMC	Surface moisture flux convergence
SCC	Moisture flux convergence change
SMR	Surface mixing ratio
SQC	Mixing ratio change
STA	Surface theta advection
SAA	2 hour average theta advection
SSW	Surface streamlines/wind plot
SAC	Graphic of total 2 hour altimeter change
SPC	Altimeter falls given in script form
SC2	Surface change plot
SC1	Same as SC2 except need zoom on 16:1
SS1	Three panel map of SSL, SSU, and SSC
SS2	Three panel map of SMC, SCC, and SQC
SS3	Three panel map of STA, SAA, and SMR

USEFUL AFOS PRODUCTS

94o	SELS Day 1 Severe weather outlook graphic
SWODY1	SELS Day 1 Severe weather outlook discussion
98o	SELS Day 2 Severe weather outlook graphic
SWODY2	SELS Day 2 Severe weather outlook discussion
9AM	Surface geostrophic wind chart
01G	2-6 hour thunderstorm probability map
01o	2-6 hour severe weather probability map
0WD	24 hr Trajectory model surface dew points
8W1	24 hr Traj. 850 mb trajectories (W. U.S.)
8WJ	" " (E. U.S.)
7W1	24 hr Traj. 700 mb trajectories (W. U.S.)
7WJ	" " (E. U.S.)
0w1	24 hr Traj. SFC trajectories (W. U.S.)
0WJ	" " (E. U.S.)
I(n)L	NGM 4-layer Lifted Index prog (n=0,2,4,6,8)
FTJxx	Trajectory output (xx=50 to 57)
FRHxx	LFM FOUS output (xx=60 to 78)
FRHTxx	NGM FOUS output (xx=60 to 78)
P38	Regional surface plot
L(n)D	NGM boundary layer RH prog (n=0,2,4,6,8)
L(n)M	NGM bndry layer wind prog (n=0,1,2,3,4,6,8)
(n)0A	Upper air mandatory level plots (n=2,3,5,7,8)

2Ø3,24Y	NGM ØØ hr and 24 hr 25Ø mb isotachs
3ØY	LFM ØØ hr 3ØØ mb isotachs
3EY,3GY	AVN 24 hr and 36 hr 3ØØ mb isotachs
2ØB	25Ø mb plot
FDxFAn	Forecast temperatures and winds aloft x=1,2,3 for 6, 12, and 24 hr fcst, n=1-6
LDS	Lightning detection summary
L1Z,L2Z,L3Z	Ø6, 12, and 18 hr NGM moisture convergence
EIS	Equilibrium and maximum parcel levels graphic
EISTAB	RAOB parameters
EIT	Positive energy/Bulk Richardson No. graphic
Ø4o	MOS 12-36 hr severe weather probability
Ø4G	MOS 12-36 hr thunderstorm probability
NMCGRDWRx	6 hr T-storm Prob. for W. U.S. (x=1,2,3,4)

USEFUL UPPER-AIR ANALYSES (UA) GRAPHICS

8ØP	85Ø mb dew points
8ØR	85Ø mb mixing ratio
8ØI	85Ø mb isotachs
8ØA	85Ø mb temperature advection
8ØC	85Ø mb moisture convergence
8ØM	85Ø mb moisture advection
7ØA	7ØØ mb temperature advection
7QD	7ØØ mb Q vector divergence
5ØI	5ØØ mb isotachs
5ØV	5ØØ mb vorticity
5QV	5ØØ mb geostrophic vorticity
5QD	5ØØ mb Q vector divergence
5ØA	5ØØ mb temperature advection
3ØI	3ØØ mb isotachs
3ØD	3ØØ mb divergence
2ØI	2ØØ mb isotachs
2ØD	2ØØ mb divergence