NOAA TECHNICAL MEMORANDUM NWS CR-69

SOME BASIC ELEMENTS OF THUNDERSTORM FORECASTING

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Topeka, Kansas

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U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

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UNITED STATES DEPARTMENT OF COMMERCE
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John V. Byrne, Administrator

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SOME BASIC ELEMENTS OF THUNDERSTORM FORECASTING

1. INTRODUCTION

Convective weather phenomena occupy a very important part of a Weather Service office's forecast and warning responsibilities. Severe thunderstorms require a critical response in the form of watches and warnings. (A severe thunderstorm by National Weather Service definition is one that produces wind gusts of 50 knots or greater, hail of 3/4 inch diameter or larger, and/or tornadoes.) Nevertheless, heavy thunderstorms, those just below severe intensity or those producing copious rainfall, also require a certain degree of response in the form of statements and often staffing. (These include thunderstorms producing hail of any size and/or wind gusts of 35 knots or greater, or storms producing sufficiently intense rainfall to possess a potential for flash flooding.) It must be realized that heavy thunderstorms can have as much or more impact on the public, and require as much action by a forecast office, as do severe thunderstorms. For the purpose of this paper the term "significant convection" will refer to a combination of these two thunderstorm classes.

It is the premise of this paper that significant convection, whether heavy or severe, develops from similar atmospheric situations. For effective operations, forecasters at Weather Service offices should be familiar with those factors which produce significant convection.

The purpose of this paper is to describe several basic elements of thunderstorm forecasting, including the use of mesoanalysis. Discussion will center on four specific topics and is not intended to be an in-depth dissertation on convective forecasting. But the four topics are discussed in some detail and illustrative examples used as appropriate.

The ideas presented are neither new nor fully documented in the literature. Further research and refinements are needed in some of the areas discussed. This approach incorporates some of the "classical" ideas of Technical Report 200 (rev) (Miller, 1972), but also differs significantly from them. What is presented here is a realistic and operationally feasible approach to the forecasting of significant convection. It is very similar to the approach used in severe weather forecasting at SELS.

2. SCALE CONSIDERATIONS

Traveling cyclones or other synoptic scale features are associated with large areas of stratiform clouds and precipitation. Synoptic scale flow patterns are well handled by numerical models and "empirical" forecast rules. Computer analyses are tuned to the synoptic scale. Dynamic and kinematic concepts have been developed best for motion on this scale.

On the other hand, convection is the predominant ingredient of subsynoptic and mesoscale systems. Their effect is parameterized in synoptic models. Regional scale models are in the development stage but may be severely limited at the operational level by data availability. Physical concepts are not as well developed or understood as those on the synoptic scale. As a result, forecast concepts for mesoscale systems are limited.

The mesoscale can be subdivided as follows (Orlanski, 1975):

meso-α	250	-	2500 km (155-1553 mi)	1-7 days
meso-β	25	-	250 km (15.5-155 mi)	3-24 hrs
meso-γ	2.5	-	25 km (1.6-15.5 mi)	½-6 hrs

This paper will concentrate on phenomena in the meso-α and meso-β range. Such phenomena can be determined from the surface observing network. Single thunderstorm cells are of minimal interest. Clusters and complexes of thunderstorms, and their resultant effects, are of prime concern to the ideas presented here.

3. CONCEPTUAL ELEMENTS OF THUNDERSTORM FORECASTING

From a basic point of view, four parameters are necessary for the occurrence of significant convection:

(1) unstable air or a source of destabilization

(2) moisture

(3) divergence aloft

(4) low level convergence (including terrain forcing)

3a. Instability or Destabilization

There are many measures of instability. Numerous indices have been developed over the years to aid the forecasting of severe weather and thunderstorms in general. All provide a means of gaging the convective potential. Some work better for severe weather (e.g., SWEAT index); others work better for non-severe convection (e.g., K index). It is beyond the scope of this paper to go into detail on any of these indices. The important point is that unstable air is a necessary ingredient. But, an index by itself will not produce a consistently good forecast.

An initially stable environment can be destabilized within a few hours to produce the needed instability. Warm, moist air intruding at low levels and/or cooling aloft are factors in such a process.

In either situation unstable air is not the only parameter needed to produce significant convection. Three other factors are also required.

3b. Moisture

Thunderstorms need sufficient moisture in the lower layers to develop and grow. Williams (1976) showed that surface dewpoints greater than 55^{O}F were most favorable for the occurrence of severe convection. Generally, enough moisture must be present so that any lifting of the inflowing air goes above the level of free convection (LFC).

Dewpoint temperature analyses are an excellent way to recognize surface moisture patterns. Areas of strong moisture gradient or tongues of moisture intruding into relatively dry regions, features favorable to thunderstorm occurrence, become obvious via such analyses. Satellite infrared (IR) and visual imagery can often give qualitative pictures of moisture locations on a mesoscale level, e.g., dark (warm) moist tongues in IR imagery or CU fields on visual pictures.

3c. Divergence Aloft

Divergence aloft refers to the need for an upper tropospheric system that will produce an environment condu ive to the development of significant convection. Studies have shown synoptic scale divergence to be present in the upper troposphere during both severe (McNulty, 1978) and non-severe thunderstorm events.

Divergence aloft, when properly coupled with low level convergence, can create areas of upward vertical motion. Synoptic scale upward motion appears to be a factor favorable for the development of significant convection. Upper level divergence, by itself, will not generate thunderstorms. But the presence of divergence aloft, when combined with the other three parameters discussed here, creates a vertical structure receptive to the development of significant convection.

Unpublished results have related thunderstorm occurrence to the divergence aloft. These results show that:

(1) Strong convergence aloft tends to suppress significant convective development.

(2) Weak convergence aloft can often be overcome by highly unstable air forcing its way upward from the lower troposphere.

(3) Weak to moderate upper divergence appears to create the most favorable environment for significant convection.

(4) Strong upper divergence favors stratiform rather than cumuliform development due to the widespread large scale vertical motion.

In practice, severe weather forecasters have inferred divergence aloft from three primary upper level features: short wave troughs (divergence downstream from the trough), jet maxima (divergence in the left front and right rear quadrants, depending upon curvature), and areas of positive vorticity advection (PVA) increasing with height. These features are also important to the development of significant convection. For short term thunderstorm forecasts (< 12 hours), these are the only features routinely available for divergence identification. For long term forecasts (12-36 hours), numerical model fields, including vertical motion directly, can be useful. But the concepts discussed in this paper are routinely applied in short term situations when numerical model guidance is of secondary importance.

As an aside, upward vertical motion can also be inferred from 850 and 700 mb warm advection. This thermal advection may or may not occur at the same time and location as the divergence aloft.

Satellite imagery has introduced a new dimension to divergence identification. Clouds, which by their presence imply upward moving air somewhere in the vertical column, are routinely associated with short wave troughs, jet maxima and axes, and areas of differential vorticity advection. Satellite cloud patterns have enhanced the ideas associated with synoptic scale forecasting, and have also allowed forecasters to identify systems previously buried between rawinsonde stations. Satellite imagery, has at least qualitatively, opened the door to mesoscale analysis of upper tropospheric systems. The result has been significant improvement in short term forecasting, especially of convection. Satellite imagery will probably be the only type of upper level, mesoscale data available operationally until satellite sounding techniques become routine.

3d. Low Level Convergence

The fourth parameter required for the occurrence of significant convection is low level convergence. In some ways, this may be the most important of the four parameters. Without low level convergence to start the initial forcing from the bottom, significant convection usually does not occur. An area, zone, or line of convergence provides the mechanical lift needed to get the air beyond the LFC.

This low level forcing is best identified from the surface observing network. Mesoanalysis of surface data provides the means to identify convergence areas, e.g., boundaries. The boundary concept is a very important part of this identification process and will be discussed in depth in section 4. Terrain induced convergence may also play a role in low level forcing. This requires the forecaster to be familiar with the topography of his/her particular forecast area and the local convergence effects that can occur. Terrain effects should not be minimized.

One quantity which has been recognized as useful in identifying areas of surface forcing is moisture convergence (Hudson, 1971). Moisture convergence has been shown to lead the development of significant convection by several hours. Moisture convergence ($\nabla \cdot r V$) (where r is mixing ratio and V is vector velocity) mathematically combines mass convergence ($r \nabla \cdot V$) and moisture advection ($V \cdot \nabla r$). It maximizes where convergence and moist inflow are best. Several numerical analysis programs are available to calculate this quantity.

3e. Forecast Implications

The four parameters discussed above occur somewhere in the atmosphere most of the time. It is only when they occur over the same geographical area at the same time that significant convection results.

When the four parameters described above are derived from synoptic scale data (analyses or prognoses), relatively broad areas can be defined where thunderstorm occurrence is possible. This is done routinely for severe weather occurrence by SELS in the Convective Outlook (ACUS). In order to reduce this area in both space and time, surface data must be examined. This is where mesoanalysis becomes important. Mesoanalysis allows the forecaster to identify the low level forcing mechanisms, e.g., boundaries, thus localizing the area for potential thunderstorm occurrence. This process is used in laying out SELS severe weather watches, but will also identify the area with the best potential for non-severe thunderstorms.

During this process a forecaster must examine all available data, identify areas of instability, moisture, and divergence, and then decide if all factors will occur in the presence of a low level boundary. Sometimes this process is easy. At other times, timing is critical, or something will be missing. This synthesis of the four necessary ingredients is what makes convective forecasting a challenge.

4. MESOSCALE SYSTEMS

It has been found that thunderstorms often occur in groups, called complexes. These complexes are essentially mesoscale systems having common features, identifiable structures, and characteristics useful to the thunderstorm forecaster. Very few of these systems have been identified and classified. Several that have will be discussed below. The mesosystems referred to here are those that can be identified from surface analyses with the help of satellite and radar. Much research time has been spent on systems and structures observed in special networks (e.g., NSSL). But the field forecaster does not have special networks available. He must work with the surface observing network. Efforts need to be made to identify meso-α and meso-β systems that can be seen in surface data. Maddox (1980) has shown a start in this direction with the Mesoscale Convective Complex (MCC), but a much greater effort in this area is needed.

4a. Boundaries

A mesoscale feature common to many mesoscale systems is the boundary. A boundary refers to any low level quasi-linear discontinuity characterized by cyclonic shear and convergence. The main premise of this paper is that significant convection occurs along boundaries, and that these boundaries can be identified from surface data with the aid of satellite via mesoanalysis. The boundary discussion that follows assumes that moisture, instability, and upper divergence are also present. Boundaries are important because they tend to maximize moisture convergence and surface geostrophic relative vorticity. Both quantities are related to localized low level upward vertical motion.

Boundaries can be subdivided into several types: deep (depth of the troposphere) boundaries, shallow boundaries, and convectively induced boundaries.

Deep boundaries include cold fronts, warm fronts, and stationary fronts. These are familiar to meteorologists and need not be discussed in detail here. They are easy to identify and have been associated with thunderstorms for many years. The "classic squall line" and overrunning thunderstorms are a type of significant convection often associated with deep boundaries.

Shallow boundaries are those that do not extend upward through the depth of the troposphere. The best example here is the dry line (Schaefer, 1974). It is best analysed on surface charts along the 45°F isodrosotherm (Schaefer, personal communication). It is the most common over the High Plains and is a known source of significant convection. The strong moisture contrast along the dry line will be illustrated by the example in section 7a.

Often the thermal and moisture fields contain strong gradients and/or weak wind shift lines. Convective precipitation, usually in the form of showers, can form along these gradients. This phenomenon is observed frequently by forecasters but such processes are not documented in the literature, probably because they do not produce significant convection.

Convectively induced boundaries refer to lines of temperature, moisture and/or wind discontinuties produced by the cold outflow from thunderstorms. These act as excellent low level forcing surfaces for further convective development. These boundaries are often referred to as "bubble" boundaries. Maddox's MCC's are often associated with "bubbles" and will be discussed separately in section 5.

"Bubble" boundaries result from the accumulated outflow of numerous thunderstorms. Precipitation induced mesoanticyclones (mesohighs or "bubble highs") form in the outflow region. The leading edge of the outflow is the "bubble" boundary. Often mesolows are identified along the boundary itself. If these mesosystems grow in size, they can reach MCC proportions. These mesohighs are characterized by colder air with higher relative humidity than the surrounding environment. They often have a significant wind shift across their leading edge. The boundary often shows up in satellite imagery as an arc cloud. The interaction of two "bubble" boundaries, or a "bubble" boundary with a front, tends to enhance thunderstorm development. "Bubble" boundaries often persist well after the convection which produced them has ceased. A boundary produced by yesterday's thunderstorms is often the low level forcing mechanism for today's convection.

Fig. 1 shows an example of a "bubble" and its boundary. The "bubble" itself (marked B) is a 1014 mb mesohigh. It is associated with a thunderstorm complex covering much of eastern Kansas. The complex has been moving south and east and its leading edge (the "bubble" boundary) extends from near Topeka (TOP) to Chanute (CNU) into north central Oklahoma. A weak 1009 mb mesolow has formed in its wake near Concordia (CNK). Cooler air with higher relative humidity is in evidence within the "bubble". The isodrosotherm pattern (dashed line) shows how the "bubble" has driven a cooler, drier wedge into the generally warm, moist air mass over the Central and Southern Plains.

4b. Boundary Identification

Experience has shown that three factors are useful in boundary identification: wind shifts, thermal gradients, and moisture (dewpoint) gradients. Satellite imagery and radar are useful additions that can assist in the initial recognition and subsequent placement of boundaries. It must be realized that a wisp of cloud on a satellite image does not in itself constitute a boundary. Satellite features must be supported by surface data.

The identification of wind shift lines should be the first item of order. Some of the wind shifts are rather subtle. Subsequently, if the thermal and moisture analyses concur, a boundary can be placed. Examples of several boundary types will be given in section 7.

The recognition, delineation and tracking of boundaries has reached a highly tuned level, particularly in SELS. SELS watches are most often based on the presence of some type of boundary. On the other hand, going from the existence of a boundary to a forecast of significant convection is still tenuous. <u>Better forecast rules are needed that say when or if a boundary will light up</u>. This is an area where more applied research is needed.

4c. Boundary Inflow

In an attempt to identify some forecast-related ideas, despite their limited nature, this subsection and the next will discuss two concepts useful to thunderstorm forecasting.

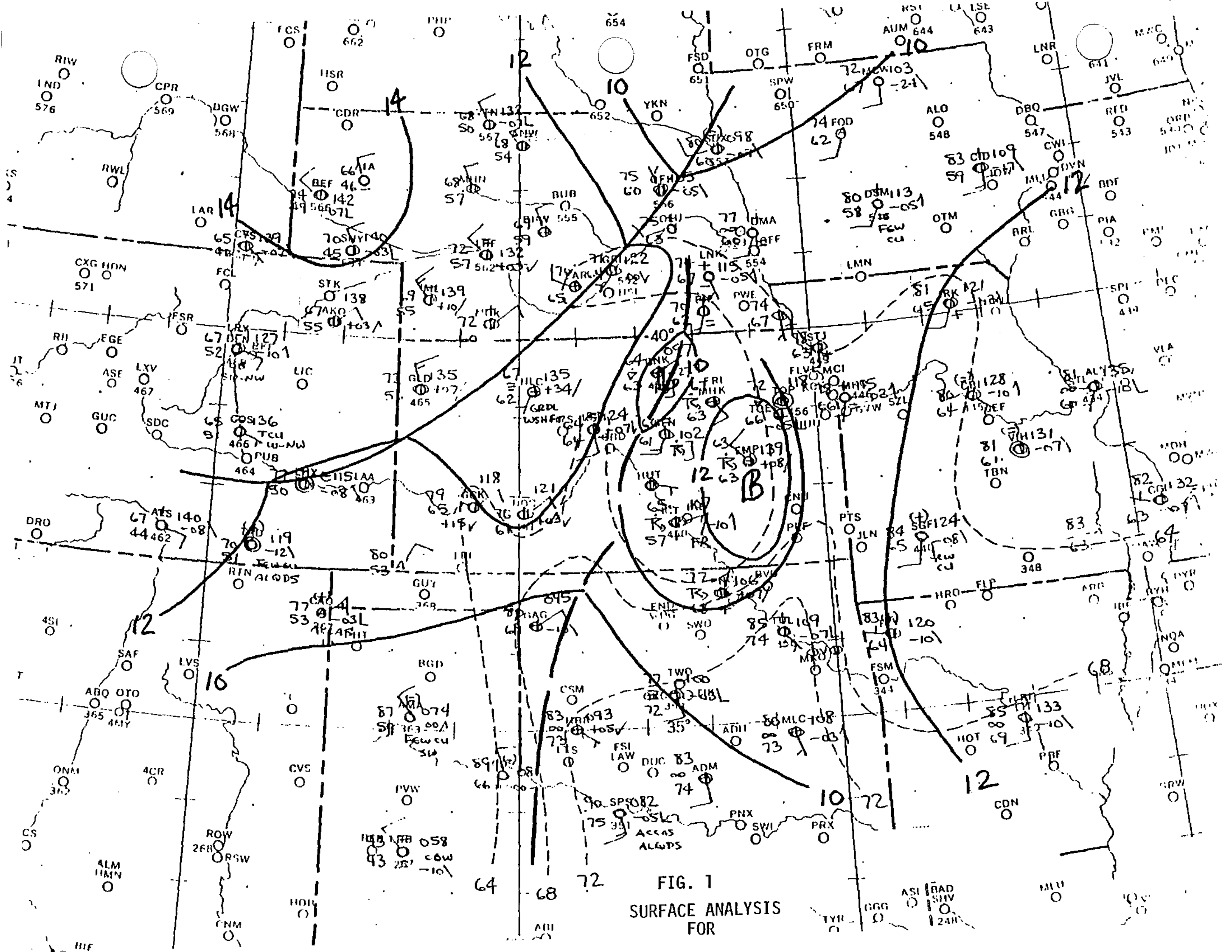

FIG. 1

SURFACE ANALYSIS
FOR

The strongest thunderstorms, often severe, tend to occur most often where the deepest moist inflow intercepts a boundary at a right angle. Fig. 2 gives a conceptual illustration. The steeper the angle between the moist air and the boundary, the better the convergence will be, and thus the higher the probability of significant convection.

The line of strongest inflow can often be identified by examining surface wind gusts. A surface gust isotach analysis in the warm, moist air will reveal the line of best surface inflow. If this isotach pattern points into a boundary, the strongest convection will most likely be at the tip of this point.

This concept is analogous in many ways to the synoptic/sub-synoptic overrunning process that occurs with a boundary layer wind maximum (Sangster, 1958). With overrunning, strong, moist, low or mid level flow is forced over a frontal boundary producing widespread precipitation. On the mesoscale, the process is more localized and can occur with any of the boundaries described above. The resultant precipitation (thunderstorms) is also more localized.

4d. Motion Relative to Boundary Orientation

Maddox, Hoxit and Chappell (1980) examined the relationship of tornado path length to the surface thermal field. They found that storms moving across a thermal boundary tend to produce intense, short-lived tornadoes (see Fig. 3a). These storms start in favorable air, then weaken as they move relatively quickly into less favorable air. On the other hand, storms moving along or parallel to a thermal boundary produced intense, relatively long-track tornadoes (see Fig. 3b). These storms maintain contact with the favorable air which produced them and maintain themselves longer.

Realizing that most storms tend to move with the mean 700-500 mb flow, a forecaster can anticipate shorter long-track storms by examing the relative orientation of the mid-tropospheric flow to the surface thermal gradient orientation. Similarly the conclusions reached above can be extended to the lifetime of significant convection without too much loss of generality. (Note: even for overrunning thunderstorms associated with flash floods, the mid-tropospheric wind turns parallel to the boundary immediately after crossing it - Hales, 1978).

5. MESOSCALE CONVECTIVE COMPLEXES

A first step was taken by Maddox (1980) when he identified and classified the Mesoscale Convective Complex (MCC). The MCC was discovered in the enhanced (MB) infrared satellite imagery during the warm season (March through September). It is smaller than synoptic scale systems but larger than an individual thunderstorm.

A satellite identified convective cluster is classified as an MCC if it satisfies the requirements set forth in Table 1. The MCC is characterized by a large scale environment with weak pressure gradients and light winds. Surface analyses show outflow boundaries, pressure troughs and mesohighs. Within the boundaries of an MCC surface temperatures and dewpoints drop relative to the surrounding environment, winds become light and variable.

Maddox (1980) describes the life cycle of an MCC and its interaction with the large scale environment. Follow-up papers by Fritsch et al (1981) and Maddox and Heckman (1982) relate MCC's to warm season rainfall and MOS temperature guidance

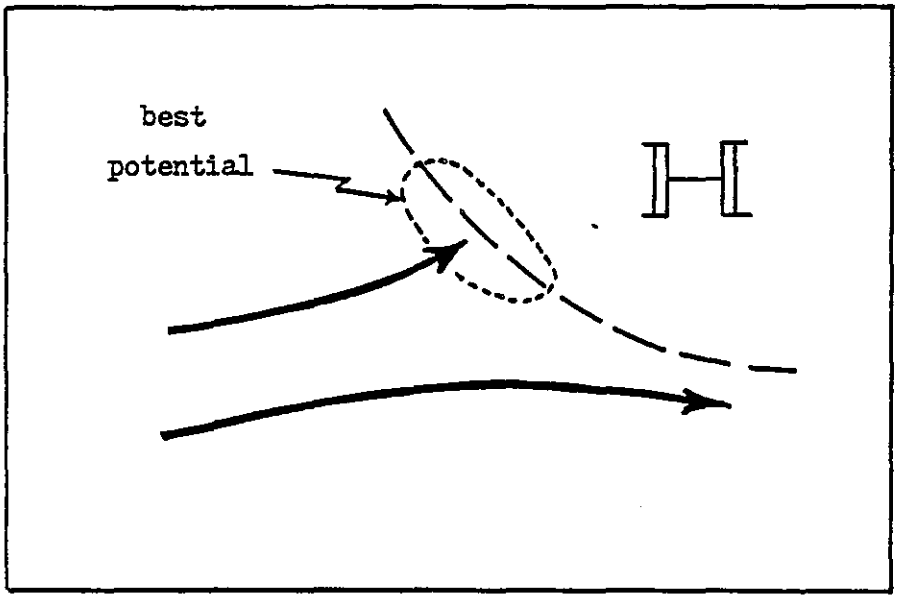

Figure 2: Conceptual Illustration of Best Inflow Area

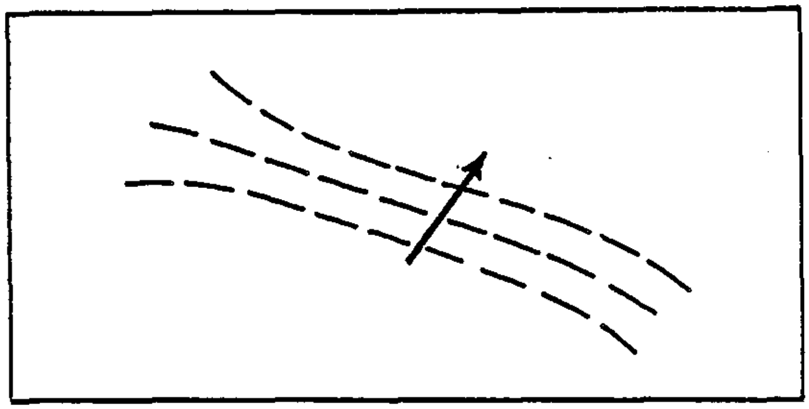

Figure 3a: Short Track Storms Tend to Cross Thermal Gradients

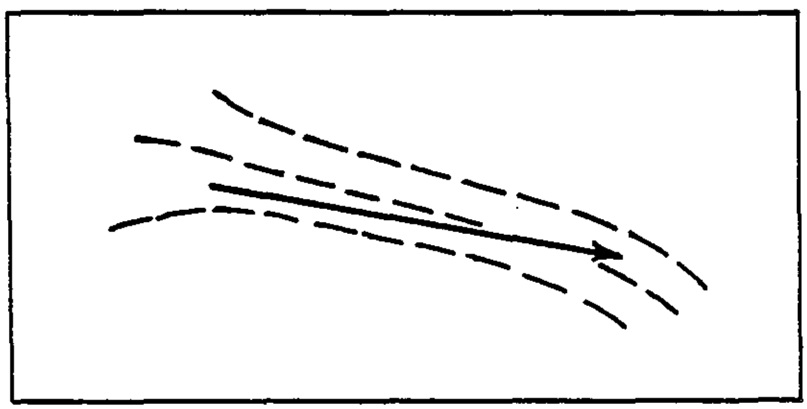

Figure 3b: Long Track Storms Tend to Parallel Thermal Gradients

TABLE 1: Mesoscale Convective Complex (MCC)
(based upon analyses of enhanced IR satellite imagery)
Physical Characteristics

Size:	A - Cloud shield with continously low IR temperature ≤-32°C must have an area ≥ 100,000 km squared
	B - Interior cold cloud region with temperature ≤ -52°C must have an area ≥ 50,000 km squared
Initiate:	Size definitions A and B are first satisfied
Duration:	Size definitions A and B must be met for a period ≥ 6 hours
Maximum extent:	Contiguous cold cloud shield (IR temperature ≤ -32°C) reaches maximum size
Shape:	Eccentricity (minor axis/major axis) ≥ 0.7 at time of maximum extent
Terminate:	Size definitions A and B no longer satisfied

The reader is referred to these papers for details on the MCC. What will be covered here are some facts that are useful to the operational forecaster.

These facts were based upon a sample of 43 cases during 1978:

a. duration:

1. the first thunderstorms typically develop during the afternoon (2000 GMT).

2. transition to a large, highly organized mesosystem usually does not occur until evening (average time classified as an MCC, 0130 GMT).

3. the MCC grows to maximum size after midnight and persists into the morning hours (average time of maximum extent, 0730 GMT).

4. average duration from first thunderstorm to decay...16½ hours.

b. significant weather:

1. severe thunderstorm phenomena (tornadoes, large hail, strong wind) usually occur during the initial storm development (e.g., Grand Island, NE tornadoes, 6-30-80).

2. torrential rains and/or flash floods often are associated with MCC's and contribute to the nocturnal maximum in thunderstorms over the central U.S.; 17 of 43 cases produced heavy rain.

c. once developed, MCC's move with the mean 700-500 mb wind flow.

d. systems moved eastward to, or just beyond the large scale ridge position before they began to decay.

e. some MCC's developed from the merger of individual storms, some from initially linear systems.

f. MCC's modify the large scale thermal and wind structure of the troposphere.

g. the area of intense rainfall (> 0.50 in/hr) remains fairly steady until an hour or two after maximum extent, then coverage becomes less.

As stated by Maddox, "the probability of receiving measurable rain during any given MCC event is 100% over 60,000 sq. km...Thus, for the forecaster who is confronting a MCC approaching his station, it is not a question of 'is it going to rain', but rather 'how much rain is likely'?".

The MCC is just one of several mesoscale systems seen in satellite imagery. The next step is to extend what has been done for MCC's to these other systems. Someone has to do for the mesoscale what the Norwegian School did for synoptic meteorology.

6. FLASH FLOOD VERSUS SEVERE THUNDERSTORMS

Flash flood and severe weather events both result from thunderstorms, both are an element of significant convection. The question arises then, how does the forecaster distinguish between flash flood and severe thunderstorm events? Although Maddox and Dietrich (1981) examined the simultaneous occurrence of these events (11 cases), no indepth study of this question has been pursued. In a crude attempt to do such a comparison, the list of flash flood factors from Maddox et al (1979) will be compared with the factors important to severe convection listed by Miller (1972).

With reference to Table 2, both flash floods and severe weather are convective storms (item 1). Both events occur in regions of high surface dewpoints (item 2). Items 3 and 4 show a difference. Flash floods are most frequent where there is relatively high moisture content present through a deep tropospheric layer. On the other hand, a dry intrusion at 700 mb is very favorable for severe convection. Similarly the difference in vertical shear seems to distinguish the two events. Stronger shear favors severe convection while weaker shears favor heavy rainfall.

Item 5 of Maddox's flash flood list has no comparable factor in Miller's list. Items 6 and 7 of Maddox's list are effectively the same as 7 on Miller's list. Both type storms form east of a trough and die as they approach a ridge line. Item 8 is a statistical difference and would not necessarily help improve a forecast.

Thus the depth of tropospheric moisture and the vertical wind shear appear to be the main factors available to distinguish severe weather from flash floods. Although not a complete answer to the original question, this comparison is a good starting place for future research.

7. ANALYSIS CONCEPTS AND EXAMPLES

As mentioned earlier the purpose of mesoanalysis of surface data is to identify low-level boundaries which produce thunderstorms. The analysis includes isotherm and isodrosotherm analyses (at 4°F intervals or smaller) as well as isobars (at 2 mb intervals). Minimal smoothing of these fields is employed in order to bring out the small scale features. This is contrary to "classic" synoptic analysis methods which emphasize a fair degree of smoothing during the analysis process. Wind shift lines, no matter how weak, are marked first. Using the other parameters plus any satellite or radar information, wind shift locations are finalized and examined for boundary characteristics. If moisture and thermal conditions concur, a boundary is identified.

Boundaries that are important have continuity. If a boundary is found on one analysis but is missing two hours later, it will not produce much in the way of convection. Analyses at least every two hours are needed to produce good continuity.

Remember that a boundary by itself will not produce significant convection. The other three parameters discussed earlier must also be present. The forecaster should also be familiar with local topography. Topography, combined with moisture and wind flow, may affect convective development.

Once the analysis is complete, the forecaster must perceive what physical processes the analysis implies. Then these processes must be fit together into a forecast.

TABLE 2

FLASH FLOOD vs SEVERE THUNDERSTORMS

Flash Flood (Maddox)	Severe Storm (Miller)
1.,associated with convective storms	1.,associated with convective storms
2.,storms occurred in regions with high sfc dewpoints	2.,dewpoints $\geq$ 55^{o}F for at least weak potential
3.,relatively high moisture content present through a deep tropospheric layer	3.,dry intrusion at 700 mb seems to be best
4.,weak to moderate vertical shear of horizontal wind through the cloud depth	4.,jet present (implies moderate to strong vertical shear)
5.,convective storms and/or cells repeatedly formed and moved over same area	5.,not readily applicable
6.,weak, mid-tropospheric meso-α scale trough helped to trigger & focus the storms	6.,forms ahead of a mid-tropospheric trough
7.,the storm area was very near (but to the west of) the mid-tropospheric large scale ridge position	7.,usually decays as it crosses a ridge
8.,storms often occurred during nighttime hours	8.,maximum occurrence during late afternoon and evening

7a. Example #1: 1800 GMT, April 5, 1978

Figs. 4a and 4b show a classic dry line situation. A low pressure center is developing over eastern Colorado and western Kansas. An excellent example of a dry line extends north-south along the High Plains. This is illustrated very well by the isodrosotherm analysis in Fig. 4b. This dry line produced a squall line by late afternoon. The squall line affected all of eastern Kansas and Oklahoma.

Meanwhile a warm front extends from southern Nebraska into central Missouri. Note the strong, moist southerly flow into the warm front. The numbers at the end of the wind barbs are gusts. The gusts indicate the core of the strongest wind from western Oklahoma into central Kansas, intersecting the front just north of Concordia (CNK). An area of late morning and afternoon convection between Grand Island (GRI) and Lincoln (LNK) produced large hail and severe wind gusts. This case is typical of Spring when strong upper tropospheric dynamics are often coupled with good moisture and thermodynamics.

7b. Example #2: 1200 GMT, May 29, 1980

A situation typical of weak Summer flow is shown in Figs. 5a and 5b. Several boundaries can be found based upon moisture and wind shift considerations. The weak "bubble" (B) over southern Wisconsin was obvious in the satellite imagery. This boundary moved southeast and produced afternoon thunderstorms over central Illinois.

The boundary through eastern and southern Nebraska including a weak mesohigh, shows up quite well with both a moisture contrast and wind shift. As the day progressed the moisture spread into northern Nebraska and the boundary disappeared. As a result no convection formed along this boundary; instead the returning moisture helped light off the boundaries further north. By late afternoon thunderstorms were occurring along the boundary through central and northeast South Dakota. Other thunderstorms formed along the Minnesota boundary and a new boundary developed in northwest Iowa.

Both these examples show how a detailed surface analysis relates boundaries to significant convection. They are by no means all encompassing examples but do illustrate several of the features discussed in this paper. The reader is encouraged to examine Figs. 4 and 5. Determine why boundaries were placed where they were. The best way to gain confidence in boundary identification and an understanding of the boundary concept is to do some analysis during thunderstorm situations. See if the ideas presented here work.

8. SUMMARY

This paper has described several basic elements important to forecasting significant convection. Significant convection includes severe thunderstorms, but also encompasses non-severe thunderstorms. The four parameters needed for the occurrence of significant convection were discussed. These were the presence of instability or a destabilization mechanism, abundant low-level moisture, upper level divergence, and a low-level boundary to force the thunderstorms into existence. The basic concept of a boundary was discussed and several types of boundaries described. The purpose of mesoanalysis of surface data is to identify these boundaries. It was also realized that once a boundary has been identified, it is still not easy to say when or if the boundary will produce convection.

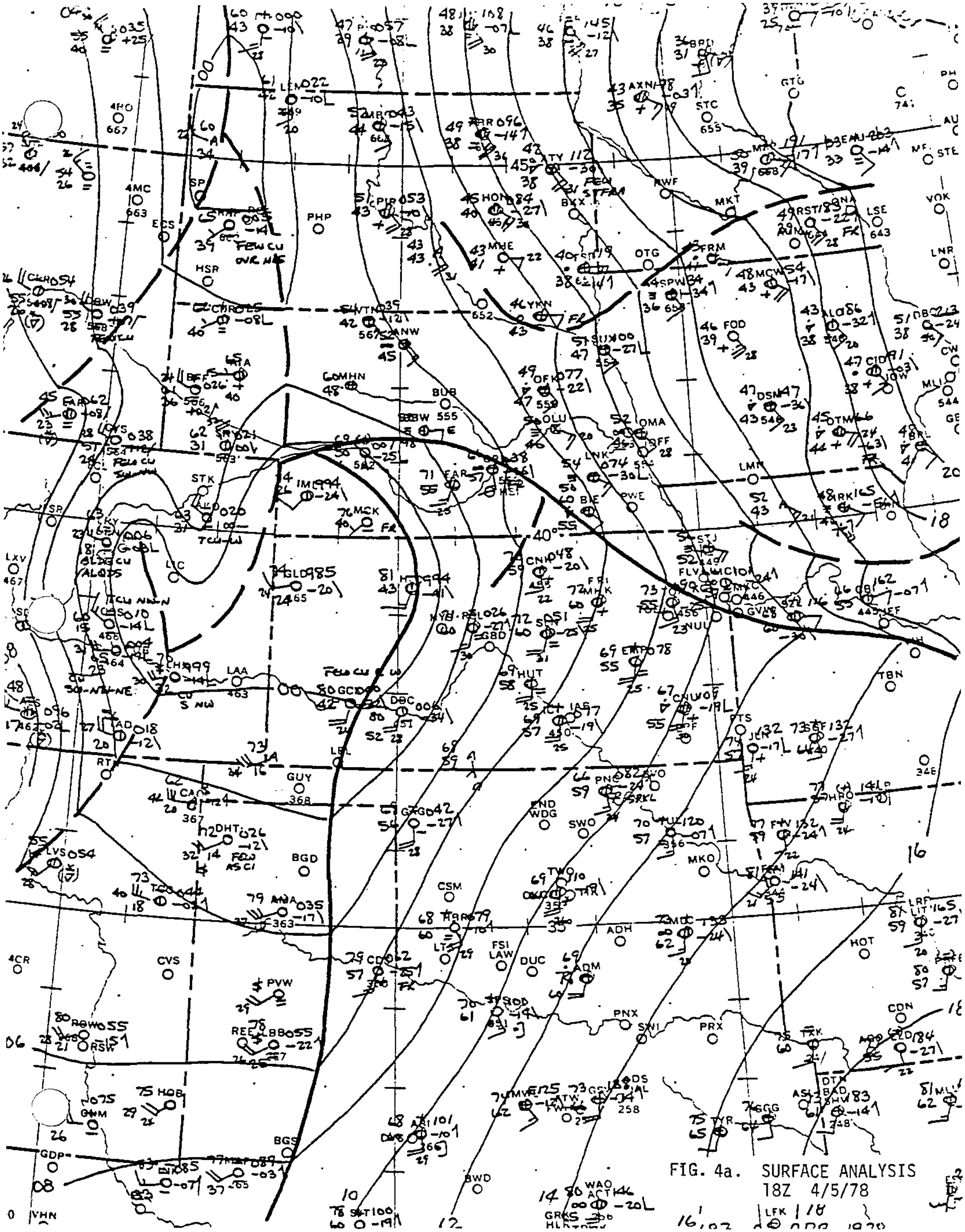

FIG. 4a. SURFACE ANALYSIS
18Z 4/5/78

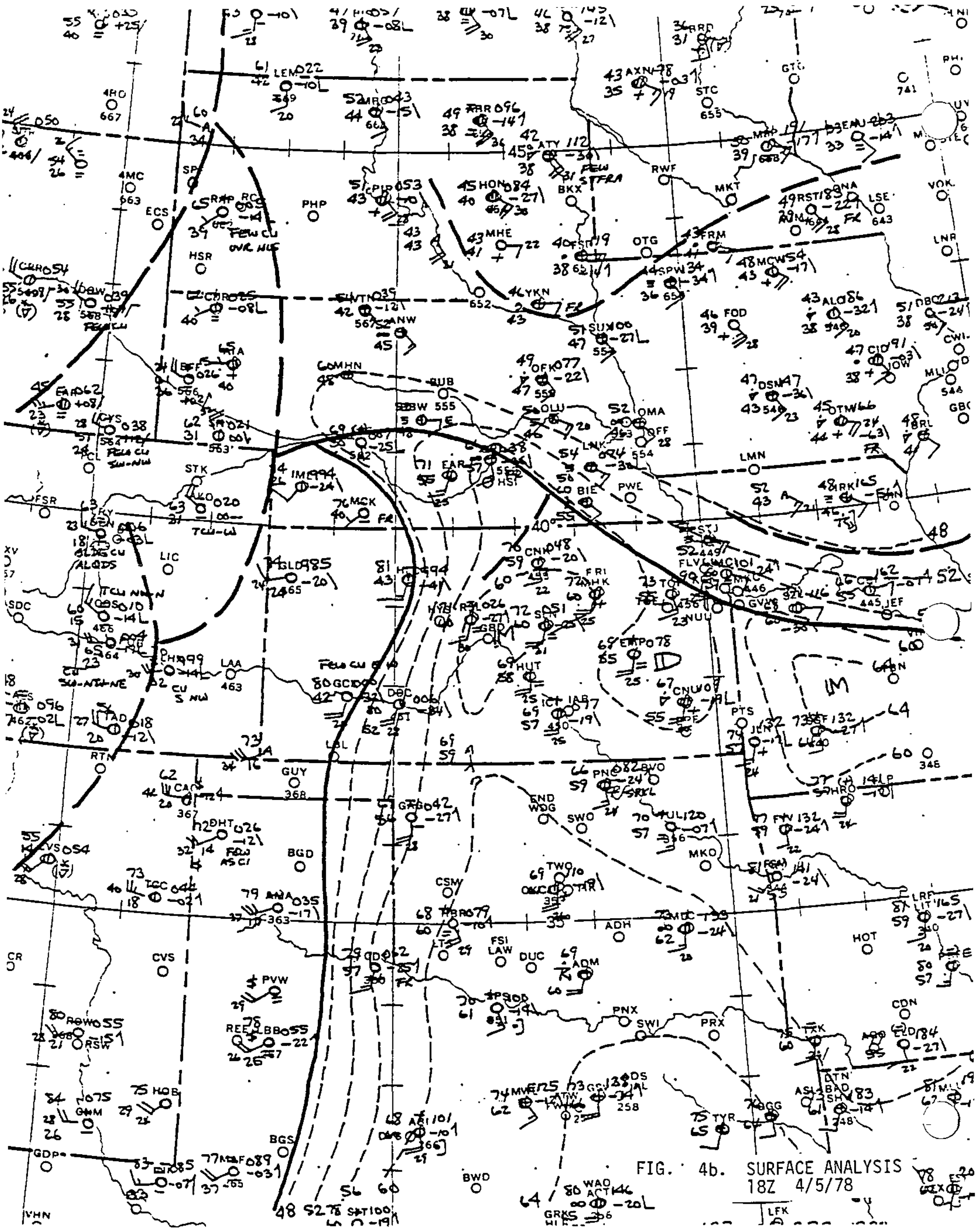

FIG. 4b. SURFACE ANALYSIS 18Z 4/5/78

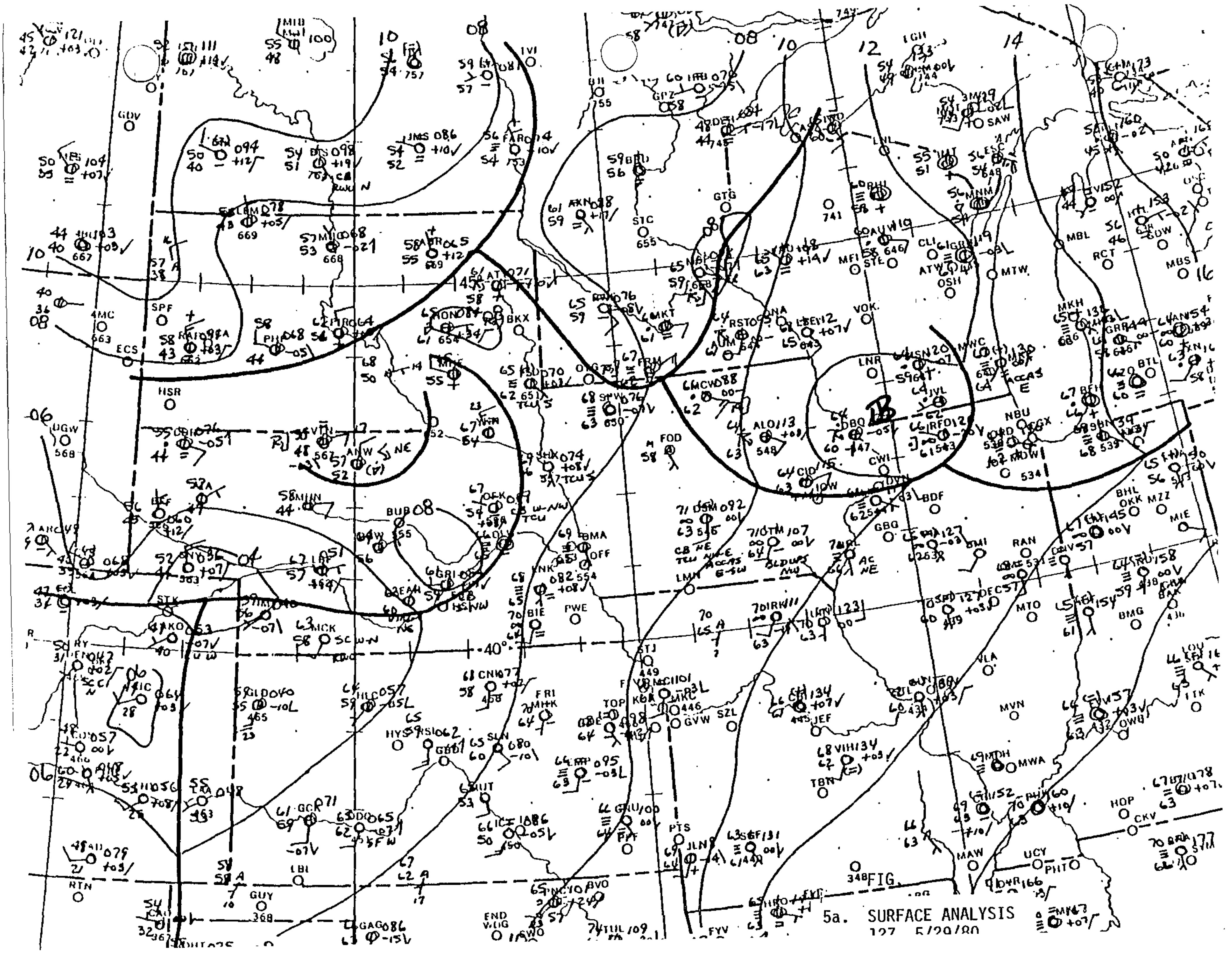

FIG. 5a. SURFACE ANALYSIS 127 5/29/80

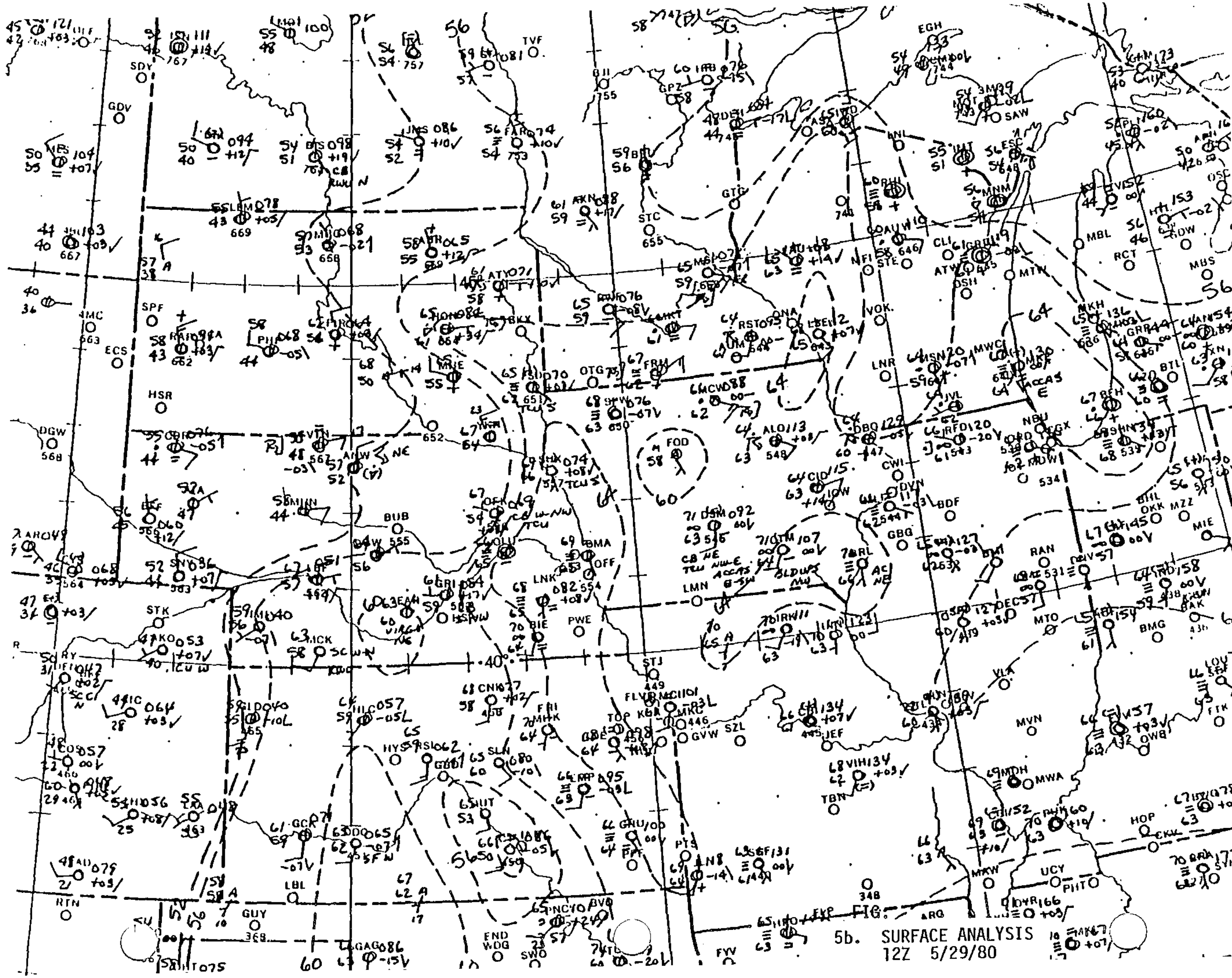

FIG. 5b. SURFACE ANALYSIS
12Z 5/29/80

An appeal for the classification of mesosystems was made. A first step in this direction, the MCC, was described in some detail. A crude comparison between flash flood and severe weather occurrence was made. The main difference in atmospheric parameters appeared to be in the depth of the tropospheric moisture and the vertical wind shear. Basic analysis concepts were briefly discussed and two examples of mesoanalysis and thunderstorm occurrence examined.

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