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# OPERATIONAL USE OF WATER VAPOR IMAGERY

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ABSTRACT

Real-time operational applications of GOES satellite imagery derived from the 6.7 micron "moisture channel" band or channel 10, are discussed. Interpretation of the imagery is not straight forward. The sensor measures integrated radiant energy which is dependent on the temperature and moisture composition of the sensed column through a deep layer of the atmosphere. These inherent interpretation problems are discussed.

Moisture channel imagery is found to be most useful in identifying and evaluating the strength or development stages of vorticity maxima and closed mid/upper lows. It is also very useful in determining zones of maximum winds aloft, studying mesoscale relationships between mid-level dry areas and thunderstorm development and monitoring changes in synoptic-scale upper air patterns. Brief examples are presented.

## 1. Introduction

The Visible-Infrared Spin-Scan Radiometer (VISSR) Atmospheric Sounder commonly called VAS on existing GOES satellites produces the standard visible and IR images plus 12 spectral bands. These are often referred to as channels and are sensitive to various absorbing gases ($CO_2$, $NO_2$, $H_2O$) in specific layers in the atmosphere. The resolution of this imagery at satellite nadir (location on earth surface directly below satellite) is 8 nm. Several image elements must be used to average out noise and to handle broken cloud cover in the field of view as the earth curves from a straight line satellite view. Therefore, the effective resolution is 15-20 nm. The moisture channel imagery referred to in Satellite Imagery Messages (SIMs) are derived from the 6.7 micron band or channel 10 which is sensitive to water vapor ($H_2O$) in a layer from about 620 to 240 mb. This imagery is available through the GOES Tap network as an EC3 sector from the GOES East satellite (Dial codes 6, 15, 23 and 24) and as a WC3 sector from GOES West (Dial codes 16 and 17).

This kind of satellite information has been routinely available at the Kansas City Satellite Field Services Station (SFSS) for several years. During this time, the SFSS has used these unique images to better interpret atmospheric motions. Water vapor is a tracer for horizontal and vertical atmospheric motions. Since moisture patterns are generally aligned with the wind, the images often imply the orientation of streamlines over data-sparse regions. Moisture patterns are present even when clouds are absent.

It has been found that by using animated images (looping), satellite interpretations are not as ambiguous because of continuity in pattern evolution. Experience has also shown that storing satellite imagery every six hours to use in the looping process is unsatisfactory because of the large "jumps" in weather features which lead to questions on continuity and trends. A one hour loop interval is the smoothest; but, two hour increments between images are sufficient to maintain continuity.

Section 3 will briefly describe specific features in the moisture channel imagery which have been found by the SFSS staff to be most helpful in real-time operational applications to forecast problems. There has been little written on moisture channel imagery in formal documents. Many published papers are brief, generally present a case or two and are not readily available to the operational forecaster. The references in the attached list are primarily operationally oriented for those desiring additional reading.

## 2. Interpretation

Interpretation of 6.7 micron imagery is not straight forward. The sensor measures integrated radiant energy emitted by water vapor through a deep layer of the atmosphere. The amount of energy detected by the satellite sensor depends on the temperature and moisture composition of the column being sensed (remember that the satellite is looking through the atmospheric column from the top of the atmosphere). This energy is converted to equivalent black body temperatures and displayed in the images as various shades of grey. The radiances (or temperatures) are sensitive to the amount of water vapor in the column, the temperatures at the water vapor locations (may be several layers) and the viewing angle. The grey shade at each element composing the image (pixel) represents the average equivalent temperature of all the water vapor radiating to the satellite sensor (through the entire viewing column).

The uncertainty in the image interpretation arises from the fact that the measured radiation is not from a single level, but, from a layer. A precise height of the observed water vapor cannot be determined since the amount of radiation received by the satellite sensor is a function of both the atmosphere's water vapor content and temperature. For a standard atmosphere, the maximum return at the 6.7 micron channel is centered at 400 mb with 80% of the energy coming from a layer between 620 and 240 mbs. Therefore, the satellite is generally sensing a layer in the mid to upper levels of the troposphere (between the level of non-divergence and the upper jet).

The less moisture present in the middle and upper troposphere, the more likely low-level moisture will be detected. Since low-level moisture is warm, the grey shades on the image will be darker. Therefore the grey shades can be thought of as an indication of the presence or absence of middle and high-level moisture content.

In most cases, very light shades (almost white) in the imagery indicate that middle and/or high cloud ceilings (broken or overcast) are being detected. This also seems to relate to a relatively deep layer of moist air (usually 300-400 mb deep) above about 700 mb. Thus, thin cirrus appears brighter in the water vapor than the conventional IR since it is associated with a high moist layer radiating at cold temperatures. It is nearly impossible to determine from the moisture channel imagery alone where the cirrus cloud ends and only moisture exists. Many times very light (not completely white) grey shades are seen surrounding a closed upper system. This is because the satellite is sensing the very cold (and deep) air column in addition to some low level moisture (generally overcast stratocumulus).

Very dark grey shades (almost black) indicate that little or no middle or high water vapor or clouds are present. This is referred to as a mid-level dry slot or area. It is not possible to determine from the moisture channel imagery how deep into the atmosphere the sensor "sees" or the degree of low-level moisture present. Middle grey shades can be attributed to a wide range of moisture amounts and vertical distribution combinations between these two extremes.

## 3. Application

It has been found that moisture channel imagery is most useful in identifying and evaluating the strength or development stages of vorticity maxima and closed mid/upper lows. The imagery is also valuable in determining zones of maximum winds aloft, studying mesoscale relationships between mid-level dry areas and thunderstorm development and monitoring changes in synoptic-scale upper air patterns.

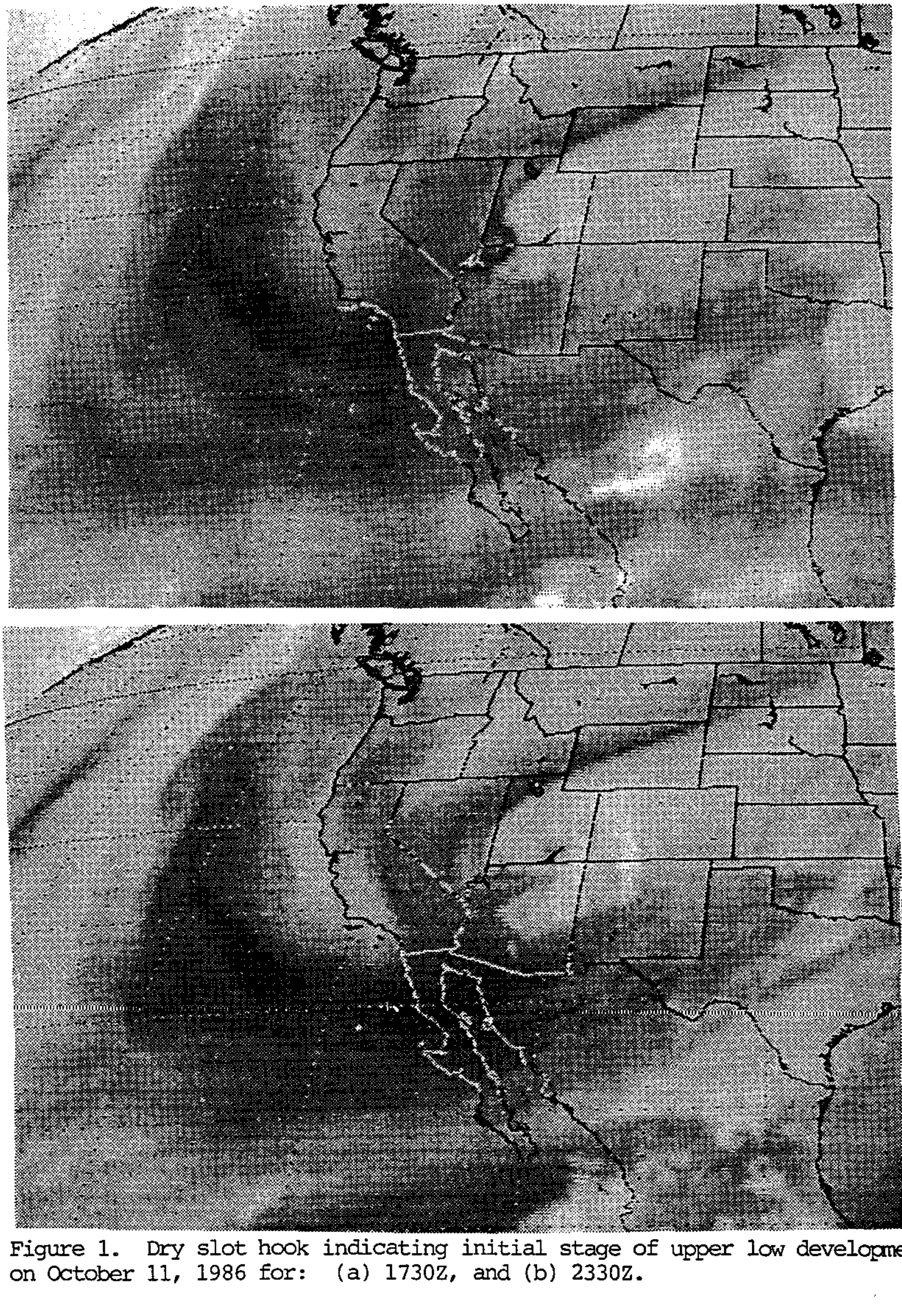
### a. Vorticity Maxima/Upper Lows

Occasionally, a vorticity maximum can be identified by moisture channel imagery in areas void of any clouds. Of course, these features are not related to any "weather" but they do verify a stray "x" (positive vorticity center) in the models that may later produce "weather" when superimposed on favorable moisture/temperature fields.

Trends in the moisture channel imagery can imply strengthening or weakening of upper lows/vorticity maxima. A beginning dry slot turning cyclonically around a common point generally indicates the development of a closed center (Figure 1). A system begins to weaken when these dry slots wrap completely around (perhaps several times in the larger ones) the center.

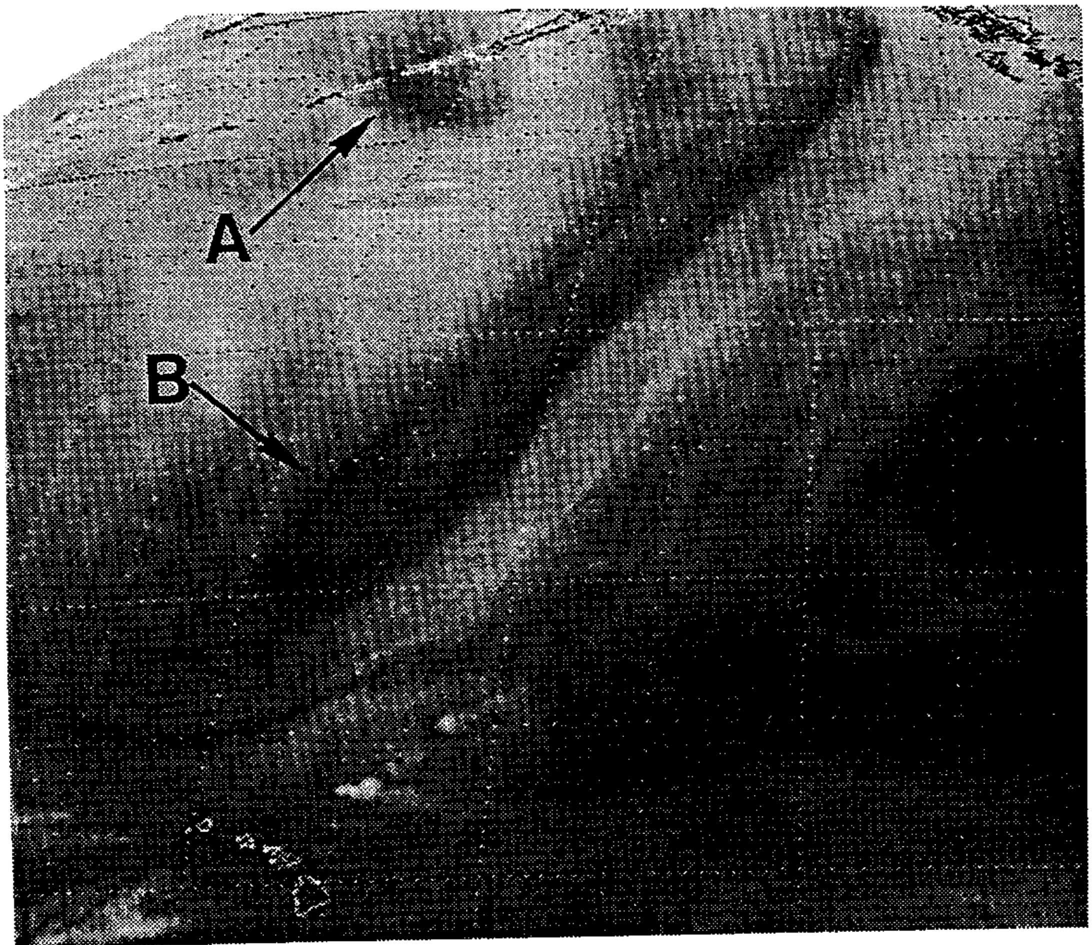
Figure 2 is a classic example of complete system evolution. A shortwave (A) drops into a long-wave trough and merges with the part remaining on the south end (B). As the two vorticity centers (and associated dry areas) combine, a new center is formed. The dry area wraps around the center as the system matures. The system then fills, degrades back into a vorticity center and starts to move east generating positive vorticity advection (PVA) as it taps tropical moisture. Unfortunately, this type of evolution is not as clear cut over the Rockies where many systems evolve in the winter.

a



b

Figure 1. Dry slot hook indicating initial stage of upper low development on October 11, 1986 for: (a) 1730Z, and (b) 2330Z.

a
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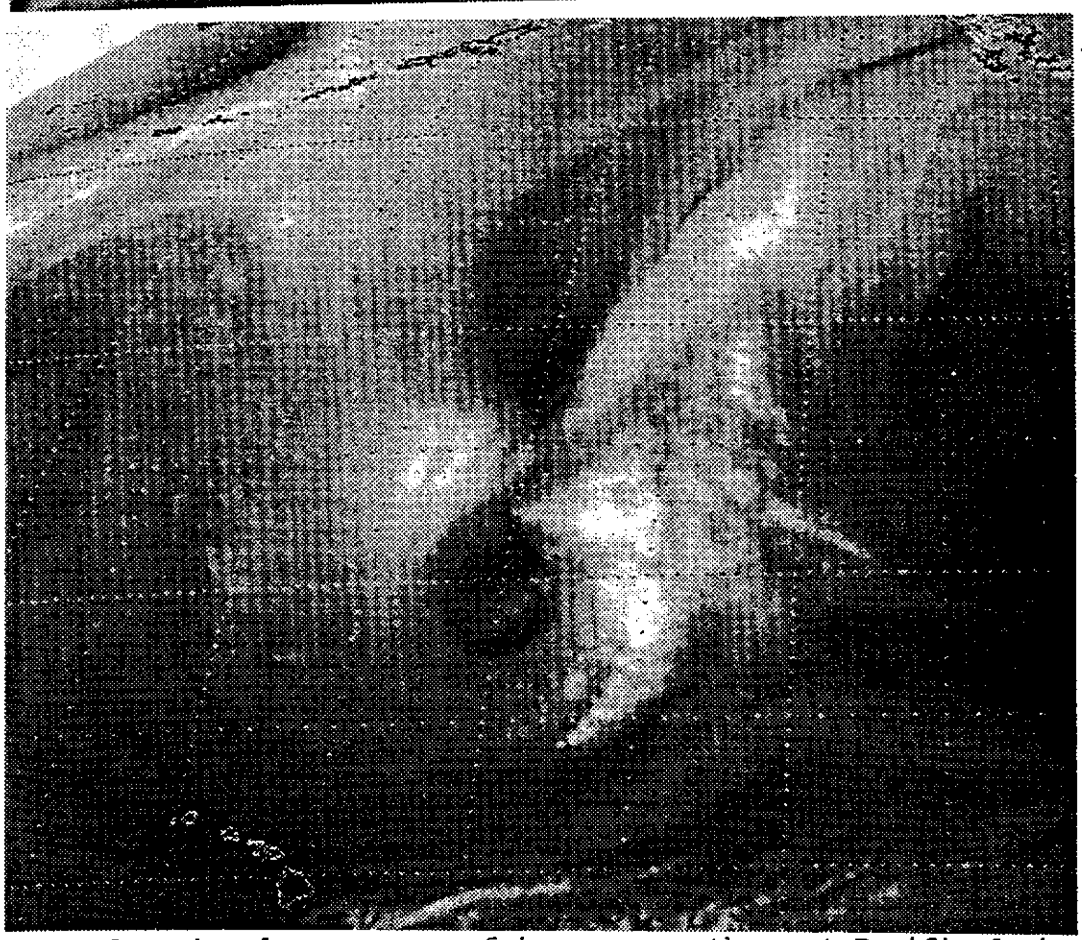


Figure 2. Five day sequence of images over the east Pacific during May 1987 showing the evolution of a large upper low (all times are for 1715Z) for: (a) 6th, and (b) 7th.

c

d

Figure 2. Five day sequence of images over the east Pacific during May 1987 showing the evolution of a large upper low (all times are for 1715Z) for: (c) 8th, and (d) 9th.

e

Figure 2. Five day sequence of images over the east Pacific during May 1987 showing the evolution of a large upper low (all times are for 1715Z) for: (e) 10th.

A well defined hook, which is caused by partial dry slot entrainment near the vorticity center, often helps to define the classic PVA comma cloud. This pattern often indicates a strong vorticity center and can be very useful when evaluating the numerical models. An example is presented in Figures 3 and 4. The developing, twisting moisture pattern (Fig. 3b) over Kansas midway between upper air stations suggested a vigorous vorticity center which will track east into central Missouri by 00Z (Fig. 3c). Comparing this to the model runs, it can be seen that, typical of the Limited-area Fine Mesh model (LFM), a vorticity center was averaged near the Iowa/Illinois border. In contrast, the Nested Grid Model (NGM) was much better, but, not quite strong enough. The difference in strength between the LFM and the actual analyses became much greater by 12Z the next morning over northeast Kentucky. Although rainfall was not excessive, it was more extensive across the Ohio Valley with most stations measuring precipitation.

b. Zones of Maximum Winds Aloft

The moist and dry areas which appear in the moisture channel imagery result from a combination of both vertical motion and moisture advection. The moisture patterns in different areas of the image will generally relate to flow at different altitudes. The white (colder) parts of the image will represent flow at a higher layer than adjacent patterns in darker gray (warmer) parts of the image.

Figure 5 shows the typical sharp cirrus edge usually associated with an upper jet. In this example, the jet is subtropical with roots in the ITCZ. A common interpretation error is the placement of the jet maximum wind speed axis along the cirrus edge. In some cases the maximum wind axis is embedded closer to the coldest clouds. In this case, the maximum wind axis is about 60 nm southeast of the sharp edge. In other cases, long narrow dark bands are related to upper confluent or deformation zones which may not be entirely along an axis of maximum winds. In Figure 5, corresponding maximum wind analyses are presented beneath the satellite images. Note the backing of the wind directions to the southwest across New Mexico and West Texas with about a 35 kt increase in speeds. The jet also bends eastward through the cirrus and does not follow the edge northward on the east side of the upper low lifting northeast from Nevada into Wyoming and Colorado.

Northwest flow situations in advance or in front of ridges on the back side of long-wave troughs usually lack cirrus to locate the upper jet axis. However, a dark zone which parallels the jet axis often appears in the moisture channel imagery. The dark band is not always well-defined and is thought to represent sinking and drying associated with the jet circulation. Similar dark bands may represent advection patterns of drier air aloft or a deformation zone where upper winds are converging in an axis through a col area near a sharp cirrus edge, generally on the north or west side of an upper closed system.

Greater than normal reports of moderate turbulence have been found to be related to dark bands in moisture channel imagery associated with certain types of deformation zones. Ellrod (1985) has shown that a number of significant turbulent events are correlated with a darkening trend in the moisture channel

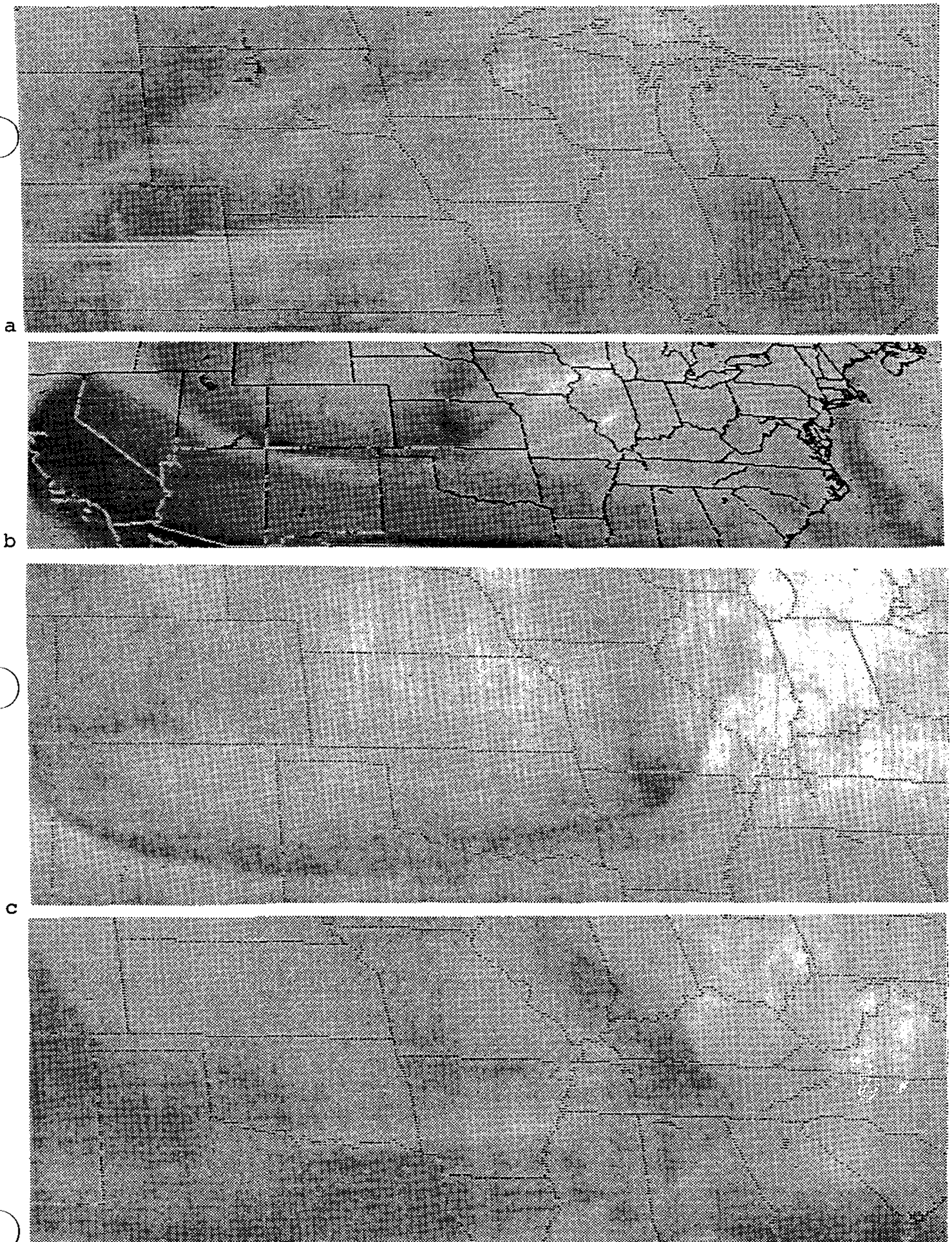
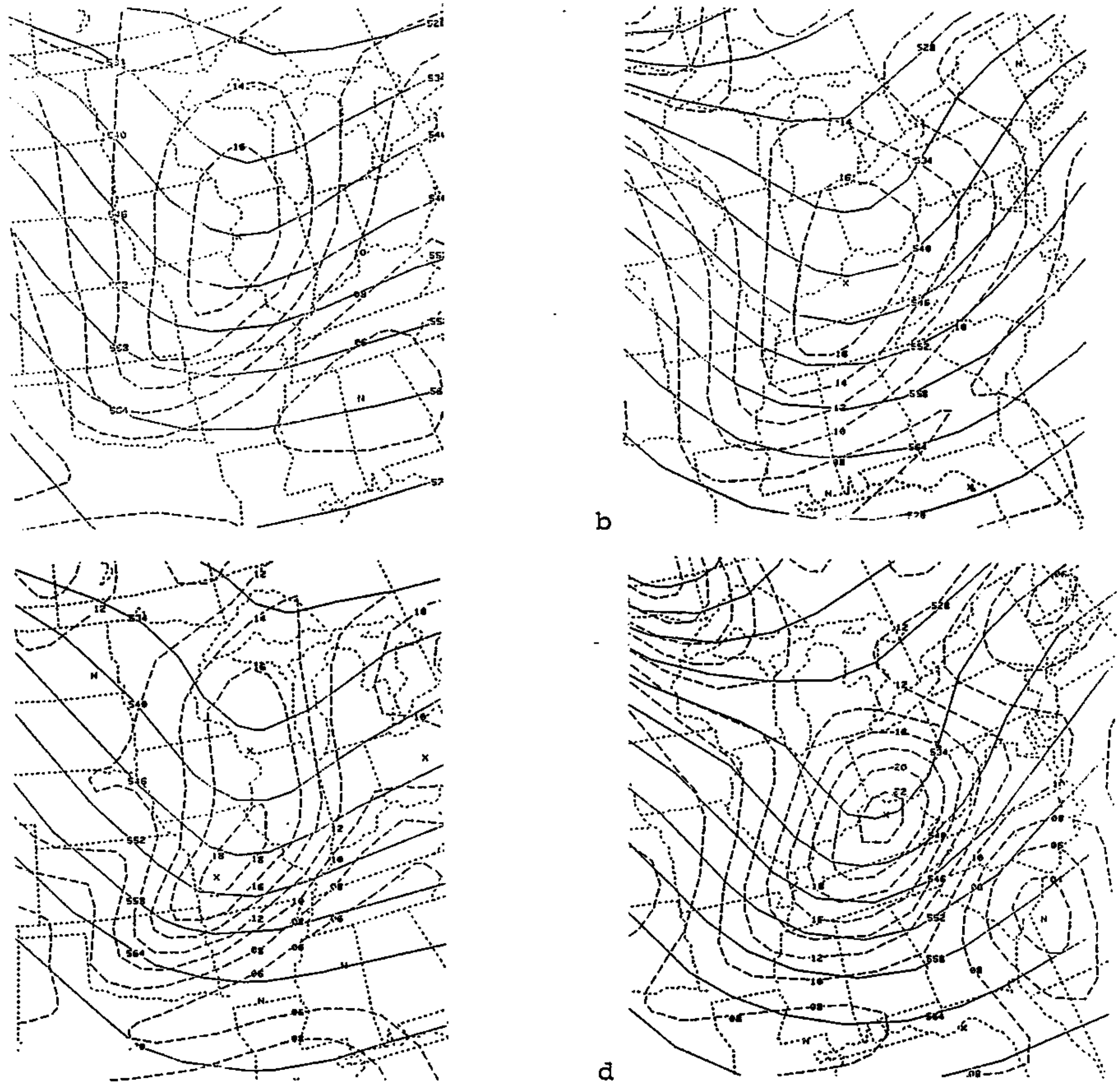



Figure 3. Assessing the strength of the vorticity center on March 5-6, 1987 for: (a) 1130Z, (b) 1730Z, (c) 2330Z, and (d) 0530Z.



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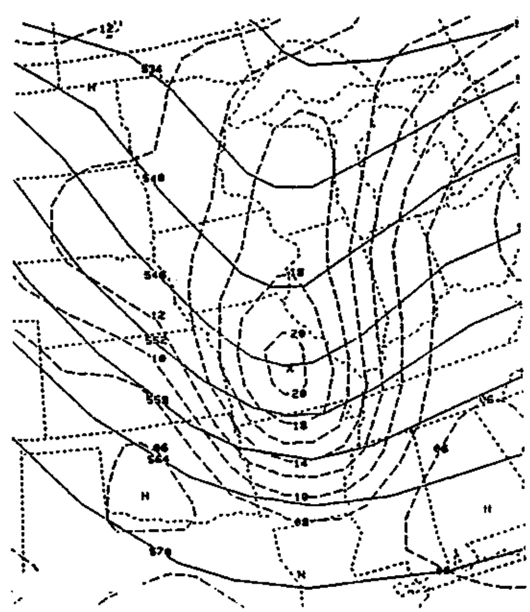


e

Figure 4. NMC LFM and NGM 500 mb trends during the images in Figure 3 for: (a) 12-hr LFM; (b) 24-hr LFM; (c) 12-hr NGM; (d) Initial analysis for March 6, 00Z; and (e) Initial analysis for March 6, 12Z. (Note: All left side panels are for 00Z and all right hand panels are for 12Z.)

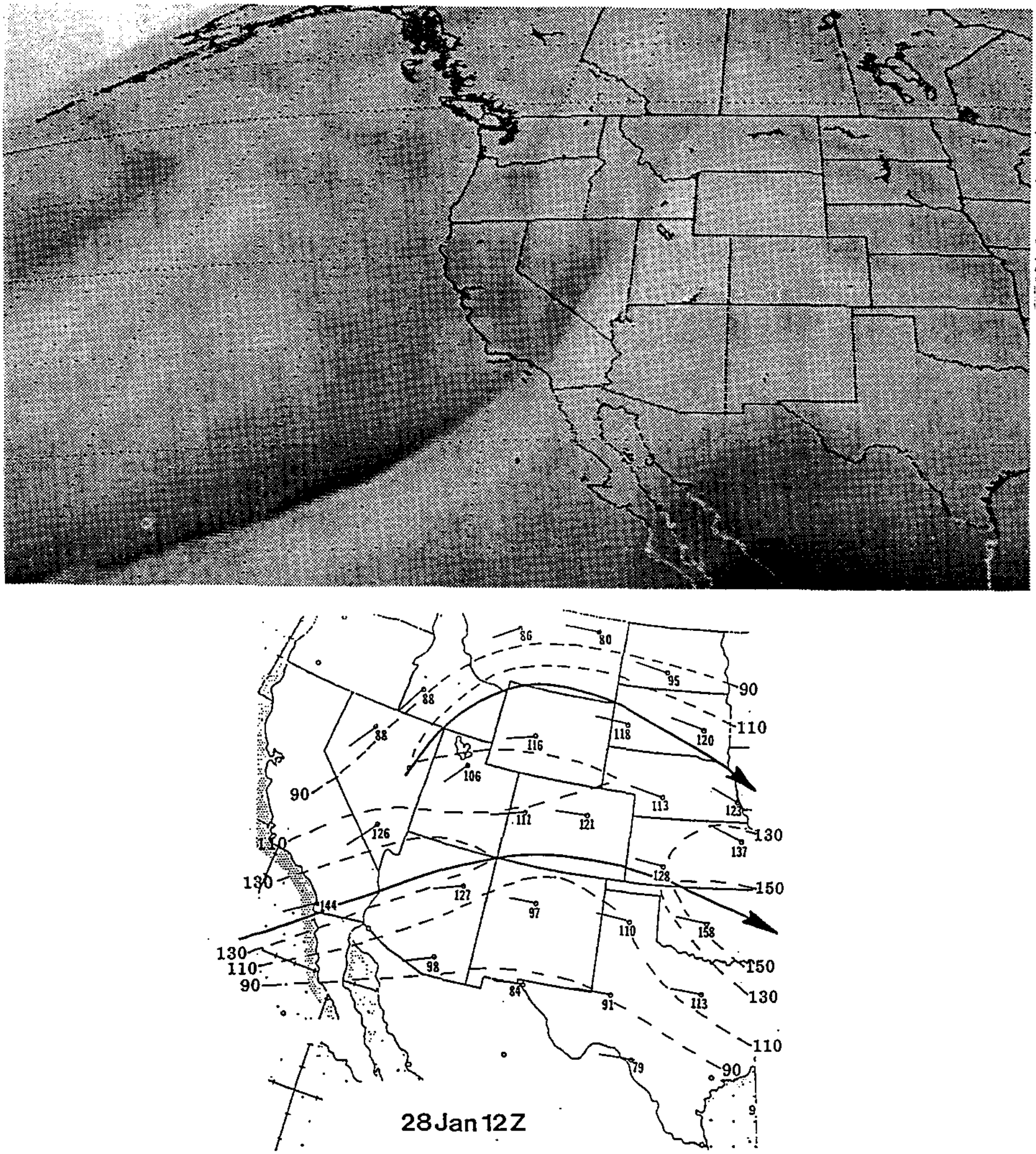
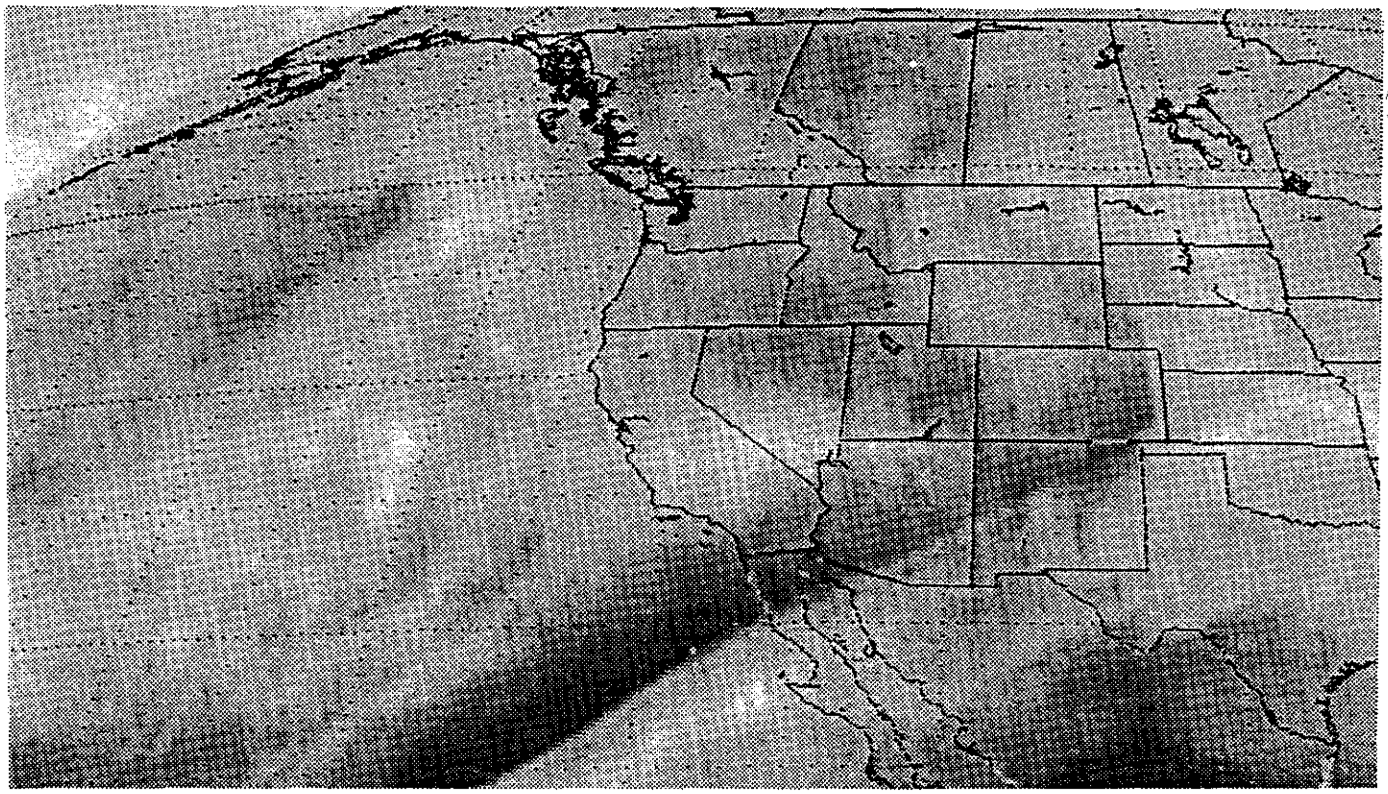



Figure 5a. Moisture channel image and corresponding maximum wind analyses for January 28, 1987 at 12Z.



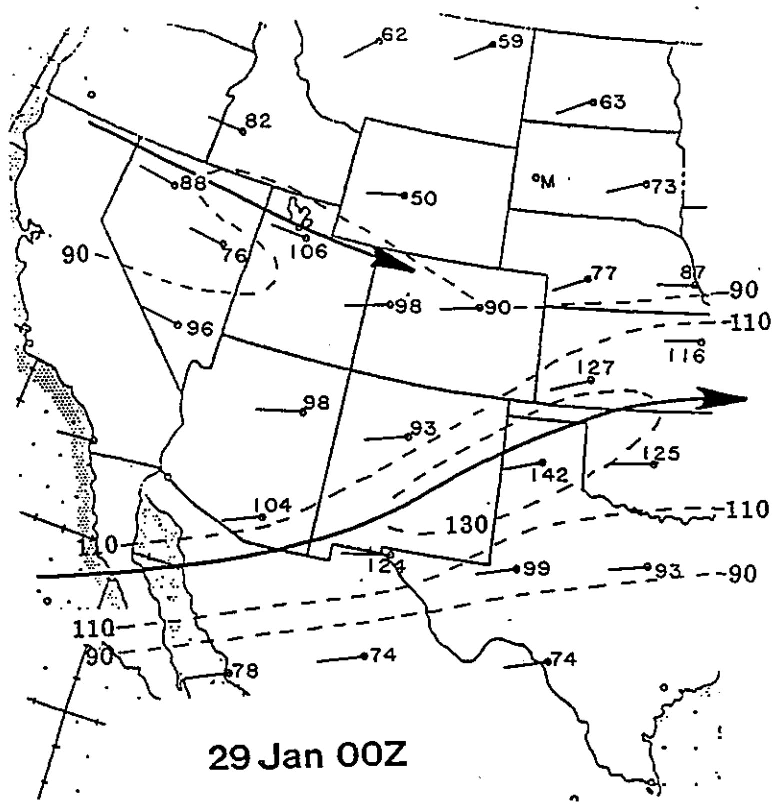



Figure 5b. Moisture channel image and corresponding maximum wind analyses for January 29, 1987 at 00Z.

imagery. The darkening was not related to advection of dry air but appeared to occur in place as a result of dynamic processes which cause the tropopause to descend or "break" when the Polar jet is present (Ramond et al., 1981).

The darkening seems to occur simultaneously with reports of turbulence and thus may not always be useful as a precursor. Turbulence is typically observed within the area of darkening and immediately adjacent to it. When the darkening ceases, turbulence diminishes. The darkening tends to occur most often in northwest flow type deformation zones, in strong short-wave troughs and near the head region of comma clouds.

c. Relationships to Thunderstorm Development

During the past few years there has been some documentation on the relationships between dark bands in the moisture channel imagery and thunderstorm (usually severe) development. Petersen and Mostek (1982) have noted a strong tendency for thunderstorms to develop along the leading edges of these dark bands which are hypothesized to represent mid-level dry air. The dark bands are on the south side of mid-tropospheric lows and apparently associated with polar and subtropical jet streams. Convective instability is implicated in regions where the dark areas are superimposed over the low level moisture. Anthony and Wade (1983) have noted that the location of thunderstorm development in the dark bands or areas seems to be a function of the degree of low-level instability, position of surface convergence and upper-level diffluence.

An example is presented in Figure 6. RAOB's at 12 and 00Z indicated a 90 to 100 kt jet at 40-45,000 ft extending from El Paso northeastward across the Texas Panhandle. Across west Texas, at 500 mb, winds also were quite strong (55-65 kt) and dew point temperatures -35C to -40C (30C depressions). Dew point temperature depressions at 700 mb were around 15C. Clearly the dark area was in a zone of strong upper winds and mid-tropospheric dry air.

An early morning thunderstorm formed over the southeast corner of New Mexico and developed into a cluster northeast across the Texas panhandle into Oklahoma (Fig. 6a). During the day cells continued to form in the moisture image dry slot on the surface dry line in west Texas (Fig. 6b). Around twenty five severe weather events occurred with the storms between 21 and 00Z from just south of Gage into central Oklahoma. The reports were wind damage and hail, ranging from 3/4 to 1 3/4 inch. Additional severe weather events (1 3/4 to 2 3/4 inch hail) occurred during the afternoon and early evening from scattered cells which developed southwestward across west Texas to near Midland.

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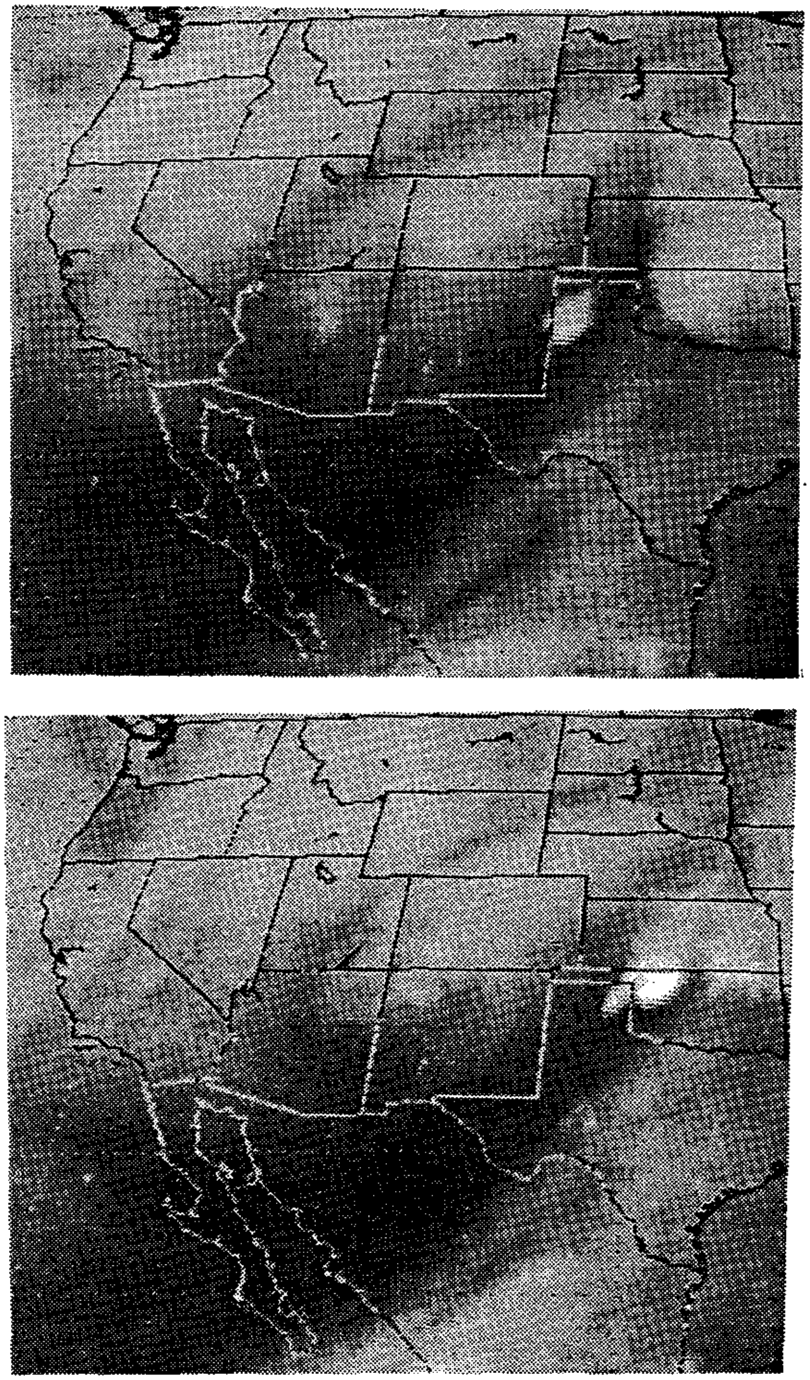

a

b

Figure 6. Severe thunderstorms developing in image dry area over west Oklahoma and the Texas Panhandle on September 29, 1986 for: (a) 1130Z, and (b) 1730Z.

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