NOAA TECHNICAL MEMORANDUM NWS CR-83

DEFORMATION ZONES AND HEAVY PRECIPITATION

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August 1986

UNITED STATES DEPARTMENT OF COMMERCE
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ABSTRACT

During the winter season of 1982-83 and the spring of 1983, a number of deformation zone cloud systems were monitored in satellite imagery to determine the relationship between these systems and locations of heavy precipitation. Several examples are presented showing this relationship.

Previous studies have shown that the heaviest precipitation often occurs along the southern edge of the tight IR temperature gradient. This paper documents that the heaviest precipitation area also includes the unenhanced portion of the IR imagery from about 1 degree latitude south or southeast of the tight IR temperature gradient to nearly the midpoint of the enhanced cloud area, and the unenhanced area up to 2 degrees latitude south or southwest of the southern tip of the enhanced cloud band.

Guidelines are also presented that may prove useful to forecasters when dealing with deformation zone cloud systems.

1. INTRODUCTION

Since the mid-70's when infrared satellite data became available at half hour intervals, it has been shown that these data could be used to determine areas of heavy precipitation (Weinrich, 1975).

More recently a number of authors (Beckman and Hirt, 1983; Kadin, 1982; Scofield et al., 1982) have shown that the heaviest precipitation often occurs along the southern edge of the tight IR temperature gradient of deformation zone cloud systems as seen in IR satellite imagery. This is usually where the best combination of deep layered moisture and vertical motion is located.

Weber and Wilderotter (1981) mentioned that deformation zone cloud systems usually form on the north and west sides of developing synoptic scale comma-shaped cloud systems. The developing deformation zone clouds imply cyclogenesis (closed low forming) in the mid and/or upper levels.

Deformation zones are associated with light winds within a mid and/or upper level col region (Fig. 1). The converging air slows and undergoes diffluence, turning cyclonically around the developing mid and/or upper low. The shape of these clouds depends upon the synoptic pattern, the amount of convergence and the availability of moisture.

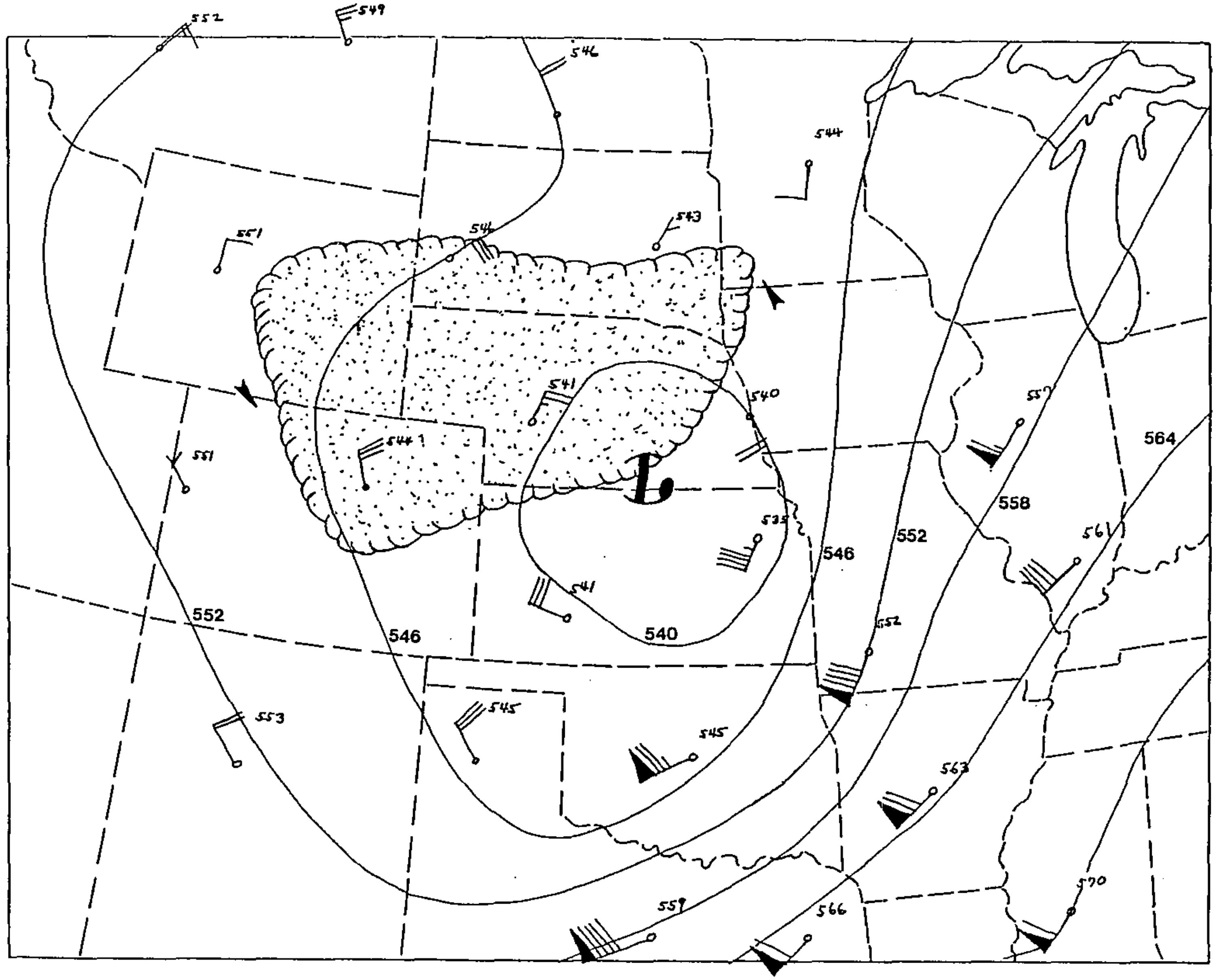

Fig. 1. 500 mb wind and height analysis for 0000 GMT, April 14, 1983.

Deformation zones often affect very deep layers of the atmosphere, and because of this, significant clouds and precipitation are associated with them.

Many large scale comma-shaped cloud systems evolve from deep cloud systems which resemble a leaf pattern (Fig. 2a). The leaf-shaped cloud pattern, referred to as a "baroclinic leaf" by Weldon (1979), is a cloud system associated with frontogenesis aloft within a westerly wind flow. Usually the system is vertically deep and surface frontogenesis is also occurring.

The leaf system evolves into a comma-shaped cloud by continued digging of a jet maximum into the west portion of the leaf (Figs. 2a and b). While the baroclinic leaf is associated with the "frontogenetic" phase of a synoptic scale storm system, the comma pattern is the "cyclogenetic" phase (Weldon, 1979).

All comma clouds have three basic features (Fig. 2b), whether they are associated with small scale short wave vorticity (mid level) systems, or those associated with the main vorticity (mid and high level) systems located within a synoptic scale comma-shaped cloud system. The three basic parts are: (1) the comma head, (2) the surge region, and (3) the comma tail (Weldon, 1975a).

The comma head is located to the left of the axis of maximum winds. It is in an area of large positive vorticity advection, and therefore can produce moderate to heavy precipitation.

The surge region is the area of the comma where the translation of the back cloud edge is large (in contrast to the comma head which tends to lag and shows the most tendency for rotation). It is the dry intrusion of air into the comma.

The comma tail extends back from the surge region to the south and becomes parallel to the axis of maximum winds, with the edge just to the right of the axis. Note that the winds referred to are at or near cloud top level.

Continued development of the comma cloud in Fig. 2b results in the mature stage of a large scale comma-shaped cloud system (Fig. 2c). The arrows represent the circulation at high levels, with the axis of maximum winds indicated by the heavy arrows (Weldon, 1976). The deformation zone cloud band is the last cloud system to develop.

Fig. 3 shows the individual cloud systems and how they fit together to make up the mature comma-shaped cloud system. Note the location of the deformation zone cloud system C in the figure, and the location of the vorticity comma cloud system B. The vorticity comma cloud part of the large scale system often is hidden below the higher level baroclinic zone clouds, and therefore many times is not observable on satellite imagery.

Also note in Fig. 3 how the deformation zone clouds merge with the baroclinic zone clouds. Sometimes each of the cloud systems in a synoptic

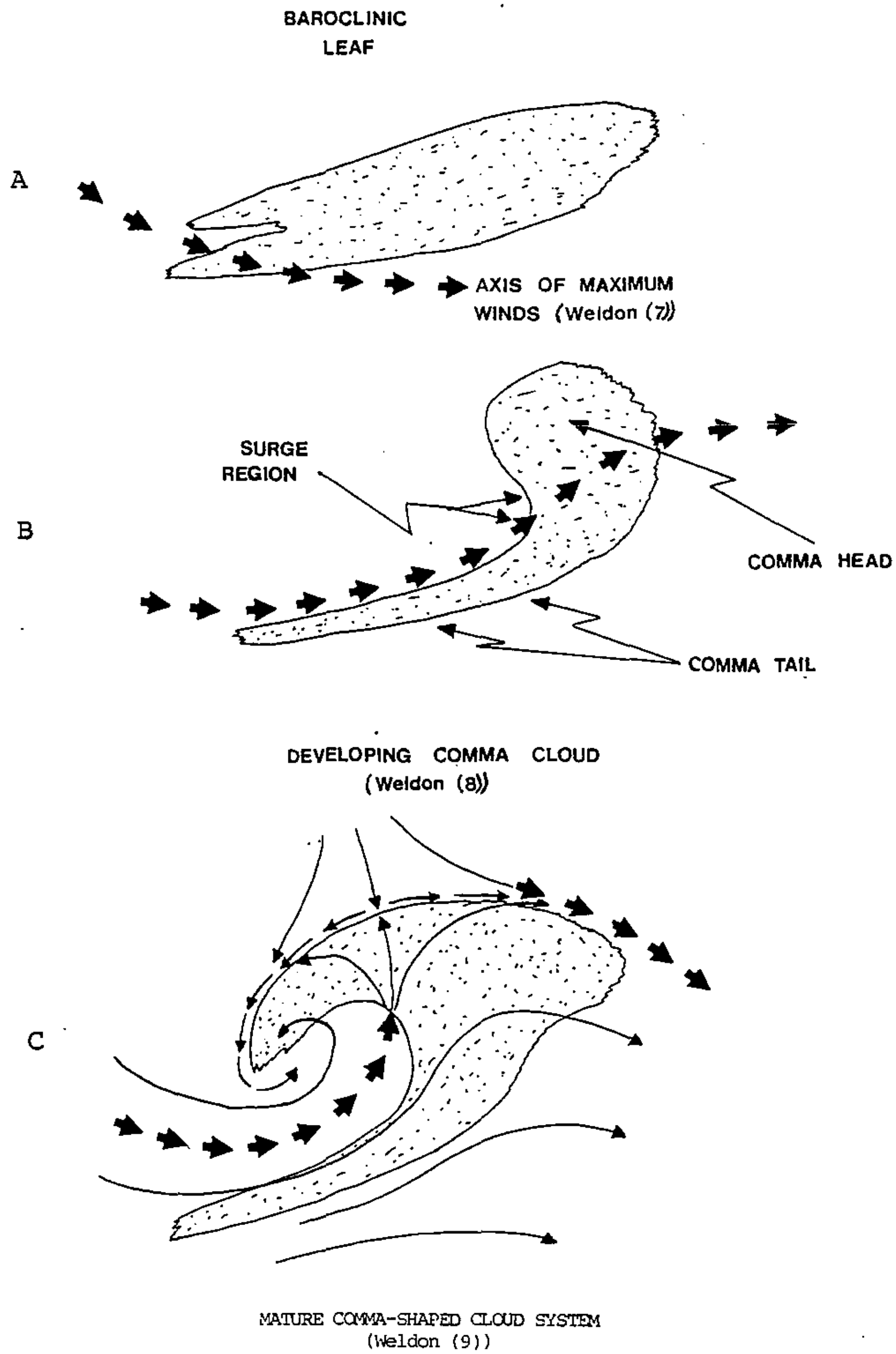

Fig. 2. The schematic of a comma cloud development: (a) baroclinic leaf, (b) developing comma cloud, and (c) mature comma cloud.

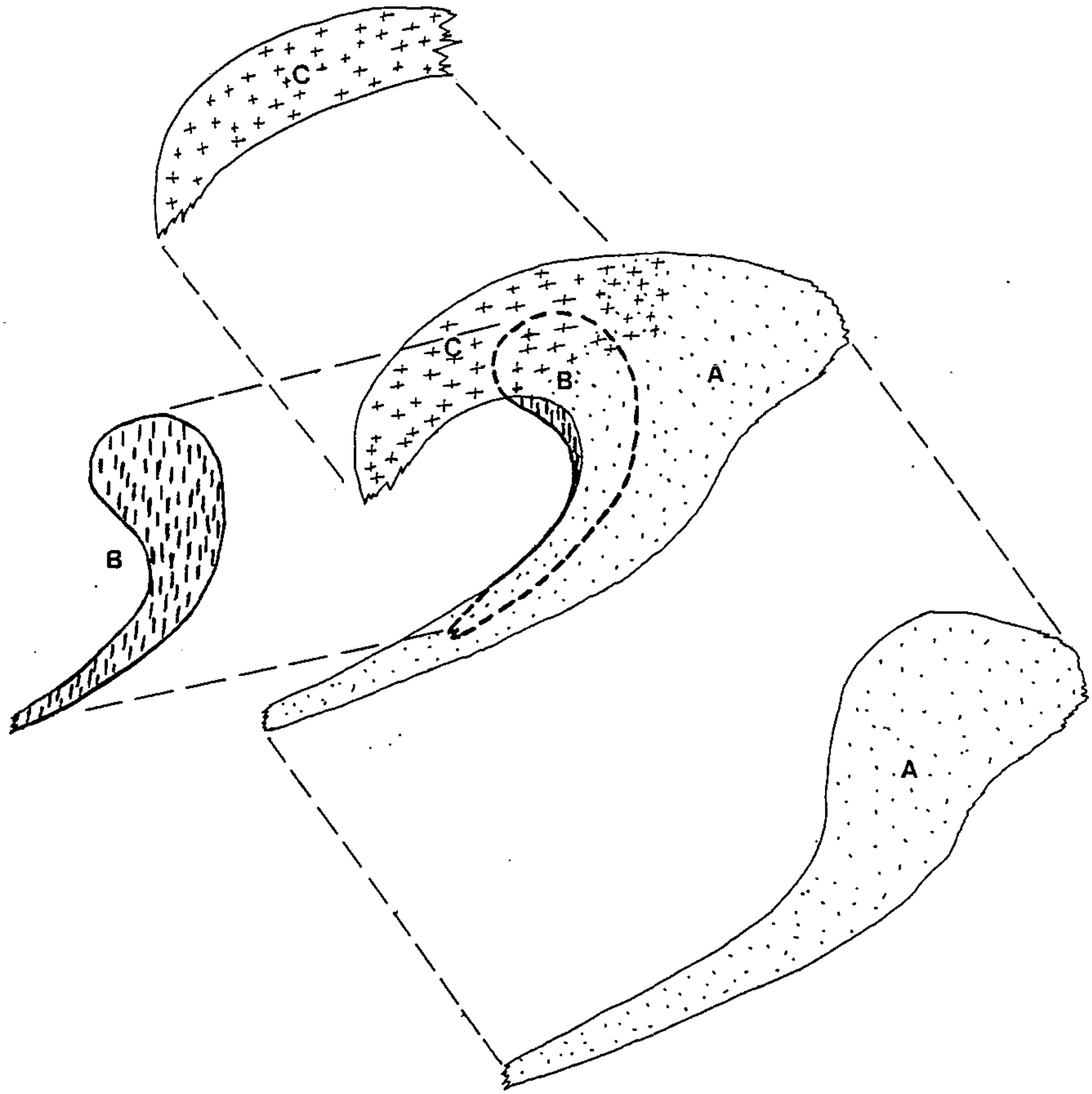

Fig. 3. Cloud systems which comprise a mature comma-shaped cloud system: (a) baroclinic zone cloud system, (b) vorticity comma cloud system, and (c) deformation zone cloud system.

scale comma cloud system can be easily recognized because they are separated somewhat from one another. Otherwise, for example, determining just where the deformation zone clouds end and the vorticity comma clouds and/or the baroclinic zone clouds begin is next to impossible.

It should be mentioned that a deformation zone cloud system is not always the last cloud system to develop. For example, it is the first cloud system to develop in split flow cyclogenesis, which is the most prevalent form of cyclogenesis over the Great Plains east of the Rocky Mountains (Weldon, 1975b).

The baroclinic zone cloud system has the highest level cirrus tops, and cold or occluded and warm fronts are associated with it. Precipitation is usually steady except for thunderstorms. The vorticity comma cloud system is usually composed of mid to low level clouds and is highly convective. Precipitation is usually showery and cold or occluded fronts are associated with it. The deformation zone cloud system has cirrus level tops, but they are lower than the baroclinic zone cirrus. Occluded fronts and steady precipitation are associated with it.

Sometimes a deformation zone cloud system is associated with a closed low at 500 mb which does not have an attendant surface system (cutoff low). Moderate to heavy precipitation may still occur with the deformation zone.

2. ANALYSIS

Satellite IR imagery at 0000 GMT 14 April 1983 (Fig. 4) showed a deformation zone cloud system extending from Wyoming and Colorado to extreme southwest Minnesota.

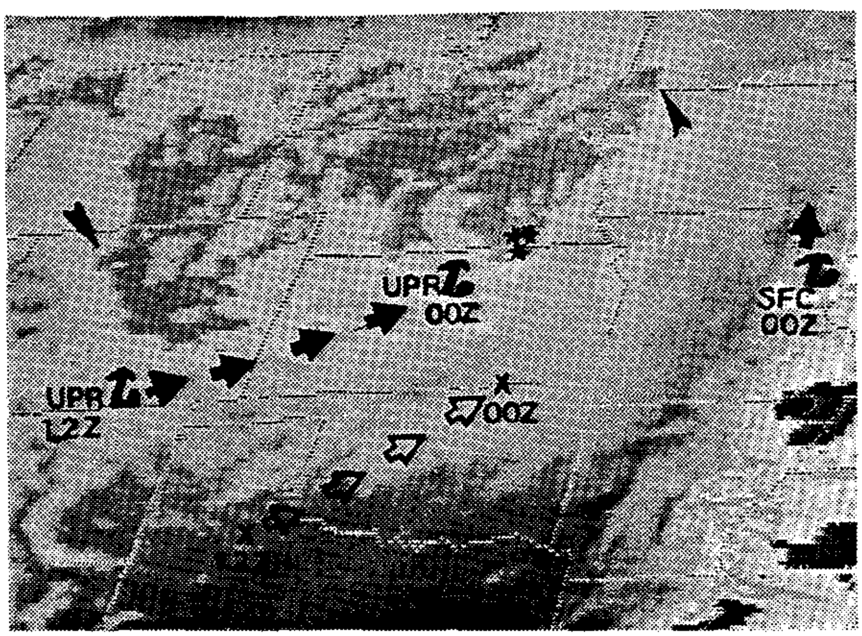

Fig. 4. Satellite imagery at 0000 GMT, April 14, 1983 (MB enhancement curve).

The 12-hour 500 mb height fall center had moved from the Texas Panhandle northeast to the eastern Kansas-Oklahoma border (X's in Fig. 4). The corresponding 500 mb closed low had moved nearly parallel and to the left of the height fall center track from the southern Colorado-New Mexico border northeast to north central Kansas.

At 0000 GMT a surface low was located near St. Louis and was moving north. One location reported moderate snow and that was near the southeast Nebraska-Kansas border. In the last 12 hours, 500 mb heights had fallen 110 meters. The distance between the surface low and its upper level support was narrowing and a major snowstorm was developing.

When an upper level closed low is stationary and not filling, the deformation field will remain strong and the associated deformation cloudiness will persist (see Weber and Wilderotter, 1981). However, at 0000 GMT the deformation cloudiness was decreasing with time and indicated that the upper low was on the move, as the current and past positions showed.

Satellite imagery at 0800 GMT (Fig. 5) showed the deformation cloud system redeveloping from western Iowa through northwest Wisconsin to the western tip of Lake Superior. The deformation zone clouds to the west (A to B in Fig. 5) had almost completely dissipated.

At 1200 GMT (Fig. 6) the deformation zone cloud system was well organized and extended from western Iowa to western Lake Superior.

A band of moderate snow extended from near the mid-point of the enhanced clouds over north central Iowa through east central Minnesota. It most likely continued across northwest Wisconsin into the west portions of Lake Superior and upper Michigan. Part of the band had to be inferred due to lack of surface reporting stations.

The 12-hour 500 mb height fall had increased to 240 meters, with the center now near Moline, Illinois. The 500 mb low had correspondingly moved to east central Iowa. The surface low was now over west central Wisconsin.

Light snow was falling to the northwest of the moderate snow band. The northern fringe of the enhanced clouds (A to B in Fig. 6) was devoid of precipitation. Minneapolis received a total of 13.6 inches of snow from this mid-April snowstorm.

Other deformation zone cloud systems were monitored for locations of heavy precipitation. Three other examples follow.

Satellite imagery at 0500 GMT 28 December 1982 (Fig. 7) showed a deformation zone cloud system extending from southeast Nebraska to northern Lake Superior. A surface low was located over southeast Iowa.

A band of moderate snow extended from south central Nebraska and northeast Kansas across northwest Iowa to east central Minnesota. Moderate

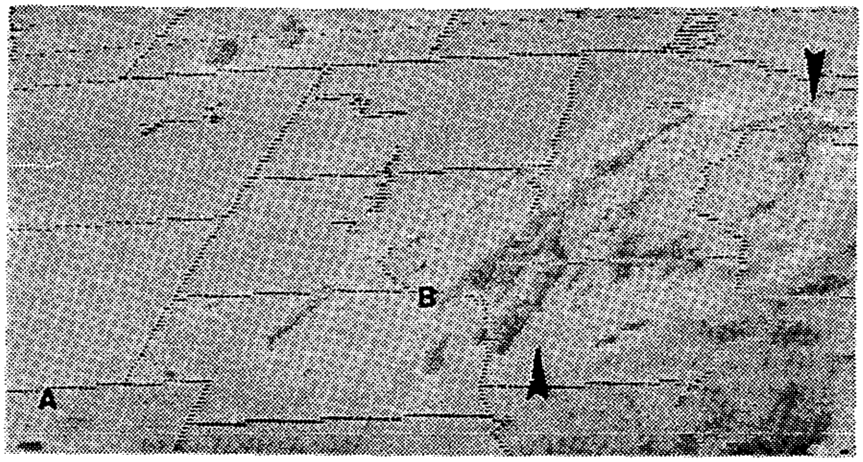

Fig. 5. Satellite imagery at 0800 GMT, April 14, 1983 (MB enhancement curve).

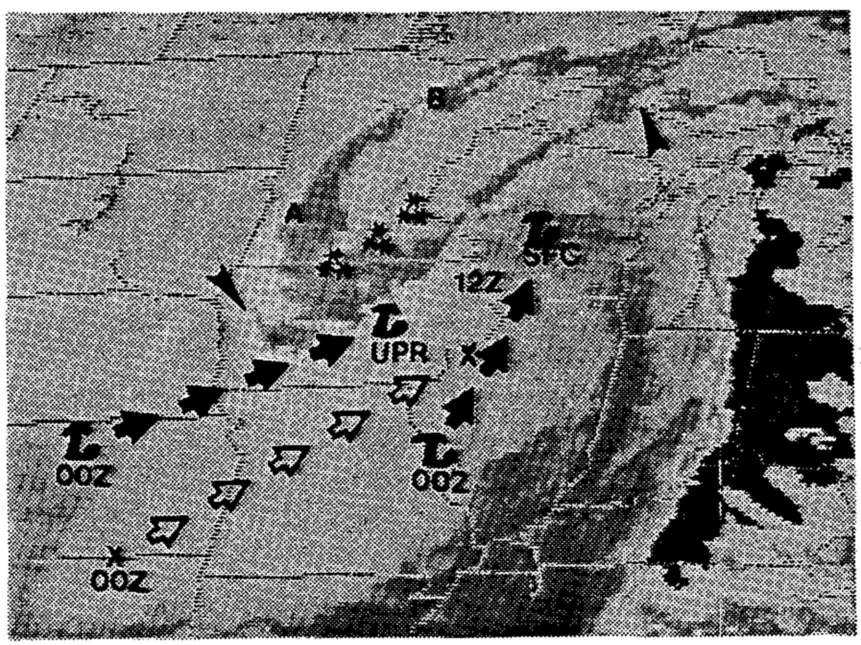

Fig. 6. Satellite imagery at 1200 GMT, April 14, 1983 (MB enhancement curve).

rain was falling over north central Iowa to the southeast of the band of moderate snow. Note that the moderate snow falling in south central Nebraska and the moderate rain in north central Iowa were both occurring in an unenhanced portion of the IR imagery (CC curve).

The remains of the deformation zone cloud system that existed earlier to the west (it had redeveloped eastward to its location at 0500 GMT) can be seen as scattered colder cloud tops from north central Nebraska to northern Minnesota (A to C in Fig. 7). Because of this, light snow extended over a large area to the north of the band of moderate snow. In this instance this included the area under the north portion of the enhanced clouds of the newly developed deformation zone cloud system (D to F in Fig. 7). Many times, however, this area is devoid of precipitation.

In another example, satellite imagery at 1800 GMT 20 January 1983 (Fig. 8) showed a deformation zone cloud system extending northeast from northern Louisiana and merging with a comma head over the central parts of Tennessee and Kentucky. A surge region (the dry intrusion of air into the comma cloud indicating the jet stream punching into the system) can be seen from the Gulf of Mexico across Alabama and western Georgia. A surface low was located just south of the Mississippi coast.

A band of moderate rain was occurring across southwest, central, and into east central Mississippi, from near the southern edge of enhanced clouds to about 2 degrees latitude (120 nautical miles) to the northwest. Light rain was falling to the northwest of this band. No precipitation was occurring farther to the northwest under the north portion of the enhanced clouds of the deformation zone (A to C in Fig. 8).

In the final example, satellite imagery at 1700 GMT February 1, 1983 (Fig. 9) showed a deformation zone cloud band extending from Nebraska and northern Kansas to eastern Iowa, where it merged with the vorticity comma head. A surface low was along the Oklahoma-Arkansas border.

A band of moderate snow extended from near the mid-point of the deformation clouds over south central Nebraska and the north central Kansas-Nebraska border, northeast along the tight IR temperature gradient to southern Iowa. Light snow was falling to the north of this band. No precipitation was occurring under the north portion of the enhanced clouds (A to C in Fig. 9).

The deformation zone continued moving north, causing visibilities to lower in moderate to heavy snow at stations located farther to the north in eastern Nebraska and central and northern Iowa. Snow became light and visibilities increased over south central Iowa after the southern edge of the enhanced clouds (first level medium gray in MB curve) passed to the north.

3. FORECAST GUIDELINES

a. If a surface low pressure system (or upper level cutoff low with no attendant surface system) has a well formed deformation zone cloud system, the most likely location of moderate to heavy precipitation will be within an area

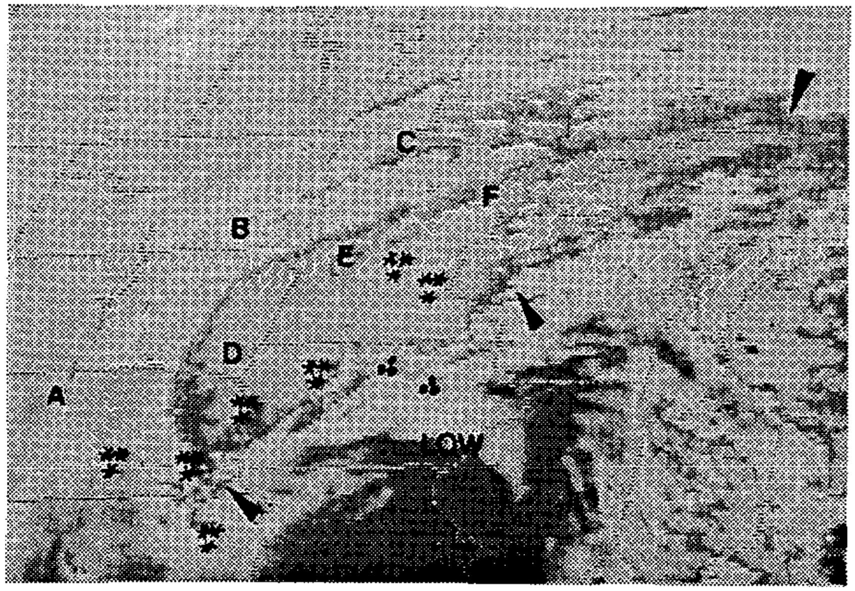

Fig. 7. Satellite imagery at 0500 GMT, December 28, 1982 (CC enhancement curve).

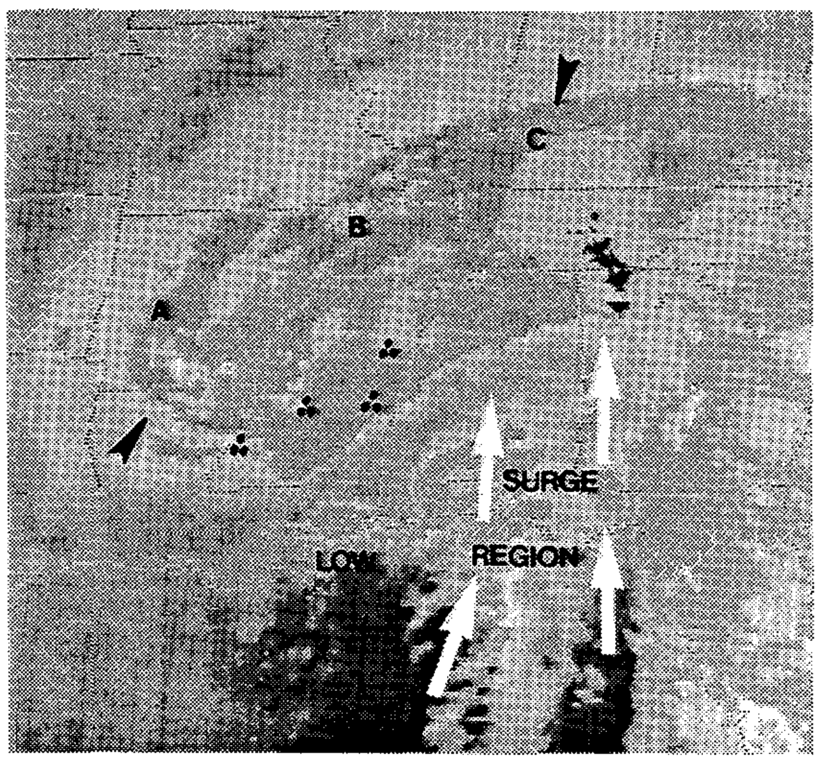

Fig. 8. Satellite imagery at 1800 GMT, January 20, 1983 (MB enhancement curve).

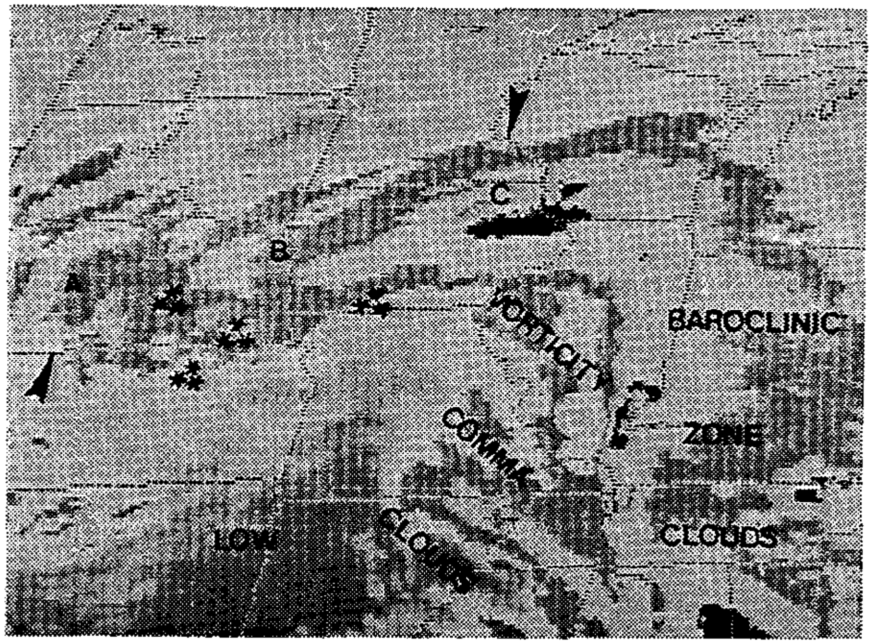

Fig. 9. Satellite imagery at 1700 GMT, February 1, 1983 (MB enhancement curve).

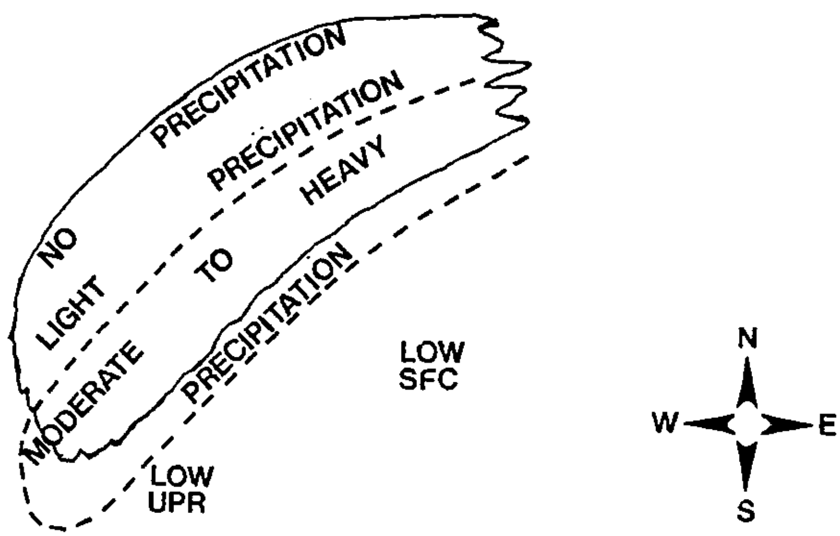

Fig. 10. The location of precipitation areas often observed in a well-formed deformation zone cloud system.

from about 1 degree latitude south or southeast of the tight IR temperature gradient in the unenhanced portion of the imagery, to nearly the mid-point of the enhanced cloud area, and in the unenhanced area up to 2 degrees latitude south or southwest of the southern tip of the enhanced cloud band (Fig. 10).

b. If the deformation zone cloud system is rather fragmented (unorganized), chances are it is either weak or is dissipating and may be reforming farther east. There will be no well defined large area of moderate to heavy precipitation. Only spotty areas will exist at best.

c. In a well formed deformation zone cloud system, do not expect moderate to heavy precipitation for the entire length of the cloud system. It appears that the moderate to heavy precipitation band will extend northeast to a point generally north or north-northeast of the surface low, and to the northeast of the upper low (Fig. 10). The stage of development of the system is a factor here.

d. A band of light precipitation occurs to the north or northwest of the moderate to heavy precipitation band. Just how far north or northwest cannot be estimated, because the width of both the moderate to heavy precipitation band and the width of the deformation zone cloud system is determined by a number of factors, such as the intensity of the low pressure system and the amount of available moisture, etc.

e. Frequently, the area under the north or northwest part of the deformation zone cloud band is devoid of precipitation.

f. If the associated vorticity comma and the baroclinic zone cloud systems separate from the deformation zone cloud system, and the deformation zone cloud band elongates, upper level changes are occurring. The closed and vertically deep upper low is lagging behind and is probably filling, and will most likely redevelop farther to the east nearer the baroclinic zone cloud system (Weber and Wilderotter, 1981).

g. Since moderate to heavy precipitation occurs in the south or southeast part of the deformation zone cloud band and the north or northwest part of the band is frequently devoid of precipitation, it follows that a tight PoP gradient must exist across the deformation zone cloud band.

Therefore, one must pay close attention to the movement of the edges of the band. For example, if your location is to the north of the band, a slight shift toward you would mean increasing PoP's and may bring light precipitation into your area; a greater shift and heavy precipitation may occur. If your location is east of the band, a slight shift toward you would also mean increasing PoP's and may bring unexpected heavy precipitation into your area.

4. DISCUSSION AND CONCLUSION

Satellite IR imagery using both the CC and MB curves was used in monitoring deformation zone cloud systems. First level enhancement (medium gray) in both curves begins between temperatures of -30 and -40°C with only a couple of degrees difference between the two. As a result, it does not seem to matter which curve is used in applying the imagery to deformation zones.

The apparent and actual cloud positions with respect to a surface position will coincide only for a cloud located precisely over the satellite sub-point (the point on the earth's surface directly under the satellite).

The greater the cloud's distance from the sub-point and the greater the cloud's height, the greater the difference between the apparent and actual cloud positions with respect to a surface position (National Weather Service, 1977).

To correct for this difference when using East GOES imagery (when two GOES satellites are in operation and East GOES is in its normal position), one must shift the satellite imagery to the south-southeast so the apparent and actual cloud positions with respect to the surface position will coincide. For example, a 20,000 ft top over North Dakota would have to be shifted about 6 nautical miles to the south-southeast, over Missouri about 4 nautical miles, and over Mississippi about 3 nautical miles. Since the distances involved are rather small, the points mentioned in this discussion remain valid.

Satellite IR imagery must be monitored for the development and movement of not only deformation zone cloud systems, but also the comma head portion of vorticity comma cloud systems. Both are important heavy precipitation producers. They are most common during the fall, winter, and spring months when low pressure systems are more strongly developed.

During the winter season of 1982-83 and the spring of 1983, forecasts from two offices were observed that might have been improved by using IR satellite imagery to monitor the movement of the edges of deformation zone cloud bands, and by reading the latest satellite information messages.

In the first instance, a winter storm warning was in effect for heavy snow for the "tonight" period. The southeast edge of a deformation zone cloud system was far to the west. Satellite IR imagery showed the edge not moving any closer. The late evening zone release continued the winter storm warning that was in the late afternoon zones.

Using the satellite imagery, the forecaster should have been able to determine that the heavy snow band would not move any closer. The late evening zone release should have cancelled the winter storm warning over most if not all of the area. The band of heavy snow fell far to the west and northwest of the area.

In the second instance, an aviation forecaster issued several terminal forecasts at the 1440 GMT release time with either no mention of any precipitation for the entire forecast period (24 hours beginning at 1500 GMT) or just mentioned "CHC 2S-". A deformation zone cloud band pushed rapidly northward and within five to six hours two locations reported "W1 x 1/4SF".

Higher PoP's are the possibility of moderate to heavy rain (snow) should be mentioned in forecasts if a deformation zone cloud band is observed developing over or moving into the forecast area.

Finally, forecasters are reminded not to leave a winter storm watch or warning in forecasts if it is obvious, not only using conventional data (radar, surface observations, etc.) but satellite imagery as well, that a deformation zone cloud band and its associated moderate to heavy precipitation will not be moving into the forecast area.

5. ACKNOWLEDGEMENTS

Special thanks go to Dr. Joseph T. Schaefer, Chief, Scientific Services Division, National Weather Service Central Region, for his review and commentary on this manuscript. Also, the author wishes to thank the Satellite Field Services Station in Kansas City, Missouri for reviewing parts of this manuscript.

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