P6.3

SOME UNUSUAL ASPECTS OF THUNDERSTORM

CLOUD TOP BEHAVIOR ON MAY 11, 1982

John F. Weaver and James F.W. Purdom
Regional and Mesoscale Meteorology Branch
Development Laboratory, NOAA/NESDIS
Colorado State University
Fort Collins, Colorado

1.   INTRODUCTION

On the 11th of May 1982, more than one hundred severe weather events were verified in five states of the central United States. The most active area was a small region some 130 km north-south by 100 km east-west in extreme southwestern Oklahoma (OK). This region had over one third of the severe events. The most destructive activity occurred when a tornado touched down near Altus, OK, then crossed Altus Air Force Base (LTS). Total damage to the town and air base (from both the tornado and large hail) exceeded $200 million. Forty-one persons were injured. In this paper, three minute interval data from GOES-E are used, along with data from other sources, to study the storm environment in southwestern OK during this period.

As always when utilizing satellite data, there are viewing problems to consider. Thus, while one can often see both the tops and sides of thunderstorms on the imagery, in this case anvil material from storms to the west blocked the view of everything but storm tops. Nevertheless, storm top evolution in the 11 May case revealed many intriguing features of storm behavior. Several apparent overshooting tops (OSTs) were identified from the visual wavelength (VIS) data. OSTs often signal strong thunderstorm activity (Fujita, 1974; Shenk, 1974). They generally are associated with updraft regions which penetrate above the equilibrium level. Additionally, the OSTs were each associated with cold tops on the infrared (IR)--further evidence of their intensity. The relation between CTs and severe potential is well documented (Adler and Fenn, 1977, Pryor, 1978, or Reynolds, 1979). Finally, wedge-shaped plumes of warmer cloud matter, or warm plumes, were observed downstream from the OSTs. This downstream warming has been observed in a number of severe thunderstorm cases (Reynolds, 1979; Fujita, 1981).

The following discussion presents the spatial and temporal relationship of each of these features to the other. Speculations regarding the implications of these relationships to storm structure are made.

2.   DATA

May 11th was a Research Rapid Scan Day (RRSD), thus three minute interval images were available for the case. Both VIS and IR data were processed on Colorado State University's (CSU's) Interactive Research and Imaging System (IRIS). The main data processor on the system is a DEC VAX~11/780, while image processing is done on a two station, COMTAL Vision One/20. Both workstations have a CRT connected to the host computer, a keyboard for control of the image processing system, and a high-resolution RGB video monitor. Cursor control is via a data tablet on Station 1 and a trackball on Station 2. For a more complete description of the CSU system, see Green and Kruidenier (1982).

The IR data for the study were not used in the conventional "blocky" form with the standard MB curve--instead, the IRIS was employed to make the data a bit more comprehensible. It is generally accepted that IR data from geostationary satellites have serious limitations in terms of spatial resolution. For example, at the latitude of Oklahoma City (OKC), the size of an IR PIXEL (Picture Element) is a little over 12.5km along its north-south axis, by more than 6.5km east-west (Ensor, 1978). This broad-scale averaging eliminates many small extremes in radiance which may, in turn, eliminate details that help make the image unique. This filtering cannot be corrected for--the data are lost. However, another problem about which something can be done is encountered when using IR imagery on the mesoscale. It is caused by human perception being sensitive to geometric pattern. Thus, the regular-shaped rectangles which dominate GOES IR images may draw nearly as much attention as the storms themselves. This problem is partially solved in this study by applying a smoothing function to eliminate the "blocky" appearance. Furthermore, a color table which varies with every degree C is substituted for the MB curve. With the application of these enhancements, features such as warm plumes, etc. are simple to follow and maintain excellent continuity over time.

In addition to satellite data, conventional National Weather Service teletype and facsimile data and reflectivity data from the National Severe Storms Laboratory (NSSL) WSR-57 and 10 cm Doppler radars were available. Also, a few Doppler velocity scans were supplied by the NSSL for the period of interest.

3.   11 MAY 1982 CASE STUDY

3.1   Synoptic Situation

A deep, synoptic low over the western U.S. left OK and western Texas (TX) under diffluent, southwesterly flow aloft. A shortwave trough was identified on morning upper air analyses moving into western New Mexico. Numerical prognoses showed that the wave would be entering west TX by midday.

Figure 1 shows the important surface features as they appeared in the early afternoon. These features include surface lows in north-central Kansas (KS) and western TX, a stationary front connecting the two, a large outflow area in eastern KS, and a dry line in west TX. Satellite imagery also showed a region in western TX and extreme southwestern OK in which cumulus and cumulus congestus had been prevalent during the mid to late morning. Just before noon, thunderstorms began forming in that region, as well as along most of the low-level boundaries.
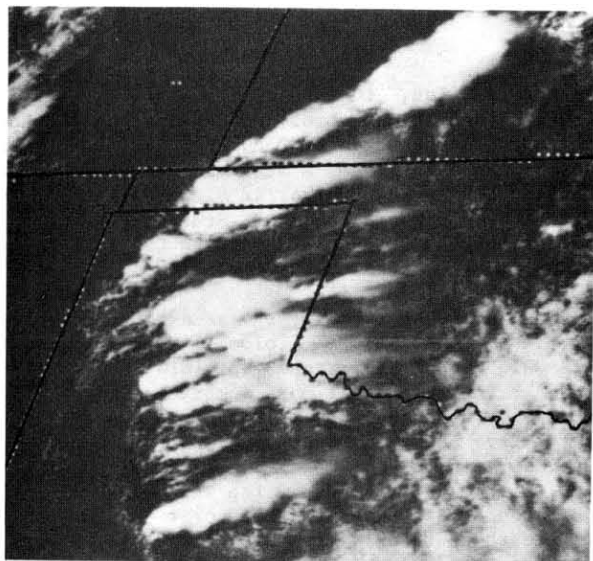

Figure 1: a) Visual satellite photo from 1941GMT, 11 May 1982. b) Important surface features from 1900GMT analysis. Dotted line outlines region where congestus clouds (on earlier satellite photos) have become thunderstorms. Refer to text for other details.

3.2 Overview of Activity in Southwest OK

At approximately 2045GMT a thunderstorm crossed into southwestern OK traveling from 207 degrees at 11 ms^{-1}. The cell produced baseball size hail at 2100GMT, a funnel at 2149GMT and, finally, an F2 tornado some 20km west-southwest of LTS at 2203GMT.

Meanwhile, a second storm formed about 40km to the south-southeast of the first (at ~2115GMT). This cell increased in intensity as it moved from 192 degrees at 14 ms^{-1}. It crossed into OK at 2130GMT. Both storms were moving slightly left of the mean cloud layer winds (which proximity sounding data indicated were from 220 degrees at 9 ms^{-1}). The second storm traveled 15 degrees left of the first (northern) and some 3 ms^{-1} faster, placing the two storms on a collision course.

NSSL ground-based storm intercept personnel were filming the Duke tornado (produced by the northern storm) at 2200GMT. A few minutes later they reported that the updraft-scale mesocyclone appeared to be occluding, the tornado dissipating, and a new wall cloud was trying to form just east of the old updraft. Before this could occur, a heavy precipitation shaft moved up from the south-southwest, and within minutes rain seemed to have smothered the updraft of storm 1. This merger can be seen in radar data in Figure 2 which shows the relative positions of the 40 and 50dbz echo contours from the two storms. The echoes shown are at 0.3° elevation which, at the range of LTS from NSSL, represents PPI slices at roughly 2km altitude. Note that the merger at that height seems to begin at 2200GMT, and that shortly after 2230GMT, echo 1 begins to dissipate while echo 2 continues to grow.

A second point of interest (found in both the WSR-57 and Doppler reflectivity) is that the strongest cores were on the west side of the storms. When storm 1 dissipated, the large core disintegrated rapidly, leading one to speculate on the possibility of a strong outflow region to the west of the old storm. Although anvil material covered the lower cloud portion of the storm, supporting evidence for this hypothesis can be found in visual satellite imagery of nearby storms. The imagery shows outflow "arc cloud lines" (Purdom, 1973) to the west of most of the storms in TX. These arc lines were oriented generally from south-southeast to north-northwest. The possible importance of this orientation will be discussed later.

As storm 2 intensified, it developed a strong circulation center at about 190 degrees, and some 2-3km, from the precipitation core (Doppler analysis--not shown). At approximately 2230GMT the 60dbz core and mesocyclone turned its movement to slightly west of north. As the intense echo moved into the town of Altus, large

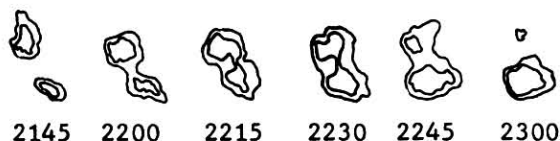| 2145 | 2200 | 2215 | 2230 | 2245 | 2300 |

Figure 2. Relative positions of the 40 and 50 dbz echo contours at the times indicated for the two storms described in text. Radar data is from the NSSL, 10 cm, WSR-57 radar at Norman, OK. Scan elevation is 0.3 degrees.

hail (described as 1" X 4" oblate spheroids) was reported. At 2250GMT a large tornado touched down just southeast of the town.

3.3 Satellite Analysis

Three-minute interval RRSD satellite data for the period discussed above are currently being studied. Figure 3 illustrates some of the more interesting features noted thus far. Inspection of the VIS imagery (Fig. 3a) reveals two OSTs on the thunderstorm complex in southwestern OK. Also note that in the IR data (Fig. 3b), the regions identified as OSTs each has an associated cold top. At this image time the minimum temperature observed (same for both tops) was −69C, while the tropopause temperature was estimated at −62C. These tops correspond to the two storms discussed above.

The OST region associated with storm 1 (the northern top in Fig. 3) had been evident on satellite imagery even before the storm moved into OK. The top from storm 2 appeared at 2214GMT and immediately began moving northward while the other top moved northeast. The two tops merged at roughly 2235GMT. This is approximately 30 minutes after the lower portions of the two were observed to merge by radar. The merger of the tops may be interpreted as meaning that the upper portion of the updraft from storm 2 overrode that from storm 1--particularly in light of the subsequent dissipation of storm 1.

Another interesting feature noted in the character of the OSTs was a displacement between the (subjectively) estimated position of the OST on VIS imagery versus the location of the cold top on IR. In nearly every case the cold top was found to be 10-12km upwind from the OST. Such a finding was unexpected, so a renavigation of the satellite data was performed and independent judgments of the OST locations gathered. The results were the same. Interested colleagues have suggested that, since the IR PIXELS are so large, a part of the displacement might be explained by how the cold top is sampled. That is, an OST located near the intersection of two IR PIXELS could easily be recorded on either one. In this manner, the actual top could be offset by as much as 3.5km. However, this is not enough to account for the amount of displacement observed. Furthermore, we argue that such an error would be normally distributed. One would expect to find as many easterly errors as westerly, while what was observed were consistent westerly displacements of the cold tops. Another suggestion was that IR instrument lag time might be a factor. However, this would cause the cold top to appear east of its´ actual position. Thus, the characteristic is likely to be real. In fact, it appears that, for this case, the OST is juxtapositioned more with the strong temperature gradient east of the cold top than with the cold top itself.

The last feature to be described will be the plumes of warmer cloud matter downstream from the OSTs. The enhancement table on the IR data in Figure 3b is actually a black and white photo of a color enhancement. Nevertheless, the reader should be able to distinguish a subtle shading difference in the region just east of the cold
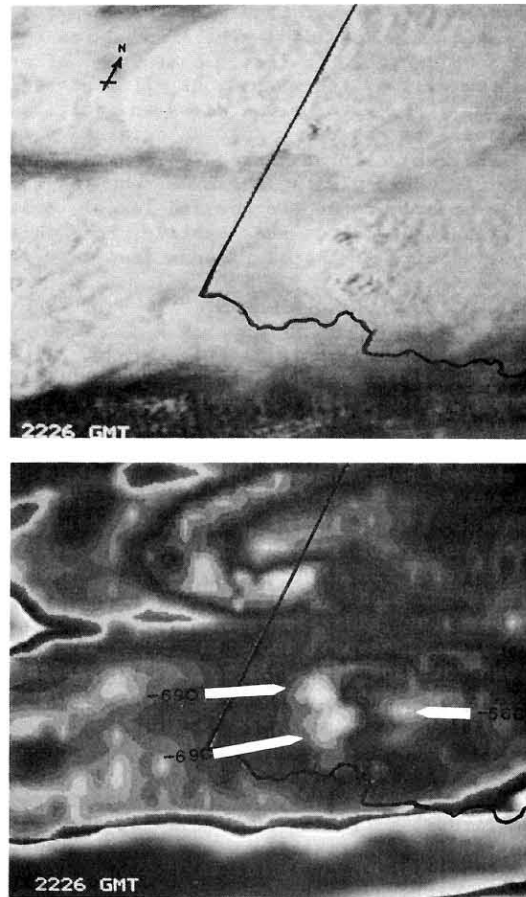

Figure 3. a) Visual satellite photo from 2226 GMT on 11 May 1982. The border shown is that separating southwestern OK (to the right) from TX; b) IR satellite data from 2226GMT, 11 May 1982. The enhancement spots corresponding to the OST's in the southern storm complex are -69C. 1C Contours.

tops. Quantitatively, this area is some 13C warmer than the coldest tops to the west, and the separation is 36km (measured from the western edge of the warmest temperature to the eastern edge of the coldest). The most intense gradient observed over the period of time under discussion occurred at the time of the merger of the two tops. At this time the cold top decreased to −71C and the gradient increased to 15C over 20km.

The absolute value of the cold top/warm plume gradient was probably much greater. As mentioned above, temperature extremes may be filtered-out by the GOES IR sampling process. However, there were some notable features observed by considering relative values. For example, the cold top/warm plume gradient varied considerably with time. Additionally, at the time of the Duke, Altus, and Friendship (2302GMT, F3 intensity) tornadoes, the magnitude of the gradient in each case was decreasing. Without knowing the mechanism of the warm plume, it is impossible to speculate on the meaning of this decrease--even should it prove to occur frequently in tornadic situations. Adler, et al (1981) suggest that the warm plume is a region of subsidence which occurs in response to air flow up around the OST. Fujita

(1981) believes the warm plume to be made up of cirrus which is discharged by the OST into the stratosphere, warmed, then advected downwind above the anvil. We do find a hint of downwind response to the OST merger, in that, 6 minutes after the cold top reaches its minimum of −71C and begins to subside, the warm plume warms an additional 2C. This could be the time lag associated with new (and higher) cirrus being warmed and advected east. It could also be the time required for flow moving up and around the new and larger obstacle, to travel downwind and subside the additional amount. Neither viewpoint seems favored.

4.   CONCLUDING REMARKS

The data from this study pose some interesting questions and lead to some fascinating speculation concerning thunderstorm motion, the nature of overshooting tops and, perhaps, even satellite clues to tornado formation. For example, given that an outflow boundary may have formed to the west of storm 1, and that storm 2 moved toward the north-northwest after 2230GMT, one is tempted to speculate that the outflow from the first interacted with the second to alter its motion (e.g., Weaver, 1979). If this did occur, the horizontal vorticity associated with this boundary could have been tilted into the vertical by the second storm's updraft (as per Klemp and Rotunno, 1983) to supply the increase in circulation observed by Doppler radar.

Satellite data show an updraft intensification (i.e., a 2C decrease in cold top temperature) following the storm top merger. This temporary intensification would have increased the pre-existing vorticity associated with the updraft through stretching. It may well be that an impending OST merger should be taken as a sign of approaching storm intensification, including strengthening of the mesocyclone circulation if one exists. Further research on this case will require correlating mesocyclone intensity with all of the above features.

Another factor requiring further research is the relative positioning of the OST versus the cold top. Standard interpretation associates the coldest top with the highest point of the overshooting dome. If, in some cases, the cold top is upwind of the highest overshooting tower by several kilometers, some new questions occur. For example--it is easily understood how the OST might be too small to be the absolute coldest point on the IR, but why would the area upwind from the tower be colder than any other part of the anvil? Is this evidence for obstacle flow (i.e., back-shearing cloud matter which is being "packed" up and around the OST by the winds)?

Closely related to the problem of relative positioning is that of the structure and life-cycle of the warm plume, and the cold top/warm plume gradient. However, the 11 May data does not contain sufficient information to address these questions.

The 11 May 1982 case study has revealed a wealth of intriguing questions which will be addressed in the near future. Answering some of these questions may result in new interpretations of (and, thus, new uses for) satellite imagery in severe thunderstorm situations.

5.   REFERENCES

Adler, R.F., and D.D. Fenn, 1977: Satellite based thunderstorm intensity parameters. Preprints 10th Conf. on Severe Local Storms, Omaha, Amer. Meteor. Soc., 8-15.

Adler, R.F., D. Fenn, and D. Moore, 1981: Spiral feature observed at the top of rotating thunderstorm. Mon. Wea. Rev, 109, 1124-1129.

Ensor, G.J., 1978: User's guide to the operation of the NOAA geostationary satellite system. NOAA/NESS, S/R 79-2801, Washington, DC, 101 pp.

Fujita, T.T., 1974: Overshooting thunderheads observed from ATS and Learjet. Report No. 117, Satellite and Mesometeorology Research Project, Dept. of Geophys. Sci., University of Chicago, 29 pp.

Fujita, T.T., 1981: Mesoscale aspects of convective storms. Proc. IAMAP Symposium: Nowcasting: Mesoscale Observations and Short-range Prediction, Hamburg, European Space Agency, 3-10.

Klemp, J.B., and R. Rotunno, 1983: A study of the tornadic region within a supercell thunderstorm. J. Atmos Sci., 40, 359-377.

Pryor, S.P., 1978: Measurement of thunderstorm cloud-top parameters using high-frequency satellite imagery. M.S. Thesis, Dept. of Atmospheric Science, Colorado State University, Fort Collins, CO, 101 pp.

Purdom, J.F.W., 1973: Meso-highs and satellite imagery. Mon. Wea. Rev., 101, 180-181.

Reynolds, D., 1979: Observations and detection of damaging hailstorms from geosynchronous satellite digital data. Preprints 11th Conf. Severe Local Storms, Kansas City, Amer. Meteor. Soc., 181-188.

Shenk, W.E., 1974: Cloud top height variability of strong convective cells. J. Appl. Meteor., 13, 917-922.

Weaver, J.F., 1979: Storm motion as related to boundary layer convergence. Mon. Wea. Rev., 107(5), 612-619.