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SATELLITE ANALYSIS OF THE 6 JUNE 1990 LIMON, COLORADO TORNADO

by

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1. INTRODUCTION.

Late on the afternoon of Wednesday, June 6, 1990 a series of severe thunderstorms produced numerous incidents of large hail (up to 2.5" diam.), torrential rains, and nine tornadoes (NOAA, 1990) on the High Plains of east-central Colorado (CO). Although the region is sparsely populated, the impact was significant in this case, since one of the tornadoes (a 1/4 mile wide, F3) struck the town of Limon causing $12.8 million in damage and injuring 14 people. Most of the main street of the town was destroyed.

The outbreak was well forecast, nowcast, and warned. The purpose of this paper is to present a review of the case with an accent on satellite data. The data clearly show an early morning, mesoscale feature which played an important role in later storm development. The imagery also reveals clues to thunderstorm behavior as the outbreak unfolds.

2. EARLY MORNING CONDITIONS.

Atmospheric conditions on the morning of 6 June fit all the criteria to make it a "classic" day for severe weather on the High Plains (Doswell, 1980). Morning surface analysis showed that a synoptic-scale cold front had pushed through the state leaving most of eastern CO in low-level, southeasterly flow. Dewpoints in the low 50s (F) had reached most front range cities by 1500 UT. 500mb winds were west-southwest at 35 knots. These conditions are associated with the majority of severe thunderstorm events in eastern CO (Weaver and Doesken, 1991). The late afternoon vertical wind structure was expected to veer from southeast at 10-15 knots at the surface, to westerly at 45-60 knots aloft (e.g., 400 - 300mb). This type wind profile is extremely favorable for tornadic thunderstorms. Furthermore, the airmass was extremely unstable. With an expected afternoon temperature of 85F, and afternoon mixed dewpoint in the low 50s (F), the Denver (DEN) morning radiosonde suggested an afternoon Lifted Index of about -10 (see Fig. 1 for all geographical references).

A broad mesoscale region of convective activity had occurred in Nebraska and Kansas during the pre-dawn hours of the outbreak day. The result was an extremely large region of moist, rain-cooled air which began pushing westward after sunrise. Satellite imagery during the late morning showed that this airmass had moved well into northeastern CO. It was marked by lower IR temperatures (on the order of 10K lower in the outflow cooled region), and by a broad region of (apparently) capped cumulus clouds in the stable air along and near its leading edge. When the airmass passed through Akron, CO (AKO) on its way westward, the dewpoint rose 5F.

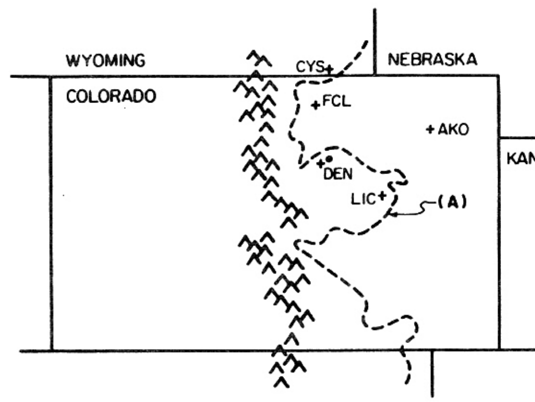

Figure 1. Map showing geographical features and sites referred to in text. Carats show the location of the Front Range of the Rockies. Dashed line is the 5500' terrain contour. Feature A is the Palmer Lake Divide. The small circle near DEN marks the location of MHD radar.

3. AFTERNOON DEVELOPMENT.

a. 1800 - 1930 UT.

By midday, locally available mesonet data indicated the formation of a terrain induced convergence boundary called the Denver Convergence and Vorticity Zone -- DCVZ (Szoke et al, 1984). The location of this feature is shown in Figure 2. Because the DCVZ has played an important role in many past convective incidents, the attention of local forecasters was focused on that feature for first storm development east of the Rockies.

However, the first deep convection did not develop along the DCVZ. In fact, satellite imagery showed no cumulus development along the DCVZ throughout the entire day. Between 1900 and 1930 UT, satellite did show a cluster of growing towering Cu about 30 miles northwest of Limon, CO (LIC). This activity was forming at the intersection of the northern side of a terrain feature called the Palmer Lake Divide (feature A in Figure 1), and a ridge of high temperatures which extended from southeast CO to the northern CO border along the front range of the Rockies. By this time, the leading edge of the mesoscale outflow stretched from near Cheyenne, WY (CYS) to a spot roughly 55 miles east of LIC. Cloud tracking algorithms indicated this feature to was moving westward at 15 to 20 knots.

b. 1930 - 2100 UT.

Shortly after they developed, the cluster of

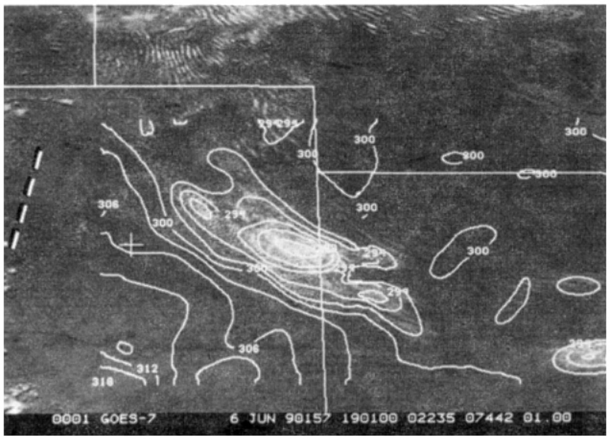

Figure 2. GOES, visible wavelength satellite image from 1901 UT, 6 June 1990. Contours of radiated temperature in deg. K are taken from corresponding IR image. Dashed line at left is the DCVZ (see text) and '+' marks the location of LIC.

towers northwest of LIC evolved into two large thunderstorms. By 2100 UT, Mile-High Doppler (MHD) radar found two cells northwest of LIC with maximum reflectivities approaching 60 dbz (Figure 3). In all future discussion, these cells will be designated storm 1 for the southernmost of the two, and storm 2 for the northern. Both storms were moving toward the east-northeast during this time period. Furthermore, a new Cb had formed south of DEN near the junction of the front range and the apex of the Palmer Lake Divide. This storm, hereinafter called Storm 3, grew from a cluster of congestus to a 30 dBz echo in less than 1/2 hour.

The westward progress of the moist, mesoscale airmass associated with the Kansas-Nebraska convection slowed somewhat during this period. Cloud tracking software marked the speed at 10 to 15 knots. An objective extrapolation algorithm suggested that the feature would reach the LIC vicinity around 2346 UT, and that it would intersect both storms 1 and 2 between 2200 - 2230 UT. Of course, this would occur only if both the storms and the outflow feature continued moving at the same speeds.

c. 2100 - 2230 UT.

For reasons not fully understood, storm 1 began to dissipate between 2100 and 2130 UT, and did not reach the moisture rich air just a few miles to its east. It may be that this cell was too close to storm 2, which was intensifying at this time. That is, the sudden demise of storm 1 may have been caused by environmental subsidence around the vigorously growing storm 2. One factor lending credence to this possibility is that storm 2 was further east, and reached the moist air about the time storm 1 began to weaken.

On satellite imagery one could see storm 1 move east-northeastward and apparently merge with its (now) eastward moving neighbor. However, radar data shows that a merger did not occur. Instead, storm 1 simply died as it came closer to storm 2. By 2200 UT, storm 2's reflectivity had exceeded 65dbZ and the core had developed a rotation, as indicated by Doppler velocity data. At this point, its direction of movement turned from east to southeast as it apparently began to move along the boundary. At 2215 UT meteorologists on site reported a tornado near the tiny town of Deer Trail, CO.

During this period, storm 3 continued moving eastward at 15 kts. By 2230 UT it was situated about 70 miles west of LIC, and its core exceeded 50 dBz.

One other interesting phenomenon appeared toward the end of this period. On satellite imagery (Figure 4) a mesoscale, arc-shaped line of convective

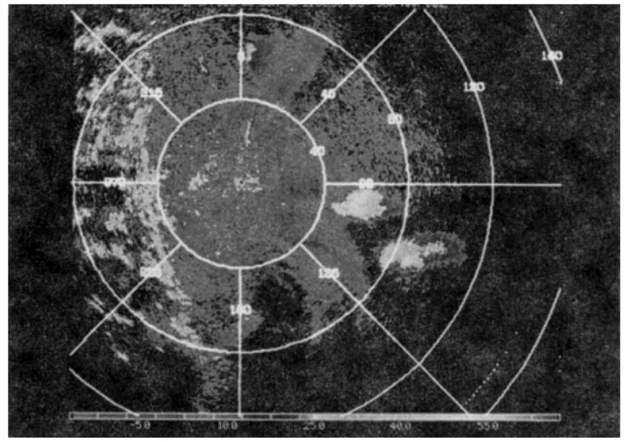

Figure 3. 0.5 deg. tilt, PPI reflectivity display from MHD radar taken at 2100 UT, 6 June 1990. Figure courtesy of NCAR.

cloudiness in central CO began moving rapidly northward. This feature was not noted in real time, and no explanation is offered for its existence. However, the coincident location of this line with later significant activity is worth mentioning.

d. 2230 - 0000 (7 June) UT.

As the storm which produced the tornado near Deer Trail moved southeastward, an arc of trailing cumulus cloudiness could be seen on visible satellite imagery extending from its southwest flank. This feature marked the edge of outflow left behind by the storm. It could tracked easily on animated satellite imagery from 2200 to 2246 UT, but was lost beneath the anvil of storm 3 after that time. Subsequently, the feature could be followed on MHD radar, 0.5 degree tilt reflectivity data (Figure 5).

Between 2330 (6 June) and 0000 UT (7 June), storm 3 reached the approximate position of the moist, mesoscale airmass. At that time, the storm intensified dramatically -- its areal extent increased by about 40% on MHD radar, its reflectivity increased by about 15 dBz, and it developed a notch on southwest edge of its echo. Also during this 1/2 hour period, the mesoscale, arc-shaped line of cumulus, and cumulus congestus, intersected the southwestern flank of storm 3 (Figure 6). Again, it is unclear what, if any, role this feature played in the storm's subsequent intensification.

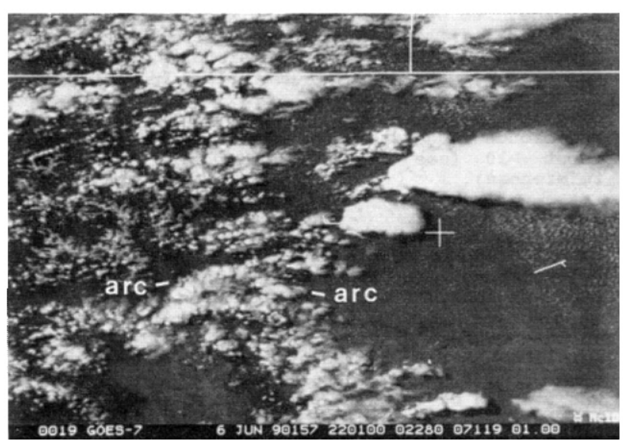

Figure 4. GOES, visible wavelength satellite image from 2201 UT, 6 June 1990. The '+' symbol marks the location of LIC, and 'arc' is as described in text.

e. 0000 - 0230 UT (7 June).

Storm 2 weakened and died abruptly after 0000 UT. Once again, the 'baton had been passed' and storm 3 became the focus of attention. This was the nature of the activity throughout the day -- in terms of severe weather, one storm always seemed to dominate.

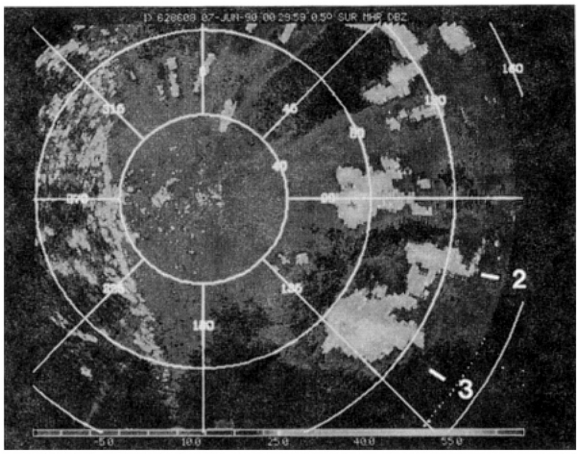

Figure 5. 0.5 deg. tilt, PPI reflectivity display from MHD radar taken at 0029 UT, 7 June 1990. Dying storm 2 causes new growth on northern side of building storm 3. Fig. courtesy of NCAR.

When storm 2 died, its outflow signature on MHD radar intensified dramatically. Small intense cores developed within storm 3 as this feature swept into it. Perhaps coincidentally, a circulation developed in storm 3 during the 0000 to 0100 UT time frame -- about the time extrapolation suggests storm 2's outflow would have reached the updraft of storm 3. However, due to intervening echo it is impossible to establish a connection with any degree of certainty. We mention the possibility merely as interesting speculation. At about 0110 UT on-site meteorologists reported a large tornado several miles southwest of LIC. The tornado stayed on the ground for about 7 minutes. Its strength was estimated at F3.

As the storm continued toward Limon it dropped 1.75" to 2.5" hail at the National Weather Service radar site several miles south of the town. Shortly before 0200 UT the largest tornado of the day touched down, moving into Limon at 0208 UT.

CONCLUDING REMARKS

A complex series of events combined to produce severe weather over the plains of Colorado on the 6th of June. In addition to the normal severe parameters often found on the High Plains on severe weather days (Doswell, 1980), there was an unusually unstable airmass present. Also, moist, low-level air from thunderstorm activity that occurred in Kansas and Nebraska the previous night entered the region to play a vital role in the outbreak. This last feature is not unique. For example, Weaver and Toth (1990) found that outflow from overnight convection to the east of CO was responsible for the extremely damaging hailstorm outbreak of August 2, 1986.

The Doswell severe criteria occur fairly frequently in north central CO, as does the DCVZ. Yet extremely large hail and large tornadoes are rare. Thus, it makes sense to look for additional forcing when such incidents do occur. More importantly, if such additional mesoscale forcing mechanisms can be identified on a day when most synoptic conditions are favorable for severe development, forecasters should be particularly alert. Special attention should be given to regions where these features are found.

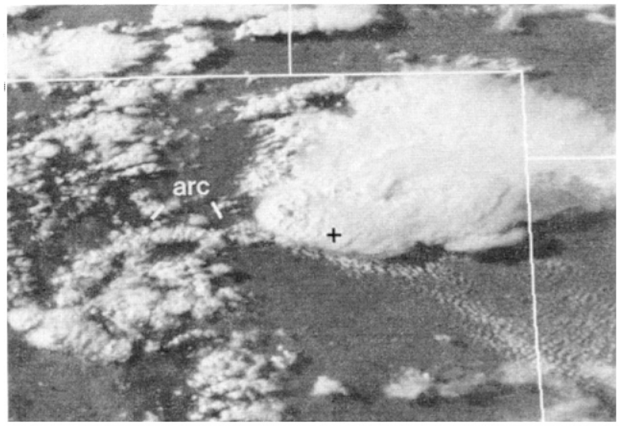

Figure 6. GOES, visible wavelength satellite image from 2346 UT, 6 June 1990. '+' symbol marks location of LIC, and 'arc' is as in text.

ACKNOWLEDGEMENTS

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Note: The copy of this paper that appeared in the preprint volume was a next-to-the-final draft version, and was sent in error. There were two corrections that have been made in the present version; 1) the title in the preprint had a date error which has now been corrected, & 2) there was a typographic error in line 5 of the text which has also been corrected.