PICTURE OF THE MONTH

A Low-Precipitation Cumulonimbus along the Dryline in Colorado

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ABSTRACT

An unusual low-precipitation cumulonimbus that developed in northeastern Colorado is photographically documented in some detail. The storm produced at least 12 funnels, mostly at midlevels on the north side of the main updraft. The base of the cloud consisted of a lenticular "bell" that rotated cyclonically, while a couplet of counterrotating storm-scale eddies prevailed aloft. The funnels originated in a region of enhanced shear between easterly low-level flow on the north side of the bell and westerly flow aloft on the north side of a midlevel anticyclonic eddy.

1. Introduction

The purpose of this note is to present and interpret a series of photographs of a low-precipitation (LP) thunderstorm that occurred on the evening of 1 July 1989 (LST) along a dryline in northeastern Colorado. Low-precipitation storms have been observed along or near drylines on the High Plains from Texas northward to Wyoming and Nebraska. The distinguishing features of these unusual storms have been noted by Bluestein and Parks (1983): 1) little or no rain from the main updraft base, and absence of strong surface downdrafts and outflow; 2) strong updrafts, especially on the storm's rear flank; 3) possible large hail falling out of the anvil downshear of the main updraft; 4) possible tornadoes and funnels, especially along the north and northeast flanks of the storm; and 5) the almost circularly symmetric lenticular ("bell-shaped") appearance of the updraft base. Because LP storms produce relatively little precipitation, their radar echoes are usually weak. The absence of heavy precipitation and the accompanying low-level accessory clouds, which often accompany it, make LP storm circulation and structure easy to observe visually.

The LP storm described here displayed all the aforementioned characteristics except that, according to our eyewitness observations and police and National Weather Service (NWS) reports, it produced no hail. For much of the storm's lifetime, precipitation at the surface was limited to light rain showers of large drops falling east of the storm. A vigorous, apparently quasi-steady, updraft ascended above the lenticular cloud base, which was especially large and well-formed during the storm's mature phase. At least 12 separate funnels developed aloft during the storm's approximate 2-h lifetime, almost all of which occurred on the north flank of the main updraft, above the top of the lenticular base. Although some of the funnels were quite large and persistent, none produced tornadic circulation at the ground.

2. Meteorological conditions

The storm began along a westward-moving (i.e., retreating) dryline just northwest of Iliff, Colorado, at about 0050 UTC 2 July (i.e., 1750 LST 1 July). Earlier severe storm activity had occurred along and near this dryline about 150–200 km south and 50 km north-northeast. Dewpoint temperatures in the moist air were in excess of 20°C at Goodland, Kansas, with temperatures near 30°C (Fig. 1). In the dry air to the west, temperatures were around 35°C, with dewpoints in the range 0°–5°C. Figure 2 depicts the thermal and wind profiles from North Platte, Nebraska (LBF) and Denver, Colorado (DEN) at 0000 UTC 2 July 1989. The

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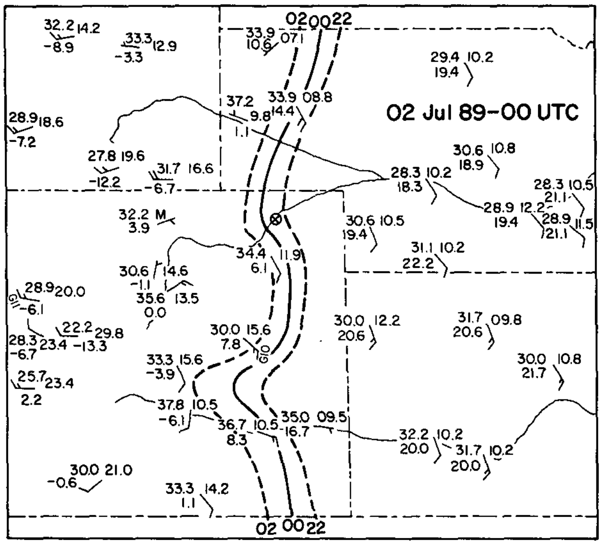

FIG. 1. Surface weather conditions at 0000 UTC 2 July 1989 near the dryline in Colorado. Each weather observation consists of Celsius temperature and dewpoint (upper left and lower left respectively), and altimeter setting (hPa, leading "10" removed). Full wind barbs are 5 m s^{-1}, and half barbs are 2.5 m s^{-1}. Successive positions of the 15°C isodrosotherm are shown in either solid or dashed line for 2200 UTC 1 July and for 0000 UTC and 0200 UTC 2 July. The westward-moving surface dryline is estimated to lie just east of this isodrosotherm. The 0100 UTC position of the LP storm described in this note is shown by an encircled "X".

moist layer at LBF was quite deep and strongly capped, while the dry air at DEN was well mixed. Because of the fact that surface conditions at Sidney, Nebraska (SNY) and Akron, Colorado (AKO) at storm time were quite similar to those at LBF, we believe the sounding profiles at LBF are roughly representative of conditions in the moist air near where the Iliff storm developed. Surface winds were from the east-southeast at speeds of 5–10 m s^{-1} just east of the dryline during the late afternoon and early evening. A midtropospheric "short wave" approached from the west during the afternoon, with westerlies in excess of 10 m s^{-1} at 500 hPa, reaching 43 m s^{-1} at 236 hPa. Inspection of upper-air winds from Colorado profiler stations at Flagler, Platteville, and Stapleton Airport (not shown) confirms the existence of the shortwave.

The LBF thermal profile in Fig. 2 is indicative of considerable severe storm potential, provided the capping inversion could be broken. The convective available potential energy (CAPE) at LBF was 2266 J kg^{-1}, but the convective inhibition (CIN) was a rather large 152 J kg^{-1}. The inversion height at LBF was a relatively high 1.8 km. Although the exact height of the inversion at Iliff is not known, it seems likely it was also relatively high, and that the inversion was relatively strong. Indeed, the development of the large laminar updraft base in the Iliff storm is indicative of strong static stability through a relatively deep layer of the lower troposphere. The bulk Richardson number (Weisman and Klemp 1982) of the LBF sounding was 54, which suggests probable multicell convection with some possibility of supercells.

3. Photographic documentation

Significant visual aspects of the Iliff storm's structure are depicted in Figs. 3–9. As seen in Fig. 3, a photo taken at 0059 UTC looking south, a laminar cloud base was evident below the developing storm from the outset. The growing cumulus leaned sharply to the east, along the direction of the midtropospheric vertical

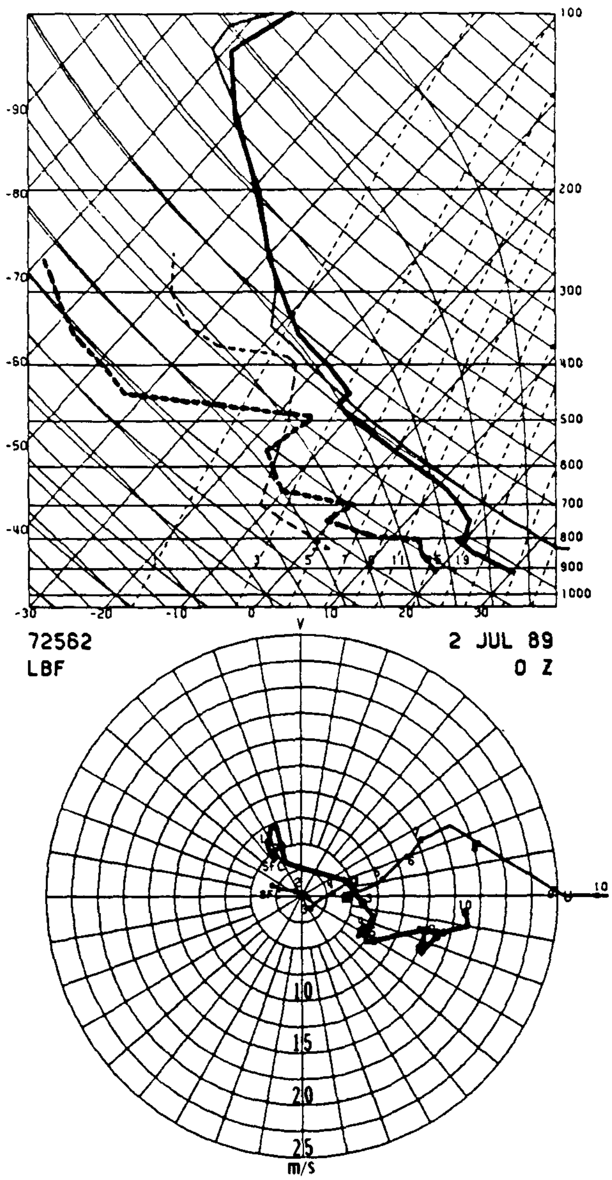

FIG. 2. Skew T–log$p$ and hodograph diagrams for LBF (bold) and DEN (light), 0000 UTC 2 July 1989. LBF sounding is believed to be representative of the environment of the Iliff storm. CAPE and CIN at LBF were 2266 and 152 J kg^{-1} respectively. Hodographs above 10 km are not shown.

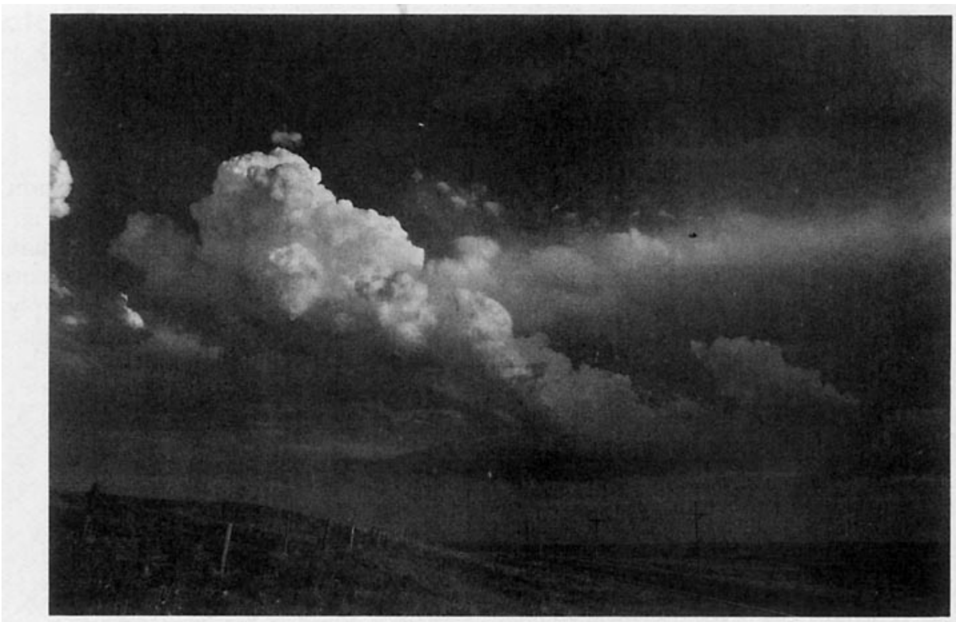

FIG. 3. Initiation phase of the Iliff storm at 0059 UTC 2 July. View is toward the south. Lenticular cloud base was present from early stages of cloud growth. Cirrus in background at right was probably from approaching shortwave, not nearby convection. Towers are leaning eastward in response to strong ambient vertical shear. Photo by E. W. McCaul, Jr.

FIG. 4. View toward the south of the developing, more erect Iliff storm at 0107 UTC 2 July. Lenticular base is becoming more circular as storm matures. Photo by E. W. McCaul, Jr.

shear. A cirrus overcast, probably produced by the approaching shortwave, is visible to the southwest. Building cumuli appeared to the southwest of the main tower, but never developed into cumulonimbi. Most of the cumuli were arranged in an irregular north-northeast–south-southwest line, and a weakening severe storm was located on this line along the Colorado–Nebraska border southeast of SNY. Increases in dewpoint and backing and strengthening winds at AKO, some 70 km south of the developing Iliff storm, suggest that this line of cumulus and cumulonimbus activity marked the location of the westward-moving dryline.

By 0107 UTC, the growing storm had become more erect (Fig. 4) and the laminar base more nearly circular. The top of the updraft was beginning to glaciate and form an anvil. The first funnels began to appear a few minutes later in a region of midlevel vortical motions on the north side of the storm. At 0127 UTC, we drove under the northern edge of the storm and observed one of these midlevel funnels directly overhead (Fig. 5). Although the photo shows that the funnel axis curved anticyclonically as it ascended into the cloud tower, direct observation and additional photos show that the sense of rotation of this funnel was cyclonic.

After observing the funnel for some minutes, we proceeded east to Iliff, where the Fig. 6 photo was obtained. The cloud base at this time (0131 UTC) bore

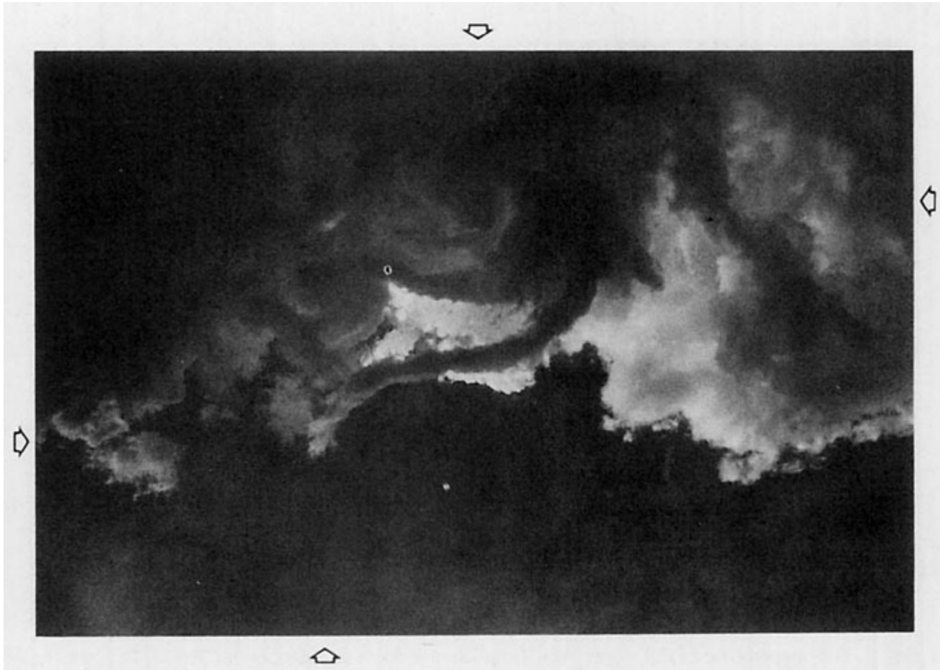

FIG. 5. View directly overhead of midlevel funnel cloud circulation along north side of Iliff storm, 0127 UTC 2 July. Arrows at top and right sides (bottom and left sides) of photo mark the top (bottom) of the visible funnel cloud. North is at the bottom of the picture. Photo by E. W. McCaul, Jr.

a remarkable resemblance to a bell; this configuration persisted in its purest form for about 10 min. The base of the bell displayed several circularly symmetric horizontal striations. We remained in Iliff for about 20 min watching the storm as it drifted to the south at approximately 6 m s^{-1}. Inspection of the hodographs in Fig. 2 shows that this motion deviated considerably to the right of the mean winds and mean shear, as is observed in many supercell storms.

Figure 7 shows the appearance of the main updraft

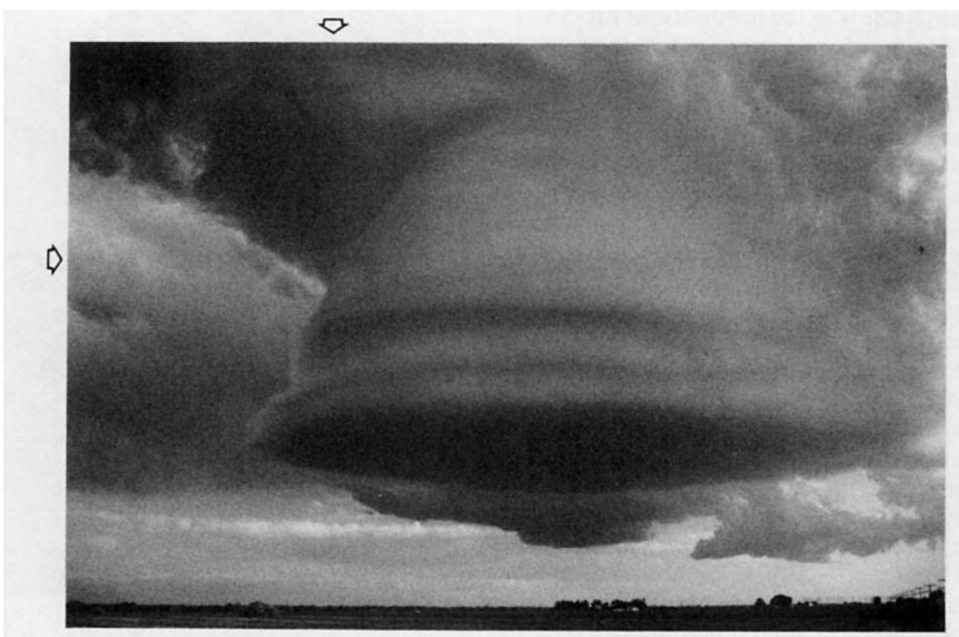

FIG. 6. Lenticular "bell" base of Iliff storm, as seen from Iliff, Colorado, at 0131 UTC 2 July, looking southwest. Note small turbulent "imperfection" at left edge of bell (see arrows). Photo by E. W. McCaul, Jr.

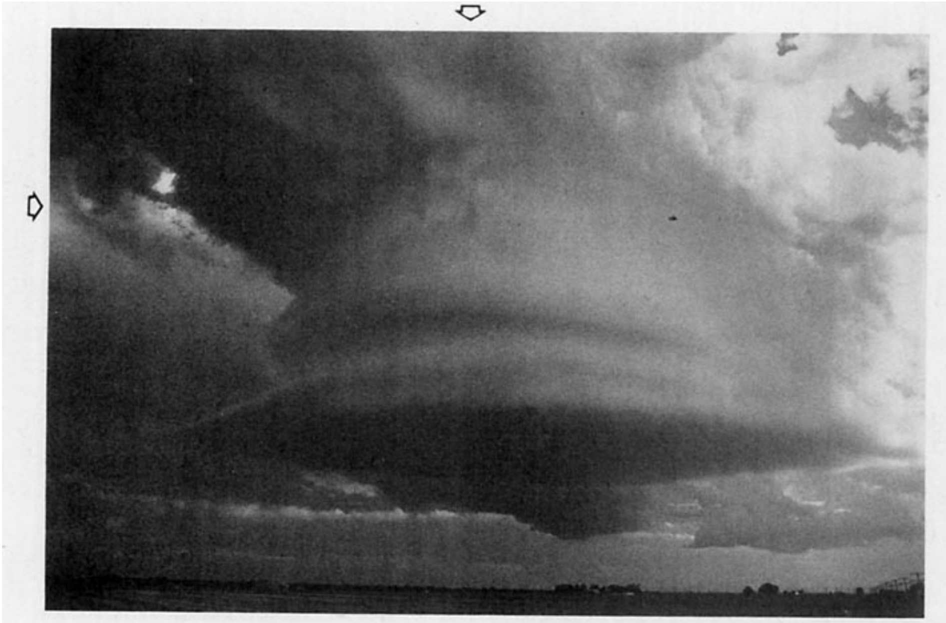

FIG. 7. Bell-shaped base of Iliff storm from same vantage point as Fig. 6, but at 0133 UTC. Note new position of turbulent patch (see arrows) relative to that shown in Fig. 6. Entire bell-shaped base appeared to be rotating cyclonically. Photo by E. W. McCaul, Jr.

base at 0133 UTC, some 2 min after the time of Fig. 6. The entire bell-shaped base was rotating cyclonically, as can be inferred from comparison of the positions of a small turbulent "imperfection" in the upper left part of the bell in Figs. 6 and 7 (the imperfection is located along the left edge of the bell in Fig. 6). Above the bell, the main updraft tower featured a pair of counter-rotating eddies, cyclonic on the south side and anticyclonic on the north side. On the north side of the cloud there was therefore a region of enhanced vertical shear near the top of the bell, where the cyclonic low-level flow regime adjoined the anticyclonic regime aloft. This pattern of circulation has also been seen in LP storm simulations (Weisman and Bluestein 1985). Furthermore, Bluestein (1984) has documented cases of anticyclonically rotating LP storm towers, although those cases may have been the result of storm splitting. We observed no storm splitting in the present case.

In the Iliff storm, eddies formed repeatedly in the strongly sheared region on the north side of the updraft tower, and the midlevel funnels occurred exclusively in that location. Another of these funnels is shown in Fig. 8, a photo taken at 0138 UTC. This funnel, both the top and bottom of which were embedded in the parent cumulonimbus, rotated cyclonically. The figure depicts the juxtaposition of the cloud base circulation and that of the funnel-producing region aloft. Most of the eddies that spawned the funnels appeared to rotate primarily about a vertical axis, but we also witnessed some funnels that were oriented horizontally.

While the storm was southwest of Iliff, a few large raindrops fell at our location, and there were several flashes of intracloud lightning and attendant rumbles of thunder. At 0125 UTC, the NWS WSR-57 radar at

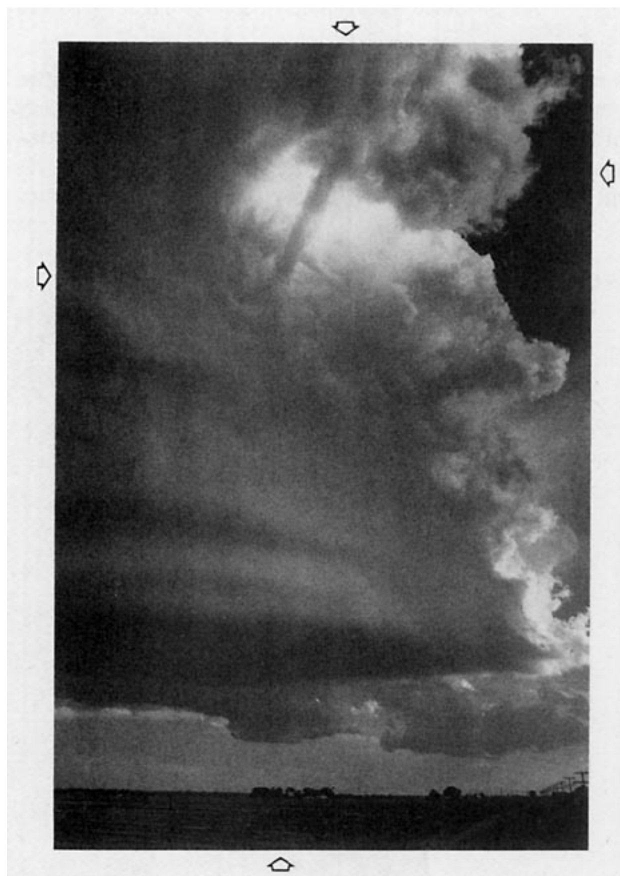

FIG. 8. View of Iliff storm looking west-southwest at 0138 UTC 2 July, showing region of funnel-producing eddies at midlevels along north side of storm. Note funnel at top center with top and bottom ends (see arrows at top, right and bottom, left respectively) embedded in parent cumulonimbus. Photo by E. W. McCaul, Jr.

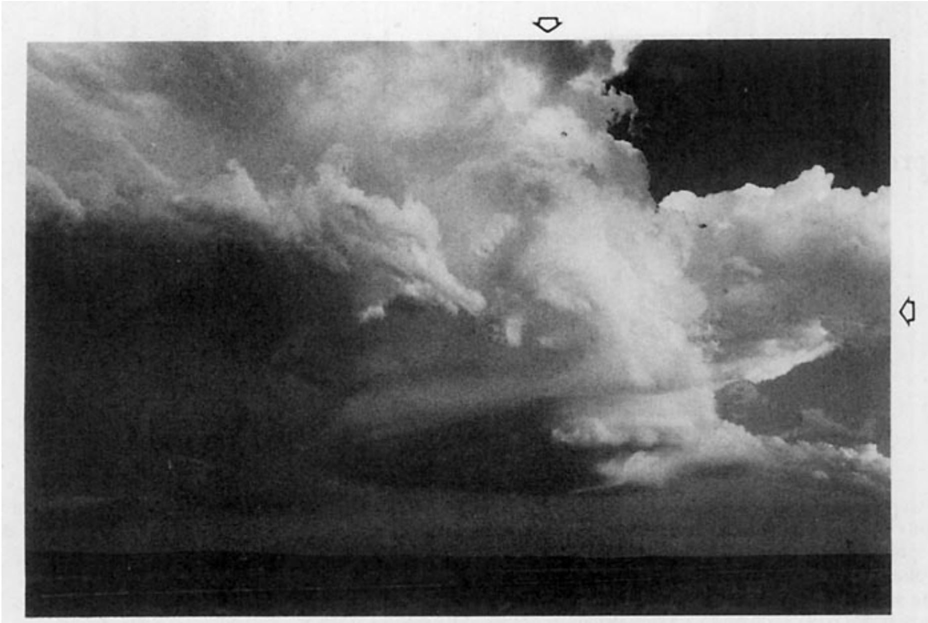

FIG. 9. View of Iliff storm at 0208 UTC, looking south. Note continued presence of laminar base, with anticyclonic eddy (see arrows) on north side. Incipient clear intrusion is visible along western edge of cloud base. Photo by D. O. Blanchard.

Limon, Colorado, some 170 km south-southwest, measured storm tops to 15.2 km (50.0 kft) in the vicinity of Iliff. However, maximum reflectivity in the storm was only 30–40 dBZ.

As the storm moved south, we continued to follow it and observe the rotating cloud base until sunset. The shape of the bell-shaped base gradually evolved into a curved, striated form with a clear (dry) intrusion on its west side. Strong cyclonic rotation was still occurring at low levels, especially in the northernmost portion of the base. The appearance of this phase of the storm is shown in Fig. 9, a photo that was taken at 0208 UTC. The continued presence of strong anticyclonic vortical motions on the north side of the storm is evident in the figure.

The storm began to weaken after sunset, as it continued to drift slowly southward toward AKO. It persisted until shortly after 0300 UTC, after which time it dissipated.

4. Summary

The Iliff storm was an especially good example of a low-precipitation thunderstorm. Its structure and circulation were readily visualized because of the relative absence of cloud structures and precipitation that often accompany other types of thunderstorms. From our vantage point on the north side of the storm, it was apparent that the midlevel funnels, a common feature of LP storms, were generated in and above a strongly sheared region of the cloud between the cyclonically rotating updraft base and upper-level anticyclonic eddy on the north flank of the updraft.

To the best of our knowledge, this mode of funnel generation has not previously been described in the severe storm literature. Future observations of LP storms should address the question of how regularly this mode of funnel production occurs. Its relevance to other types of severe storms is not known at this time, but in view of the rough similarity of many aspects of the circulations in simulated LP and supercell storms, it should perhaps not be ignored. The exact three-dimensional configuration of the zone of enhanced shear and the specific mechanisms whereby it produces, reorients, and intensifies the vortices remain subjects for future observational and numerical investigations.

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