PICTURE OF THE MONTH

Photographs of a Funnel-Producing Indented Cloud-Base Swirl

KEITH A. BREWSTER*

Program for Regional Observing and Forecasting Services, Boulder, CO 80303

24 February and 10 March 1986

ABSTRACT

An interesting swirl in the cloud base of a severe thunderstorm near Denver, Colorado, is documented with photographs and Doppler radar velocity measurements. The swirl, which produced two funnel clouds, may have been an eddy of a weak midlevel mesocyclone or a result of surface vorticity stretching by the storm's intense updraft.

1. Introduction

In the severe thunderstorms that are typically documented in the scientific literature (e.g., those described by Lemon and Doswell, 1979; Fankhauser et al., 1983), the area of storm updraft and cyclonic rotation is revealed to the surface observer as a lowered cloud base. This lowering is referred to as a wall cloud or pedestal cloud. The wall cloud may be preceded or accompanied by bands of low-level cumulus clouds, which curve into the updraft area, delineating the large-scale circulation. A case is presented here in which cyclonic rotation within a storm is instead revealed through a smaller scale vortex that appeared as a swirling indentation in the cloud base. This event is similar to a swirl observed in an Oklahoma storm by Doswell and Tegtmeier (1972), except that in this case funnel clouds were produced within the circulation, and Doppler radar data provide evidence that this event may have been associated with a mesocyclone.

2. Discussion

On the afternoon of 3 June 1985 a thunderstorm formed southwest of Denver, Colorado, and moved east to a point near the center of an existing surface mesoscale shear/convergence zone of the type described by Szoke et al. (1984). By 1400 LST (2100 GMT) the shear/convergence zone had developed into a closed mesoscale cyclone as depicted in Fig. 1a, a plot of surface data from an observing network operated by the NOAA Program for Regional Observing and Forecasting Services (PROFS).

A chase team, part of a real-time forecasting exercise at PROFS, was dispatched to an area of increasing storm-scale rotation indicated by the NCAR CP-2 Doppler radar (located about 50 km north-northwest of the storm). The 1410 LST radar scan showed a weak midlevel mesocyclone with coincident shear and convergence at low levels. The shear and convergence observed by the radar at low levels had followed the motion of the storm and had been independent of the surface cyclone. The radar data also showed areas of smaller scale shear along the storm's low-level shear zone. The first visual observation of the updraft cloud base (1410 LST) was of a large area of rain-free cloud base with no cloud-base lowering or visible indications of rotation. The storm had a strong updraft, however, as evidenced by strong radar-measured upper-level divergence (maximum divergence of 8×10^{-3} s^{-1}, associated with a radial velocity difference of 34 m s^{-1} over a distance of 4 km) and by public reports of large hail (over 6 cm in diameter). Figure 1b shows the area of observation of the cloud-base features. The 1410 observations were made from the same locations as those indicated by the arrow marked 1417. By 1417 LST the cloud base developed a cyclonic circulation of approximately 200 m in diameter, which appeared as an indented swirl (Fig. 2). A smooth, conically shaped funnel cloud formed at the center of the swirl (1422 LST, Fig. 3). Figure 4 shows the funnel as it appeared at 1429 LST, the bulbous cloud mass toward the far left of the photograph. Also visible is a second, spindly funnel to the right (north and west) of the first. At 1429 LST surface winds 2 km southeast of the funnel were northwesterly at approximately 20 m s^{-1}, but no outflow arcus clouds were evident. Between 1421 and 1429 the circulation took on a more classic structure as a clear slot (the brighter area behind the funnels in Fig. 4) became more obvious to the west and an in-

* Also affiliated with T. S. Infosystems, Lanham, MD.

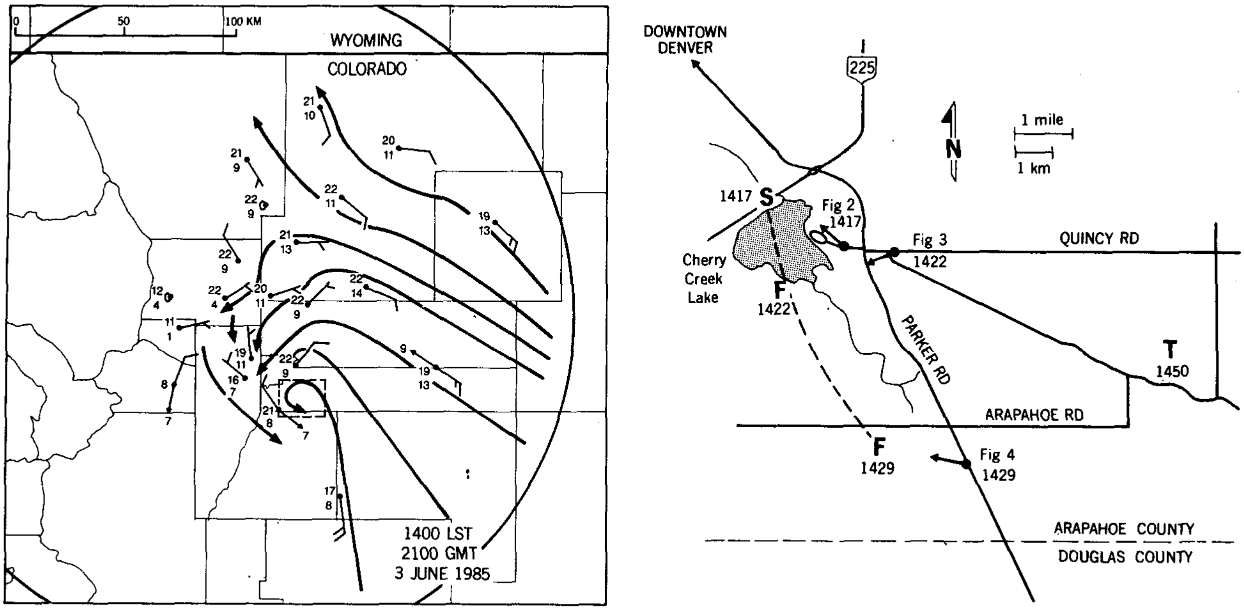

FIG. 1. (a) PROFS mesonet surface observations for 1400 LST 3 June 1985. Standard plotting conventions are used. Full wind barbs represent 5 m s^{-1} and half barbs represent 2.5 m s^{-1}. Gust direction indicated by arrow, with gust speed printed adjacent to arrowhead. Network is within an area of northeast Colorado; the small county near the center of the figure is Denver. Position of enlarged map (b) is indicated by the dashed box.

(b) Map of swirl and funnel observation area. Photograph sites and direction of photographs are indicated by arrows. The approximate locations of the swirl (S) and funnels (F) are marked. The position of a subsequent tornado is indicated by the "T."

crease in the neighboring cloud-base height left the circulation with a cloud base lower than the surrounding rain-free base.

Doppler radar data were not available for the period of the swirl's formation, but at 1429 LST when data were next available, the midlevel mesocyclone was still present, although it was rather weak (shear of 3.3×10^{-3} s^{-1} across 5 km); the observed funnels were on its southwestern edge. Low-level (0.7 km AGL) radial velocities show areas of small-scale shear along the

FIG. 2. Indented cloud-base swirl near the Cherry Creek Reservoir, southeast of Denver (1417 LST). Photo looking northwest approximately 2 km from the circulation. (PROFS photo by Keith Brewster.)

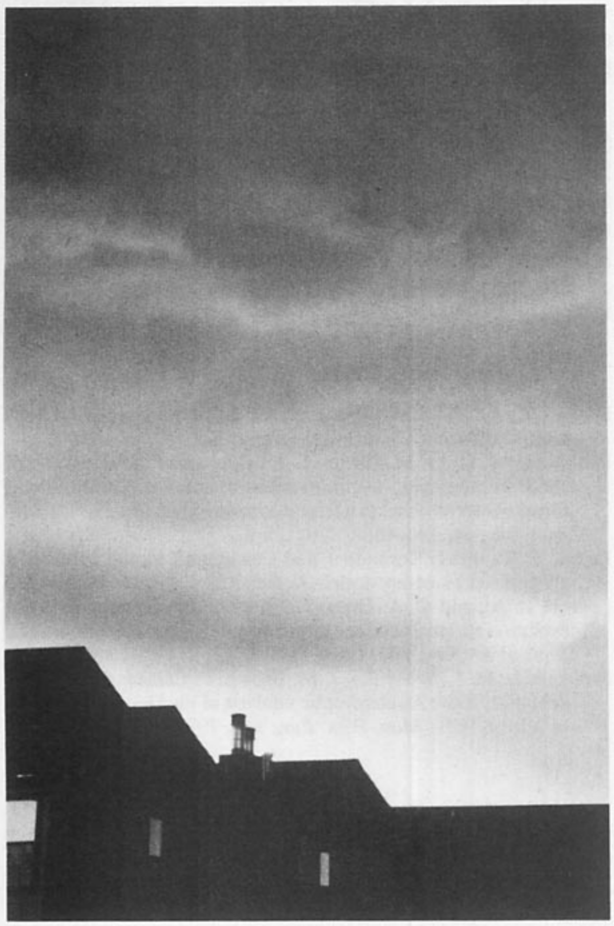

FIG. 3. Funnel cloud produced within the cloud-base swirl (1422 LST). Photo looking west approximately 3 km from the funnel. (PROFS photo by Thomas King.)

storm's broader low-level shear zone, with a local shear maximum (3×10^{-3} s^{-1}) coincident with the funnels.

The final disposition of the rotating base is unknown due to encroachment of rain and hail, which forced the chase team to move out of visual contact, but the funnels had dissipated by 1435 LST. The companion mesocyclone later intensified and produced a moderate tornado (F1; Fujita, 1981), which was on the ground from 1450 to 1453 LST, 8 km east of the funnel observation (position indicated as a "T" in Fig. 1b). That tornado did not evolve in the same way as the swirl; instead it developed in the manner described by Lemon and Doswell (1979).

One possible explanation for the funnel-producing swirl is that there was a source of dry air near the edge of the rain-free base, perhaps provided by subsiding air in the rear flank of the storm. The dry air then could have advected around a developing circulation creating the indented swirl in the cloud base. Later, larger scale entrainment of dry air into the area of the circulation was likely responsible for the erosion of neighboring cloud material, while continued tapping of moist low-level air by the updraft would explain how the circulation avoided erosion.

While no humidity measurements are available to support the presence of dry air near the swirl, the Doppler radar data reveal the presence of a downdraft immediately (no more than a few kilometers) to the west of the cloud base circulation that could have been a source of dry air. Although low-level divergence cannot be measured in that area due to the lack of reflectivity, the trajectories of reflectivity and velocity tags show divergence. Also, reflectivities just to the northwest of the circulation drop from 59 to −10 dBZ over a distance of less than 9 km.

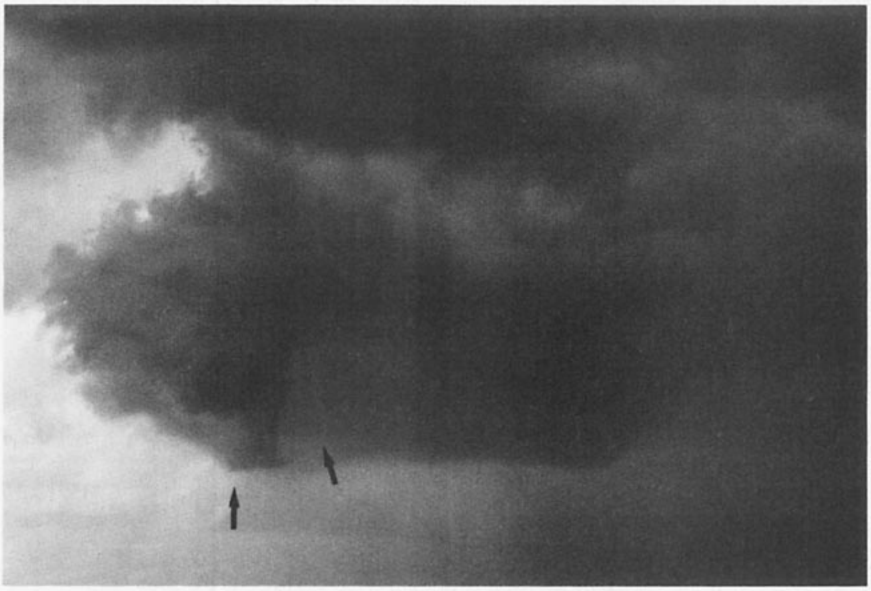

FIG. 4. Two funnel clouds (arrows) produced from the swirl (1429 LST). Note the bright area indicating increased drying behind (to the west of) the circulation as the cloud takes a more classic shape. Photo taken looking west from a distance of 2 km. (PROFS photo by Keith Brewster.)

Other explanations for the creation of the cloud-base indentation certainly are possible, but the one just described is consistent with the available observations.

The circulation itself may have been a vortex spawned by the mesocyclone or it may have been created by vortex-stretching of the existing surface mesoscale cyclone. Rotation forced by surface-based features alone is usually manifested as surface dust-whirls ("gustnadoes") with little, if any, indication of rotation in the clouds. In this case it is possible, however, that the surface cyclone contributed to the formation of the swirl and subsequent funnels through an interaction with the storm updraft (such as the vortex-stretching process mentioned previously) and may also have interacted with the storm's mesocyclone. Other cases of rapid development of storm-scale rotation and tornado production following intersection of a storm with a surface-based shear/convergence zone have been observed (Szoke et al., 1984).

3. Conclusions

Although a definitive explanation of the photographed cloud-base swirl cannot be advanced, it was probably associated with a storm-scale cyclone observed by Doppler radar that later produced funnels and a large tornado. Thus, observation of similar features could be useful in severe storm spotting efforts.

Acknowledgments. Thanks to Dr. John McGinley (visiting forecaster from the Cooperative Institute for Mesoscale Meteorological Studies) and Dr. Sandy MacDonald of PROFS, who provided expert chase team guidance. The author was joined in the storm interception by Mr. Don Baker and Dr. Stan Benjamin of PROFS and Mr. Tom Dulong of the National Weather Service Forecast Office in Denver.

REFERENCES

Doswell, C. A., and S. A. Tegtmeier, 1972: Rotating clouds at Norman, Oklahoma. *Bull. Amer. Meteor. Soc.*, **53**, p. 1180.

Fankhauser, J. C., G. M. Barnes, L. J. Miller and P. M. Roskowski, 1983: Photographic documentation of some distinctive cloud forms observed beneath a large cumulonimbus. *Bull. Amer. Meteor. Soc.*, **64**, 450–463.

Fujita, T. T., 1981: Tornadoes and downbursts in the context of generalized planetary scales. *J. Atmos. Sci.*, **38**, 1511–1534.

Lemon, L. A., and C. A. Doswell, III, 1979: Severe thunderstorm evolution and mesocyclone structure as related to tornadogenesis. *Mon. Wea. Rev.*, **107**, 1184–1197.

Szoke, E. J., M. L. Weisman, J. M. Brown, F. Caracena and T. W. Schlatter, 1984: A subsynoptic analysis of the Denver tornadoes of 3 June 1981. *Mon. Wea. Rev.*, **112**, 790–808.