PICTURE OF THE MONTH

Wall Clouds with Eyes

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ABSTRACT

Photographs are presented of wall clouds having holes or small regions of raised cloud base near the center. These eyelike features may be due to descending air (Lemon and Doswell) near the middle of the mesocyclone circulation or to the ingestion of relatively dry air into the updraft (Fankhauser *et al.*).

1. Introduction

It has been known for a long time that many intense tropical cyclones have eyes. With the advent of meteorological satellites, eye-like features in intense, wintertime, oceanic, extratropical cyclones have also been observed (e.g., Bosart, 1981). Lemon and Doswell (1979), on the basis of published and unpublished case studies, have discussed the similarity in form (but not dynamics) of the extratropical cyclone to the much smaller scale mesocyclone which occurs in supercell thunderstorms. The purpose of this report is to present a summary of visual and numerical evidence that a feature like an eye can occur in the wall-cloud region of a mesocyclone.

2. Observations

Fujita (1959) termed the phrase wall cloud in reference to the lowered, often precipitation-free cloud base in the vicinity of the updraft region in a supercell. Rotunno and Klemp (1985), using evidence drawn from three-dimensional numerical simulations, have attributed the formation of the wall cloud to the upward dynamical forcing of cool, negatively buoyant, relatively humid outflow air from a region of precipitation. Bluestein and Parks (1983) have described the wall-cloud formation process as the appearance of scud beneath cloud base, followed by the rising of the scud and its attachment to the cloud base above.

A summary of some earlier visual observations of upward indentations of the base of the wall cloud or other types of cloud bases in the updraft region is given in Fankhauser *et al.* (1983). This upward indentation has been termed the "cloud-free vault." It has also been described by Marwitz (1972), Weaver (1975), Donaldson *et al.* (1965) and Bluestein (1984).

Figure 1a shows a wall cloud associated with an isolated hailstorm. Most of the precipitation is located to the northeast and east (right) of the wall cloud. A thin cloud band extends from the cloud base above the wall cloud into the area of precipitation (denoted by arrow). Clear air is seen to the north and west (left). A bright region (denoted by arrow) is visible under the wall cloud several minutes later (Fig. 1b). An arc of light is also seen above the cloud base. (The author has observed similar arcs of light above gust fronts in squall lines.) A close-up view (Fig. 1c) of the wall cloud in Fig. 1b clearly shows a hole (denoted by arrow) near the center of the wall cloud. A hole (denoted by arrow) is also seen in the smaller wall cloud shown in Fig. 2. Finally, Fig. 3 shows a wall cloud which occurred before the one shown in Fig. 2, in which the cloud base is indented upward (denoted by arrow). Unfortunately, it was not possible to analyze photogrammetrically Figs. 1–3 because neither the distance to the wall cloud nor the cloud-base height was known precisely.

The author has also observed similar phenomena on 23 May 1981 near Elmore City, Oklahoma and 22 April 1978 near Ada, Oklahoma. Both were observed by a University of Oklahoma-National Severe Storms Laboratory (NSSL) intercept team. The

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FIG. 1a. Wall cloud near Sedan, KS. Early evening, 19 June 1981 (looking to the northeast). Wall-cloud motion was from northwest to southeast. Photographed with a 50 mm lens. (Composite photograph by Howard B. Bluestein.)

FIG. 1b. Wall cloud with a hole in the center. As in Fig. 1a but several minutes later. Photograph taken with a 28 mm lens.

FIG. 1c. As in Fig. 1a but at the same time as Fig. 1b. Not a composite.

FIG. 2. Wall cloud southwest of Norman, OK, early evening, 20 June 1979 (looking to the northwest). (Photograph by Howard B. Bluestein.)

author, a member of this team, drove underneath the 22 April 1978 wall cloud and noted a bright, hollow, cylindrical tube extending upward. Since the nowcaster at NSSL reported a tornadic vortex signature (TVS) (Brown *et al.,* 1978) at our location, we did not take time to photograph it. No tornado was subsequently observed, however. The wall cloud of 23 May 1981 was characterized by a blue-green color as discussed by Fankhauser *et al.* (1983), and later was accompanied by a tornado.

3. Discussion

Hypotheses for the formation of cloud-free vaults are suggested from observations and numerical model simulations. Golden and Purcell (1978; Fig. 8), using storm-intercept observations, noted an intrusion of cool, dry air at the surface into the region of the wall cloud and its attendant circulation. Lemon and Doswell (1979) attributed the clear slot often seen around a wall cloud to the rear-flank downdraft

FIG. 3. Wall cloud with an upward indented base southwest of Norman, OK, early evening, 20 June 1979. (looking to the northwest). Not the same wall cloud as that shown in Fig. 2. (Photograph by Howard B. Bluestein.)

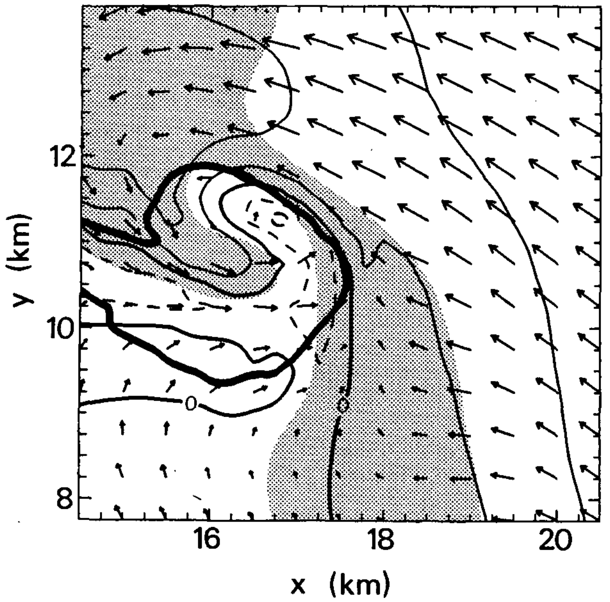

FIG. 4. Numerical simulation of the tornadic region of a supercell. Horizontal flow field plotted at every other grid point (one grid interval represents 10 m s^{-1} for wind vectors) at 1 km. Heavy solid line represents the 0.5 g kg^{-1} rainwater contour. Vertical velocity contoured at 5 m s^{-1} intervals (dashed lines are isopleths of descent and thin solid lines are isopleths of rising motion). Shaded region is characterized by cloud water mixing ratio in excess of 0.4 g kg^{-1}. (From Klemp and Rotunno, 1983.)

upwind of the updraft in a supercell. Although this clear slot is visually transparent, it does produce echoes on radar due to a few large raindrops. Klemp and Rotunno (1983), in a fine-scale numerical simulation nested in the tornadic region of a supercell, found that near cloud base there was a clear slot due to sinking motion. In particular, their simulation showed a maximum of descent in excess of 10 m s^{-1} (Fig. 4; see $x = 16.875$, $y = 11.25$) in a cloud-free region near the center of the circulation. This configuration is similar to that inside the eyewall of a hurricane. In some real and numerically simulated hurricanes the strongest descent averaged azimuthally appears to be concentrated in an annulus just inside the eyewall (Jones, 1980, Fig. 4; Jorgensen, 1984, Fig. 14). However, the grid spacing in the Klemp and Rotunno (1983) simulation (250 m) is large compared to the mesocyclone "eyewall" diameter (750 m–1 km, as estimated from the diameter of the relatively cloud-free region in Fig. 4), and it is possible that the descent could in fact be concentrated on a smaller scale. Klemp and Rotunno (1983) found that in time the region of strong descent became cut off, i.e., occluded from the rest of the slot of sinking motion. This configuration is suggestive of the "echo-free eye" seen in the Grand Island, Nebraska storm of 3 June 1980 (Fujita, 1981) and the "echo-weak hole" observed in the Binger, Oklahoma storm of 22 May 1981 (Lemon *et al.*, 1982), both of which were associated with tornadoes.

Fankhauser *et al.* (1983), using radar data and *in situ* measurements of vertical velocity, temperature, and moisture made aboard an aircraft, attributed the cloud-free vault they observed to the ingestion of relatively dry air into the updraft. This explanation is contrasted with that of Lemon and Doswell (1979) and corroborated by Klemp and Rotunno in their numerical simulation, in which strong subsidence, not ascent, is present at the location of the numerically simulated cloud-free vault. The cloud-free vault which Fankhauser *et al.* (1983) observed, however, was not co-located with the center of the circulation, but instead was located over the surface position of an outflow boundary.

4. Summary and conclusions

It is concluded that eyelike features sometimes seen in wall clouds are the result either of strong subsidence at the center of an occluding mesocyclone, or of the advection of dry air which originated in the rear-flank downdraft, into the updraft. More *in situ* aircraft measurements and fine-scale numerical simulations are needed to explain the wall-cloud eye.

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