Locating the Organized Updraft on Severe Thunderstorms

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1. Organized updrafts in severe thunderstorms

The severe thunderstorm is driven by a continuous source of warm, moist low-level air. This air is normally fed into the storm through an organized updraft area. To understand the kinematics and dynamics of storms as well as anticipate their direction of motion, it is valuable to be able to determine the location of the updraft area in those cases where direct observations are not available.

Browning and Ludlam (1960, 1962) noted an "echo-free vault" on the RHI echo photographs from the Wokingham storm. The echo-free vault was located directly ahead of the echo wall and beneath the highest radar tops. From the echo pattern and subcloud winds they inferred that strong updrafts existed on the right front of the storm and produced the echo-free vault,

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overhang and wall. The same echo features (vault, overhang and wall) were also noted on the Geary storm by Browning and Donaldson (1963). The dimensions of the vault were 5–10 km wide (normal to the direction of motion), up to 4 km in height, and less than 4 km in depth (along the direction of motion). The region identified as an echo-free vault extended upward from the *base of the overhang* into the storm and was bounded by radar echo on every side except the right flank.

The phrase "weak echo region" (WER) was suggested by Chisholm (1970) to describe the region above cloud base and below the radar echo which contains a strong updraft and freshly formed cloud. Since the WER extends upward from *cloud base* to the echo, it encompasses a larger volume of cloud than the echo-free vault of Browning and Ludlam (1960, 1962).

Several research groups have flown aircraft ahead of the precipitation curtain in the subcloud air of several hailstorms on the High Plains and reported the presence of "smooth" inflow areas in which the vertical velocities were normally 4–6 m sec^{-1} over a few tens of square kilometers of horizontal area (Auer and Sand, 1966; Auer and Marwitz, 1968; Hart and Cooper, 1968; Dennis *et al.*, 1970). The updrafts occurred generally on the front, right front or right flank. The atmospheric research team of the University of Wyoming has flown an instrumented aircraft at cloud base through the updrafts of over 50 severe hailstorms. Each severe hailstorm contained an "organized updraft" at cloud base. The identifying characteristics of an organized updraft at cloud base have been described by Auer *et al.* (1970). It has the following characteristics:

"a. Threshold vertical velocities are greater than or equal to 2 m sec^{-1}. These updraft velocities should persist over a period of time (approximately 15 min) and should exist in a constant or enlarging area.

b. The normal position of the organized updraft is the concomitant location with "scud" cloud. Scud cloud most commonly takes shape resembling fractostratus, but also can be identified as a lens-shaped cloud or pedestal attached to the main cloud base.

c. Organized updrafts appear to possess laminar flow characteristics with turbulent air found upon entering and leaving the strong updraft regions."

2. Visual appearance of cloud bases in an organized updraft

A cloud base which forms in an organized updraft has a distinctive visual appearance. Auer and Sand (1966) and Auer *et al.* (1970) presented photographs of cloud bases formed in organized updrafts. The distinctive feature of this type of cloud base is its flat uniform appearance when viewed from a distance. When viewed from close range the cloud base often has a distinct "rippled" appearance. Scud (pannus) cloud is often noted beneath cloud base in the region of strongest updraft. When flying in the subcloud region and approaching a thunderstorm which has an organized updraft, an experienced observer can detect the distinctive cloud base and/or scud cloud up to 30 km away.

Updrafts detected at cloud base by aircraft have been related to simultaneously obtained radar echoes. It was noted that directly above an organized updraft at cloud base a region of weak reflectivity (20 dBZ[2]) or WER invariably occurred (Marwitz *et al.*, 1969; Chisholm, 1970).

Marwitz and Berry (1970) described several systematic flights through the WER of a supercell storm which occurred in Alberta. The updraft area at cloud base was beneath a WER. The airflow within the WER was smooth and appeared well organized, although moderate to severe turbulence was encountered upon entering and exiting the cloud.

3. Locating an organized updraft

The atmospheric research team of the University of Wyoming has helped develop some techniques for identifying the presence and position of an organized updraft on severe thunderstorms. The most reliable method is by direct observation while flying an aircraft through the updraft. In lieu of direct observations, another method is visual observation of the distinctive cloud base which forms in organized updrafts. One's confidence in the visual technique is very much reinforced when scud cloud is present.

In order to anticipate and/or locate the organized updraft on an intense storm, some rather reliable empirical methods have been developed which involve rawin data and radar echo patterns. If the low-level PPI echo contains a hook or other sharp, distinctive projection, such that the concave portion of the echo is open toward the subcloud winds, one can be rather sure of the presence of a WER in front of the hook and, therefore, of an organized updraft. The hook and the radar echo bounding the WER will be distinct, indicating a steep horizontal reflectivity gradient. The detection of a bounded WER when scanning at higher levels is also a sufficient condition to identify the presence of an organized updraft. If the outline of the low-level PPI echo is straight or convex, then another empirical test is used based on a determination of the azimuth sector which contains *all* of the environmental winds in the cloud layer. For example, all of the environmental winds in the cloud layer might blow from 240–270°. The next step is to determine the direction of tilt of the top of individual reflectivity cores within the echo. This can best be determined by marking the location of a particular core on the PPI scan nearest cloud base and noting the location of the core as the antenna is increased in elevation. If the top of the core is tilted

[2] dBZ≡dB above $Z=1\ mm^6m^{-3}$.

from a direction different from what one might expect from the environmental winds in the cloud layer (240–270° in our example), then an organized updraft can be anticipated beneath the overhang of the tilted reflectivity core. Moreover, the direction of motion of the storm will deviate from the mean environmental winds toward the side of the storm containing the updraft. For example, if the core tilt is from 290°, then the updrafts will be on the right flank and the deviate motion toward the right; if the core tilt is from 210°, then the updrafts will be on the left flank and the deviate motion to the left of the mean environmental wind.

Finally, in the case in which the storm is moving with the mean environmental winds and the updraft is anticipated to be on the leading edge of the storm, e.g., in the case of a squall line, the degree of certainty with which one can predict the presence of an organized updraft is directly related to the steepness of the horizontal and vertical reflectivity gradients bordering the updrafts. If the horizontal and vertical reflectivity gradients are steep, then one can be relatively sure of the presence of an updraft; if the gradients are weak, then an organized updraft is probably not present and any observed overhang is probably due to downwind shear.

4. Applications to forecasting

From the previous discussion, it appears possible to determine the probable existence and the location of an organized updraft in severe hailstorms. This can be done by a close analysis of the environmental wind hodograph and the three-dimensional structure of the radar echo. The direction of motion of the storm's radar echo consists of a translational component which is *along* the mean winds and a propagational component which is *toward* the organized updrafts. Therefore, if the updrafts are on the right flank, the storm will have a direction of motion which is to the right of the mean winds. If the updrafts are on the back side, the storm will move very slowly. Recently, a storm was observed in northeast Colorado which had updrafts on the *left* flank and the storm moved ~30° to the *left* of the mean winds until the updrafts ceased. After that time, the storm was observed to move with the mean environmental winds. A more detailed analysis of this "left deviate" storm is forthcoming.

The authors' experience indicates that a necessary condition for a "severe hailstorm" is that it contain an organized updraft area at cloud base. Although the intensity and duration of thunderstorms vary from storm to storm, severe hailstorms invariable display a high degree of organization and persistence in the inflow region and in the echo structure. If one is able to identify and locate the presence of a WER and, hence, an organized updraft region in a thunderstorm, one can reliably anticipate the direction of motion in a quantative sense and its severity in a qualitative sense.

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