The Airflow Within the Weak Echo Region of an Alberta Hailstorm

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ABSTRACT

A severe hailstorm having many of the characteristics of Browning's right-moving severe local storms occurred in Alberta on 28 July 1969. This storm was systematically scanned by the Alberta Hail Studies high-resolution 10-cm radar and by the 3-cm radar in the Desert Research Institute's B-26 research aircraft. The former obtained reflectivity factor data throughout the volume of the storm while the latter obtained ground-reference PPI radar contours at flight levels varying from cloud base (7000 ft MSL) to 16,000 ft, and updraft measurements on the southern side of the storm in the Weak Echo Region (WER). Updrafts were smooth and reached a speed of 3500 ft min^{-1} (18 m sec^{-1}). The width of the WER narrowed from ~4 mi near cloud base to 2 mi at 16,000 ft. The radar echo was found to tilt approximately 40° from the vertical toward the right of the mean environmental winds. The echo intensity reached 30 dBZ at 25,000 ft directly above the WER.

1. Introduction

Browning and others have synthesized radar data from storms which occurred in England (Browning and Ludlam, 1962) and Oklahoma (Browning and Donaldson, 1963; Browning, 1964, 1965). From these synthesized radar data they inferred an airflow structure containing a strong updraft on the right flank which produced an "echo-free vault," an "echo wall" and an "overhang." Several workers have flown aircraft ahead of the precipitation curtain at the bases of severe hailstorms on the High Plains and reported the presence of "smooth" updrafts. The updrafts occurred generally on the right front (with respect to the direction of motion). The vertical speed was normally 4–6 m sec^{-1} over a few square miles of horizontal area (Auer and Sand, 1966; Auer and Marwitz, 1968; Hart and Cooper, 1968; Dennis *et al.*, 1969). Other researchers have penetrated severe storms with instrumented aircraft at levels above 25,000 ft and reported high levels of turbulence and an absence of organized updrafts (Steiner and Rhyne, 1962; Sinclair, 1969).

Updrafts observed at cloud base by aircraft have been related to radar data. It was noted that directly above smooth organized updrafts a region of weak reflectivity (<20 dBZ, i.e., dB above $Z=1$ mm^6 m^{-3}) invariably occurred. Sometimes these regions were bounded (as the word "vault" implies) by a stronger radar echo as in the storms of Browning (1965), Chisholm (1968) and Marwitz *et al.* (1969). At other times this region of weak reflectivity was not completely bounded (Chisholm, 1970). The phrase "Weak Echo Region (WER)" was suggested by Chisholm (1970) as being more descriptive of the regions in thunderstorms which contained strong updrafts and freshly formed clouds. The vertical extent of the WER varies from ~3000 ft in Chisholm's 25 July 1968 case to ~15,000 ft in Chisholm's 29 June 1967 and Browning's 24 May 1963 cases. To our knowledge the data in this paper are the first direct systematic observations of the updraft to be obtained *within* a WER.

2. Radar and surface observations

A severe hailstorm with many of the characteristics of Browning's (1965) severe right-moving (SR) storms occurred in Alberta on 28 July 1968. This storm developed about 1500 (all times MST) about 50 mi (all miles statute) southwest of the Alberts Hail Studies (ALHAS) radar. The storm moved east-southeastward such that it was from 40–60 mi from the radar for 3½ hr. The range from the ALHAS radar was near optimum for radar observations.

The ALHAS radar is S-band with a 1.2° pencil beam and a continuous spiral scan from 0° to 20° elevation at 1° per revolution. The power returned is displayed at 10-db discrete gray scale levels and recorded on 35-mm film. The cycle time for one complete three-dimensional scan is 3 min.

The radar film was projected at a map scale (1 inch = 8 mi) common to the aircraft and hailfall data and the gray scale thresholds were traced for each elevation scan for every other three-dimensional scan (every 6 min). Each three-dimensional scan was studied in detail but space does not allow a complete presentation

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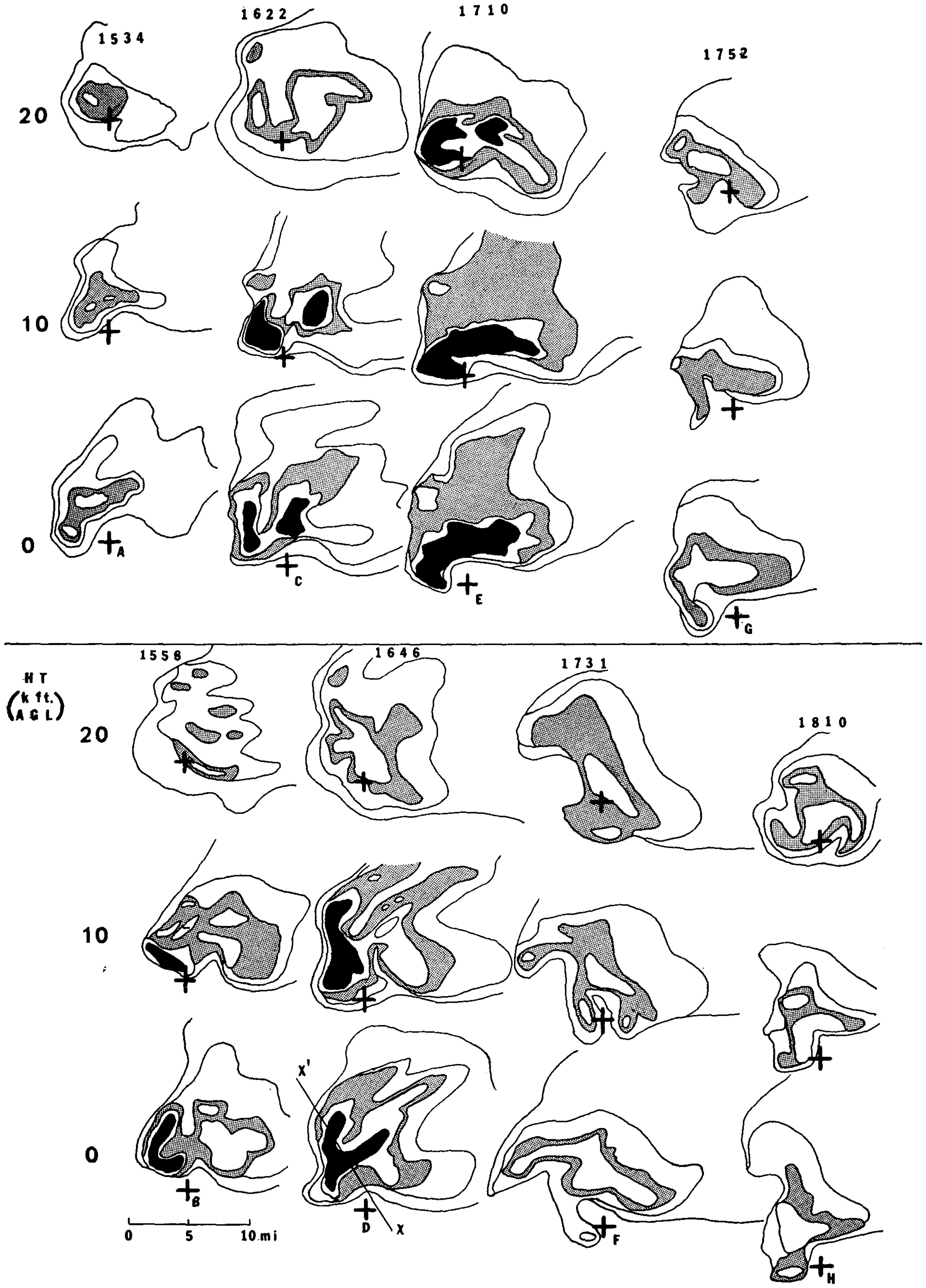

FIG. 1. The PPI radar echo pattern (a., upper; b., lower) for 28 July 1969 obtained by the ALHAS radar with elevation scans nearest the surface (0) and 10,000 and 20,000 ft above the ground (AGL) at the times indicated. See text for definitions of contours and the fiducial marks.

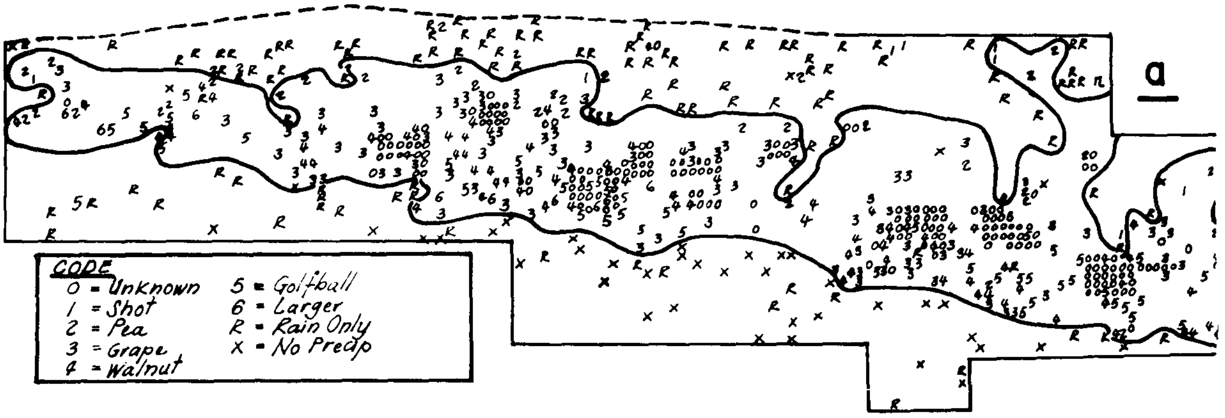

FIG. 2a. The hailfall for 28 July 1969. The inner contour bounds the area of hail occurrence at the ground. The outer solid boundary was the areal extent of the survey. Rain and hail occurred from another storm north of the dashed boundary.

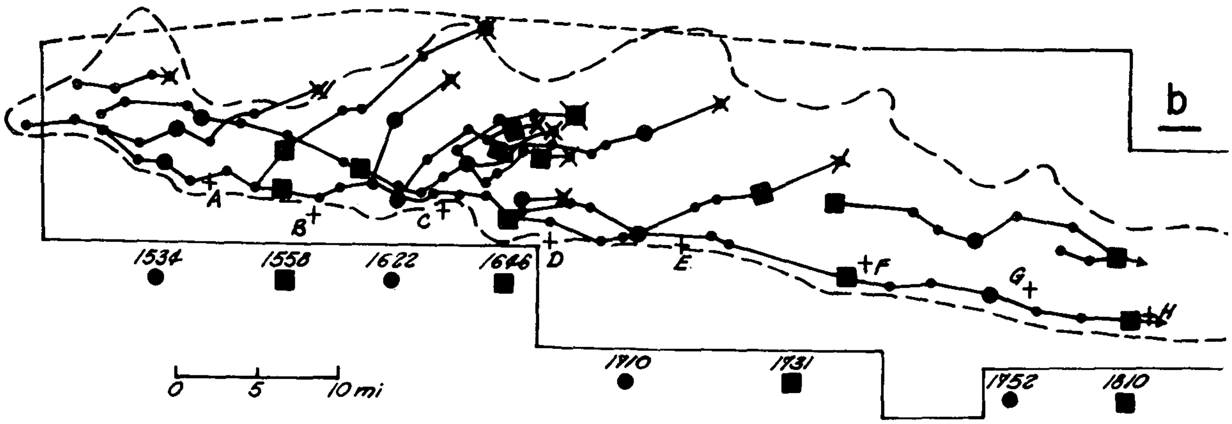

FIG. 2b. The boundary of $Z_e \sim 35$ dBZ (dashed line) with the cloud base Z_e cores located at 6-min intervals. The large dots correspond to the locations of Z_e cores at cloud base from Fig. 1a while the large squares correspond to the cores from Fig. 1b. The fiducial marks (A–H) from Fig. 1 are included for easier cross reference. An X indicates the Z_e core dissipated within the following 6 min.

of the data in this paper. Figs. 1a and 1b contain the PPI scans for the elevation scans closest to the surface and 10,000 and 20,000 ft above the surface. The scans presented are 21 or 24 min apart. The echoes for the respective altitudes are positioned with the radar location fixed so the true storm motion is as appears. The isocontours of reflectivity factors are 15, 25, 35, 45 and 55 dBZ with the light and dark shaded areas having threshold values of 35 and 55 dBZ, respectively. Fiducial marks (A–H) are placed on each scan such that the marks are vertically one above the other. Each of these fiducial marks are 1–2 mi south of the surface radar echo. At 10,000 ft most of the marks are near the edge of the radar echo while at 20,000 ft each mark is several miles within the echo. The top of the radar echo thus always tilted toward the southeast. The magnitude of the tilt was near 40°.

A presistent area of strong reflectivity appears to partially surround the WER in the lower levels. From visual observations and photos available (see Section 3) no new turrets were observed to build along the south or west side. From these observations it was concluded that this storm was maintained by a single "supercell" rather than several developing cells or turrets.

Fig. 2a shows the largest hailstone sizes observed for this storm. These were obtained by means of a telephone survey plus voluntary reports by cooperative observers. Other storms occurred to the north of this storm on this day but the data have been deleted from the figure for simplicity. In any case, the other storms were sufficiently separated such that the hailswaths did not overlap. From this figure it may be noted that this storm produced a persistent swath of hail for over 3 hr. There were several reports of golfball-sized hail with a few intermittant reports of larger than golfball-sized hail. The dashed line in Fig. 2b is the boundary of the level 3 echo ($\sim$35 dBZ). The centers of maximum reflectivity factor cores at cloud base are located at 6-min intervals. The large solid dots correspond to the cores in Fig. 1a while the squares correspond to the cores in Fig. 1b. The smaller dots are the intervening reflectivity cores at 6-min intervals. The fiducial marks from Fig. 1 (A–H) are also noted on Fig. 2b for easier cross reference. It may be seen that the boundary of the

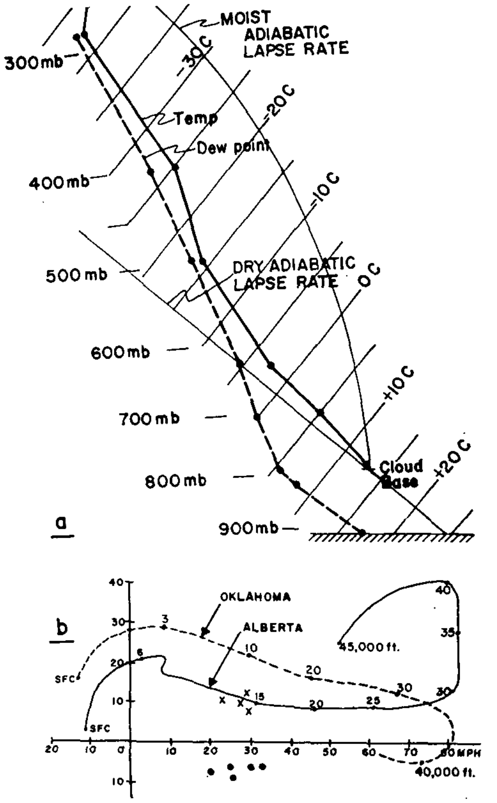

Fig. 3. Rawinsonde data obtained at 1600 MST from ALHAS radar site on 28 July 1969, a., and the wind hodograph for the Alberta storm of 28 July 1969 and the Oklahoma storms of Browning (1965), b. The velocities are miles per hour. The vector motions of the Z_e cores of Fig. 2b are included with the persistent cores on the right flank noted by dots and the dissipating cores on the left flank noted by crosses.

level 3 echo corresponds rather well with the area of hail occurrence in the above figure. The motion of the intense echo cores near the southern side of this storm had the same vector motion as the general echo pattern while the weaker dissipating echo cores on the northern side of the storm had vector motions 30° to the left of the general echo pattern. The vector motions of the strong persistent cores were near 285° at 25 mph while the vector motion of the dissipating cores had motions near 250° at 30 mph.

Fig. 3a is the temperature and dew-point sounding obtained at ~1600 from the radar site on this day. The observed cloud base height of 7000 ft MSL (795 mb) is noted on this sounding. The wind hodograph obtained from this radiosonde is presented in Fig. 3b (the wind hodograph for Browning's Oklahoma storm is also shown for comparison). The vector motion of the strong persistent cores is indicated by dots on Fig. 3b while the motion of the dissipating cores is noted by crosses. These results indicate that the general echo pattern and the strong persistent echoes had a vector motion which was 30° to the right of *all* winds, while the weaker dissipating echoes had vector motions near the mean environmental winds.

From Figs. 1–3 one may observe that this storm had several characteristics in common with Browning's (1965) SR storms. Each storm attained a persistent condition which it maintained for 2–3 hr. During this phase:

1) The echo motions for both storms were consistently 20°–30° to the right of all environmental winds as described by the hodograph winds.

2) A single "supercell" was indicated by an area of strong reflectivity near the south side of the echo.

3) The echoes maintained an apparent tilt toward the southeast. The southerly component of the tilt in the Alberta storm was against the winds and is thought to be analogous to Browning's "overhang."

4) Both storms produced a continuous hailswath.

5) The inflow air entered the storm on the south-southeast side, ascended within the storm and much of this air moved off toward the east-northeast in a cirrus plume.

The environmental conditions surrounding this Alberta storm also resembled the conditions surrounding Browning's Oklahoma storms in that a constant potential temperature existed in the subcloud air in both cases and the wind hodographs below 35,000 ft bore remarkable shape similarity. The vertical wind shear was 2.6 and 3.0 kt $(1000\ \text{ft})^{-1}$ for the Oklahoma and Alberta storms, respectively.

The Alberta storm was unlike Browning's storm in that:

1) The Alberta storm was smaller in diameter (8–12 mi vs 20–30 mi) and not as tall (35,000–40,000 ft vs 55,000–60,000 ft).

2) The Alberta storm did not produce tornadoes although there was an appendage on the southwest quadrant at 1750 which could be interpreted as a "hook echo."

In summary, we can say that, although this Alberta storm was smaller in diameter and height, it displayed echo characteristics and existed in an environment very similar to Browning's SR storms of England and Oklahoma. Inasmuch as the SR storms represent a class of severe thunderstorms, the observations presented in this paper should be representative of other SR storms.

3. Aircraft observations

The Desert Research Institute's B-26 research aircraft systematically observed this storm during the period 1520–1653. This aircraft contained an onboard ground-referenced 3-cm radar with a 22-inch gyrostabilized antenna that produced a 3° pencil beam. The system is such that it can display and store the data from a single rotation of the antenna on a storage tube. The continuously stored aircraft track as determined from a local VORTAC station is superimposed upon this tube. Absolute position accuracy is limited by the VORTAC system; echo interception accuracy by the aircraft is limited by the radar. The onboard radar contained an iso-echo contouring circuit.

Some tests were conducted to determine the capability of using the aircraft radar to vector the aircraft into WER's and near the vicinity of hail. The aircraft was skin-tracked by the ALHAS radar at varying distances from the boundary of well-defined echoes and into regions of expected updrafts or WER's. During these tests the meteorologist in the aircraft (EXB) was able to vector the aircraft with respect to storm echoes with position accuracies of $\sim\frac{1}{2}$ mi. Other tests determined that when the aircraft flew through areas in which the aircraft radar displayed a high intensity storm as indicated by the highest intensity contour, hail was invariably intercepted or observed in the immediate vicinity. From these tests it was concluded that the meteorologist working closely with his pilot was able to vector the aircraft safely into and out of portions of the WER's using the onboard radar system.

The aircraft was systematically flown through the WER from cloud base (7000 ft MSL) to 16,000 ft MSL. Flights were made at selected altitudes in a right-hand race-track pattern along the south and southwest boundaries of the echo. This flight pattern brought the downwind or eastbound leg of the race-track pattern along the southern boundary of the echo and through the WER (i.e., through cloudy air and updrafts). When the aircraft meteorologist felt he had obtained a true display of the echo on his storage tube, he traced the boundary of the echo contours, the flight path and updrafts on an acetate overlay. On the upwind or west-bound leg, the aircraft was flown away from the cloud and a series of cloud photos were taken from the southwest quadrant of the storm. During this leg, a climb to the next higher altitude was made in preparation for the next WER penetration. Fig. 4 is a partial series of the radar patterns obtained from the aircraft radar. The area inside the higher level iso-echo contour is shaded. Locations of observed updrafts are indicated by plus signs on the figure. The air within the WER was smooth and the updrafts reached vertical velocities of approximately $\sim$3500 ft min^{-1} (18 m sec^{-1}) at 12,000 ft.

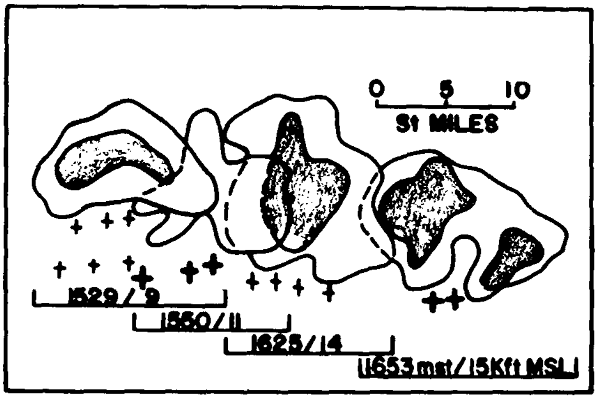

Fig. 4. A partial series of contour patterns obtained from the aircraft radar as the aircraft penetrated the WER. The area inside the higher level iso-echo contour is shaded. The times and altitudes of the penetrations are as indicated. The locations of updrafts for each penetration are noted by different plus signs.

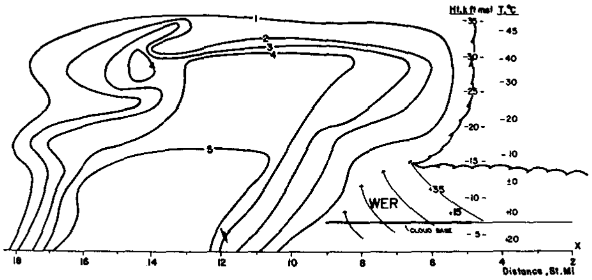

Fig. 5. Vertical section of 28 July 1969 storm from X to X′ (see Fig. 1) at 1646 MST. The visual boundary was sketched from a series of photos taken by the air crew. Streaklines within the WER were inferred from the updrafts such as presented in Fig. 4. The +35 and +15 in the WER are estimated updrafts by the B-26 crew in hundreds of feet per minute. The environmental temperatures are as presented. The contours 1–5 correspond approximately to 15–55 dBZ, respectively.

The ALHAS radar photos were compared to the aircraft radar overlays. All aircraft overlays except one bore a substantial resemblance to the ALHAS radar data, especially along the side of the storm nearest the aircraft (south and west side). By means of this comparison, it was possible to position the aircraft flight paths with respect to the ground and ALHAS radar echoes.

From Fig. 4 one may note that the updrafts were along the southeast side of the radar echo at cloud base and changed to the south side of the radar echo at 10–12,000 ft and then along the south-southeast side above 14,000 ft. One may also note that the updrafts extend 4–5 mi south from the echo at cloud base and narrow to 2 mi south from the echo at 15,000 ft. This narrowing of the width of the WER could have been a function of time and/or height. The radar echo increased in size and intensity prior to 1627 MST (see Fig. 1). Three WER penetrations were made prior to this time of which 2 are shown in Fig. 4. This increase in echo during the penetrations of the WER indicates that the WER was probably *wider* at cloud base rather than narrower by the time the last penetration was made near the top of the WER.

A vertical section was constructed from X to X′ from the ALHAS radar data obtained during the three-dimensional scan at 1646 (see Figs. 1 and 5). The position and orientation of the vertical section was selected to be through the WER and orthogonal to the mean wind vector.

The streaklines[2] within the WER were inferred from the updrafts presented in Fig. 4. An approximate visual

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[2] A "streakline" is the instantaneous position of all particles emanating from a single source, the moving WER in this case.

boundary of the south side of this cloud was reconstructed from photos taken from the aircraft. A band of stratocumulus clouds extended for several miles south of this storm. The sounding indicated that the tops of these clouds were near −5C. The last couple of passes were made just above this band of clouds and next to the visual boundary of the main storm.

One may note from Fig. 5 that the radar echo has an apparent tilt over the WER of 40° from the vertical and toward the right of the mean environmental winds. One may also note that the echo intensity reached 30 dBZ at 25,000 ft directly above the WER. The observations indicate that the strong smooth updrafts within the WER flow directly into the radar echo rather than being deflected around the echo.

Since the airflow within the WER was smooth, this indicates a lack of small-scale turbulent eddies which would produce mixing in the WER. During penetrations above 25,000 ft, high levels of small-scale turbulent eddies have invariably been detected (Steiner and Rhyne, 1962; Sinclair, 1969). Doppler radar observations of a hailstorm in Arizona indicated a highly variable vertical field of motion with eddies having characteristic sizes of 1500–3000 ft (Battan and Theiss, 1970). It is thus proposed that a very rapid precipitation growth process occurs near the top of the WER which results in radar detectable particles and a breakdown of the smooth adiabatic flow into turbulent flow.

It would seem that the breakdown of the smooth laminar flow within the WER into turbulent flow occurred above 16,000 ft in this case. The WER of the thunderstorm deserves considerable more study.

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