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MICROBURST PREDICTION AND DETECTION

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Introduction

Prediction and detection of microbursts are a significant forecast challenge in the western U.S. There are several factors that affect the detection of microbursts.

1) Microburst storms and their sub-cloud environment can evolve very quickly.

2) Microbursts typically form over very dry boundary layers.

3) Radar reflectivities of the storm can be below cell identification and tracking algorithm thresholds.

4) Several of the NWS Western Region WSR-88Ds are located on mountain peaks with the lowest tilt high above the surface.

This Technical Attachment is the first in a series that examines microbursts, in particular, the "dry" microburst. It is acknowledged that "wet" microbursts can occur in the Intermountain Region as well. The NSSL Warning Decision Support System was used in this study. However, the concepts presented here can be equally-applied to the WSR-88D PUP.

"Dry" Microburst Precursors

A typical "dry" microburst environment has ~500 J/kg of convective available potential energy, weak winds, and a deep, well-mixed, dry boundary layer (see e.g., Knupp 1996). Cloud bases can be as high as 450 mb. The classic sounding has been referred to as the "inverted-V" sounding.

The most significant radar precursors are convergence near or above cloud base and a descending reflectivity core (see e.g., Eilts et al. 1996). Results from Phoenix data show that 40 kt convergence over 5 nm or less on one or two tilts near the cloud base and a 6000 ft descent of the reflectivity core over two volume scans can be associated with severe surface winds. Secondary indicators are rotation in the descending core and a reflectivity core at least 1000 ft higher than surrounding storms.

9 June 1996 Microburst

Environment

The 9 June microburst occurred during the afternoon hours in the Salt Lake Valley (SLV; see Fig. 1). The 0000 UTC 9 June sounding (Fig. 2) had a dry-adiabatic lapse rate from the surface to ~450 mb. A thin layer of moisture in the morning sounding had all but disappeared leaving little potential instability. The cloud base at 0000 UTC was approximately 450 mb or 14,000 ft above the radar and 16,300 ft above the Great Basin. Winds near the surface were weak and moderate in strength above 700 mb.

Initial Outflow Development

As the event unfolded, forecasters were focused on a line of strong storms in northwest Utah (Fig. 3). The initial storm that would eventually produce the Magna microburst cell formed from an area of diffuse echoes to the west of the Oquirrh Mountains near T62, about 50 nm south of the radar. Note that the reflectivity values are less than 30 dBZ. This is significant since the WSR-88D storm cell identification and tracking (SCIT) algorithm uses 30 dBZ as a minimum (default) threshold to define a storm cell. Thus, storm attributes determined by the algorithms may not be tracked (e.g., height of maximum reflectivity and convergence). A reduction in the SCIT minimum reflectivity threshold to enable identification of the weak cells south of the radar can produce unwanted consequences. A lower SCIT threshold may cause the system to attempt to track too many cells or spurious features. Changing the SCIT should be evaluated on a case-by-case basis. In this example, a lower SCIT threshold would have produced an over-abundance of cell detections in the storm complex in the northwest part of the area.

In the western U.S., it is important to remember that microbursts are typically generated from storms with elevated cloud bases. The forecaster must be aware of which radar tilt is actually detecting the cloud base and look for signatures of convergence at or above the elevated cloud base. As an example, the cloud bases were estimated to be 14,000 ft above the radar. At 50 NM from the radar, the 2.4 deg beam height is near cloud base and the 1.4 is scanning approximately 3,000 ft below cloud base (Fig. 4). An important point to remember is that the beam height increases with range. In the example, the center of the 2.4 deg beam is 14,000 ft above the radar at 50 NM and 19,300 ft at 57 NM, a difference of 3,000 ft in only 7 NM.

Doppler velocities from the 1.4 and 2.4 deg tilts (Fig. 5) show two areas of weak-to-moderate convergence near the initial storm's genesis area (red indicates motion away from the radar and green is toward). Maximum radial convergence anywhere in the volume did not exceed 15 kt over 5 nm or less. The strongest signatures were on the 1.4 deg and 2.4 deg tilts, as expected. As mentioned earlier, this type of convergence signature is a precursor to microbursts. Unfortunately, because of the sparse population, there was no ground truth data to verify whether or not microbursts actually developed. However, it is believed that outflow from these cells initiated the storm that moved over the Oquirrhs.

A descending reflectivity core is the other significant change in the cloud structure that has been associated with strong microburst events. A descending reflectivity core occurs when the precipitation associated with the storm starts to rapidly descend through the cloud base. The maximum vertical extent of the Oquirrhs storm occurred at 0133 UTC with 30 dBZ observed at 15,700 ft AGL. Recall from the sounding that the cloud base was about 14,000 ft above the radar. Twelve minutes later the "core" had descended to 11,300 ft AGL; 4,000 ft in two volume scans (~12 min). At the same time, outflow began spreading down the east slopes of the Oquirrhs and initiated the Magna microburst cell. As the storm moved east across the mountains, it broke into small areas of weak reflectivity which spread laterally. Before 0145 UTC, the reflectivity echo appeared as a solid mass and had peaked in reflectivity values. Afterward, the storm had a ragged appearance and individual cores were difficult to identify. This structure is reminiscent of a ring gust front with the small echoes representing new cell development. Thus, a ring-shaped radar echo indicates that a collapsing storm cell.

Magna Microburst Development

At 0150 UTC, a small cell forming aloft along the outflow boundary was evident at 0150 UTC near Magna and appeared to be the beginning of a microburst-producing cell. Reflectivity and velocity features were tracked for that cell (Figs. 6a and 6b). The first echo formed at 15,000 ft above the radar level (ARL). Note the low reflectivity values and shallow nature of the cloud. By 0202 UTC, the precipitation had descended to 3,500 ft; a "reflectivity core" descent of 11,500 ft in about 12 minutes. Also, a coherent 12 kt convergent velocity difference developed just above cloud base by 0156 UTC.

Time series wind data from Magna (Fig. 7) showed a wind shift, probably from the initial outflow from the Oquirrhs storm, from northeasterly at 0144 UTC to southwesterly at 0159 UTC. The wind remained weak and steady for about 10 minutes before a strong south wind occurred at 0210 UTC with a peak 1-min average wind speed of 34 mph at 0214 UTC. As seen in Table 1, a peak gust of 54 mph was reported at 0210 UTC near Magna. It is believed that the 0214 UTC peak wind reflects microburst winds from the "collapsing" Magna storm cell. The 12 kt convergent velocity difference at 0156 UTC indicates that a 16 minute lead time may have been possible.

Subsequent Microbursts and Possible Tornado

At 0214 UTC, the echo had a solid round shape (Fig. 8a) and the 0.5 deg velocity field (Fig. 8b) hinted strongly of an outflow boundary with divergence between BCH and just beyond U42. This is the outflow from the Oquirrhs storm. A well-defined double convergence signature was evident at the 4.3 deg tilt with maximum velocity difference of 18 kt just south of West Kearns (Fig. 6b). The 1.4 and 2.4 deg tilts showed less well-defined convergence. This signature was a precursor to the subsequent peak microburst winds at Magna at 0221 UTC and 0244 UTC, indicating lead times of 7 and 30 minutes, respectively. There were additional reports of strong winds, 60+ mph gusts, in the area east of Magna -West Valley City (WVC) and West Kearns (KRN). Unfortunately, few of the reports included wind direction.

With time, the reflectivity structure reintensified into a single, large echo mass, reaching 31 dBZ at 0227 UTC. The maximum velocity difference in the convergence signature reached 25 kt. By 0236 UTC, a hook echo (Fig. 9a) and a tight convergent rotation signature formed triggering the NSSL mesocyclone detection algorithm (Fig. 9b). This circulation passed directly over the most intense damage in South Salt Lake and a funnel cloud was reported just to the west of this area (Table 1). The focused narrow damage path discovered in the damage survey (Table 2) indicates tornadic damage. In addition, Doppler velocities at the next 0.5 deg tilt (Fig. 10) showed a distinct vortex couplet that was not present earlier, suggesting that the vortex had built downward. Interestingly, the 33 kt rotation at 0243 UTC, was preceded by strong divergence on the 0.5 deg tilt (Fig. 6b). The vortex then rapidly dissipated and the storm moved over the Wasatch Range.

Summary

Key findings from this study are:

1. Microbursts are generated from storms with elevated cloud bases. Research has shown that convergence in the cloud and a descending reflectivity core occur relative to the elevated cloud base. Understanding which radar tilt is actually observing the elevated cloud base is important. The lowest radar tilt may be well below the cloud base. The higher tilts are frequently the more appropriate tilts to use to observe the structure of the cloud. The forecaster should use sounding data to develop an estimate of the anticipated base of the storms. In this example, the cloud base inferred from the 0000 UTC sounding was approximately 14,000 feet above the radar and helped verify that the convergence signatures were being observed where they should have been (near or above cloud base). In this case, the cloud base was mostly on the 3.3 deg tilt.

2. WSR-88D signatures may provide 10 to 15 minutes microburst warning lead time. However, those signatures were initially weak (~12 kt convergence over 5 nm or

less) and relying solely upon convergence above the cloud base may result in false alarms. Stronger convergent signatures (~22-25 kt) did occur prior to peaks in severe surface winds. In this case, the reflectivity core descended 4,200 ft in 12 minutes before the microburst was observed. However, descending reflectivity cores can be very small in size, and forecasters need to monitor cell tendencies very closely.

3. The radar echo associated with microbursts on this day formed a cluster of small cells rather than a single isolated cell. This appears to be typical of many western storms microburst storms and attempting to observe the individual storm characteristics presents a challenge for the forecasters.

4. Storm reflectivities were too small for detection of the storms by the WSR-88D SCIT algorithm. Changing the SCIT minimum reflectivity threshold may produce unanticipated consequences with too many weak cells or spurious features being identified.

5. The morning sounding showed high relative humidity at midlevels and a dry boundary layer, the classical "inverted-V". However, the storms on this day occurred after 0000 UTC when the nearby sounding indicated very little mid-level moisture. Thus, there are probably significant mesoscale variations in instability (and vertical winds) not measured by the current sounding network.

Acknowledgments

One-minute average surface wind data were provided by the Utah State Department of Environmental Quality Air Monitoring Center.

References

Eilts, M. E., J. T. Johnson, E. D. Mitchell, R. J. Lynn, P. Spencer, S. Cobb, and T. M. Smith, 1996: Damaging Downburst Prediction and Detection Algorithm for the WSR-88D, *Preprints,* 16th Conf. On Severe Local Storms, San Francisco, AMS.

Knupp, K. R., 1996: Structure and evolution of a long-lived, microburst-producing storm. *Mon. Wea. Rev.*, **124**, 2785 -2806.

List of Figures

Figure 6a Figure 6b

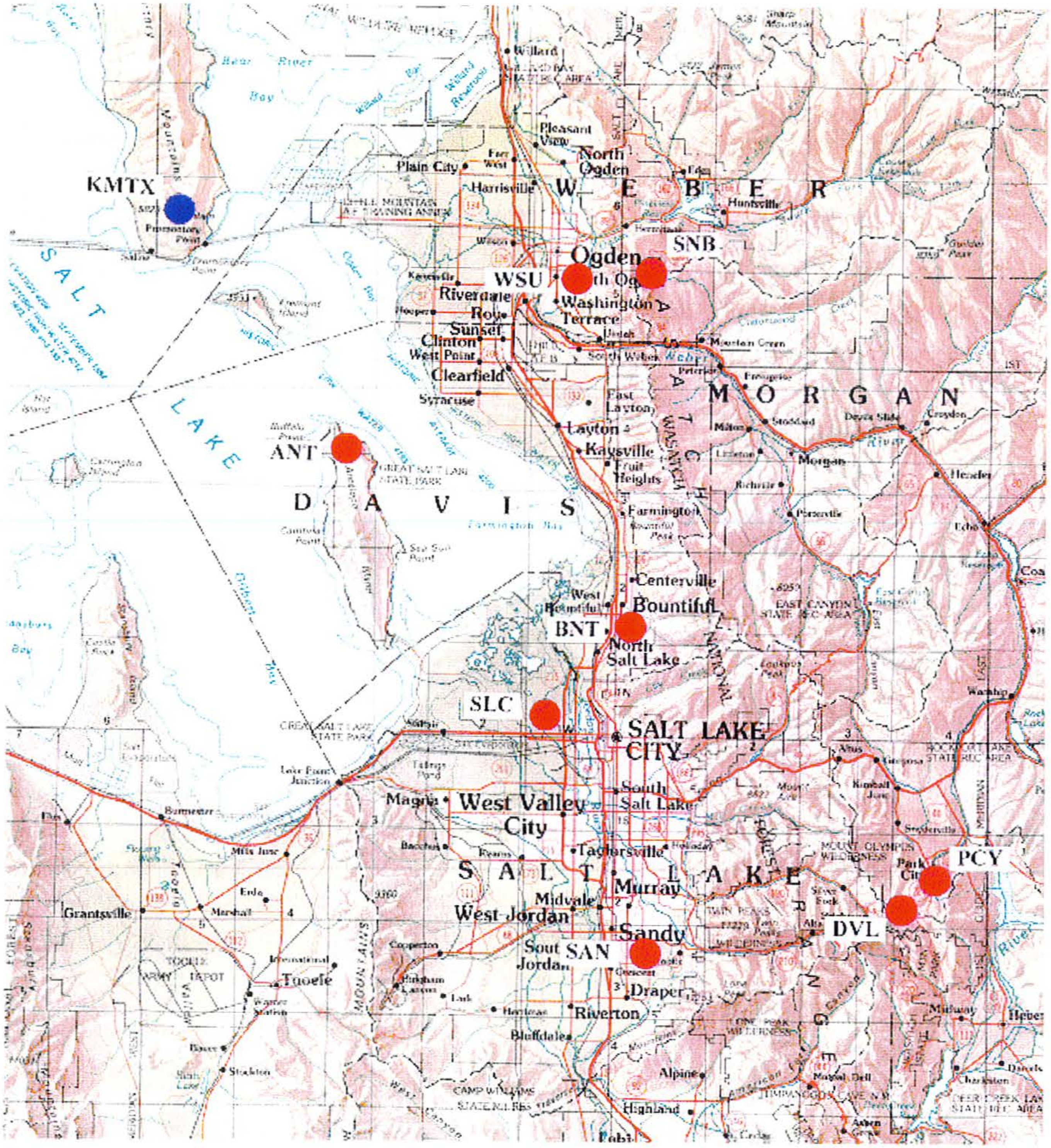


Figure 1. Map centered on the Salt Lake Valley. Note the series of north-south mountain ranges west of the Wasatch Range to the east of Salt Lake City.

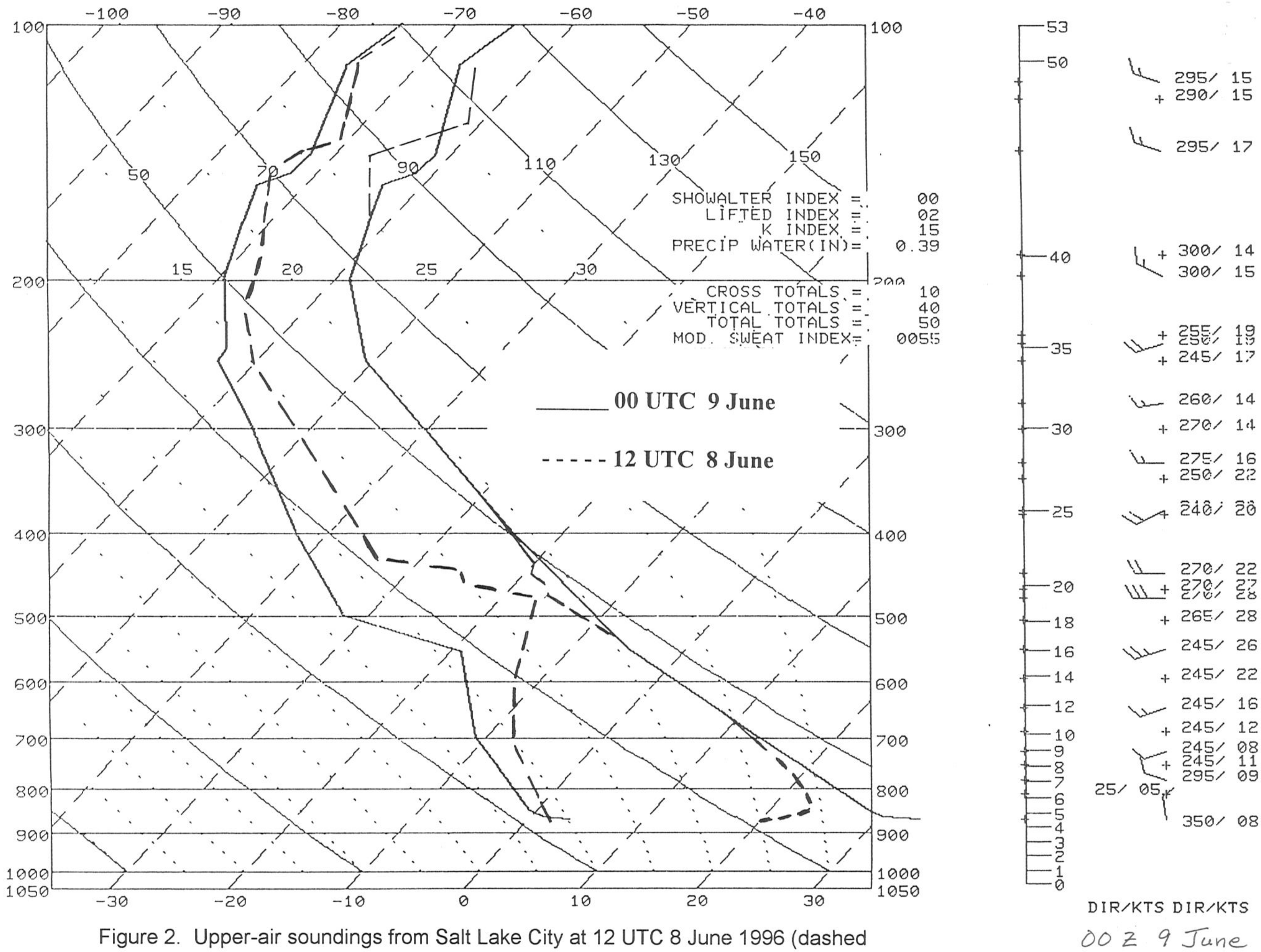


Figure 2. Upper-air soundings from Salt Lake City at 12 UTC 8 June 1996 (dashed lines) and 00 UTC 9 June 1996 (solid lines).

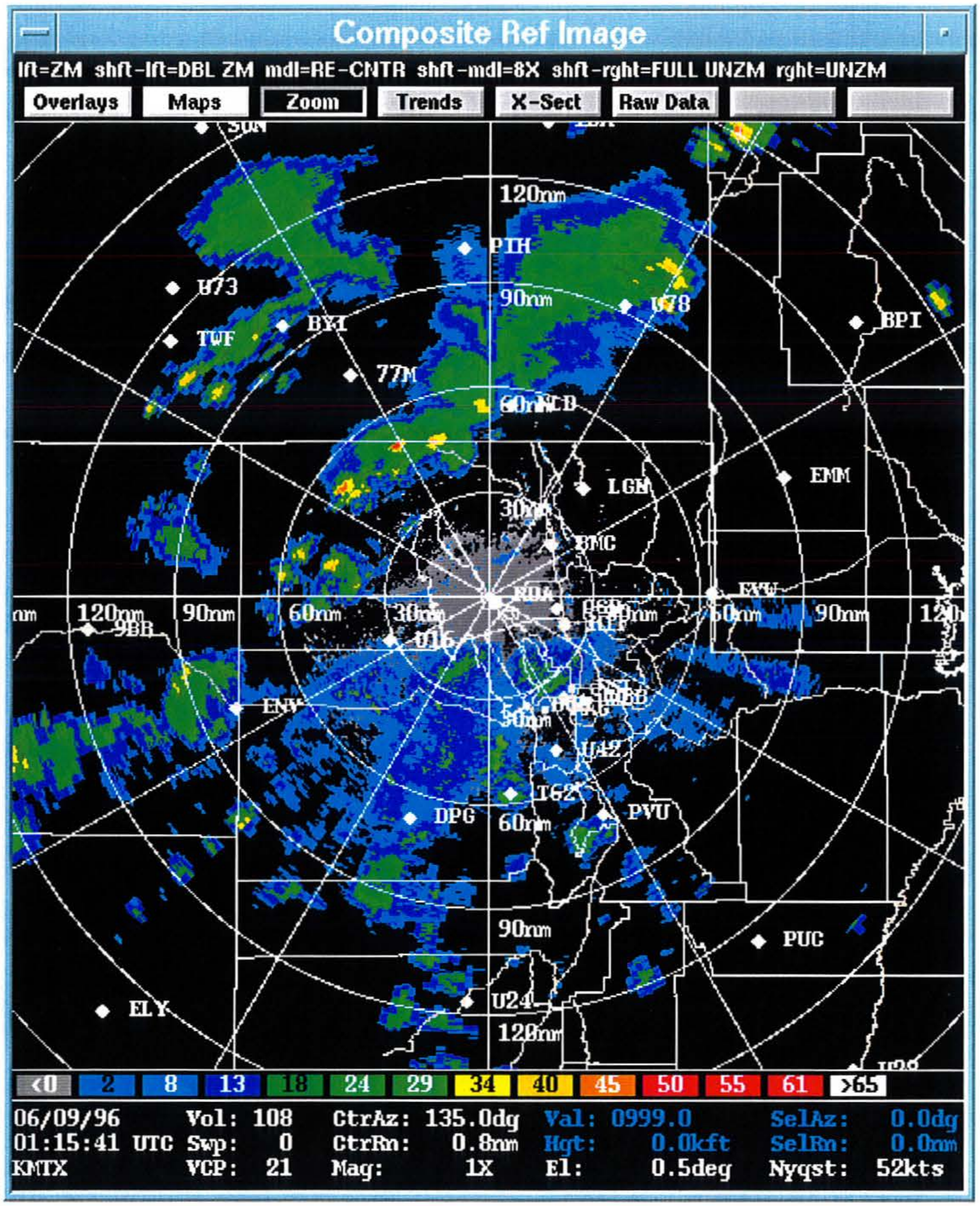


Figure 3. Composite reflectivity from the KMTX WSR-88D at 0117 UTC on 9 June 1996.

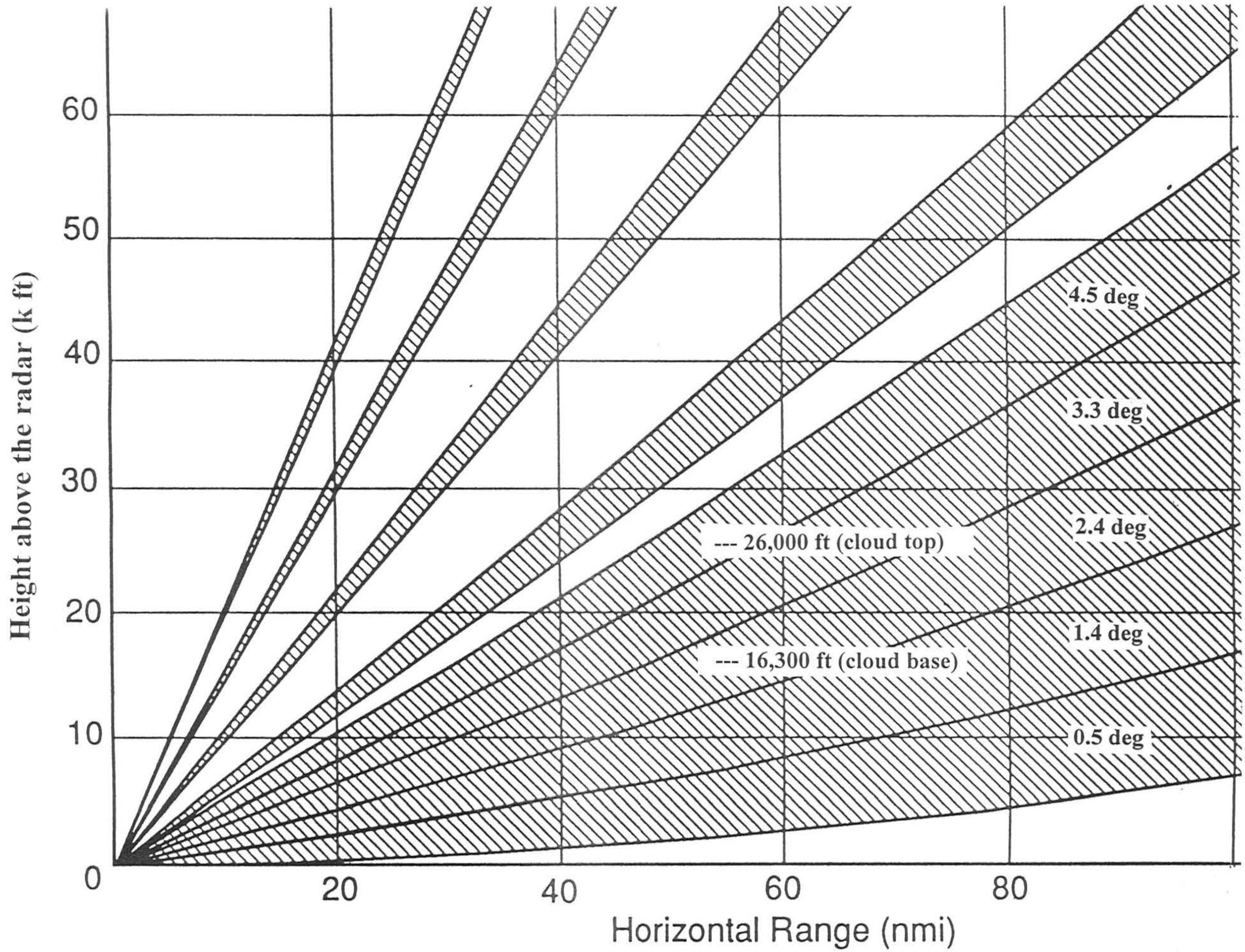


Figure 4. WSR-88D volume coverage pattern 21 (from FMH-11) with cloud base and cloud top indicated.

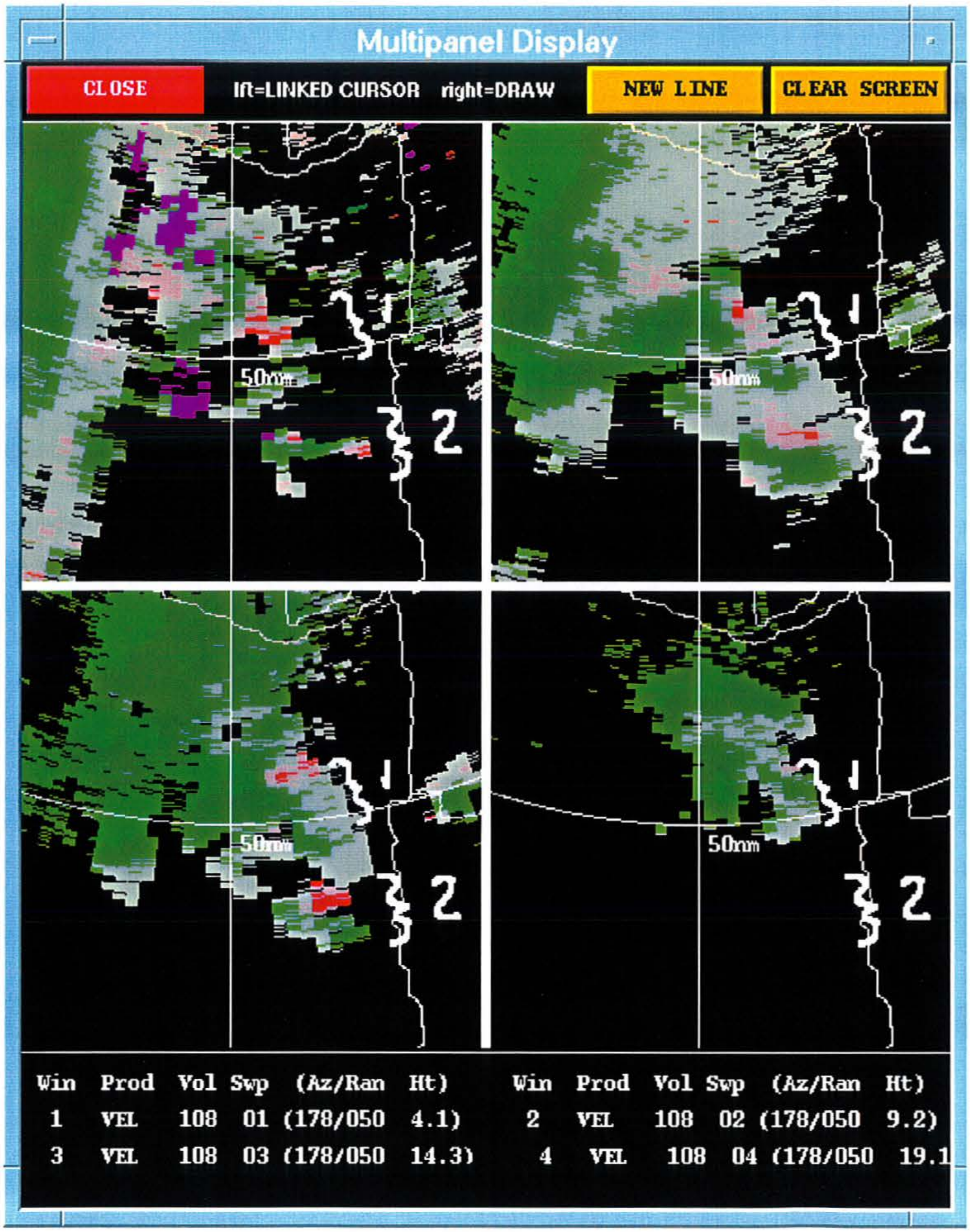


Figure 5. 4-panel display of Doppler velocity at 0117 UTC with the upper-left being the 0.5 deg tilt, upper-right the 1.4 deg tilt, lower-left the 2.4 deg tilt, and lower-right the 3.3 deg tilt. Two areas of radial convergence are indicated by the numbers 1 and 2.

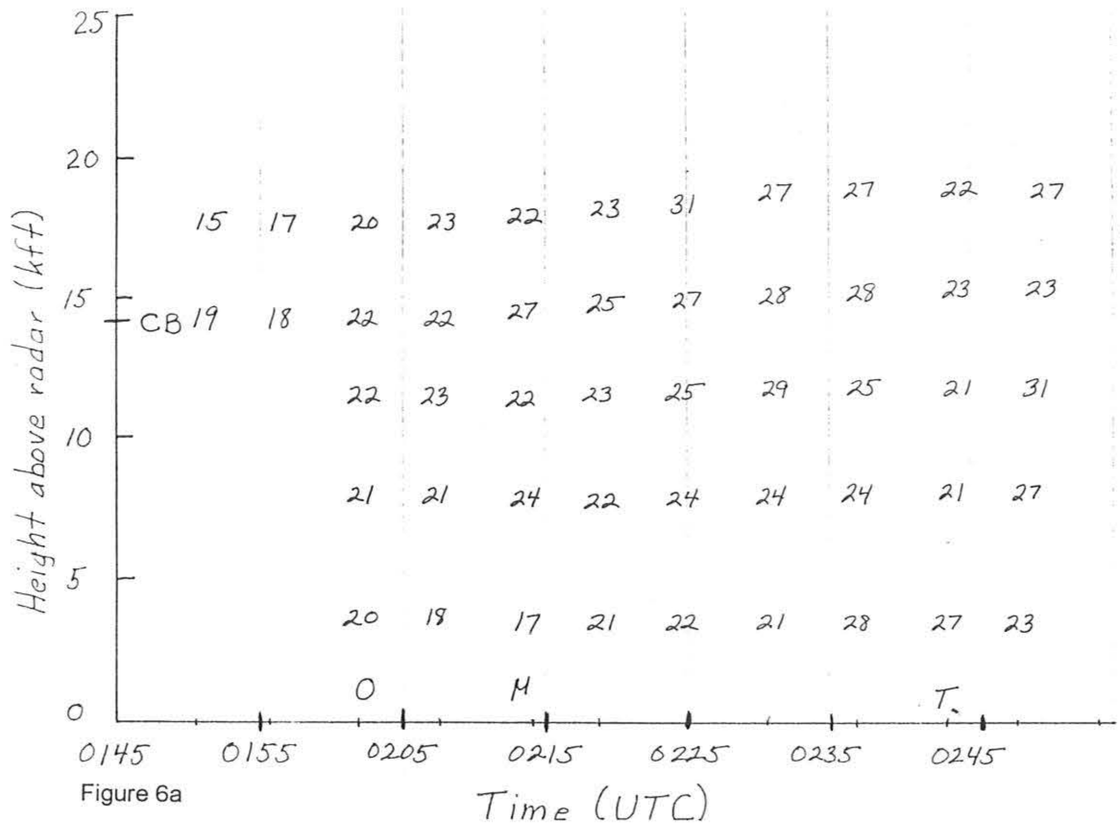


Figure 6a

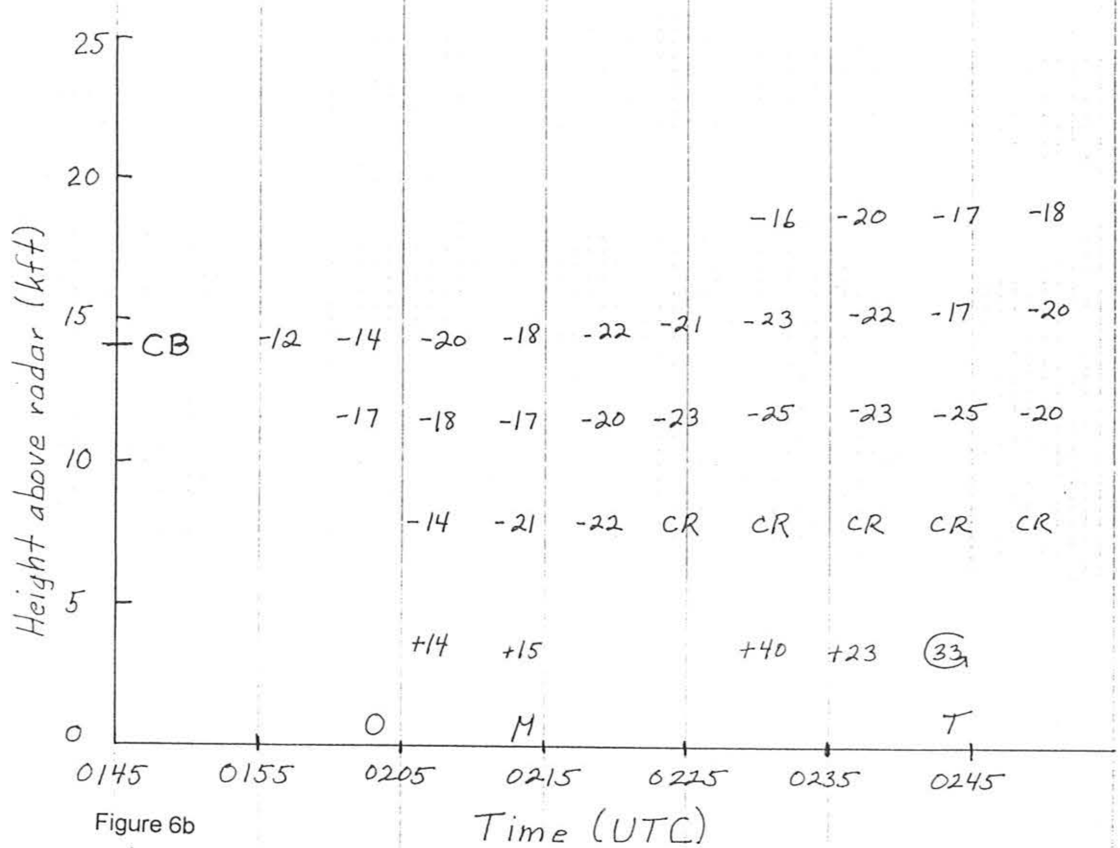


Figure 6b

Time-height plot for the Magna storm of a) the maximum reflectivity (dBZ) and b) maximum radial convergence (kt). The maximum allowable distance for determining the convergence was 5 nm. The times of the initial outflow at Magna, peak wind at Magna, and the 0.5 deg Doppler rotation signature are indicated by the O, P, and T, respectively. The cloud base height from the 00 UTC sounding (Fig. 2) is indicated on the left axis.

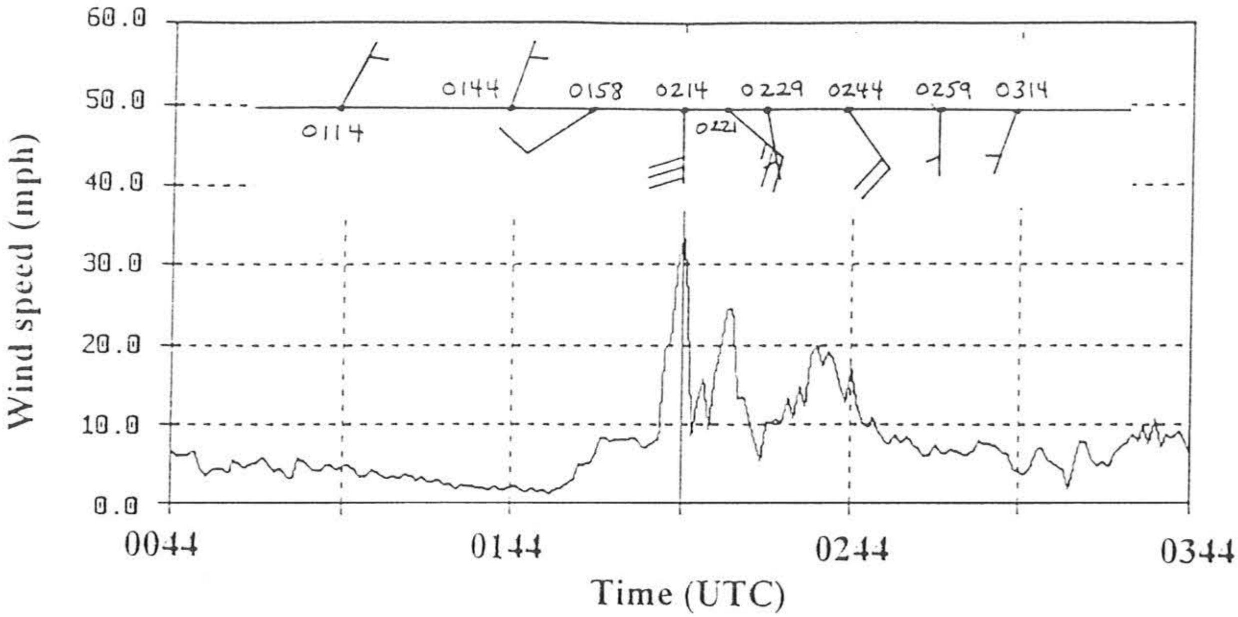


Figure 7. Time series plot of 1-minute averaged wind speed from the Utah State Air Monitoring Center's Magna site (times are in UTC). Overlaid are station model wind barbs at selected times.

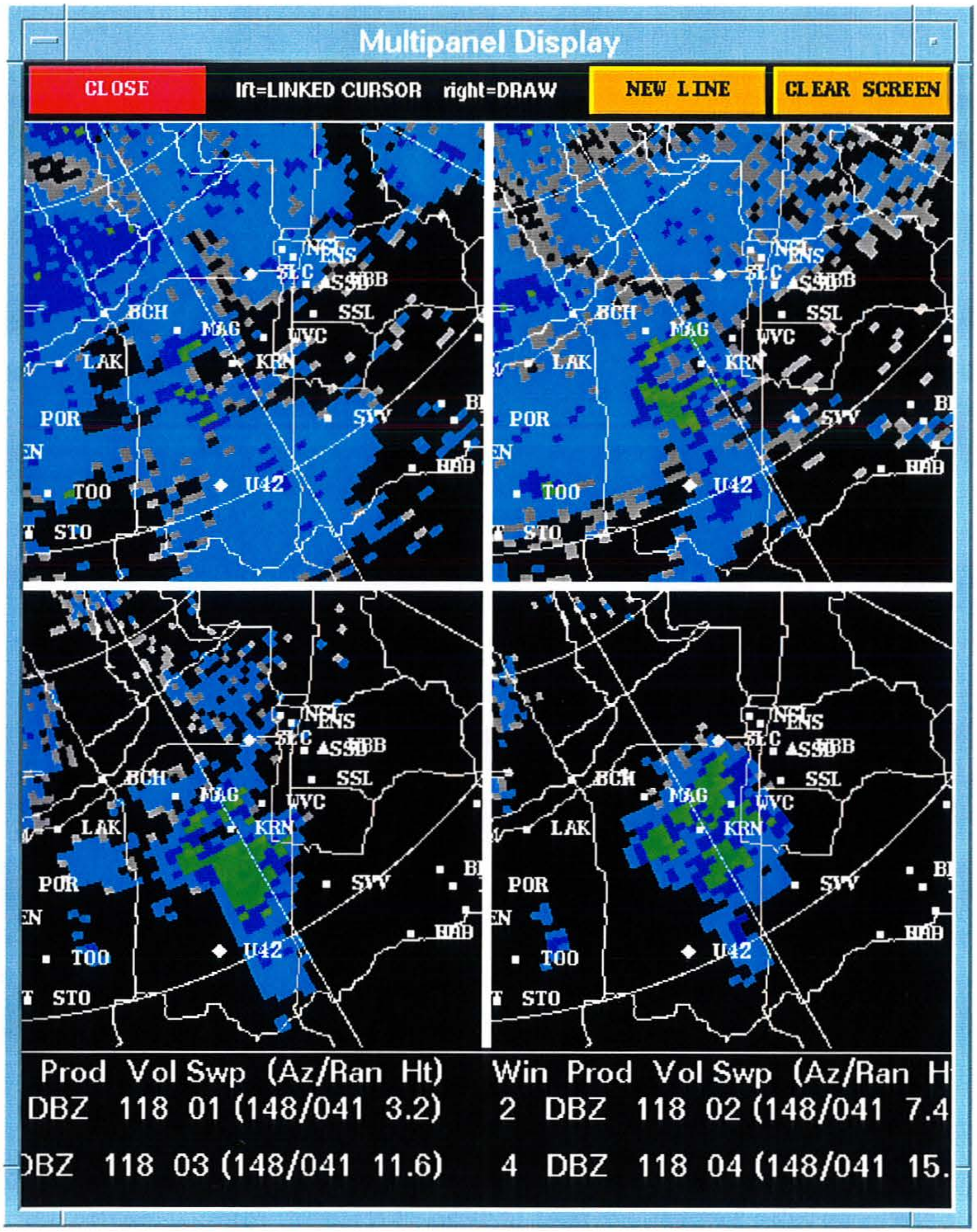


Figure 8a. As in Fig. 5 except for a) reflectivity and b) velocity at 0214 UTC.

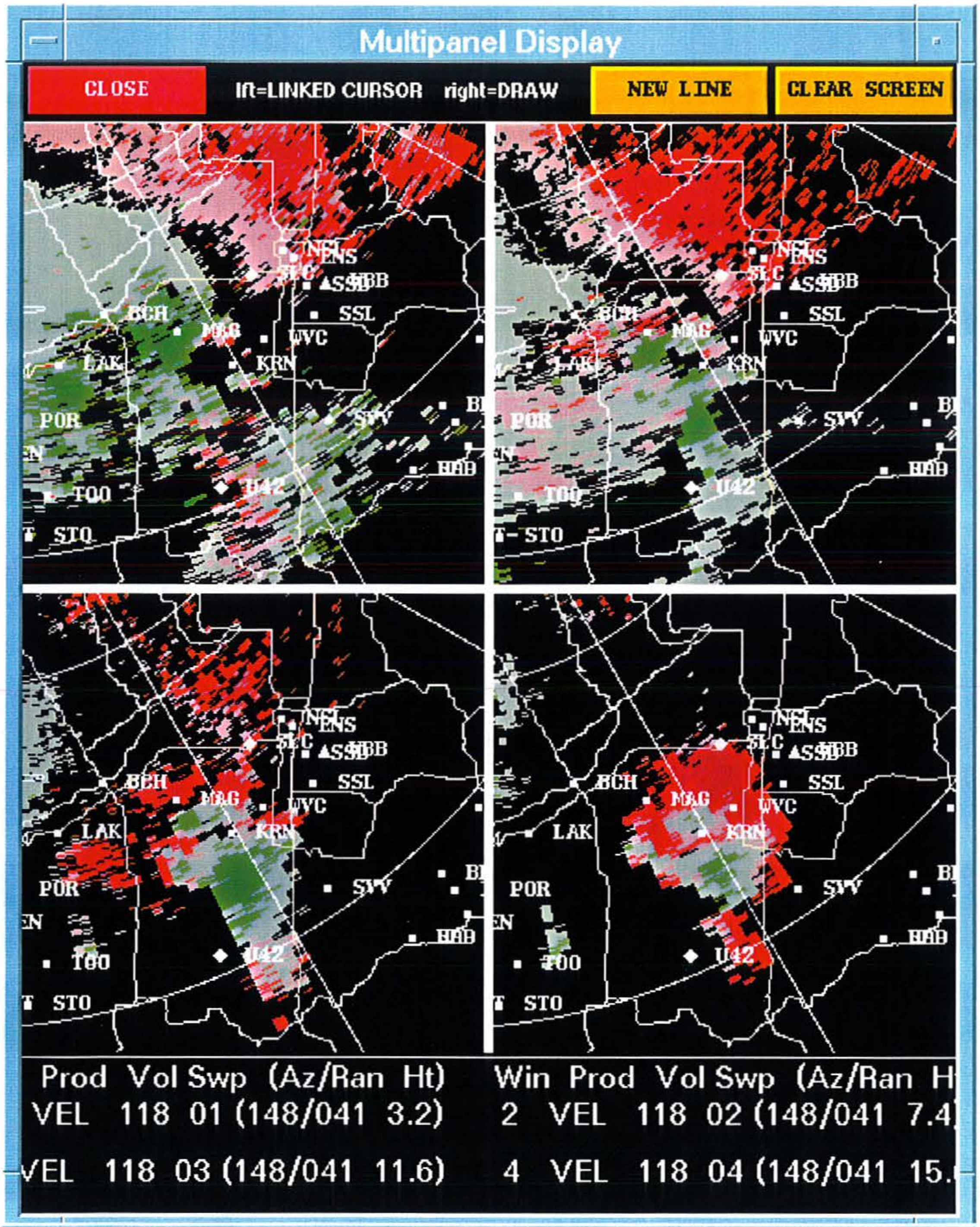


Figure 8b. As in Fig. 8 except for 0236 UTC. The yellow circle in Fig. 9b indicates a 3-D circulation identified by the NSSL mesocyclone detection algorithm.

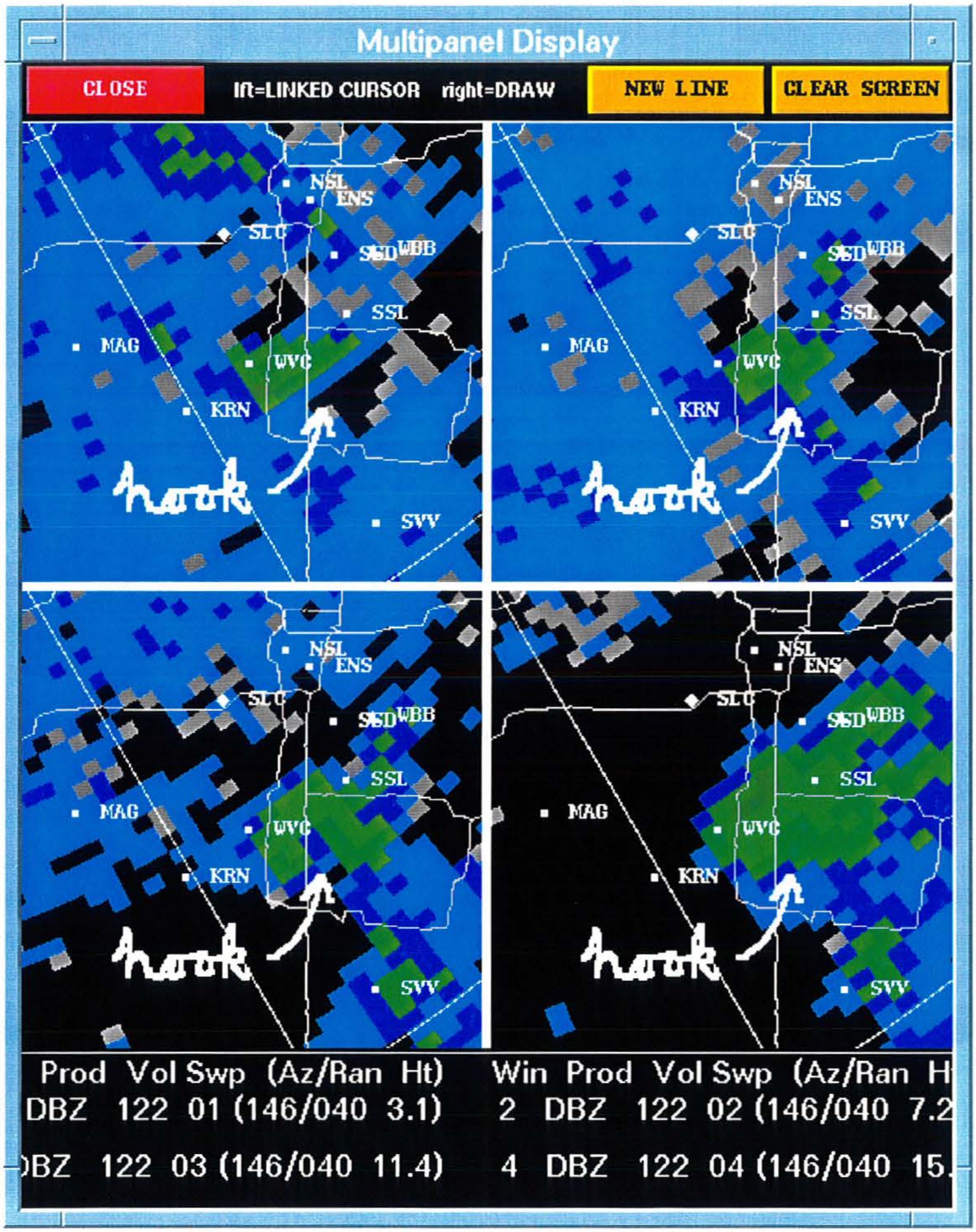


Figure 9a. As in Fig 7 except for 0236 UTC. The yellow circle in Fig. 9b indicates a 3-D circulation identified by the NSSL mesocyclone detection algorithm.

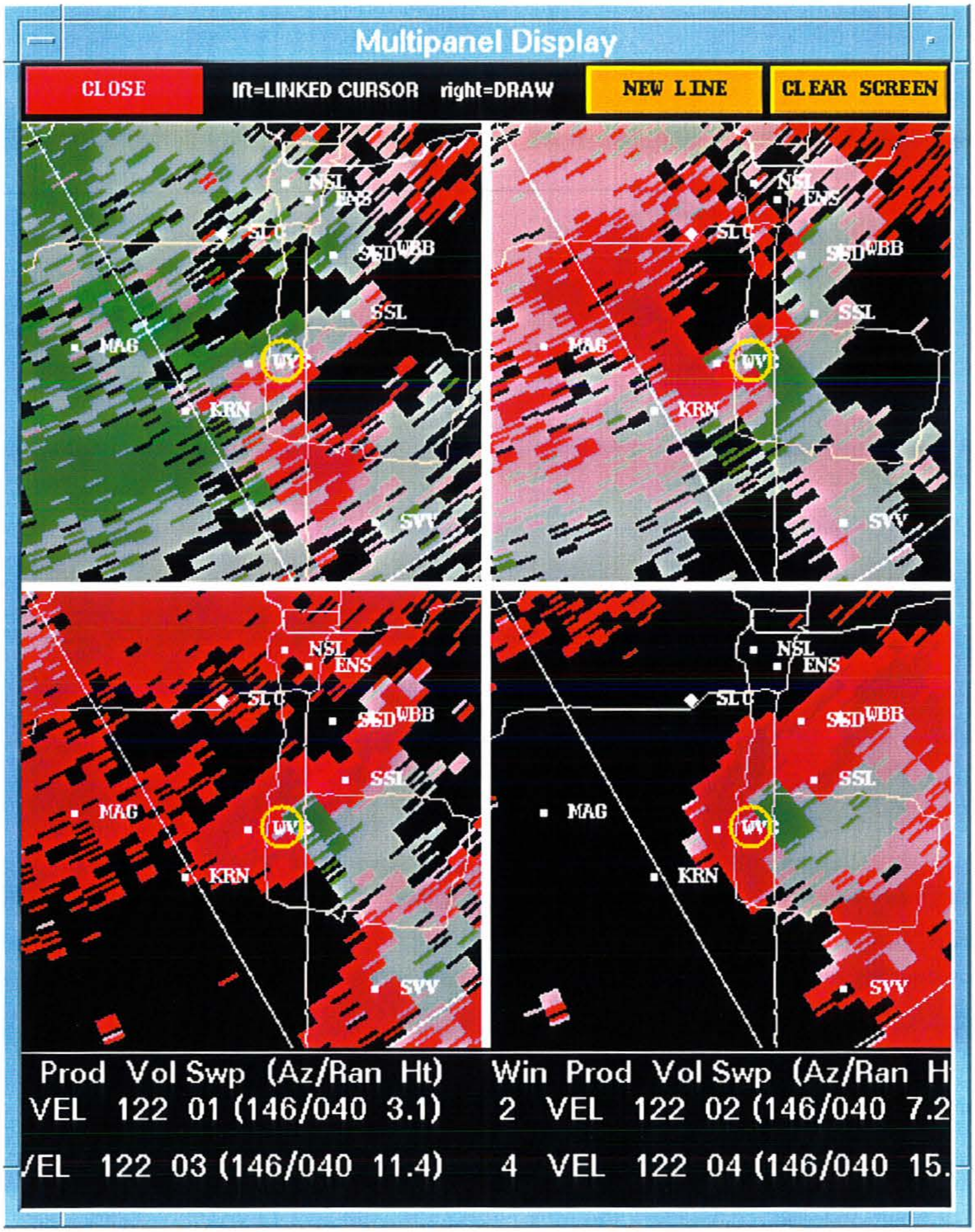


Figure 9b. As in Fig. 8 except for 0236 UTC. The yellow circle indicates a 3-D circulation identified by the NSSL mesocyclone detection algorithm.

Table 1. Forecaster event log from 9 June 1996

Time (UTC)	Location/Spotter Name/Event
0200	Called [airport control] tower about gust front 40 kt possible
0210	Shawn Buchanan [near Magna] west wind 54 mph
0226	Channel 2 [WVC] 49 mph
0230	W. Kearns 62 mph
0240	W. Valley [City] Clayton Brough's wife <83 mph> on anemometer... Correction: think anemometer off based on damage reports...maybe about 60 mph.
???	3000S 2000W 3 ft diameter tree knocked into house. Witness claimed to see funnel cloud.

Table 2. 9 June 1996 Wind Damage Survey Results

High winds from microburst outflows moved from southwest to northeast across the Salt Lake Valley. There were three areas of damage reported to the forecast office. None of the reports were logged in the FO event log (see Table 1).

Area 1: 6200 South and 5887 West (coordinates are from the LDS Temple in downtown SLC; 700 = 1 mile)

The only noticeable damage within a 3 mile radius was a few leaves stripped from trees. One citizen expressed concern that trees may have been blown over but there was minimal damage.

Area 2: 3000 South and 2000 West

This was the area where a 3 ft tree was reported to be blown into a house. The tree was not found nor was any other visible damage within a 2-3 mile radius.

Area 3: 2700 South and 792 East

This area had quite a bit of small to large (5 to 10 ft long) tree limb damage. However, there were no whole trees downed. The damage was confined to an area ~1 mile N-S and 0.5 mile E-W. The most intense damage, in terms of number and size of tree limbs, was near 2700 S and 700 E. Following are detailed observations:

2700 S/700 E to 2825 S/ 800 E -considerable limb damage
2100 S/800 E -a few 5-7ft limbs
1940 S/500 E -a few 7-10ft limbs
1830 S/500 E -small limbs damaged
1870 S/800 E -one 3 ft limb

Survey Conclusions

From the damage described above, it is obvious that the highest winds were associated with Area 3, with Areas 1 and 2 having a sufficient number of trees that COULD HAVE experienced more damage. Estimates of wind speed based on tree damage tend to be gross and inaccurate. A first guess of minimum winds needed to cause tree damage can be deduced from reports of high wind but otherwise no damage. The reports of 49 mph at Channel 4 and 62 mph at W. Kearns imply that winds from 50-60 mph may not cause much damage. One reason for this may be that eventually, the damage-prone materials have already damaged with objects becoming less susceptible to damage. This also assumes that all areas have been scoured uniformly. Given these assumptions, it appears that the peak winds may have exceeded 60 mph in Area 3.

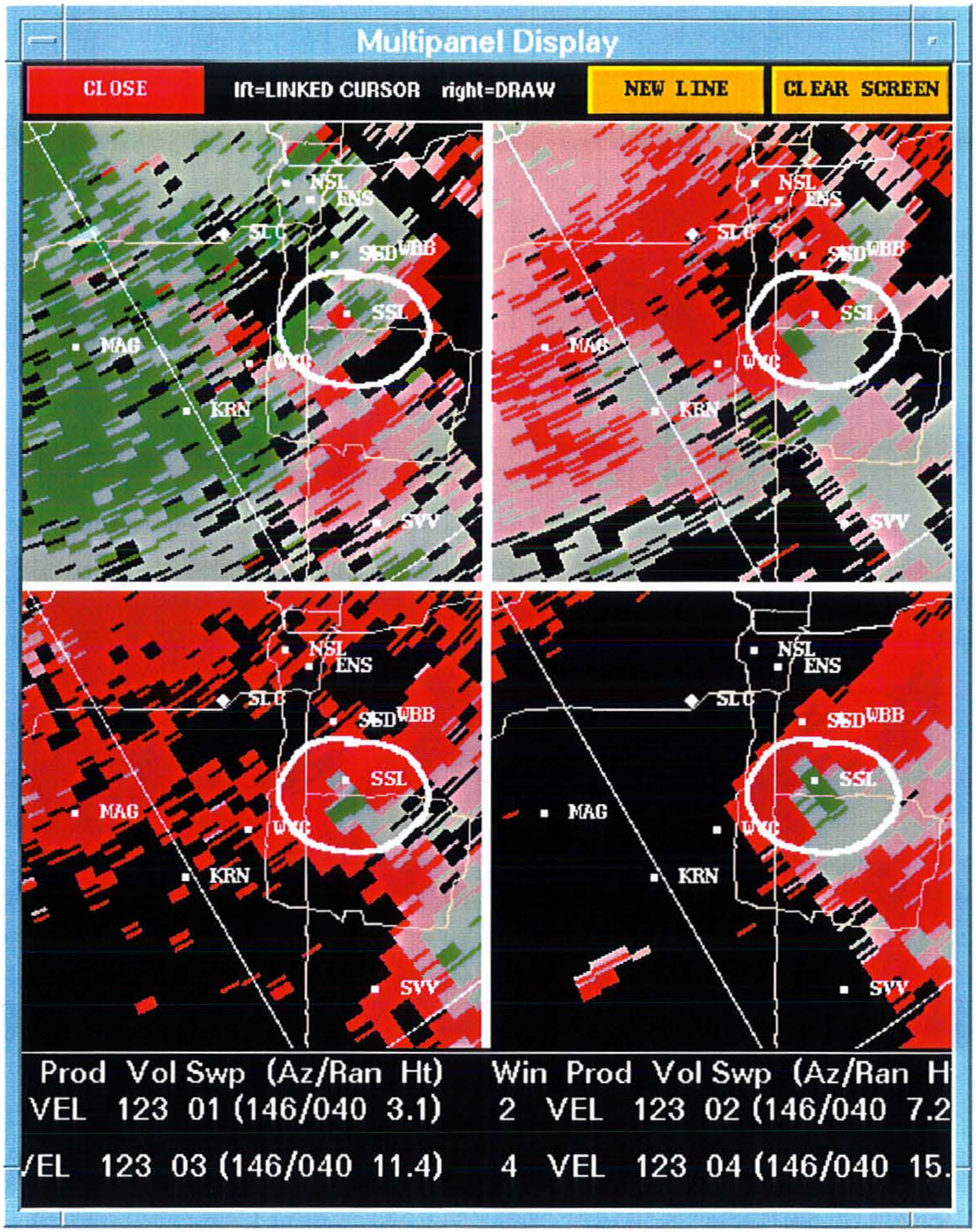
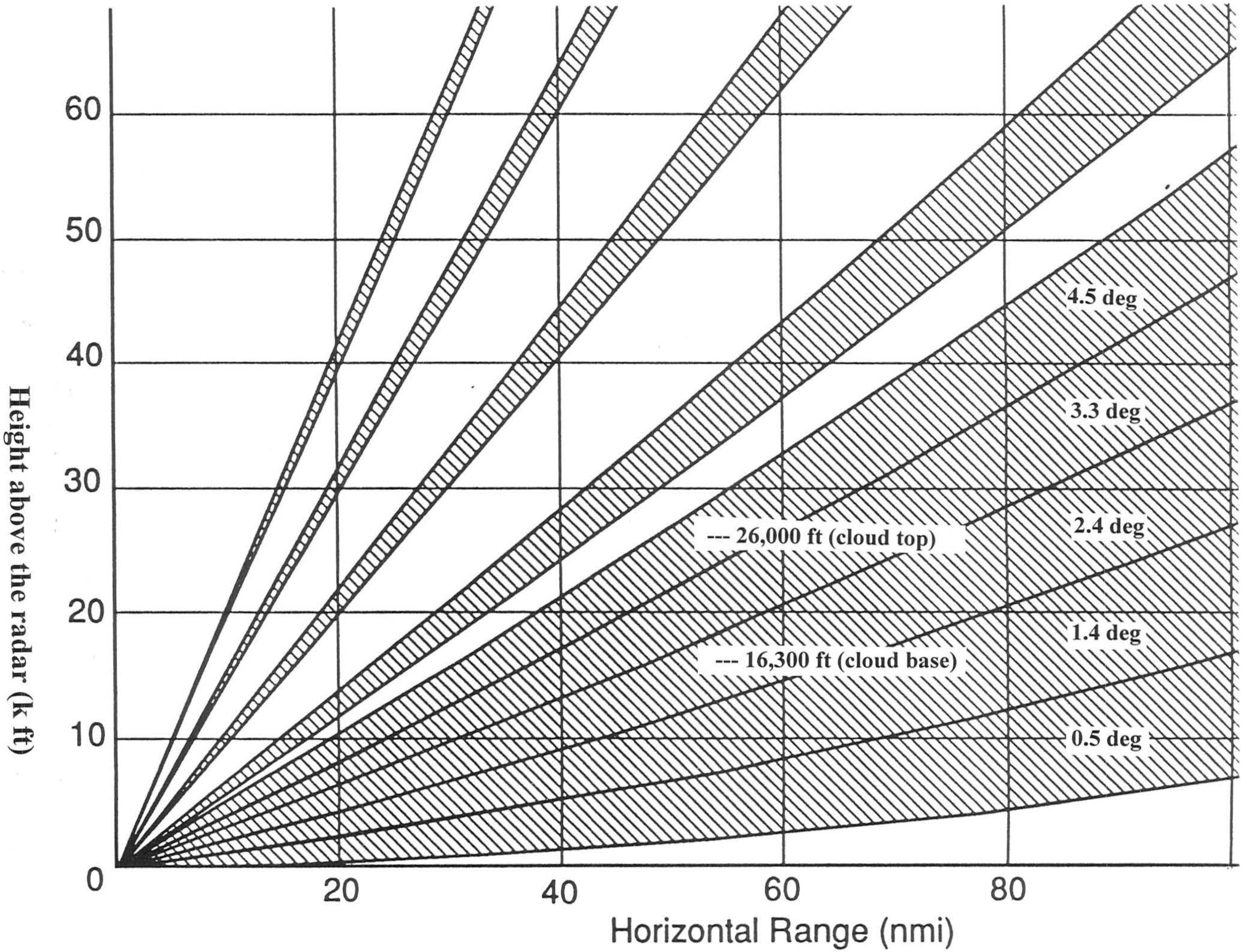


Figure 10. As in Fig. 8 except only velocity at 0242 UTC. The circulation at 0.5 deg is circled.


60
50
40
30
20
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20
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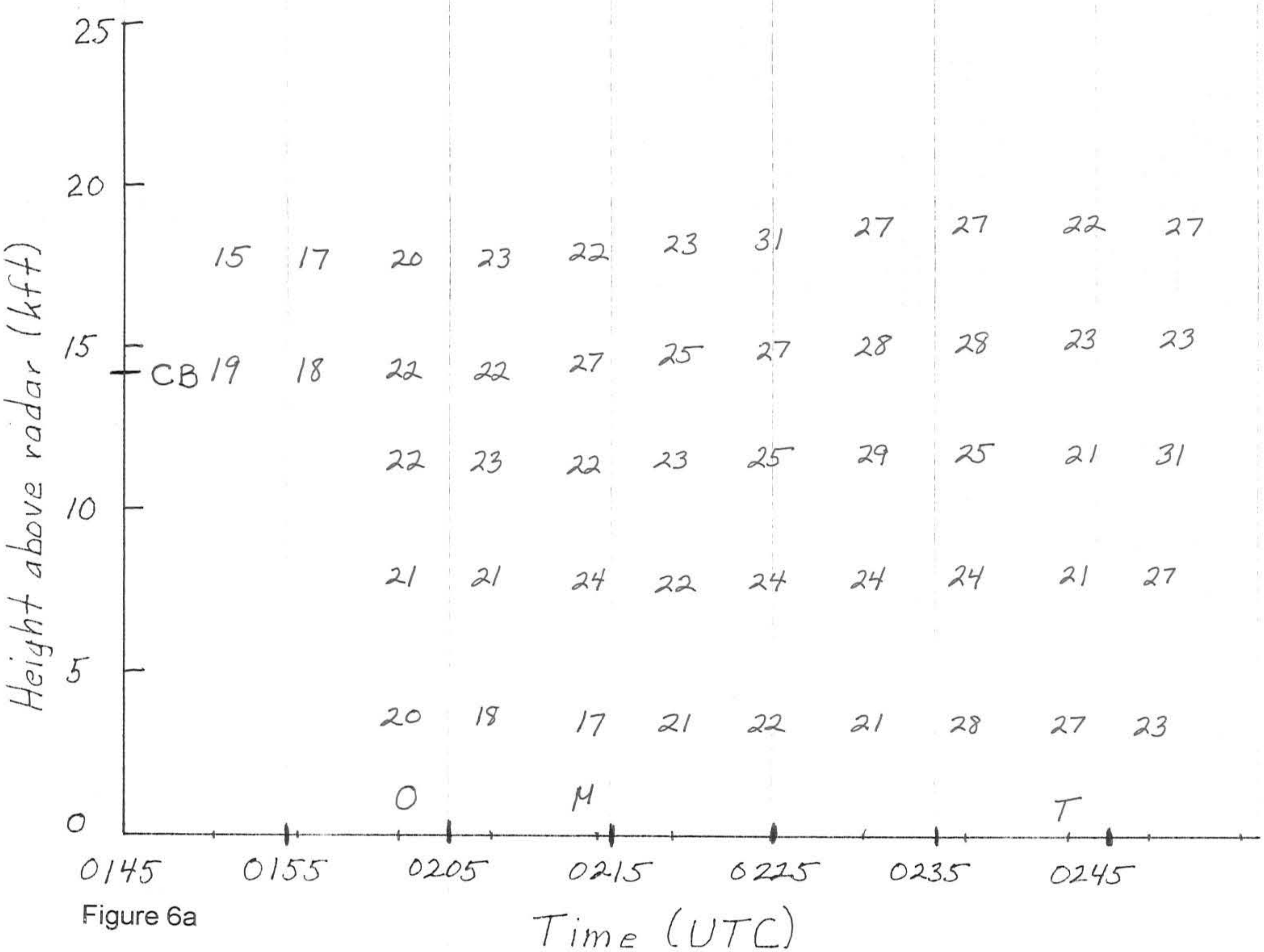
80
Horizontal Range (nmi)
Height above the radar (k ft)
4.5 deg
3.3 deg
2.4 deg
1.4 deg
0.5 deg
--- 26,000 ft (cloud top)
--- 16,300 ft (cloud base)


Height above radar (kft)
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19 18 22 22 27 25 27 28 28 23 23
22 23 22 23 25 29 25 21 31
21 21 24 22 24 24 24 21 27
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0145 0155 0205 0215 0225 0235 0245
Time (UTC)

Figure 6a

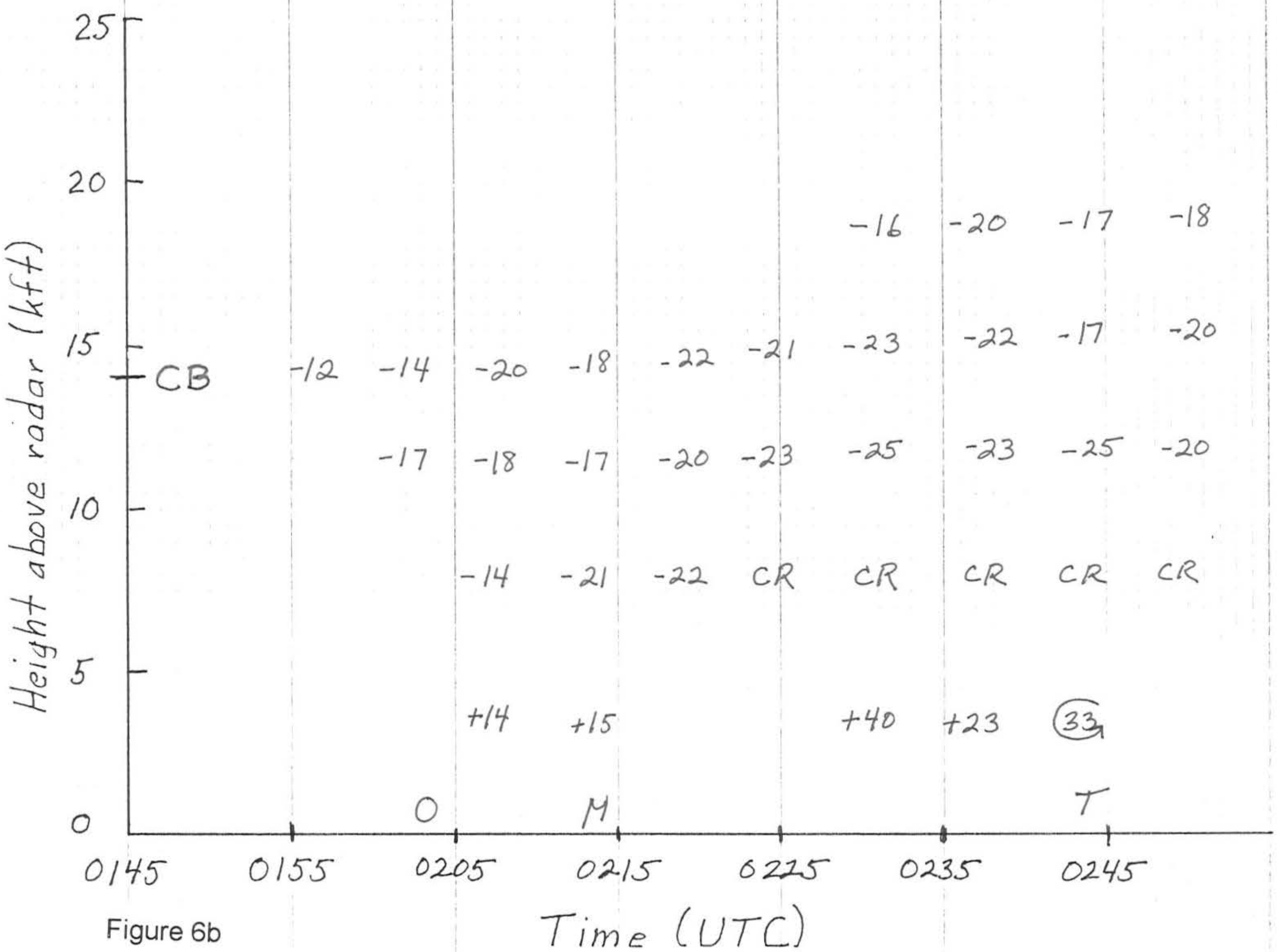

Figure 6b

Time-height plot for the Magna storm of a) the maximum reflectivity (dBZ) and b) maximum radial convergence (kt). The maximum allowable distance for determining the convergence was 5 nm. The times of the initial outflow at Magna, peak wind at Magna, and the 0.5 deg Doppler rotation signature are indicated by the O, P, and T, respectively. The cloud base height from the 00 UTC sounding (Fig. 2) is indicated on the left axis.