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THE LAS VEGAS CONVERGENCE ZONE: ITS DEVELOPMENT, STRUCTURE AND IMPLICATIONS FOR FORECASTING

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Introduction

Recent deployment of mesoscale data sets to operational meteorologists has afforded new opportunities to monitor and document local features which, prior to the routine availability of these data, had not been observable. However, coincident with the ability to observe such features is the challenge to understand the processes associated with their formation and subsequently, to improve forecasting their associated causes and effects. In particular, the formation of mesoscale convergence zones associated with the interaction between ambient wind flow and mountain barriers has been shown to have profound influence on local scale sensible weather (e.g., Tyson and Preston-White, 1972; Szoke et. al., 1984; Smolarkiewicz and Rotunno, 1989; Crook et. al., 1990). Under certain synoptic conditions, a mesoscale zone of low-level convergence and attendant boundary layer vorticity has been observed to form in the Las Vegas valley in southern Nevada. This paper will document the typical synoptic setting in which the convergence zone develops, then present a case in which explosive convective growth within the convergence zone resulted in a severe thunderstorm event over west Las Vegas. Other factors, such as upper-level forcing, moisture advection, etc., may also have played a role on this day. We will examine the mesoscale evolution and structure of the convergence zone during the afternoon of August 23, 1995 utilizing output from a nested high-resolution (4 km horizontal grid spacing on the fine nest) RAMS simulation initialized with real data. We compare the characteristics of this event with a conceptual model of the diurnal convective cycle that occurs in regions of complex terrain (Tripoli and Cotton, 1989) and draw some conclusions regarding practical implications for forecasting as a consequence of physical understanding.

Data Sources

Observational data sources for this study include the National Weather Service WSR-88D Doppler Radar, GOES-7 satellite imagery, synoptic surface observations and a mesonet of hydrometeorological ALERT gages maintained by the Clark County Regional Flood Control District. The latter consists of an array of 30 automated surface weather stations which transmit real-time temperature, wind, and rainfall data every 5 minutes. The network contains an additional 61 gages which measure rainfall only. That portion of the mesonet which records a full range of weather data is shown in Figure 1. The Radar Data Acquisition tower (RDA) for the WSR-88D is located at 4988 feet above mean sea level (MSL) on Nelson Peak, approximately 25 miles south of metropolitan Las Vegas. Nonhydrostatic mesoscale simulations in this study were conducted using version 3a of the CSU RAMS (Colorado State University Regional Atmospheric Modelling System) with permission from CSU and Mission Research Corporation. A detailed description of this model can be found in Pielke et al., 1992.

Local Geography

Las Vegas is situated in a north-south valley, the floor of which is approximately 2200 feet MSL. To the west are the Spring Mountains, which average about 6000 feet MSL, but include two peaks which are significantly higher: Mt. Charleston and Mt. Potosi, at 11,910 feet and 8,800 feet respectively. The crest of the Spring Range is 20-25 miles west of the valley floor. At the north end of the valley is the Sheep Range, topped by Hayford Peak at 9,912 feet. To the east and south are several isolated mountains which average 4500-6000 feet. Farther east, the terrain slopes downward rapidly into the Colorado River basin, then ascends again into the high mesa country of northwest Arizona. A detailed color view of the these topographical features over the southern Nevada portion of the local County Warning Area (CWA) is depicted in Fig. 2. This complex terrain creates an environment which significantly influences the local diurnal evolution of lower tropospheric circulations.

Observations

Periods of intense diurnal sensible heat flux are typical in the southwestern United States during summer. Under these conditions, if the background synoptic flow aloft is from the southwest and relatively light (i.e., 10-20 kts), a discrete zone of low level convergence has been observed to form across the Las Vegas valley. An investigation of several specific cases has revealed some interesting insights regarding the synoptic and mesoscale features governing this convergence zone's evolution. A classic example of such evolution occurred on August 23, 1995.

The synoptic setting for this date was characterized by a weak southerly flow of 5-10 knots within the boundary layer veering to a southwesterly flow of 15-20 kts above 700 mb. At 23/1200 UTC, a mid-tropospheric trough was located offshore Washington and Oregon with a weaker short wave of subtropical origin approaching the southern California coast (Fig. 3). A time section of omega from the 23/1200 UTC Eta model run indicates marginal synoptic forcing through the forecast period (Fig. 4).

The Desert Rock sounding from 23/1200 UTC indicated a layer of stable air up to about

2 km AGL superimposed by a nearly neutral layer extending to about 400mb. Total column static stability was moderately low as evidenced by lifted index values of -2 to -4, and a 700-500 mb lapse rate of -6.9 deg C km-1 (Figs. 5 and 6).

A narrow region of convective instability was present on the sounding between 600-400 mb. Low level moisture values were initially modest (surface dewpoints in the northern portion of the valley were near 50 deg F). However, just above the surface, southerly flow had transported high values of moisture northward from the Gulf of California. The 310-315K isentropic layer, for example, showed mixing ratios greater than 11 g Kg-1 through the lower Colorado River valley (Fig. 7). Dewpoints in the 60s were common throughout the area by early afternoon, apparently the result of this elevated moisture mixing downward as heating caused the low-altitude isentropes to intersect the surface.

Until late morning, wind sensors from the Clark County mesonet indicated a light southerly surface flow throughout the Las Vegas valley. As the day progressed, the mesonet depicted development of a distinct zone of low level convergence. This boundary extended east-west from the Lake Mead National Recreation Area across the southern portion of the Las Vegas valley, then veered to a more north-south alignment along the eastern foothills of the Spring Mountains, where strengthening upslope impinged on the ambient southwesterly flow. By 1500-1600 UTC, a convective boundary layer had developed although it appeared to be suppressed by a capping layer up to around 2 km AGL. This was evidenced by the structure of radar echoes on the WSR-88D, and was reinforced by the high-resolution RAMS simulation. As the heating continued, the convective boundary layer moistened and deepened in response to the intensifying low level upslope flow.

Radar and satellite imagery indicated the initial development of deep convection around 1800 UTC over the Spring Mountains and Sheep Range, as well as the smaller McCollough range to the south. The southern arm of the convergence zone remained oriented east-west, but had drifted northward from its genesis area. The northern extension of the boundary had shifted to the east, displacing the primary source of lift and vorticity within the convective boundary layer toward the valley. A pocket of cooler air aloft, ostensibly created by the lifting of moist air within the convergence zone, is evident on the RAMS simulation by 2000 UTC. Directly downstream from this cold pool is an area of strong subsidence which is superimposed on the lee pressure trough. Thus the mountain-valley solenoid was acting to locally destabilize the atmosphere as vertical motion increased within its upward branch.

Scattered thunderstorms continued to develop over the higher terrain between 1800-2100 UTC with an average movement of 220 degrees at 12 knots. Maximum Reflectivity and Vertically Integrated Liquid (VIL) values during this period were in the range of 45 dBZ and 35 Kg m2-1 respectively. These cells were short-lived convective elements, apparently forced by local flow regimes, which subsequently moved away from their formative source of moisture convergence.

At 2144 UTC, a thunderstorm moved into west Las Vegas intersecting the convergence zone. Within 12 minutes, reflectivity increased from 40 to 67 dBZ and VIL escalated from 25 to 63 Kg/m2 (Figs. 8 and 9). The corresponding storm relative velocity map indicated cyclonic rotation in the lowest four elevation angles (Fig. 10 shows the 0.5 degree elevation angle). A cross-section of the storm from 2156 UTC depicted a VIP5 core (i.e., reflectivity in excess of 50 dBZ) suspended to 26,000 feet above radar level (ARL), with precipitation echo extending to 43,000 feet ARL (Fig. 11). The radar indicated storm top divergence at 50-60 knots. Based on this trend, a severe thunderstorm warning was issued for western Clark County at 2159 UTC. A few minutes later, the reflectivity core descended rapidly to the surface as depicted on the 2208 UTC cross-section (Fig. 12). From 2215-2230 UTC, numerous reports of hail up to one inch in diameter and damaging downburst winds were received. The exceptional development of this storm, being coincident with its intersection of the existing convergence zone, suggests the possibility that the convective updraft of the thunderstorm took control of the mountain-valley solenoid's up-branch, deepening it to tropopause level within minutes. This instantaneous surge of moist lift and vorticity was arguably the primary factor in its observed explosive growth.

Discussion and Conclusions

Initial simulations of the convergence zone focused on the contribution made by terrain blocking in low Froude number flow. These simulations, run at 12km horizontal resolution without solar insolation, produced a broad zone of weak convergence oriented east-west through the center of the Las Vegas valley, which fed into a cyclone located approximately 60km northeast of Las Vegas in the vicinity of Moapa (Fig. 13). While similar in some respects to the expected development, it did not reproduce the structure observed on the mesonet during classic convergence zone events.

Fig. 13. Surface winds over southern Nevada from dry, horizontally homogeneous RAMS simulation with no radiation. Horizontal resolution=12km.

Subsequent simulations were nested to 4km horizontal resolution on the fine nest, executed with full radiation and initialized with real data. These results, which are identical to the evolution of the wind field observed on the mesonet data (Fig. 14), suggest that the modulation of the background shear by the diurnal mountain-valley solenoid plays a key role in the life cycle of this convergence zone. Cross-sections of the convergence zone at 23/2100 UTC reveal a complete vertical solenoidal circulation with boundary layer vorticity values on the order of 10-3 s-1 in the up-branch and substantial divergence near the barrier top (Fig. 15).

This evolution is consistent with the diurnal convective cycle documented over the Front Range of the Rockies (Tripoli and Cotton, 1989; Wolyn and McKee, 1994). The evidence suggests that this convergence zone can act as an important and identifiable source of concentrated vorticity and vertical motion for developing convective towers. This process can be viewed as linkage between convective updrafts and the up-branch of a mature mountain-valley solenoid (Fig 16). Physical and conceptual understanding of this interactive process should improve the capability to forecast its impact on similar convective events in the future.

Furthermore, it has been shown that the vertical circulation associated with these orogenic solenoids can remain intact for several hours after the initial breakdown and decoupling phase forces them away from the genesis zone. Thus as the circulation drifts downstream, it can continue to influence convective organization by geostrophically inducing low level cyclonic shear beneath anti-cyclonic shear aloft. Specific investigation of this process in the Desert Southwest is a topic for further study.

References

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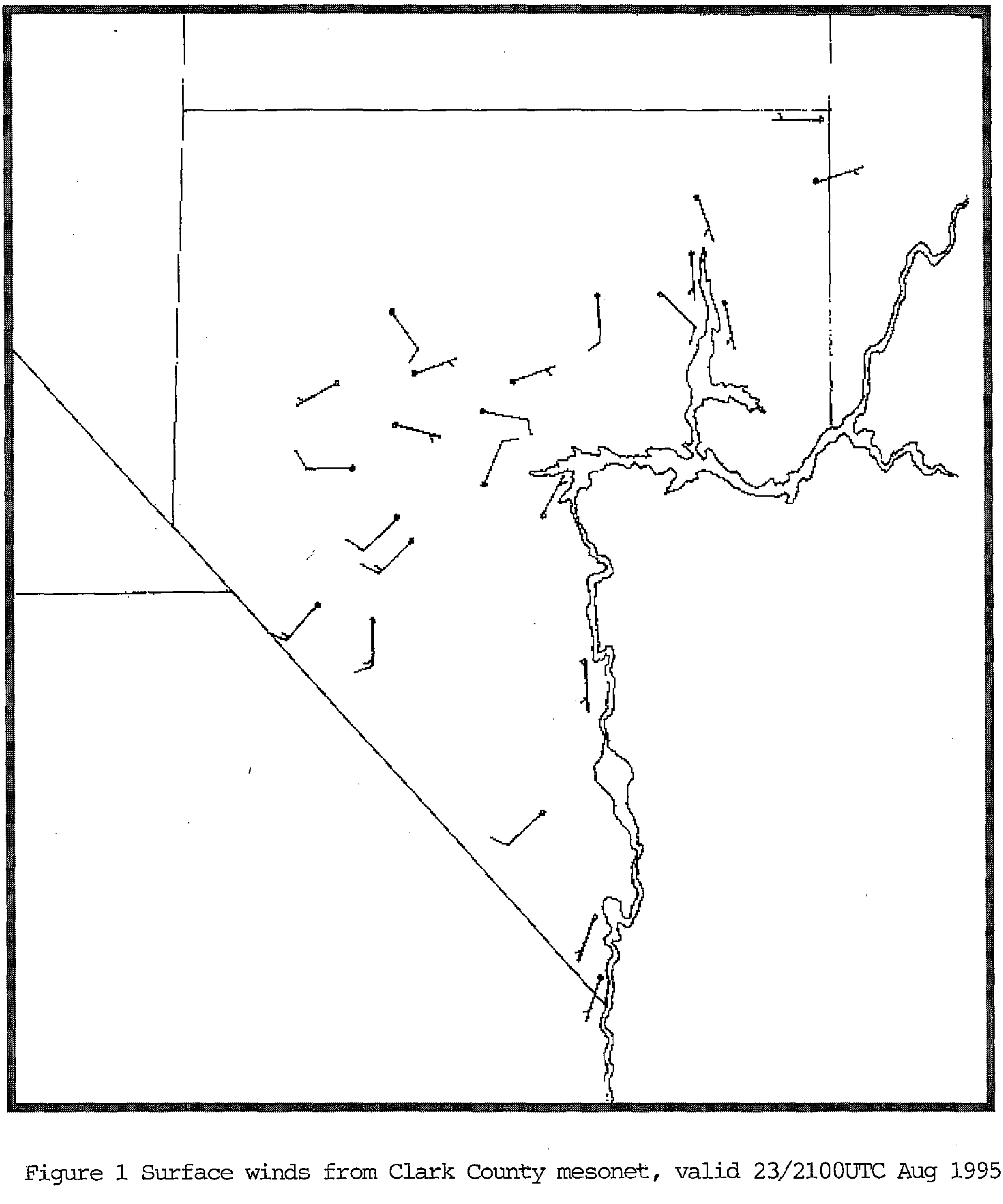


Figure 1 Surface winds from Clark County mesonet, valid 23/2100UTC Aug 1995.

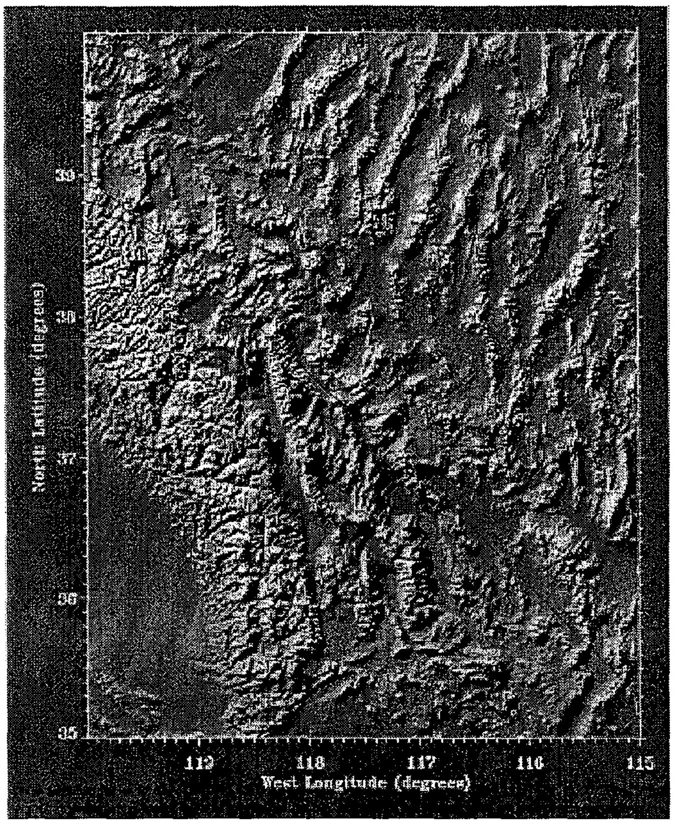


Figure 2 Detailed topo map of souther Nevada and Southeastern California.

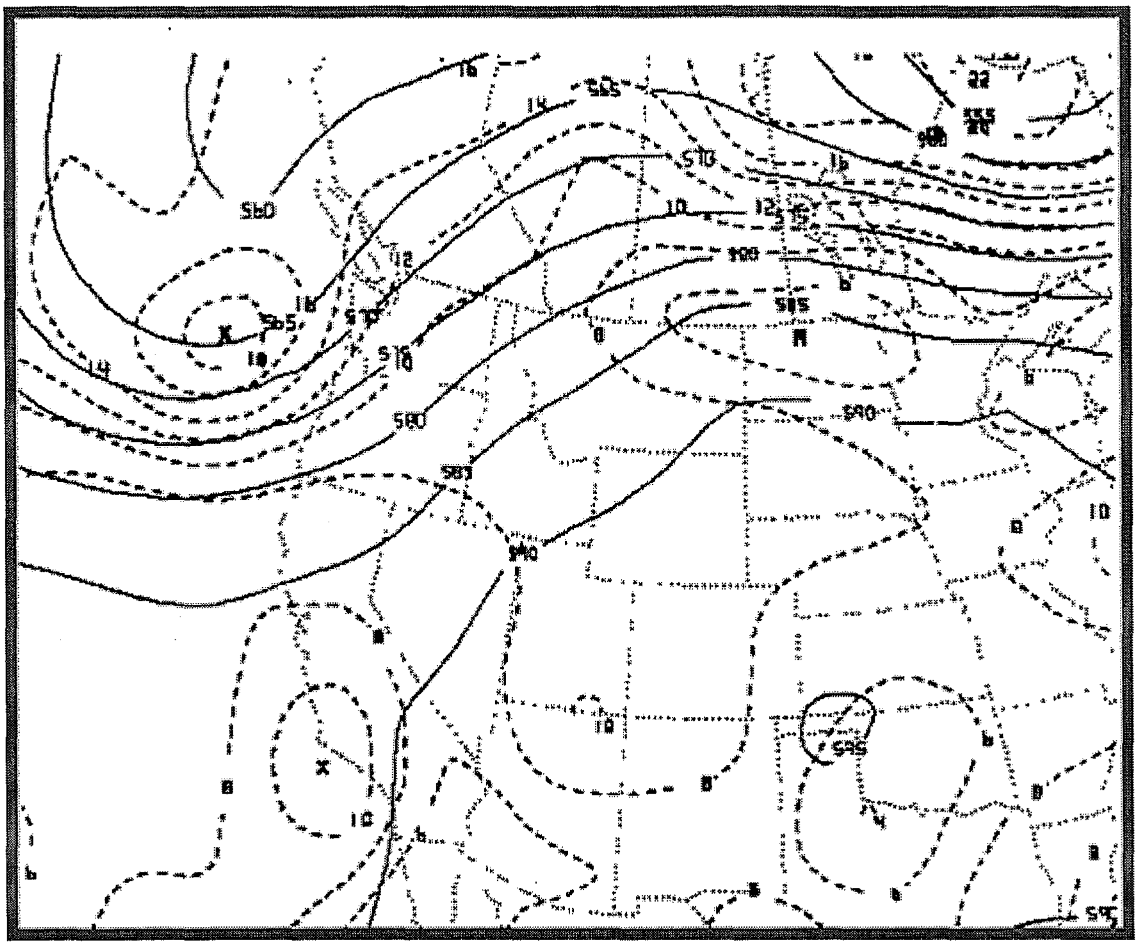


Figure 3 Eta model 500mb analysis, valid 23/1200UTC, August 1995.
Solid lines=geopotential heights in dm;
Dashed lines=absolute vorticity

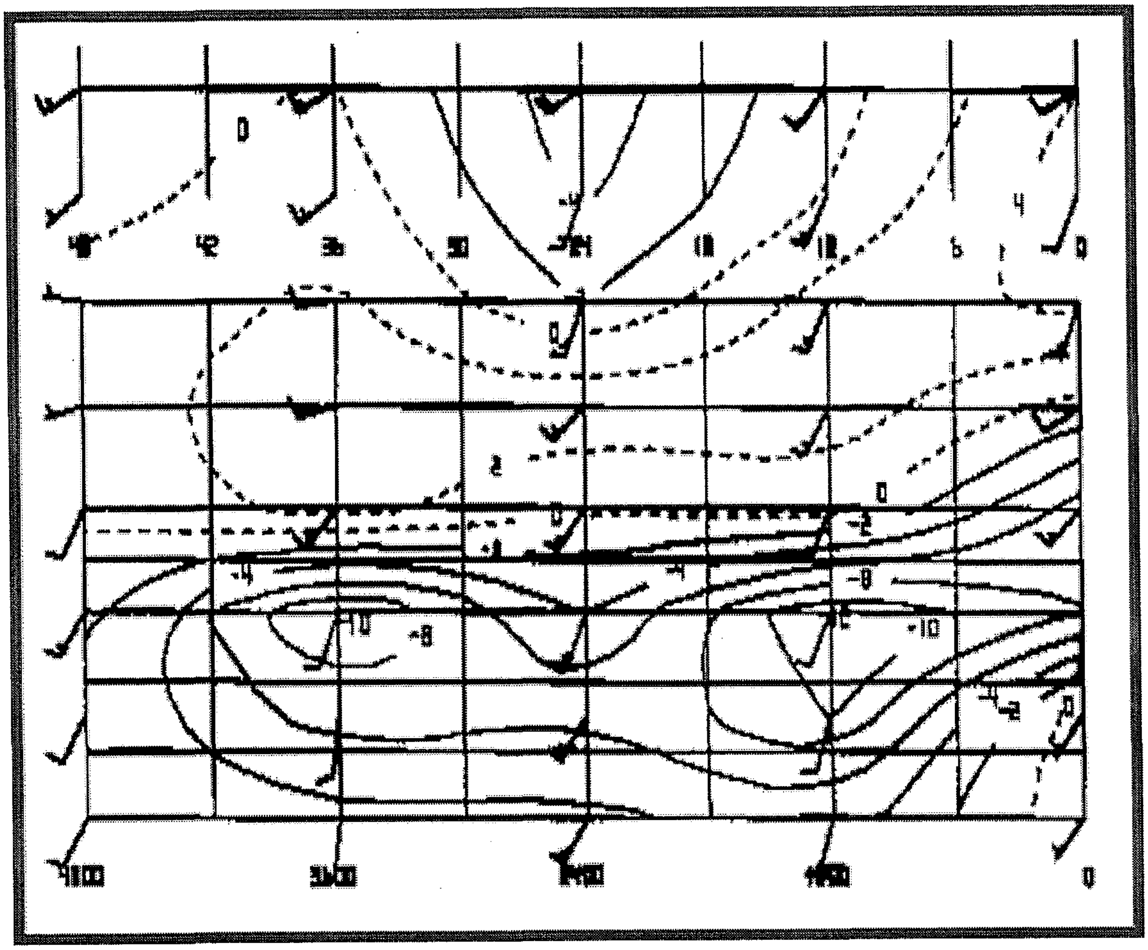


Figure 4 Eta time section of omega over Las Vegas, Valid 23/1200-25/1200 UTC August 1995
Abscissa = time in hrs
Ordinate = pressure in mb

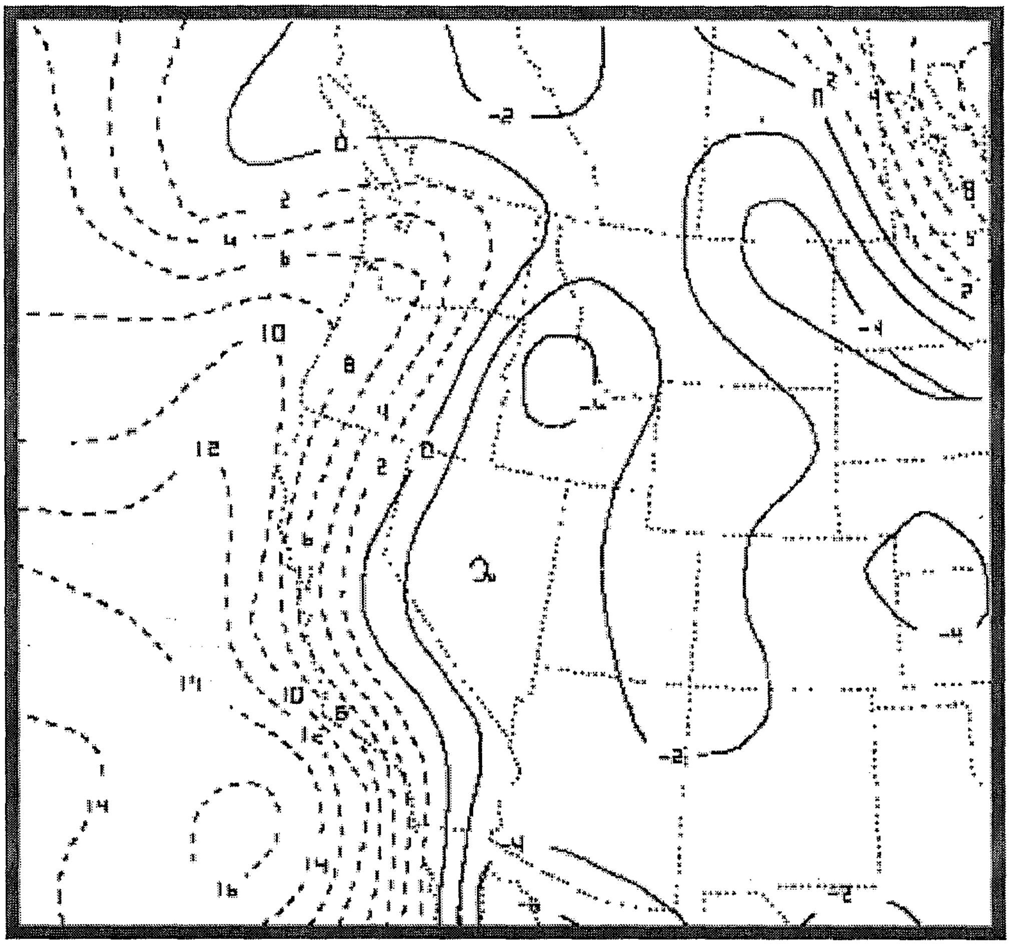


Figure 5 Lifted Index (degrees,C), valid 23/1200 UTC August 1995

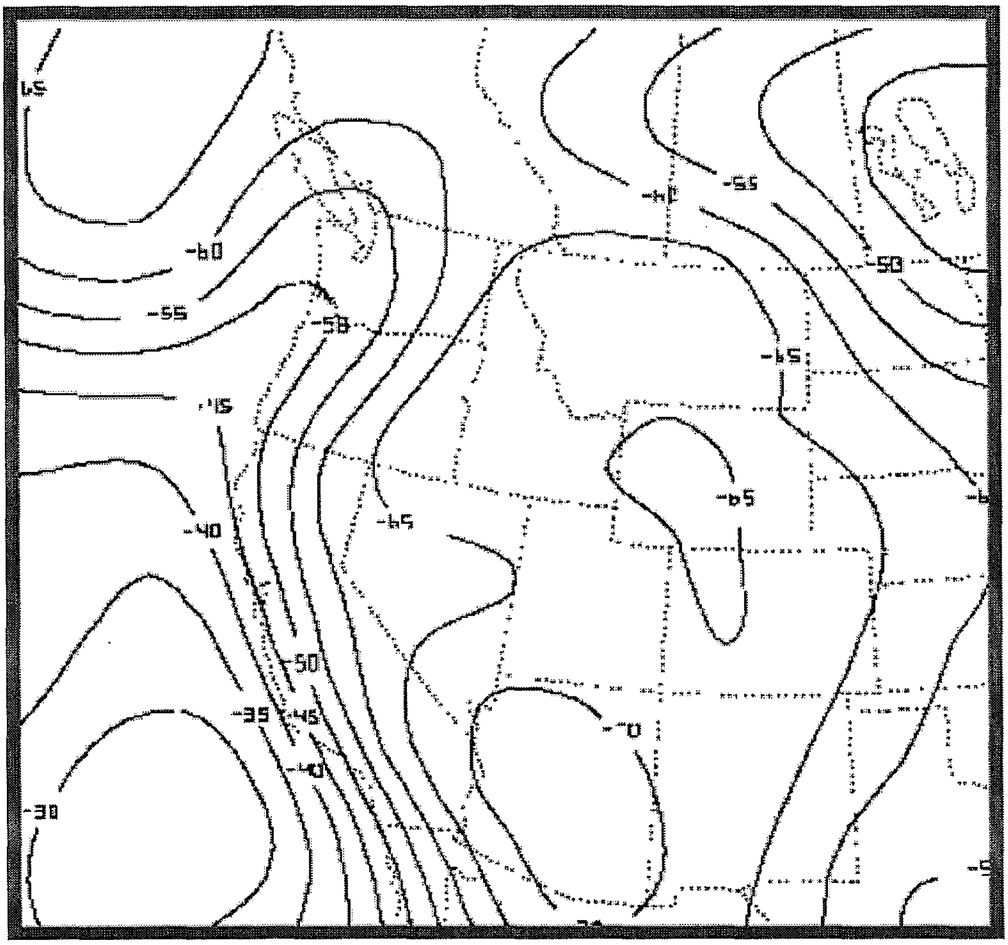


Figure 6 Lapse rate, 700-500mb, valide23/1200 UTC August 1995

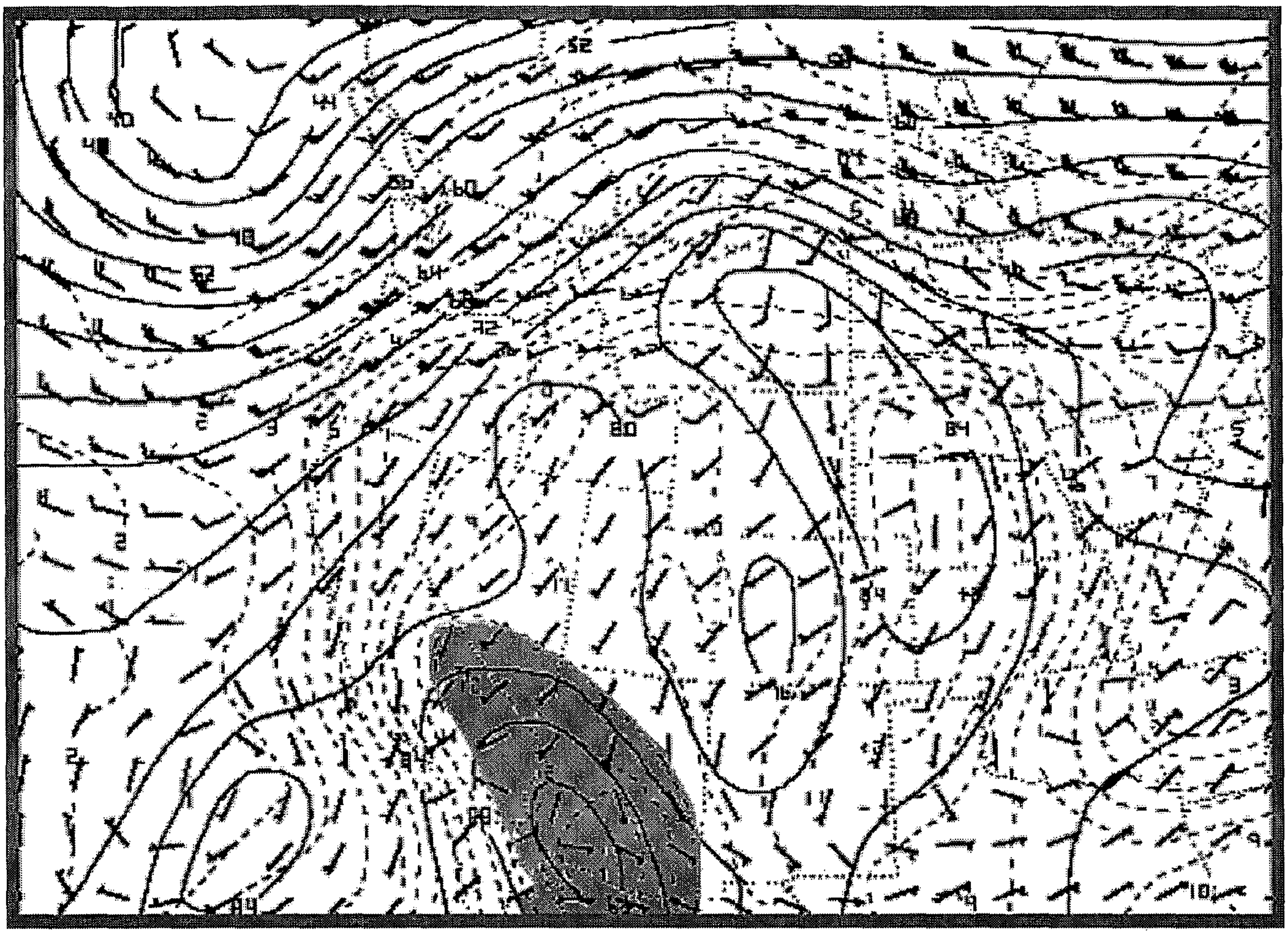
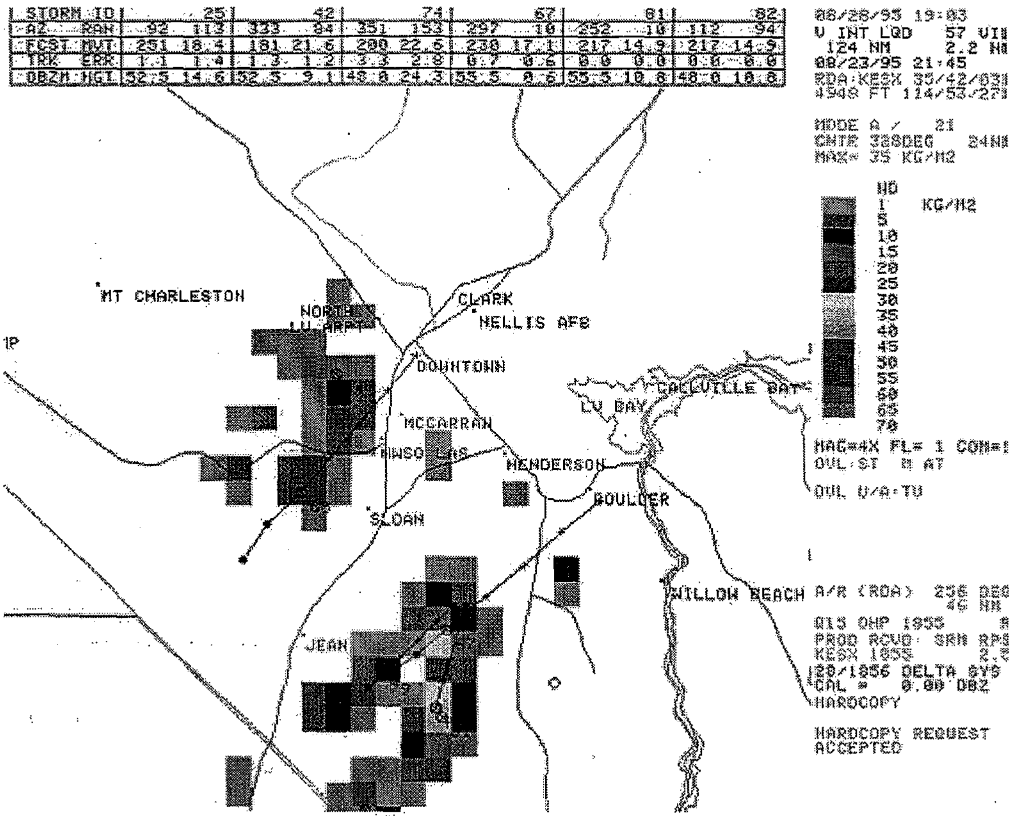


Figure 7 310-315K iawntropic layer at 23/1200 UTC August, 1995.
Solid lines = pressure in mbx10
Dashed lines = mixing ration in g Kg-1 with values >11g Kg-1 in green
Winds bars plotted kts



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AZ RAN	92 113	333 84	351 153	297 10	252 10	112 94
FCST MVT	251 18.4	181 21.6	200 22.6	238 17.1	217 14.9	217 14.9
TRK ERR	1.1 1.4	1.3 1.2	3.3 2.8	0.7 0.6	0.0 0.0	0.0 0.0
DBZM HGT	52.5 14.6	52.5 9.1	48.0 24.3	55.5 0.6	55.5 10.8	48.0 10.8

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08/28/95 19:03
V INT LQD    57 VI
 124 NM      2.2 N
08/23/95 21:45
RDA:KESX 35/42/03
4940 FT 114/53/27

MODE A /    21
CNTR 338DEG    24N
MAX= 35 KG/M2

MAG=4X FL= 1 COM=
OVL:ST  N AT
OVL V/A:TV

A/R (RDA)  256 DEG
             46 NM

015 OHP 1955      
PROD RCVD: SRM RP
KESX 1955        2.
120/1856 DELTA SYS
CAL =   0.00 DBZ
HARDCOPY

HARDCOPY REQUEST
ACCEPTED
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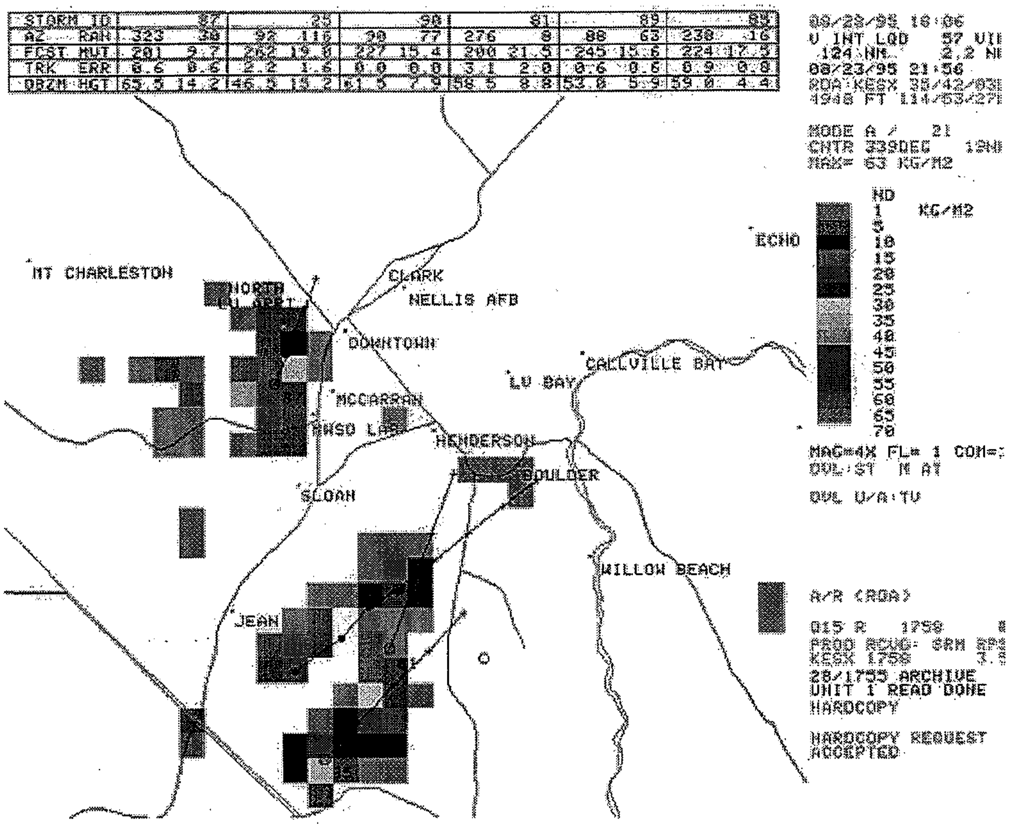
Figure 8 KESX WSR-88D Vertically Intregrated Liquid estimates, 23/2144UTC Aug96.



STORM ID	87	25	90	81	89	83
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FCST MVT	201 9.7	262 19.0	227 15.4	200 21.5	245 15.6	224 17.5
TRK ERR	0.6 0.6	2.2 1.6	0.0 0.0	3.1 2.0	0.6 0.6	0.9 0.8
DBZM HGT	65.5 14.2	46.5 15.2	61.5 7.9	58.5 8.8	53.0 5.9	59.0 4.4

Figure 9 KESX WSR-88D Vertically Integrated Liquid estimates, 23/2156UTC Aug 95

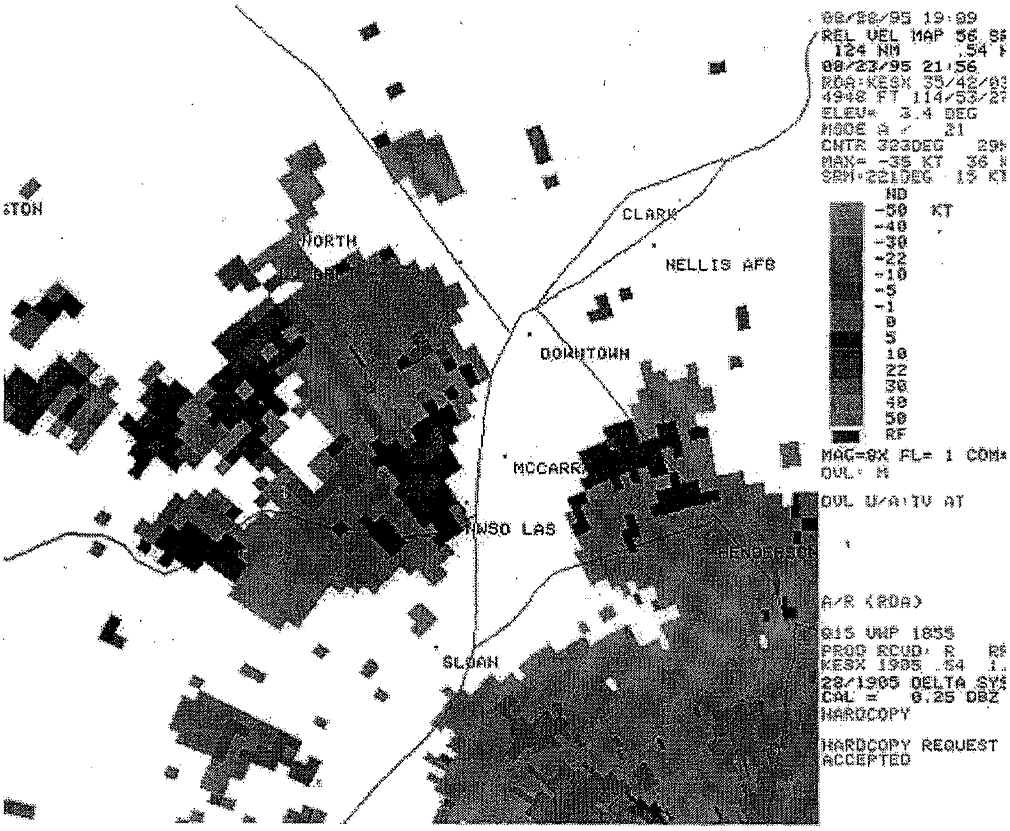
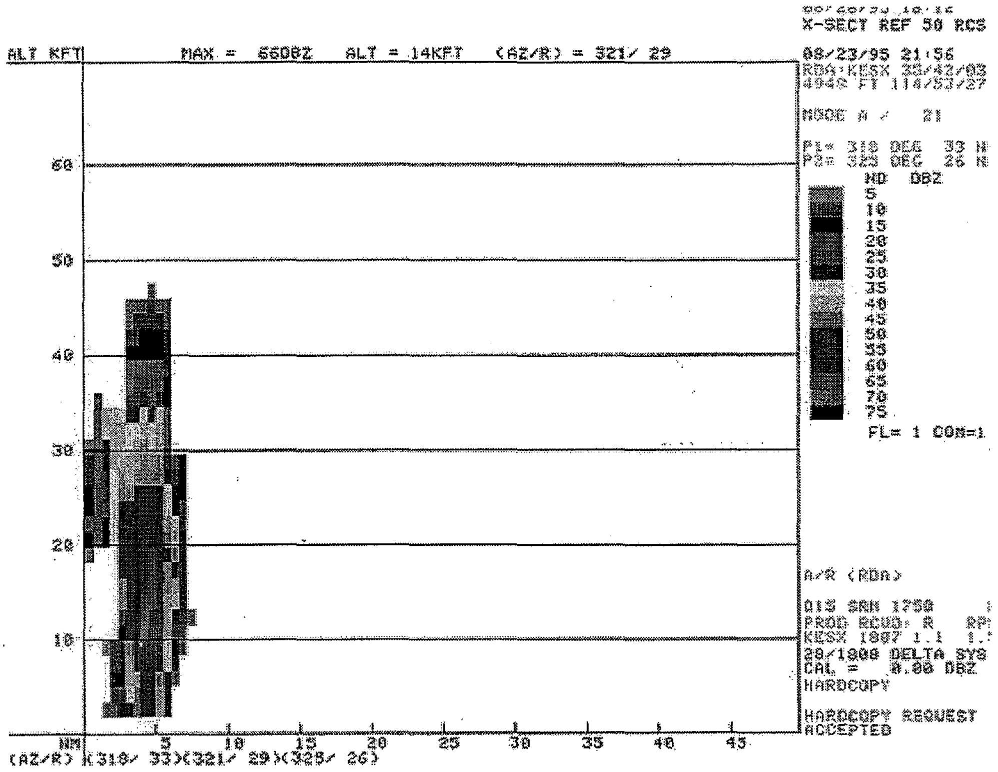


Figure 10 KESX WSR-88D Strom Relative Velocity Map at 0.5 degrees elevation, 23/2156 UTC Aug 1995.



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RDA:KESX 35/42/03
4948 FT 114/53/27

MODE A / 21

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P2= 325 DEG 26 N

A/R (RDA)

DIS SRN 1759
PROD RCVD: R RP
KESX 1997 1.1 1.
29/1900 DELTA SYS
CAL = 0.00 DBZ
HARDCOPY

HARDCOPY REQUEST
ACCEPTED
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Figure 11 KESX WSR-88D Reflectivity Cross-Section, 23/2156 Aug 1995

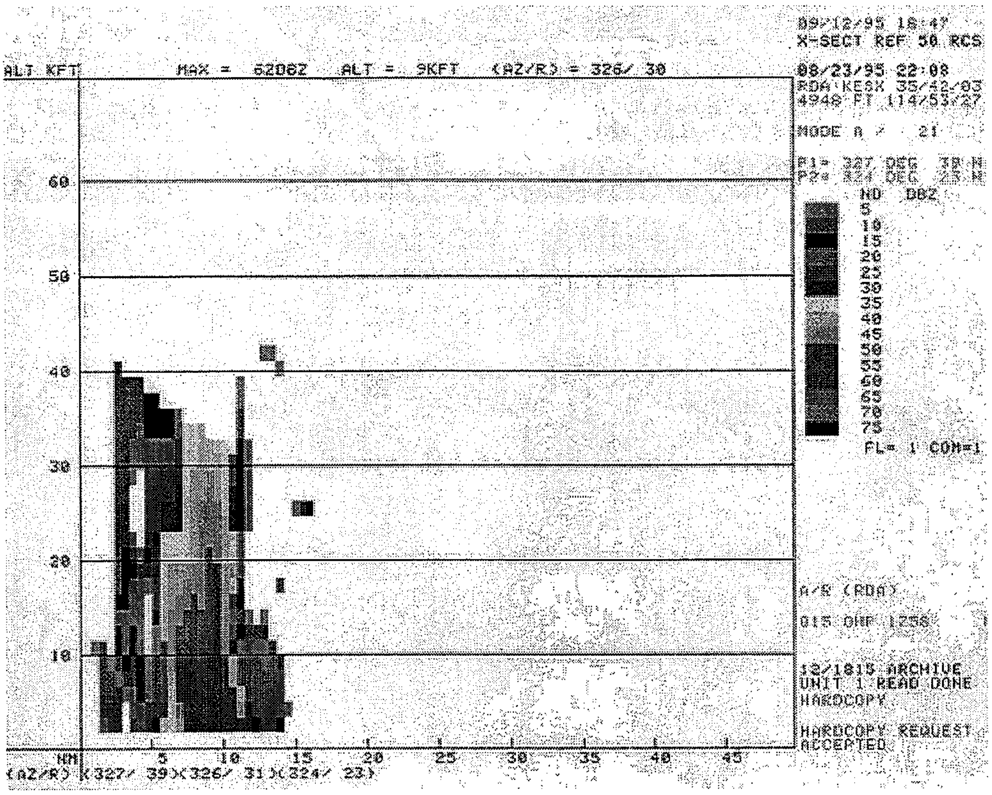

Figure 12 KESX WSR-88D Reflectivity Cross-Section, 23/2156UTC Aug 199

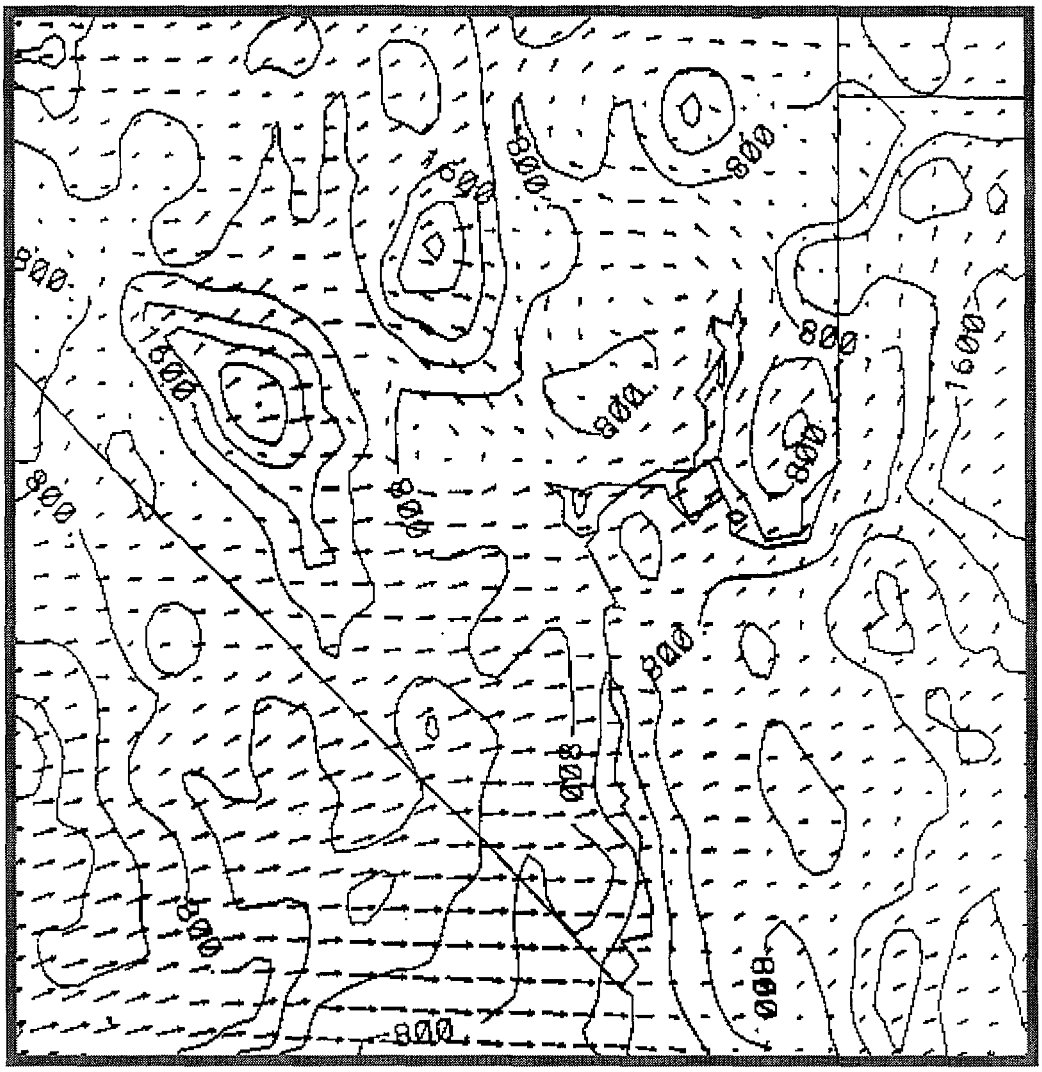

Figure 13 Surface winds over southern Nevada from dry, horizontally homogeneous RAMS simulation with no ratiation. Horizontal resolution = 12 km

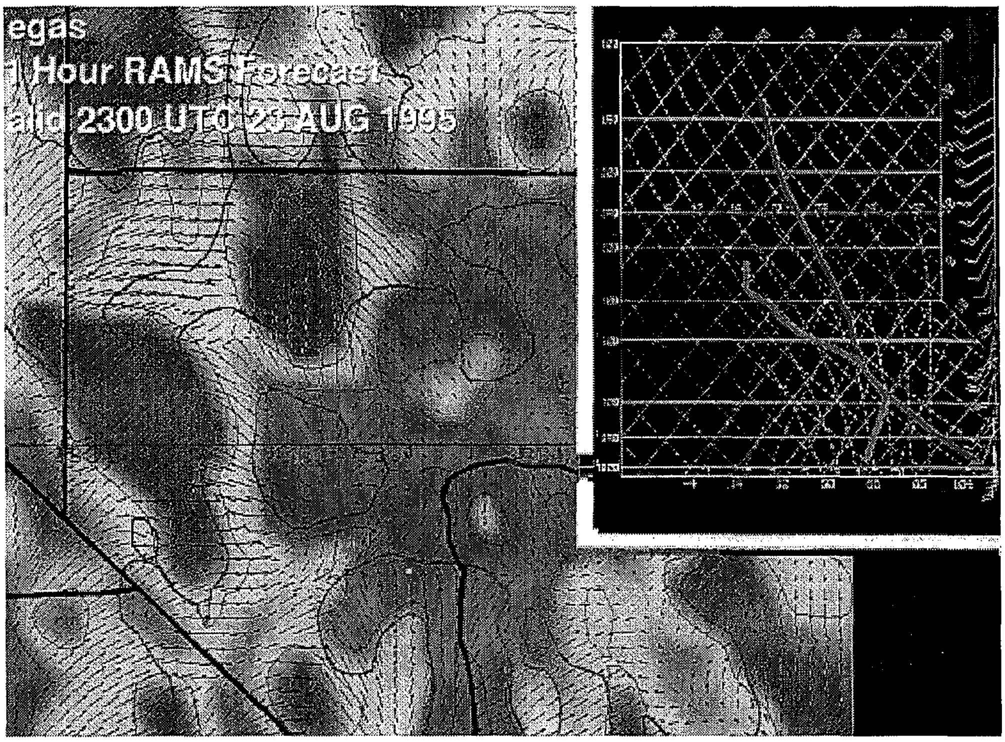

Figure 14 Surface winds over souther Nevada from 4km RAMS simulation,
valid 23/2100UTC Aug 1995
Insert = model sounding for Las Vegas

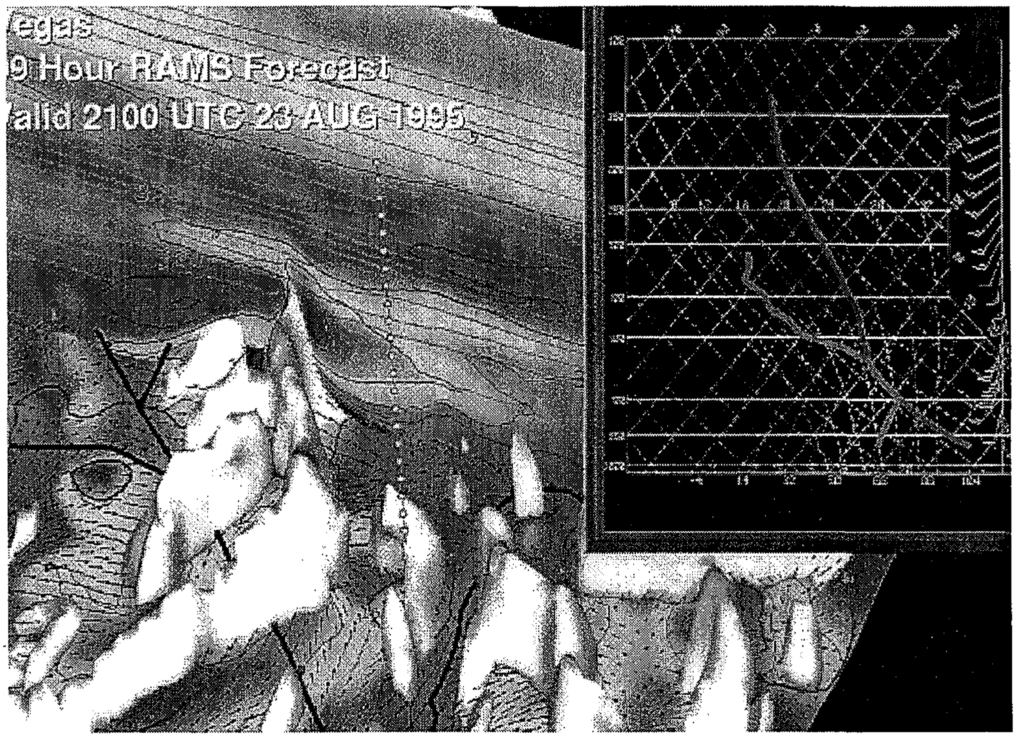

Figure 15 Tilt view of winds and isentropes from 4km RAMS simulation,
valid 23/2100UTC Aug 1995.
Insert = model generated inflow sounding.
Isosurface represents upward vertical velocity greater than11 m s-1.

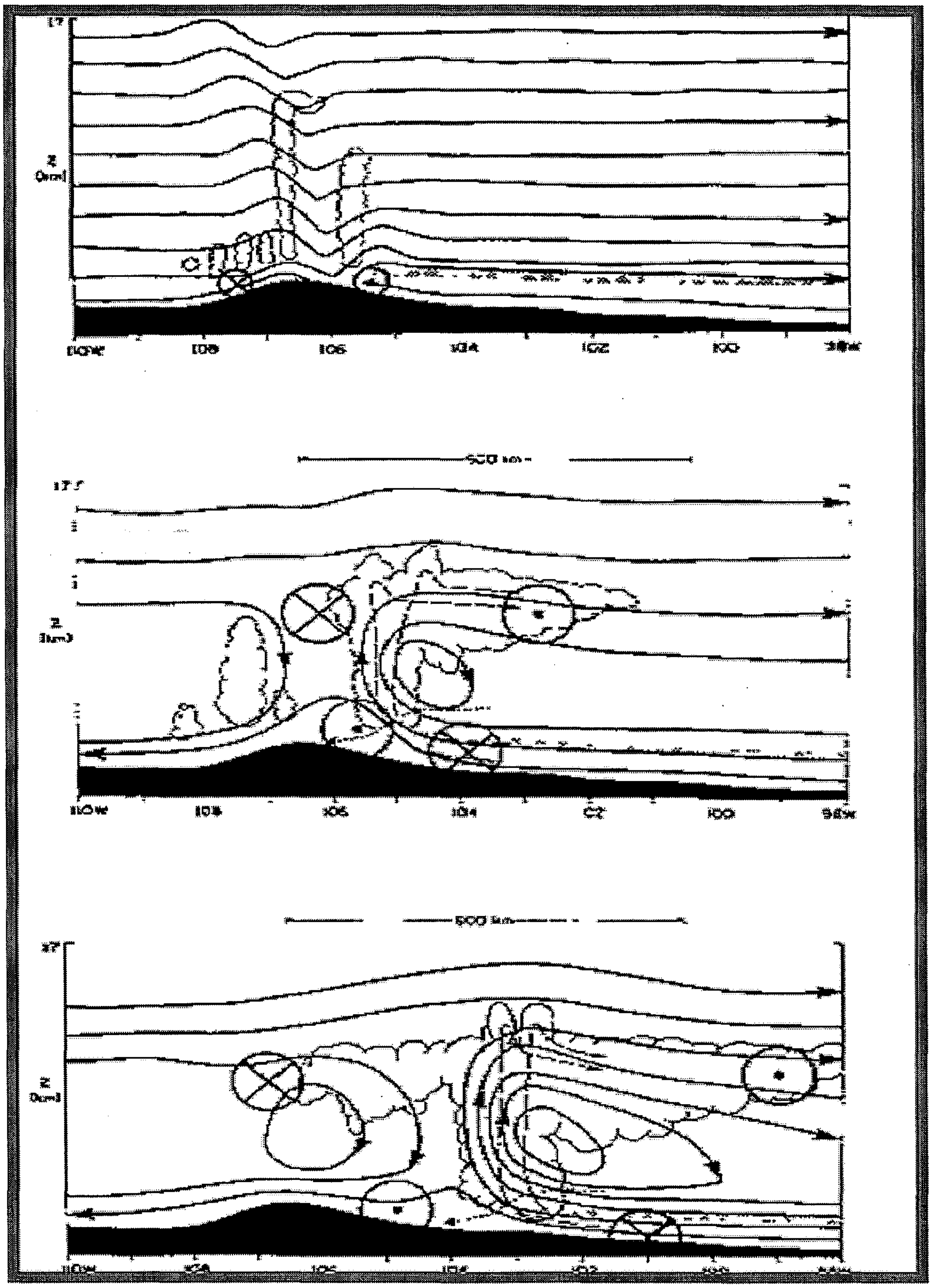

Figure 16 Conceptual diagram of diurmal convective cycle in complex terrain (taken from Tripoli and Cottom, 1989). Top panel represents initial convection over the mountains. Middle view depicts linkage between convective updrafts an and the mountain-valley solenoid. Bottom panel illustrates vertical decoupling and horzontalddownwind growth of the solenoid.