Analysis of the Western Arizona/Eastern California Hail and Tornado Event of August 7th, 1997

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Abstract

Severe storms are not uncommon over the Desert Southwest in the summer months as a result of the North American Monsoon. On 7 August 1997, a line of storms formed in central and western Arizona that produced reports of hail and flash flooding over western Arizona, and later merged with a tornadic cell over eastern California. In this paper, I will look into the conditions that sparked these storms and caused them to develop in to severe thunderstorms and supercells.

Introduction:

On the afternoon of 7 August 1997, a line of strong to severe thunderstorms developed over the region of the Arizona-California border. This line of convection stretched across nearly the entire state of Arizona and was responsible for several severe weather reports throughout both states. These cells that formed in the late afternoon and early evening produced a pair of hail reports in western Arizona as well as a funnel cloud and F0 tornado in southeastern California. In this paper, I will analyze the conditions that led up to the severe weather over the AZ-CA border region. I will present evidence how the storms were able to develop under synoptic conditions that were not as conducive for supercell development compared to a case of a Great Plains supercell. However, there were sufficient meso-beta and meso-alpha forcings to support the storms. In lieu of traditional synoptic forcings, I will show that these storms began as "popcorn convection" and over the course of the evening became organized into a line of cells by convergent winds along the Mogollon Rim of the Colorado Plateau. I will show that once these storms began to develop, there were moderately good conditions for supercell development that produced the medium to large hail and the brief tornado.

Data:

In my analysis of this severe weather event, I used various data sources. To look at the synoptic-scale features, I used the GOES-8 (visible) satellite as well as archived upper-air plots of the US from Unisys Weather. In my mesoscale analysis, I used WSR-88D radar output from the ESX and IWA radar stations. In addition, I used analyses and short-term forecast data from the MesoETA model.

Synoptic Overview:

On the 7th at 12Z, the synoptic scale features (figure 1a) were quite "fair weather." The surface analysis shows a low pressure center over the

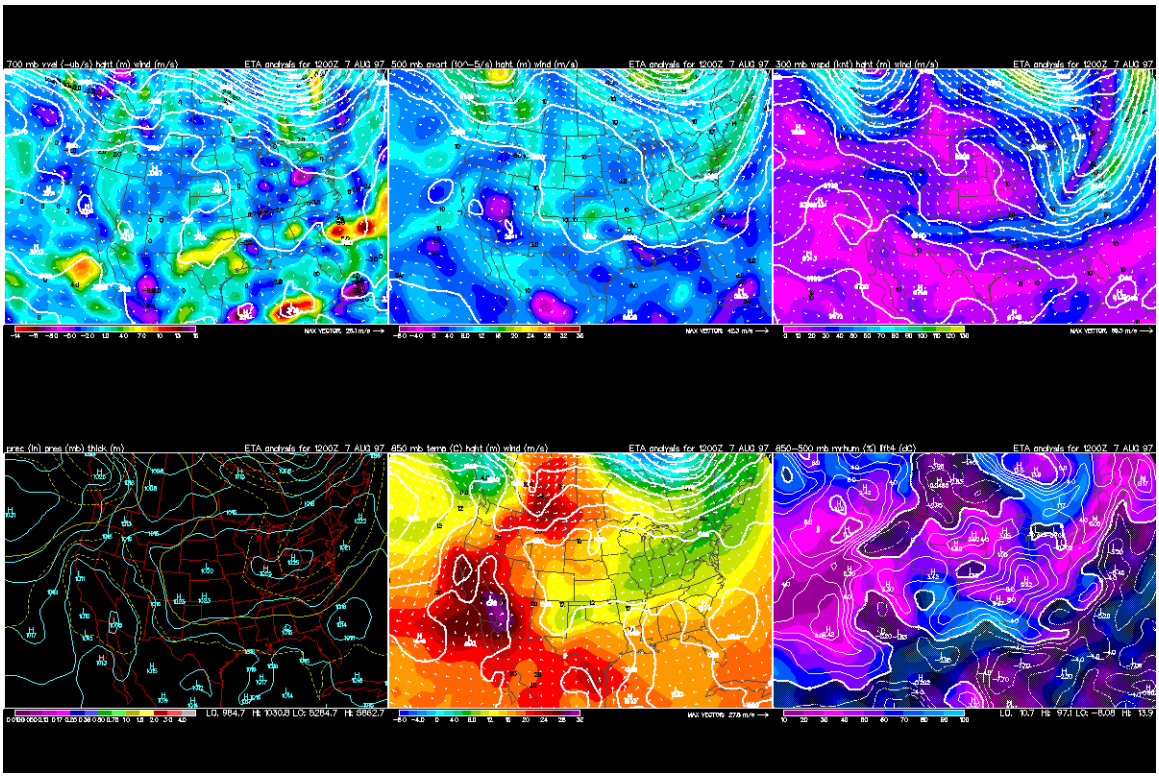

Figure 1a: Surface and upper-air plots from the Eta model analysis at 12Z 7 Aug 1997

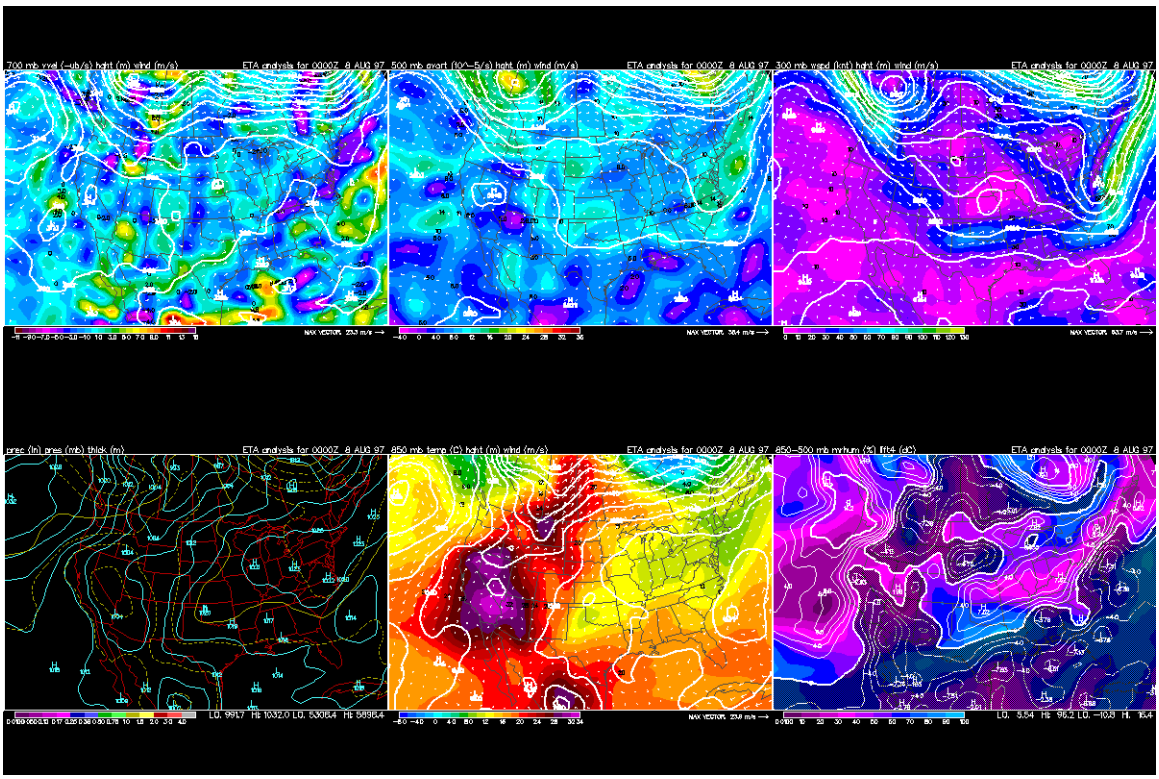

Figure 1b: Surface and upper-air plots from the Eta model analysis at 00Z 8 Aug 1997

southern AZ-CA border. This low is a classic "heat low" and is a prevalent feature over the Desert Southwest during the summer months. The warm temperatures over the region are quite clear in the 850mb analysis, with temperatures in the 28-32 degC range. The 700mb and 500mb analyses show that there is a weak high pressure center over the same region, with a very weak anticyclonic flow in association with this high. The 300mb analysis shows relatively stagnant flow in the upper levels, and there is no defined jet streak within at least 1000km of the southwestern US, therefore there is no chance for any form of dynamic lifting due to the ageostrophic winds of jet streaks. With these upper level conditions, one would not expect to see much convection. However other features such as the relative humidity and lifted index values are much more conducive. In the 850-500mb RH/LI analysis, there are moderate relative humidity values over the Arizona region in the range of 30-40% and the lifted indices are in the range of -2 to -3, which shows that the mid-levels of the atmosphere have moderate instability in the early morning hours before any sort of daytime heating has begun.

The 00Z analysis (figure 1b) on the 8th shows that the heat low at the surface has remained over the region throughout the day, and the 850mb temperatures increased to 34 degC in the region where the storms were occurring. The 700mb analysis shows little change in the flow pattern at that level but there exists a region of predicted upward velocity of -4 to -6 ub/s over western Arizona, which implies that rising motion and moderate convection were likely in this region. The 700mb map also shows that the high pressure located over California and Nevada has remained throughout the day. This high shows up on the 500mb analysis as well and the general flow at both 700 and 500mb is from the north-northwest. The 500mb map shows very little in the form of mid and upper level vorticity, which means that any vorticity generated by the heat low must be confined to the surface and low levels. Like the 12Z analysis, there are light winds at the 300mb level and no distinct jet streak in the region. The RH/LI analysis shows the mid-level air over the region is still fairly dry, with relative humidities in the 30% range and lifted indices increased to -6 and -8 degC over some areas of Arizona. This set-up is similar to that of the "loaded gun" sounding, although in this case there are lower humidities in the boundary layer than with a classic "loaded gun." These conditions reflect that low pressure at the surface could potentially initiate vertical motion and that there would be moderately favorable conditions aloft for buoyant parcels to continue rising if they are lifted high enough.

Mesoscale Analysis:

August 7th was marked by mostly fair weather throughout the morning and early afternoon, with clear skies over much of western Arizona. However, as I have shown in the previous section, lifted indices were conducive for buoyant and convective motions over the region. The clear skies throughout the first part of the day allowed for maximum surface heating. This resulted in theta-e values reaching into the low to mid 340's in degK in the 15Z MesoETA analysis (figure 2a).

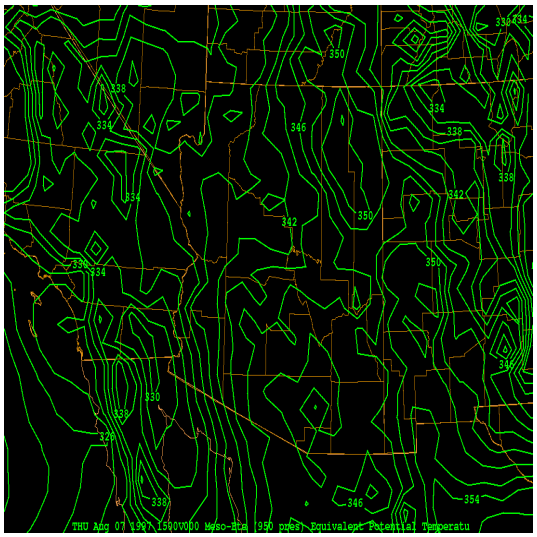

Figure 2a: 950mb theta-e from the Meso-Eta model analysis at 15Z 7 Aug 1997

The MesoETA forecast for the rest of the day called for theta-e values to reach the 350's and low 360's degK by 21Z (figure 2b). These high theta-e values were driven primarily by the warm surface temperatures since there was only a moderate amount of available moisture in the low levels of the atmosphere.

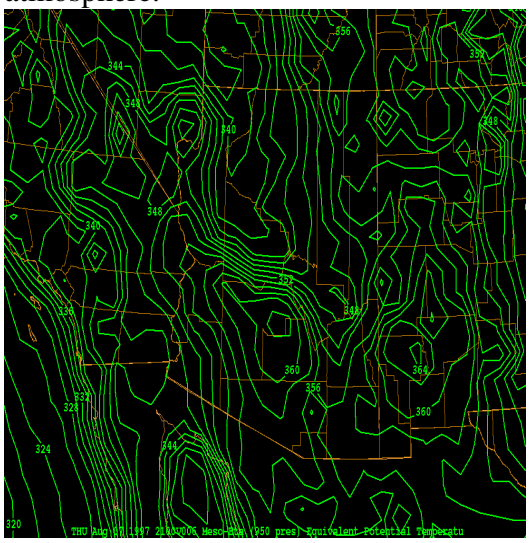

Figure 2b: 950mb theta-e from the Meso-Eta model forecast valid 21Z 7 Aug 1997

Earlier in the day at 15Z, the highest relative humidities were confined to the southernmost part of Arizona. At 15Z, RH only ranged from 24-32 over the AZ-CA border region (figure 3a)while the 9-hour MesoETA forecast called for RH levels to remain nearly identical by 00Z (figure 3b).

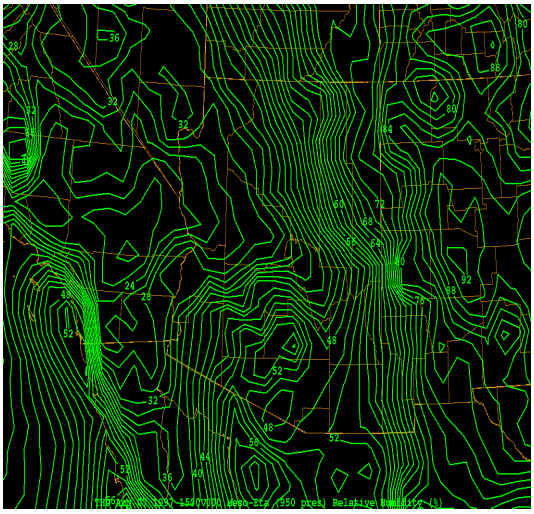

Figure 3a: 950mb relative humidity from the Meso-Eta model analysis at 15Z 7 Aug 1997

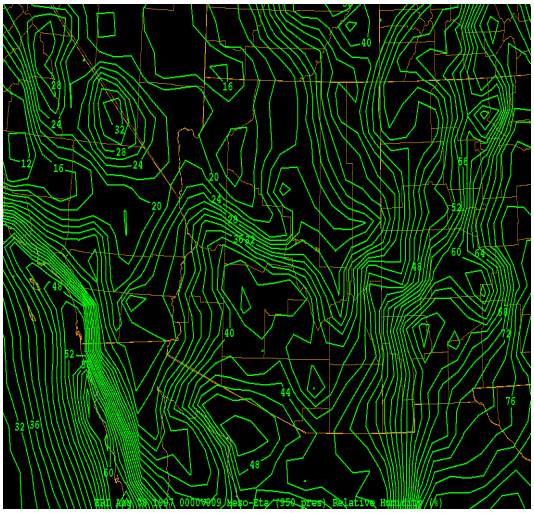

Figure 3b: 950mb relative humidity from the Meso-Eta model forecast valid 00Z 8 Aug 1997

The 00Z map also shows nicely how the highest low-level values of RH are confined along the edge of the Colorado Plateau. A look at the 00Z maps of 950mb winds and 950mb moisture divergence, combined below in figure 4, show an increase in wind speed from 5-

7kts at 21Z to 10-12kts at 00Z, coming from the southwest, served to aid the increased levels of moisture convergence present at the base of the Colorado Plateau.

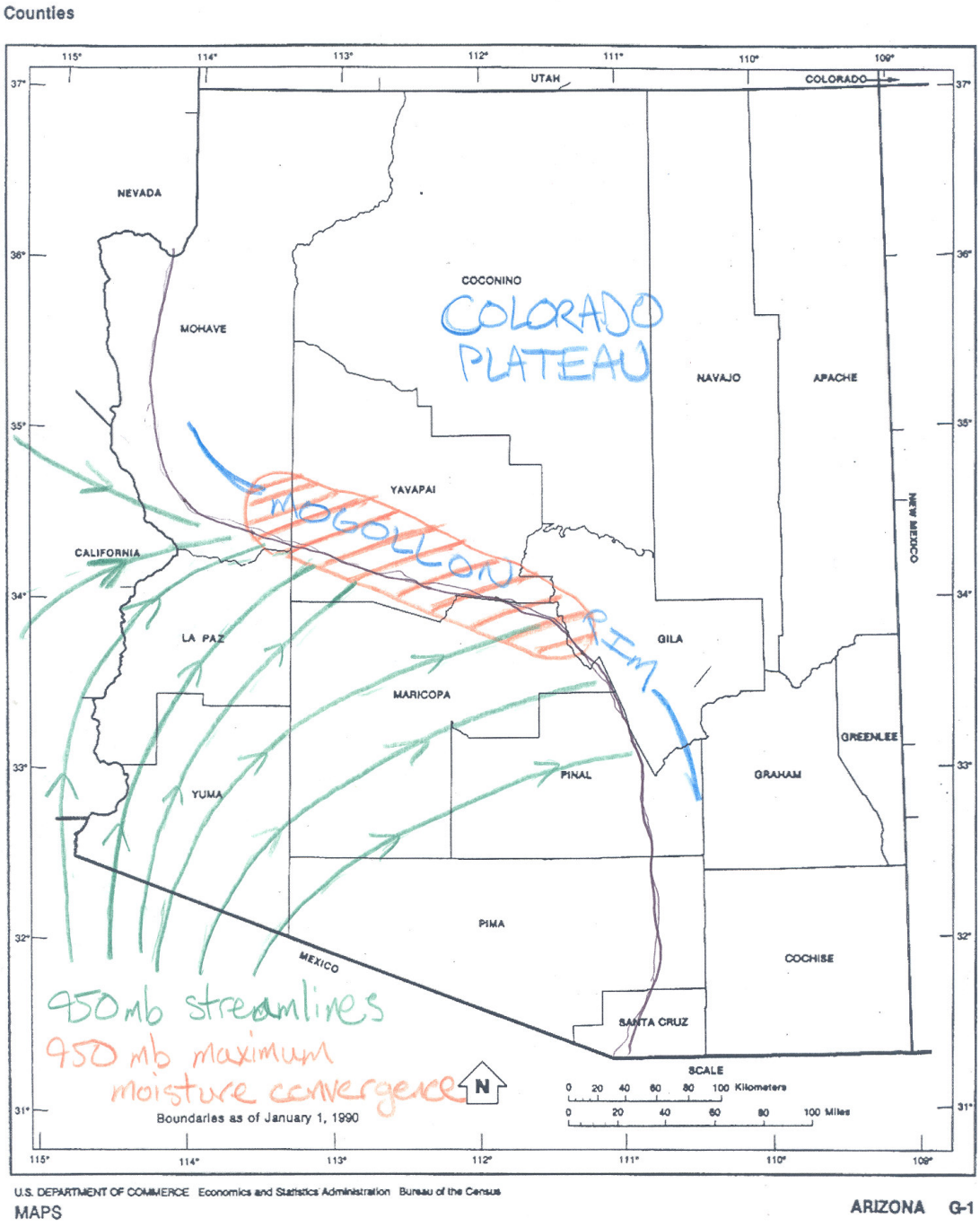

Figure 4: 950mb streamlines and maximum moisture convergence from valid 00Z 8 Aug 1997

While these low-level features were taking shape, the mid and upper levels were becoming more conducive to severe weather as the day went on. Early in the day at 12Z, the sounding from Flagstaff (figure 5), located in a region on the Colorado Plateau at an elevation of about 7000ft, there is a well-defined mixed layer in the layer from the station elevation at about 800mb to about 525mb. Looking at the 700mb and 500mb winds from the sounding as well as at 15Z and progressing through the day to 00Z, it is clear that the 700mb flow was north and north-northwesterly throughout the day while the 500mb flow was out of the north and north-northeast.

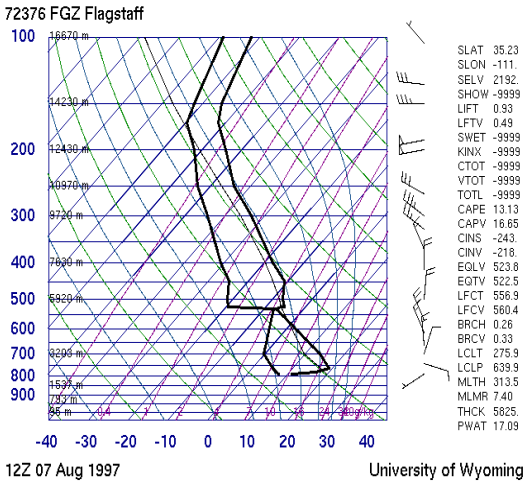

Figure 5: Flagstaff, AZ (station FGZ) sounding taken 12Z 7 Aug 1997

This steady flow associated with the mid-level high pressure located over Nevada resulted in the advection of the Flagstaff mixed layer as an EML over the lower elevations to the south and southwest. The effects of this EML and the moisture convergence can be seen in the vertical cross-section shown in figure 6. From this cross-section of theta-e from San Diego to Flagstaff, there are clear levels of high theta-e in the boundary layer over the AZ, along with lower values in the mid-levels. This contrast is consistent with the instability that was prevalent over western Arizona.

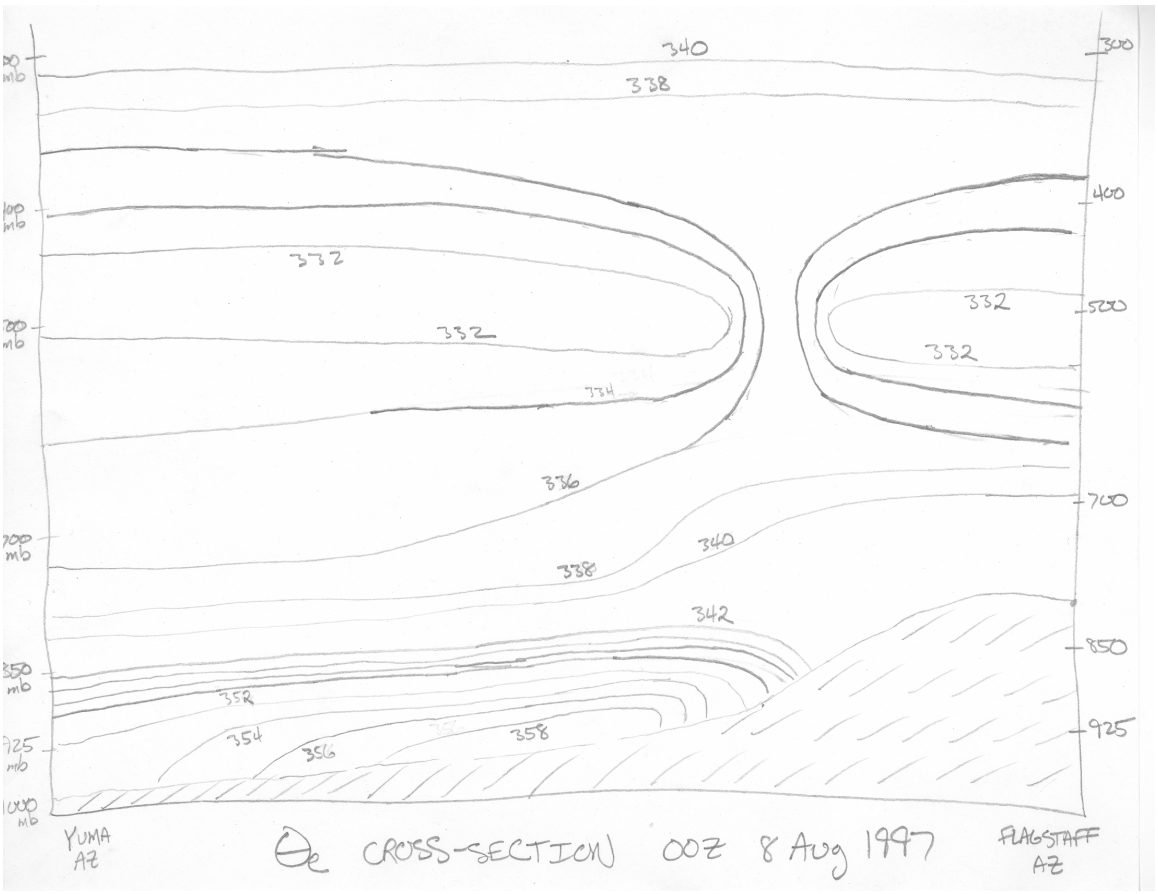

Figure 6: Theta-e cross section (Yuma-Flagstaff) valid 00Z 8 Aug 1997

Leading up to and after the initial convection, there clearly exists a convergence of winds, theta-e, and moisture at low levels. This fact coupled with the conditional instability and high negative lifted indices combines for a very good set up for convective storms to form and develop. Further supporting this claim are the MesoETA estimates of CAPE throughout the region (figures 7a-b), which range from 500-1000 at 15Z over southern Arizona to 1500-2500 at 00Z over much of southern and western Arizona.

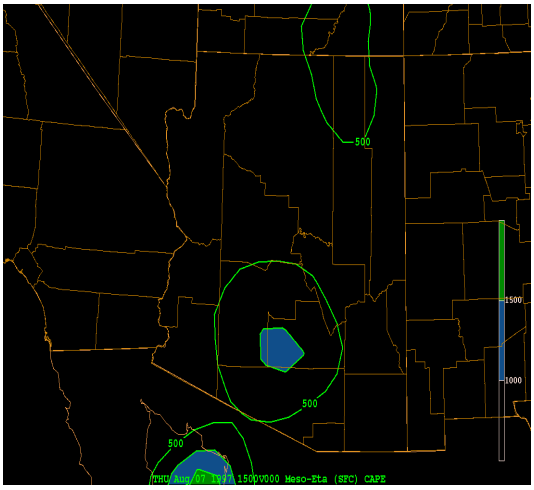

Figure 7a: CAPE from the Meso-Eta model analysis at 15Z 7 Aug 1997

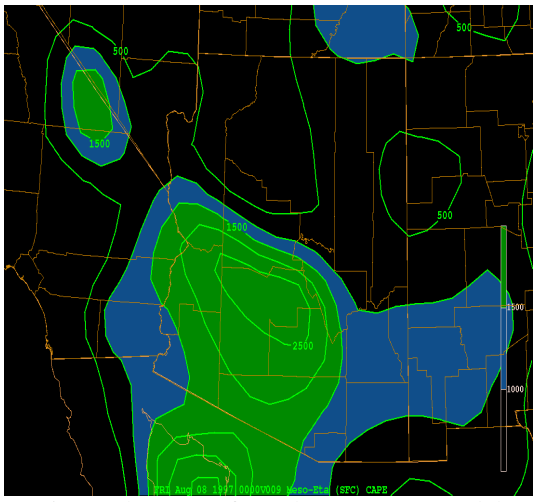

Figure 7b: CAPE from the Meso-Eta model forecast valid 00Z 8 Aug 1997

Again looking to the visible satellite data, the storms begin to first develop at 2015Z and are located right along the edge of the Mogollon Rim. With low-level winds coming from the southwest, it is likely that orogenic forcings aided the initial convection since the storms began right at a distinct rise in elevation. Progressing forward in the satellite imagery, it is clear that four small clusters of thunderstorms develop between the hours of 2015Z and continue developing until beyond 0215Z when the sun sets over the region. In the sequence of visible satellite images, there are indeed several classic supercell features, such as large anvils that develop at tropopause height. This and other severe cell characteristics are described visually in the conceptual model in figure 8.

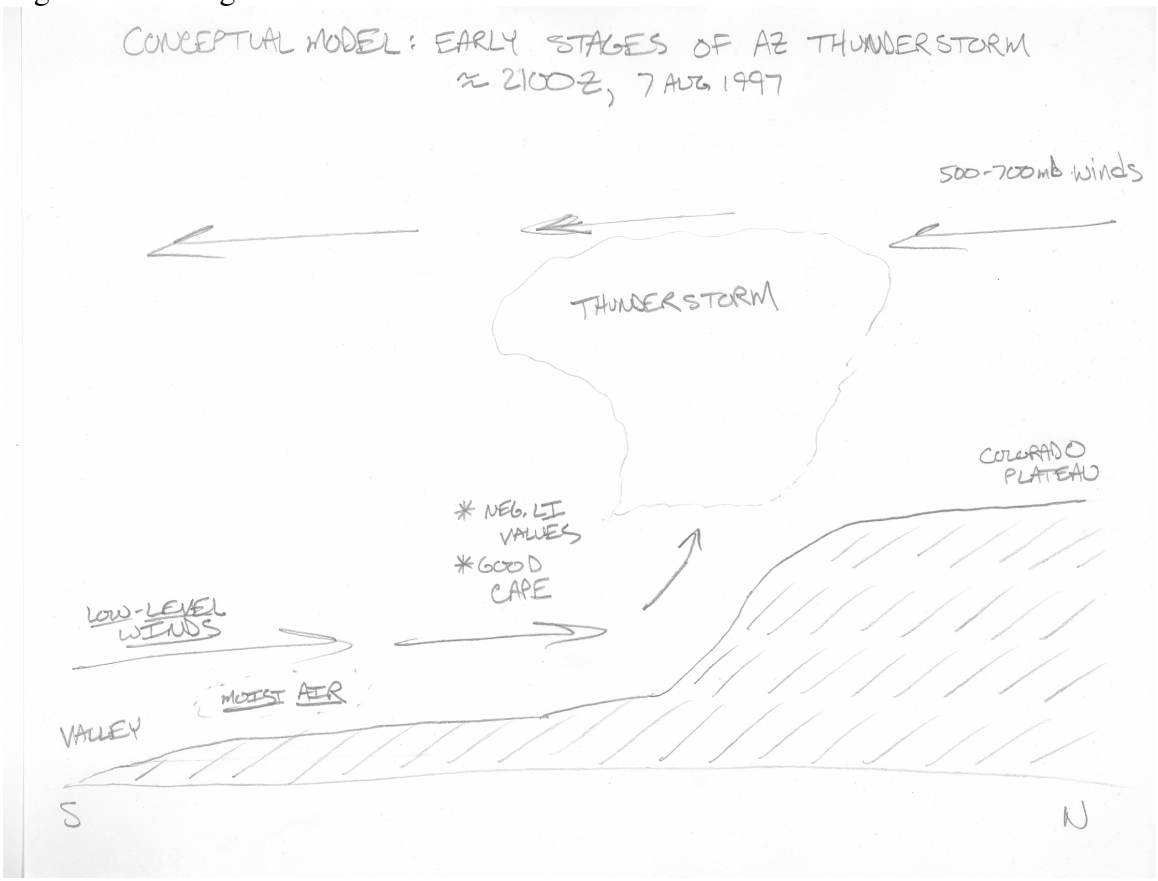

Figure 8: Conceptual model of Arizona thunderstorms of 7 Aug 1997

As the storms continued to develop, the individual cells began to merge as each cumulonimbus complex grew and as mid-level steering winds brought the cells southwestward. The upper level winds are evident by the strong shearing of the cloud tops of the anvil. At approximately 0045Z, the storms reached their mature stage and had developed in to a distinct line structure, similar to the classic squall lines of the Great Plains. This line would also merge with a lone cell that developed over eastern California. As this line was poised to cross the AZ-CA border, the major severe reports were beginning to come in from throughout western Arizona, including one inch hail at Lake Havasu, AZ at 0050Z, and 1.75 inch hail south of the town of Salome. The storm also produced reports of heavy winds and flooding as well. Backing up the satellite evidence, the Doppler radar outputs verify the exact location and intensity of the storms as they were hitting their peak intensity. There are clear regions of intense radar reflectivity associated with the four cells over Arizona and the cells are shown to merge together at approximately 0004Z on the 8th. As the storms progressed to the southwest, high reflectivities continued and a small region of extremely intense precipitation formed right over the AZ-CA border at 0051Z. The data confirms heavy rainfall and hail to be occurring over the Lake Havasu region of Arizona that had one of the initial storm reports for 1.00 inch hail. The other report of an F0 tornado came out of eastern California near the town of Needles and there indeed is a large swath of high reflectivity over the reporting area, as the Arizona cluster and the California cell had merged completely.

Conclusion

As I have shown, the set up for the severe weather that occurred over the Desert Southwest on 7 August 1997 was fairly conducive to convective development, despite the lack of certain traditional synoptic forcings. A convergence zone was created at the edge of the Colorado Plateau that focused high values of theta-e and moderate values of relative humidity over the region. Those surface features, in addition to some moderate orogenic forcing, allowed convection to be sparked along the Mogollon Rim. These cells were then able to feed off conditional instability and high CAPE values and develop into severe thunderstorms with some supercell characteristics. This sequence of events produced dangerous storms, which produced several severe reports and followed a unique track, moving from northeast to southwest.