

# Large CAPE, Converging Boundaries: A Mesoscale Complex Event Using the WES August 13, 2004

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## Introduction

The set of thunderstorms that developed on Friday, August 13, 2004 were characterized by being one of the longest sustained complexes of the 2004 monsoon season. The day before, forecasts for long-lived storms did not look promising and the initial thoughts of forecasters were for the days following the 13<sup>th</sup> to be more active. The potential for an active day presented itself with the 12Z sounding on the 13<sup>th</sup> (Figure 1). This sounding had great moisture and instability present; yet it had an anemic wind profile, generally pointing to short-lived pulse storms with little organization. With the North American Monsoon Experiment (NAME) being run in summer 2004, special Intense Operational Period (IOP) soundings were available. On this day, the 18Z IOP sounding (Figure 2) was more indicative of what was to come. This sounding had an unmodified convective available potential energy (CAPE) of over 2000 J/Kg, and a lifted index of near -7. The main concern of forecasters was flooding because there was an abundant amount of moisture present, and once storms developed, they would be very slow moving due to the weak flow. After the 18Z IOP sounding was shown to be a little more wet and unstable than the 12Z raob, a Flash Flood Watch was issued for all of the Tucson County Warning Area (CWA).

## Synoptic Situation

In the half-week leading up to August 13, the only day with enhanced convective activity in southeast Arizona was August 11. The storms on the 11<sup>th</sup> developed into a small mesoscale complex in the evening hours, producing copious amounts of rainfall in central Pima County. This cooled the boundary layer, leading to a less favorable environment for thunderstorm development on the 12<sup>th</sup>. An upper level low sitting off the coast of southern California was expected to feed a series of disturbances into Arizona through the weekend, acting as convective triggers (Figure 3). Moisture was brought into the region via outflows from thunderstorm complexes in Sonora, Mexico the previous evening and the enhanced monsoonal flow due to the position of an upper level high over Northern Mexico and an upper low off the California coast (Figure 4).

An abundant amount of moisture was present in southeast Arizona, as evident from GOES estimated precipitable water (PW) values of 1.4 to 1.6 inches across the region. This was again confirmed through both the 12Z and 18Z soundings having PW values of around 1.4 inches, and surface dew point temperatures in the lower 50s in the eastern portions of the Tucson CWA and 60s in the western portion. The 12Z sounding showed extremely weak to no flow below the 400 mb level; and while the 18Z sounding showed an increase in the flow at the 700 mb level, the flow was still lackluster. Even with the weak flow present, there was enough dynamic forcing from the upper level low moving into southern California and adequate heating with a high of 97 F recorded at the Tucson International Airport to initiate widespread showers and thunderstorms. The converging outflows from the organized thunderstorms are what helped to intensify and sustain the

existing storms and initiate new rapid storm development. The storms lasted well into the evening hours and overnight due to the dynamics moving in from the upper level disturbances and intersecting storm boundaries.

## **Storm Evolution**

Skies were relatively clear in the Tucson CWA on the morning of August 13<sup>th</sup>. Around 1700Z the first cell of the day developed in the northern portion of the Tohono O'odham Nation, in central Pima County; however, this cell was fairly short-lived. By the end of the hour, many other individual cells were beginning to grow over the mountainous regions, including the Santa Catalinas in Pima County, the Pinalenos in Graham County, and the Chiracahuas in Cochise County (Figure 5). The cells continued to grow and develop, remaining only over the higher terrain, until about 1845Z. By this time, there were scattered cells in Eastern Pima, Santa Cruz, Cochise, and Graham Counties.

As smaller individual cells were continuing to form in the Tucson CWA, a group of thunderstorms present in the Phoenix CWA were continuing to organize. This set of storms extended from the California deserts into a large portion of west central Arizona (Figure 6). Intense lightning, hail, and heavy rain were associated with these storms. The organized thunderstorms continued to grow and sustain themselves due to cell mergers and converging outflow boundaries.

The smaller cells located in the Tucson CWA also began to merge into larger cells, and new cells grew along converging outflow boundaries, just as with those in the Phoenix CWA. The first of the cell mergers occurred over northeast Santa Cruz County in the area where it joins Pima and Cochise Counties. This merger greatly increased the strength of this set of storms leading to a Flash Flood Warning and a Severe Thunderstorm Warning being issued for southeast Pima and northern Santa Cruz Counties. Hail ranging from half an inch to an inch and extremely heavy rainfall were both reported with this particular storm (Figure 7). Simultaneously, organized thunderstorms of similar size and strength were impacting the area between Three Points and Sahuarita. Both clusters of thunderstorms had composite radar indicated reflectivities between 60-70 dBz.

Continuously growing and expanding areas of storms with overshooting tops were noticeable in a 2010Z visible satellite image (Figure 8). Throughout the afternoon, storm development continued to be initiated along outflow collisions, intensifying in both the Phoenix and Tucson CWAs. When the outflow from the thunderstorm cluster in the Phoenix CWA converged with the outflow from the developing complex (Figure 9) in the Tucson CWA, an intense line of thunderstorms with exceptionally heavy rainfall extended from south central Pima County up through Marana, and into Pinal County (Figure 10 and Figure 11) Around 0020Z on the 14<sup>th</sup>, convergence and rotation signatures were noticeable along the line of intense thunderstorms. Rotation aloft was noted over the northwest side of Tucson via SRM scans, which at 1.3 degrees showed a couplet of inbound and outbound winds exceeding 22 knots (Figure 12), and numerous spotter reports of a wall cloud were reported with this feature.

By 0200Z most of the thunderstorms had either dissipated or become sub-severe in intensity, but heavy rainfall persisted across a large part of the Tucson CWA. The heaviest of the rainfall was in central Pima County, where radar estimated rainfall rates exceeded two inches per hour in some locations. The large area of heavy rainfall dissipated after 0600Z, but light to moderate precipitation persisted throughout the overnight hours.

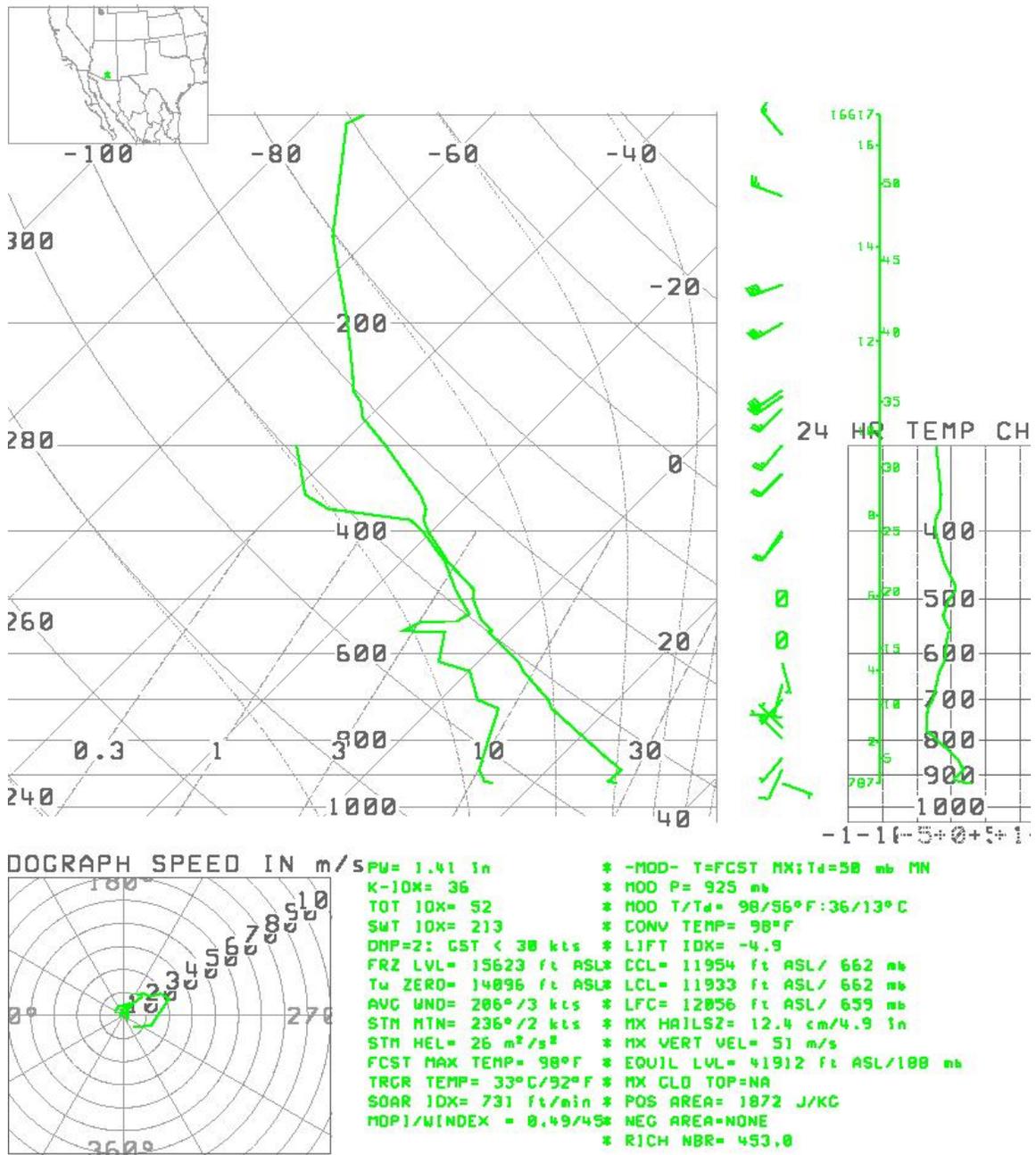
## **Results and Conclusions**

In all, 11 flash flood warnings, 7 severe thunderstorm warnings, 2 small stream flood advisories, and 1 small stream flood warning were issued throughout the duration of this event, from when the Flash Flood Watch was issued at 1910Z on the 13<sup>th</sup>, until the last flood advisory expired at 1900Z on the 14<sup>th</sup>. While there were several reports of half inch to one inch hail, as well as fences and power poles being knocked down, the worst damage was caused by the flooding in Pima and Santa Cruz counties. Being aware of the environment in place helped forecasters have a decent lead time for severe thunderstorm warnings and an excellent lead time for flash flood warnings, at 17.6 minutes and 41.75 minutes on average, respectively. In addition, there was an 80 minute lead time for the Flash Flood Watch.

Although the 12Z sounding already showed decent potential for storm development, it was still thought that the shear would be too weak to support longer-lived storms. The special 18Z NAME IOP sounding gave forecasters greater confidence in what the actual weather situation could be. From this information, forecasters knew that their largest concern would be flooding due to the development of strong storms in an extremely moist and unstable atmosphere, leading to the Flash Flood Watch being issued for all of the Tucson CWA. This shows how important an additional 18Z sounding can be in a changing convective environment for predicting storm development.

After the complex worked over the atmosphere, it led to a much less favorable environment for storm development over the next couple days, despite the persistence of upper level forcing due to the series of disturbances moving through the area. August 14 was the second coolest day of the month, with a high of only 89 recorded at Tucson International Airport (compared to the climatological average of 100), and remained mostly cloudy throughout the day. Severe convective activity did not occur again in southeast Arizona until August 16<sup>th</sup>.

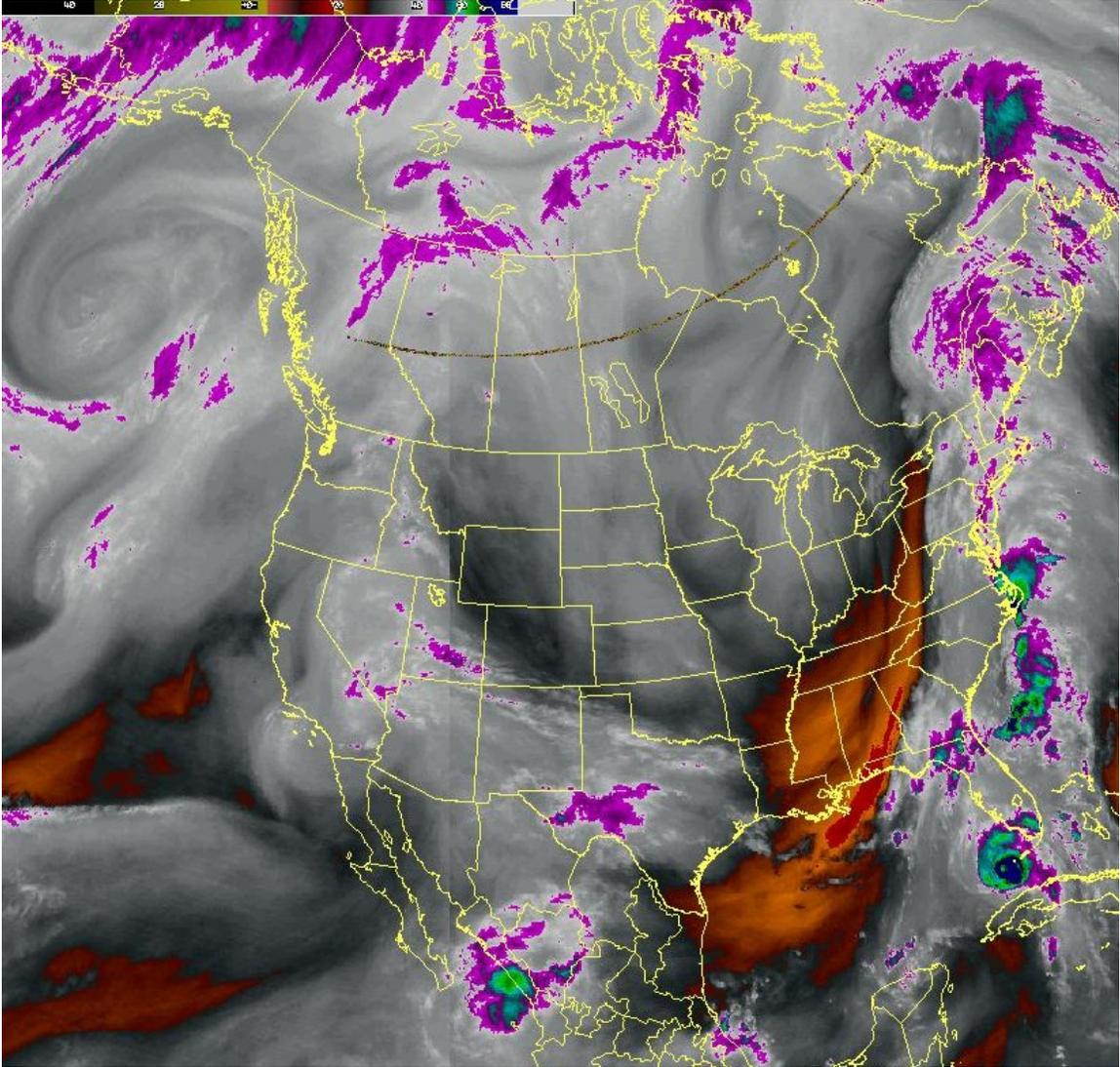
This was a great event for use on the Weather Event Simulator to show how storms can quickly develop in an environment with a large amount of CAPE and some dynamic forcing despite very weak wind shear. The key to the storms' persistence was the convergence of outflow boundaries. This case shows that, while strong flow and shear are important, they are not necessary for the development and persistence of thunderstorm complexes when there are other mechanisms for storm development in place.



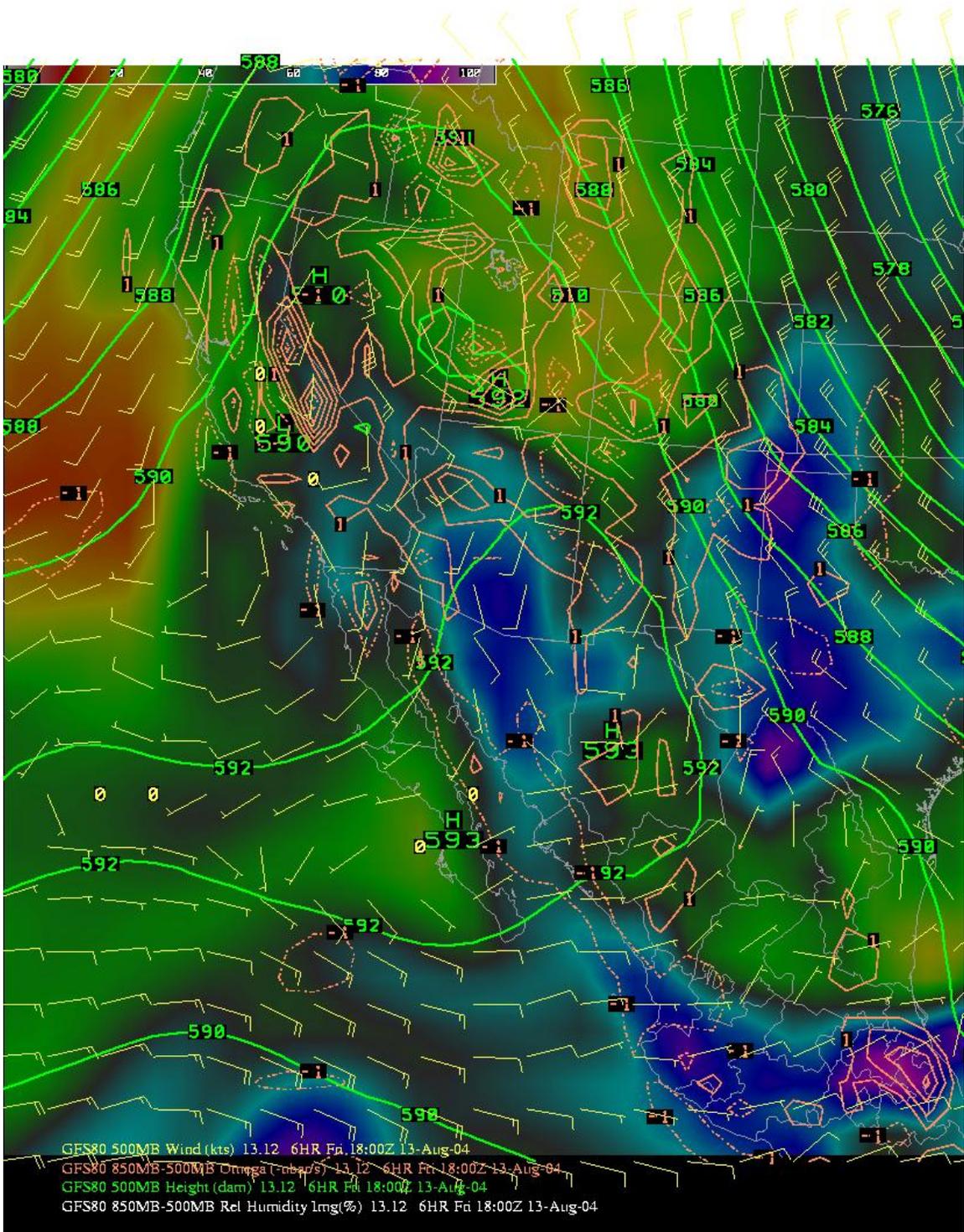
KTUS Skewt. Fri 12:00Z 13-Aug-04

**Figure 1:** The KTUS 12Z sounding, August 13, 2004.

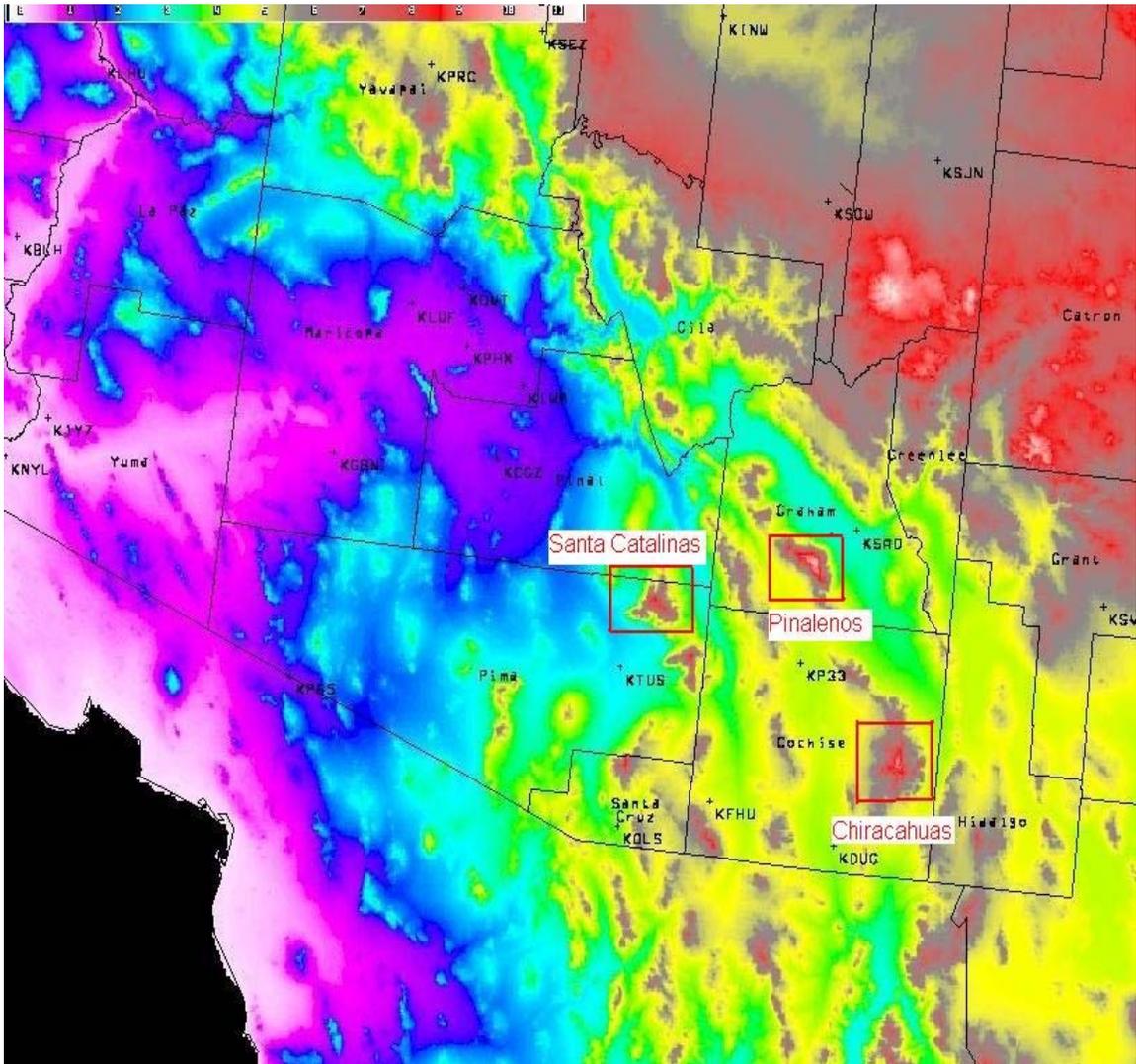




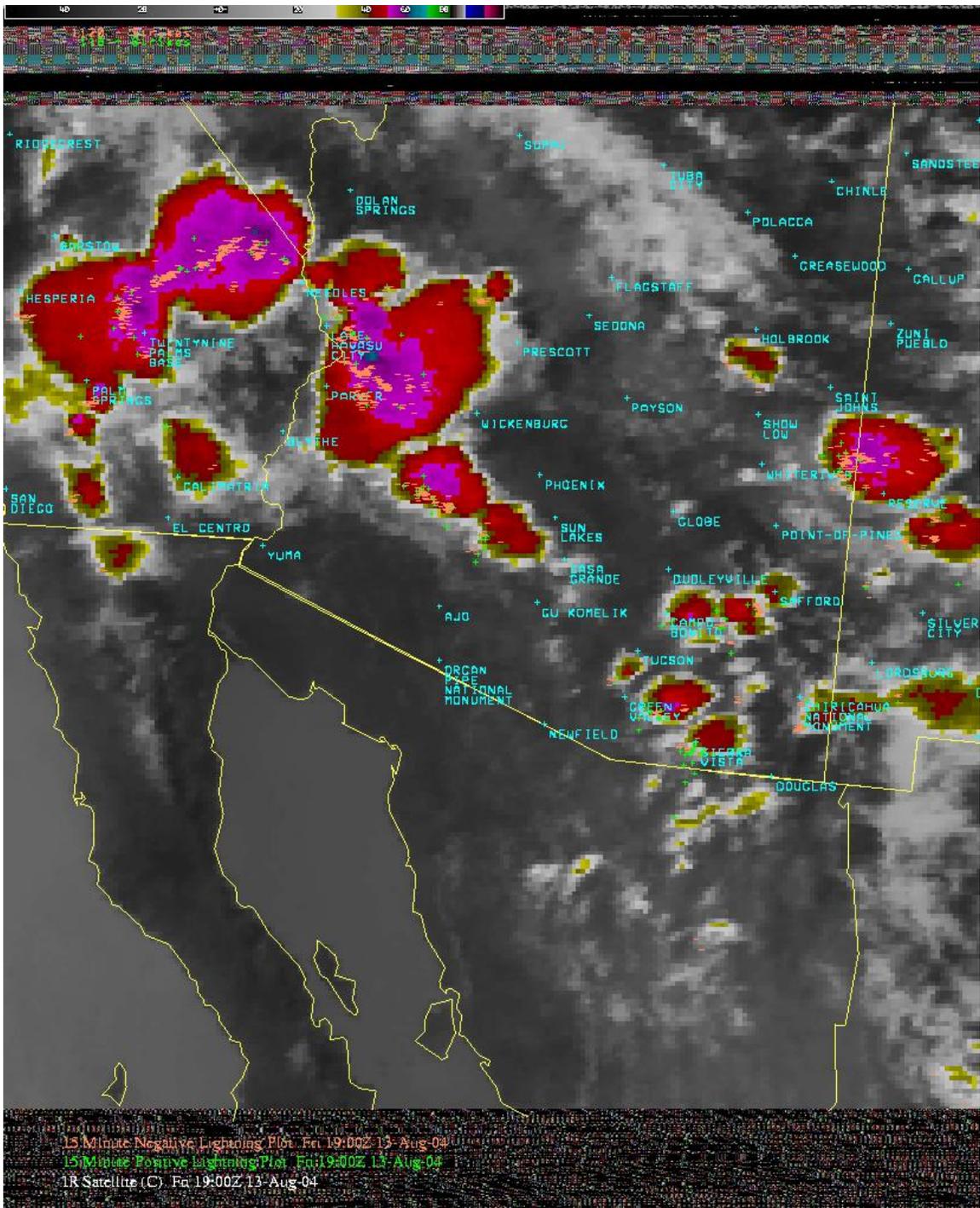
**Figure 3:** Water vapor satellite image 12Z, August 13, 2004. Note the disturbance off the southern California coast and the moisture present in the southwestern United States.



**Figure 4:** GFS80 500 mb wind in knots, 850-500 mb omega, 500 mb heights, and 850-500 mb relative humidity image showing the moisture present.



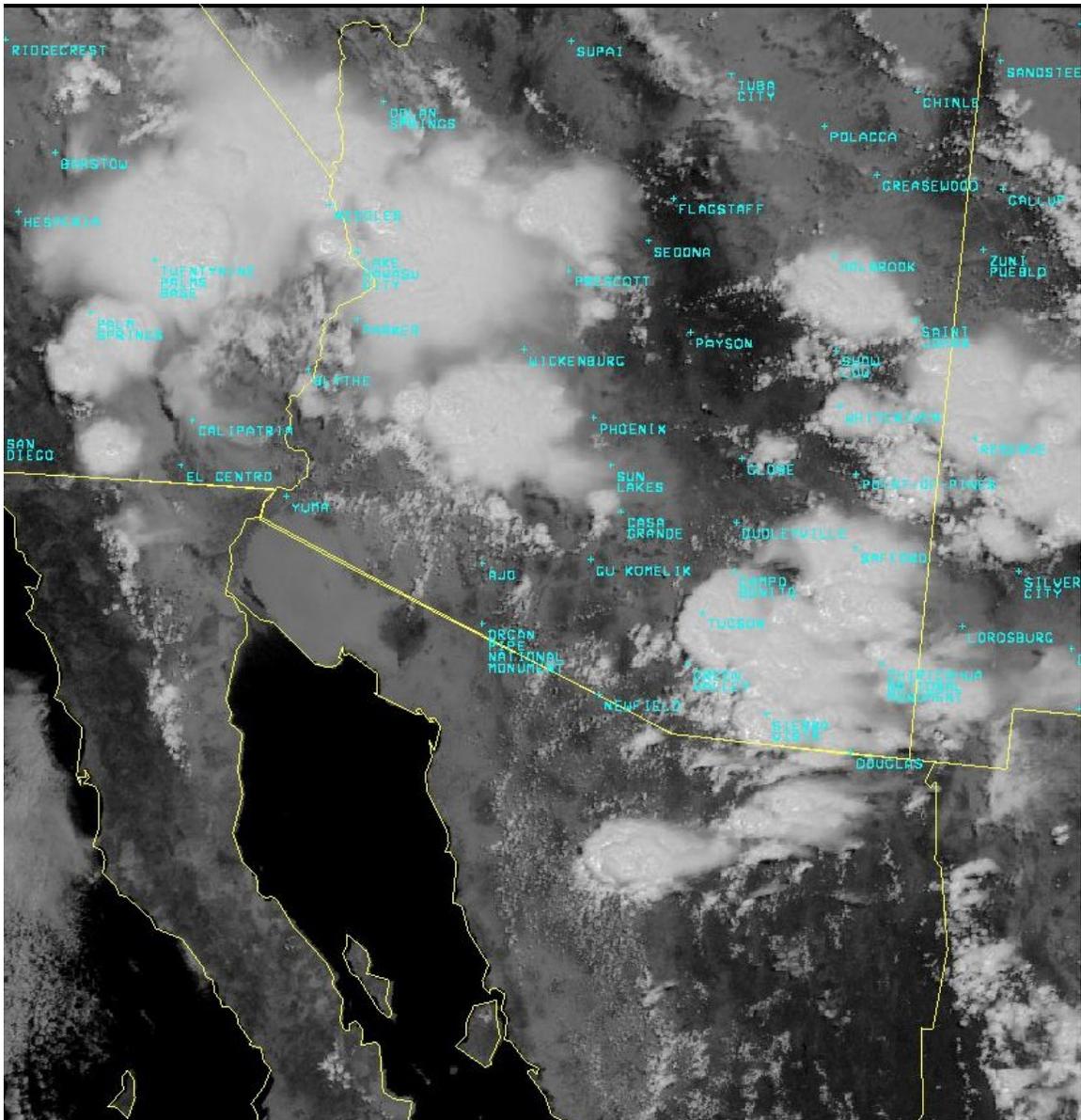
**Figure 5:** A topography map of southeast Arizona showing the Santa Catalina Mountains, the Pinalenos, and the Chiricahua Mountains. Mountains of interest are boxed in red.



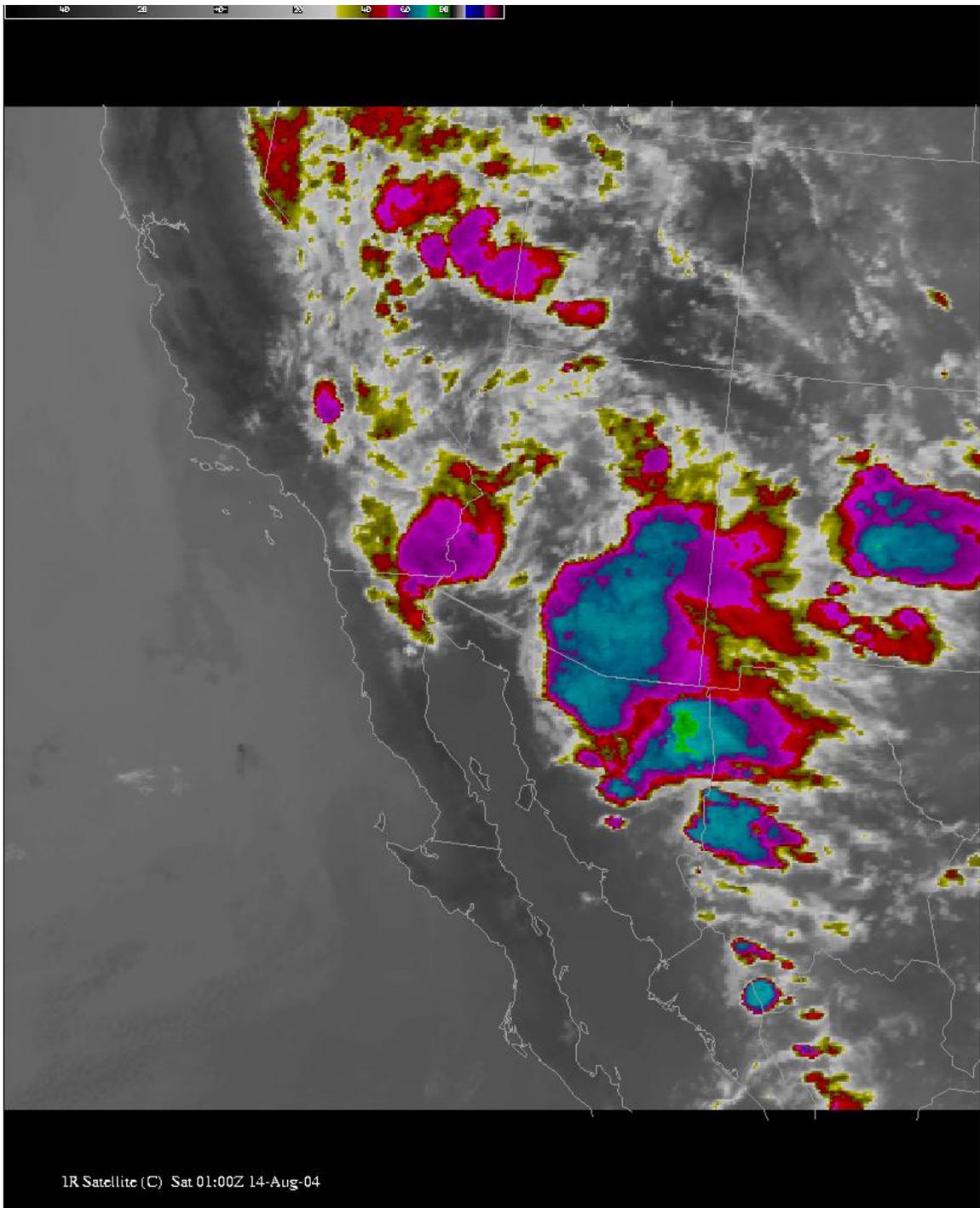
**Figure 6:** Infrared satellite imagery with 15 minute positive and negative lightning, 19Z, August 13, 2004. Note the thunderstorm cluster in the Phoenix CWA and the developing cells in the Tucson CWA.



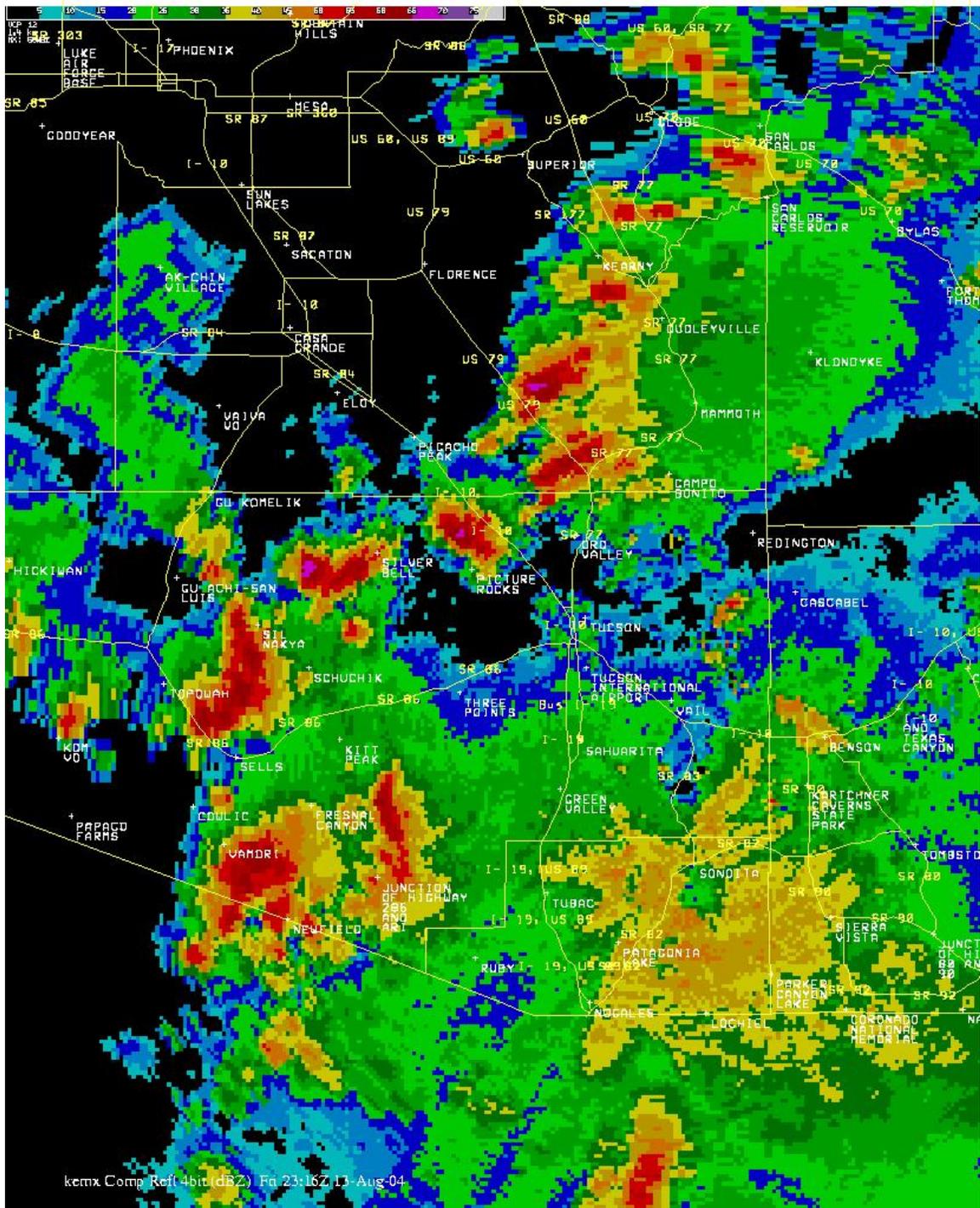
**Figure 7:** A flooded street in Santa Cruz County, showing a real perspective of the copious amounts of rainfall on August 13, 2004.



**Figure 8:** Visible satellite image, 2010Z, August 13, 2004. Note the growing areas of storms and the overshooting tops on some of the cells.

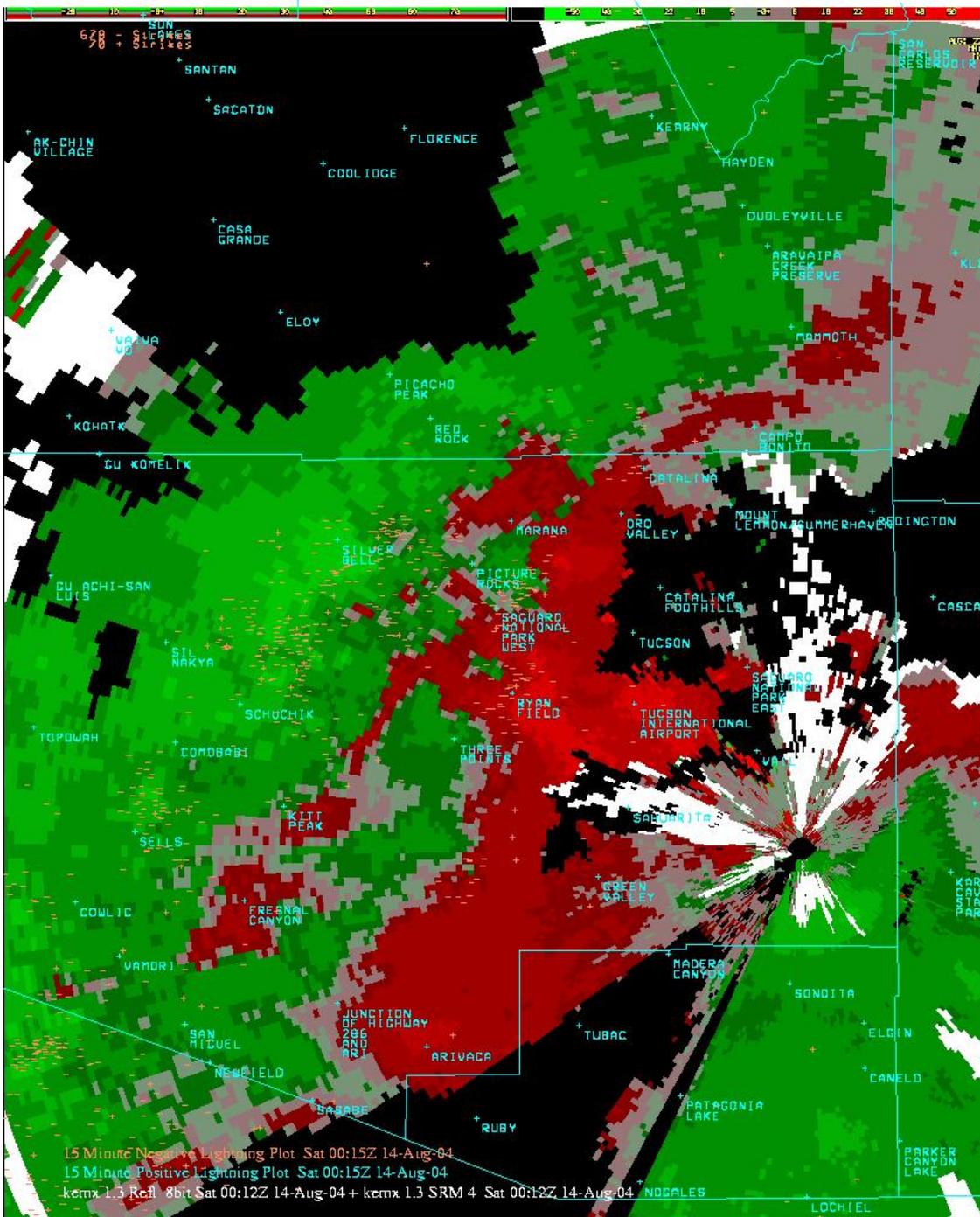


**Figure 9:** Infrared satellite image, 0100Z, August 14, showing the complex in southeast Arizona.



**Figure 10:** Composite reflectivity, 2316Z, August 13, 2004.





**Figure 12:** KEMX 1.3 SRM image, 0012Z, August 14, 2004. Note the inflow and outflow couplet on the Northwest side of Tucson, south of Marana, showing the upper level rotation in this storm.