Investigation of the Arizona Severe Weather Event of August 8th, 1997

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Abstract

Synoptic scale forcings were very weak for these thunderstorms on August 7-8, 1997 over the desert southwest, whose main affect was severe flash flooding over parts of Arizona. These storms can instead be described by looking at the surface wind patterns as well as by comparing a topography map to the radar image. In doing this, it is clear that this is almost completely an orographically forced event. There were multiple factors that aided in making this such an explosive orographic event, such as very warm temperatures at the surface, as well as high moisture content in the lower levels of the atmosphere. The rainfall was also enhanced on the evening of the 8th by the formation of a surface heat low that enhanced surface convergence and upward vertical motion. Weak synoptic scale forcing also aided in the formation of these storms due to the proximity to the jet streak.

Introduction

Severe weather events are very common over the central United States during the summer months. These events are often highly publicized throughout much of the country. Severe weather happens throughout the entire country, however. One place people may not consider when thinking about the effects of severe weather is the desert southwest. A severe weather event affected Arizona on August 7-8, 1997, bringing large hail, damaging winds and devastating flooding rain to the region.

These thunderstorms, which occurred over much of Arizona on these days, caused hundreds of thousands of dollars in damages, hundreds of injuries, and one death, mostly as a result of the flash flooding. Heavy rain persisted on the evening of the 8th and early into the morning of the 9th.

The conditions that led to these storms were much different than those normally associated with Midwestern thunderstorms. Synoptic scale forcing for this event was very weak, with only the presence of the persistent summer heat low to promote this convection. There were, however, a number of mesoscale features that led to this event. This event, which appears to be almost purely orographic in nature, was enhanced by warm and moist air at lower levels, with cool, dry air aloft. Along with these factors, the development of another heat low over the Arizona/New Mexico border also enhanced surface convergence and upward vertical motions that led to these powerful thunderstorms.

Data

Synoptic conditions were analyzed using plots from Unisys Weather. These plots were analyzed at 12Z on August 8th, 1997 and 0Z on August 9th. These are the times that coincide with the development and propagation of the severe weather.

Radar and satellite images, as well as surface observation plots were derived using GARP. Gempak was also used to look at many features of this storm, even though those plots may not be included in the paper.

A topography image courtesy of Ray Sterner and Johns Hopkins University was used to explain the orographic lifting that propelled these storms.

Synoptic Overview

As was stated previously, the synoptic conditions for these storms are very atypical of what is normally observed in conjunction with severe thunderstorms over most parts of the country.

There is no major synoptic low pressure system that is forcing this event. The only anomaly in the surface pressure field is the heat low that is almost always present over the Arizona/California border during the summer months. The cyclonic circulation around this low helps increase the surface convergence that forces these thunderstorms over central Arizona.

The location of the jet streak supports upward vertical motion only very slightly. Northern Arizona appears to be in the right entrance region of a very weak jet streak maximum that begins over the 4-corners region. This is generally a position that is favorable for large scale upward vertical motion, and this may have helped lead to some of the lift for the thunderstorms on August 8th.

There is no large scale vorticity feature that is forcing these storms. This was determined after looking at endless vorticity plots of different times and levels without observing any positive vorticity. There was also no large scale forcing due to other factors such as PVA by the thermal wind, frontogenesis or Q-vector convergence.

A major factor in these storms, however, was the contrast in air masses present at different levels over much of Arizona. Surface temperatures were very warm on the afternoon of the 8th (Fig 2), reaching into the low 100's over central and eastern Arizona, the warmest air in the surrounding area. Upper level air was also relatively warm when compared to its surroundings, but not as anomalously warm as the surface air.

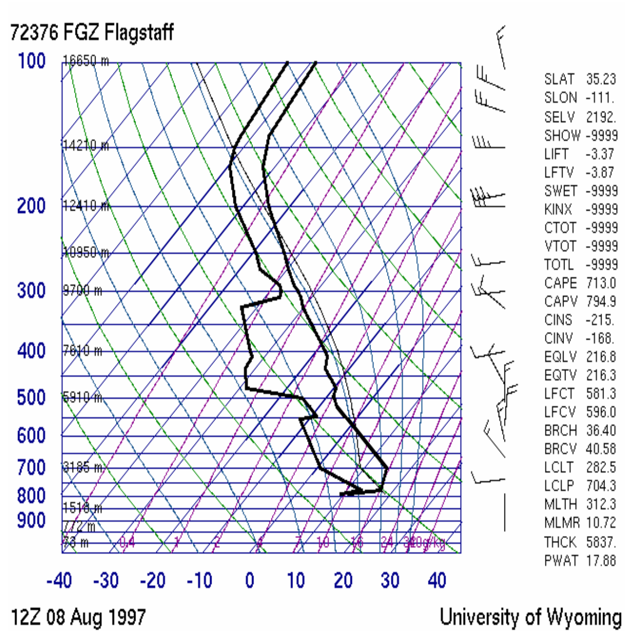

Fig 1) This is an atmospheric sounding from the University of Wyoming is from Flagstaff, Arizona at 12Z on August 8th, 1997.

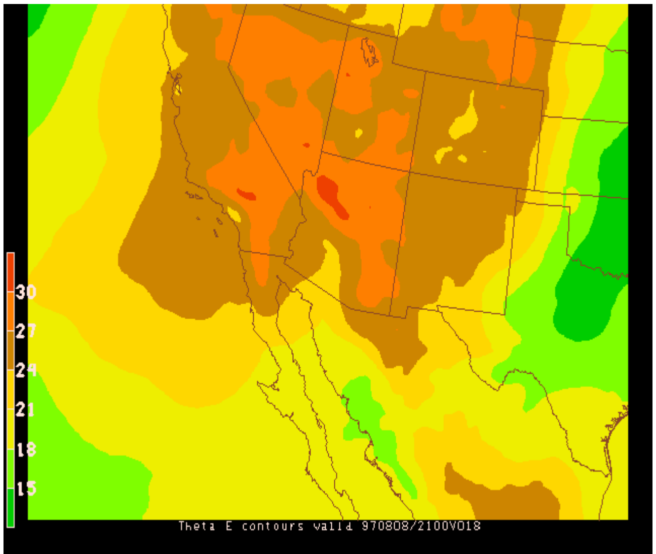

Fig. 2) This is an 850mb temperature plot, which can be assumed to be near the surface due to elevation. This is a plot from 3pm on the 8th, showing the warmest air over Arizona.

The moisture difference between these two air masses proved to be even more crucial in helping this severe weather form. This difference can be seen by looking at a sounding from Flagstaff, Arizona at 12Z on the 8th. This image (Fig. 1) shows very moist air at the surface, with a very small dew point depression. Looking above the surface layer, however, shows two pronounced dry air masses, one from 750mb to 550mb, and then another from 500mb to 300mb. There was also a strong inversion in the lowest layers of the atmosphere, providing a sufficient cap to build up instability during the day.

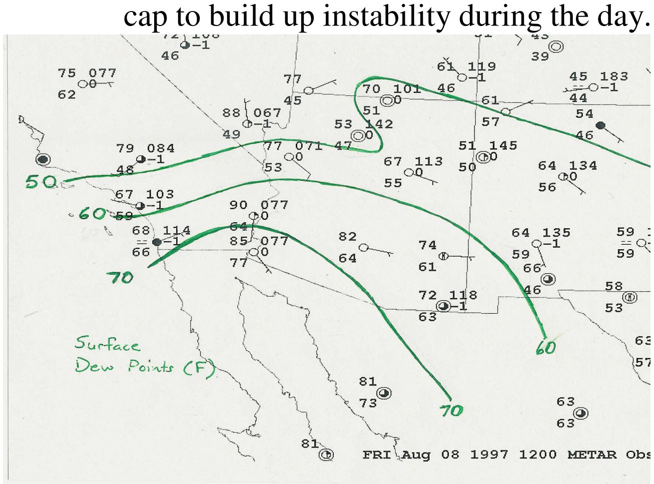

Fig. 3) This is surface dewpoints at 12Z on the 8th, showing very moist air over the entire desert southwest.

This moisture difference can be further seen by looking at the surface dewpoints at 12Z on the 8th (Fig. 3). Surface dewpoints were in the upper 50's and 60 degrees Fahrenheit, which shows that sufficient moisture was available to fuel these storms.

Mesoscale Discussion

Without any large scale forcings for vertical motions, the cause of these storms appears to be almost completely orographic. The southern Rocky Mountains stretch from northwest to southeast across central Arizona. The surface winds later in the day on the 8th over northeastern Arizona shifted from the west, to be out of the northeast, pushing flow up against the mountains. To the south and west of these mountains, a southwesterly flow existed, pushing air from the southwest up against the mountains as well.

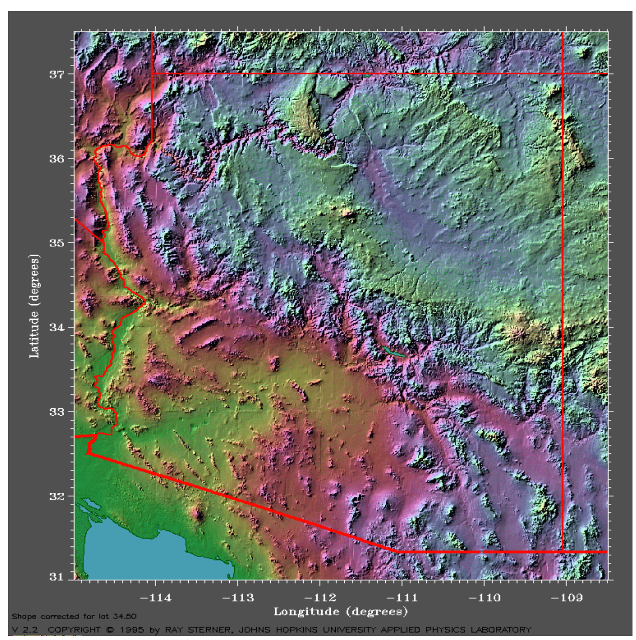

Fig. 4) This is a topographic image of the state of Arizona, showing mountains stretching from northwest to southeast over the state. Image courtesy of Ray Sterner, Johns Hopkins University.

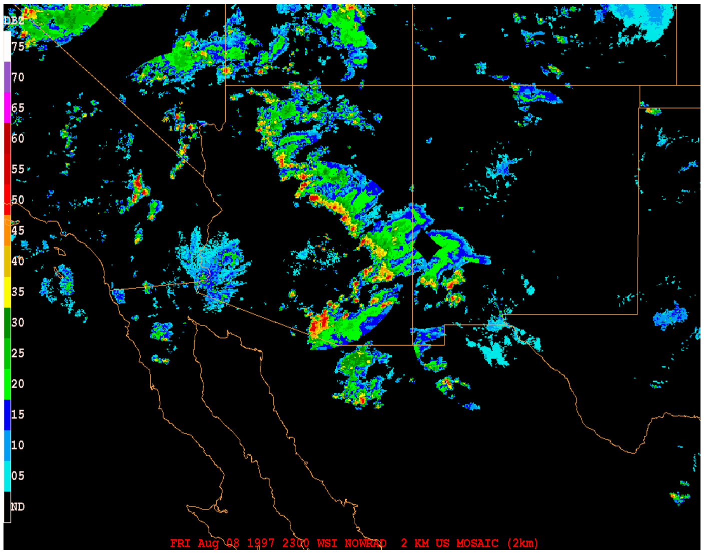

Fig. 5) This is a composite radar image from 23Z on August 8th. Comparing this to the topographic image shows a strong correlation with the location of the mountains.

Fig. 4 is a topographic map of Arizona. The mountains over the central part of the state can be clearly seen on the relief map. Flagstaff is just to the north of these mountains over north-central Arizona at an elevation of 6986 feet.

Comparing the topographic map to an image of radar reflectivity (Figure 5) at 23Z on the 8th shows a correlation between the location of the precipitation and the highest topography in the area.

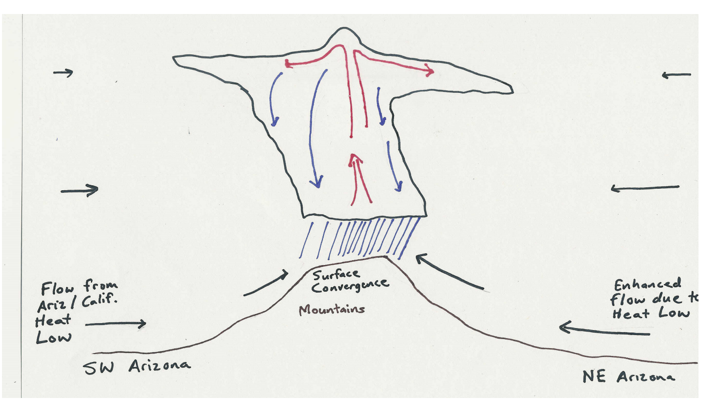

Fig. 6) This is a conceptual model of how the thunderstorms formed in this case.

This precipitation was actually moving southwest, pushing up against the southern Rocky Mountains.

This orographic formation process can be seen by looking at a conceptual model of this event (Figure 6). This model shows how the air is moved up the mountains due to the general flow pattern, and convection is forced due to this lifting. Since the air is unstable, it will continue to rise with respect to its' surroundings and thunderstorms will result.

One of the biggest factors that allowed these storms to easily form and keep their intensity was the very unstable air over the area. One way to assess the stability of an air mass is by looking at a cross section of equivalent potential temperature, or theta E. In a normal stable atmosphere, theta E increases with height. If theta E decreases with height, then the atmosphere is unstable, and air at the surface can rise without resistance. Figure 7 is a cross section from south-central Arizona to southwestern Colorado. This figure was constructed using the eta model analysis and shows that theta E decreases with height over much of Arizona up to at least 500mb.

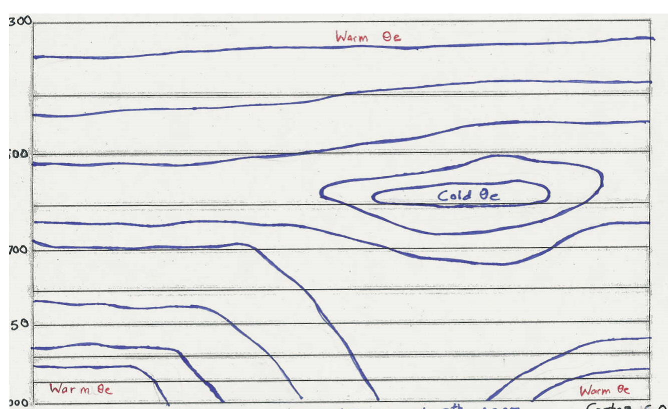

Fig. 7) This is a cross section of theta E from Gila Bend, AZ to Cortez, CO. It shows low values of theta E at upper levels indicating great instability.

This means that the air was free to rise as long as there was something to force it upwards. This forcing came in the form of surface wind convergence, as well as orographic lifting of this air over the mountains.

Figure 8 is a Gempak derived cross section from the eta model analysis. This is a forecast for 3pm on the 8th. This is a cross section of theta E. This plot shows how daytime heating has acted to decrease the stability of the air even more throughout the course of the day. The entire area is now capped with a layer of low theta E values, making the atmosphere very unstable.

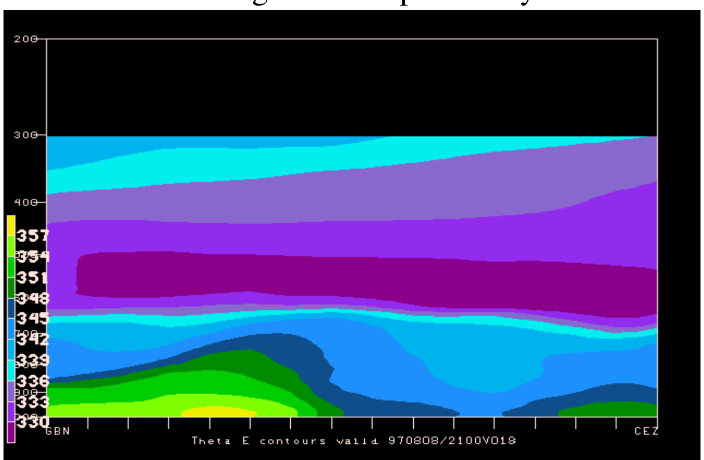

Fig. 8)This is a cross section of the same location as above, but a model forecast for 3pm on the 8th. Theta E values are lower as height increases to 500mb, indicating an unstable layer up to that pressure level.

One good way to assess the stability of the air mass over Arizona is by looking at the Lifted Index, or LI. Lifted index values are high negative numbers if the air mass is unstable. LI is an indication of the difference in air masses between 850 and 500mb. In this case, LI values were as low as -8 to -10 at 12Z on the 8th (Fig 9), which would indicate conditions are very favorable for severe weather due to a warm, moist air mass at 850mb capped with a cool, dry layer at 500mb.

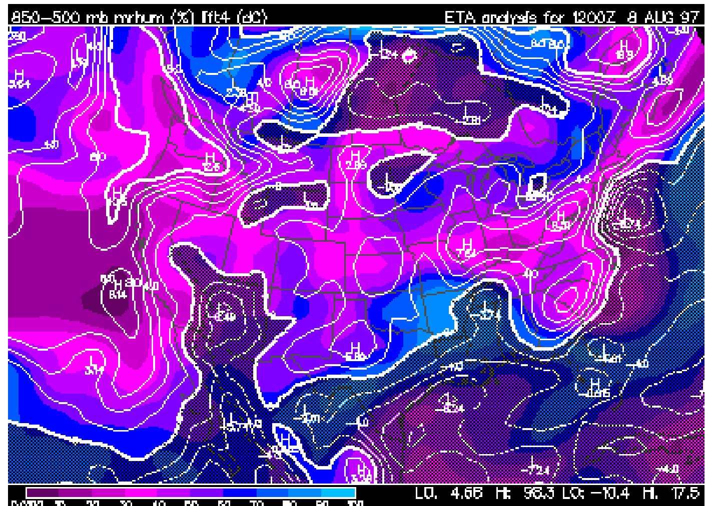

Fig. 9) This is an image from Unisys weather that shows lifted index values at 12Z on the 8th . Highly negative values indicate instability, and the highest negative values exist over Arizona.

Looking at the surface streamlines at 23Z (Fig. 10) gives another insight as to how these storms remained intense and were able to drop such large amounts of rainfall. A cyclonic circulation can be seen centered over the southern Arizona/New Mexico border. This circulation developed due to an area of extremely high temperatures surrounded by lower temperatures. This is known as a "heat low." This heat low circulation enhanced the surface convergence over Arizona, and led to enhanced vertical

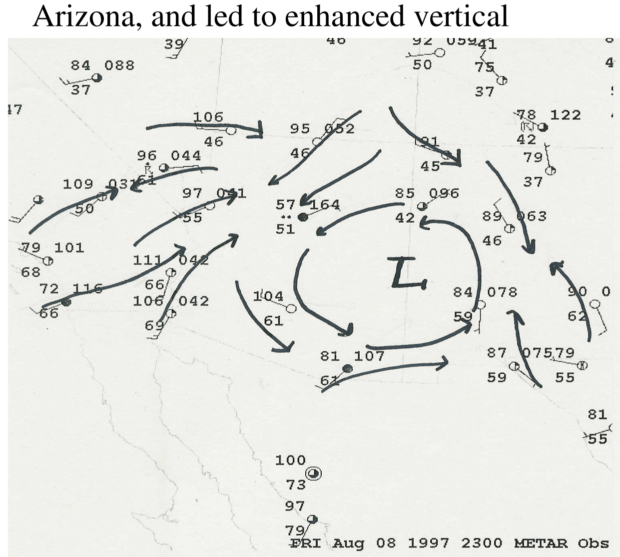

Fig. 10) This is an image of surface streamlines at 23Z on the 8th. This image shows the heat low that developed later in the day on the 8th. The circulation helped enhance rainfall.

motions in the area of the low pressure center. Both the increased convergence and enhanced vertical motions helped intensify the rainfall in the late hours of the 8^{th} and early hours of the 9^{th}, leading to the severe flash flooding.

These storms also moved very slowly due to weak winds at upper levels. There were no strong winds to steer the storms in any one direction very quickly. Since the lower level winds out of the northeast were slightly stronger than the surface winds converging from the other direction, the storms slowly drift off to the southwest.

All of these factors would not have culminated in such severe flooding, except for the fact that this area does not see heavy rain like this often, and the land is not capable of dealing with large amounts of rain in a short time. The features of the topography helped to channel the rainwater into canyons and creek beds that are normally only a trickle of water. The land could not absorb large amounts of rain in the short time period because the sandy and rocky soil cannot hold water efficiently. All of this extra water becomes runoff with no place to go, and looks to find the lowest area surrounding it. People in this area are also not used to such large amounts of rain, as the infrastructure is not designed to handle these environmental issues. This is what led to the collapse of a train bridge early in the morning of the 9^{th} after it had been weakened by flowing flood waters. One person was killed and 116 others were injured after the bridge collapsed that the passenger train had been traveling over.

Conclusion

High values of low level moisture, along with very unstable air that formed as a result of daytime heating allowed flow over the southern Rocky Mountains in Arizona to lead to this severe weather outbreak over the desert southwest. Rainfall was enhanced by the development of a surface heat low late in the day on the 8^{th}.

None of the conditions associated with this storm pointed to a widespread severe weather event. Had these storms happened anywhere besides in the desert southwest, they may not have even turned any heads. Because of the environmental conditions of the area, however, the heavy rain led to severe flash flooding, property damage, injury and death.