Diagnosis of the Fallon Hail Event 21 July 2008: A Rarity in Nevada

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Abstract

The hail event that occurred on 21 July 2008 at 22:45Z in Fallon and Silver Springs, Nevada was a rare event due to its production of heavy rains, a large amount of hail and two tornadoes. The event occurred as a result of the coupling of favorable synoptic and mesoscale conditions. The synoptic environment prior to the storm helped create favorable conditions for severe weather at both the 300 MB and 500 MB levels. At the 300 MB level, the curvature of the upper level flow created a weak region of upper divergence, which acted as a weak dynamical lifting mechanism. At the 500 MB level, a cut-off low located west of the storm site helped to decrease temperatures and destabilize the middle layers. The cut-off low also created a southerly flow that feed moisture into the Nevada region at mid and low levels. The 700 MB and 850 MB set-up aided the influx of moisture. Going further into the mesoscale set-up, daytime radiation heating caused thermals in the atmosphere to warm the lower levels, overcome the convective inhibition present earlier in the day, and destabilize the lower atmosphere. With a destabilized atmosphere, orographic lifting over the mountains provided enough lifting to place air parcels into a region of free convection. A favorable wind profile, CAPE, low wet bulb freezing height and abundant moisture enhanced the convection and formed a rare, Nevada supercell.

I. Introduction

On the 21st of July, 2008 a devastating hail event struck western Nevada, devastating the Silver Springs and Fallon areas. The event began mid-afternoon and quickly developed into a severe supercell event. The first reports of severe weather were called in at 22:45 Z, reporting localized flooding with nickel sized hail. Then, at 22:49 Z, another report was called in saying an accumulation of three to four inches of hail was blanketing the ground. The following reports, only minutes later, called in the sightings of rain-wrapped tornados 5 miles west and north of Fallon. Storm reports throughout Nevada continued to for nearly an hour and a half, each claiming heavy rain and hail.

The hail event that occurred on July 21, 2008 was a unique and rare event to the state of Nevada due to its mountainous and dry location. However, the atmospheric conditions of 21 July 2008 took advantage of and manipulated these persistent conditions to develop such a rare system. Figure 1 illustrates a schematic of the manipulations that were prevalent during the supercell hail event. Represented in the figure are two often unique and separate processes that where combined: orographic lifting and the resulting developing supercell. In the first process, daytime heating of the earth's surface cause the atmosphere to destabilize and a slight pressure gradient to form along the mountain slope. The small pressure gradient along the mountain side causes a weak upslope flow and convergence atop the mountain. Here, convection enhanced by the destabilization of daytime temperatures occurs. As the time progresses, the mean flow carries the system off the mountain top and convection continues to occur; this schematic shows the mean wind travelling upslope from the left side of the image to the right side. As the system increases in size and strength, processes two represented in Figure 1 occurs. In process two, a strong updraft begins to carry cloud droplets and rain droplets past the freezing level, supercooling them as they are lifted. The supercooled droplets then become accreted onto a nuclei and begin to form a hail stone. As the hail stone continually smashes into supercooled droplets in the updraft, the droplets glaciate and cause the hail stone to grow. Once the hail stone is either too heavy to be sustained by the updraft or is shot out of the updraft, it falls to the ground, melting on its way down. Often times, the hail stone will once again re-enter the updraft column and continue to grow. The cyclic process of formation and decay can occur many times throughout the life-time of a hail stone and can produce a various sizes and amounts of hail.

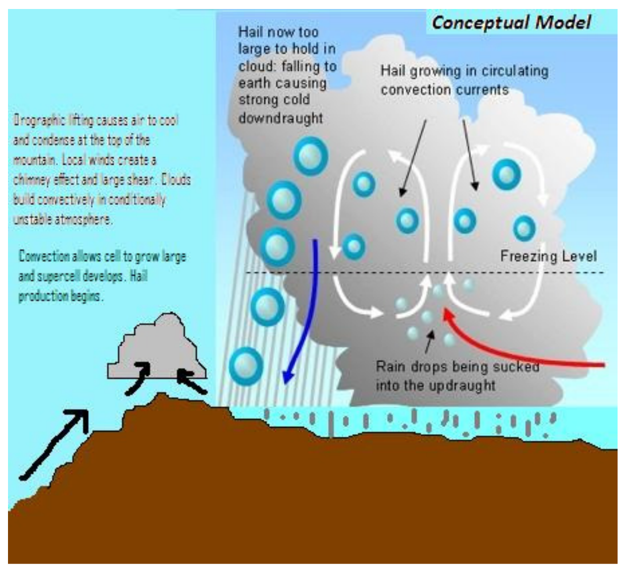

Figure 1: A Conceptual Model of the Nevada Hail Event.

This case study of 21 July 2008 will analyze the key synoptic and mesoscale features present to cultivate this supercell hail event. It will argue that multiple dynamic mechanisms were present to destabilize the atmosphere above Nevada and that orographic lifting initiated the upwards vertical motions carried out by free convection. The paper will also argue that the combination of wind shear, low CAPE levels, a low wet bulb freezing height and abundant moisture caused the large hail amounts and heavy rains that occurred on 21 July 2008.

II. Data

This report utilized many different sources of information. The primary source used was the Storm Prediction Center: Severe Storm Archive; this source provided data concerning the Nevada Hail Event in the form of 300 MB, 500 MB 700 MB and 850 MB level flow charts, surface observations, radiosonde and index data, and storm reports received during the event. More data concerning the 300 MB level, 850 MB level, the LI indice and radiosonde data was utilized using the Unysis Archives and the University of Wyoming Archives. Additional sources of information concerning hail formation, geography, and environmental characteristics commonly associated with severe weather were used to supplement my own knowledge and verify details.

In addition to internet and lecture sources, computer programs were used to assess a visual progression of the storm. The program known as GARP was used to create a radar and cross sectional analysis of the system throughout its development and decay. Similarly, McIDAS-V was used to create a visible imagery of the storm. With the data from these two animations, an understanding of the development and progression of the hail event was found and was used in combination with dynamics to discover the synoptic and mesoscale mechanisms that forced the event's production.

III. Synoptic Overview

The synoptic conditions leading to the hail event, in no way, were the classical text book examples commonly depicted. Despite the non-classical set-up however, the conditions did provide an atmosphere suitable for breeding such a hail event.

a. *300 MB Analysis*

Analyzing the upper levels on 21 July 2008 at 12Z, the 300 MB synoptic set-up was partially responsible for creating the dynamical forcings key to development of this event. Prior to the hail storm, the 300 MB analysis, represented in Figure 2b, showed a ridge-trough pattern located over the United States, with a large ridge placed directly over the Rocky Mountains. Upstream of the ridge, a cut-off low pressure system existed within the pattern as a shortwave feature just west of northern California. This feature, coupled with the large ridge over the Rocky Mountains, created a small region of divergence over northern California and northwest Nevada. The divergence was a result of the separation of the supergeostrophic winds within the ridge and the subgeostrophic winds within the trough of the cut-off low. Though minor, the upper level divergence helped to generate an upwards vertical motion that would lift the atmospheric parcels to a region of free convection.

Within the flow pattern of the 300 MB set-up as seen in Figure 2b, was a small jet streak. The jet streak, oriented in a southwest to northeast direction, was located over the California coastline and was composed of southwesterly winds. Using the four quadrant model, a region of upper level convergence developed over northeast California and northwest Nevada. This region of convergence created an area of sinking motion and divergence in lower levels. This subsidence created by the jet's right exit region caused a separation in theta contours which, in turn, destabilized the atmosphere and caused temperatures to cool at mid-levels from -7° C to -8° C. As a result of the destabilization, the atmosphere was primed for convection responsible for the hail event.

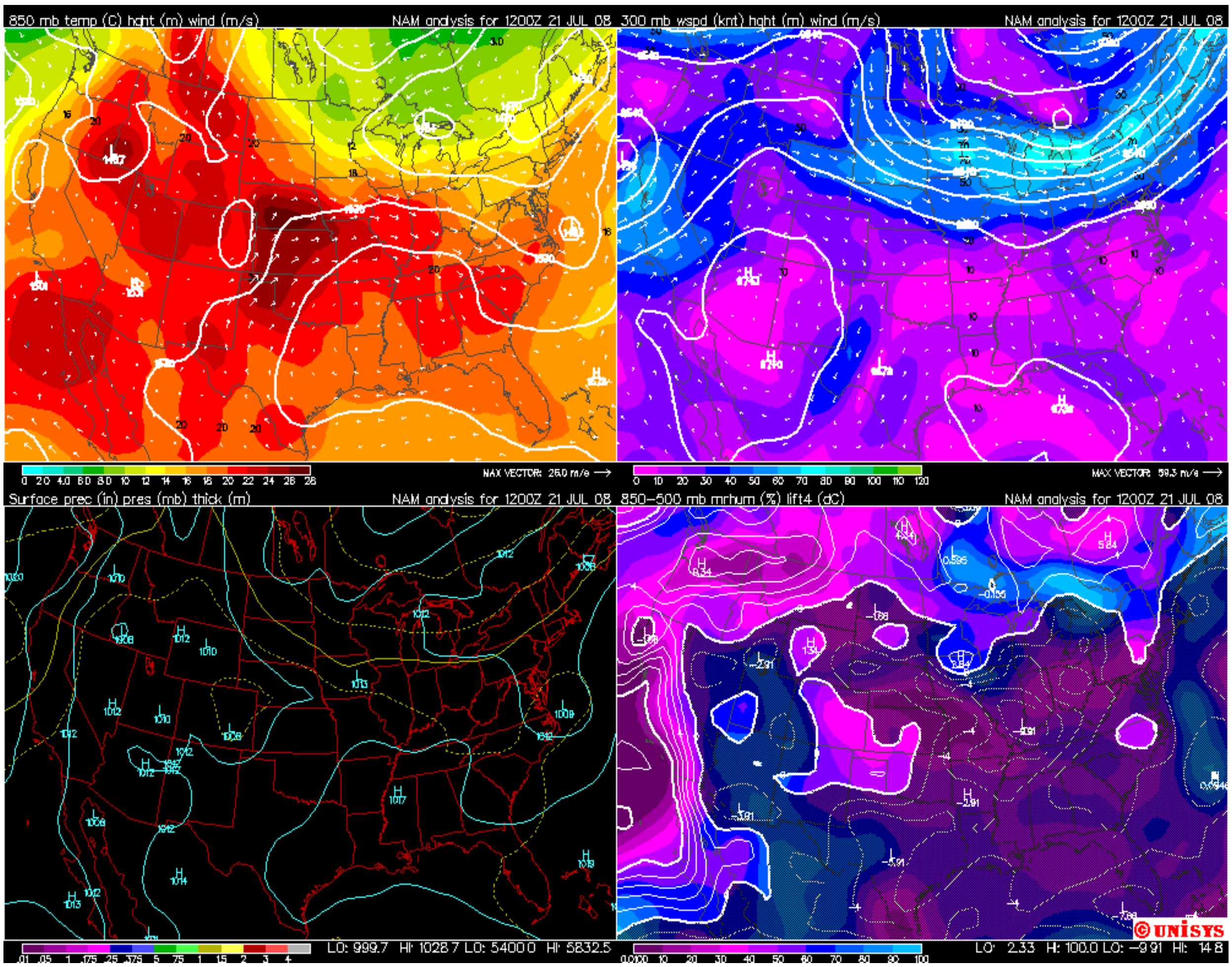

Figure 2: This figure is a four-panel plot of major atmospheric levels. Panel A shows the 850 MB heights and temperatures. Panel B shows the 300 MB heights and wind flow. Panel C shows the surface pressures. Panel D shows the relative humidity of the air and the Lifted Index values.

Both the curvature of the flow and the jet’s right exit region played a role in the setting up the atmosphere for the supercell to form. However, these two actions do inhibit one another. Figure 3 shows the addition of upper level divergence due to curvature and the upper level convergence due to the right jet exit region. From the figure, it is deduced that the addition of these opposing forces produce an environment in which the atmospheric divergence remains slightly stronger than the atmospheric convergence; this is seen by the divergence (yellow) contours. Therefore, the curvature of the flow acts on the environment as a dynamic lifting mechanism to spawn upwards vertical motions.

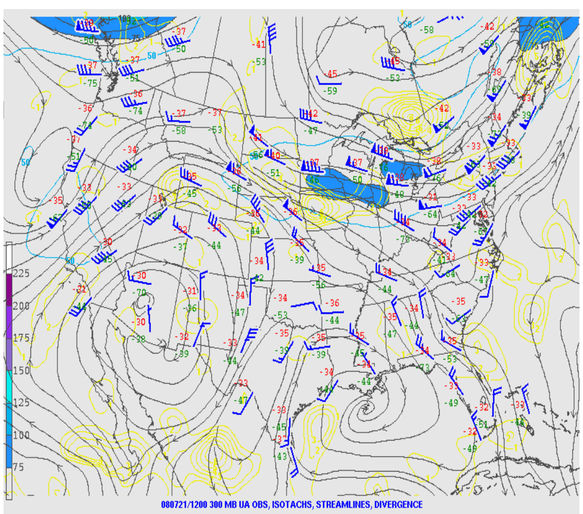

Figure 3: This figure shows the 300 MB streamlines (black contours) and wind field (wind barbs and color fills). The figure also depicts regions of atmospheric divergence (yellow contour).

a. *500 MB Analysis*

While dynamical forcings for upwards vertical motion were present at the 300 MB level, the 500 MB level had very few contributions to the dynamical forcings. The 500 MB level did, however, impact the storm’s development in other ways. One manner in which the 500 MB level increased the potential for severe weather was the positively tilted cut-off low pressure system located just west of the California coast, represented in Figure 4. The mid-level cut-off cyclone aided in the generation of the storm in two separate and unique ways. The first manner, in which the low aided the storm, was the destabilization of the middle levels of the atmosphere. Over time, this feature became more developed, deepening and decreasing the 500 MB heights to minimum levels of 576 m, also depicted in Figure 4. At same time, however, temperatures cooled from -7° C to -8° C over Silver Springs and Fallon. The drop in atmospheric temperatures acted to decrease the environmental lapse rate in the middle levels as well as the stability of the atmosphere within the region.

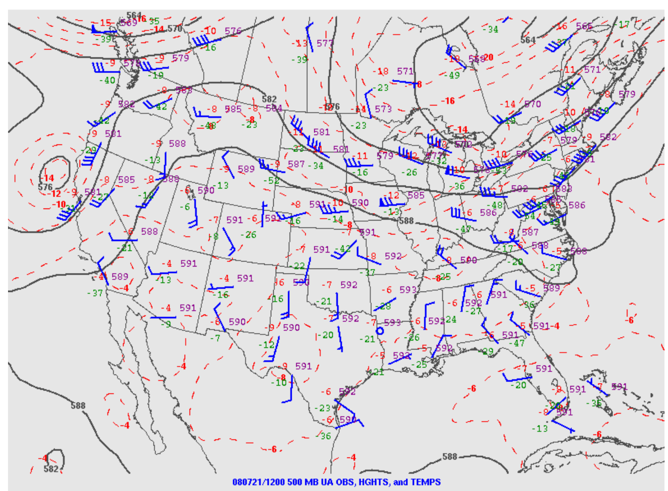

Figure 4: This figure shows the 500 MB heights (solid black) and temperatures (dashed red).

The second manner in which the 500 MB acted to aid in the development of the system was to supply an abundance of moisture to the region. The cut-off low, positioned over California’s northern Pacific Coast, caused a southwesterly wind at the upper levels and a southerly wind at the lower levels. This wind carried large amounts of moisture from the Pacific Ocean into Nevada, creating a reservoir of energy for convective systems. In most situations, atmospheric moisture will condense and precipitate out of the air while traveling over the mountains. However, in the case with a southerly flow, the moisture remained in the atmosphere as a result of the wind flow carrying the moisture between mountain ranges and not allowing it to be lifted high enough into the atmosphere to force condensation and precipitation.

a. 700 MB and 850 MB Analysis

The lower levels, 700 MB and 850 MB, were the next primary levels of interest. At the 700 MB level, a general south-southwesterly flow of the winds existed and continued to feed low level moisture into Nevada. At the 850 MB level, or the surface, daytime radiation heating due to the sun occurred. As seen in Figure 2c, the morning temperatures began in the upper teens, but rose to over 30° C over the course of the day. This daytime heating directly acted to destabilize the atmosphere. The stability of the morning atmosphere at 12Z, using the Lifted Index, is depicted in Figure 2d. This figure shows an atmospheric stability value of less than -1.66, indicating thunderstorms are, at minimum, probable. As the daytime heating increases throughout the day however, the Lifted Index decreases to a value -3.57 by 00Z. At this value, index indicates severe weather is possible.

IV. Mesoscale Analysis

The supercell hail event that occurred on July 21, 2008 was one in which favorable synoptic features ripened the atmosphere while mesoscale features triggered the event. There were three key, intermingled processes that lead to the formation of this supercell event: localized daytime heating over the Silver Spring and Fallon region, the orographic lifting caused by the Sierra Nevada, and the wind shear profile that gave the storm rotation and generated a tilted updraft column.

a. Local Radiational Heating

The daytime heating that occurred on July 21, 2008 greatly aided in the production of the Nevada supercell in two ways. First, as seen in Figure 5, morning temperatures were near 17° C and were accompanied by a small surface radiation inversion. This small radiation inversion, was enough to act as a capping mechanism and allowed potential energies of the storm to grow.

The local atmosphere over western Nevada at 12Z on July 21 did not seem one favorable for generating the events the occurred later that afternoon. The radiosonde sounding released by the weather station in Reno, Nevada at 12Z July 21, Figure 5, showed weak promise of severe weather. The first element noticed within the sounding was the small radiation inversion present at the surface and another second small inversion present in the upper levels. The surface inversion, caused from night-time radiation cooling of the earth’s surface, acted as a capping mechanism for convection during the early daytime hours and inhibited upwards vertical motions below 800 MB. As the day wore one however, radiation heating from the sun increased the surface temperature to over 30° C, a 13° C increase. The effects of daytime heating are seen directly in Figure 6. Figure 6 depicts a radiosonde released at 18Z on 21 July 2008. In the sounding, the warming of surface temperatures can be seen from 17° C at 12Z to 25° C at 18Z. With warmer temperatures at the surface, pockets of warm air formed, creating thermals and atmospheric stirring. As a

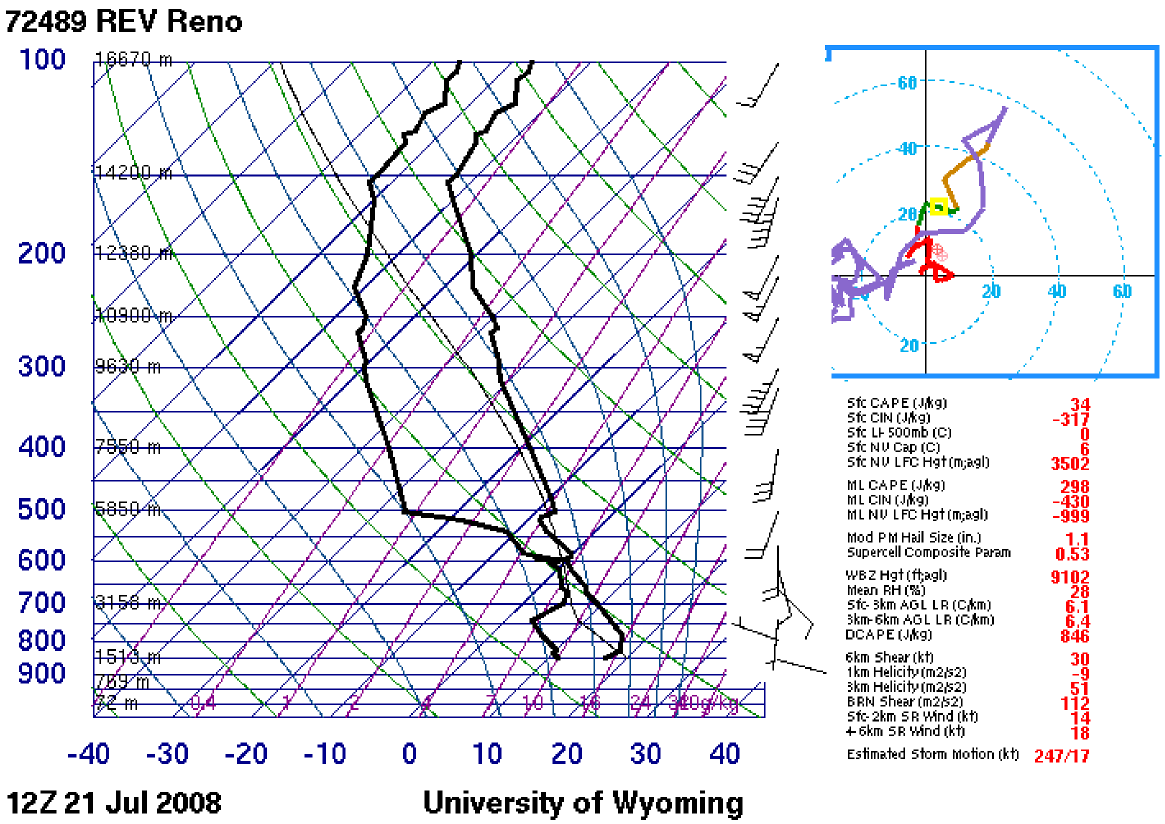

Figure 5: The radiosonde sounding data taken from Reno, Nevada on 21 July 2008 and 12Z. A list of index values and a hodograph are also depicted.

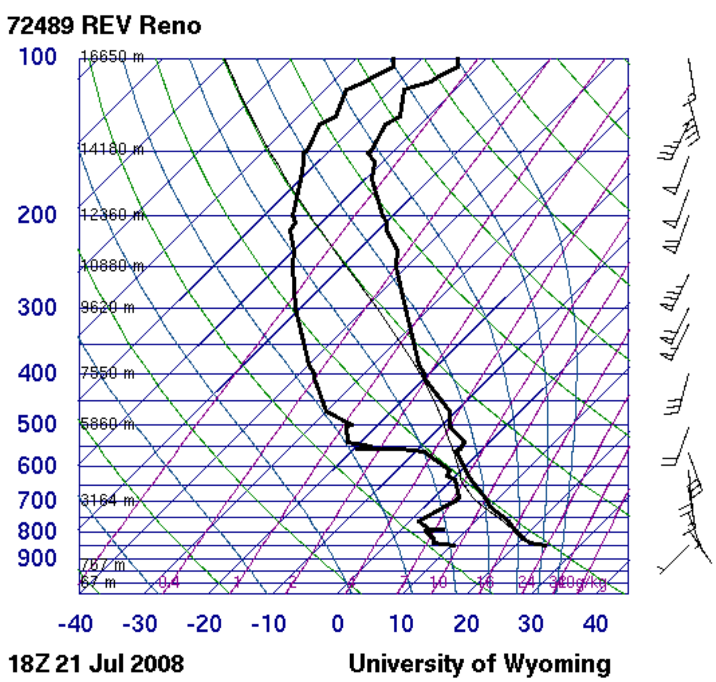

Figure 6: The radiosonde sounding data taken from Reno, Nevada on 21 July 2008 at 18Z.

result, a well mixed layer was created, causing a decrease in the lapse rate throughout the lower levels. This can also be seen directly within Figure 6 between the 760 MB and 700 MB levels. This mixing of the lower levels eliminated the small radiation capping mechanism evident in the atmosphere in the early hours. Without the capping mechanisms, the atmosphere was less stable and convection could now occur.

The warming of surface temperatures did aid in destabilizing the lower layers of the atmosphere, however a slight cooling of temperatures aloft further destabilized the layer. Comparing Figures 5 and 6, the mid-levels from 400 MB to 600 MB are seen to have decreased in ambient temperatures. The temperatures at 400 MB decreased from -18° C to -21° C while the temperatures at 500 MB have decreased from -8° C to -9° C. The temperatures at 600 MB remained at a relatively constant – 20° C throughout this time. Though the ambient temperature decreases were slight, the cooling of these upper levels via the jet streak's subsidence in coincidence with the 500 MB low subsidence created an even more unstable atmosphere with a smaller lapse rate.

The destabilization of the atmosphere due to latent heating is explicitly illustrated in Figure 7. The figure below depicts a cross section with the variables omega and theta-e plotted from Reno, Nevada on the right to Vandenberg Afb, California on the left at 18Z on 21 July 2008. In this image, an atmospheric destabilization is seen just left of Reno as a bubble of theta-e contours. The decrease in theta-e contours with height created by this "bubble", represents the environmental thermals created by daytime heating. Also present in the figure is omega, or vertical motions. This variable depicts rising vertical motions in the same region the atmosphere is least stable, just left of Reno. This upwards vertical motion further proves the instability of the atmosphere.

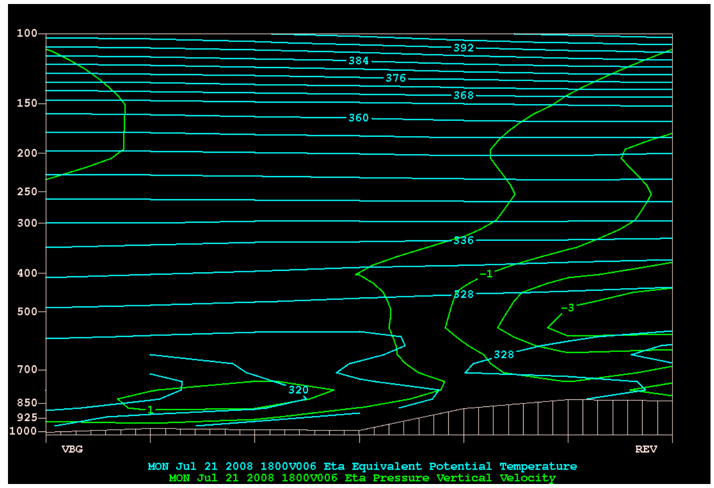

Figure 7: The figure shows a cross section taken on 21 July 2008 at 18Z from Vandenberg Afb, California to Reno, Nevada. The cross-section depicts omega in green contous and theta-e in blue contours.

b. Orographic Lifting

Local radiational heating of the earth's surface was responsible, in part, for creating the conditionally unstable atmosphere present on 21 July 2008; however it was orographic lifting that created a local chimney effect and convection over the state of Nevada. On July 21, a southerly wind flow was the primary flow throughout California and Nevada. As the wind traveled however, it had to pass over the Sierra Nevadas. The Sierras are a mountain range along the California and Nevada border that extend over 400 miles long. They have maximum elevations ranging from 5000 to 8000 feet and increase in elevation from north to south (Sierra Nevada: Geography). As air flow attempted to pass over these 5,000 foot mountains, the mountain gradually forced the parcels to rise with its slope. The air parcels passing the Sierras typically cooled enough to temperatures at which the parcel would condense into liquid water but would not always precipitate out. In the hours prior to the event, at 12 Z, the surface and mid-level inversions prevented any free convection of these orographically lifted parcels. As the day wore on, daytime heating of the atmosphere and surface caused, in addition to atmospheric cooling within the middle levels, caused a steepening of the lapse rate, a build-up of Convective Available Potential Energy and deterioration of the convective inhibitions present in the early hours. As the flow continued to be southerly and forced over the Sierras, the orographically lifted parcels previously stopped, were then lifted to the level of free convection and the parcels rose freely.

c. Features Forming the Supercell

As all the synoptic and mesoscale forcing mechanisms came together for hail event to occur over Silver Springs and Fallon, so did local characteristics important to the development of the hail producing supercell. The elements required for supercell development can be seen in Figure 4 using the wind profile, CAPE values, wet bulb freezing height and available moisture. First, the wind profile to the right of the sounding data in Figure 4 provides evidence of a veering wind profile with height in the bottom three kilometers of the atmosphere. The profile shows a weak backing wind from the surface to the 700 MB level, followed sharply by a moderate veering wind to the 500 MB level. The strong directional shear, at this time, was the primary shear and produced a Bulk Richardson Number of 112, three times the maximum value indicative of supercell development. By 18Z however, the large directional shear diminished. The wind profile at 18 Z, as shown in Figure 5, had changed to weak backing winds from the surface to 800 MB, followed by a stronger veering wind from 800 MB to 500 MB. The decrease in directional shear was replaced with a stronger speed shear and a clear veering profile. The change to a more dominantly veering profile helped to introduce a cyclonic rotation into the region, increasing surface helicity and vorticity. Strong helicity and shear values are important to the development of hail as they work to simplify and sustain the process by intensifying and tilting the updraft column. Strong and more tilted updrafts can allow for hail stones to make multiple passes through the updraft column and grow larger.

The Convective Available Potential Energy, wet bulb freezing height and available moisture were three more important characteristics that aided in the development of the supercell. The middle level CAPE, as noted in Figure 4, began the day at a value of 298 Joules per Kilogram. Compensated by wind shear, the CAPE value increased only slightly throughout the day as a result of atmospheric destabilization. The 300 Joules per Kilogram of CAPE provided enough energy to trigger the hail events of July 21 and can be used to estimate the updraft speed with which the hail was formed. By taking the square root of twice the CAPE value, the estimated updraft speed of the supercell was approximately 24.5 meters per second.

Sq Rt (2*300) = 24.49 m/s

An updraft column with a speed maximum of 24.5 m/s would not have the momentum to support large hail formation, but could support small hail formation. The favorable conditions for small hail formation increased the potential amount of hail stones produced by the event given the amount of moisture available. In other words, the potential for more hail grew as the conditions favored small hail development.

Another variable that favored hail production was the wet bulb freezing height. With a height of just over three kilometers, the wet bulb freezing height was close to earth's surface, indicating a large portion of the atmosphere was cool enough to promote hail growth. The freezing level height indicated hail for this event would be located within a freezing zone for relatively longer periods of time and had potential to grow to large sizes. The lower freezing level also ensured that the hail stones created in this event would not melt entirely before researching the surface.

The final element key to this large hail and precipitating event was the amount of moisture present within the atmosphere. As previously noted, the 500 MB cut-off low pressure system, just west of northern California, created a dominant south-southwesterly to southerly flow that carried moist, marine air into Nevada. This moisture influx created a reservoir of water vapor and energy for the supercell to utilize. Nearly 23.85 mm of precipitable water was available for the storm to use at 12Z; this high moisture content allowed the system to cultivate both large amounts of hail and large amounts of rain.

The contribution of each of these elements, wind shear, CAPE, wet bulb freezing height, and abundant moisture, is evident in the progression of the cell. Figures 8 and 9 represent the radar reflectivity of the hail event at 22:39Z and 23:01Z respectively. In Figure 8, an unorganized cell structure is seen with a maximum reflectivity between 65 and 70 dBZ. Twenty-two minutes later, an organized cell structure with a reflectivity between 65 and 70 dBZ is seen in Figure 9. This organization and high reflectivity is the direct result of the elements working together to create strong cyclonic vortex that drives the progression of the cell and feeds off the energy of the environment; this direct marriage is evident in the hook echo of the Silver Springs and Fallon cell in Figure 9.

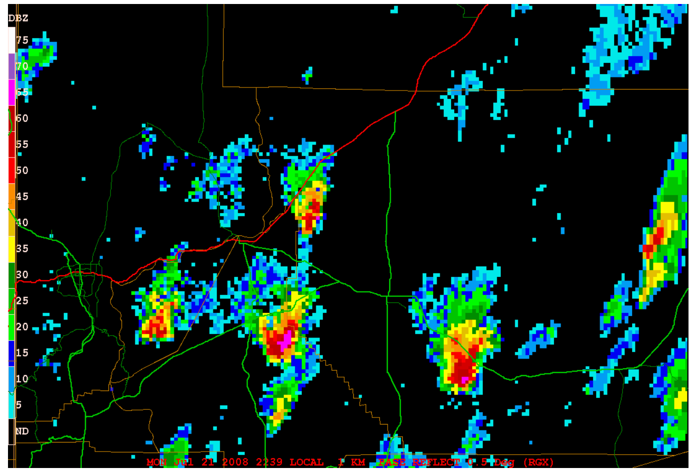

Figure 8: This figure is a radar snapshot taken from the Reno, Nevada radar at 22:39Z, when the cell is weak and unorganized. The cell that of focus is located directly over the Lyon and Churchill county border, just down and left of the center of the shot. The maximum reflectivity is between 65 and 70 dBZ.

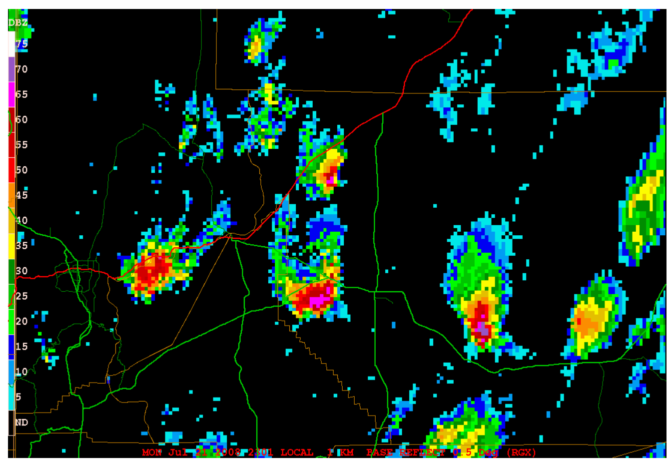

Figure 9: This figure depicts a radar snapshot taken from the Reno, Nevada radar at 23:01Z, when the cell is strongest and returns a hook echo. The cell of focus is located just east of the Lyon and Churchill county borders and is in the center of the snapshot. The maximum reflectivity of this cell is between 65 and 70 dBZ.

V. Conclusion

The Nevada 21 July 2008 supercell hail event was a unique and rare event that was the result of complimentary synoptic and mesoscale conditions. Together, the synoptic and mesoscale conditions created a hail event that produced large amounts of hail and rain throughout its life. The event produced three to four inch accumulation of hail in Silver Springs, nickel sized hail with flooding at the Lahontan Reservoir as well as in Fallon, and a rain-wrapped tornado in Fallon. The environmental elements that created such an event began in the upper levels, near 300 MB. At the 300 MB level, a jet streak over northern California's coast placed a right exit region directly over the northern California and Nevada border. In this region, upper level convergence acted to destabilize the column by forcing a separation between the theta contours. Also in this same region however, the curvature of the flow from trough to ridge placed the northern California and Nevada border in a region of upper level divergence. The divergence due to curvature acted as a dynamic lifting mechanism for the surface air. When the two feature's effects were added together, the upper level divergence due to curvature won. At the 500 MB level, a cut-off cyclone over northern California's Pacific coastline intensified with time to create two effects on the atmosphere over Nevada. The first effect of the cut-off low was a cooling of the mid-levels by 1° C. The cooling effect steepened the lapse rate over the region and caused the atmosphere to destabilize to a conditional unstable state. The second effect of the cut-off low was to provide an abundance of moisture to the Nevada region from the Pacific Ocean via the southerly wind. The moisture transported to this region provided a large energy source for convective systems to develop and mature to be very powerful. In the lower levels, 700 MB and 850 MB, a southerly flow continued to feed moisture into the region.

On the mesoscale, daytime heating, orographic lifting, wind shear, CAPE, the wet bulb freezing height and moisture content all worked together to build the supercell storm. The daytime heating created warm thermals to rise from the surface and mix the air over Silver Springs and Fallon. This mixing warmed the overall atmosphere, erasing the convective inhibition at the surface and destabilizing the lower levels of the atmosphere. Once the atmosphere was destabilized, the orographic lifting caused by an upslope flow was strong enough to push air parcels up to a level of free convection. The orographic lifting was the trigger mechanism for the convection and storm to begin building. Atmospheric characteristics, such as the wind shear, CAPE, wet bulb freezing height and moisture, then added to the growing cumulus and returned the evolution of a supercell with heavy rains, a lot of hail and even a tornado.

The supercell was undeniably a rare, heavy precipitating event in which atmospheric conditions on both the mesoscale and synoptic scale were favorable for a severe weather outbreak. Perhaps a future study could look at how rare these events truly are and what atmospheric conditions are common among them. It would be intriguing to discover if an atmospheric pattern existed for these events. Due to the rarity of such events, however, a general pattern would not be a surprise.

VI. References and Acknowledgements

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