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A Preliminary Look at Well-Developed Vortices near and behind The Monsoon Frontal Boundary Area during the Mid July through Early August 2017 Monsoon Outbreak in Southern California

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1. INTRODUCTION

On occasion, an "East-West Ridge Axis to the North" pattern develops during the monsoon season in the southwest. This allows, convection-enhancing features to develop and move westward beneath it into Southern California. During this time, the southwest edge of the monsoon frontal boundary and strong moisture gradient can bring severe weather and flash flooding, especially if it arrives with an abrupt increase in moisture and large moisture gradient. During the period 19 July through 4 August 2017 rather impressive-looking small vortices as well as the larger Mesoscale Convective Vortices (MCVs) affected Southern California and the coastal waters. Inland convection was developing on outflows, and was enhancing convection on other terrain generated features as well as other outflows as and the convection it encountered. The vortices seemed to develop and thrive in this moisture-rich environment.

Near the beginning of this monsoon period, the moisture was mainly elevated, and a deformation zone very close to the monsoonal front generated showers and thunderstorms.

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Conditions may have been more favorable for even very small vortices to develop in Southern California due to the monsoonal boundary and associated gradients. Initially, conditions for deep convection were not favorable as the moisture was mainly elevated.

Top-down moistening was taking place near the middle of this multi-day event as the transition began to take place. The night and morning elevated convection events merged with moist unstable low level flow interacting with terrain. In addition, afternoon and evening surface heating/terrain driven showers and thunderstorms developed in the typical diurnal fashion, which basically became more and more prevalent. Also large inverted troughs began enhancing the monsoonal boundary moisture, instability, and forcing for severe weather and flash flooding developed. These inverted troughs showed up as huge circulations on the monsoonal boundary.

This monsoonal event ended the evening of 4 August, when westerly flow pushed the monsoonal boundary to the east with drier air moving in aloft. In this study, an inspection of the numerous waves, potential causes, and detection strategies will be presented. Although initially considered to be preliminary, non-operational data, some information can be gleaned from GOES-16 data, so some thoughts on GOES-16 possibilities will be included. Other tools will also be utilized to further analyze these very interesting weather phenomena and the conditions associated with them.

Below, the rotations along a cold front will be shown first, and how similar they are to rotations near the monsoonal boundary layer. As the events progress during this mid-July through early August period the moisture and instability increases from mainly just lightning events to severe weather/flash flood events. The moisture evolves in the top-down manner, and at the end there are mainly low-end flooding events as the drying progresses in this top down manner. Along the way, rotating phenomena and convergence zone events will be pointed out. Finally in early September, an event that could have easily occurred at the tail end of the early August event, shows how volatile the drying-out period of a monsoonal episode can be.

2. BASIC CONVECTIVE CONDITIONS

Most of the time in southern California rainfall develops with mainly low level moisture from the west during the cool season. During the monsoon season, most of the precipitation events are due to mid-level moisture from the south and southeast, with occasional extensions of the moisture closer to the surface with possible flooding and severe weather. If the moisture remains aloft with some dynamics and instability as well, usually the chief concern is dry lightning, and sometimes microbursts.

Figures 4-6 show a relationship between the Showalter index, or SI (Showalter, 1953) and the High Level Lifted Index, or HLLI (Vanderburg et al., 2010). The Showalter index is based on lifting a parcel from 850 hPa, and measuring the lifted index at 500 hPa. The high level lifted index (HLLI) is similarly computed, except parcels are lifted from 700 hPa. In this manner, the HLLI can detect elevated moisture and instability, even when the lower levels are generally dry. The SI looks at the lower levels for moisture and instability. In the graphs, elevated convection seen to occur stands out where the HLLI approaches zero and/or becomes negative, and can occur without surface-based convection when the SI has large positive values. The strong to very strong convection (often involving severe weather and flash flooding) occurs when both are near zero and/or becomes negative.

Figures 7-8 show a relationship between the SI, the HLLI, in addition to the Most Unstable CAPE (MUCAPE) and the 850 hPa CAPE (CAPE due to lifting a parcel at 850 hPa). This parameter was introduced to have a consistent level to lift from, and also to be above the marine layer, which contaminates the CAPE calculation at KNKX if parcels are lifted from the marine layer. Also, the MUCAPE here is the most unstable CAPE, but only computed from the most unstable parcel lifted from a point above the marine layer. It seemed like the days when the MUCAPE and 850 hPa CAPE exceeded 100 for a couple of days it allows the airmass to basically be likely to produce nuisance flooding type issuances for convection (FLSs) along with Flash Flood Warning issuances (FFWs) and severe thunderstorm Warning issuances (SVRs). (Two-day exceedances of 1.5 inches of precipitable water also seem to give likely probabilities of warning issuances when the mid-level steering winds are around 10 knots or less with ample sunshine). Not much happened during the episodes that were less than about 48 hours at the triple digit CAPE values during the late July through early August 2017 episodes. Vanderburg et. al., 2010 mentioned that

"HLMUCAPE values of 200 J/kg or more and HLLI values of around -1.5 degrees C or lower appear to be "significant values"

(basically showers and thunderstorms expected any time of day). Slightly more stable values mainly just produce showers, (Typically, as long as there is 700-500 mb relative humidity around 65 % or higher and there are mid-level clouds, showers are possible).

During the afternoon when the 50 % relative humidity contour dipping down to at least the 650 mb level and relatively light (20 knot or less 500 mb winds) prevail, a solar heating and terrain-based convergence component is introduced (including low level flow interactions), and can result in the initiation of showers and thunderstorms, even with slightly more stable values of HLMUCAPE and HLLI than is shown above (this is related to lower-level instability, for example, the Showalter Index (Showalter, 1953).

The 0000 UTC 4 June 2009 HLMUCAPE in Vanderburg et al., 2010, was 501 J/kg, and the HLLI was -3.2 degrees C, far more unstable than was forecast by the NAM80 model.

Apparently the destabilization shown by the models was much less than the destabilization that actually occurred. Figure 5 shows the 2027 UTC 3 June 2009 composite reflectivity from the KNKX radar. The 3 pixels of 65-70 dBZ near the time of the reported 1 inch diameter hail (near Solana Beach) can be seen. Seems as though such extreme values (501 J/kg, and the HLLI was -3.2 degrees C) were sufficient for severe hail.

It is a good idea to look at relative humidity (in addition to precipitable water) in cases where the moisture is elevated (Precipitable water values are "bottom heavy", or in other words strongly skewed downward if the moisture is elevated). This can allow situations to seem "too dry" when there is actually plenty of moisture aloft for precipitation and possibly thunderstorms.

Widespread nocturnal and diurnal convection can occur as moisture, HLLI, and Showalter indices approach favorable values for convection to develop (anywhere and at any time when those values are around -2 or more negative at the same time).

Classic southern California loaded gun soundings for a severe microburst threat with huge low level lapse rates occasionally occur. This shape is seen in the early August 2017 events with drier conditions aloft favoring a large hail threat, and wetter conditions aloft favoring flash floods. Also if afternoon high temperatures are well over 90 inland coastal plain and well over 100 in the valleys along with the inversion top near 30 C, it is a classic profile for such outbreaks, especially severe microbursts. In the highly populated areas, especially in the coastal plain, even wind gusts 45-55 mph can produce severe wind damage, in part due to the infrequency of events there and sometimes assisted by saturated soils. This increased vulnerability at lower speeds was noted and discussed in Small, 2006.

3. FIRST ACTIVITY EARLY IN THE MONSOONAL EPISODE AROUND MID-JULY 2017

Rotations along a cold front are rather common (Fig. 2.), and some were captured and shown in the loops in the recorded presentation version (https://ams.confex.com/ams/98Annual/webpr ogram/Paper335870.html). Some interesting things occurred on 19 July, 2017 with weak waves moving through the southwest edge of the monsoon boundary, one even off the coast of Southern California (Figs. 1 and 2.). A band of convection consisting of showers and thunderstorms developed, extending from the small wave just southwest of Southern California to over Southern California (Fig. 3).

This occurred when the monsoonal front pushed west, and the airmass began the process of moistening for about a week, then finally drying near the end of an approximately 2 week period, along with changes in the sounding indices. For 19 July, the HLLI and SI show very unstable values, and nocturnal convection with rotation occurs, but little if any afternoon convection occurred. This may be in part due to the short duration of the very unstable values.

A closer look at the band, it appears to be near the monsoonal front (Fig 9), and also in an area where the deformation zone associated with a small wave off the coast is situated. There is a strong moisture gradient across it (Fig. 10) similar to a mid-latitude front. Radar imagery shows circulation (Fig. 11). The sounding shows good instability (Fig. 12). The models forecast a nearly identical scenario to develop on 24 July (Fig. 13). The models indicate another wave moving north in the 66 and 72 hour forecasts, which should push up the relative humidity once again, interact with the weak wave off the coast near the monsoon front, and add dynamics to strengthen the monsoon front area on 24 July 2017.

Large lows over west-central Arizona moving through created very moist easterly flow into California, with convection racing southwestward across the deserts (on what appeared to be convergence zones at times). Figures 14 and 15 both show the deformation zones on both days. This deformation zone was a strong factor in creating convective activity over San Diego County. This large low also created moisture and wind shear via large, terrain driven mesoscale convective systems triggered by the low moving toward the west.

Counter to this moist east flow, one system off the Northern California coast along with yet another low west of the Baja Peninsula supplied drier south to west flow. This helps to sharpen the moisture gradient over Southern California. This also enhanced the shear and instability (Fig. 16) near the monsoonal boundary, possibly making it easier for even very small vortices (Fig 17) to develop on 24 July (conditions seemed exceptionally strong for convection, and easily sufficient for thunderstorms, for example, the large MUCAPE). Figure 18 shows how a line-oriented system began to rotate as the system approached the monsoonal boundary. Figure 17 shows that this circulation is a member of a family of circulations near the monsoonal boundary, and is similar to a mid-latitude cold front as shown earlier.

4. EVOLUTION OF THE 24 JULY 2017 CONVECTION

On 24 July 2017 the band of convection consisting of showers and thunderstorms was still extending from the small wave just southwest of Southern California to over Southern California. It is likely to have been generated and maintained via some contribution from a deformation zone off the coast, extending to the northeast.

A large low over west-central Arizona created very moist easterly flow into California, with convection racing southwestward across the deserts (on what appeared to be convergence zones being enhanced by large outflow boundaries moving to the southwest at times). This large low over Arizona also created moisture and wind shear near the monsoonal front via large, terrain driven mesoscale convective systems triggered by the low. Counter to this low and its moist east flow, there was a second low pressure system off the Northern California coast with dry west to southwest flow.

Also added is a 3rd low, sitting off the Baja California coast, helping to supply drier south to west flow This helps to sharpen the moisture gradient over Southern California to what is likely to be an unusually intense strengthening of the gradient, hence a "strong monsoonal front".

This also enhanced the shear near the monsoonal boundary, possibly making it easier for even very small vortices to develop under very marginal conditions (however, conditions seemed exceptionally strong for convection and easily sufficient for thunderstorms, for example, the large MUCAPE).

5. MIDDLE OF THE EPISODE – DEEP MOISTURE AND INSTABILITY AND CLASSIC FLASH FLOOD/SEVERE WEATHER SOUNDINGS

Waves moving to the west continue to help to locally sharpen the moisture gradient over Southern California near the "monsoonal front" and strengthen convection into early August. This also likely creates wind flow patterns near the monsoonal boundary that make it easier for even very small vortices to develop under seemingly marginal conditions (however, conditions seemed exceptionally strong for convection and easily sufficient for thunderstorms in these cases). Outflow boundaries from the east could also be seen enhancing convection along bands that were moving so slowly that they were overtaken by this faster moving outflow boundary. These are best seen via loops in the recorded presentation. Figure 19 shows mid-episode, very moist and unstable conditions as the transition into the severe weather/flash flood conditions continued. Figure 20 shows circulations and feature well in the GOES-16 Data. Figure 21 shows a very strong thunderstorm developing on a convergence zone in the low levels. Figure 22 on 2 August 2017 gives an excellent look at the monsoonal boundary. Note the majority of the convection is on the south to southwest side of the huge plume extending through Southern California. Figure 23 shows the moisture pattern with rather high moisture values. Severe weather/flash flood soundings are noted in figure 24. A sharp moisture boundary can be seen moving north in figure 25, with the airmass becoming moist and unstable from the surface upward. General east-west moving convection in Arizona in figure 26 with outflow boundaries are seen, and they temporarily enhance convection on downstream boundaries and convective cells as boundaries raced across and offshore during the morning. The flow became more southeasterly during the day.

There was spin up of a circulation in the KONT area around 2100 UTC (Fig 27) as rotation developed and convection was enhanced (possibly also interacting with higher terrain, or possibly flow from the west also aided spin). This was the second day in a row showing a spin-up in the Inland Empire. Conditions may be favorable under the correct flow conditions for such spin-ups.

A “V” shaped boundary moving across Imperial and San Diego Counties around 0300 - 0800 UTC was sparking convection to its north when it hit higher terrain in the Borrego Springs area of eastern San Diego County during the morning hours in figure 26.

Moisture increasing in a top-down manner is rather typical of a developing long lasting event. The monsoonal moisture boundary tightens over the area as a low approaches on the boundary from the south and may be a factor increasing the incidences of propagation. Now it seems that the airmass is moist and unstable enough for easy propagation and increased convective strength). Some clues are as follows:

Cells over northern San Diego County and southern Riverside County areas actually propagated south along the mountains as the convection developed, then traveled along higher terrain, and almost reached the Mexican Border (slightly lower mountain terrain just north of the border may have helped halt the progression into Mexico) during the afternoon (Fig. 27). Slower movement, quasi-stationarity, or even propagation back toward the deep moisture elevates the possibilities of flash flooding as cells redevelop or back build over some areas for nearly continuous rainfall.

6. MID-LATE PORTIONS OF THE 2 WEEK EPISODE

The activity on the 3 August 2017 consisted of;

1. General east-west moving convection in Arizona with outflow boundaries temporarily enhancing convection on downstream boundaries and convective cells as boundaries raced across and offshore during the morning.
2. A large northward moving circulation brought precipitable water up to 2.14 inches.

Figure 28 and figure 29 point toward a monsoonal flow that has very deep moisture, is very mature, and has morning outflow boundaries from the east approaching and striking the mountains, and results in several places on the desert slope areas (Burns Canyon, south past Palm Springs to the Mexican Border) being vulnerable to persistent upslope flow with heavy rain amounts, even in the morning (Fig. 30). The slower flow with slower storm movement led to flash flooding even into the afternoon (Fig 31).

There was a large circulation apparent in the upper desert around Hesperia/Apple Valley (Fig. 30). As the various rotations developed, at least some of the convection in and near the rotations was enhanced (even interacting with higher terrain to create/enhance storms there).

Moisture had continued to increase in a top-down manner (Fig 29) as the monsoonal moisture boundary tightened over the area as the monsoon matured. This is supported by a low approaching, making the air mass moist and unstable enough for easy storm propagation and increased convective strength. Cells propagating south along the mountains during the afternoon as they moved along the higher terrain almost made it to the Mexican Border (there are slightly lower mountains just north of the Mexican Border). The photograph looking to the northeast from the office in figure 32 shows the common scenario as the flow switches to predominantly south-southwest. The moisture and high clouds over WFO SGX along with coastal/valley area thunderstorms are pushed east, the convection becomes more confined to the mountains and deserts to the north and east, and typically become more confined to the afternoon and evening hours).

7. END STAGES OF THE 2 WEEK EPISODE

Figure 3 shows the lows and associated moisture pushing east as the westerlies return. The airmass shows the top-down drying and westerly flow developing in figure 34. Convergence zones, which can be the focus of severe weather and flash flooding during more volatile conditions, are easily noted under these more benign conditions (when cloudiness aloft is reduced). The zones help determine where to focus on (as far as where the strongest convection is likely to develop). A similar, relatively benign condition is shown in figure 35. Figure 36 on 1 September 2017 with numerous convergence and zones is easily seen, along with circulations at the surface. Convection can be seen to be continuously enhanced as it tracks along the heating and convergence of east-west flow on an east-west mountain range under marginal moisture conditions. This is another way to determine where the strongest convection is likely to form.

8. HUGE ROTATION NEAR THE MONSOONAL BOUNDARY IN THE DESERTS

On 12 August 2017, (as well as some other days in the past) conditions mimicked Texas/Oklahoma dryline conditions

1. Rich gulf of California moisture mimics the southeast flow of Gulf of Mexico moisture.
2. Sea breeze arcs (and maybe a bit of dry weak descending flow from the west off the mountains, possibly later in the afternoon) mimics the dry, subsiding westerly flow from the Rockies over the plains.
3. Solid sea breeze flow with the approaching trough and associated onshore trend is possible.

Troughs move through to increase the westerly drying flow aloft and CAPE as it moves eastward. Winds aloft are westerly, but flow over the top of residual lower level S-SE flow for significant shear to support supercell development is in place.

The monsoonal moisture boundary may be moving back and forth, similar to the diurnal back and forth motion of the Midwest dryline, and it may have made a trip back west (possibly modulated by waves on the monsoon frontal boundary or associated with the trough). There could have also been some oscillation in the surface dew point data as well, for example, sea breeze cycles or gulf surges. With the Yuma (KNRL) sounding being much further east of the convection, and a rather dry looking Miramar (KNKX) sounding to the west, it is difficult to determine where exactly the monsoonal boundary was, but it is likely the storm developed near the edge of it.

Low Level circulations in the deserts as seen by the 1.5 km WRF in the past adds a cyclonic moisture convergence factor. This can result in enhanced moisture convergence during this event. (Small and Maxwell, 2014). This helps add a bit of a “twist” to our local type of dry line (Fig. 37 and Fig. 38).

Moisture associated with the monsoon frontal boundary may be more “mid-level (850-700 hPa) in Southern California, as opposed to sfc-850 hPa in the Midwest, but 850-700 hPa is basically “surface” as far as the mountains and higher terrain is concerned in Eastern San Diego County.

Based on the surface dew points in the 60's, (including the desert mountain slopes),

1. The "gulf" was open for business (Gulf of California, that is).
2. The shear and instability was in place.
3. The trough was moving in to support the shear and instability profile with drying westerly flow on top of south to southeast moist "lower level flow".
4. Surface cyclonic moisture convergence was in play from the combination of low level flows.
5. Explosive, Midwest-like convection occurred as a result, and hence our own "Dryline with a twist – Southern California style".

9. SUMMARY AND CONCLUSIONS

This extended monsoonal episode involving an "East-West Ridge Axis to the North" pattern began on 19 July 2017, and continued with little interruption through 4 August 2017.

It began in typical fashion with MCVs, easterly waves/inverted troughs, and at times large upper level lows moving in a trajectory that would take them in a southwest through northwest direction under the ridge to inject mainly mid and upper level moisture into the region, and optimally set up the wind shear and moisture gradients on the monsoonal moisture boundary for the development of vortices and deformation zones.

Vortices became rather prevalent near the monsoonal boundary, with a large variation in vortex sizes.

Deformation zones associated with the lows and various vortices, for example, on the monsoonal boundary, helped enhance the convection.

East-west moving convection in Arizona with outflow boundaries temporarily enhanced convection on downstream boundaries and convective cells as the boundaries raced across Southern California, and then offshore.

This helped generate and/or enhance the associated convection.

As the event matured and the moisture increased in a top-down fashion, boundaries would even generate or enhance surface based convection even more, and the interactions between vortices, convective boundaries and terrain-based boundaries increased.

Drier, severe microburst/downburst activity evolved from the stage when the boundary layer was still relatively dry with large low level lapse rates, to relatively high dew points for wetter types of microbursts (but still not as wet as the fully matured monsoon with very high dew points). A switch to more of a flash flood mode occurred as;

1. The winds continued to decrease for slower moving storms.
2. The slower flow with slower storm movement led to flash flooding possible at any time.
3. Low level moisture continued to increase and moist upslope flow became more prevalent.

With the monsoonal flow becoming very mature, outflow boundaries from the east approaching and striking the mountains resulted in several places on the desert slope areas (especially Wrightwood in the mountains north of KRIV, to the Lucerne Valley, Burns Canyon area around to the Big Bear area, south near Palm Springs to the Mexican Border, locally into the deserts, and even the Palomar Mountain area south of KRIV) being vulnerable to persistent upslope flow with heavy rain amounts, even in the morning.

Cells eventually became more stationary or even propagated into the approaching, very moist air mass. The air mass became moist and unstable enough for easy storm propagation and increased convective strength. Cells propagated south along the mountains during the afternoon as they moved along the higher terrain, and almost made it to the Mexican Border (there are slightly lower mountains just north of the Mexican Border). Precipitable water values of 2 inches or more occurred numerous times, with at least one day where both the morning and afternoon soundings at KNKX reported 2+ inches of precipitable water.

Some “wet type” microbursts can still occur with the huge cells generated by a mature monsoon.

Late in this event, large circulations associated with upper lows began to concentrate the gradients along the monsoonal boundaries, and vortices became rather frequent.

At one point at least a couple of vortices enhanced the convection on the Elsinore Convergence Zone near KRIV as well as on the nearby higher terrain. In the Inland Empire, westerly low level flow may have helped enhance rotation

Eventually the lows began lifting north, and the mainly easterly winds aloft began to shift to the south, then west as the air mass dried in a top-down fashion. When this occurs, it basically slows (decreases the coverage), then ends the activity west of the mountains.

The coastal/valley air mass is no longer moist and unstable enough to support convection, and there is no longer any “advection of activity” into the area from the interior or south. As the situation evolves, the showers and thunderstorms eventually become confined to the mountains and deserts, before ending there, similar to what occurred on the evening of 4 August 2017.

Overall, the negative values of the HLLI approaching -2 should be a tip-off that elevated thunderstorms will likely develop, and when the HLLI and SI are both negative, severe thunderstorms and flash flooding can be expected (especially if those conditions last about 48 hours or longer). Slightly more stable values point more toward lowered likelihood of thunderstorms/severe weather/flash flooding problems.

10. REFERENCES

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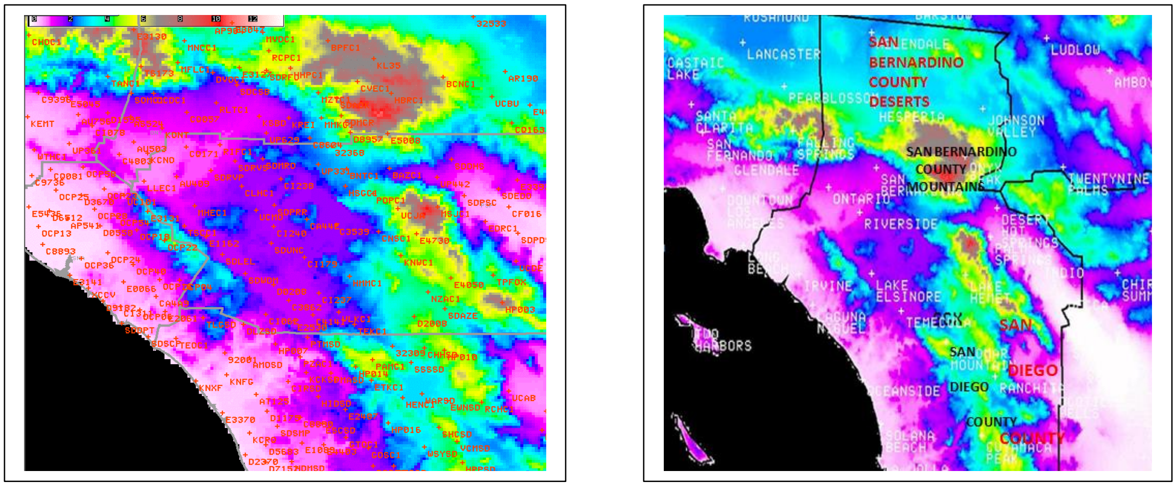


FIG. 1. Terrain map of the WFO SGX CWFA. Color coding in the legend is in thousands of feet MSL.

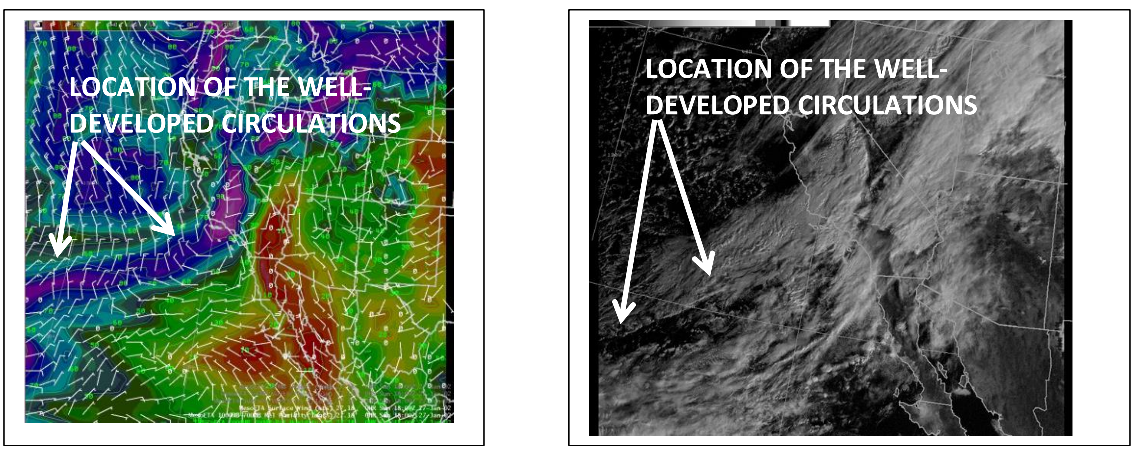


FIG. 2. 1800 UTC 27 January 2002 Surface wind and 1000-700 hPa MESOETA Relative Humidity (left) and 1615 UTC 27 January 2002 visible satellite imagery.

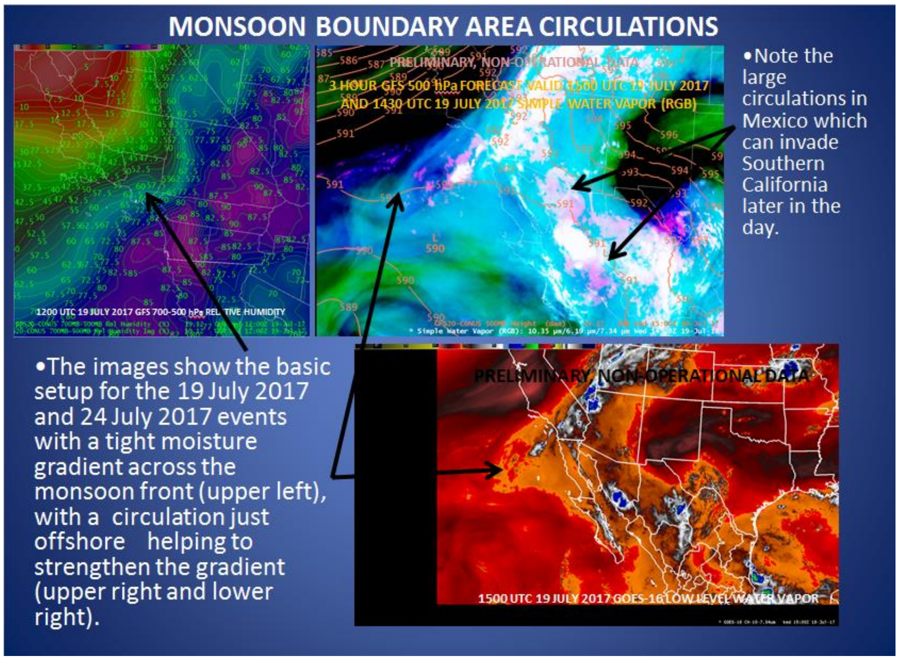


FIG. 3. Imagery from 19 July 2017 showing the basic setup for 19 July and 24 July.

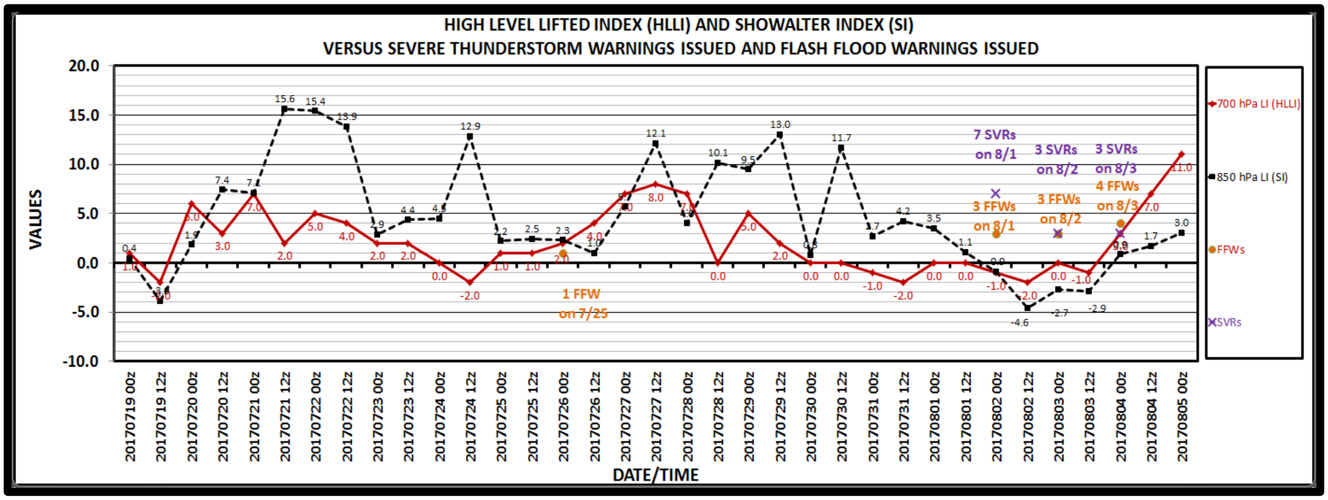


FIG. 4. The High Level Lifted Index (HLLI) and Showalter Index (SI) versus severe thunderstorm warnings issued and flash flood warnings are shown above, based on the Miramar sounding (KNKX). Note that when both values approach 0 around 25 July, there was a flash flood warning issued, and when both were negative (beginning around 1 August), not only were flash flood warnings issued, severe thunderstorm warnings were also issued.

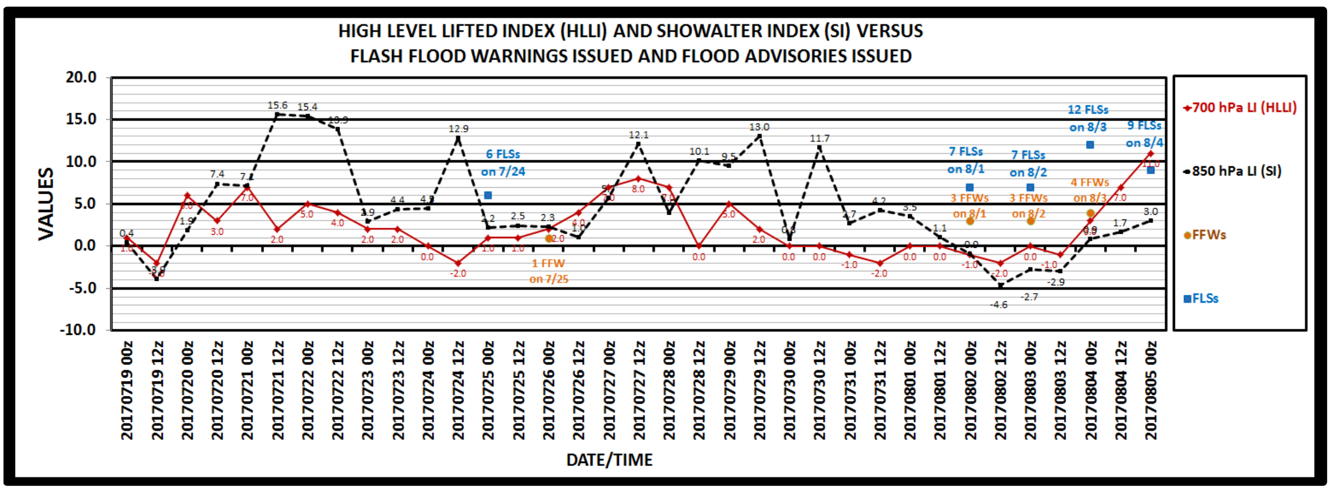


FIG.5. The High Level Lifted Index (HLLI) and Showalter Index (SI) versus flash flood warnings (FFWs) issued and flood statements (FLSs) issued are shown above, based on the Miramar sounding (KNKX). Note that when both values approach 0 around 25 July, there was a flash flood warning issued, and when both were negative (beginning around 1 August), not only were flood statements issued, flash flood warnings were also issued. Note that even after the indices rose above 0, there was still residual flood activity going on. Note also that beginning around 4 August the higher altitudes (HLLI) has stabilized faster than the low levels (SI) as the top-down drying /stabilizing continues, and was allowing for some strong convection, which supported the continued need for low-end flood products.

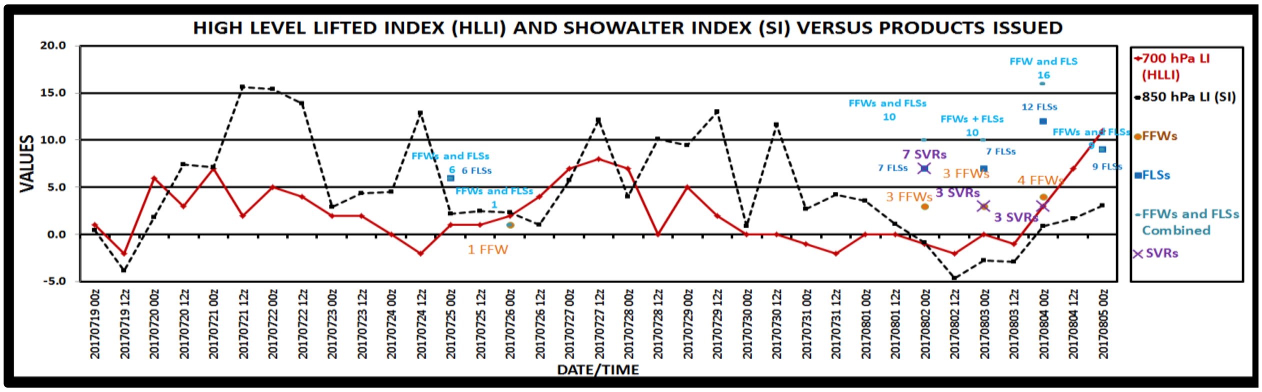


FIG. 6. The High Level Lifted Index (HLLI) and Showalter Index (SI) versus flash flood warnings (FFWs) issued, flood advisories issued (FLSs), severe thunderstorm warnings issued (SVRs), and the sum of the FFWs and FLSs (FFWs and FLSs) issued are shown above, based on the Miramar sounding (KNKX).

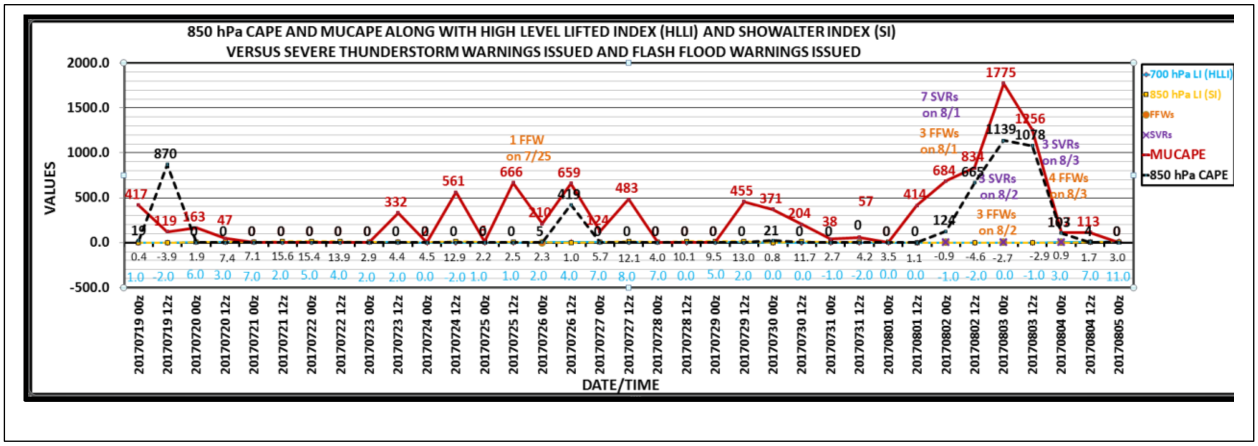


FIG. 7. 850 hPa CAPE and MUCAPE along with the High Level Lifted Index (HLLI) and Showalter Index (SI) versus flash flood warnings (FFWs) issued and severe thunderstorm warnings (SVRs) issued based on the Miramar sounding (KNKX). Note the SVR/FFW threat is high for CAPE values 100 or more.

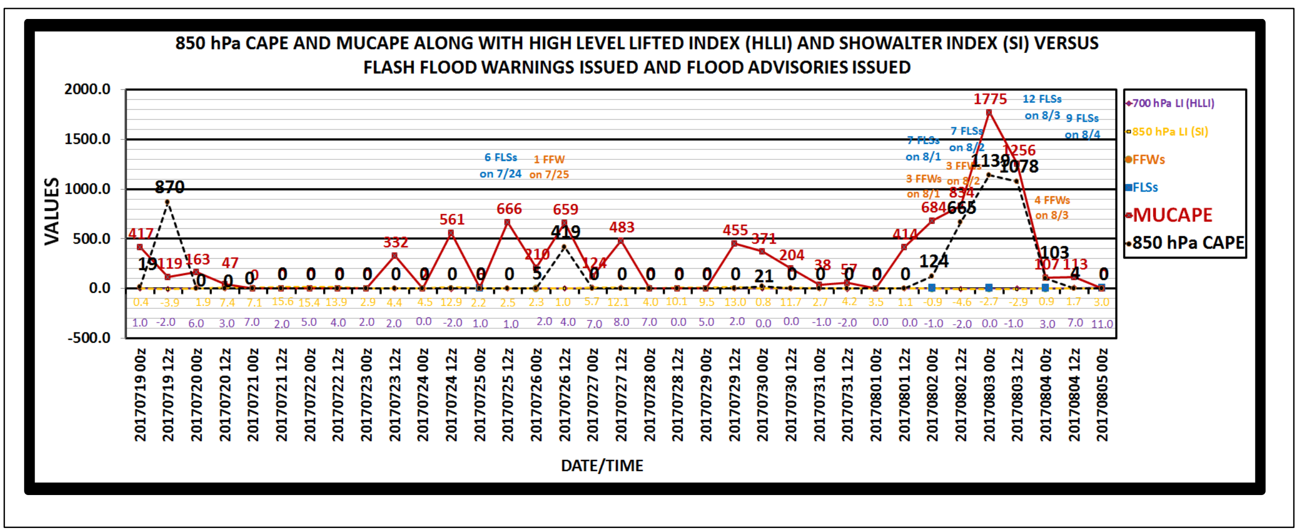


FIG. 8. 850 hPa CAPE and MUCAPE along with the High Level Lifted Index (HLLI) and Showalter Index (SI) versus the sum of the FFWs issued and FLSs issued are shown above based on the Miramar sounding (KNKX). Note the threat for floods is high for CAPE values of 100 or more.

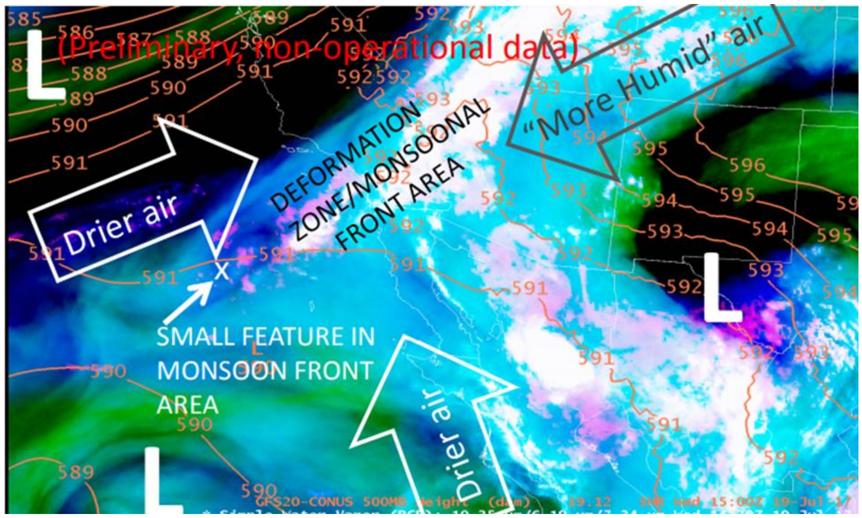


FIG. 9. 3 HR GFS20 500 hPa heights valid at 1500 UTC 19 July 2017 and GOES-16 Simple Water Vapor (RGB) AT 1430 UTC 19 July 2017

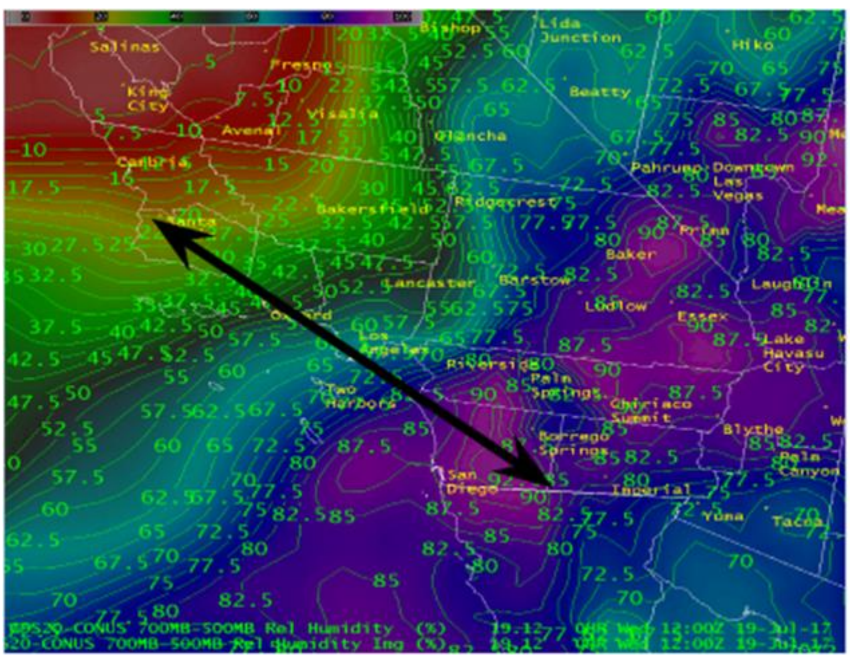


FIG. 10. 1200 UTC 19 July 2017 GFS20 700-500 hPa relative humidity. There is a strong moisture gradient across the monsoonal front area.

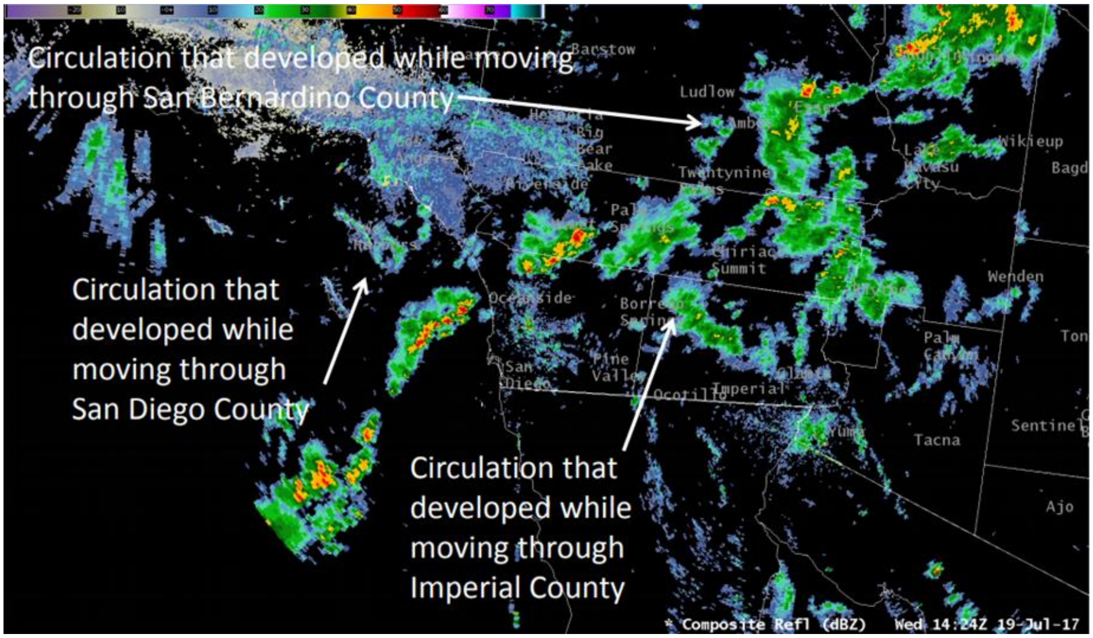


FIG. 11. 1424 UTC 19 July 2017 radar composite reflectivity image.

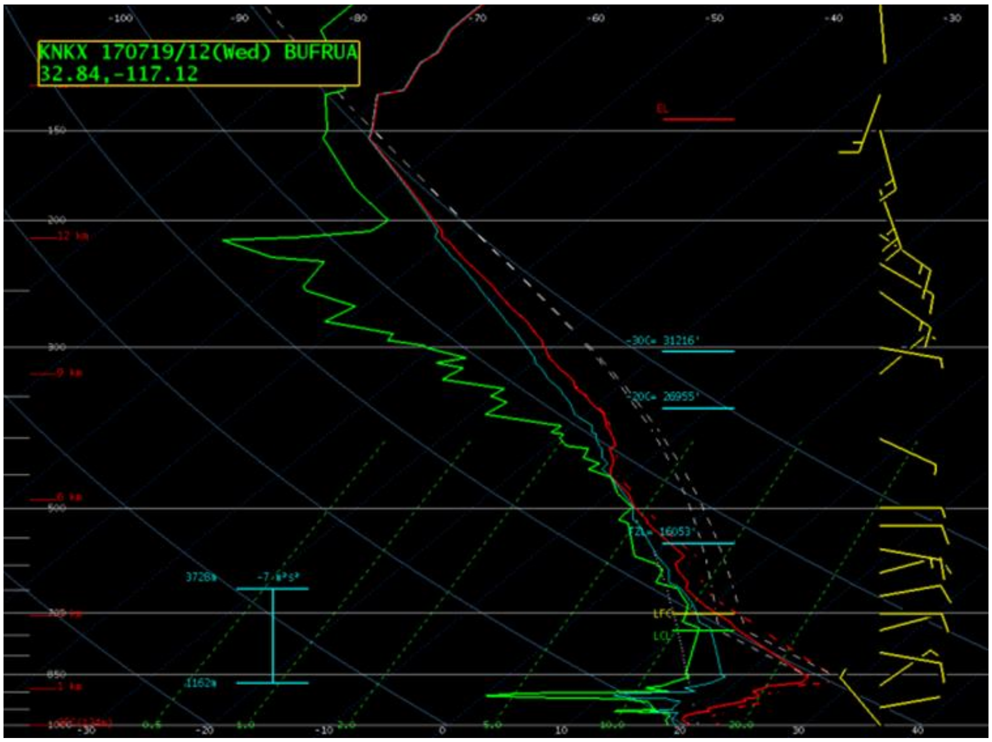


FIG. 12. 1200 UTC 19 July 2017 KNKX Sounding

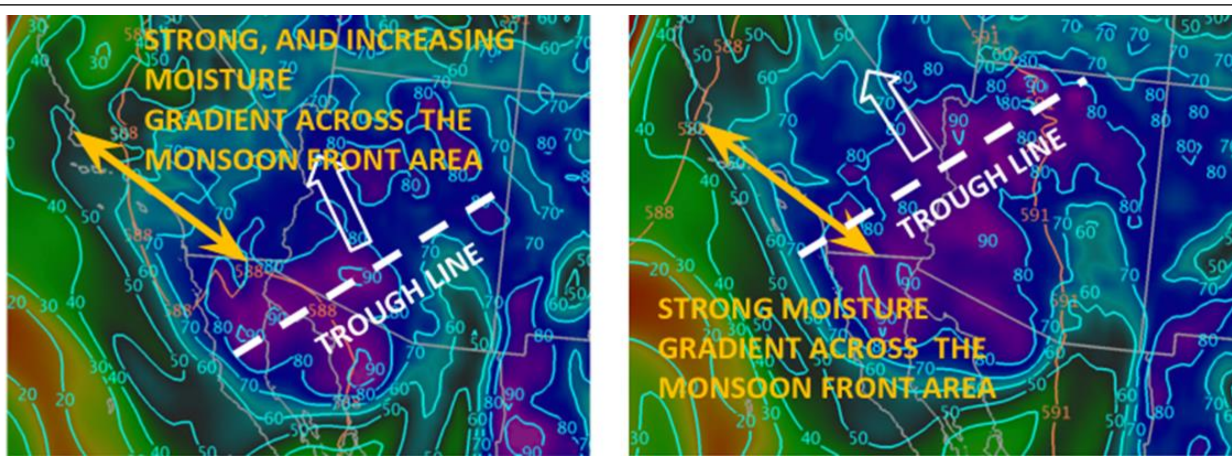


FIG. 13. 66 hour GFS 700-500 hPa relative humidity forecast valid 1200 UTC 24 July 2017 (left) and 72 hour 700-500 hPa relative humidity forecast valid 1800 UTC 24 July 2017 (right).

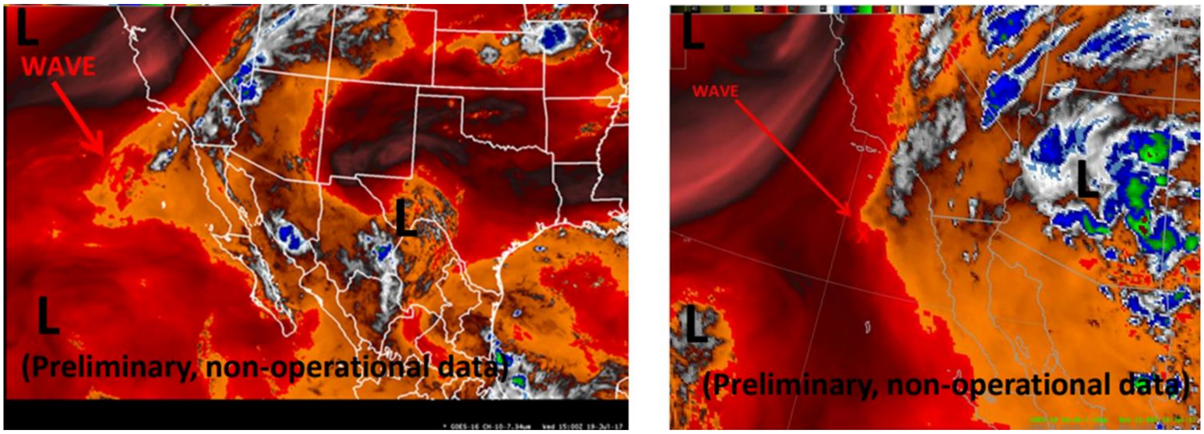


FIG. 14. Comparison of the 1500 UTC 19 July 2017 and 2110 UTC 24 July 2017 GOES-16 Low-Level Water Vapor Imagery data. A wave can be seen near the monsoonal front both days.

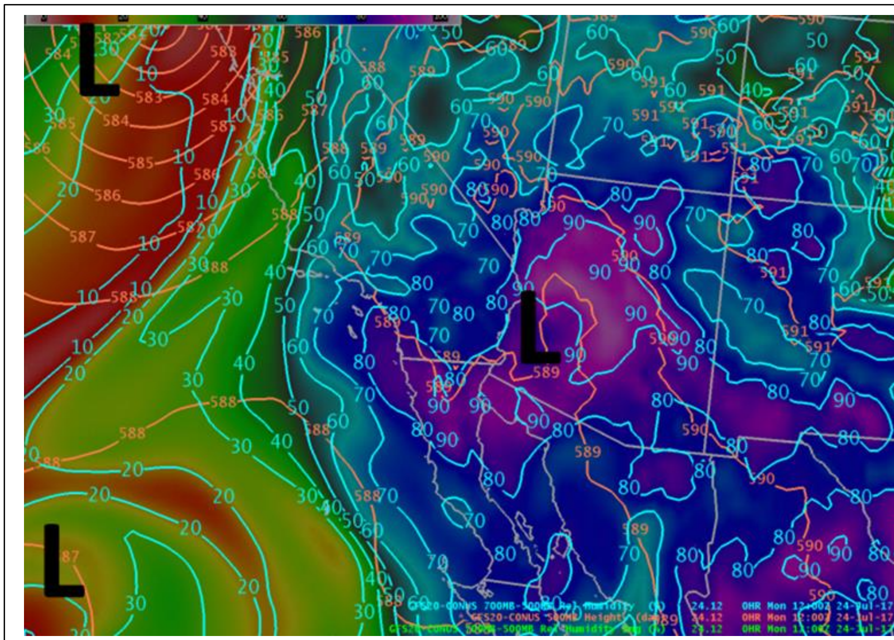


FIG. 15. The GFS20 700-500 hPa relative humidity forecast valid 1200 UTC 24 July 2017 shows copious mid-level moisture approaching again.

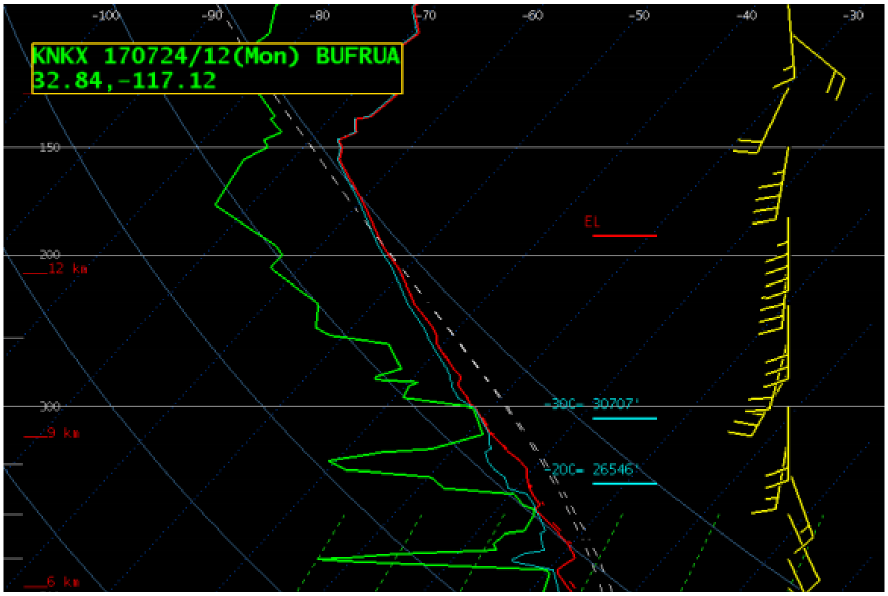


FIG. 16. 1200 UTC 24 July 2017 KNKX Sounding

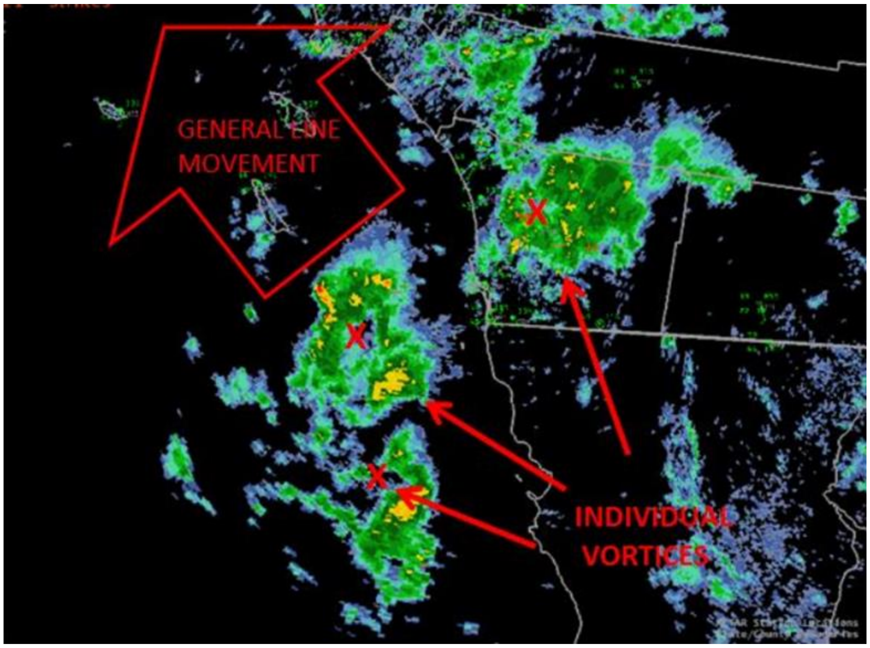


FIG. 17. 1600 UTC 24 July 2017 Radar Composite Reflectivity showing three large areas of thunderstorms near the monsoonal front, all rotating, and moving northwest.

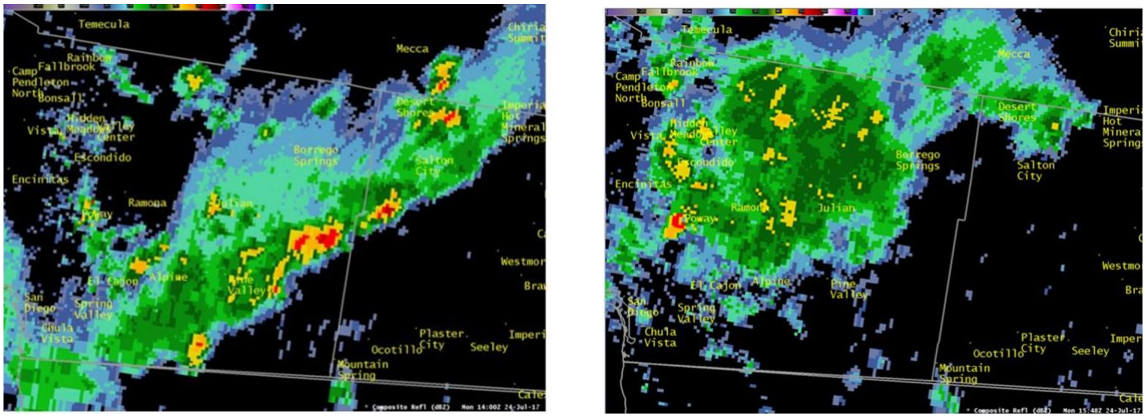
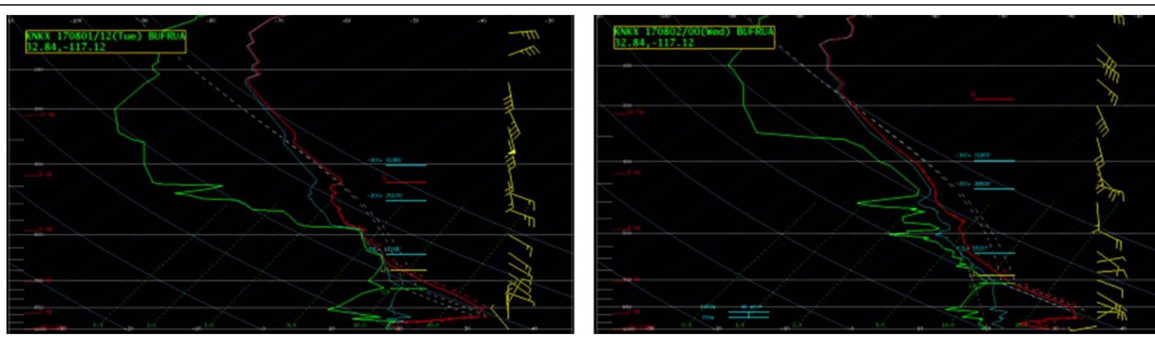


FIG. 18. 1400 UTC 24 July 2017 (left) and 1548 UTC 24 July 2017 (right) Radar Composite Reflectivity shows the evolution of the easternmost circulation as it develops over San Diego County.



FIG, 19. 1200 UTC 1 August 2017 and 0000 UTC 2 August 2017 KNKX Sounding Data. It is at this point that the lower level airmass becomes very moist and unstable. The sharp inversion nose and large lapse rate indicate classic Southern California severe microburst low level profiles.

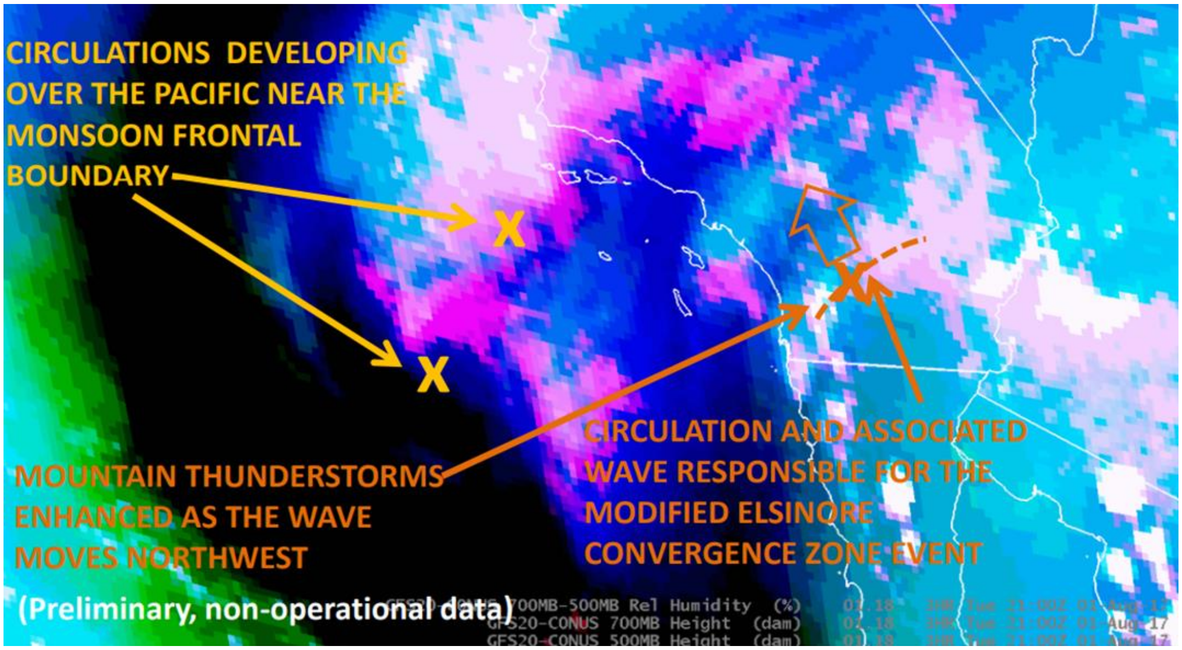


FIG. 20. GOES-16 Simple Water Vapor (RGB) imagery at 2100 UTC 1 August 2017

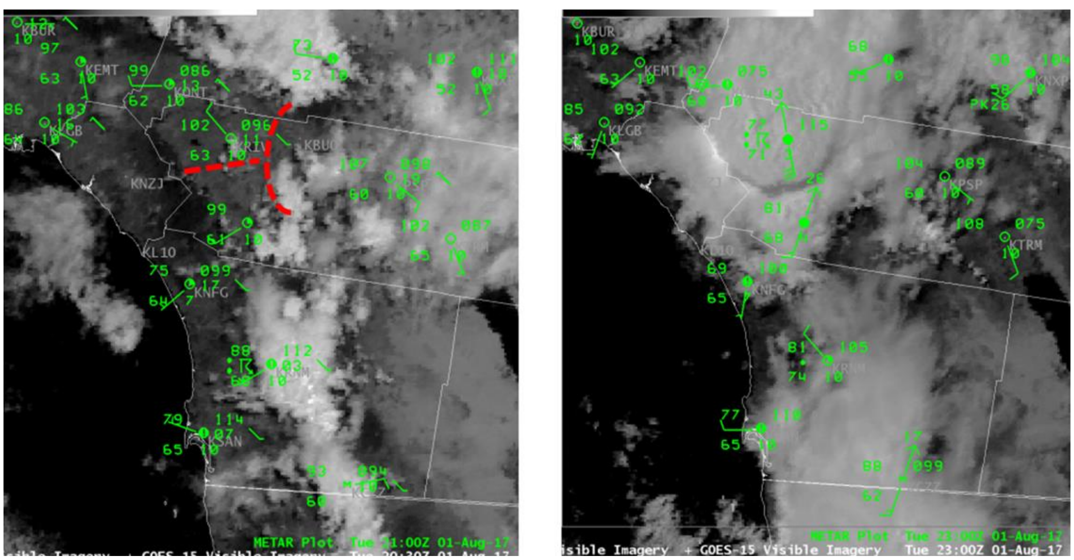


FIG. 21. 2100 UTC 1 August 2017 METAR Observations and 2030 UTC 1 August 2017 Visible Satellite Imagery (left) and 2300 UTC 1 August 2017 METAR Observations and Visible Satellite Imagery (right). This is often a high-impact convergence zone setup for severe weather and flash flooding.

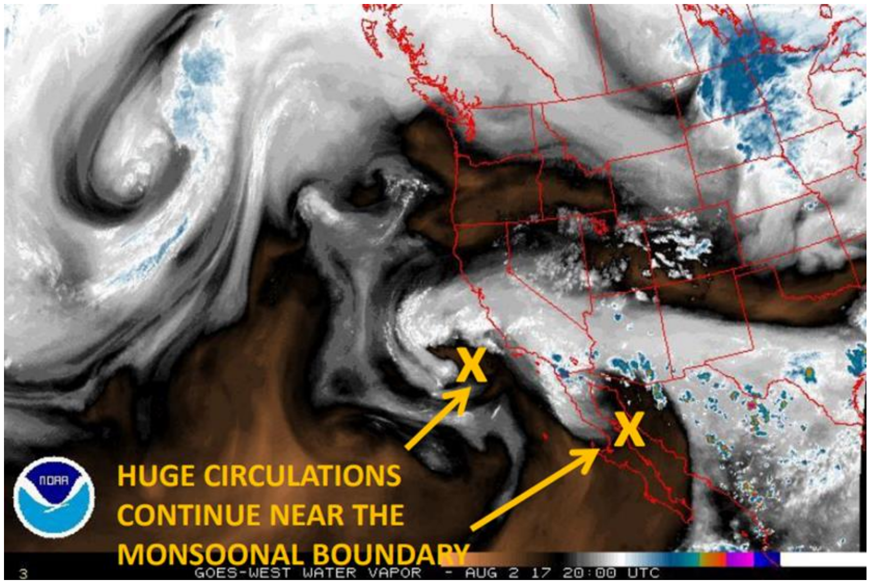


FIG. 22. Water Vapor Imagery at 2000 UTC 2 August 2017

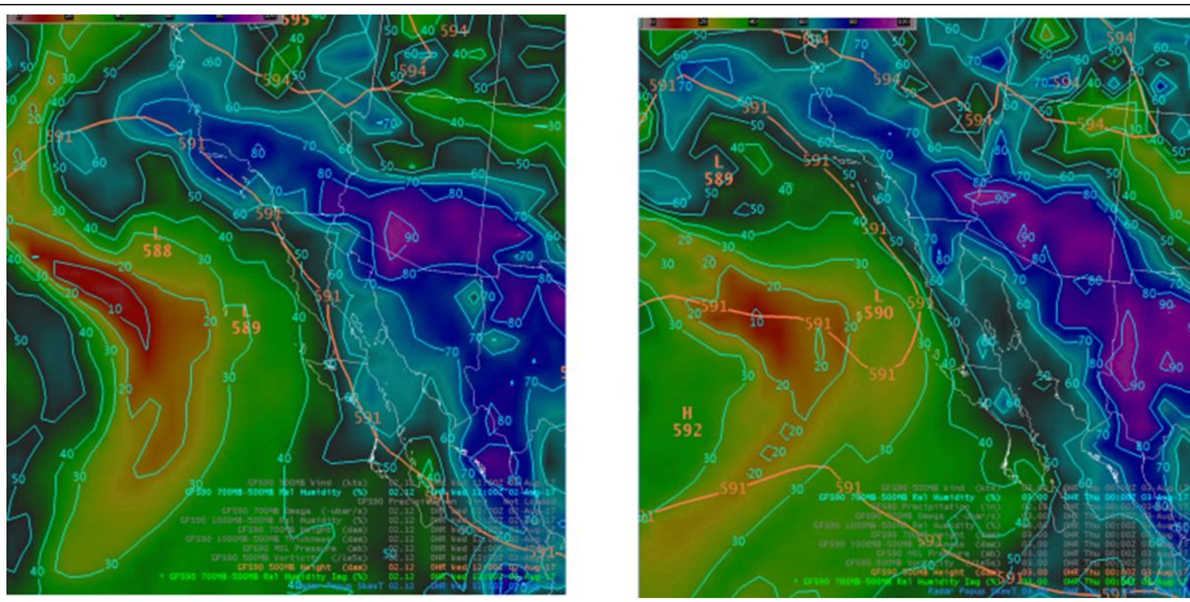


FIG. 23. GFS90 500 hPa Heights and 700-500 hPa relative humidity for 1200 UTC 2 August 2017 (left) and 0000 UTC 3 August 2017 (right).

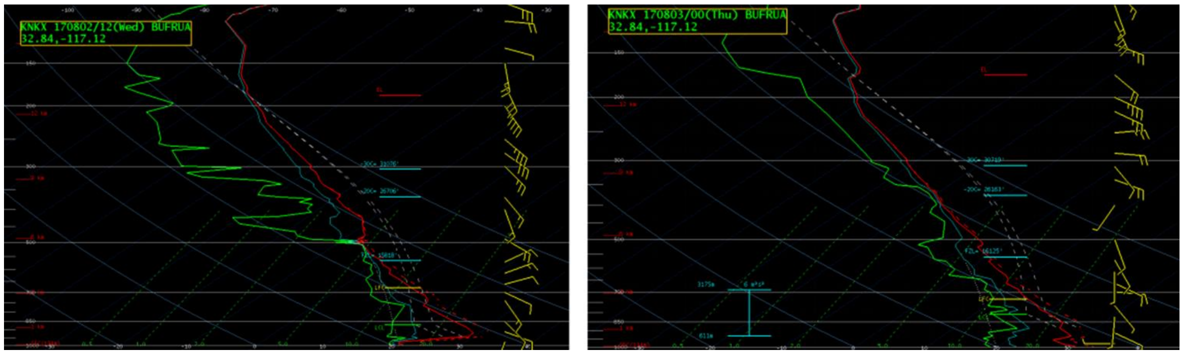


FIG. 24.1200 UTC 2 August 2017 and 0000 UTC 3 August 2017 KNKX Sounding. Sharp inversion nose and large lapse rate indicate classic Southern California severe microburst low level profiles.

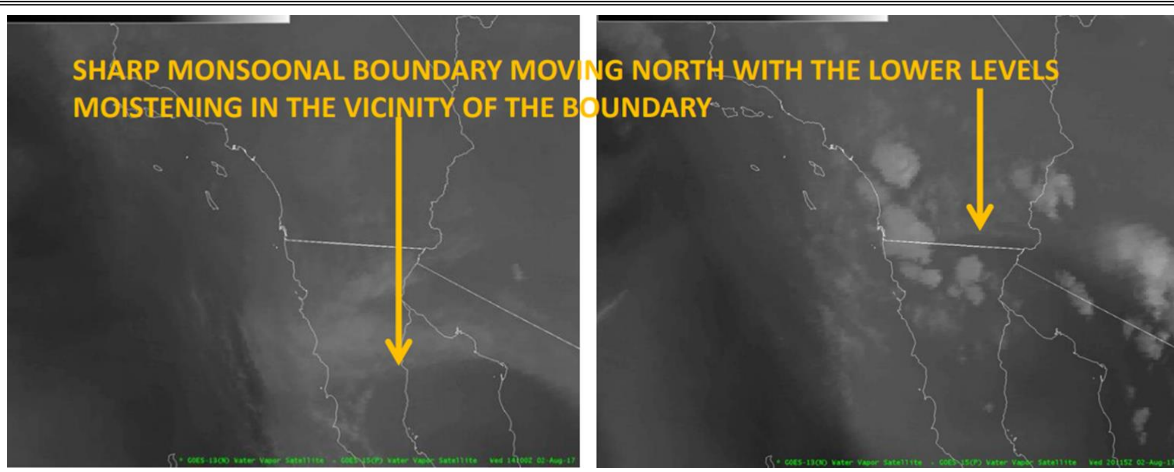


FIG. 25. Water Vapor Imagery at 1400 UTC 2 August 2017

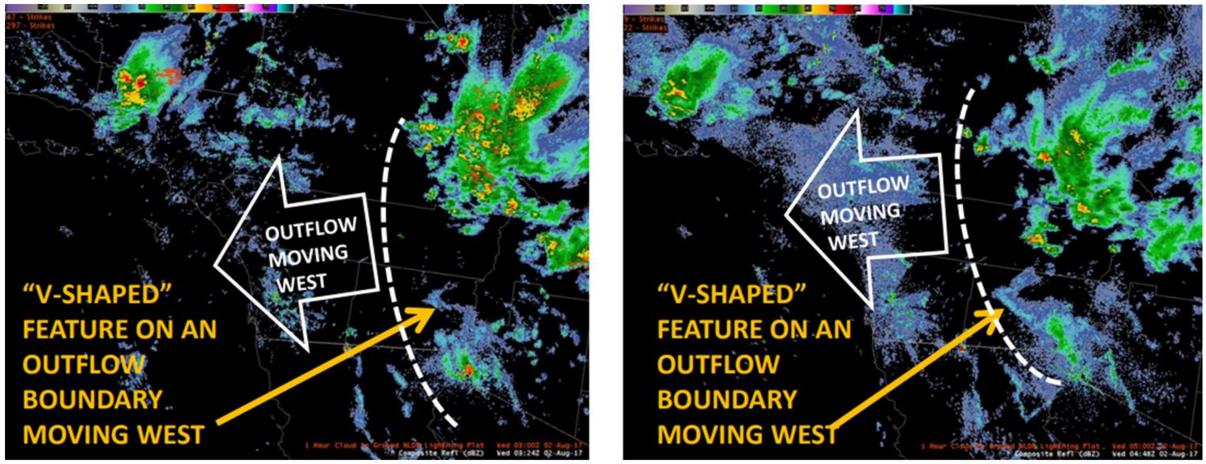


FIG. 26. 1 hour cloud-to-ground lightning at 0300 UTC 2 August 2017 and Composite Reflectivity at 0324 UTC 2 August 2017 (left) and 0500 UTC 1 hour cloud-to-ground lightning and 0445 UTC 2 August 2017 Composite Reflectivity (right).

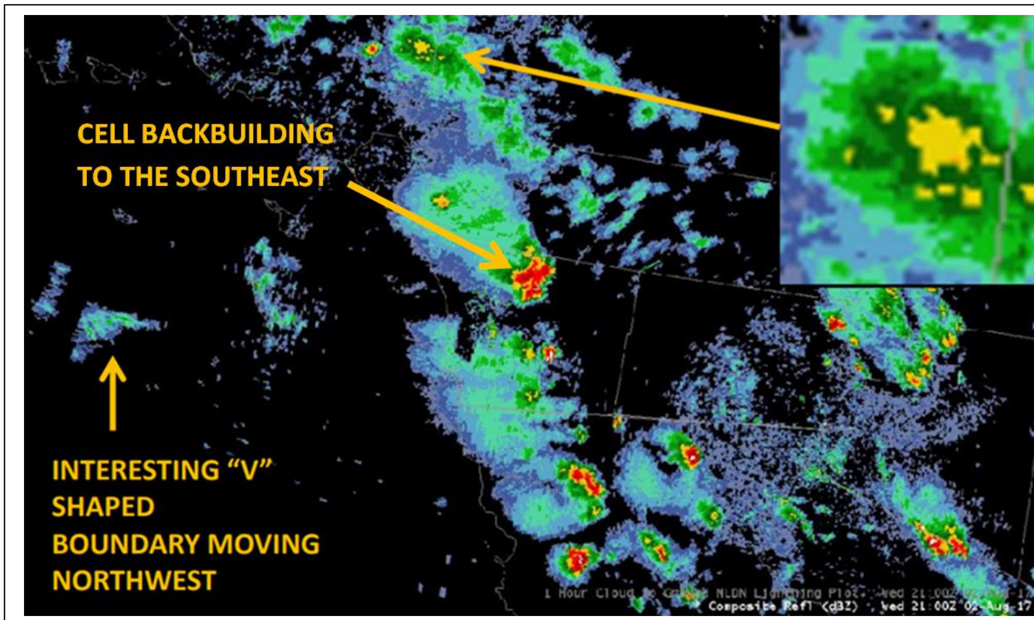


FIG. 27. 2100 UTC 2 August 2017 Radar Composite Reflectivity . The inset shows rotation that began in the Riverside area (KRIV) as well as a strong backbuilding cell in San Diego County.

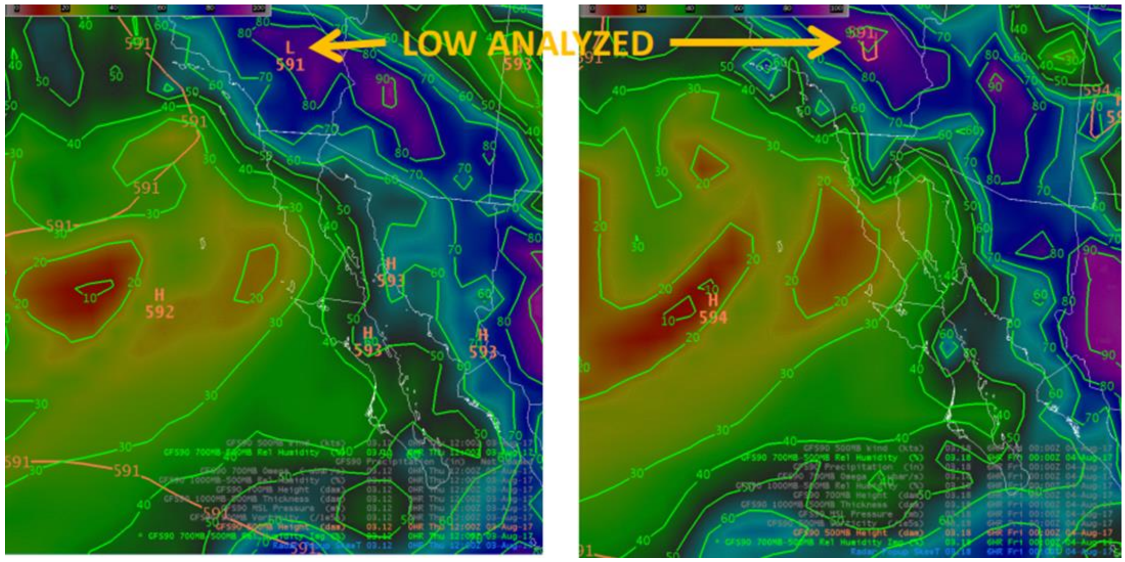


FIG. 28. GFS90 500 hPa heights and 700-500 hPa relative humidity for 1200 UTC 3 August 2017 (left) and 0000 UTC 4 August 2017 (right).

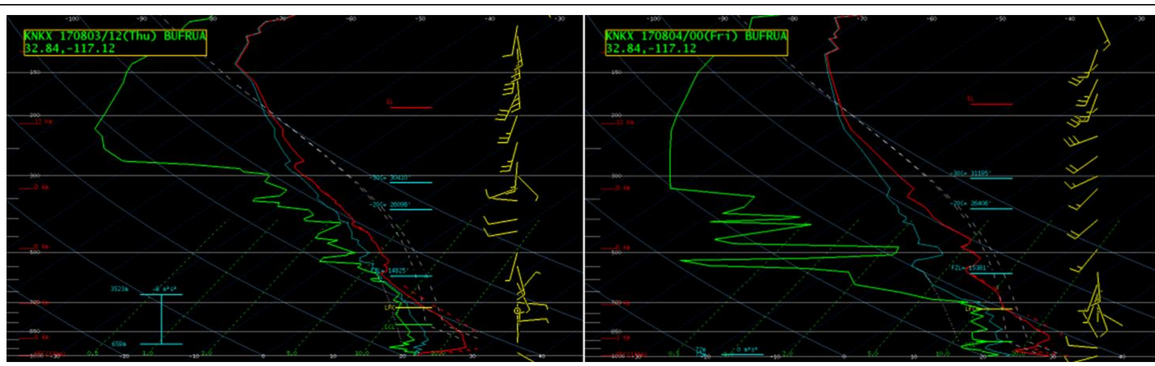


FIG. 29. 1200 UTC 3 August 2017 and 0000 UTC 4 August 2017 KNKX soundings

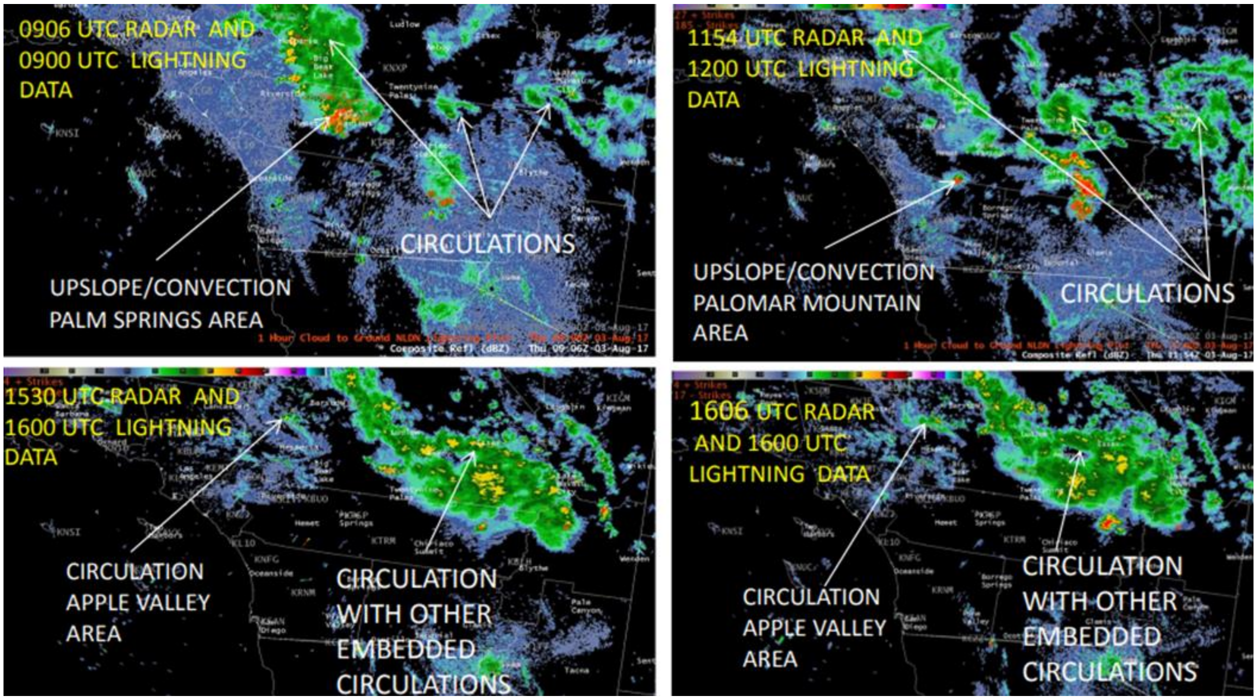


FIG. 30. Radar Composite Reflectivity and 1 hour cloud-to-ground lightning on 3 August 2017.

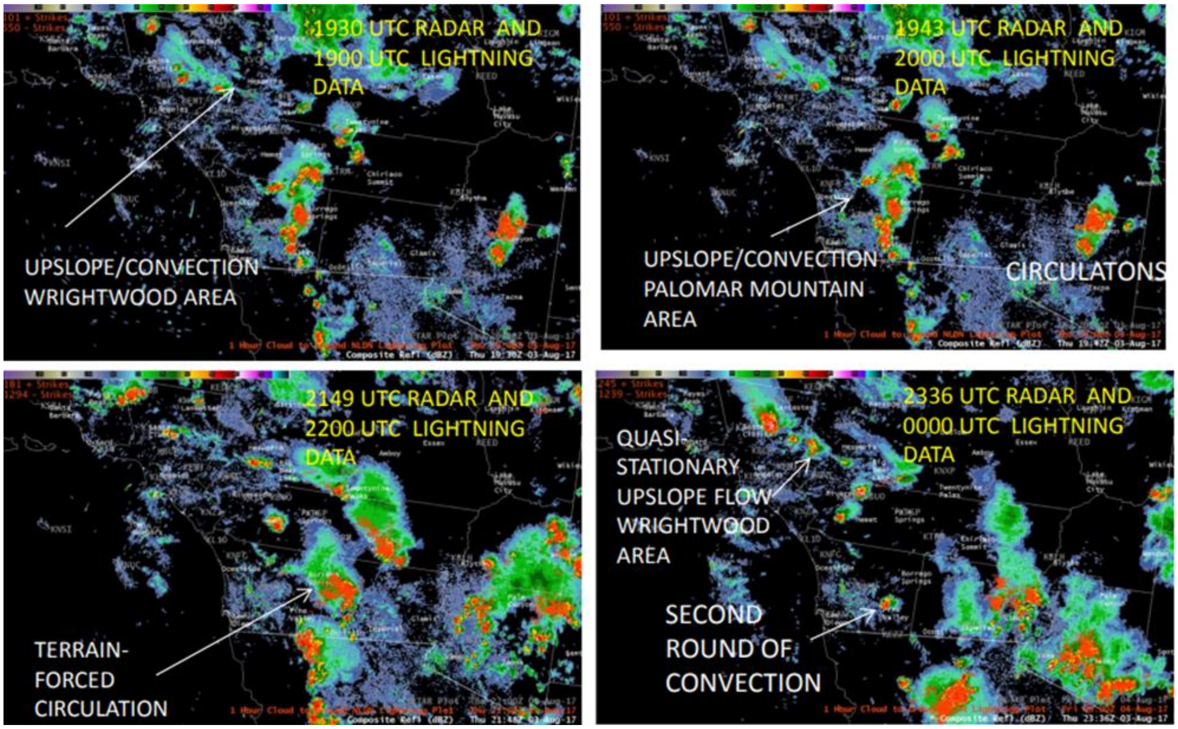


FIG. 31. Radar Reflectivity and 1 hour cloud-to-ground lightning on 3 August 2017.

FIG. 32. Final thunderstorm of the day at 730 PM 3 August 2017 over the Santa Rosa Mountains (looking through the window of WFO SGX to the northeast). There is also an orphan anvil seen.

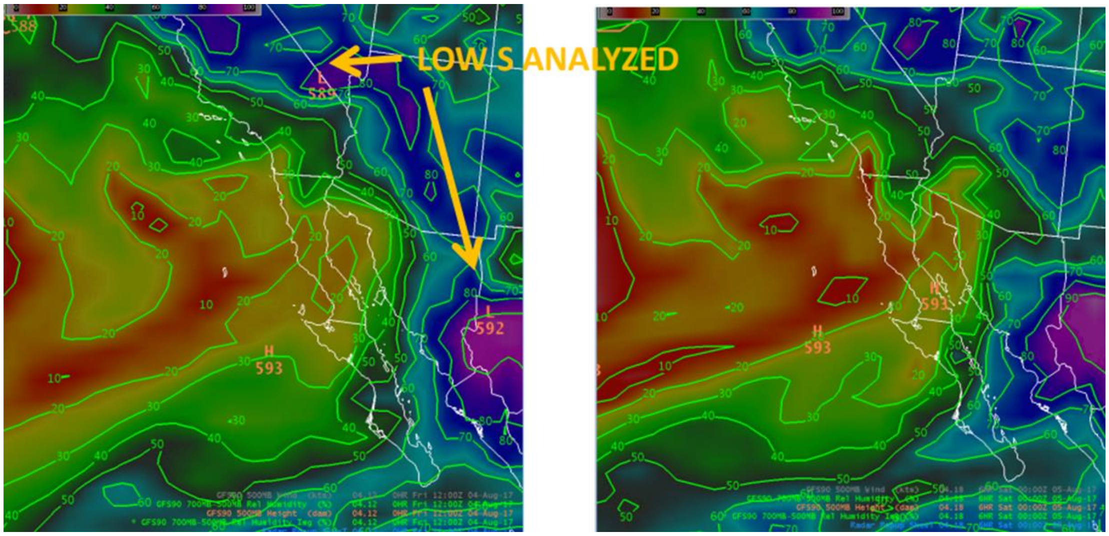


FIG. 33. GFS90 hPa Heights and 700-500 hPa relative humidity for 1200 UTC 4 August 2017 (left) and 0000 UTC 5 August 2017 (right).

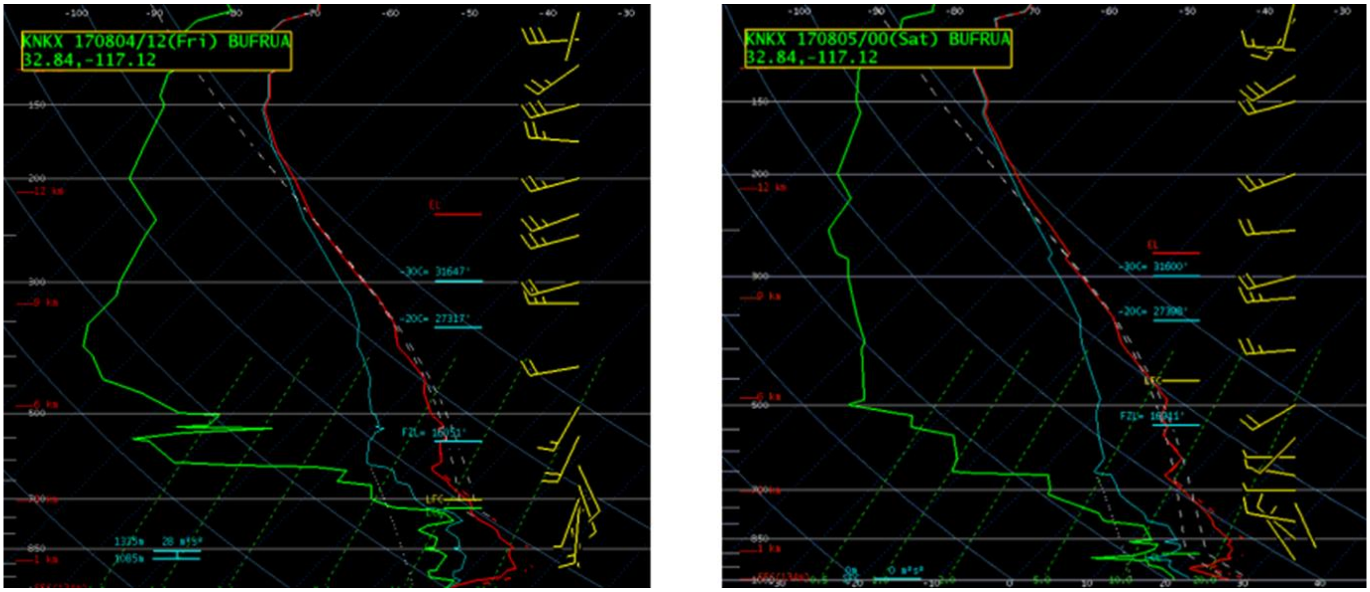


FIG. 34. 1200 UTC 4 August 2017 and 0000 UTC 5 August 2017 KNKX Soundings. Note the “top-down drying.

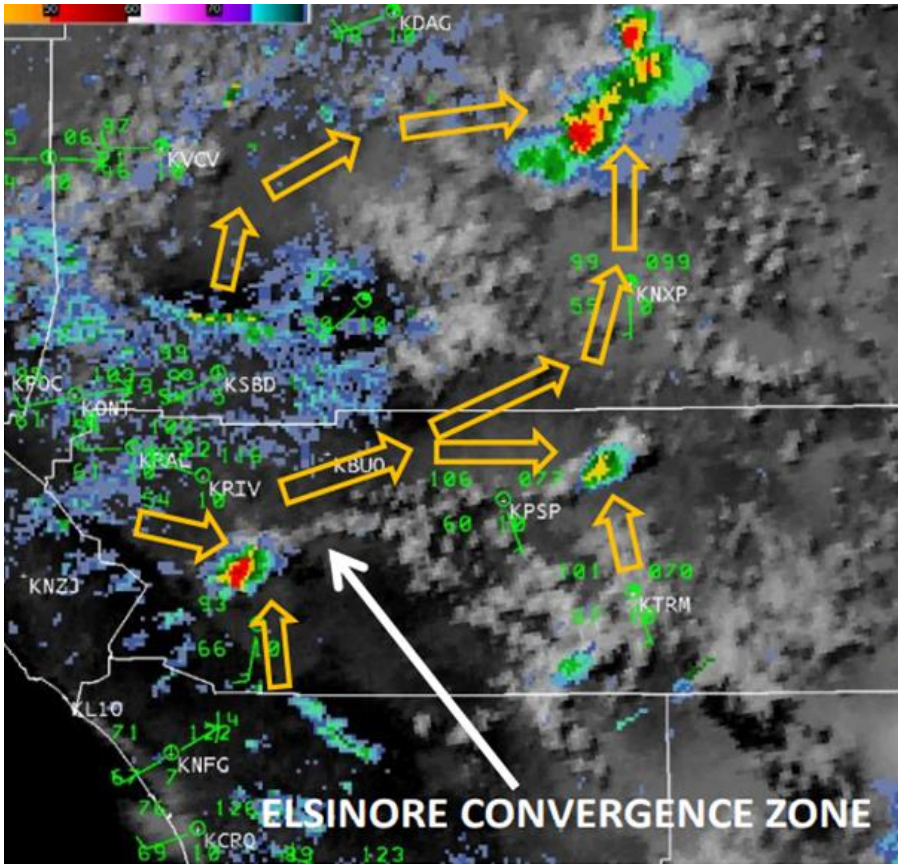


FIG. 35. 2245 UTC Visible Satellite Imagery overlaid with the 2248 UTC Radar Composite Reflectivity and 2300 UTC Surface METAR Observations on 4 August 2017.

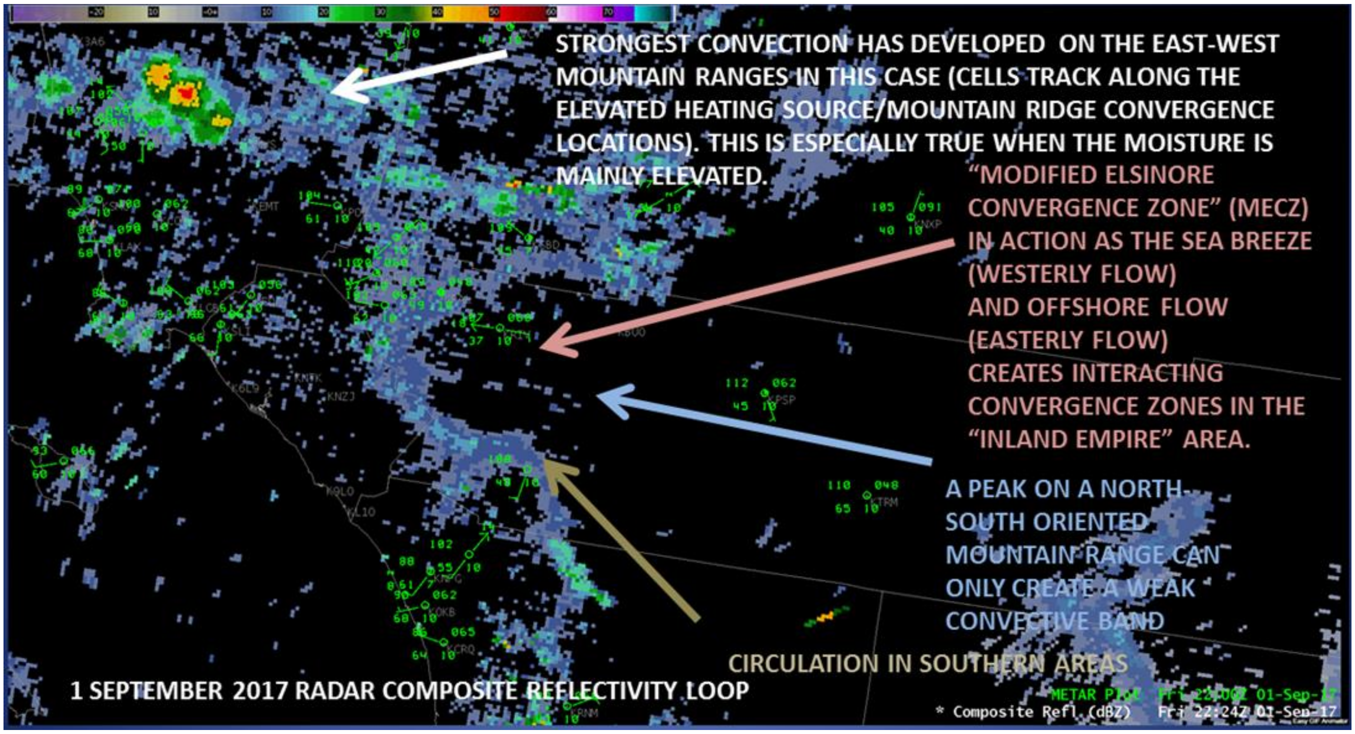
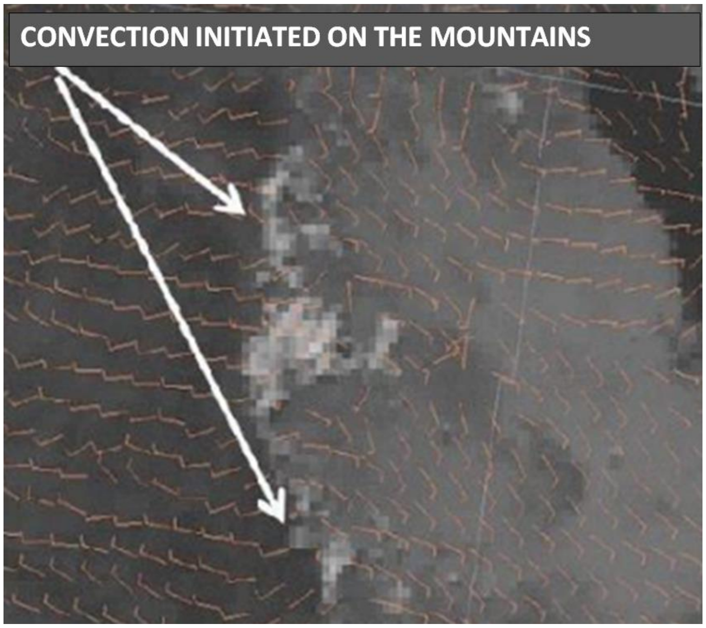


FIG. 36. 2224 UTC 1 September 2017 Radar Composite Reflectivity and 2200 UTC METAR observations.



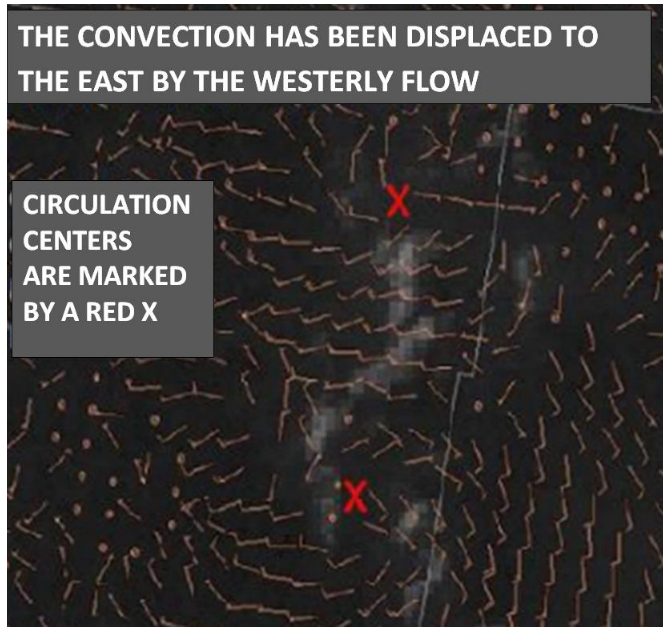


FIG. 37. The left panel is the 10 hour 1.5 km WRF-EMS surface wind forecast valid at 2200 UTC 13 August 2014, overlaid on the 2200 UTC 13 August 2014 visible satellite imagery. The right panel is the 14 hour 1.5 km WRF-EMS surface wind forecast valid at 0200 UTC 14 August 2014 overlaid on the 0200 UTC 14 August 2014 visible satellite imagery (image is dark since it is just before sundown).

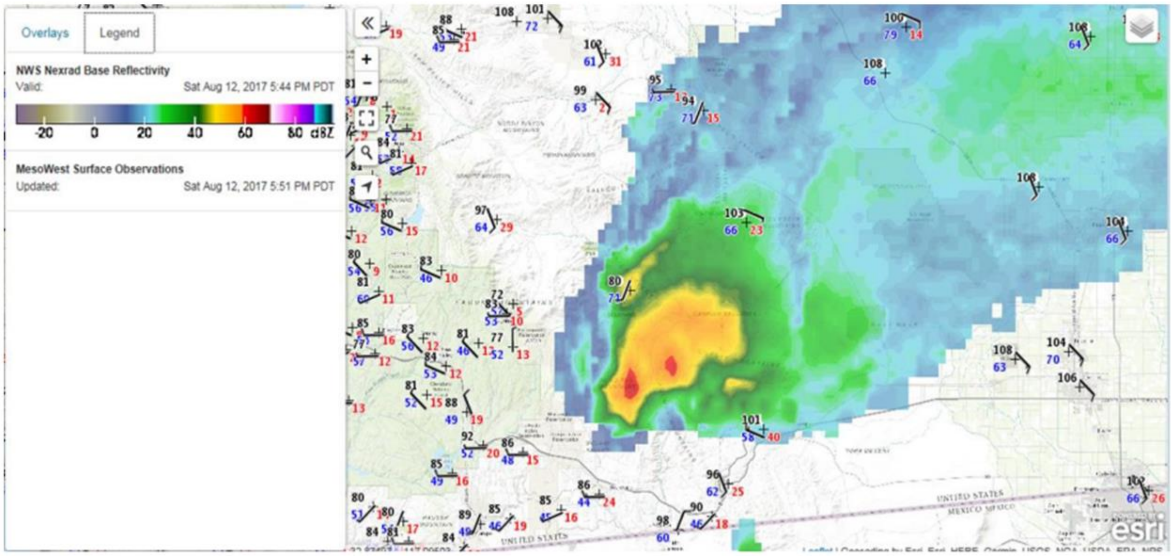


FIG. 38. The 0044 UTC 13 August 2017 Radar and Surface Observations is showing a large circulation and moisture convergence. In this case, the KNKX sounding, on the coastal side of the mountains, was very unrepresentative of the low level airmass on the desert side of the mountains where this large thunderstorm developed.