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FORECASTING APPLICATIONS FOR ELEVATED THUNDERSTORMS PART 2: NOCTURNAL THUNDERSTORMS OVER CENTRAL CALIFORNIA IN AUGUST 1999

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[Note: Because of the large number of figures, only the text will be published in hard copy. The figures can be accessed on the Web version at http://www.wrh.noaa.gov under Technical Attachments.

1. INTRODUCTION

Thunderstorms developed on the afternoon of 9 August 1999 across the Sierra Nevada foothills upward to along the crest. Thunderstorm formation over the Sierra Nevada is common in the afternoon and early evening hours during the summer months. This is primarily the result of subtropical moisture being advected northward across Mexico into the Intermountain West and California on the westside of the seasonably strong high pressure system over the southwest United States (monsoon flow). This moisture interacts with diurnal instability over the higher terrain and often results in intense deep moist convection. In this study, the thunderstorms were not the more typical diurnal activity, but rather, became more numerous during the night hours. The thunderstorms on 9 August dissipated during the evening hours, however, moist convection redeveloped during the early morning of 10 August. None of the thunderstorms in this paper showed severe radar characteristics on Weather Surveillance Radar-1988 Doppler (WSR-88D) located in KDAX (Davis). However, several thunderstorms showed reflectivity values exceeding 60 dBZ, and radar echo tops (ET) between 30,000 and 40,000 ft mean sea level (MSL). These values are similar to the surface-based diurnal thunderstorms that occur over the higher terrain during the monsoon flow. In addition, the thunderstorms during the early morning of 10 August were almost continuously forming in the same general area and tracked northwest from the northern Sierra Nevada to the southern Cascades. A direct result of the thunderstorms was several grass and forest fires ignited by the lightning strikes.

The Sacramento Valley (the northern portion of the Central Valley in California) is usually much less favorable for summer thunderstorms because of, but not limited to, downsloping drying effects, a dry boundary layer, and the lack of surface moisture convergence. On 23 August 1999, a similar event to the one previously discussed occurred, except these thunderstorms developed in the central Sacramento Valley. The thunderstorms showed

4. RADAR AND SATELLITE DATA

Case 1

Figure 3 shows the early stages of thunderstorm development on 10 August. The thunderstorms persistently developed over the Motherlode and Sierra Nevada, as well as parts of western Plumas County (Figs. 4 and 5) between 0500 and 1200 UTC. During this time period, radar echo tops for the thunderstorms were as high as 40,000 ft MSL and maximum reflectivity reached 60 dBZ (Fig. 4). Figure 5 shows the diminishing reflectivity returns over the Sacramento Valley indicative of the weakening thunderstorms in this area. The mountain and foothill thunderstorm activity reached its peak intensity around 1000 UTC when numerous thunderstorms were depicted over the Motherlode and Sierra Nevada (Fig. 6). Corresponding GOES-10 infrared (10.7 μm) satellite imagery showed significant cloud top cooling (-40 to -45°C) associated with the thunderstorms (Fig. 7). This satellite imagery also showed deep moist convection occurring over the southwest United States where more abundant subtropical moisture was available. By 1152 UTC the last area of thunderstorms moved over the I-80 corridor and diminished to light showers shortly afterwards (Fig. 8).

Case 2

On 22 August, prior to the thunderstorm outbreak, KDAX composite reflectivity detected an outflow boundary associated with thunderstorms that occurred during the late afternoon across the Sierra Nevada (Fig. 9). A radar time lapse showed that this mid-level boundary moved into the far west side of the southern Sacramento Valley and dissipated, while manual observations by the author showed altocumlus castellanus clouds were produced along it. This type of cloud is indicative of mid-tropospheric moisture and instability, and sometimes precedes thunderstorm development. Late in the evening on 23 August, satellite images showed that skies became mainly clear (not shown). At 0702 UTC 23 August, a narrow line of thunderstorms rapidly developed in the central Sacramento Valley (Fig. 10). Radar reflectivity and areal coverage continued to increase in this region, but showed little organization, (Fig. 11) resulting in numerous cloud-to-ground lightning strikes through 1100 UTC (not shown). Figure 12 shows intense thunderstorms that became concentrated at 1015 UTC over the valley floor of Butte County and produced locally heavy rain. All of the activity was carried to the north in the southeasterly flow.

5. OBSERVED INSTABILITY, MOISTURE, AND WIND

In these cases, the boundary layer stabilized after the loss of solar insolation, but this did not preclude deep moist convection. Conditions present above the boundary layer were supportive for thunderstorm development independent of the boundary layer stability. This stable boundary layer is clearly visible in Figure 13, which displays a sounding near Blue Canyon from Rapid Update Cycle (RUC) initialization at 1200 UTC 10 August 1999. It is very important to understand what type of atmosphere this sounding is depicting, specifically the elevated instability and moisture above the boundary layer. The sounding shows high static stability and dry air in the boundary layer. The sounding in Figure 13 below the LFC. This region of stable air (nocturnal radiational inversion) was not a limiting factor since the thunderstorm development occurred in the mid-troposphere. The model sounding accurately depicted steep environmental lapse rates above 10,000 ft MSL (700 mb) and correctly indicated a significant increase in moisture above 15,000 ft MSL (600 mb), denoted by the smaller dew point depression (see fig. 15).

7. FORECASTING APPLICATIONS

The use of the forecast or observed soundings alone is not sufficient to recognize the elevated thunderstorm potential. Using basic model depictions of 500-mb geopotential height and vorticity fields similar to those in Figures 1 and 2, and 500-mb relative humidity (or preferably a 600 to 400 mb mean layer), layer precipitable water trends, and omega contours, can give the forecaster an idea of the most favorable area where subtropical moisture and atmospheric lift will be sufficient for elevated thunderstorm formation. Water vapor satellite image trends and characteristics will help in determining whether the regions of best upward motion (associated with short waves and upper divergence) and instability will interact with the moisture necessary for elevated thunderstorms (Tardy 2001). Near real-time instability analyses on AWIPS can be helpful, but may sometimes severely underestimate the convective potential in the mid-levels of the atmosphere. Synoptic scale cold and warm air advection associated with the upper low, could also result in steeper mid-level lapse rates similar to what was observed (see fig. 13). Most important, sufficient destabilization will result from the synoptic scale layer lifting which effectively lowers the LFC.

8. CONCLUSION

This study showed a type of deep moist convection that can occur over northern California, which can result in lightning initiated forest fires. Two cases were presented in an attempt to show that elevated thunderstorms can and will occur over valleys or higher terrain given certain synoptic conditions. Despite the extreme difficulty in forecasting thunderstorms, there are available resources, such as model soundings which, when combined with pattern recognition and satellite trends, can yield the best forecast of the more infrequent weather events.

Most important, these thunderstorms are not rooted in the boundary layer, and are not dependent on terrain or boundary layer conditions, but can be influenced by them. This paper showed how mid-level convective processes need to be recognized in order to capture the potential for elevated thunderstorms. Given a sufficient amount of subtropical moisture, air mass lift and instability, the atmosphere can often yield deep moist convection when it might otherwise not be expected above a stable boundary layer. Forecasting this type of event is very important across northern California because of the extreme fire hazards present during the hot and dry summer months. In addition, since precipitation is infrequent across the Central Valley during the summer, any rainfall can have an impact on people and agricultural.

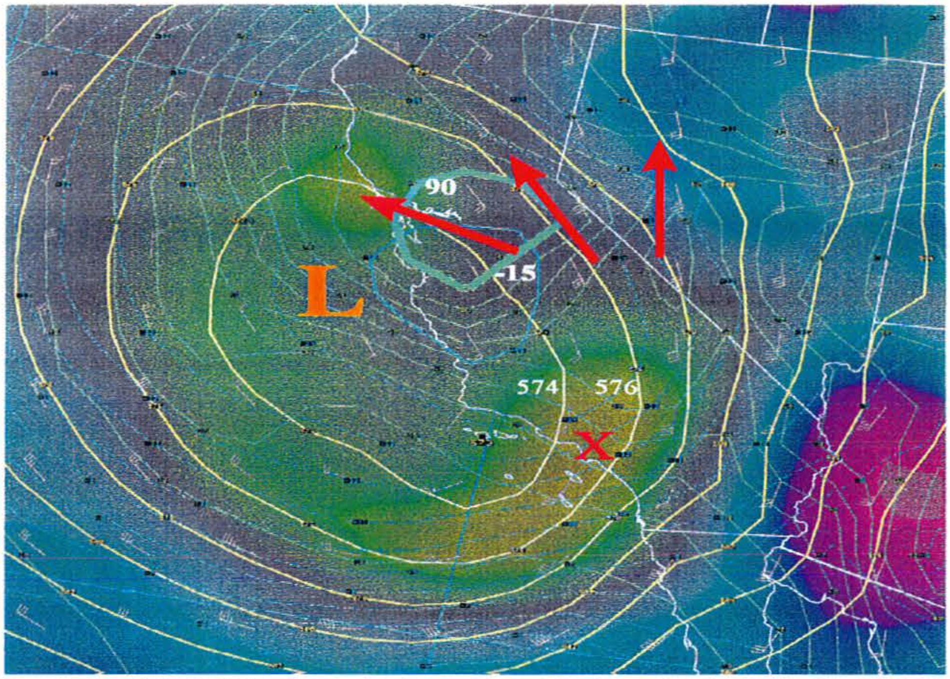

Figure 1. RUC 500-mb analysis at 0900 UTC on 10 August 1999. Thick yellow lines are geopotential heights labeled every 20 m. Wind barbs are every 2.5 ms^{-1} and thick red arrows show a divergent region positioned over eastern California. Shaded green area depicts absolute vorticity (1 $e5s^{-1}$) with a strong short wave rotating around the base of the circulation. Thicker blue line denotes coldest air with a -15 °C isotherm over central California. Solid thin green lines are relative humidity contoured every 10 percent. Ninety percent is depicted over central California with a thick green line.

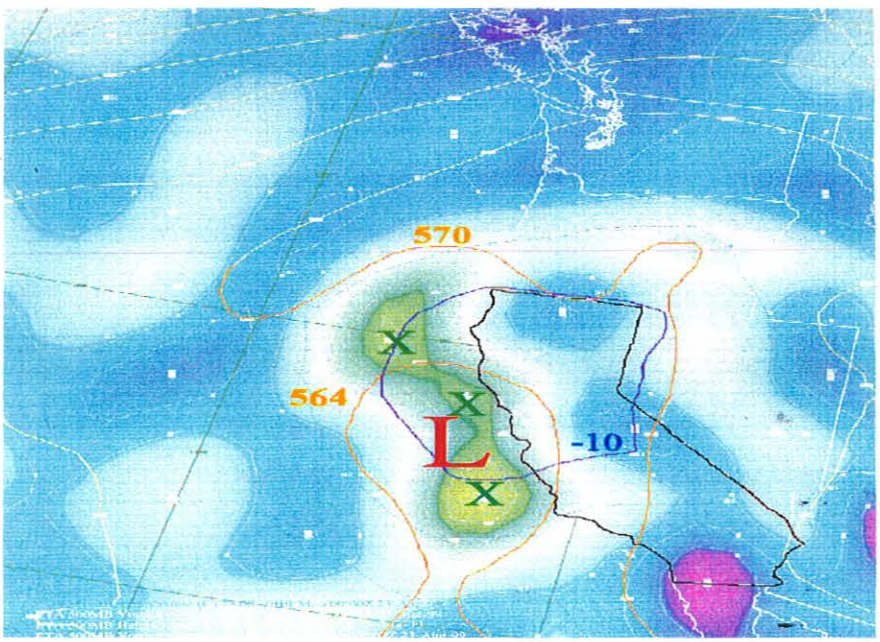

Figure 2. Eta 500-mb analysis at 0000 UTC 23 August 1999. Geopotential height lines contoured at 564 and 570 dm are shown as thicker orange lines. Dark blue line is the -10°C isotherm. Green shaded area is absolute vorticity ($1e5s^{-1}$).

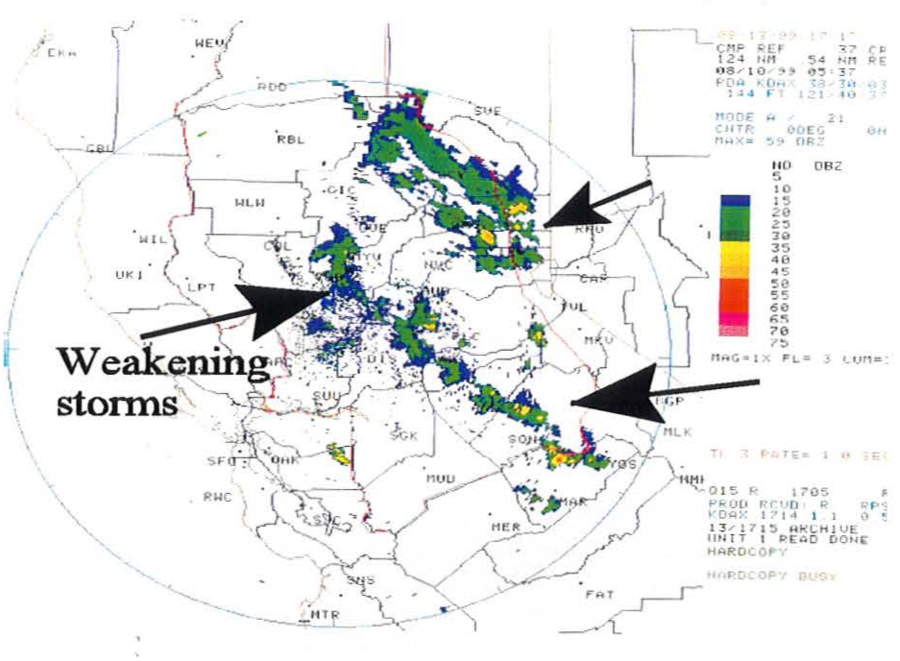

Figure 3. KDAX composite reflectivity at 0537 UTC 10 August showing the developing thunderstorms over the Motherlode and Sierra Nevada. Storm movement was towards the northwest near 10 ms[-1]. Arrows on right side of image point to the persistent areas of thunderstorm development. The NWS Sacramento County Warning Area (CWA) is shown by the thin red line.

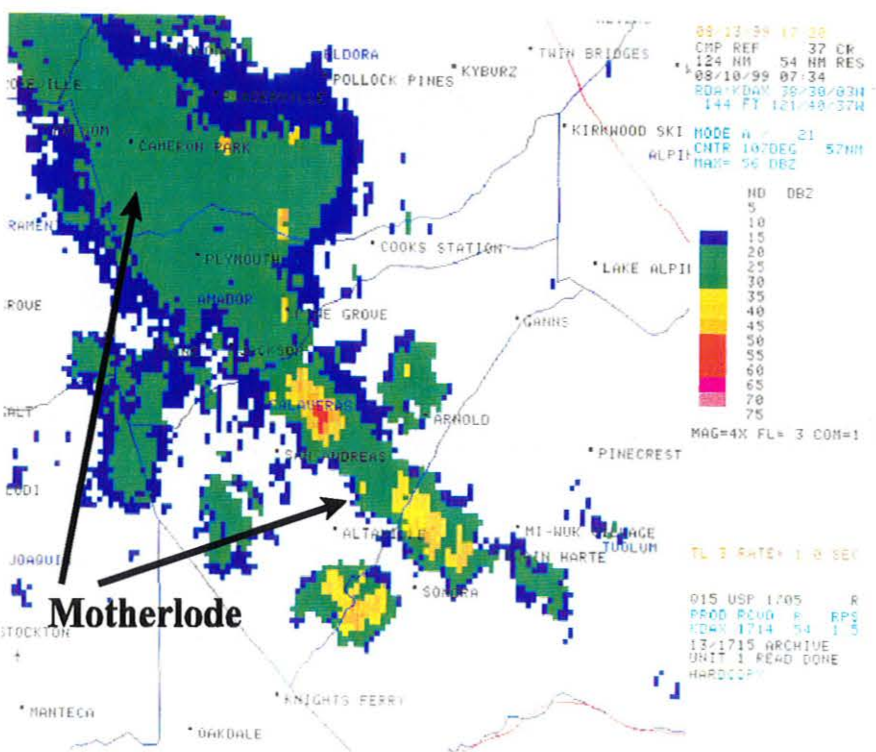

Figure 4. KDAX Doppler radar composite reflectivity image over the Motherlode at 0734 UTC. Echo tops for these thunderstorms were between 25,000 and 38,000 ft MSL.

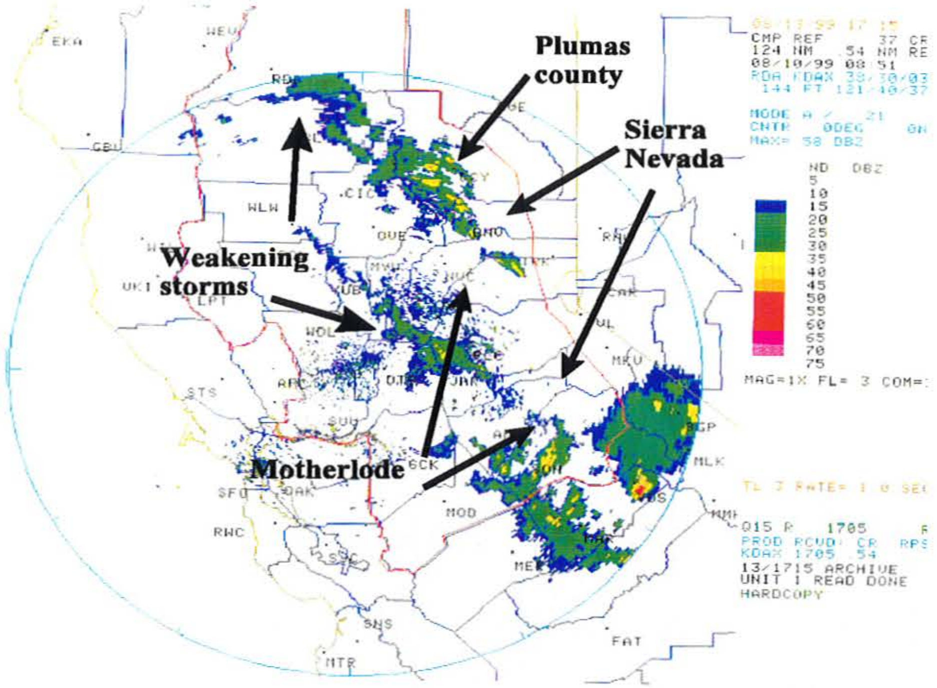

Figure 5. KDAX composite reflectivity image at 0851 UTC showing a continuation of thunderstorms over the Motherlode and northern Sierra Nevada. Notice that the thunderstorms dissipated as they descended into the Sacramento Valley.

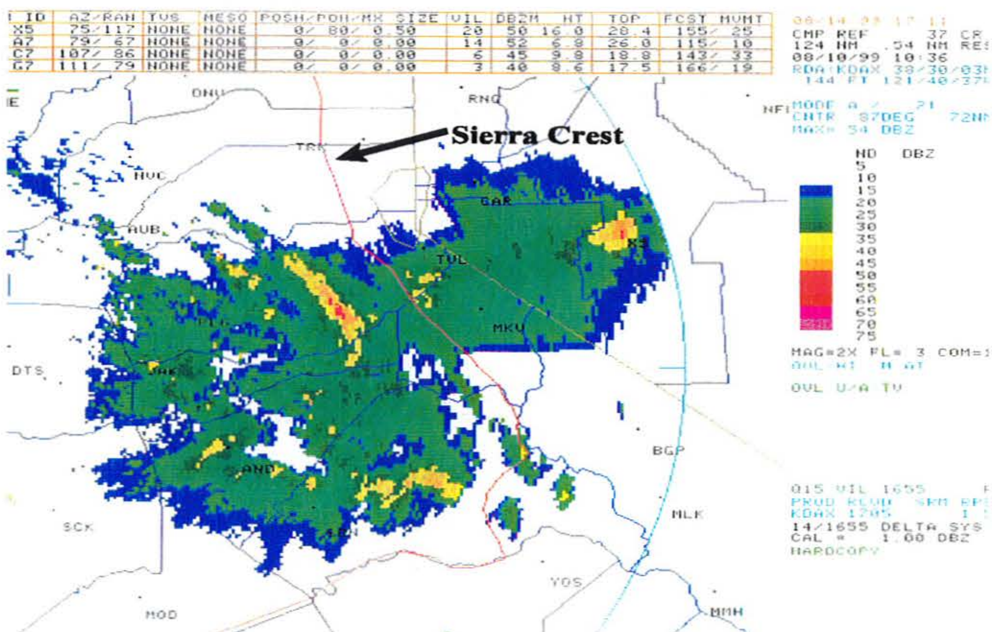

Figure 6. KDAX composite reflectivity at 1036 UTC on 10 August depicting a large cluster of thunderstorms over the Sierra Nevada in the southeast portion of the NWS Sacramento CWA.

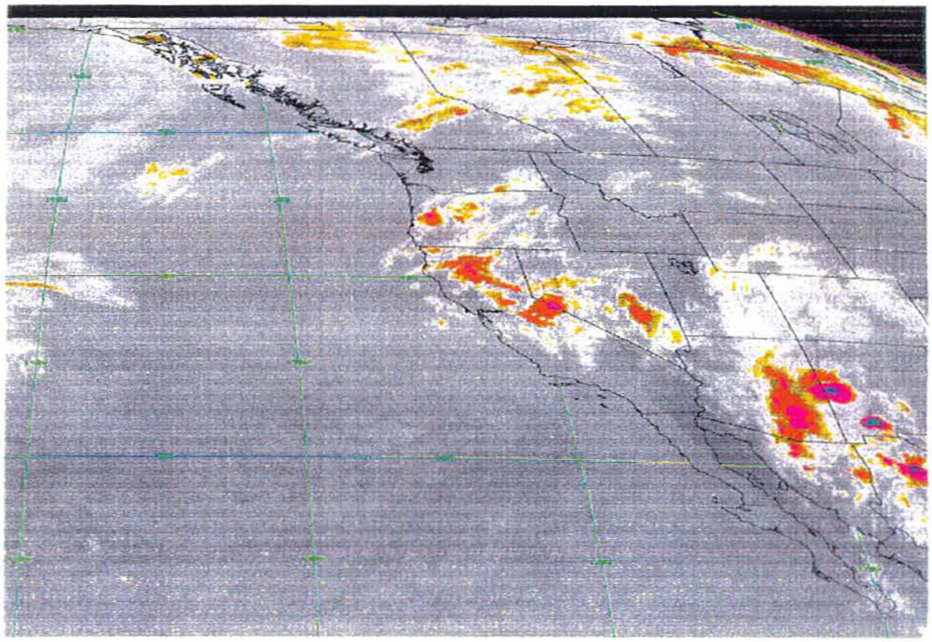

Figure 7. GOES-10 10.7 µm image at 1000 UTC on 10 August 1999.

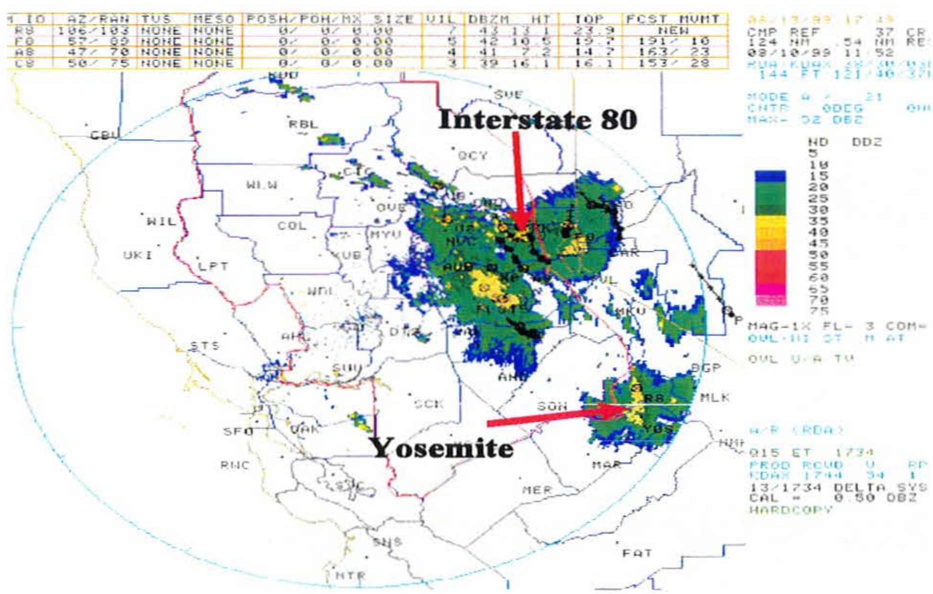

Figure 8. A large cluster of showers and thunderstorms seen on KDAX composite reflectivity image at 1152 UTC moving across the Interstate 80 corridor. Other storms are seen to the southeast over Yosemite National Park. At this time, the southeast mid-level flow had begun to weaken as the short wave passed. This was evident by the slower storm cell motions in the attribute table on the top.

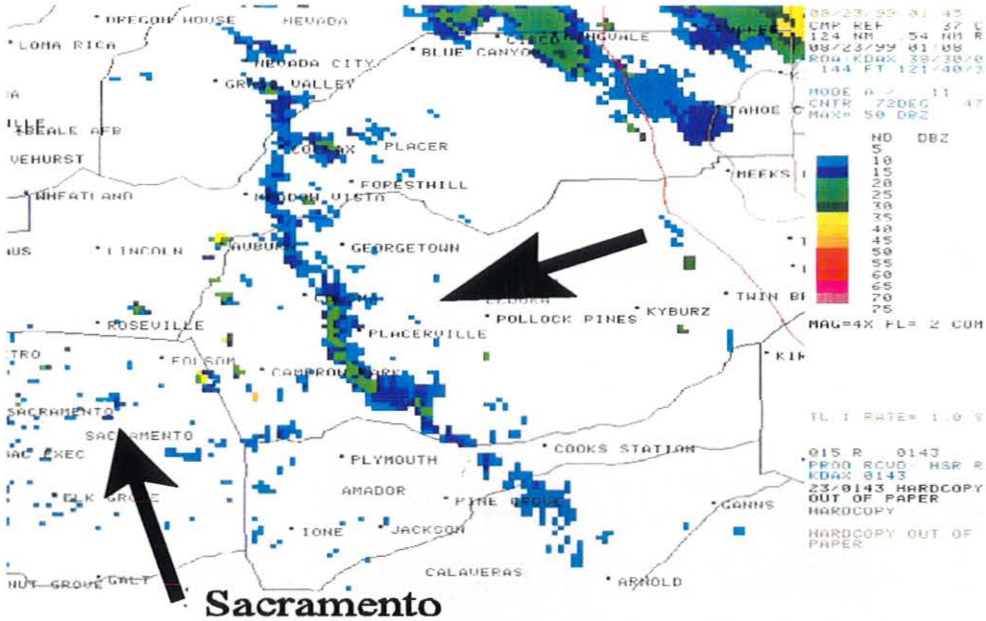

Figure 9. A well defined outflow boundary (reflectivity values as high as 25 dBZ) moving into the Sacramento Valley as seen on KDAX composite reflectivity at 0155 UTC on 23 August 1999. This boundary originated from late afternoon thunderstorms along the Sierra Nevada crest. The large arrow denotes the direction that the boundary was moving.

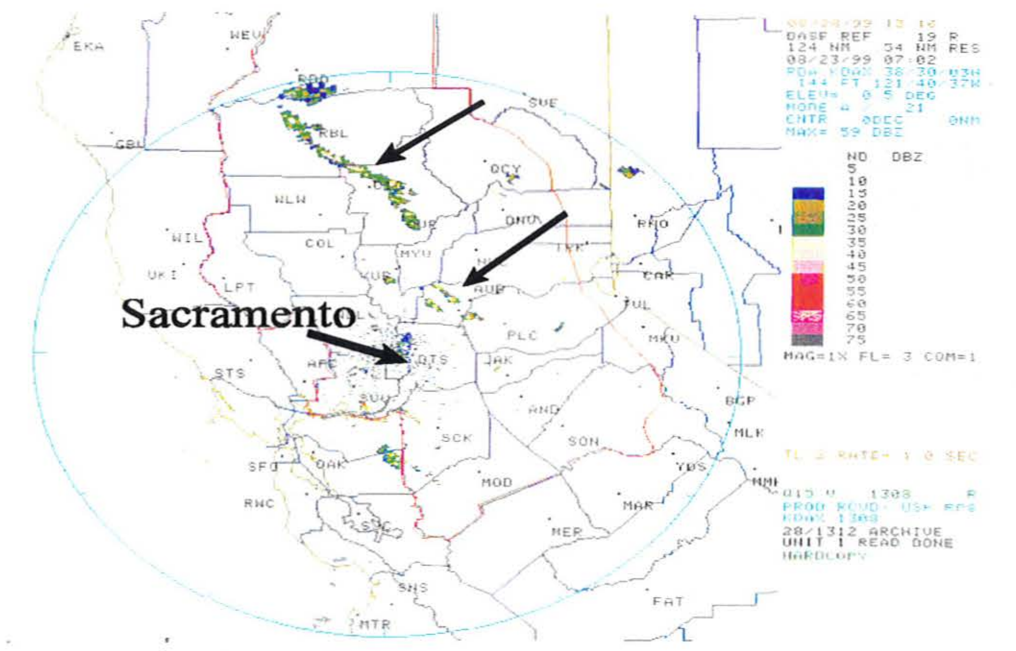

Figure 10. KDAX composite reflectivity at 0702 UTC showing the early stage of thunderstorm development. The top arrow points to a line of thunderstorms that spread northward with time. The middle arrow points to a few individual thunderstorms northeast of Sacramento, which is located in the middle of the circle (bottom arrow). Red line is the CWA boundary.

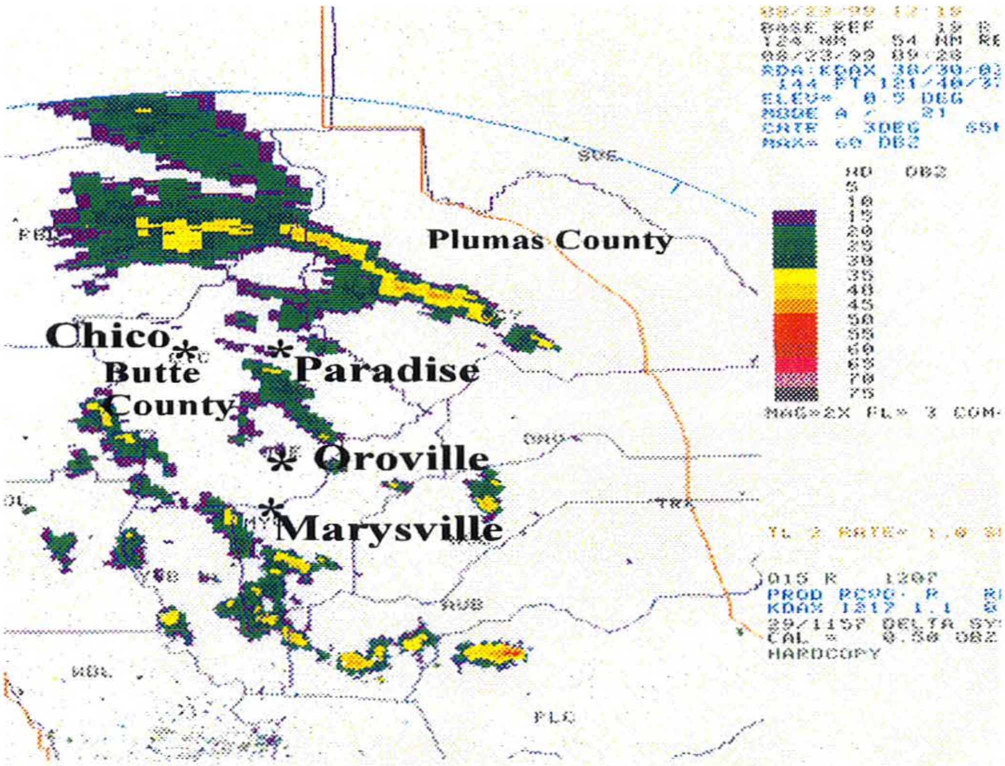

Figure 11. KDAX composite reflectivity at 0928 UTC on 23 August 1999 shows scattered thunderstorms from northeast of Sacramento north to the northern Sierra Nevada and northern Sacramento Valley.

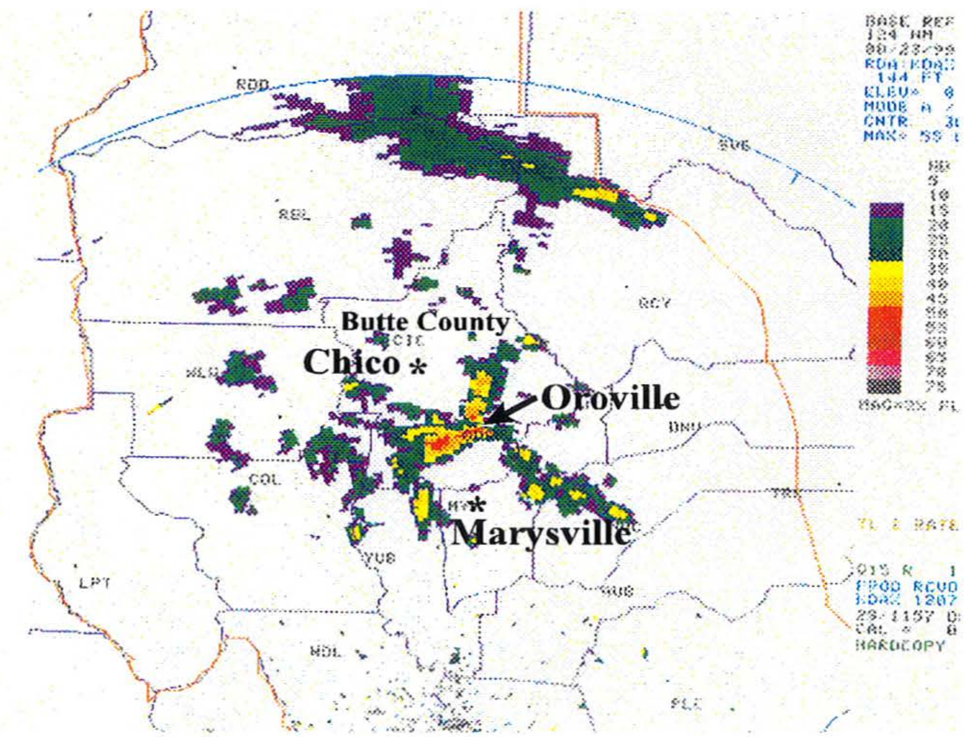

Figure 12. KDAX composite reflectivity at 1015 UTC showing an intense cluster of thunderstorms between Marysville and Chico. These storms produced numerous grass fires in Butte County.

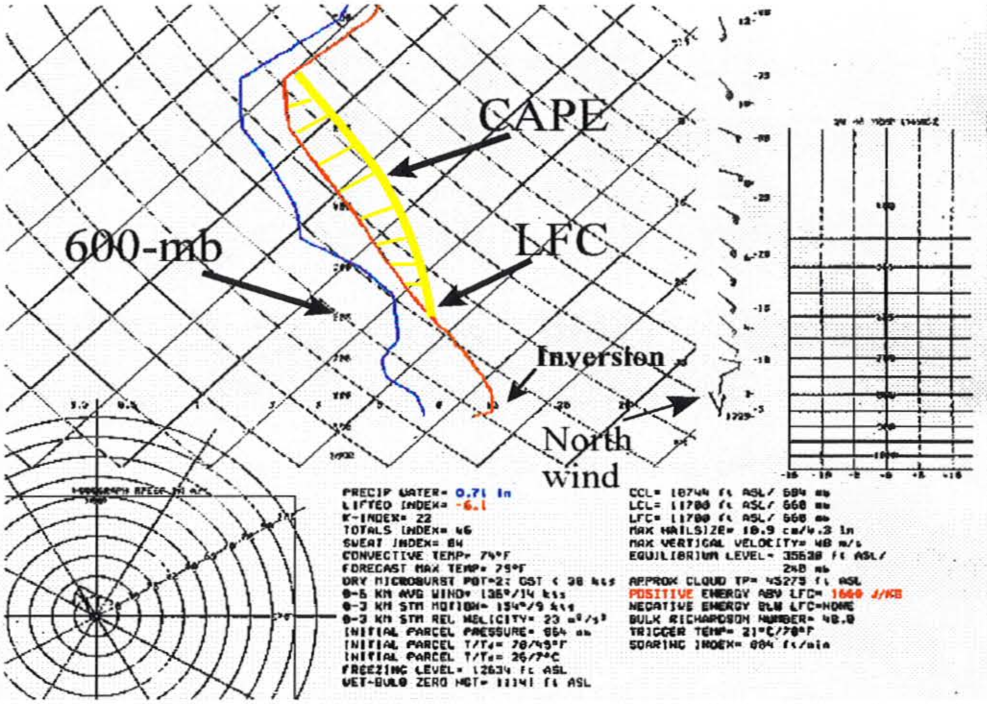

Figure 13. RUC analysis at 1200 UTC on 10 August 1999 at a location in the vicinity of Blue Canyon. This sounding clearly depicts the moderate instability that was present above the nocturnal inversion. Elevated (most unstable parcel) CAPE values were observed at 1660 Jkg^{-1} with an LI value of -6.1. The precipitable water value was 0.71 in. Notice the deeper moisture above 600 mb. Yellow line denotes an air parcel lifted from an elevated layer with the resultant CAPE seen as the yellow hatched area.

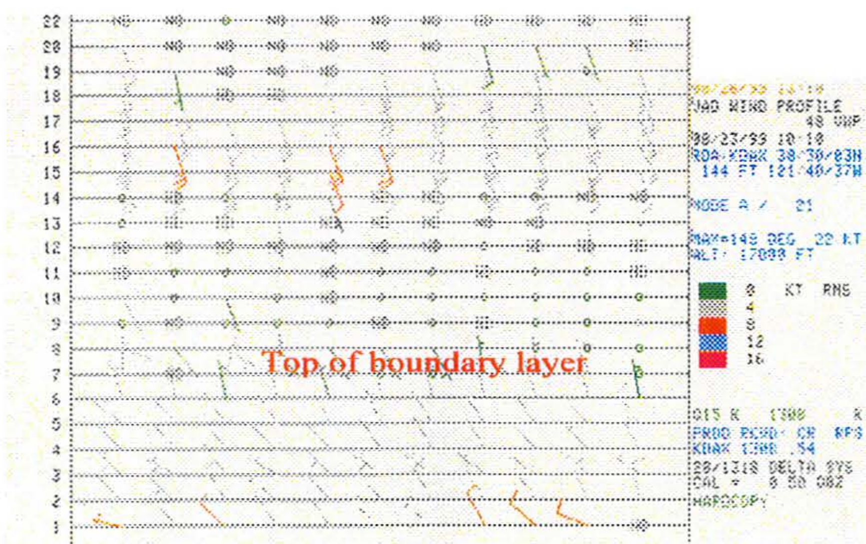

Figure 14. KDAX VAD wind profile between 0910 and 1018 UTC on 23 August 1999. This shows the 10 to 12 ms^{-1} southeast steering wind near 15,000 ft MSL overrunning the boundary layer northwest winds.

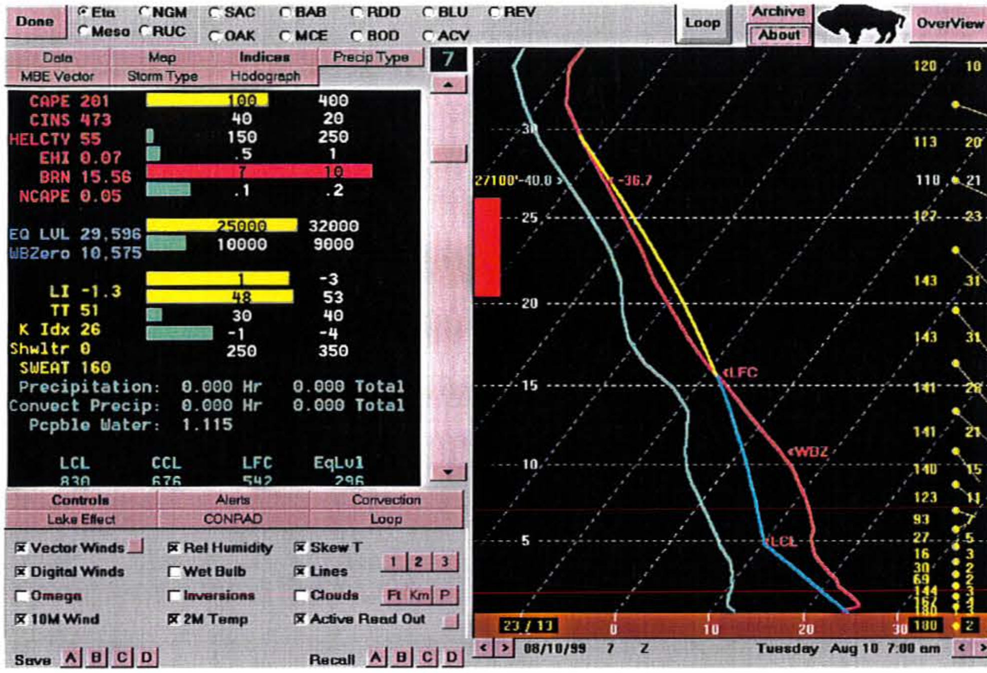

Figure 15. 0000 UTC 10 August 1999 Eta run on BUFKIT at 0700 UTC. The sounding is for Beale Air Force Base (KBAB) near Marysville, and shows the potential instability by the yellow line with a large negative area indicated by the blue line. Better indices in this event were evident with a Lifted Index of -1.3 and Total Totals at 51.