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THE NORTHERN SACRAMENTO VALLEY SURFACE MOISTURE CONVERGENCE ZONE

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1. Introduction

The interior valley of California, also known as the Central Valley, is generally not climatologically favorable for thunderstorms. This can be attributed to prevailing synoptic conditions with marginal instability, moisture and inversion layers (i.e., capped). Thunderstorms can occur anytime during the winter months since low-level moisture is often readily available and cold air advection aloft increases the depth of the instability. Thunderstorms are most common during the months of March and April since increased solar heating leads to further destabilization while boundary layer moisture is still sufficient. The majority of thunderstorms that do occur are post-frontal and the pulse type (short lived). Thunderstorms are much less common across the Central Valley in the summer because of a relatively dry boundary layer and inversions that result from a prevailing upper-level ridge of high pressure. There is often sufficient convective available potential energy (CAPE), but the convective inhibition (CINS) is too large, or the level of free convection (LFC) is too elevated to be reached by surface-based air parcels. In addition, the valley is split by the Sacramento River Delta which is located just west of Sacramento. The Delta has a great influence on surface convergence, and often promotes divergence of the surface wind flow which can inhibit thunderstorm development. A stabilizing effect can also be associated with the Delta as cool marine air sometimes advects into the Central Valley during the summer months.

The northern portion of the Central Valley, or the northern Sacramento Valley, is different from the rest of the interior valley since it is actually a much more climatologically favored region for thunderstorms. This is primarily due to a prevailing southerly surface wind flow that convergences on the north end of the narrowing Sacramento Valley. It has been found that the number of thunderstorm occurrences is greater in this region and the convective activity can often be much more persistent. During some events, thunderstorms have been observed to continuously redevelop in the same general area for up to 6 hours. In other cases, isolated thunderstorms will develop in the northern Sacramento Valley while the rest of northern California is experiencing clear skies. In addition, the topography of this region has also been documented to be conducive to supercellular thunderstorms (Monteverdi 1993; Staudenmaier 1995). The purpose of this paper will be to discuss the relatively high number of non-supercell thunderstorm occurrences in the northern Sacramento Valley and develop forecasting applications.

2. Synoptic and Mesoscale Pattern

The general synoptic pattern that has been observed with thunderstorms in this study for the northern Sacramento Valley is a post-frontal scenario with a mid-tropospheric short wave trough moving through northern California. First, a lee-side trough develops in the valley (i.e., valley-induced trough). This is due to westerly wind in the lower levels (i.e., 850 mb) of the atmosphere that is forced to descend down the coastal mountain range which is located west of the Sacramento Valley. This downsloping air flow undergoes adiabatic compressional warming and stretching which lowers surface pressures, and can sometimes induce a low-level circulation across the interior valley (i.e., dynamic trough). The valley trough can also form or intensify when surface heating lowers surface pressures in the northern Sacramento Valley. In these mesoscale patterns, a prevailing southerly surface wind flow will persist in the northern Sacramento Valley. Whiteman and Doran (1993) showed that terrain channeling of the geostrophic wind can also be very important towards sustaining the southerly flow in a north- to south-oriented valley and developing secondary boundaries (Fig. 1). When a mid-level trough passes over the northern Sacramento Valley (veering mid-level winds), the surface reflection is often seen as a wind shift or redirection of wind due to terrain blocking. At the same time, post-frontal subsidence and cold air advection will cause surface pressure rises over the north coast of California thus inducing a wind shift to northwesterly flow (Fig. 1).

The combination of the above can produce a mesoscale surface boundary (i.e., convergence zone) that propagates or remains stationary across the northern Sacramento Valley as shown in Figure 1. The surface boundary consists of a windshift and moisture discontinuity with southerly flow (upvalley) opposing the somewhat drier northwest flow from the Trinity Alps. Adequate atmospheric destabilization will often come from a mid-tropospheric short wave and insolation. If moisture and instability are sufficient the surface flux convergence may be enough to develop thunderstorms near this boundary. Several cases will be documented in this paper that show how this surface boundary interacted with available moisture and instability to produce thunderstorms.

3. Events

Case A

An early season thunderstorm outbreak occurred during the evening hours on 10 October 2000. An organized area of thunderstorms developed between Corning and Redding by 0000 UTC 10 October (Fig. 2). Figures 3 and 4 shows that the thunderstorms persistently developed in the same area through 0400 UTC producing locally very heavy rain. Weather Surveillance Radar-1988 Doppler (WSR-88D) precipitation estimates indicated that a maximum of 2.5 in (63.5 mm) fell just east of Red Bluff (not shown). This thunderstorm activity developed behind a primary cold front that moved through the Sacramento Valley between 1800 and 2300 UTC 9 October producing widespread showers and thunderstorms (not shown). Figure 5 shows the Eta sounding viewed with BUFKIT (Mahoney and Niziol 1997) and depicts that the model accurately forecast a southeasterly wind at Red Bluff (KRBL) that later shifted to the northwest (not shown). The sounding also forecast sufficient moisture and instability.

Case B

On 9 April 2000 a similar event to Case A occurred in the northern Sacramento Valley. Figure 6 shows the surface boundary that was present in this region during the thunderstorm outbreak. WSR-88D images showed an organized line of thunderstorms between Redding and Red Bluff (Fig. 7). The thunderstorms with heavy rain persistently developed through 0500 UTC 9 April 2000, several hours after diurnal thunderstorms had occurred over the surrounding mountains. It is possible that after sunset, the increasing downslope northwest wind component (colder air sinking) from the Trinity Alps could have acted to enhance the surface convergence boundary. This may explain why the thunderstorms were able to persistently develop well into the evening. Surface observations from Redding (KRDD), KRBL and Chico (KCIC) showed the convergent flow during this event (not shown). The upper air pattern was dominated by a closed upper-level low during this event as seen in Figure 8.

Case C

This case is similar to both Cases A and B except the thunderstorms that developed were less numerous. Figure 9 is a WSR-88D image at 2202 UTC 9 March 2000 which shows the thunderstorms located between Redding and Red Bluff. Post-frontal thunderstorms developed near 2100 UTC 9 March 2000 and continued in the same region until 0500 UTC 10 March (Figs. 10 and 11). The 0356 UTC observation at KRDD reported moderate rain and south wind at 5 ms^{-1} (not shown). By 0456 UTC the wind became calm and rain ended. Several hours after the first thunderstorms were depicted, radar showed the activity still persisting well after maximum diurnal heating (Fig. 12). A stationary surface boundary remained over the northern Sacramento Valley (Fig. 13) and provided surface moisture flux convergence in a region of instability and moisture. Thunderstorms continuously developed on the moist side (south) of this boundary where southerly surface wind flow provided sufficient inflow and surface lifting.

Case D

On 2 May 1999, isolated thunderstorms formed in the northern Sacramento Valley during the early evening hours (Fig.14). This case differs from the other events in that thunderstorm development was more than 12 hours after the main frontal passage, and was of much shorter duration. During this event, intense surface heating developed a thermal low in the northern Sacramento Valley. Sufficient instability resulted from insolation, which combined with the available moisture and a surface boundary (Fig. 15) to the initiate thunderstorms. This boundary, seen in Figure 15, formed between the warm thermal low pressure area in the northern Sacramento Valley and the drier northwest flow across the Trinity Alps and southern Cascades of interior northwest California.

Case E

Case E is similar in characteristics to the previous case since isolated thunderstorms developed in the northern Sacramento Valley during the late afternoon on 26 April 1999 (Fig. 16) south of a stationary surface boundary (Fig. 17). A similar surface boundary to

Case D was found in a region of instability and southerly surface wind flow near Redding (Fig. 17). This boundary was formed by the development of a thermal low pressure area in the northern Sacramento Valley, which was the result of diurnal heating. The thermal surface low acts to create a southerly upvalley surface wind. The drier northwest flow in the Trinity Alps and southern Cascades existed prior to the thermal low and was a product of post-frontal subsidence (i.e., pressure rises). The boundary provided the necessary surface forcing to initiate thunderstorm development after convective temperatures were reached (maximum surface heating).

Case F

On the evening of 2 April 2001, thunderstorms developed between Red Bluff and Chico (Fig. 18). This was associated with a relatively dry cold front that moved through northern California. This case was included to show how well the numerical model guidance performed with its prediction of convective precipitation and surface flux convergence. Figure 19 shows an Eta forecast which accurately predicted precipitation in the northern Sacramento Valley. In addition, the 22-km resolution (at the time of this event) of the Eta model showed superior performance in depicting the surface boundary that was needed to initiate thunderstorms in a region of marginal instability and moisture. A mid-tropospheric short wave trough lowered 500-mb geopotential heights to 558 dm and destabilized the air mass over northern California (not shown), but only the northern Sacramento Valley had precipitation. As discussed earlier, a mid-tropospheric trough may also develop and enhance post-frontal boundaries due to wind channeling through complex terrain.

4. Forecasting Applications

Post-frontal thunderstorms across the northern Sacramento Valley are more common than in other parts of the Central Valley. The cases in this study showed the surface boundary that often develops in this region has a very important role towards initiating and sustaining deep moist convection. A surface boundary can form in this region, which consists of a wind shift, density and moisture discontinuity, with southerly flow (upvalley) opposing the somewhat drier northwest flow from the Trinity Alps (see Fig. 1). Recognizing a mid-level wind shift (i.e., short wave trough passage) and existing upvalley surface flow may be the key to identifying the potential for such a boundary. This boundary needs to be identified by the forecaster in order to accurately predict this type of thunderstorm development and to successfully recognize the potential long duration of these events. Though not discussed in this paper, the movement and interaction of this boundary with other synoptic and mesoscale features can also be crucial to diagnosing the potential for severe weather (Monteverdi 1993; Staudenmaier 1995).

Using available tools such as the Local Analysis and Prediction System (LAPS) or the Mesoscale Surface Analysis System (MSAS) have been found to be most useful towards identifying surface boundaries in the northern Sacramento Valley. Simple graphics, such as what are seen in Figures 15 and 17, can instantaneously show CAPE, Lifted Indices (LI), mean sea level pressure, and streamline wind analyses in near real-time. These analyses can effectively target the favorable region for initiating and sustaining deep moist convection. The forecaster also needs to consider the narrowing and rugged topography of the northern Sacramento Valley and surrounding mountains, and recognize how this will help enhance thunderstorm development even without an observed boundary. If a boundary is established, thunderstorms can persist and redevelop well into the evening hours provided there is sufficient moisture and instability. Finally, the amount of moisture will determine how widespread the moist convection becomes and the potential for heavy rain. In this study, the post-frontal events that developed less than 6 h after a moist primary frontal passage resulted in the heaviest and most widespread rainfall. However, it is also important to consider thunderstorm development 12 h or more after the main frontal passage or with a relatively dry frontal passage since available moisture can be sufficient for isolated thunderstorms once the surface convergence and instability develops or intensifies.

This study also showed that available high resolution numerical model data can be helpful towards detecting the low level surface flux convergence that often develops in the northern Sacramento Valley. Case F showed that the Eta model can be successful in predicting a sub-synoptic convective event despite the limitations of spatial resolution. The forecaster needs to consider potential instability (e.g., CAPE), available moisture and surface convergence that may be concentrated in the northern Sacramento Valley because of the topography. Even though the moisture and instability may not be sufficient to form moist convection across most of northern California, the northern Sacramento Valley convergence zone can be the added mechanism required to initiate thunderstorms.

5. Conclusion

This study focused on the northern Sacramento Valley convergence zone, a region that favors thunderstorms development because of the narrowing topography. This terrain forces air to converge at the north end of the valley. Similar regions can also be found across the United States. In the northern Sacramento Valley, a boundary can be formed by the channeling of geostrophic wind through complex topography of nearby mountains, surface pressure rises across northwest California, and surface pressure falls caused by a valley induced trough (see Fig. 1). These synoptic and mesoscale interactions create opposing wind directions, density and moisture characteristics that meet over the northern Sacramento Valley. Given sufficient moisture and instability, this boundary can initiate and sustain thunderstorms.

The forecaster needs to identify these regions in order to accurately predict the development and duration of deep moist convection. Some forecaster tools include real-time data from surface analyses for short-term forecasting (less than 12 h), and surface wind pattern guidance from numerical model data (12 to 24-h forecasts). Both can be useful towards accurately predicting thunderstorms. Surface convergence zones and boundaries can make the difference between thunderstorms and clear skies, brief showers and prolonged heavy rain, or general thunderstorms and severe thunderstorms.

References

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Mahoney, E. A., cited 2000: BUFKIT Documentation [Available on-line from http://www.nws.noaa.gov/er/buf/bufkit/bufkitdocs.html.]

Mahoney, E. A., and T. A. Niziol, 1997: BUFKIT: A software application toolkit for predicting lake-effect snow. Preprints *13th Intl. Conf. on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, Long Beach, CA, Amer. Meteor. Soc., 388-391.

Monteverdi, J.P., 1993: A case study of the operational usefulness of the SHARP workstation in forecasting a mesocyclone-induced cold sector tornado event in California. *NOAA Technical Memorandum.* NWS WR-219.

Whiteman, C.D., and J.C. Doran, 1993: The relationship between overlying synoptic-scale flows and winds within a valley. *J. Appl. Meteor.*, **32**, 1669-1682.

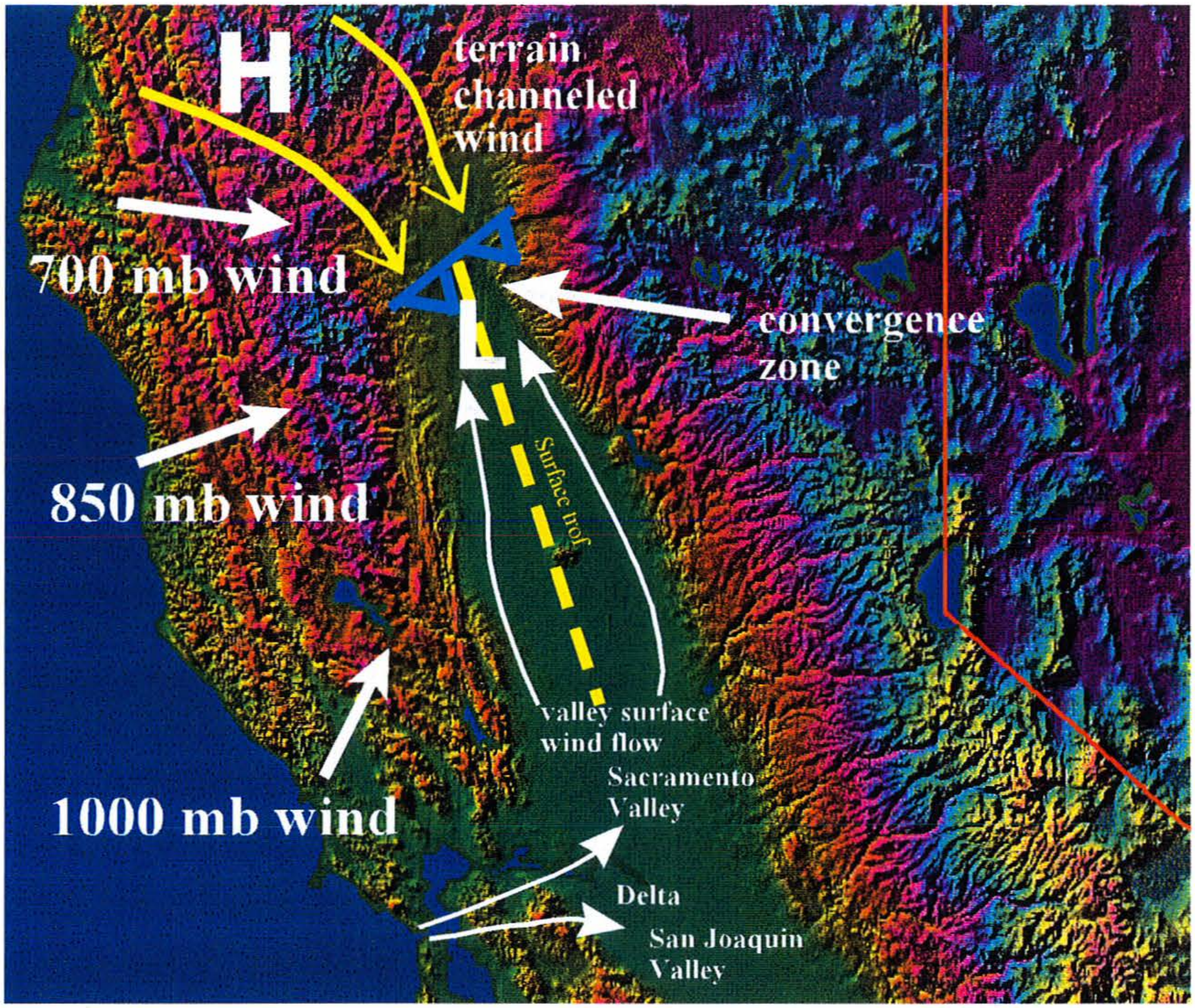

Figure 1. Composite topographic map, surface and upper-air wind flow showing the surface convergence features over the northern Sacramento Valley (located near the low pressure center labeled L). The blue triangles indicate the leading edge of drier air descending from the Trinity Alps (located under the mid-level high pressure center labeled H) that intersects the more moist surface valley trough producing the convergence zone.

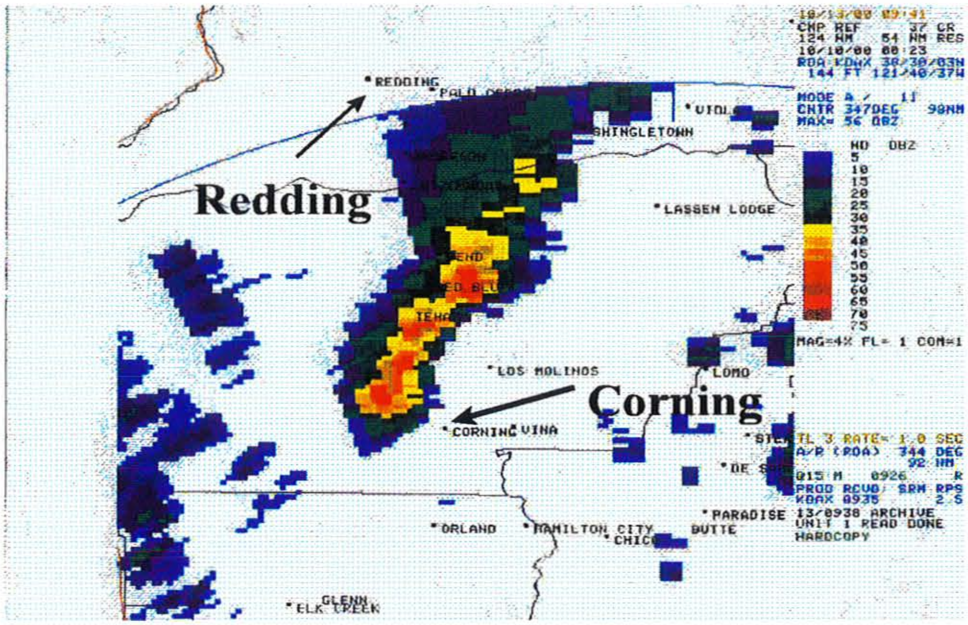

Figure 2. KDAX composite reflectivity at 0023 UTC 10 October 2000 showed an organized area of thunderstorms between Redding and Corning.

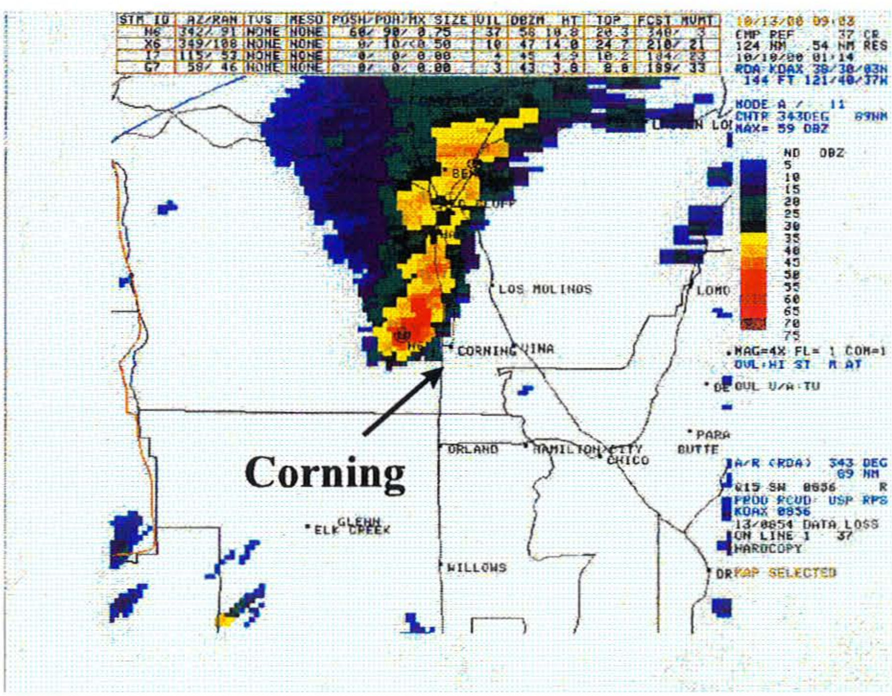

Figure 3. KDAX composite reflectivity at 0114 UTC 10 October showed the continued development of thunderstorms on the southern end of the surface moisture convergence region near Corning.

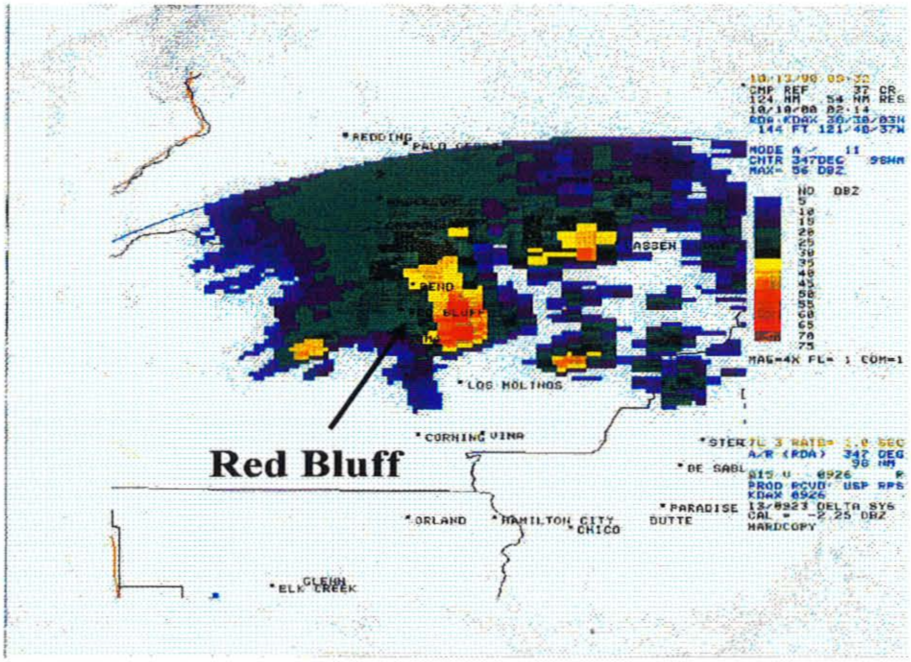

Figure 4. KDAX composite reflectivity showed thunderstorms at 0214 UTC have continued to develop in the same area and are most intense near Red Bluff.

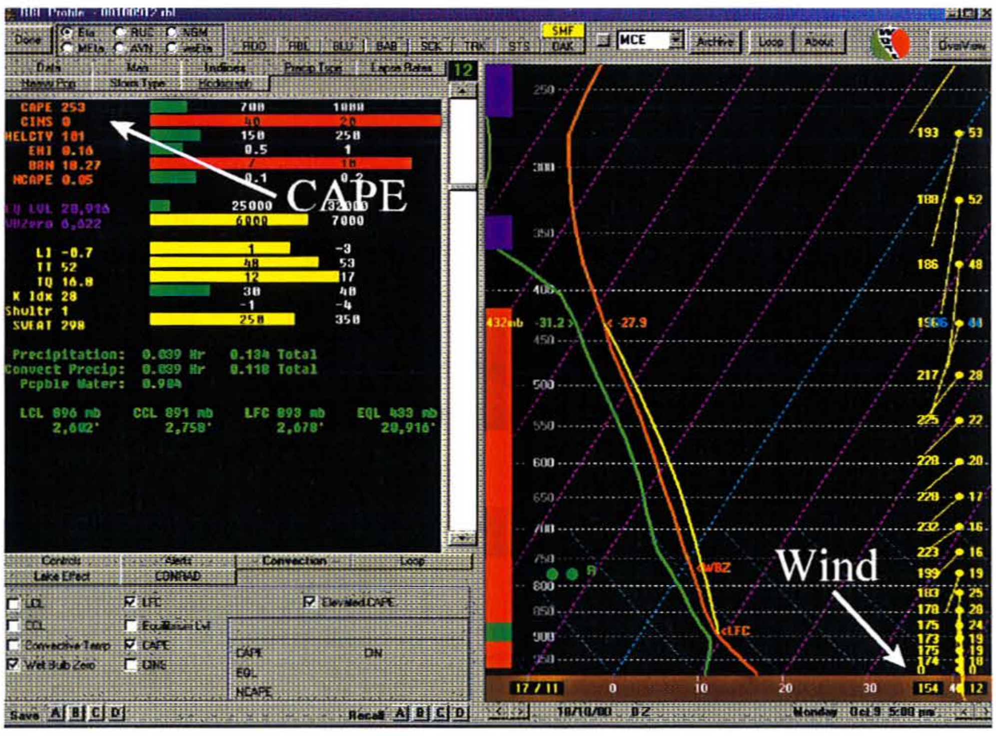

Figure 5. BUFKIT Eta KRBL (Red Bluff) sounding at 0000 UTC 10 October 2000 from the 1200 UTC 9 October run. The model was forecasting a CAPE value of 253 Jkg^{-1}, NCAPE 0.05 ms^{-2} and a southeast 10-m wind.

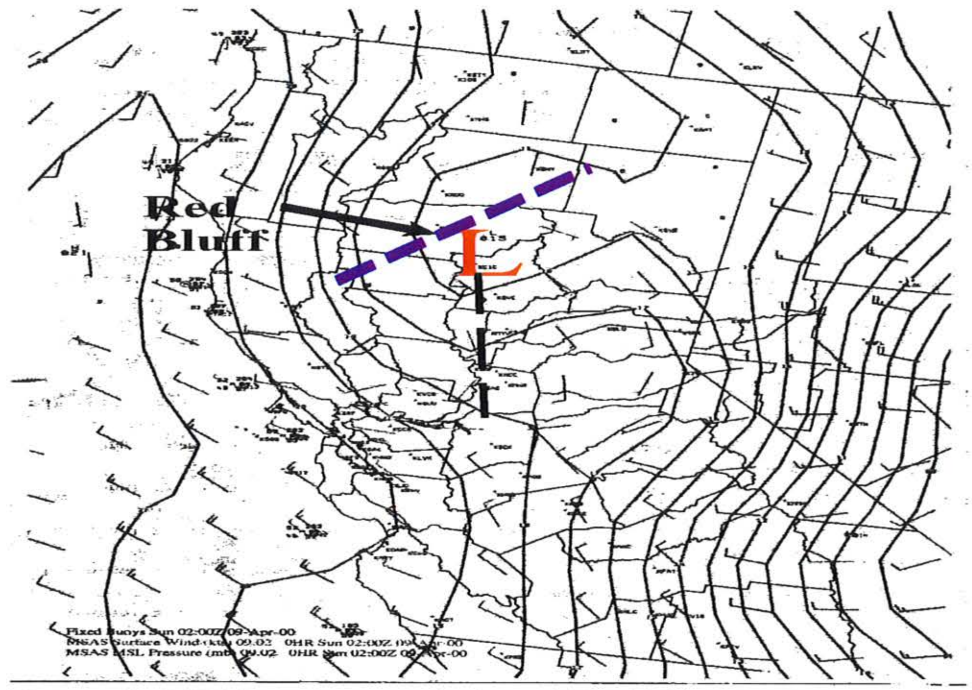

Figure 6. MSAS surface analysis at 0200 UTC 9 April 2000. Low pressure area is indicated at the intersection of the two surface troughs of lower pressure in the northern Sacramento Valley. Solid lines are MSL contoured every 1 mb. Surface wind barbs are every 2.5 ms^{-1}.

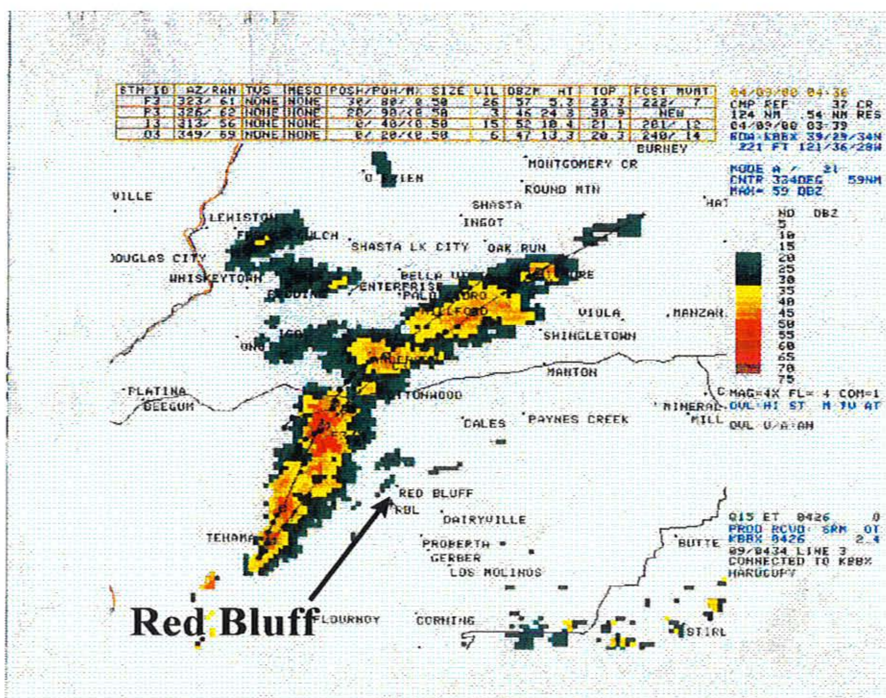

Figure 7. KDAX composite reflectivity at 0339 UTC 9 April 2000 showed a well-organized line of thunderstorms.

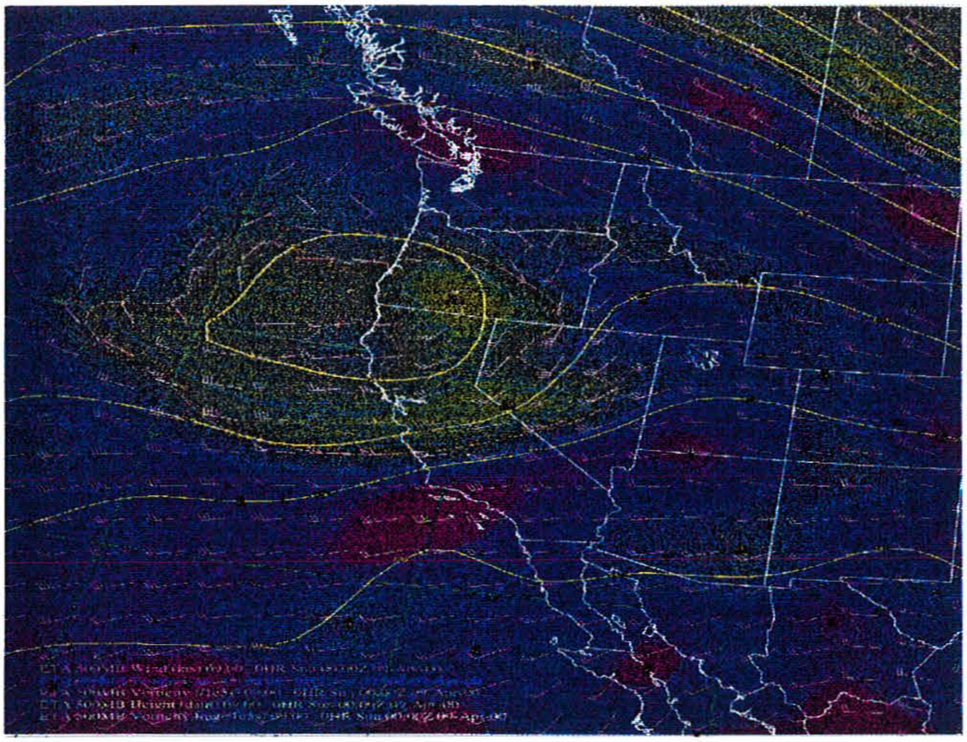

Figure 8. Eta analysis of geopotential heights and vorticity at 0000 UTC 9 April 2000. Solid height lines are every 60 m and vorticity is every 1 unit e5s^{-1}. Wind barbs are every 2.5 ms^{-1}.

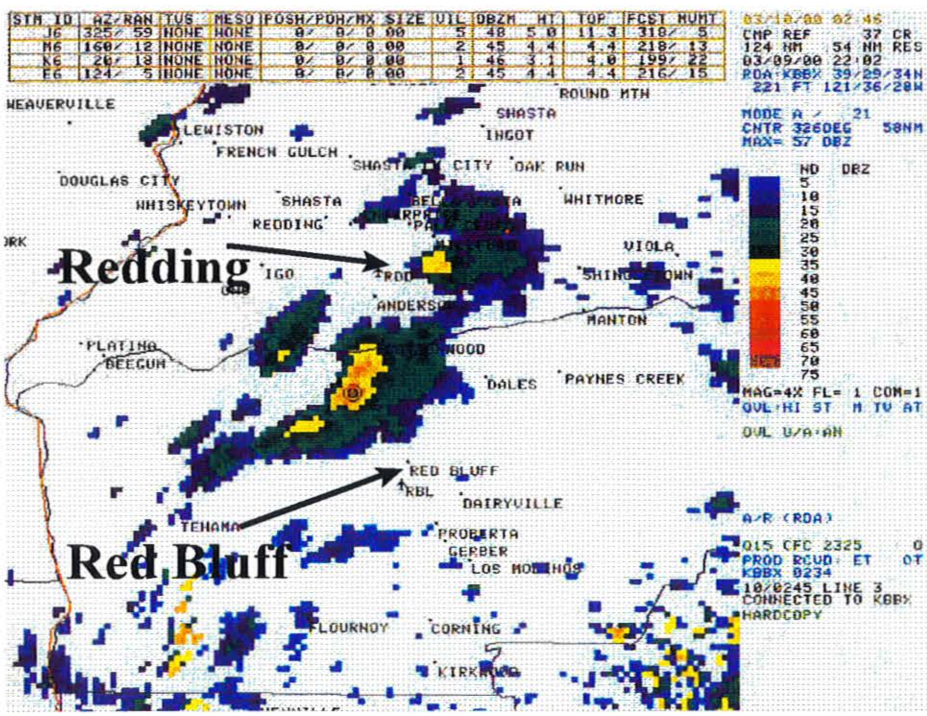

Figure 9. KBBX composite reflectivity at 2202 UTC 9 March 2000 showing thunderstorms that developed between Redding and Red Bluff.

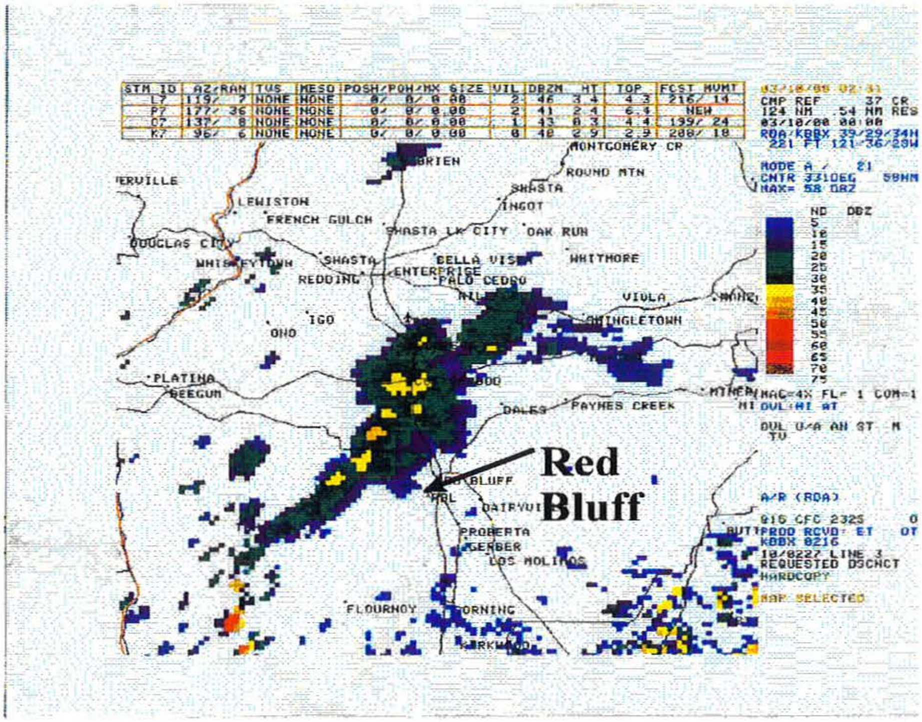

Figure 10. At 0000 UTC 10 March, KBBX composite reflectivity indicates persistent thunderstorms just north of Red Bluff.

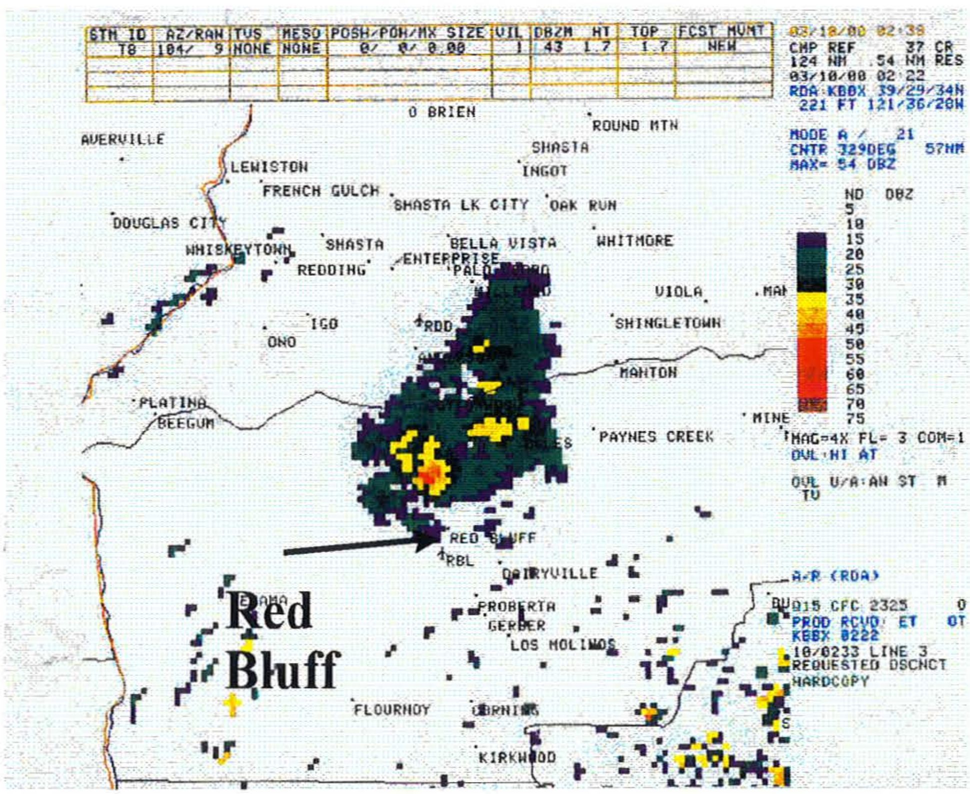

Figure 11. Thunderstorms persist, as shown by this KBBX composite reflectivity image at 0222 UTC 10 March.

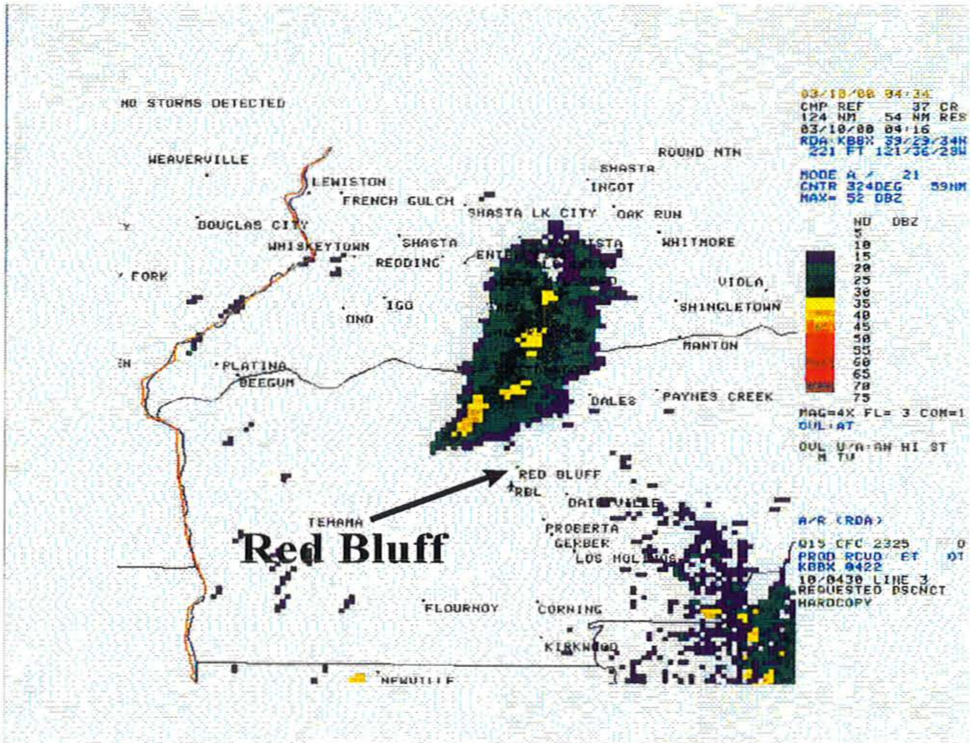

Figure 12. Thunderstorms continue, but have weakened, as shown by this KBBX composite reflectivity image at 0416 UTC 10 March.

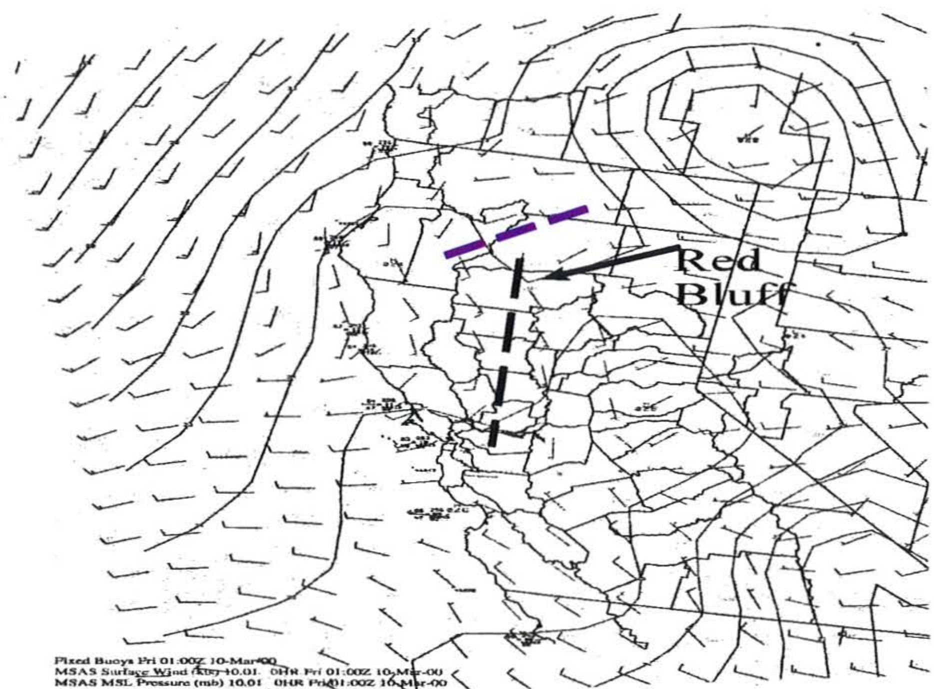

Figure 13. MSAS analysis at 0100 UTC 10 March depicts a surface trough of low pressure (black dashed line) which intersects the drier and cooler air (blue dashed line) near the northern Sacramento Valley. Isobars are solid lines and contoured every 1 mb. Surface wind barbs are every 2.5 ms^{-1}.

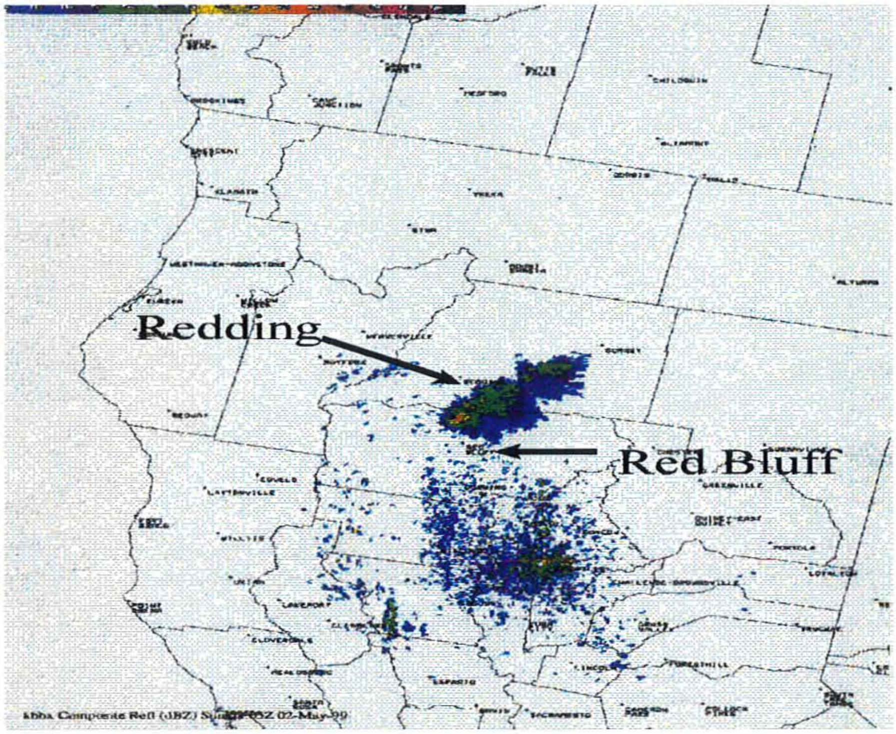

Figure 14. KBBX composite reflectivity at 0305 UTC 2 May 1999 showing thunderstorms between Redding and Red Bluff.

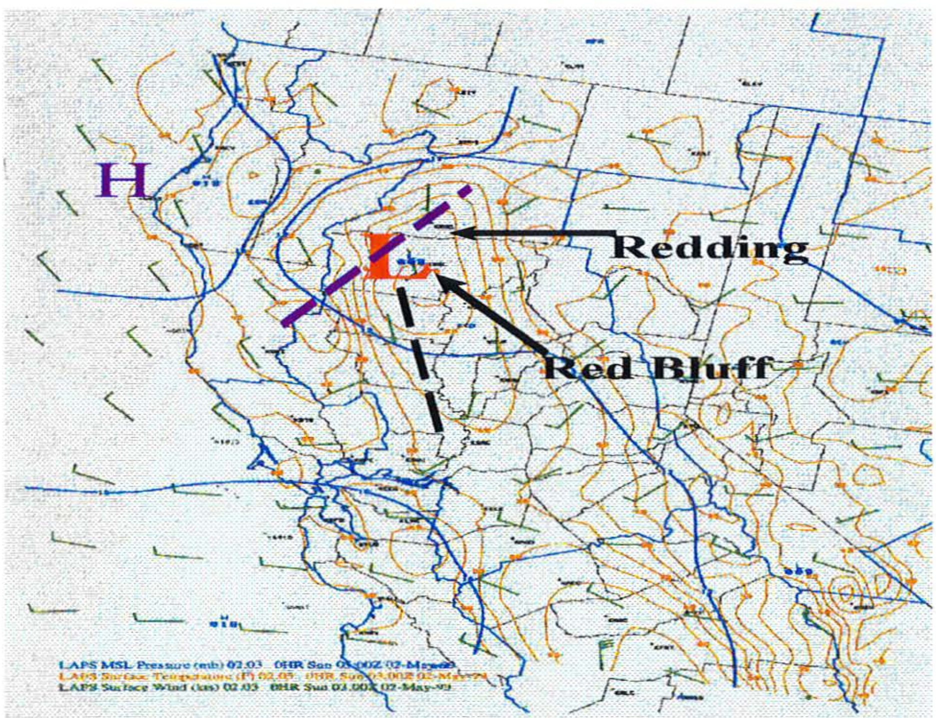

Figure 15. LAPS surface analysis at 0300 UTC 2 May 1999 showed a surface low pressure area near Red Bluff. Two boundaries intersect near Redding. Solid blue isobars are MSL pressure every 4 mb. Solid red lines are temperature contoured every 5 degrees F.

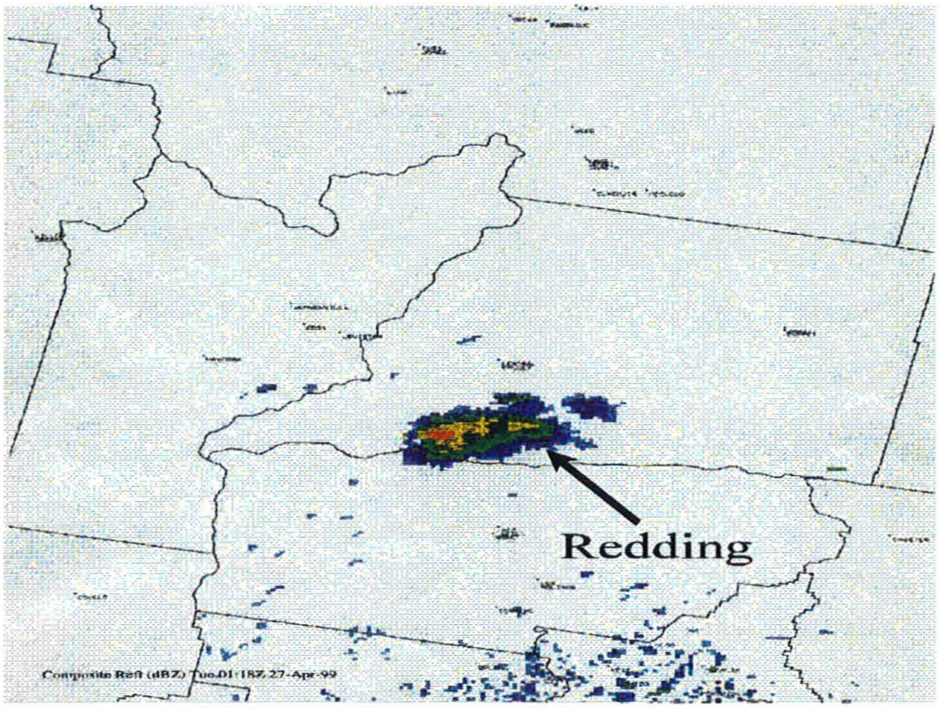

Figure 16. KBBX composite reflectivity at 0118 UTC 27 April 1999 which showed showers and thunderstorms developing near Redding.

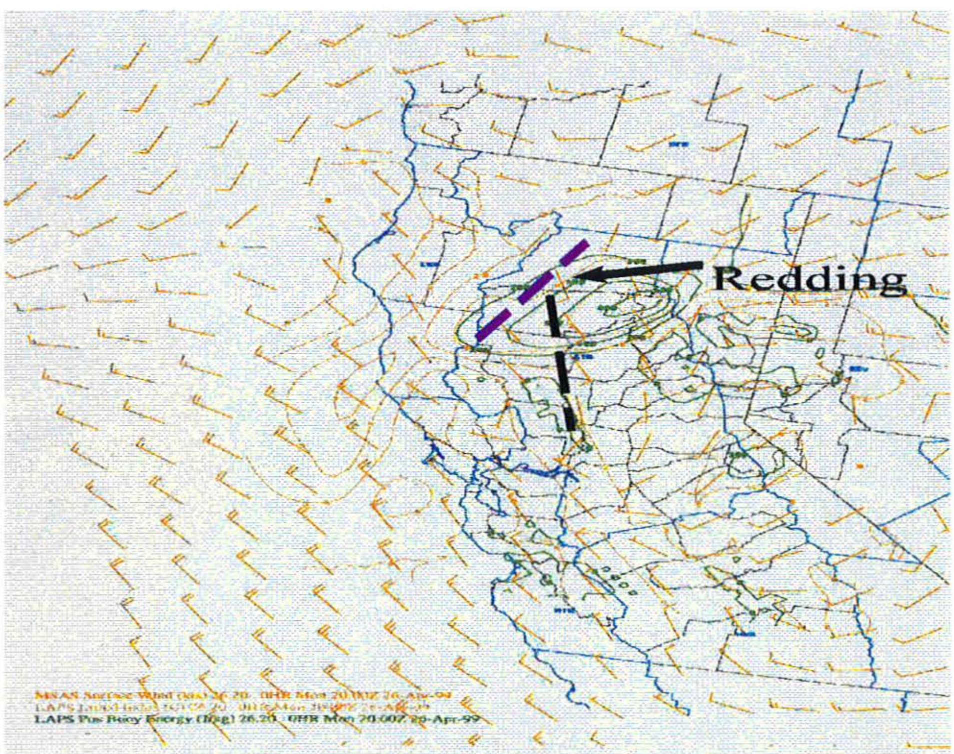

Figure 17. LAPS surface analysis at 2000 UTC 26 April 1999. Solid red lines are LI's contoured every 2. Solid green lines are CAPE every 200 Jkg^{-1}. MSAS surface wind barbs are every 2.5 ms^{-1}. Two boundaries intersect near Redding.

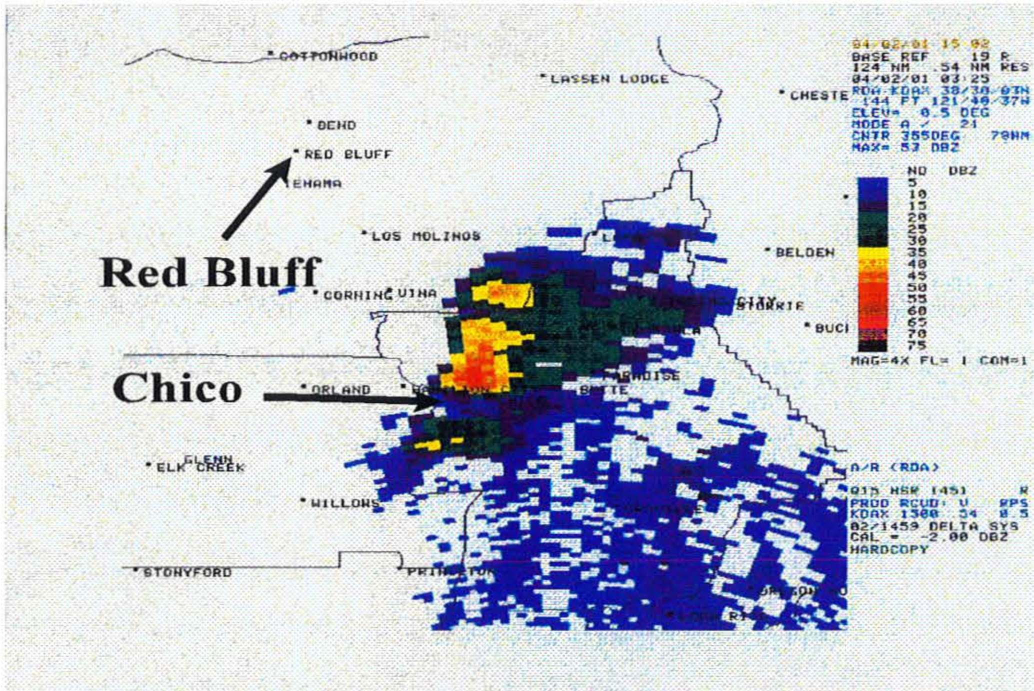

Figure 18. KDAX composite reflectivity at 0325 UTC 2 April 2001 showed thunderstorms near Chico.

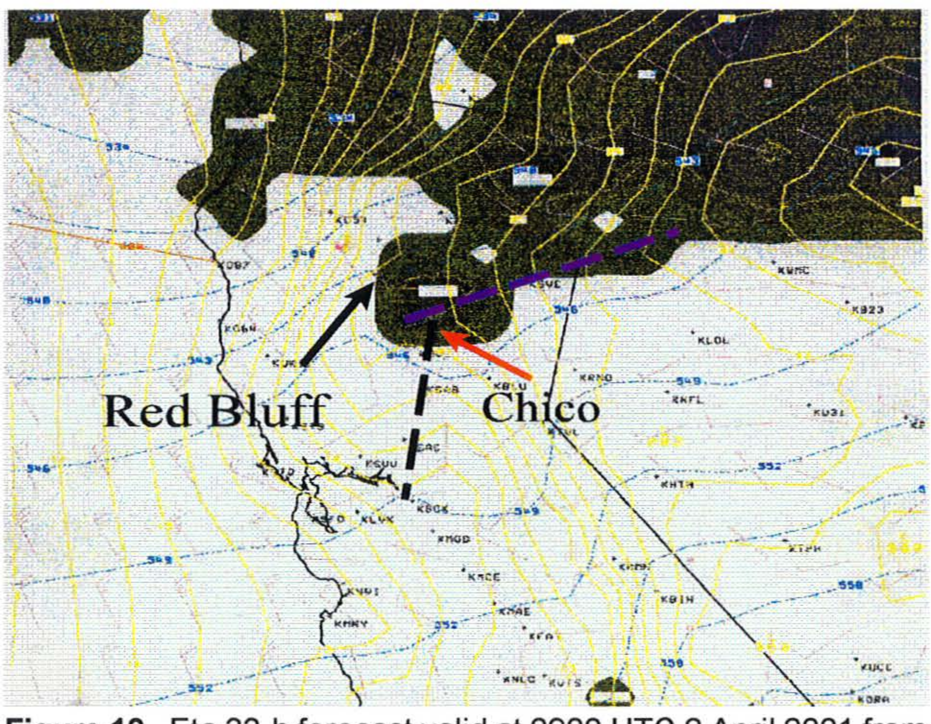

Figure 19. Eta 33-h forecast valid at 0900 UTC 2 April 2001 from the 0000 UTC 1 April run. Yellow lines are MSL pressure every 1 mb. The model produced convective precipitation (green shaded area) near Chico along a surface convergence zone (dashed lines intersection). Surface wind barbs are every 2.5 ms^{-1}.