Frontogenesis, Conditional Symmetric Instability and Microphysics: A Rare Desert Snow Event

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Introduction

During the overnight and early morning hours of November 21, 2004, a strong low pressure system brought up to 12 inches of snowfall to the deserts of San Bernardino County in Southern California. Snow accumulations of this magnitude over the deserts of Southern California are rare. The study of this event concentrates on the town of Yucca Valley, CA which received between 8 and 12 inches of snowfall. Yucca Valley is located in the south central portion of San Bernardino County at an elevation of 3500 ft (Fig. 1).

This paper will examine the ingredients that came together to produce this heavy snowfall event, particularly how strong dynamics and favorable cloud microphysics can overcome the lack of a deep layer moisture tap to produce significant snowfall accumulations. This case also underscored the importance of utilizing analysis skills and maintaining a high level of situational awareness in order to deduce the presence of mesoscale processes that may require adjustments to model predictions.

Synoptic Overview

At 0000 UTC on November 20, 2004, a longwave trough was located over the western two-thirds of the United States, and a high amplitude ridge extended off the west coast of California northward into the Gulf of Alaska. Water vapor imagery showed a strong shortwave dropping southward out of British Columbia (Fig. 2), along the eastern side of the ridge. Model and upper air data indicated this shortwave was located in the left exit region of a 120 knot jet streak (Fig. 2), which was likely helping to intensify this feature.

By 0600 UTC on November 21, 2004, the shortwave was continuing to move southward and carving a strong upper low out of the backside of the longwave trough near the southern Nevada/California border (Fig.3). Surface and satellite observations indicated that the system had undergone rapid cyclogenesis. This was particularly apparent in the 3-hour pressure change (Fig. 4), which indicated pressure falls of 7-mb between 1800 and 2100 UTC across Inyo and San Bernardino Counties. Cyclogenesis was likely intensified by a tropopause fold, evident by a PVA anomaly that extended down to about 500mb (Fig. 5). A very strong vorticity maximum at 500mb (Fig. 6) was also evident rotating around the southern end of the system and was intensifying development in the southeastern quadrant of the upper low.

A “pre-event” cold front pushed across south central San Bernardino County around 0400 UTC dramatically modifying the atmospheric conditions so that the main precipitation event, which occurred between 1230 UTC and 1600 UTC, fell entirely as snow. The passage of this front played a significant role in lowering snow levels prior to the main event through shower development and enhanced evaporative cooling.

Discussion

Radar imagery showed multiple thin intense bands of precipitation developing immediately behind the cold frontal passage between 0400 UTC and 0800 UTC (Fig. 7). This banding was most likely caused by a combination of frontogenetical forcing and the release of conditional symmetric instability (CSI) aloft. The precipitation bands did display several classic CSI characteristics. The bands were parallel to thickness lines, had a component of propagation towards the warmer air and were occurring in an area of large scale ascent. The Eta in particular, indicated that rapid frontogenesis would occur over Southwest San Bernardino County. Analysis of the 3-hour forecast from the 0600 UTC Eta highlighted an area of intense frontogenesis (using the 850-700mb Petterson 2-D Frontogenesis parameter) that stretched across San Bernardino County near the time of frontal passage (Fig. 8). In addition, the Eta model showed there was the potential for CSI aloft to be released. A cross section across southern California from the Eta is provided in Figure 9 and indicates an area where the lines of θ_e became more vertical than the lines of M_g. Also, values of Equivalent Potential Vorticity (EPV) were slightly negative (Moore, 1993) over south central San Bernardino County.

There was a distinct airmass difference behind the front, including a pronounced drying in the surface layer. Surface observations in Yucca Valley indicated a 5°C drop in surface dewpoint between 0300 UTC and 0400 UTC (falling from 4.0C to -1.4C). Surface dewpoint depressions also increased from 3°C to around 11°C during the same time period. Only light precipitation amounts were recorded immediately behind the front between 0400 UTC and 0700 UTC due to the initially, very dry low levels (no precipitation reaching the surface). No precipitation was recorded by automated sensors after 0700 UTC in the vicinity of Yucca Valley, but it can be inferred from surface and radar observations that precipitation likely changed to snow around this time. Spotter reports indicate around 2 inches of snowfall accumulated in Yucca Valley under the precipitation bands by 0900 UTC.

Actual snow levels were well below those suggested by the 1000-500mb thickness or 700mb temperatures. The best predictors of snow levels in advance for this event were the EtaBufr soundings, including the wet-bulb zero heights and 850-700mb shallow layer thickness values (850-700mb thickness values fell below the 1540m critical value between 0900 UTC and 1000 UTC). Analysis of the EtaBufr soundings from KPSP and KDAG did indicate that given a sufficient dry layer at the surface, precipitation type at 3500 ft would change to snow after the frontal passage. However, model timing of the front was 3-4 hours too slow and the model did not fully represent the drying that would occur in the lower levels. Continual mesoanalysis was required to identify these discrepancies and make short-term adjustments to the model output and forecast soundings.

Although several snow showers occurred after 0800 UTC, it was not until around 1230 UTC that radar imagery began to show steady moderate to heavy precipitation. Radar data and spotter reports indicate the heaviest precipitation fell between 1230 UTC and 1600 UTC. During this time-frame, Yucca Valley was in the southeast quadrant of the upper low where synoptic lift was the greatest. The 0000 UTC run of the Eta, which did the best job of forecasting the eventual track of the upper low, had depicted an extremely intense area of Q-vector convergence over San Bernardino County at the forecast hours of 1200 UTC and 1500 UTC (Fig. 10). Q-vector forcing was enhanced by steep mid level lapse rates in excess of 7.0°C/km. Strong cloud microphysics played an important role in enhancing snowfall rates. Analysis of 0600 UTC EtaBufr time heights from KPSP (Fig. 11) showed a strong area of upward vertical motion coinciding within the -10°C to -16°C temperature band where dendritic crystal growth is maximized (Steenburgh, 2004). Aggregation of ice crystals within the clouds was also likely occurring as satellite estimates during the period of heaviest precipitation indicated cloud top temperatures around -40°C (Fig. 12).

Both the GFS and ETA models produced a QPF forecast that was dramatically underestimated. Satellite estimates of precipitable water were around 0.37 inches over southwest San Bernardino County during the event, which is fairly low for significant precipitation in the deserts and may have played a role in the models under-forecast of QPF.

Spotter reports from Yucca Valley verify intense snowfall rates of up to 3 inches per hour occurring between 1230 UTC and 1600 UTC. Strong vertical motion and very favorable cloud microphysics were likely responsible for the heavy snowfall rates. Upslope flow into the Yucca Valley area was probably also a contributing factor. By 1630 UTC (830AM PST) several spotters had reported between 8 and 12 inches of snow accumulation had occurred in under 12 hours.

Summary

This case demonstrated the importance of conducting continual mesoscale analysis, performing mental adjustments to model output, and maintaining a high level of situational awareness during the forecast process. Many factors including rapid frontogenesis, CSI, dendritic crystal growth, and orography coincided to provide a rare, intense snow event across the deserts of Southern California. This event also provided further evidence in the value of utilizing EtaBufr soundings including the wet bulb zero height and 850-700mb thickness values to provide a better estimate for desert snow levels.

References

Moore, James T., and Lambert Thomas E., 1993. The Use of Equivalent Potential Vorticity to Diagnose Regions of Conditional Symmetric Instability. *Weather and Forecasting.* 8, 301-308.

Steenburgh, W. James, 2004. “Dynamics and Microphysics of Cool-Season Orographic Storms” on-line Comet Module. The COMET Program.

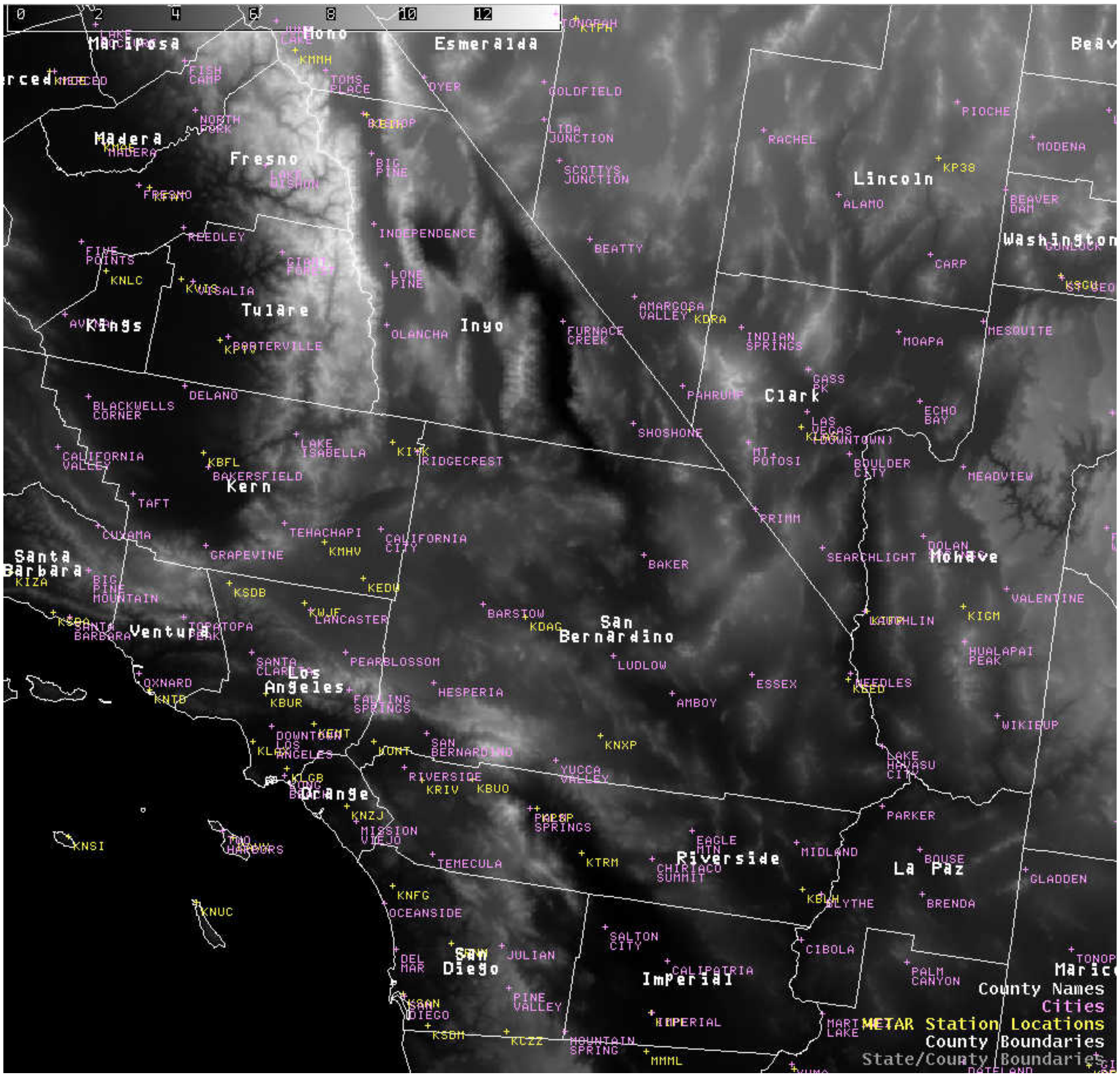

Figure 1. Topography of southern California. Yucca Valley, CA is located in the south central portion of San Bernardino County.

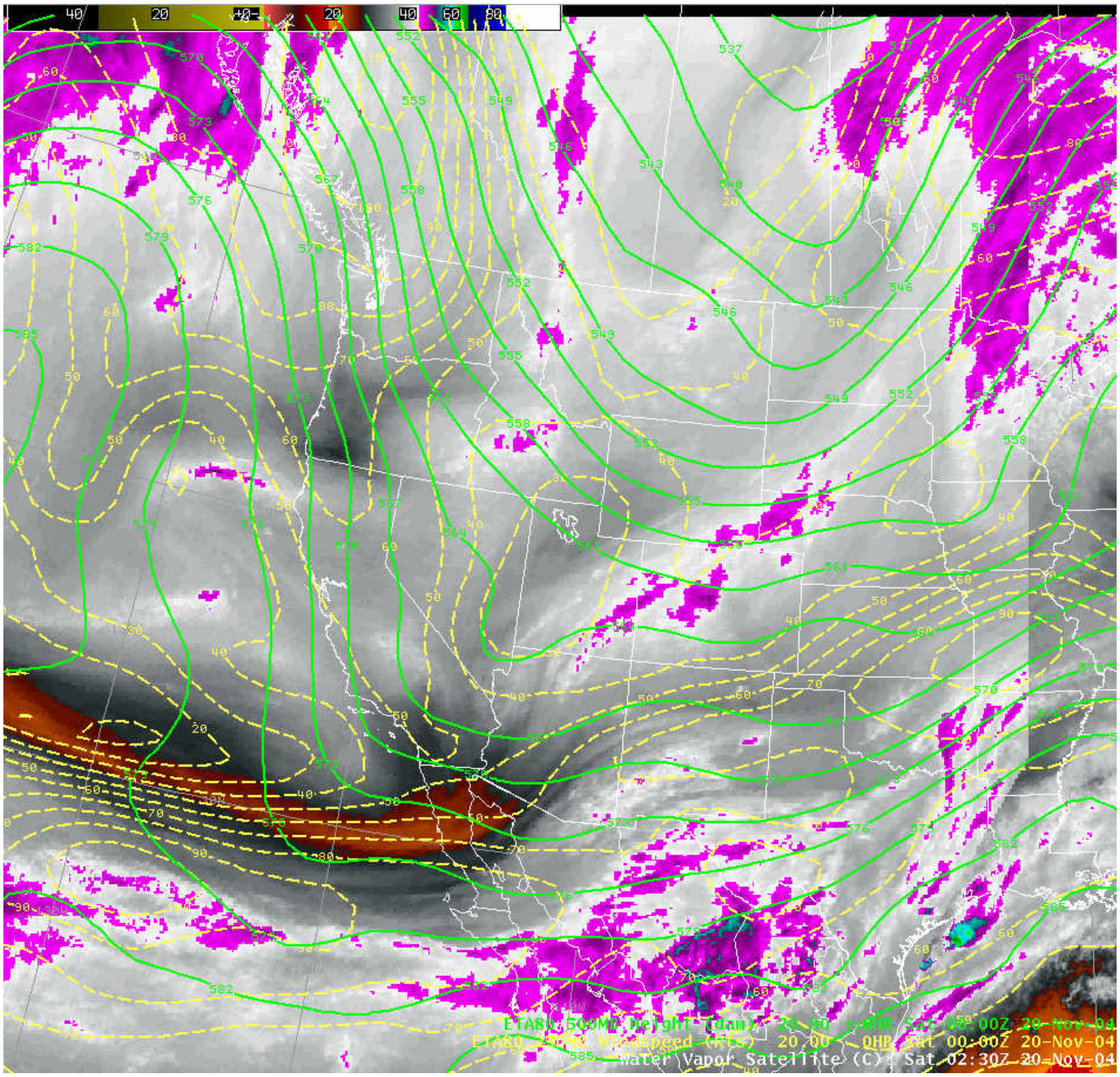

Figure 2. GOES-10 Water Vapor Imagery (0230 UTC), 0000 UTC Eta 0-hr analysis of 500-mb Heights (green lines) and 250-mb Isotachs (yellow lines) for November 20, 2004.

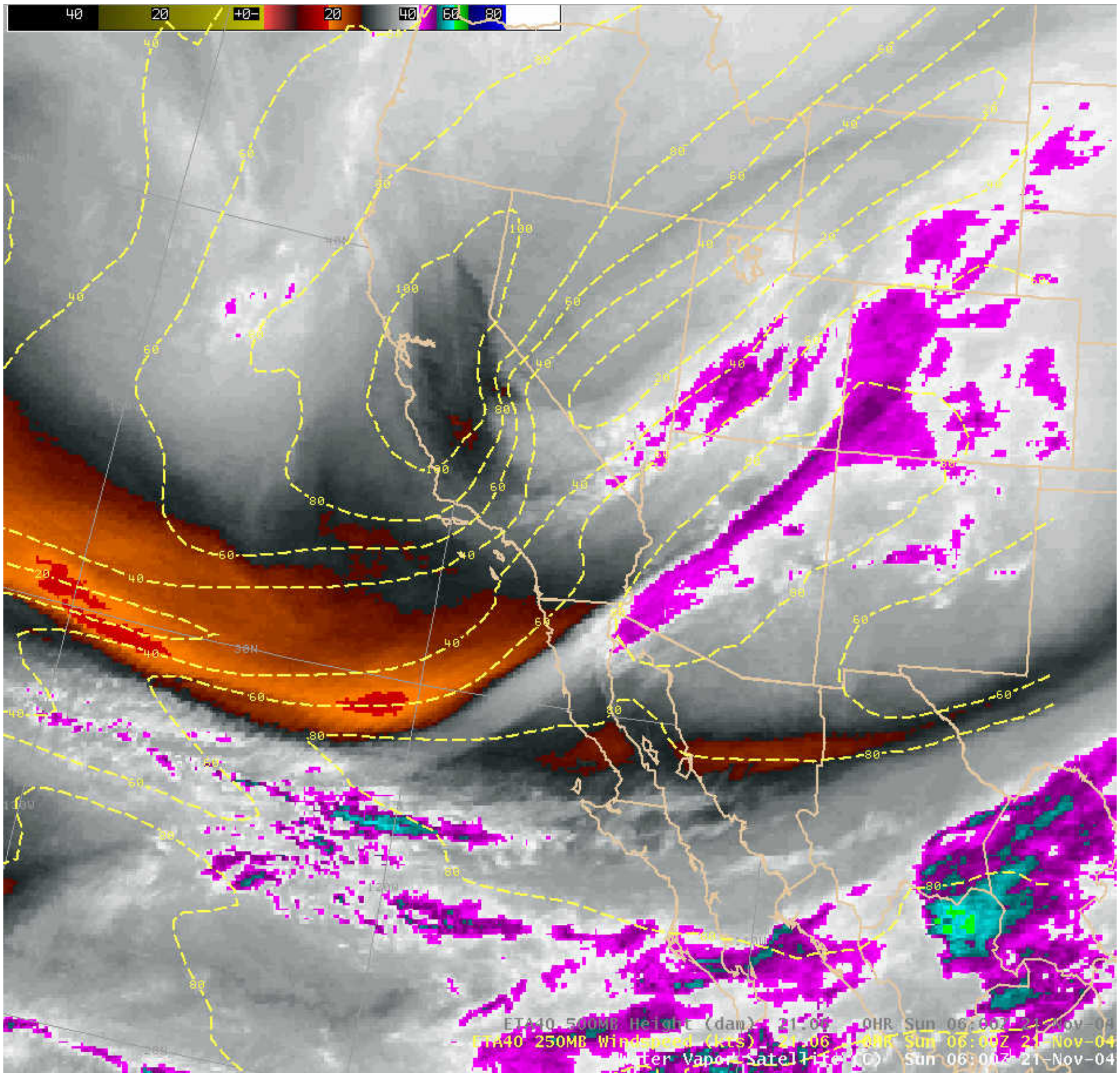

Figure 3. Water Vapor Imagery (0600 UTC) and Eta 0-hour forecast of 250-mb isotachs (0600 UTC) for November 21, 2004.

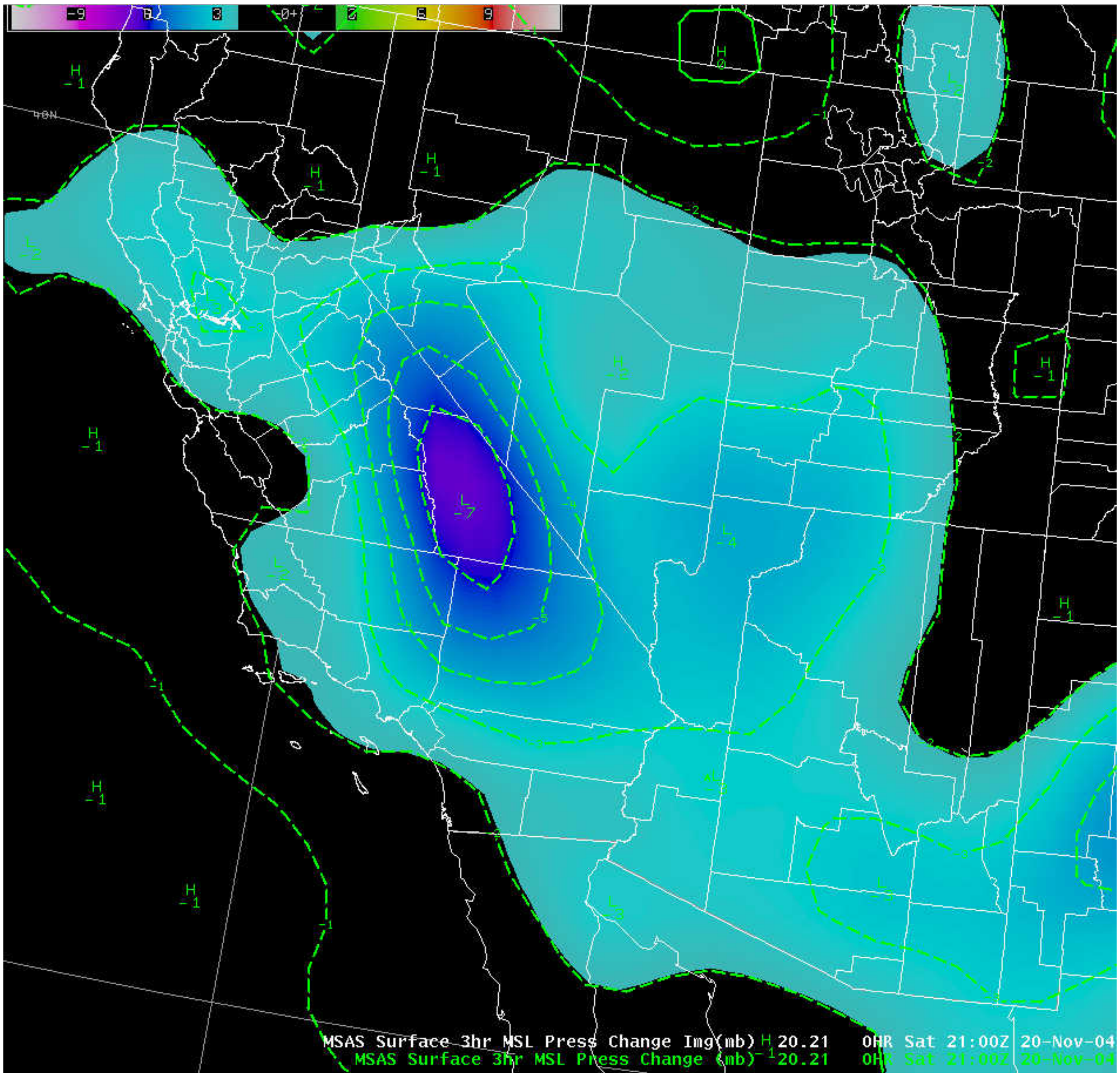

Figure 4. Three-hour MSAS pressure change between 1800 UTC and 2100 UTC November 20.

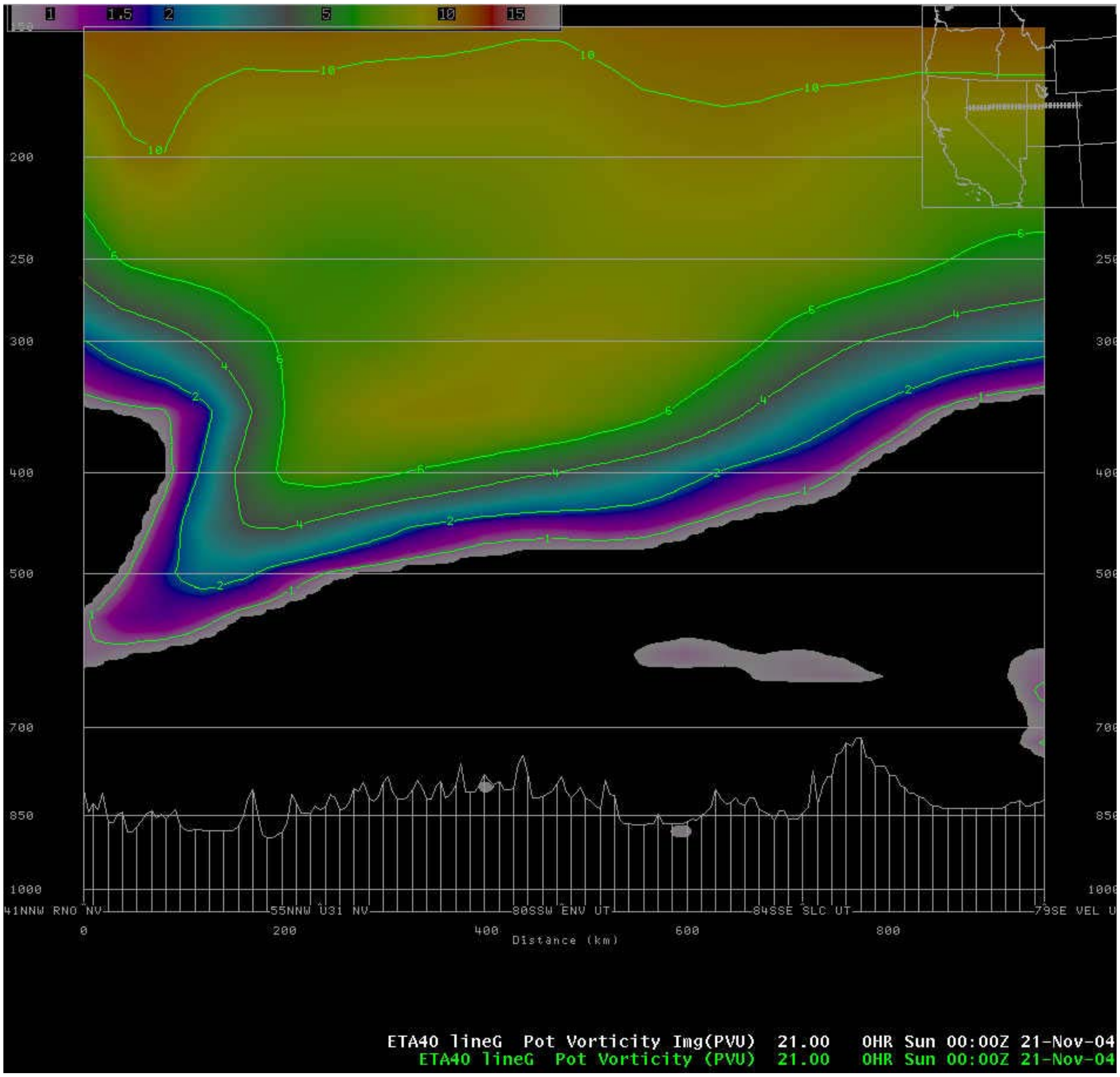

Figure 5. Cross-section of Potential Vorticity from the Eta 0-hour analysis for 0000 UTC November 21, 2004 orientated west to east across the center of the 500-mb cyclone. The cross section stretches from 41 miles north-northwest of KRNO (NV) to79 miles southeast of KVEL (UT).

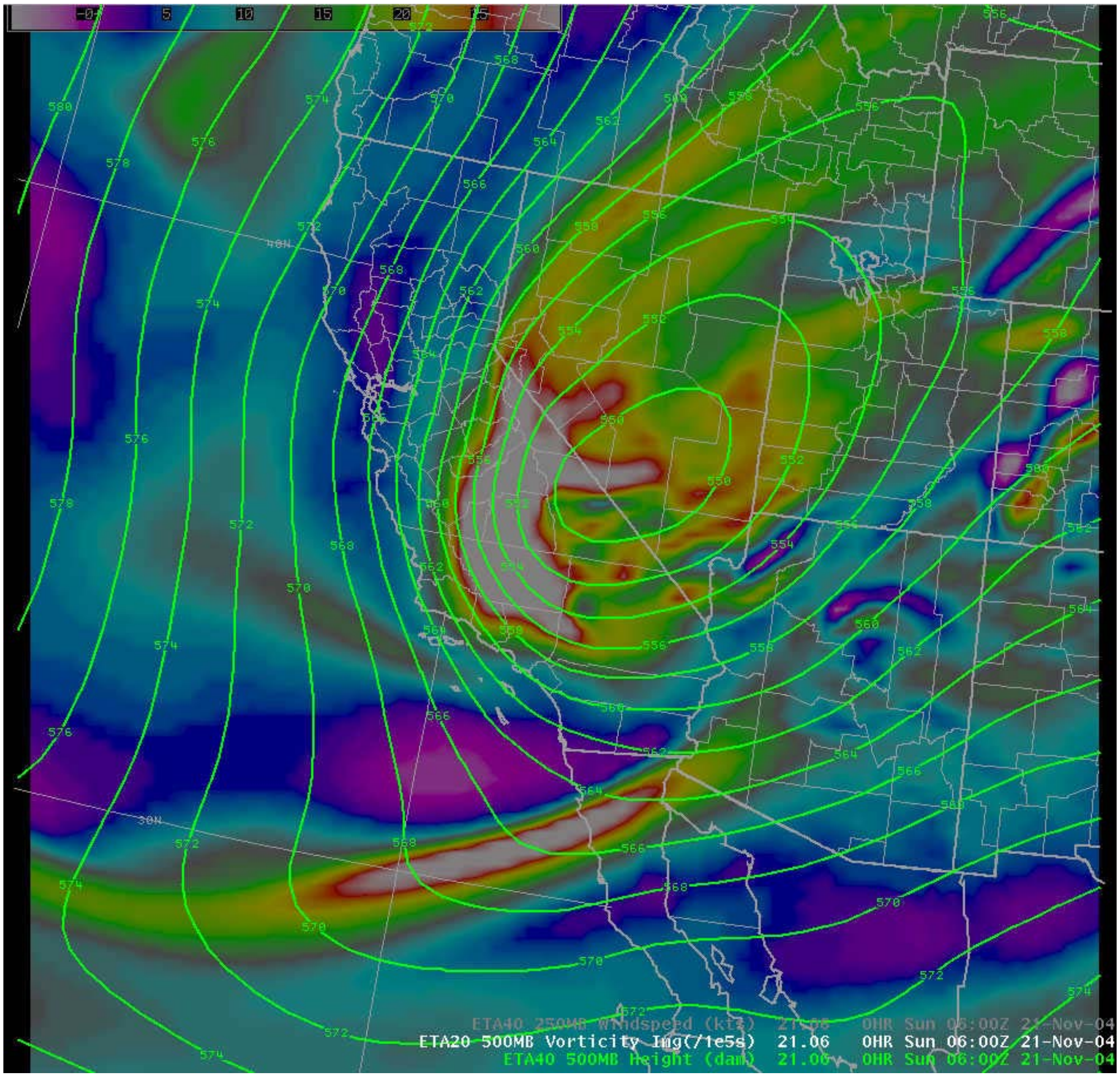

Figure 6. Eta 0-hour analysis of 500-mb Heights (contours) and Vorticity (image). for 0600 UTC November 21, 2004.

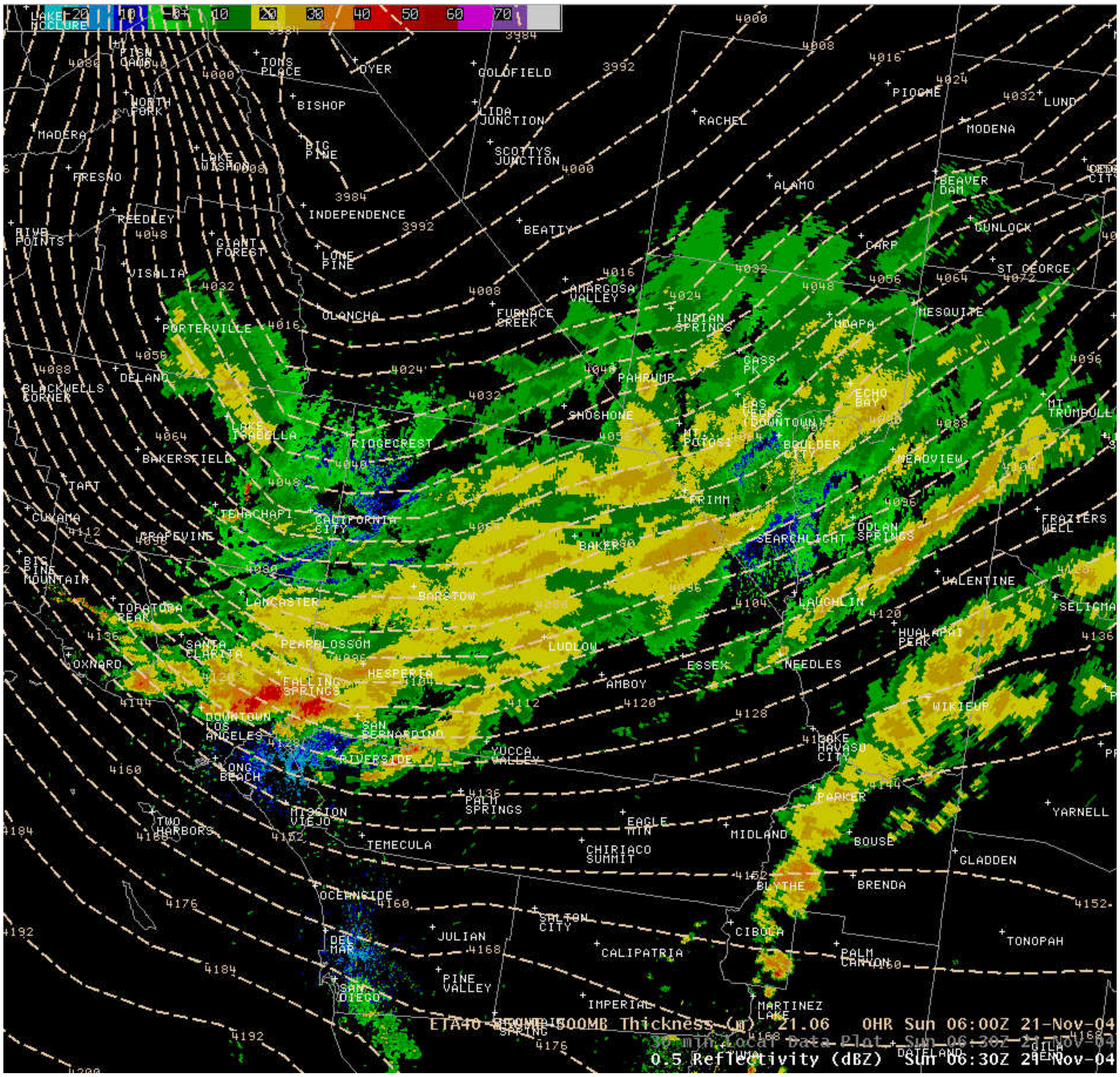

Figure 7. Radar Mosaic (0630 UTC) and Eta 0-hour analysis of 850-500-mb thickness (0600 UTC) for November 21, 2004.

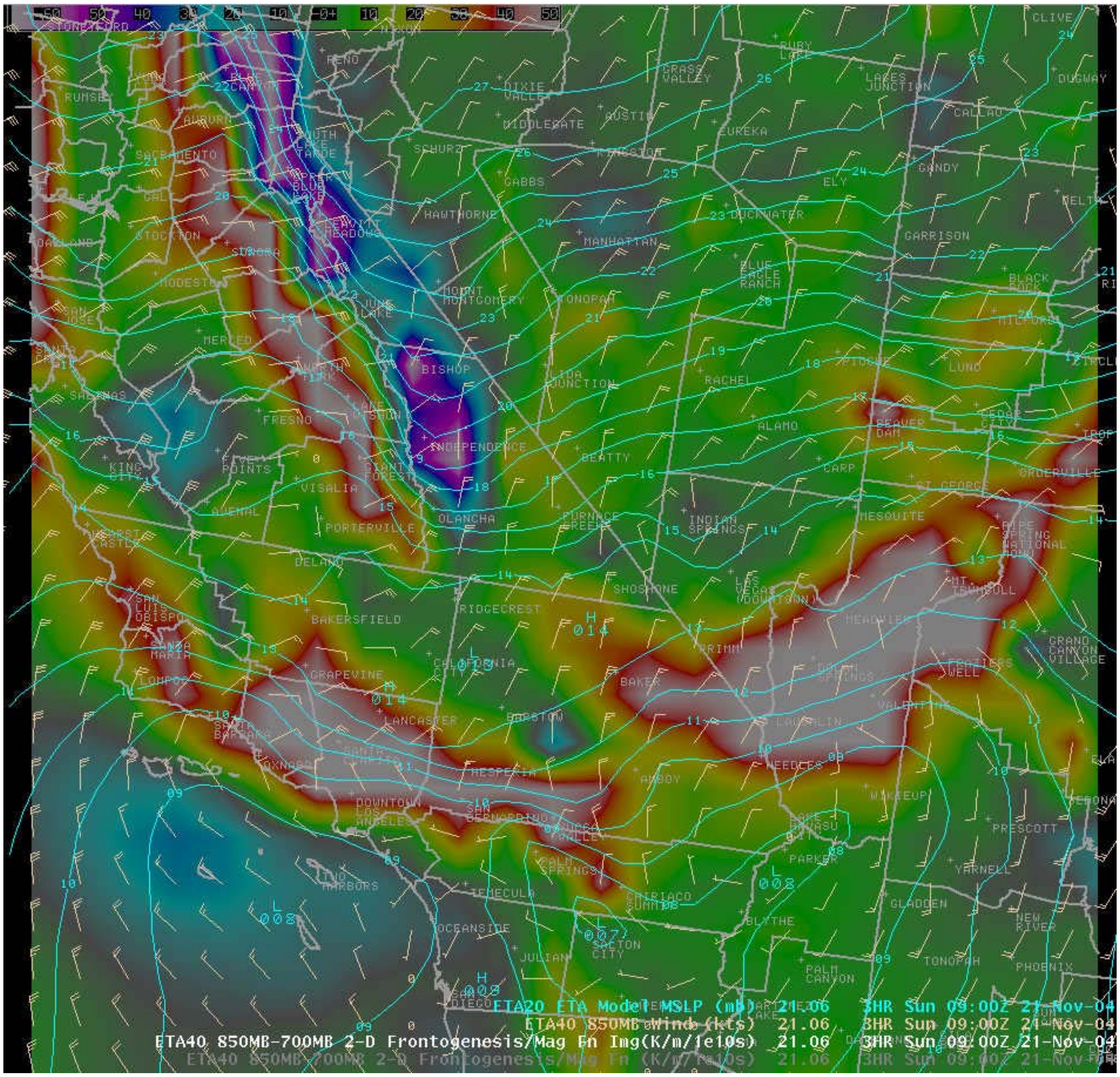

Figure 8. Eta 3-hour forecast for 0900 UTC November 21, 2004. 850-700-mb Petterson 2-D Frontogenesis (image), 850-mb winds, and MSLP.

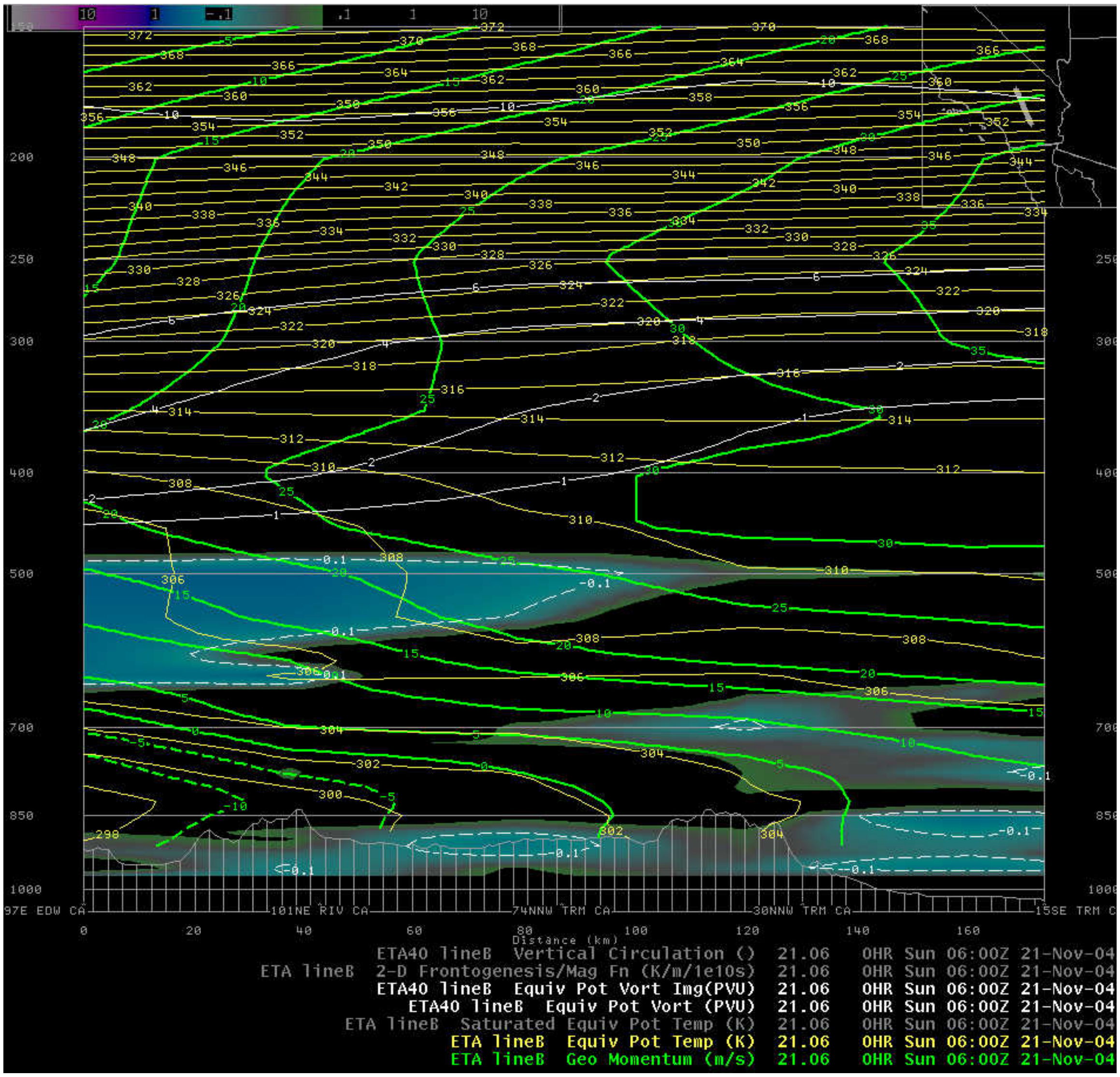

Figure 9. Eta 0-hour forecast for 0600 UTC November 21, 2004. Cross-section of Theta-E (yellow lines), Absolute Geostrophic Momentum (green lines) and Equivalent Potential Vorticity (white lines and image). The cross section was taken normal to the 850-500mb thickness lines and stretches from 97 miles east of KEDW to 15 miles southeast of KTRM.

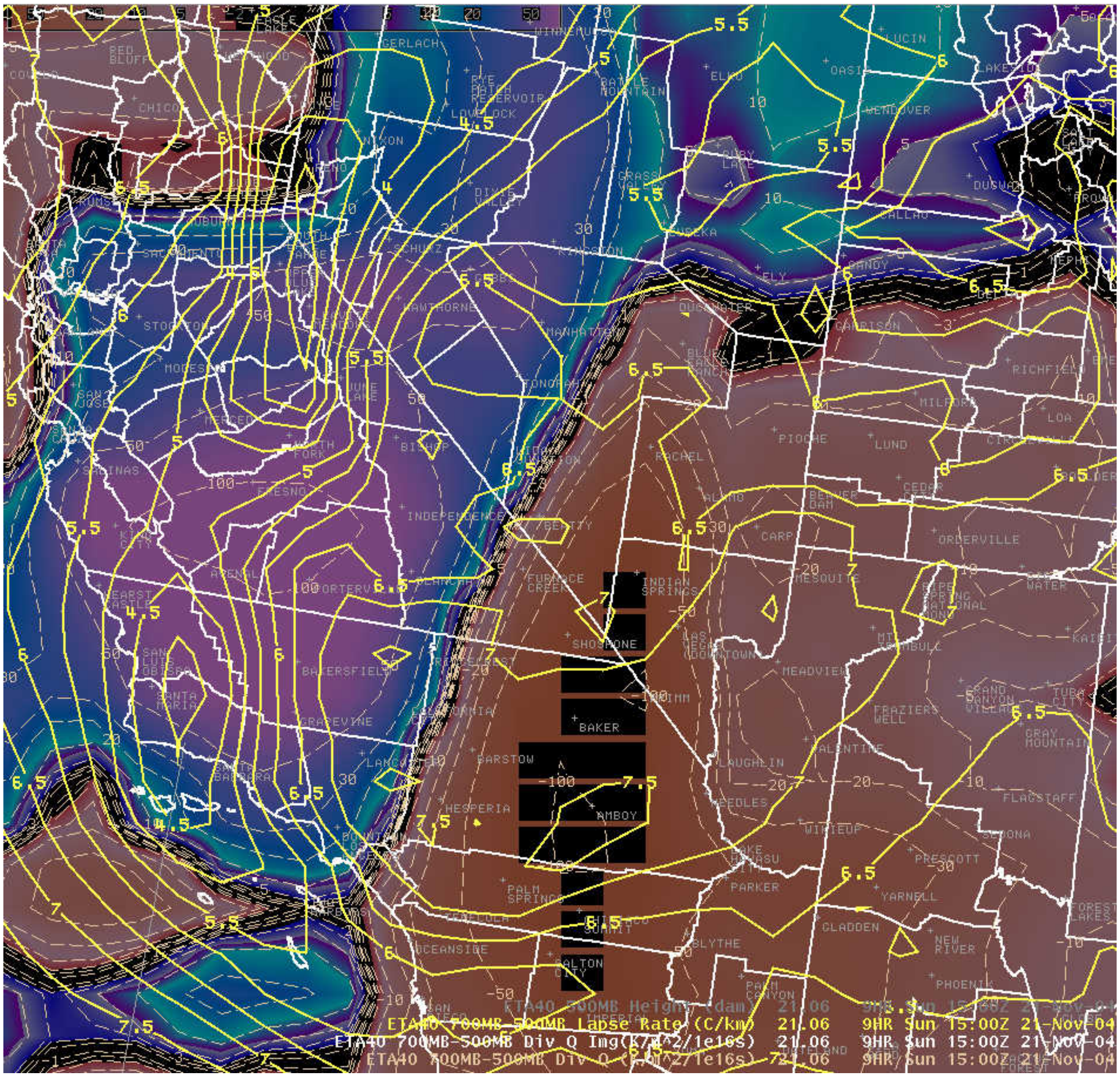

Figure 10. Eta 9-hour forecast for 1500 UTC November 21, 2004. 700-500-mb Q-vector Divergence (shading and dashed tan contours) and 700-500-mb lapse rates (solid yellow contours).

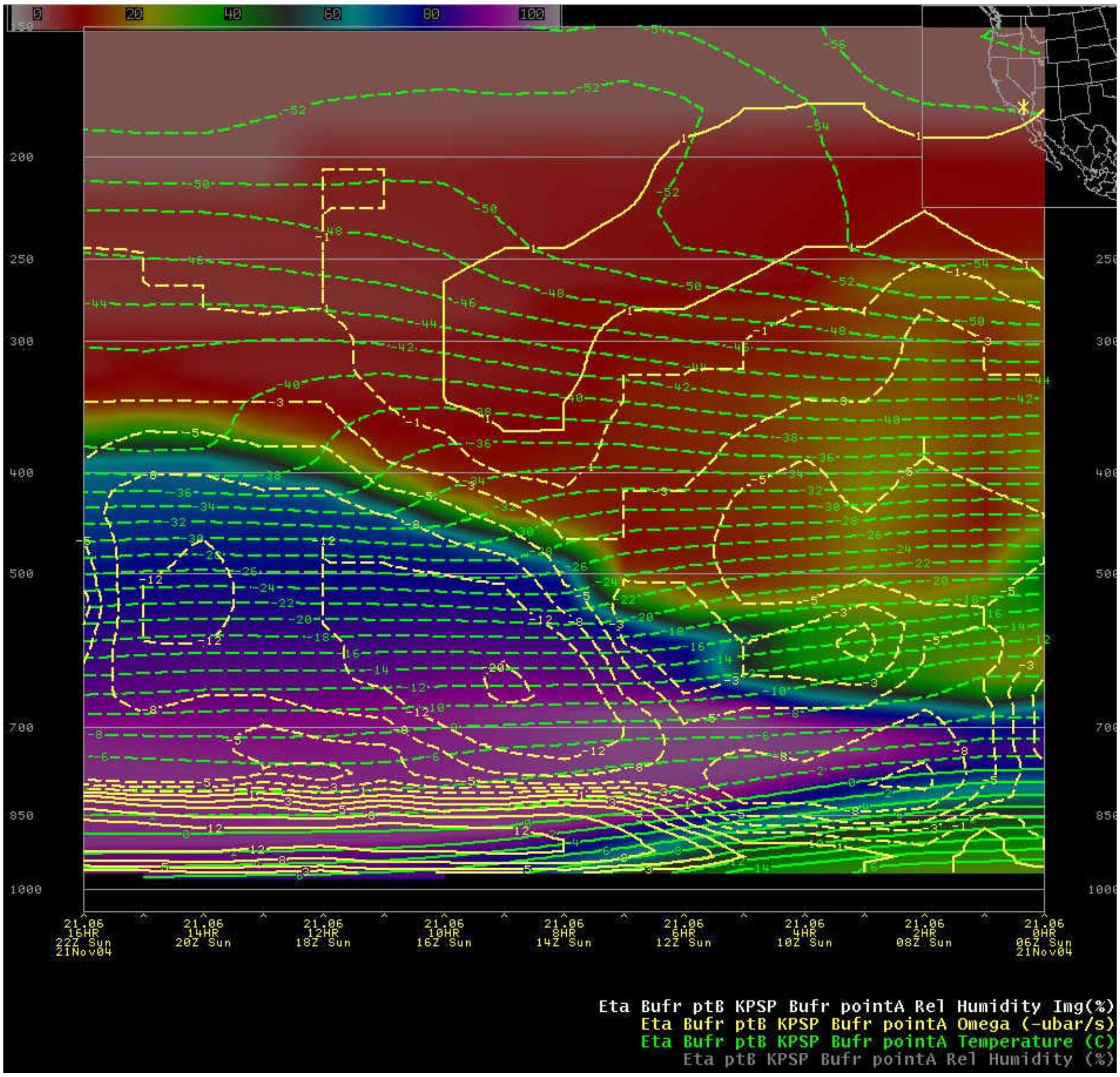

Figure 11. Eta time-height centered over KPSP (19 miles south-southwest of Yucca Valley, CA). Shown are temperatures (green lines), omega (yellow lines), and relative humidity (image).

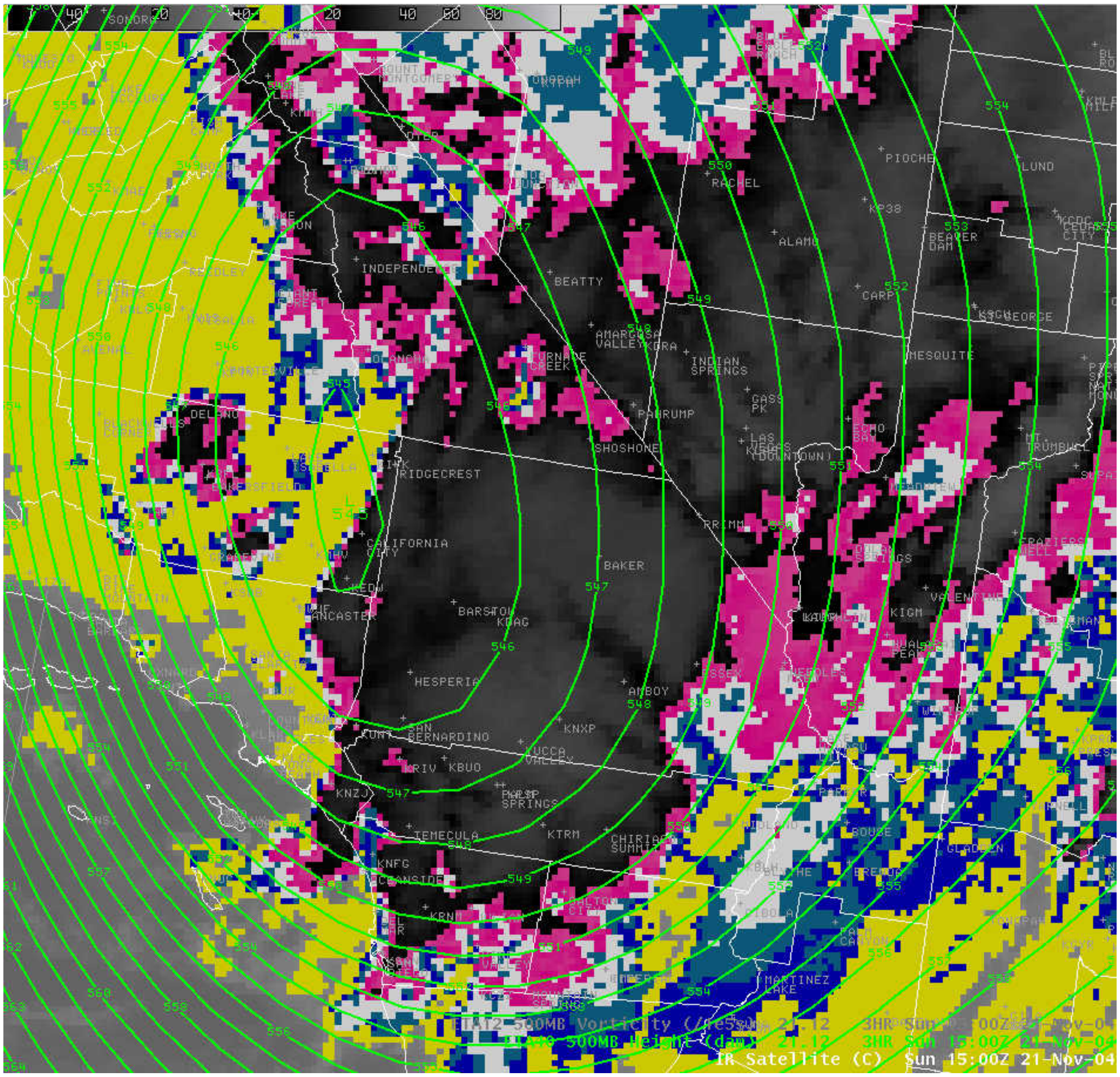

Figure 12. IR Satellite Imagery (1500 UTC) and Eta 3-hour forecast for 500-mb Heights (1500 UTC) for November 21, 2004.