The Unusual Frost Event of Nov 29 to Dec 4, 2004

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Abstract:

During the period from Monday morning, November 29th, through Saturday, December 4th, the Central and Southern San Joaquin Valley experienced a radiational cooling event that threatened the resident citrus industry. While winter freeze concerns are typical, the nature of this freeze event was unusual in its meteorological parameters' behavior and accompanying synoptic meteorological situation. Area forecasters relying heavily upon past freeze event behavior would not expect a lack of moderation in temperatures that occurred during this event. This TA-Lite is written for the purpose of forecaster education by documenting the unusual pattern and its potential for economic damage to area agriculture.

Background:

The Central and Southern San Joaquin Valley is an agricultural cornucopia with approximately 60% of California's gross agricultural product originating in this area, including citrus commodities. Meteorological concerns for agriculture originally focused on the citrus industry after a series of devastating freezes in California in the early 20th Century. Initially growers were concerned only with a freeze threat prior to crop maturing and the harvest time. But cultural practices have changed in the last few decades as growers leave the fruit on the trees for a longer period of time as a means of storage rather than harvesting at fruit maturation. Subsequently the exposure to damage from freezes is now longer. Climate historically shows that periods of low temperatures threatening freeze to area citrus crops occur from mid-November through mid-February with the hardest freezes typically in the mid-December to mid-January time period. While temperatures close to or just below 32 degrees F. are considered good for the development of attractive and quality citrus fruit, temperatures of any significant duration below 28 degrees F. can lead to loss of crop. Growers will use protective measures to mitigate frost threats, i.e., water, wind machine, and/or orchard heater use, to attempt to keep grove temperatures above damaging temperature thresholds. The aforementioned threshold for potential damage is considered to be 27 degrees F. Early in the frost season while fruit is still thickening its skin and the buildup of sugars is underway, the onset of damage may actually be 1 to 2 degrees higher, especially in the mid- to late-November time frame.

Damaging freeze events are typically caused by extensive radiational cooling. Beneath post-frontal high pressure aloft with its cleared skies and light winds, in an air mass that is both cool and having depressed dew points, and during the winter season with its short nights, strong radiational cooling will allow overnight temperatures to drop to potentially damaging thresholds. Of course, the bounded topographic configuration of the San Joaquin Valley does support such conditions for radiational cooling. The Southern Sierra Nevada often protects the area from advection freezes as colder air dams to the northeast over the Great Basin. A typical wintertime, citrus frost event is characterized by a consecutive string of morning sub-freezing temperatures. Due to the prevalent subsidence "capping" temperature inversions associated with high pressure and the

California topography, further cold air advection is short-lived in a post-frontal situation and low-level, cold, dry air mass modification begins quickly. Moisture from the Valley floor raises surface dew points over time. While overnight frost may pose a threat for several post-frontal days with persistent high pressure aloft, the strongest radiational cooling is typically on the second morning after post-frontal cold air advection reached its full potential and surface pressure gradients either weakened or no longer supported any appreciable wind mixing. Subsequent mornings typically see minimum temperatures moderate upward 1 to 2 degree F. per night until the frost threat either disappears or another frontal system mixes cold air away from the Valley floor.

Event Description:

During the week from Monday, November 29th, through Saturday, December 4th, unseasonable and record minimum temperatures occurred in several San Joaquin Valley locations. I interviewed John Fisher, a South San Joaquin Valley citrus grower and ranch manager who oversees a historical citrus monitoring weather station at Jasmin, in regard to this cold event. NWS evaluation and confirmation by Mr. Fisher showed temperatures during this event dropped low enough with durations long enough to cause damage to area citrus if frost protection had not been effective (**see Table 1)**. However, there was still an economic impact as protection measures come with additional costs for running irrigation pumps, wind machines, and orchard heaters.

	Min Temp (Deg.F)	<28 deg.F (Hours)
Mon, Nov 29	**25**	**6**
Tue, Nov 30	**25**	**8**
Wed, Dec 1	**26**	**9**
Thu, Dec 2	**25**	**7**
Fri, Dec 3	**26**	**6**
Sat, Dec 4	**25**	**8**

Table 1. Jasmin Minimum Temperatures and Durations; Mon, Nov 29th – Sat, Dec 4th

This cold episode was atypical or unusual in its lack of moderating surface afternoon temperatures and subsequent persistent minimum temperature readings during the referenced time period. Also, the synoptic pattern that supported this string of unseasonably low minimum temperatures was unusual with low pressure aloft in proximity during the latter part of the event time period rather than broad, persistent high pressure. While temperatures did drop typically in the post-frontal air mass on Monday the 29th and Tuesday the 30th, minimum temperatures during the week remained relatively consistent and arguably the coldest morning of the week occurred on the last morning, Saturday, December 4th (**See Table 2**).

Minimum Temperature (Deg F.)							
	Normal Fresno Tx/Tn 57/38	Mon Nov 29	Tue Nov 30	Wed Dec 01	Thu Dec 02	Fri Dec 03	Sat Dec 04
	Merced	**26**	**26**	**27**	**27**	**26**	**25**
Station	**Fresno**	**31**	**30**	**31**	**31**	**30**	**29**
	Hanford	**26**	**24**	**23**	**23**	**24**	**21**
	Bakersfield	**30**	**29**	**27**	**28**	**28**	**28**

Table 2. Central and South San Joaquin Valley Minimum Temperatures; Monday, Nov 29th – Saturday, December 4th

Following a frontal passage through Central California on Sunday the 28th, northwest wind flow aloft over the West Coast of the United States advected post-frontal cold air into the San Joaquin Valley (**see Figure 1**). Representative temperatures at 500mb were observed from the Oakland raob to be around -20 degrees Celsius

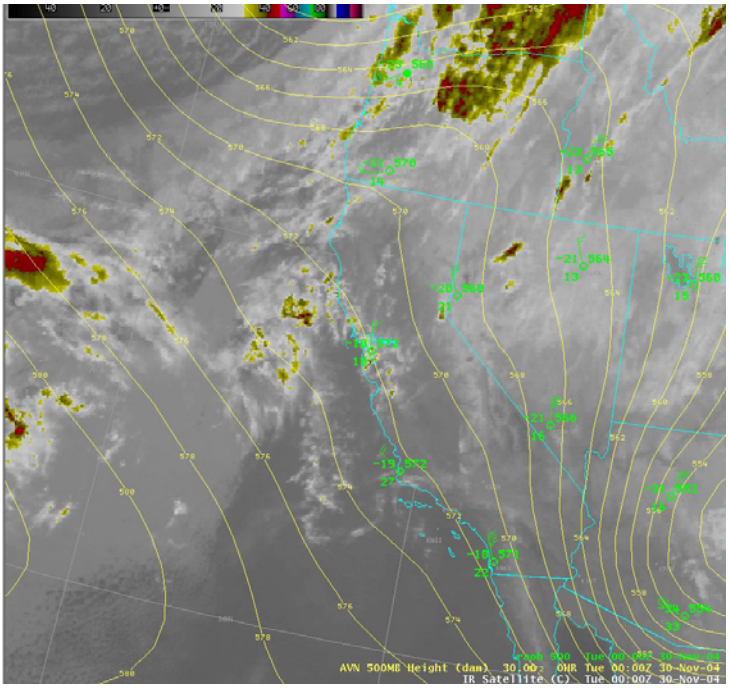


Figure 1. 500mb/IR Satellite – Monday, Nov 29; 1600 PST

With post-frontal, short-wave ridging aloft and subsequent strong radiational cooling, freezing temperatures occurred in the Valley on the morning of Monday, November 29th. Characteristic of a prevalent synoptic pattern this Fall of 2004, a blocking ridge along the Pacific Northwest Coast developed with a closed, cut-off 500mb low near Central California already in place by the morning of Thursday, December 2nd (**Figure 2),** then drifting southwest and offshore by the 4th **(Figure 3**).

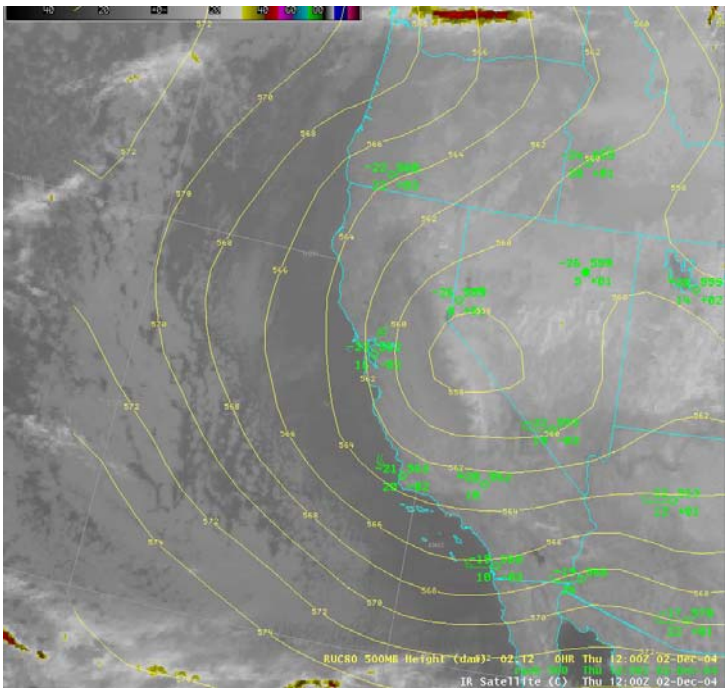


Figure 2. 500mb/IR Satellite – Thursday, Dec 2; 0400 PST

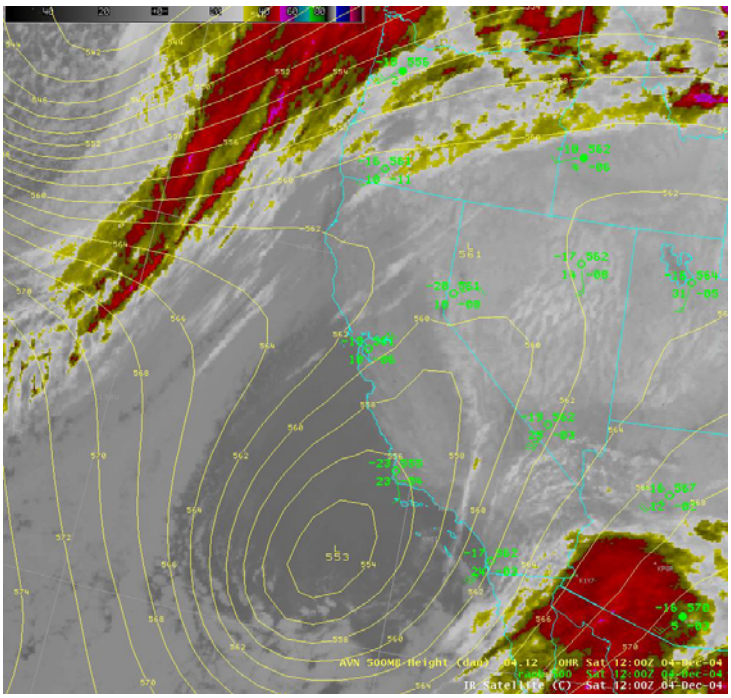


Figure 3. 500mb/IR Satellite – Saturday, Dec 4; 0400 PST

As central California remained under clear skies, subsequent overnight radiational cooling was strong which lead to the persistent freeze for the week**.** Also observed at selected stations were afternoon temperatures that **did not** moderate upward despite an apparent moderation in the lower air mass afternoon dew points (discussed later). Diurnal dew point ranges usually remain consistent during a typical winter freeze period for the San Joaquin Valley. During this event, however, maximum diurnal dew point ranges occurred during the latter part of the period (**Table 3**).

	Merced	Fresno	Hanford	Porterville	Bakersfield
Mon, Nov 29, 1600 PST	**51/35**	**54/25**	**53/25**	**52/28**	**54/23**
Wed, Dec 1, 1600 PST	**52/33**	**51/33**	**52/31**	**50/30**	**51/27**
Fri, Dec 3, 1600 PST	**52/32**	**53/35**	**53/34**	**52/34**	**54/33**

Table 3: Afternoon Temperature(deg.F)/Dew Point(deg.F) for Valley Stations

The surface pattern exhibited strong high pressure nosing into the Pacific Northwest and extended southeast over the intermountain region. In addition, an inverted surface trough was located just off the west coast. Surface wind during the period displayed no obvious cold air advection into the Valley air basin as winds remained generally variable in direction and at or below 5 knots in speed for the entire time period.

Surface pressure gradients over Interior Central California remained consistent and moderately offshore during the freeze event (**Figures 4, 6, and 8**). While surface winds were not strong for the San Joaquin Valley due to terrain blocking, neighboring coastal areas and passes to the west and south experienced classic offshore wind conditions and accompanying mild temperatures. **Table 4** depicts offshore pressure gradients during the morning hours of the event.

	Mon, Nov 29th 0400 PST	Thu, Dec 2nd 0400 PST	Sat, Dec 4th 0400 PST
Reno-Sacramento	**6.2**	**6.6**	**3.9**
Tonopah-Fresno	**3.4**	**3.7**	**2.7**
Tonopah-LosAngeles	**7.3**	**7.6**	**4.8**

Table 4: Pressure Gradients (millibars)

Weak, closed low pressure aloft was the dominant upper air weather feature in proximity to the Valley late in the event rather than the typical high pressure aloft. The cutoff nature of the low and its location over central California and offshore waters provided only minimal vertical motion such that little cloudiness developed over the agricultural areas depicted by the IR satellite imagery (**Figures 1, 2, and 3**).

Of interest are the 850 mb omega fields depicted in the following set of figures. At the beginning of the freeze episode a widespread downward motion reflected by the omega field (**Figure 5**) covered the state with one maxima (10 ubars/sec) near the Monterey Bay

Area. This vertical motion pattern persisted through the middle of the week even with the development of the weak upper low (**Figure 7**). By Saturday, December 4, the omega field (–6 ubars/sec) changed to reflect upward vertical motion at 850 mb off the central coast in response to low level convergence under the upper low. Downward motion was still occurring over the San Joaquin Valley and Sierra Nevada Foothills (**Figure 9**), though, indicating a subsidence process was still present there.

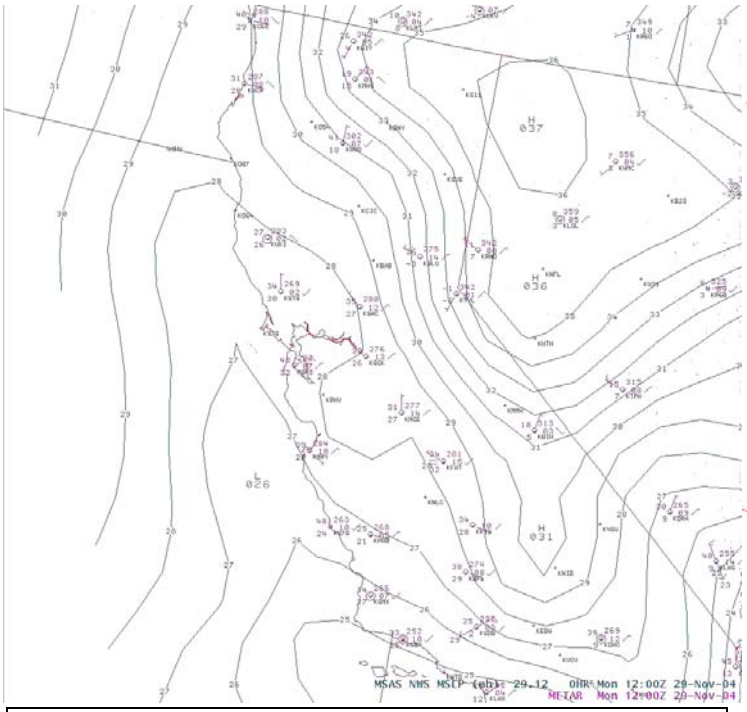


Figure 4. Surface Analysis – Mon, Nov 29; 0400 PST

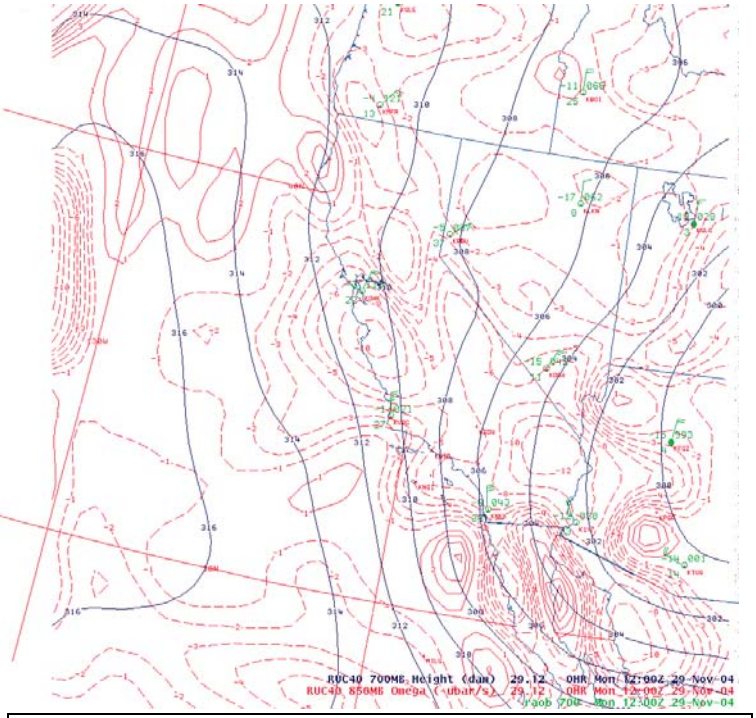


Figure 5. 700mb Plot/850mb Omega – Mon, Nov 29; 0400 PST

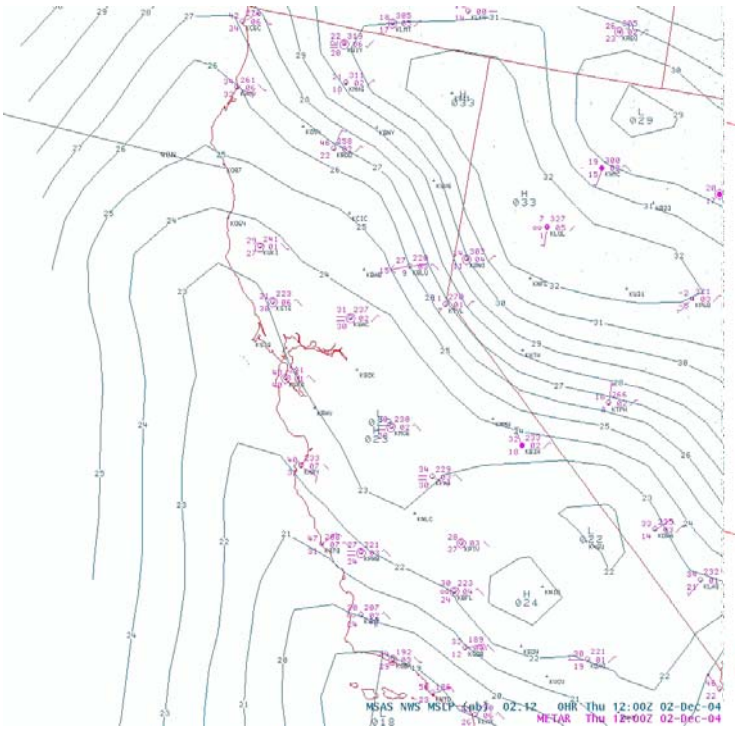


Figure 6. Surface Analysis – Thu, Dec 2; 0400 PST

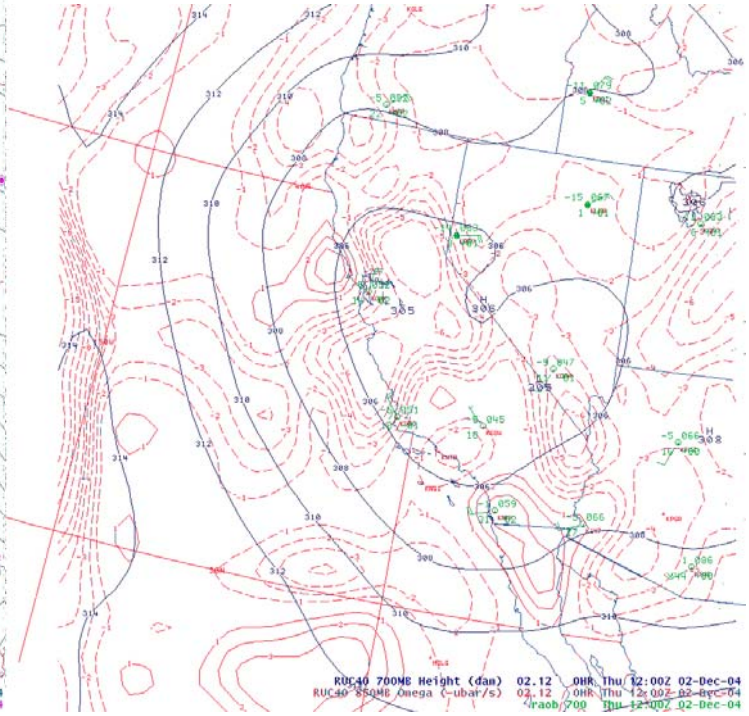


Figure 7. 700mb Plot/850mb Omega – Thu, Dec 2; 0400 PST

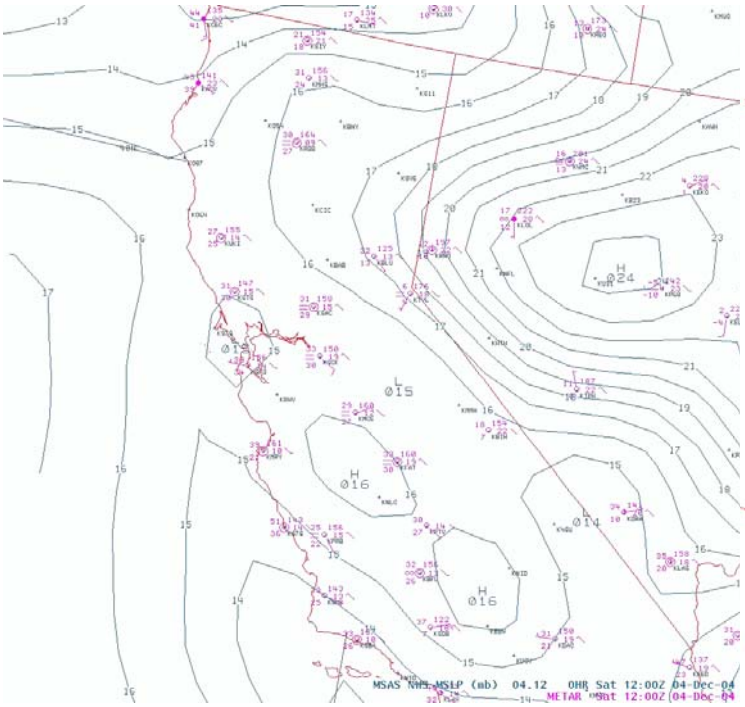


Figure 8. Surface Analysis – Sat, Dec 4; 0400 PST

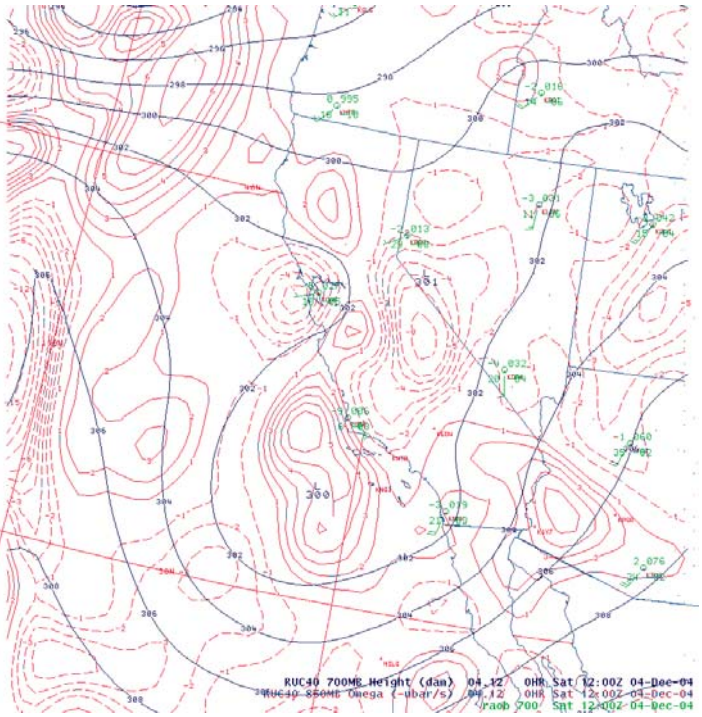


Figure 9. 700mb Plot/850mb Omega – Sat, Dec 4; 0400 PST

In the following series of upper air soundings (**Figures 10, 11 and 12**) taken at Reno(blue) and Oakland(purple), note the establishment of a deep layered cold air pool over the Great Basin by Dec 2 as depicted by the Reno raob. By the end of the period, subsidence warming aloft lowered the associated inversion to near the surface resulting in a dramatic reduction in the depth of the cold air pool over Nevada.

Subsidence warming also took place over Central California during the week. The Oakland raob indicated 2 degrees C at 900 mb on November 29 at 12Z, and subsequent low level warming resulted in a reading of 8 degrees C by the 4th of December.

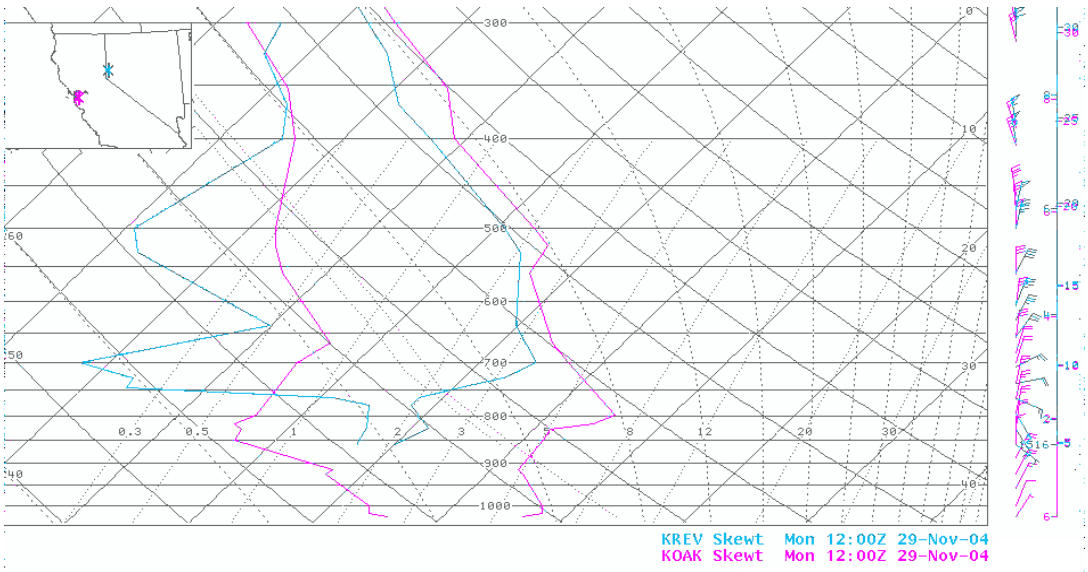


Figure 10. Raob: Oakland/Reno – Monday, Nov 29; 0400 PST

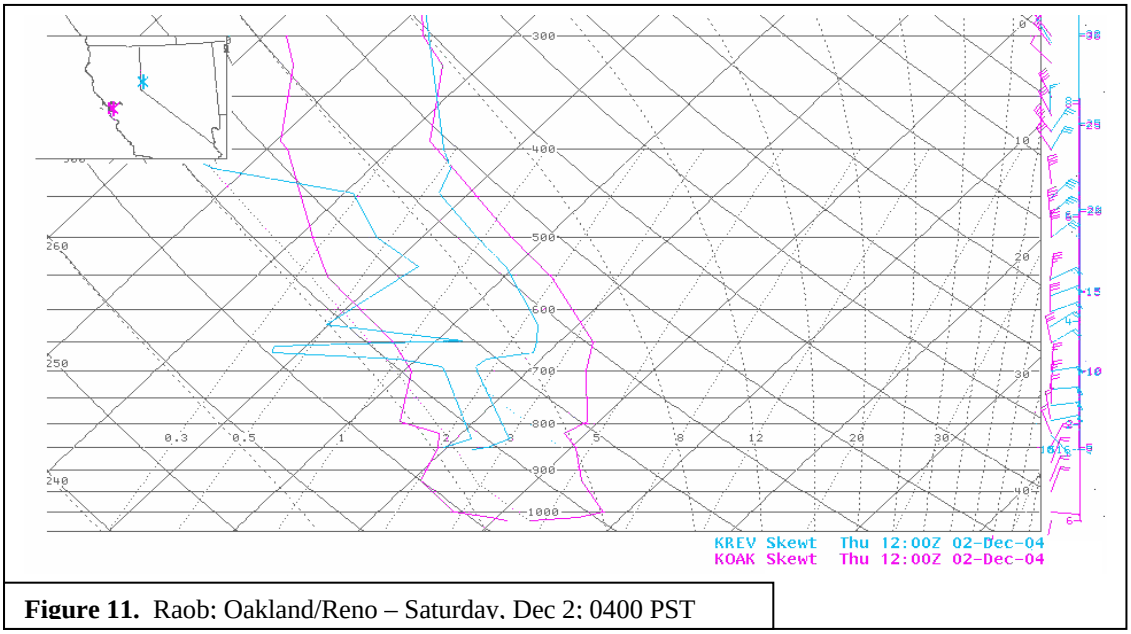


Figure 11. Raob: Oakland/Reno – Saturday, Dec 2: 0400 PST

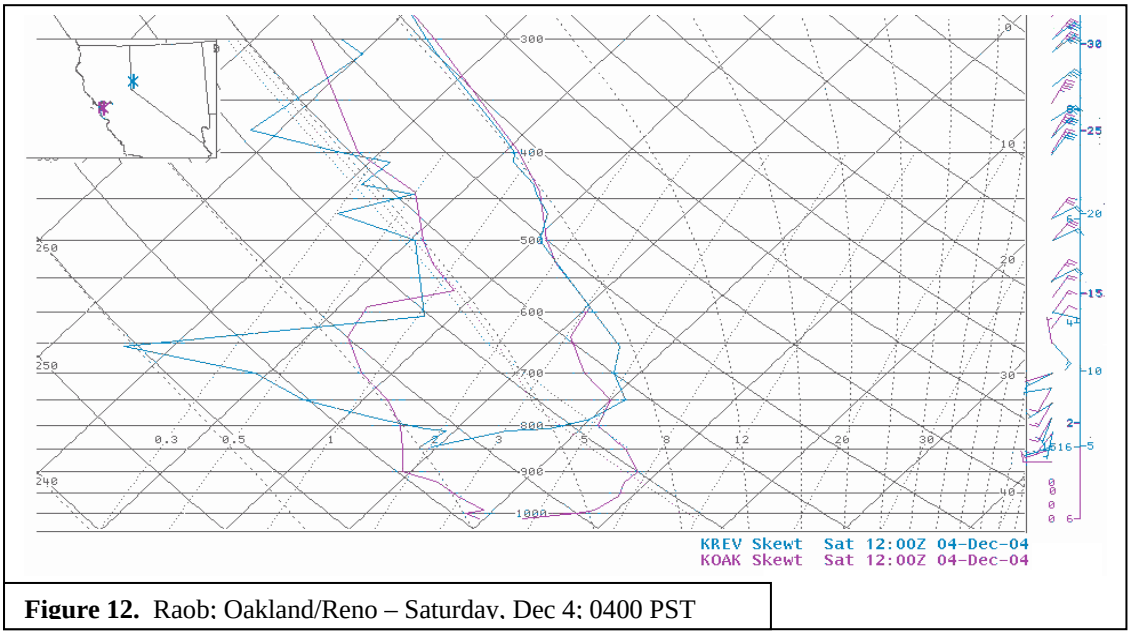
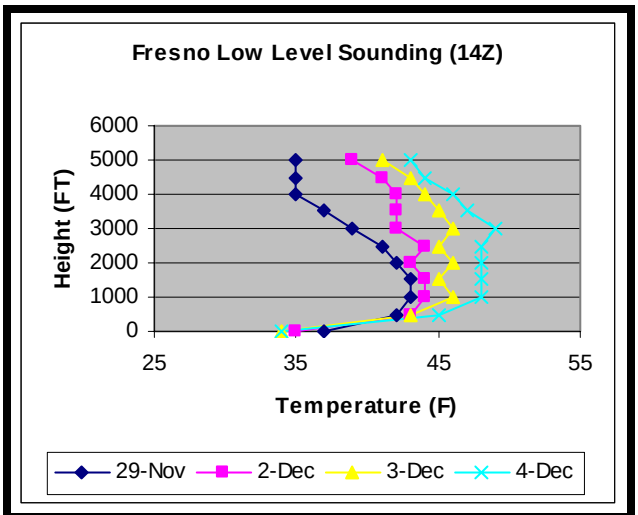


Figure 12. Raob: Oakland/Reno – Saturday, Dec 4: 0400 PST

As low-level warming occurred at the synoptic scale, the air aloft over the San Joaquin Valley also moderated. Based on Fresno Low-Level Temperature Soundings (**Plot 1**), a significant warm-up of 11 degrees F. took place at 4,000 feet AGL while at 1,000 feet an increase of 6 degrees F. occurred through the event period. But the shallow cold air pool on the Valley Floor essentially remained unchanged as reflected by afternoon maximum or morning minimum temperatures (**Tables 2 and 3 above**).



Plot 1: Fresno Low Level Temperature Sounding

As reported by John Fisher, a nocturnal, surface-based temperature inversion was persistently present over citrus grove canopies and wind machines were extremely effective (**Plot 1**). Grove air temperatures were consistently raised 3-4 degrees F. upon startup of wind machines.

Summary and Conclusions:

This cold episode was definitely unique in its behavior from a more "typical" citrus frost event, i.e., progressively moderating. Admittedly my assessment of the cause of this unusual event is subjective but with years of forecast experience in this agricultural area, I do not recall many freeze events with the following characteristics:

This freeze threat began typical in behavior during the first two nights (Monday morning the 29th and Tuesday morning the 30th) with the colder morning arguably Tuesday. But the evolving synoptic pattern provided for the unusual circumstance of a freeze threat in the proximity of an upper low. Contrary to the typical "flat gradient" beneath broad high pressure, the development of the dry, low pressure system aloft was a major factor that maintained the surface trough near the west coast. The associated convergence near the central coast helped to keep offshore pressure gradients intact over the San Joaquin Valley and high pressure over the Great Basin combined to continue the subsidence over the Southern Sierra Nevada foothills. This pattern helped to reinforce the normal nighttime downslope drainage winds with the associated drying effects that accompany such winds. It appears likely that entrainment of this drier air into the San Joaquin Valley allowed overnight dew points in the San Joaquin Valley to consistently slide downward. The resulting overnight dew point "slides" therefore resulted in persistent surface temperature falls back to the mid-20s even though the above-surface environment moderated during the period.

The time of year, with its minimum incoming solar energy, and a lack of strong surface winds provided little daytime mixing of warmer air aloft onto the cold pool of air residing at the surface of the valley. Therefore, the duration of the prevailing offshore flow and associated dry air was maintained by the presence of the upper cut-off low. This, in turn, resulted in a period of prolonged overnight freezing temperatures.