A WINTER TIME ANALYSIS OF THE MARINE BOUNDARY LAYER INVERSION OFF OF THE CALIFORNIA COAST

LCDR Steven Mancini

19 Mar 2004

OC3570 Cruise Project

1. Introduction

Off the California coast, the marine boundary layer is often capped by an inversion at its upper boundary. This inversion, characterized by increasing temperature and rapidly decreasing moisture with height, is formed by a combination of subsidence, or sinking of air, produced by the Eastern Pacific High (EPH) and cooling from below by the cold Pacific waters in this region. Its strength and altitude is influenced by many factors, including synoptic scale pattern changes and coastal effects, such as sea breezes and coastal jets.

In the summer time, the EPH is stronger and positioned further north, which increases the subsidence and, thus, the adiabatic warming aloft in the region. A strong northwesterly wind results from this change in the synoptic pattern, which causes Ekman transport of the upper water layer offshore. This results in upwelling of deeper, cooler water to replace the surface water. The combination of the increased subsidence and upwelling along the coast creates an inversion that is generally much stronger in the summer time. This strong inversion traps the cool, moist air close to the surface, which is the reason why much of the California coastline is blanketed by a thick stratus layer for many hours each day in the summer.

For reasons opposite those mentioned for the summer case, the inversion is much weaker in the winter months. Subsidence is not as strong since the EPH is further south, and the air-sea temperature difference is much less since the air is cooler and there is a lack of upwelling. Also, the synoptic pattern is more variable as mid-latitude cyclones transit close by in winter. The inversion is, therefore, a much different phenomenon to study in the winter season.

2. Measurements

Measurements for this analysis were made during both legs of the OC3570 2004 winter cruise on board the R/V Point Sur. The first leg occurred on Jan 27th to the 30th and the second occurred on Jan 30th to Feb 3rd. Data was also collected by a CIRPAS Twin Otter aircraft on Jan 27th and Feb 2nd and 4th. The cruise data consisted of time and position information collected from GPS receivers, rawinsonde soundings, and meteorological conditions recorded on the underway data acquisition system (UDAS) as the ship transited in the Monterey Bay and along the California coast. The aircraft data included time, position, altitude, flight level air and dewpoint temperatures, and pressure. Also used in this study were NOGAPS analysis fields, satellite images, hourly station observations, upper air soundings from Vandenberg and Oakland, and Fort Ord wind profiler diagrams, all collected via the Naval Postgraduate School (NPS) Meteorology Department.

3. Data Processing

The rawinsonde printouts generated on the ship during the soundings were used for the initial analysis. For a more in depth look, the rawinsonde, UDAS, and aircraft data were processed and viewed graphically using MATLAB code. Many of the included figures are a result of this processing. The NOGAPS fields, observations, and satellite images were viewed and analyzed using GARP software in the Meteorology Department’s computer laboratory. The NPS Meteorology website was used to find and view the Vandenberg and Oakland soundings in skew-t format. Fort Ord profiler data was displayed in height versus time charts for each day.

4. Synopsis

During the first three days of the first leg of the cruise, a subsidence inversion formed then strengthened and lowered. On Jan 30th, the inversion disappeared and was not present for the next two days. By Feb 1st, the inversion began to recover for a brief period, but did not reestablish itself in earnest until Feb 4th.

5. Discussion

The synoptic pattern at 1200 UTC on Jan 27th showed the 1027 mb EPH centered to the west of San Diego. A weak 1012 mb shortwave trough was approaching the northern California coast. (See slide 6 of accompanying power point presentation.) A subsidence inversion was just beginning to form at about 1,400 m as shown by rawinsonde 2 (Fig. 1), launched at 2250 UTC just west of Monterey Bay.

By 0000 UTC on the 28th, the high had built to 1030 mb and moved north, centering itself west of San Francisco, and the trough was at the coastline. The trough moved inland by the 1200 UTC Oakland sounding, a portion of which is shown in Fig. 2. It showed a double inversion, each about 3 °C, with bases near 3,000 ft and 6,000 ft. Rawinsonde 4 (Fig. 3), launched about 100 nm west of Point

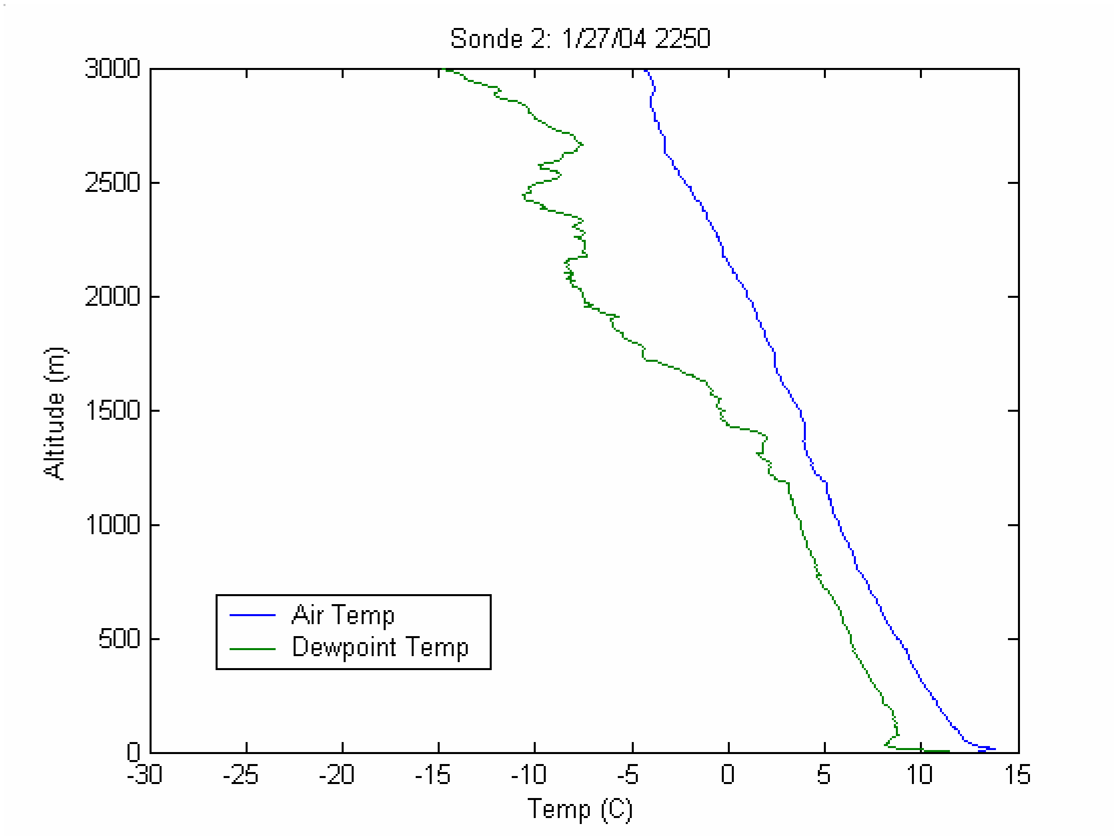

Figure 1: Rawinsonde 2

Sur at 1734 UTC, showed a very similar situation with inversions of about 2 and 1 °C, near 1,000 m and 1,700 m, respectively.

The inversion reached its strongest on the 29th and 30th after being squashed down by the EPH for the previous few days. Rawinsonde 7 (Fig. 4), launched about 100 nm west of Point Conception, shows the inversion at its peak of about 6 °C. Both the Vandenberg and Oakland soundings at 0000 UTC on the 30th also showed this peak. Later on the 30th, another shortwave trough approached, creating enough

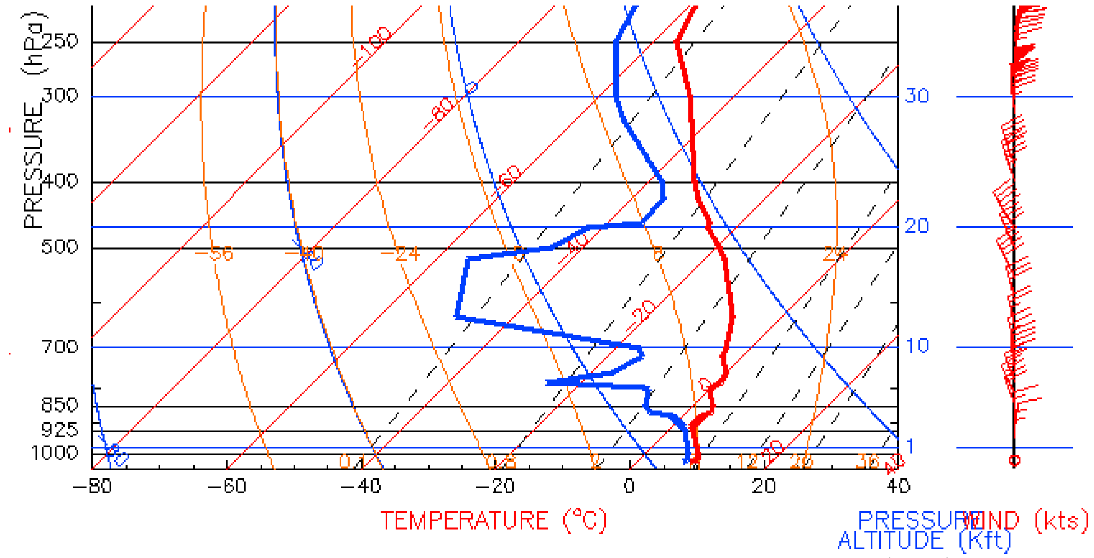

Figure 2: Sounding for Oakland 1200 UTC 1/28/2004

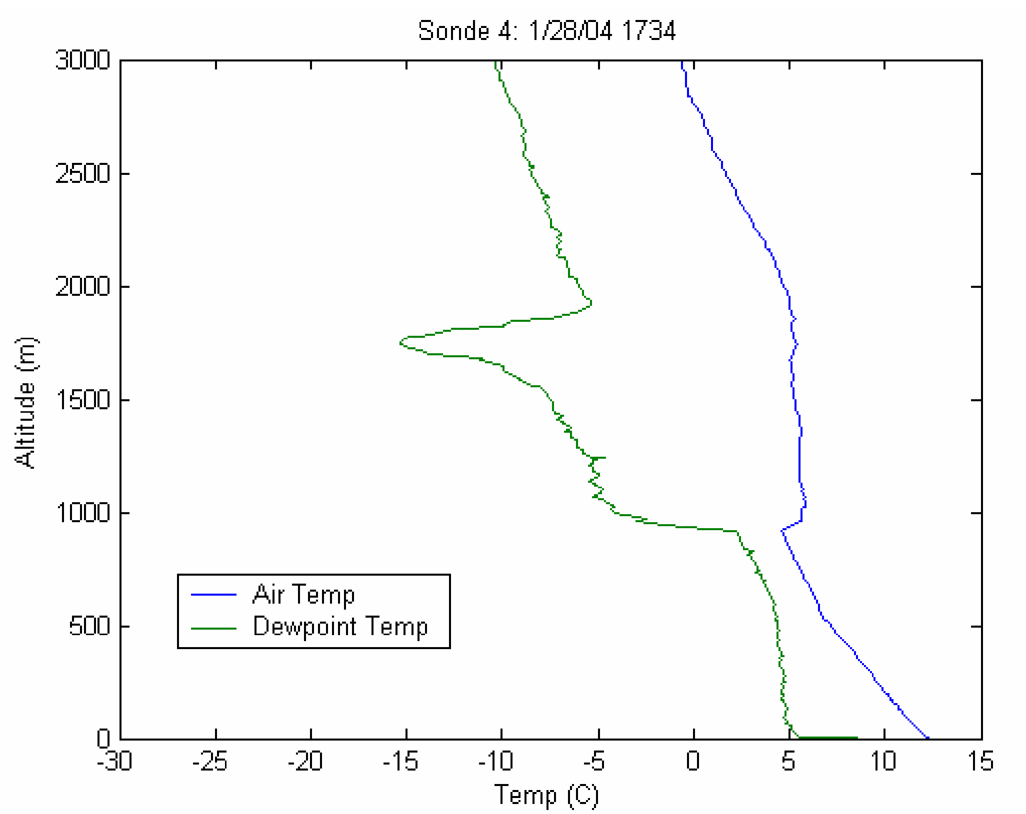

Figure 3: Rawinsonde 4

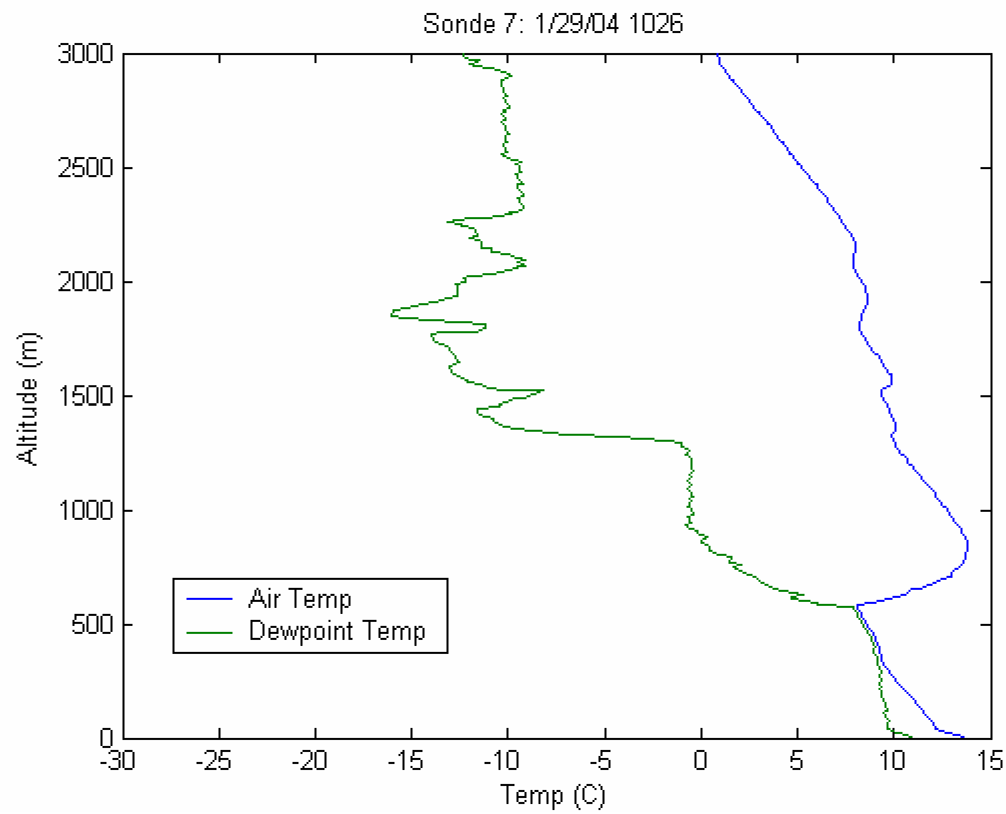

Figure 4: Rawinsonde 7

positive vorticity to mix up the air column and eliminate the inversion until Feb 1st, when ridging of the EPH over California began to form a subsidence inversion once again.

Rawinsonde 17 (Fig. 5), launched just west of the Monterey Peninsula at 0227 UTC on the 1st, shows the weak inversion reforming at about 700 m. This time the inversion was short lived due to instability associated with a mid-latitude cyclone. By 1200 UTC, the NOGAPS surface analysis indicated the cyclone's warm front was just off the California coast, based on the locations of the packing of thickness isopleths and isotherms, the

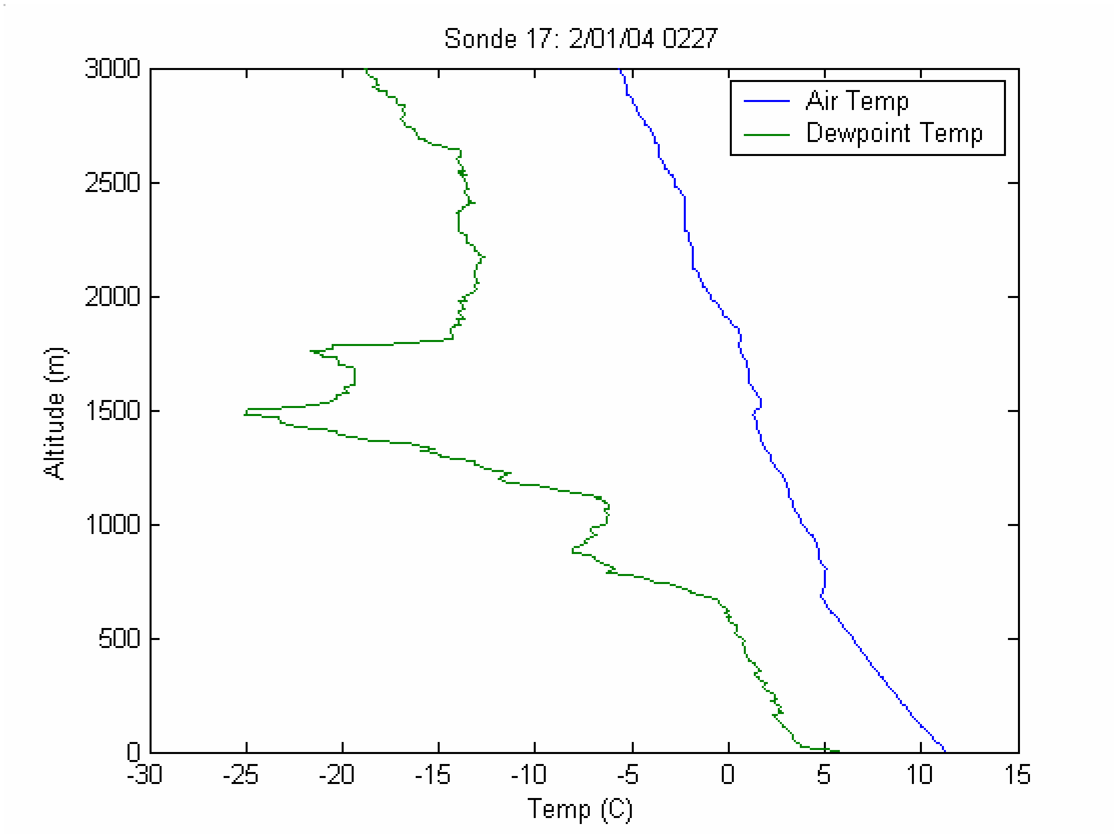

Figure 5: Rawinsonde 17

frontal pressure trough, and the surface wind shift. (See slide 10 of the power point presentation.)

The frontal inversion, typically characterized by increasing temperature and dewpoint temperature with height, is apparent on the 1200 UTC Oakland sounding (Fig. 6) just above 10,000 ft. Its progression toward the surface can be seen when this sounding is compared to rawinsonde 18 (Fig. 7), launched four hours later, showing the inversion near 1,700 m. The veering winds aloft across the front from southeasterly to westerly are seen in the Oakland sounding, rawinsondes 18 and 20 (not shown), and the Fort Ord

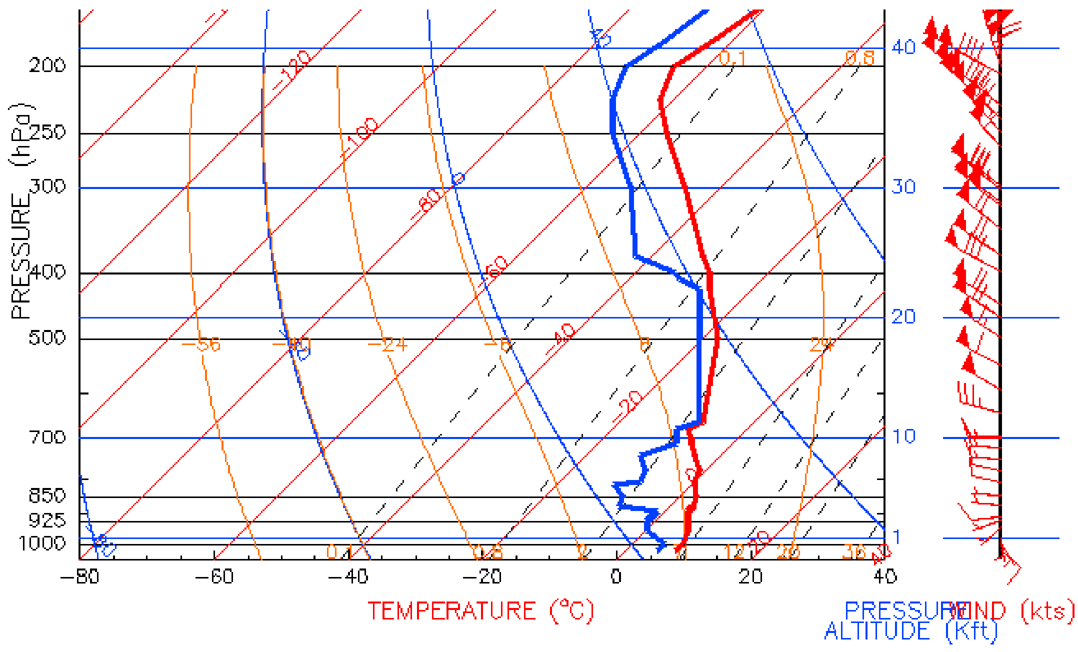

Figure 6: Sounding for Oakland 1200 UTC 2/1/2004

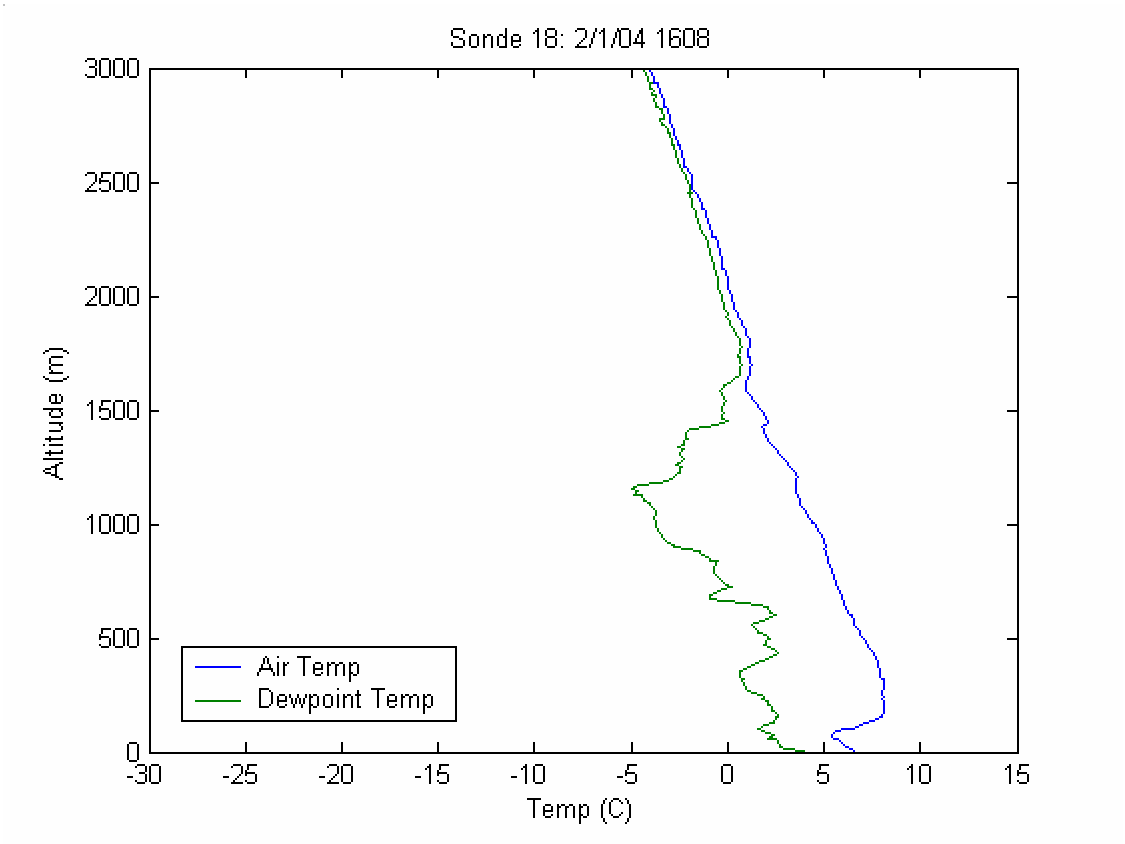

Figure 7: Rawinsonde 18

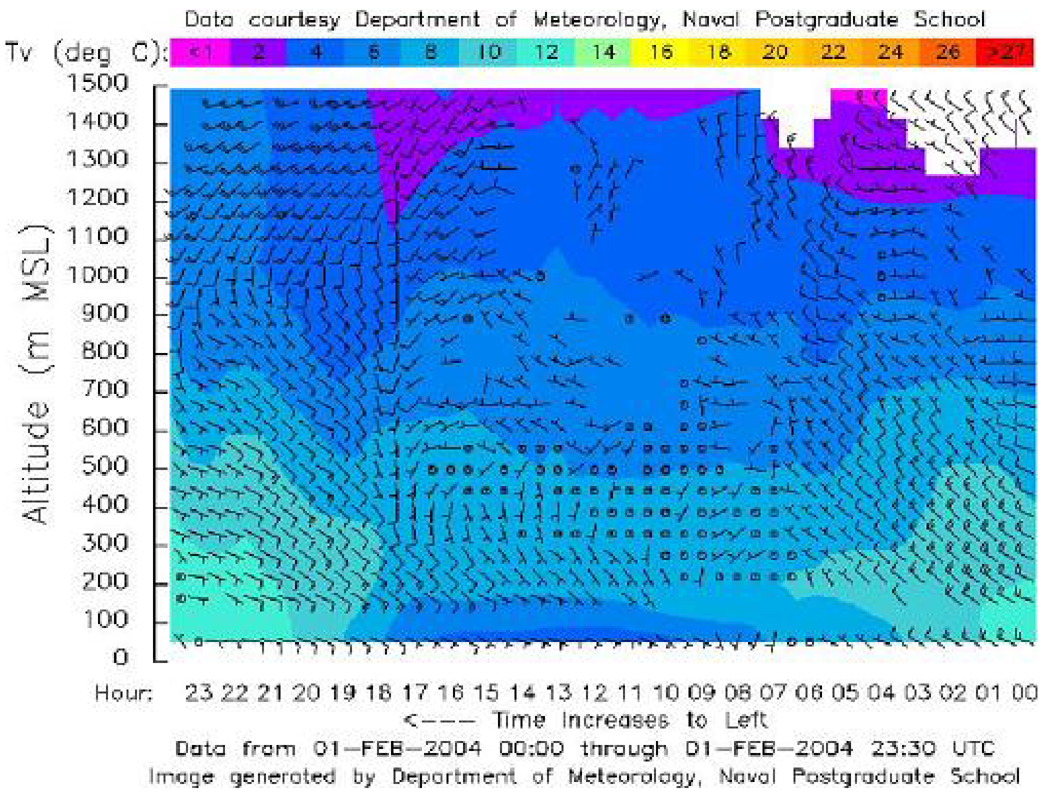

Figure 8: Fort Ord wind profiler for Feb 1st

profiler (Fig. 8) from about 1700 UTC on.

The next day was another meteorologically active day. The warm front reached the surface early on the 2^{nd} as confirmed by hourly station observations, which showed the highest temperatures and dewpoints and the lowest pressures occurring at about 0000 UTC. The NOGAPS analysis indicated the storm's cold front moved through the area later on the 2^{nd} (see slide 15 of the power point presentation), which is supported by hourly station observations that showed a 6 °F temperature drop and lowest pressures between the 1900 and 2000 UTC observations. The southerly to westerly wind

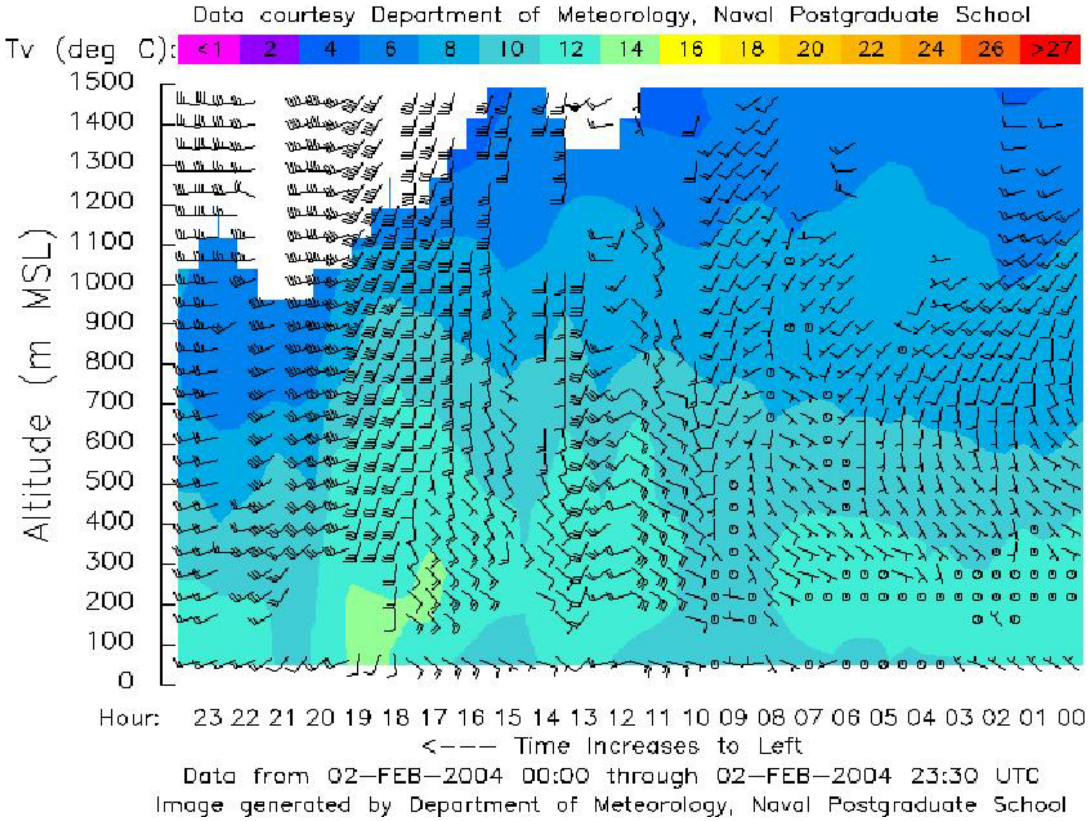

Figure 9: Fort Ord wind profiler for Feb 1st

shift recorded by the Fort Ord profiler (Fig. 9) at about 1930 UTC provides more evidence of frontal passage. So does the UDAS data (Fig. 10), which shows the pressure and temperature drops, increase in humidity, and wind shift at about 1930 UTC.

The cold front was very weak by the time it made landfall; too weak to create a frontal inversion, but it is still noticeable at about 850 mb on the 0000 UTC Oakland sounding on the 3rd (Fig. 11). Rawinsonde 27 (Fig. 12), launched in Monterey Bay at 0812 UTC, shows a fairly moist and well mixed, post-frontal air column.

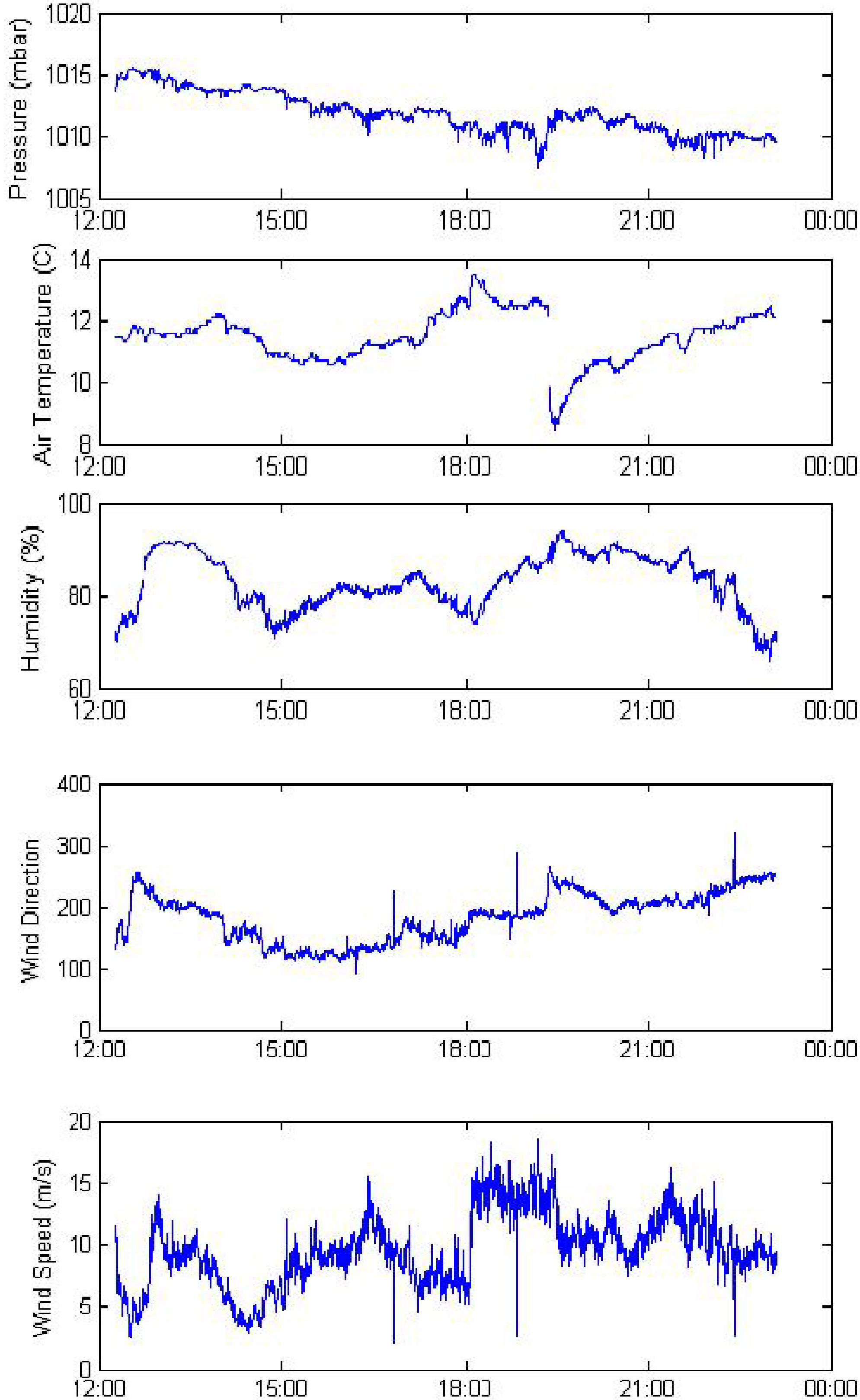

Figure 10: UDAS data from Feb 1st

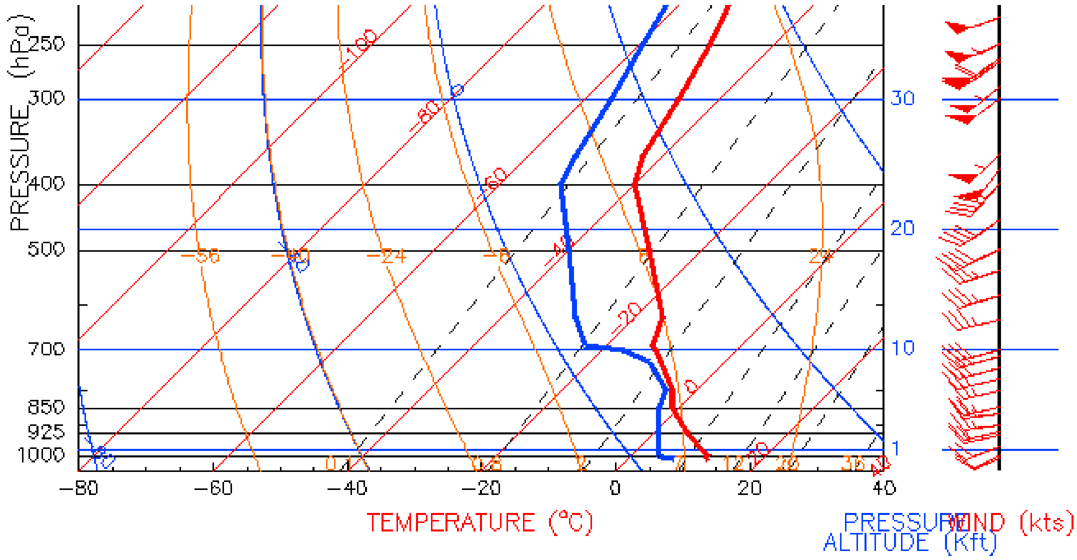

Figure 11: Sounding for Oakland 0000 UTC 2/3/2004

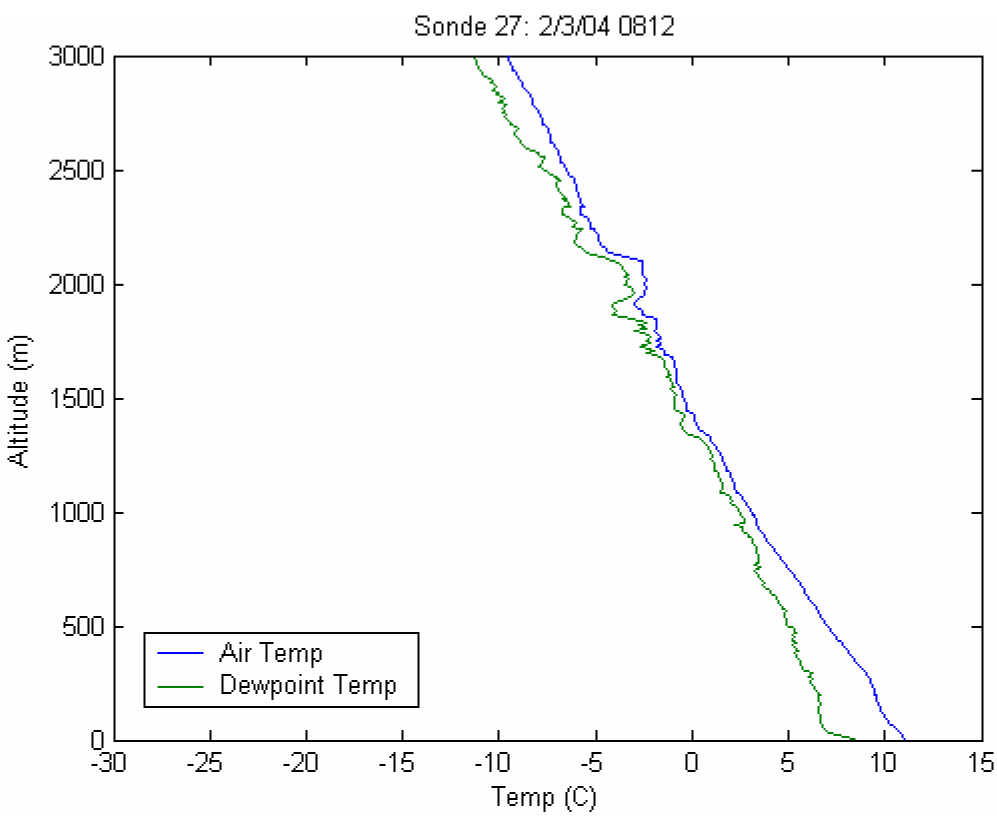

Figure 12: Rawinsonde 27

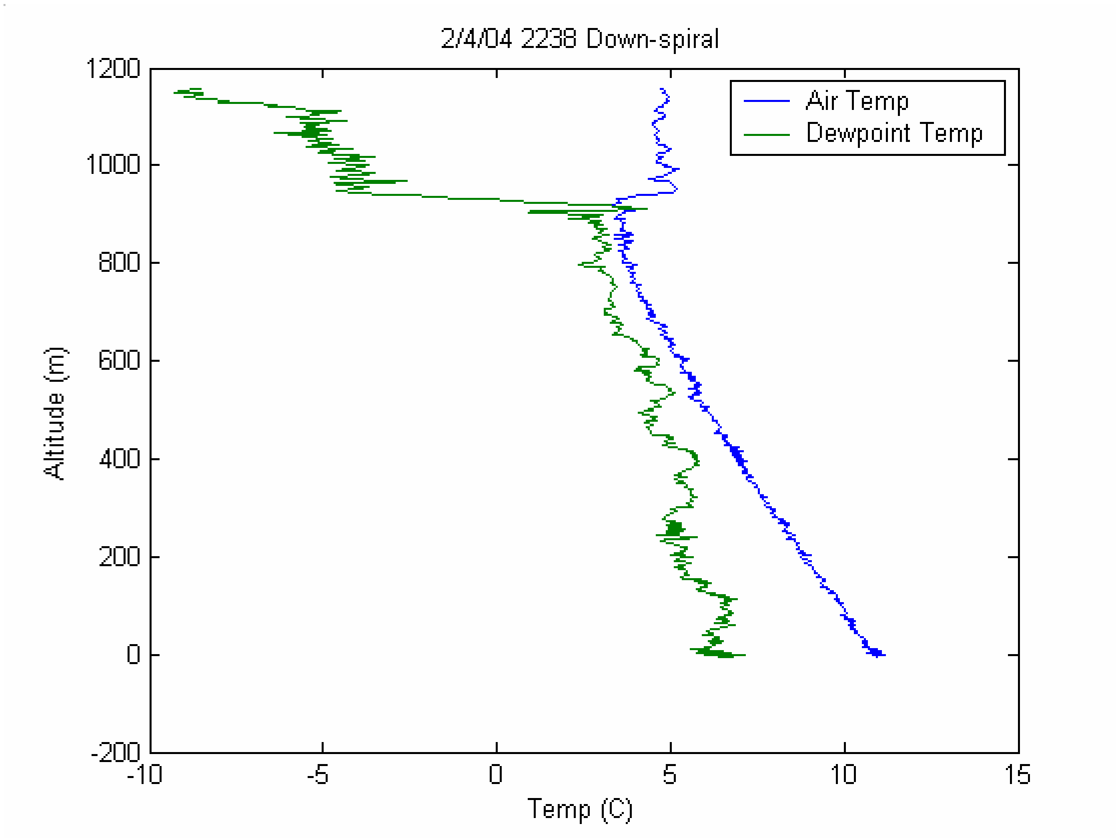

Figure 13: Aircraft data from 2238 UTC on Feb 4th

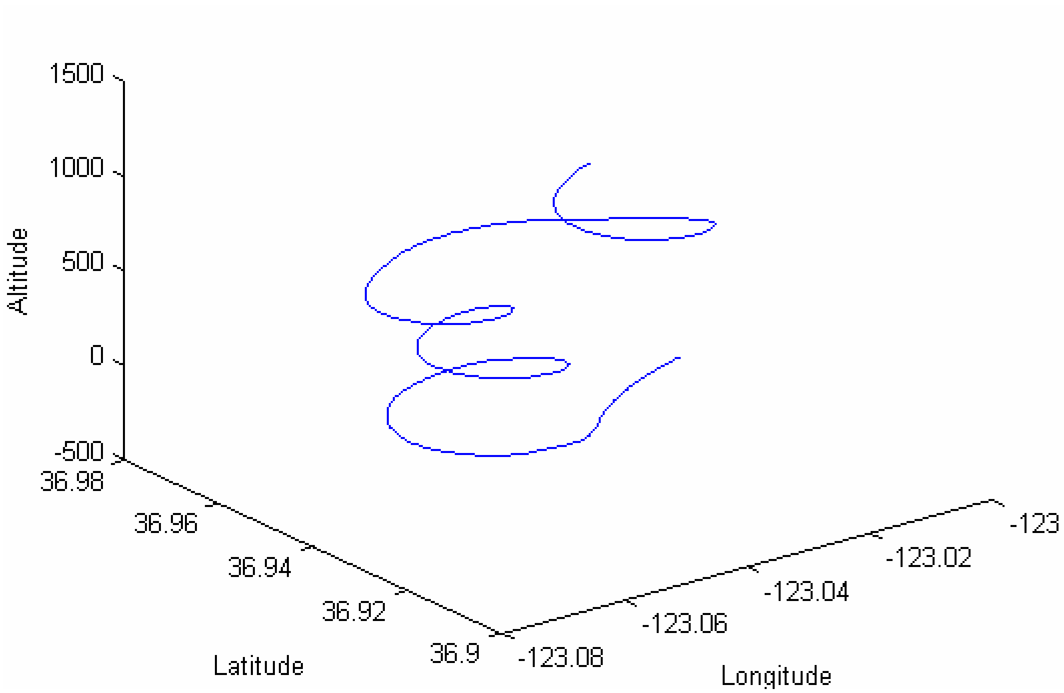

Figure 14: Aircraft flight profile

As the filling low moved inland, the EPH began ridging back into the area causing subsidence once again. The aircraft data on the 4th shows a new inversion had formed at about 1,000 m (Fig. 13). The airplane performed a spiral descent maneuver about 50 nm west of Monterey Bay at 2238 UTC while collecting this data (Fig 14). Oakland's Feb 4th 1200 UTC and Feb 5th 0000 UTC (Fig. 15) soundings showed the inversion lowered from about 5,000 to 3,000 ft during the 12-hour period.

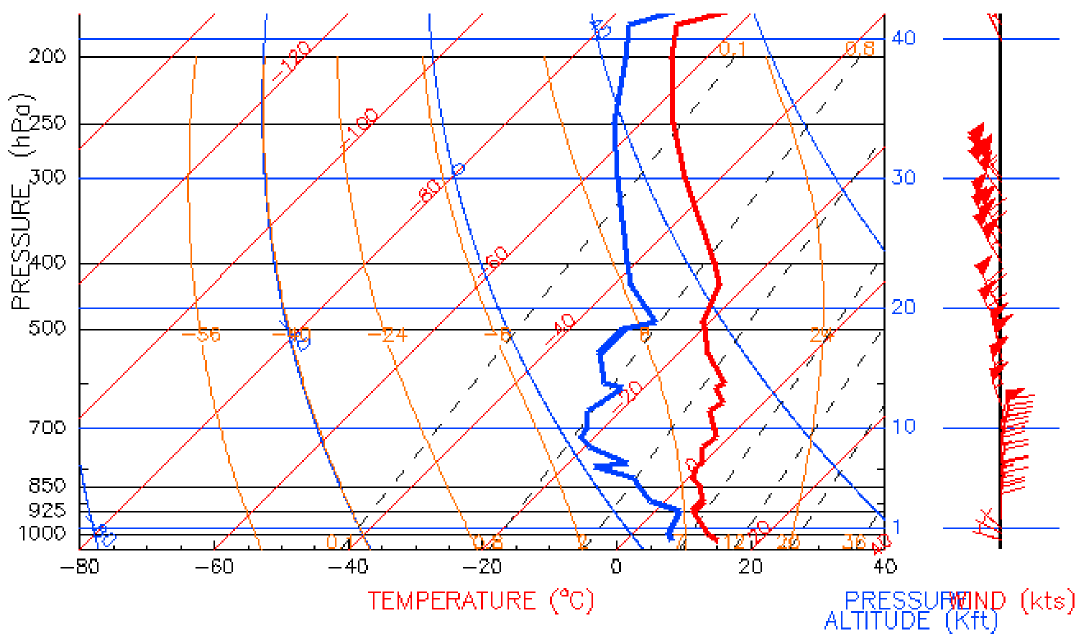

Figure 15: Sounding for Oakland 0000 UTC 2/5/2004

5. Conclusions

The OC3570 2004 winter cruise proved to be a very interesting and dynamic period, meteorologically. The effect of the variable synoptic weather on the weak marine boundary layer inversion was considerable. During the first few days, a subsidence inversion had a chance to form and even strengthen, but on Jan 30th a shortwave trough approached the coast and just about wiped the inversion out for the next two days. The inversion began to reform by Feb 1st, but a warm front associated with an approaching mid-latitude cyclone kept it from fully establishing itself. The next day, conditions remained unfavorable for formation of the inversion as the cyclone's cold front passed. The inversion finally reestablished itself on Feb 4th after a period of relative calm.