Western Region Technical Attachment
No. 96-03
February 6, 1996

MESOSCALE ETA FORECASTS OF STRATUS SURGES ALONG THE CALIFORNIA COAST

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Introduction

With the introduction of the new NCEP Mesoscale Eta model (MESOETA), forecasters along the west coast can anticipate better forecasting of mesoscale phenomena. One such phenomena is the coastal stratus surge or "southerly surge" which occurs on the average of one to two days a month along the central California coast. Forecasting the onset of stratus along the California coast and adjacent valleys is a major priority at the NWSFO in Monterey, California. With the MESOETA now available, forecasters can view some of the larger mesoscale phenomena such as the Catalina eddy and the southerly surge, and better predict stratus onset/dissipation times. This Technical Attachment (TA) will discuss two cases in which the MESOETA, although indicating that surge conditions were possible, failed to turn the winds in the boundary layer from northerly to a southerly direction as was observed. AVHRR satellite imagery, coastal and buoy reports, the Fort Ord profiler, and the Oakland sounding will be used to confirm the presence of the southerly surges. This (TA) will not discuss the theory of orographically trapped waves, Kelvin waves, gravity waves, or density surges that are associated with southerly surges. Instead, this (TA) will focus on the ability of the MESOETA to forecast stratus surges by comparing 10-meter and 850 mb wind forecasts to observations. The MESOETA was able to predict the general synoptic scale setting and, in well defined surges, the 850 mb flow pattern, yet most often failed to predict the southerly reversal of winds at the surface.

Southerly Surge Characteristic

A southerly surge is defined as the advection of a narrow band of stratus northward along the coast, with a rapid transition from northerly to southerly flow at coastal buoys. A surge typically covers 500-1000 km of coastline, propagates at an average speed of 7-9 m/s, and lasts 24-36 hours. Every summer, southerly winds develop along the coast one or two times a month that are not associated with fronts or troughs but are related to synoptic scale flow. The transition from northerly to southerly winds often correspond to the end of a coastal heat wave and the abrupt onset of stratus. Mass and Albright (1987) found that southerly surges are deep (up to 5 km), and produce 2-3°C cooling between 500-1500 meters. In some cases the southerly surge is not entirely a mesoscale phenomena, rather it is forced by a synoptic scale upper-level low off the southern California coast. The upper-level low deepens the cool marine air in the south, reversing the mesoscale pressure gradient, thus triggering the surge (Mass and Albright, 1987). At least four surges occurred during the period June to August 1995 along the central California coast.

Description of the Mesoscale Eta Model

The Mesoscale Eta Model (MESOETA) is an enhanced version of the hydrostatic Eta model which can resolve and predict meso-alpha scale weather phenomena. The MESOETA uses a horizontal grid space of 29 km and has 50 vertical layers with greatest resolution near sea level and near the mean height of the tropopause (Black, 1994). The model is run twice daily at 03Z and 15Z. This allows completion of the other operational models. Model forecasts are made at 3 hour intervals and extend out 33 hours. The MESOETA is capable of capturing at least some small-scale circulations that are forced by either internal dynamics or by orography. The MESOETA is initialized by the EDAS (Eta Data Assimilation System), beginning 12 hours prior to the start of the forecast. This technique attempts to minimize any spin-up problems that occur in the early hours of the run.

Summer of 95 Surge Cases

Of several southerly surges that were observed during the summer of 1995, two surges in August will be discussed. These cases offer the best match for model run times and the occurrence of southerly flow along coastal sections of California. In all cases the surges were preceded by above normal temperatures over coastal sections of central California. Figure 1 shows the location of several buoy and coastal locations that will be used in the discussion below. A technique developed by Felsch et al. (1990) was used to determine if these cases matched Felsch's southerly surge criteria. In both cases the day prior to the surge was cloud free along the central coast, while stratus was present over the southern California waters, and no cold air cumulus were present off the coast. The 00Z Oakland sounding 850 mb temperatures were greater than 9.8°C and the SFO-SMX pressure gradients were less than -0.2 mb. These conditions satisfy the criteria set by Felsch et al. for a stratus surge event.

July 31 - August 1

During the period July 31 to August 1, 1995, a weak stratus surge moved northward along the central California coast putting an end to a brief heat wave. A weak 500 mb short-wave trough moved through the Pacific Northwest on 7/30/12Z and a surface high developed behind the system associated with large-scale subsidence. As the high developed over the Great Basin, the thermal trough moved off the coast of northern and central California. Off the southern California coast, a shallow marine layer persisted, producing locally higher pressures in the cooler air. With lower pressure to the north associated with heating and the thermal trough, a south to north pressure gradient developed (Fig. 2). At 7/31/12Z, the pressure gradient between SFO and SMX was 2.4

mb, indicating a light southerly flow would develop. The AVHRR images in Figs. 3a-3c show that between 7/31/02Z and 7/31/22Z a region of extensive stratus extended northward to San Simeon , with a narrow band of stratus extending as far north as Pigeon Point. Buoy observations show that winds shifted to the south and pressures began to rise at nearly all central coast locations between 11Z and 15Z on the 31st (Fig. 4). On the 31st, the thermal trough shifted north and eastward, increasing the onshore pressure gradient and allowing the stratus to move northward to near the Golden Gate Bridge by 31/22Z. The next day the thermal trough shifted into the Central Valley, allowing for the rapid development of stratus along the entire California coast from the west. Although this case was not a strong surge, it exhibited features normally associated with a stratus surge such as southerly surface winds and a narrow band of stratus along coastal sections.

Model Performance for July 31- August 1

The 07/31/03Z MESOETA failed to predict southerly winds at the 10-meter level throughout the forecast period. Figures 5 and 6 show the 10-meter and 850 mb winds for times when AVHRR data were available. The satellite imagery clearly shows the movement of stratus northward along the coast associated with southerly winds. The predicted northerly winds at 10-meters were nearly 180 degrees out of phase with observed winds throughout the forecast period (Fig. 7). The 850 mb winds show a trend toward southerly flow, yet continuously forecast the southerly flow well to the north of the observed surface southerly flow or stratus. The 850 mb winds do provide an indicator that a southerly surge is possible.

The 7/31/12Z and 8/1/00Z Oakland sounding clearly show the transition from an off-shore flow to an on-shore flow near the surface (Fig. 8a, 8c). Both figures show southerly winds extending above 850 mb. The MESOETA 9 hour forecast valid 7/31/12Z shows that southwesterly flow existed above 850 mb, with northerly flow near the surface, and a strong marine inversion separating the two regions (Fig. 8b). The marine inversion corresponds to the wind shift from the west above 850 mb to the north below. The MESOETA failed to predict the easterly flow which helped produce record high temperatures, and only marginally predicted the southerly flow above 850 mb. The 21 hour MESOETA forecast sounding valid 8/1/00Z (Fig. 8d) predicted northwesterly winds below 850 mb and southwesterly winds above. The wind shift from northwest to southwest is once again associated with the top of the marine inversion. The southwesterly flow corresponds reasonably well with the Oakland sounding for this time period, with only a minor error in the westerly component. The Oakland sounding would not show the southerly surge near the surface as the local sea breeze produces a nearly constant westerly flow into Oakland, thus this sounding does not truly represent features near coastal sections. The MESOETA 850 mb winds may also be influenced by the strong tendency to predict an onshore flow over the San Francisco Bay Area in response to the thermal low over the interior. Although the synoptic scale features were present for a southerly surge, the MESOETA failed to predict southerly surface winds as were observed at coastal buoys. The 850 mb winds do not couple with the surface winds, possibly due to the strong marine inversion inhibiting downward fluxes of momentum as seen in skew-T diagrams.

Aug 14-16

From August 14-16, another disorganized southerly surge moved northward along the central California coast. The AVHRR visible images for 8/15/15Z and 8/15/21Z (Fig. 9) show the narrow band of stratus extending as far north as Point Arena. Several eddies developed between the Monterey Bay and Point Arena, and a well-defined structure existed in the off shore stratus. This surge was accompanied by rapid wind shifts from the northwest to the south and gradual pressure rises at all central coast buoys (Fig. 10).The surge was initiated by the passage of a weak short-wave trough over northern California which induced subsidence over central California, warming coastal sections. The thermal trough extended off the northern California coast, reversing the usual northerly gradient, thus initiating the southerly surge.

Model Performance for August 14-16

Once again the MESOETA failed to predict the southerly surface winds associated with the surge, instead north to northwesterly winds were predicted (Fig. 11). At 850 mb, the MESOETA predicted a well-developed southerly flow along coastal California, and the 6 hour forecast valid 8/15/09Z predicted a closed circulation south of Point Arena (Fig. 12). In this case, the 850 mb winds accurately predicted the northward push of stratus to near Point Arena, and caught the beginning of the eddy circulation off Point Arena. A comparison of the observed Oakland sounding and the initial MESOETA sounding for 8/15/03Z shows that the MESOETA failed to initialize the southerly component in the wind below 700 mb, and the southeasterly winds from 850mb to near 950 mb (Figs. 13a, 13b). The 9 hour forecast sounding valid 8/15/12Z (Fig. 13d) accurately predicted the state of the atmosphere except for a slight westerly bias in the wind direction. In this case, the sea breeze has tainted the Oakland sounding (Fig. 13c) so that surface winds do not reflect those of coastal buoys.

The Fort Ord profiler for August 15 (Fig. 14) shows that southwesterly flow existed near 700 meters prior to the onset of southerly winds at buoy 42. At 07Z, winds at buoy 42 shifted to the south and shortly afterwards the Fort Ord profiler showed a region of southerly winds from 500 meters to 900 meters. After the southerly wind shift along the coast, temperatures through 1500 meters cooled significantly as seen in the profiler. The profiler also shows the warmest temperatures were at a time when there was no marine inversion. The marine inversion developed shortly after pressures rose along the coast and the layer average temperature began to decrease as seen in Fig. 14.

Although southerly surface winds were observed during this case, the MESOETA failed to analyze or predict southerly surface winds. The 850 mb winds did show a trend towards southerly flow, yet did not accurately depict the position of the southerly winds.

Conclusion

Several southerly surges occurred on the central California coast during July and August of 1995. The 29 km resolution MESOETA model is supposedly the first NMC model with the horizontal resolution capable of observing such meso-alpha features as southerly surges. However, it appears that it exhibits a problem in forecasting the reversal of the winds within the marine boundary layer during most southerly surge cases. Model and observed soundings show that the model failed to couple the winds at 850 mb and above with the surface, possibly due to a strong marine inversion.

Other possible causes of model error at the surface are:

1) Buoy observations along the central coast may be neglected, causing poor initialization.

2) Overall poor initialization of the model as seen by the difference in winds in Figs. 13a and 13b.

3) Stratus surges may have a horizontal scale too narrow to be resolved by the MESOETA.

4) Surges are coastally trapped disturbance, that owe part of their existence to the coastal topography and the MESOETA may not have the topographic resolution required to accurately model surges.

Several other errors are present in the MESOETA forecasts that are not touched on in this (TA).

References

Black Thomas L., 1994: The New NMC Mesoscale Eta Model: Description and Forecast Examples. *Wea. Forecasting*, **9,** 265-278.

Felsch, P. and W. Whitlatch, 1990: Stratus Surge Prediction Along The Central California Coast. NOAA Technical Memorandum NWS WR-209.

Mass, C.F., and M.D. Albright, 1987: Coastal southerlies and alongshore surges of the west coast of North America: Evidence of mesoscale topographically trapped response to synoptic forcing. *Mon. Wea. Rev.*, **115**, 1707-1738.

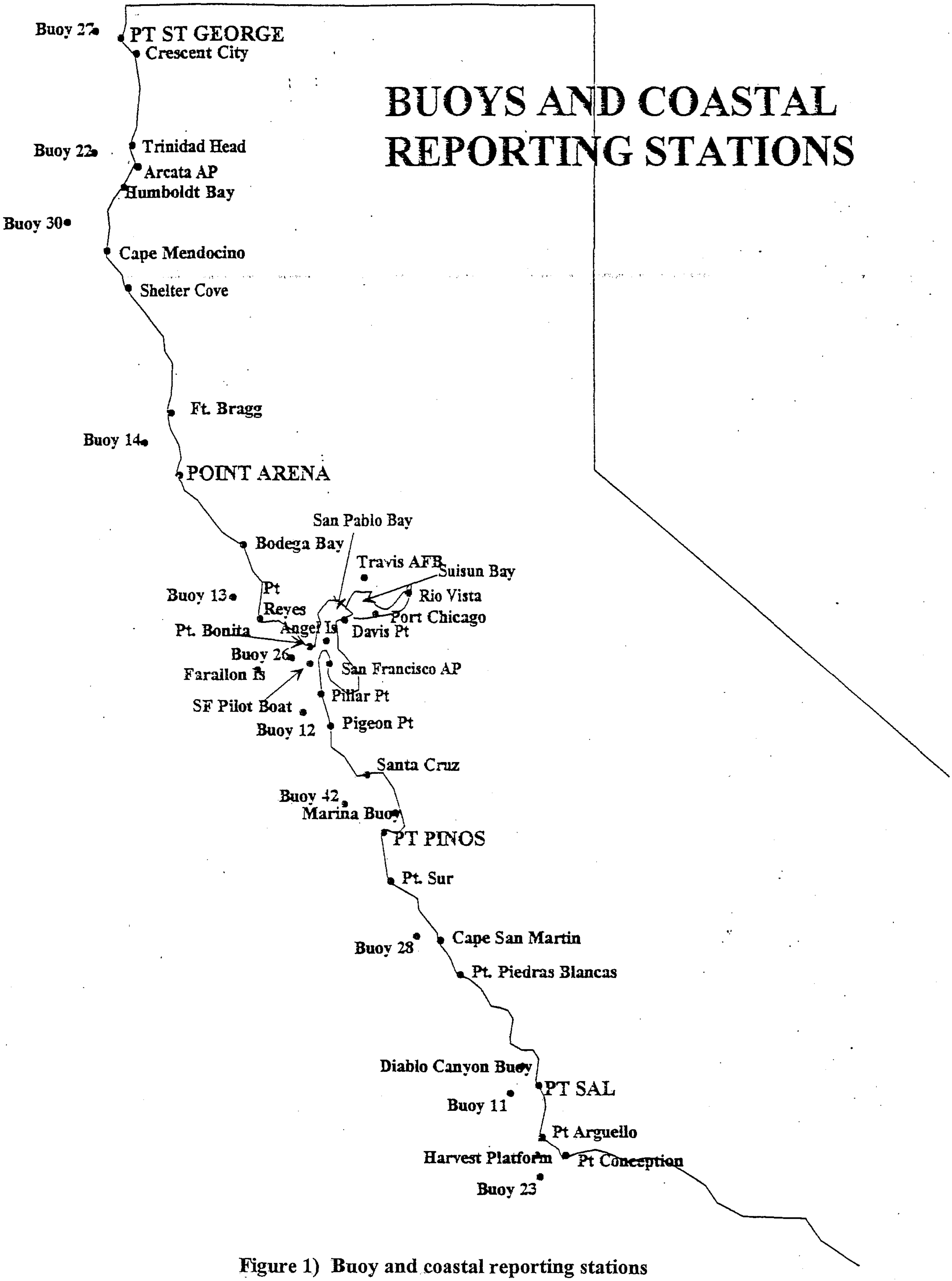


Figure 1) Buoy and coastal reporting stations

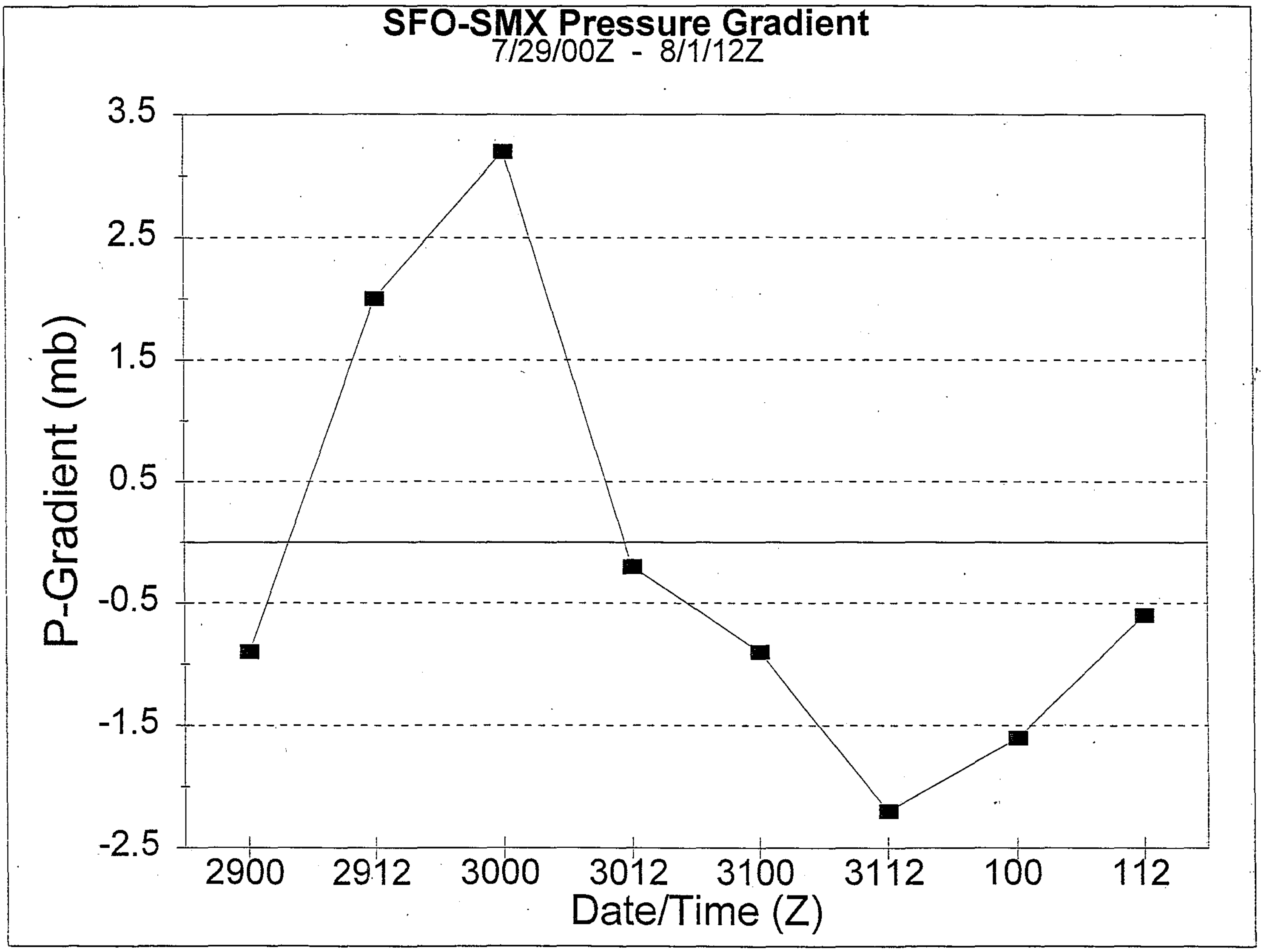


Figure 2) San Francisco airport to Santa Maria pressure gradient. (negative = south to north)

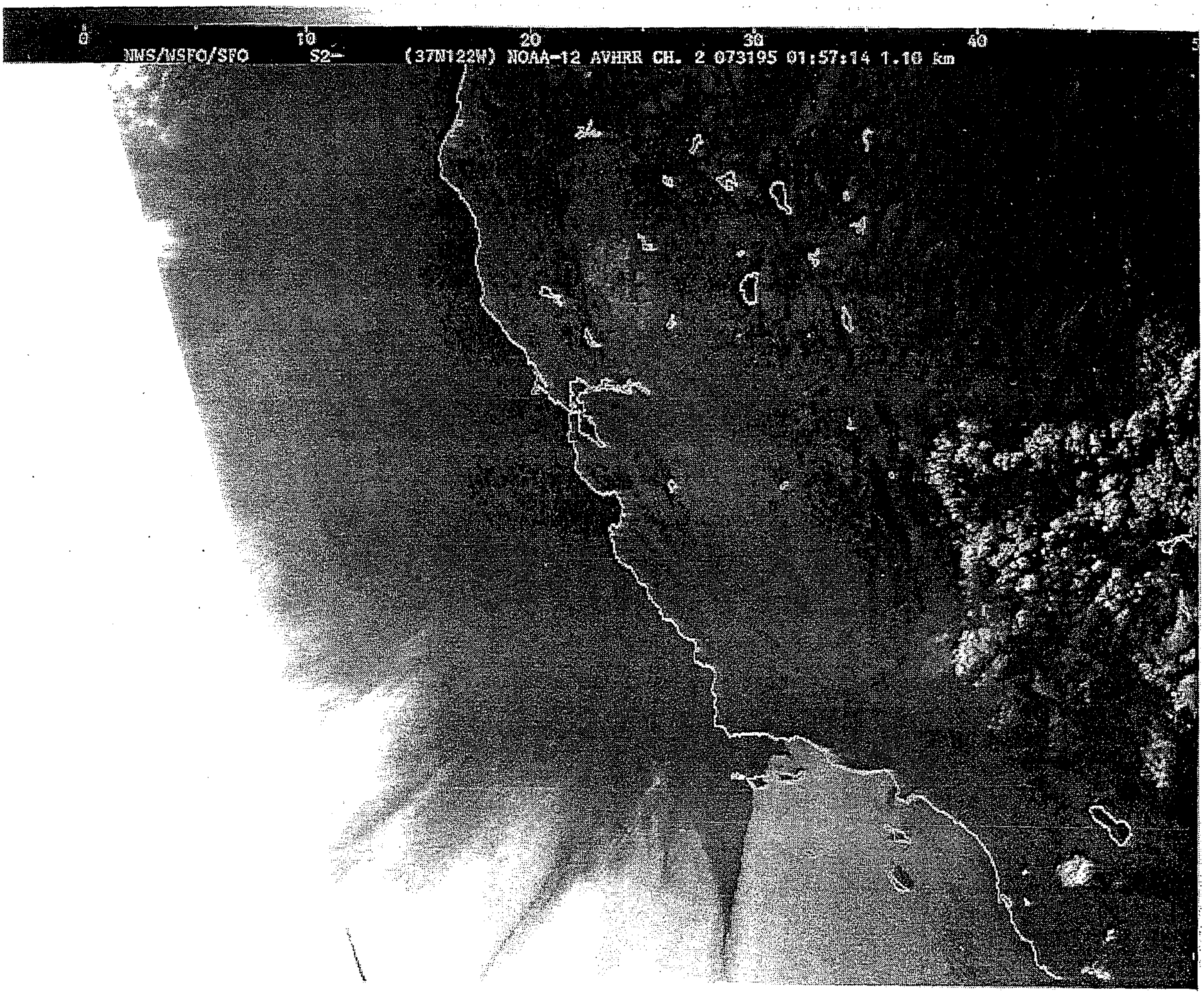


Figure 3 a) AVHRR image for 7/31/0157Z

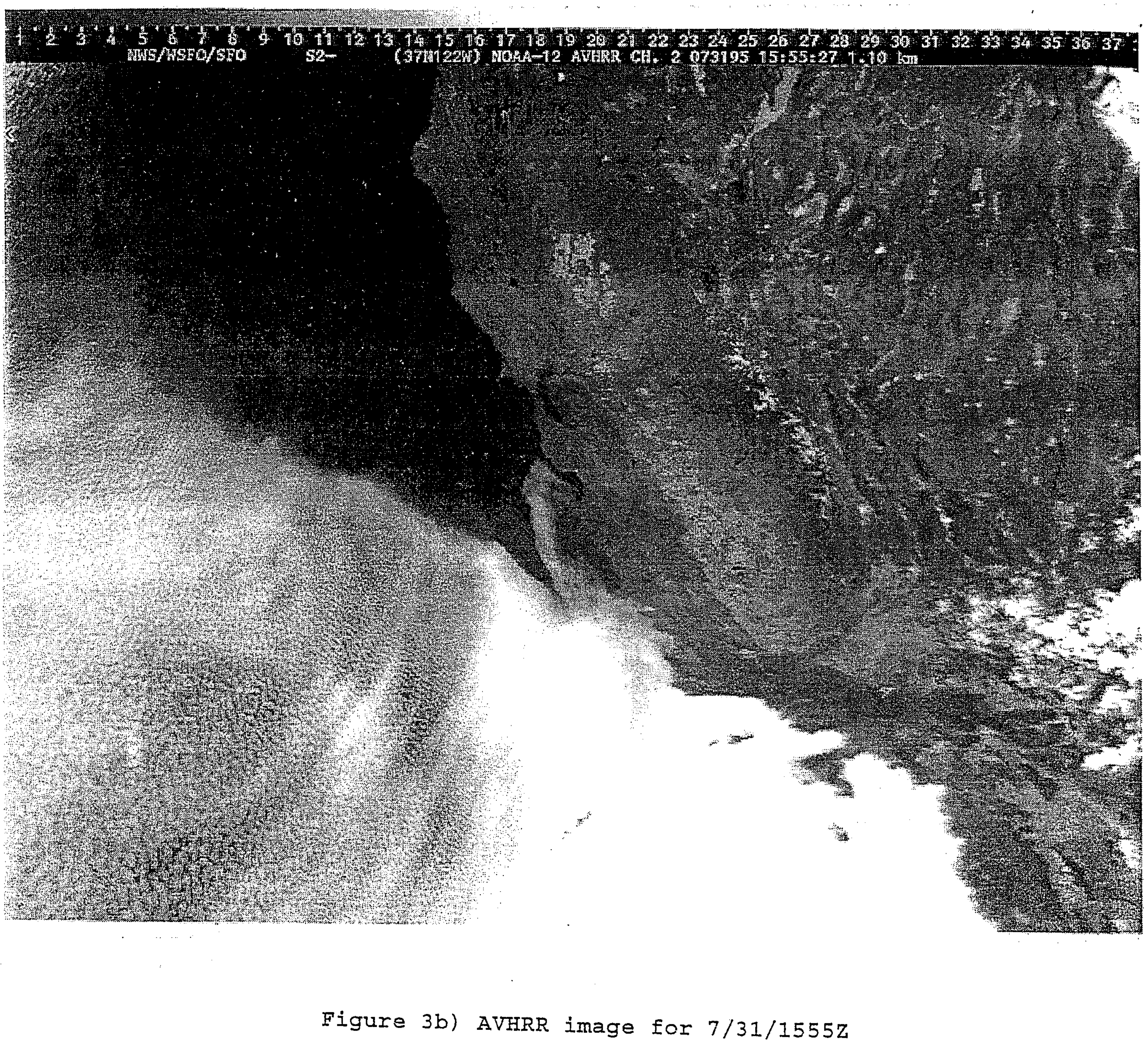


Figure 3b) AVHRR image for 7/31/1555Z

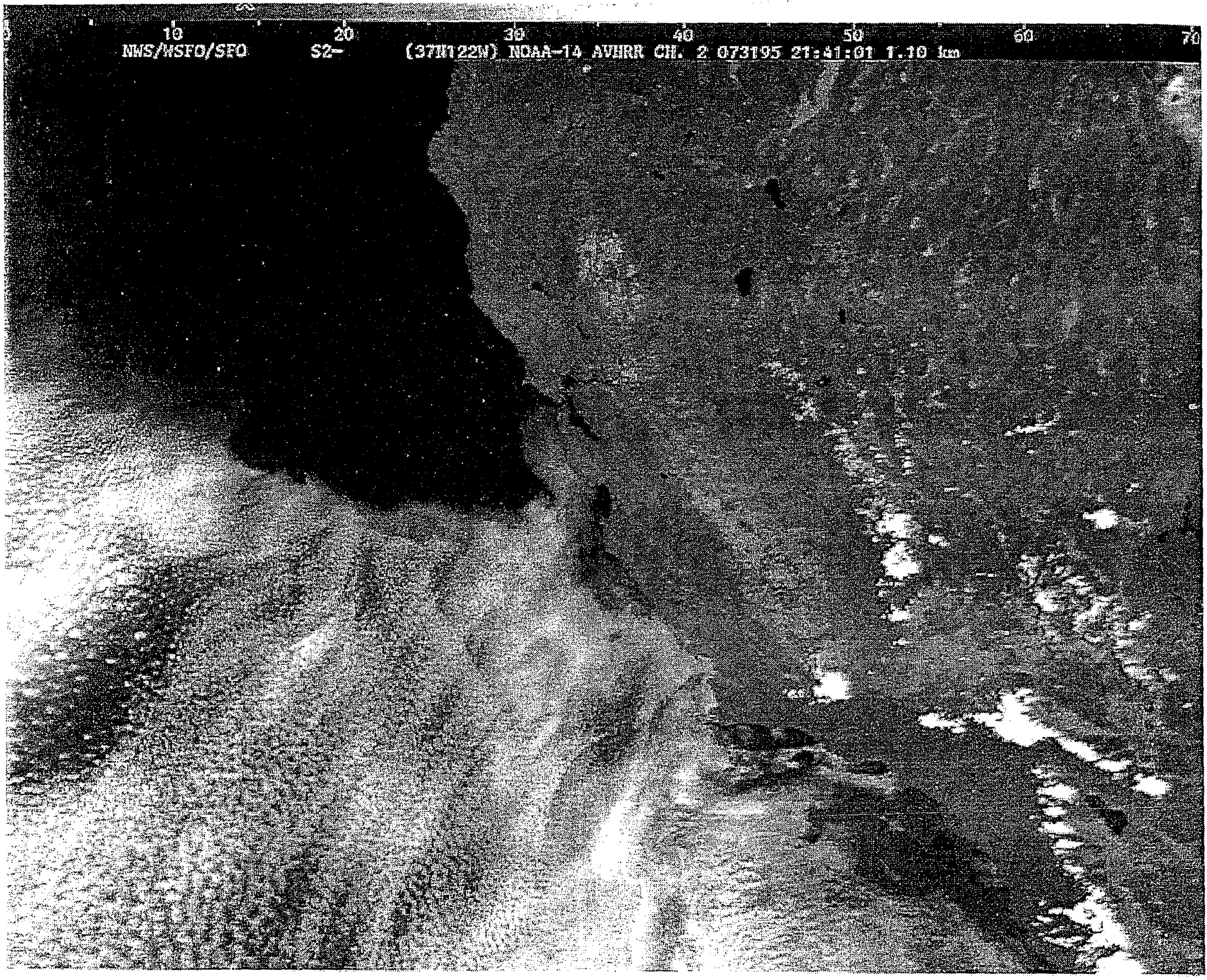


Figure 3 c) AVHRR image for 7/31/2141Z

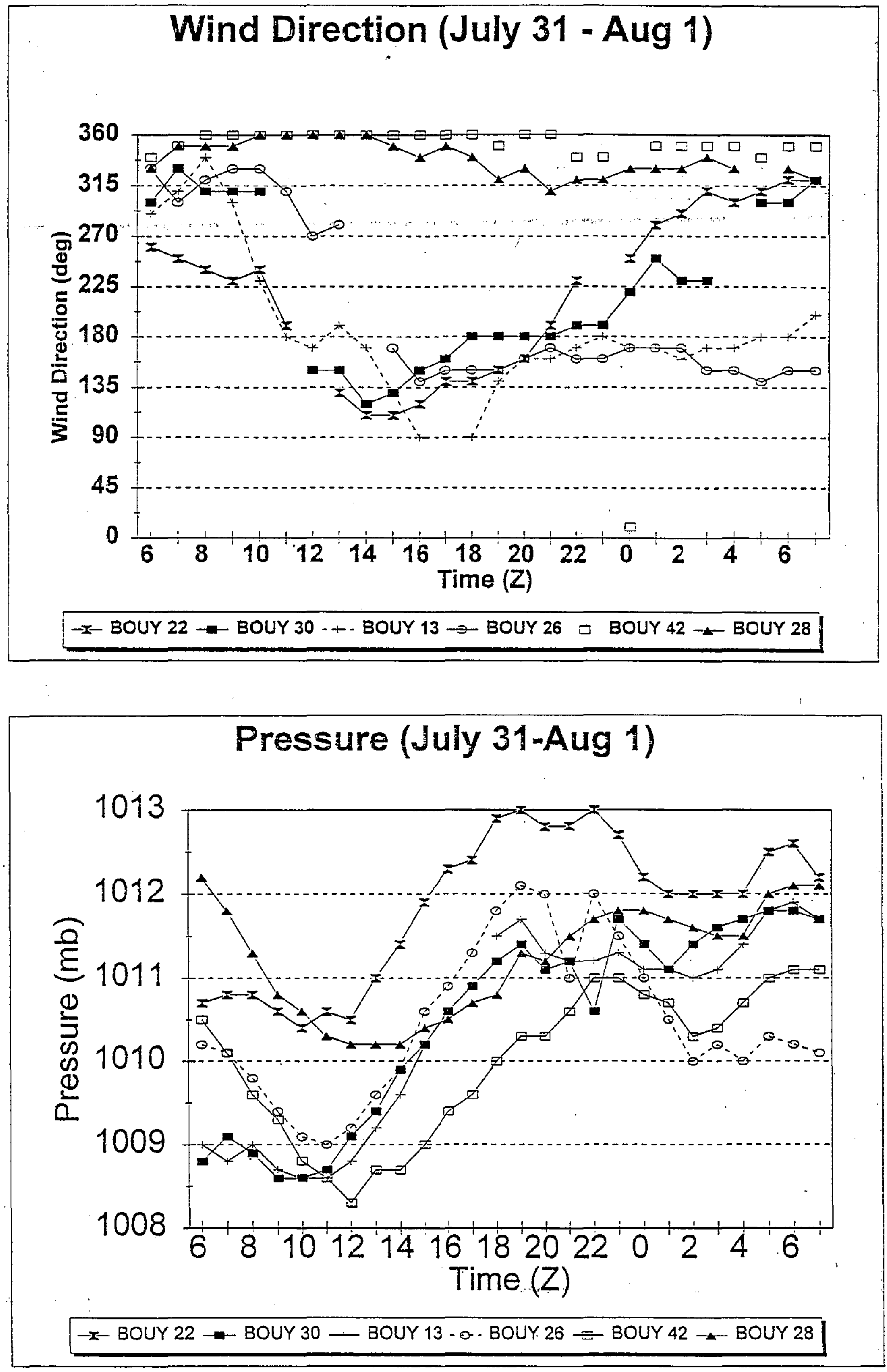
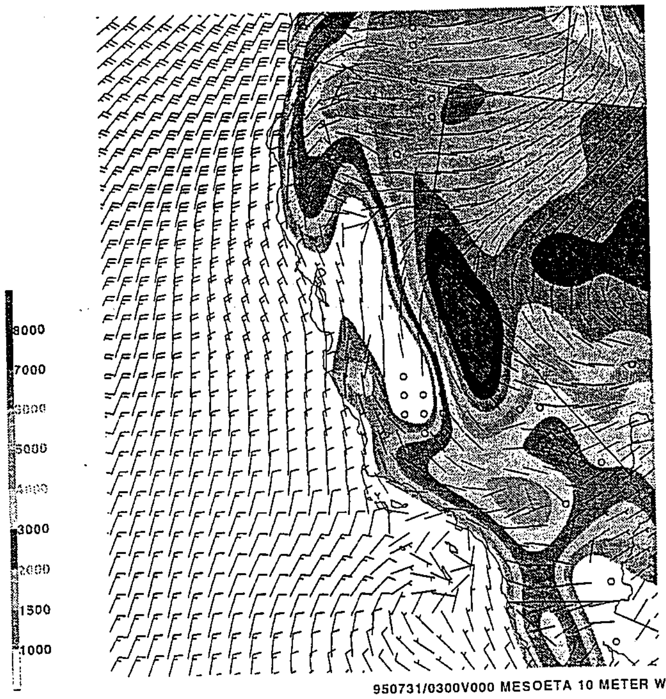
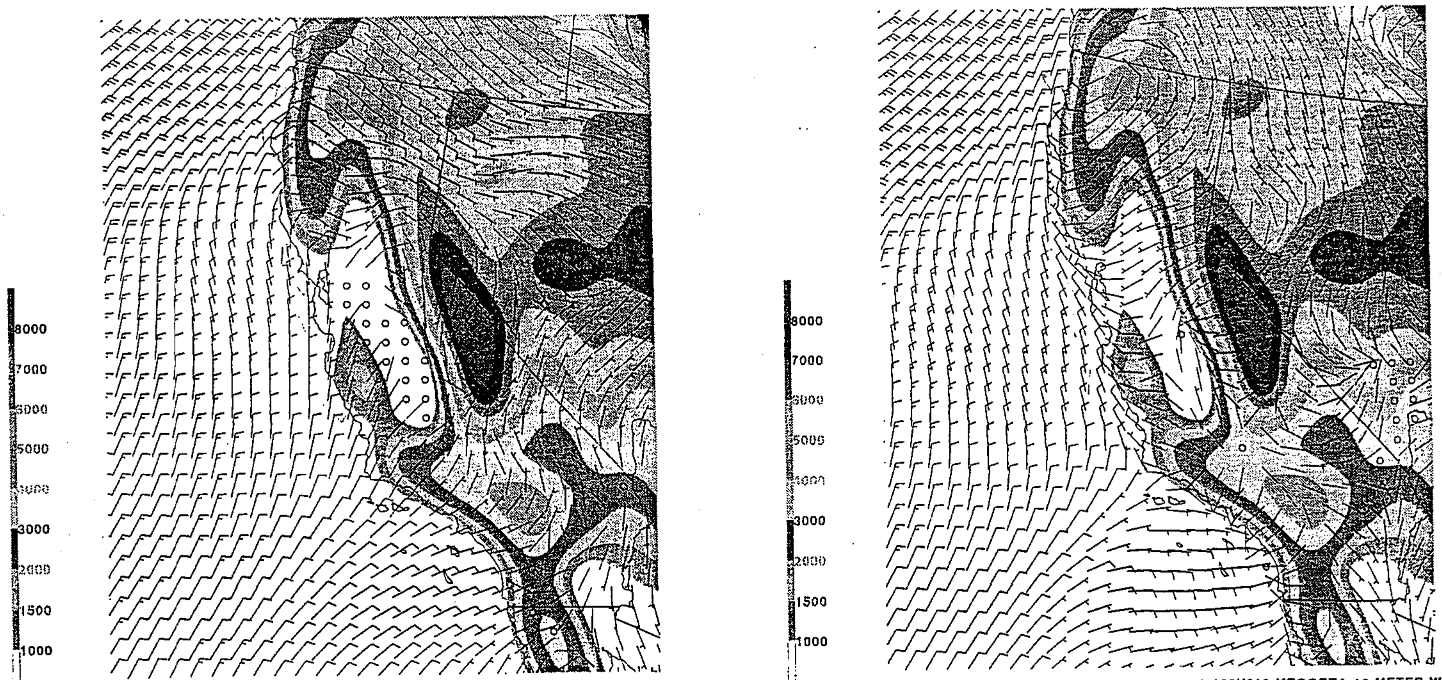


Figure 4) Observed wind direction and sea level pressure for coastal buoys. (note pressure rises prior to wind shifts)



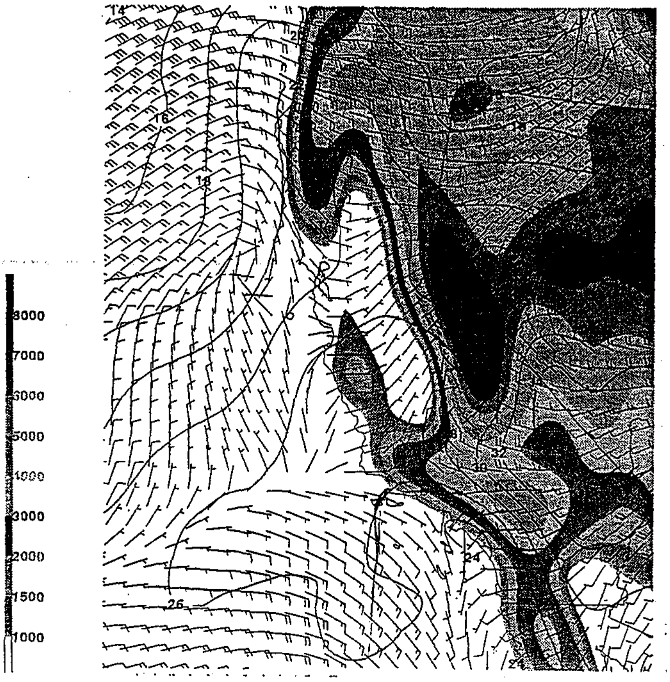
950731/0300V000 MESOETA 10 METER WIND



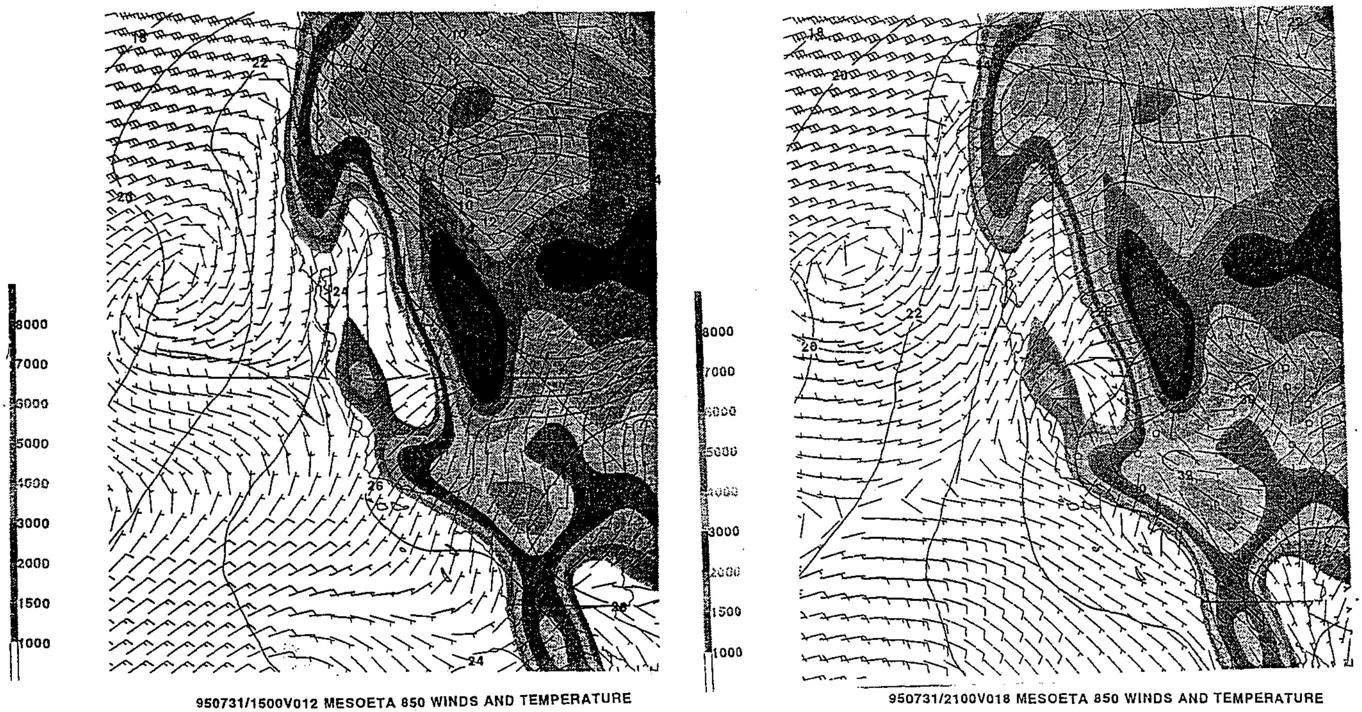
950731/1500V012 MESOETA 10 METER WIND

950731/2100V018 MESOETA 10 METER WIND

Figure 5) **MESOETA 10-meter winds and temperature for; 1) 0-hour analysis at 7/31/03Z 2) 12 hour forecast valid 7/31/15Z and 3) 18 hour forecast valid 7/31/21Z. Shading indicates model topography**



950731/0300V000 MESOETA 850 WINDS AND TEMPERATURE



950731/1500V012 MESOETA 850 WINDS AND TEMPERATURE

950731/2100V018 MESOETA 850 WINDS AND TEMPERATURE

Figure 6) **MESOETA 850 mb winds and Temperature for; 1) 0-hour analysis at 7/31/03Z 2) 12 hour forecast valid 7/31/15Z and 3) 18 hour forecast valid 7/31/21Z. Shading indicates model topography**

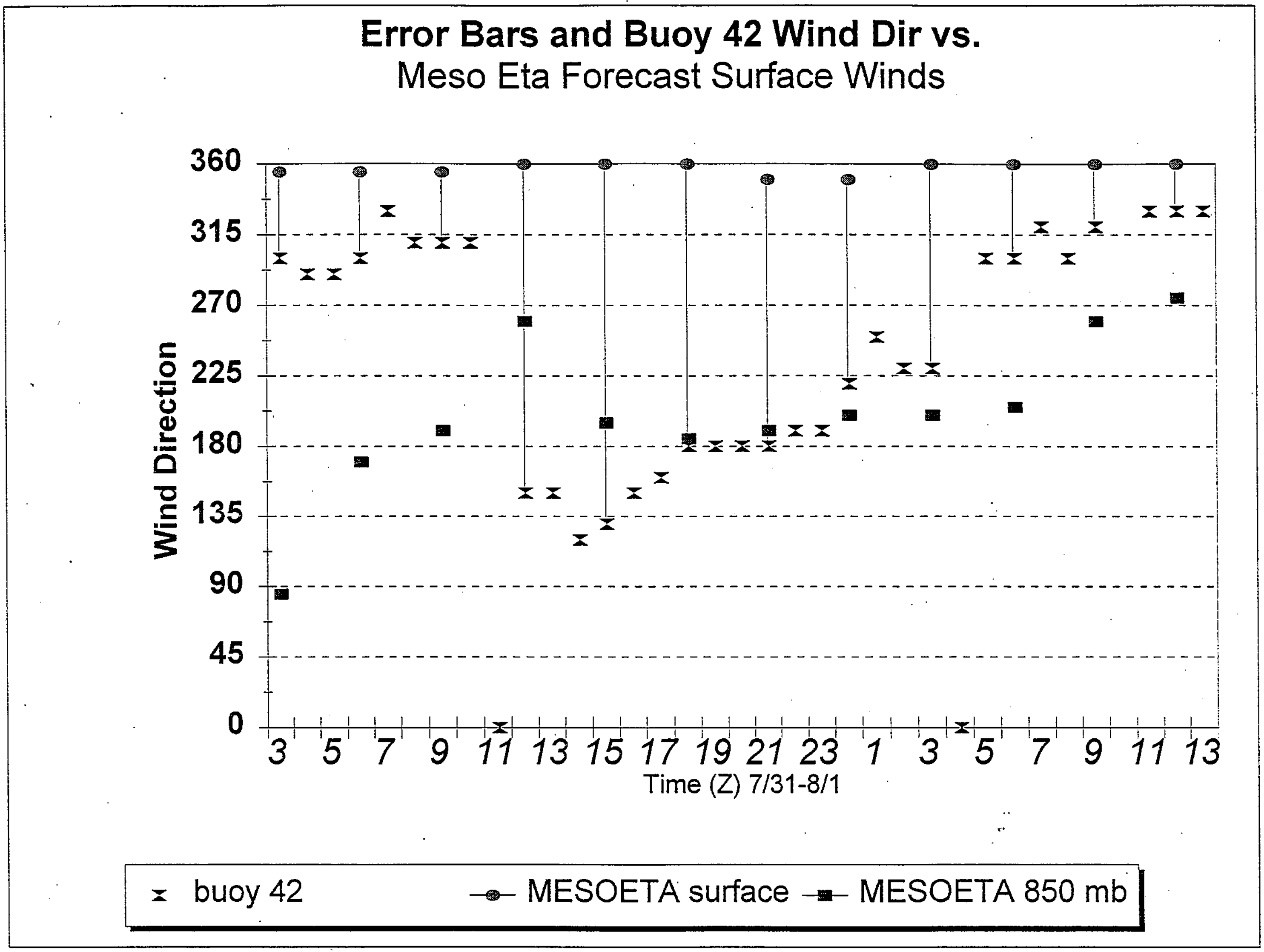


Figure 7) **Observed wind direction vs. MESOETA 850 mb and surface wind forecasts. (error bars indicate difference between observed and forecast surface winds)**

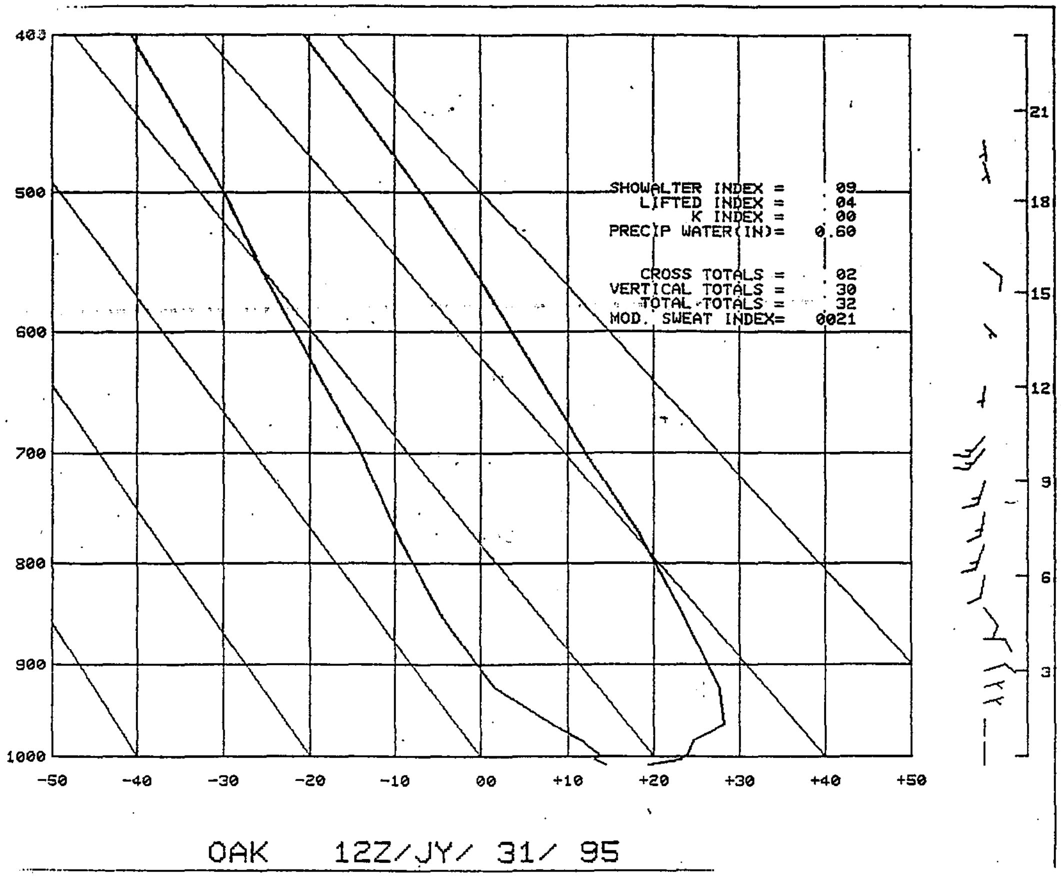


Figure 8a) Observed Oakland sounding for 7/31/12Z.

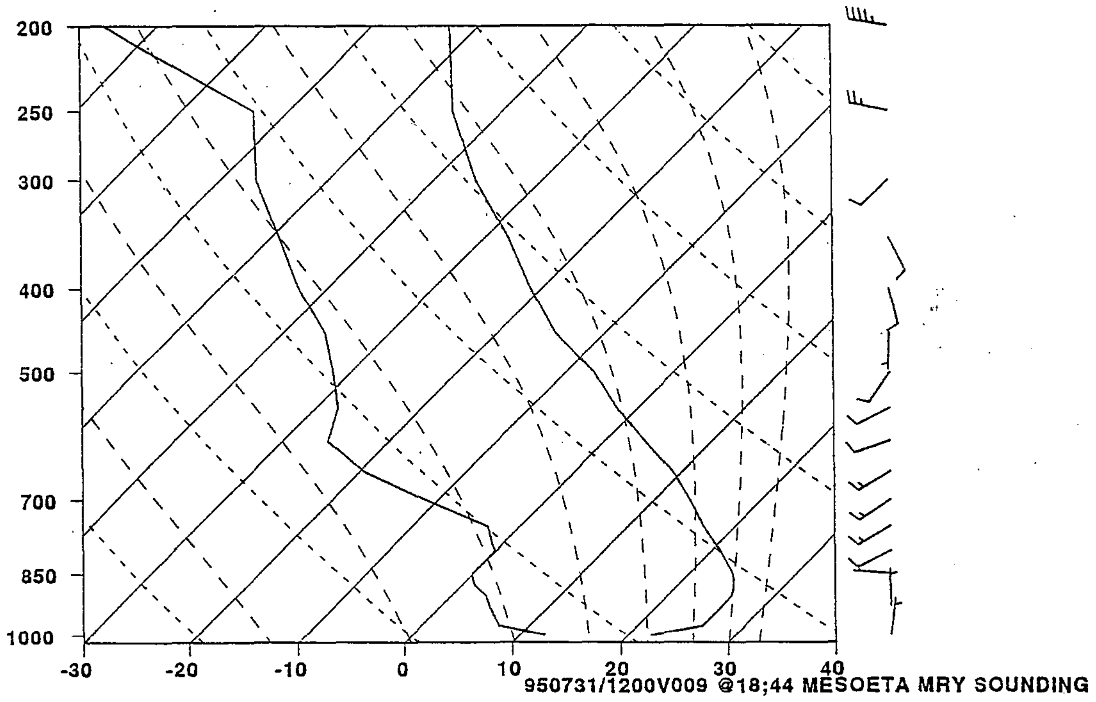


Figure 8b) Predicted Monterey sounding for 7/31/12Z.

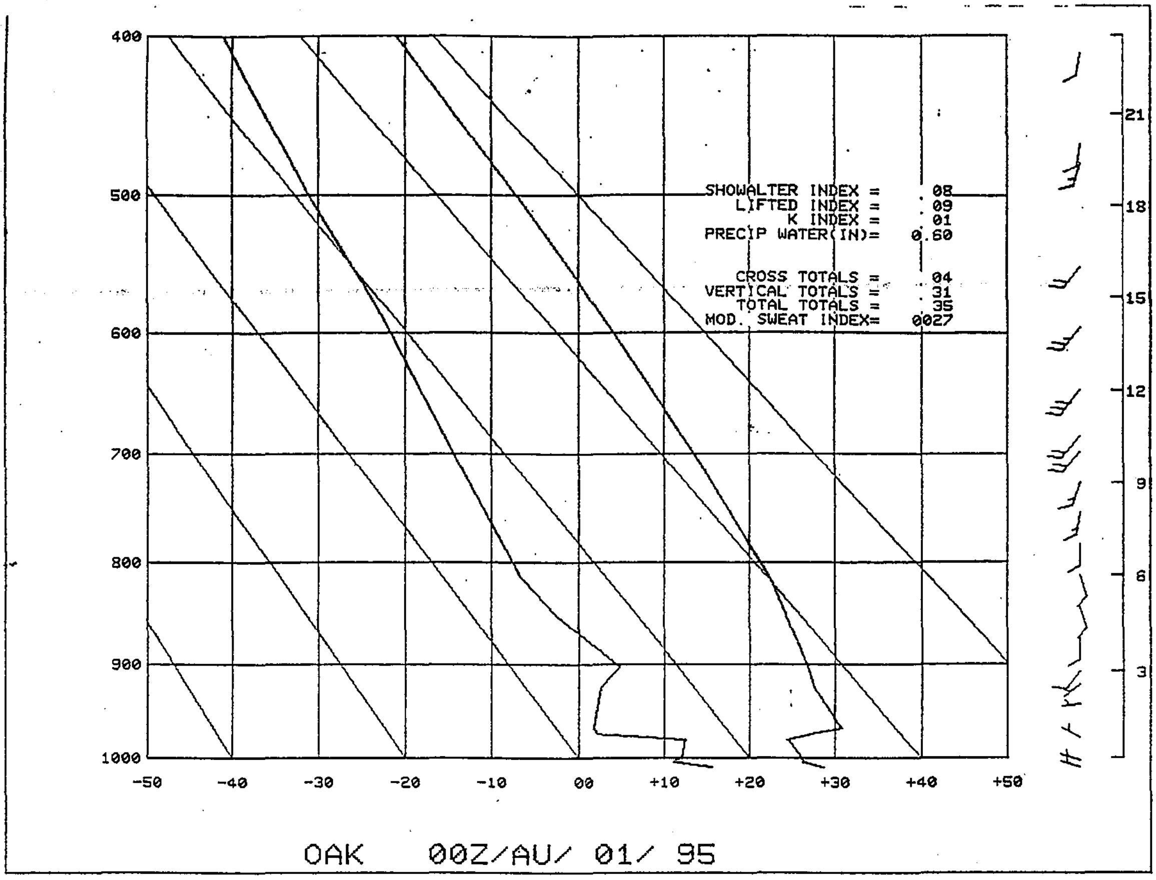


Figure 8c) Observed Oakland sounding for 8/01/00Z.

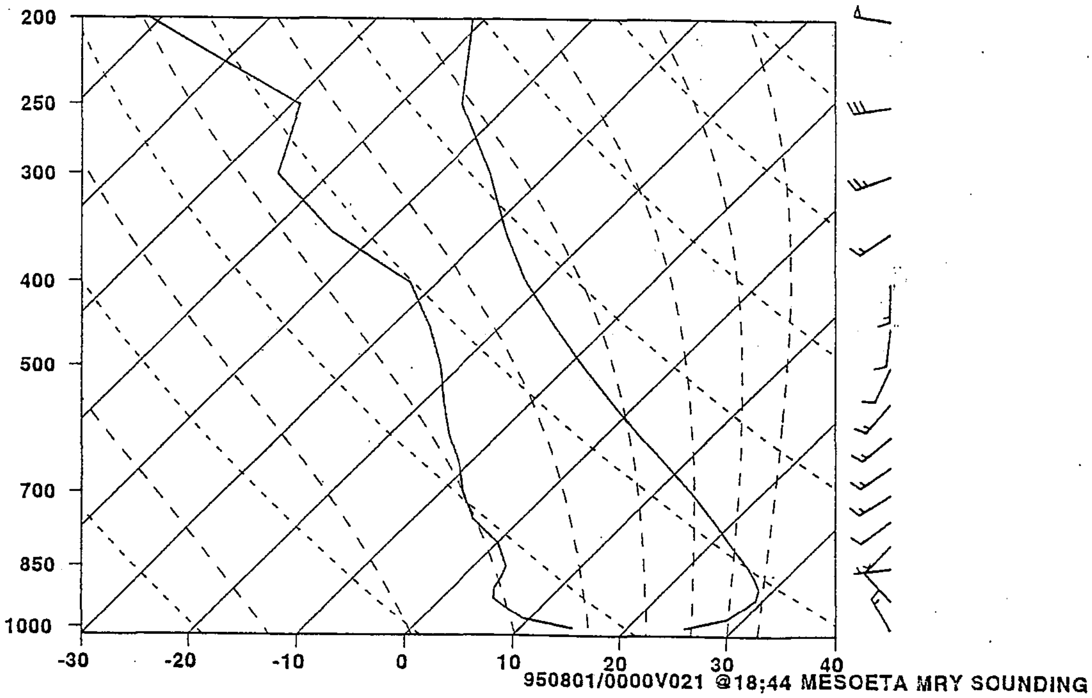


Figure 8d) Predicted Monterey sounding for 8/01/00Z.

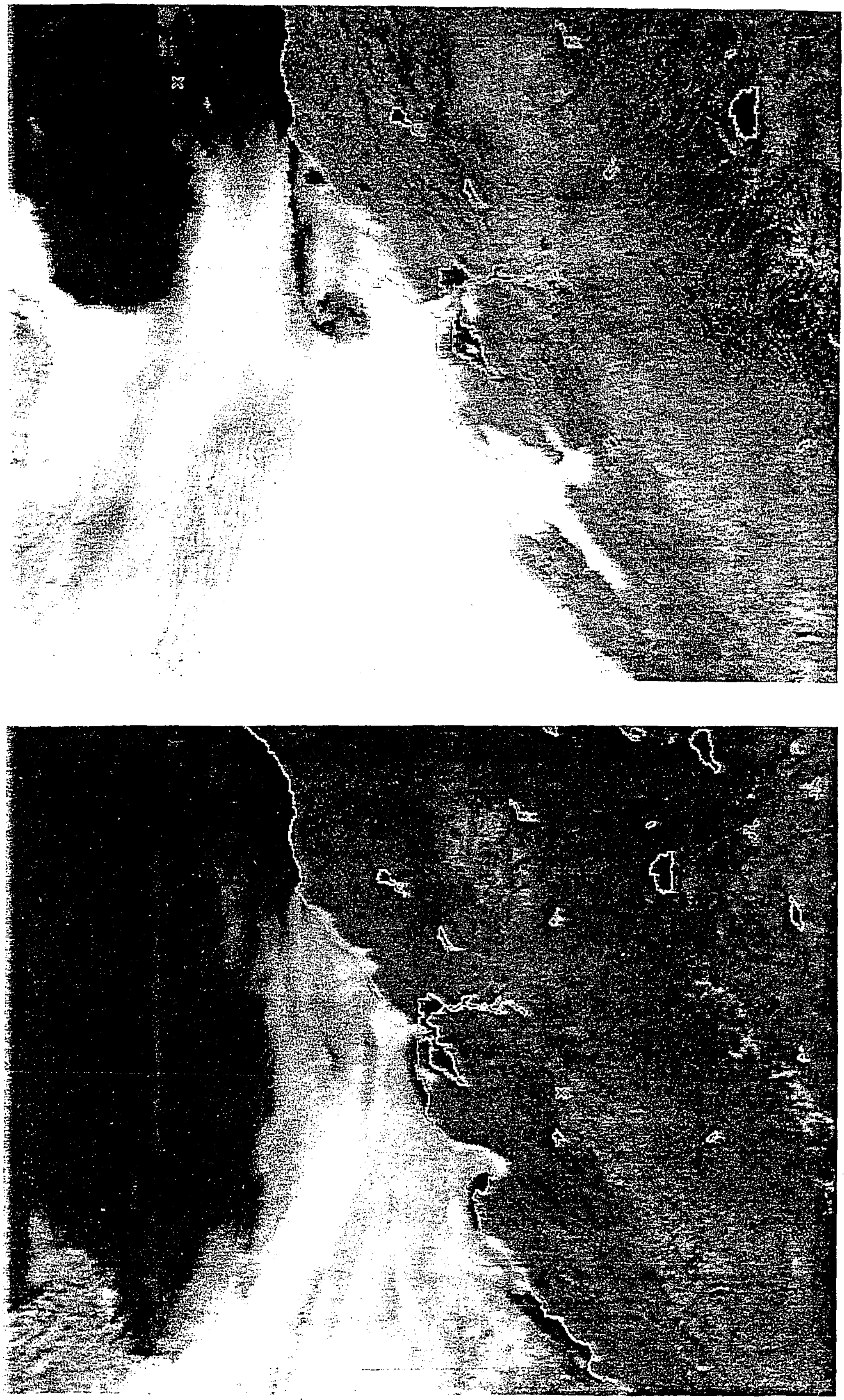
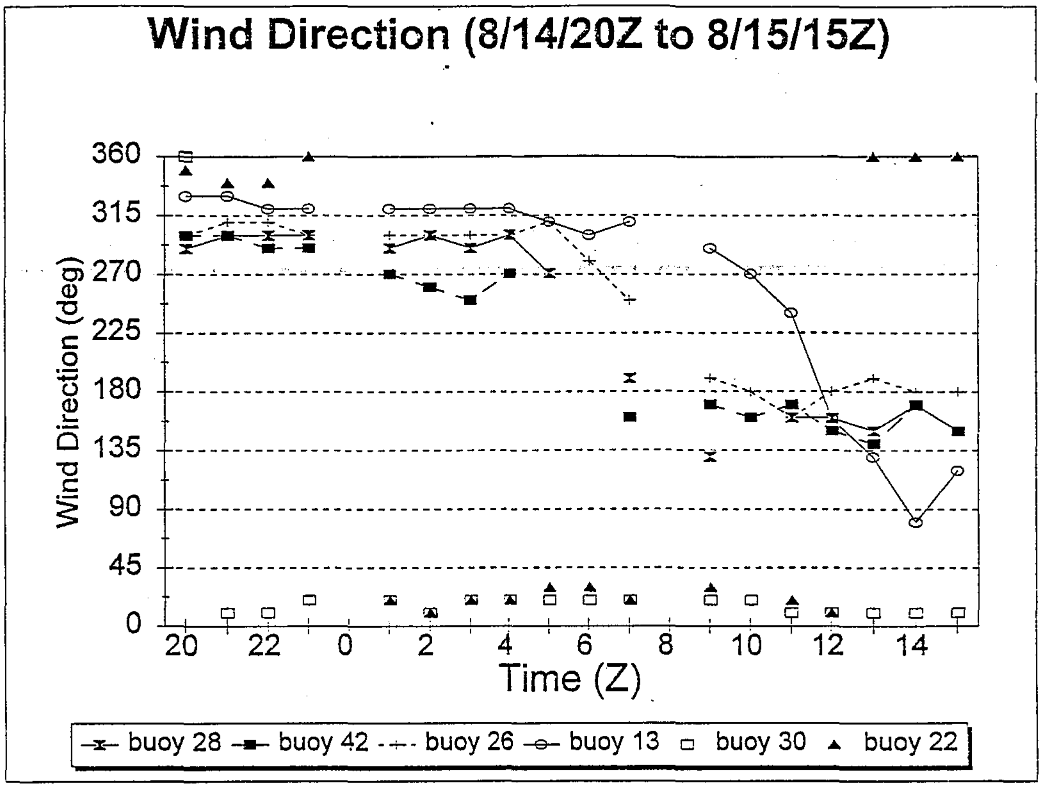


Figure 9) AVHRR imagery for; 1) 8/15/95 at 1529Z and, 2) 8/15/95 at 2039Z.



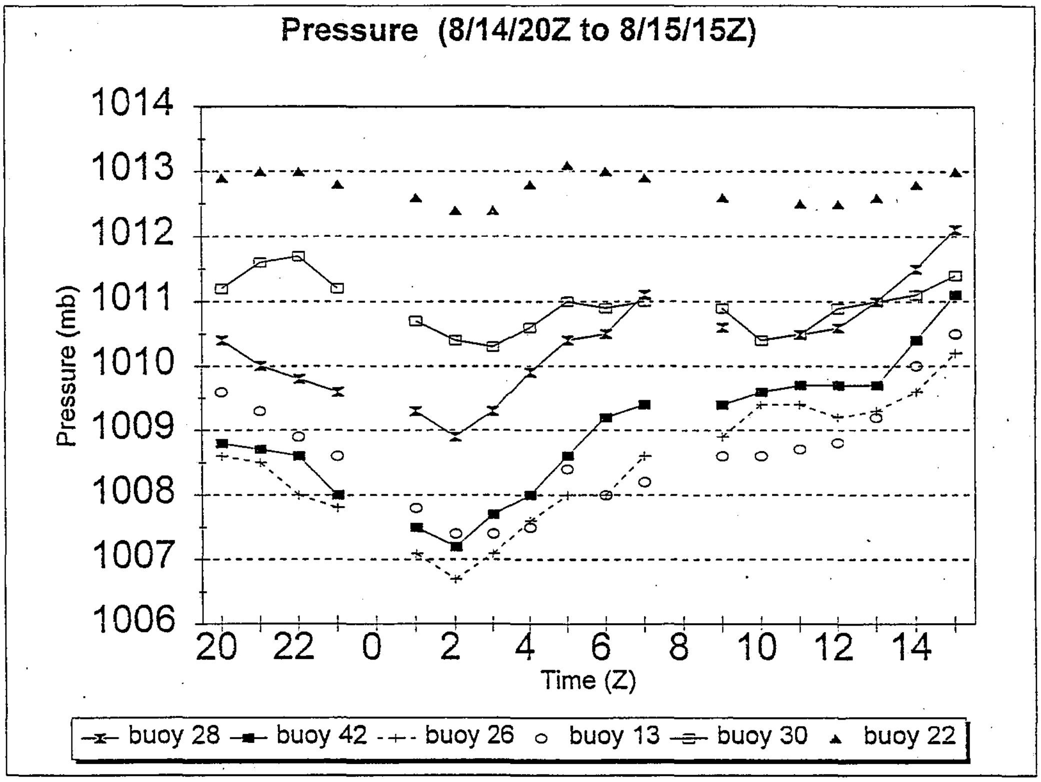


Figure 10) Observed wind direction and sea level pressure at coastal buoys. (note pressure rises prior to wind shift)

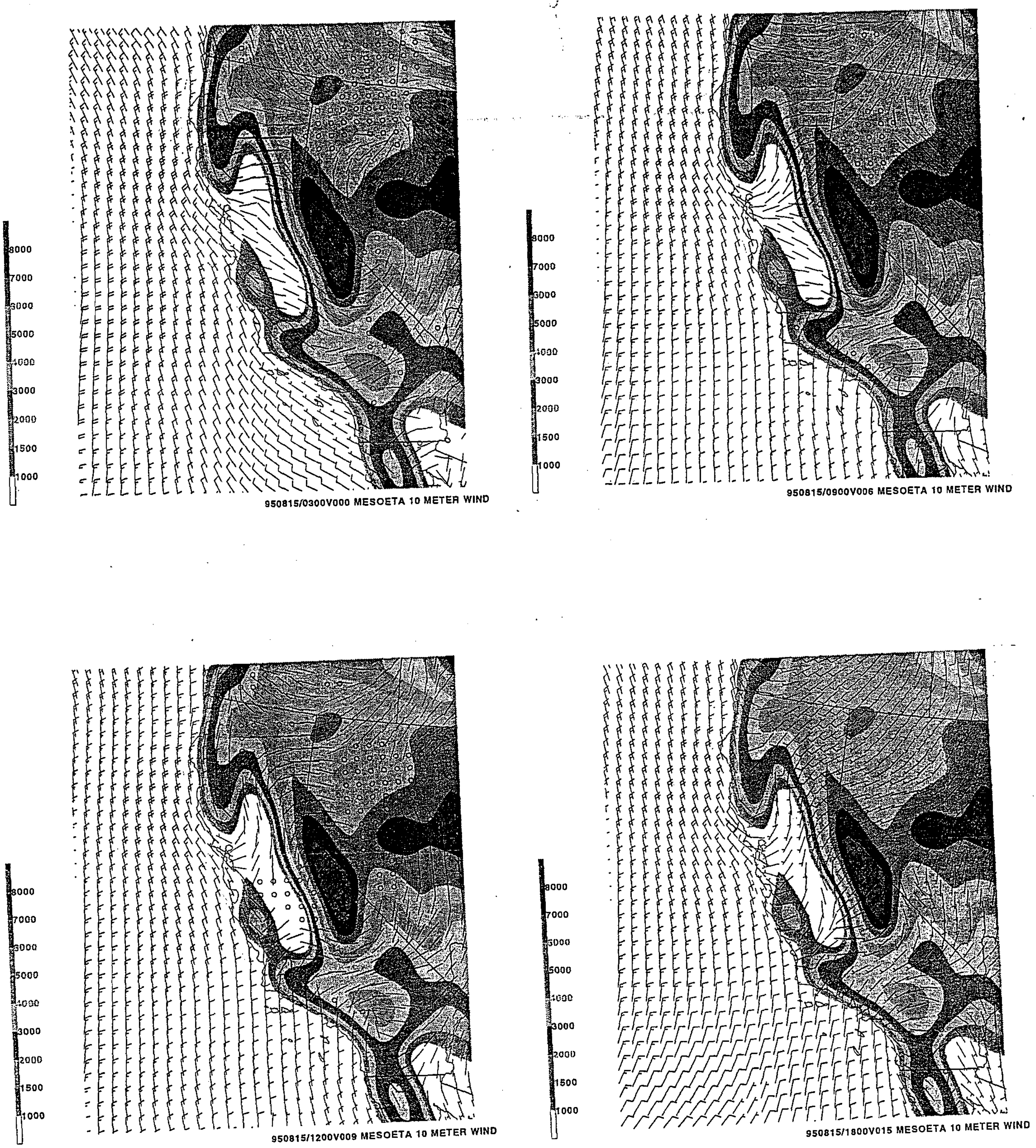
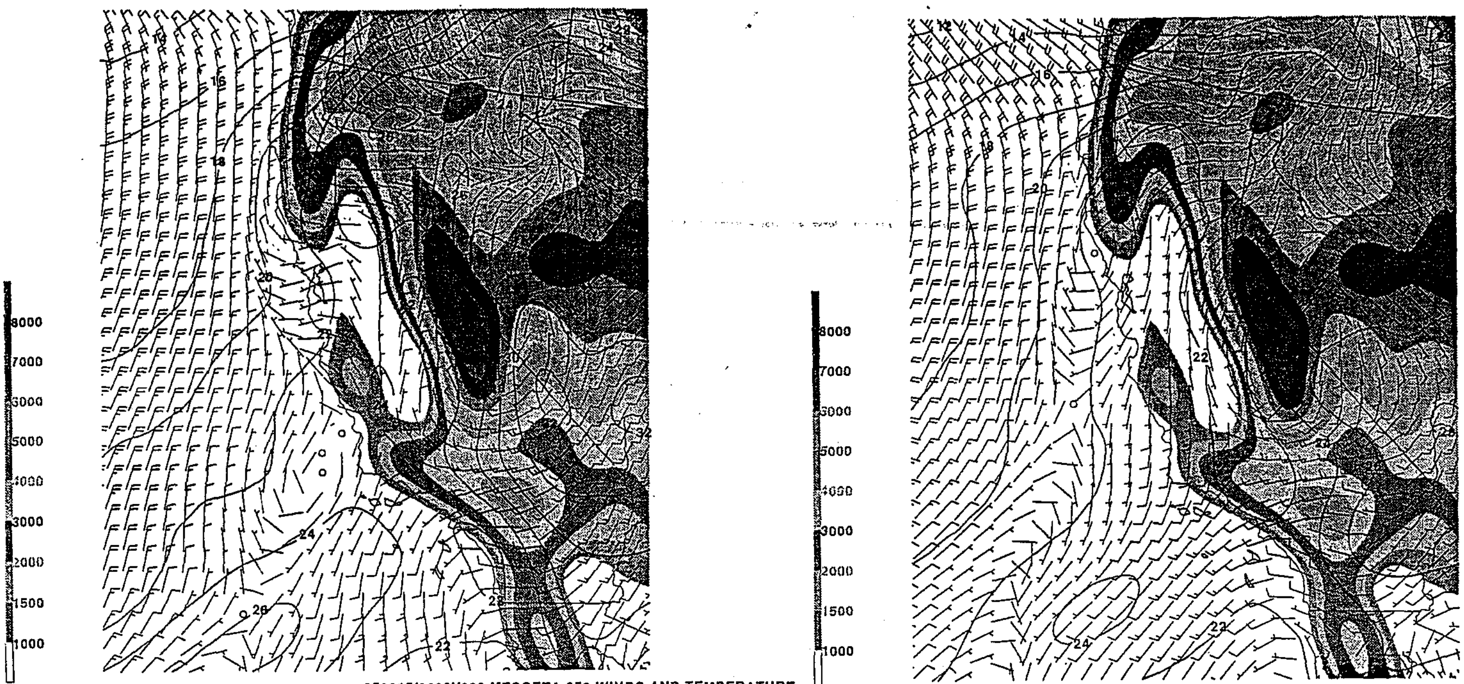
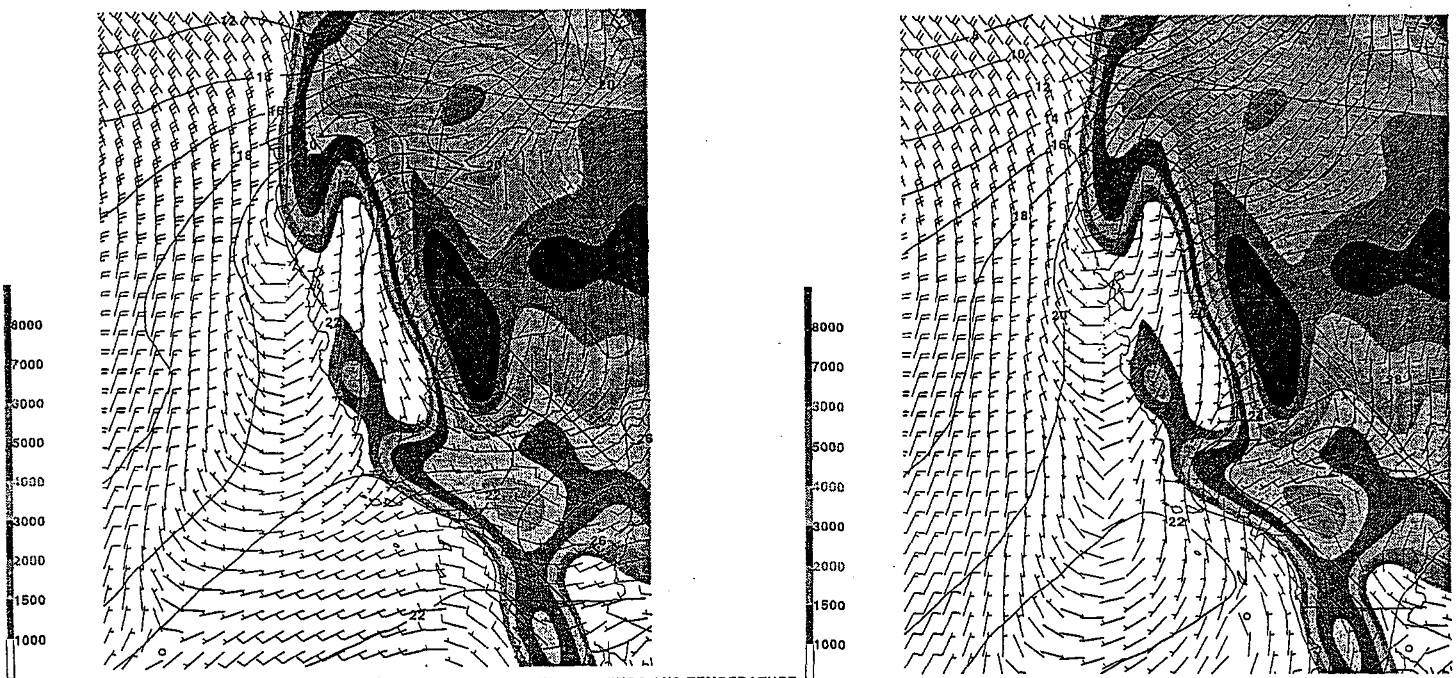


Figure 11) MESOETA 10-meter wind forecasts for; 1) 0-hour analysis at 8/15/03Z 2) 6-hour forecast valid 8/15/09Z 3) 9-hour forecast valid 8/15/12Z and 4) 15-hour forecast valid 8/15/18Z. Shading indicates model topography.



950815/0300V000 MESOETA 850 WINDS AND TEMPERATURE

950815/0900V006 MESOETA 850 WINDS AND TEMPERATURE



950815/1200V009 MESOETA 850 WINDS AND TEMPERATURE

950815/1800V015 MESOETA 850 WINDS AND TEMPERATURE

Figure 12) MESOETA 850 mb wind forecasts for; 1) 0-hour analysis at 8/15/03Z 2) 6-hour forecast valid 8/15/09Z 3) 9-hour forecast valid 8/15/12Z and 4) 15-hour forecast valid 8/15/18Z. Shading indicates model topography.

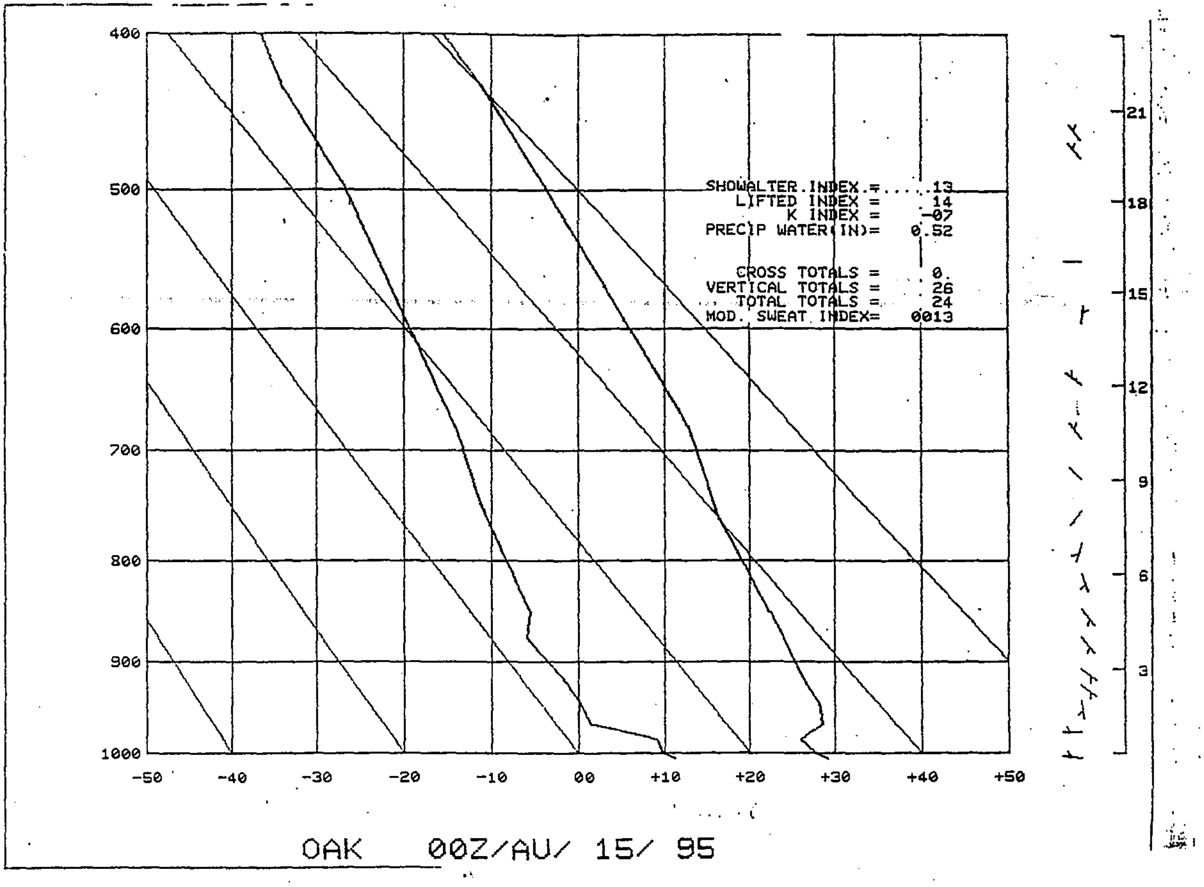


Figure 13a) Observed Oakland sounding for 8/15/00Z.

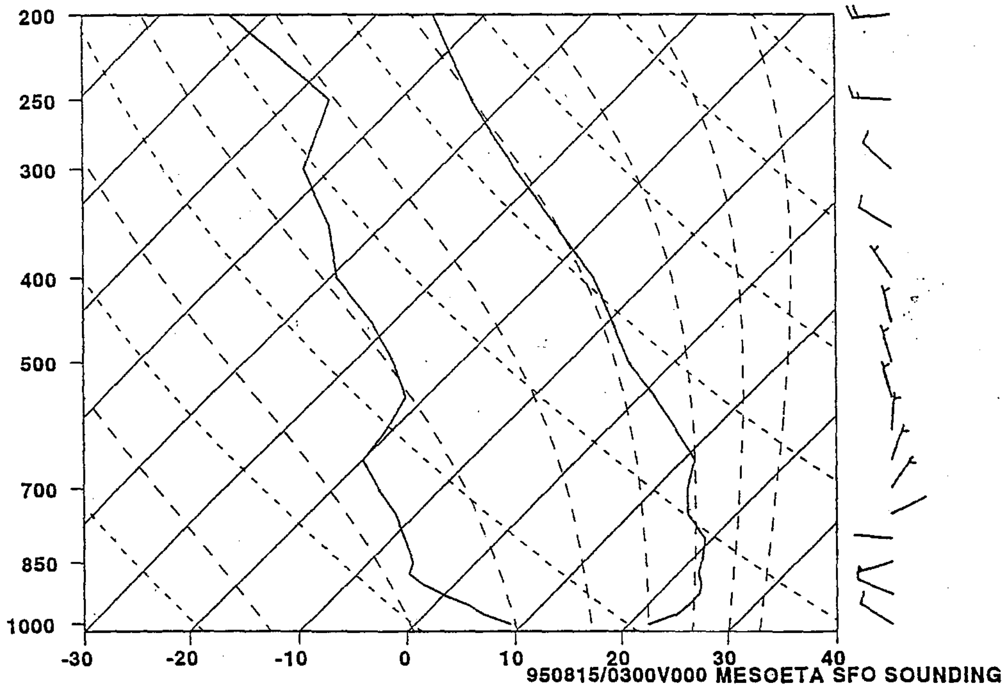


Figure 13b) Predicted San Francisco sounding for 8/15/03Z.

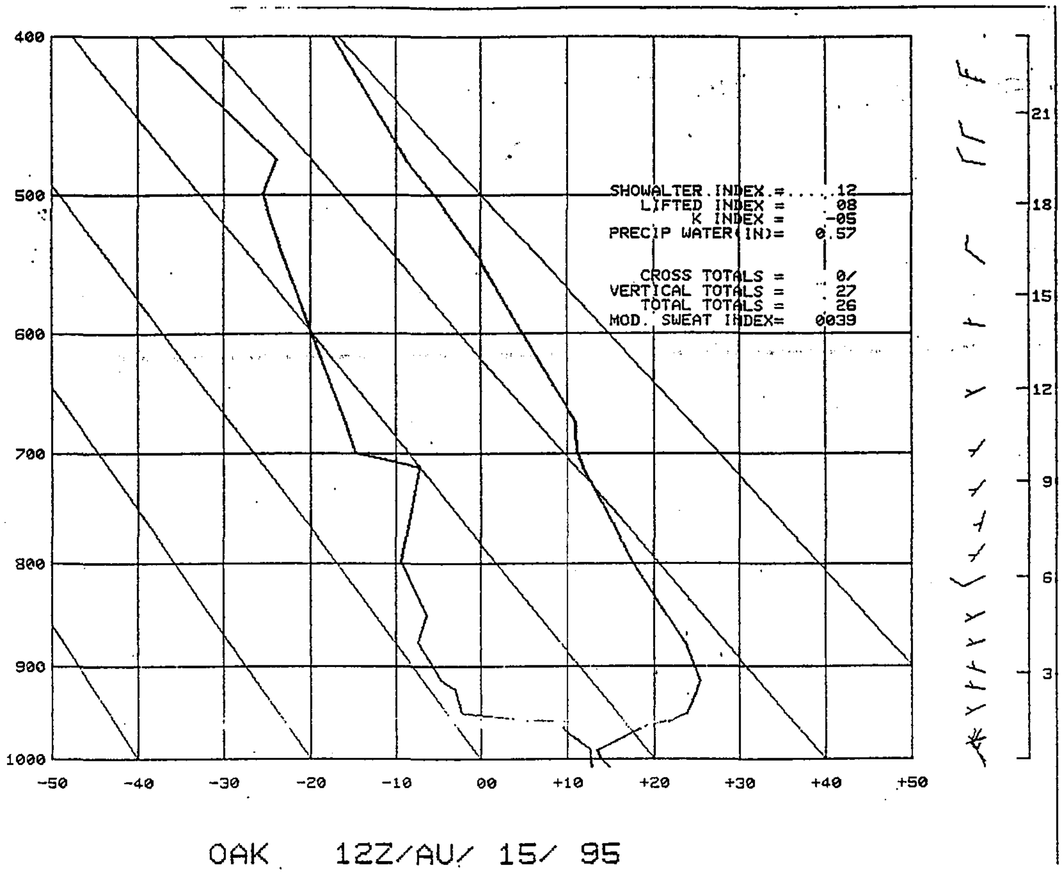


Figure 13c) Observed Oakland sounding for 8/15/12Z.

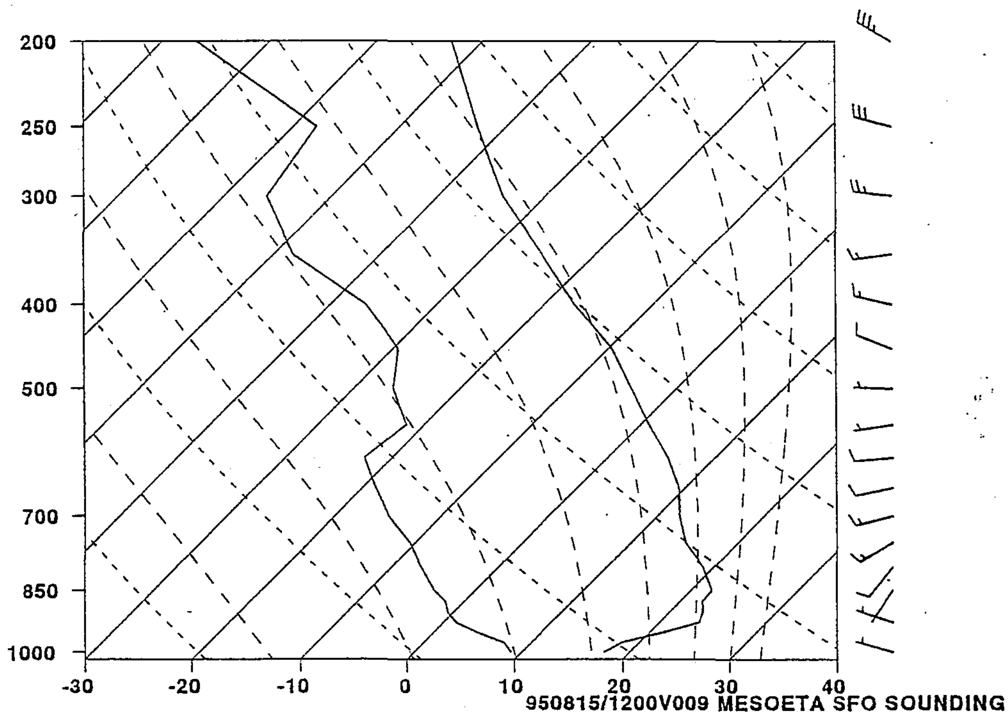


Figure 13d) Predicted San Francisco sounding for 8/15/12Z.

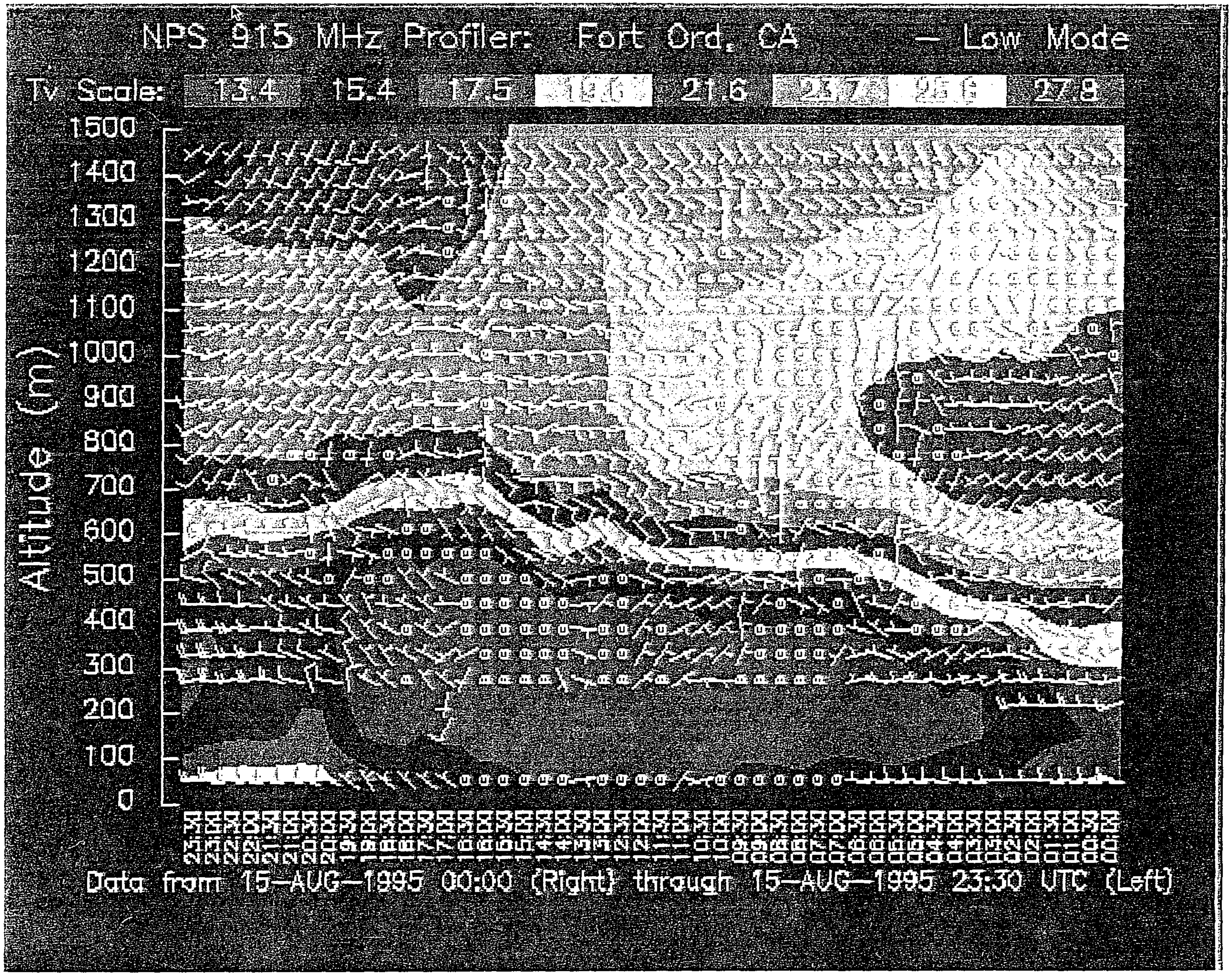


Figure 14) Fort Ord Profiler (915 MHz) Aug 15