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AN EXAMPLE OF PC-GRIDDS DIAGNOSTIC TECHNIQUES SPACIAL AND TEMPORAL CROSS-SECTIONS

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Introduction

A heavy rain event occurred over northern California and southwest Oregon during the 1993 Memorial Day weekend. Medford, Oregon received 1.06 inches of rain between 1200 LST 30 May and 1200 LST 31 May. The 0.74 inches received during the 30 May climate day (0000-2400 LST) was a new daily record. Redding, California received 4.17 inches during the storm and heavy rainfall in the mountains of northwest California produced flooding on the Trinity River. This case provides an opportunity to evaluate a significant precipitation event in the western United States using the latest tools available to the NWS field offices: gridded datasets from the regional scale models of the NMC, analyzed through PC-GRIDDS.

Data

Gridded forecast data from the "early" version of the Eta model (Black 1993) initialized at 1200 UTC 30 May 1993 is examined here. This Eta model run was well initialized with regard to synoptic-scale features (not shown) and provides an acceptable dataset for examining this system. The terrain of the Eta model (Fig. 1a) has considerably more structure than the NGM (Fig. 1b). The horizontal gridpoint resolution is approximately 80 km for the Eta (Black 1993) and 91.5 km for the NGM C grid at 60°N over North America (Hoke 1987). It should be noted that NWS field offices currently receive Eta/NGM gridded model output (PC-GRIDDS format) after interpolation to the 190 km resolution LFM grid. Forecast data were available every 12 hours for the model run considered here.

Synoptic Situation

The weather system producing the heavy rainfall event can be described as a persistent "warm conveyor belt" (Browning 1986) located off the coast of central California and extending northward into Washington. The Eta model forecast a strong, west-east oriented gradient in the 1000-500 mb thickness field at 0000 UTC 31 May along the West Coast (Fig. 2a). A surface low was also centered near 45°N 137°W, with a weak ridge paralleling the California and Oregon coastline. As the larger scale frontal zone moved ashore, a weak frontal wave pivoted northward along the West Coast. At 0000 UTC 31 May, this front extended from the offshore low to the Washington coast, then merged southeast into a thermal trough over Nevada. Some light rain fell at Medford between 0000 and 1200 UTC 30 May with this feature, but attention is directed toward a developing cold front due west of San Francisco. This front moved inland across northern California during the next 12 hours (Fig. 2b) accompanied by heavy rainfall. A surface low associated with the system developed and deepened moderately to 1006 mb by 1200 UTC 31 May. Why did this benign looking system produce such heavy rainfall?

At 850 mb, a wind maximum of 20 to 25 knots from the south to southwest was forecast to be located immediately off the West Coast at 0000 UTC 31 May (Fig. 3a). An area of weak convergence was located south of the offshore wind maximum and just northeast of the surface front (Fig. 2a). By 1200 UTC 31 May (Fig. 3b), the 850 mb wind maximum was forecast to extend from central Nevada, northward to Idaho. A second, weaker speed maximum remained along the northern California coast extending towards southwest Oregon. A large area of speed convergence was forecast from northern California into northern Nevada and Oregon.

The Eta forecast for 0000 UTC May 31 generated a closed cyclonic circulation center at 250 mb (Fig. 4a) directly above the 850 mb low center. A jet core of 80+ knots was located over the California-Oregon border and was forecast to persist in this position through 1200 UTC May 31 (Fig. 4b), but decrease in strength. The wind field forecast by the Eta model at 0000 UTC 31 May is highly speed divergent around the jet core (Fig. 4a) with the largest values of divergence collocated with the right entrance region of the speed maximum. This area of divergence was forecast to persist through 1200 UTC 31 May (Fig. 4b) over northern California but decrease in magnitude. It should also be noted that the broad area of net divergence downstream of the trough axis, although not solely ageostrophic, parallels the results of Moore and VanKnowe (1989). They found that in a curved jet-flow regime, the quasi-geostrophic (QG), four-quadrant ageostrophic divergence pattern was instead represented by two broad divergence cells. The cells were defined by QG, ageostrophic divergence downstream, and convergence upstream, of the trough axis as illustrated here.

Cross-sections

Cross-sections through the jet stream over northern California have been constructed (**A** to **B** in Fig. 1b). Heavy rain had developed over northwest California and southwest Oregon by 0000 UTC 31 May. Forecast cross-sections depicted a frontal zone at that time (Fig. 5a) in the potential temperature field where temperature decreases towards the west and isentropes slope from 700 mb towards the model surface. This temperature gradient diagnoses the larger scale thickness gradient forecast along the West Coast (Fig. 2a). Weak, upward vertical motion within the cross-section plane is forecast in a column directly under the jet core (see Fig. 4a for jet core location). The ageostrophic circulation vectors (Fig. 5b) show weak circulation at low-levels but a divergent horizontal component to the ageostrophic flow above 400 mb. Ageostrophic circulation vectors are produced using the command ACRC within PC-GRIDDS. This function combines the horizontal ageostrophic flow within the plane of the cross-section and a scaled omega, to derive the vector size and direction. The model forecasts a maximum of divergence, of the total wind, within the cross-section at 250 mb. Weak convergence is forecast just east of the frontal zone, sloping upward to a location just west of the surface front.

Along the same cross-section, but 12 hours later (1200 UTC 31 May), the Eta model forecast the vertical velocity values to double in magnitude and the core of upward motion to lower slightly to near 500 mb (Fig. 6a). The forecast pattern of potential temperature did not change since 0000 UTC, despite the mid-level development, and northeastward movement of the surface frontal wave within the Eta forecast (Fig. 2). Divergence aloft within the cross-section has increased somewhat (Fig. 6b) while convergence increased at low levels. This pattern of convergence of the total wind below 700 mb and highly divergent flow aloft diagnoses a well-developed mechanism for producing vertical motion. The ageostrophic circulation is more intense by this time, but is less divergent aloft than at 0000 UTC. At low levels, the circulation is weakly convergent, just above the model terrain surface, suggesting frontogenesis. Petterson's frontogenesis, as calculated by PC-GRIDDS, was positive over northern California at this time (not shown).

Time-Height Diagrams

The front developing and moving through the long-wave trough is depicted well by time-height sections forecast by the Eta model over Medford, Oregon (Fig. 7a) and for an offshore location (Fig. 7b). Locations of the data used for construction of the diagrams are indicated on Fig. 1b. The heaviest rains occurred at Medford between the 06 hour and 30 hour forecast times (Fig. 7a). During this period, the relative humidity was forecast to average 75 percent to 95 percent from the surface to 300 mb, but begin to decrease aloft after 36 hours. The forecast equivalent potential temperature pattern changes little for the first 24 hours then dramatic cooling occurs throughout the column during the second half of the 48 hour period. The largest amount of cooling was forecast at the 700 mb level where the temperature decreased 10K in 24 hours (after the Pacific cold front passed the Medford area. Some of the decrease in the 700 mb equivalent potential temperature is due to the decrease in relative humidity, although it remained above 80 percent. Cold advection calculated directly by PC-GRIDDS reached a maximum at 850 mb at the 36 hour forecast time (not shown). The wind forecast by the Eta model indicated strong southerly flow during the rain period with the jet-level flow rapidly decreasing in magnitude after the 36 hour forecast time. Low- to mid-level geostrophic cold advection (wind backing with height) was forecast after the frontal passage. For the entire forecast, equivalent potential temperature decreased with height from the surface to 700 mb indicating the atmosphere was convectively unstable. Interestingly, surface pressures at Medford were near 970 mb throughout the storm.

Over the eastern Pacific, the Eta model forecast a distinct and sharp cold frontal passage without the disruptive effects of terrain on the lower atmosphere (Fig. 7b). The cold front moved past this location between the 12 and 24 hour forecast times. After the front passed, distinct cooling was forecast at all levels with dramatic drying aloft and clouds (relative humidity > 60 percent) restricted to below 700 mb by the 24 hour forecast time. Passage of the upper-level trough is evident in the wind field (veering with time), leading to subsidence (not shown) which further supported the mid- to upper-level drying aloft. The convectively unstable layer is present in the forecast and increases in strength after the cold frontal passage. This feature intensifies as post-frontal cooling, and drying, occurs more rapidly at 700 and 850 mb than at 1000 mb. This environment is partially explained by the upward flux of specific and latent heat occurring from the model ocean surface into the lower layers of the model atmosphere over this grid point.

Discussion

The system examined here provides an opportunity to present some techniques of evaluating vertical motion and thermodynamic processes with gridded data. Rainfall totals for the event are not excessive for the region during a cold season storm, but are unusual for late May. Apparently the weak surface feature, forming on the cold side of the larger scale baroclinic band, became collocated with a nearly stationary jet speed maximum near the California-Oregon border. Strong upward motion developed within the middle and upper troposphere, as evident in the cross-sections oriented perpendicular to the jet core.

Knowledge of the regional topography allows further statements to be made about the rainfall pattern. A major feature of this storm was the persistent southerly flow throughout the depth of the troposphere (Figs. 2 and 3). In this pattern, orographics produce significant lift within the lower atmosphere over the northern end of the Sacramento Valley (Redding) and over the south facing slopes of the surrounding mountains. The orographic component of the lifting mechanism during this type of storm helps explain the heavy rainfall observed across northern California. Conversely, the valleys of southwest Oregon are within a rain shadow produced, in southerly flow, by the crest of the Siskiyou Mountains, located along the California-Oregon border. Therefore, the rainfall over southwest Oregon occurred largely without the orographic component that inflated the rainfall totals in California. It would seem that the rainfall recorded in southwest Oregon was more a product of persistent jet-level dynamics (a strongly divergent ageostrophic component to the wind field) and the forcing provided by the cold front circulation (convergent ageostrophic flow). Mesoscale models, including the 30 km Eta model now being run at the NMC, will assist in studying this type of hypothesis. Meanwhile techniques for evaluating vertical motion on various scales via PC-GRIDDS need to be developed and made familiar to the operational community.

Acknowledgements

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References

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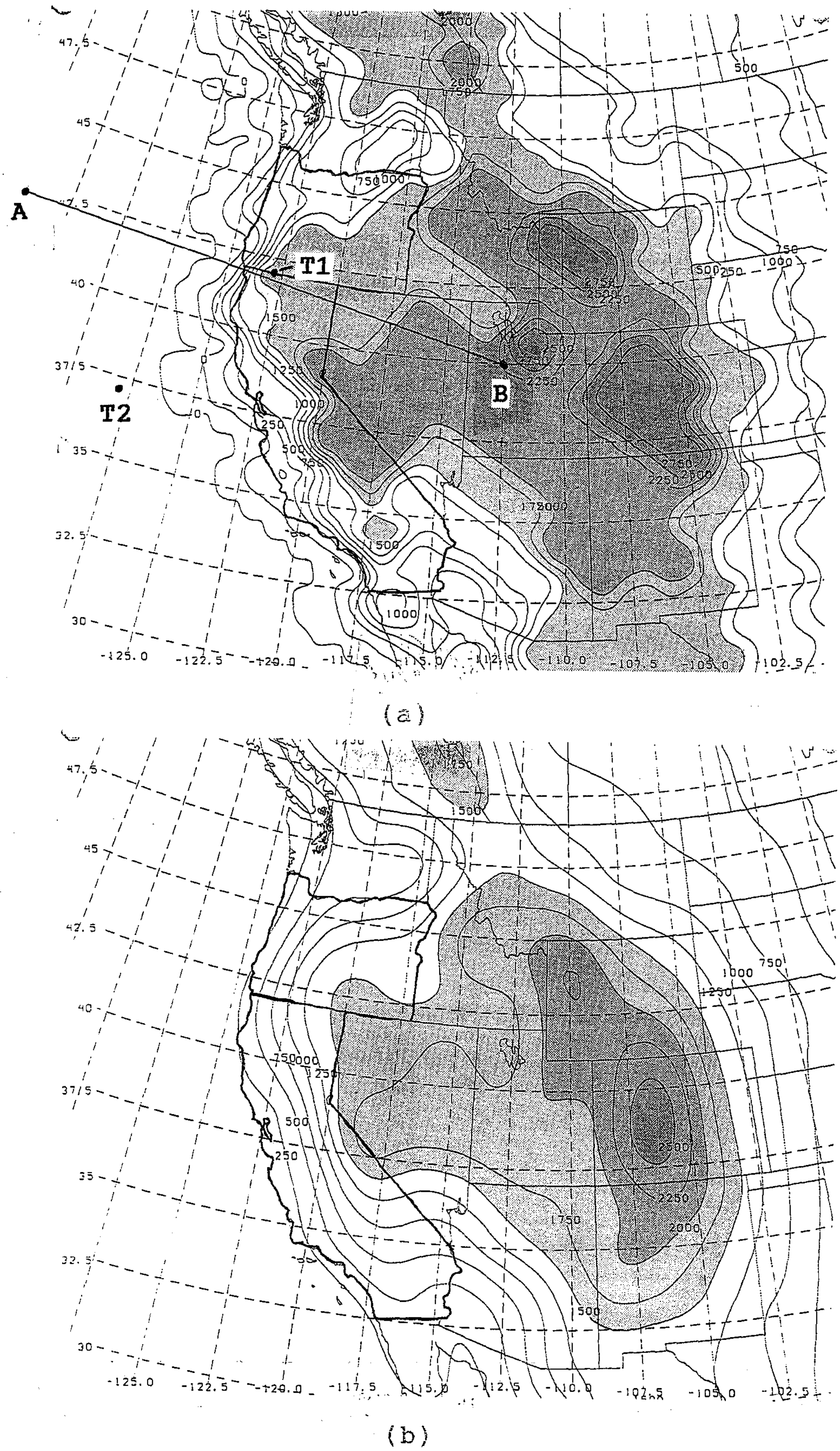
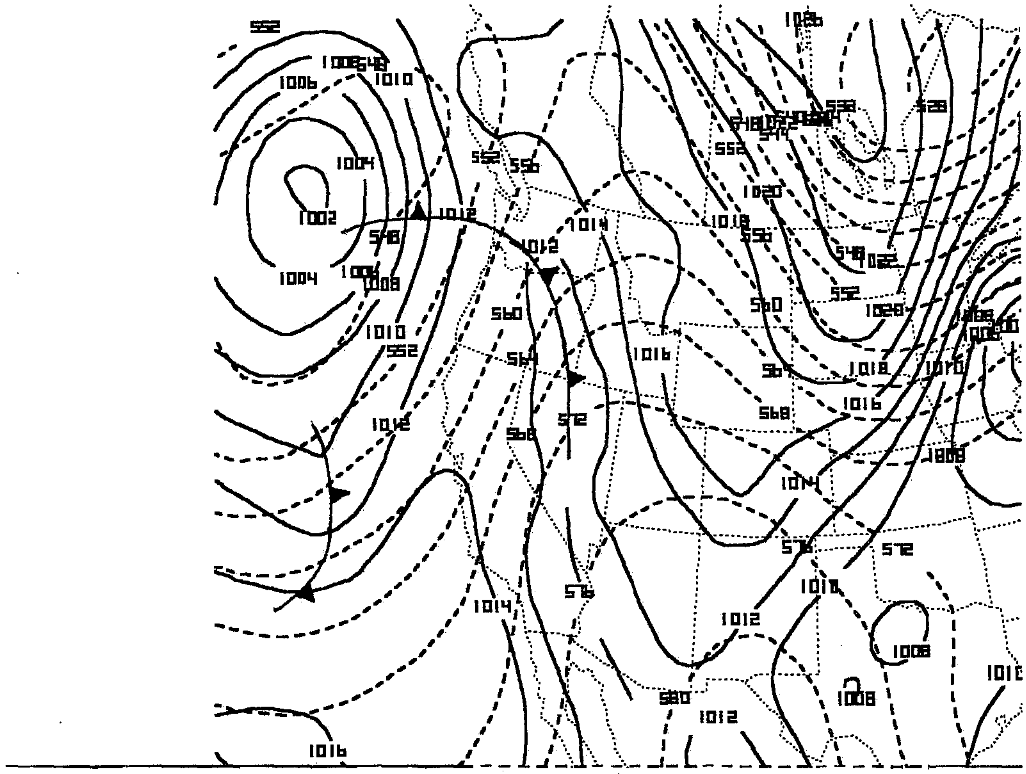
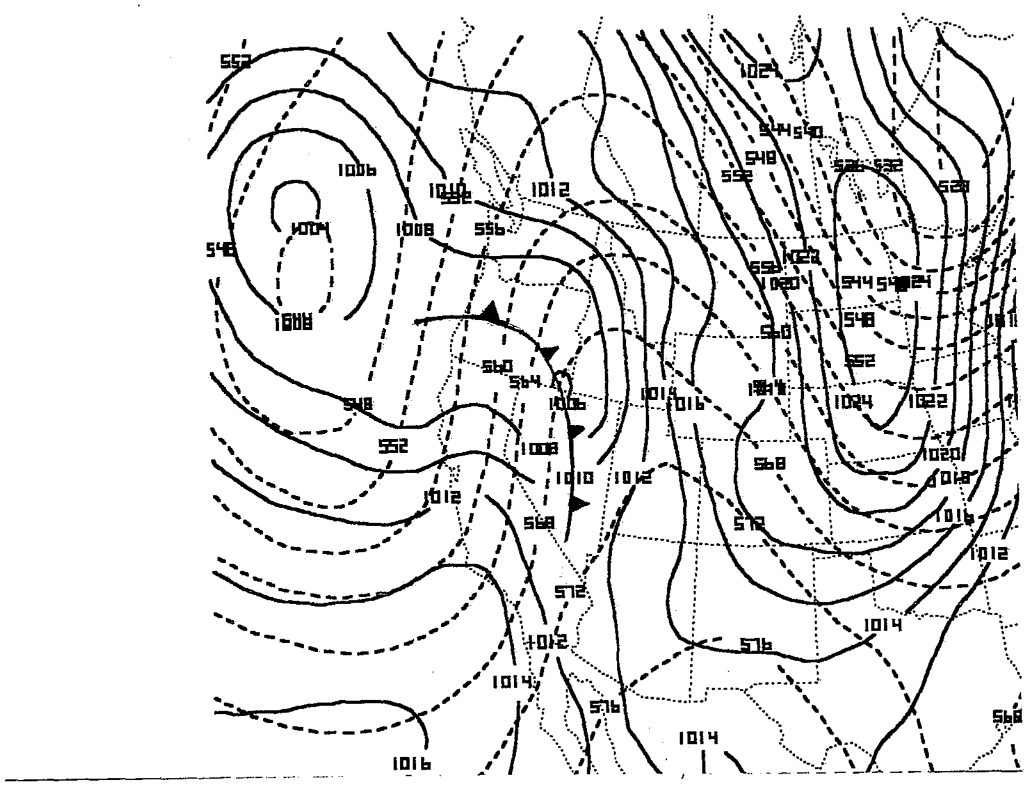


Figure 1. Terrain height of (a) Eta model and (b) NGM over the western U. S. at full grid point resolution. Contour interval 250 meters, shaded above 1500 m. Cross-sections described in text indicated from **A** to **B** on Eta terrain. Locations of time-height diagrams indicated at **T1** and **T2**.

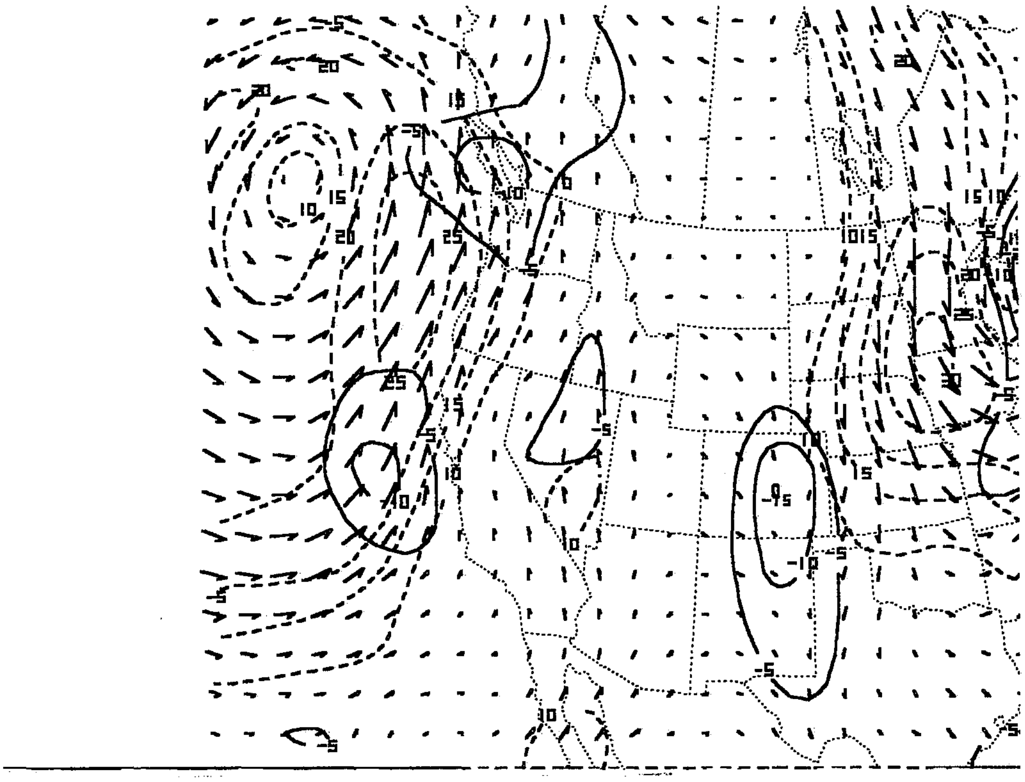


(a)

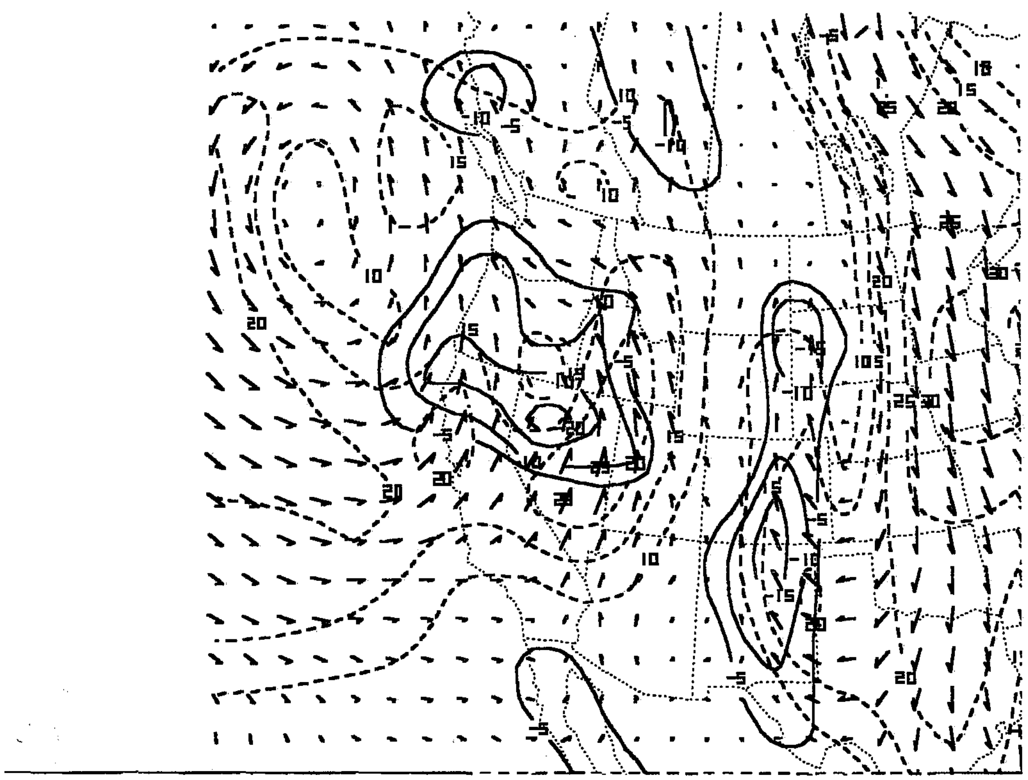


(b)

Figure 2. Eta forecast of mean sea level pressure (solid) every 2 mb and 1000-500 mb thickness (dashed) every 40 m for (a) 0000 UTC and (b) 1200 UTC 31 May 1993. Position of cold front discussed in text also indicated.

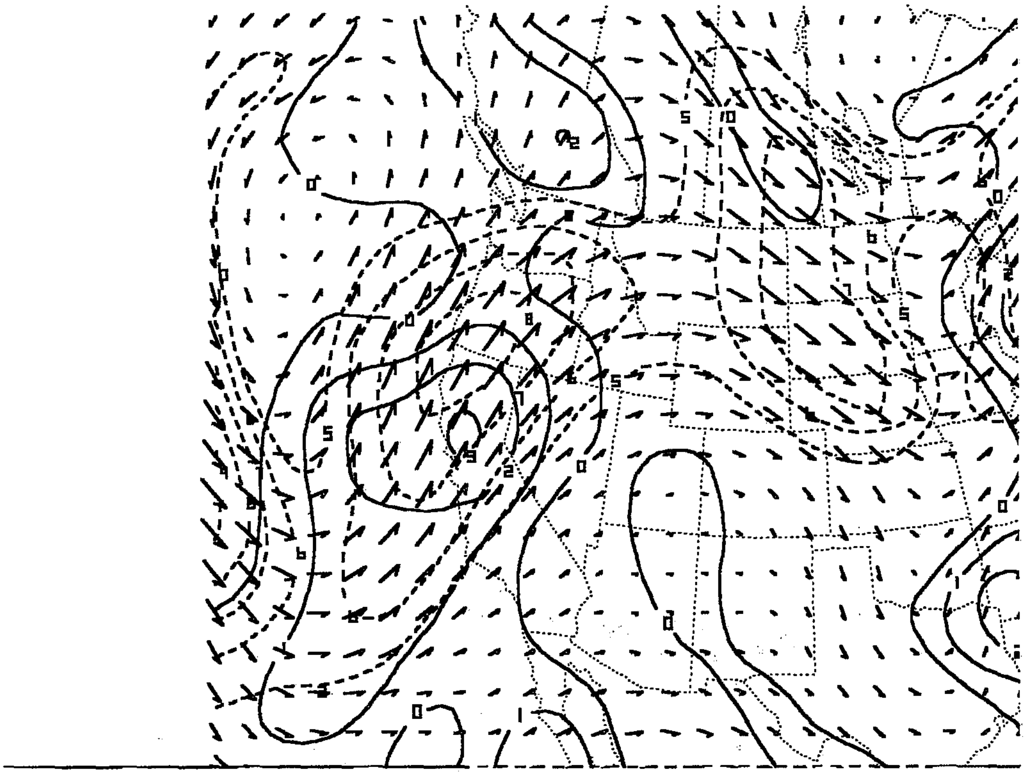


(a)

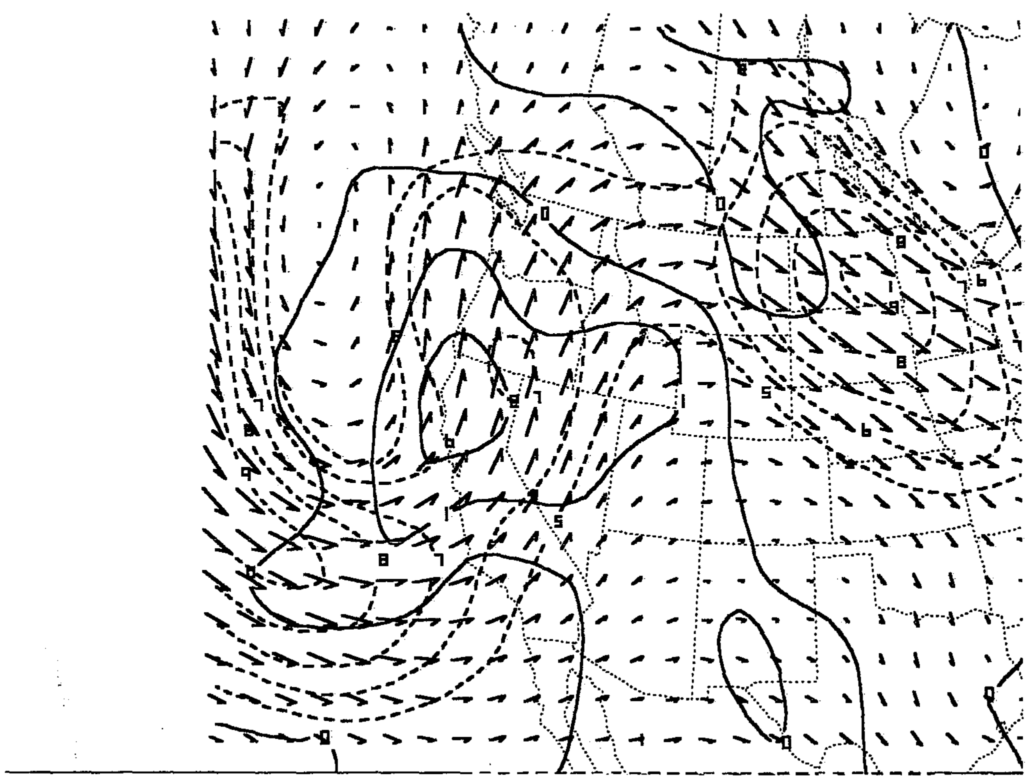


(b)

Figure 3. Eta forecast of 850 mb wind (arrows), isotachs (dashed) greater than 10 knots every 5 knots and divergence (solid) less than zero every 5x10-6 sec-1 for (a) 0000 UTC and (b) 1200 UTC 31 May 1993.

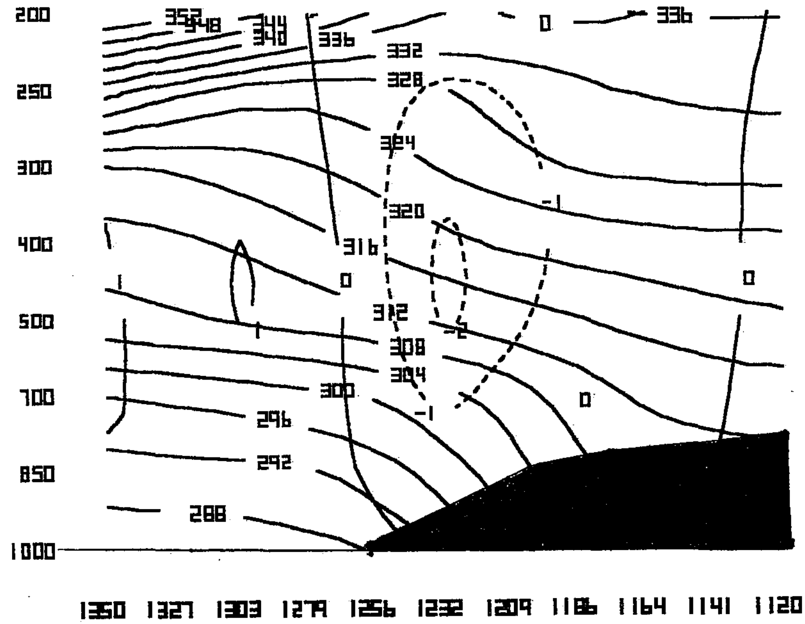


(a)

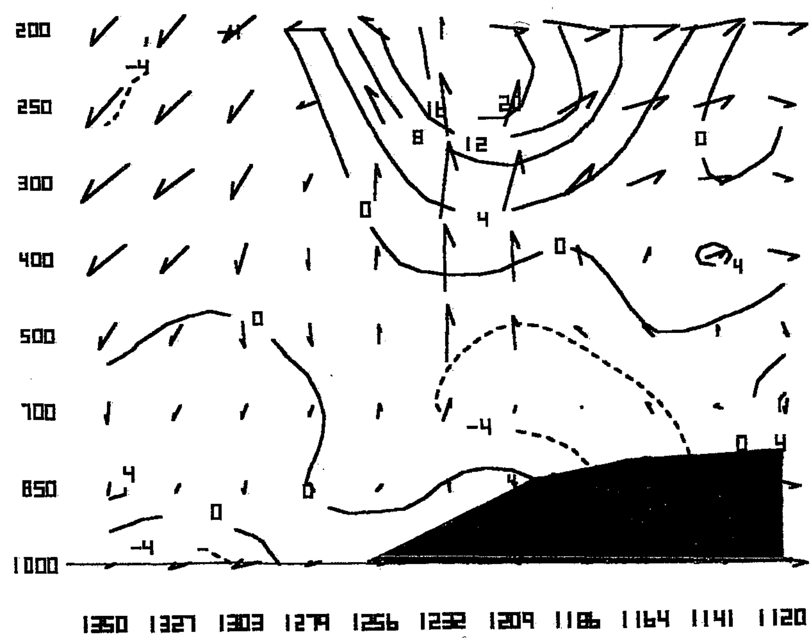


(b)

Figure 4. Eta forecast of 250 mb wind (arrows), isotachs (dashed) greater than 50 knots every 10 knots and divergence (solid) greater than zero every 10x10-6 sec-1 for (a) 0000 UTC and (b) 1200 UTC 31 May 1993.



(a)



(b)

Figure 5. Eta forecast at 0000 UTC 31 May along cross-section for (a) potential temperature (solid) every 4K and omega (positive solid, negative dashed) every 1x10-3 microbars/second and (b) ageostrophic wind vectors (arrows) and divergence (positive solid and negative dashed) every 4x10-6 sec-1. Vertical axis is pressure (mb) and horizontal axis is longitude (degrees times 10). Cross-hatched area in the lower right corner represents the Eta terrain.

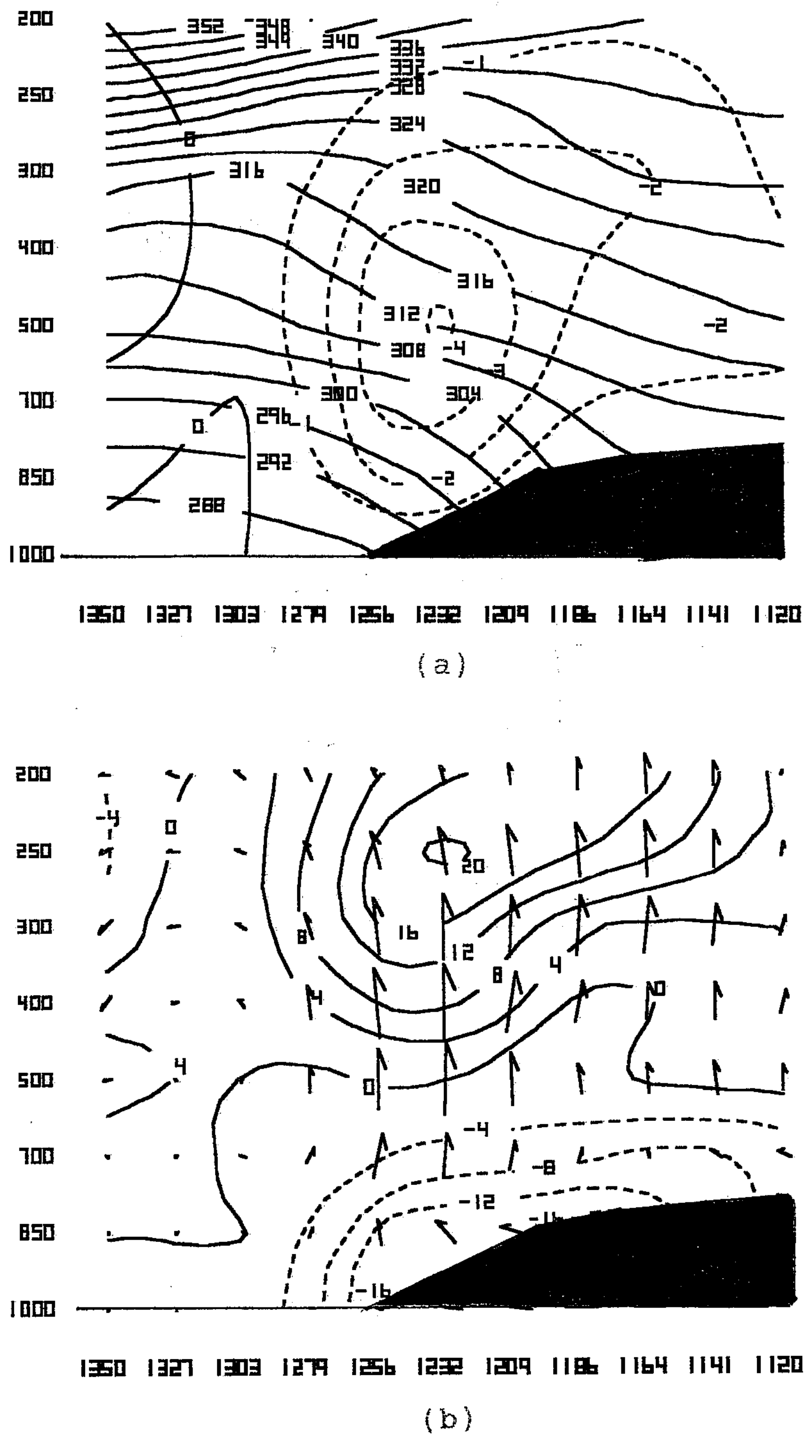
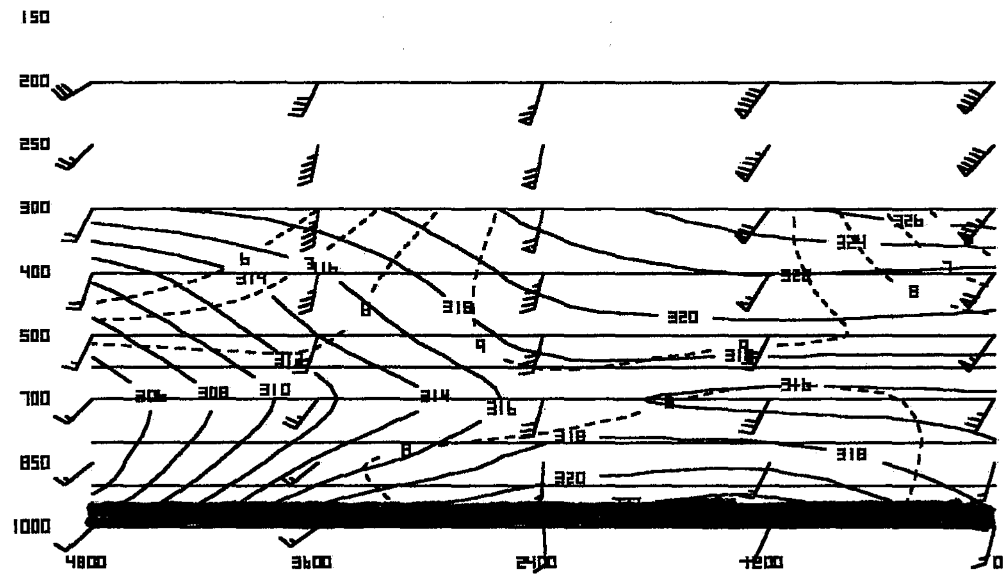
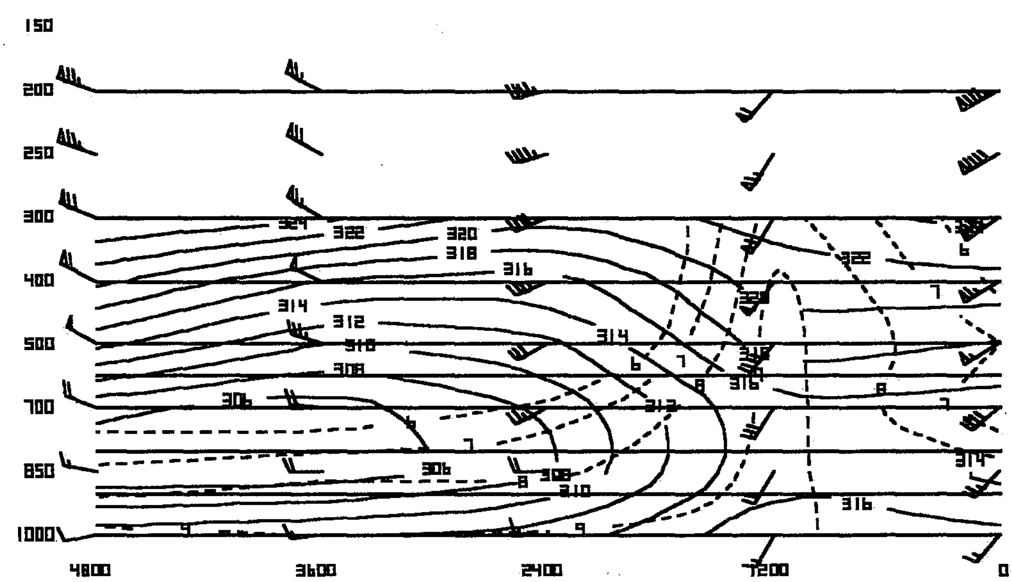


Figure 6. Same as in Fig. 5 except Eta forecast at 1200 UTC 31 May.



(a)



(b)

Figure 7. Time-height diagram of Eta model forecast (00-48 hours) at (a) point **T1** and (b) point **T2** in Fig. 1b valid 1200 UTC 30 May to 1200 UTC 1 June 1993. Equivalent potential temperature (solid) every 2K, relative humidity 60% and greater every 10% and wind (knots) in standard plotting convention. Vertical axis is pressure (mb) and horizontal axis is forecast time (hours times 100).