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# AN EXAMPLE OF WEAK DYNAMIC FORCING IN AN UNSTABLE WINTERTIME ATMOSPHERE

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### Introduction

On March 4 and 5, 1998 convective snow showers were reported across eastern Washington, eastern Oregon, and most of Idaho. The interesting part of this event was that these convective showers occurred mainly during the night and early morning hours, as opposed to the afternoon. Although the resulting snowfall amounts were only in the 1" to 3" range, the rush-hour timing and melting/freezing on roadways caused considerable disruption to the public, including numerous traffic accidents.

This Technical Attachment (TA) will briefly document the event and examine the likely mechanisms for the nocturnal convection. The main focus of this study is the effect of wintertime instability on apparently weak dynamic forcing.

### Omega Equation and Stability

Before examining the event, the quasi-geostrophic omega equation should be revisited. The equation in its usual form indicates that quasigeostrophic vertical motion is forced by vertically varying geostrophic vorticity advection and horizontally varying geostrophic temperature advection (terms 1 and 2 on the right-hand-side respectively).

$$\nabla^2(\sigma\omega) + f_0^2\frac{\partial^2\omega}{\partial p^2} = -f_0\frac{\partial}{\partial p}(-V_g\cdot\nabla\zeta_g) - \frac{R}{p}\nabla^2(-V_g\cdot\nabla T)$$

Term 1 Term 2

Note that while forecasters often approximate (or assume) the vertical/horizontal variations, these approximations can be misleading. However, using gridded data, it is a relatively easy task to actually compute these variations.

An often overlooked component of this equation is the bulk static stability ($\sigma$), which is defined as:

$$\sigma = -\frac{RT}{p\theta}\frac{\partial\theta}{\partial p}$$

Since $\partial\theta/\partial p$ is typically less than 0, then $\sigma > 0$. Large values of $\sigma$ indicate high static stability, while low values indicate low stability. Thus, the same geostrophic "forcing" (right-hand terms) in a less stable atmosphere produces a larger value of $\omega$ than if the atmosphere were stable. This is somewhat intuitive since stability means that the atmosphere is resistant to vertical motions.

In day-to-day forecasting, the implications of this fact can be very important. A minor short wavelength feature is often discounted as "lacking dynamics." But in an atmosphere with low static stability, the corresponding forcing produced by this minor wave can be equal to that of a much stronger wave in a more stable environment. Therefore, it is worthwhile to monitor the stability of the atmosphere at all times, not just during the summer convective months.

Another measure of instability is potential instability (also known as convective instability). Bluestein (1992) states that a layer of air in which air-parcel motion is stable with respect to saturated, vertical displacements, can become conditionally unstable when the entire layer is lifted to saturation if $\theta_e$ (equivalent potential temperature) decreases with height ($\partial\theta_e/\partial z < 0$). Pages 221-222 in Bluestein (1992) shows this in Figs 4.43 and 4.44. Note that this is distinctly different from the traditional parcel instability (e.g., Lifted Index and CAPE), because in this case, a layer of the atmosphere needs to be lifted to saturation by some mechanism first before it becomes unstable. This layer can be lifted via a number of methods, such as a large-scale synoptic disturbance or upslope flow against a mountain.

## Snow Shower Events

### *a. 4 March 1998*

On the morning of March 4, a strong Omega block was located over the central US. Upstream of the block, a deep cold low resided over the northwestern US with 500 mb temperatures of -36°C (Fig. 1). Moisture in Wyoming was being forced northwestward into Alberta and British Columbia before going over the blocking ridge (Fig. 2). This plume of moisture was coincident with an old occluded front which was located over western Montana. This is seen in the 04/12Z Eta analysis of winds and temperatures (Fig. 3). Overlaid on this figure is the Laplacian of the horizontal geostrophic temperature advection (term 2 in the omega equation). Note that the negative Laplacian (dashed lines) results in negative omega, or upwards vertical motion. Thus, while the temperature advection looks weak, there is a well-defined area of forcing for ascent by geostrophic temperature advection.

Low-level winds were weak (less than 10 kts) so orographic lift was minimal. The jet stream was well south of the area so that there was no contribution from jet streak ageostrophic dynamics. And since the time of the event was in the night and early morning hours, there was no destabilization due to solar heating. The horizontally varying geostrophic temperature advection was the only apparent "forcing" mechanism. This forcing was rather weak, but the low levels of the atmosphere were potentially unstable. A time-height cross section from the 04/12Z Eta model (Fig. 4) at Mullan Pass, ID (MLP, see Fig. 3 for location) of $\theta_e$ and relative humidity shows $\partial\theta_e/\partial z < 0$ in a layer from the surface up to about 700 mb in a nearly saturated environment. The resulting weak Omega from the temperature advection was able to lift this potentially unstable layer to saturation and initiate convection, resulting in significant bursts of heavy snow.

Sheriff and spotter reports in the Idaho Panhandle indicated brief heavy snowfalls during the morning hours (i.e., 0400 to 1000 local time, 1200-1800 UTC) with amounts averaging 1" to 3" in most areas. During the early afternoon, a ski resort in the northern Panhandle picked up 5" of new snow in 2 hours. The relatively warm roadways initially melted the snow, but as the air temperature was below freezing this quickly turned to ice. There were numerous accidents (including several jack knifed tractor-trailers) on Highway 95 near Bonners Ferry, ID (BON on Fig. 3).

### *b. 5 March 1998*

On the morning of March 4, the Eta model analyzed a weak shortwave over the Dakotas, which is apparent on the 04/12Z Water Vapor imagery (see Fig. 2). This shortwave was forecast to move westward across Montana overnight (Fig. 5), placing the Idaho Panhandle and extreme eastern Washington in weak Positive Vorticity Advection (PVA) at the 500 mb level by the morning of the 5th. In order to assess the change in PVA with height, a time-height cross section from the 04/12Z Eta model run (Fig. 6) was constructed at Coeur d'Alene (COE, see Fig. 3 for location). The figure shows that while the PVA was weak at 500 mb around 05/12Z, there was much stronger PVA above 500 mb, resulting in increasing PVA with height over COE at this time. Additionally, the low levels of the atmosphere remained potentially unstable with $\partial\theta_e/\partial z < 0$ up to about 700 mb. The Laplacian of geostrophic temperature advection (not shown) was near zero at this time so there was no contribution from this term of the Omega equation.

The interaction of the weak shortwave moving into western Montana with the unstable and moist air mass, initiated convection once again during the night and early morning hours of March 5, with observed snowfall rates of approximately 1" to 3" per hour. The morning "rush-hour" timing of this event was especially hazardous to commuters as the snow once again turned the road to ice. A number of major roads in the Spokane/Coeur d'Alene metro area were closed due to numerous accidents.

## Conclusion

Forecasters often attempt to judge the relative strength of various dynamic forcing mechanisms (e.g., PVA, Warm Advection). A system with weak dynamics is often discounted in its ability to provide enough lift to produce precipitation. However, the stability of the atmosphere also needs to be taken into account. The same dynamic forcing produces a much larger response in a less stable atmosphere than in a stable one. As a result, a "weak" shortwave can produce precipitation if the atmosphere is unstable enough.

The cases presented here are a good example of weak dynamic forcing acting on a very unstable wintertime atmosphere. Evaluation of potential instability ($\partial\theta_e/\partial z < 0$) was important in correctly assessing the possibility of convection, even in a wintertime atmosphere.

## Acknowledgments

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## References

Bluestein, H. B., 1992: Synoptic-Dynamic Meteorology in Midlatitudes, Volume I Principles of Kinematics and Dynamics. Oxford University Press, New York.

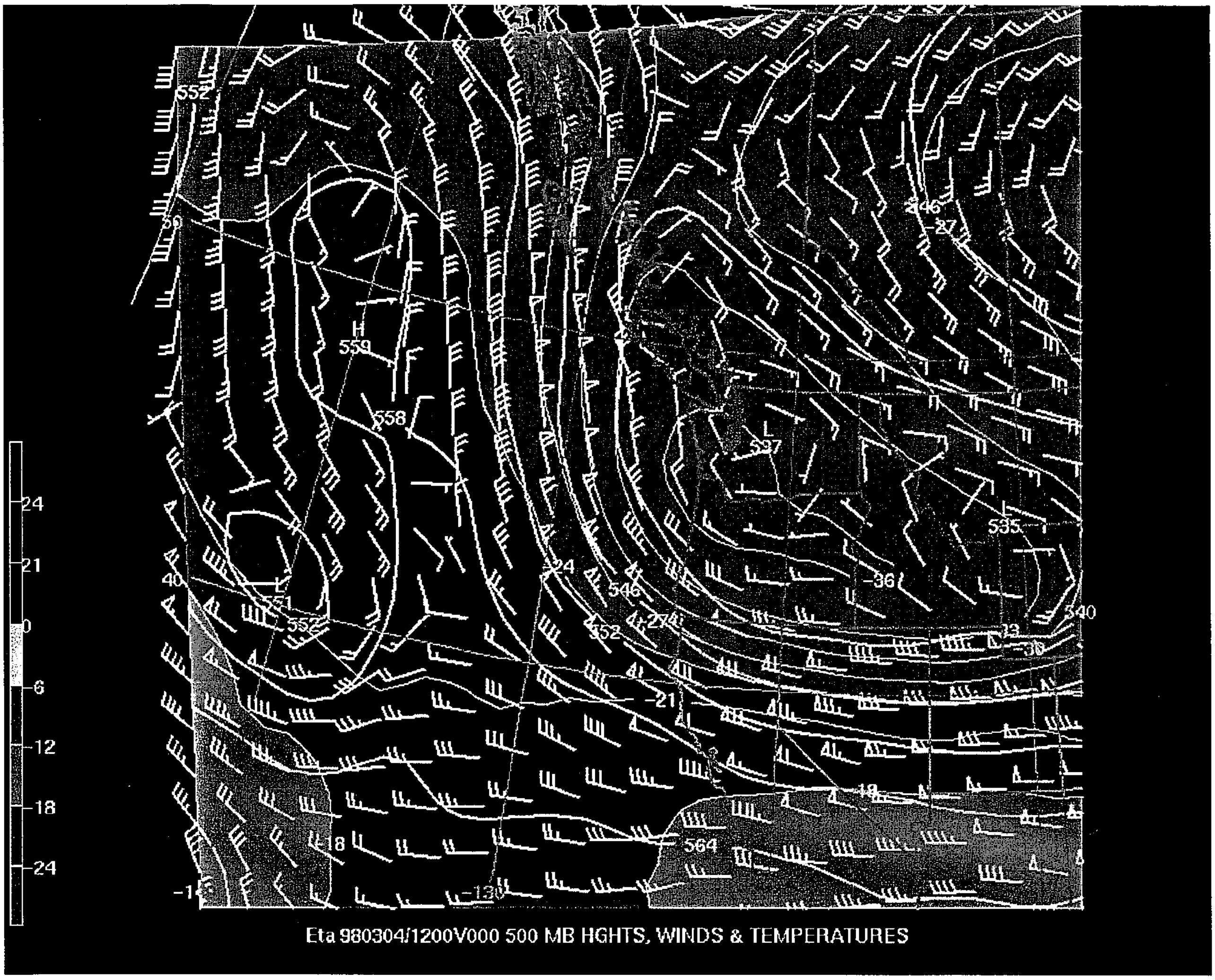


Fig. 1 Eta 980304/1200V000 500 MB Heights, Winds, and Temperatures

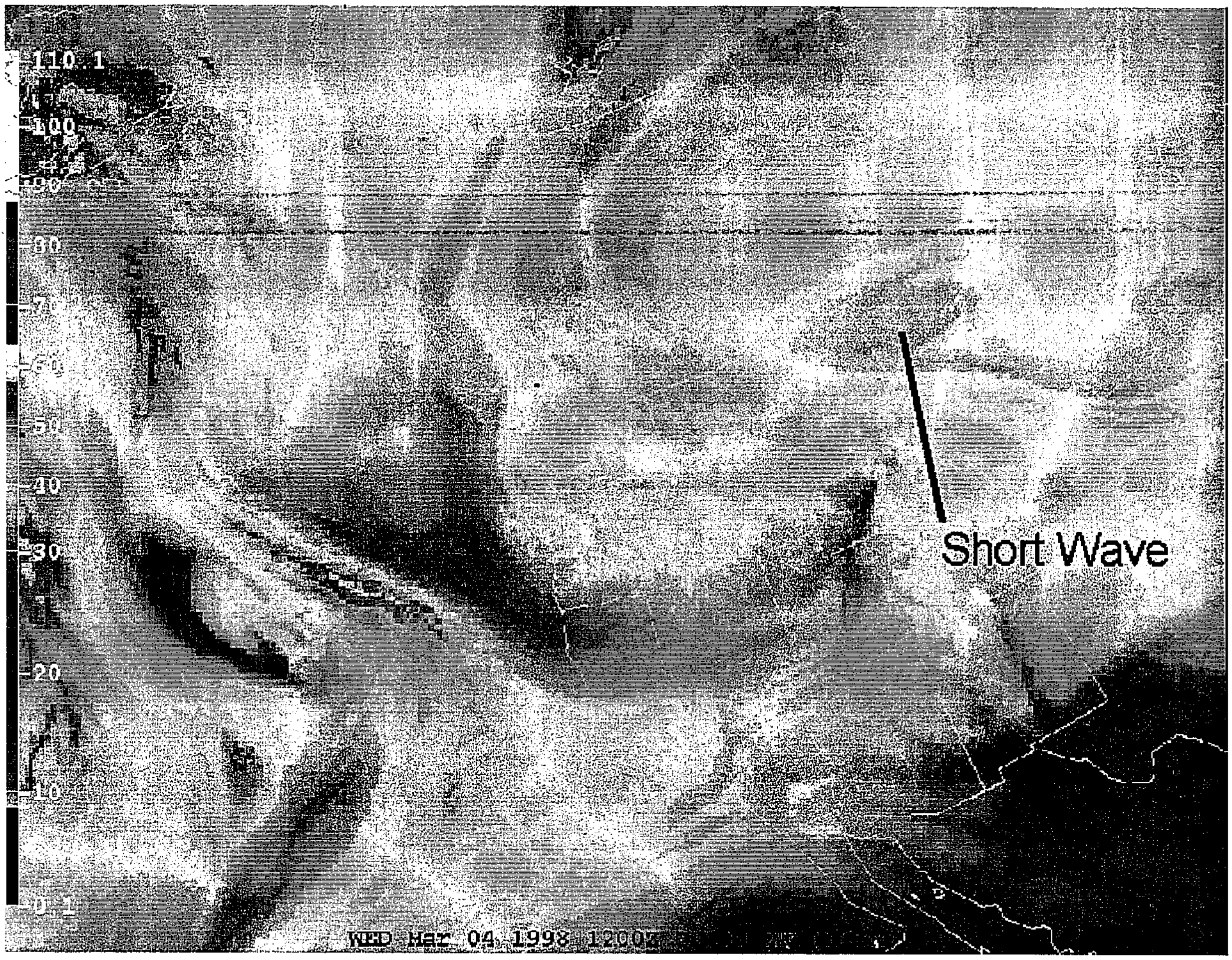


Fig. 2 - Wednesday, March 4, 1998 - 1200Z

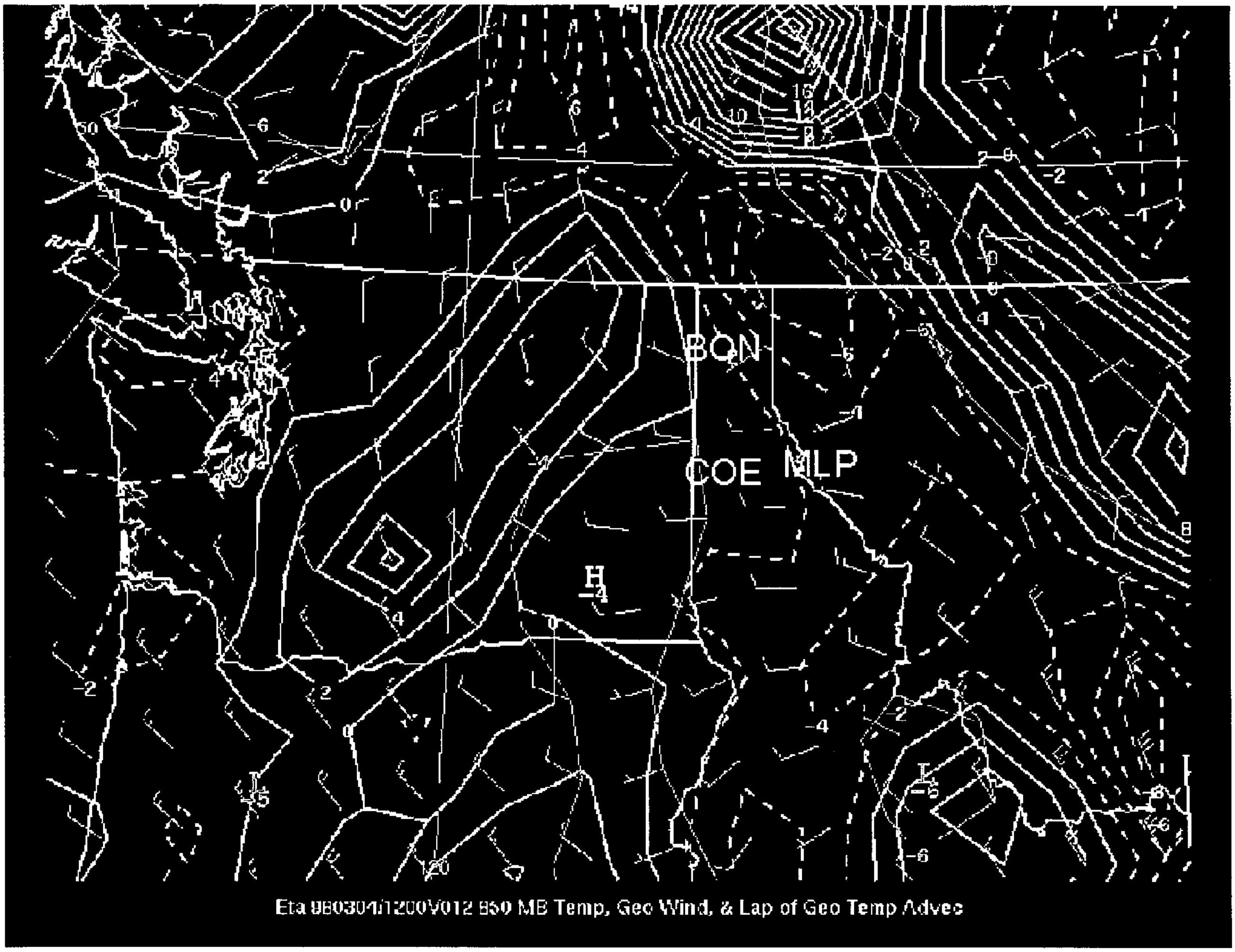


Fig. 3 - 04/12Z Eta analysis of winds and temperatures

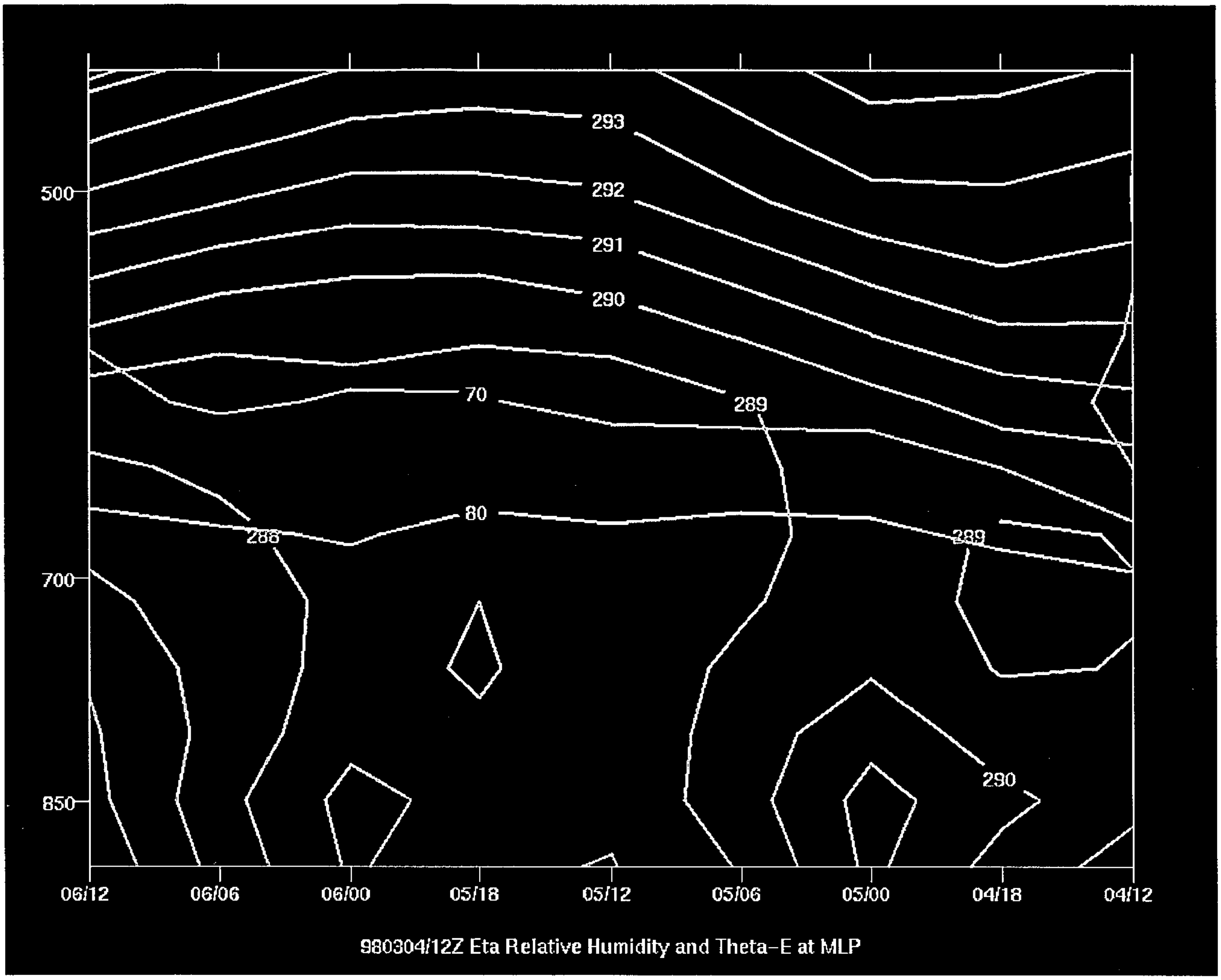


Fig. 4 - 980304/12Z Eta Relative Humidity and Theta E at MLP

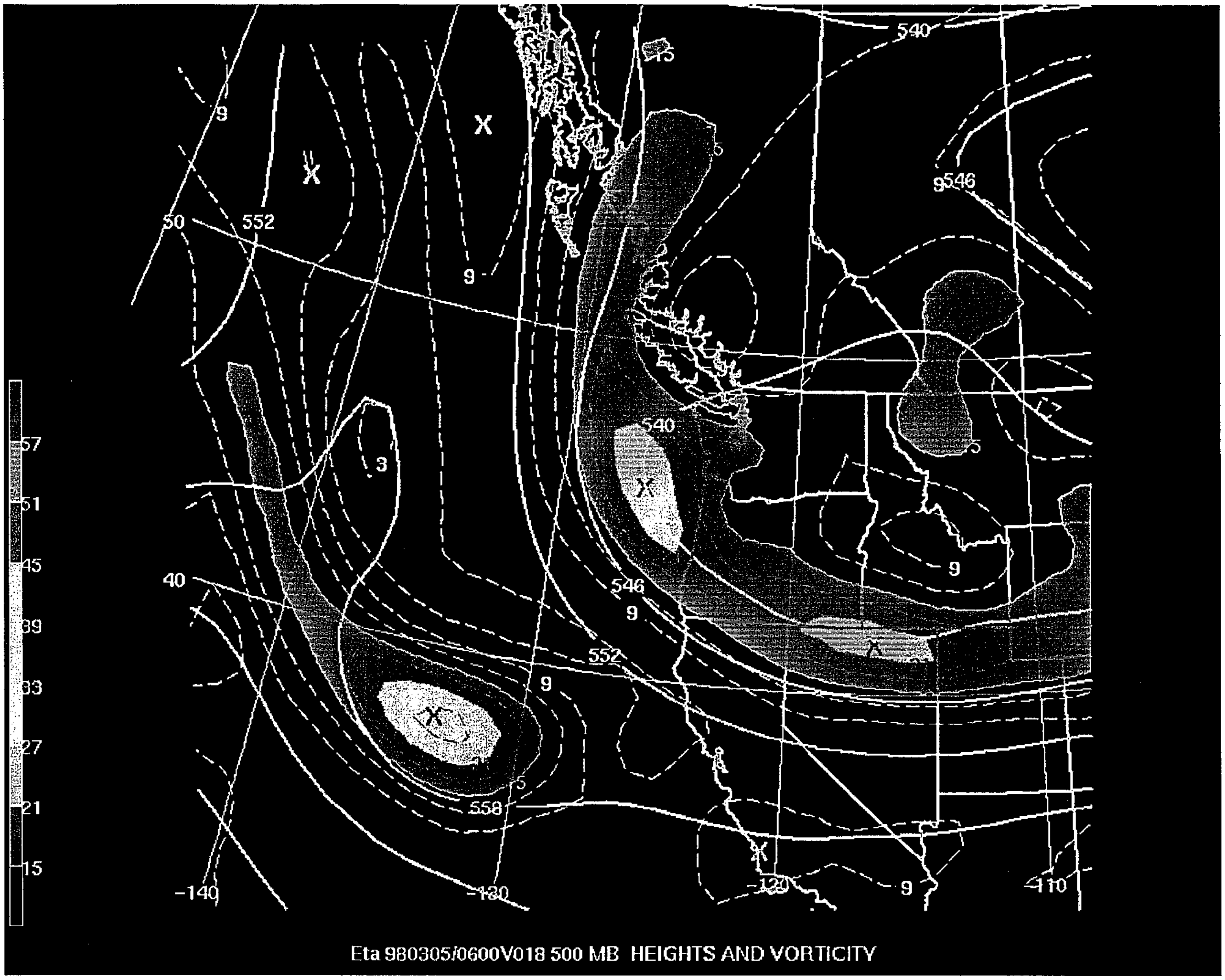


Fig. 5 - Eta 980305/0600V018 500 MB Heights and Vorticity

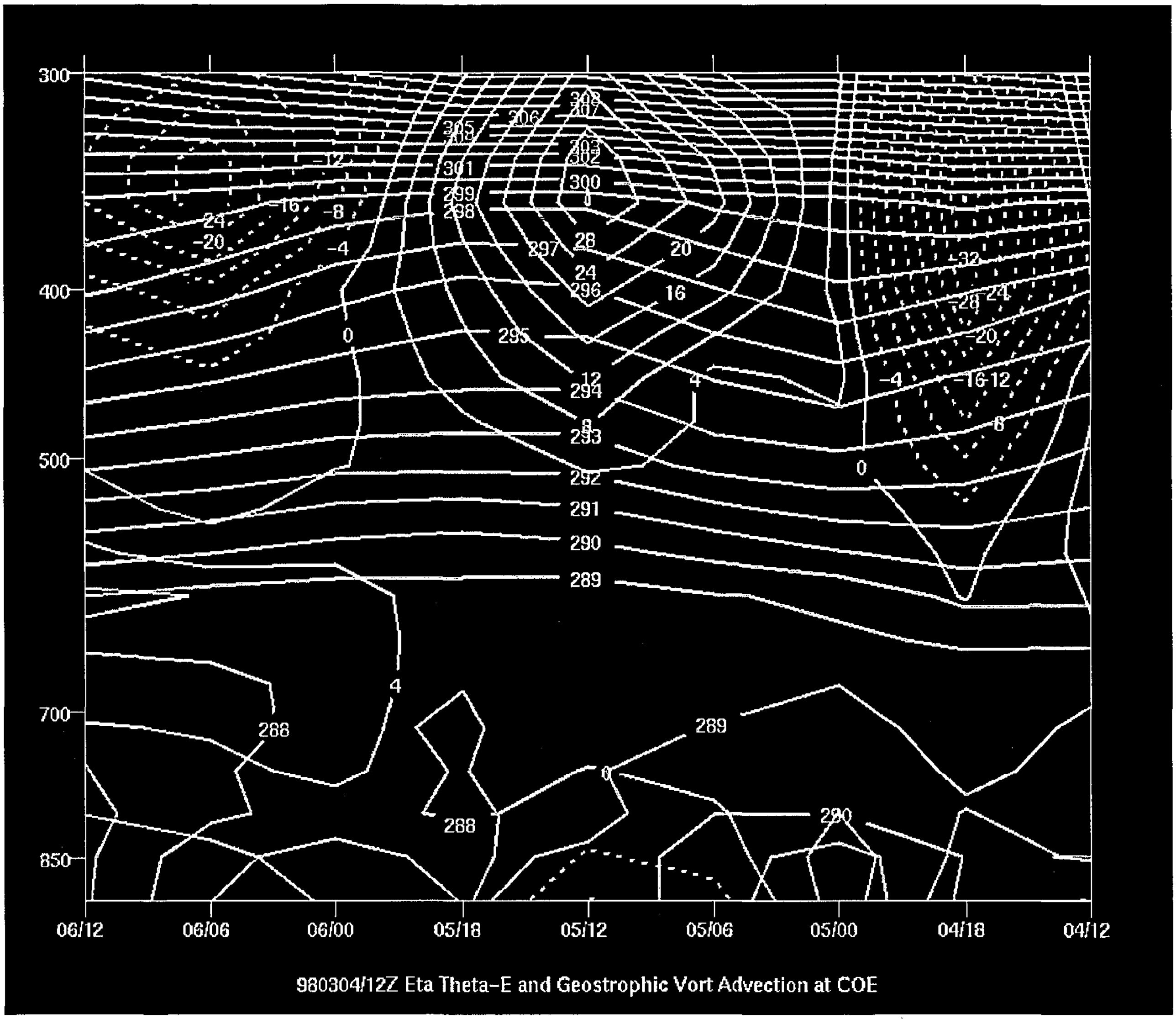
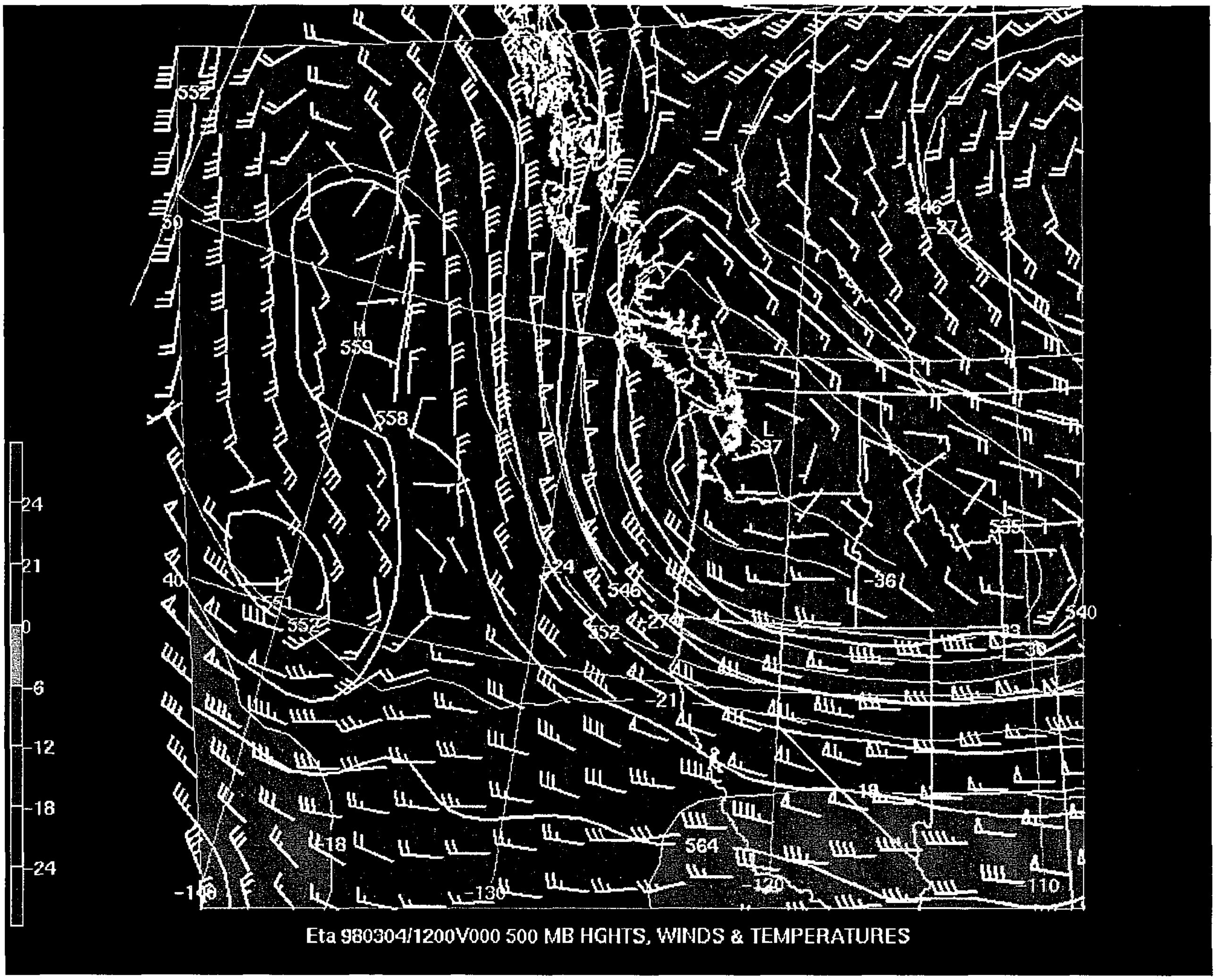


Fig. 6 - 980304/12Z Eta Theta-E and Geostrophic Vort Advection at COE



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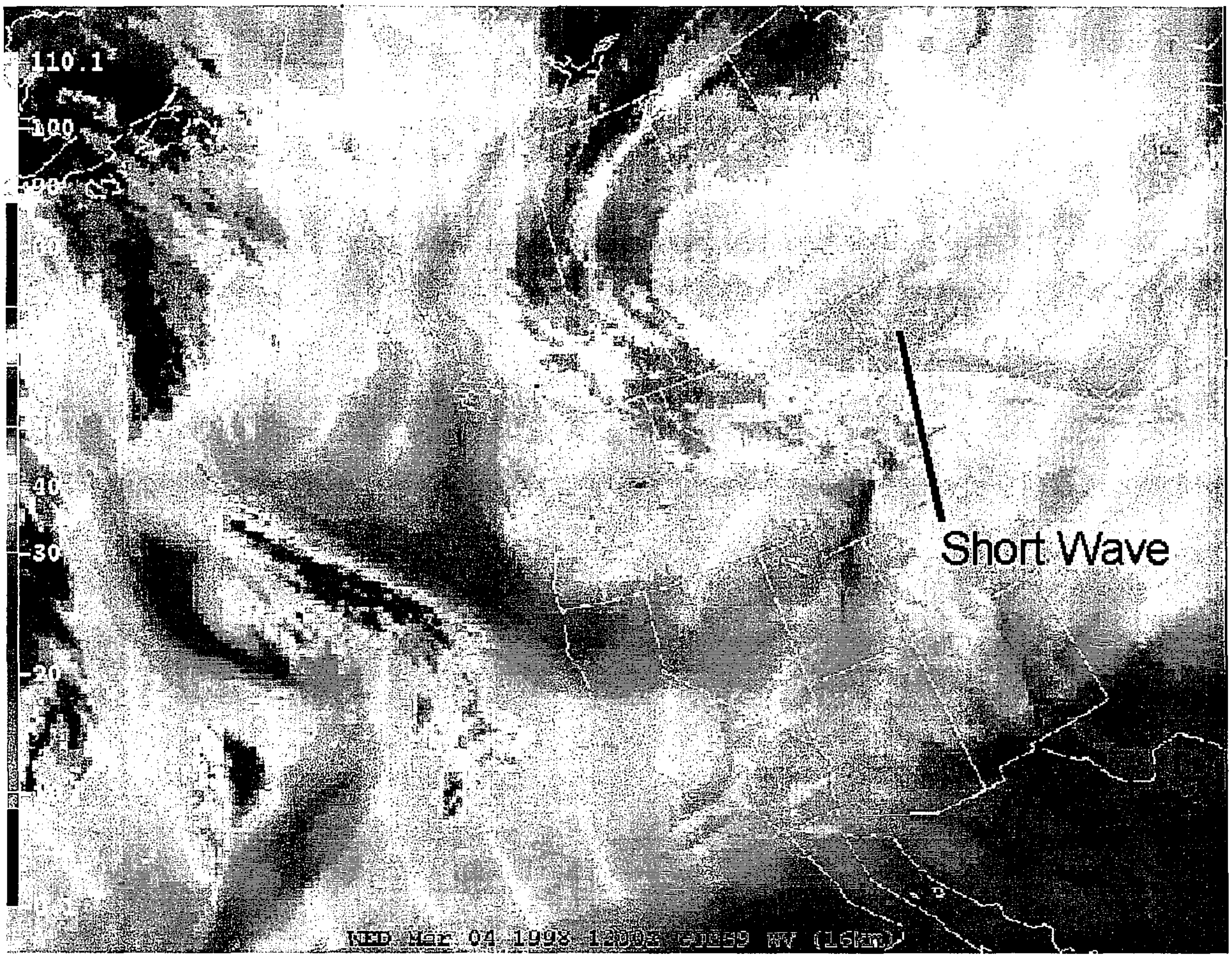


Fig. 2 - Wednesday, March 4, 1998 - 1200Z

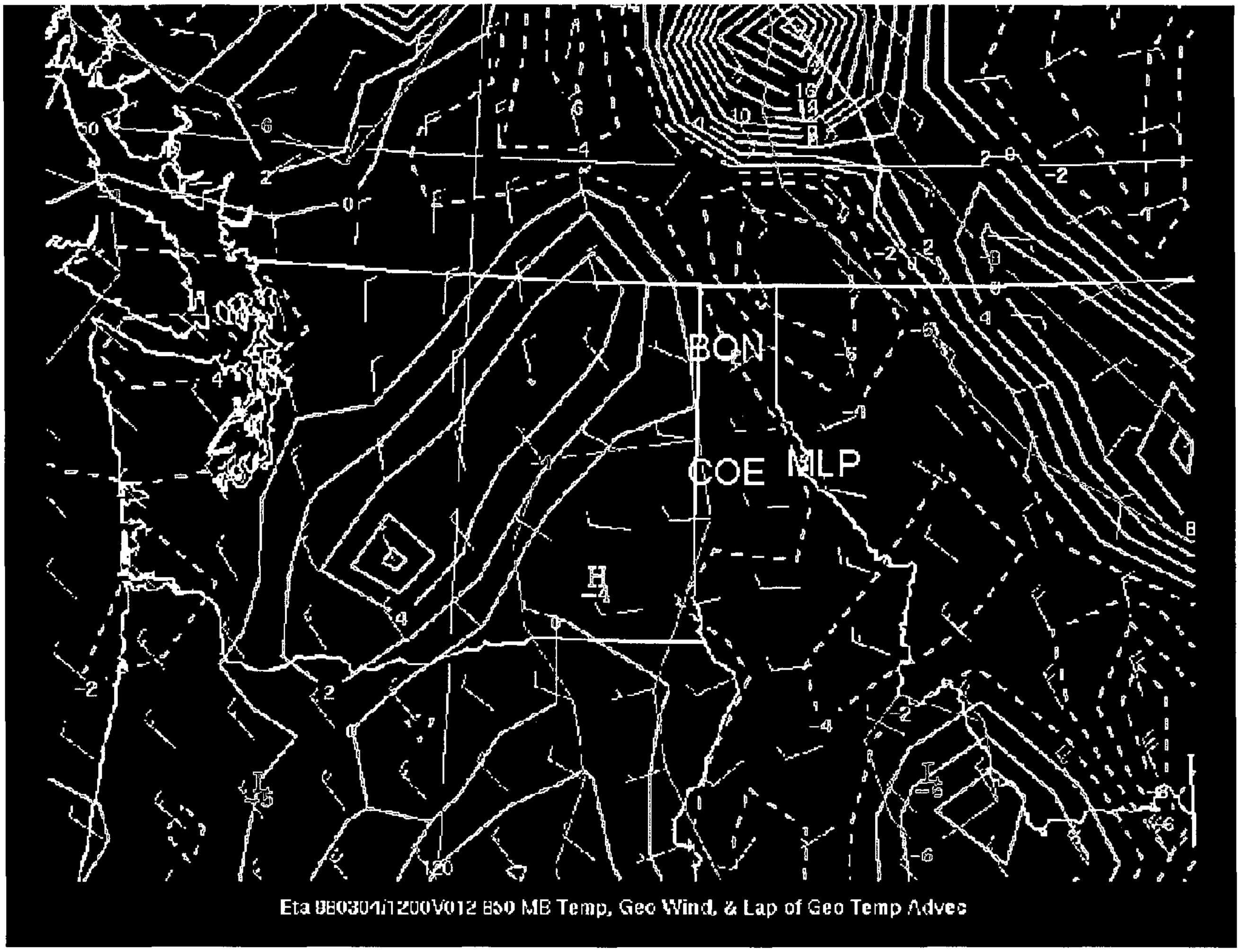


Fig. 3 - 04/12Z Eta analysis of winds and temperatures

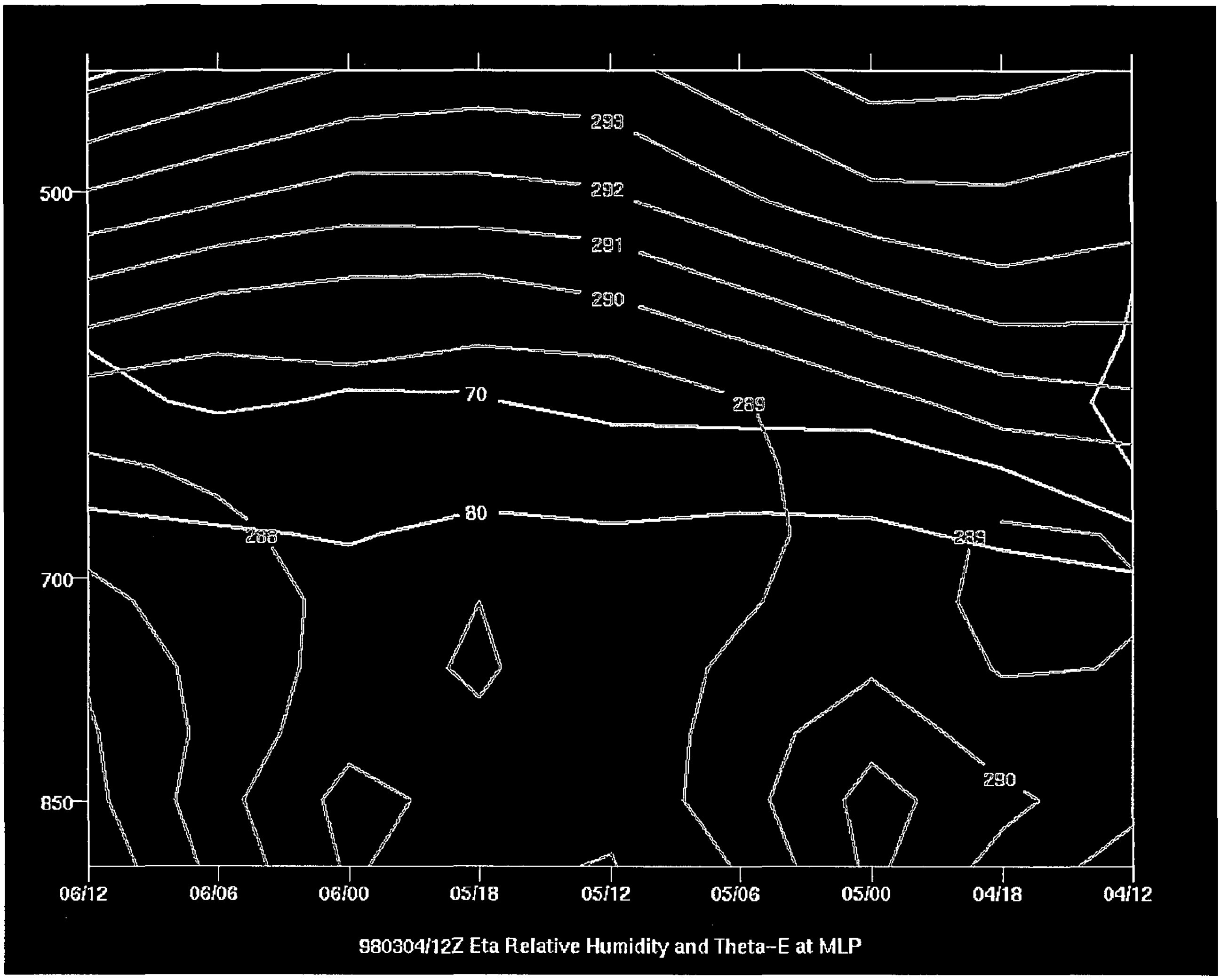
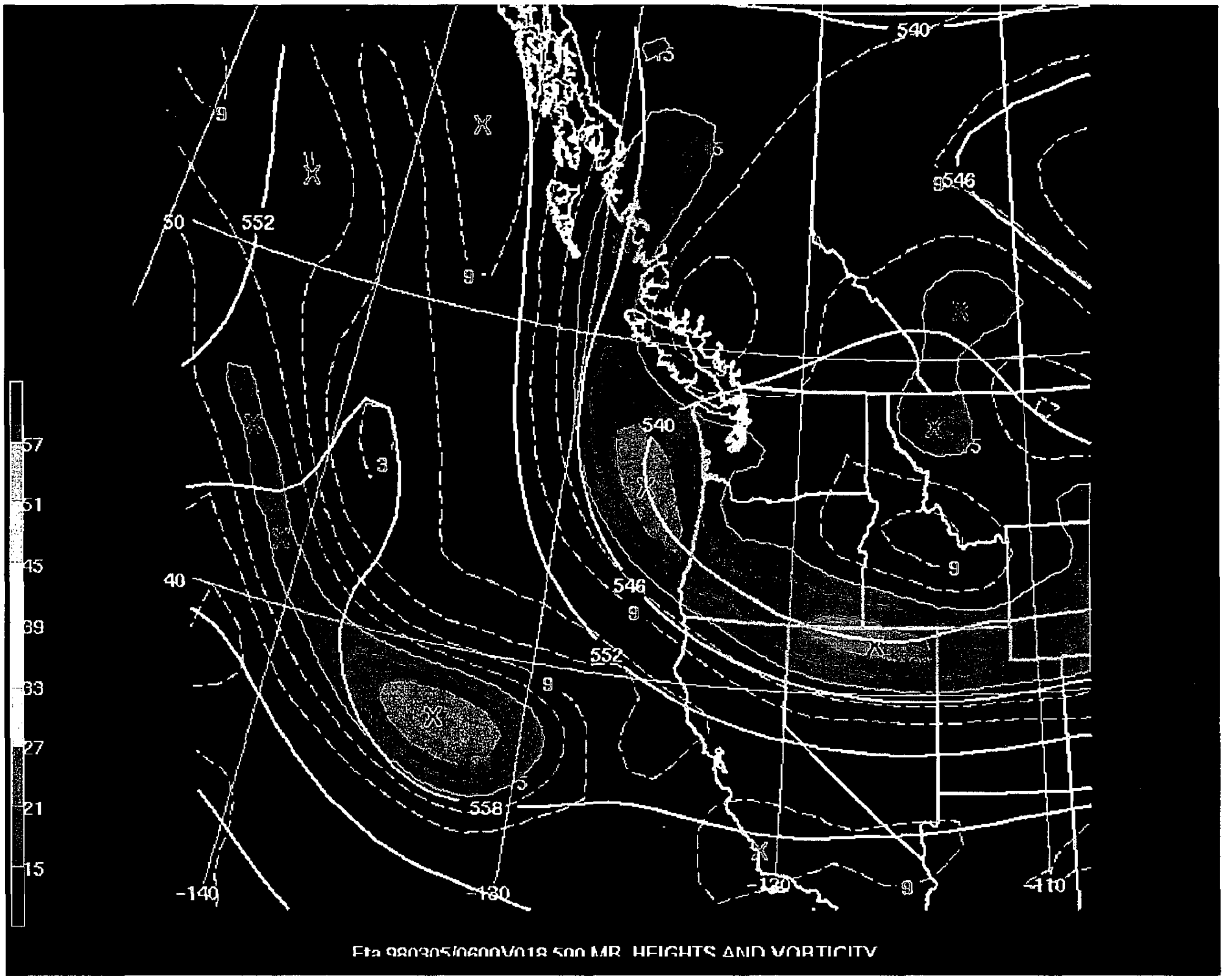


Fig. 4 - 980304/12Z Eta Relative Humidity and Theta E at MLP



Eta 980305/0600V018 500 MB HEIGHTS AND VORTICITY

FIG. 5

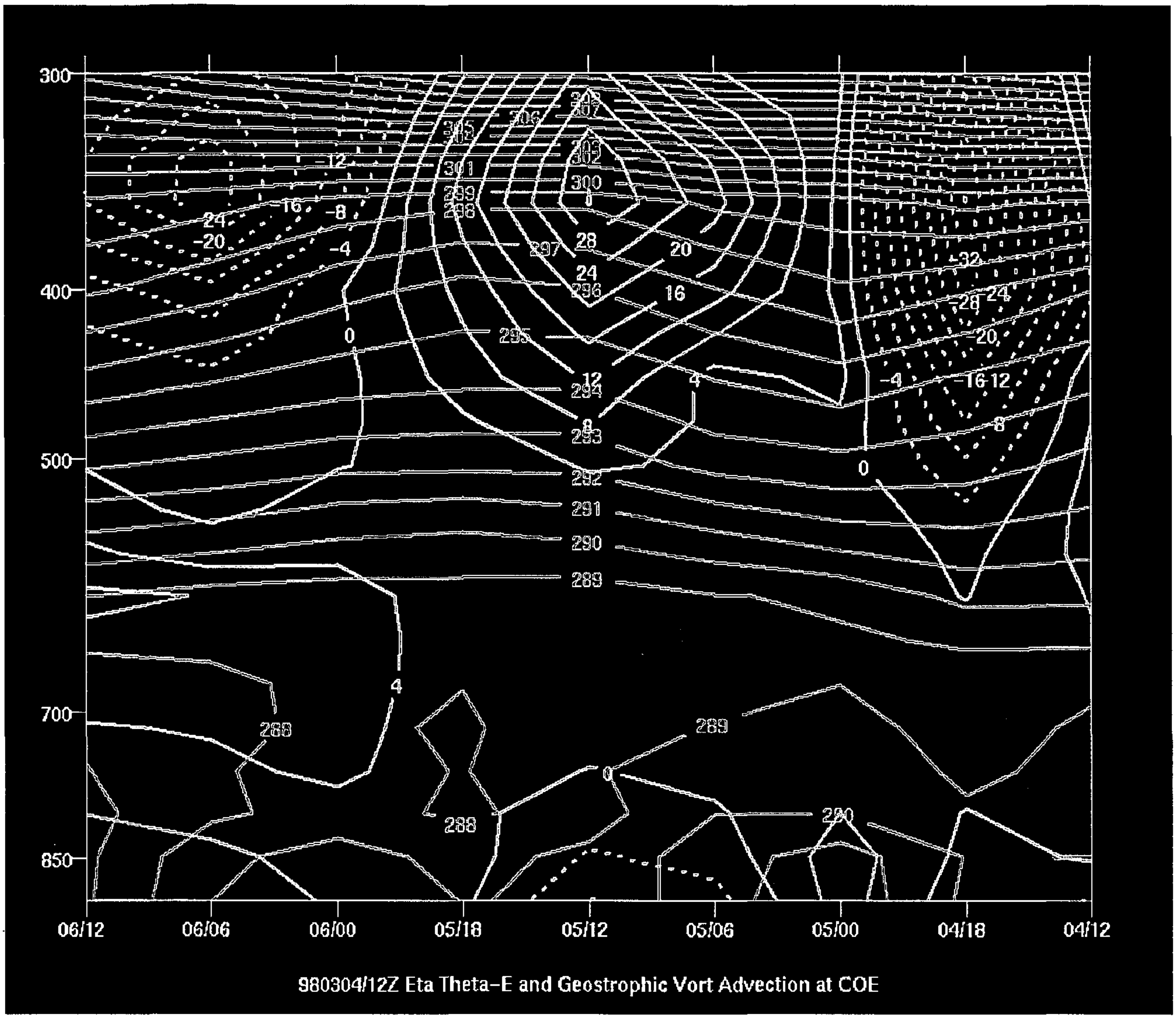


Fig. 6 - 980304/12Z Eta Theta-E and Geostrophic Vort Advection at COE