Western Region Technical Attachment
No. 93-04
February 9, 1993

USING PCGRIDS TO DIAGNOSE VERTICAL MOTION IN A UTAH HEAVY PRECIPITATION EVENT

Michael C. Conger - WSFO Salt Lake City, Utah

Introduction

The evaluation of vertical motion in the current forecast environment, whether through convention or necessity, is commonly viewed in a two-dimensional (2-D) reference frame. Vorticity advection at 500 mb is one of the more widely used methods to estimate vertical motion. Jet streak dynamics is another method used, but operationally, its application is often limited to the simplified four quadrant, straight-line jet streak configuration (i.e. upward motion left-front/right-rear quadrants and downward motion right-front/left-rear of the jet streak). This method typically neglects the effect of orientation and thermal advection structure of the jet streak which have been shown by Cammas and Ramond (1989) and numerous others to impact the location of vertical motions associated with this feature.

Three-dimensional (3-D) representations of vertical motion such as couplets of divergence/convergence between constant pressure surfaces (typically 700-300 mb) are also employed. This method, while it does well in identifying regions of strong vertical motions, lacks the vertical resolution to identify weaker events.

One of the main problems in using a 2-D approach to estimate vertical motion is that assumptions are made about the dynamical contribution to forcing through a vertical column. In the case of vorticity advection, vorticity is assumed to increase (decrease) with height when positive (negative) vorticity advection (PVA/NVA) exists at 500 mb. Further, it is assumed that strong PVA (NVA) at 500 mb implies strong upward (downward) motions in a vertical column above and below 500 mb, while weak PVA (NVA) implies vertical motions of a lesser magnitude.

In many cases, the above assumptions are valid. However, most forecasters can remember situations where these assumptions did not hold true. Were these cases where the models erred, or was the 2-D forecasting technique unable to properly diagnose the vertical motion in those situations? Using Regional Analysis and Forecasting System (RAFS) gridded data with graphics created through PCGRIDS software, vorticity advection will be used as a means to illustrate the importance of viewing Quasi-Geostrophic (QG) forcing potential in 3-D, instead of the more conventional 2-D method.

Synopsis

Widespread precipitation events, especially in a semi-arid climate such as Utah's, are normally associated with cold season synoptic-scale weather disturbances. One such event occurred in Utah beginning at 1200 UTC, 30 October, 1992. Over the next 24 hours, the state received anywhere from a trace to 50mm of precipitation (Fig. 1). The RAFS initialized 500 mb height field valid at 1200 UTC, shows of a negatively tilted, diffluent trough with the axis extending from the eastern Gulf of Alaska into the Pacific Northwest (Fig. 2a). The associated vorticity field shows only weak PVA over northwest Utah/eastern Idaho. Over the next 12 hours, this trough was forecast to move inland and maintain a negative tilt with the axis extending into the Great Basin (Fig. 2b). Positive vorticity advection, while evident, was still rather weak over western Utah. Mean layer relative humidity values (700-300 mb) were very high throughout the 24-hour period (Figs. 3a&b). The distribution of precipitation was far from uniform during the 24-hour period. Between 1200 and 0000 UTC, the heaviest precipitation occurred over northern Utah (Fig. 4a). This area diminished around 0000 UTC as a second area of heavy precipitation developed over southwest/central Utah (Fig. 4b). Substantial precipitation (>35mm) was reported in that region until shortly before 1200 UTC.

Differential Vorticity Advection

In the diagnostic omega equation (eq. 1), vertical motion is estimated from the contribution of two terms: the differential vorticity advection (Term B) and the negative of the

$$\underset{\textbf{A}}{\left(\nabla^2+\frac{f_o^2}{\sigma}\frac{\partial^2}{\partial p}\right)\omega} = \underset{\textbf{B}}{\frac{f_o}{\sigma}\frac{\partial}{\partial p}\left[V_g\cdot\nabla\left(\frac{1}{f_o}\nabla^2\Phi+f\right)\right]} \quad \underset{\textbf{C}}{+\frac{1}{\sigma}\nabla^2\left[V_g\cdot\nabla\left(-\frac{\partial\Phi}{\partial p}\right)\right]} \qquad \text{(eq. 1)}$$

horizontal Laplacian of the thickness advection (Term C). Term B is proportional to the rate of increase with height of the advection of absolute vorticity while Term C is proportional to the thickness (temperature) advection. Qualitatively, rising (sinking) motion results from both the contribution of the rate in which positive (negative) vorticity advection increases with height and the rate of warm (cold) advection.

According to Holton (1992, 1979), the two terms on the right-hand side of the omega equation, while each are separate as physical processes, often have significant amounts of cancellation between them. Nevertheless, to illustrate the importance of viewing vertical motion forcing in 3-D, omega will be diagnosed strictly through differential vorticity advection (i.e., neglecting the contribution of thickness advection).

Vorticity advection computed from the 1200 UTC, 30 October, RAFS initialized gridded data shows PVA increasing with height through the 700-300 mb layer over northern and eastern sections of Utah (Figs. 5a-d). During the 12-hour period beginning at 1200 UTC, the heaviest precipitation occurred over the north while the southwest portion of Utah received little or no precipitation. A meridional cross section of vorticity advection through Utah (Fig. 6a) shows PVA increasing with height between 37-44° N with a local maximum between 40-42°N. From the omega equation, it would be expected that the magnitude of negative omega (upward vertical motion) would be greatest within the same region (neglecting the thickness advection term). A cross section of the total omega (Fig. 6b) does in fact show this maximum, which also corresponds to the area of heaviest precipitation.

At 0000 UTC, the 12-hour gridded forecast data shows PVA increasing with height over southwest Utah (Figs. 7a-d). This corresponds well with the southward shift and onset of heavy precipitation over that region. At the same time, PVA shows little increase in the vertical over northern/eastern sections of the state where the precipitation had decreased substantially. A meridional cross section of vorticity advection (Fig. 8a) shows an increase of PVA with height between 34-41°N, with the rate of increase maximized between 37-39°N. The cross section of omega (Fig. 8b) again highlights this maximum which corresponds to the area of heavy precipitation.

Conclusions

When viewed subjectively, differential vorticity advection does a better job explaining upward vertical motion and the associated precipitation than the conventional 500 mb vorticity advection method. Also, the qualitative contribution of differential vorticity advection in the omega equation was well illustrated using vertical cross sections of vorticity advection and omega through Utah.

More important, however, this case demonstrates the need to evaluate vertical motion in 3-D. Arguably, vertical motion does not result from any single forcing mechanism, but from a combination of different mechanisms, from different levels in the troposphere. Software such as PCGRIDS gives the forecaster the ability to objectively view a number of elements (i.e. divergence of Q-vectors, advective parameters, and vertical cross sections) that otherwise would be difficult to analyze subjectively. This valuable tool will improve the assessment of QG-forced vertical motion which will lead to better forecasts.

References

Bluestein, H. B., Synoptic-Dynamic Meteorology in Midlatitudes., Vol 1., Oxford University Press, 431 pp.

Cammas, J-P, and D. Ramond, 1989: Analysis and diagnosis of the composition of ageostrophic circulations in jet-front systems, *Mon. Wea. Rev.*, 117, 2447-2461.

Holton, J. R., An Introduction to Dynamic Meteorology. 2nd ed., Int. Geophys. Ser., **23,** Academic Press, 391 pp.

---, An Introduction to Dynamic Meteorology. 3rd ed., Int. Geophys. Ser., **48,** Academic Press, 511 pp.

National Weather Service, Western Region Tech. Attach. No. 92-38.

Uccellini, L. W., and D. R. Johnson, 1979: The coupling of upper- and lower-tropospheric jet streaks and implications for the development of severe convective storms. *Mon. Wea. Rev.*, 107, 682-703.

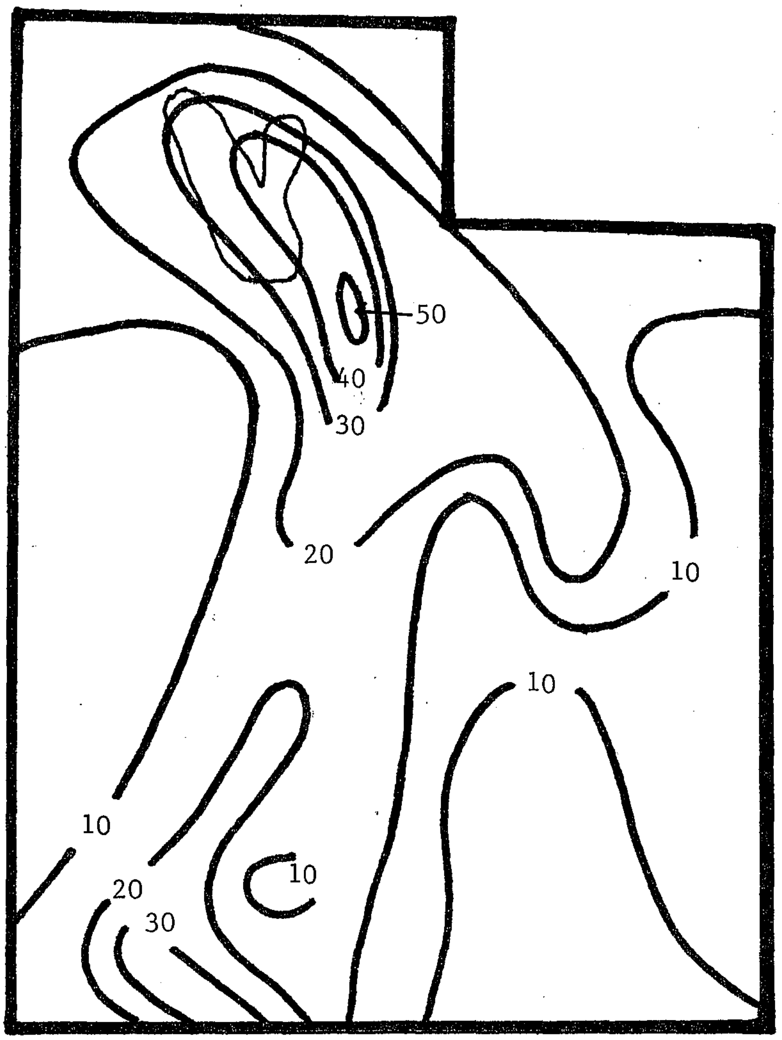
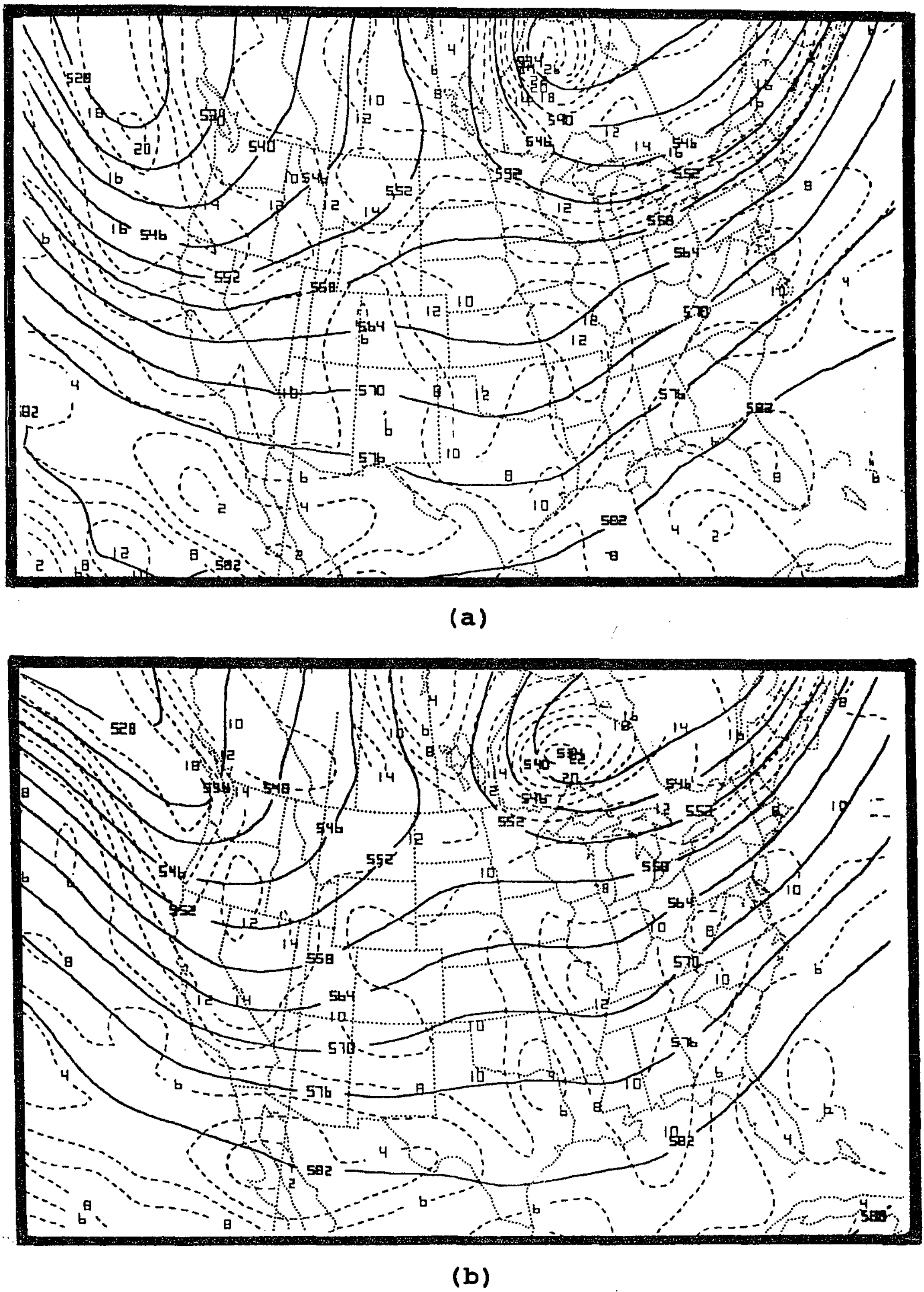


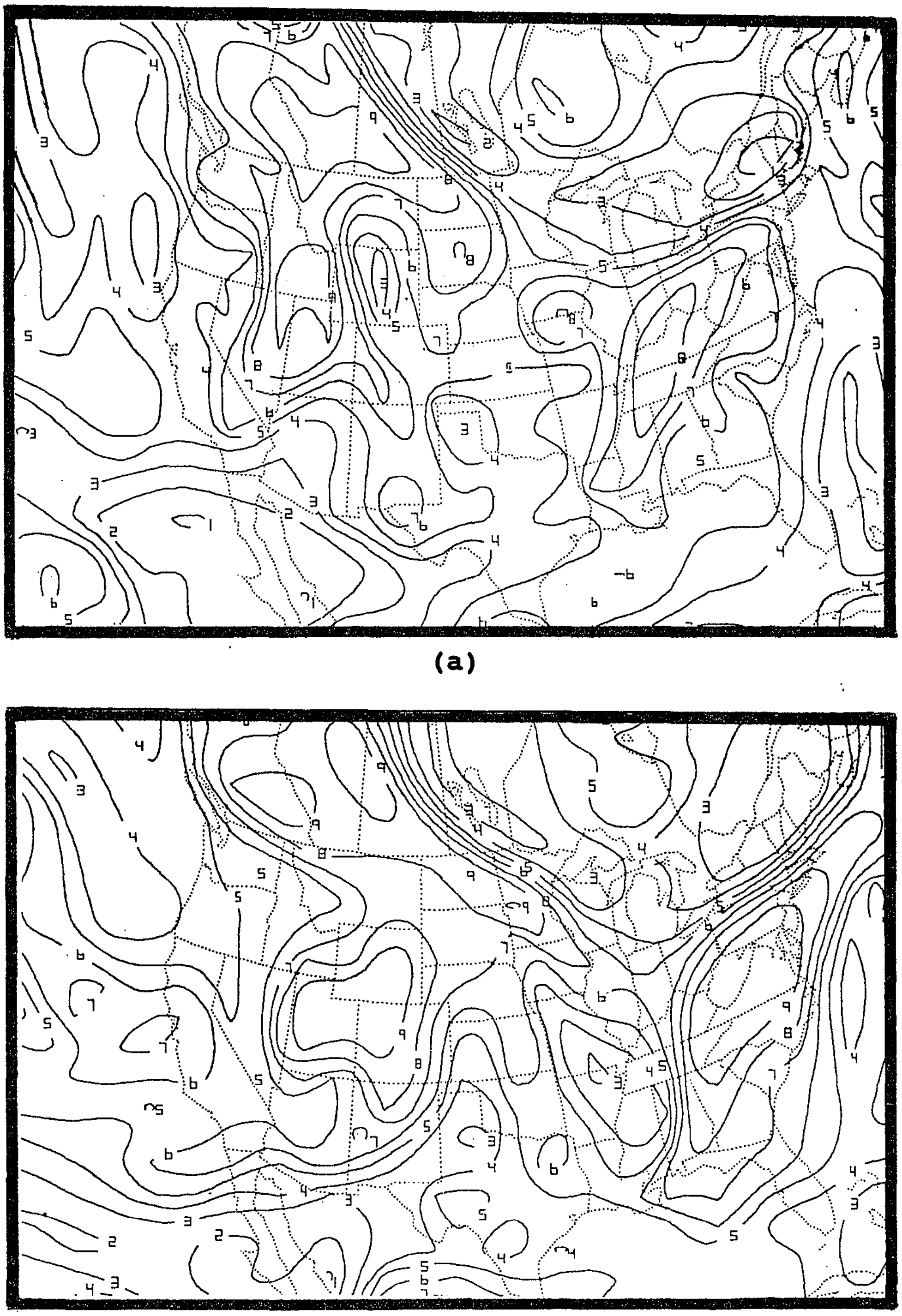
Figure 1. Total 24 hour precipitation beginning 1200 UTC, 30 October, through 1200 UTC, 31 October, 1992. Contour intervals are 10 mm above 10 mm.



(a)

(b)

Figure 2. RAFS height (solid, intervals 60m) and vorticity (dashed, intervals $2\times10^{-5}/s$) fields from 1200 UTC, 30 October, 1992 (a) initialized data, and (b) 12 hour forecast data.



(a)

(b)

Figure 3. RAFS 700-300mb mean layer relative humidity (intervals 10%) from 1200 UTC, 30 October, 1992 (a) initialized data, and (b) 12 hour forecast data.

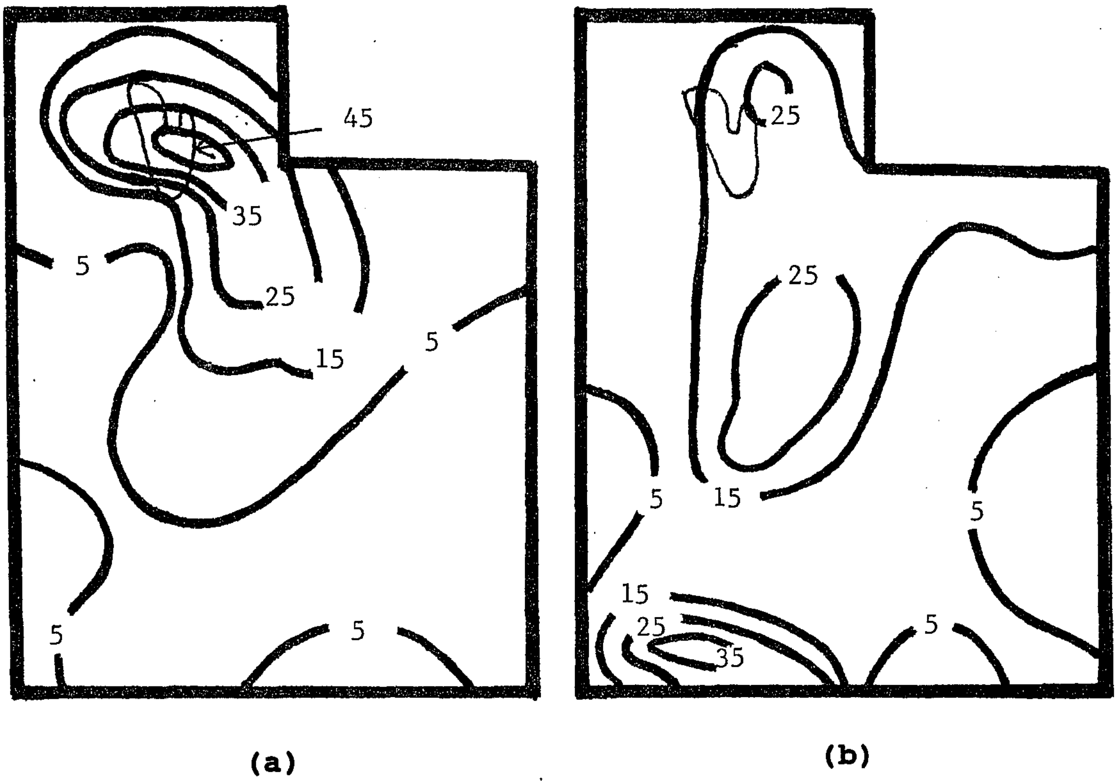
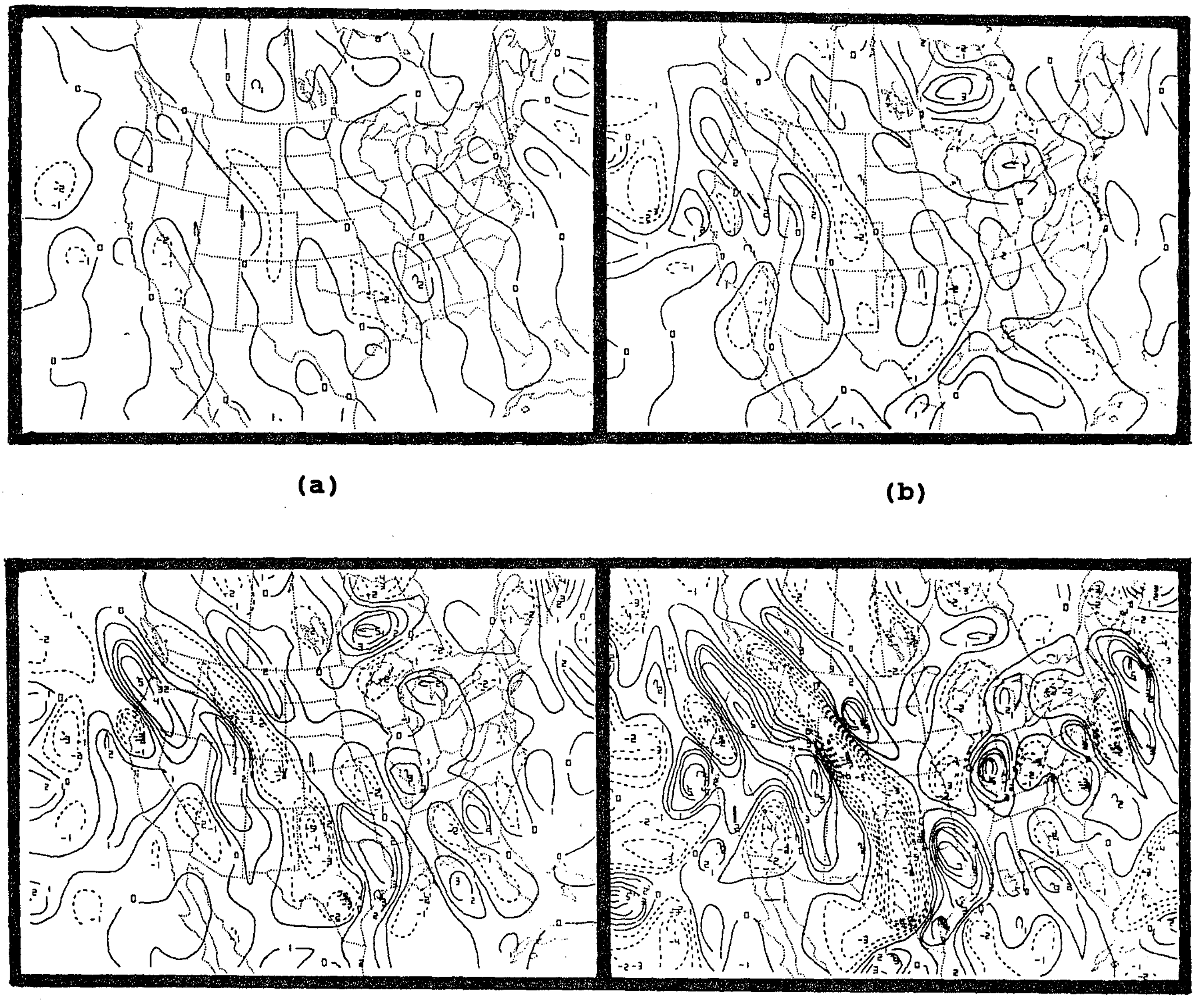


Figure 4. Accumulated 12 hour precipitation for (a) 1200 UTC, 30 October, through 0000 UTC, 31 October, 1992, and (b) 0000 UTC, 31 October, through 1200 UTC, 31 October, 1992. Contour intervals are 10 mm above 5 mm.



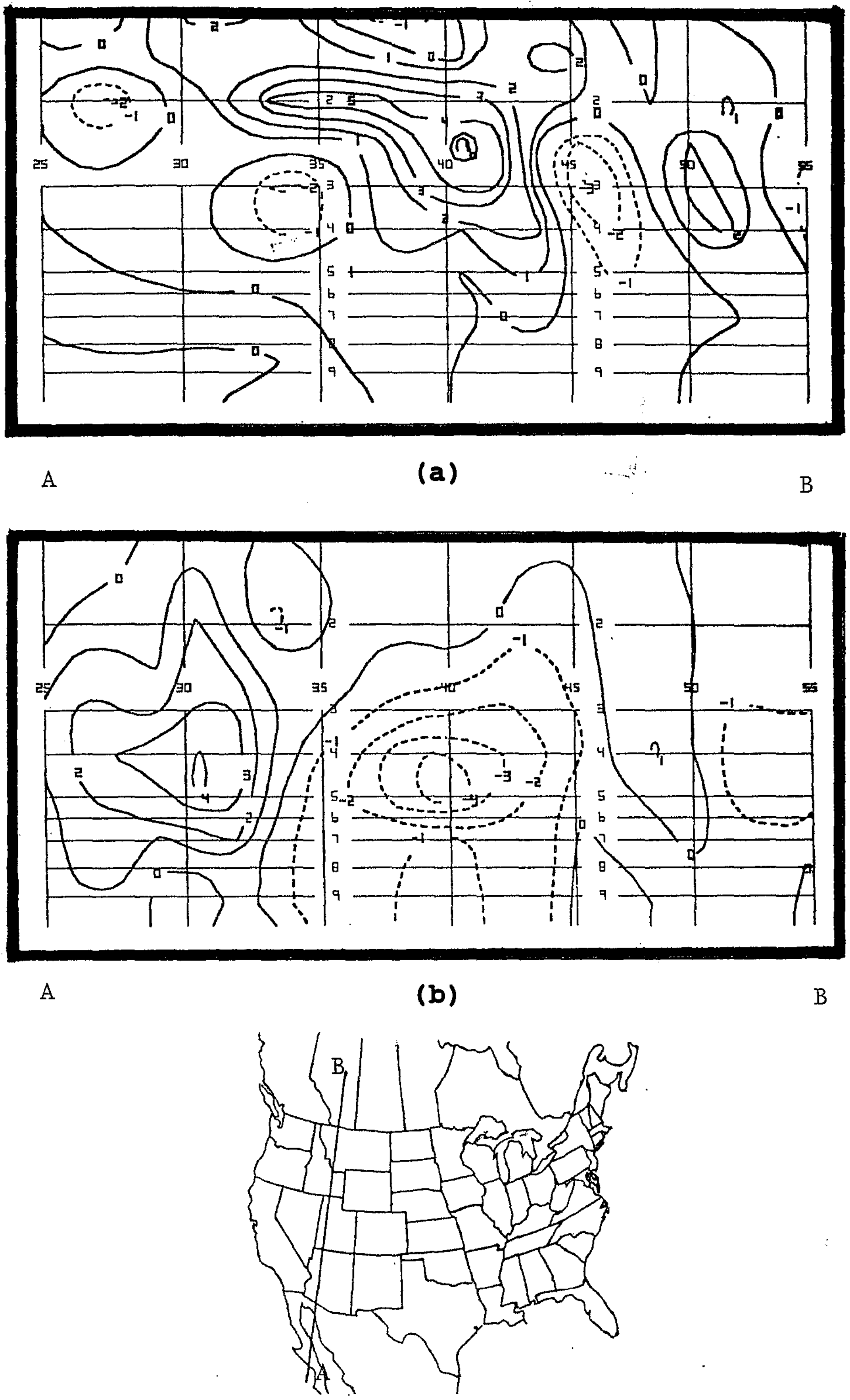
(a)

(b)

(c)

(d)

Figure 5. RAFS 1200 UTC, 30 October, 1992 advection of absolute vorticity by the total wind (initialized data) at (a) 700 mb, (b) 500 mb, (c) 400 mb, and (d) 300 mb. Contour intervals are $1\times10^{-9}/s^2$ (PVA, positive/solid).



(a)

(b)

Figure 6. RAFS 1200 UTC, 30 October, 1992 initialized data of (a) advection of absolute vorticity by the total wind (PVA positive/solid), and (b) omega (upward motion, negative /dashed). Cross section A-B along 113W, 25°-55°N. Contour intervals are $1 \times 10^{-9}/s^2$ and $\mu b/s$ respectively.

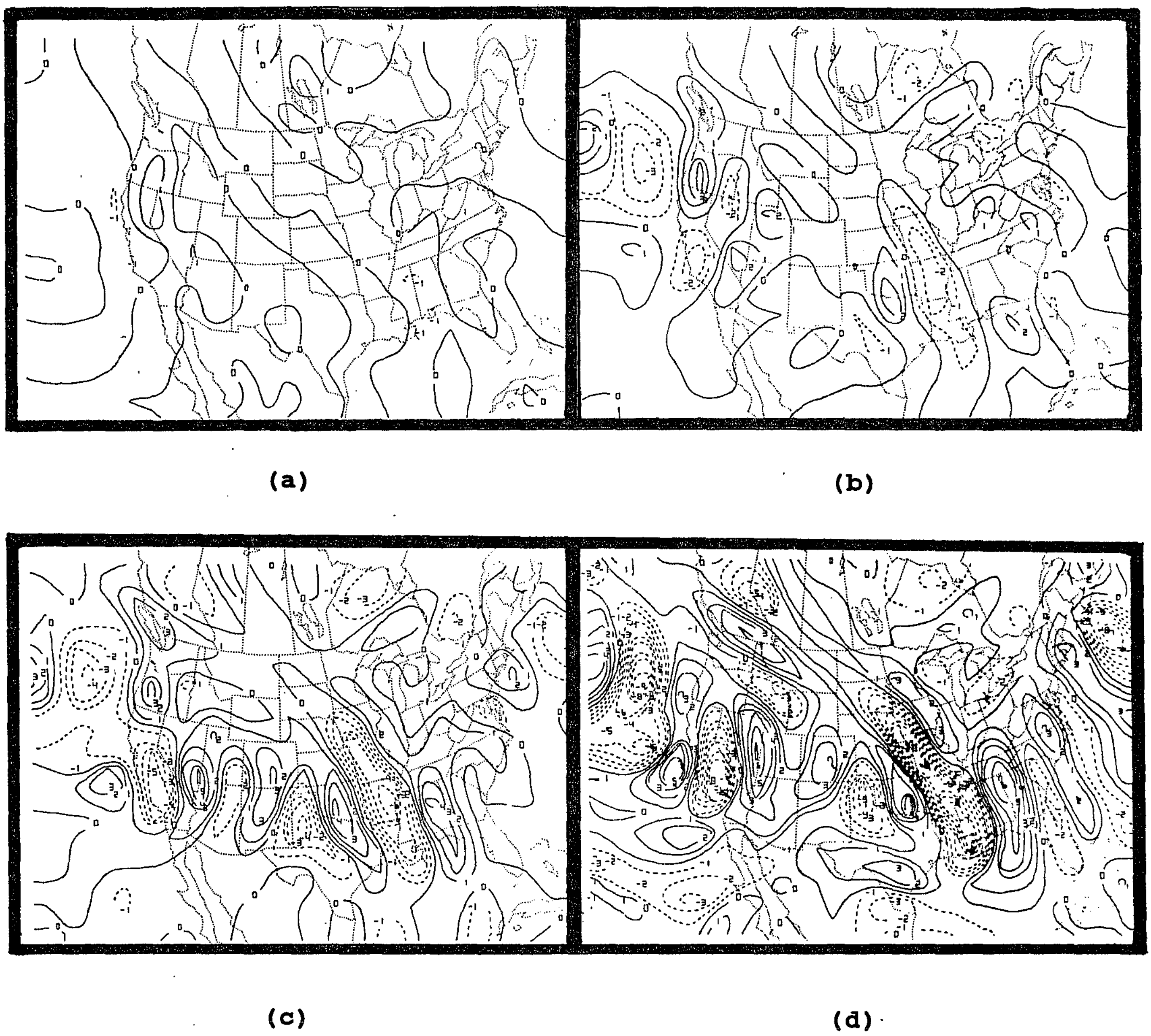


Figure 7. RAFS 0000 UTC, 31 October, 1992 advection of absolute vorticity by the total wind (12 hour forecast) at (a) 700 mb, (b) 500 mb, (c) 400 mb, and (d) 300 mb. Contour intervals are $1\times10^{-9}/s^2$ (PVA, positive/solid).

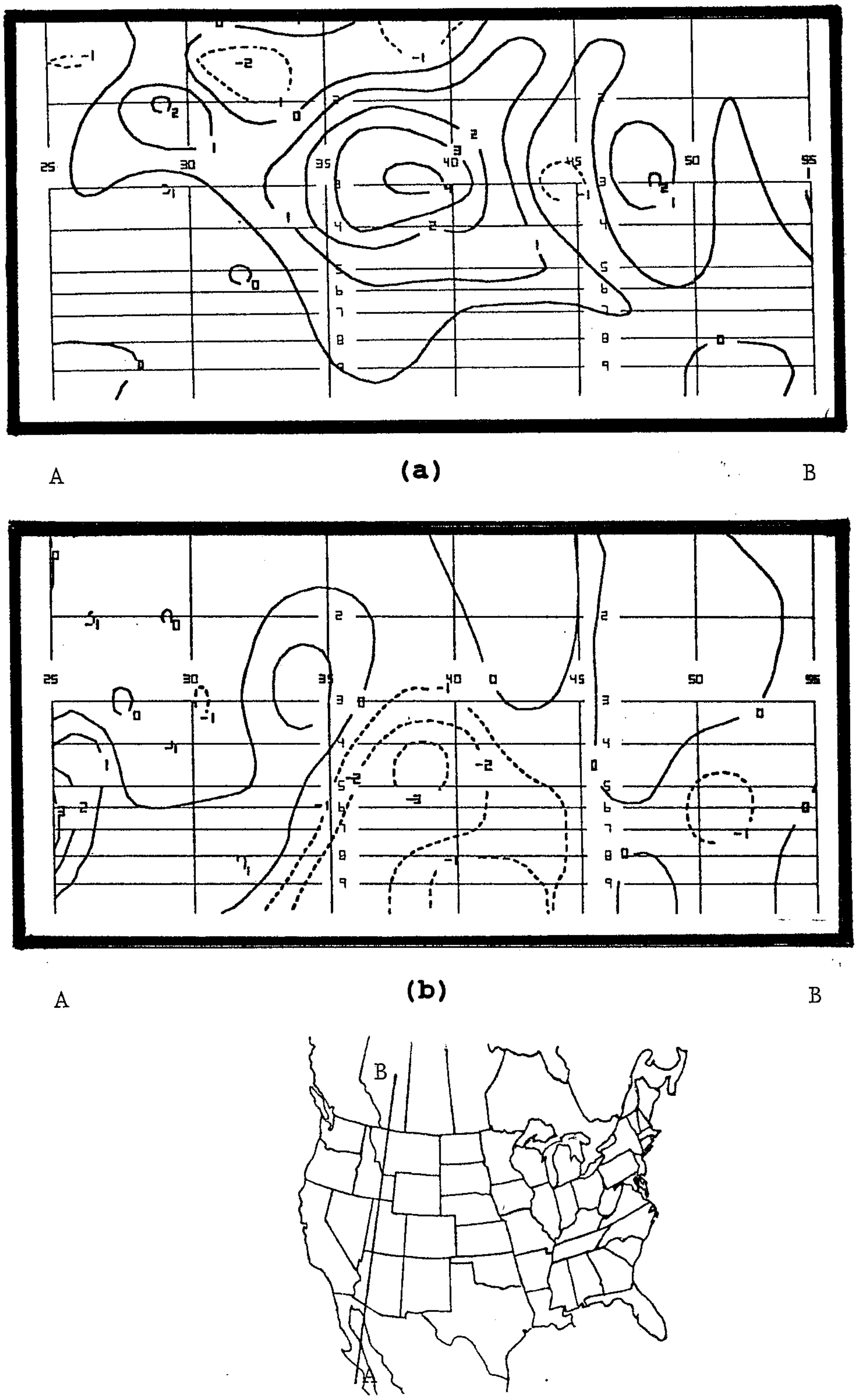


Figure 8. Same as 6 except for 12 hour forecast valid 0000 UTC, 31 October 1992.