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ISENTROPIC VERTICAL MOTION USING PCGRIDS

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INTRODUCTION

The recent acquisition of the PCGRIDS software in concert with real time gridded data fields from the ETA and Nested Grid (NGM) models, allow different meteorological parameters to be evaluated. Specifically, isentropic coordinates can be used to assess vertical motion (ω) according to the equation:

$$\omega = \underbrace{\left[\frac{\partial P}{\partial t}\right]_\theta}_{\text{Term A}} + \underbrace{\vec{V}\cdot\nabla_\theta P}_{\text{Term B}} + \underbrace{\frac{\partial P}{\partial \theta}\frac{d\theta}{dt}}_{\text{Term C}} \qquad (1)$$

where term B refers to the advection of pressure along an isentropic surface. Term A is the local pressure tendency which considers the amount an isentropic surface moves vertically (up or down) at a specific point. This term is usually smaller than term B, however for strong cyclogenesis, fast moving storms, or sharp temperature discontinuities this term can be large. Term C is the diabatic heating component (hard to evaluate operationally) and except in events with strong latent heating (i.e., deep convection), it too is usually small. When latent heating occurs, the potential temperature of an air parcel is not conserved and upward vertical motion ($\omega < 0$) *through* the isentropic surfaces occurs.

Term B is the mathematical dot product of the total wind (**V**) and the pressure gradient (∇P) on an isentropic surface (θ), or $|\mathbf{V}|\,|\nabla P|\cos\phi$. In this equation, ϕ refers to the angle between the pressure gradient vector and the wind vector on the isentropic surface of interest. Thus, on a given isentropic surface (i.e., 290K), adiabatic upward motion ($\omega < 0$) can be assumed where the wind is directed toward lower pressure, and subsidence ($\omega > 0$) occurs where the wind is orientated toward higher pressures. The greater the opposition between the two vectors, the greater the vertical motion (as $\cos\phi \rightarrow -1$, which yields $-\omega$). Also, as the pressure gradient increases, so does the slope (either up or down) of the isentropic surface, resulting in greater vertical motion (this is the $|\nabla P|$ contribution).

PCGRIDS TO EVALUATE TERM B

Since PCGRIDS can create isentropic surfaces at any level, the ability to assess the contribution of term B in eq.(1) is simplistic according to the approximation of ω below:

$$\omega \cong \vec{V}\cdot\nabla_\theta P \qquad (2)$$

First, the isentropic surfaces are created via the 'MTHT' command. Once the desired isentropic level is set, overlaying the total wind (**V**) and pressure contours onto the same frame will give the needed data to evaluate eq.(2) qualitatively. Since PCGRIDs has the ability to perform mathematical operations, eq.(2) can be solved quantitatively and contoured. Using the "DOTP" command, the dot product between two vectors can be evaluated (here, V and ∇P).

It should be stated that the preferred isentropic level (i.e., the level which yields the best information) can vary from storm-to-storm, season-to-season, and depends on station elevation. Experimentation using various levels is the best way for each forecaster to determine which level is most useful. Mixing ratio can also be added to the graphic to investigate moisture advection along the isentropic surface. The commands used in the following section to create the figures are listed below:

SLVL I290 (horizontal figures)
BKNT&PRES CI50&MIXR DASH C1-3&LATT CI10&LONG CI10
DOTP WIND GRAD PRES (term B)

XSCT 55 118 45 132 (cross sections)
THTA CIN2&VVEL
MIXR DASH C1-3&

CASE STUDY - DECEMBER 16, 1992

PCGRIDS data is used to illustrate the vertical motion associated with an intensifying cyclone located off the West Coast of the United States on December 16, 1992. The vertical motion at two time periods, 1200 UTC December 16 (12Z/16) and 0000 UTC December 17, 1992 (00Z/17) will be analyzed using NGM gridded model data in conjunction with satellite imagery. Although the NGM is used for this case, the ETA model data can be used similarly. The NGM gridded fields used are the 00-hr initial analysis and the 12-hr forecast from the 12Z/16 model run. For this case study, the 290K isentropic surface was utilized as it was found to best represent the low- to mid-levels, ranging from 950 mb over the ocean to 500 mb over Alberta.

1200 UTC December 16, 1992

At this time, a strong wave was approaching the Pacific Northwest with most of Washington and Oregon in a region of warm advection downstream of the trough. The infrared (IR) satellite image from 1231 UTC (Fig. 1) depicts an area of clouds orientated southwest-northeast from approximately 135° W/45° N to 118° W/55° N. The most enhanced region was located near the northern end of Vancouver Island with another area located over southern British Columbia. The sharp northern edge of the cloud region was followed upstream by a region of open cellular convection indicative of substantial cold air aloft and instability. At this time, the cyclone center was only a weak surface wave, located west of Vancouver Island.

Most of the enhanced clouds in the satellite image were producing light surface precipitation. This precipitation, pre-frontal in nature, was primarily caused by isentropic upglide or "overrunning". The vertical motion induced from overrunning and the advection of moisture eastward over the cooler air mass located over most of western North America is illustrated in Fig. 2a. The isobar contours showed that the 290K isentropic surface slopes vertically upwards to the northeast, ahead of the trough (i.e., along the dotted A-B line). The pressure gradient vector is orientated in nearly the opposite direction of the total wind observed at point 'X', indicating that cos ϕ is near -1, and that term B is maximized and negative ($-\omega$, or upward vertical motion).

Quantitatively assessing term B using PCGRIDS, the largest contribution ($\approx$-2 to -4 μb/s) parallels line A-B and is located slightly to the southeast (Fig. 2b). Figure 2b also illustrates two maximum regions of ascent along the axis, similar in structure to the two enhanced regions of the IR imagery over Vancouver Island and southern British Columbia. Also, the mixing ratio axis is located in the same upward motion region previously discussed (from Fig. 2a).

A cross section located along the enhanced cloud axis (from 'A' to 'B' in Fig. 2) highlights the NGM's vertical motion field (Fig. 3). The strongest vertical motion along the 290K surface is near 51° N ($<-5\ \mu b/s$), located over the northern tip of Vancouver Island. In this same are, Fig. 2b depicts vertical motions of about -3 $\mu b/s$. Thus, greater than 50% of the total rising motion is due to term B at that point. In the cross section, the winds are directed from left to right, and "up" the isentropic surfaces. Remember, isentropic surfaces tilt upwards toward colder air (cold "dome"). It should also be noted that the wind orientation is favorable for effective moisture transport up the sloping surfaces. All of these components, when in concert, create an effective overrunning precipitation event.

Upstream from the overrunning region of upward motion, the wind vectors are orientated "down" the pressure surfaces, indicating subsidence ('Y' in Fig. 2a). This region is behind the cold front, characterized by cold advection, subsidence, and drying. The isohumes illustrate the large moisture gradient existing across the front separating the two different air masses. The moisture gradient is better evaluated through the use of a cross section, which extends through the front (Fig. 4, 'C' to 'D' on Fig. 2a). Near 49° N, subsidence and drying is occurring behind the front, as was seen on the 290K isentropic surface. Near 46° N, upward vertical motion dominates ahead of the cold front, composed of both overrunning in the warm sector and convective ascent.

The sharp edge on the northern side of the cloud region is explained well by the use of Fig. 2a-b. The "inflection" point, the point where the wind vectors change from a downward to an upward orientation with respect to the isobars, is where no vertical motion is occurring (from term B). Figure 2b shows the dipole structure to the vertical motion field with the inflection axis orientated southwest to northeast. For this case, the axis of inflection corresponds to the sharp northern edge of the cloud field, where subsidence upstream hinders cloud formation.

0000 UTC December 16, 1992

During the previous 12 hours, the central pressure of the surface cyclone had deepened 13 mb from 1008 mb to 995 mb. The cyclone was located off shore, approximately 200 km west of Astoria, Oregon. The storm had a classic "comma-shaped" cloud structure (Fig. 5) with most of Washington and Oregon reporting light to moderate precipitation at the surface. The visible satellite image from 2231 UTC (Fig. 6) showed a sharp cloud line extending to the southwest from near Astoria, OR, with open cellular convection occurring over much of the eastern Pacific behind the front. The large pre-frontal cloud mass can be seen over much of Oregon and Washington.

The 12-hour NGM forecast for the 290K isentropic surface continued to produce a large region of overrunning and upward motion ahead of the front (Fig. 7a). Over much of the Pacific Northwest, winds were orientated opposite to the pressure gradient, or perpendicular to the isobars toward lower pressures. Air parcels advecting up the 290K surface ($\approx 18 m/s$) originating near 850 mb over the Pacific Ocean, were at 650 mb upon reaching eastern Washington (along A-B). Using this data, term B is estimated to be $\omega_B \approx -3.7$ $\mu b/s$ (average). The quantitative evaluation of term B by PCGRIDS yields similar values of ascent in the area (Fig. 7b).

A southwest-northeast orientated cross section from 39° N/130° W to 47° N/116° W shows that the vertical velocity values (ω) ranged up to $\approx -5.5\ \mu b/s$ along the 290K surface (Fig. 8). At point "Z" (Fig. 7b and 8), term B ($\approx -3.8\ \mu b/s$) accounts for approximately 70% of the total vertical motion. In this case of a rapidly deepening cyclone, term A can become large, however in this case, the contribution to the total ω was only about -1.2 $\mu b/s$. This was calculated by considering the 12 hour pressure change at this point between 12Z/16 and 00Z/17. Thus, the residual (term C) or the vertical motion due to diabatic effects, is approximately -0.5 $\mu b/s$, or only 10% of the total ω.

The subsidence occurring behind the front is again detectable at 00Z/17 on the 290K surface (Fig. 7a-b). The synoptic wave has intensified, as can be seen by the S-shape to the pressure contours. On an isentropic surface, isobars are identical to isotherms on a pressure surface. Thus, the "S" shape to the isobars reflects the classic "S-shaped" isotherm pattern on a pressure surface. The cross-frontal moisture gradient has also increased, with a large tongue of moisture wrapping up and around the cyclone within the warm sector (i.e., ahead of the cold front). A cross section through the front (Fig. 9) illustrates the subsidence and drying found to the north of 42° N.

CONCLUSION

From this discussion, it is easy to see the tools PCGRIDS brings to the forecaster to help in the decision making process. In the future, one of the greatest uses of PCGRIDS will be its capability to create isentropic data. A majority of the time, air flows adiabatically or along isentropic surfaces. Therefore, isentropic coordinates are both intuitive and extremely useful. Also, vertical motion can be assessed through the use of both horizontal and vertical isentropic analysis. Isentropic data is not useful in all cases (i.e., strong diabatic effects), however a majority of the time it is, especially for overrunning events or cases with weak dynamical forcing. All in all, the analysis of isentropic data should be used to its fullest potential since it is now easily accessible via PCGRIDS.

REFERENCES

Moore, James T. 1992: Isentropic analysis and interpretation: operational applications to synoptic and mesoscale forecast problems. Saint Louis University. 88pp.

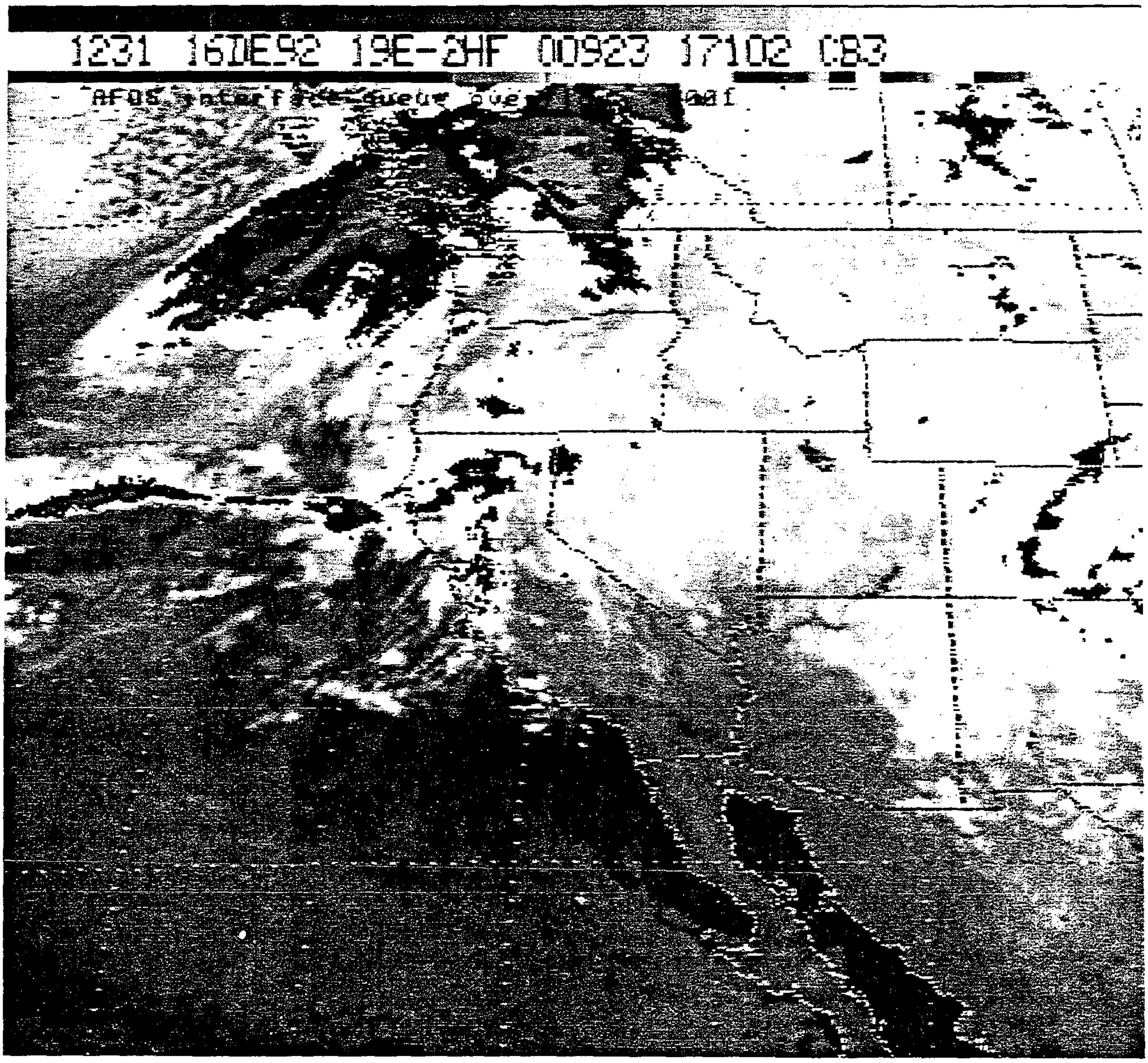
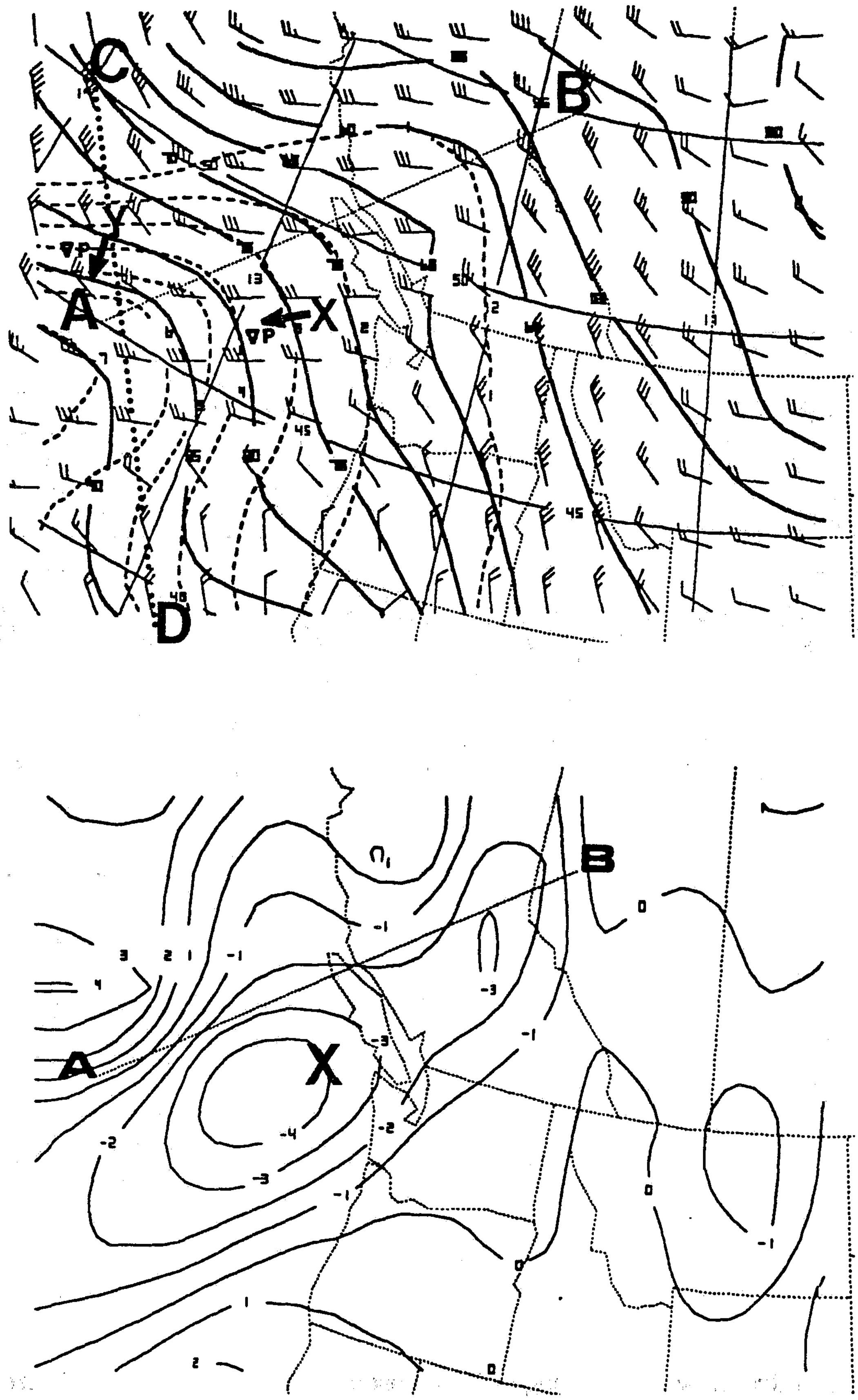


Figure 1. Infrared satellite image (2 km resolution, HF enhancement) from 1231 UTC December 16, 1992.

a)



b)

Figure 2. NGM initial analysis of the 290K isentropic surface at 1200 UTC, December 16, 1992. (a) Pressure (every 50 mb, solid), mixing ratio (g/kg, dashed). A-B (dotted line) is the plane view of the along-frontal cross section depicted in Figure 3. C-D (heavy dotted line) is the plane view of the cross-frontal cross section in Figure 4. 'X' ('Y') is a point of ascent (descent), vector indicates P. (b) ω due to Term B (in μb/s) from PCGRIDs.

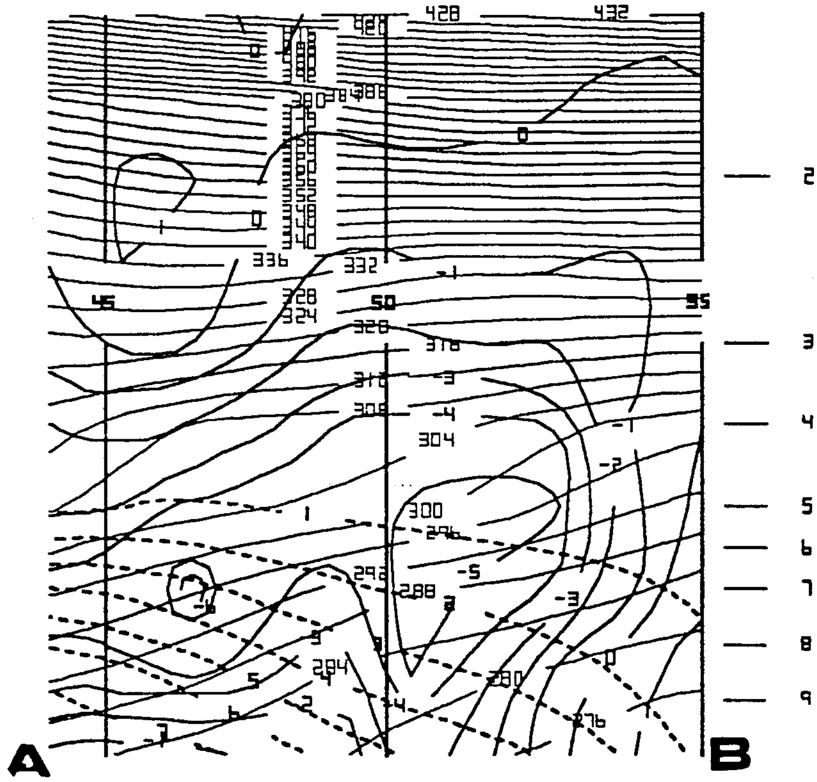


Figure 3. Along-front, vertical cross section from A-B in Figure 2 with isentropes (every 4K, thin solid), total ω (μb/s, thick solid), mixing ratio (every g/kg, dashed), and latitude.

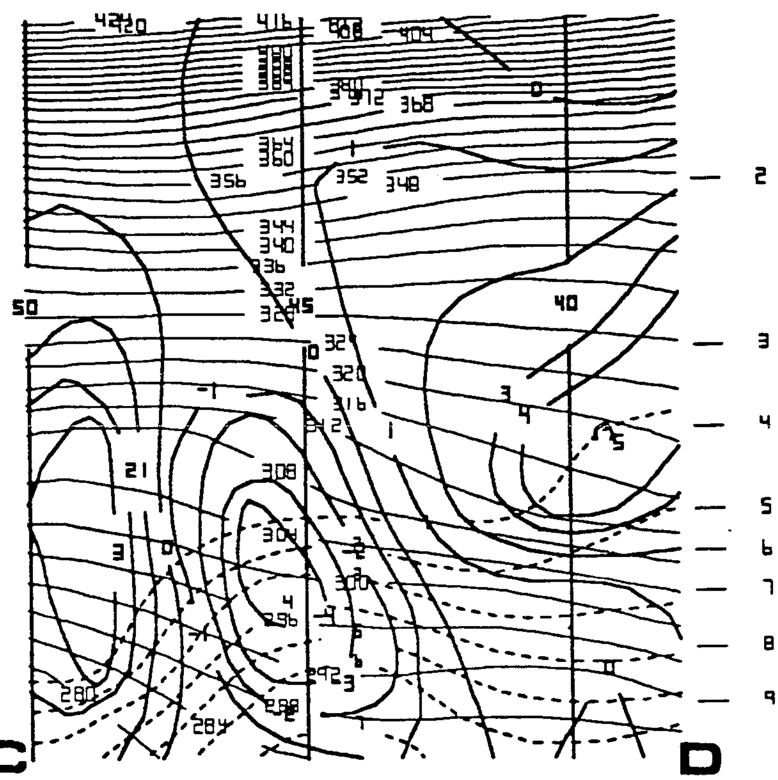


Figure 4. Cross-front, vertical cross section valid at 1200 UTC, December 16, 1992 (00-hr NGM analysis data) from C-D in Figure 2 with isentropes (every 4K, thin solid), total ω (μb/s, thick solid), mixing ratio (every g/kg, dashed), and latitude of the cross section (every 5°, vertical solid).

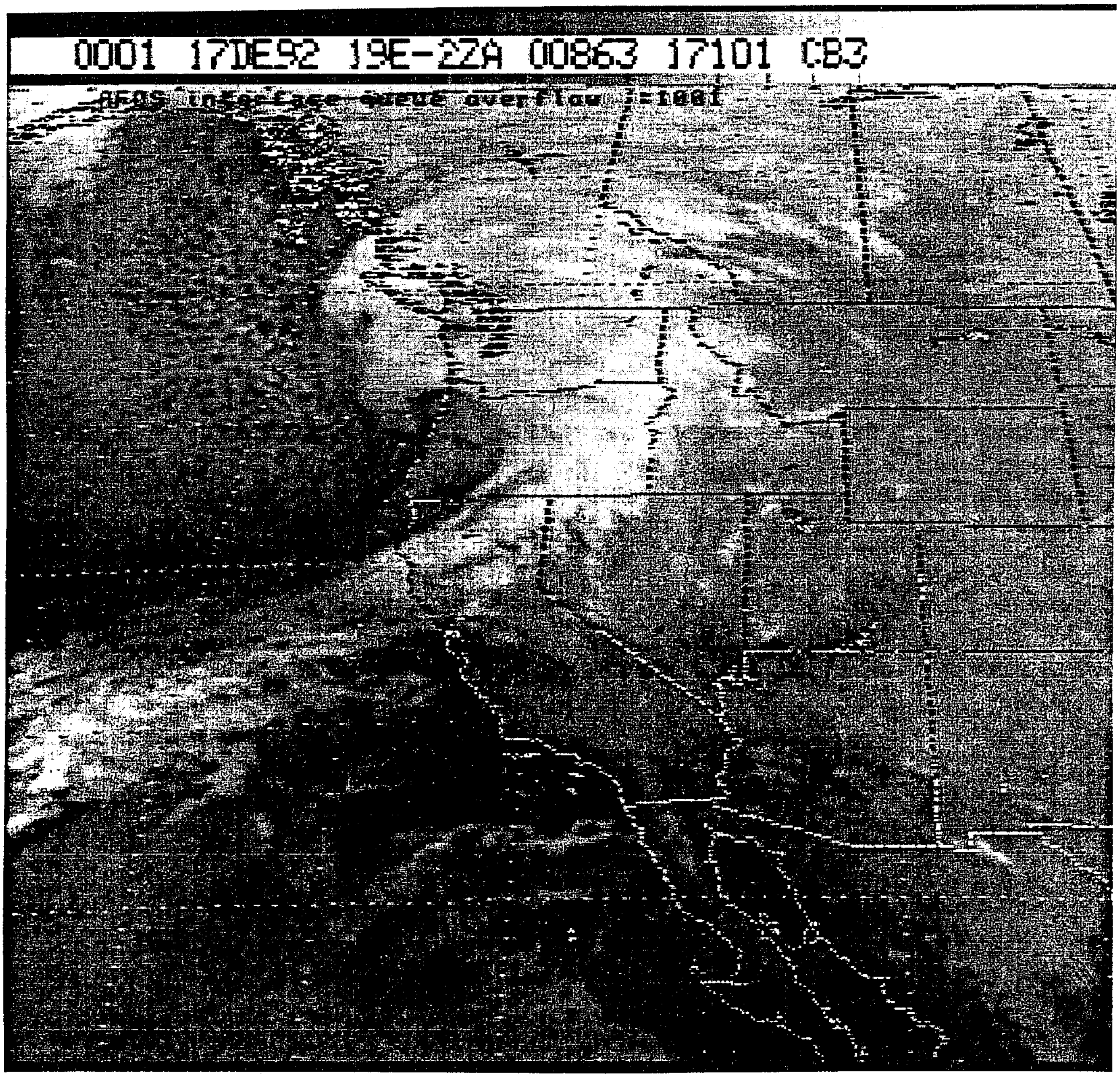


Figure 5. Infrared satellite image (2 km resolution, ZA enhancement), 0001 UTC December 17, 1992.

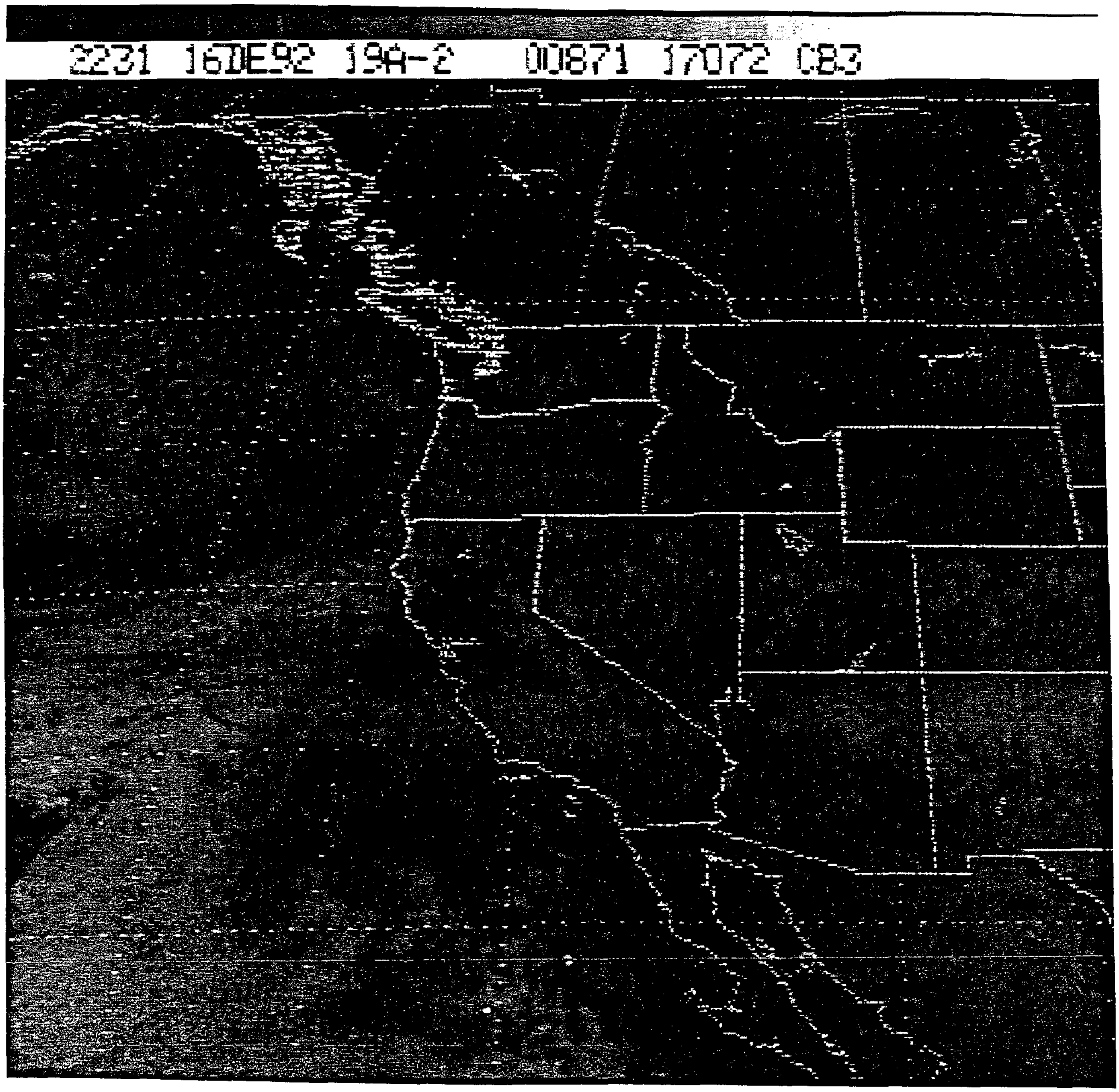


Figure 6. Visible satellite image (2 km resolution), 2231 UTC December 16, 1992.

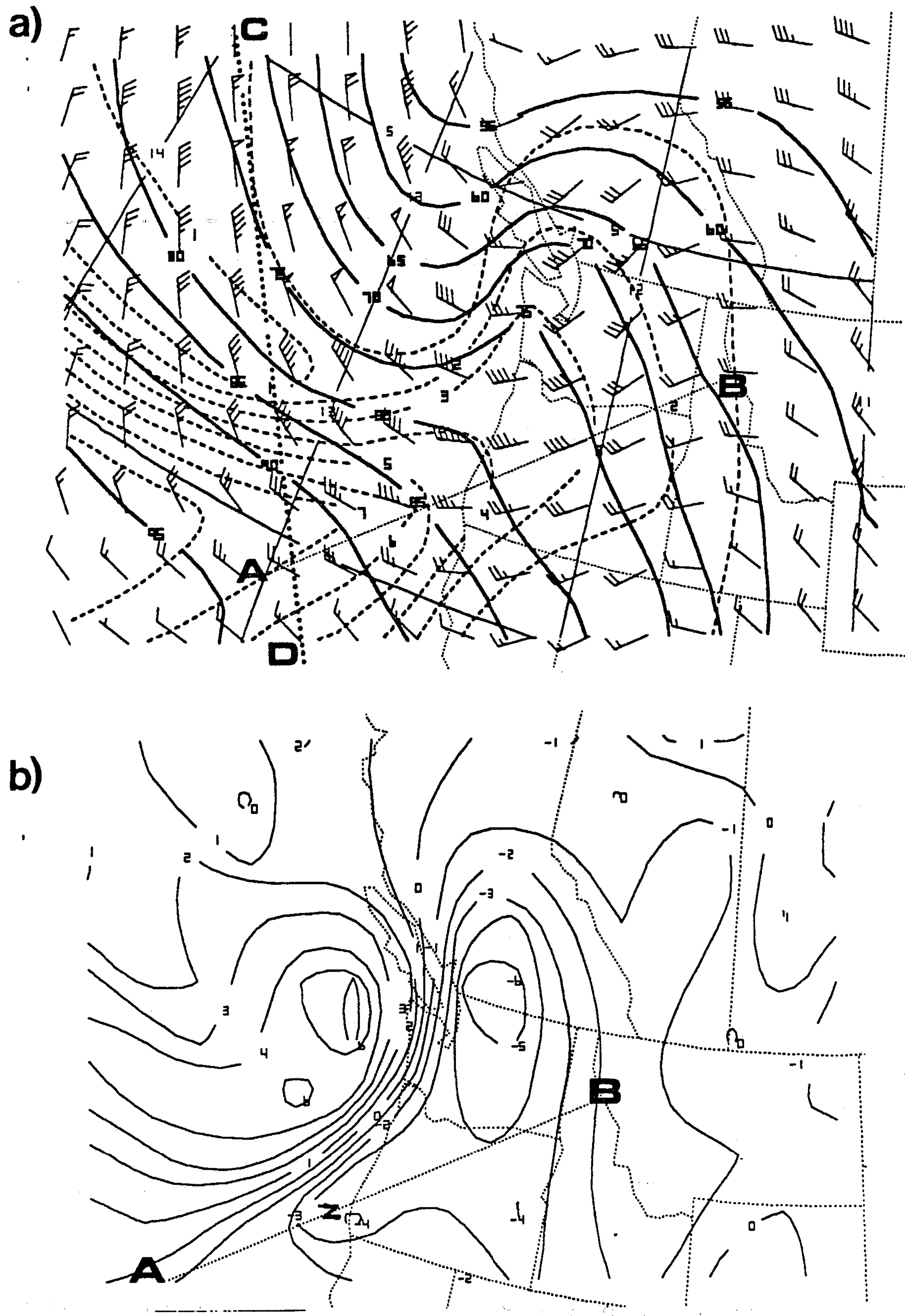


Figure 7. Same as Figure 2 except using the 12-hr forecast from the NGM, valid 0000 UTC, December 17, 1992. (a) A-B (dotted line) is the plane view of the along-frontal cross section depicted in Figure 8. C-D (heavy dotted line) is the plane view of the cross-frontal cross section in Figure 9. (b) ω due to Term B (in μb/s) from PCGRIDs.

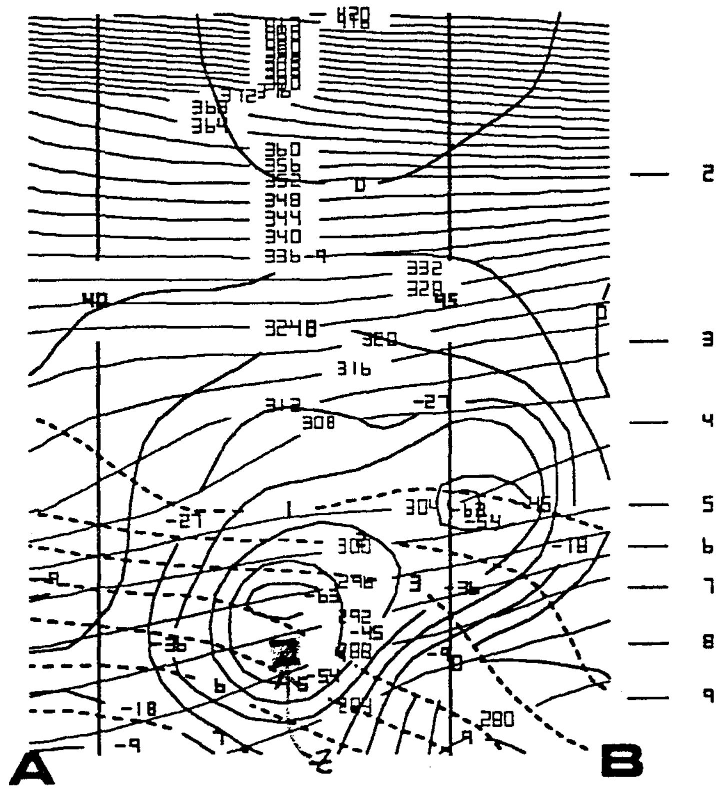


Figure 8. Along-front, vertical cross section from A-B in Figure 7 with isentropes (every 4K, thin solid), total ω (μb/s, thick solid), mixing ratio (every g/kg, dashed), and latitude.

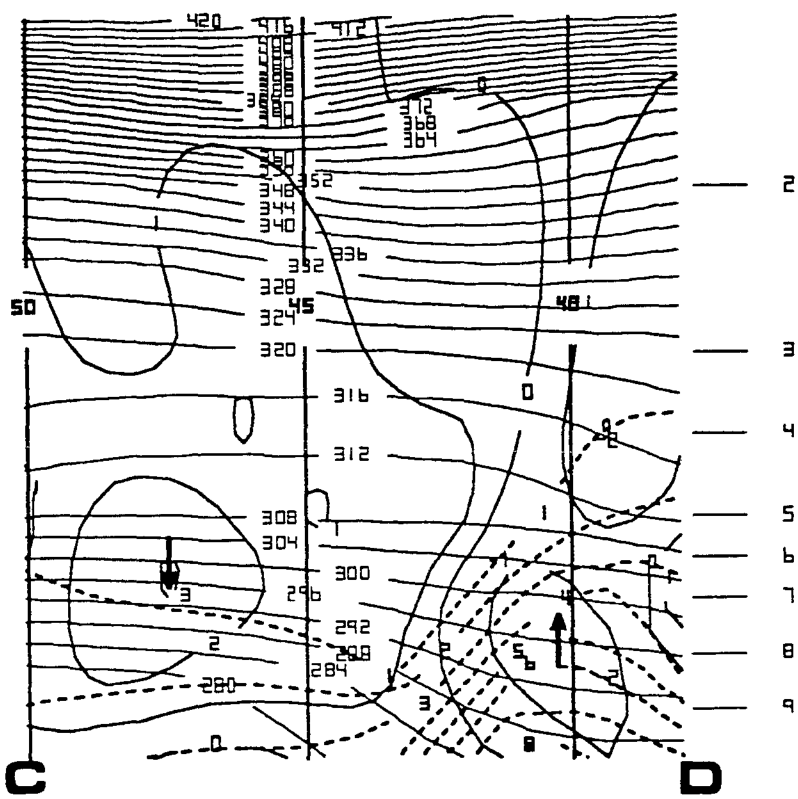


Figure 9. Cross-front, vertical cross section valid at 0000 UTC, December 17, 1992 (12-hr NGM forecast data) from C-D in Figure 7 with isentropes (every 4K, thin solid), total ω (μb/s, thick solid), and mixing ratio (every g/kg, dashed), and latitude of the cross section (every 5°, vertical solid).