Western Region Technical Attachment
No. 93-03
February 2, 1993

JET STREAK DYNAMICS: EFFECTS OF CURVATURE

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[Editor's Note: This Technical Attachment summarizes the results of a modeling study identifying the effects of jet streak curvature on kinematic vertical motion fields, completed by James Moore and Glenn VanKnowe which appeared in the November 1992 issue of Monthly Weather Review. Observed examples of these modeling results will also be discussed.]

The possible implications of jet streaks are addressed almost daily when creating a forecast. Whether looking for an initiation mechanism for convection or added ascent to increase snow amounts over a region, determining the influence of jet streaks becomes an important forecasting task. Too many times jet streaks are thought to be associated with a four-cell pattern of divergence/convergence, which typically accompanies only straight jet streaks and not those located in the base of a curved trough or climbing over the top of a ridge. Using the four-cell pattern of divergence/convergence with jet streaks within curved flow leads to misleading diagnoses of the forecast forcing associated with the jet streak and possibly a busted forecast. Moore and VanKnowe (1992) completed a relatively simple modeling experiment to determine the kinematic vertical motion fields associated with straight, cyclonically curved, and anticyclonically curved jet streaks. This Technical Attachment presents the results of Moore and VanKnowe (1992) and discusses the operational applications.

Experience, and an understanding of dynamics, has lead to expectations of ascent (descent) in advance of (behind) an upper-level trough. This occurs as a result of subgeostrophic wind fields (ageostrophic winds opposing the observed winds in downstream of the trough) within the trough and supergeostrophic wind fields (ageostrophic winds supplementing the observed winds upstream of the trough) within the ridge. This results in the divergence of the ageostrophic wind fields at upper levels (indicative of ascent) downstream of the trough axis and the convergence of the ageostrophic wind fields at upper levels (indicative of descent) upstream of the trough axis. Thus, troughs ideally are expected to have a two-cell vertical motion pattern associated with them, with the ascent leading the trough and the descent following. Too often attempts are made to apply straight jet dynamics to jets within the base of both sharp and somewhat flatter troughs. This results in erroneous diagnosis of vertical motion patterns.

Figures 1a-c display the various jet configurations used by Moore and VanKnowe (1992) in this simple model experiment, details of which may be found within the actual text. The initial strength of the: 1) straight jet streak (Fig. 1a) was 36.0 m s^{-1}; 2) the cyclonically curved jet streak (Fig. 1b) was 35.6 m s^{-1}; and 3) the anticyclonically curved jet streak was 34.2 m s^{-1}. The vertical motion field associated with the straight jet streak (Fig. 2a) depicts the expected four-cell pattern. However, with the slight addition of curvature to the jet streaks, the areas of ascent and descent become aligned into a two-cell pattern straddling the trough and ridge axes. In the case of cyclonically curved jet streaks (Fig. 2b), the ascent (descent) occurs in a narrow region downstream (upstream) of the trough axis with a magnitude on the order of 2.5 times greater than that of the straight jet case. On the other hand, the anticyclonically curved jet streak had a broad area of ascent (descent) situated upstream (downstream) of the ridge axis with maximum magnitudes about one-third weaker than the cyclonically curved case, but nearly twice as strong as a straight-line jet. From these results Moore and VanKnowe (1992) concluded that the magnitude of the maximum vertical motion accompanying a jet streak is a function of the degree of curvature. Thus, vertical motion, with similar strength jet streaks, may be expected to be strongest with cyclonically curved jet streaks, more modest with anticyclonically curved jet streaks, and weakest with straight-line jet streaks (Moore and VanKnowe, 1992).

Using PCGRIDS and gridded model data, the role of jet dynamics on inducing vertical motion may also be understood. Figure 3a provides an example of a cyclonically curved jet at 300 mb off the coast of the Baja Peninsula at 1200 UTC 18 January 1993. The modeling results shown in Fig. 2b suggest that a two-celled divergence/convergence pattern should exist in association with cyclonically curved jets, with the divergence (and implied ascent) occurring downstream of the jet core and trough axis. The divergence of the ageostrophic wind at 300 mb (Fig. 3b) appeared in the area from southern Nevada southward through southern California and off the Baja Peninsula, while convergence occurred over a large area of the Pacific Ocean upstream of the jet core. An anticyclonically curved jet (Fig. 4a), depicted over Nevada, Utah, and Colorado in the 48 hour ETA-X forecast valid 1200 UTC 17 January 1993, has a divergence/convergence pattern (Fig. 4b) which resembles the model results of a similar case. Convergence of the 300 mb ageostrophic wind (Fig. 4b) was forecast to occur downstream of the ridge axis and jet core with associated descent implied.

Even though the atmosphere does not separate the forcings for vertical motion, it is helpful to do so for purposes of understanding the evolution of the vertical motion. Thus, the jet streak dynamics may not be the only important contribution to vertical motion in the chosen cases. Although these two cases do not have the classic appearance of the model examples, the two cases show that the signatures suggested by the modeling results may be diagnosed from the model gridded data.

A good example of straight jet dynamics appeared in association with a very strong surface cold front on 2 March 1972 (Meier, 1993). Figure 5a displays a very straight 300 mb jet stretching from the Louisiana Gulf Coast to Quebec, Canada with winds in excess of 120 knots. What is most interesting about this particular jet are not the wind speeds, but that this jet is very long and straight and, thus, a very good candidate for straight jet dynamics to be considered. The ageostrophic wind field at 300 mb (Fig. 5b) shows the ageostrophic flow directed perpendicular to the height field towards lower pressure, with a region of very strong upper-level divergence located over Mississippi and Alabama. This identifies an area of strong tropospheric ascent (7 μb s^{-1}) associated with the direct circulation (Fig. 6a & b) in the upper-level jet entrance region.

Operationally, this provides useful quantitative insight into jet streak dynamics which should be considered when diagnosing the possible impacts of jet streaks on the forecast. Awareness of the differences between straight and curved jet streak vertical motion patterns, as well as the changes due to increases or decreases in the curvature of jet streaks, will provide more insightful determinations of cases where jet streak dynamics are or are not important. Even though the ultimate goal of such diagnoses is to determine the vertical velocity over a particular region, a nearly equal goal must be to understand the forcing for the vertical velocity. In doing this, it is more likely that an understanding of the evolution of the forcing will lead to a better appreciation of the evolution of the vertical velocity field. This allows a critical analysis of the model solutions.

These types of diagnostics are currently viewed using PCGRIDS on the model forecast fields and may prove insightful in determining where straight jet streak dynamics are important. Cross-sections should be chosen perpendicular to the jet axis to gain the most insight into ageostrophic vertical circulations associated with a particular straight jet.

In short, jet streaks are more typically curved than straight. Thus, the challenge becomes incorporating the implications of curvature, on the idealized four-cell ascent/descent patterns associated with straight jet streaks, into a daily assessment of the impact jet streaks may have on each synoptic situation. Incorrectly applying straight jet streak dynamics to curved jet cases could lead to a busted forecast, while sorting out the details associated with each jet streak can prove to be a worthwhile exercise.

References

Meier, K. W., 1993: Analysis of a long-lived intense low-level front: A case study of 28 February through 3 March 1972. M.S. thesis, State University of New York at Albany.

Moore, J. T., and G. E. VanKnowe, 1992: The effect of jet-streak curvature on kinematic fields. *Mon. Wea. Rev.*, **120**, 2429-2441.

Shapiro, M. A., 1983: Mesoscale weather systems of the central United States. *The National STORM Program: Scientific and Technological Bases and Major Objectives* (R. A. Anthes, Ed.), University Corporation for Atmospheric Research, P. O. Box 3000, Boulder, CO 80307, 3.1-3.77.

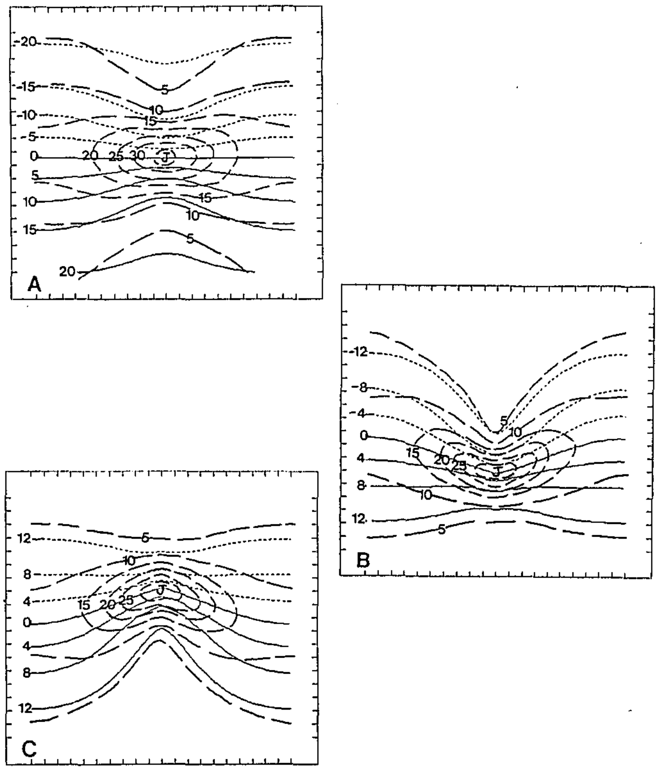

Fig. 1. Streamfunction values (10^6 m^2 s^{-1}), small dashed (negative values) and solid (positive values) lines, and isotachs (m s^{-1}, thick dashed lines) for (a) straight-line jet, (b) cyclonically curved jet, and (c) anticyclonically curved jet. Here J marks the jet core. All values are for the initial time at 400 mb. (From Moore and VanKnowe, 1992).

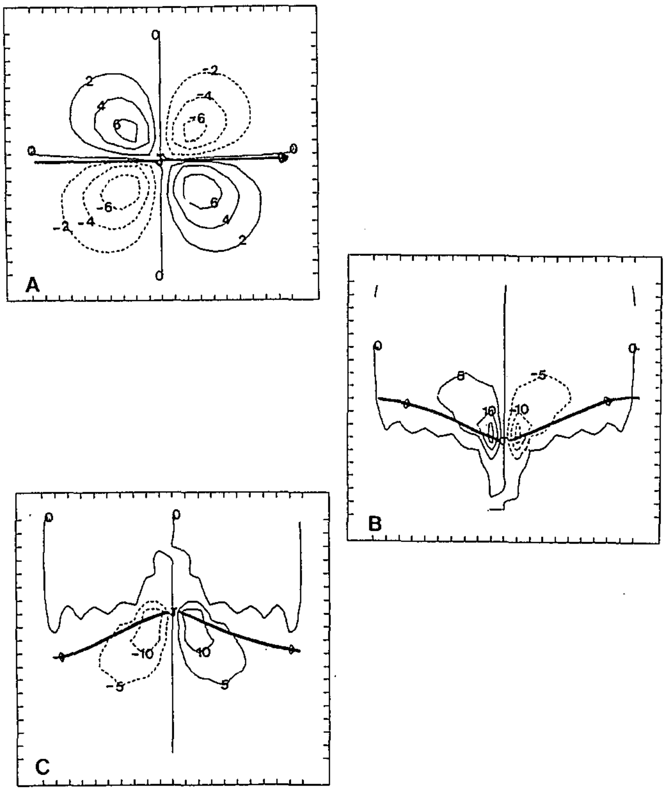

Fig. 2. Vertical motion at 600 mb ($10^{-1}\mu$b s^{-1} for all figures) at initial time for (a) straight-line jet, (b) cyclonically curved jet, and (c) anticyclonically curved jet. Here J marks the jet core and the thick black line is the jet axis. (From Moore and VanKnowe, 1992).

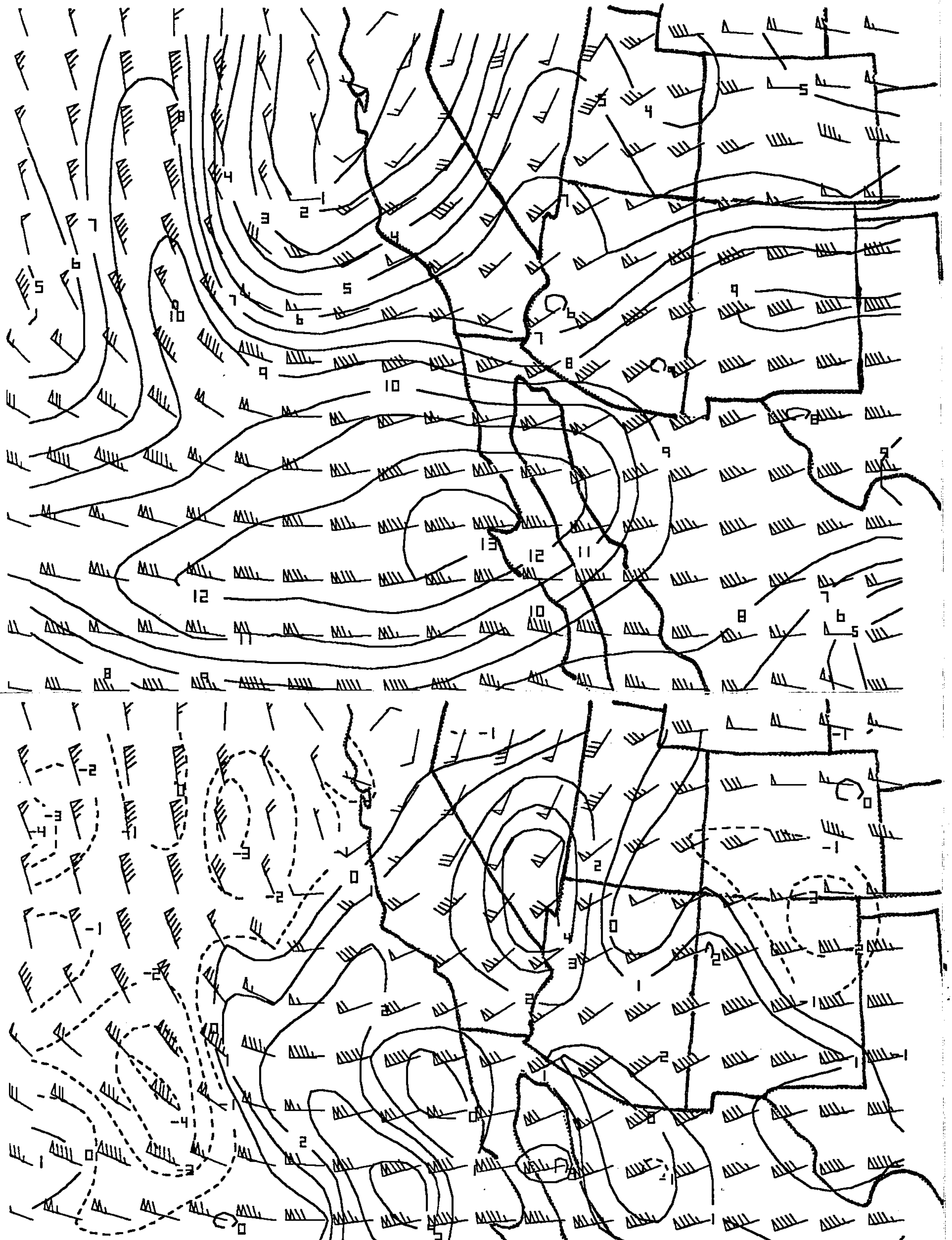

Fig. 3. ETA-X 00 hour initialization valid 1200 UTC 18 January 1993 for: a) 300 mb wind barbs and isotachs, contour interval = 10 knots; b) 300 mb wind and divergence of the ageostrophic wind, contour interval = $1\text{x}10^{-5}$ s^{-1}.

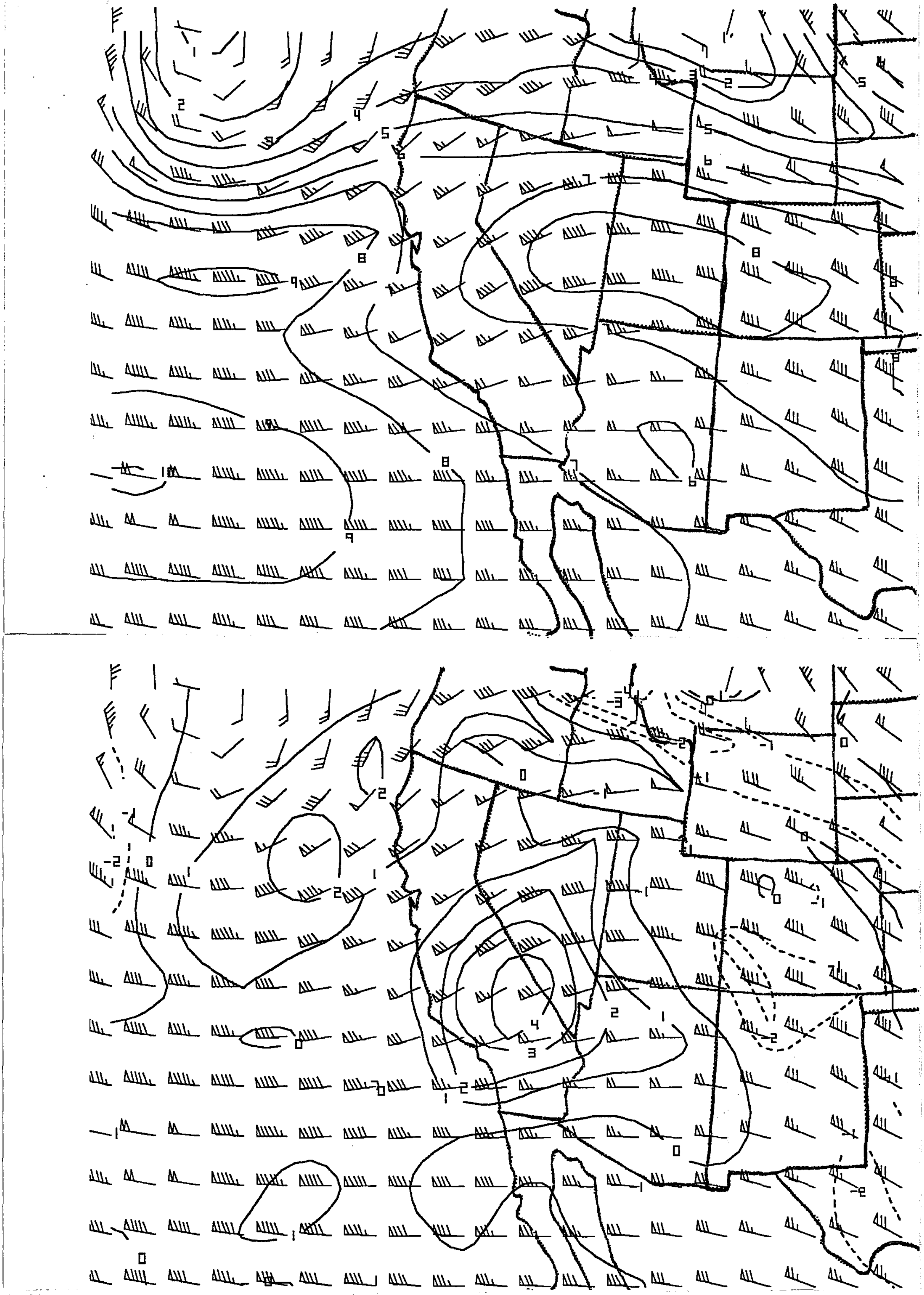

Fig. 4. ETA-X 48 hour forecast valid 1200 UTC 17 January 1993 for: a) 300 mb wind barbs and isotachs, contour interval = 10 knots; b) 300 mb wind and divergence of the ageostrophic wind, contour interval = 1×10^{-5} s^{-1}.

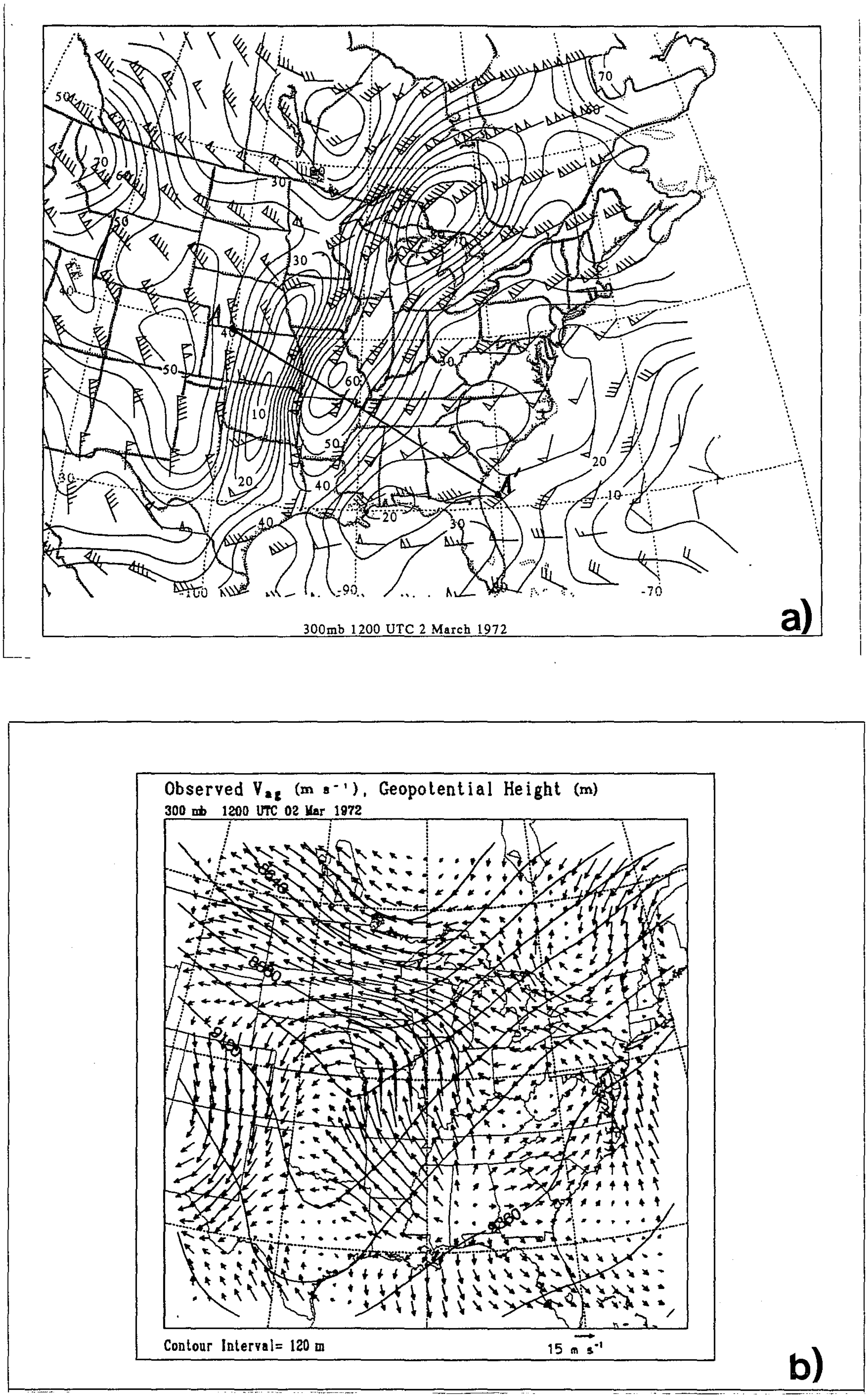

Fig. 5. 1200 UTC 2 March 1972: a) 300 mb wind speed, in knots, and isotachs, contoured every 10 m s^{-1}; and b) 300 ageostrophic winds, in m s^{-1} and height field. The line A-A' denotes the orientation of the cross-sections displayed in Fig. 6. (From Meier, 1993).

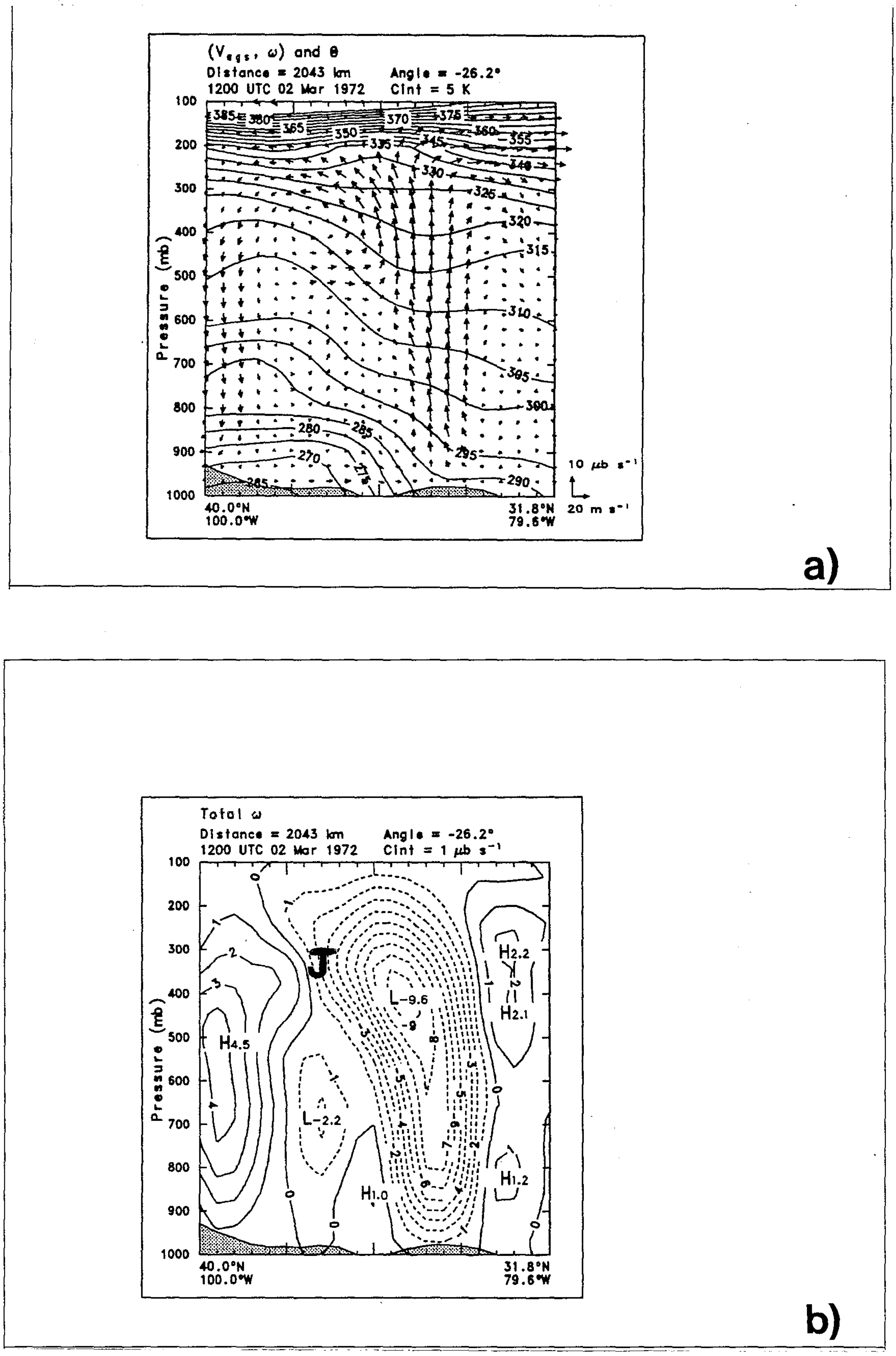

Fig. 6. Cross-sections, located from 40°N, 100°W to 32°N, 80°W at 1200 UTC 2 March, of: a) ageostrophic wind, total ω, and potential temperature (contoured every 5K); and b) total ω, contoured every μb s^{-1}. The **J** represents the approximate position of the upper-level jet axis, oriented into the page. (From Meier, 1993).