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A HEAVY SNOW EVENT ASSOCIATED WITH JET STREAK INTERACTION

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Introduction

This paper is a case study of a heavy snow event in the western United States that was influenced by the interaction of transverse vertical circulations associated with two separate jet streaks.

Jet Streak Dynamics

Before looking at the case, a brief review of jet streak dynamics is in order. Figure 1 is a schematic of a jet streak in the x-y plane. The dashed lines represent isotachs and the solid lines represent height contours. The entrance and exit regions of the jet streak are defined as shown because air typically flows through the jet streak faster than the jet streak itself propagates (air "enters" the jet streak core through the entrance region and "exits" the jet streak core through the exit region).

The air flowing into the entrance region is subgeostrophic (below the velocity necessary for the coriolis force to balance the pressure gradient force). Therefore, since the pressure gradient force (PGF) is stronger than the coriolis force, the wind blows to the left of the geostrophic wind towards lower heights. Similarly, air flowing out of the exit region is supergeostrophic (the coriolis force is stronger than the PGF) so the wind blows to the right of the geostrophic wind towards higher heights. In Figure 1, heavy arrows depict the resultant winds in the entrance and exit regions.

This acceleration of the flow towards lower heights in the entrance region and deceleration of flow towards higher heights in the exit region leads to the familiar four cell pattern of convergence/divergence. If one were in the jet streak facing downstream, there would be upper-level convergence in the front-right and rear-left flanks of the jet streak, and upper-level divergence in the front-left and rear-right flanks of the jet streak.

Due to mass continuity these upper-level convergence/divergence patterns lead to transverse circulations throughout the depth of the troposphere. Rising motion occurs beneath areas of upper-level divergence and sinking motion occurs beneath areas of upper-level convergence. Figure 2a shows a cross section within the entrance region of the jet streak. In this region there is a direct circulation marked by rising motion on the warm (anticyclonic) side of the jet streak and sinking motion on the cold (cyclonic) side of the jet streak. Figure 2b shows a cross section within the exit region of the jet streak. Here, there is an indirect circulation marked by rising motion on the cold (cyclonic) side of the jet streak and sinking motion on the warm (anticyclonic) side of the jet streak.

The review above only considers one jet streak, but one could imagine a scenario in which two jet streaks are aligned such that rising motion underneath the rear-right flank of one jet streak coincides with rising motion underneath the front-left flank of a separate jet streak. Increased vertical motion due to the juxtaposition of the particular flanks of the two jet streaks could then produce significant precipitation under the right conditions.

Uccellini and Kocin (1987) studied over 20 intense snowstorms along the East Coast of the United States and found the interaction of transverse vertical circulations associated with two separate jet streaks was a common feature in cyclogenetic events which produced heavy snow. Figure 3, which is a reproduction of Figure 16 from their article, is a schematic of jet-related circulation patterns during a "typical" East Coast snowstorm. The direct circulation in the entrance region of a jet streak upstream from an upper-level trough over southeast Canada interacts with the indirect circulation in the exit region of a jet streak associated with an upper-level trough approaching the East Coast. This interaction contributes to differential moisture and temperature advection and the vertical motion needed to produce heavy snow.

Uccellini (1976) looked at the relative locations of several light-to-moderate snow events in the Midwest and found they occurred between the rising branch of an indirect circulation associated with one jet streak southwest of the surface low and the rising branch of a direct circulation associated with a separate jet streak northeast of the surface low. Wollander (WRTA 86-13) discussed an example of jet streak interaction over the western United States. Significant precipitation occurred over central California, northern Nevada, and western Utah. These areas were under the influence of the front-left flank of a jet streak propagating across southern California into northwestern Arizona, and the rear-right flank of a jet streak over the northern Rockies. In this case, warm air advection at 700 mb was weak and vorticity advection at 500 mb was neutral to weakly positive.

Interactive Jet Streak Case

The following is an example of a heavy snow event over Montana in which the interaction of jet streaks likely played a significant role. During the period 03Z-15Z March 15, 1989 portions of northwest Montana east of the Continental Divide received 4-6 inches of snow. During this period the airport at Great Falls measured 3 inches of new snow while downtown Great Falls measured 6 inches of new snow. Some of the mountains surrounding Great Falls reported over a foot of new snow.

Figure 4a shows the 300 mb height and isotach charts for 00Z March 15. A high-over-low blocking pattern can be seen over the Gulf of Alaska. One branch of the polar jet stream was over western Canada while another branch extended from south of the low through Oregon into Colorado. At this time, the jet streak is in an unfavorable position for upward vertical motion over Montana. Relatively light (30-50 knots) northwest flow was over western Montana. Figure 4b shows 700 mb data for the same time. Moist northwest flow was over western Montana with weak cold advection. At the surface (not shown), a stationary front was located near the Continental Divide west of Great Falls and extended to the southeast into central Wyoming. There was a light upslope gradient east of the Continental Divide.

By 12Z March 15, the surface and 700 mb charts had not changed significantly. At the surface (Figure 5), the stationary front was still near the Continental Divide west of Great Falls, and a cold front was just to the north of the Canadian border in Alberta. At 700 mb (not shown), moist northwest flow was still over western Montana. Cold advection had increased due to stronger flow and a tighter thermal gradient. However, at 300 mb (Figure 6) the pattern over western Montana had changed dramatically. Northwest flow over Montana had increased to between 70 and 90 knots, which was likely due to warm advection building the ridge near the Pacific coast and cold advection northeast of Montana. The "dove-tail" configuration of the 70 knot isotach seemed to indicate one branch of the polar jet extended from southeastern Alberta through central Montana, while a second branch extended from northwestern Washington through central Idaho (note the 90 knot isotach near Spokane).

Continuous light snow began at Great Falls after 09Z and became moderate after 13Z. Two inches of snow fell during the period 14Z-15Z. After 15Z snow became light.

What caused the snow to increase in intensity after 13Z? One factor may have been the interaction of jet streaks. Figure 7 is a close-up of the 300 mb isotach pattern over the northwestern United States for 12Z March 15. Rising motion associated with the rear-right flank of the jet streak from southeastern Alberta through central Alberta (dashed line) is denoted by "A", while rising motion associated with the front-left flank of the jet streak from northwestern Washington through central Idaho (dotted line) is denoted by "B". It is possible that these two areas of rising motion combined after 12Z to enhance the vertical motion and development of heavy snow. Another factor may have been increasing low-level convergence due to the approach of the surface cold front from Alberta. Still another factor may have involved latent heating. The release of latent heat may have enhanced the vertical motions associated with the jet streak interaction.

Summary

Considering that lower tropospheric patterns did not change much during the period 00Z-12Z March 15, it is possible that the interaction of the upper-level jet streaks over the northwestern United States played an important role in producing heavy snow over portions of northwest Montana. In a cold, moist air mass near a surface front, jet stream interactions can often play an important role in producing heavy snow events. Since constant pressure charts from the lower and middle troposphere may not always reveal upward vertical motions, it is important to understand and consider the dynamics of jet streams and jet stream interactions.

References

Uccellini, L.W., 1976: Operational Diagnostic Applications of Isentropic Analysis. National Weather Digest., Vol. 1, pp. 4-12.

Uccellini, L.W. and P.J. Kocin, 1987: The Interaction of Jet Streak Circulations During Heavy Snow Events Along the East Coast of the United States. Weather and Forecasting., Vol. 2, pp. 289-308.

Wollander, J., 1986: Jet Streak Interaction - Another Good Clue. National Weather Service Western Region Technical Attachment 86-13.

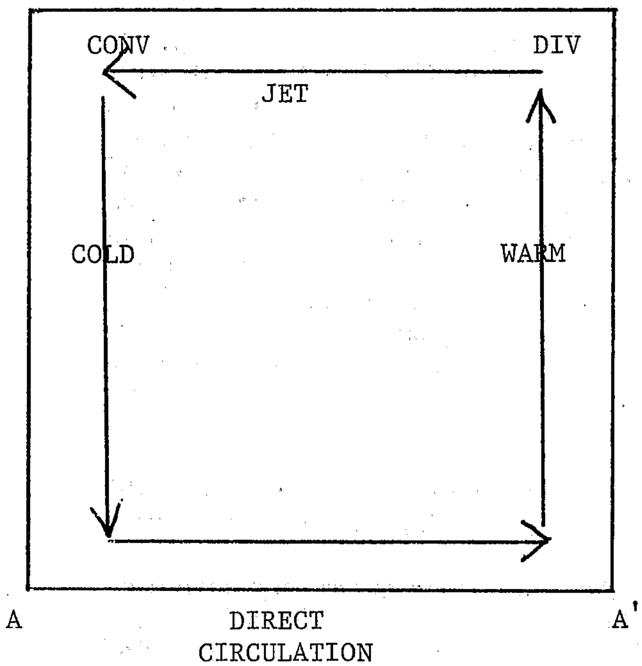

Figure 2A. Vertical cross section illustrating a direct circulation in the entrance region of a jet streak.

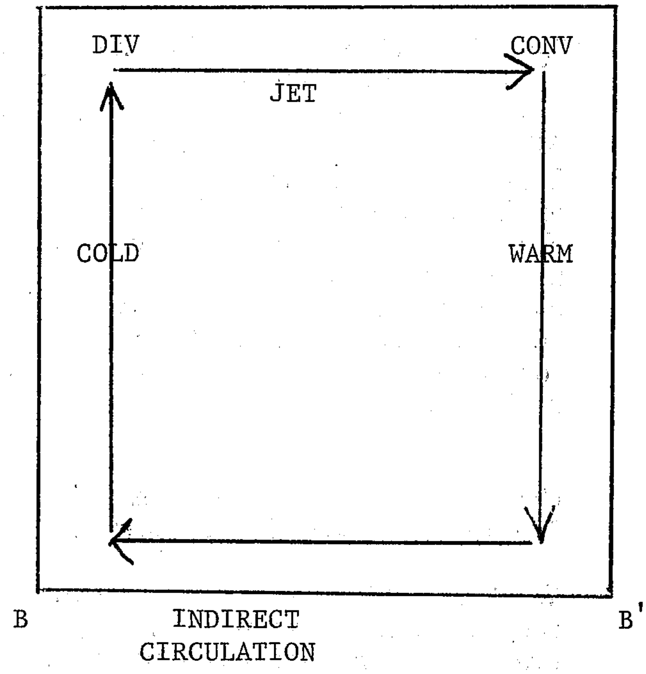

Figure 2B. Vertical cross section, illustrating an indirect circulation in the exit region of a jet streak.

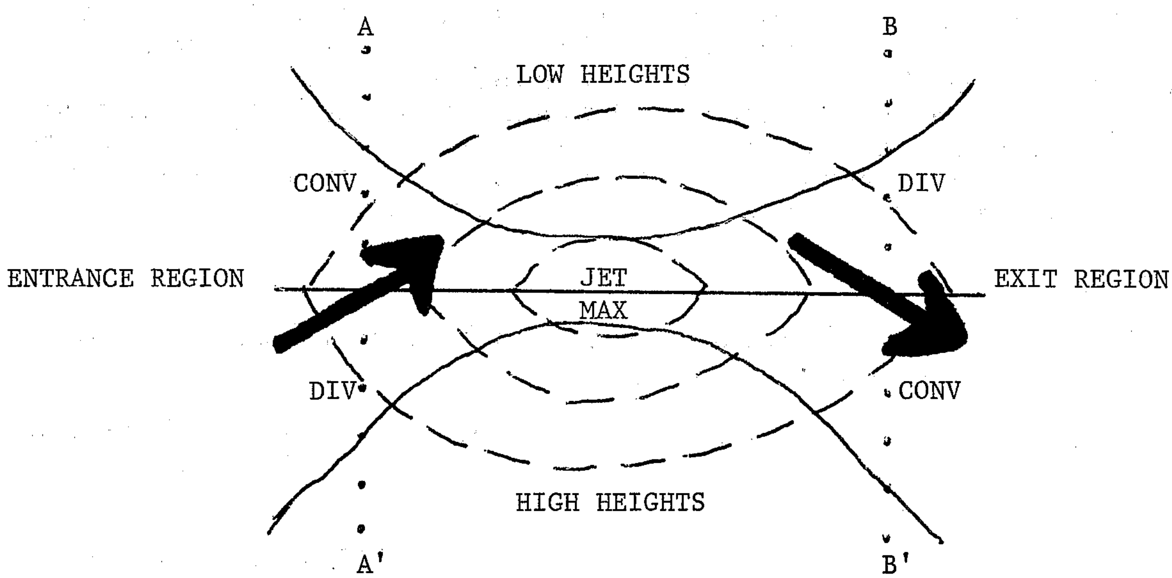

Figure 1. Schematic of acceleration/deceleration and patterns of convergence/divergence associated with the entrance and exit regions of a jet streak.

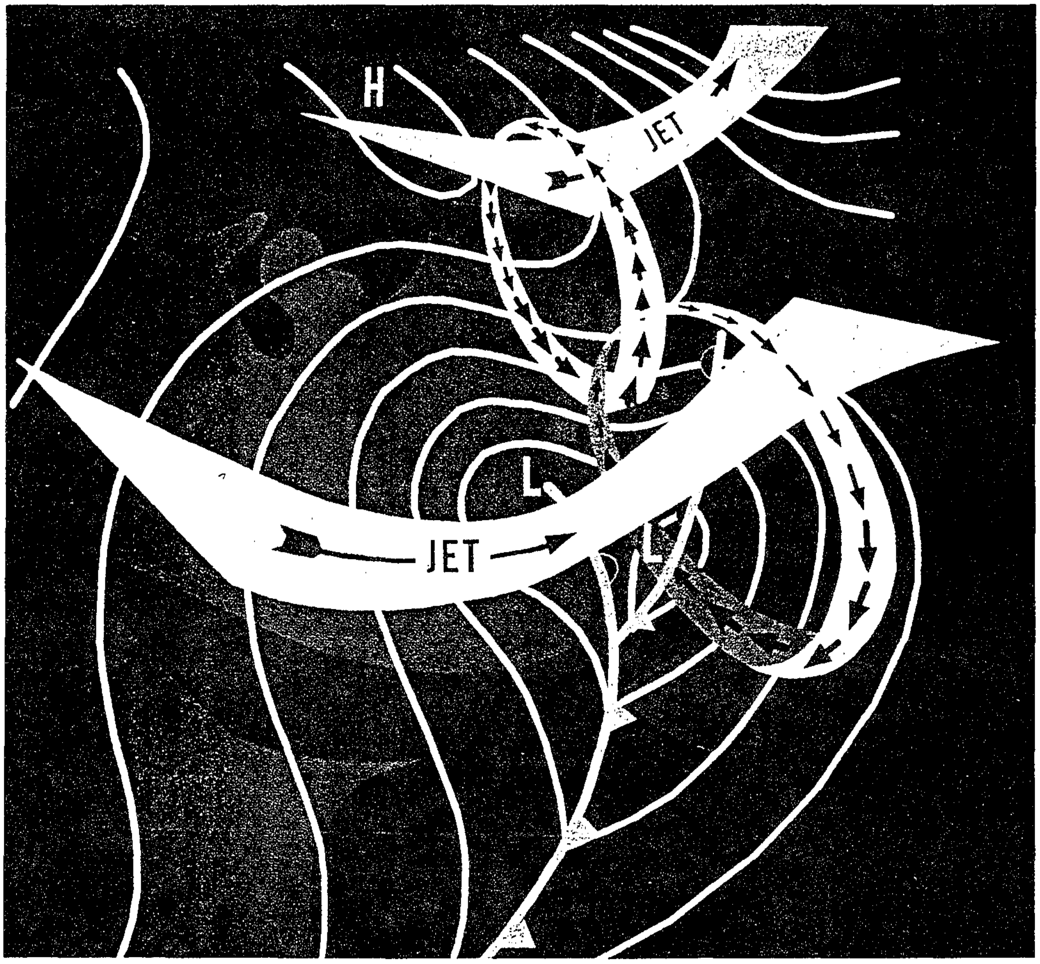

FIG. 16. Three-dimensional schematic of jet-related circulation patterns during East Coast snowstorms. The transverse circulations are associated with diffluent exit and confluent entrance regions of jet streaks embedded, respectively, at the base of troughs moving across the Ohio and Tennessee valleys and across southeastern Canada. Surface low and high pressure systems, isobars, and frontal positions are also indicated.

Figure 3. Schematic of jet stream interactions.

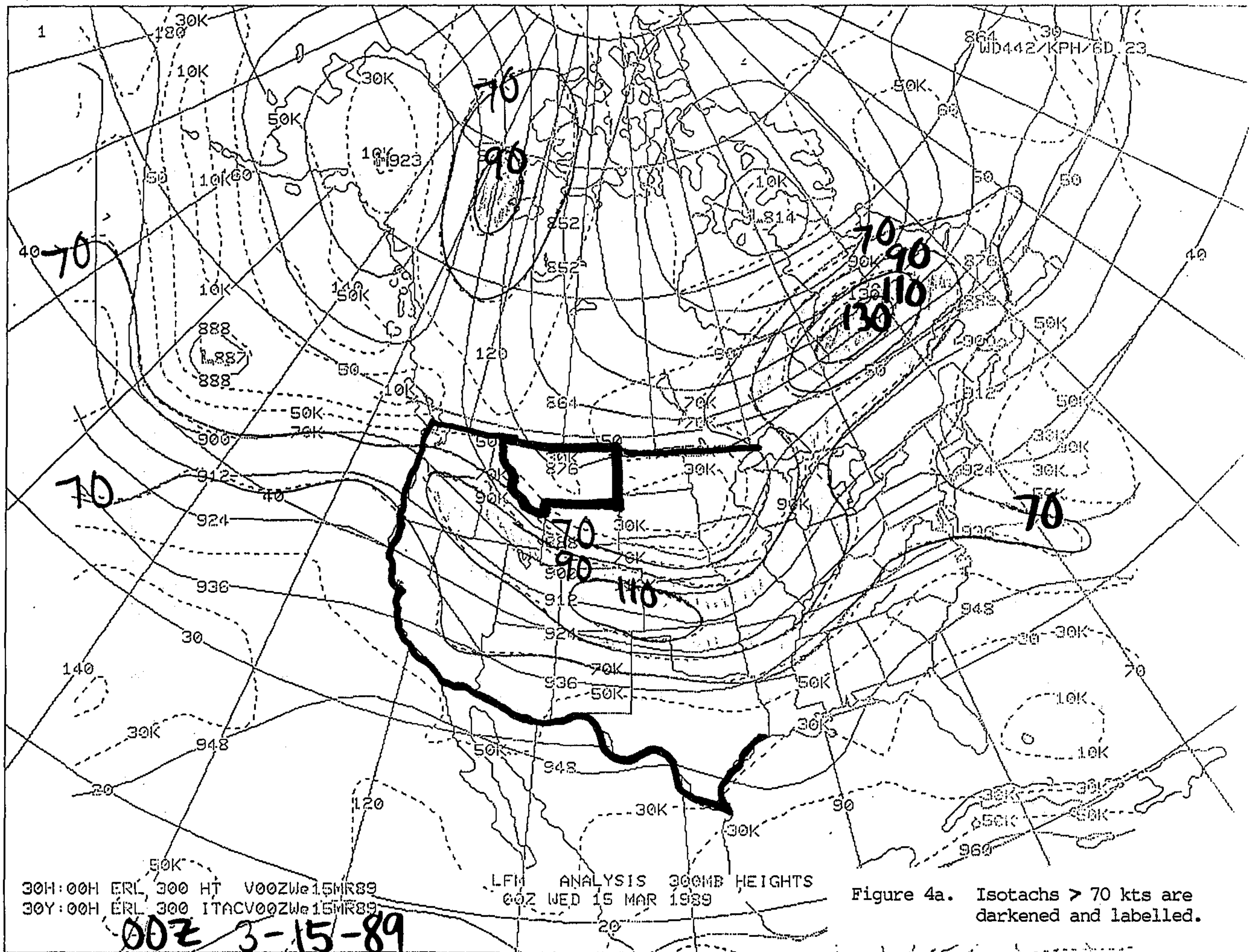

Figure 4a. Isotachs > 70 kts are darkened and labelled.

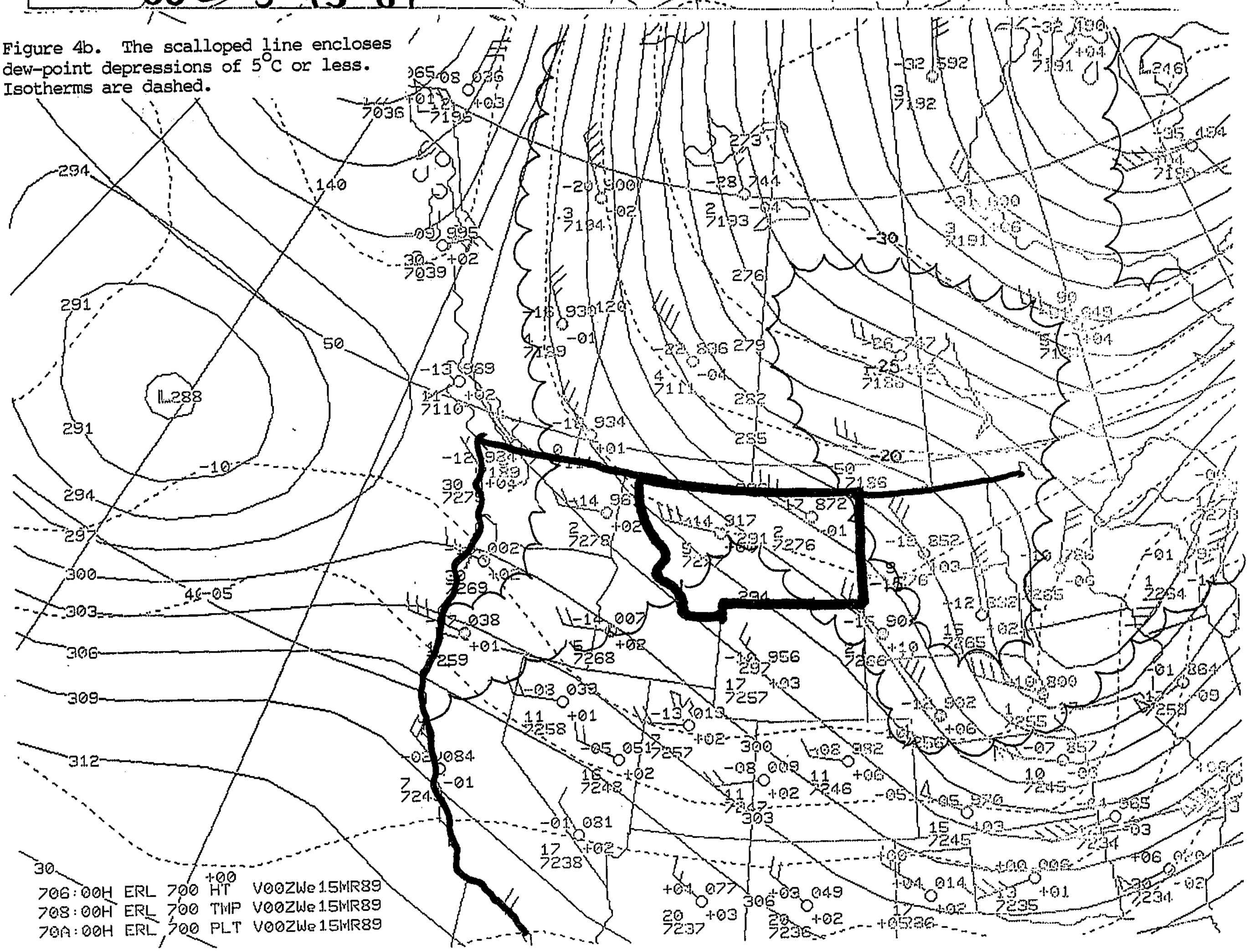

Figure 4b. The scalloped line encloses dew-point depressions of 5°C or less. Isotherms are dashed.

Figure 5.

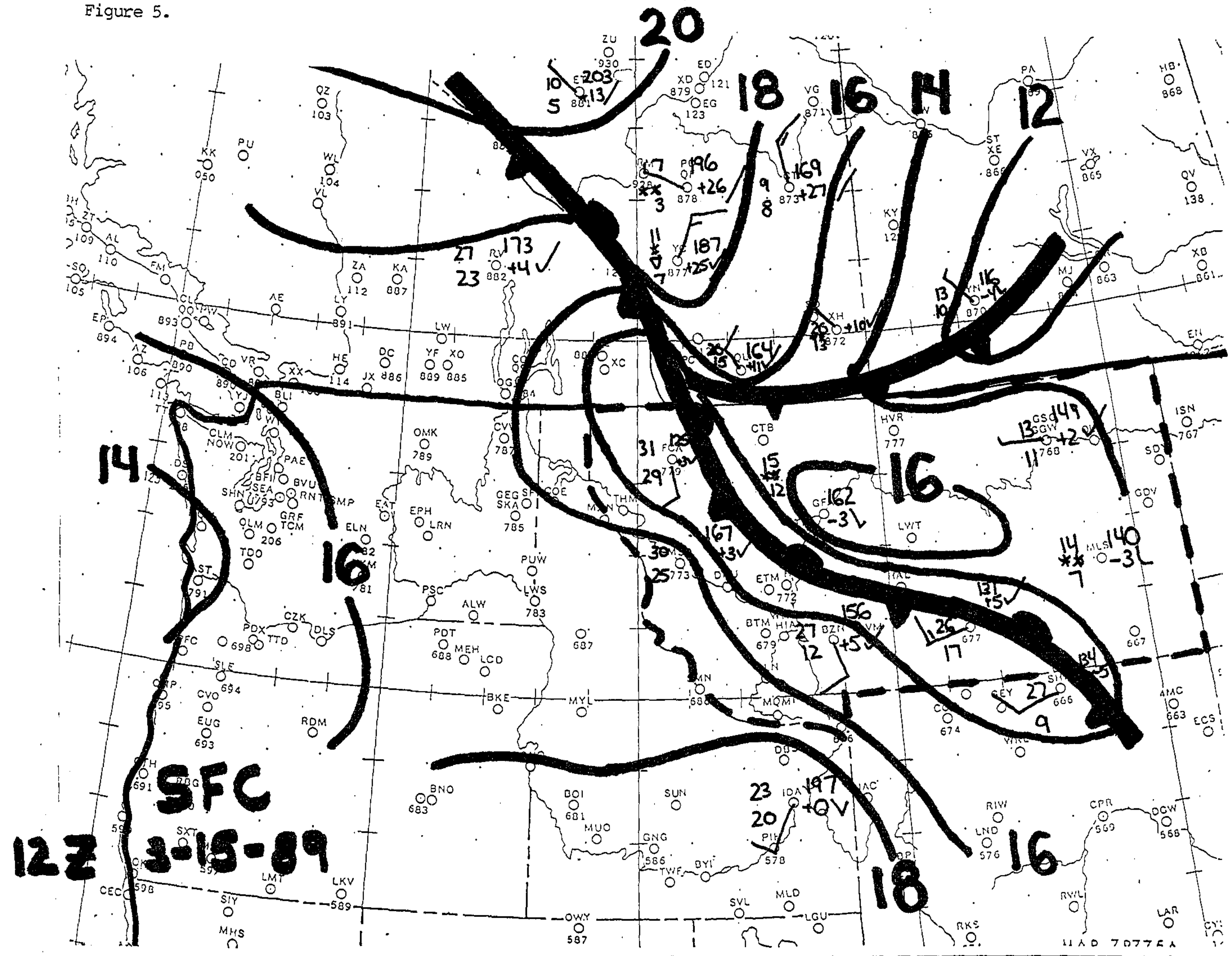

Figure 6. 300 mb heights and isotachs.

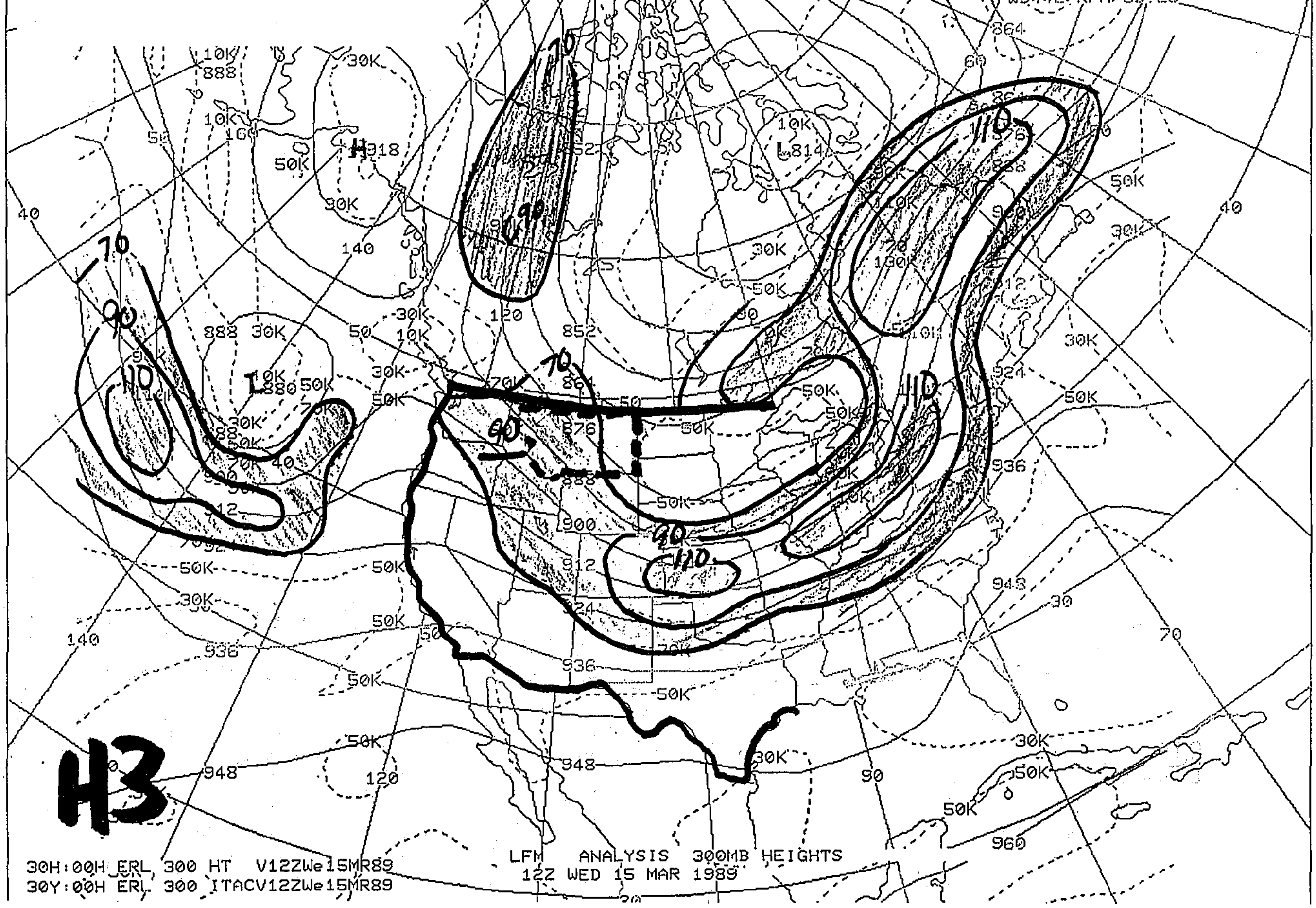

Figure 7.