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CONDITIONAL SYMMETRIC INSTABILITY CONTRIBUTING TO HEAVY PRECIPITATION IN THE PACIFIC NORTHWEST

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Introduction

Beginning the evening of February 23rd, 1994, precipitation began falling in west-east oriented bands across northern Oregon and southern Washington. The precipitation intensity peaked during the day on the 24th and ended the evening of the 24th. Six-hourly precipitation amounts during the event are shown in Fig. 1. Record rainfall and snowfall totals were measured at many locations.

During the event ,many rivers in northwest Oregon went above flood stage. At the Portland NWSFO, the 24-hour rain total of 2.46 inches established a new 24-hour precipitation amount for February and was the third highest 24-hour total on the all-time list. Record precipitation was measured at NWSO Pendleton, Oregon, which received an all-time record 24-hour snow amount of 16.1 inches and record February 24-hour precipitation with 1.41 inches. In south central Washington, Yakima received 8.5 inches of snow in a 24-hour period, breaking their February record. In the Washington Cascades, Crystal Mountain Ski Resort near Mt. Rainier reported 65 inches of new snow in 24 hours, setting a new record for 24-hour snowfall in the state of Washington.

Traditional synoptic features alone did not appear to be dynamic enough to produce the heavy precipitation that occurred. However, the contribution of another atmospheric process, conditional symmetric instability (CSI), could help to better explain the event. This Technical Attachment will show how CSI contributed to the heavy amounts of rain and snow on February 24th, 1994.

Synoptic Pattern

The typical synoptic pattern for significant precipitation over the Pacific Northwest is characterized by an upper-level trough (i.e., 500 mb) off the west coast and strong west to southwest flow aloft. Entrained in this flow is a long fetch of moisture, often extending to the tropics. This sort of moisture plume is commonly referred to locally as the "pineapple express". In the event examined here, conventional methods of meteorological analysis did not indicate prime conditions for a heavy precipitation event. Synoptic-scale features included northwesterly flow aloft over the Pacific Northwest (Fig. 2). Nor did Washington and Oregon appear to be in

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an area favorable for upward motion, when jet stream dynamics theory was applied, as most of the heavy precipitation occurred on the anticyclonic side of a strong polar jet (Fig. 3). An upper-level short wave was moving through Washington, brushing the northern part of Oregon (Fig. 2) and a warm front producing over running precipitation did not appear to make a strong contribution (Fig. 4). Overall baroclinicity vaguely depicted by the 850 mb height/temperature overlay along the Washington/Oregon border (Fig. 5) seemed weak.

Conditional Symmetric Instability

When evaluating for potential CSI on a vertical cross-sectional view, two major environmental characteristics must be met:

1) On a cross-section taken perpendicular to the thermal wind, theta-e surfaces have steeper slopes than the momentum surfaces (Fig. 6).

2) The airmass must be saturated or nearly so. The more moisture there is in the atmosphere, the steeper the slope of the theta-e surfaces. This will increase the likelihood that the theta-e surfaces will have a steeper slope than the momentum surfaces.

Figure 7 shows dry theta-e surfaces and moist theta-e surfaces. Above the Lifted Condensation Level (LCL), theta-e surfaces have a greater slope than the momentum surfaces (necessary for CSI). Below the LCL, the theta-e surfaces have less slope than the momentum surfaces. Thus, Fig. 7 illustrates that when motions are unstable with respect to saturated slantwise displacements, but stable with respect to dry slantwise displacements, the atmosphere has CSI.

Other indicators to look for are (Snook, 1992):

1) Wind speed increasing with height.

2) A veering wind profile in a frontogenetical area (the warm advection in the frontogenetical Region provides uplift that can release the slantwise instability).

3) A well-mixed layer close to saturation.

4) Multiple bands of cloudiness oriented parallel to the thermal wind (i.e., parallel to 1000 - 700 mb thickness lines).

Analysis

IR satellite imagery shows a single band of clouds stretching across the Washington/Oregon border (Fig. 8). Close examination of the imagery shows several enhanced cloud tops parallel to each other across southern Washington. The clouds imply the possibility of a cold front or frontogenesis in the area contributing to the release of CSI. Visible satellite imagery also reveals some striations oriented parallel to the thermal wind (NW-SE) (Fig. 9). WSR-88D data would have been useful in identifying precipitation banding, but this event occurred before

NEXRADs were operational in the Pacific Northwest.

Figure 10 shows a series of vertical cross-sections taken through the area of the heavy rain accumulation perpendicular to the thermal wind. (Refer to Fig. 1 for location of cross- sections). Momentum surfaces, equivalent potential temperature surfaces, and relative humidity surfaces are shown. Weather observing station along (or near) the cross-sections and 6h precipitation amounts, are shown along the bottom of each cross section. The dark shaded area indicates a favorable CSI environment, which correlates well with the precipitation maxima location. It must also be pointed out that on 00Z on the 24th, there is convective instability near the surface (theta-e decreasing with height), which would overwhelm the CSI.

Slantwise convective available potential energy (SCAPE), a measure of the amount of energy available in a CSI environment, is proportional to the 2nd power of vertical wind shear (Snook, 1992). SCAPE can be estimated by using a sounding created from data points taken along a constant momentum surface. From the February 24th event a sounding has been constructed from data points taken along a momentum surface roughly over the rainfall maxima area (Fig. 11). The SCAPE result from this is 147 J/KG. This is not substantial compared to CAPE values, which can reach into the thousands, but it might have been enough to create an unstable situation in an environment that appeared to be stable to upright convection.

Conclusion

It appears that CSI played an important role in the development of a heavy precipitation event in the Pacific Northwest on 23-24 February 1994. CSI, along with a trigger mechanism to release it (cold front, short wave, frontogenesis, etc.), could have contributed to producing the observed precipitation amounts. Indeed, model gridded data analysis did show a frontogenetical area near the heavy precipitation (Fig. 12). Forecasters have at their disposal the tools necessary to ascertain the potential for CSI. Through experience, the forecaster can also begin to recognize weather patterns that are conducive to CSI, and know when to analyze its potential further through gridded data.

Acknowledgment

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References

Snook, J.S., 1992: Current techniques for real-time evaluation of conditional symmetric instability. *Wea. Forecasting*, **7,** 430-439.

Bluestein, H.B., 1993: *Synoptic-Dynamic Meteorology in Midlatitudes.* Oxford University Press, 545-561.

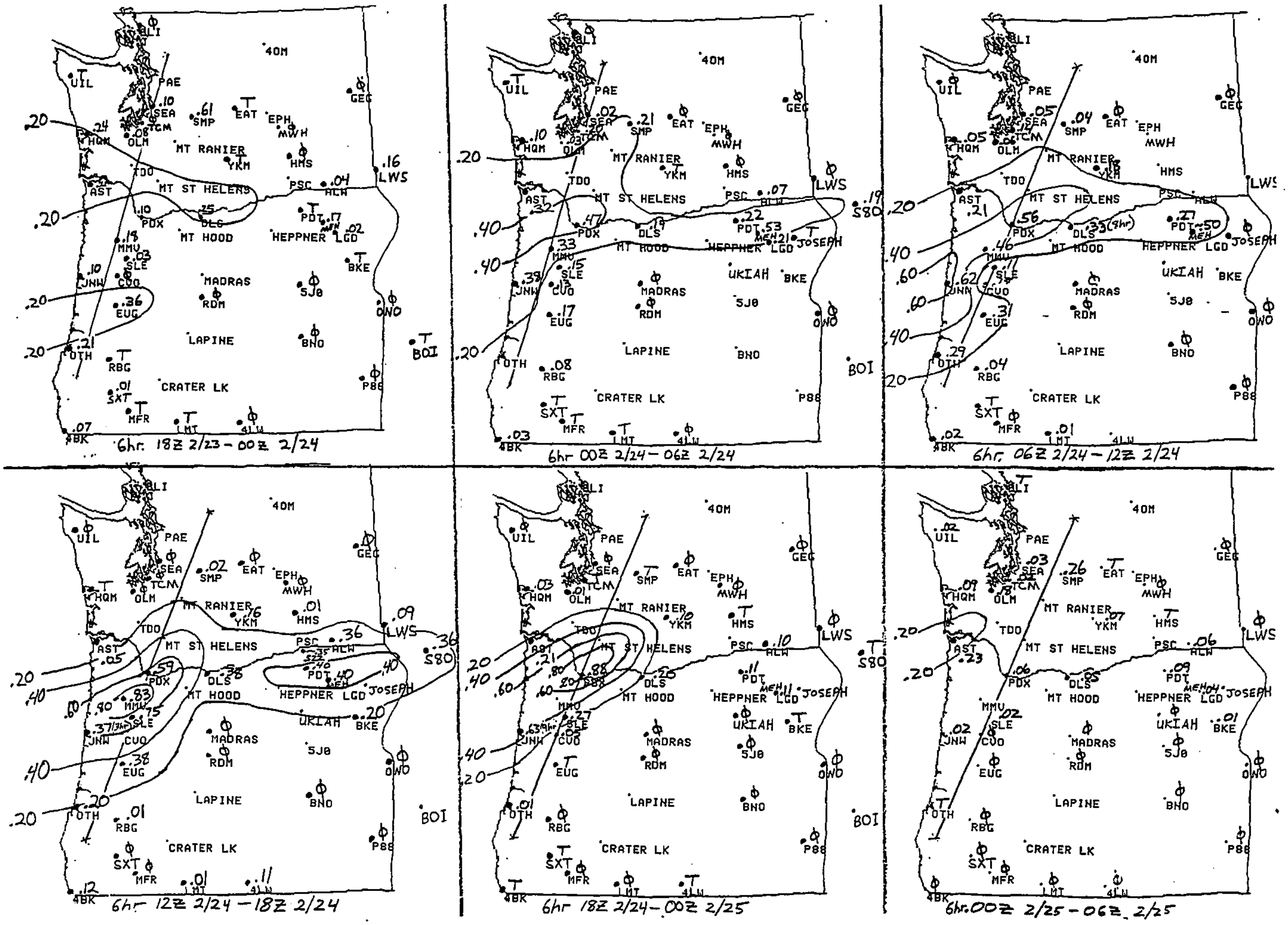


Fig. 1. 6-hour precipitation contours (every .20"). Also shown are the orientation of the cross-sections displayed in Fig. 10.

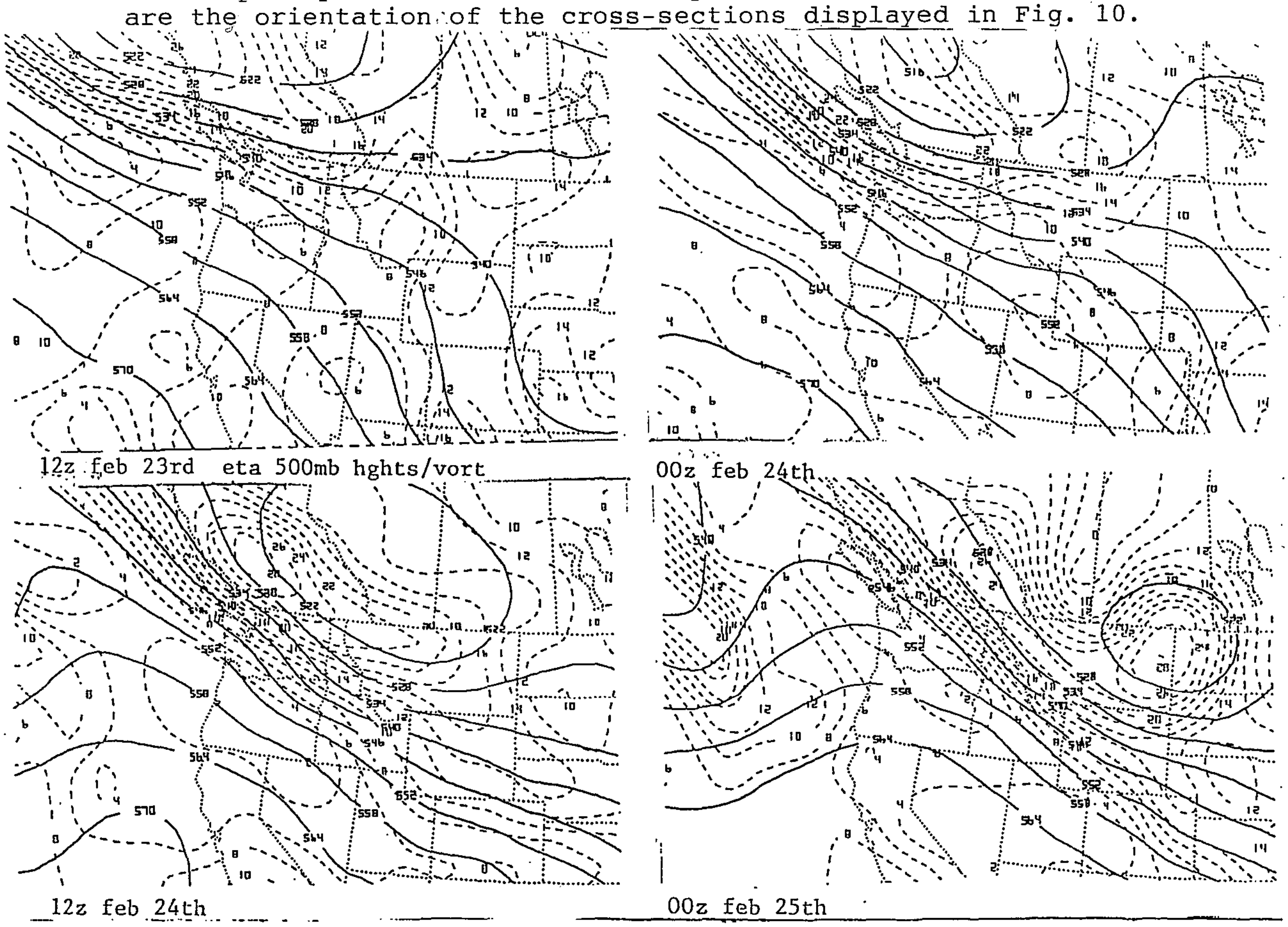


Fig. 2. 00-hour initializations of Eta 500 mb heights (solid) and vorticity (dashed).

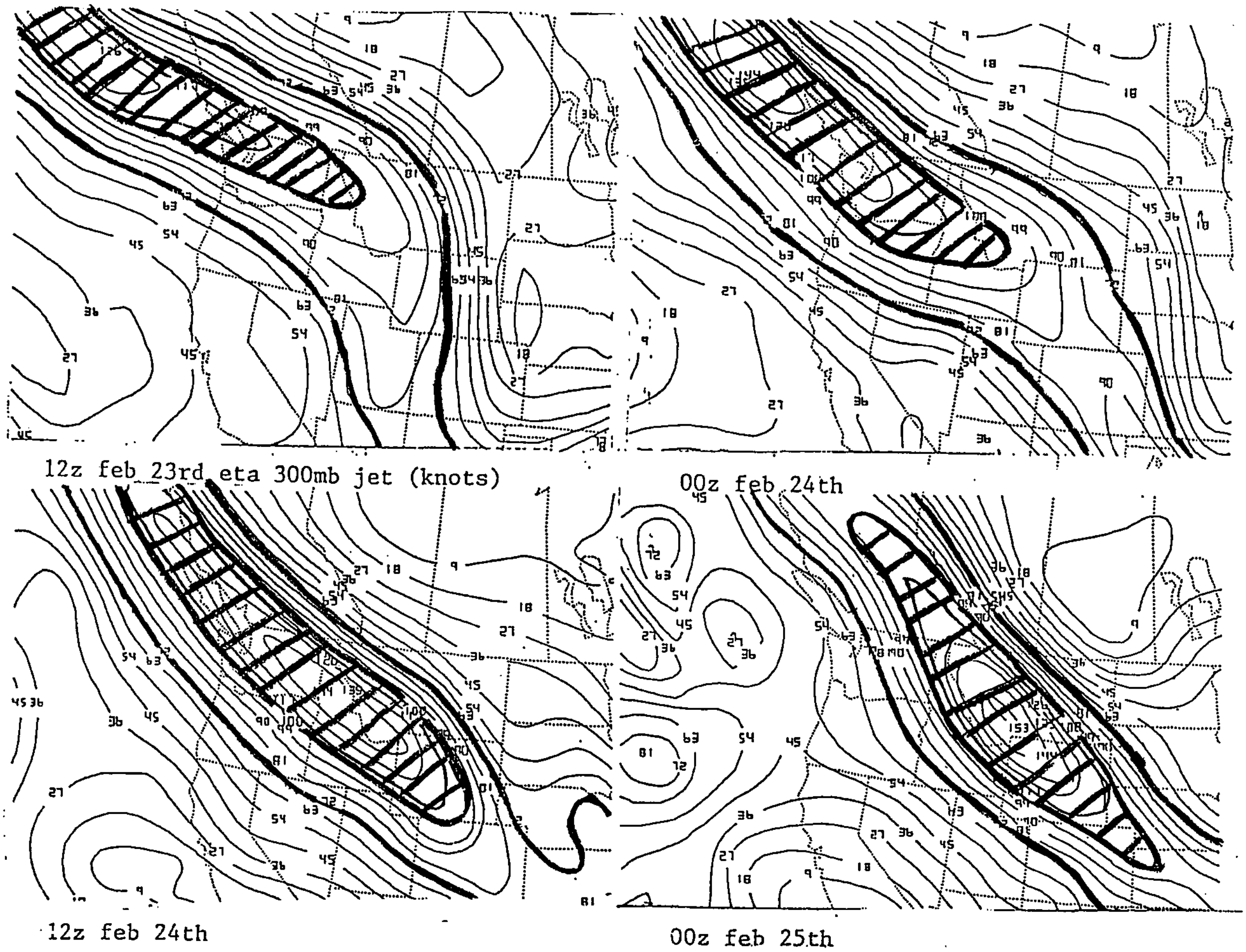


Fig. 3. 00-hour initializations of Eta 300 mb jet-stream (70 kt and 110 kt isotachs highlighted).

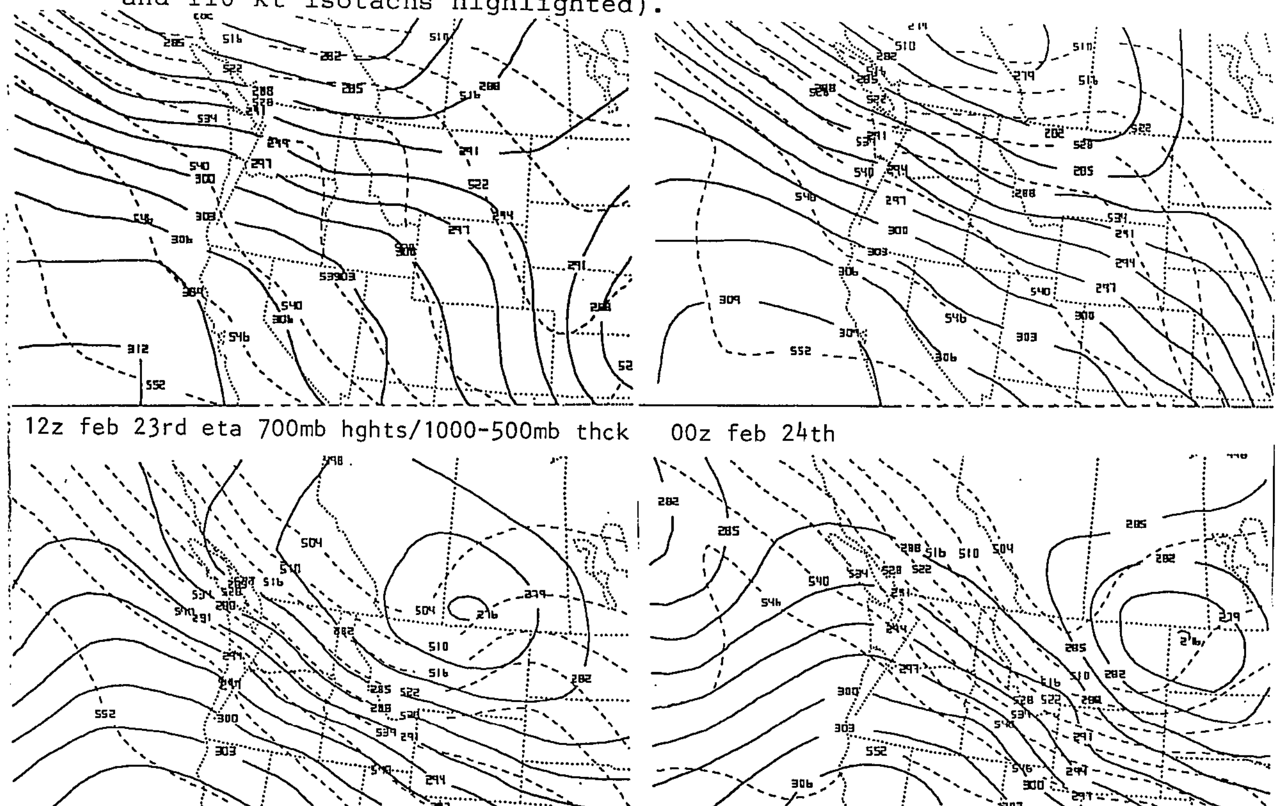


Fig. 4. 00-hour initializations of Eta 700 mb heights (solid) and 1000-500 mb thicknesses (dashed).

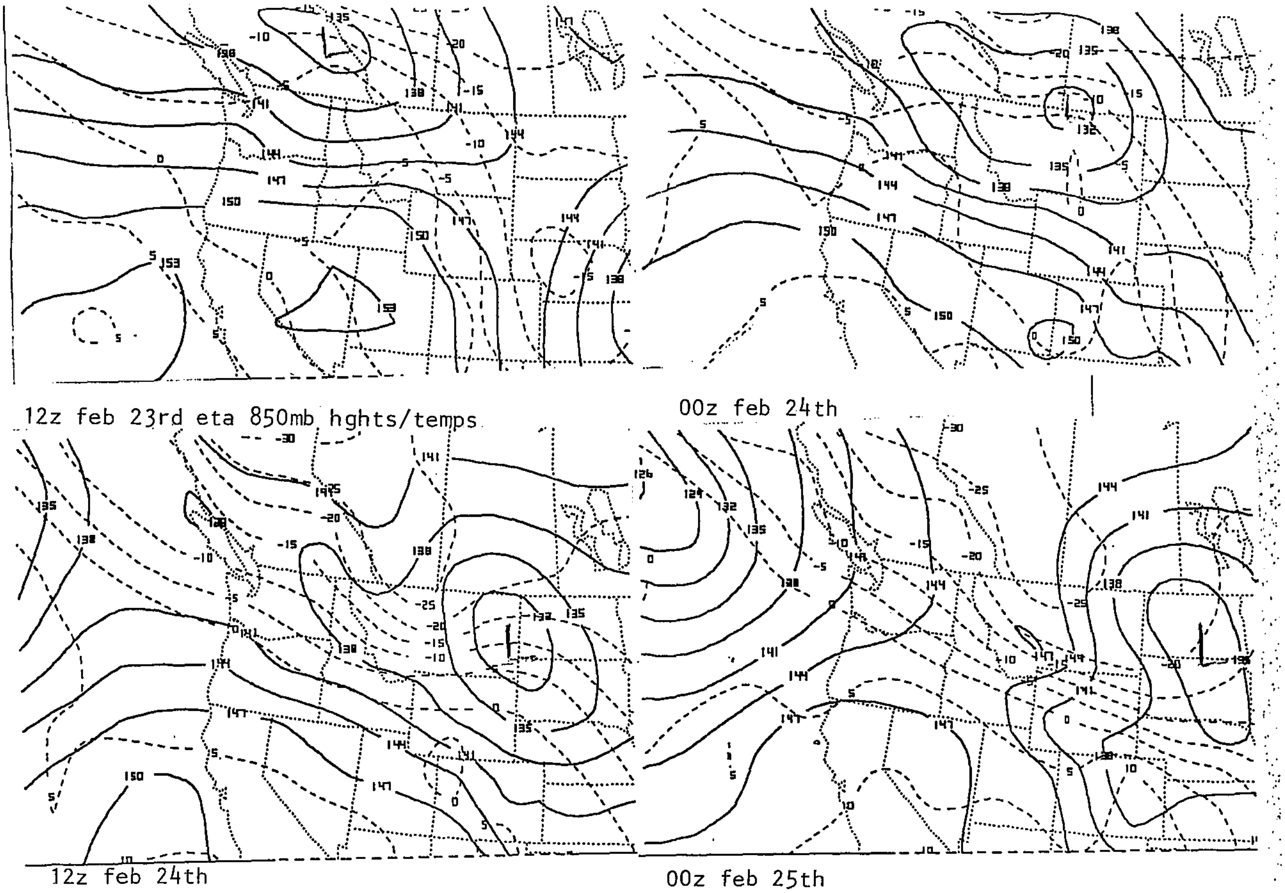


Fig. 5. 00-hour initializations of Eta 850 mb heights (solid) and temperatures (dashed).

Hypothetical east–west vertical cross section of a saturated atmosphere. The straight line represents a constant M_g surface that results from a southerly geostrophic wind increasing linearly with height. The curved line depicts a constant θ_{vg} surface representative of an atmosphere with conditional stability decreasing with height. The atmosphere is symmetrically stable below the dashed line and is symmetrically unstable above the dashed line. The arrow represents the slantwise motion of a parcel perturbed diagonally from point B that results from symmetric instability.

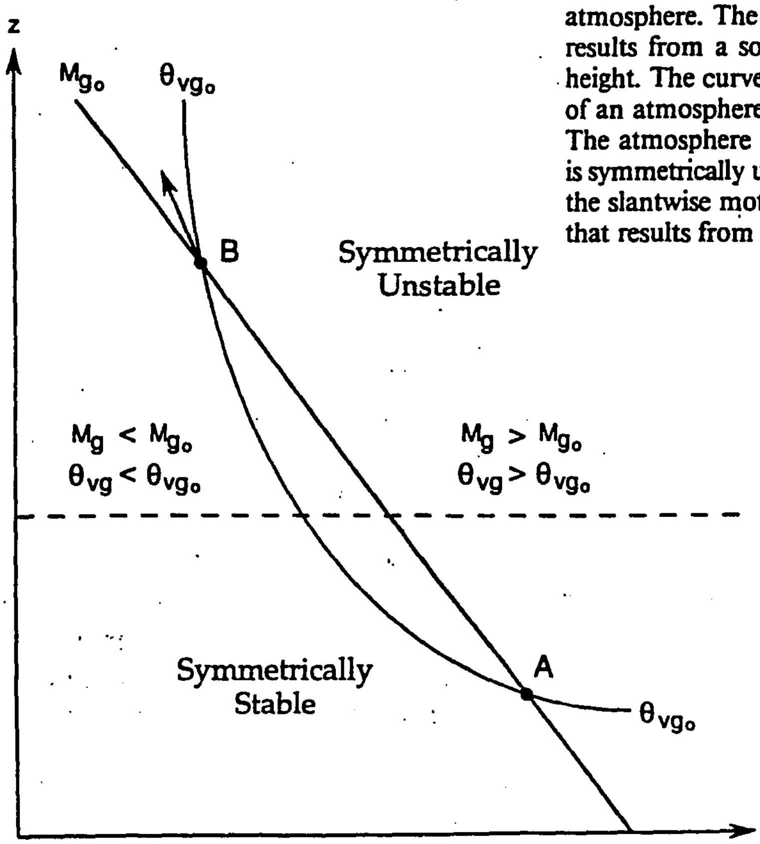
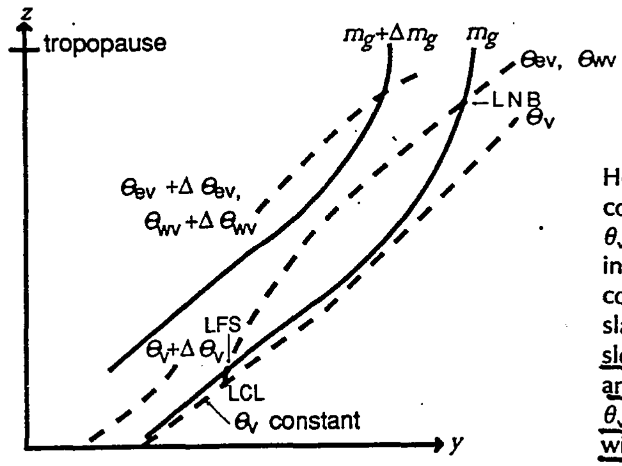


Fig. 6. Cross-section demonstrating a CSI environment (M_g is the geostrophically balanced momentum and θ_{vg} is the geostrophically balanced virtual potential temperature) (Snook, 1992).



Idealized example of a vertical cross section in the Northern Hemisphere, normal to the thermal-wind shear vector, showing surfaces of constant m_g (solid lines), and constant θ_v, θ_{ev}, and θ_{wv}. In this example θ_v, θ_{ev}, and θ_{wv} increase with height (gravitational and conditional stability), m_g decreases with increasing y (inertial stability), and θ_v decreases with y (baroclinic atmosphere, with colder air at larger values of y). Lifting condensation level (LCL); level of free slantwise convection (LFS); level of neutral buoyancy (LNB). Below the LCL the slope of the θ_v surface is less than that of the m_g surface. Note that the slope of θ_{ev} and θ_{wv} surfaces is greater than the slope of θ_v surfaces because the lapse rate of a θ_v surface is greater than that of a θ_{ev} or θ_{wv} surface, and θ_v, θ_{ev}, and θ_{wv} decrease with y.

(BLUESTEIN 1993)

Fig. 7. Cross-section demonstrating how if a parcel is lifted along a moist θ surface (θ_{ev}, θ_{wv}) it is symmetrically unstable, and if it is lifted along a dry θ surface (θ_v) conditions become symmetrically stable. M_g is the geostrophically balanced momentum. (Bluestein, 1993)

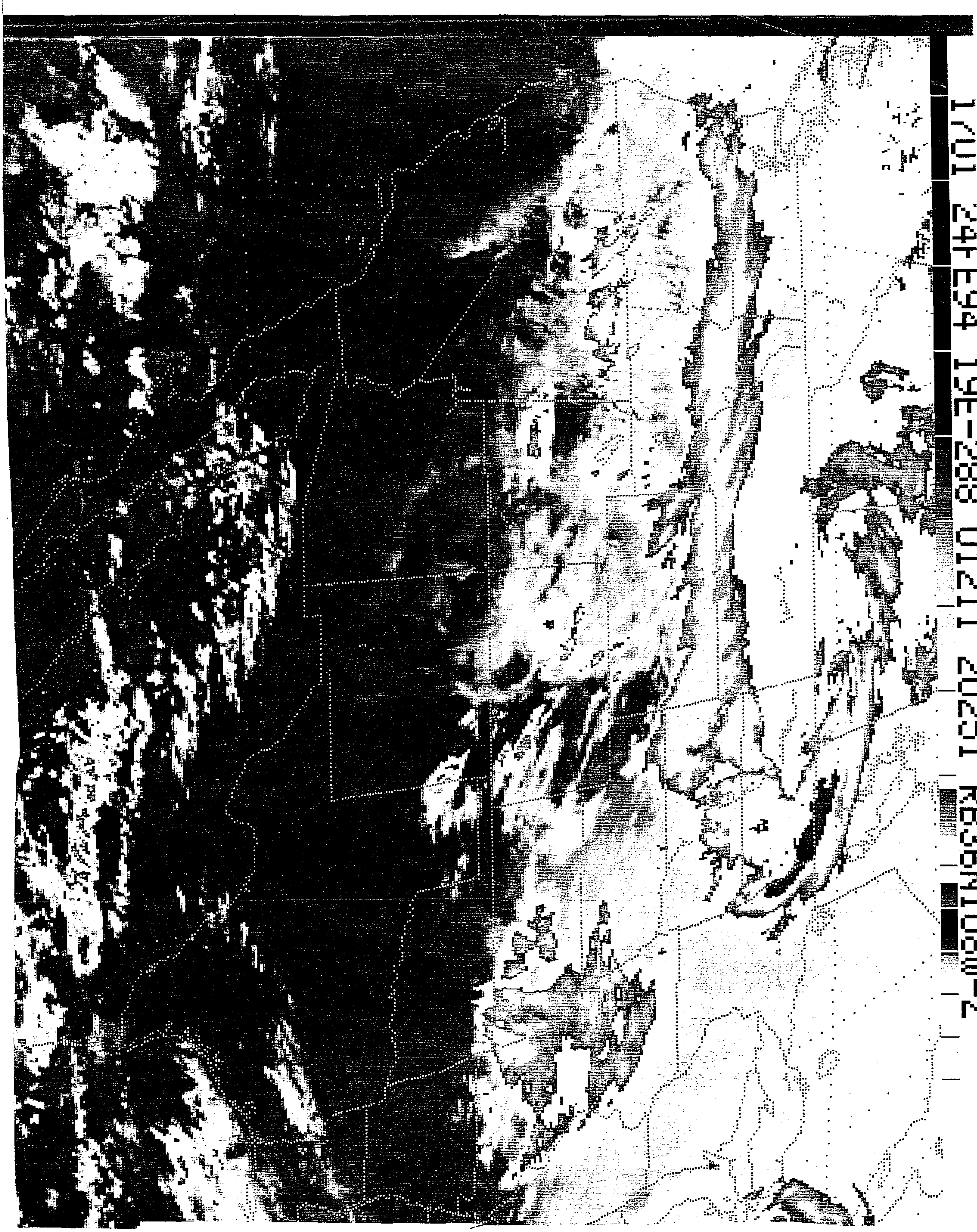


Fig. 8. Infrared imagery showing a broad band along the Oregon-Washington border. 17z 2/24/94

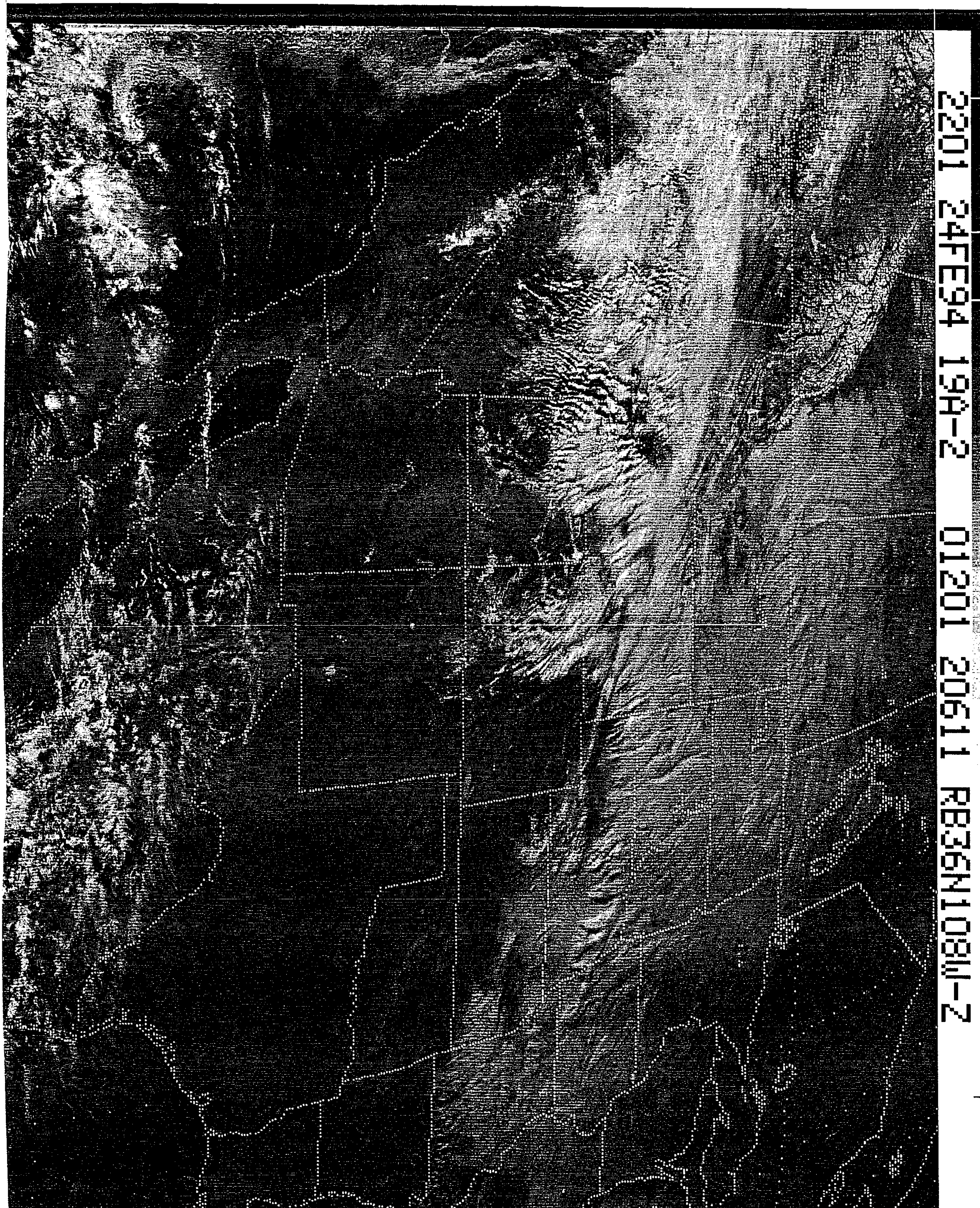


Fig. 9. Visible imagery showing striations oriented along the thermal wind. 22z 2/24/94

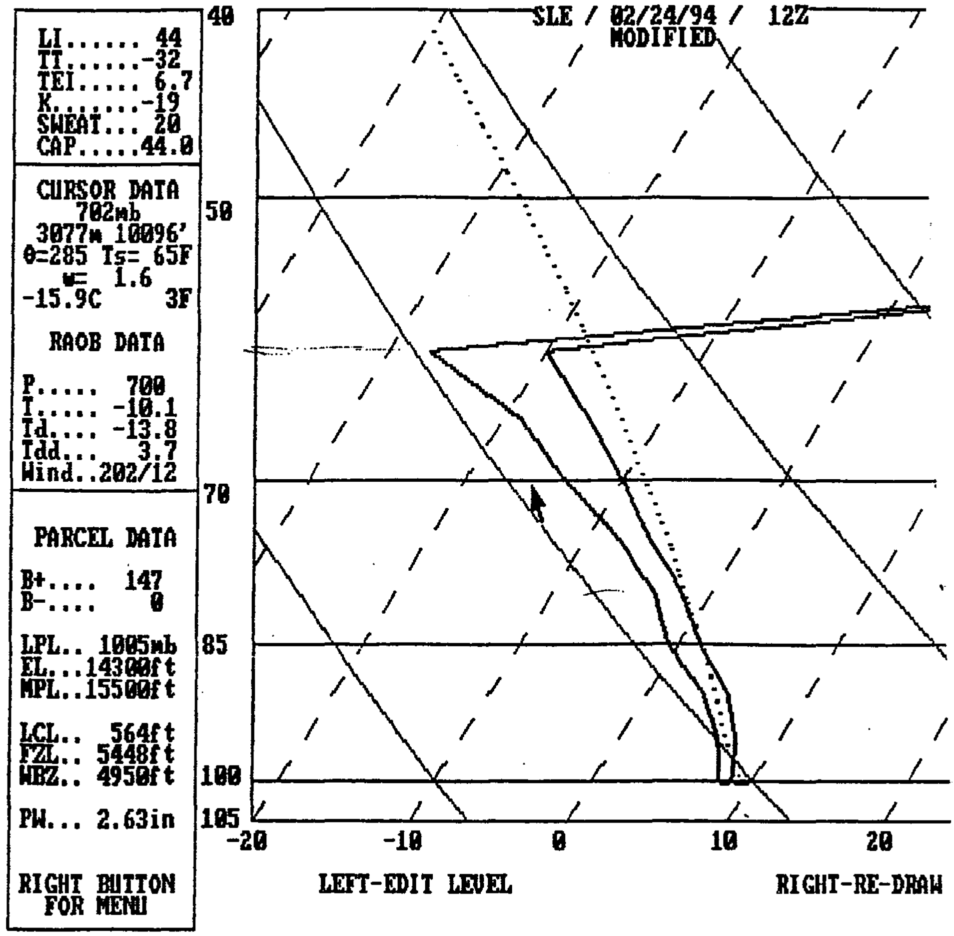


Fig. 11. Sounding constructed from data points taken along a constant momentum surface roughly over the precipitation maxima location.

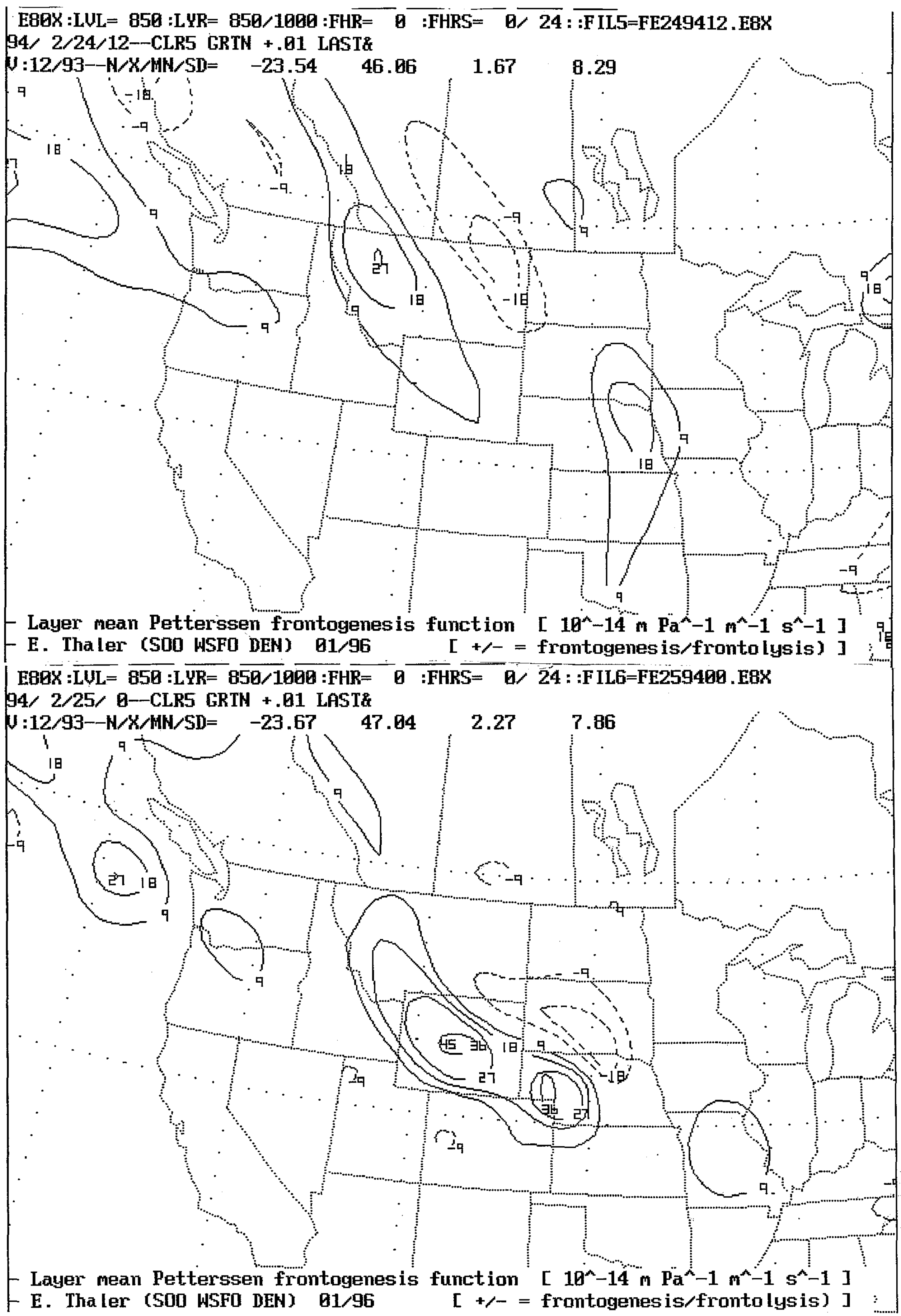


Fig. 12. 00-hour initializations of the 1000-850 mb "layer mean Petterssen frontogenesis function". +/- = frontogenesis/frontolysis.