CRH SSD
FEBRUARY 1992

CENTRAL REGION TECHNICAL ATTACHMENT 92-03

AN EXAMPLE OF CONDITIONAL SYMMETRIC INSTABILITY[1]

Brad Colman
National Weather Service Forecast Office
Seattle, Washington

The operational meteorologist is challenged daily by the manifestation of many different types of atmospheric hydrodynamic instabilities. In fact, the forecasting process relies heavily upon the anticipation, recognition, and characterization of such instabilities. It is therefore paramount that forecasters strive to understand all phenomena that have the potential to significantly impact or modulate forecast parameters. Conditional symmetric instability (CSI) or "slantwise convection" is one such instability.

CSI is simply a combination and generalization of two other instabilities, namely, static instability and inertial instability. Static instability deals with the vertical buoyancy of a parcel of air and results in the vertical mixing of heat and moisture. Inertial instability involves an imbalance of the horizontal wind field and results in the lateral mixing of momentum. Thus, a combination of these two instabilities includes at least two dimensions and some characterization of the thermodynamic and kinematic structures. Emanuel (1979) and Bennetts and Hoskins (1979) described this generalization and were able to show that the atmosphere can be stable to vertical displacements (static stability) and stable to horizontal displacements (inertial stability), yet be unstable to slantwise displacements. This slantwise instability is CSI. [Note: The "Conditional" is tied to the occurrence of saturation. Symmetric instability can also occur in a dry atmosphere just as dry thermals can occur in the vertical. Here we will limit our discussion to a saturated environment.]

CSI is manifest in the atmosphere as sloped, two-dimensional, rolls aligned with the geostrophic shear. Figure 1 shows the perturbation streamfunction resulting from CSI; the thermal wind (geostrophic shear) is perpendicular to the cross section and the rolls tilt toward cold air. Although not

---

[1] Reprinted from Western Region Technical Attachment 92-03, January 14, 1992.

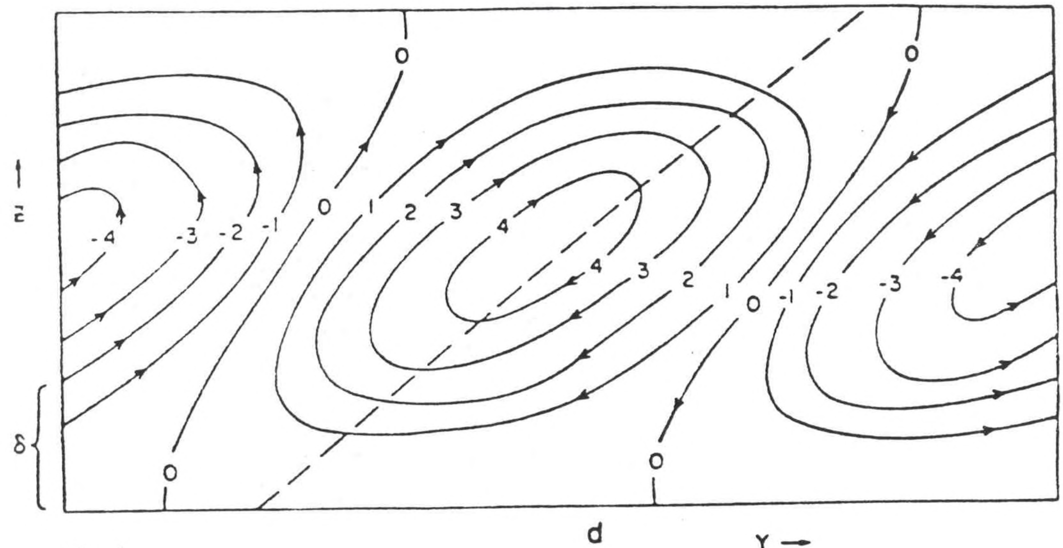

0
0
-4 -3 -2 -1 0 1 2 3 4
4 3 2 1 0 -1 -2 -3 -4
z
δ
0
0
d
Y

Fig. 1

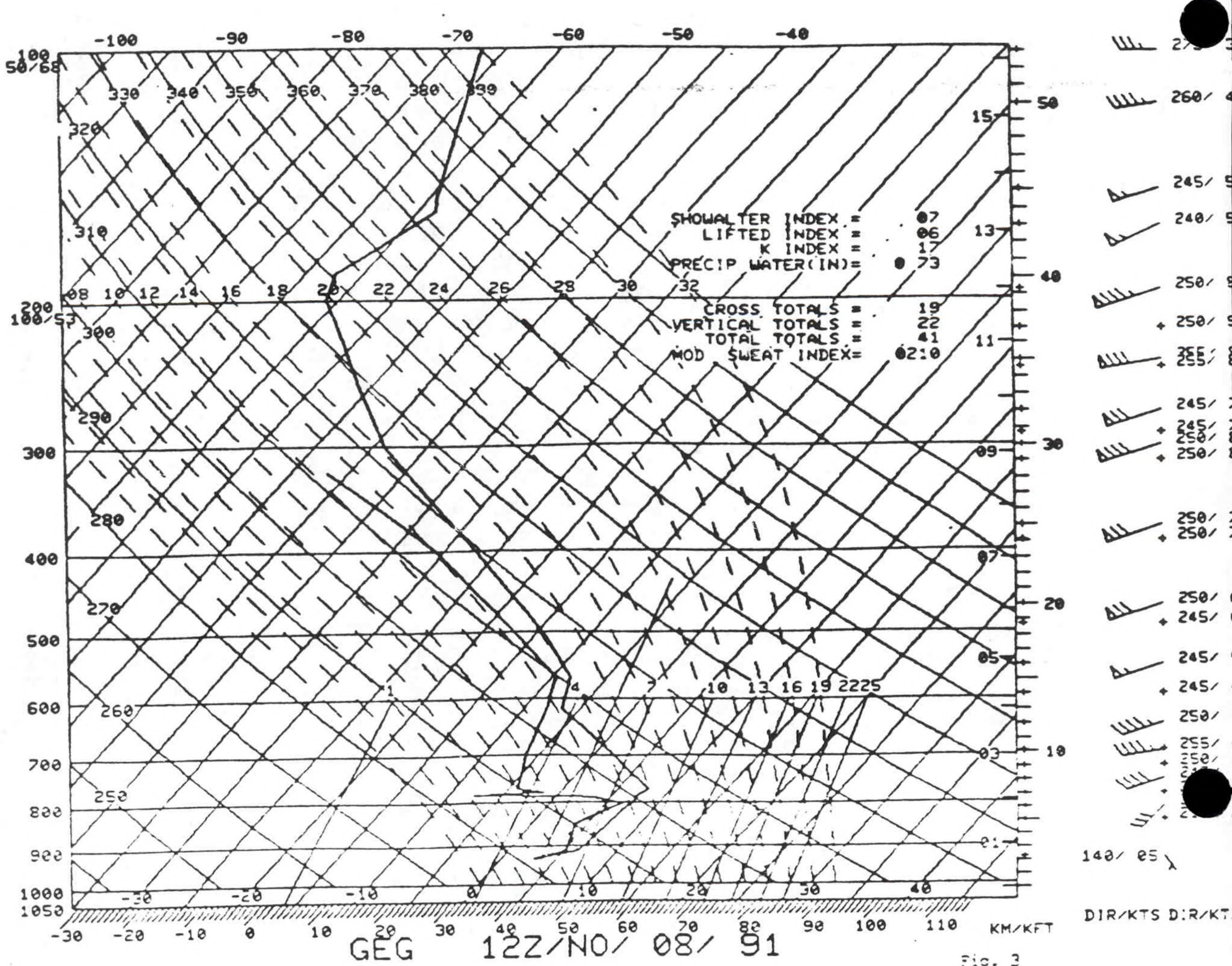
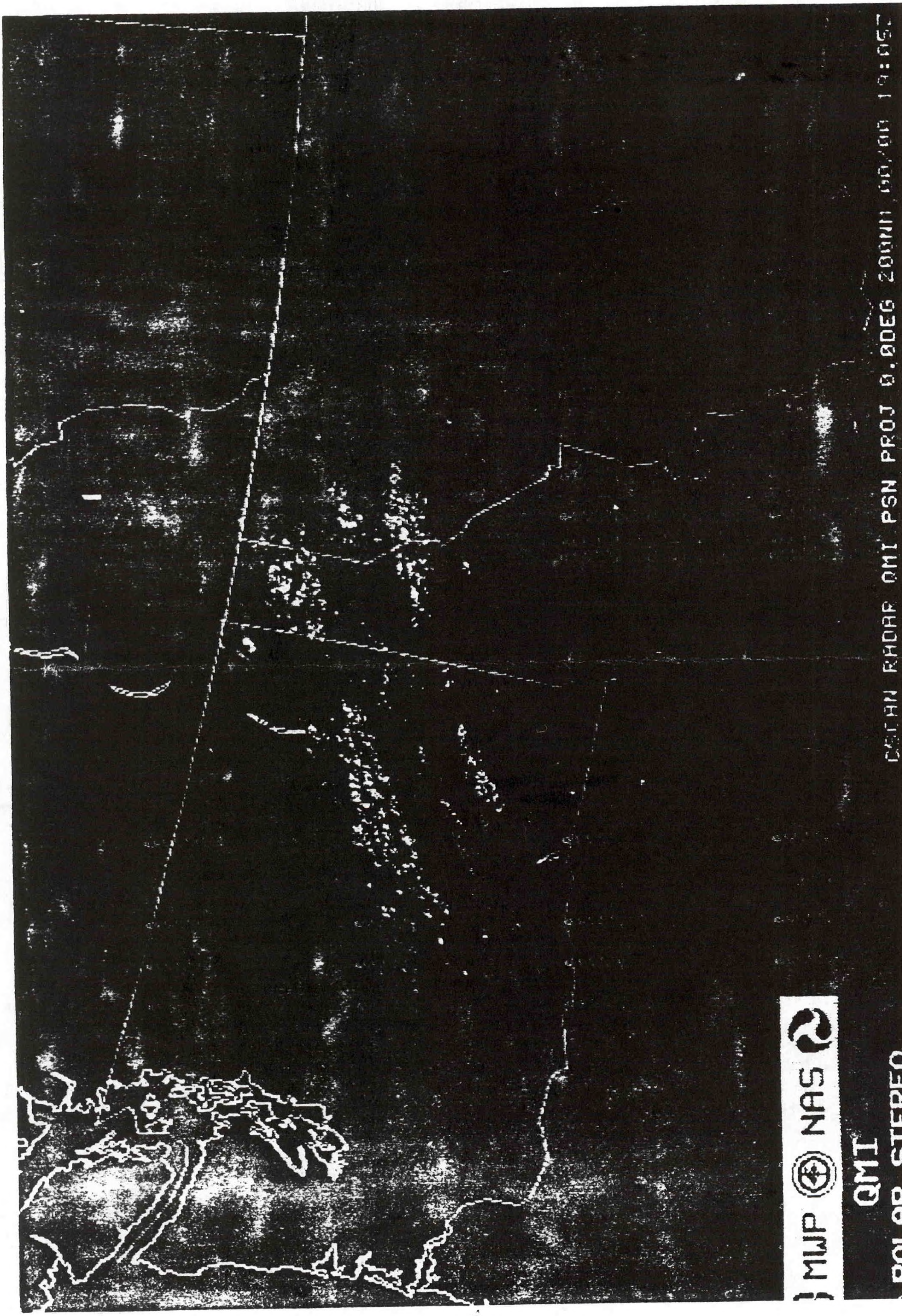

SHOWALTER INDEX = 07
LIFTED INDEX = 06
K INDEX = 17
PRECIP WATER(IN)= 0.73
CROSS TOTALS = 19
VERTICAL TOTALS = 22
TOTAL TOTALS = 41
MOD SWEAT INDEX= 02:0
KM/KFT
DIR/KTS DIR/KT
140/ 05
GEG 12Z/NO/ 08/ 91

Fig. 3

dynamically-defined, experience dictates a horizontal wavelength somewhere between ten and one hundred km. The vertical velocities associated with the instability are on the order of 1 m/s - an order of magnitude greater than stable ascent associated with an extratropical cyclone. CSI occurs on the mesoscale where both Coriolis accelerations and ageostrophic advections are important. An important feature of CSI is that the growth rate is tied to the inertial timescale, and it can take several hours for the perturbation to develop fully. However, we know that upright convection can develop in tens of minutes. Thus, when both upright and slantwise convection are possible, the adjustment occurs vertically.

The CSI environment is characterized by (1) low static stability, (2) low absolute vorticity, (3) strong baroclinicity, and (4) saturation. There are a couple methods used to quantitatively determine the symmetric stability of a given environment. Emanuel (1983) presented a generalized parcel theory that permits the calculation of Slantwise Convective Available Potential Energy (SCAPE), which is analogous to CAPE except that it has an additional inertial contribution. A second quantitative way to assess CSI is by calculating equivalent potential vorticity; where it drops below zero and there is saturation, there is instability. A more qualitative way to determine conditional symmetric stability is to compare the slopes of surfaces of equivalent potential temperature (θe) with slopes of angular momentum ($M = fx + Ug$; where f is the Coriolis parameter, x is the horizontal distance along a cross section, and Ug is the component of the geostrophic wind that is perpendicular to the cross section). The cross section is selected perpendicular to the thermal wind through the layer of interest. Where the slope of the M surface is shallower than the slope of the θe surface, there is instability. Barker (1987) presented a computer program that generates vertical cross sections of M, θe, and dew point from coded rawinsonde data using up to five stations. This is a relatively easy way to diagnostically assess the likelihood of CSI using AFOS.

On November 8, 1991, the Spokane radar display showed several significant band's in the reflectivity field (Fig. 2; 1905 UTC). The rawinsonde observation from 1200 UTC November 8 (Fig. 3) reveals a deep saturated layer extending from 600 mb to nearly 300 mb. The lapse rate through this saturated layer is slightly stable with respect to moist adiabatic displacements, diminishing the potential for upright convection.



Figure

The wind profile shows a thermal wind of approximately 15 m/s (30 kt) with very little directional shear. This is in good agreement with the 6-h forecast thickness field from the NGM (Fig. 4; recall that the thermal wind is parallel to the layer thickness). Thus, the atmosphere is baroclinic.

The 500 mb absolute vorticity (Fig. 5) is forecast to be approximately 6×10^{-5} S^{-1}, which is relatively low and, as earlier noted, also favorable for CSI. Finally, the infrared satellite image from 1301 UTC (Fig. 6) shows several enhanced bands that extend southwest to northeast across the area of interest.

North-to-south cross sections (YXS to WVK to GEG to BOI), generated using Barker's program, are shown in Fig. 7. The saturated layer noted in the sounding is well defined in the dew point depression cross section. Also the M and θe cross section through this same layer over GEG shows the slopes are essentially the same. Thus, within the resolution of these data, this area is neutral to slantwise displacements. This condition is sometimes referred to as "moist neutral." The absence of an unarguably unstable environment is not unusual (e.g., Sanders and Bosart 1986; Wolfsberg et al., 1986) and is most likely a reflection of inadequate data resolution and/or the atmosphere's ability to adjust to neutrality in the presence of ongoing destabilization. Nonetheless, these analyses, in concert with the observed character of the bands, strongly suggest that the bands were generated by CSI. A more thorough analysis should include an assessment of other mechanisms known to produce mesoscale bands.

In the case presented here, no significant precipitation was produced due to the very dry underlying layers. However, if the lower layers were saturated or if the moist neutral layer were closer to the ground, the outcome could have been dramatically different. Such a situation was described by Lussky (1987). Even in this case, it is likely that significant turbulence could be associated with the CSI, and an awareness of this instability would be very helpful to the forecaster.

In cases where CSI occurs, large amounts of precipitation can be produced (often exceeding expectations) and very large gradients in precipitation intensity are likely. These are critical factors in the forecast arena and forecasters need to be on the watch for this significant instability. He/she must be aware that the atmosphere has a variety of instabilities that are dependent upon the static stability, vertical and horizontal shear, and the Coriolis parameter. We can no longer identify precipitation as simply stratiform or convective (upright).

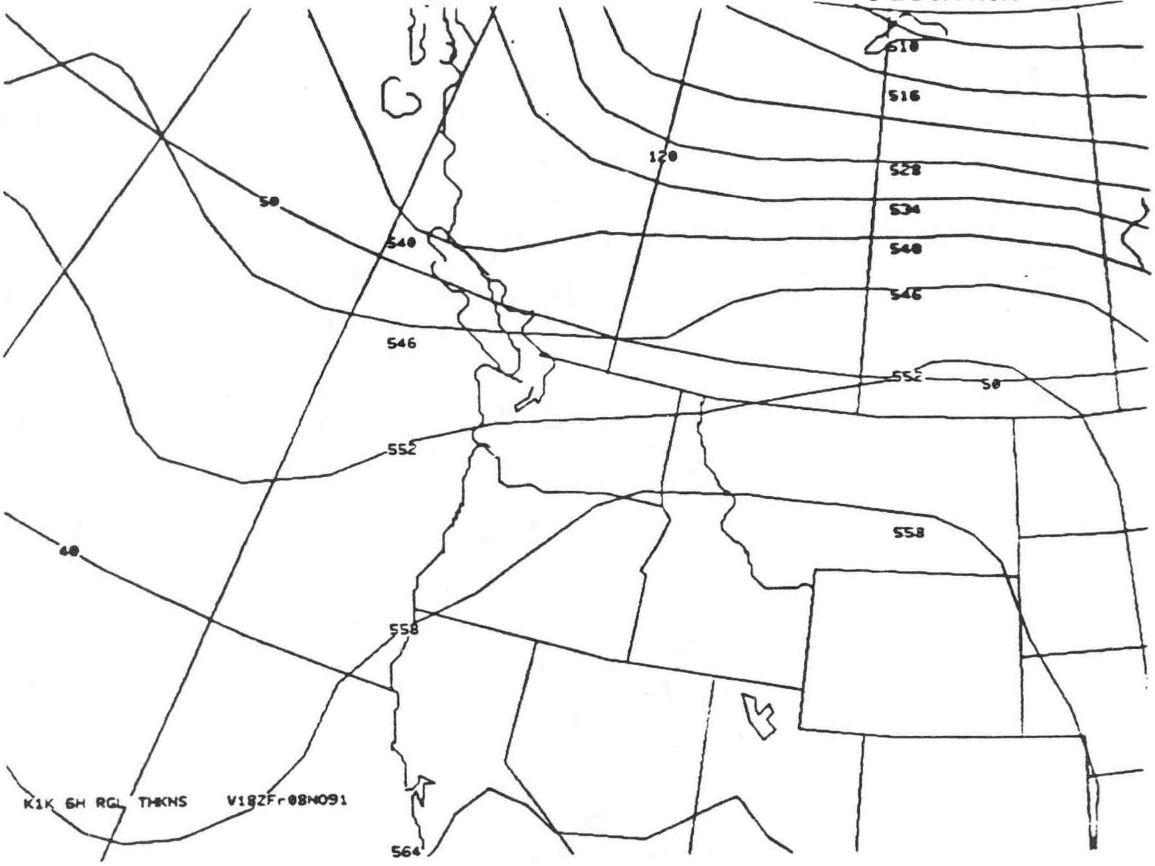


Fig. 4

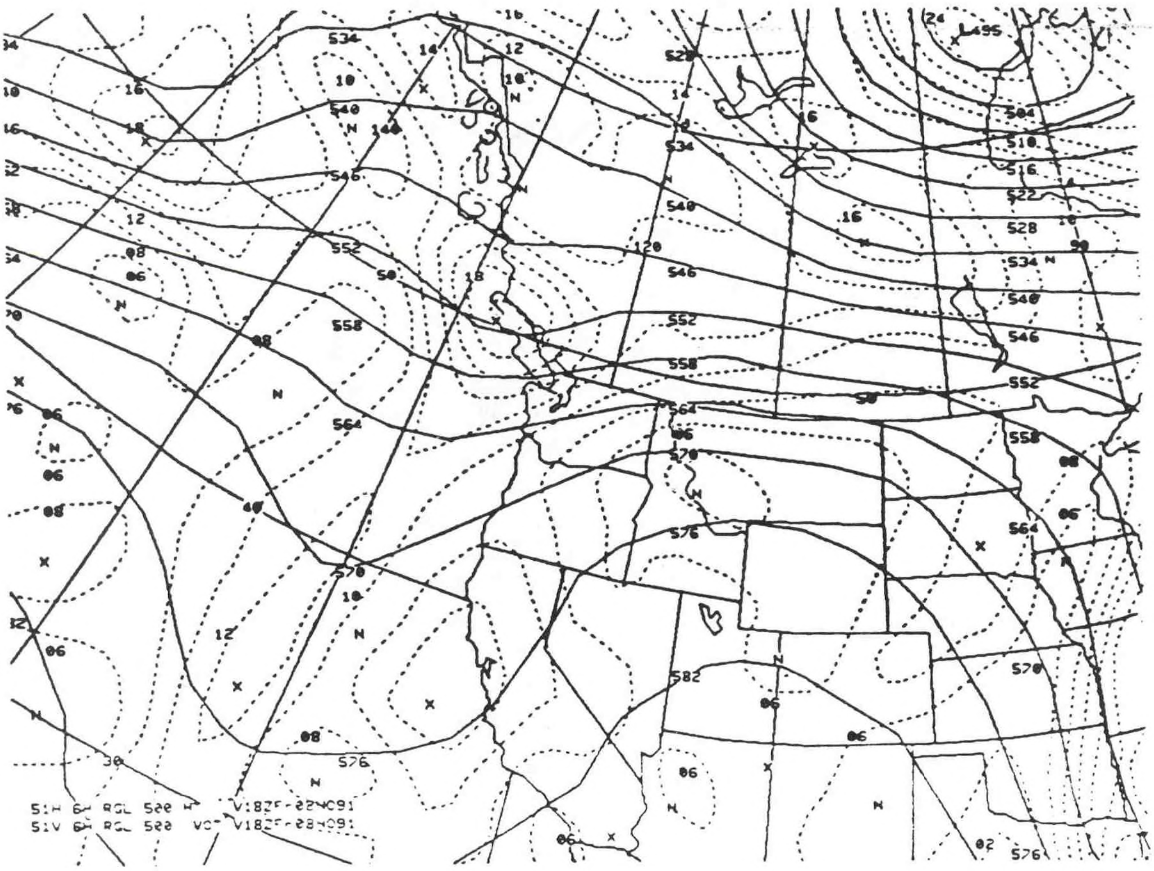


Fig. 5

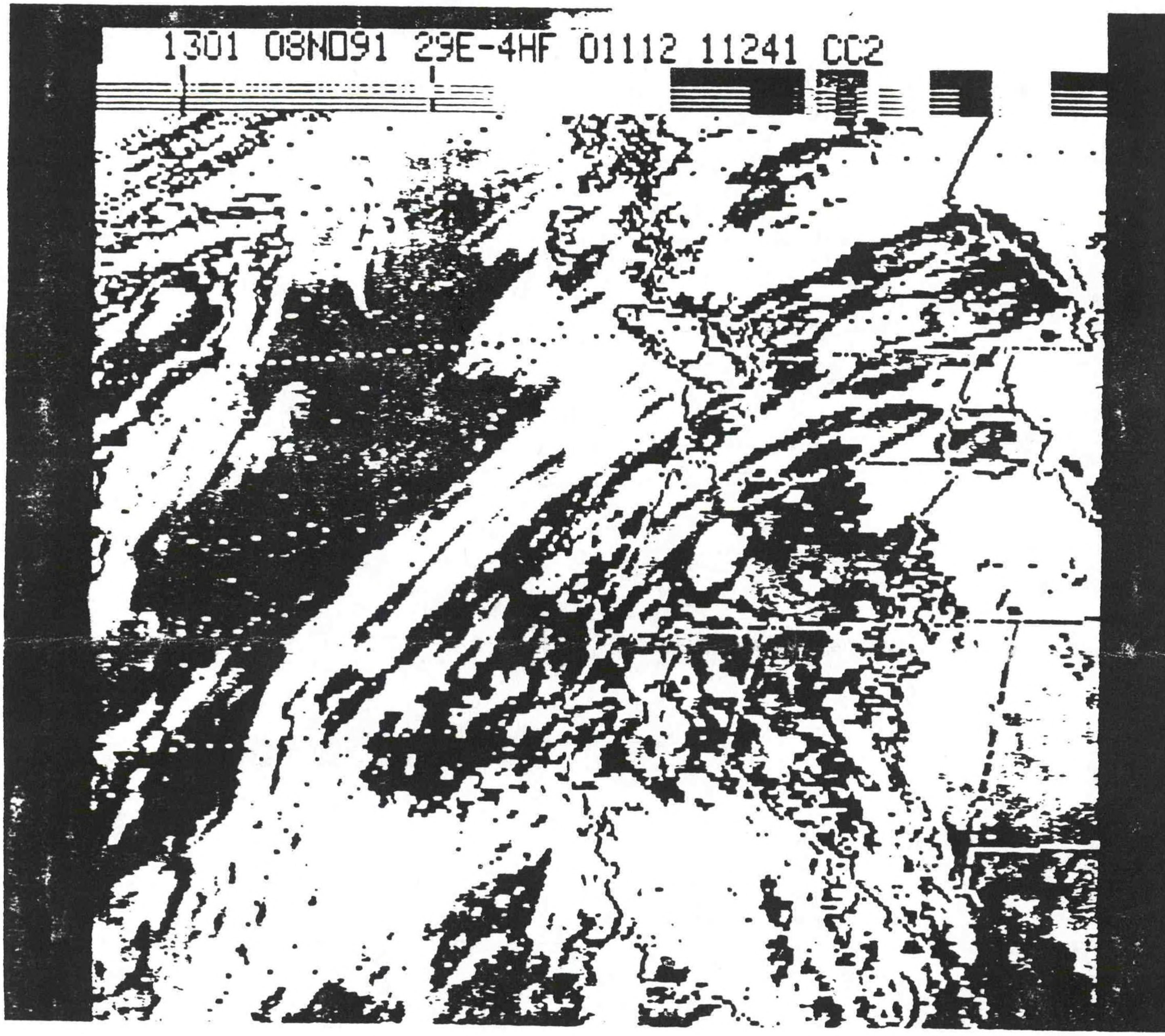
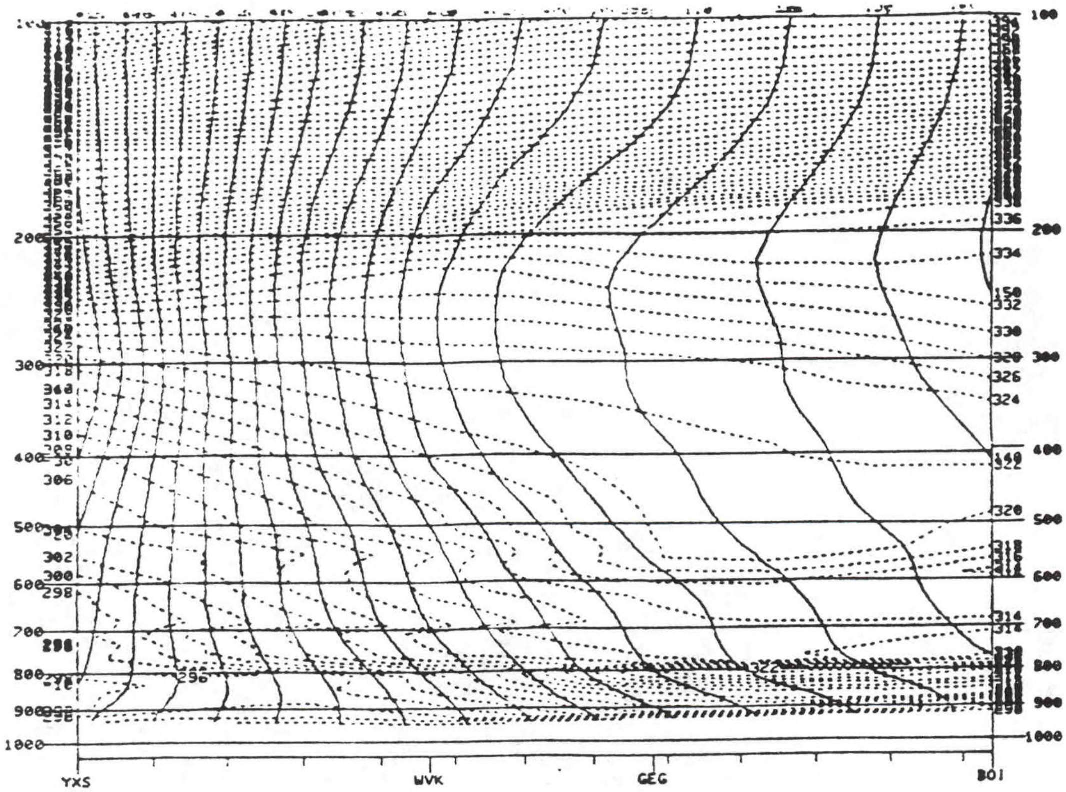


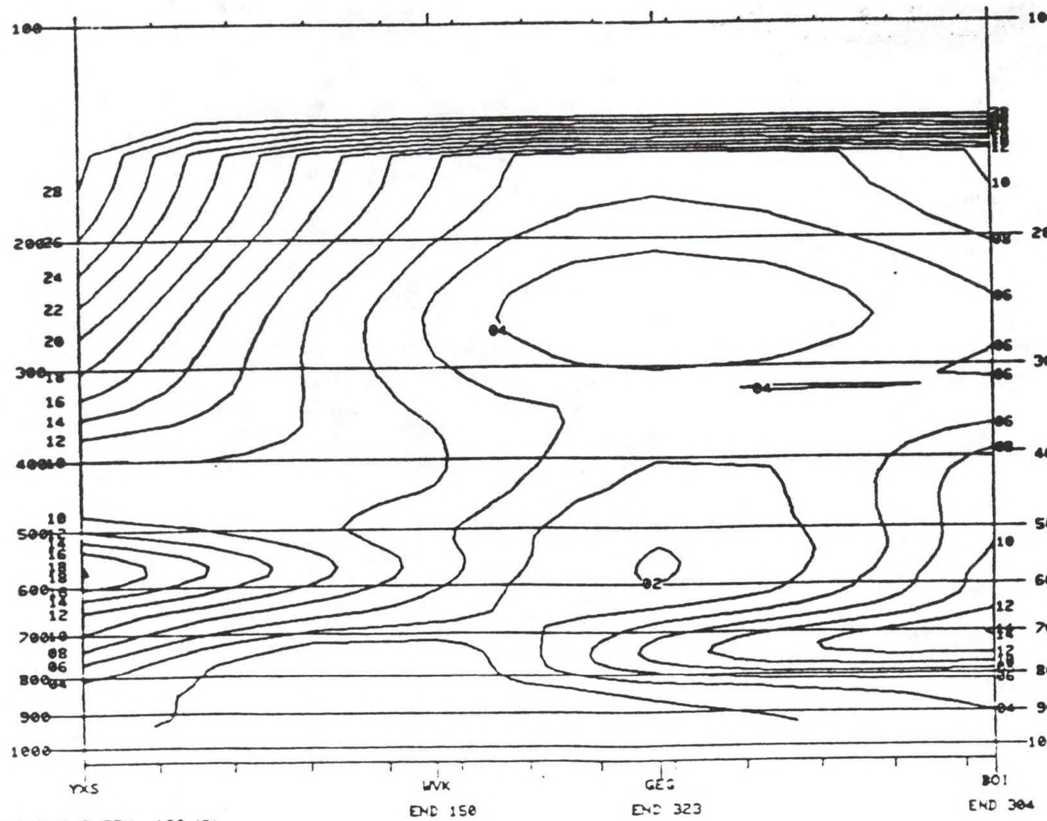
Fig. 6



TICK MARKS EVERY 100 KM

[illegible]CROSS SECTION FOR 12Z NO/ 08/ 91

Fig. 7 (b)



TICK MARKS EVERY 100 KM

DEWPOINT DEPRESSION FOR 12Z NO/ 08/ 91

Fig. 7 (a)

References

Barker, T.W., 1987: Convective cross section analysis. NOAA Western Region Computer Programs and Problems, NWS WRCP No. 55, available from NWS Western Region, Salt Lake City, UT.

Bennetts, D.A and B.J. Hoskins, 1979: Conditional symmetric instability - a possible explanation for frontal rainbands. *Quart. J. R. Met. Soc.*, **105**, 945-962.

Emanuel, K.A., 1979: Inertial instability and mesoscale convective systems. Part I: Linear theory of inertial instability in rotating viscous fluids. *J. Atmos. Sci.*, **36**, 2425-2449,

_____________, 1983: On assessing local conditional symmetric instability from atmospheric soundings. *Mon. Wea. Rev.*, **111**, 2016-2033.

Lussky, G.R., 1987: Heavy rains and flooding in Montana: A case for slantwise convection. NOAA Technical Memorandum, NWS WR-199, available from NWS Western Region, Scientific Services Division, Salt Lake City, UT.

Sanders, F., and L.F. Bosart, 1986: Mesoscale structure in the megalopolitan snowstorm of 11-12 February 1983. Part I: Frontogenetical forcing and symmetric instability. *J. Atmos. Sci.*, **42**, 1050-1061.

Wolfsberg, D.G., K.A. Emanuel, R.E. Passarelli, 1986: Band formation in a New England winter storm. *Mon. Wea. Rev.*, **114**, 1552-1569.