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WAVE CLOUDS - SHEAR VS. STABILITY

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Wave clouds are common enough phenomena in the mountainous West. They can often be an indicator of moderate or severe turbulence. Their existence is a function of internal atmospheric stresses related to vertical wind shears, viscosity and stability. The clouds are the visual manifestation of turbulent eddies created when the critical value of the Reynolds Number (a non-dimensional ratio of vertical shear vs. fluid viscosity) is exceeded. A blustery March day in 1988 provided a good illustration of these relationships. Figure 1 shows a large cyclonic vortex over southern Manitoba and a broad northwest flow westward into the Great Basin. Wave clouds (Figure 2) are already present from Idaho into northern Utah (A) while streaked cloud bands are evident over Colorado (B). The 12Z 700mb analysis in Figure 3 shows moderate northwesterly flow over the region. On this day, moderate or severe low level turbulence was widespread from the eastern Great Basin to central Rockies.

Upon closer examination one can get a more comprehensive feel for what the satellite photo reveals, PIREPs confirmed and the atmosphere is really saying. First, it might be useful to review some aspects of cumulus convection in a sheared environment characterized by thermal inversions. This is important because that is the type of situation encountered here. Raobs in the zone where the turbulence and wave clouds exist revealed a marked stable layer between 600 and 700 mb. Figures 4 (SLC) and 5 (GJT) show this especially well. LND (Figure 6) has a little higher stable layer while BOI (Figure 7) shows only a broad layer of relative stability in the 600-700mb range. Moisture is well-mixed through these layers at BOI and SLC. Winds increase through and above the stable layers indicating a strongly sheared environment. See Figure 3 for location of these raob sites.

Cumulus convection within a vertically sheared air column is often organized into "cloud streets". They can be aligned parallel or orthogonal to the mean wind flow depending upon thermal structure and shear. In a stably stratified setting, such as in this case, the clouds are perpendicular to the shear and referred to as Kelvin-Helmholtz waves. Some are terrain induced but can generally be considered a result of imbalances between vertical shear and static stability associated with shallow inversions.

Examination by researchers indicates that for vertical shear through a stable profile, such as an inversion, the cloud rolls tend to lie with axes perpendicular to the shear. For neutral or unstable regimes (well mixed), the rolls are parallel to the flow. An example of this latter condition can be noted at C in Figure 8, across the northern plains. Cloud elements are parallel to the wind, indicating the environment is well-mixed and lacking stable layers. Note the GGW raob in Figure 9.

Strength of stable layers can also be inferred from the imagery. Where the stability is strong, such as at SLC, vertical motion segments within the rolls are well defined. Note the uniform waves over northwest Utah in Figure 8. Upstream at BOI, the profile is less stable. Correspondingly, clouds in southwest Idaho are much more stratified though still wavy in appearance.

Perhaps the most unique way of viewing these phenomena is via a cross-section analysis (Barker, 1987). Figure 10a is an equivalent potential temperature profile along a line from DRA to LND (see Figure 8). The base of the inversion is denoted by the dashed line. It is sharpest near SLC. Shear within this zone is seen in the momentum profile of Figure 10b. Momentum, as displayed here, is roughly the wind component perpendicular to the cross-section axis (see note below). Thus, an axis from SW-NE would display the NW (or SE) component best. Here the contours become more horizontal indicating wind speed increasing in the vertical. Note the acceleration of speed (changing the slope of the line) through the inversion over the SLC-LND segment of the profile.

This TA is a good illustration on how the character and axes of wave clouds can be used to infer atmospheric structure. Rugged terrain of the West certainly enhances wave action in strong flows. It is equally important, however, to realize that mechanical turbulence is substantially augmented by the inherent fluid characteristics of the troposphere. Shears and thermal stratifications are significant interacting mechanisms for overturning shallow layers. Through careful analysis of data and use of satellite imagery we can also infer subtle variations within a seemingly uniform flow pattern and temperature profile.

Note: Numerical depiction of momentum here follows the equation $v+fx$, where f is the coriolis parameter, x is the distance from the left edge of the cross section, and v is the wind component normal to the cross section. Values decreasing with height indicate increasing winds out of the cross section (from the northwest).

Reference:

Barker, T.W., 1987: Convective Cross Section Analysis. NOAA Western Region Computer Programs and Problems NWS WRCP No. 55, June.

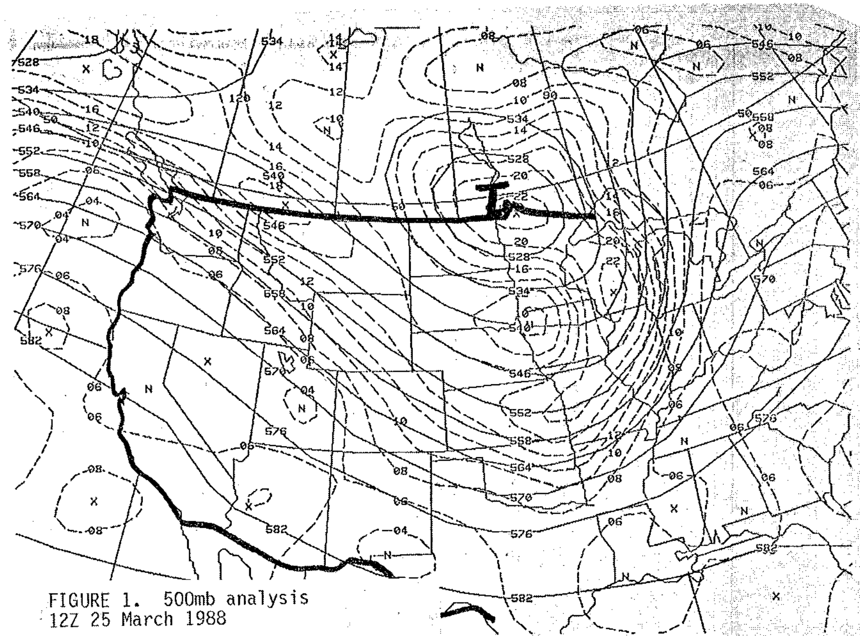

FIGURE 1. 500mb analysis
12Z 25 March 1988

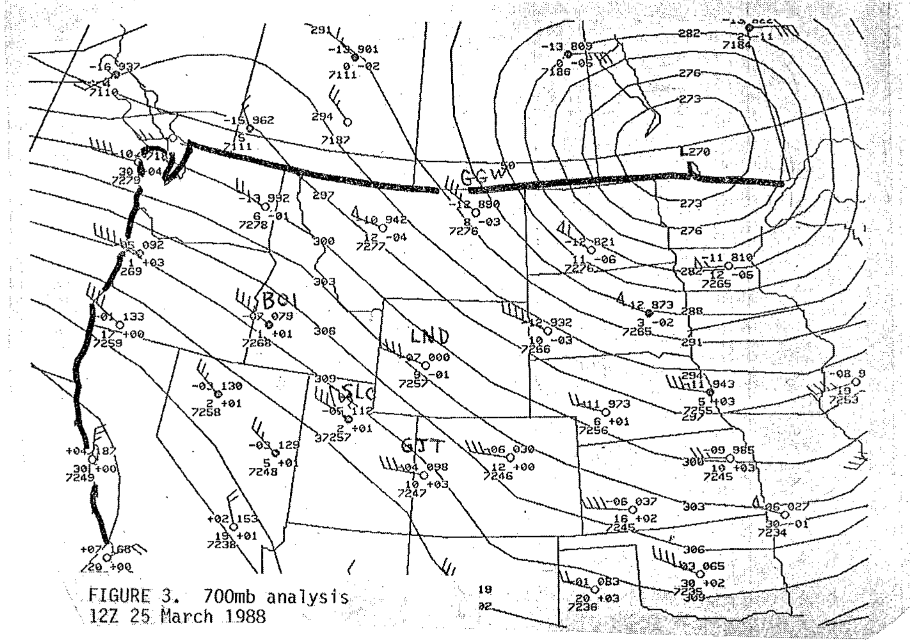

FIGURE 3. 700mb analysis
12Z 25 March 1988

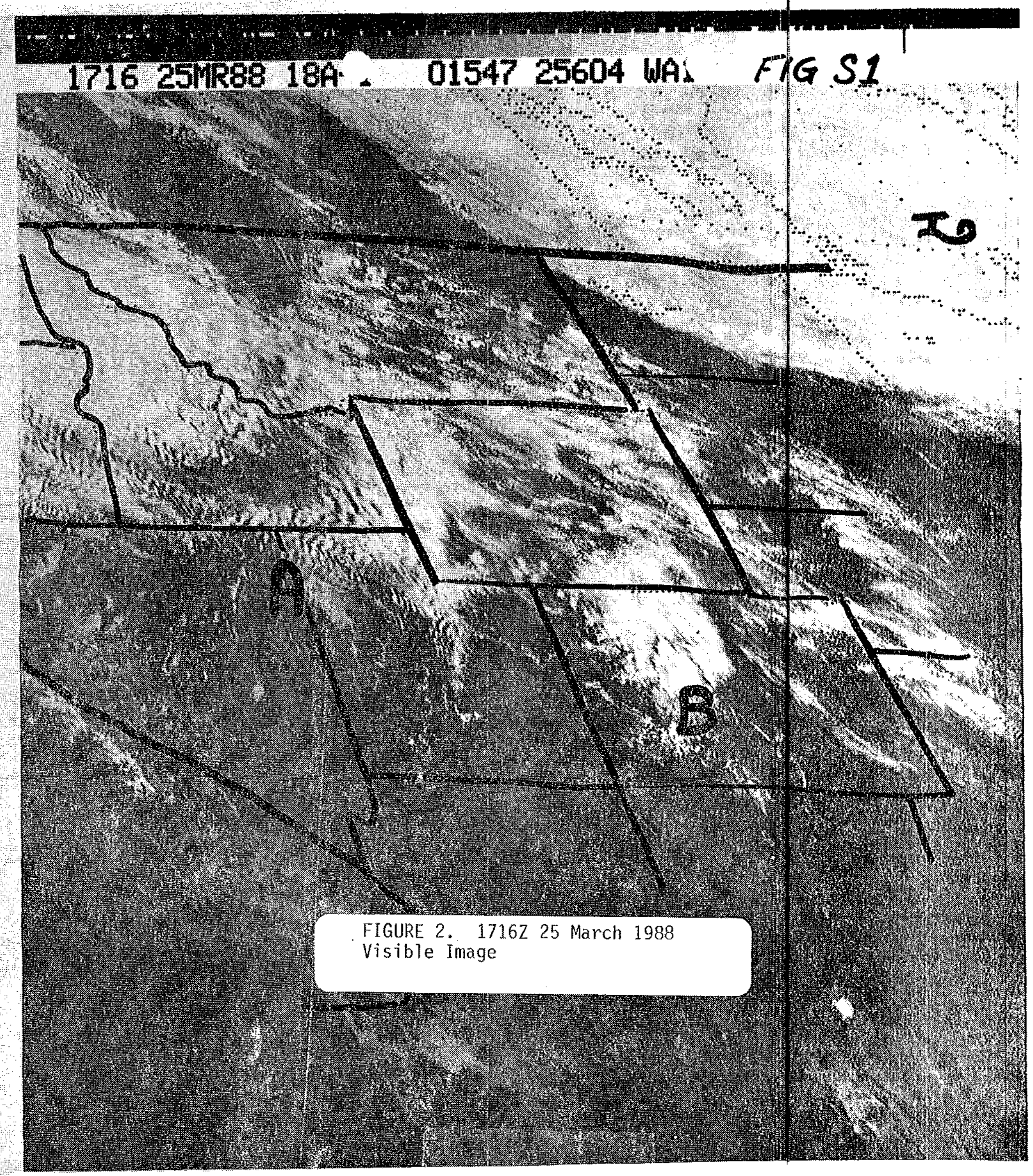

FIGURE 2. 1716Z 25 March 1988
Visible Image

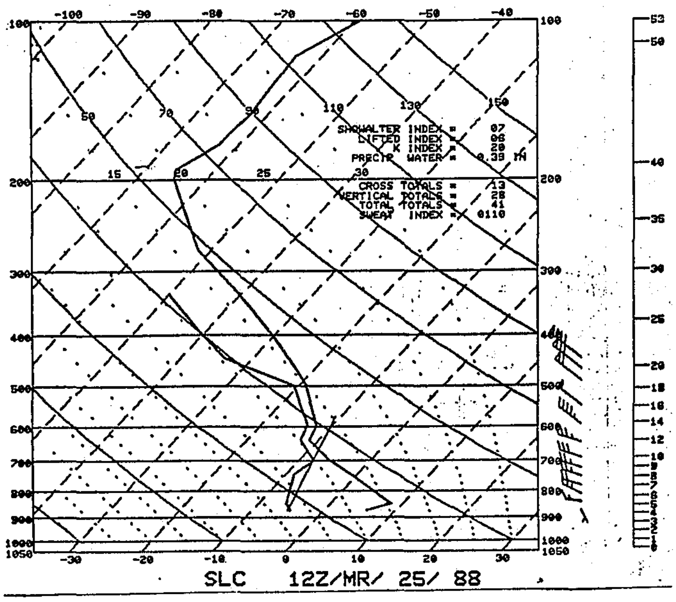

FIGURE 4.

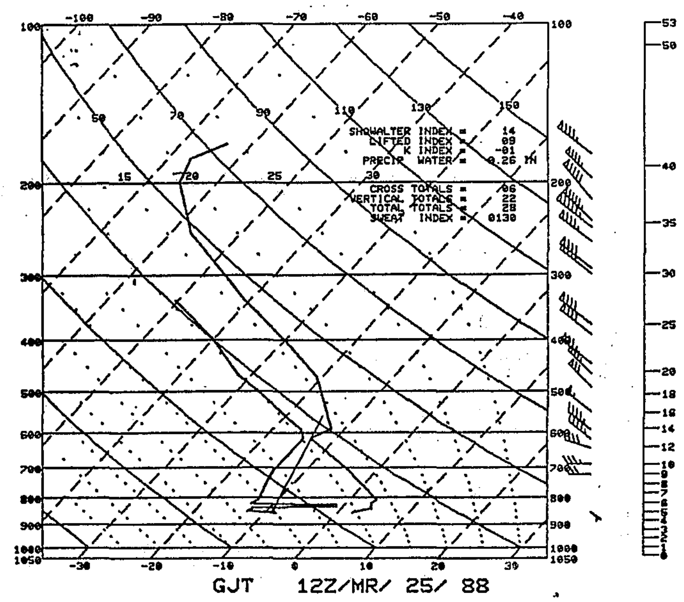

FIGURE 5.

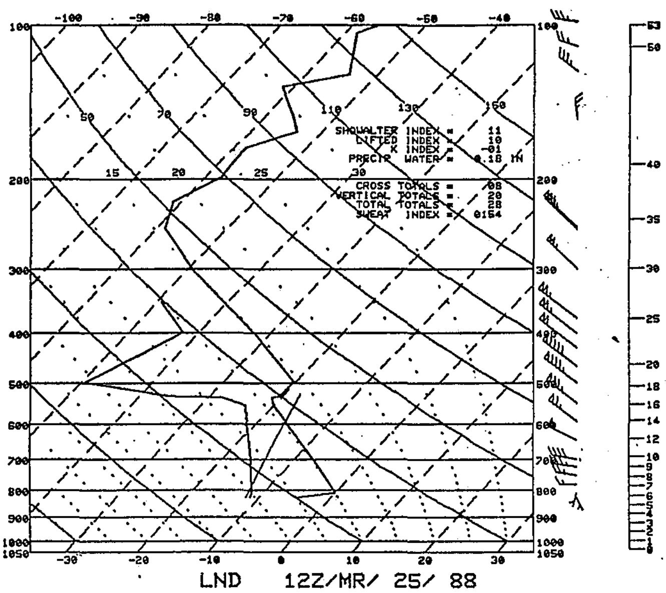

FIGURE 6.

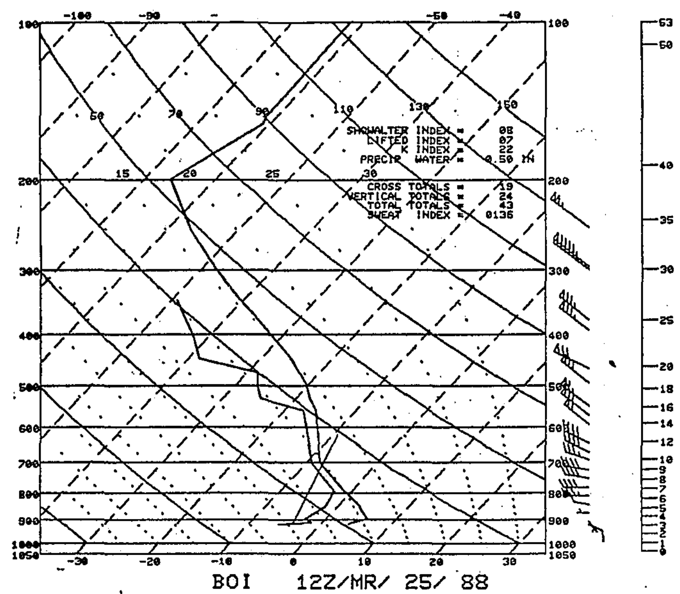

FIGURE 7.

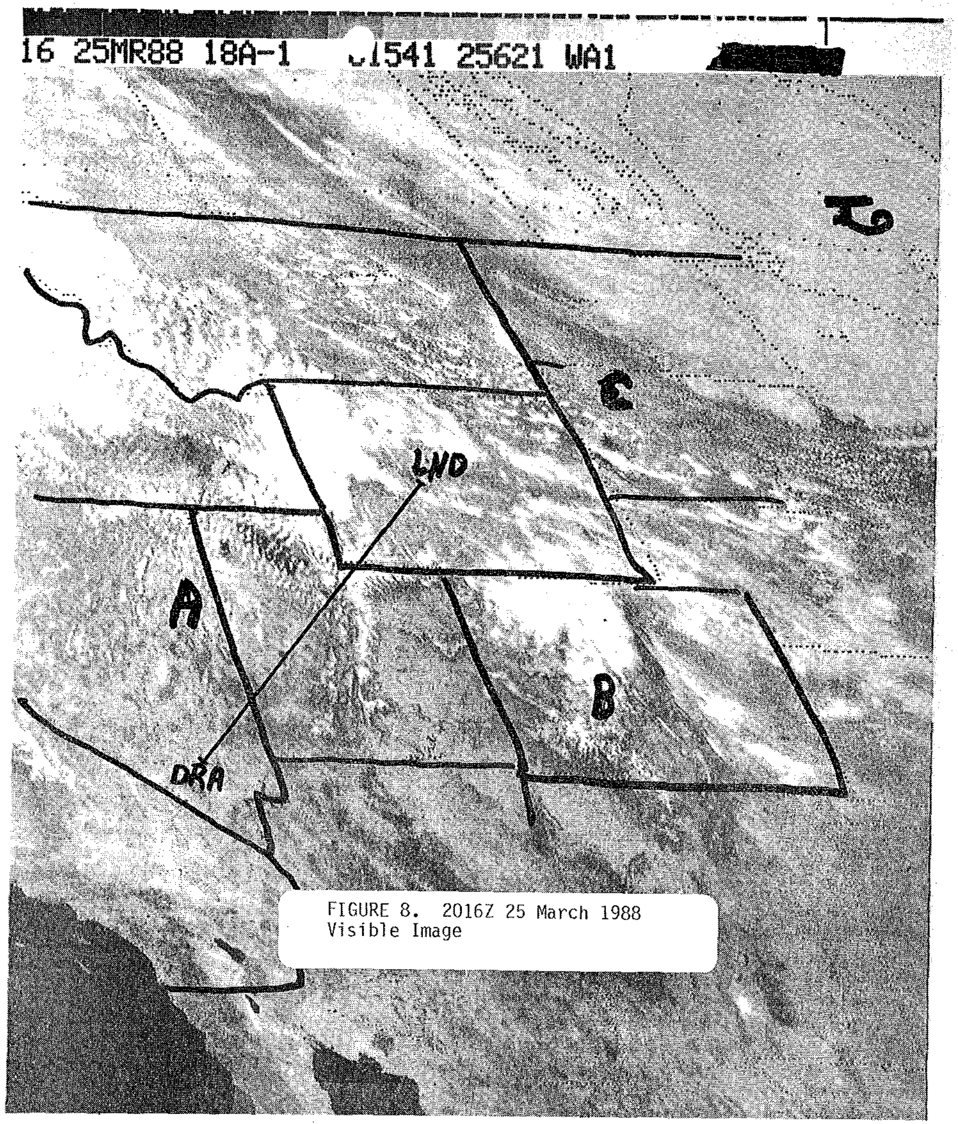

FIGURE 8. 2016Z 25 March 1988
Visible Image

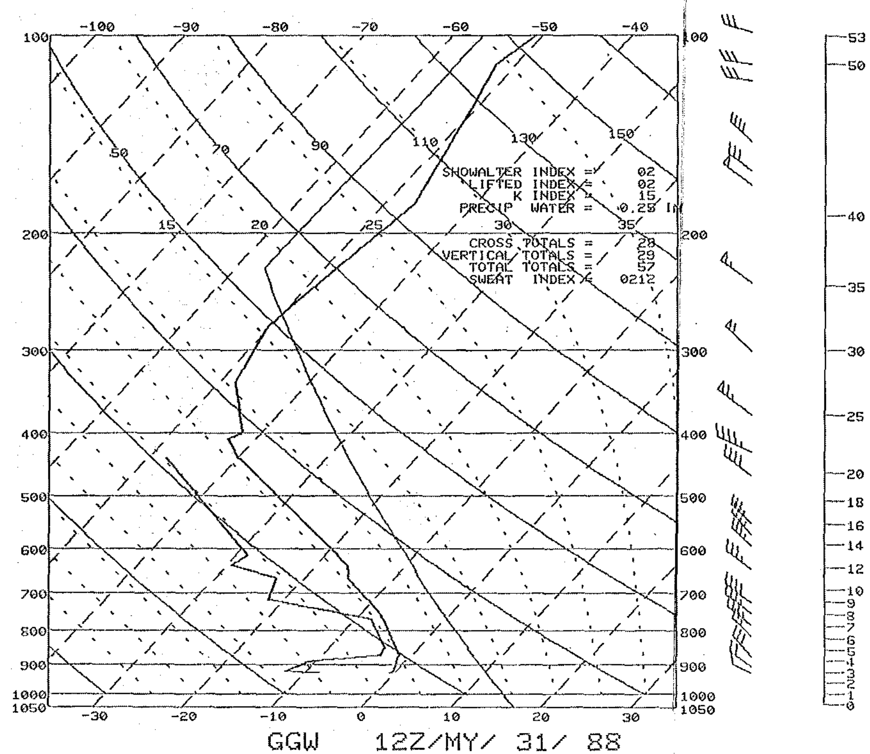

FIGURE 9.

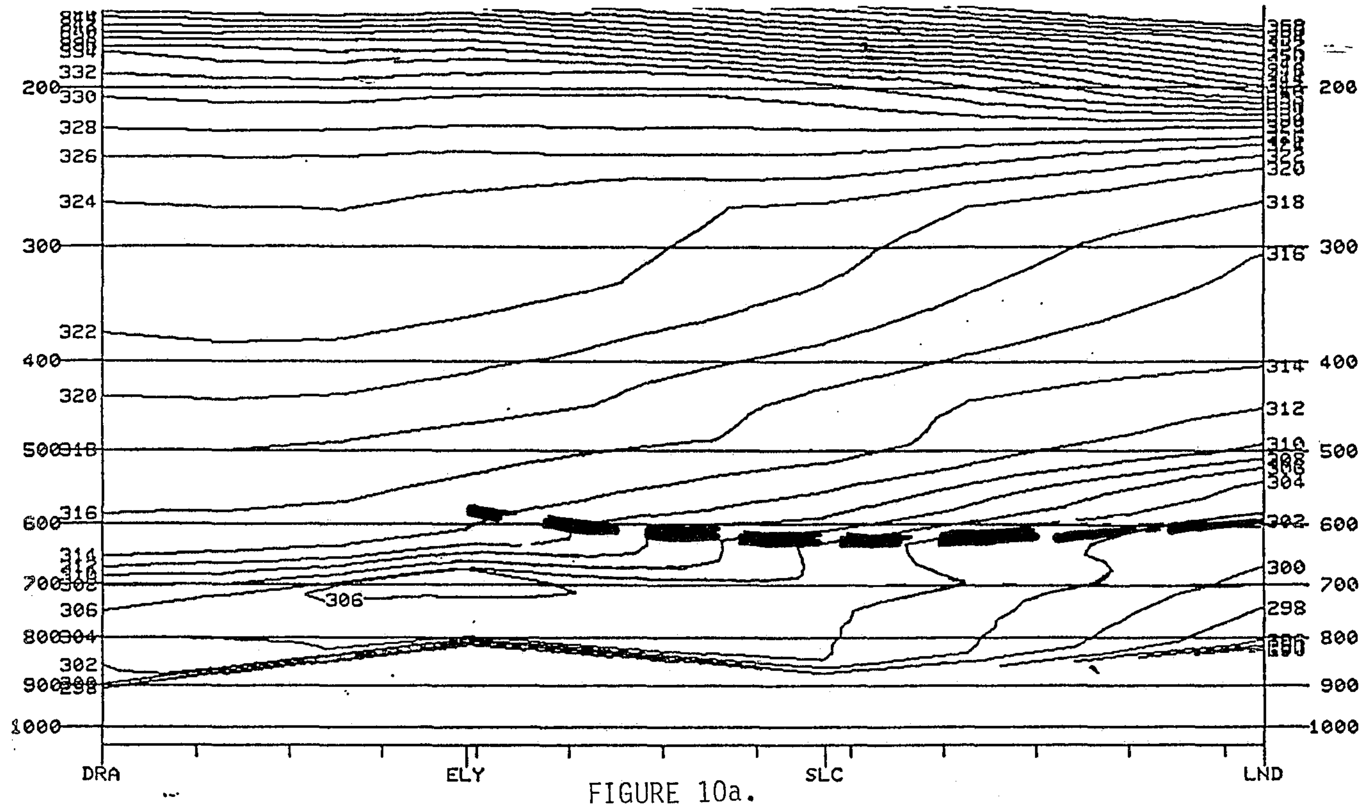

FIGURE 10a.

TICK MARKS EVERY 75 KM

THETA-E CROSS SECTION FOR 12Z MR/ 25/ 88

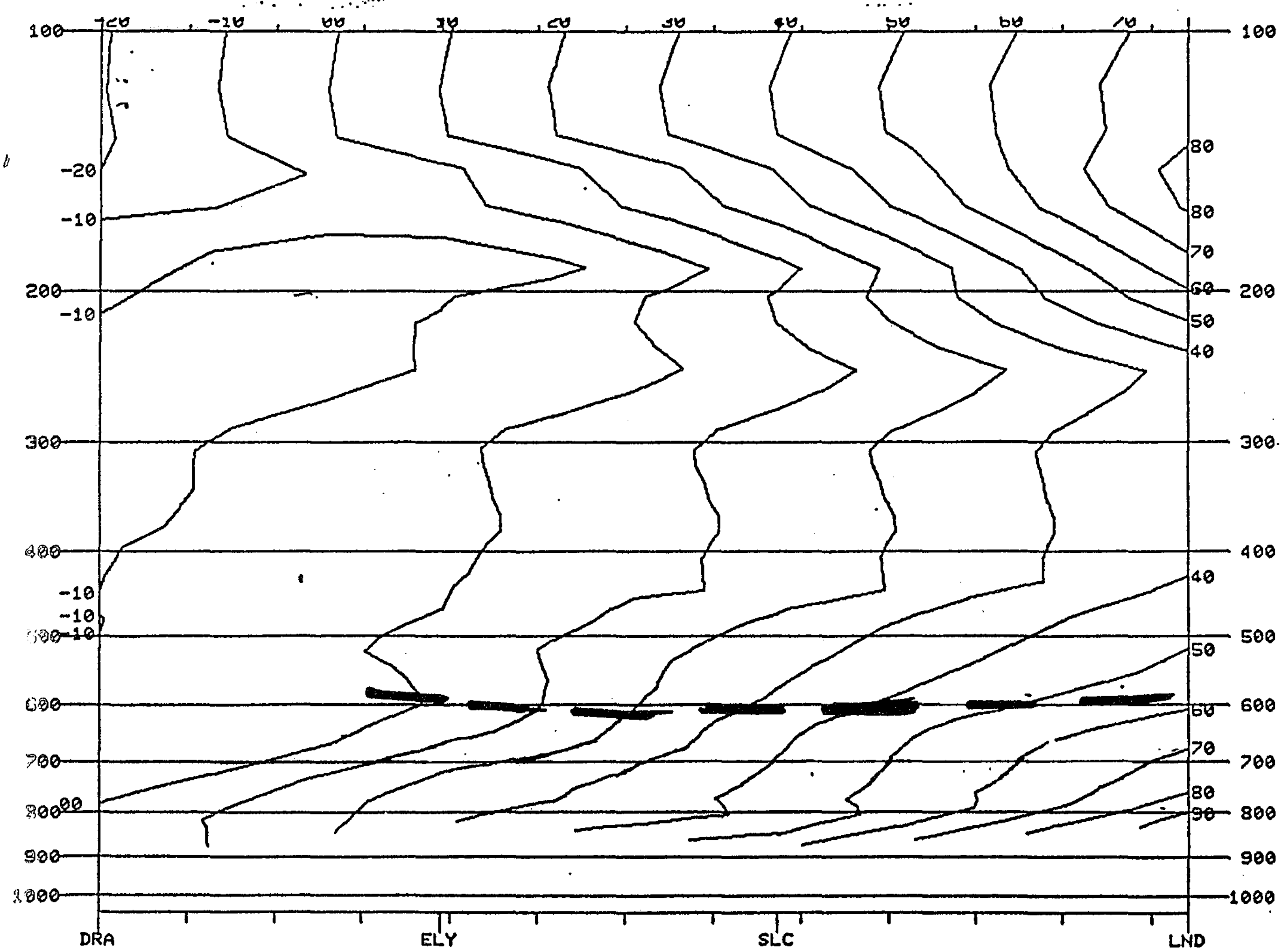

FIGURE 10b.

TICK MARKS EVERY 75 KM

MOMENTUM FOR 12Z MR/ 25/ 88.