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A HEAVY RAINFALL AND SEVERE WEATHER EPISODE IN CENTRAL SOUTH CAROLINA
PART I: Synoptic Features Leading to Heavy Rainfall

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1. INTRODUCTION

On 22-23 October 1990, a heavy rainfall event occurred in central South Carolina. The heavy rain began on the afternoon of October 22, and persisted until the early morning hours on October 23. Most of the area received 24-hr rainfall totals of 2 to 3 inches with local amounts in excess of 5 inches. Less than two weeks prior to this event, much of the state was inundated by up to 10 inches of rain from the remnants of tropical systems Klaus and Marco, which caused widespread flooding. As a result of the saturated ground conditions, the rainfall with this storm was efficient in producing runoff, with flooding occurring along many rivers. The synoptic and mesoscale features leading to the abundant rainfall will be discussed in this paper. In general, it appears that flow blocking, and low-level cold-air damming influenced the location of heaviest rainfall.

2. SYNOPTIC ANALYSES

Figure 1 is a surface analysis at 1200 UTC, 22 October. The major surface features included a strong high pressure ridge just off the mid-Atlantic Coast, and a slow-moving cold front extending from the Ohio Valley southwest to the Mississippi Coast. A weak frontal wave of low pressure was located near Birmingham, AL. At 1200 UTC, light rain extended approximately 150 miles on either side of the frontal boundary. The front was forecast to move east, spreading rain into South Carolina.

Moisture was copius ahead of the front, with precipitable water values of around 1.5 inches at both Athens (AHN) and Charleston (CHS). The 24-hr QPF (Quantitative Precipitation Forecast) guidance (Figure 2) ending at 1200 UTC, 23 October produced by the Heavy Precipitation Branch (HPB) at NMC, indicated 2 inch rainfall amounts over northwest South Carolina, with lesser amounts to the east. Figure 3 shows the observed 24-hr accumulated rainfall ending at 1200 UTC on October 23. The map indicates that most of the state received abundant rainfall. Amounts were lightest along the south coast. The northwest portion of the state received around 2 inches of rain as was forecast. However, the central part of the state had much more rain than predicted. Many areas received 3 to 4 inches of rain, with local amounts exceeding 5 inches. As a result, maximum rainfall amounts were underestimated, and the location of heaviest precipitation was displaced.

A possible explanation for the heavier than predicted rainfall amounts comes from an unusual source. Hurricane Trudy was located a few hundred miles south of the southern tip of the Baja Peninsula during, and a few days prior to, the time of this event. Although the low-level circulation was still intact, the upper portion of the storm was sheared eastward by the subtropical jet. As a result, moisture was transported across Mexico into the Gulf of Mexico. This flow was readily detected by the water vapor satellite (not shown) loop from SWIS (Satellite Weather Information System). The moisture was "picked up" by the 500 mb trough depicted in Figure 4, and advected into the southeast U.S. This influx of moisture probably enhanced the rainfall.

3. FLOW BLOCKING AND COLD-AIR DAMING

As mentioned earlier, flow blocking and low-level cold-air damming may have influenced the location of heaviest rainfall. Damming often occurs to the lee of mountains such as the Appalachians when a surface anticyclone is located to the northeast of the mountain barrier. If the near-surface air circulating around the anticyclone is sufficiently cold and stable, it will not flow over the barrier. Rather, the cold air is **blocked** and accumulates just east of the mountains (hence the name cold-air damming). The cold air produces a mesohigh which often advects the cold air southward parallel to the mountains (i.e., north or northeast low-level flow). Cold-air damming can lead to overrunning precipitation as a moist onshore flow overrides the dome of cold air (which usually has a depth slightly greater than the mountain height).

The process of flow blocking can be explained mathematically through the use of the Froude number (F_r), which is defined as:

$$F_r = \frac{U}{N h}$$

where U is the wind component of the undisturbed flow normal to the mountains; N is the Brunt-Vaisala frequency, which is a measure of atmospheric static stability; and h is the height of the barrier (Forbes et al. 1987). This equation is essentially the ratio of inertial to buoyancy forces. As this ratio becomes small, blocking occurs (F_r approaches 0, as is the case with light winds and stable air for a given mountain height). As the inertial force approaches the buoyancy force (F_r approaches 1), the air flows over the barrier (Stull 1988).

In an operational setting it is difficult to compute the Froude number for a given airmass to determine whether flow blocking and damming is a threat. However, a forecaster should be alert to the possibility of damming if a cold airmass, associated with a surface high, is retreating to the northeast of the mountains (as was the case for this event). An effective way to determine if cold-air damming is occurring is through an examination of the surface potential temperature field (θ). When a region is under a uniform airmass, θ will increase with increasing surface elevation. This relationship can be determined through the use of Poisson's equation (Holton 1979). In damming situations, θ actually decreases with elevation toward the mountains because of the cold high pressure dome associated with the damming.

To determine if damming was occurring in this case, surface isentropes were plotted. Figure 5 is a terrain height contour map of South Carolina and adjacent portions of North Carolina and Georgia. The diagram indicates that terrain height increases northwestward, with the strongest gradient between Columbia (CAE) and Greenville (GMU). Therefore, if cold-air damming was occurring, the surface isentropes should have decreased toward the northwest.

Figure 6 displays an analysis of the surface isentropes at 0000 UTC, on October 23 (which was about midway through the heavy rain event at CAE). The analysis shows a decrease in θ from southeast to northwest despite the increasing surface elevation. This signature is indicative of damming.

The surface isobaric analysis at this time (Figure 7) displays an inverted trough over the central portion of the state with a quasi-stationary frontal boundary. The cold front associated with the advancing upper-level trough was located in central Georgia at this time. The higher pressure and northeast winds over the northwest portion of the state were associated with the cold dome. This interface between the warm onshore flow, and the cold pool associated with the damming, has been referred to as a "coastal front" by Bosart (1975), Bosart et al. (1972), and Ballentine (1980).

The significance of cold-air damming is explained by the schematic x-z cross section of θ displayed in Figure 8. Note that CHS has a higher surface θ than CAE and GMU. If the flow is adiabatic, (which is the case for an unsaturated air parcel in the absence of radiative cooling or diabatic heating), the air will flow along the isentropes. Once condensation occurs, parcel ascent is even greater (if the latent heat release stays with the parcel). Thus, in a damming situation, the mountain barrier is essentially extended, causing the heaviest precipitation to occur away from the mountains toward the coastal plain. This was the case for the heavy rainfall event (Figure 2) of October 22-23, 1990.

4. SUMMARY

On 22-23 October 1990 flooding rains occurred in central South Carolina. The heavy rainfall in this area, came as somewhat of a surprise since heaviest amounts were forecast to occur in the higher elevations over the northwest portion of the state. The NMC/HPB QPF guidance predicted 24-hr amounts of 2 inches in the northwest with lesser amounts to the east. Observed 24-hr rainfall totals exceeded three inches in the central portion of the state with local amounts in excess of 5 inches. It appears that the precipitation was enhanced by a supply of mid- and high level moisture from hurricane Trudy located south of the Baja Peninsula. The moisture appeared to be transported via the subtropical jet.

Cold-air damming apparently influenced the location of heaviest rainfall. The cold air trapped to the lee of the Appalachians acted as an extension of the mountain barrier. Thus, the heaviest rain, associated with the moist upslope flow, was displaced well to the east. The topic of cold-air damming deserves further study, since objective forecasts may be in considerable error in damming regimes (Forbes et al. 1987). Therefore, a forecaster must anticipate the possibilty of damming even if it is not indicated by NMC guidance products.

5. REFERENCES

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Holton, J. R., 1979: An Introduction to Dynamic Meteorology. Academic Press, NY, 391 pp.

Stull, R. B., 1988: An Introduction to Boundary Layer Meteorology. Kluwer, Norwell.

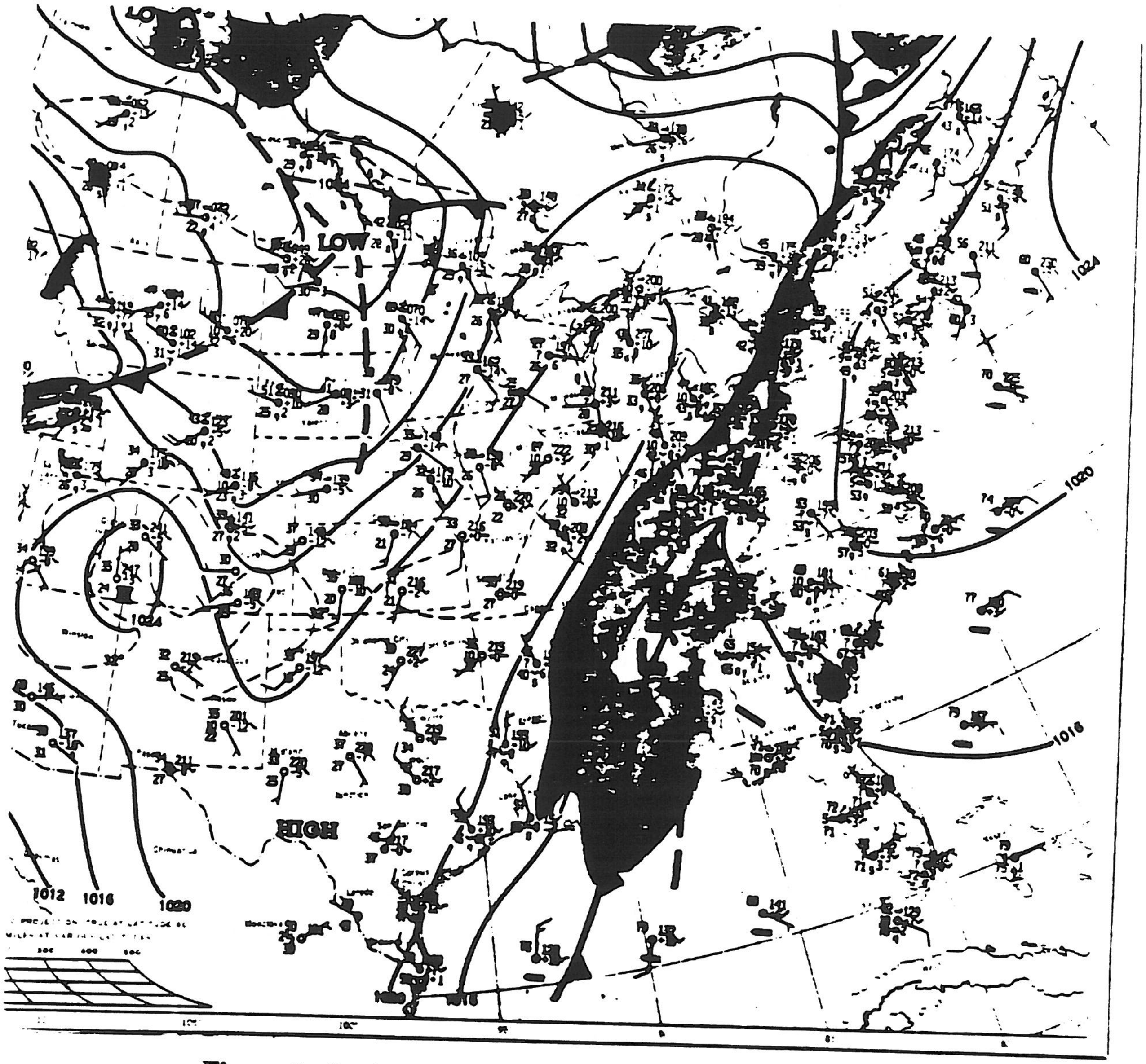

Figure 1. Surface analysis for 1200 UTC, 22 October 1990.

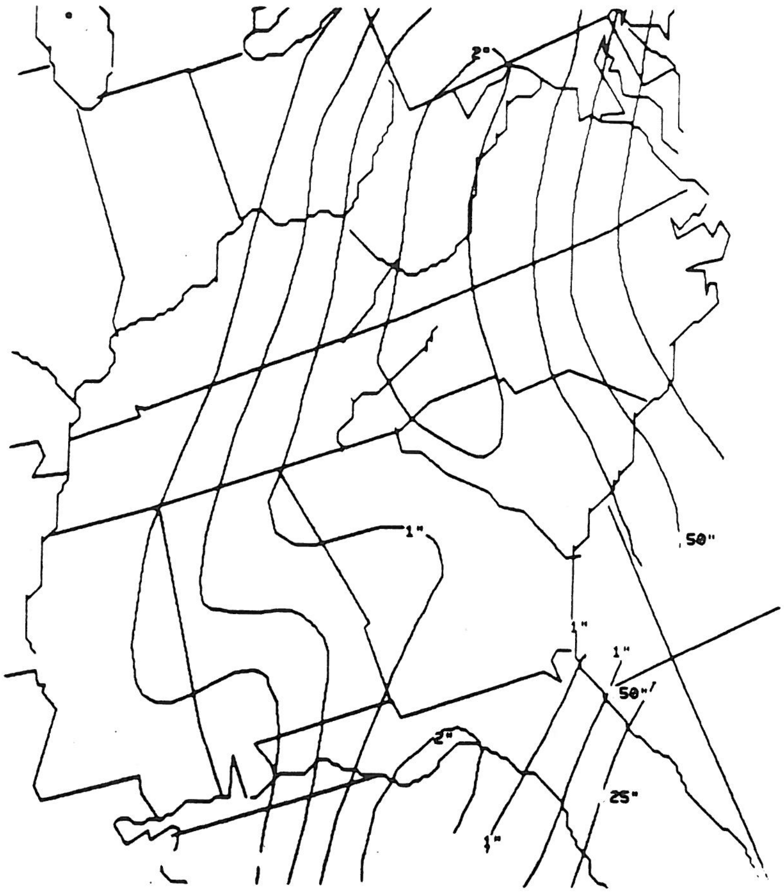

Figure 2. NMC HPB QPF for the 24-hr period ending 1200 UTC, 23 October 1990.

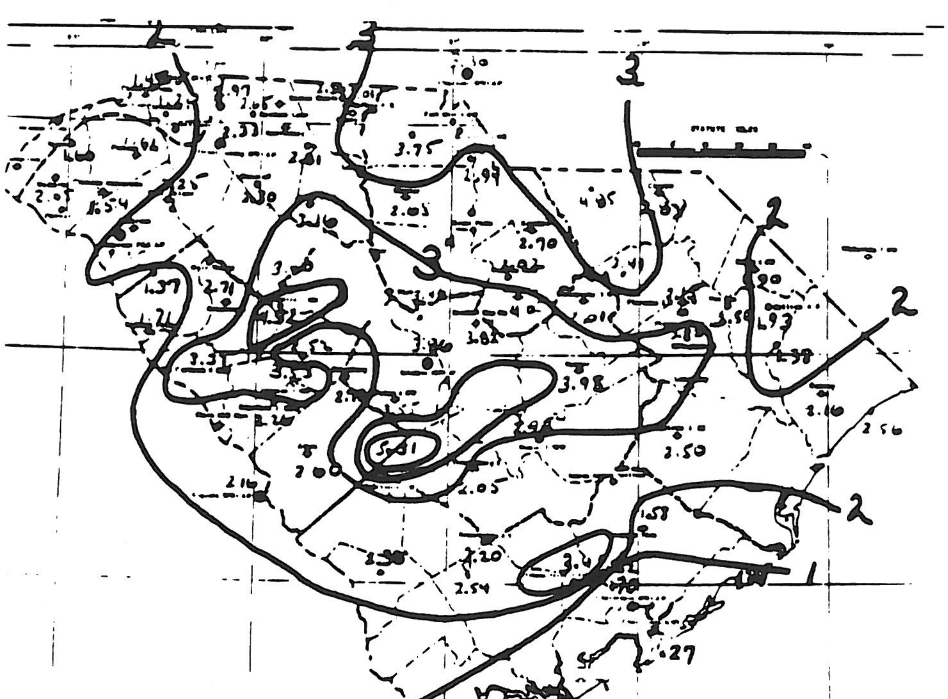

Figure 3. Observed 24-hr precipitation ending 1200 UTC, October 1990.

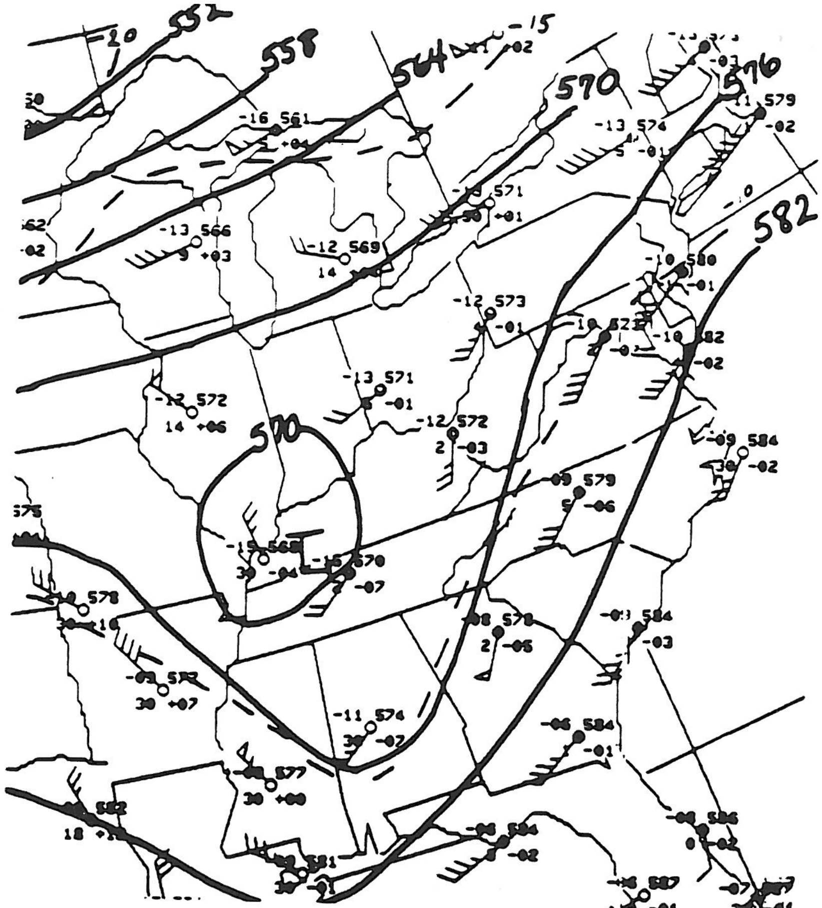

Figure 4. 500 mb height analysis for 0000 UTC, 23 October. Solid lines are height contours (60 m), dashed lines are isotherms (5°C).

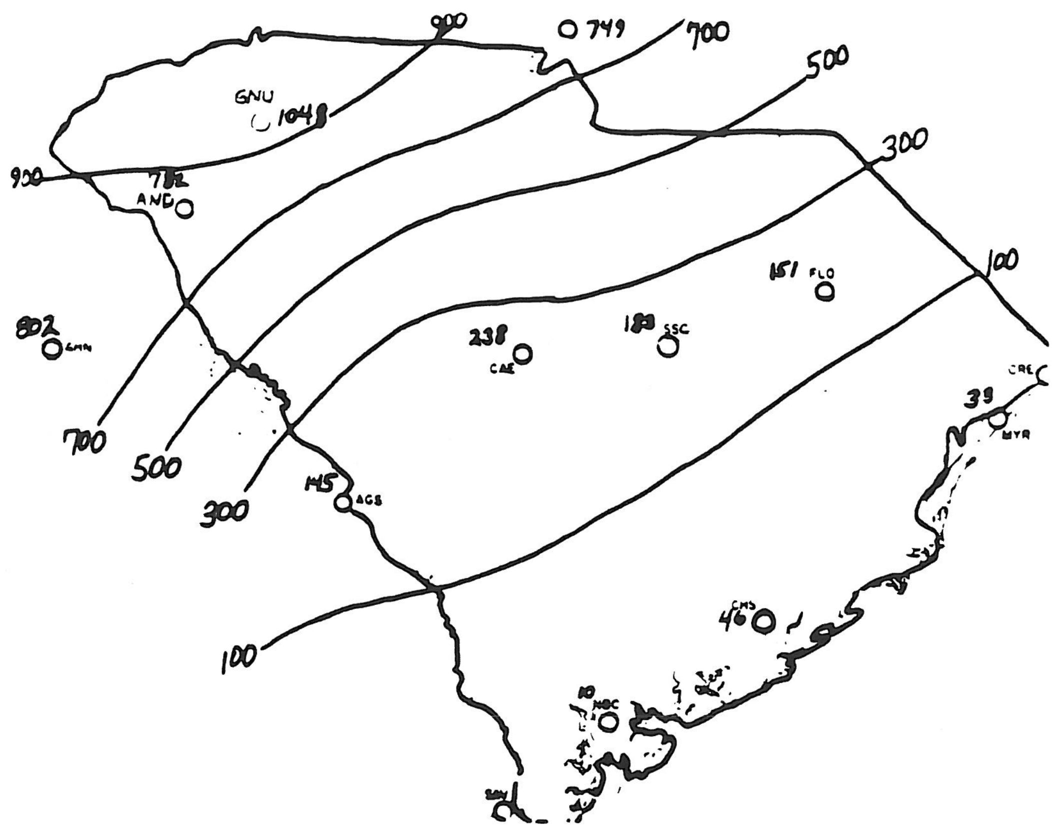

Figure 5. Terrain height (ft) for South Carolina and adjacent areas of North Carolina and Georgia.

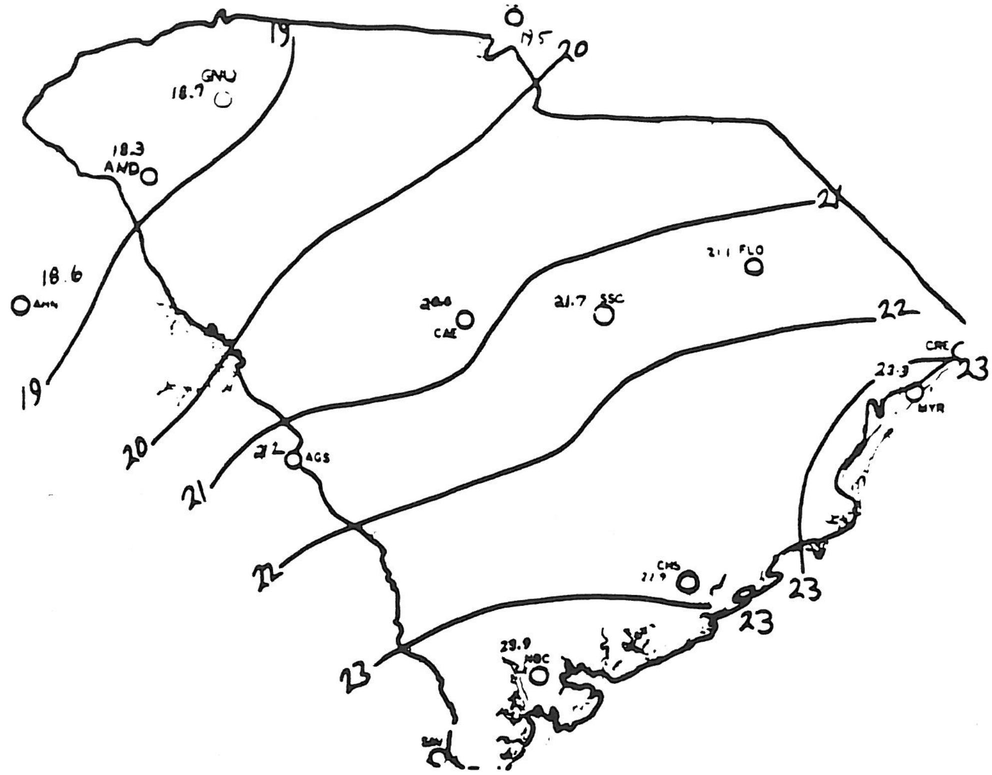

Figure 6. Surface isentropic analysis (°C) for 0000 UTC, 23 October 1990.

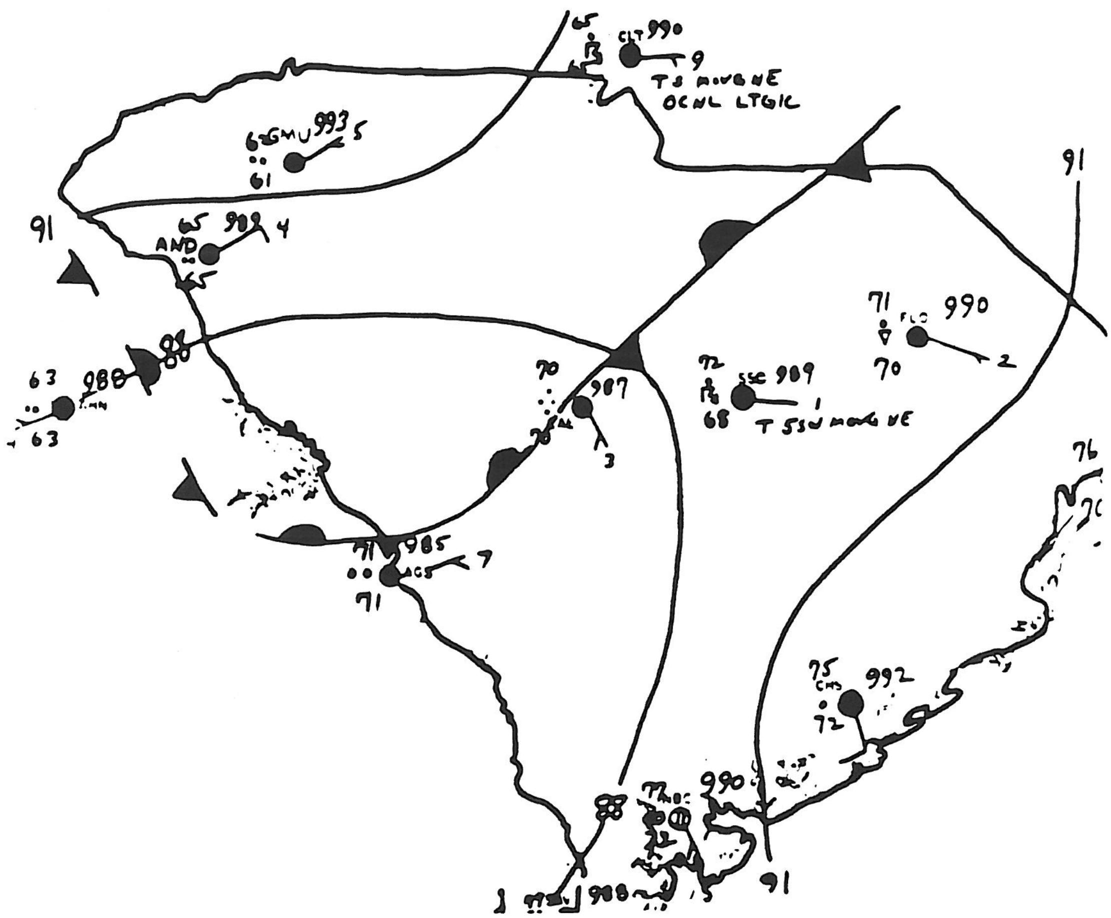

Figure 7. Surface analysis for 0000 UTC, 23 October 1990. Pressures are derived from altimeter settings.

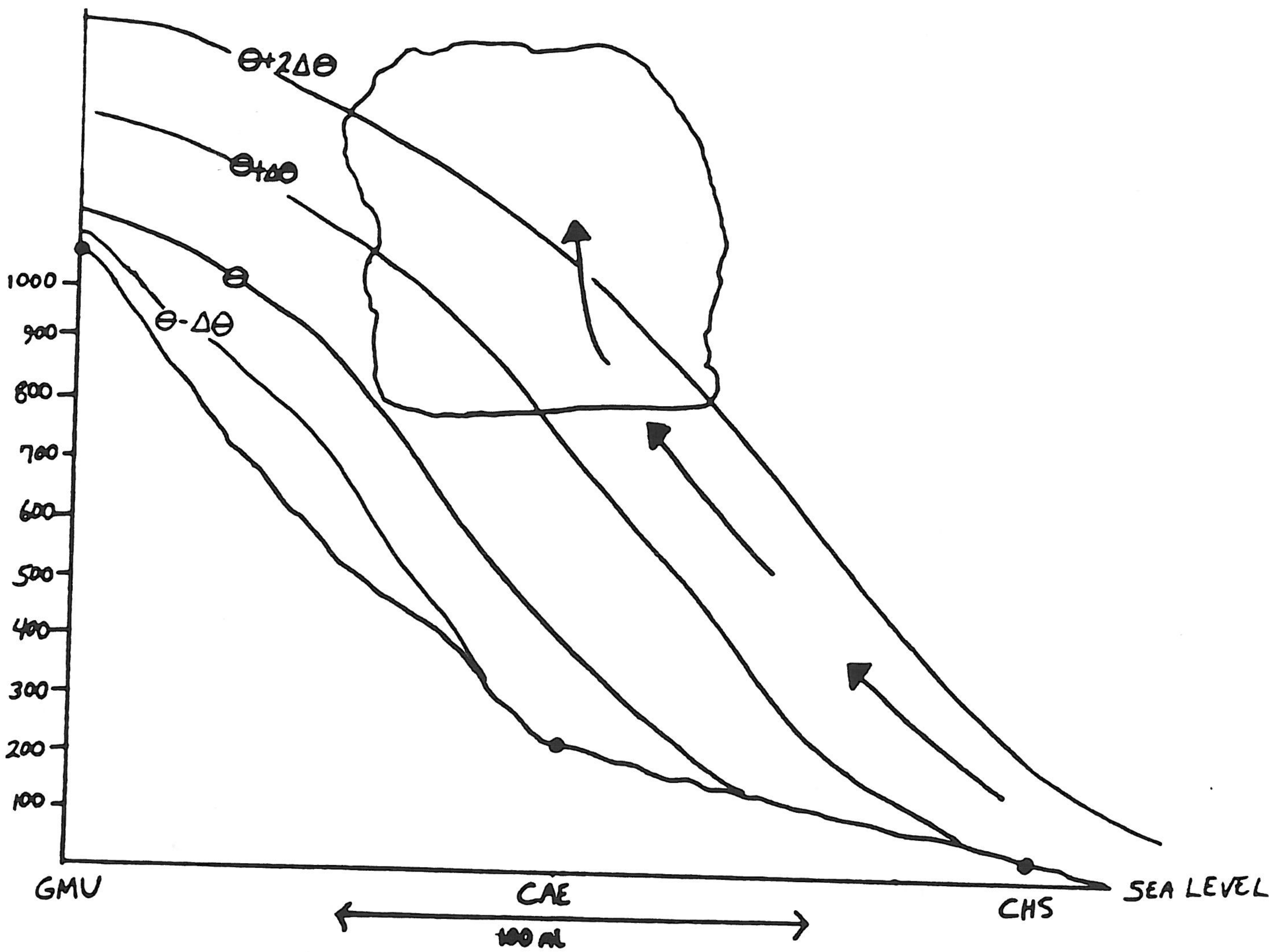

Figure 8. Schematic x-z cross section of θ in damming regimes.