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THE SEVERE LOCAL STORMS OF AUGUST 27-28, 1988, OVER SOUTH CENTRAL NEW YORK AND NORTHEAST PENNSYLVANIA

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1. INTRODUCTION

Historically, tornadoes have occurred, albeit infrequently, across the southern tier of New York and northeast Pennsylvania (Figure 1); however, an event such as the one which took place on the weekend of August 27-28, 1988, is rare. Three tornadoes occurred over the southern tier of New York and northeast Pennsylvania (Figures 2a and 2b). These were the first tornadoes in the region in over a year. What separated this case from many of the previous occurrences was that the airmass that weekend remained sufficiently unstable to produce tornadoes on two consecutive days. Furthermore, both days had thunderstorms, which developed and moved along a warm front meandering through the region, with both severe weather outbreaks apparently involving the formation of supercells over New York. The study presented here is an attempt to identify the conditions that led to tornadic development by using surface, upper-air and sounding data.

2. STORM SUMMARY

On Saturday, August 27, 1988, the day had been hot, with only scattered low clouds reported across the region during the afternoon. By 0000 UTC, however, lower clouds were on the increase over the region, associated with a warm front moving into northeast Pennsylvania. A thunderstorm was reported at Bradford, PA, (BFD), and a southeasterly flow of tropical air was advected into southern New York from eastern Pennsylvania. Weak surface troughing was evident over central Pennsylvania, with an associated dewpoint discontinuity. Around 0028 UTC, a VIP (Video Integrated Processor) level 4 cell developed over central Tioga County, PA, near Wellsboro (Figure 3).

This cell moved east-northeast at 25 kt, entering southeast Chemung and southwest Tioga Counties of New York shortly after 0130 UTC. Storm reports indicated that damage first occurred around 0145 UTC near Litchfield in northeast Bradford County, PA. Damage was reported in New York around 0155 UTC in the town of Barton, southwest Tioga County. By 0206 UTC, the WSR-74S (Weather Surveillance Radar S-Band (10 cm)) at WSO Binghamton (BGM) indicated a VIP level 5 cell to near 30,000 ft just south of Owego in Tioga County, NY. At 0210 UTC, an F1 tornado touched down in the town of Nichols, in south central Tioga County, and continued along a path 5.6 miles long, into the town of Apalachin, in southeast Tioga County, where it ended around 0220 UTC.

VIL (vertically integrated liquid water) values from the RADAP II (Radar Data Processor) system were not available at the time of the tornado; however, VILs at 0130 UTC were 40 kg m^{-2} over southeast Chemung County, NY, and north central Bradford County, PA (Figure 4). Previous studies (Beasley 1986) indicated that severe thunderstorms in Oklahoma had average VILs above 55 kg m^{-2} from July through September during the period 1983-1984. In contrast, Davis and Drake

(1988) found a VIL above 45 kg m^{-2} to be an indicator of severe weather in western Pennsylvania.

This storm continued to do damage until 0415 UTC when it exited the Fly Creek area in northern Otsego County, NY. The storm caused $500,000.00 damage in Tioga County, NY alone, and also produced 1-inch hail over portions of northern Broome County around 0315 UTC.

The situation on Sunday afternoon, August 28, 1988, was different in several ways from Saturday evening. The low-level moisture was already in place from the rain the night before. A cold front was sweeping through the eastern Great Lakes region. Finally, the time of occurrence of the severe local storms coincided with the period of maximum surface heating. As a result, the storm damage was much more widespread. Similar to the previous evening, the severe thunderstorms again developed along the warm front over the southern tier of New York and northeast Pennsylvania.

By 1828 UTC, a VIP level 4 cell with a maximum top of less than 20,000 ft developed over eastern Allegany and western Steuben Counties of New York in relatively cool air; however, this thunderstorm was moving very rapidly east-northeast at 50 kt (Figure 5). The storm developed rapidly during the next 40 minutes as it moved into the warm sector over eastern Steuben County. By 1908 UTC, the storm had a VIP 6 level core with a diameter of 7 n mi, a hail spike, and a maximum top of 53,000 ft. Storm damage began around 1903 UTC over eastern Steuben County, with the storm spawning an F1 tornado after crossing Seneca Lake in Schuyler County around 1940 UTC. Once the storm reached Seneca Lake it had a maximum top of 56,000 ft, with a hail spike extending off of the RHI (Range Height Indicator) scope as the hail was ejected out the top of the storm. The storm also had a VIL of 55 kg m^{-2} (Figure 6). The forward speed of the storm was east-northeast at 45-50 kt.

The tornado crossed into Tompkins County, NY, where it ended 1 mi east of Jacksonville in northern Tompkins County around 1948 UTC, just west of Cayuga Lake. As is typical with many supercell storms that spawn tornadoes, golfball size hail fell just north, and in close proximity to the path of the funnel. The storm continued to produce damage until around 2200 UTC, when it exited northeastern Otsego County. There were many other storms which produced damage that afternoon and evening, but only one other storm spawned a tornado. An F2 tornado occurred over northwest Wyoming County of Pennsylvania in the town of Mehoopany around 2350 UTC. The tornado appeared to be the result of a storm which had a collapsing top. The WSR-74S at WSO BGM indicated a VIP level 5 cell over northwest Sullivan County of Pennsylvania at 2330 UTC, which was moving east-northeast at 30 kt. By 0030 UTC on August 29, this storm could no longer be identified.

3. DATA ANALYSES

From the surface and upper-air data at 1200 UTC, Saturday, August 27, 1988, it was not initially apparent that severe local storms would occur later that day. Neutral vorticity advection was indicated across the region. No jets (850 mb, 500 mb, or 300 mb) were in the area at this time (Figure 7); drier air was being advected into the region at 700 mb; and unstable air, as indicated by stability index calculations (George 1960 and Miller 1972), was confined well to the south of the region (Figure 8). Sounding plots of temperature (t) vs. dewpoint (t_d) for Pittsburgh (PIT), Albany (ALB), Buffalo (BUF) and Atlantic City (ACY) all showed a surface inversion with dry air aloft. These soundings also exhibited large negative energy areas for a lifted surface parcel.

Another indicator of the convective instability of the airmass is a plot of the equivalent potential temperature (θ_e). In convectively unstable air, θ_e decreases with height. The moisture and temperature profiles combine to produce a minimum in θ_e at mid levels (Doswell 1982). Further, Doswell and Lemon (1979) found that during the time from the sounding well before the storm to the sounding closest to storm occurrence, the minimum equivalent wet-bulb potential temperature (θ_w) actually increased slightly (about 1.5 ^oC) and the height of the minimum θ_w rose (about 80 mb). This is a result of upward vertical motion that causes the moist layer to deepen and rise during the period before storm development. This scenario should hold true for values of θ_e as well, since there is a non-linear, one-to-one correspondence between θ_w and θ_e. Sounding plots of potential temperature θ vs. θ_e for ALB, BUF, PIT, and ACY for 1200 UTC on Saturday, August 27, 1988, indicated very steep inversions near the surface in all but the ACY sounding. The ACY sounding exhibited a steep lapse rate to the middle-level minimum which occurred around 600 mb.

By 0000 UTC, August 28, 1988, major changes were taking place, despite neutral, or weak negative vorticity advection (NVA) throughout the region. The upper-level jet (300 mb) was moving into eastern Michigan with cyclonic curvature evident, an indication of upper-level divergence. Meanwhile, a low-level jet (850 mb) was located over western Pennsylvania. This jet was oriented such that the area where tornado occurred was in the right-front quadrant, which indicates low-level convergence (Figure 9) (McNulty 1978). The stability indices showed a marked decrease in stability across the region: TT index values of over 45; SWEAT index values of over 300; and NGM Lifted index values less than -4^oC (Figure 10). Sounding plots at ALB and PIT were much more unstable than they had been at 1200 UTC. The ALB sounding had a large positive energy layer aloft beginning around 800 mb for a lifted surface parcel, a sharp increase in low-level moisture, and substantial vertical wind shear in the low-levels (Figure 11). The PIT sounding also had a very large positive layer aloft, beginning around 850 mb for a lifted surface parcel, and vertical wind shear evident in the lower-levels (Figure 12). The θ_e plot (figures 13a and 13b) for PIT indicated the minimum θ_e increased (43.5 ^oC at 1200 UTC to 51 ^oC at 0000 UTC) and its height rose (725 mb at 1200 UTC to 650 mb at 0000 UTC).

At the surface, a warm front was meandering into northeast Pennsylvania, transporting moist unstable air into the region. A thermal ridge was located over the region, just to the west of the moisture ridge, which is favorable for convective development (Moller 1979). A fall-rise couplet in the isallobaric field also developed just north of the region. Perhaps the most important feature, however, was that drier air at mid-levels from the southwest was advected behind a moisture tongue at 700 mb that extended over a narrow band from south central Illinois into central New York (Figure 14) (Weiss 1988).

In the aftermath of the initial convective development, the 0300 UTC, August 28, 1988, surface analysis indicated a fall-rise couplet in the isallobaric field, associated with a bubble high present over BGM (Figure 15). Pressure falls in the wake of the bubble high were also evident. Thus a rise-fall couplet developed as a result of the outflow from the convective activity (Doswell 1982).

By 1200 UTC, August 28, 1988, the warm front was still over the region, but a cold/occluded front was pushing into the eastern Great Lakes (Figure 16). Vorticity advection over the region remained neutral; however, the stability indices revealed unstable air over southwest Pensylvania with TT index values in excess of 50, SWEAT index values over 300, and a lifted index of -4^oC at PIT (Figure 17). The PIT sounding showed very little directional wind shear (although some speed shear was present), with some dry air present near the surface (Figure. 18). No convection was occurring at the time of the sounding. The θ/θ_e plot at PIT indicated only a very small layer (800-700 mb) where θ_e decreased with height, therefore the airmass did not appear to be conducive to the development of severe weather at that time (Figure 19). What appeared to be lacking at 1200 UTC was a lifting mechanism to trigger convection.

By 1800 UTC, August 28, 1988, surface heating and low-level moisture were in place, and the cold/occluded front moved much closer to southern New York and northeast Pennsylvania. The lifting mechanism was now in place, and thunderstorms began to develop shortly after 1800 UTC over eastern Allegany and western Steuben counties in New York. Another key ingredient in the convective development was a thermal ridge that stretched from southwest Pennsylvania through northeast Pennsylvania into western New England. This thermal ridge was positioned west of a moisture ridge situated along the Atlantic seaboard from eastern North Carolina into eastern New York and central New England. Furthermore, a weak fall-rise couplet in the isallobaric field developed over the region (Figure 20). By 2100 UTC, the fall-rise couplet had grown even stronger, stretching from eastern New York to eastern Lake Erie (Figure 21).

Even though by 0000 UTC, Monday, August 29, 1988 the event was just about over, several important conclusions can be drawn from analyses of the surface and upper-air data at that time. Once again, the vorticity advection was neutral. By 0000 UTC, the remnants of Tropical Storm Chris, located over central South Carolina were evident in the upper-air data. The cold front had moved east of BUF and PIT. ALB, however, was still in the unstable air ahead of the front. The ALB sounding (Figure 22), in addition to having a large positive energy layer aloft beginning around 870 mb for a lifted surface parcel, exhibited considerable vertical wind shear (both speed and directional) at low-levels, with a very strong middle-level jet (75 kt at 400 mb). The θ_e plot at ALB indicated a convectively unstable airmass was over the region, with a very sharp decrease of θ_e with height from near 1000 mb to about 660 mb, with a secondary θ_e minimum around 580 mb (Figure 23). The stability indices still depicted unstable air in the Upper Hudson Valley of New York, with a SWEAT index of over 350, and an NGM lifted index around -4°C (Figure 24). The 300 mb jet exhibited cyclonic curvature, and was located over central Ontario. The severe weather occurred in the right-rear quadrant, where upper-level divergence is expected. A low-level jet extended from off the northern South Carolina Coast to the Saint Lawrence River Valley, with the severe weather occurring in the right-front quadrant. A 65 kt jet at 500 mb over the Greater Capital District Area of New York helped focus the severe weather activity over this area (Figure 25).

4. CONCLUSIONS

Both severe weather outbreaks on the weekend of August 27-28, 1988, occurred with southwest flow aloft, and exhibited supercell type development. Jet maxima were positioned such that upper-level divergence (at 300 mb) and lower-level convergence (at 850 mb) were occurring; features that are favorable for severe weather development (Harnack and Quinlan 1989). At the surface, a thermal ridge was over the region, positioned west of a moisture ridge. A fall-rise couplet in the isallobaric field was also present. Mid-level drier air from the southwest was advected into an area where a moisture tongue at 700 mb had previously been established. This appeared to play an important role in the development of the tornado which occurred on Saturday night, August 27, 1988.

The dynamic forcing for the tornadoes that occurred on Sunday afternoon, August 28, 1988, were more pronounced than those the night before. First, an abundance of surface heating was present, as well as a cold/occluded front that was moving toward the region. A capping inversion of 3°C at 950 mb was present on the 1200 UTC sounding for ALB, which coupled with the movement of the thunderstorms into the warm sector supported the rapid development. A strong thermal ridge was in place over the region to the west of the moisture ridge, and an isallobaric fall-rise couplet was present from eastern New York to eastern Lake Erie. Another important feature was a 65 kt jet at 500 mb moving into eastern New York.

A useful tool was the θ vs. θ_e sounding plot. This analysis showed why no convective activity was present on Sunday morning, August 28, 1988, over southwest Pennsylvania since the convective instability was marginal for convective development. The θ_e analysis also was useful in identifying where and when convective activity would develop, as evidenced by the θ vs. θ_e plots for PIT at 0000 UTC, August 28, 1988, and for ALB at 0000 UTC, August 29, 1988.

The study presented here illustrates that there are many conditions, both at the surface and aloft, which must be analyzed in order to understand the dynamics involved in severe local storms. Although the operational forecaster will not always have the time to incorporate and analyze all of the information, he or she must be able to review enough information to assess the weather problem at hand. It is hoped that this study will give some insight as to what to look for when dealing with the problem of predicting tornadic development in the northeastern United States.

5. ACKNOWLEDGMENTS

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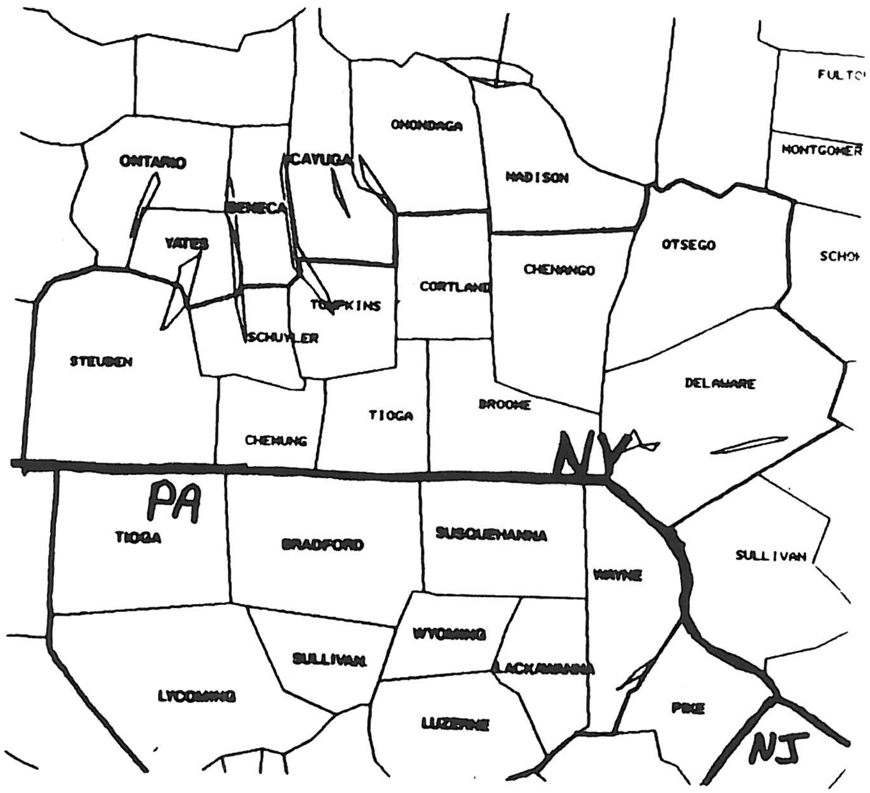

Figure 1. County map of northeastern Pennsylvania and the southern tier of New York.

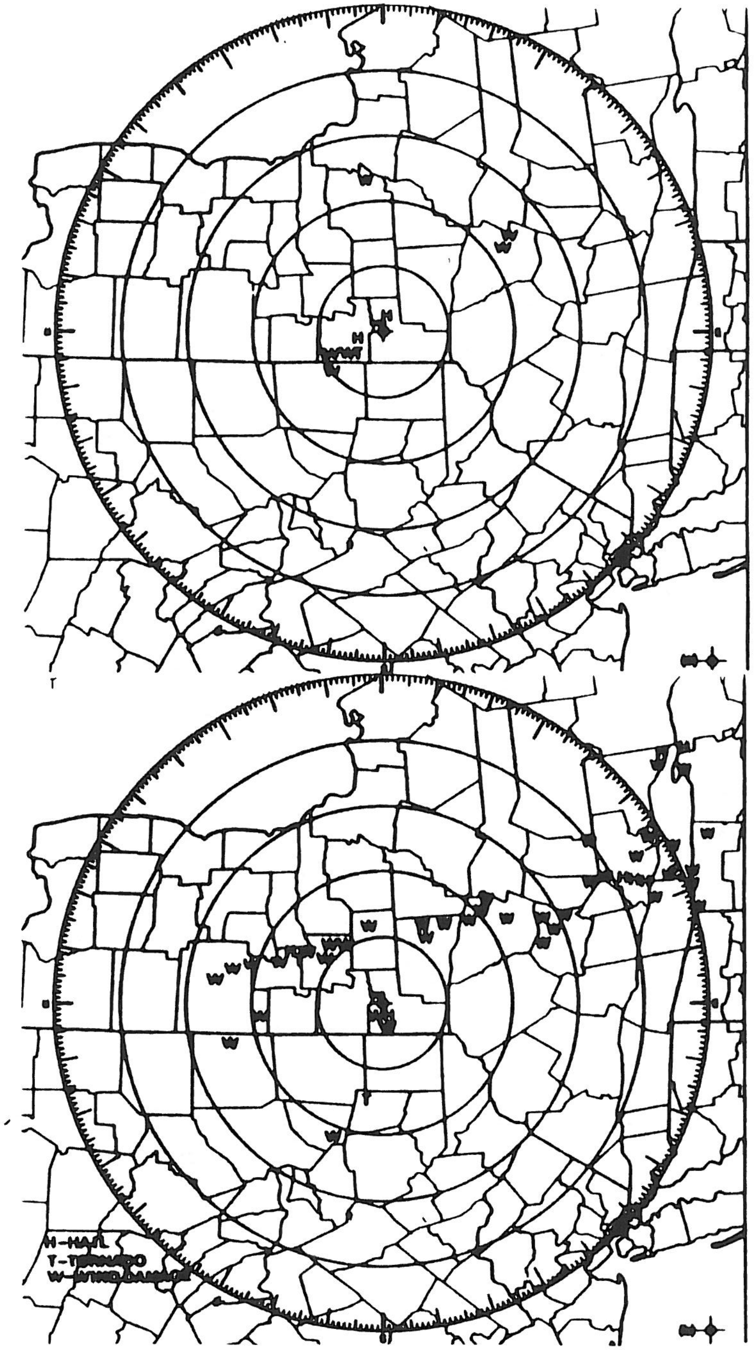

Figure 2. Severe weather reports for: a) August 27, 1988, and b) August 28, 1988. (W - indicates wind damage, H - are reports of hail 3/4" or larger, and T - indicate reports.)

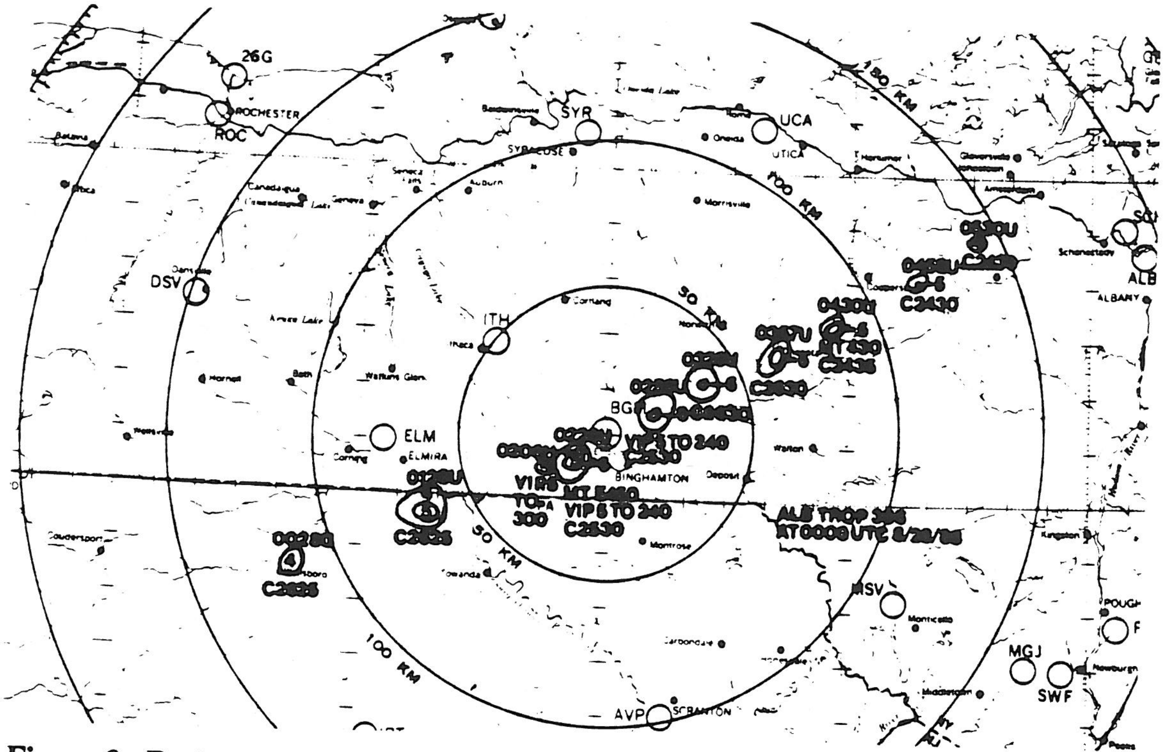

Figure 3. Radar composite overlay from the WSR-74S at WSO BGM for tornado producing supercell (heights in 100's of ft, A - hail, U - UTC, C - cell movement) for 0028-0530 UTC, August 28, 1988.

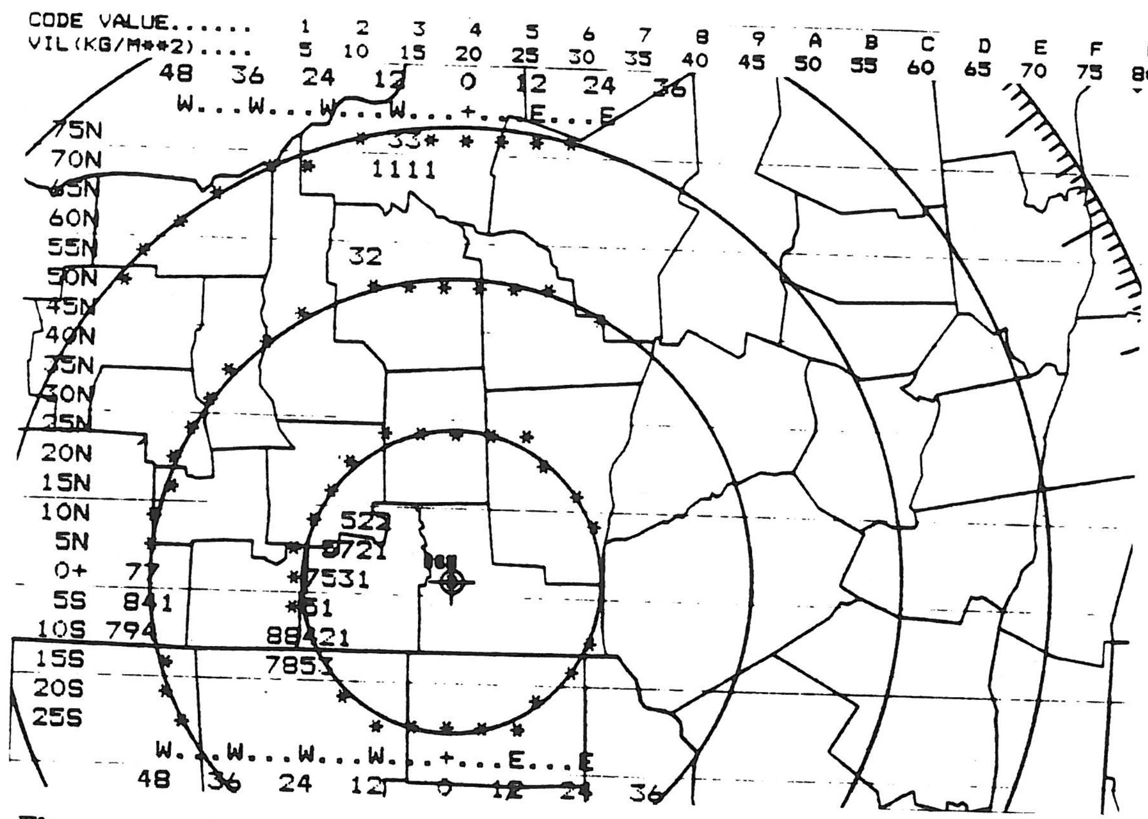

Figure 4. RADAP-II VIL output for 0130 UTC, August 28, 1988.

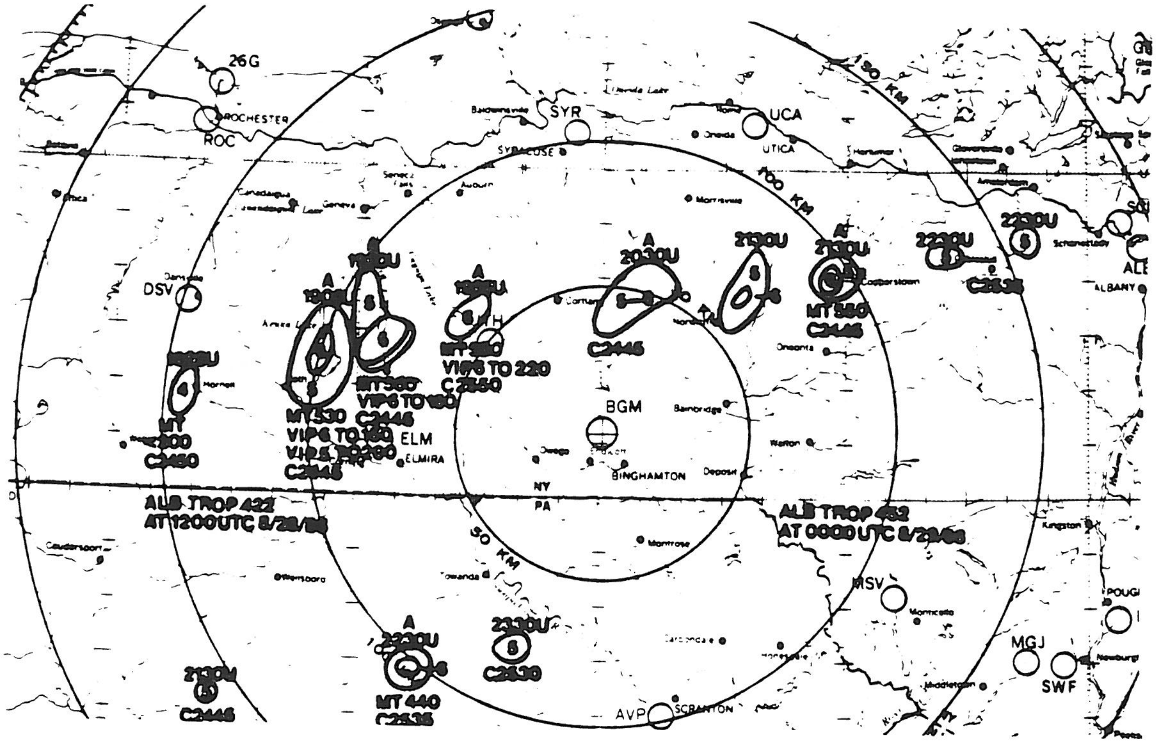

Figure 5. Same as Figure 3 except for 1828-2330 UTC, August 28, 1988.

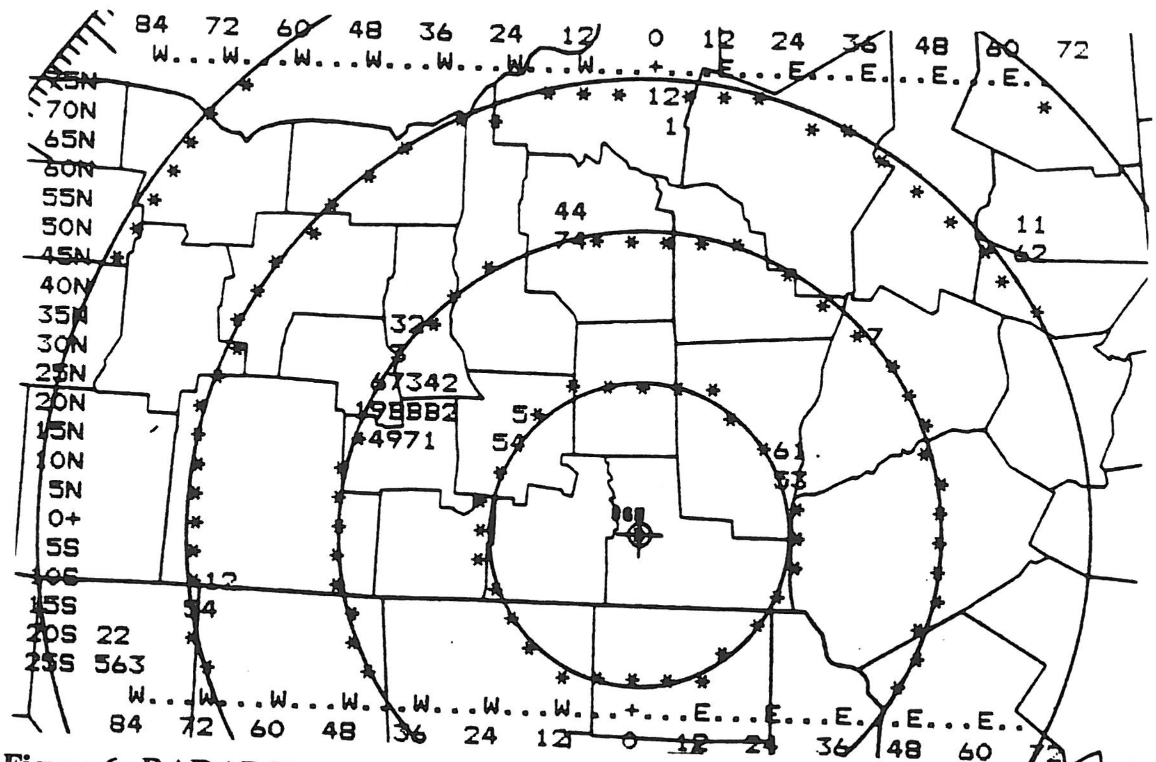

Figure 6. RADAP-II VIL output for 1924 UTC, August 28, 1988.

Figure 7. Composite chart showing surface frontal positions, 850 mb jet (—>), 500 mb jet (---->), and 300 mb jet (····>) at 1200 UTC, August 27, 1988.

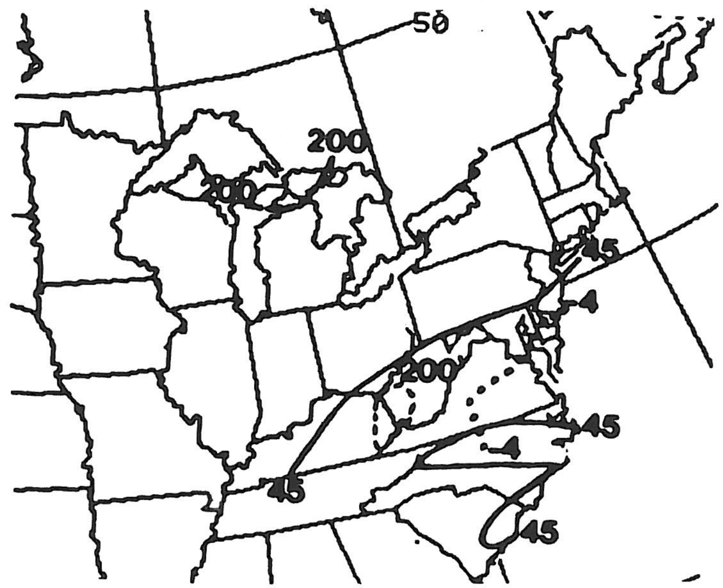

Figure 8. Stability indices: Total Totals index (-----), SWEAT index (——), and NGM Lifted index (·····) at 1200 UTC, August 27, 1988.

Figure 9. Same as Figure 7 except for 0000 UTC, August 28, 1988.

Figure 10. Same as Figure 8 except for 0000 UTC, August 28, 1988.

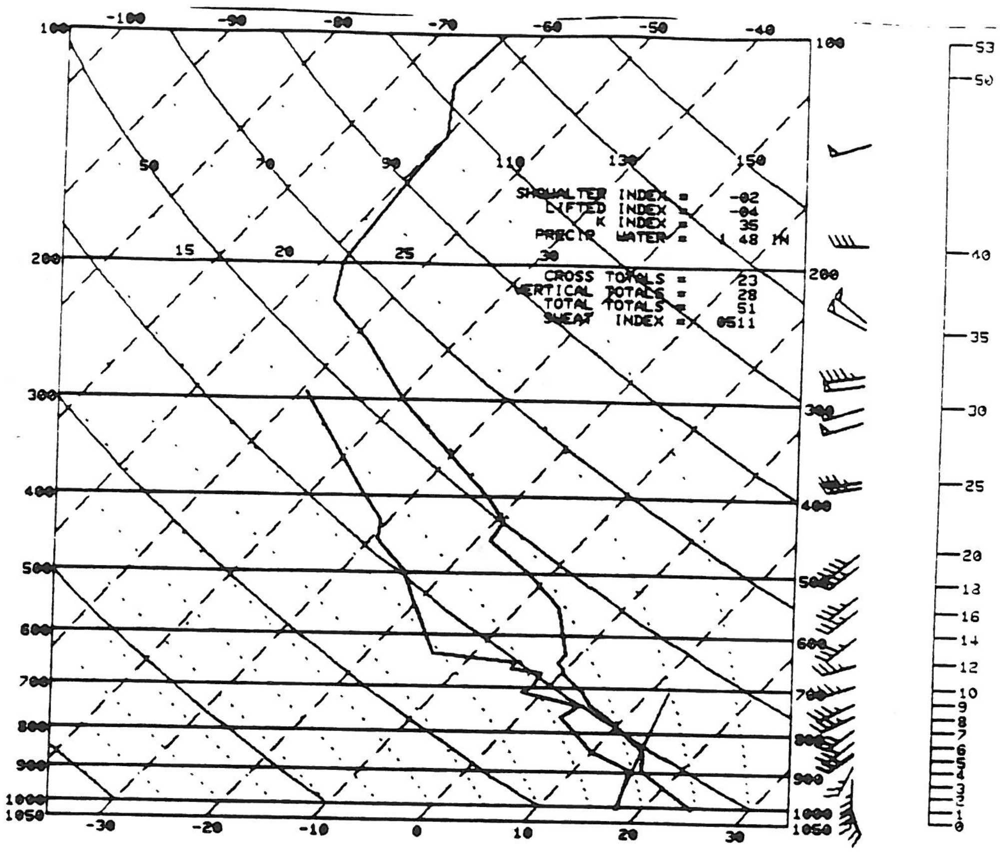

Figure 11. Albany, NY (ALB) sounding (t/t_d) for 0000 UTC, August 28, 1988.

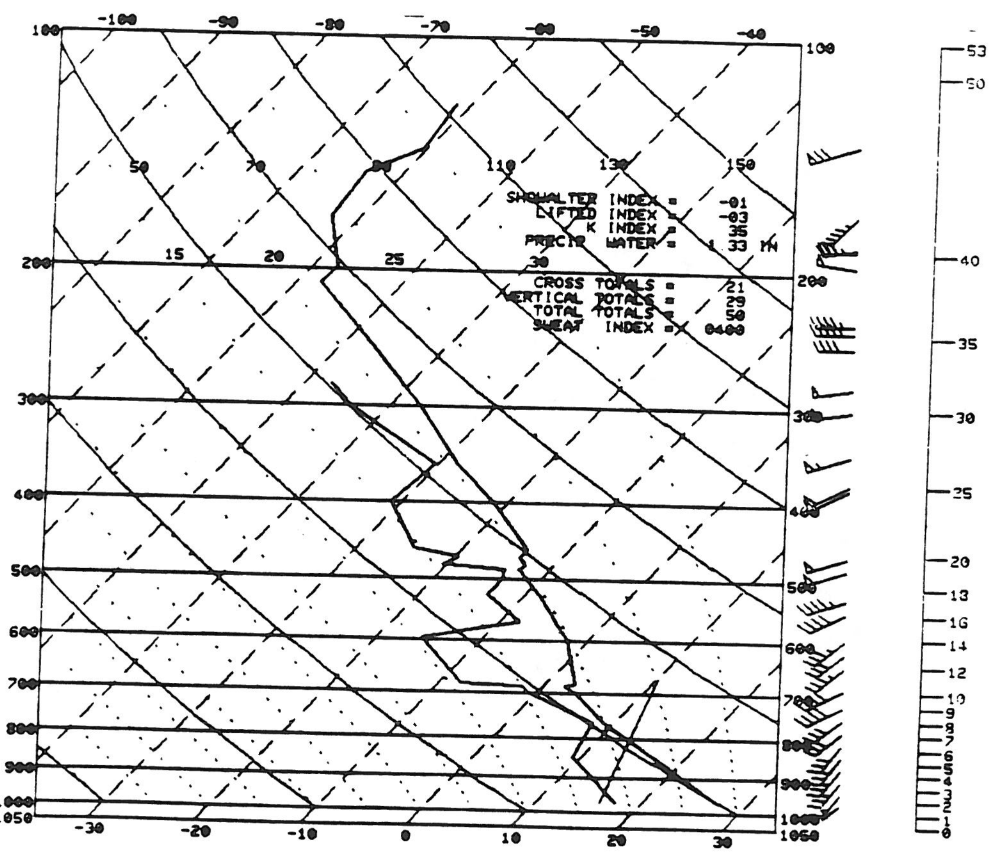

Figure 12. Pittsburgh, PA (PIT) sounding (t/t_d) for 0000 UTC, August 28, 1988.

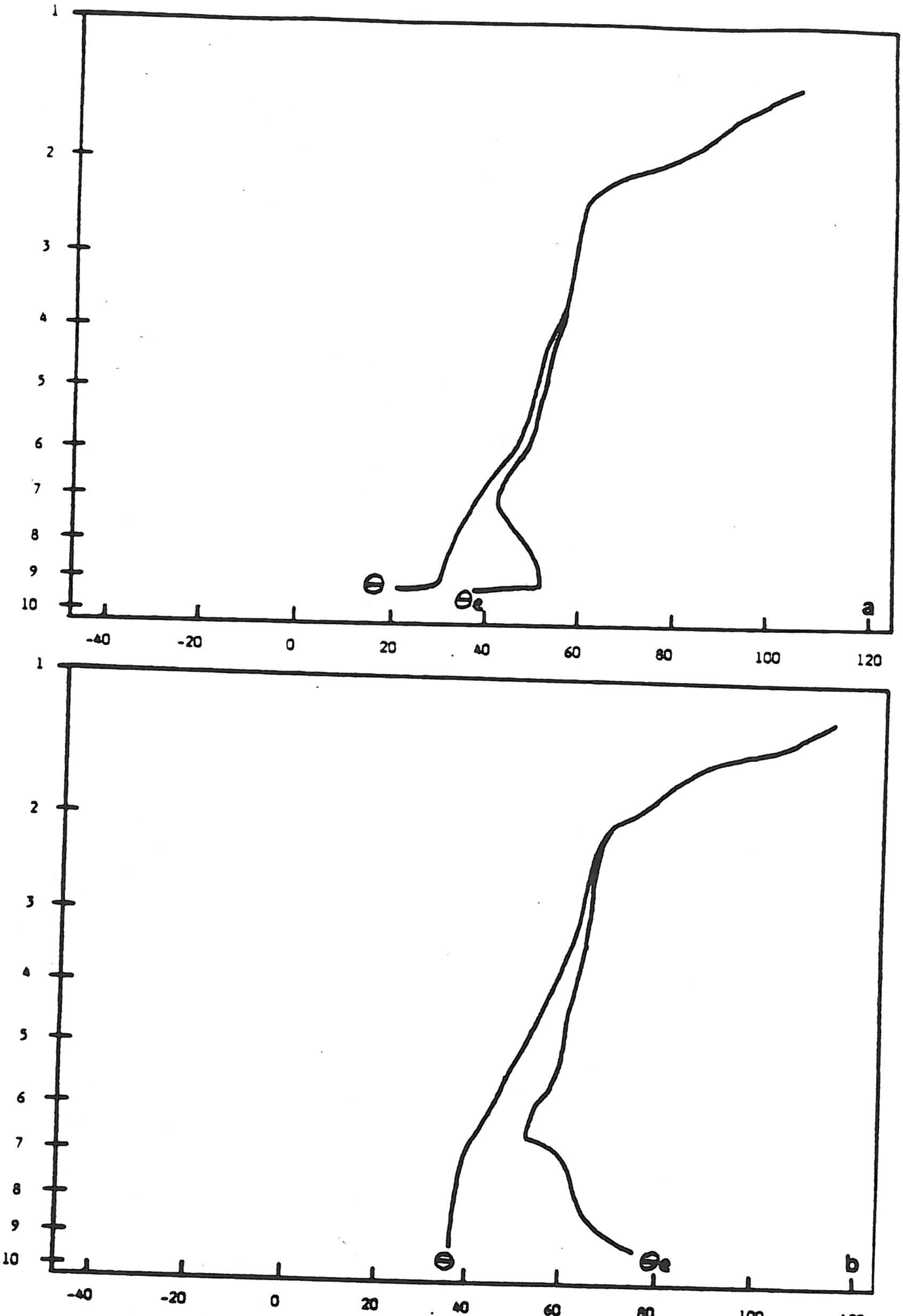

Figure 13. PIT soundings (θ/θ_e) for: a) 1200 UTC, August 27, 1988, and b) 0000 UTC, August 28, 1988.

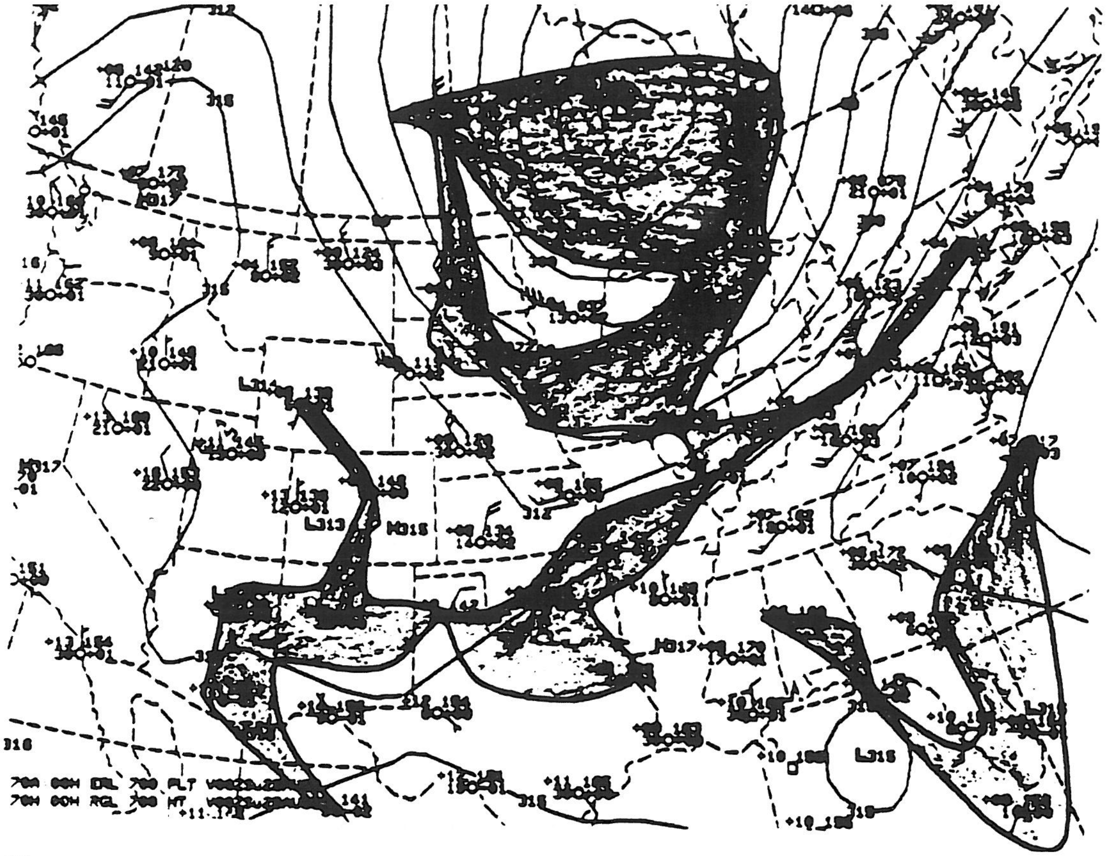

Figure 14. 700 mb analysis (< 5°C dew point depression shaded) for 0000 UTC, August 28, 1988.

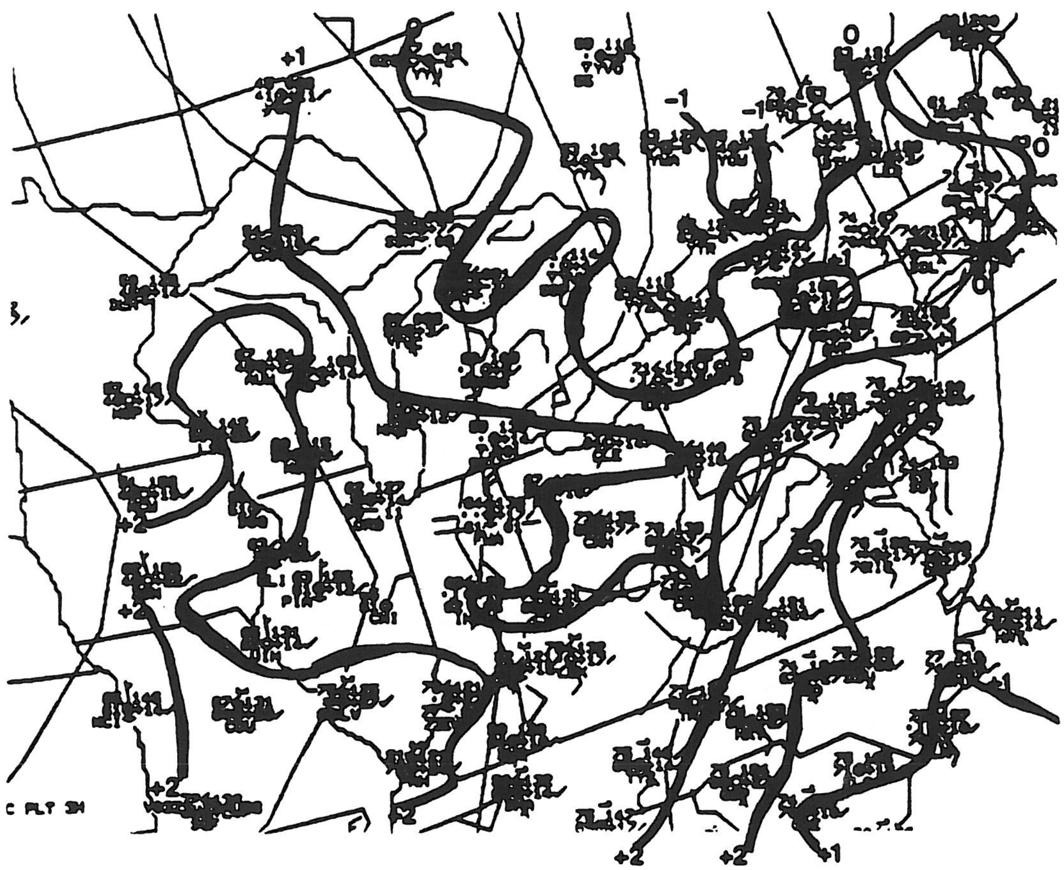

Figure 15. Surface isallobaric analysis (mb) for 0300 UTC, August 28, 1988.

Figure 16. Same as Figure 7 except for 1200 UTC, August 28, 1988.

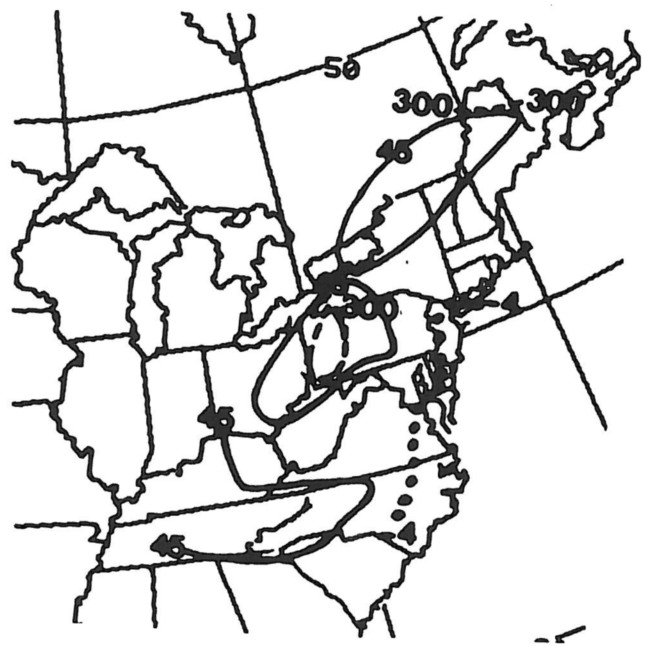

Figure 17. Same as Figure 8 except for 1200 UTC, August 28, 1988.

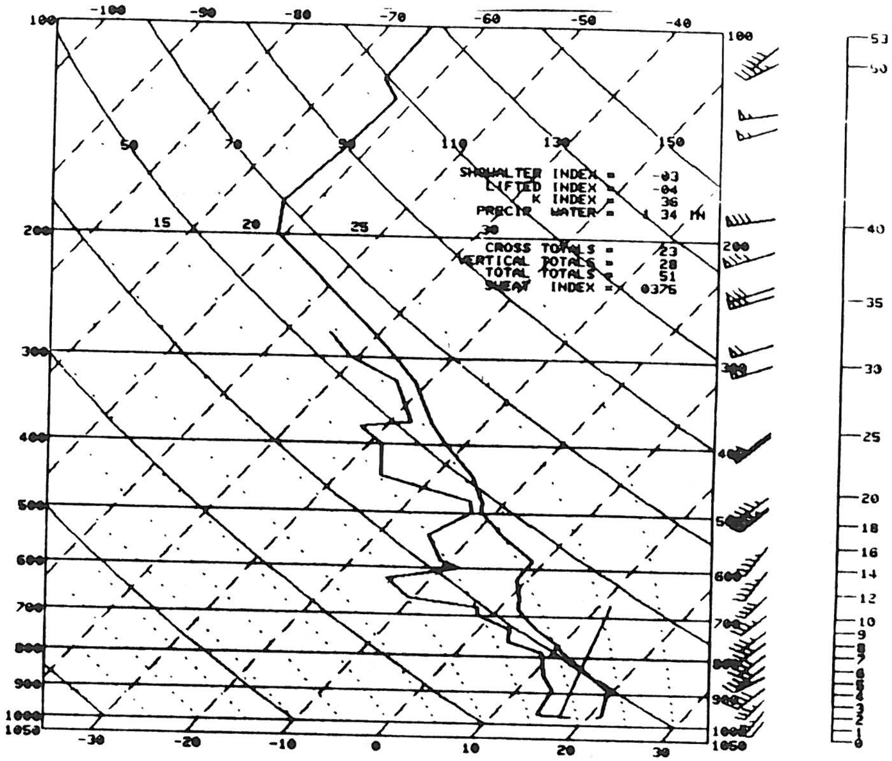

Figure 18. PIT sounding (t/t_d) for 1200 UTC, August 28, 1988.

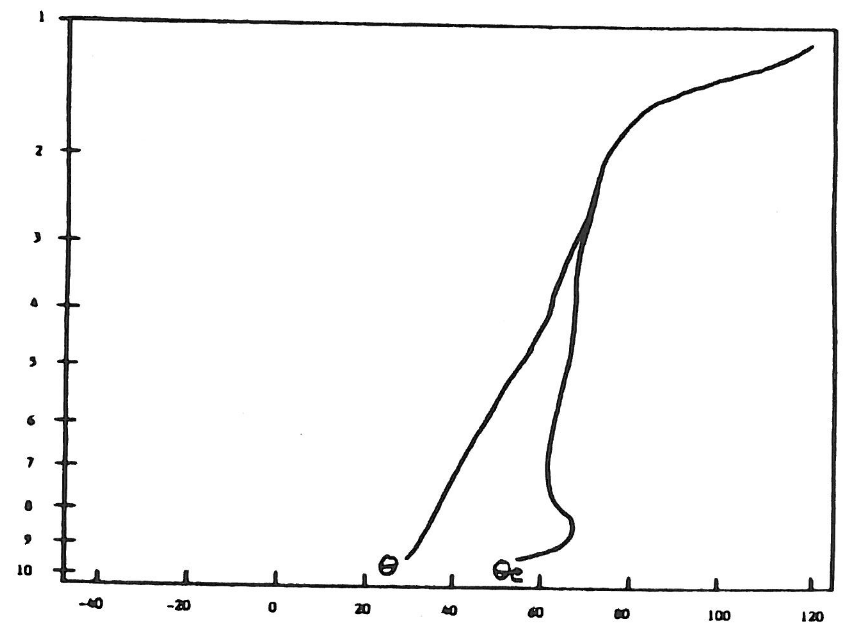

Figure 19. PIT sounding (θ/θ_e) for 1200 UTC, August 28, 1988.

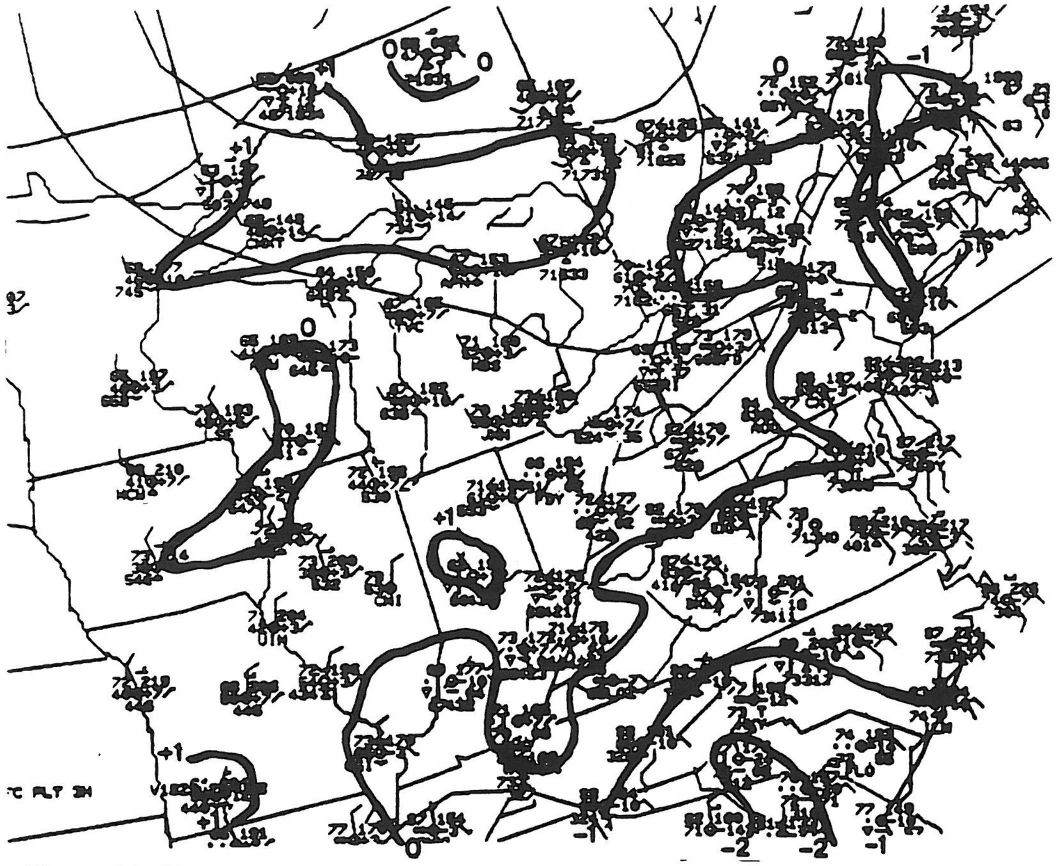

Figure 20. Surface isallobaric analysis (mb) for 1800 UTC, August 28, 1988.

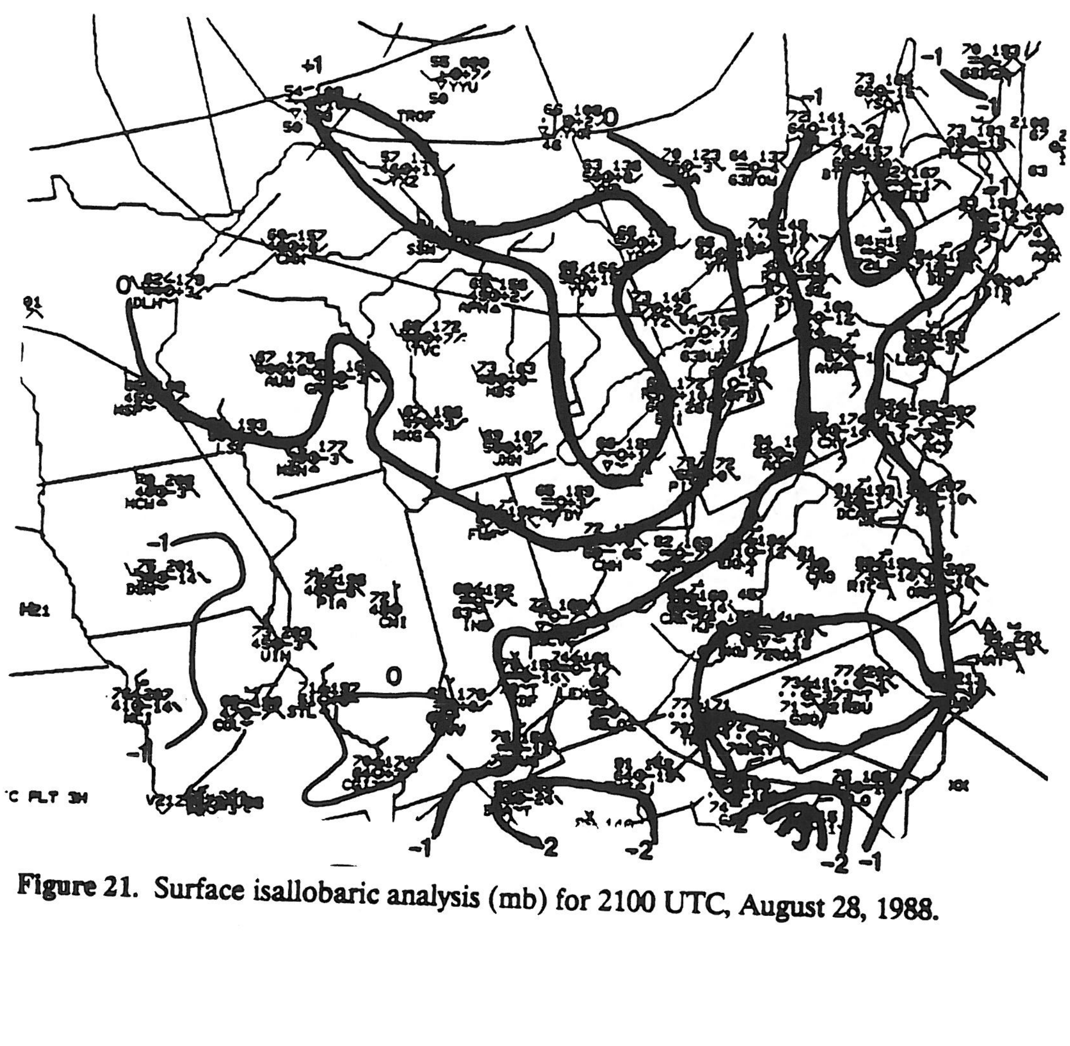

Figure 21. Surface isallobaric analysis (mb) for 2100 UTC, August 28, 1988.

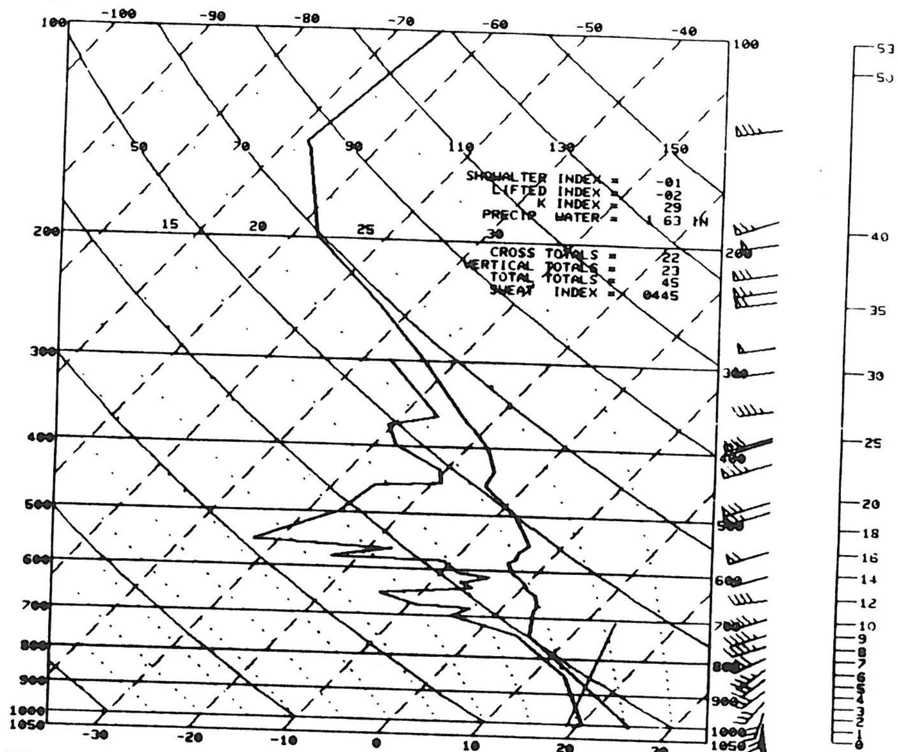

Figure 22. ALB sounding (t/t_d) for 0000 UTC, August 29, 1988.

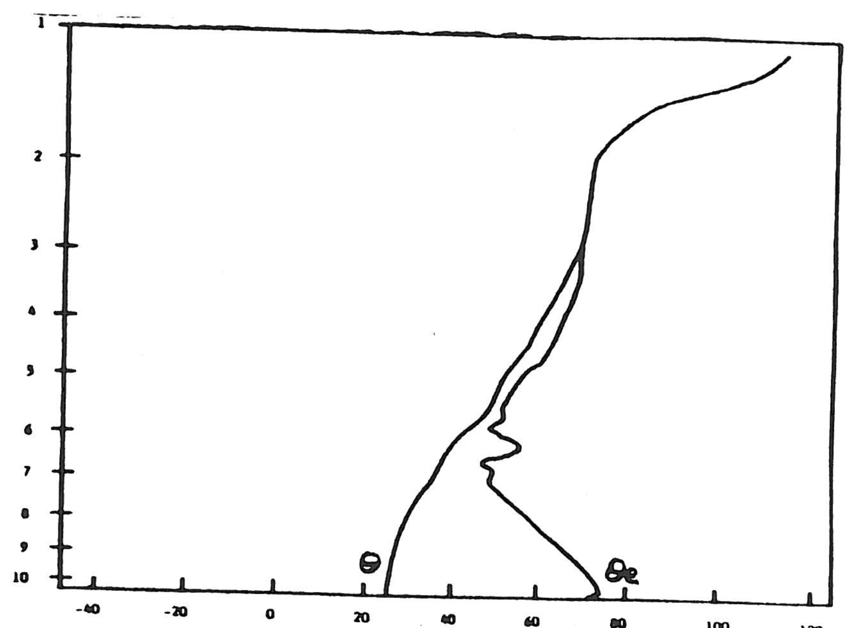

Figure 23. ALB sounding (θ/θ_e)) for 0000 UTC, August 29, 1988.

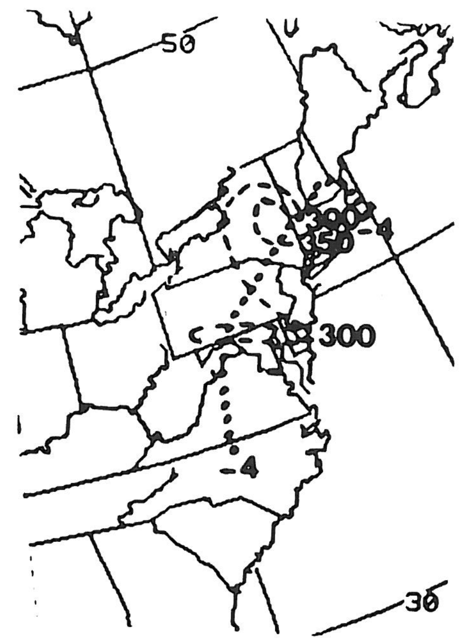

Figure 24. Same as Figure 8 except for 0000 UTC, August 29, 1988.

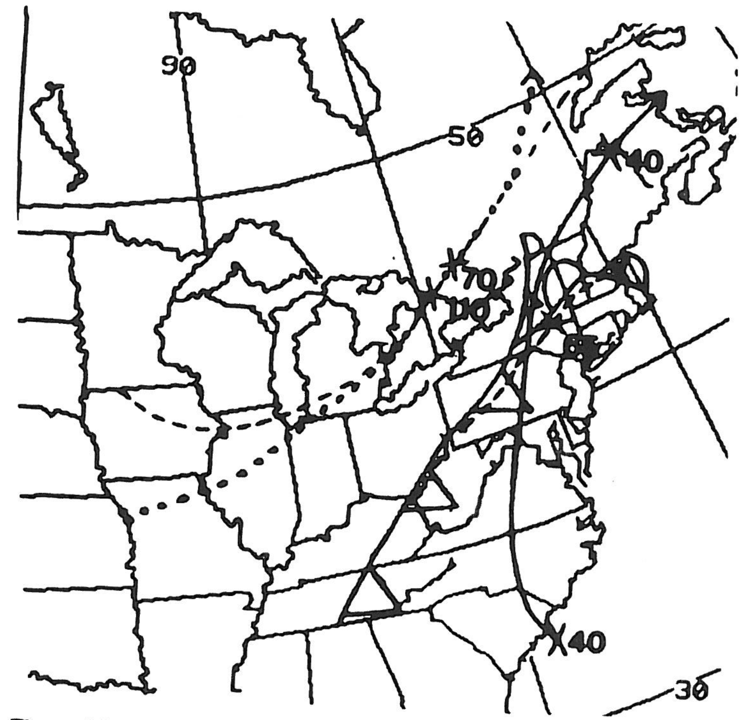

Figure 25. Same as Figure 7 except for 0000 UTC, August 29, 1988.