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# THE 20 NOVEMBER 1989 NORTHEAST SEVERE WEATHER OUTBREAK

*Kenneth LaPenta*
*Robert Barton*
*National Weather Service Forecast Office*
*Albany, New York*

## 1. INTRODUCTION

Severe thunderstorms develop under a wide variety of atmospheric conditions. According to Johns and Doswell (1990), there are three ingredients necessary to produce the deep convection that is almost always associated with severe thunderstorms; a moist layer of sufficient depth through the lower troposphere, a steep enough lapse rate above the moist layer to create substantial potential buoyant energy, and a mechanism to lift a parcel in the moist layer to its level of free convection. Some lifting mechanisms include low-level convergence, low-level warm advection, upslope flow, frontal forcing, and differential heating. While the thermodynamic structure of the atmosphere strongly influences vertical accelerations, vertical wind shear is important in determining the character of thunderstorms (Weisman and Klemp 1986). Observational studies and numerical simulations have indicated that wind shear is important in determining the type and severity of convective storms (Fawbush and Miller 1954; Weisman and Klemp 1984). As vertical wind shear increases, the potential for longer-lived updrafts, and hence, severe weather increases.

During the cold season, synoptic scale systems are significantly stronger than during the warm season. Consequently, large scale atmospheric wind fields are generally stronger during the cold season. During the warm season, the atmosphere usually possesses much greater convective available potential energy (CAPE). Severe thunderstorms during the warm season typically develop in an atmosphere characterized by significant CAPE, and weak to moderate shear. Severe convection during the cold season in the northeast United States, although rare, usually develops in a highly sheared atmosphere with relatively low values of CAPE.

On 20-21 November 1989, intense low pressure moved across southern Canada to the Gulf of Maine. A cold front crossed New York and Pennsylvania during the late afternoon and evening of 20 November. Although the airmass ahead of the cold front was quite dry and apparently stable, severe thunderstorms developed in an atmosphere with strong environmental winds and considerable shear in the lower troposphere.

## 2. 1200 UTC 20 NOVEMBER

The 1200 UTC 20 November surface analysis (Fig. 1a) showed low pressure (988 mb) centered near Kapuskasing, Ontario. A warm front extended from the low across southern Canada, northeast New York and southern New England. A cold front trailed across the western Great Lakes. Ahead of the warm front, temperatures were from 25 to 35°F (-4 to 3°C) over northeast New York and northern New England with overrunning resulting in light snow. The airmass south of the warm front was cool and relatively dry. Temperatures were in the 30s and 40s (0 to 10°C) over southern and western New York, Pennsylvania, and New Jersey, with dew points from the mid 20s (-4°C) to near 40°F (4°C).

The 1200 UTC upper-air analyses at 850 mb, 700 mb, and 500 mb (Figs. 1b, 1c, 1d) showed strong winds over the northeast United States. At 850 mb (Fig. 1b), the wind was 50 kt at Albany (ALB), 55 kt at Pittsburgh (PIT) and Buffalo (BUF), and 35 kt at Atlantic City (ACY). There was slight warm air advection over most of the northeast United States. At 700 mb (Fig 1c) the air was moist with dew point depressions less than 2°C over New York, Pennsylvania, and New Jersey. To the west, over the Great lakes and Midwest, the air was drier at both 850 mb and 700 mb.

The 1200 UTC soundings from ACY, ALB, BUF and PIT all were stable (Table 1). CAPE was zero for each of the four stations. In addition, lifted indices ranged from +10 to +14 with K indices from +16 to +18. Total Totals and SWEAT indices indicated little severe weather potential. Mean 0-6 km winds were high, ranging from 33 kt at ACY to about 50 kt at ALB, BUF, and PIT.

The 1200 UTC sounding data for BUF is shown in Figure 2. As indicated by the stability indices, the atmosphere was stable but with strong winds. The hodograph showed considerable speed and directional shear through the lower levels of the atmosphere. Winds veered from 250° at the surface, to 287° at 3 km. Speed shear was large with winds increasing from 22 kt at the surface, to 66 kt at 2.5 km. Thus, although the atmosphere was not unstable, there was considerable shear through the lower troposphere.

## 3. SEVERE STORM EVOLUTION

The 2100 UTC 20 November 1989 surface analysis (Fig. 3) showed intense low pressure (983 mb) in Ontario about 100 miles northwest of Massena. A cold front trailed southwest from the low center to northwest Ohio. The airmass in the storm's warm sector remained relatively dry. Dew points were in the lower 40s (5°C) just ahead of the cold front, and along the mid Atlantic coast. Dew points were generally in the 30s (0-4°C) from interior New England to eastern New York, and south along the Appalachians. Showers were scattered from northwest Pennsylvania through central and western New York. Rain induced cooling had dropped temperatures into the 40s (4-9°C) in western New York. Temperatures were generally between 55°F and 65°F (13-18°C) from the Washington, D.C., area to extreme southeast New York.

The cold front moved steadily southeast and provided the lifting mechanism necessary to initiate convection. The first cloud-to-ground (CG) lightning strike occurred in Cattaraugus County (extreme southwest) New York at 2149 UTC. Thunderstorms ahead of the cold front became more numerous, and by 2331 UTC, thunderstorms were concentrated between Binghamton, Syracuse, and Elmira (Fig. 4). Maximum tops were 23000 ft (7 km) and the cells were moving southeast at 50 kt (25 m $s^{-1}$). The thunderstorms continued rapidly southeast reaching coastal waters about 0300 UTC.

Upper air observations at 1200 UTC gave little indication of thunderstorm potential. Surface observations through the day indicated warming of the lower levels of the atmosphere, but with little moisture influx, there didn't appear to be enough destabilization to produce thunderstorms. The National Severe Storms Forecast Center composite analysis for 0000 UTC 21 November 1992 (not shown) still indicated little instability. Minimum lifted indices were 0 to +2 over northeast New York and New England. Lifted indices were greater than +2 over the southern tier of New York and Pennsylvania (Hales and Crowther 1991).

The 0000 UTC 21 November upper air analyses at 850 mb, 700 mb, and 500 mb (Figs. 5a, 5b, and 5c) showed a very tight thermal gradient across the northeast United States. In addition, strong west-northwest winds, nearly perpendicular to the thermal gradient provided extremely strong advection of cold air into the severe weather area. The rate of cold air advection was calculated at 850 mb, 700 mb and 500 mb (Figs. 6a, 6b, and 6c) using the Southern Region Upper Air Diagnostic Program (SRUA; Foster 1988). At 850 mb, the rate of cold air advection was as high as 28°C/12 hr. Cold air advection increased with height to a maximum of 52°C/12 hr at 500 mb. Thus, strong differential temperature advection was working to destabilize the atmosphere in the severe weather area.

Surface and upper air analyses were used to construct an atmospheric sounding approximating conditions in the severe weather area (near Binghamton) at 0000 UTC on 21 November 1989 (Fig. 7). The proximity thermal profile was characterized by a nearly dry adiabatic lapse rate from the surface to 800 mb. A lifted surface parcel possessed a small CAPE of 448 J $kg^{-1}$. Winds were strong reaching 50 kt just above 850 mb, 60 kt near 500 mb and 95 kt at 200 mb. Observed upper level winds were even stronger just southwest of the severe weather area; at 0000 UTC, the Pittsburgh observed winds were 125 kt at 500 mb. The location of a wind maximum near Pittsburgh placed the severe weather area in the left front quadrant of the approaching jet, favorable for upward vertical motion. Divergence at 300 mb calculated using the SRUA was maximized (greater than 60 X $10^{-5}$ $s^{-1}$) over western New York. Once thunderstorms developed, they may have provided the mechanism to transfer momentum of the strong winds aloft down to the surface.

While the 1200 UTC hodograph for Buffalo (Fig. 2) showed considerable turning through the low-levels of the atmosphere, the hodograph constructed for Binghamton (Fig. 7) was nearly straight. The wind direction veered from about 220° at the surface, to 260° at 3 km. Speed shear was large due to the rapid increase in wind through the lower troposphere. Due to the strength of the wind field, and observed storm motion to the right of the environmental winds, storm-relative (s-r) helicity in the 0-3 km layer was large at 448 $m^2$ $s^{-2}$. The Energy-Helicity Index (EHI), which represents potential tornadic intensity as a function of CAPE and s-r helicity, was 1.12. The reliability of the EHI is unproven, but based on empirical studies of strong and violent tornadoes, values greater than 1 appear to indicate the potential for strong (F2-F3) tornadoes and values greater than 5 indicate the potential for violent (F4-F5) tornadoes (Hart and Korotky 1991; LaPenta 1992).

Damaging winds were widespread in New York from the southern tier to New York City, and across Pennsylvania and New Jersey. There were 206 reports of severe thunderstorms with damaging winds, one report of large hail, and two tornadoes (one F0 and one F2) (U.S. Dept. of Commerce 1989). Figure 8 shows the location of severe weather reports (Hales and Crowther 1991) and Table 2 lists maximum wind gusts at a number of locations.

## 4. LIGHTNING DATA

The first CG lightning strike occurred in Cattaraugus County, New York (extreme southwest), at 2149 UTC. The CG rate gradually increased and peaked between 0000 and 0100 UTC 21 November (Table 3). Kane (1991) suggested that a CG lightning peak followed by a sharp decline in flashes might be related to severe thunderstorms in the northeastern United States. Figure 9 displays the cloud to ground lightning strikes observed over the northeast between 2149 UTC and 0412 UTC. The strikes are relatively evenly spaced across southern New York, northern Pennsylvania and northern New Jersey. The number of strikes decreased in southeast Pennsylvania, southern New Jersey and the New York City area, toward the end of the event. Thus, there appeared to be a lag between the time convection had begun to decrease and the time the damaging winds subsided. This may indicate that although the convection that initiated the widespread surge of damaging wind was diminishing, the momentum of the wind surge took a while to dissipate.

Table 3 indicates a high ratio of positive to negative CG strikes. A high ratio of negative to positive strikes is typical of warm season convection (Beasley et al. 1983; Brook et al. 1989). Rust et al. (1981) suggested that positive strikes may be indicative of the particular phase of thunderstorm evolution. Positive strikes often show a tendency to increase in the dissipating stage (Orville et al. 1983; Brook et al. 1989). Also, strong thunderstorms in a highly sheared environment can produce a shield of positive strikes, downshear of the maxima of negative strikes and the radar reflectivity core (Rust et al. 1981; Stolzenburg 1990; LaPenta et al. 1990). Brook et al. (1982) hypothesized that strong vertical wind shear creates conditions favorable for positive discharges by horizontally displacing the net charge areas in clouds. In the case of downshear positive shields, positive CG strikes were still only a small percentage of the total CG strikes. Takeuti et al. (1978) reported positive CG lightning in winter storms near Japan. Because of the significant tilt to these storms, they suggested that shear played an important role in the production of positive CG strikes.

## 5. SUMMARY

An intense storm moved from Ontario to off the Maine coast on 20-21 November 1989. Height falls at 500 mb of 280 m (at Buffalo) in the 12 hours ending 0000 UTC 21 November attest to the very strong dynamic forcing that occurred. The usual stability indices associated with upper air observations at 1200 UTC 20 November showed little potential for thunderstorms. Examination of the 0000 UTC 21 November upper data showed a very tight thermal gradient across the northeastern states. Strong west-northwest winds, nearly perpendicular to the thermal gradient, produced a strong injection of cold air into the severe weather area. The rate of cold air advection increased with height and the differential advection destabilized the atmosphere. Lower tropospheric winds were strong and exhibited considerable speed shear while veering from 220° at the surface to 260° at 3 km. A cold front provided the lifting necessary to initiate convection. The thunderstorms may have provided the mechanism to transfer the momentum from the strong winds aloft down to the surface. There were 206 reports of damaging thunderstorm winds and 2 tornadoes.

The initial lightning occurred in extreme southwest New York State, and Figure 9 indicates considerable lightning across southwest New York and western Pennsylvania. It is interesting to note that Figure 8 indicates no severe thunderstorm reports in these two areas. The explanation lies in the type of warnings used by individual National Weather Service Offices; and the manner in which information on this storm was entered into *Storm Data*[1]. National Weather Service Offices in western New York and western Pennsylvania classified this event as a (non-convective) high wind event since High Wind Warnings, and not Severe Thunderstorm Warnings, were used to warn the public of damaging winds.

[1]*Storm Data* is a monthly publication of the National Environmental Satellite, Data, and Information Service. It contains confirmed information on tornadoes, severe thunderstorms, and other significant meteorological phenomena, as compiled by National Weather Service Forecast Offices.

The severe weather outbreak of 20 November falls into a meteorologically gray area where thunderstorms develop in an atmosphere characterized by strong synoptic scale wind fields. The delineation between convectively generated, and non-convectively generated damaging winds is not always clear. In this case, it appears that thunderstorms played an important role in transferring the momentum of strong winds aloft down to the surface. Significant lightning over the southern tier of New York and Pennsylvania corresponds reasonably well with the occurrence of damaging winds (Figs. 8 and 9). During the later stages of the event (over southeast Pennsylvania, New Jersey and the New York City area) damaging winds persisted as the lightning decreased. Despite the fact that the convection that initiated the widespread surge of damaging wind was diminishing, the momentum of the wind surge may have taken a while to dissipate.

## 6. ACKNOWLEDGEMENTS

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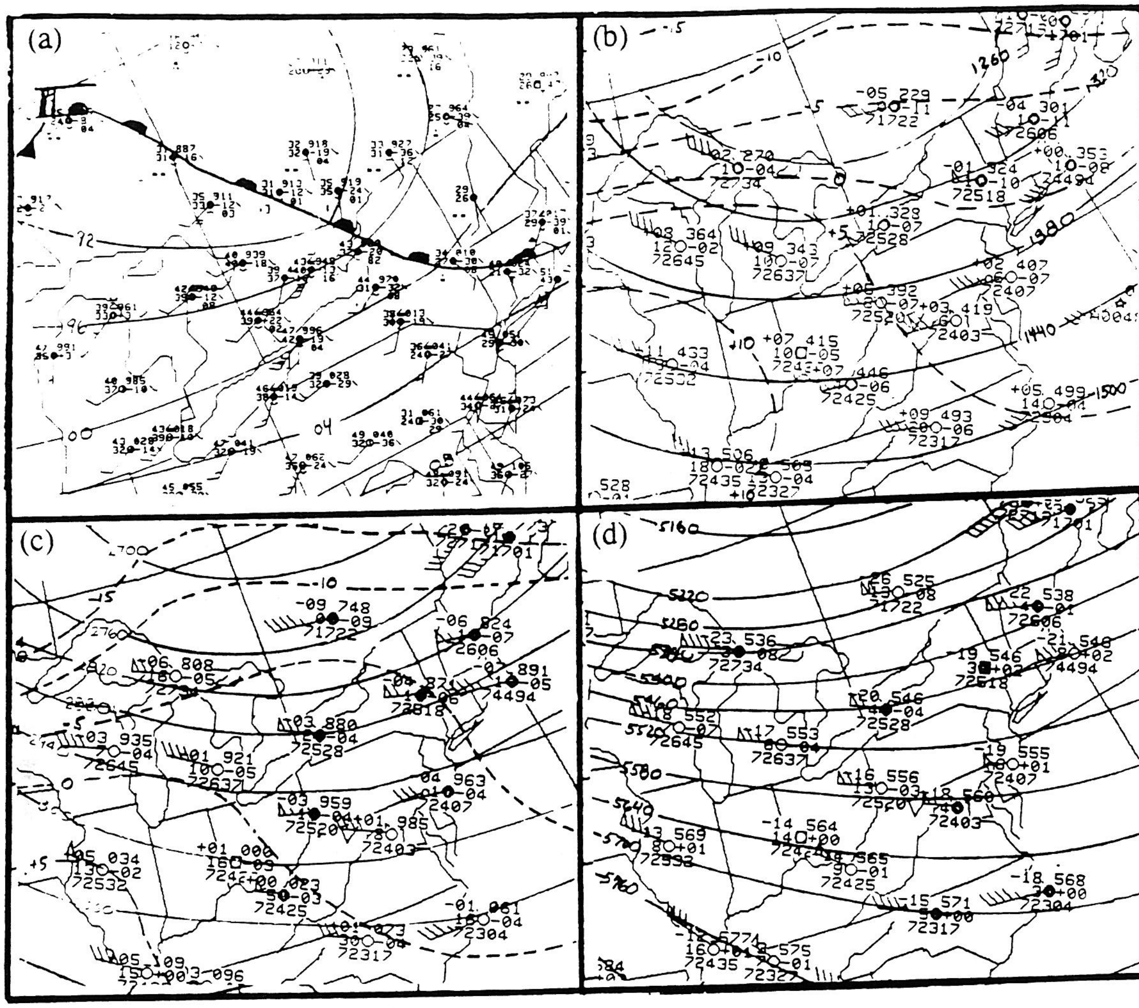


**Figure 1.** 1200 UTC 20 November 1989 analyses for (a) surface, with solid lines isobars (mb); (b) 850 mb, with solid lines geopotential height (m) and dashed lines isotherms (°C); (c) 700 mb, with solid lines geopotential height (m) and dashed lines isotherms (°C); and (d) 500 mb, with solid lines geopotential height (m).

**Table 1.** Observed sounding parameters for 1200 UTC 20 November 1989.

| | ACY | ALB | BUF | PIT |
|---|---|---|---|---|
| K index | 17 | 16 | 18 | 18 |
| Precipitable Water (in) | .65 | .73 | .73 | .60 |
| Lifted Index | 12 | 14 | 10 | 11 |
| Mean Wind 0-6 km (deg/kt) | 277/33 | 279/49 | 277/50 | 279/48 |
| CAPE (J kg$^{-1}$) | 0 | 0 | 0 | 0 |
| Total Totals | 36 | 36 | 39 | 36 |
| SWEAT Index | 122 | 169 | 162 | 174 |

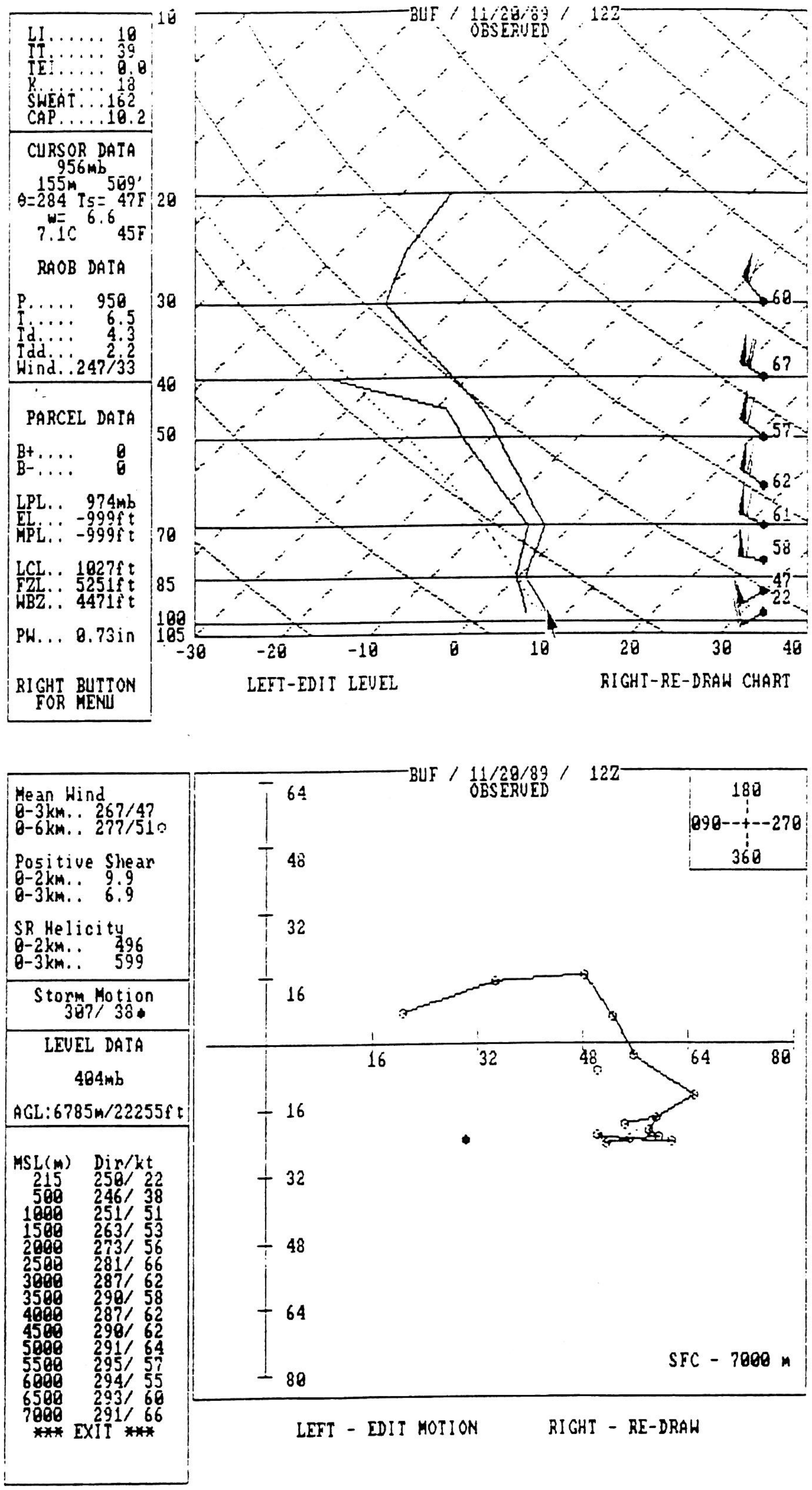


**Figure 2.** Observed 1200 UTC 20 November 1989 Buffalo sounding and hodograph.

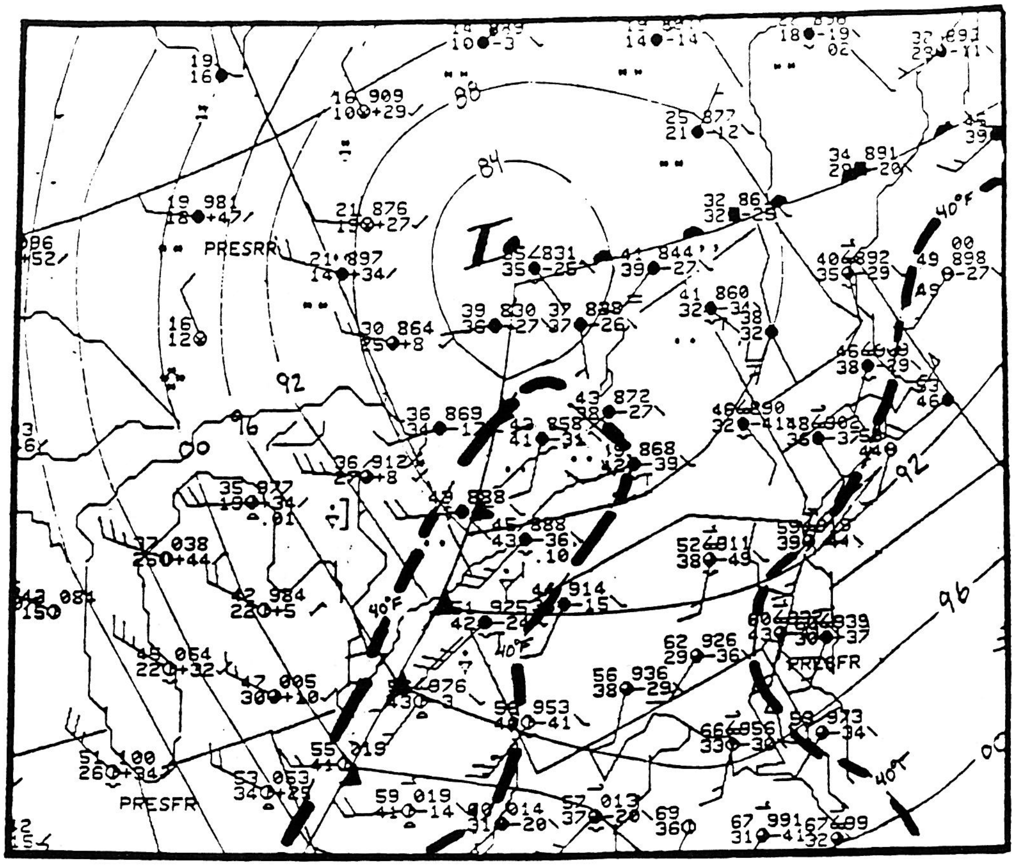


**Figure 3.** Surface analysis for 2100 UTC 20 November 1989. Solid lines depict isobars (mb) and the dashed lines represents the 40°F isodrosotherm.

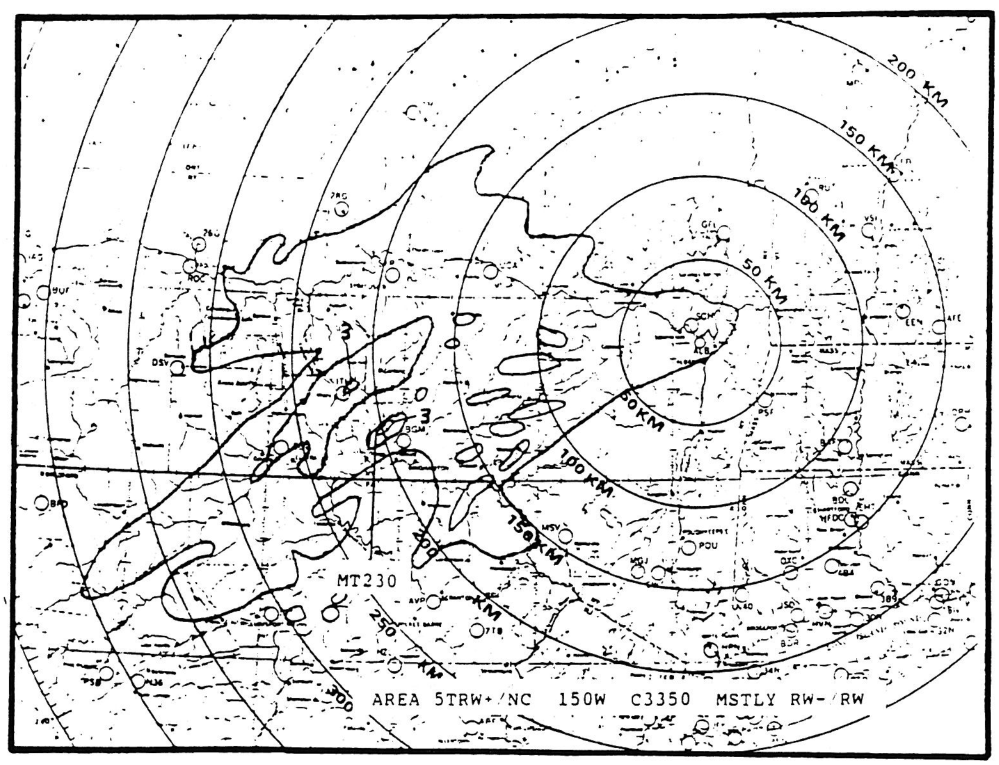


**Figure 4.** Radar reflectivity from Binghamton (plotted on Albany overlay) for 2331 UTC 20 November 1989.

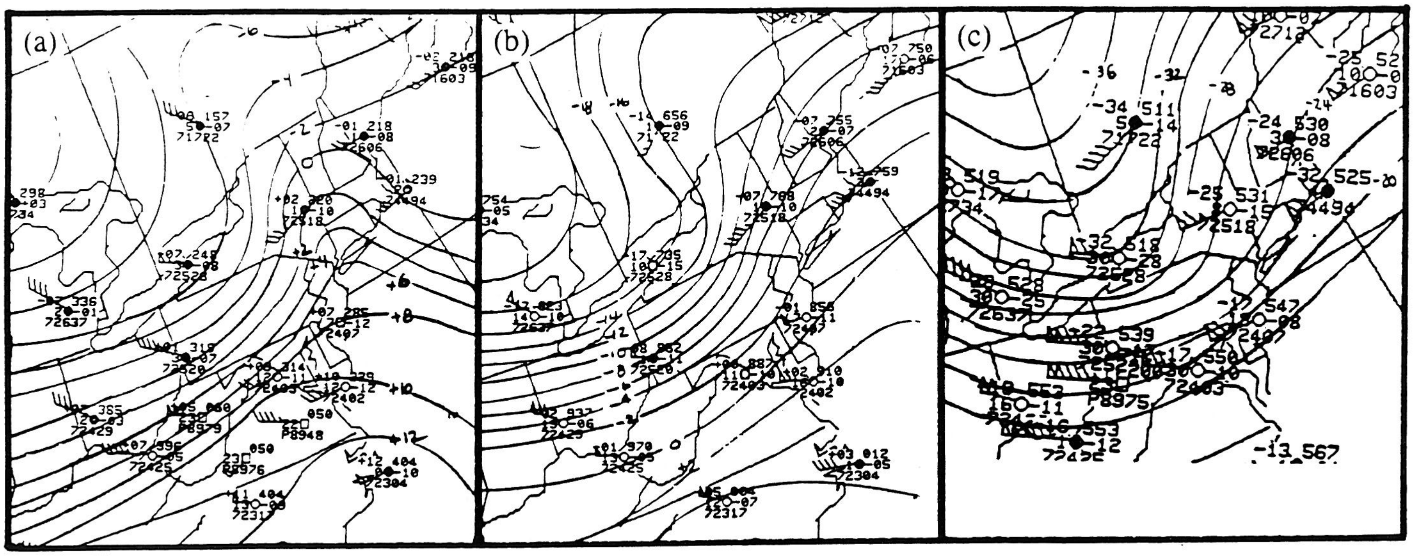


**Figure 5.** Upper air temperature (°C) analyses for 0000 UTC 21 November 1989 at (a) 850 mb, (b) 700 mb, and (c) 500 mb.

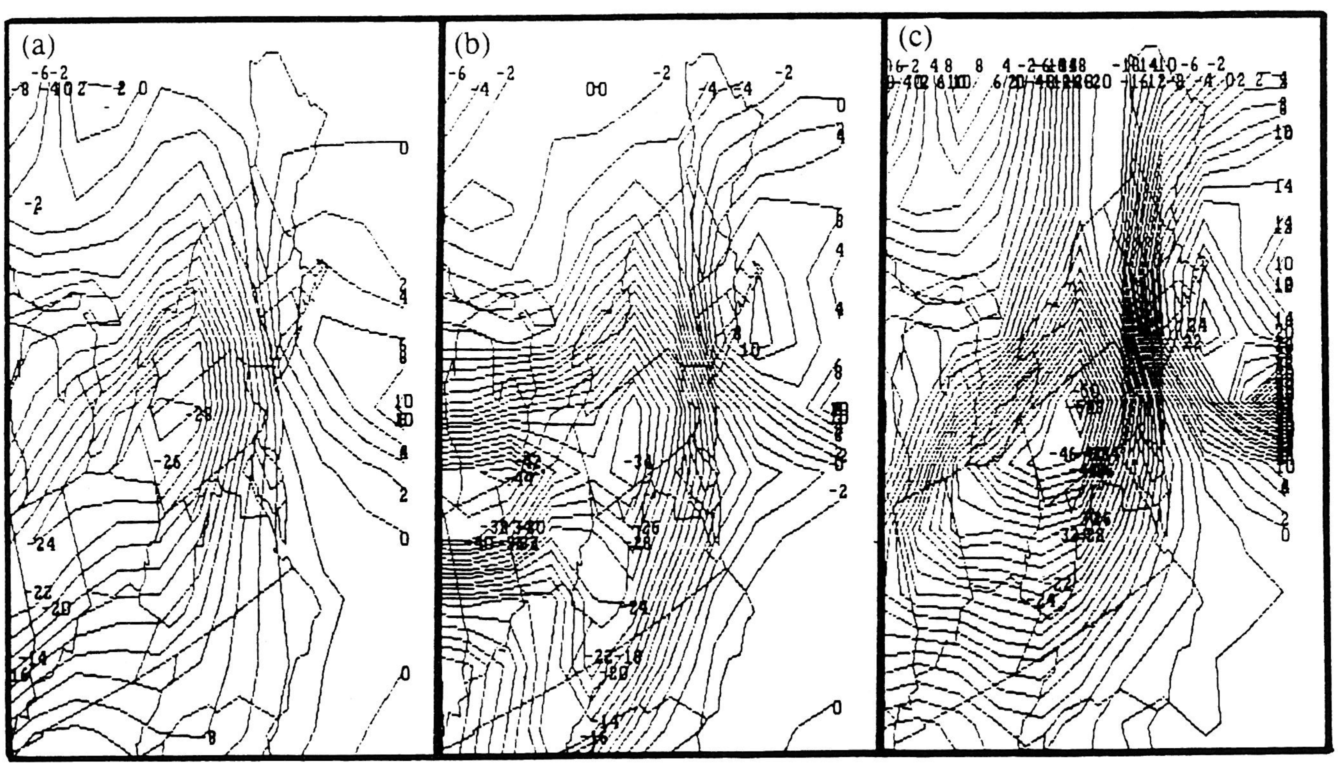


**Figure 6.** Temperature advection (°C/12 hr) at (a) 850 mb, (b) 700 mb, and (c) 500 mb.

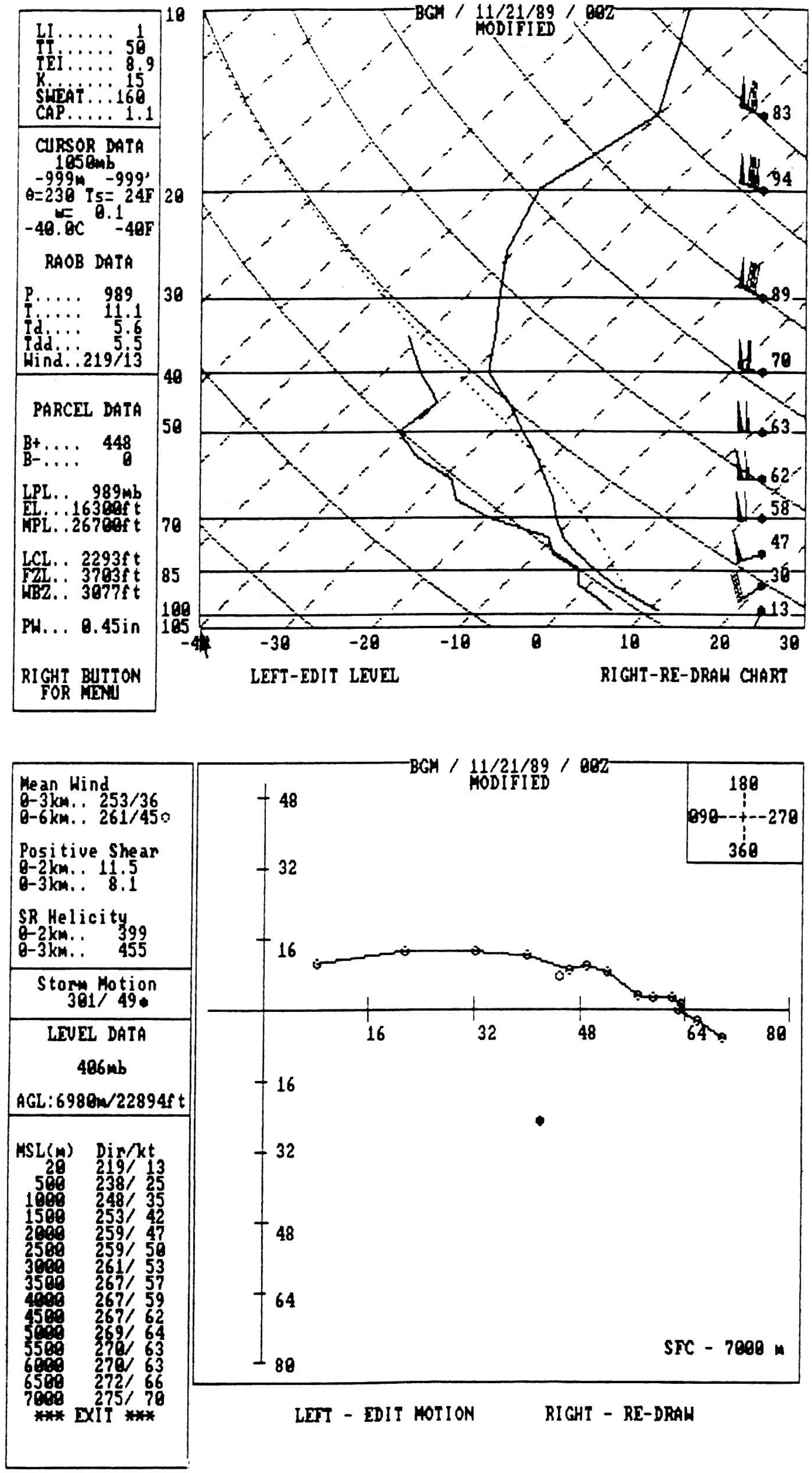


**Figure 7.** Sounding constructed for severe weather area (near Binghamton) at 0000 UTC 21 November 1989.

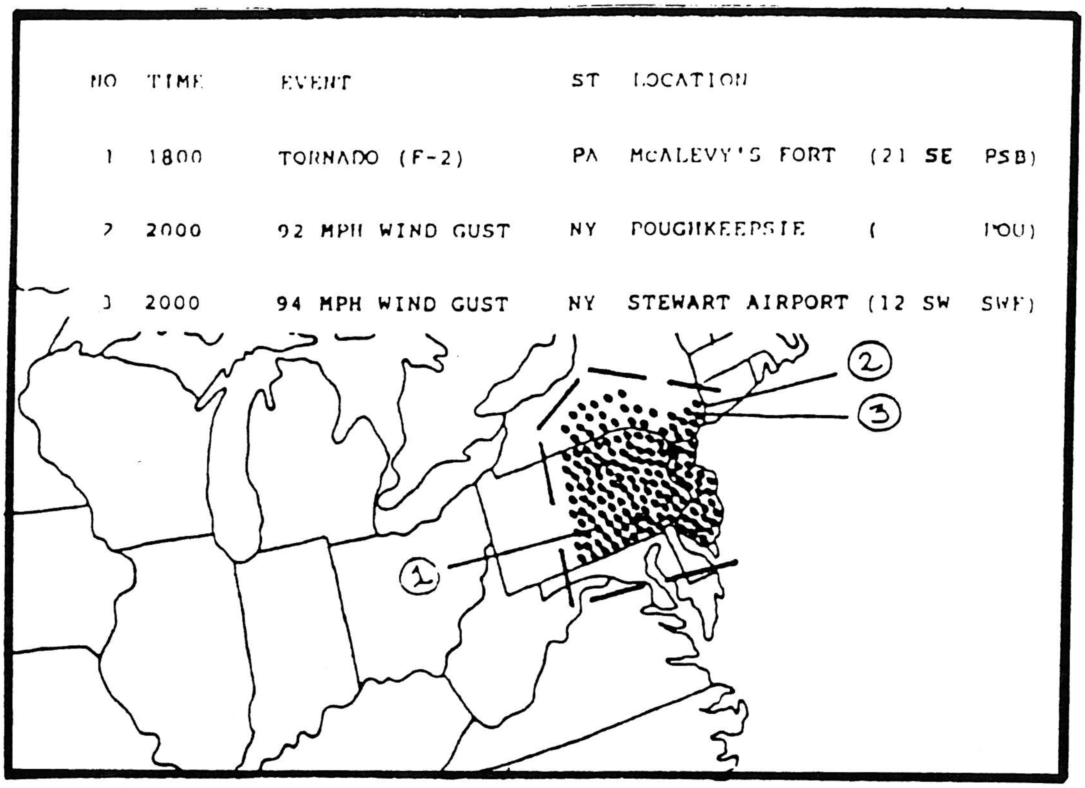


**Figure 8.** Severe weather reports for 20-21 November 1989 (Hales and Crowther 1991).

**Table 2.** Highest wind gusts reported during 20-21 November 1989.

| Location | State | Peak Wind (kt) |
|---|---|---|
| Wayne | NJ | 74 |
| Franklinville | NJ | 65 |
| Trenton (TTN) | NJ | 52 |
| Atlantic City (ACY) | NJ | 53 |
| Binghamton (BGM) | NY | 58 |
| Poughkeepsie (POU) | NY | 55 |
| Newburgh (SWF) | NY | 82 |
| LaGuardia Airport (LGA) | NY | 66 |
| New York City (Central Park) | NY | 50 |
| State College | PA | 74 |
| Harrisburg (CXY) | PA | 75 |
| Wilkes Barre-Scranton (AVP) | PA | 52 |
| York | PA | 74 |
| Allentown (ABE) | PA | 68 |
| Lancaster (LNS) | PA | 60 |
| Philadelphia (PHL) | PA | 53 |

**Table 3.** Hourly CG lightning rate over the northeast United States for 2000-0400 UTC 20-21 November 1989.

| Time (UTC) | Total CG Strikes | Percent Positive |
|---|---|---|
| 2000-2100 | 0 | 0 |
| 2100-2200 | 4 | 75 |
| 2200-2300 | 51 | 73 |
| 2300-0000 | 77 | 78 |
| 0000-0100 | 118 | 68 |
| 0100-0200 | 61 | 71 |
| 0200-0300 | 11 | 100 |
| 0300-0400 | 7 | 43 |

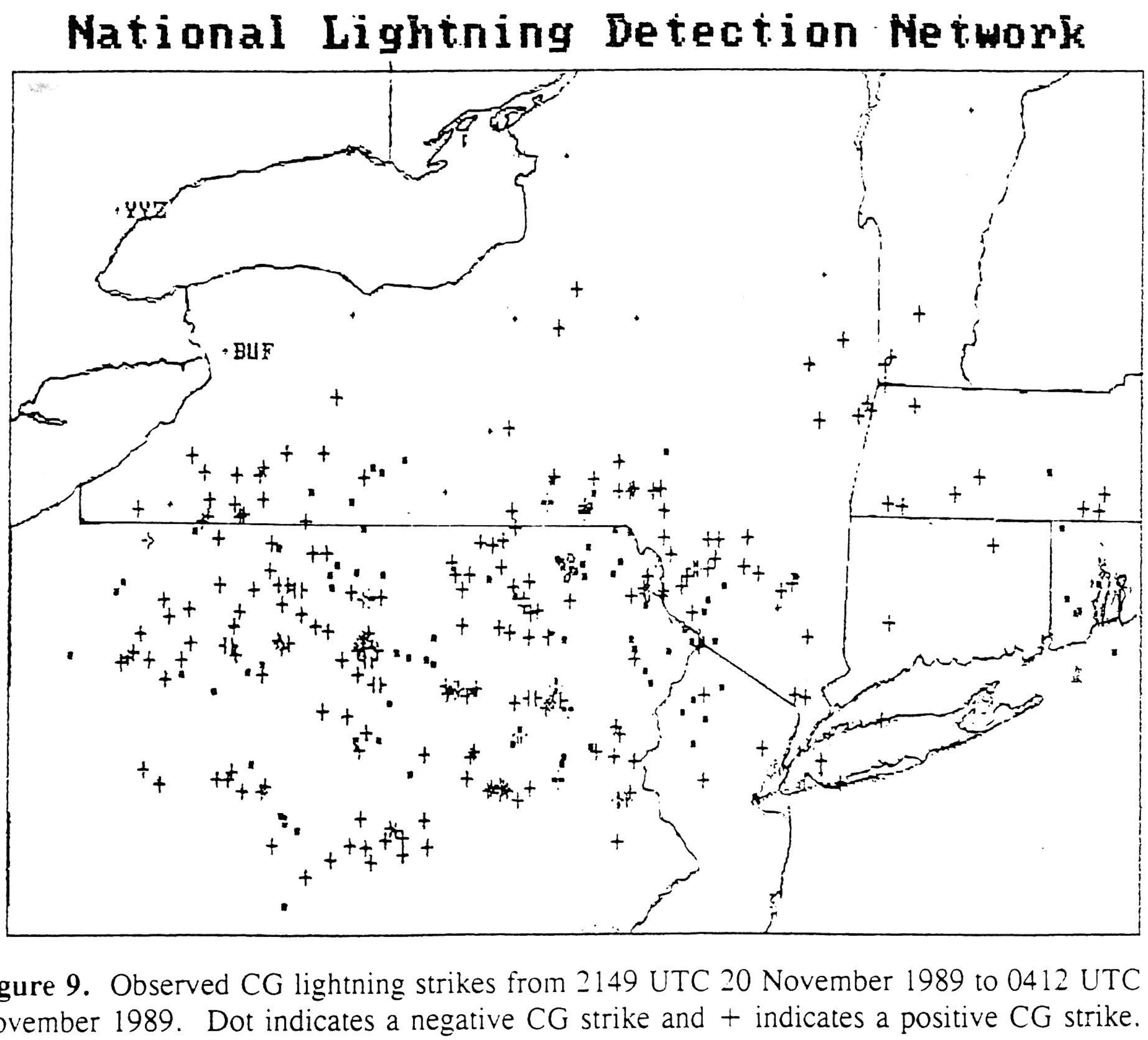


**Figure 9.** Observed CG lightning strikes from 2149 UTC 20 November 1989 to 0412 UTC 21 November 1989. Dot indicates a negative CG strike and + indicates a positive CG strike.