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A LOOK AT THE LIGHTNING CHARACTERISTICS OF THE NORTHERN ILLINOIS TORNADIC SUPERCELL OF AUGUST 28, 1990

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1. INTRODUCTION

At the recent 16th AMS Conference on Severe Local Storms held at Kananaskis Park, Alberta, Canada, Donald Burgess of the National Severe Storms Laboratory brought to our attention an interesting lightning pattern associated with a tornadic thunderstorm in Illinois on 28 August 1990. The storm, a long-lived supercell, developed near the Illinois-Wisconsin border about 1800 UTC and moved southeast, producing an F5 tornado near Joliet and Plainfield, IL. During the early portion of the storm's life, it exhibited the interesting characteristic of producing primarily positive cloud-to-ground (CG) lightning strikes. Rather abruptly, the dominant character of the CG discharges changed from positive to negative. Don encouraged us to share the information with other offices in the Eastern Region. He is currently performing more detailed research on the storm.

2. BACKGROUND

A high ratio of negative to positive CG lightning strikes is typical of warm season convection (Beasley et al. 1983; Brook et al. 1989). Rust et al. (1981a) researched the electrical properties of Great Plains severe thunderstorms and found the percentage of positive strikes to be small. However, they suggested that the positive strikes may be indicative of the particular phase of severe storm development. Positive strikes often show a tendency for higher frequency in the later or dissipating stages of many convective systems (Orville et al. 1983; Brook et al. 1989). At times, strong thunderstorms in a highly sheared environment produce a shield of positive strikes, downshear of the maxima of negative strikes and the radar reflectivity core (Rust et al. 1981b; 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. For these 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 the storms, it was suggested that shear played an important role in the production of positive CG strikes.

There have been several documented cases of thunderstorms that produced predominantly positive CG strikes. Rust et al. (1985) examined a set of storms on 13 May 1983 that contained a very high percentage of positive CG strikes. They stated that the region where the polarity of CG lightning changed from mostly positive to almost all negative, coincided with the transition zone where the 850-300 mb wind shear became less than 2 x 10^{-3} sec^{-1}. Other storms that remained in the higher shear environment continued to produce mostly positive CG strikes. The Oklahoma City, OK, sounding for 0000 UTC, 14 May 1983 revealed a nearly dry adiabatic layer from about 750 mb to 500 mb. This layer capped a moist low-level layer.

Curran and Rust (1988) found that some low precipitation (LP) thunderstorms in Oklahoma on 26 April 1984, had a high percentage of positive CG strikes. One storm eventually evolved into a supercell that produced mostly negative CG strikes. The 850-300 mb wind shear magnitude exceeded 2 x 10^{-3} sec^{-1} by a magnitude of 3, even when negative CG lightning became dominant. They concluded that the magnitude of the vertical wind shear was not directly related to the flash polarity. The authors postulated that once the LP thunderstorms moved away from a dryline into a moisture-rich environment to the east, the flash polarity changed. This led to the speculation that the production of positive CG strikes may be related to the amount of boundary layer moisture available to the storm. They also stated that this relationship, combined with the low precipitation efficiency of the LP thunderstorm, suggested that microphysical processes (precipitation production and subsequent charge generation and separation) had an important influence on the type of flash produced. If the available moisture increased, the precipitation efficiency increased, thus, limiting the production of positive CG lightning. The nearby Fort Sill, OK, sounding at 0010 UTC 27 April 1984 (Burgess and Curran 1985), showed a nearly dry adiabatic layer from about 750 to 500 mb. The low-levels were not especially moist.

3. METEOROLOGICAL CONDITIONS

The atmosphere late on the afternoon of 28 August 1990, was characterized by moderate shear and very large potential buoyant energy. Figure 1 is the 850 mb analysis for 0000 UTC, 29 August 1990. A moderate west-southwest jet (25-30 kts) extended from eastern Kansas across Illinois to Lake Erie. This jet lay over an axis of very warm (22-26°C), moist (dewpoints 12-20°C) air. At 500 mb (not shown), the flow was west-northwest at 20-30 kt over Illinois with a band of stronger winds (50 kt) to the north over Minnesota, Wisconsin and northern Michigan. At 300 mb (Figure 2) the axis of an 80 kt jet was just north of Illinois. Diffluence is also indicated across central Illinois and southern Indiana.

Soundings for stations from the Midwest to New York were characterized by a nearly dry adiabatic layer from approximately 800 mb to 600 mb. Figures 3 and 4 are the Peoria, IL, soundings for 1200 UTC, 28 August 1990, and 0000 UTC, 29 August 1990, respectively. The steep lapse rate contributed to extremely large positive buoyant energy. The positive buoyant energy (B+) at 1200 UTC was 3832 J/kg. At 0000 UTC, B+ had increased to 7986 J/kg. A low-level cap (Figure 3) delayed the onset of convection until a cold front, approaching from the north, combined with destabilization due to surface heating and moisture advection to initiate convection. At 1200 UTC and 0000 UTC, the 0-2 km positive wind shear was 4.7 x 10^{-3} sec^{-1} and 4.0 x 10^{-3} sec^{-1}, respectively. Based on Davies (1989) and Johns et al. (1990), these values are not considered exceptionally high.

4. CG LIGHTNING CHARACTERISTICS

The thunderstorm began to produce CG lightning along the Illinois-Wisconsin border about 1810 UTC. At the onset, the convective system atypically produced mostly positive strikes. Figure 5 shows the lightning for the 10-min period ending at 1902 UTC as the convective system propagated across northern Illinois. Almost 80% of the strikes were positive at this time. By 1952 UTC (Figure 6), almost 95% of the strikes were positive. The percentage of positive CG strikes increased to 99% for the 10-min period ending at 2002 UTC (Figure 7). Twenty minutes later (2022 UTC), the ratio of positive to negative CG strikes had dropped to one-half, with a substantial reduction in the total number of CG strikes (Figure 8). The next 10-min interval showed a complete reversal in polarity to completely negative CG strikes (Figure 9). The total CG lightning for the lifetime of this supercell (1732-2213 UTC) is shown in Figure 10. Here, the transition from predominantly positive to predominantly negative strikes can be seen along with the storms northwest to southeast propagation.

Figure 11 represents the polarity versus 5-min CG lightning rate from 1820-2130 UTC. As was previously stated, the polarity remained predominantly positive through about 2020 UTC. In fact, a study of 1-min intervals reveals that the CG strikes reached 100% positive several times within this period. Meanwhile, the 5-min flash rate progressively increased, with some oscillations noted, through 2000 UTC. At this time, there was a sharp drop in the 5-min CG rate to near zero at 2010 UTC, approximately coincident with the change of polarity (predominantly positive to negative). Four small tornadoes touched down between 2000 and 2015 UTC. The major tornado touched down about 2015, with F3 or greater damage primarily from 2020-2045 UTC. It is interesting that the tornado occurred about 15 to 20 minutes after the 5-min positive CG rate peaked. This is similar to the findings of Kane (1991), in which tornadoes over the southern tier of New York State occurred approximately 10 to 15 min after a pronounced peak in the total (positive and negative) 5-min CG rate.

Once the transition in polarity occurred, and after the tornado touched down, the 5-min CG rate again increased (now predominantly negative strikes) as the storm continued to move southeast toward the Indiana border. In addition to the intense F5 tornado (which caused 29 fatalities), there were numerous reports of large hail and wind damage, especially prior to the primary tornado touchdown. Hail as large as 2.5 inches was reported at the Rockford, IL airport at 1910 UTC.

5. DISCUSSION

The 28 August 1990, thunderstorm that produced a deadly F5 tornado in northern Illinois exhibited unusual lightning characteristics. During the early phase of the storm, CG lightning was predominantly positive, during which time, numerous reports of large hail and damaging winds were received. The F5 tornado touched down coincident with a change to predominantly negative CG lightning flashes. Although rare, there have been several documented cases of similar storms. Soundings from the 3 storms sited in this report shared an interesting characteristic. They all contained a 150-250 mb deep, nearly dry adiabatic layer between about 700 mb and 500 mb. On 28 August 1990, and 13 May 1983, this mixed, dry adiabatic layer capped a moist low-level atmosphere. Low-level moisture was limited in the 26 April 1984, case. The steep lapse in the mid-levels of the atmosphere on these three storm days, contributed to very large positive buoyant energy of saturated parcels lifted into to this layer.

Numerical model studies (Weisman and Klemp 1986), and analysis of actual meteorological data (Rasmussen and Wilhelmson 1983; Johns et al. 1990) imply that a relationship, or balance, exists between buoyant energy and wind shear in the development of tornadic mesocyclones. Johns et al. (1990) suggests that for storms with large amounts of buoyant energy, lesser amounts of wind shear may be necessary to develop tornadic mesocyclones. The steep, nearly dry adiabatic lapse rate in the mid-levels present in these cases would suggest very large potential buoyant energy, and hence very strong thunderstorm updrafts. This may have been important in generating the predominantly positive CG lightning storms. If this is the case, the observation of predominant positive CG strikes could be an indication of a storm with a strong updraft. These type storms could occur in a highly buoyant atmosphere, above a certain value of wind shear, with the "threshold" value of wind shear decreasing with increasing buoyancy. Judging by the rarity of these storms, the high buoyancy and shear values are not often met. Rust et al. (1985) noted the change from predominantly positive CG to negative CG lightning, as a storm moved into a lower shear environment. Earlier studies looked at 850-300 mb shear in positive CG lightning storms, while recent research in severe storms has concentrated more on wind shear in lower (0-2 km AGL) segments of the atmosphere. Further examination of the shear in the lower atmosphere may help better define the shear characteristics of a positive CG lightning storm environment.

A great deal of uncertainty still exists in the relationship between tornadoes and lightning. Convective systems with different synoptic and mesoscale moisture, forcing, and thermal structure may produce different lightning characteristics. MacGorman et al. (1989) thoroughly investigated two tornadic Oklahoma storms which occurred on 22 May 1981. Neither storm exhibited any clear relationship between tornadoes and the CG flash rate, however, the CG rates were the highest after the tornado. On the other hand, Taylor (1973) found the sferic (electromagnetic signals from lightning) burst rates increased progressively from general thunderstorms to tornadic storms. Additionally, Turman and Tettelbach (1980) studied lightning trigger rates sensed by a polar orbiting satellite and found an increase in lightning activity about 30 min before tornado touchdown. The fact that the tornado occurred 25 to 30 min after a pronounced peak in the 5-min rate is in close agreement with results of Kane (1991). Hence, real-time lightning data may have some predictive capability. However, many more cases need to documented and studied to determine various storm-lightning relationships.

Only a limited set of meteorological data from 28 August 1990 were used for this study. The unusual lightning characteristics of this storm made it worth a preliminary examination. No doubt other individuals will be looking at all the meteorological data available in greater detail, and perhaps will be able to better define the processes involved in a predominantly positive CG storm, and its transition to the more typical negative CG storm. Such a major change in lightning characteristics might indicate a significant change in storm structure.

6. ACKNOWLEDGMENTS

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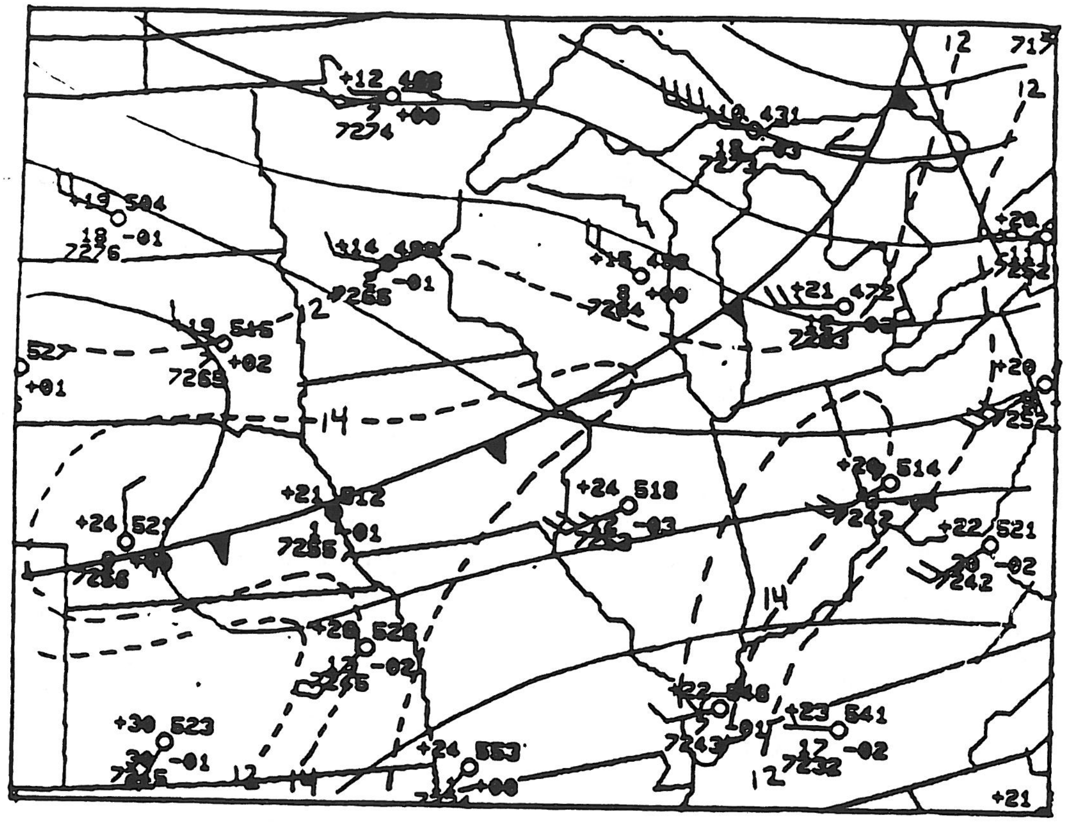

Figure 1. 850 mb analysis for 0000 UTC, 29 August 1990. Solid lines are height contours (20 m interval). Dashed lines are isodrosotherms (12°C and 14°C).

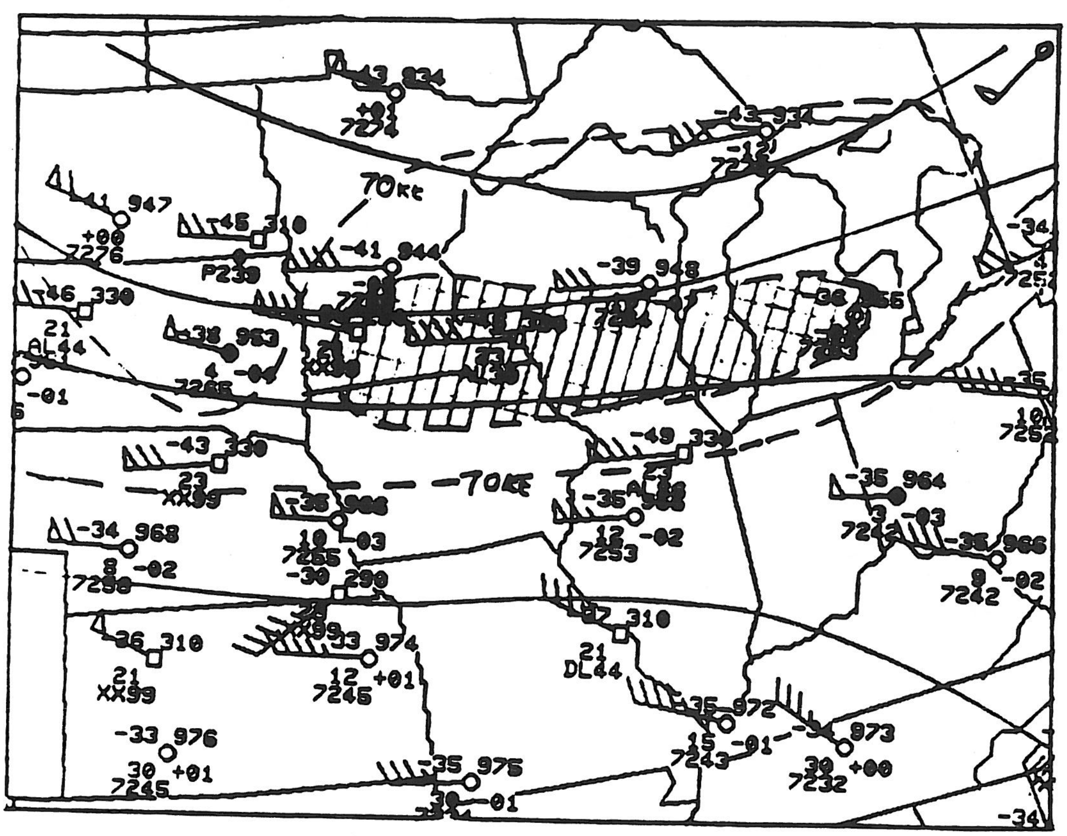

Figure 2. 300 mb analysis for 0000 UTC, 29 August 1990. Solid lines are height contours (100 m interval). Dashed lines are isotachs (70 knots and 80 knots).

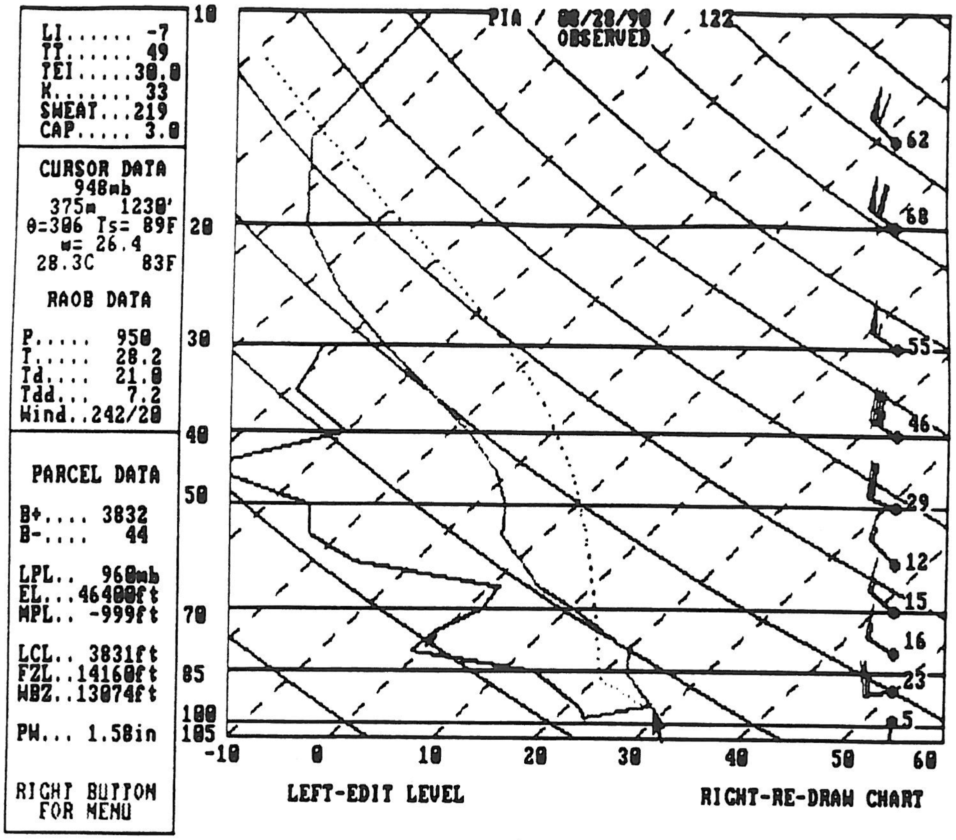

Figure 3. Peoria, IL (PIA) sounding for 1200 UTC, 28 August 1990.

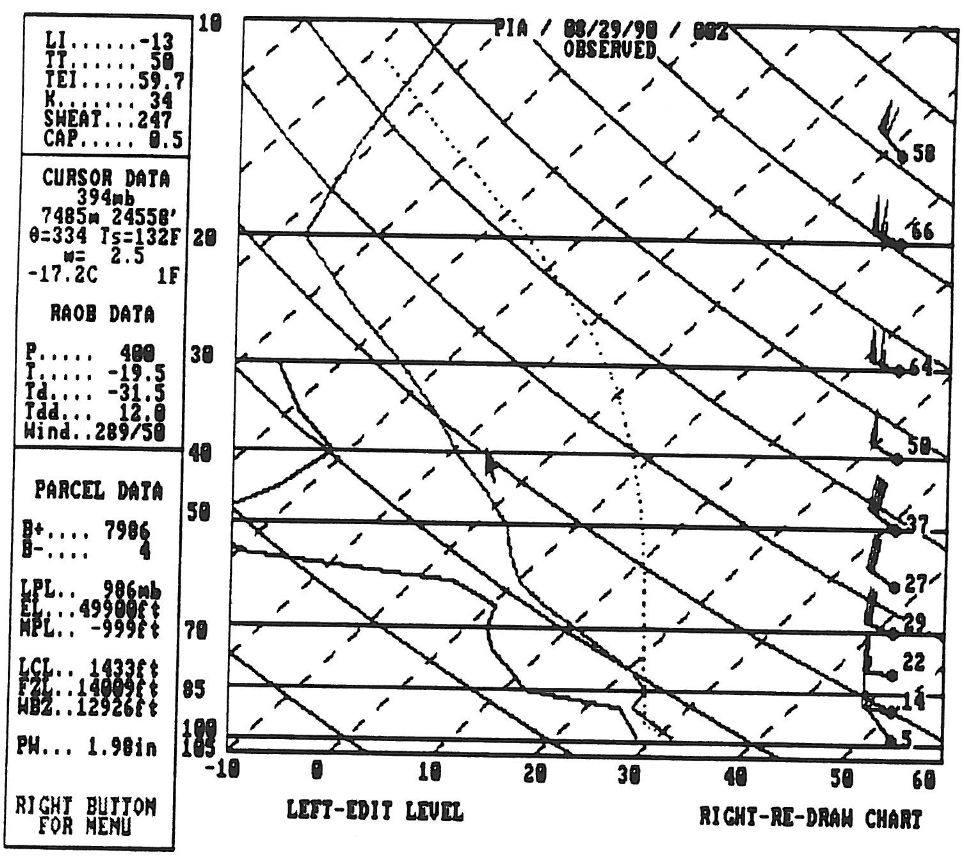

Figure 4. Peoria, IL (PIA) sounding for 0000 UTC, 29 August 1990.

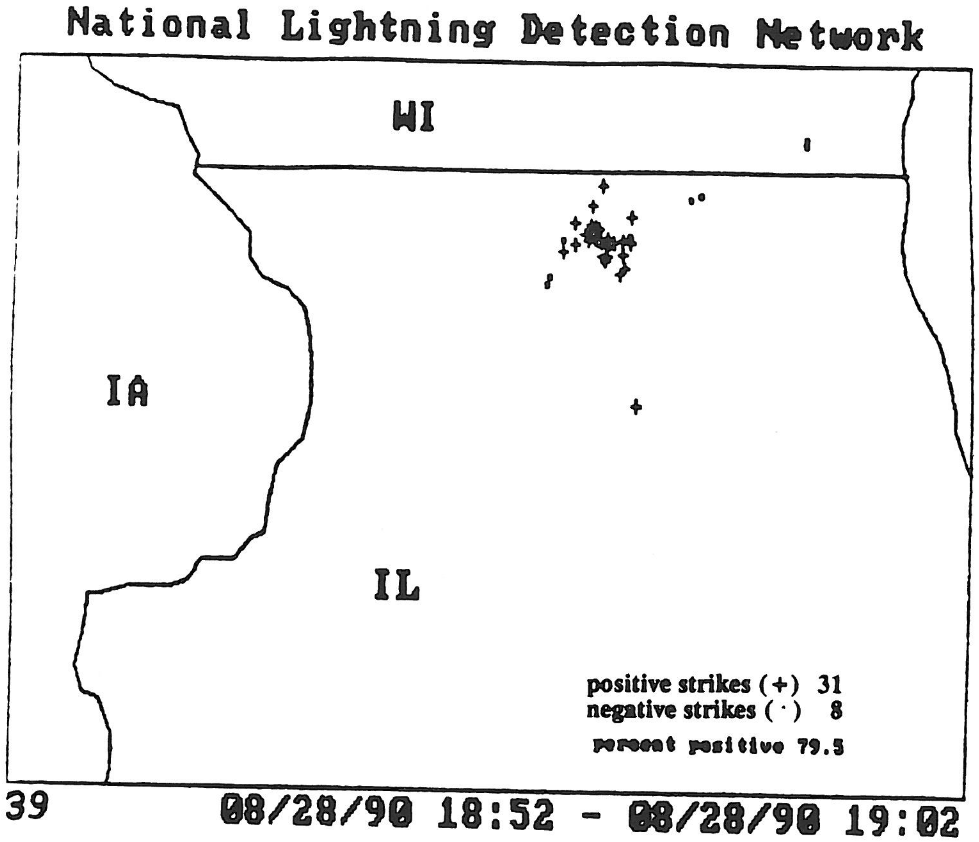

Figure 5. CG lightning flashes for 1852 to 1902 UTC, 28 August 1990. Plus (+) indicates positive strikes while dots (·) indicate negative strikes.

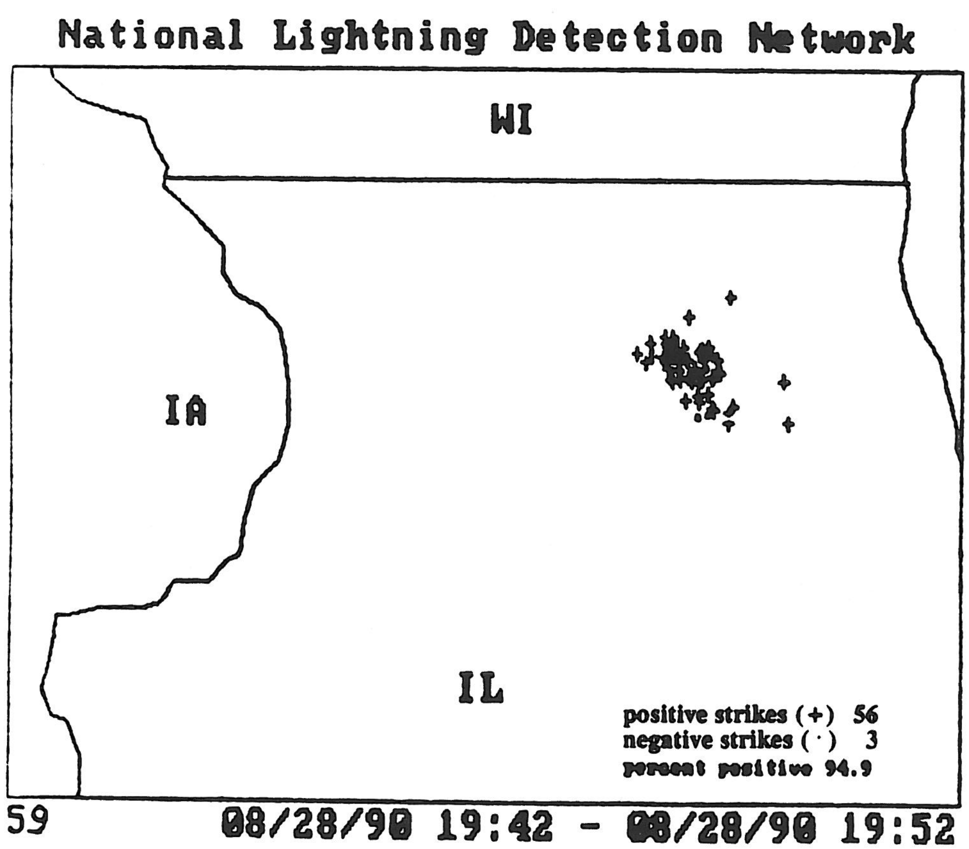

Figure 6. CG lightning flashes for 1942 to 1952 UTC, 28 August 1990. Plus (+) indicates positive strikes while dots (·) indicate negative strikes.

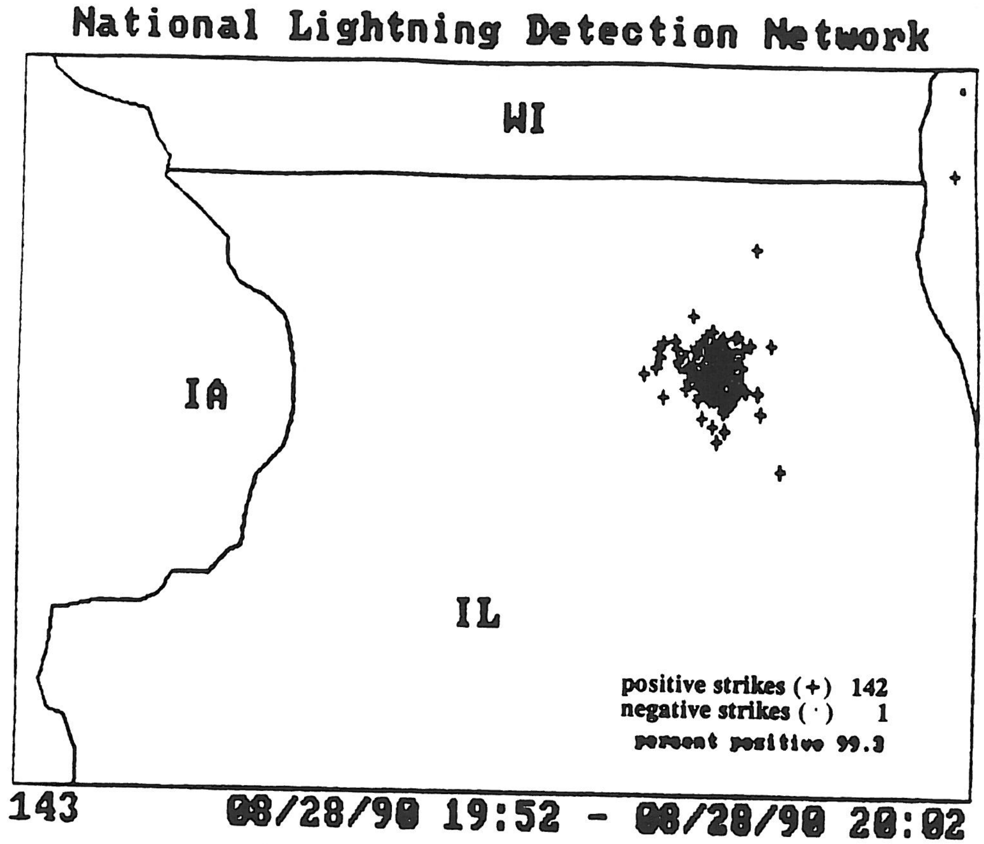

Figure 7. CG lightning flashes for 1952 to 2002 UTC, 28 August 1990. Plus (+) indicates positive strikes while dots (·) indicate negative strikes.

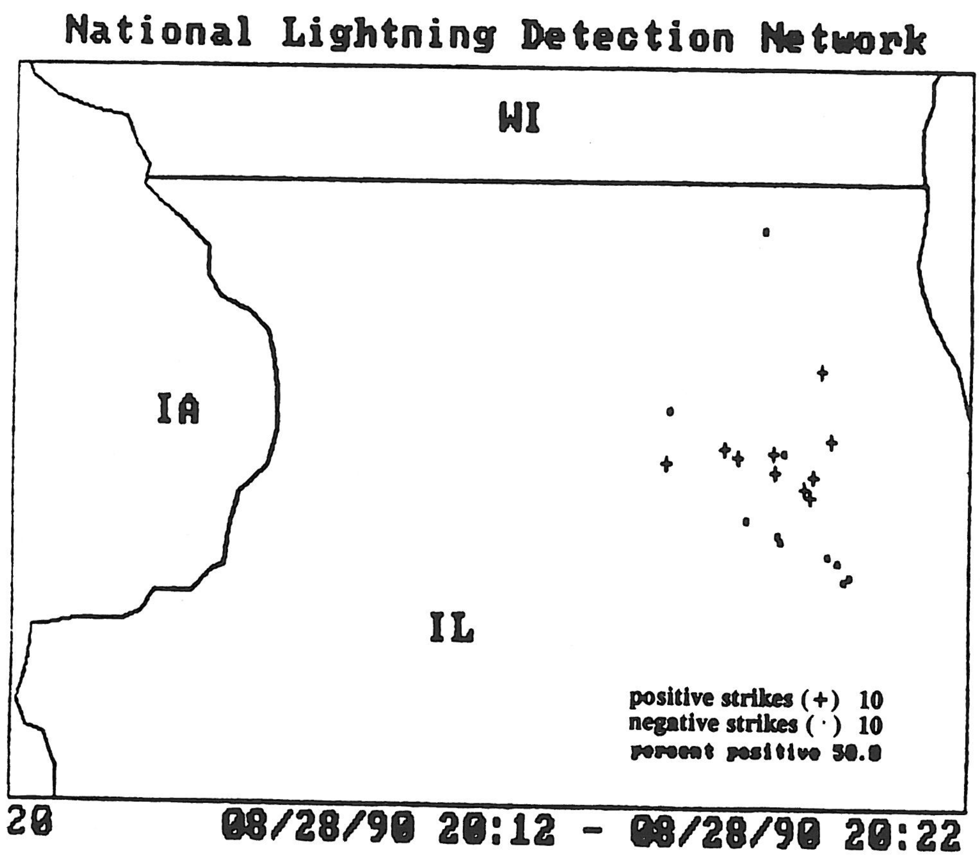

Figure 8. CG lightning flashes for 2012 to 2022 UTC, 28 August 1990. Plus (+) indicates positive strikes while dots (·) indicate negative strikes.

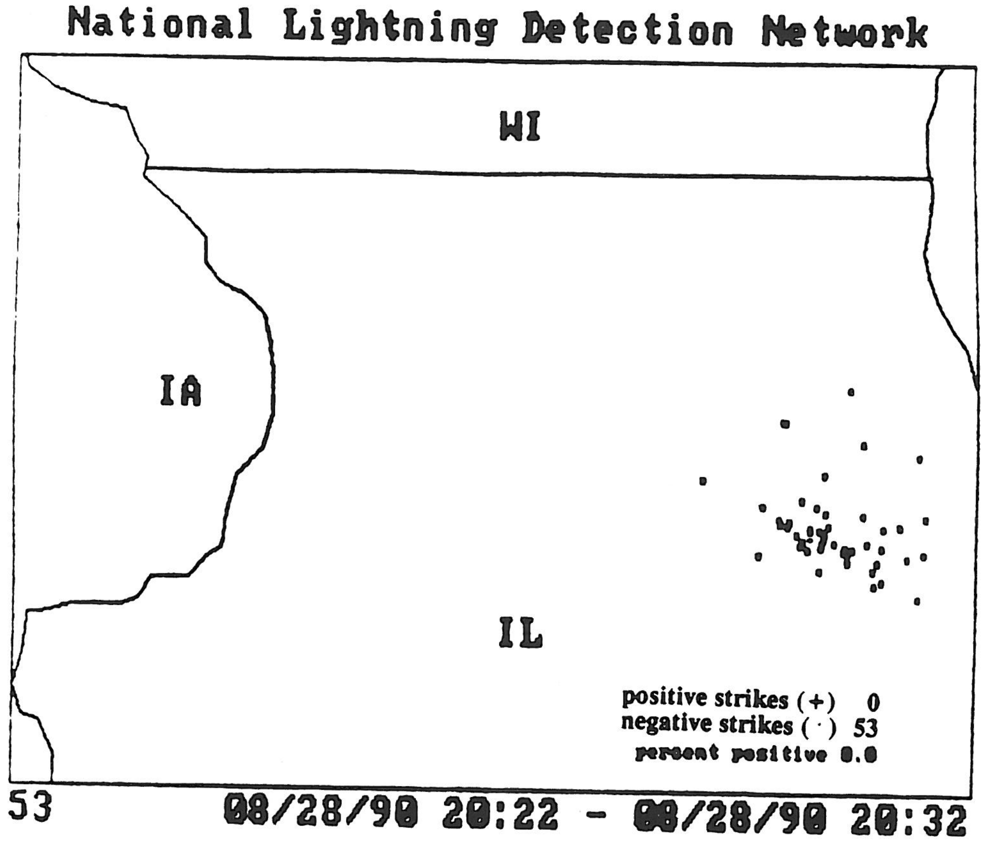

Figure 9. CG lightning flashes for 2022 to 2032 UTC, 28 August 1990. Plus (+) indicates positive strikes while dots (·) indicate negative strikes.

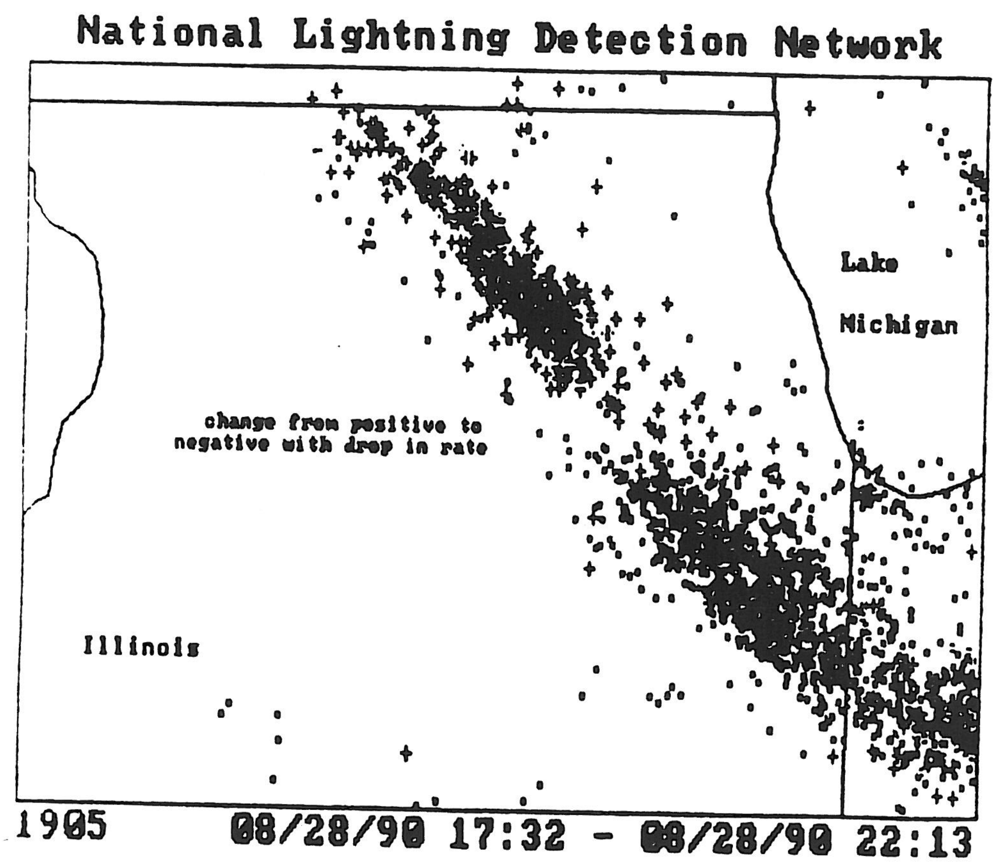

Figure 10. Total CG lightning flashes for 1732 to 2213 UTC, 28 August 1990. Plus (+) indicates positive strikes while dots (·) indicate negative strikes.

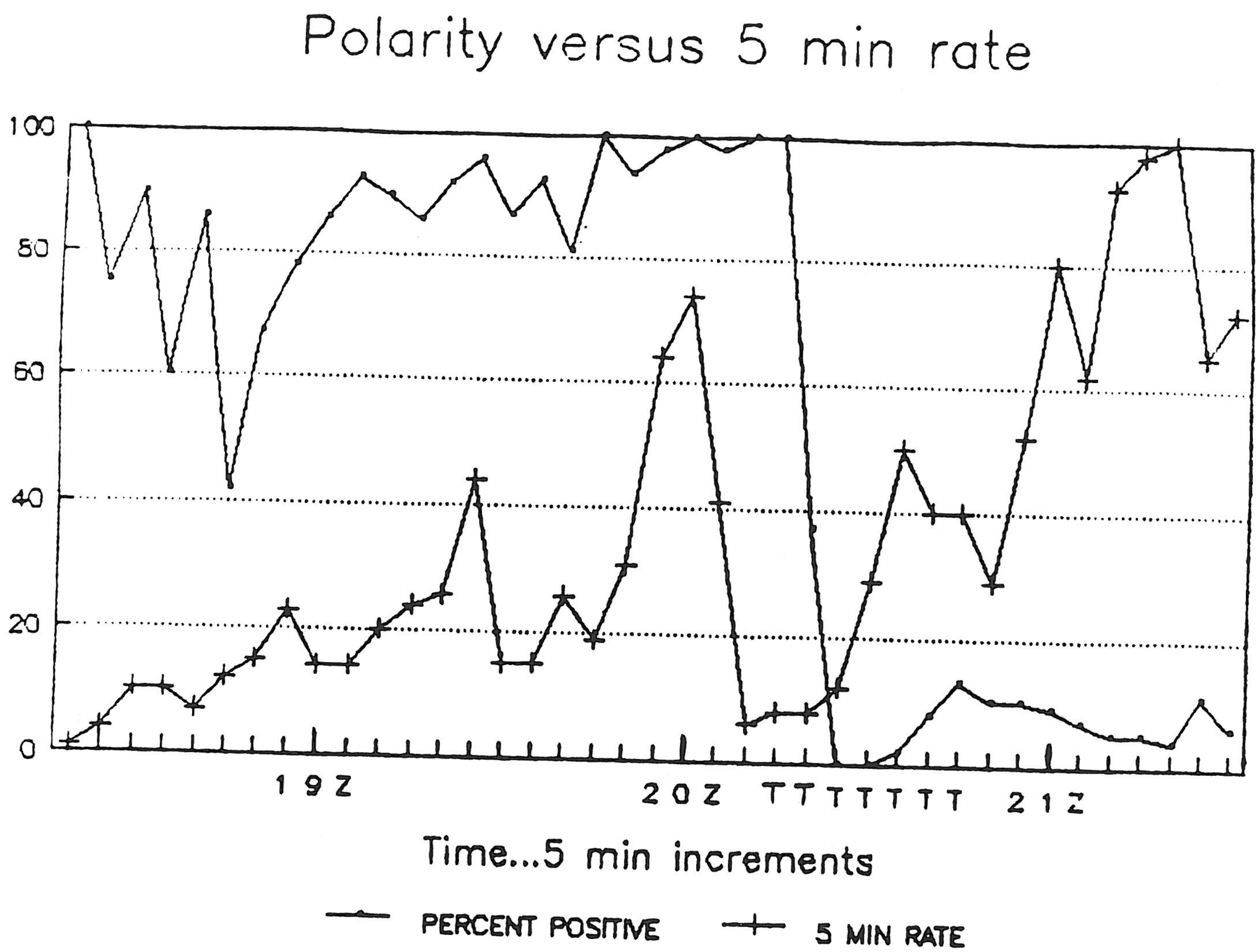

Figure 11. Plot of lightning polarity versus the 5-min CG lightning rate for the 28 August 1990, Plainfield, IL, tornado. "T" indicates the time of tornado occurrence.