EASTERN REGION TECHNICAL ATTACHMENT
NO. 90-8A
SEPTEMBER, 1990

A PRELIMINARY ANALYSIS OF THE 14 JUNE 1990 EASTERN OHIO FLASH FLOOD BASED ON CLOUD-TO-GROUND LIGHTNING DATA

Richard J. Kane
National Weather Service Forecast Office
Albany, New York

1. INTRODUCTION

On the evening of 14 June 1990, a devastating flash flood occurred in Belmont County, Ohio, near the town of Shadyside, where 3 to 4 inches of rain fell in about 1 hour. Rainfall totals in southeast Harrison county, just north of Belmont county, were over 5 inches in 3.5 hours (Figure 1).

The following analysis is a cursory investigation of the flash flood event based <u>only</u> on cloud-to-ground (CG) lightning data. The State University of New York at Albany (SUNYA) lightning detection network (Orville et al., 1983) was used. The SUNYA system uses colors to differentiate when the CG strikes occurred within a displayed time interval (e.g., strikes occurred during the last 20 minutes of a 1 hour display). Unfortunately, this cannot be reproduced here.

2. DISCUSSION

A Mesoscale Convective System (MCS) was propagating through Ohio, Kentucky, and Indiana on the evening of 14 June 1990. A concentrated line of convection along the southeast periphery (or leading edge) of the system extended through central Ohio in a northeast to southwest orientation at 2150 UTC (Figure 2). By 2235 UTC (Figure 3), the convective line extended from east-central Ohio to Ohio's southwest border. The line had shown a relatively slow but steady movement to the southeast. Studies, such as Rutledge and MacGorman (1988), and Engholm et al. (1990), have found that the deepest convection and strongest radar reflectivities in an MCS are associated with a squall line embedded within the convective system. This squall line is often characterized by an intense line of predominantly negative strikes. Additionally, to the rear of the squall line, the trailing stratiform precipitation shield is characterized by a higher frequency of positive CG strikes. The lightning associated with the trailing stratiform precipitation shield can be seen in Figure 3 behind the main convective line. Some positive strikes are apparent, but negative strikes predominated the stratiform area at this time.

At 2242 UTC, convection began in southwestern Pennsylvania, just to the west of Pittsburgh (Figure 4). Meanwhile, the main convective line continued its steady southeast progression. By 2310 UTC (Figure 5), new convection had started in eastern Ohio just to the north of Belmont County. At this time, the northern end of the main convective line was showing signs of dissipation. At 2328 UTC, (Figure 6) convection was well underway just to the north of Belmont County and extended east into Pennsylvania. Although Figure 6 shows the lightning strikes for the 1-hour period from 2228-2328 UTC, the majority of strikes just north of Belmont County and through the panhandle of West Virginia occurred during the last 20 minutes of the 1-hour period (2308-2328 UTC). The (CG) lightning data also shows that the north end of the main convective line continued to fragment as indicated by the presence of separate individual cells (CG lightning clusters).

Figures 7a through 7e represent the CG lightning data in 20-min increments, and shows the interaction between particular cells (lightning clusters). Three separate cells are noted in Figure 7a, all of which appeared to have had an impact on the flooded area. Cells 1 and 3 are the new convection discussed in Figures 4-6, while cell 2 is residual convection from the original MCS convective line. It is likely that all three cells were involved in the excessive rainfall. At 2349 UTC (Figure 7b), the three distinct cells were still evident, with the flash count in cells 1 and 3 increasing during the previous 20 min. In addition, more convection began south of Belmont County (cell 4 in Figure 7b). Figure 7c (0001 UTC) shows all four cells. The strikes in cells 1 and 3 indicated that the convection was propagating in a more southerly direction, rather than southeast like the main MCS line. The propagation was also very slow. Forty-three minutes elapsed between Figures 7a and 7c, yet the convection appears to have moved very little.

By 0042 UTC (Figure 7d), cell 1 had merged with cell 3 very near the Ohio River, just upstream of Shadyside. Cell 2 continued to trail the merged cells. Meanwhile, only a few remnant strikes lingered from cell 4 south of Belmont County. Figures 7b through 7d indicate that Cell 4 developed and then dissipated with little movement. It is possible, however, that cell 4 produced an outflow boundary which could have moved north, further enhancing low level convergence in Belmont County. Other data sources would be required to confirm this hypothesis. Figure 7e shows the merged cells approximately over the hardest hit area, with Cell 2 remaining to the rear. Cell 2 subsequently crossed over the exact area traversed by the merged pair.

Figure 8 represents the CG lightning for the 1-hour period ending at 0116 UTC. Note the number of strikes that occurred southwestward of the main cluster (compare Figures 7c-e with Figure 8). This indicates a deviation in motion from the convection in the main MCS line which was toward the southeast. The 500 mb and 700 mb winds at 0000 UTC 15 June 1990 were from the northwest. Convective systems can often be viewed as propagating rather than moving. That is, the convective elements on the meso-beta scale and below tend to form and accrete on the side of the convective system exposed to the warm moist low-level inflow. This governs the speed orientation of propagation (Merritt and Fritsch, 1984). As a result, two types of convective motion are usually evident:

1. <u>Continuous propagation</u> (Browning, 1964) occurs when newer cells form on the inflow side of the system and sustain the larger complex.
2. <u>Discrete propagation</u> (Newton and Newton, 1959) occurs when new cells form slightly away from the periphery of the main convective unit and then merge.

The southwestward or backward propagation suggested by the CG lightning signatures in Figure 8 is indicative of intense convection which produces excessive rainfall (Scofield and Shi, 1987; Juying and Scofield, 1989) (Here backward refers to convective systems that have a component of motion to the west (e.g., NW, W, or SW) rather than the usual eastward component (e.g, to the NE, E, or SE) of motion). In particular, backward propagating convective systems usually produce heavier rainfall and more flash flooding than forward propagating systems (Shi and Scofield, 1987). The 23 July 1987 Minneapolis Flash Flood (Schwartz et al., 1990) also had backward propagating tendencies.

Figure 9 (0242 UTC) shows the lightning cluster as it continued a southward propagation. By this time, the cell was showing signs of diminishing since the number of strikes had decreased considerably (compare Figure 8 and 9). In addition, many more positive strikes can be seen in Figure 9. In fact, only 2% of the strikes were positive at 0116 UTC (Figure 8) while 12% were positive by 0242 UTC (Figure 9). Often, positive CG strikes show a tendency toward a higher frequency in the dissipating stage of a convective system (Fuquay, 1982; Orville et al., 1983; Holle et al., 1988; Brook et al., 1989). Also, it is interesting to note that the first CG lightning strike occurred in Belmont County at 2323 UTC and the last at 0309 UTC. Convection, as defined by CG lightning strikes, occurred in some part of Belmont county for over 3 hours and 45 minutes. Of course, cloud-to-cloud lightning may have continued for even a longer period.

Finally, Figure 10 shows the total CG strikes for an 8-hour period from 2001 through 0400 UTC. The path of the cell that was originally part of the main MCS line is clearly evident. Note, how the cell track leads into the cluster which formed in eastern Ohio. Also evident is the southeast propagation of the main convective line, the southward movement of the Belmont Cluster, and the proliferation of positive strikes as the cells dissipated.

3. COMMENTS AND SUMMARY

There was a large amount of lightning in eastern Ohio over Belmont and the surrounding counties that evening. However, it is obvious from Figure 10 that there was even more lighting through other sections of Ohio and Kentucky with apparently no major flooding. Based on the CG lightning data only, there seemed to be a number of meteorological factors and effects which contributed to the excessive rainfall in Belmont County. These are:

A) The slow movement of the convective system over eastern Ohio.

B) The southwest (backward) propagation or development of the convection in Belmont county.

C) The merging of cells (lightning clusters).

D) The possible influence of the last cell, originally part of the main convective line, which traveled over the exact area traversed by the merged pair. The extent to which this cell affected the flood event is uncertain since the cell moved over Belmont county near the time the heavy rain ended.

Additionally, other factors may have played roles in the events over Belmont county that can be inferred, but not confirmed by using CG lighting data. These factors require further study and inclusion of additional data sources to be confirmed. This should include the role mesoscale boundaries may have played in enhancing low-level convergence. The cell evident in the CG lightning data that formed just to the south of Belmont county could have produced a boundary that might have interacted with the convection to the north, which was propagating southward. An outflow boundary from the main MCS line also may have interacted with the Belmont County cluster as well.

This analysis was performed with the use of CG lightning data only. Radar data and satellite imagery were not used in the analysis, and important mesoscale and synoptic factors were not investigated such as the moisture field, instability, upper-level dynamics, etc. These fields and data will add more insight into the excessive rainfall event. However, there was still an enormous amount of information provided by the lightning data. The lightning data could become even more valuable when integrated with the other data sources.

Traditionally, radar data has been a primary tool, along with satellite imagery, for forecasting and diagnosing excessive rainfall events. Lightning data has the potential to be an important forecast tool in flood situations. It has advantages over radar data, such as no attenuation and no gaps in coverage. The absence of any gaps in the lightning data could prove extremely important, especially in those western states where radar data are scarce, and topography plays an important role in enhancing flash flood potential. For example, Reap (1985) studied over two million CG lightning strikes in the western United States and found that about 41% occurred with no reported radar echo. Additionally, 87% of these strikes occurred with echo reflectivities less than VIP 3. This could also have significance for the rest of the country, since the VIP 3 threshold is often used for reporting thunderstorm activity. It is possible that lightning data will depict the first sign of convection, even before radar data and satellite imagery will. Lightning data can also provide insight into many small-scale interactions, such as the tracking of boundaries or potential boundaries. It also provides an excellent view of cell (lightning cluster) interactions which are extremely important in flood forecasting. It seems that an accurate, efficient and effective method for diagnosing and forecasting excessive convective rainfall would be to use real-time lightning data in conjunction with radar and satellite imagery.

Finally, it must be remembered that in hindsight most meteorological events can be explained and understood, but in an operational real-time environment it's often quite difficult. Real-time lightning data might have helped to diagnose the eastern Ohio flash flood. However, at this time, the SUNY lightning data shown in the figures are only available in real time to a limited number of NWS offices. Unfortunately, WSFO Cleveland, WSFO Pittsburgh and WSO Canton-Akron do not have real-time access to the data. Lightning detection and the availability of this information in an operational environment is relatively new. Additional studies, especially those linking lightning data to excessive rainfall are needed. It is also not known how many events have similar characteristics as this one without producing excessive rain. Research, training, and experience with this new technology are needed in order for operational meteorologists to utilize lightning data to its fullest potential.

ACKNOWLEDGMENTS

I would like to thank Jeff Waldstreicher and Gary Carter of the Eastern Region Scientific Services Division for their help and encouragement in preparing this paper. I would also like to thank the Shadyside Disaster Survey team, especially Bud Dorr (Eastern Region Meteorological Services Division) and Frank Brody and Bill Read (Office of Meteorology) for their comments and suggestions.

REFERENCES

Brook, M., R. W. Henderson, and R. B. Pyle, 1989: Positive lightning strikes to ground. J. Geophys. Res., 94, 13,295-13,303.

Browning, K. A., 1964: Airflow and precipitation trajectories within severe local storms which travel to the right of the winds. J. Atmos. Sci., 21, 634-639.

Engholm, C. D., E. R. Williams, and R. M. Dole, 1990: Meteorological and electrical conditions associated with Positive cloud-to-ground lightning. Mon. Wea. Rev., 118, 470-487.

Fuquay, D. M., 1982: Positive cloud-to-ground lightning in summer thunderstorms. J. Geophys. Res., 87, 7131-7140.

Holle, R. L., A. I. Watson, R. E. Lopez, and D. R. Macgorman, 1988: Lightning in mesoscale convective complexes on 3-5 June 1985 in Oklahoma and Kansas. Proceedings, 1988 International Aerospace and Ground Conference on Lightning and Static Electricity, Oklahoma City, Apr. 19-22, 1988, 310-317.

Juying, X. and R. A. Scofield, 1989: Satellite-derived rainfall estimates and propagation characteristics associated with mesoscale convective systems (MCSs). NOAA Technical Memorandum NESDIS 25, 49 pp.

Merritt, J. H. and J. M. Fritsch, 1984: On the movement of the heavy precipitation areas of mid-latitude mesoscale convective complexes. Tenth Conference on Weather Forecasting and Analysis, Clearwater Beach, Florida, American Meteorological Society, 529-536.

Newton, C. W. and H. R. Newton, 1959: Dynamical interactions between large convective clouds and environment with vertical shear. J. Meteor., 16, 483-496.

Orville, R. E., R. W. Henderson, and L. F. Bosart, 1983: An east coast lightning detection network. Bull. Amer. Meteor. Soc., 64, 1029-1037.

Reap, R. M., 1986: Evaluation of cloud-to-ground lightning data from the western United States for the 1983-84 summer seasons. J. Climate Appl. Meteor., 25, 785-799.

Rutledge, S. A. and D. R. MacGorman, 1988: Cloud-to-ground lightning activity in the 10-11 June 1985 mesoscale convective system observed during the Oklahoma-Kansas Pre-Storm project. Mon. Wea. Rev., 116, 1393-1408.

Schwartz, B. E., C. F. Chappell, W. E. Togstad, and X. Zhong, 1990: The Minneapolis flash flood: Meteorological analysis and operational response. Wea. and Forecasting, 5, 3-21.

Scofield, R. A. and Shi, J., 1987: Evolutionary "Satellite" characteristics of mesoscale convective systems and extratropical cyclone systems. Proceedings of Satellite and Radar Imagery Interpretation Conference, Reading, England, July 1987, 395-414.

Shi, J. and R. A. Scofield, 1987: Satellite observed mesoscale convective system (MCS) propagation characteristics and a 3-12 hour heavy precipitation forecast index. NOAA Technical Memorandum NESDIS 20, 43 pp.

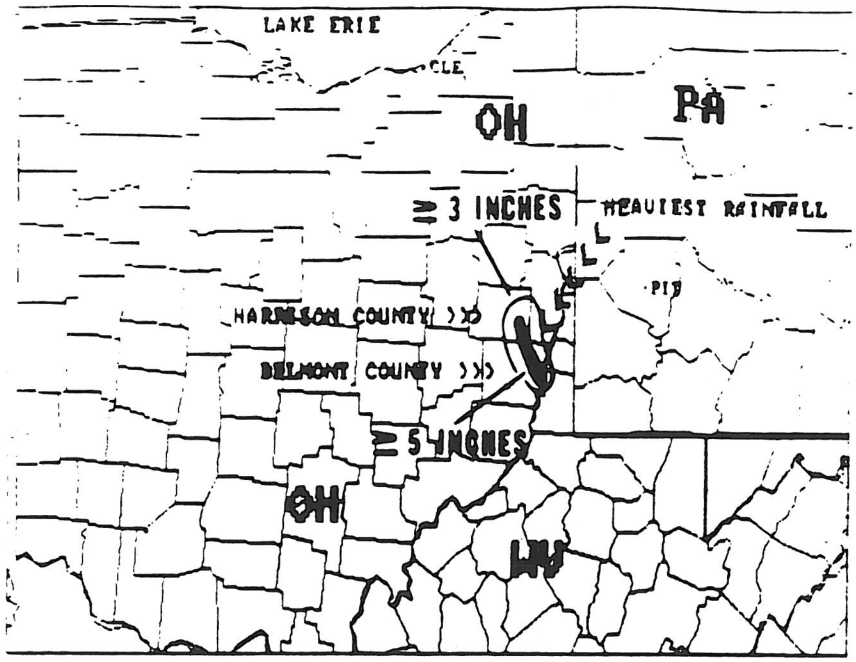

Figure 1. Excessive rainfall area. The dark line approximates the the 3 inch isohyet, while the shaded region approximates the 5 inch isohyet.

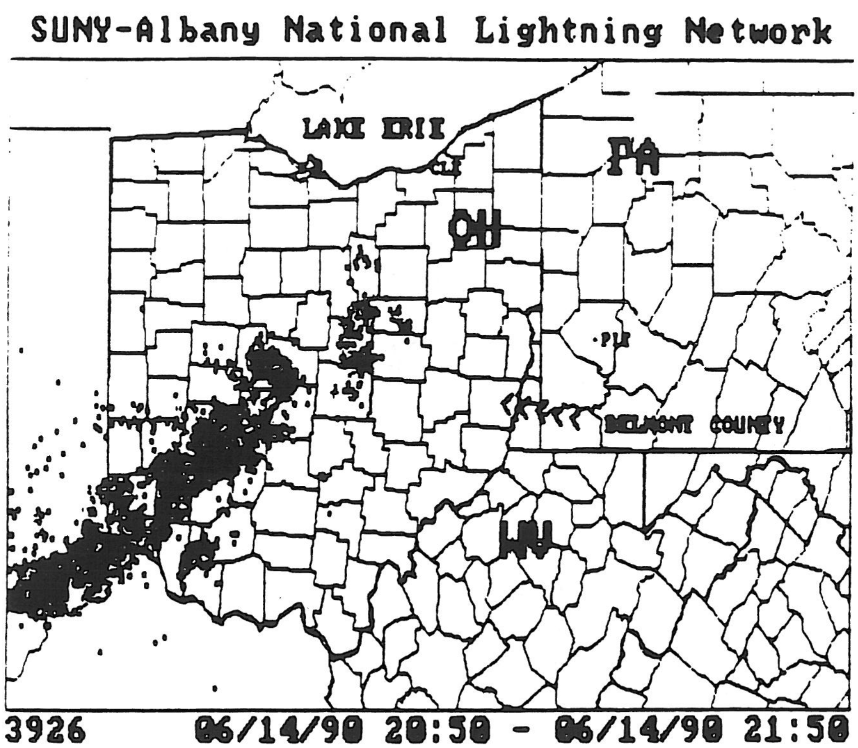

Figure 2. Accumulated CG strikes for the 1-hour period from 2050-2150 UTC, 14 June 1990. Pluses (+) are positive strikes. The number in the bottom left corner (3926) indicates the number of strikes through the period over the particular geographical area shown in the figure.

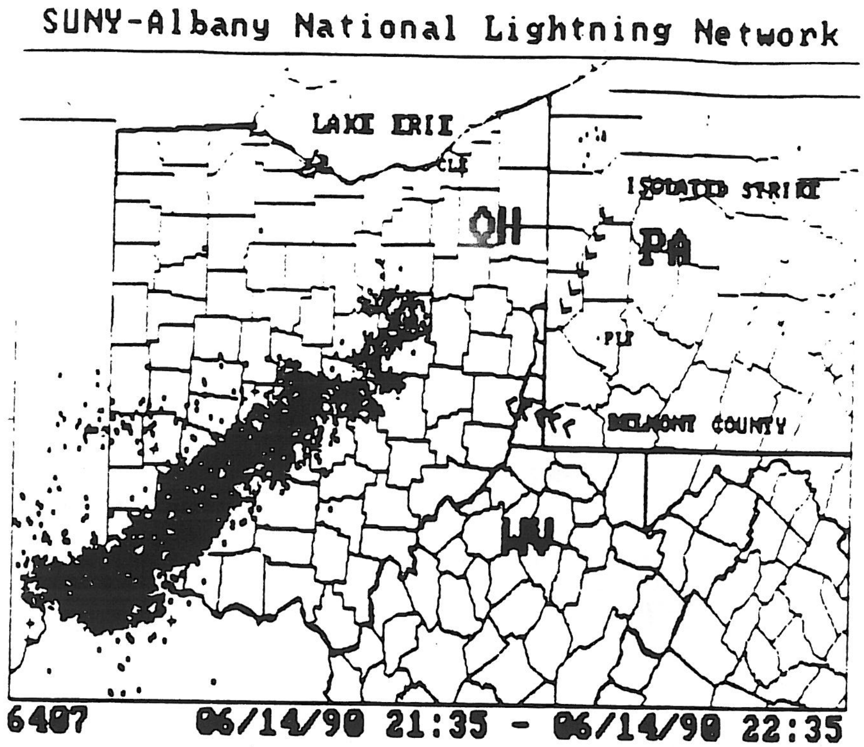

Figure 3. Same as in Fig. 2 except for 2135-2235 UTC.

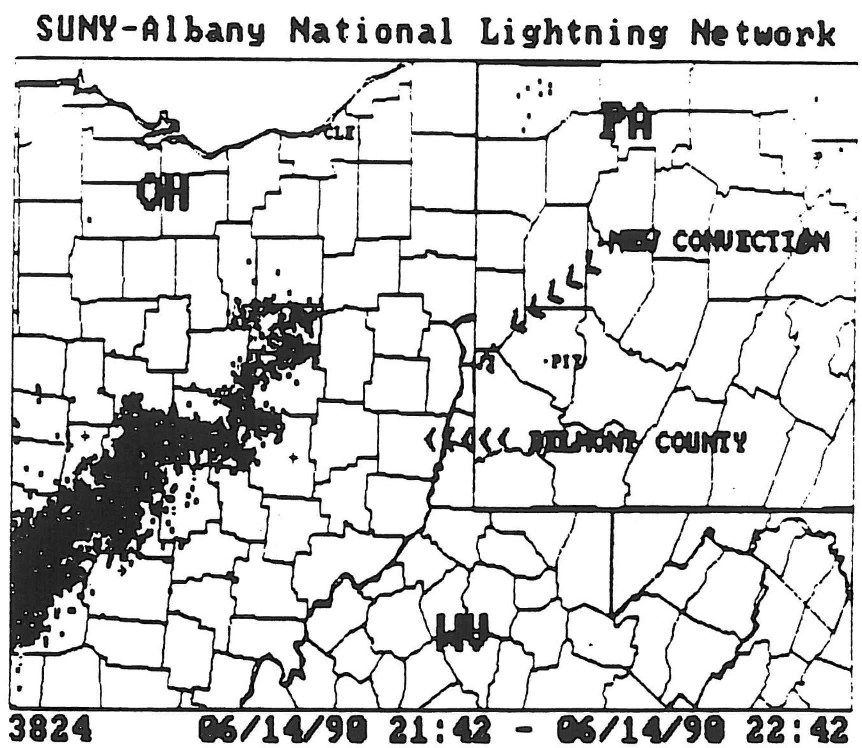

Figure 4. Same as in Fig. 2 except for 2142-2242 UTC. Area of new convection is indicated.

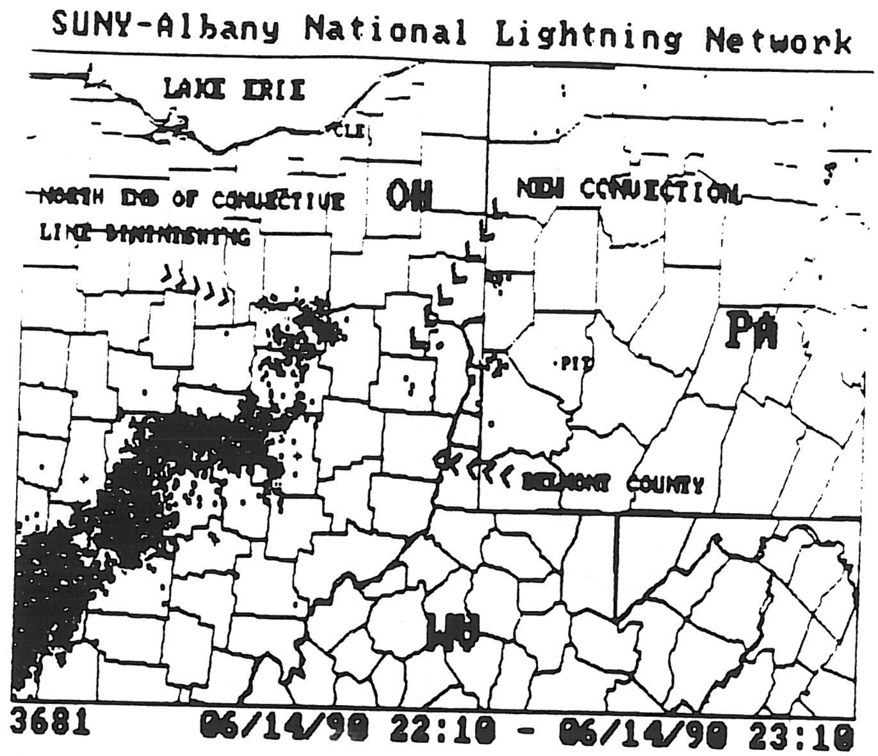

Figure 5. Same as in Fig. 2 except for 2210-2310 UTC. New convection and diminishing section of main convective line are depicted.

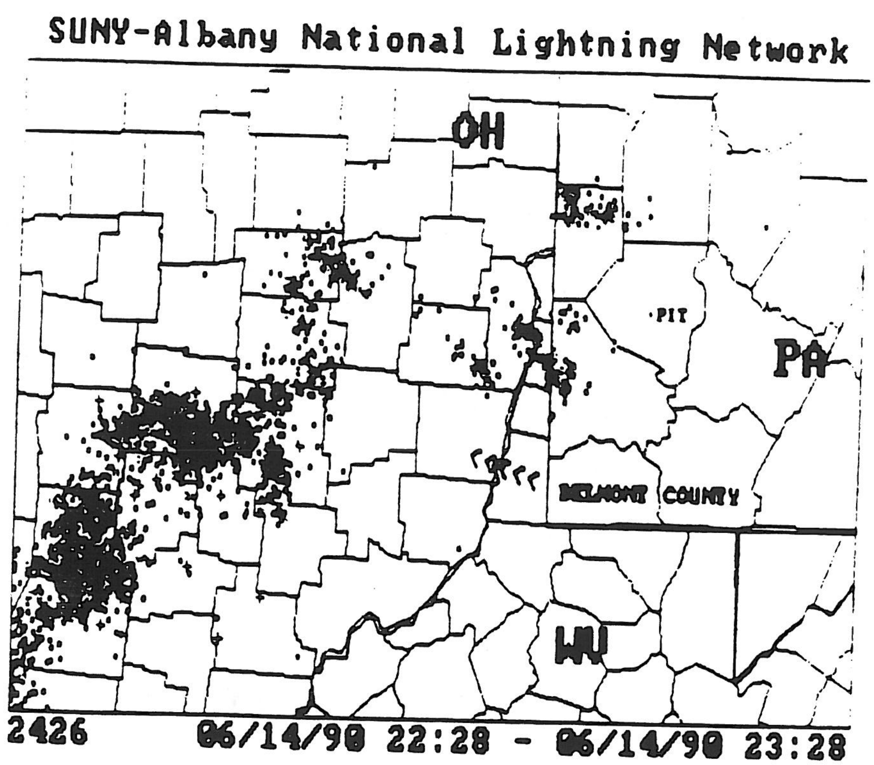

Figure 6. Same as in Fig. 2 except for 2228-2328 UTC.

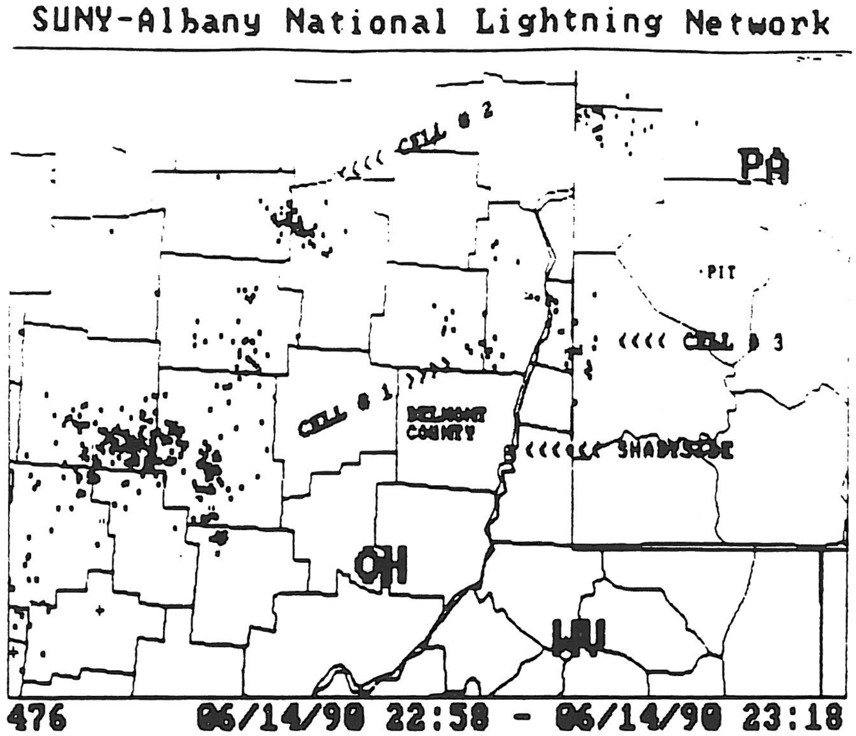

Figure 7a. Same as in Fig. 2 except for the 20-min period from 2258-2318 UTC. Cells (lightning clusters) 1, 2, and 3 are shown.

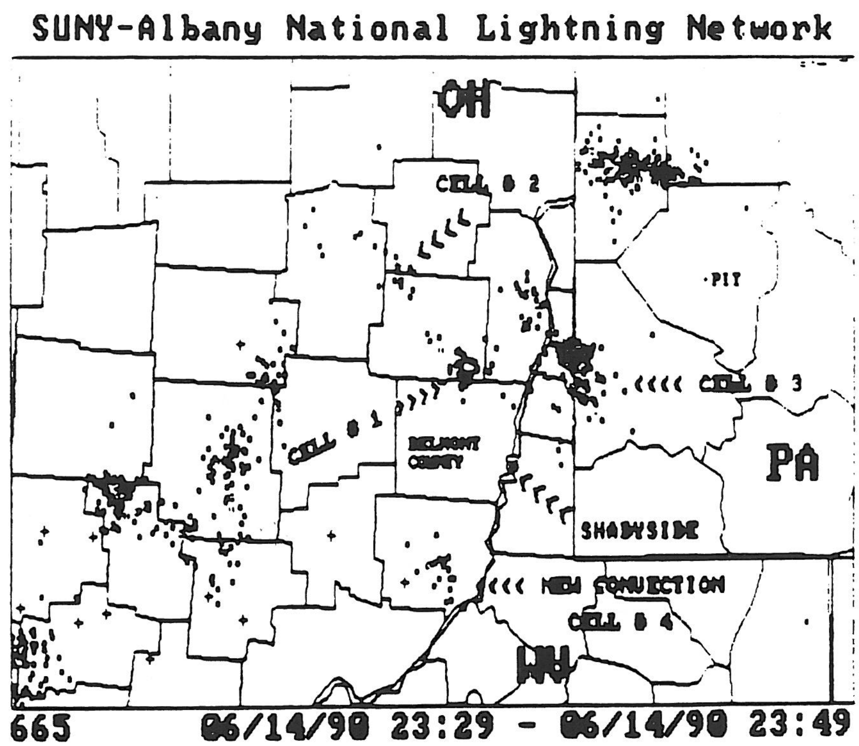

Figure 7b. Same as in Fig. 2 except for the 20-min period from 2329-2349 UTC. Cells (lightning clusters) 1, 2, 3, and 4 are shown.

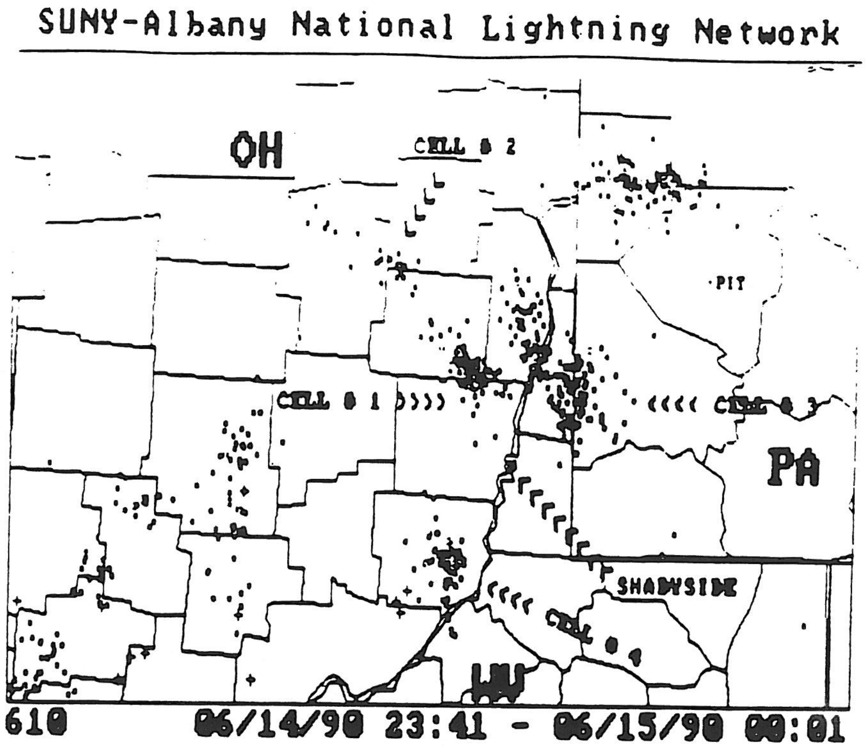

Figure 7c. Same as in Fig. 2 except for the 20-min period from 2341-0001 UTC. Cells (lightning clusters) 1, 2, 3, and 4 are shown.

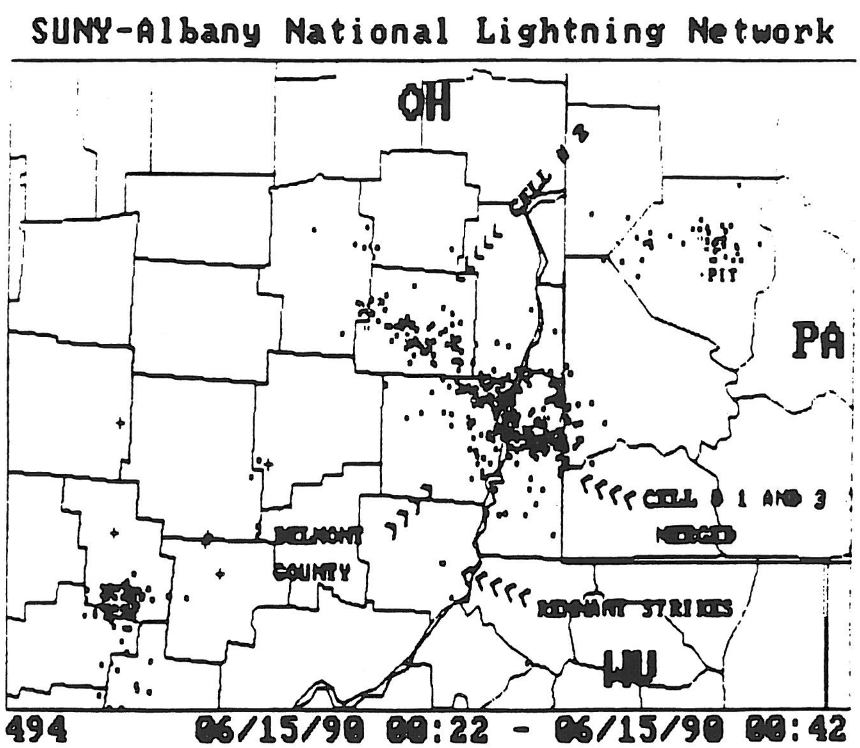

Figure 7d. Same as in Fig. 2 except for the 20-min period from 0022-0042 UTC. Cell (lightning cluster) 2, the merged cells 1 and 3 and the remnants of cell 4 are shown.

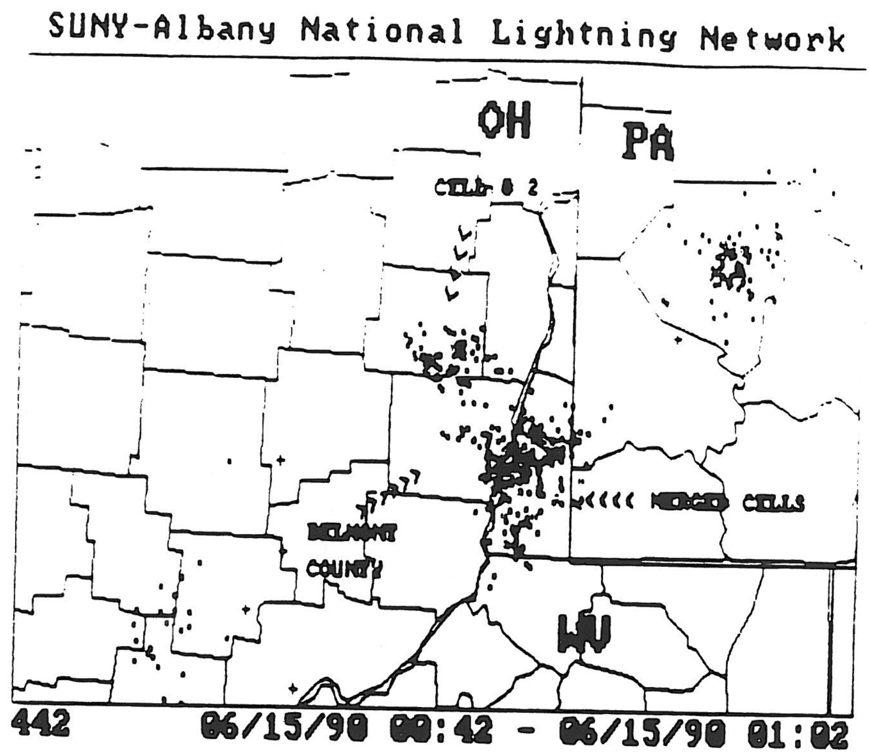

Figure 7e. Same as in Fig. 2 except for the 20-min period from 0042-0102 UTC. Cell (lightning cluster) 2 and merged cells are shown.

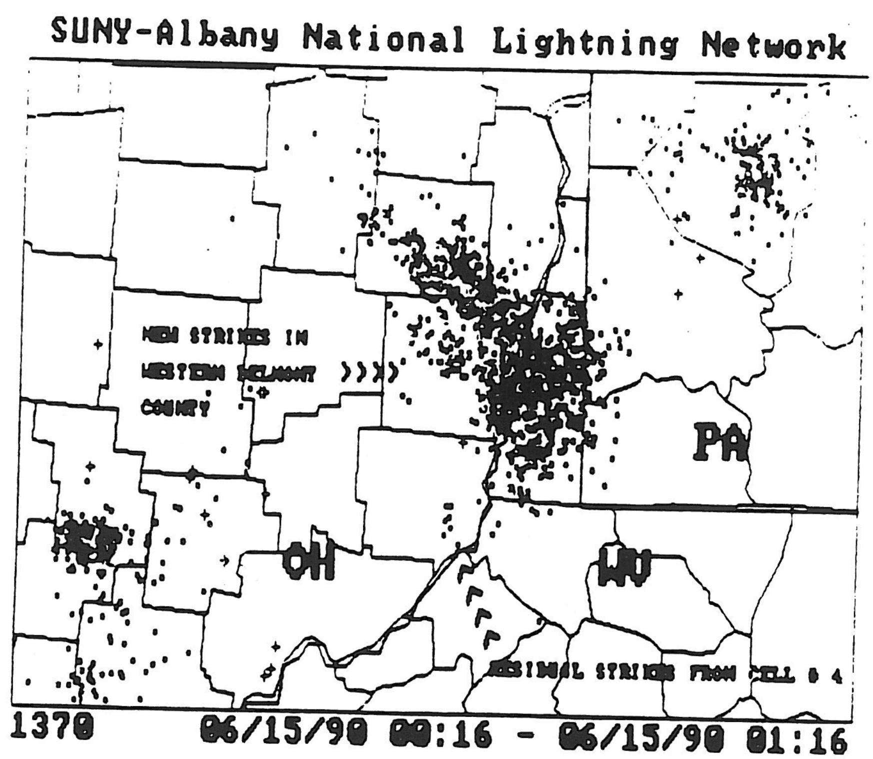

Figure 8. Same as in Fig. 2 except for 0016-0116 UTC. New strikes in western Belmont County and residual strikes from cell 4 are shown.

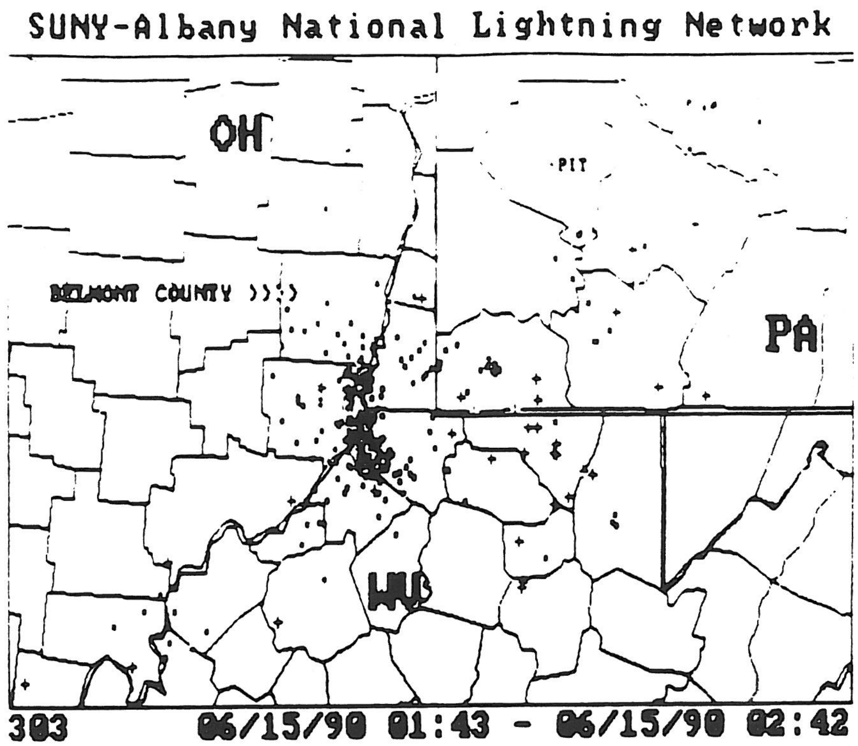

Figure 9. Same as in Fig. 2 except for 0143-0242 UTC.

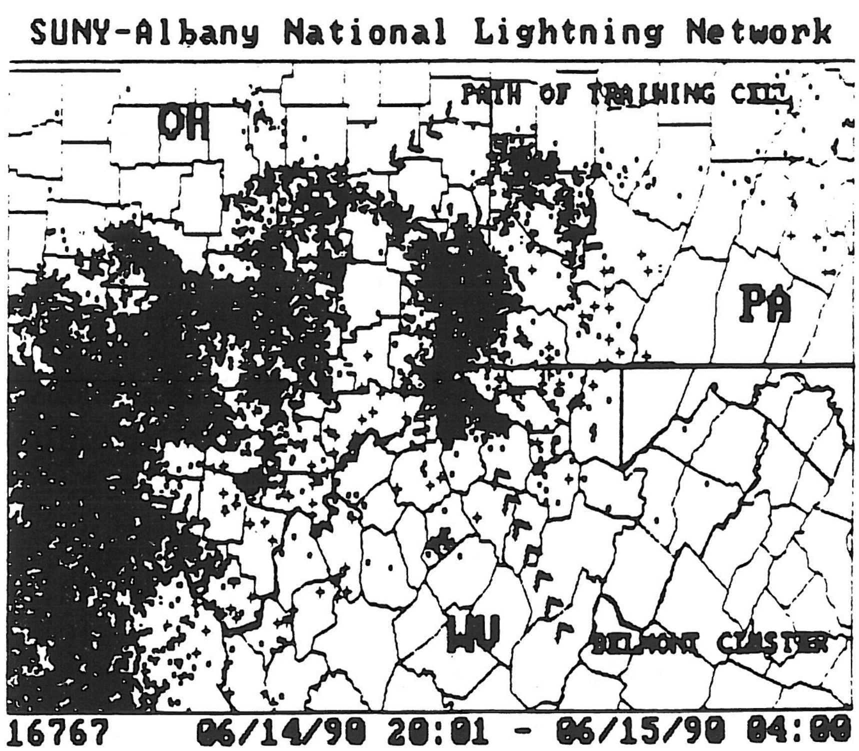

Figure 10. Same as in Fig. 2 except for the 8-hour period from 2001-0400 UTC.