P1.6 COMBINING LIGHTNING WITH SATELLITE DATA FOR ANALYSIS AND PREDICTION

Roderick A. Scofield *, Robert J. Kuligowski,
NOAA/NESDIS/ORA, Camp Springs, MD

Shuang Qiu
QSS Group, Inc., Lanham, MD

1. INTRODUCTION

Lightning data represent a very useful complement to satellite imagery for analyzing and predicting the evolution of Msoscale Convective Systems (MCS's). MCS's are the most prolific lightning producers in the world. As Meso-Gamma Towers develop within an MCS, graupel begins to form in the upper portions of the cloud and then falls through a layer of supercooled water droplets and ice crystals. The resulting collisions induce a charge separation that is resolved in the form of lightning strokes (Black and Hallett 1998). The relationships between cloud properties and lightning will be explored using a combination of National Lightning Detection Network (NLDN; Cummins et al. 1996) data (detects cloud to ground (CG) stokes only) and Geostationary Operational Environmental Satellite (GOES) Imager visible and infrared (IR) (3.9-µm, and 10.7-µm) data to depict the life cycle of a MCS. Polar Orbiting Environmental Satellite (POES) microwave data will also be examined. Initially, lightning data were combined with the GOES 10.7-µm data. As expected, the lightning frequency was a function of the life cycle stage of the MCS; i.e., initiation, maturity, and dissipation. Life cycle stages are also a function of the location of the MCS with respect to the theta-e ridge axis. The strengths of NLDN data are the capability to pinpoint cores of rainfall and as an aid in assessing storm propagation for nowcasting purposes. Weaknesses include that lightning is not always present and only CG strikes are measured. This paper briefly discusses the results of an observational study as to the applicability of IR and NLDN to MCS rainfall estimation and nowcasting. An idea is also presented on a potential sounding signature that may be a pre-cursor to severe/intense lightning events..

2. RAINFALL ESTIMATION

There is a correlation between CG lightning strikes and rainfall, though this relationship can be quite variable from region to region (Moore et al. 1964; Scott et al. 1997). Thus, frequent CG lightning in moist environments are associated with rainfall. There appears to be some relationship between the low GOES 10.7-µm cloud top temperatures (CTT)—especially in the upwind (tighter gradient) portion of the MCS—and the most intense lighting. A critical threshold for cloud to ground lightning to occur seems to be CTT's colder than –25°C. Other useful re-occurring features include increases in lightning intensity as CTT's become lower and decreases in lightning as tops become warmer. Grecu et al. (2000) illustrated that a rainfall algorithm that combines both GOES IR and lightning data is superior to a technique that uses only the IR data. Figures 1-3 illustrate how the lightning data superimposed on the IR displaces the Hydro-Estimator (H-E; Scofield and Kuligowski 2003) derived rainfall southward toward the upwind gradient. The corresponding Stage III radar-rain gauge product product shows that this southward displacement of the H-E rainfall was correct.

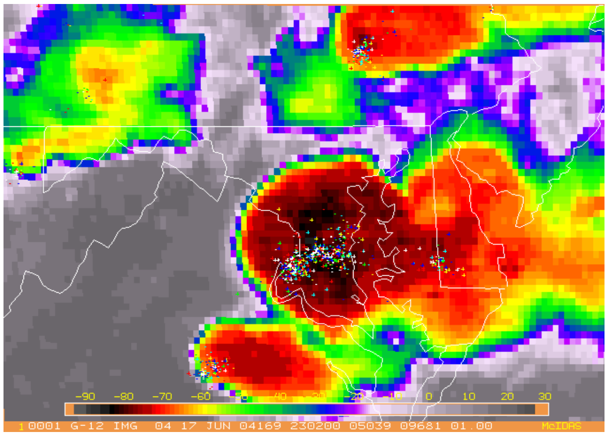

Figure 1. *GOES-12 10.7-µm infrared with 6-minute cloud to ground lightning strikes superimposed for 2302 UTC 17 June 2004.*

---

* *Corresponding author address*: Dr. Roderick A. Scofield, NOAA/NESDIS/ORA, E/RA2 RM 712 WWBG, 5200 Auth Rd, Camp Springs, MD, 20746-4304; e-mail: Roderick.scofield@noaa.gov.

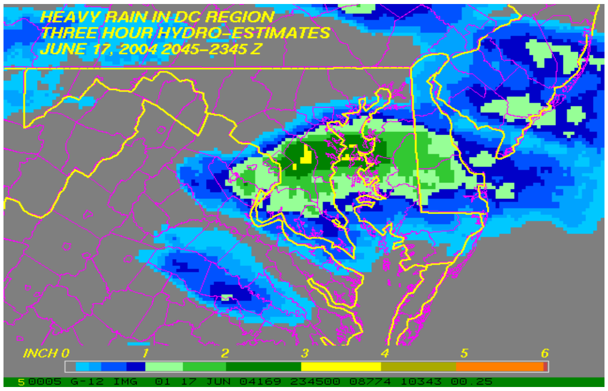

Figure 2. *Hydro-Estimator rainfall totals (inches) for the three hours ending 2345 UTC 17 June 2004.*

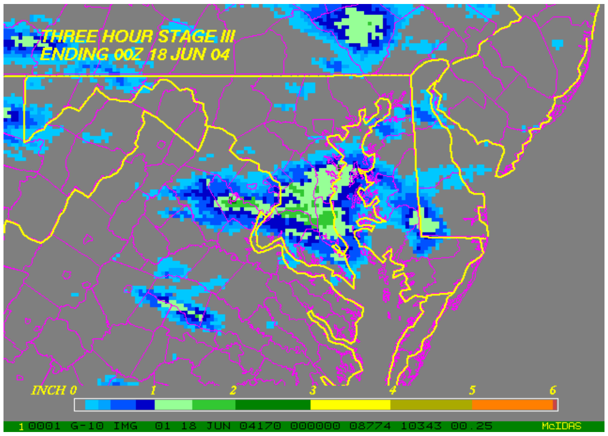

Figure 3. *Stage III field (gauges + radar) totals (inches) for the 3 hours ending 0000 UTC 18 June 2004.*

3. NOWCASTING

The nowcasting of MCS propagation and mergers is more readily accomplished through a combination of NLDN and GOES than by GOES alone (Goodman et al. 1998). For example, mergers are sometimes followed by increasing lightning intensity. Lightning is often located along the leading edge of forward propagating MCS's, or along the rear edge of backward propagating MCS's. For stationary or slow moving MCS's, lightning remains in the same area from the center to the upwind edge. Lightning regeneration is defined as when a new storm cell develops within the core of the MCS (usually not detectable in the IR imagery) and can be in either the upwind or downwind portion. An example of a backward propagating MCS is shown in Figs. 4-6. Notice, that mergers, increased lightning intensity and colder tops (the black area in Fig. 6 which is –80°C or colder) accompany this backward development. These extremely cold tops are regions of maximum upward vertical motion.

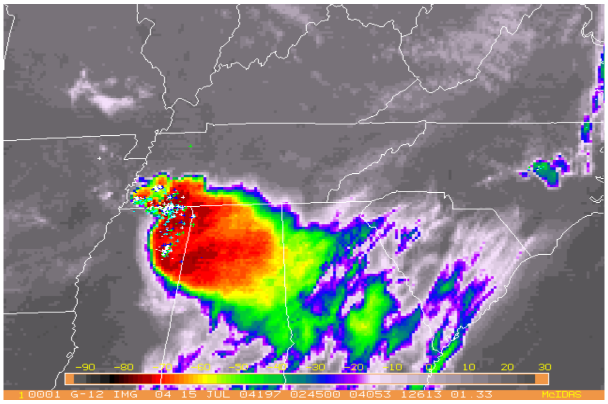

Figure 4. *GOES 12 10.7-µm infrared with 12-minute cloud to ground lightning strikes superimposed for 0245 UTC 15 July 2004.*

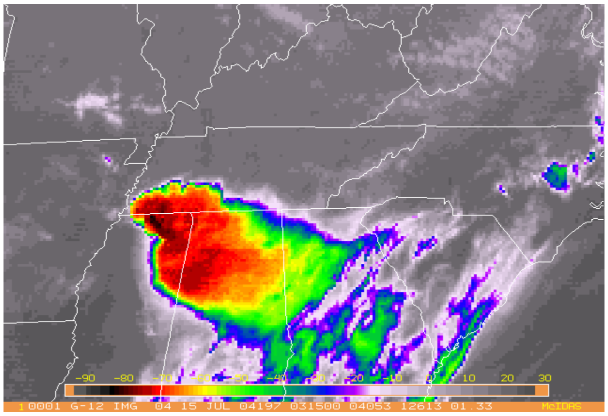

Figure 5. *GOES-12 10.7-µm infrared for 0315 UTC 15 July 2004.*

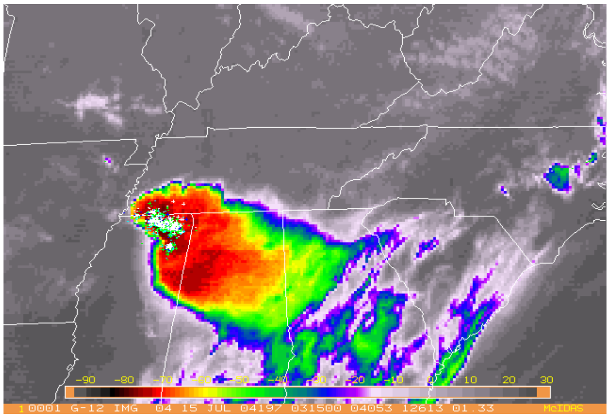

Figure 6. *GOES-12 10.7-µm infrared with 12 minute cloud to ground lightning strikes superimposed for 0315 UTC 15 July 2004.*

Figure 7 shows the corresponding rain rate estimate derived from the NOAA-17 Advanced Microwave Sensing Unit (AMSU; Ferraro et al. 2000). The greatest scattering and rainfall is located near the most intense lightning and cold tops in the IR (compare to Mohr et al. 1996). Hopefully, a combination of lightning and IR data can be used to detect short term periods of extreme rainfall called rain bursts. It appears that the incorporation of lightning data will improve the performance of the Hydro-Nowcaster (Scofield et al. 2004), especially for MCS's.

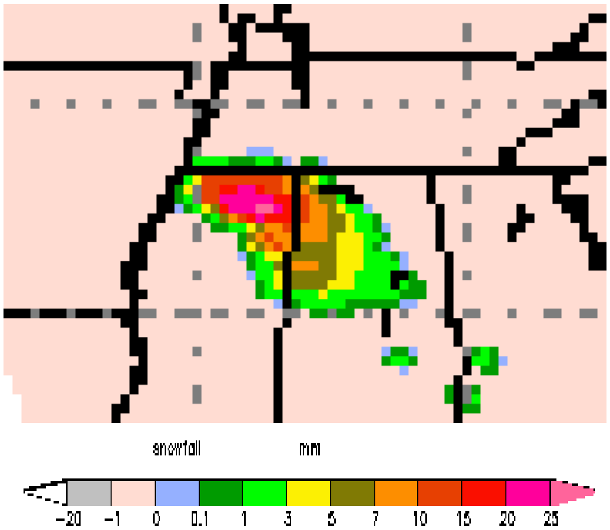

Figure 7. *NOAA-17 Advanced Microwave Sensing Unit (AMSU) rainfall rate (mm/h) for 0315 UCT 15 July 2004.*

A conceptual model used in illustrating the life cycle of a MCS is depicted in Fig. 8. The basis for the model is the location and stage of the MCS with respect to the low level theta-e ridge axis. This nowcasting model is useful for tracking a MCS (through its life cycle) from the west side to the east side of a theta-e ridge axis. On the west side the MCS is initiated and exhibits positive CG lightning strikes and a low precipitation efficiency echo. The MCS grows and the tops become colder as it approaches the theta-e ridge axis. This ridge axis location is where the MCS may become a supercell and the CG lightning strikes change from positive to negative. As the MCS moves east of the ridge axis, the MCS can become a high precipitation efficient echo with negative CG strikes. This eastern side is where the MCS reaches full maturity and continues to grow as the cloud tops become colder. The precipitation efficiency is normally quite high on the eastern side and MCS's are capable of producing flash floods at this stage. Normally, the flash flood stage is followed by dissipation.

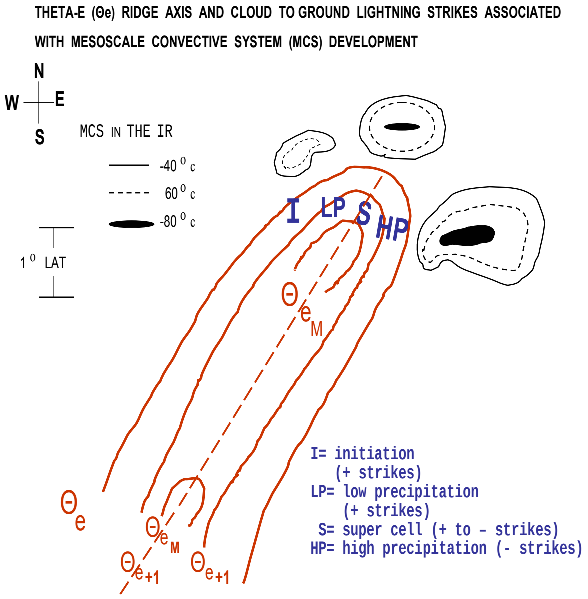

Figure 8. *Low-level theta-e ridge axis and cloud-to-ground lightning strikes associated with Mesoscale Convective System (MCS) development.*

4. PREDICTION

In addition, the possibility of using proximity soundings to predict severe lightning events will be evaluated. Former National Weather Service forecaster Doyle Cook (personal communication) hypothesized that severe lightning events are signaled by a stability reversal in the mid-levels: that the temperature lapse rate changes from potentially unstable in the lower portion of the MCS-producing air mass to potentially stable in the middle and upper troposphere. This reversal should occur between the 0ºC and -10ºC isotherms, allowing graupel to impinge on supercooled water droplets and thus to produce lightning prior to the initial downdrafts of the individual cumulonimbus (CB). Figure 9 shows a hypothetical lightning sounding with a stability reversal. This sounding would indicate that frequent lightning flashes would occur before the mature stage is reached and would continue until the CB enters the dissipating stage.

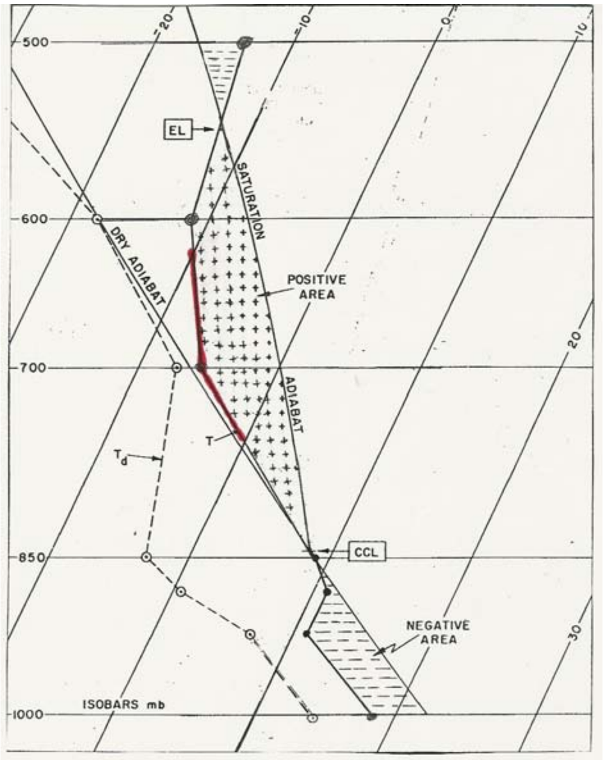

Figure 9. *Pre-cursor lightning sounding with a stability reversal between 0ºC and -10ºC.*

5. SUMMARY AND OUTLOOK

Prediction of severe lightning events has many potential applications. In a dry environment, wildfire risk from lightning strokes could be predicted. In a moist environment, flash flood risk from heavy rain associated with severe lightning events could be more accurately evaluated. Consequently, forecasters and response personnel could benefit significantly from an expansion of the understanding of the relationship of lightning to the convective life cycle. Additional possible applications include precipitation estimation (Kuligowski and Im, 2005) and nowcasting. In this study, it appears that NLDN and GOES 10.7-µm data have similar relationships to rainfall, where the lightning is much better at pinpointing the heavy rainfall cores. Table 1 summarizes some of these characteristics. In the future, when the lightning detectors are placed on GOES R, total flash counts (cloud to ground and in-cloud) can be measured that would lead to improved severe weather nowcasting and prediction.

GOES IR	Lightning	Outcome
Coldest tops	Present	Heavy rain
Upwind gradient	Present	Heavy rain
Downwind gradient	Isolated or none	Light rain or none
Mergers	Present	Heavy rain
Growing//becoming colder	Present	Heavy rain
Decreasing/becoming warmer	Decreasing or none	Light or no rain
Colder tops in E-SE portion of MCS	Along leading edge	Forward propagation
Colder tops in W-NW portion of MCS	Along trailing edge	Backward propagation
Colder tops near center and either in the upwind or downwind direction	Present	Slow movement
(In many cases, no pronounced signature)	Regenerative lightning	Core regeneration
Cells developing upwind	Increasing as a function of cell development	Regenerative MCS's

Table 1. *Some signatures of GOES IR and lightning as related to MCS rainfall and nowcasting.*

6. REFERENCES

Black, R.A. and J. Hallett, 1998: The mystery of cloud electrification, *American Scientist*, 86, **6**, 526-534.

Cummins, K. L., A. Bardo, W. L. Hiscox, R. B. Pyle, and A. E. Pifer, 1996: NLDN'95: A combined TOA/MDF technology upgrade of the U.S. National Lightning Detection Network. Preprints, *12th Conf. on Interactive Information and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology*, Atlanta, GA, Amer. Meteor. Soc., 347-355.

Ferraro, R.R., F. Weng, N. Grody, and L. Zhao, 2000: Precipitation characteristics overland from the NOAA-15 AMSU sensor. *Geophysical Res. Lett*., **27**, 2669- 2672.

Grecu, M. N. Anagnostou, and R.F. Adler, 2000: Assessment of the use of lightning information in satellite infrared rainfall estimation. *J. Hydrometeorol,* **1**, *211-221*.

Goodman, S.J.. Buechler, and P.J.Meyer: 1988: Convective tendency images derived from a combination of lightning and satellite data. *Wea. Forecasting*, **3 ,** *173-188.*

Kuligowski, R.J. and J.-S. Im, 2005: Combining lightning with satellite data for analysis and prediction. Preprints, *Conf. on Meteorological Applications of Lightning Data,* Amer. Meteor. Soc., San Diego, CA, CD-ROM.

Mohr, K.I., E.R. Toracinta, E.J. Zipser, and R.E. Orville, 1996: A comparison of WSR-88D reflectivities, SSM/I brightness temperatures, and lightning for mesoscale convective systems in Texas: Part II: SSM/I brightness temperatures and lightning. *J. Appl. Meteor.,* **35,** 919-931.

Moore, C.B., B. Vonnegut, E.A. Vrablik, and D.A. McCaig, 1964: Gushes of rain and hail after lightning, *J. Atmos. Sci.,* **21,** 646-665.

Scofield, R.A. and R. J. Kuligowski, 2003: Status and outlook of operational satellite precipitation algorithms for extreme precipitation events, *Wea. Forecasting*, **18**, 1037-1051.

Scofield, R.A., R.J. Kuligowski, and J. C. Davenport, 2004: The satellite-derived hydro-estimator and hydro-nowcaster for mesoscale convective systems and landfalling tropical storms. Preprints, *IEEE conference on Remote Sensing of the Atmosphere, Ocean, Environment, and Space 2004 with a Special Session on Applications with Weather Satellites II*, Honolulu, Hawaii, November, 2004.

Scott, C.S., J.F. Griffiths, and R.E. Orville, 1997: Warm season cloud to ground lighting-precipitation relationships in the south-central United States. *Wea. Forecasting*, **12**, 449-457.

7. DISCLAIMER

The contents of this conference preprint are solely the opinions of the authors and do not constitute a statement of policy, decision, or position on behalf of NOAA or the U.S. Government.