Total Lightning as an Indicator of Mesocyclone Behavior

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Introduction

• Apparent relationship between total lightning (in-cloud and cloud-to-ground) and severe weather suggests its operational utility.

• Goal of fusion of total lightning with proven tools, i.e. radar-lightning algorithms

• Preliminary work here investigates circulation from Weather Surveillance Radar - 1988 Doppler (WSR-88D) coupled with total lightning data from Lightning Mapping Arrays
Background

- Ongoing work relates severe events with rapid increases in lightning flash rate, known as lightning jumps (Schultz et al. 2009, 2011; Darden et al. 2010; White et al. 2012; Stano et al. 2014)

- Identification of a rotating updraft, or quasi-steady mesocyclone, often primary factor in determining a severe storm

- Conceptual relationship between lightning, mesocyclone, and storm severity based upon the low-to-mid-level updraft of a convective storm, or specifically, a supercell

Stolzenburg et al. [1998], Fig. 3

Williams et al. [1999], Fig. 7

Lemon and Doswell [1979], Fig. 9
Motivation

• Remaining challenges with forecasting severe weather (Brotzge and Erickson 2009, Brotzge and Donner 2013):
  ○ marginal severe convective events
  ○ first confirmed tornado warning of an event
  ○ tornadic versus non-tornadic supercells

• If lightning can give earlier indication of updraft strength, when coupled with radar can it then:
  ○ improve situation awareness and increase lead time?
  ○ provide earlier differentiation between tornadic and non-tornadic supercells, or ability to “tip the scales”?

• Preliminary investigation of temporal relationship between enhancement of storm rotation and intensification of lightning activity, signaled by lightning jumps
Data

• Lightning Mapping Arrays: VHF sensors in a network for 2-D/3-D lightning depiction of total lightning

○ Flash clustering and Schultz et al. two-sigma lightning jump algorithms

• Storm rotation and mesocyclone analysis:
  ○ WSR-88D Level-III National Severe Storms Laboratory (NSSL) Mesocyclone Detection Algorithm (MDA) strength attributes
  ○ Maximum azimuthal shear derived from WSR-88D data
Methods

• Warning Decision Support System - Integrated Information (WDSS-II) tool used to compute flash extent density to identify and track storms for flash association

• Flash rate calculated from storm-associated flashes then analyzed for jumps
Case Overview

• North Alabama/Tennessee Valley Region:
  ○ 10 April 2009 - nontornadic supercell (S. TN)
    ‣ Cellular convection ahead of convective line, some supercellular structure
  ○ 25 April 2010 - long-track tornadic storm (N. AL)

• Southern Plains Region:
  ○ 20 May 2013 - tornadic storm (OK)
10 April 2009 - Tennessee Valley

Flash extent density

Radar reflectivity at the approximate -10°C height
Lightning jump precedes MDA by a minute, TVS detection by several minutes. MDA strength and max low-to-mid shear correlate with lightning flash rate.
Lightning jump precedes MDA by a minute, TVS detection by several minutes. MDA strength and max low-to-mid shear correlate with lightning flash rate.
Case Overview

• North Alabama/Tennessee Valley Region:
  ◦ 10 April 2009 - nontornadic storm (S. TN)
  ◦ 25 April 2010 - long-track tornadic storm (N. AL)
    ‣ Isolated supercellular structure
    ‣ Two reports of EF1 tornadoes during first hour of storm life cycle
    ‣ Long-track EF3 tornado roughly an hour later

• Southern Plains Region:
  ◦ 20 May 2013 - tornadic storm (OK)
25 April 2010 - Alabama

First tornadic period of storm

Flash extent density

Radar reflectivity at the approximate -10°C height
25 April 2010 - Alabama

Second tornadic period of storm

Flash extent density

Radar reflectivity at the approximate -10°C height
25 April 2010 - Alabama

Earlier tornadic period, two reported EF1 tornadoes.

Jumps precede the mesos, peaks in AzShr. Mid-level max AzShr mirrors lightning flashrate trends.

Later tornadic period, long-track EF3 tornado.

Jump, meso, simultaneous after tornado but flash rate and azshr increase prior.
25 April 2010 - Alabama

Earlier tornadic period, two reported EF1 tornadoes

Jumps precede the mesos, peaks in AzShr. Mid-level max AzShr mirrors lightning flashrate trends

Later tornadic period, long-track EF3 tornado.

Jump, meso, simultaneous after tornado but flash rate and azshr increase prior

$\Delta = \text{TVS}$
Case Overview

• North Alabama/Tennessee Valley Region:
  ◦ 10 April 2009 - nontornadic storm (S. TN)
  ◦ 25 April 2010 - long-track tornadic storm (N. AL)

• Southern Plains Region:
  ◦ 20 May 2013 - classic supercell structure, tornadic storm (OK)
    ‣ Classic supercell structure
    ‣ Strong EF5 tornado developed early in storm life cycle
20 May 2013 - Oklahoma

Flash extent density

Radar reflectivity at the approximate -10°C height
Mesocyclone detected several minutes prior to first lightning jump, put prior to first peak in azimuthal shear. Jump preceded TVS detections by <10 minutes, actual tornado by 30 minutes.
Mesocyclone detected several minutes prior to first lightning jump, put prior to first peak in azimuthal shear. Jump preceded TVS detections by <10 minutes, actual tornado by 30 minutes.
Summary of Preliminary Results

• Increased lightning activity (i.e., a jump) coincides with or precedes the increase in radar-derived circulation

• More agreement between flash rate and low-level azimuthal shear vs. mid-level azimuthal shear, yet trends between three parameters are consistent

• Tornadoes not always preceded by lightning jump or mesocyclone – other dynamic factors involved in severe weather production than result from the updraft alone
Ongoing and Future Work

• Additional cases in a variety of climatologic regions and seasons
  • LMA data from Colorado, Washington D.C.

• Further assessment of nontornadic storms

• Analyze other characteristics/components of total lightning for further trends. Does the charge structure or ratio of IC/CG lightning provide further insight?

• Do trends in azimuthal shear at other levels of the storm offer additional insight compared with lightning activity?

• Add analysis dual-polarization radar signatures that indicate storm relative helicity (e.g., $Z_{DR}$ arc and separation of $Z_{DR}$ and $K_{DP}$)
References and Acknowledgements

Brotzge and Ericksen [2009]
Brotzge and Donner [2013]
Schultz et al. [2009, 2011]
Stumpf et al. [1998]
http://wdssii.org/


NOAA/NASA GOES-R GLM Risk Reduction Research (R3)
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Questions?