Determining Relationships between Lightning and Radar in Severe and Non-Severe Storms

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Dissertation Research

- Three Part Study
  - Investigate the influence of environmental conditions on CG and IC lightning distributions
  - First two manuscripts have been accepted by Monthly Weather Review

1) NLDN Upgrade and National CG Distributions
   - Document regional CG patterns and investigate the influence of the recent upgrade

2) Florida's CG Distributions
   - Examine seasonal and regional CG patterns

3) Storms in the Mid-Atlantic Region
   - Investigate storm-scale variability in many storms

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Pre- and Postupgrade Distributions of NLDN Reported Cloud-to-Ground Lightning Characteristics in the Contiguous United States

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ABSTRACT

The National Lightning Detection Network (NLDN) underwent a major upgrade during 2002–03 that increased its sensitivity and improved its performance. It is important to examine cloud-to-ground (CG) lightning distributions before and after this upgrade because CG characteristics depend on both measurement capabilities and meteorological variability. This study compares prepgrade (1996–99, 2001) and postpgrade (2004–09) CG distributions over the contiguous United States to examine the influence of the recent upgrade and to provide baseline postpgrade averages. Increased sensitivity explains most of the differences in the pre- and postpgrade distributions, including a general increase in total CG and positive CG (+CG) flash densities. The increase in +CG occurs despite the use of a greater weak +CG threshold for removing misclassified IC pulses (post 15 kA versus pre 10 kA). Conversely, the average −CG peak current decreased from 30.6 kA to 4.05 kA following the upgrade. The average −CG (+CG) multiplicity increased from 1.31 (2.69) before to 1.54 (2.41) after the upgrade. Since one +CG flash rarely contains more than one return stroke, explanations for the greater than unity +CG multiplicities remain unclear. Postpgrade results indicate that regions with mostly weak peak current +CG flashes now exhibit greater average +CG multiplicities, whereas regions with mainly strong −CG flashes now exhibit smaller average −CG multiplicities. The combination of NLDN performance, meteorological conditions, and physical differences in first −CG return strokes serves to bolster produce storms in −CG multiplicity and peak current over the coastal waters of the southeast United States.

1. Introduction

Lightning-related fatalities and economic losses have inspired extensive cloud-to-ground (CG) lightning research, much of which has used data from the National Lightning Detection Network (NLDN). The NLDN began full-time operations in 1989 (Orville 2008), and changing performance requirements have motivated major upgrades during 1994–95 and 2002–03 (Cummins and Murphy 2009). It is important to examine NLDN-derived CG characteristics following the most recent upgrade because regional verification studies and operational applications require knowledge of its detection capabilities. Lyons et al. (1998) stated that "given the large regional variability in lightning characteristics, one might ask if they are truly meteorological in nature, or could they be in part artifacts of the measurements?" Cummins et al. (2005) also emphasized the need to differentiate between real climatological differences in measured lightning parameters and the performance of the lightning-detection network. Therefore, we apply the same methodology to pre- and postpgrade NLDN datasets to allow direct quantitative comparisons between them and thereby examine the influence of the recent upgrade on observed CG lightning characteristics.

Several climatologies have described CG patterns over the contiguous United States prior to the 2002–03 upgrade (e.g., Orville and Huffines 1999, 2001; Zajac and Rutledge 2001; Orville et al. 2002). These climatologies documented the spatial and temporal distribution of CG flashes, as well as their polarity, estimated peak current, I_p, and multiplicity (i.e., number of return strokes). They revealed complex patterns that showed strong geographical, diurnal, and interannual variability (Orville et al. 2002). These studies also related variability in the CG distributions to varying environmental conditions and storm-scale processes. This large-scale

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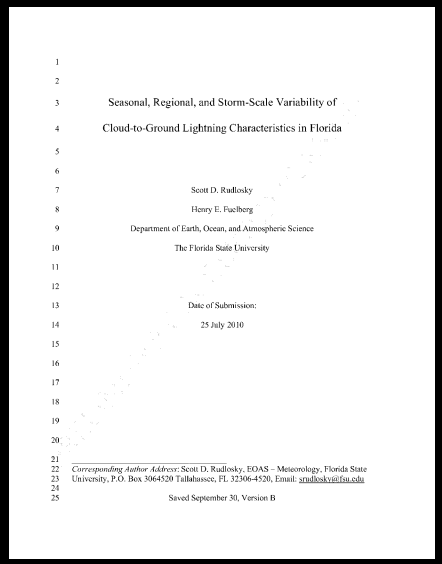

Seasonal, Regional, and Storm-Scale Variability of

Cloud-to-Ground Lightning Characteristics in Florida

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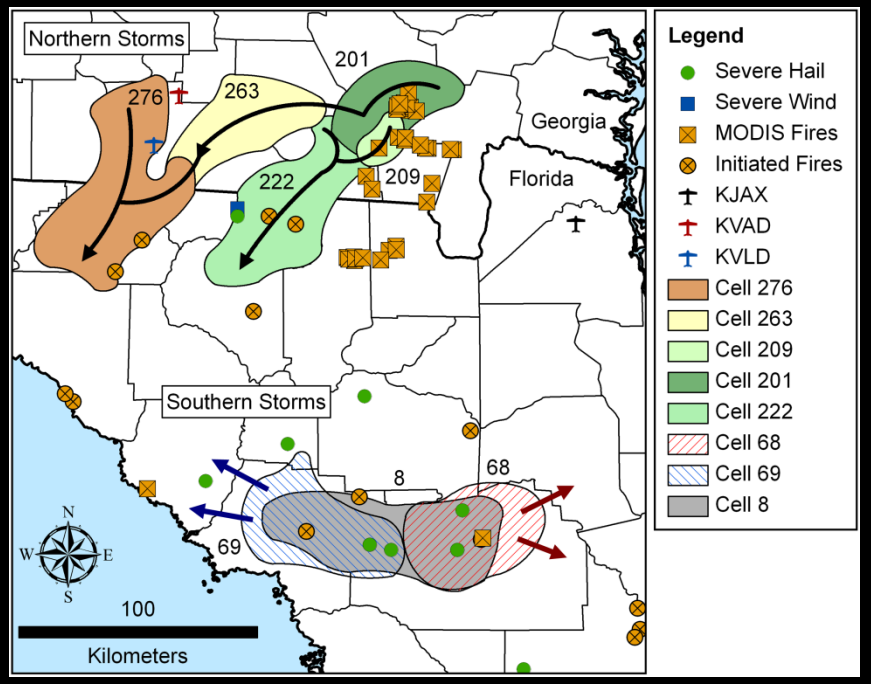
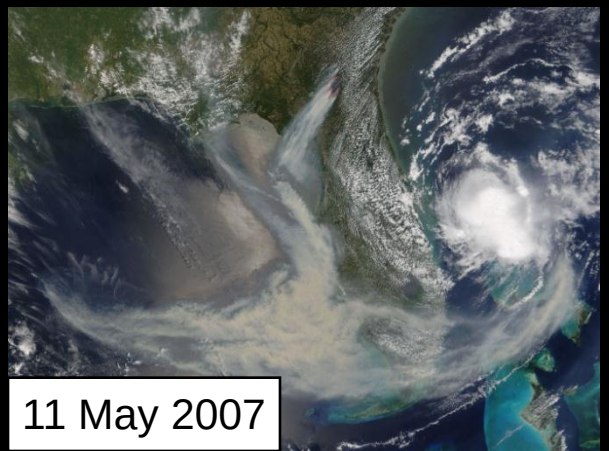
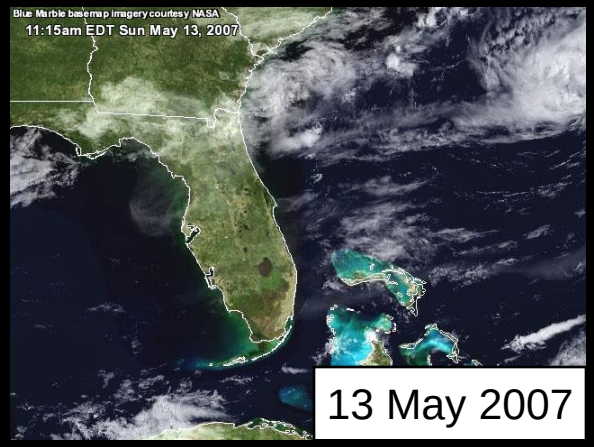
Saved September 30, Version B

Case Study 13-14 May 2007

- Much of Florida was experiencing a severe drought as a surface cold front approached the area
- Okefenokee wildfires were producing widespread smoke
- Two distinct regions of storms
  - Drier environment to the north
  - Sea-breeze induced convergence to the south
- Both regions initiate wildfires and produce severe weather





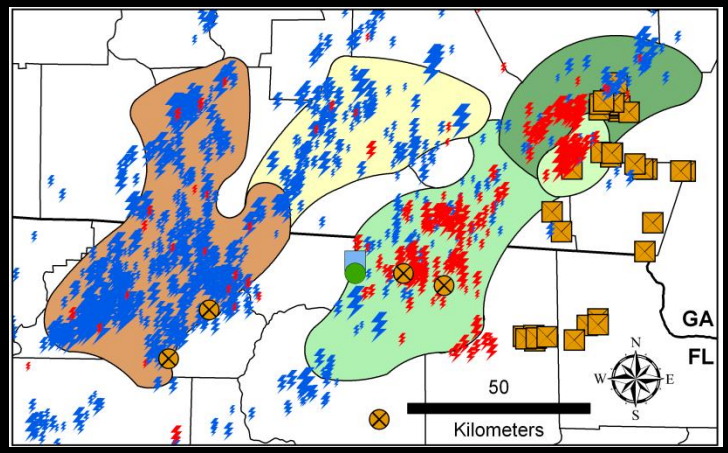


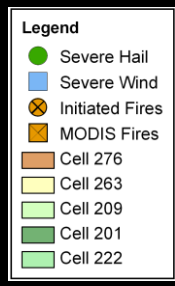
Storms nearest the active wildfires produce predominately +CG flashes

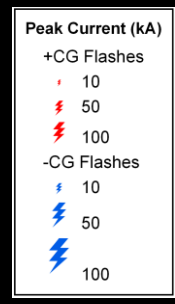
- Smoke-enhanced +CG production
  - Observed in storms directly associated with the source fires, and also in storms at long distances down wind
- Reversed polarity charging likely is related to…
  - Strong updrafts (less entrainment)
  - Smoke-related CCN (larger, but fewer) increased competition
  - Greater supercooled water content in the mixed phase region
- Strong +CG flashes often exhibit both large I_p and LCC

Red = +CG
Blue = -CG

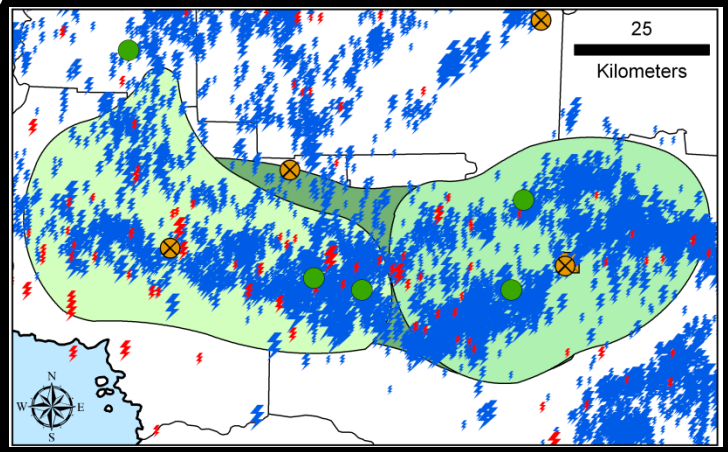
Northern Storms

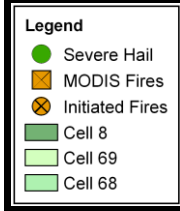






Southern Storms





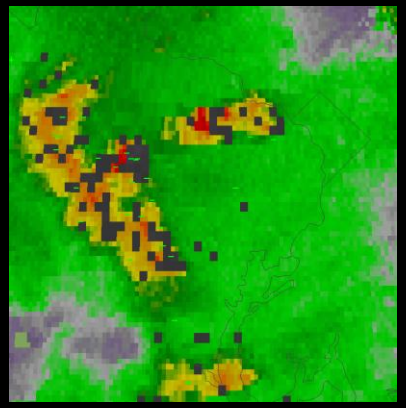
Research Objectives

- Determine relationships between lightning and radar to better differentiate between severe and non-severe storms
- Examine environmental influences on storm structure, severity, and lightning production in the Mid-Atlantic region
- Compute correlations between CG and IC characteristics, and also between lightning and radar parameters
- Investigate how storm structure (isolated vs. line/multicell) influences lightning production and its relation to storm severity
- Compare IC products at 2×2 and 8×8 km resolutions with both CG lightning and radar-derived parameters to investigate the suitability of the coarser GLM resolution

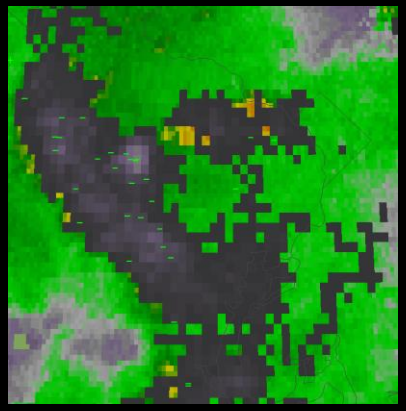
Warning Decision Support System

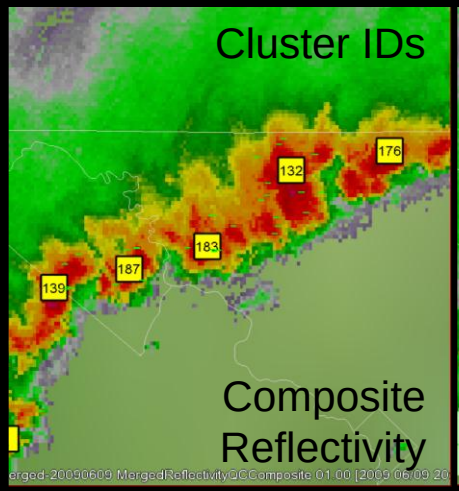
- Generate lightning and radar products
  - NLDN, LDAR/LMA, GLM-FED
  - RUC-derived near-storm environment
  - WSR-88D, plus *merged* parameters
- Identify and track individual storm cells
  - Track total lightning and radar parameters within individual storms
  - Many variations of parameters
- Prepare storm database
  - Automated procedures
  - Statistical analyses of many lightning and radar-derived parameters

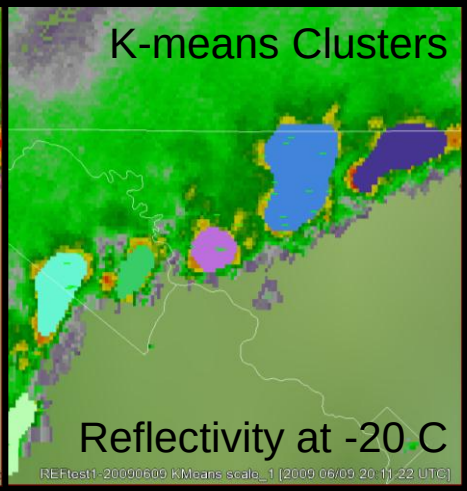
Flash Initiation Density



Flash Extent Density



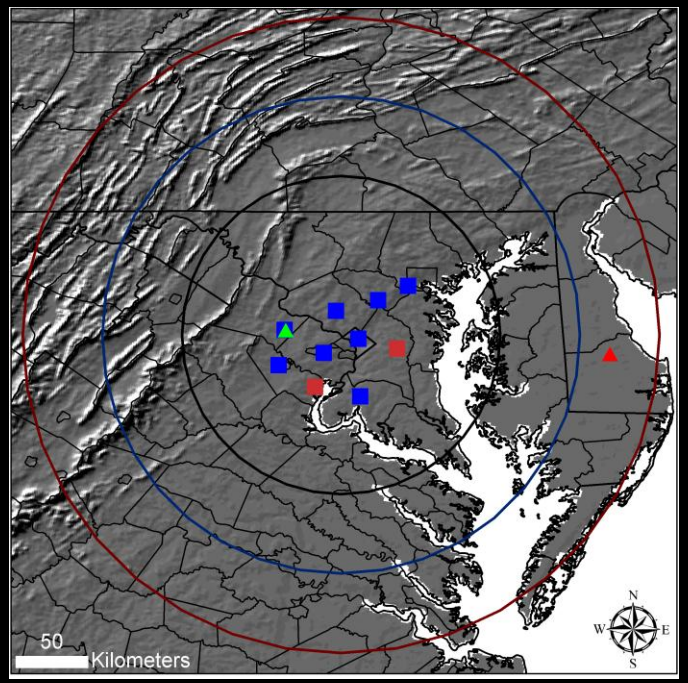




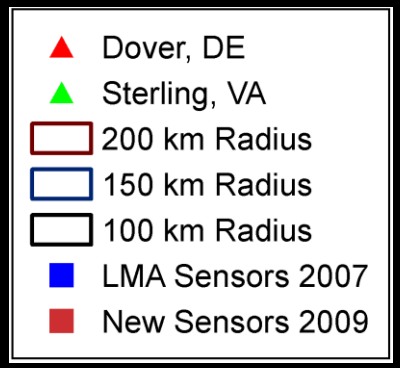
Study Overview

- Introduces our analysis methods and the resulting storm database
- Many storms on 61 case study days
- Compare and Contrast
  - Severe versus Non-Severe
  - Isolated versus Line/Multicell
- Total Storms = 1697 (1242)
  - 59,869 (34,953) 2-min points = 1995 h
  - Average duration = 61 min
  - 471 Severe
  - 1217 Non-Severe

Mid-Atlantic Study Domain



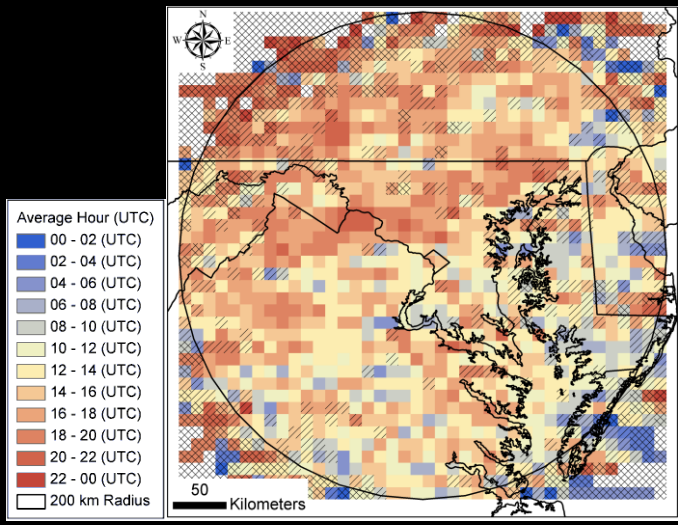
- Sample size (N) strongly influences our statistical results



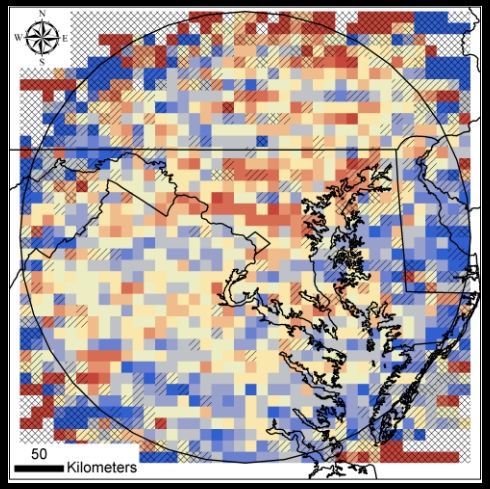
Synoptic and mesoscale systems influence storm distributions

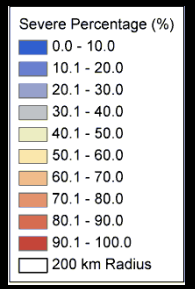
- Manual inspection of all 1697 storms revealed several recurring features
- Spatial GIS plots illustrate these features
  - Help identify locations where synoptic and mesoscale lifting mechanisms most often combine to support severe storm initiation
- Average hour shows the importance of diurnal heating in this region
- Isolated (severe) storms occur most frequently over central Maryland

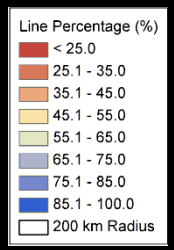
Average Hour (UTC)



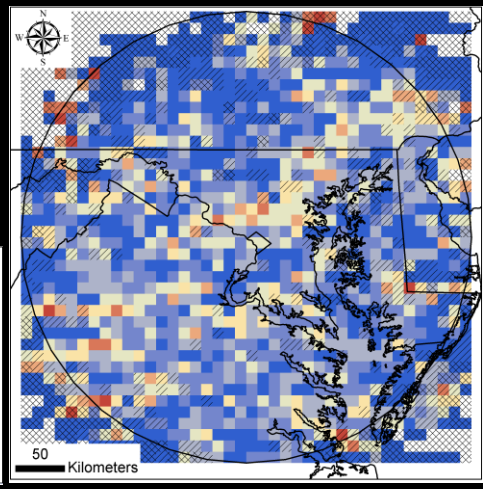
Severe Percentage







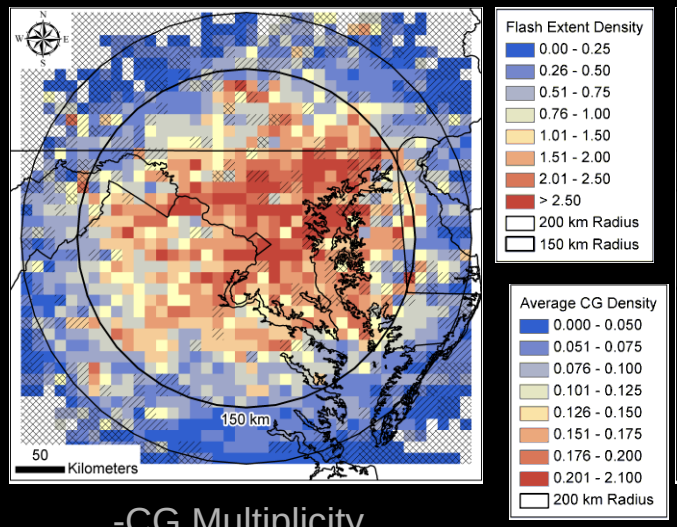
Line/Multicell Percentage



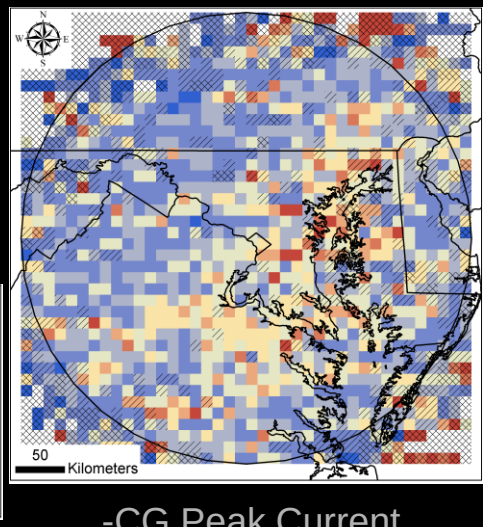
Storms exhibit considerable variability within the Mid-Atlantic Region

- Storm Interaction
  - Proximity of cells effects the IC/CG ratio
  - Varying lifecycle stages
- Isolated Storms
  - Large IC/CG ratio
  - Less frequent CG
- Line/Multicell Storms
  - More frequent CG
  - Most common in the coastal regions
- -CG Characteristics
  - Greatest in coastal regions and line/multicell storms

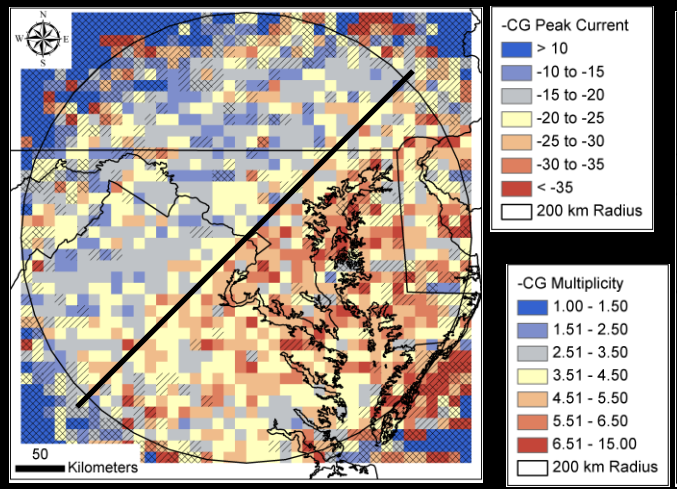
IC Flash Extent Density



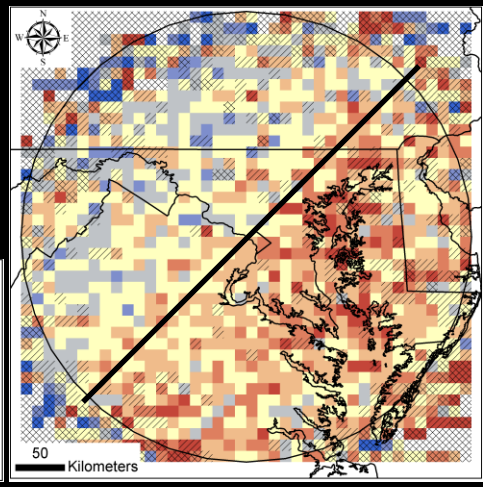
-CG Flash Density



-CG Multiplicity



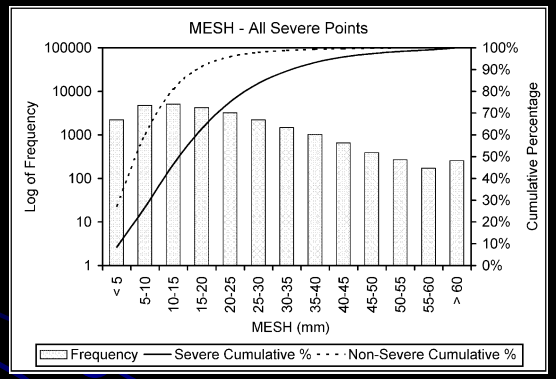
-CG Peak Current

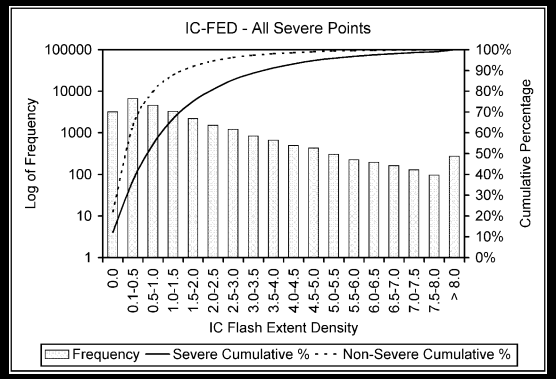


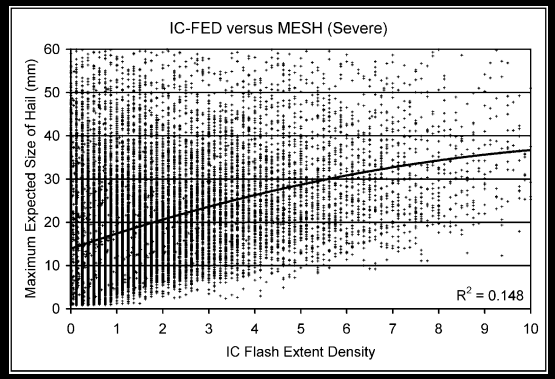
Both lightning and radar characteristics are indicative of storm intensity

- Histograms can provide a first guess if a storm is severe or not
- Scatter plots reveal differences between severe and non-severe storms, but show similar relationships between lightning and radar

Severe Storm Points

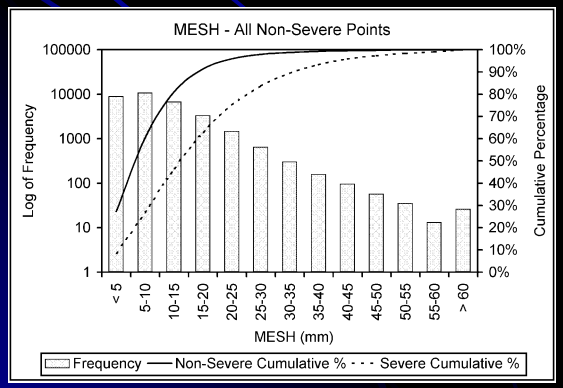


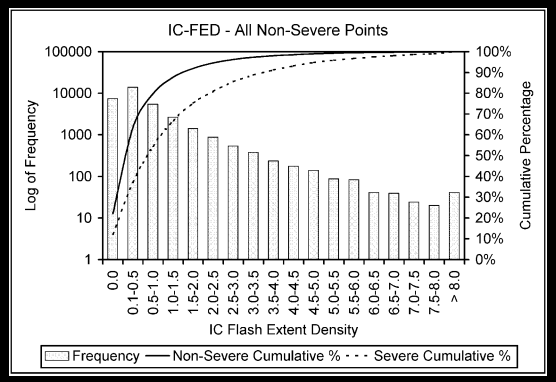


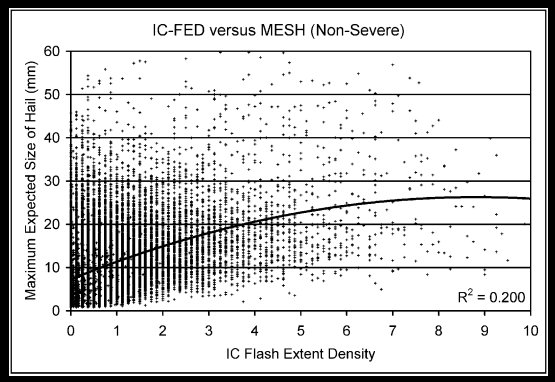


MESH (mm) IC-FED IC-FED versus MESH

Non-Severe Storm Points







Correlations identify relationships between lightning and radar parameters

- Confirmed several relationships that previously had only been documented in relatively few storms
- Flash-based IC products are better correlated with CG lightning and radar-derived parameters than are source-based products
- MESH, a composite of several radar parameters, is better correlated with IC–FED (0.542) than –CG flash density (0.482)
- Strong correlation between 2×2 km and 8×8 km IC-FED (0.935)
  - Both resolutions are similarly correlated with CG and radar parameters
  - Suggests that the GLM will provide valuable storm-scale IC information comparable to the 2–D information provided by local LMA networks

Additional Results

- Similar relationships exist between IC, CG, and radar-derived parameters in both severe and non-severe storms
- +CG peak current is inversely correlated with IC lightning and radar-derived measures of storm intensity
- -CG multiplicity and I_p are inversely related on the storm scale, and are greatest in deep (line/multicell) storms
- Although IC products appear necessary to diagnose the severity of isolated storms, –CG characteristics might help diagnose the severity of line/multicell storms

Summary

- Demonstrated our ability to examine many lightning and radar parameters in a large number of storms
- Revealed storm-scale relationships between CG and IC characteristics, and also between lightning and radar parameters
- Identified differences between isolated and line/multicell storms
- Showed that individual lightning and radar parameters can help determine the likelihood that a given storm is severe
- Combinations of CG and IC datasets will ensure that these data are used to best advantage both now and in the future

Ongoing Research

- Future research topics
  - Determine the proper sample size – time scale of independence
  - Establish an IC correction factor to expand our domain
  - Examine more specifically defined structure and severity categories
  - Develop a probabilistic measure of storm severity
- Analysis of IC and CG lightning and their relation to specific atmospheric conditions and storm-scale processes will help provide for a smooth transition to GLM operations