Characteristics of Positive Cloud-to-Ground Lightning

Scott D. Rudlosky, Dept. of Meteorology, Florida State University

Henry E. Fuelberg, Dept. of Meteorology, Florida State University

Motivation and Goals

- Florida Power and Light Corporation dispatchers have observed increased damage from positive cloud-to-ground (+CG) lightning strikes.
- Describe the characteristics and patterns of +CG in Florida to determine the threat that it poses and if the daily variability in its occurrence can be predicted.

Data and Methods

- National Lightning Detection Network (NLDN) cloud-to-ground (CG) lightning data.
- Rawinsonde data from Tallahassee, Jacksonville, Tampa, and Miami.
- Flash densities are computed on a 2×2 km grid utilizing Geographic Information System techniques.

Image depicts the location of NLDN sensors in the Southeast U.S. **Jerauld et. al. 2005.**

Positive CG Characteristics

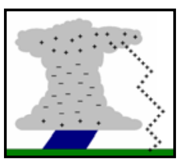
- +CG lowers positive charge from cloud to ground.
- Accounts for ~10% of CG globally (Uman 1987).
- Characterized by Rakov (2003)
  - Greatest recorded lightning currents
  - Largest charge transfer to the ground
  - Normally consists of a single return stoke

Charging Mechanism

- Non-inductive charging occurs as particles of varying size and phase collide in the charging zone (Saunders et al. 1991).
- Above the charge reversal level, the larger graupel and/or hail particles carry negative charge to the lower levels, while the updraft carries smaller positively charged ice crystals to the upper levels, resulting in the typical dipole charge structure.
- However, the charge structure in deep convection is more complex, with three or more significant charge layers (Stolzenburg et al. 1998).

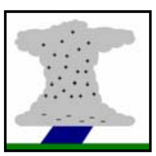
Positive CG Mechanisms

- **Tilted Dipole (Tripole)**
  - Occurs as upper level positive charge is exposed to the ground in highly sheared environments (Brook et al. 1982).
  - The advection of charge explains some of the +CG that occurs in the anvil and stratiform regions of thunderstorms.



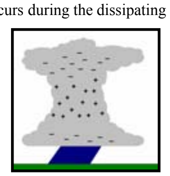
Tilted Dipole

- **Precipitation Unshielding**
  - After the heaviest precipitation has fallen from a cell, the upper level positive charge is exposed to the ground.
  - Abundance of positive charge depends on the duration and severity of an individual storm (Carey and Buffalo 2007).
  - Explains some of the +CG that occurs during the dissipating stage of thunderstorms.



Precipitation Unshielding

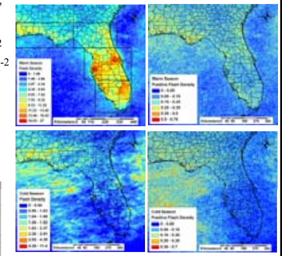
- **Inverted Dipole**
  - Under certain conditions, the riming graupel and/or hail particles are positively charged, while the smaller ice crystals receive a negative charge (Saunders et al. 1991).
  - Explains some of the +CG occurring in the region of deepest convection and heaviest precipitation.



Inverted Dipole

Large Scale Distribution

- The percentage of +CG varies by season, by geographical region, and by storm.
- Flash densities have units of flashes km^{-2} season^{-1} (warm and cold) and flashes km^{-2} year^{-1} (annual).
- The percentage of +CG generally is greater during the cool season and in the northwestern portion of the domain.



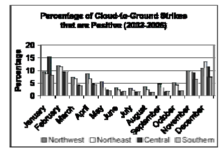
Warm and cool season total and positive CG flash densities. Four regions used in regional analyses also are depicted (top left).

	Positive			Total			
Month	Median kA	Mean Multiplicity	Count	Median kA	Mean Multiplicity	Count	Percentage Positive
January	24	1.28	24 030	20	2.42	176 857	13.59
February	26	1.37	31 720	18	2.54	306 540	10.35
March	22	1.39	79 479	16	2.34	1 040 930	7.64
April	22	1.42	97 305	16	2.42	1 238 759	7.86
May	22	1.45	60 373	16	2.53	1 241 854	4.86
June	20	1.67	78 833	18	2.66	2 937 316	2.68
July	20	1.77	105 645	20	2.65	4 385 558	2.41
August	20	1.89	118 538	20	2.75	4 560 952	2.60
September	20	1.73	39 069	20	2.80	1 236 970	3.16
October	20	1.47	20 939	18	2.64	485 666	4.31
November	22	1.43	28 488	20	2.57	282 110	10.10
December	24	1.37	29 773	20	2.38	264 022	11.28

Composite monthly (2002-2006) statistics and counts for the entire domain depicted to the upper right.

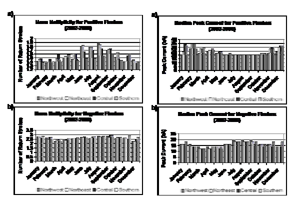
Regional Distribution

- The percentage of +CG is greater during the cool season; however, the number of +CG flashes actually peaks during the warm season.
- Greater median peak current and smaller multiplicity of +CG occur during the cool season (consistent with previous studies).
- However, during the warm season +CG is characterized by smaller median peak currents and greater multiplicity.
- The maximum annual +CG flash density was 0.75 flashes km^{-2} year^{-1}, while the maximum total CG density was 28.1 flashes km^{-2} year^{-1}.

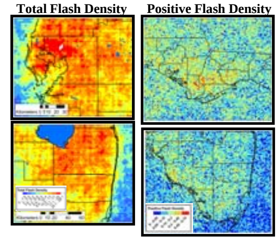


Above: Composite percentage of +CG, Below: Composite counts of +CG.

Month	Northwest	Northeast	Central	Southern
January	3 506	1 429	677	612
February	4 998	2 543	2 612	1 421
March	11 283	6 970	3 224	1 495
April	16 855	5 174	5 051	2 946
May	8 199	3 283	3 716	2 028
June	10 657	8 680	10 324	6 504
July	20 061	11 869	13 215	7 996
August	20 759	9 485	12 696	9 327
September	4 001	2 082	3 522	4 045
October	2 881	1 689	1 483	677
November	5 215	1 721	1 096	987
December	3 794	1 550	1 430	344



Composite regional and monthly mean multiplicity (left) and median peak current (right) for positive (top) and negative (bottom) flashes.



Annual total and positive flash densities for selected regions of interest.

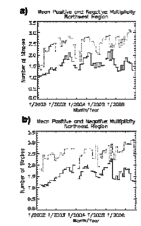
Long Continuing Current

- Enhanced damage associated with +CG is linked to its greater peak current and to the occurrence of long continuing current (LCC).
- LCC can occur with both positive and negative CG flashes and can follow each return stroke.
- Image to the right depicts LCC as faint glow between return strokes.
- +CG strikes result in the transfer of current into the ground whereas –CG strikes result in the transfer of current out of the ground.

Ron Holle (Holle Meteorology and Photography, Oro Valley, AZ)

NLDN Upgrade

- The second major upgrade to the NLDN occurred during 2002-2003, resulting in an increased stroke detection efficiency of 60-80%.
- The network also was modified to detect some cloud flashes.



Above: Mean monthly multiplicity used to depict enhanced stroke detection efficiency during 2002-2003.

	Weak Positive (+10 < BPC < +15 kA)				Positive (BPC > +15 kA)			(x / x + y)
Month	Mean Peak kA	Median Peak kA	Mean Multiplicity	Count (x)	Median Peak kA	Mean Multiplicity	Count (y)	Percentage Weak
January	12.56	12	1.31	9 077	24	1.28	24 030	27.42
February	12.67	12	1.38	15 187	26	1.37	31 720	32.38
March	12.66	12	1.40	46 762	22	1.39	79 479	37.04
April	12.61	12	1.42	55 417	22	1.42	97 305	36.29
May	12.61	12	1.52	29 389	22	1.45	60 373	32.74
June	12.65	12	1.61	63 182	20	1.67	78 833	44.49
July	12.67	12	1.67	80 994	20	1.77	105 645	43.38
August	12.66	12	1.65	81 638	20	1.89	118 538	41.51
September	12.56	12	1.54	22 638	20	1.73	39 069	36.69
October	12.66	12	1.40	15 855	20	1.47	20 939	43.09
November	13.00	14	1.32	12 644	22	1.43	28 488	30.74
December	12.66	12	1.28	12 745	24	1.37	29 773	29.96

Right: Composite statistics for entire domain comparing weak positive flashes (10-15 kA) with all positive flashes (> 15 kA) during each month.

Weak Positive Flashes

- Prior to the 2002-2003 upgrade, a threshold of +10 kA was recommended to distinguish between in-cloud and cloud-to-ground flashes.
- A post upgrade study by Biagi et al. (2007) noted *"Clearly there is no unique threshold for classifying a small-positive report as a CG stroke, but and Ip of +15 kA appears to be the value where the number of false CG reports equals the number of correct reports".*
- *"The (small) population of positive discharges between 10-20 kA are a mix of CG and cloud discharges"* (Cummins et al. 2006).
- Clearly this population is far from small during the warm season in Florida (i.e. ~ 40%).

Daily Variability of +CG

- During the passage of cold fronts, soundings can be used to determine if favorable conditions exist for the occurrence of +CG (Carey and Buffalo 2007).
  - Higher cloud base
  - Smaller warm cloud depth
  - Greater conditional instability
  - Greater buoyancy in the mixed phase zone
  - Drier middle to lower troposphere

Forecasting +CG in Florida

- 56 sounding parameters describe the stability and moisture profiles, the heights of various pressure levels, severe weather indices, and wind shear.
- The 1200 UTC soundings were compared with lightning counts and the percentage of +CG within 100 km radii of the sounding location between Noon and Midnight.
- Stepwise linear regression techniques were used to develop equations for the percentage of +CG for Tallahassee, Jacksonville, Tampa, and Miami (equation for Jacksonville shown below).

$$\text{Pos \%} = -8.772 + 0.375(\text{mean}) - 0.773(\text{TT}) + 0.405(\text{Show}) - 0.37(\text{shr}) + 0.273(\text{thetaE}) - 1.180(\text{mix}) + 0.077(\text{Pressure})$$

- Jacksonville's equation explains 9.6% of the variance; however, the equations still must be compared with climatology and/or persistence to determine the skill.
- The equations for all four cities were used to determine the following relationships.
  - Percentage Positive <u>increases</u> as...
    - Freezing level height increases
    - 1000 – 700 hPa wind speed increases
    - Showalter Stability Index increases
    - Theta E at 850 hPa increases
  - Percentage Positive <u>decreases</u> as…
    - Surface to 1 km shear increases
    - Total Totals Index increases
    - Height of -10 C increases
    - Mean mixing ratio in lowest 100 hPa increases

References: See accompanying handout.