Lightning Meteorology and Operational Considerations

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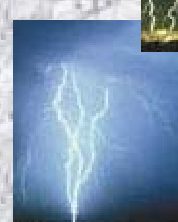
Lightning Discussion Points

- National Lightning Detection Network
- Lightning climatology
- Charge distributions within isolated storms
- Charge distributions within MCSs
- Charge distributions in cool season storms
- Negative strike dominated severe storms
- Positive strike dominated severe storms
- Operational examples



National Lightning Detection Network (NLDN)

The NLDN was started by University of Arizona scientists; it monitors millions of cloud-to-ground (CG) lightning strikes every year across the lower 48 states. The network operates 24 hours day, 365 days a year.

NLDN consists of over 100 remote, ground-based sensing stations located across the U.S. that instantaneously detect the electromagnetic signals given off when lightning strikes the earth's surface.

These sensors send data via satellite to the Network Control Center operated by Global Atmospherics, Inc. in Arizona. The data is processed to determine the location, time, polarity, and amplitude of each strike. This information then is communicated to users across the country.

Definitions

CG Flash Count: number of CGs over a specific time and area

CG Flash Rate: number of CGs per unit time over a specific area

CG Flash Density: number of CGs per unit time *and* area

CG Flash Rate (FR) depends on 4 main factors:

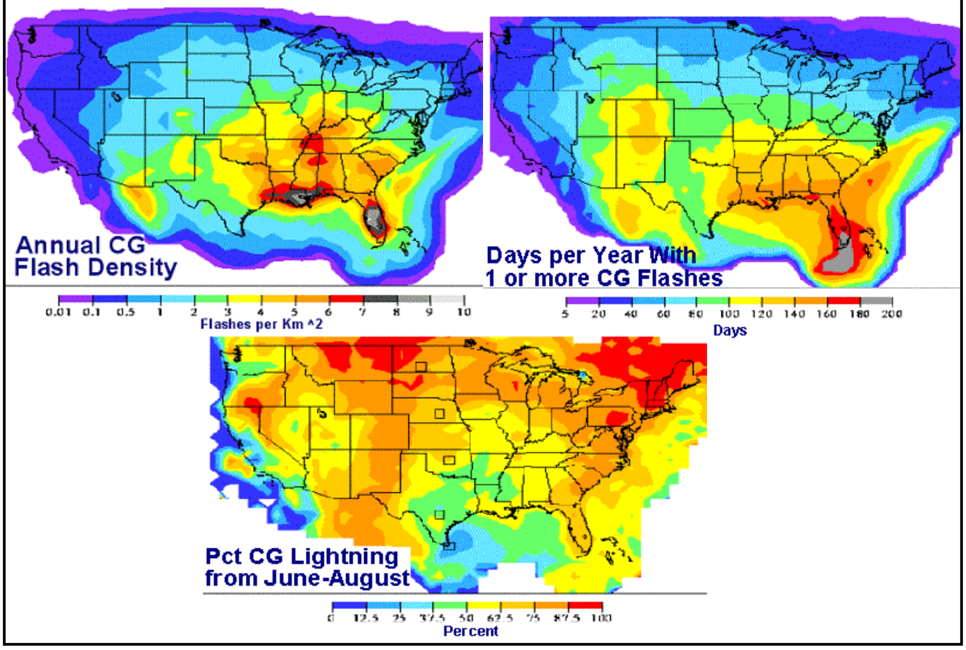
-rate of charge separation and advection
-density of cloud
-distance from cloud to surface
-amount of shielding

NSD: Negative strike dominated storms: Most thunderstorms (severe and non-severe) are NSD.

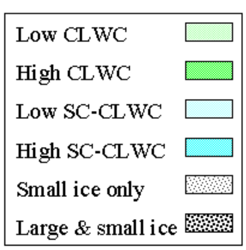
PSD: Positive strike dominated storms: Some severe storms, mainly classic supercells, can be PSD during their mature stage (but not usually throughout the entire life cycle of the storm).

CLWC: Cloud liquid water content; important to amount of graupel and polarity of charges in a thunderstorm

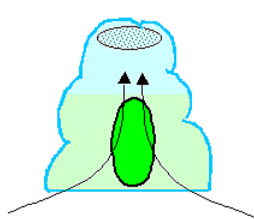
Lightning Climatology



Isolated Storms: Charge Development and Distribution

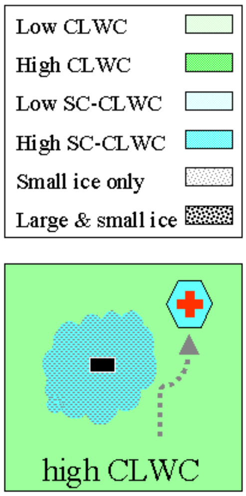


Developing Cu Stage



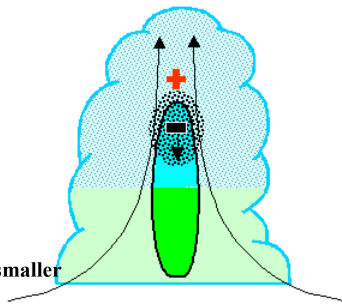
1. No graupel,
no electrification

Isolated Storms: Charge Development and Distribution



Tcu Stage

Graupel develops due to riming as supercooled water droplets contact and freeze on ice crystals between -10 and -20 C to form soft ice.



Larger graupel has (-) charge; smaller crystals above have (+) charge

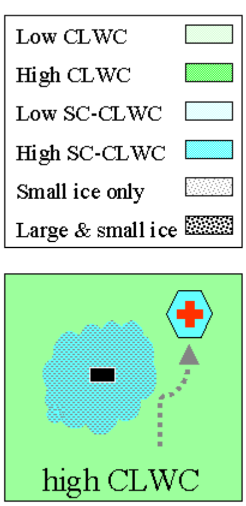
1. Electrification begins at mid-levels with the development of graupel

2. Electrification results from millions of collisions between graupel and ice crystals

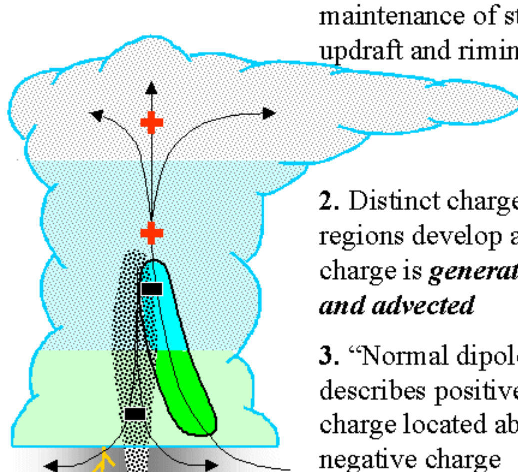
3. A small amount of charge is transferred during each collision

4. Graupel charges negative, ice crystals charge positive

Isolated Storms: Charge Development and Distribution



Mature Stage



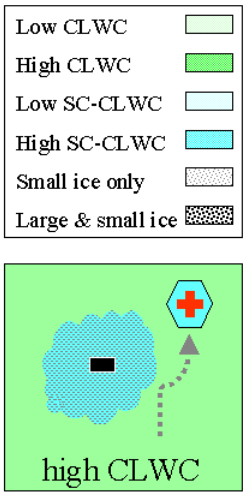
1. Electrification continues with the maintenance of strong updraft and riming

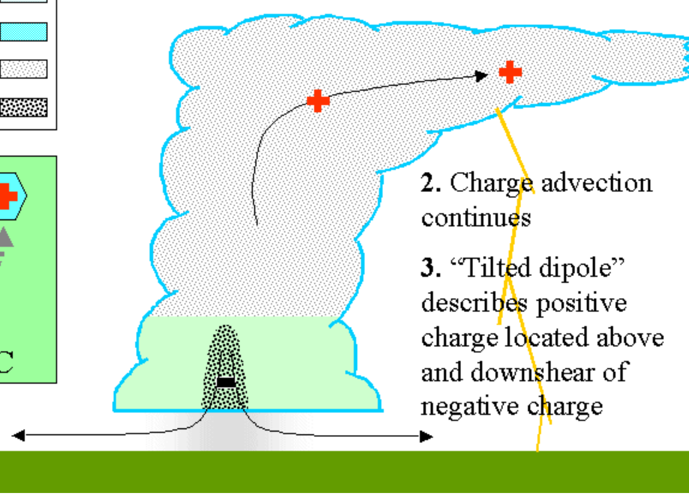
2. Distinct charge regions develop as charge is ***generated and advected***

3. "Normal dipole" describes positive charge located above negative charge

Isolated Storms: Charge Development and Distribution

Dissipation Stage





1. Charge generation ceases with weakening of updraft (no riming)

2. Charge advection continues

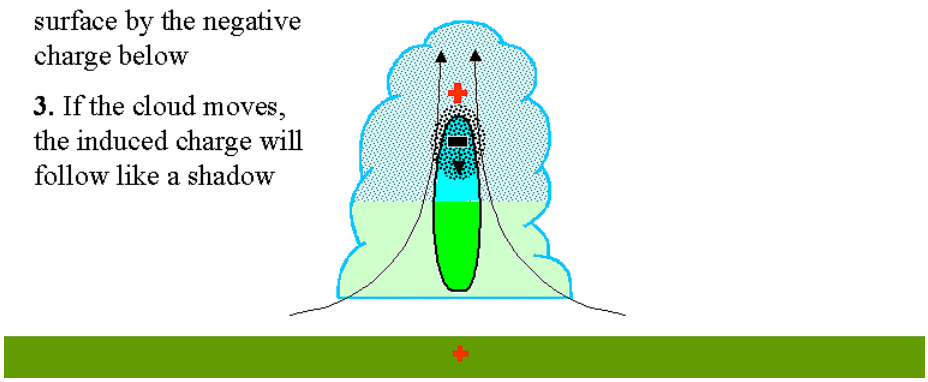
3. "Tilted dipole" describes positive charge located above and downshear of negative charge

Induction of Charge at the Earth's Surface

1. Positive charge is induced at the surface beneath the cloud as normal dipole develops

2. Upper positive charge is "shielded" from the surface by the negative charge below

3. If the cloud moves, the induced charge will follow like a shadow



Induction of Charge at the Earth's Surface

1. As graupel descends, more positive charge is induced at the surface

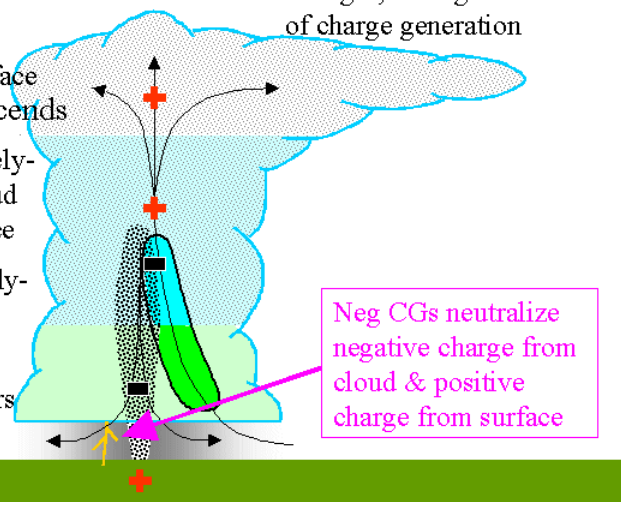
2. Electrical potential between cloud and surface builds as graupel descends

3. Channels of negatively-ionized air form in cloud and step towards surface

4. Channels of positively-ionized air extend from surface towards cloud

5. A negative CG occurs when channels meet

6. Frequency of negative CGs depends on updraft strength, riming and rate of charge generation



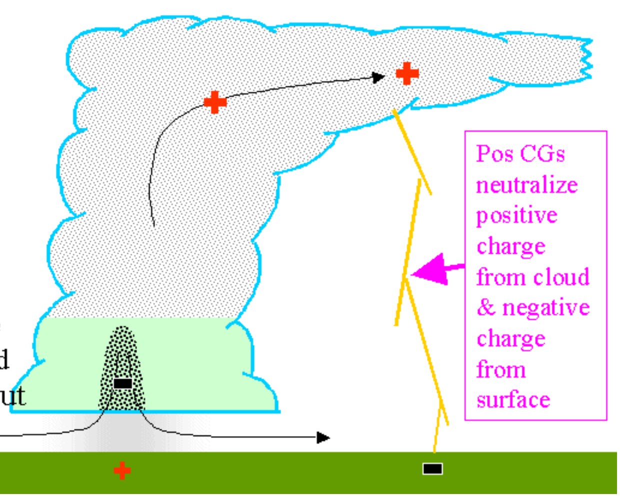
Induction of Charge at the Earth's Surface

1. Positive CGs differ in shielding and have a longer cloud-to-surface path

2. Shielding favors positive CGs downshear of negative storm core

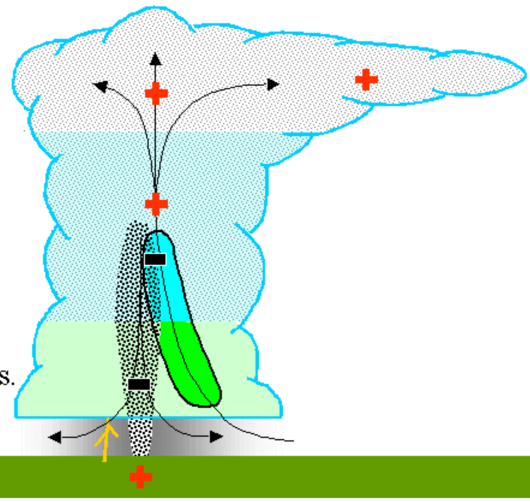
3. Longer path makes positive CGs rare, but often more powerful ("bolt from the blue")

4. Negative CGs are rare ***at this stage*** since charge generation has ceased and most graupel has fallen out



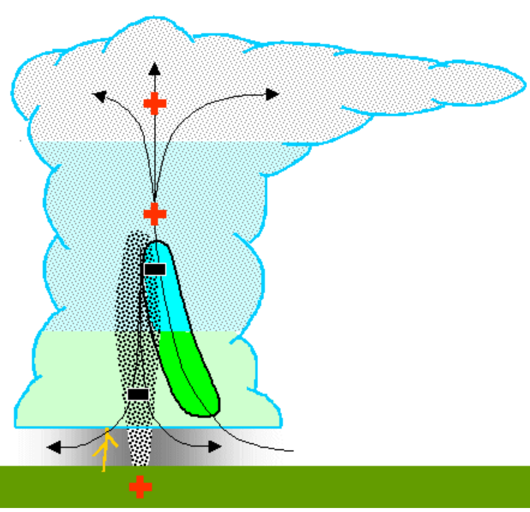
Charge Distribution in Isolated Storms

- The following characteristics are common to most warm season isolated thunderstorms
  - neg CGs are associated with convective precip
  - pos CGs are associated with the anvil
  - neg CGs greatly out-number pos CGs (except for dissipation stage)
- Exceptions occur in some severe storms and in many winter storms.



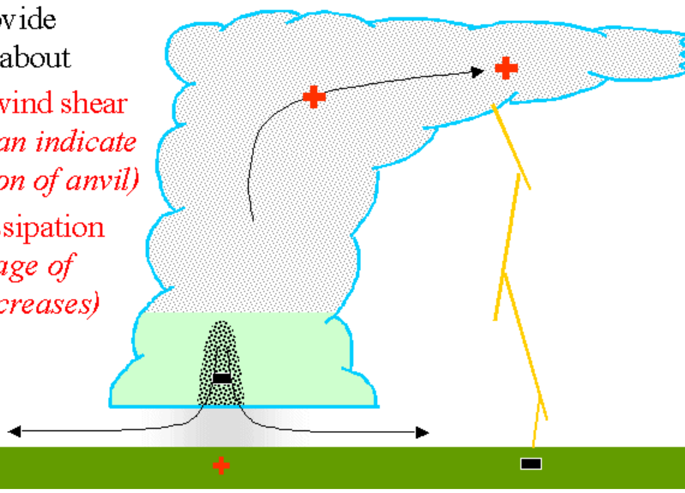
Utility of Negative and Positive CGs

- Negative CGs are associated with the fallout of graupel and provide ***spatial and temporal*** information about convective precip
- Spatial
  - storm location
  - motion
  - morphology
  - areal coverage
- Temporal
  - onset
  - intensification
  - dissipation
  - redevelopment



Utility of Negative and Positive CGs

- Positive CGs are associated with the formation of an anvil and its exposure to the earth's surface
- Pos CGs provide information about
  - vertical wind shear *(+CGs can indicate orientation of anvil)*
  - storm dissipation *(percentage of +CGs increases)*



Summary of Electrification

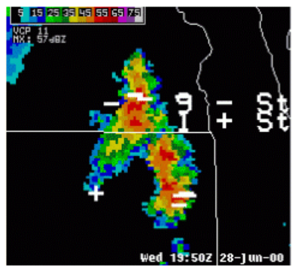
- Initial electrification occurs at what range of temperatures?
  - around T = –10° to –20°C
- What two particles are associated with electrification?
  - graupel
  - ice crystals
- What charge do these two particles acquire during collisions?
  - graupel acquires negative charge
  - ice crystals acquire positive charge
- Please describe the normal and tilted dipole charge distributions
  - normal dipole: positive charge above negative charge
  - titled dipole: positive charge above and downshear from negative charge

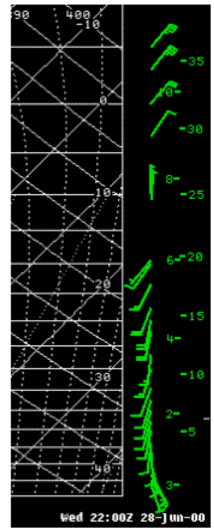
Florida Thunderstorm Case

- Positive CG occurring 10 miles away from storm core is consistent with
  - tilted dipole charge structure with positive charge on ice in anvil
  - vertical wind shear for the layer between steering- and anvil-level

Tilt
3.4°

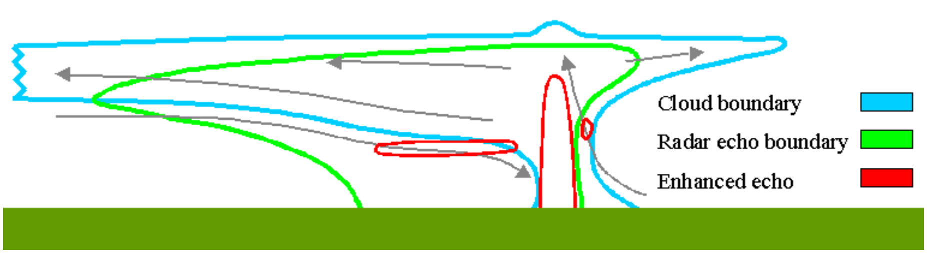
Height/Temp
9,000' ASL
9° C





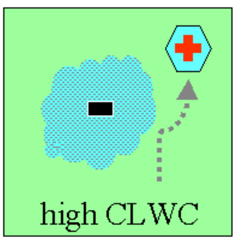
MCS Dynamics and Microphysics

- Formation of precipitation is different between convective & stratiform regions
- Convective regions are characterized by
  - -strong vertical motions (~10 m/sec) and high CLWC
  - -ice growth by ***deposition and riming***
- Stratiform regions are characterized by
  - -weak vertical motions (~0.1 m/sec) and low CLWC
  - -***advection of ice*** from convective regions
  - -ice growth by ***deposition and aggregation***
  - -no graupel (riming occurs but is secondary)



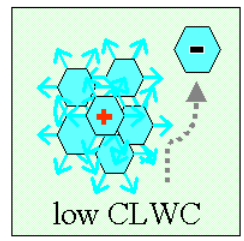
Electrification in MCSs

- Electrification is dominated by collisions between large and small ice particles due to *opposite charge* and *fall speed differential*
  - graupel-ice collisions in convective regions
  - aggregate-ice collisions in stratiform regions
- For low CLWC, cloud chamber-riming rod studies show that
  - the riming rod charges positive
  - less charge is transferred (compared to high CLWC)



In convective regions (high CLWC), graupel is (-) charged, while crystals above become (+) charged.

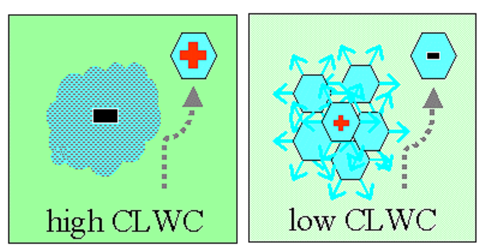
In stratiform regions (low CLWC), aggregates attain (+) charge, while crystals aloft acquire (-) charge. Less charge develops & is transferred.



Charge Distributions and CG Lightning in MCSs

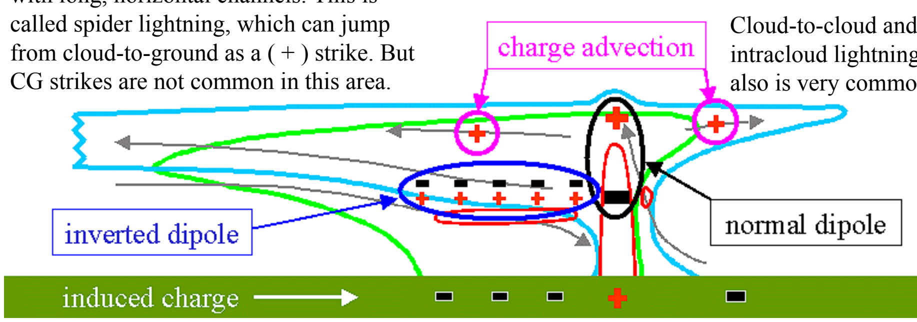
Overall charge distribution within MCSs takes into account:

-cloud liquid water content
-amount of charge transferred
-particle fall speed
-charge advection
-charge induction at surface



Broad layers of (+) and (-) charge in the stratiform area favor intracloud lightning with long, horizontal channels. This is called spider lightning, which can jump from cloud-to-ground as a (+) strike. But CG strikes are not common in this area.

Cloud-to-cloud and intracloud lightning also is very common.



Charge Distributions and CG Lightning in MCSs

Convective region:

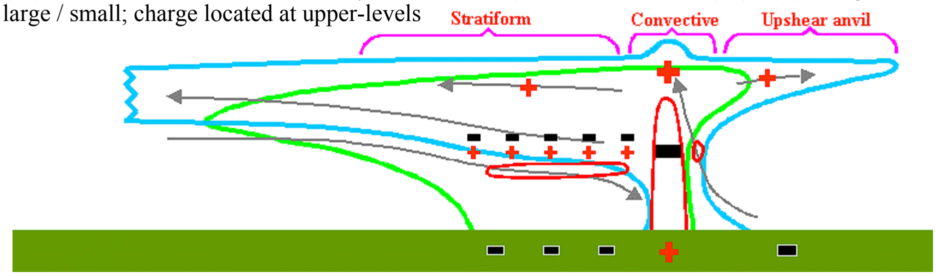
(-) CGs dominate with high flash rate (FR); low FR for (+) CGs; charge generation is high; (-) charge is dense and concentrated on graupel; (+) charge is less dense and dispersed on cloud ice at upper-levels and shielded from surface by (-) charge at mid levels

Stratiform region:

(+) CGs dominate with low FR; very low FR for (-) CGs; charge generation is small; advection of (+) / (-) charge is large / small; (+) charge located closer to surface (inverted dipole); FR is slightly higher in stratiform area than anvil region

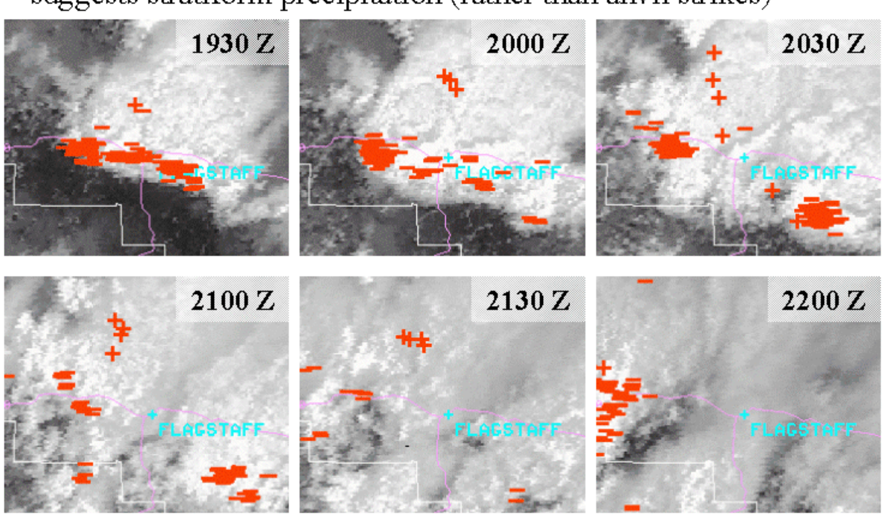
Upshear anvil region:

(+) CGs dominate with low FR; very low FR for (-) CGs; advection of (+) / (-) charge is large / small; charge located at upper-levels

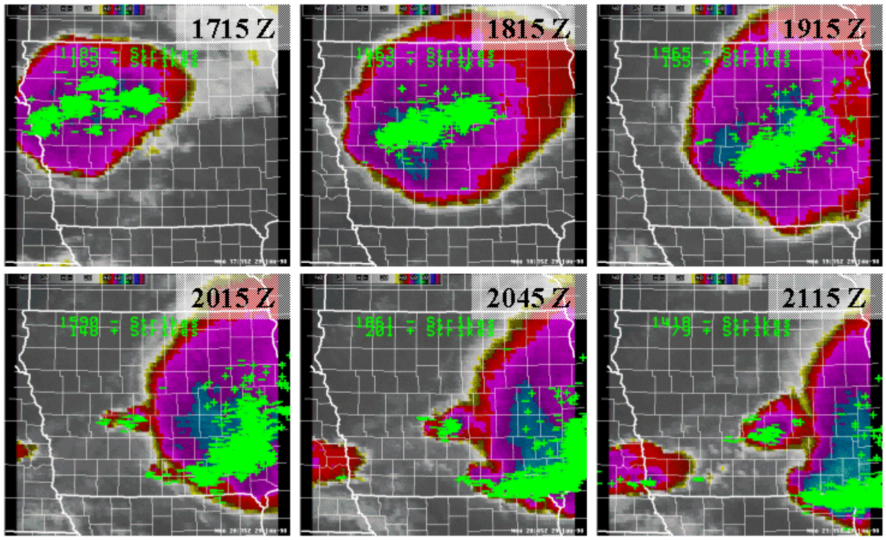


Arizona Thunderstorm Case

- Persistence of +CGs well behind the convective line strongly suggests stratiform precipitation (rather than anvil strikes)



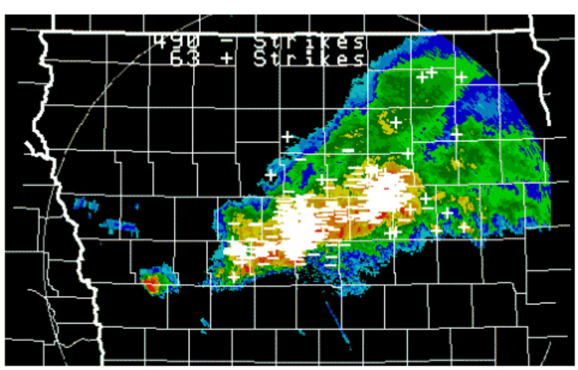
Iowa Thunderstorm Case



CG strike trends can help determine active convective regions and the evolution of storms within an MCS cloud canopy. Here, CGs suggest several active storms at 1715Z that organize into a bow echo as it races southeast by 2045Z. Some positive CG strikes appear in the stratiform portions of the MCS.

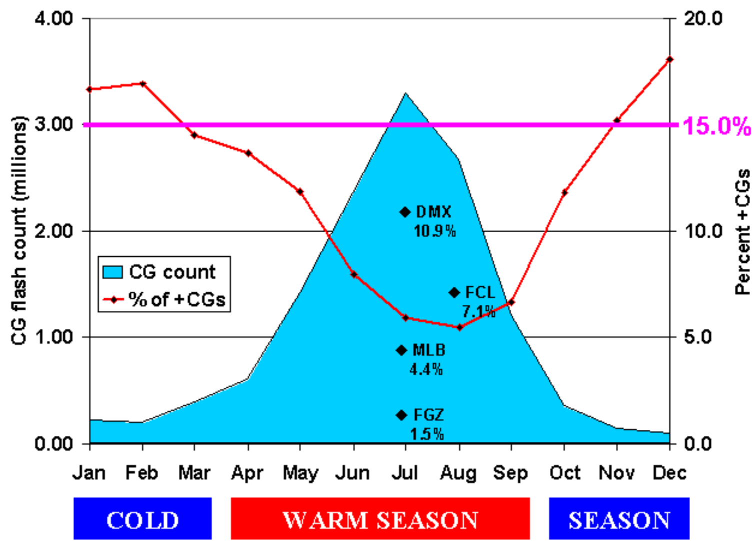
Iowa Thunderstorm Case

- Radar-lightning overlay shows the correspondence between
  - negative CGs and convective precipitation
  - positive CGs and stratiform precipitation
  - positive CGs and anvil regions (southeast portion of MCS?)



Cool Season Thunderstorms and Lightning

monthly means, averaged over the CONUS from 1995–99



The chart shows that the number of CG strikes peaks in summer, although the percentage of positive CGs is at a minimum in summer and maximum in winter. Greater than 15 percent positive CGs is considered relatively high for an average non-severe storm.

Cool Season Thunderstorms and Lightning

Warm Season Lightning:

-Most storms over most of the U.S. are characterized by less that 15% +CG strikes

Cool Season Lightning:

-Percent of +CGs (%P) is 15% or greater over most of the U.S.

-CG lightning production is much lower than in the warm season (only about 10% of annual total over U.S.)

Three factors may increase the %P during the cool season:

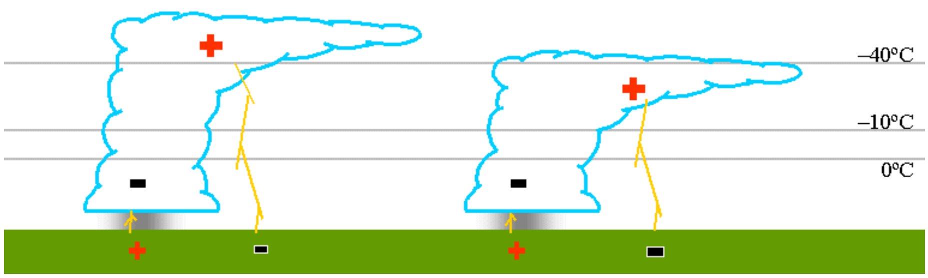
-shallower storms

-more vertical wind shear

-less cloud liquid water

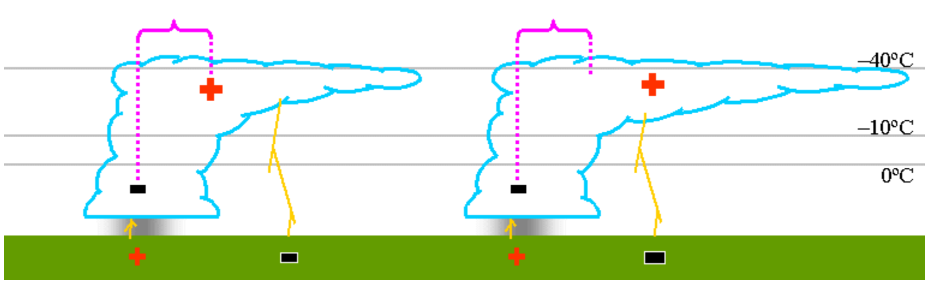
Cool Season Thunderstorms and Lightning

- Shallow storm tops
  - storms are more <u>shallow</u> during the cold season, on average, due to less heating, moisture, and vertical motions
  - cloud tops—***and upper-level positive charge***—are located closer to the surface
  - as a result, more negative charge is induced at the surface and +CGs are more likely



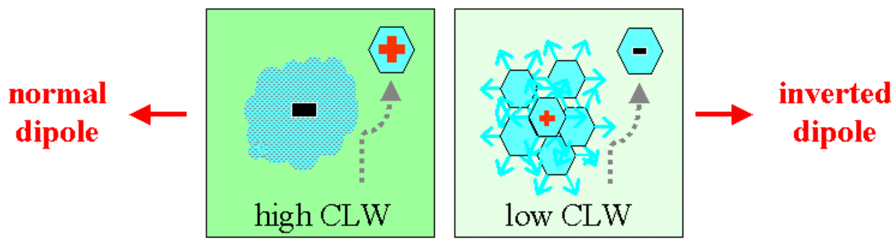
Cool Season Thunderstorms and Lightning

- More vertical wind shear
  - storms are more <u>tilted</u> during the cold season, on average, due to greater vertical wind shear
  - cloud tops—***and upper-level positive charge***—are displaced further downshear from storm core (less shielding of + charge)
  - as a result, more negative charge is induced at the surface and +CGs are more likely



Cool Season Thunderstorms and Lightning

- Less cloud liquid water
  - cloud liquid water is a function of moisture and vertical motions
  - CLW is less during the cold season, on average, due to less heating, moisture, and vertical motions
  - less CLW favors the formation of an ***inverted dipole***
  - an inverted dipole places + charge closer to surface, increasing the likelihood of +CGs



CG Flash Rate Vs. Storm Intensity

- As the updraft strengthens…
  - liquid water is condensed at a greater rate
  - graupel is produced at a greater rate
  - charge is generated and advected at a greater rate
  - the electrical potential from cloud-to-surface is ***increased***
  - CGs are produced at a ***greater*** rate

Enhanced Charging

This is a negative strike dominated (NSD) severe storm.

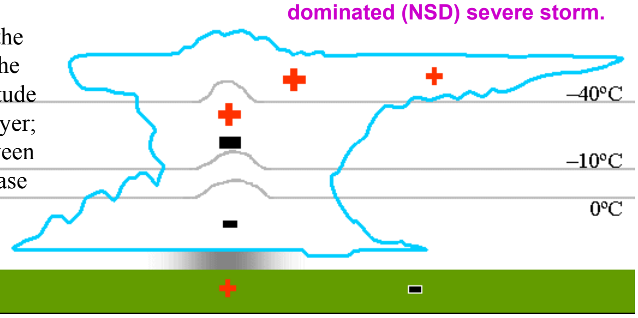
CG Flash Rate Vs. Storm Intensity

Elevated Dipole

- As the updraft strengthens …
  - the balance level for graupel & ice is elevated
  - charges of both polarities are displaced away from the surface
  - the cloud-to-surface electrical potential is ***decreased***
  - CGs are produced at a ***lesser*** rate

This is a negative strike dominated (NSD) severe storm.

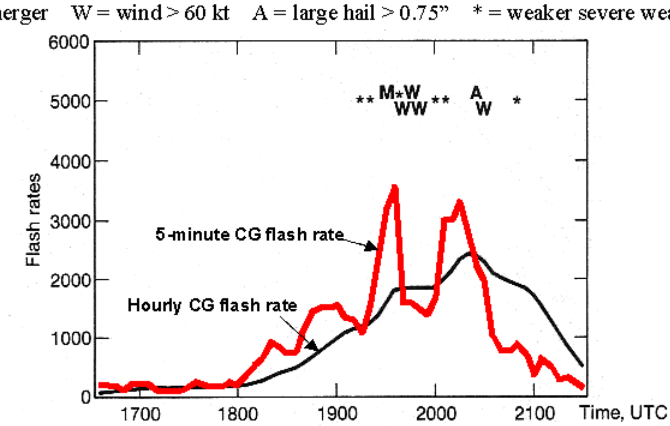
Due to an intense updraft, the thermal ridge axis within the storm results in a higher altitude of the crucial -10 to -20 C layer; thus, a greater distance between it and the ground can decrease the CG strike rate.



CG Flash Rate Vs. Severe Weather Reports

central MA on 2 June 1989

M = cell merger W = wind > 60 kt A = large hail > 0.75" * = weaker severe weather



Summary: **Unusually high and variable flash rates associated with NSD storms often are a severe weather signature as enhanced versus elevated charging occurs within the storm. Severe weather is likely near the time of pulses in CG activity.**

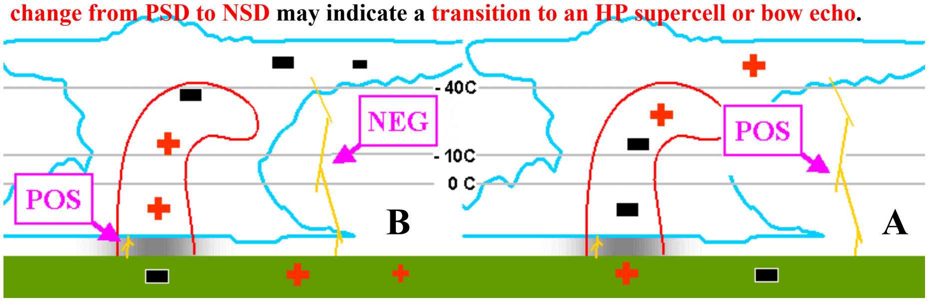
Supercells: Increased +CG Strikes

In severe storms with a tilted updraft and anvil, (+) charge aloft becomes exposed (less shielding) to the surface (-) charges. This results in an increased percentage of +CG (%P) strikes, although the storm should still be NSD (Fig. A).

Also, in severe storms with high surface theta-e but drier environmental air aloft, a relatively low cloud water content results in an inverted dipole (Fig. B). An elevated dipole (due to an intense updraft) also can lead to a relatively low flash rate at times.

Thus, classic supercell storms tend to have a relatively large percentage of +CG or are PSD during their mature stage, unlike normal thunderstorms or non-supercell storms.

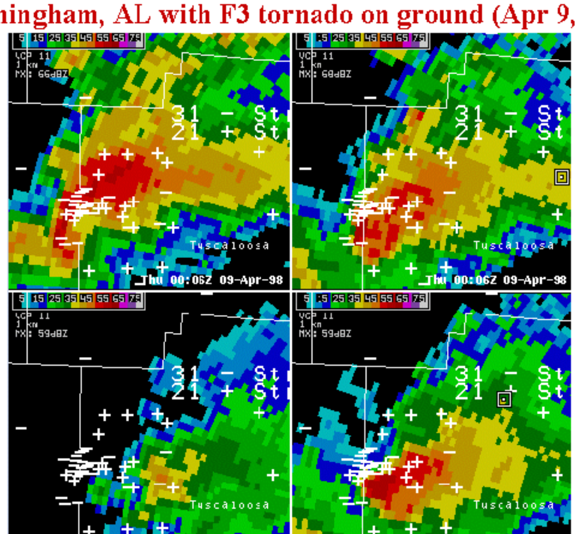
Severe PSD classic supercells are associated with large hail and tornadoes. Supercells that change from PSD to NSD may indicate a transition to an HP supercell or bow echo.



+CG Strikes in Tornadic Supercells

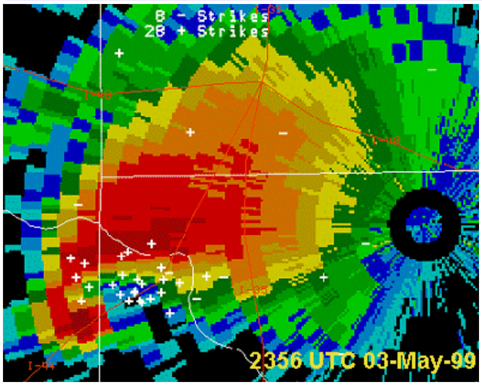
Birmingham, AL with F3 tornado on ground (Apr 9, 1998)

Tilt 0.5°		Tilt 2.4°
Height/Temp 4500' ASL 15° C		Height/Temp 13,900' ASL –1° C
Tilt 7.5°		Tilt 4.3°
Height/Temp 39,000' ASL –53° C		Height/Temp 23,200' ASL –21° C

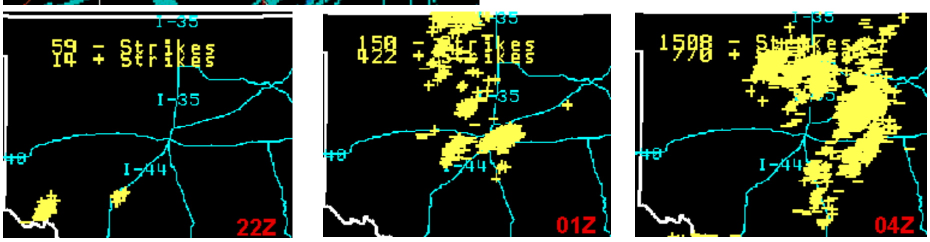


Note high percentage (40 pct) of +CG's (21) to total number (52); indicates a severe, tilted storm. Also note 3 +CG's at bottom of images; these are anvil strikes overtop of low-level weak echo region.

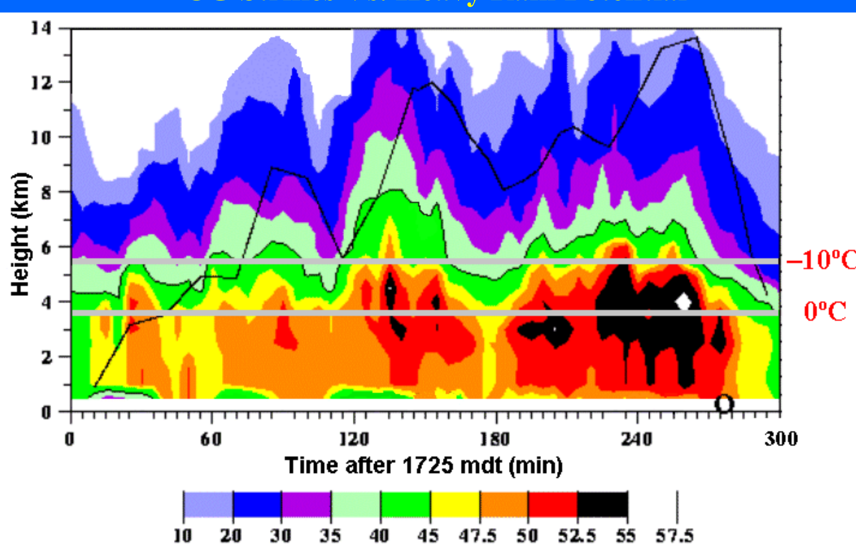
+CG Strikes in Tornadic Supercells



This supercell produced a violent tornado near Oklahoma City on May 3, 1999. Notice that it is PSD with a tornado on the ground. Note also the CG transition from NSD to PSD back to NSD as storms begin to form an MCS.



CG Strikes Vs. Heavy Rain Potential



This time-height cross-section shows a series of thunderstorms passing over same location for a few hours in Colorado. Note that highest reflectivity values are below -10 C. Thus, graupel and subsequent CG strike production would be reduced resulting in storms that are not severe (no elevated reflectivity cores) and producing relatively few CG strikes. However, efficient collision-coalescence in the low-level warm cloud (> 0 C) would result in very heavy rain and possible flooding in this cell training situation.

Summary

-Individual thunderstorms exhibit a normal dipole resulting in mostly -CG strikes; this is due to a high CLWC and charge generation via graupel and ice crystal collisions.

-MCSs are dominated by -CG strikes in the convective region, with some +CGs in the stratiform area.

-Lightning strike trends provide clues to storm location, movement, and evolution.

-Cool season storms tend to have a higher percentage of +CGs due to lower cloud tops, smaller CLWC, and more vertical wind shear.

-Severe storms tend to have a higher percentage of +CGs than ordinary storms due to a tilted updraft, but still are NSD; very high flash rates and fluctuations in flash rates often are good indicators of severe weather.

-Some classic supercells may be PSD during their mature stage due to an inverted dipole; this often is an indication that large hail and/or tornadoes may be occurring in the storm; HP storms tend to be NSD due to a high CLWC.

-There still is much to learn about lightning and its behavior in severe storms.