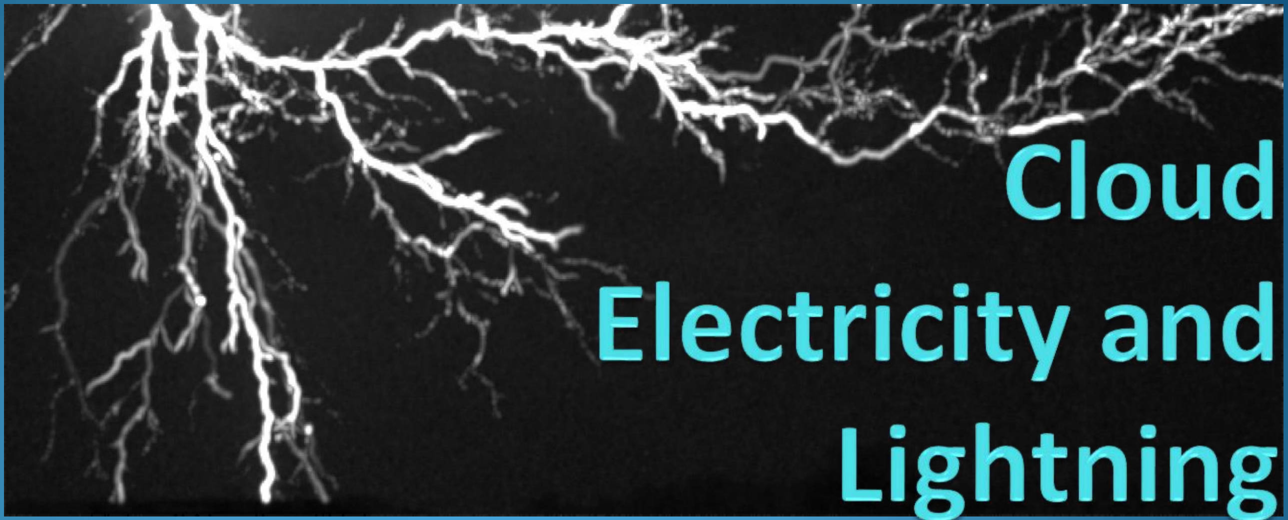


Lightning Image Courtesy Phillip Bitzer

# C-RITE Workshop

## Physical Processes in Convection

Lawrence Carey

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Lightning Image Courtesy Phillip Bitzer

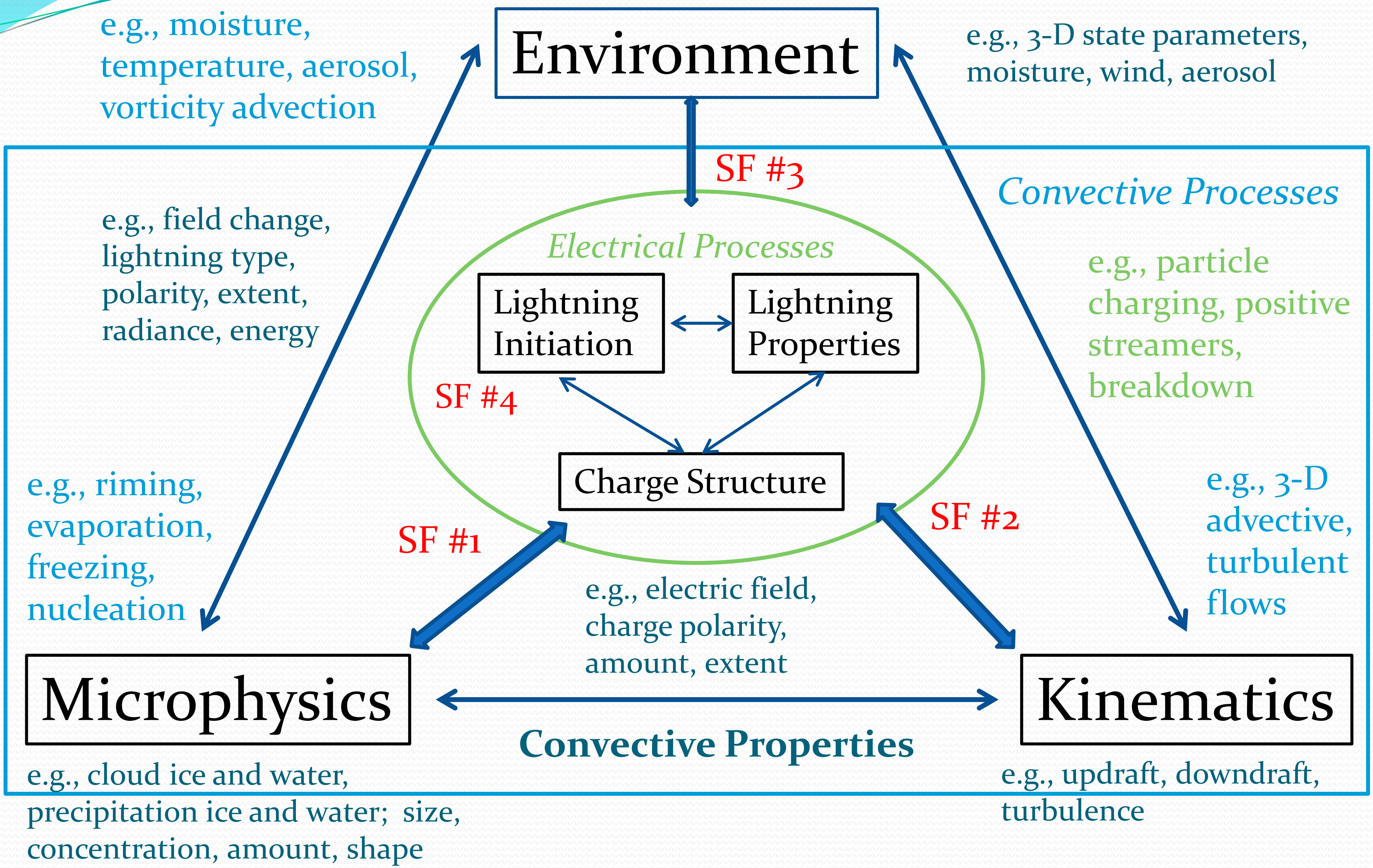
# Properties to Processes

- Community has made substantial progress in characterizing co-evolving kinematic, microphysical, electrical and lightning **properties** in storms
- NSF investment in community wide availability of facilities, e.g.
  - Lightning Mapping Array (LMA)
  - Fixed and mobile Doppler and dual-polarization radar
- Remaining gaps in measurement capabilities make it difficult to fully resolve some complex convective **processes**

# Science Frontiers

- Difficult to constrain processes with gaps in properties
  - Missing link in multi-link hypothesis chain: speculation
  - Gaps can be in scale (temporal, spatial), accuracy or availability of needed observations
- Science Frontiers – opportunities to discover, innovate, refine and validate
  - Charge structure, lightning properties
    - 1. Microphysics
    - 2. Kinematics
    - 3. Environment
  - 4. Lightning initiation

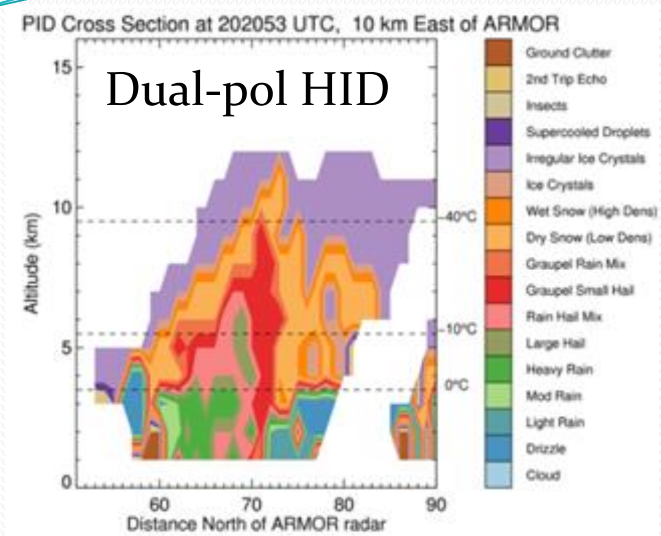
# Science Frontiers (SF)



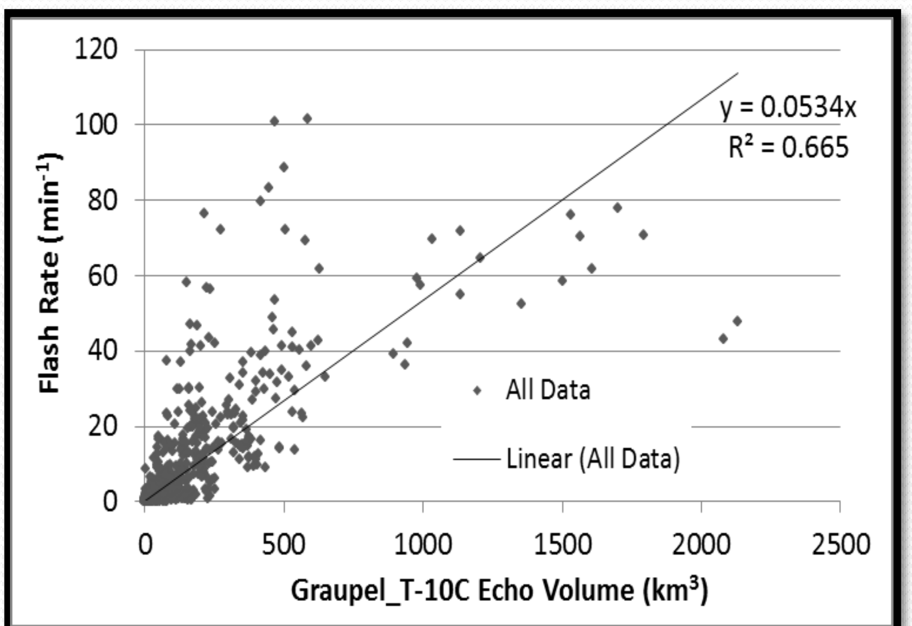
# Science Frontier #1

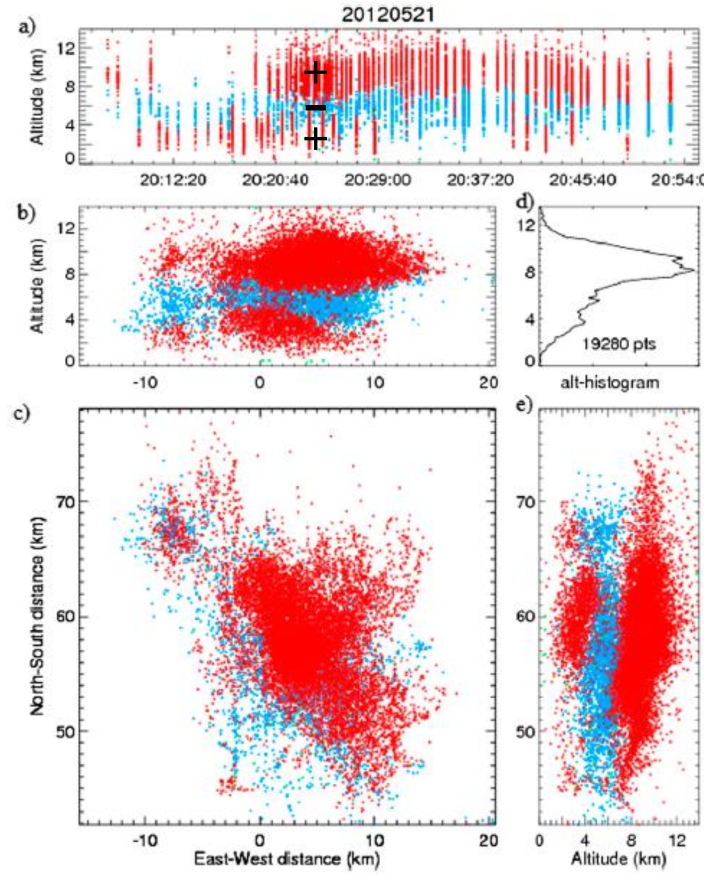
What is the role of varying *microphysical properties and processes* in establishing charge structure and polarity and resulting lightning properties as a function of storm morphology and lifecycle?

DC3
AL




- Gross relationship between graupel, charge structure and lightning well understood
- Storm to storm variability likely due in part to poorly observed properties (e.g., cloud water, cloud ice concentration).

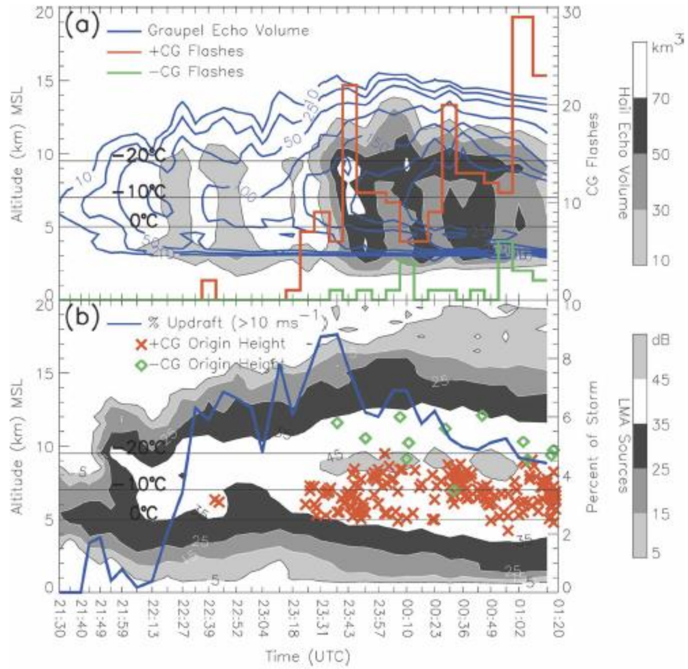



Normal
Polarity
Tripole

Lightning
Mapping
Array
(LMA)

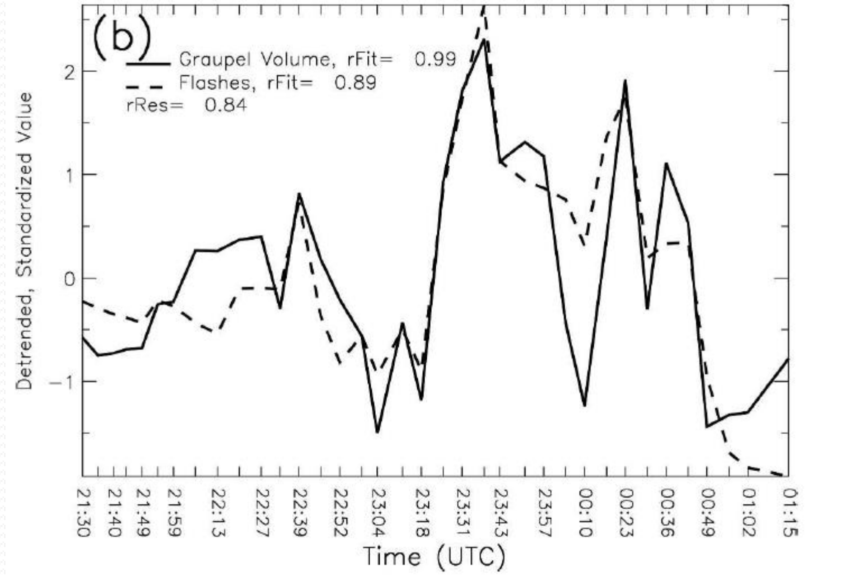
Mecikalski et al. (2015)




STEPS (2000)

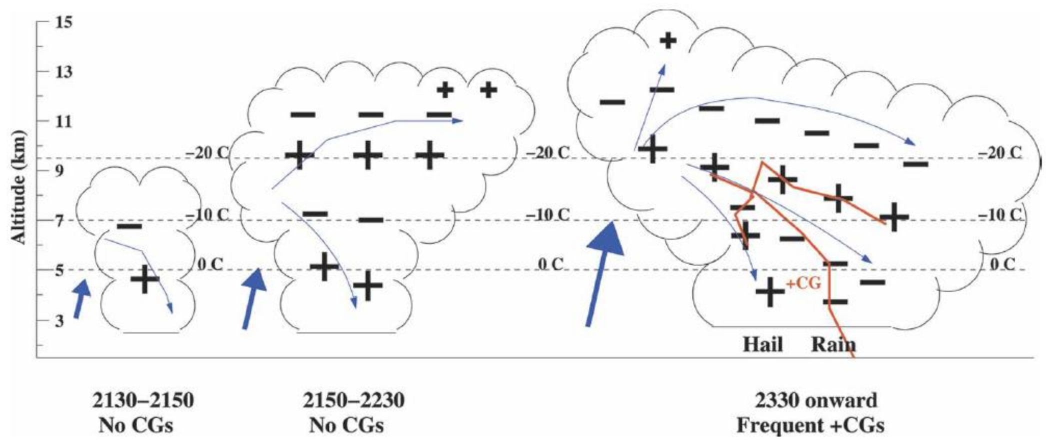
29 June CO/KS

Inverted Polarity Supercell




Wiens et al (2005)

- LMA established inverted polarity charge structure associated with +CG production in +CG dominant storms
- Total lightning and graupel similarly correlated as in normal storms
- Non-inductive charging (NIC) can explain but still speculative without new observations (e.g., super-cooled cloud water)

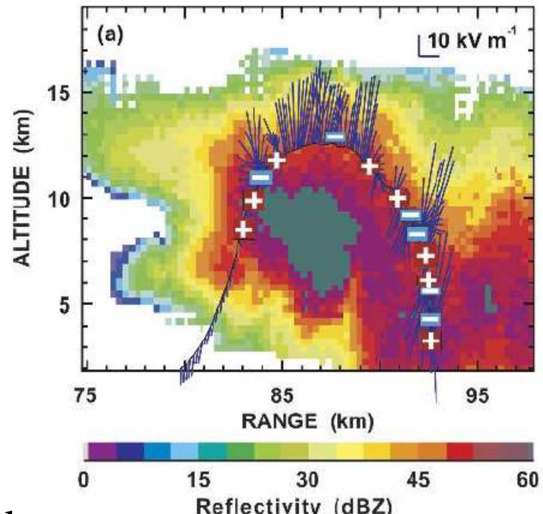



LMA inferred charge structure

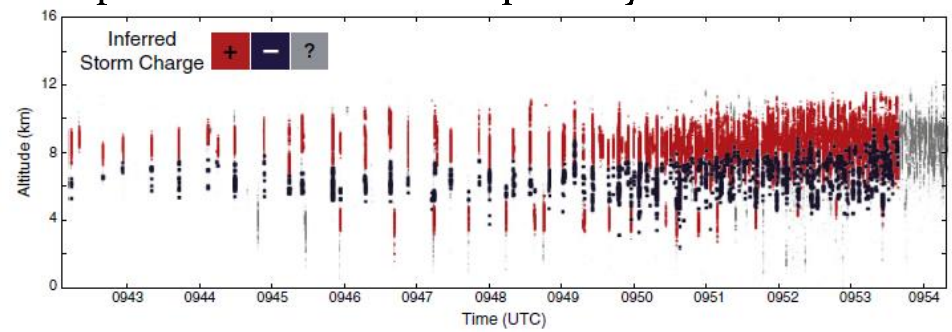
MacGorman et al. (2005)

Not all supercells have inverted polarity or dominant +CG…

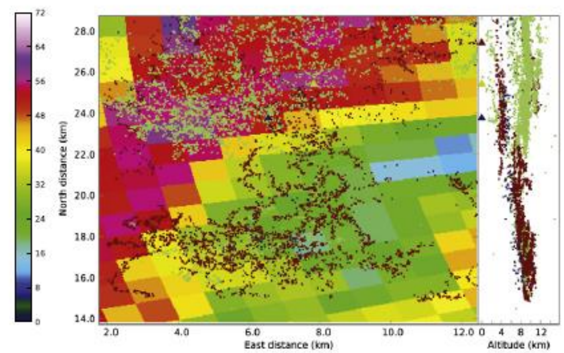
STEPS
(2000)




29 June
CO/KS
Inverted
Polarity

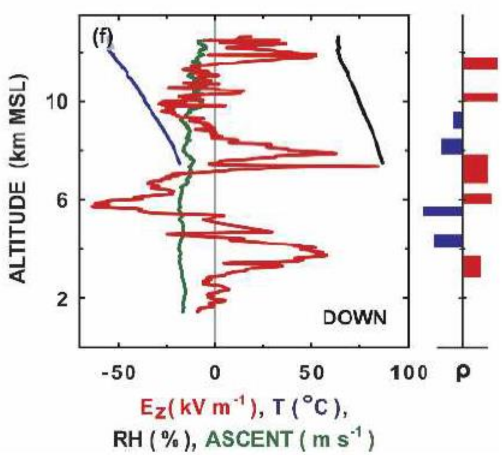


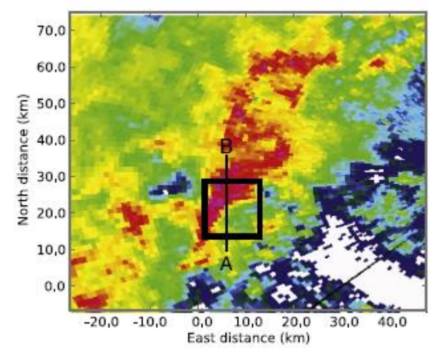

AL
Supercell
6 Feb 2008

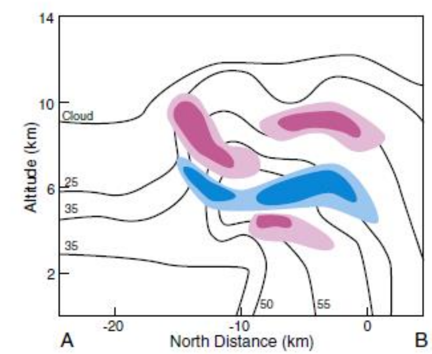



Normal
Polarity
Charge
Structure

In-situ
balloon



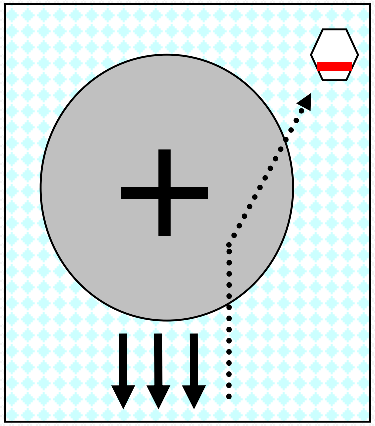



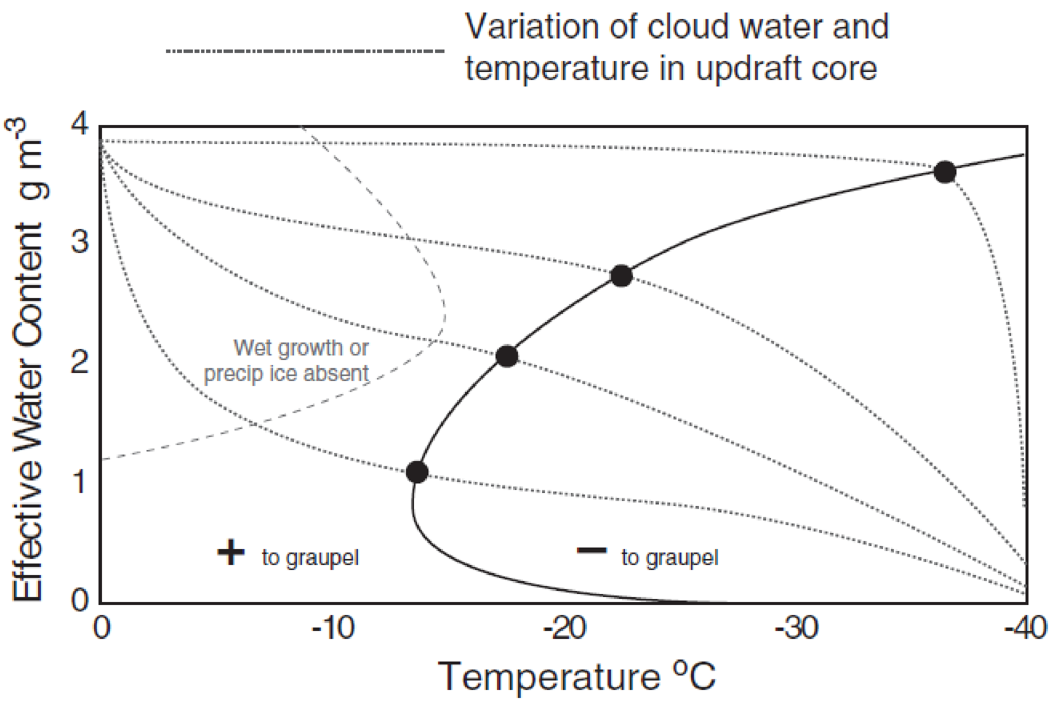

In-situ observations of E-field
(inferred charge) still important

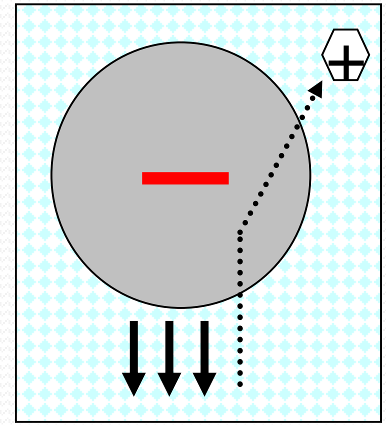
Bruning et al. (2012)

Bruning et al. (2012)

Non inductive charging (NIC)



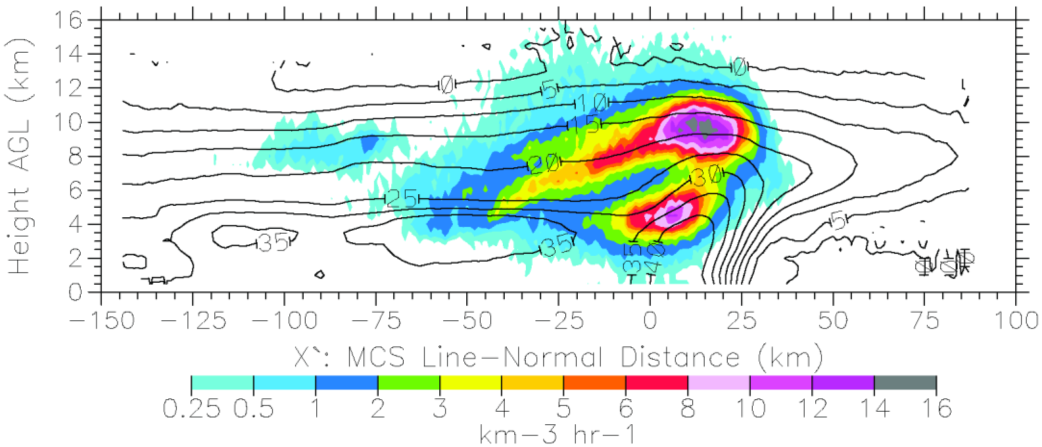


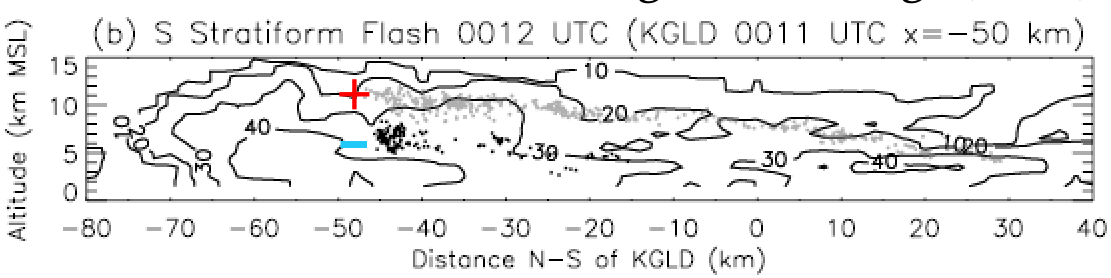
- NIC lab studies (and relative growth rate theory) explain observed charge structure and lightning based on
  - Dependence of NIC on temperature and cloud water content
  - Depletion of cloud water through convective processes (e.g., warm rain, entrainment)
- Need to measure precipitation and cloud particle size and concentration, notably **cloud water content** in convection
  - Although modeling useful, science speculative until cloud water, in particular, measured

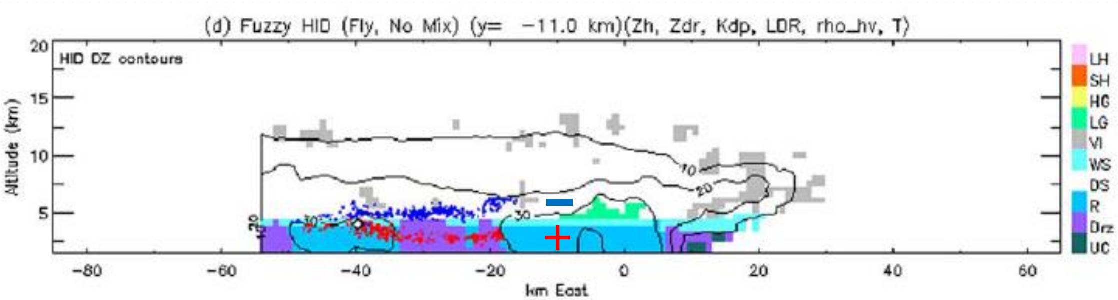
**MCS Stratiform**

Carey et al. (2005)




Lang and Rutledge (2008)




- Along with in-situ balloon observations (e.g., Stolzenburg 1998, MacGorman et al. 2008), LMA and dual-polarization radar have allowed progress in defining the lightning and charge structure of MCS stratiform
- Refining hypotheses of MCS stratiform charging and lightning processes has been somewhat limited by lack of detailed microphysical information in stratiform
  - Cloud water
  - Ice crystal habits and concentrations
- Enhanced aggregation, enhanced deposition, weak riming, melting

# Key measurements

- Detailed cloud and precipitation hydrometeor (individual and bulk) properties (type, size, concentration, shape, density, fall mode)
  - Urgent need for in-situ measurements to capture details and validation of dual-pol, especially in ice:  Storm Penetrating Aircraft (full instrument suite), Balloon-sonde (e.g., video, Parsivel disdrometer)
  - Mobile truck-based (airborne?) and transportable dual-polarization radar
  - Multi-frequency dual-polarization (Ka, Ku, X, C, S) to infer more properties
  - Profilers can also provide useful column information in storms
  - Surface mobile disdrometers useful (but really need in-situ)
  - CASA like radar network for long-term, large-sample process studies (?)
  - (NASA Satellite observations (GPM/Cloudsat like) synergistic with GLM)
- Cloud water content (supercooled, in mixed phase)
  - Column integrated is not as useful – need water content at specific (x,y,z)
  - Remote sensing is tough; not sure possible with any accuracy
  - Urgent need for in-situ: Storm Penetrating Aircraft (balloon-borne, other?)

# Physical validation of radar remote sensing

AUGUST 2000 STRAKA ET AL.

Precipitation Model

- N(x): hydrometeor size distribution
- shape
- Canting angle
- Density/dielectric

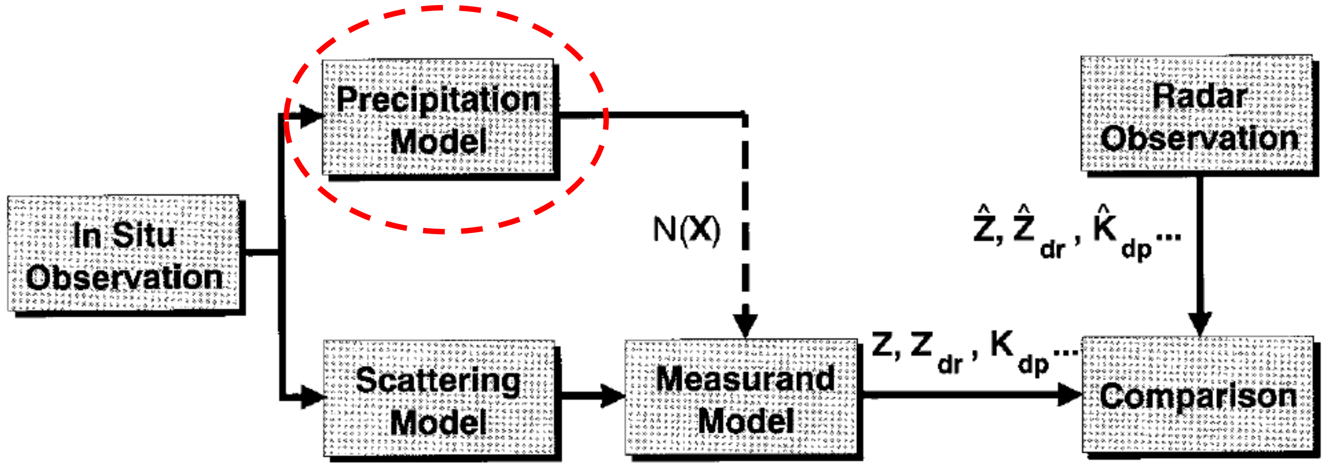
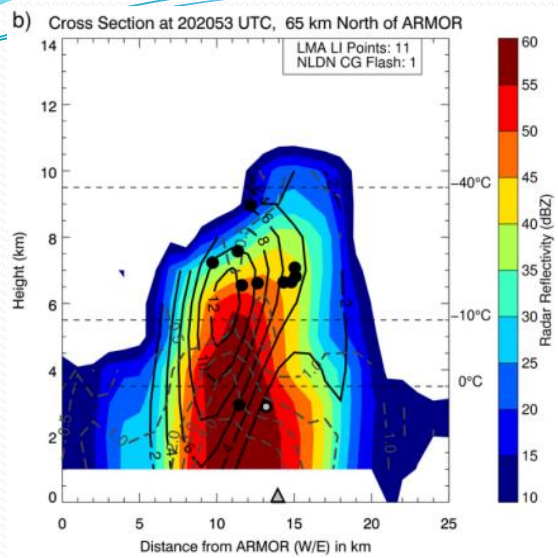



FIG. 1. Schematic of hydrometeor discrimination philosophy. Note the linkages among the in situ observation, precipitation model, scattering model, and measurand model for comparing radar observations with actual observations of hydrometeors: $\mathbf{N}(X)$ represents concentrations of hydrometeors and includes their characteristics (i.e., shape, canting angle, dielectric constant); $Z$, $Z_{dr}$, and $K_{dp}$ (among others) are polarimetric variables from models; $\hat{Z}$, $\hat{Z}_{dr}$, and $\hat{K}_{dp}$ are polarimetric variables from observations.

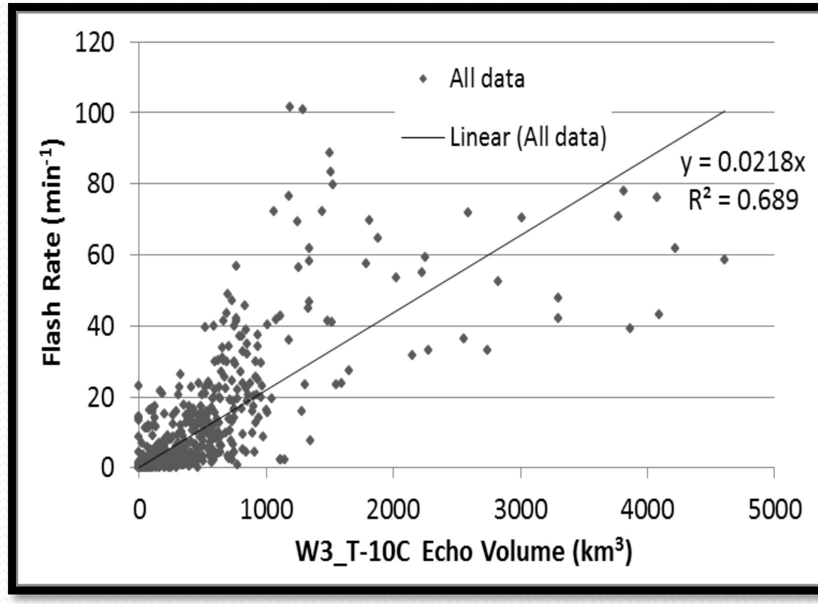
- In developing polarimetric radar methods, including hydrometeor identification (HID)
  - Precipitation model is required to close the loop between measurand model results ($Z_h$, $Z_{dr}$, $K_{dp}$, $\rho_{hv}$) and radar observations $(\hat{Z}_h, \hat{Z}_{dr}, \hat{K}_{dp}, \hat{\rho}_{hv})$
  - Model of precipitation **properties** and **processes**

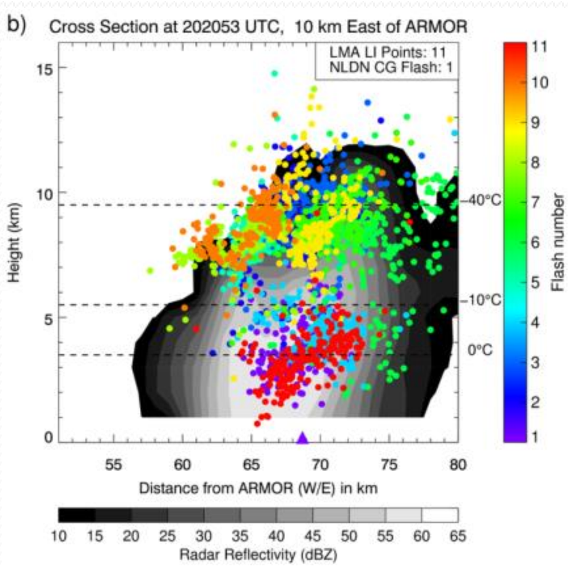
# Science Frontier #2

What is the role of *kinematic properties and processes* in establishing charge structure and polarity and resulting lightning properties as a function of storm morphology and lifecycle?



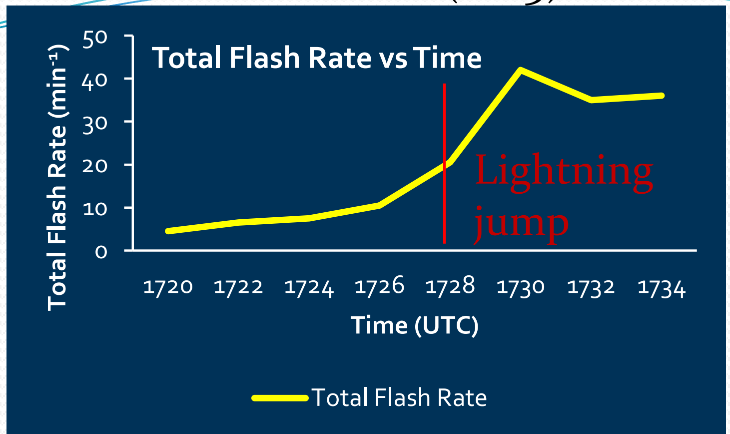

Mecikalski et al. (2015)

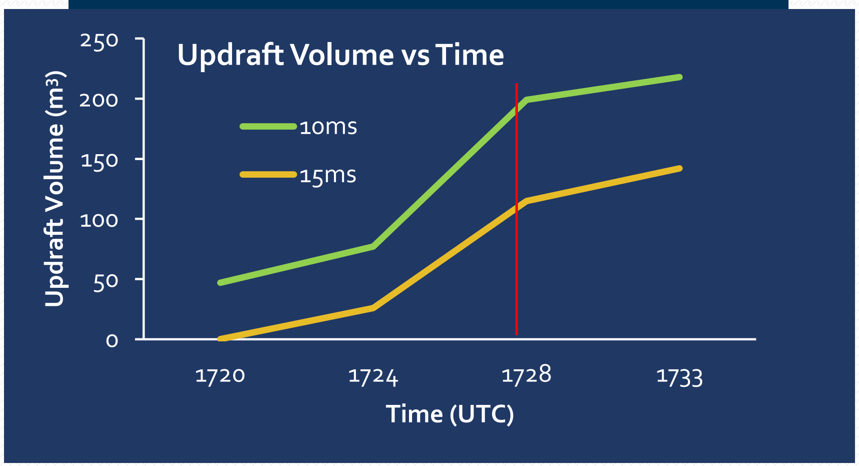


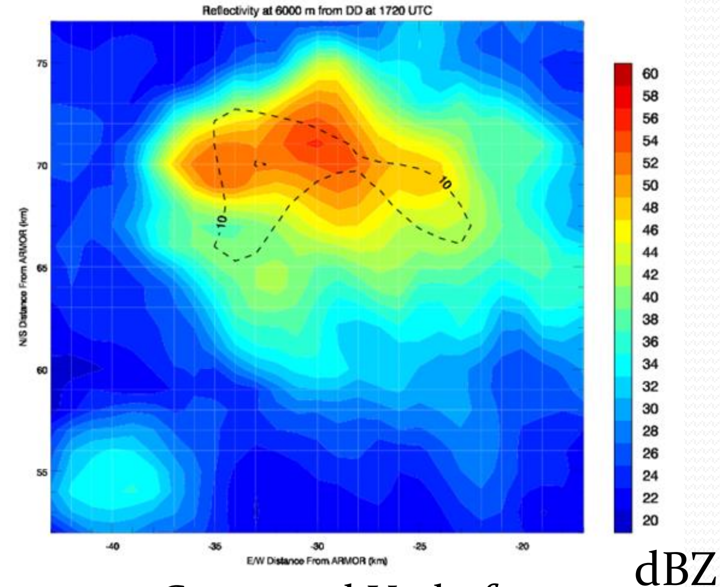

- Convective updraft volume well correlated to lightning flash rate
- Traditional view is that updraft provides condensate for growth, maintains graupel aloft while growing/charging and transports small ice aloft (relative to graupel) to aid storm scale charge separation
- Variation in relation suggests other processes both microphysical and kinematic are at work

Schultz et al. (2015)



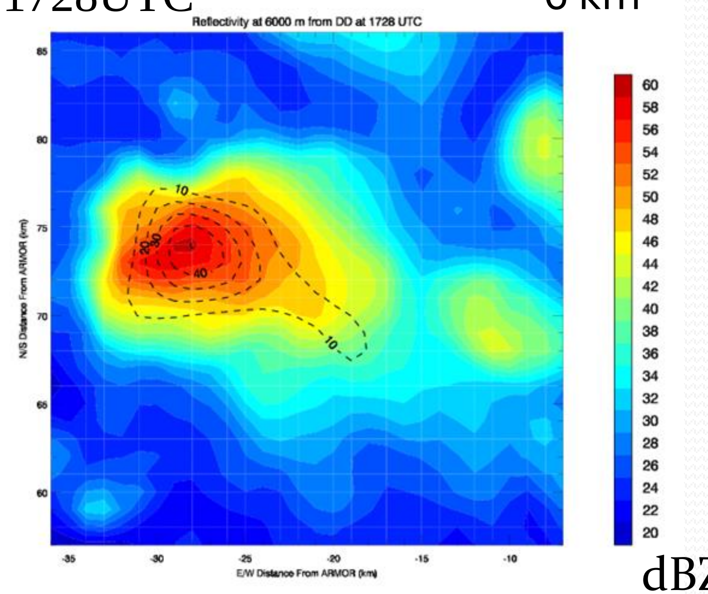




1720UTC 6 km



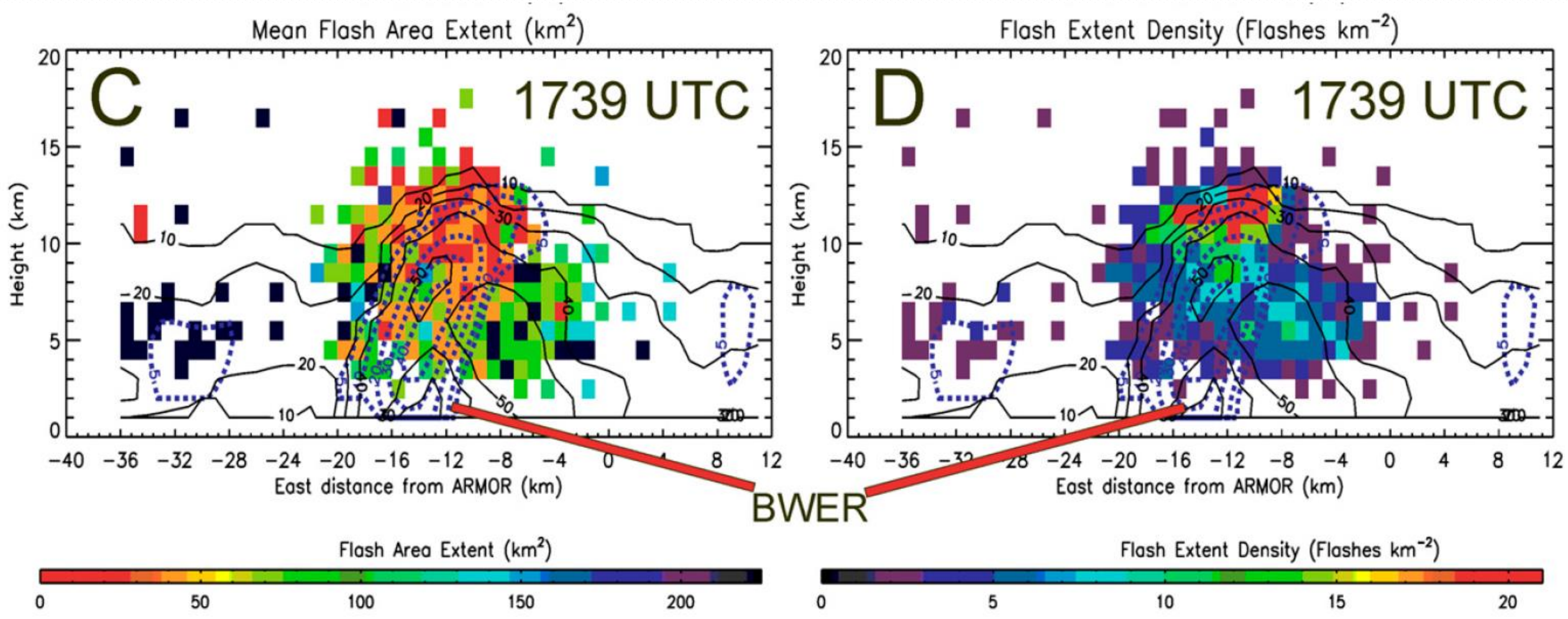

Contoured Updraft

1728UTC 6 km




- Lightning trend is also related to trend in convective updraft volume and maxima
- Updraft pulses prior to 'lightning jump'
  - Rapid convective processes – minutes
  - Precede severe weather production

Schultz et al. (2015)

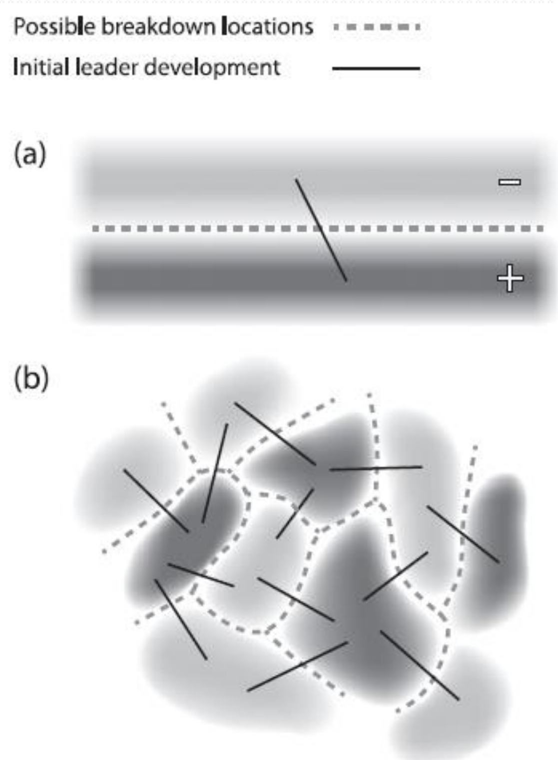


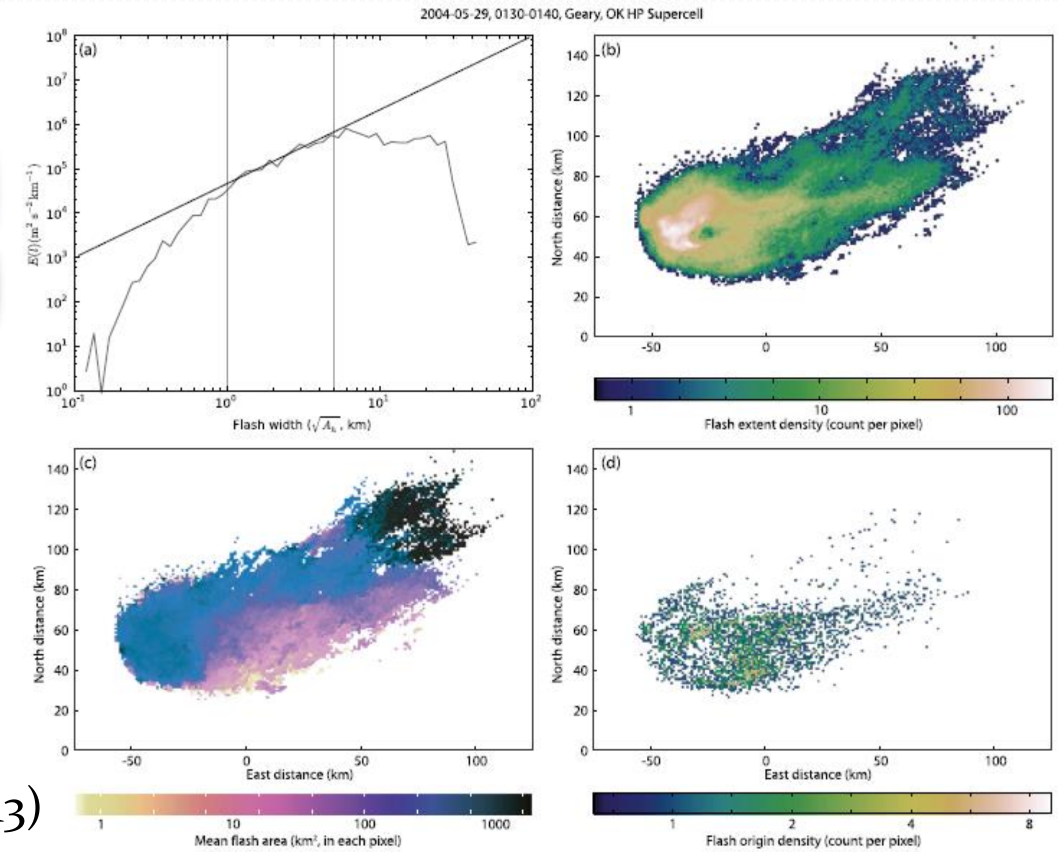

- In and near strong updrafts, flashes tend to be smaller and more frequent, while flashes far from strong vertical drafts exhibit the opposite tendency
- Along with LMA and in-situ balloon data showing complex charge structure, begs question of whether traditional role of updraft based on tripole is complete

- Electrostatic theory demonstrates that frequent breakdown and large flash extents are opposed
- Energetic scaling (flash rate and area) exhibits a 5/3 power-law scaling on few km scale
  - Similar to turbulent kinetic energy spectra in convection
- Advection of charge-bearing precipitation by storm updraft and 3-D flow, including in *turbulent eddies*, couples electrical and kinematic properties
  - Places additional temporal and spatial constraints on kinematic observations

Extensive, stratified charge = infrequent large flashes

Small pockets of charge = Frequent small Flashes




Bruning and MacGorman (2013)

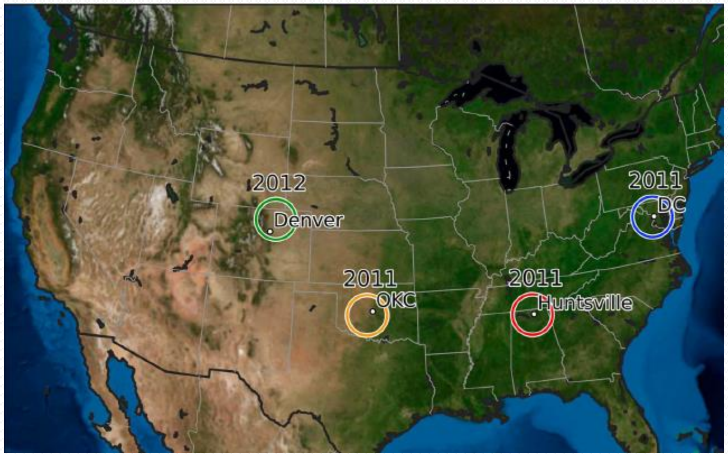
# Key measurements

- 3-D flow at high temporal and spatial resolution - updraft, downdraft, advective flows and turbulent eddies
  - Urgent need for ≤ 1 minute and order 100 m sampling required to capture convective scale processes
  - Rapid scan: suggests phased array or imaging radar
- Continued requirement for mobility or flexible-fixed for IOP
  - Networks of parabolic (mechanical scanning) radars have served community well. Can we continue to do this with rapid scan?
  - Need to support multiple truck-based radars network and/or aircraft to sample 3-D in variety of storm morphology and intensity
- Fixed network(s) for longer-term (non-IOP) studies that sample 3-D storm volume. Process studies from large-sample statistics.
  - Network of CASA like "inexpensive" radars might be better for longer-term fixed process studies
- Profilers can also provide useful column information in storms
- (NASA) satellite observations (e.g., TRMM/GPM/Cloudsat; multi-frequency passive microwave) synergistic with GLM

# Science Frontier #3

How does the *environment* control storm kinematics, microphysics and the resulting charge structure and lightning properties?

Fuchs et al. (2015)

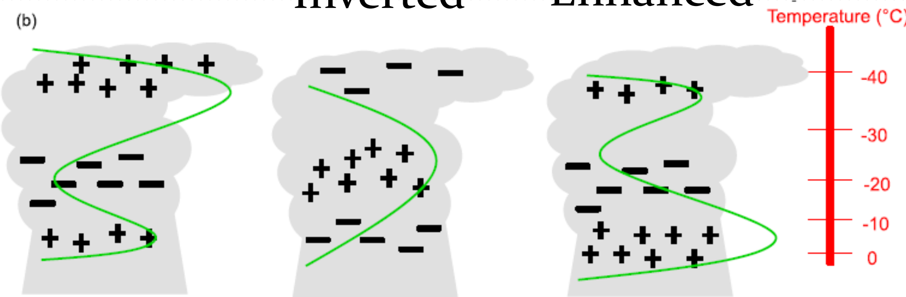


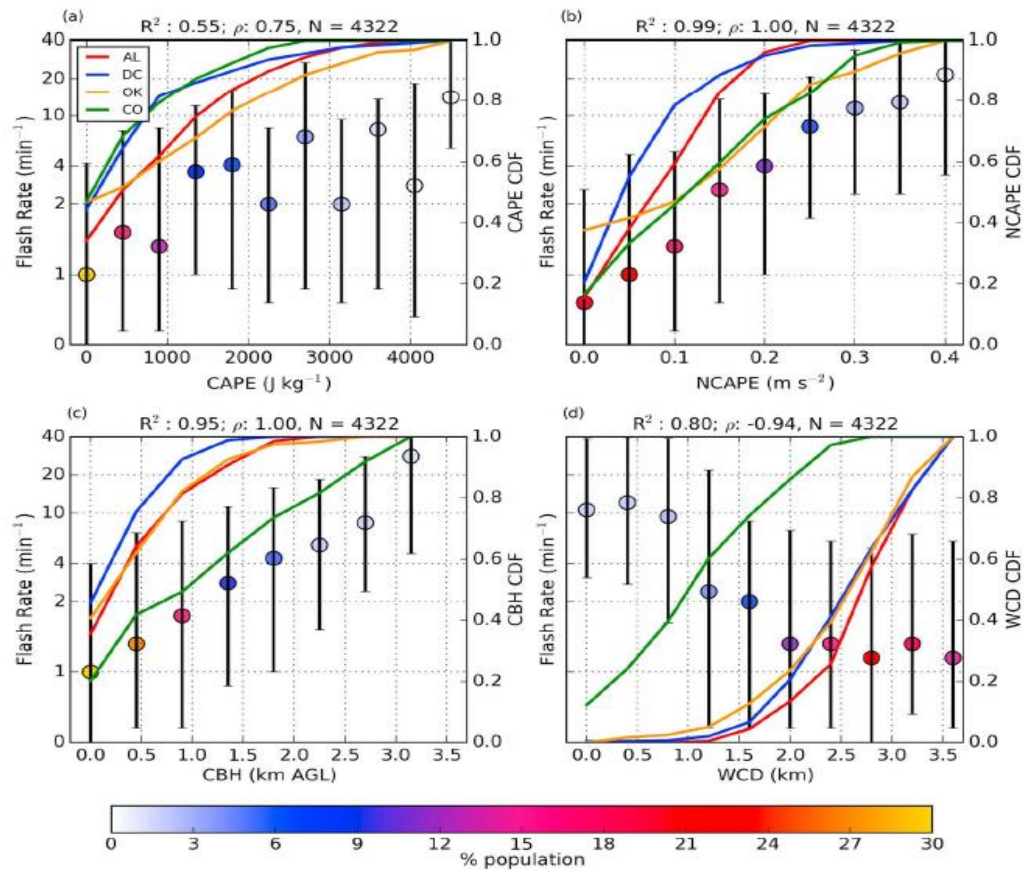

ordinary tripole

Anomalous

Inverted

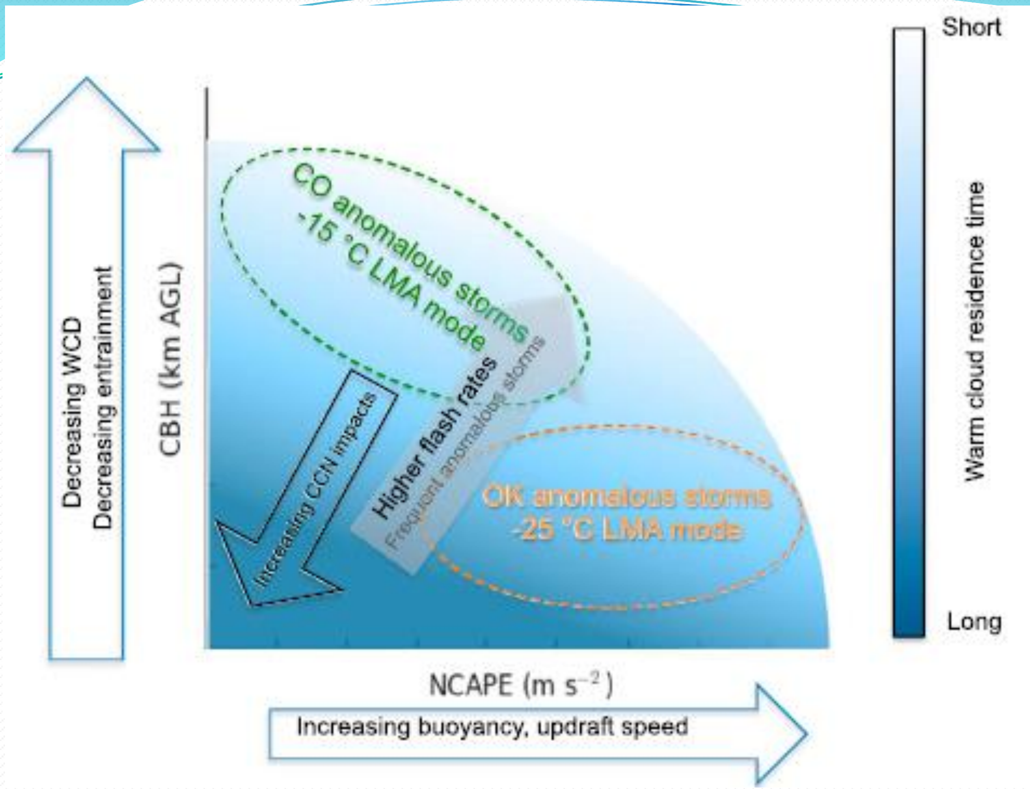
Enhanced

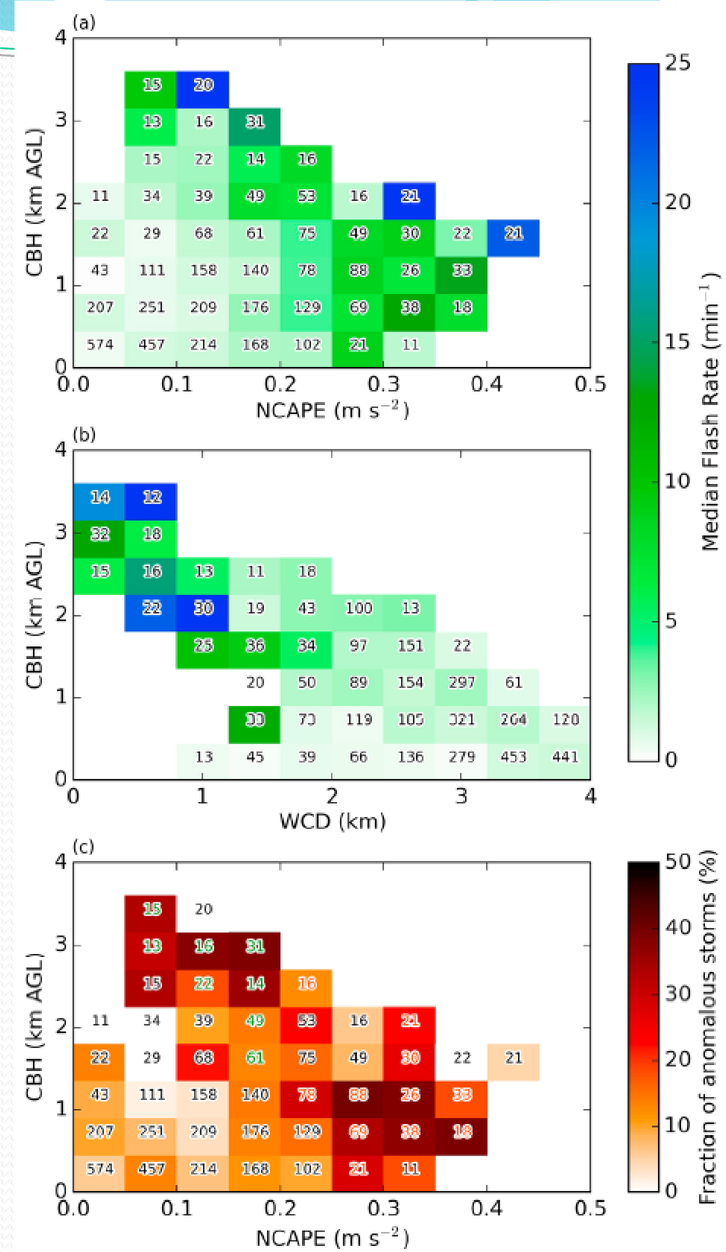



- AL/DC ordinary tripole, modest flash rates, low IC/CG, and low +CG fraction
- CO/OK exhibit more anomalous charge structure, enhanced flash rate, high IC/CG ratio and high +CG fraction
- CO/OK have higher NCAPE while CO also has higher (smaller) cloud base height or CBH (warm cloud depth or WCD)

# Fuchs et al. (2015)




- Increasing CBH -> decreasing WCD, decreased entrainment, shorter warm cloud residence time
- Increased NCAPE -> increased updraft
- Optimal aerosol for enhanced flash rate ~ 1000 $cm^{-3}$
- Less cloud water depletion -> more charging, positive charging graupel -> higher flash rates, inverted or anomalous storms, increased IC/CG and +CG
- *Motivates need for observing cloud water depletion*

Fuchs et al. (2015)

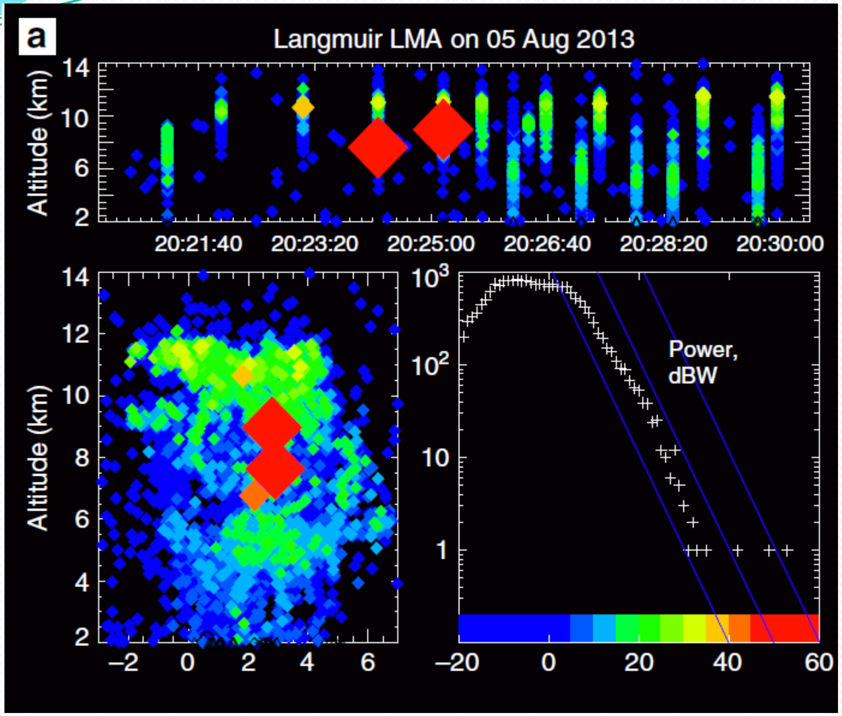
# Key measurements

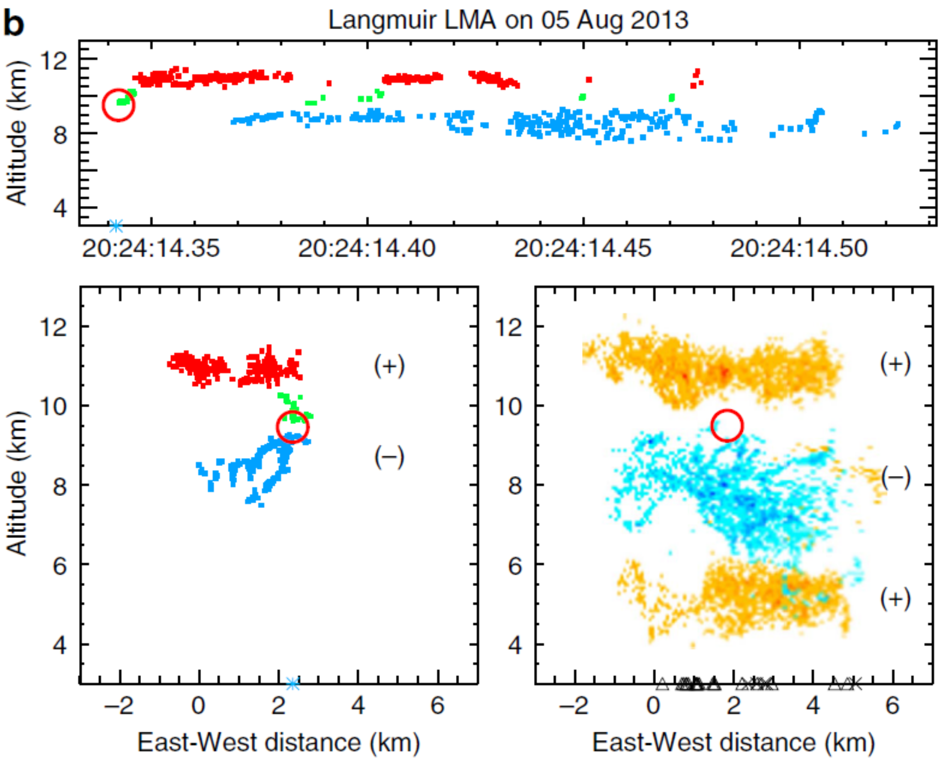
- State parameters, wind, moisture, aerosol (CCN, IN) in and near storm environment (preferably updraft in-flow air)
  - Still often forced to use model analysis and diagnostic fields to link environment to kinematic, microphysical, electrical/lightning processes
- Surface measurements
  - Expand the fleet of mobile mesonet facilities for IOP
  - Fixed mesonets still very useful for long term studies: assess cost vs. accuracy requirements for long-term measurements (maybe we can do it cheaper for 'good enough' ?)
- Boundary layer and full troposphere in/around storm
  - Aircraft, UAV, drones, drifters: reliability, accuracy, access, cost (?)
  - Balloon Sondes, tethersondes, profilers for "nearby environment"
- (NASA) satellite retrievals increasingly useful but major limitations at low-levels and around storms where it matters most

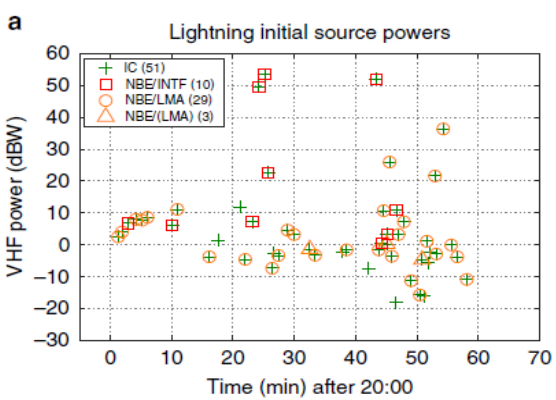
# Science Frontier #4

How is *lightning initiated* inside storms and what is the role of local cloud electrical and microphysical properties and processes?

# Rison et al. (2016)
# Nature Communications




- **Fast positive breakdown** cause of high-power discharge known as narrow bipolar event (NBE)
- Found wide range of strengths and is **initiating event of numerous lightning discharges**, *maybe all flashes*
- Purely dielectric (as opposed to runaway electron avalanches)
- Consist of system of positive streamers initiated by *corona from ice crystals or other hydrometeors* in locally intense E-field
- At streamers' start location, initiates negative breakdown, flash

# Key measurements

- Flash rate, extent, type, polarity, energy, radiance
  - Development and support of mobile LMA's for IOP support
  - Continued operational support of fixed Lightning Mapping Arrays (LMAs) for long term studies (expansion of fixed LMA's with public-private partnerships)
  - Other frequencies and techniques to expand 'visibility' to all components and locations of the flash – e.g., VHF broadband interferometer array, E-field change (Marx) meter array
  - (NOAA) satellite optical: Geostationary Lightning Mapper (GLM)
- Charge structure (polarity, amount)
  - Balloon-borne, storm penetrating aircraft e-field and particle charge instruments
    - UAV/drone for nearby storm e-field?
  - Fixed/mobile LMA and other lightning mapping networks (Marx meter array, interferometer)

# Summary of potential priorities

- **Microphysics**
  - In situ microphysical (e.g., water content, individual hydrometeor properties especially ice in mixed phase) and thermodynamic
    - Storm Penetrating Aircraft (Balloon-borne, other?)
  - Multi-frequency, dual-polarization (Ka through S)
    - Mobile to transportable for IOP mobile to flexible-fixed
- **Kinematics**
  - Rapid scan (phased array, imaging) to improve temporal resolution
  - Multi-frequency (Ka to C) mobile to allow ready sampling of variety of scales to study 3-D advective and turbulent flows

# Summary of potential priorities

- **Electrical**
  - Continued operational support to LMA's for community use of lightning properties
  - Develop new community lightning mapping network approaches (e.g., broadband interferometer, Marx Meter Array) to see all components of flash
  - In-situ electrical (e-field, particle charge) from Storm Penetrating Aircraft and other systems (e.g., Balloon-borne)
- **Environment**
  - Support for community mobile mesonet(s)
  - Continued support and development of profilers, balloons
  - Development of novel community facilities: UAV, drone, drifters