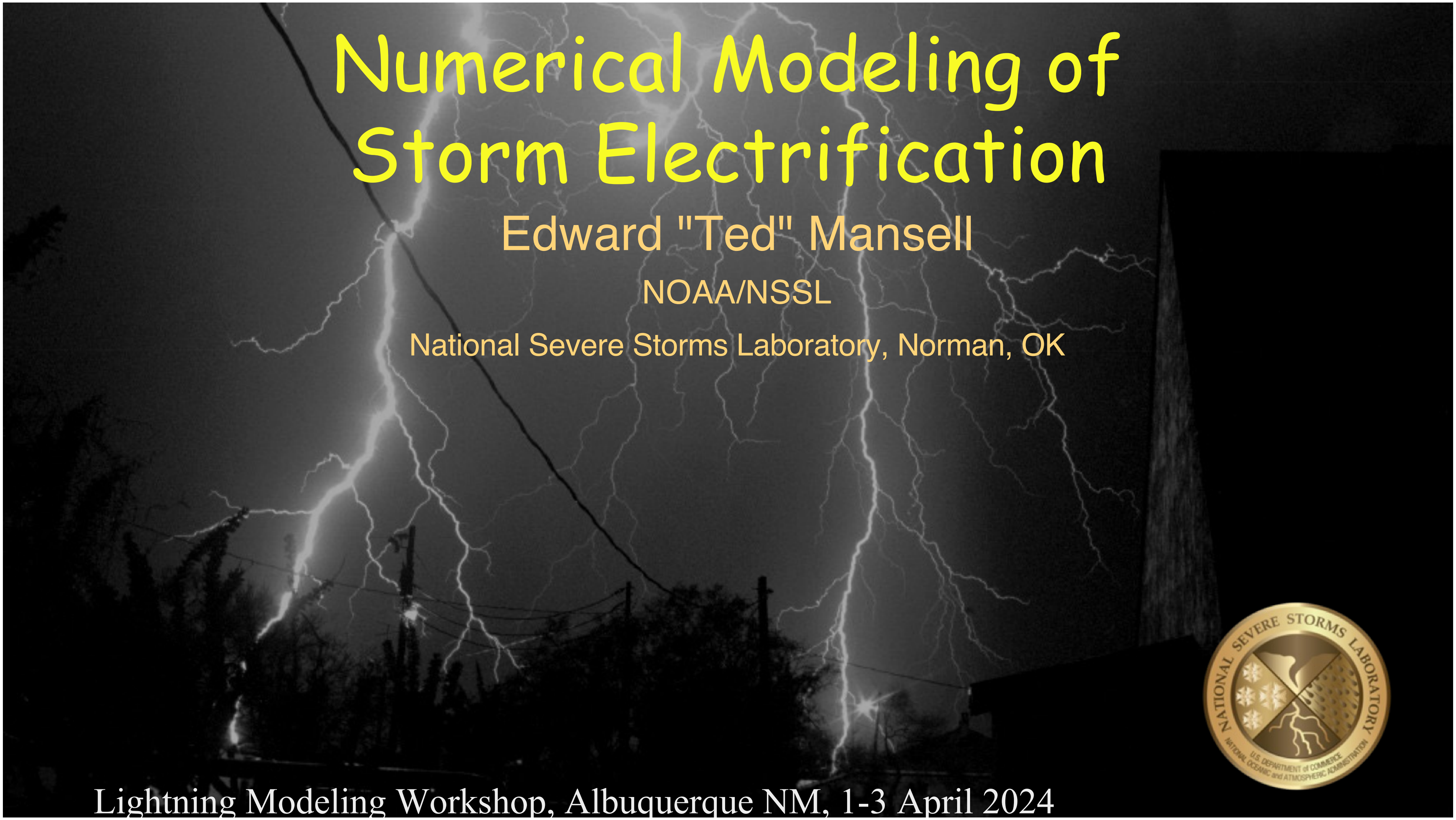
Numerical Modeling of Storm Electrification



Edward "Ted" Mansell

NOAA/NSSL

National Severe Storms Laboratory, Norman, OK

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Basic Requirements:

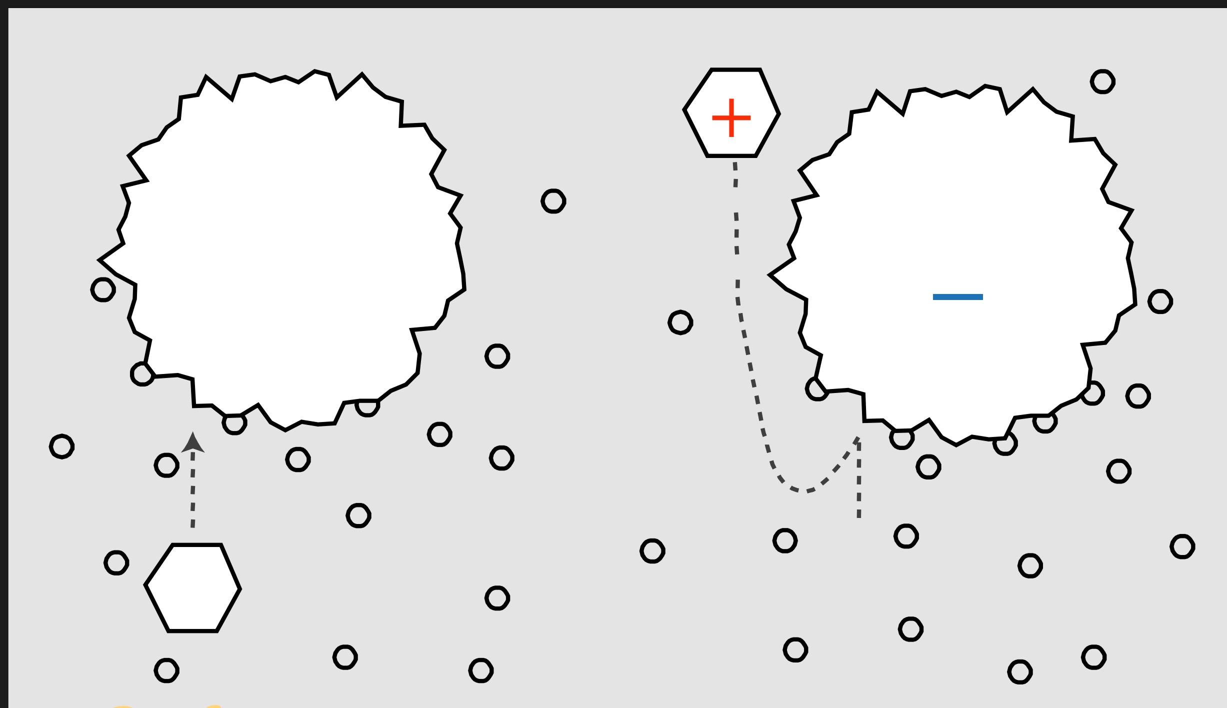
- Storm-scale numerical model (dx < 2km)
  - Accurate (monotonic) advection
- Cloud microphysics with ice
  - Bulk: At least two categories (graupel and small ice/snow)
  - Bin: Still want distinct graupel and crystals
- Physical parameterizations:
  - Primary: Non-inductive graupel-ice charge separation
  - Secondary: inductive, small ion physics, etc.
- Poisson equation solver ("easy" on Cartesian grid)
  - Unstructured grid (e.g., MPAS) more challenging (i.e., not me)
- Lightning discharge: simple/fast to complex/slow

Uses

- Test and form hypotheses
- Relationships between lightning and storm properties
  - e.g., graupel mass, updraft mass flux, etc.
- Lightning prediction/forecasting
- Sensitivity testing (e.g., aerosol)
- Provide realistic conditions for other needs

- Existing cloud models with electrification:
  - COMMAS (not public; shared with collaborators)
  - WRF-ELEC (public, but less physics than COMMAS)
    - Also ported to NASA version (NU-WRF –elec)
    - Works the same as regular WRF for inputs/post processing
  - MESO-NH (not public? Similar to WRF-ELEC?)

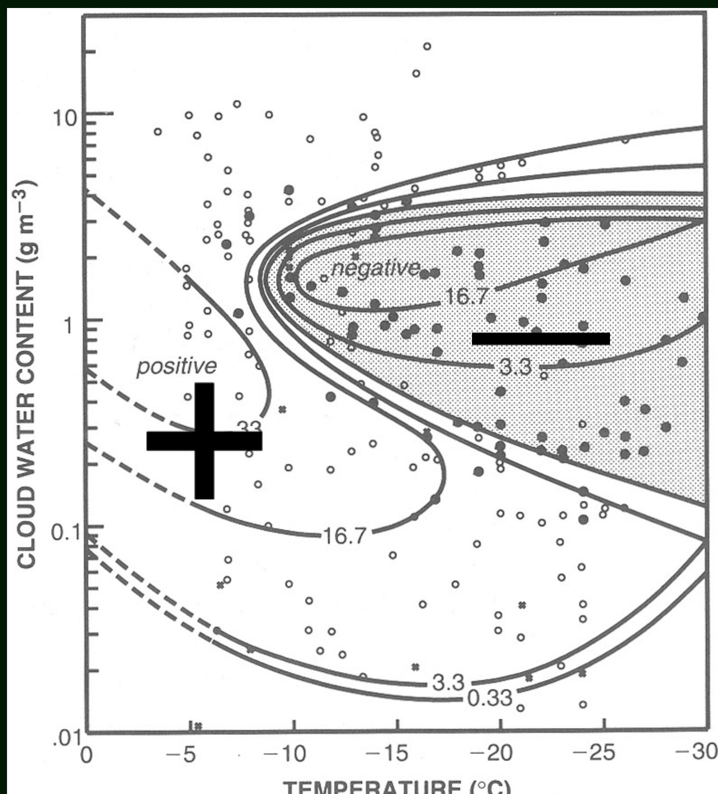
Noninductive Charge Separation



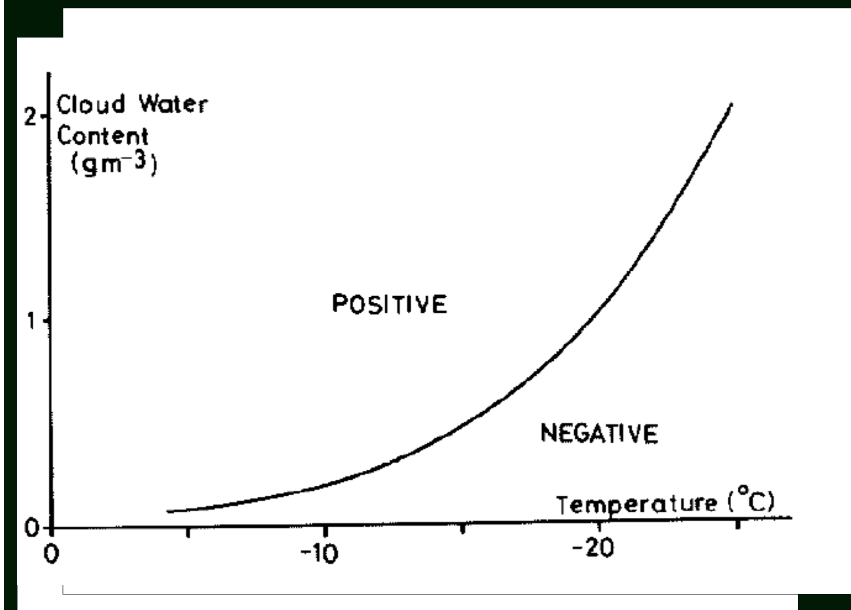
Before Collision

After collision

Noninductive Charge Separation in the Lab:



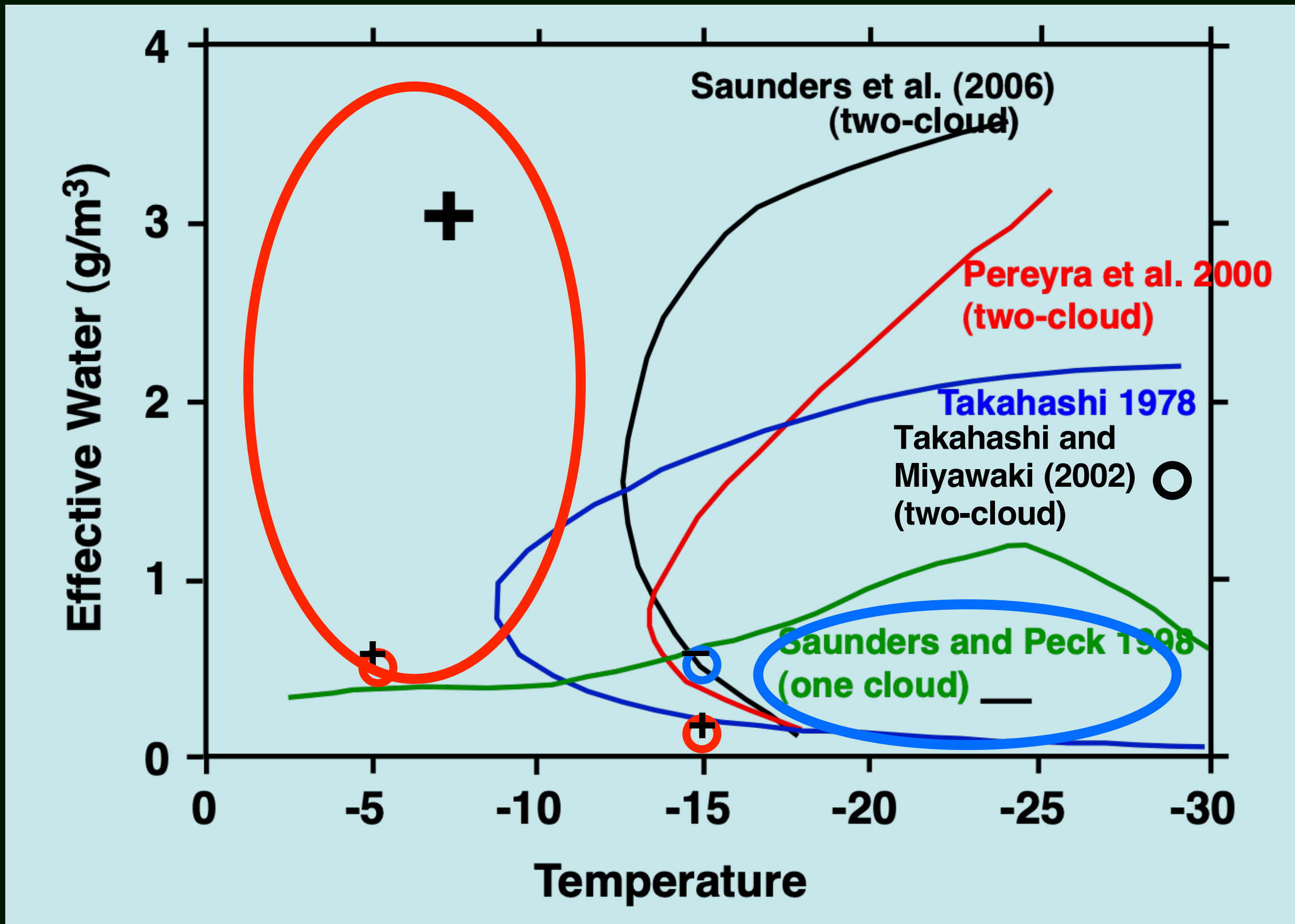
Takahashi, 1978



Jayaratne et al. (1983)
Brooks et al. 1997
Saunders et al. 1991
Saunders and Peck. 1998

Helsdon et al (2001): 2D model comparison of Takahashi (1978) and Saunders et al (1991)

Summary of Non-inductive charging results:

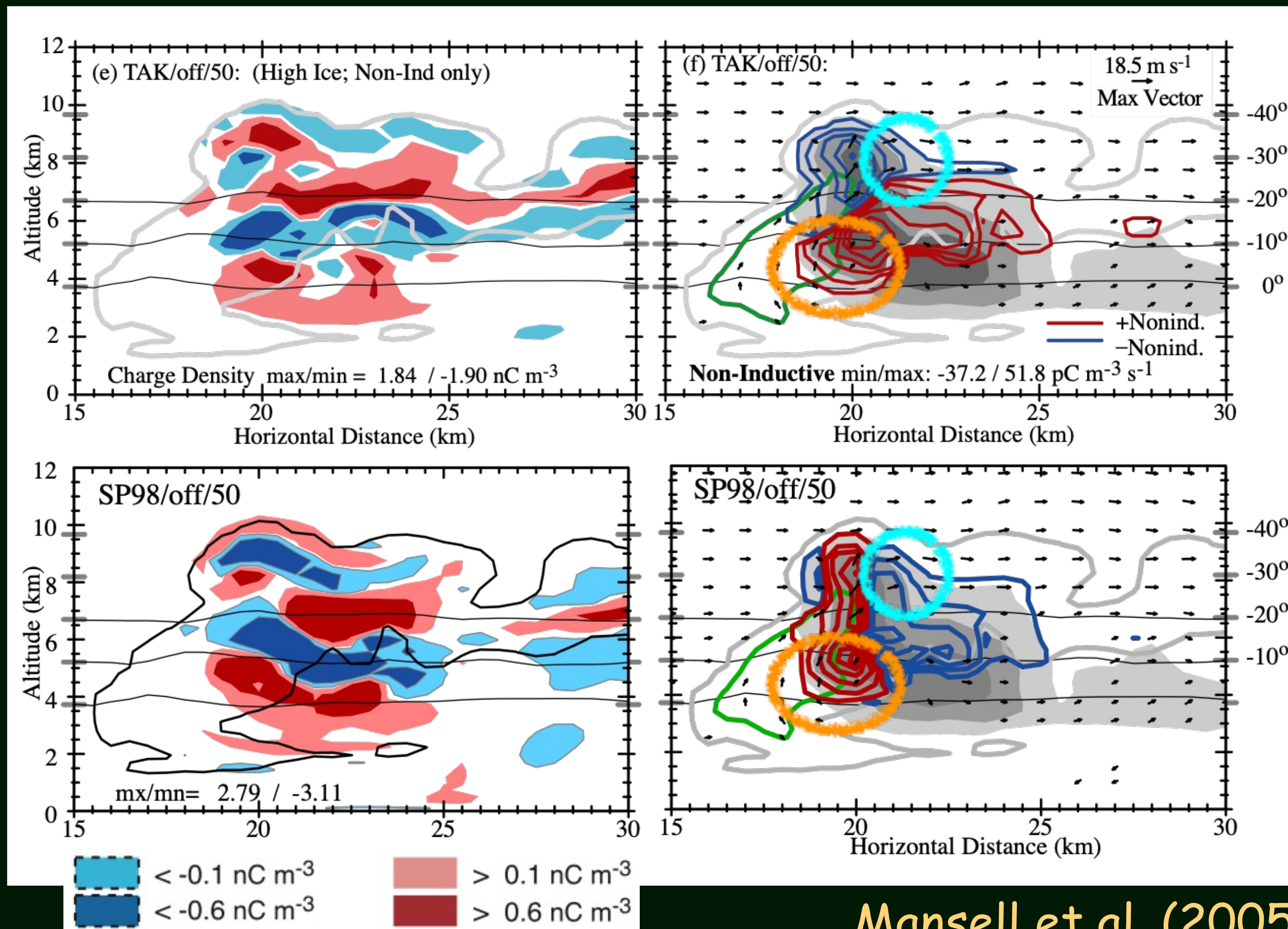


Adapted from Saunders et al., (2006)

Net Charge   Graupel charging rate

Takahashi 1978

Saunders-Peck 1998



Mansell et al. (2005)

Stochastic Lightning Model

- Segment-by-segment development of lightning channels (derived from Niemeyer, et al. 1984)
- As channel grows, recalculate the electric field via Poisson's equation:

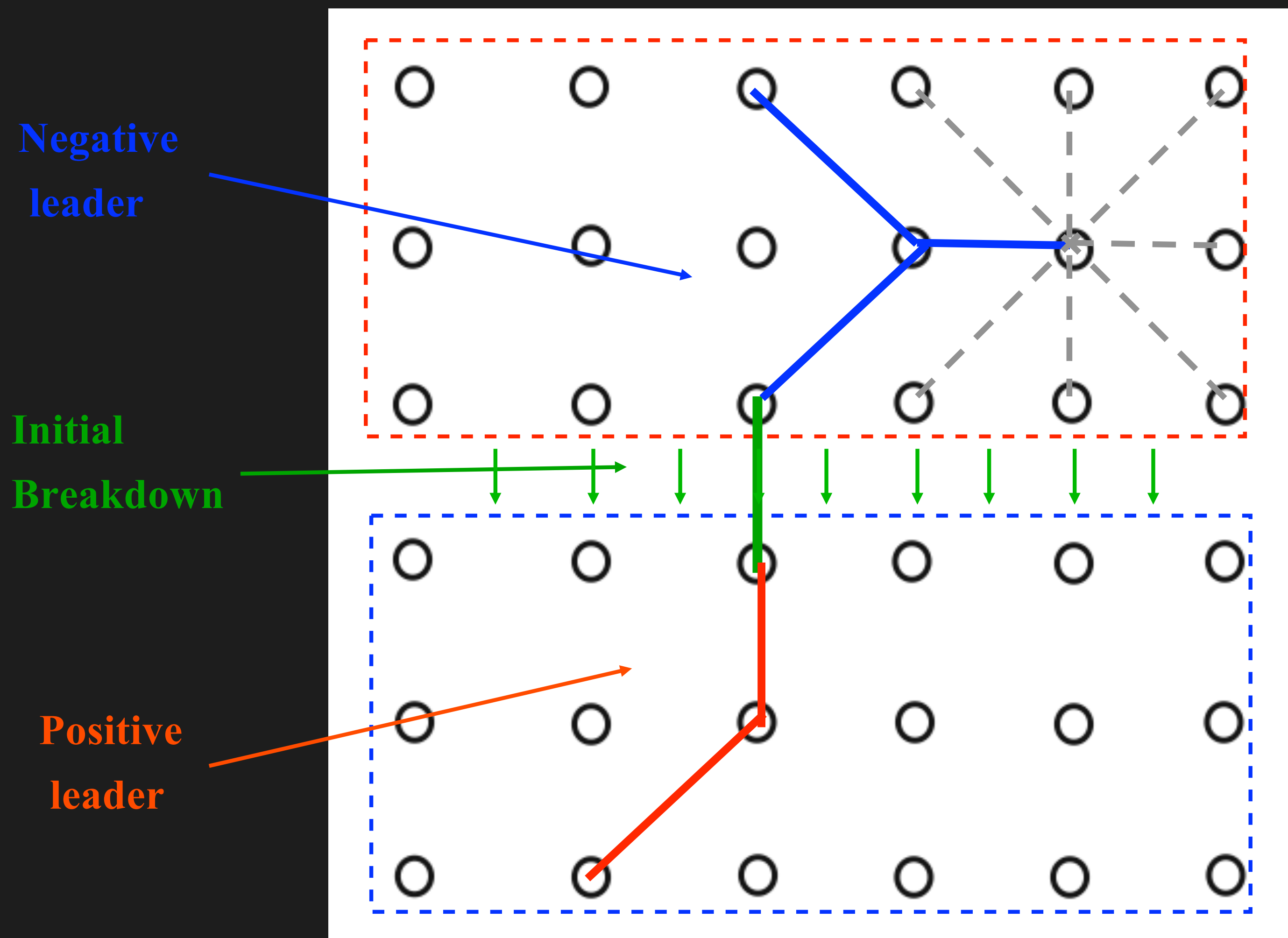
$$-\nabla^2\phi = \rho / \varepsilon$$

- Get E-field from ϕ:

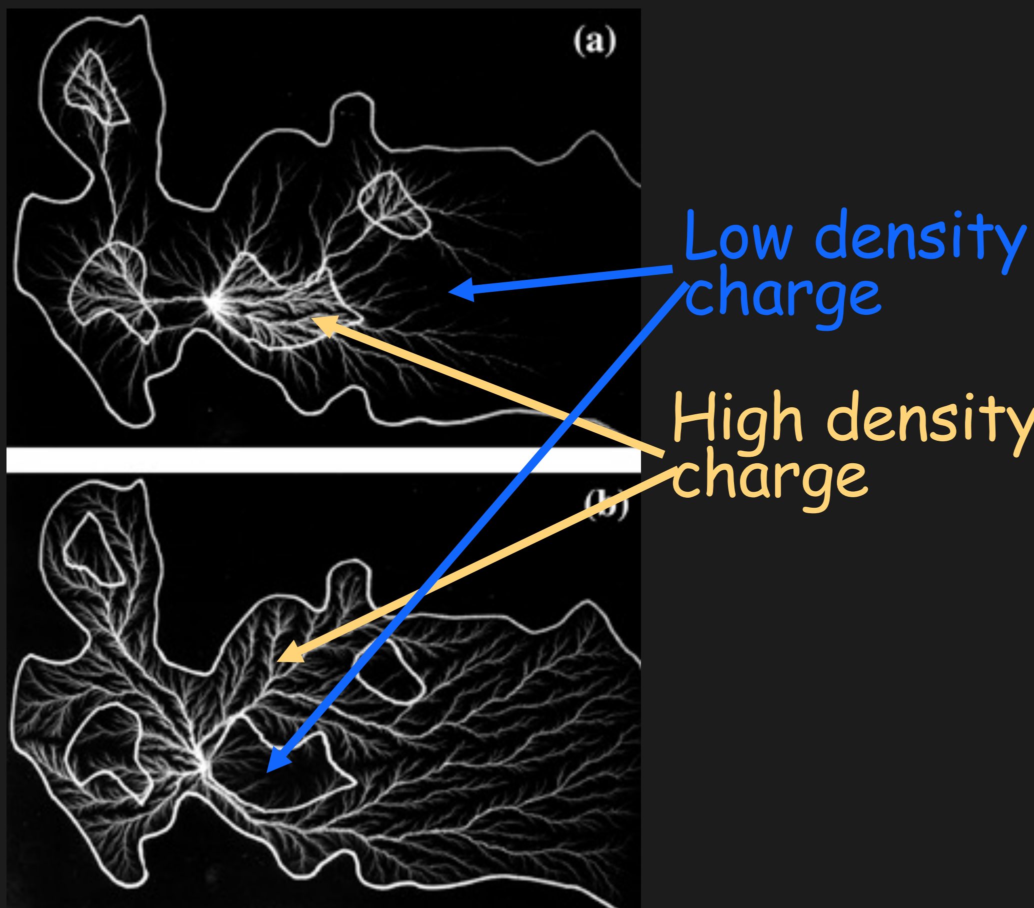
$$\vec{E} = -\nabla\phi$$

No real lightning physics, but produces fractal-like, realistic structures

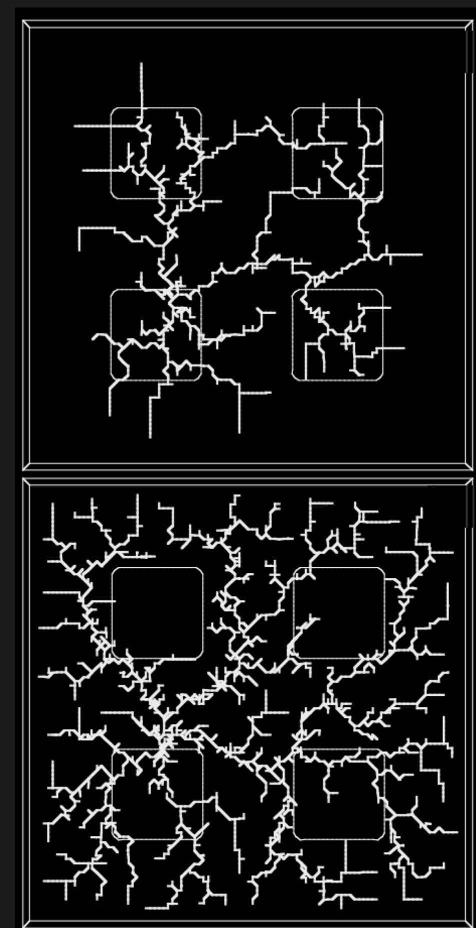
Simulated Lightning Propagation



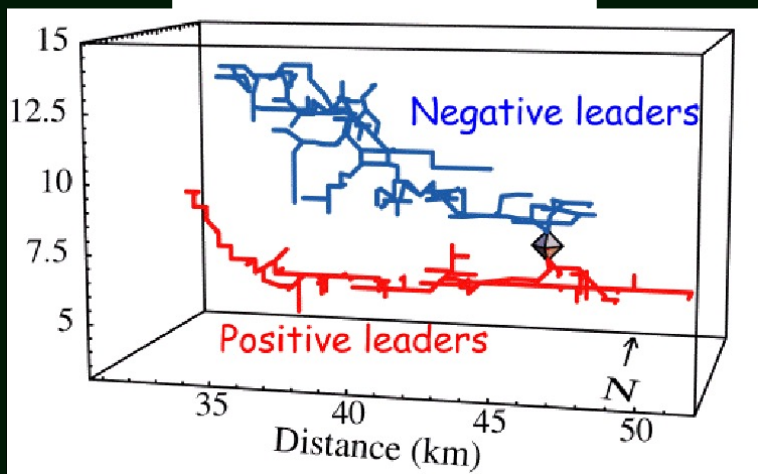
Laboratory discharges and simulations



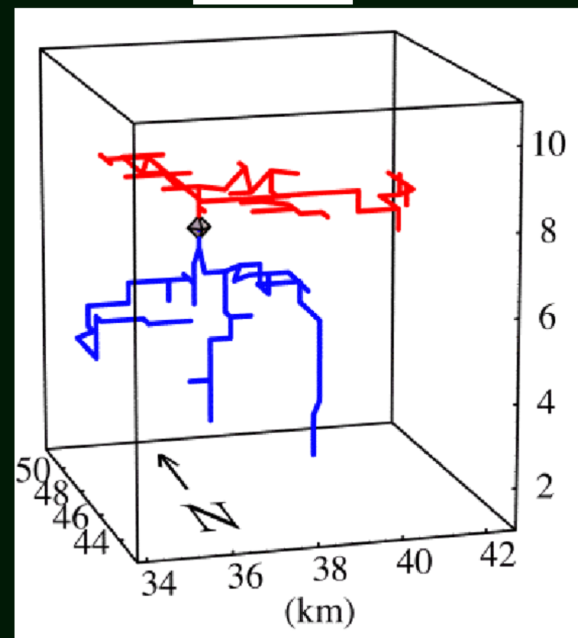
Williams et al. (1985, JGR)



Intracloud



-CG

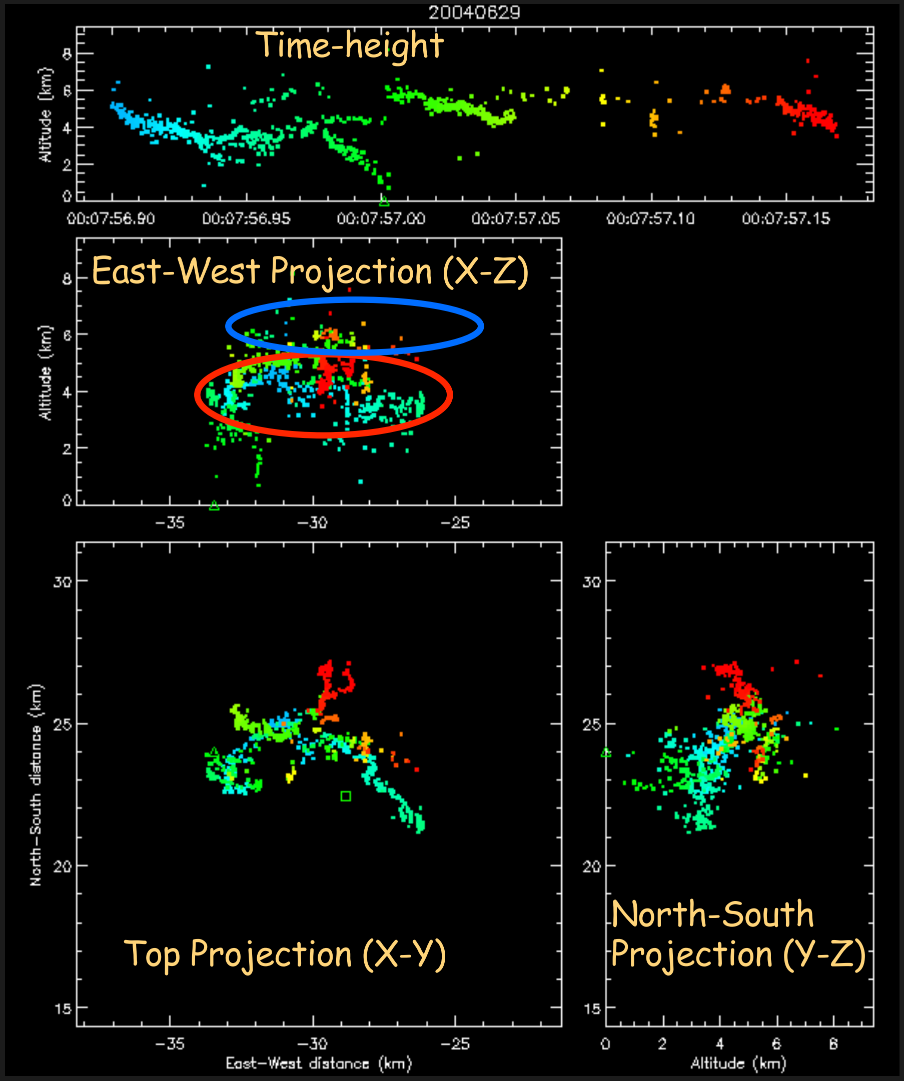


Mansell et al. (2002)

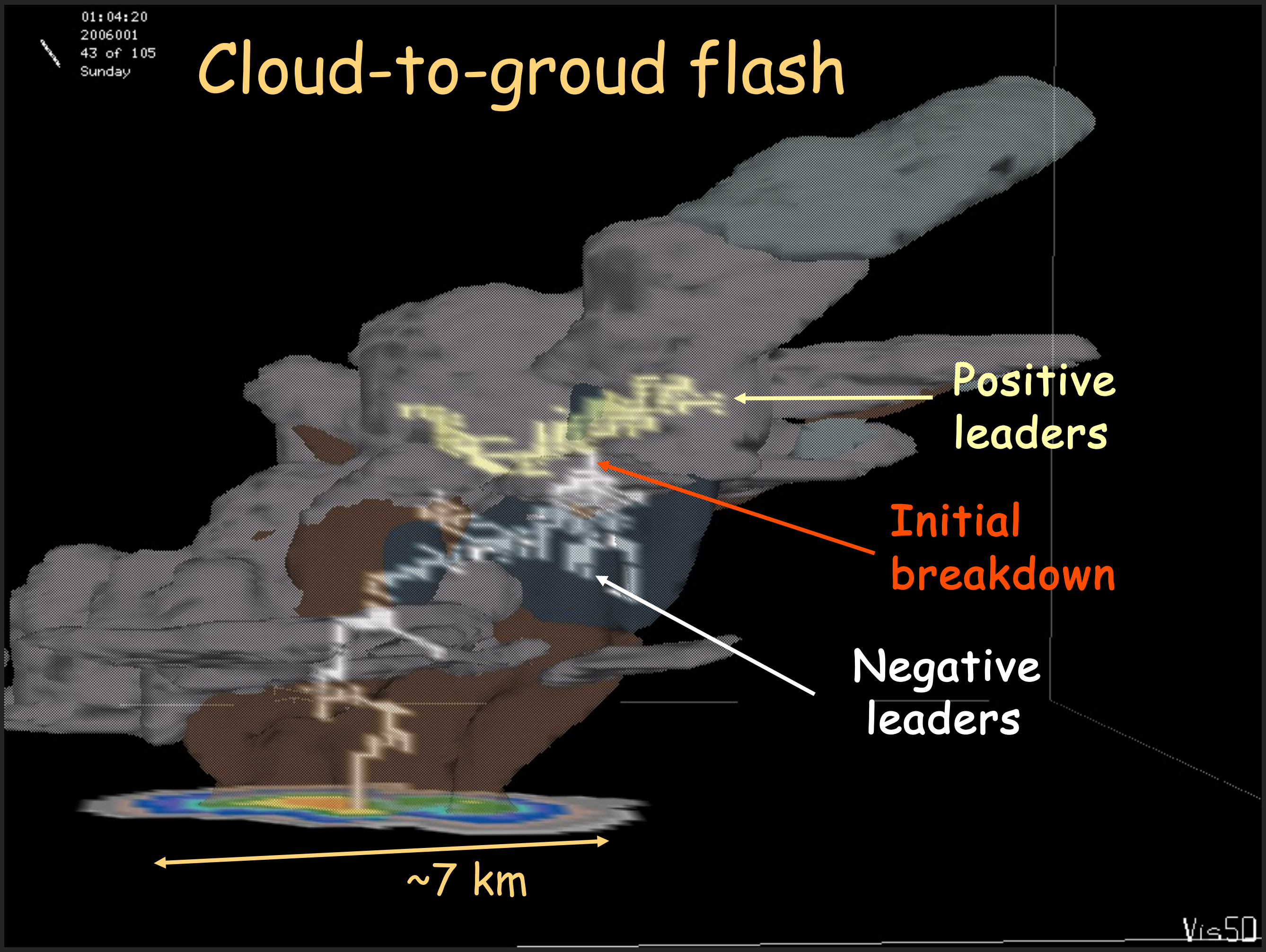
More advanced versions

- Iudin et al. 2017 (JGR):
  - Channel current, conductivity, and decay parameterized
  - 50 μs physical timing
  - used with idealized stacked cylindrical charge regions
- Syssoev et al. 2020 (JGR):
  - Iudin model at 3m grid spacing. Tries to simulate negative leader step formation. (No positive channels)
  - Electrode-plane configuration
- Limitation remains that numerically the 'channels' are really Lego blocks with thickness of grid dx

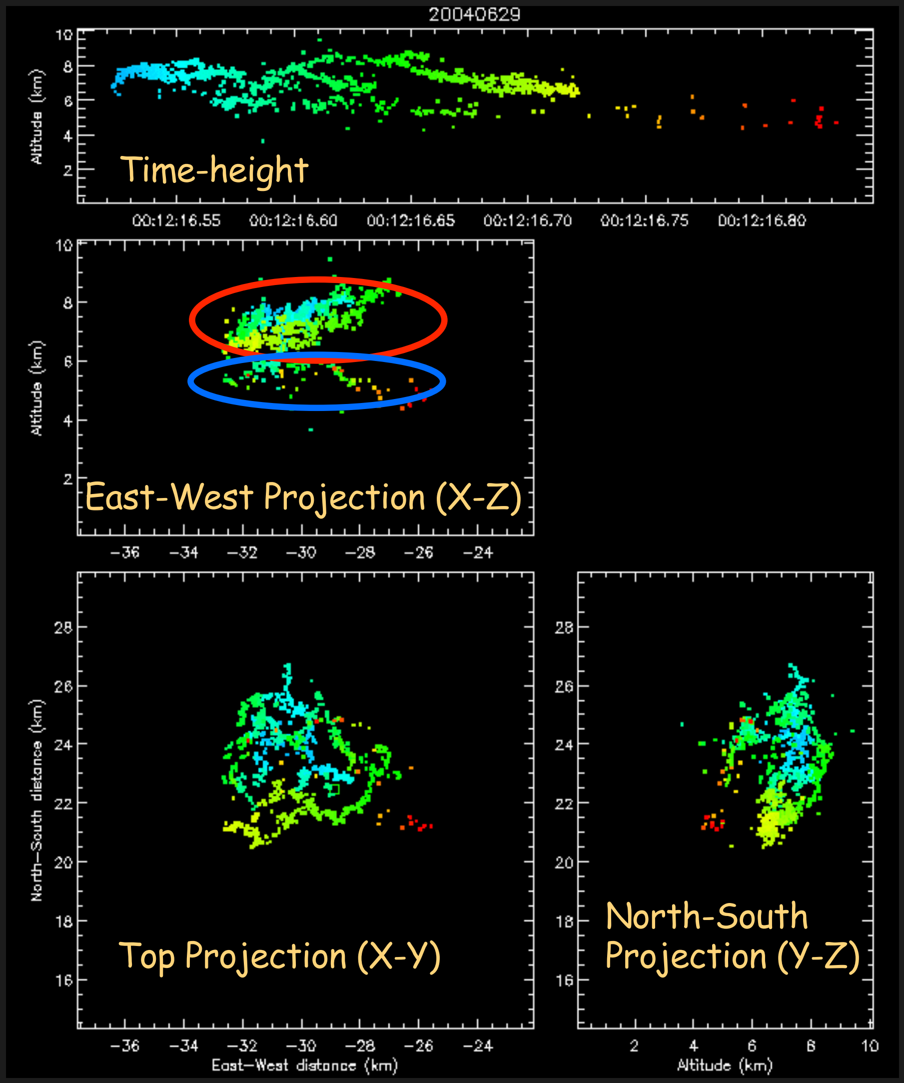
Observed negative CG flash (LMA) (29 June 2004)



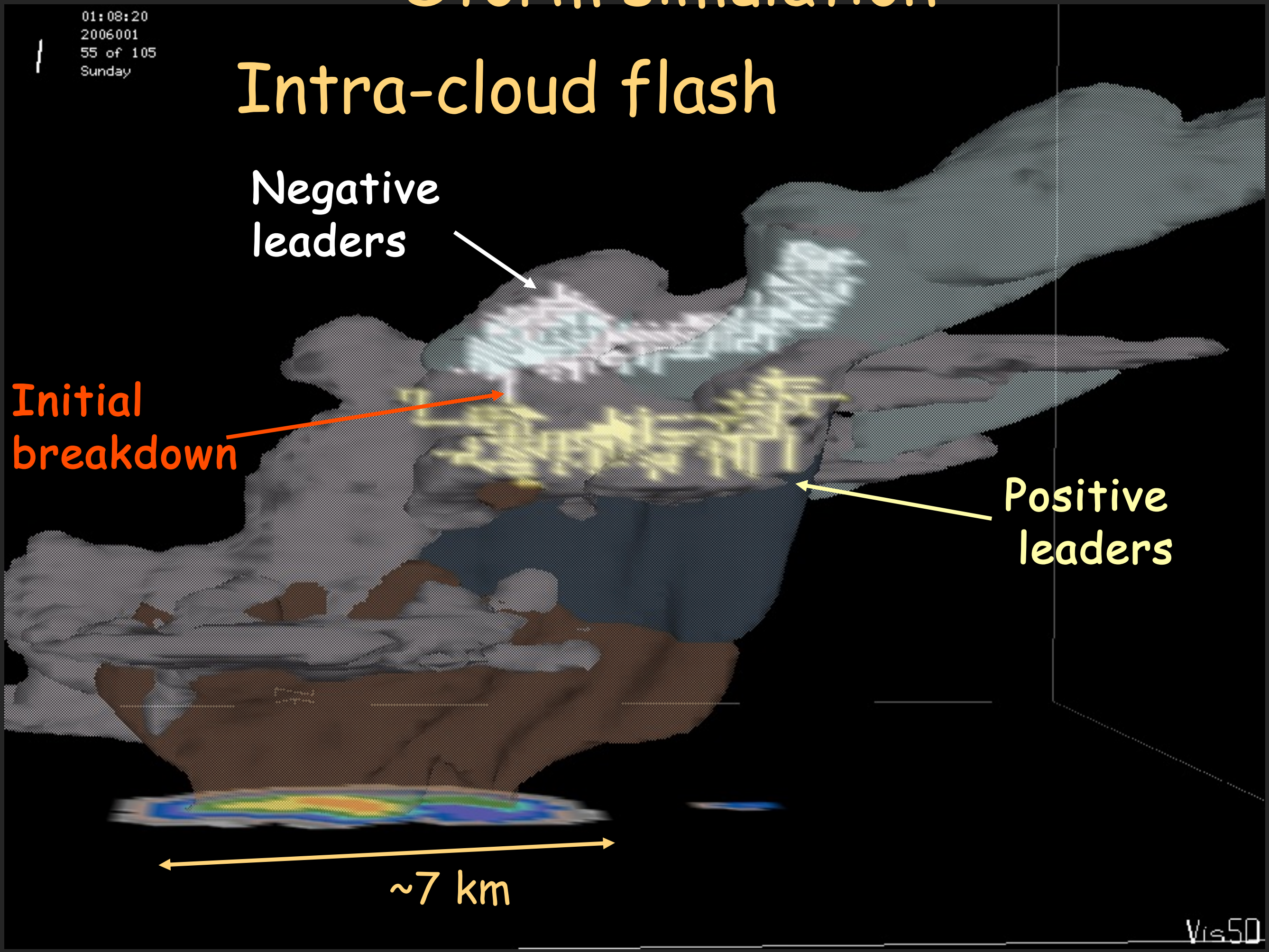
Storm simulation



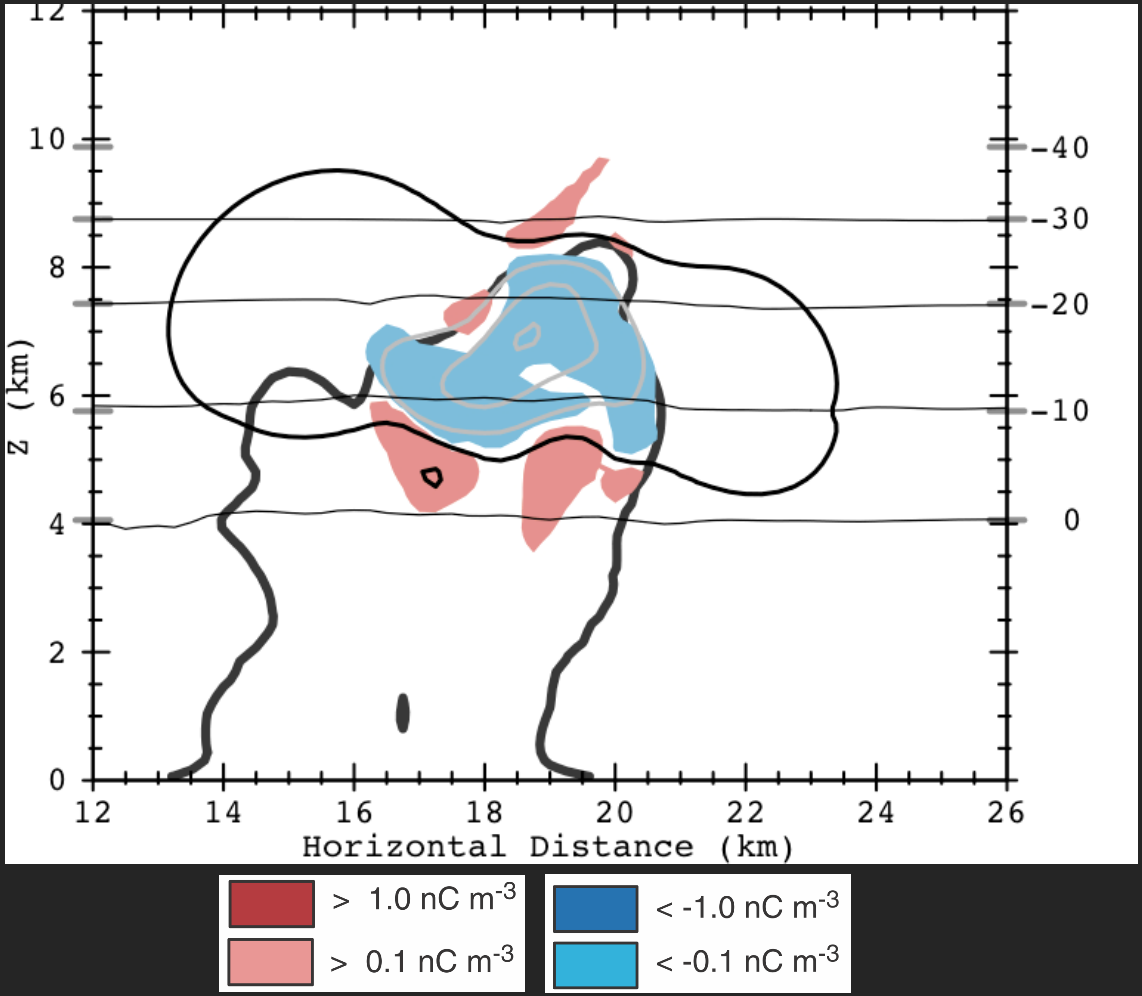
Observed upper IC flash (LMA)



Storm simulation



Charge, Potential, & Lightning



Gaps 1: Charging

- Lab results of graupel-ice charging don't represent the range of real cloud conditions.
  - Not clear what the true dependent variables are: Relative growth rate hypothesis has little predictive power.
  - Limited results are extrapolated to a wide range phase space
- Charging in anvils and stratiform regions with very little to no supercooled liquid. Unsuccessfully/poorly modeled
  - Limited data on charging with just ice supersaturation (Luque 2016)
  - May need bin microphysics
- Stratiform melting layers: Some proposed non-collision mechanisms that are probably not viable
- Lightning initiation: Threshold? Dependence on hydrometeors?

Gaps 2: cloud physics

- Secondary ice production
- Ice Collection efficiencies (i.e., small ice sticking to graupel)
- Ice growth/aggregation in anvils, stratiform (e.g., Dye 2019)
- Snow melting (physics and possible weak charging mechanism)
- Charge separation and extreme flash rates in deep updrafts (~ -40°C, ~10km AGL) (e.g., Calhoun et al. 2013)
- Volcanic lightning (ash-hydrometeor interactions)
- Pyrocumulous: Does wood ash affect electrification? (Reisner@LANL)
- Aerosol/CCN effects on microphysics -> electrification

Avenues for Collaborations

- Across national organizations or agencies (public and private)
  - NASA Goddard: Toshi Matsui (& Chris Schultz): NU-WRF-Elec (ltg. fcst)
  - NASA Marshall: Patrick Gatlin et al.: Light scattering; Porting branched lightning/ion physics
  - Texas Tech grad students
- International partnerships
  - Hebrew Univ.: Lynn and Yair: Electrification with SBM microphysics in WRF
  - Students of Xiushu Qie (WRF-ELEC: Aerosol effects)
  - Cambridge Univ.: Michael Herzog: Volcano plume electrification/lightning
- Developer has shifted focus more to cloud microphysics

Funding Sources

- Past funding from NSF for students
- NOAA/NESDIS for data assimilation work (GLM)