TEXAS TECH UNIVERSITY™

Overview of
Inverted Lightning Studies

Eric C. Bruning[1]
with contributions from
Brody Fuchs[2], Paul R. Krehbiel[3], Timothy J. Lang[4], Donald R. MacGorman[4], Vanna Sullivan[1], and Conrad Ziegler[5]

[1]*Texas Tech University*
[2]*Colorado State University*
[3]*New Mexico Tech*
[4]*NASA / MSFC*
[5]*NOAA / OAR / National Severe Storms Laboratory*

DC3 Science Team Meeting
25 February 2013

DC3: INVERTED POLARITY STORM HYPOTHESIS

DC3: Inverted polarity storm hypothesis

"Storms that produce inverted-polarity IC flashes in the upper part of storms and inverted-polarity CG flashes are those in which a large fraction of the adiabatic liquid water profile is realized as cloud liquid in the mixed phase region."

DC3: Inverted polarity storm hypothesis

"Storms that produce inverted-polarity IC flashes in the upper part of storms and inverted-polarity CG flashes are those in which a large fraction of the adiabatic liquid water profile is realized as cloud liquid in the mixed phase region."

DC3: Inverted polarity storm hypothesis

"Storms that produce inverted-polarity IC flashes in the upper part of storms and inverted-polarity CG flashes are those in which a large fraction of the adiabatic liquid water profile is realized as cloud liquid in the mixed phase region."

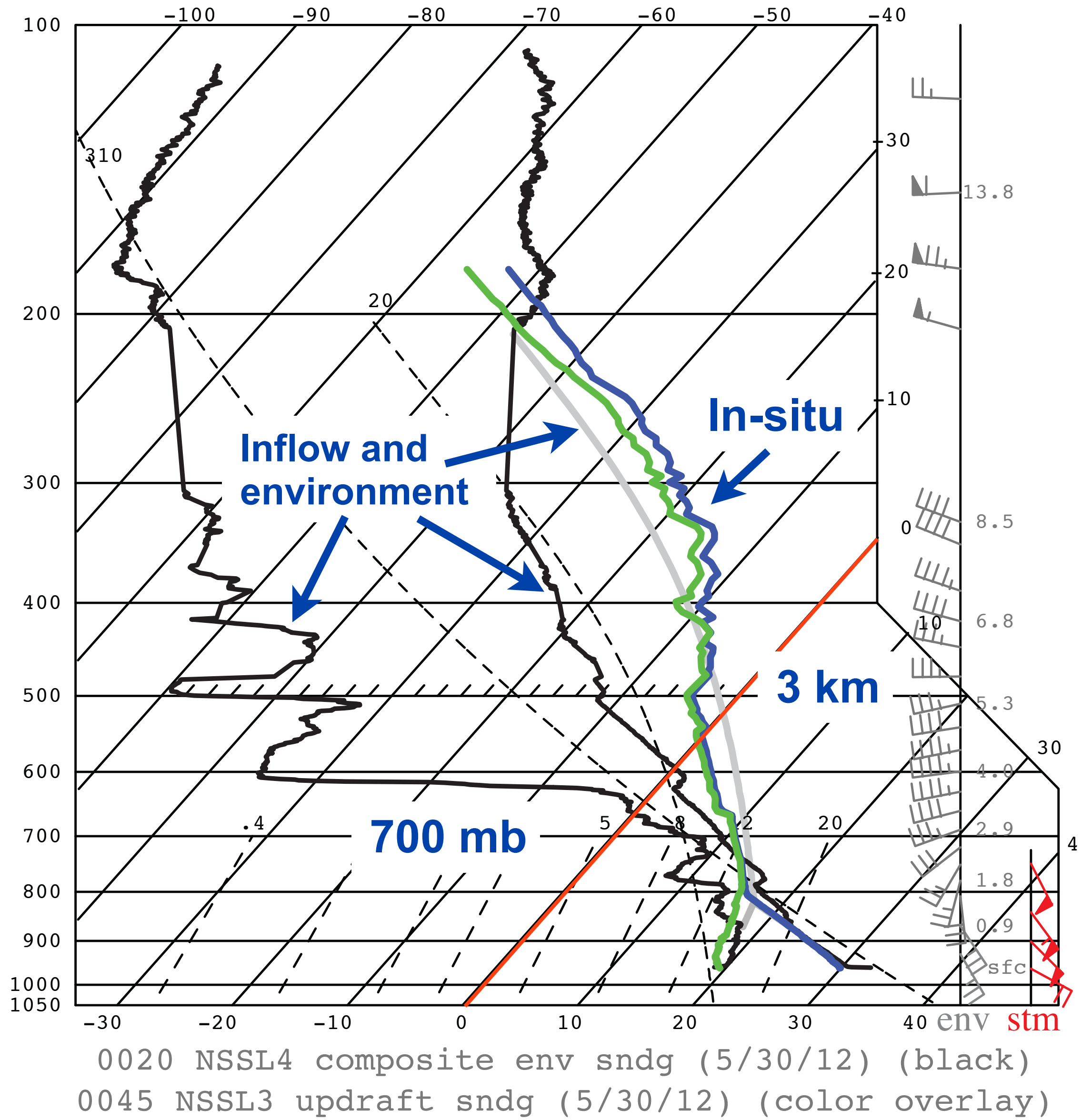
Relevant to DC3 NOx objectives: Vertical distribution of lightning activity for "inverted" storms varies substantially from a "typical" profile.

IN-SITU MEASUREMENTS VS. PARCEL THEORY

Ziegler, MacGorman, Bruning et al., 2012, AMS Conf. SLS

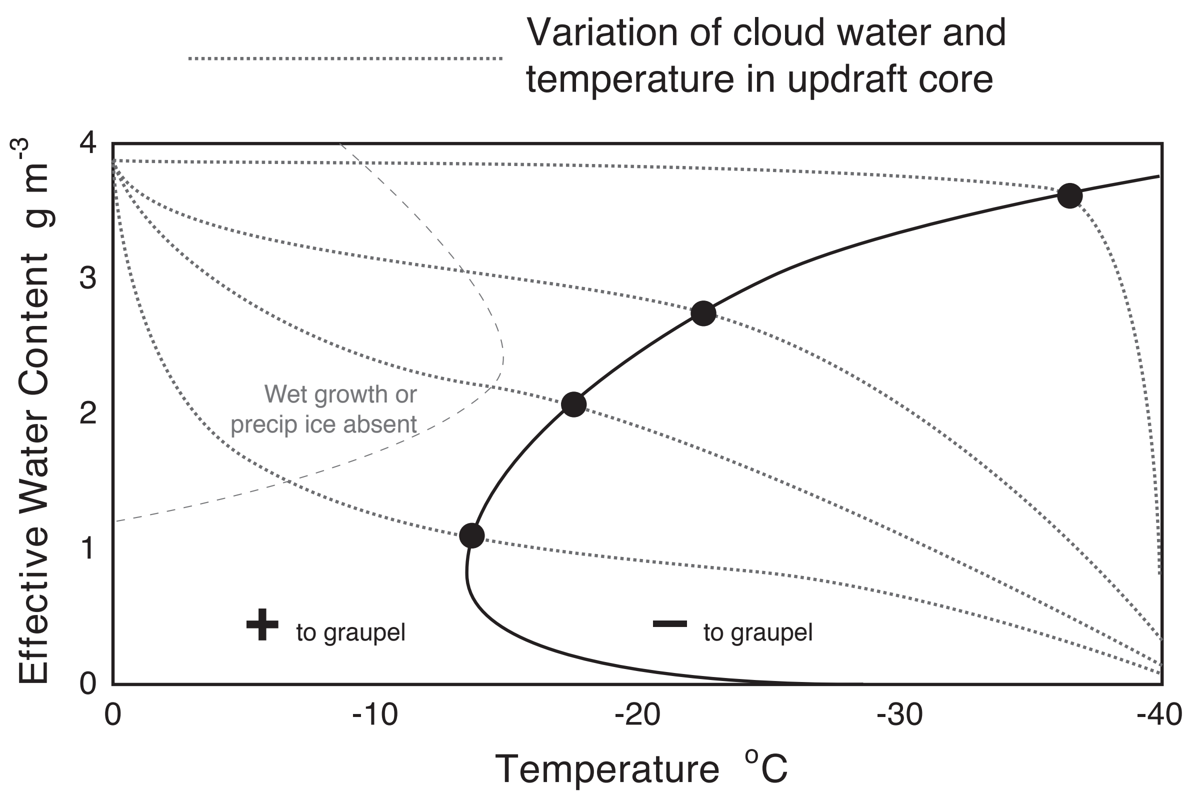
- Moist adiabatic to 650 mb, then a 3°C cooler, moist adiabatic layer to ~500 mb.
- Strong warming above 500 mb to storm top. 10-20% supersaturated w.r.t. ice.
    - *Evidence that cloud liquid was reserved until onset of latent heat of fusion by riming?*
    - *What are the instrument errors in this challenging measurement environment?*
- Warming signal was seen in other updraft core soundings in anomalously electrified cases during STEPS, TELEX programs

Oklahoma, 30 May 2012, ~ 0100 UTC



ELECTRIFICATION: NON-INDUCTIVE, GRAUPEL-ICE CRYSTAL

Bruning, Weiss and Calhoun (2013, Atmos. Res.)

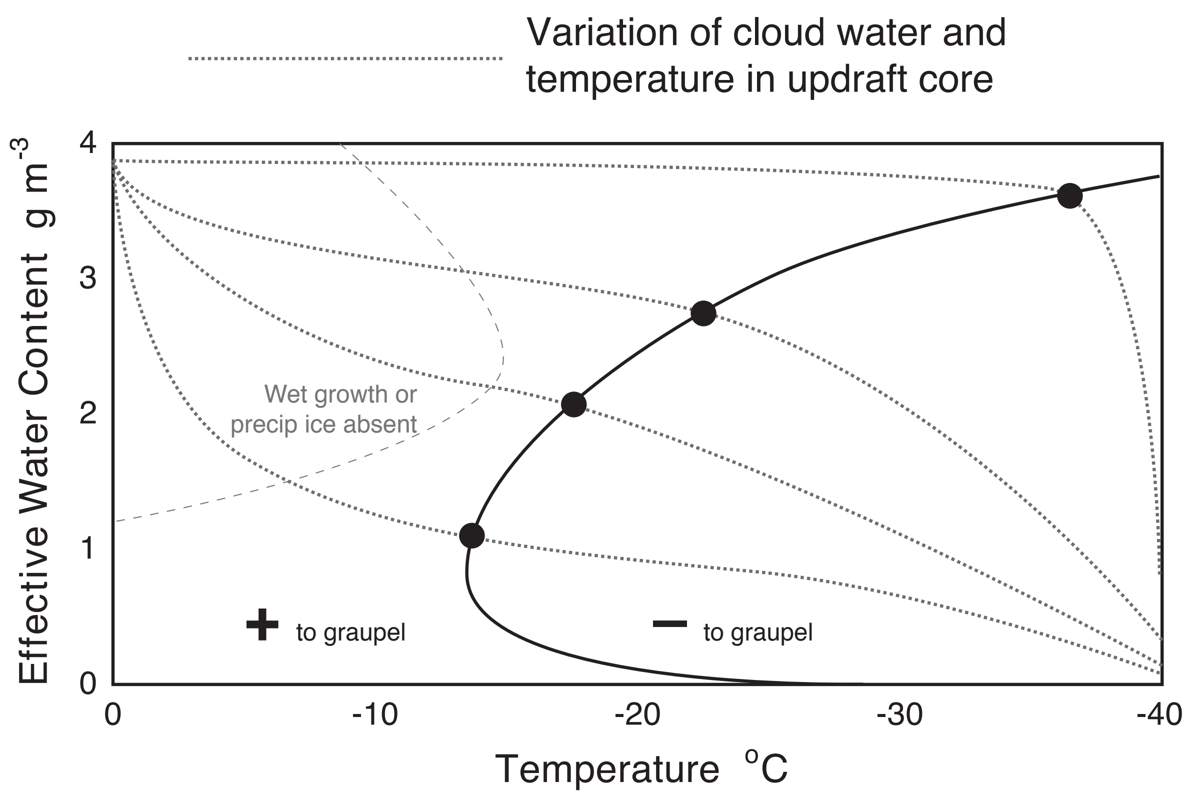


ELECTRIFICATION: NON-INDUCTIVE, GRAUPEL-ICE CRYSTAL

Depletion of liquid water along updraft trajectory seems to be a key factor

- "Weight" of electrification process in + vs. – gained by graupel (crystals opposite)

Bruning, Weiss and Calhoun (2013, Atmos. Res.)



ELECTRIFICATION: NON-INDUCTIVE, GRAUPEL-ICE CRYSTAL

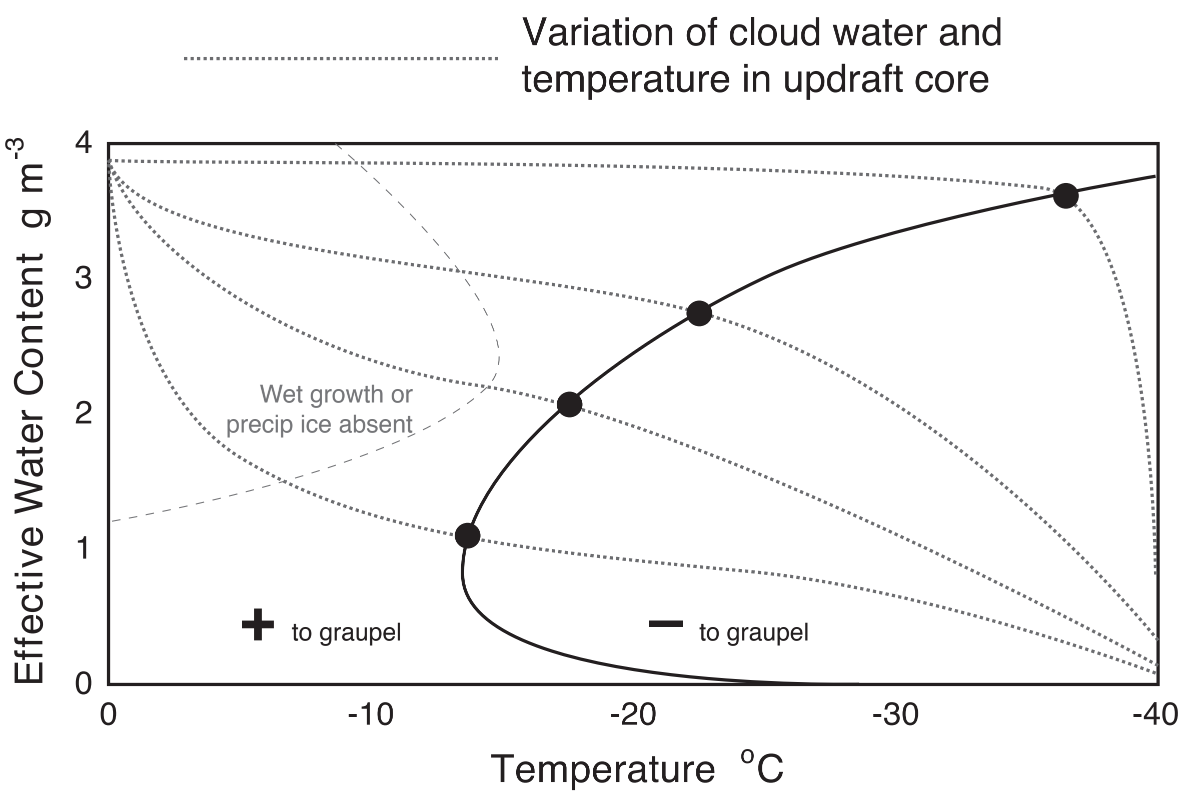
Depletion of liquid water along updraft trajectory seems to be a key factor

- "Weight" of electrification process in + vs. – gained by graupel (crystals opposite)

What are the *mechanisms* by which depletion rates change?

- Moisture availability
- Precipitation efficiency (warm vs. cold DSD growth, recirculation)
- Aerosol/CCN effects

Bruning, Weiss and Calhoun (2013, Atmos. Res.)



Electrification: Non-inductive, graupel-ice crystal

Depletion of liquid water along updraft trajectory seems to be a key factor

- "Weight" of electrification process in + vs. – gained by graupel (crystals opposite)

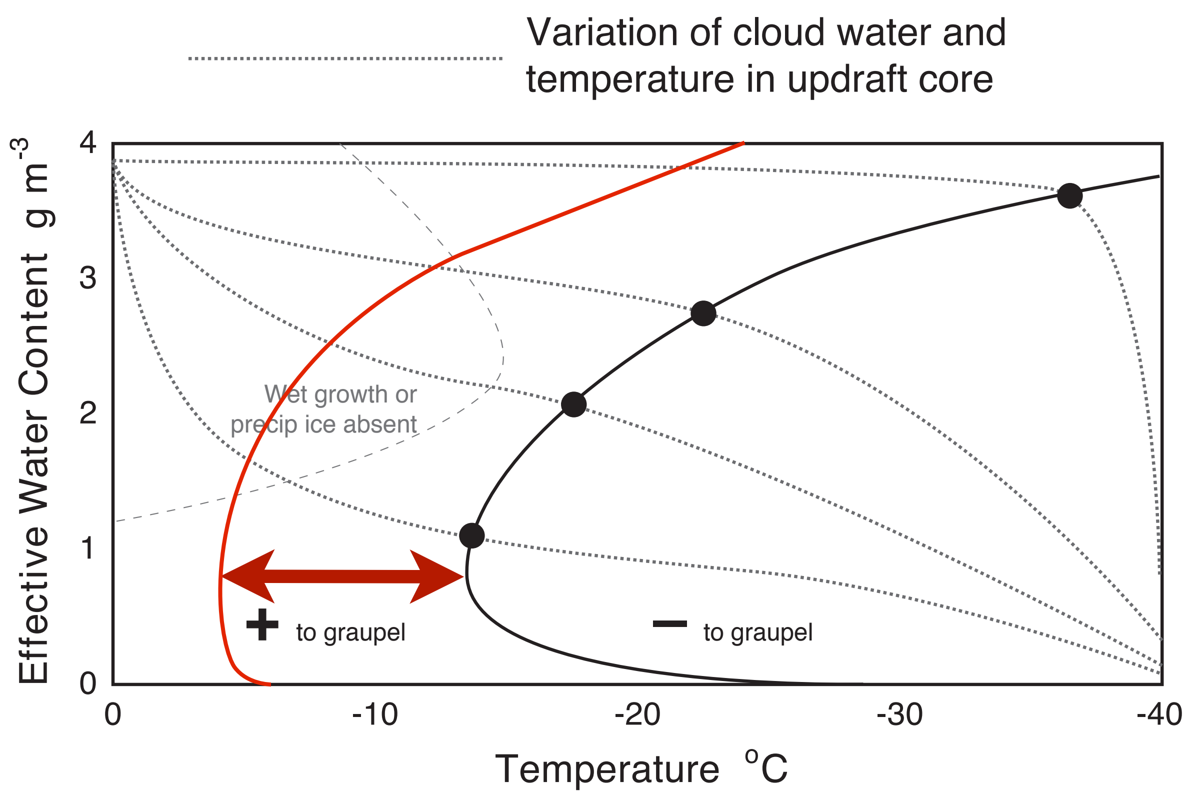
What are the *mechanisms* by which depletion rates change?

- Moisture availability
- Precipitation efficiency (warm vs. cold DSD growth, recirculation)
- Aerosol/CCN effects

Dis-equilibrated vapor field can substantially shift reversal line

- Emersic & Saunders (2010) — lab work
- Role for entrainment in drier midlevel environments?

Bruning, Weiss and Calhoun (2013, Atmos. Res.)



ELECTRIFICATION: NON-INDUCTIVE, GRAUPEL-ICE CRYSTAL

Depletion of liquid water along updraft trajectory seems to be a key factor

- "Weight" of electrification process in + vs. – gained by graupel (crystals opposite)

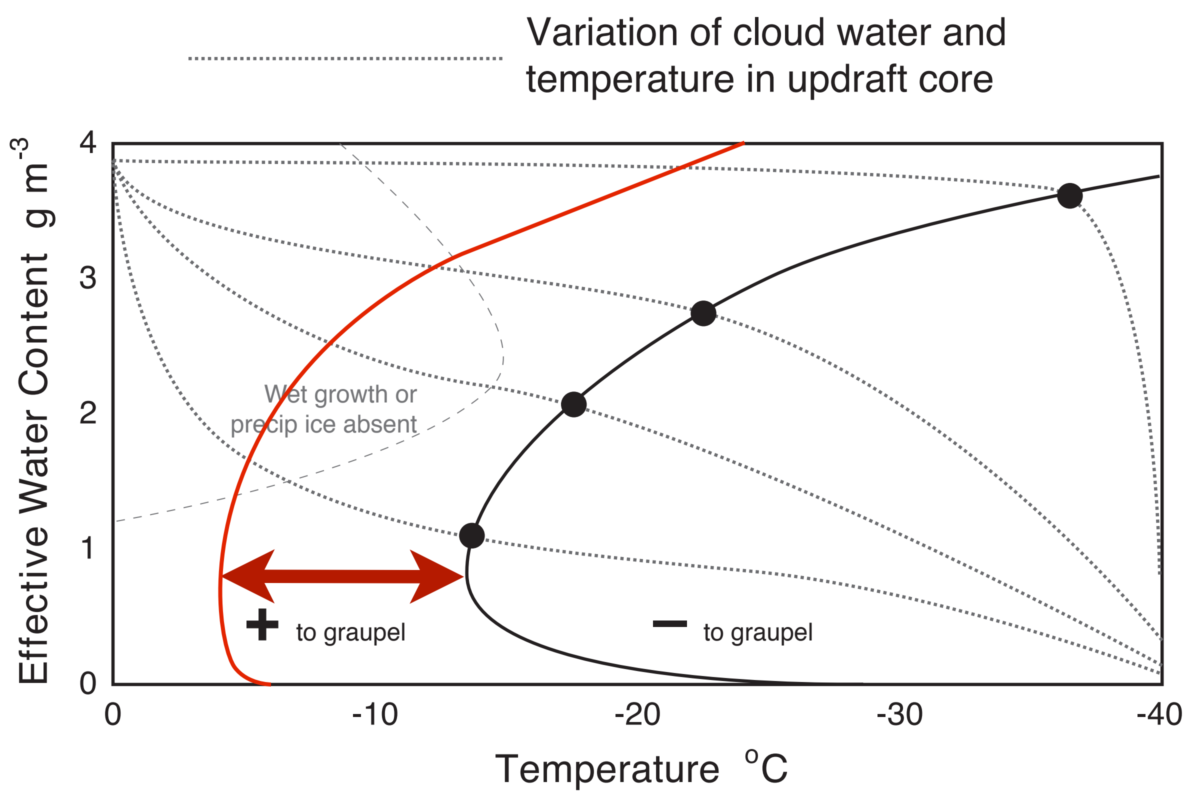
What are the *mechanisms* by which depletion rates change?

- Moisture availability
- Precipitation efficiency (warm vs. cold DSD growth, recirculation)
- Aerosol/CCN effects

Dis-equilibrated vapor field can substantially shift reversal line

- Emersic & Saunders (2010) — lab work
- Role for entrainment in drier midlevel environments?

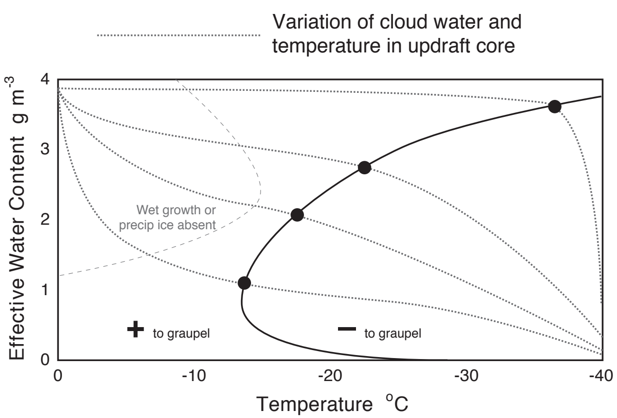
Bruning, Weiss and Calhoun (2013, Atmos. Res.)



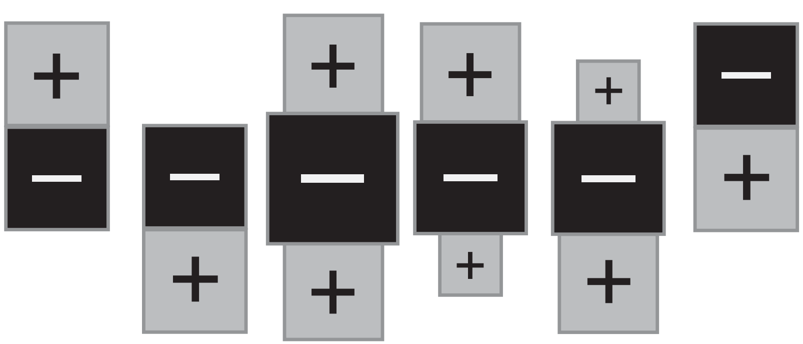
- Electrification is continuously variable — dependent on thermodynamic state space traversal. Can we build a more complete picture of the electrification state space with DC3 data?

Charging leads to charge structures

Electrification in a 1D updraft



Easily explains these



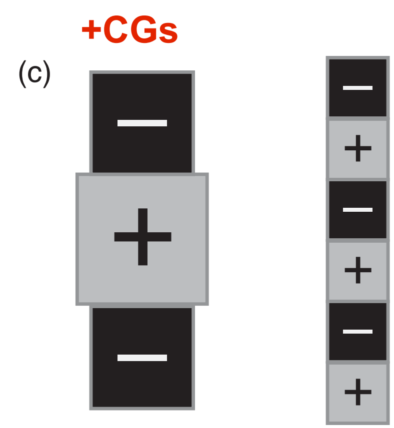
CGs? -CGs Few CGs

Various charge sequences produced by the NI-RGR mechanism

- After electrification, advection, sedimentation, other electrification mechanisms, and lightning itself complicate the resulting charge structure
- Storm-relative precipitation trajectories matter, and can vary substantially from 1-D multicells through 2-D MCSs to 3-D supercells.

But not these

Advection,
Sedimentation,
Lightning,
Other electrification mechanisms

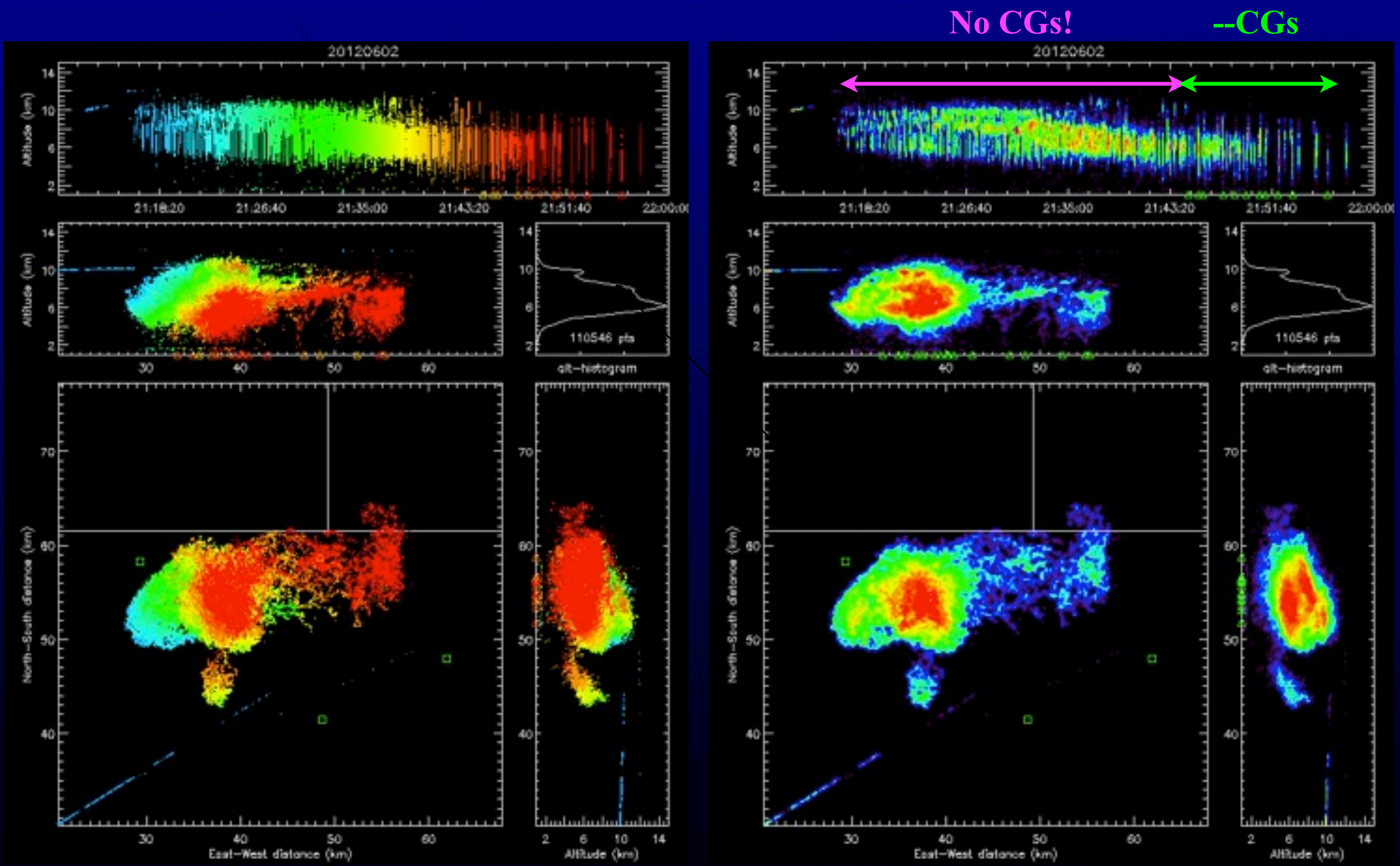


Inverted tripole

Normal, (outside updraft)

Hereford storm, June 2, 2012

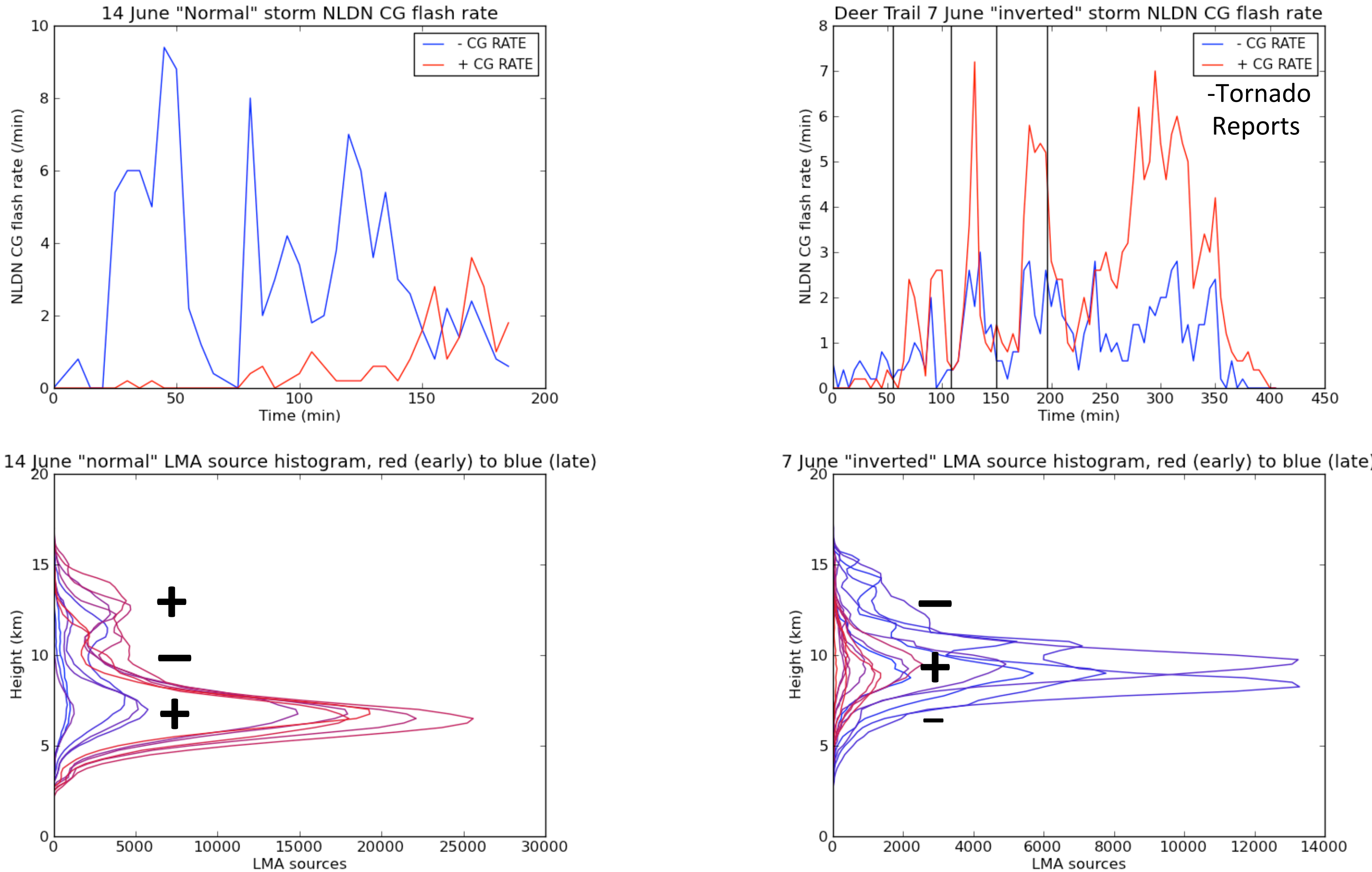
45 minute duration: No CGs for first 34 minutes,
then a steady stream of --CGs during decaying stages



Courtesy Krehbiel/Rison/Thomas

Comparison of “normal” and “inverted” polarity storms during DC3

–CG dominant | **+CG dominant**

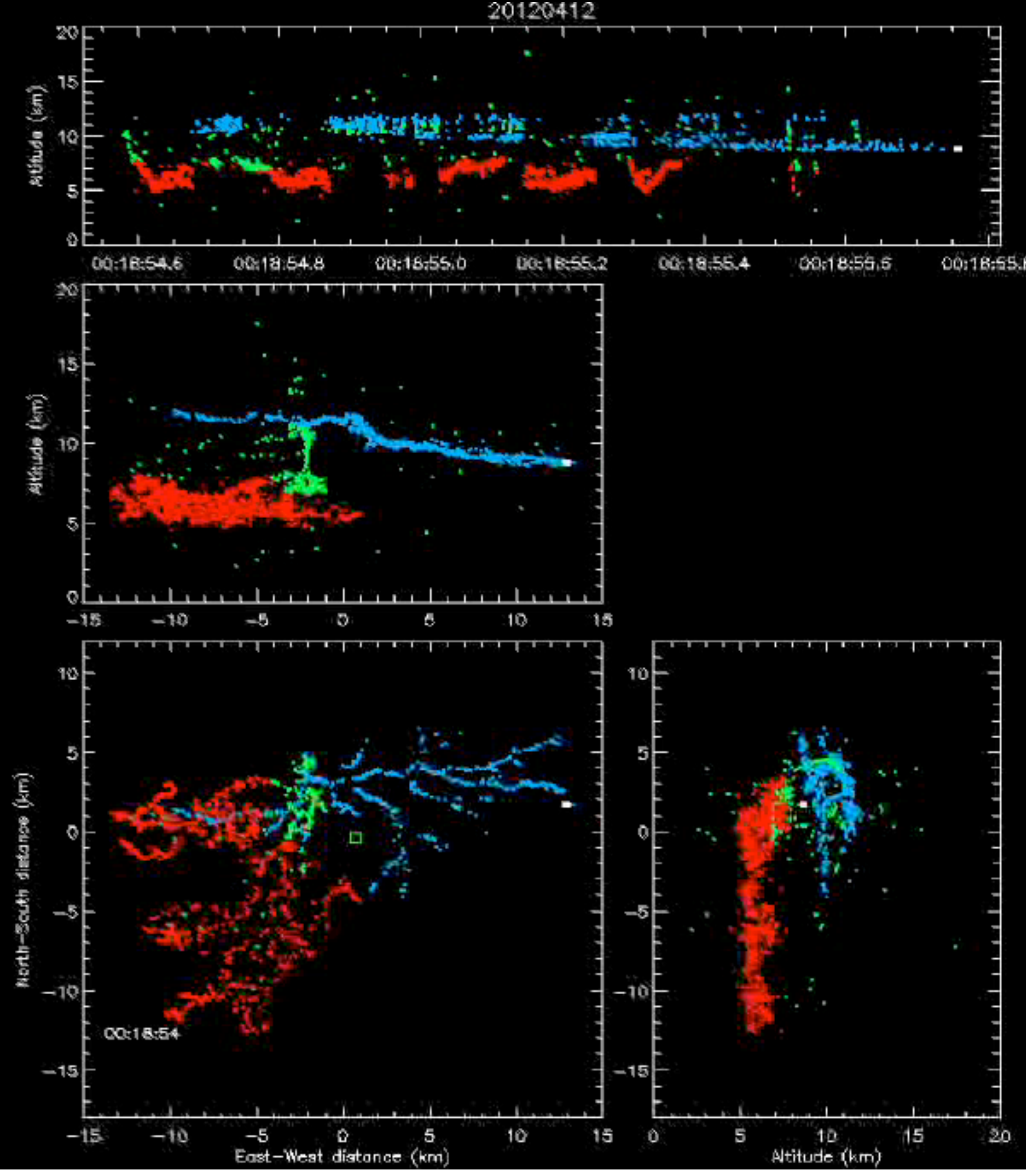


- Storms can develop different vertical charge structures that can determine polarity of the majority of CG’s
- Bottom plot shows temporal evolution of vertical LMA source densities
- Both storms maintain consistent charge structures throughout lifetime

Courtesy Brody Fuchs

“Inverted” -IC flash in upper part of storm. “Normal” storms typically have +ICs in this vertical position.

Courtesy Krehbiel/Rison/Thomas

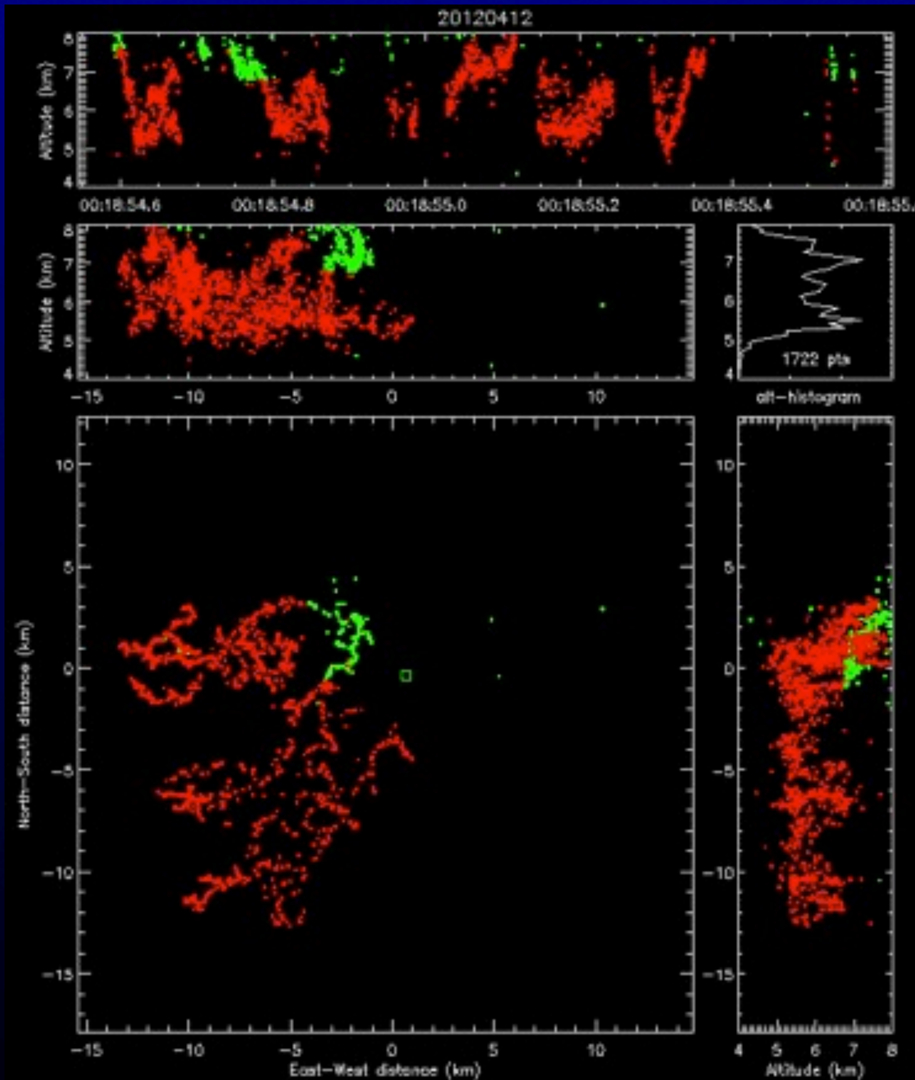


“Inverted” -IC flash in upper part of storm. “Normal” storms typically have +ICs in this vertical position.

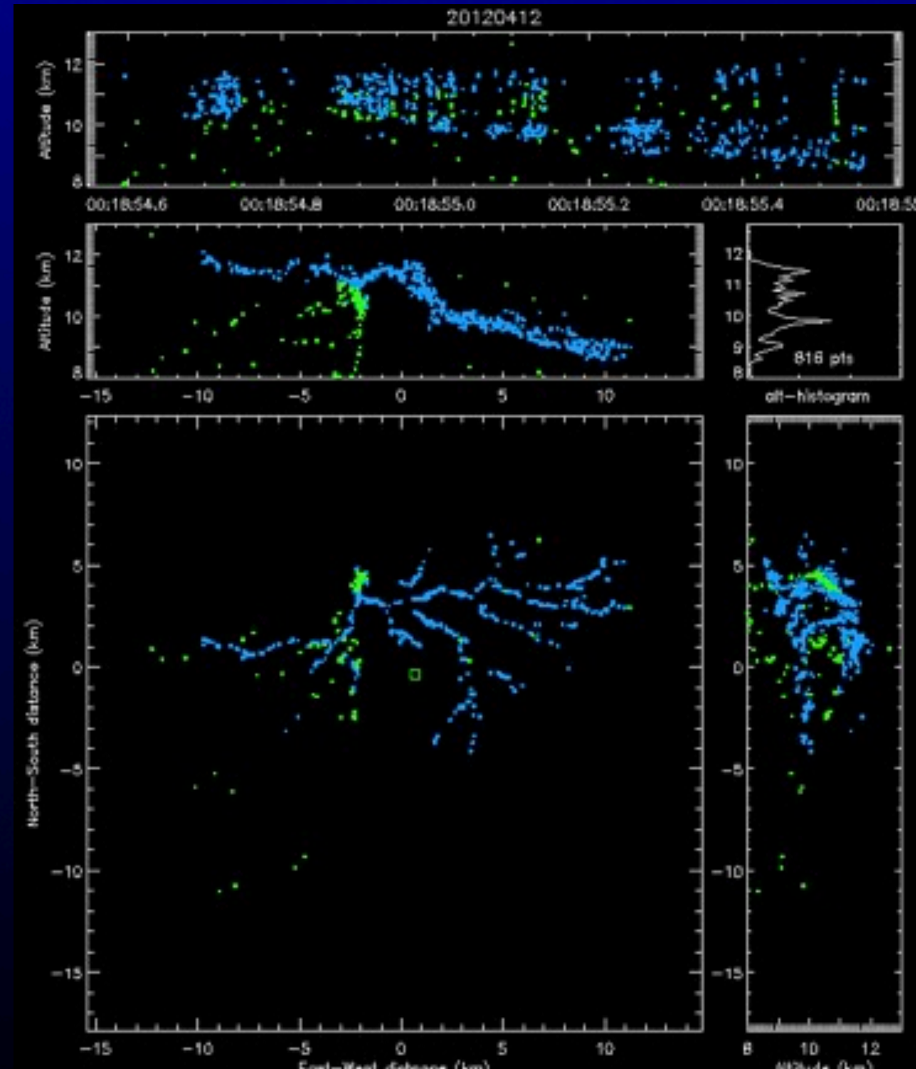
Courtesy Krehbiel/Rison/Thomas

Separate out positive and negative breakdown channels

Negative leaders
one main branch at a time; spatially noisy



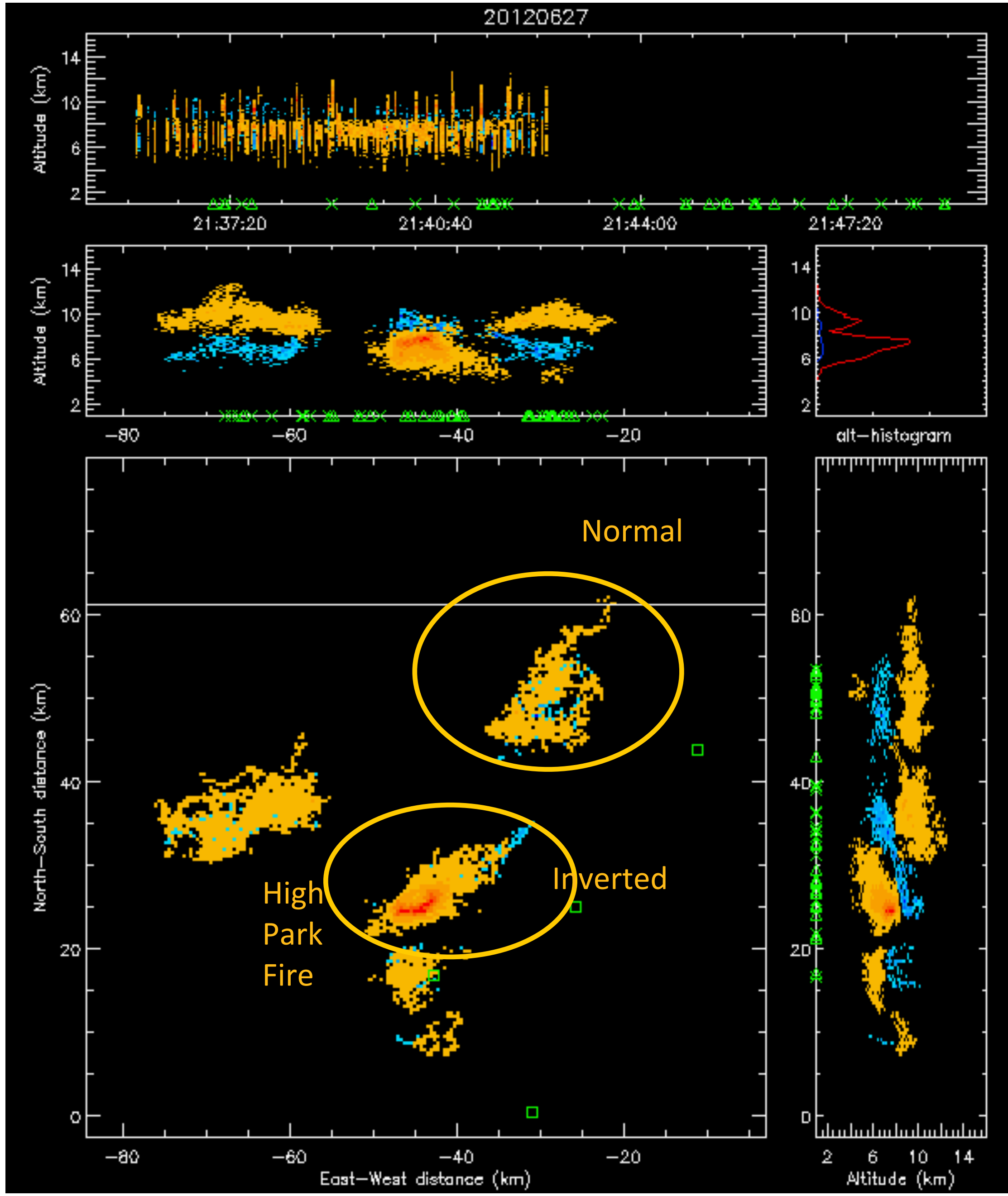
Positive leaders
well-defined filamentary structure, all in parallel



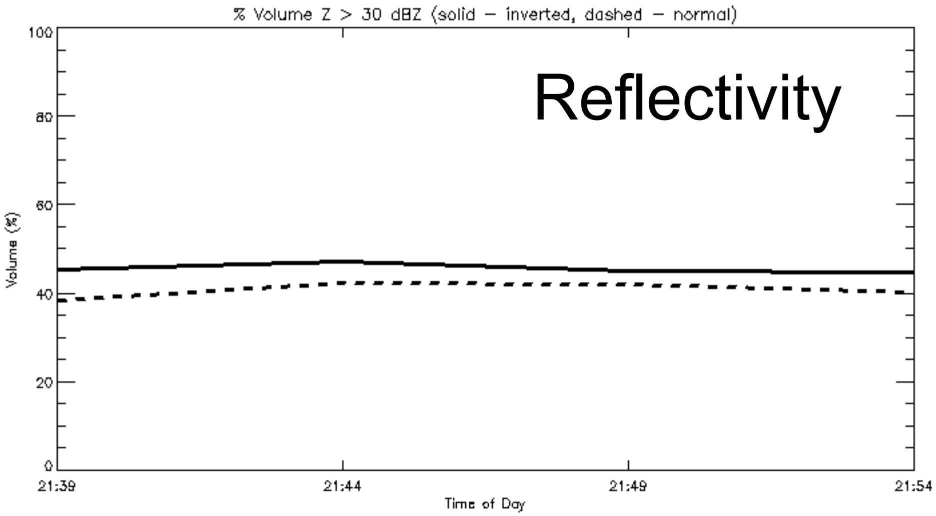
Courtesy Krehbiel/Rison/Thomas

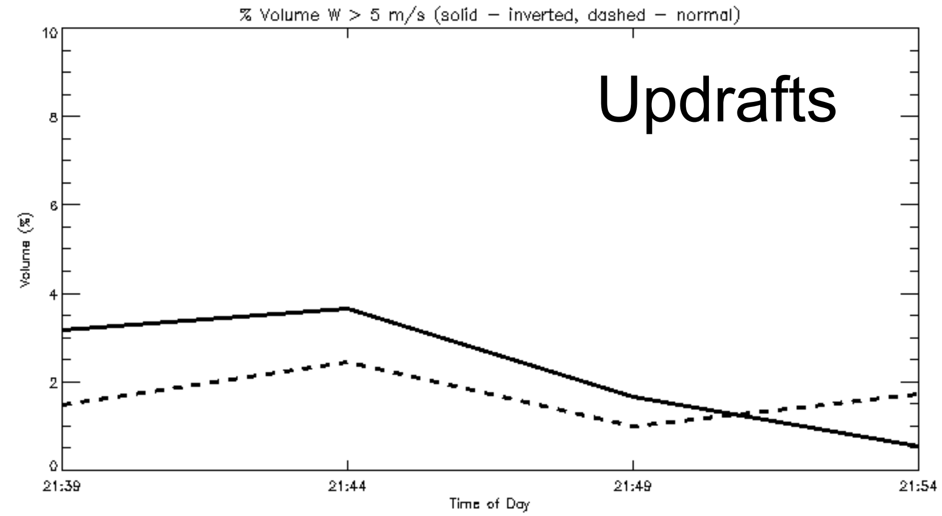
27 June 2012

Did the major fire activity and smoke in the Colorado domain during DC3 cause anomalous electrification of thunderstorms (i.e., “inverted storms”)? Case studies of inverted and normal-polarity charge structures in adjacent “garden variety” convection may offer a way to test this hypothesis.



Courtesy Timothy Lang





The *normal* (dashed) and *inverted* (solid) polarity storms presented similar updraft and reflectivity statistics, despite their vastly different charge structures.

At first glance, this does not fit the paradigm from STEPS, where the strongest and largest storms tended to be inverted. Here, both storms appear similar in strength, and both were best classified as “garden variety.” Is smoke ingestion to blame? The inverted storm was closer to the High Park Fire. But we need to dig deeper!

Courtesy Timothy Lang

Statistical Comparison of Colorado storms during DC3

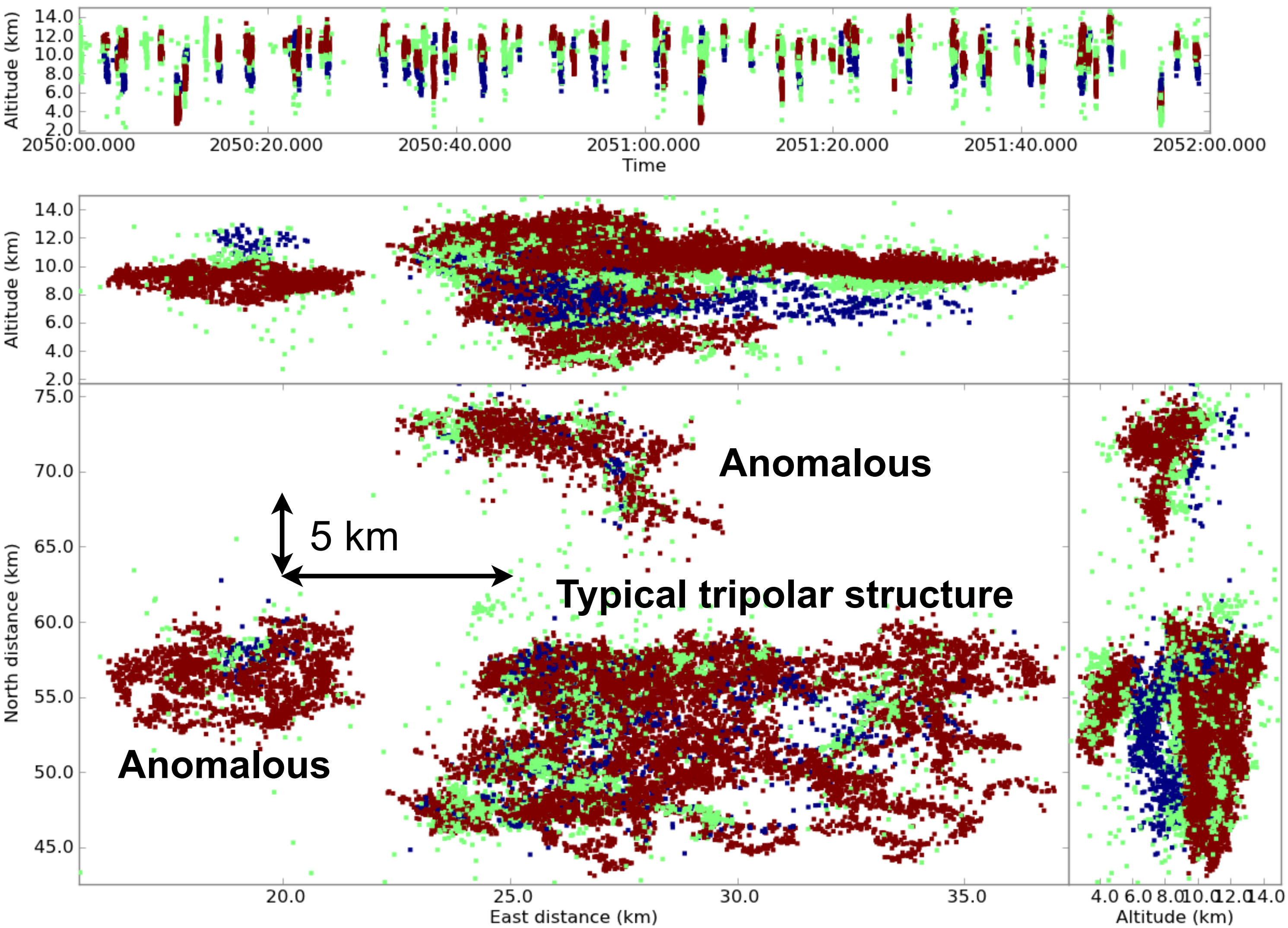
Parameter	- CG Dominated storms	+ CG Dominated storms	NO (or little) CG storms
Number of cell	360	253	937
CAPE (J/kg)	788	1146	925
- CG rate (min^{-1})	1.14	0.34	0.05
+ CG rate (min^{-1})	0.14	1.19	0.03
LMA mode ht/ std dev (km)	8.01 / 1.70	8.11 / 1.60	8.15 / 1.51
LMA total source rate (min^{-1})	12400	17100	5750
30 dBZ max ht (km)	13.97	15.13	13.44
30 dBZ vol. in mixed phase region (km^3)	1640	2550	800

Courtesy Brody Fuchs

West Texas, 4 June 2012

Courtesy Vanna Sullivan

- Isolated cells are anomalous. Cell complexes in more-moist or previously-overturned environment are normal.



SUMMARY: STORM POLARITY

SUMMARY: STORM POLARITY

- Key idea: liquid availability in mixed phase region

Summary: storm polarity

- Key idea: liquid availability in mixed phase region
- Proposed mechanisms for enhancing liquid availability

Summary: storm polarity

- Key idea: liquid availability in mixed phase region
- Proposed mechanisms for enhancing liquid availability
    - *Environmental moisture availability and precipitation efficiency*

Summary: storm polarity

- Key idea: liquid availability in mixed phase region
- Proposed mechanisms for enhancing liquid availability
  - *Environmental moisture availability and precipitation efficiency*
  - *Large mixed-phase updraft volume*

SUMMARY: STORM POLARITY

- Key idea: liquid availability in mixed phase region
- Proposed mechanisms for enhancing liquid availability
  - *Environmental moisture availability and precipitation efficiency*
  - *Large mixed-phase updraft volume*
  - *Stage of cell lifecycle relative to upscale growth*

SUMMARY: STORM POLARITY

- Key idea: liquid availability in mixed phase region
- Proposed mechanisms for enhancing liquid availability
  - *Environmental moisture availability and precipitation efficiency*
  - *Large mixed-phase updraft volume*
  - *Stage of cell lifecycle relative to upscale growth*
  - *Smoke / CCN effects*

SUMMARY: STORM POLARITY

- Key idea: liquid availability in mixed phase region
- Proposed mechanisms for enhancing liquid availability
  - *Environmental moisture availability and precipitation efficiency*
  - *Large mixed-phase updraft volume*
  - *Stage of cell lifecycle relative to upscale growth*
  - *Smoke / CCN effects*
- Many processes …

SUMMARY: STORM POLARITY

- Key idea: liquid availability in mixed phase region
- Proposed mechanisms for enhancing liquid availability
  - *Environmental moisture availability and precipitation efficiency*
  - *Large mixed-phase updraft volume*
  - *Stage of cell lifecycle relative to upscale growth*
  - *Smoke / CCN effects*
- Many processes …
- … but many storms in many environments during DC3

SUMMARY: STORM POLARITY

- Key idea: liquid availability in mixed phase region
- Proposed mechanisms for enhancing liquid availability
  - *Environmental moisture availability and precipitation efficiency*
  - *Large mixed-phase updraft volume*
  - *Stage of cell lifecycle relative to upscale growth*
  - *Smoke / CCN effects*
- Many processes …
- … but many storms in many environments during DC3

SUMMARY: STORM POLARITY

- Key idea: liquid availability in mixed phase region
- Proposed mechanisms for enhancing liquid availability
  - *Environmental moisture availability and precipitation efficiency*
  - *Large mixed-phase updraft volume*
  - *Stage of cell lifecycle relative to upscale growth*
  - *Smoke / CCN effects*
- Many processes …
- … but many storms in many environments during DC3

- Given storm mode and environment, can we predict the expected electrical structure?