Relating lightning to storm parameters

Plenary talk, DC3 Science Team Meeting, 25-28 February 2012

Presenter

Timothy Lang

Contributors

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Alabama: Larry Carey

Modeling: Kristin Cummings, Ken Pickering

Evaluation of WRF Parameterized Flash Rates

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1) Evaluation of flash rates in cloud-resolved (3-km) WRF forecasts during the DC3 mission using NLDN data; three schemes employed.

2) Evaluation of flash rates in post-mission cloud-resolved WRF simulations using NLDN and LMA data; 4 storm cases identified as top priority; initially at 3-km resolution, later at 1-km. Use same three schemes, but also test others that are more microphysically based.

3) Collaboration with Steve Rutledge and Brett Basarab for testing in WRF of relationships they derive between DC3 LMA flash rates and radar-derived storm parameters.

Flash Rate Parameterization Schemes used in 3-km Resolution WRF Forecasts during DC3

Type of FRPS	Equation (*flashes min^{-1}*)
• Updraft volume	$f = 6.75 \times 10^{-11} w_5 - 13.9$
• Maximum vertical velocity	$f = 5.7 \times 10^{-6} \times w_{max}^{4.5}$
• Cloud top height	$f = 3.44 \times 10^{-5} H^{4.9}$

f = total flash rate; IC/CG ratios based on *Boccippio et al. (2001)*

Evaluate flash rate output with NLDN (adjusted by Boccippio ratio); Focus on cases in which WRF performed well in timing, location, and strength of convective systems

Evaluation of WRF Flash Rates in Post-mission Case Study Storm Simulations

- **The same three schemes (updraft volume, maximum vertical velocity, and cloud-top height) will be run in cloud-resolved 3-km and 1-km resolution WRF simulations of selected DC3 storms and tested against LMA flash counts.**

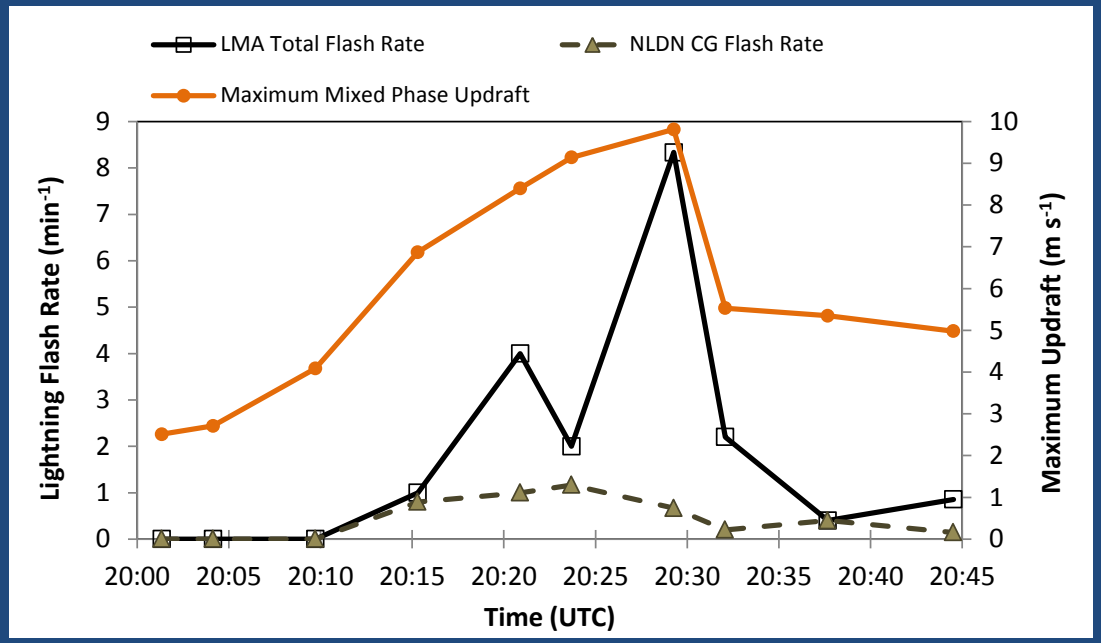
  May 21 Alabama
  May 29 Oklahoma
  June 6 Colorado
  June 22 Colorado

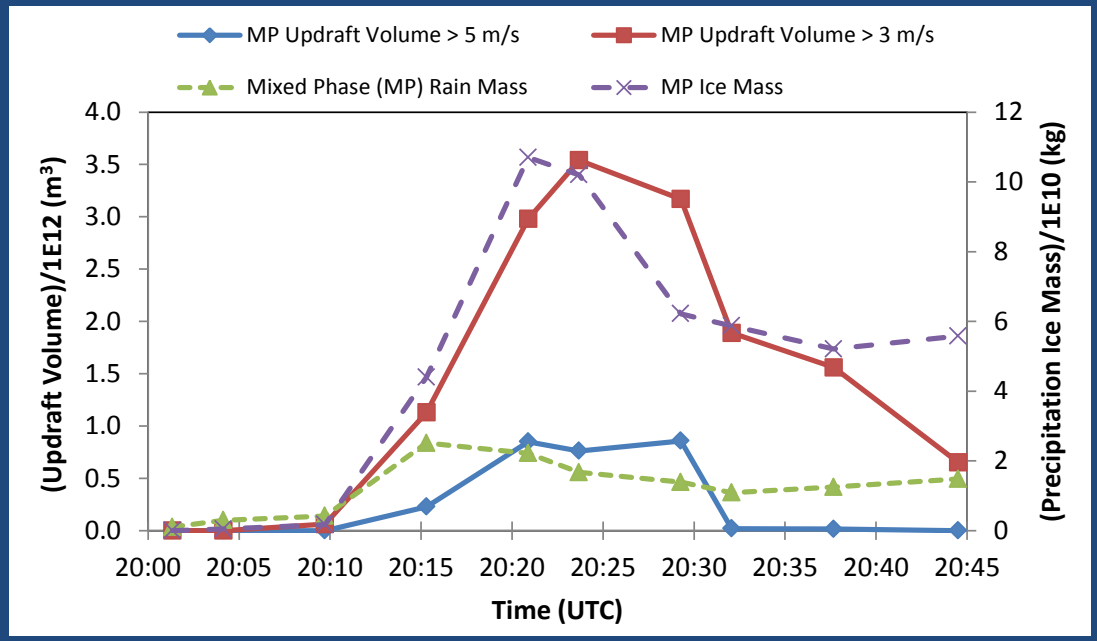
- **Test other more microphysically-based schemes:**

  precipitation ice mass
  ice water path
  precipitating and non-precipitating ice mass flux
  volume of graupel region
  relationships derived by Basarab/Rutledge from DC3 radar/LMA data

DC3 AL: May 21, 2012 (Aircraft Case #1)

- Lightning commenced after maximum mixed-phase (MP) updraft > 5 m s^{-1}, ample ice mass and significant MP updraft volume (> 3 m s^{-1})
- Freezing of supercooled rain water (Z_{dr} columns) source of precipitation ice
- Correlation between lightning and ice mass (1-lag) reasonable ($\rho \approx 0.8$)
- NLDN CG lightning 100% negative polarity
- Normal polarity IC flashes: low shear/low CAPE





DC3 AL: June 11, 2012 (Aircraft Case #2)

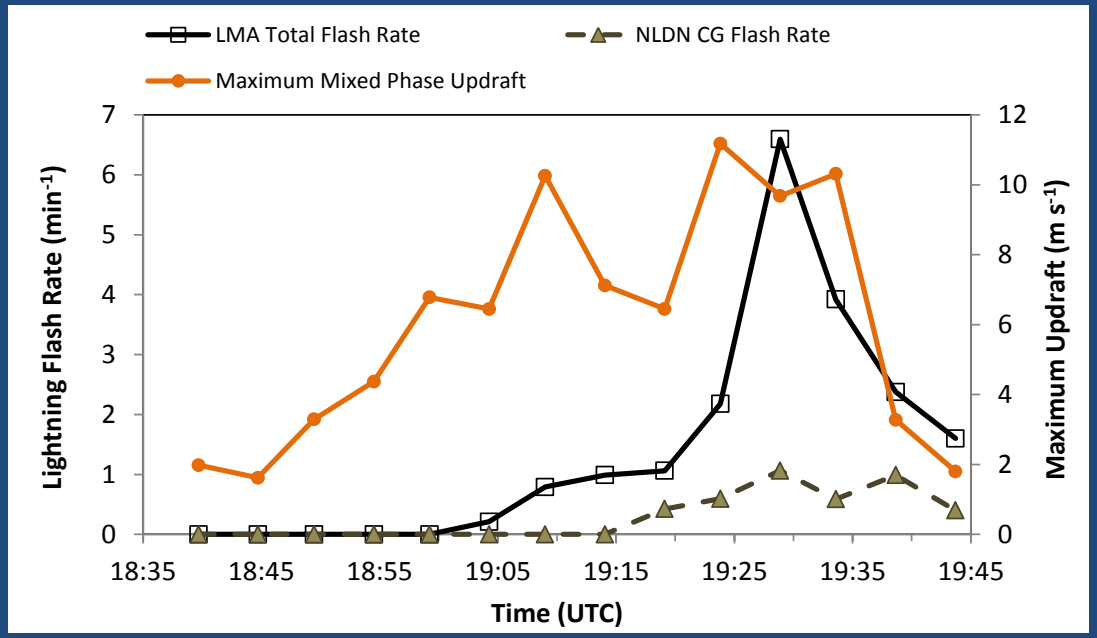
- 100% -CG; normal polarity flashes in low CAPE/shear
- Onset of **lightning** and **ice** delayed as **MP supercooled rain** fraction high early;
  - Moister, larger warm cloud depth and weaker low-level lapse rates
- Excellent trend correlation **lightning** and **ice** (ρ=0.9) but

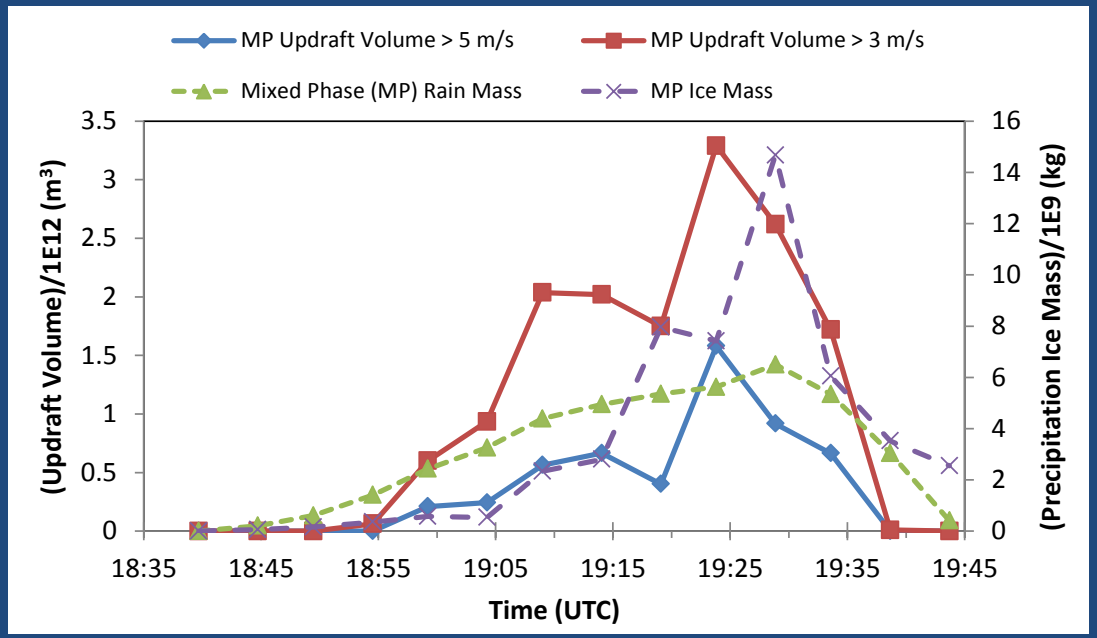
$(\text{Ice Mass})_{11\ \text{June}} \ll (\text{Ice Mass})_{21\ \text{May}}$

$(\text{Updraft})_{11\ \text{June}} \approx (\text{Updraft})_{21\ \text{May}}$

$(\text{Flash Rate})_{11\ \text{June}} \approx (\text{Flash Rate})_{21\ \text{May}}$

- Other microphysical differences? Parameterization implication? Investigate more.

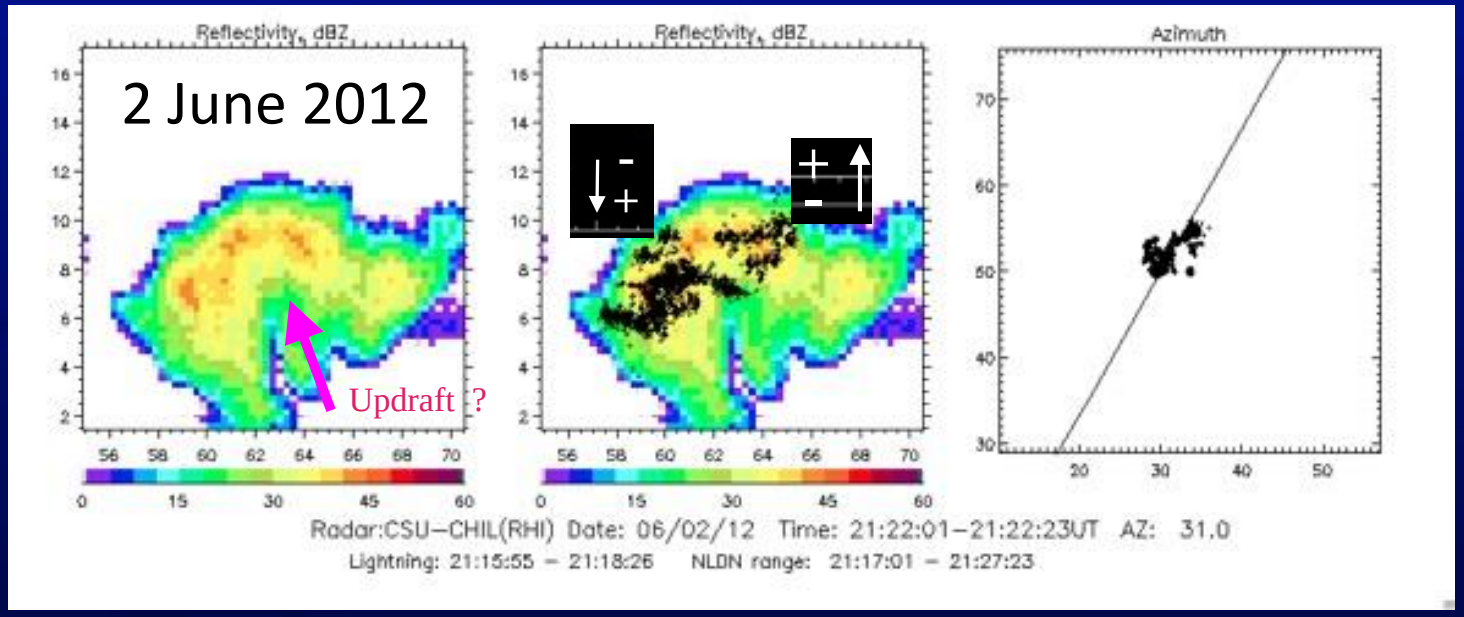




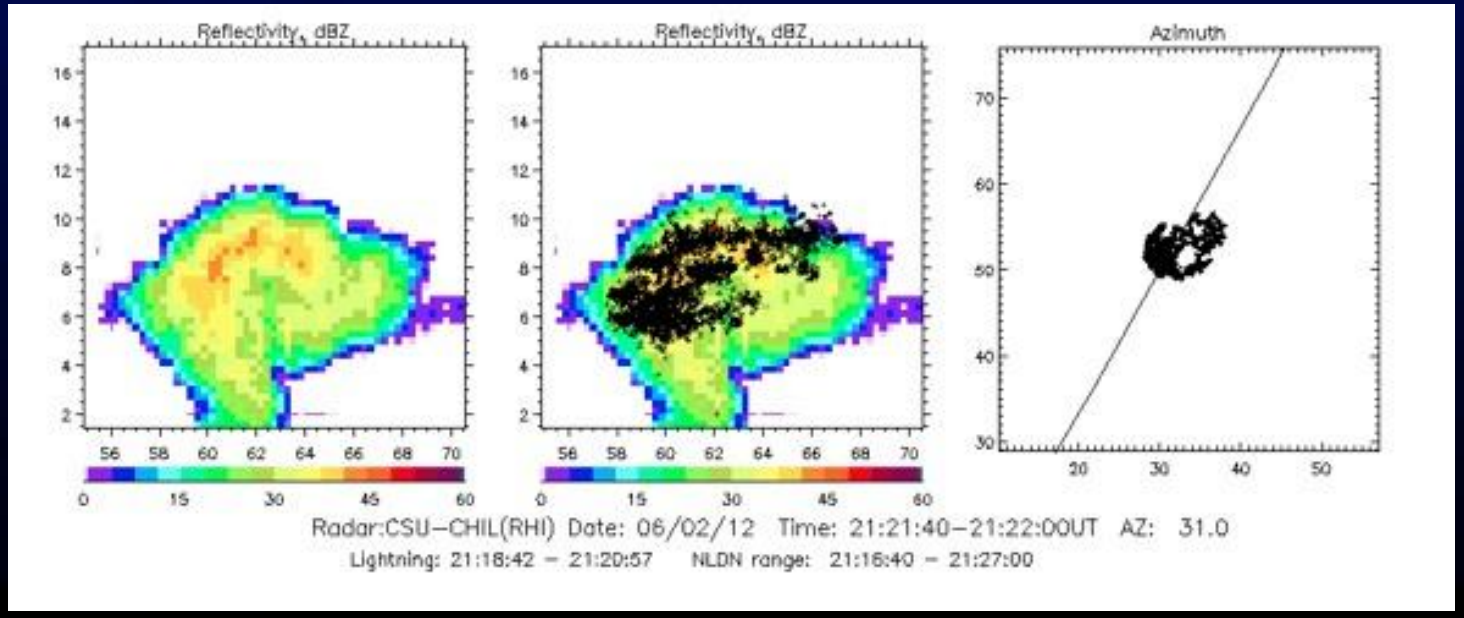
Comparison of lightning with CHILL vertical radar scans

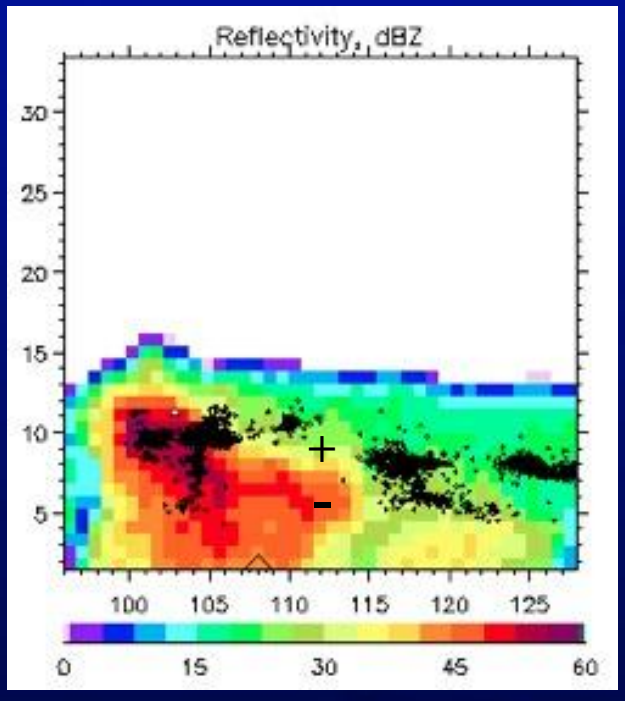
Multiple dipolar charge regions correlated with overhanging reflectivity structure

2.5 min of first lightning

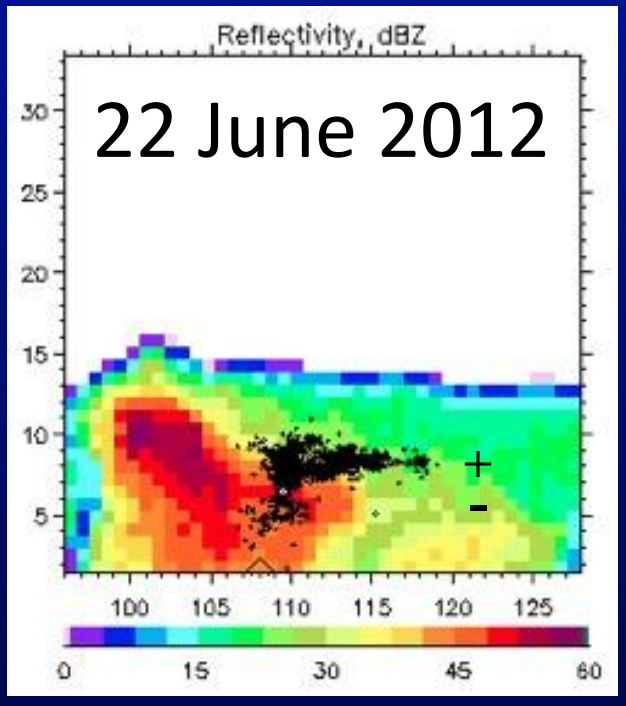


Next 2 min of activity

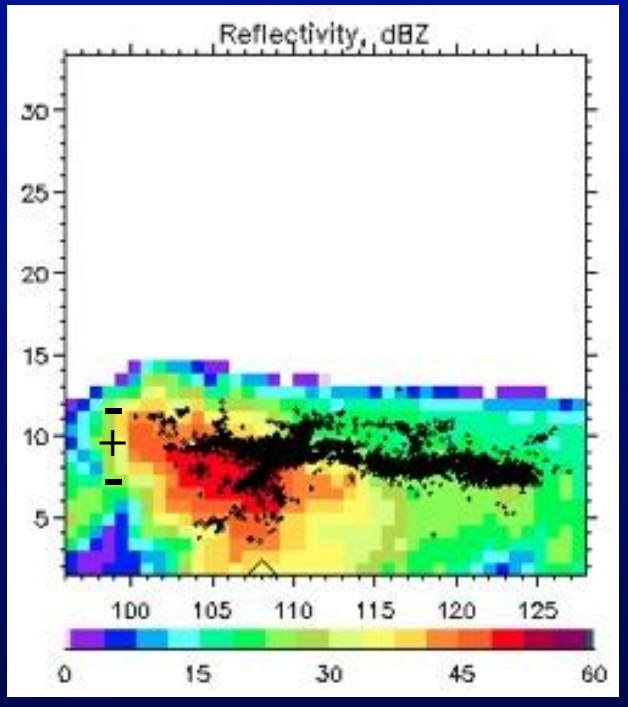




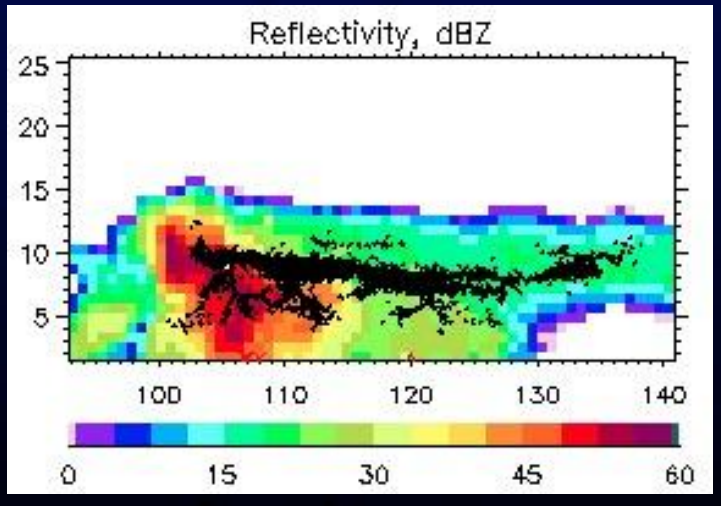
21:18:48 to 21:19:10
22 seconds of activity before +CG



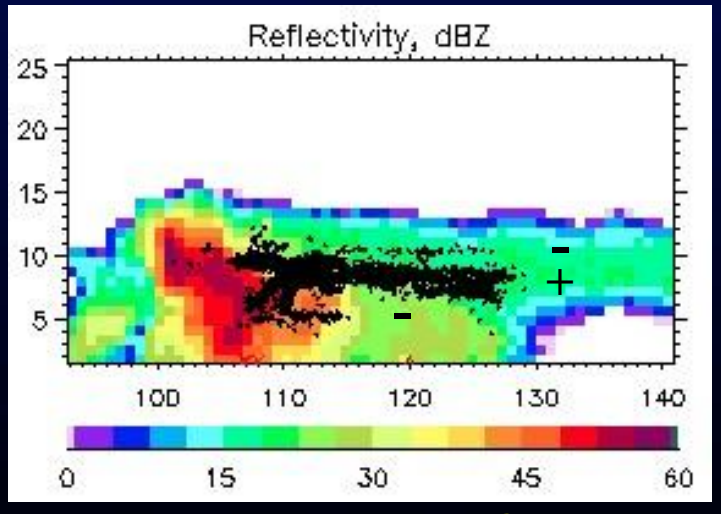
53.5 kA +CG at 21:19:12



21:19:16 to 21:19:42
26 seconds of activity after +CG



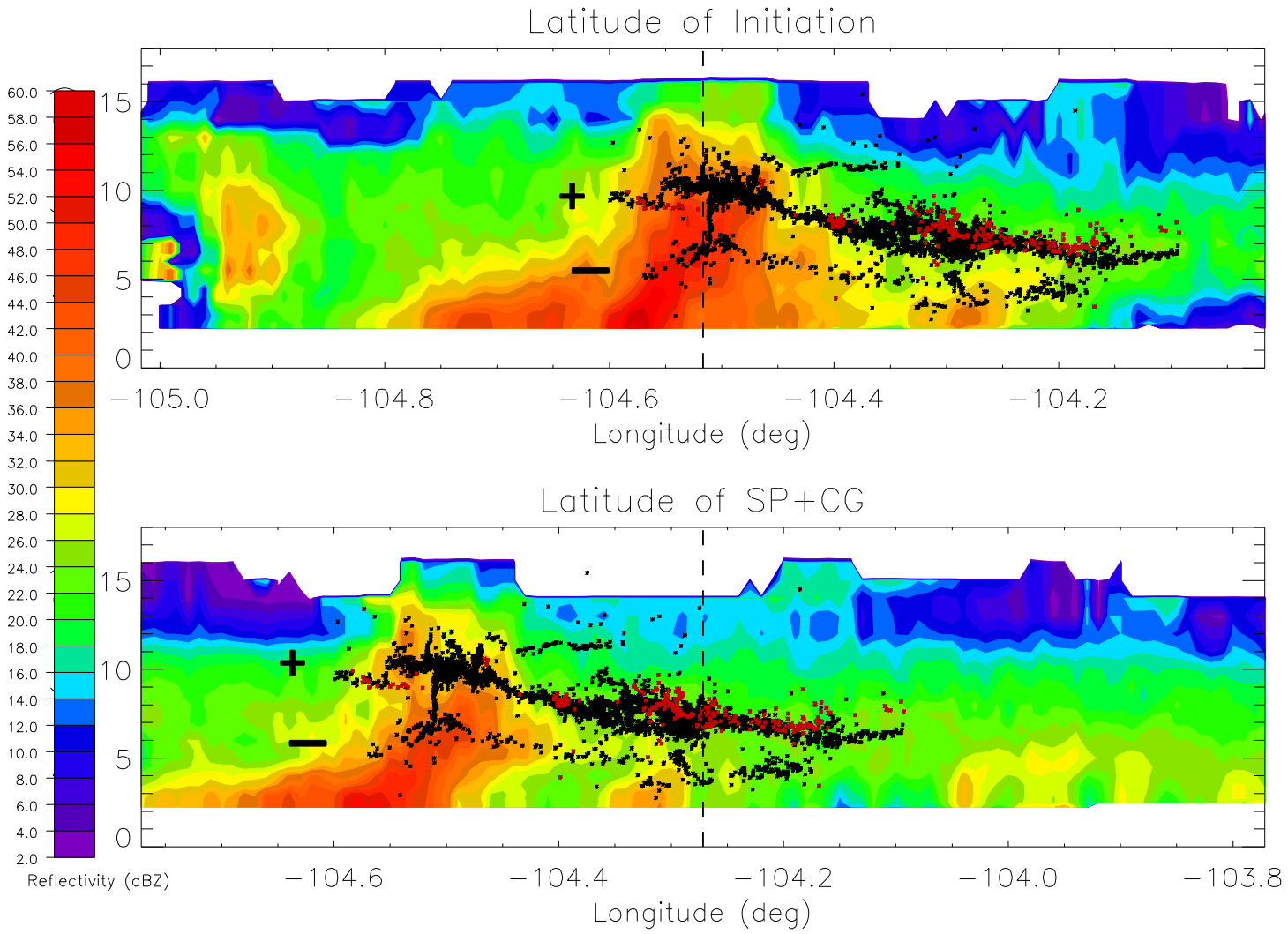
21:20:51 to 21:21:16
25 seconds of activity



21:21:24 to 21:22:13
49 seconds of activity

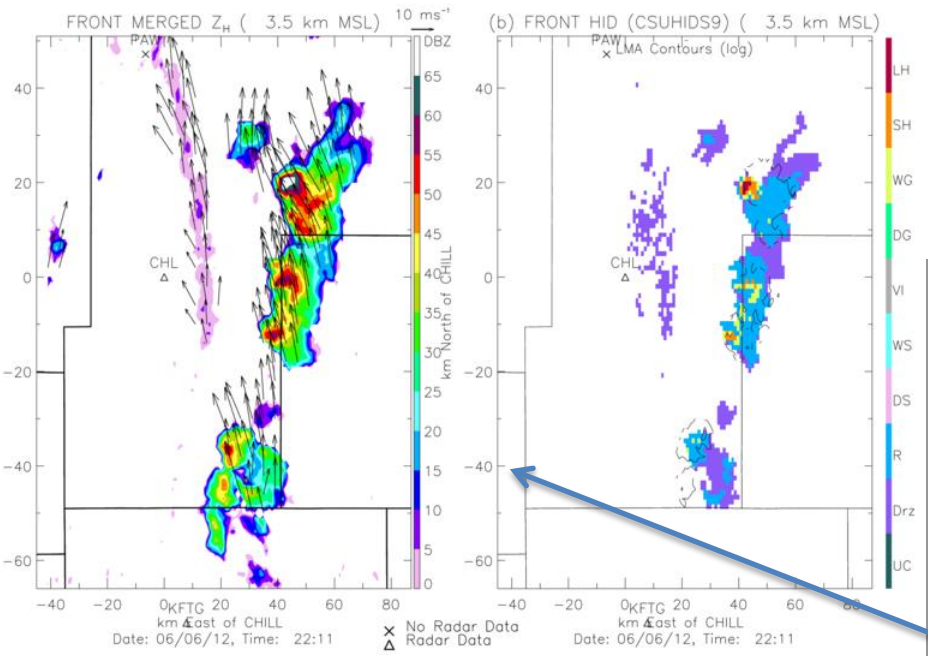
NEXRAD Composite Radar Mosaic
Positive Sprite Parent
8 June 2012
0500 UTC

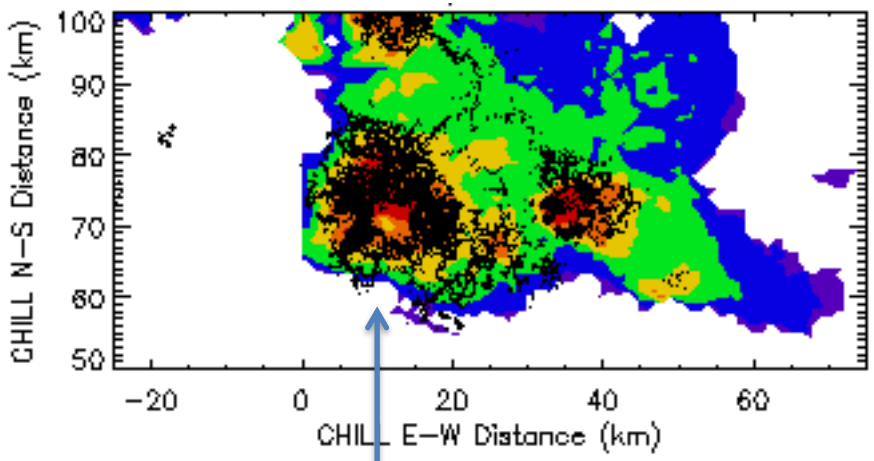
Positive dipole in convection, downward sloping outside convection

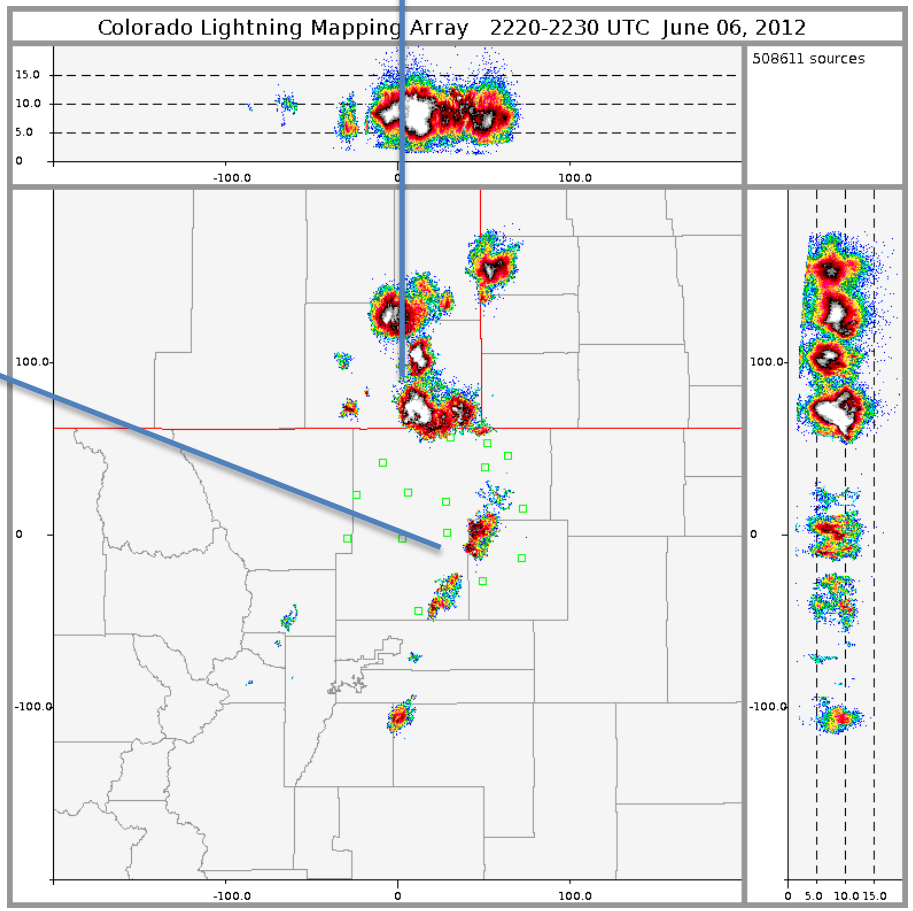


Black Dots: CO LMA Sources
Red Dots: Sources during SP+CG + 100 ms

6 June 2012 (~2200 hour)
Lightning from COLMA
Transient lightning holes (match BWERs)







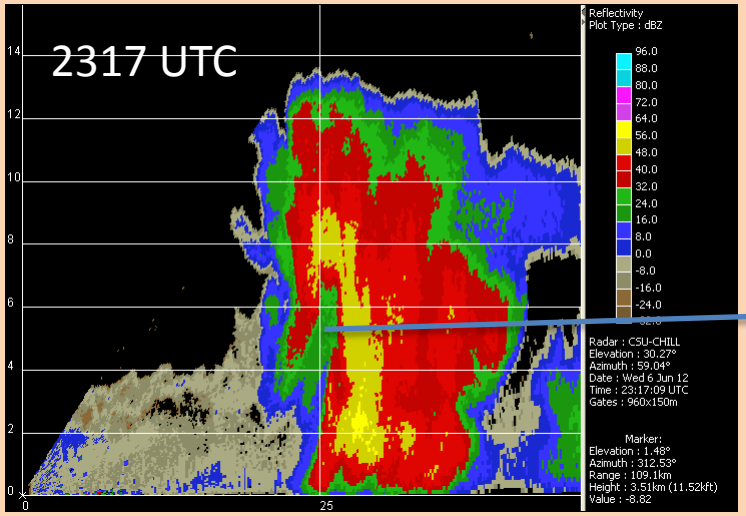
Data Example: 2200-2215 UTC

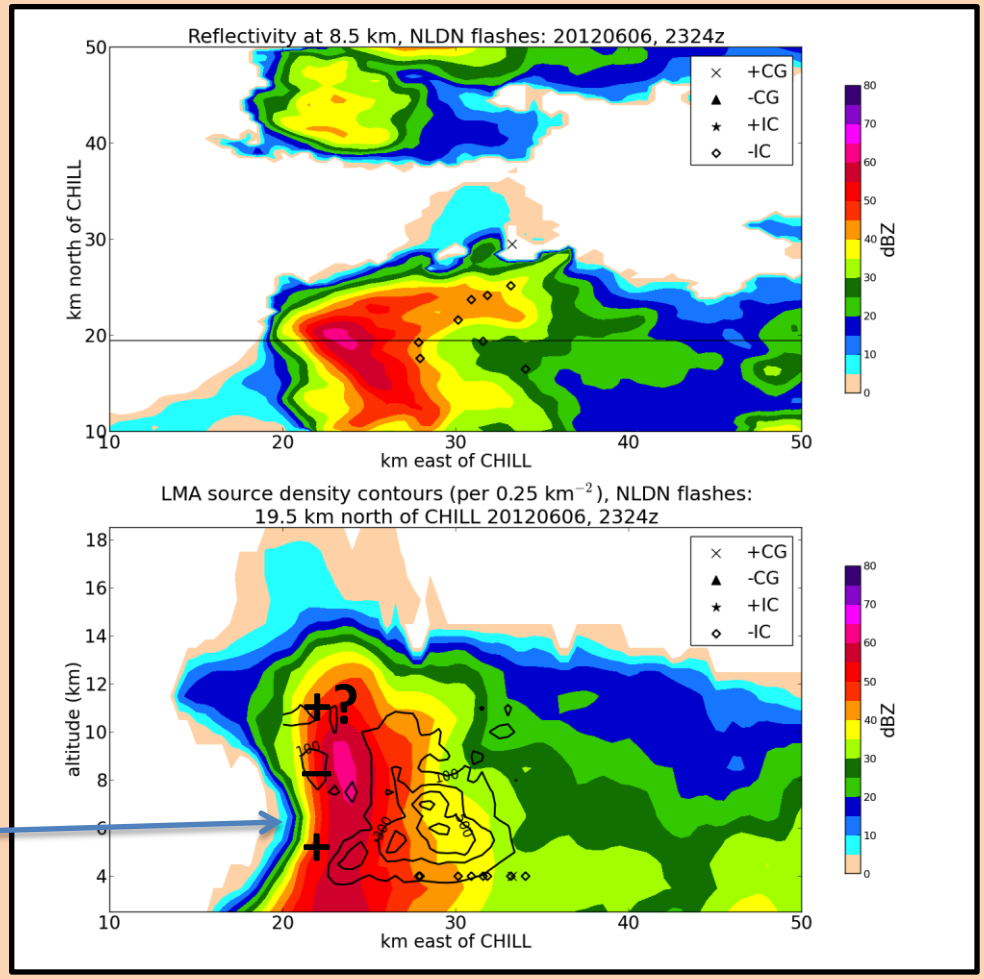
Real-time merged radar imagery
http://radarmet.atmos.colostate.edu/dc3

Line of convection near Fort Morgan.
Northern cell in line featured large hail (high Z, ~0 Z_{DR}, increased LDR), mesocyclone.

Developing Lightning Parameterizations from DC3 Observations

- Investigate relationship of flash rates to storm parameters for three Colorado DC3 storms (6 June, 7 June, 22 June 2012)
- Current objectives: Doppler-derived winds, hydrometeor identification, analyze charge structure
- Will incorporate aircraft observations to analyze impact of lightning on storm chemistry





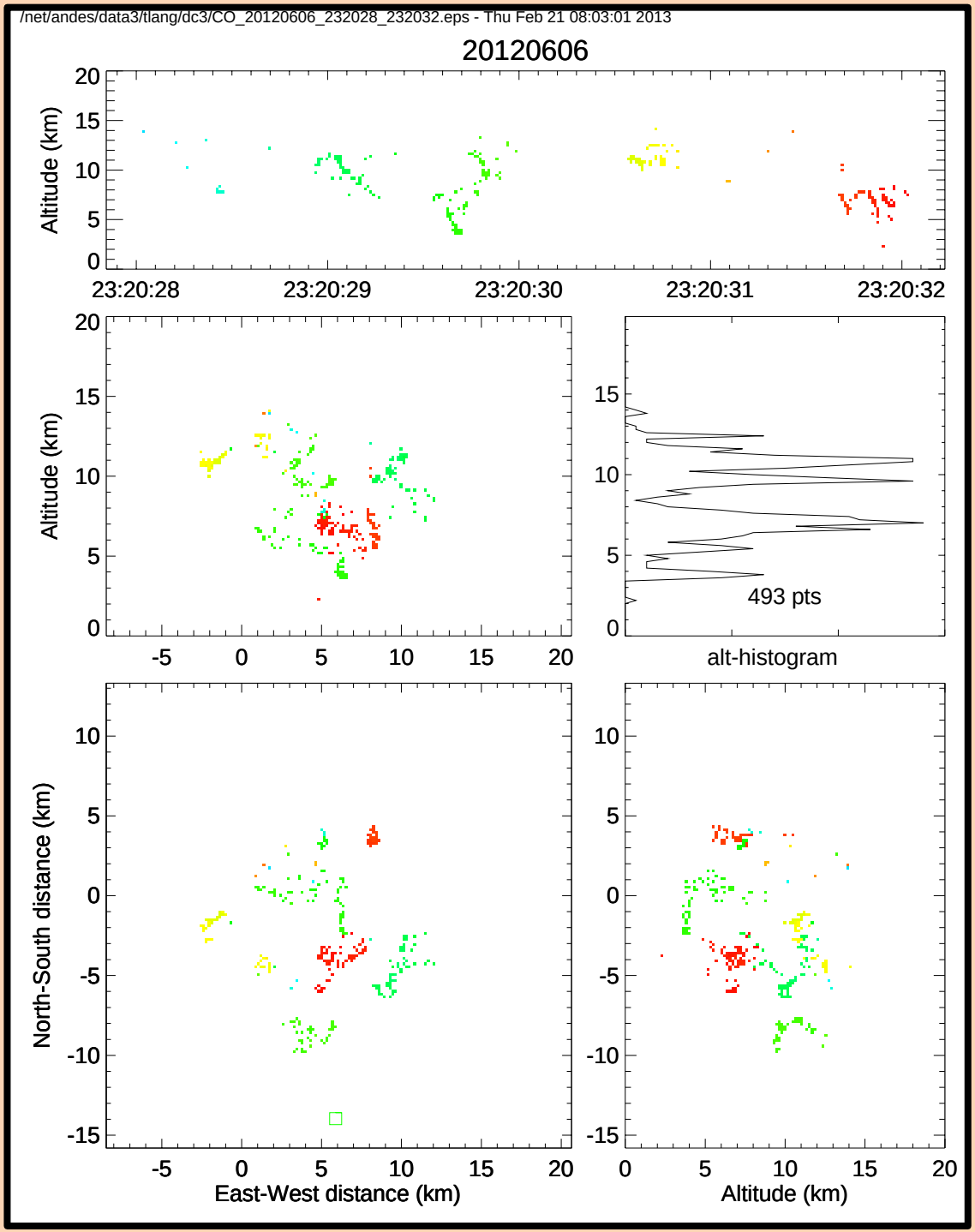
6 June storm featured active lightning between the lower positive charge and mid-level negative charge (2320-2325z). Some small, high-altitude ICs also were mapped.

Brett Basarab, Brody Fuchs, Steven Rutledge
Colorado State University

- Distinctive characteristic of this 6 June storm: Flash size was very small.

- Horizontal scale for individual flashes ~5 km. Vertical depth often so shallow that little space could be seen between charge layers.

- <u>Right</u>: ~5 seconds of decimated COLMA data around 2320 UTC. This was typical lightning behavior in this storm.

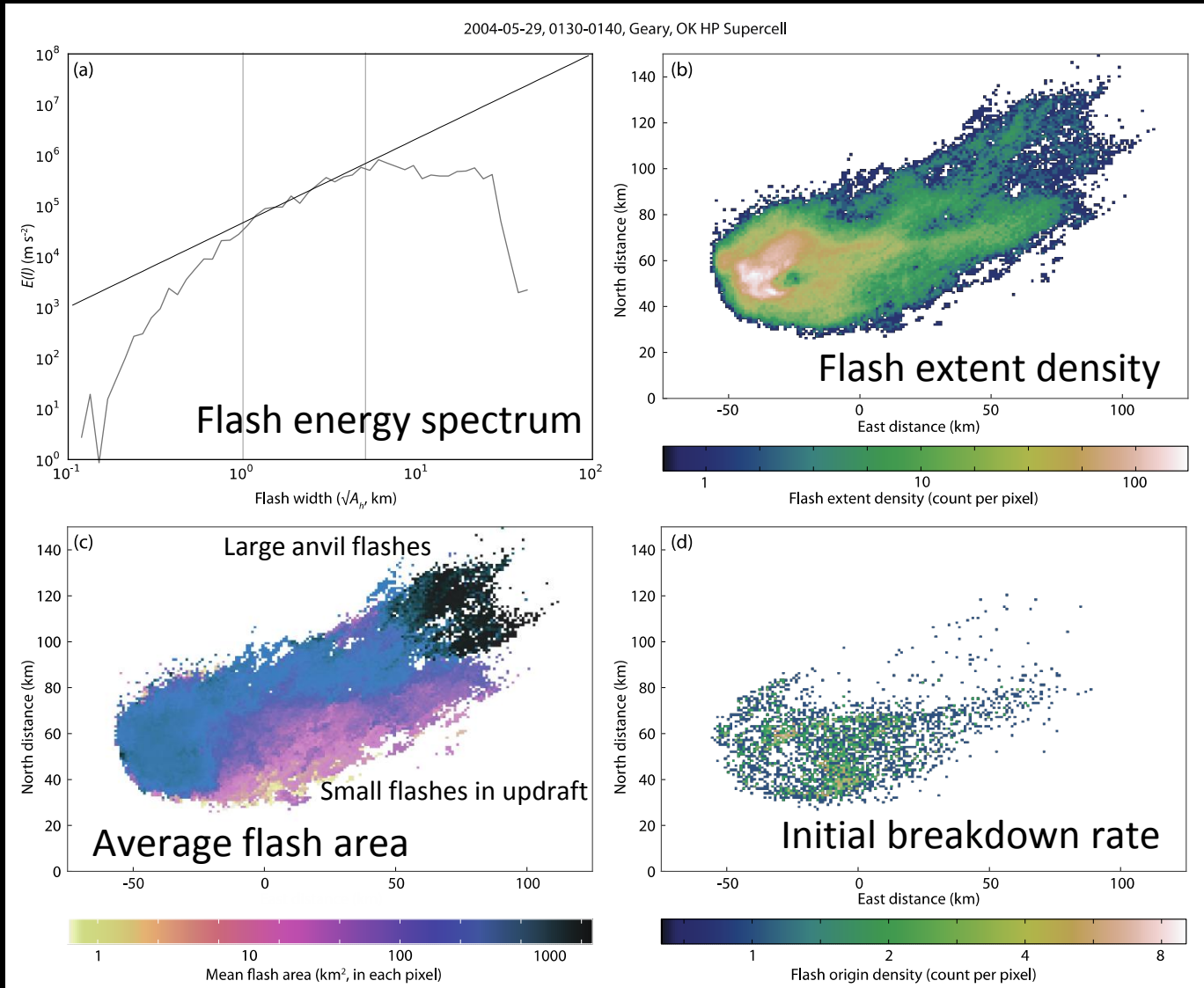


Flash size spectrum and thunderstorm convective character (Bruning and MacGorman, JAS, in review)

Regions with an abundance of flash initial breakdown events are expected to have less-extensive flashes

Flash area times the square of the flash rate at that flash area = flash energy spectrum. Looks like a thunderstorm's TKE spectrum.

Average local flash area may be a better indicator of energy dissipated per lightning flash than a simple flash rate and IC/CG partition?



Other Oklahoma/Texas Research

MacGorman – Lightning relative to storm evolution on 29-30 May, particularly kinematic interactions and microphysics associated with lightning during storm mergers and splits.

Biggerstaff – 29-30 May, supercell dynamics during the period with triple Doppler radar data.

Ziegler – Particle imaging data for a very weak storm (almost a stratiform region) on last day of OK/TX operations June 21 (imager and Parsivel available). Also possibly imager data for the 29-30 May supercell case, and simulation of one or more cases.

Mansell – Simulation/data assimilation for one or more cases.

Plenary Conclusions

- There appear to be fundamental differences in the characteristics of lightning in/near updrafts (small, elevated, IC, transient holes) and outside of them (larger, sunken, CG).
    - What can we do to better quantify this result?
    - What are the chemical implications of this result?
    - How do we model this process?
- Alabama results suggest large uncertainties with relating absolute ice mass to absolute flash rate (11 June AL modeling needed?)