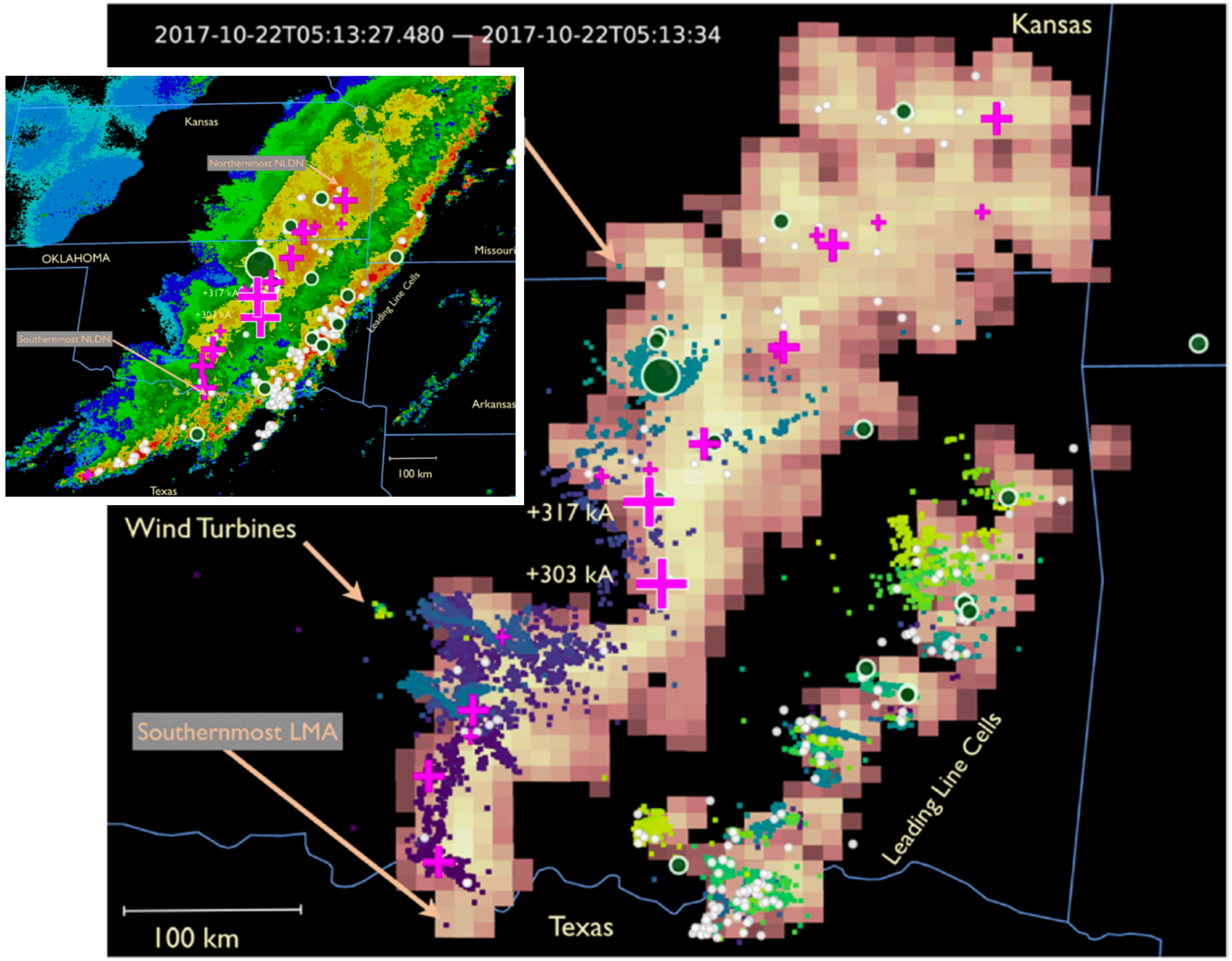
Integrated lightning observations for operational calibration/validation, data assimilation, and process understanding

CIWRO Mesoscale and Stormscale Modeling Workshop

One Lightning Megaflash from Oklahoma behind dozens of ordinary flashes within a convective line. GLM, LMA, NLDN.

Lyons, Bruning et al. (2019, BAMS, Megaflashes: Just How Long Can A Lightning Discharge Get?)



Eric Bruning, Texas Tech University, 6 December 2021

Dr. Kelcy Brunner (postdoc)
Jessica Souza (Ph.D. student)
Stephanie Weiss (research staff)
… and Ph.D. graduates Chmielewski and Salinas

Recent activities

Storm electricity for meteorology

DOE TRACER / NSF ESCAPE

VORTEX-USA

Electrified Cloud Modeling

Radar polarimetry and multi-scale velocity

Lightning Data Assimilation

Operational Users

(NCEP, European)

WMO lightning records; essential climate variable

Mixed-phase microphysics and kinematics

Meteorological signals in lightning datasets

Different signals from different lightning sensors

GOES GLM program

Theory and Basic Physics

Storm electrical structure

Balloon-borne electric field meter

Lightning Mapping Arrays

GLM imagery

NASA/NOAA GLM Science Program

Recent activities

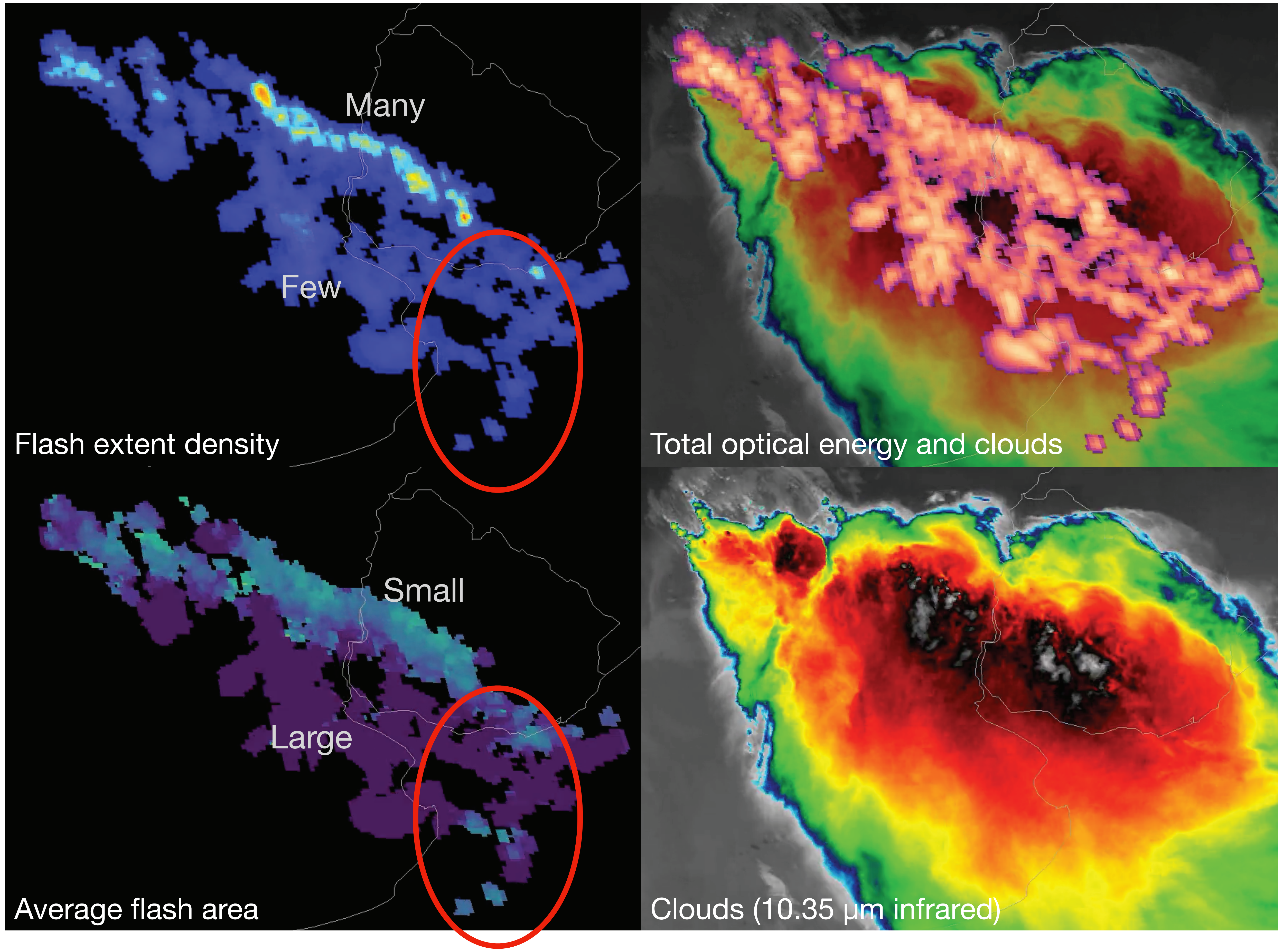
GOES Geostationary Lightning Mapper

- GOES GLM Science Team (2008-present) and EUMETSAT MTG LI Mission Advisory Group
- Wrote core code that creates operational imagery for GLM used nationally in AWIPS.
    - Open source supports R&D on same code base (Bruning et al. 2019, github.com/deeplycloud/glmtools)
    - Integrated in NWS ISatSS; NESDIS ground system in early 2022. Vetted in NSSL HWT EWP.
    - As seen on CoD, NESDIS websites; data flowing publicly from Unidata.
- Cal/val efforts have been focused on understanding flash detection efficiency relative to other lightning instruments - about 70-80%.
- Brunner: expertise in modeling light transfer through deep convection to GLM.

Nocturnal LLTS MCS on 13 Dec 2018, Argentina and Uruguay, as observed by GLM

Bruning et al. (2019, JGR, Meteorological imagery for the GLM)
Images: NESDIS/Rudlosky et al, as in AGU EOS feature.

Updates every 1 min



Flash area identifies active deep convection below cirrus shield

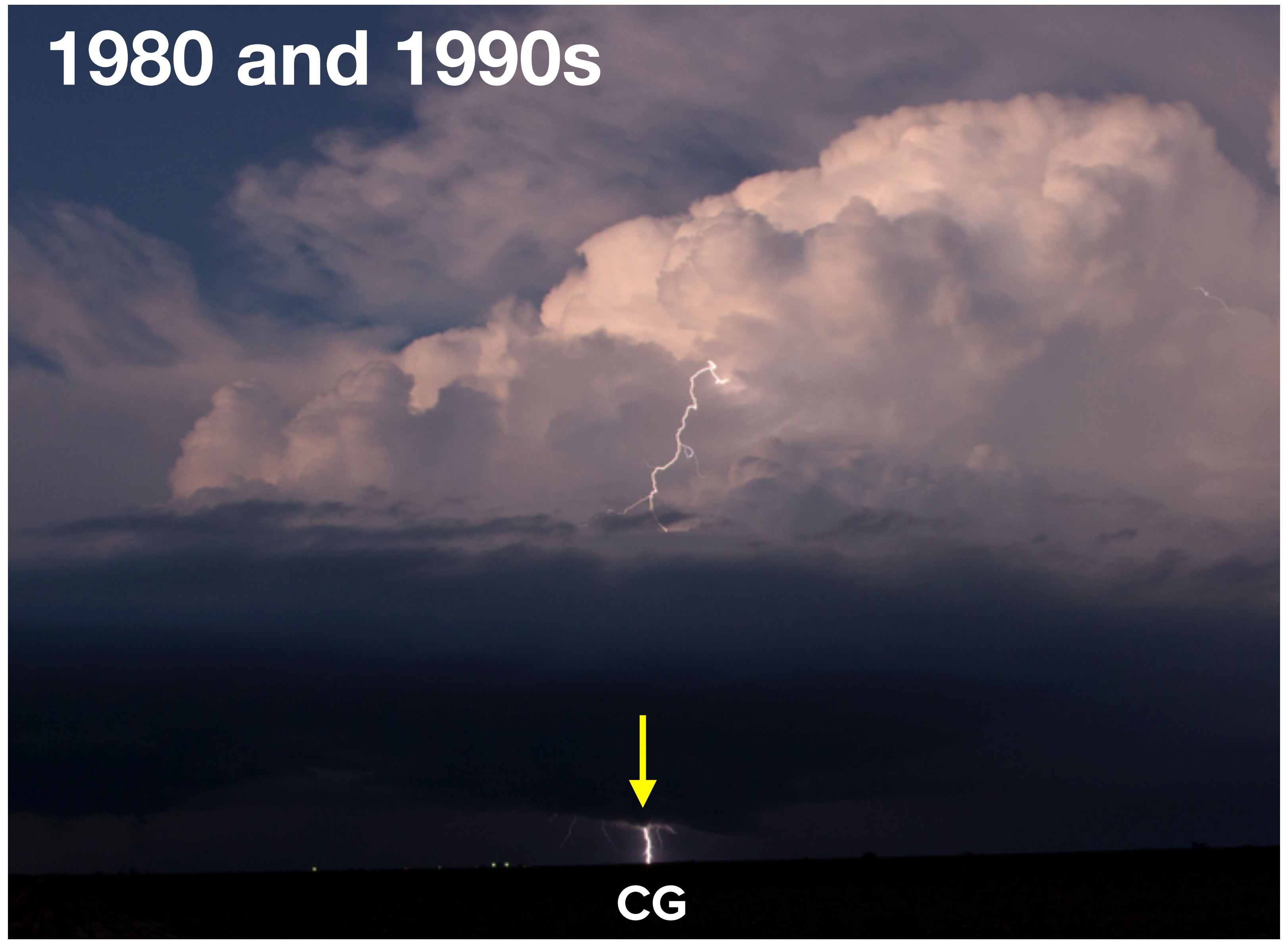
Operational lightning detection then and now

1st Generation

Singular focus on CGs
peak current and location

Instrument

NLDN (CG)

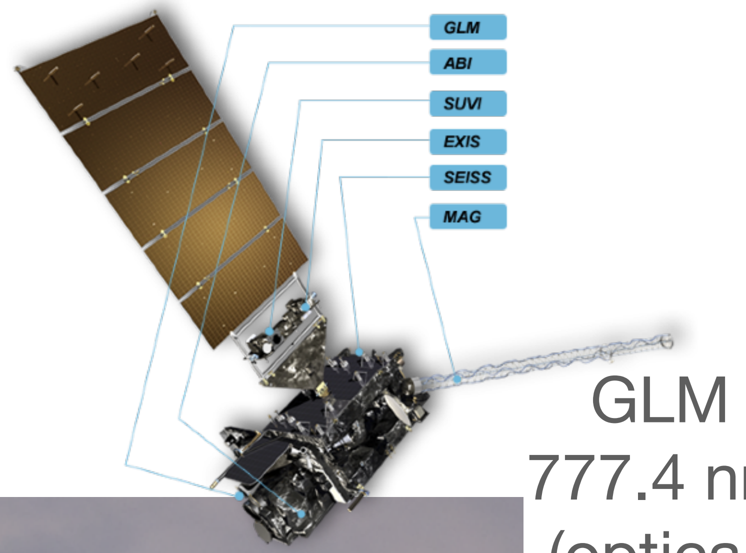


Radio Band
3-30 kHZ
1 - 350 kHz
1 Hz - 12 MHz
60-66 MHz

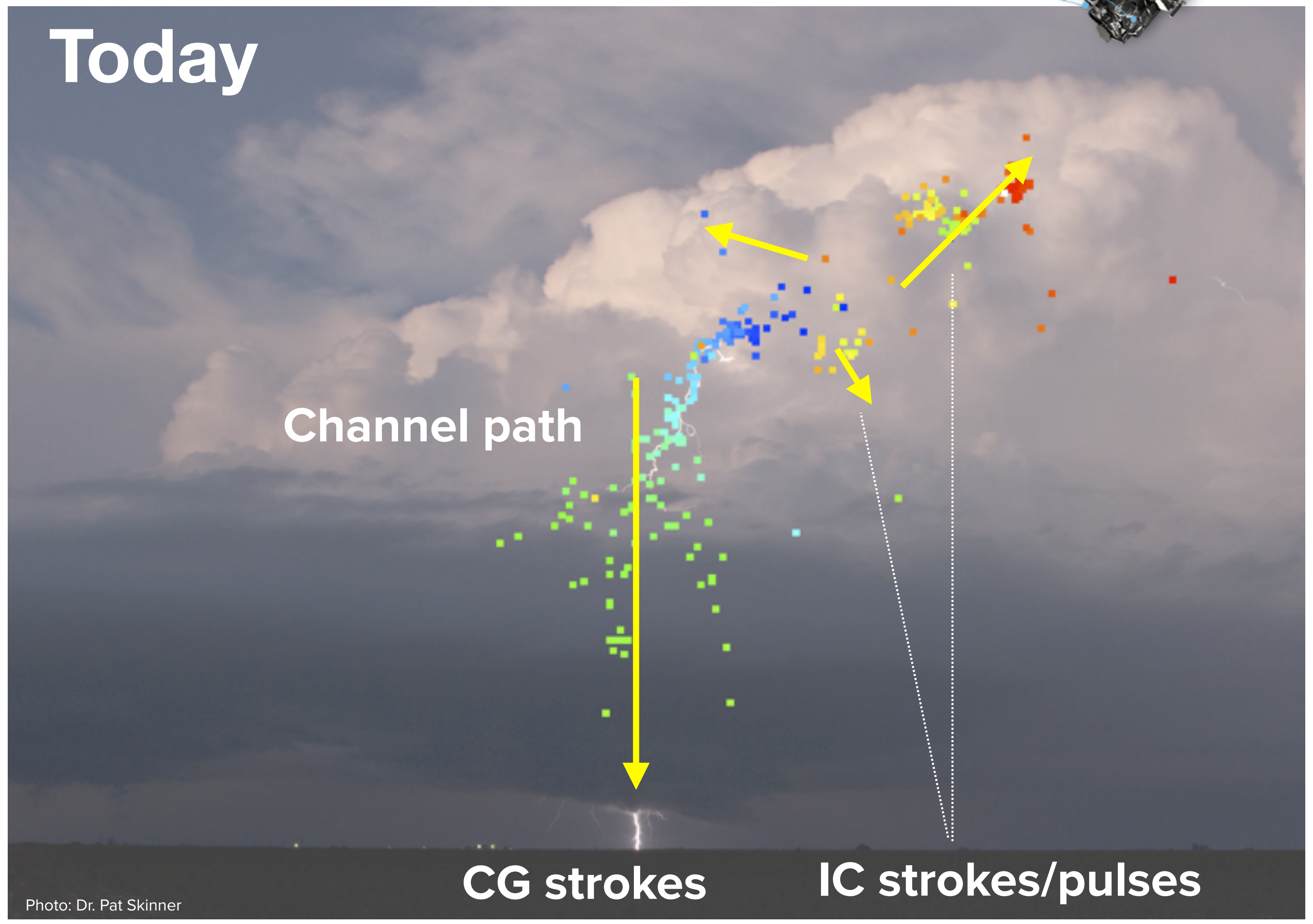
Today

Diversification of measurements
IC, CG strokes; channel mapping

Instrument
WWLLN
NLDN (CG, IC)
ENI
LMA (for reference)



GLM
777.4 nm
(optical)



Status

We now routinely observe the small charge motions of channel development, various intermediate scales of charge transport, and finally the largest-scale currents: CGs.

These measurements happen continuously and flash rates, sizes, and polarities fluctuate as other storm processes vary, and detection efficiency varies based on instrument and location.

A flash is no longer a just a strike

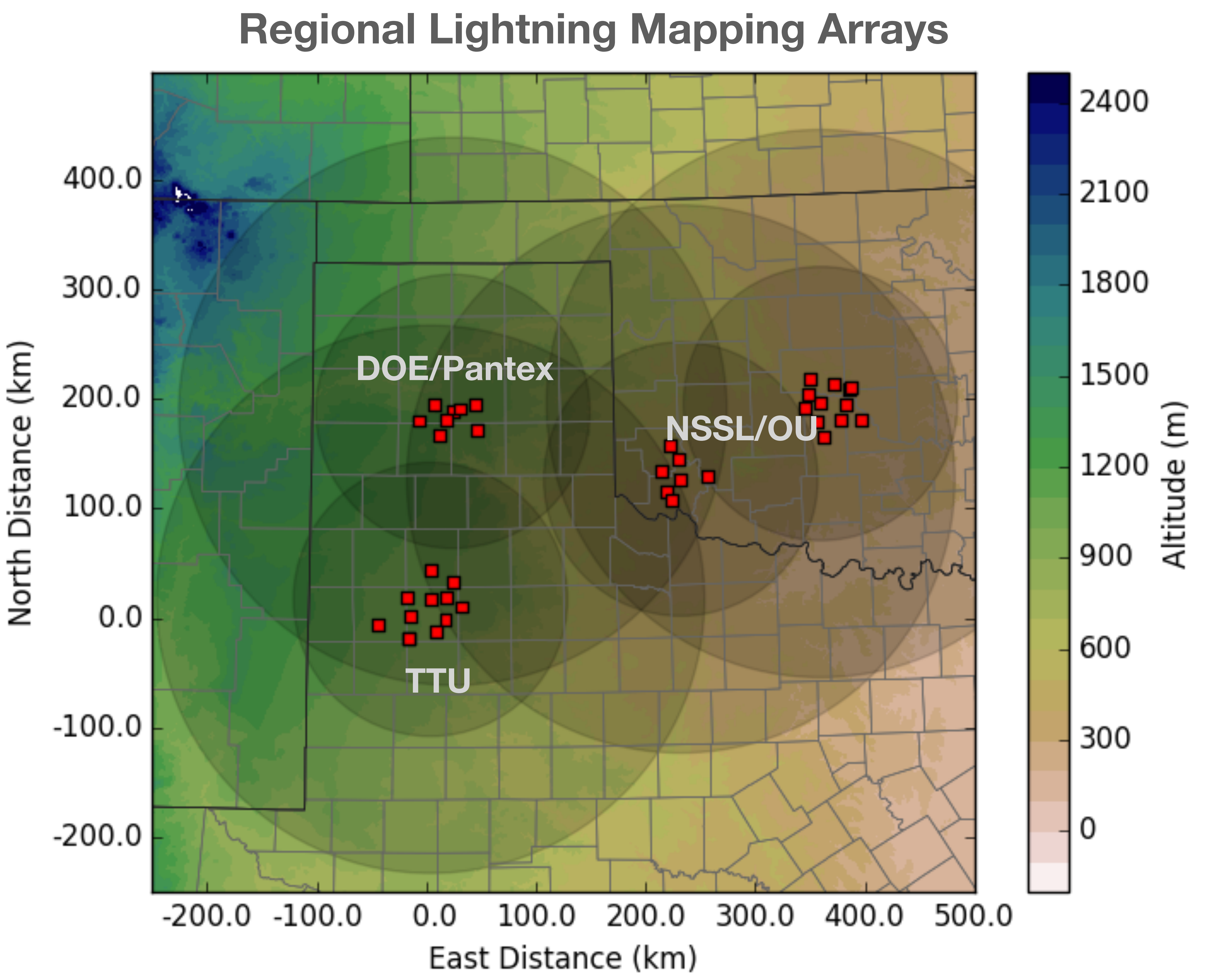
How do we help for operational users navigate so much information?

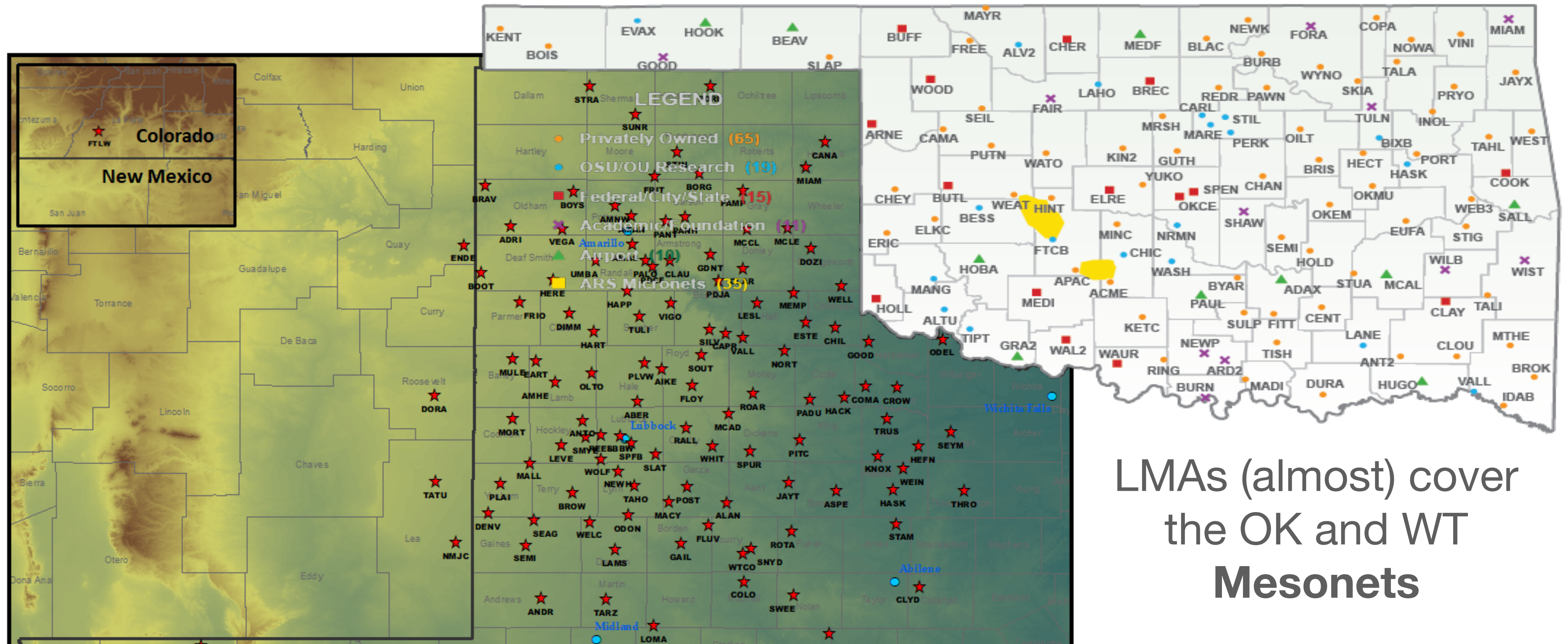
How do we build data assimilation operators that account for variations among and strengths of each dataset?

The Oklahoma, West Texas and Pantex Lightning Mapping Arrays

A regional-scale resource for lightning cal/val and basic science - essentially 100% detection efficiency

- WTLMA supported for 10+ yrs by GOES GLM program, alongside OKLMA and now Pantex. (Chmielewski and Bruning 2016)
- LMA observes channel development, while other lightning sensors measure charge transport along these channels, which adds more information about the storm's electrical structure.
- Reveal 3D electrical structure and have allowed for major scientific advancements linking flash rate and size to meteorological dynamics.
- **We can build on this uniquely extensive geographic coverage to lead with a world-class, operational lightning calibration-validation dataset**
    - Add slow- and fast-antennas to quantify 3D charge transport for hours, instead of just a few flashes
    - Serve NOAA cal-val and R2O needs *and* industry R&D with a public archive of research-grade measurements.
- Measurement of other regions is crucial: lightning behavior and operational DE vary by region.

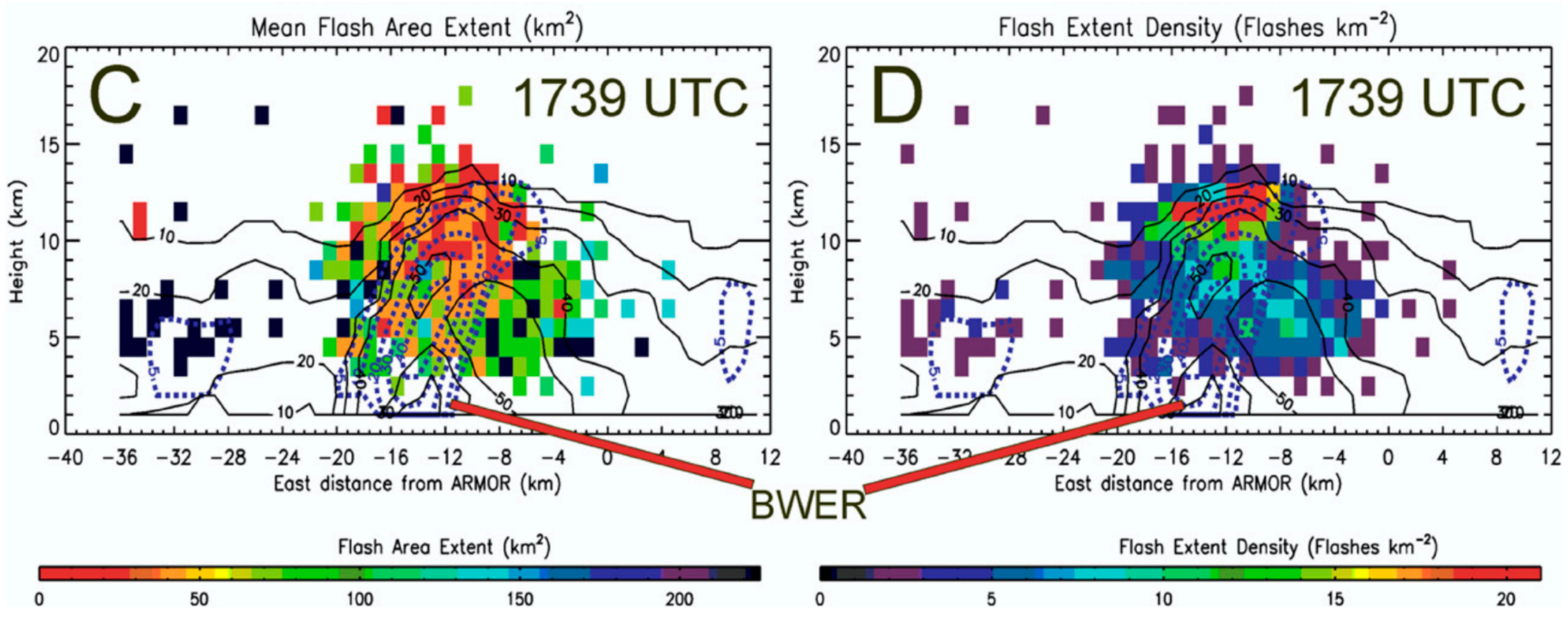




LMAs (almost) cover the OK and WT **Mesonets**

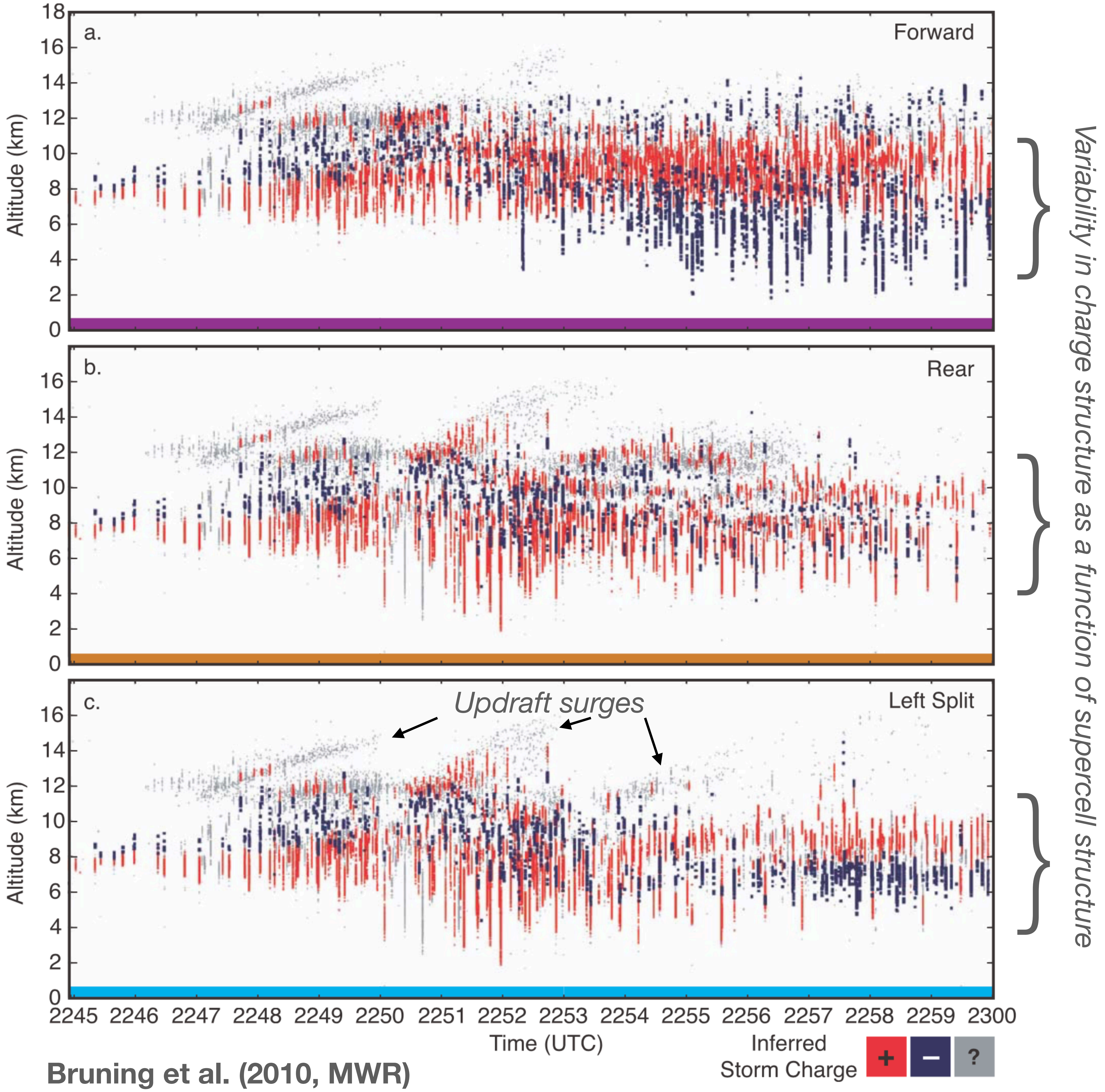
Meteorological signals from LMAs: Connecting eddy-scale physics to operations

- The distribution of flashes, their sizes, and the underlying charge structure fluctuate with the mixed phase updraft
- Channel paths and flash energy are closely coupled to inertial-range eddy structure of storms (Bruning and MacGorman 2013, and next slide)
- These ideas were directly applied to GLM operational product design and training: *flash size matters.*



Statistically significant increases in flash rate ("lightning jumps") correspond to a decrease in flash size — Schultz et al. (2015, WAF)

15 min of Evolving Charge Structure in Three Regions of a Supercell



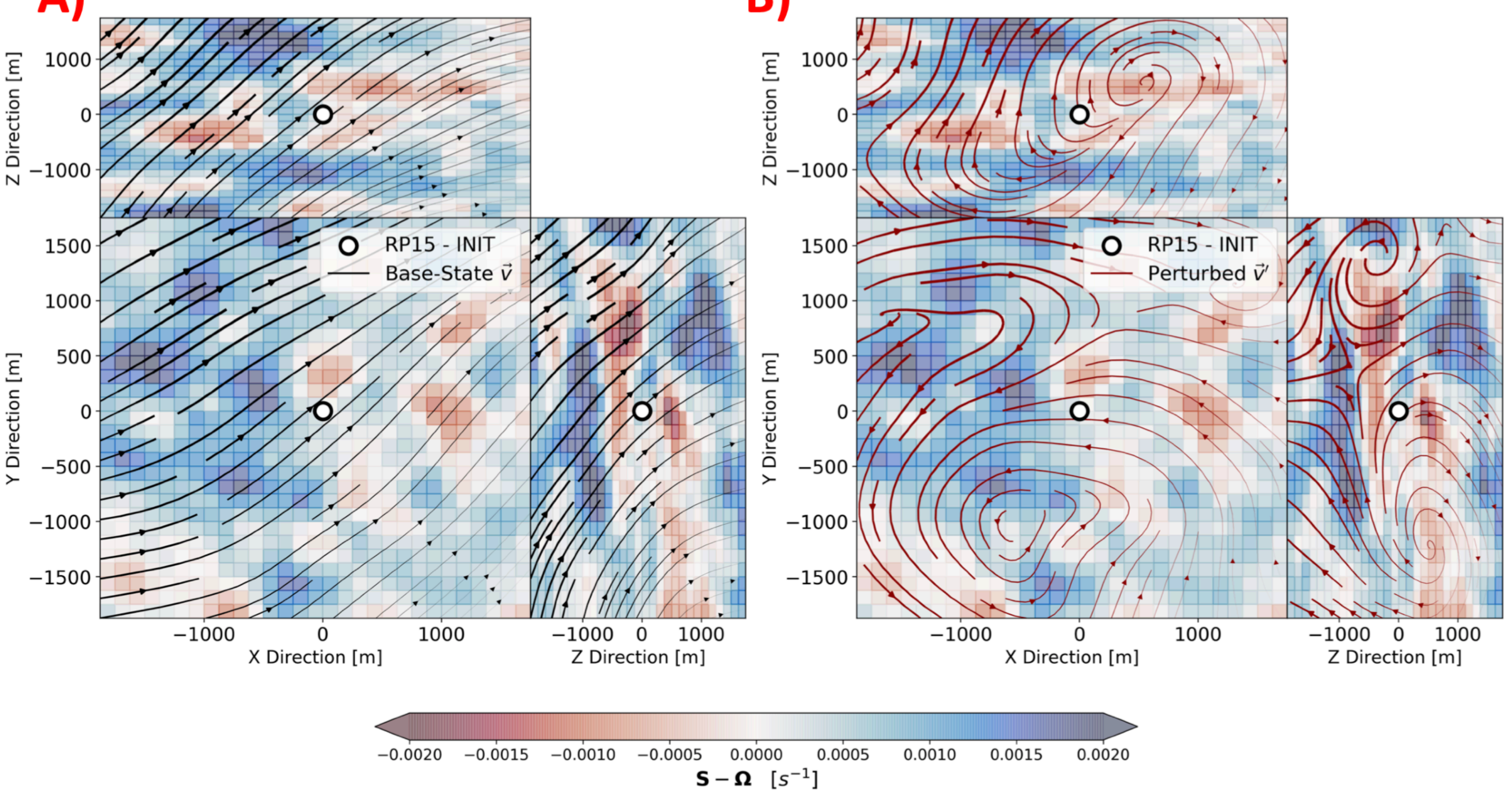
Bruning et al. (2010, MWR)

Recent simulations and observations link lightning to inertial range turbulence in thunderstorms

The perturbation flow near lightning initiation has the size scale and spatial structure of inertial range large eddies. Thermal bubbles?

Salinas, Bruning and Mansell (2021, JAS)
Electrified N-COMMAS simulations

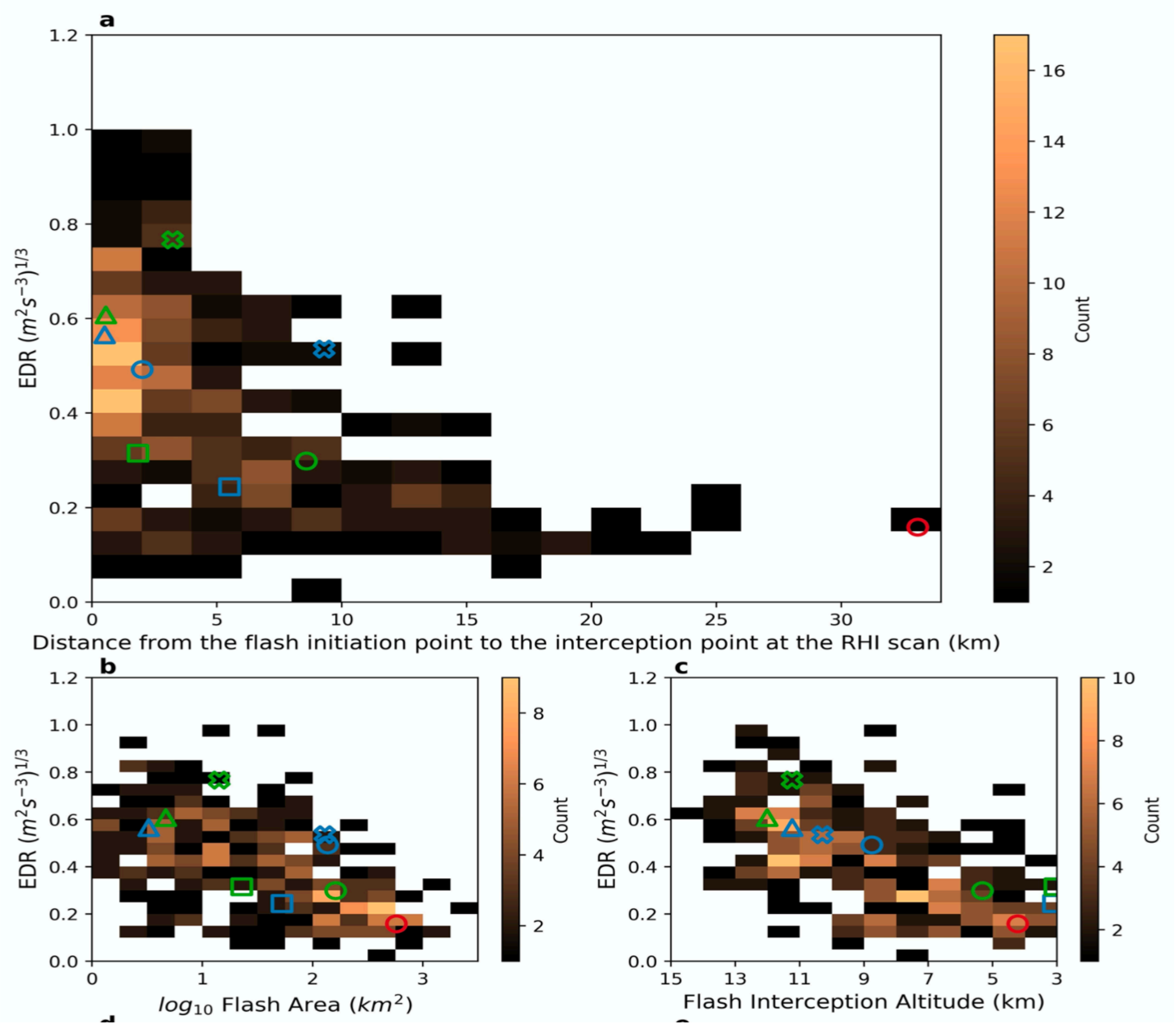
Mean flow near all flashes **Perturbation flow near all flashes**



Magnitude of (strain - rotation) tensor near flash initiation is typically near zero

Turbulent flow from radar EDR corresponds to small flashes, short flash propagation distances, and small flash areas at high altitudes.

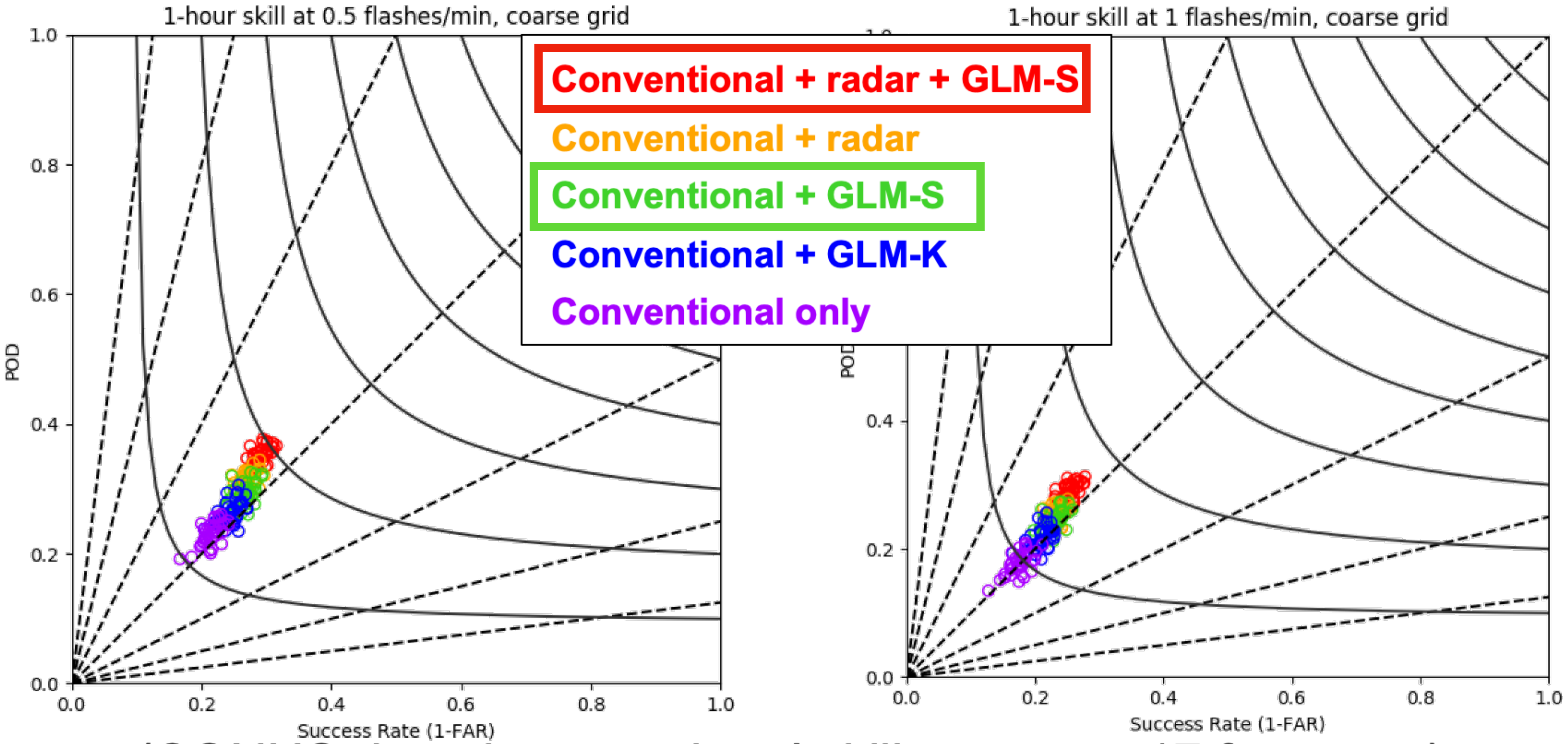
Souza and Bruning (2021, GRL)



Assimilation of GLM FED into HRRR-E

Collaborative work led by Back & Dowell w/Kong & Xue, Wang & Yussouf

- Part of TTU VORTEX-SE efforts.
- Recalibrated probability-matched graupel mass operator (A. Sebok) evolved from Allen, Mansell, et al. (2016, MWR) and Kong, Xue, et al. (2020)
- Thinning of GLM FED to stroke centroids, ignore zero-flash areas, handle parallax
- **GLM DA gives perhaps half** the **improvement of radar DA**, and **contributes positively to DA with radar**.
- Possible short-term advancements:
    - Use flash size information to better discriminate deep convection vs. stratiform)
    - Demonstrate added value in radar-poor areas
- Need to understand and correct for systematic variability in flash DE across GLM field of view.



(CONUS domain—members' skill avg. over 17 forecasts)

Back et al. (2021, GLM Science Meeting)

Concluding remarks: can we go beyond correlative use of lightning by pursuing a more ambitious physical science program of storm electricity forecasting?

Physical covariances

Lightning data → **Measures** → Spatial structure of electrification and local discharge rates → **Covaries with** → Mixed phase hydrometeor count, mass, collision rate → **Covaries with** → Environment Storm dynamics Draft fluctuations

Grand challenge

Time-evolving retrieval of a storm's electrical structure at the large eddy scale.

$$\frac{\text{electrostatics (J/C)}}{\phi}$$

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

$$-\nabla^2\phi = \rho/\epsilon_0$$

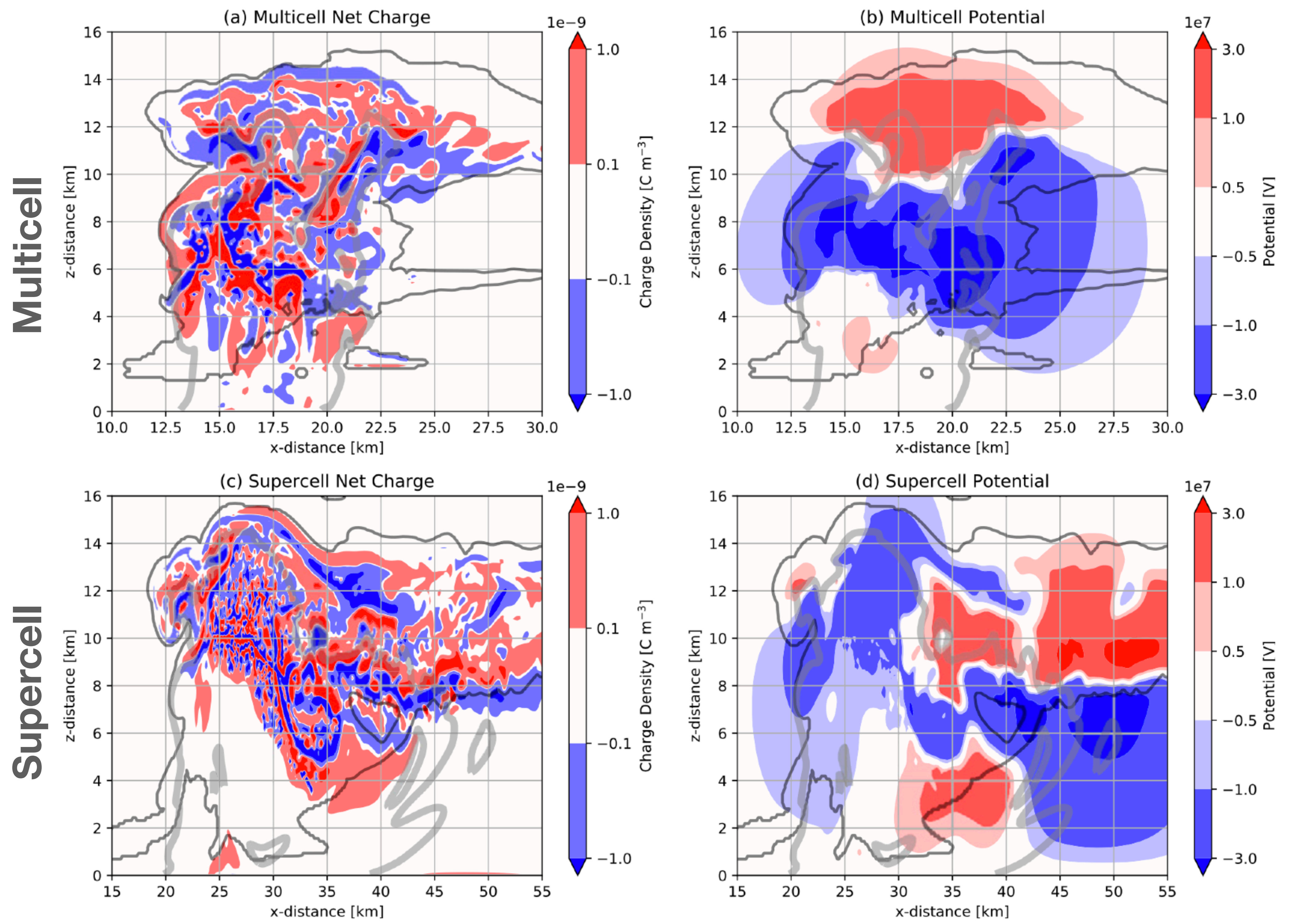
Potential
(net flash shape)

Electric field
(flash origin)

Charge density
(channel density)

Practical application

If we can retrieve this picture from observations, we can also *predict* the next flash and its most likely path as it taps the electrical energy in the storm.



Charge

Potential

125 m electrified simulations from Brothers, Bruning and Mansell (2018, JAS)

Too ambitious?

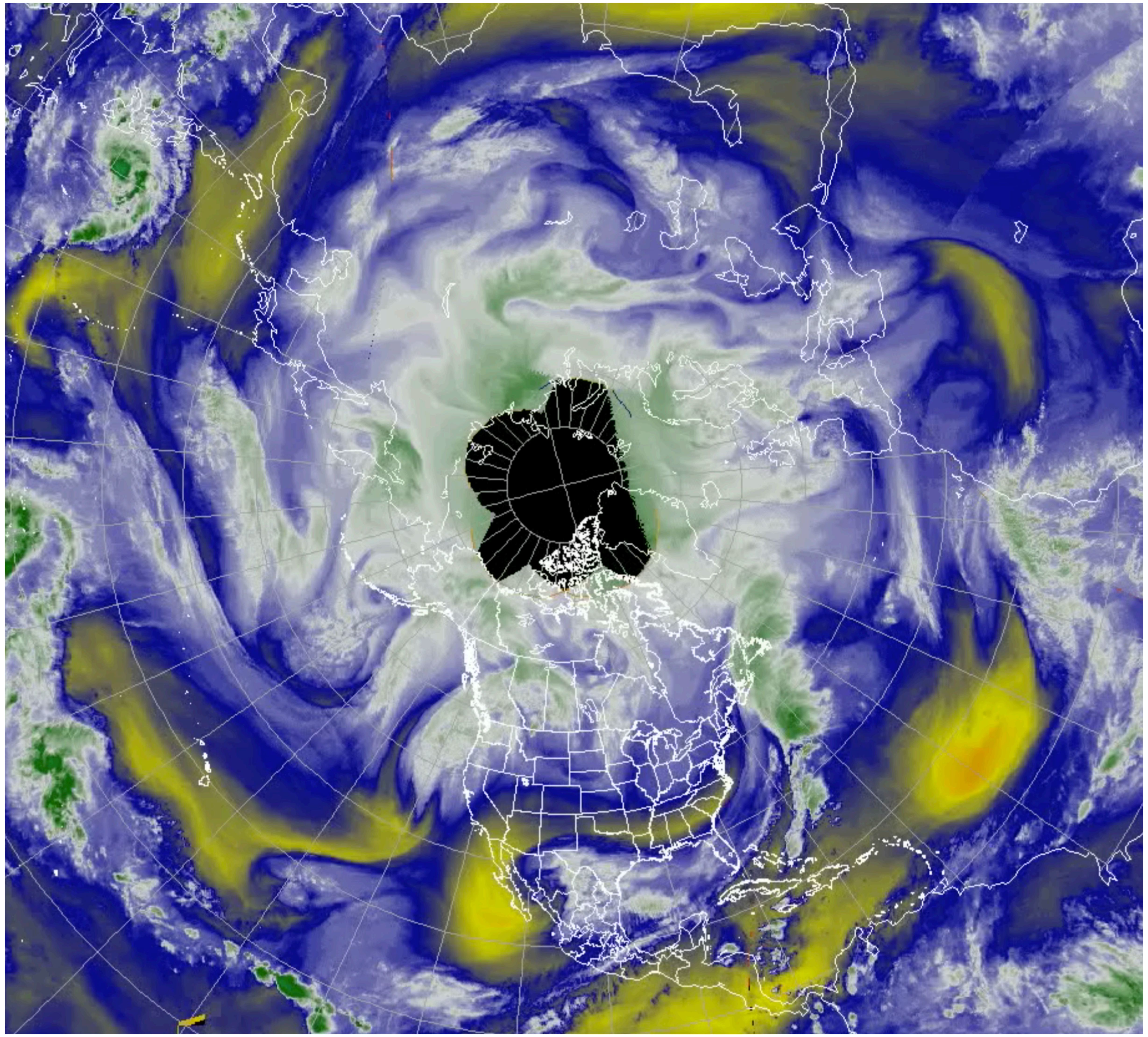
Consider the history of meteorology

We've used theory, an ambitious global observing infrastructure, and computing to make progress on topics where there were severe, well-founded doubts.

Lorenz (1963, JAS, Deterministic Nonperiodic Flow)

When our results concerning the instability of nonperiodic flow are applied to the atmosphere, which is ostensibly nonperiodic, they indicate that prediction of the sufficiently distant future is impossible by any method, unless the present conditions are known exactly. In view of the inevitable inaccuracy and incompleteness of weather observations, precise very-long-range forecasting would seem to be non-existent.

N. Hemisphere Water Vapor Composite (UW/SSEC)



Synoptic eddies sure look hard to forecast!
But their prediction is now routine.