Lightning development and charge structures during LEE

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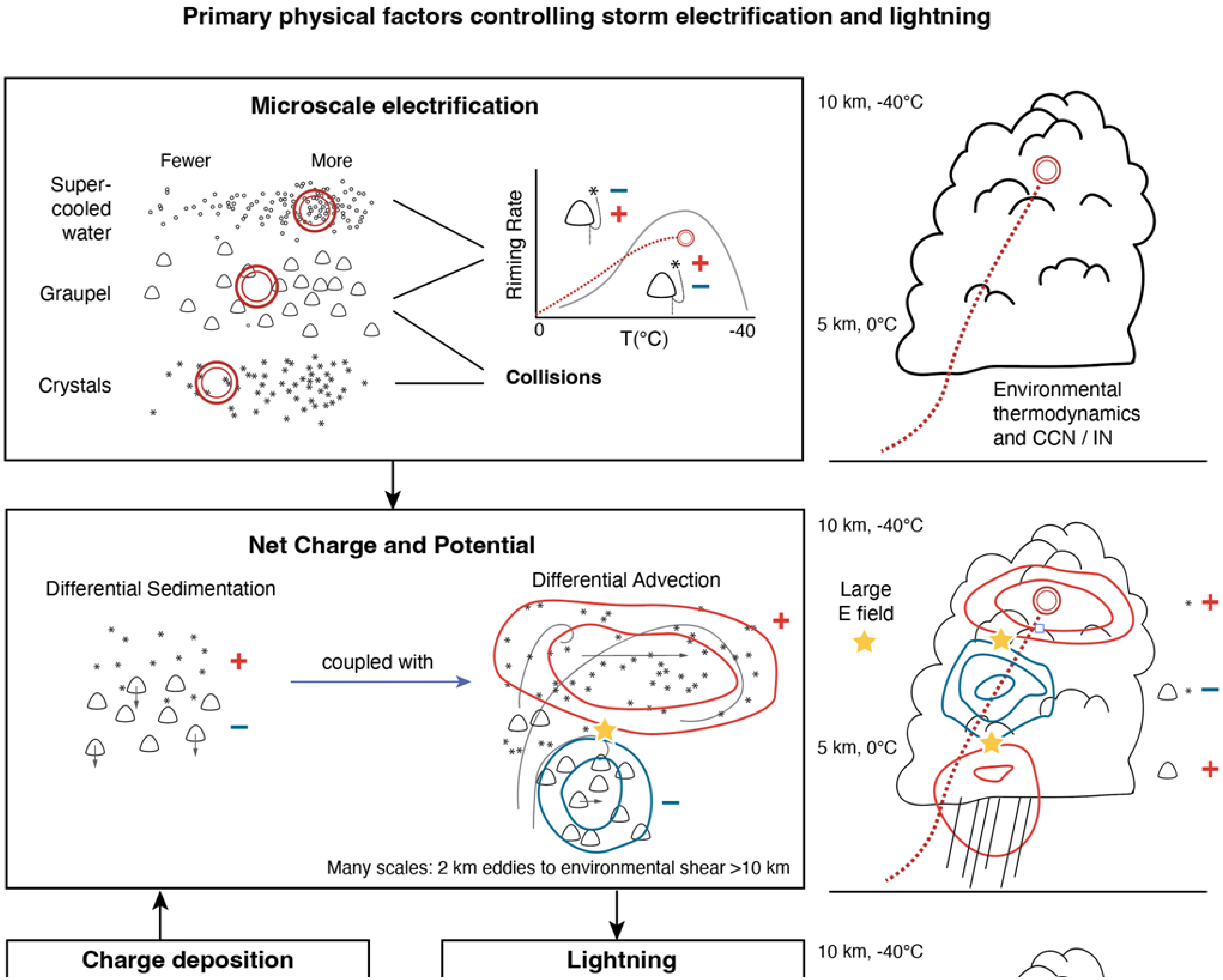
And all participants who made possible the LEE observations

Science with meteorological field observations

Adapting to nature and logistics

- How can we make the best use of what we actually observed to test our understanding of the physics of electrification?
- The hypotheses and observing strategies we proposed were generated from a robust physical theory.
- We did as much as we could to act on that plan, but couldn't fully execute it. How do we adapt to maximize the scientific value of our measurements?
- Just as important are the physical uncertainties that drove the generation of the original hypotheses. We can return to the driving uncertainties in our physical theories and use that to reflect on what was observed.

Figure 1: A sad balloon.

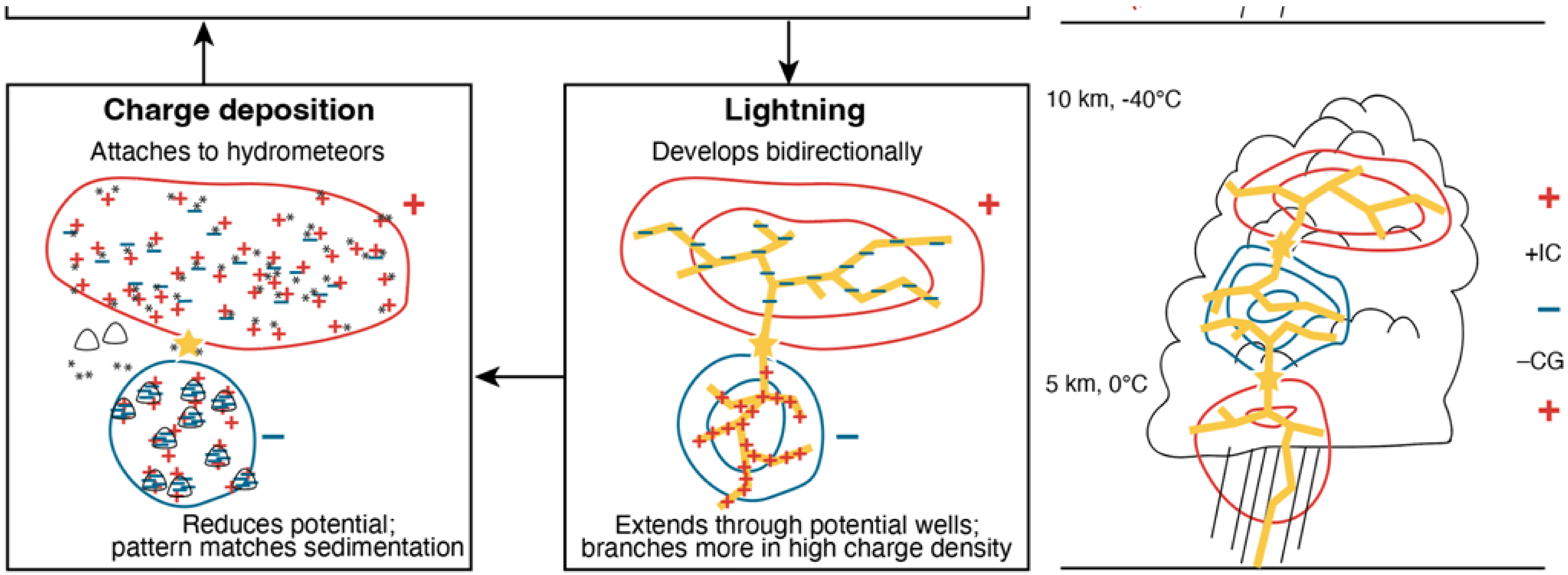


Primary Electrification in Thunderstorms:

Collisions between graupel and ice crystals in the presence of supercooled water result in three charge layers.

Independent of the background electric field.

As presented at the GLASS workshop just before LEE



Temperatures in lake effect clouds

Past observations in winter storms are consistent with this charge structure

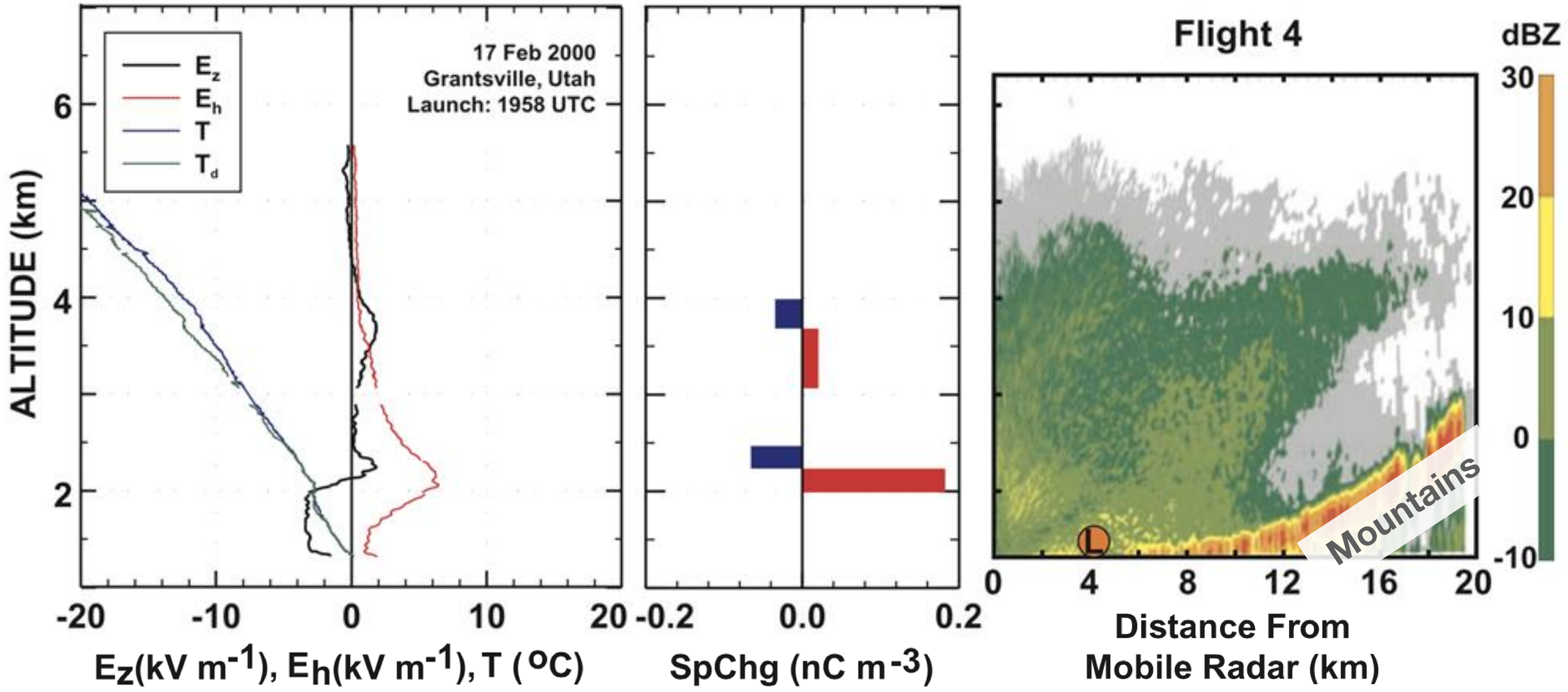
- Lake effect storms will have convective regions (like those above), where we expect near-shore convective structures like as in Kumjian and Deierling (2015, WAF) including depressed differential reflectivity from graupel near shore.
- Thereafter, graupel will fall out and convective motions will turn to a more stratified cloud. What might we find there?

As presented at the GLASS workshop just before LEE

Electric Field Measurements

In winter clouds

- Nimbostratus with *no lightning* in Utah: Rust and Trapp (2002, GRL). Order of magnitude lower fields and charge densities than in summer storms.
- These few flights are the only in-situ measurements of electricity in US winter storms!



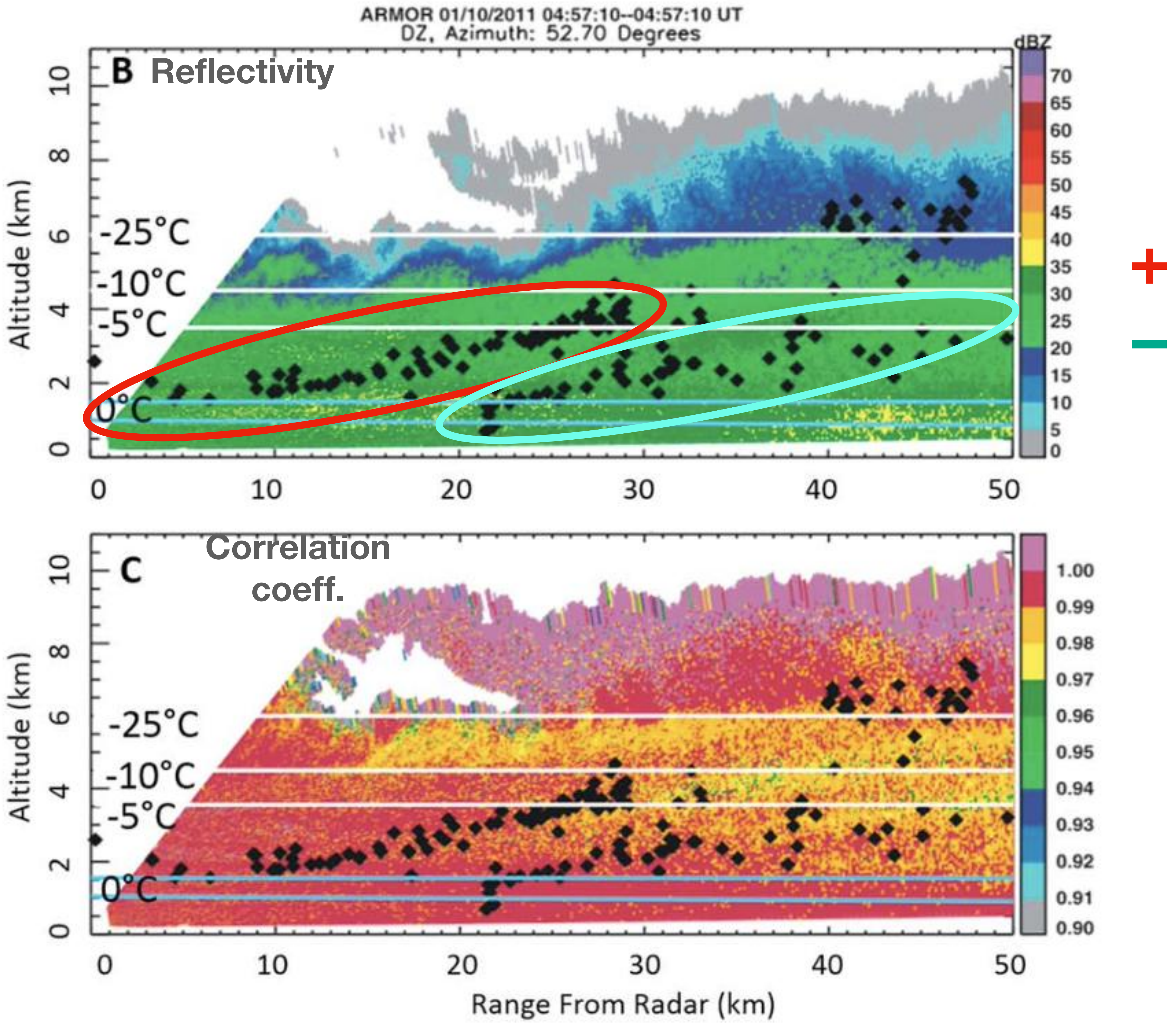
As presented at the GLASS workshop just before LEE

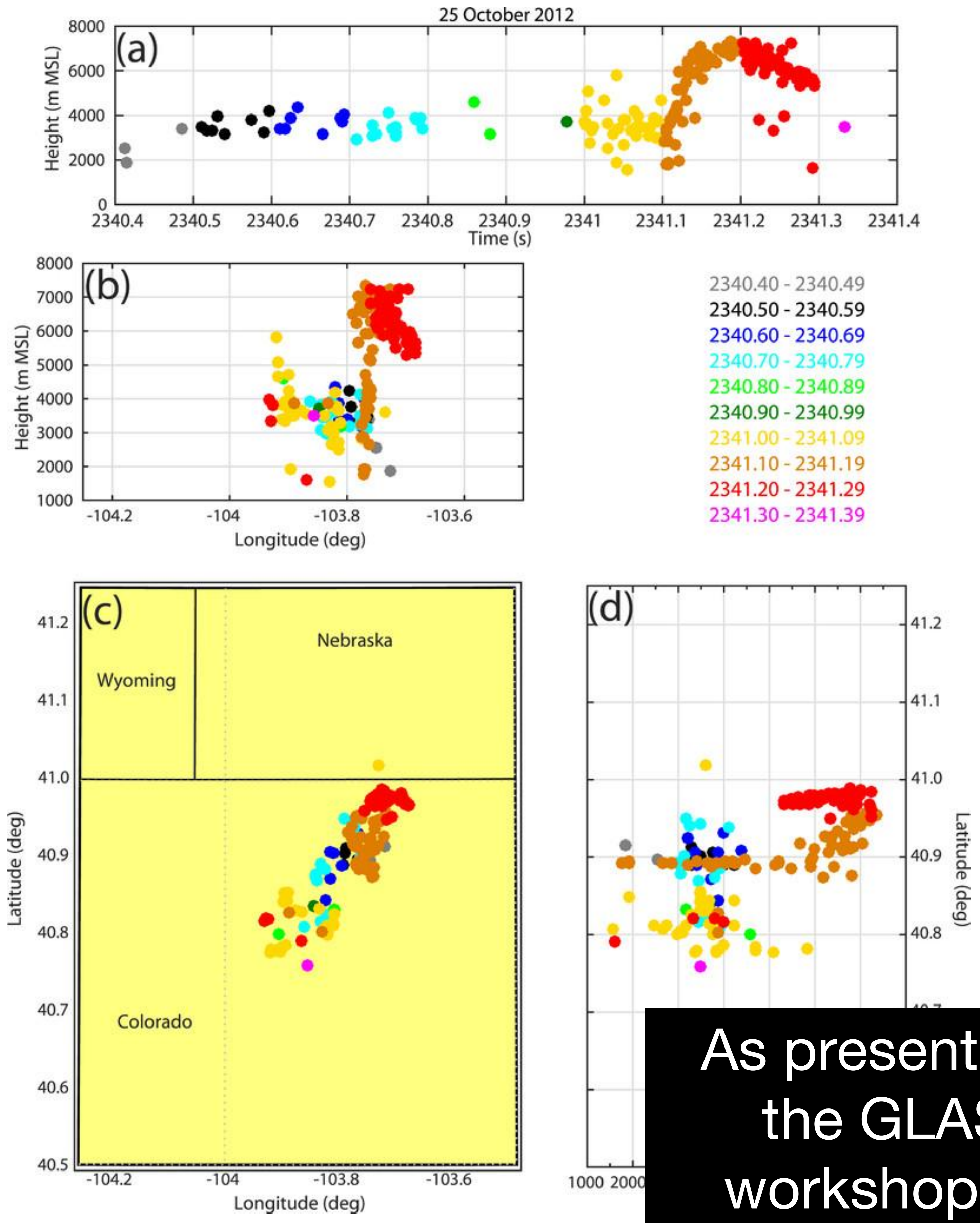
Previous winter lightning observations

LMA, dual-pol radar; Schultz et al. (2018, JGR) and Kumjian & Deierling (2015, WAF)

(Left) Channels followed boundaries between diverse and more uniform hydrometeor types.

Both exhibited positive above negative charge structure.





As presented at the GLASS workshop just before LEE

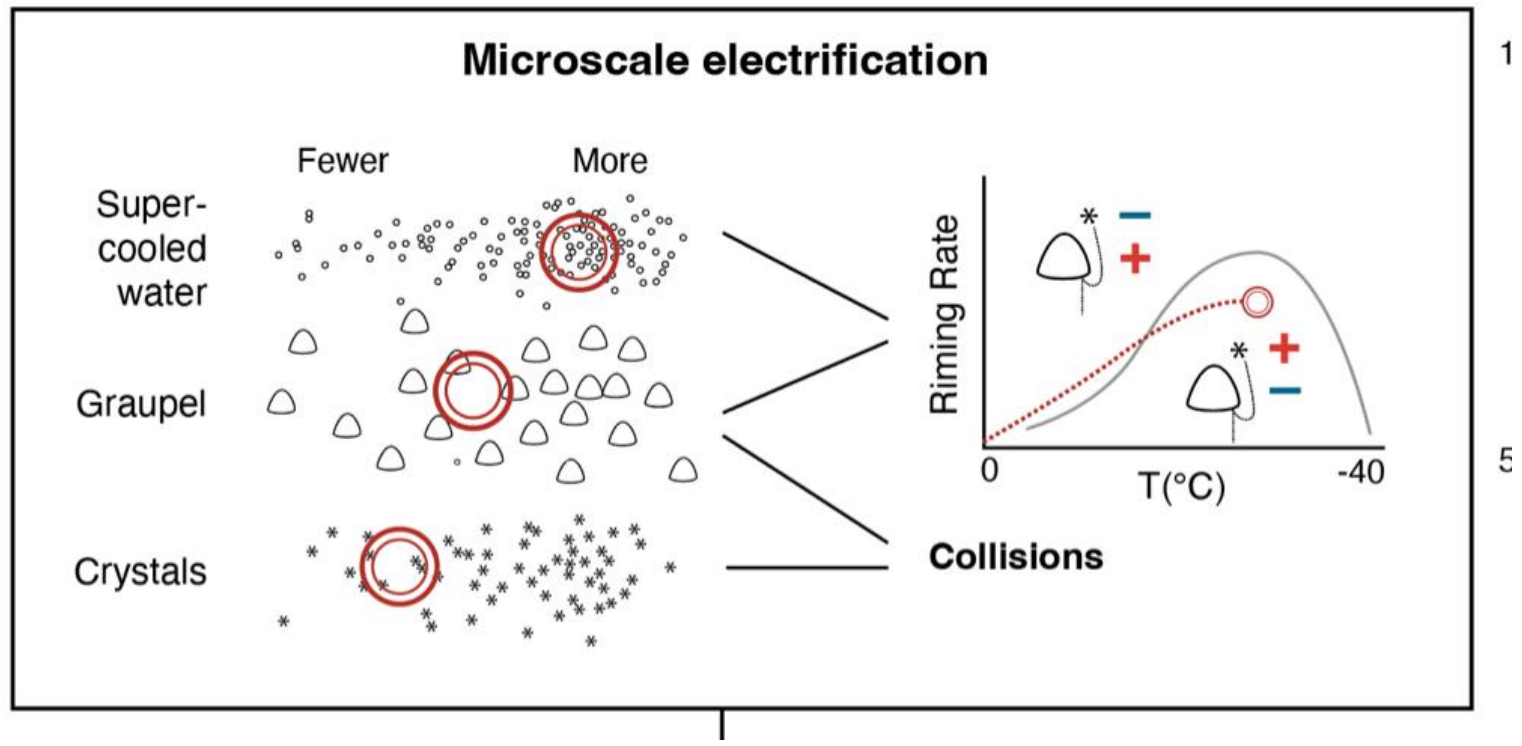
Microphysical uncertainty in electrification

Laboratory charging experiments are still quite uncertain — the reversal line is very sensitive to state of equilibrium of the ice surface.

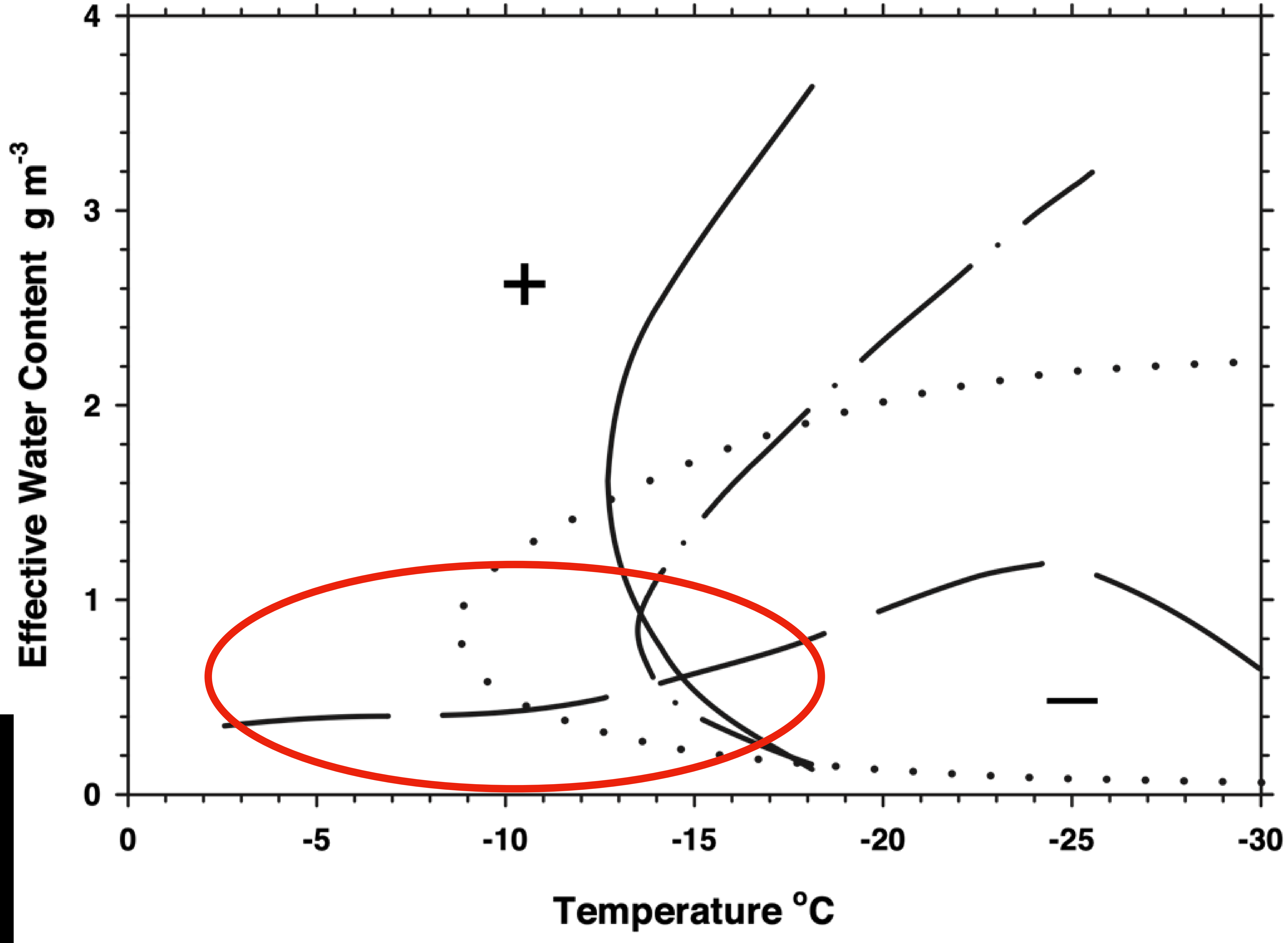
There is especially large *uncertainty at low- and no-cloud liquid water* - conditions we are likely to encounter in lake effect storms, especially in stratified clouds far from shore.

Lake effect storms also lack warm rain processes, making them a unique laboratory for isolating mixed phase microphysical processes.

(Figure: Saunders et al. 2006, QJRMS)



Polarity of charging to graupel



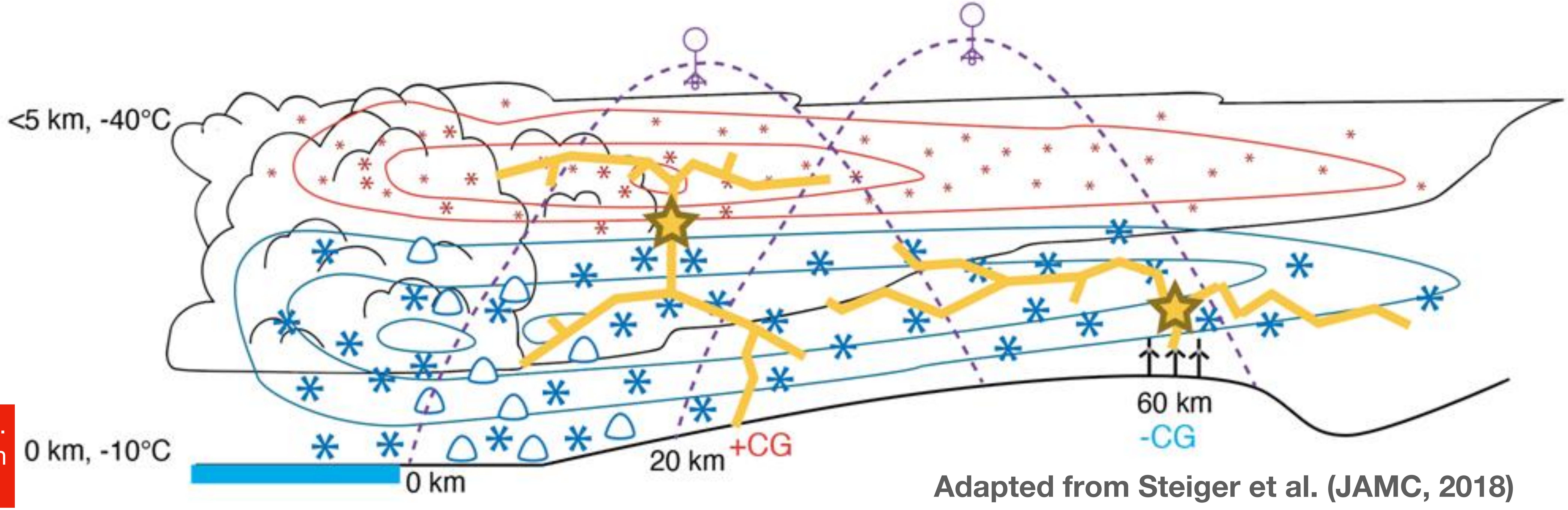
As presented at the GLASS workshop just before LEE

Expected electrical structure

in lake-effect snow during LEE

As presented at the GLASS workshop just before LEE

- Balloons will greatly expand on the handful of coordinated in-situ measurements of electrical and microphysical conditions inside winter storms, and will be the first in lake effect storms.
- Turbine-initiated -CGs will be most common; +CGs initiated from within the cloud (as in Moore and Orville, 1990, MWR) will be less common.



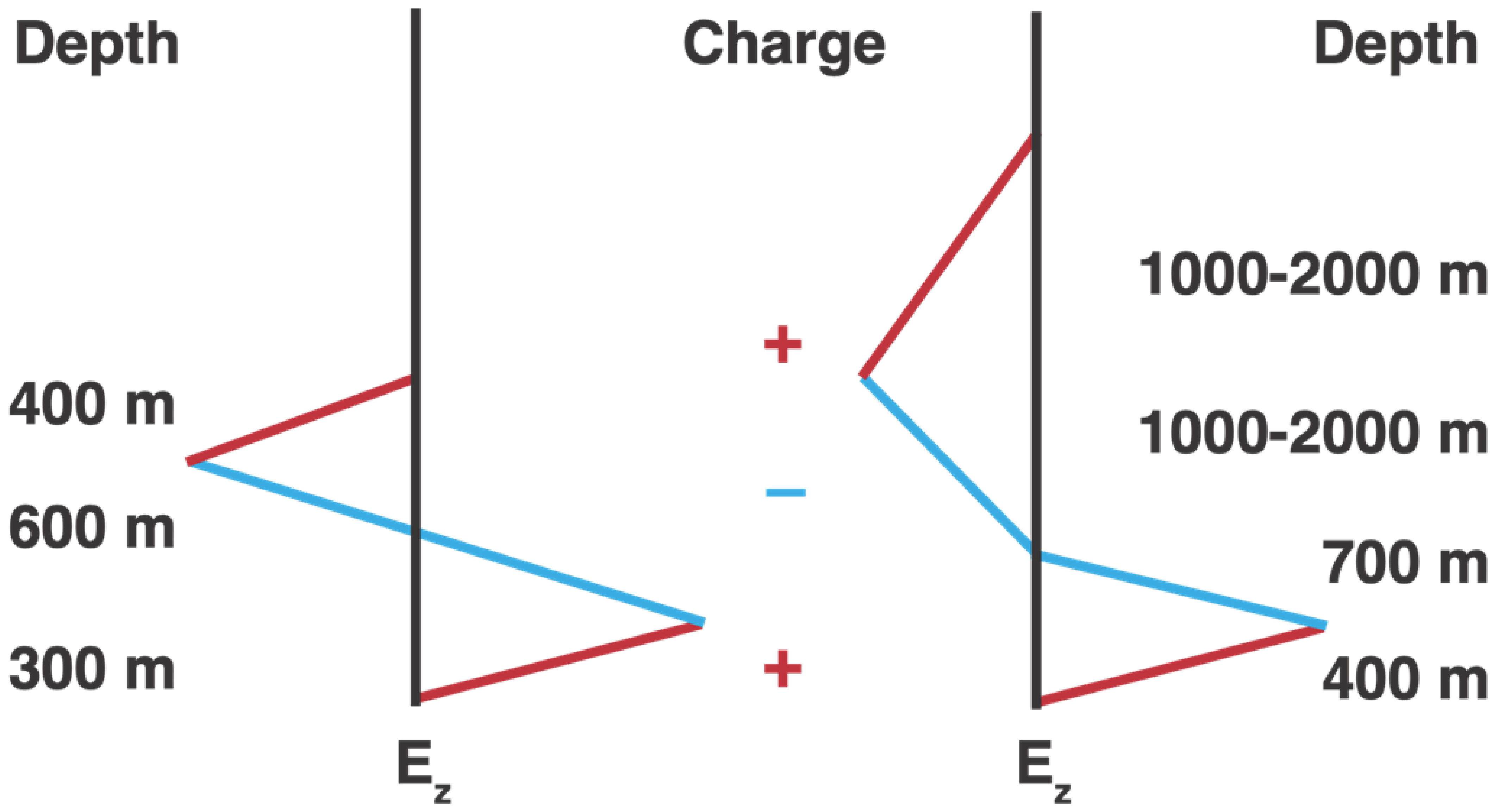
Note -10°C … we were often closer to 0°C

Adapted from Steiger et al. (JAMC, 2018)

Common characteristics of LEE electric field profiles

Near shore, soundings with fields > 20 kV/m

- A very shallow and dense positive charge layer near ground.
- Larger charge densities in the lower part of the negative charge layer.
- Varied depths of charge layers in the upper halves of many clouds, usually with lower charge density.
- Very shallow (each 500 m) charge layers giving a tripolar structure is consistent with observing an active electrification zone.
    - Just enough time for sedimentation to separate net charge.
    - The center of the negative charge layer (0 kV/m) was typically at -10 to -15°C, consistent with the a rule-of-thumb reversal line temperature, but sometimes warmer.
- **These fields are consistent with positive charging to graupel. I didn't expect this!**
    - Can modeling reproduce this observation?
    - We'll return to electrification microphysics in a moment.



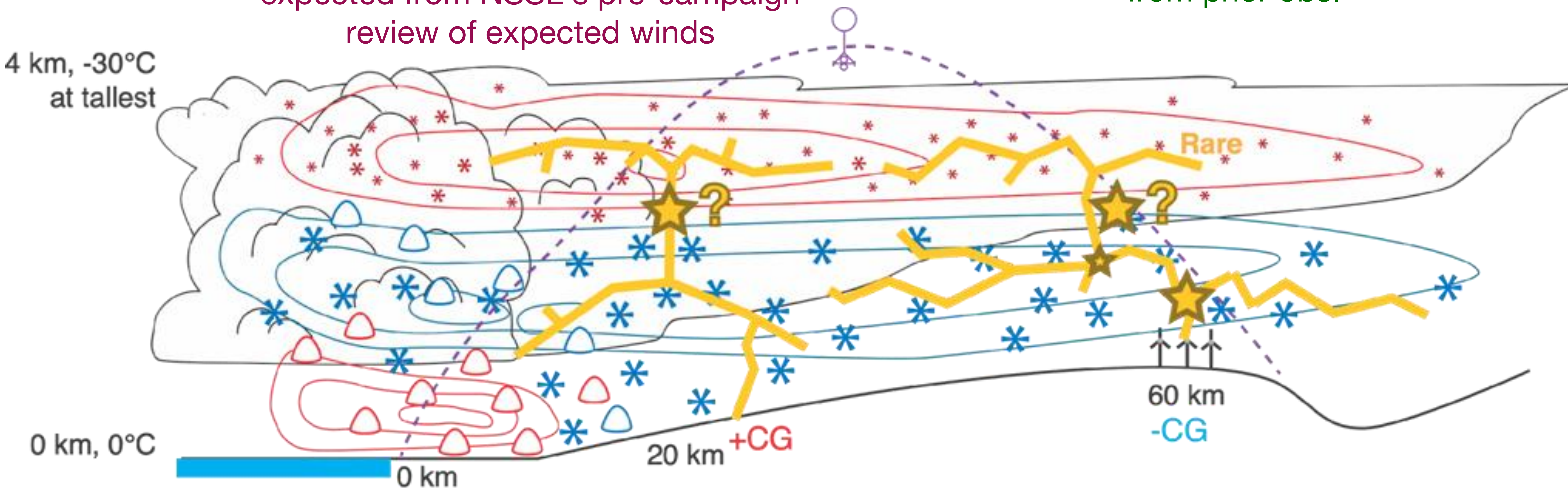
Observed electrical structure

in lake-effect snow during LEE

Did we observe any flashes that initiated in cloud and produced a downward ground strike?

Balloons traveled to far side of Tug, as expected from NSSL's pre-campaign review of expected winds

Lots of upward positive leaders from turbines, and occasional upward negative leaders into upper positive charge, both as hypothesized from prior obs.



Near-shore tower-initiated flashes were observed (e.g., Oswego power plant). What polarity were these leaders?

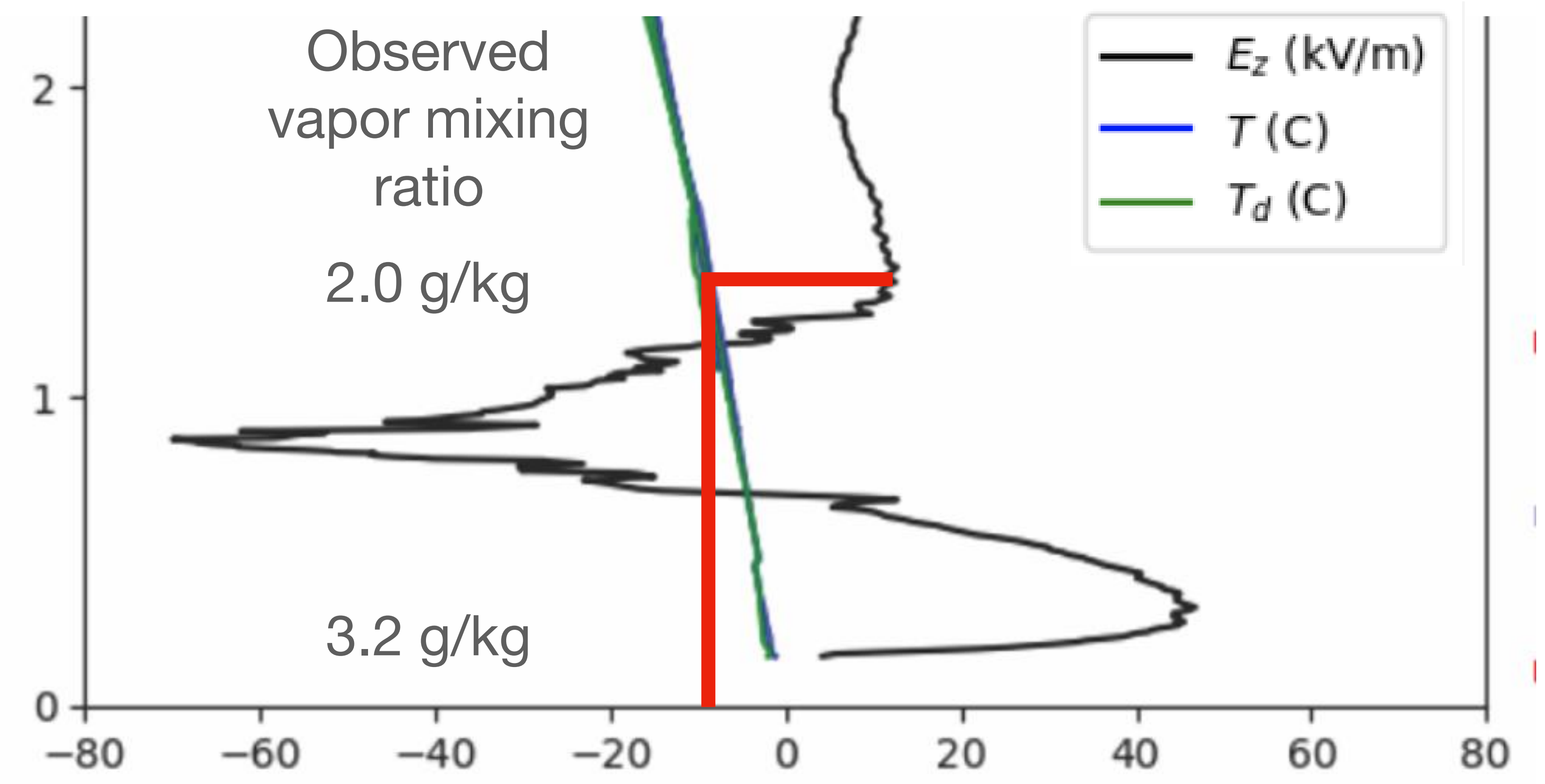
EFM data revealed a shallow, intense lower positive charge layer near shore, consistent with large observed graupel concentrations at launch. Evidence for positive charging to graupel in warm/liquid rich conditions.

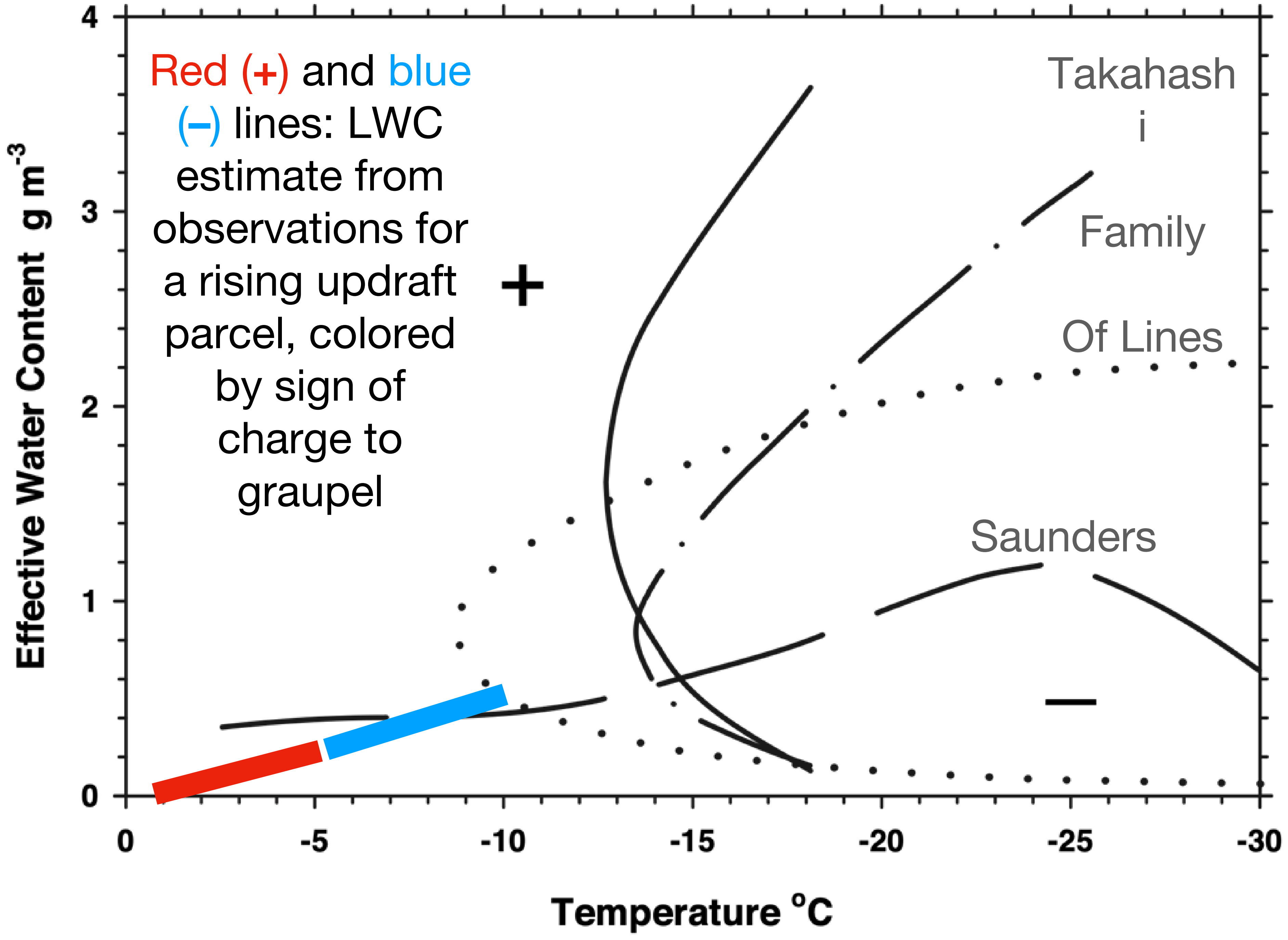
Many observed upward positive leaders are evidence that shallow lower positive charge was absent on the Tug. Consistent with quick sedimentation of low-level near-shore graupel.

Implications for electrification microphysics

A study of IOP4, 18 Dec, 0359Z

- This sounding had three charge layers lines below -10°C! Estimate a -5°C reversal temperature for graupel charging polarity.
- To the right, we estimate (very roughly and with large error bars) LWC in this cloud, and place it in context of the laboratory charging results.
  - This is the LWC and temperature range of greatest uncertainty.
  - None of the Takahashi lines permit negative charging to graupel at the necessary temperatures.
  - The Saunders reversal line is in proximity to the observations, but of the wrong polarity.
  - *These observations should be investigated deeply* to help refine laboratory experiments, and to suggest new ones.
- **LEE provided an excellent natural laboratory for studying cloud electrification (as expected)!**





Start with 0 g/kg liquid at cloud base (~surface). Sounding shows 1.2 g/kg was converted to liquid or ice by -10°C.

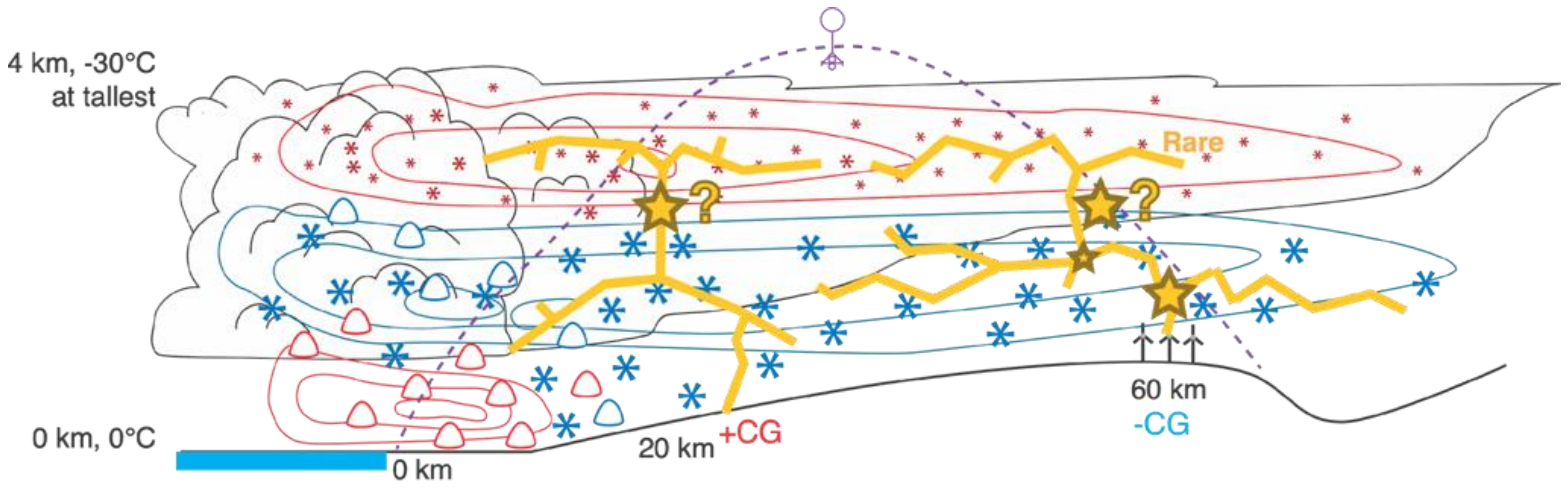
If 50% remains as liquid water (an upper bound) and is collected at 80% efficiency then we expect EW ~0.5 g/kg at -10°C.

Welsh et al. (2016) observed LWC = 0.2 g/kg at similar altitudes and location, but in somewhat colder clouds, during OWLeS.

Downwind near the turbines …

… lower positive charge is probably absent

- The near-shore positive charge was likely carried on positive graupel, and so it is reasonable to expect it to fall out.
- The origin of negative charge on snow and positive ice crystals aloft is also a mystery, but is probably analogous to negative charging to graupel expected at colder temperatures and low LWC.
- Lighting behavior (many observed upward positive leaders) is also consistent with the absence of lower positive charge.
  - It is energetically unfavorable for positive leaders to initiate and develop into/toward positive charge.
  - The flash initiation process also requires the largest electric field, which by the electrostatic laws implies the greatest energy hurdle and the hardest condition to achieve.



Concluding remarks

We have already **discovered** some things we didn't know about **lake effect electrical structure**.

Those surprises are tied to areas of great **interest** in the **microphysics** of **cloud electrification**.

We can continue to use the observed lightning, electric field and thermodynamic profiles, radar-inferred microphysics, and ground observations **to establish benchmark results for the electrical structure in lake effect storms**.