

Explicitly Resolving Lightning and Electrification Processes From the 10-12 April 2019 Thundersnow Outbreak

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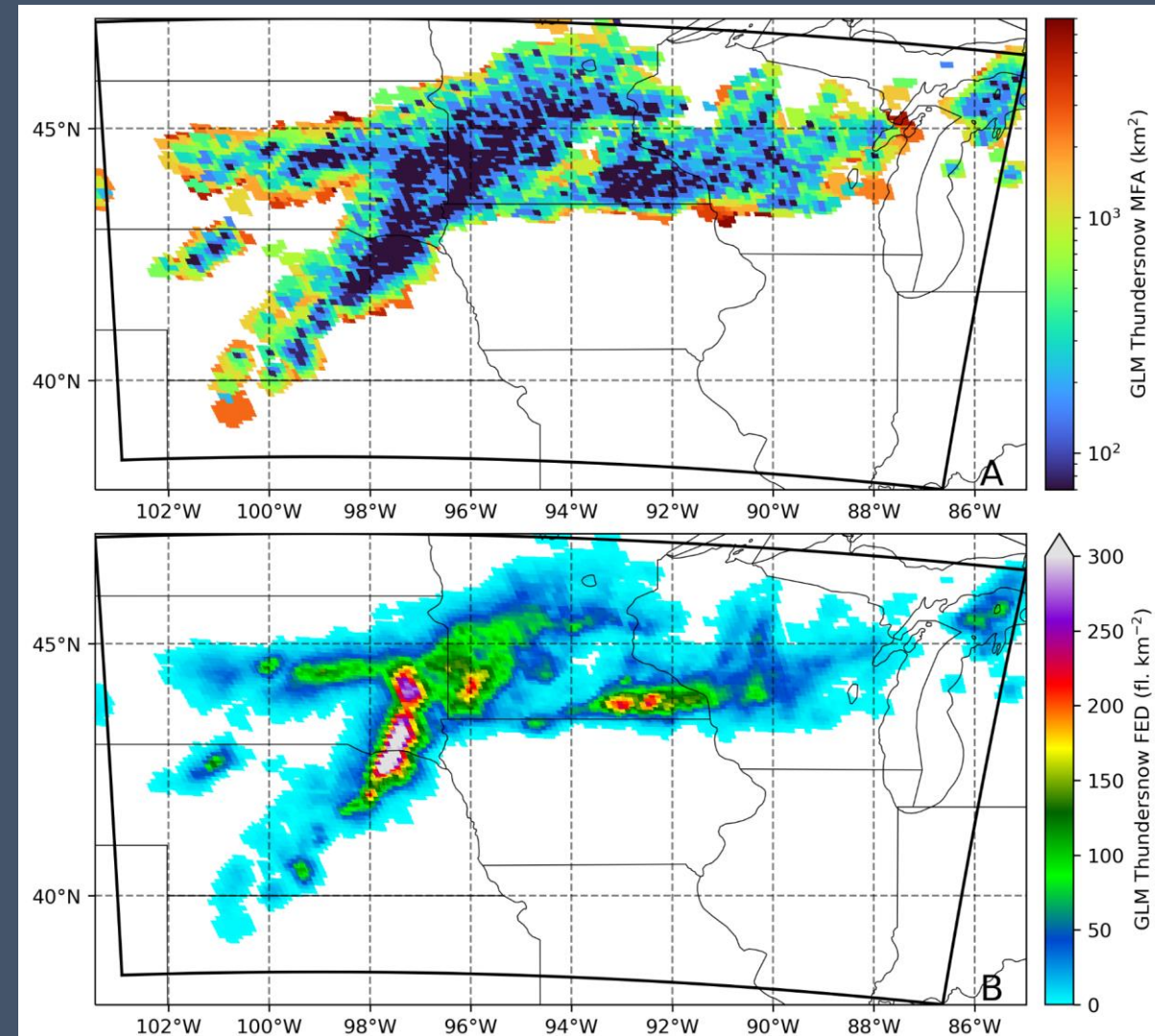
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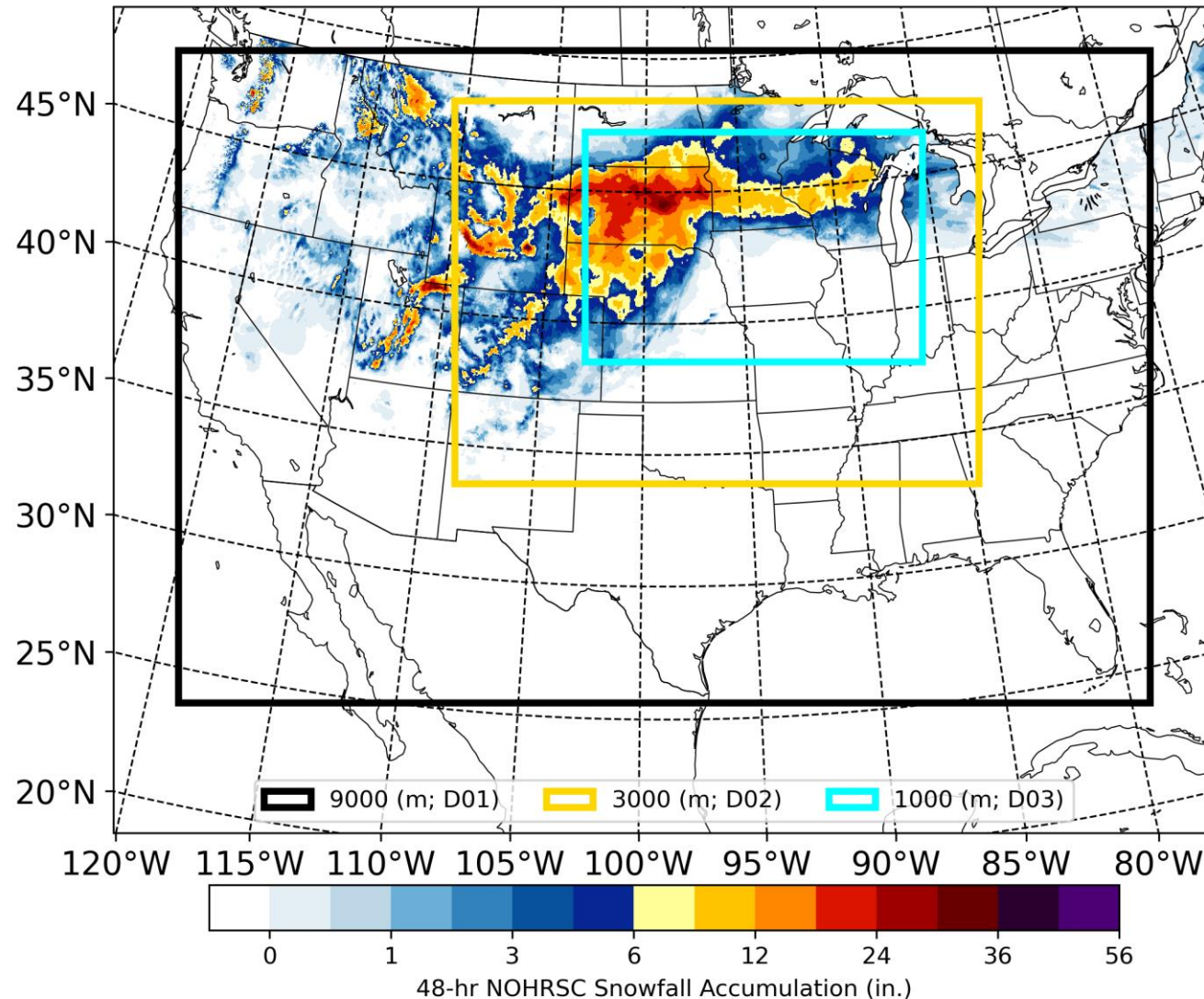


Background/Motivation

- Weather Research and Forecasting Electrification (WRF-ELEC) explicitly resolves hydrometeor charge, electric field, and lightning discharges (Fierro et al. 2013)
- Previous attempts to generate large regions of enhanced electrification and lightning discharges for winter cases have proven challenging (Fierro et al. 2013; Dafis et al. 2018)
- More recent attempts have proven successful with generating meaningful charge separation and electric fields for snowstorms
 - Max electric fields: $O(10 \text{ kV/m})$ (Harkema et al. 2023)
- Lightning initiation within snowfall has yet to be explicitly resolved using WRF-ELEC
- The Geostationary Lightning Mapper (GLM) detected 19,667 thundersnow flashes
 - 00 UTC 10 April 2019 to 06 UTC 12 April 2019
 - GLM flashes classified using the Thundersnow Detection Algorithm (Harkema et al. 2019)



WRF Configuration



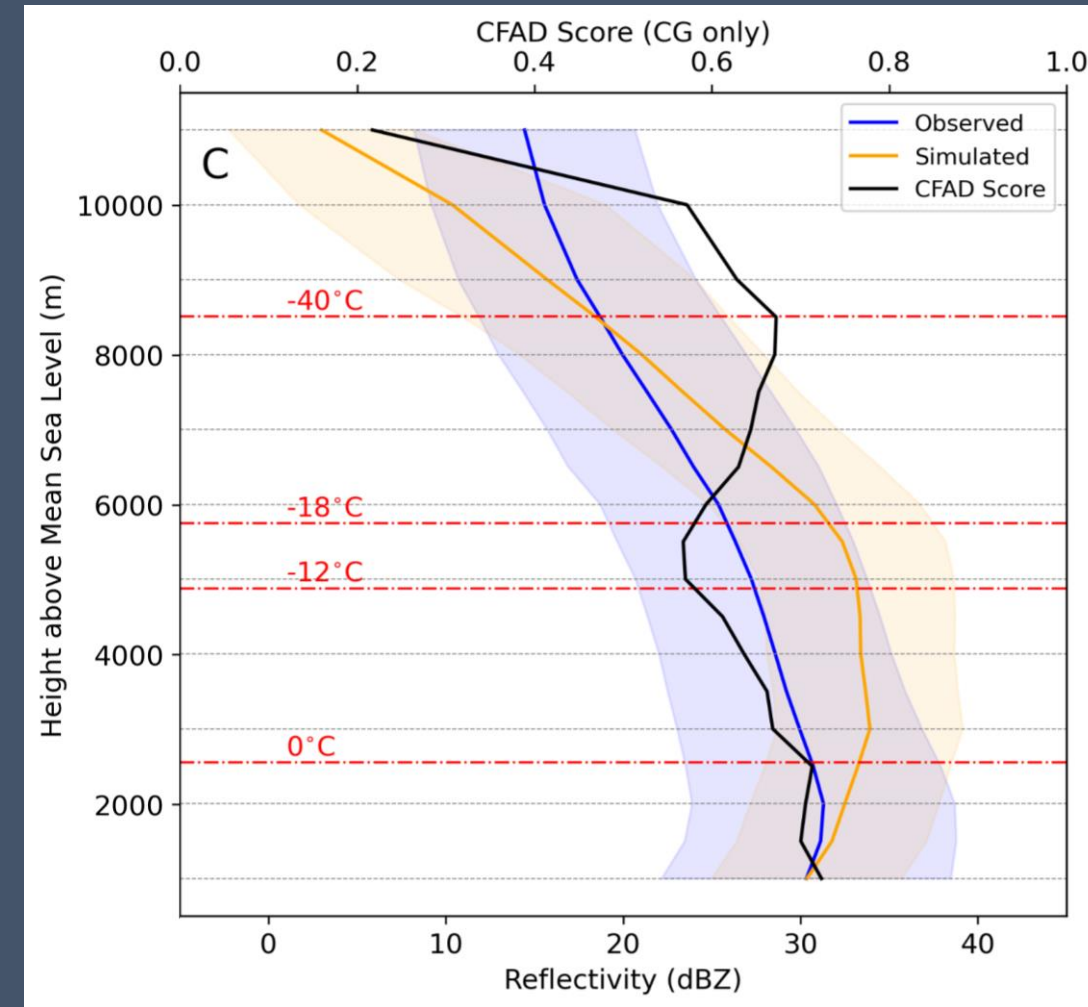
Parameters	Midwest (10-12 April 2019)
ΔX (m)	1000
N_z	70
$N_x \times N_y$	1426 x 973
dt (s)	5
Boundary Layer Scheme	YSU
Radiation Scheme	RRTMG
Microphysics Scheme	NSSL two-moment
Land Surface Model	Noah
Initial-Boundary Conditions	HRRR (v3)

Simulated Thundersnow

Lightning discharge with (wet-bulb temperature and 2-m temperature) $\leq 2^\circ\text{C}$

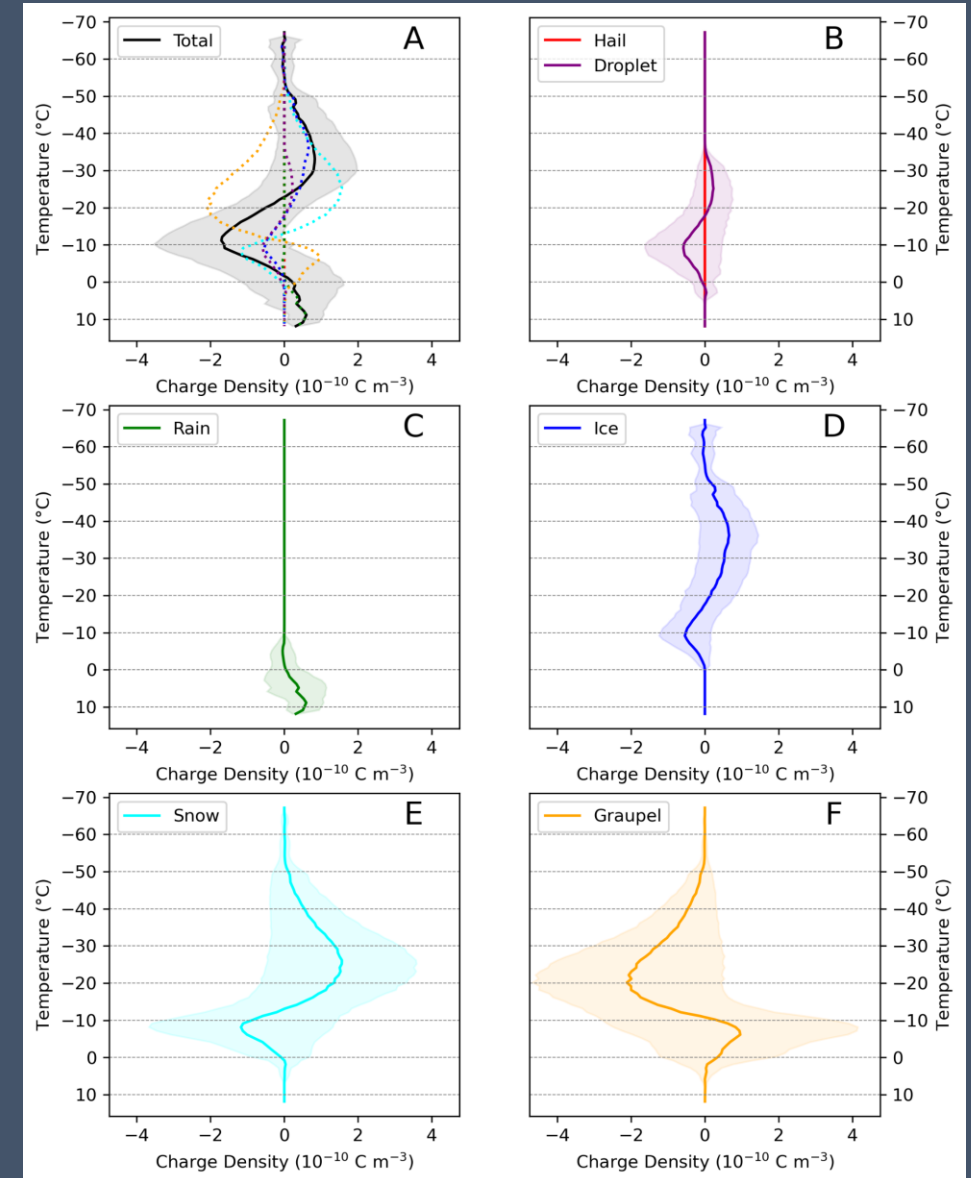
Radar Reflectivity Analysis

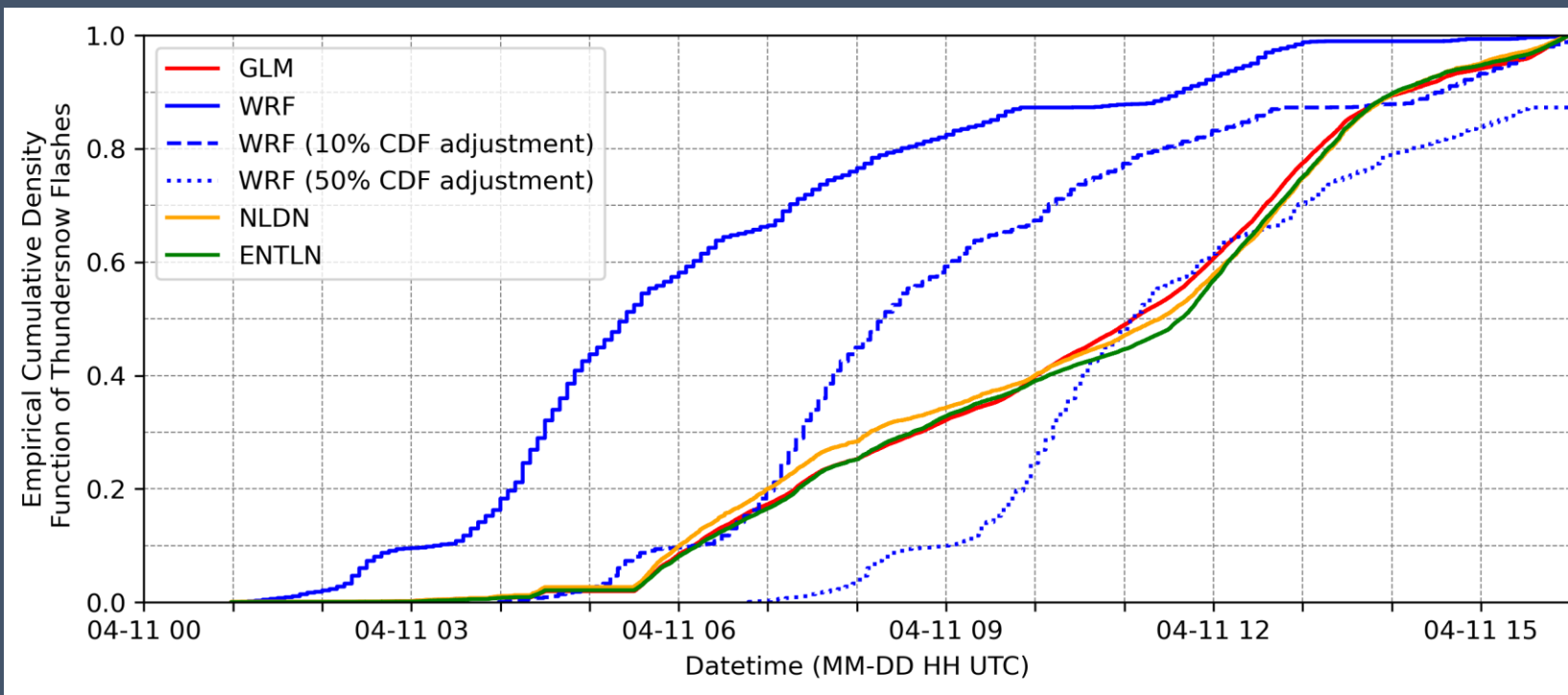
- NLDN detected 26,953 thundersnow flashes and WRF-ELEC simulated 1,195 individual thundersnow flash footprints
 - Between 00 and 16 UTC on 11 April 2019
 - Majority of thundersnow flashes were classified as IC
- Comparison using the radar reflectivity structure via contour frequency by altitude diagram (CFAD)
 - Shading: ± 1 standard deviation
 - Solid line: Mean reflectivity vertical profile
- CFADs match well between observed and simulated IC thundersnow flashes with simulated reflectivity being lower compared to observations
 - Mean observed IC reflectivity profile never exceeded 28 dBZ
- WRF simulation exaggerated the radar reflectivity for CGs compared to observations
 - Likely associated with larger rates of aggregation within the simulated environment (Stith et al. 2002; Fierro et al. 2015)



Hydrometeor Charge Structure

- Lightning cannot occur without ample charge separation; therefore, it is paramount to understand the vertical charge structure that makes it possible*
 - *Vertical profile analysis by temperature and not height
- Simulation produced 1,733 individual thundersnow flash footprints throughout the inner domain
 - 00 UTC 10 April 2019 – 06 UTC 12 April 2019
 - 17.3% of the total simulated flash footprints produced by the simulation
- The mean charge density vertical profile (black line) indicates a normal tripole charge structure associated with simulated thundersnow flashes
 - Lower negative (-11°C); Upper positive (-33°C)
- Snow/Ice hydrometeors contribute notable amount of charge that make thundersnow possible
 - Similar total charge density magnitudes as graupel

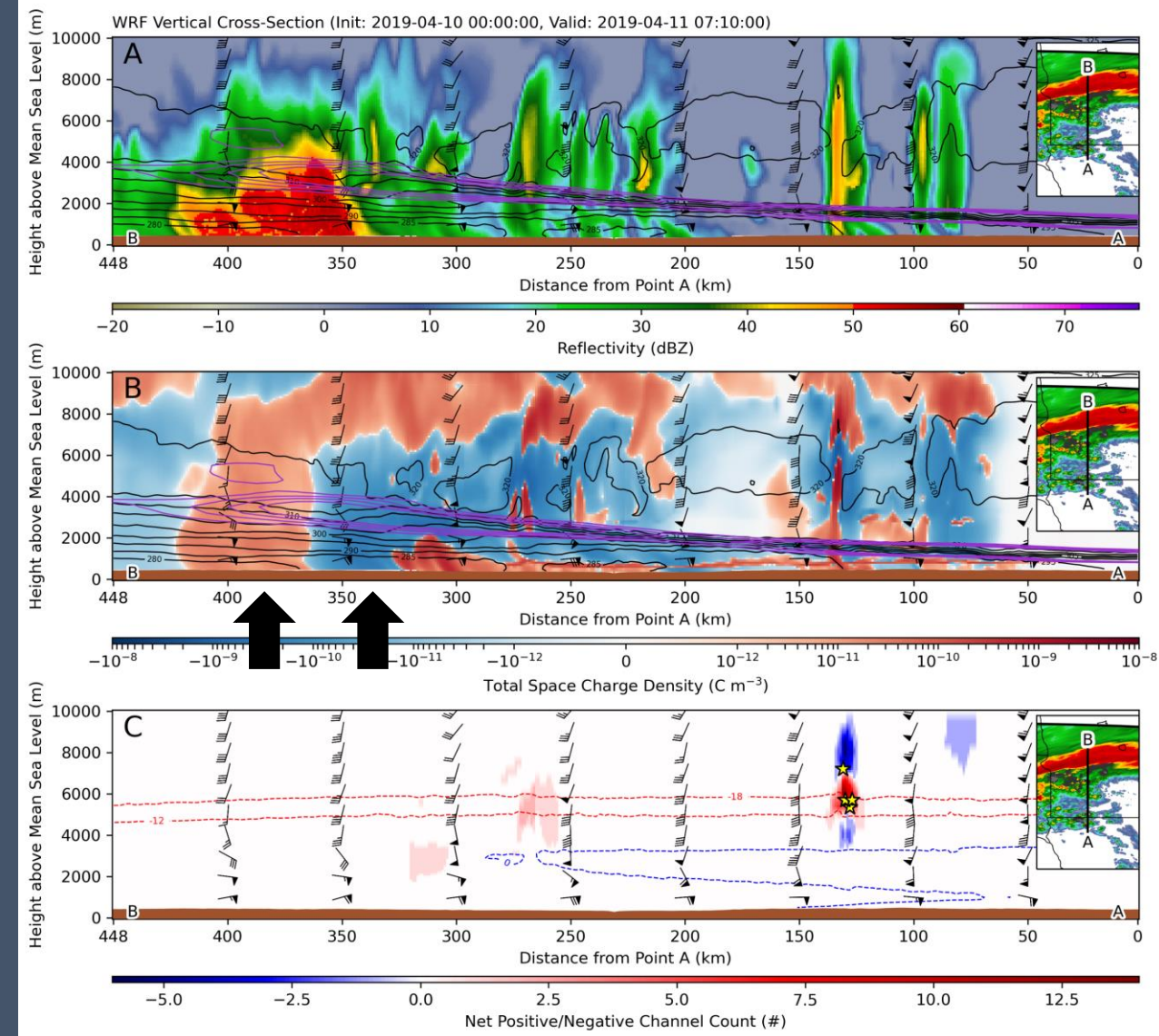


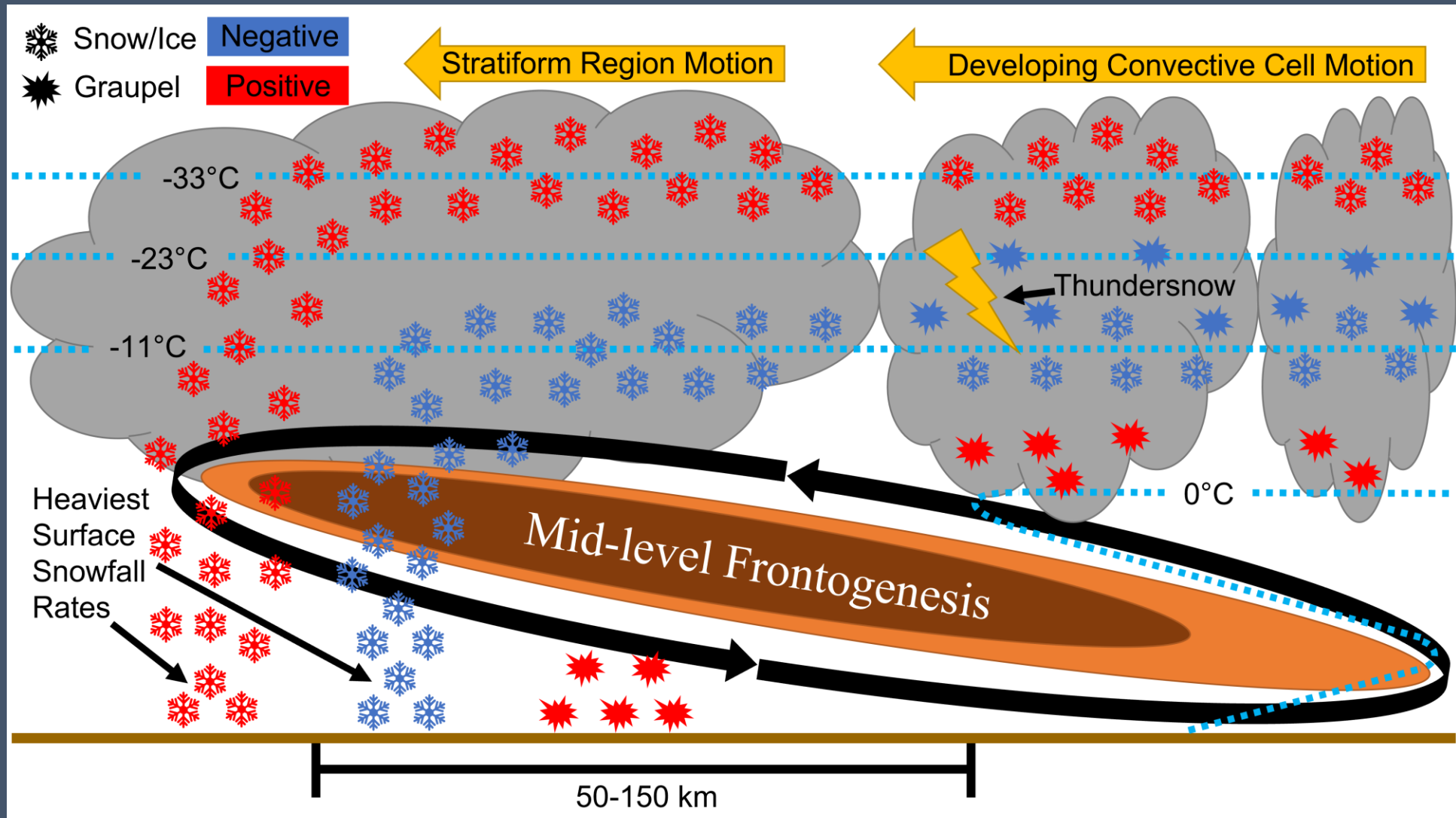


- Total flashes classified as thundersnow between 00 UTC and 16 UTC on 11 April 2019:
 - ENTLN: 115,510
 - NLDN: 26,953
 - GLM: 19,667
 - WRF: 1,733
- WRF-ELEC simulated thundersnow flashes were statistically smaller compared to thundersnow flashes observed by GLM
 - Mean: 206 km² vs. 514 km²
 - Max: 5,142 km² vs. 7,322 km²
- Individual flash rate comparisons are not feasible due to differences between observed and simulated thundersnow flashes characteristics and how they are detected
 - Thundersnow flashes rates must be relative to each other
- Empirical cumulative density functions provide a way to estimate relative flash rates without considering the magnitude and spatial offsets

Cross-Section Analysis

- Cross sections were examined to explain why thundersnow is spatially separated from the heaviest surface snowfall rates (Market and Becker 2008; Harkema et al. 2020)
- Cross-sections from Northern Iowa to Central Minnesota: reflectivity (top), snow charge density (middle), and simulated lightning (bottom)
- Elevated convection travels north isentropically along the mid-level frontogenesis before merging with the main synoptic snowband
 - Associated with a gross tripole charge structure (pos-neg-pos)
- Charge structure was vertically homogenous in polarity within the main synoptic snowband (black arrows)
 - No lightning initiation within the main synoptic snowband





Summary

- Simulated charge densities indicated a gross tripole charge structure with ice/snow hydrometeors contributing most to the lower portion of the negative charge region
- WRF-ELEC simulated 1,733 thundersnow flashes but underestimated the spatial extent and magnitude compared to observed thundersnow flashes
- The simulated synoptic snowband was associated with two nearly homogenous vertical charge structures (one positive and one negative)
 - Potentially explains why thundersnow is displaced from the heaviest surface snowfall rates

Harkema, S. S., Mansell, E. R., Fierro, A. O., Carey, L. D., Schultz, C. J., Matsui, T., & Berndt, E. B. (2024). Explicitly resolving lightning and electrification processes from the 10–12 April 2019 thundersnow outbreak. *Journal of Geophysical Research: Atmospheres*, 129, e2023JD039987.
<https://doi.org/10.1029/2023JD039987>.

