Kinematical, microphysical, and lightning characteristics of a tornadic supercell

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Motivation

Charge structure of a supercell thunderstorm can be complex. Updraft as well as non-updraft regions can deviate from a normal-polarity tripole model of a thunderstorm.

- Supercooled liquid water concentration (SCLW) and environmental thermodynamics influence normal or anomalous polarity of a thunderstorm (Baker & Baker, 1987; Emersic & Saunders, 2010)
- Updraft strength can explain the mechanism for the variation in lightning altitude and the flash rates (Ziegler and MacGorman 1994).
- Differential reflectivity (Z_{DR}) columns from polarimetric radar data can be used as a proxy for updraft intensity to infer such variations.

Polarimetric and Electric Signatures of Supercells

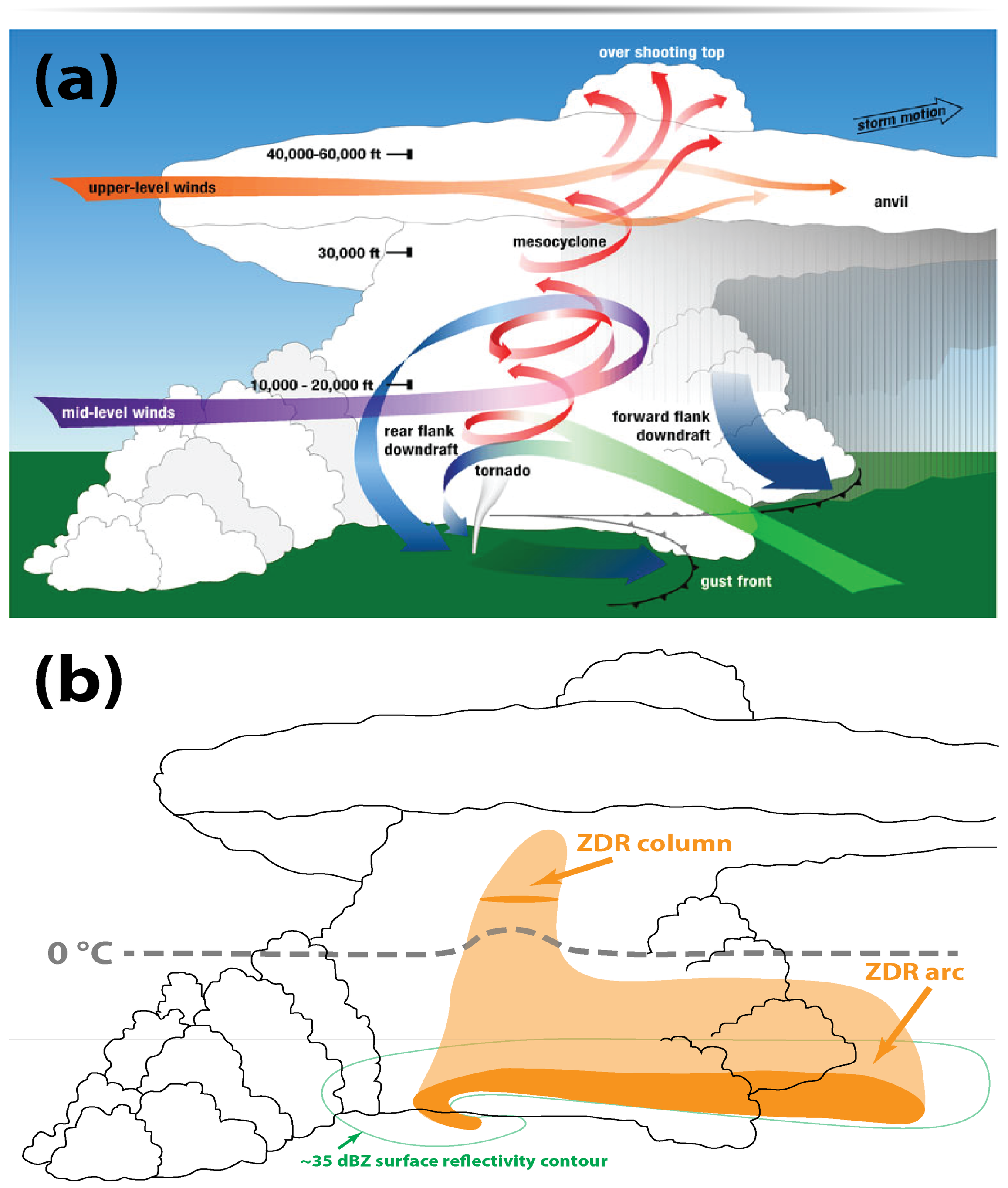

Figure 1: (a) Dynamic structure of a supercell (b) Z_{DR} column and Z_{DR} arc signatures from radar scans. Courtesy: NOAA

Narrow columnar enhancements of differential reflectivity called 'Z_{DR} columns' extending above the freezing level are typical of convective storms. Located at the periphery of the updraft maximum in supercells, these columns form as a result of upward lofting of small rain drops above freezing level. The transition of supercooled liquid water to frozen hydrometeors leads to glaciation of clouds. Differential sedimentation of ice crystals and graupel particles in the mixed phase region leads to rebounding collisions and separation of charges in the clouds.

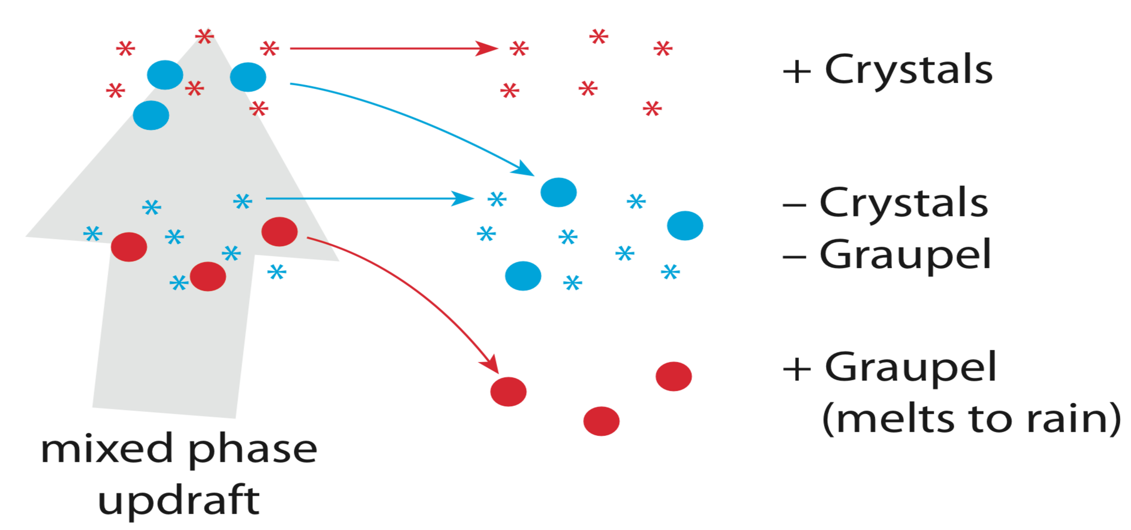

Figure 2: Depending upon SCLW concentration and ambient temperature, ice particles gain different charge polarity. Courtesy: https://github.com/deeplycloudy

Charge Analysis & Flash Rates

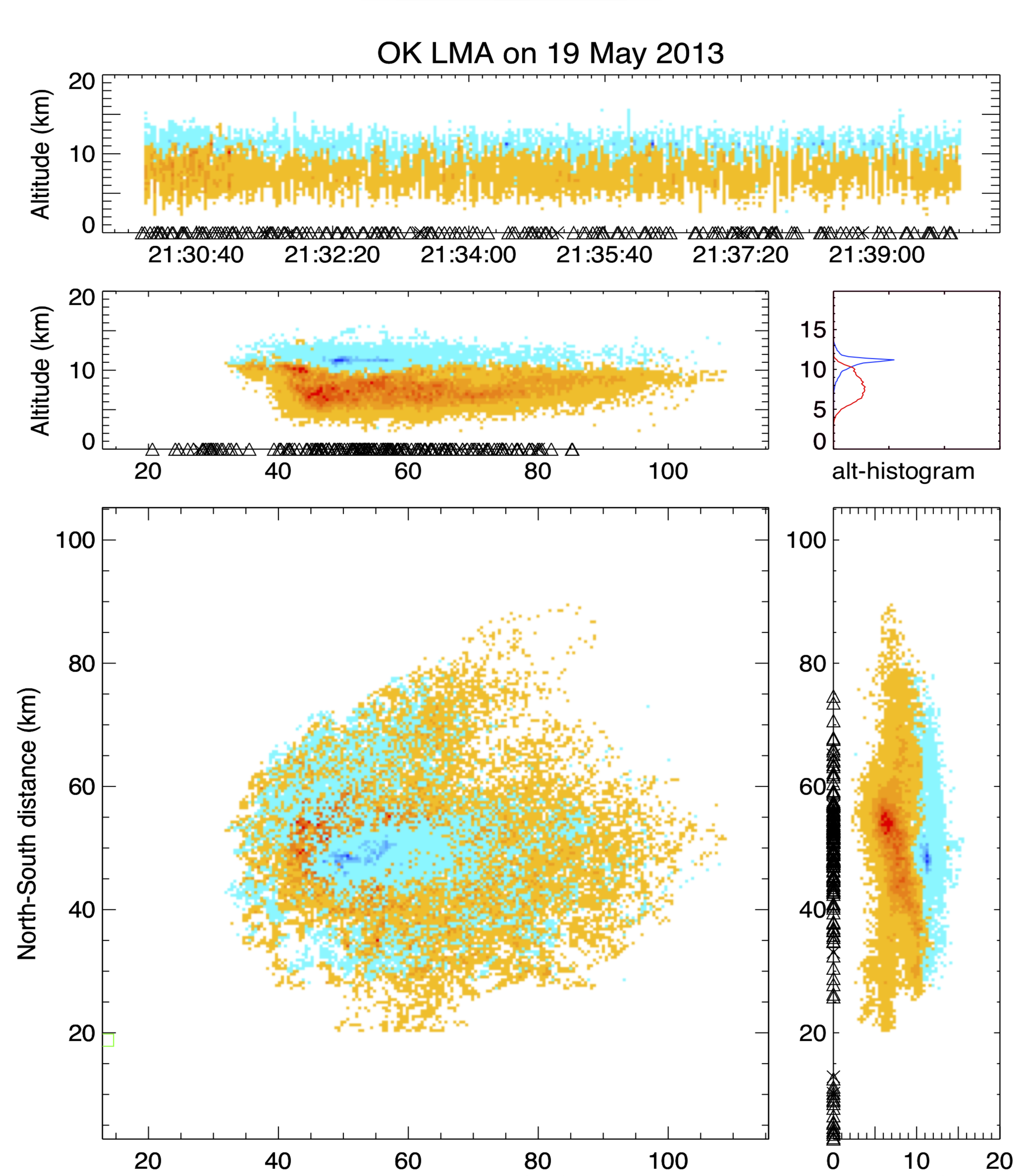

Figure 3: Storm charge classification using XLMA software. The supercell had an inverted polarity structure through 2120-2150 UTC. Most CG flashes had negative polarity during this time. Note that positive (orange shade) and negative charge (blue shade) regions were centered at an altitude of 7.5 km and 11 km respectively. Black triangles along x-axis denote negative CG flashes from NLDN data.

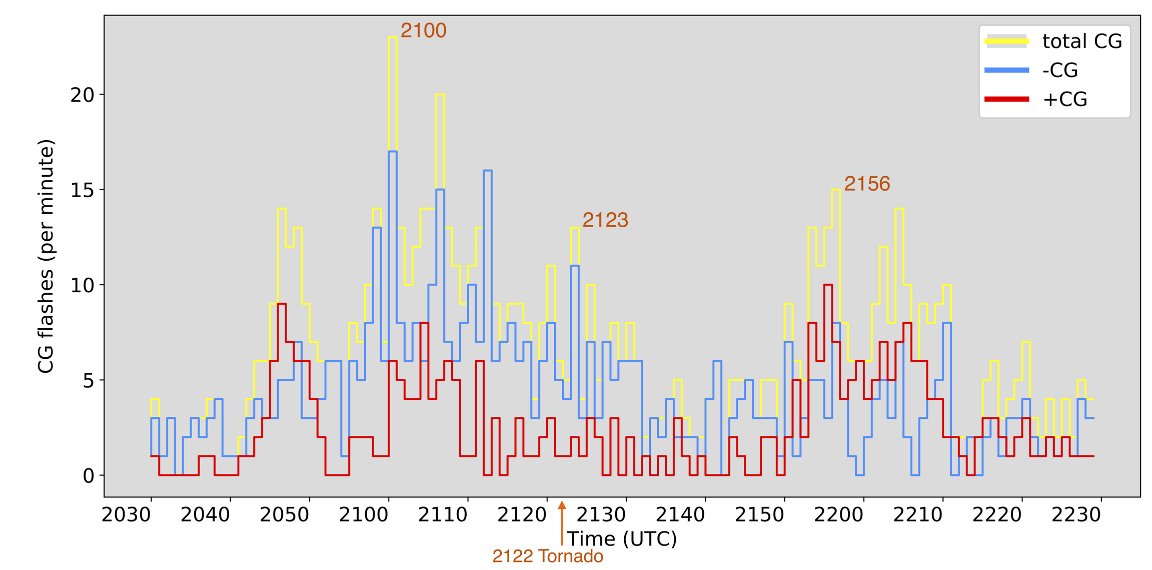

Figure 4: Cloud-to-ground flash rate from NLDN data

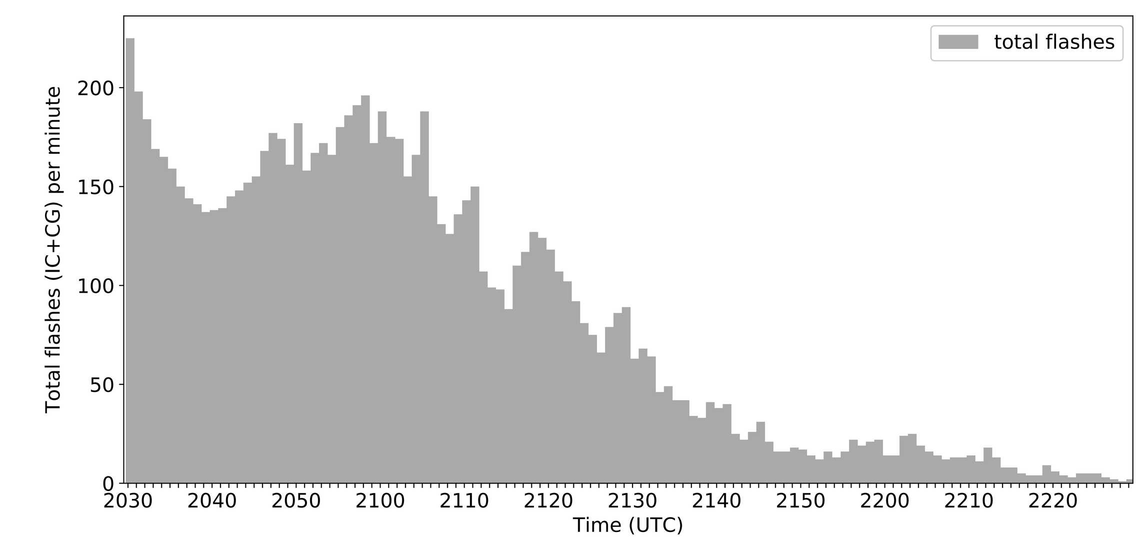

Figure 5: Total flash rate in the storm from OKLMA data

Flashes with peak power between -10 kA and 10 kA were removed to omit IC flashes misclassified as CG in the NLDN data. Storms with an anomalous structure generally favor positive CGs (Kuhlman et al., 2006) but this supercell is likely an exception.

Fig. 4 shows at least three peaks in total CG flash rate at 2100, 2123, and 2156 UTC (23, 13, and 15 flashes, respectively) corresponding to before, during, and after tornadogenesis. Thus, CG flash rate does not correlate well with tornadogenesis (Schultz et al., 2011, Calhoun et al., 2013). Fig. 6 highlights the gradual increase in source density altitude after 2117 UTC. We investigated updraft intensity variations to explain that behavior in Fig. 7.

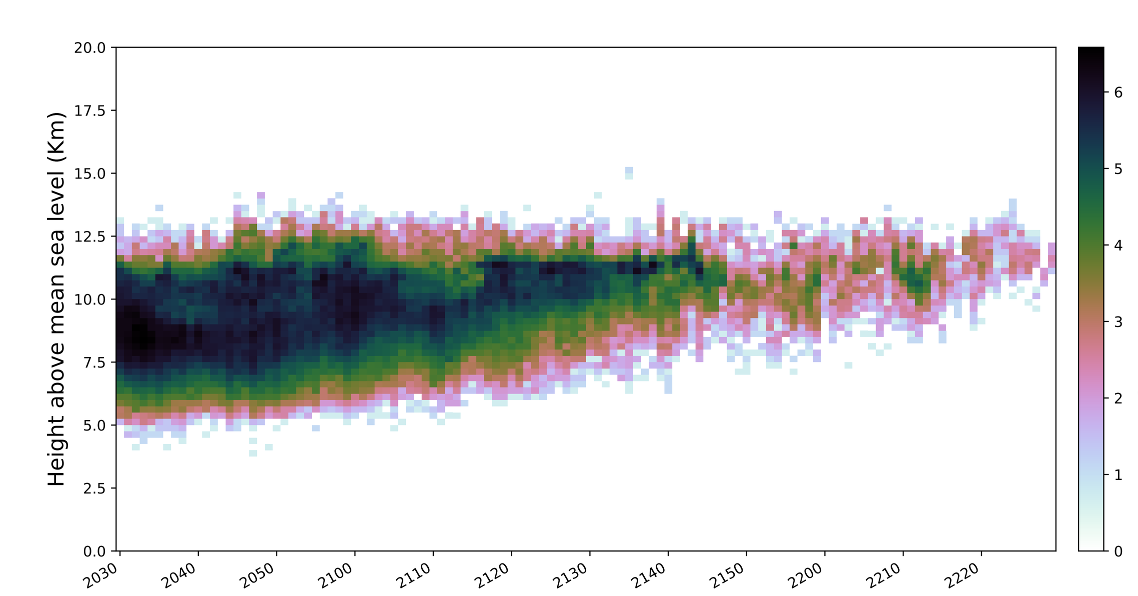

Figure 6: Time-height plot of VHF source density from OKLMA. Densities calculated by counting the number of sources that fell into a 0.5x0.5x0.25 km^3 grid volume. Note the upward trend in source density altitude between 2106 and 2117 UTC.

Z_{DR} Column Analysis

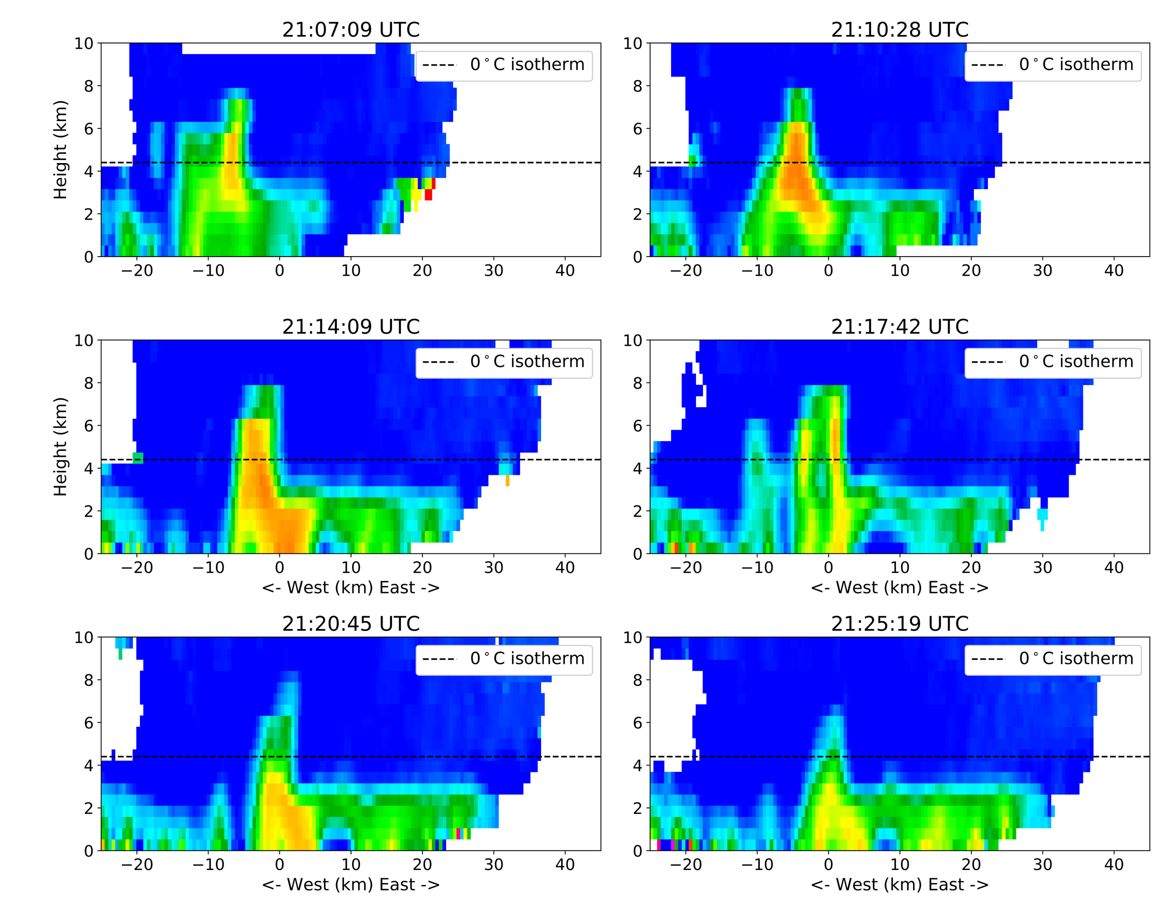

Figure 7: Upward trend in source density in Fig.7 can be explained by the evolution of Z_{DR} column from KOUN radar data. As the updraft strengthens, it leads to glaciation of clouds after some time lag, resulting in eventual charge separation and increase in altitude of flash activity. Z_{DR} column depth was also found to decrease 0-5 minutes prior to tornadogenesis which supports observations by Picca et al. (2015).

Conclusions

- Edmond supercell had an anomalous charge structure with most CG strikes being negative.
- There was no direct correlation between CG flash rates and time of tornadogenesis.
- Strengthening of Z_{DR} column correlates well with altitude of flash activity.

Acknowledgements

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