Concerning the coupling of fluid flows to thunderstorm electrostatics and lightning

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An introduction to thunderstorm electricity and recent work on electrostatic laws, fluid flows and texture

Electric potential is smoother than charge

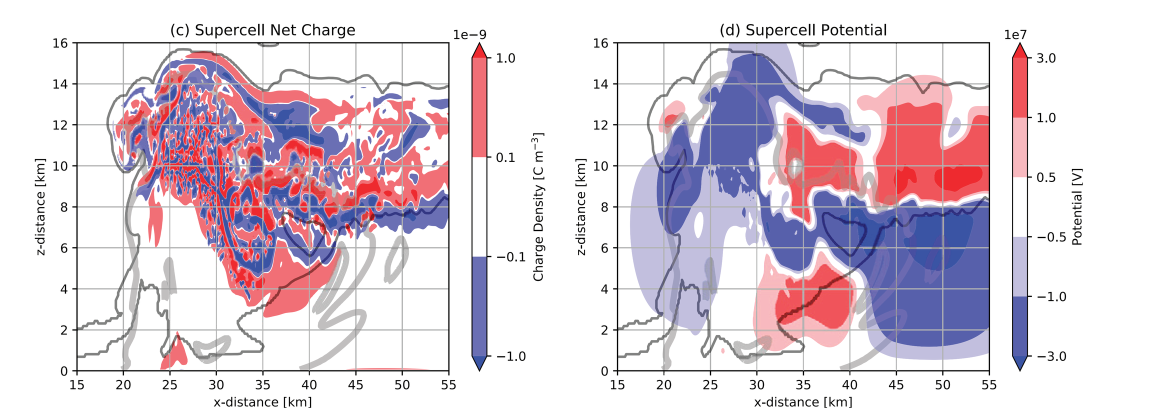
Pressure perturbations are smoother than forcing

Kinetics notation from Davies-Jones (2002, JAS)

kinetics (J/m^3)	wave component	electrostatics (J/C)
p_{nh}	e^{ikx}	ϕ
$-\nabla p_{nh} + ... = \rho_s \frac{d\vec{v}}{dt}$	ike^{ikx}	$-\nabla\phi = \vec{E}$
$-\nabla^2 p_{nh} = F_B + F_L + F_{NL}$	$-k^2 e^{ikx}$	$-\nabla^2\phi = \rho/\epsilon_0$

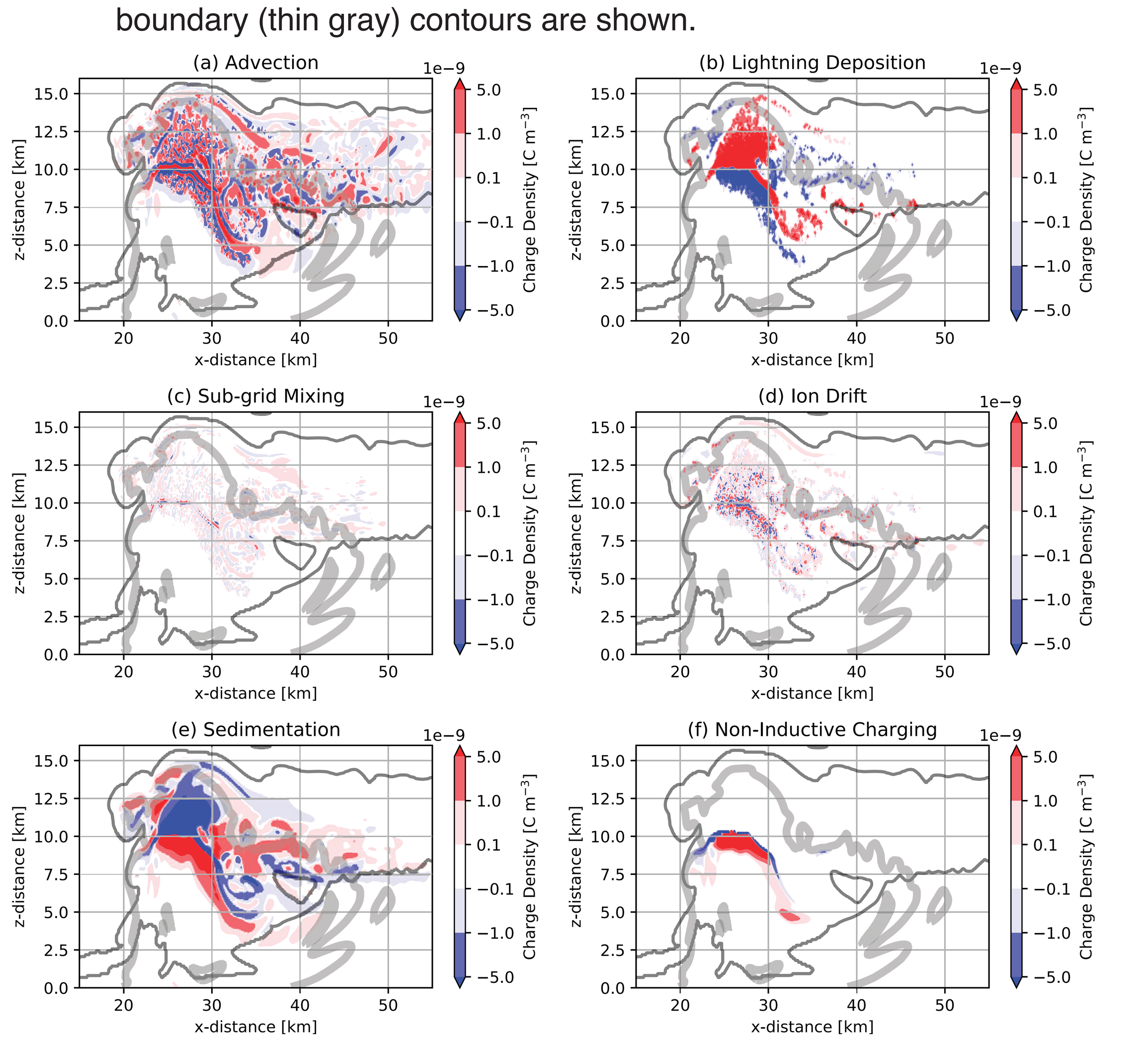
Textbooks show thunderstorm charge structure that looks like electrical potential because it explains low-flash-rate thunderstorms. But it really is much more textured.

Electrified cloud simulations (dx=125 m) by Brothers et al. (2018, JAS, Fig. 4) of a supercell using the classic Weisman-Klemp (1982) sounding in the N-COMMAS model. Simulations were at 125 m grid spacing, using two-moment microphysics and electrification, and a branched lightning scheme. Vertical cross-sections show charge and electric potential (with respect to ground). Prior literature would tend to summarize the charge structure in a way that reflectied the potential structure, not the full complexity of charge.

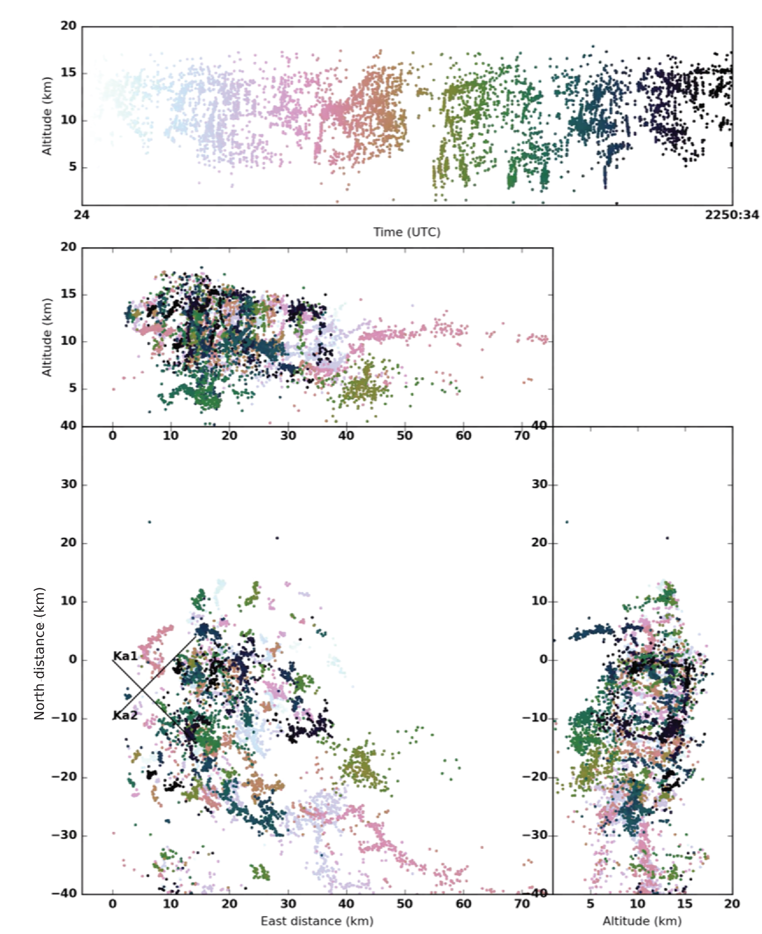


Turbulent advection of charge contributes to the textured net charge field.

Tendency terms in the net charge budget over a 30 s interval (Brothers et al. 2018, Fig.6). 35 dBz (thick gray) and cloud boundary (thin gray) contours are shown.



In high flash rate storms, lightning is not stratified in layers, but fills space. Many small flashes are found in the turbulent updraft.

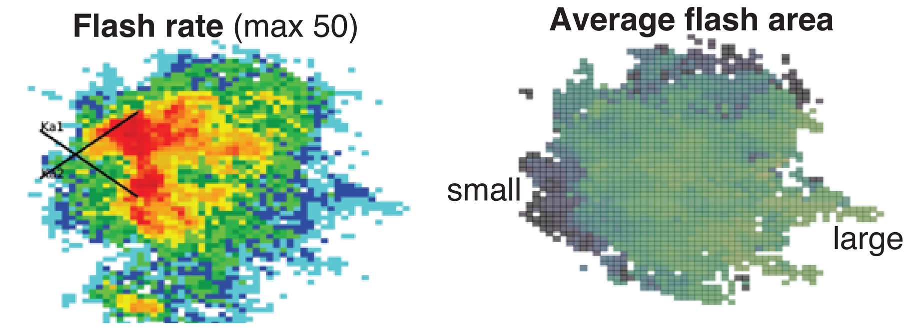


Observations

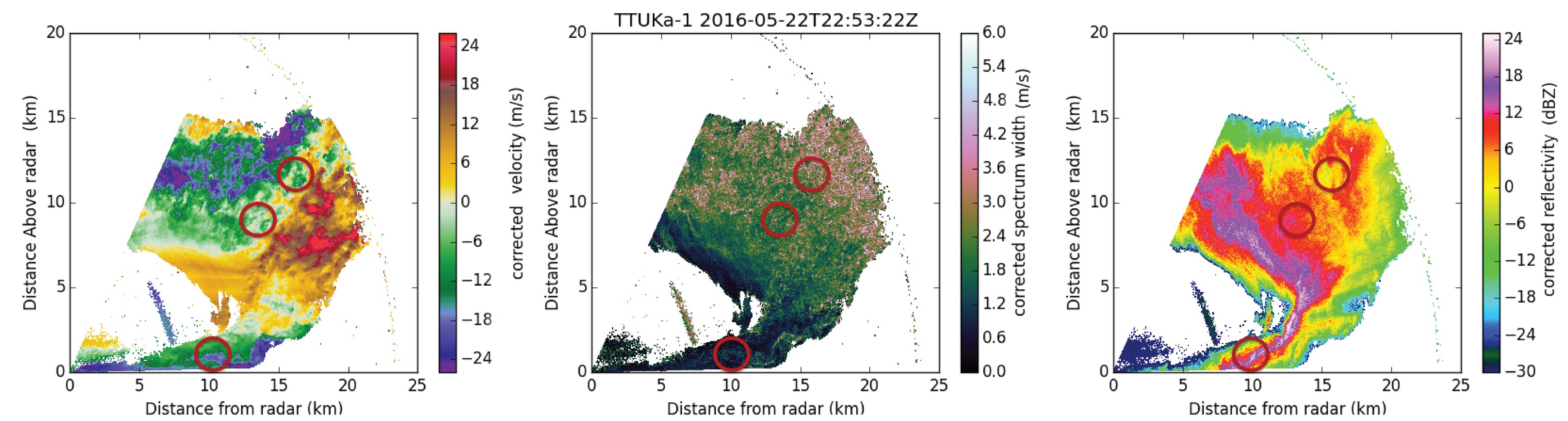
22 May 2016, Slaton, TX
Left-moving supercellular thunderstorm
CAPE, ~2000 J/kg CAPE, 45 kt eff. shear
40% of flashes are ≤ 4 km wide

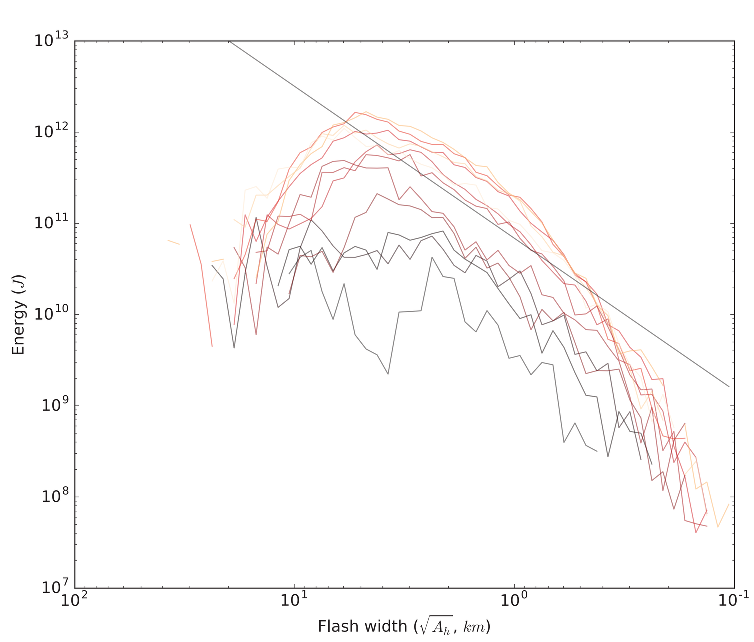
1 min gridded flash counts and sizes

Flash rate (max 50) **Average flash area**



(Above) 10 s of VHF Lightning Mapping Array observations in a left-moving supercell storm on 22 May 2016 near Slaton, TX. **(Below)** Vertical cross-section of spectrum width, velocity, and reflectivity from the TTU-Ka band mobile Doppler radar located at Ka1 above. Red circles indicate regions of varying degrees of turbulence intensity.





The electrical energy spectrum looks like a storm's TKE spectrum.

(Left) Electrical energy spectra every 10 min for two hours. Dark colors are earlier, and as the storm grows the energy increases and for a range of scales of O(1 km) matches a -5/3 power law reference line, as first shown by Bruning and MacGorman (2013, JAS).

Electrostatic Variability as a function of Strain and Rotation Rates

Do fluid properties control flash properties?

Hypothesis: Regions of increasing rotation and strain will favor flash initiation by concentrating charge and electric potential, giving rise to enhanced electric fields.

Data

Simulations by Brothers et al. (2018, JAS) using N-COMMAS were adapted to model the 22 May 2016 case near Slaton, TX. Simulations were at 125 m grid spacing, using two-moment microphysics and electrification, and a branched lightning scheme.

Methods

The velocity gradient tensor was decomposed into the rates of strain (S) and rotation (Ω),

$$\nabla\vec{v} = \mathbf{S} + \mathbf{\Omega}$$

and computed in 3D over the full model domain. The fluid characteristics were investigated at three thresholds as a function of the electrostatic characteristics:
1. No threshold, at random locations
2. A moderate electric field of 1 kV m^{-1}
3. Locations of large electric field where lightning flashes begin, O(100 kV m^{-1})

The mean charge density, electric potential, electric field at each pair of strain and rotation rate values are shown to the right, alongside the number of model grid cells having each fluid property.

Results:

Increasing values of electric field, potential, and charge density aligned with increasing strain and rotation rates.

Median Strain and Rotation Rates

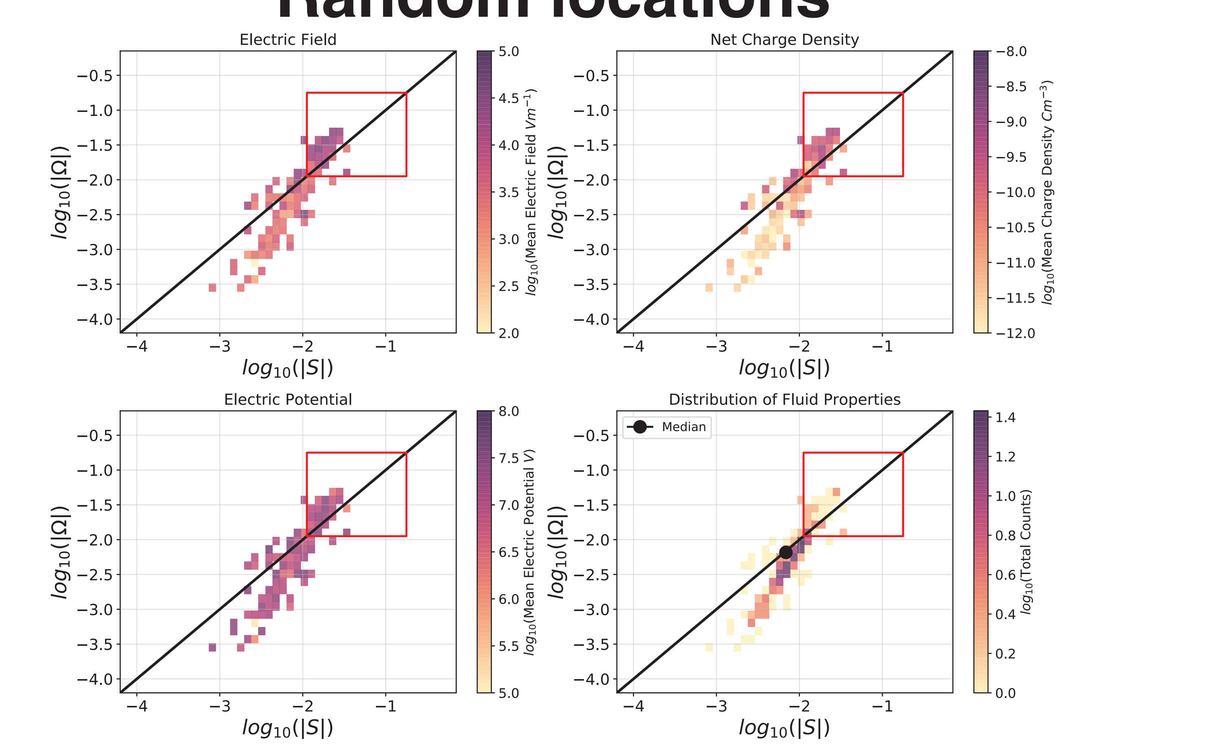
Location	$\|\|S\|\| \; s^{-1}$	$\|\|\Omega\|\| \; s^{-1}$
Random	$10^{-2.16}$	$10^{-2.18}$
Electric Field $> 10^3 V m^{-1}$	$10^{-1.82}$	$10^{-1.84}$
Flash Initiations	$10^{-1.35}$	$10^{-1.32}$

Strain and rotation rates shown in the *red box* encompassed 95% of all flash initiations, and aligned with the largest charge density, potential and electric fields throughout the entire model domain.

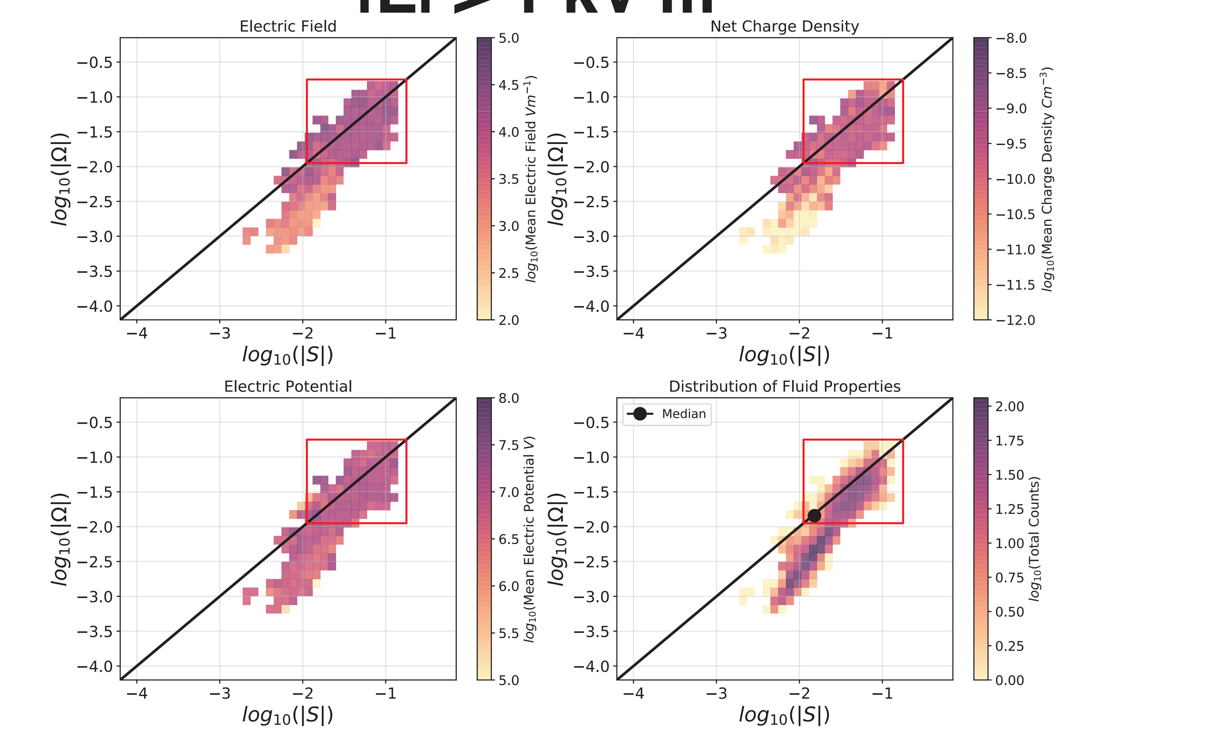
Strain and rotation rates near flash initiations were approximately equal; one location known to have such characteristics is the edge of a vortex. Higher electric fields were found on the strain-dominated side of the 1:1 line as conditions became more favorable for flash initation.

Even for locations with no flash initiations, larger strain and rotation implied larger electrostatic fields, especially charge density.

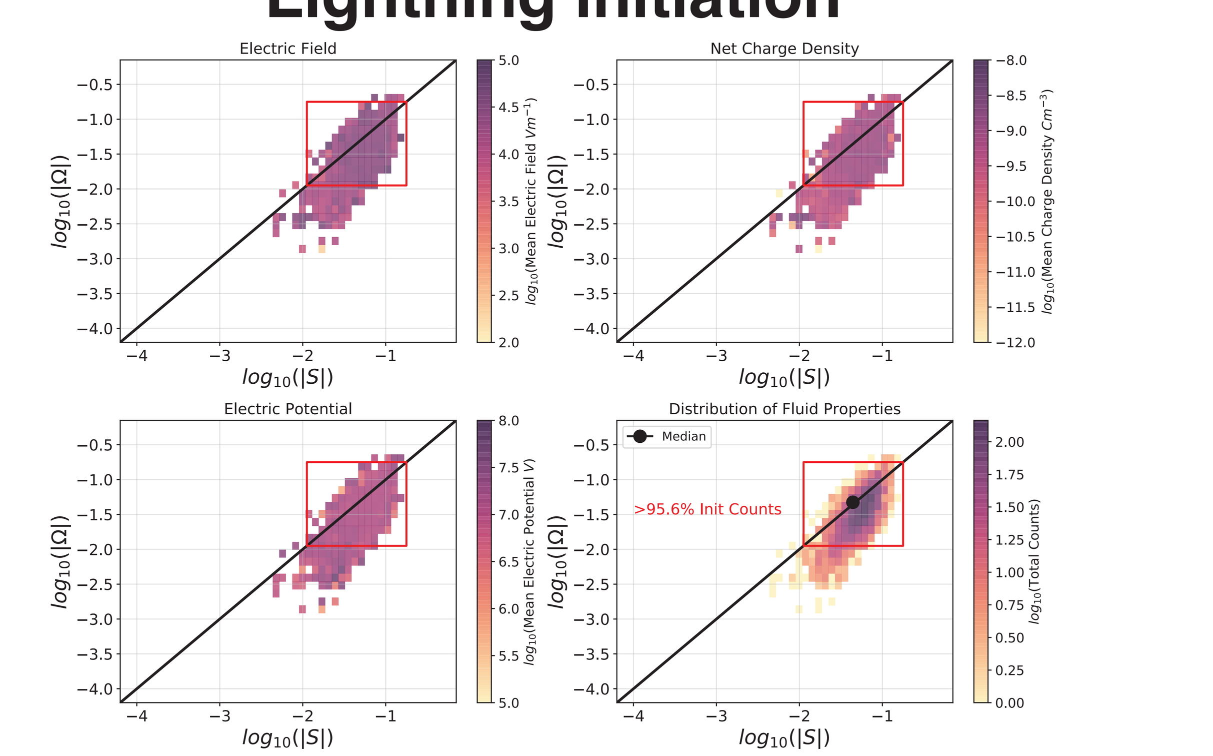
Random locations



|E| > 1 kV m^{-1}



Lightning initiation



Acknowledgments

This work was supported by NSF-AGS1352144 under the CAREER program. The authors are grateful for the ongoing assitance of Ted Mansell with N-COMMAS and simulations completed by Matt Brothers in earlier work. Samantha Berkseth and Vanna Chmielewski also contributed to the observational analyses.