Interpretation of total lightning density patterns in the GOES-R Proving Ground

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What storm processes are responsible for the overall patterns in total lightning density?

Definitions

Lightning: an electrically connected, ionized and conducting tree of channels.

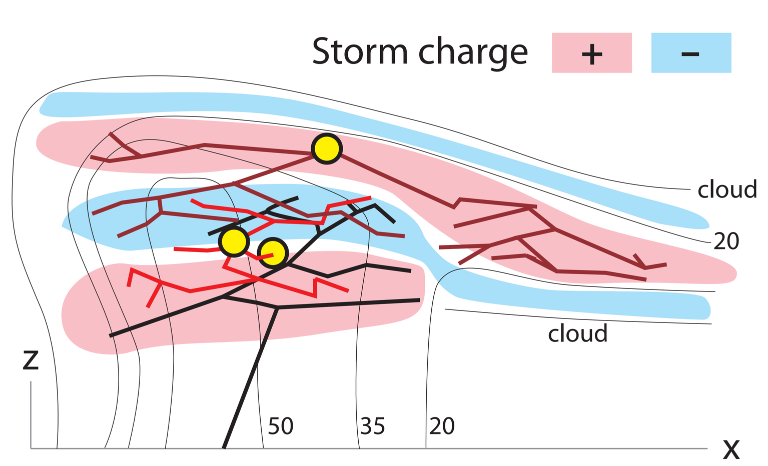
Large charge transfers (currents) make light that scatters through the cloud and is seen from space.

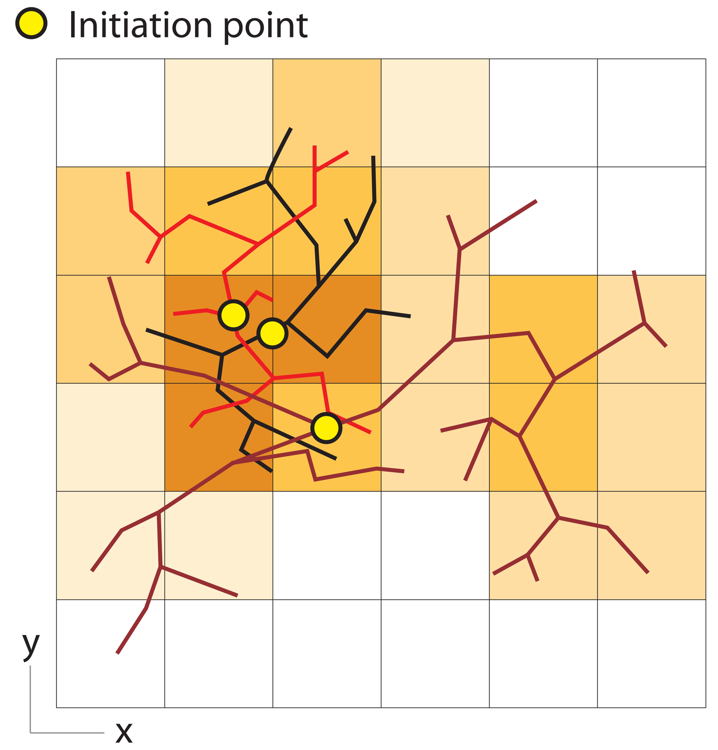
The Initial breakdown location is where the opposite-polarity ends of the lightning tree connect. There is likely lots of current through this location that makes light.

Channel extent determines the extent of the region that can light up, and together with flash rate (discussion to right) links storm processes to GLM measurables.

Total: all lightning in the cloud, including flashes that come to ground
- On average, 5x more activity in cloud

Density: column total detections
- Might be flashes, channel segments, optical pulses, etc.
- Patterns may differ depending on phenomenon detected, and are due to multiple physical processes





Where will lightning start?

The condition for initial breakdown that leads to an extensive lightning channel tree is that the local electric field be maximized in excess of some threshold (Maggio et al. 2005, Marshall et al. 2005). The condition for maximization is:

$$\nabla \cdot E = 0$$
$$|\nabla^2 E| > 0.$$

Via Gauss's Law ($\rho = \varepsilon_0 \nabla \cdot E$), the maximization criteria in terms of charge density equate to

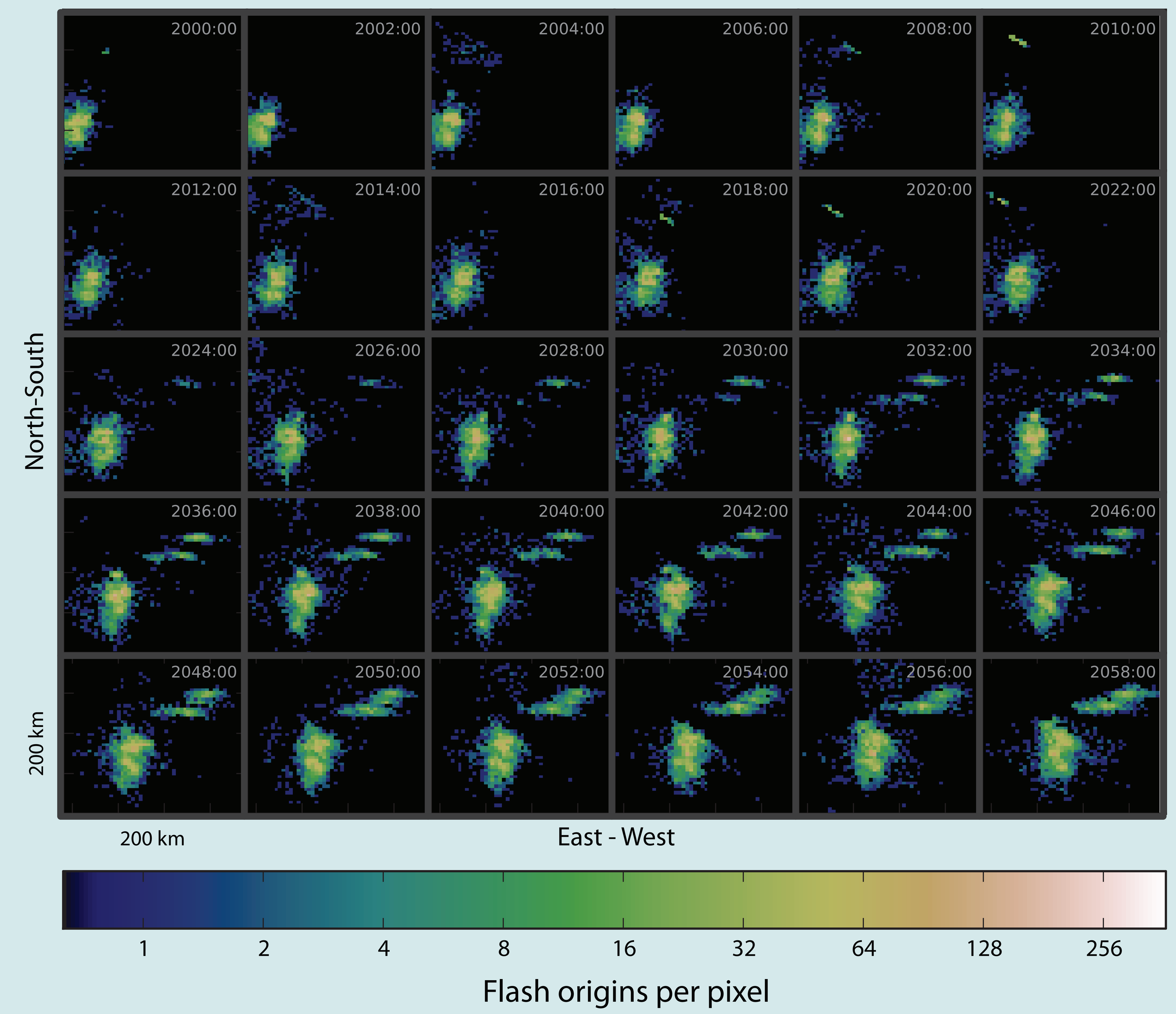
$$\rho = 0$$
$$|\nabla \rho| > 0.$$

i.e, between + and – charge.

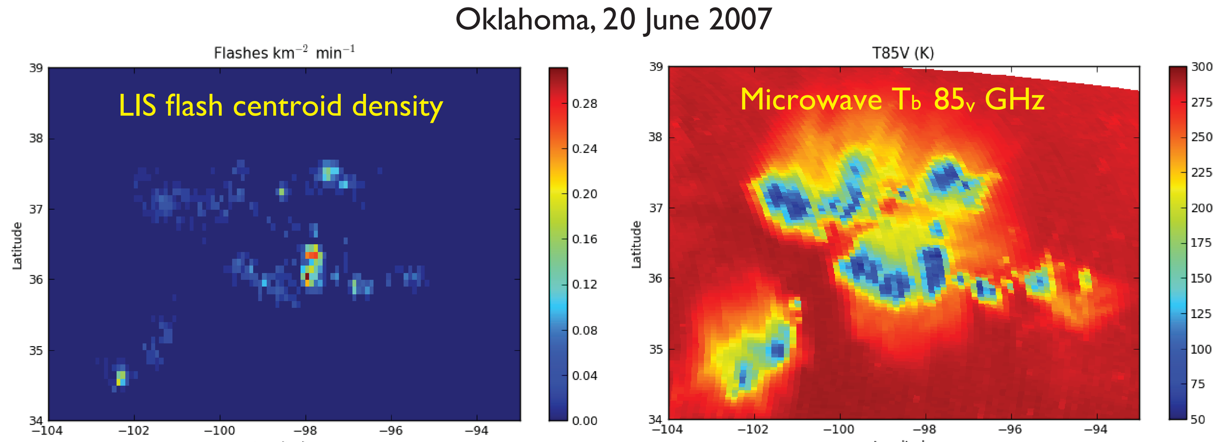
Frequent flash onset highlights storm updraft processes that are cellular in nature.

Storm cells and flash rate for assesment of storm severity

10 June 2009, South-Central Oklahoma, 4 km pixels

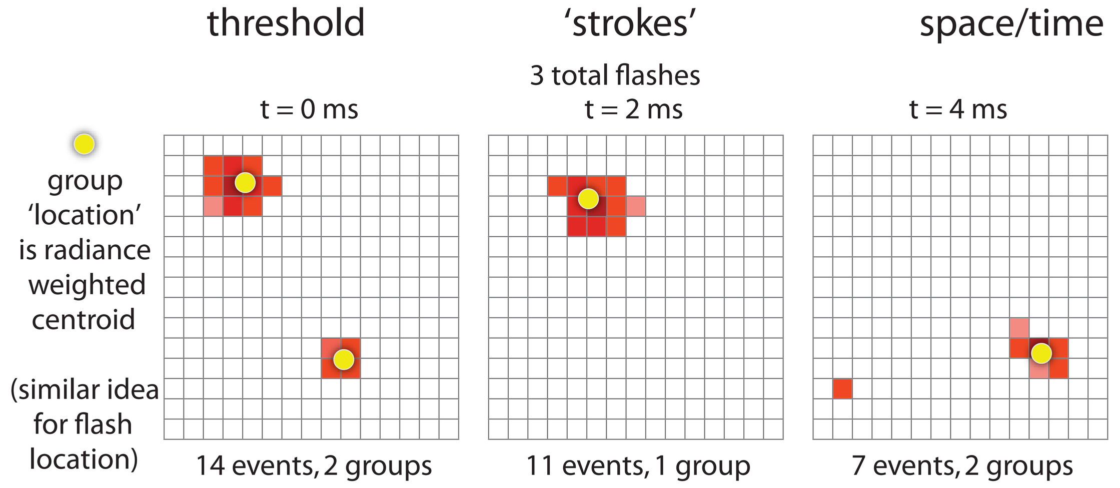


Oklahoma, 20 June 2007



Events, groups, flashes (TRMM LIS, GOES-R GLM)

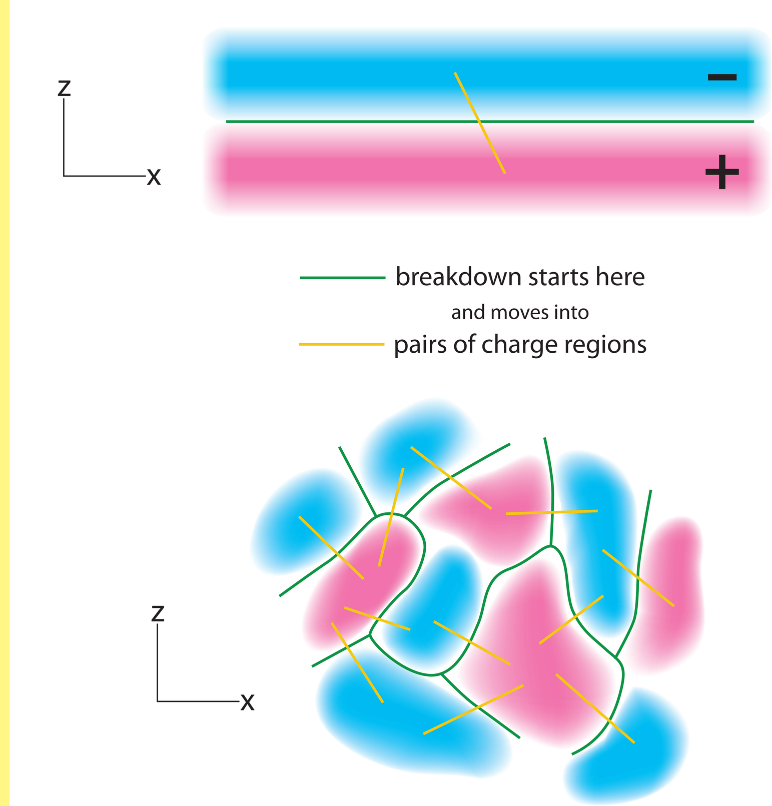
- Events: triggered pixels above background threshold
- Groups: adjacent pixels in a single frame – 'strokes'
- Flashes: collection of groups close enough in space/time



Conflicting condtions for charge gradients

Origin	Extent
$|\nabla\rho| > 0$	$\nabla\rho \approx 0$

Result: a local increase in the initial breakdown rate is met with a corresponding decrease in channel extent, and vice versa.



Where will the channel go?

Lightning channel propagation takes place within potential extrema (MacGorman et al. 1981, Coleman et al. 2006), so find the extrema in potential,

$$\nabla \varphi = 0$$
$$|\nabla^2 \varphi| > 0$$

Using the definition of potential and Gauss's Law, propagation is within regions of charge (Williams et al., 1985) according to the criteria

$$E = 0$$
$$|\rho| > 0.$$

So, channels have large extent when

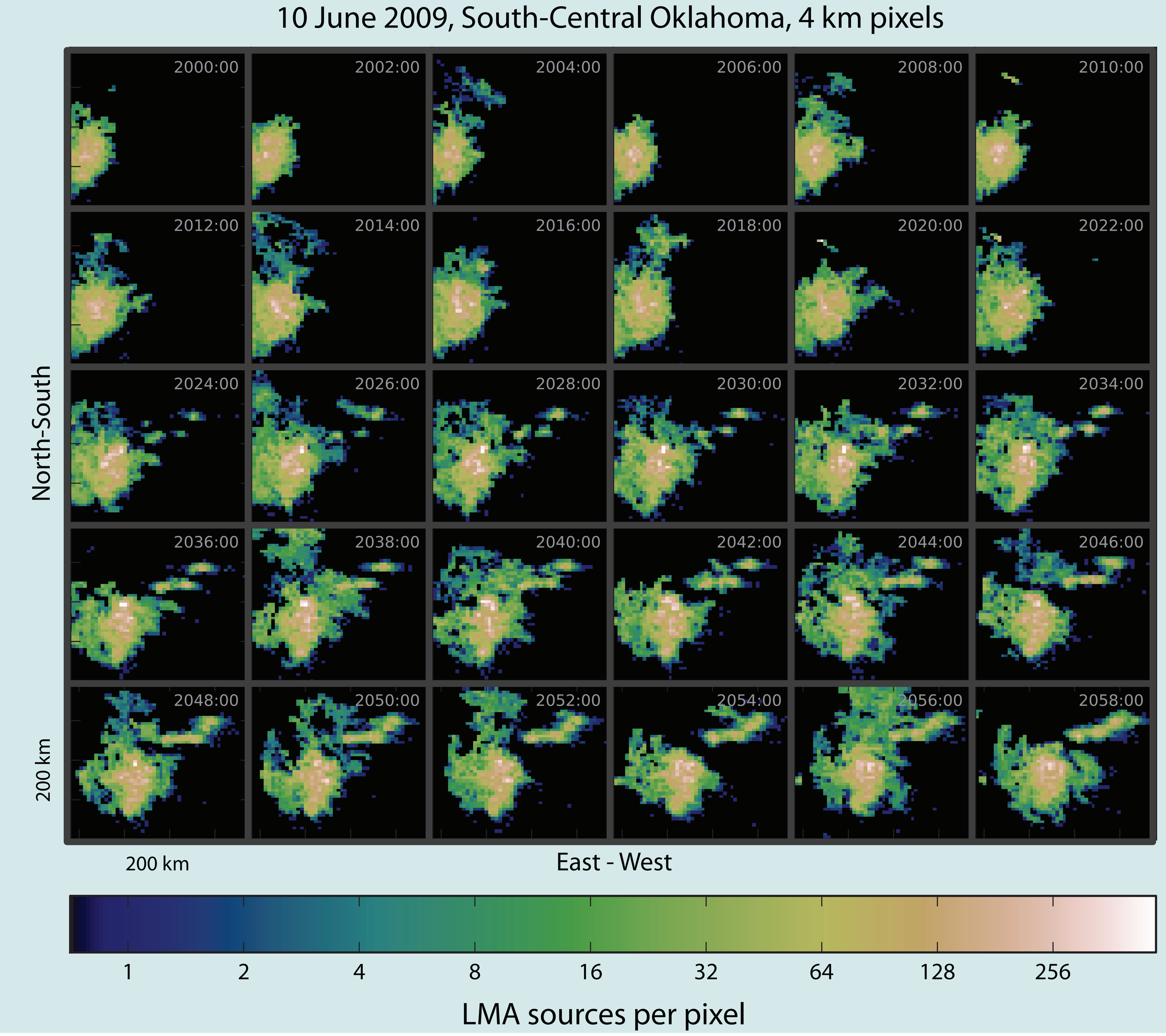
$$\nabla \rho \approx 0$$

i.e., the charge gradients are at least small enough along the direction of channel propagation to prevent a change in charge polarity.

Lots of channels where there are high flash initation rates, but each flash is smaller in extent. A few extensive channels in regions with few flash initiations

Overall lightning hazard for public safety and aviation

10 June 2009, South-Central Oklahoma, 4 km pixels



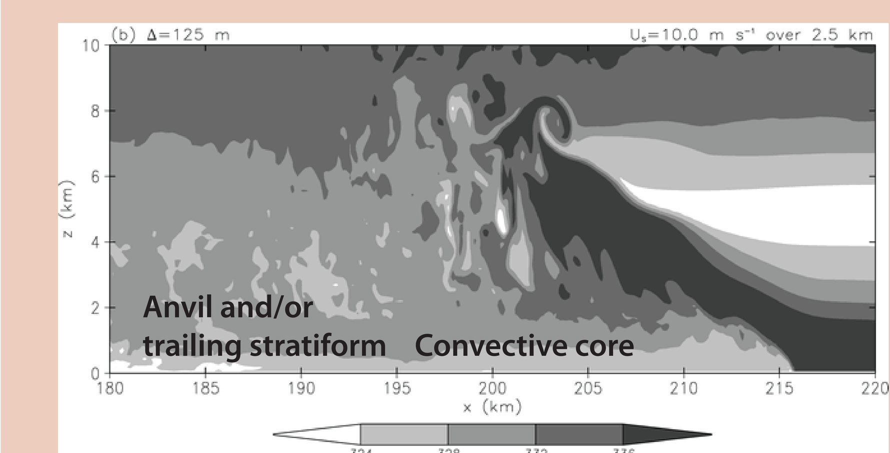
Charge Gradients and Meteorology

Regions that rapidly rebuild gradients will be the locus of the largest number of flash initiations, and will have flashes with small extents

Large gradients may readily be produced in the thunderstorm's deep updraft, where collisions of graupel and crystals in the presence of supercooled water drive thunderstorm charging and lightning.

Maximum density and lots of flash initiations near convective cores where updraft maximizes microphysical charging

Away from convective cores, lighting initation is mostly absent, and charge accumulates more slowly by advective processes.



Potential temperature (K) from a 125 m simulation in Bryan et al. (2003) that reproduces a reasonable turbulent kinetic energy spectrum. For this squall line system, note that the flow in the convective core forms pockets and large gradients in θ_e, a conserved scalar quantity like charge

Future work: Time trends of charge gradients by considering charge conservation for a single species of hydrometeor (Ziegler et al. 1991, Mansell et al. 2005):

$$\partial\rho / \partial t = = -\rho\nabla \cdot v - v \cdot \nabla\rho - \partial(\rho V t)/\partial z + \nabla \cdot (Kd \nabla\rho) + Sp$$

Convergence – Advection – Diff'l Sedimentation + Diffusion + Charging/Lightning

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