Detecting Lightning Jumps using the LMX

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DETECTING JUMP SIGNATURES

A "lightning jump" signifies a sudden and significant increase in the total lightning flash rate within a thunderstorm. This rapid increase is believed to be caused by a strengthening updraft within the storm, leading to an increase in collisions between ice particles and subsequent charge separation.

Is this an accurate definition?

- I would remove the word “flash”

How are jumps detected?

Historically with LMAs where a variable number of located RF events are combined to determine a flash

GLMs have not been nearly as effective in detecting lightning jumps. Nor have long range ground based arrays. WHY?

Neither LMAs or GLMs actually directly detect lightning flashes, however GLMs do better because they detect energetic processes whereas LMAs detect low energy high frequency RF events. For example LMAs are excellent at deteching airplanes as they fly through thunderclouds.

It has been know for some time that severe thunderstorms while having very high lighning rates, produce very few cloud to ground flashes. Almost all the flashes are intracloud.

What is a Lightningn Flash?

A lightning flash is the visible result of a quick electrical discharge in the atmosphere. It happens because opposite electrical charges build up in a thunderstorm cloud or between the cloud and the ground. When air can no longer contain these charges, electricity suddenly discharges, creating a bright flash of light.

How it Happens

- **Charge Separation**: Within a thunderstorm, ice particles and grauple collide, causing a separation of charges. Lighter ice crystals become positively charged and rise to the top of the cloud. Heavier, negatively charged ice particles fall towards the base. This creates areas of positive and negative charge within the cloud.
- **Leader Formation**: As negative charges accumulate at the cloud base, a downward-moving, negatively charged channel, called a stepped leader, extends towards the ground. This leader is made of ionized air and moves in fast steps.
- **Streamer Connection**: When the stepped leader gets close to the ground, the strong negative charge attracts positive charges on the ground and in tall objects. These positive charges form upward-reaching streamers.
- **Return Stroke**: When a leader and streamer connect, a conductive channel is made, allowing a large electrical current to flow. This is the return stroke. It is the brightest and most visible part of the lightning flash.

A lightning flash is the entire discharge. It often has several shorter, individual discharges called strokes. These strokes happen quickly, so the human eye might see the lightning flicker.

There are many lightning processes that never make it to a flash. LMAs are excellent at detecting the processes.

Lightning and Severe Thunderstorms

As a storm intensifies, the updraft grows stronger, both in size and velocity. Consequently, more water (fuel) is ingested and more ice is produced. Hence more electrical energy is produced, resulting in more lightning discharges, but few CGs. Again why?

- What we know
    - Oceanic storms have low flash rates, but the flashes are more energetic. They have weaker updrafts, thus less turbulence. While the charging current is clearly weaker, the low rate of high energy flashes suggests a slow charge build up with greater stored charge at the time of breakdown.
    - For severe thunderstorms, lightning rates tend to be high, but the strokes are weaker suggesting less charge separation and storage, the opposite of oceanic storms.
    - The big difference is updraft velocity and consequently, turbulence.

Thunderstorm Turbulence

Thunderstorms are powerful and unpredictable weather phenomena that can produce severe turbulence, also known as convective turbulence. It is caused by the strong updrafts and downdrafts of air within storm systems.

How thunderstorms create turbulence

- Warm, moist air rises rapidly within the storm, creating powerful updrafts.
- As the warm air rises, it mixes with colder air, triggering chaotic interactions and abrupt shifts in wind speed and direction.
- This creates swirling masses of air known as eddies, resulting in turbulent conditions both inside and around the storm cloud.
- Downdrafts associated with precipitation and cooled air also contribute to the turbulence and can be particularly hazardous near the ground, where microbursts can cause sudden losses of altitude.

Turbulent Eddies

In fluid dynamics, particularly within turbulent flows, an eddy is a swirling or circulatory motion of a fluid element that deviates from the general flow direction.

- Formation: Eddies form when inertial forces within the fluid overcome viscous forces, leading to flow instabilities and swirling motions. They can be observed behind obstacles in a flowing fluid, like rocks in a river.
- Scale: Eddies exist across a wide range of scales within turbulent flows.
    - Large Eddies: These are the largest structures and contain most of the turbulent kinetic energy, responsible for transporting momentum and energy.
    - Intermediate Eddies: These eddies transfer energy from larger to smaller scales.
    - Small Eddies: At the smallest scales, viscous forces dissipate the kinetic energy into heat, converting it from the organized motion of the eddy to thermal energy.
- Energy Cascade: A key concept in turbulence is the energy cascade, where kinetic energy is transferred from large eddies to progressively smaller eddies until it is dissipated by viscosity at the smallest scales (Kolmogorov scales).

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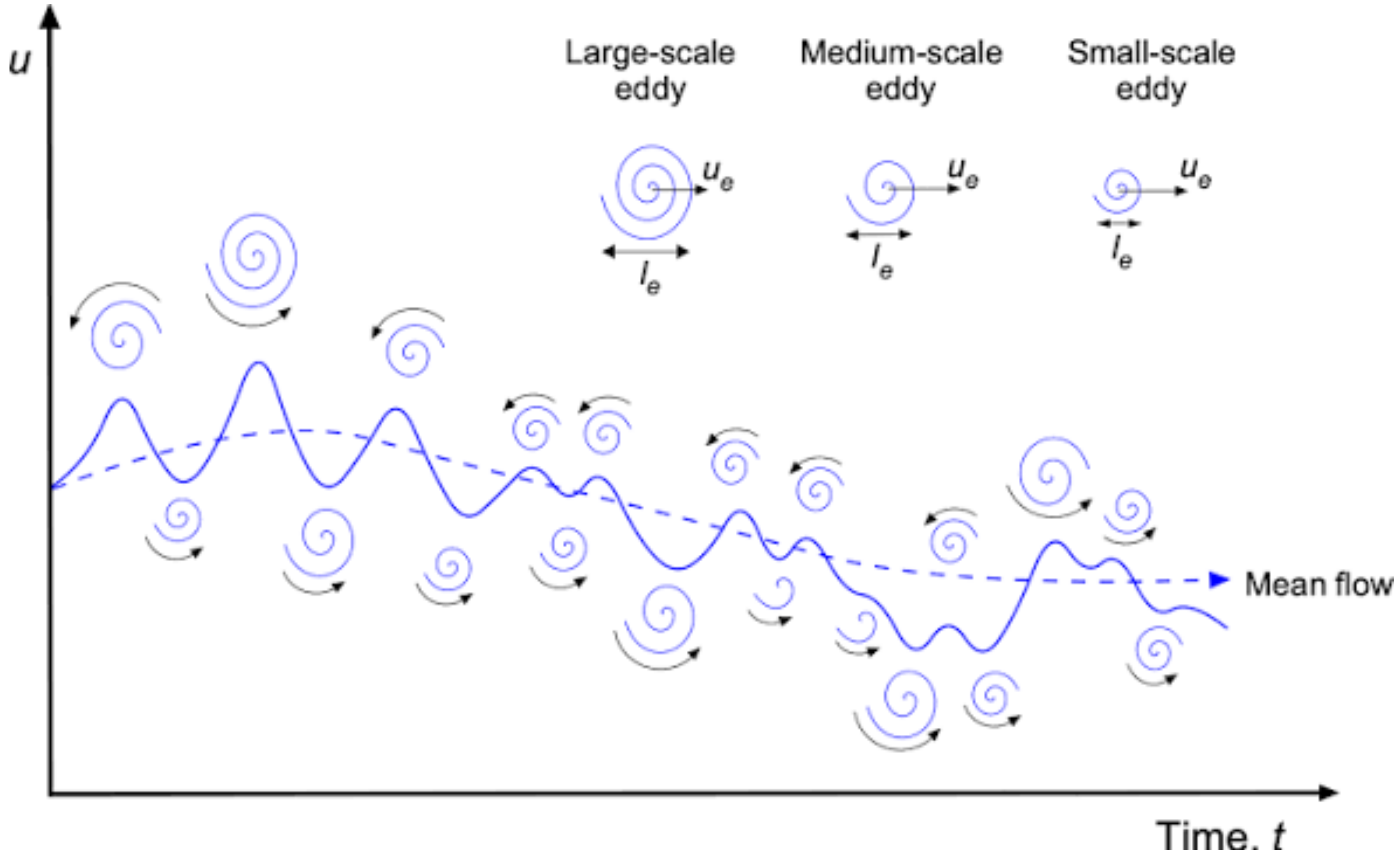


Importance of Turbulence in Thunderstorms

Size of thunderstorm turbulent eddies:

In thunderstorms, air currents move in a complex, turbulent pattern across a wide range of scales.

- Large scales (order of kilometers): At the larger end, eddies can be the size of the storm itself, driven by buoyant updrafts and downdrafts. These large eddies are responsible for the initial energy input into the system.
- Intermediate scales (tens of meters to a few kilometers): Eddies in this range are crucial for processes like entrainment, where dry environmental air mixes with the moist air inside the storm. Some studies indicate the presence of eddies greater than 500 m in size at mid-storm levels.
- Smallest scales (millimeters): At the smallest scales, turbulence influences microphysical processes like collision, coalescence, and collection of hydrometeors (water droplets and ice crystals). This is where energy is finally dissipated into heat by viscosity.

This wide range of eddy sizes highlights the complex and multi-faceted nature of turbulence within thunderstorms, making it challenging to fully characterize through observations and modeling alone.

Can Turbulent Eddies Concentrate Hydrometeors?

- Microphysics equipped aircraft making horizontal passes through thunderclouds show order of magnitude variance in graupel concentrations over 100 meter distances (personal communication with Jim Dye).

- Thuderstorm eddies (TE) rotate as they flow from the updraft and cascade to smaller and smaller sizes. Because they rotate, they have angular momentum. As they cascade to smaller sizes, conservation of angular momentum causes them to rotate faster, greater centrifugal forces.

- The rotation and shrinkage causes smaller ice crystals and droplets to be preferentially discarded (centrifuge effect), thus concentrating the graupel and associated negative charge.

Rough Estimates of Resulting Elecric Field Strength

- For a strong storm, the charging current might be 5 amperes. Assume an updraft of 20 m/s and 5 km across. In this case, the charge density flowing in the updraft would be on the order of 10^{-8} c/m^3/s, which seems reasonable given that measurements elsewhere in clouds suggest charge densities on the order of 10^{-9} c/m^3.

- A Kilometer eddie might contain a total charge of 10 c, with a net charge of say a few coulombs. As the Eddie cascades to say 50m, assuming the positive charged small hydrometeors have been discarded, leaving mainly grauple and a net charge density of 10^{-6} c/m^3 or about 10^{-1} c. Resulting in a electric field of about 500 kV/m well on the way to breakdown.

- Storms in the process of going severe have high charging rates and turbulence resulting in small pockets of concentrated charge.
  - These pockets result in numerous weak discharges because breakdown occurs prior to large quantities of charge (10s of coulomb) being stored in the normal positive and negative regions.

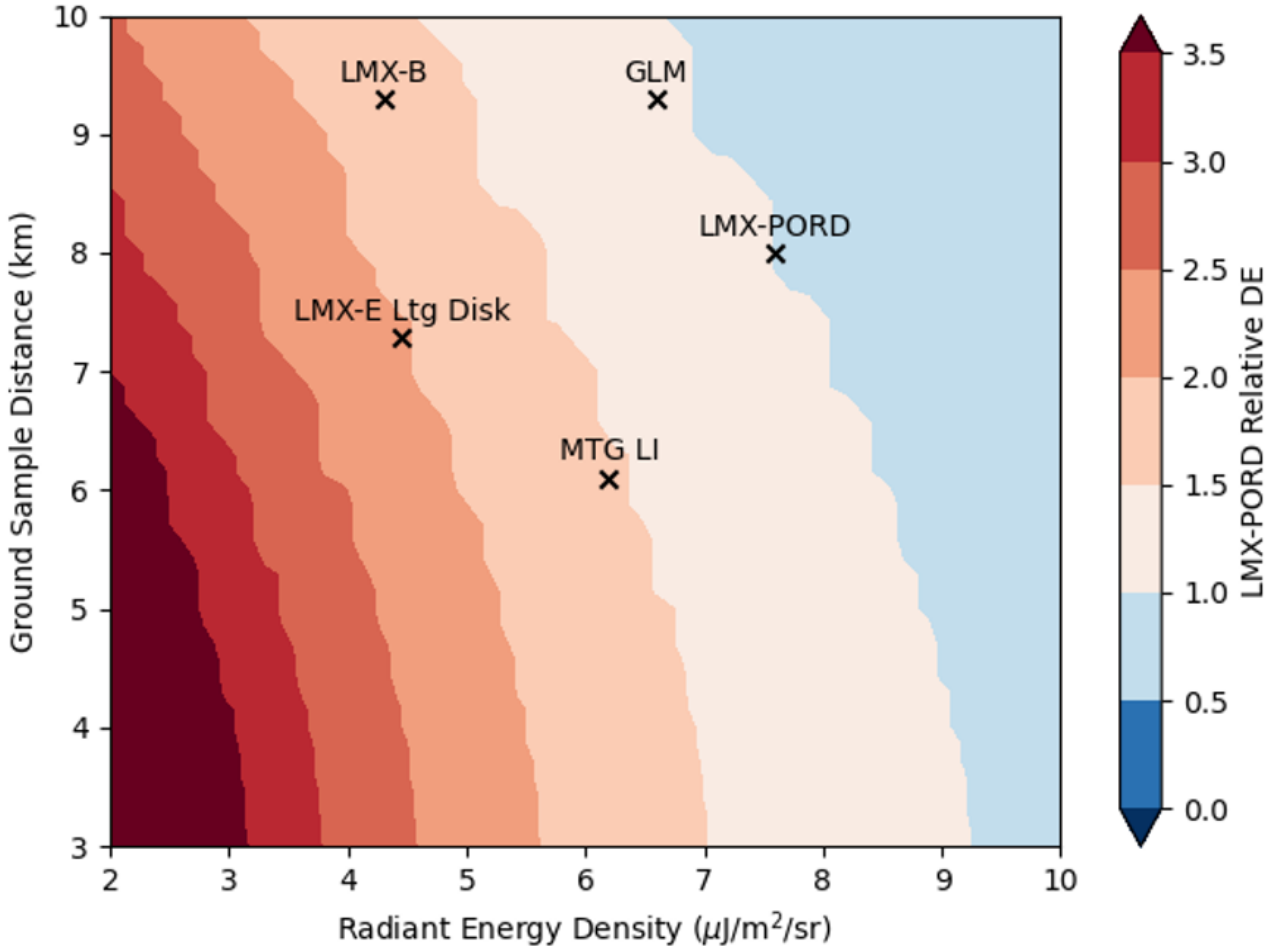
Consequences for Lightning Jump Detection

- Because of the large number of “premature lightning discharges”, many are weak, moving small quantities of charge. Without a stroke connecting large charge regions, they fail to meet the definition of a lightning flash. Few actual strokes are produced during these high event rate periods. It is stroke that that is mainly detected by the GLMs. Thus, GLMs have not been great in detecting Jumps.
- For the monitoring of developing severe storms it might be best to not concentrate on detecting flashes, but to optimize for the detection weak discharges.
    - For LMAs, do not group x number of detections and call it a flash. Rather, perform a running average of detections within a cell and look for trends. Increasing event rates should be a good indication of a jump. Counting events directly should result in earlier jump determination.
        - If this approach has not been tested, it should be.

Optimizing LMX for Lightning Jump Detetection

- LMX has multiple advantages over GLMs (thanks to technological and research advances)
  - Ex: CMOS detection array, sophisticated onboard processing, smaller footprint, etc
    - In addition to enhanced sensitivity and lower noise, leading to lower threshold settings, the LMX sets thresholds for each pixel individually and transmits the full background for each pixel. This advanced capability should have a profound impact for LJ detection.
    - It also has a feature for allowing lowered thresholds for the brightest clouds.

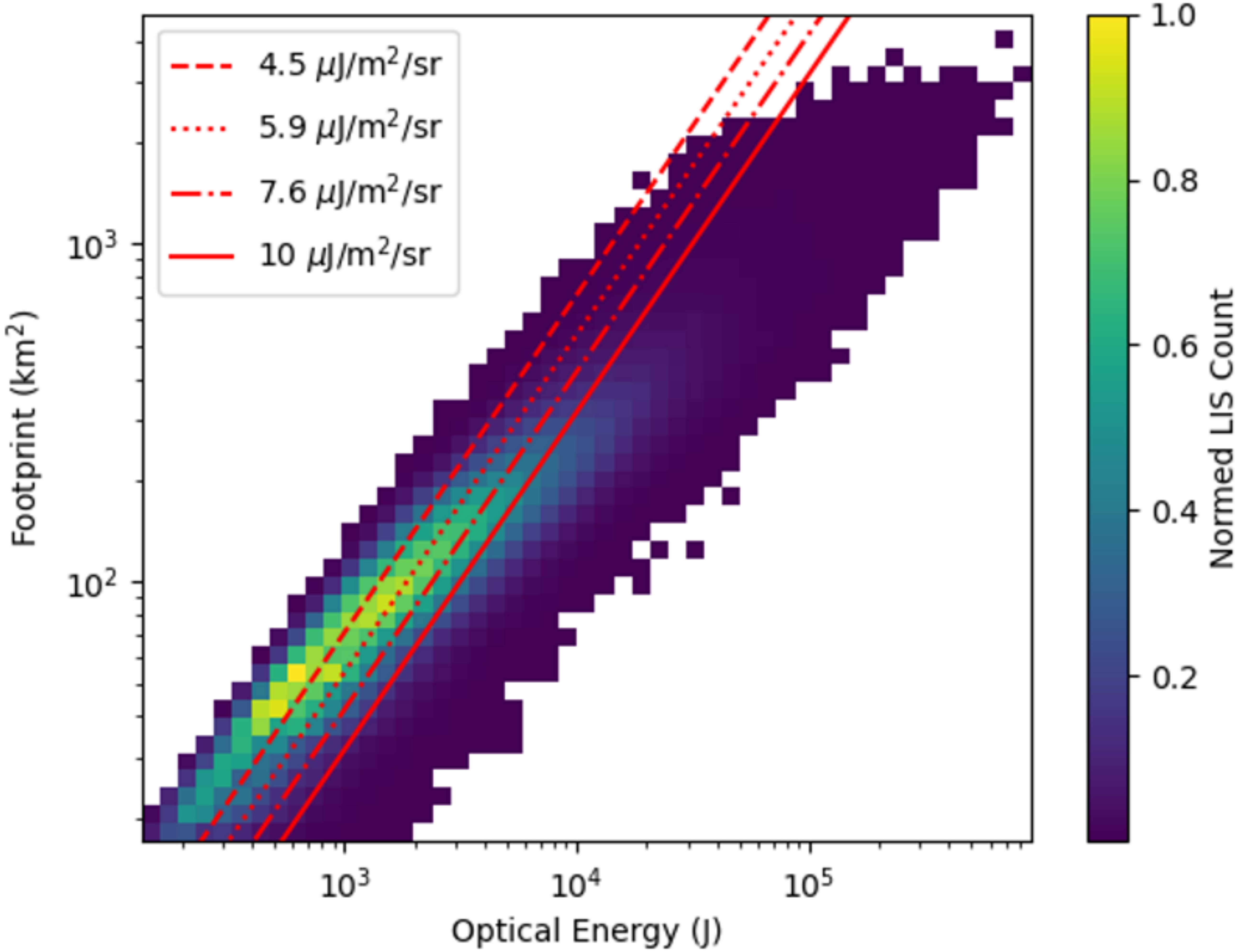
Lightning phenomenology



LMX detects over twice as much lightning pluses as GLM

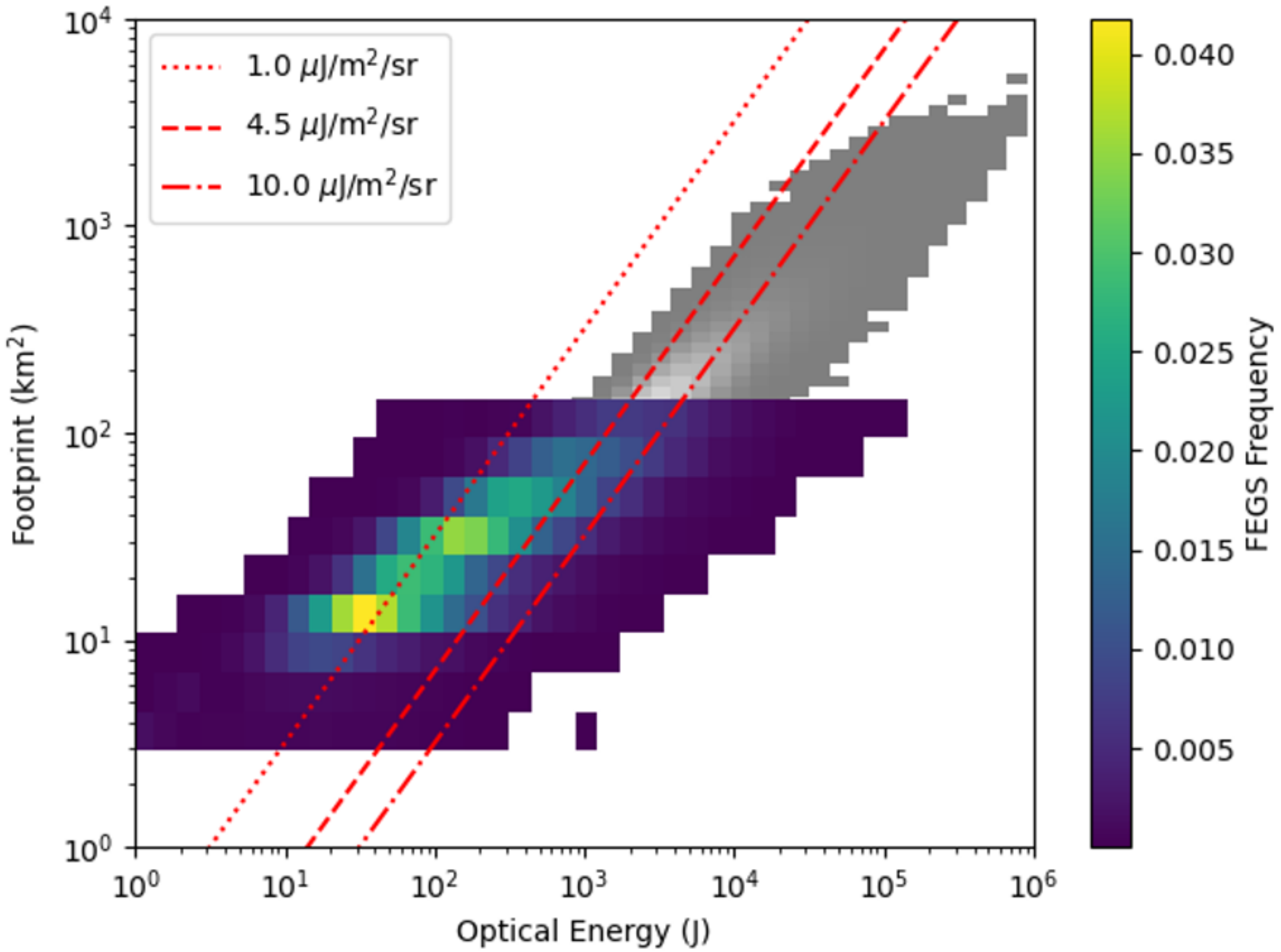
Lightning phenomenology – optical pulses

- **FEGS, LIS and GLM agree: smaller pulses have a lower radiant energy density than larger pulses.**
- Or, smaller pulses are *even dimmer* than you might expect just from their smaller size.
- While decreasing pixel size helps with detection, the smaller and dimmer pulses also require an improvement in sensitivity.



sLightning phenomenology – optical pulses

75% of FEGS pulses have a radiant energy density less than 4.5 μJ/m²/sr



Smaller pulses have lower radiant energy density

Optimizing LMX for Lightning Jump Detection (cont.)

- In addition to the significant benefits associated with much lower thresholds, leading to detection of much weaker lightning events, LJ detection could benefit from an additional ground processing algorithm that does not require grouping.
    - In a parallel processing channel, do not discriminate between lightning events and false events. Rather, use the background intensity to estimate the expected shot noise events which you then subtract from the total events detected in a given pixel during a given frame.
        - Shot noise is totally gaussian, thus the number of events above a set threshold for a given background luminosity is easily calculated. While the number of background events may vary frame to frame, over time, the gaussian will prevail.
    - The processing consists of subtracting on a pixel basis, the number of expected background events for the measured events.

Optimizing LMX for Lightning Jump Detection (cont.)

- While this approach will undoubtably remove some lightning events and pass some false events, it does not matter for we are searching for trends.
    - For example, even if our background estimate is slightly off, it does not matter. This would result in a content offset and we are looking for trends rather than absolutes.
- Performing a running average of the event rates within a given cell, should be a sensitive means for detecting increasing rates associated with lightning jumps.
- Detecting lightning jumps from geostationary orbit would greatly enhance the value of the LMXs and would provide, for the first time, improved severe weather detection over all the Americas.