Eack, K. B., Beasley, W. H., Rust, W. D., Marshall, T. C., & Stolzenburg, M. (1996). Initial results from simultaneous observation of X-rays and electric fields in a thunderstorm. *Journal of Geophysical Research: Atmospheres*, *101*(D23), 29637-29640.

Eack et al. formulate their paper on the correlation of X-rays with the Electric Field of a storm.

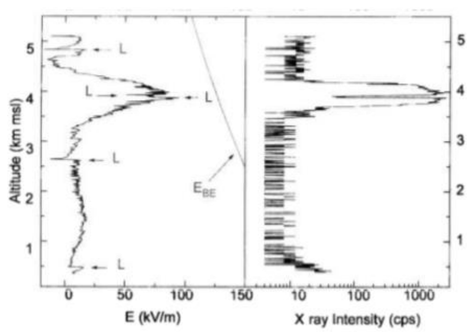


Figure 2. X ray and electric field sounding. The left panel shows the electric field measured at the balloon with the breakeven field strength (E_{BE}) also plotted. Electric field transients due to lightning are marked by an "L." The right panel shows X ray intensity for X rays between 30 and 120 keV in energy.

Observing this chart, Eack et al. have confirmed – though through very few, or only one test – that X-ray intensity shifts in the same manner that Electric Field does in a storm. That is, if Electric Field increases, as does X-Ray intensity. Their results are relatively inconclusive, but tell an interesting story about what a storm is truly made of; it is not simply runaway electrons, but gamma and X-rays that we observe so much less than the former.

In telling the story of the thunderstorm, I wish to portray as much of the storm as possible. This includes the mysteries, the smaller pieces that transpire as a result of electromagnetic phenomena. The correlation between X-ray intensity an Electric Field is something that strikes as a definite phenomenon of the storm. This paper also has a great description of the 'runaway electron' formation of lightning, with the quote, 'they gain more energy from the electric field than they lose from interactions with the air molecules'. This encapsulates the initial thought of a storm as a phenomenon and begins my paper's description of E&M in storms with accurate, powerful facts.

Krider, E. P. (1986). Physics of lightning. *The Earth's electrical environment, National Academic Press. Washington DC*, 30-39.

Krider, in his addition in the book 'The Earth's electrical environment', seeks to describe lightning and its mystery, beginning with the idea of a 'return stroke' within lightning. As lightning strikes, it creates a connection with what it strikes and with the cloud it forms from, allowing a two-way interaction. He also shortly describes the time-derivative of current to explore this, plus uses this equation for electric field:

$$E_{\mathrm{RAD}}(t) = -\frac{\mu_0 v}{2\pi D} I(t - D/c),$$

This represents electric field of radiation field, which relates to the current of the channel formed. As well, he describes how lightning can be artificially triggered along-side natural occurrence. This allows insight on what outside influences may drive a storm to pose a threat.

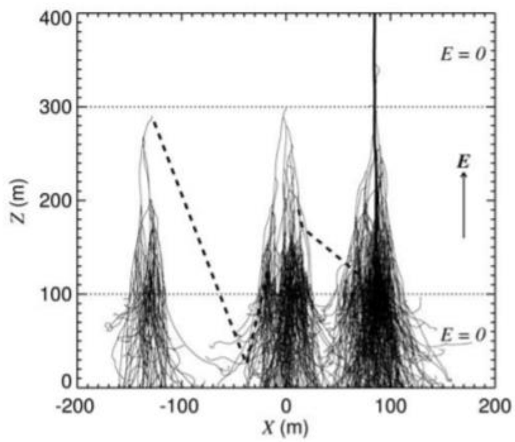
This article adds a lot of phenomenological insight to lightning in particular – as a key part of a storm, lightning is close to being explained in full with Krider's work. My paper seeks to highlight the electromagnetic causes and effects of storms, lightning included. Krider does a wonderful job highlighting mathematical properties of lightning while also bringing conceptual and theoretical reasoning to support his research. This article will be useful when describing lightning *as it strikes* rather than how it forms, unlike other articles have done for the latter.

Petrov, N. I., & Petrova, G. N. (1999). *Physical mechanisms for the development of lightning discharges between a thundercloud and the ionosphere*. Technical Physics, 44(4), 472-475.

Petrov and Petrova write in their article a short, descriptive context of the effects of altitude and pressure on the formation of lightning in storms. Through several figures and equations, the phenomena is described using intensity, pressure, electric field, and charge, with correlations between them and several references to support the values or concepts they did not personally conceive. Overall, their paper successfully points out the strong correlation between amplitude of cloud structure and air pressure to the formation of lightning, plus the type or vague expected trajectory of lightning produced.

This paper provides a flourishing start to describing the phenomena of lightning, electrically. Petrov and Petrova describe an approximation of the cloud being an electric dipole charge distribution to model the cloud 'predominantly positively charged' at the top and negatively at the bottom. As well, among many other elements that contribute to the formation of lightning, there is described a 'cellular type structure' of clouds, where parts of the clouds can be denser with excess charge, increasing the likeliness of lightning formation. Added with several threshold values for possible lightning formation, this article presents a foundation for the intent of describing, fully, the occurrence of lightning.

Dwyer, J. R. (2003). *A fundamental limit on electric fields in air.* Geophysical Research Letters, 30(20).



With a strong focus on the nuclear and radiative aspects of storms, Dwyer presents a paper on the effect of 'feedback' on the Electric Field threshold for the production of lightning. Excluding atmospheric pressure and the Earth's own field, it is described that certain feedbacks can induce the breakdown of Electric Fields in air, causing somewhat of an 'electron avalanche' that sparks lightning. In the end, the goal of the paper is to present a new fundamental upper limit on how strong the Electric Field can be due to these conditions.

In relation to my research, I wish to incorporate the assumptions made in this paper; ignoring the Earth's magnetic field, plus *starting* with a uniform electric field before an intruding event causing the actual event process. With the additional information on possible causes of lightning – besides the known limit of Electric Field being reached – this adds another level to storm creation. It pulls electricity and magnetism and collides it with the nuclear sciences, which is still explainable and far more interesting than before. It also provides some numerical values to 'stable' or 'unstable' Electric Fields, much needed for a more conceptually driven research paper. As well, the Monte Carlo method is used to evaluate lightning in this paper: with this inherent connection to my own paper, I intend to utilize the graph provided above to compare between other sources using the MC method and lightning together.

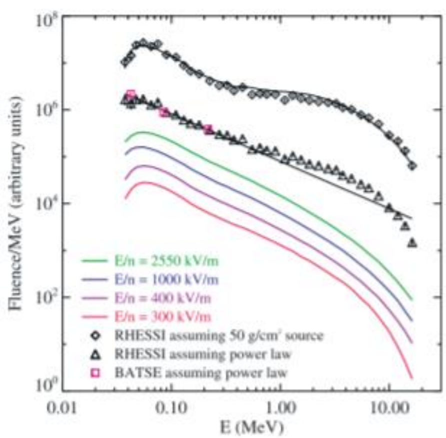
Dwyer, J. R., & Uman, M. A. (2014). The physics of lightning. *Physics Reports*, *534*(4), 147-241.

Dwyer reappears with an analysis of the *strike* of lightning – rather than focusing on nuclear connections to lightning, there is instead a focus of what happens during its formation and recession. Lightning forms like a ladder, while expressing movement of charge to create a current. This step-wise formation of lightning can vary depending on if forming ground-up or cloud-down. With many types of lightning formation, it is no wonder that '*The physics of lightning*' exists as the broad title that it is.

This paper provides an interesting analysis of lightning, as one of the only papers gathered to mention the current in lightning. I incorporate this aspect as a hypothetical question: can the Monte Carlo method of simulation apply to the concepts presented in Dwyer's paper? The models used in his paper are entirely computational-free, despite his other works. In terms of the MC method, though, it turns out to be something too random, as the path that lightning takes is far too random to bear patterning.

Dwyer, J. R., & Smith, D. M. (2005). A comparison between Monte Carlo simulations of runaway breakdown and terrestrial gamma-ray flash observations. *Geophysical Research Letters*, *32*(22).

In Dwyer's third appearance, we this time explore Dwyer & Smith's work comparing the breakdown of Electric Field with gamma rays. It has already been seen that the threshold of Electric Field is relatively flexible – however, it should also be noted that the breakdown of Electric Field is an event on its own, directly tied to bursts of gamma rays, as evidenced by this paper. The Monte Carlo simulation, here, is used to compare curves of runaway events in the clouds with the activity of X-Ray emission spectra:

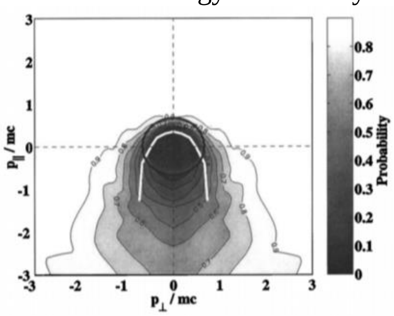


In my paper, I use this graph as a piece of proof that Monte Carlo simulation can be used in a more versatile way – not simply with random compilations of random data, but with several lines and trends of different data *sets*. One can see the obvious trend in the data above, described in more detail in my paper. This, with the other papers using MC methods, is a prime 'evidence' factor as to the applicability of MC methods *overall* to help shape lightning's story.

Lehtinen, N. G., Bell, T. F., & Inan, U. S. (1999). Monte Carlo simulation of runaway MeV electron breakdown with application to red sprites and terrestrial gamma ray flashes. *Journal of Geophysical Research: Space Physics*, *104*(A11), 24699-24712.

Lehtinen et al. here act as a ‘forefather’ figure in this paper: we have seen two papers from Dwyer utilizing the Monte Carlo method to analyze lightning, where Lehtinen is credited in the workload of having the *starting model* for MC’s usage in Dwyer’s analysis. This specific paper has a wonderful graph:

This graph above plots momentum/energy of runaway electrons with the *probability* that these



electrons will cause an avalanche. This ‘avalanche’ was previously described as a runaway electron tipping the energy and Electric Field of the cloud like a landslide, creating the beginning of lightning formation. This graph signifies the actual relationship that the start has – the more energy that particle has, the more likely it is that that particle *causes the entire strike*.

As incredible as that phenomenon is, we mostly use the graph as another Monte Carlo example of versatility. Now, instead of peering at Electric Field again, we see another side to lightning: the *statistical* side. This is quite unique, despite the outpour of mathematics elsewhere in Lehtinen’s work which is what we expect from physical explanations of lightning. No – here, we again focus on the MC method, and revel in its different forms.