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Fractal Modeling of Cloud-to-Ground Lightning

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Outline

1. Introduction
2. Tripole Model of the Thundercloud
3. Fractal Model of the Discharge Trees
4. Simulation Results and Comparisons with Actual Discharges
5. Conclusions

Outline

Brief Lightning Model History

- Early work in lightning research
  - *Franklin* [1774]
  - *Schonland et al.* [1930s]
  - *Kasemir* [1960]
- Fractal models
  - *Niemeyer et al.* [1984]
  - *Petrov and Petrova* [1993]
  - *Riousset et al.* [2006]

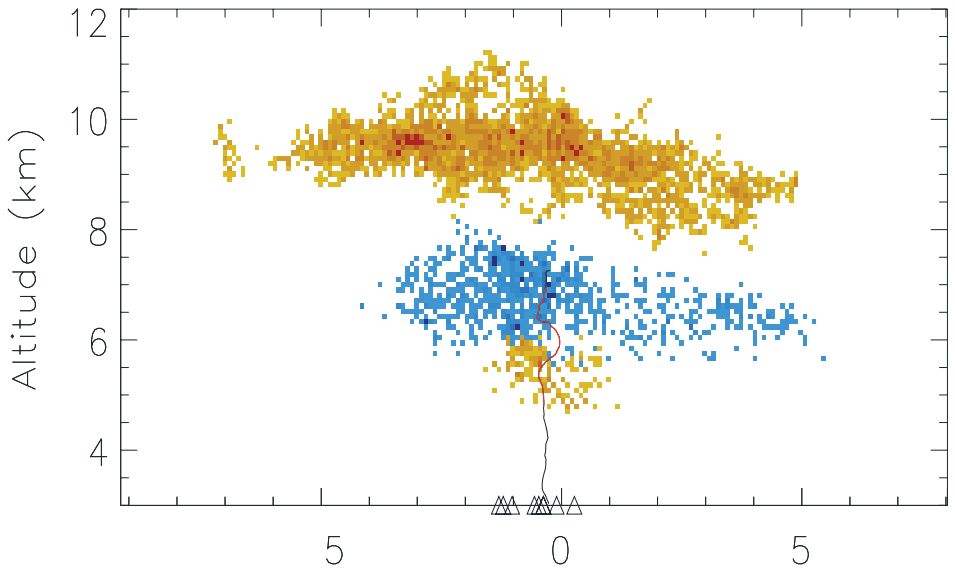
Objectives

Lightning over Albuquerque, NM

[*http://www.macro-photo.org/photo-gallery/nature-images/*]

- Investigate cloud charge configurations leading to positive and negative cloud-to-ground lightning
- Apply *Riousset et al.*'s [2006] three-dimensional fractal model to cloud-to-ground discharges

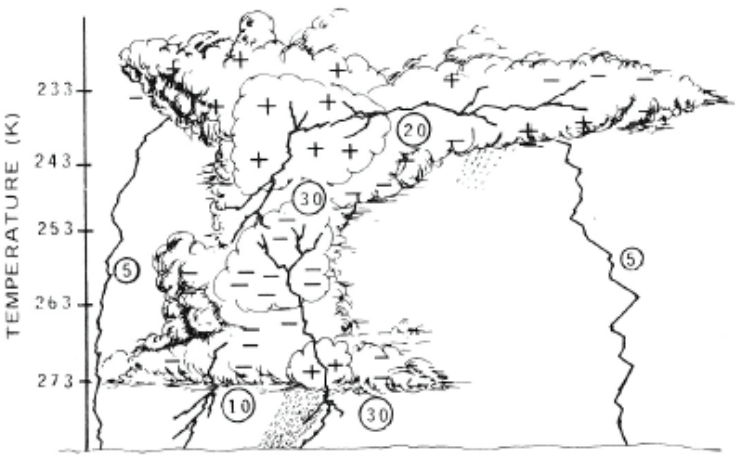
Outline



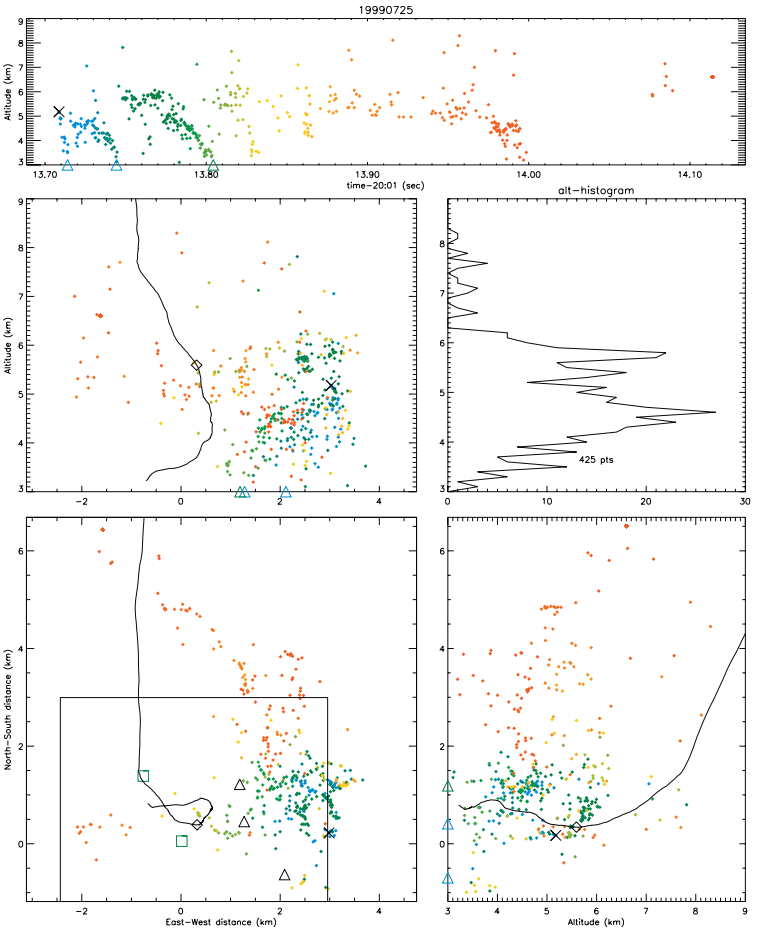
Inferred electric structure of a New Mexico thundercloud [*Krehbiel et al.*, 2004; *Marshall et al.*, 2005]

- Three main charge layers
- Possible occurrence of different types of lightning discharges from the same cloud charge configuration
- Non-uniform charge densities
- Gaussian approximation vs. uniform disk of charge

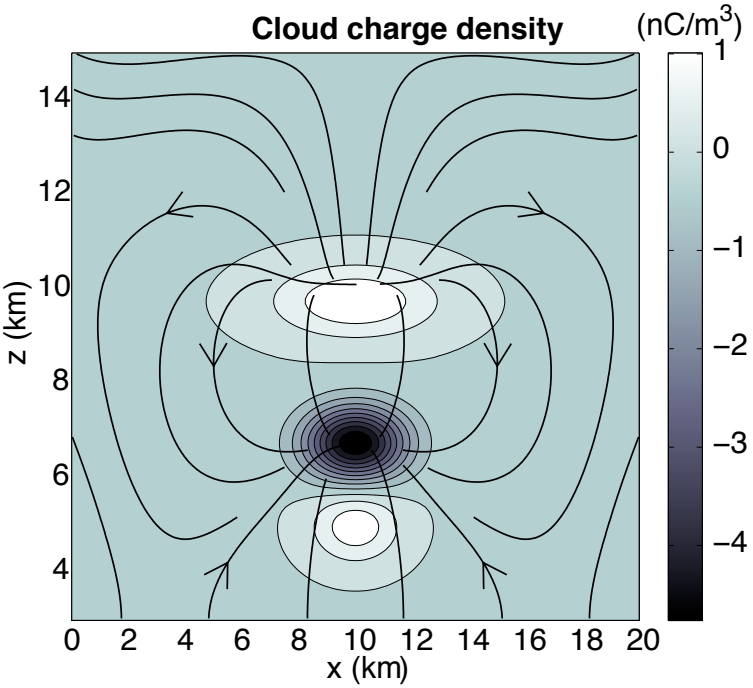
Thundercloud Structure



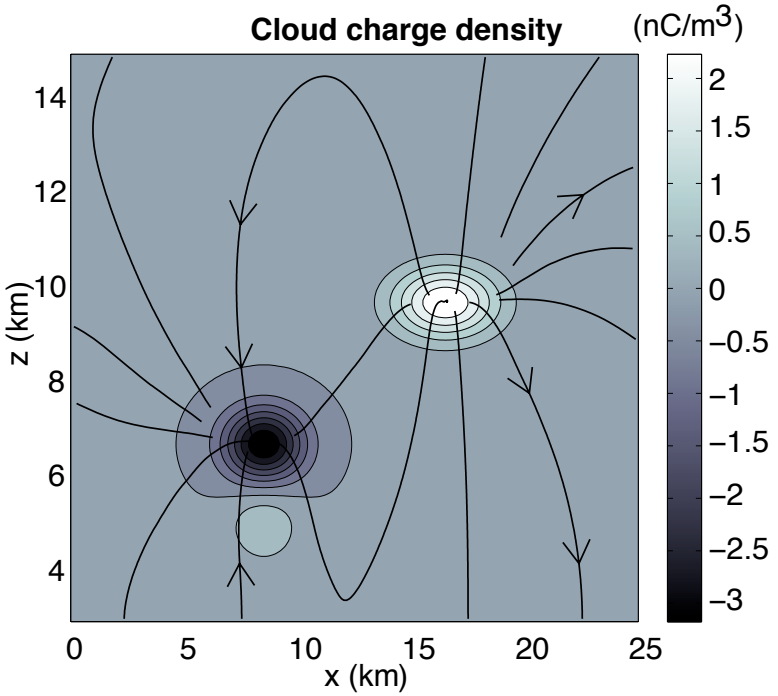
Typical thundercloud charge structure and lightning patterns [*Jursa*, 1985, p. 20-21]



Representative example of a negative cloud-to-ground discharge measured by LMA [*Coleman et al.*, 2003]



Model thundercloud structure leading to negative cloud-to-ground and intracloud discharges



Model thundercloud structure leading to positive cloud-to-ground and negative cloud-to-ground discharges

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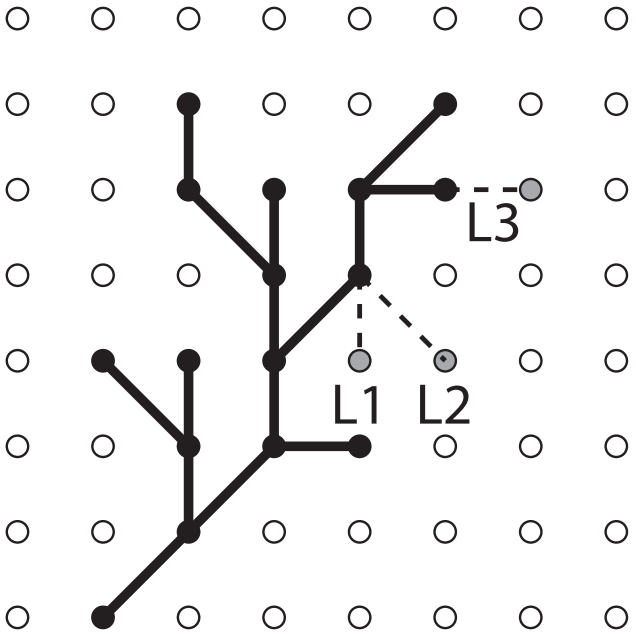

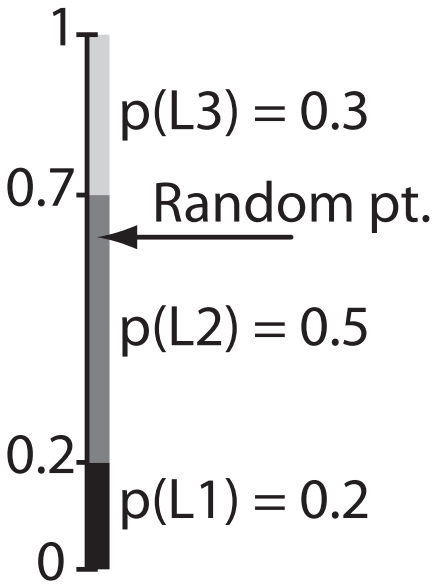

- List candidate links
- Select and add a link using [e.g., *Femia et al.*, 1993]:

$$p_i = \frac{|E_i - E_{th}^{\pm}|^{\eta}}{\Sigma_i |E_i - E_{th}^{\pm}|^{\eta}}$$

- Update channel potential to ensure neutrality
- Update boundary conditions
- Proceed to next step

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4. Simulation Results and Comparisons with Actual Discharges
   (a) Model of Negative Cloud-to-Ground Discharge
   (b) Model of Positive Cloud-to-Ground Discharge
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3-D Model Discharge: Negative Cloud-to-Ground

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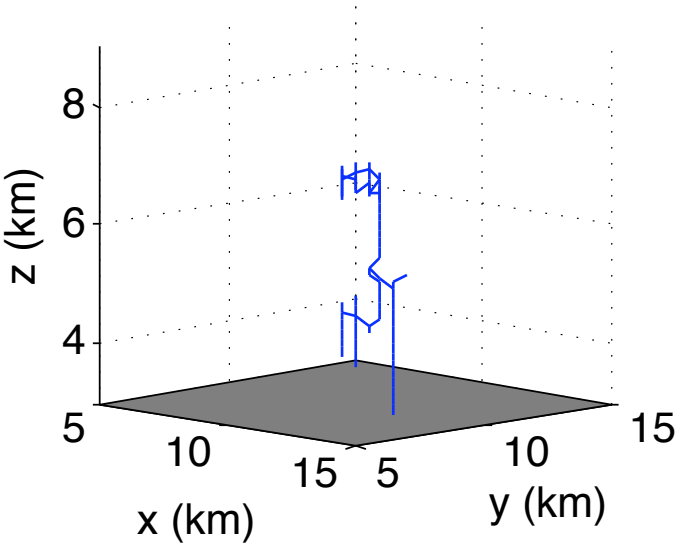
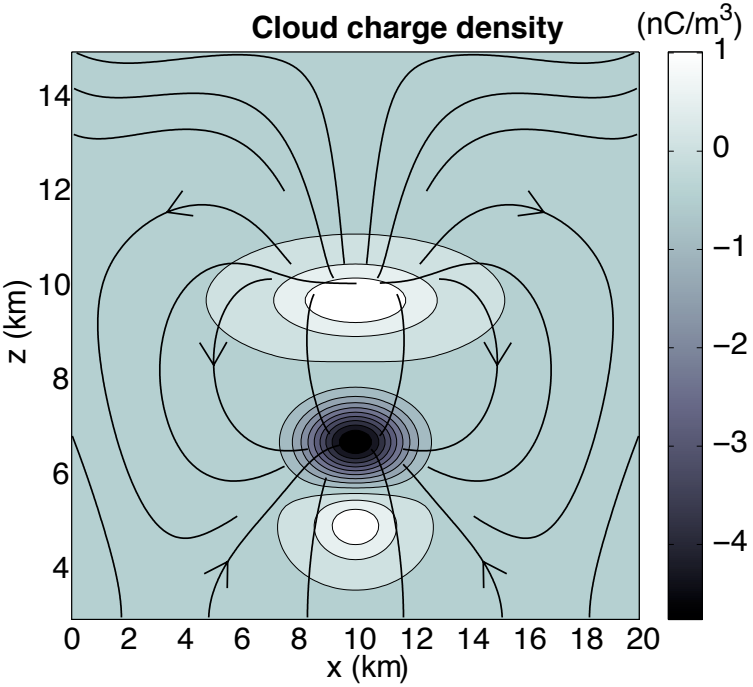
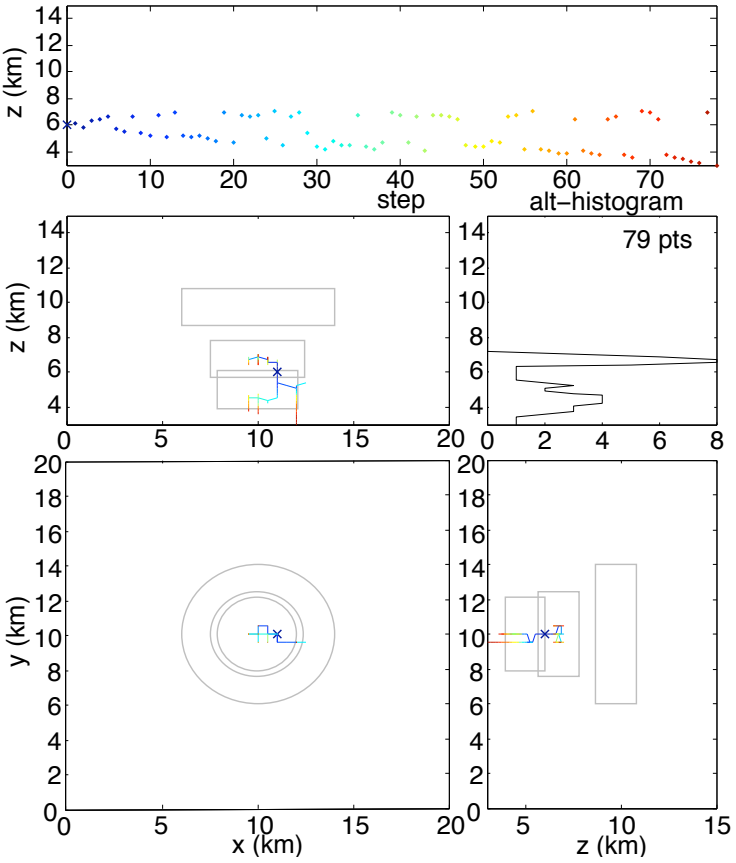


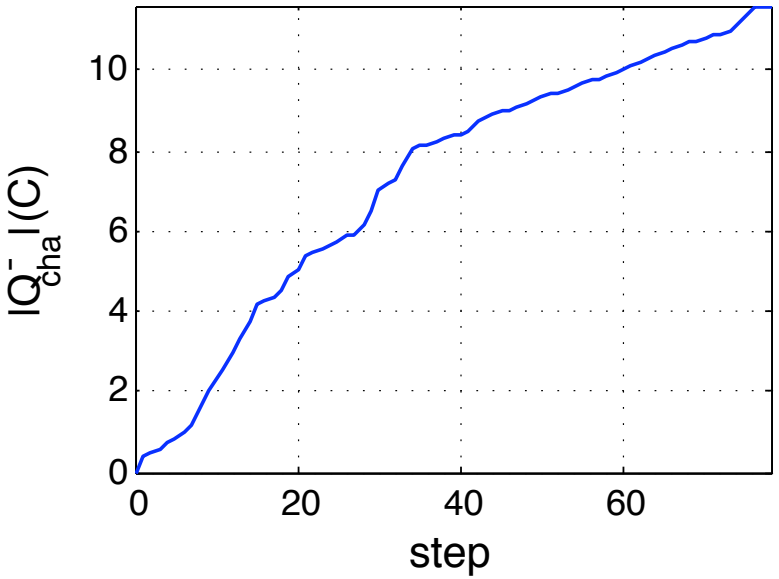
(lightning.avi)

Slow Normal Fast Pause/Resume

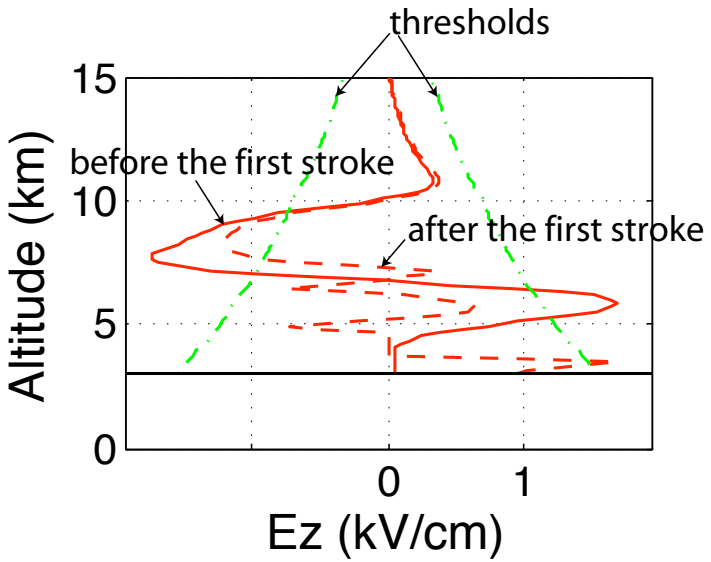


Layer	x_Q (km)	y_Q (km)	z_Q (km)	Q (C)
LP	10.0	10.0	5.00	13.0
N	10.0	10.0	6.75	−60.0
P	10.0	10.0	9.75	40.0





- Model charge transfer: $\sim\pm 11.6$ C
- Measured charge transfer: 1.1–24 C [*Rakov and Uman*, 2003, p. 146]
- Model average linear density: $\rho^l_{cha} = \frac{Q^+_{cha}+|Q^-_{cha}|}{L} \simeq 1.35$ mC/m
- Measured average linear charge density: 0.7–8.7 mC/m [*Rakov and Uman*, 2003, p. 327]



- Before the first contact to ground: threshold exceeded by ∼80% for intracloud initiation and by ∼45% for cloud-to-ground initiation
- After the first contact to ground: net field reduction of ∼65%

Model Positive Cloud-to-Ground Discharge

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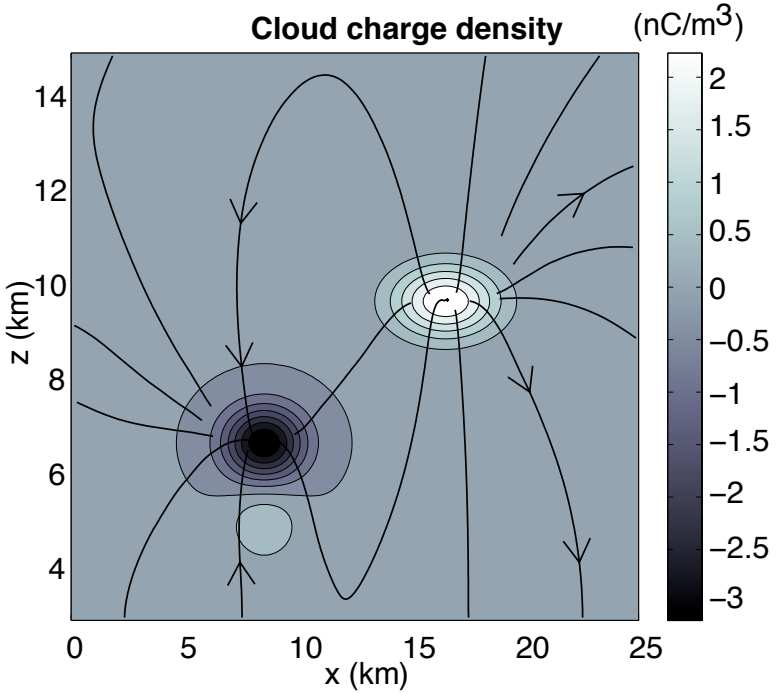
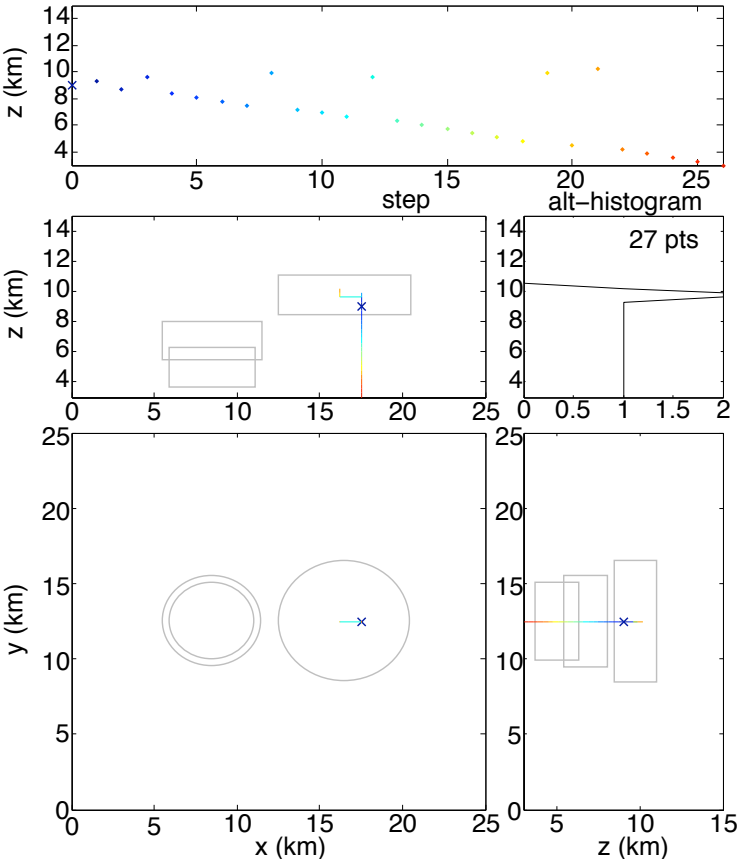
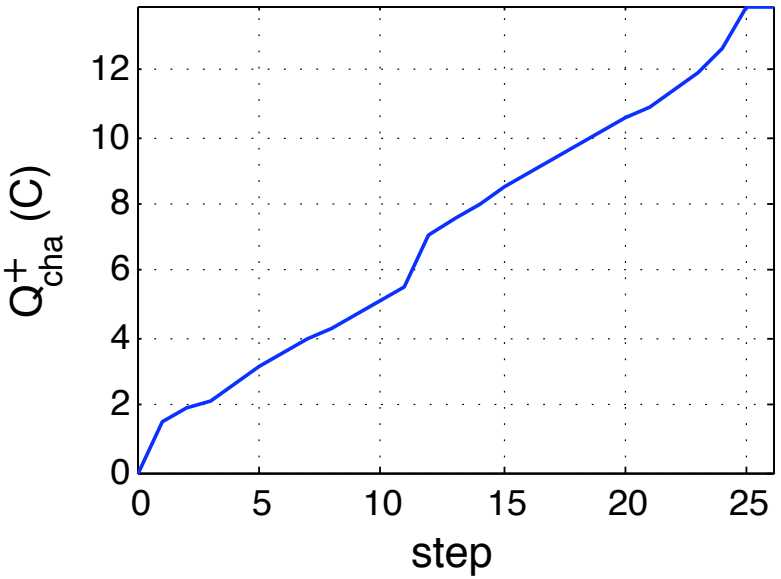


Layer	x_Q (km)	y_Q (km)	z_Q (km)	Q (C)
LP	4.5	12.5	5.00	8.0
N	4.5	12.5	6.75	−40.0
P	20.5	12.5	9.75	60.0





- Model charge transfer: $\sim\pm 13.2$ C
- Measured charge transfer: 20 C–80 C [*Rakov and Uman*, 2003, p. 215]
- Model average linear density: $\rho^l_{cha} = \frac{Q^+_{cha}+|Q^-_{cha}|}{L} \simeq 3.18$ mC/m
- Measured average linear charge density: $\sim$1 mC/m [*Helsdon et al.*, 1992]

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This work makes several contributions to the fields of atmospheric electricity and gas discharge modeling, which can be summarized as follows:

- The ability of the lightning model described in [*Riousset et al.*, 2006] to simulate both negative and positive cloud-to-ground discharges has been demonstrated by comparisons of simulation results to LMA data and other relevant data available in the referred literature.
- The initiation of cloud-to-ground discharges has been shown to be easier with configurations involving layers of non-uniform Gaussian charge density rather than with configurations employing disks of uniform charge density for the same amount of net charges in each layer.

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Thank You For Your Attention
Questions?

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