

Introducing Time & Current in the Fractal Model of Electrical Discharges (FraMED)

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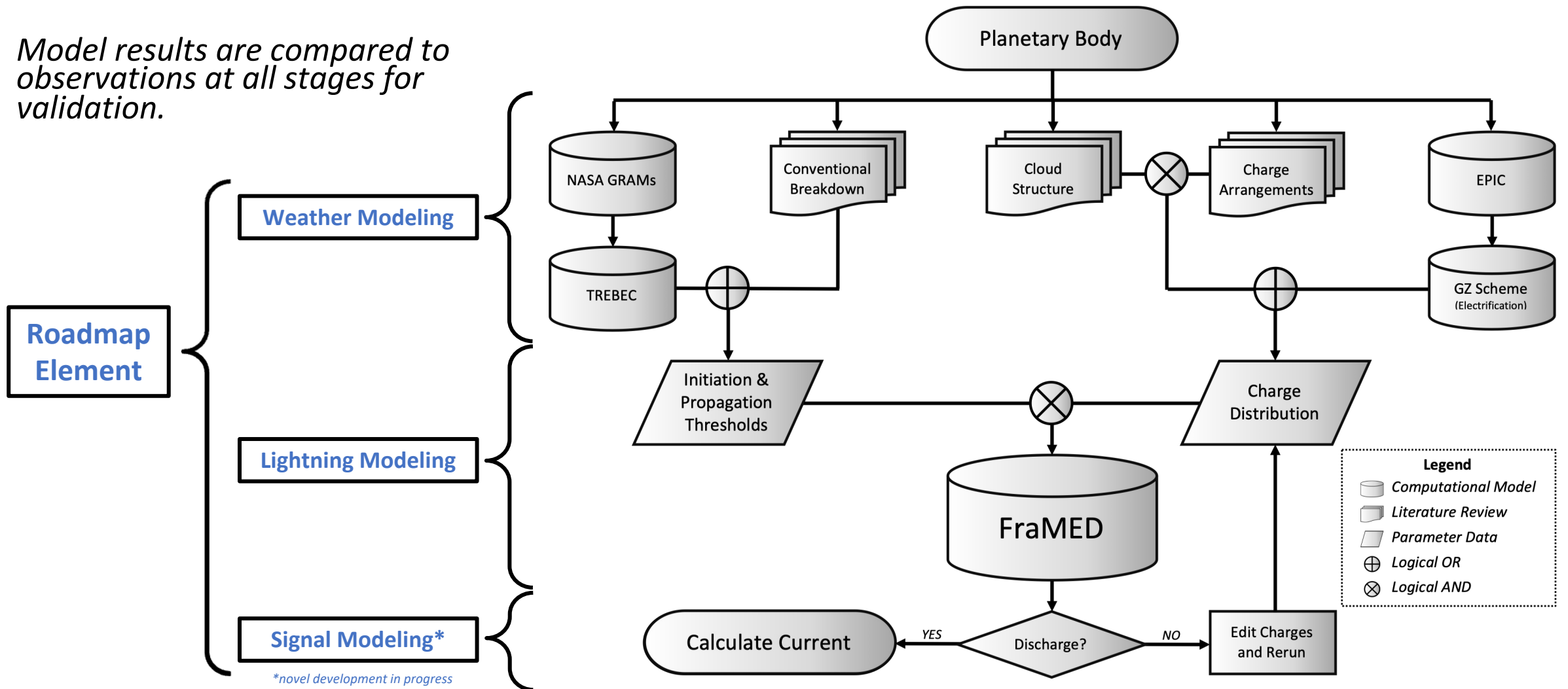
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Overview

1. **Introduction** → *model interoperability, purpose*
2. Methods
3. Results
4. Discussion
5. Conclusions

Introduction: Our Modeling Approach

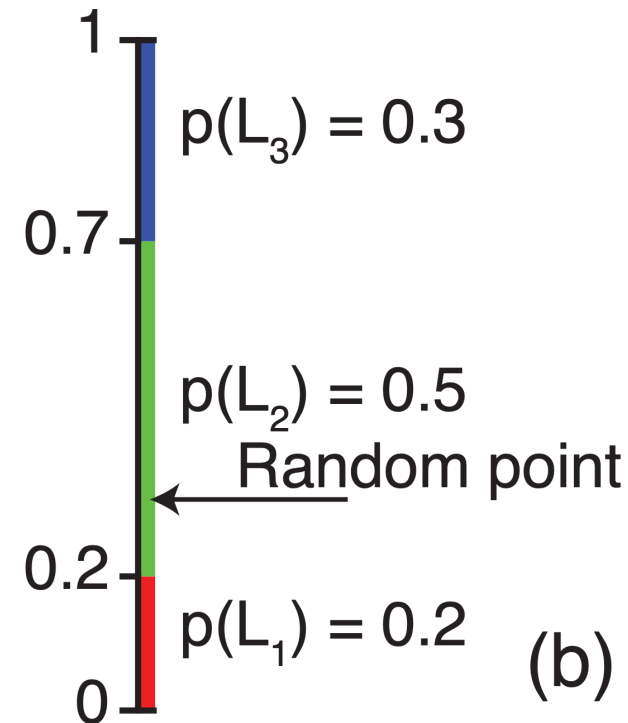
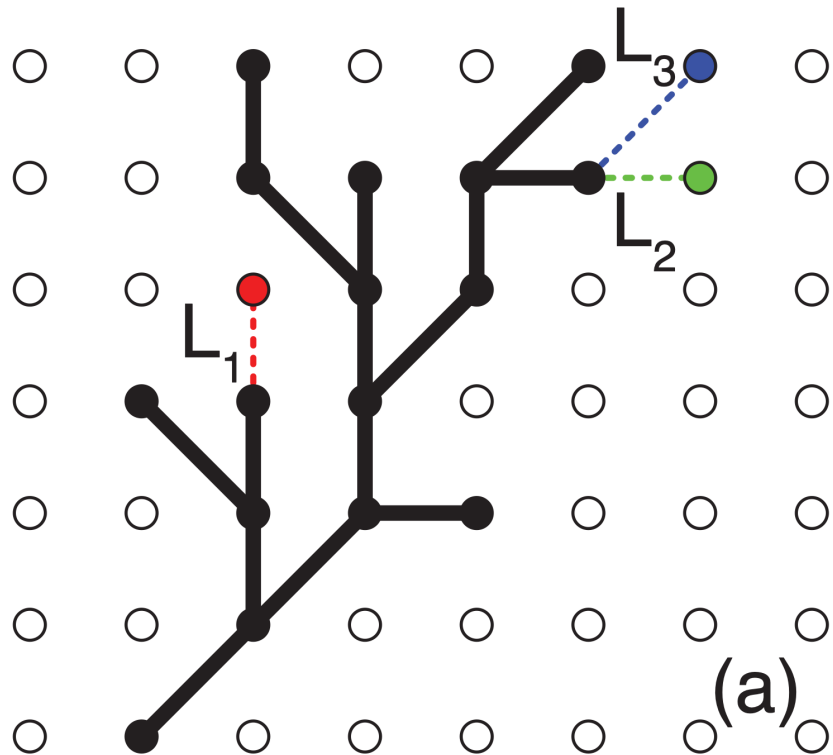
Model results are compared to observations at all stages for validation.



Overview

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2. **Methods** → *physical approach & branching differences*
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Methods: Fractal Model of Electrical Discharges



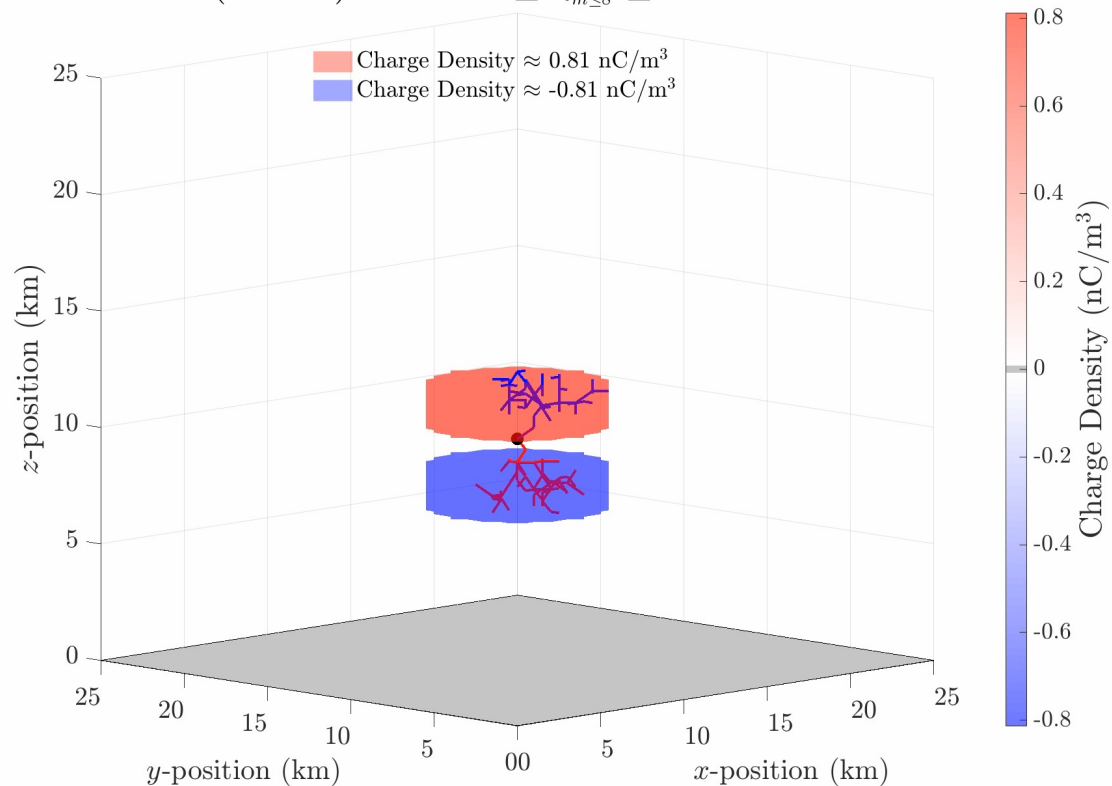
$$p(L_i) = \frac{|E_i - E_{th}^{\pm}|^{\eta}}{\sum_j |E_j - E_{th}^{\pm}|^{\eta}}$$

	Leader	Streamer
E_{init}	$\pm \frac{1}{10} E_k$	$\pm 1.5 E_k$
E_{prop}	$\pm \frac{1}{20} E_k$	$-\frac{1}{3} E_k$ or $+\frac{1}{6} E_k$
V_d	0	E_{prop}

Methods: Visualizing Time-Integration

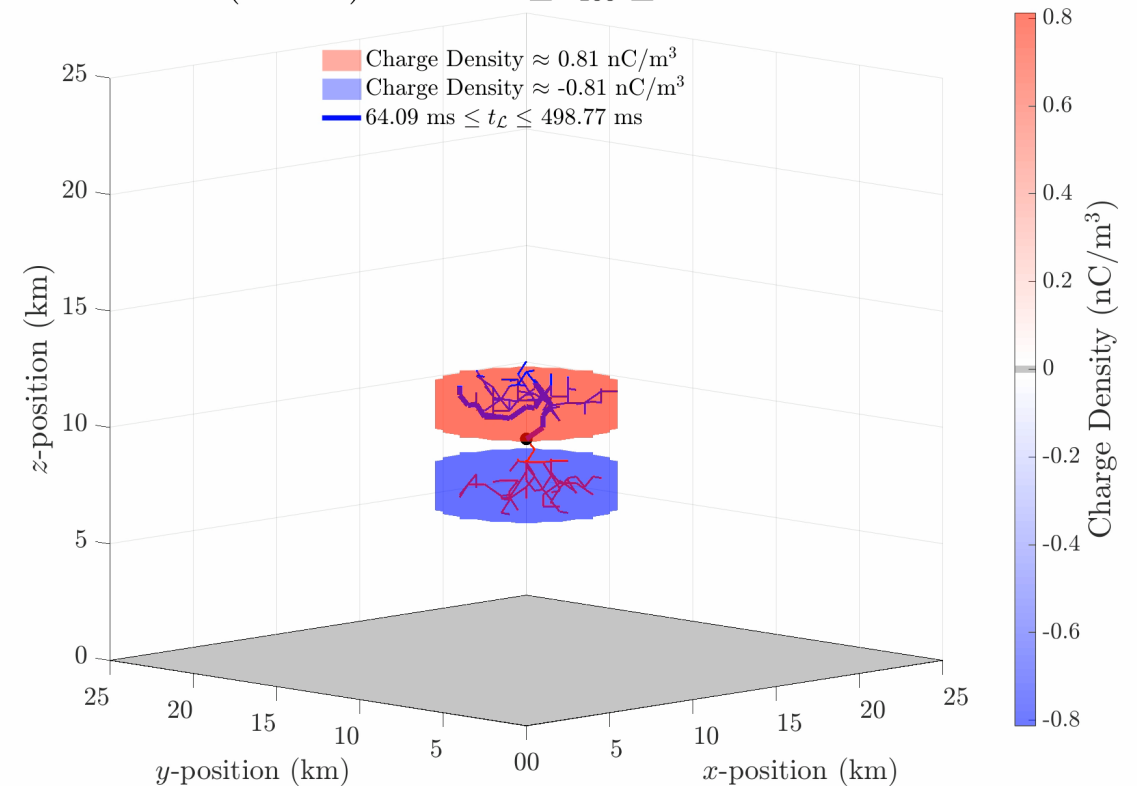
Simultaneous Branching ($t_{\min}$)

(Leader) $37.04 \text{ ms} \leq t_{l_{m \leq 8}} \leq 330.15 \text{ ms}$



Successive Branching ($t_{\max}$)

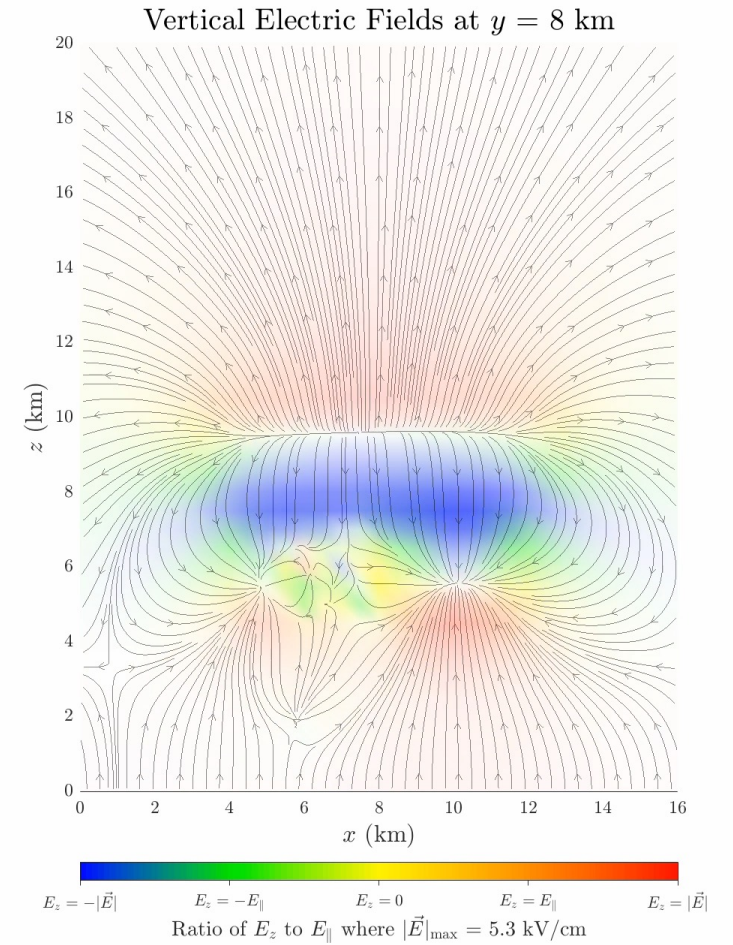
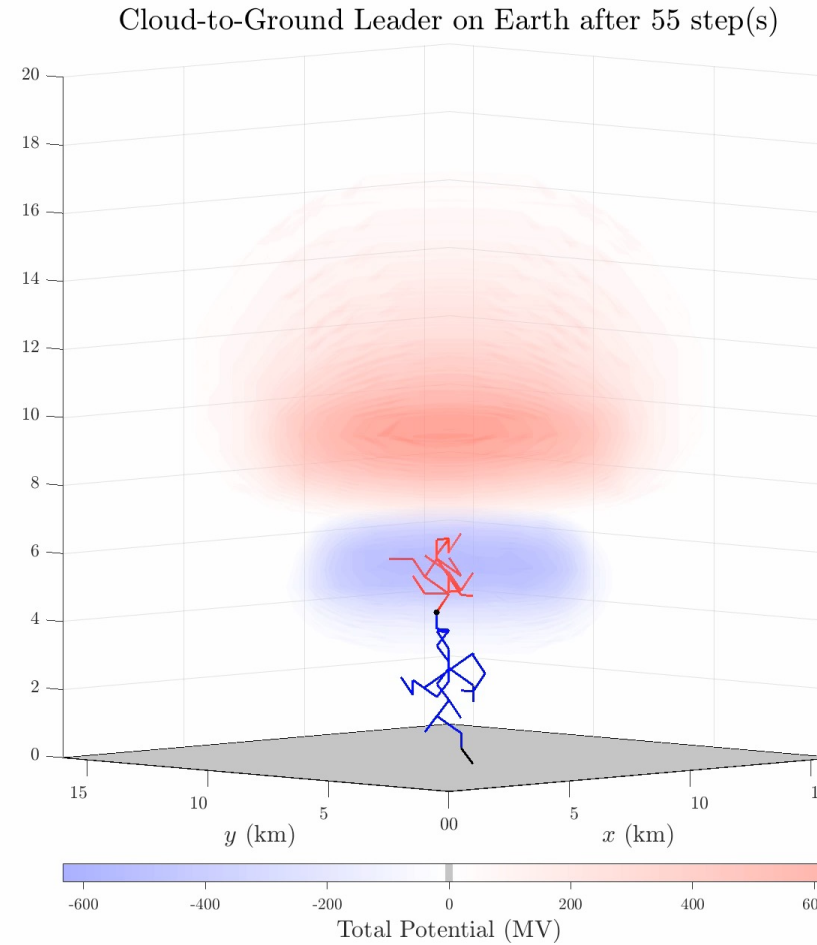
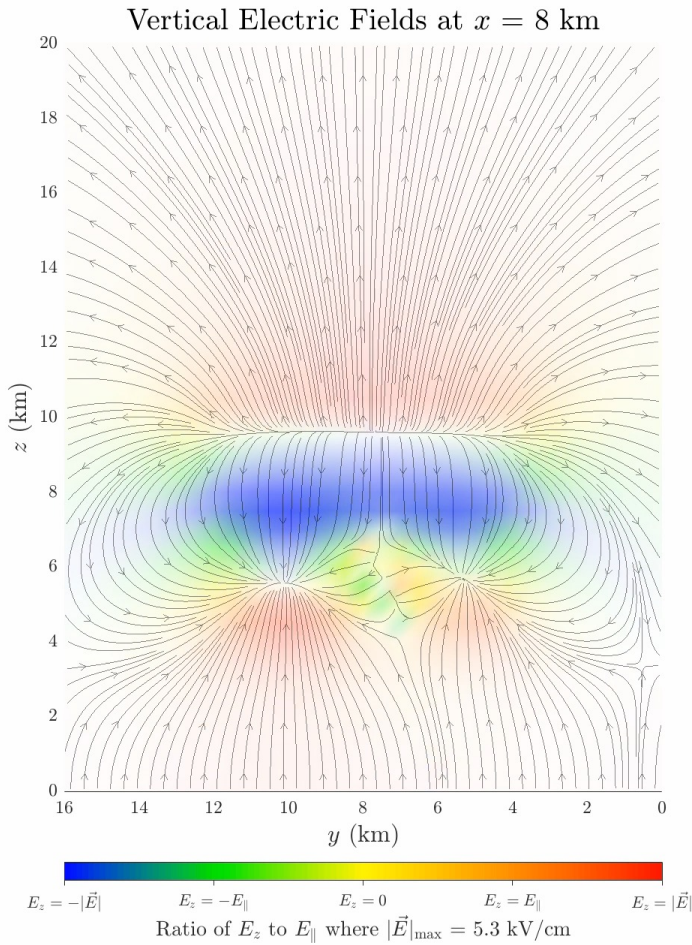
(Leader) $64.09 \text{ ms} \leq t_{155} \leq 498.77 \text{ ms}$



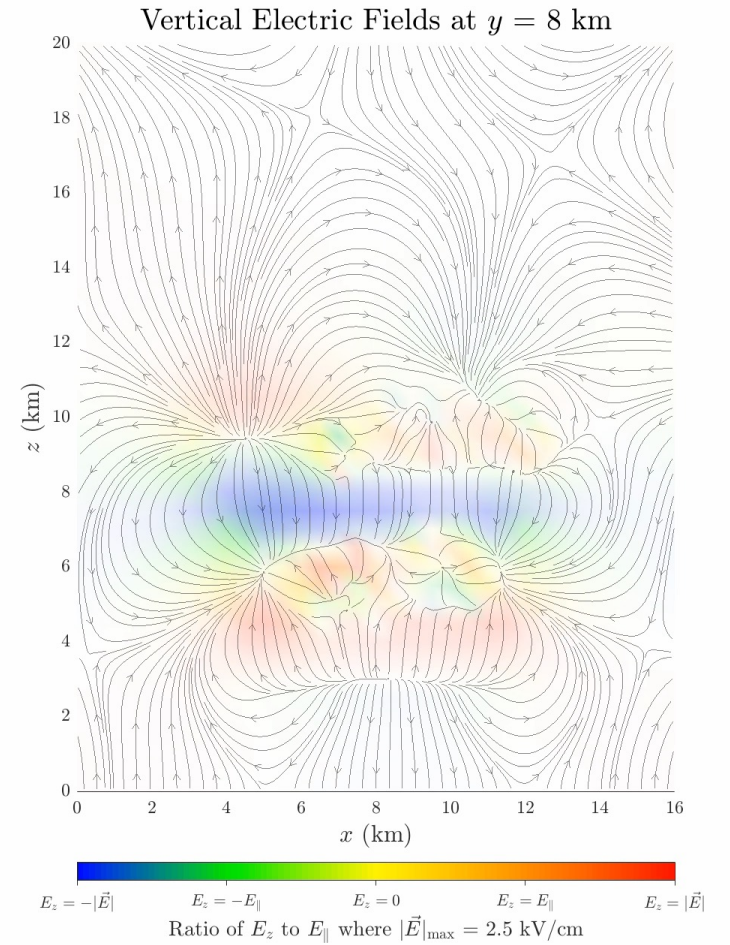
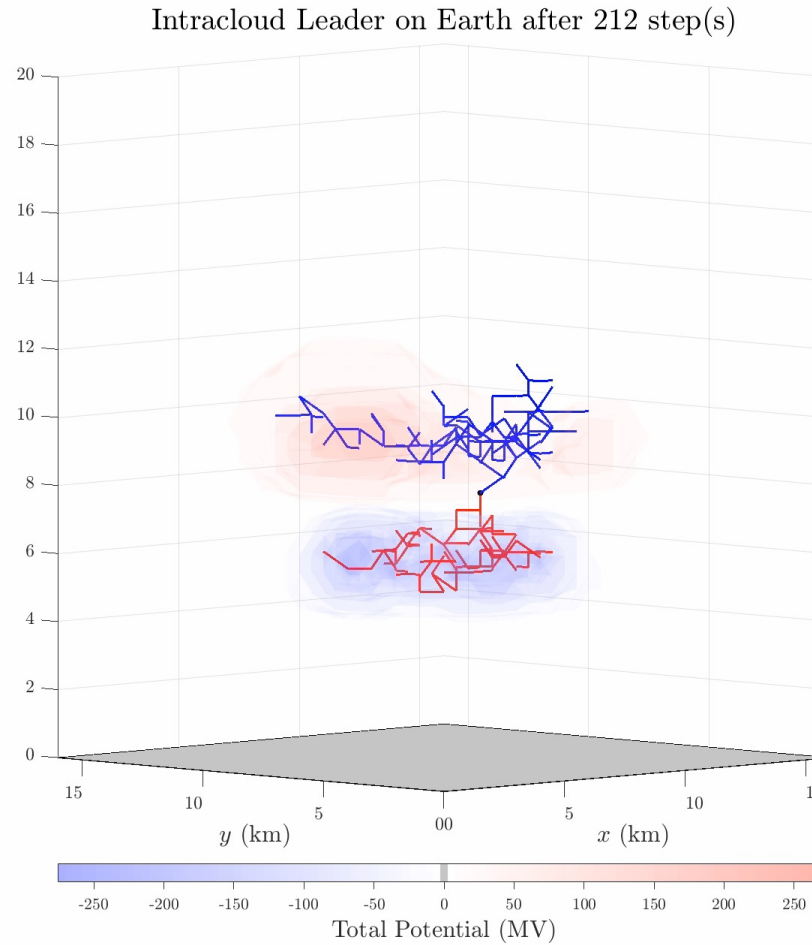
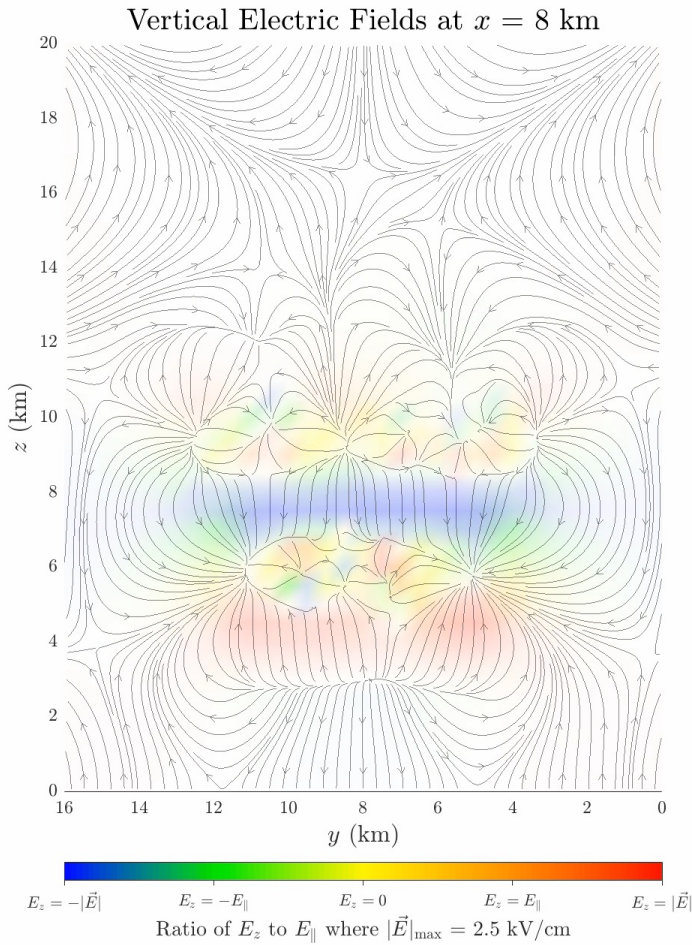
Overview

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3. **Results** → *cloud-to-ground, intracloud*
4. Discussion
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Results: Cloud-to-Ground Discharge



Results: Intracloud Discharge



Overview

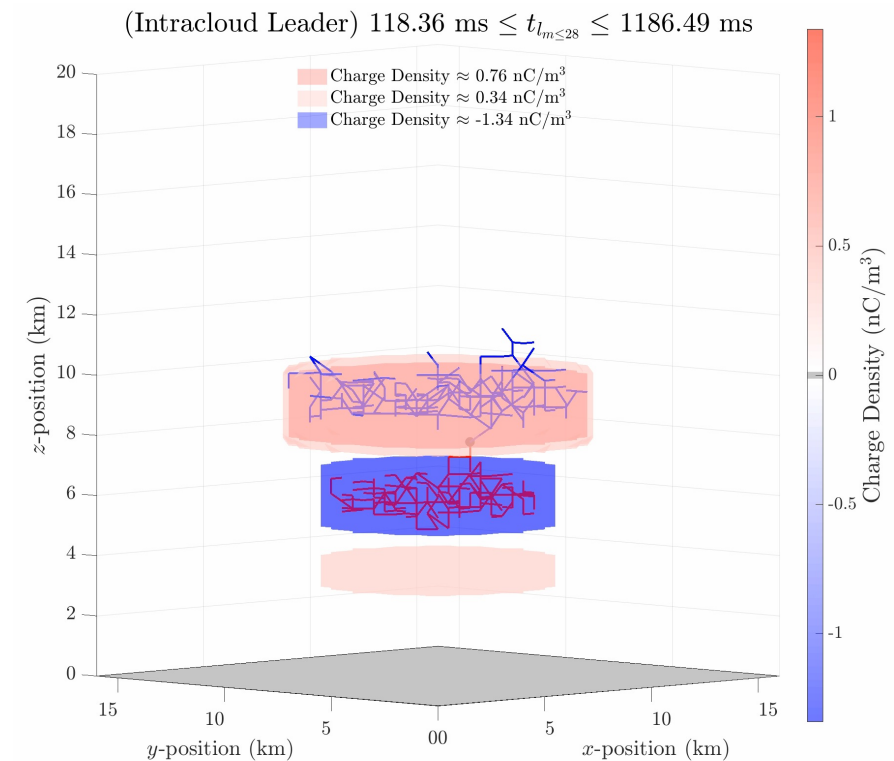
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Discussion: Observations & Intracloud Discharge

- $v_{\text{prop}} = 440 \text{ km/s}$ (Thomson et al., 1985)
- $\rho_{\text{amb}} \leq 10 \text{ nC/m}^3$ (Krehbiel, 1986)
- Intracloud:
 - Initiated $\gtrsim 7.5 \text{ km}$ (Karunarathna et al., 2017)
 - Mean currents $1.3 \pm 1.0 \text{ kA}$, range $110 \text{ A} - 5.0 \text{ kA}$ (Thomson et al., 1985)
- Cloud-to-Ground:
 - Initiated $\lesssim 6.8 \text{ km}$ (Karunarathna et al., 2017)
 - Negative CGs:
 - Up to 200 kA (Anderson and Eriksson, 1980)
 - Positive CGs:
 - Up to 208 kA (Schulz et al., 2013)

Intracloud Leader

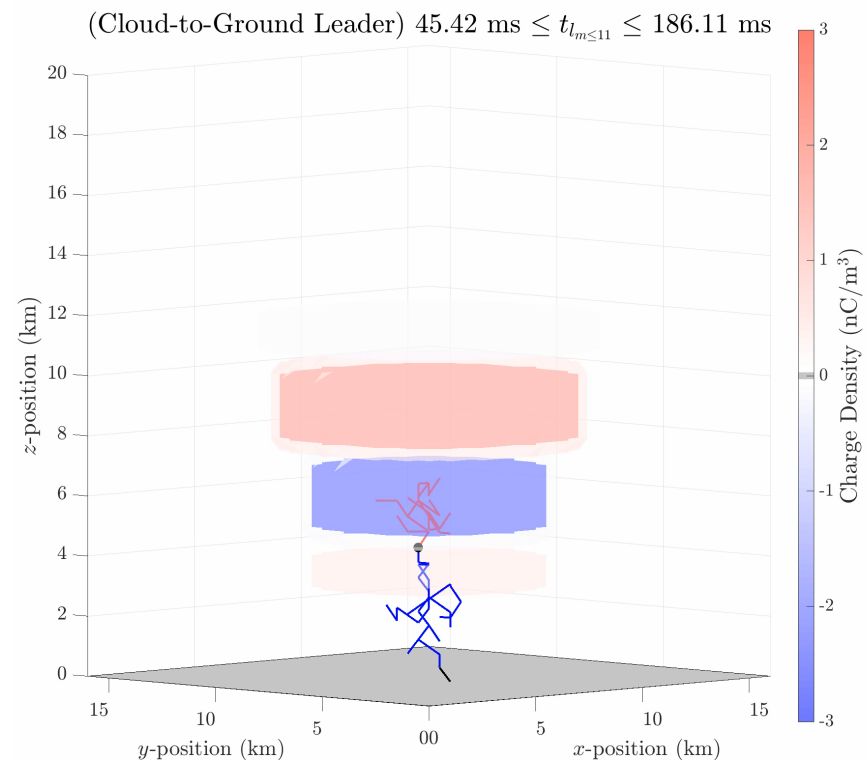
7.5 km	Min.	Max.	Mean	Std. Dev.
Time	118.4 ms	1186.5 ms	-	-
Current	0.39 kA	2.52 kA	0.90 kA	0.32 kA



Discussion: Cloud-to-Ground Discharges

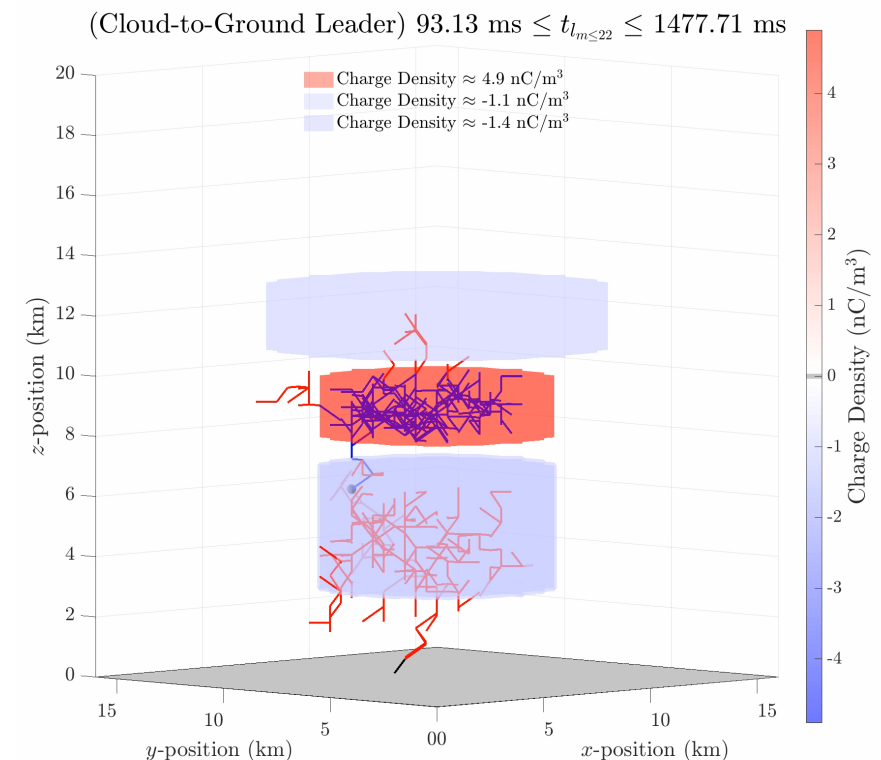
Negative Cloud-to-Ground Leader

4.5 km	Min.	Max.	Mean	Std. Dev.
Time	45.4 ms	181.6 ms	-	-
Current	0.95 kA	49.1 kA	1.59 kA	0.39 kA



Positive Cloud-to-Ground Leader

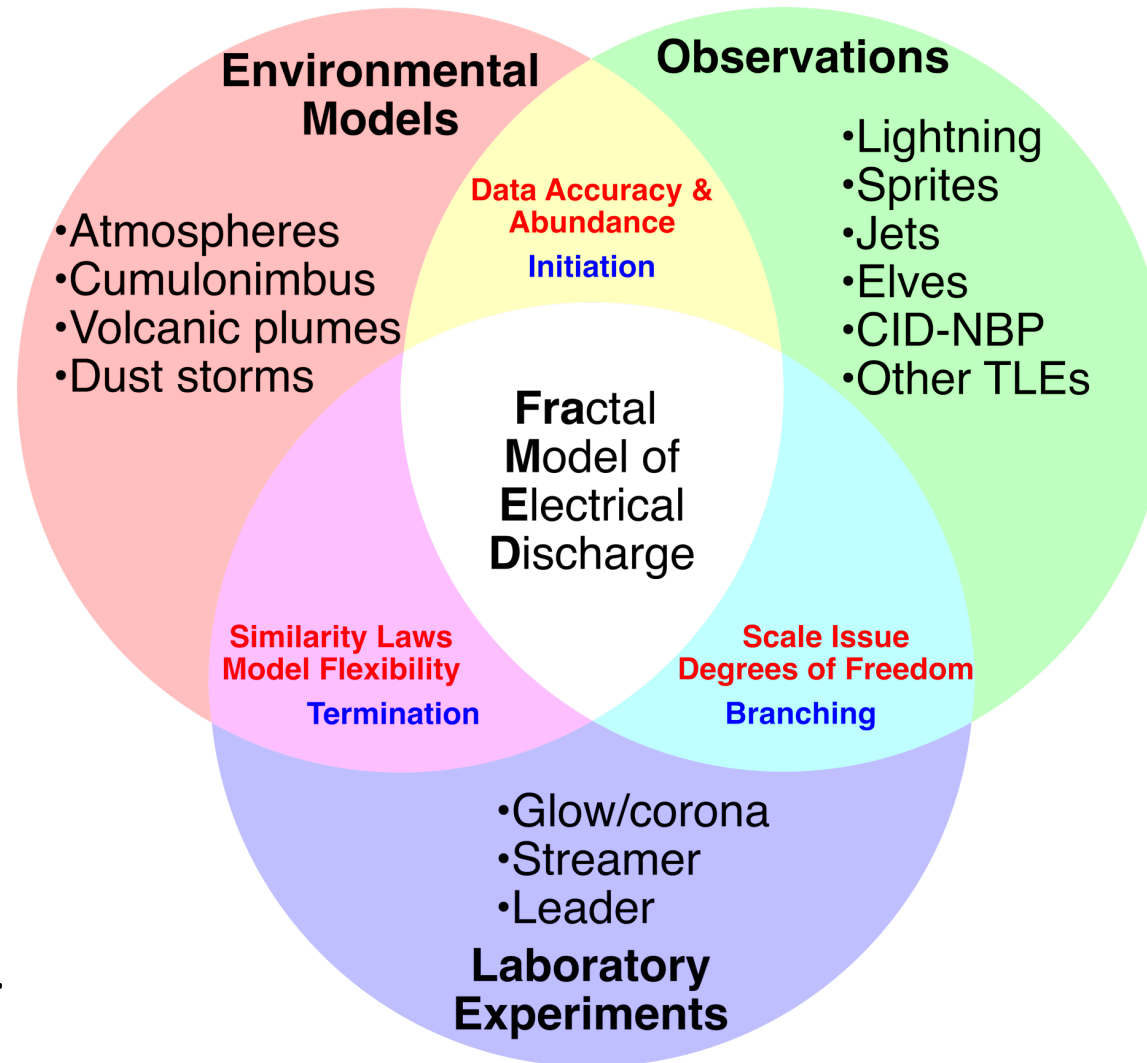
6.0 km	Min.	Max.	Mean	Std. Dev.
Time	93.1 ms	1477.7 ms	-	-
Current	0.47 kA	114.9 kA	2.30 kA	1.20 kA



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Conclusions: Future Work



Model improvements will introduce **waveform prediction** and continue validation through **in-situ and remote observations**.

Code is available on GitHub:

- <https://github.com/stroeum/FraMED>
- FraMED itself is in C++ (.cpp).
- Visualizations are in MATLAB (.m).
- Model coupling aspects are mixed.

Acknowledgements



This work was supported by the National Science Foundation under CAREER grant 2047863 to Embry-Riddle Aeronautical University.