

Self-consistent modeling of currents in leader and return stroke channels

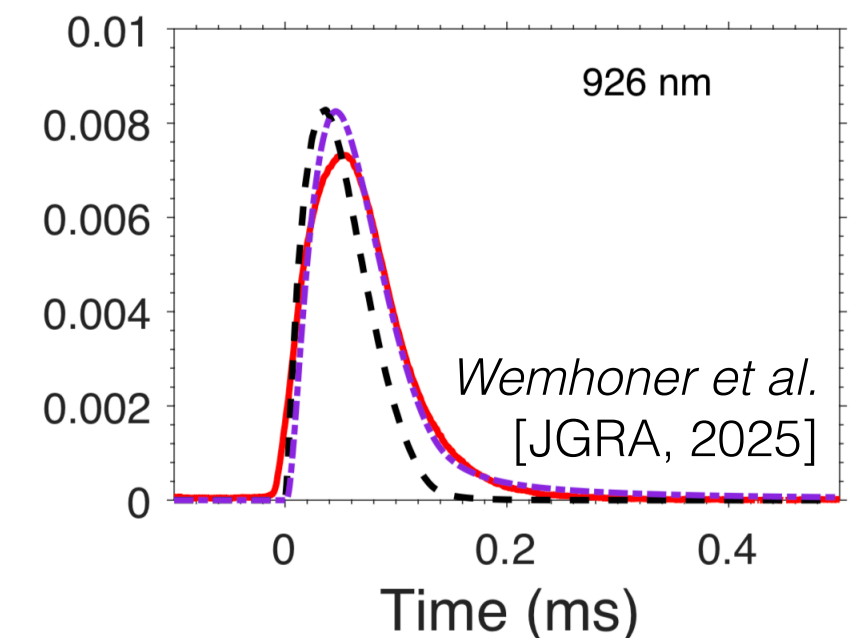
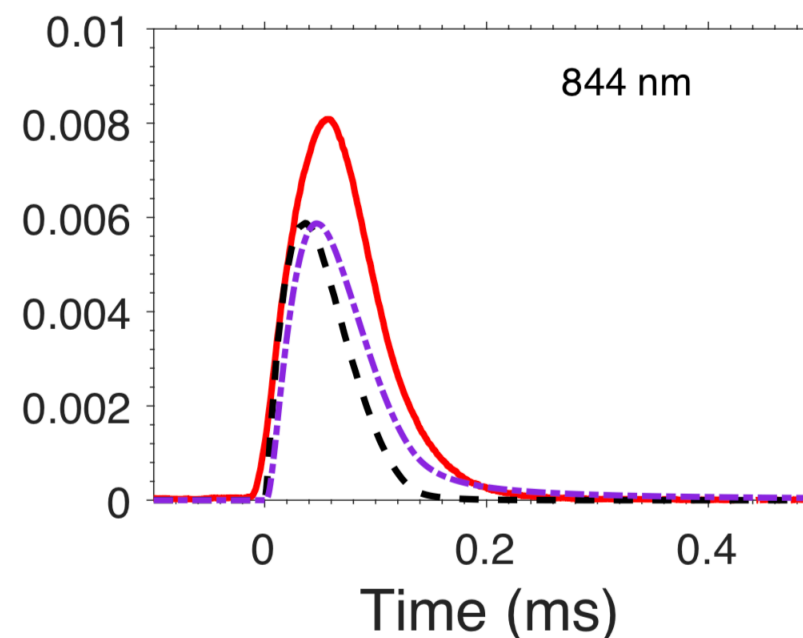
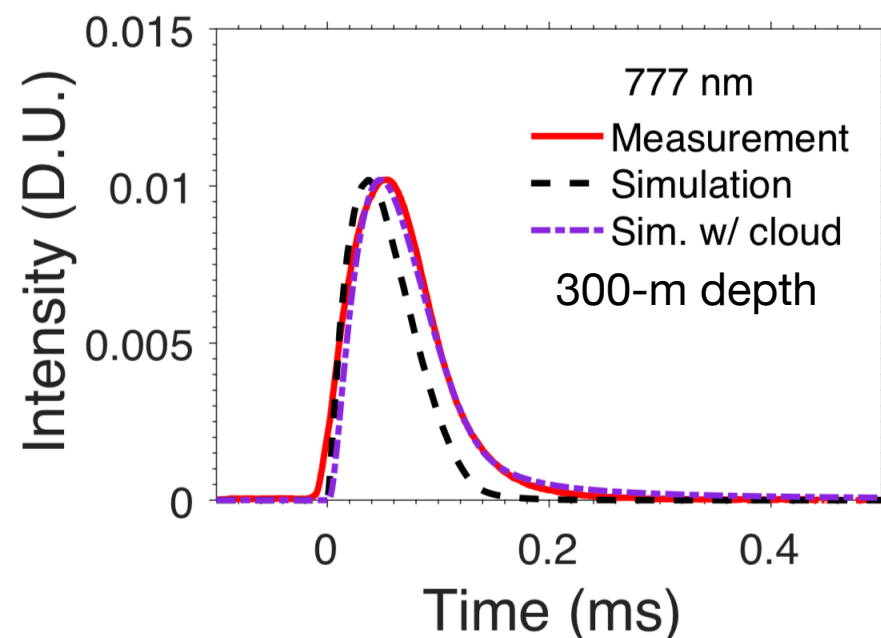
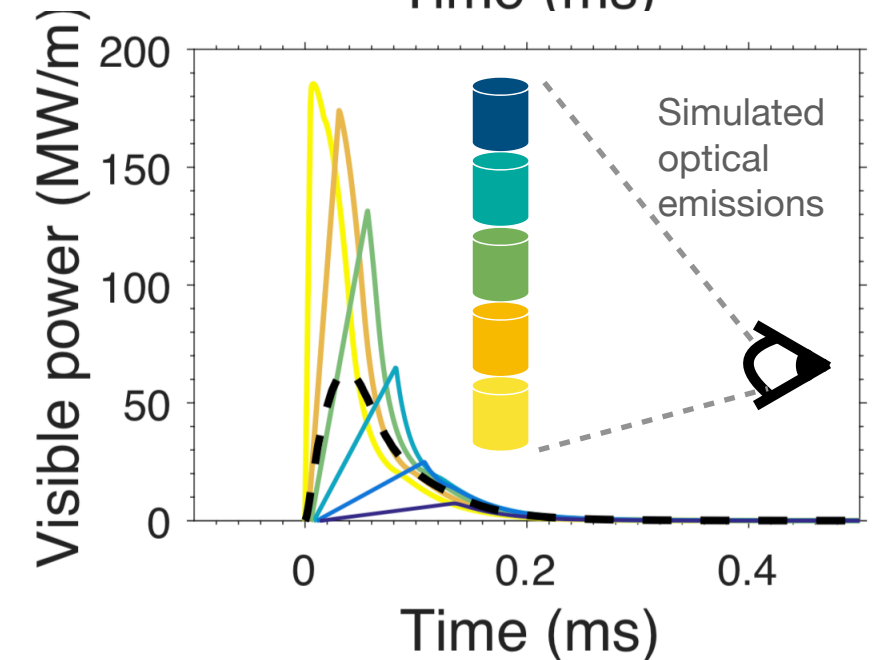
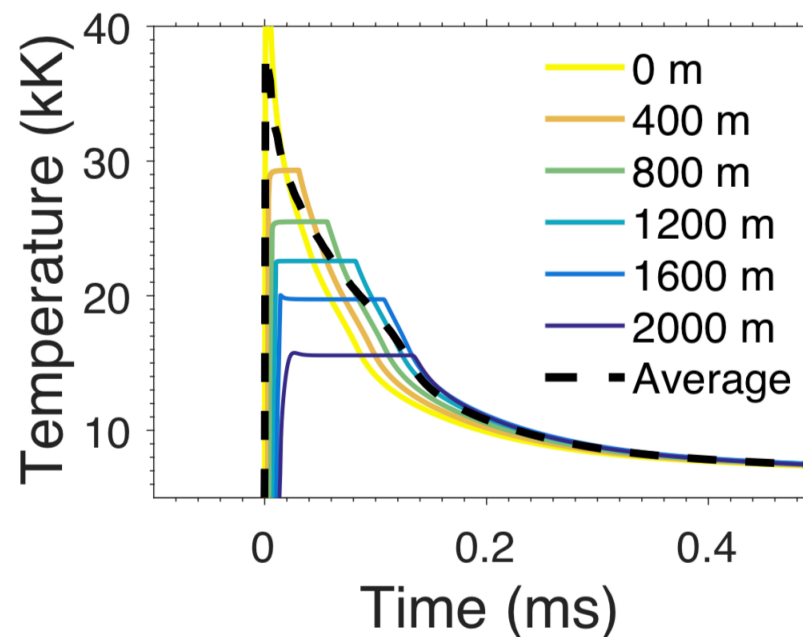
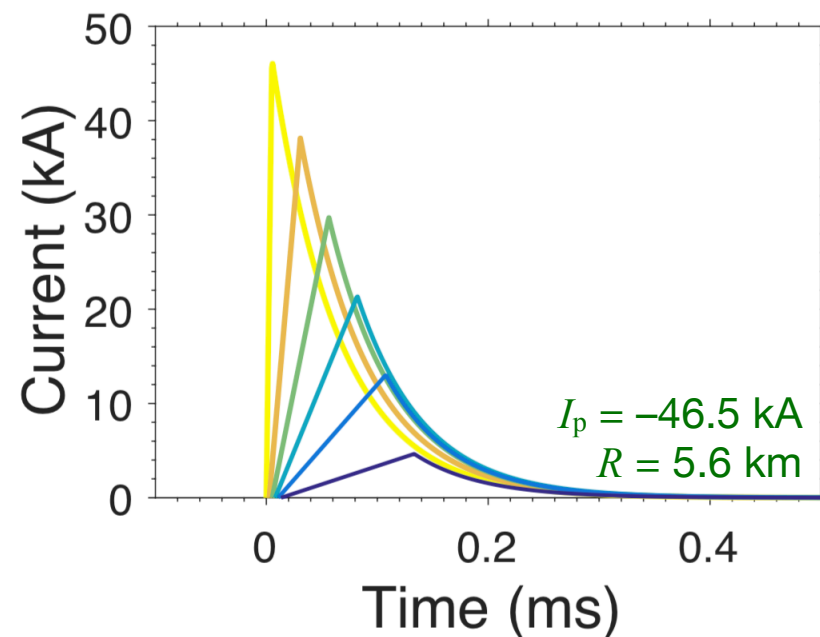
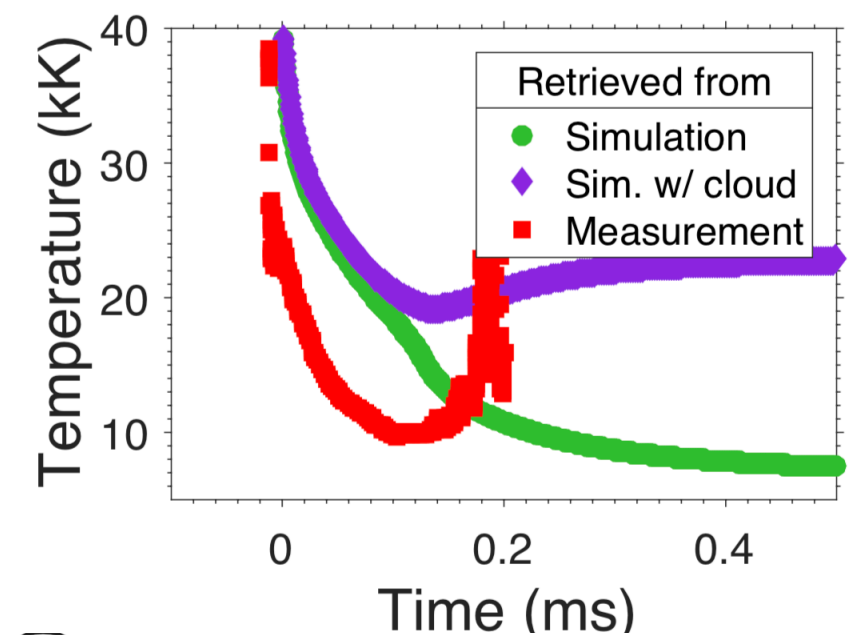
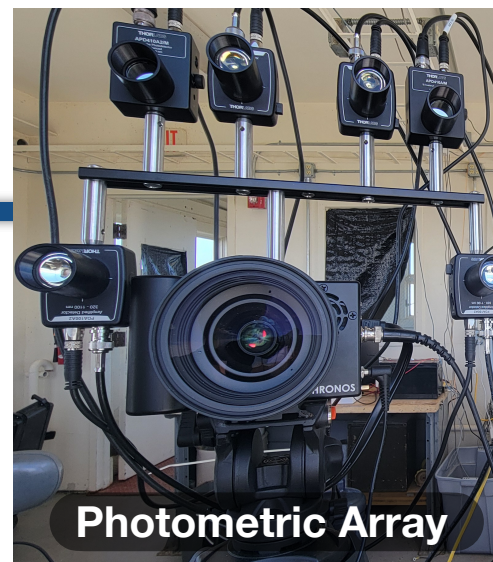
Caitano L. da Silva, J. G. Pantuso, J. Wemhoner,
D. P. Jensen[‡], A. F. R. Leal, R. G. Sonnenfeld

“Semi-empirical
models are great for
interpreting signals ...”

Temperature

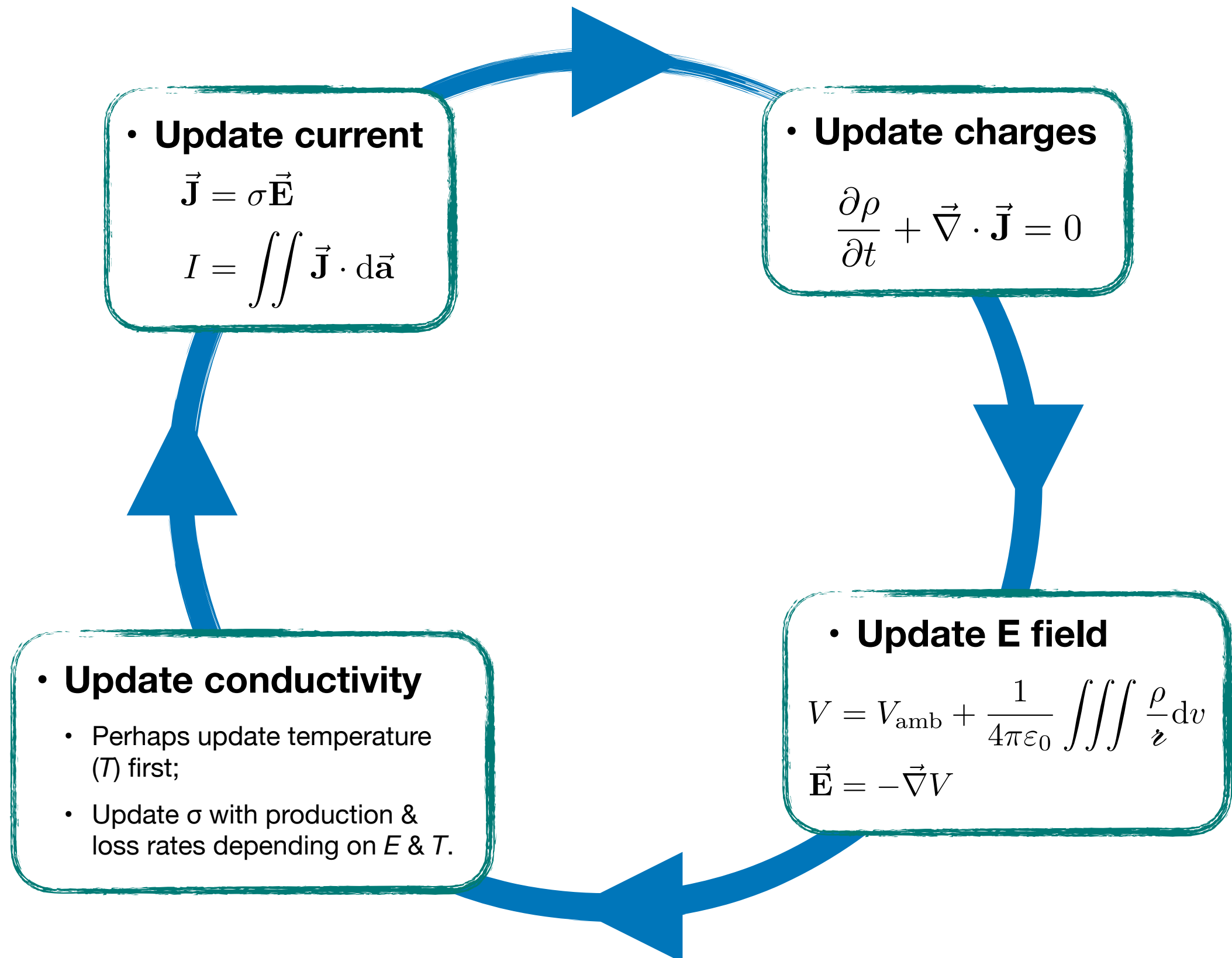
Measurements vs. Modeling

- Current modeled with MTLL model.
- Then plugged into plasma model.



“... but self-consistent
models are necessary to
improve understanding and
to make predictions.”

What do we mean by self consistency?

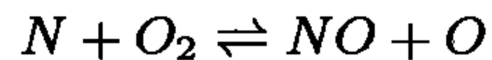
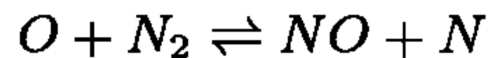
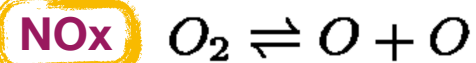


Temperature is Important

(in leaders and return strokes)

- The lightning plasma temperature is a key quantity to determine its impacts.

Atmospheric



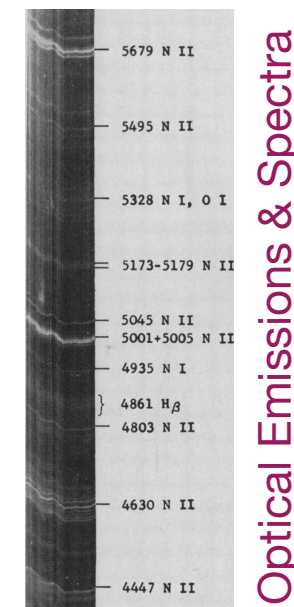
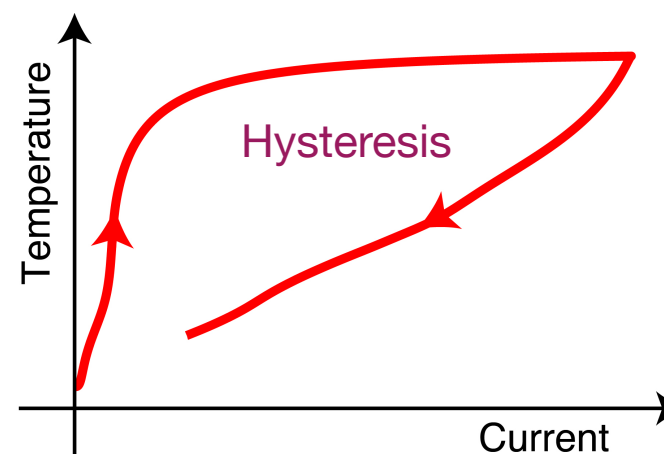
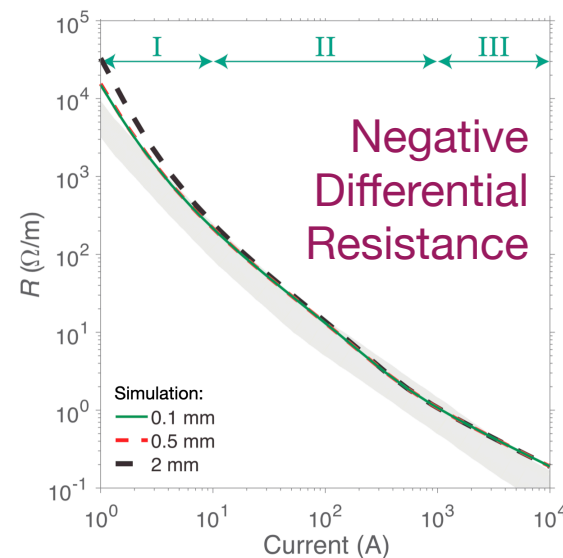
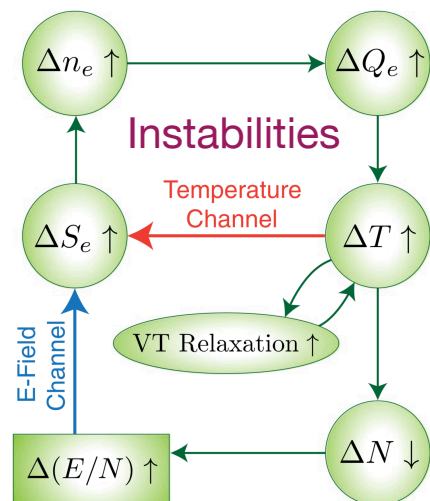
Environmental



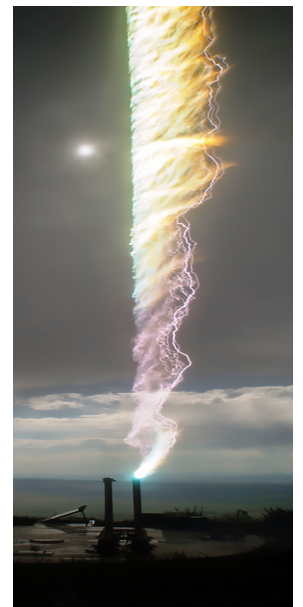
Societal



- It is also key to probe its fundamental physics.



Optical Emissions & Spectra

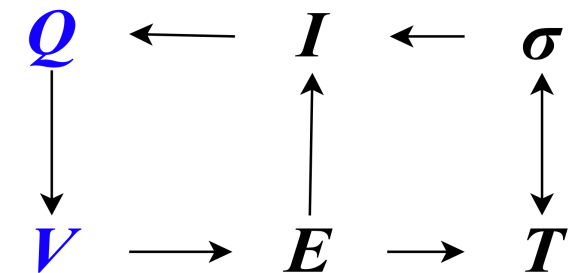


- Therefore, we must extend data availability and inclusion in models.

Modeling Conductivity

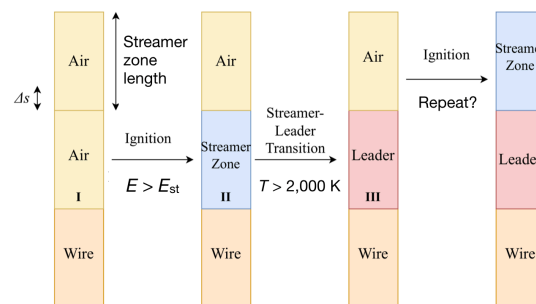
- ◆ First principles: hydrodynamic equations including species-dependent continuity and energy balance equations.
- ◆ Model reduction is key: reduction in dimensionality, number of source processes [*da Silva et al.*, JGRA, 2019].

◆ Example:



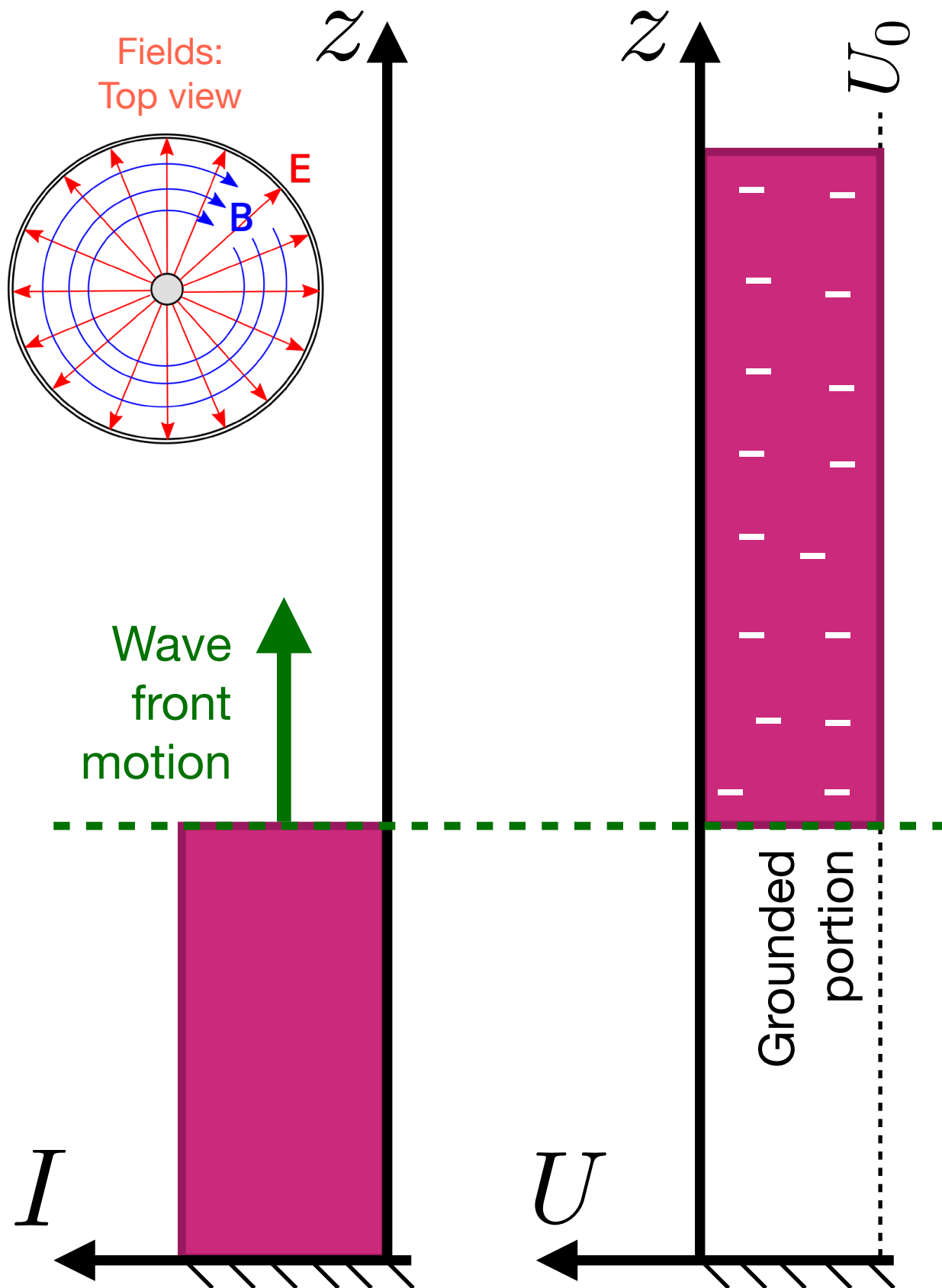
$$C \frac{\partial T}{\partial t} = \underbrace{\eta \sigma E^2}_{\text{Joule Heating}} - \underbrace{\frac{4\kappa}{r_g^2} (T - T_{\text{amb}})}_{\text{Radial Thermal Cond.}} + \underbrace{\kappa \frac{\partial^2 T}{\partial s^2}}_{\text{Axial Thermal Cond.}} - \underbrace{4\pi \epsilon}_{\text{Radiative Emission}}$$

$$\frac{\partial \sigma}{\partial t} = - \frac{\sigma - \max(\sigma_{\text{min}}, \sigma_{\text{LTE}})}{\tau}$$



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Return Stroke: Charge Neutralization Wave



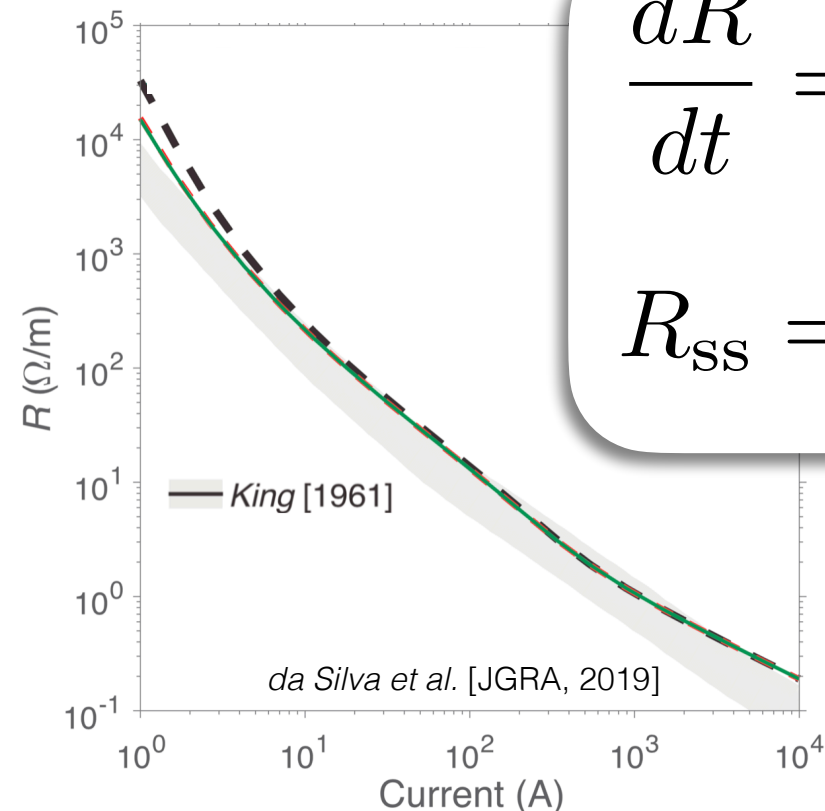
Adapted from Bazelyan and Raizer [Lightning Physics and Protection]

Telegrapher's Equations:

$$L \frac{\partial I}{\partial t} + \frac{\partial U}{\partial z} + RI = 0$$

$$C \frac{\partial U}{\partial t} + \frac{\partial I}{\partial z} = 0$$

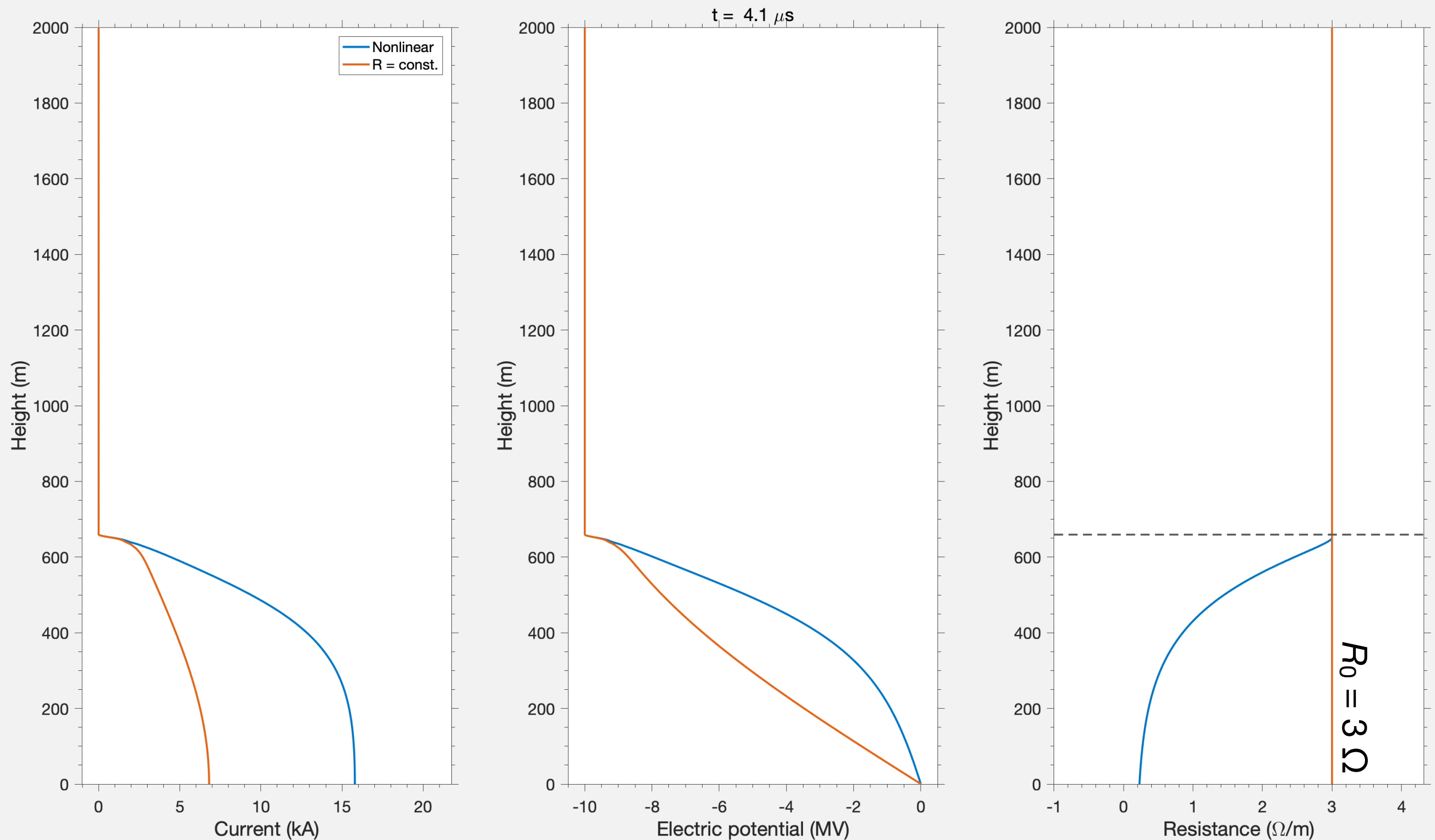
Nonlinear Resistance Model:



$$\frac{dR}{dt} = -\frac{R - R_{ss}}{\tau_{ss}}$$

$$R_{ss} = \frac{E_{ss}}{I}$$

Self-Consistent Return Stroke Simulation



Driving boundary condition: $U(0, t) = U_0[1 - (1 - e^{-t/\tau_a})H(t)]$

τ_a : ground attachment time

“All models are wrong.
Some are useful.”

-Caitano da Silva

-Andy Fierro

-Matt Hopkins

-Someone else before him

Acknowledgements

CAREER: Self-consistent and Data-constrained Simulations of the Leader and Return Stroke Processes in Lightning Discharges (AGS-2046043)

- NSF/AGS/PDM
- Program officer:
Dr. Chungu Lu
- Aug 2021–2026



Lightning Physics Session at AGU25

Physics of Streamers, Leaders, and the Lightning Discharge

- Session shall be proposed once again to AGU.
- Speakers today should consider submit update abstracts to this session.
- 15-19 December, 2025, New Orleans, LA.

AGU FALL
MEETING



References

(relevant recent work at NMT)

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