Study of Lightning Data with Time Domain Fractal Lightning Modeling (TDFL)

C. Liang*, B. E. Carlson, N. G. Lehtinen, M. B. Cohen, U. S. Inan

Contact:
canliang@stanford.edu
Stanford University

Abstract

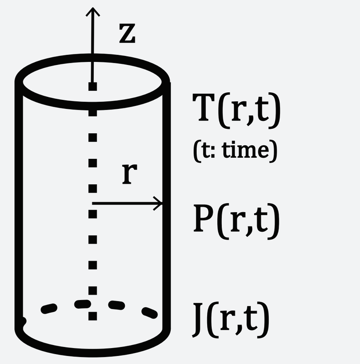
A wide range of experimental data exist for the study of lightning. In particular, experimental study of Return Stroke (RS) is rich both in its diversity and quantity.

TDFL is based on the theoretical understanding of lightning related microprocesses and predicts a wide variety of observable quantities.

TDFL is a framework within which a theory can be tested against experimental data. On the other hand, progress in the theory improves TDFL's predictive power.

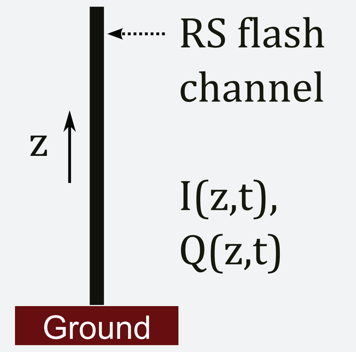
TDFL vs. Other models

Gas Dynamic Model:



Pro:	*Con:*
Calculate T (temperature) P (pressure) and thus σ (conductivity) Optical emission	No variation in z; No I (current), Q (charge) distribution along flash channel

Electromagnetic Model:



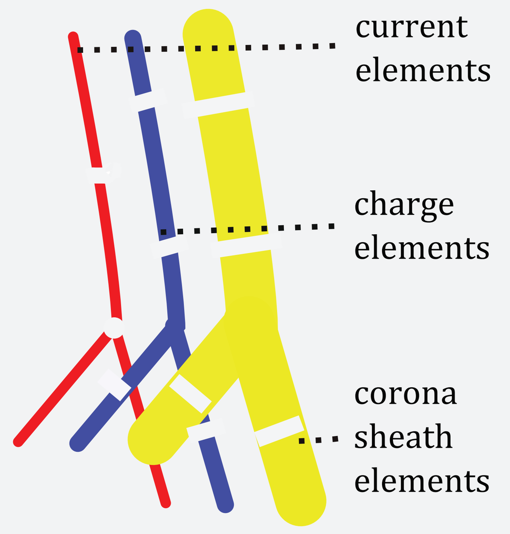
Pro:	*Con:*
Calculate I (current), Q (charge) distribution over flash channel	Assumes properties: R (resistance) C (capacitance) L (inductance)

TDFL:

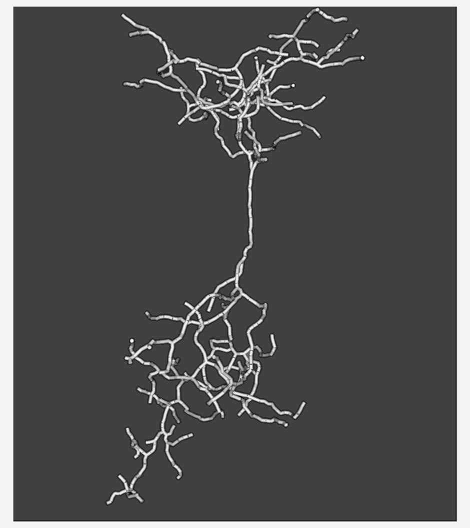
Predicts flash channel distribution of T, P as well as I, Q.
Make possible the comparison to optical, ground base current, remote EM field measurements all **at the same time.**

TDFL: Channel Structure

Core & Sheath



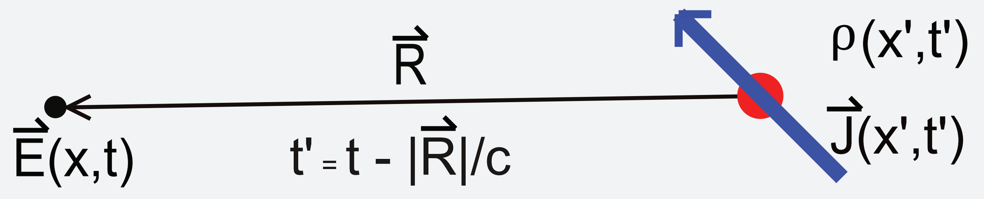
Flash Geometry



TDFL: Electromagnetics (I,Q)

Electric Field Integral Equation(EFIE):

$$\vec{\mathbf{E}}(\vec{\mathbf{x}},\mathbf{t}) = \frac{1}{4\pi\epsilon_0}\int \mathbf{d^3x'}\left\{\frac{\hat{\mathbf{R}}}{\mathbf{R^2}}[\rho(\mathbf{x'},\mathbf{t'})]_{\mathbf{ret}} + \frac{\hat{\mathbf{R}}}{\mathbf{cR}}\left[\frac{\partial\rho(\mathbf{x'},\mathbf{t'})}{\partial \mathbf{t'}}\right]_{\mathbf{ret}} - \frac{1}{\mathbf{c^2R}}\left[\frac{\partial\vec{\mathbf{J}}(\mathbf{x'},\mathbf{t'})}{\partial\mathbf{t'}}\right]_{\mathbf{ret}}\right\}$$



Ohm's law: $\boldsymbol{\sigma}\vec{\mathbf{E}} = \vec{\mathbf{J}}$

I: current, J:current density, Q: charge, ρ :charge density

TDFL: Thermodynamics

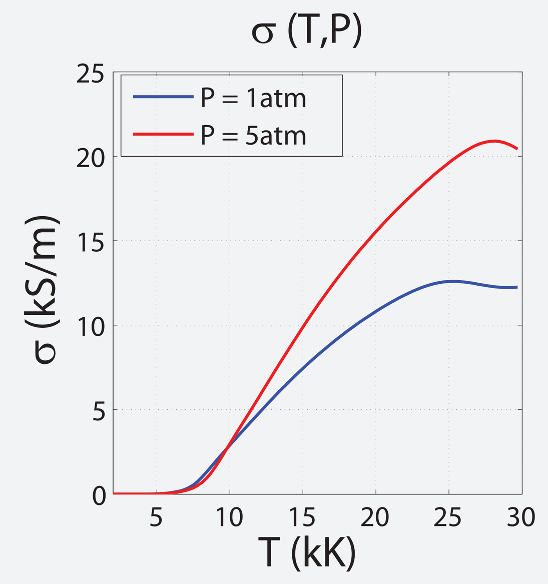
Channel Core is ionized air at high T (temperature)

σ (condictivity) depends on T and P (pressure)

Energy balance affects T, P

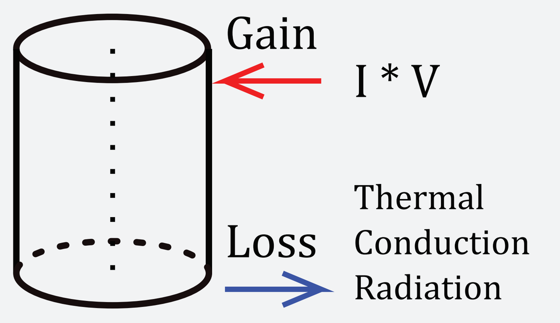
Air thermal properties are complicated due to air composition change

Conductivity σ



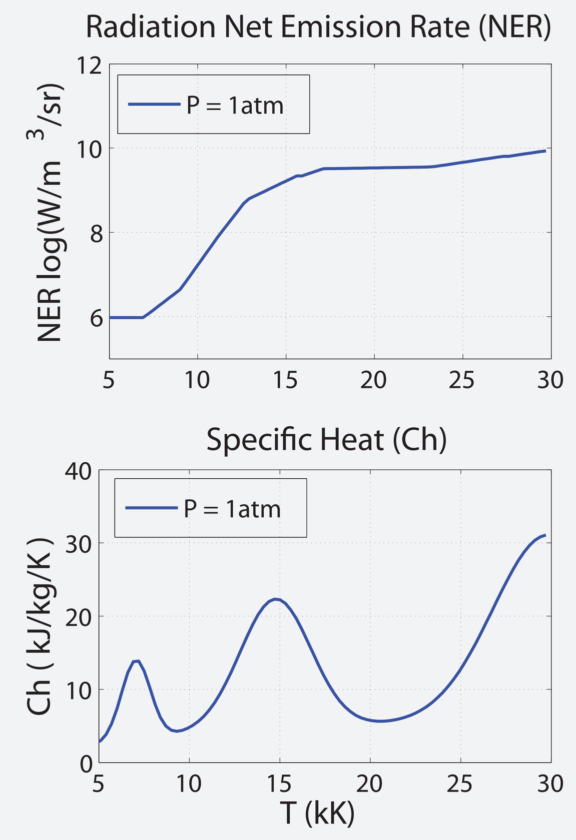
(A.D'Angola 2008)

Heat Balance



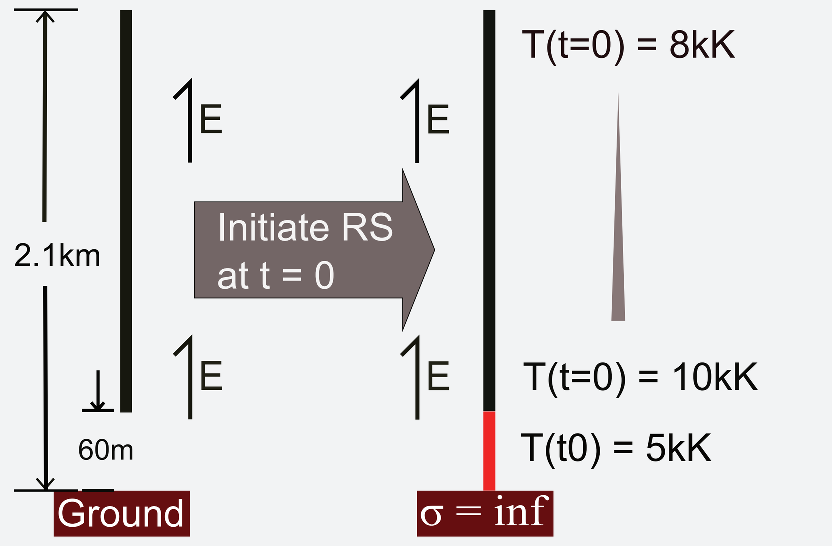
$$\Delta T = \frac{\text{Gain} - \text{Loss}}{\text{Specific Heat}}$$

Thermal Properties



A.D'Angola 2008, J.J Lowke 1974 and V.Aubrecht

RS Simulation Setup



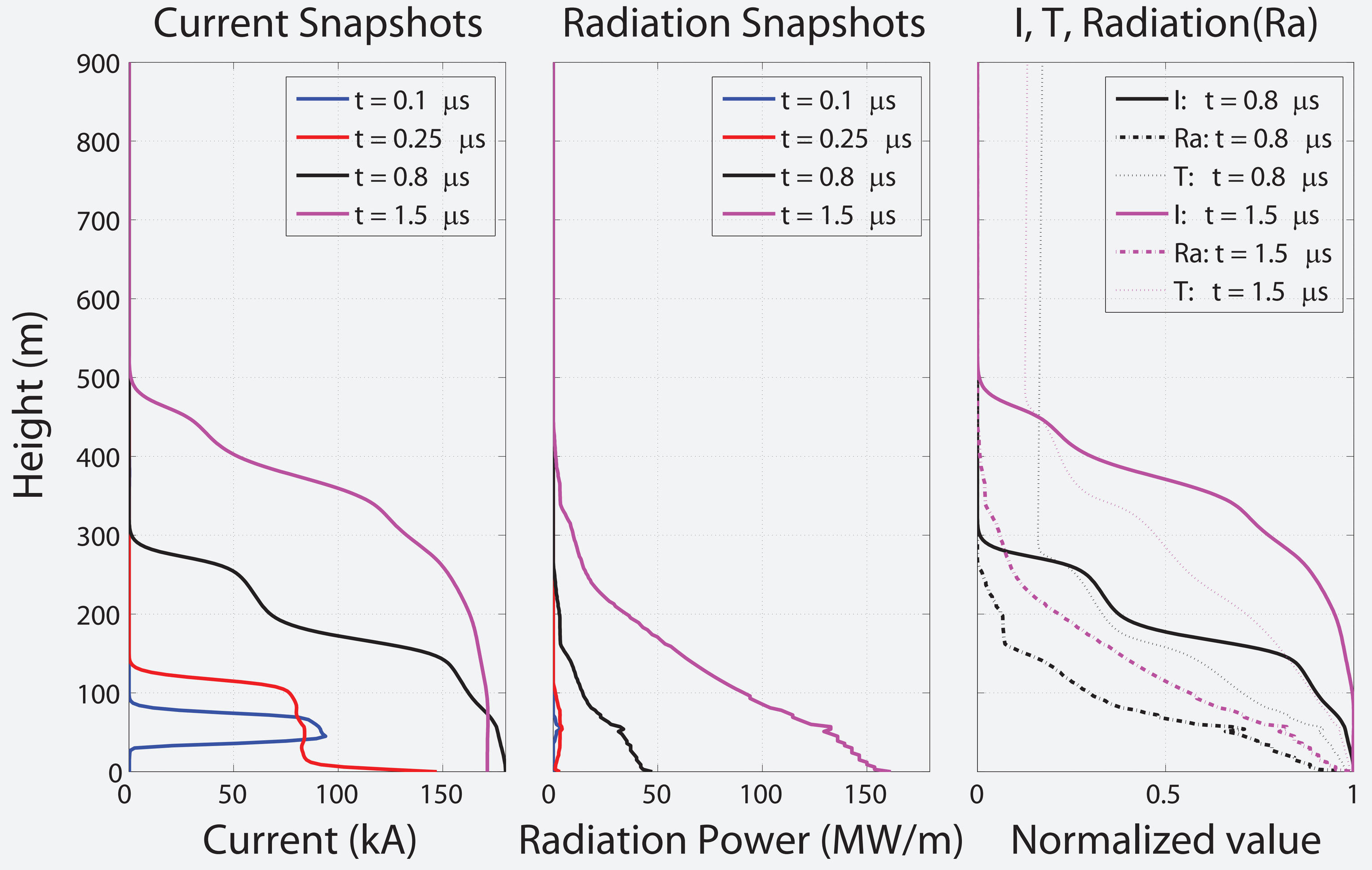
Cloud charge induced E field: E = 1e5(v/m)

Constant core radius: Rcore = 5mm

Constant core air mass

Implicitly, local thermal equilibrium

RS Simulation Results



Reference:

A. D'Angola, G. Colonna (2008). *Thermodynamic and transport properties in equilibrium air plasmas in a wide pressure and temperature range.* Eur. Phys. J. D, 46, 129-150. DOI: 10.1140/epjd/e2007-00305-4

K. Eisazadeh-Far, H. Metghalchi (2011) *Thermodynamic Properties of Ionized Gases at High Temperatures.* Journal of Energy Resources Technology. DOI:10.1115/1.400.388

J.J Lowke (1974) *Predictions of arc temperature profiles using approximate emission coefficients for radiation losses,* JQSRT, Vol. 14

V. Aubrecht, M. Bartlova *Radiation transfer in thermal plasma of air, N2 and CO2*

Acknowledgement:

Supported by DARPA grant HR0011-10-1-0058