Welcome to Texas Tech!

2025 Lightning Modeling Grand Challenge Workshop
Texas Tech University, 1-3 April
Supported by a US National Science Foundation Conference Grant

- **Enjoy lunch! And prepare for the activity below.**
- 12:00h: Welcome Remarks from TTU
- 12:15h: Get to know each other activity
  - While you eat, visit with the person next to you and learn from them:
    - What do you do (scientifically)?
    - What is an interesting fact about you?
    - Online – put answers to those questions in the chat.
  - At 12:15, roam the room with your conversation partner and introduce your partner to other pairs.
- 12:30h: Roadmap Overview

Workshop and Roadmap Overview

2025 Lightning Modeling Grand Challenge Workshop
Texas Tech University, 1-3 April
Supported by a US National Science Foundation Conference Grant

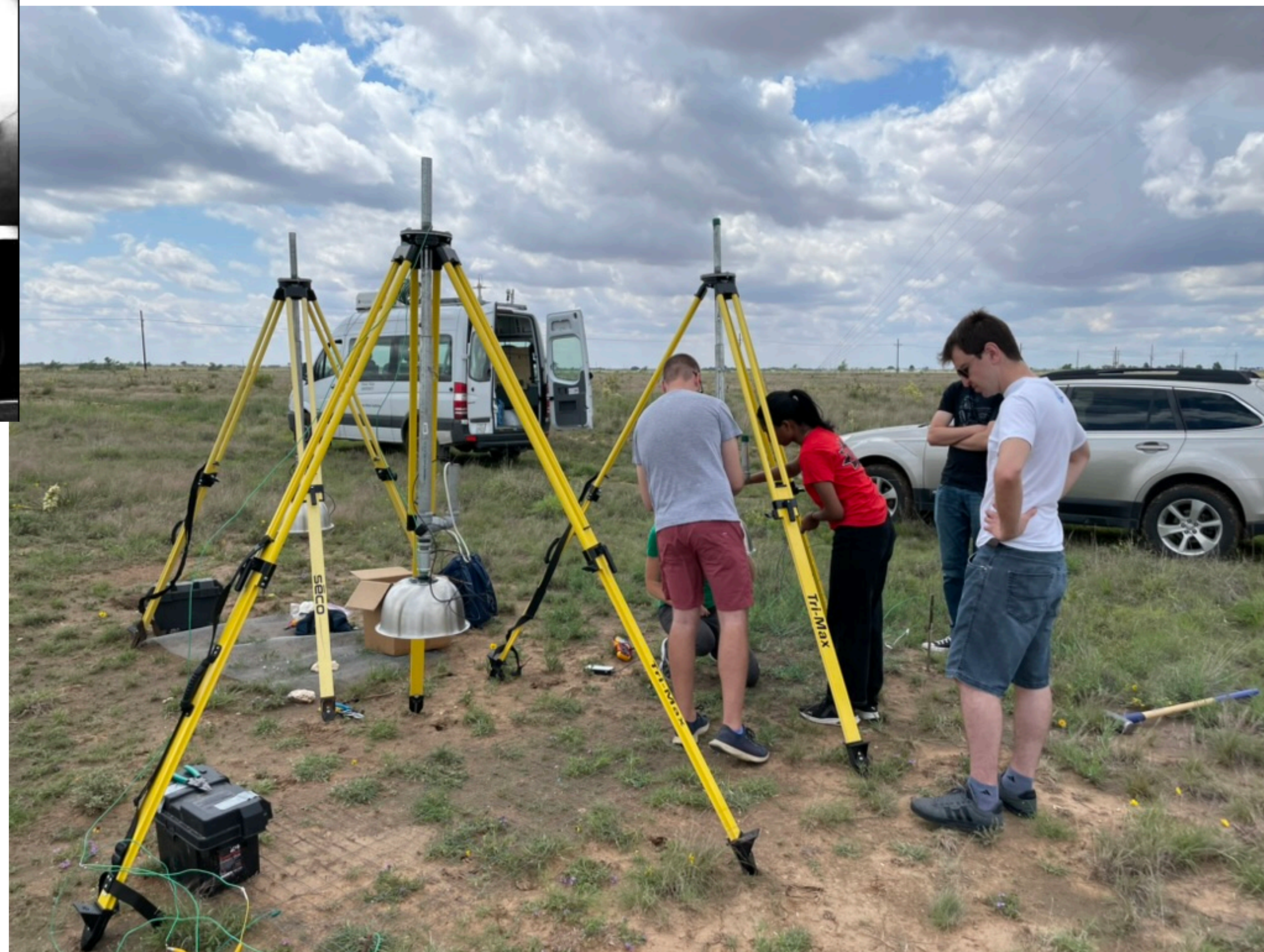
Eric C. Bruning, Texas Tech University
Amanda Back, NOAA Global Systems Laboratory
Sonja Behnke, Los Alamos National Laboratory
Steve Goodman, Thunderbolt Global Analytics
Chris Hogg, Sandia National Laboratories
Timothy Lang, NASA Marshall Space Flight Center
Julia Tilles, Sandia National Laboratories

Thanks: Samantha Smith, TTU College of Arts & Sciences; International Cultural Center and Department of Geosciences staff;
TTU Atmospheric Science students and staff

Logistics

WIFI
TTUguest
fearlesschampion

- Restrooms
- Code of Conduct and Safety
  - Eric Bruning, Samantha Smith (TTU)
  - Julia Tilles, Amanda Back (Panelists)
- Parking is free in lots marked for visitors, north and south of ICC building.
- Tuesday evening:
  - No-host dinner … *how many?* (show of hands)
- Thursday afternoon:
  - Implementation / code sprint (Eric B.)
  - Field site tour (Kelcy B., et al.)



Purpose of this year's workshop

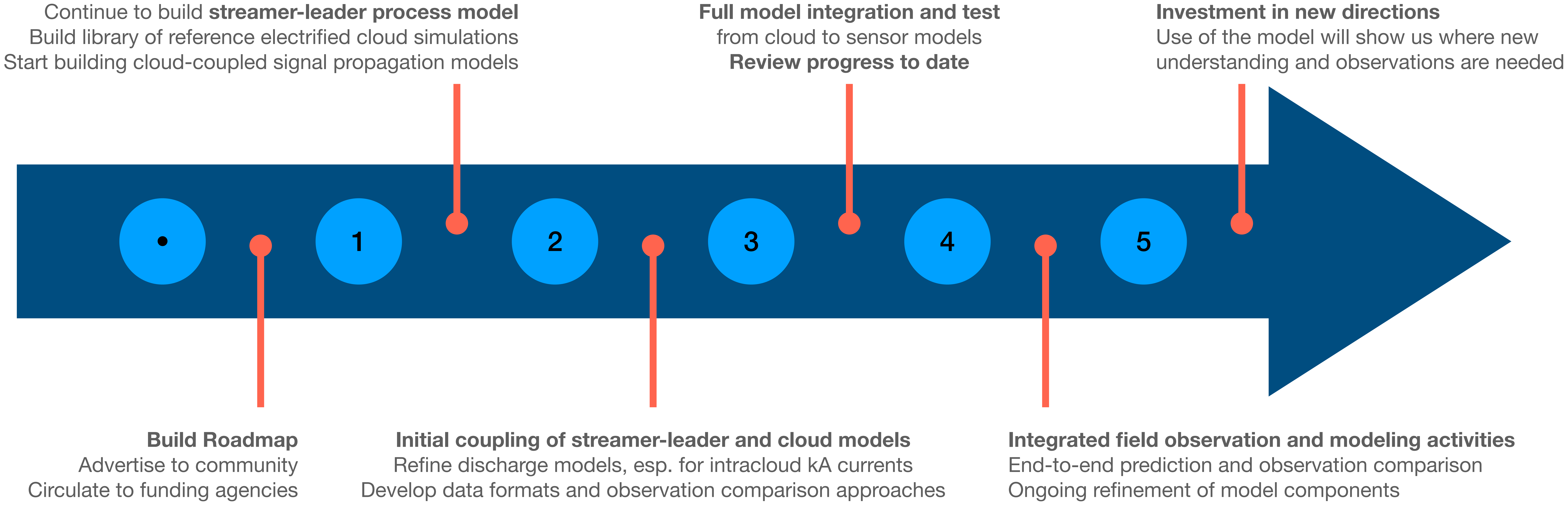
Building the model

- We can observe much more than we can model, especially at full scale for complex flash geometries in realistic clouds. How can we model those things?
- **Last year:** Reviewed state of the science, wrote roadmap, identified needs and uncertainties. *doi: 10.5281/zenodo.14624043.*
    - Lightning physics, meteorology of electrification, sensors
    - Homework for tonight: read the overview, the summary, and the sections most relevant to your scientific expertise.
- **This year:** implementation planning, pragmatically using what is already known
    - Regularly exercising a model will uncover new needs in theory and observations

Five year timeline

Given goals in yrs 4-5, what model can we build in yrs 2-3?

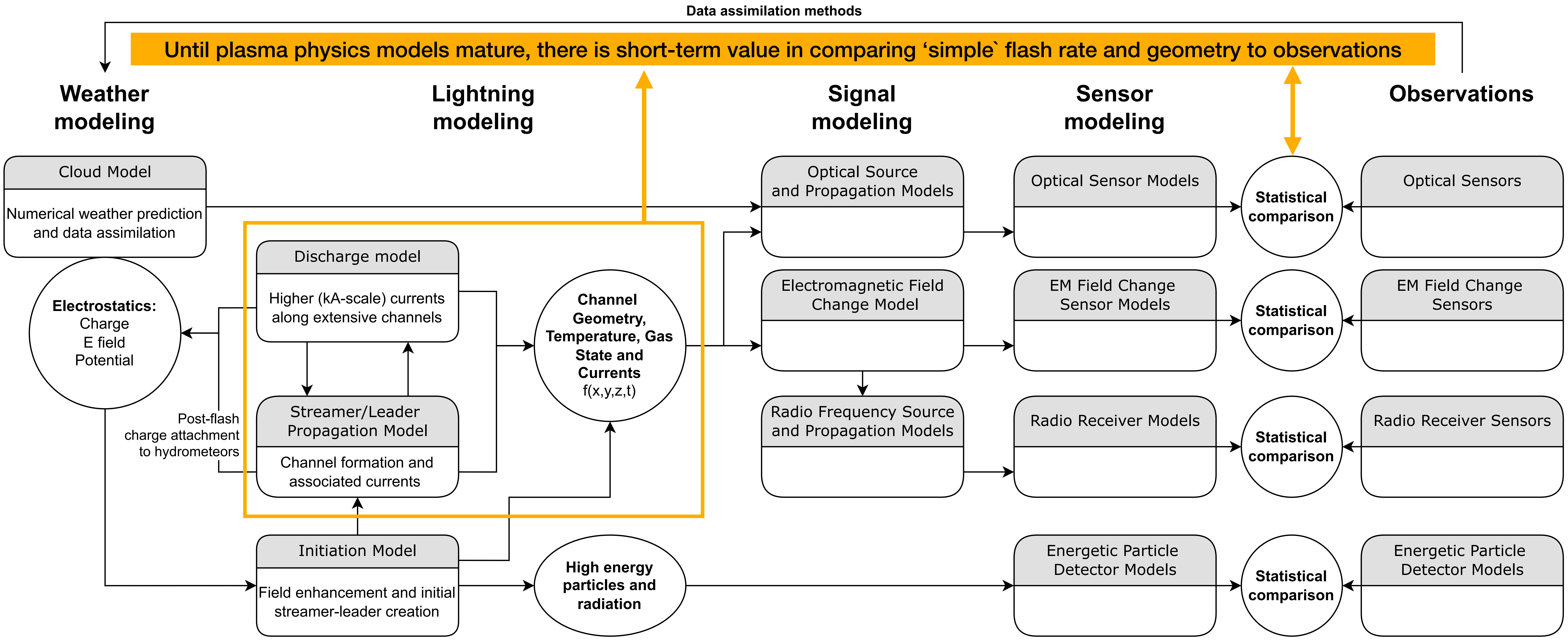
Timeline as envisioned in the roadmap



Forthcoming Bull. Amer. Meteorological Society article: proposal accepted; due in August.

Panel will outline the implementation plan for each model component.

Major model components

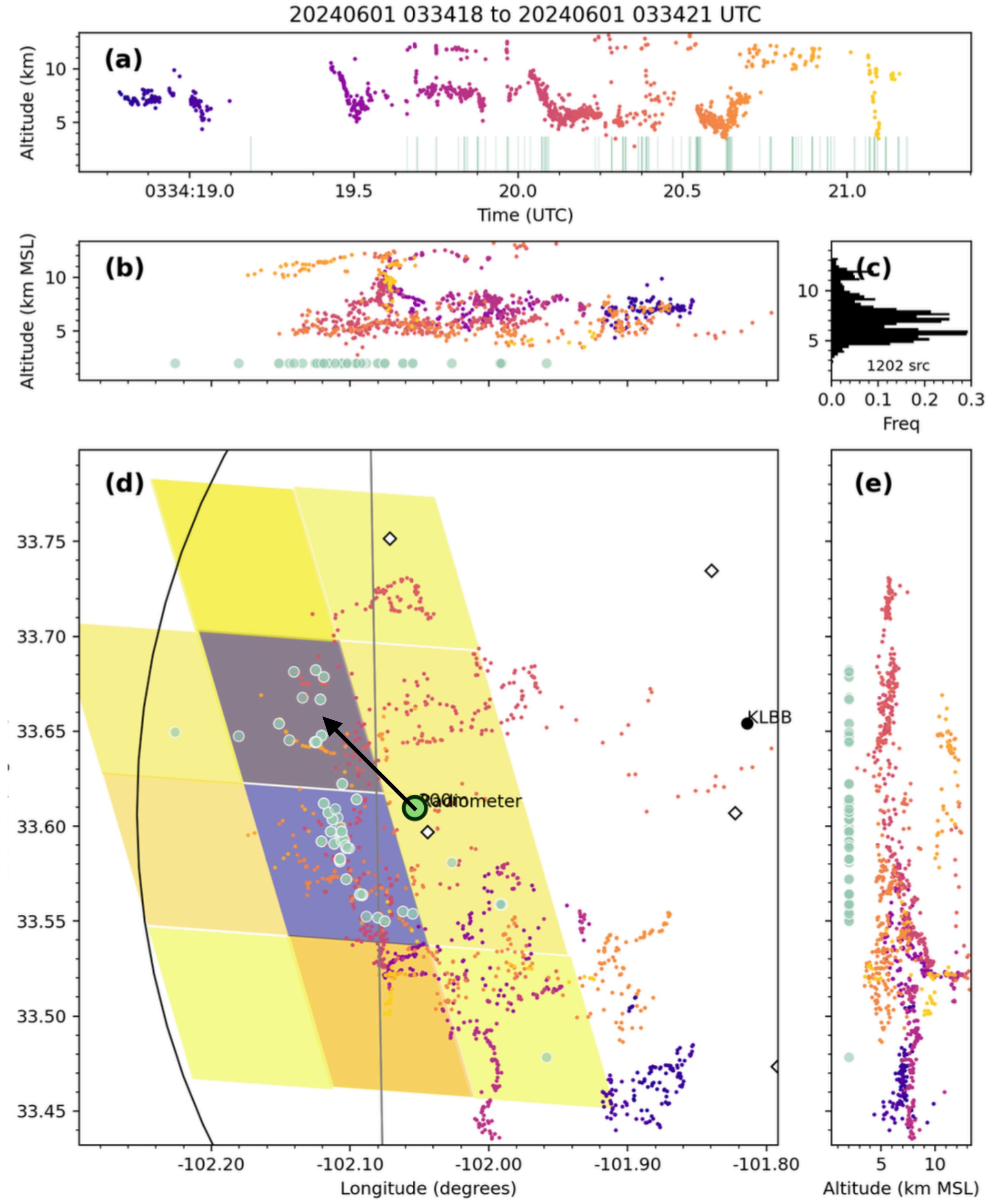


Loose coupling between components is preferred where possible

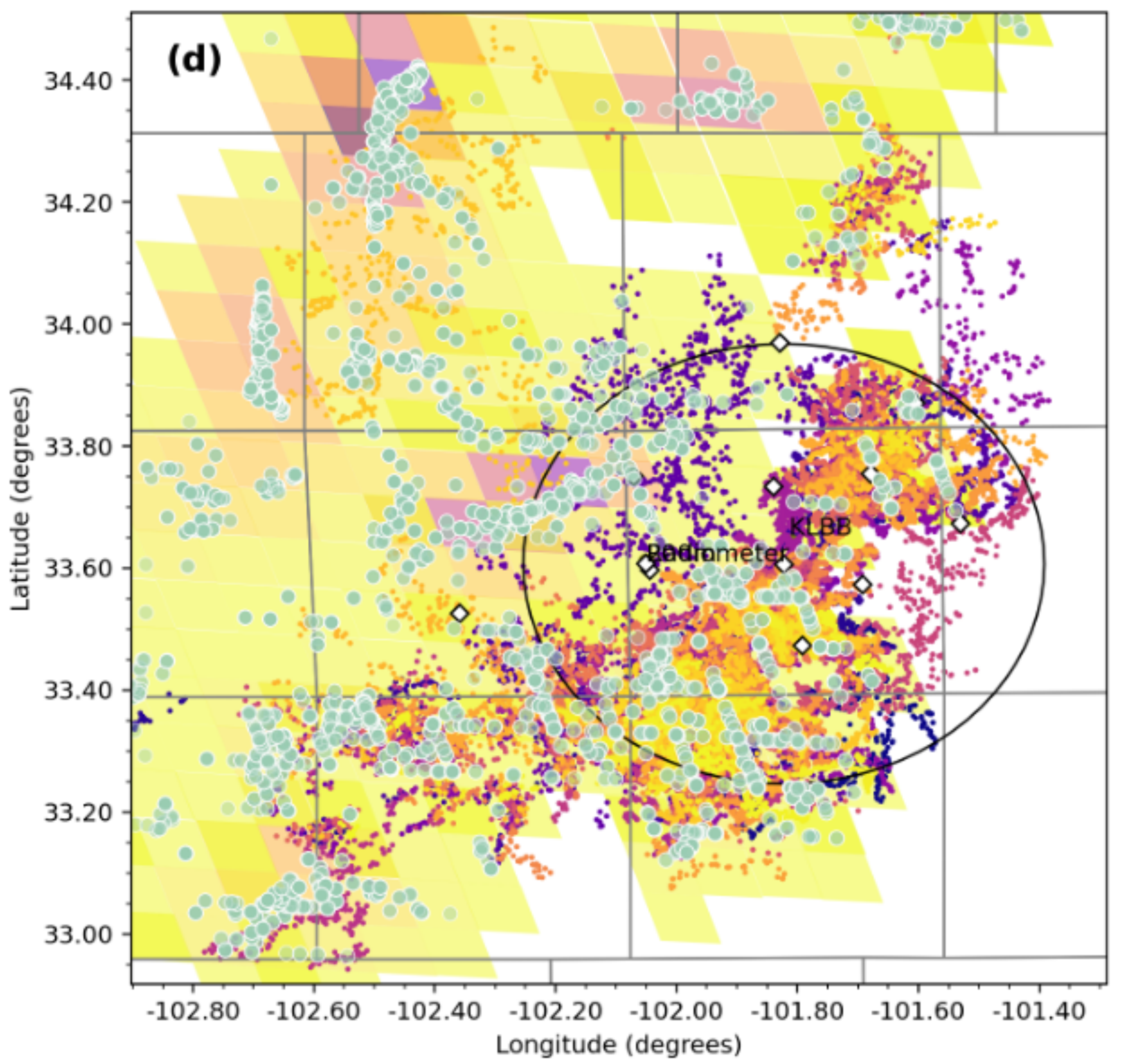
Ancillary models for chemistry, impacts to human and natural environments, etc. are envisioned.

Modeling what we observe

Observed GLM TOE and LMA, 2 s, one flash



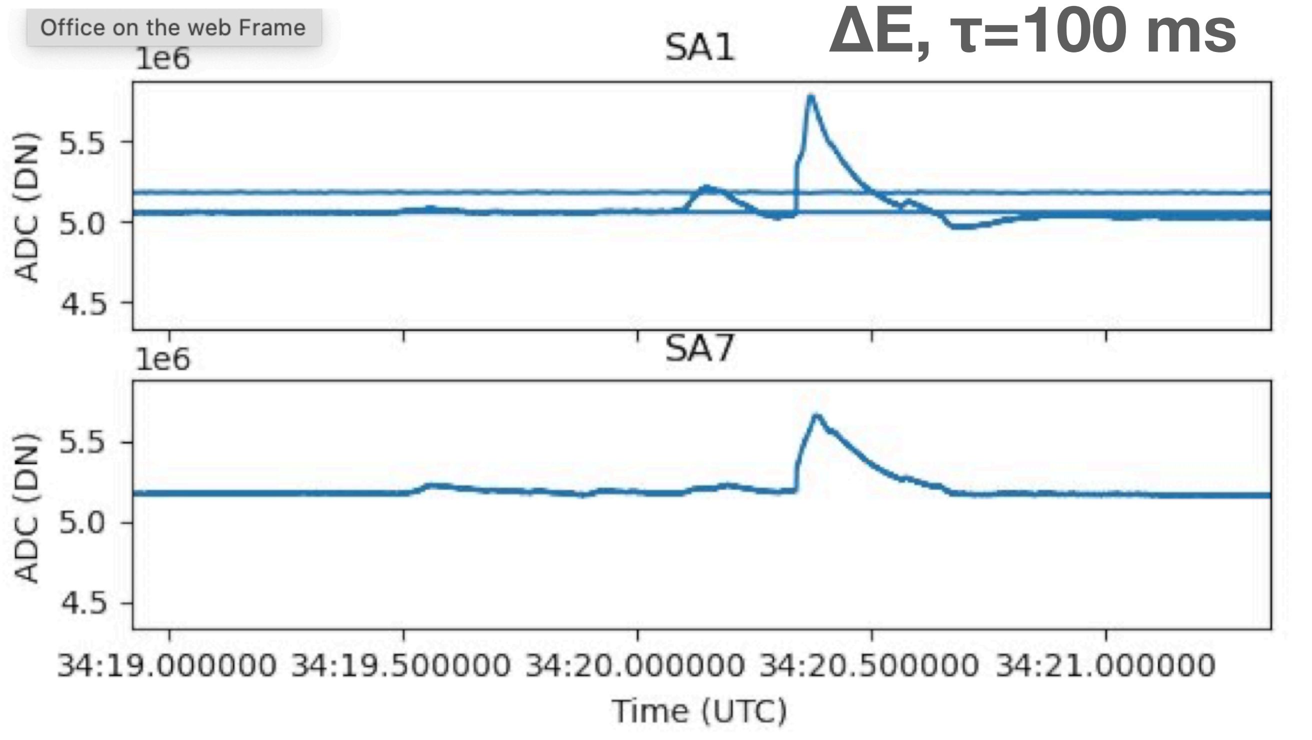
Observed GLM TOE and LMA, 90 s

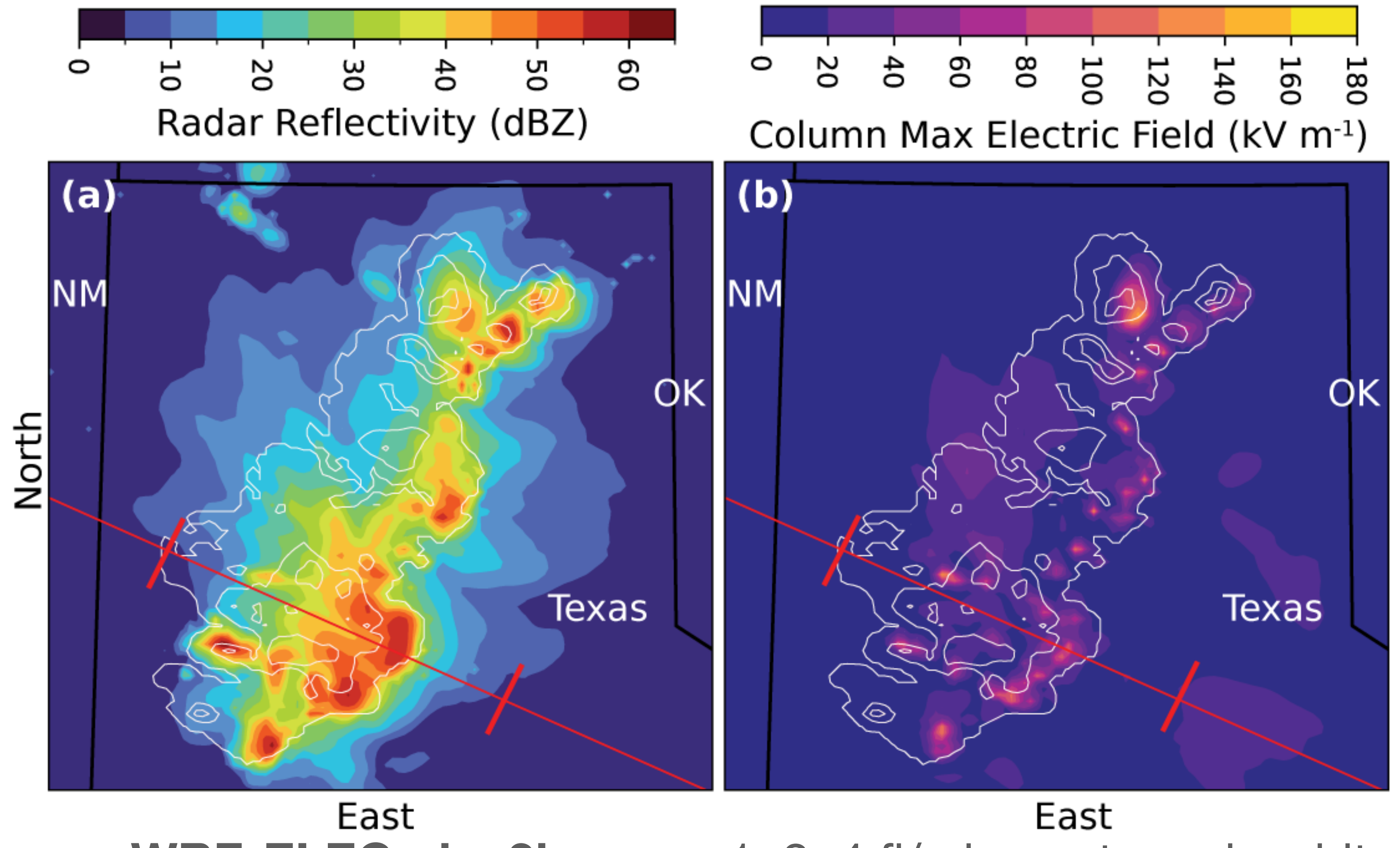


- **Observed** with Sandia radiometers, West Texas LMA, GLM, and electric field change
    - Extensive stratiform flashes and smaller flashes in convective cores
- **Successful simulation** of this mesoscale convective system.
    - "Trivial" extension of existing real-time TTU-WRF runs

What is the path to modeling each sensor type?

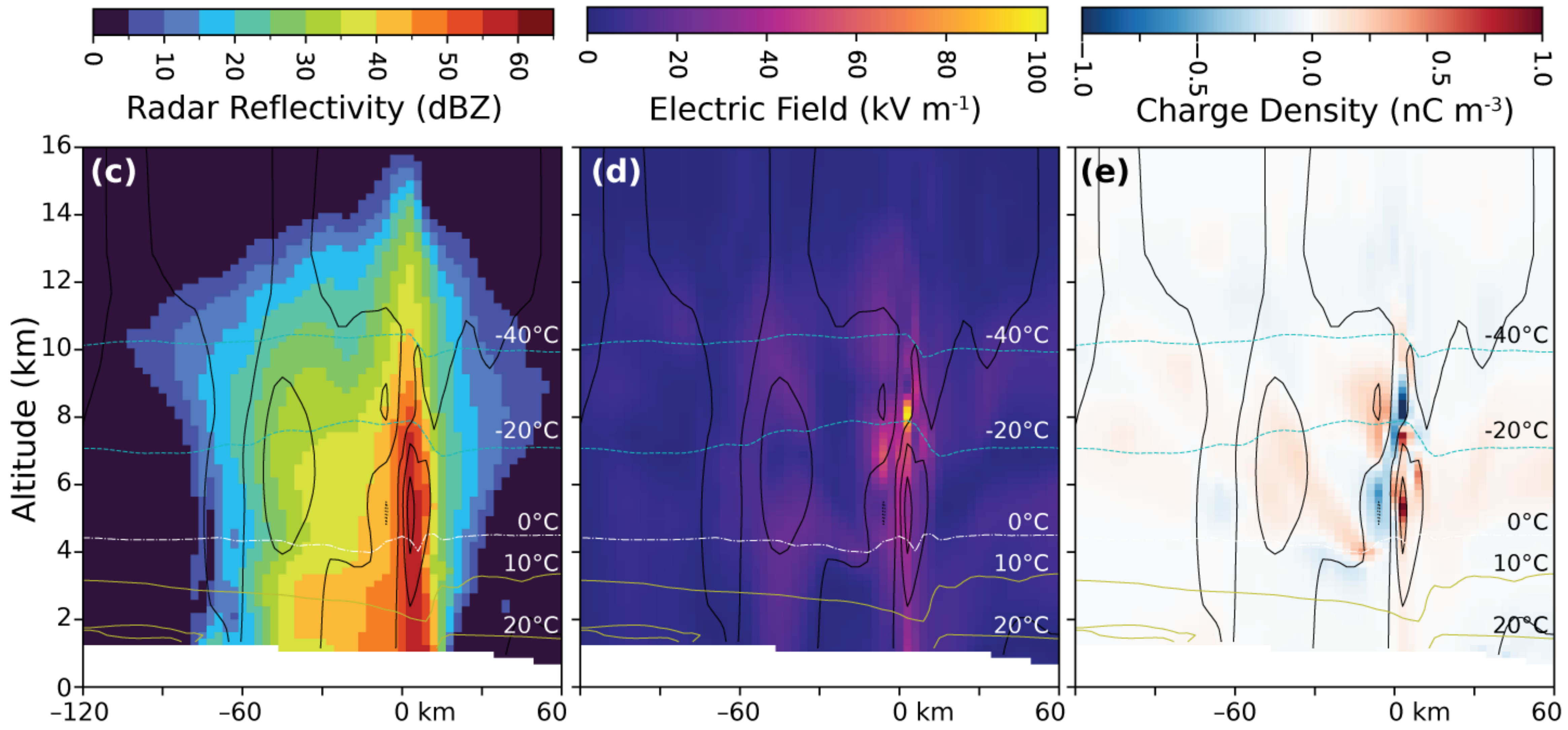
ΔE, τ=100 ms





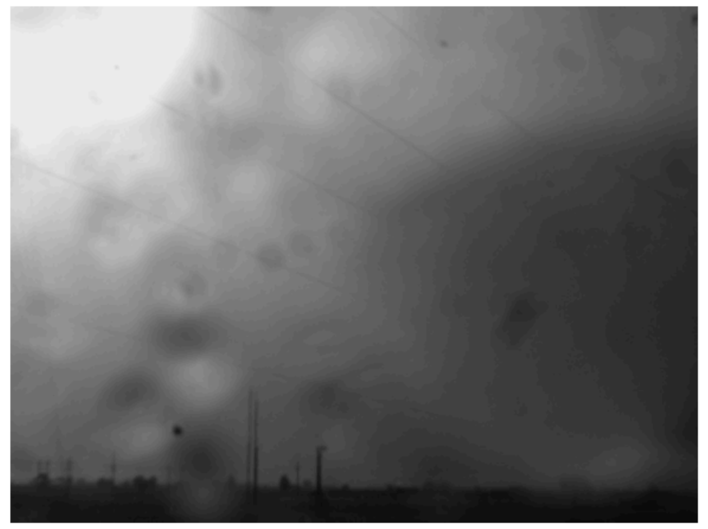
WRF-ELEC, dx=3km

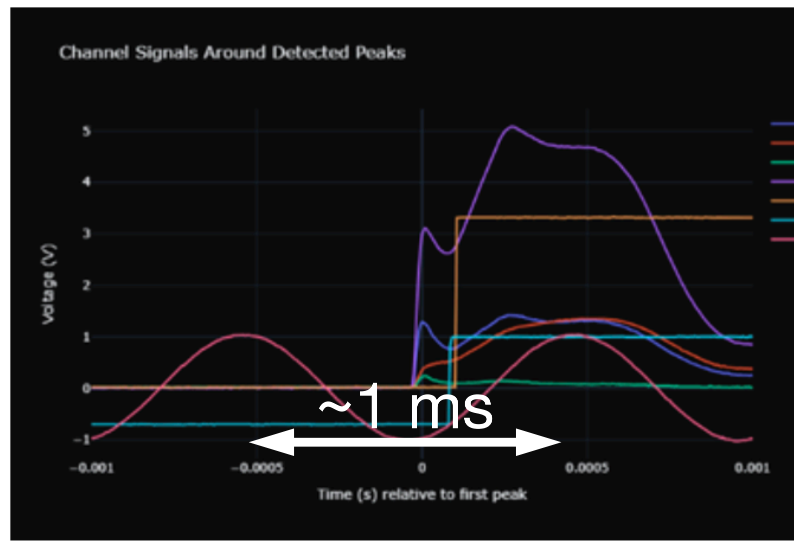
1, 2, 4 fl/min contours in white



Horizontal distance along cross section, electric potential contoured in black

ΔE, camera, radiometer





Practical first steps *(one example)*

What to do while models of channel physics mature?

It is real labor to:
- define interfaces
- write and connect reusable code
- develop well-documented sample datasets
- Teach others to use these

Observations of flash geometry

Share plentiful GLM and LMA data.

Task

Community coordination

Existing WRF-ELEC simulations with flash geometry

Share existing simulation output.

Develop approximations to channel current space-time distribution. **It will be wrong, but how wrong?**

Draw on literature and physical intuition for essential principles.

Optical scattering and sensor modeling

Use existing optical scattering code with 3D bulk microphysics.

RF and field change sensor modeling

Theory for prediction of dE/dt and dB/dt is mature.

Statistical comparison of modeled and observed data

Share validation data.

Model system R&D

Output at flash initiation instead of at fixed times.

Define data structures that flash physics schemes can adopt.

Define data structures that future sensor emulators can adopt.

Develop (automated) validation approaches

Work from the past year

Advertisements

- AGU, AMS Town Hall and Panel discussions on the roadmap
  - Dozens of attendees at each, easily filled up the 1+ hr of discussion
- ICAE, AGU newsletters
- Visits with program managers at NSF, NASA, NOAA

- The review of individual contributions on upcoming slides is not an exhaustive list. See also invited talks later today.
- Help us capture relevant pieces during discussions and breakouts.

Work from the past year

Practical implemention steps toward a model

- Email correspondence on the roadmap, focused on extant models:
  - U. Ebert (CWI, Netherlands): streamer models, working toward simplified ODEs and parameters that are more readily computed; note open source work. https://www.cwi.nl/en/groups/multiscale-dynamics/. https://dx.doi.org/10.1029/2024JD041385. https://arxiv.org/abs/2409.04282.
  - A. Kostinsky (Technion U., Israel): experimental and theoretical work on the coupling between streamer/leader/discharge dynamics in turbulent clouds with hydrometeors that make unique plasma discharge features. Many references provided.
  - N. Lehtinen (U. Bergen, Norway): streamer parameter model at https://gitlab.com/nleht/ and associated papers; presentation translating some of the results from Gorin's 1970s work on space stems for leaders.
  - P. Dreike (Sandia N.L., USA): names of internal tools that can model many of the signal propagation needs.
  - T. Mansell (NOAA/NSSL, USA): new mode for COMMAS to run his branched discharge scheme with idealized / a priori charge structures in the absence of meteorology.
  - X.-M. Shao (Los Alamos N.L., USA): cleanup of Jefimenko current -> EM model; nearly ready for release

Open data, open code

- **Data library**
  - NASA, DOE labs have their own repositories. NSF Atmosphere Cluster has the NCAR EOL Field Data Archive
    - A **goal for this week** is to **estimate data volumes** we might want to store, leading to a proposal for storage at EOL.
  - Examples from TTU:
    - WRF ensemble at dx=3km, WT Mesonet, and LMA data from a case during DC3 with unusual electrical structure, Chmielewski et al. (2018, JGR), https://data.eol.ucar.edu/dataset/353.220
    - Hard drive with several TB of electrified COMMAS runs at dx=125m with branched discharge output, Brothers et al. (2018, JAS)

- **Repositories** – would like to set up an org-level one for the grand challenge, to serve as a clearinghouse for code led by others.
  - WRF-ELEC: https://github.com/MicroTed/wrf4-elec
  - Riousset's fractal discharge model: https://github.com/stroeum/FraMED
  - glmtools, xlma-python, lmaworkshop: https://github.com/deeplycloudy/
  - Geant4: https://github.com/Geant4
  - …
  - …
  - …

Work from the past year

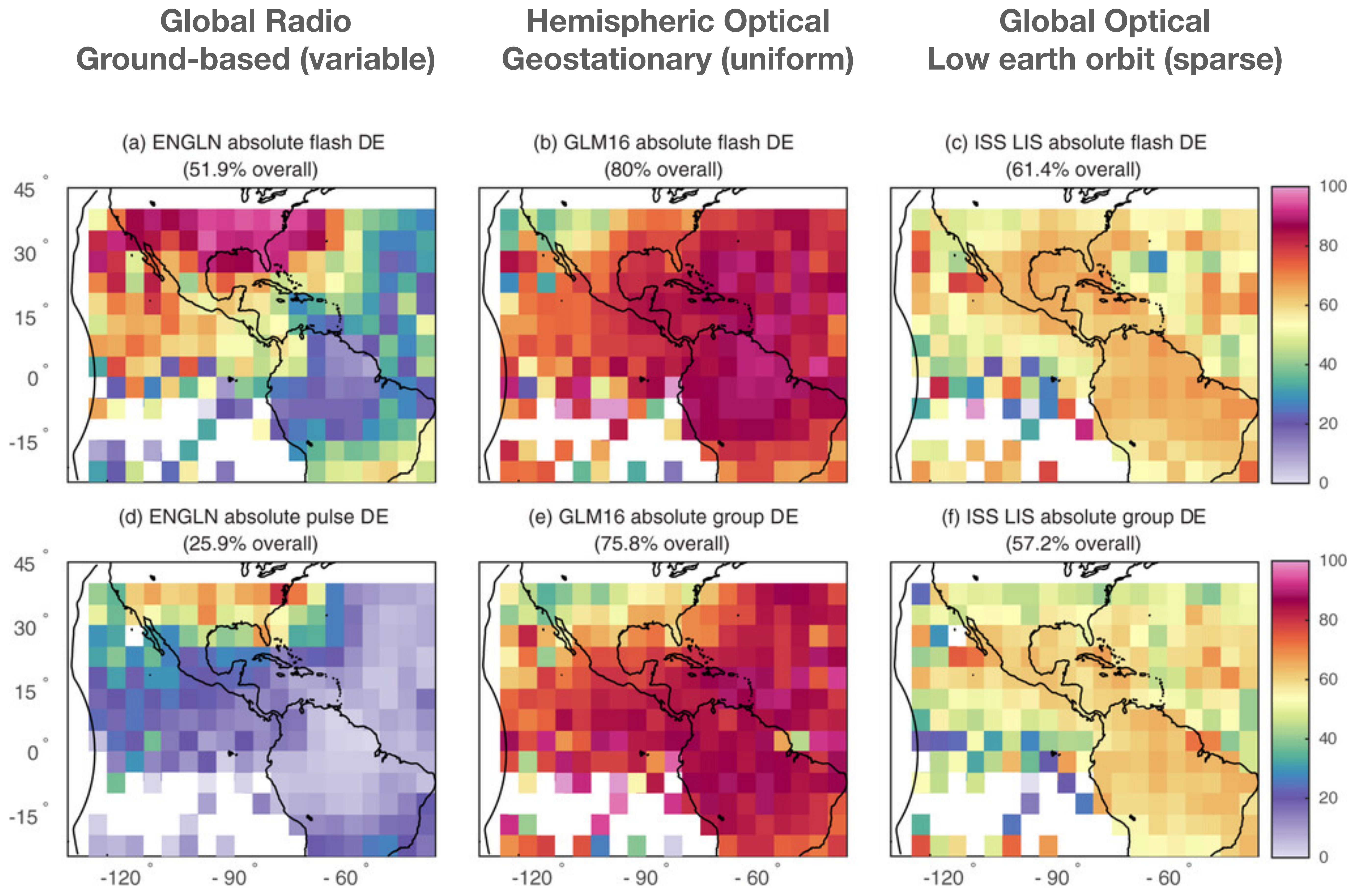
Institutional investments, funding successes, strategy development

- NSF support for this workshop, and awareness of the possibility of proposals mentioning alignment with the roadmap.
- NASA investments in OSSE work for future space-borne sensors
- NOAA GSL continues to work on lightning data assimilation
- NOAA GEOXO-LMX funding for radiometer/spectrometer measurements
- TTU including modeling and related obs in one funded project; several proposals in review
- *Your efforts here …*
- Sandia 5-year plan - Thom Edwards

Motivating example

Implications for data assimilation and climate monitoring

- Lightning is an excellent, globally available indicator of mixed phase rimed precipitation in deep convection — a key process uncertainty in forecast and global climate models. (e.g., Bruning et al. 2024, doi: 10.1175/MWR-D-24-0060.1.)
- Lightning is an WMO essential climate variable (Aich et al. 2018, doi: 10.1029/2018eo104583).
- Right: Lightning sensors measure different processes, and so have spatially variable detection efficiencies. Optical measurements are further modified by cloud optical depth. Ground based sensitivity depends on sensor spacing.
- Related talks:
    - Weiss et al., Tue 8:45 am, Rm. 219, *Winter Lightning Flashes as Detected by a Lightning Mapping Array (LMA) During the Lake Effect Electrification (LEE) Field Campaign*
    - Allen et al., Tue 2:30 pm, Rm. 219, *Assimilation of Geostationary Lightning Mapper Observations into the NOAA GSL Rapid Refresh Forecast System*



Detection efficiency of joint flash population

Flashes: 52 - 80%

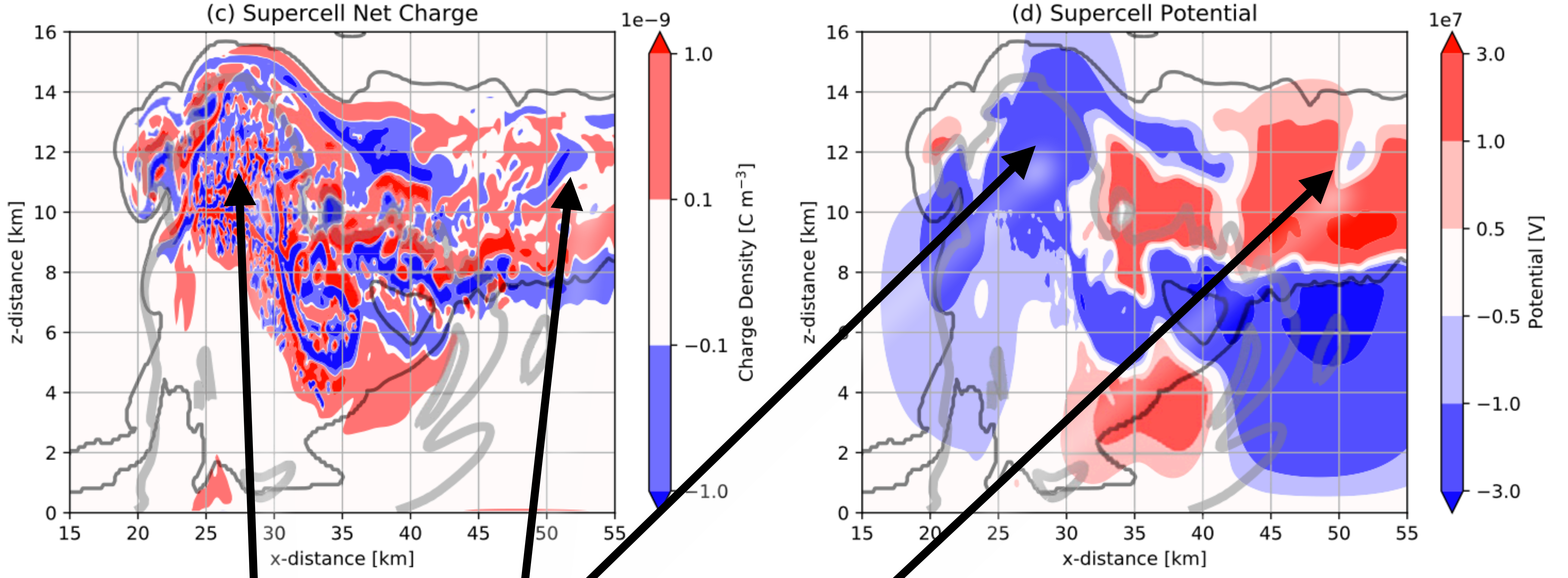
Regional variability of +-50% in some sensors

Sub-flash processes (“strokes”): 26-76%

Virts et al. 2024, *Bayesian Analysis of the Detection Performance of the Lightning Imaging Sensors*, doi: 10.1175/JTECH-D-23-0090.1

Existing model capabilities

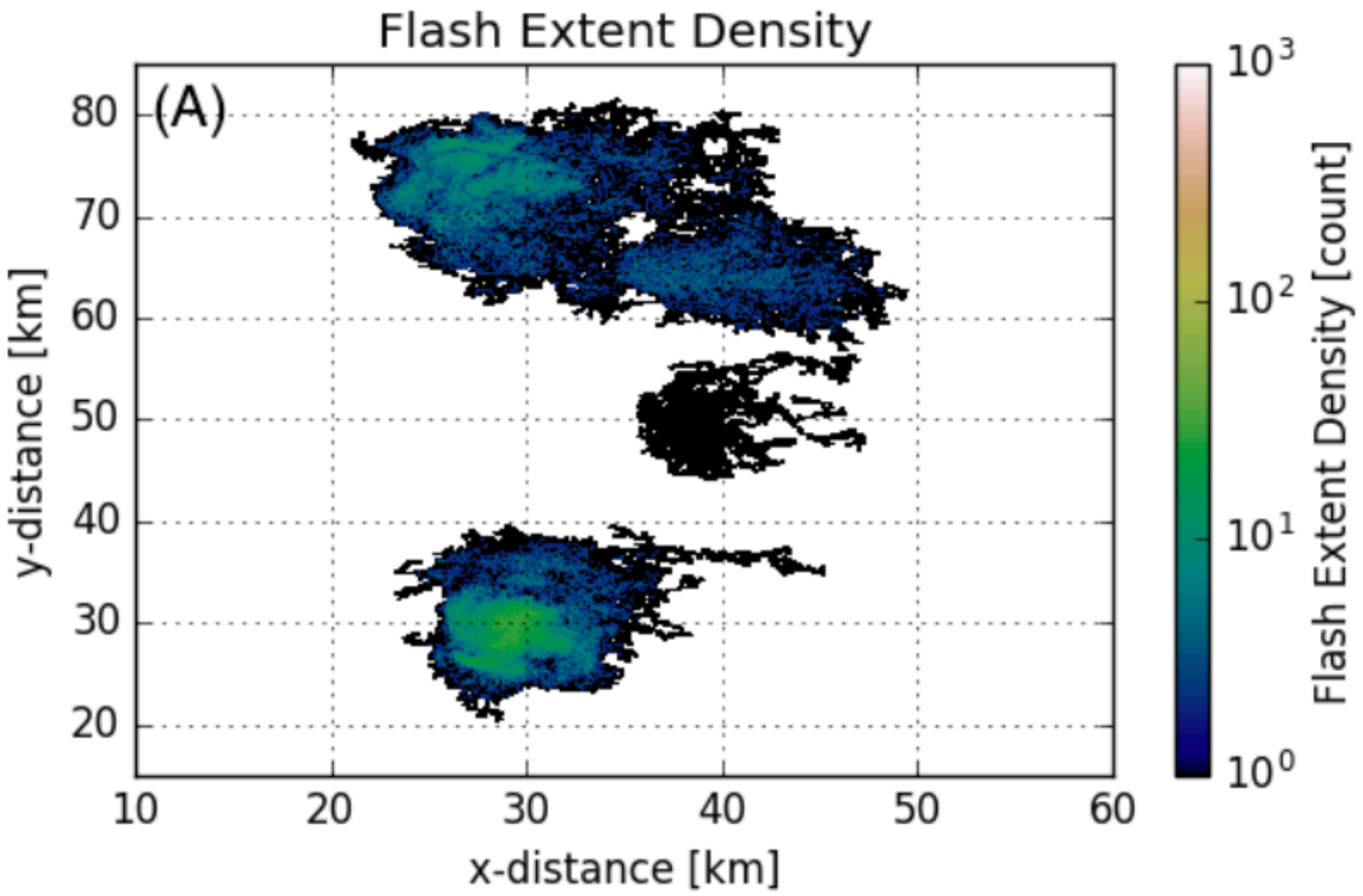
125 m LES simulation of a supercell storm observed during a field campaign in West Texas

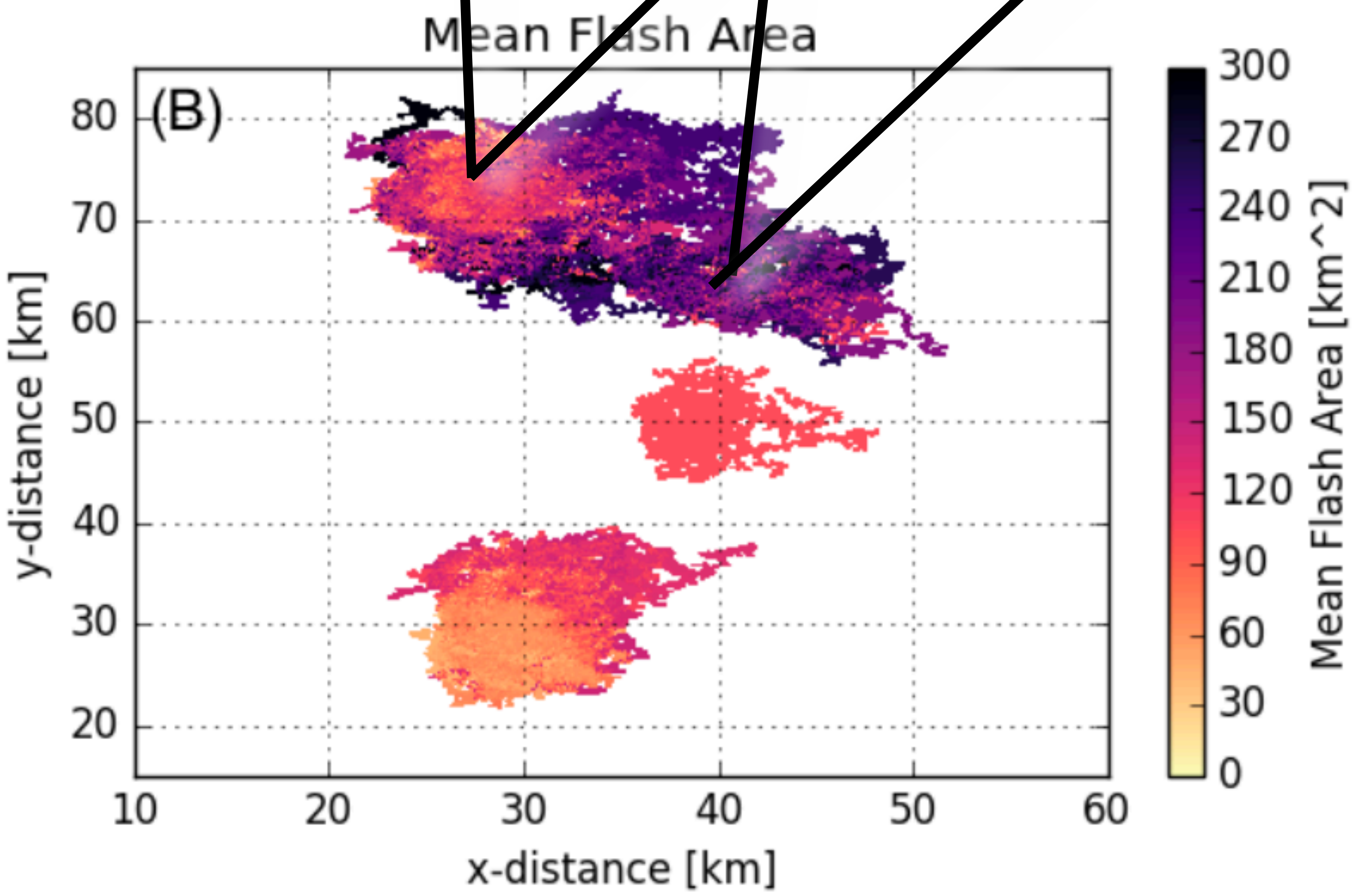


Brothers et al. (2018, doi: 10.1175/JAS-D-18-0007.1.)

Cloud electrification models (e.g., WRF-ELEC, COMMAS) can predict realistic lightning flash rates and channel extents. (T. Mansell, NSSL)

Those models produce geometrically reasonable channels, but lack realistic current dynamics to drive the varied radio and optical signals observed during each flash (microsecond time scales across O(10-100) km spatial extent).





The simulated flash rate and spatial distribution of flash areas (left) matches that observed with a 3D lightning mapping array

The flash area gradient corresponds to the gradient from complex to layered charge structure

Supporting work on the roadmap

- NSF conference proposal submitted to support some student travel and food at the next workshop. Internally reviewed.
- Ad-hoc proposals to NSF always welcome by the usual mechanisms. Please mention the roadmap, and use it to stimulate proposal ideas.
- Contribute to NASA decadal survey - what ideas do we have for whitepapers, links to characterizing convection in the earth system? (Lang)
- Other ideas?

Costs associated with university grant-year efforts typically total $150K/yr, including overhead of about 50% at most universities, so the minimal plan below of 60 total grant-years is $9M over 5 yrs. Such costs put the lightning modeling effort into the funding class typically provided by NSF Science and Technology Centers and DOE Grand Challenges.

Task	**Yr1**	**Yr2**	**Yr3**	**Yr4**	**Yr5**	**Total**
Cloud	1	1	1	1	1	**5**
Lightning initiation	1	1	1	1	1	**5**
Streamer-leader	1	1	2	2	2	**8**
Discharge		1	2	2	2	**7**
Signal generation: E-field and RF		1	1	2	2	**6**
Signal generation: Optical		1	1	2	2	**6**
Signal propagation and observation: E-field and RF	1	1	1	1	1	**5**
Signal propagation and observation: Optical	1	1	1	1	1	**5**
Model integration and testing		1	1	2	2	**6**
Community coordination	1	1	1	1	1	**5**
Annual workshop	1 (next 3 yrs)			1 (next 3 yrs)		**2**
Estimated total (grant-years)	**7**	**10**	**12**	**16**	**15**	**60**
Estimated cost ($M)	**1.1**	**1.5**	**1.8**	**2.4**	**2.2**	**9.0**

Table of effort from the Roadmap document, Bruning et al. (2024)

Discussion

How can the community outside of the planning committee secure funding to contribute to the effort?

What capabilities would like to see in an end-to-end lightning model?

What uses would you have for such model?

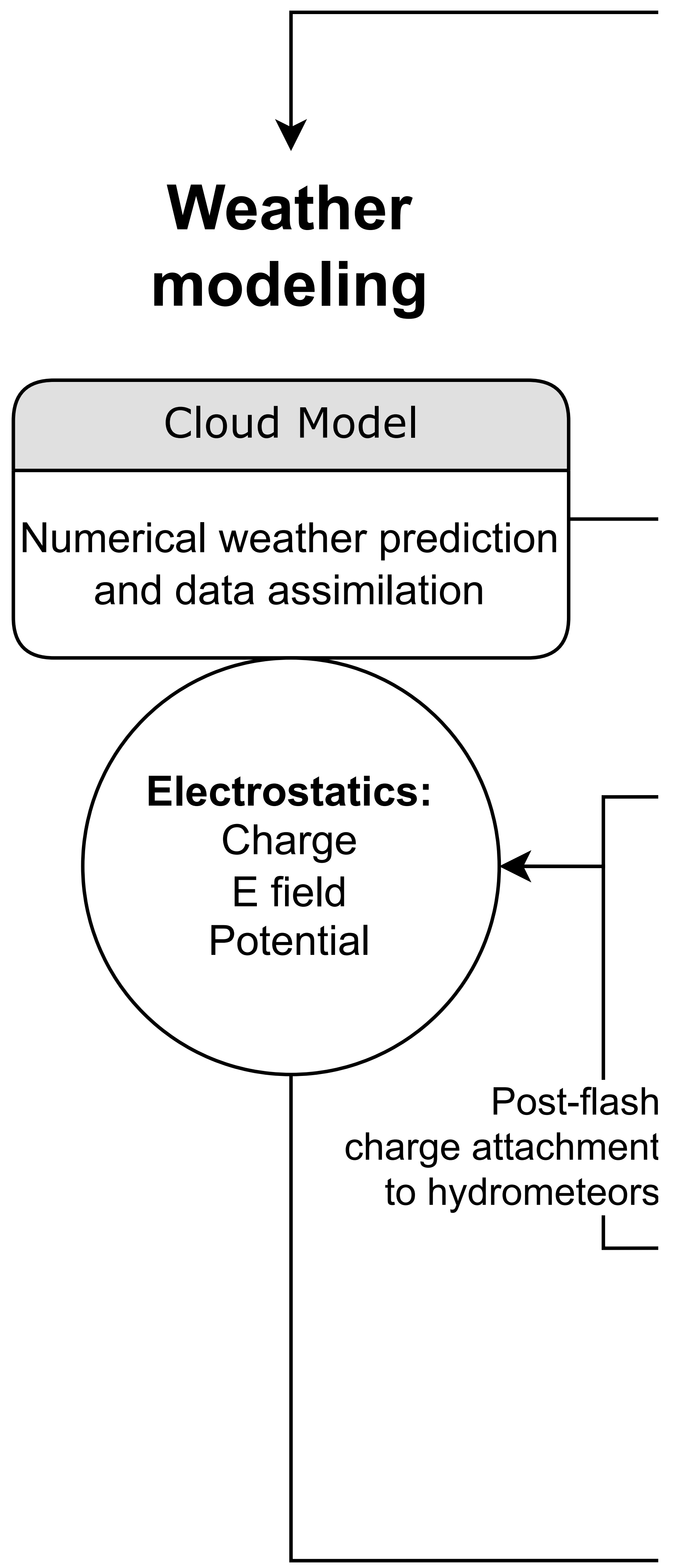
What components do you have that could fit in?

What (new) observations are necessary?

For existing observations, can they be shared in a legible format?

Recommended next steps:
Weather modeling

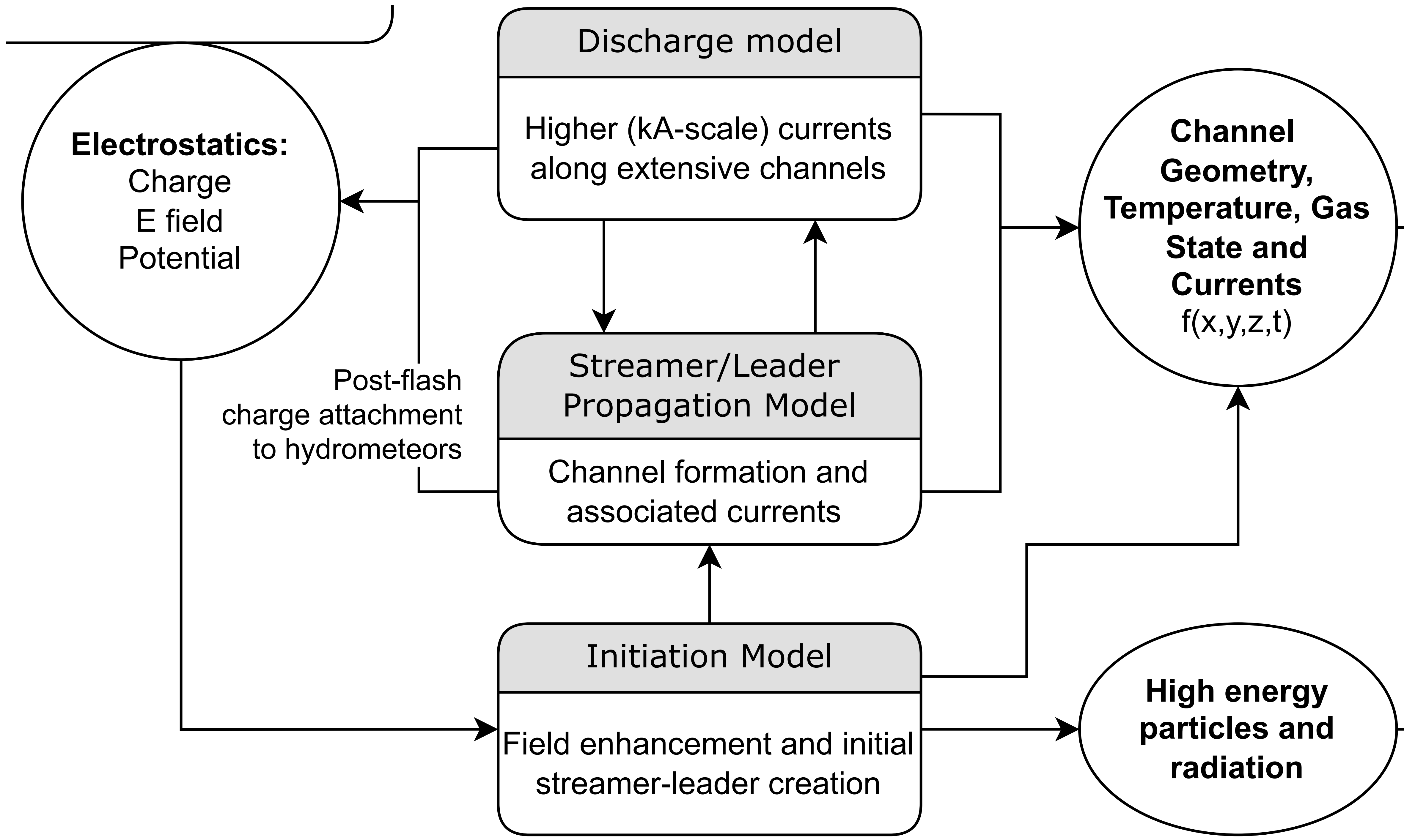
- Develop interfaces for integration of various lightning initiation, streamer-leader, and discharge schemes within electrified cloud models.
- Port electrification and lightning schemes to next-generation modeling systems.
- Compare modeling systems with a retrospective analysis of past field campaign data, validating storm structure as well as electricity.
- Develop a public library of canonical, observationally validated reference simulations of clouds at the km and LES scales, with a guide to data structures that can be used to drive other lightning models. (e.g., Brothers, Bruning, and Mansell 2018, J. Atmo. Sci.)



Recommended next steps:

Lightning initiation

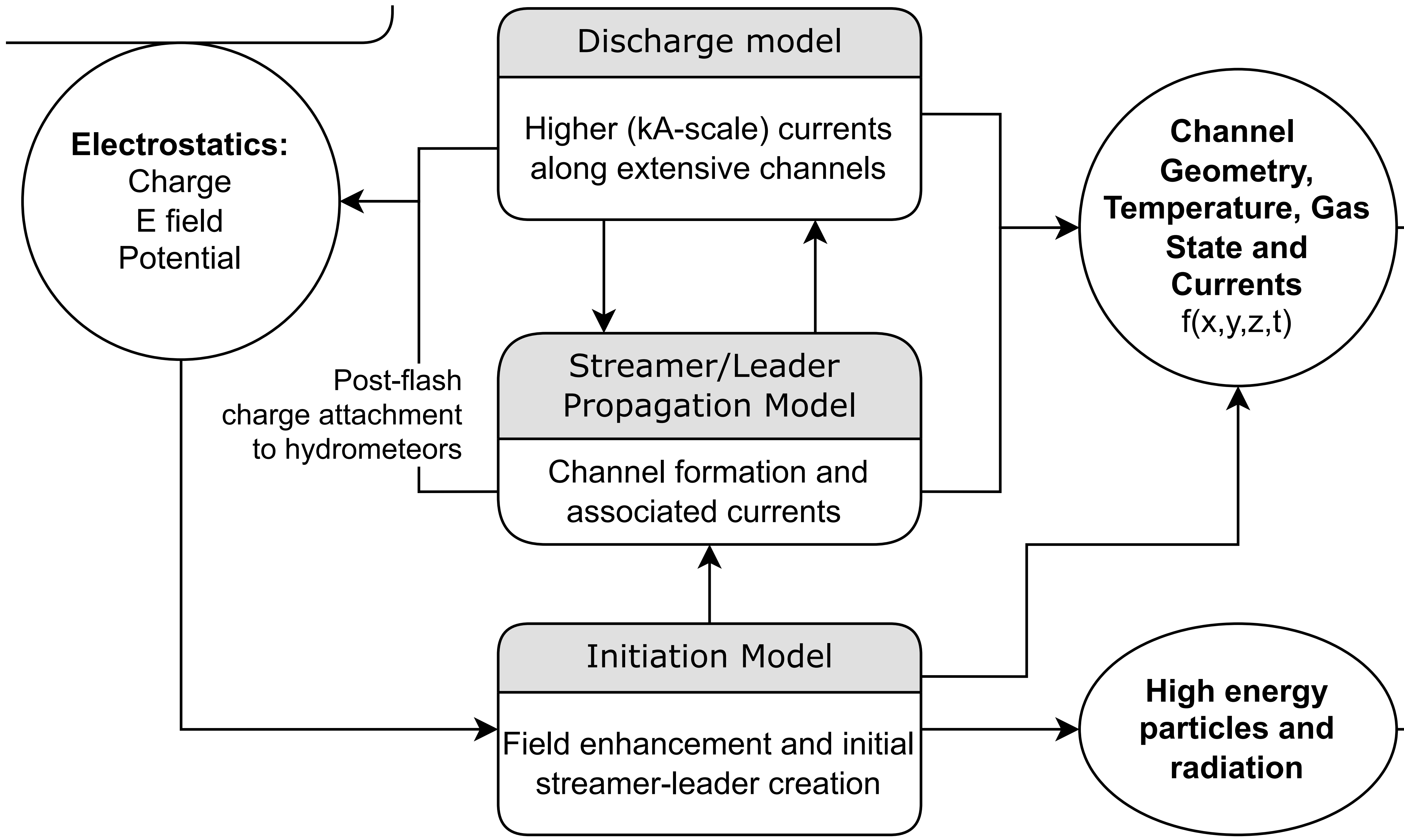
- Stages: (1) initial field enhancement (cosmic rays, RREA, role of turbulence). (2) streamer networks from hydrometeors (3) streamer-leader conversion.
- Need to condense detailed process models to work with high-level inputs and outputs.
- Link to cloud hydrometeor particle size and species distributions from cloud models.



Recommended next steps:

Streamer-leader propagation

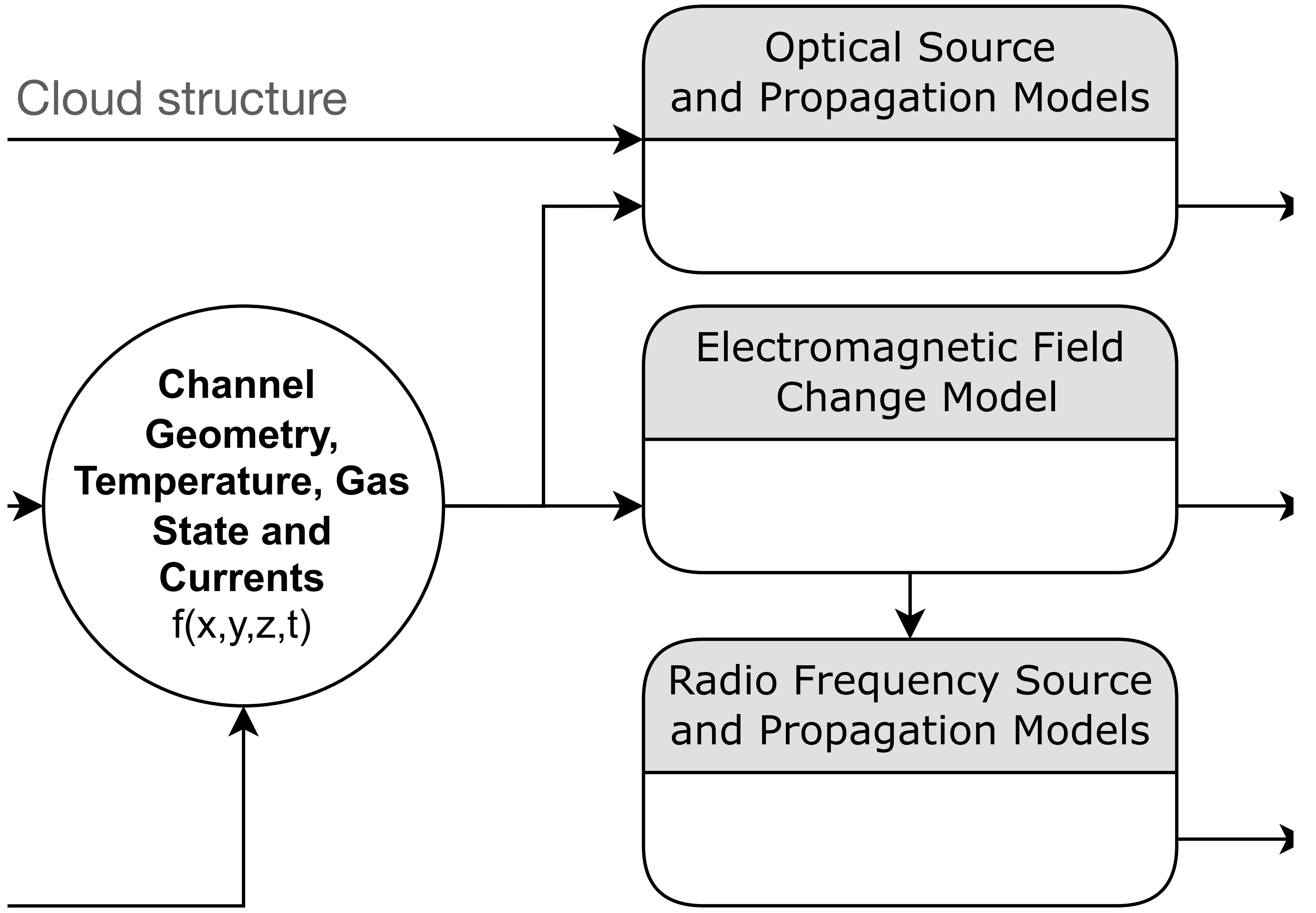
- Among the most crucial pieces.
- Understand computational burden when integrated with existing cloud models.
- Compare channel geometries of quasi-electrostatic and plasma-aware models.
- Work out the coupling to the discharge (kA-scale) model — it's a process loop.



Recommended next steps:

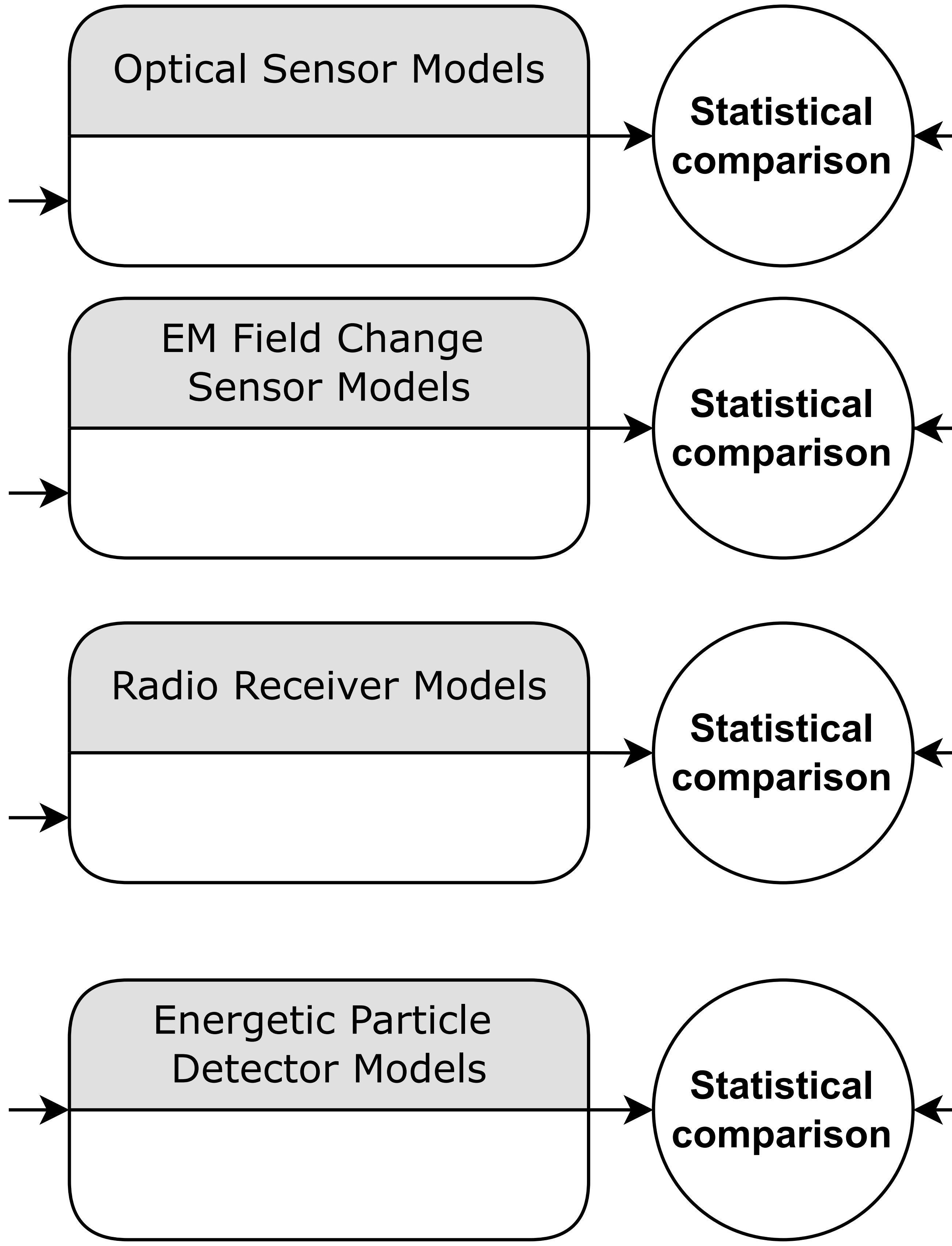
Signal modeling

- Refine and make available existing, mature forward models of optical and electromagnetic sources and propagation in atmosphere and to space.
- Optical source and propagation models are likely less mature than EM models.
- Test limitations of simplified "engineering" models in the context of full channel geometry.



Recommended next steps:
Sensor models

- Generally high-maturity, or easily envisioned from a mature signal model and propagation.
- Development of open reference implementations for each existing or desired observing system.
- Opportunity for detailed forward modeling of new sensor designs?



Recommended next steps:
Observations

- Develop a validation strategy, ensuring modeled signals each have a matching observation.
    - Identify needed new instruments.
    - Plan a coordinated, multi-agency, and perhaps international, observing campaign for research grade measurements.
    - Plan for routine, semi-automated validation using (quasi-)operational instruments and modeling systems.
- Expect errors, and use statistics.
    - Cloud model errors, lightning model, chaotic dynamical uncertainty?