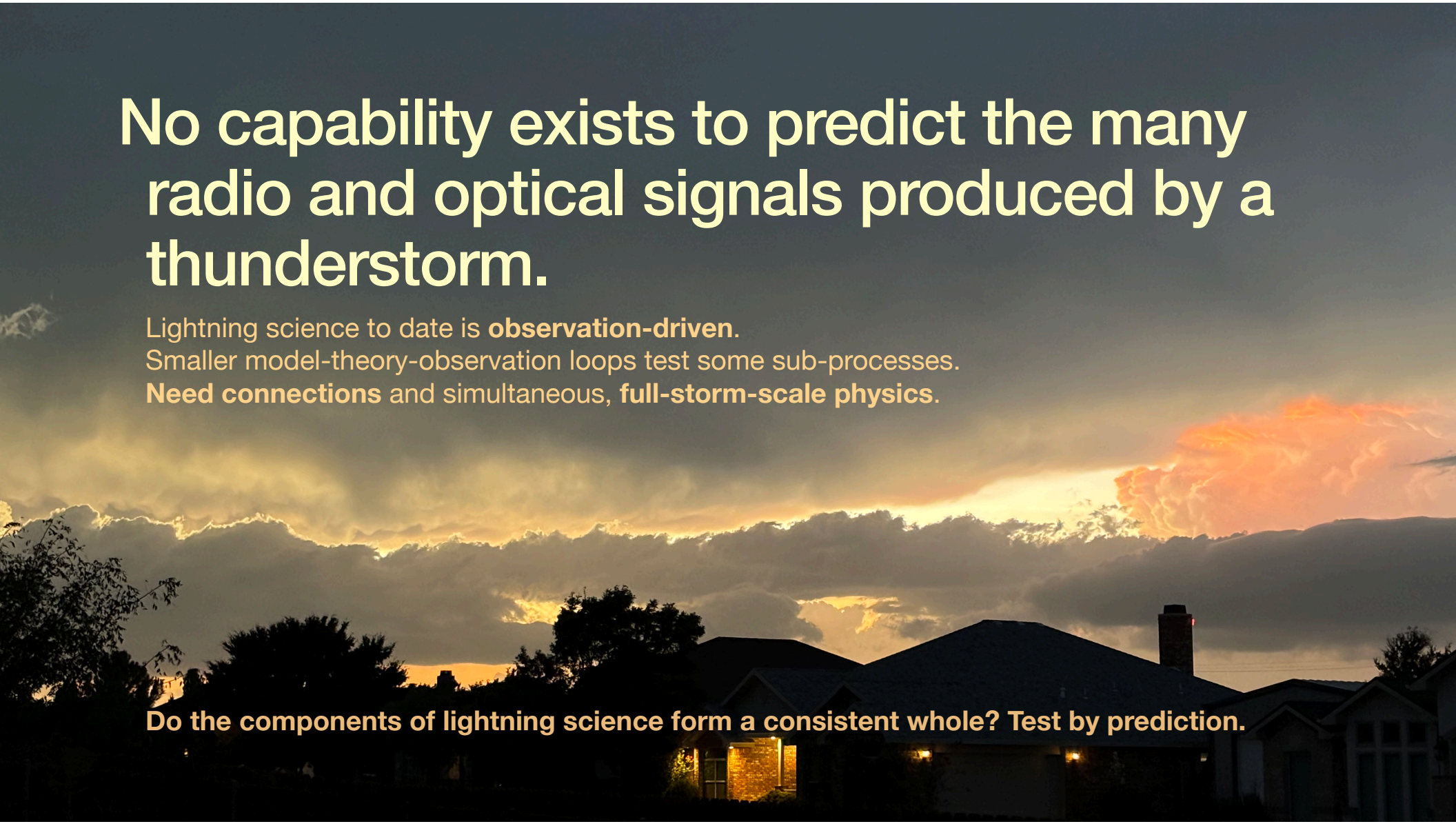
Toward a physical model of lightning: a community grand challenge

105th AMS Annual Meeting, New Orleans, LA
Fourth Symposium on Community Modeling and Innovation
2.5, 13 January 2025, 11:45 am

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

Thanks to Sandia National Laboratories for instigating and supporting the initial draft of the roadmap



No capability exists to predict the many radio and optical signals produced by a thunderstorm.

Lightning science to date is **observation-driven**.
Smaller model-theory-observation loops test some sub-processes.
Need connections and simultaneous, **full-storm-scale physics**.

Do the components of lightning science form a consistent whole? Test by prediction.

Why a lightning model?
Some Stakeholders (USA)

- **NSF:** basic science of lightning
  - Lightning physics, meteorology of electrification
- **NASA/NOAA:** optical lightning sensors and climate-scale observations
  - Need for physics-based observing system simulation experiments
- **NOAA:** Explicit forward modeling of lightning for Numerical Weather Prediction
  - Data assimilation of varied lightning sensor types, hazard modeling
- **DOE:** Earth-observing platforms and sensors
  - Lightning a near-constant background signal

Writing a roadmap



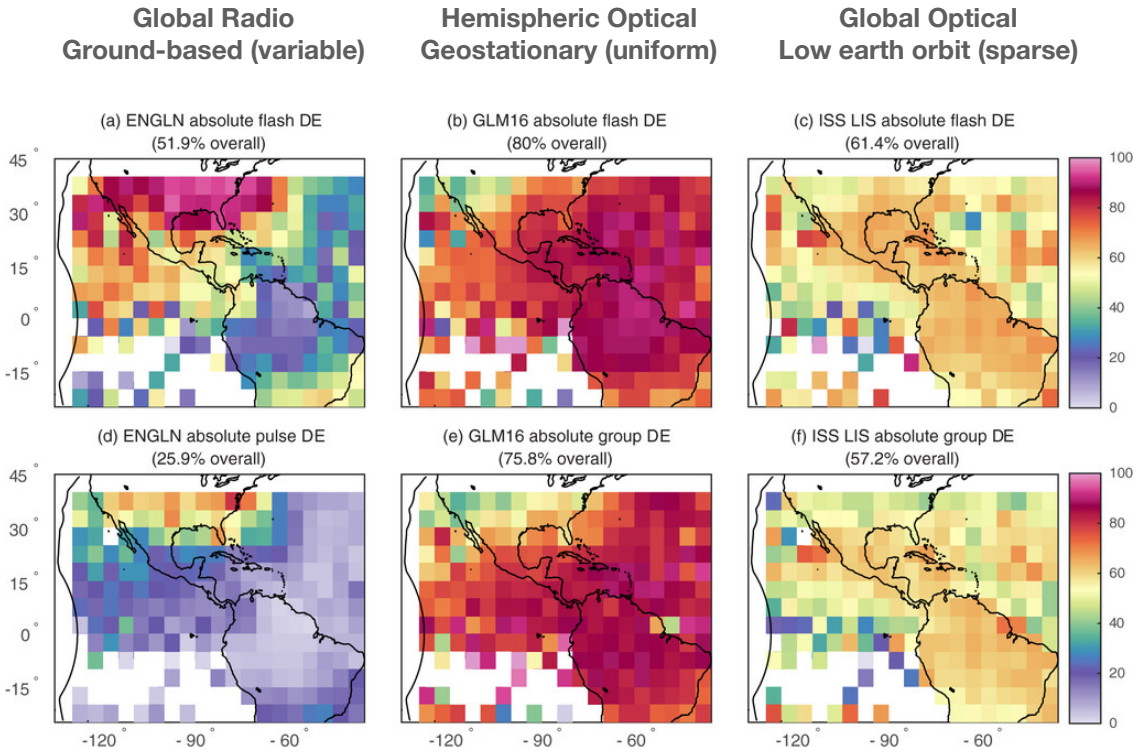
http://lightning.ttu.edu/workshop

- Formed **lightning advisory panel** to organize an initial workshop
- **Held 60-person workshop** with a day of invited talks and a day of breakouts
  - Identified requirements, gaps, and recommendations.
  - Strong consensus that computing, observations, and knowledge are mature enough to try integration
  - No need to reinvent — focus on stitching together existing models and comparing to observations
- **Visited** with NSF, NASA, NOAA, DOE, etc. to build awareness of the roadmap effort
- **First version** of a 5-year **roadmap** is complete, about 30 pages in length
  - **Practically-focused**: what exists, how can we stitch it together?
  - *Inputs, outputs, uncertainties, evaluation methods, next steps*
  - Roadmap v. 1.0 available at lightning.ttu.edu/workshop

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*



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

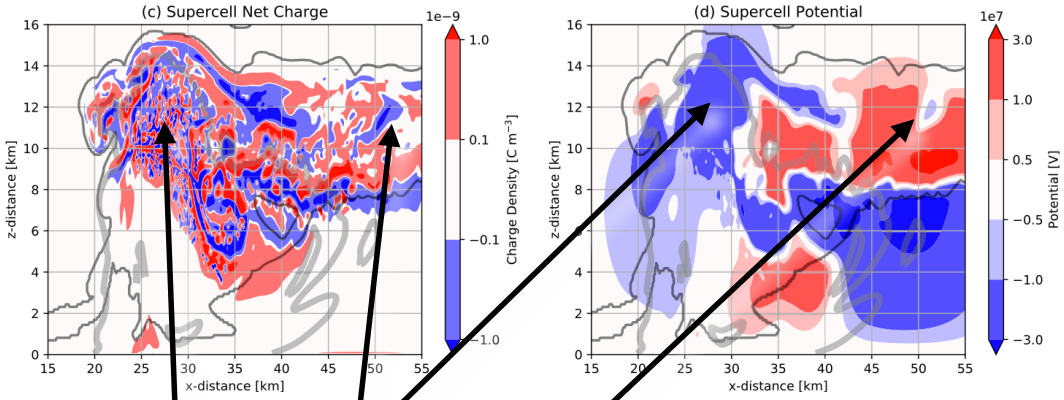
Existing model capabilities

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

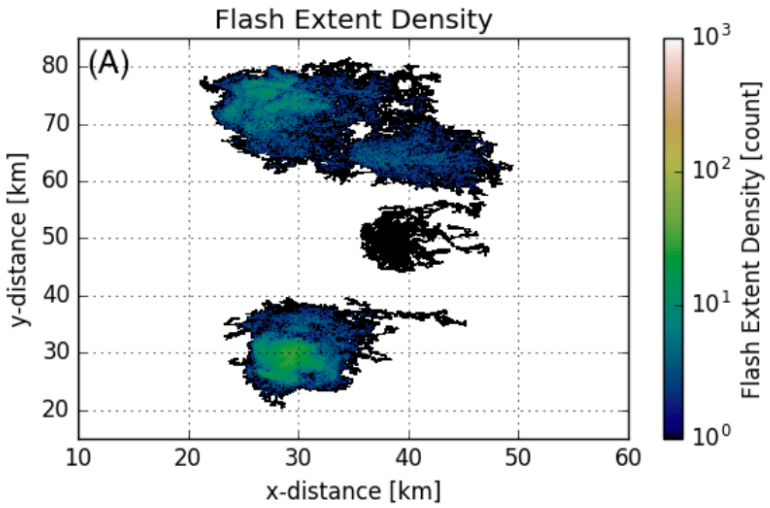
Those models produce geometrically reasonable channels, but lack realistic current dynamics to drive the varied radio and optical signals observed during each flash (microsecond time scales across O(10-100) km spatial extent).

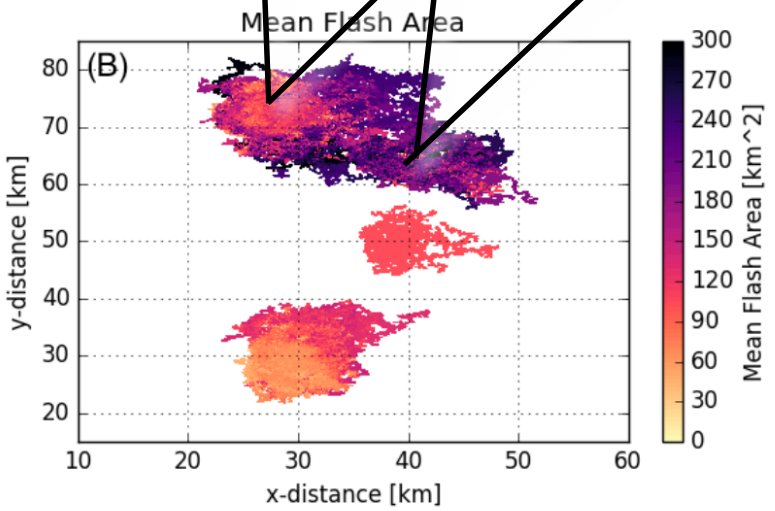


125 m LES simulation of a supercell storm observed during a field campaign in West Texas



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

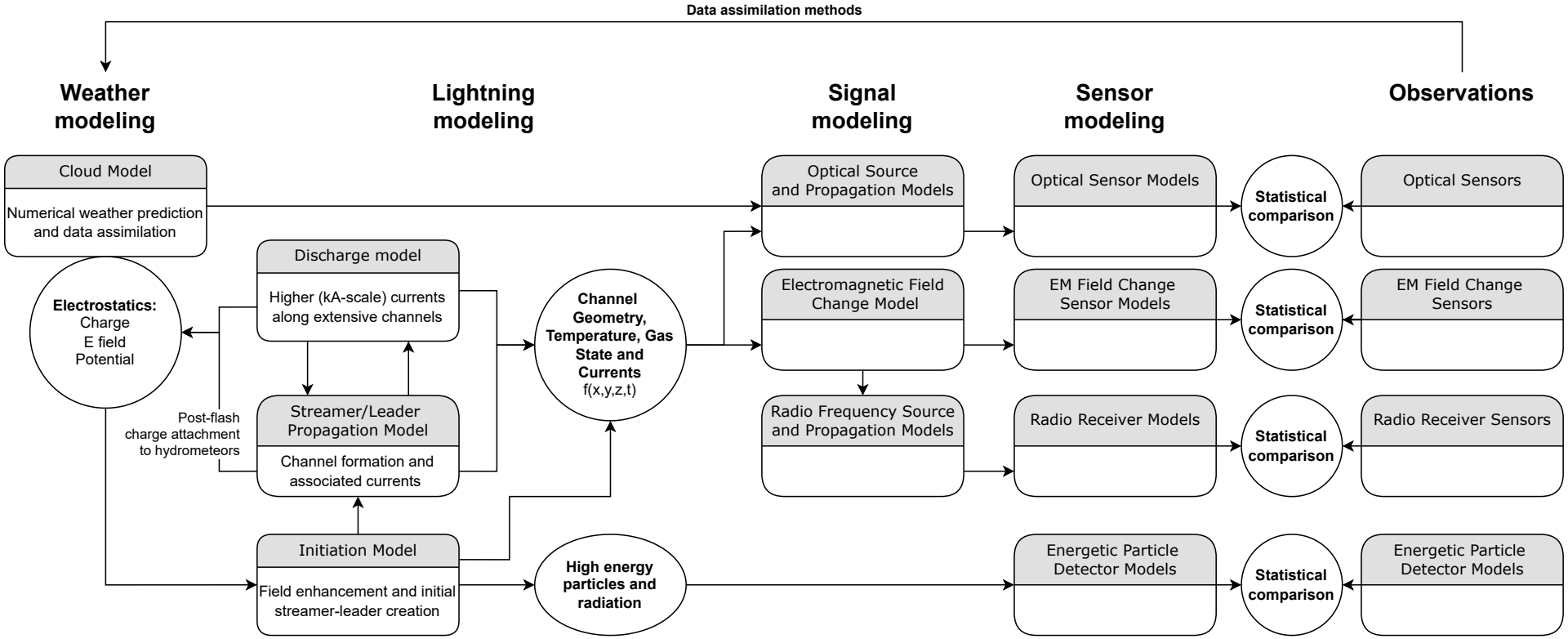




The simulated flash rate and spatial distribution of flash areas (left) matches that observed with a 3D lightning mapping array

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

Major model components

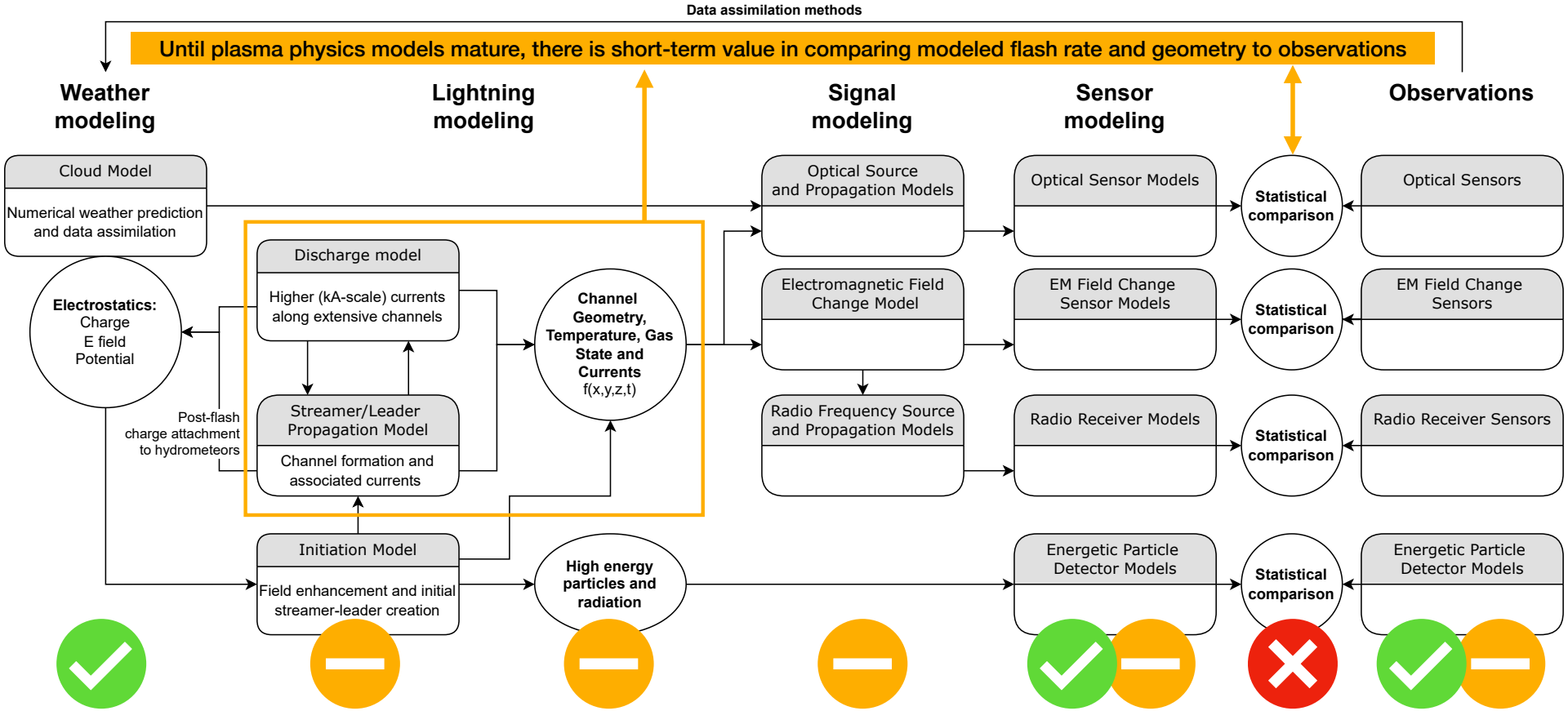


Loose coupling between components is preferred where possible

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

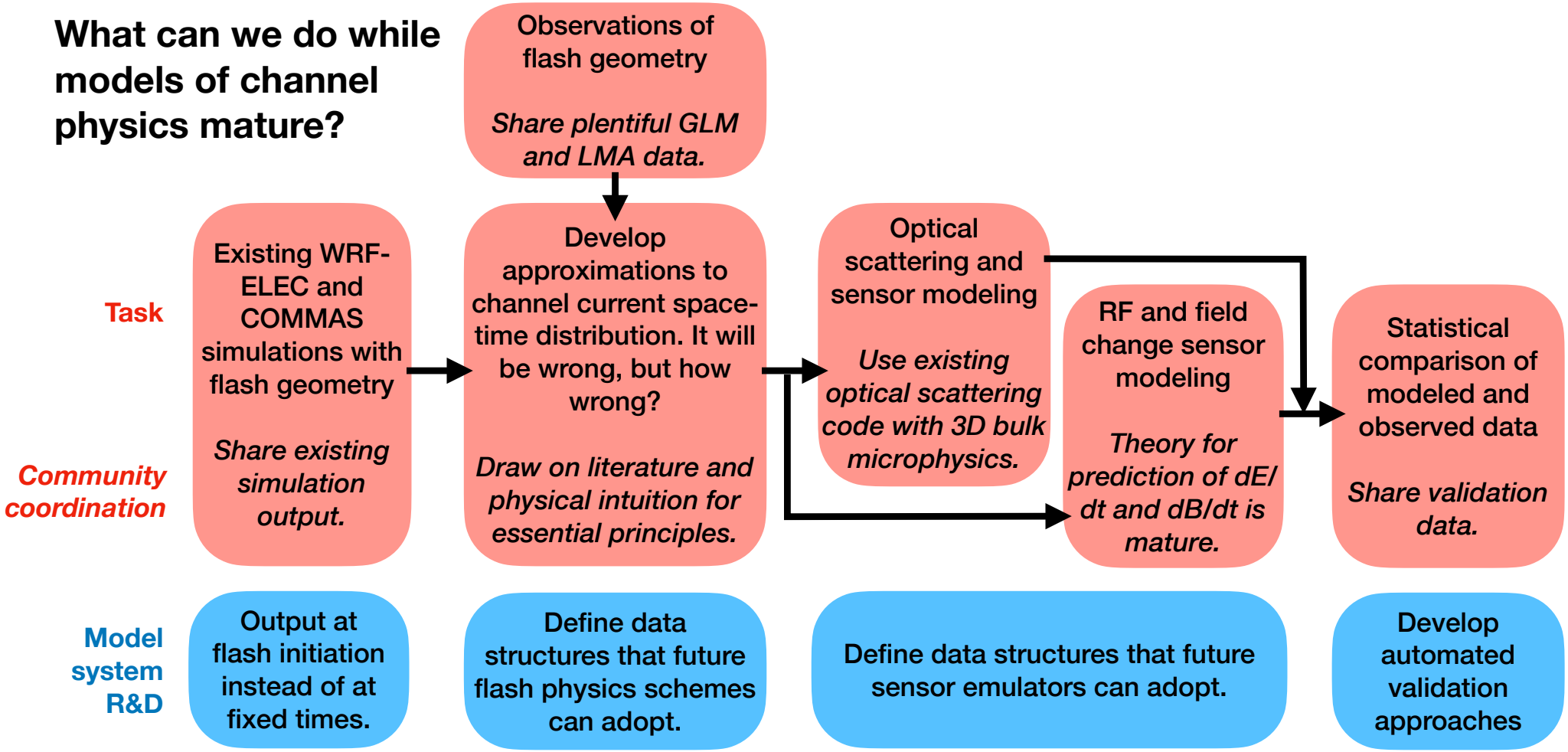
Qualitative readiness

≠ **perfect**, but is mature enough for use in an initial end-to-end prediction

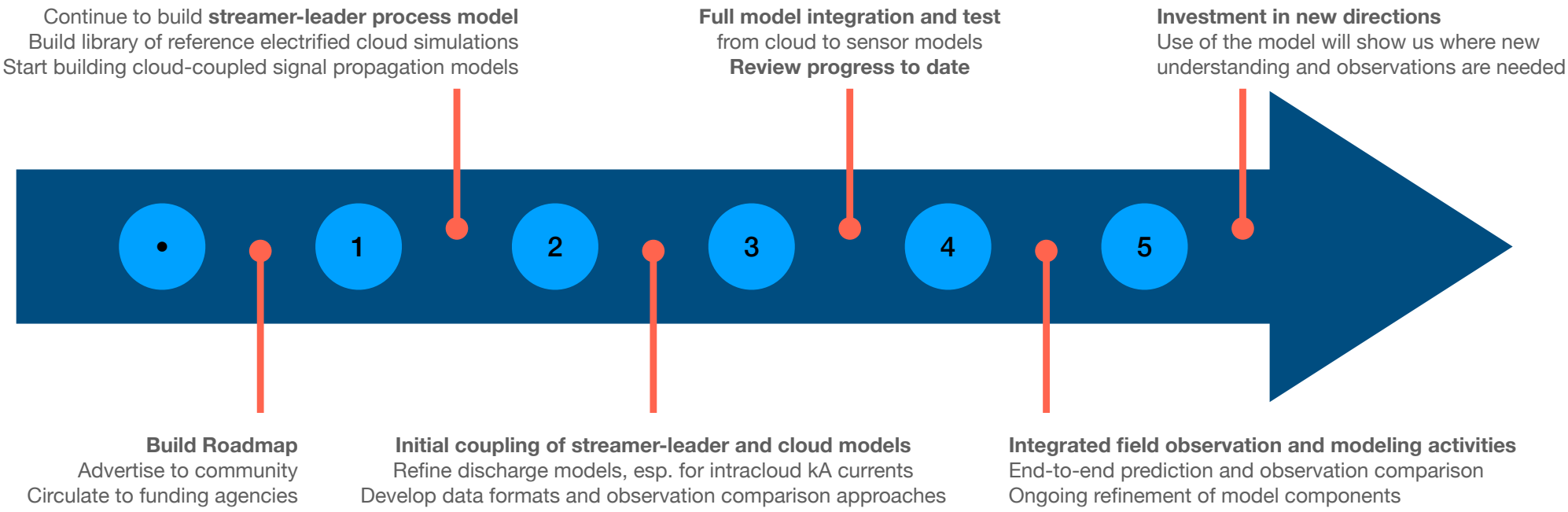


Practical first steps *(one example)*

What can we do while models of channel physics mature?



Five year timeline



Implementation will follow a community-governed open source model.

Community Input

Upcoming events

- **Roadmap v. 1.0 available**
  - Visit lightning.ttu.edu/workshop
  - Working on institutional approvals for release on Zenodo with DOI; BAMS proposal to be submitted soon.
  - Contributions from international community welcome!
- **Panel discussion this Tuesday at AMS**
  - 14 January 2025, 1630–1800, Rm. 210
- **Next Workshop**, 1-3 April 2025, Texas Tech University
  - Preregistration/mailing list signup at the workshop website.
  - Goals: review roadmap and begin implementation planning



Preregistration

Workshop invited speakers

- Joe Dwyer, University of New Hampshire
- Ted Mansell, NOAA National Severe Storms Laboratory
- Amitabh Nag, Los Alamos National Laboratory
- Caitano da Silva, New Mexico Tech
- Patrick Gatlin, NASA Marshall Space Flight Center
- Matthew Hopkins, Sandia National Laboratory
- Patrick McFarland, Penn State University
- Kristen Rasmussen, Colorado State University
- Xuan-Min Shao, Los Alamos National Laboratory
- Scott Wolff, United States Air Force