# CACTI model-observation integration for advancing convective cloud understanding

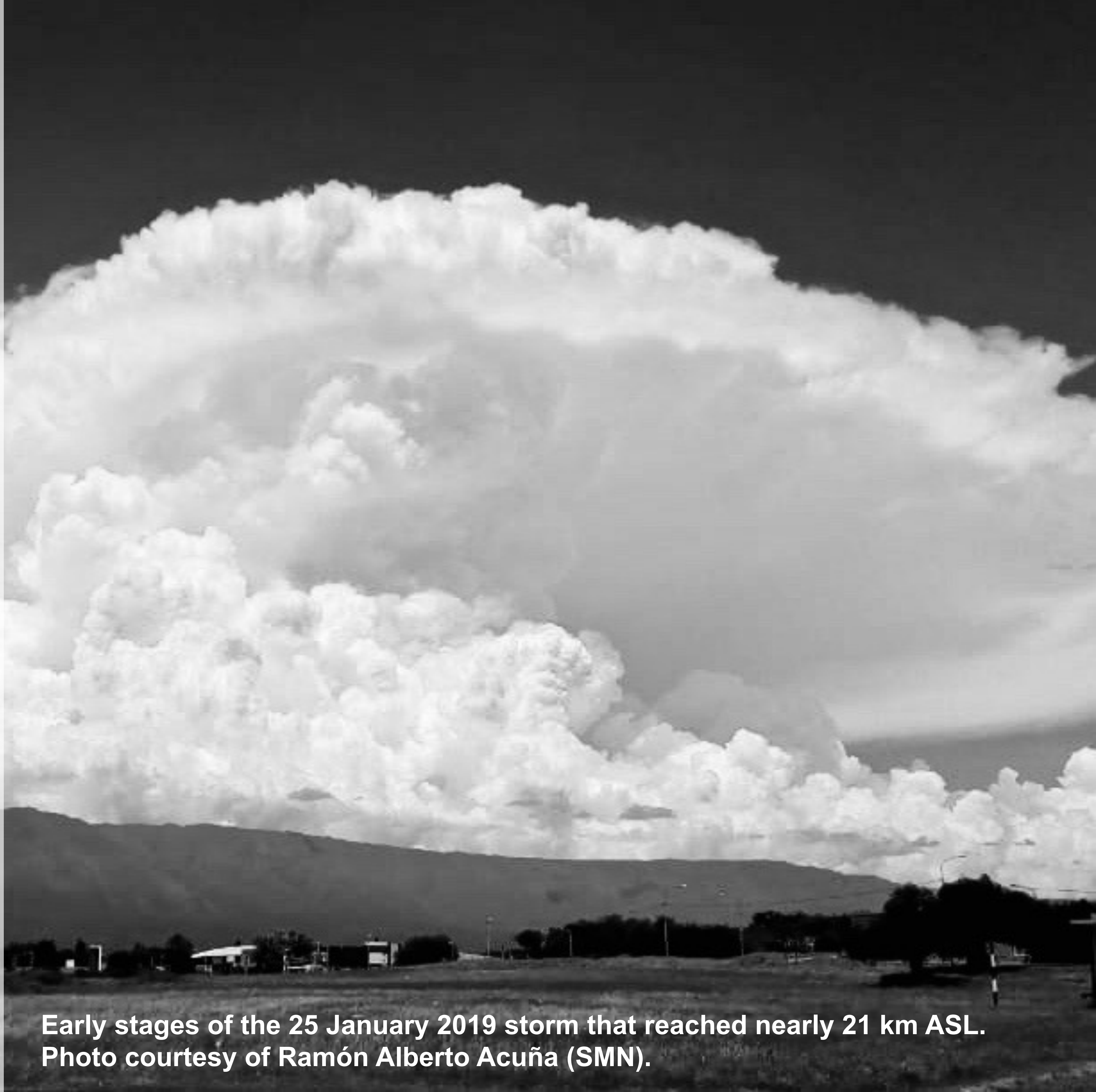

**Adam Varble[1], Zhe Feng[1], Joseph Hardin[1]**
**James Marquis[1], and Zhixiao Zhang[2]**

*[1]Pacific Northwest National Laboratory*
*[2]University of Utah*


2022 ARM/ASR Joint User Facility and PI Meeting

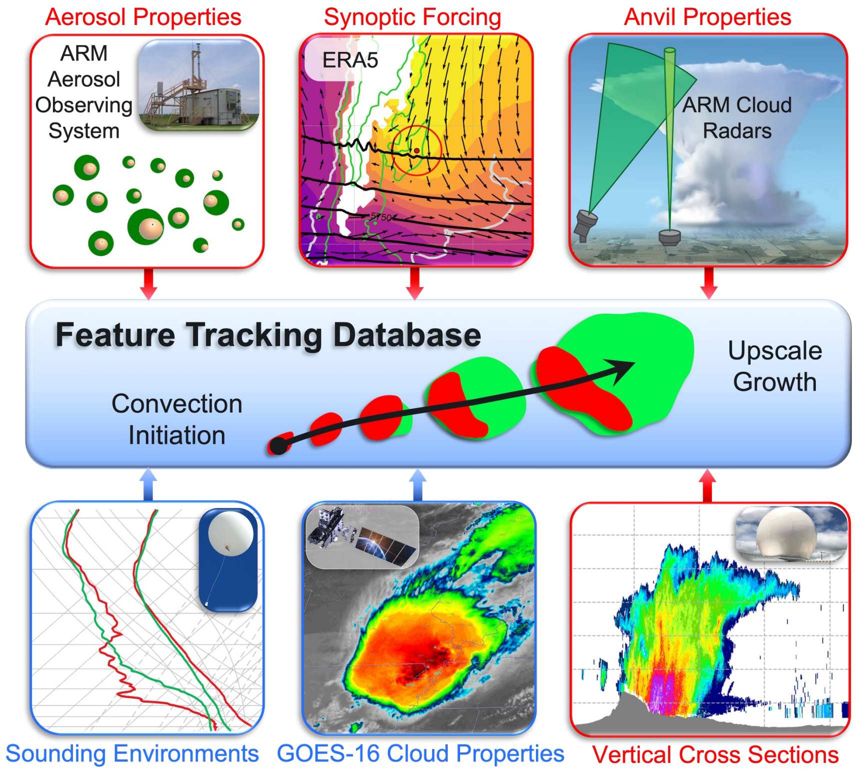
October 24, 2022

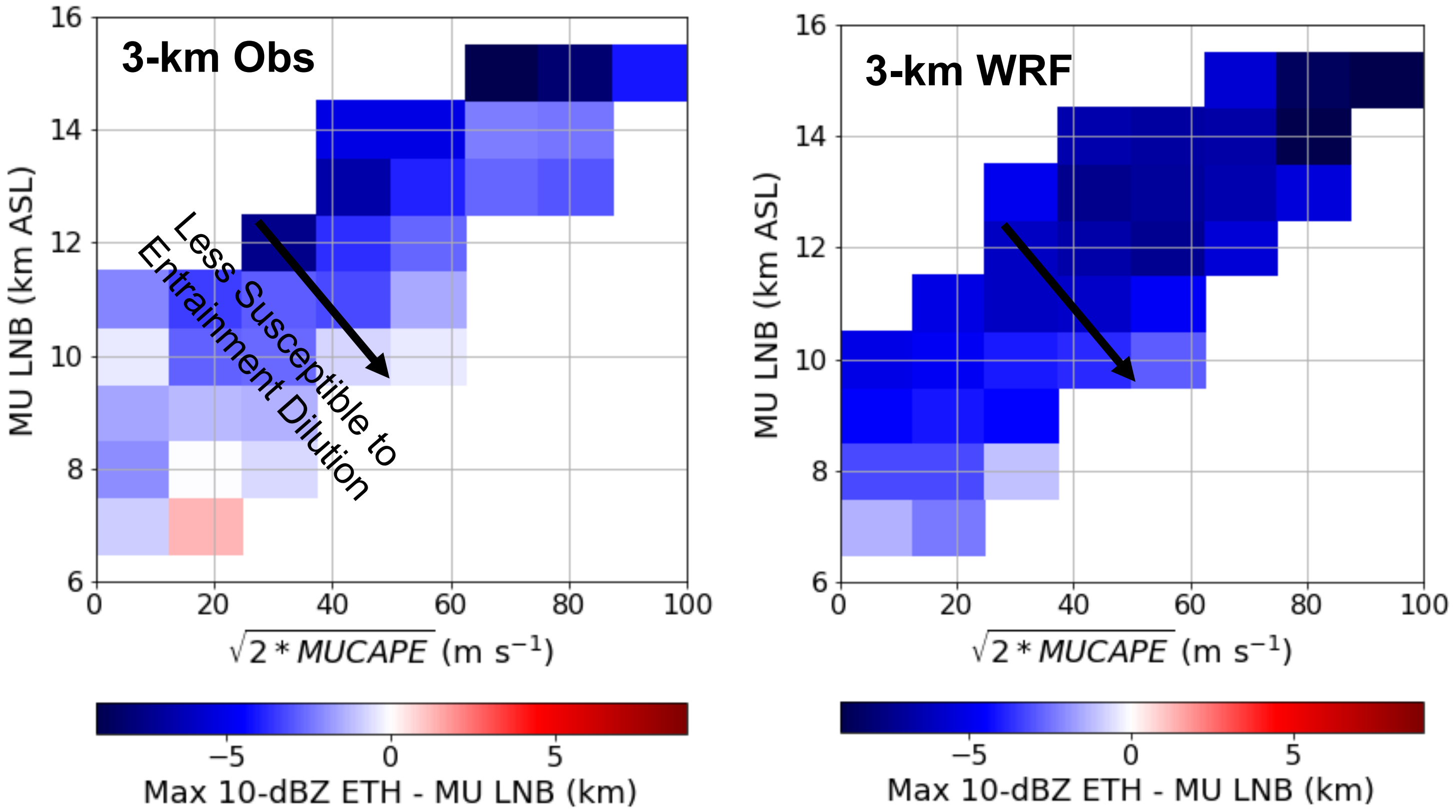

PNNL is operated by Battelle for the U.S. Department of Energy

**Early stages of the 25 January 2019 storm that reached nearly 21 km ASL.**
**Photo courtesy of Ramón Alberto Acuña (SMN).**

# Processes = D/Dt(Integrated Properties)




Feng, Z, et al., 2022: Deep Convection Initiation, Growth, and Environments in the Complex Terrain of Central Argentina during CACTI, *Mon. Wea. Rev.*, 150, 1135-1155.

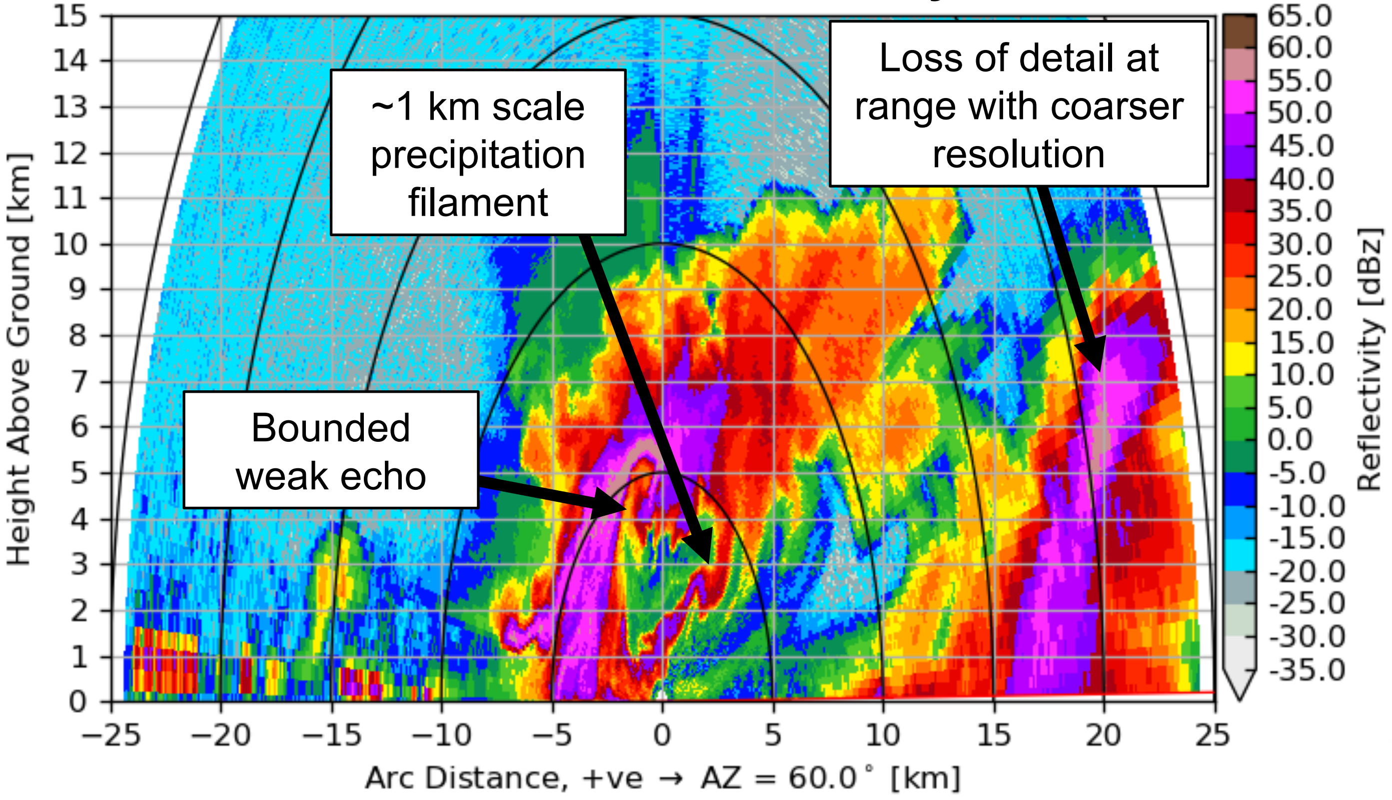
- Processes can be approximated by **changes of measurable structures in space and time (D/Dt)** and **comprehensive integration of complementary datasets**
  - Signals of dynamics and microphysics impacts on one another are lagged in time
  - Couple satellite/radar feature tracking databases with detailed snapshots and in situ measurements (e.g., CACTI cell track database; Feng et al., 2022)
  - Use for model evaluation but also use models for additional spatiotemporal and process context (ongoing work for CACTI using LASSO and other simulations) → Come to the CACTI breakout session tomorrow

# Structural shapes and sizes as advanced observational constraints

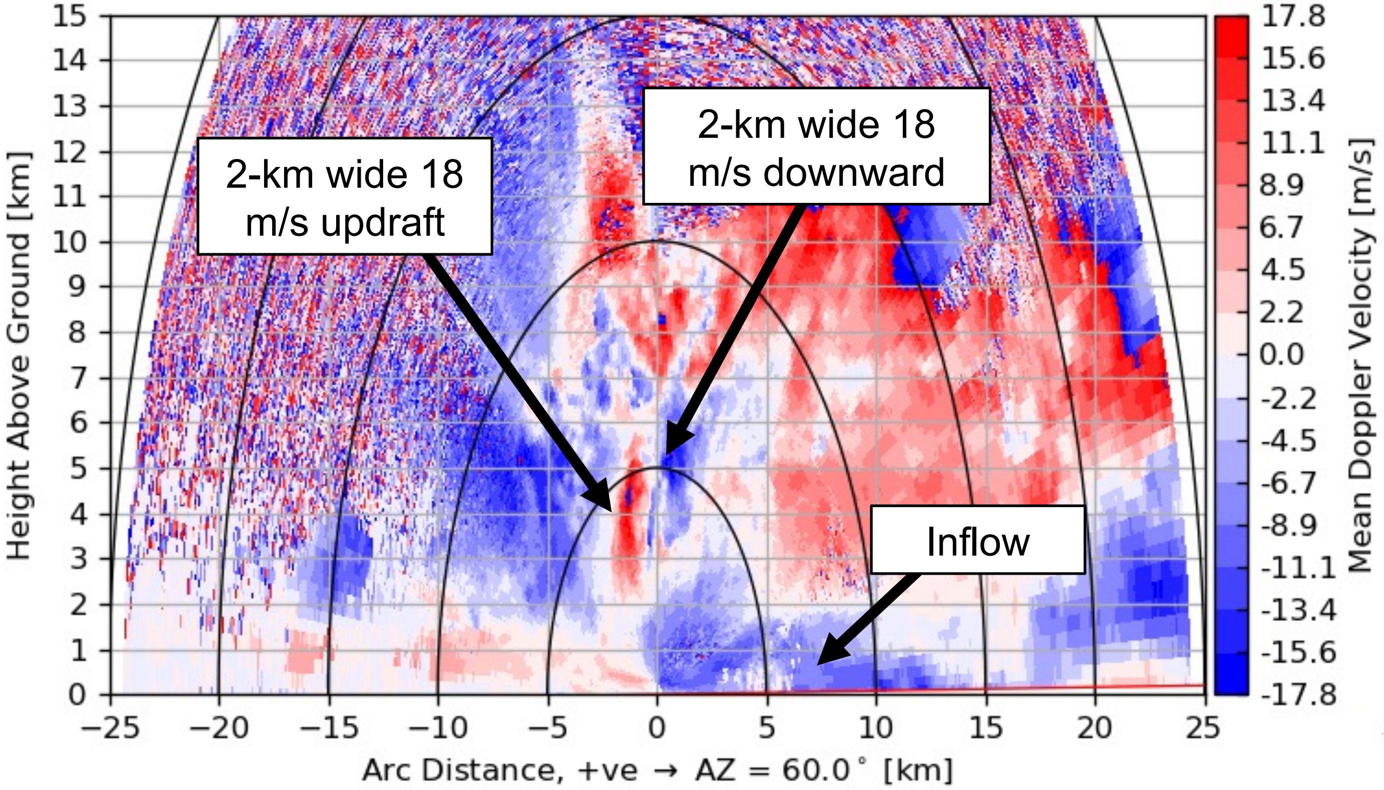
High-resolution measurements regularly show km-scale structures associated with inflow, outflow, updrafts, downdrafts, and precipitation processes.

These can be accumulated in greater numbers than vertical velocity or microphysical retrievals. How can they be used to inform difficult to observe variables and evaluate models?

**CACTI X-band Reflectivity**



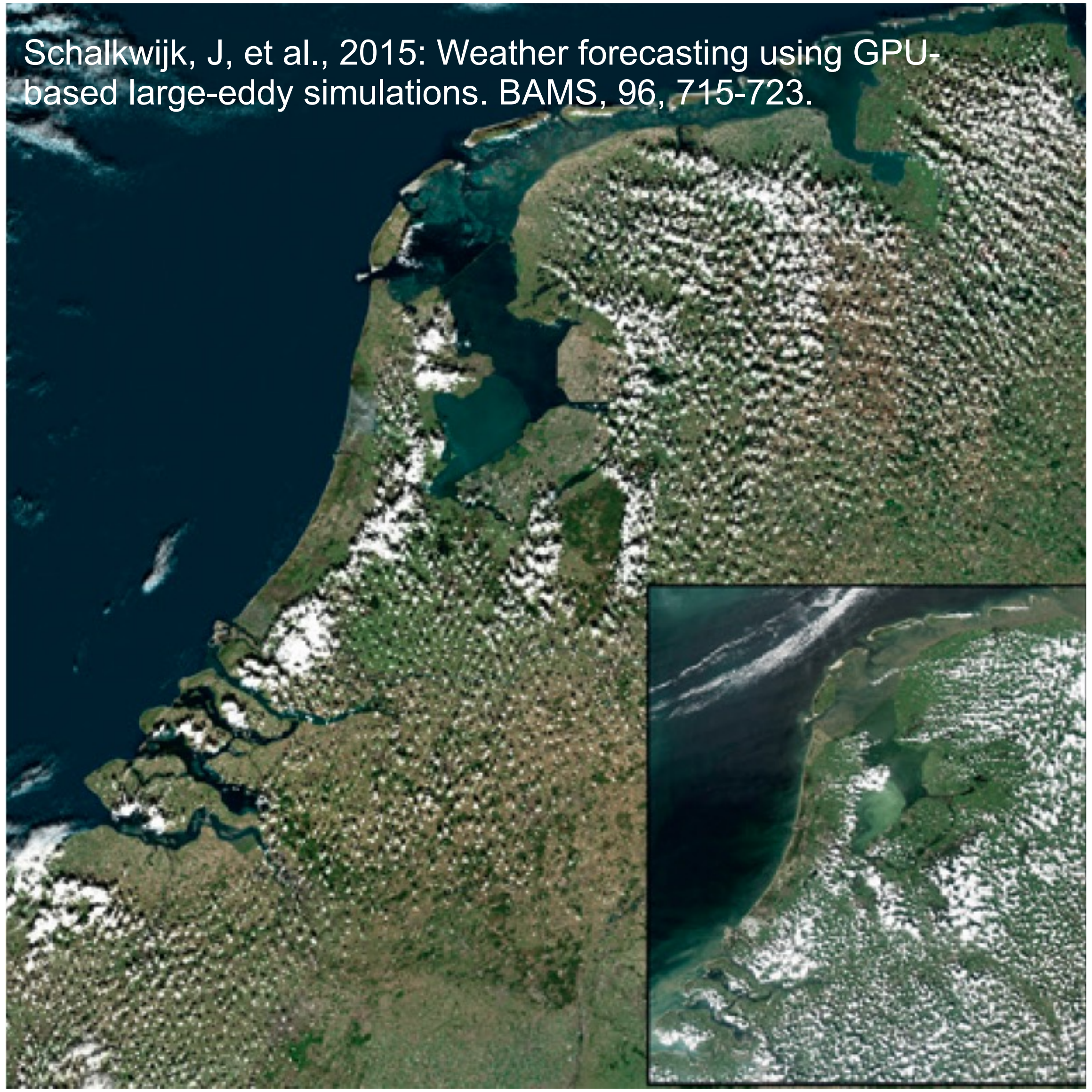

**CACTI X-band Doppler Velocity**

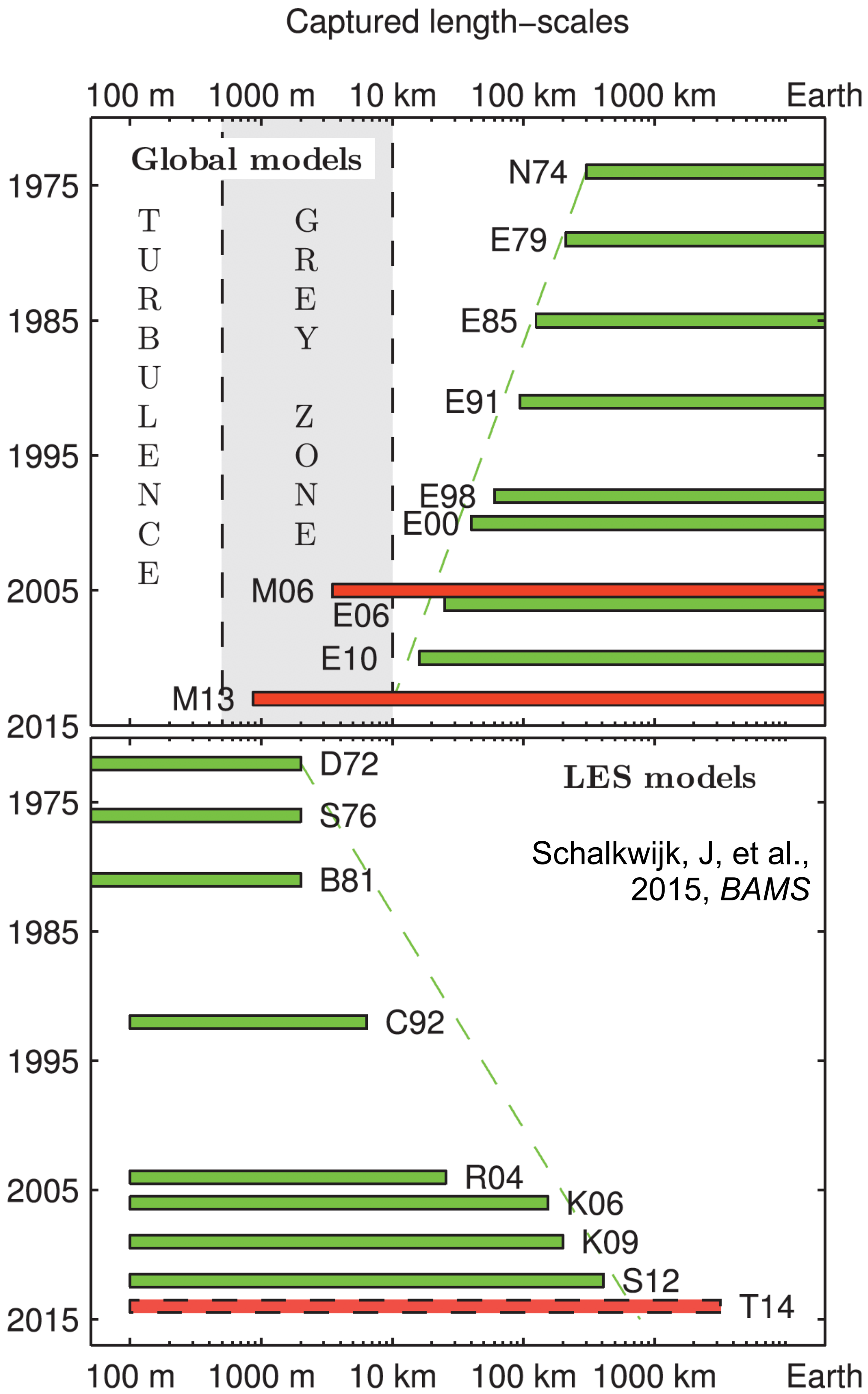



Courtesy Joseph Hardin and Nitin Bharadwaj (PNNL)

# Use models to inform observations

- Mesoscale domain LES is established with ensembles are beginning
- Km-scale, decade-long regional runs with shorter global runs are here



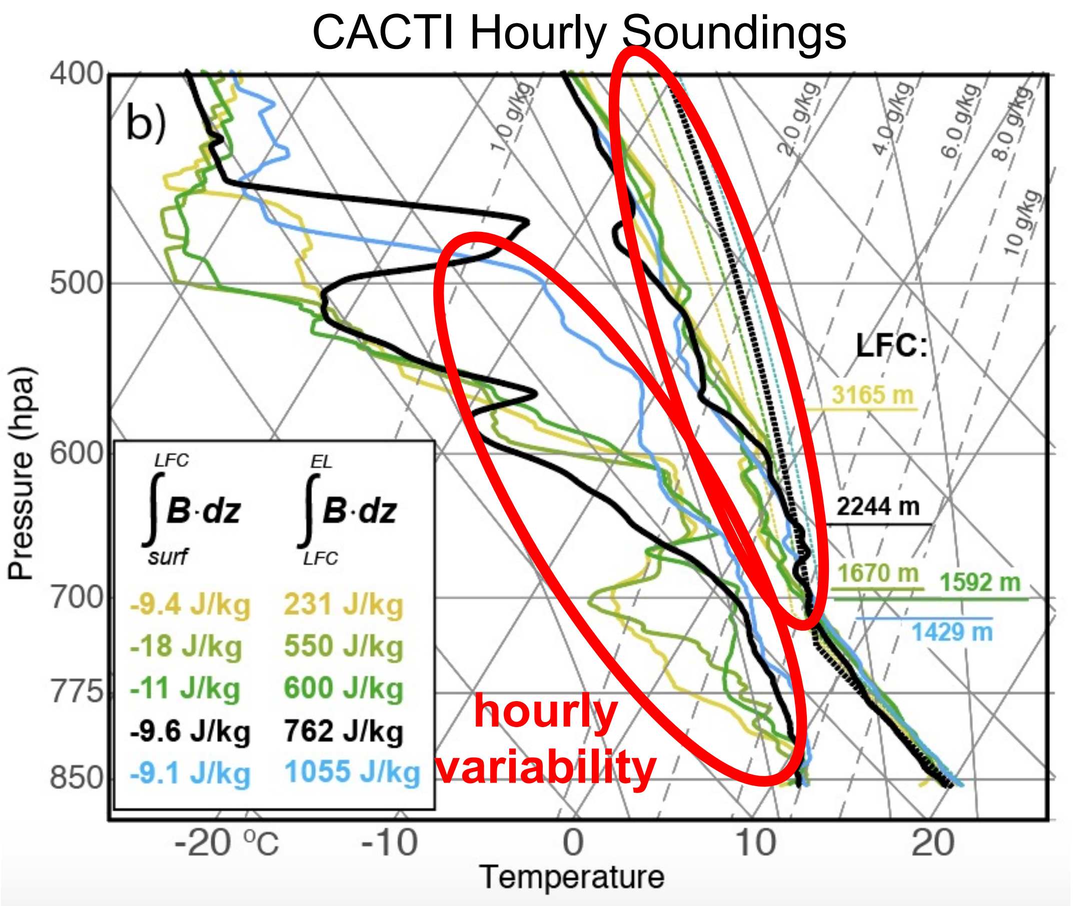
# Model context is key for atmospheric variability characterization

## Meteorological variability

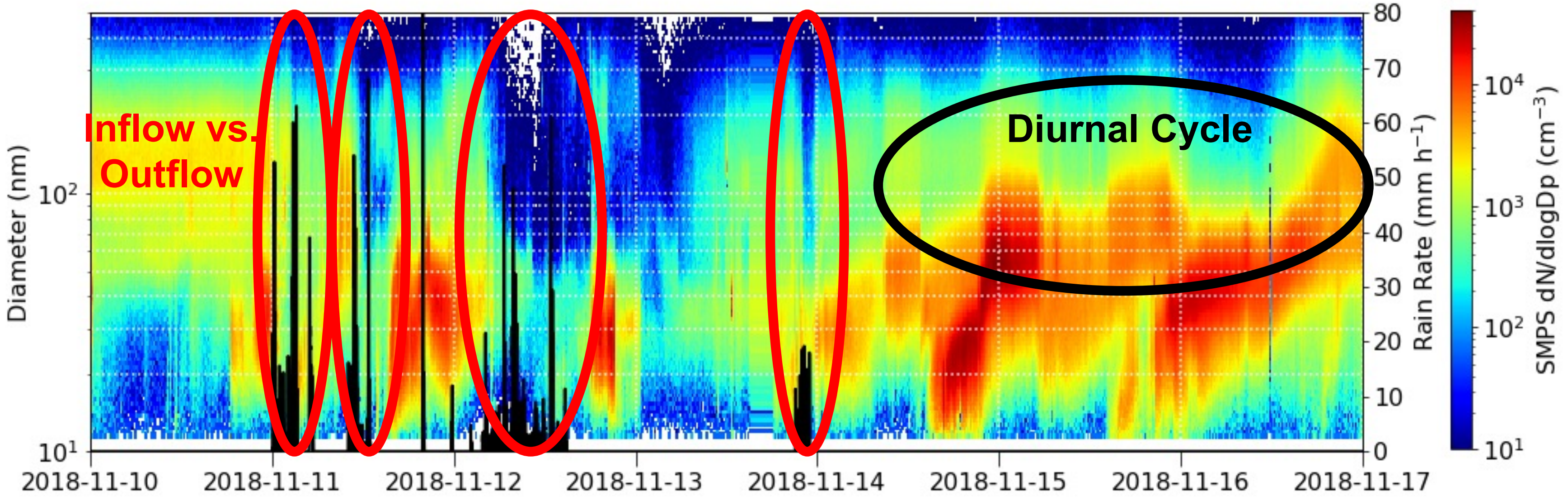
- 30 km and 1-h scales matter for clouds
  Nelson, TC, et al., 2021: Radiosonde observations of environments supporting deep moist convection initiation during RELAMPAGO-CACTI. MWR, 149, 289-309.
- Need to separate updraft inflow and cold pool outflow
- Difficult to get comprehensive observations above the surface
- Some sensitivities (e.g., clouds to moisture) are very large and need to be controlled to isolate lesser critical sensitivities

## Aerosol variability

- Limited surface data and even less aloft
- AOD and lidar have limitations in representing CCN
- Correlations with meteorology caused by clouds (transport and deposition) and diurnal cycle (NPF, circulations)



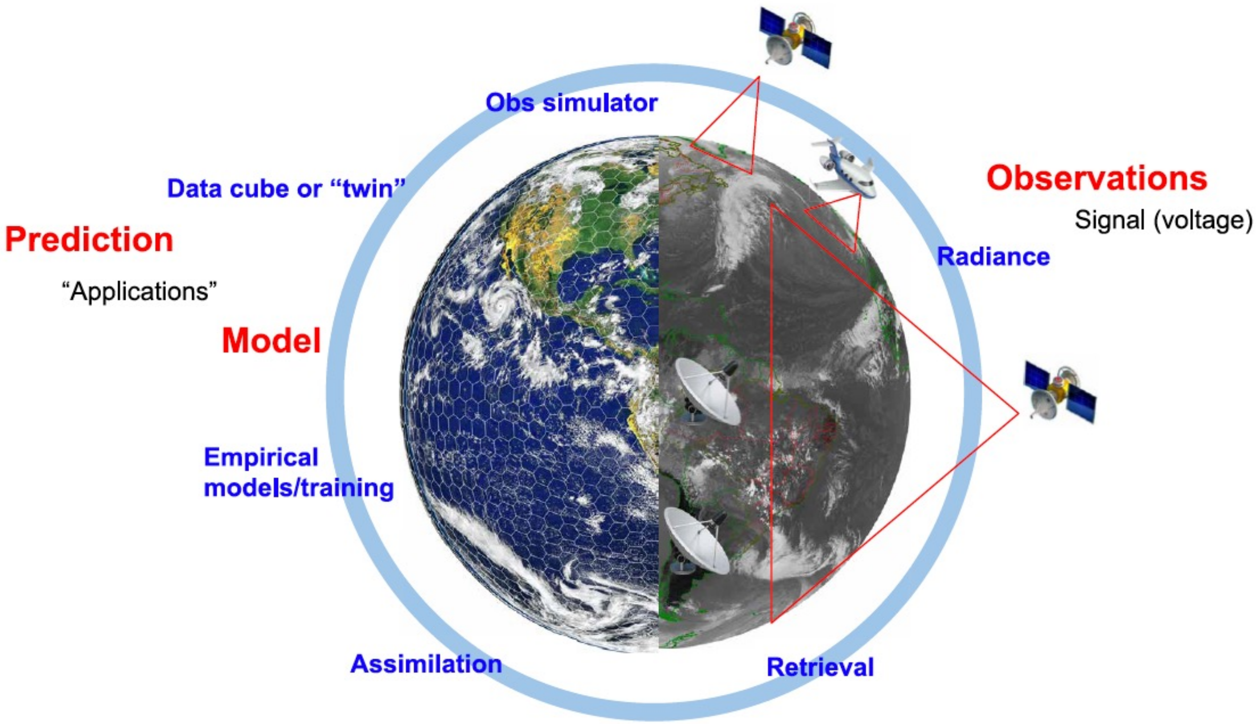

Marquis J. N., et al., 2021: Low-level Mesoscale and Cloud-scale Interactions Promoting Deep Convective Initiation. *Mon. Wea. Rev*., 149, 2473-2495.




Varble, A. C., et al., 2021: Utilizing a Storm-Generating Hotspot to Study Convective Cloud Transitions: The CACTI Experiment. *BAMS*, 102, E1597-E1620.

# Summary

- Convection-permitting models continue to have **persistent convective dynamical and microphysical biases.**
- **Observational sampling will continue to have major limitations** in representativeness, resolving relevant scales, and retrieving critical variables.
- **Can we combine multi-scale models and observations in novel ways to overcome these problems?**




Gettelman, A., et al., 2022: The future of Earth system prediction: Advances in model-data fusion.. *Sci. Adv.*, 8, eabn3488.

1. **Properties respond over space and time to processes:** Employ Lagrangian (D/Dt) observational and modeling analyses to use structural changes in time as constraints on cloud processes.
2. **Isolate signals using large, comprehensive datasets:** Integrate complementary observations (satellite, surface network, field campaign) to build databases and do the same in model output (e.g., CACTI cell track database).
3. **Provide critical spatiotemporal context to sampling-limited measurements:** Data mine continental and global domain km-scale models and design their output to match observational sampling as much as possible.
4. **Retrieve more information from available measurements:** Build LES libraries with built-in instrument simulators and emulators to link the spatiotemporal structural evolution of observations to key poorly observed variables and unobservable processes.
5. **Improve understanding and build better observations:** Learn from process-property-structure linkages built from model-observation integration, and design informed observational strategies targeting specific process constraints.