Case Libraries of Shallow and Deep Convection Large-Eddy Simulations from the US DOE Atmospheric Radiation Measurement Facility's LASSO Activity

LASSO = Large-Eddy Simulation (LES) Atmospheric Radiation Measurement (ARM) Symbiotic Simulation and Observation

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Town Hall at 2021 AMS Annual Meeting

Agenda

1. Introduction to LASSO
2. Overview of the LASSO shallow-convection scenario
3. Roadmap for the future of LASSO with a focus on deep convection
4. Open discussion

What is LASSO?

- LASSO uses large-eddy simulation (LES) modeling combined with observations to enable researchers to more easily use ARM's suite of observations
- Focus on targeted scenarios to optimize model configuration and obs. choice
- Packages the LES results with a curated set of observations and diagnostics

- Motivated by goal of bridging the gap between observations and scales within large forecast and climate models
  - Increase understanding of linkages between observations and advancement of cloud theory and parameterizations
  - Enable model development
- Vetted LES provides a plausible proxy for unobservable details in the context of the observations

Science drivers & motivation

- Understanding relationships between observed variables
- LES can inform improvements for observation strategies
- Facilitating understanding of boundary layer and cloud processes and their related parameterizations
- Provide an easily digestible dataset for use in teaching and research

LASSO's Shallow-Convection Scenario

Case library

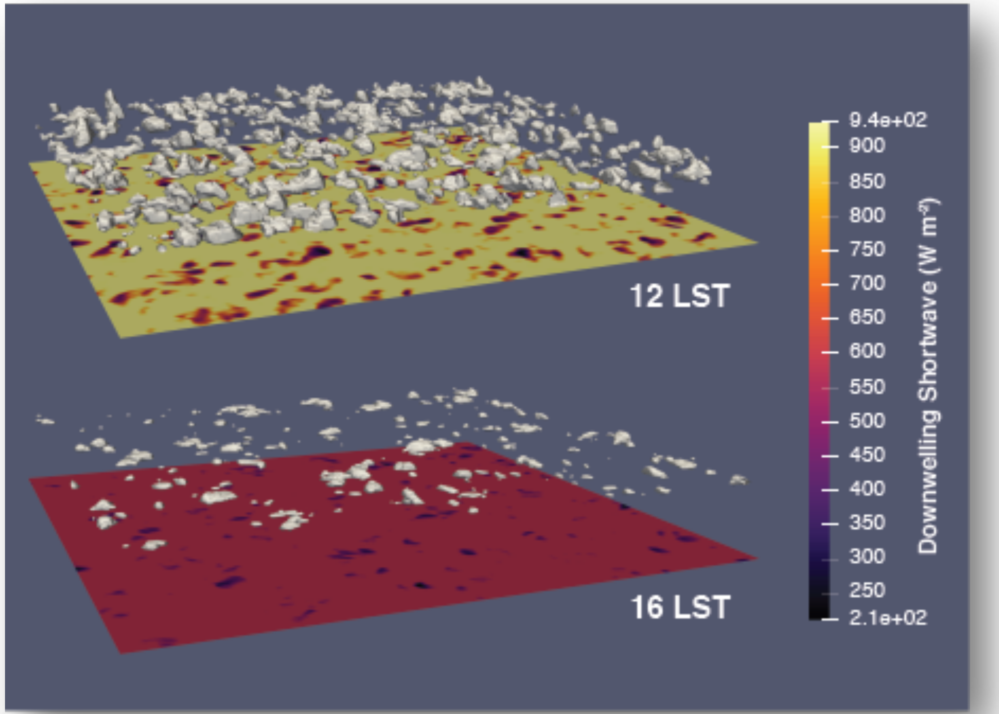
- LASSO is structured around the concept of data bundles that contain the observations and model data
- Case dates within the library are chosen based on the meteorological regime, which so far has been shallow convection at the Southern Great Plains (SGP) facility
- An LES ensemble is run for each case date based on large-scale forcings to the LES
- Shallow-convection season at the SGP runs from April to September

Available Cases

Year	Number of Cases
2015	5
2016	13
2017	30
2018	30
2019	17
Total	95

LASSO's LES approach

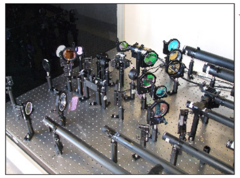
- Use WRF model with additional LES outputs
- Traditional LES approach w/ doubly periodic boundaries
- dx = 100 m, domain width = 25 km (early runs use 14 km)
- Initialized with observed sounding at ~6 LST
- Large-scale forcing ensemble to inform forcing uncertainty
- Output ever 10 minutes



Observations in LASSO

- Curated observations from the SGP network
- Focus on boundary layer and cloud macro characteristics
  - Boundary layer T and Q
  - Lifting condensation level
  - Cloud base height
  - Cloud thickness
  - Cloud fraction
  - Liquid water path

Raman lidar

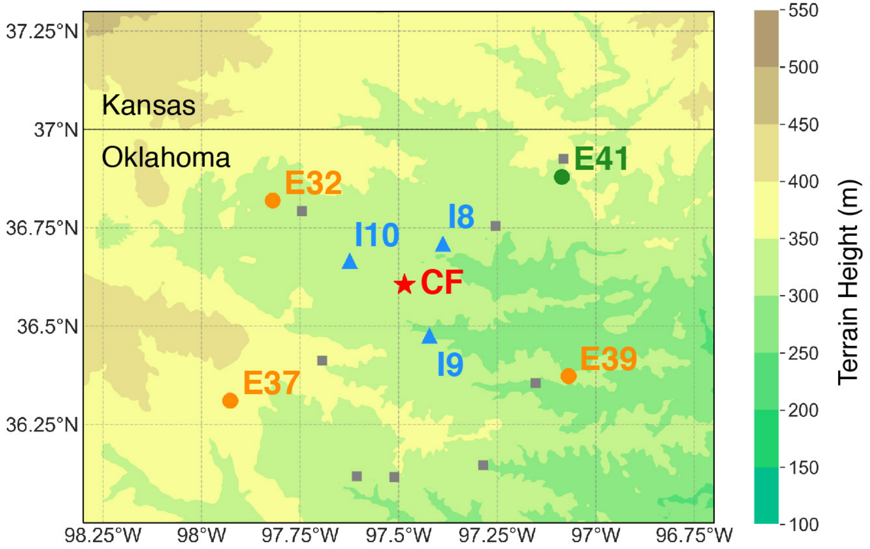


Total-Sky Imager

Micropulse lidar

KAZR

ARM Southern Great Plains Atmospheric Observatory



Facility Types
- ★ Central Facility
- ▲ Intermediate Facilities
- ● Extended Facilities
- ■ Surface Met. Facilities for LCL

Radiosonde

Microwave radiometer

AERI

Doppler lidar

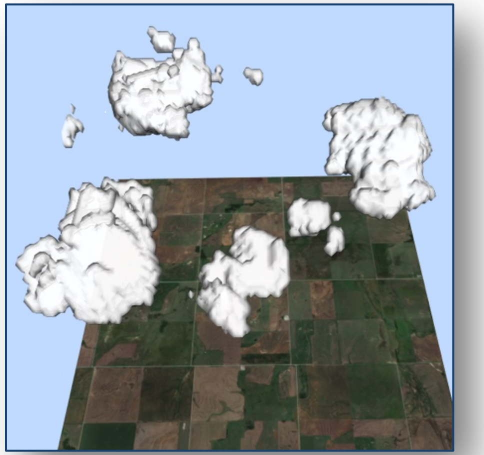
Surface meteorology

Radar wind profiler

Data bundles

- LASSO data distributed via two tar files per data bundle
  - Small tar file has hourly observation suite, LES inputs and hourly summary output, diagnostics, quick-look plots, and skill scores
  - Large tar file has WRF model output every 10 minutes, which includes raw snapshots and traditional LES statistics averaged over the 10 minutes
- Sidecar products
  - LASSO High-Frequency Observations value-added product (VAP)
    - Contains observations prior to hourly averaging
  - LASSO Clouds Optically Gridded by Stereo (COGS) photogrammetry cloud mask VAP for 2018 & 2019 cases
    - Cloud fraction profile based on 3 cameras spaced 12 km apart
    - Avoids issues associated with insects that contaminate the radar-based cloud thickness data

COGS Cloud Mask



LASSO Bundle Browser

- User interface via the Bundle Browser
  - https://adc.arm.gov/lassobrowser
- Designed to pick data bundles of interest and simplify the download
- Based around skill scores and diagnostic plots
- Potential tool for teaching and hands-on lab sessions

For more details about the shallow convection scenario…

- **BAMS article**

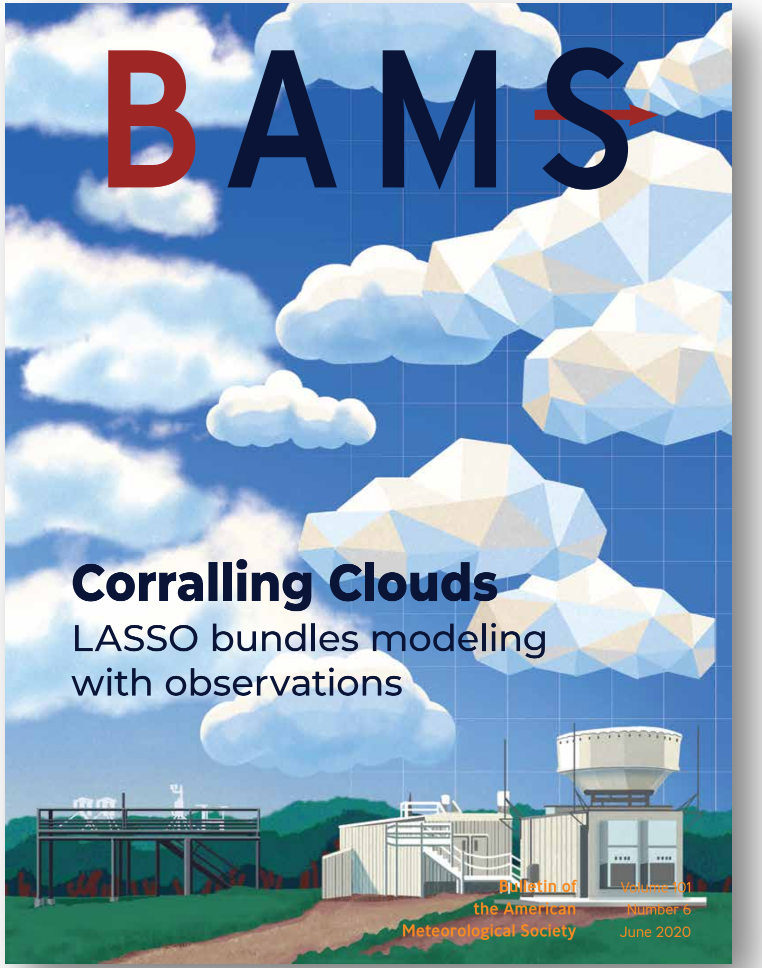
  Gustafson, W. I., A. M. Vogelmann, Z. Li, X. Cheng, K. K. Dumas, S. Endo, K. L. Johnson, B. Krishna, T. Fairless, and H. Xiao, 2020: The Large-Eddy Simulation (LES) Atmospheric Radiation Measurement (ARM) Symbiotic Simulation and Observation (LASSO) activity for continental shallow convection. *Bull. Amer. Meteor.*, 101, E462–E479, https://doi.org/10.1175/BAMS-D-19-0065.1

- **LASSO technical document**

  https://www.arm.gov/publications/tech_reports/doe-sc-arm-tr-216.pdf

- **LASSO website**

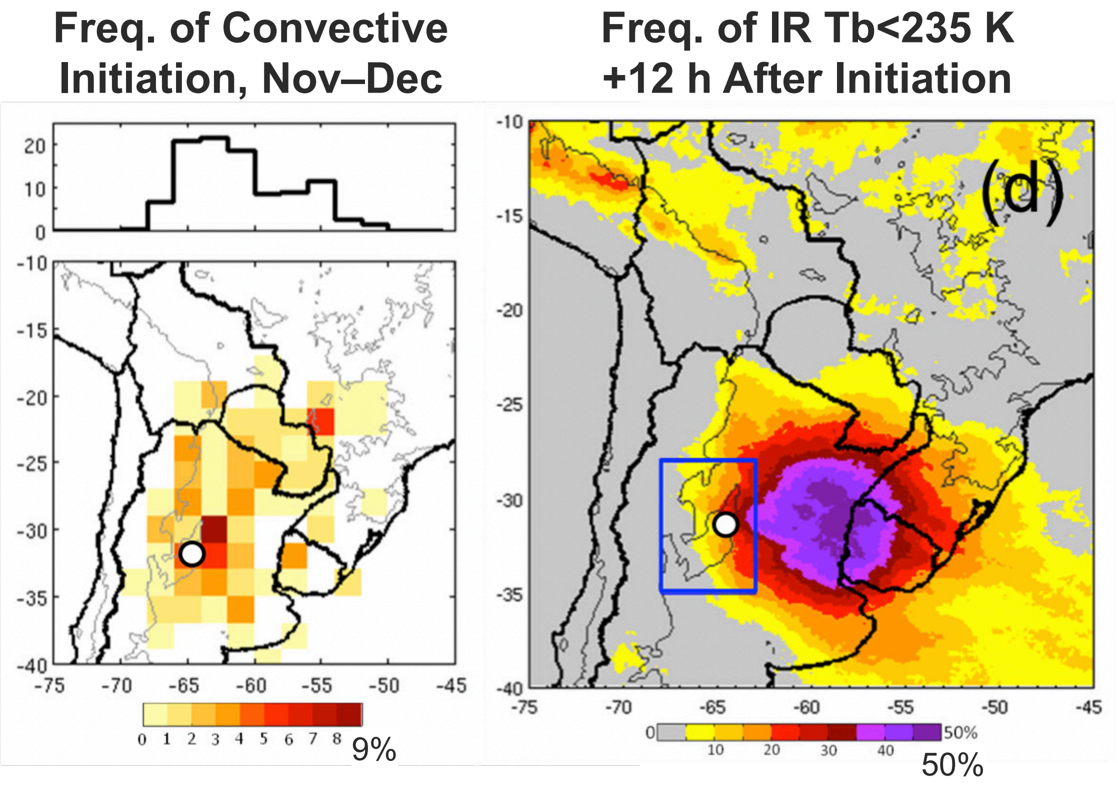
  https://www.arm.gov/capabilities/modeling/lasso



Roadmap to the Future:
Deep Convection During CACTI

Next LASSO scenario: CACTI deep convection

- Two combined field campaigns
  - DOE ARM's Cloud, Aerosol, and Complex Terrain Interactions (CACTI)
  - NSF's Remote Sensing of Electrification, Lightning, and Mesoscale/Microscale Processes with Adaptive Ground Observations (RELAMPAGO)
- Sierras de Córdoba mountain range of north-central Argentina, Oct. '18 to April '19
- Frequent terrain-induced convective initiation of mesoscale convective systems



Vidal et al. (2014, in prep.) via *CACTI Science Plan* (DOE/SC-ARM-17-004)

Science drivers guiding scenario design

- Convective cloud dynamics
  - e.g., thermal-like structures, updraft strength, and entrainment; the relationship to critical features like updraft and downdraft mass fluxes, vertical transport, and the shallow-to-deep convective transition
  - Convection-environment interactions, e.g., cold pools
  - Convective drafts in turbulent flow
- Microphysics-dynamics interactions
  - Especially in the context of cloud-scale eddies and smaller-scale turbulence

- Science drivers chosen to balance relevant science with computational capacity
  - LES resolution governed by cloud core requirements
  - Domain size determines portion of lifespan simulated
  - Limiting ensembles to mesoscale simulations with the potential for a small number of LES ensembles for specific cases
  - Focusing on ~10 cases with varying convective behavior

Modeling approach

- **Stage 1:** Mesoscale ensemble used to pick cases and identify good boundary conditions
- **Stage 2:** LES for primary region around the observation site and to capture cloud initiation
- **Stage 3:** Simplify usage of the many TBs of data
  - Provide subsets of variables by theme
  - Stage data on ARM cluster for users who cannot download the data

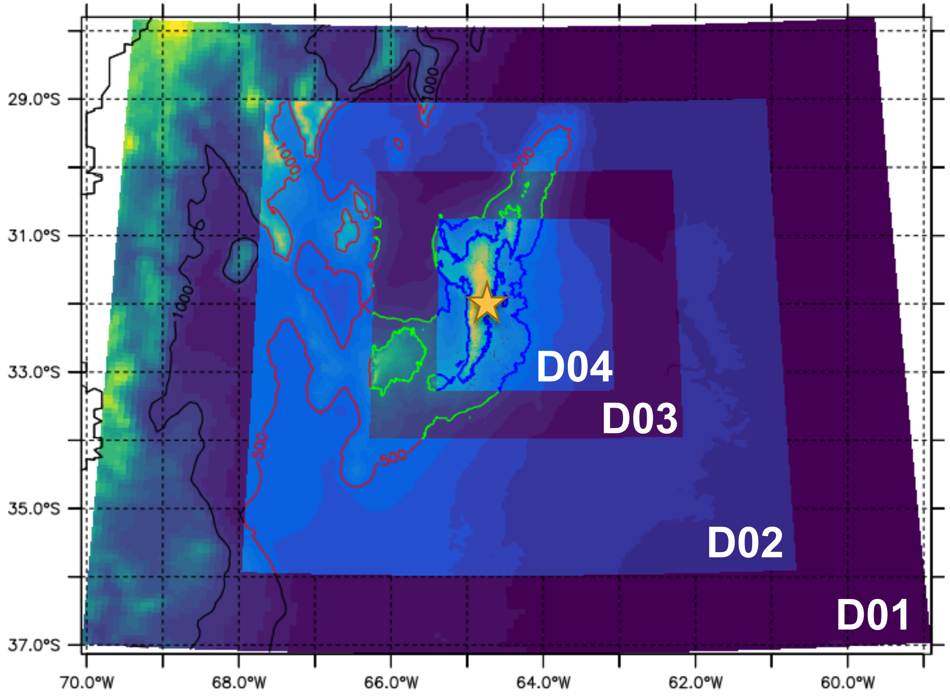
What might the CACTI LES look like?

- Leaning toward a hero-run configuration:

  big domain + high resolution + frequent output
- Nature runs using nested domains
- Duration focusing on initiation and early upscale growth
- Inner domain location and size might differ between cases

- Example domain setup at right:
  - 4 grids from 7.5 km down to 100 m
  - D03, Δx = 500 m
    - 751 x 866 grid cells = 375.5 x 433 km^2
  - D04, Δx = 100 m
    - 2146 x 2776 grid cells = 214.6 x 277.6 km^2

Δx = 7.5 km, 2.5 km, 500 m, & 100 m

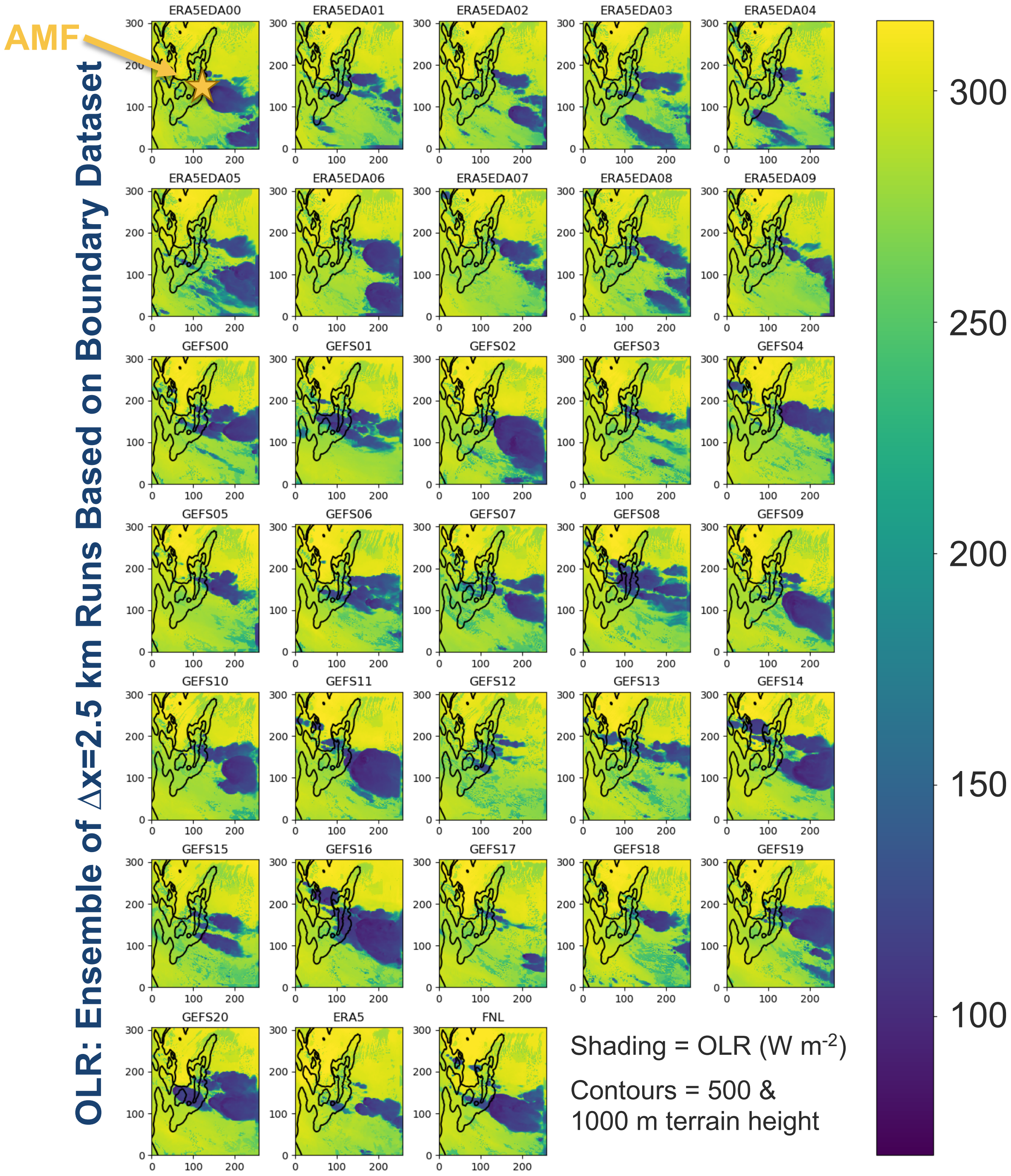


☆ = AMF location

Ensembles

- For deep convection we will use boundary-condition ensembles for *mesoscale runs* to identify a small subset to use for the LES
  - We used ensembles of forcings to generate ensembles of *LES* for the shallow convection
- Envision using km-scale ensembles for understanding dynamical sensitivities and GCM comparisons

- Ensemble example at right showing OLR
  - 10-Nov-2018 21 UTC, Δx = 2.5 km
  - Different boundary condition dataset for each ensemble member
    - ERA5-EDA for 10 members
    - GEFS for 21 members
    - ERA5
    - FNL



Number of LES Per Case is TBD

- Need to balance cost vs. simulation count
  - What is more valuable?
    - Multiple simulations per case with fewer cases
    - One or two simulations per case with twice as many cases
  - ARM is buying more computing power later this year, ~8k new cores to add to existing 4k

- Cost of example domain
  - Current ShCu case: wall time = 21.5 h on 500 cores per LES simulation
  - Estimated cost of 214.6 x 277.6 km^2 domain: wall time ≅ 2–3 weeks on 4000 cores per simulation
    - Assumes we integrate LES for 12 h, dx=100 m, 180 levels
    - Implies we could do max of ~10 cases per year with 12k cores and 2–3 LES per case

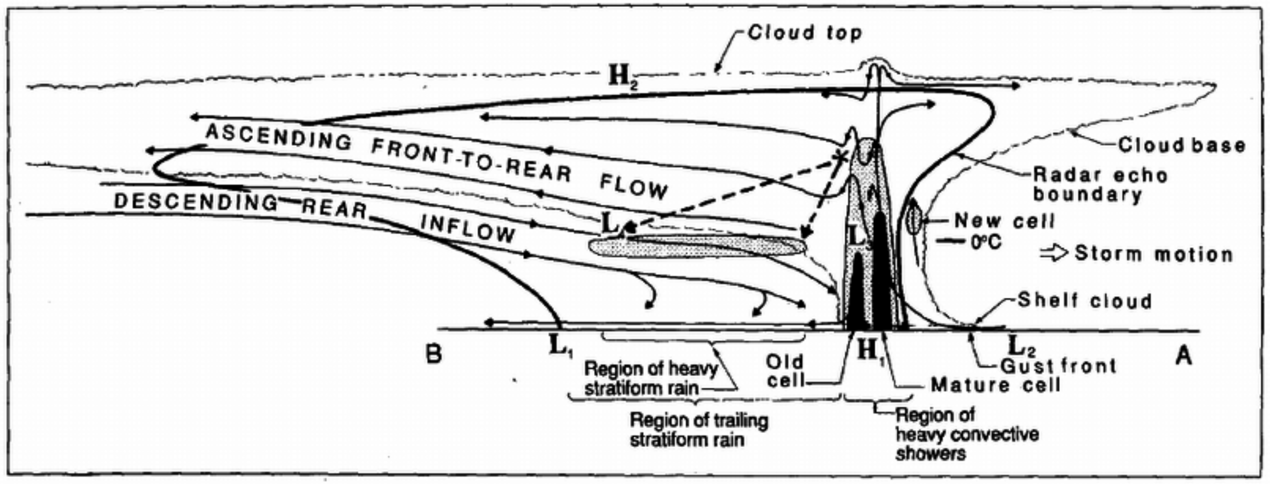
Observational Data and Skill Scores for the CACTI Scenario

Andrew M. Vogelmann (BNL), William I. Gustafson Jr. (PNNL)
Satoshi Endo, Tami Fairless, Karen Johnson (BNL)
Heng Xiao (PNNL)

Helpful discussions with Adam Varble, Joe Hardin, Zhe Feng, and Jiwen Fan (PNNL)

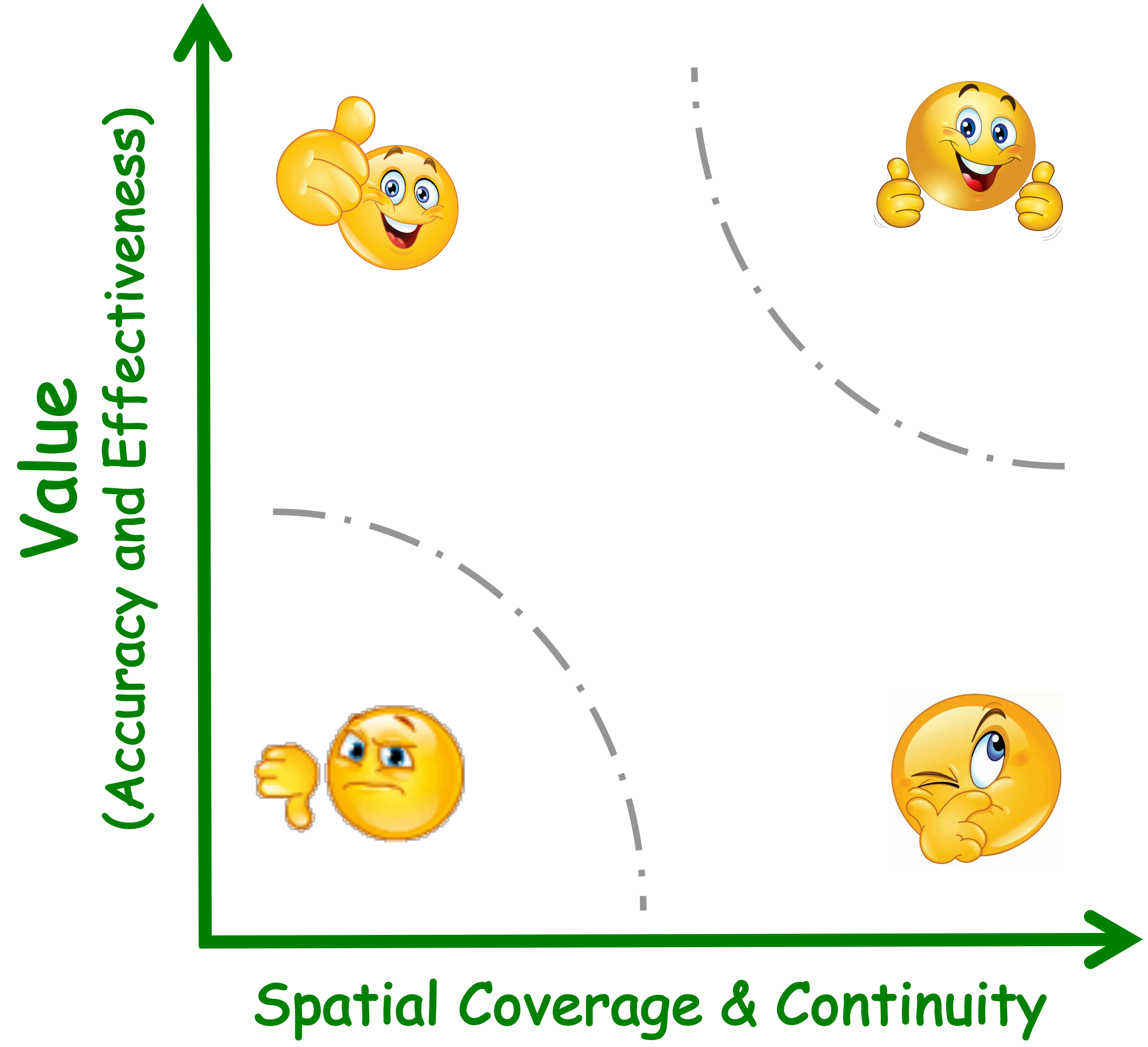
The Task at Hand

- Need approach to quantitatively evaluate model output with CACTI observations
  1. Assess model setup/configuration from sensitivity tests
  2. In operations, identify promising ensemble members for further use
  3. Communicate quality to community through simulation skill scores



Houze et al. (*BAMS*, 1989)

Data Priorities

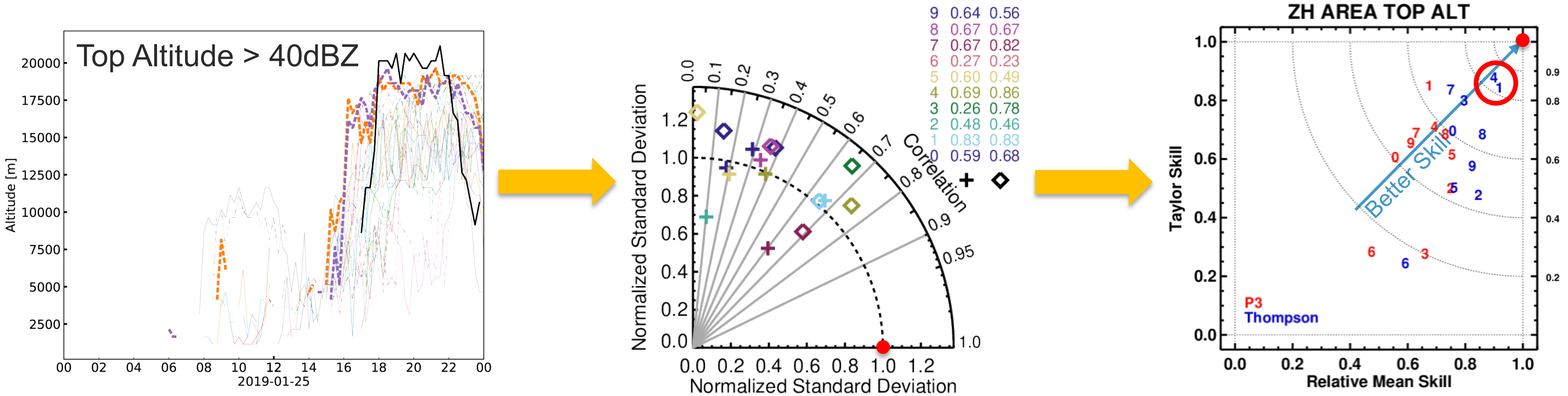


Multiscale Observational Datasets

- **Regional: Satellite-based**
  - Sources
    - GOES-16 brightness temperatures
    - VISST: Pixel and gridded radiation and cloud property retrievals
  - Application
    - Time-dependent convective area coverage of the anvil and colder cores
- **Local: Scanning Radar-based**
  - Sources
    - CSAPR-2, X/Ka-Band SACR, RELAMPAGO
  - Applications
    - Time-dependent radar reflectivity, CFADs, Surface rain rates, Winds
- **Point Measurements**
  - Radar Wind Profiler (vertical velocity, winds), Sondes (thermo), G-1 (thermo, cloud prop)

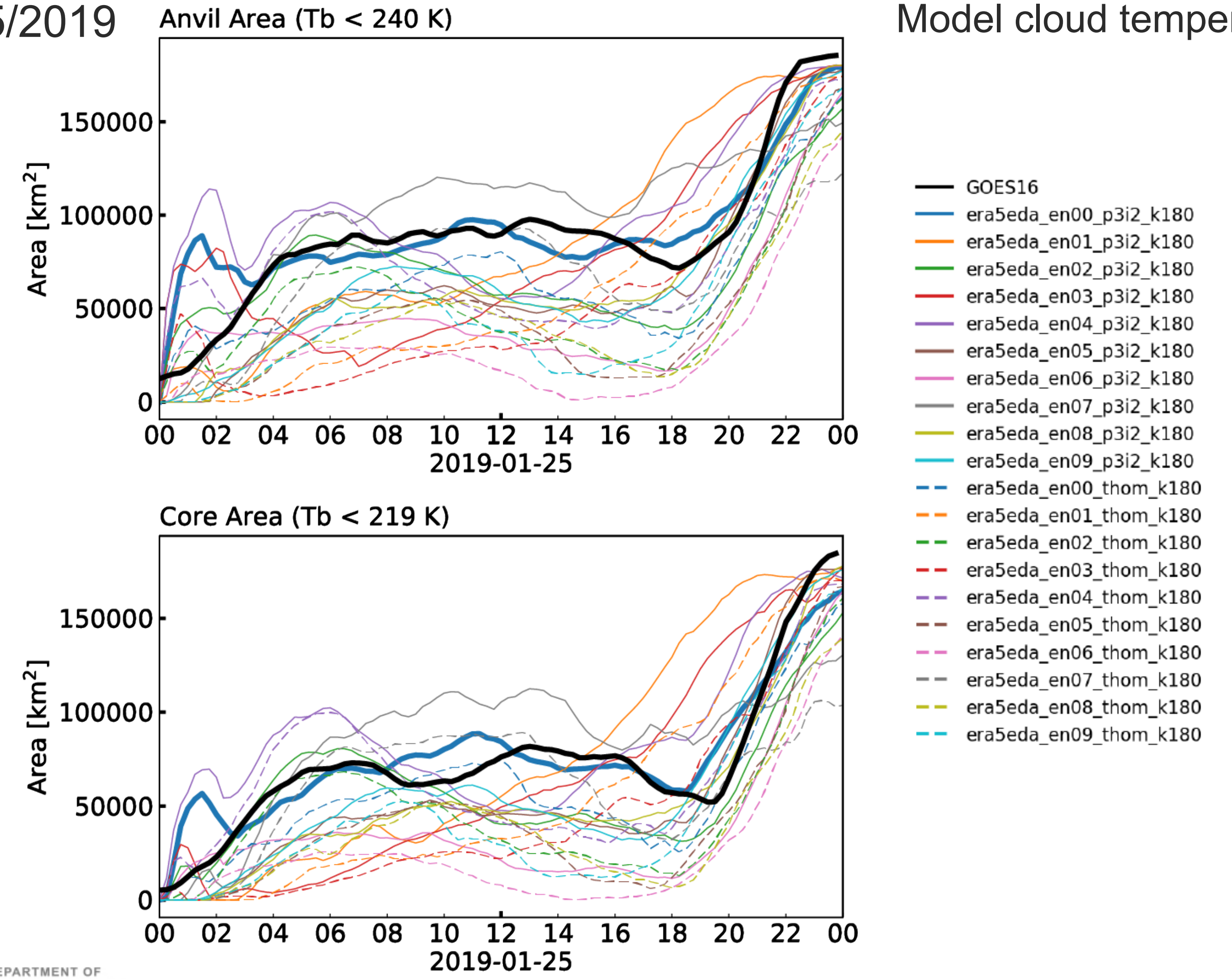
Simulation Skill Scores

- Simulation skill scores
  - Based on the Taylor diagram skill and relative mean of a time series
  - A skill score per variable or based on their combination

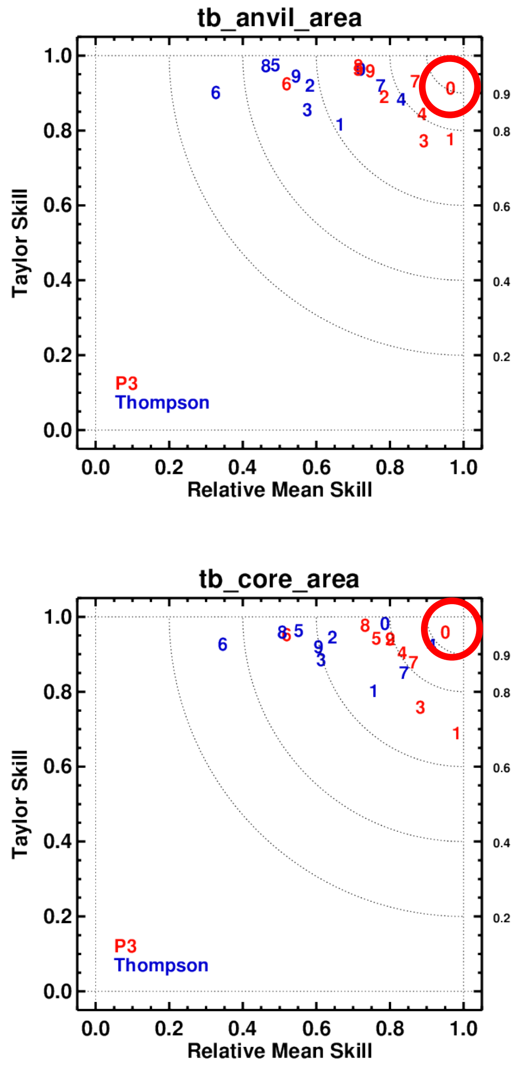


Satellite Brightness Temperature Example

1/25/2019

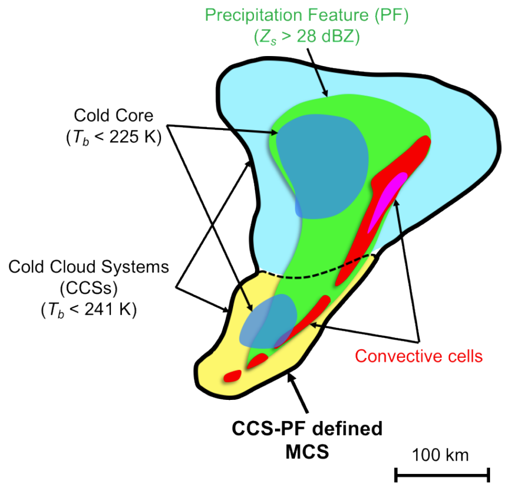


Model cloud temperature at τ_a=1



Location, Location, Location

- Requires object-based location of the AMF within the model domain
  - Even the best simulation will not locate the storm genesis in the same relative AMF model location
  - Propose minor shifts in the model's AMF grid location based on relative distances to observed objects
- Radar analyses
  - Position/shift the AMF within the model domain by optimal matching of the radar reflectivity objects
  - Apply the location to the radar and satellite diagnostics and skill scores
    - e.g., Satellite anvil/core analyses and radar-based CFADS

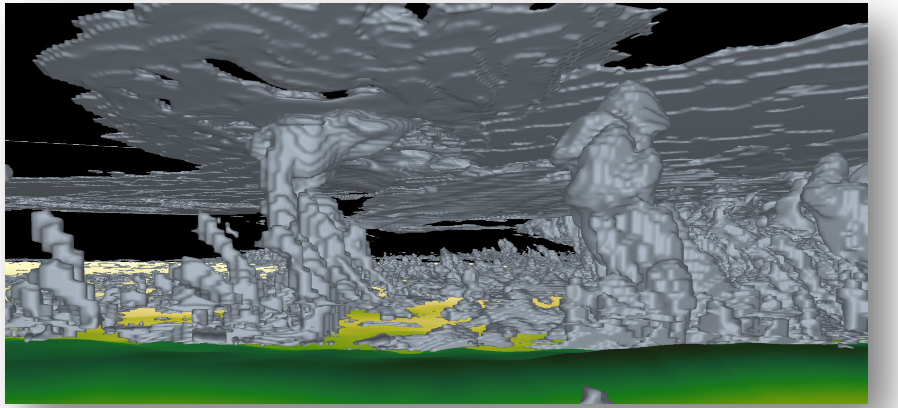


Feng et al. (2019)

Open discussion

- Additional suggestions for useful observations or analyses for model diagnostics/metrics?
- Feedback on modeling approach? Suggested output strategy?
- How important is characterizing the ShCu properties prior to the sh→ deep onset?
- Other thoughts or suggestions?

25-Jan-2019 20 UTC, Δx=500 m



Sign up for the LASSO email list: http://eepurl.com/gy5Wxn
LASSO questions and feedback: lasso@arm.gov (goes to Bill Gustafson and Andy Vogelmann)