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

William I. Gustafson Jr., Andrew M. Vogelmann, & James H. Mather

1Pacific Northwest National Laboratory; 2Brookhaven National Laboratory

Town Hall at 2021 AMS Annual Meeting
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
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

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>5</td>
</tr>
<tr>
<td>2016</td>
<td>13</td>
</tr>
<tr>
<td>2017</td>
<td>30</td>
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<tr>
<td>2018</td>
<td>30</td>
</tr>
<tr>
<td>2019</td>
<td>17</td>
</tr>
<tr>
<td>Total</td>
<td>95</td>
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</tbody>
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LASSO’s LES approach

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

https://www.arm.gov/capabilities/modeling/lasso
LASSO Bundle Browser

- User interface via the Bundle Browser
  - [https://adc.arm.gov/lassobrowser](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**


**LASSO technical document**


**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)
- 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
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, $\Delta x = 500$ m
  - 751 x 866 grid cells = 375.5 x 433 km$^2$
- D04, $\Delta x = 100$ m
  - 2146 x 2776 grid cells = 214.6 x 277.6 km$^2$
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, $\Delta x = 2.5$ km
  - Different boundary condition dataset for each ensemble member
    - ERA5-EDA for 10 members
    - GEFS for 21 members
    - ERA5
    - FNL

OLR: Ensemble of $\Delta x=2.5$ km Runs Based on Boundary Dataset

Shading = OLR (W m$^{-2}$)
Contours = 500 & 1000 m terrain height
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 km² 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

Value
(Accuracy and Effectiveness)

Spatial Coverage & Continuity
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

Top Altitude > 40dBZ
Satellite Brightness Temperature Example

1/25/2019

Anvil Area (Tb < 240 K)

Core Area (Tb < 219 K)

Model cloud temperature at $T_a = 1$

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

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

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?

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