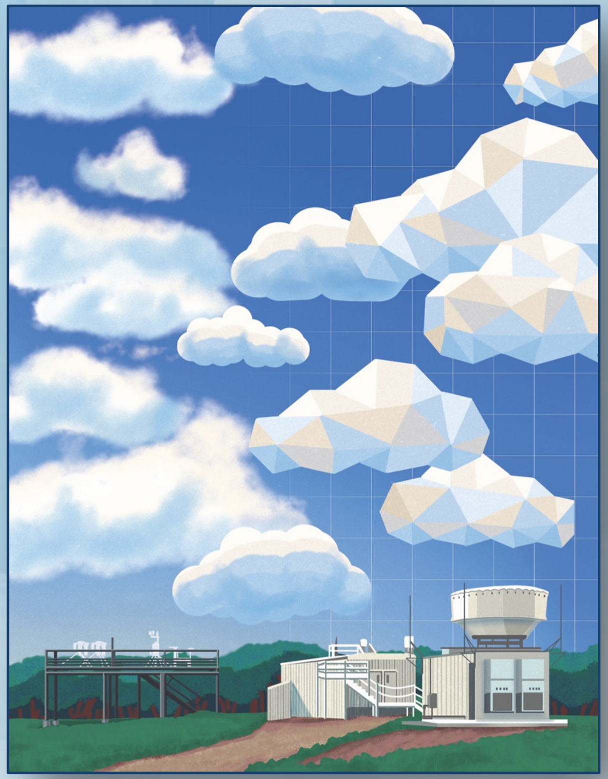


Welcome to the Tutorial for the LES ARM Symbiotic Simulation and Observation (LASSO) Activity

Today's presenters:

William I. Gustafson Jr.[1], Andrew M. Vogelmann[2], Tami Fairless[2], Krista Gaustad[1], & Carina Lansing[1]

[1] Pacific Northwest National Laboratory; [2] Brookhaven National Laboratory

LASSO – a story in 3 parts

2:00*	**Prologue**	Welcome and introduction
2:10	**Part 1**	Library of large-eddy simulation for shallow convection & the ensemble approach
2:45	**Part 2**	Observations and Data Bundle Selection
	Intermission if ahead of schedule	
3:20	**Part 3**	LASSO-O workflow software
3:55	**Epilogue**	Closing thoughts

*Eastern time

What is LASSO? The 5-minute overview…

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

- **Intent of LASSO:** leverage high-resolution modeling to enhance the value of ARM's suite of observations for researchers
- Motivated by goal of bridging the gap between observations and scales used in forecast and climate models
  - Increase understanding of linkages between different observations
  - Advancement of cloud theory and parameterizations
  - Enable model development
- Vetted large-eddy simulation (LES) provides a plausible proxy for unobservable details in the context of the observations

What is LASSO? The 5-minute overview…

- **Approach:**
  - Target specific weather regimes with libraries of LES cases
  - Curate a suite of relevant observations associated with the chosen regime
  - Provide a basic comparison between the observations and the LES
  - Package the observations and model data into “data bundles” to simplify downloading and use

- **Scenario #1:** Shallow convection at the Southern Great Plains atmospheric observatory in Oklahoma
- More scenarios to come…

New scenarios in development

- Several scenarios proposed at the *LASSO Expansion Workshop*; details in workshop report: https://www.arm.gov/publications/programdocs/doe-sc-arm-19-023.pdf

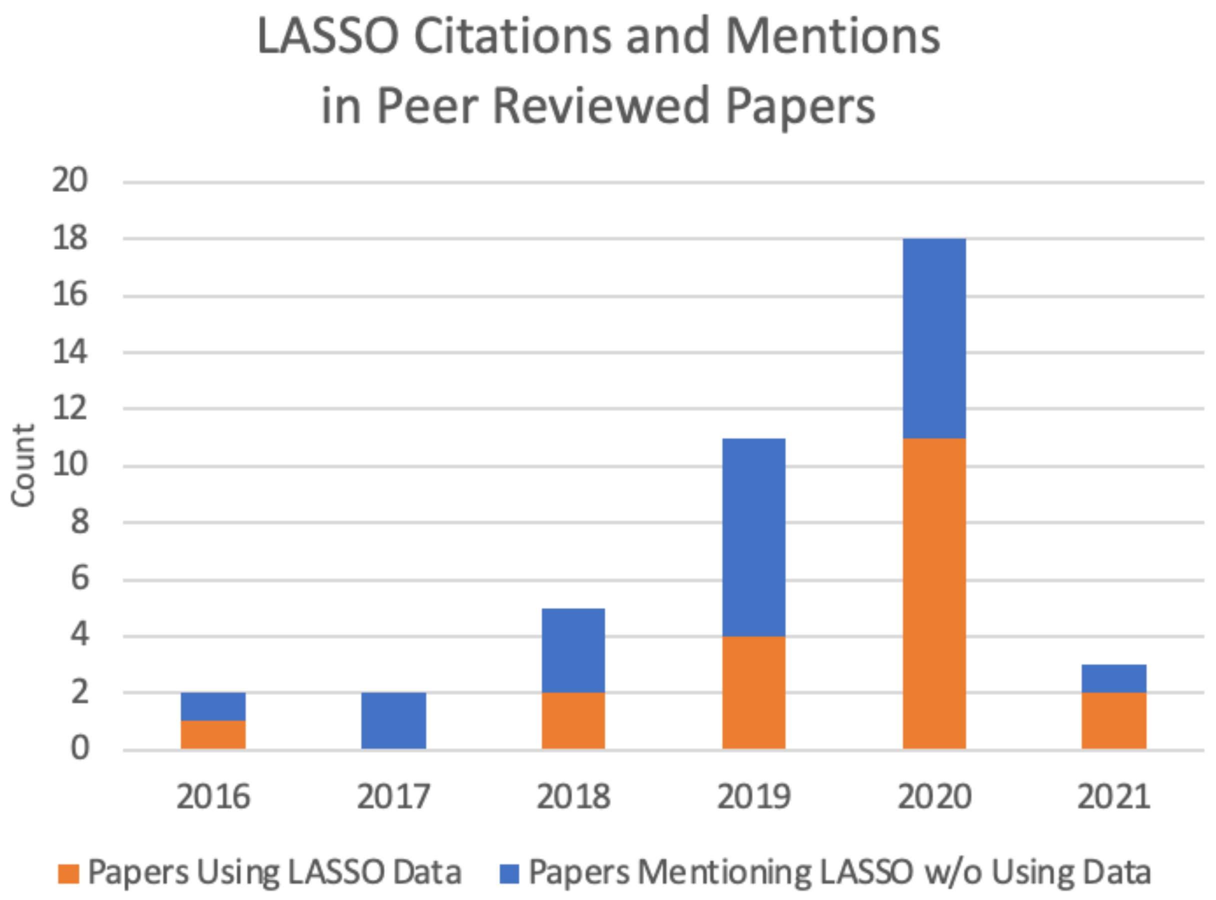
- **Shallow-convection:** Put on hiatus after 2019 season to develop new scenarios

- **LASSO-CACTI:** Planned public availability in 2022
  - Focus on convective initiation and early stages of convective upstage growth for deep convection

- **LASSO-ACE-ENA:** Just starting development, release timeline tentatively 2023 or 2024
  - Focus on maritime stratiform and related precipitation processes

LASSO being applied to a range of atmospheric topics

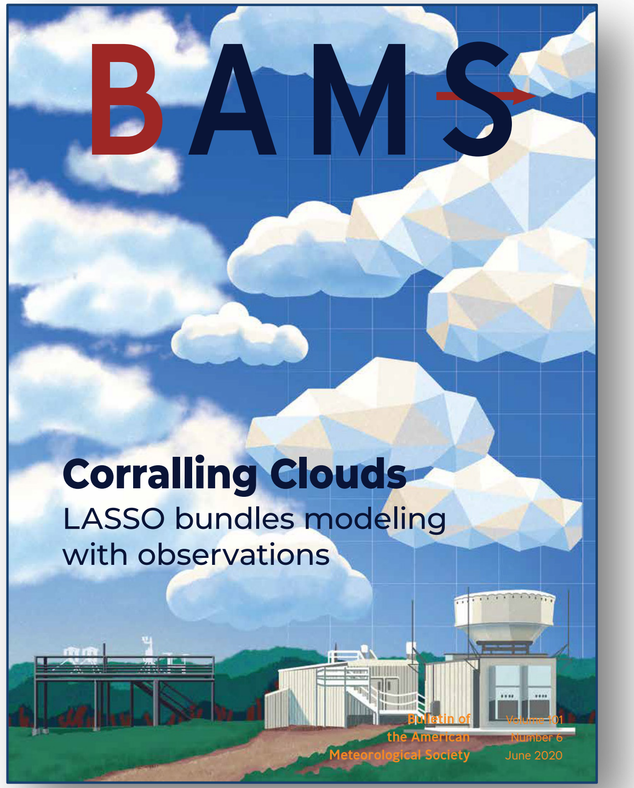
- Published examples using LASSO
  - Quantifying shallow convection statistics
  - Understanding shallow convection processes
  - Cloud-radiation connections
  - 1D vs. 3D radiation methodologies
  - Parameterization development & evaluation
  - Radar scan strategies for shallow clouds
  - Understanding dust transport in boundary layer
  - Included within the Global Modeling Testbed (GMTB) for parameterization evaluation and single-column model use
- Also a great tool for teaching!



As of 18-Feb-2021

Where to find more information

- High-level description and primary citation: BAMS article
  - Gustafson et al., 2020, BAMS, https://doi.org/10.1175/BAMS-D-19-0065.1
- Nitty gritty details: LASSO Technical Description
  - https://www.arm.gov/publications/tech_reports/doe-sc-arm-tr-216.pdf
- Web page: https://www.arm.gov/capabilities/modeling/lasso
- Technical support
  - lasso@arm.gov (goes to Andy and Bill)
    - Works for any sort of question
    - Best for reporting something broken
    - Not publicly searchable
  - LASSO Discussion Forum on new ARM Discourse website: https://discourse.adc.arm.gov/
    - **This is a new capability**–today's tutorial is the soft rollout!
    - Encouraging folks to use this for general questions and discussion
    - Content will build over time and become a community asset
- LASSO email list: http://us11.campaign-archive1.com/home/?u=74cd5b8a5435b8eca383fc18c&id=38f02e1568

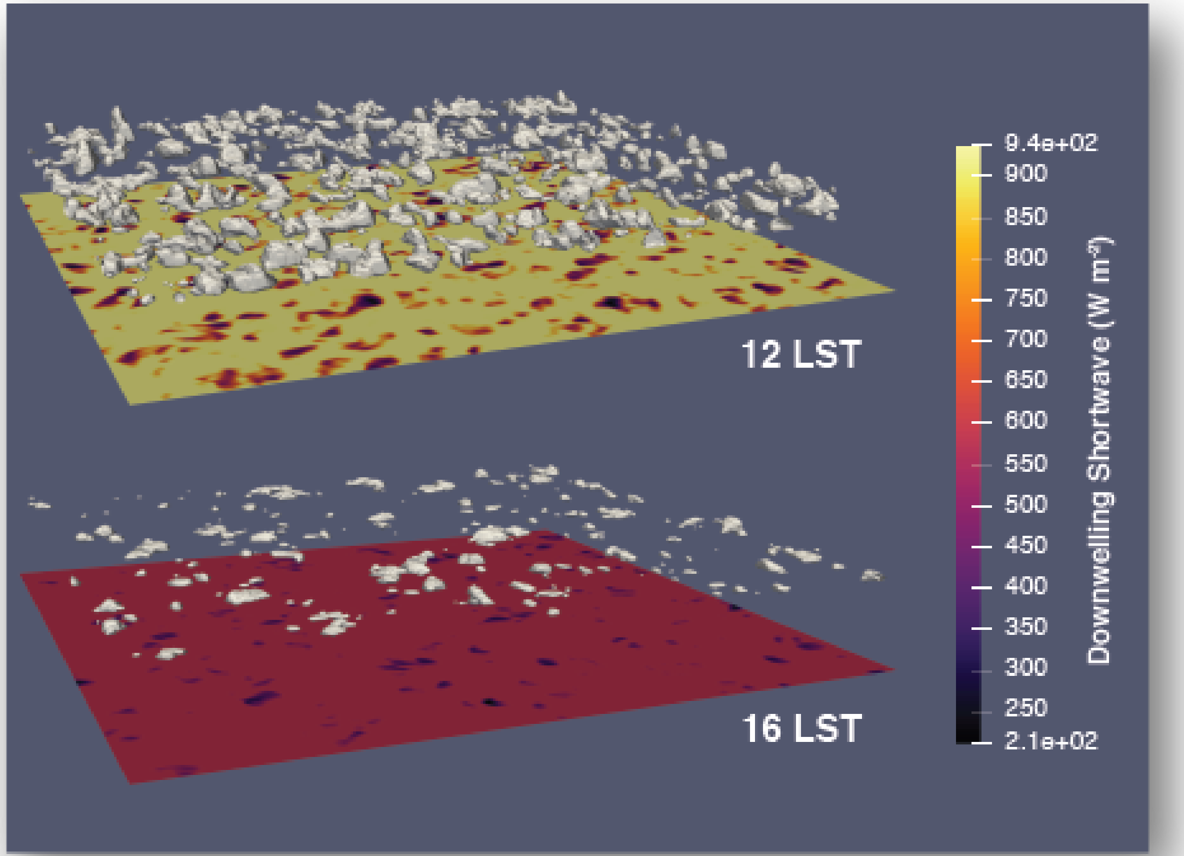


Part 1:
Large-eddy simulation for shallow convection

Presenter: William I. Gustafson Jr., PNNL

LASSO’s LES methodology: the basics

- Use WRF model with added LES capabilities (early years also include SAM runs)
- Provide a statistical representation of the clouds; a traditional LES approach with doubly periodic boundaries and homogeneous surface
- 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 every 10 minutes



LASSO's version of WRF model

- Available at https://code.arm.gov/lasso/lasso-wrf or by request
  - In the "wrf_faster" branch of the repository
- Traces heritage back to the Fast-physics System Testbed and Research (FASTER) project at BNL circa 2010
- Based on WRF v3.8.1
- Added features over default WRF in a new em_crm build category
  - Extra LES-related output
    - Time averaged between output times
    - Volumes, profiles, and column-integrated quantities; spatial averaging
    - Specialized LES diagnostics, e.g., vertical fluxes of heat and moisture, in-cloud vs. all-domain averages
  - Streamlined handling of LES initialization and large-scale forcing
  - Ability to use large-scale forcing and/or nudging toward profiles
  - Customized Morrison microphysics with 4-mode aerosol inputs (used during LASSO testing phase)

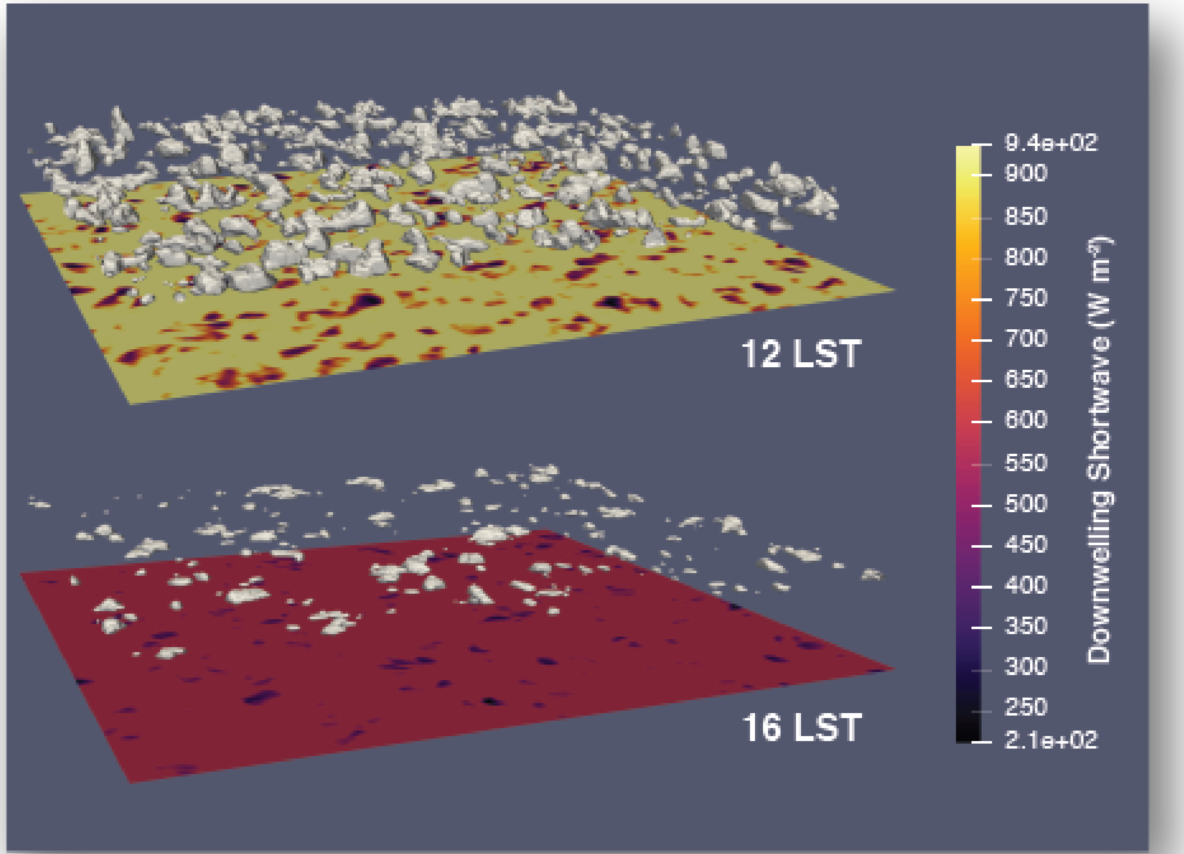
Domain configuration

- Grid spacing: dx=100 m; dz=30 m up to 5 km, then stretches to 300 m at domain top
  - Captures shallow convection processes sufficiently to provide a good representation of the clouds
  - Resolution chosen to capture the clouds—grid spacing too large to capture stable conditions and boundary layer transitions, particularly during evening
  - Implications
    - Simulations good to use during midday
    - Avoid first several hours due to model spin-up and evenings when turbulence does not decay accurately
    - Timing of cloud decay can be off due to not capturing turbulence decay timing
- Flat, uniform lower boundary
  - No terrain or vegetation variability
  - Time-dependent, specified sensible and latent heat fluxes from Variational Analysis VAP
  - Implications
    - No feedback between land and atmosphere
    - Radiation has no impact on surface fluxes or energy balance
    - Surface gradients across the region are not represented

Physics configuration settings for “production years”

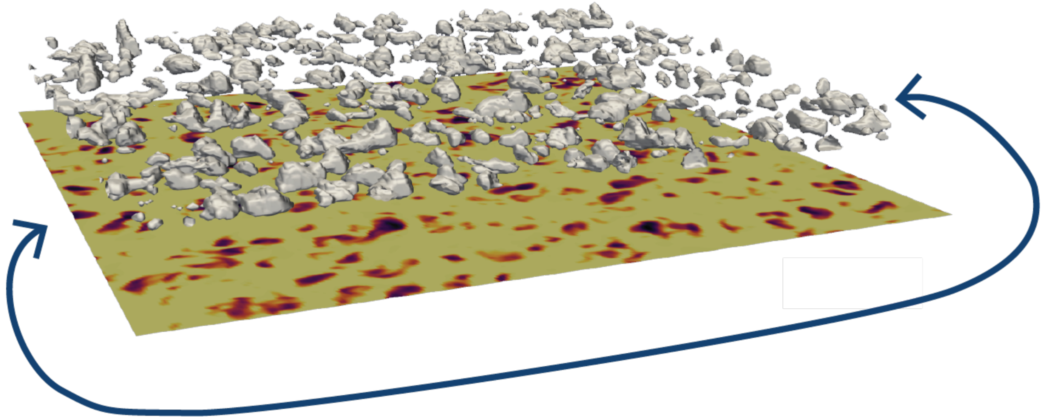
Category	Setting
Microphysics	Thompson (8, most cases)
Radiation	RRTMG SW & LW (4)
Surface Layer	Revised MM5 Monin-Obukhov (1)
Surface Physics (Land)	Thermal Diffusion (1)
SGS Scheme (km_opt)	1.5 order TKE (2)

- Ice microphysics activates even though we focus on shallow convection because of tall model top
  - Attempt to capture cirrus clouds to varying success
  - Some ensemble members transition to deep or mid-level cloud



Lateral boundary conditions

- Doubly periodic lateral boundary conditions
- Assuming scale separation between larger, mesoscale conditions and the LES domain
  - Connection to larger scales achieved through a uniform, domain-wide, large-scale forcing tendency
- Implications
  - Largest scales of simulated variability and motion are on order of the domain size, 25 km (14 km for early years)
  - Each model column is statistically identical
    - Cannot think in terms of one-to-one comparisons to point locations
    - LES represents the average conditions around the SGP



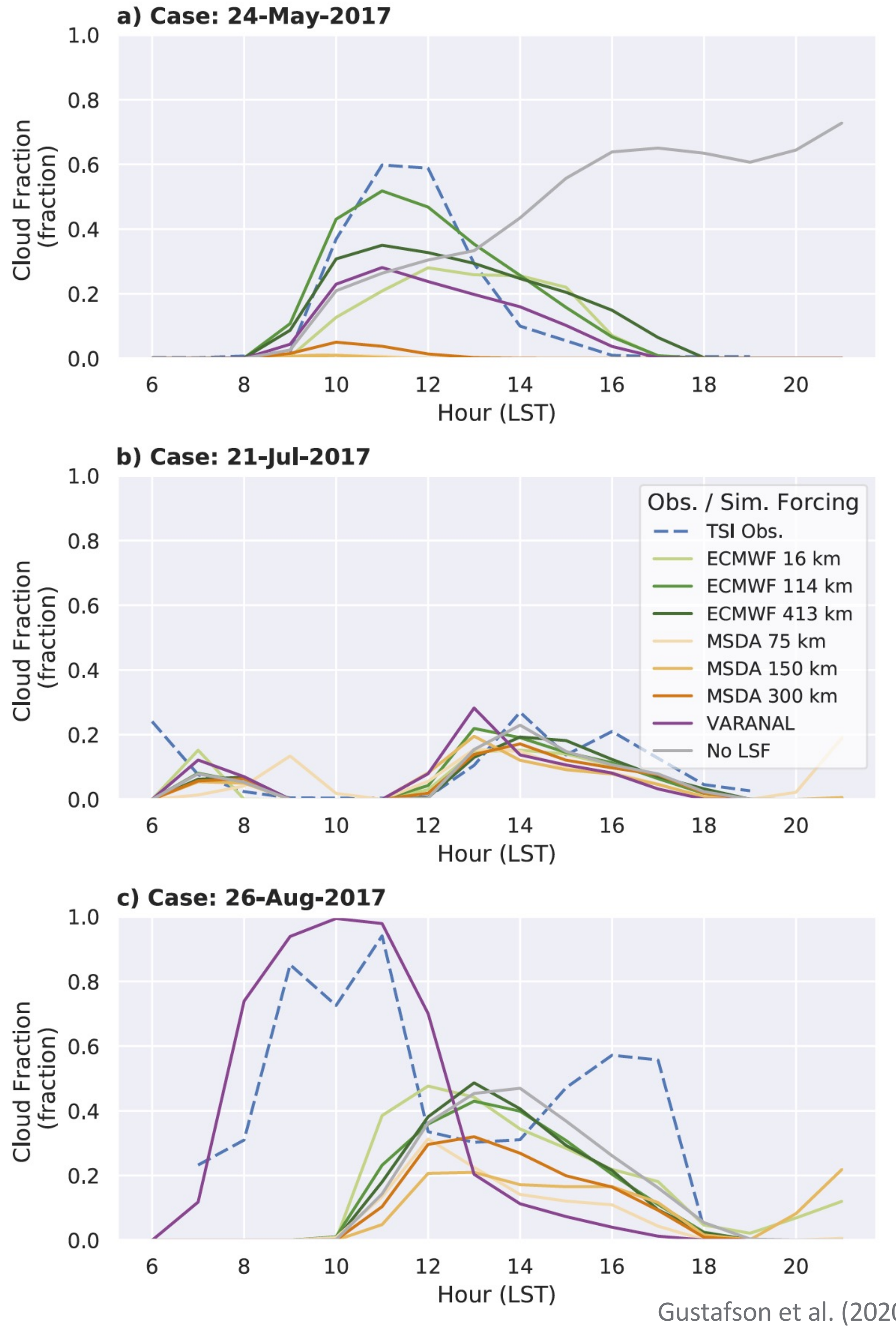
Model inputs

- Initial conditions
  - Temperature, moisture, and wind profiles from 12 UTC sounding (5 or 6 LTC depending on day of year)
  - Random perturbations to potential temperature in lowest 33 model layers (~990 m), 0.1 K max. amplitude
- Surface forcing
  - Regionally averaged sensible and latent heat fluxes from EBBR and ECOR stations via Variational Analysis VAP, updated hourly
- Large-scale forcing
  - Provided as a domain-wide tendency for temperature and moisture profiles
  - Represents large-scale horizontal advection and heating/drying due to subsidence
  - Nudging to observations not used for LASSO
  - Implications
    - Synoptic changes impact whole domain at the same time—they do not propagate across the region
    - Large-scale winds not updated after initial time

LASSO employs an ensemble of forcings to capture the range of possible conditions

ARM

- Large-scale forcing (LSF) datasets generated from 3 sources
  - **Variational Analysis:** ARM product, 300 km spatial scale
  - **ECMWF IFS model:** ~16, 115, & 413 km spatial scales
  - **Multiscale Data Assimilation (MSDA):** 75, 150, & 300 km scales;
    - GSI 3DVar data assimilation package at dx=2.5 km
    - Directly incorporates ARM observations into the analysis
      - RWP wind profiles
      - Surface meteorology
- Total of 8 LSF ensemble members per case (includes 1 no-LSF)



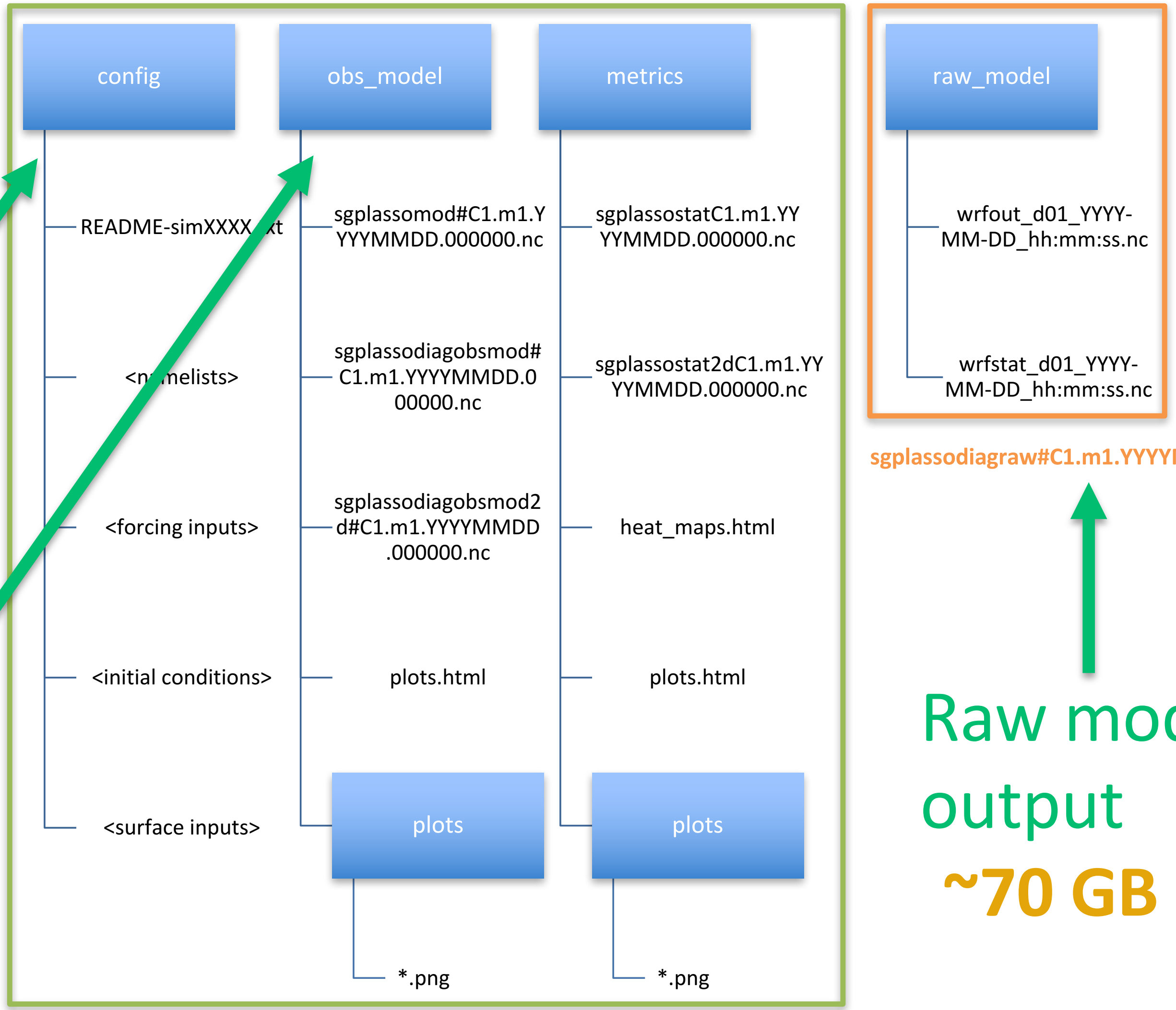
Gustafson et al. (2020, BAMS)

U.S. DEPARTMENT OF ENERGY

Model data available in LASSO data bundles

- LASSO "data bundles" organize data into a series of tar files
  - sgplassodiagconfobsmod#C1.m1.YYYYMMDD.tar
  - sgplassodiagraw#C1.m1.YYYYMMDD.tar
  - sgplassohighfreqobsC1.c1.YYYYMMDD.000000.tar
  - sgplassocogsC1.c1.YYYYMMDD.000000.tar

Data Bundle Tar-file Structure



sgplassodiagraw#C1.m1.YYYYMMDD.tar

Model inputs

Post-processed model output

Raw model output
~70 GB

sgplassodiagconfobsmod#C1.m1.YYYYMMDD.tar

~70 MB

config directory of “confobsmod” tar

- Contains input files necessary for reproducing the simulation
  - Initial sounding: wrfinput_d01.nc
  - Large-scale forcing: input_ls_forcing.nc
  - Surface fluxes: input_sfc_forcing.nc
  - WRF’s configuration file: namelist.input

Format for em_crm option

- Script to convert WRF inputs to SAM inputs: sam_input_generation.py

raw_model directory of “raw” tar

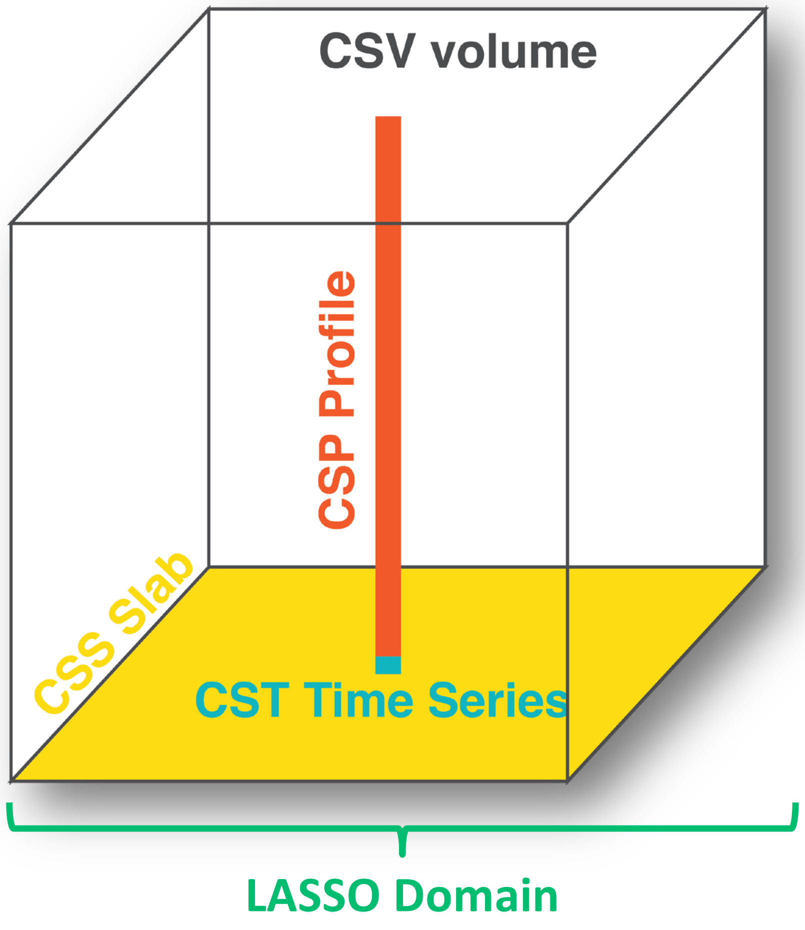
- Contains all the raw model output from WRF
  - Every 10 minutes
  - Separate wrfout files for each model hour, i.e., 6 times per file
  - One wrfstat file per run with all times in it

- **wrfout_d01…** = Standard WRF output format in netCDF
  - See WRF ARW Users Guide for most details, http://www2.mmm.ucar.edu/wrf/users/docs/user_guide_V3/user_guide_V3.8/ARWUsersGuideV3.8.pdf
  - Some variables split into base and perturbation values, e.g., geopotential height = PHB + PB
  - Staggered variables: U, V, W, PH+PHB

wrfstat_d01 files = LES diagnostic output

- Variables averaged/accumulated between 10-min. output times
- Meteorological state, turbulent fluxes, cloud details, radiation, etc.
- Variable suffixes indicate type of averaging (CS refers to “CRM statistic” from the em_crm build mode)
  - CSV = volume variable, i.e., cell-by-cell for whole volume, only time averaged and no spatial averaging
  - CSP = domain-wide horizontally averaged profile
  - CSS = slab variable, i.e., a horizontal surface either from column integrated or a surface variable
  - CST = time series, i.e., single point per time from horizontal averaging of column-integrated or surface variables

Types of wrfstat Variables
CSV is to CSP as CSS is to CST



obs_model directory of "confobsmod" tar

- Contains post-processed and summarized model data
  - Generated via the LASSO-O workflow that will be presented in Part 3
- Consists of a subset of values used to calculate the skill scores
- Three file variations
  - sgplassomod = "ingested" wrfout data on original time 10-min. interval; diagnostic variables
  - sgplassodiagobsmod = adds time reduction to hourly time sampling & side-by-side with observations
  - sgplassodiagobsmodz = height-dependent cloud fractions, model+observations, 10-min. interval
- Much easier to download confobsmod file if you do not need detailed raw output

LASSO Metadata Table for identifying simulations

https://adc.arm.gov/lassometadata

- LASSO data bundles identified by combination of
  1. Case date
  2. Simulation ID
- Identify the simulation ID when publishing!
- Metadata associated with each simulation ID can change between case dates
- Metadata Table helps identify metadata and search for relevant simulations

ARM LASSO METADATA TABLE

DATA DISCOVERY //LASSO HOME //ARM ARCHIVE //LASSO BUNDLE BROWSER

Introduction

Welcome to the LASSO Metadata Table. This page lists the metadata information for each LASSO large-eddy simulation. More information about LASSO can be found at the LASSO information page. The table can be searched globally by using the search button on the top right of the table or by individual columns through a dropdown below each column. The table can be filtered and downloaded as CSV or PDF using the buttons on the top left of the table. More detailed filtering can be done by downloading the complete list in CSV format and importing it into Excel.

COPY CSV PRINT PDF

Search:

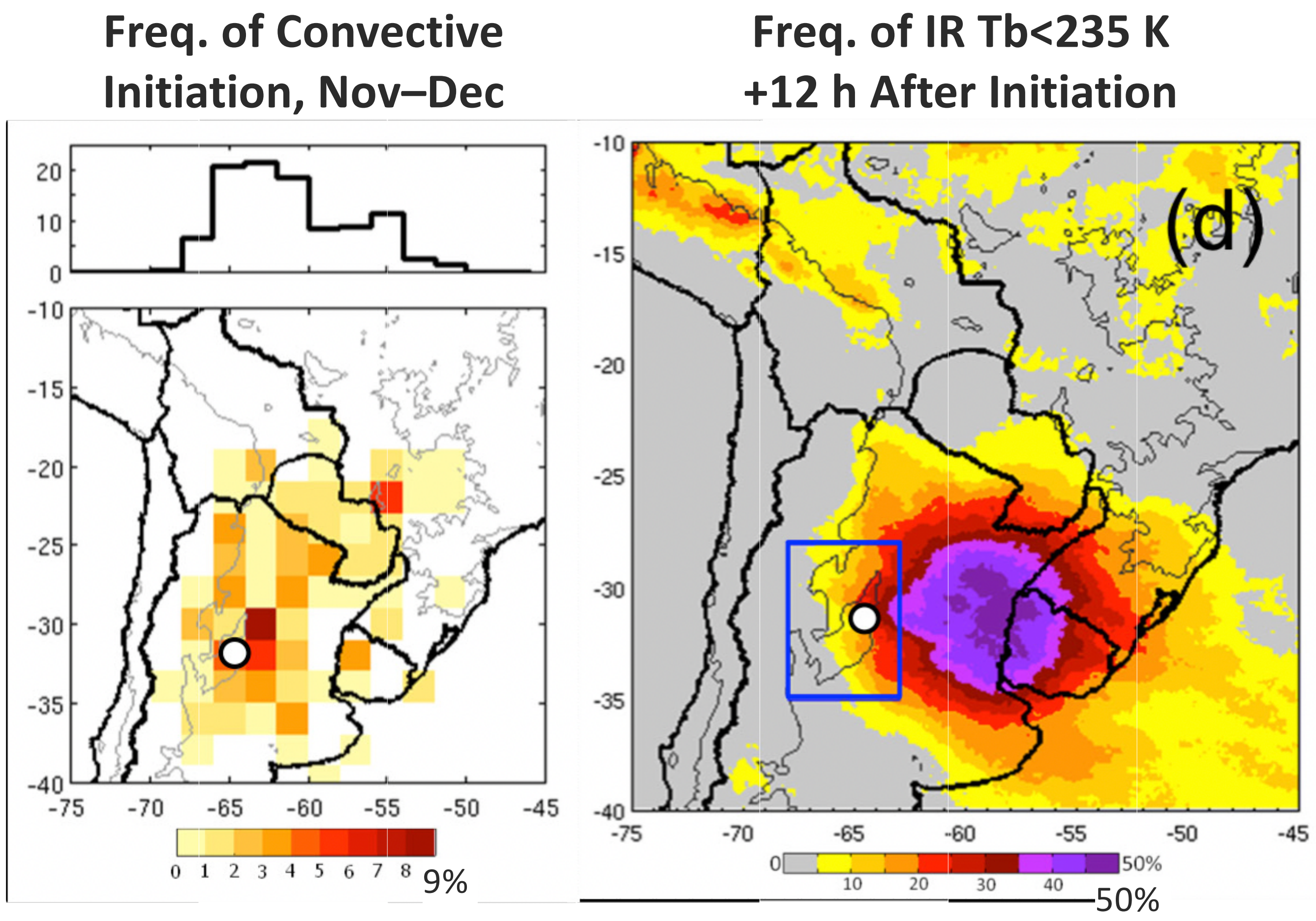
Date	Simulation ID	Model Type	Output Domain Size	Output Number Of Levels	Large Scale Forcing	Large Scale Forcing Scale	Surface Tre
04-03-2017	1	WRF	25 km	226	None	NA	VARAN
04-03-2017	2	WRF	25 km	226	VARANAL	300 km	VARAN
04-03-2017	3	WRF	25 km	226	ECMWF	16 km	VARAN
04-03-2017	4	WRF	25 km	226	ECMWF	413 km	VARAN
04-03-2017	5	WRF	25 km	226	ECMWF	114 km	VARAN
04-03-2017	6	WRF	25 km	226	MSDA	75 km	VARAN
04-03-2017	7	WRF	25 km	226	MSDA	150 km	VARAN
04-03-2017	8	WRF	25 km	226	MSDA	300 km	VARAN
04-04-2019	1	WRF	25 km	226	None	NA	VARAN
04-04-2019	2	WRF	25 km	226	VARANAL	300 km	VARAN
04-04-2019	3	WRF	25 km	226	ECMWF	16 km	VARAN
04-04-2019	4	WRF	25 km	226	ECMWF	114 km	VARAN
04-04-2019	5	WRF	25 km	226	ECMWF	413 km	VARAN
04-04-2019	6	WRF	25 km	226	MSDA	75 km	VARAN
04-04-2019	7	WRF	25 km	226	MSDA	150 km	VARAN
04-04-2019	8	WRF	25 km	226	MSDA	300 km	VARAN
04-05-2017	1	WRF	25 km	226	None	NA	VARAN
04-05-2017	1	WRF	25 km	226	None	NA	VARAN
04-05-2017	2	WRF	25 km	226	VARANAL	300 km	VARAN
04-05-2017	2	WRF	25 km	226	VARANAL	300 km	VARAN
All	All	All	All	All	All	All	All

https://www.arm.gov/ca

Extras

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 LASSO-CACTI 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

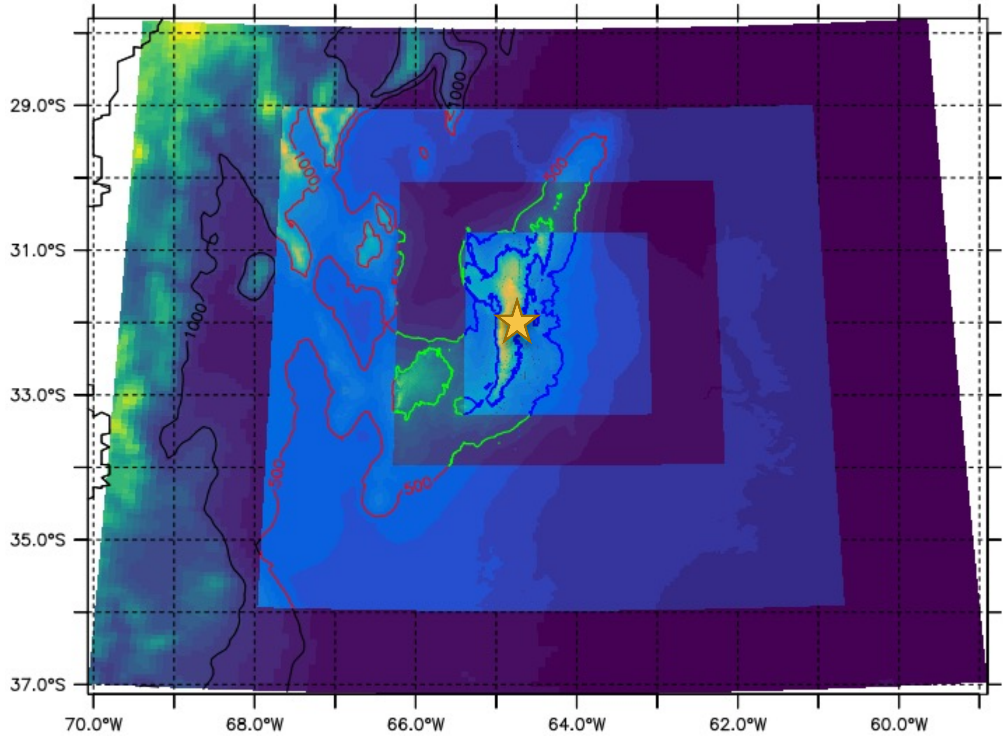
- Science drivers chosen to balance relevant science with computational capacity
  - LES resolution governed by cloud core requirements
  - Domain size determines portion of lifespan simulated
  - Limiting ensembles to mesoscale simulations with the potential for a small number of LES ensembles for specific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

LASSO-CACTI modeling approach

- **Stage 1:** Mesoscale ensemble used to pick cases and identify good boundary conditions
  - 2.5 km grid spacing, ~30 ensemble members
- **Stage 2:** LES for primary region around the observation site and to capture cloud initiation
  - 500 and 100 m grid spacings (nested instead of doubly periodic)
- **Stage 3:** Simplify usage of the many TBs (PB?) of data
  - Provide subsets of variables by theme
  - Stage data on ARM cluster for users who cannot download the data
  - Access via Jupyter notebook server & cluster sessions

Nested CACTI Domains

Δx = 7.5 km, 2.5 km, 500 m, & 100 m



☆ = AMF location