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LASSO, Year 1

LES ARM Symbiotic Simulation & Observation Workflow

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LASSO Webpage: http://www.arm.gov/science/themes/lasso

LASSO e-mail list sign up: http://eepurl.com/bCS8s5

U.S. DEPARTMENT OF ENERGY | Office of Science

Tonight's agenda

- Introductions
- Update on year 1 & the master plan
- Cloud classification VAP
- Forcing generation
- Data bundles & model evaluation
- Advanced data access
- Open discussion

Who's involved (so far)

Primary team members

- **PNNL:** Bill Gustafson, Heng Xiao, Larry Berg, Jerome Fast, Mikhail Ovchinnikov
- **BNL:** Andy Vogelmann, Satoshi Endo, Tami Toto, Ed Luke
- **UCLA:** Zhijin Li, Xiaoping Cheng

Key ARM infrastructure leads and supporting team members

- **PNNL:** Sherman Beus, Jennifer Comstock, Zhe Feng, Rob Newsom, Laura Riihimaki, Tim Shippert, Chitra Sivaraman
- **BNL:** Alice Cialella, S. Giangrande, Mike Jensen, Karen Johnson, Pavlos Kollias
- **ORNL:** Giri Palanisamy, Bhargavi Krishna
- **NOAA:** Dave Turner

Atmospheric Modeling Advisory Group

Bill Gustafson (Leader, LASSO PI, PNNL), Andy Vogelmann (LASSO Co-PI, BNL)
Maike Ahlgrimm (ECMWF), Chris Bretherton (U. WA), Graham Feingold (NOAA ESRL),
Chris Golaz (LLNL), David Turner (NOAA NSSL), Minghua Zhang (Stony Brook U.),
Jim Mather (ex-officio, ARM Technical Director)

Broader Community, communications in progress

- ARM News, LASSO E-mail List (261 subscribers), AGU, website, ARM meetings
- Beta users through FOAs: ASR, Climate Model Development & Validation

The LASSO Vision

- Use LES to add value to ARM observations
  - Self-consistent representation of the atmosphere
  - Provide a dynamical context for the observations
  - Elucidate unobservable processes & properties

- Generate a simulation library for researchers
  - Enable statistical approaches beyond single-case mentality
  - Provide tools necessary for modelers to reproduce the LES

What can you do with an Obs+LES library?

- As an observationalist
  - Inform instrument remote retrievals
  - Test implications of radar scan strategies or flight paths
- As a theoretician
  - Get estimates of fluxes & co-variability of values
  - Test relationships w/o having to run the model yourself
- As a modeler
  - Know ahead of time which days have good forcing
  - Have inputs and corresponding outputs to test parameterizations

The road to LES at SGP

Goal of running routine LES for shallow convection in 2017

Role of the pilot project

- ARM's goal: a fully functional, operational weather hindcast (for data assimilation) and LES modeling system with all the bells and whistles for enabling ease of data discovery, analysis, and delivery

- Pilot project's scope: recommend how to reach this goal and provide a prototype workflow for the modeling and data bundle

Tasks for the pilot project

- Recommend model and its configuration to use
- Recommend forcing dataset(s) and how to incorporate ARM data to constrain the LES
- Recommend evaluation methodology
- Recommend analysis and visualization tools
- Estimate costs to do routine LES
- Provide a prototype workflow
- Work with developers to implement workflow

Work done in year 1

- Forcing development
  - Acquired constrained variational analysis data for Jun-Aug 2015
  - Worked through technique for converting ECMWF analyses into forcings
  - Set up MS-DA for using profiles from ARM and ingesting NARR & FNL background fields
- Model configurations
  - Matched physics for SAM and WRF
  - Testing with 7, 14, and 25-km domains, dx=100 m
  - Microphysics comparisons
  - Started testing nested LES and bin microphysics
- ShCu test cases
  - 6, 9, 27 June 2015; no ShCu days in July, some cases in August
- Data bundle design and coding
  - Identification of critical observations
  - Skill score, metric, and diagnostics development
  - Automation

Work to-do in year 2

- Implement new boundary facility profiles into MS-DA
- Full evaluation of forcings & model configuration
  - Debating the appropriate number & variety of cases
  - Nested vs. periodic LES boundaries
  - Interactive soil model vs. specified fluxes
- Finalize model outputs and post-processed fields
- Work with ARM infrastructure and development team to implement codes
- Determine data access methodologies
- Provide prototype software for community use
- Don't blow the budget!

LASSO Timeline

May 2015	Pilot project began
June 2016	Initial ShCu simulations from spring-summer 2015 made available • Ensemble of forcings • LES simulations from SAM and WRF (bulk microphysics) • Observations in comparable form • First cut at metrics and diagnostics
January 2017	2nd batch of ShCu simulations from spring-summer 2016 • Will include influence of boundary facility profiles • Both bulk and spectral-bin microphysics versions
April 2017	Additional test cases for year-round shallow cloud conditions Beta software suite Recommended configurations for ongoing simulations
May 2017	Pilot project over and transition to routine simulation mode

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Value Added Products (VAPs); CLDTYPE (Classified Cloud Types) and ShCuTime (Shallow cumulus time period)

K. SUNNY LIM[1], LAURA RIIHIMAKI[1], JESSICA KLEISS[2], LARRY BERG[1], YUNYAN ZHANG[3], AND YAN SHI[1]

[1]PACIFIC NORTHWEST NATIONAL LABORATORY, RICHLAND, WA

[2]LEWIS AND CLARK COLLEGE, PORTLAND, OR

[3]LAWRENCE LIVERMORE NATIONAL LABORATORY, LIVERMORE, CA

Acknowledgements:

VAP Science Sponsors & Helpful discussions: William Gustafson, Andrew Vogelmann, Jennifer M. Comstock, Chitra Sivaraman, Michael Jensen, and Justin W. Monroe

Schematic diagram of ShCu period selection procedure

K.-S. S. Lim, L. Riihimaki, J. Kleiss, L. Berg, Y. Zhang, and Y. Shi

Classified cloud types

↓

Selection of single-layer **low cloud type**

↓

0.5 < TSI < 70
0 < ceilometer

↓

Frequency of low clouds during 1 hour > 2

↓

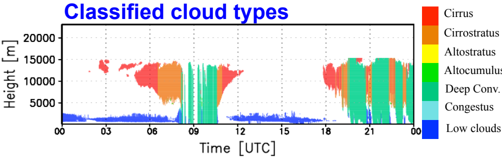
Duration of ShCu > 1.5 h
Separation of each ShCu case > 2.5 h

↓

Separation of transition case (St, Ci, Ac)

↓

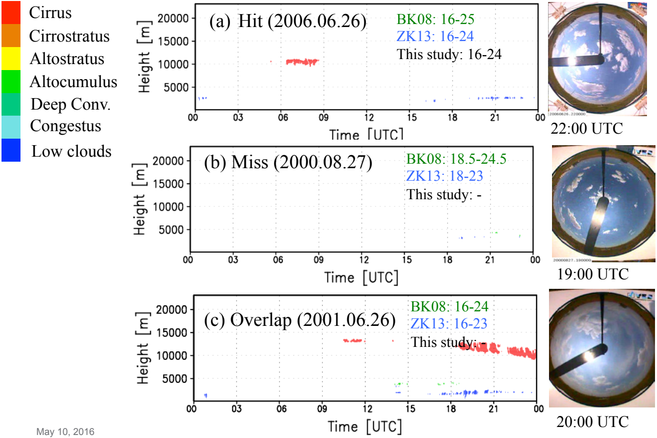
Selected ShCu



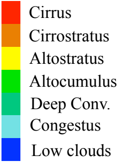
Evaluation of algorithm using the dataset from Berg and Kassianov (BK08) and Zhang and Klein (ZK13) during 9 years (2000-2008)

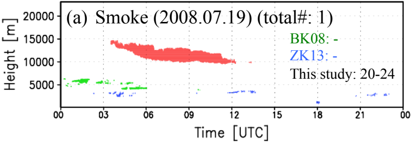
Hit Both (either)	Miss	Overlap	False positives (Large-scale/smoke/Ac)	Transition	Data issues
35 (59)	5	9	17 (3/1/10)	15	17

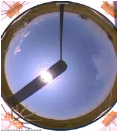
Example of Hit, Miss, and Overlap cases



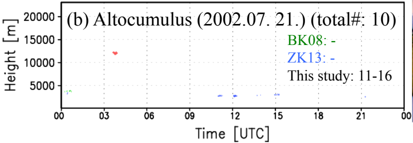
Example of false positive cases

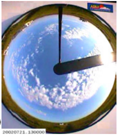






20:00 UTC





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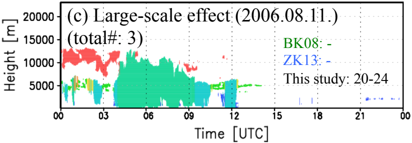
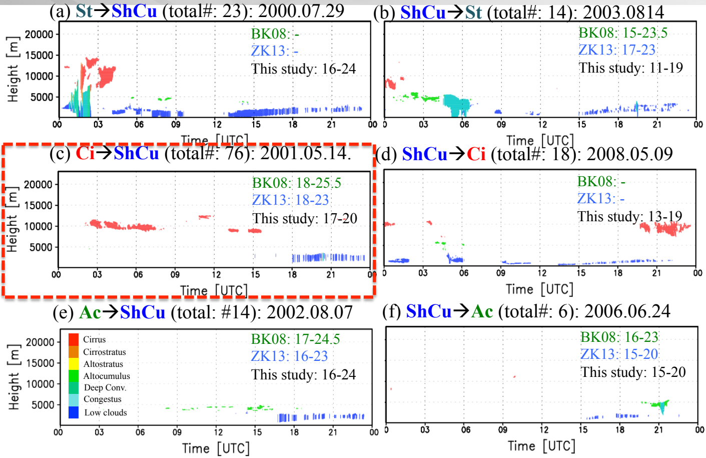


22:00 UTC

Example of transition cases



Forcing Datasets for LASSO

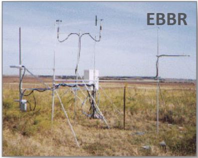
Input data critical for ARM's success

- Forcing data will make or break ARM's modeling endeavor
- Past experience implies forcings will be the largest inter-case uncertainty—physics tend to be more of a systematic bias

- Different input data categories
  - Surface fluxes (or soil initial conditions)
  - Atmosphere initial conditions
  - Column-based forcing (or lateral boundary conditions)
  - Nudging fields (optional)
- Choice of using a fully consistent input data set or mix-and-match from different sources

Specified surface fluxes

- ARM's primary surface flux measurements
  - ECOR = eddy correlation flux measurement system
  - EBBR = energy balance Bowen ratio station



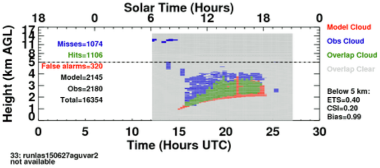
- Using a spatial average of ECOR and EBBR from across SGP
  - Choice of a simple average or weighted by land cover type
- Alternative is using model-derived fluxes, e.g., from MS-DA or interactive soil module

Atmos. profiles for horizontally uniform initial conditions and forcing

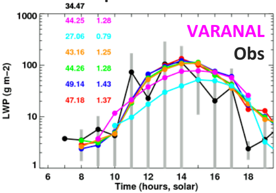
- Constrained variational analysis product from ARM (VARANAL)
  - Historically has had reasonable results and is commonly used for modeling ARM sites
  - It has produced reasonable results, but not consistently at top of the pack
  - Shaocheng is working w/ ARM developers to automate VARANAL
  - 3-D VARANAL can soon be tested

27-Jun-2015 Case

Cloud Fraction



Liquid Water Path

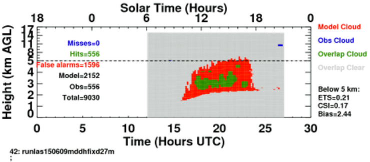


Option 2: NWP based atmos. profiles

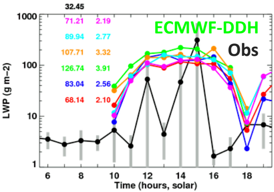
- Average the model state/tendencies over a specified spatial scale and back out the physical tendencies to get a large-scale forcing
- Working with ECMWF/IFS analyses
  - Model has the diagnostics built into it to output the necessary tendencies
  - Currently testing with a pre-release version of the model
  - Two methodologies are now giving similar results

9-Jun-2015 Case

Cloud Fraction



Liquid Water Path

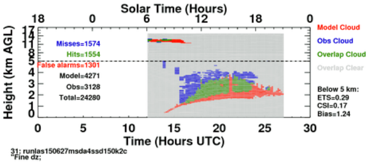


Option 3: Multiscale Data Assimilation MS-DA

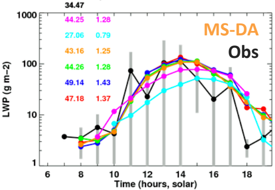
- MS-DA directly ingests ARM observations to constrain the atmospheric state around SGP
- Current testing uses ARM profiles from the Central Facility
  - Radiosondes
  - AERIoe temperature and water vapor
  - Radar wind profiler horizontal wind components (not using, but could in future)
- New boundary facility profiling instruments should become available in May to improve estimate of spatial variability

27-Jun-2015 Case

Cloud Fraction



Liquid Water Path

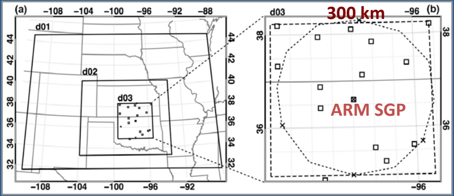


Challenges and Requirements for Large Scale Forcing

1. Capability of fully using existing data (ARM, satellite, radar, etc.)
2. High temporal and spatial resolution
3. Multi-scale/scale-selectable forcing

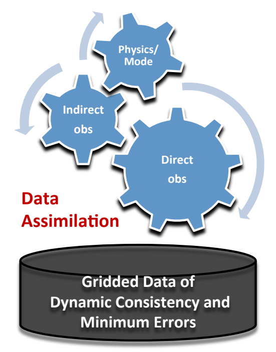
Three-domain nested configuration

2 km grid spacing in the inner domain



Strategy: Nested WRF at a cloud resolving resolution with multi-scale data assimilation (Used for the FASTER Project)

Conventional Data Assimilation: Optimal Estimation

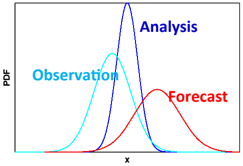


Last two decades have witnessed great progress in data assimilation Methodologies and satellite data

$$\min_x J = \frac{1}{2}(x - x^f)^T B^{-1}(x - x^f) + \frac{1}{2}(Hx - y)^T R^{-1}(Hx - y)$$

Background/Forecast | Observation

B, R - background and observational error covariance



Maximum Likelihood

- Variational methods (3Dvar/4Dvar)
- Sequential methods (Kalman filter/smoother)
- Multi-scale schemes

A Multi-Scale Three-Dimensional Variational Data Assimilation (MS-DA) System

Decomposition of Large and small scales

$$x = x_L + x_S$$

$$\min_{x} J(\delta x) = \frac{1}{2}\delta x^T \left(B_L + B_S\right)^{-1} \delta x + \frac{1}{2}(H\delta x - \delta y)^T R^{-1} (H\delta x - \delta y)$$

(NARR, FNL, ECMWF …)

$$\min_{\delta x_L} J(\delta x_L) = \frac{1}{2}\delta x_L{}^T B_L^{-1} \delta x_L + \frac{1}{2}(H\delta x_L - \delta y)^T \left(HB_S H^T + R\right)^{-1} (H\delta x_L - \delta y)$$

$$\min_{\delta x_S} J(\delta x_S) = \frac{1}{2}\delta x_S{}^T B_S^{-1} \delta x_S + \frac{1}{2}(H\delta x_S - \delta y)^T \left(HB_L H^T + R\right)^{-1} (H\delta x_S - \delta y)$$

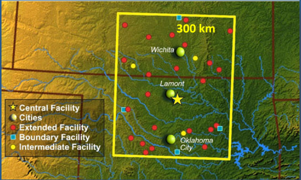
Small scale data assimilation

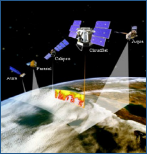
1. **Enhanced effectiveness of assimilating ARM observations**
2. **Leveraging existing analysis and reanalysis**
3. **Developed on top of the NCEP operational GSI system**

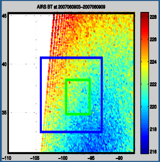
Li et al., 2012, CSR; 2015 MWR; 2015 JGR; Feng et al. 2015 JGR; Li et al., 2016

Assimilation of Observations from ARM Facility and Meteorological Observing Networks

- **ARM observations**
  - Balloon-Borne Sounding System (SONDE)
  - Soil Water And Temperature System (SWATS)
  - AERI profiles
- **Processed conventional data (NCEP)**
- **Processed satellite data (NCEP)**
  - Microwave Radiances (Brightness Temp, several channels)
  - High-resolution infrared radiances (IASI,~230 channels; AIRS, ~50 channels)
  - GPS bending angle profiles (high vertical resolution)

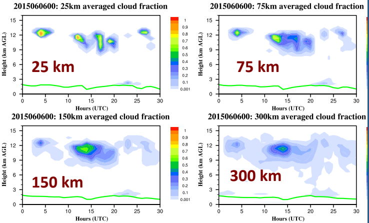




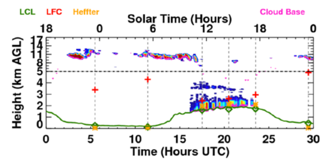


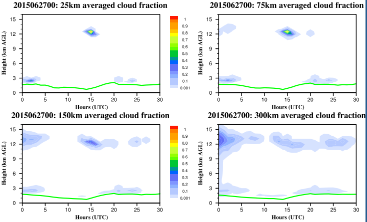
Atmospheric Infrared Sounder (AIRS)

Scale Selectable Forcing: 50 km – 150 km

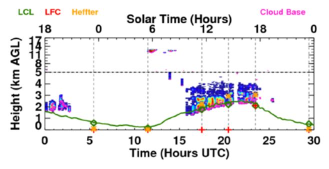


June 6, 2015, Observation





June 27, 2015, Observation



The optimal scale varies from 50 km to 150 km

Summary of available forcings

Category	Includes ARM Data	Scale Selectable	Surface Fluxes	Soil Profiles	Atmos. Profiles	3-D Atmos.
VARANAL	✔	(3-D)	✔		✔	
ECMWF	~	✔	✔	✔	✔	✔
MS-DA	✔	✔	✔	✔	✔	✔

- Use of ARM data is a priority
- 300-km diameter forcings average a lot of variability that can lead to biases
- Nested LES will require 3-D atmospheric fields

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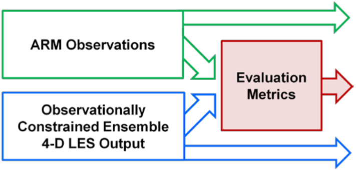
Data Bundles* and User Access

Package of observations and simulations aimed at providing the best description of the atmosphere

*The data structure formerly known as data cubes

Model-Observation Data Bundles



Data Bundles

1. Case descriptors
2. Evaluation metrics
3. Model input and output fields

Data Bundle Example Fields

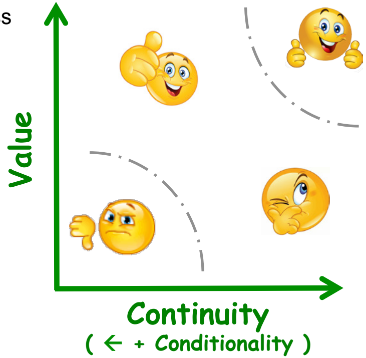
1. **Case descriptors**
   - Cloud type, weather state, inversion strength, etc.
2. **Evaluation Metrics**
   a. **Model-observation diagnostics**
      - Co-registered model-comparable obs and obs-comparable model output.
      - Includes use of instrument simulators where applicable
   b. **Model skill scores**
      - Model performance of cloud an environmental observables
3. **Model input and output fields**
   - Include 3-D model fields, profile statistics, and model-based budget terms
   - Forcings and initial conditions

LASSO Data Priorities

Value

1 = Critical
2 = Important
3 = Nice to have

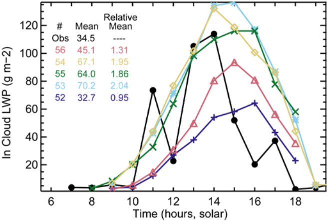
- Accuracy
- Applicability
- Effectiveness

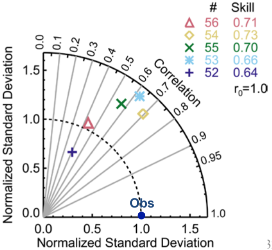


Model-Observation Diagnostics

Ensemble LES simulations are assessed using ARM observations of cloud and environmental variables (currently ~7)

- **Time series** with average difference, RMS, and correlation coefficient
- **Taylor diagrams** for standard deviation and correlation phase space
- **Regression analysis** for slope and intercept
- **Heat maps** for differences of the simulated time series from observations
- **Relative Euclidean distance** for overall model performance of a variable
- **Phase space relationships** for relative relationships between a set of variables
- **2-D cloud masks** for simulated model location and timing

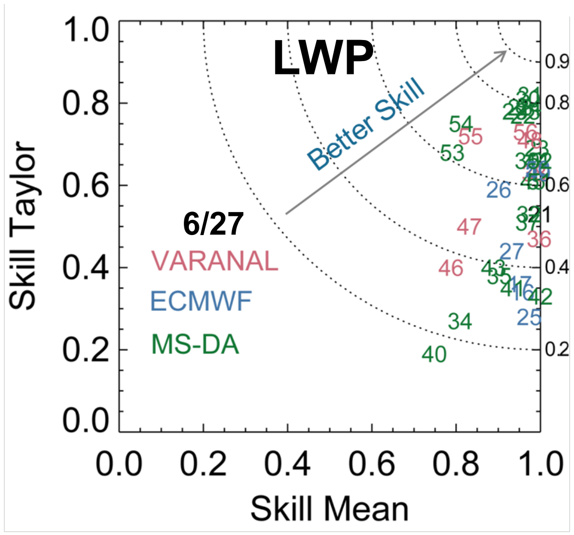


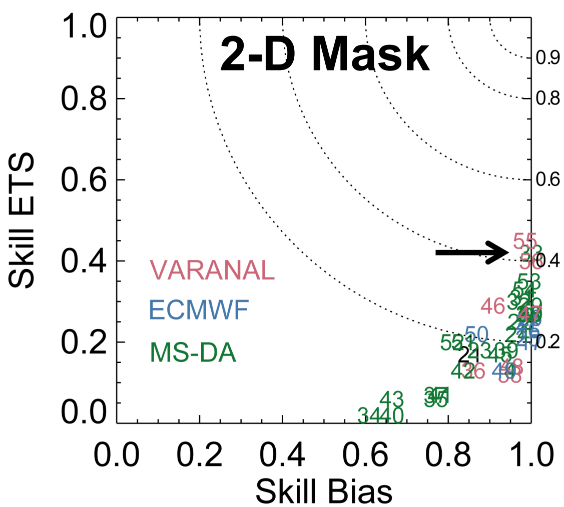


Model Skill Scores

Cloud properties skills from the time series of LWP & TSI cloud fraction

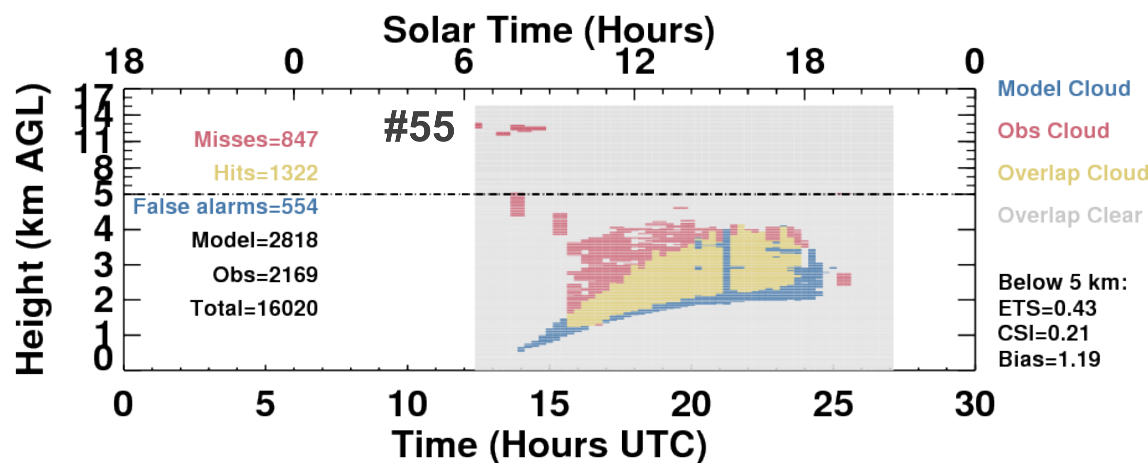
- Based on the Taylor diagram skill and relative mean
- A skill score per variable is based on their combination





2-D masks of obs & sim cloud occurrence

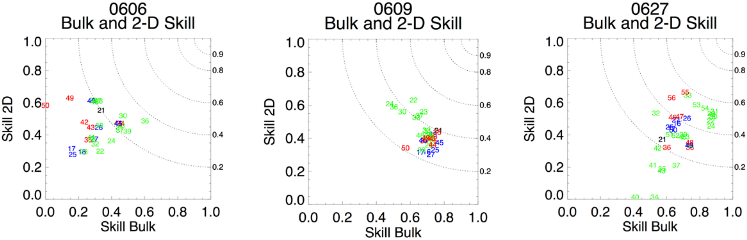
- Based on the Equitable Threat Score (ETS) & bias
- A single skill score is based on their combination



Will be expanding to include more environmental variables

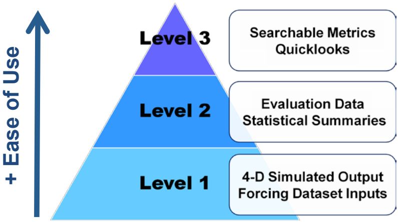
Overview of Test Simulations

About 100 simulations across three test days



VARANAL
ECMWF
MS-DA

Data Bundle Search and Access



- The data bundles will be searchable, have quick-looks, and efficient filtering methods to find and order cases of interest.
- Tools will be developed to simplify analysis and visualization. Examples include:
  - On-the-fly mix and match for multi-case comparisons and compositing
  - Interactive computation, display, and order
  - Goal to enable easier data transfer from the ARM Archive via Globus

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Advanced Data Access

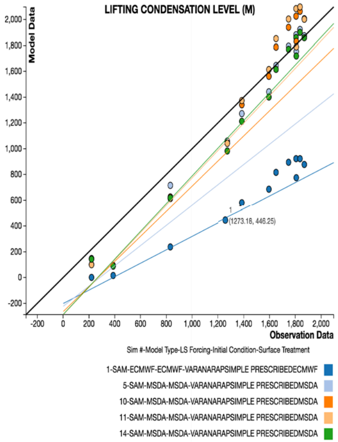
Bhargavi Krishna, ORNL

Data Processing & Visualization Abilities

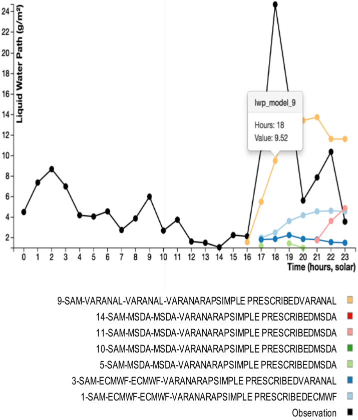
- Data Processing
  - Basic statistical analysis
    - Processed values stored in the database for each output data
  - Customizable statistical analysis based on user needs
  - Big data processing framework
  - NoSQL database
    - Horizontal scalability
    - Schema-less – Add columns dynamically
- Visualization
  - On the fly data retrieval from database
  - Interactive, some more than the other ☺
  - Scalable web service technologies

Screenshots

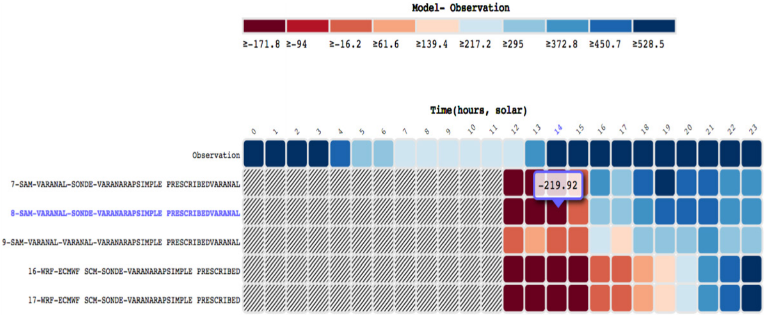
Scatter Plot



Time series



Heat Map



Model- Observation
≥-171.8 ≥-94 ≥-16.2 ≥61.6 ≥139.4 ≥217.2 ≥295 ≥372.8 ≥450.7 ≥528.5
Time(hours, solar)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Observation
7-SAM-VARANAL-SONDE-VARANARAPSIMPLE PRESCRIBEDVARANAL
8-SAM-VARANAL-SONDE-VARANARAPSIMPLE PRESCRIBEDVARANAL
9-SAM-VARANAL-VARANAL-VARANARAPSIMPLE PRESCRIBEDVARANAL
16-WRF-ECMWF SCM-SONDE-VARANARAPSIMPLE PRESCRIBED
17-WRF-ECMWF SCM-SONDE-VARANARAPSIMPLE PRESCRIBED
-219.92

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- Website:

  http://www.arm.gov/science/themes/lasso

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- Posters
  - 145: Gustafson, The LASSO Workflow Pilot Project
  - 147: Endo, LASSO Workflow: Ensemble forcings and LES sensitivity
  - 146: Vogelmann, LASSO Workflow: model-observation “data cubes”
  - 148: Comstock, Boundary layer profiling modules…
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  - 138: Krishna, Large-scale data analysis and vis. for ARM using NoSQL

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Thank you!