

Overview of ARM diagnostic package (ARM-Diags) and its applications to climate model evaluation

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Thanks to the ARM/ASR community, PCMDI and E3SM for their support to this project.

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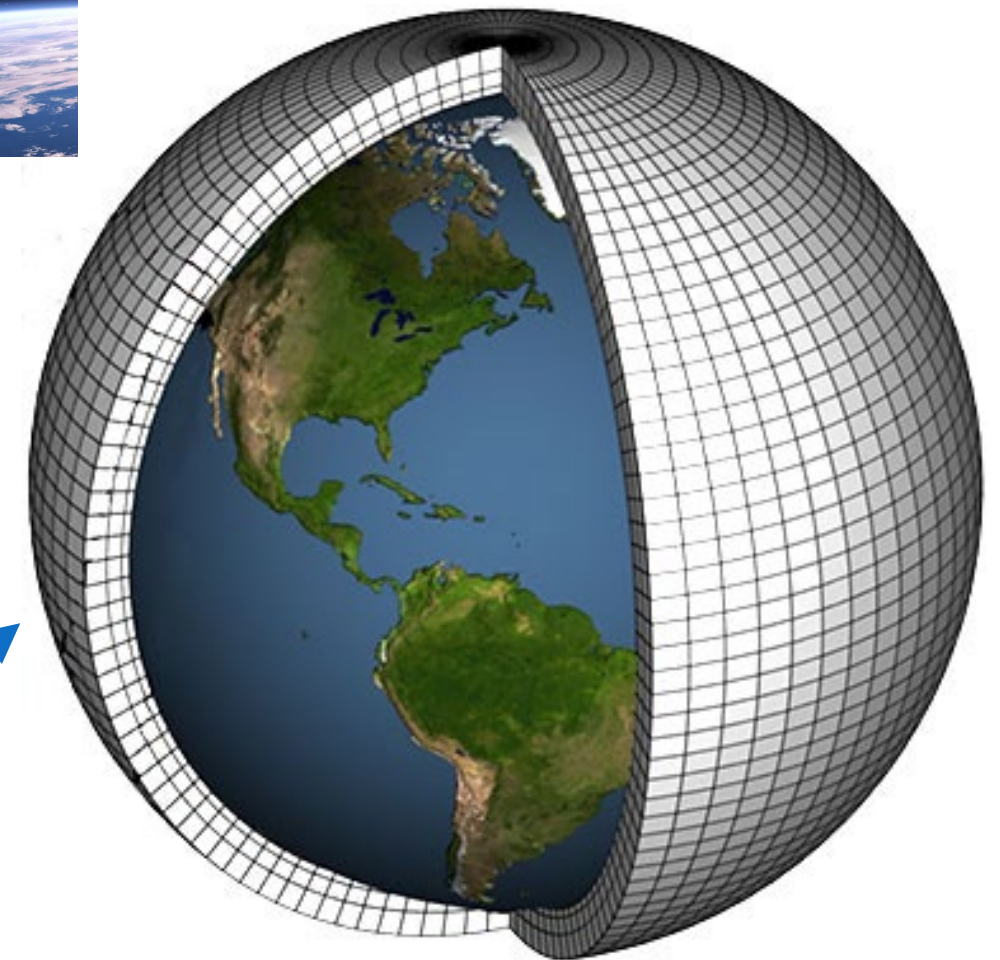
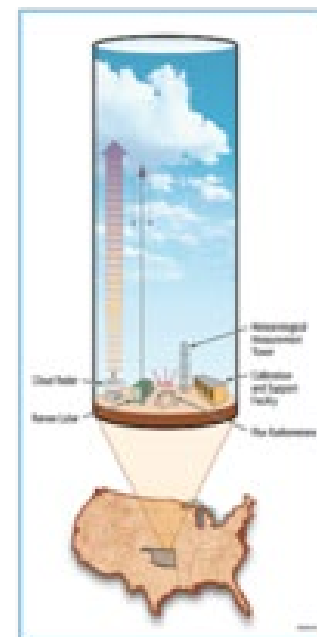
- A set of standard metrics and diagnostics provides an effective way for routine evaluation on climate models.
- Climate model developers have often relied on satellite datasets to calibrate and tune their models.
- ARM's high-frequency, ground-based measurements complements the satellite remote sensing products for model evaluation and development.



Satellite data



ARM data



Global Climate Model (GCM)

1

Objective: To facilitate the use of ARM ground-based in-situ measurements in climate model evaluation and model inter-comparison.

2

ARM-Diags Phase 3 (Released):

- Included both ARM observational datasets and a Python-based analysis toolkit for computation and visualization.
- ARM/ASR scientists can run the standalone package for comparing their model output with ARM and CMIP5/6 simulations.

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ARM-Diags v3 Viewer



[GitHub repo under ARM Project](#)

Model: testmodel

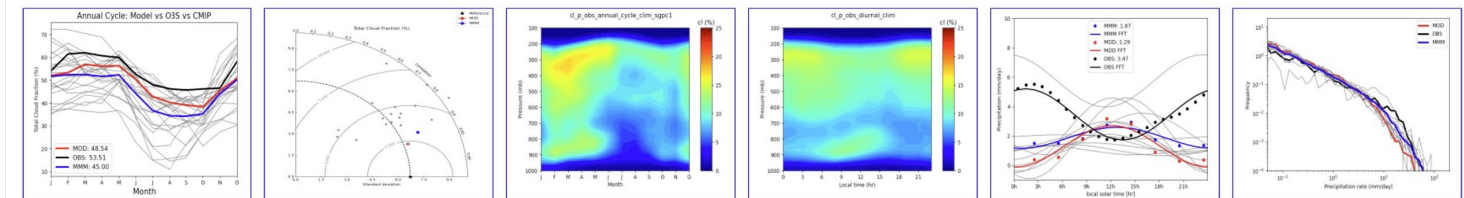
Basic Diagnostics Sets

- 1 [Tables](#) of DJF, MAM, JJA, SON and Annual Mean.
- 2 [Line plots and Taylor diagrams](#) of Annual Cycle.
- 3 [Line plots and Taylor diagrams](#) of ACI Annual Cycle.
- 4 [Contour and Vertical profiles](#) of Annual Cycle.
- 5 [Line and Harmonic Dail plots](#) of Diurnal Cycle.
- 6 [Contour plots](#) of Diurnal Cycle.
- 7 [Line plots](#) of Probability Density Function.

Process-oriented Diagnostics Sets

- 1 [Basic diagnostics plots](#) for Convection Onset.
- 2 [Basic diagnostics plots](#) for Aerosol Activation.

Click on Plot Type



*Observational data assembled from: VARANAL, ARMBE, ACRED, MFRSR, SWATS and other Value-Added Products (VAPs).

*Reference model data from: CMIP5/CMIP6 and CFMIP2/CFMIP3 output archived at ESGF.

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ARM-Diags Phase 3 (Released):

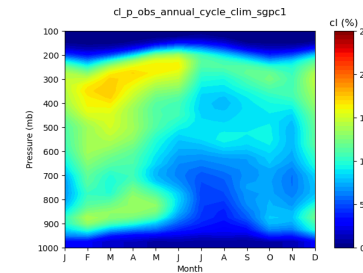
- Included metrics and diagnostics that covers basic climate variability, diurnal and seasonal cycle, and statistics that enables process-level studies.
- Currently available for the SGP, NSA Barrow, TWP Manus, Nauru and Darwin sties, ENA and MAO sites.

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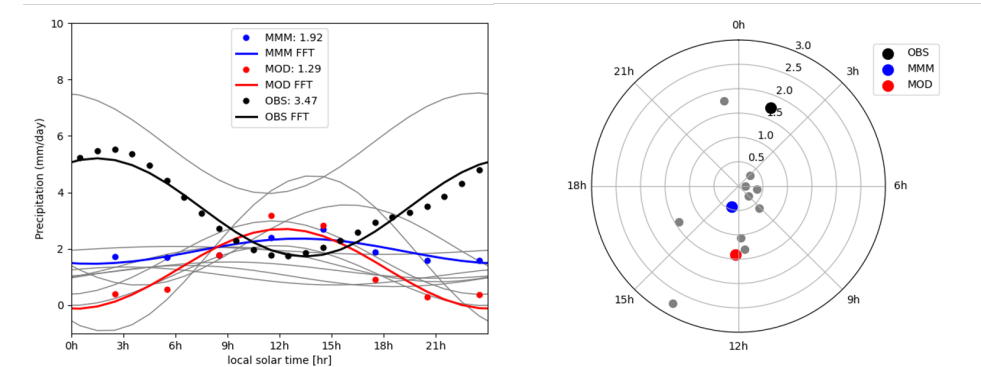
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Annual Cycle of Cloud Fraction

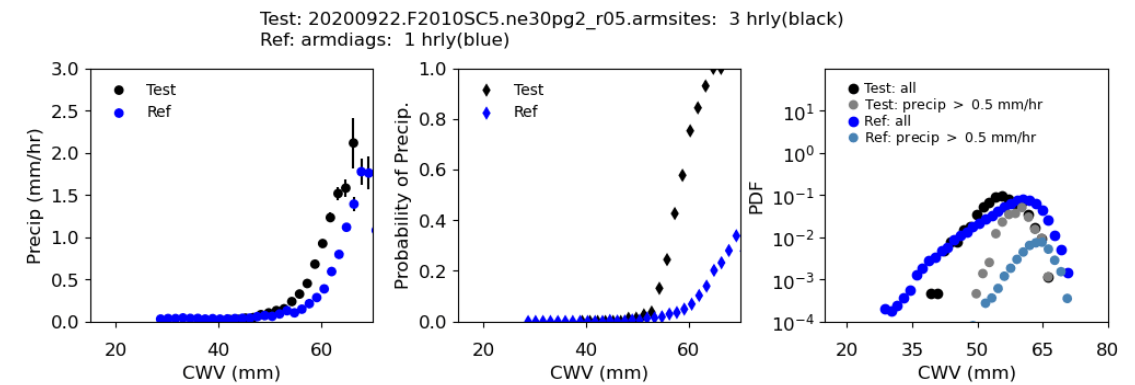


Diurnal Cycle of Precipitation



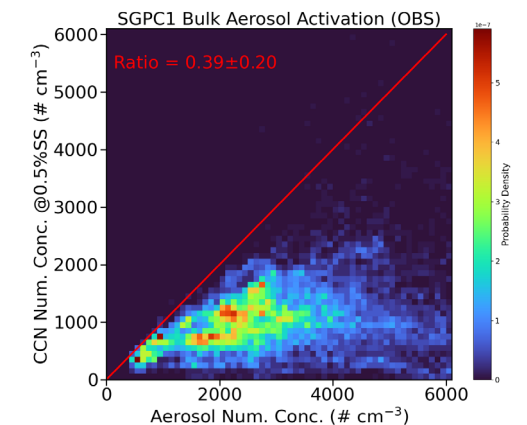
Convection Onset Metrics

(contributed by T. Emmenegger and D. Neelin from UCLA)



Aerosol-CCN Activation Metrics

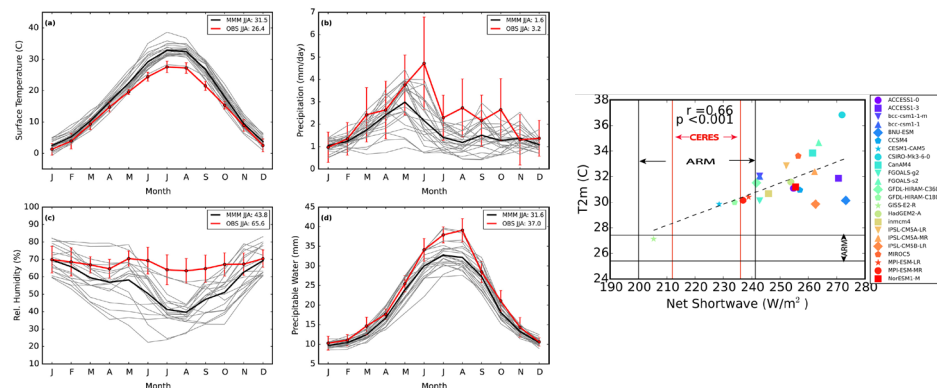
(contributed by X. Zheng and X. Dong from U. of Arizona)



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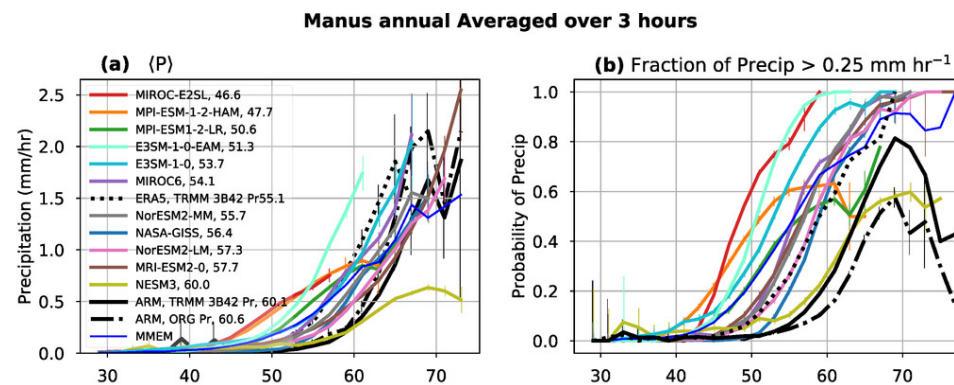
ARM-Diags has been used in climate model evaluation.

- Summertime warm bias in CMIP5 over SGP (Zhang, C., et al. 2018, JGR)



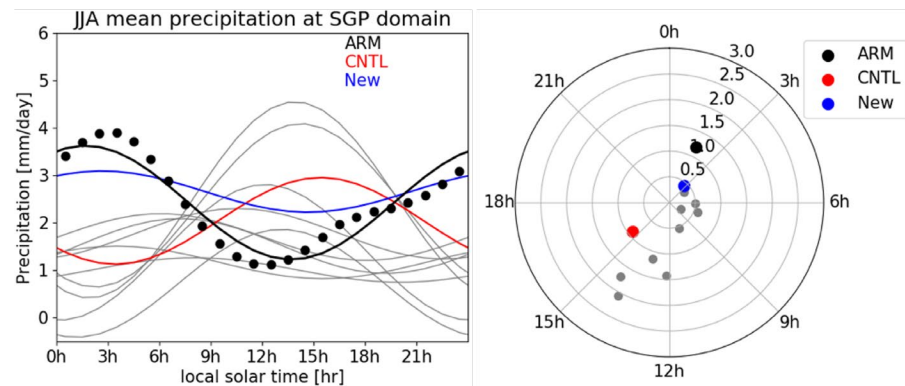
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- Tropical precipitation relations in CMIP6 models (Emmenegger, T., et al. 2022, JCLI)



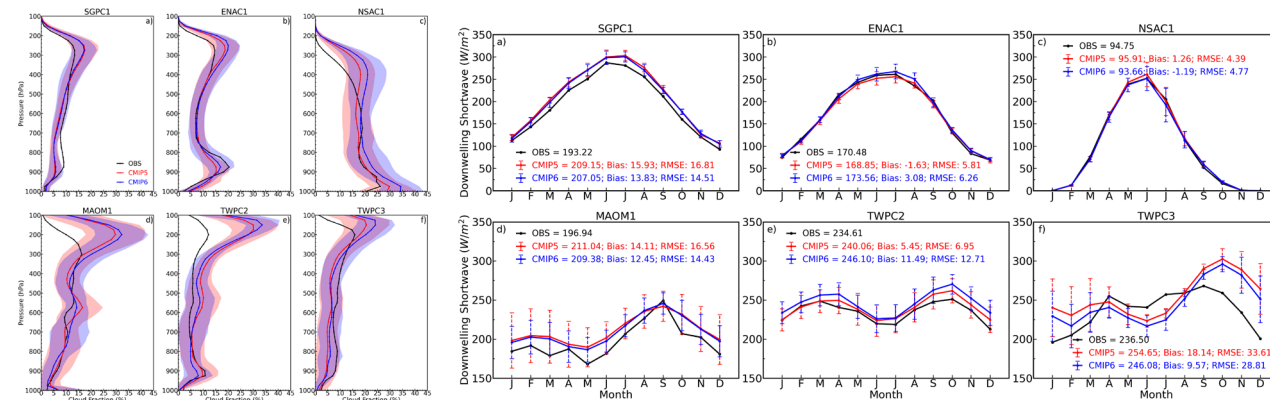
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- Diurnal cycle of precipitation in E3SM (Xie, S., et al. 2019, JAMES)



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- Clouds and surface radiation in CMIP5 and CMIP6 (Zheng et al. 2023, JCLI, revised version submitted)



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ARM-Diags has been used routinely in the E3SM atmosphere model (EAM) development.

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E3SM Diags Viewer

E3SM Diagnostics Package v2.3.0
 Test: 20200922.F2010SC5.ne30pg2_r05.arm/sites
 Reference: Observation and Reanalysis
 Created: 2021-02-12 12:24:16

E³SM
 Energy Exascale Earth System Model

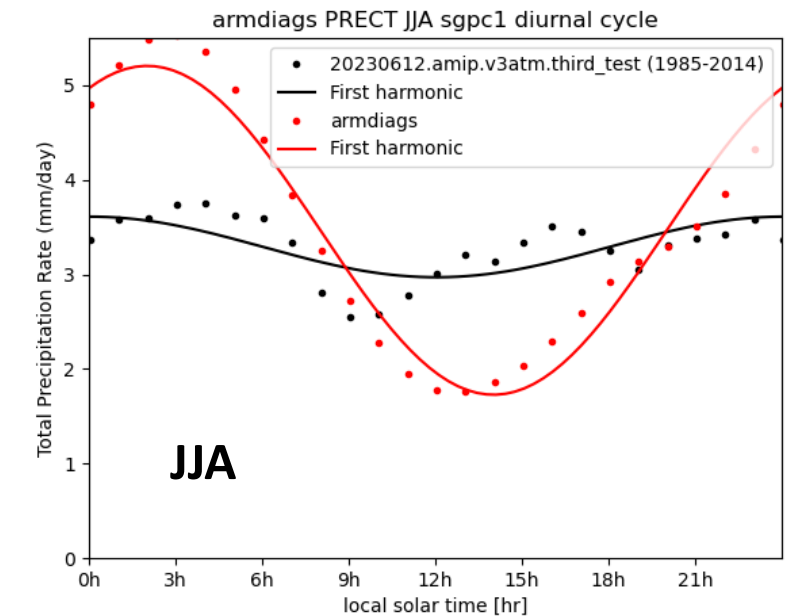
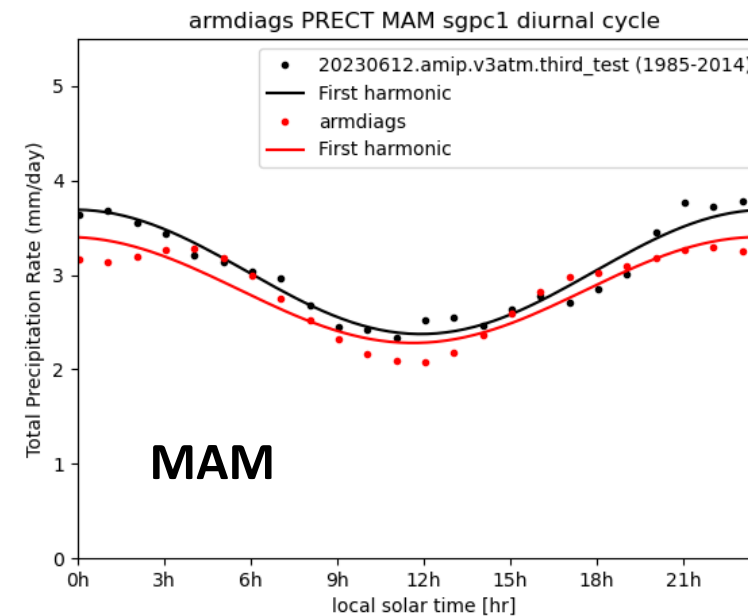
Diagnostics at ARM stations

Jump To:

Annual Cycle	Description	Plot
PRECT at Southern Great Plains (sgp)	Annual cycles of Total (convective and large-scale) precipitation rate (liq + ice)	Plot
TREFHT at Southern Great Plains (sgp)	Annual cycles of Reference height temperature	Plot
CLDTOT at Southern Great Plains (sgp)	Annual cycles of Vertically-integrated total cloud	Plot
LHFLX at Southern Great Plains (sgp)	Annual cycles of Surface latent heat flux	Plot
SHFLX at Southern Great Plains (sgp)	Annual cycles of Surface sensible heat flux	Plot
FLUS at Southern Great Plains (sgp)	Annual cycles of Upwelling longwave flux at surface	Plot
FLDS at Southern Great Plains (sgp)	Annual cycles of Downwelling longwave flux at surface	Plot
FSUS at Southern Great Plains (sgp)	Annual cycles of Upwelling shortwave flux at surface	Plot

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Diurnal Cycle of Precipitation at the ARM SGP site (Results of EAM v3 dev are shown in black, ARM in red)



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- The simulated diurnal cycle of precipitation (DCP) at the ARM SGP site matches pretty well with the ARM observations in March-April-May seasons.
- But the amplitude of DCP is much lower than the observed in June-July-August seasons.

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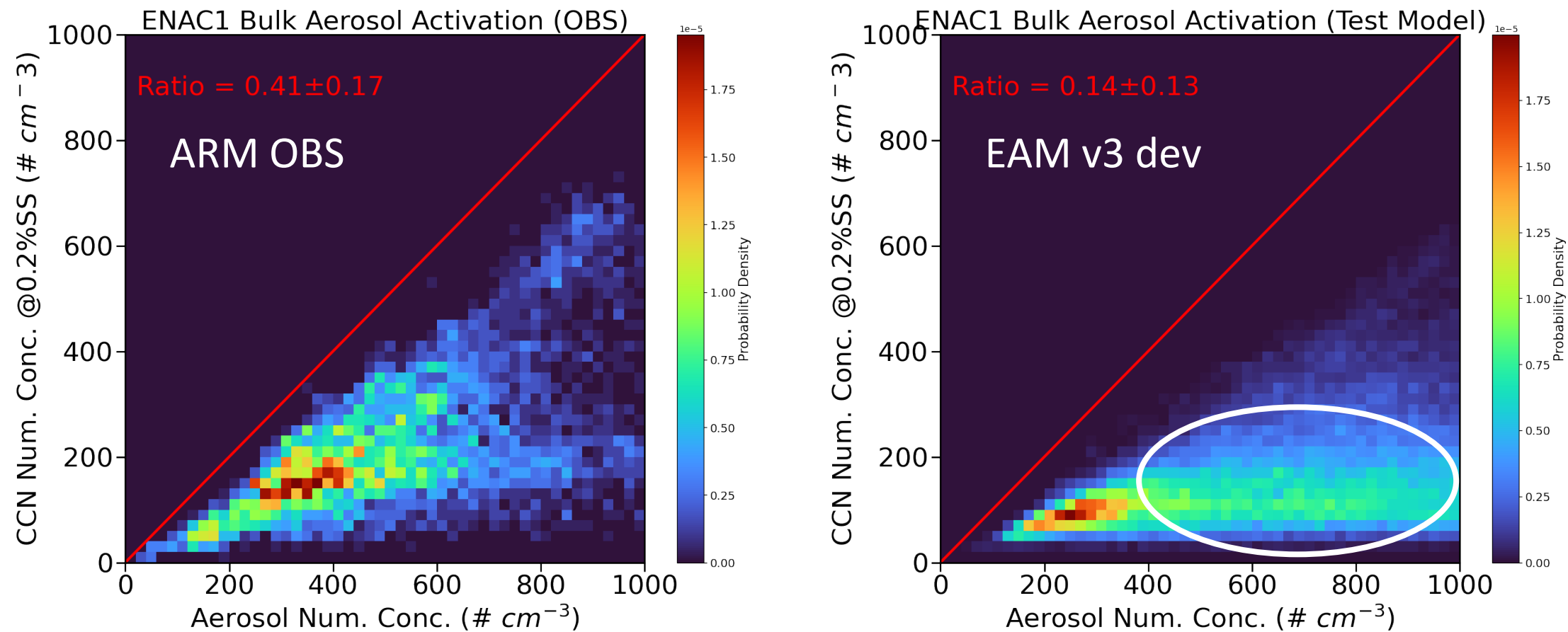
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ARM-Diags has been used routinely in the E3SM atmosphere model (EAM) development.

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Aerosol-CCN Activation at the ARM ENA site



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- The EAM v3 dev. predicts too many aerosols that cannot be activated to CCN.

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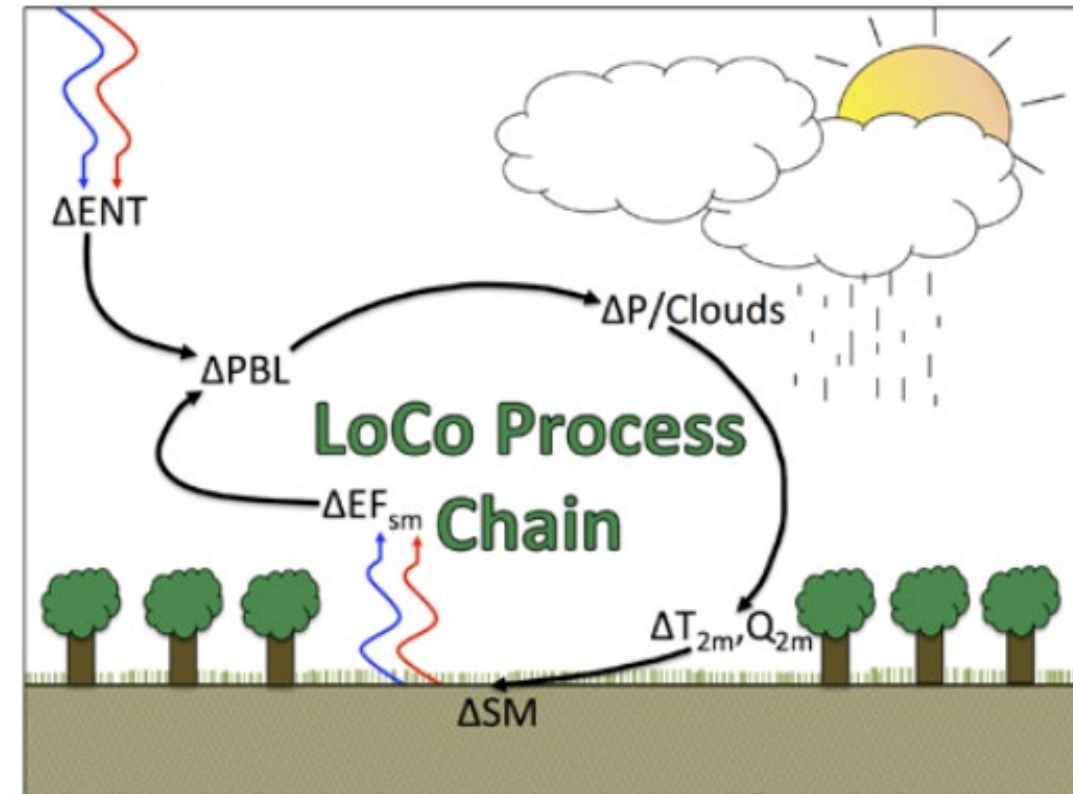
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- Accurate representation of the land-atmosphere (L-A) coupling processes is an ongoing challenge for current state-of-the-art climate models.
- The Local Land-Atmosphere Coupling (LoCo) metrics were developed to comprehensively diagnose the model performance.
- These metrics can be calculated from the high-frequency in-situ data collected by the ARM program, and can then be compared directly with model results.



$$\Delta SM \rightarrow \Delta EF_{sm} \rightarrow \Delta PBL \rightarrow \Delta ENT \rightarrow \Delta T_{2m}, Q_{2m} \rightarrow \Delta P/Clouds$$

Figure 1. Schematic of the LoCo process chain describing the components of L-A interactions linking soil moisture to precipitation and ambient weather (T_{2m} , Q_{2m}), where SM represents soil moisture; EF_{sm} is the evaporative fraction sensitivity to soil moisture; PBL is the PBL characteristics (including PBL height); ENT is the entrainment flux at the top of the PBL; T_{2m} and Q_{2m} are the 2-m temp and humidity, respectively; and P is precipitation. Citation: AMS 99, 6;

10.1175/BAMS-D-17-0001.1

Santanello et al. (2018)

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Objective: To allow quick evaluation of model simulated L-A coupling processes against the ARM ground-based observations.

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ARM-Diags Phase 4 (Ongoing):

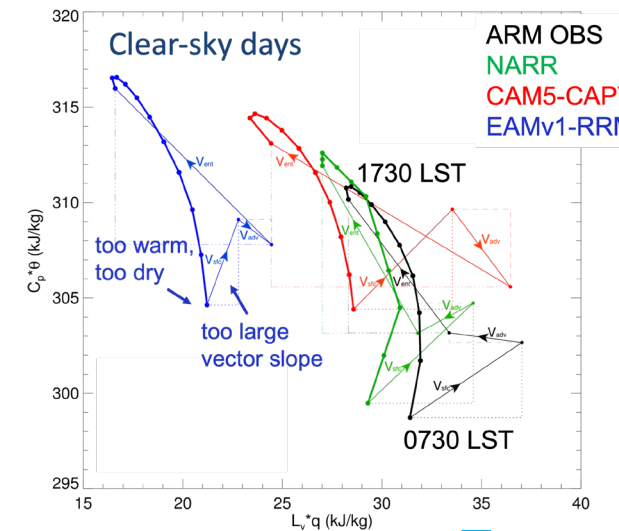
- Basic diagnostics sets: diurnal evolution of θ , q , PBL height, and the fluxes of heat and moisture.
- Process-oriented diagnostics sets: mixing diagrams, LCL deficits, relationship of evaporative fraction (EF) vs. soil moisture.
- Observational data assembled from: VARANAL, ARMBE, PBLHT, LSSONDE and other VAPs.

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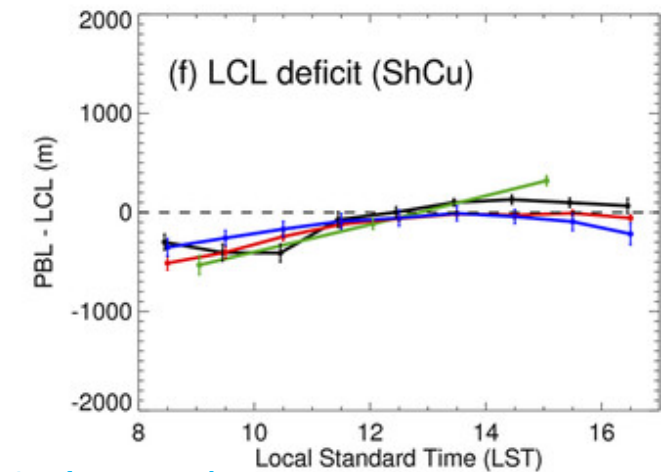
Collaboration: Prof. Minghua Zhang at Stony Brook University.

Mixing diagrams

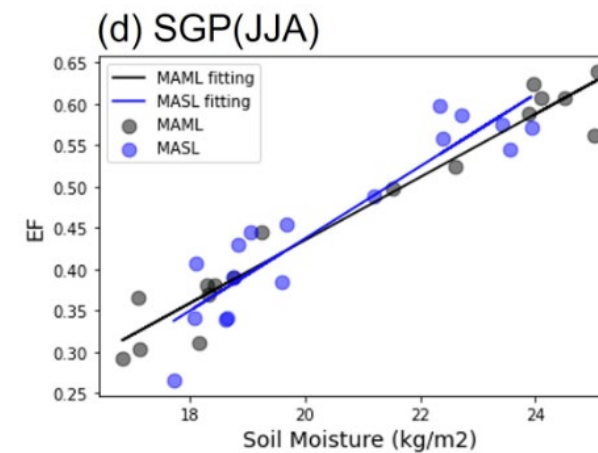


Tao et al. (2021)

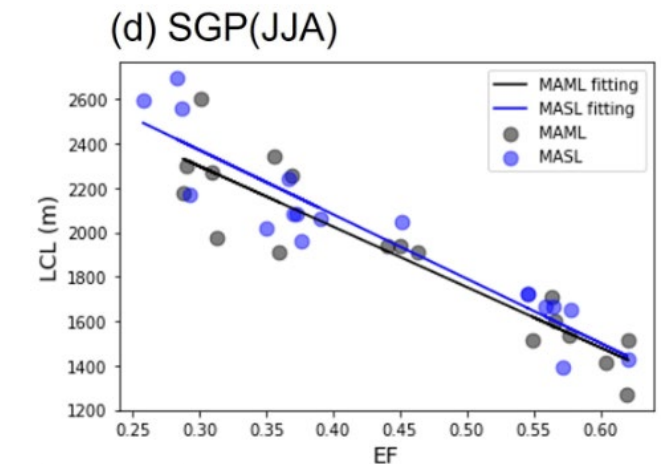
LCL deficits (PBL minus LCL)



Land component (SM vs. EF)



Atm component (EF vs. LCL)

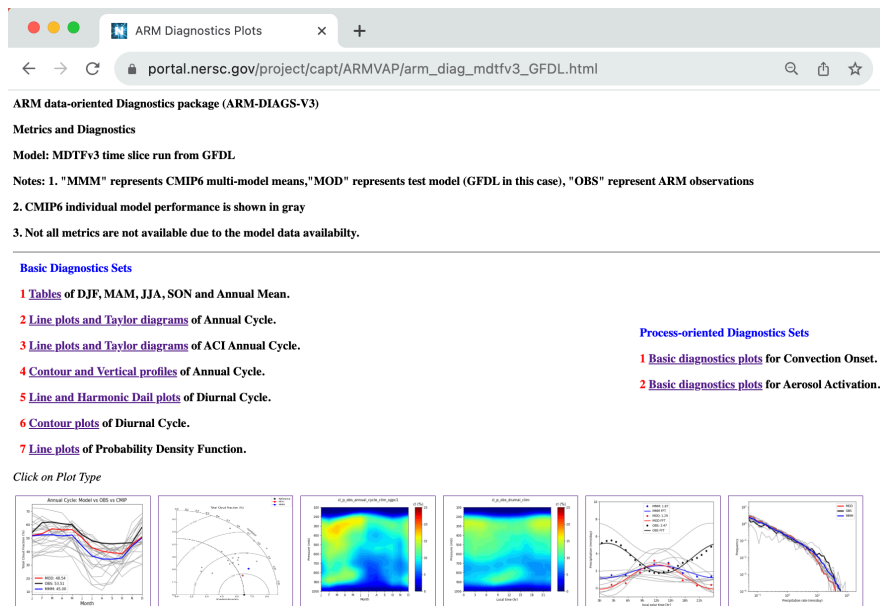


Lin et al. (2023)

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Objective: To effectively synergy the ARM-Diags with other model diagnostics efforts within the community.

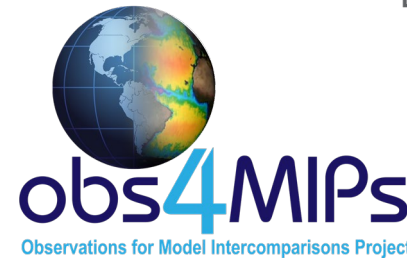
ARM-Diags



Model development



Data



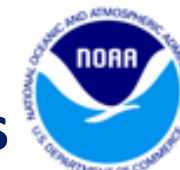
Analyses



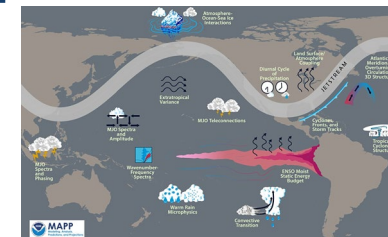
PCMDI/CMEC

Coordinated Model Evaluation Capabilities

Metrics & diagnostics



NOAA Model Diagnostics Task Force (MDTF) Diagnostics Package



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- The ARM-Diags is designed to facilitate the use of ARM measurements in climate model evaluation and to create a central location for collecting valuable analyses developed from the **ARM/ASR** and broader community.
- The ARM-Diags has been integrated in the **DOE E3SM** standard diagnostics workflow (E3SM Diags), and has been used routinely in the E3SM atmosphere model development for version 2 and 3.
- Efforts on integrating the ARM-Diags into other commonly used packages (**MDTF, CMEC, PMP**) for routine model evaluation at ARM sites are underway.
- Future plan:
 - Continue to engage in the DOE E3SM model development for low-res.
 - Extend the ARM-Diags for high-res model evaluation (e.g., THREAD, SCREAM).
 - Incorporate the ARM radar/lidar simulator as part of the ARM-Diags.

Questions and/or Feedbacks? Please contact Cheng Tao (tao4@lnl.gov).

*Wed, 2:00-4:00 pm: Open Science for ARM and ASR – Session 3 -
ARM/ASR Community Open-Source Tool Tutorials*

GitHub Repo



Thanks for your attention!

Selected References

- Zhang, C., S. Xie, C. Tao, S. Tang, T. Emmenegger, J. D. Neelin, K. A. Schiro, W. Lin, and Z. Shaheen, 2020: The ARM Data-Oriented Metrics and Diagnostics Package for Climate Models: A New Tool for Evaluating Climate Models with Field Data. *Bull. Amer. Meteor. Soc.*, 101, 10: E1619-E1627.
- Santanello, J. A., and Coauthors, 2018: Land–atmosphere interactions: The LoCo perspective. *Bull. Amer. Meteor. Soc.*, 99, 1253–1272.
- Tao, C., Y. Zhang, Q. Tang, H. Ma, V. P. Ghate, S. Tang, S. Xie, and J. A. Santanello, 2021: Land–Atmosphere Coupling at the U.S. Southern Great Plains: A Comparison on Local Convective Regimes between ARM Observations, Reanalysis, and Climate Model Simulations. *J. Hydrometeor.*, 22, 463–481.
- Lin, G., Leung, L. R., Lee, J., Harrop, B. E., Baker, I. T., Branson, M. D., et al., 2023: Modeling land-atmosphere coupling at cloud-resolving scale within the multiple atmosphere multiple land (MAML) framework in SP-E3SM. *JAMES*, 15, e2022MS003101.