DOE/SC-ARM-TR-202

ARM Data-Oriented Metrics and Diagnostics Package for Climate Model Evaluation

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Revised October 2020

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Acronyms and Abbreviations

ABRFC	Arkansas-Red River Basin Forecast Center
ACRED	ARM Cloud Retrieval Ensemble Data Set
ARM	Atmospheric Radiation Measurement
ARMBE	ARM Best Estimate
ARMBE-ATM	ARM Best Estimate Atmospheric Measurements
ARM-DIAGS	ARM Data-Oriented Metrics and Diagnostics Package
ARSCL	Active Remote Sensing of Clouds
BAEBBR	Best-Estimate Fluxes from EBBR and Bulk Aerodynamic Calculations
BOM	Bureau of Meteorology (Australia)
CDAT	Project Critical Decision Assessment Tool
CF	Central Facility
CMIP	Coupled Model Intercomparison Project
DOE	U.S. Department of Energy
DOI	Digital Object Identifier
EBBR	energy balance Bowen ratio station
GCM	global climate model
KAM	Kansas MESONET
LOS	line of sight
MFRSR	multifilter rotating shadowband radiometer
MWR	microwave radiometer
MWRRET	Microwave Radiometer Retrievals
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NSA	North Slope of Alaska
OKM	Oklahoma MESONET
QCECOR	Quality-Controlled Eddy Correlation Flux Measurement
QCRAD	Data Quality Assessment for ARM Radiation Data
RUC	Rapid Update Cycle
SGP	Southern Great Plains
SMOS	surface meteorological observation system
SWATS	soil water and temperature system
TWP	Tropical Western Pacific
VAP	value-added product

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1.0 Introduction

A Python-based metrics and diagnostics package is currently being developed by the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility Infrastructure Team at Lawrence Livermore National Laboratory to facilitate the use of long-term, high-frequency measurements from ARM in evaluating the regional climate simulation of clouds, radiation, and precipitation. This metrics and diagnostics package computes climatological means of targeted climate model simulation and generates tables and plots for comparing the model simulation with ARM observational data. The Coupled Model Intercomparison Project (CMIP) model data sets are also included in the package to enable model intercomparison as demonstrated in Zhang et al. (2018) and Zhang et al. (2020). The mean of the CMIP model can be served as a reference for individual models.

Basic performance metrics are computed to measure the accuracy of mean state and variability of climate models. The evaluated physical quantities include cloud fraction, temperature, relative humidity, cloud liquid water path, total column water vapor, precipitation, sensible and latent heat fluxes, and radiative fluxes, with plan to extend to more fields, such as aerosol and microphysics properties. Process-oriented diagnostics focusing on individual cloud- and precipitation-related phenomena are also being developed for the evaluation and development of specific model physical parameterizations. As an extension of version 1.0, the version 2.0 package included data collected at ARM facilities in additional to the Southern Great Plains (SGP) observatory in Oklahoma.

The metrics and diagnostics package is currently built upon standard Python libraries and additional Python packages developed by DOE (Project Critical Decision Assessment Tool [CDAT]). The ARM metrics and diagnostic package is available publicly with the hope that it can serve as an easy entry point for climate modelers to compare their models with ARM data.

In this report, we first present the input data, which constitutes the core content of the metrics and diagnostics package in section 2; and a user's guide documenting the workflow/structure of the version 2.0 codes and including step-by-step instructions for running the package in section 3.

2.0 Observations and Model Data Description

2.1 Observation Data Sets

The observations used to assess model performance primarily rely on the ARM Best Estimate (ARMBE) data products (Xie et al. 2010) and other ARM value-added products (VAPs) (https://www.arm.gov/capabilities/vaps), which are available for all the ARM observatories and some ARM mobile facilities. These data often rely on measurements at the ARM Central Facility (CF) locations (i.e., single-point measurements). To improve model-observation comparison, the ARM long-term continuous forcing data (Xie et al. 2004), which represents an average over a Global Climate Model (GCM) grid box, is also used when available. For cloud properties such as cloud liquid and ice water contents, the ARM Cloud Retrieval Ensemble Data (ACRED) (Zhao et al. 2012) is used. The detailed information about ARM data used in the ARM-DIAGS package is listed in Tables 1 and 2. The observational data product consists of hourly averaged, diurnal cycle, monthly means or climatological summaries of the measured quantities, with variable names, units, and vertical dimensions remapped to CMIP convention. They are currently available for the SGP site (Table 1) as well as the North Slope of Alaska (NSA) Utqiagvik (formerly Barrow) site and the Tropical Western Pacific (TWP) Manus, Nauru, and Darwin sites (Table 2). Other than the ARM observations, ARM-DIAGS also includes simulation data from models participating in CMIP, which will allow climate-modeling groups to compare a new candidate version of their model to existing CMIP models. A full list of metrics and diagnostics are as follows:

- A set of basic metrics tables: mean, mean bias, correlation and root mean square error based on annual cycle of each variable.
- Line plots and Taylor Diagrams (Taylor 2001) for annual cycle variability of each variable.
- Contour and vertical profiles of annual cycle and diurnal cycle of cloud fraction.
- Line and harmonic dial plots (Covey et al. 2016) of diurnal cycle of precipitation.
- Probability Density Function plots of precipitation rate (Pendergrass and Hartmann 2014).
- Convection onset metrics showing statistical relationship between precipitation rate and column water vapor (Schiro et al. 2016).

Table 1. Observed quantities selected in the evaluation package, including the quantity names, the data sources, and the temporal and spatial information of the data for SGP (1999-2011).

Quantities	ARM Data Products	Data Source/Instruments	Time Resolution	Spatial Information
Surface screen-level temperature/humidity	ARM Continuous forcing data set	Surface meteorological observation system (SMOS), Oklahoma and Kansas MESONET stations (OKM and KAM) (Xie et al. 2004)	mon, day, hr	sgp domain averaged
Temperature/humidity profile/wind speed/large scale tendencies	Same as above	NOAA/National Centers for Environmental Prediction (NCEP) Rapid Update Cycle (RUC) analysis data (Xie et al. 2004)	mon, day, hr	sgp domain averaged
Surface precipitation	Same as above	Arkansas-Red Basin River Forecast Center (ABRFC) Nexrad radar precipitation estimates with rain gauge	mon, day, hr	sgp domain averaged
Precipitable water	Same as above	Microwave radiometer (MWR) water liquid and vapor along line of sight (LOS) path (MWRLOS)	mon, day, hr	sgp domain averaged
Surface all-sky radiative fluxes	Same as above	Data Quality Assessment for ARM Radiation Data (QCRAD) (Long and Shi 2006, 2008)	mon, day, hr	sgp domain averaged
Aerosol optical depth 550nm	MFRSRAOD1MICH	Multifilter rotating shadowband radiometer (MFRSR) (Knootz et al. 2013)	mon	Averaged over sgp Site C1 and E13

Quantities	ARM Data Products	Data Source/Instruments	Time Resolution	Spatial Information
Surface latent/sensible heat	BAEBBR	Best-Estimate Fluxes From energy balance Bowen ration (EBBR) Measurements and Bulk Aerodynamics Calculations (BAEBBR) (Cook 2019)	mon	sgp domain averaged
	QCECOR	Quality-Controlled Eddy Correlation Flux Measurement (Cook 2016)	mon	sgp domain averaged
Surface soil moisture content (10 cm)	SWATS	Soil water and temperature system (SWATS) (Cook 2018)	mon	sgp domain averaged
Cloud fraction	ARSCL	Active Remote Sensing of Clouds (Clothiaux et al. 2001)	mon, day, hr	sgp Site C1
Ice water content/liquid water content	ACRED	ARM Cloud Retrieval Ensemble Data Set (Zhao et al. 2012)	mon, day, hr	sgp Site C1

Table 2. Observed quantities selected in the evaluation package, including the quantity names, the data sources, and the temporal and spatial information of the data for NSA and TWP sites. The time ranges are: NSA: atm 2001-2010, cld 1998-2010; TWPC1: atm 1996-2010, cld 1997-2010; TWPC2: atm 1998-2010, cld 1998-2010; TWPC3: atm 2002-2010, cld 2002-2010.

Quantities	ARM Data Products	Data Source/ Instruments	Time Resolution	Spatial Information
Surface screen-level temperature/humidity	ARMBE-ATM	ARM-standard meteorological instrumentation at the surface (Xie et al. 2010)	mon	twp C1,2,3; nsa C1
Surface precipitation	ARMBE-ATM	Same as above	mon, hr	twp C1,2,3; nsa C1
Precipitable water	ARMBE-ATM	Microwave Radiometers Retrievals (MWRRET) (Xie et al. 2010)	mon, hr	twp C1,2,3; nsa C1
Surface radiative fluxes	ARMBE-CLD	Data Quality Assessment for ARM Radiation Data (QCRAD) (Long and Shi 2006, 2008)	mon	twp C1,2,3; nsa C1
Cloud fraction	ARSCL	Active Remote Sensing of Clouds (Clothiaux et al. 2001)	mon, hr	twp C1,2,3; nsa C1

2.2 CMIP5 AMIP Simulations

Simulations of 23 models contributing to the CMIP5 (Taylor et al. 2012) multi-model experiments have been used (see Table 3 for details). We evaluate these models from the CMIP5 atmospheric only (AMIP) experiments from year 1979 to 2008. The nearest model grid points to the ARM central facilities are selected.

Table 3. Models used in the evaluation.

Modeling groups	Model name
Commonwealth Scientific and Industrial Research Organisation and Bureau of Meteorology (BOM), Australia	ACCESS1.0 ACCESS3.0
Beijing Climate Center, China Meteorological Administration	BCC-CSM1.1 BCC-CSM1.1(m)
College of Global Change and Earth System Science, Beijing Normal University	BNU-ESM
Canadian Centre for Climate Modelling and Analysis	CanAM4
National Center for Atmospheric Research	CCSM4
Community Earth System Model contributors	CESM1-CAM5
Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence	CSIRO-Mk3-6-0
LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University	FGOALS-g2 FGOALS-s2
NOAA Geophysical Fluid Dynamics Laboratory	GFDL-HIRAM-C360 GFDL-HIRAM-C180
NASA Goddard Institute for Space Studies	GISS-E2-R
United Kingdom Met Office Hadley Centre	HadGEM2-A
Institut Pierre-Simon Laplace	IPSL-CM5A-LR IPSL-CM5B-LR IPSL-CM5A-MR
Institute for Numerical Mathematics	Inmcm4
Atmosphere and Ocean Research Institute, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC5
Max Planck Institute for Meteorology	MPI-ESM-MR MPI-ESM-LR
Norwegian Climate Centre	NorESM1-M

Note that for certain quantities, especially for sub-monthly output variables, only subsets of models are available for analysis.

2.3 Data Limitation/Uncertainty

The ARM data used in the package have been through stringent data quality control and represent the "best" estimate of the selected quantities. Fully addressing data uncertainty is a challenging task and ARM is making efforts to address this issue. More information will be provided once the uncertainty of these selected fields is better quantified. We recommend the user to read the references on the observational data products and contact principal investigators of each data product for additional data quality information.

3.0 User's Guide

3.1 Package Overview/Workflow

Figure 1 illustrates the flowchart of creating the diagnostic results by applying the diagnostics tool. The steps are straightforward. The step-by-step procedure to set up a working prototype is presented in section 3.

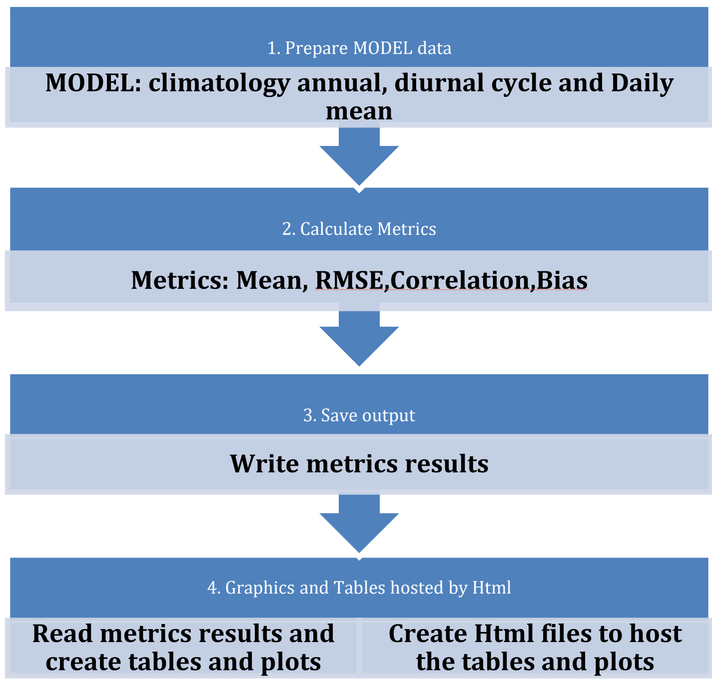


Figure 1. Workflow of the diagnostics package.

The project has the following structure:

```
a |____arm_diags
| |____.DS_Store
| |______init__.py
| |____arm_driver.py
| |____arm_parameter.py
| |____arm_parser.py
| |____basicparameter.py
| |____diags_all.json
| |____examples
| | |____diags_set1.json
| | |____diags_set2.json
| | |____diags_set3.json
```

```
| | |____diags_set4.json
| | |____diags_set6.json
| | |____diags_sets.json
| |____misc
| | |____ARM_logo.png
| |____src
| | |______init__.py
| | |____annual_cycle.py
| | |____annual_cycle_zt.py
| | |____create_htmls.py
| | |____diurnal_cycle.py
| | |____pdf_daily.py
| | |____seasonal_mean.py
| | |____taylor_diagram.py
| | |____varid_dict.py
| | |____convection_onset_driver.py
| | |____convection_onset_statistics.p
|____ARM_gcm_diag_pkg_TechReport_v2.docx
```

3.2 Obtain ARM-DIAGS

ARM Diags v1 with basic sets of diagnostics is now publicly available. The data files including observation and CMIP5 model data are available through the ARM Data Center. The analytical codes to calculate and visualize the diagnostics results are placed via repository (arm-gcm-diagnostics) at https://github.com/ARM-DOE/

For downloading data:

- Click https://www.arm.gov/data/eval/123 or www.arm.gov/data/data-sources/adcme-123
- Following the **Data Directory** link on that page, it will lead to the area where the data files are placed. A short registration is required if you do not already have an ARM account.
- The DOI for the citation of the data is 10.5439/1646838

For obtaining codes:

$ git clone https://github.com/ARM-DOE/arm-gcm-diagnostics/

3.3 Set Up a Test Case

The software environment is managed through conda. Either Anaconda or Miniconda needs to be installed for setting up the environment of the package.

First, to create a conda environment and then activate it:

$ conda create -n arm_diags_env_py3 cdp cdutil cdms2 libcdms matplotlib scipy python=3 -c conda-forge
$source activate arm_diags_env_py3

To install the package, cd <Your directory>/, type following:
$python setup.py install

A working test case has been set up for users to run the package out of the box. In this case, all the observation, CMIP data, and test data should be downloaded and placed under directories:
<Your directory>/arm_diags/observation
<Your directory>/ arm_diags /cmip5
<Your directory>/ arm_diags /testmodel, respectively.

To configure basic parameter file: basicparameter.py and edit parameters such as input and output paths, model name (used to search the file), and case name (to create a new folder for the case).

To run the package, simply type in the following:
$ python arm_driver.py -p basicparameter.py

To view the diagnostics results:
For Mac OS:
$ open <Your directory>/arm_diags/case_name/html/ARM_diag.html
For Linux:
$xdg-open <Your directory>/ arm_diags/case_name/html/ARM_diag.html

For setting up customized runs and creating new cases, check details at:
https://github.com/ARM-DOE/arm-gcm-diagnostics/

3.4 Diagnostics Examples

The main html page hosting the results is shown below:

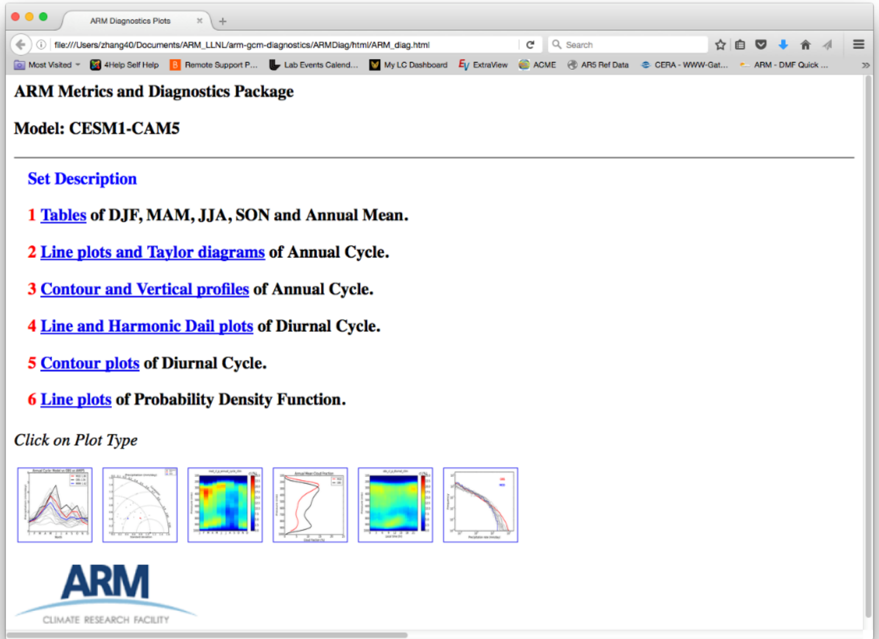
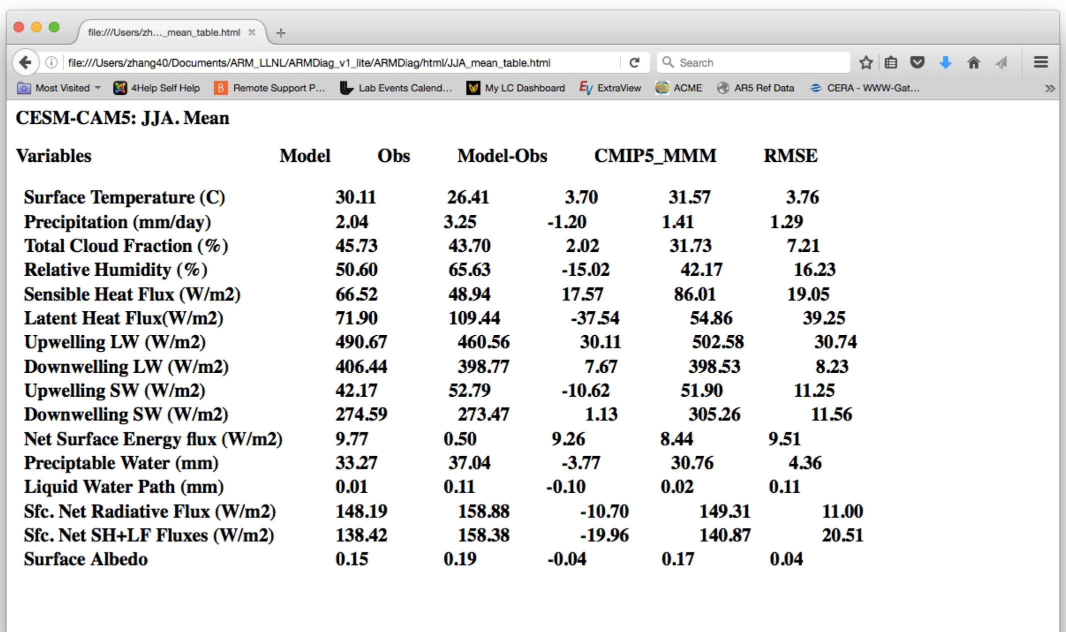


Figure 2. Main html page generated to host the diagnostic results.



CESM-CAM5: JJA. Mean

Variables	Model	Obs	Model-Obs	CMIP5_MMM	RMSE
Surface Temperature (C)	30.11	26.41	3.70	31.57	3.76
Precipitation (mm/day)	2.04	3.25	-1.20	1.41	1.29
Total Cloud Fraction (%)	45.73	43.70	2.02	31.73	7.21
Relative Humidity (%)	50.60	65.63	-15.02	42.17	16.23
Sensible Heat Flux (W/m2)	66.52	48.94	17.57	86.01	19.05
Latent Heat Flux(W/m2)	71.90	109.44	-37.54	54.86	39.25
Upwelling LW (W/m2)	490.67	460.56	30.11	502.58	30.74
Downwelling LW (W/m2)	406.44	398.77	7.67	398.53	8.23
Upwelling SW (W/m2)	42.17	52.79	-10.62	51.90	11.25
Downwelling SW (W/m2)	274.59	273.47	1.13	305.26	11.56
Net Surface Energy flux (W/m2)	9.77	0.50	9.26	8.44	9.51
Preciptable Water (mm)	33.27	37.04	-3.77	30.76	4.36
Liquid Water Path (mm)	0.01	0.11	-0.10	0.02	0.11
Sfc. Net Radiative Flux (W/m2)	148.19	158.88	-10.70	149.31	11.00
Sfc. Net SH+LF Fluxes (W/m2)	138.42	158.38	-19.96	140.87	20.51
Surface Albedo	0.15	0.19	-0.04	0.17	0.04

Figure 3. Tables summarizing JJA mean climatology.

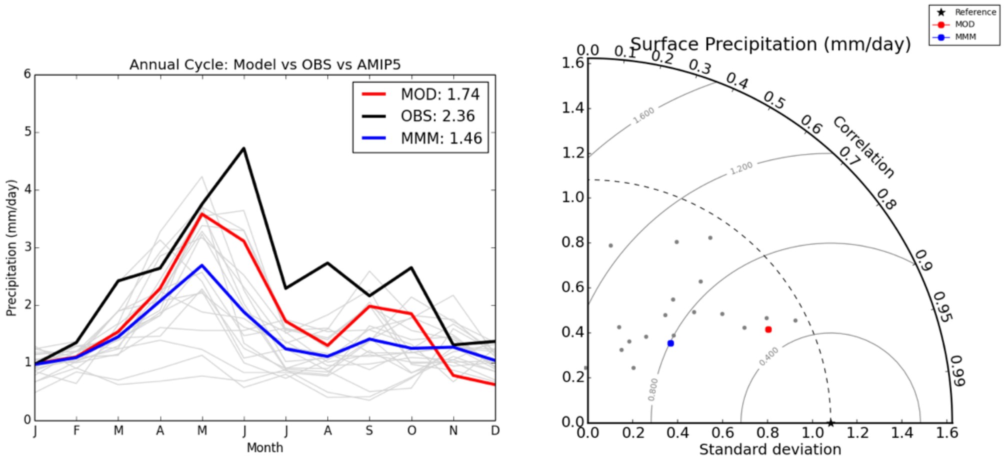


Figure 4. Line plots and Taylor diagrams for diagnosing annual cycle of precipitation.

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