ESM Aerosol-Cloud Diagnostics Package (ESMAC Diags)

Version 1.0.0-beta

Shuaiqi Tang (shuaiqi.tang@pnnl.gov)

Jerome D. Fast

Joseph C. Hardin

Po-Lun Ma

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Abstract

This document describes the **version 1.0.0-beta** of Earth System Model (ESM) aerosol-cloud diagnostics package (**ESMAC Diags**) that facilitate routine evaluation of aerosols, clouds and aerosol-cloud interactions simulated by the Department of Energy's (DOE) Energy Exascale Earth System Model (E3SM). This version focuses on comparing simulated **aerosol** properties with in-situ aircraft, ship and surface measurements. Various types of diagnostics and metrics are performed for aerosol number, size distribution, chemical composition, and CCN concentration to assess how well E3SM represents observed aerosol properties and aerosol-cloud interactions across spatial scales. Metrics for various meteorological and aerosol precursor quantities from the same field campaigns are also included. This document describes field campaign measurements, the structure of the diagnostics package, as well as the instruction of how to run or modify this package. The diagnostics package is coded and organized in a way that can be easily adapted to other model simulations and are flexible to add more field campaigns in the future.

1. Field campaigns and observations

The diagnostics package initially focuses on four geographical regions: Eastern North Atlantic (ENA), Northeastern Pacific (NEP), Central U.S. (CUS, where the ARM Southern Great Plains, SGP, site is located in), and Southern Ocean (SO), where liquid clouds occur frequently and extensive measurements are available from ARM and other agencies. Aerosol properties also vary among these regions. Among the four testbeds, ENA, NEP and CUS are regions typically have high effective radiative forcing (ERF) associated with aerosol-cloud-radiation interactions, while SO is a remote region with more pristine conditions characterized by low ERF, which serves a good contrast to the other three testbeds. Six field campaigns from these four testbeds are selected in the initial phase of ESMAC Diags (Table 1). HI-SCALE and ACE-ENA are based on long-term ARM ground sites with aircraft field campaign sampling within a few hundred kilometers around the sites. Aircraft sampling during HI-SCALE and ACE-ENA occurred below, within, and above shallow clouds forming at the top of the convective and marine boundary layers, respectively. CSET and MAGIC are field campaigns with aircraft and ship platforms, respectively, that sample transects between California and Hawaii characterized by transitions between stratocumulus to cumulus dominated regions. SOCRATES and MARCUS are field campaigns with aircraft and ship platforms, respectively, based out of Hobart, Australia. Aircraft transects during SOCRATES extended south to around 60°S, while ship transects during MARCUS extended southwest from Hobart to Antarctica. The aircraft (black) and ship (red) tracks for these field campaigns are shown in Figure 1.

The instruments and measurements used in ESMAC Diags version 1.0.0-beta are listed in Tables 2 to 7. Each table corresponds to each field campaigns. Note that some instruments are only available for certain periods, so that model evaluation is limited by the availability of collected data. These evaluation data as well as a sample model output (preprocessed) are available at Zenodo: https://doi.org/10.5281/zenodo.6369120.

1.1 Data quality control

Various types of data quality controls and corrections are applied to the observational datasets used in ESMAC Diags. ARM datasets usually include quality control (QC) flags indicating bad or indeterminate data. These flagged data are filtered out. One exception is surface CPC measurements for HI-SCALE, that some QC bits may be good data and should be retained (e.g., aerosol loading can be greater than maximum value: 8000 #/cm^3 during NPF events). According to the instrument mentor Ashish Singh <asingh@bnl.gov>, only the following qc_bit is applied:

- CPCF – bit value 7, 8, 11, 12, 13, 14
- CPCu or CPCuf – bit value 4, 5, 6, 15, 16

NCAR research flight (RF) data do not include quality control flag but occasionally show suspiciously large or negative values. A simple minimum and maximum threshold is applied to some of the NCAR RF variables:

- aerosol number concentration from CNC (CONCN): minimum 0
- aerosol number concentration from UHSAS (UHSAS100): minimum 0
- aerosol size distribution from UHSAS (CUHSAS_RWOOU or CUHSAS_LWII): minimum 0, maximum 500 #/cm^3

For aircraft measurements, sometimes they are contaminated by cloud droplets when aircraft was flying through a cloud, or using different sampling methods such as counterflow virtual impactor (CVI) which samples particle residuals inside cloud and fog droplets, and thermal denuder (TD) mode that heats aerosols to measure their volatility. These data with a positive cloud flag (or simultaneously measured LWC > 0.02 g/m^3 if no cloud flag) or sampling mode is not isokinetic are removed to ensure fair evaluation of model results under ambient condition. Moreover, for statistical evaluation, aircraft measurements 30 minutes after take-off and before landing are excluded to remove possible contamination from the airport.

For ship measurements, aerosol instruments occasionally measured samples from ship emission, with large spikes in aerosol and CCN number concentrations. This happened more frequently in MARCUS. Humphries (2020) published a reprocessed CN and CCN data from ARM MARCUS measurements to remove ship exhaust influence (DOI: 10.25919/ezp0-em87), which is used in this diagnostics package. For MAGIC, we could not find any data for ship exhaust contamination information. Therefore, a simple maximum threshold (2.5e4 cm^{-3} for CPC, 5000 cm^{-3} for UHSAS100, 2000 cm^{-3} for 0.1% CCN and 4000 cm^{-3} for 0.5% CCN) is applied to remove possible contamination from ship emissions.

Surface SMPS and nanoSMPS are used in HI-SCALE to measure aerosol number size distribution. However, nanoSMPS systematically overcounts aerosol numbers and the reason is still under exploration. We divided the nanoSMPS measurements by 3.8 to ensure a smooth transition between nanoSMPS and SMPS when merging aerosol size distribution from these two instruments.

2. ESMAC Diags Structure

The diagnostics package is designed to be flexible so that additional field campaign measurements and functionality can be included in the future. The structure of ESMAC Diags, illustrated in Figure 2, consists of six major components. The “scripts” directory contains executable scripts and user-specified settings. The “testcase” directory provides a small amount of data and verify figures that can be used to verify the package is successfully installed and code is working correctly. The “src” directory contains all source code including code used to preprocess model output, read files, merge aerosol size distributions, compute observed versus simulated statistical relationships, and plot results. All observational and model data are in the “data” directory and are organized by field campaign. The diagnostic plots and statistics are put in the “figures” directory, also organized by field campaign. These two directories are linked to the diagnostics package through the settings in the run script. The “webpage” directory provides a simple interface to view output plots. It is relatively straight-forward to add other field campaign datasets using this structure.

3. How to run ESMAC Diags.

3.1. Download and verify the code

The source code of ESMAC Diags are available at GitHub: https://github.com/eagles-project/ESMAC_diags. Download them and put in your work directory. This code is best run using a conda virtual environment. To install the required environment one can do

```
conda env create -f environment.yml
```

to set up an esmac_diags environment. Note if running this on a HPC system, you may need to load the appropriate module for anaconda.

Once the environment has been created you can activate it with

```
conda activate esmac_diags
```

and then this code can be installed with

```
pip install -e .
```

Which will install the code as editable allowing you to make changes to the codebase and it be reflected in the installed package. Later when you open a new terminal you will need to run conda activate esmac_diags each time to activate the environment.

To verify the package, enter scripts/ directory and run

```
python run_testcase.py
```

Then go to the directory in testcase/figures/. There should be three figures generated:

flighttrack_ACEENA_20170630a.png
flightheight_ACEENA_20170630a.png
AerosolComposition_ACEENA_20170630a.png

Directory testcase/figures_verify/ contains what the three figures should look like. If the three figures in testcase/figures/ are consistent with figures_verify/, the testcase is successfully run.

3.2 Prepare field campaign data

3.2.1. download observation data

The entire field campaign data as well as pre-processed data can be downloaded at Zenodo: https://doi.org/10.5281/zenodo.6369120. Section 3.2.2 introduces preprocessing of merging observed aerosol size distribution. Section 3.3 introduces preprocessing model output data. Users can also skip these preprocessing steps and directly run plotting code using existing data downloaded from Zenodo.

3.2.2 Preprocess merged aerosol size distribution

For some field campaigns (HI-SCALE and ACE-ENA), there are several instruments (e.g., FIMS, PCASP, OPC for aircraft, SMPS and nanoSMPS for ground) measuring aerosol size distribution over different size ranges. It is useful to merge these datasets to create a broader size distribution information. The aerosol concentrations in the "overlapping" bins measured by multiple instruments are weighted by the reliability of each instrument based on the knowledge of the instrument mentors. This is included in the preprocessing step.

The merged aerosol size distribution data is already in the Zenodo data bundle. The instruction on how to run preprocessing is in Section 3.3.2.

3.3 Prepare model data

This diagnostic package is currently used to evaluate E3SM model, so we use E3SM as an example to show how to prepare model data. For other ESMs, users can create their own pre-processed model files similar to the model file format in the Zenodo data bundle.

3.3.1 run E3SM model

Note: an example of preprocessed E3SM data are included in the Zenodo data bundle for testing the package. Here we provide the instruction from model run to preprocessing.

E3SM output over the field campaign regions including all aerosol-related variables are needed for evaluation. The default time resolution is 1hr. An example of namelist in `user_nl_cam` in the E3SM running script is given below, which includes hourly output variables and region domains. Here *fincl4* defines output variables with the 4th frequency (1 hr) and interval (24 per day) in *nhtfrq* and *mfilt*, respectively. *fincl4latlon* defines the latitude and longitude range of *fincl4* output.

```
nhtfrq      = 0,-24,-3,-1
mfilt       = 1,1,8,24
...
fincl4      = 'PS',       !! dynamical fields
              'U',        !! ..
              'V',        !! ..
              'T',        !! ..
              'Q',        !! vapor (kg/kg)
              'CLDLIQ',   !! cloud hydrometeors (kg/kg)
              'CLDICE',   !! ..
              'CLDTOT',
              'NUMLIQ',   !! ..
              'NUMICE',   !! ..
              'PBLH',     !! PBL height
              'LHFLX',    !! energy fluxes
              'SHFLX',    !! ..
              'FLNT',     !! ..
              'FSNT',     !! ..
              'FLNS',     !! ..
              'FSNS',     !! ..
              'TREFHT',   !! ..
              'Z3',       !! geopotential height
              'RELHUM',   !! relative humidity (RH)
              'RHW',      !! RH with respect to water
              'RHI',      !! RH with respect to ice
```

```
'CLOUD',     !! cloud fraction
'AWNI',      !! in-cloud values
'AWNC',      !! Average cloud water number conc (1/m3)
'CCN1',      !! CCN concentration at S=0.02% (#/cm3)
'CCN3',      !! CCN concentration at S=0.1% (#/cm3)
'CCN4',      !! CCN concentration at S=0.2% (#/cm3)
'CCN5',      !! CCN concentration at S=0.5% (#/cm3)
'AREI',      !! ..
'AREL',      !! ..
'PRECT',     !! precipitation
'PRECC',     !! ..
'PRECL',     !! ..
'FICE',      !! ice mass fraction
'IWC',       !! grid box average ice water content (kg/m3)
'LWC',       !! grid box average liquid water content (kg/m3)
'TGCLDLWP',  !! liquid water path (including convective clouds)
'TGCLDIWP',  !! ice water path (including convective clouds)
'AODVIS',    !! AOD
'DMS',       !!
'SO2',       !!
'H2SO4',     !!
'bc_a1',     !! aerosols mass (kg/kg)
'bc_a3',     !!
'bc_a4',     !!
'dst_a1',    !!
'dst_a3',    !!
'mom_a1',    !!
'mom_a2',    !!
'mom_a3',    !!
'mom_a4',    !!
'ncl_a1',    !!
'ncl_a2',    !!
'ncl_a3',    !!
'pom_a1',    !!
'pom_a3',    !!
'pom_a4',    !!
'so4_a1',    !!
'so4_a2',    !!
'so4_a3',    !!
'soa_a1',    !!
'soa_a2',    !!
'soa_a3',    !!
'num_a1',    !! aerosols number (#/kg)
'num_a2',    !!
'num_a3',    !!
'num_a4',    !!
'num_c1',    !! aerosols number (#/kg)
'num_c2',    !!
```

```
            'num_c3',    !!
            'num_c4',    !!
            'dgnd_a01',  !! dry aerosol size
            'dgnd_a02',  !! ..
            'dgnd_a03',  !! ..
            'dgnd_a04',  !! ..
            'dgnw_a01',  !! wet aerosol size
            'dgnw_a02',  !! ..
            'dgnw_a03',  !! ..
            'dgnw_a04',  !! ..
            'EXTINCT',   !! Aerosol extinction (1/m)
            'AODABS',    !! Aerosol absorption optical depth 550 nm
            'ABSORB',    !! Aerosol absorption (1/m)
fincl4lonlat = '260e:265e_34n:39n',  ! SGP (~5x5 degs)
           '330e:335e_37n:42n',  ! ENA
           '202e:240e_19n:40n',  ! CSET
           '202e:243e_20n:35n',  ! MAGIC
           '60e:160e_42s:70s',   ! MARCUS
           '133e:164e_42s:63s',  ! SOCRATES
```

Model should be nudged to reanalysis to ensure realistic large-scale circulation. In a successful run, hourly variables for each field campaign domain should be seen in the E3SM output file *.cam.h3.yyyy-mm-dd-00000.nc. (e.g., "PS_ 260e_to_265e_34n_to_39n" for PS at SGP region).

3.3.2 Preprocess E3SM data

Because of large size of hourly model output, we preprocess model output to extract the model variables at the surface site, along the flight tracks or along the ship tracks depending on what measurements are available for each field campaign. We also calculate aerosol size distribution from 1nm to 3000nm with 1nm increment in E3SM.

To run the preprocessing code (including preprocessing of observations):

a. Enter *scripts*/ directory
b. Edit the script *run_preprocess.py*
    i. Edit user-specified settings for field campaign name, model information and data path
    ii. Edit running command to specify the preprocessing type (a full list of commands can be found in *run_preprocess_all.py*)
c. Run the script:

```
python run_preprocess.py
```

The preprocessed data should be output at *datapath*/*campaign*/model/ (for model) and *datapath*/*campaign*/obs/aircraft/merged_bin/ (for observation).

4. Plotting:

Currently, ESMAC Diags produces the following diagnostics and metrics:

For aircraft measurements:

- aircraft track maps.
- Timeseries of aerosol variables (total aerosol number concentration, size distribution of aerosol number, total composition, CCN number concentration) for each flight.
- mean aerosol size distribution for each field campaign or IOP.
- Percentiles of aerosol variables by height for each field campaign or IOP.
- Percentiles of aerosol variables by latitude for each field campaign or IOP.
- Vertical profile of cloud fraction, LWC and cloud droplet number concentration composite of aircraft measurements for each field campaign or IOP.
- Mean value, 10%, 25%, 75%, and 90% percentiles, bias, RMSE and correlation of aerosol number concentration output as txt file

for surface measurements:

- Timeseries of aerosol variables (total aerosol number concentration, size distribution of aerosol number, total composition, CCN number concentration) for each field campaign or IOP.
- timeseries of aerosol size distribution for each field campaign or IOP.
- diurnal cycle of these surface measurements for each field campaign or IOP.
- mean aerosol size distribution for each field campaign or IOP.
- Pie/bar charts of observed and predicted aerosol composition averaged over each field campaign or IOP.

- Mean value, 10%, 25%, 75%, and 90% percentiles, bias, RMSE and correlation of aerosol number concentration output as txt file.
- Timeseries of basic meteorological fields, time-height profile of cloud fraction.

For ship measurements:

- Ship track maps.
- Timeseries of basic meteorological fields, time-height profile of cloud fraction.
- Timeseries of aerosol variables (total aerosol number concentration, size distribution of aerosol number, total composition, CCN number concentration) for each ship trip
- timeseries of aerosol size distribution for each ship trip
- mean aerosol size distribution
- Percentiles of aerosol variables by latitude for each field campaign or IOP.
- Mean value, 10%, 25%, 75%, and 90% percentiles, bias, RMSE and correlation of aerosol number concentration output as txt file.

To run the plotting code:

a. Enter *scripts*/ directory
b. Edit the script *run_plot.py*
   i. Edit user-specified settings for field campaign name, model information and data path
   ii. Edit running command to specify the plotting type (a full list of commands can be found in *run_plot_all.py*)
c. Run the script:

```
python run_plot.py
```

running the script below generates all figures currently available in ESMAC_diags v1.0.0-beta:

```
python run_plot_all.py
```

The webpage of webpage/index.html provides an interface to look at the diagnostics plots. Users will need to put webpage/ and the figure directory (specified as figpath in running script; should have the directory name "figures") under the same directory to view the plots using this interface. Users may also go to the figure directory to browse the plots and metrics.

5. Update history

V1.0.0-alpha (November 28, 2021): first release of ESMAC diags for the initial submission of GMD paper: "*Earth System Model Aerosol-Cloud Diagnostics Package (ESMAC Diags) Version 1: Assessing E3SM Aerosol Predictions Using Aircraft, Ship, and Surface Measurements*" https://doi.org/10.5194/gmd-2021-350.

V1.0.0-beta (March 18, 2022): updated for the revision submission of GMD paper "*Earth System Model Aerosol-Cloud Diagnostics Package (ESMAC Diags) Version 1: Assessing E3SM Aerosol Predictions Using Aircraft, Ship, and Surface Measurements*" (https://doi.org/10.5194/gmd-2021-350) addressing comments from reviewers and some other updates:

- Re-organize data quality-control module
- Fix a bug that uses incorrect temperature and pressure for FIMS measurements
- Update quality controls for surface CPC for HI-SCALE
- Use a ship exhaust-free CN and CCN data for MARCUS
- Some other minor bug fixings

6. Contact:

Shuaiqi Tang (Shuaiqi.tang@pnnl.gov)

Table 1. Descriptions of the field campaigns used in this study. Numbers after aircraft or ship represent number of flights or ship trips in each field campaign or IOP.

Campaign name	Period	Measuring platform	Cloud/Aerosol properties	Reference
HI-SCALE	IOP1: 24 Apr – 21 May 2016 IOP2: 28 Aug – 24 Sep 2016	Ground, aircraft (IOP1: 17, IOP2: 21)	Continental shallow cumulus clouds	(Fast et al. 2019)
ACE-ENA	IOP1: 21 Jun – 20 Jul 2017 IOP2: 15 Jan – 18 Feb 2018	Ground, aircraft (IOP1: 20, IOP2: 19)	Marine PBL clouds	(Wang et al. 2021)
MAGIC	Oct 2012 – Sep 2013	Ship (18)	Stratocumulus to cumulus transition	(Lewis and Teixeira 2015; Zhou et al. 2015)
CSET	1 Jul – 15 Aug 2015	Aircraft (16)	Same as above	(Albrecht et al. 2019)
MARCUS	Oct 2017 – Apr 2018	Ship (4)	Pristine region with low aerosol loading	(McFarquhar et al. 2021)
SOCRATES	15 Jan – 24 Feb, 2018	Aircraft (14)	Same as above	(McFarquhar et al. 2021)

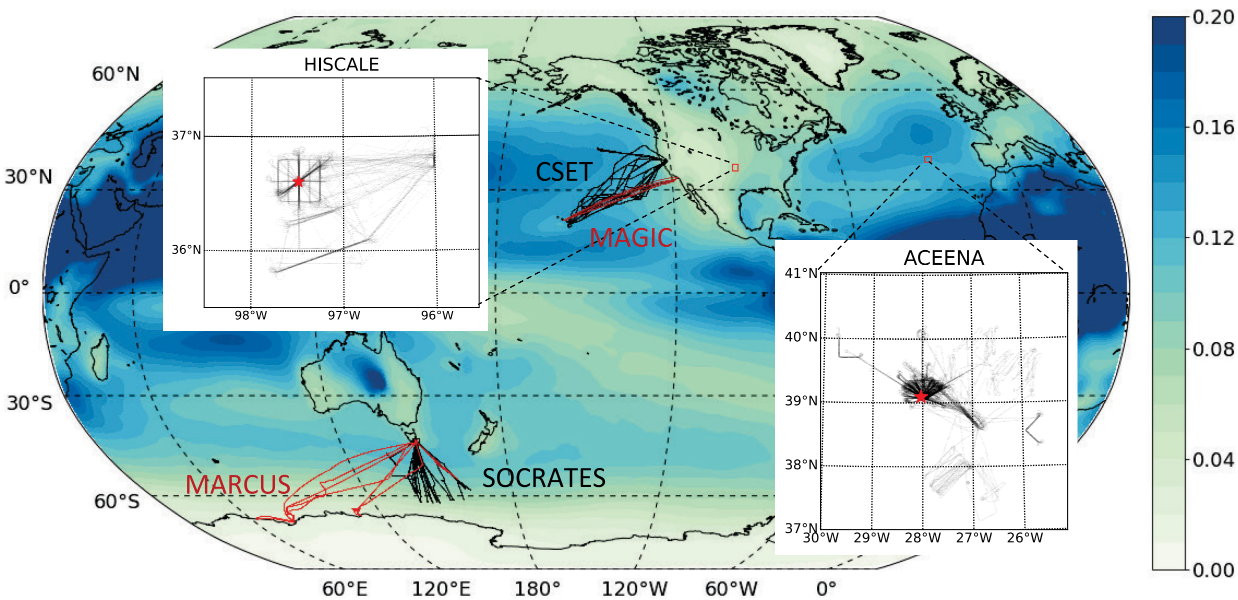

Figure 1. aircraft (black) or ship (red) tracks for the six field campaigns. Overlaid is aerosol optical depth at 550nm averaged from 2014 to 2018 simulated in EAMv1.

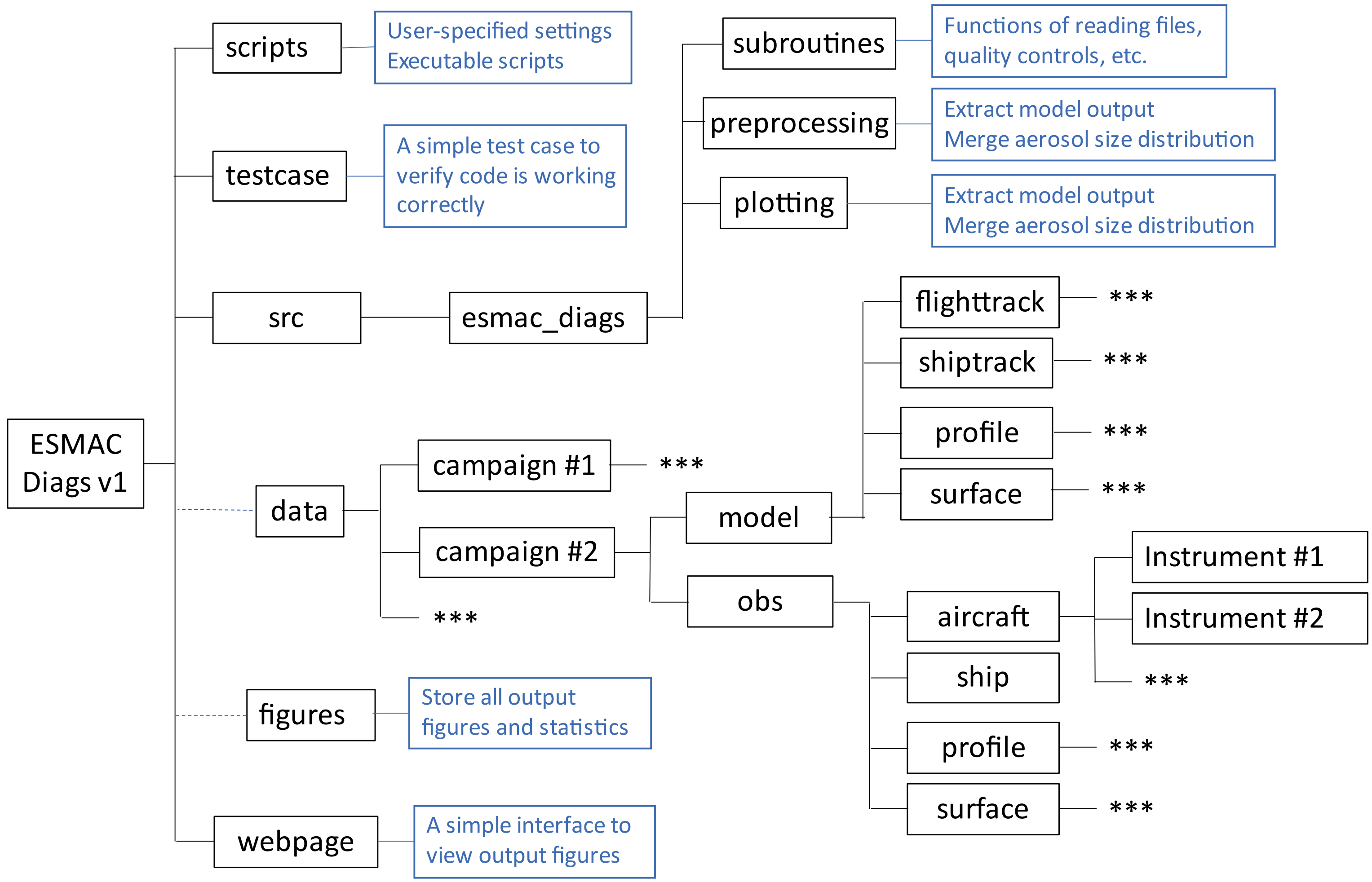

Figure 2: Structure of ESMAC Diags. Boxes in blue describe the functions. Asterisks represent boxes that follow the same format as those shown in parallel.

Table 2: Instruments for HI-SCALE

Platform	Instrument	Measurements	Datastream name	DOI or link
Ground	Surface meteorological station (MET)	Temperature, relative humidity, wind, pressure	sgpmetE13.b1	DOI: 10.5439/1786358
	Scanning mobility particle sizer (SMPS)	Aerosol size distribution (20-700 nm)	sgpaossmpsS01.a1 (IOP1) and shilling-smps (IOP2)	DOI: 10.5439/1476898
	Nano scanning mobility particle sizer (nanoSMPS)	Aerosol size distribution (2-150 nm)	sgpaosnanosmpsS01.a1	DOI: 10.5439/1242975
	Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)	Aerosol size distribution (60 – 1000 nm), number concentration	sgpaosuhsasS01.a1	DOI: 10.5439/1333828
	Condensation particle counter (CPC)	Aerosol number concentration (> 10 nm)	sgpaoscpcC1.b1	DOI: 10.5439/1025152
	Condensation particle counter – ultrafine (CPCU)	Aerosol number concentration (> 3 nm)	sgpaoscpcuS01.b1	DOI: 10.5439/1046186
	Cloud condensation nuclei (CCN) counter	CCN number concentration	sgpaosccn1colavgC1.b1	DOI: 10.5439/1342133
	Aerosol chemical speciation monitor (ACSM)	Aerosol composition	sgpaosacsmC1.b1	DOI: 10.5439/1762267
Aircraft	Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)	Aerosol size distribution (60 – 1000 nm), number concentration	tomlinson-uhsas	https://iop.archive.arm.gov/arm-iop/2016/sgp/hiscale/tomlinson-uhsas
	Condensation particle counter (CPC)	Aerosol number concentration (> 10 nm)	mei-cpc	https://iop.archive.arm.gov/arm-iop/2016/sgp/hiscale/mei-cpc
	Condensation particle counter – ultrafine (CPCU)	Aerosol number concentration (> 3 nm)	mei-cpc	https://iop.archive.arm.gov/arm-iop/2016/sgp/hiscale/mei-cpc
	Cloud condensation nuclei (CCN) counter	CCN number concentration	mei-ccn	https://iop.archive.arm.gov/arm-iop/2016/sgp/hiscale/mei-ccn

	Interagency working group for airborne data and telemetry systems (IWG)	navigation information and basic atmospheric state parameters	mei-iwg1	https://iop.archive.arm.gov/arm-iop/2016/sgp/hiscale/mei-iwg1
	Fast integrated mobility spectrometer (FIMS)	Aerosol size distribution (10 – 425 nm)	wang-fims	https://iop.archive.arm.gov/arm-iop/2016/sgp/hiscale/wang-fims
	Passive cavity aerosol spectrometer (PCASP)	Aerosol size distribution (120 – 3000 nm)	tomlinson-pcasp	https://iop.archive.arm.gov/arm-iop/2016/sgp/hiscale/tomlinson-pcasp
	High-resolution time-of-flight aerosol mass spectrometer (AMS)	Aerosol composition	shilling-ams	https://iop.archive.arm.gov/arm-iop/2016/sgp/hiscale/shilling-ams
	Water content measuring system (WCM)	Cloud liquid and total water content	matthews-wcm	https://iop.archive.arm.gov/arm-iop/2016/sgp/hiscale/matthews-wcm

Table 3: Instruments for ACE-ENA

Platform	Instrument	Measurements	Datastream name	DOI or link
Ground	Surface meteorological station (MET)	Temperature, relative humidity, wind, pressure	enametC1.b1	DOI: 10.5439/1786358
	Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)	Aerosol size distribution (60 – 1000 nm), number concentration	enaaosuhsasC1.a1	DOI: 10.5439/1409033
	Condensation particle counter (CPC)	Aerosol number concentration (> 10 nm)	enaaoscpcfC1.b1	DOI: 10.5439/1046184
	Cloud condensation nuclei (CCN) counter	CCN number concentration	enaaosccn1colavgC1.b1	DOI: 10.5439/1342133
	Aerosol chemical speciation monitor (ACSM)	Aerosol composition	enaaosacsmC1.b2	DOI: 10.5439/1762267
	Condensation particle counter (CPC)	Aerosol number concentration (> 10 nm)	mei-cpc	DOI: 10.5439/1440985
Aircraft	Condensation particle counter – ultrafine (CPCU)	Aerosol number concentration (> 3 nm)	mei-cpc	DOI: 10.5439/1440985
	Cloud condensation nuclei (CCN) counter	CCN number concentration	enaaafccn2colaF1.b1, enaaafccn2colbF1.b1	No DOI
	Interagency working group for airborne data and telemetry systems (IWG)	navigation information and basic atmospheric state parameters	mei-iwg1	https://iop.archive.arm.gov/arm-iop/2017/ena/aceena/mei-iwg1
	Fast integrated mobility spectrometer (FIMS)	Aerosol size distribution (10 – 425 nm)	wang-fims	https://iop.archive.arm.gov/arm-iop/2017/ena/aceena/wang-fims
	Passive cavity aerosol spectrometer (PCASP)	Aerosol size distribution (100 – 3000 nm)	tomlinson-pcas	https://iop.archive.arm.gov/arm-iop/2017/ena/aceena/tomlinson-pcas

	Optical particle counter (OPC)	Aerosol size distribution (390 – 15960 nm)	pekour-opc_iso	https://iop.archive.arm.gov/arm-iop/2017/ena/aceena/pekour-opc_iso
	High-resolution time-of-flight aerosol mass spectrometer (AMS)	Aerosol composition	shilling-hrfams	Doi: 10.5439/1468474
	Water content measuring system (WCM)	Cloud liquid and total water content	matthews-wcm	Doi: 10.5439/1465759

Table 4: Instruments for MAGIC

Platform	Instrument	Measurements	Datastream name	DOI or link
Ship	Meteorological station (MET)	Temperature, relative humidity, wind, pressure	raynolds-marmet	https://iop.archive.arm.gov/arm-iop/2012/mag/magic/reynolds-marmet/
	Microwave radiometer (MWR)	Liquid water path, precipitable water vapor	magmwrret1liljclouM1.s2	DOI: 10.5439/1027369
	Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)	Aerosol size distribution (60 – 1000 nm), number concentration	magaosuhsasM1.a1	DOI: 10.5439/1333828
	Condensation particle counter (CPC)	Aerosol number concentration (> 10 nm)	magaoscpcfM1.a1	DOI: 10.5439/1046184
	Cloud condensation nuclei (CCN) counter	CCN number concentration	magaosccn100M1.a1	DOI: 10.5439/1227964

Table 5: Instruments for MARCUS

Platform	Instrument	Measurements	Datastream name	DOI or link
Ship	Meteorological station (MET)	Temperature, relative humidity, wind, pressure	maraadmetX1.b1	DOI: 10.5439/1593144
	Microwave radiometer (MWR)	Liquid water path, precipitable water vapor	marmwrret1liljclouM1.s2	DOI: 10.5439/1027369
	Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)	Aerosol size distribution (60 – 1000 nm), number concentration	maraosuhsasM1.a1	DOI: 10.5439/1333828
	Condensation particle counter (CPC)	Aerosol number concentration (> 10 nm)	maraoscpcf1mM1.b1	DOI: 10.5439/1418260
	Cloud condensation nuclei (CCN) counter	CCN number concentration	maraosccn1colavgM1.b1	DOI: 10.5439/1342133
	Reprocessed CN and CCN	CN and CCN number concentration	MARCUS ARM CN and CCN data reprocessed to remove ship exhaust influence. v1.	DOI: 10.25919/ezp0-em87

Table 6: Instruments for CSET

Platform	Instrument	Measurements	Datastream name	DOI or link
aircraft	Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)	Aerosol size distribution (60 – 1000 nm), number concentration	Low Rate (LRT - 1 sps) Navigation, State Parameter, and Microphysics Flight-Level Data. Version 1.3	DOI: 10.5065/D65Q4T96
	Condensation nuclei counter (CNC)	Aerosol number concentration (11-3000 nm)	Same as above	DOI: 10.5065/D65Q4T96
	Passive cavity aerosol spectrometer (PCASP)	Aerosol size distribution (120 – 3000 nm)	Same as above	DOI: 10.5065/D65Q4T96

Table 7: Instruments for SOCRATES

Platform	Instrument	Measurements	Datastream name	DOI or link
aircraft	Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)	Aerosol size distribution (60 – 1000 nm), number concentration	Low Rate (LRT - 1 sps) Navigation, State Parameter, and Microphysics Flight-Level Data. Version 1.3	DOI: 10.5065/D6M32TM9
	Condensation nuclei counter (CNC)	Aerosol number concentration (11-3000 nm)	Same as above	DOI: 10.5065/D6M32TM9
	Cloud condensation nuclei (CCN) counter	CCN number concentration	SOCRATES CCN measurements. Version 1.1	DOI: 10.5065/D6Z036XB