InterComparison of Multiple Aerosol Reanalyses and Multi-Reanalysis-Consensus for Climate Studies

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Four global full-species aerosol reanalyses

	Organization	Meterology	Resolution lat x lon	DA metho	Assimilated obs.	Species	Anthro. & Biogenic Emission	BB Emissions	Available time	reference
CAMSRA	ECMWF	Inline ERA5	0.7 x 0.7	4D-Var	DAQ MODIS PMAp	BC, OM, Sulfate Dust, Sea Salt	MACCity (trend: ACCMIP + RCP8.5), monthly VOC	GFAS	2003-present	Inness et al., 2019
MERRA-2	NASA	Inline MERRA-2	0.5 x 0.6	2D-Var +LDE	Neural Net MODIS, MISR, AVHRR, AERONET	BC, OC, Sulfate Dust, Sea Salt	EDGAR V4.1, AeroCom Phase II	GFED before 2009, QFED after 2009	1980-present	Randles et al., 2017
NAAPS-RA	NRL	Offline NOGAPS/NAVGEM	1 x 1	2D-Var	DAQ MODIS, MISR	BB smoke, Dust, Sea Salt, ABF	MACCity, BOND POET, monthly SOA	FLAMBE	2003-present	Lynch et al., 2016
JRAero	JMA	Inline	1.1 x 1.1	2D-Var	DAQ MODIS	BC, OC, Sulfate Dust, Sea Salt	MACCity	GFAS	2011-present	Yumimoto et al., 2017
MRC	-	-	1 x 1	-	-	BB smoke, Dust, Sea Salt, ABF	-	-	2003-present	this work

- https://egusphere.copernicus.org/preprints/2023/egusphere-2023-2354/

Data and Methods

Data used in this study:

- Remote Sensing :

MODIS v6 QA/QCed AOD at 550 nm
AERONET V3L2 (Giles et al, 2019) with Spectral Deconvolution Algorithm (SDA, O'Neill et al. 2001, 2003)

- Reanalyses:

NRL NAAPS-RA speciated AOD at 550 nm (Lynch et al. 2016)
NASA MERRA2 speciated AOD at 550 nm (Randles et al. 2017)
ECMWF CAMSRA speciated AOD at 550 nm (Inness et al. 2019)
JMA JRAero speciated AOD at 550 nm (Yumimoto et al., 2017); 2011-2019.
Multi-Reanalysis-Consensus based on the three/four reanalyses.

- PM measurements

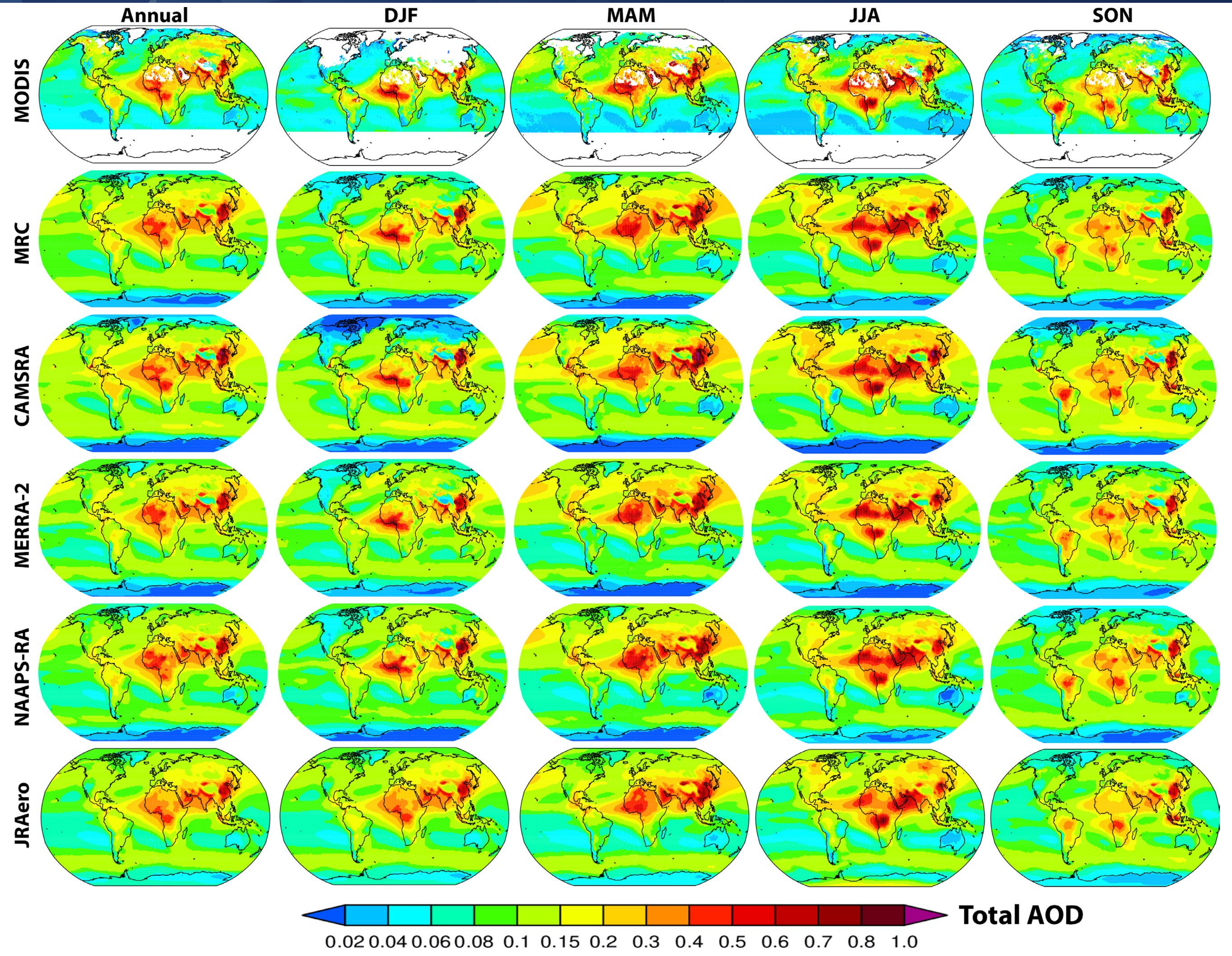
OpenAQ QAed PM10 and PM2.5

Method:

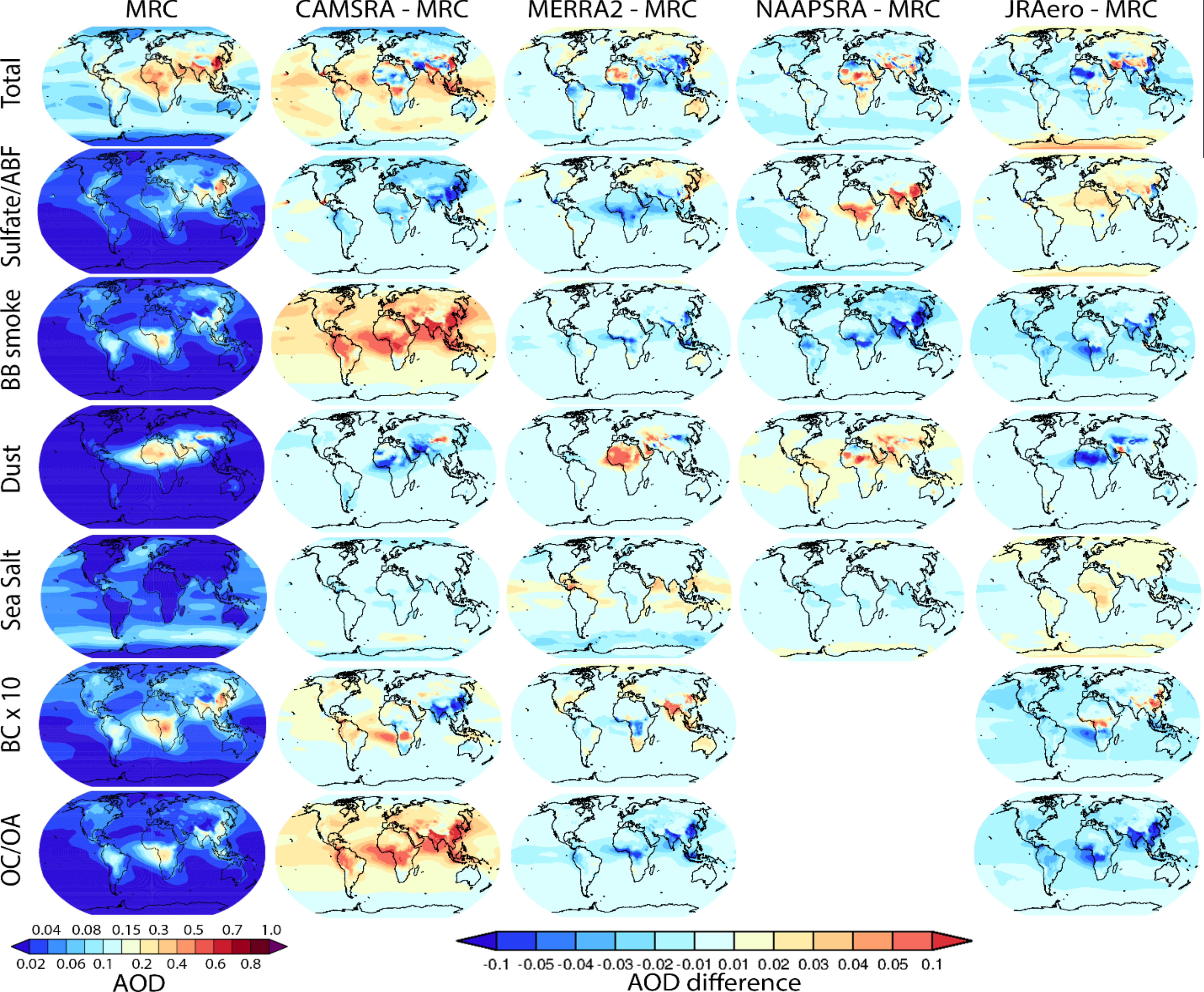
- The 550 nm AOD was employed as the benchmark parameter for this study.
- Use fine mode (FM) and coarse mode (CM) AOD derived from AERONET with SDA.
- The species of interest: biomass burning (BB) smoke, anthropogenic and biogenic fine aerosols (ABF) in NAAPS, and its equivalent of sulfate for MERRA-2, CAMSRA and JRAero, dust and sea salt aerosols.
- Sum of OC/OA+BC used to approximate BB smoke from CAMSRA, MERRA-2 and JRAero.

Note: Total, dust and sea salt AODs are trackable variables as all the RAs have these species. While fine mode species are less trackable as they are defined differently in the RAs.

Seasonal total AOD climatology (2003-2019, except for 2011-2019 from JRAero)

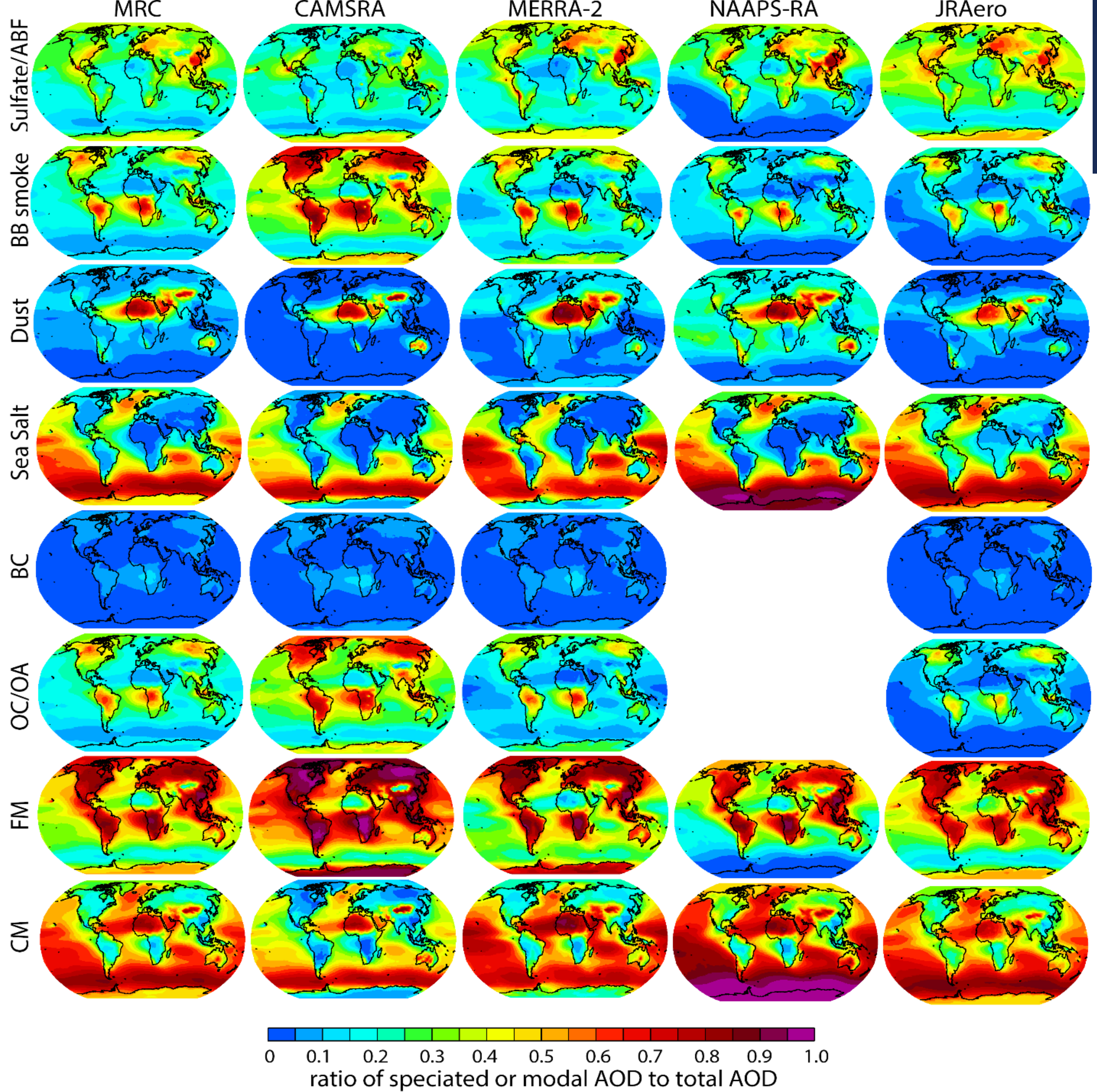


- In general, very similar spatial AOD distribution patterns and AOD magnitude among the reanalyses and MODIS for all four seasons.
- More divergence among the reanalyses in regions with little satellite observation (e.g. bright desert, snow/ice-covered, high-cloud-coverage and polar regions).



Differences in annual mean total and speciated AODs

- CAMSRA is higher than the other three RAs in smoke/OA AOD, and total AOD in general.
- For dust AOD, MERRA-2 is relatively higher over north Africa and Arabian Peninsula and NAAPS-RA is relatively higher over most regions, including oceanic areas, while CAMSRA and JRAero are relatively lower over most regions except around Gobi desert for CAMSRA and Iran for JRAero.
- NAAPS-RA ABF AOD is higher than sulfate AOD in other RAs in some regions. This is expected as ABF in NAAPS-RA includes biogenic and anthropogenic primary and secondary aerosols besides sulfate.
- JRAero sea salt AOD is relatively higher over most continents, which is probably unphysical.

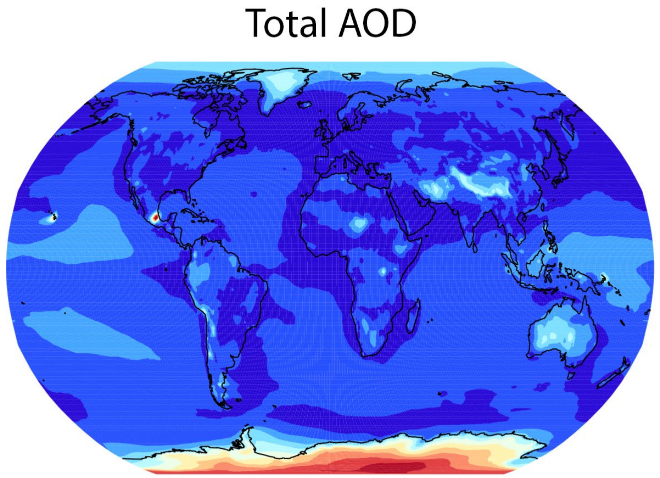


Ratio of speciated AOD to total AOD

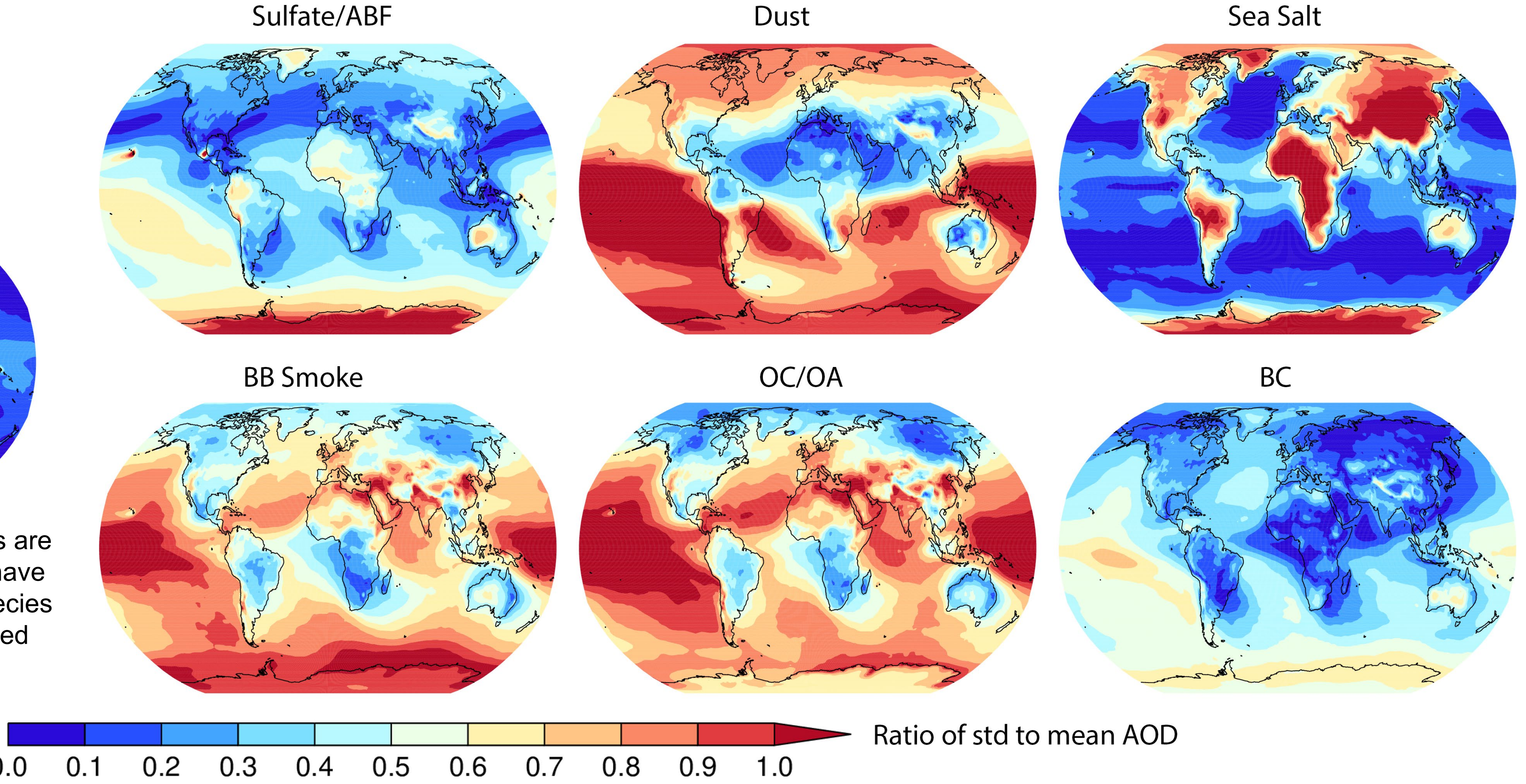
Some numbers

- Smoke AOD contributes to 41% of total AOD in CAMSRA, while ranging from 16%-22% in other RAs.
- The contribution of dust AOD to total AOD varies from 13% to 28% for all the RAs, with NAAPS dust AOD being the highest among the RAs and about 2 times that of CAMSRA, which has the lowest dust AOD among the RAs.
- The contribution of sulfate/ABF AOD to total AOD ranges from 23% to 34%, with the highest contribution observed in JRAero.
- Sea salt AOD contributes 25% to 35% to total AOD in the RAs.
- BC AOD contributes only 3% to 4% of total AOD across the RAs.

Diversity of speciated AOD among the four reanalyses



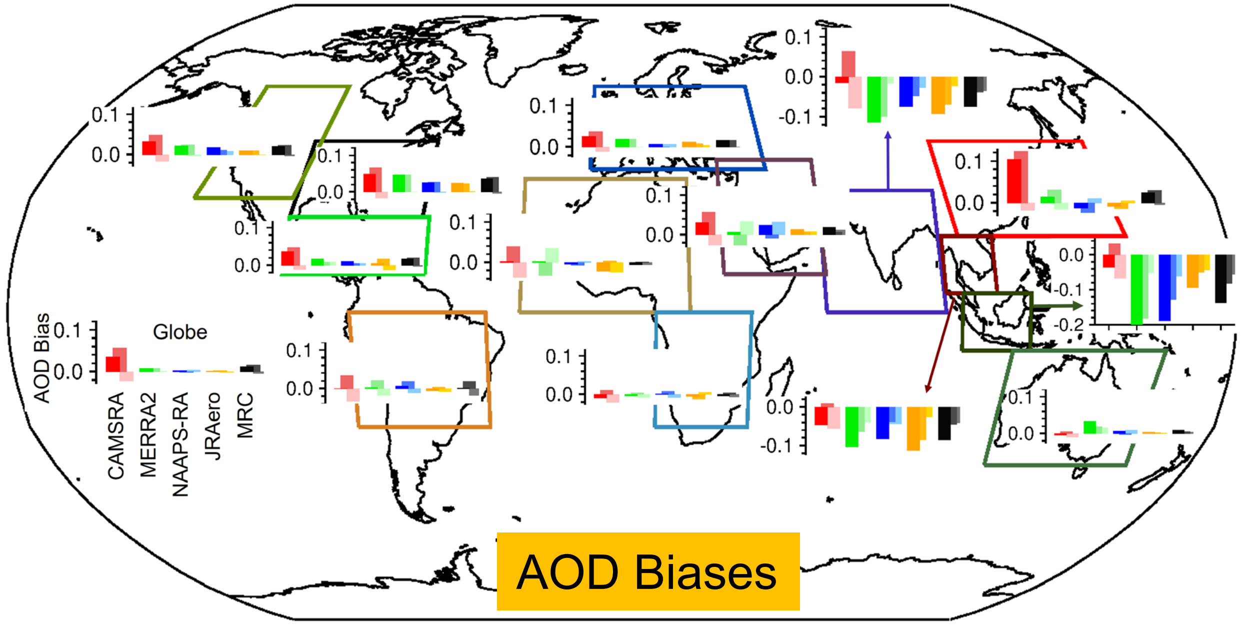
Note: Total, dust and sea salt AODs are trackable variables as all the RAs have these species. While fine mode species are less trackable as they are defined differently in the RAs.

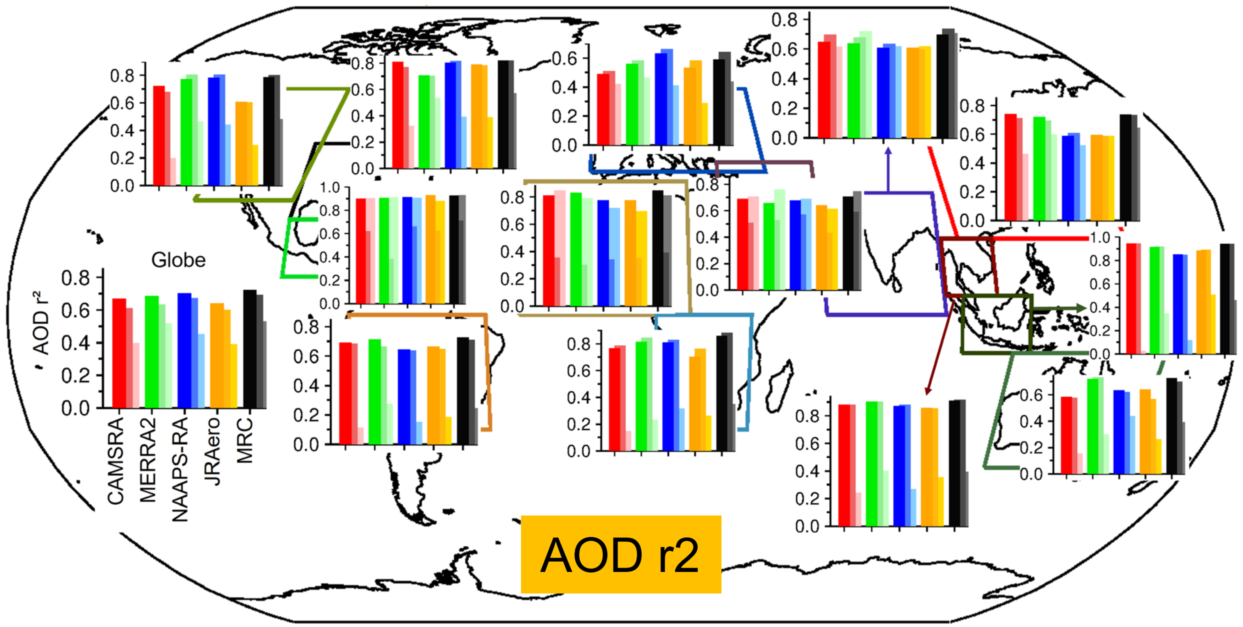


Relative spread (ratio of standard deviation of the reanalyses AOD to the mean)

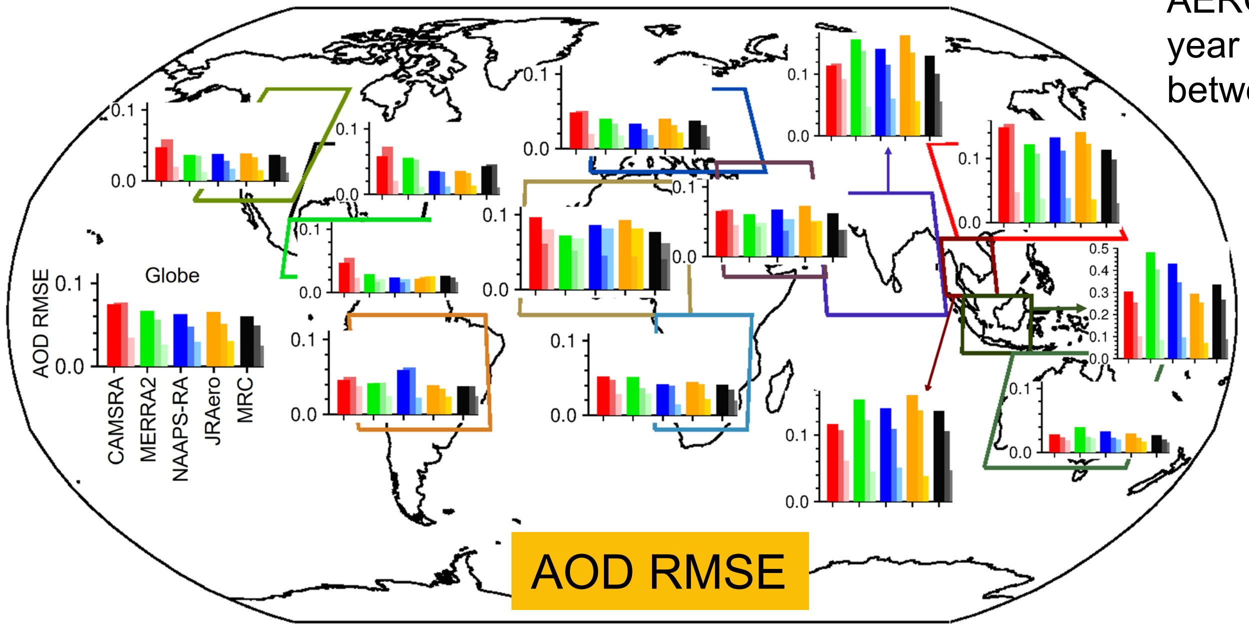
- Small for total AOD (except for polar regions and a few hotspots),
- But can be large for speciated AODs, especially in regions remote to aerosol sources.

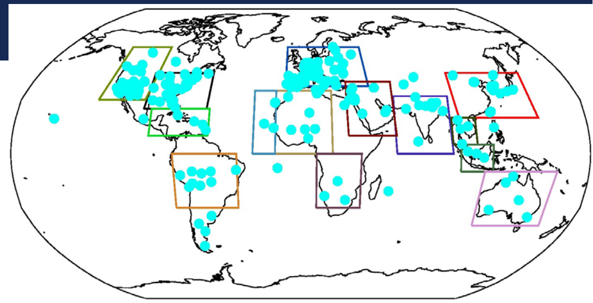
Verification of total, FM, CM AODs with AERONET regionally





Within each bar group from left to right are total, FM and CM AOD RMSEs.





AERONET sites with >5 year and >1000 daily data between 2011-2019.

- Each RA exhibits its own unique regional strengths.
- Specifically, CAMSRA performs better in South and Southeast Asia,
- MERRA-2 excels in in African and Arabian Peninsula dust regions.
- NAAPS-RA shows relatively better performance over Europe and East CONUS
- JRAero performs relatively better over South North America and the Caribbeans.

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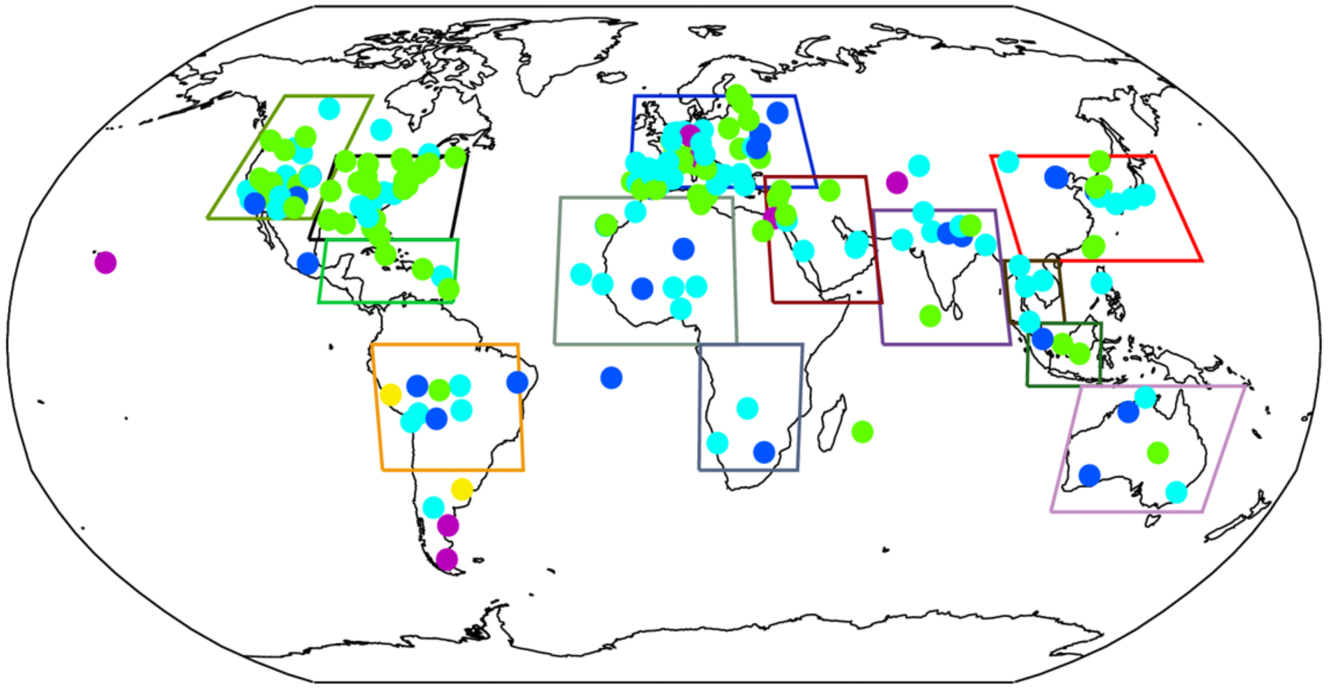
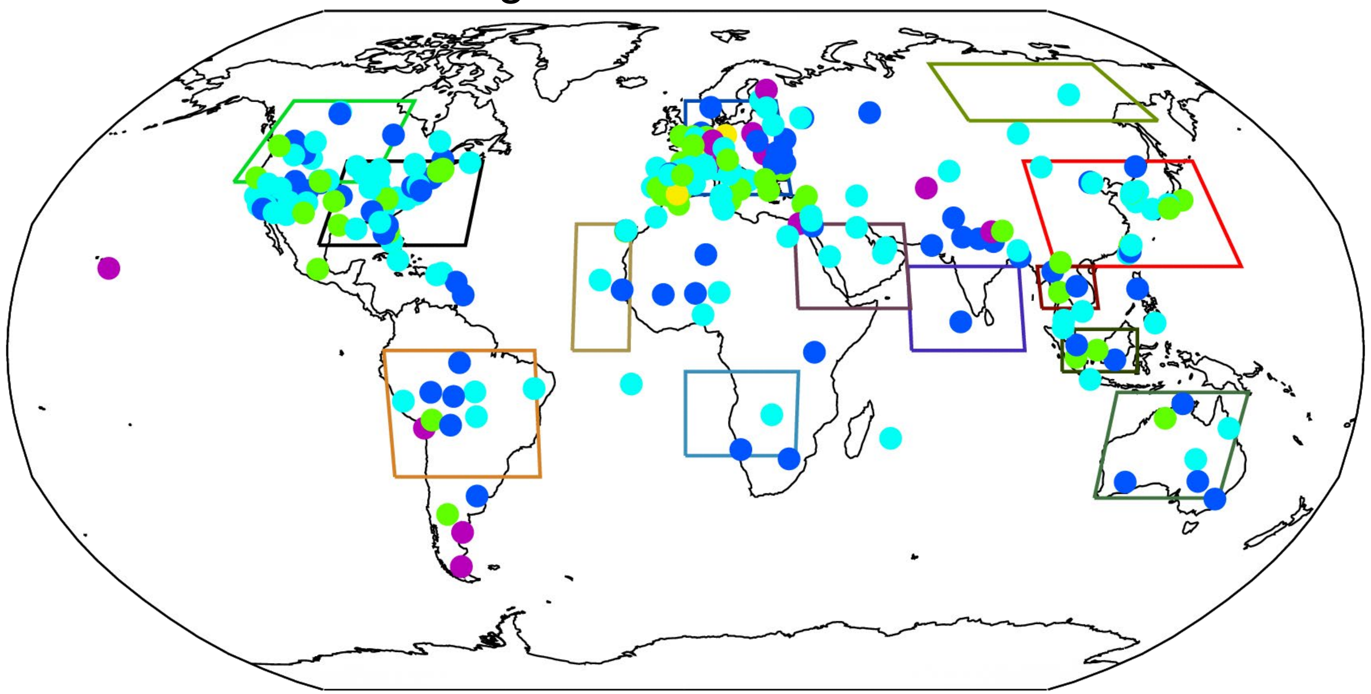
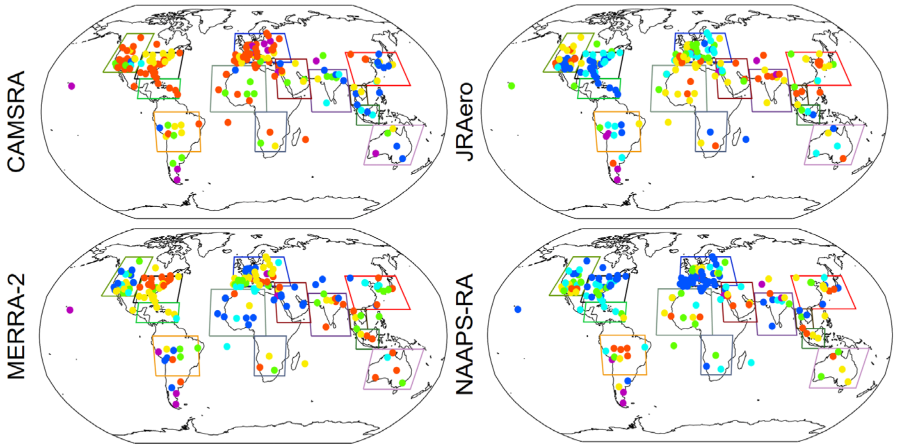
Ranking of MRC in terms of monthly AOD RMSE/r^2

Ranking of MRC RMSE of total AOD



Ranking of MRC R^2 of total AOD





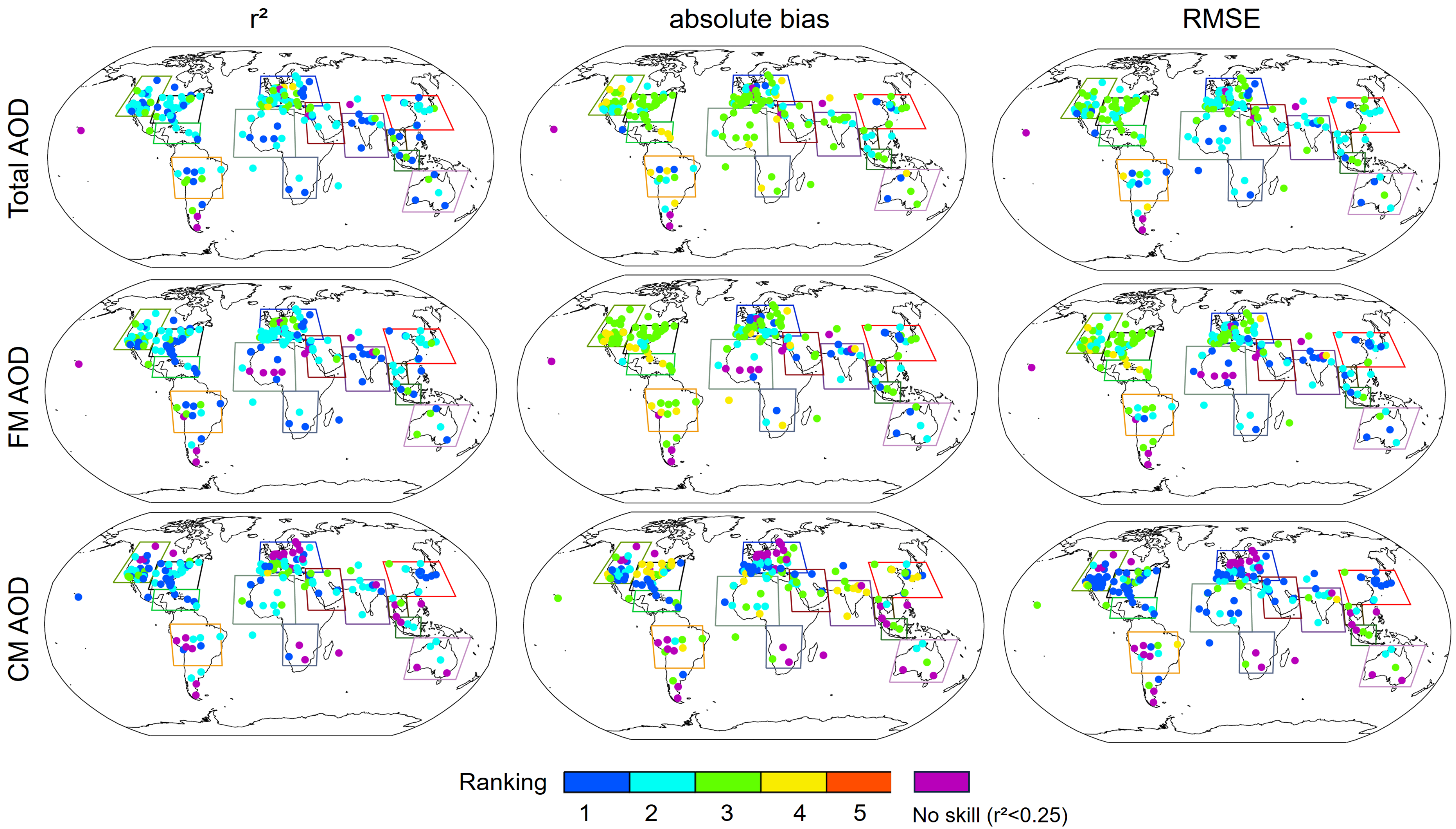
Individual RA RMSE rankings

Ranking 1 2 3 4 5

No skill (r^2<0.3)

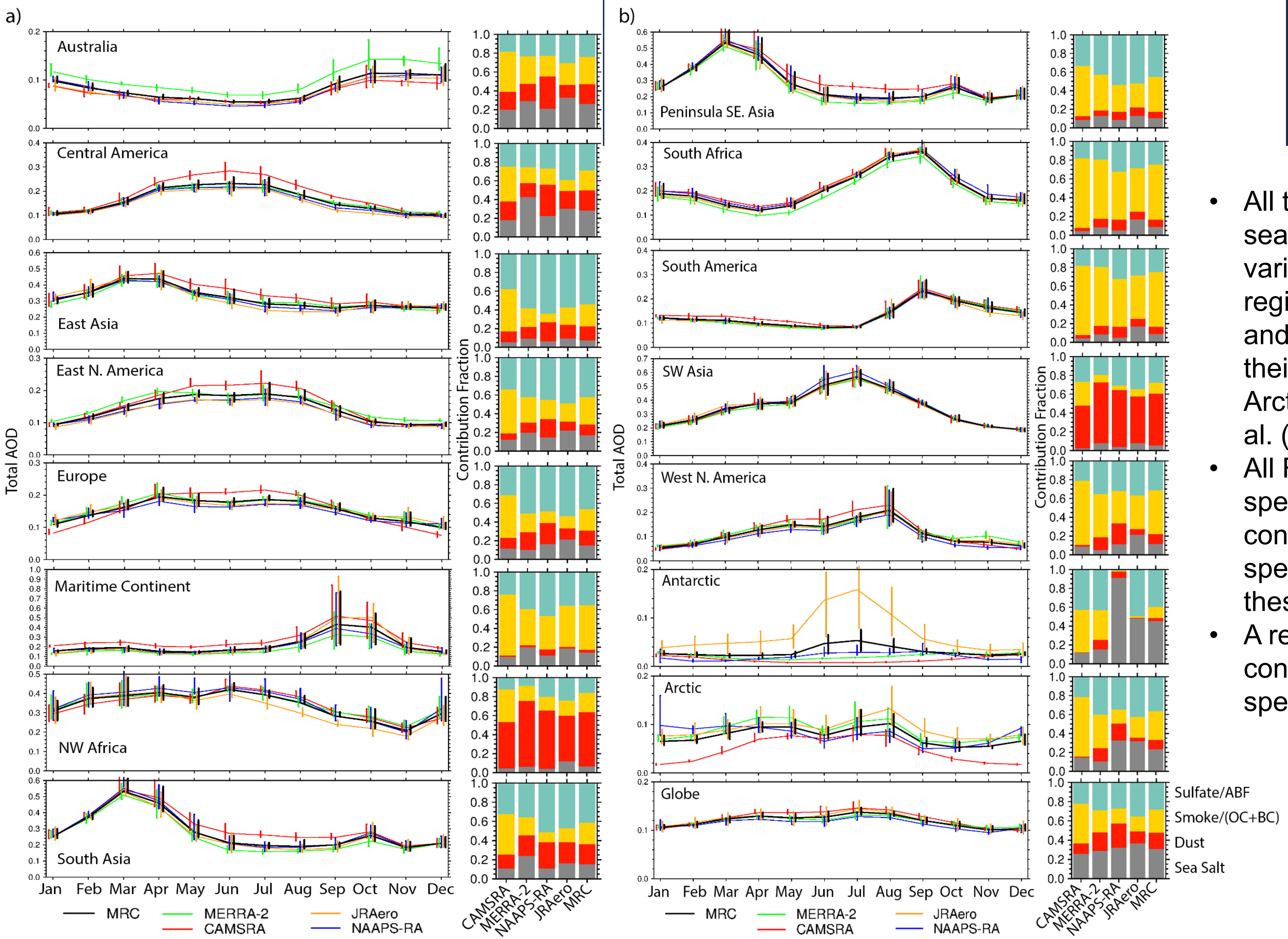
- AOD RMSE of the MRC is not always the lowest, but it is relatively low globally.
- MRC ranks often the 1st or 2nd w.r.t. RMSE and r^2.
- Consensus wins because of its averaging of independent models.
- Consistent with the result of the ICAP-MME paper on forecast (Xian, et al., 2019).
- Challenging sites identified.

Ranking of MRC



MRC is not always the top-ranked performer in terms of RMSE, bias and correlation of modal AODs for a given site or region. However, the MRC generally performs relatively well and remains stable, ranking first or second regionally and first globally among all the RAs, especially for **correlation and RMSE**.

Seasonality of regional AOD



- All the RAs exhibit a similar seasonality and interannual variability of total AOD for all regions, except for the Antarctic and Arctic, particularly during their winter seasons. For specific Arctic performances, see Xian et al. (ACP 2022a,b).
- All RAs have the same dominant species for most regions, but the contributions from different species can be quite different in these RAs.
- A result of fact that total AOD is constrained through DA, while speciated AODs are not.

Arctic Aerosol Modeling with OMI AI assimilation

A new assimilation system (Zhang et al., 2021) was constructed for the direct assimilation of OMI AI. The aim is to improve the accuracy of aerosol analyses over bright surfaces such as cloudy regions, deserts, ice/snow covered regions.

- Completed 2003-2022. Preliminary evaluation efforts were conducted for 2009 (April 01-September 30) using AERONET data over high latitudes (Latitude > =60°)
- Reduce RMSE by 40% compared with NAAPS natural runs over the high latitude regions (Latitude > =60°)
- Reduce RMSE by 10% compared with NAAPS-RA data with AOD assimilation.
- Better representation of aerosol features that are not captured by AOD assimilation over the Arctic region.

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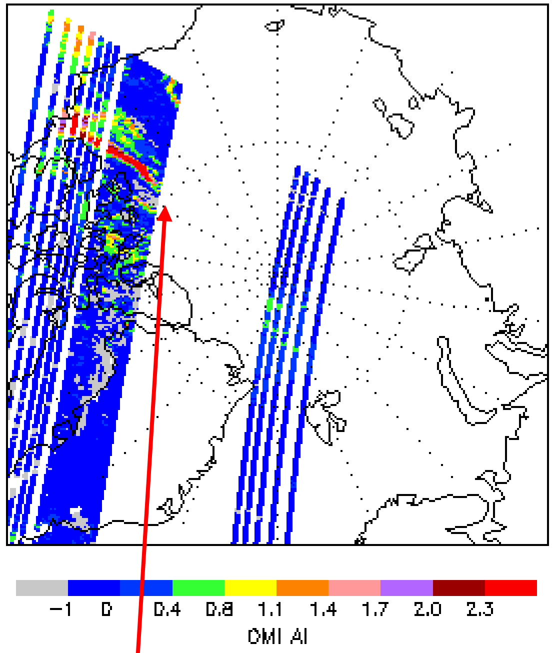
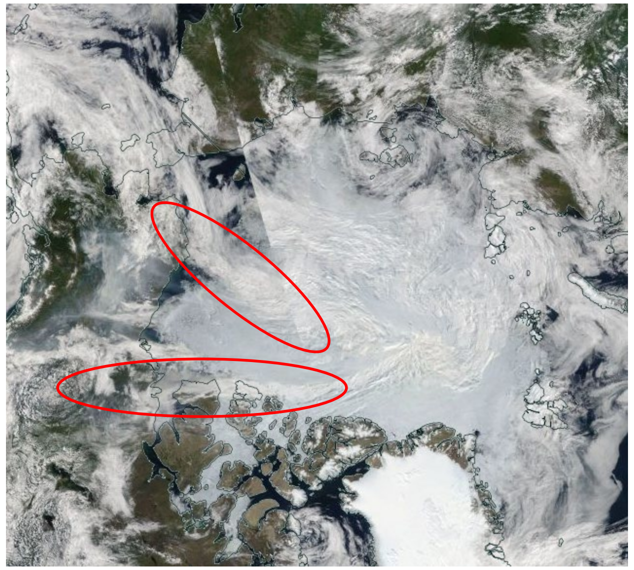
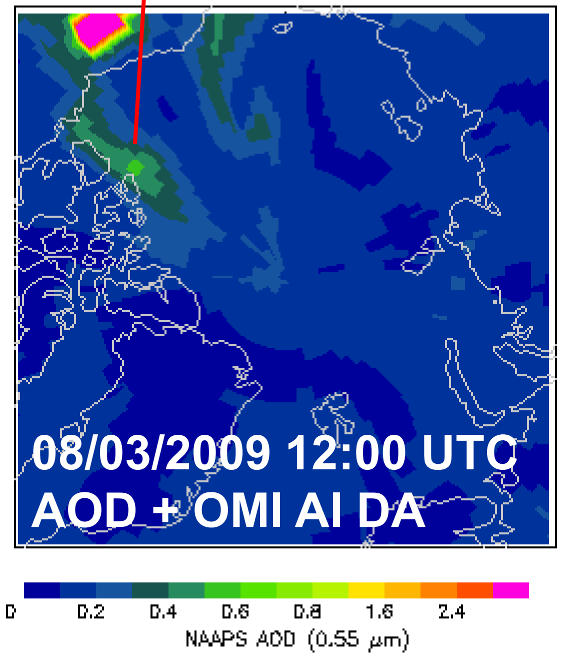
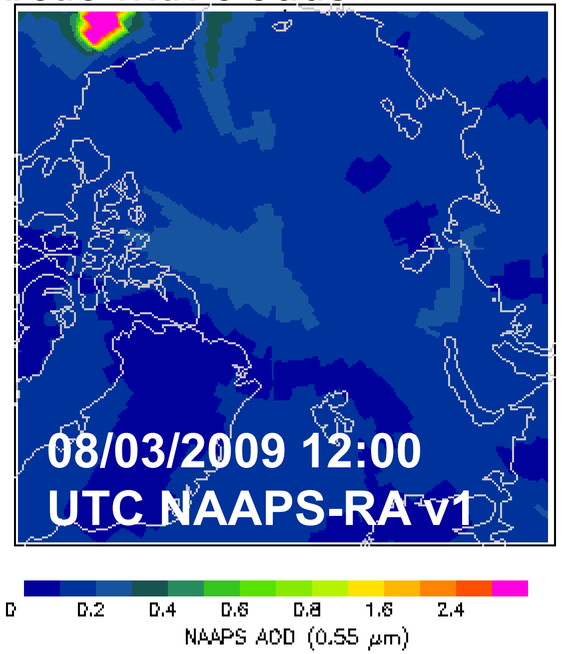




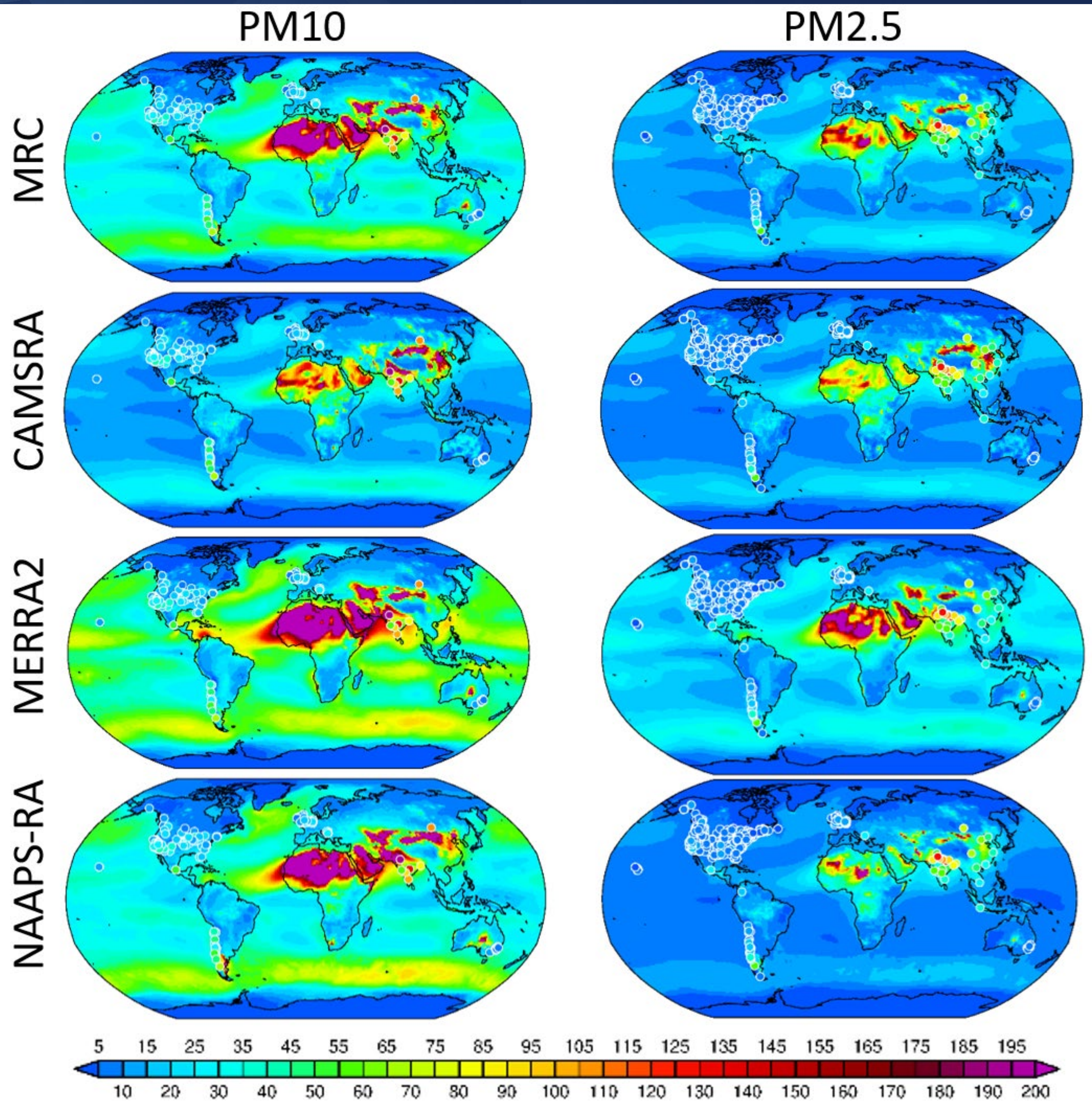
Terra true color

Smoke plumes moving into the Arctic with clouds





Evaluation of surface PMs - Preliminary result



2016-2017 model PM10 with OpenAQ site location & value highlighted

- Models have much more challenges in surface PM than column AOD simulations for the RAs.
- Compared to AOD, PM2.5 and PM10 have larger divergence among the RAs.
- Biases in PM are not necessarily the same sign of biases in AOD. Many factors affect the relation between AOD and surface PMs.

OpenAQ PM data with strict QA/QC processes.
OpenAQ monthly PM with minimum of 30 6hrly data, and at least 20 months for 2016-2017.

Summary on aerosol reanalyses intercomparison

- Global distribution and magnitude of total AOD demonstrate a high level of similarity among all four RAs.
- The relative spread of speciated AODs, however, is considerably larger than that of total AOD. CAMSRA consistently yields higher values for biomass burning (BB) smoke or OA AOD in comparison to other RAs.
- The diversity of speciated AODs in regions remote to aerosol sources are extremely large, implying different efficiencies in removal during long-range transport.
- The seasonality and interannual variability of total AOD in the 16 regions under study, with the exception of the Antarctic and Arctic, demonstrate a high degree of similarity across the various RAs.
- The dominant species of aerosols are consistent across most regions in all RAs, but the relative contributions from individual species can vary significantly. Over remote oceans or the polar regions, dominant species vary.
- Each RA exhibits its own unique regional strengths based on AERONET verification.
- The MRC is not always the top-rated performer in terms of RMSE, bias and correlation of modal AODs for a given site or region. However, the MRC generally performs relatively well, ranking first or second regionally and first globally among all the RAs.
- Simulating surface PMs is more challenging than AOD, but MRC is still likely a good candidate for climate and air quality applications based on our preliminary result and ICAP-MME experience.
- Future aerosol reanalyses

Acknowledgement: ONR for supporting the development of NAAPS-RA v2.