A-Train aerosol observations – preliminary comparisons with AeroCom models and pathways to observationally based all-sky estimates of direct radiative forcing

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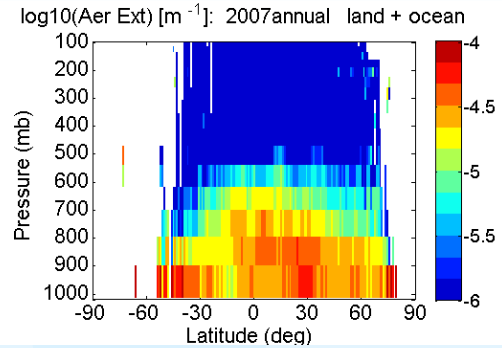
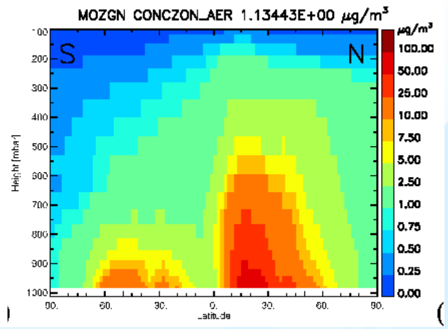
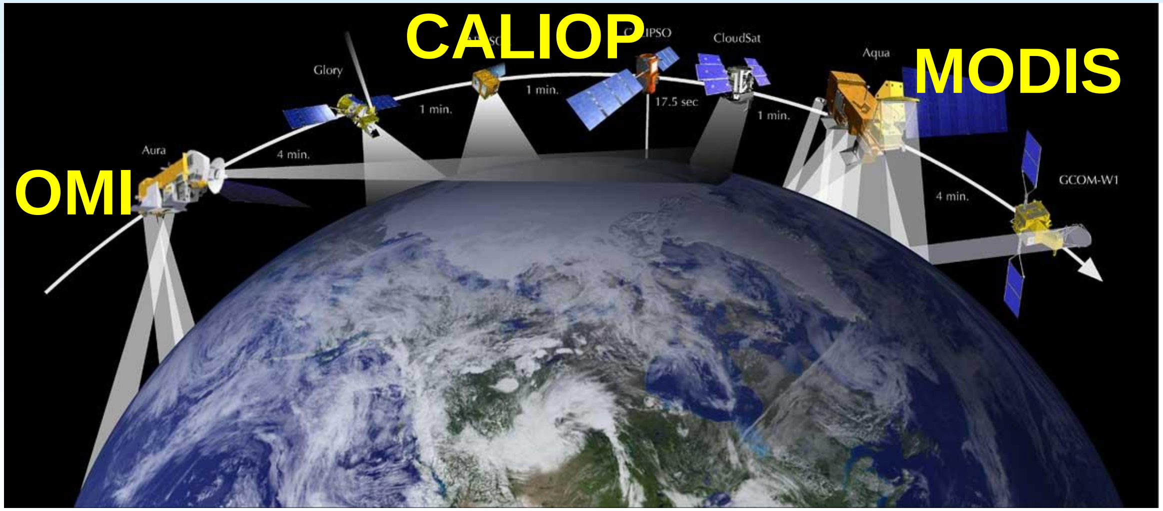
Goals and Motivation





Goal: To use A-Train aerosol obs to constrain aerosol radiative properties to calculate observationally-based $\Delta F_{aerosol}(z)$ and its uncertainty



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Approach

Constraints/Input:
- MODIS AOD (550, 1240 nm) ± (0.03+5%)
- OMI AAOD (388 nm) ± (0.05+30%)
- CALIPSO ext (532, 1064 nm) + δext
- CALIPSO back (532 nm) ±(0.1 $Mm^{-1}sr^{-1}$+30%)

Aerosol models:
7 fine and 3 coarse mode models and refractive indices for bi-modal log-normal size distribution → 100 combinations
Free parameters: N_{fine}, N_{coarse}

Comparison:
AERONET AOD, SSA, g
Airborne test bed data

Retrieval:
ext (λ, z) + δext
SSA (λ, z) + δSSA
g (λ, z) + δg

Rtx code

Target:
$\Delta F_{aerosol}(z) + \delta\, \Delta F_{aerosol}(z)$

Comparison:
CERES F_{clear}
Airborne F_{clear}

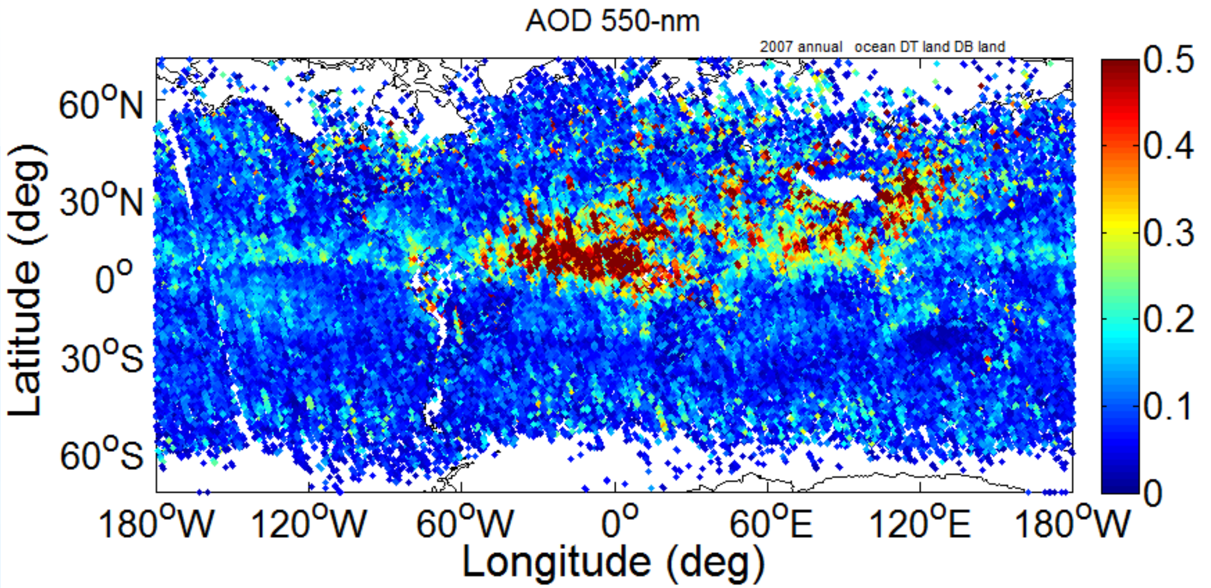
Philosophy and retrieval choices

1) Use instantaneously collocated L2 data from MODIS, OMI, CALIOP
2) Check whether collocated data from any given sensor is consistent with the pdf of the sensor's global data set
3) Observe satellite data quality flags
4) Use aerosol models that are consistent with in situ data sets from various field campaigns
5) Different choices for different locales:

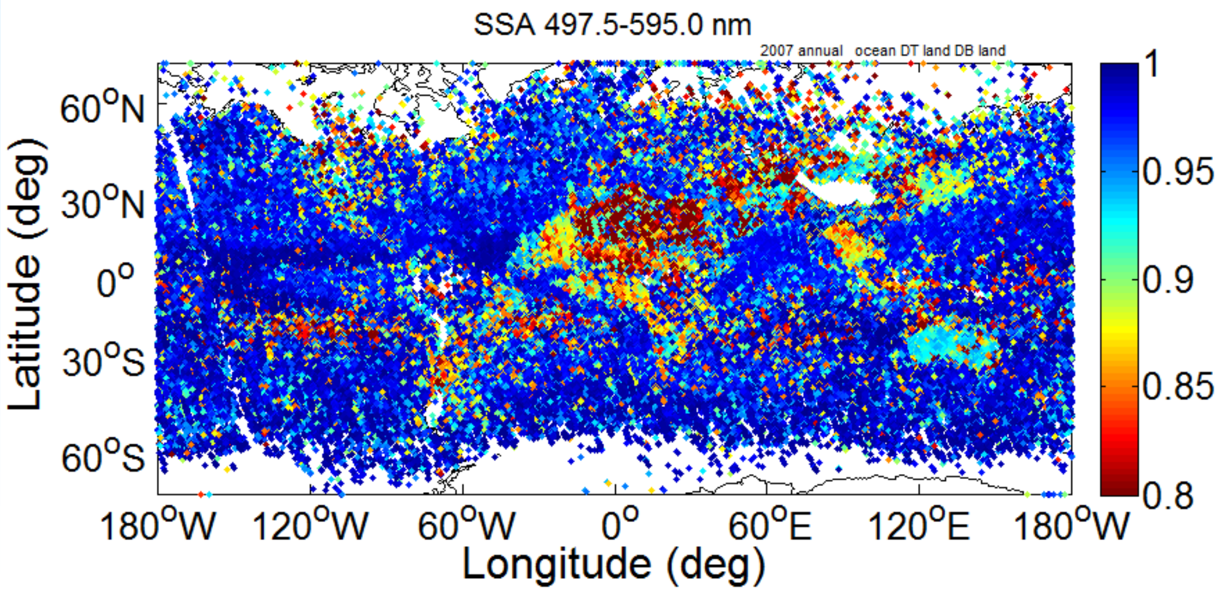
Locale → Data ↓	Land - Dark target	Land - Enhanced Deep blue	Ocean
MODIS AOD 550nm 1240nm	Corr._O._D._Land (QA_Land=3) 550 nm provided 1240 nm extrapolated from 470, 550, 660 nm	D._B._Spec._A._O._D._Land (QA_Flag=3) 550 nm provided 1240 nm extrapolated from 412, 470, 660nm	Eff._O._D._Avg_Ocean (QA_Ocean=1,2,3) 550 nm provided 1240 nm provided
OMI ***AAOD*** 388 nm	OMAERUV A.S.S.A.VsHeight (QA=0) SSA 388 nm provided + MODIS AOD 388 nm extrapolated from 470, 550, 660 nm	OMAERUV A.S.S.A.VsHeight (QA=0) SSA 388 nm provided + MODIS AOD 388 nm extrapolated from 412, 470, 660nm	OMAERO S.S.A.MW (QA=0) SSA 388nm provided + MODIS AOD 388nm extrapolated from seven bands 470- 2120
CALIOP A. backscat 532 nm	CALIOP integrated backscatter screening according to Redemann et al. 2012 (CALIOP zmax-zmin)		

Global distribution of MOC retrievals 2007

AOD ~550nm



SSA ~550nm



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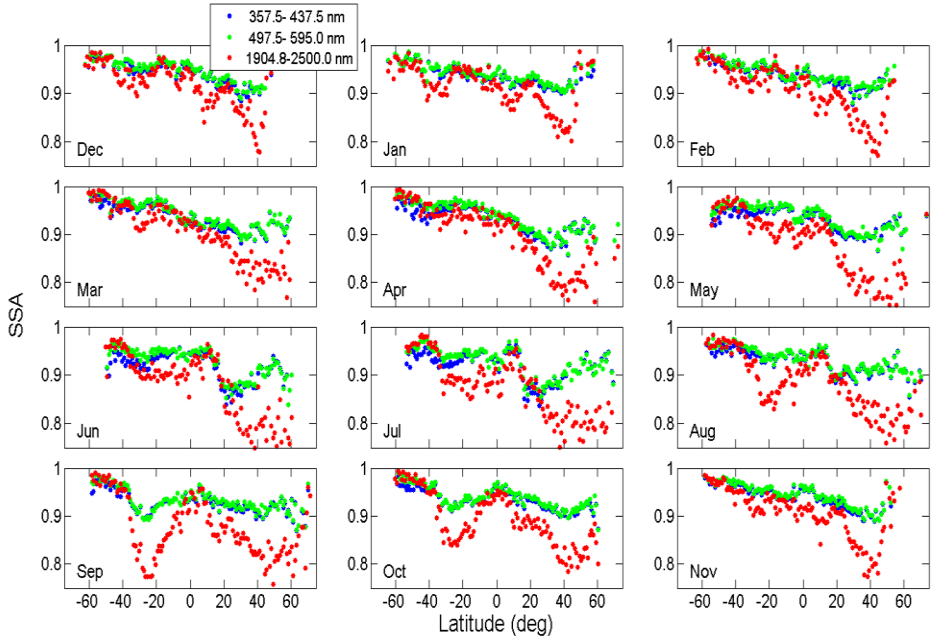
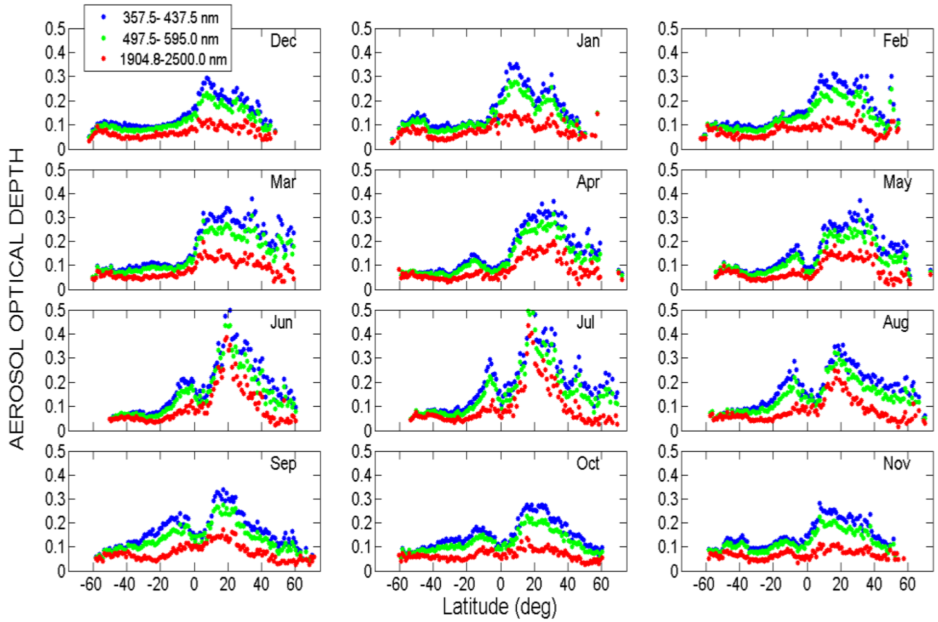
AOD and SSA distribution

SSA
400nm
550nm
2200nm



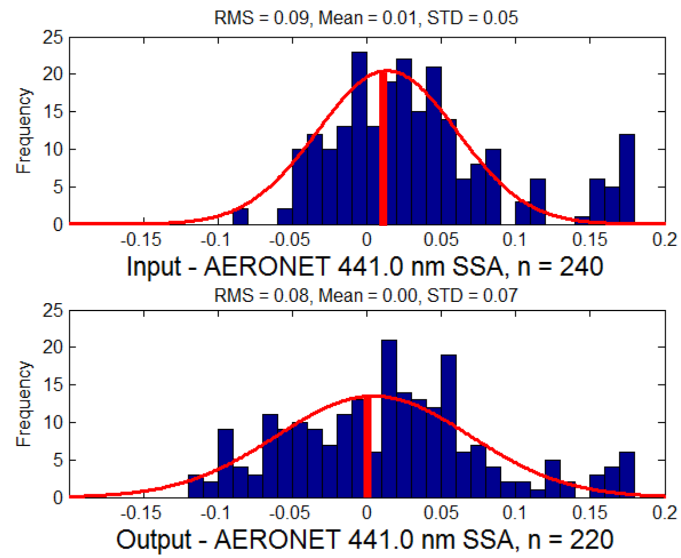
AOD
400nm
550nm
2200nm



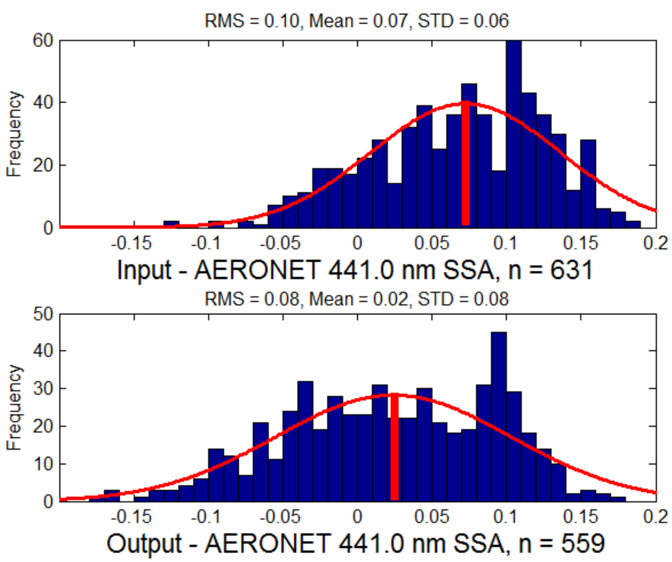
SSA comparisons to AERONET – Ocean & Land

Positive bias in input SSA data is removed in MOC retrieval

MODIS ocean + OMAERO



MODIS land DT + OMAERUV



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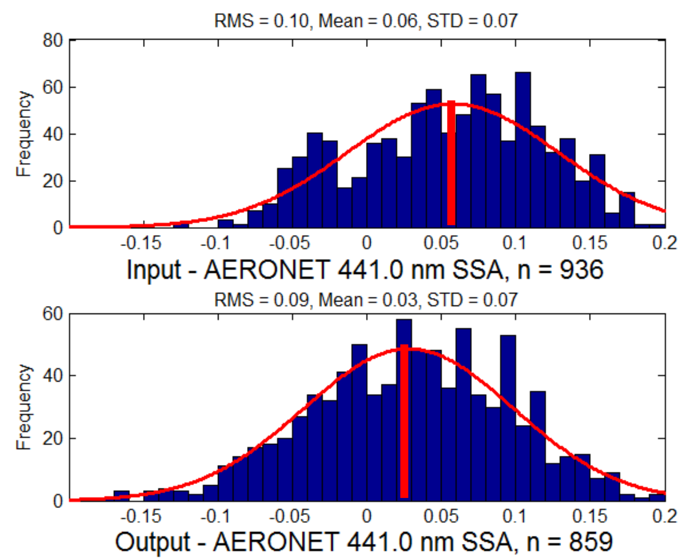

Comparisons of $\Delta F_{aerosol}$ to previous results

Seasonal clear-sky $\Delta F_{aerosol}$ results at TOA from models and observations [W/m^2] after CCSP-2009, adapted from Yu et al. 2006.

Products	DJF		MAM		JJA		SON		ANN	
	TOA	SFC	TOA	SFC	TOA	SFC	TOA	SFC	TOA	SFC
Ocean										
Observations – Median	-5.5	-8.1	-5.7	-9.3	-5.5	-9.5	-5.4	-8.8	-5.5	-8.8
Our study – preliminary	**-4.3**	**-6.6**	**-4.2**	**-7.0**	**-3.7**	**-6.4**	**-4.3**	**-6.6**	**-4.2**	**-6.7**
Observations – error	0.23	0.56	0.2	0.85	0.29	0.94	0.26	0.78	0.21	0.67
Models (5) – Median	-3.3	-4.1	-3.5	-4.6	-3.5	-4.9	-3.8	-5.4	-3.5	-4.8
Models – error	0.61	0.66	0.66	0.92	0.67	0.91	0.68	0.81	0.64	0.8
Models/Observations	**0.6**	**0.51**	**0.61**	**0.5**	**0.64**	**0.52**	**0.7**	**0.61**	**0.64**	**0.55**
Land										
Observations – Median	-3.7	-8.1	-5.1	-13	-5.8	-14.8	-4.7	-10.8	-4.9	-11.7
Our study – preliminary	**-1.4**	**-6.9**	**-2.0**	**-10.9**	**-0.9**	**-13.0**	**-2.0**	**-8.4**	**-2.1**	**-10.4**
Observations - error	0.17	0.49	0.26	0.74	0.31	0.85	0.27	0.75	0.26	0.7
Models (5) - Median	-1.6	-5.4	-3.2	-7.9	-3.6	-9.3	-2.5	-6.7	-2.8	-7.2
Models - error	0.42	0.51	0.65	1.22	0.8	1.37	0.62	0.79	0.59	0.93
Models/Observations	**0.43**	**0.67**	**0.63**	**0.61**	**0.62**	**0.63**	**0.53**	**0.62**	**0.58**	**0.62**

Comparisons of $\Delta F_{aerosol}$ to previous results

Seasonal clear-sky $\Delta F_{aerosol}$ results at the surface from models and observations [W/m^2] after CCSP-2009, adapted from Yu et al. 2006.

Products	DJF		MAM		JJA		SON		ANN	
	TOA	SFC	TOA	SFC	TOA	SFC	TOA	SFC	TOA	SFC
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Observations – Median	-5.5	-8.1	-5.7	-9.3	-5.5	-9.5	-5.4	-8.8	-5.5	-8.8
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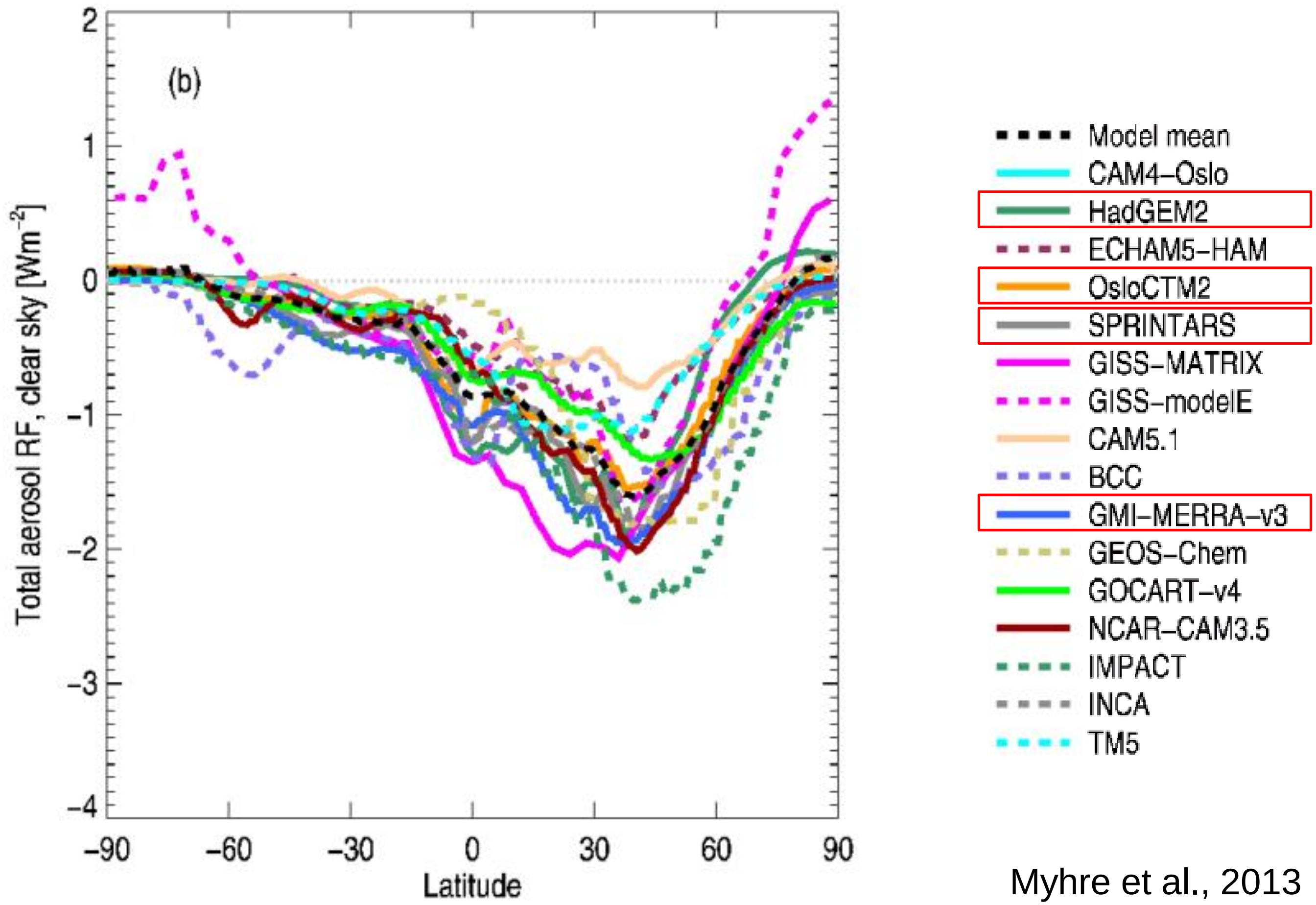
Comparisons of AOD, SSA, $\Delta F_{aerosol}$(TOA) and $\Delta F_{aerosol}$(SFC) to four* AeroCom Phase II models

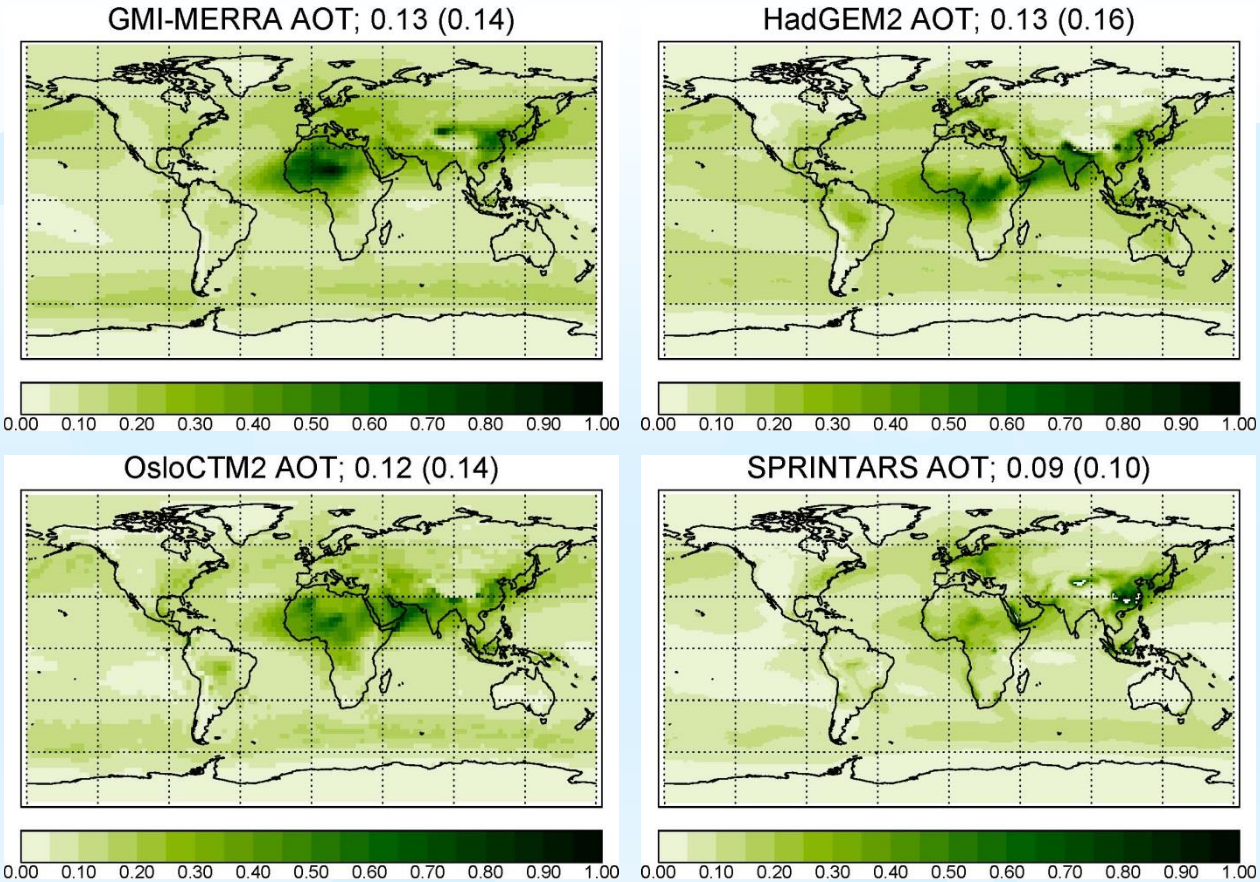
Anthropogenic clear-sky aerosol forcing, AeroCom Phase II

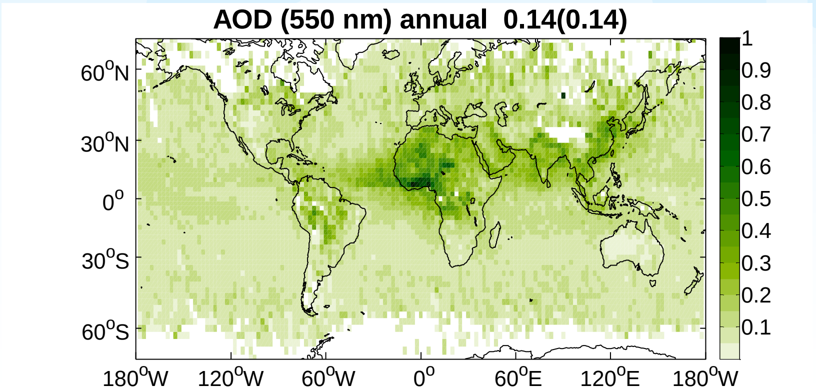


Myhre et al., 2013

* Subset of AeroCom Phase 2 models with SW fluxes and no-aerosol runs stored

Maps of AOD – compared to 4 AeroCom Ph II models





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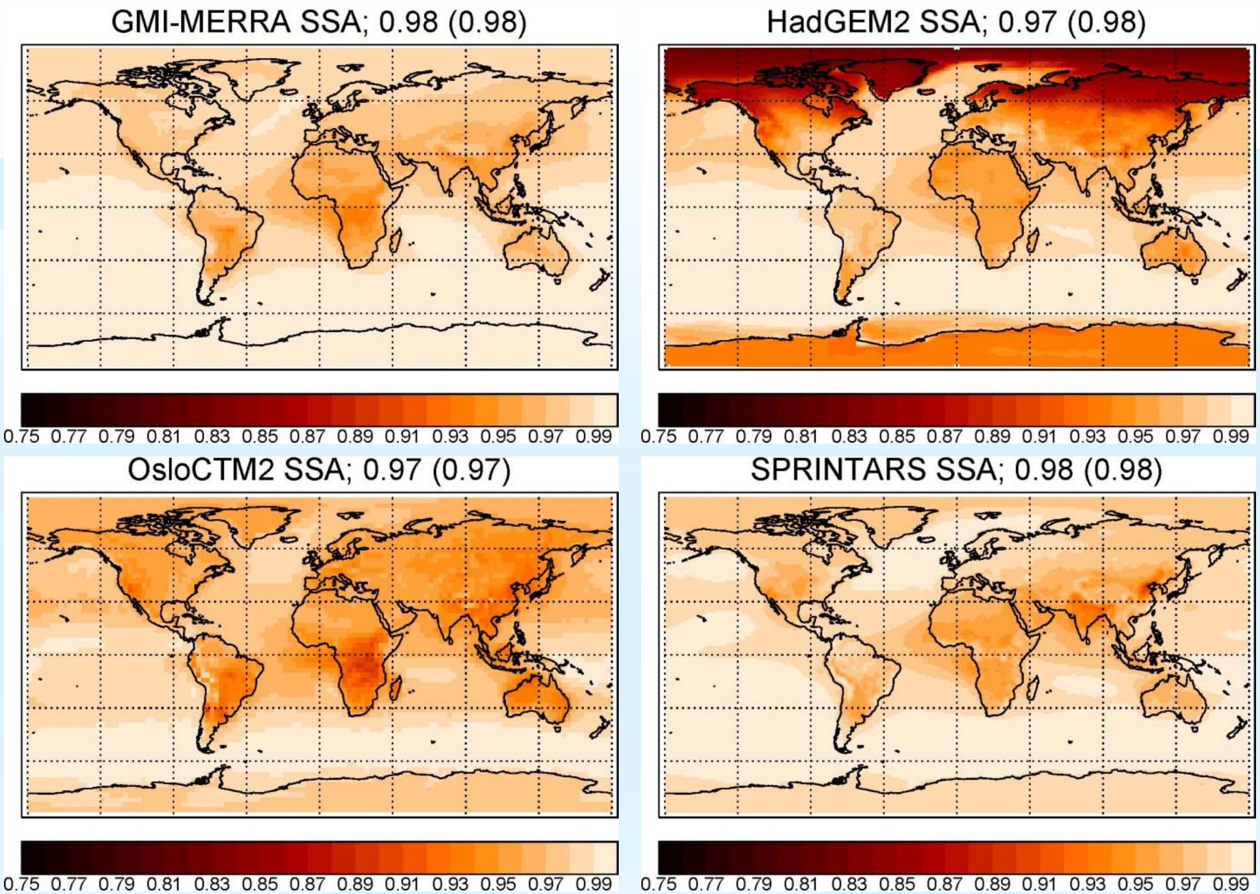
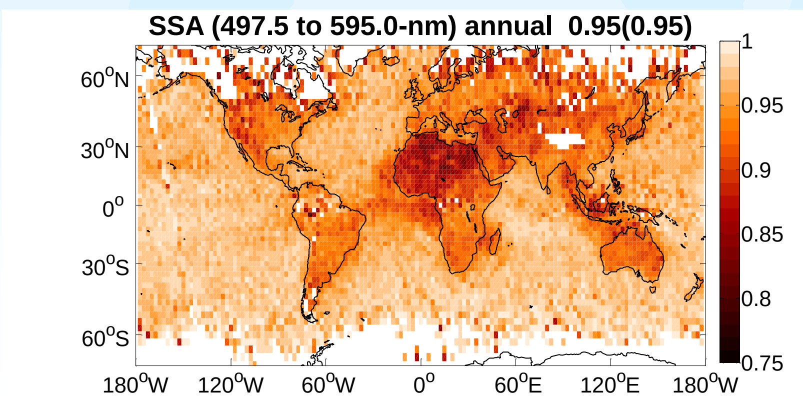
Maps of SSA – compared to 4 AeroCom Ph II models





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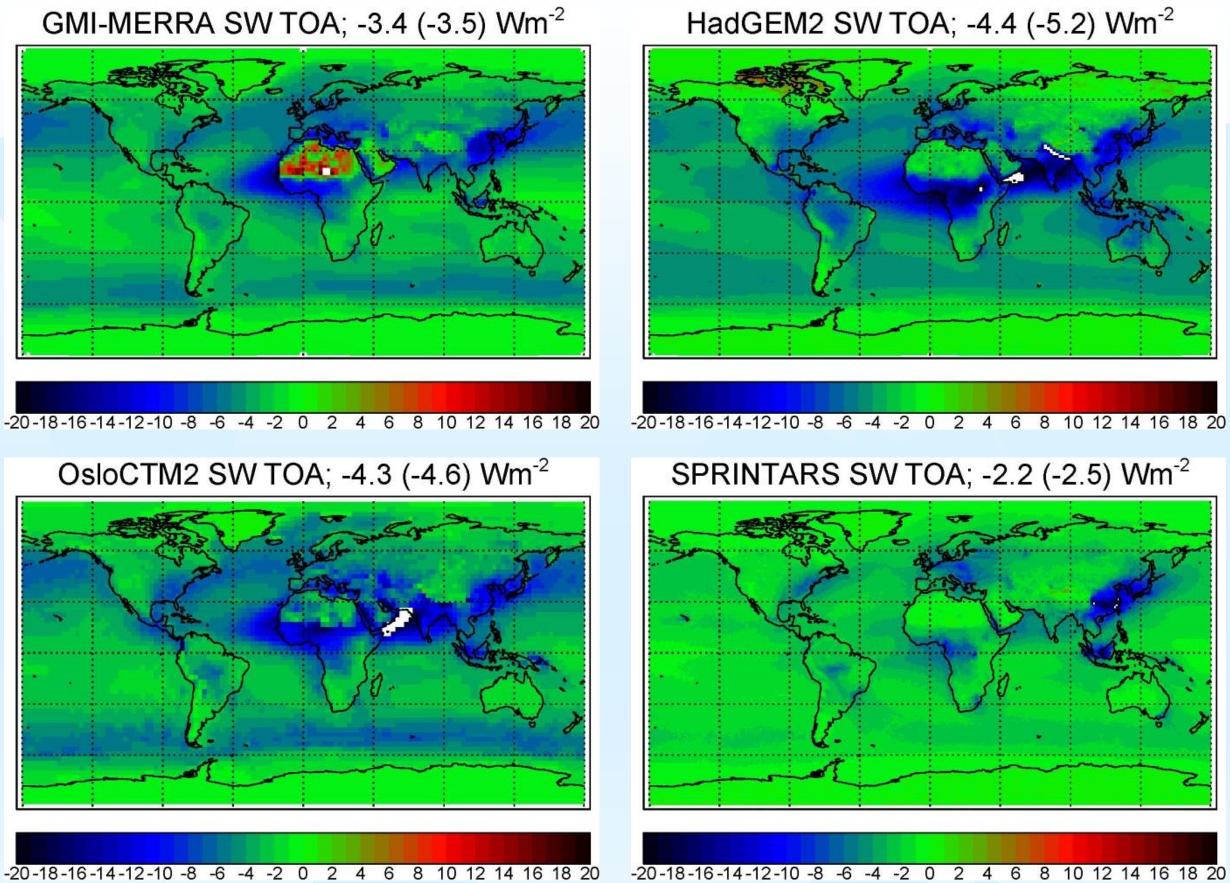
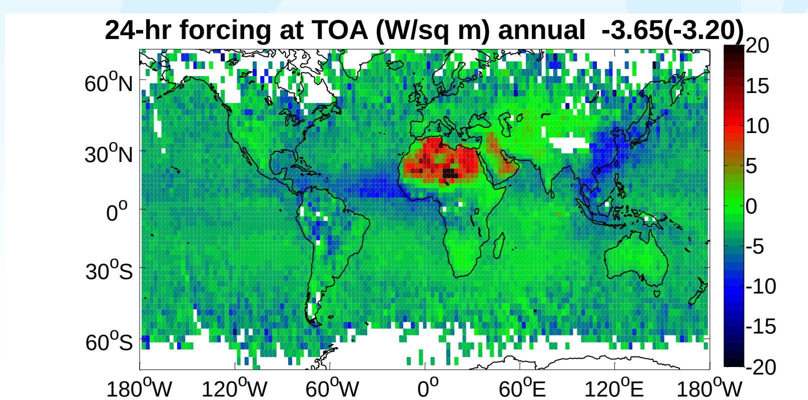
Maps of TOA clear sky $\Delta F_{aerosol}$





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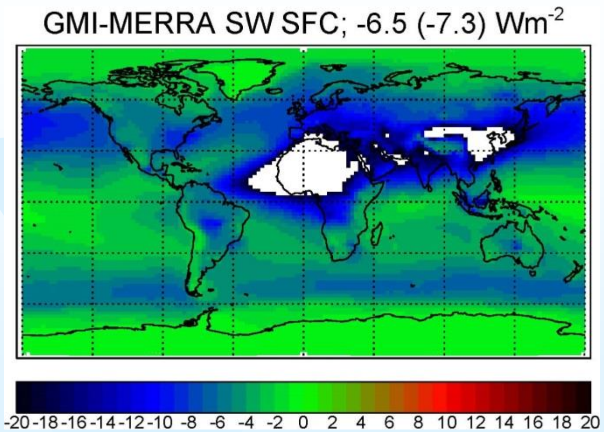
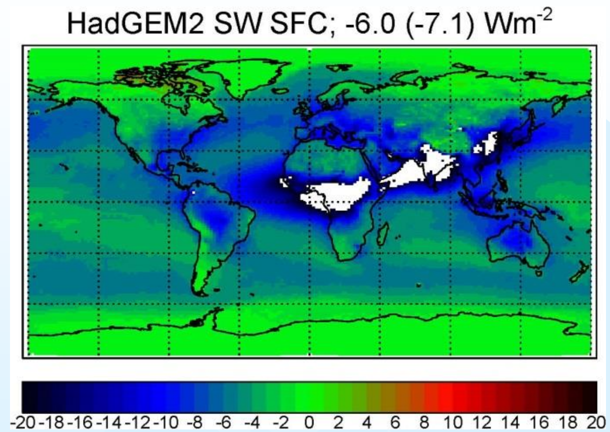
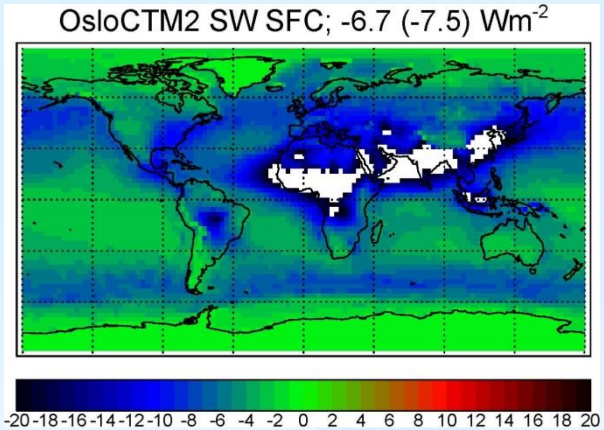
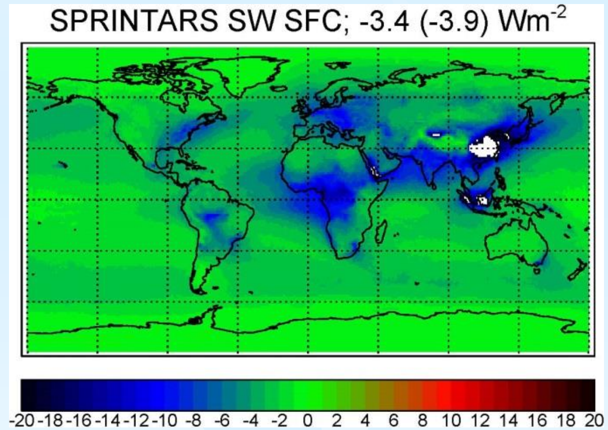
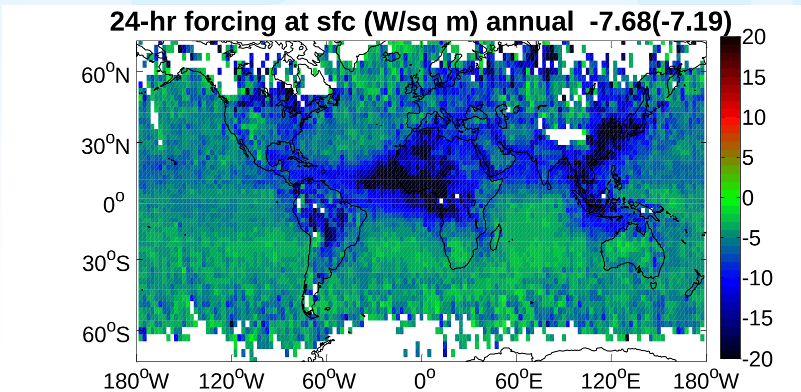
Maps of SFC clear sky $\Delta F_{aerosol}$











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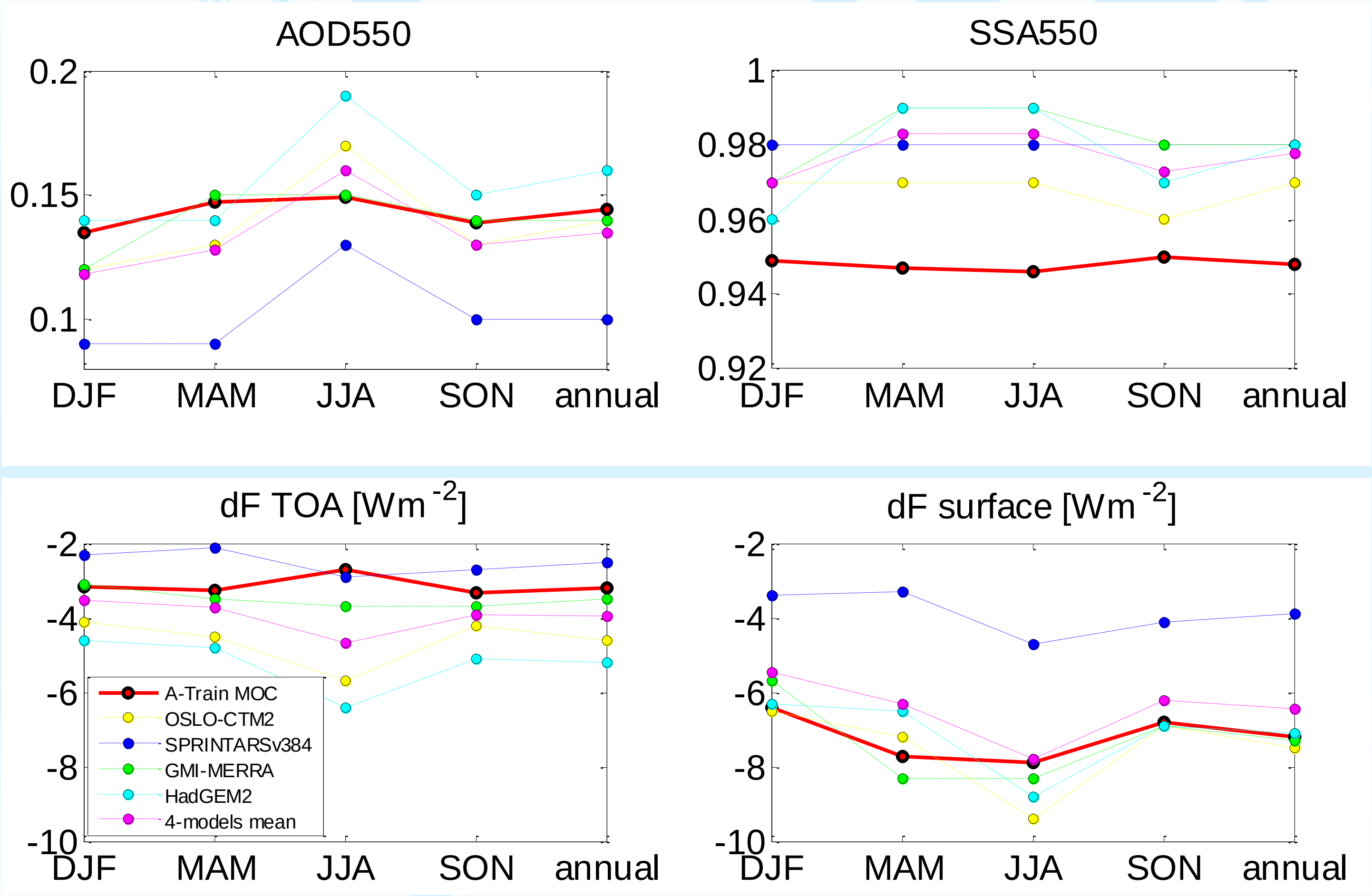
Comparisons of AOD, SSA, $\Delta F_{aerosol}$(TOA) and $\Delta F_{aerosol}$(SFC) to 4 AeroCom Phase II models



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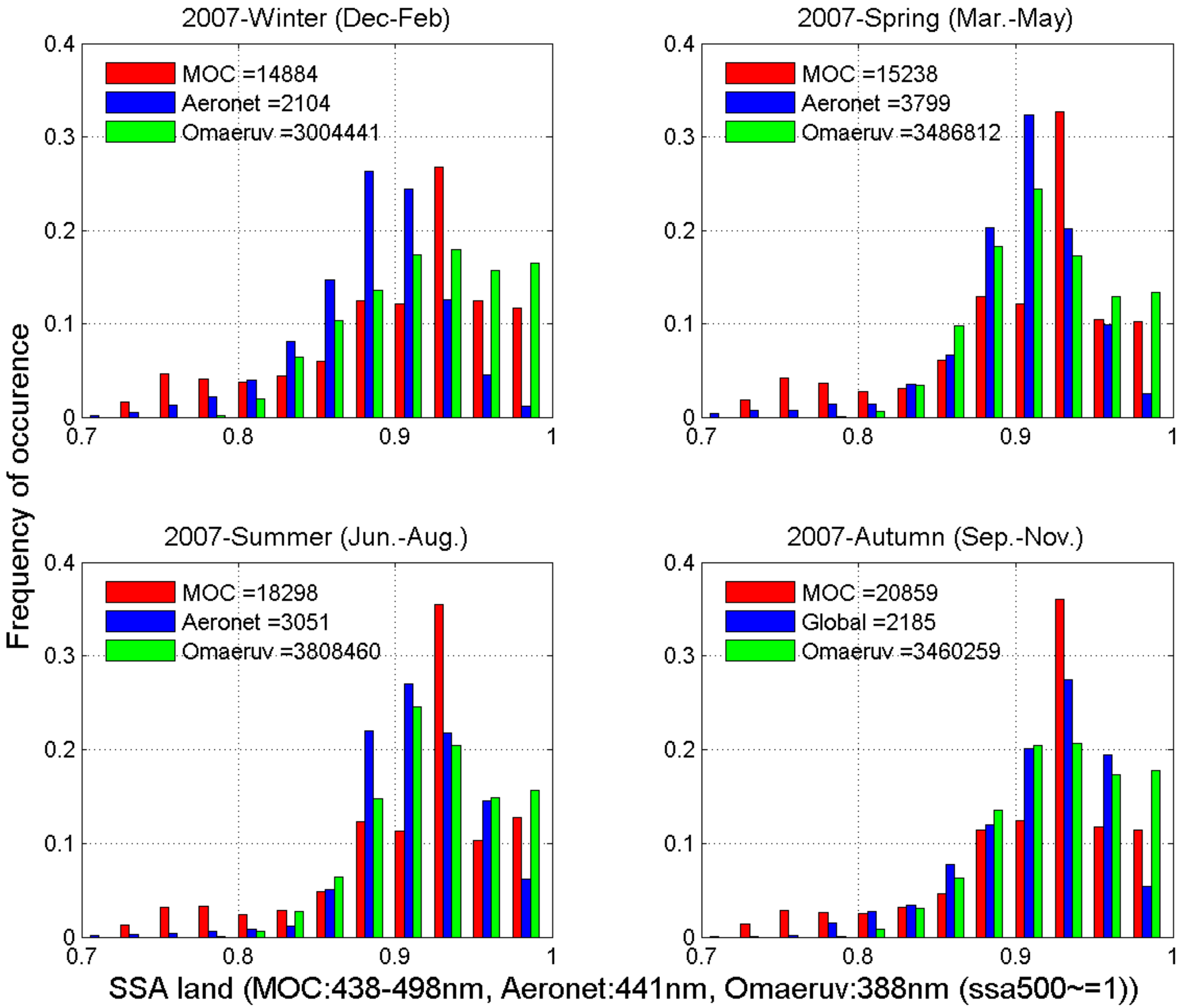
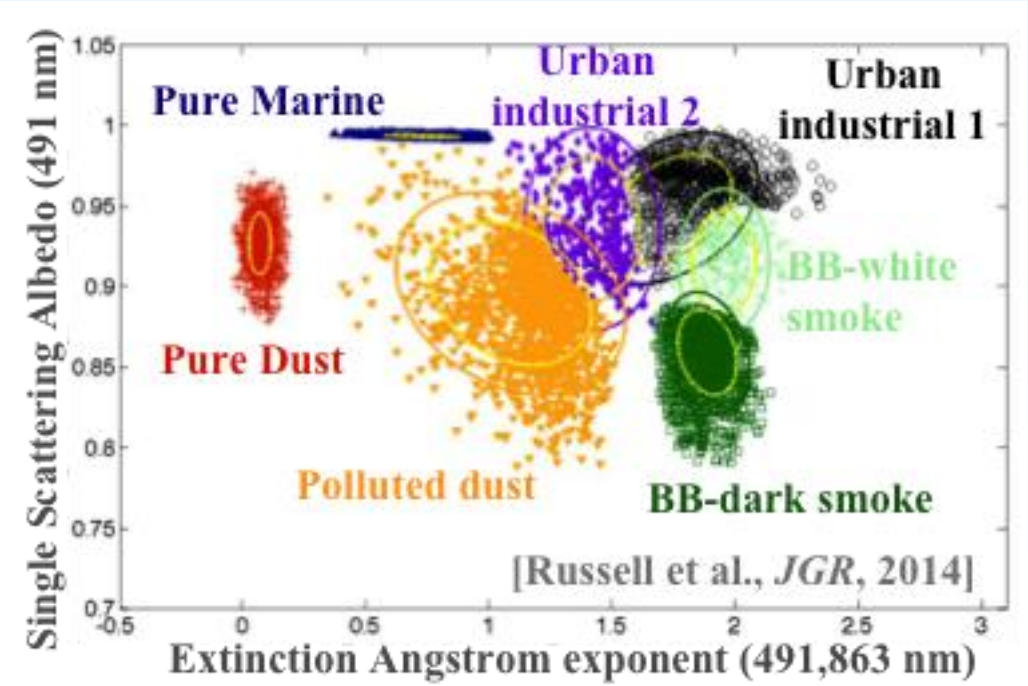
Comparisons of SSA – MOC vs AERONET vs OMAERUV: OMAERUV has values ~1, AERONET peaks near 0.925



Aerosol type classification using MOC results

1. Define **reference aerosol types (or clusters)** using AERONET L2 V2 sky retrievals with numerous filters to "purify" different types
2. Define additional type impure marine (i.e. small AOD & coarse particle [Sayer et al., 2012]); eliminate impure marine from non-marine types
3. Define **distance DM** [Mahalanobis, 1936] from each MOC observation to each of the 7 clusters (as function of center, width and tilt of each cluster) in three MOC parameter-space: **EAE491-863, SSA491, dSSA863,491** (with standard deviations)
4. **Assign each MOC observation to the type (or cluster) from which it has least DM**



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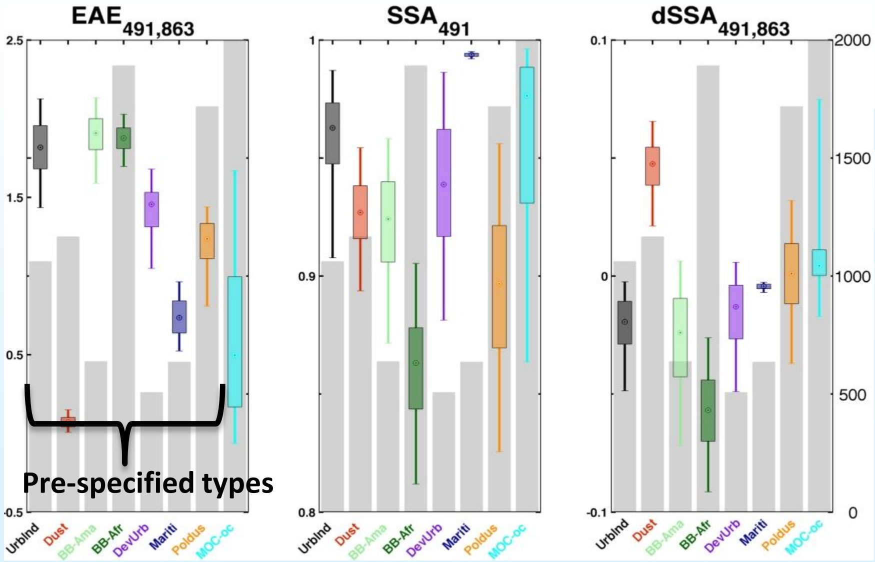
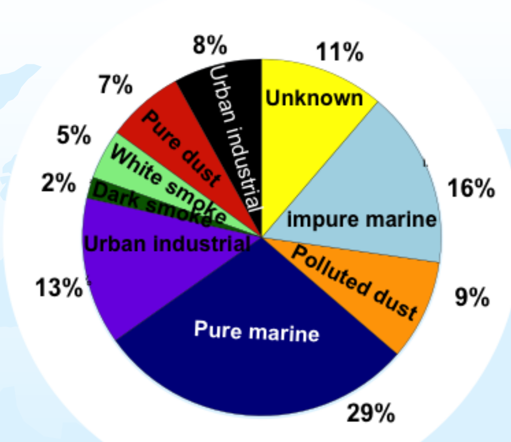
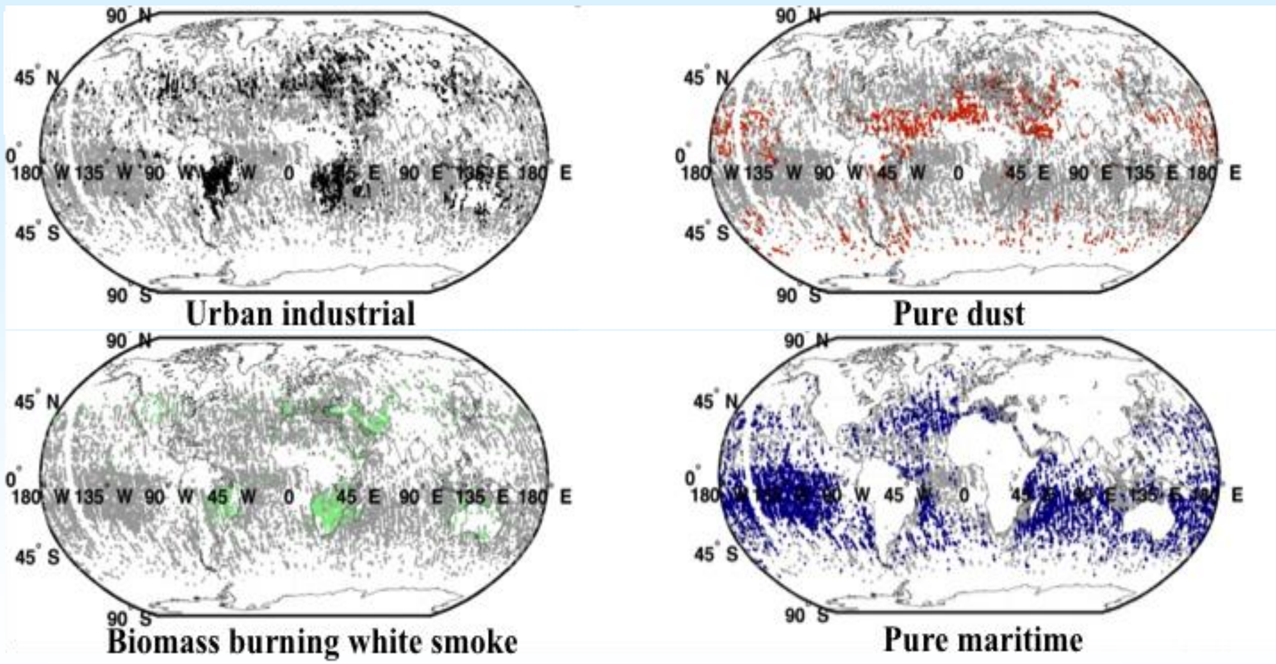




Assigned aerosol types to MOC observations



In grey, MOC observations with known aerosol type

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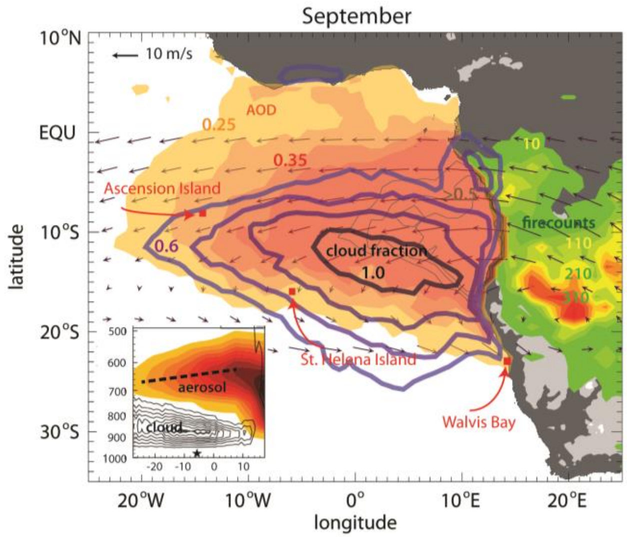
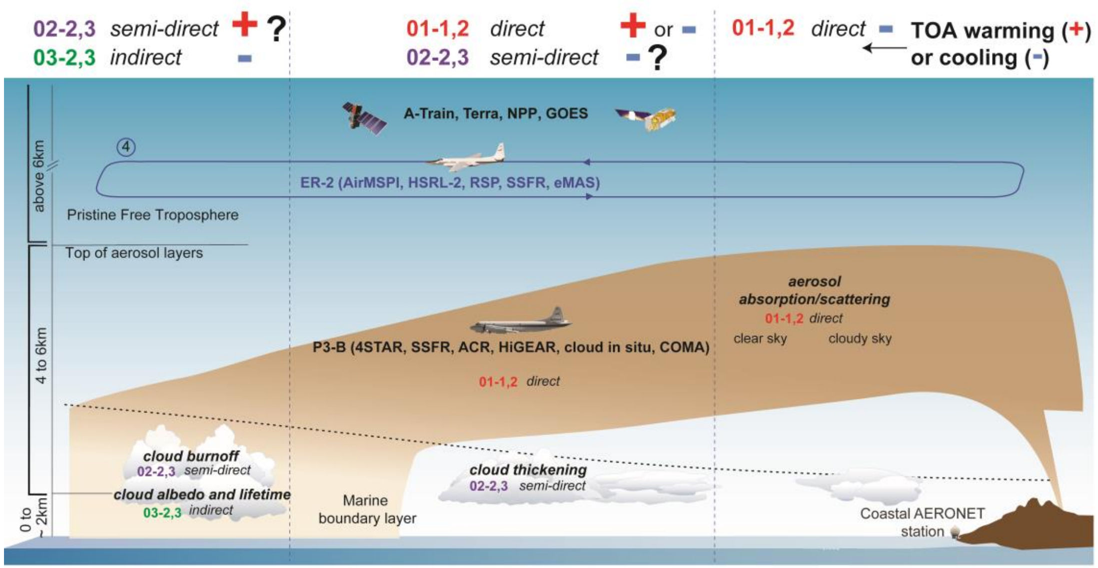
Preliminary results

ORACLES (ObseRvations of Aerosols above CLouds and their intEractionS)

Earth-Venture-2 proposal Redemann/Wood/Zuidema



- Radio-polarimetric and in situ observations of radiation, aerosol & cloud microphysics above/below aerosol and clouds.
- 3 campaigns with P-3 (2016-2018), 1 with ER-2 (prob. 2016)
- Coordinated with CLARIFY and ONFIRE
- Involves 5 NASA centers, 8 universities
- Includes LES and WRF-Chem modeling and features flight strategies to facilitate easy comparisons to global models
- Establishes 2 new AERONET sites (St. Helena & Angola)
- Selection in late 2014



Instruments - NASA ER-2:
AirMSPI, HSRL-2, RSP, eMAS

Instruments - NASA P-3B:
4STAR, SSFR, HiGEAR, radar, cloud in situ

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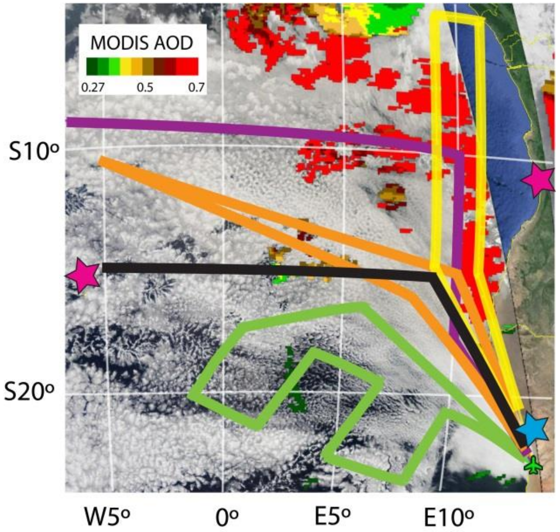

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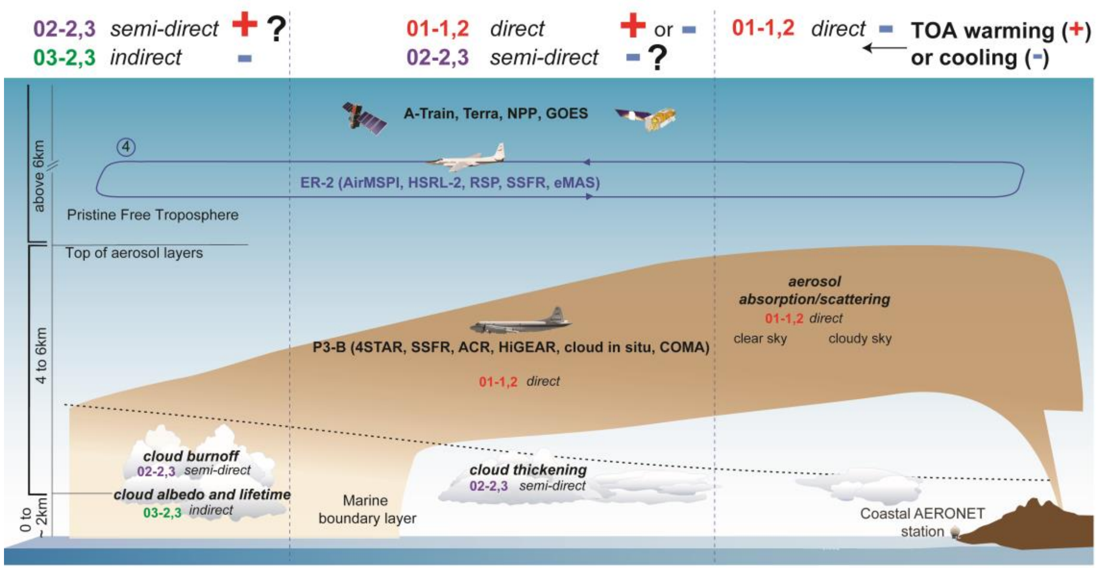


Instruments - NASA ER-2:
AirMSPI, HSRL-2, RSP, eMAS

Instruments - NASA P-3B:
4STAR, SSFR, HiGEAR, radar, cloud in situ

Conclusions

1. Our method uses stringently quality-screened, instantaneously collocated level 2 MODIS AOD (DT & DB), OMI AAOD, and CALIOP backscatter – all input data is consistent with global pdf's of original data
2. Our aerosol retrievals agree better with AERONET in terms of SSA(441nm) than input OMI+MODIS data, BUT sampling is sparse.
3. Clear-sky $\Delta F_{aerosol}$ (TOA) over land is smaller than previous model or observational estimates due to more absorbing aerosol and inclusion of brighter surfaces. $\Delta F_{aerosol}$ (SFC) over land and $\Delta F_{aerosol}$ (TOA) over land and ocean are in between previous model and observational results.
4. Comparisons of seasonal aerosol property to AeroCom Phase 2 results show generally good agreement – best agreement with forcing results at TOA is found with GMI-MerraV3.

Issues with surface forcing estimates:

1. Some remaining differences in global pdf's of SSA.
2. It is impossible to validate SSA globally at this point in time.
3. Start with AERONET L2/L1.5 validation for dominant aerosol types.

Next steps:

1. Subsample AeroCom models at exact MOC retrieval locations.
2. Incorporate AAC retrievals from CALIOP DR method for extension to all-sky results.

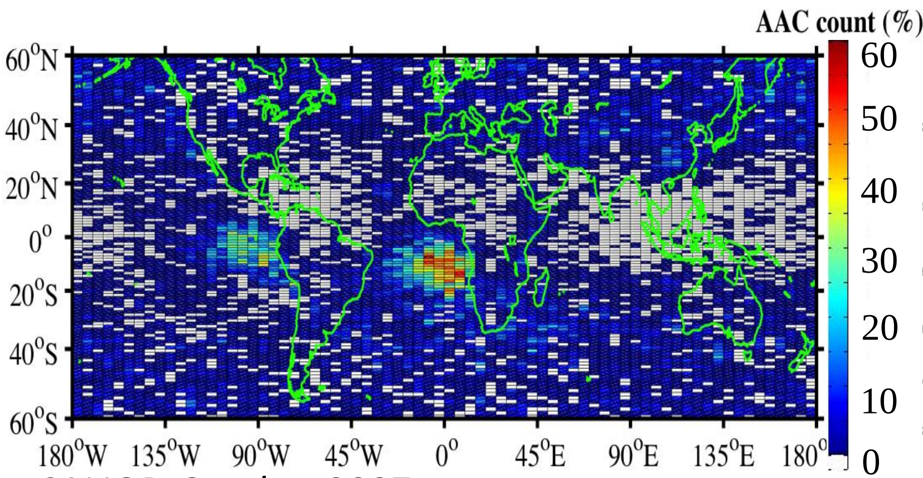
ADDITIONAL SLIDES

All satellite Aerosol Above Cloud (AAC) AOD techniques [Jethva et al., GRL, 2013]

Table 1. Salient Properties of the ACA Retrieval Techniques and Associated Sensors

	Physical Basis	Algorithmic Assumptions	Input Parameters	Retrieved Parameters	Retrieval Uncertainty
MODIS *Jethva et al.* [2013]	Change in the reflectance and color ratio in the visible (VIS)/SWIR when absorbing aerosols overlay cloud	Aerosol/cloud size distribution, aerosol spectral extinction and absorption, aerosol/cloud profiles, and surface albedo	TOA reflectance at 470 and 860 nm at $1 \times 1\ km^2$ resolution	ACAOD and aerosol-corrected COD at 860 nm; converted to 500 nm based on the model assumed spectral extinction	Depends on ACAOD and COD. Typically between −12 and 46% at COD of 10 and AOD of 0.5 for an uncertain single-scattering albedo (SSA) of ±0.03
CALIOP Operational Method *Winker et al.* [2009]; *Young and Vaughan* [2009]	Vertically resolved aerosol backscatter and inferred extinction profile	Extinction to backscatter ratio and feature/layer detection scheme	Attenuated backscatter profile at 532 and 1 064 nm at 0.3 km scale	Vertical extinction profile, AOD at 532 and 1064 nm and at 0.3 and 5 km (level 2) scales	From *Winker et al.* [2009]: $0.05 + 0.40 \times$ AOD,
CALIOP Depolarization Method *Hu et al.* [2007]	Change in the transmittance (DR) VIS/IR when absorbing aerosols overlay cloud	Cloud extinction-to-backscatter ratio at 532 nm and Rayleigh correction above cloud	Layer integrated attenuated backscatter and depolarization ratio at 532 nm	ACAOD at 532 nm	Depends on the integrated attenuated backscatter at 532 and its depolarization ratio.
CALIOP Color Ratio Method *Chand et al.* [2008]	Change in the VIS/IR transmittance when absorbing aerosols overlay cloud	Ångström Exponent (532–1064 nm) and color ratio (VIS/IR) of underlying cloud layer	Layer integrated attenuated backscatter and color ratio at 532 nm	ACAOD at 532 nm and Ångström exponent in the 532–1064 nm range	Depends on the integrated attenuated backscatter at 532 nm and 1064 nm and Ångström exponent
POLDER *Waquet et al.* [2009, 2013]	Creation of polarization at forward scattering angles. Reduction of the polarized signal in the cloudbow.	Six fine-mode spherical aerosol models with refractive index of 1.47–0.01i, one nonspherical-mineral dust model, and only one aerosol/cloud profile.	TOA polarized radiance at 670 and 865 nm at $6 \times 6\ km^2$ resolution (POLDER) and cloud droplets effective radius (MODIS)	AOD at 865 nm and Angström exponent. The AOD is converted at 500 nm using the retrieved Angström exponent.	Depends on AOD and microphysics. For an AOD of 0.2 (at 865 nm) : AOD error of 0.05 for a real refractive index uncertainty of +/−0.06 and error of 0.02 for an imaginary refractive index uncertainty of +/−0.01
OMI *Torres et al.* [2012]	Change in the near-UV reflectance and UV aerosol index (UVAI) when absorbing aerosols overlay cloud	Aerosol/cloud size distribution, aerosol spectral extinction and absorption, aerosol/cloud profiles, and surface albedo	TOA reflectance at 388 nm and measured UVAI at $13 \times 24\ km^2$ resolution	ACAOD and aerosol-corrected COD at 388 nm; converted to 500 nm based on model assumed spectral extinction	Depends on ACAOD and COD. Typically between −23 and 43% at COD of 10 and AOD of 0.5 for an uncertain SSA of ±0.03

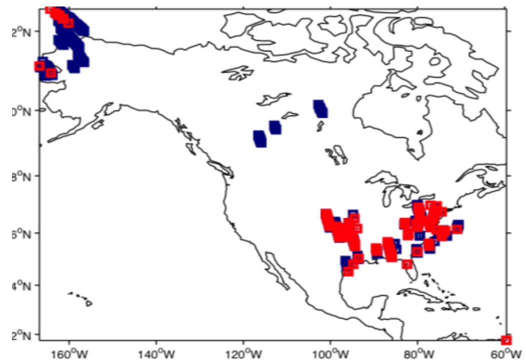
CALIOP standard AAC vs HSRL

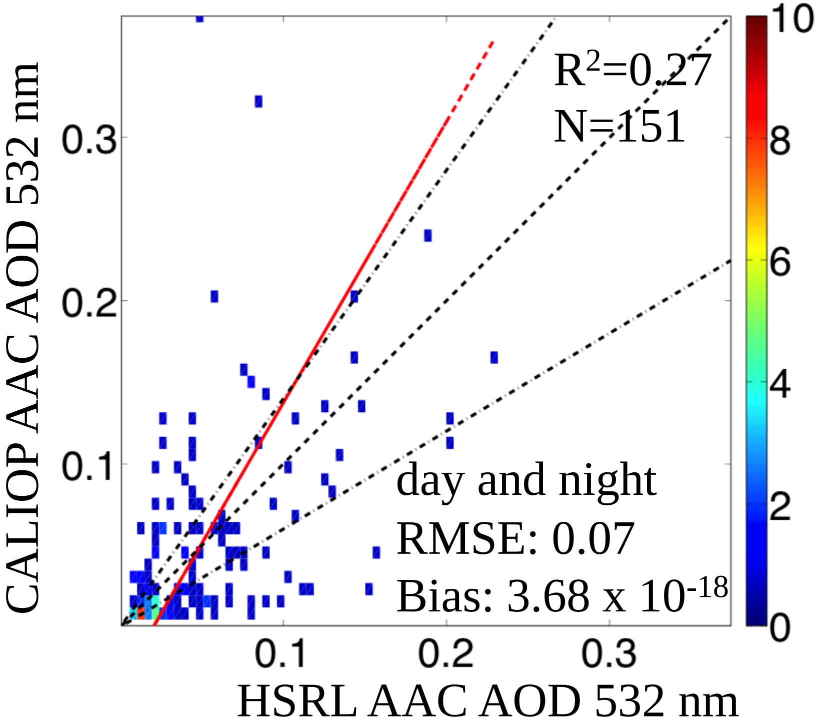


CALIOP, October 2007

HSRL vs CALIOP AAC

86 flights 2006-09





- CALIOP detects AAC in ~23% of the cases where the HSRL detects AAC
- Lack of correlation in AAC AOD; ~68% of points outside the ±40% envelope
- CALIOP underestimation of AAC AOD mostly due to tenuous aerosol layers under the CALIOP detection threshold

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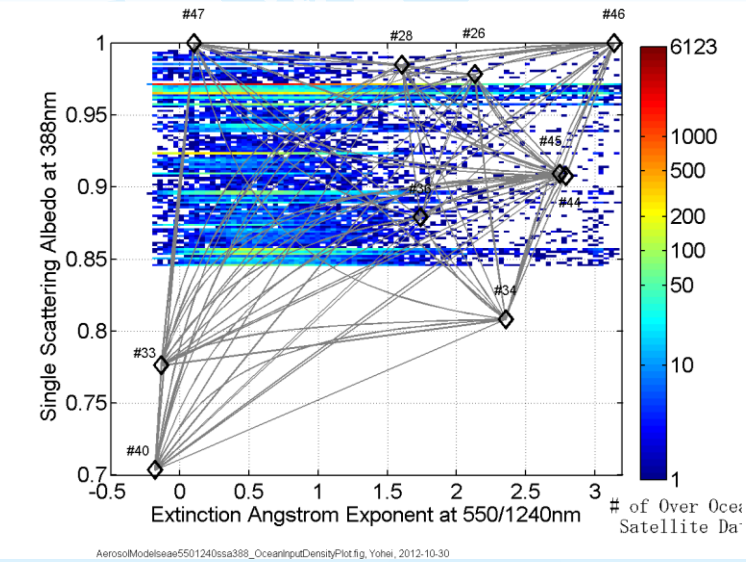
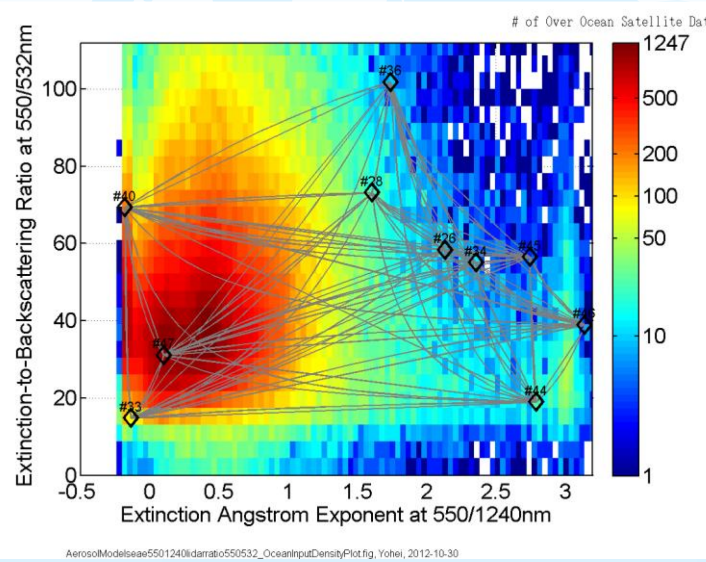
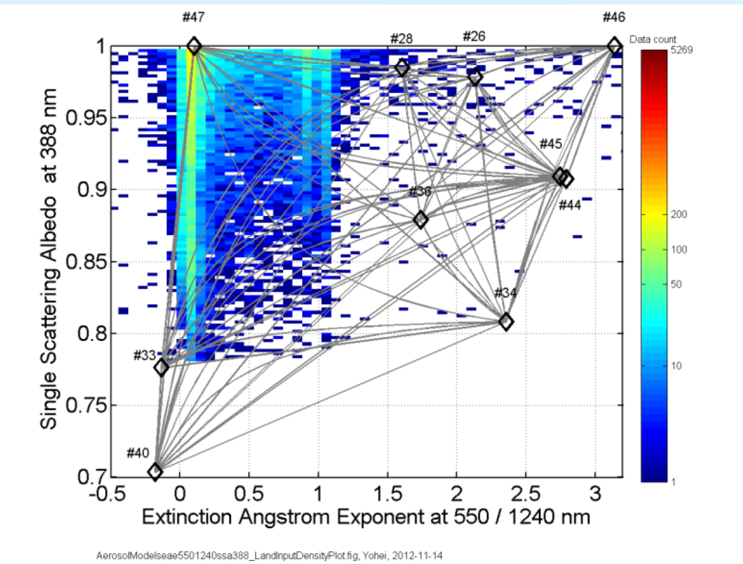
- Validity of surface forcing results
- Global pdf's of SSA
- Aerosol above cloud (AAC) AOD
- Aerosol type classification
- Conclusions

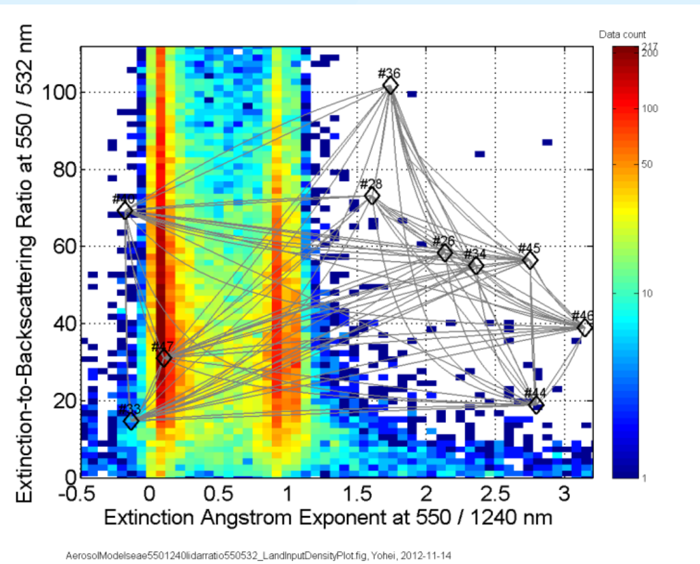
[Kacenelenbogen et al., 2014]

Aerosol models: Based on field observations, optimized to span observed range of SSA vs. EAE and lidar ratio vs. EAE



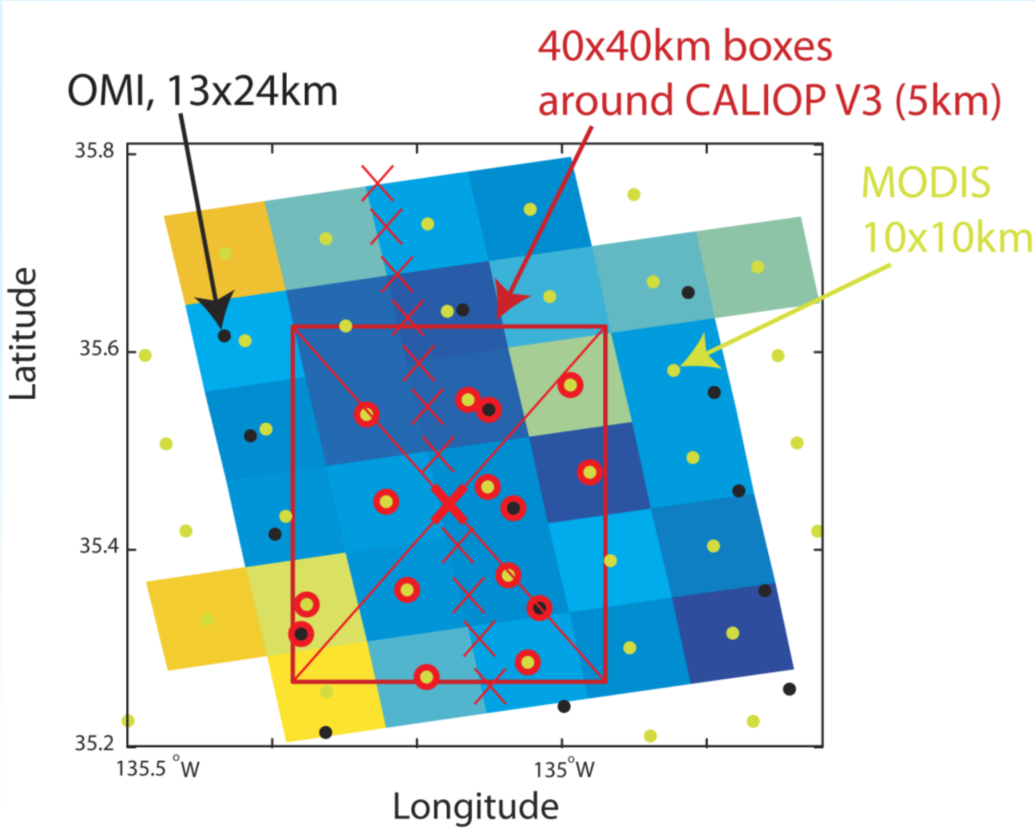






Input &Spatial Sampling

Constraints/Input:
- MODIS AOD (7/2 λ) + δAOD
- OMI AAOD (388 nm) + δAAOD
- CALIPSO ext (532, 1064 nm) + δext
- CALIPSO back (532 , 1064 nm) + δback



Metric: Simple weighted cost function

$$X = \left(\sum_i w_i \left(\frac{x_i - \hat{x}_i}{\delta \hat{x}_i} \right)^2 \right)^{1/2}$$

Minimize X and select top 3% solutions with

$$| x_i - \hat{x}_i | <= \delta \hat{x}_i$$

x_i	: retrieved parameters
$\hat{x}_i$	: observables
$\delta \hat{x}_i$	: uncertainties in obs.
w_i	: weighting factors

x_i = AOD 550nm (±0.03±5%)
AOD 1240 nm (±0.03±5%) - MODIS
AAOD 388 nm ±(0.05+30%) - OMI
β_{532} ±(0.1Mm^{-1}sr^{-1}+30%), - CALIOP

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  - Metric
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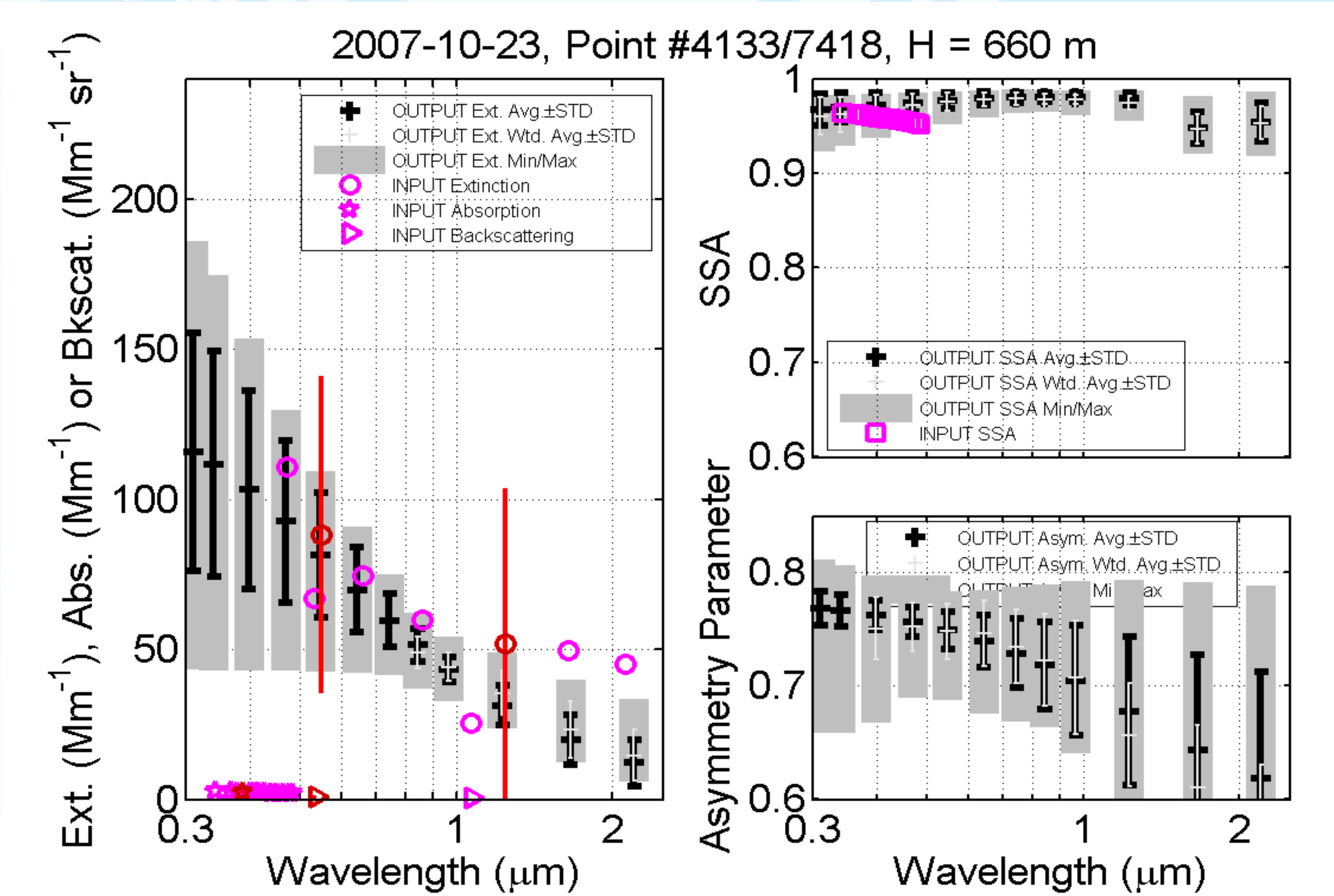
Sample retrieval



Metric: Simple weighted cost function

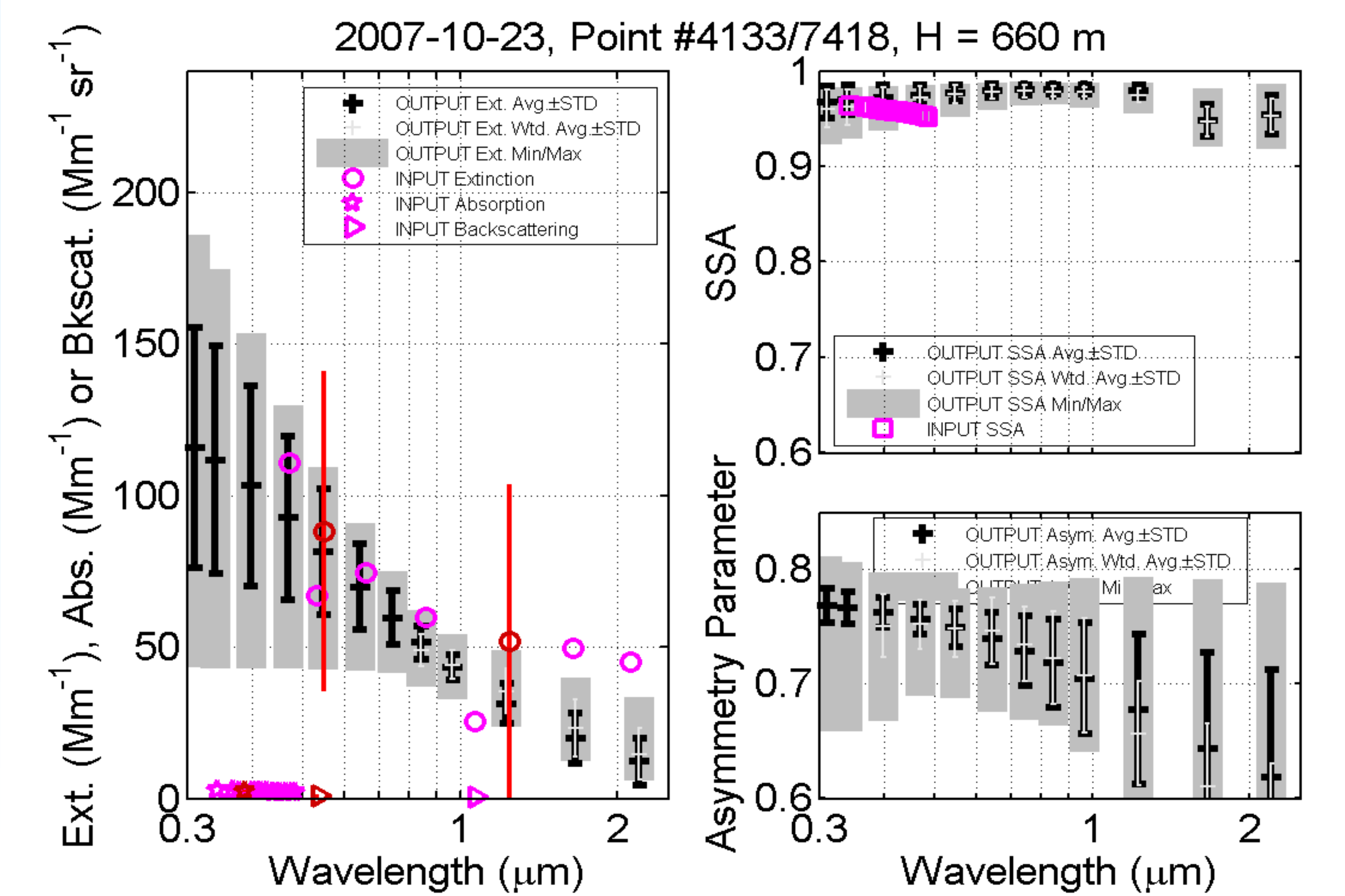
$$\mathrm{X} = \left(\sum_i w_i \left(\frac{x_i - \hat{x}_i}{\delta \hat{x}_i} \right)^2 \right)^{1/2}$$

x_i : retrieved

$\hat{x}_i$: observables

$\delta \hat{x}_i$: unc. in obs.

w_i : weighting factors



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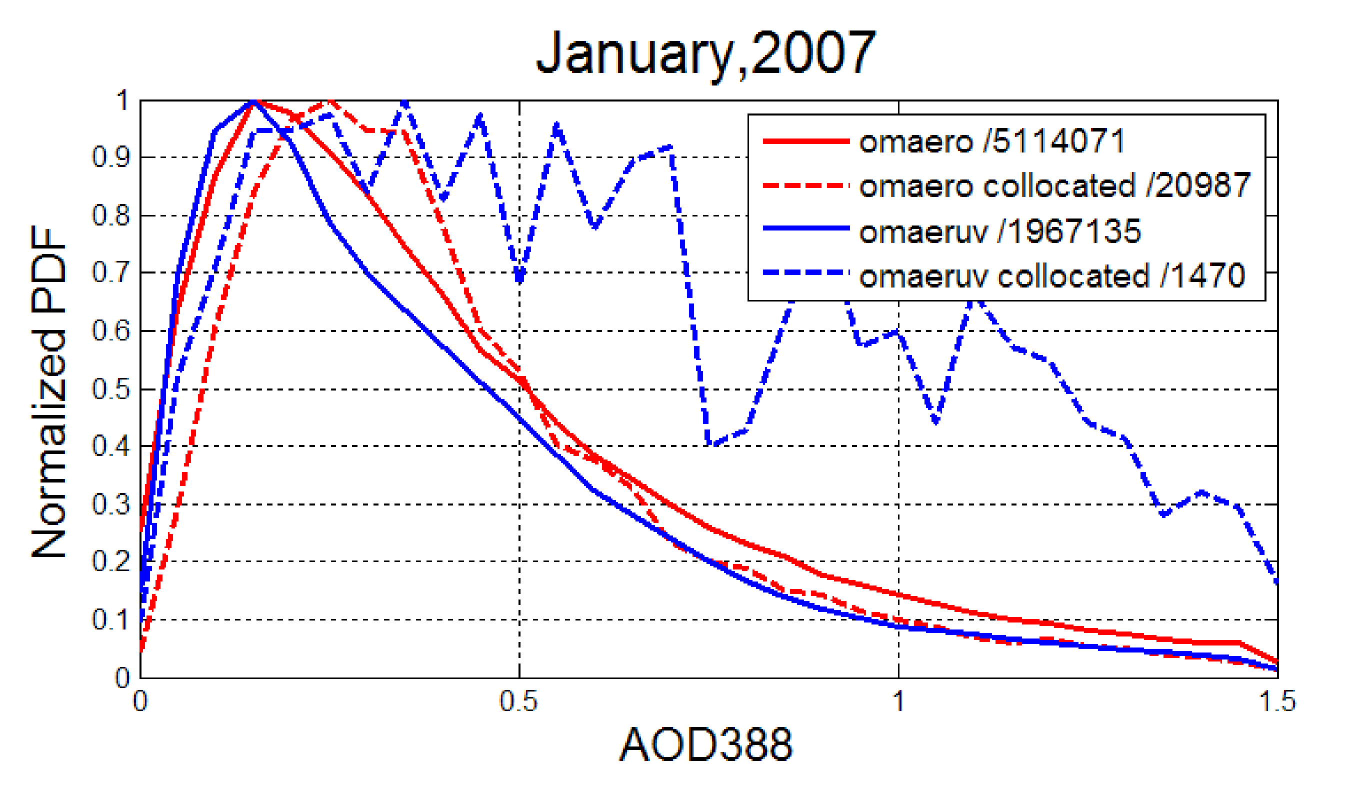
Representativeness of input - 2



OMAERO data collocated with MODIS and CALIOP is a reasonable representation of global OMAERO over ocean

OMAERUV data collocated with MODIS and CALIOP is a poor representation of global OMAERUV over ocean