Direct aerosol radiative forcing based on combined A-Train observations and comparisons to IPCC-2007 results

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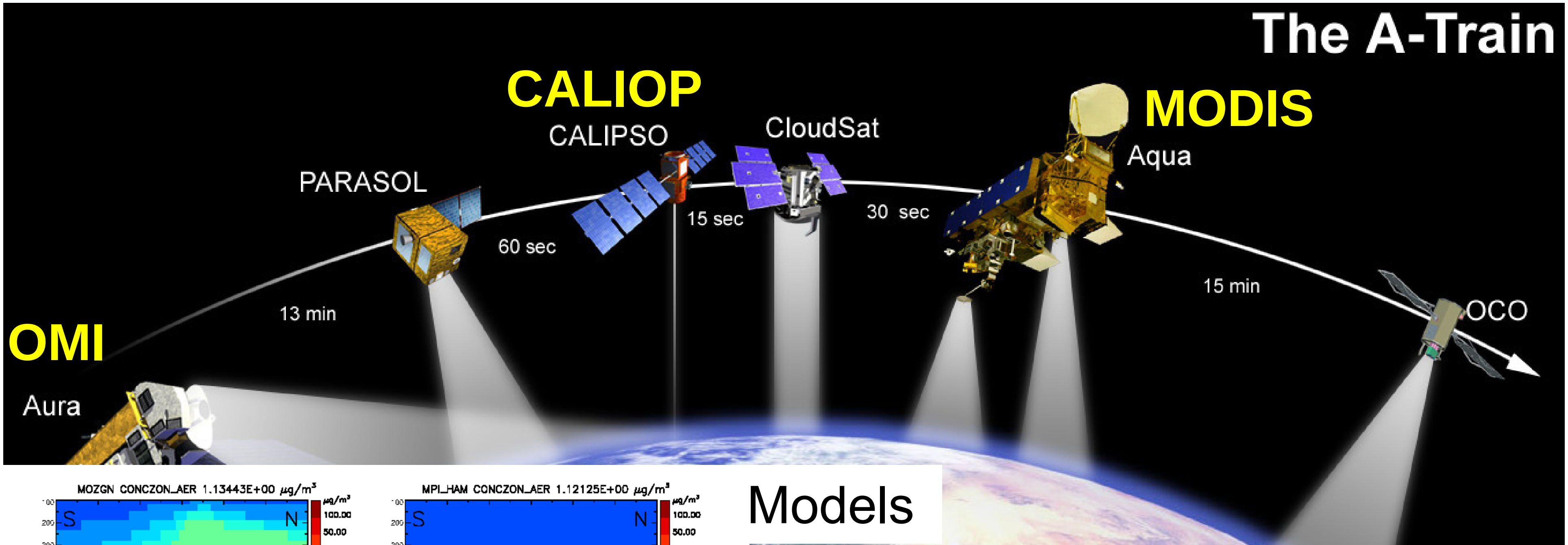
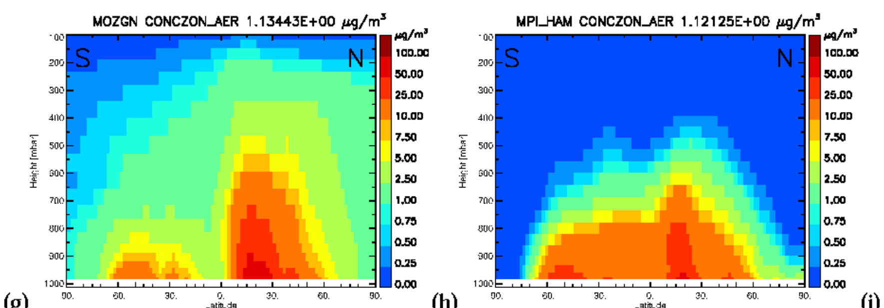
Outline

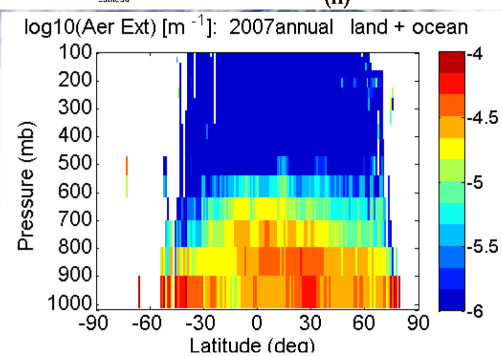
- Goal: To devise a new, methodology to derive direct aerosol radiative effects - $\Delta F_{aerosol}(z)$ including sensible uncertainty estimates, based on MODIS, OMI and CALIOP
- Motivation
- Philosophy and choices in multi-satellite-sensor (MOC) retrieval
- Methodology for combining CALIOP, OMI and MODIS data
- Checking consistency of input data
- 12-month data set – Jan. – Dec. 2007
  - Impact of input data sets
  - Comparisons to AERONET
- Conclusions

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





Models



CALIOP

IPCC, Myhre[2009], CCSP-2009, Kahn [2011]:

1) Observation-based methods for DARF too large
2) Models show great divergence in regional and vertical distribution of DARF.
3) “remaining uncertainty (in DARF) is probably related to the vertical profiles of the aerosols and their location in relation to clouds”.

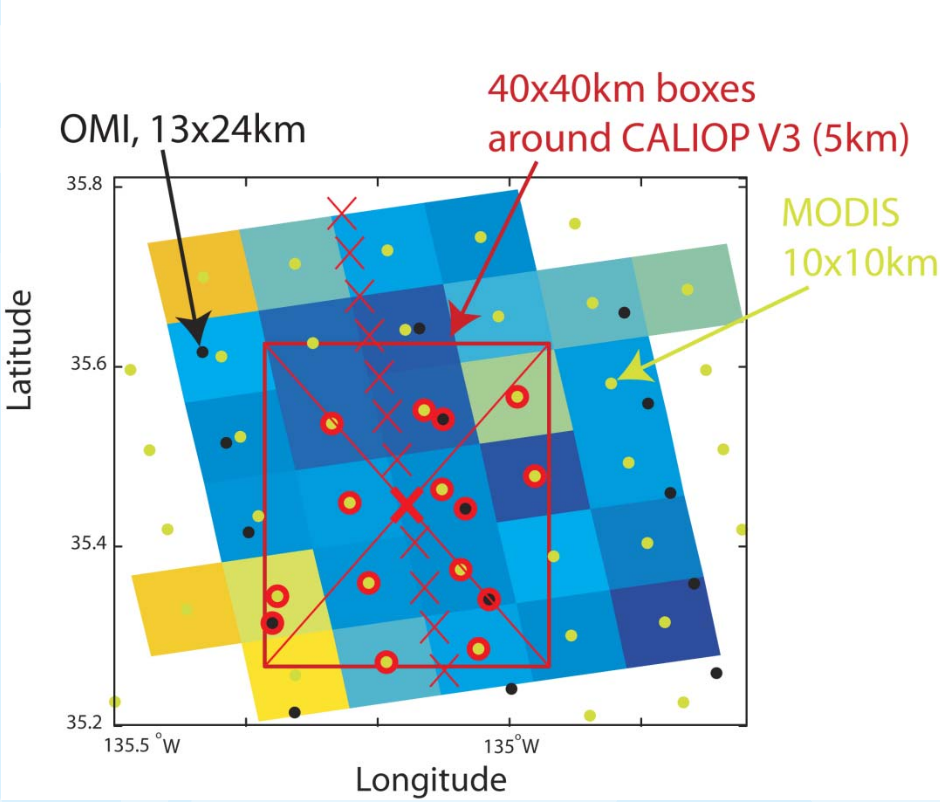
Philosophy and choices behind A-Train multi-sensor data set:

1) Use instantaneously collocated A-Train observations (MODIS, OMI, CALIOP)

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

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



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DATA set	Original parameter used
CALIPSO V3-01 (LARC DAAC)	YYYY-MM-DD, hhmm, Longitude, Latitude, Lidar_Data_Altitudes, Extinction_Coefficient_532&1064, Total_Backscatter_Coefficient_532&1064
MODIS Coll5 (LADSWEB)	Effective_Optical_Depth_Average_Ocean (AOD at 7 bands 0.47 - 2.13 µm) Corrected_Optical_Depth_Land (Corrected AOD at 0.47, 0.55, 0.66 µm)
OMAERO 2011V3 (Goddard DAAC)	AerosolOpticalThicknessMW (spectral AOD (best fit model) derived with Multi-Wavelength method using 14 bands between 342.5 and 483.5 nm) SingleScatteringAlbedoMW (Corresponding Spectral Single Scattering Albedo) AAOD (calculated as AOD*(1-SSA) from data above)
OMAERUV 2011V3	FinalAerosolOpticalDepth, FinalAerosolSingleScattAlb, AAOD, FinalAlgFlags, AerosolOpticalDepthVsHeight & AerosolSingleScattAlbVsHeight at 5 levels: 0, 1.5, 3.0, 6.0, 10.0km and 3 bands: 354, 388, 500nm.
AERONET L2.0 (AERONET website)	Station, long., lat., Date, Time, AOT (340-1640nm), Water(cm), AOTExt (total, fine, coarse at 441, 676, 870, 1020 nm), SSA, REFR & REFI, ASYM(total, fine, coarse), Inflection_Point, VolCon & EffRad & VolMedianRad & StdDev, Downward & Upward Flux(BOA&TOA), last_processing_date, %sphericity.
CCCM ReleaseB1 (Langley DAAC)	CERES SW TOA flux – up&down, CERES downw. SW surface flux – Model A, CERES net SW SFC flux – Model A, Clear area % coverage at subpixel res.

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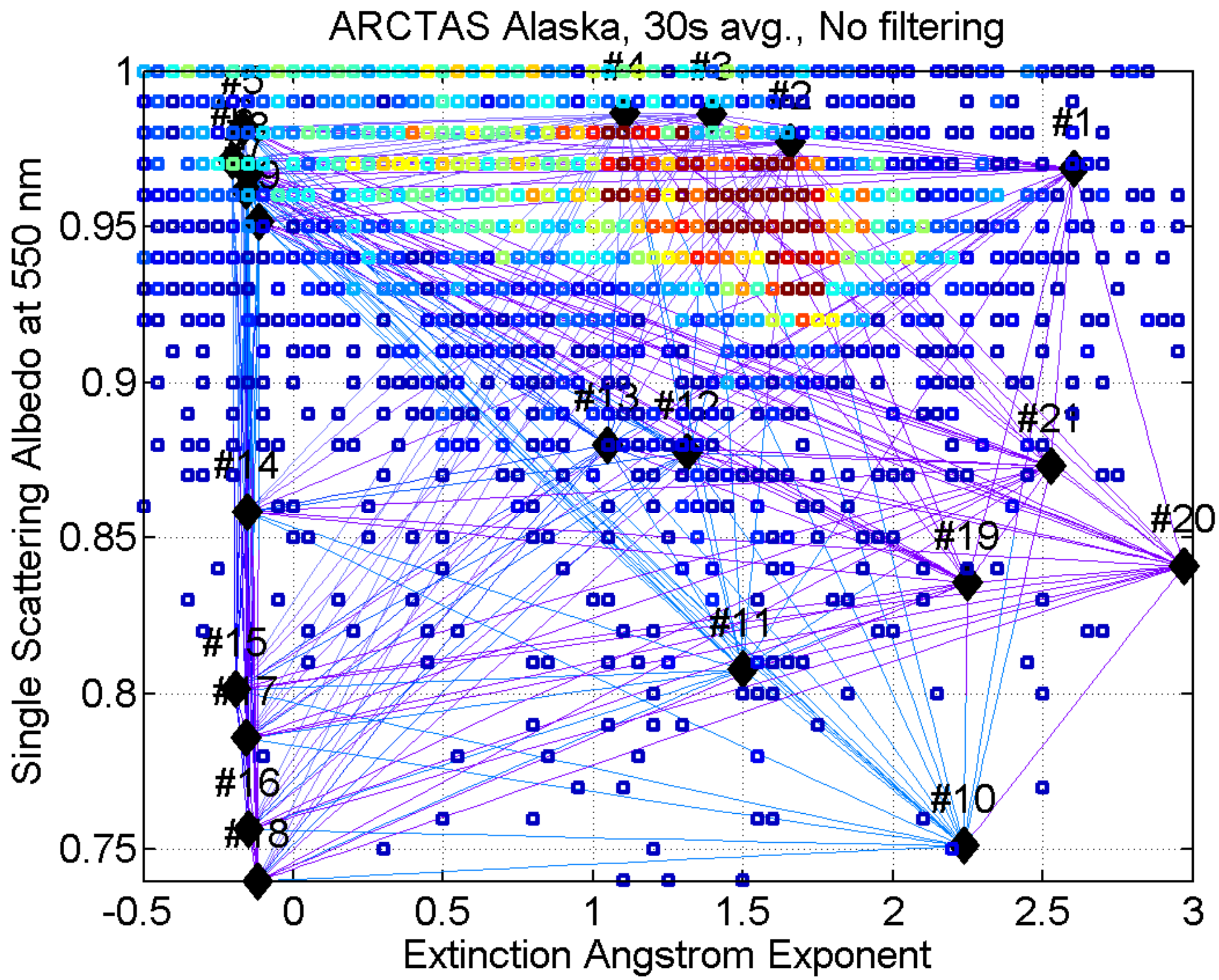
3) Use suborbital observations to guide choice of aerosol models

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



ARCTAS data are corrected after Virkkula [2010].

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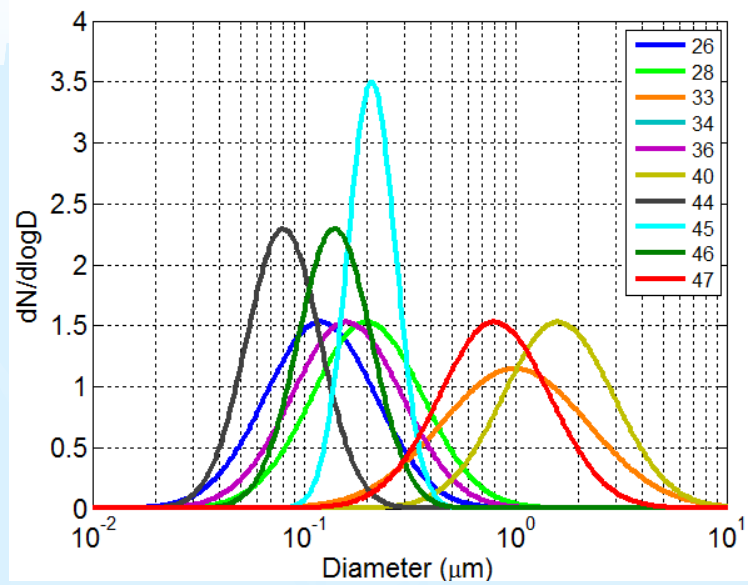

Aerosol models:

7 fine and 3 coarse mode models define size and refractive indices of bi-modal log-normal size distribution → 100 combinations

Free parameters: N_{fine}, N_{coarse}

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Issues to consider

- Differences in data quality land/ocean
- Impact of model assumptions
- Spatial variability
- Aerosols above & near clouds

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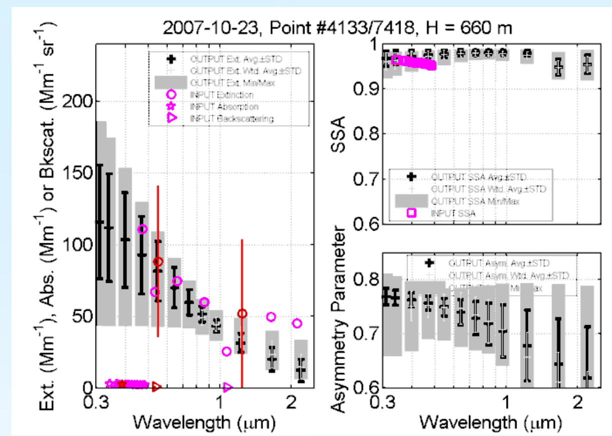

Rtx code

Retrieval:

ext (λ, z) + δext
ssa (λ, z) + δssa
g (λ, z) + δg

Target:

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

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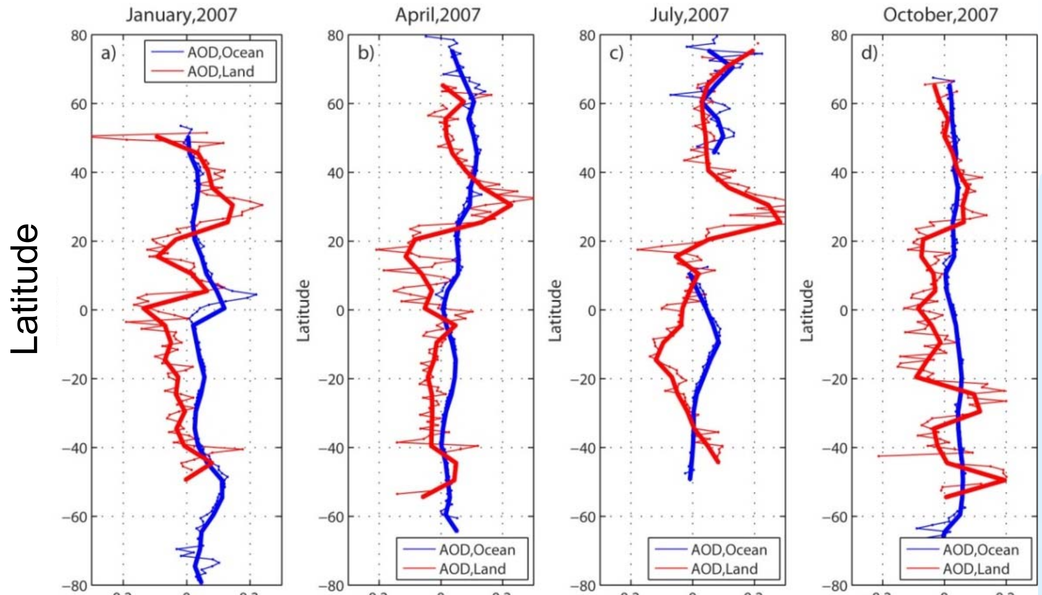
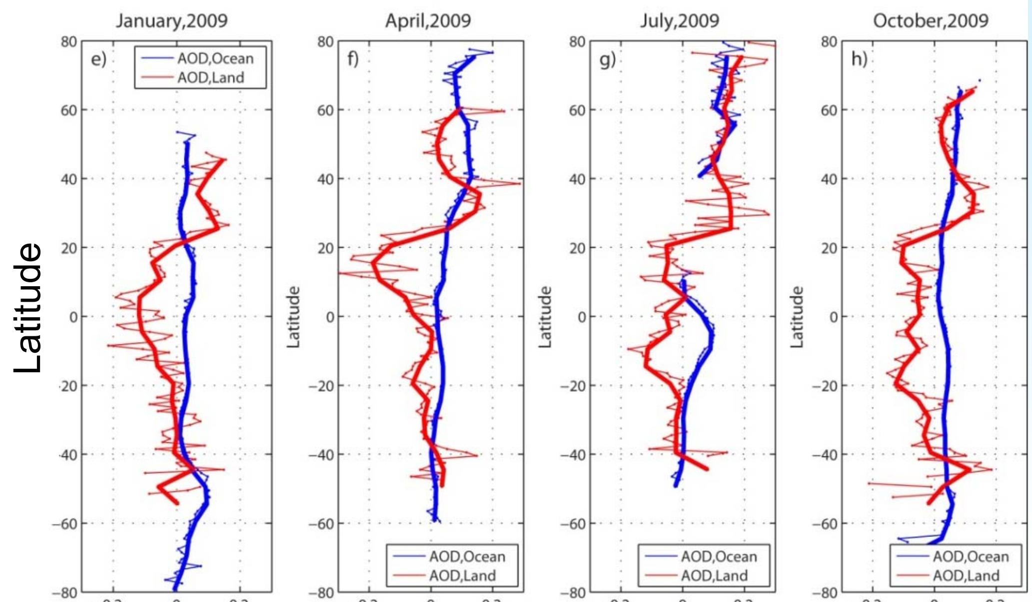
Latitudinal distribution of AOD differences between MODIS and CALIOP V3



MODIS-CALIOP AOD



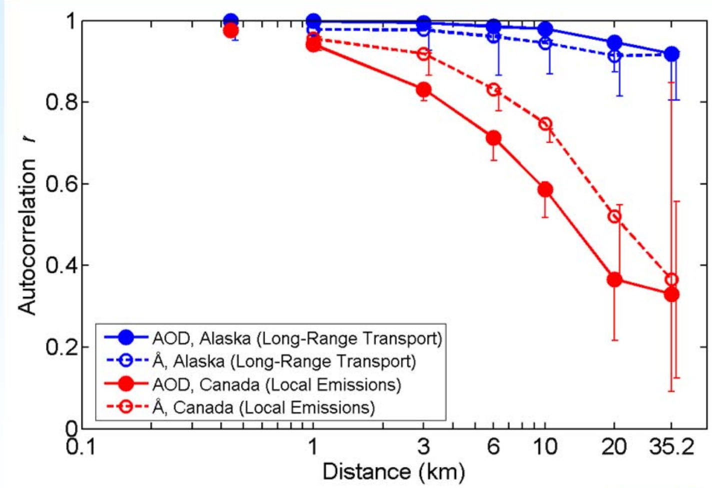
MODIS-CALIOP AOD

Main findings, ocean:

1. bias differences of 0.03 - 0.04 (with CALIOP<MODIS for all months),
2. RMS Δ of 0.09 – 0.12
3. r^2 is ~ 0.4-0.5

…all after judicious use of quality flags

Redemann et al., ACP, 2012



Shinozuka and Redemann, ACP, 2011

Current choices in retrieval method:

1) Metric / error / cost function

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

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

2) 4 Observables

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

3) Minimize X and select the top 3% of solutions that meet $| x_i - \hat{x}_i | <= \delta \hat{x}_i$ for all i

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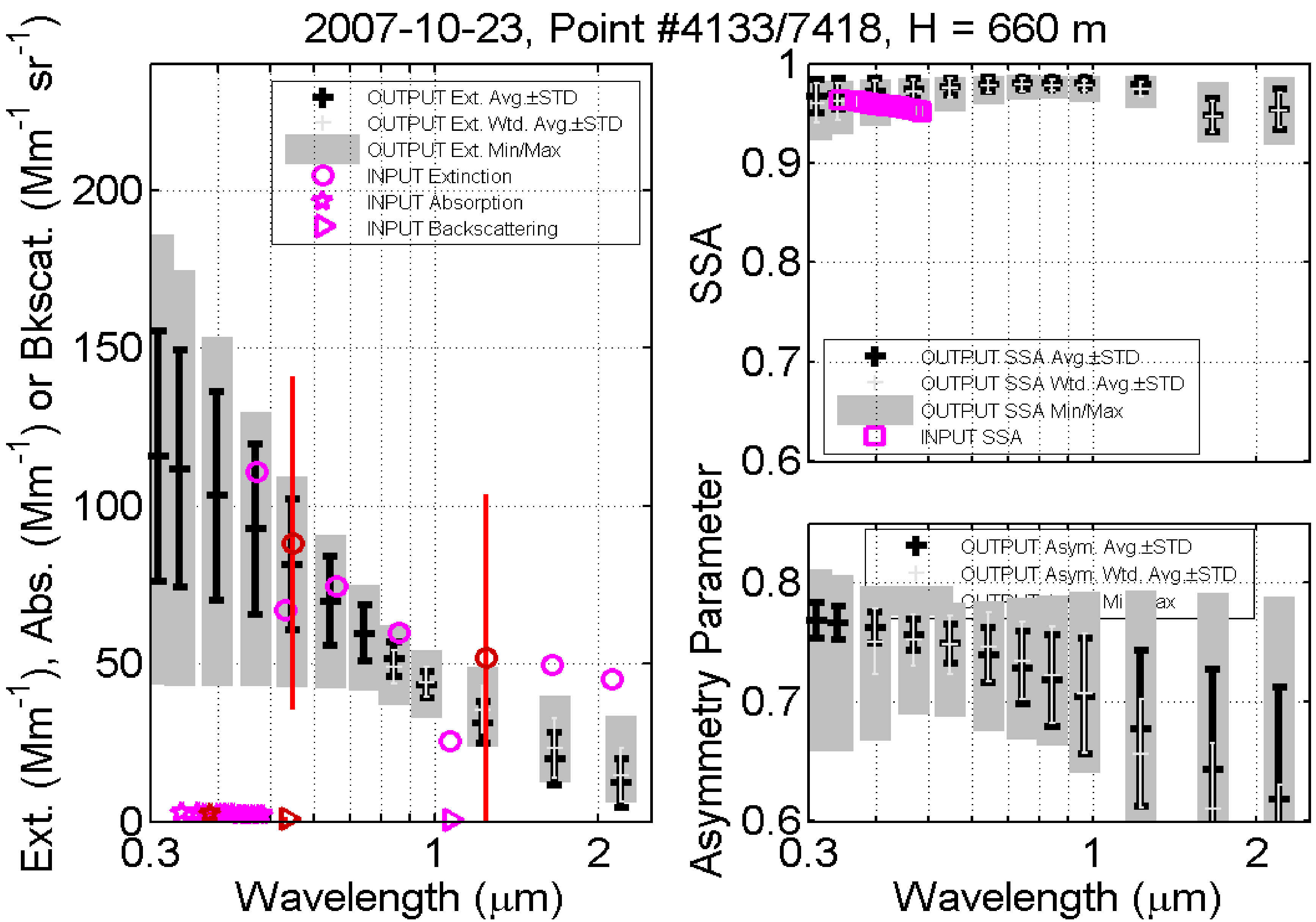
7) Provide uncertainty estimates based on range of aerosol models that are consistent with satellite measurements

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



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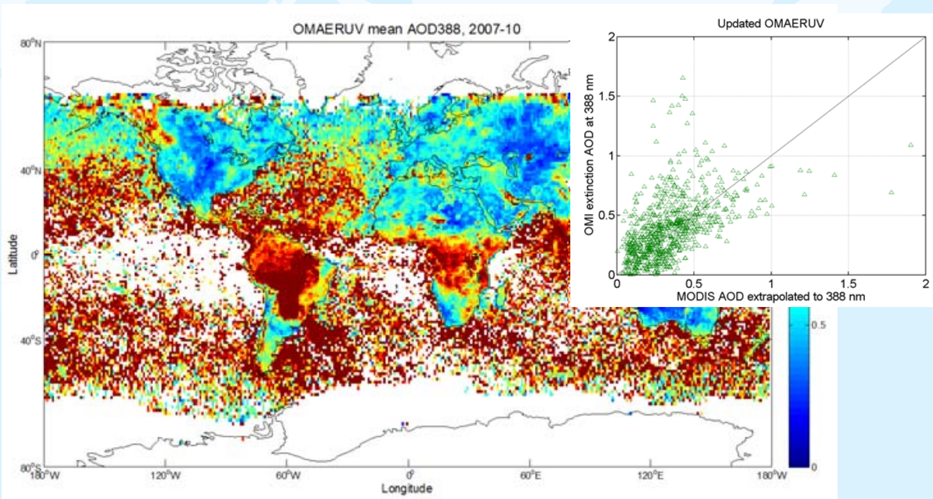
8) Test representativeness of MOC retrieval inputs
9) Use CALIOP layer heights to constrain OMAERUV AAOD retrievals

Consistency/Sampling issues: Choice of OMI data

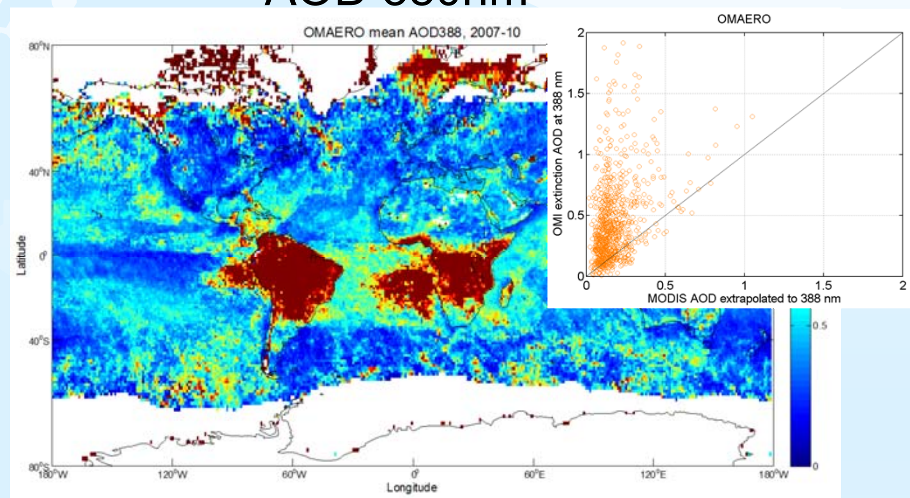
OMAERUV (Torres group)

OMAERO (KNMI group)

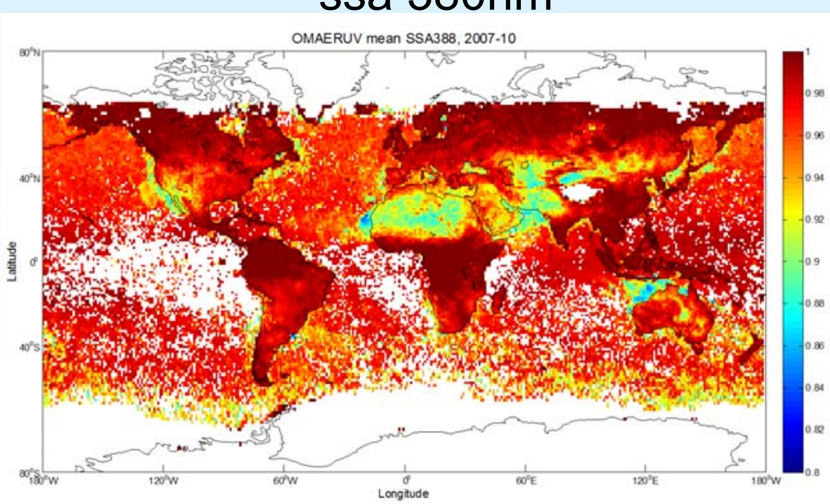
AOD 380nm



AOD 380nm



ssa 380nm



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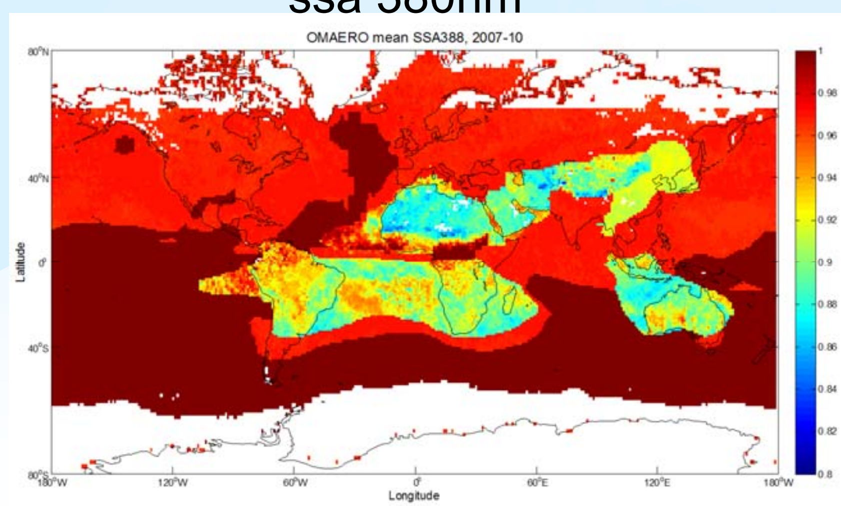
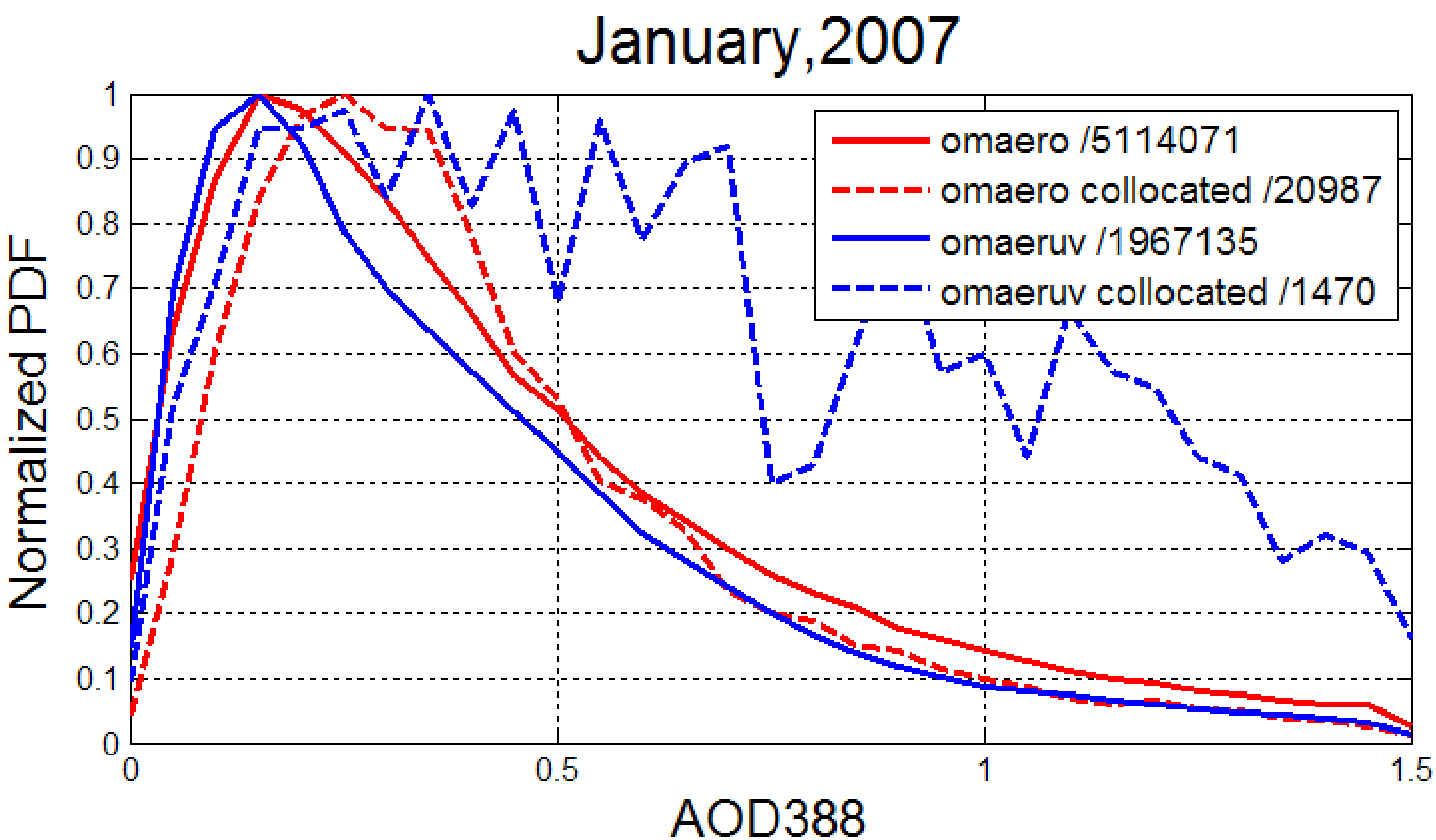


OMAERO data collocated with MODIS and CALIOP is a reasonable representation of global OMAERO over ocean

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



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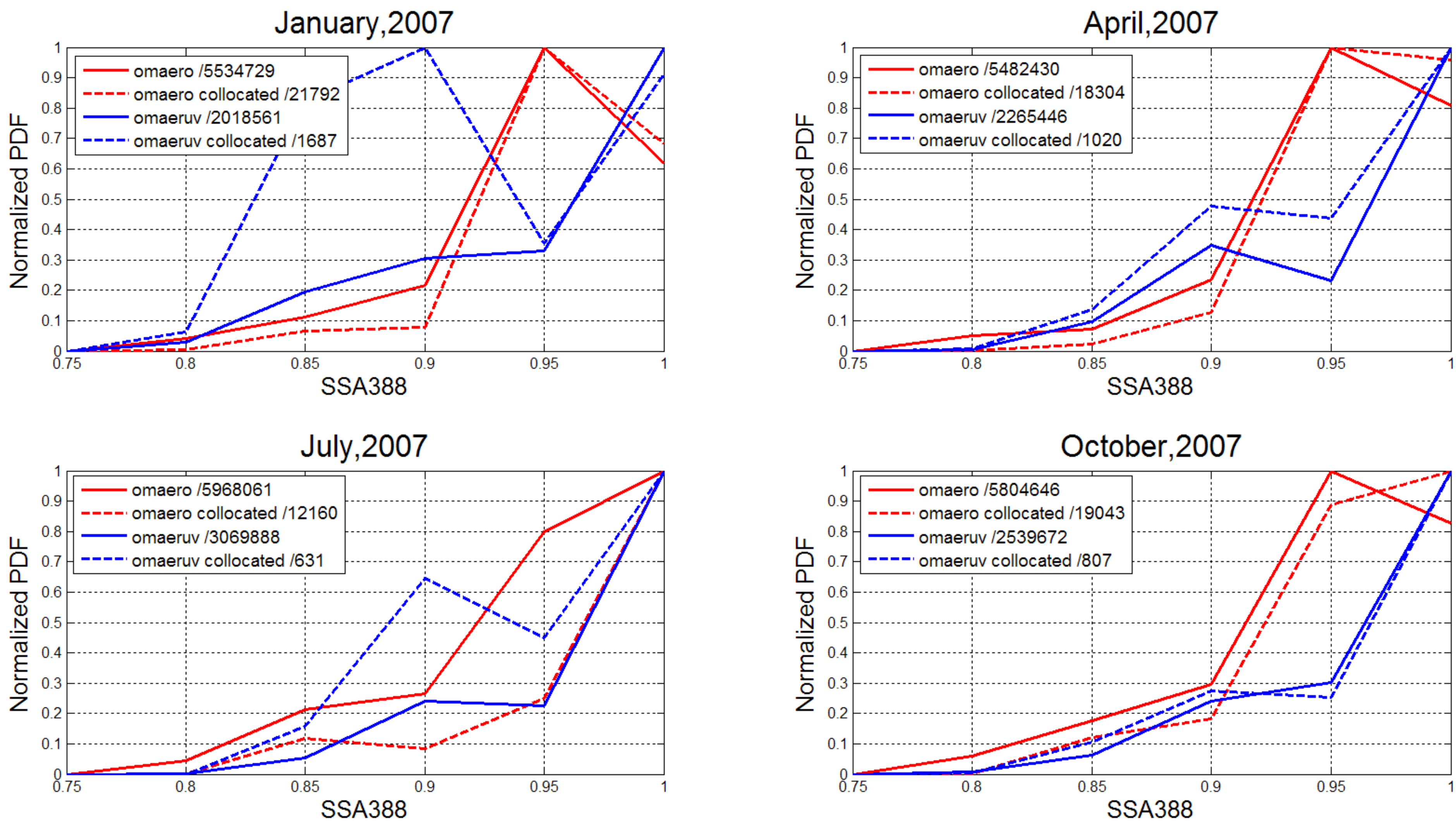

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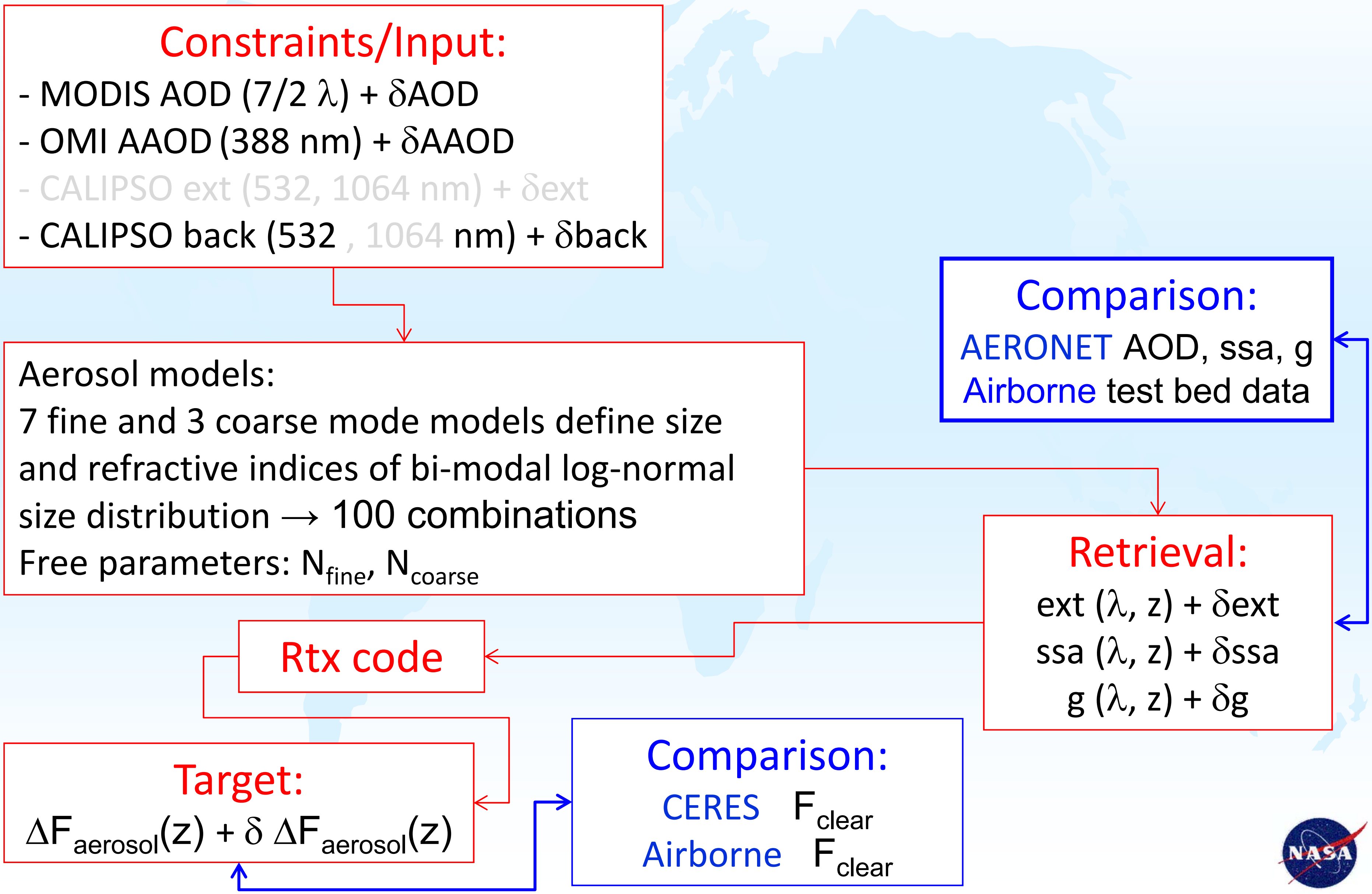
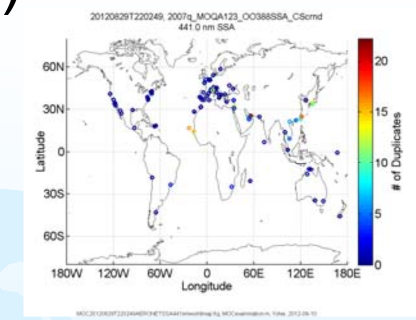
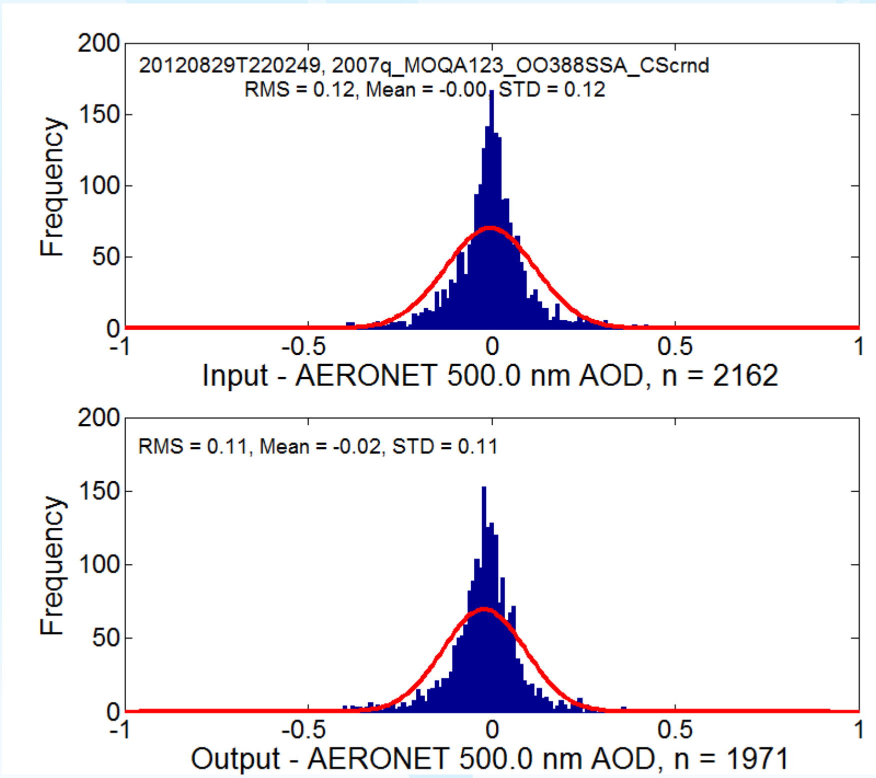
9) Use CALIOP layer heights to constrain OMAERUV AAOD retrievals
10) Test multi-sensor retrievals against AERONET and field obs

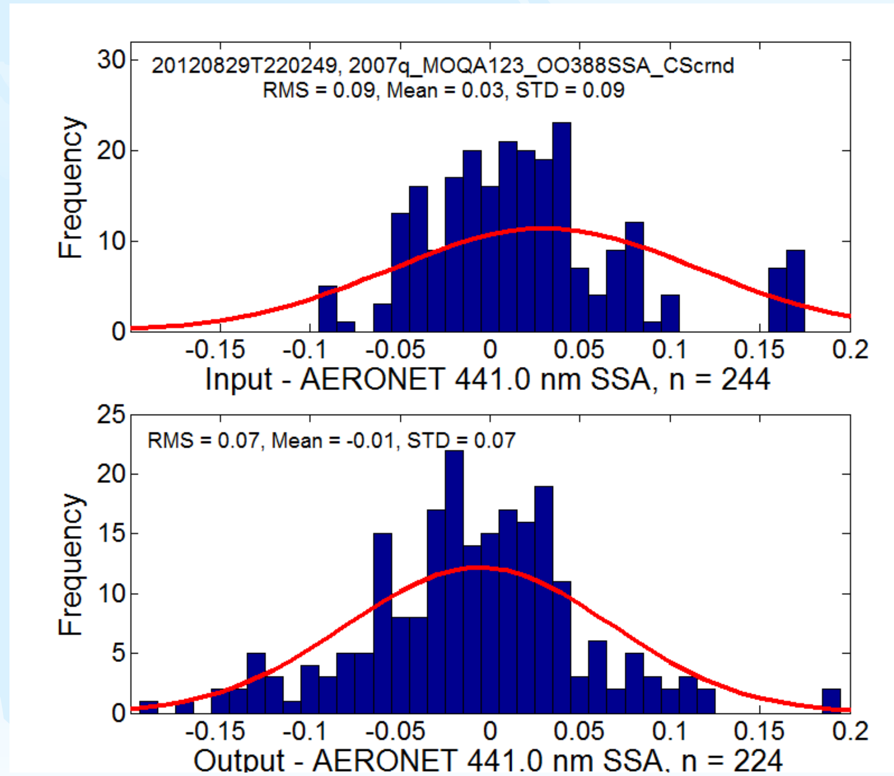
Goal: To use A-Train aerosol obs to constrain aerosol radiative properties to calculate $\Delta F_{aerosol}(z)$



MOC retrievals vs. AERONET (V2.0) Ocean (OMAERO)



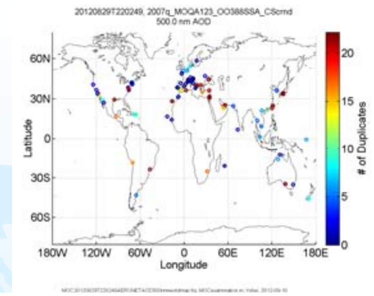


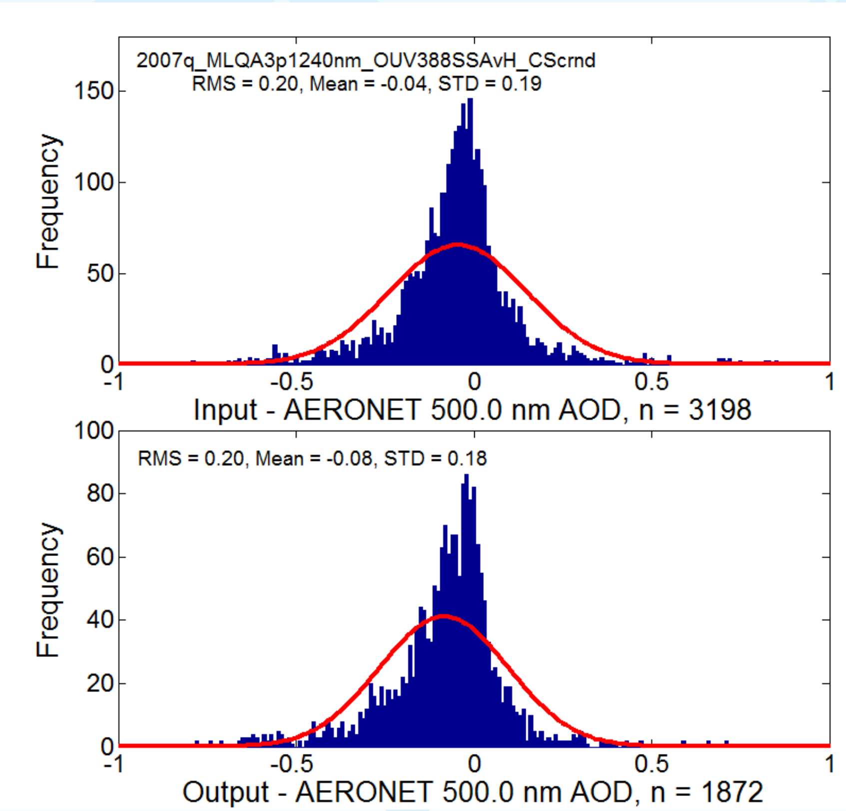


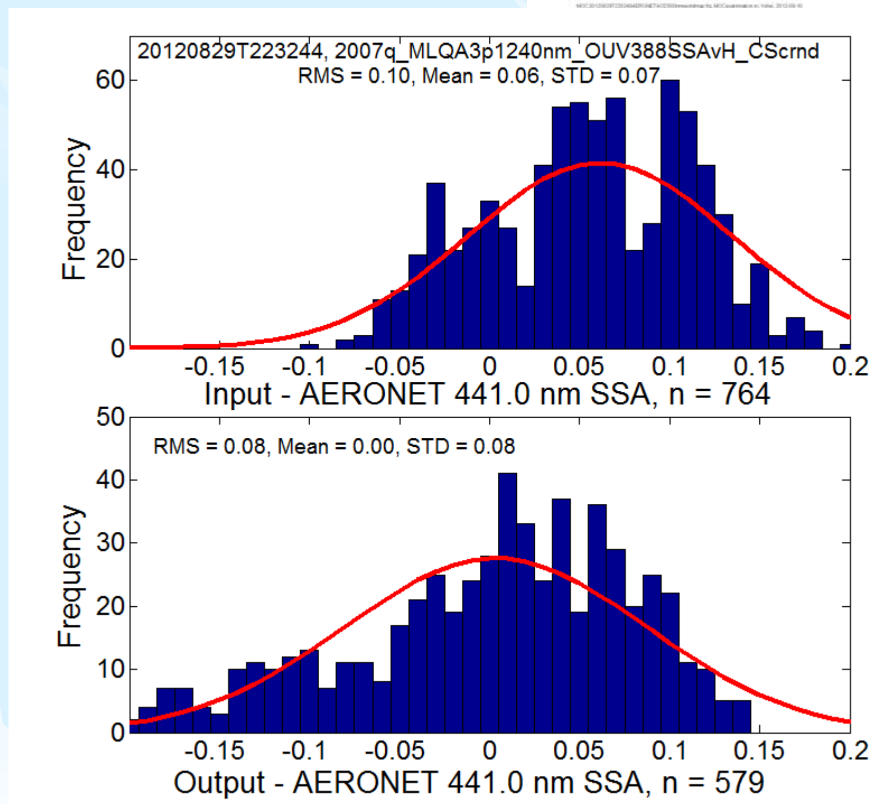
Small bias in retrieved AOD already existed in the input data

No bias in retrieved ssa, although small positive bias existed in the input data

MOC retrievals vs. AERONET (V2.0) Land (OMAERUV)





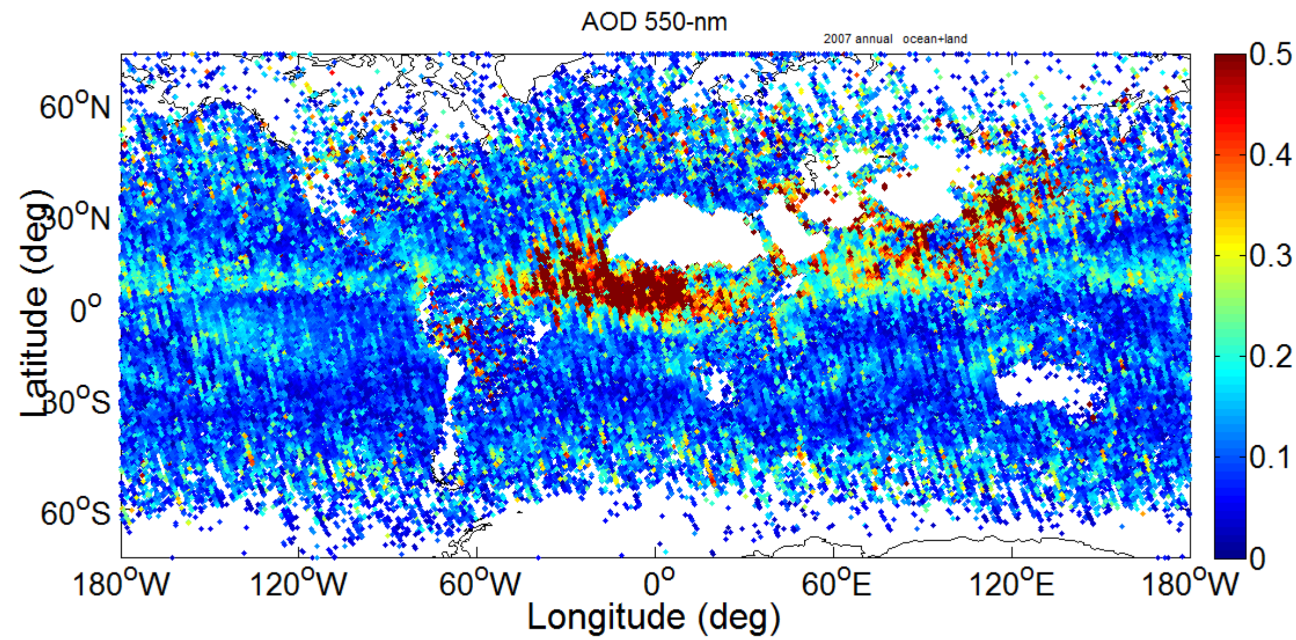


Negative bias in retrieved AOD is increased from input data

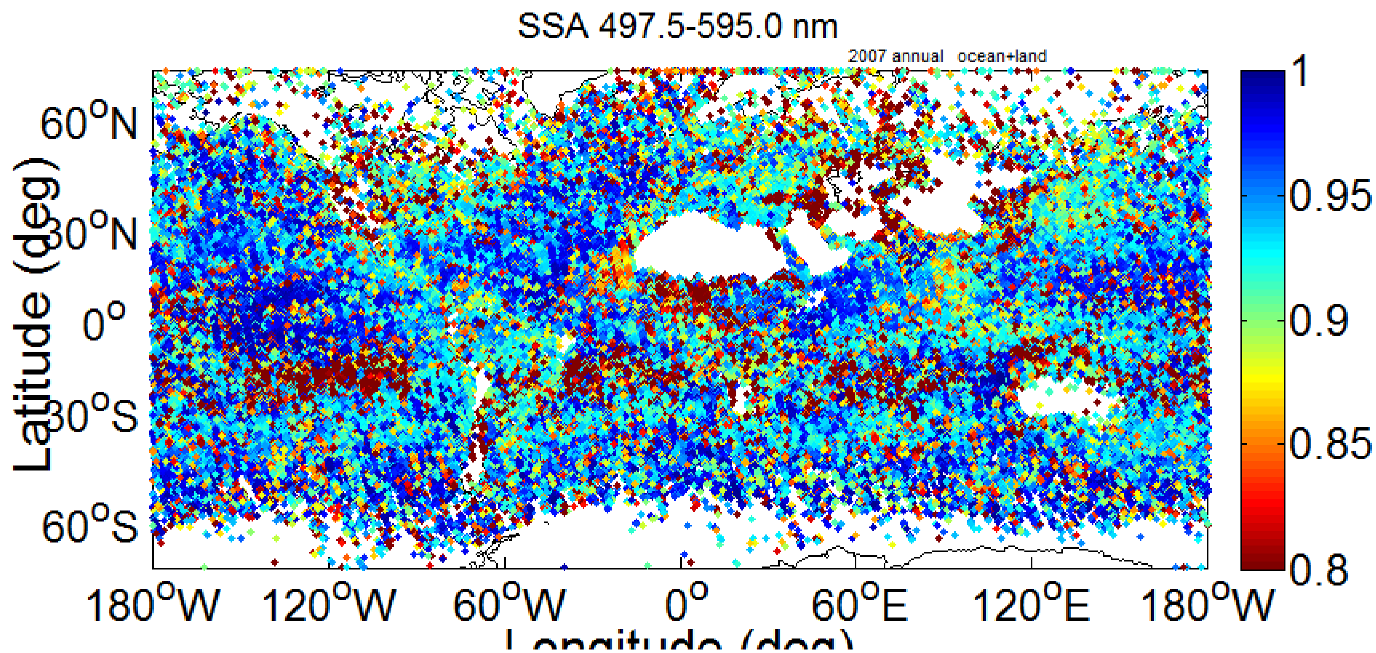
No bias in retrieved ssa, although positive bias existed in the input data

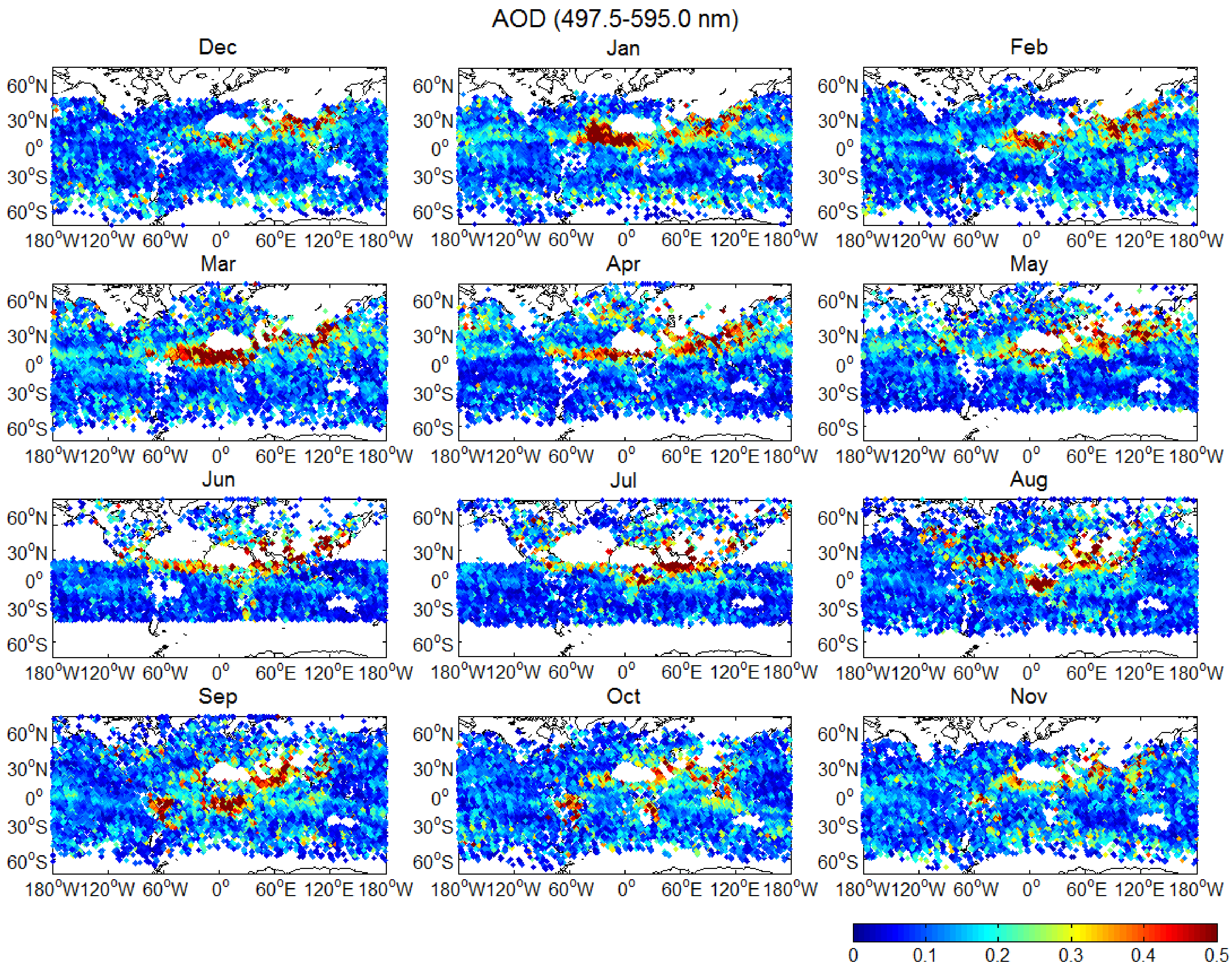
AOD and SSA retrievals from MODIS – OMI - CALIPSO

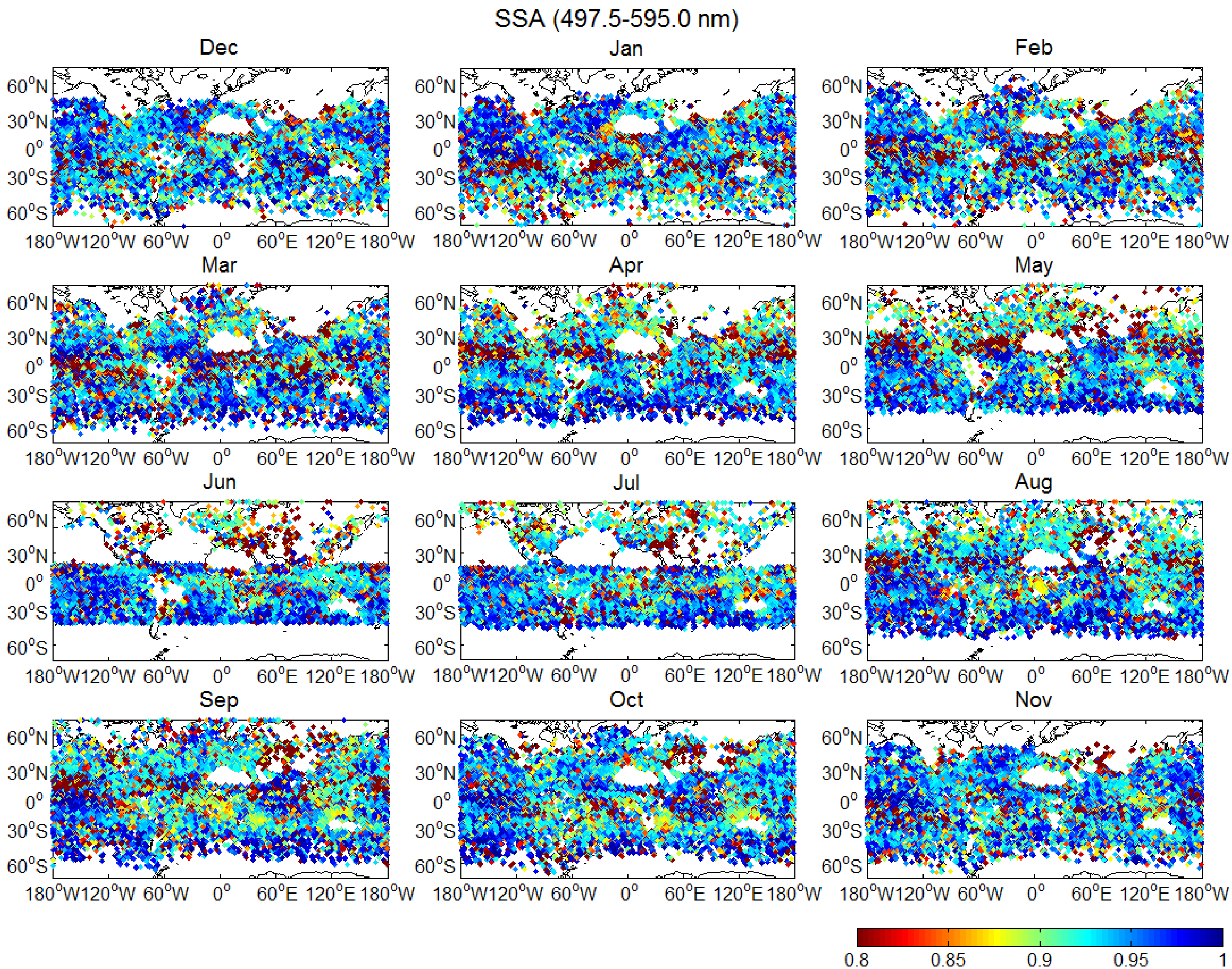
AOD
~540nm

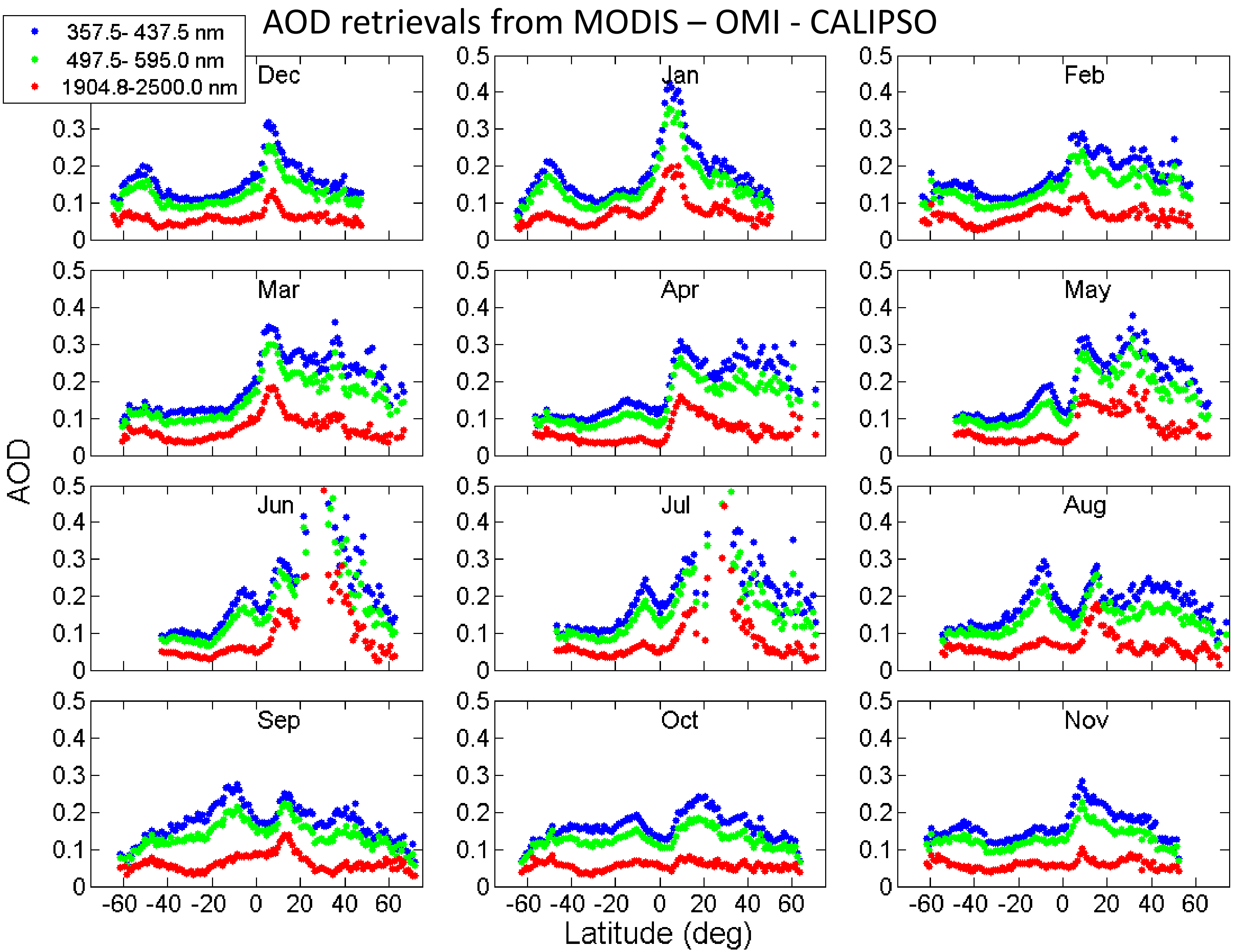


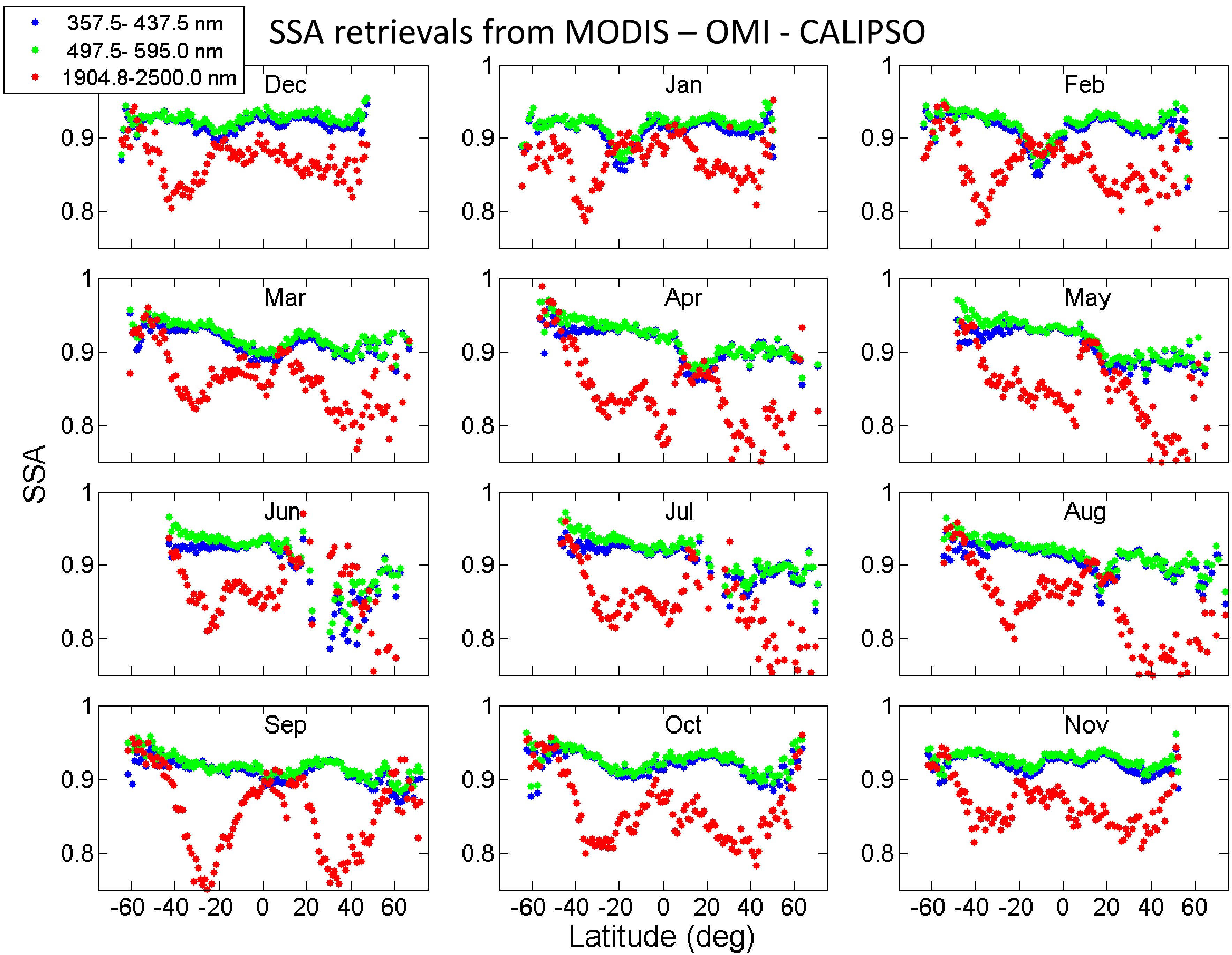
SSA
~540nm




AOD (497.5-595.0 nm)
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
60°N
30°N
0°
30°S
60°S
180°W 120°W 60°W 0° 60°E 120°E 180°W
0
0.1
0.2
0.3
0.4
0.5

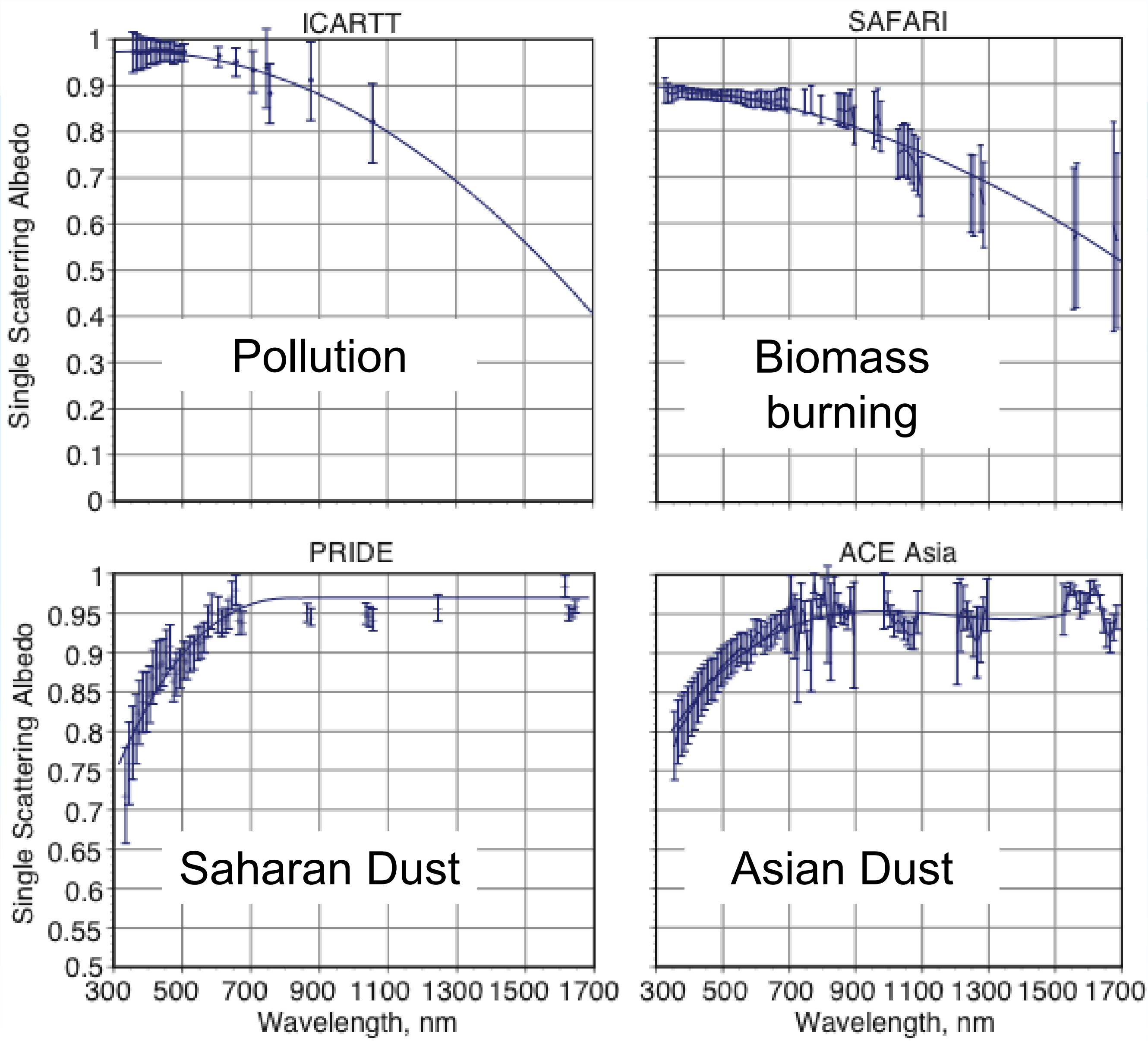

SSA (497.5-595.0 nm)
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
60°N
30°N
0°
30°S
60°S
180°W
120°W
60°W
0°
60°E
120°E
180°W
0.8
0.85
0.9
0.95
1


AOD retrievals from MODIS – OMI - CALIPSO
357.5- 437.5 nm
497.5- 595.0 nm
1904.8-2500.0 nm
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
AOD
Latitude (deg)

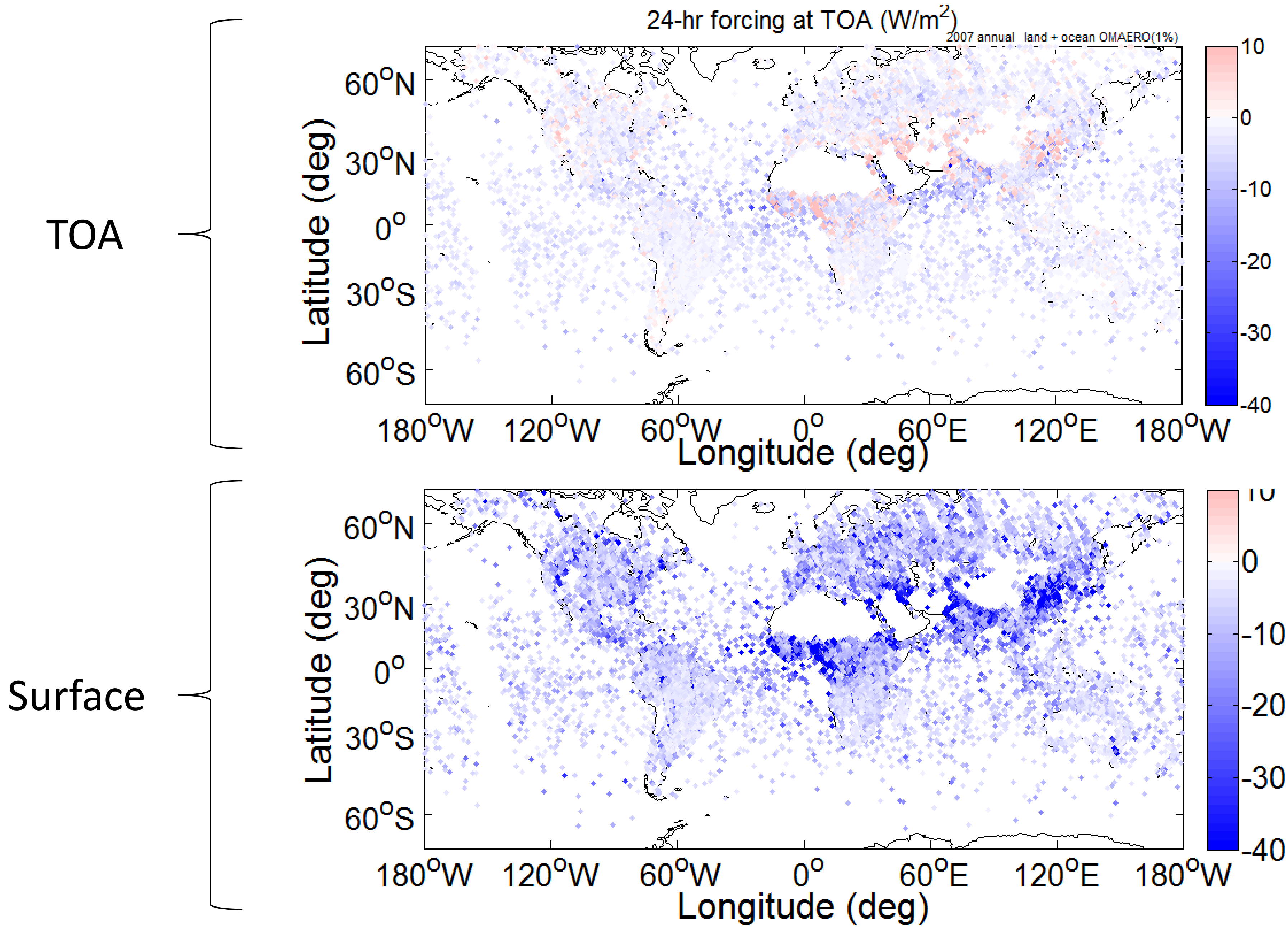


357.5- 437.5 nm
497.5- 595.0 nm
1904.8-2500.0 nm
SSA retrievals from MODIS – OMI - CALIPSO
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
1
0.9
0.8
SSA
-60 -40 -20 0 20 40 60
Latitude (deg)

AOD and SSA retrievals from MODIS – OMI - CALIPSO



24h avg direct radiative forcing from MODIS – OMI - CALIPSO



Seasonal clear-sky DARF results at TOA and SFC from models and observations [W/m²] after CCSP, adapted from Yu et al. 2006.

Products	DJF		MAM		JJA		SON		ANN	
	TOA	SFC	TOA	SFC	TOA	SFC	TOA	SFC	TOA	SFC
Ocean										
Observations (11) - Median	-5.5	-8.1	-5.7	-9.3	-5.5	-9.5	-5.4	-8.8	-5.5	-8.8
Our study - preliminary	**-4.6**	**-9.5**	**-4.7**	**-10.2**	**-4.7**	**-8.6**	**-4.9**	**-9.7**	**-4.8**	**-9.8**
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 (4) - Median	-3.7	-8.1	-5.1	-13	-5.8	-14.8	-4.7	-10.8	-4.9	-11.7
Our study - preliminary	**-1.5**	**-10.6**	**-1.7**	**-11.5**	**-1.8**	**-11.8**	**-2.5**	**-12.1**	**-2.0**	**-11.8**
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**

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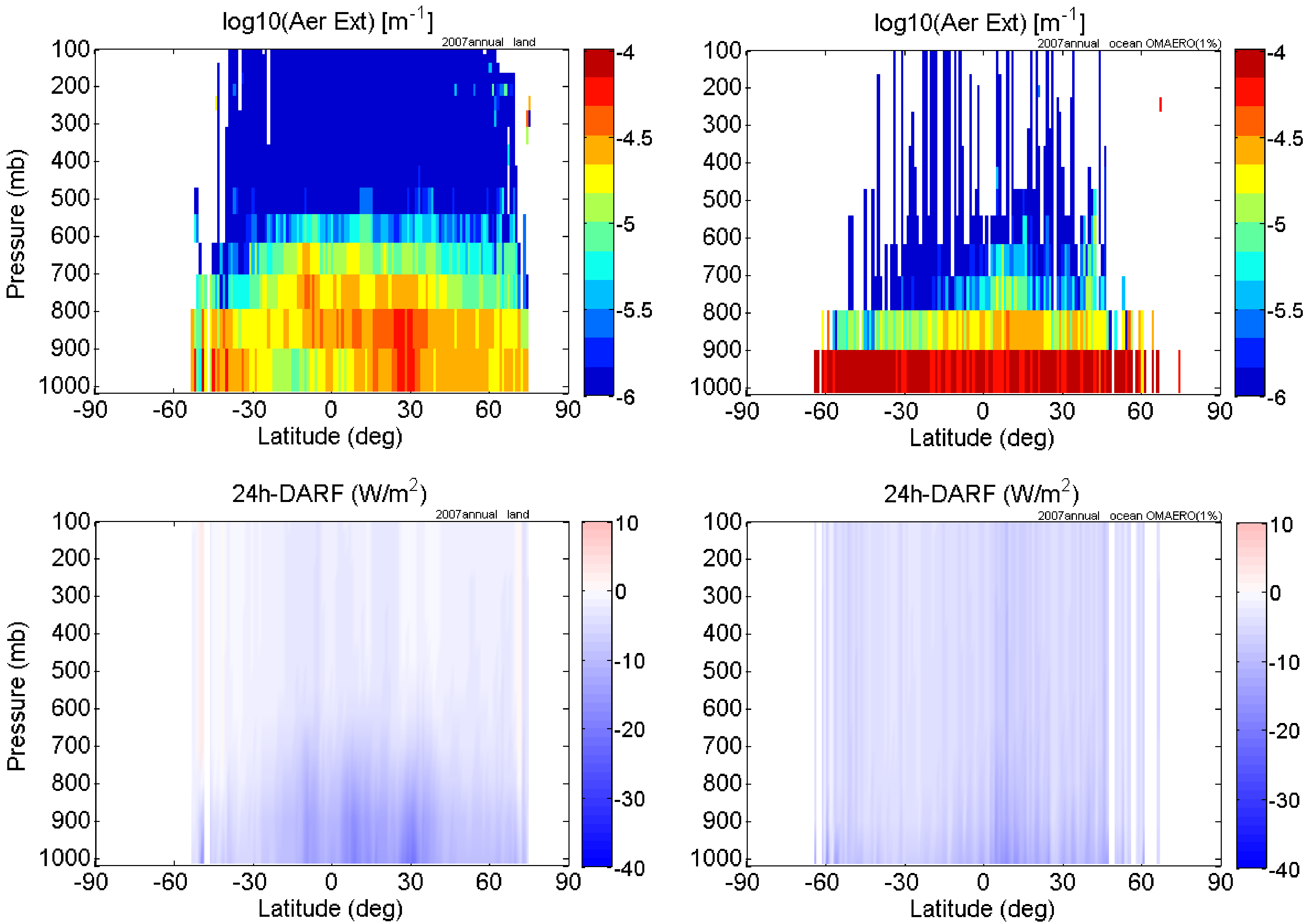
Our study - preliminary	**-4.6**	**-9.5**	**-4.7**	**-10.2**	**-4.7**	**-8.6**	**-4.9**	**-9.7**	**-4.8**	**-9.8**
Observations - error	0.23	0.56	0.2	0.85	0.29	0.94	0.26	0.78	0.21	0.67
Models (5) - Median	-3.3	-4.1	-3.5	-4.6	-3.5	-4.9	-3.8	-5.4	-3.5	-4.8
Models - error	0.61	0.66	0.66	0.92	0.67	0.91	0.68	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 (4) - Median	-3.7	-8.1	-5.1	-13	-5.8	-14.8	-4.7	-10.8	-4.9	-11.7
Our study - preliminary	**-1.5**	**-10.6**	**-1.7**	**-11.5**	**-1.8**	**-11.8**	**-2.5**	**-12.1**	**-2.0**	**-11.8**
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**

Land vs. ocean



Conclusions – what this data set is and is not

This data set:

- Is intended to lead to a PURELY observational estimate of DARF(z)
- Contains 12 months (2007) of aerosol extinction, ssa and g as f(t, lat, long, λ, z)
- Is based on instantaneously collocated level 2 MODIS AOD dark target retrievals at 2λ, OMI AAOD at 388nm, and CALIOP aerosol backscatter at 532nm
- Is based on quality-screened MODIS, OMI and CALIOP data
- Is based on aerosol models that are supported by suborbital observations
- Uses OMAERUV over land and OMAERO over ocean (representativeness)
- Agrees better with AERONET in terms of ssa(441nm) than input OMI data
- Uses CALIOP layer heights to constrain OMAERUV AAOD
- Provides uncertainty estimates based on range of aerosol models that are consistent with observation within their uncertainties
- Can be used to calculate clear-sky, direct, aerosol radiative forcing that compares favorably with previous observationally-based estimates and better with model based estimates over ocean at TOA

This data set:

- Is not based on passive sensor radiances
- Does not utilize MODIS DB data (yet)
- Does not cover all of the available collocated MODIS, OMI, CALIOP data (June 2006-Dec. 2008) (yet)
- Does not provide aerosol type from Mahalanobis cluster analysis (yet)

Conclusions – what this data set is and is not

So, is this useful to AeroCom?

If so, in what format?

Spectral aerosol radiative properties or radiative fluxes?