The combined use of MODIS, CALIPSO and OMI level 2 aerosol products for calculating direct aerosol radiative effects

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Outline

- Goal: To devise a new, multi-instrument methodology to derive vertical structure of $\Delta F_{aerosol}(z)$
- Methodology for combining CALIOP, OMI and MODIS data
- Checking consistency of input data
  - Comparison of MODIS and CALIOP-derived AOD
  - Differences in CALIOP V2 and V2.93 (V3 pre-release)
- Inversion methodology & usefulness of lidar backscatter for constraining aerosol radiative properties
- Sensitivity study using synthesized data
- Application to actual data from August 2007
- Conclusions

Motivation: Observation- and model-based estimates of direct aerosol radiatve forcing published in IPCC diverge

Mean of Observationally-based ΔF

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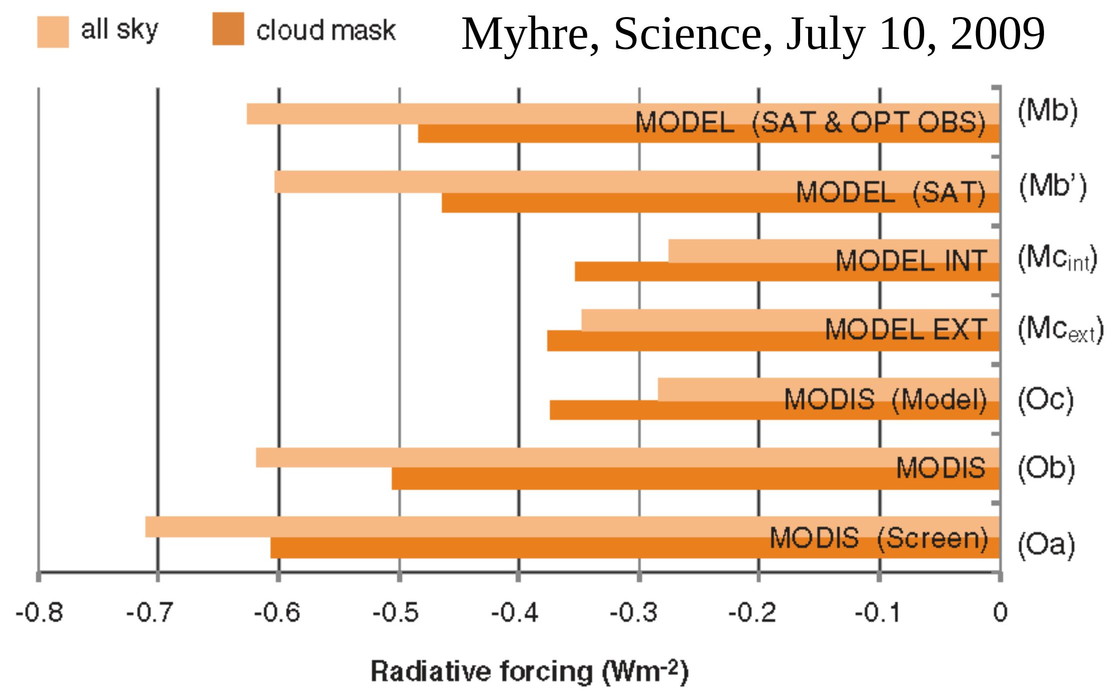
Mean of Model-based ΔF

Myhre, Science, July 10, 2009



Myhre:

1)Observation-based methods 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".

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

Issues to consider

- Differences in data quality land/ocean
- Impact of assumptions,
  e.g. refr. index (λ),
  restriction to MODIS modes

MODIS aerosol models:
4 fine and 5 coarse mode distributions define standard deviation and refractive indices of bi-modal log-normal size distribution → 20 combinations
Free parameters: N_{fine}, N_{coarse}

Retrieval:

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

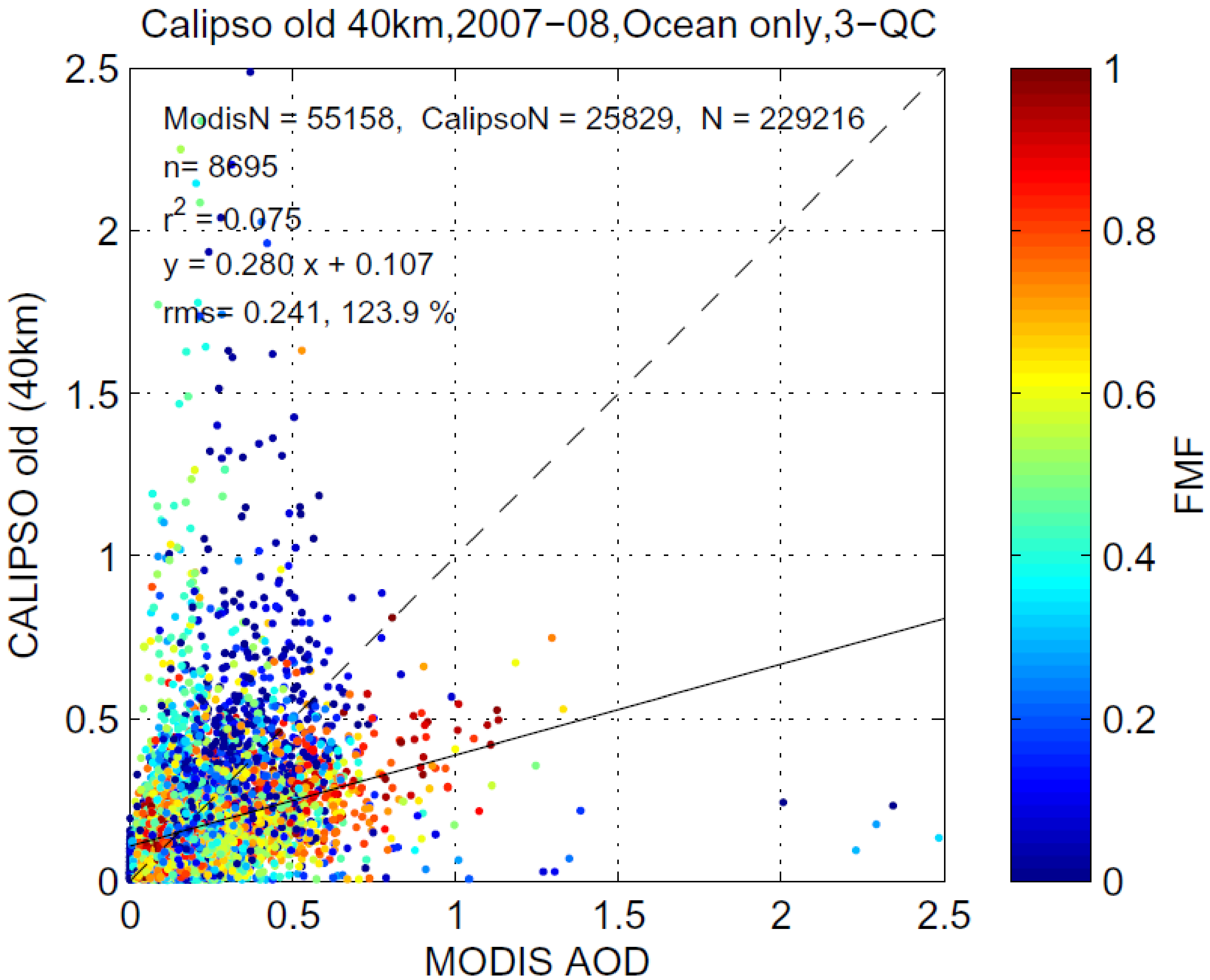
Rtx code

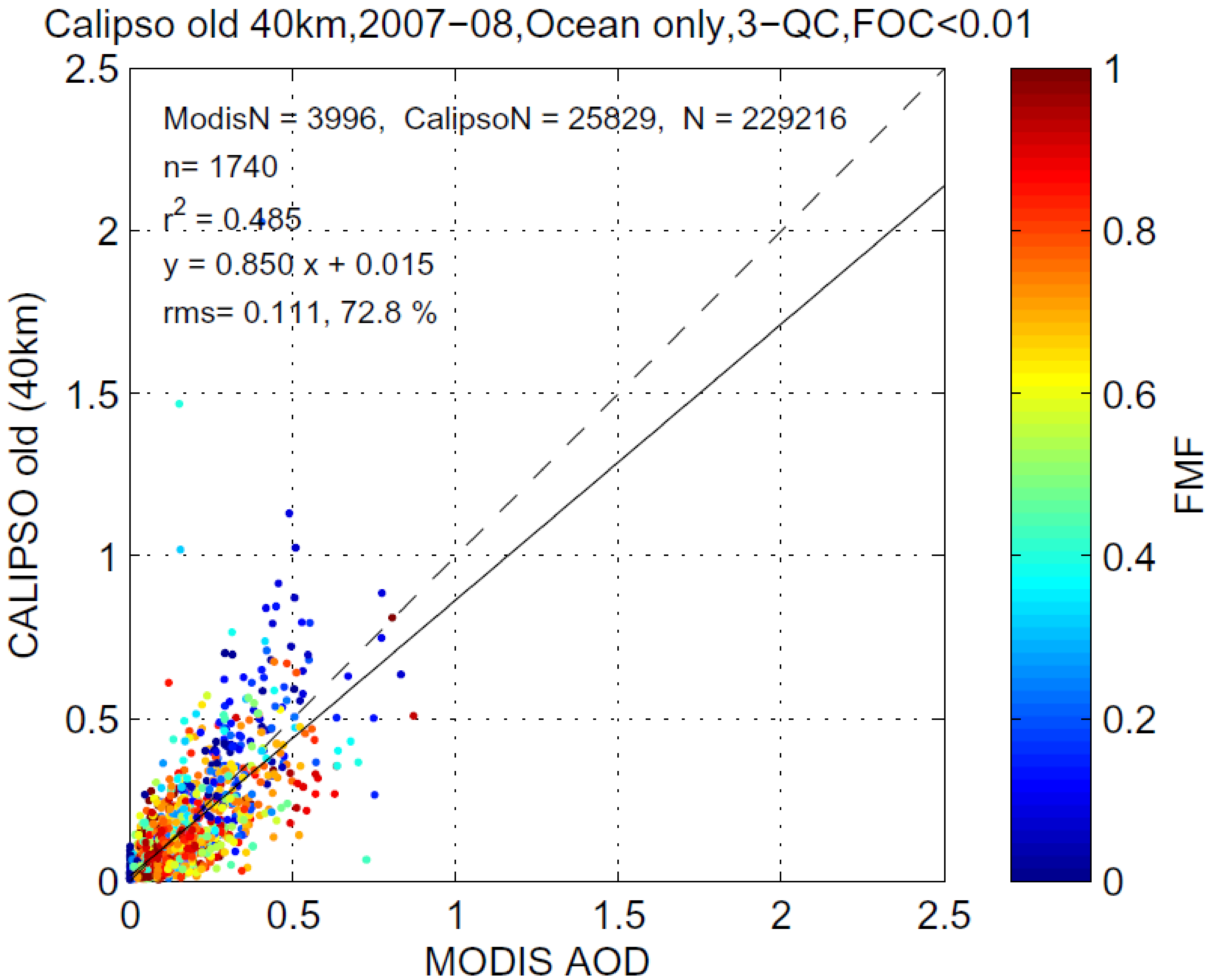
Target:

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

Aerosol Optical Depth comparisons (CALIOP V2)

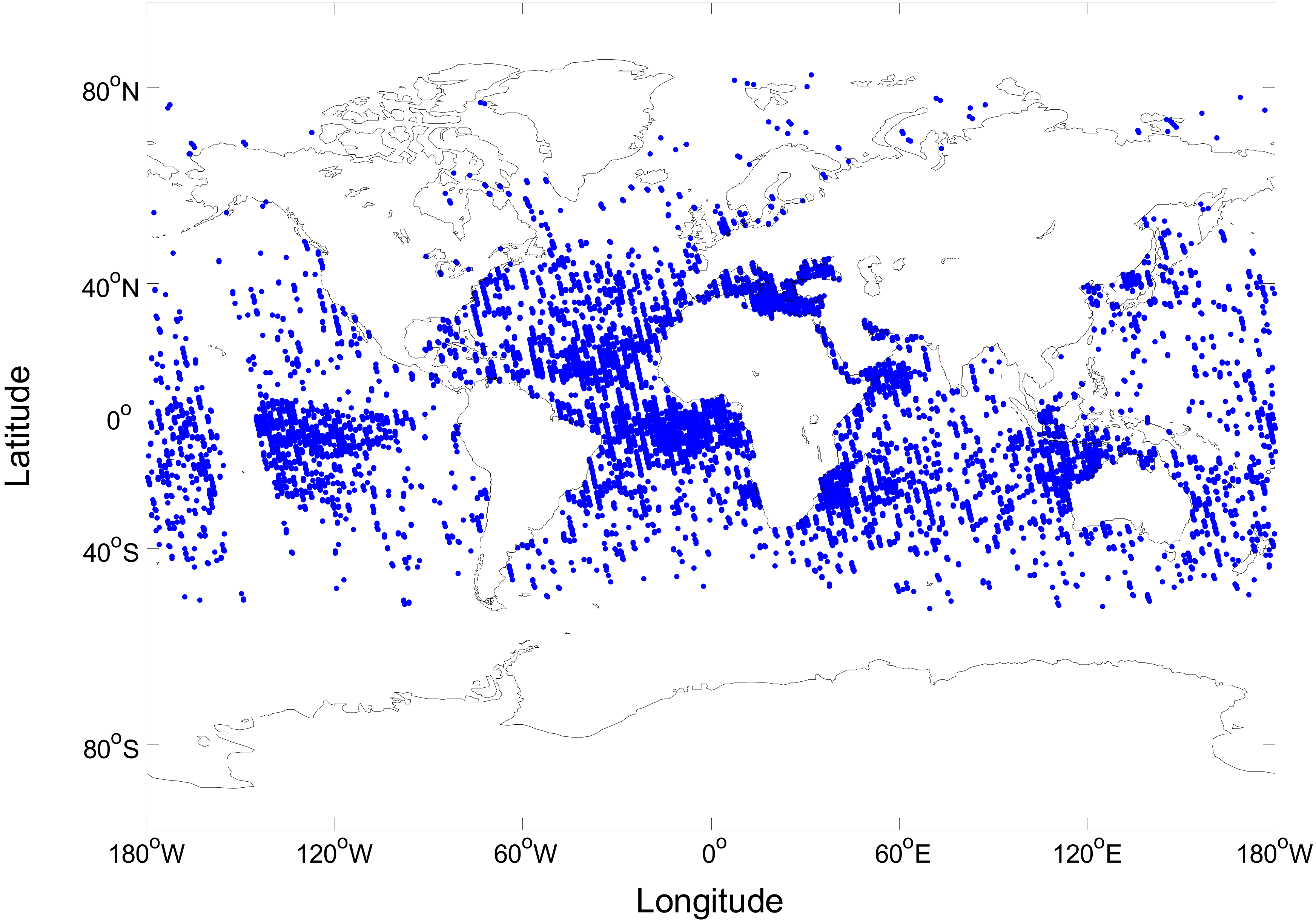
- Four months of data: January, April, July and October 2007
- Use CALIPSO 40km-avg. aerosol extinction profiles, and 5km aerosol and cloud layer products
- Find all (up to 4) instantaneously collocated, MODIS MYD04_L2 (10x10km) aerosol retrievals traversed by 40km CALIPSO track
- Apply three CALIPSO profile quality criteria:
  1. Alt_top_aerosol > Alt_top_cloud
  2. EQC532_flag = 0 or 1
  3. Integrated attenuated backscatter @ 532 <=0.011
- Stratify by MODIS cloud fraction
- Compare CALIPSO Day vs. Night retrievals
- Break down geographically → zonal mean AOD comparisons and representativeness of MODIS obs. along CALIPSO track for ALL MODIS obs.
- Compare zonal means


Calipso old 40km,2007−08,Ocean only,3−QC
ModisN = 55158, CalipsoN = 25829, N = 229216
n= 8695
r2 = 0.075
y = 0.280 x + 0.107
rms= 0.241, 123.9 %
CALIPSO old (40km)
MODIS AOD
FMF
0
0.5
1
1.5
2
2.5
0.2
0.4
0.6
0.8

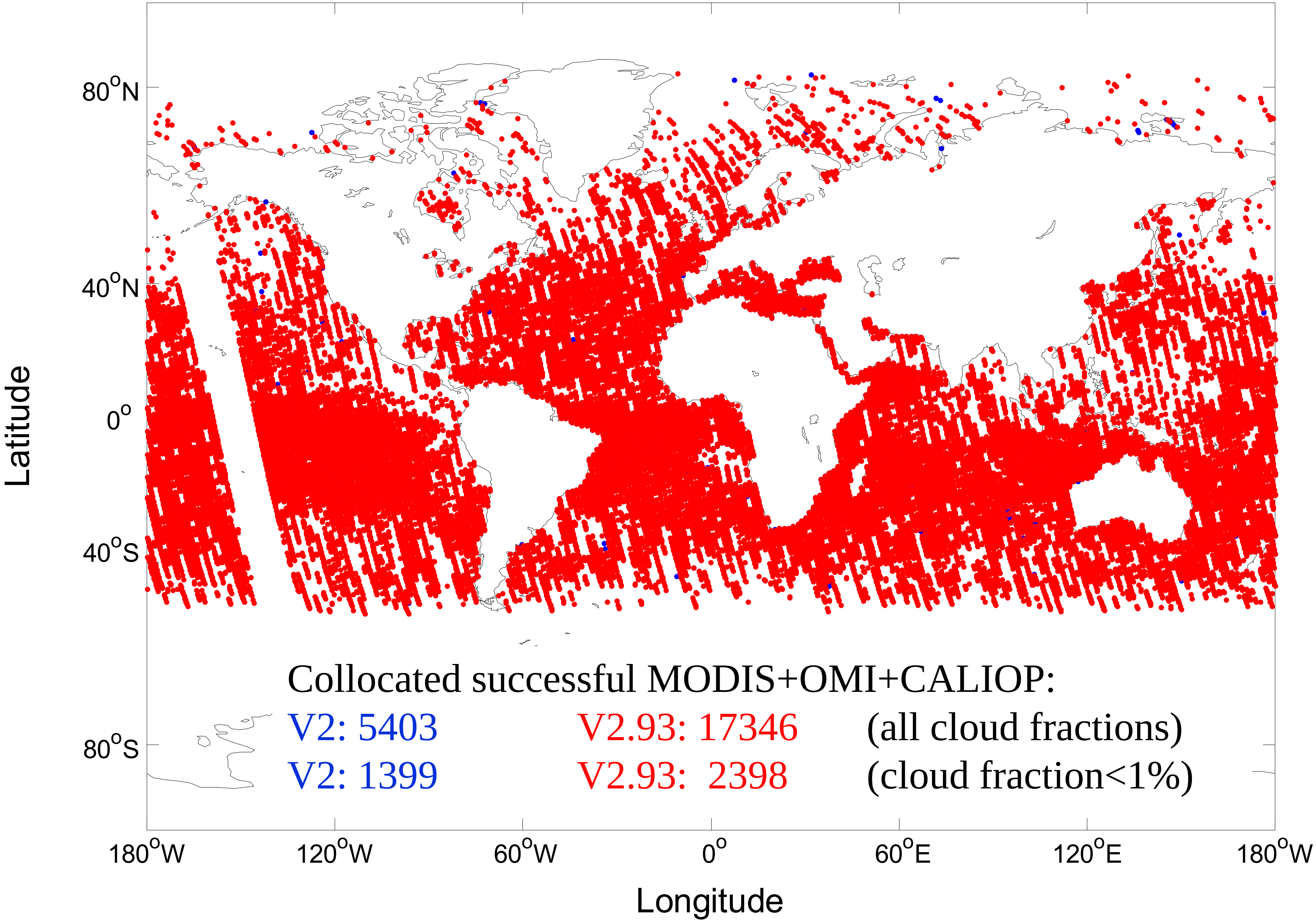


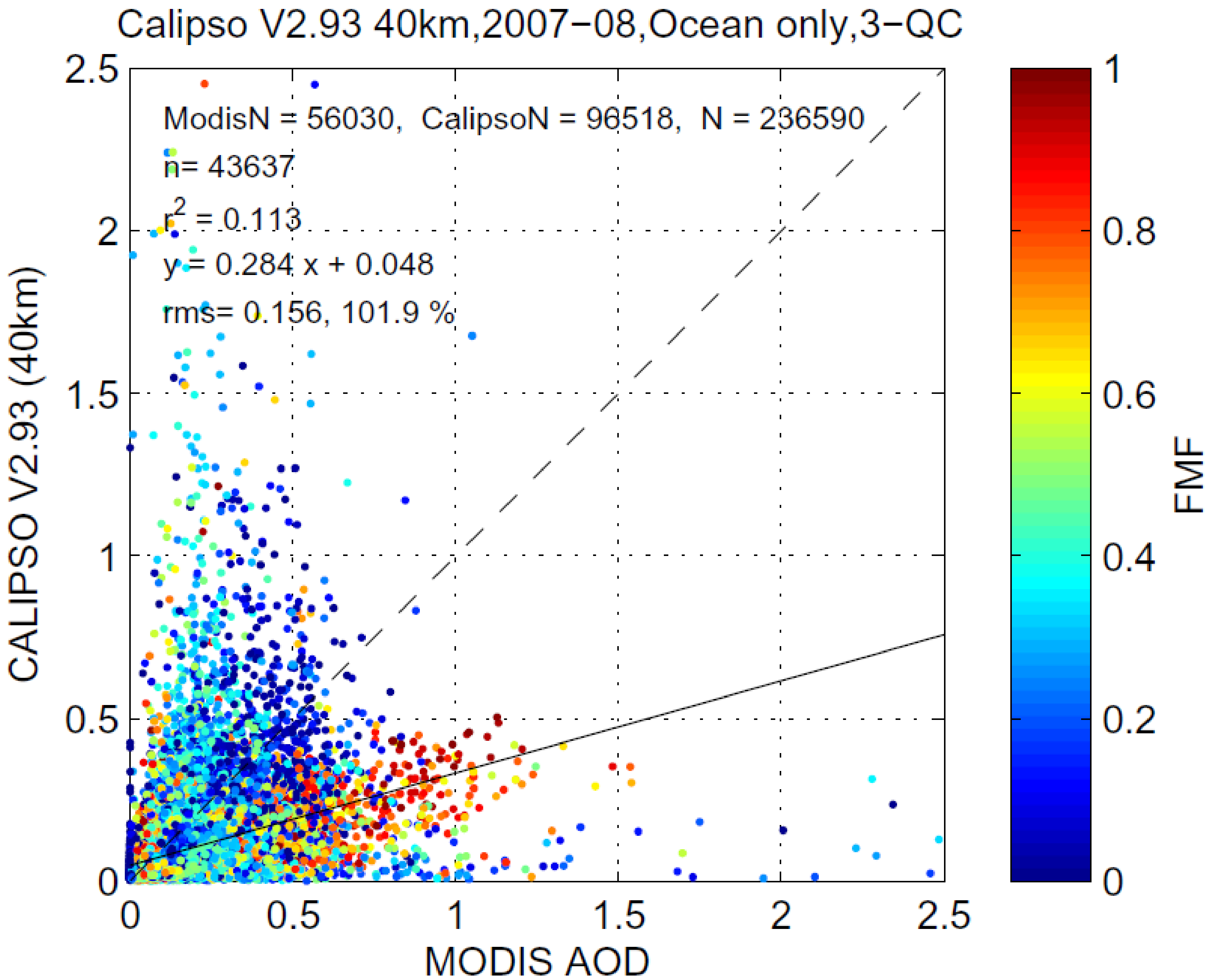
Calipso old 40km,2007−08,Ocean only,3−QC,FOC<0.01
ModisN = 3996, CalipsoN = 25829, N = 229216
n= 1740
r² = 0.485
y = 0.850 x + 0.015
rms= 0.111, 72.8 %
CALIPSO old (40km)
MODIS AOD
FMF
0
0.5
1
1.5
2
2.5
0.2
0.4
0.6
0.8

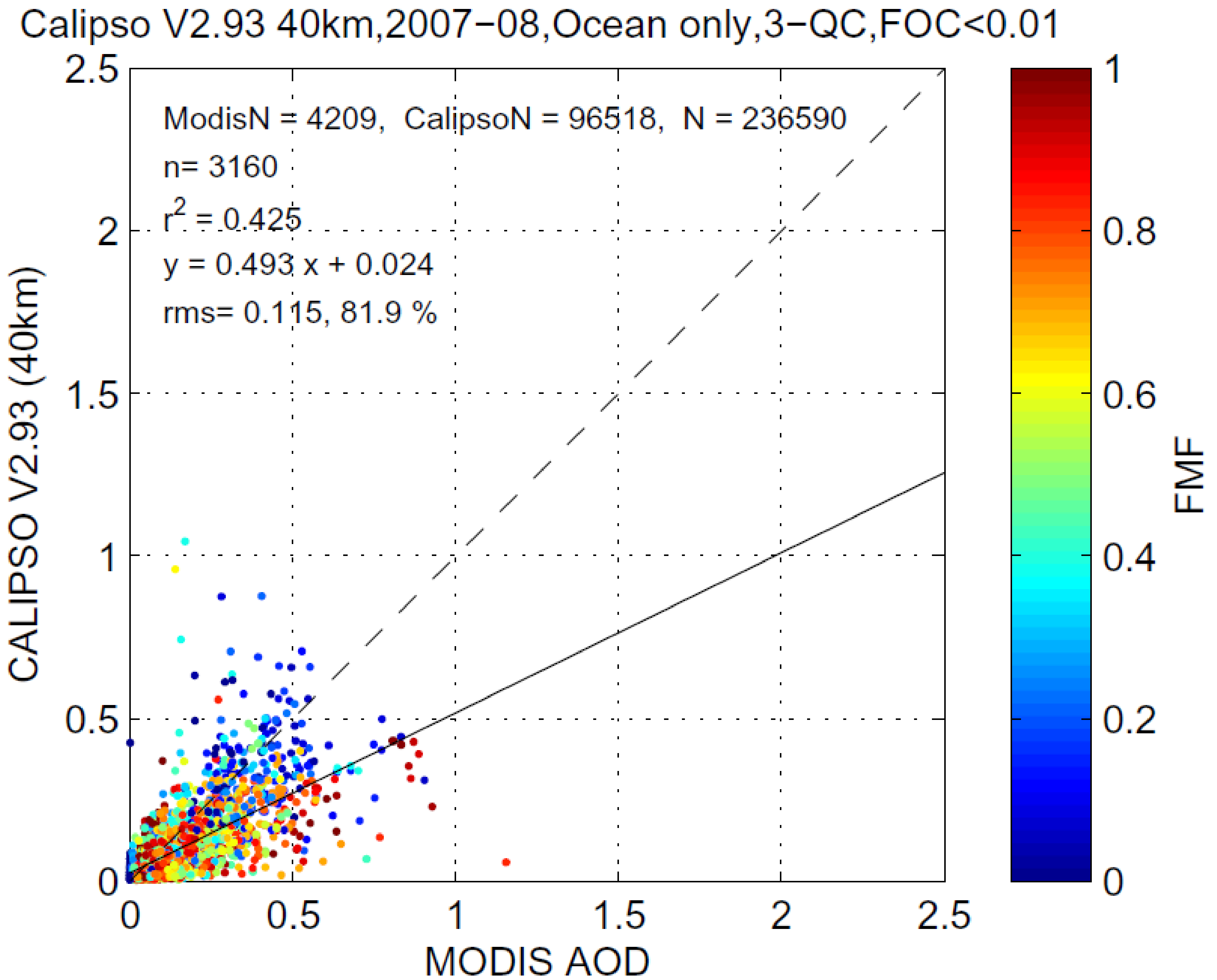
CALIOP successful AOD retrievals collocated with MODIS-Aqua: V2
August 2007

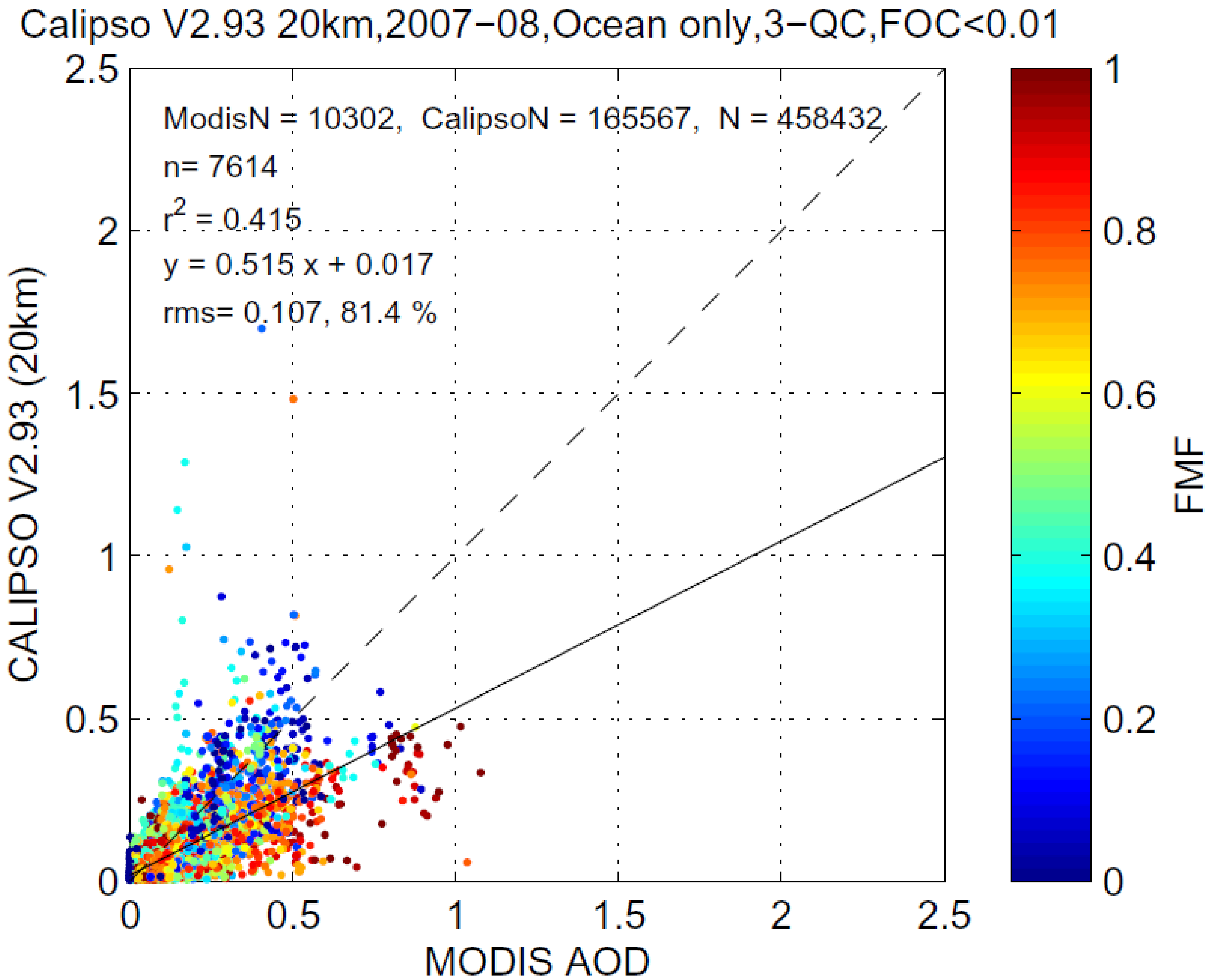


CALIOP successful AOD retrievals collocated with MODIS-Aqua: V2.93
August 2007



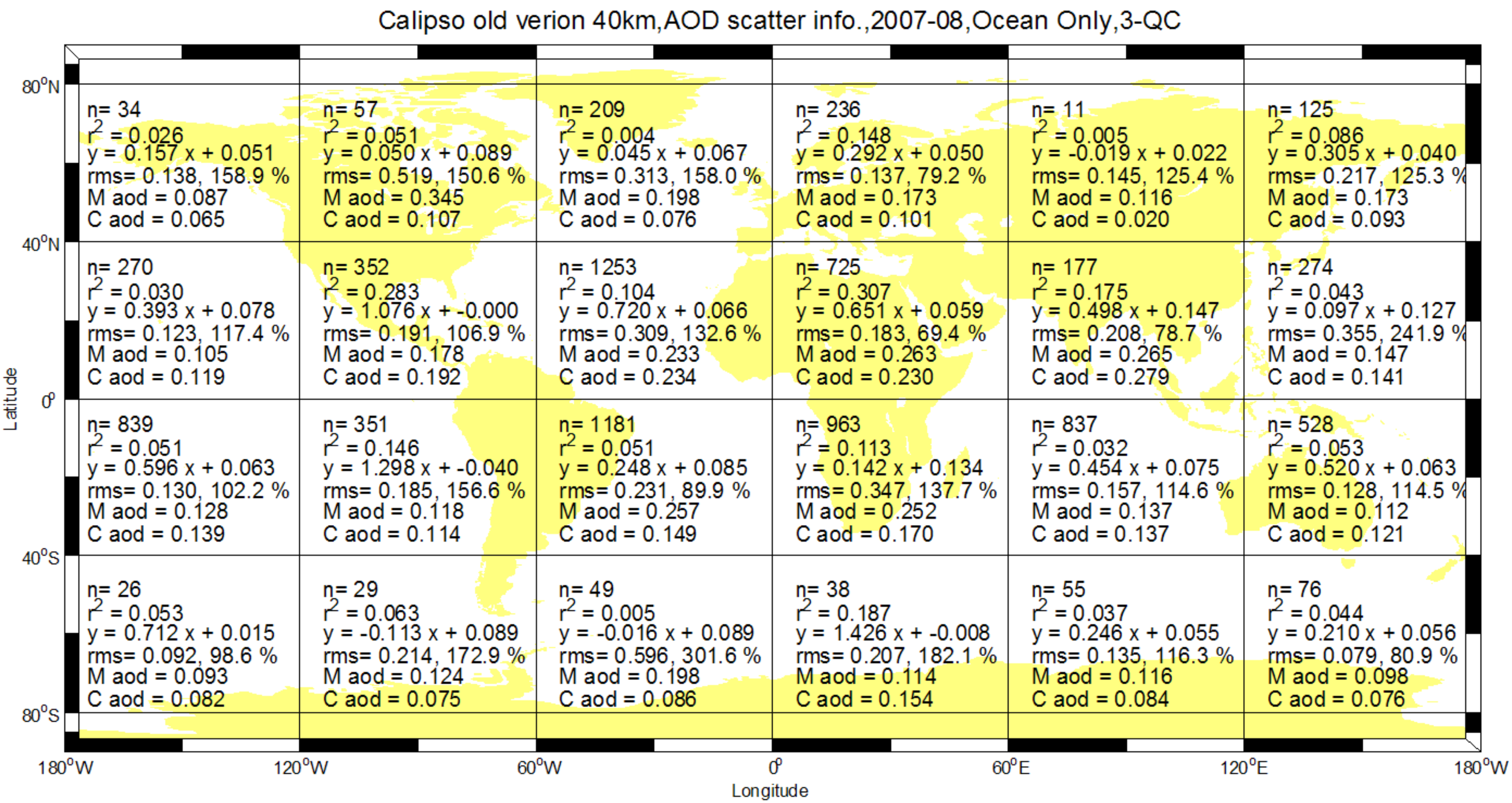

Calipso V2.93 40km,2007−08,Ocean only,3−QC
ModisN = 56030, CalipsoN = 96518, N = 236590
n= 43637
r2 = 0.113
y = 0.284 x + 0.048
rms= 0.156, 101.9 %
CALIPSO V2.93 (40km)
MODIS AOD
FMF
0
0.5
1
1.5
2
2.5
0.2
0.4
0.6
0.8


Calipso V2.93 40km,2007−08,Ocean only,3−QC,FOC<0.01
ModisN = 4209, CalipsoN = 96518, N = 236590
n= 3160
r2 = 0.425
y = 0.493 x + 0.024
rms= 0.115, 81.9 %
CALIPSO V2.93 (40km)
MODIS AOD
FMF
0
0.5
1
1.5
2
2.5
0.2
0.4
0.6
0.8

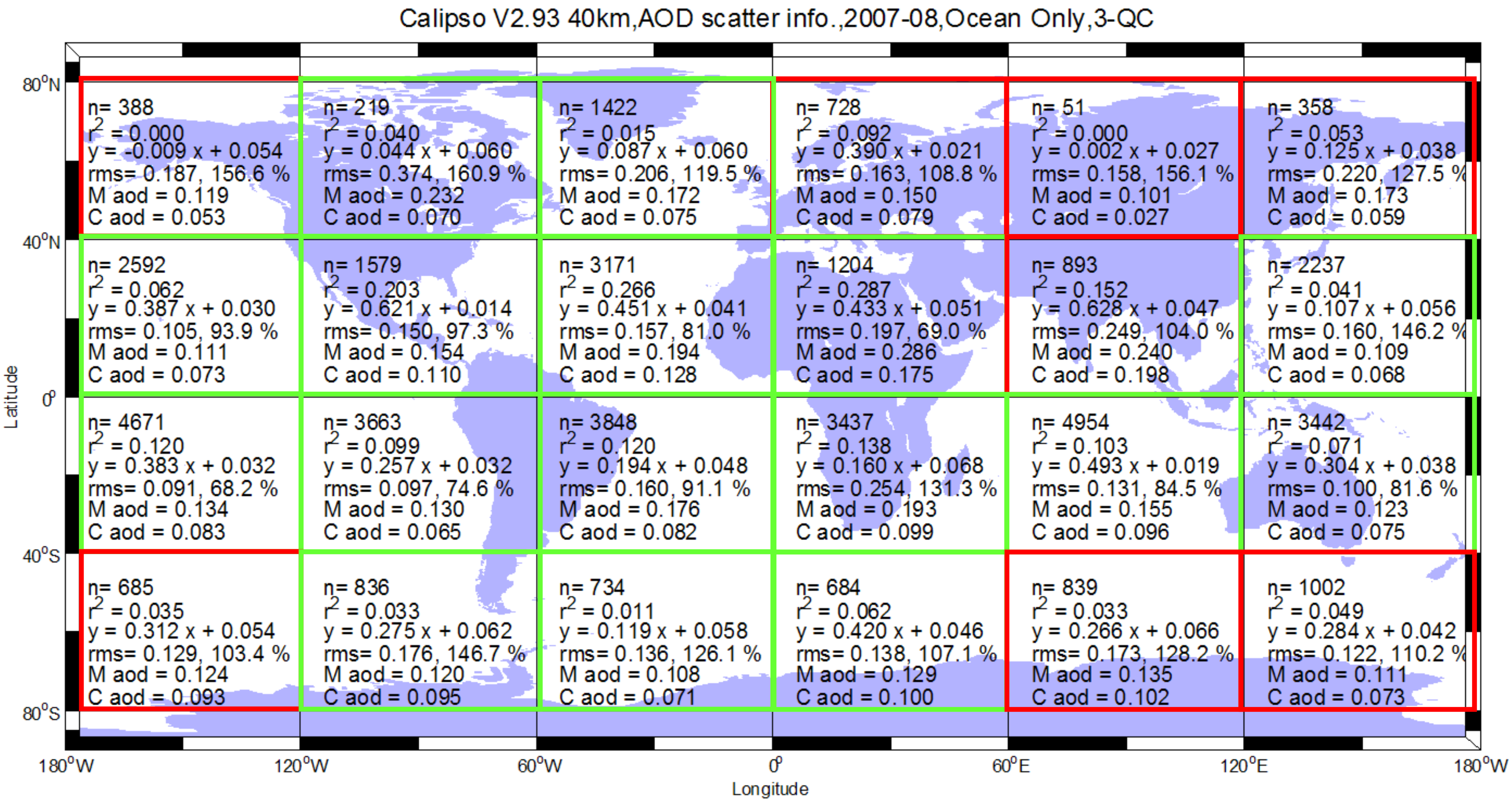


Calipso V2.93 20km,2007−08,Ocean only,3−QC,FOC<0.01
ModisN = 10302, CalipsoN = 165567, N = 458432
n= 7614
r2 = 0.415
y = 0.515 x + 0.017
rms= 0.107, 81.4 %
CALIPSO V2.93 (20km)
MODIS AOD
FMF
0
0.5
1
1.5
2
2.5
0.2
0.4
0.6
0.8

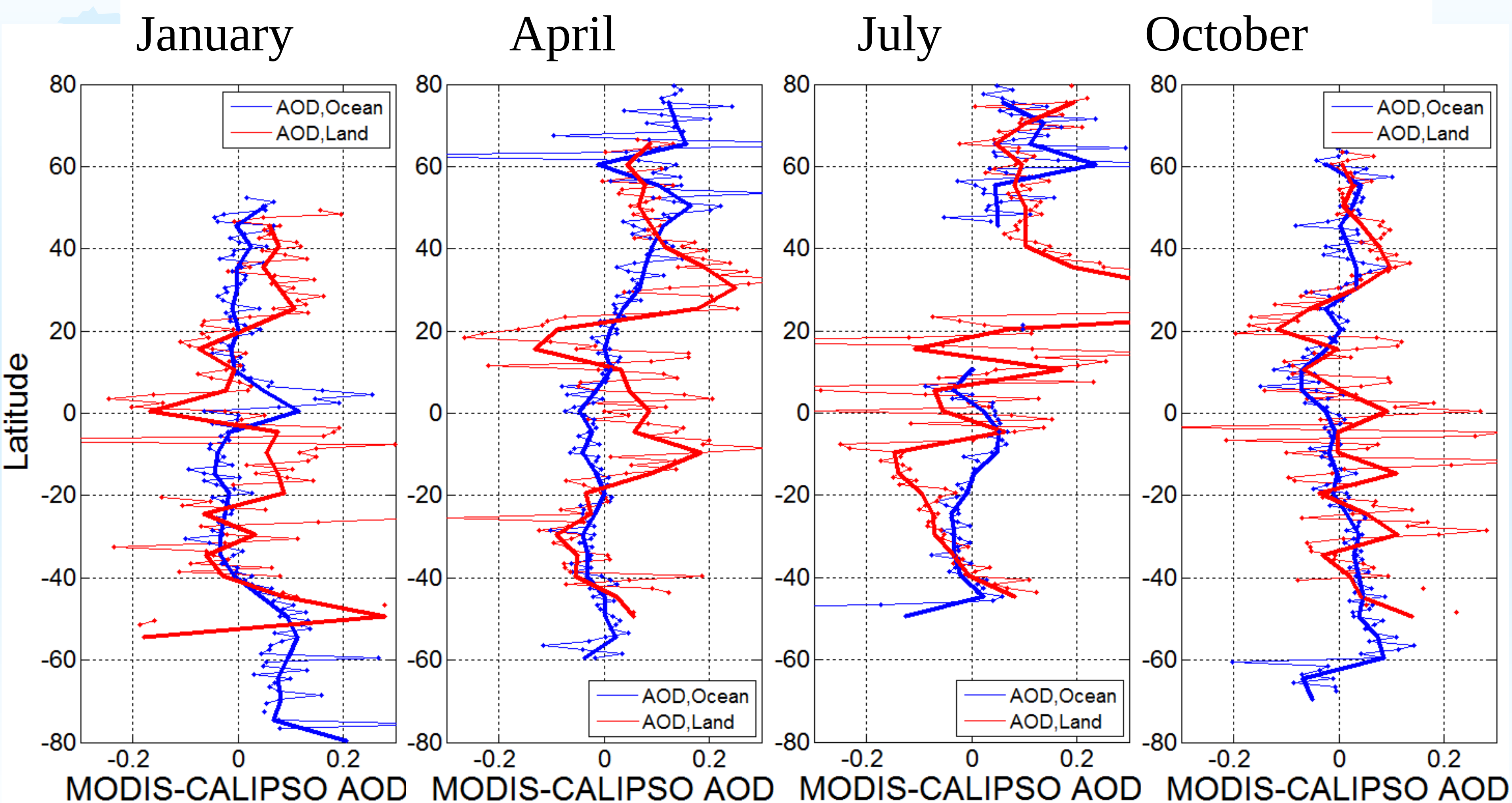
Geographical distribution of correlation data, all cloud fractions, V2



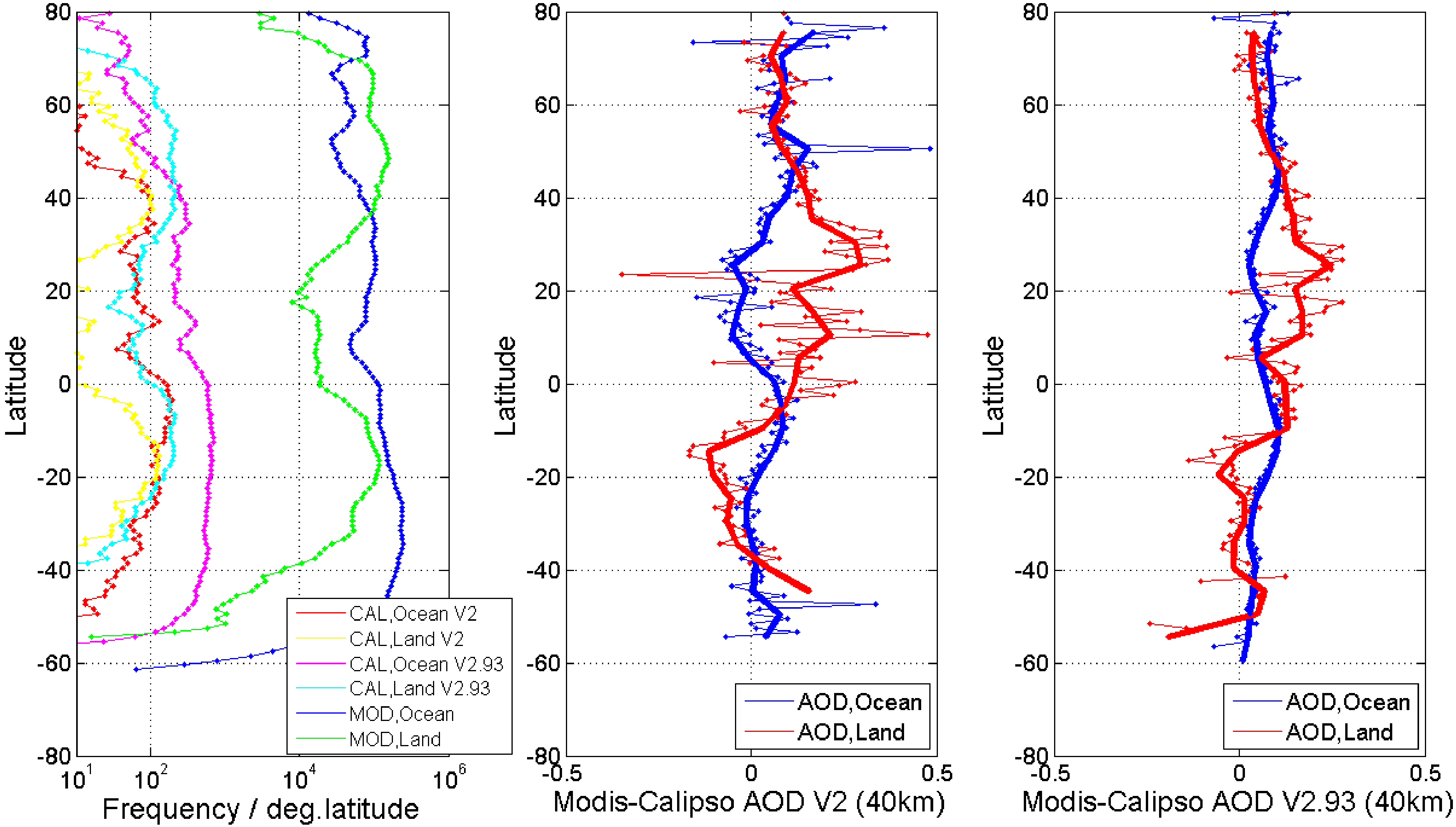
Geographical distribution of correlation data, all cloud fractions, V2.93



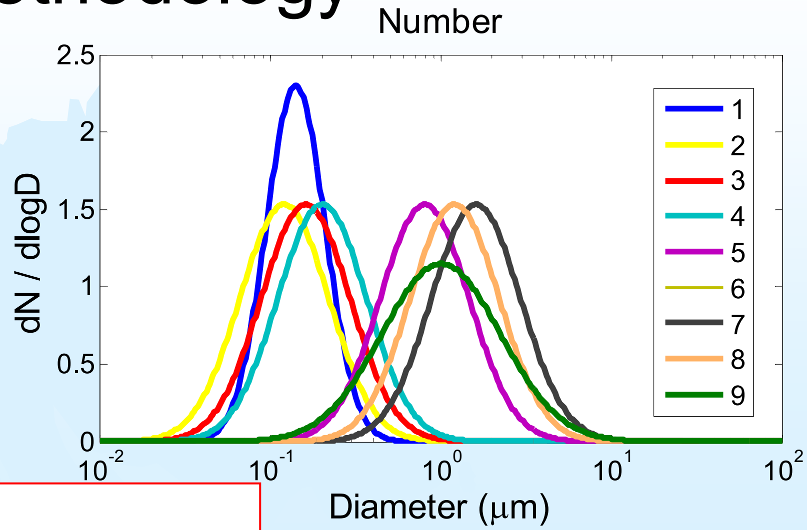
Zonal mean differences in AOD (550nm) from MODIS and CALIPSO over land and ocean during 4 months in 2007



Comparison of zonal distributions of data density and AOD between V2 and V2.93 (V3, pre-release)



Part 2: Retrieval of aerosol radiative properties from A-Train observations - Methodology



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- OMI AAOD (388 nm) + δAAOD
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- CALIPSO back (532 , 1064 nm) + δback

MODIS aerosol models:
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Free parameters: N_{fine}, N_{coarse}

Retrieval:
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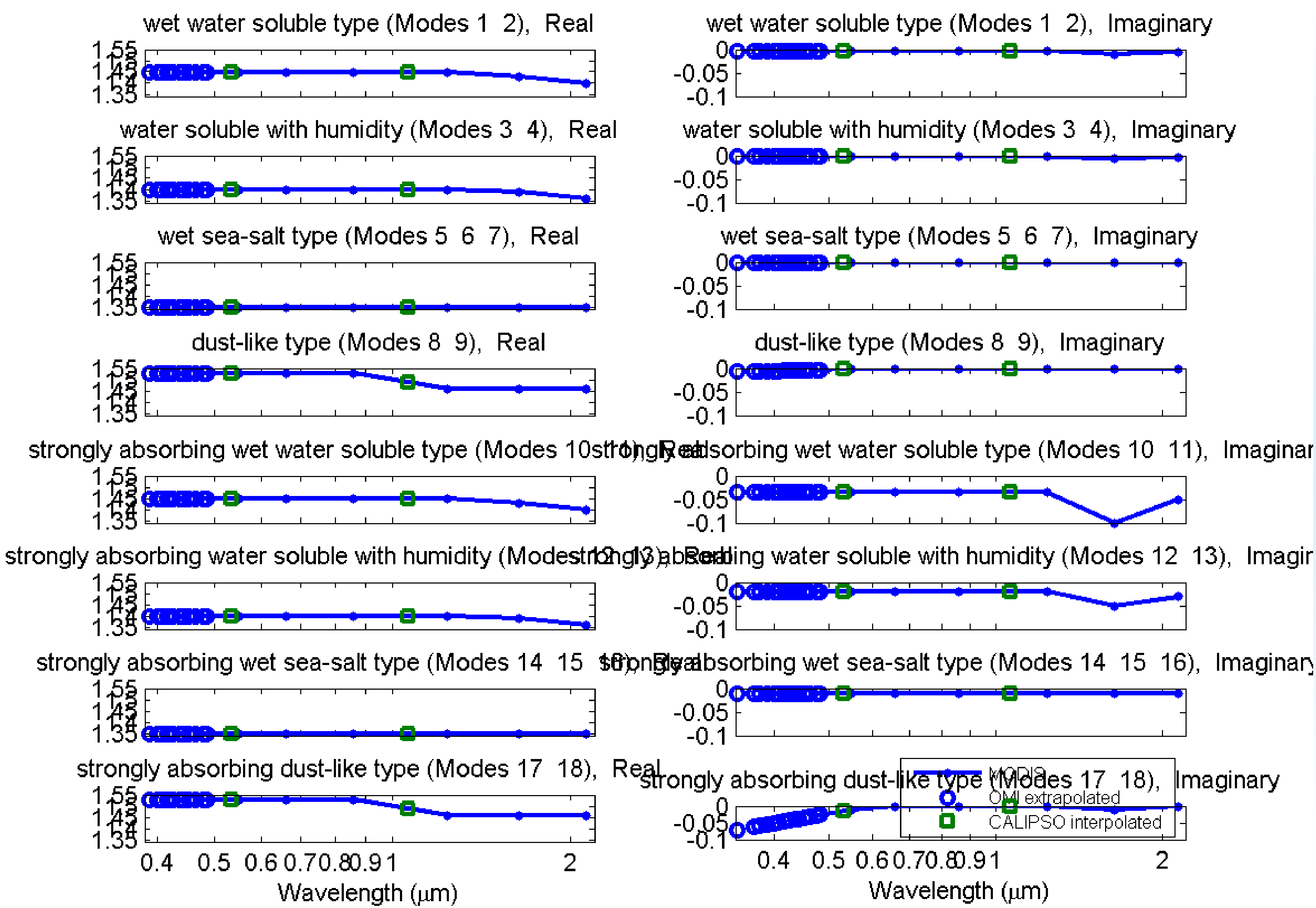
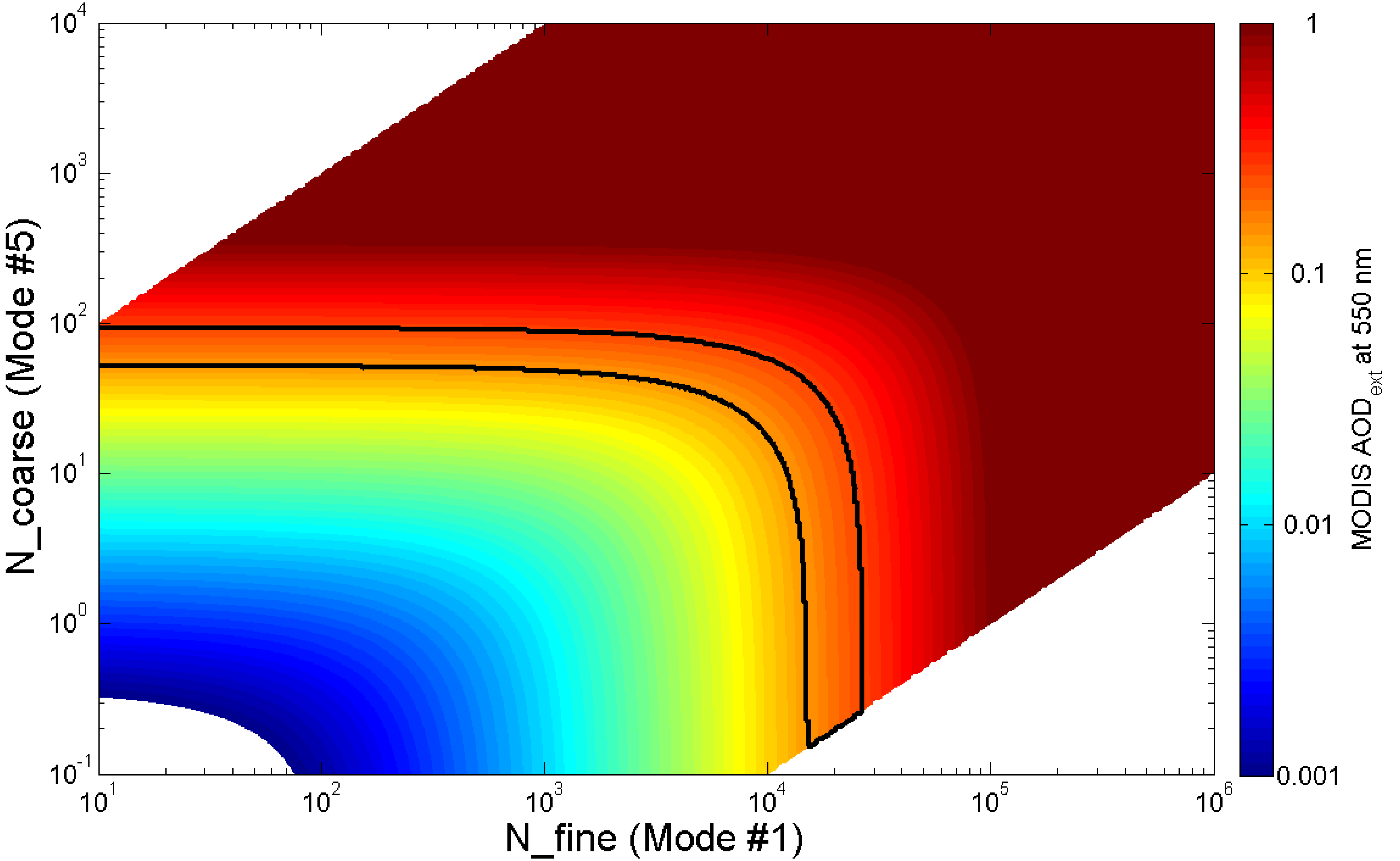
Rtx code

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

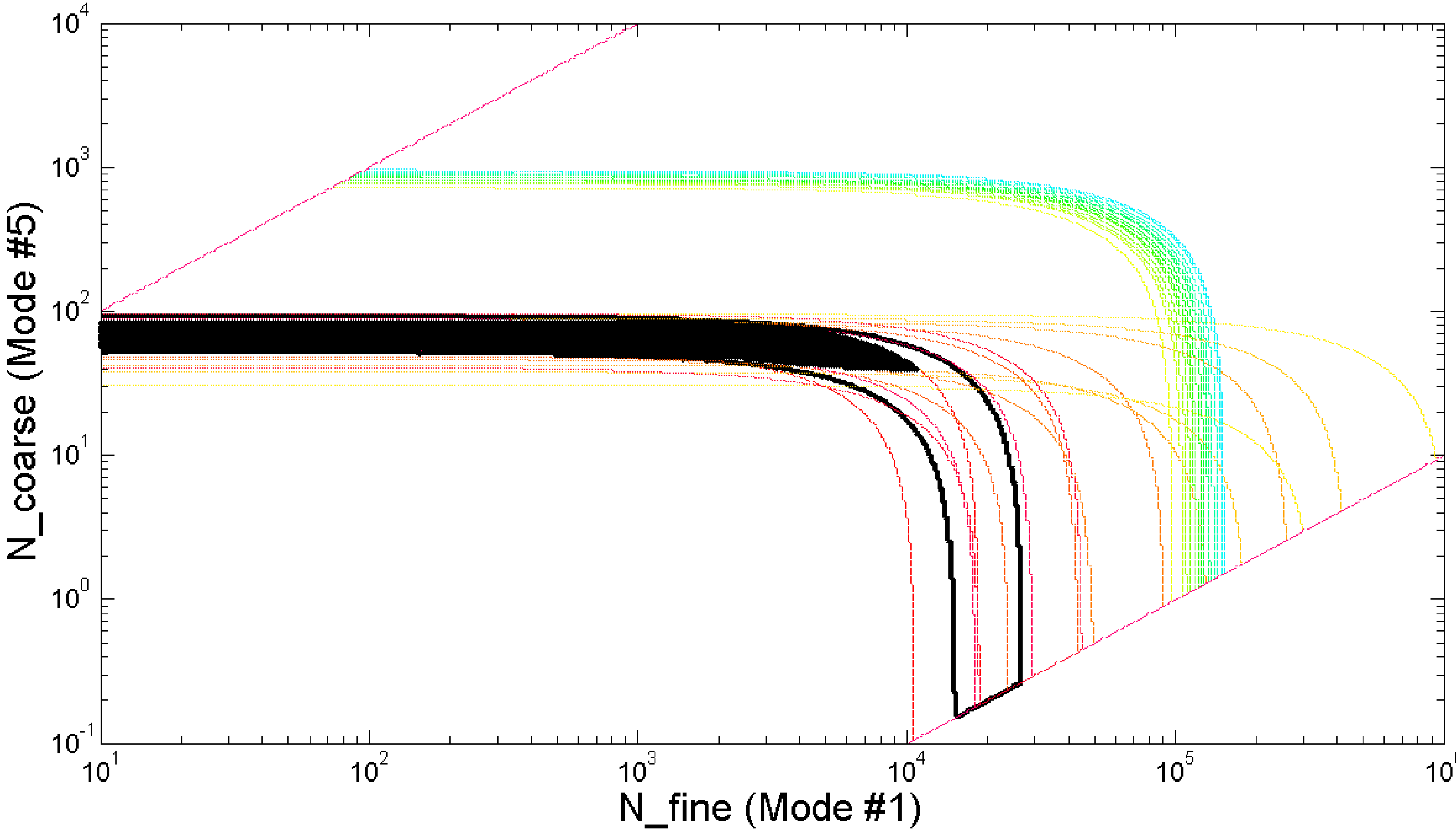
Refractive Index of MODIS modes as a function of wavelength



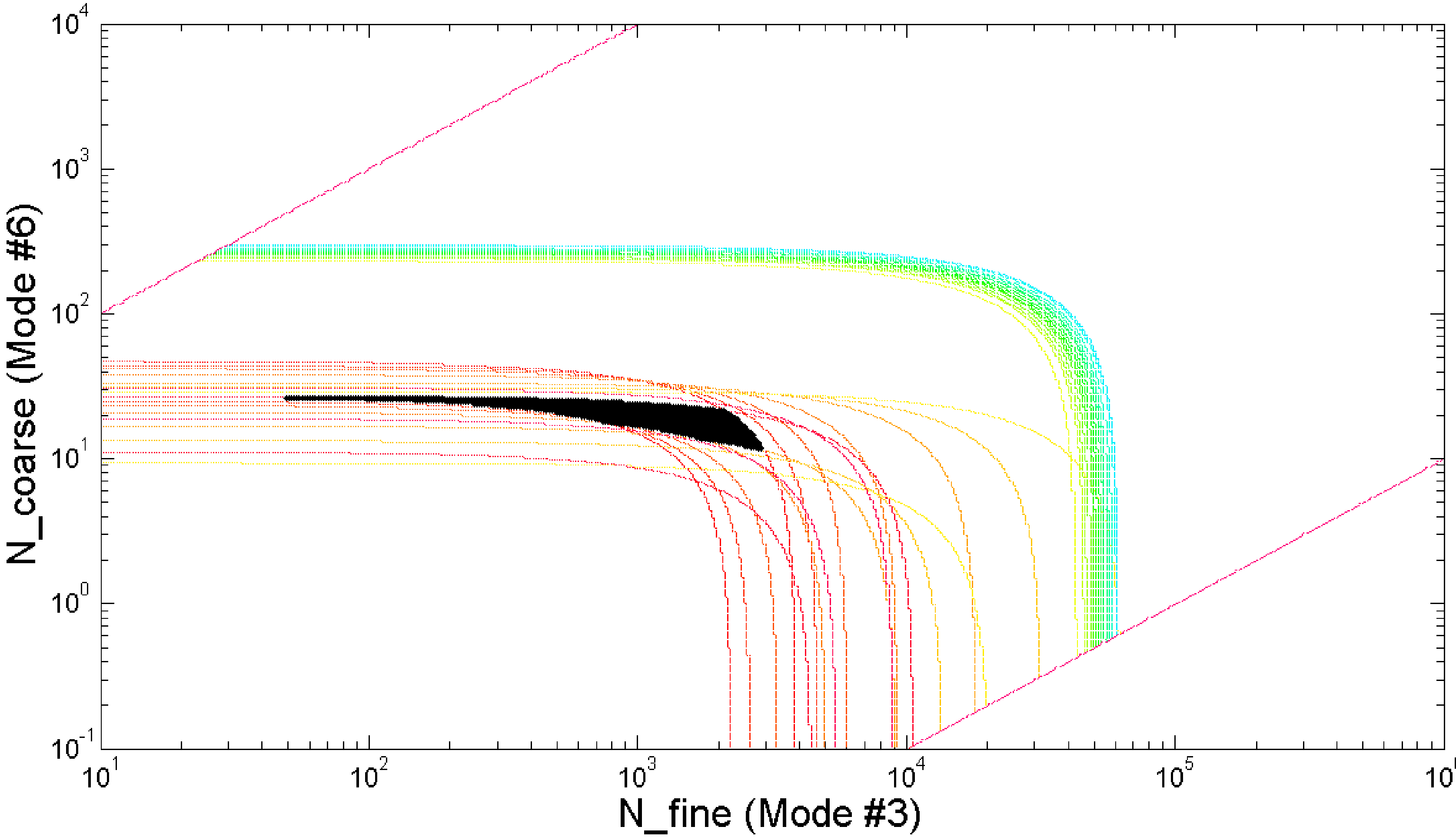
Step 1: Each observable (here AOD 550nm) is consistent with a range of fine/coarse mode particle concentrations for a given fine/coarse mode combination (here fine#1/coarse#5)



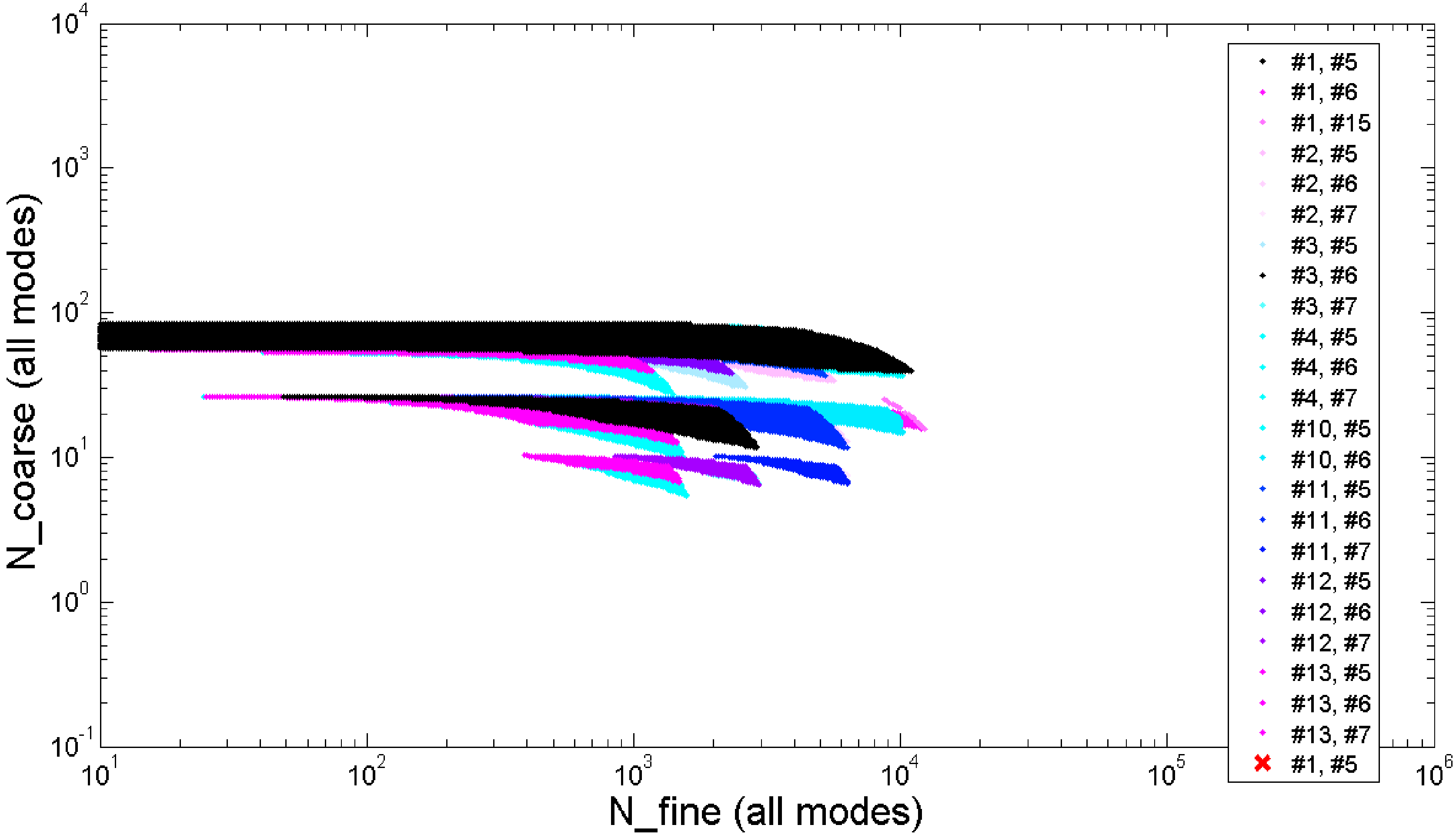
Step 2: The totality of all observables is consistent with a smaller range of fine/coarse mode particle concentrations for a given fine/coarse mode combination (here fine#1/coarse#5)



Step 3: For a different fine/coarse mode combination (here fine#3/coarse#6), the observables are consistent with a different range of fine/coarse mode particle concentrations



Step 4: For all possible fine/coarse mode combinations, the observables are consistent with a different range of fine/coarse mode particle concentrations



Current choices in retrieval method:

1)Metric

$$X = \left(\sum_i \log^2 \left(x_i / \hat{x}_i \right) \right)^{1/2}$$

x_i : retrieved parameters

$\hat{x}_i$: observables

2)Observables

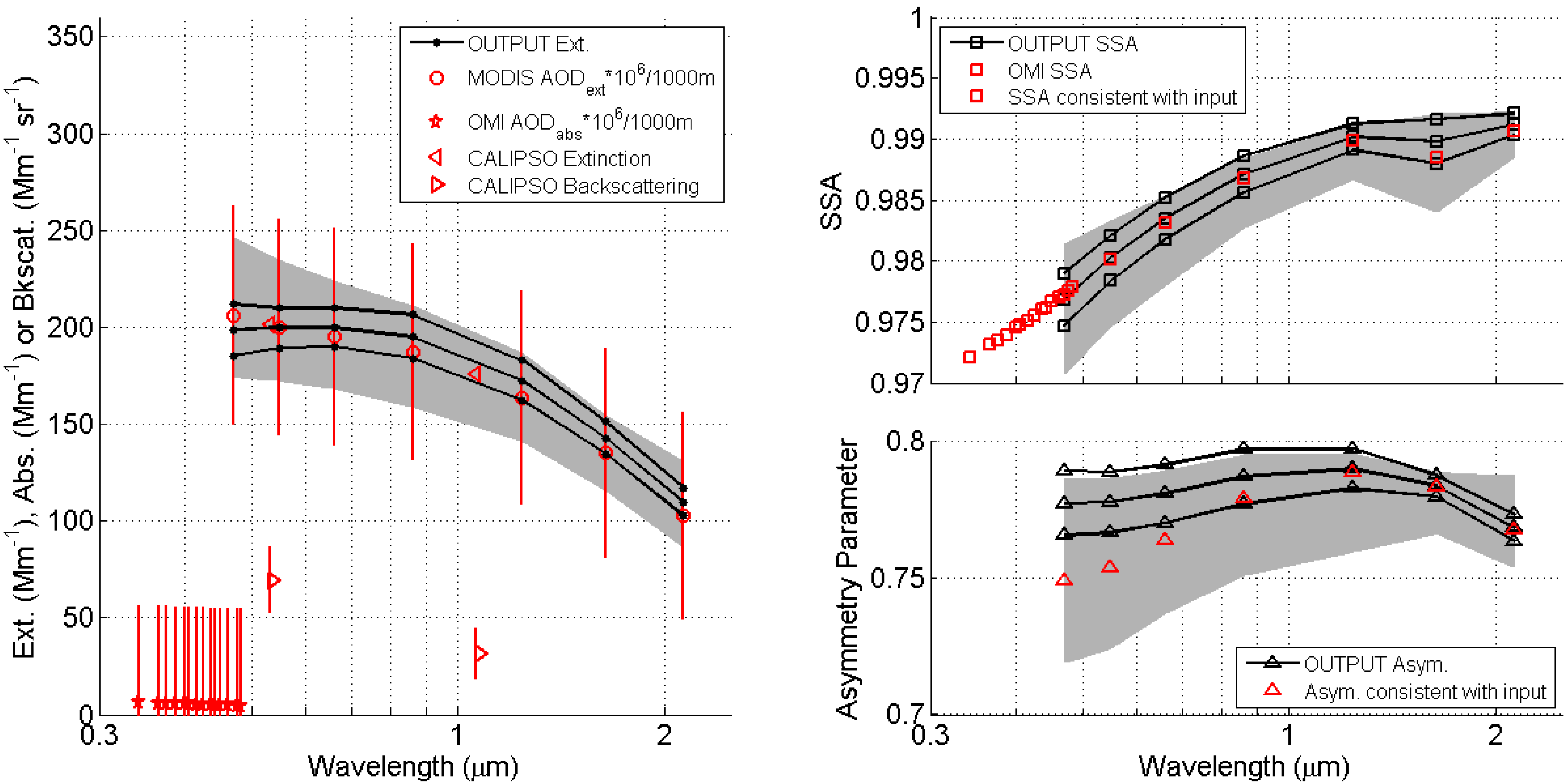
x_i = AOD 550nm, AOD 1240 nm (±0.03±5%) - MODIS

AAOD 388 nm (±0.03±5%) - OMI

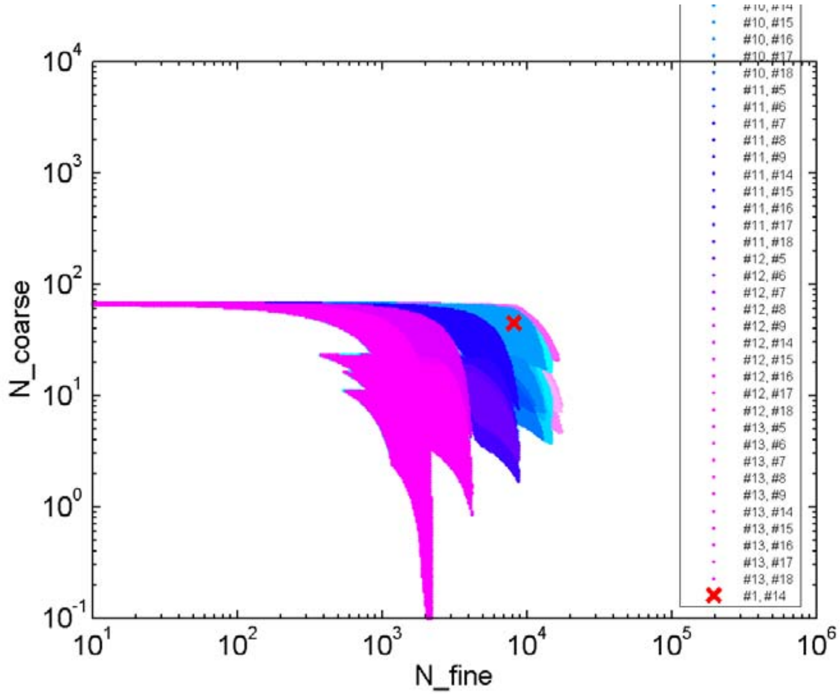
β_{532} (±10Mm^{-1}±10%) - CALIOP

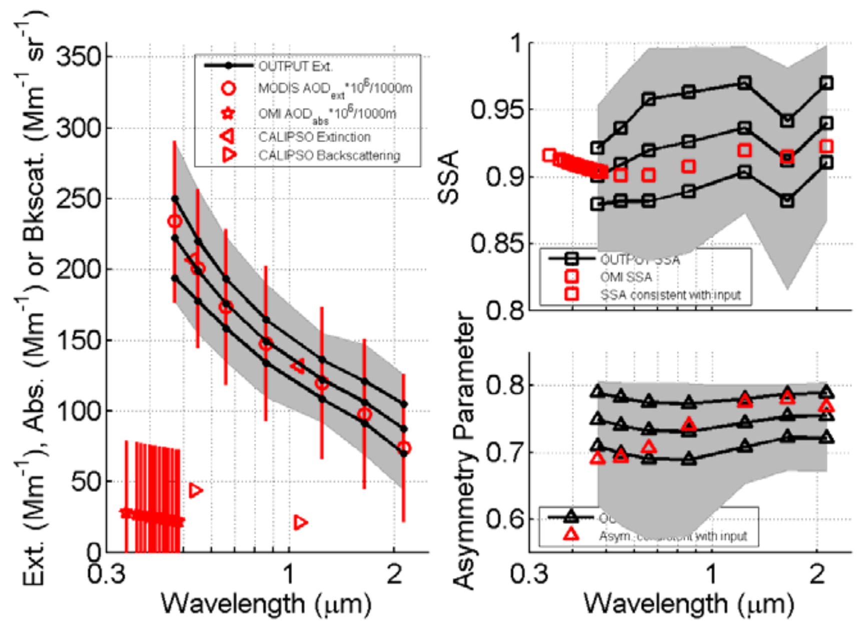
3)Use 10% best solutions in context of metric above

Step 5: The best 10% of possible fine/coarse mode combinations & concentrations, define a range of aerosol radiative properties.



Constraints afforded by lidar backscatter retrieval - 1



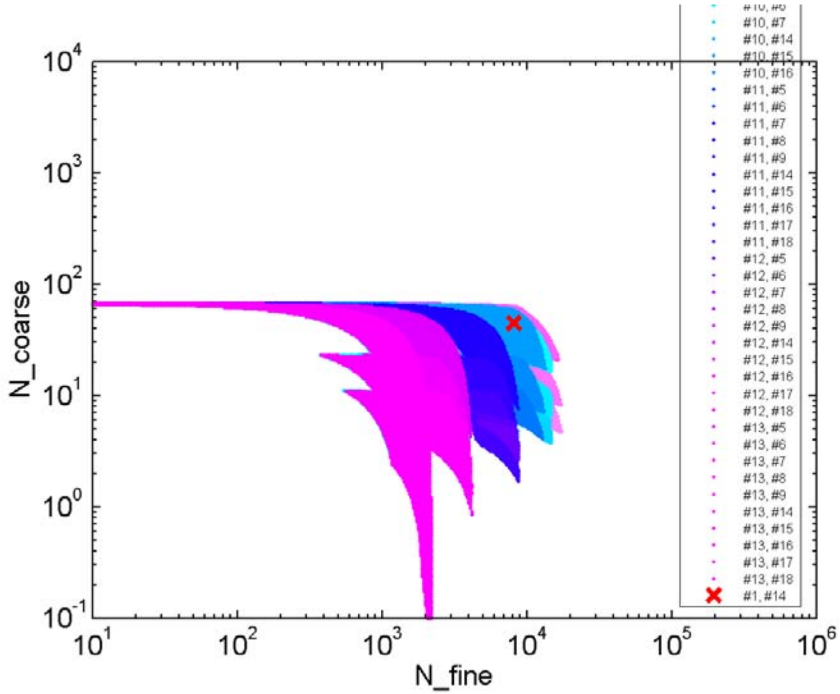


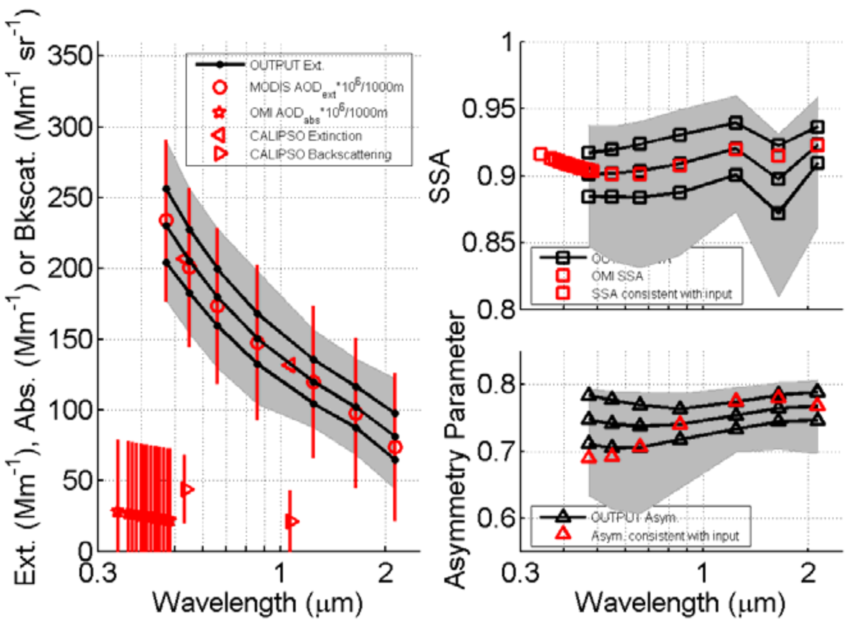
MODIS AOD (±0.03±5%)

OMI AAOD (±0.03±5%)

No CALIOP β_{532}

Constraints afforded by lidar backscatter retrieval - 2



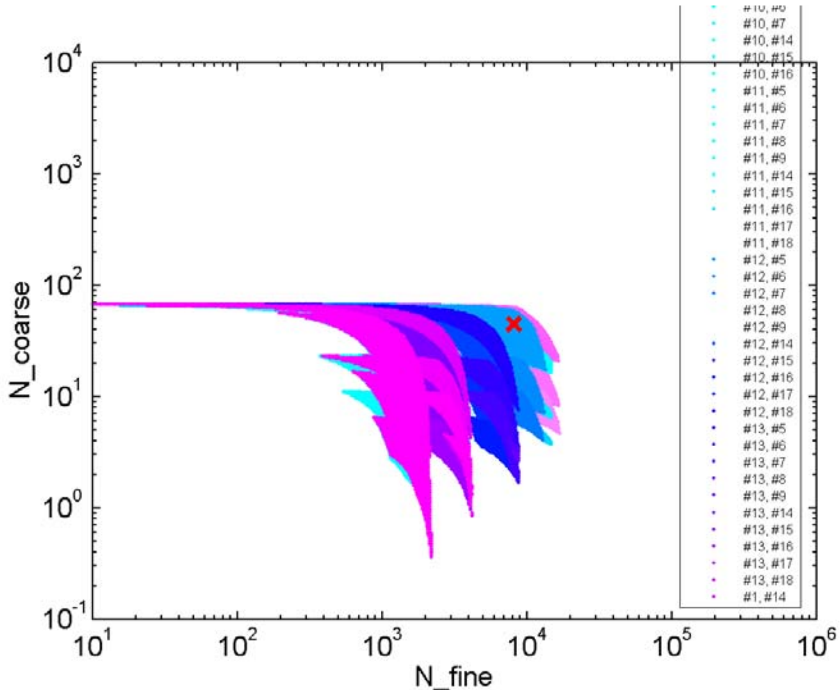


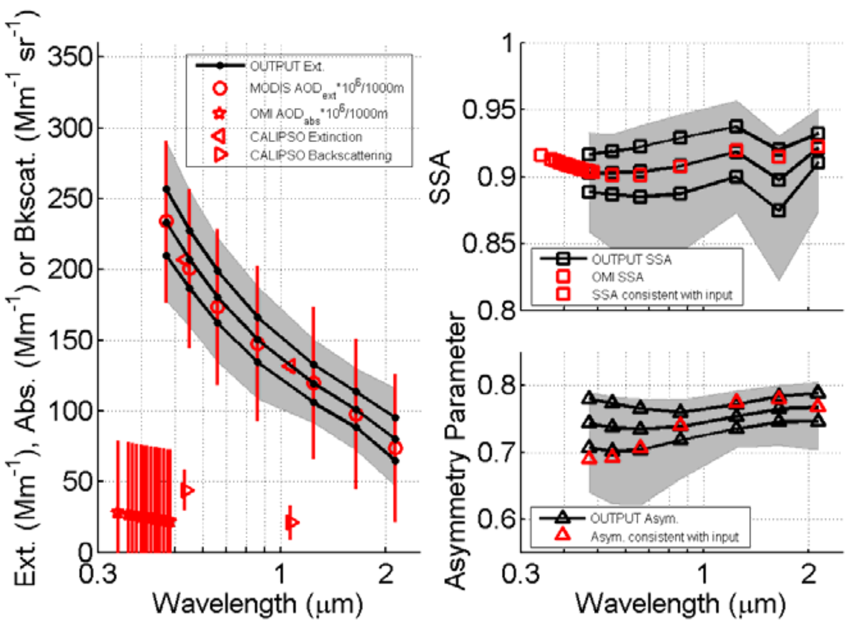
MODIS AOD (±0.03±5%)

OMI AAOD (±0.03±5%)

CALIOP β_{532} (±20Mm^{-1}±10%)

Constraints afforded by lidar backscatter retrieval - 3



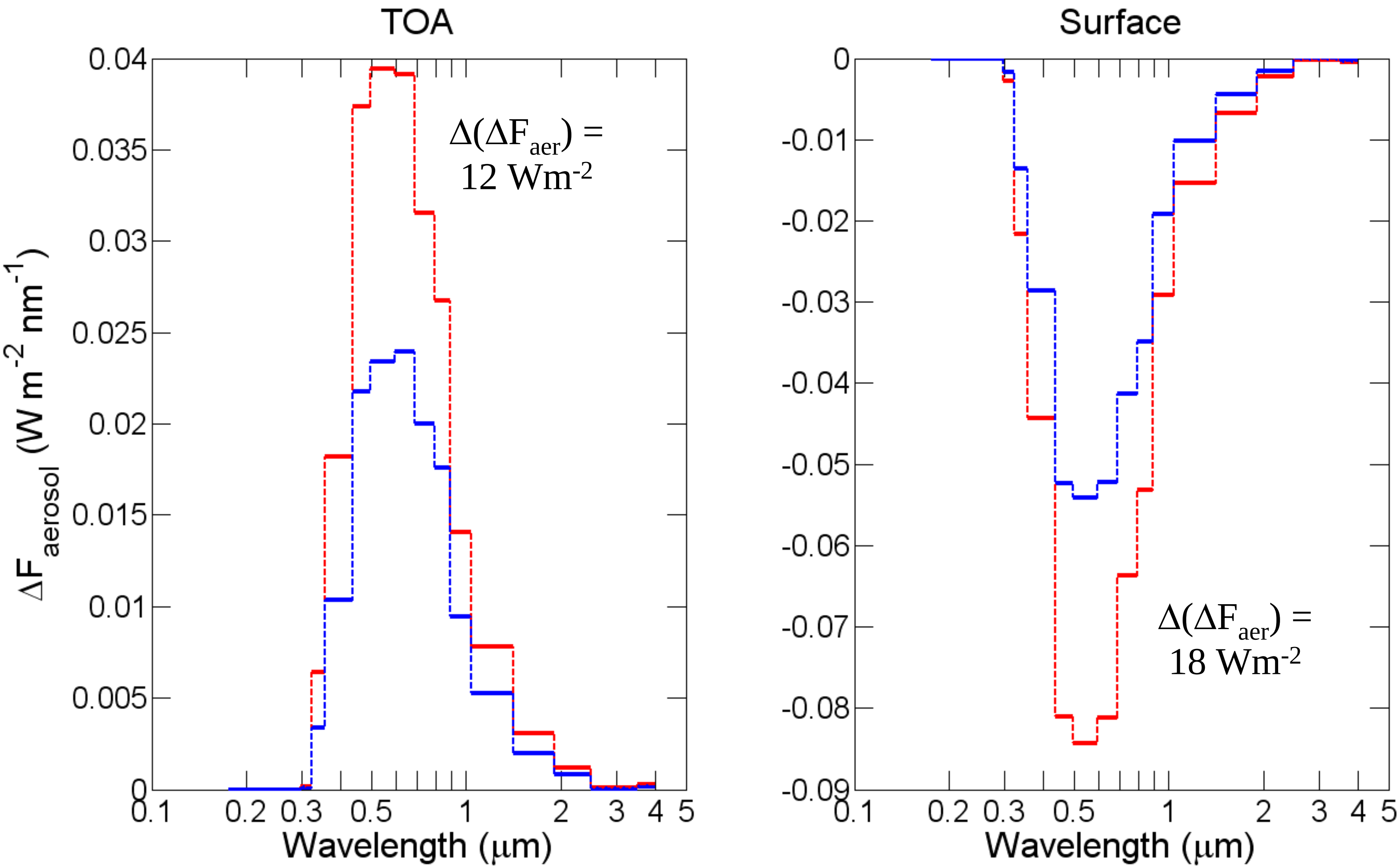


MODIS AOD (±0.03±5%)

OMI AAOD (±0.03±5%)

CALIOP β_{532} (±10Mm^{-1}±10%)

Impact of retrieval uncertainty on instantaneous aerosol DRE



Sensitivity: MODIS AOD (±0.03+5%), OMI AAOD (±0.03+5%), CALIOP β_{532} (±10Mm^{-1}±10%)

EXTINCTION

AOD\SSA	0.8	0.9	0.98
0.05	58.84 +/- 14.88 (30.88/97.62) input 50.13	49.40 +/- 13.03 (23.98/96.49) input 49.93	47.53 +/- 13.73 (25.75/93.67) input 50.01
0.2	201.71 +/- 6.87 (187.96/219.39) input 199.29	206.81 +/- 20.30 (159.51/256.14) input 200.54	199.62 +/- 10.33 (172.22/234.64) input 200.11
0.7	696.87 +/- 6.23 (689.88/717.68) input 699.13	708.94 +/- 22.61 (665.50/759.05) input 699.23	702.61 +/- 23.40 (664.51/762.79) input 699.91

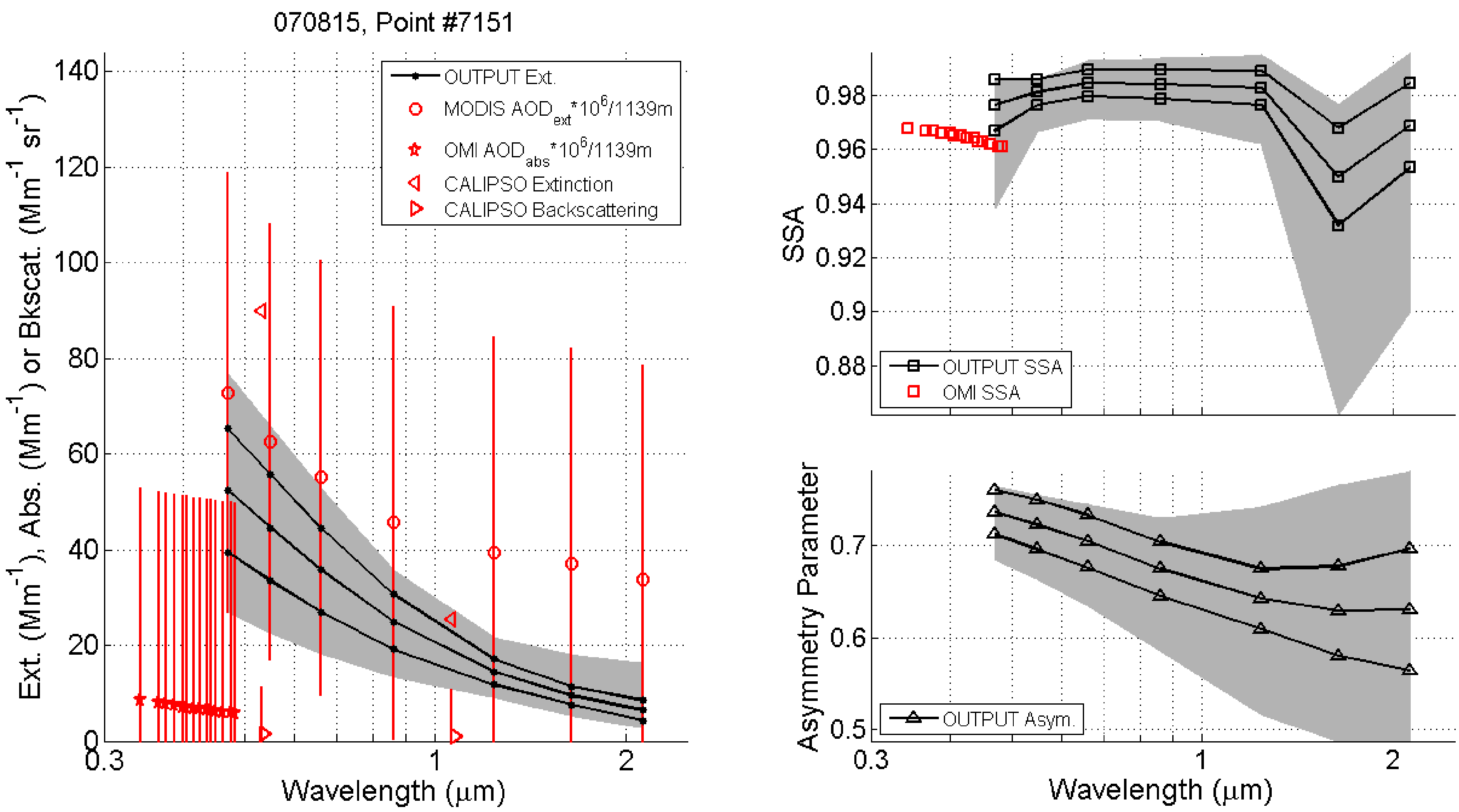
SSA

AOD\SSA	0.8	0.9	0.98
0.05	0.83 +/- 0.05 (0.75/0.94) input 0.80	0.87 +/- 0.05 (0.75/0.98) input 0.90	0.97 +/- 0.01 (0.94/0.99) input 0.98
0.2	0.80 +/- 0.01 (0.77/0.83) input 0.80	0.90 +/- 0.02 (0.85/0.93) input 0.90	0.98 +/- 0.00 (0.97/0.98) input 0.98
0.7	0.80 +/- 0.00 (0.80/0.81) input 0.80	0.90 +/- 0.00 (0.89/0.91) input 0.90	0.98 +/- 0.00 (0.98/0.98) input 0.98

ASYMMETRY

AOD\SSA	0.8	0.9	0.98
0.05	0.80 +/- 0.04 (0.62/0.85) input 0.83	0.76 +/- 0.05 (0.56/0.85) input 0.69	0.77 +/- 0.03 (0.61/0.80) input 0.75
0.2	0.82 +/- 0.01 (0.79/0.84) input 0.83	0.74 +/- 0.04 (0.62/0.78) input 0.69	0.78 +/- 0.01 (0.72/0.79) input 0.75
0.7	0.83 +/- 0.00 (0.82/0.83) input 0.82	0.71 +/- 0.02 (0.68/0.73) input 0.69	0.77 +/- 0.01 (0.73/0.79) input 0.75

Example of successful retrieval from actual collocated OMI, MODIS, CALIOP (V2.93) data: Aug. 15, 2007



Conclusions

A. Different cloud screening techniques and assumptions in MODIS, OMI, and CALIPSO have serious implications for the use of collocated data.

B. Monthly AOD comparisons show decent agreement after severe cloud clearing, and regional and zonal averaging. Initial comparisons of CALIOP V2.93 to MODIS-Aqua show increased data density and generally smaller rms differences from 40ºS to 40ºN.

C. A methodology for the retrieval of aerosol radiative properties from MODIS AOD, OMI AAOD and CALIPSO β_{532} has been devised.

D. A sensitivity study of current method shows good retrievals for almost all AOD/ssa combinations with AOD greater or equal to 0.2.

E. Next steps:

1) Test retrieval assumptions (metric, solution space, etc.)
2) Use CALIOP V3
3) Constrain OMI AOD retrievals with CALIOP height input
4) Testing additional constraints afforded by APS
5) Testing radiative properties against suborbital data
6) rtx calculations to assess $\delta\,\Delta F_{aerosol}(z)$
7) Aerosol DRE above clouds