A Global Aerosol Absorption Product from OMI Near UV Observations

Changwoo Ahn
(SSAI/NASA-GSFC)

Omar Torres (NASA-GSFC), Hiren Jethva (USRA/NASA-GSFC)

Oct 14 - 17 , 2013
The 4th GEMS Science Meeting in Seoul, Korea

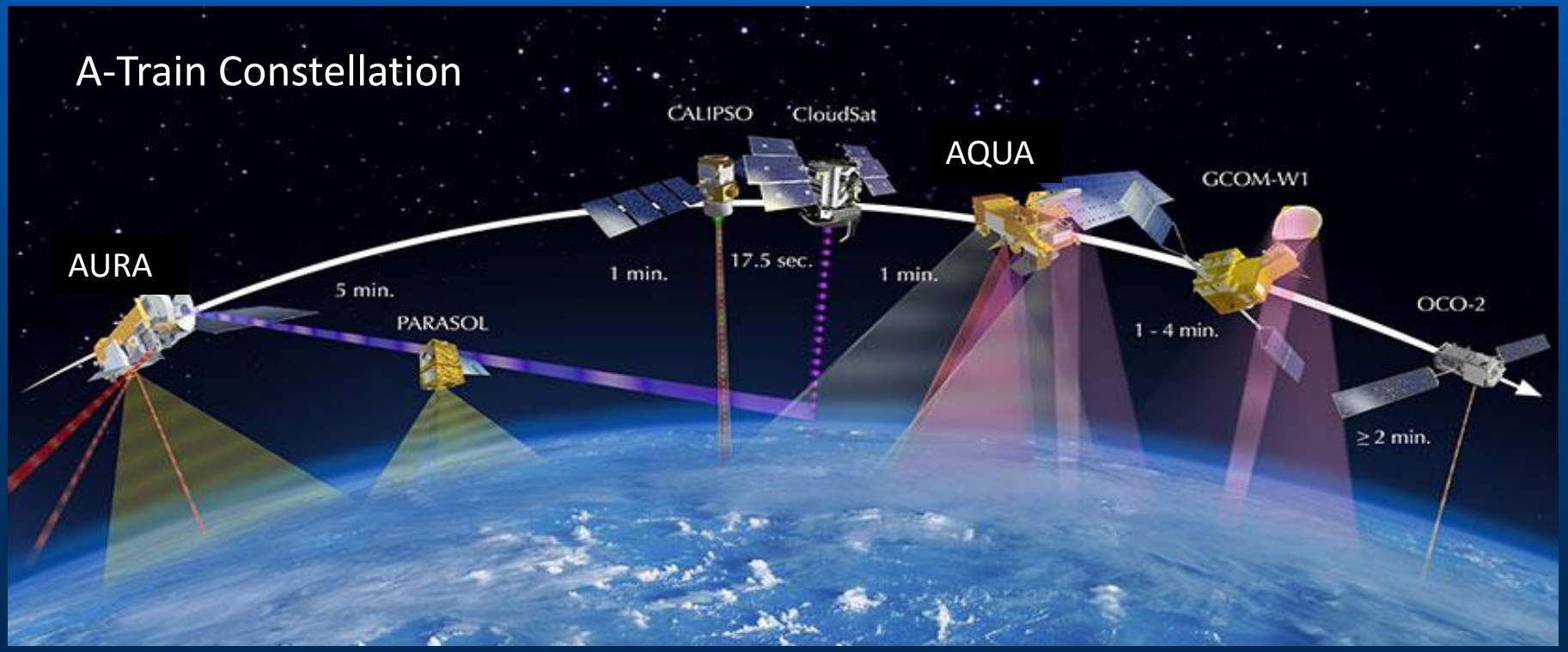
Outline

- OMI UV aerosol algorithm (OMAERUV)
  - Aerosol type determination
  - Aerosol layer height from CALIOP
  - QA flagging scheme
  - Retrieval method
- Validation results
- Summary

Aura/Ozone Monitoring Instrument (OMI)

- The OMI instrument built by the Netherlands's Agency for Aerospace Programs (NIVR) in collaboration with the Finnish Meteorological Institute (FMI) onboard the NASA's EOS Aura spacecraft has the hyperspectral capability (270 - 500 nm) for monitoring the atmospheric compositions such as total and profile O3, NO2, SO2, BrO, OClO, CH2O, and ***aerosols.***
- Launch date **:** July 15, 2004
- TOMS + OMI provides longest record on ozone and aerosols.

OMI footprint size 13 x 24 km^2 at nadir, 2600 km Swath



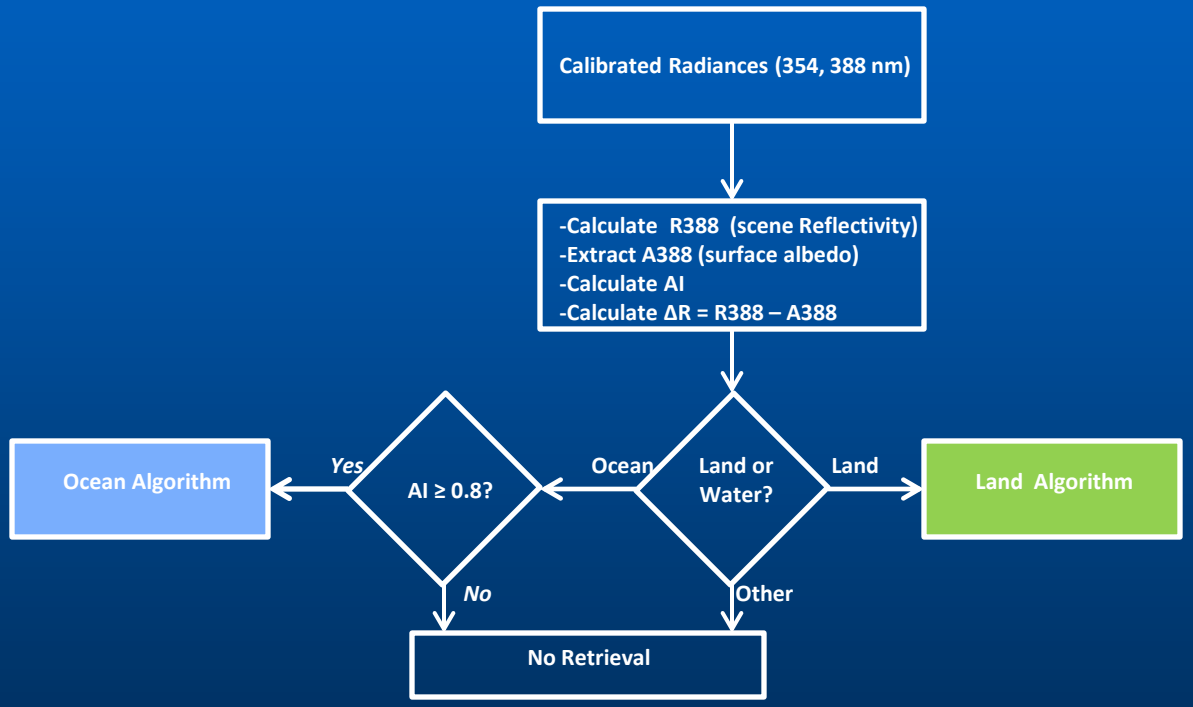
OMAERUV Algorithm

Aerosol absorption quantification using near UV observations, based on TOMS heritage.

Ancillary Data:
- Global Monthly Climatology of Surface Albedo (354, 388 nm)
- Global Monthly Climatology of Aerosol Layer Height (CALIOP)
- Global surface type distribution (CERES)
- Real Time CO data from AIRS

21 Aerosol Models (LUT's):
- Three major aerosol Types: Assumed PSD and real refractive index
  Desert Dust (DD), Carbonaceous (CB), Sulfate-based (SF)
- Each type is further categorized in 7 sub-types (varying absorption)

Nodal points on viewing geometry, AOD, ALH, SSA

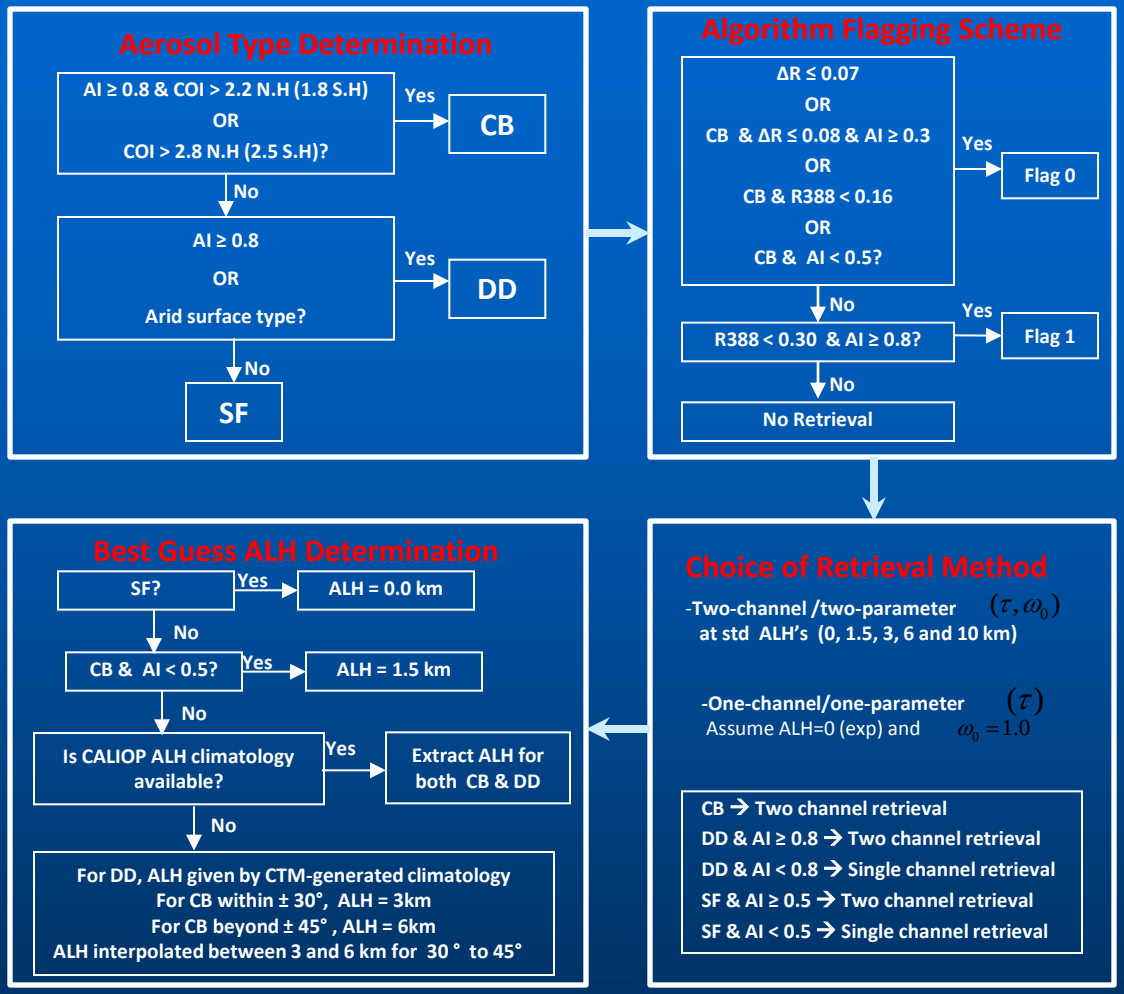


Ocean Algorithm: Absorbing Aerosols (Smoke/Dust) as identified by AI
(Difficulty in Separating Aerosol from Ocean Color Signal) for AI < 0.8

Land Algorithm: All aerosol types regardless of AI considerations.

Torres et al, JAS, 2007

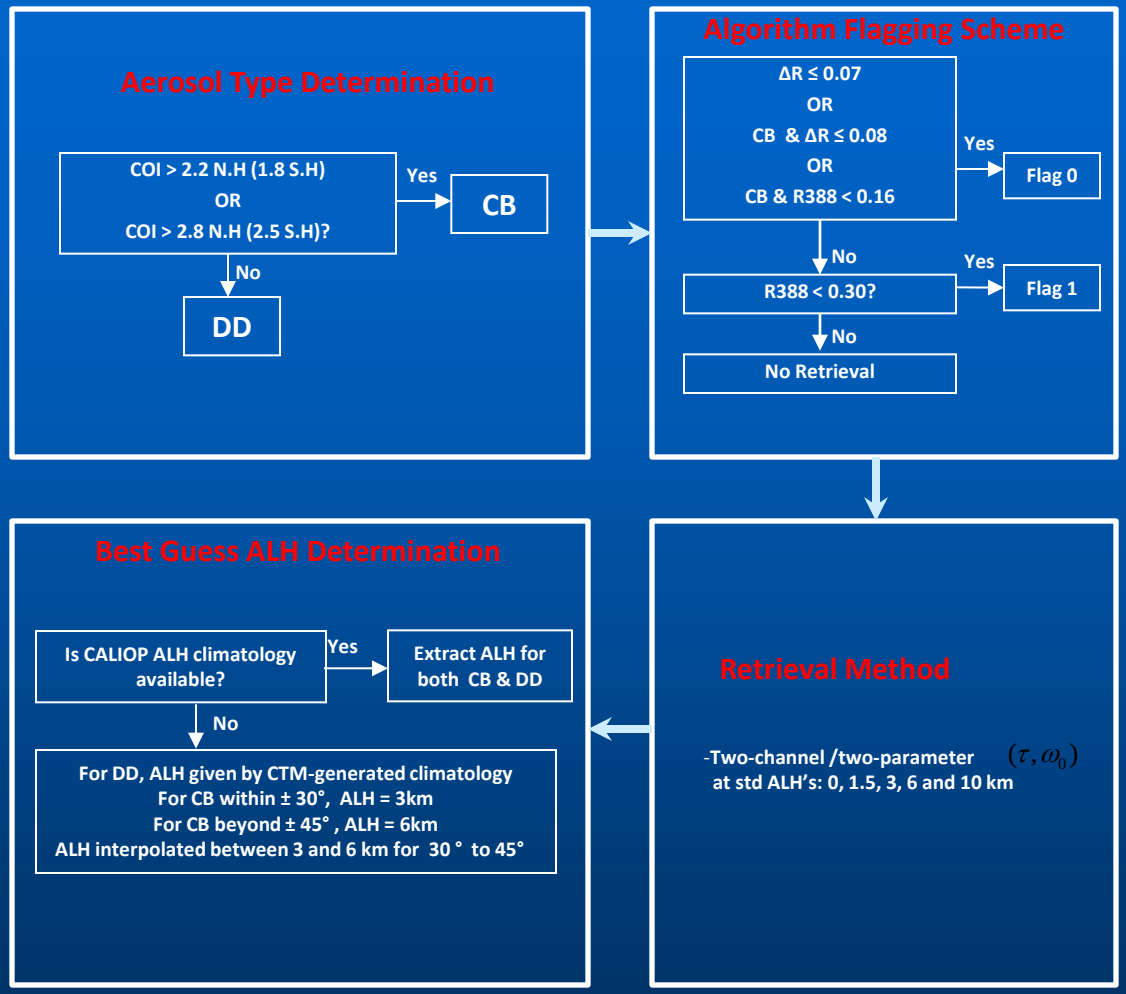
OMAERUV Land Algorithm



Retrieval Product

τ, ω_0 at 388 nm (*also reported at 354 and 500 nm*) at std ALH's (0,1.5,3.0,6.0 and 10 km) and a best guess ALH (generally from CALIOP climatology)

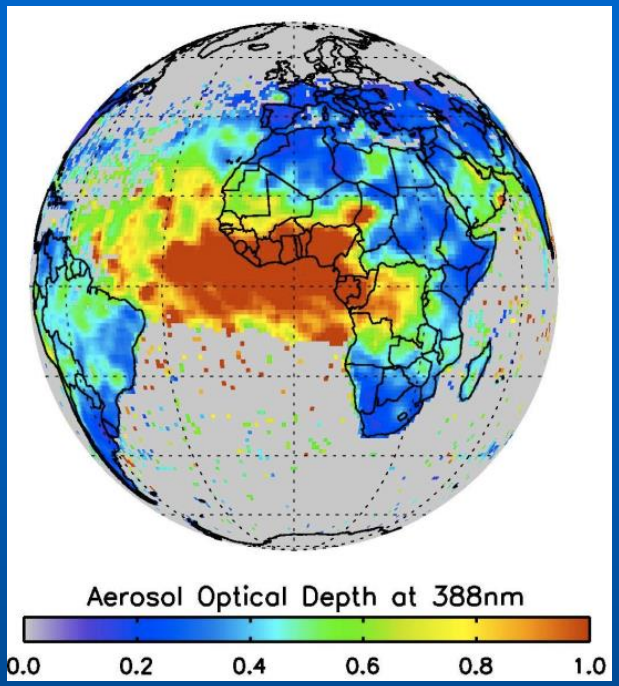
OMAERUV Ocean Algorithm

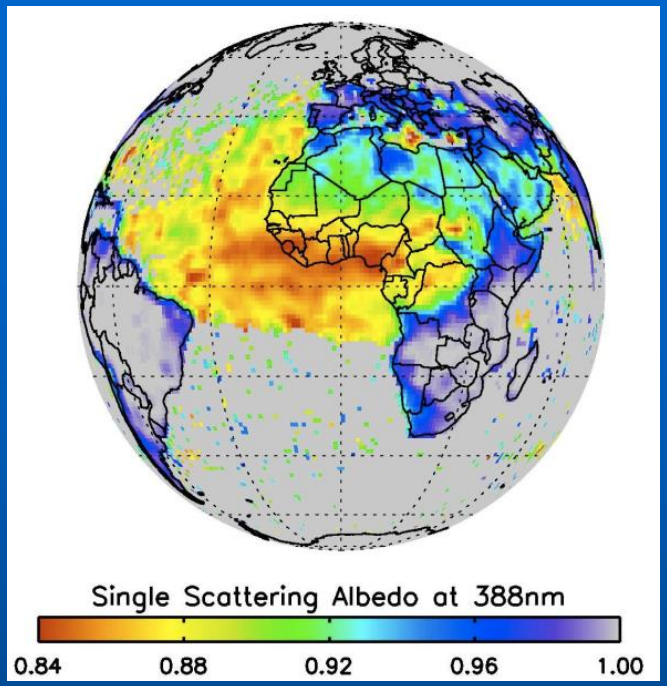


Retrieval Product

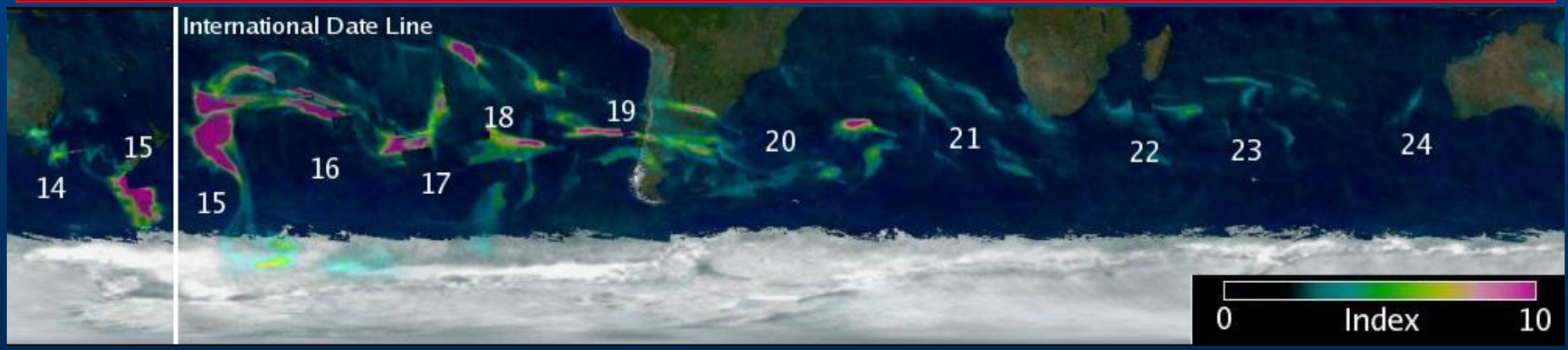
τ, ω_0 at 388 nm (*also reported at 354 and 500 nm*) at std ALH's (0,1.5,3.0,6.0 and 10 km) and a best guess ALH (generally from CALIOP climatology)

OMI UV Aerosol Products : AOD, SSA, and AI

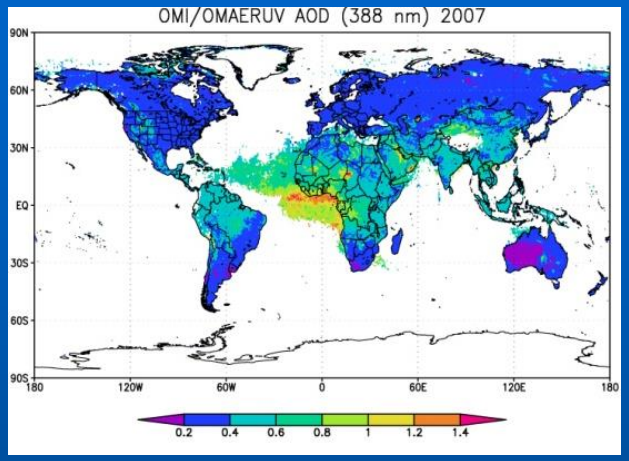


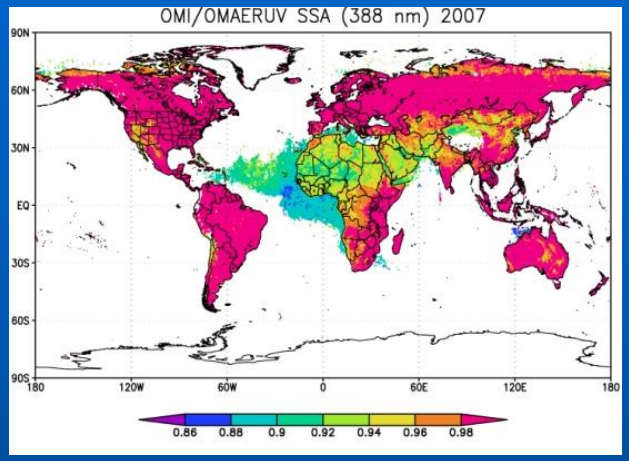


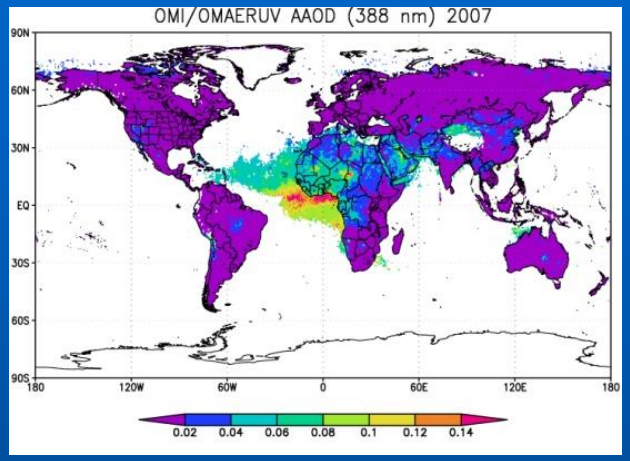
Composite OMI AI time series for the high-altitude smoke layer from the Australian Fires in December 14 – 24, 2006.

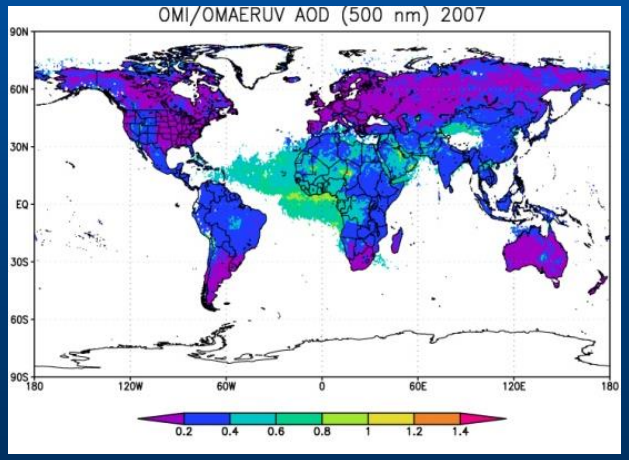


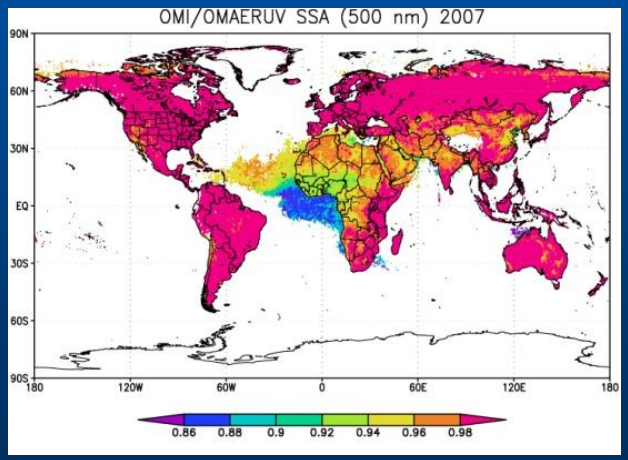
388 nm retrieved (top) and 500 nm converted (bottom) products

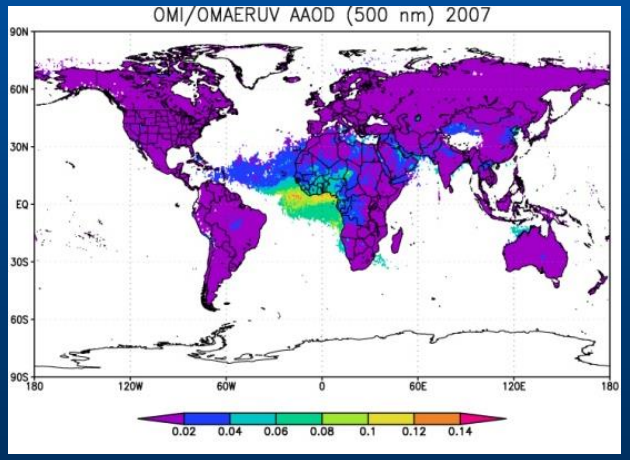








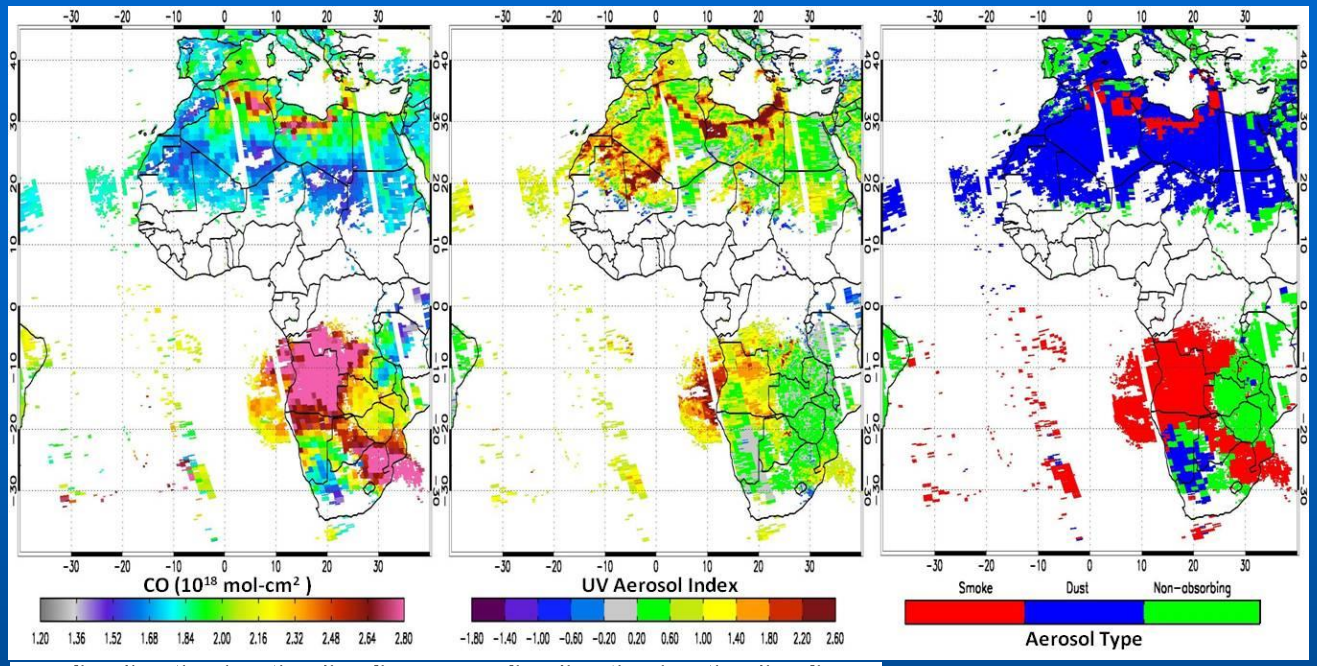


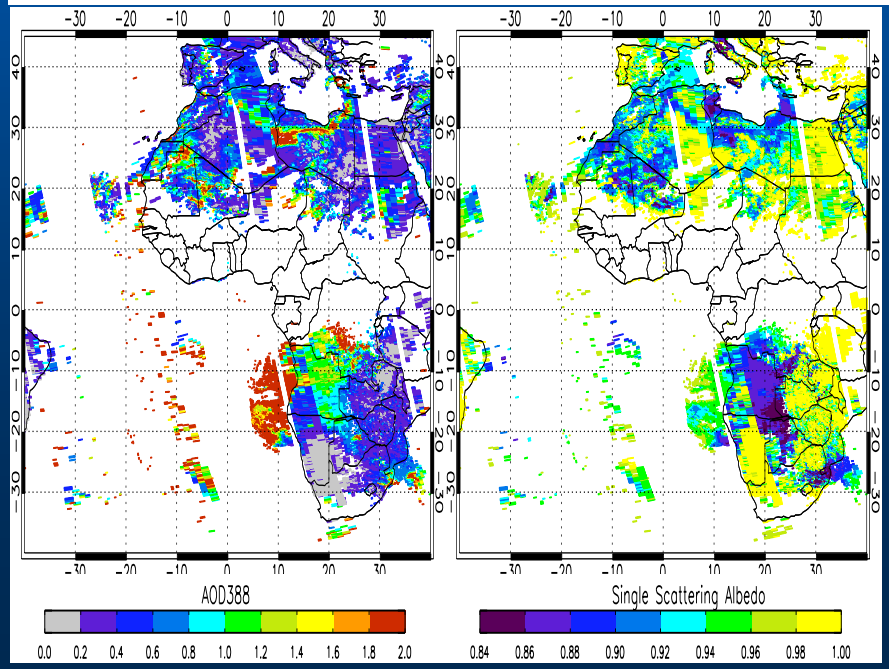


AAOD = AOD*(1.0 - SSA)

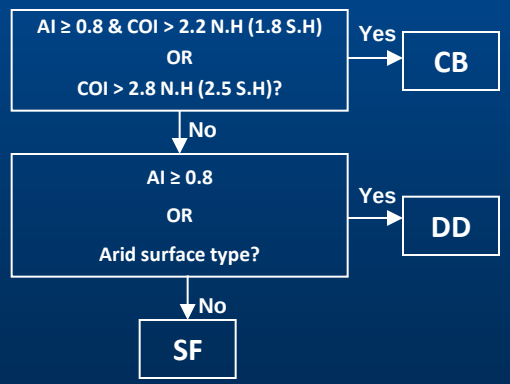
2007 Annual Averages

Aerosol Type Determination





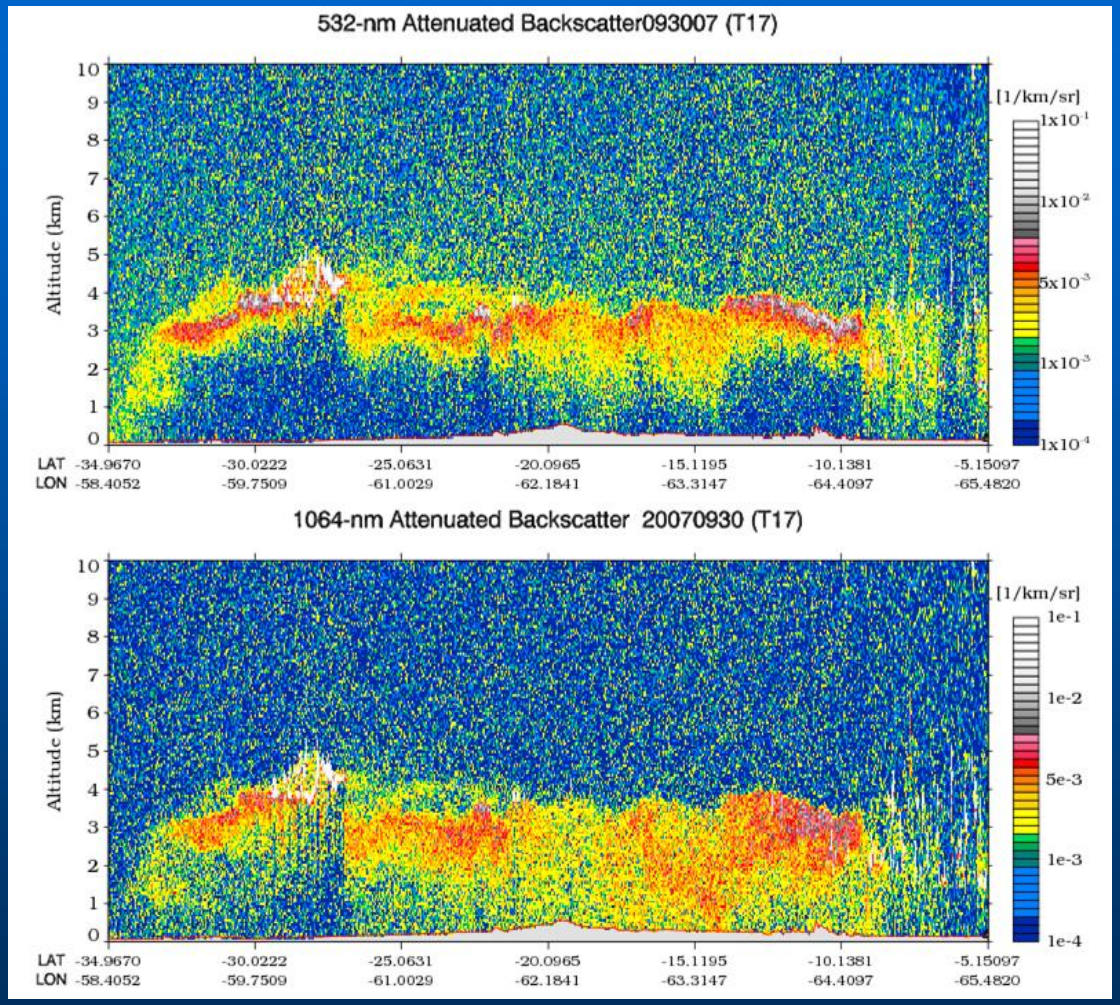
Combined use of CO and AI for Dust / Smoke Separation



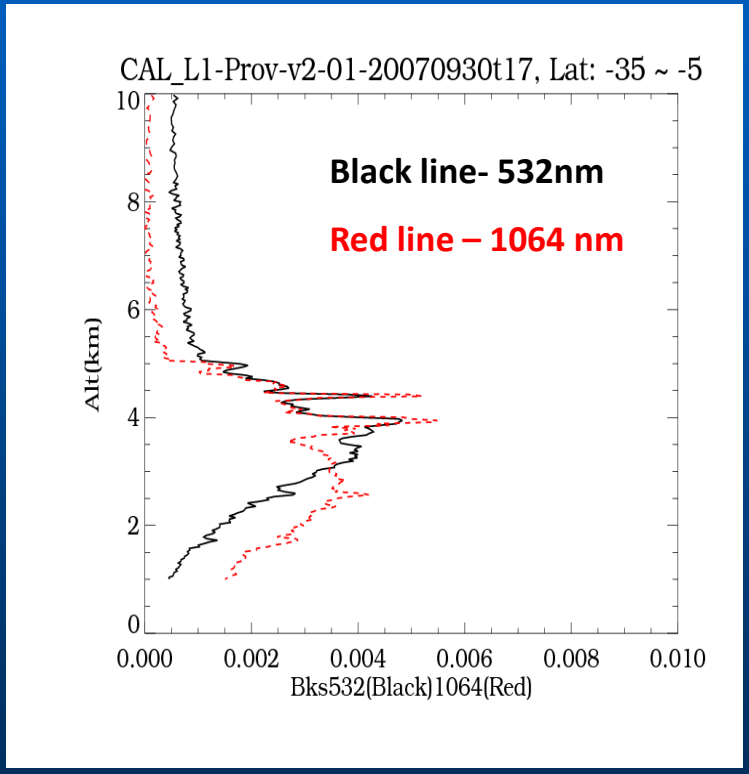
Greece Fires plume, August 27, 2007

Torres et al, AMTD, 2013

Aerosol Layer Height Determination from CALIOP Observations

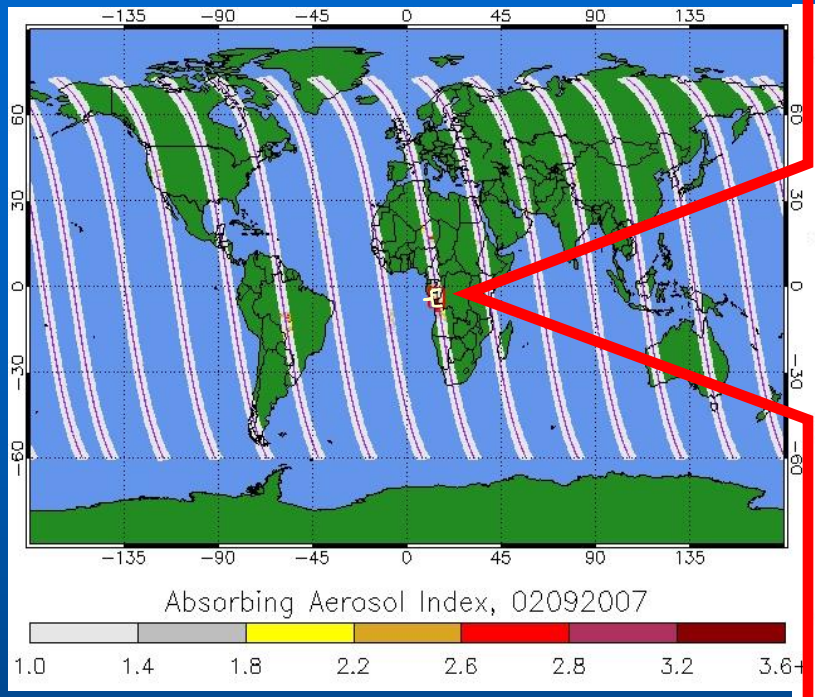


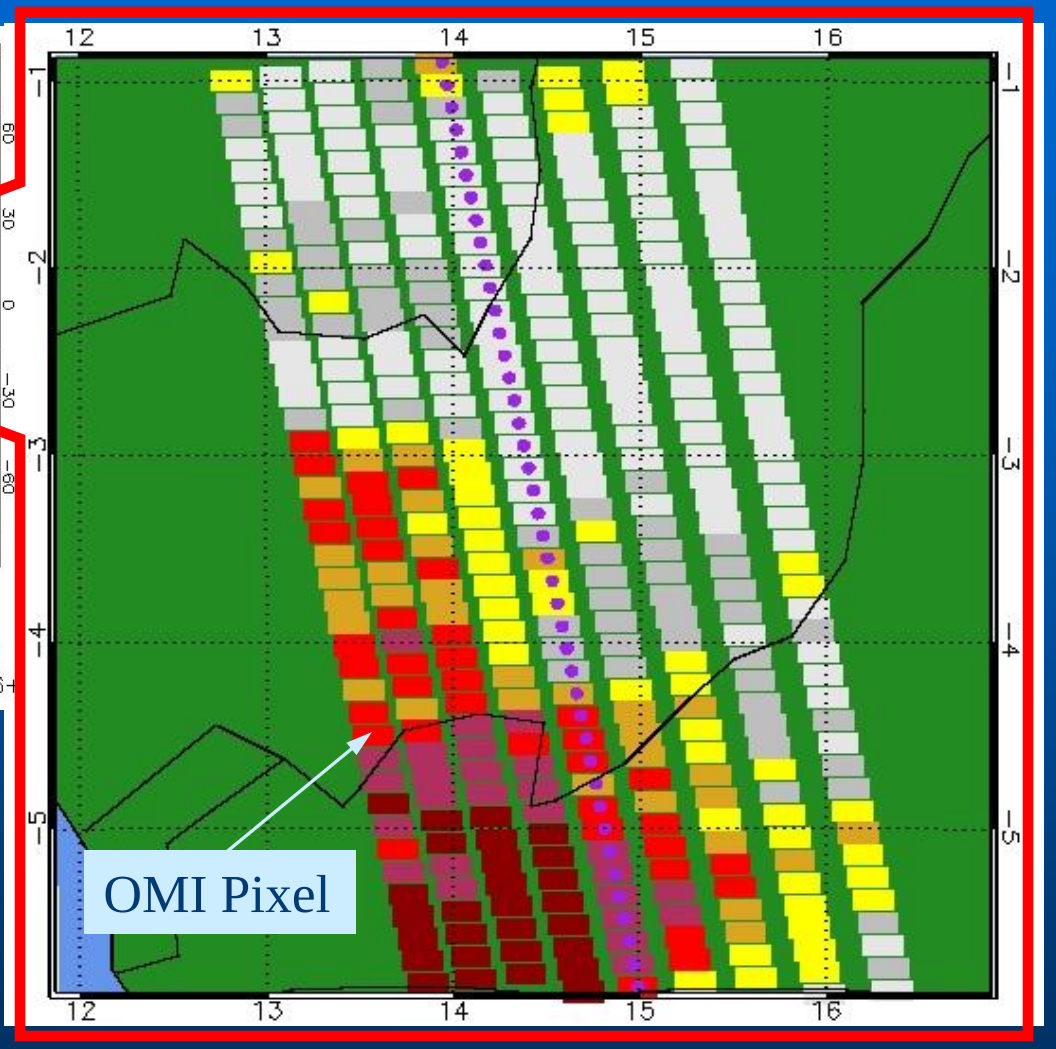
Comparison of CALIPSO Attenuated Backscatter at 532 and 1064 nm



- The 1064 CALIOP measurements penetrate lower in the atmosphere than the 532 (smoke case). No difference for dust.
- We use the 1064 nm to get a more realistic estimate of the aerosol layer height

OMI -CALIOP collocation





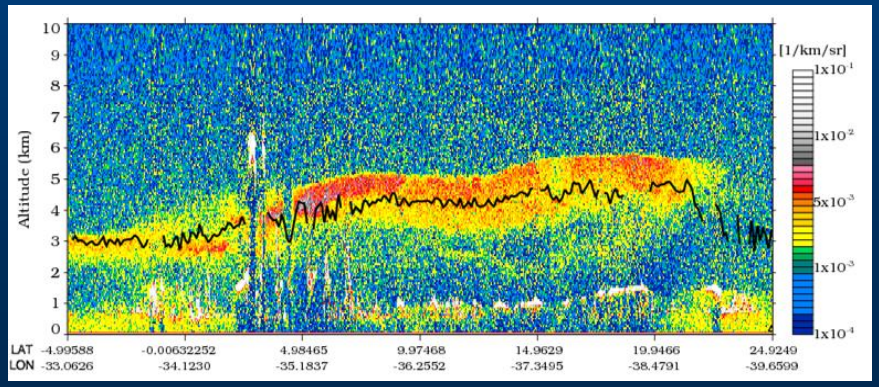
- OMI makes observations at 60 pixels across the orbital track (~2600 km)
- There are 39 vertical profiles per OMI-CALIOP collocation pixel (OCCP)
- Use OCCP plus four additional pixels on each side (200 km)

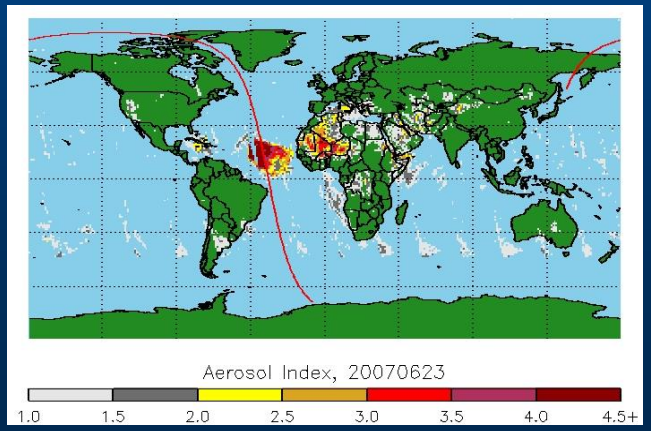
Using CALIOP observations to determine aerosol layer height: Procedure

- Check for presence of absorbing aerosols (AI > 0.5)
- Apply checks for cloud contamination at OMI and CALIOP resolutions.
- Average eligible CALIOP profiles (up to 39) in OCCP
- Calculate OMI-effective aerosol layer height as the backscatter-weighted average

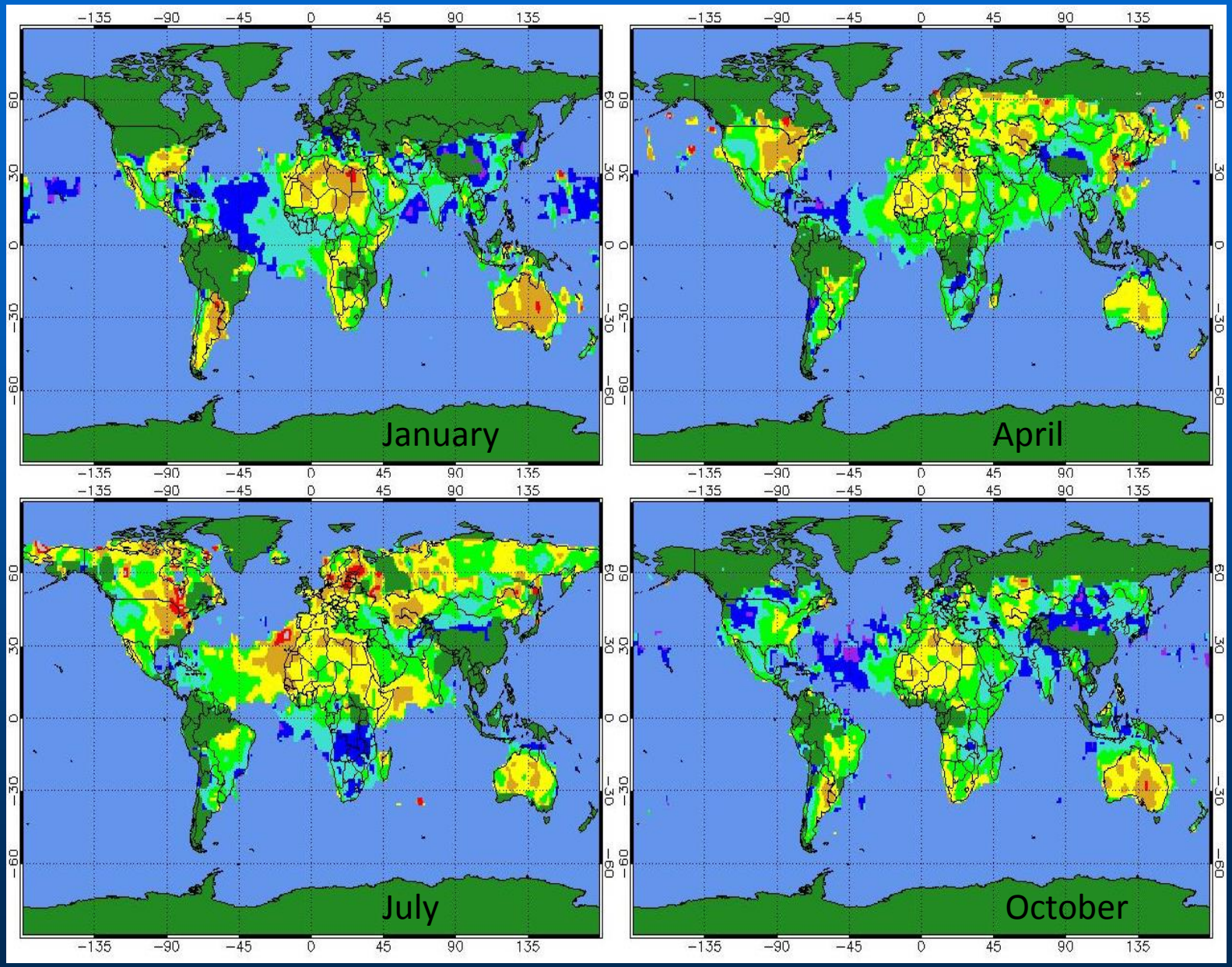
$$Z_{aer} = \sum_{i-1}^{n} H(i) \left[B_{sc}(i) \Big/ \sum_{i=1`}^{n} B_{sc}(i) \right]$$

- If AI detects absorbing aerosols in any of the additional eight pixels, the CALIOP supplied height at OCCP was assumed for that pixel.
- Resulting aerosol layer height was used in OMI near UV inversion to obtain AOD and SSA
- Apply method to data record from July 1, 2006 to June 30 2008 (30 months)

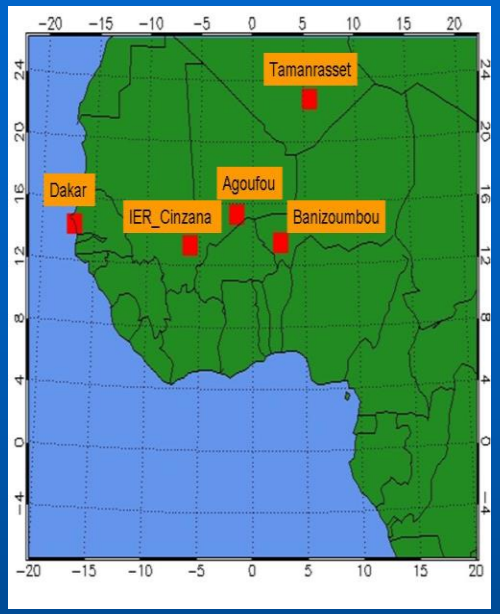




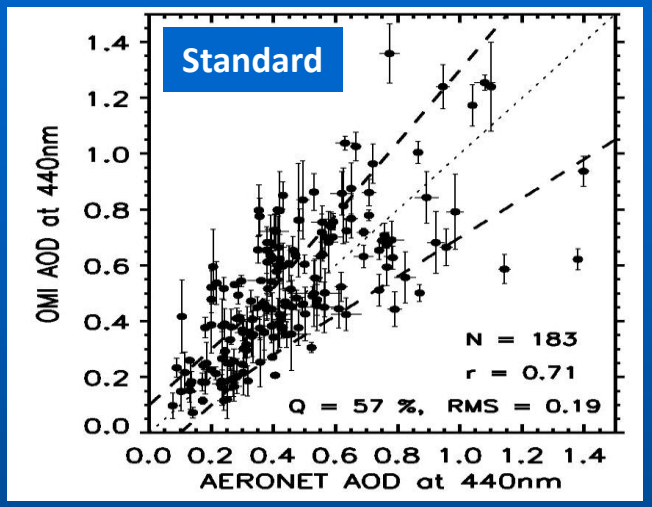
CALIOP-based Aerosol Height Climatology

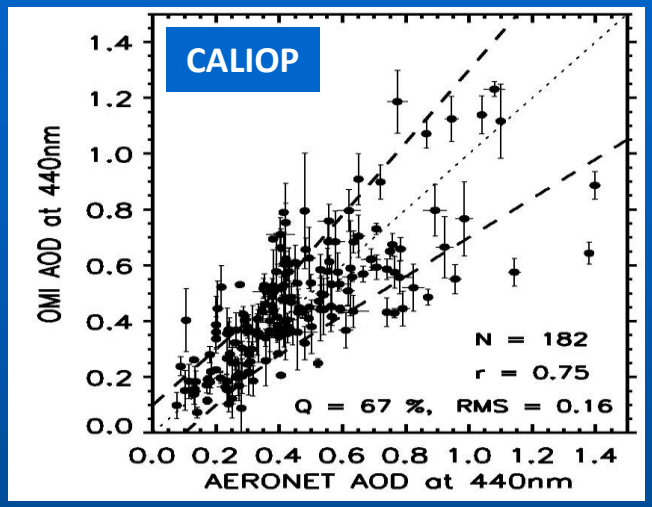


Improved OMAERUV-AOD Accuracy when using CALIOP-based climatology of Aerosol Layer Height



OMAERUV-AERONET comparison at Banizombou





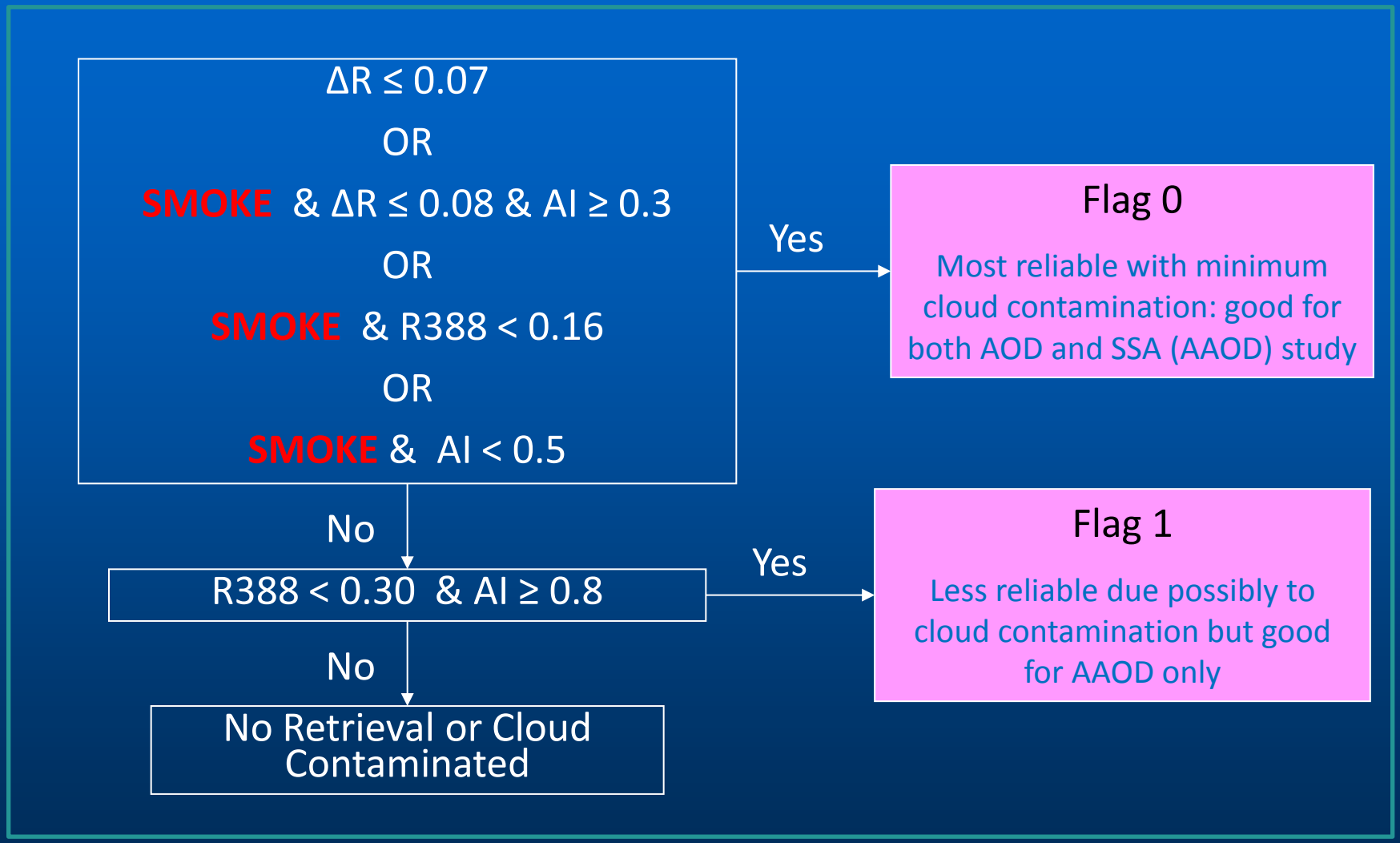
OMAERUV-AOD validation using standard and CALIOP-based aerosol layer height

$Q_{10(30)\%}$ Percent of points within 10(30)% of AERONET

AERONET Site	R Std	R Cal	Intercept Std.	Intercept Cal	RMS Std.	RMS Cal	Q_{10} Std	Q_{10} Cal	Q_{30} Std	Q_{30} Cal
Agoufou	0.82	0.83	0.13	0.10	0.17	0.16	50	58	64	71
Tamanrasset	0.83	0.84	0.09	0.08	0.10	0.10	60	63	66	69
Banizombou	0.71	0.75	0.21	0.17	0.19	0.16	45	53	57	67
Dakar	0.73	0.74	0.14	0.12	0.19	0.15	39	56	58	69
IER_Cinzana	0.79	0.83	0.09	0.08	0.21	0.17	35	47	50	60

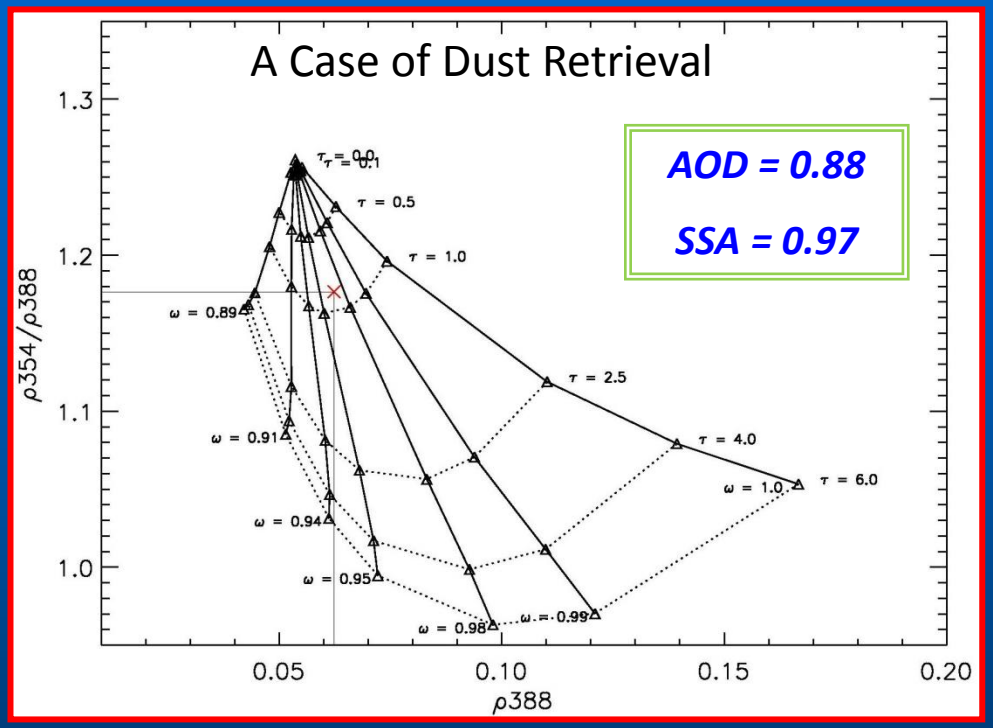
Measurable improvement in all statistical parameters

OMAERUV QA Flagging Scheme



- ΔR = R388 – Surface Albedo

Refinement of Retrieval Method (Two channel vs Single Channel)



Solar zenith angle = 21.06°

Viewing zenith angle = 11.93°

Relative azimuth angle = 15.98°

Surface pressure = 929.01 hPa

Surface albedo = 0.06

Aerosol layer height = 2.86 km

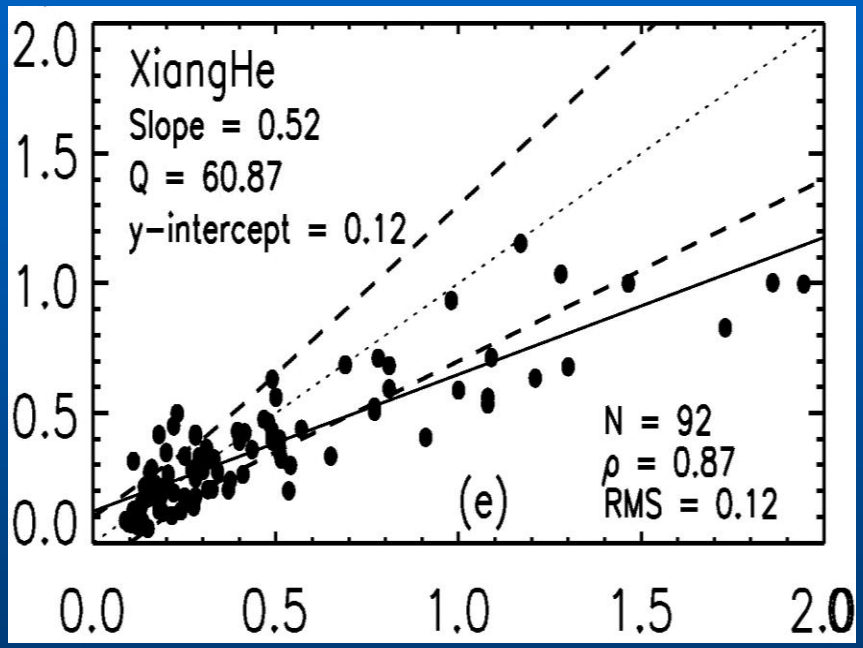
Retrieval Method at Each Layer Height (0.0, 1.5, 3.0, 6.0, and 10.0 km)

- SMOKE → Two channel retrieval
- DUST & AI ≥ 0.8 → Two channel retrieval
- DUST & AI < 0.8 → Single channel retrieval
- SULFATE & AI ≥ 0.5 → Two channel retrieval
- SULFATE & AI < 0.5 → Single channel retrieval

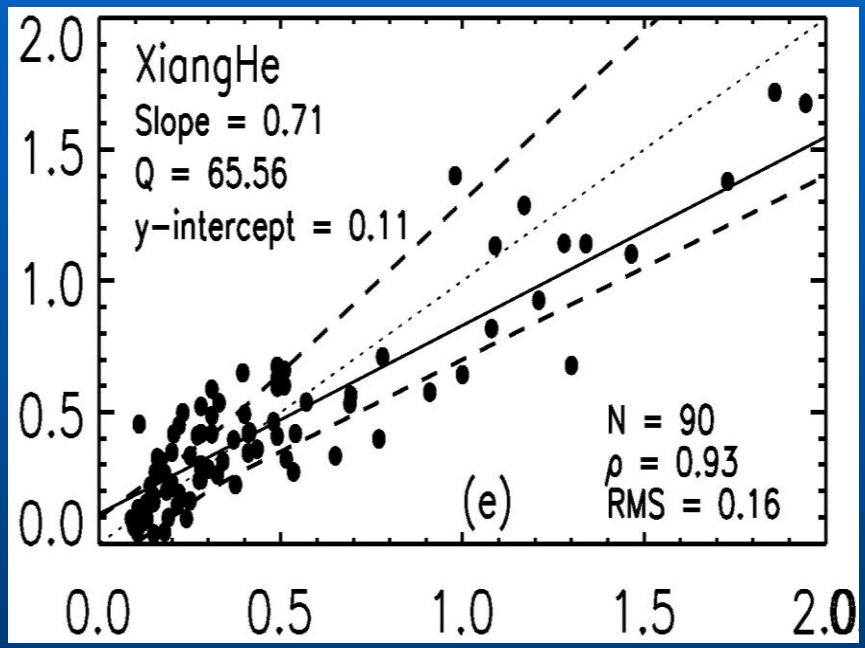
- Two channel -> two parameters (AOD, SSA)
- Single channel -> single parameter (AOD)

AOD Comparison at XiangHe AERONET Station (116.96° E, 39.75 ° N) in 2007

Before



After



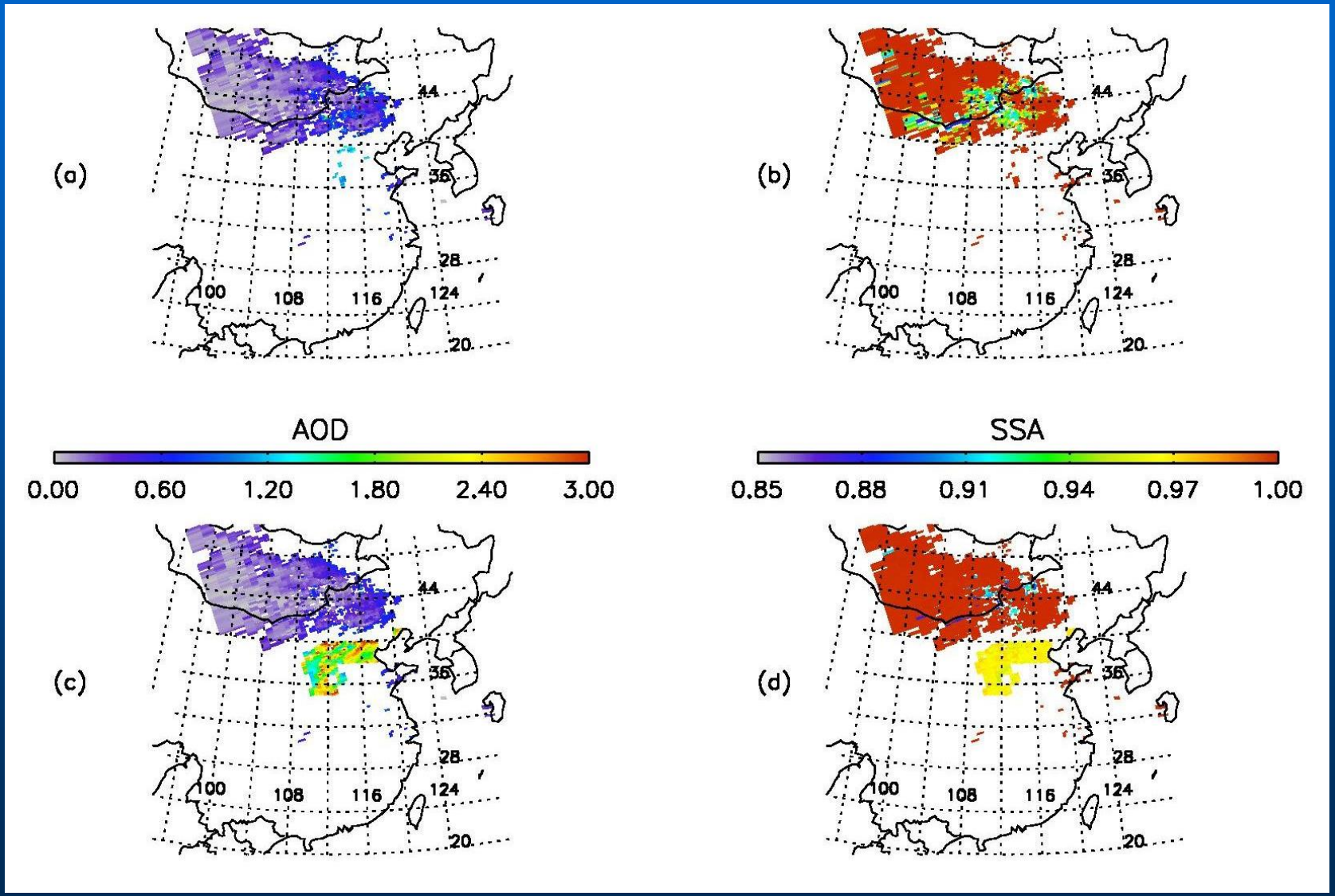
OMI AOD 388 nm

AERONET AOD 380 nm

- If AI > 0.8 → Two channel retrieval
- If 0.5 < AI ≤ 0.8 → weighted averages of two and single channel retrievals by AI
- If AI ≤ 0.5 → single channel retrieval

- **SMOKE** → Two channel retrieval
- **DUST** & AI ≥ 0.8 → Two channel retrieval
- **DUST** & AI < 0.8 → Single channel retrieval
- **SULFATE** & AI ≥ 0.5 → Two channel retrieval
- **SULFATE** & AI < 0.5 → Single channel retrieval

Retrieved AOD and SSA at 388 nm on Aug 20, 2007 Before (a , b) and After (c , d)



Assessment of OMI Near UV Aerosol Products (AOD & SSA)

Outline

- OMI AOD Evaluation
  - OMI vs AERONET AOD in 2005 - 2008 over land
  - Intercomparison of OMI, MODIS Deep Blue, and MISR AOD against AERONET AOD in 2007 over arid and semi-arid areas
- Comparison of OMI SSA to retrieved SSA from AERONET observations in biomass burning and dust environments
- Summary

Information of AOD Data Sets for Comparison

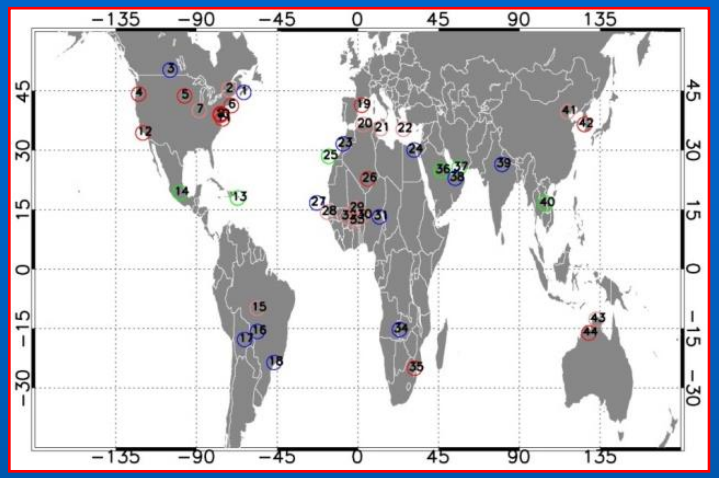
Sensor Name	Version No.	Meaning of AOD Quality Assurance (QA) Flags
Aura/OMI-NASA (OMAERUV)	version 1.4.2	QA Flag 0 (= most reliable retrievals)
AERONET	version 2.0	Level 2.0 (= cloud screened and calibrated)
Aqua/MODIS Deep Blue	collection 5.1	QA Flag 3 (= very good confidence)
Terra/MISR	version 22	QA Flags 0 and 1 (= successful aerosol mixtures)

AOD Co-location Method

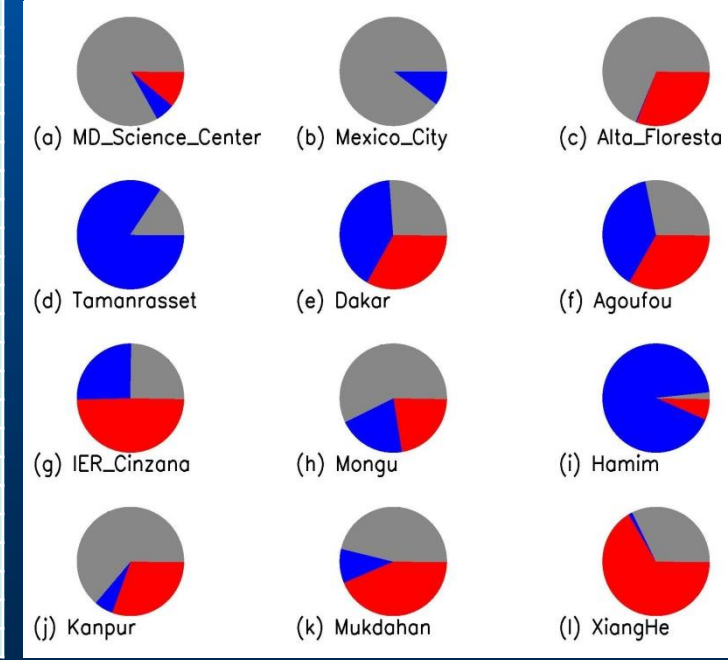
- Within a radius of 40 km and ± 10 min window of the OMI overpass at 44 AERONET sites globally distributed over land
- Discard large standard deviations of OMI (> 0.3) daily matchups roughly corresponding to 3 % extreme outliers out of total collocated pairs at 44 sites over 4 years (2005 – 2008)
- The same co-location rules are applied to other satellite data sets (i.e., MODIS and MISR)

AERONET 44 Site Locations over Land

Site No.	Site Name	Longitude	Latitude	Wavelength (nm)	Aerosol Type
1	Halifax	63.594° W	44.638° N	380	Non-absorbing
2	CARTEL	71.931° W	45.379° N	380	Non-absorbing
3	Bratts_Lake	104.700° W	50.280° N	380	Non-absorbing
4	HJAndrews	122.224° W	44.239° N	440	Non-absorbing
5	Sioux_Falls	96.626° W	43.736° N	380	Non-absorbing
6	MVCO	70.550° W	41.300° N	440	Non-absorbing
7	BONDVILLE	88.372° W	40.053° N	380	Non-absorbing
8	GSFC	76.840° W	38.992° N	380	Non-absorbing
9	MD_Science_Center	76.617° W	39.283° N	380	Non-absorbing
10	SERC	76.500° W	38.883° N	380	Non-absorbing
11	Wallops	75.475° W	37.942° N	440	Non-absorbing
12	UCSB	119.845° W	34.415° N	380	Non-absorbing
13	La_Parguera	67.045° W	17.970° N	380	Non-absorbing
14	Mexico_City	99.182° W	19.334° N	380	Non-absorbing
15	Alta_Floresta	56.104° W	9.871° S	380	Mixture
16	CUIABA-MIRANDA	56.021° W	15.729° S	380	Non-absorbing
17	SANTA_CRUZ_UTEPSA	63.201° W	17.767° S	440	Non-absorbing
18	Sao_Paulo	46.735° W	23.561° S	380	Non-absorbing
19	Barcelona	2.117° E	41.386° N	440	Non-absorbing
20	Blida	2.881° E	36.508° N	380	Non-absorbing
21	Lampedusa	12.632° E	35.517° N	440	Dust
22	FORTH_CRETE	25.282° E	35.333° N	380	Non-absorbing
23	Saada	8.156° W	31.626° N	440	Dust
24	Cairo_EMA	31.290° W	30.081° N	440	Dust
25	Santa_Cruz_Tenerife	16.247° W	28.473° N	380	Mixture
26	Tamanrasset	5.530° E	22.790° N	440	Dust
27	Capo_Verde	22.935° W	16.733° N	440	Dust
28	Dakar	16.959° W	14.394° N	440	Dust
29	Agoufou	1.479° W	15.345° N	440	Mixture
30	Banizoumbou	2.665° E	13.541° N	440	Smoke
31	DMN_Maine_Soroa	12.023° E	13.217° N	440	Smoke
32	IER_Cinzana	5.934° W	13.278° N	440	Smoke
33	Ouagadougou	1.400° W	12.200° N	440	Smoke
34	Mongu	23.151° E	15.254° S	380	Mixture
35	Skukuza	31.587° E	24.992° S	380	Non-absorbing
36	Solar_Village	46.397° E	24.907° N	380	Dust
37	Dhadnah	56.325° E	25.513° N	380	Dust
38	Hamim	54.300° E	22.967° N	380	Dust
39	Kanpur	80.232° E	26.513° N	380	Mixture
40	Mukdahan	104.676° E	16.607° N	380	Smoke
41	XiangHe	116.962° E	39.754° N	380	Smoke
42	Anmyon	126.330° E	36.539° N	380	Smoke
43	Jabiru	132.893° E	12.661° S	380	Non-absorbing
44	Lake_Argyle	128.749° E	16.108° S	380	Dust



OMI Aerosol Types in 2005-2008
(Smoke, Dust, Non-absorbing)



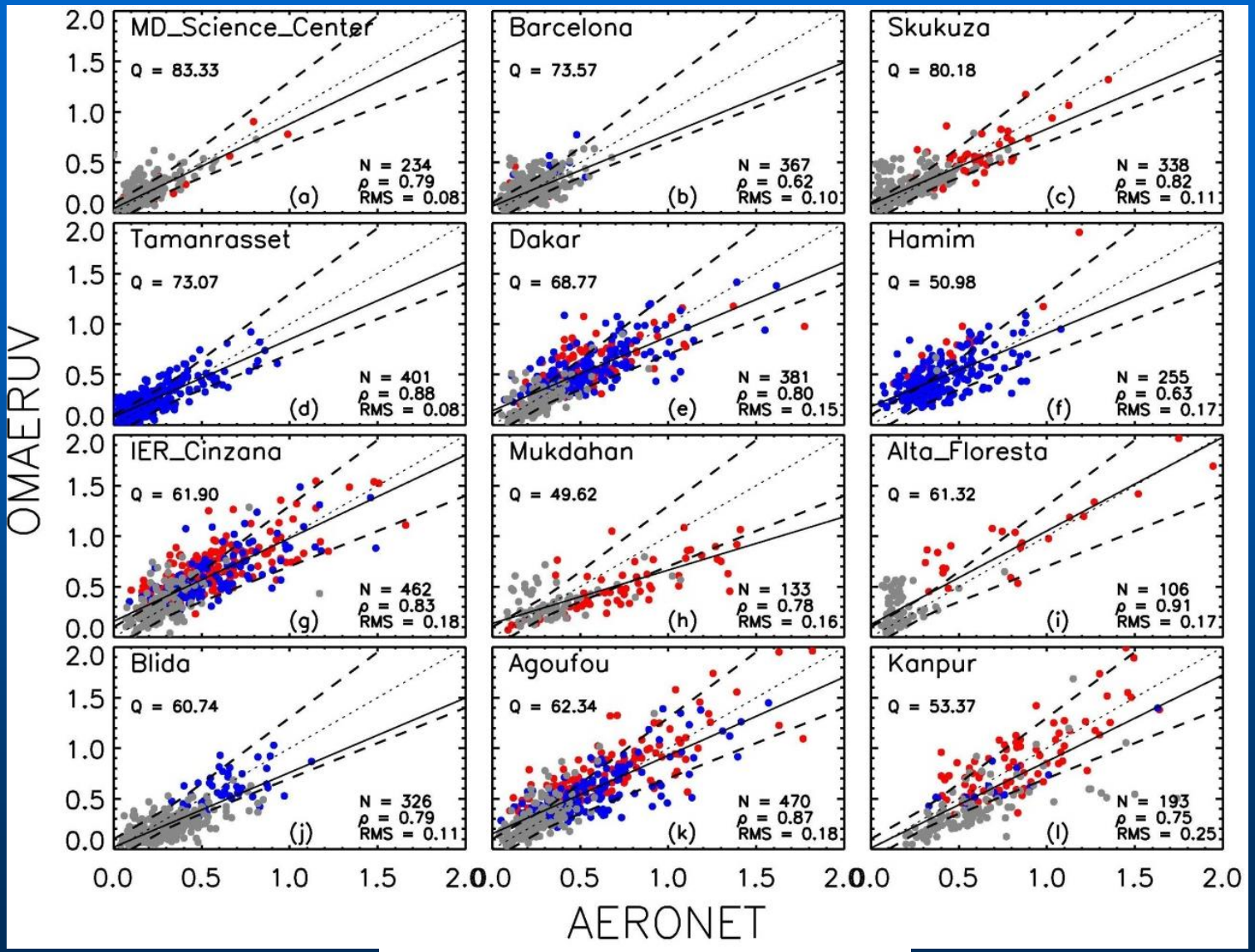
Summary Statistics of OMI vs AERONET

Site No.	N	AVG ± (SDERR)	SDEV2	SDEV1	Q	RMSE	y-intercept	Slope	ρ
26	401	0.08 (0.01)	0.09	0.2	73.07	0.08	0.08	0.76	0.88
11	294	0.06 (0.00)	0.08	0.14	88.1	0.07	0.04	0.73	0.83
35	338	0.08 (0.01)	0.12	0.2	80.18	0.11	0.08	0.74	0.82
10	132	0.06 (0.01)	0.1	0.15	80.3	0.09	0.04	0.8	0.8
20	326	0.11 (0.01)	0.12	0.2	60.74	0.11	0.01	0.73	0.79
9	234	0.06 (0.01)	0.09	0.13	83.33	0.08	0.04	0.83	0.79
23	204	0.11 (0.01)	0.12	0.14	55.88	0.12	0.08	0.99	0.77
8	294	0.07 (0.01)	0.1	0.15	81.3	0.09	0.06	0.73	0.77
39	193	0.21 (0.02)	0.25	0.32	53.37	0.25	0.01	0.85	0.75
15	106	0.15 (0.02)	0.18	0.42	61.32	0.17	0.12	0.92	0.91
29	470	0.15 (0.01)	0.21	0.42	62.34	0.18	0.15	0.77	0.87
30	406	0.15 (0.01)	0.22	0.42	63.05	0.2	0.17	0.77	0.86
32	462	0.15 (0.01)	0.19	0.32	61.9	0.18	0.15	0.82	0.83
31	286	0.14 (0.01)	0.16	0.24	55.94	0.16	0.11	0.87	0.8
28	381	0.12 (0.01)	0.17	0.28	68.77	0.15	0.14	0.73	0.8
41	314	0.15 (0.01)	0.22	0.45	65.61	0.17	0.09	0.67	0.87
17	19	0.22 (0.07)	0.3	0.52	52.63	0.15	0.21	0.48	0.86
33	109	0.16 (0.03)	0.29	0.55	65.14	0.21	0.21	0.64	0.86
16	161	0.15 (0.02)	0.22	0.37	57.76	0.16	0.12	0.59	0.8
40	133	0.20 (0.02)	0.23	0.36	49.62	0.16	0.13	0.52	0.78
42	71	0.15 (0.03)	0.24	0.36	71.83	0.17	0.14	0.54	0.75
34	146	0.14 (0.02)	0.21	0.3	56.16	0.15	0.1	0.55	0.74
44	543	0.08 (0.01)	0.11	0.14	78.64	0.11	0.07	0.75	0.7
12	205	0.07 (0.01)	0.1	0.13	73.66	0.09	0.08	0.61	0.68
1	158	0.11 (0.01)	0.12	0.12	59.5	0.12	0.11	0.86	0.67
7	183	0.09 (0.01)	0.1	0.12	68.85	0.09	0.1	0.68	0.66
18	101	0.13 (0.02)	0.17	0.23	53.47	0.13	0.12	0.5	0.66
2	94	0.11 (0.01)	0.13	0.13	62.77	0.13	0.1	0.82	0.64
38	255	0.15 (0.01)	0.18	0.19	50.98	0.17	0.18	0.72	0.63
43	253	0.12 (0.01)	0.16	0.13	62.05	0.15	0.09	0.93	0.62
19	367	0.08 (0.01)	0.1	0.11	73.57	0.1	0.06	0.71	0.62
22	309	0.10 (0.01)	0.13	0.14	66.02	0.12	0.08	0.71	0.61
36	461	0.31 (0.01)	0.2	0.19	17.79	0.19	0.38	0.76	0.61
21	17	0.13 (0.05)	0.18	0.16	64.71	0.18	0.05	0.87	0.6
6	47	0.08 (0.02)	0.11	0.11	74.47	0.1	0.1	0.72	0.6
3	190	0.11 (0.01)	0.13	0.13	59.47	0.12	0.13	0.69	0.6
13	158	0.16 (0.01)	0.17	0.14	44.3	0.17	0.17	0.79	0.57
5	244	0.09 (0.01)	0.12	0.11	72.13	0.11	0.1	0.69	0.57
27	131	0.22 (0.03)	0.31	0.27	50.38	0.3	0.21	0.74	0.55
4	248	0.07 (0.01)	0.08	0.08	77.02	0.08	0.09	0.58	0.51
14	90	0.22 (0.03)	0.3	0.33	47.78	0.2	0.3	0.33	0.48
25	72	0.18 (0.03)	0.23	0.2	48.61	0.21	0.24	0.49	0.42
37	342	0.27 (0.01)	0.26	0.22	33.04	0.24	0.45	0.48	0.41
24	59	0.16 (0.03)	0.22	0.17	52.54	0.18	0.28	0.33	0.3

Definition of Statistical Measures

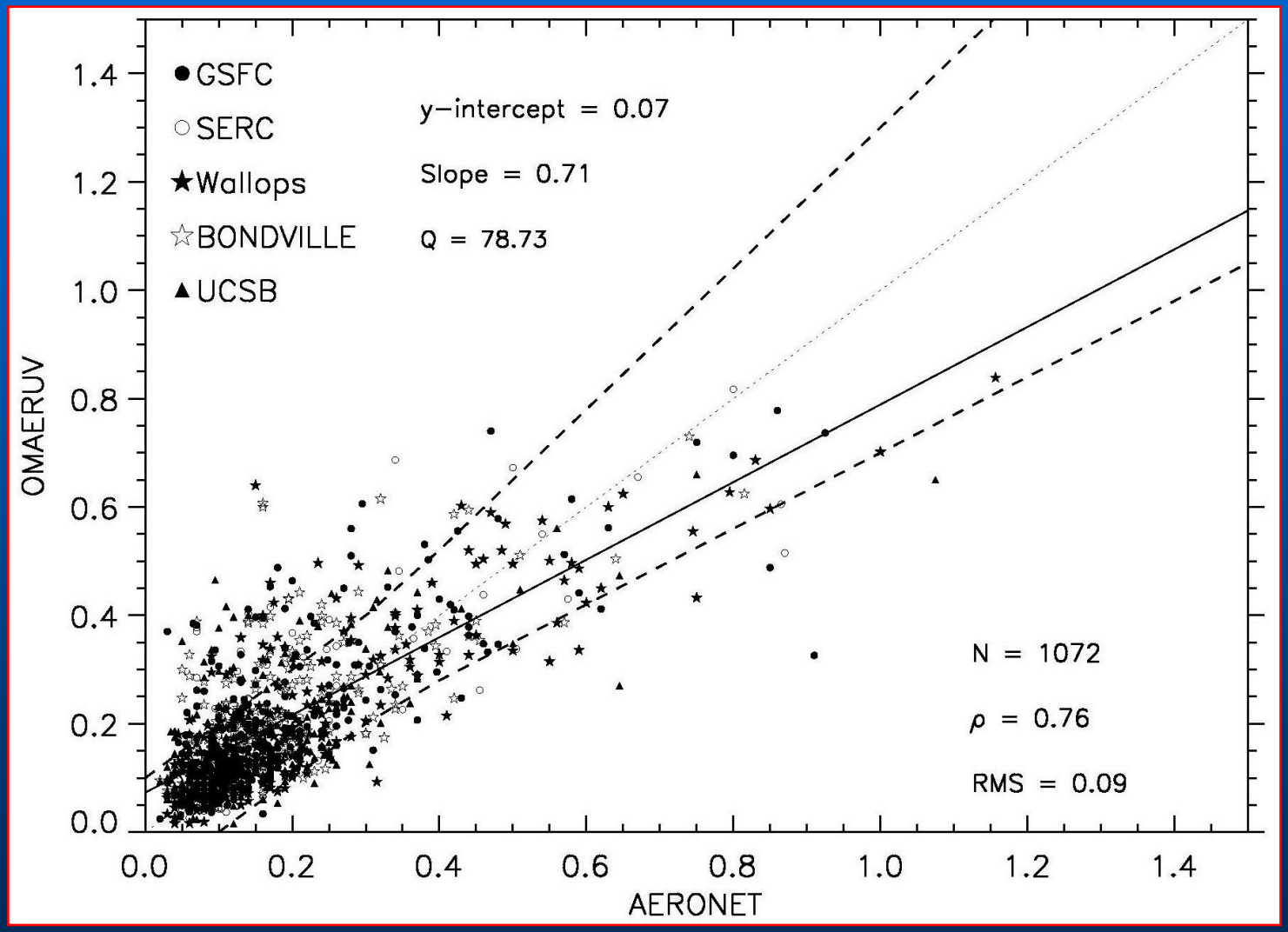
- N : Total number of daily match-ups for 2005 - 2008.
- AVG = MEAN [ABS(Y - X)], where Y is the OMI observation, X is the AERONET measurement.
- SDERR = Standard Deviation (Y -X) / SQRT(N - 1).
- SDEV2 = Standard Deviation (Y - X).
- SDEV1 = Standard Deviation (X).
- Q = Percent of match-ups within ± 30 % or 0.1 AOD uncertainty envelope.
- RMSE = SQRT[SUM (Y – LinearFitted Y)^2 / N].
- y-intercept and Slope from a linear fit.
- ρ = Correlation Coefficient.

OMI vs AERONET AOD in 2005 - 2008



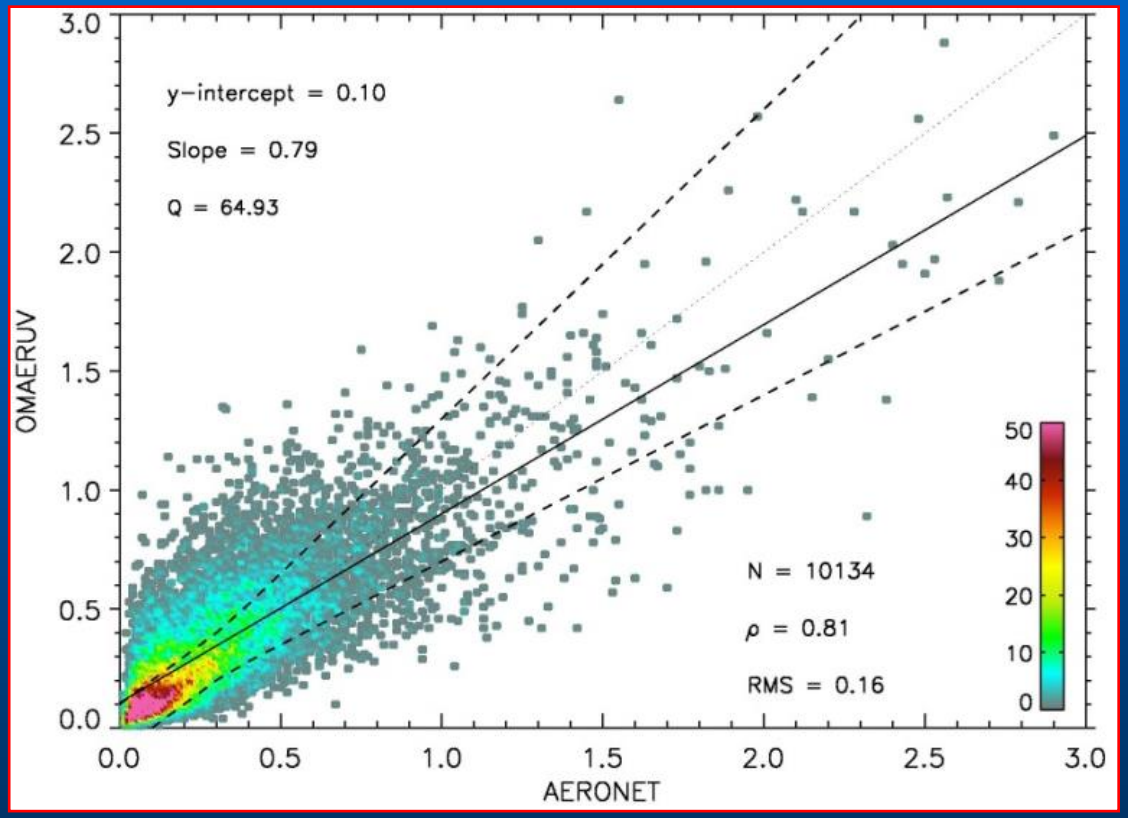
(Smoke, Dust, Non-absorbing)

Validation of OMI Aerosols in Boundary layer



Scatter Density Plot of OMI vs AERONET AOD Over Land in 2005 - 2008

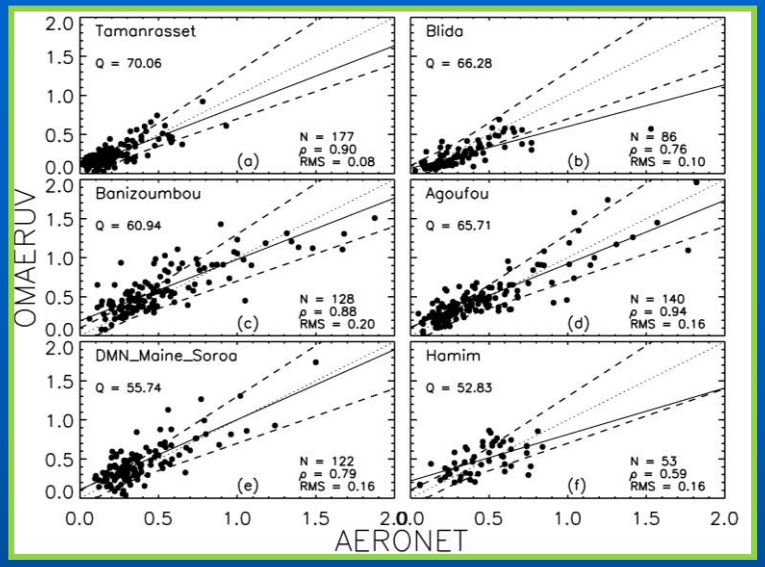
AERONET 44 Sites



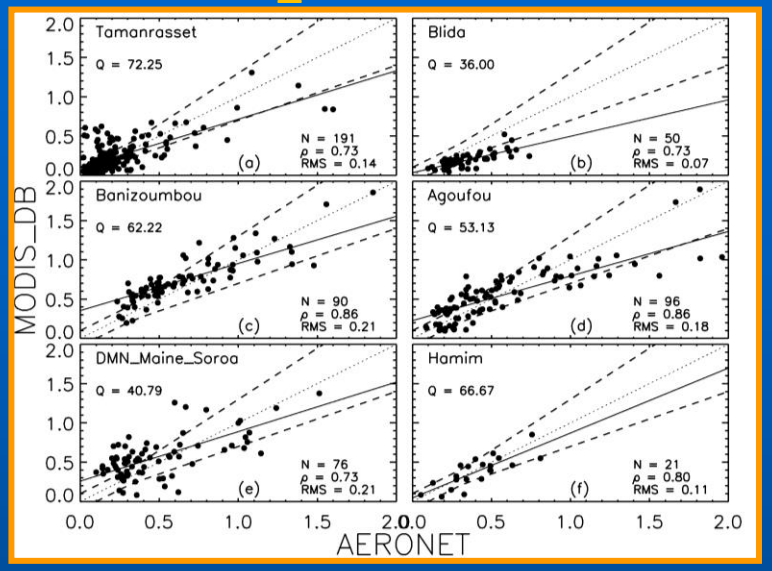
Sources of Uncertainty : surface albedo, aerosol type & model, layer height, sub-pixel cloud contamination, retrieval method (e.g., two channel vs single channel), and collocation issue

Intercomparison of OMI, MODIS Deep Blue and MISR

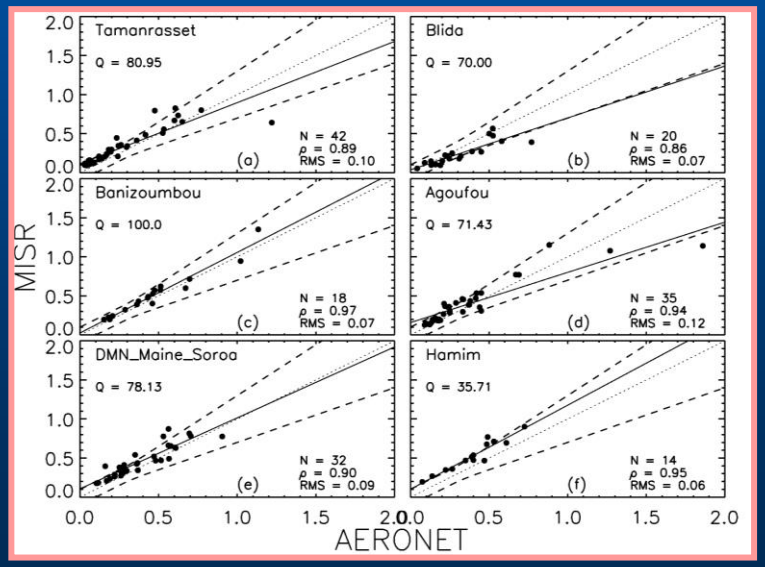
OMI vs AERONET

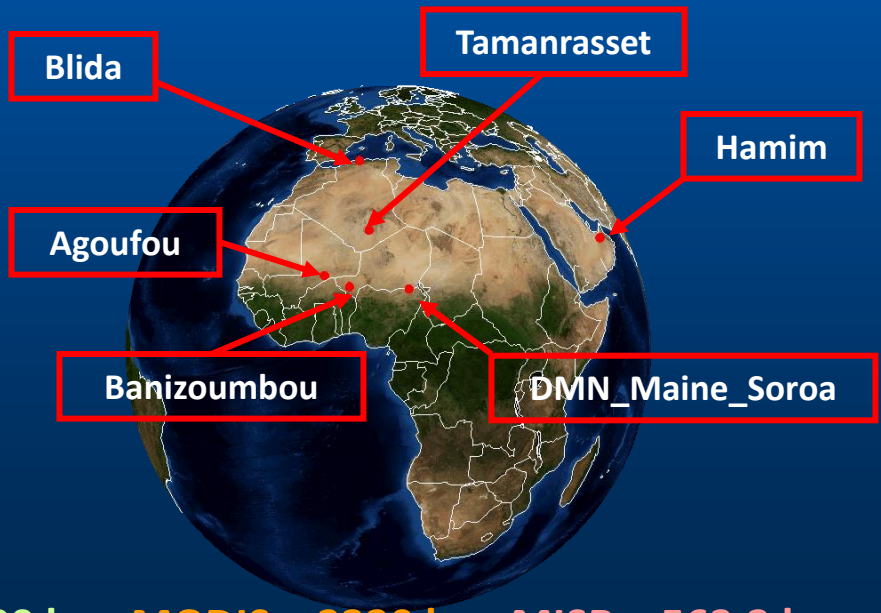


MODIS_DB vs AERONET



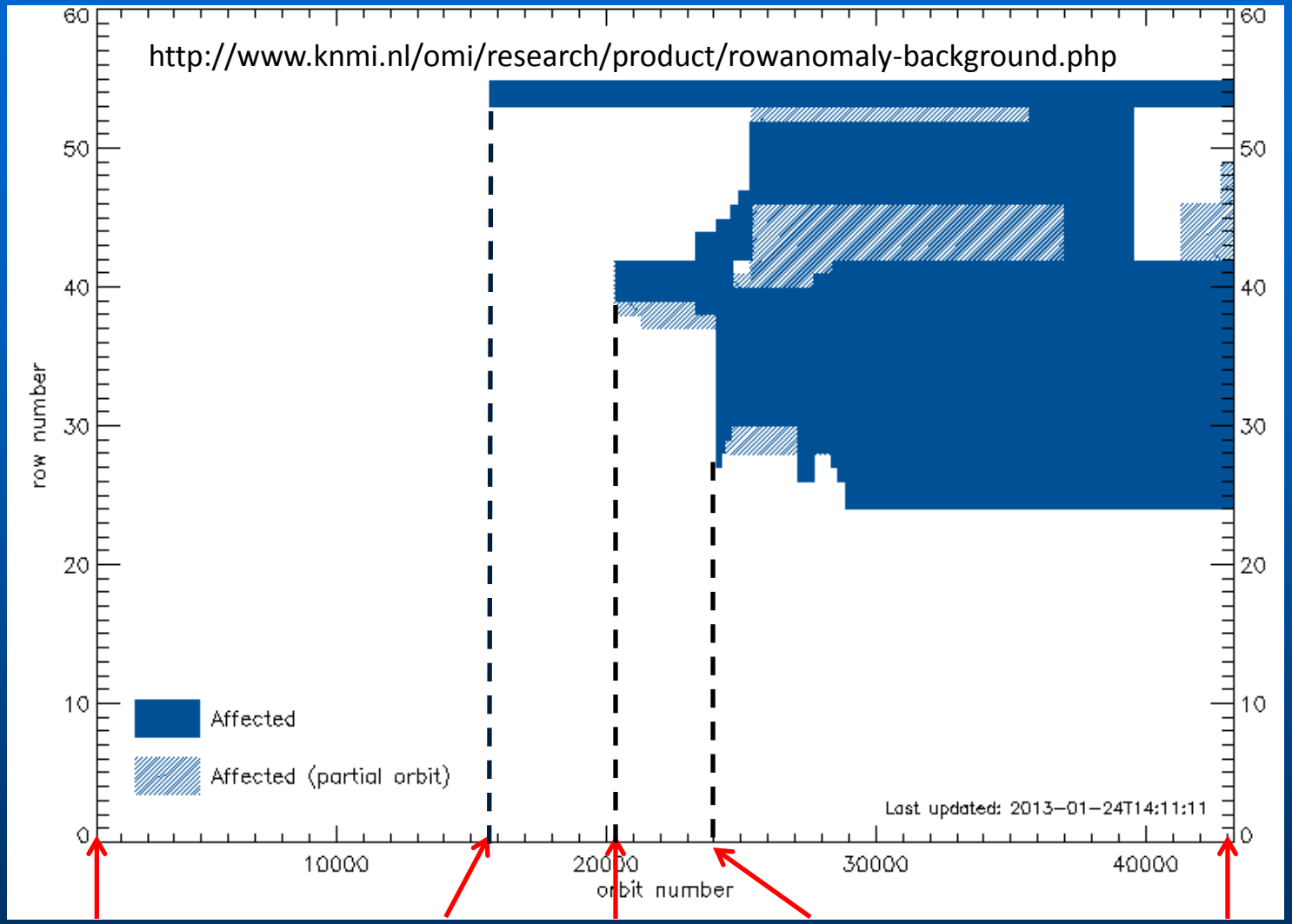
MISR vs AERONET





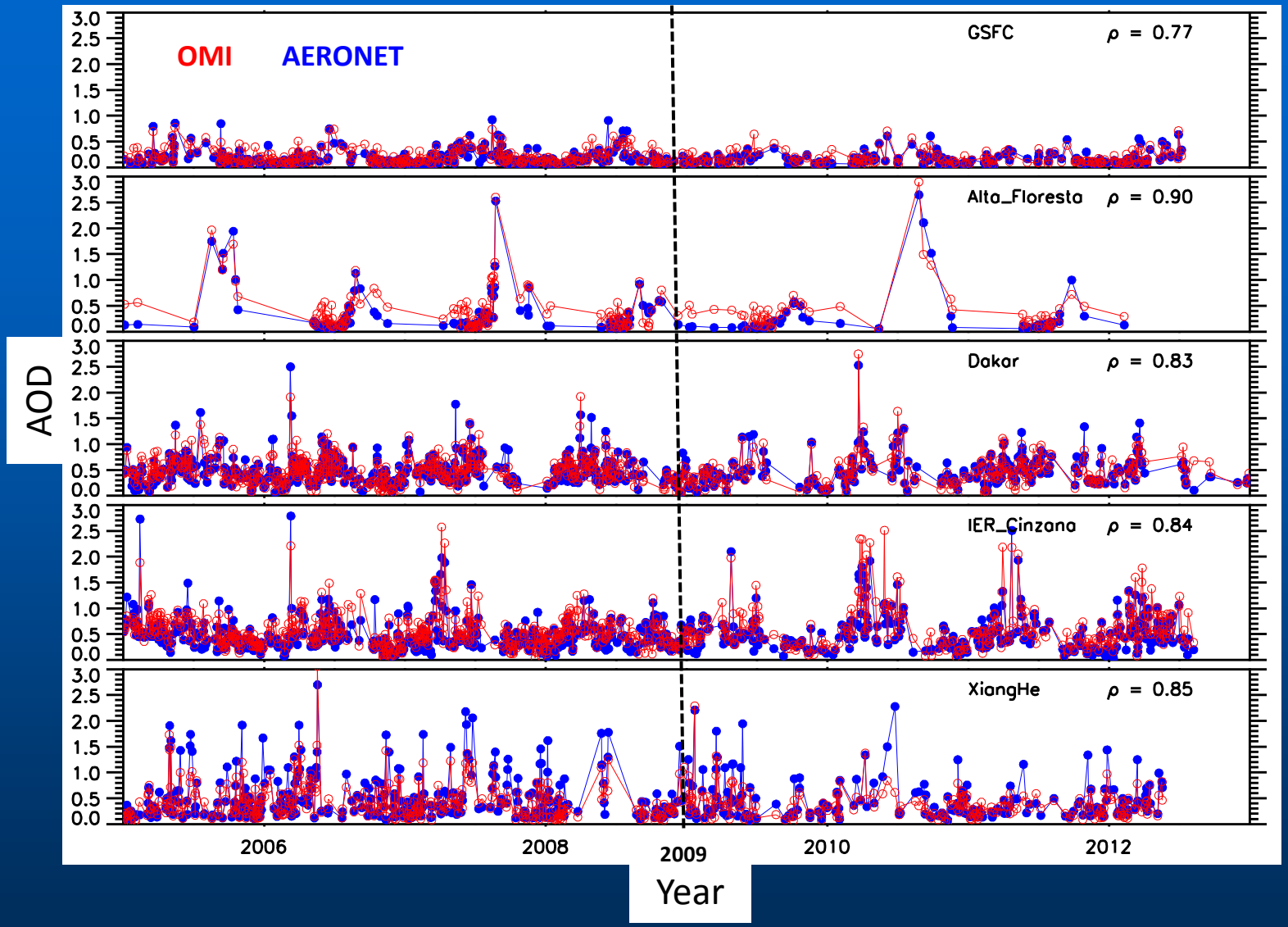
Note Cross - track Coverage : OMI = 2600 km, MODIS = 2330 km, MISR = 563.2 km

OMI Status: Row Anomaly Progression



- Physical obstruction external to the sensor affecting Earth-shine measurements
- Currently OMI achieves global coverage in 2-3 days.
- Row anomaly affected scenes are flagged in OMAERUV Level-2 file

AOD Time Series at the 5 Sites over 8 years (2005 - 2012)



Note : OMI row anomaly problem appears to be well addressed, however, caution should be taken for scientific use beyond the year 2009!

Retrieved SSA Comparison (OMI vs AERONET)

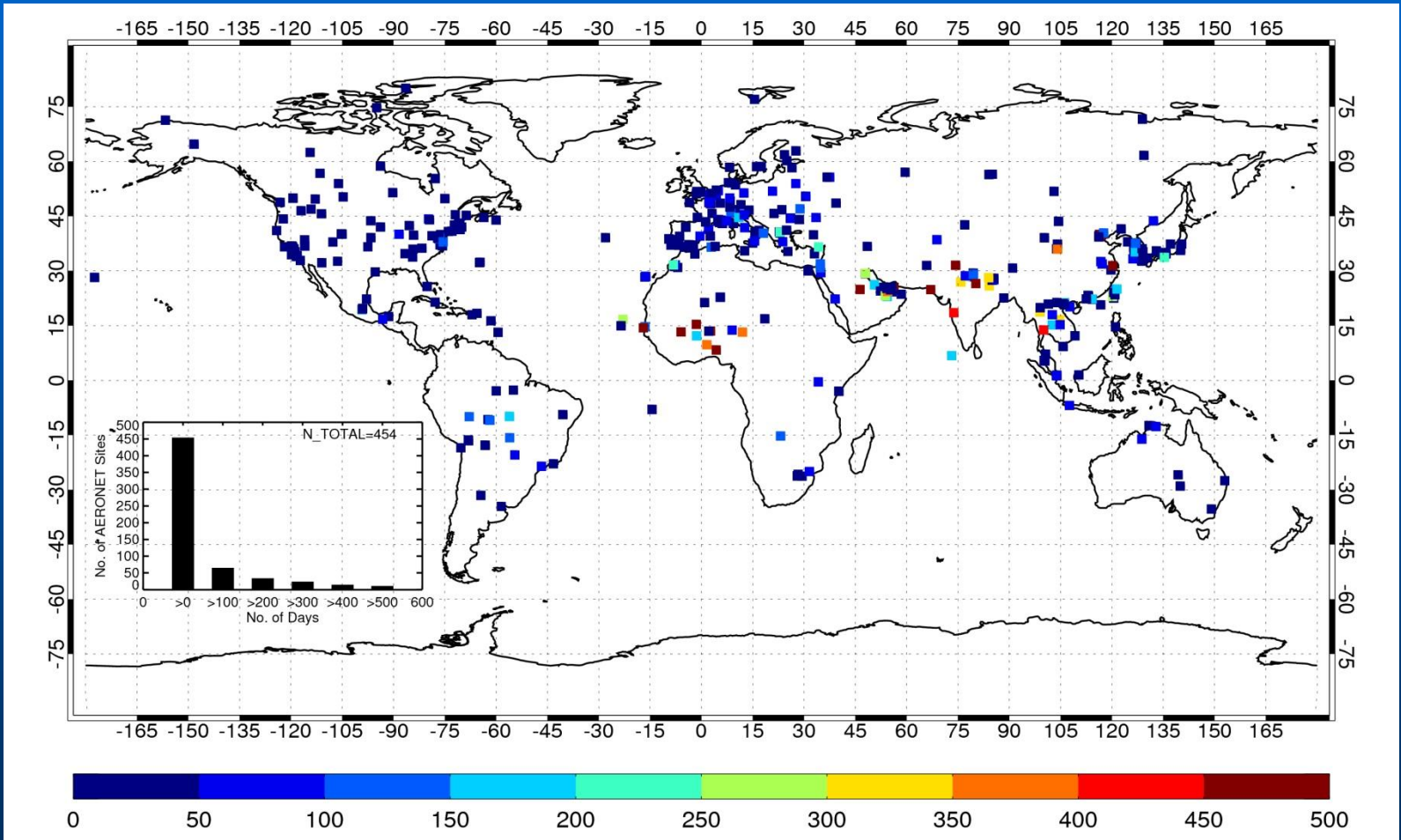
- The co-location methodology adopted here matches the 0.5° averaged OMI SSA retrievals with the temporally averaged (± 3 hours) AERONET inversion around satellite overpass time.

- Only those AERONET inversions were considered for which the measured AOT (440 nm) was greater than 0.4. In total, we get 269 AERONET sites where at least one matchup was obtained.

AERONET Site Distribution

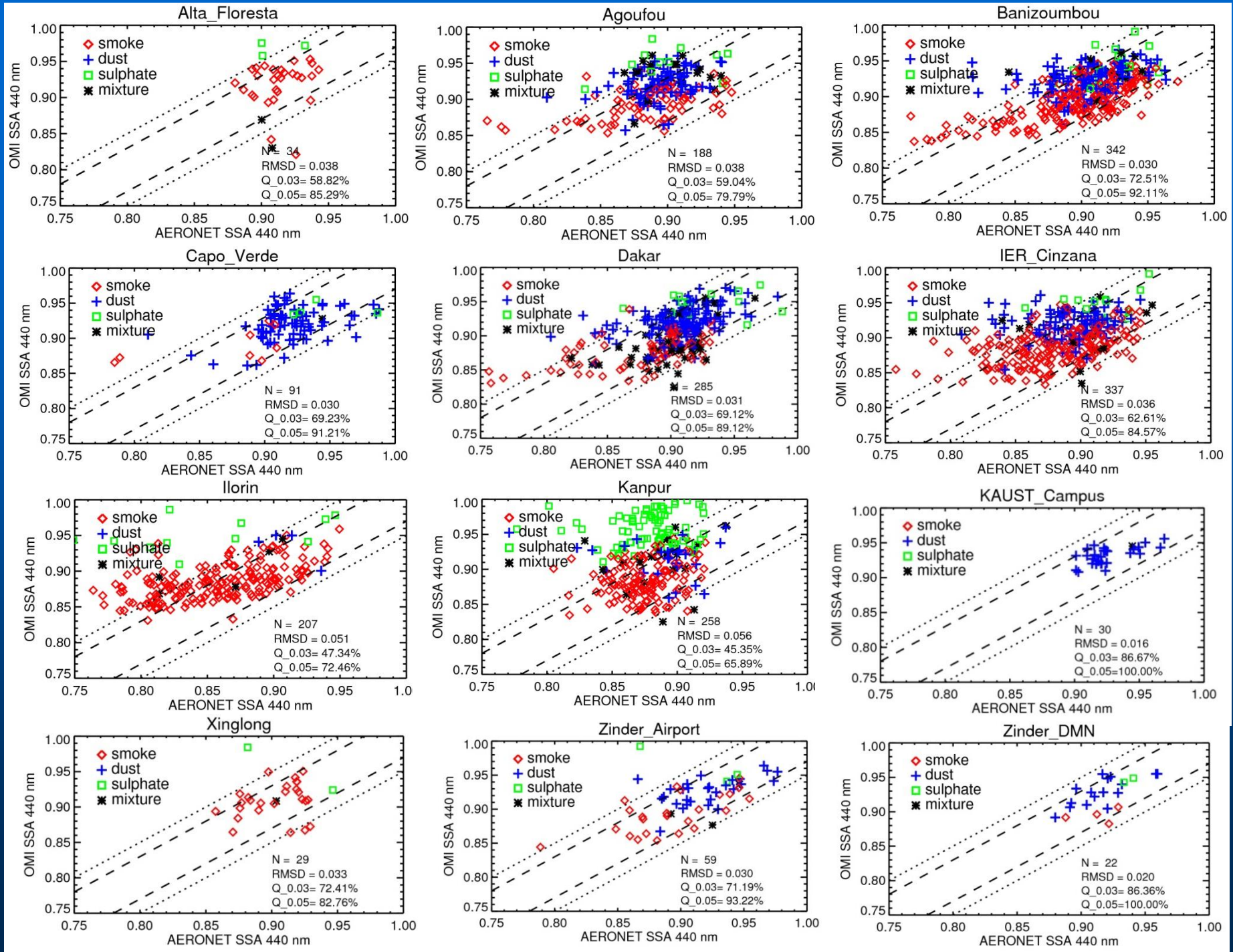
No. of days

SSA(440)>0.0; AOT(440)>0.4

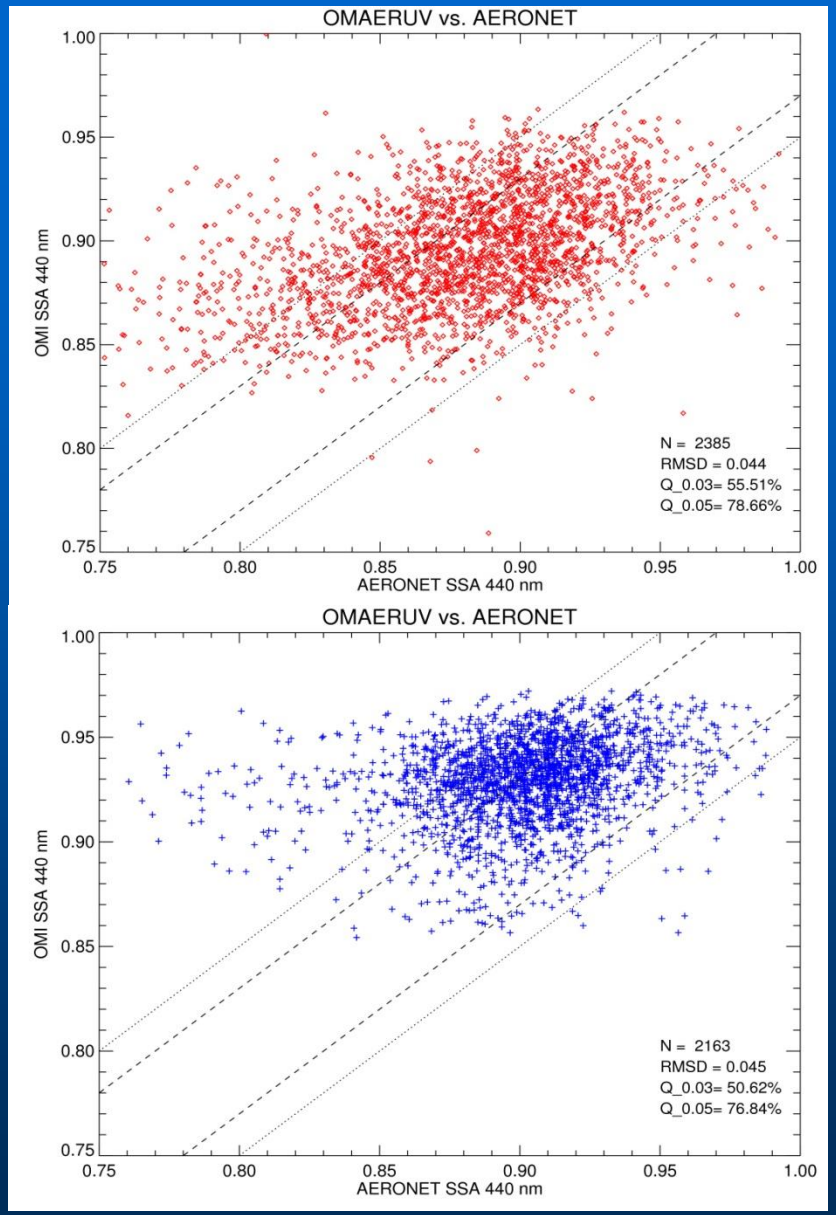


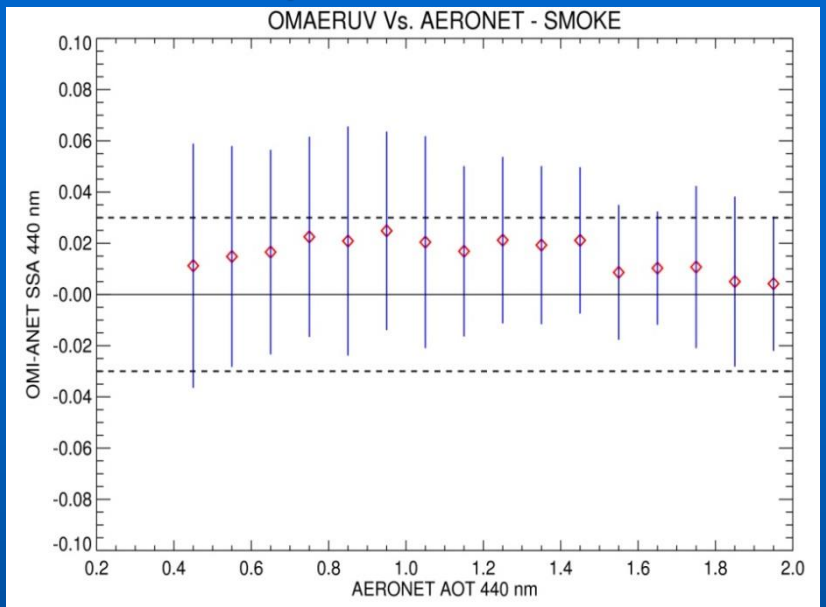
No. of ANET sites with daily observations: 702

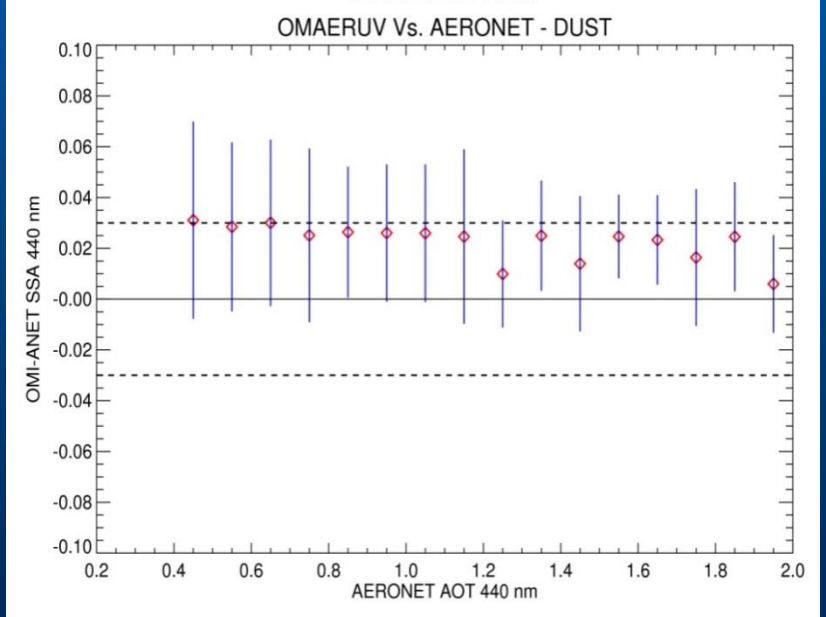
No. of ANET sites with daily observations of SSA>0. and AOT(440)>0.4: 454


Alta_Floresta
smoke
dust
sulphate
mixture
N = 34
RMSD = 0.038
Q_0.03= 58.82%
Q_0.05= 85.29%
Agoufou
N = 188
RMSD = 0.038
Q_0.03= 59.04%
Q_0.05= 79.79%
Banizoumbou
N = 342
RMSD = 0.030
Q_0.03= 72.51%
Q_0.05= 92.11%
Capo_Verde
N = 91
RMSD = 0.030
Q_0.03= 69.23%
Q_0.05= 91.21%
Dakar
N = 285
RMSD = 0.031
Q_0.03= 69.12%
Q_0.05= 89.12%
IER_Cinzana
N = 337
RMSD = 0.036
Q_0.03= 62.61%
Q_0.05= 84.57%
Ilorin
N = 207
RMSD = 0.051
Q_0.03= 47.34%
Q_0.05= 72.46%
Kanpur
N = 258
RMSD = 0.056
Q_0.03= 45.35%
Q_0.05= 65.89%
KAUST_Campus
N = 30
RMSD = 0.016
Q_0.03= 86.67%
Q_0.05=100.00%
Xinglong
N = 29
RMSD = 0.033
Q_0.03= 72.41%
Q_0.05= 82.76%
Zinder_Airport
N = 59
RMSD = 0.030
Q_0.03= 71.19%
Q_0.05= 93.22%
Zinder_DMN
N = 22
RMSD = 0.020
Q_0.03= 86.36%
Q_0.05=100.00%
OMI SSA 440 nm
AERONET SSA 440 nm

Global OMAERUV-AERONET SSA Comparison







-OMAERUV higher than AERONET (within 0.03)
-Differences are smaller at large AOD's

Jethva et al., 2013, JGR, in review

Summary

- OMI aerosol products show a good agreement with AERONET within the expected uncertainty envelope (AOD : ± 0.1 or 30 %, SSA : ± 0.03).
- Retrieval AOD accuracy of OMI, MODIS DB, and MISR over arid and semi-arid areas where cloud presence is less is comparable.
- OMI UV technique has capability of retrieving reasonable AOD values in boundary layer if sub-pixel cloud contamination is handled appropriately.
- Sources of uncertainty stated today are under investigation.
- A multi-year (2005 - present) global record of AOD and SSA (or AAOD) has been produced from OMI near UV observations.
- OMI UV aerosol (OMAERUV) data is available at the Goddard Earth Sciences Data and Information Services Center site (http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/omaeruv_v003.shtml).