Light absorption by pollution, dust, and biomass burning aerosols: A global model study and evaluation with AERONET measurements

Mian Chin[1](秦勉), Thomas Diehl[1], Oleg Dubovik[2], Tom Eck[1], Brent Holben[1], Aliaksandr Sinyuk[1], David Streets[3]

[1]NASA Goddard Space Flight Center
[2]University of Lille, France
[3]DOE Argonne National Laboratory

(Special issue "From Deserts to Monsoons", *Annales Geophysicae*, 2009)

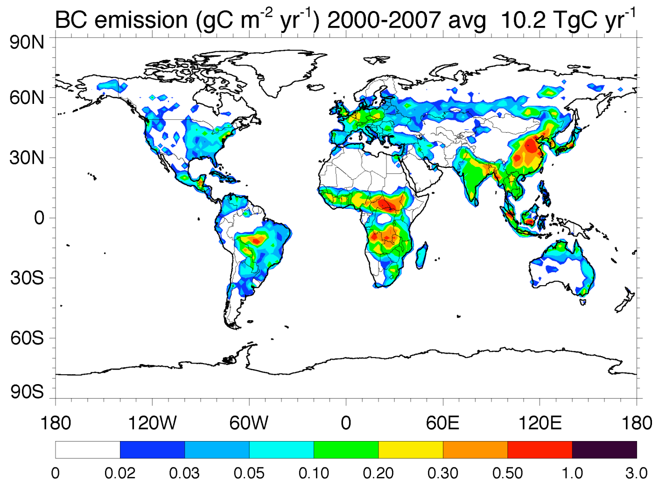
Introduction

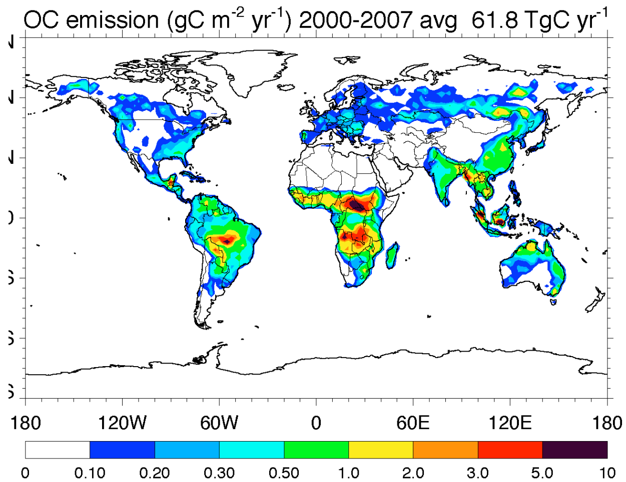
- We use the global model GOCART to estimate the aerosol absorption by pollution, dust, and smoke aerosols from 2000 to 2007 (8 years) in different world regions
- We compare model simulated aerosol optical depth (AOD), absorbing aerosol optical depth (AAOD), single scattering albedo (SSA), and Angstrom parameters (AE) with AERONET measurements or retrievals

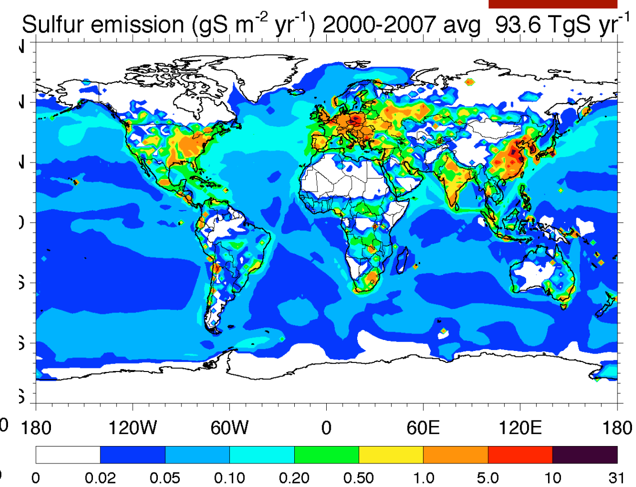
Emission, emission, emission…

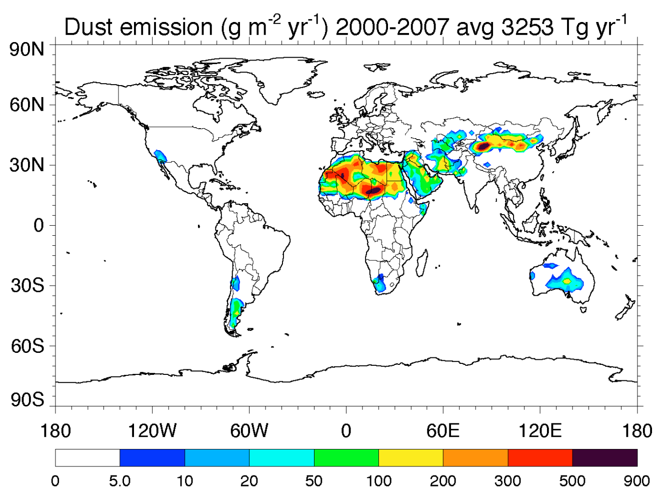
- Anthropogenic emission of SO_2, BC, OC: From Streets et al., 2009 with year-to-year variations
- Biomass burning emission of SO_2, BC, OC: GFED v2 for dry mass burned
  - Emission factors: BC – 1g/kgDM, OC – 8 g/kgDM (which are 40-100% higher than those in Andreae and Merlet 2001 (but 2x lower than Andreae et al., 1988), SO_2 – 0.35g/kgDM
- Volcanic SO_2: Based on Smithsonian GVP, TOMS and OMI SO_2, literature
- Dust: Ginoux source, emission calculated as a function of 10-m wind speed, surface wetness
- Sea salt: Based on Gong 2003 as a function of 10-m wind speed
- Other: DMS from ocean, SOA from terpene oxidation

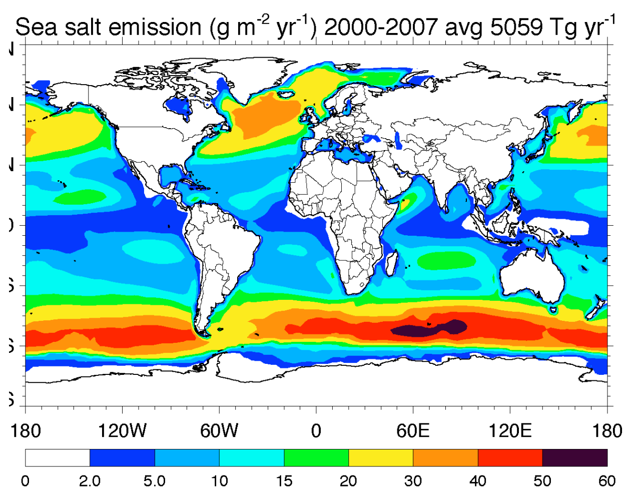
Emissions – 2000-2007 average











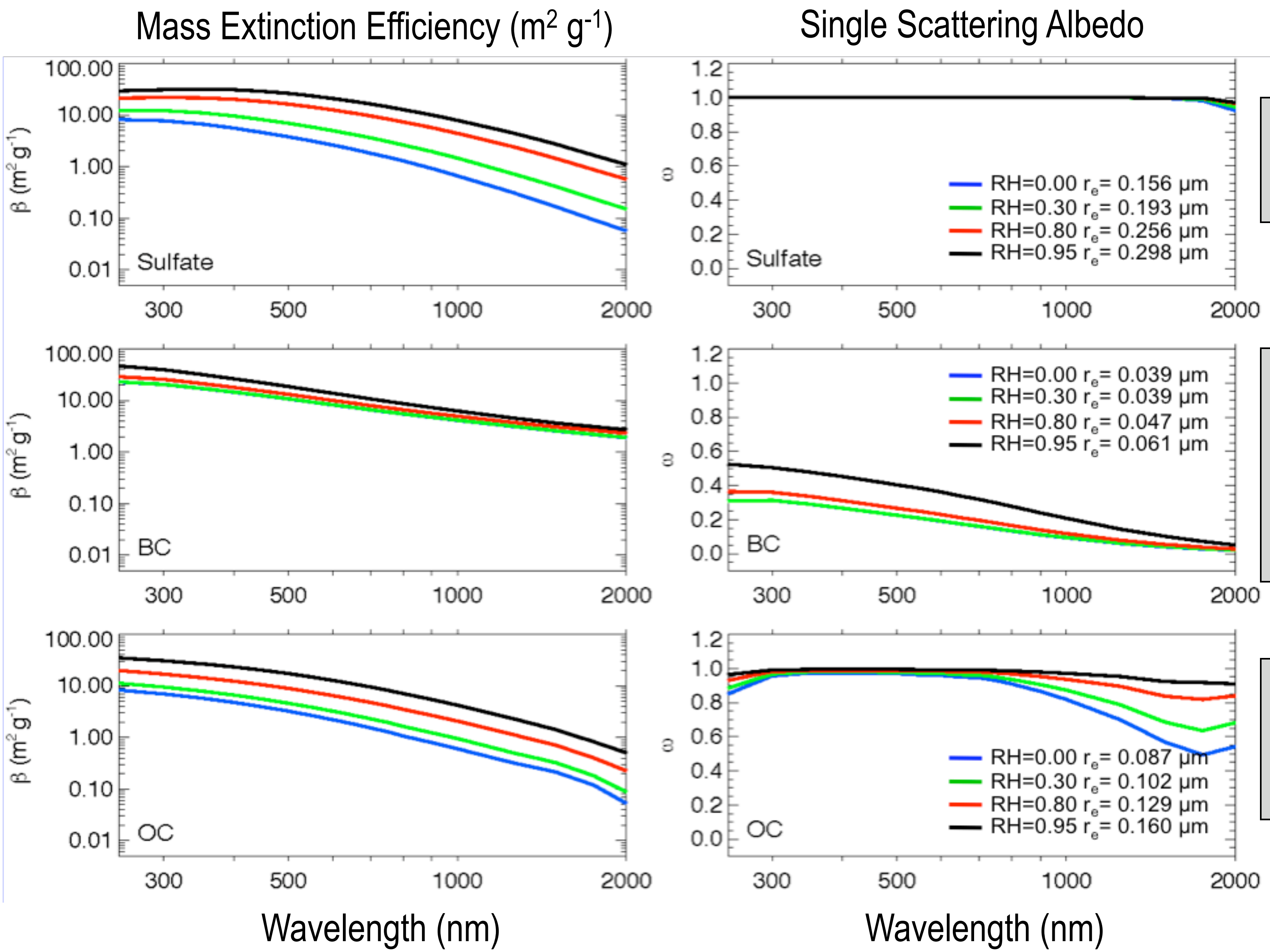
Species / Source	8-year avg. Emission ($TgM\ yr^{-1}$)§	Range ($TgM\ yr^{-1}$)§
BC	10.2	
Pollution	5.2	4.8 – 5.5
Biomass burning	5.0	4.5 – 5.3
OC	61.8	
Pollution	8.9	8.5 – 9.2
Biomass burning	40.2	36.1 – 42.3
Biogenic#	12.7	--
Sulfur*	93.6	
Pollution	65.5	60.2 – 70.2
Biomass burning	2.8	2.6 – 3.0
Volcanic	10.2	7.4 – 12.8
DMS	15.1	14.8 – 15.4
Dust	3250	3060 – 3340
Sea salt	5060	4920 – 5140

Microphysical and optical parameters

Aerosol Type	*Density ($g\ cm^{-3}$)*	*Dry r_m (μm)*	*Dry r_e (μm)*	*σ_g (μm)*	*Dry β (MEE) at 550 nm ($m^2\ g^{-1}$)*	*Refractive Index at 550 nm*
Sulfate	1.7	0.0695	0.156	2.03	3.143	$1.43 - 10^{-8}\,i$
OC	1.8	0.0212	0.087	2.20	2.668	1.53 – 0.006 *i*
BC	1.0	0.0118	0.039	2.00	9.284	1.75 – 0.44 *i*
Dust	2.6	0.0421	0.14	2.00	2.432	1.53 – 0.0055 *i*
	2.6	0.0722	0.24	2.00	2.578	1.53 – 0.0055 *i*
	2.6	0.1354	0.45	2.00	1.830	1.53 – 0.0055 *i*
	2.6	0.2407	0.80	2.00	1.015	1.53 – 0.0055 *i*
	2.6	0.4212	1.40	2.00	0.497	1.53 – 0.0055 *i*
	2.6	0.7220	2.40	2.00	0.271	1.53 – 0.0055 *i*
	2.6	1.3540	4.50	2.00	0.138	1.53 – 0.0055 *i*
	2.6	2.4070	8.00	2.00	0.075	1.53 – 0.0055 *i*
Sea Salt	2.2	0.228	0.80	2.03	1.152	$1.50 - 10^{-8}\,i$
	2.2	1.64	5.73	2.03	0.128	$1.50 - 10^{-8}\,i$

Based on the Optical Properties of Aerosols and Clouds (OPAC, Hess et al., 1998)

Spectral dependence of MEE and SSA

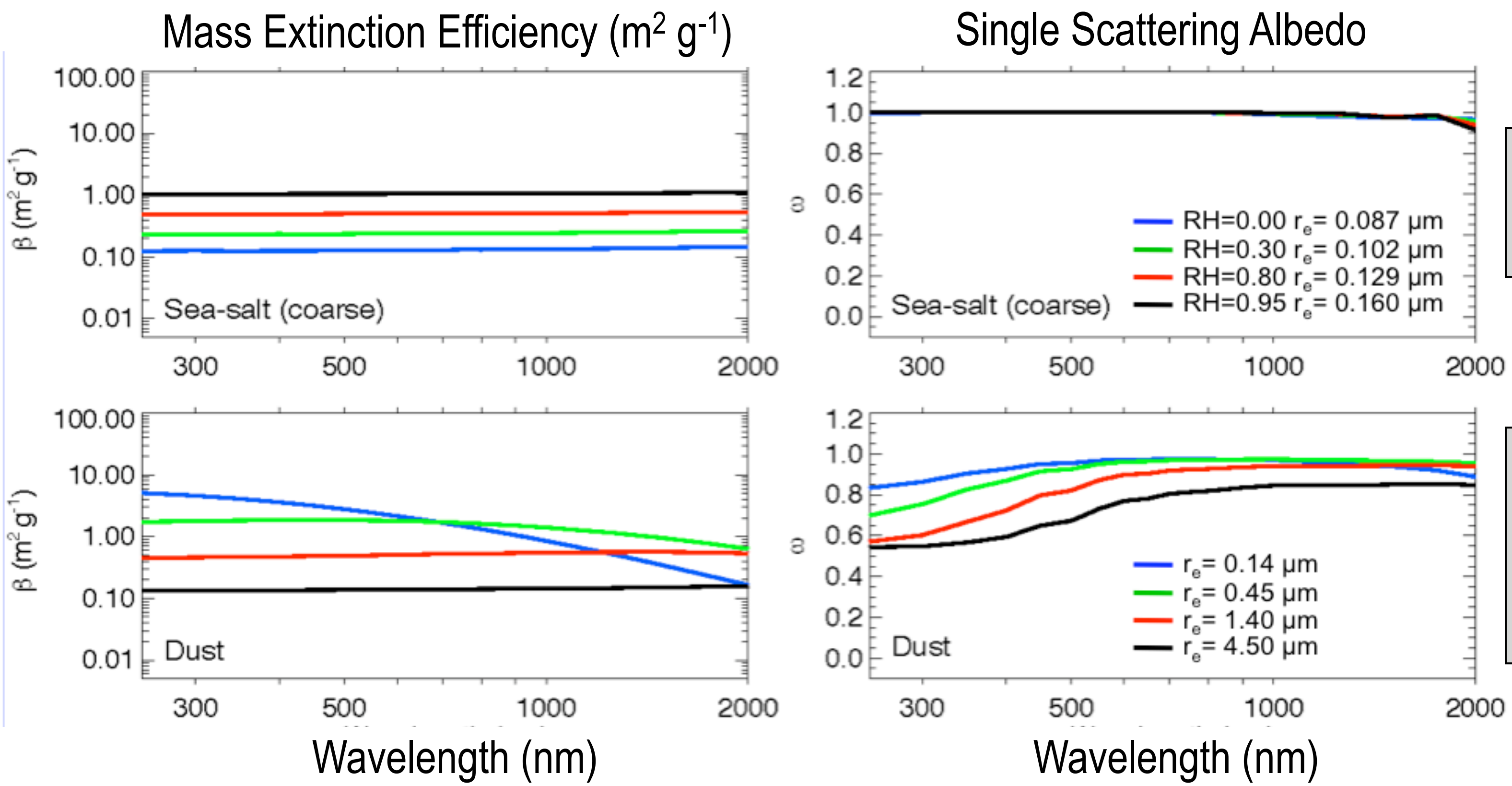


Sulfate is non-absorbing in the UV-VIS-NIR

BC is very absorbing at all spectrum range, and more so at longer wavelengths

OC is slightly absorbing in the UV and more absorbing in NIR

Spectral dependence of MEE and SSA



Sea-salt is non-absorbing in the UV-VIS-NIR

Dust is more absorbing in the shorter wavelengths with larger size

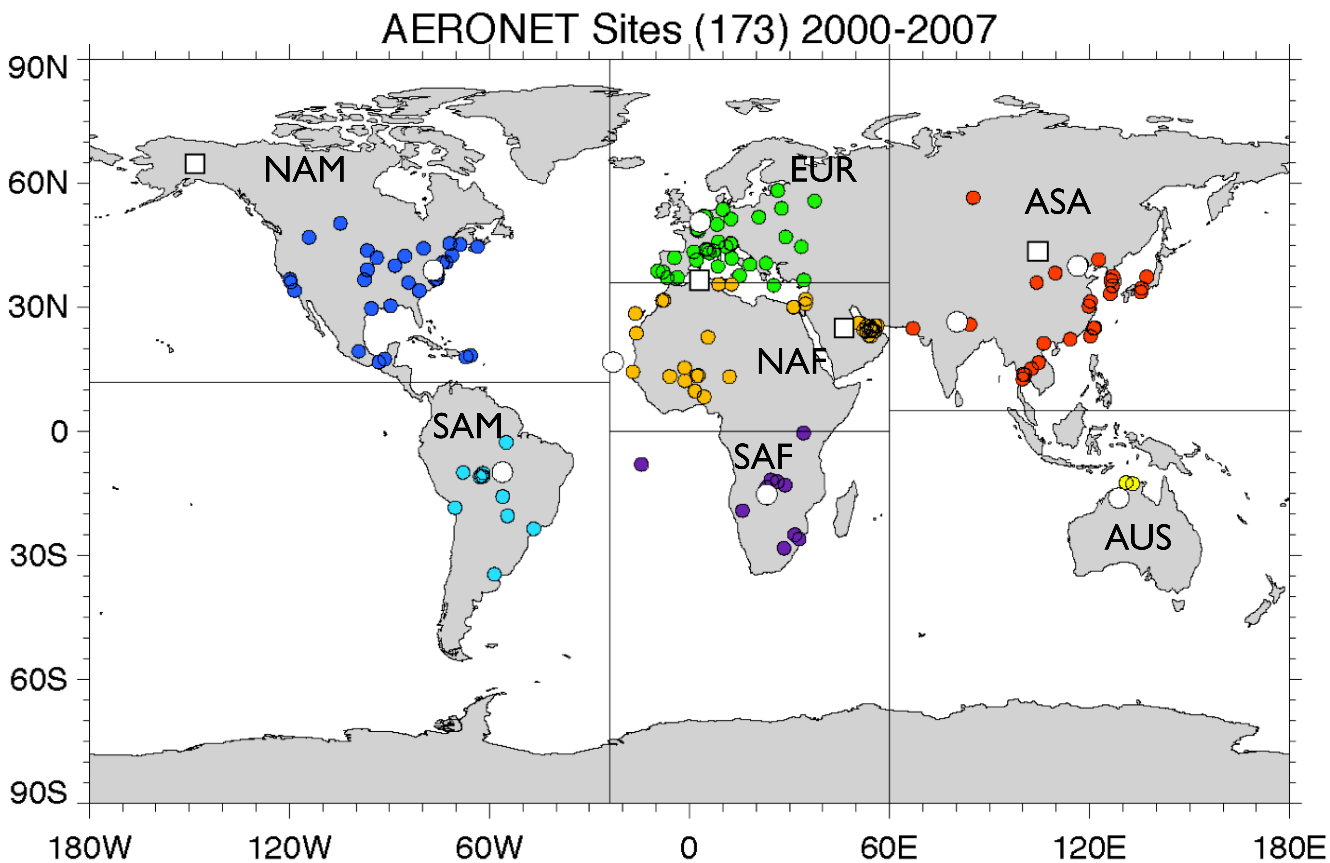
Note:

- Major absorbers in the solar spectrum are clearly dust and BC; both have large seasonal and interannual variability. OC is weakly absorbing in the UV.
- BC becomes more absorbing as wavelength increases; dust becomes less absorbing as wavelength increases.
- Even though the MEE (and MAE) of BC is much higher than that of dust, the mass loading of BC is much lower than that of dust.

Comparisons with AERONET data

- AERONET sun photometer measurements of AOD at multiple wavelengths
- AERONET Almucantar retrievals of single scattering albedo (thus absorbing AOD) at 440, 675, 870, and 1020 nm
- It is recommended that SSA should only be used at relatively high AOD (above 0.4 at 440 nm), therefore the available SSA (thus AAOD) data are much less than AOD
- We look the following quantities:
  - AOD, AAOD, SSA at 550 nm (AERONET 550 nm AOD interpolated from 440 and 675 nm)
  - Ångström exponent (AE, indication of aerosol particle size) at 440-870 nm pair
  - Wavelength dependence of SSA at pollution, biomass burning, and dust sites

AERONET sites:



There are 173 sites with simultaneous AOD and almucantar retrievals for ≥ 20 days in 2000-2007

7 regions:

R1 = North America
R2 = Europe
R3 = Asia
R4 = N. Africa/Mid. East
R5 = South America
R6 = Southern Africa
R7 = Australia & beyond

We choose 8 sites to compare daily AOD, AAOD, SSA, and AE (1 site per region except Asia where 2 sites were chosen). These sites are shown in white circles. These sites together with another four sites in white squares are used for the spectral dependence analysis of SSA later).

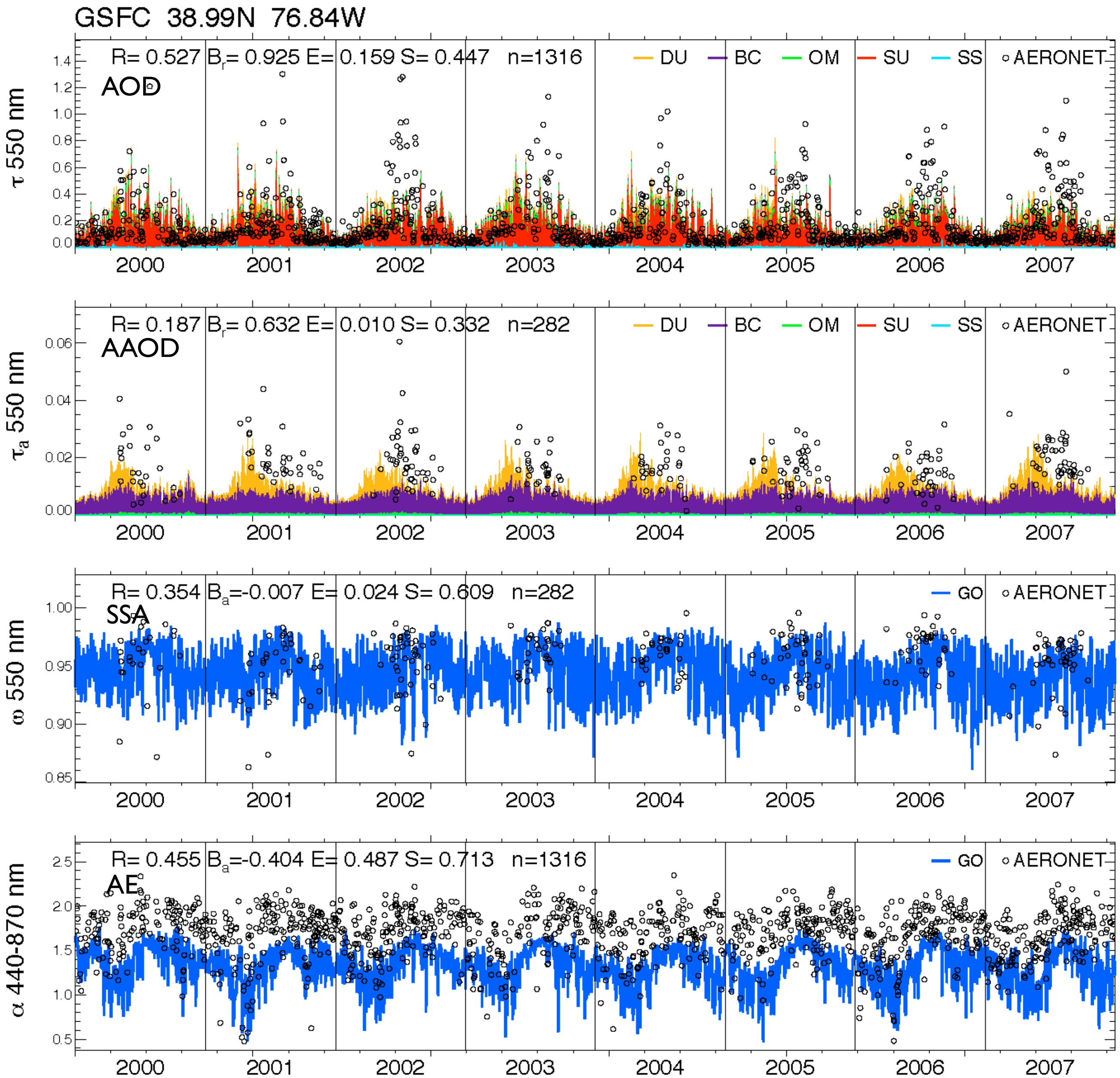
Pollution regions: GSFC, U.S.A.

AOD dominated by sulfate, with dust in the spring

AAOD dominated by BC, with dust in the spring

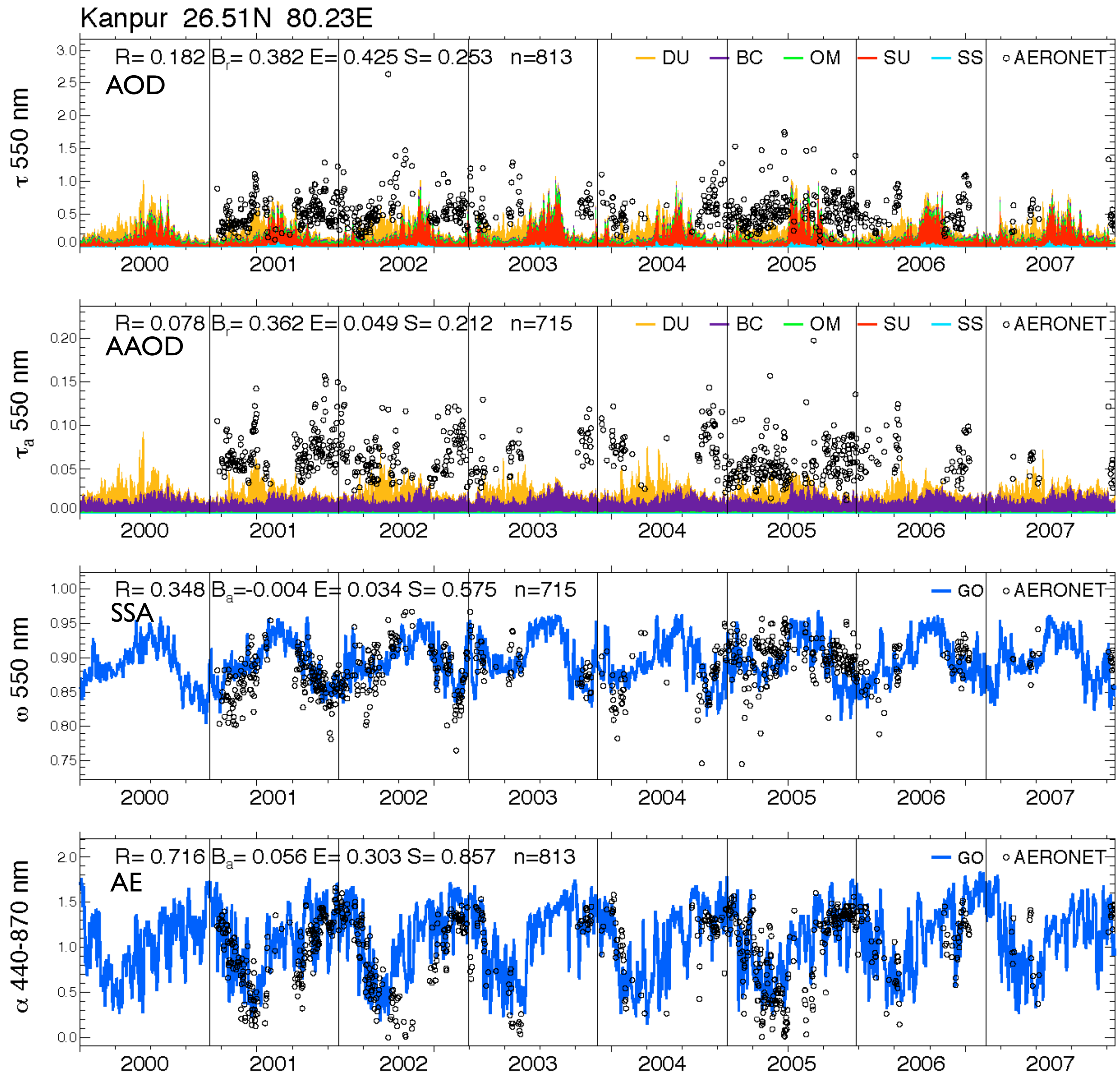
SSA varying with season, higher in summer

AE varying with season, lowest in spring, and GOCART AE too low



Pollution regions: Kanpur, India

AOD and AAOD: much too low in GOCART, poor correlation between GOCART and AERONET, low skill score of GOCART



SSA and AE: agreement much better between AERONET and GOCART – Fractions for each component are correct, but magnitudes are wrong

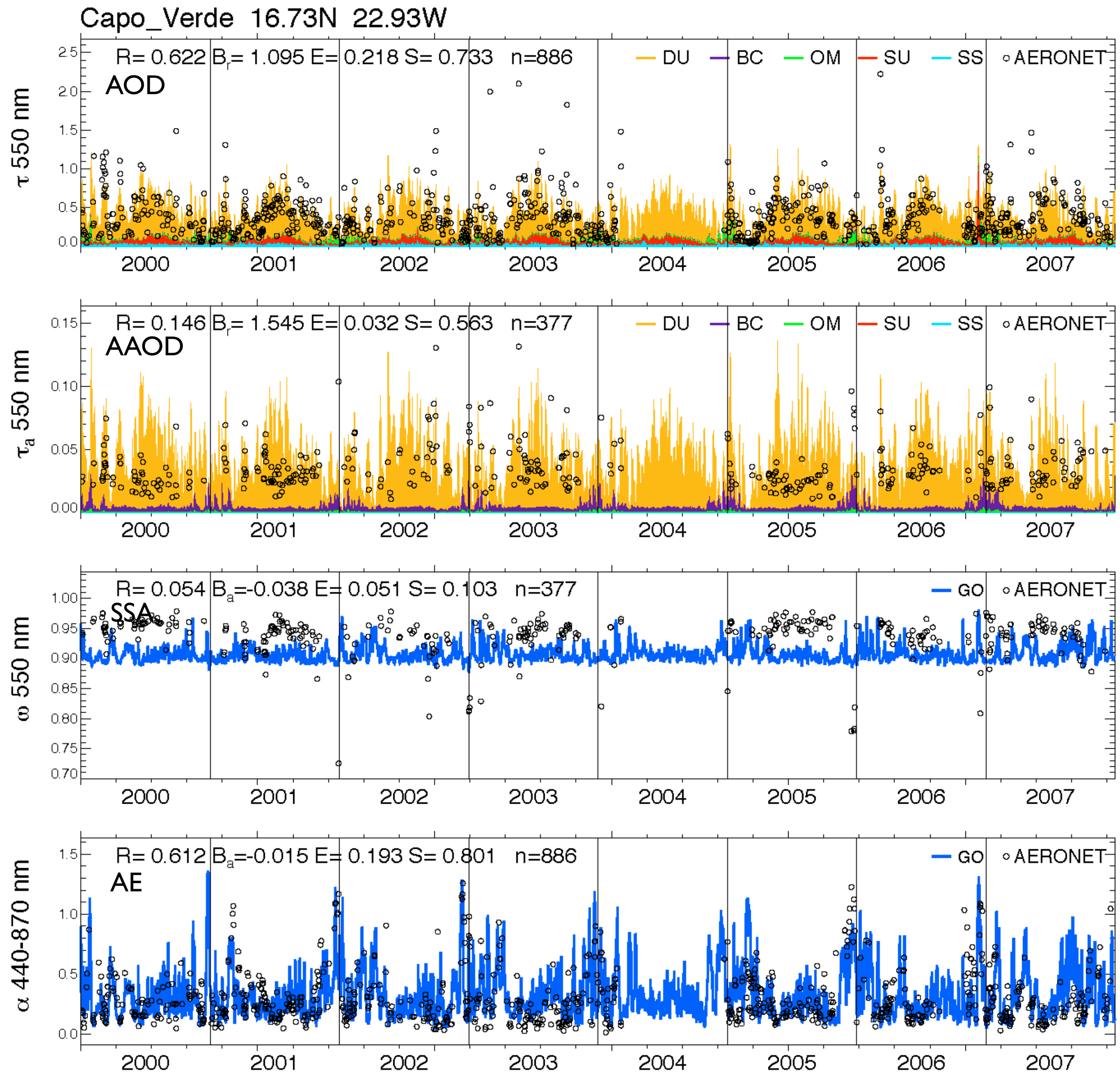
Dust region: Cape Verde, Sal Island

AOD: Dominated by dust, OM (from biomass burning) important in winter

AAOD: Dominated by dust, BC important in winter

SSA: AERONET around 0.95, GOCART 0.90

AE: Very large seasonal variations from 0 to 1, reflecting composition change



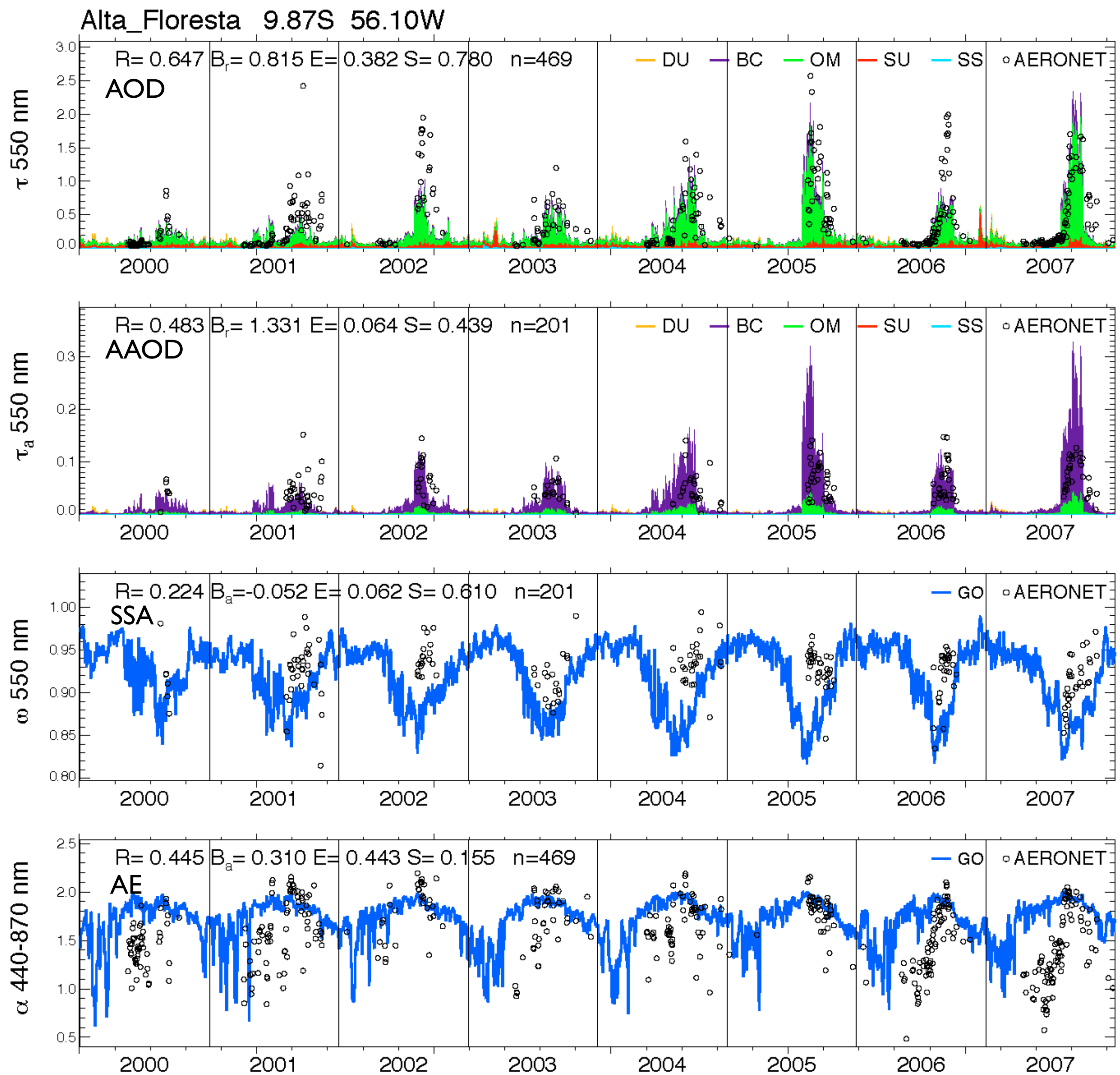
Biomass burning: Alta Floresta, Brazil

AOD: Dominated by OM (from biomass burning), profound seasonal variations

AAOD: Dominated by dust, BC, with OM weakly absorbing

SSA: AERONET data only during burning season, GOCART too low

AE: Large seasonal variations GOCART too high at the beginning of the burning season



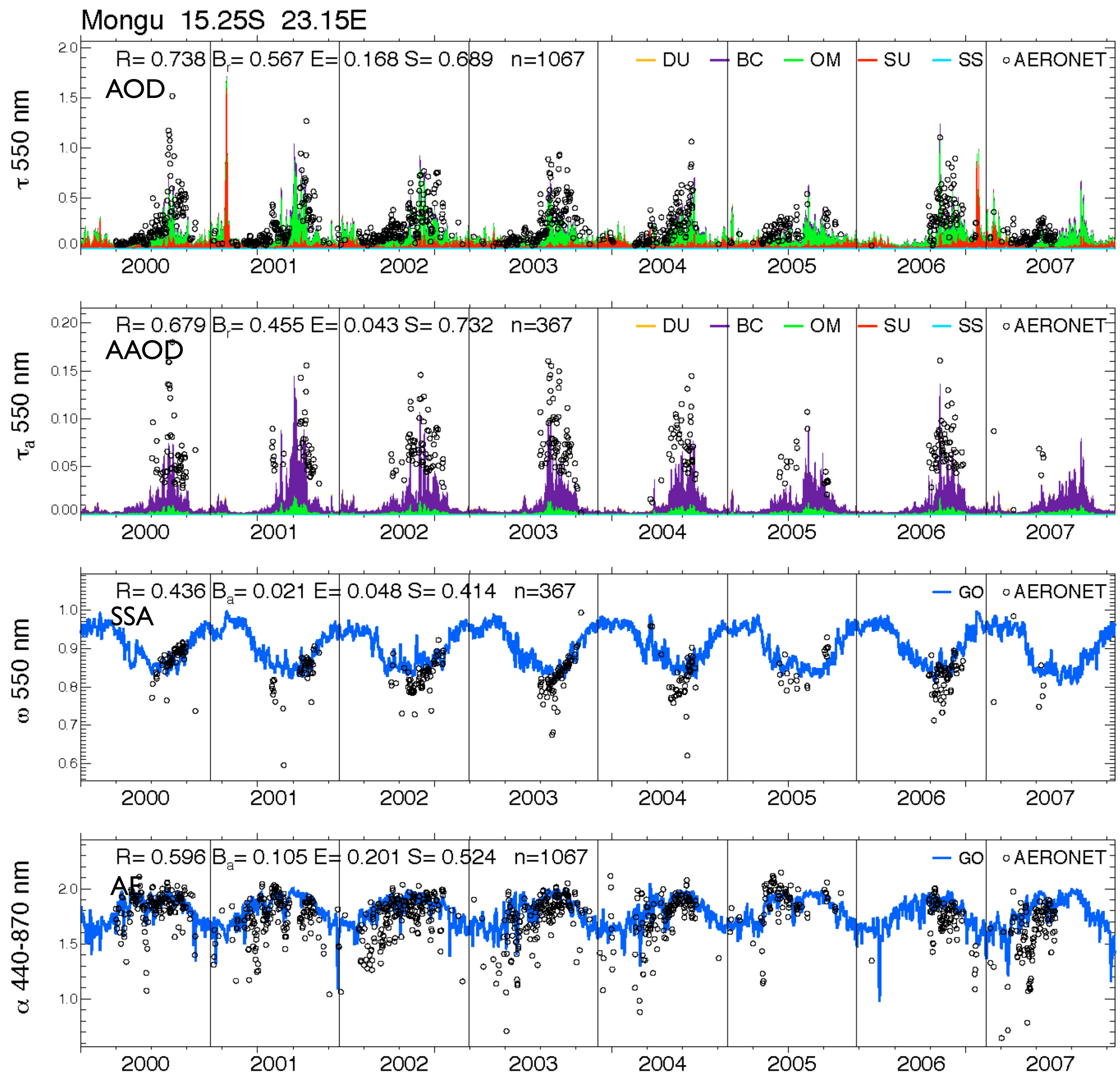
Biomass burning: Mongu, Zambia

AOD: Dominated by OM (from fire), sulfate important during non burning period (low value)

AAOD: Dominated by BC, with OM weakly absorbing. GOCART too low

SSA: AERONET data only during burning season, GOCART a bit higher

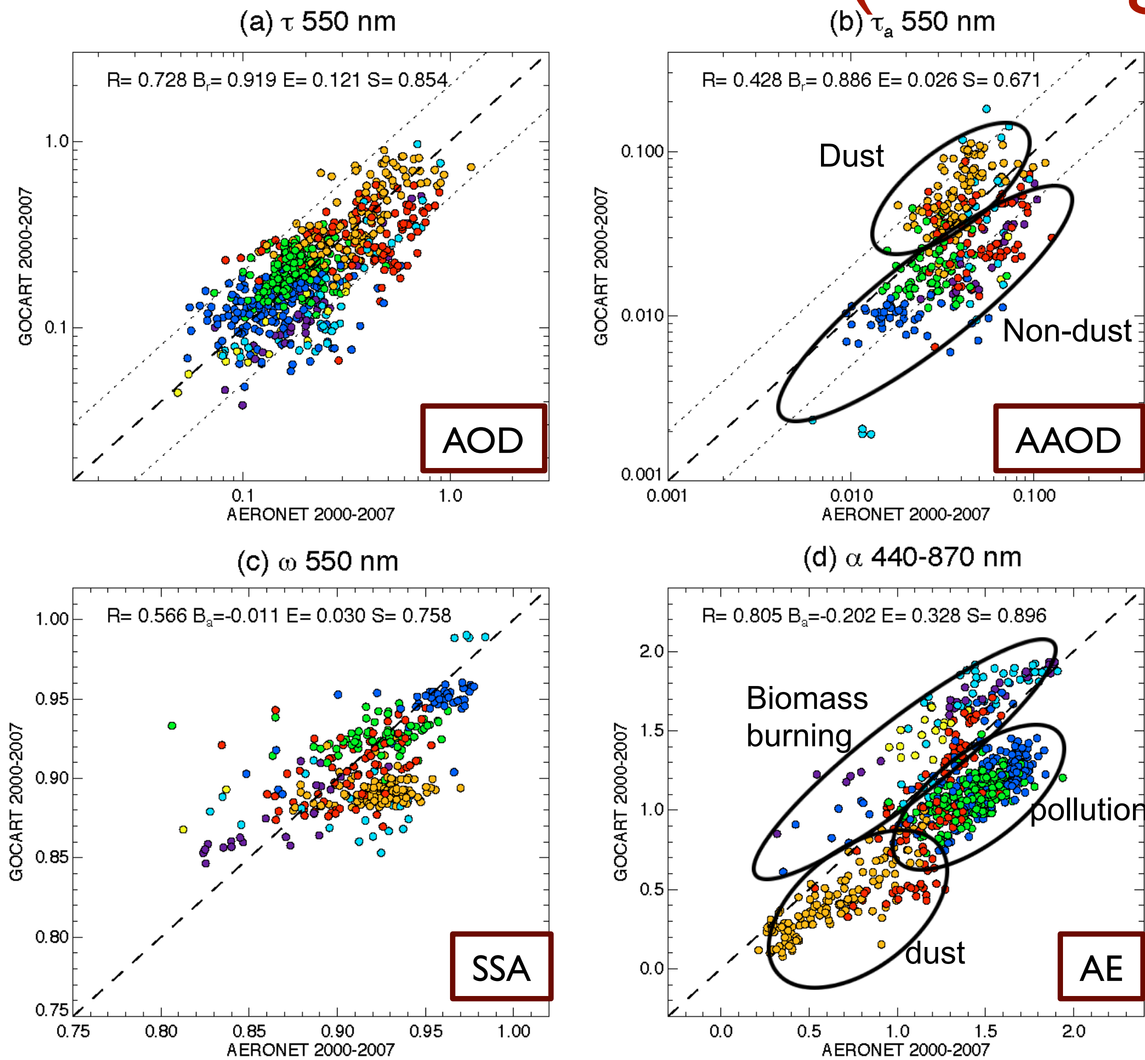
AE: Significant seasonal variation, higher in the burning season



Overall comparisons between GOCART and AERONET (ann. avg)

AOD: GOCART has no significant overall `bias

SSA: GOCART shows much narrower range in NAM, EUR, NAF than AERONET

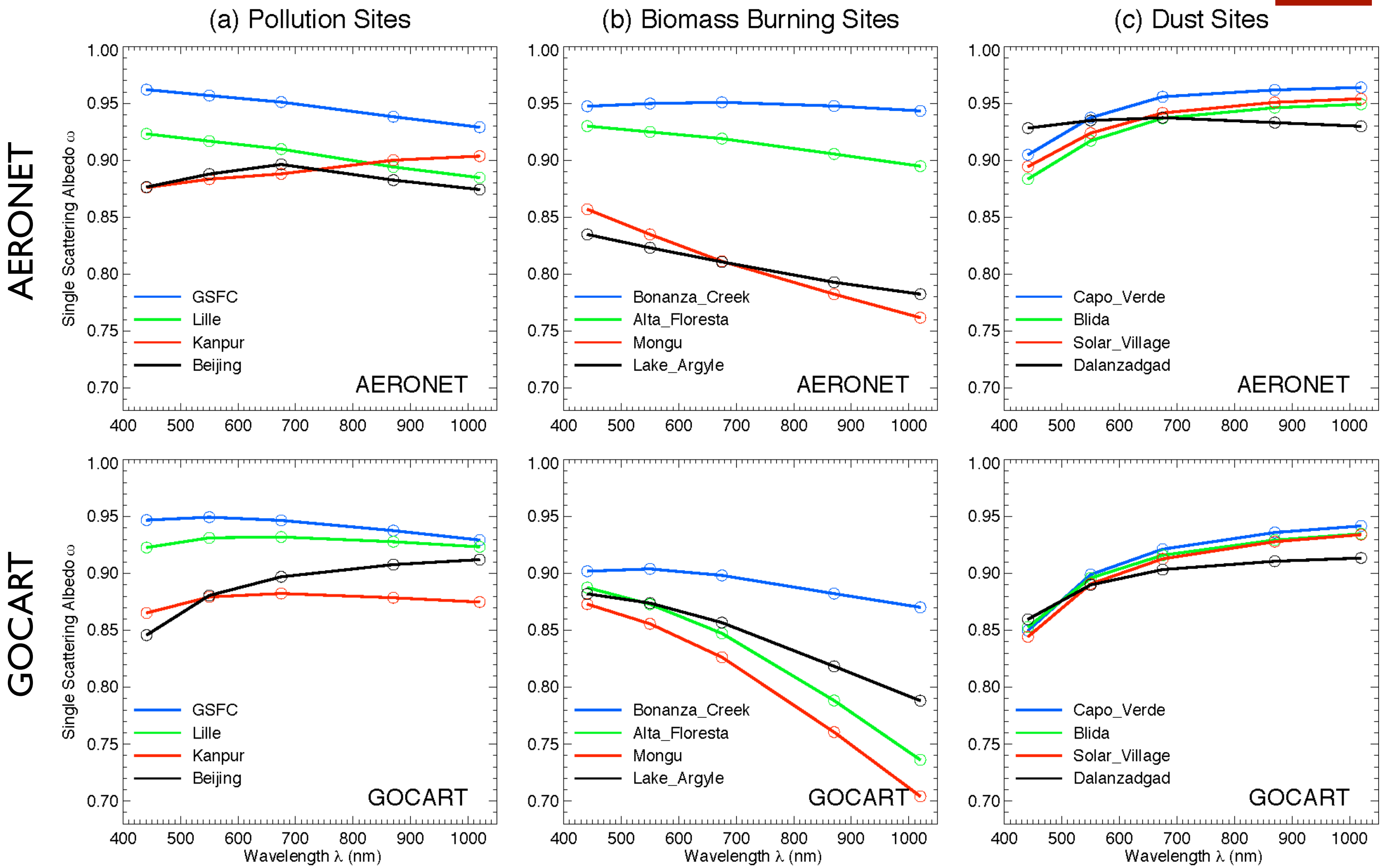


AAOD: Dust: GOCART dust higher than AERONET, most other aerosols lower than AERONET

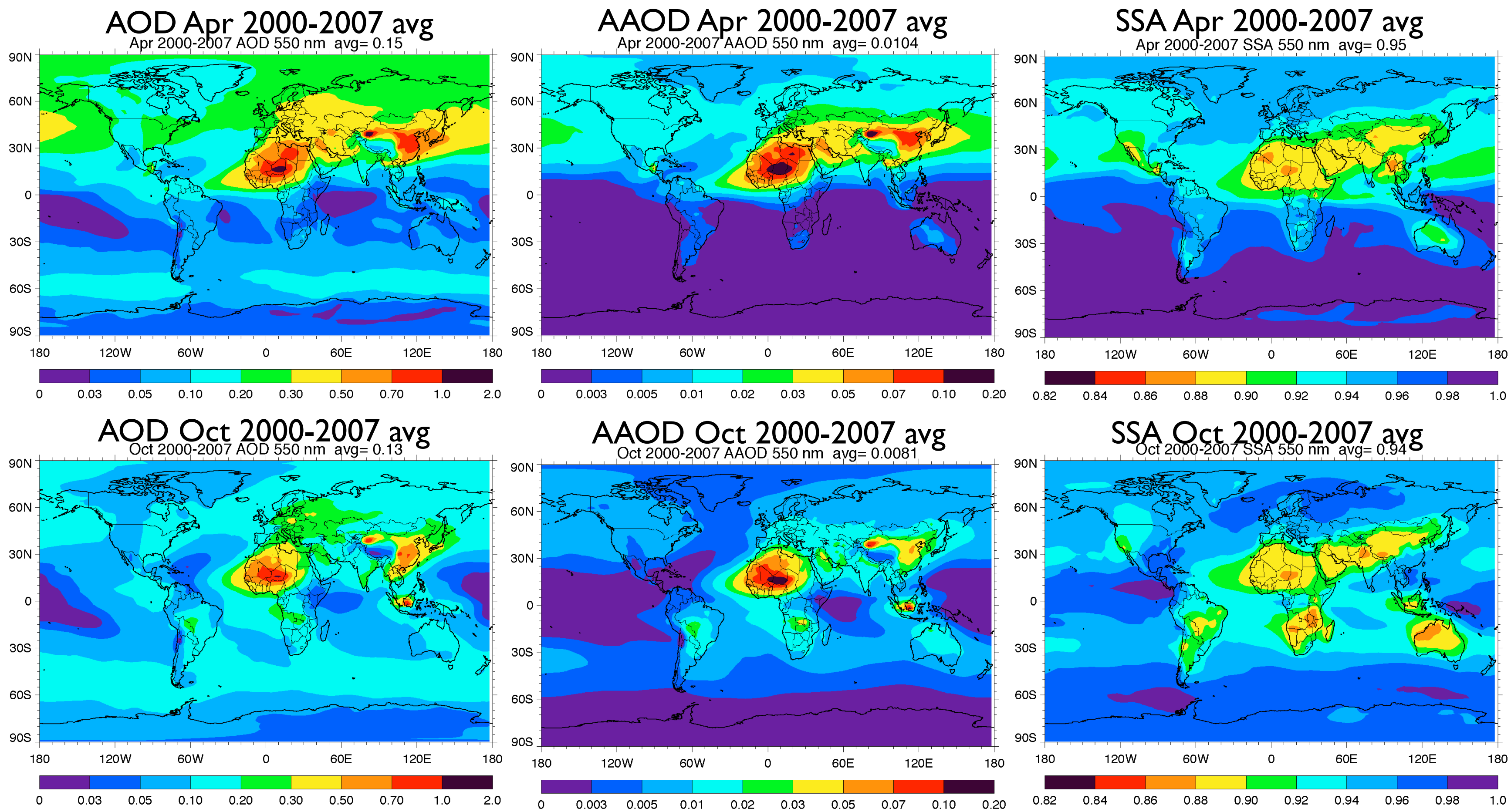
AE: GOCART too high at biomass burning sites, too low at pollution and dust sites

7 regions: **R1** = North America, **R2** = Europe, **R3** = Asia, **R4** = N. Africa/Middle East, **R5** = South America, **R6** = Southern Africa, **R7** = Australia

Spectral-dependence of SSA at sites with different aerosol type



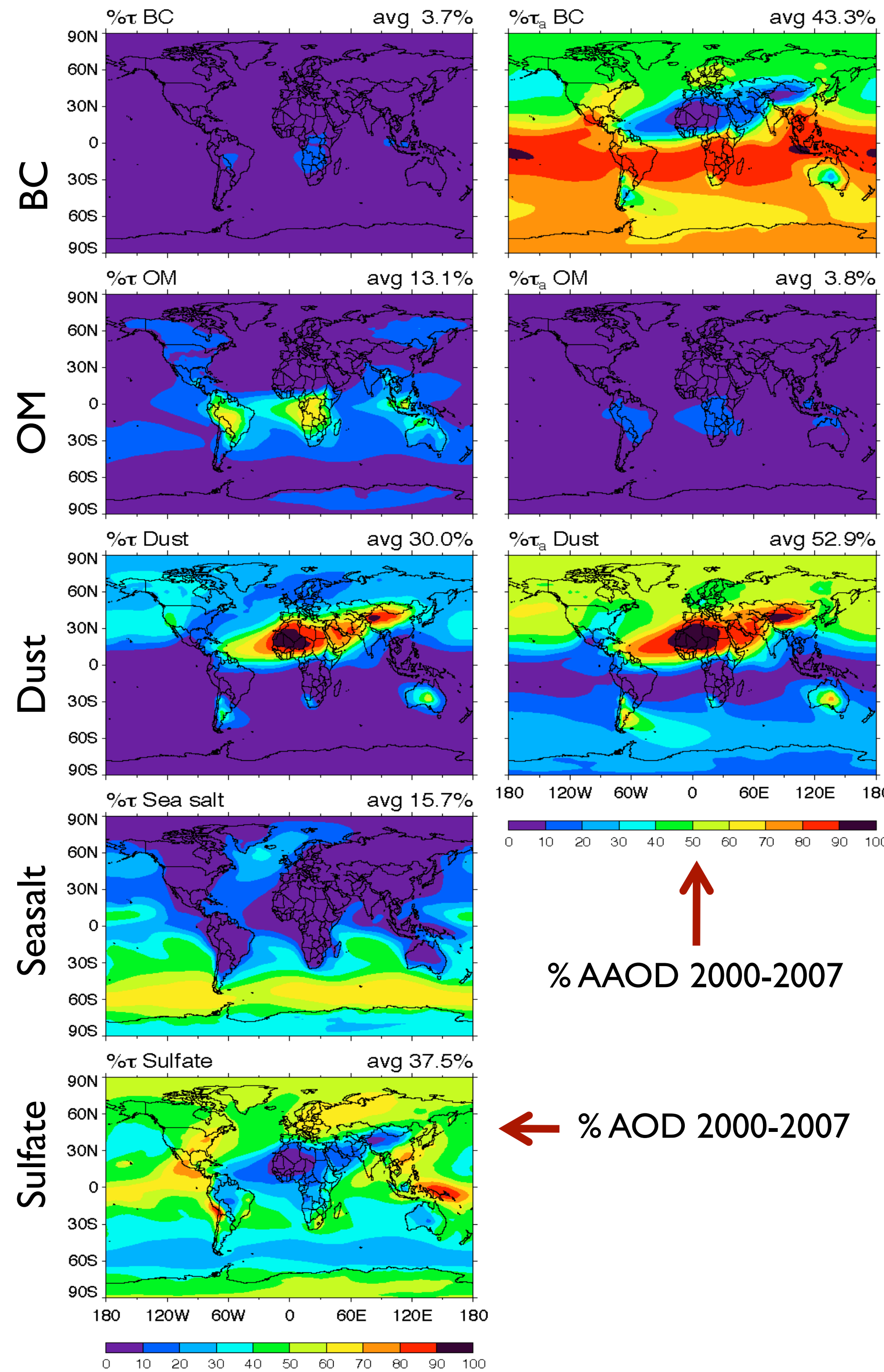
"Climatology" of AOD, AAOD, and SSA



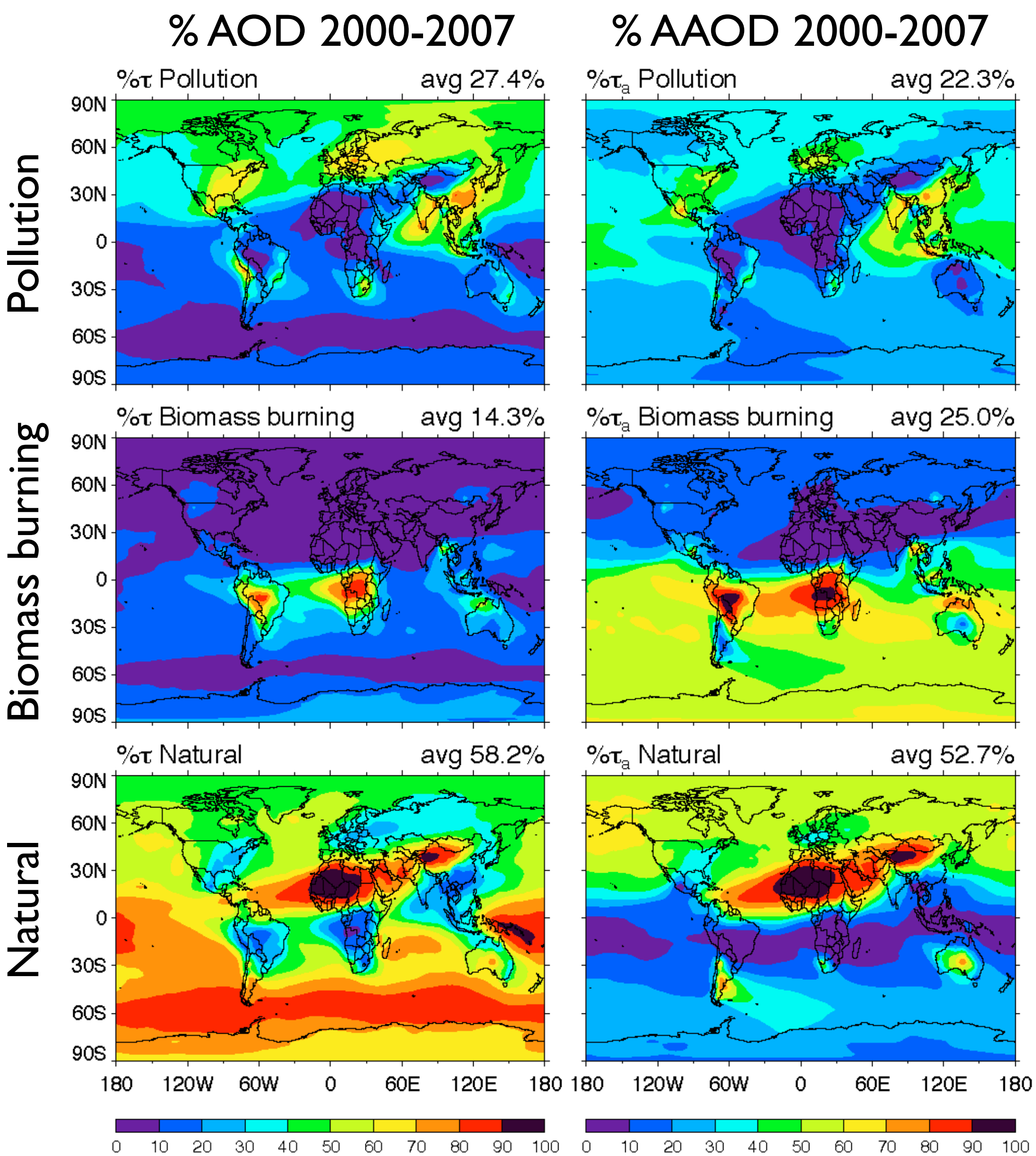
- 8-year climatology from GOCART (550nm): AOD=0.14, AAOD=0.086, SSA=0.95
- AOD and AAOD are highest in Apr when transport is the strongest
- The highest AOD and AAOD located in heavy dust, biomass burning, & pollution regions
- The lowest SSA in biomass burning regions
- NH: seasonal cycle regulated by transport of pollution and dust
- SH: seasonal cycle regulated by biomass burning

Composition of AOD and AAOD – % component

- Globally, the largest contribution of AOD from sulfate (37%), followed by dust (30%), sea salt (16%), POM (13%), and BC (4%)
- Dust (53%) and BC (43%) shares the load of AAOD, with some POM in the tropics
- BC is optically thin, but is very efficient in absorption



Origins of AOD and AAOD – % sources



- Natural sources include dust, sea salt, biogenic, and volcanic
- 58% of AOD and 53% of AAOD from natural sources
- Pollution accounts for 27% of AOD and 22% of AAOD
- Biomass burning contributes to 14% of AOD and 25% of AAOD
- In the Arctic, for AOD the influence from dust is almost as important as that from pollution, and for AAOD dust is more important

Concluding Remarks

- It is important to have multi-spectral, multi-parameter comparisons
- GOCART compares better with AERONET data on directly measured quantities of AOD and AE than on retrieved quantities of AAOD and SSA
- The 8-year (2000-2007), global averaged AOD, AAOD, and SSA at 550 nm are estimated at 0.14, 0.0086, and 0.95, respectively
- Composition-wise, sulfate makes the largest fraction of AOD (37%) globally, followed by dust (30%), sea salt (16%), OM (13%), and BC (4%), while dust and BC are the major components of AAOD (53% and 43%, respectively)
- Source-wise, natural aerosols (dust, sea salt, volcanic, and biogenic) account for 58% of AOD and 53% of AAOD with pollution and biomass burning shares the rest
- Note these fraction changes significantly with space and time, and also changes with different wavelength

Needed model improvements

- Differences in biomass burning AOD suggests:
  - biomass burning emission in GOCART is too low
- Differences in AAOD suggests:
  - the BC amount is too low
  - dust is somewhat too absorbing from OPAC
- Differences in AE suggests:
  - sulfate lognormal size distribution is too wide
  - OM effective radius too small
- Differences in SSA suggests:
  - dust is too absorbing
  - Should consider the regional difference in dust mineralogical composition
  - Should have different emission factors for forest burning and savanna/shrub burning