Aerosol Optical Depth

combining different data-sets from remote sensing to a ‘recommended’ composite

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with many satellite retrieval groups and the AERONET group (at NASA-GSFC)

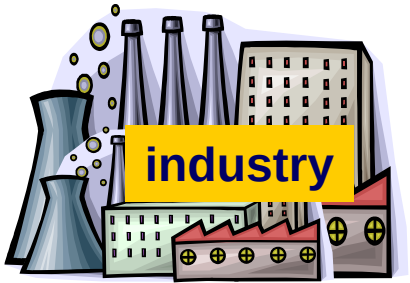
Outline

- aerosol and its properties
- aerosol remote sensing from space
- aerosol remote sensing from ground
- creating the composite
- outlook

aerosol

aerosol – *'small' atmos. particles*

- aerosol – more than an atmospheric size class
  - many sources
  - short lifetime
  - diff. magnitudes in size
  - changing over time
    - aerosol ←→ clouds
    - aerosol ←→ chemistry
    - aerosol ←→ biosphere
    - aerosol ←→ aerosol



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    - aerosol ←→ clouds
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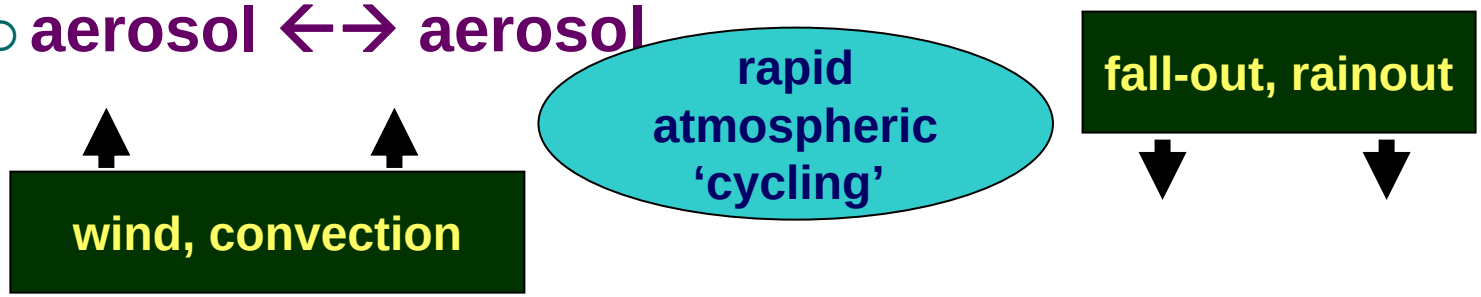
highly variable in space and time !



aerosol – *optical prop. of interest*

- **aerosol is defined by**
  - **amount** **"number concentration"**
  - **size** **"size-distribution"**
  - **absorption** **"refractive index"**

MIE–calculations → opt. properties

- **measurement substitutes are**
  - **(vis) aerosol optical thickness (aot)** ***(amount)***
  - **aot-spectral dep [Angstrom param]** ***(size)***
  - **single scattering albedo (ω_0)** ***(absorption)***

aerosol space remote sensing

aerosol retrievals difficulties

- the aerosol signal from space is
  - is usually strongest in the UV and visible spectrum
    - try to avoid trace-gas absorption,
    - deal with Rayleigh scattering and surface albedo
  - easily modulated by surface reflectance
    - surface reflectance need to be know better than 0.2%
  - usually small compared to clouds or snow
    - good cloud-screening is essential ⇨ small pixels !
  - usually unable to distinguish on processes
    - how much scattering is offset by absorption

what properties are retrieved ?

- **AOT** ***(amount)***
  - **always** ***… but only at particular wavelengths***
- **Angstrom parameter** ***(size)***
  - **sometimes** ***… if AOT retrieved at diff wavelengths***
- ω_0 ***([1-ω_0] ~ absorption)***
  - **(almost) never**
  - **aerosol absorption** ***- an essential ingredient AOT retrieval -*** **must be assumed !**

… and aot retrievals are often limited to deep oceans regions, where surface reflectance contributions can be better characterized.

different methods for AOT

- **visible reflection** ***(nadir)***
  - **MODIS, AVHRR, MERIS, POLDER (ocean) …**
- **visible reflection** ***(multi-direction)***
  - **MISR, AATSR**
- **UV reflection** ***(+ changes to spectral contrast)***
  - **TOMS, OMI**
- **polarization** ***(limited sensitivity to large sizes)***
  - **POLDER (land)**
- **IR sensor** ***(mainly for elevated dust)***
  - **AIRS, TOVS, …**

multi-annual AOT data-sets

satellite	years	limitation	major bias
TOMS	79-01	50km pixel	++ cloud c.
MISR	00-04	6day repeat	+ over ocean
MODIS	00-04	no deserts	+ over land
AVHRR,1ch	85-88	no land	? (+rad /-abs)
AVHRR,2ch	84-01	no land	+ cloud c.
POLDER	97/03	land ?	large/ hi elev.

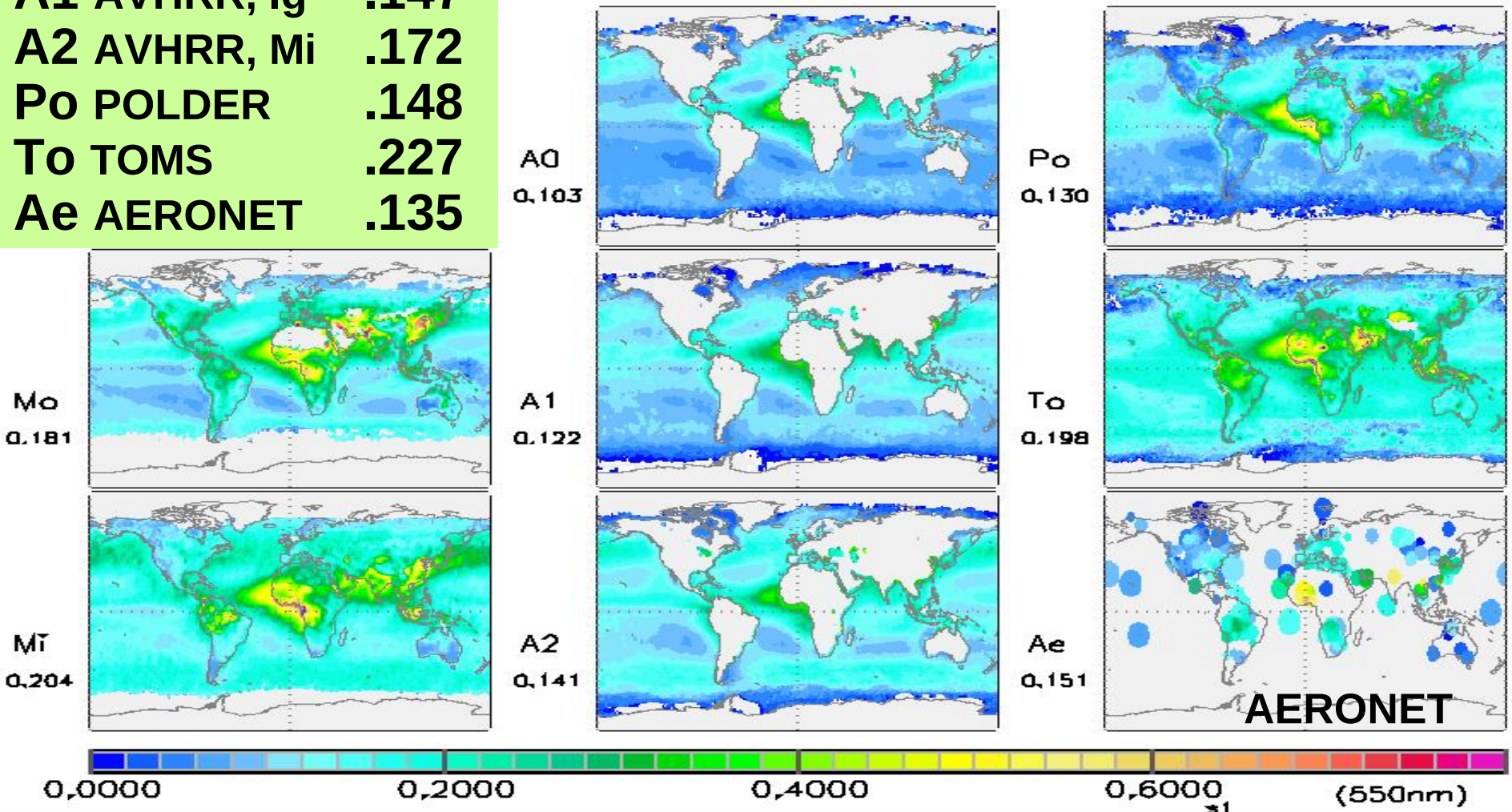
- what retrieval is the best ? where? when?
  - conduct a regional comparison to AERONET

AOT – many choices !

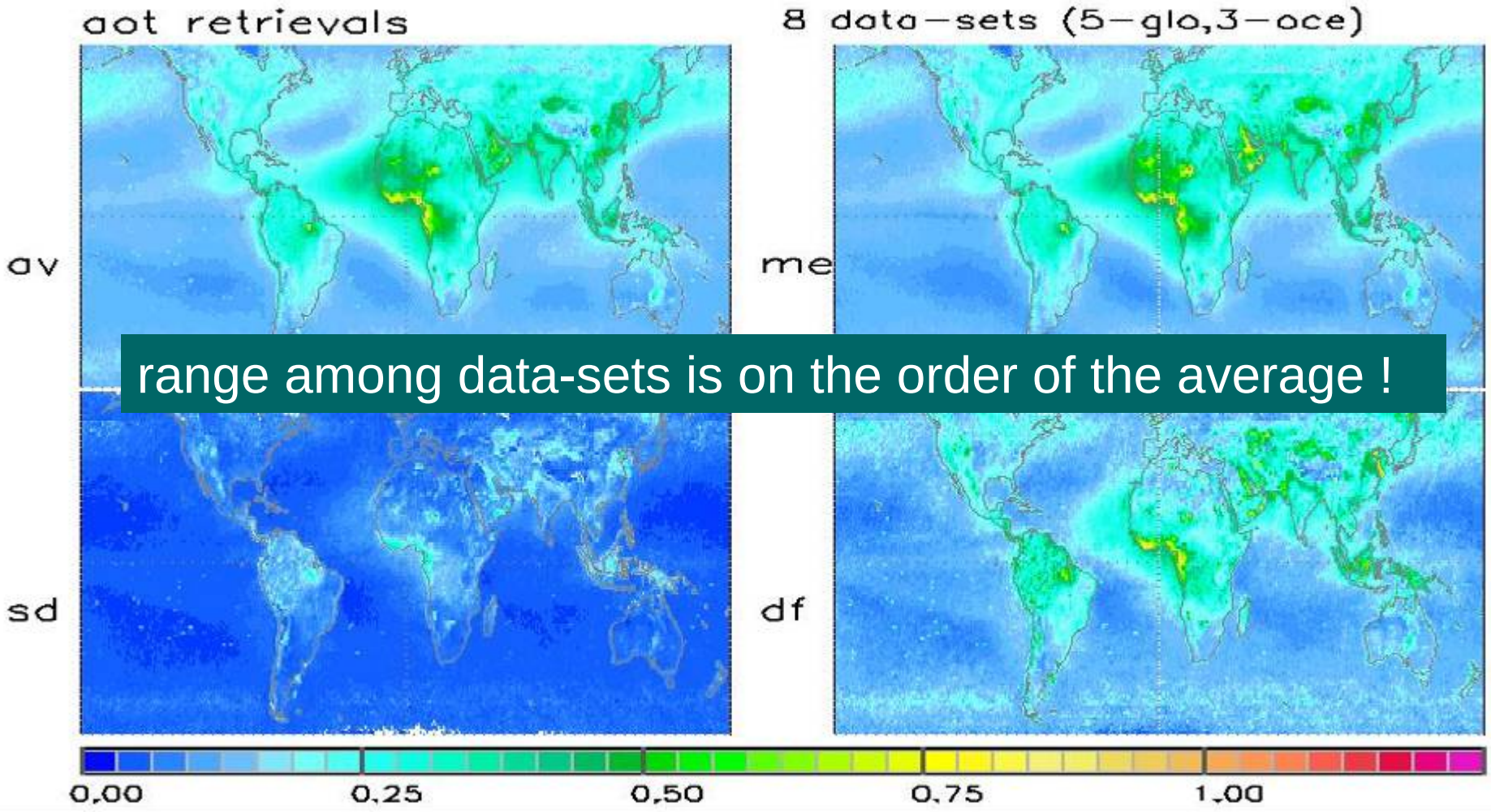
model adj. AOT

Mo	**MODIS**	**.197**
Mi	**MISR**	**.201**
A0	**AVHRR, St**	**.131**
A1	**AVHRR, Ig**	**.147**
A2	**AVHRR, Mi**	**.172**
Po	**POLDER**	**.148**
To	**TOMS**	**.227**
Ae	**AERONET**	**.135**

all annual retrieval averages refer to 0.55μm



AOT – *multi-year retrieval statistics*



range among data-sets is on the order of the average !

- **av**erage**, me**dian**, s**td.**d**eviation**, di**fference

AOT accuracy issues

- **without considering some of known problems …**
  - **cloud/snow sub-pixel contamination**
  - **uncertainty in surface reflectance**
  - **inappropriate retrieval assumption**

  …the diversity among retrievals is as large as the average retrieval value !

- **higher accuracy is demanded for useful constrains to global modeling !**

- **evaluate against AERONET quality statistics**

aerosol ground remote sensing

the CIMEL sun-photomter

- multi-spectral detector
  - .44, .50, .67, .87, .94, 1.0μm
- operational modes:
  - sun-mode *(towards the sun, 4/hr)*
    - detecting direct solar attenuation
  - sky_mode *(scan the sky, 1/hr)*
    - detecting diffuse solar radiation
- highly automated ('robotic')
  - low maintaince
  - data transfer via satellite

AERONET

… is the ‘sum’ of many inter-calibrated CIMELs

- **NASA-GFSC supervised and maintained**
- **more than 150 operational CIMELS (by 2006)**
- **DATA:**
  - **since 1994 from more than 300sites**
  - **column properties for**
    - **aerosol amount (visible Aerosol Optical Depth, AOD)**
    - **aerosol size (Angstrom, size-distribution [fwd scatt.])**
    - **aerosol absorption (w0) *…accurate if AOD >0.3***
    - **water vapor**

local → gridded monthly stats

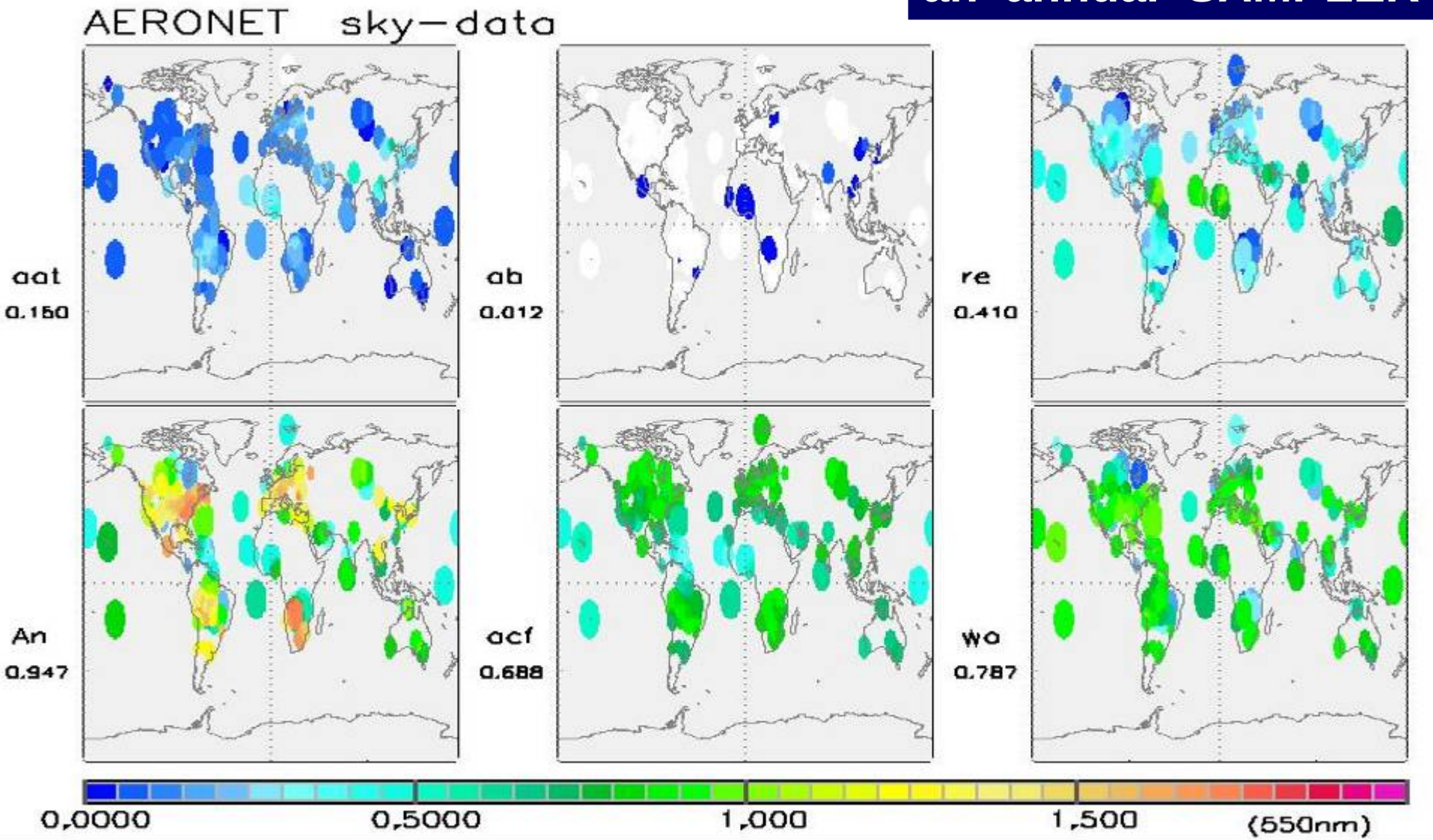
- establish local statistics (day, month, year)
  - for ‘measured’ data (AOD, Angstrom data)
  - for ‘inverted’ data (w0 *RFI*, size-distribution *r,eff*)
  - for ‘derived’ products (radiative forcing, lidar ratio)

anonymous ftp: ftp.zmaw.de cd aerocom/aeronet/grd_stat608

- combine local statistics on a regular (1^ox1^o) grid
  - rate each site on data-quality (*with help by T.Eck*)
  - rate each site on regional extension (*help by T.Eck*)
  - apply to (almost) global data from remote sensing
  - apply to global data-set of global modeling

‘quasi-global’

an ‘annual’ SAMPLER



AERONET

- **advantages**
  - **quality data on all aerosol column properties**
  - **simultaneously at many sites (intercomparable)**
  - **open and immediate data access**
- **limitations**
  - **uneven global distributions**
    - **few sites in remote and developing regions**
  - **regional application restrict. by orography, pollution**
    - **involve supplementary data (e.g. wind, satellite info)**
  - **no information on vertical distribution (*forcing issue*)**
    - **co-locate with lidar (ground and space)**

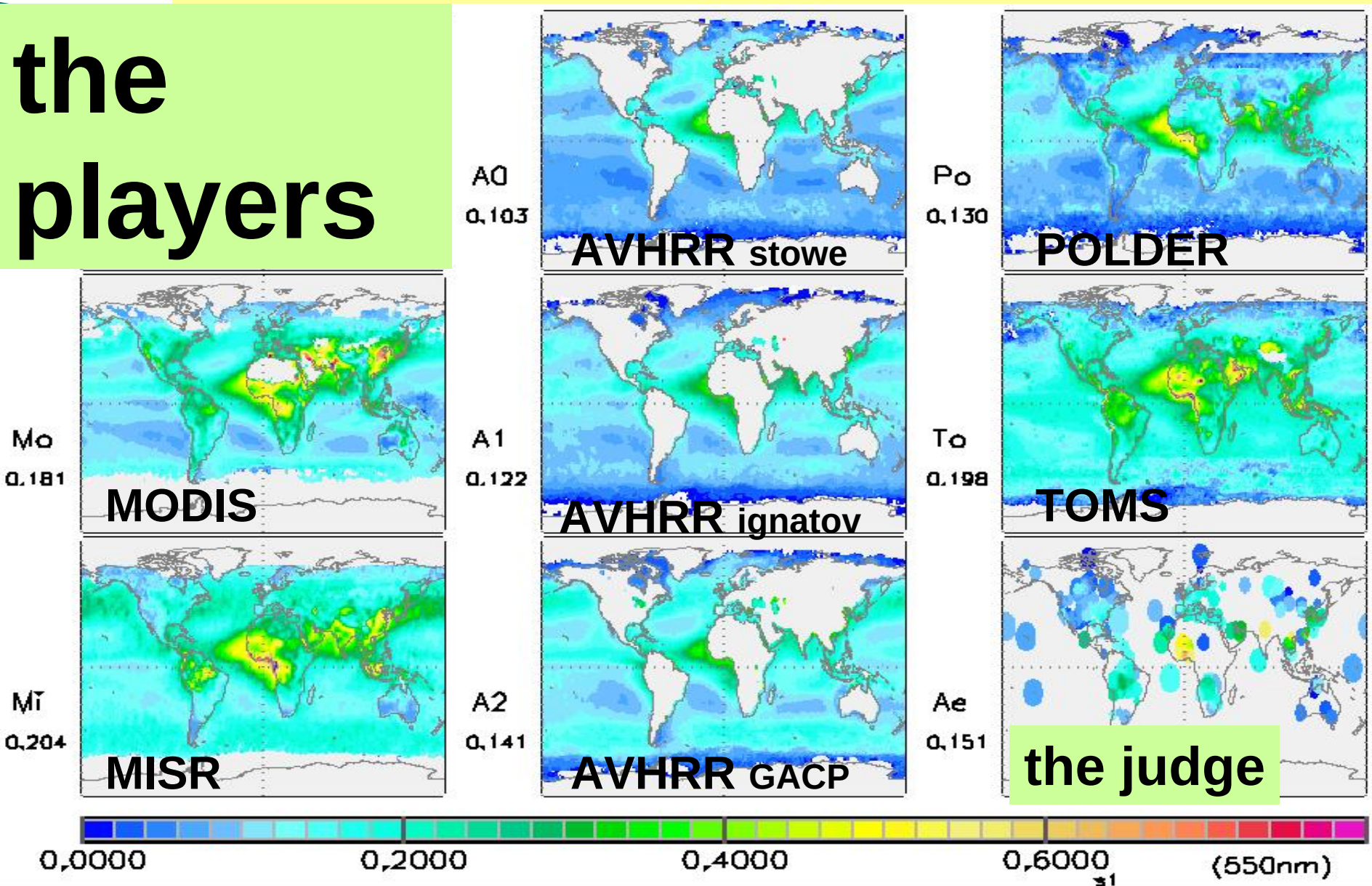
creating a composite

a recommended AOT product ?

- satellite AOT retrievals of aerosol have strengths or limitations on seasonal and regional basis
- *goal* : based on comparisons to AERONET statistics identify strengths and combine diff, sensor data into a superior global AOT data-set
- *step 1*: mix ‘best-matching’ satellite AOT by latitude zone and surface condition (land, ocean)
- *step 2*: merge AERONET statistics into data
- *step 3*: adopt scale model data for polar regions

multi-annual AOT fields

the players

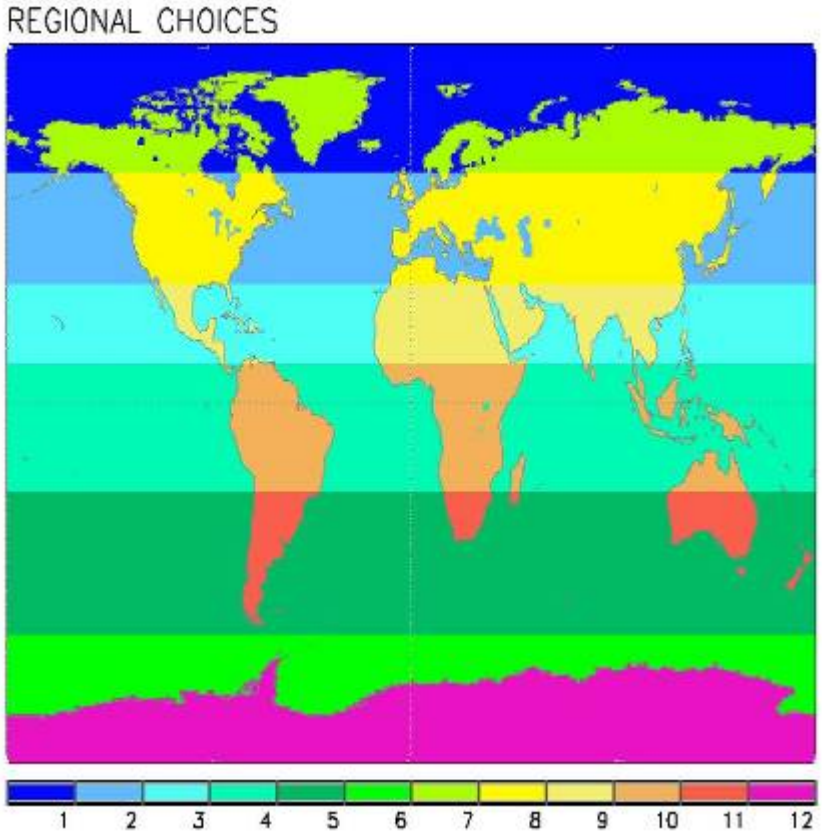


step 1

- create a AOT composite
  - stratify the globe into regions
    - 6 zonal bands for land and ocean each (12 in total)
  - establish regional averages for each month
    - for satellite data, if coverage >25%
    - for AERONET (‘the judge’), if coverage >1%
  - pick the satellite data-set closest to ‘the judge’
    - 6 ocean picks and 6 land picks
  - combine picks
    - with (6deg) latitudinal linear smoothing at transitions

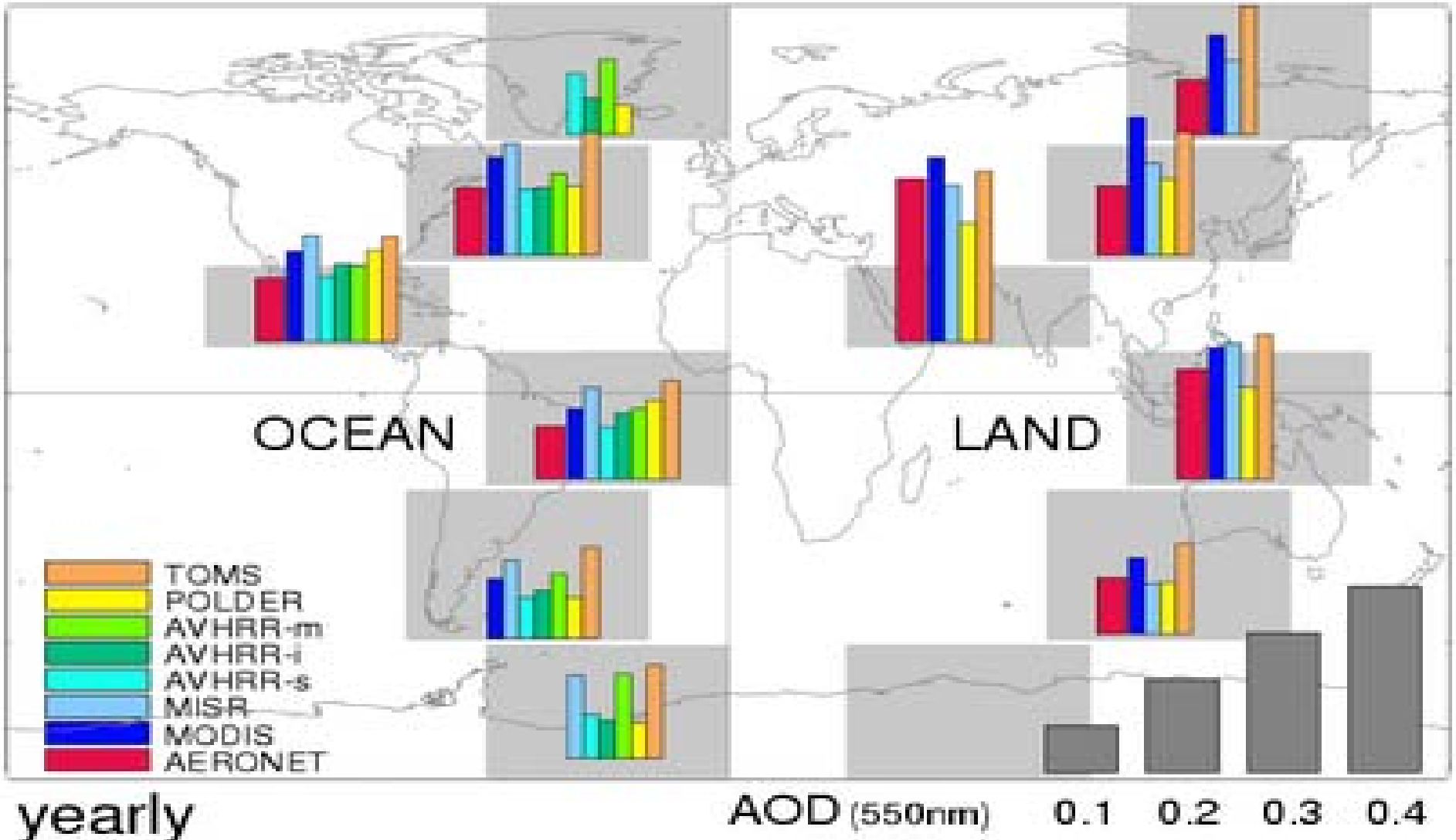
regional stratification

- separate the globe into 6 zonal regions
  - 90N-58N Arctic
  - 58N-30N industrial
  - 30N-10N dust
  - 10N-22S biomass
  - 22S-58S southern
  - 58S-90S Antarctic
- separate by surface type
  - land
  - ocean

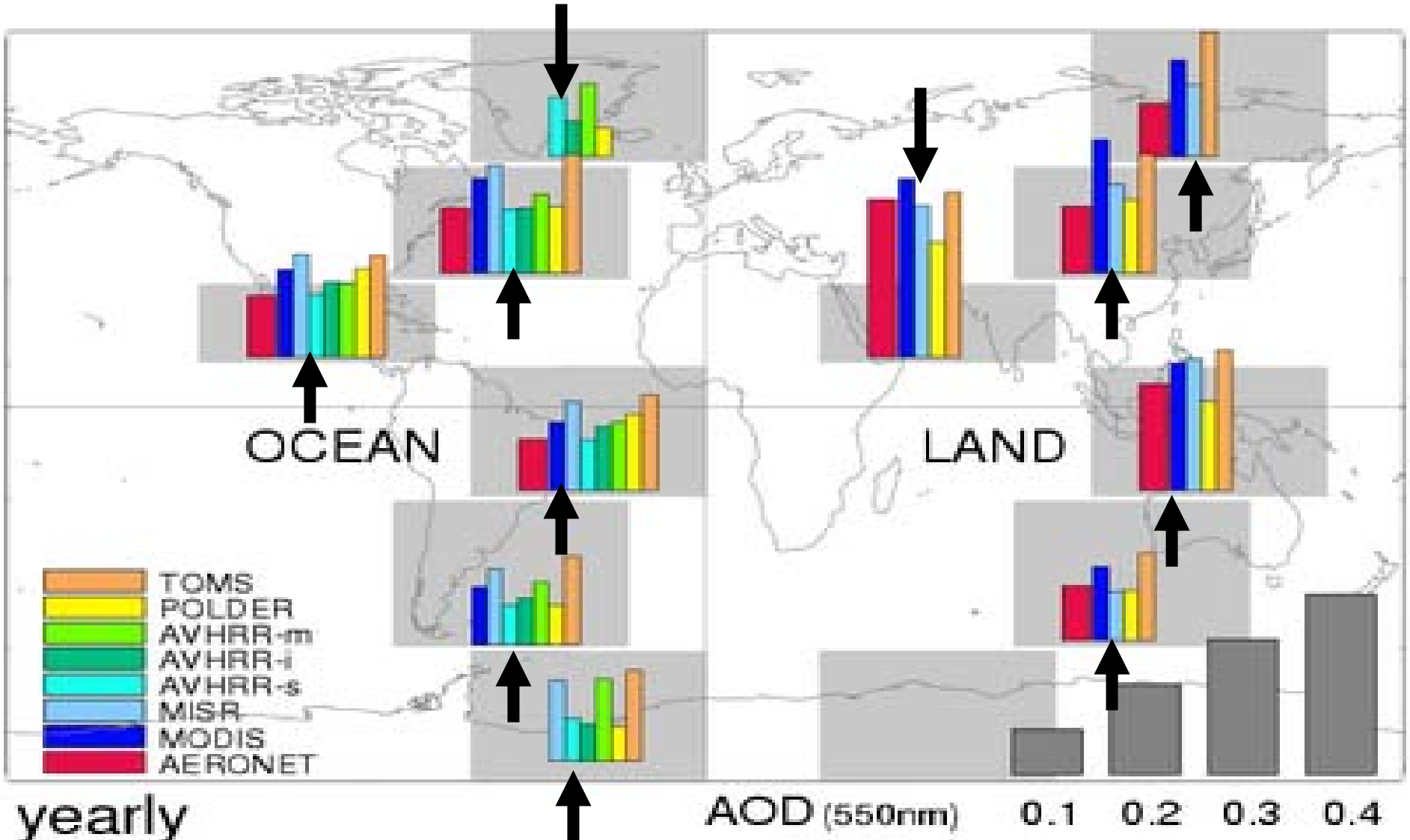


regional requirement

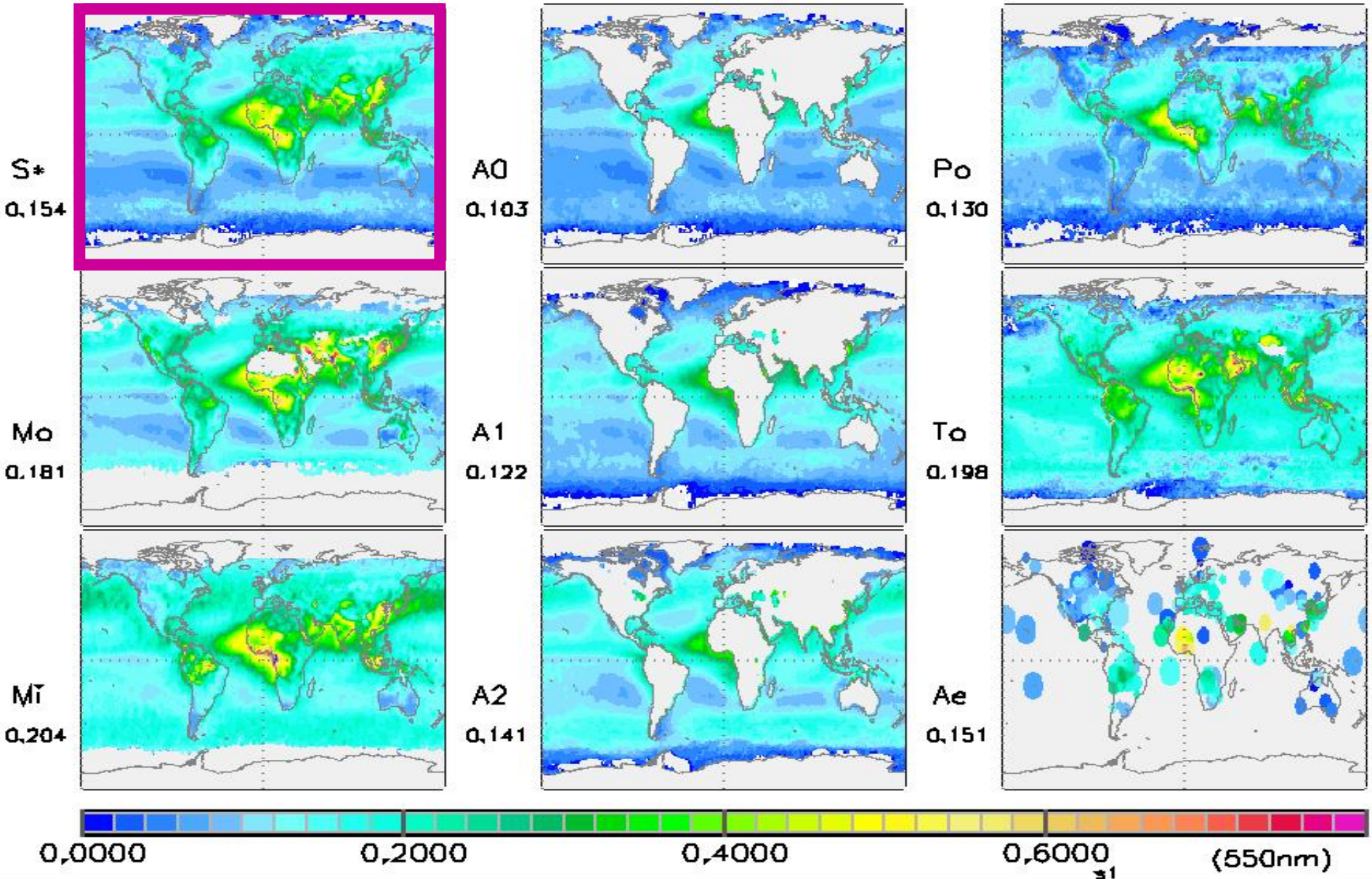
AERONET : >1% coverage
retrieval: >25% coverage



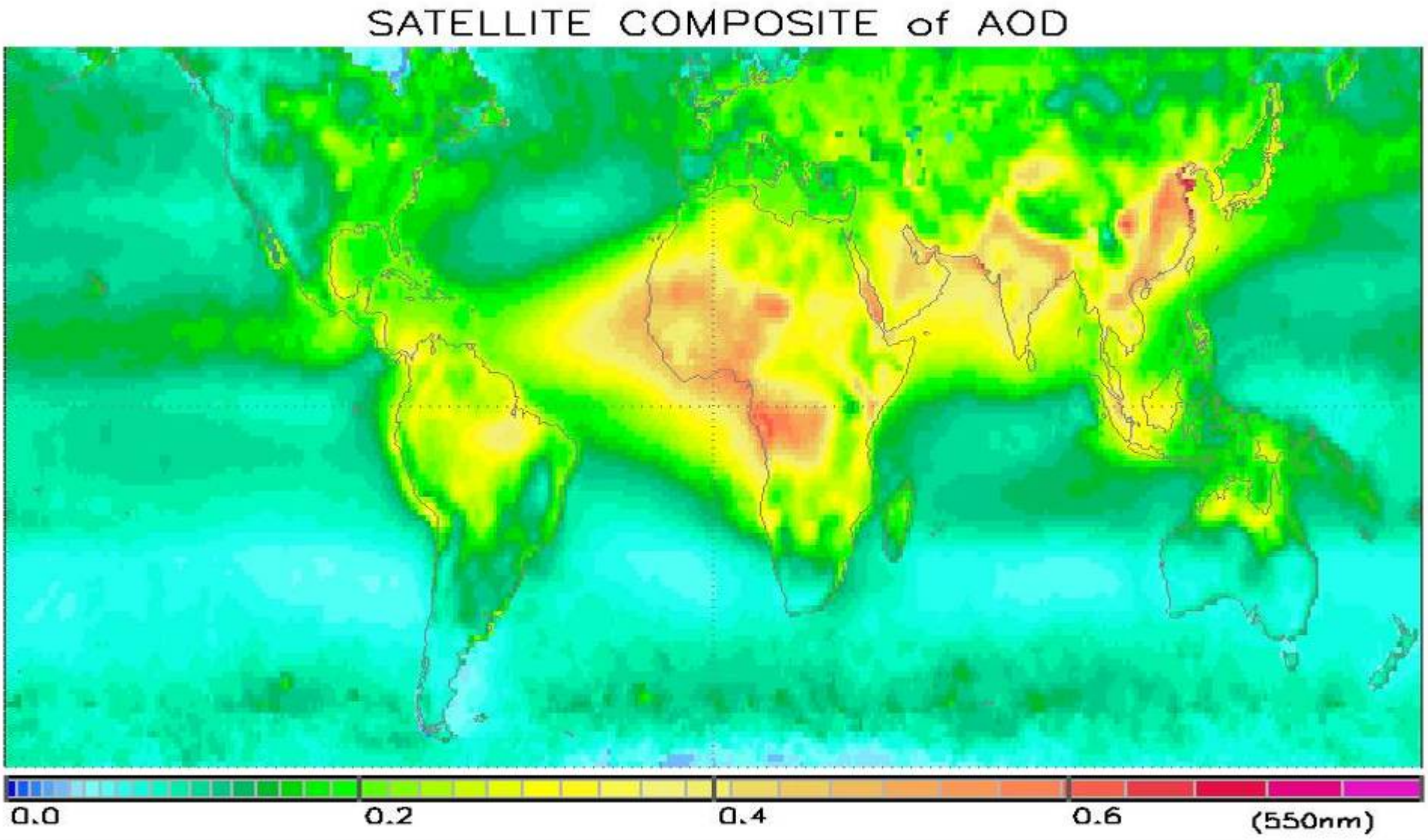
my picks


OCEAN
LAND
TOMS
POLDER
AVHRR-m
AVHRR-i
AVHRR-s
MISR
MODIS
AERONET
yearly
AOD (550nm)
0.1
0.2
0.3
0.4

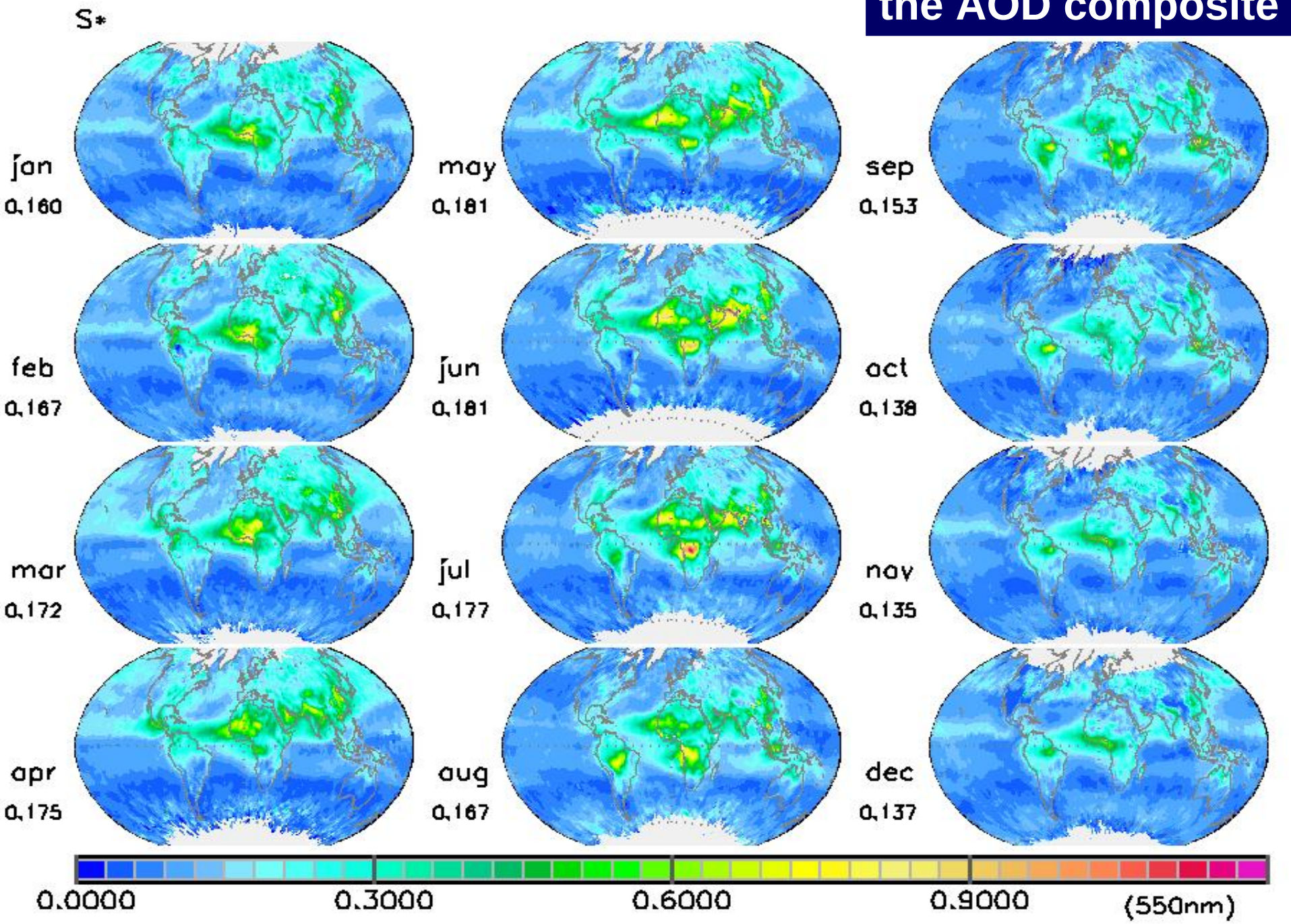
composite *- more complete ! better ?*



the annual AOT retrieval composite



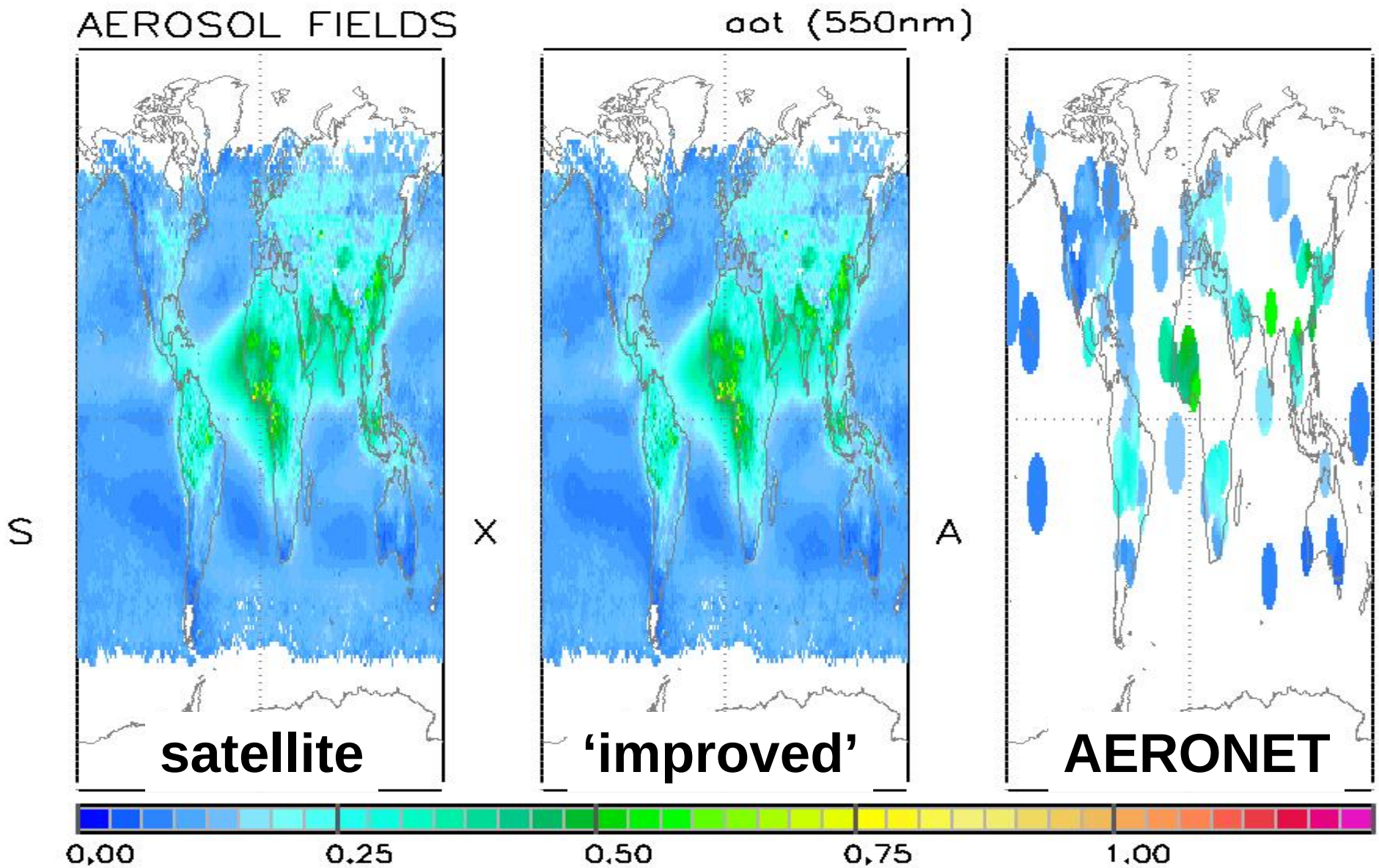
the AOD composite



step 2 / step 3

- even the best match to AERONET does not mean that AERONET data are actually matched … in fact the satellite AOT composite is still too large
- merge AERONET data into the sat. composite
  - use 1*1 gridded AERONET AOT fields
  - spread ratio of global data-pairs (+/-180lon, +/-45lat)
  - adopt ratios within each sites range domain
- adopt scaled data from global modeling in (polar) regions of no data

AOT *- AERONET first*

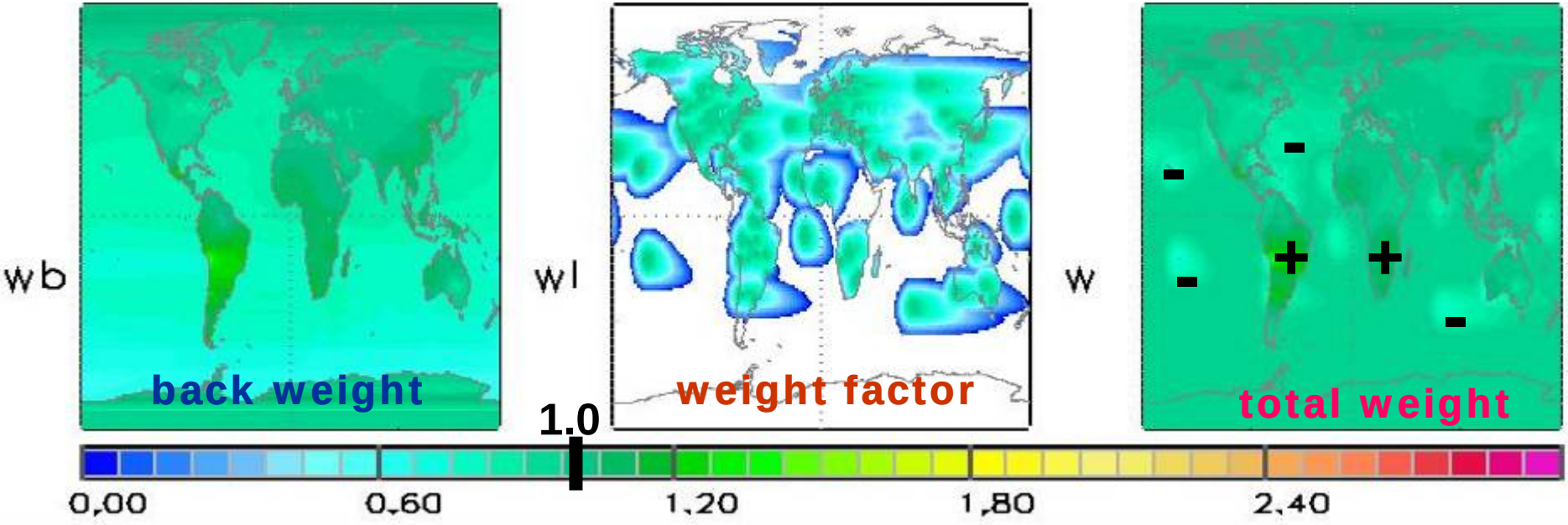


the ‘merging’ steps

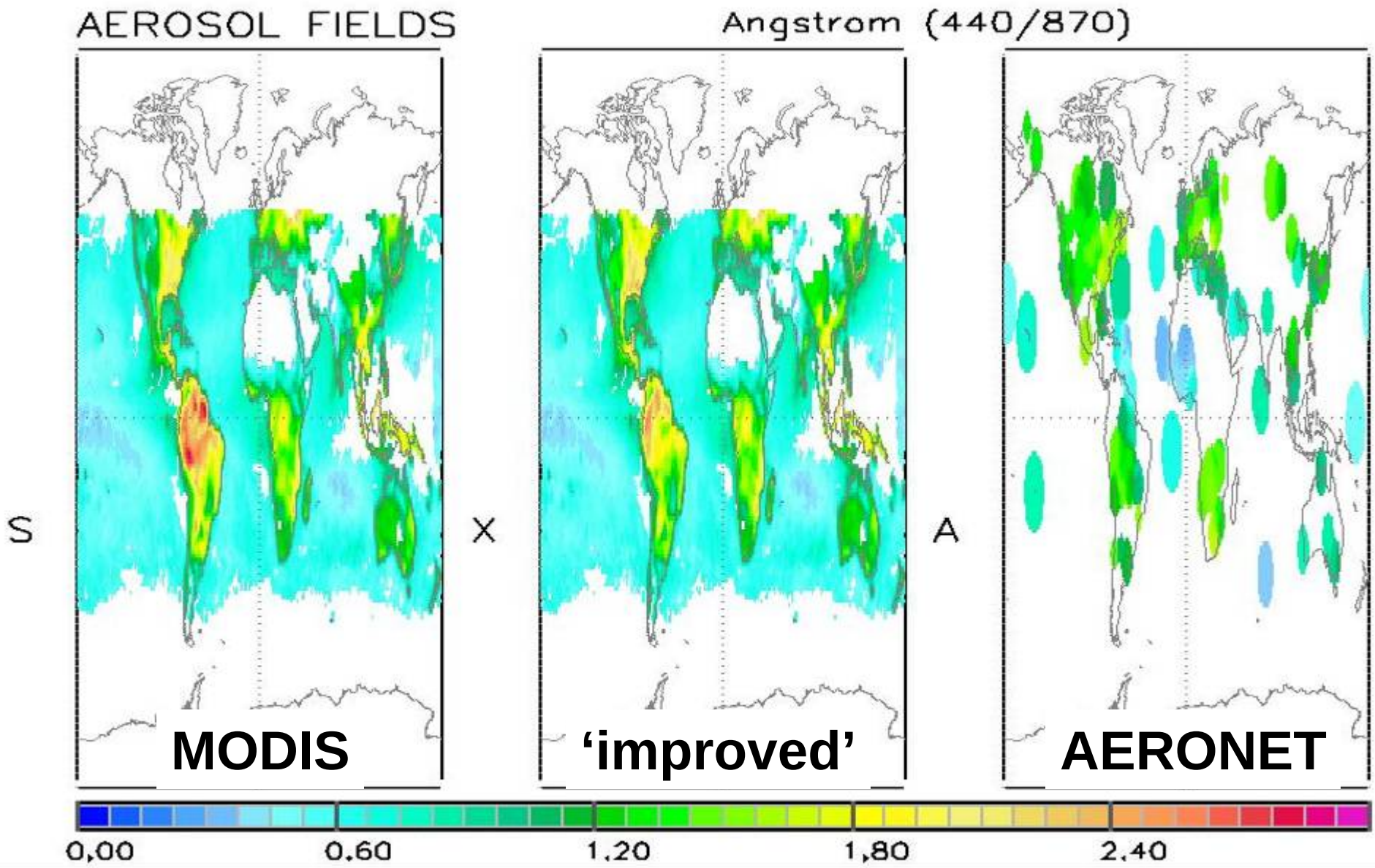
- determine local ratios for each ‘sat-data/AERONET’ pair

based on quality scores and range scores for each site:

- extend with distance decay weights: back weight field
- establish site influence ranges: weight factor field
- multiply both fields for total weight field → applied to datav



Angstrom *- AERONET first*



outlook

why this extra effort ?

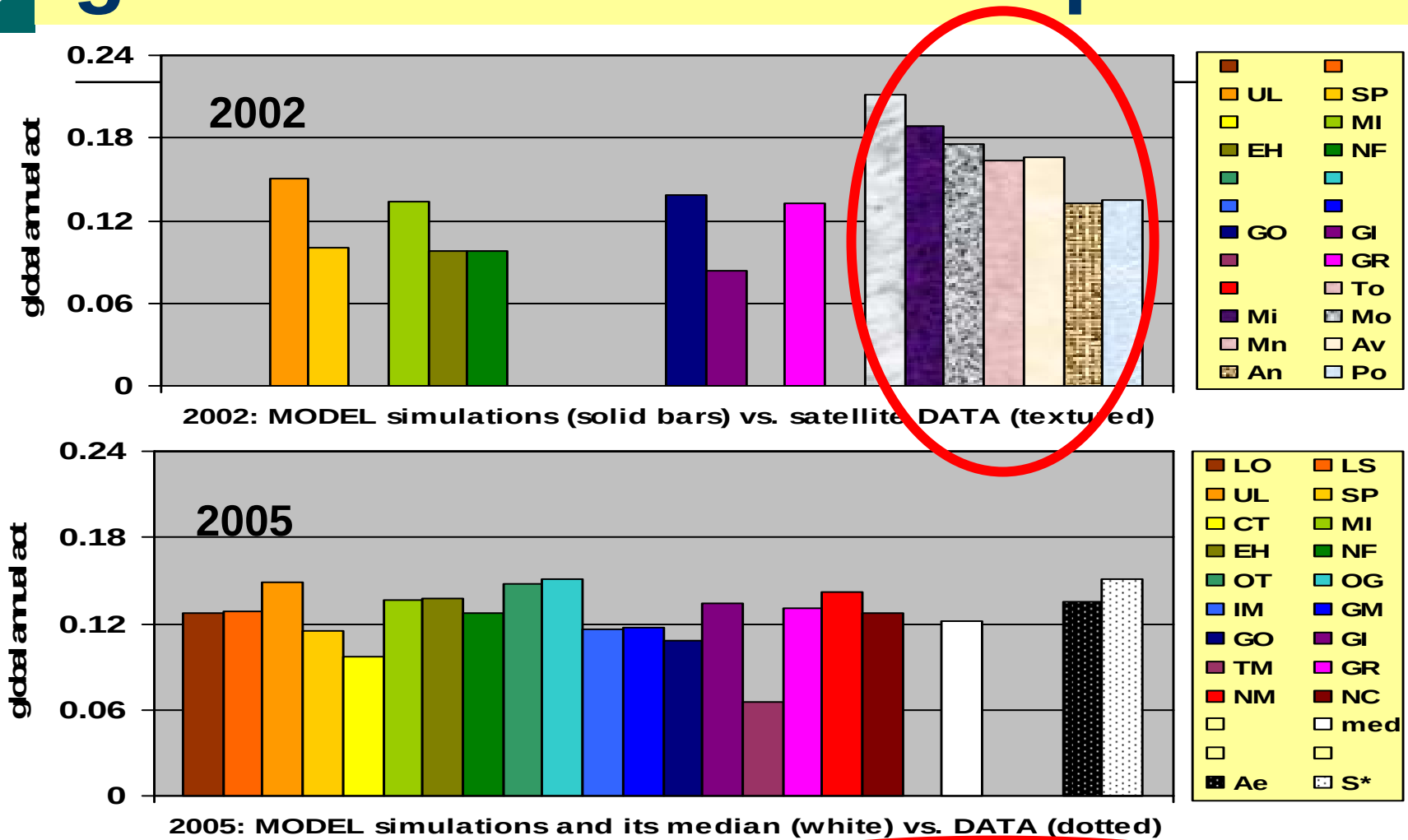
- **data inconsistencies raise questions**
  - **likely outcome: better products** ***(… not tuning)***
- **improvement in modeling demands data quality**
  - **poor data are a disfavor to modeling**
- **recommendations**
  - **always assure data quality** ***(… do not just 'trust')***
  - **seek co-location events of complementary sensors**
  - **share important findings with data providers and data users**

next

- simple approach already demonstrates benefit to modeling by setting much tighter aot constraints
- further improvements are expected with
  - considering only local matches to AERONET
  - considering more (land and ocean) regions
  - using the most recent retrievals (MODIS, MISR, TOMS, MODIS-deep blue, ….)
- another option is the use of different sensor data in a single retrieval (e.g. MISR and MODIS)
  - Just who is going to do retrieval and processing?

extras

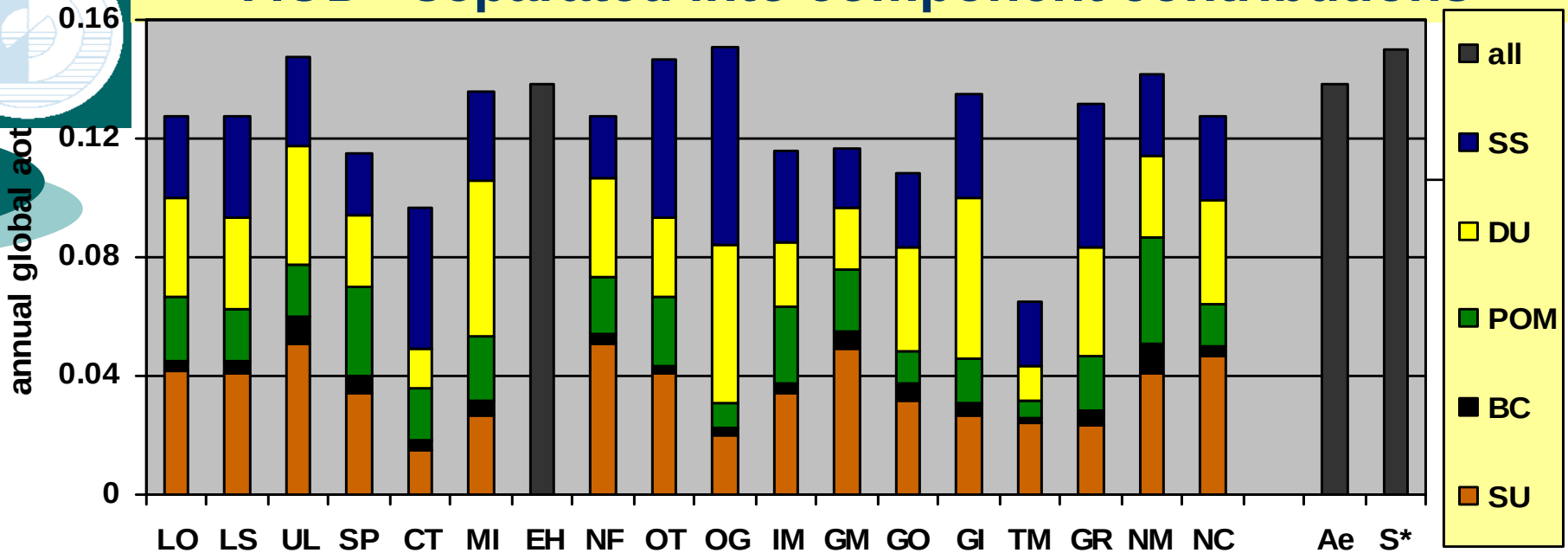
global annual AOD comparison



in 2002: large variability among satellite retrievals

by 2005: models start do 'obey' data AERONET best sat

AOD –separated into component contributions



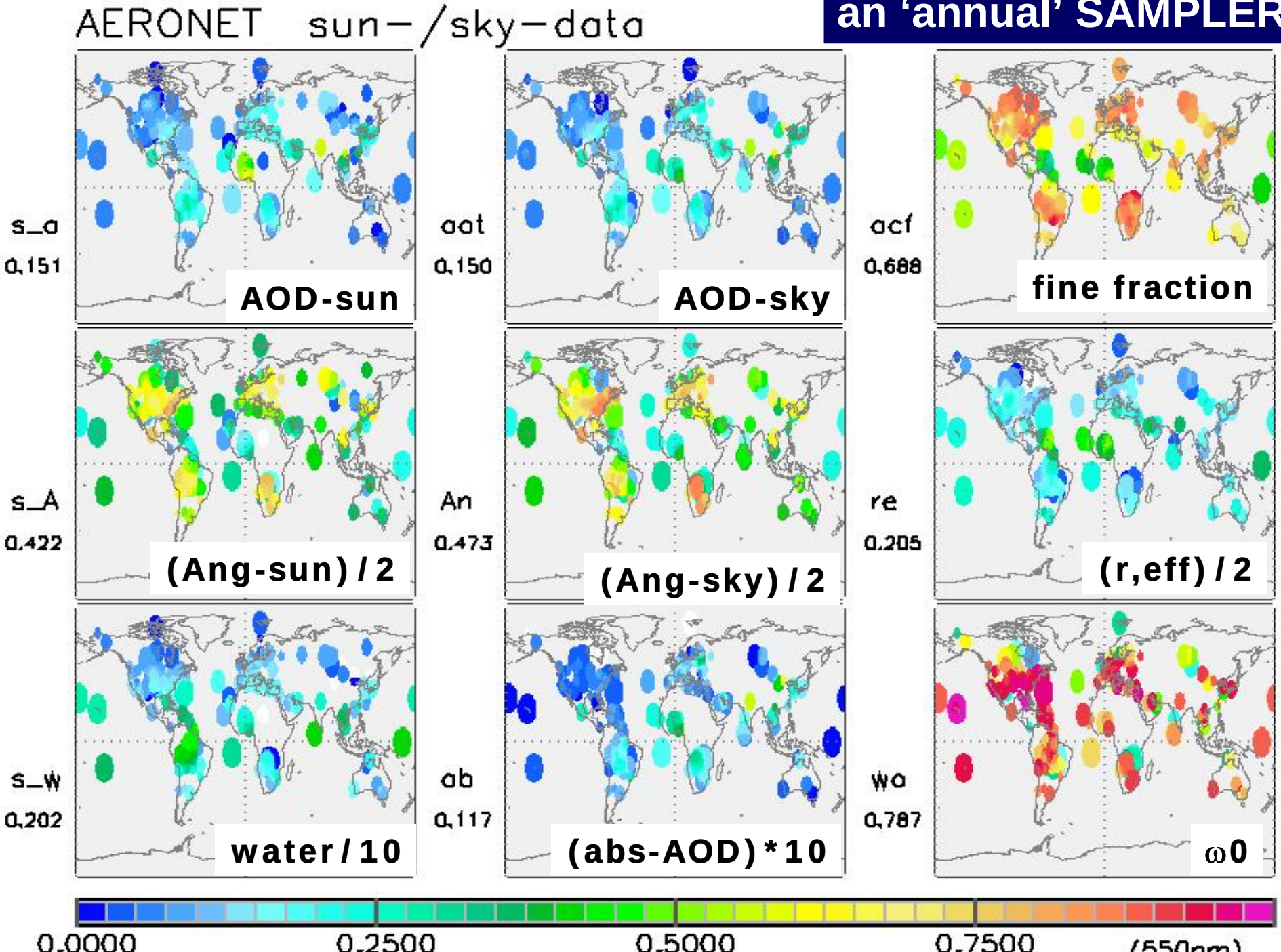
… but large differences on modeling detail remain

- a match in integrated properties (e.g. total AOD) can hide significant discrepancy (e.g. offsetting effects)

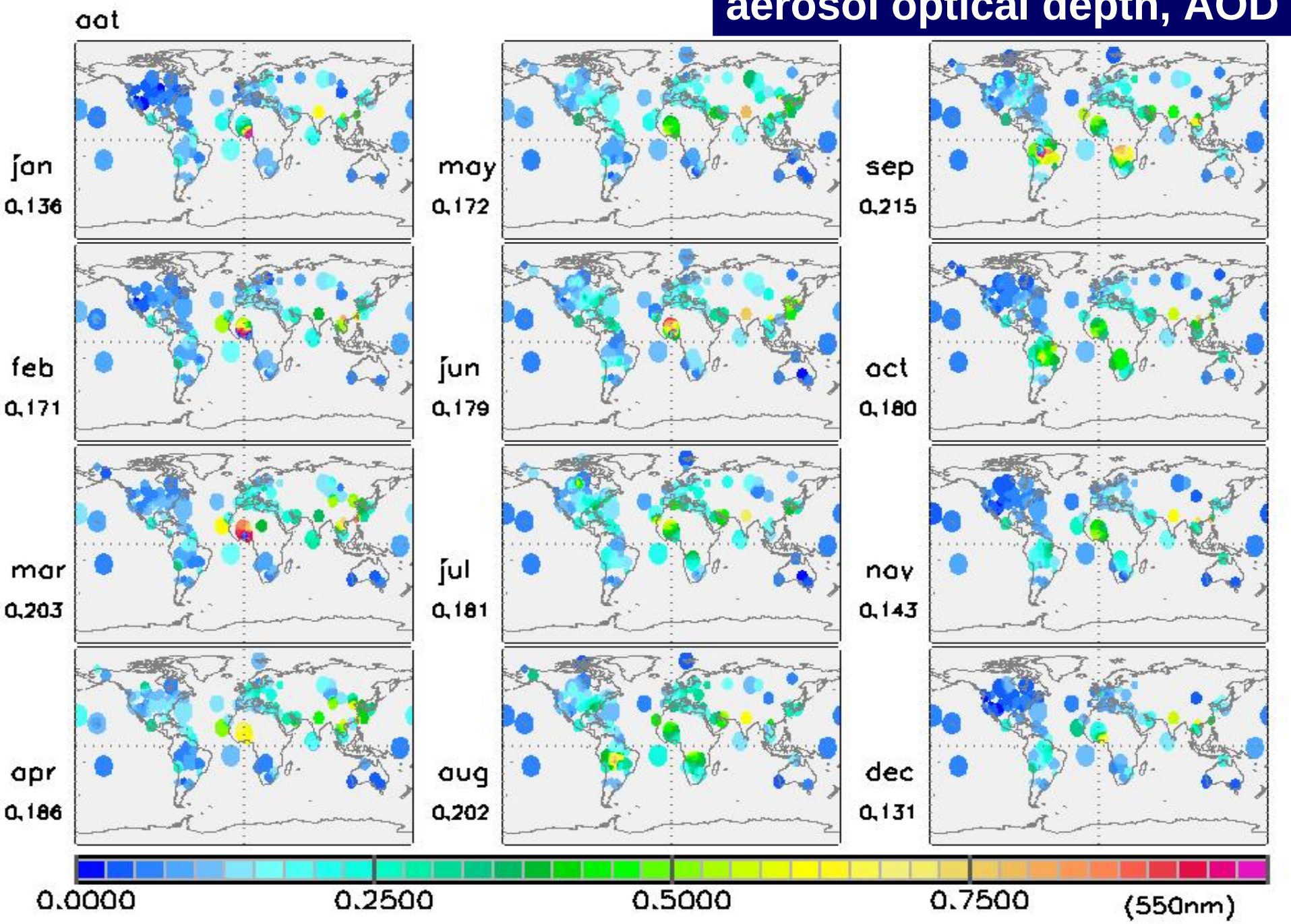
○ DATA

- more (global) data on (aerosol) detail is essential
- data are an important aspect at AeroCom meetings: (join) next workshop: 17-19 Oct. at Virginia Beach

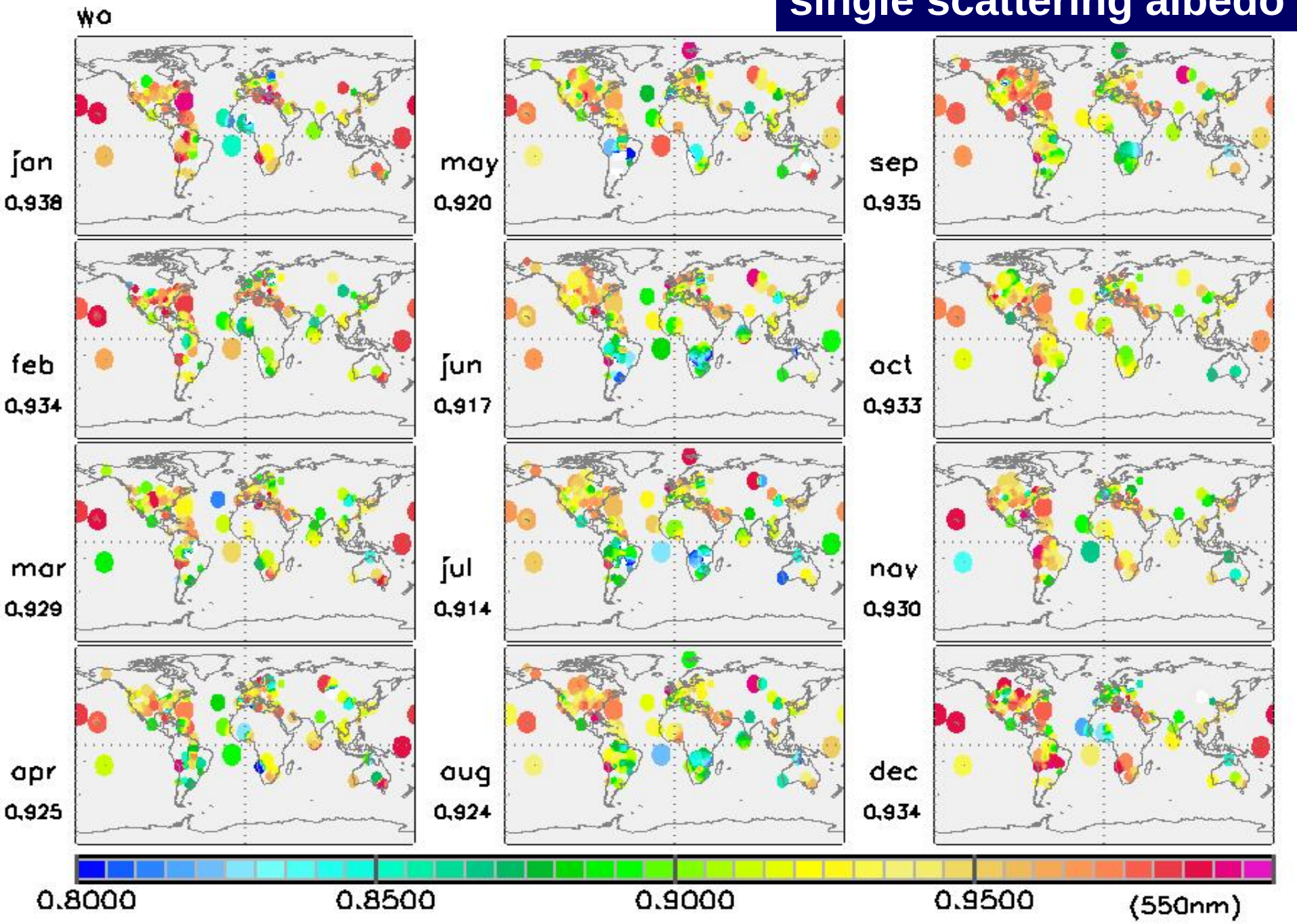
an 'annual' SAMPLER



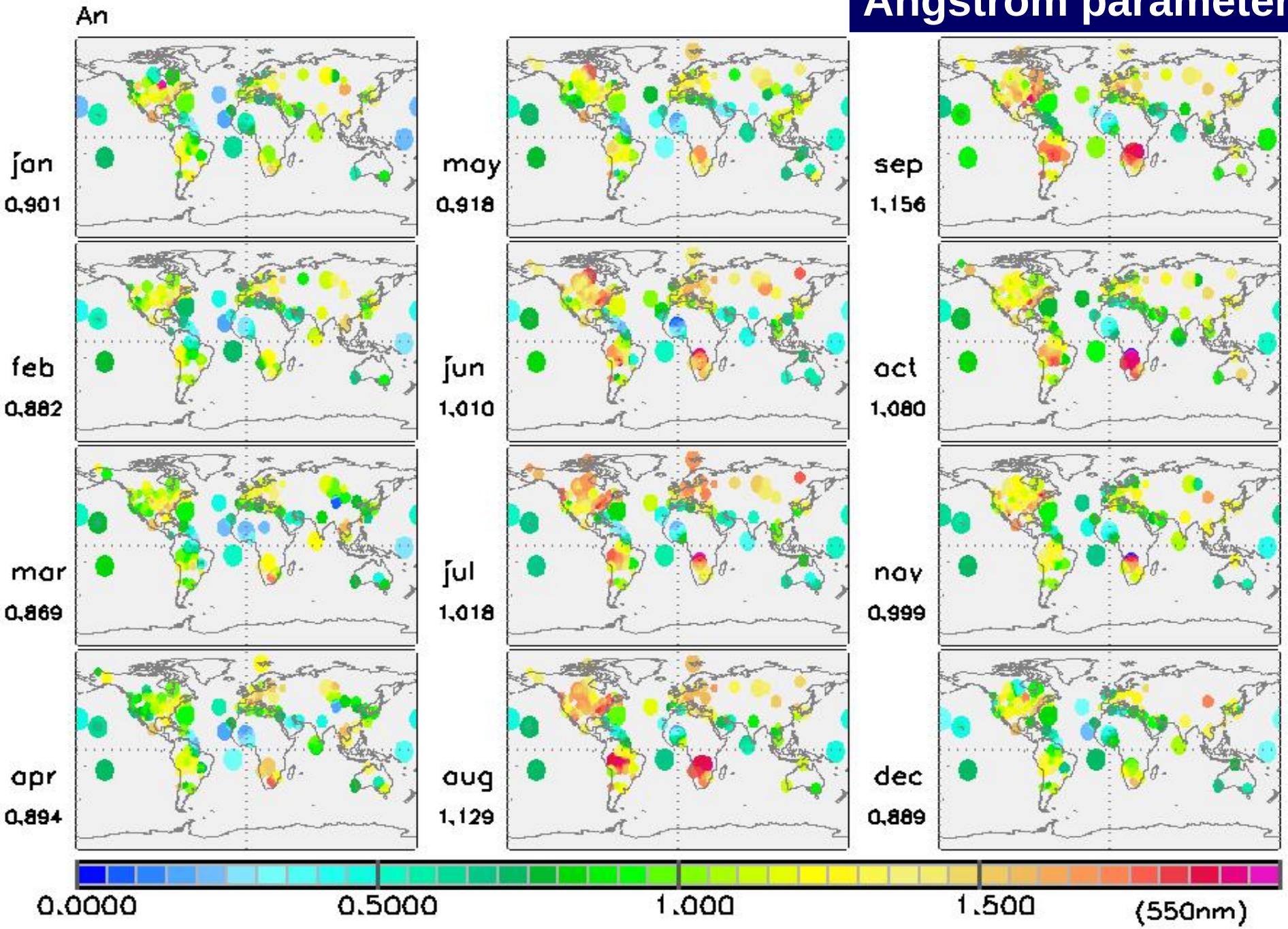
aerosol optical depth, AOD



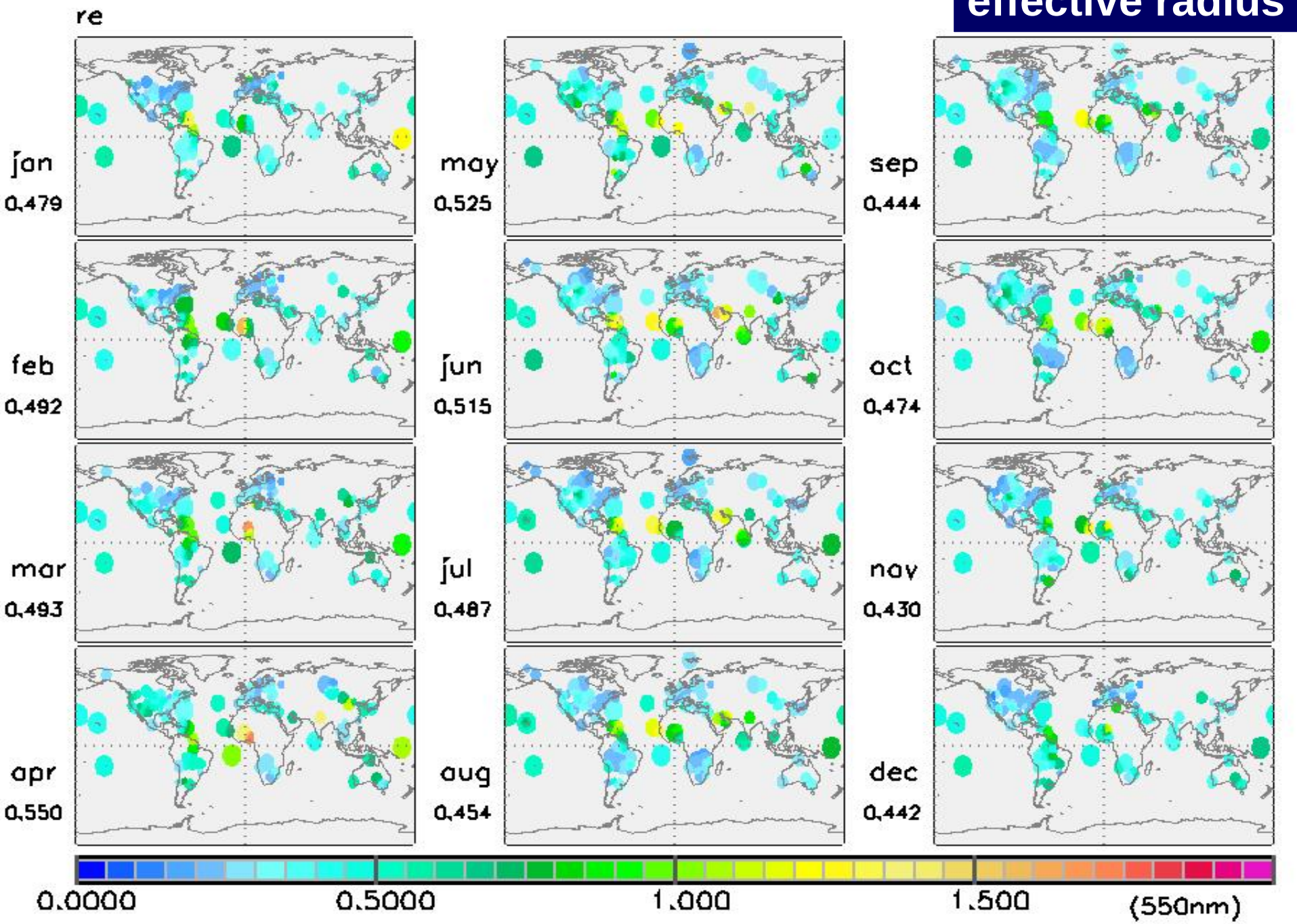
single scattering albedo



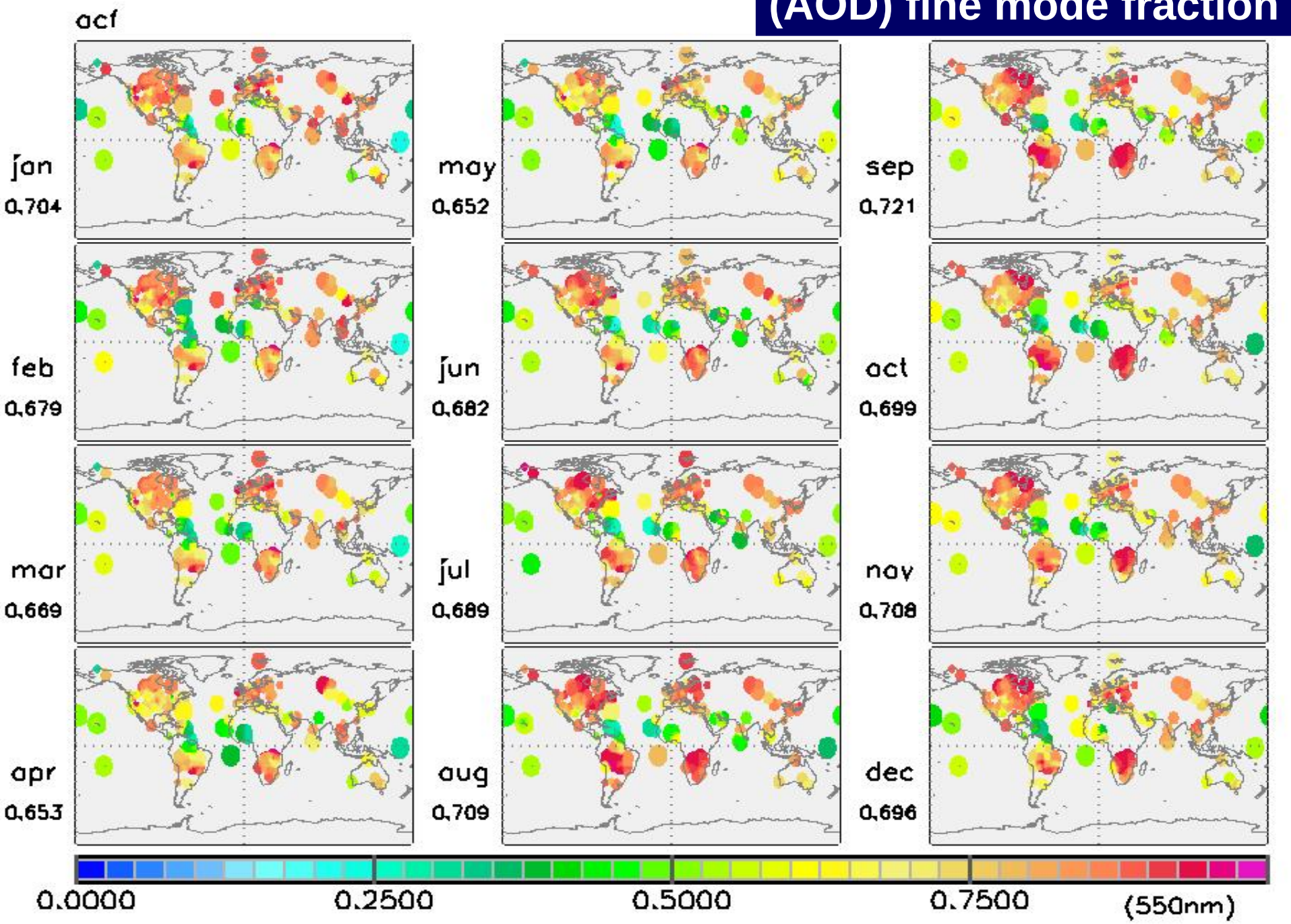
Angstrom parameter



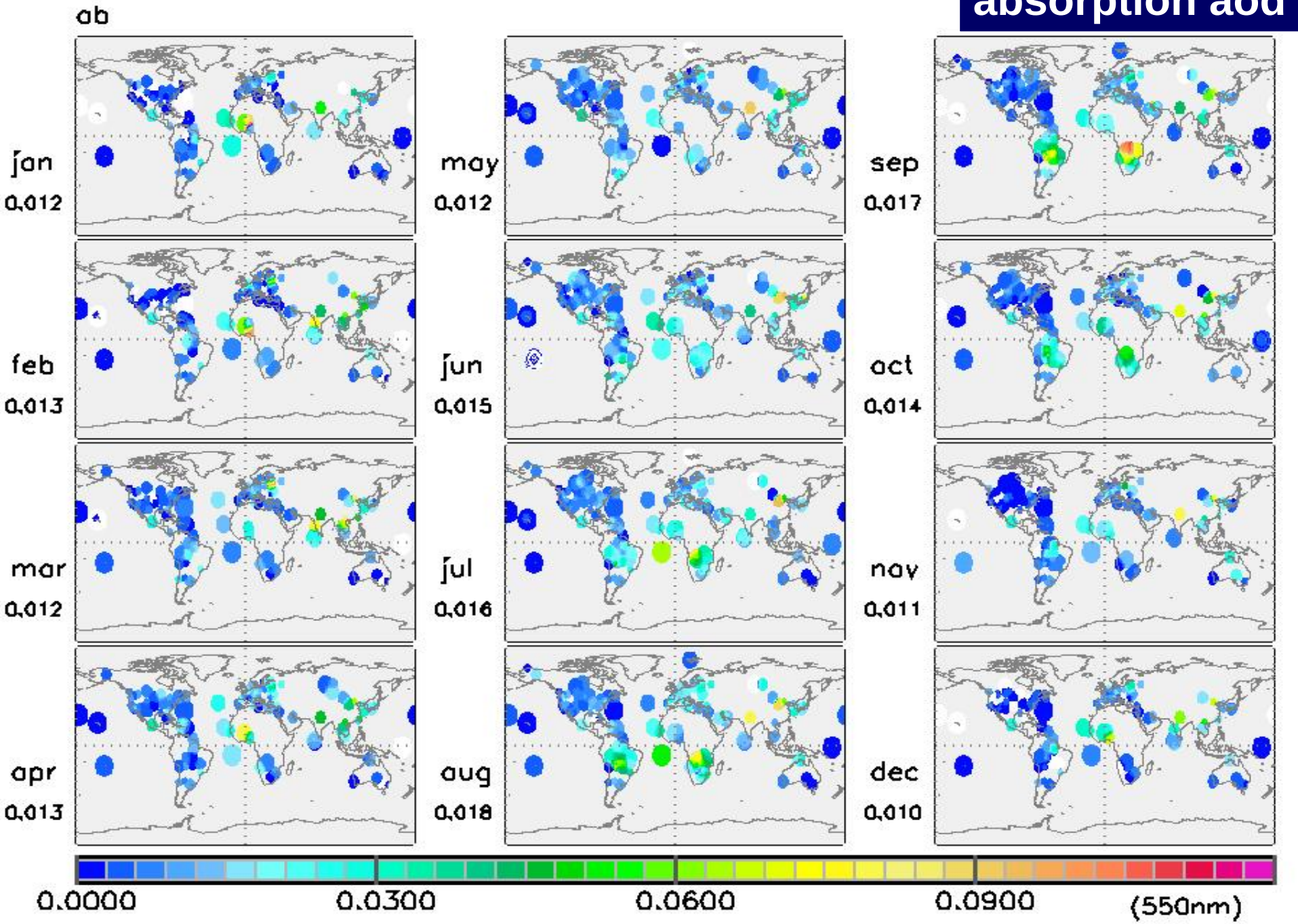
effective radius



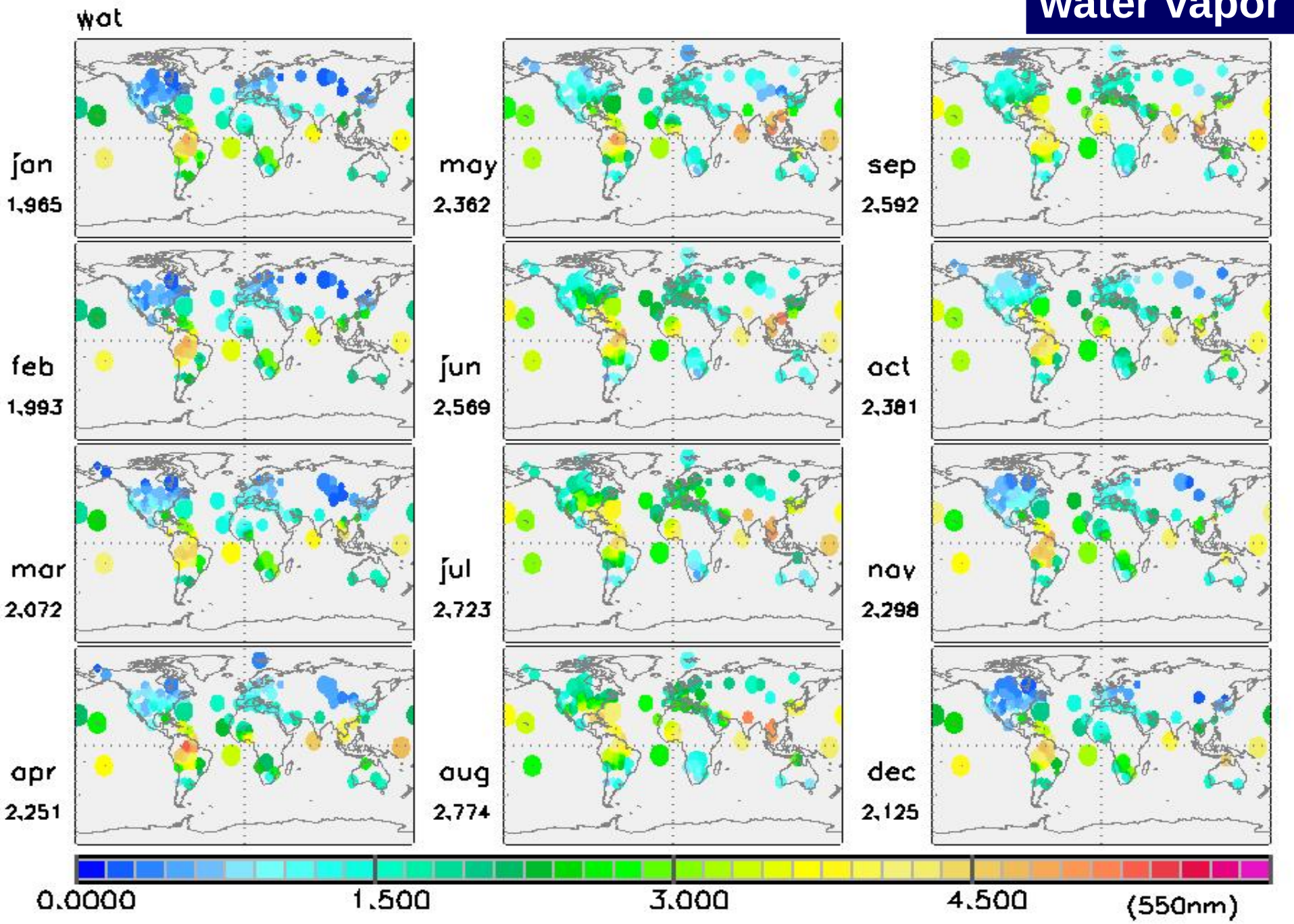
(AOD) fine mode fraction



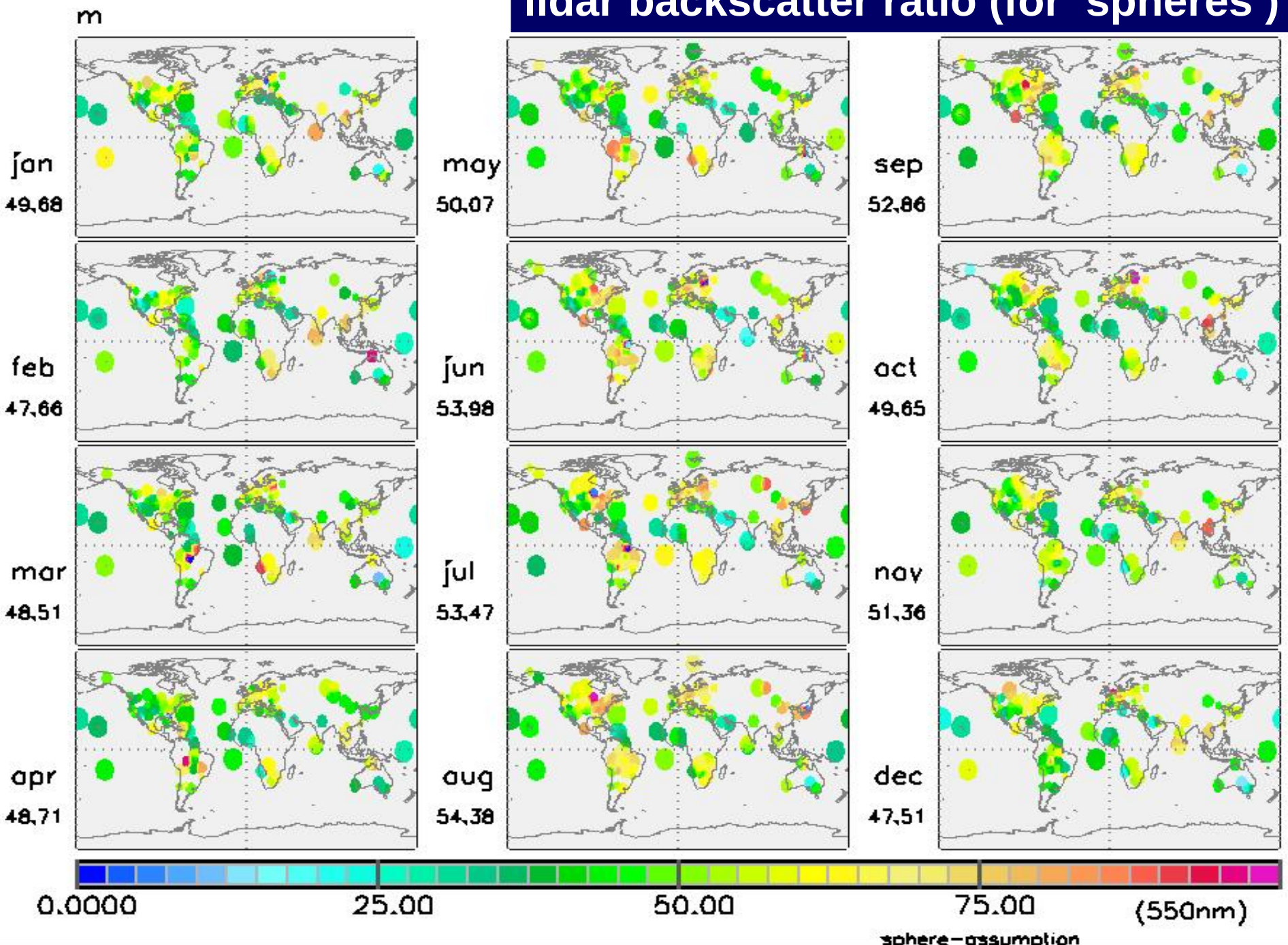
absorption aod

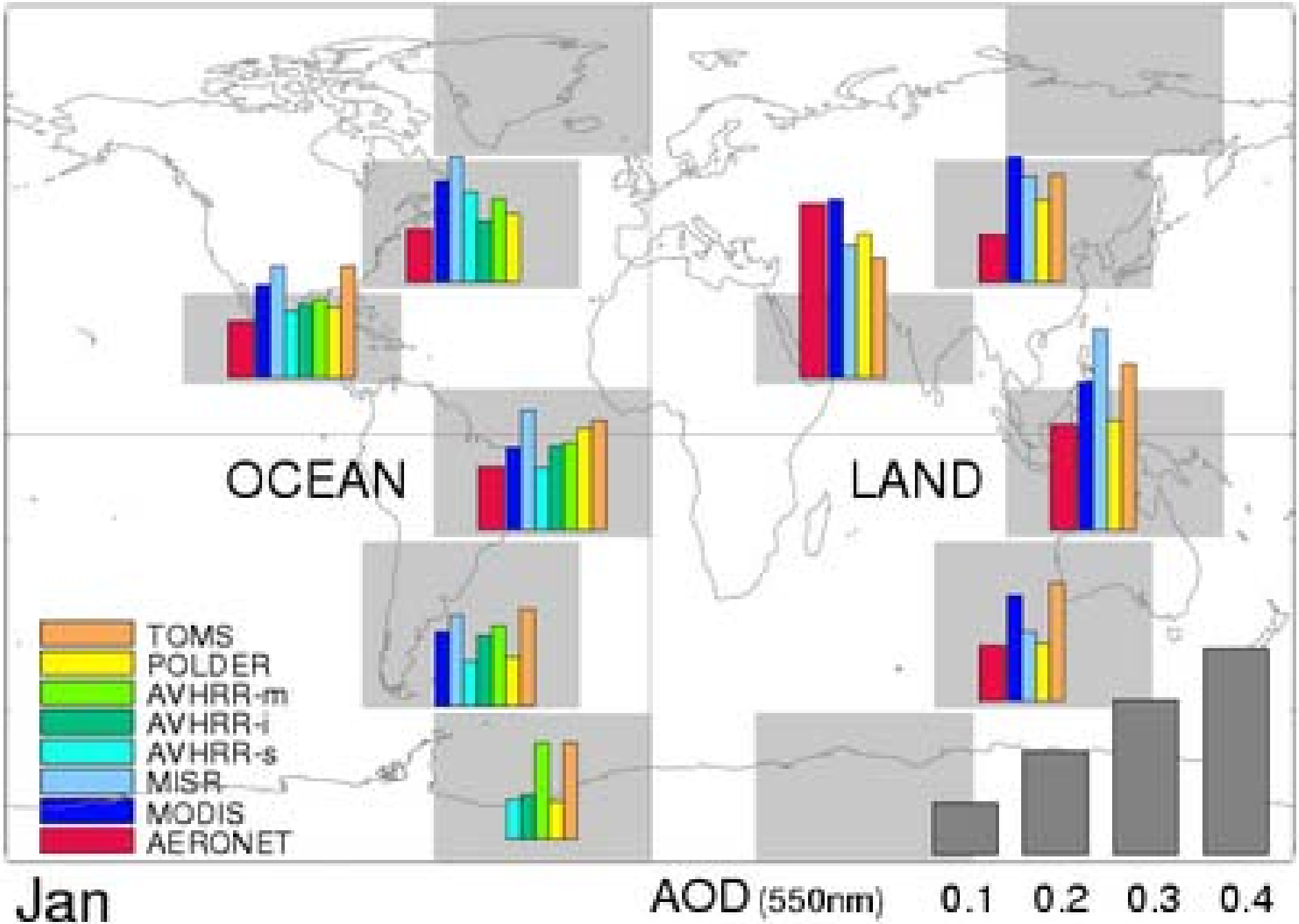


water vapor


wat
jan
1.965
feb
1.993
mar
2.072
apr
2.251
may
2.362
jun
2.569
jul
2.723
aug
2.774
sep
2.592
oct
2.381
nov
2.298
dec
2.125
0.0000
1.500
3.000
4.500
(550nm)

lidar backscatter ratio (for ‘spheres’)




OCEAN
LAND
TOMS
POLDER
AVHRR-m
AVHRR-i
AVHRR-s
MISR
MODIS
AERONET
Jan
AOD (550nm)
0.1
0.2
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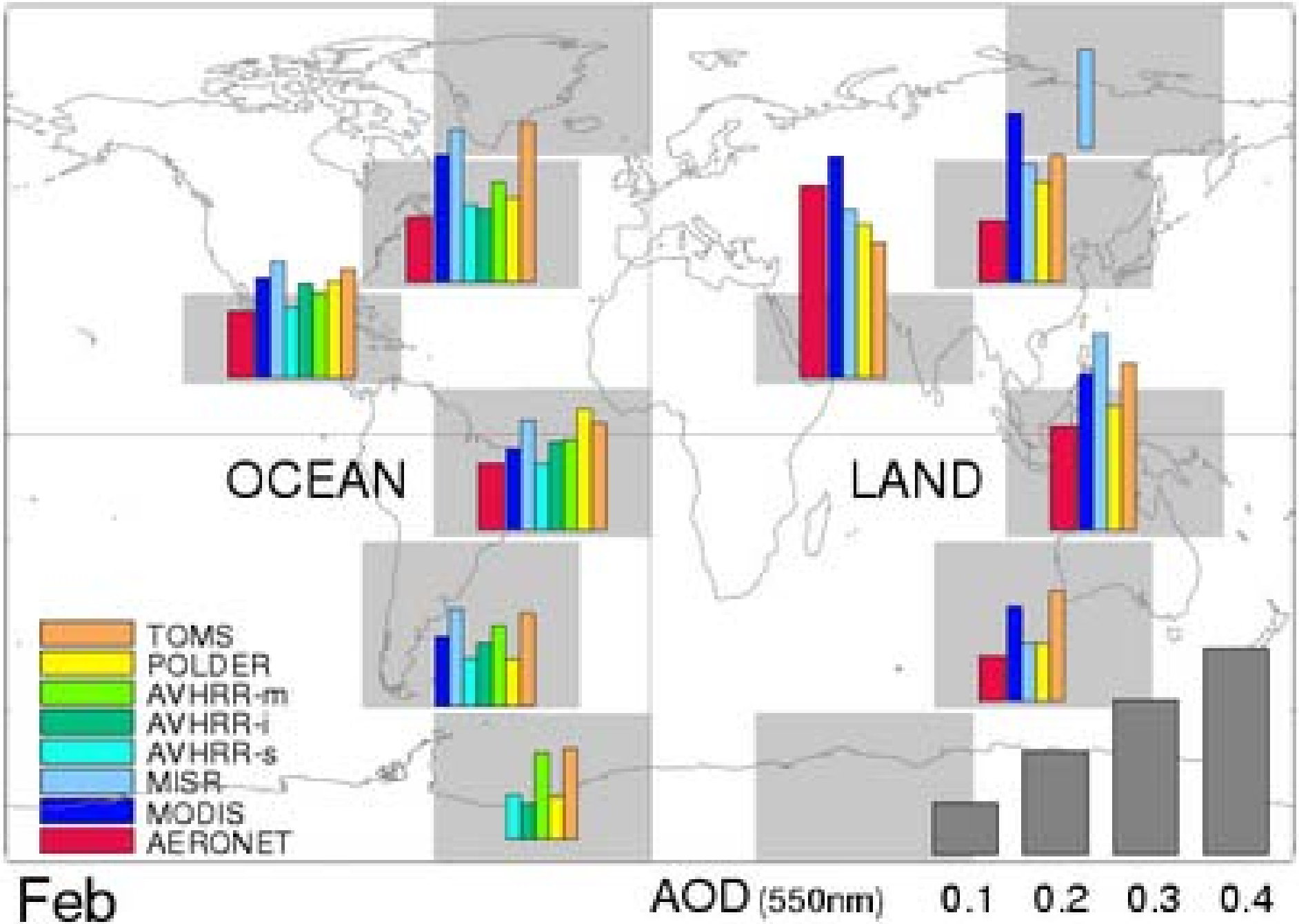
OCEAN
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POLDER
AVHRR-m
AVHRR-i
AVHRR-s
MISR
MODIS
AERONET
Feb
AOD (550nm)
0.1
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0.3
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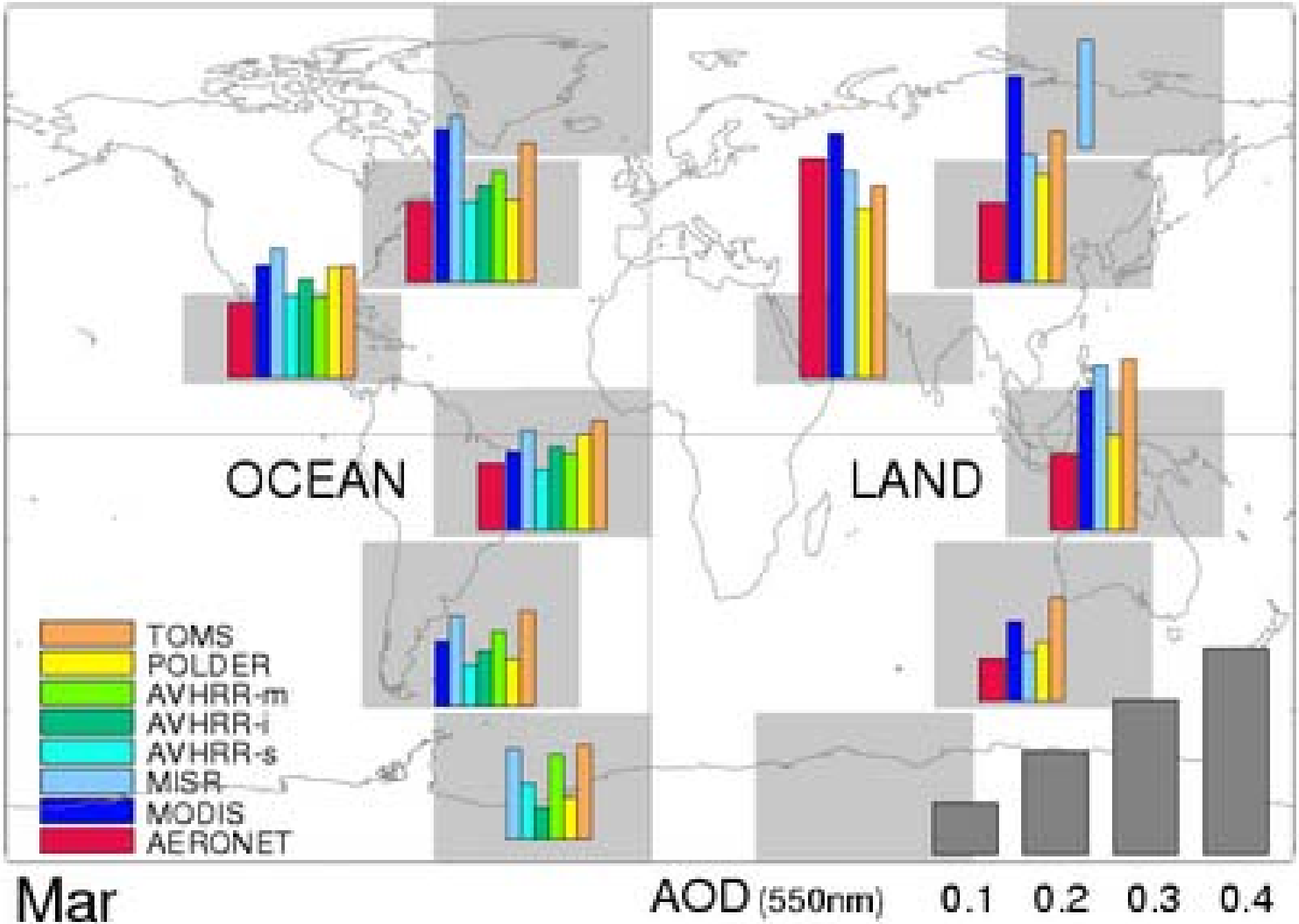
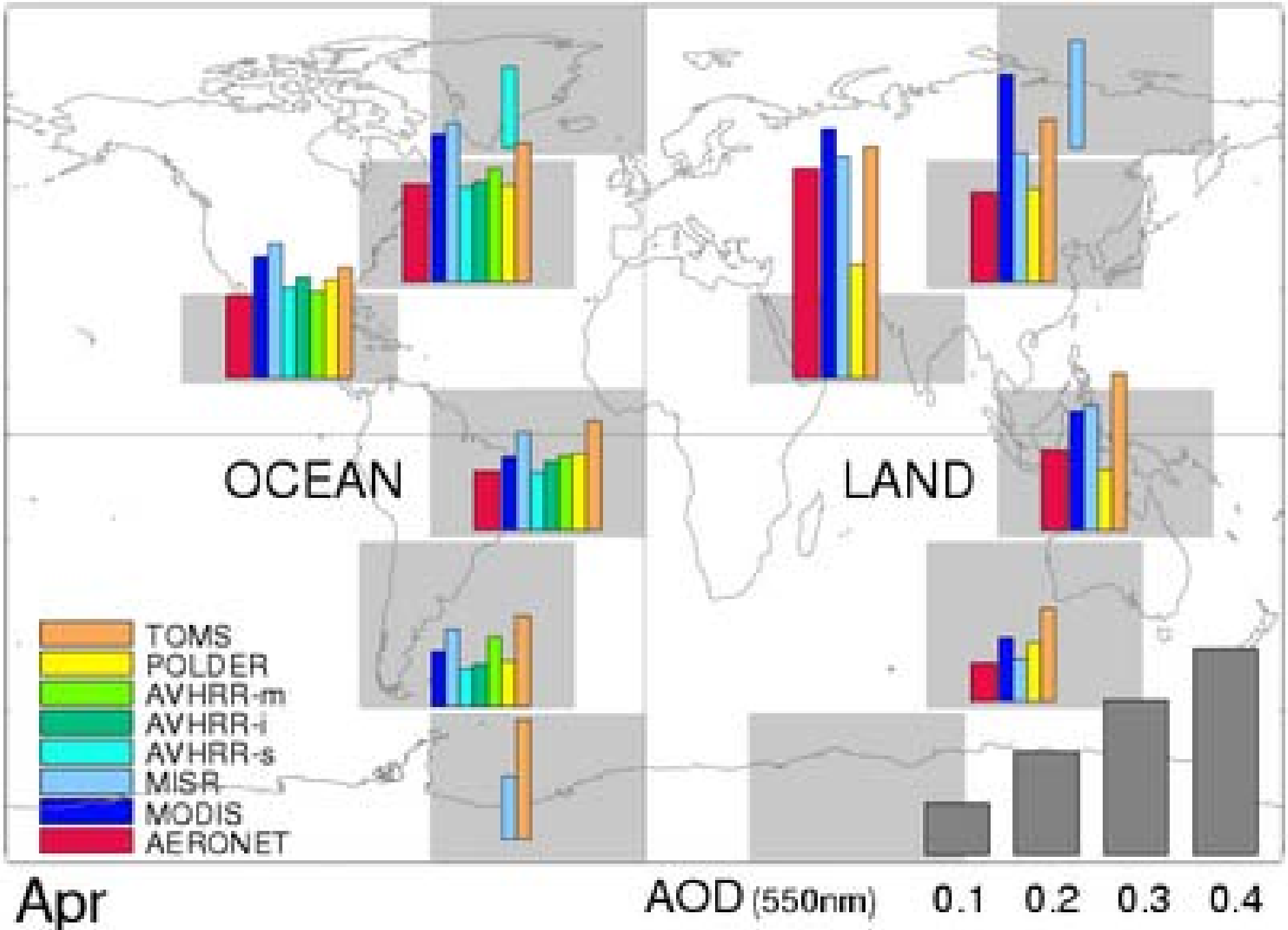
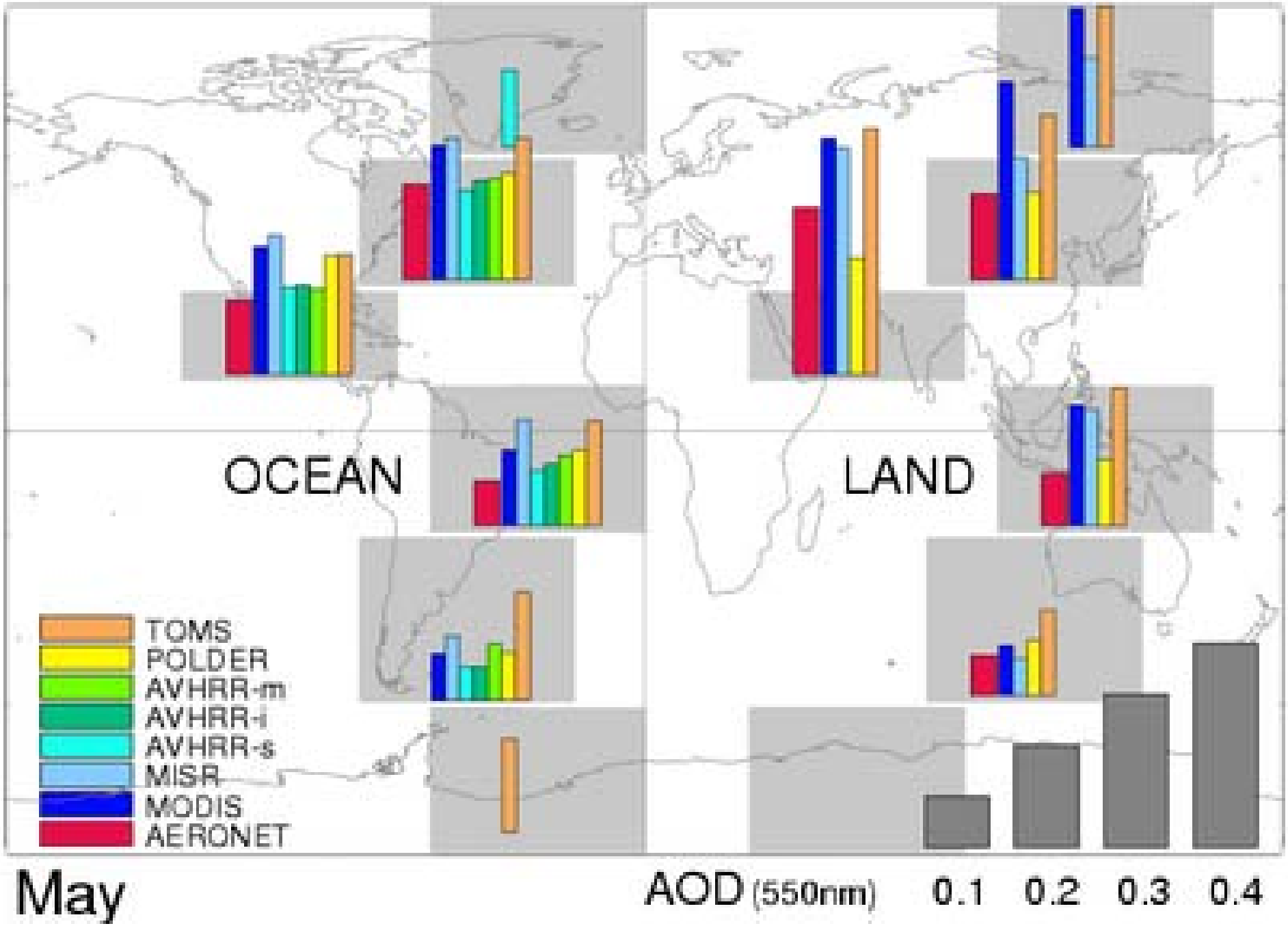
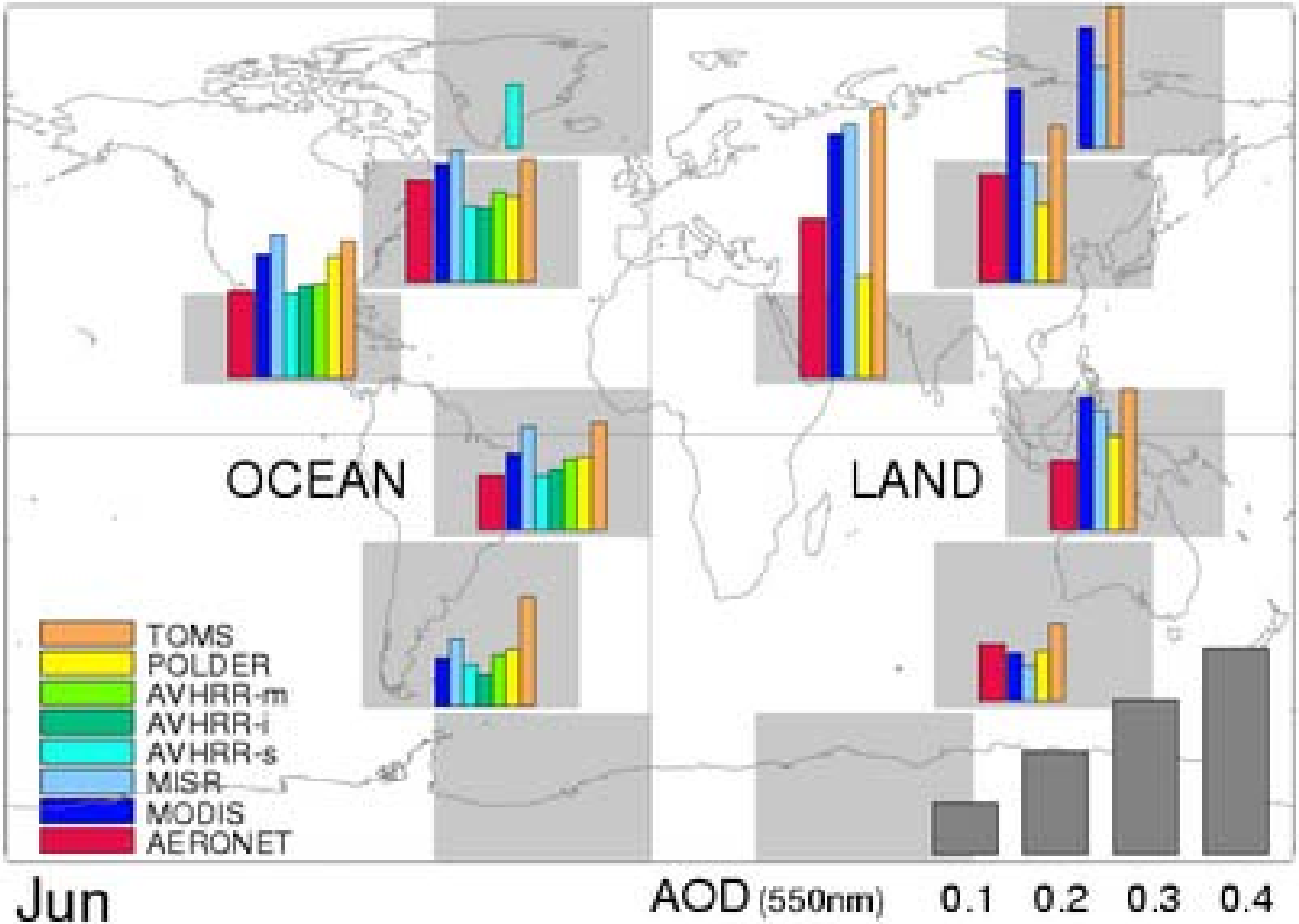
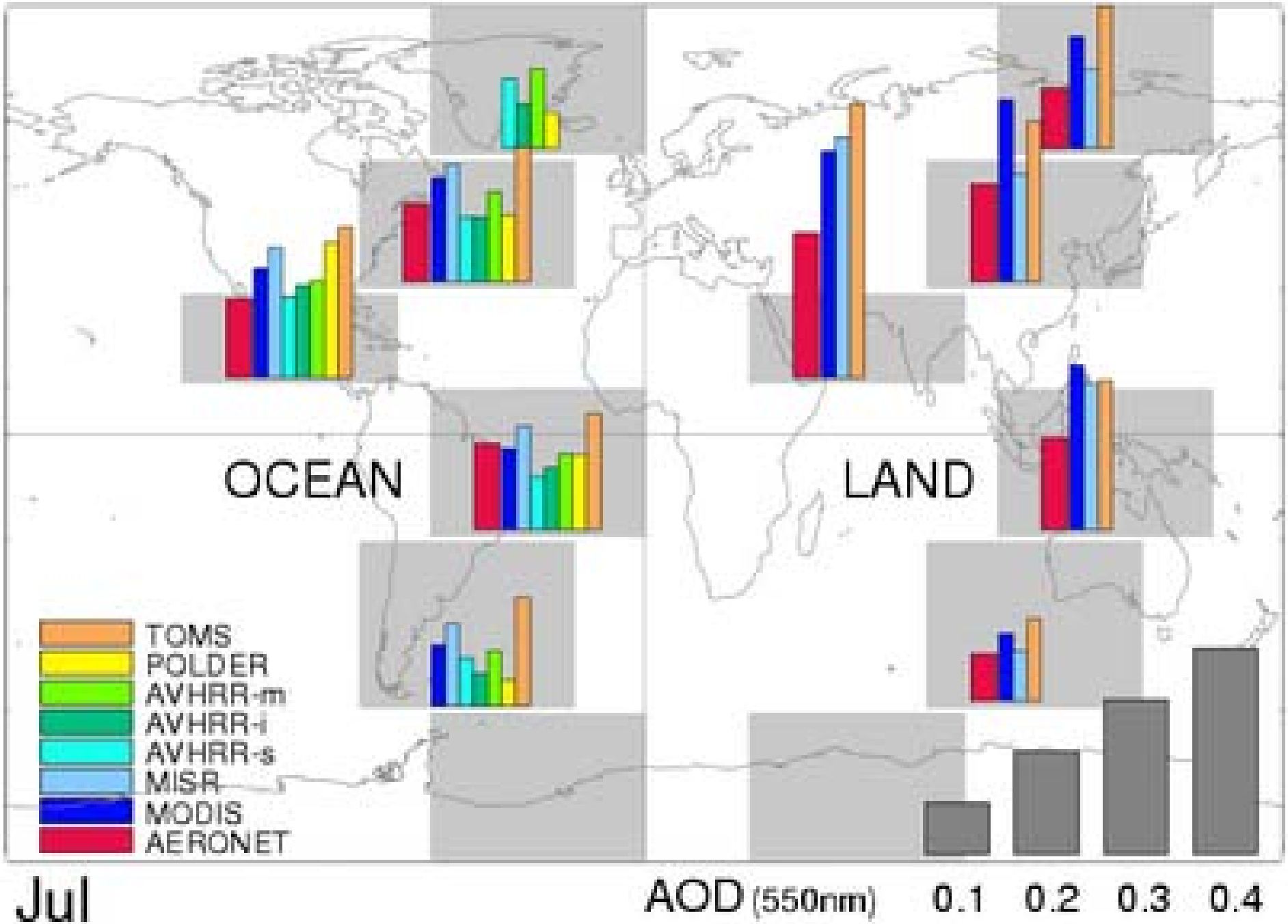
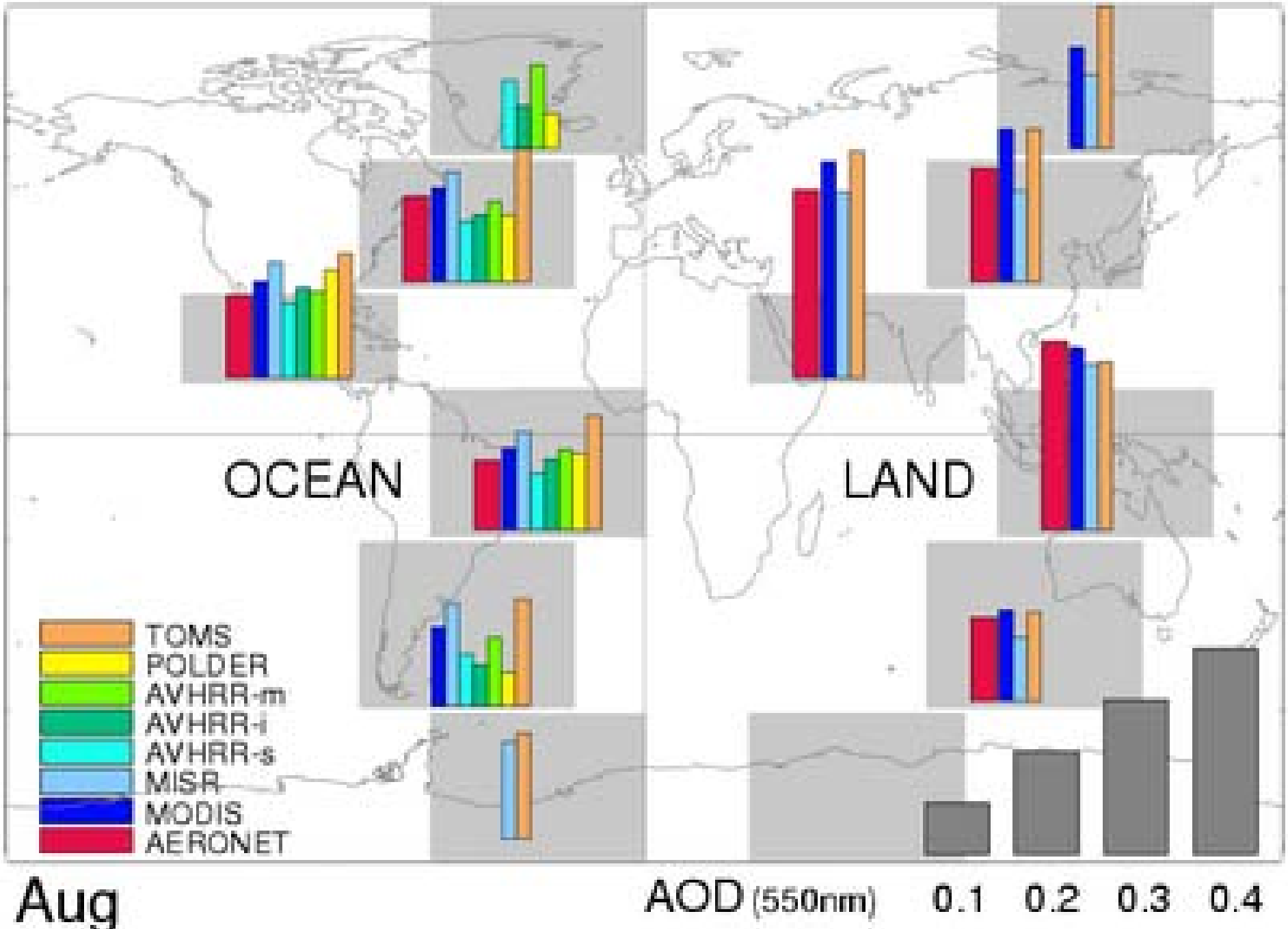

OCEAN
LAND
TOMS
POLDER
AVHRR-m
AVHRR-i
AVHRR-s
MISR
MODIS
AERONET
Mar
AOD (550nm)
0.1
0.2
0.3
0.4

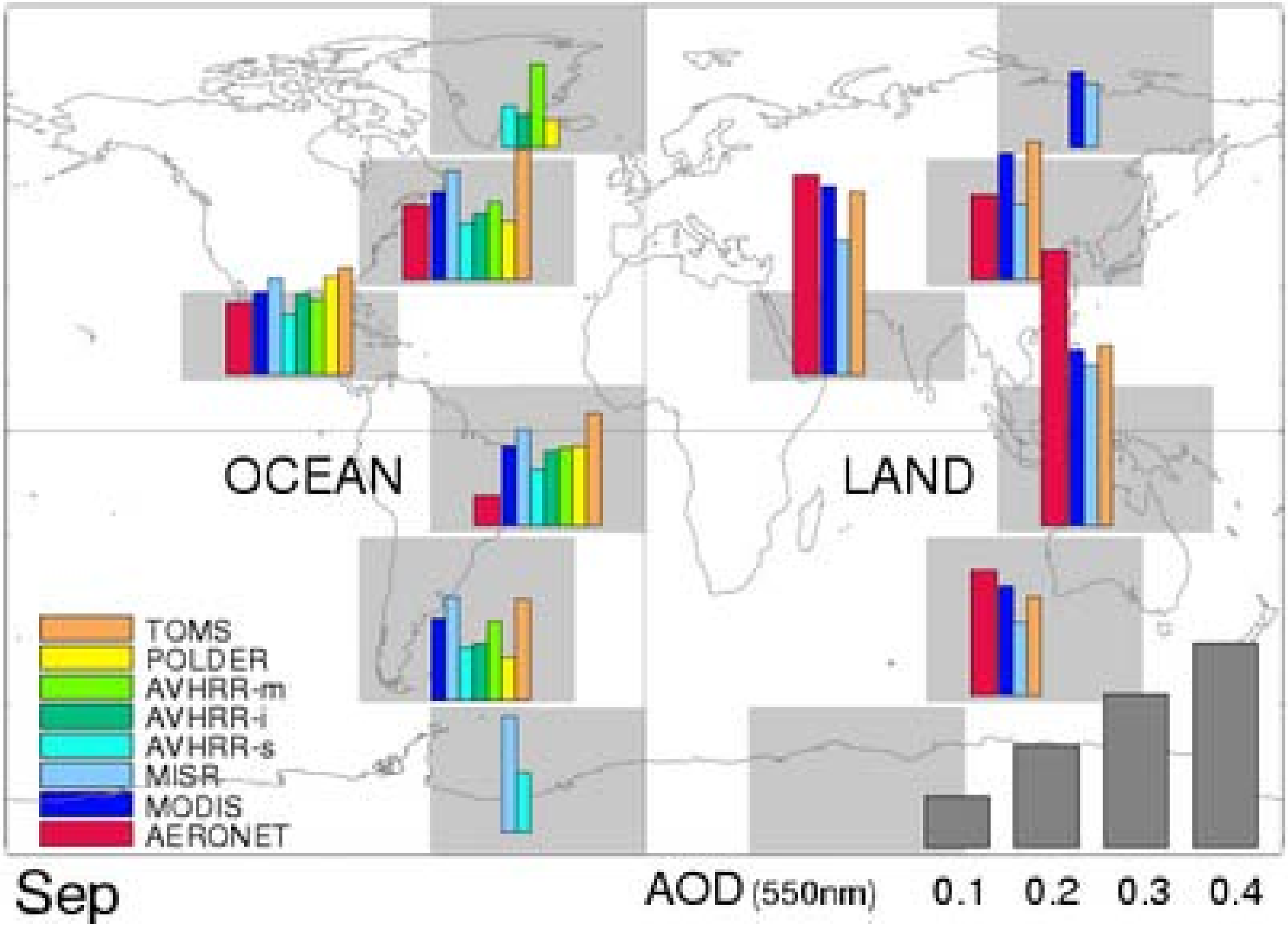

OCEAN
LAND
TOMS
POLDER
AVHRR-m
AVHRR-i
AVHRR-s
MISR
MODIS
AERONET
Apr
AOD (550nm)
0.1
0.2
0.3
0.4


OCEAN
LAND
TOMS
POLDER
AVHRR-m
AVHRR-i
AVHRR-s
MISR
MODIS
AERONET
May
AOD (550nm)
0.1
0.2
0.3
0.4


OCEAN
LAND
TOMS
POLDER
AVHRR-m
AVHRR-i
AVHRR-s
MISR
MODIS
AERONET
Jun
AOD (550nm)
0.1
0.2
0.3
0.4


OCEAN
LAND
TOMS
POLDER
AVHRR-m
AVHRR-i
AVHRR-s
MISR
MODIS
AERONET
Jul
AOD (550nm)
0.1
0.2
0.3
0.4


OCEAN
LAND
TOMS
POLDER
AVHRR-m
AVHRR-i
AVHRR-s
MISR
MODIS
AERONET
Aug
AOD (550nm)
0.1
0.2
0.3
0.4


OCEAN
LAND
TOMS
POLDER
AVHRR-m
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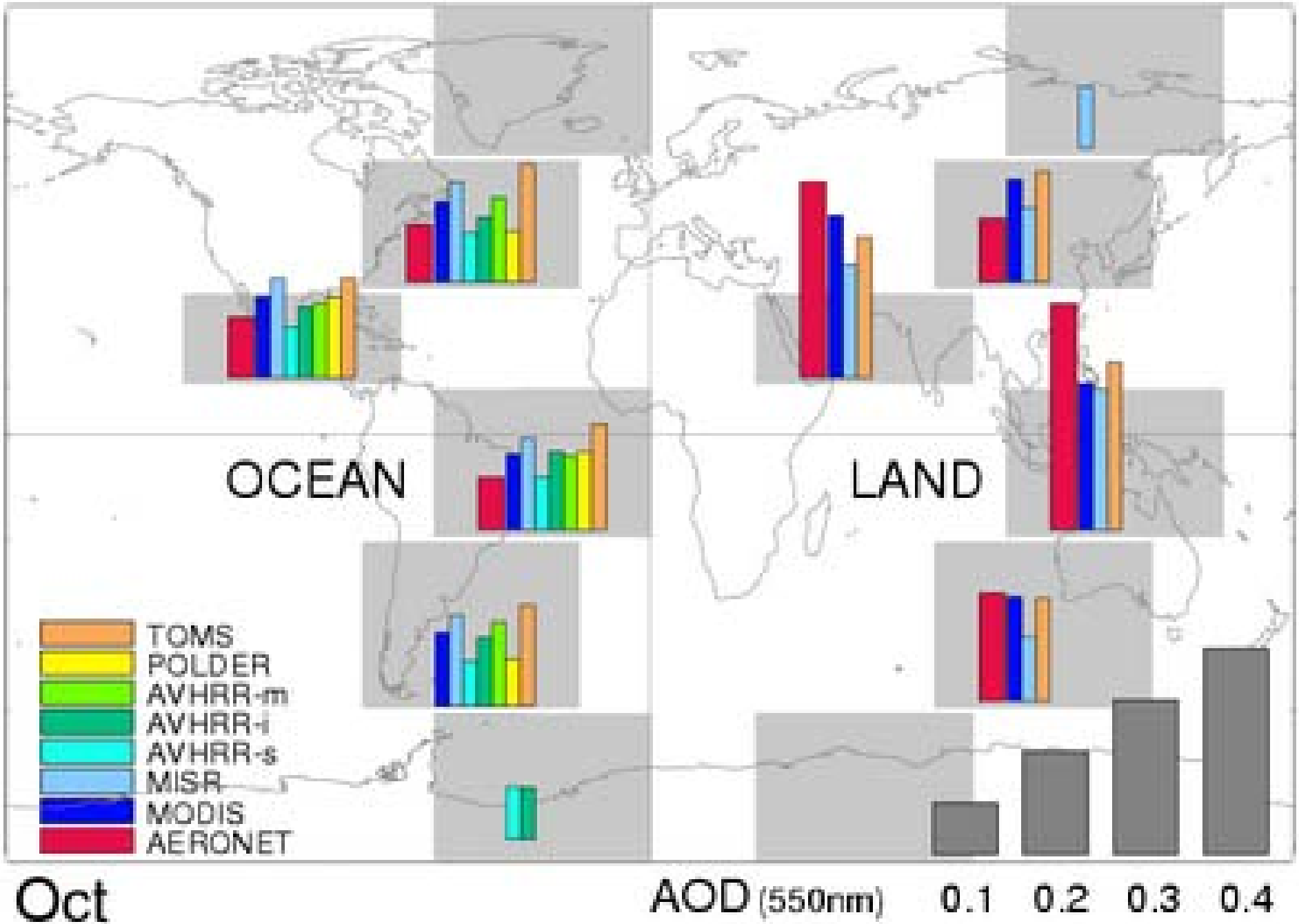
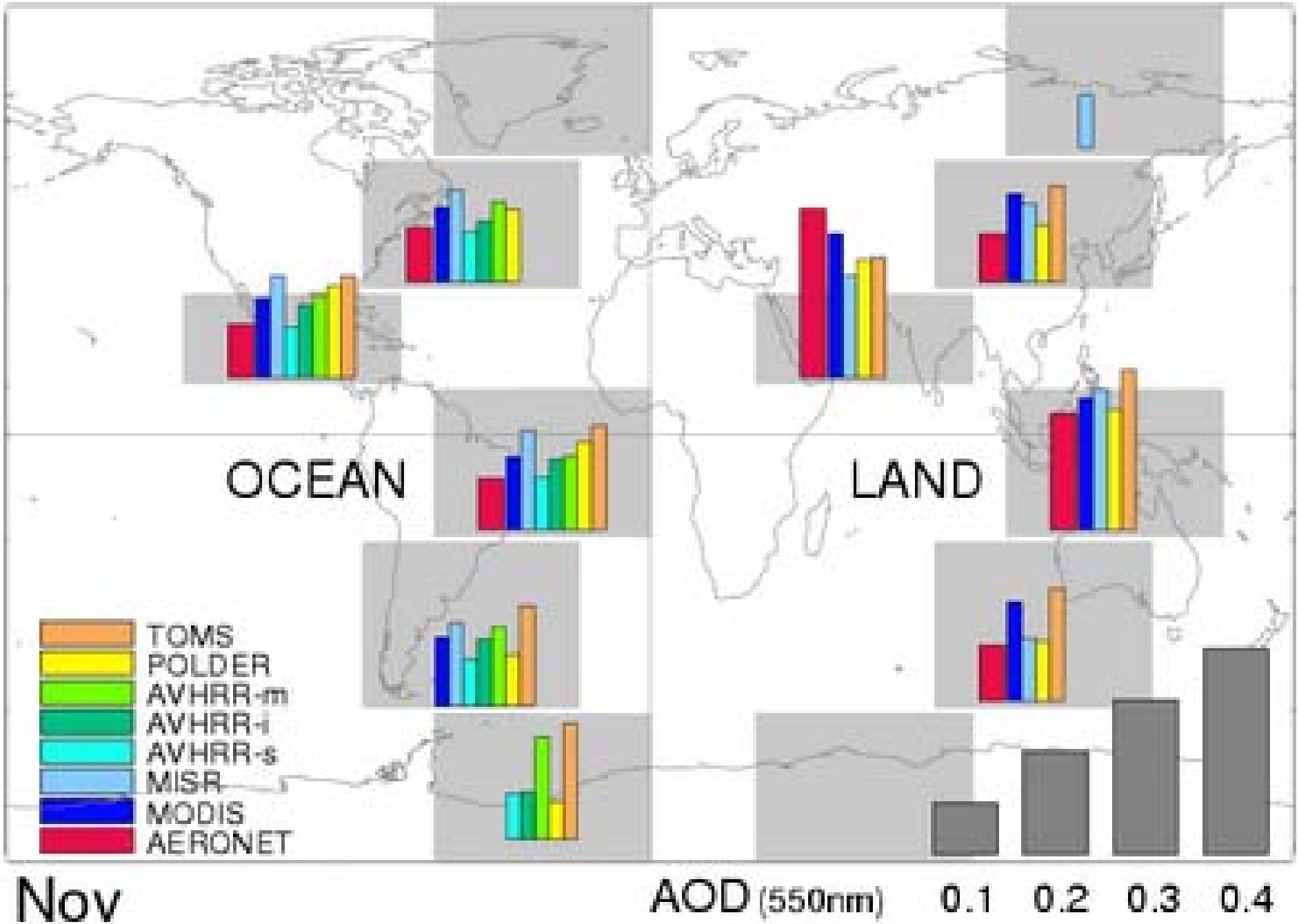
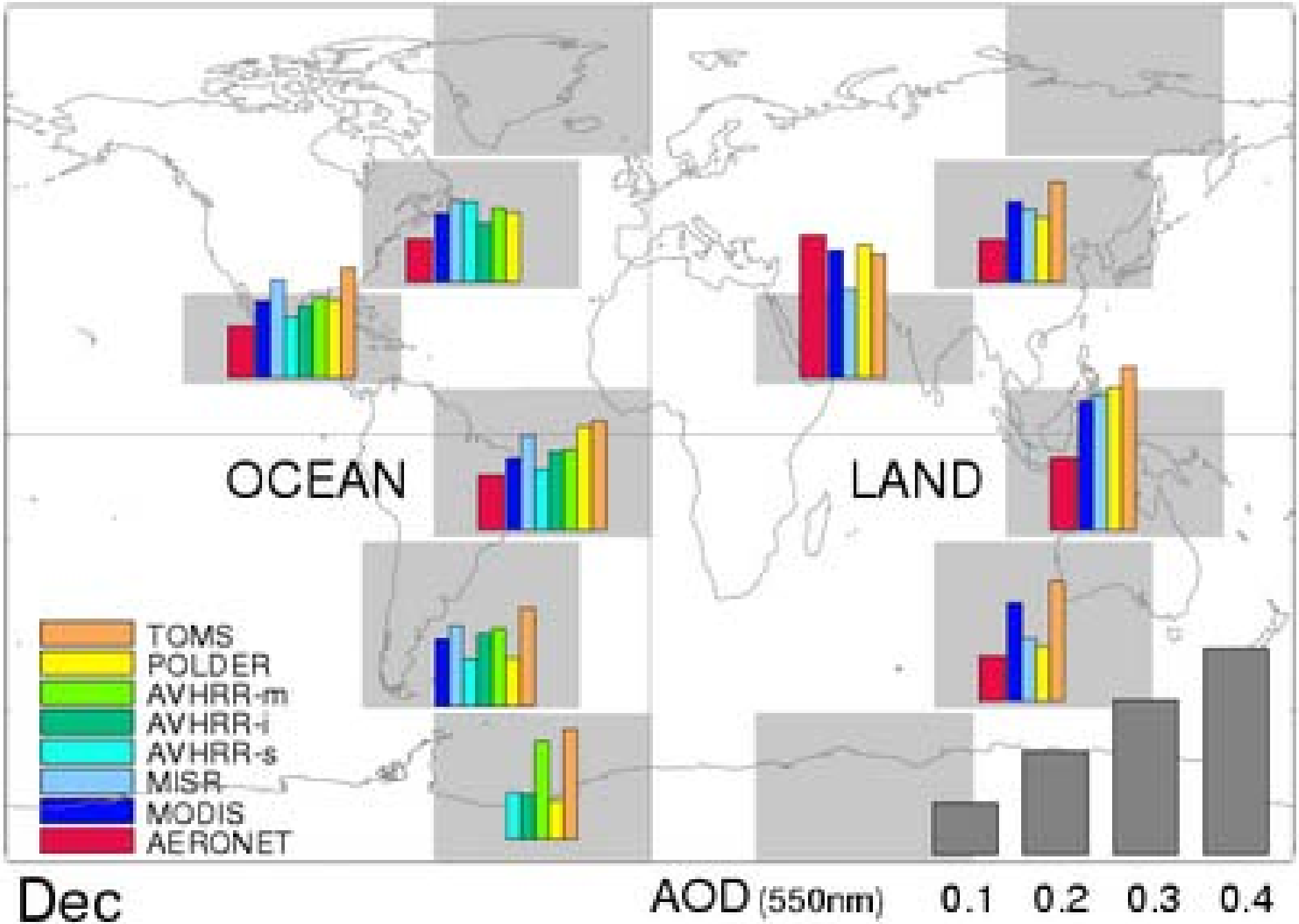
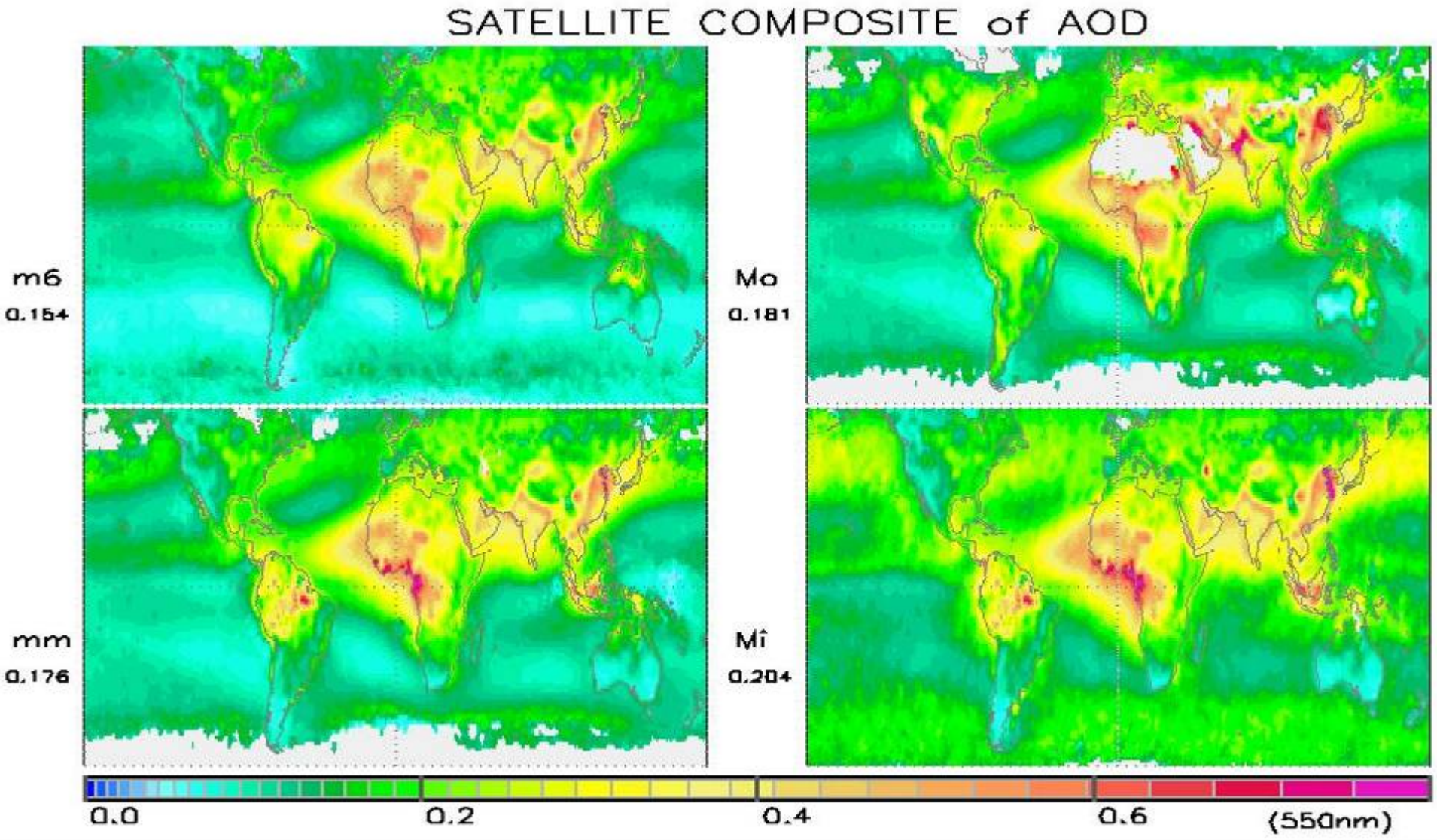
MISR
MODIS
AERONET
Sep
AOD (550nm)
0.1
0.2
0.3
0.4

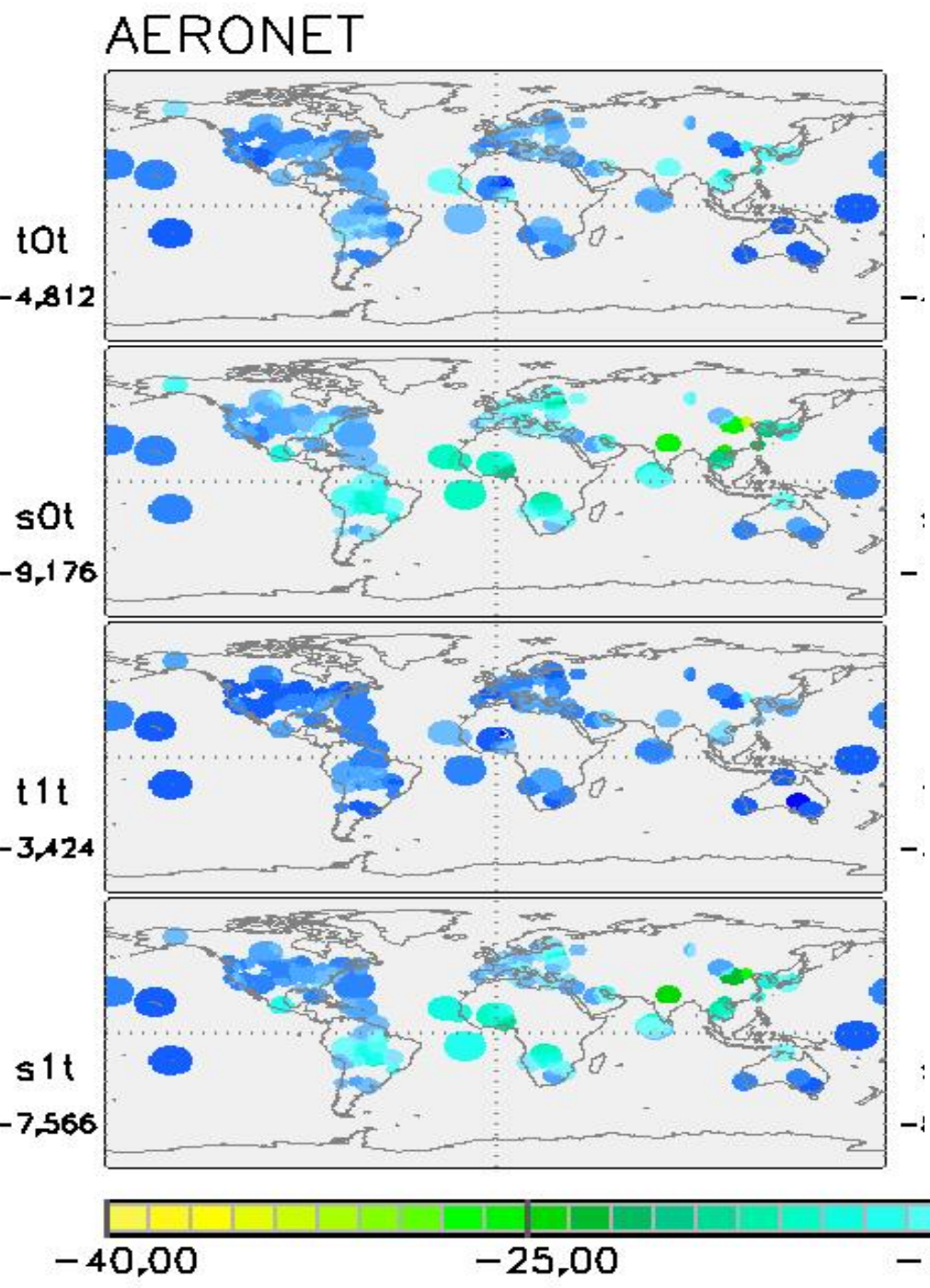

OCEAN
LAND
TOMS
POLDER
AVHRR-m
AVHRR-i
AVHRR-s
MISR
MODIS
AERONET
Oct
AOD (550nm)
0.1
0.2
0.3
0.4


OCEAN
LAND
TOMS
POLDER
AVHRR-m
AVHRR-i
AVHRR-s
MISR
MODIS
AERONET
Nov
AOD (550nm)
0.1
0.2
0.3
0.4


OCEAN
LAND
TOMS
POLDER
AVHRR-m
AVHRR-i
AVHRR-s
MISR
MODIS
AERONET
Dec
AOD (550nm)
0.1
0.2
0.3
0.4

“best” vs. “MODIS/MISR”





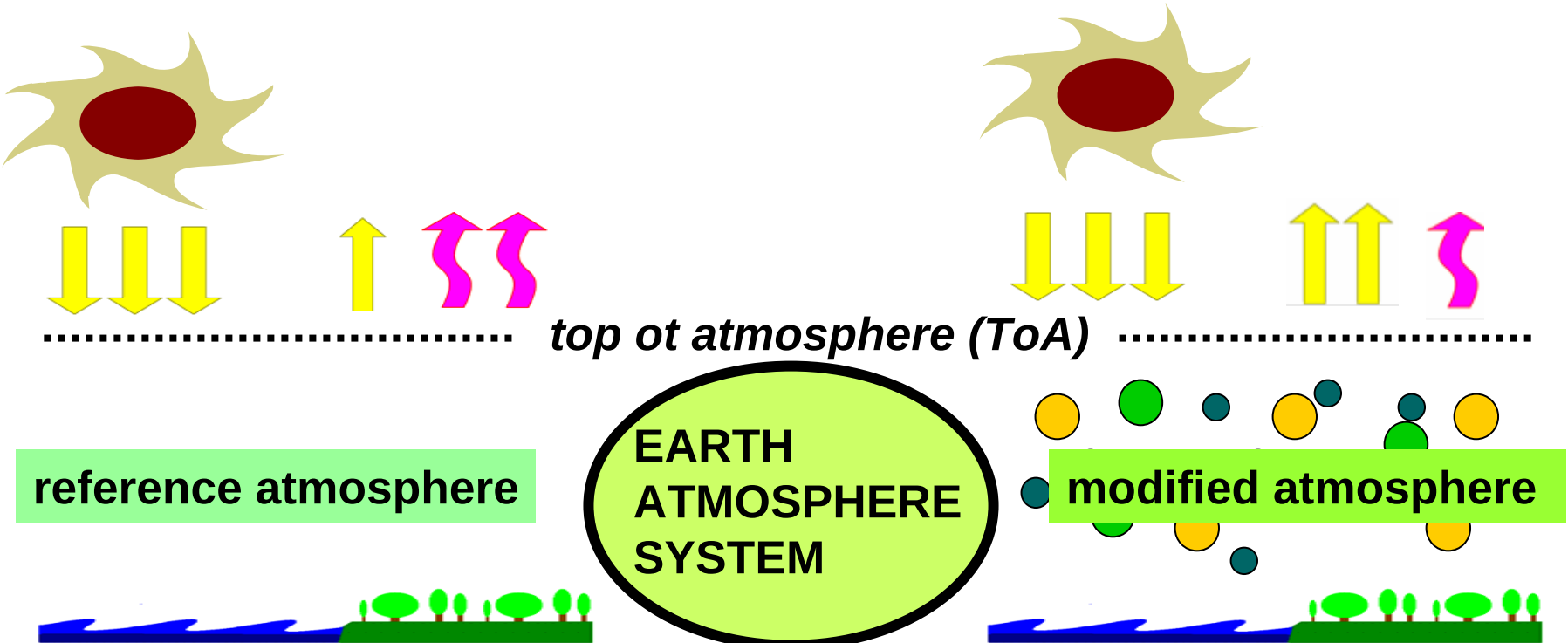
these aerosol direct forcing averages…

- **ToA clear-sky**
  - **- 4.8 W/m2**
- **surf. clear-sky**
  - **- 8.1 W/m2**
- **ToA all-sky**
  - **- 3.4 W/m2**
- **surf. all-sky**
  - **- 7,5 W/m2**

…are not global averages

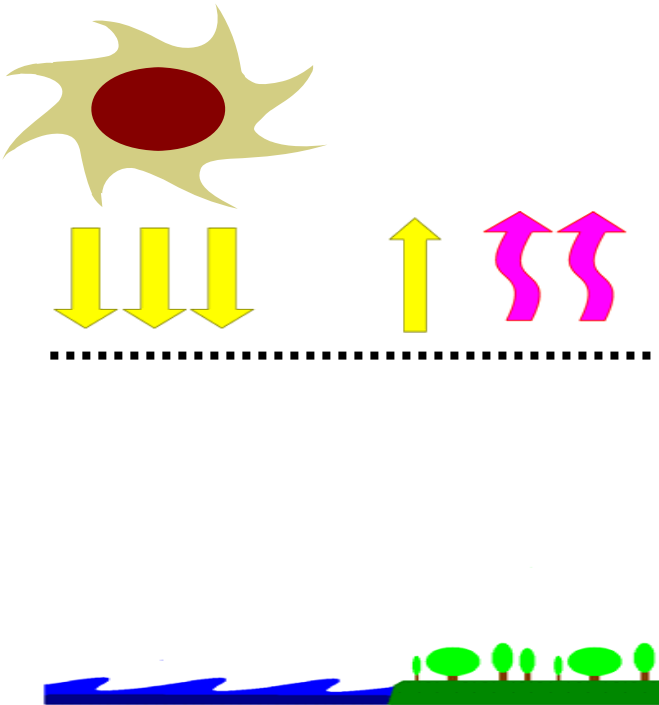
radiative forcing – *climate impact*

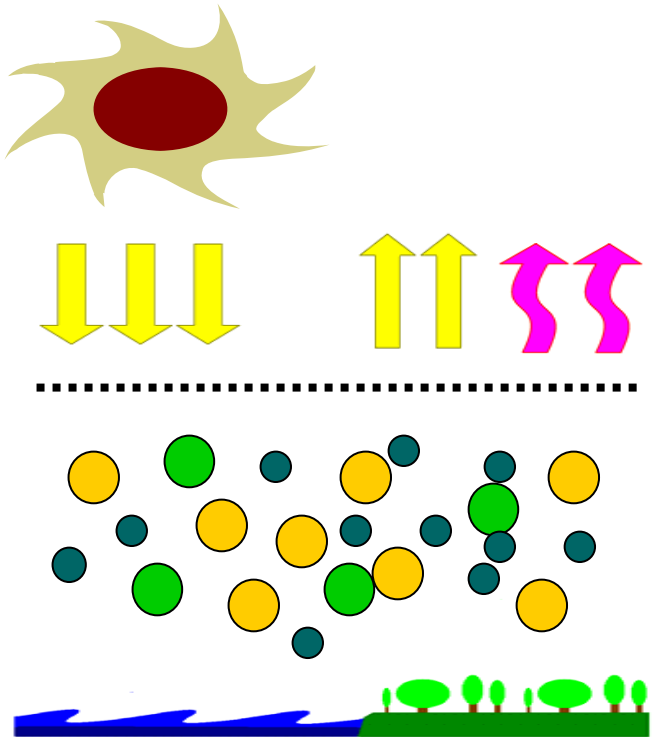
- **for the overall impact on the Earth-Atmosphere-System? ⇨ look at energy bal. changes at ToA**
  - **more ⇨ solar reflection back to space ('cooling')**
  - **less ⇨ thermal rad. lost to space ('warming')**



aerosol ‘clear-sky’ forcing

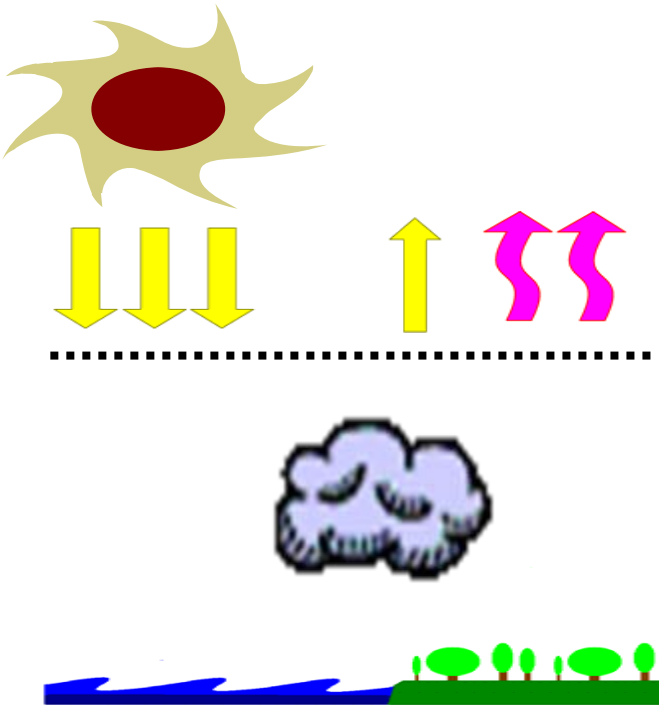
- aerosol impact under cloud-free conditions
  - ⇨ at ToA aerosol mainly affects solar energy balance
    - … significant IR changes are only expected from elevated dust

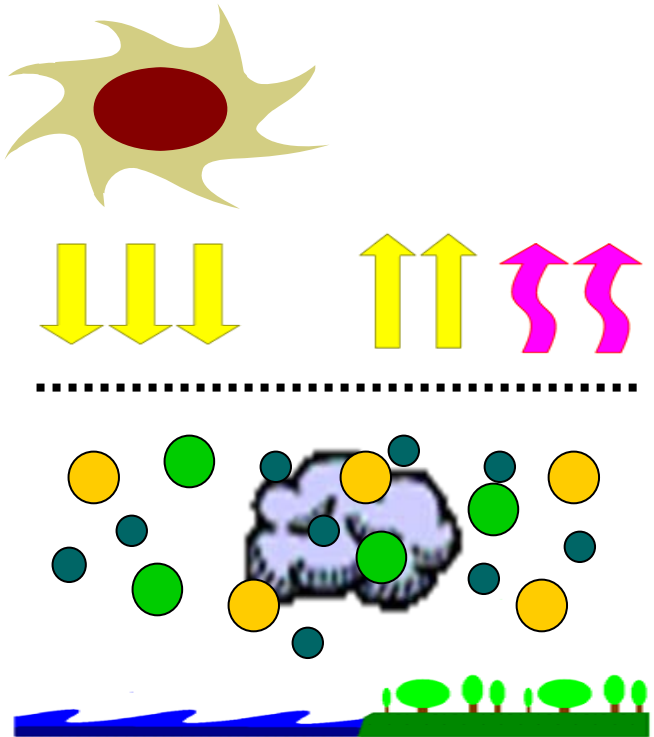




aerosol ‘all-sky’ forcing

- clouds complicate the aerosol (direct) forcing
  - ⇨ relative aerosol altitude matters for ToA forcing
    - … as absorbing aerosol above cloud warms!

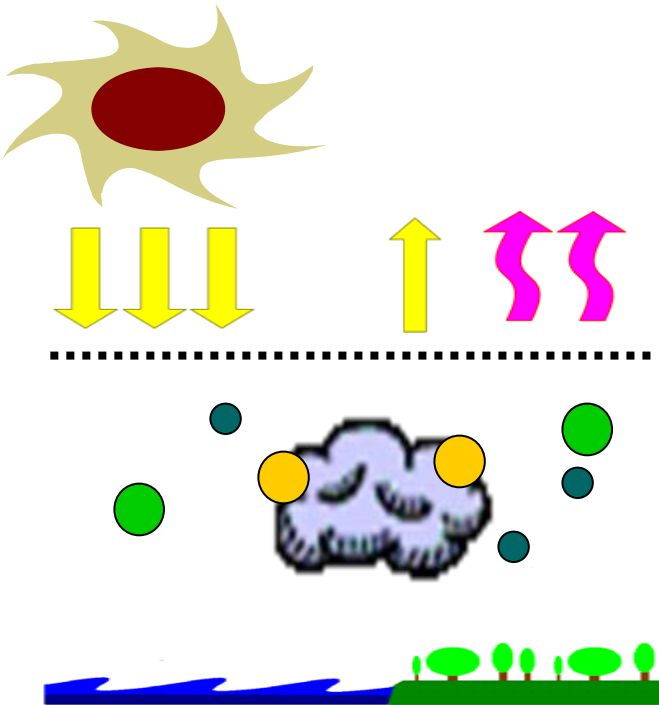


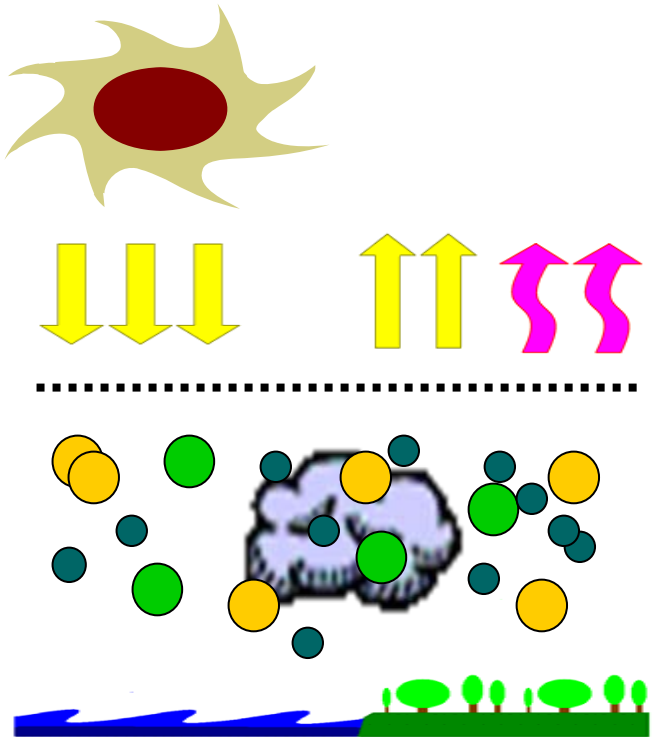


anthropogenic aerosol forcing

‘anthropogenic’ – reliance on modeling!

- **impact of man-made aerosol from is of interest**
  - ⇨ **the reference state already contains aerosol** … but how well do we know the reference state (no measurements) ?

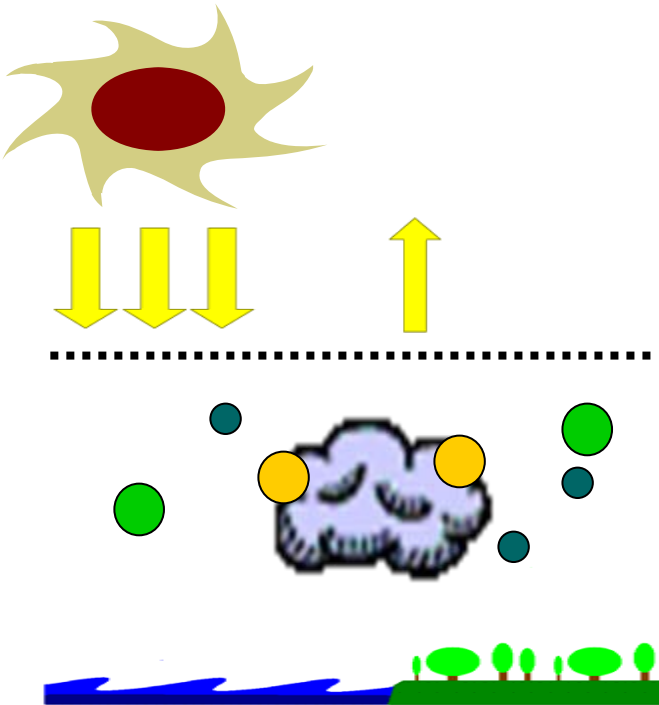


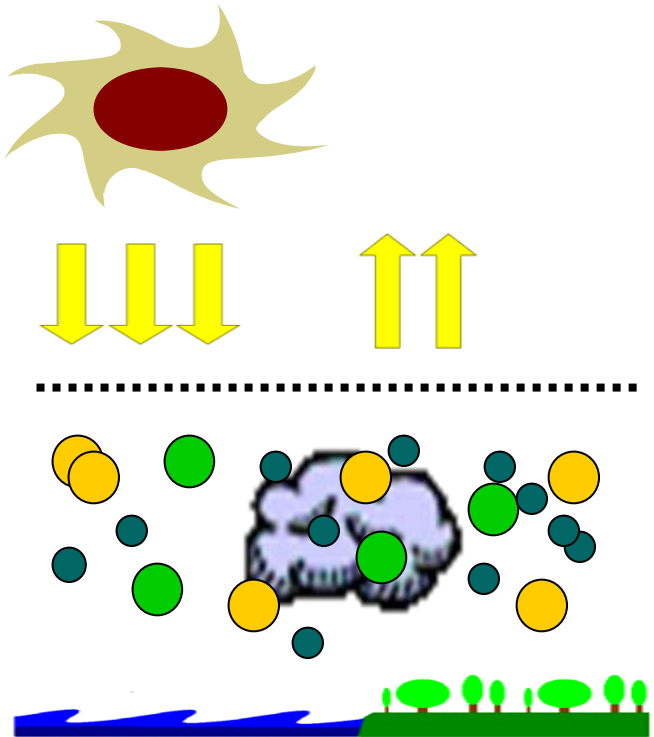


ant. aerosol solar forcing

(daily average)

- anthropogenic aerosol is usually < 1μm in size
  - ⇨ impact on IR radiation (at ToA) is often neglected
    - … thus the anthropogenic direct aerosol effect is a solar effect





AEROCOM

Aerosol Model Intercomparison Project

http://nansen.ipsl.jussieu.fr/AEROCOM/data.html

- **GOALS**
  - **document diff. of aerosol modules (esp. to data!)**
  - **assemble useful data-sets for model evaluations**
  - **identify and eliminate weak model components**
  - **reduce uncertainty of aerosol impact on climate**
- **OUTPUT**
  - **public web interfaces for model evaluations**
  - **ensemble results (*of 20 different global models*)**
    - **COMPLETE global fields on ALL aerosol properties**

AeroCom

Aerosol Model Intercomparison Project

Goals

- document diff. of aerosol modules (also to data !)
- assemble useful data-sets for model evaluations
- identify and eliminate weak model components
- reduce uncertainty of aerosol impact on climate

Products

- harmonize emission: ftp://ftp.ei.jrc.it/pub/Aerocom/
- derive an aerosol climatology
- derive new estimates for radiative forcing (→ IPCC)
- establish model benchmark tests
- public web site for interactive model evaluations: http://nansen.ipsl.jussieu.fr/AEROCOM/data.html

http://nansen.ipsl.jussieu.fr/AEROCOM/data.html

MODEL versus SURFACE OBSERVATION INTERFACE - Mozilla Firefox

File Edit View Go Bookmarks Tools Help

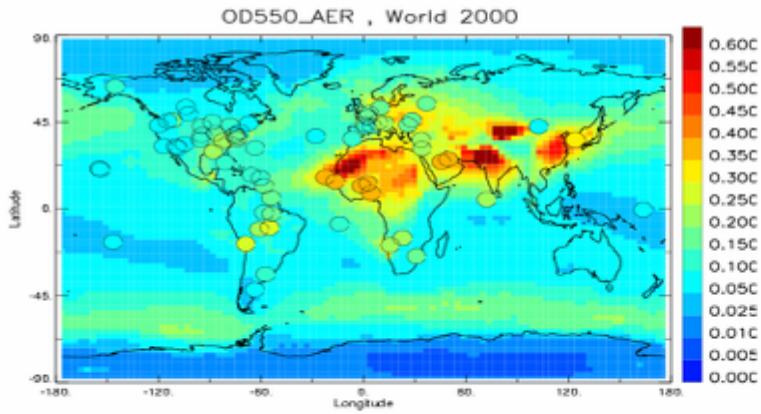
http://nansen.ipsl.jussieu.fr/cgi-bin/AEROCOM/aerocom/surfobs_annualrs.pl

Démarrage Dernières nouvelles ...

- AEROCOM PRELIMINARY RESULTS - MODEL versus SURFACE OBSERVATIONS

UPDATE - Synchron - 6-Images - Subset -> ALL DATA links -> presently on nansen surfobs interface

Graph	Data source	Species	Parameter
FIELDCOMPA	LSCE INCA ExpA	AER	OD550
WORLD	an2000	mALLYEAR	



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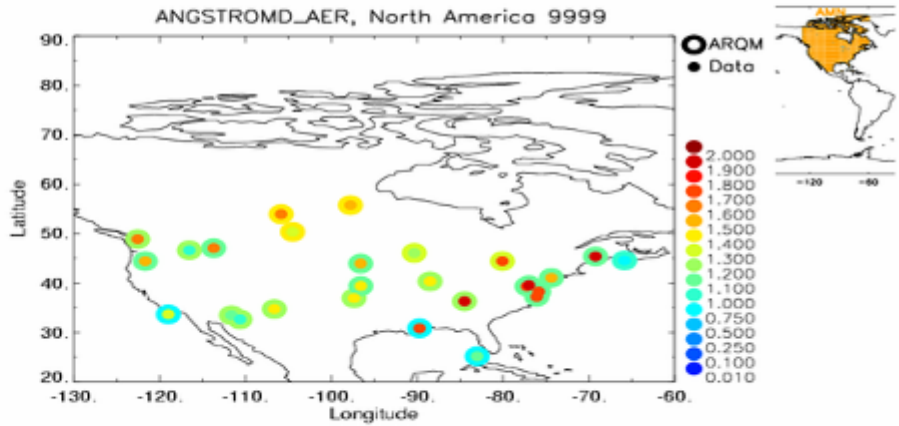
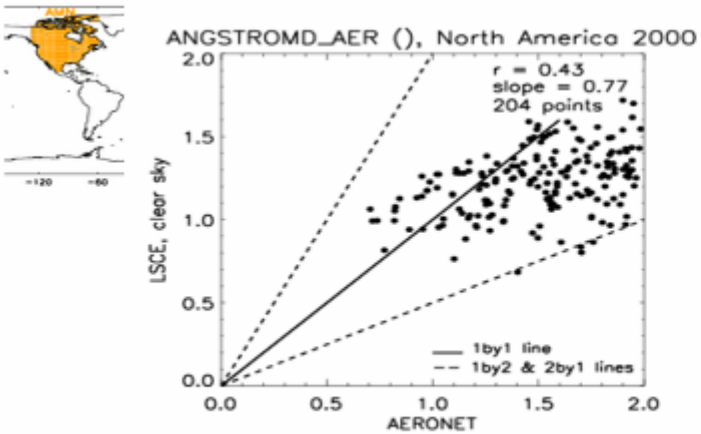
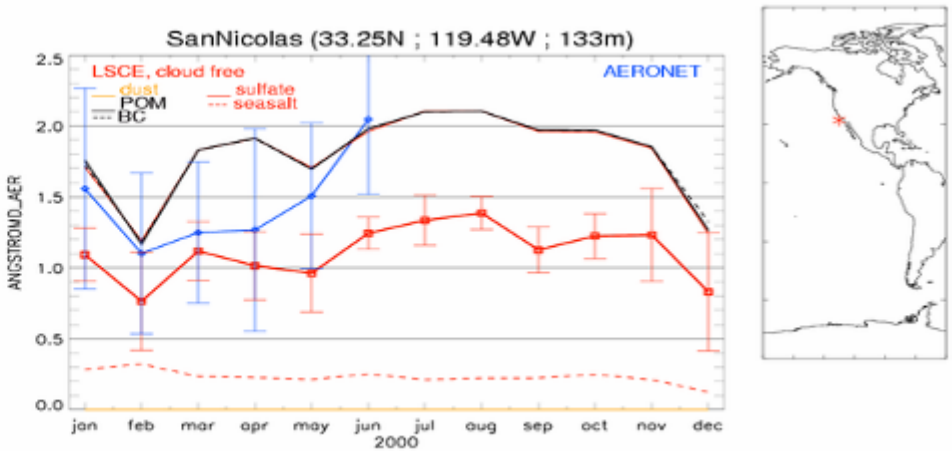
MAP	ARQM ExpA	AER	ANGSTROMD
AMN	an9999	mALLYEAR	



Graph	Data source	Species	Parameter
SCAT	LSCE INCA ExpA	AER	ANGSTROMD
AMN	an2000	mALLYEAR	



Graph	Data source	Species	Parameter
SERIES	LSCE INCA ExpA	AER	ANGSTROMD
SanNicolas	an2000	mALLYEAR	



AeroCom

Aerosol Model Intercomparison Project

CONCEPT

- **participation by any global modeling group sought**
  - **follow data protocol for specific experiments, so far:**
    - **A** – run models as they are *(if poss.year 2000)* **(17 models)**
    - **B** – run with AeroCom year 2000 emissions **(12 models)**
    - **PRE** – run with AeroCom year 1750 emissions **(9 models)**
    - **IND** – provide add. data on cloud / precipitation **(6 models)**
- **web-based model evaluation and diagnostics**
- **data storage at central database at LSCE (France)**

MODELS MODELERS: **ARQM-GCM/CAM** ARQM Meteorological Service Canda, Toronto, Canada: S. Gong, P. Huang **CAM** NCAR, Boulder,USA, N. Mahowald **DLR-ECHAM-MADE** Institut für Physik der Atmosphäre, DLR, Oberpfaffenhofen, Germany: J. Hendricks, A. Lauer **GISS** Columbia University, GISS, New York, USA: D. Koch, S. Bauer **GOCART** Goddard Space Flight Center, Greenbelt; Goddard Earth Sciences and Technology Center, University of Maryland Baltimore County, USA: T. Diehl, M.Chin **KYU-SPRINTARS** Kyushu University, Fukuoka, Japan: T. Takemura **LSCE-LMDzT-INCA** Laboratoire des Science du Climat et de l'Enivonnement, Gif-sur-Yvette, France: M. Schulz, Y.Balkanski, C. Textor, S. Generoso, S. Guibert, D. Hauglustaine **LOA-LMDzT** Laboratoire d'Optique Atmosphérique, Université des Sciences et Technologies de Lille, CNRS, Villeneuve d'Ascq, France: O. Boucher, S. Reddy **MATCH**, NCAR, Boulder, Colorado, USA: D. Fillmore, P. Rasch, B. Collins **MPI_HAM-ECHAM5-HAM**, Max-Planck-Institut für Meteorologie, Hamburg, Germany: P. Stier , J. Feichter, E.Vignati, J.Wilson, S.Kloster, M.Schulz **MOZGN** NOAA, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey, USA: L. Horrowitz, P. Ginoux, X. Tie, J.F. Lamarque **PNNL-MIRAGE** Battelle, Pacific Northwest National Laboratory, Richland, USA: S. Ghan, R. Easter **TM5** Institute for Marine and Atmospheric Research Utrecht (IMAU) Utrecht University, The Netherlands: M. Krol, EC, Joint Research Centre, Institute for Environment and Sustainability, Climate Change Unit, Italy: F.Dentener **UIO_CTM2**, University of Oslo, Department of Geophysics, Oslo, Norway: G. Myhre T. Berntsen,T. Berglen, A. Grini, **UIO_GCM-CCM-Oslo**, University of Oslo, Department of Geophysics, Oslo, Norway: T. Iversen, Ø. Seland, J.E.Kristjansson, A. Kirkevåg, **ULAQ-CCM**, Universita degli Studi L'Aquila, Italy: G. Pitari, V. Montanaro , E. Mancini **UMI-IMPACT/DAO**, University of Michigan, Ann Arbor, MI, USA: J. Penner, X. Liu

AeroCom

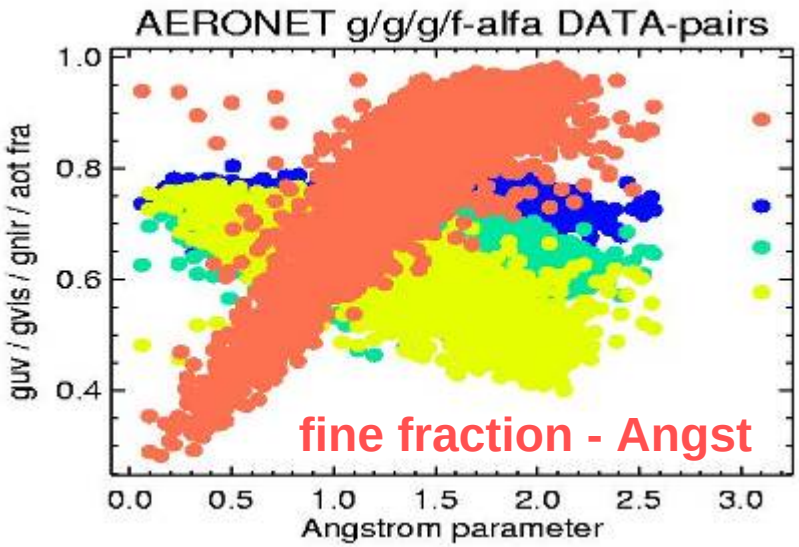
publications

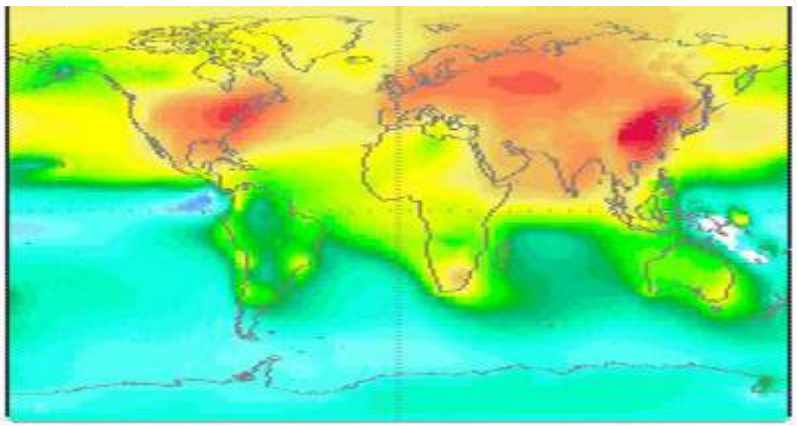
- *Textor, C. et al.,* Analysis and quantification of the diversities of aerosol life cycles within AeroCom, *ACP, 6*, 1777-1811, 2006
- *Kinne, S. et al.,* An AeroCom initial assessment – optical properties in aerosol component modules of global models, *ACP, 6,* 1-22, 2006
- *Dentener, F. et al.,* Emissions of primary aerosol and precursor gases for the years 2000 and 1750, prescribed data-sets for AeroCom, *ACP*, 6, 4321-4344, 2006
- *Schulz. et al.,* Aerosol forcing by aerosols as derived from the AeroCom present-day and pre-industrial simulations, *ACPD 2006.*

- **web:** http://nansen.ipsl.jussieu.fr/AEROCOM/data.html
- **contacts:** *michael.schulz@cea.fr*, *kinne@dkrz.de*

AOD - anthropogenic < fine mode !

- fine mode fraction
  - AERONET provides general relationship to Angstrom 'An'
  - f = 0.19 + 0.687* ln('An' +1)
  - significant scatter only allows only its general use



- anthropogenic fraction comes from modeling
  - the 'anthropogenic' AOD is only a *fraction* of the fine-mode AOD !

anthropogenic fine mode fraction