atmospheric AEROSOL

Assessment of Measurements and of efforts in Global Modeling

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Overview

- aerosol
  - a short introduction
- available aerosol data-sets
  - useful to modeling?
- AERONET and new satellite sensor data
  - the strength of synergetic approaches
- aerosol global modeling
  - a BIG can of worms
- AeroCom
  - an international effort to reduce uncertainties in aerosol global modeling

aerosol, what is it ?

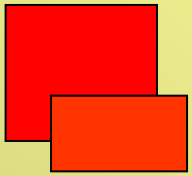
- atmospheric particles smaller than cloud droplets

aerosol, where from?

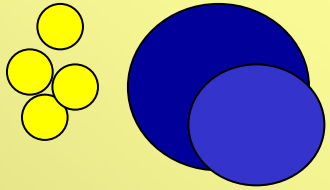
- natural sources
  - *(wind ⇨)* dust, seasalt *(lightning/fire ⇨)* biomass
- anthropogenic sources
  - *(industry ⇨)* sulfate, nitrate, carbon (fossil fuel)
  - *(land-use change ⇨)* tropical biomass burning

***'primary'** (as particles) - **'secondary'** (via the gas-phase)*

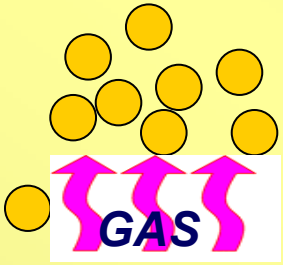
irregular shapes … not just spheres
many sizes: nanometer to micrometer
strongly absorbing (soot) to non-absorbing



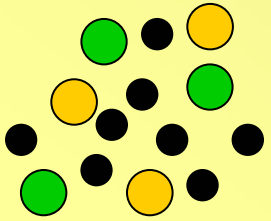
DUST

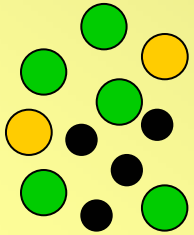


DMS, SEASALT

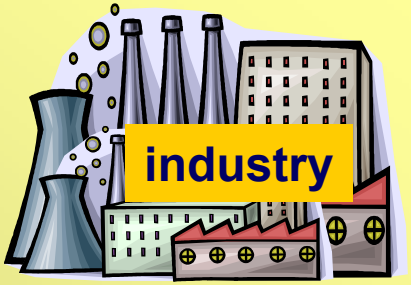


SULFATE





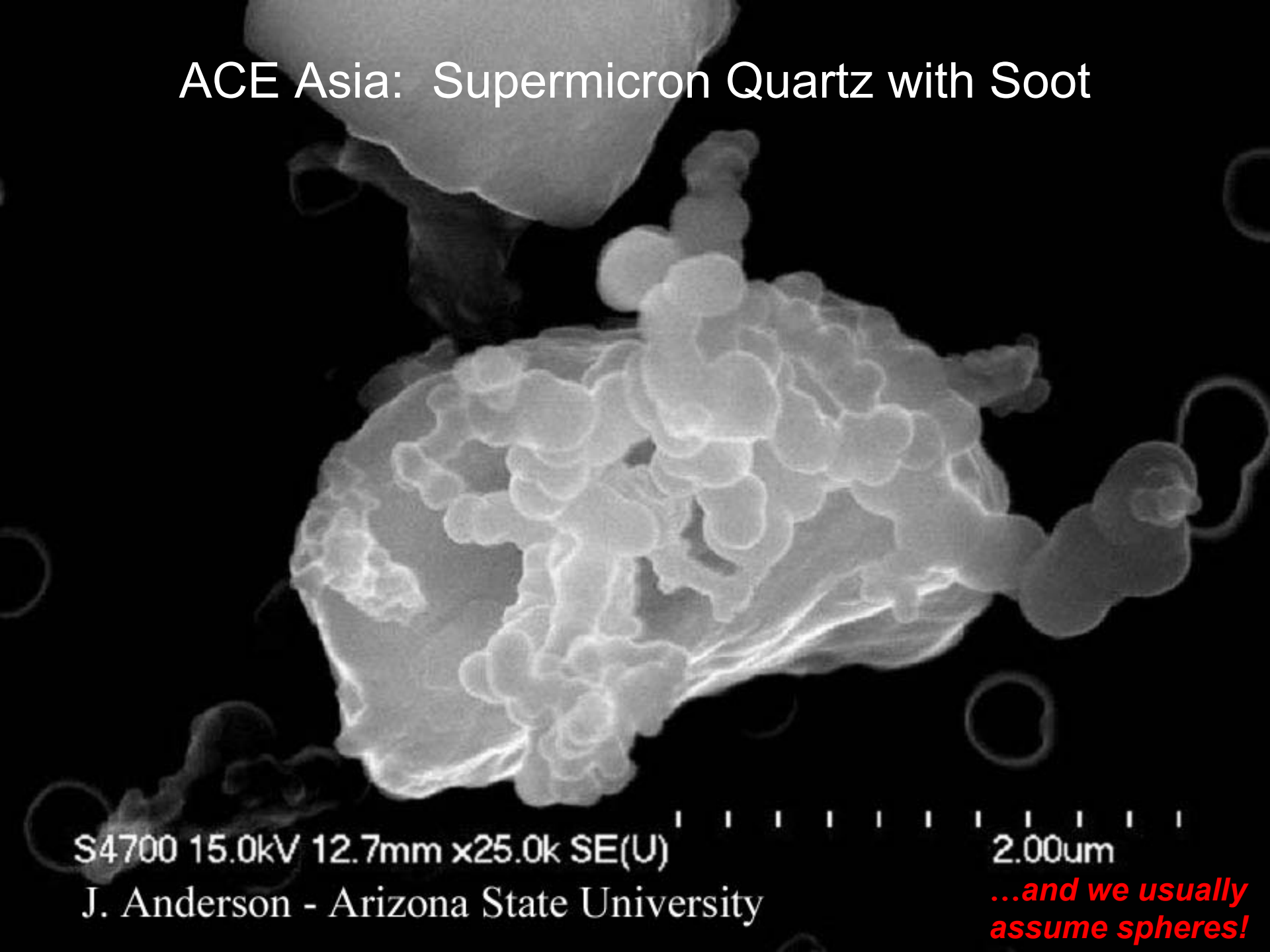
CARBONACEOUS



aerosol, what properties?

- highly variable in space and time for
  - **PROPERTY** — ***OPTICAL PROPERTY***
    - amount — *'aerosol optical thickness'*
    - composition — *'refractive index', 'ss-albedo'*
      - ⇨ absorption
    - water uptake — *'hygroscopicity' …can change with time*
    - size — *orders of magnitude!*
      - 'coarse' *(>1μm in size)* → *energy balance*
      - 'accumulation' *(.1-1μm in size)* → *solar energy balance*
      - 'Aitken' *(,01-.1μm in size)* → *health*
      - 'nucleation' *(< 0.01μm in size)*
    - shape — *we prefer spheres (MIE) but…*

ACE Asia: Supermicron Quartz with Soot



…and we usually assume spheres!

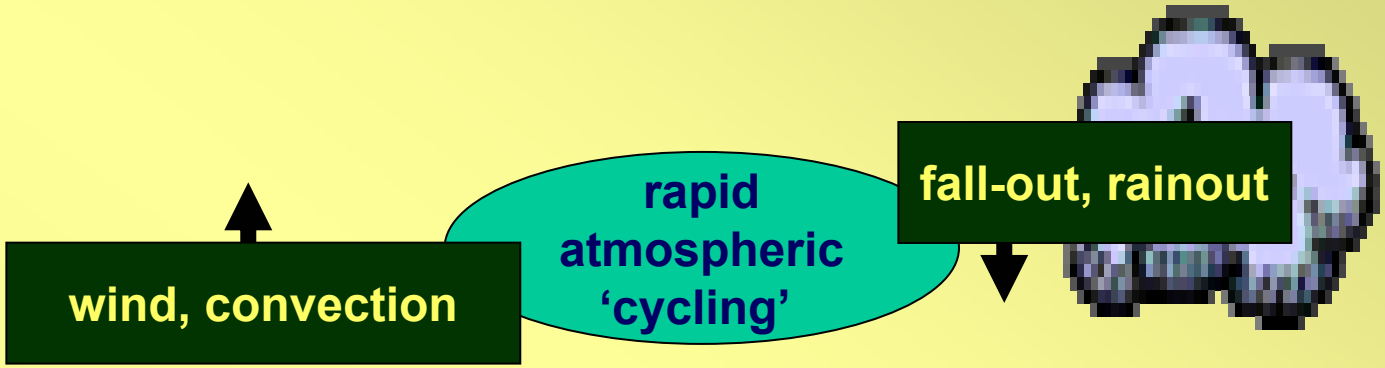
components	DU	SS	SU	OC	BC
size-range (μm)	1-5	1-10	.1-1	.1-1	.1-.5
absorption	weak	no	no	weak	strong

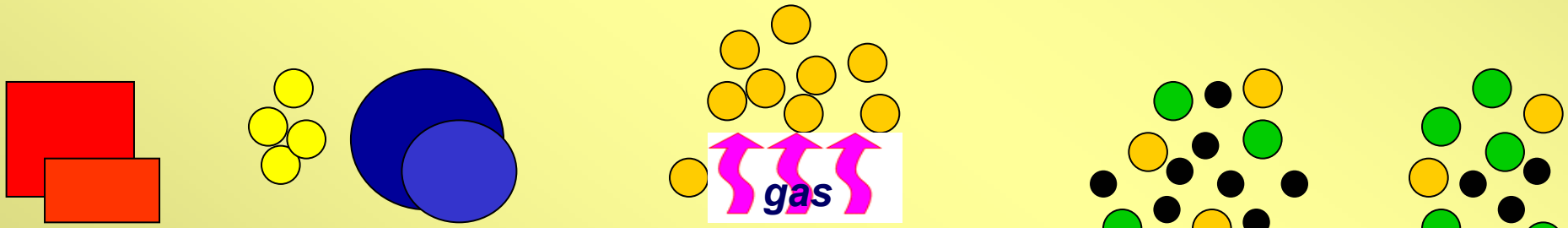
Aerosol

a modeler's nightmare

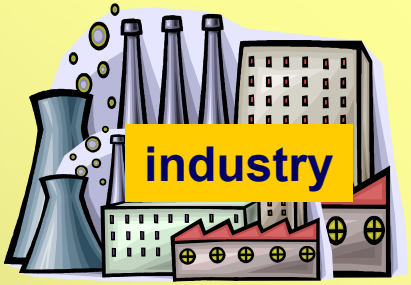
lifetime:

only a few days





DUST **DMS, SEASALT** **SULFATE** **CARBONACEOUS**



aerosol, why do we care ?

- **effects on health** (e.g. asthma cases)
- **effects on quality of life** (e.g. less clear days)
- **effects on weather** (e.g precipitation)
- **effects on climate** (or the radiative energy balance)

  - **direct effects**

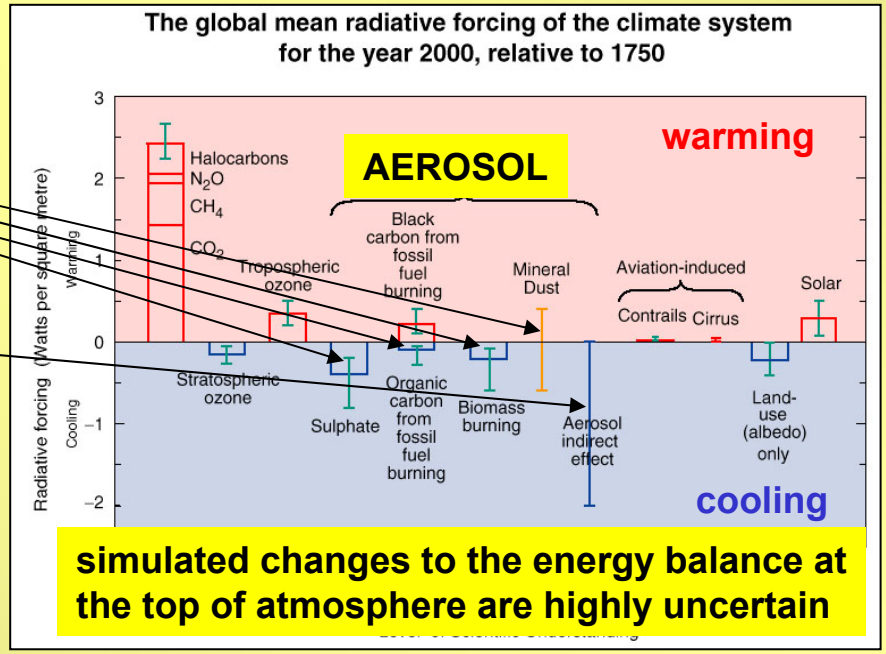
    from the presence of aerosol

    depends on the aerosol type

  - **indirect effects**

    through modifications of other atmos, parameters (e.g. clouds)

    many partially offsetting effects



aerosol, good global data needed

- understanding of the aerosol climatic impact is based on MODELS
  - MODELS are as good as the data
  - MODELS need info on aerosol detail

aerosol, data of the past (1)

- simple climatologies
  - GADS was an initial attempt to define global aerosol based on local in-situ or remote sensing data
    - limited seasonality (Jan, Jul), 5deg lat/lon resolution

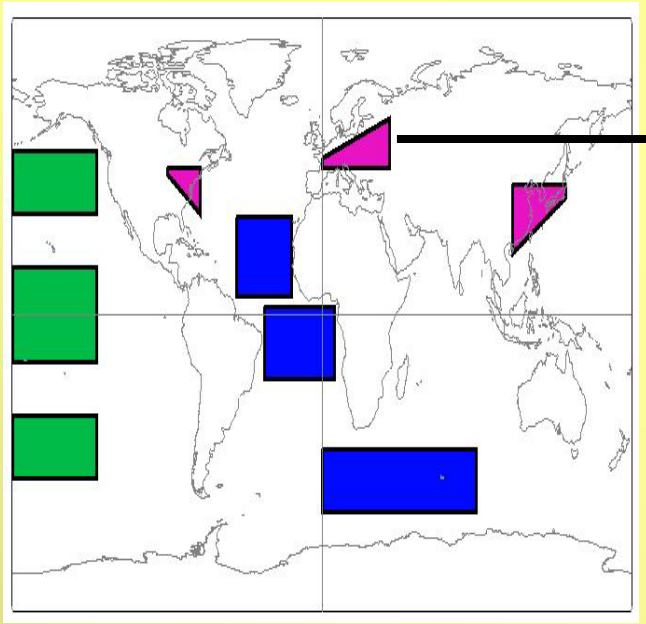
aerosol, data of the past (2)

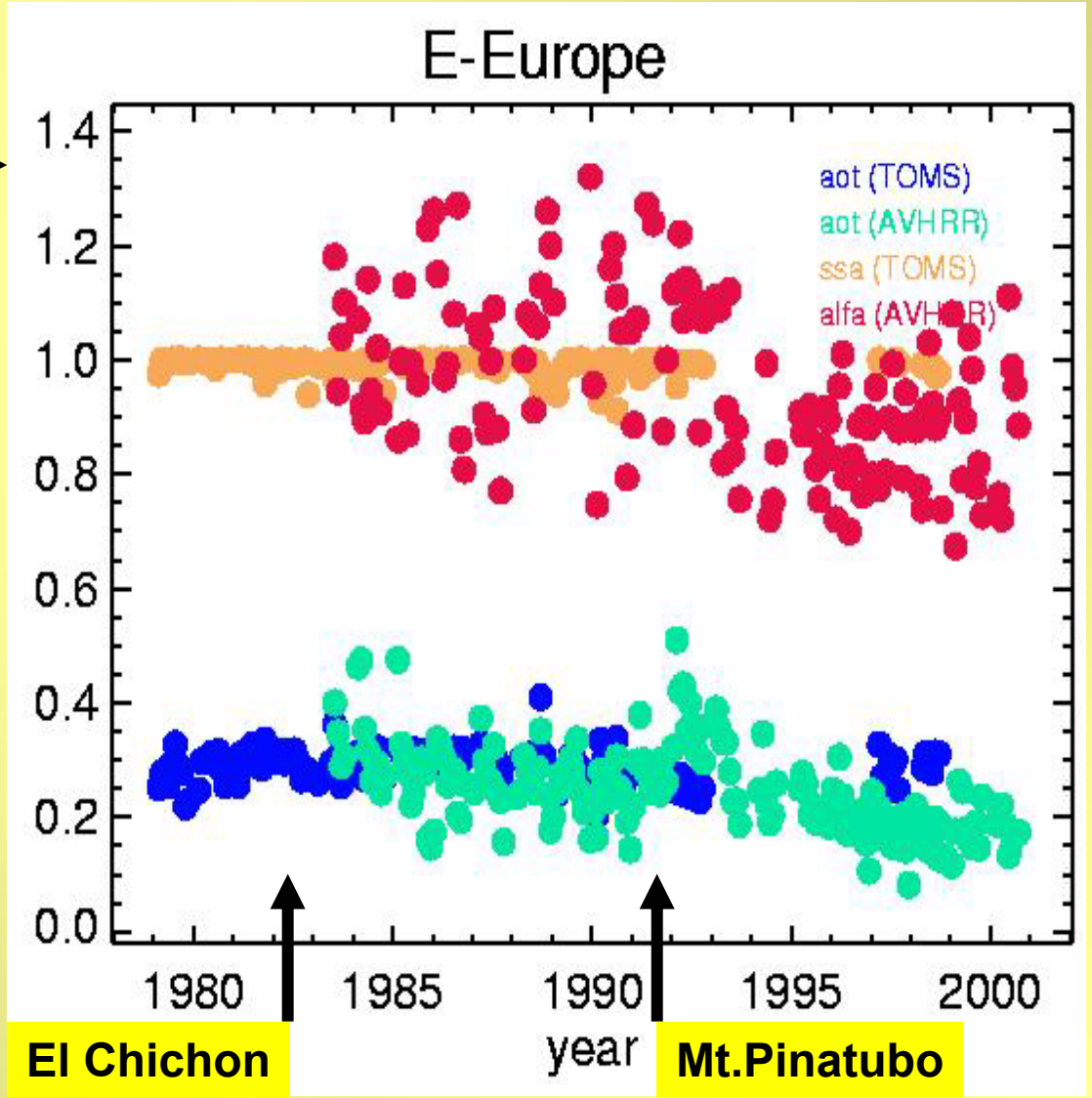
- 25 years monitoring from space
  - AVHRR (visible / n-IR backscatter)
    - amount: aerosol optical thickness (aot)
    - size: Angstrom parameter (α)
  - TOMS (UV backscatter, 'molecular' contrast)
    - amount: aerosol optical thickness (aot)
    - absorption: single scattering albedo ($\omega 0$)
  - SAGE/SAM (solar occultation)
    - concentr./amount extinction and stratospheric aot
    - size: stratos. Angstrom parameter (α)

aerosol, retrieval limitations

- a-priori assumptions are necessary
  - at best two measurements … many unknowns!
- good cloud detection is essential ⇨ fine pixels
  - false aerosol identification (sub-pixel clouds)
- accurate (land) surface contributions are needed
  - false aerosol identification (plancton, sub-pixel snow)
- sensor and platform problems
  - sensor drifts, overpass drifts, calibration issues
  - sensor data from different platforms
- poor temporal resolution of polar-orbiters
  - 'am' (TOMS) not necessarily agree with 'pm' data (AVHRR)

a regional example



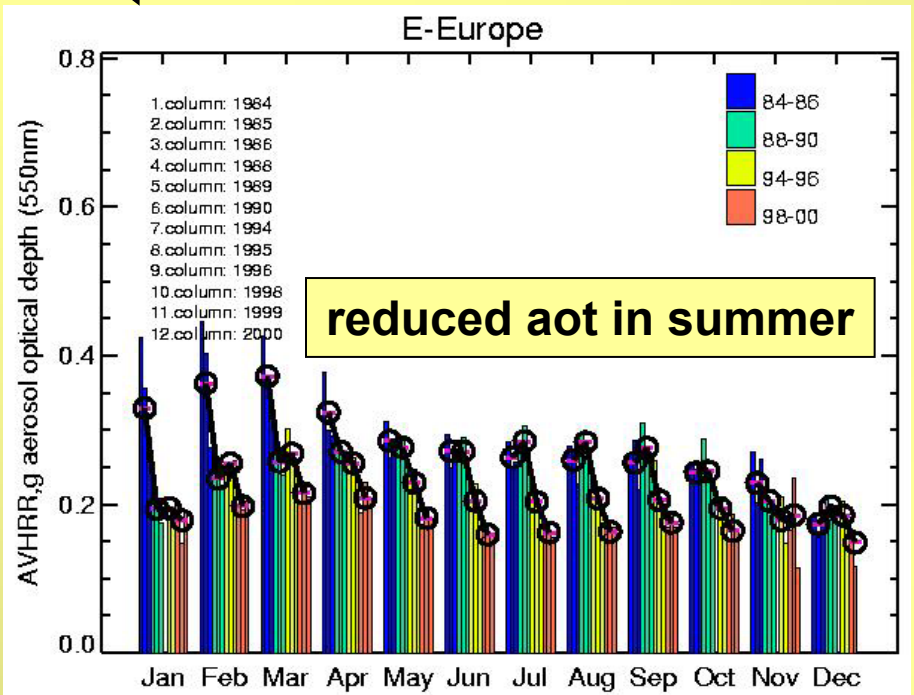


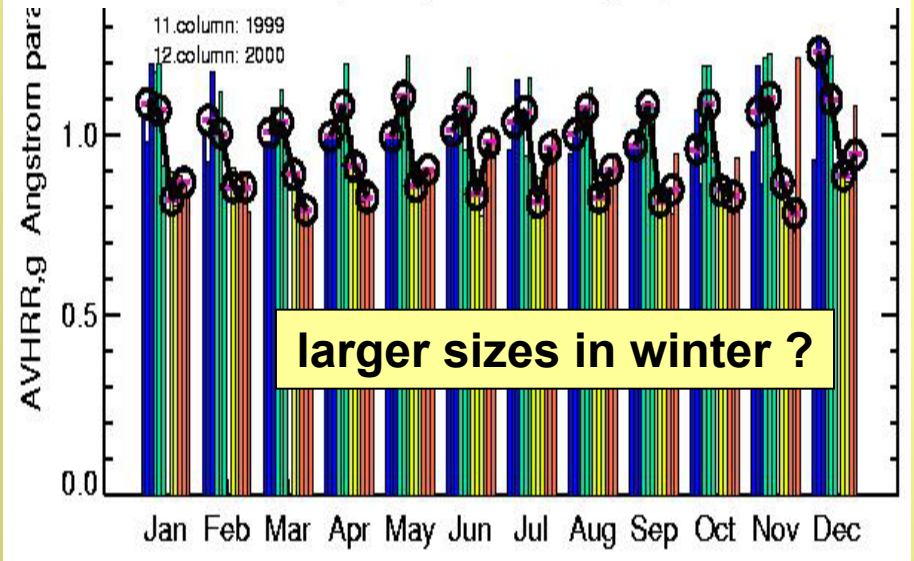
- **AVHRR: aot α**
- **TOMS: aot ssa**

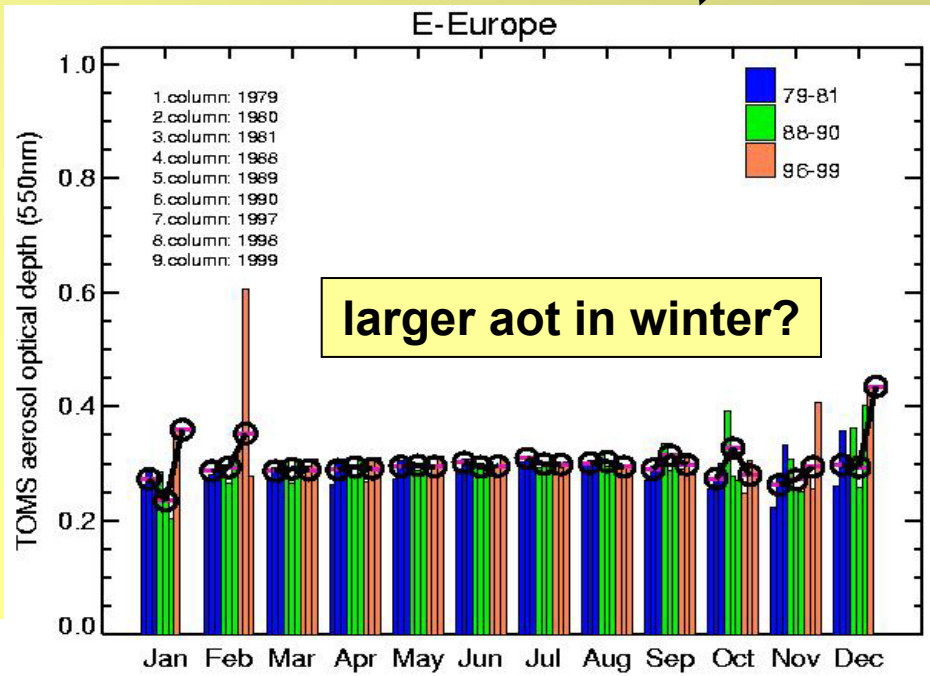
European trends ?

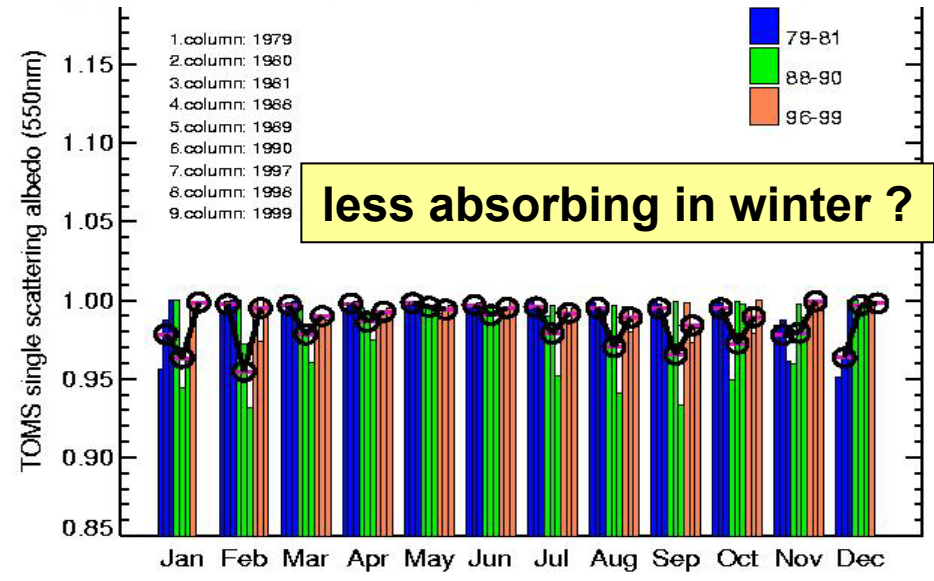
AVHRR

TOMS









aerosol, new data have arrived !

- new and improved satellite sensors
  - MODIS, MISR, POLDER, MERIS, SAGEIII, Sciamachy, …
- ground-based monitoring networks
  - AERONET, SKYNET, IMPROVE, EMEP, EARLINET,…

note: individual data-sets have individual strength

aerosol, in search of quality data

- better data reference to global modeling require synergetic approaches: *combine new information to coherent data-sets*

… thus a demonstration with AERONET data

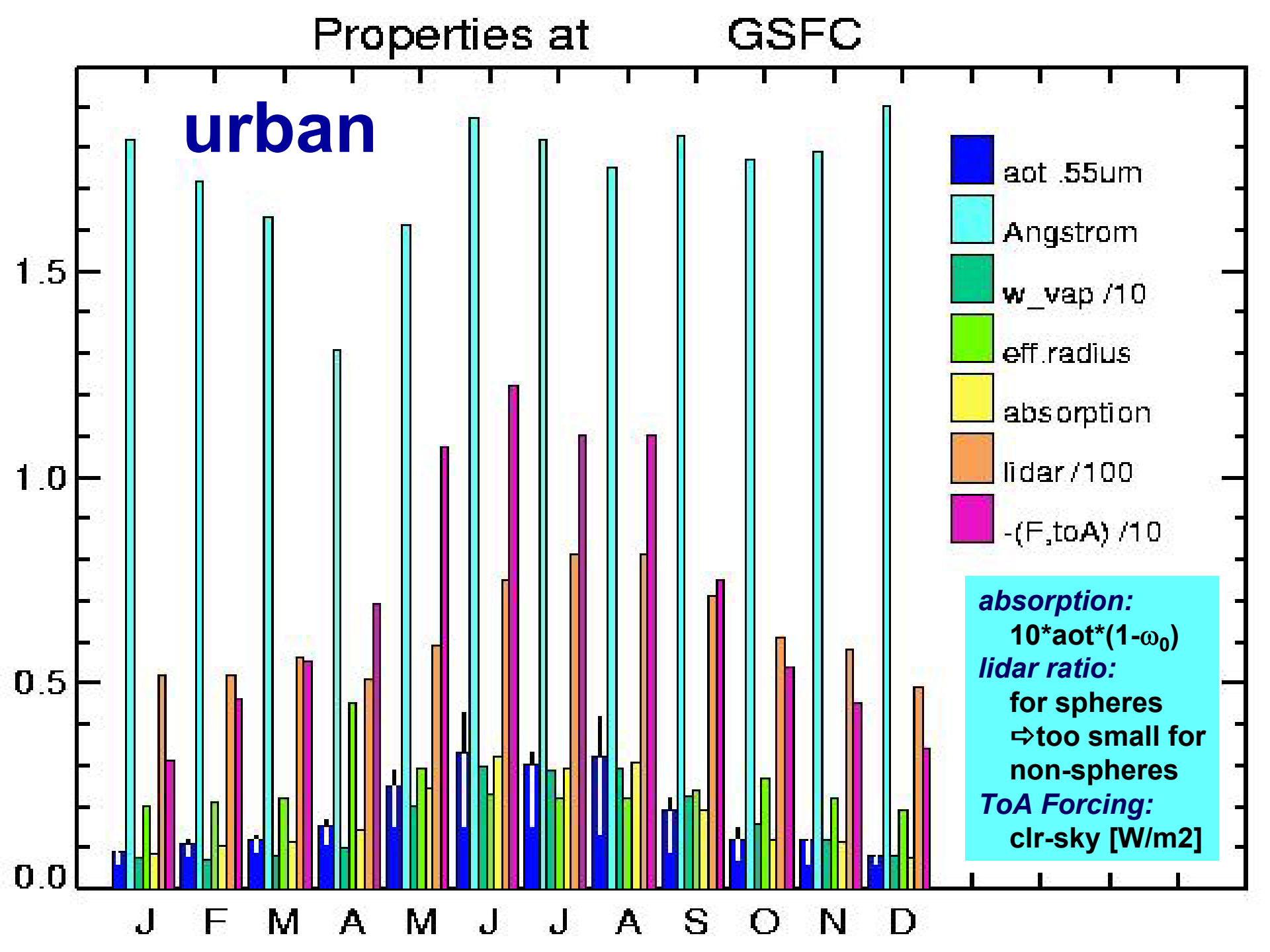
AERONET

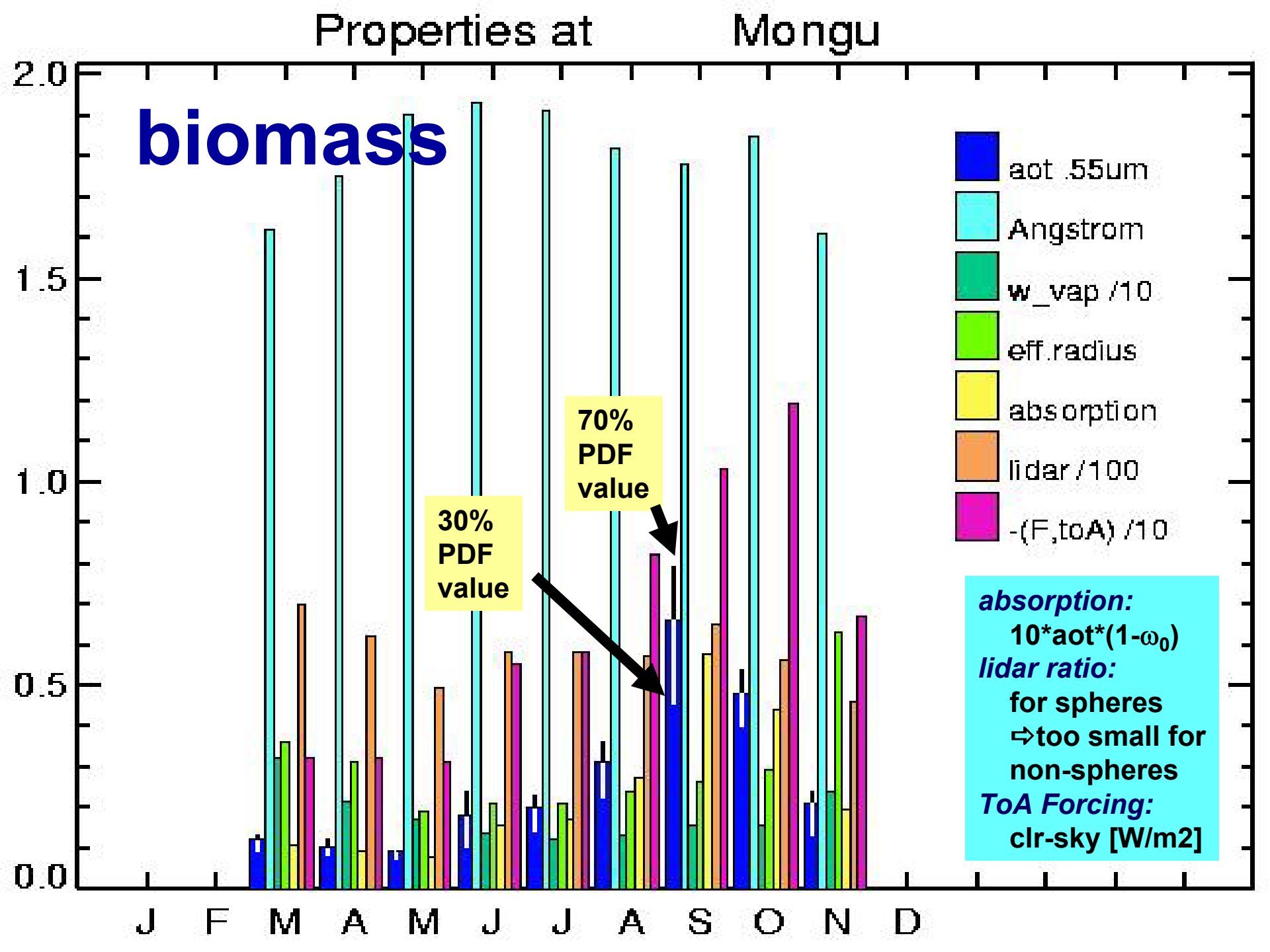
- worldwide network of robotic sun/sky-photometers (with satellite data transmission)
- supervised and maintained at NASA-Goddard
- many spectral bands
  - standard: 34, .38, .44, .50, .67, .87, .94, 1.02μm
  - polarization: 5 bands + polarization at .87μm
  - new instrument: added bands at 1.6 and 2.2μm
- sampling: 1/hr (sky-mode), 4/hr (sun-mode)
- retrieved aerosol properties
  - optical depth
  - Angstrom parameter
  - size-distribution (22 bins from .5-15μm)
  - refractive index ⇨ (ss-albedo)
  - non-sphericity

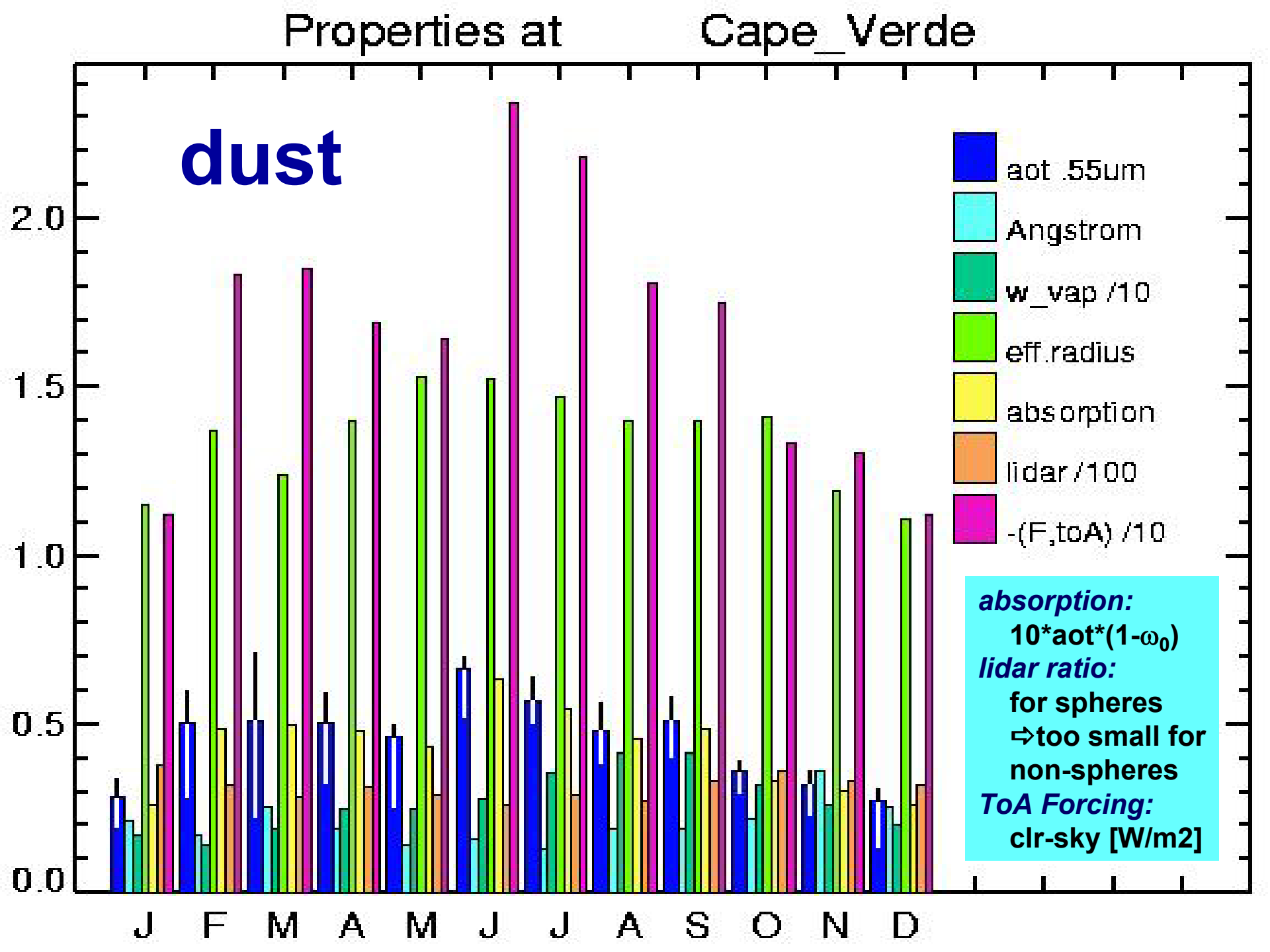
AERONET statistics

monthly average properties

- **a sampler for three sites:**
  - **GSFC (near Washington DC)** **'urban'**
  - **Mongu (Zambia)** ***(JUL-NOV)*** **'biomass'**
  - **Cape Verde (west of Sahara)** **'dust'**
  - **measured properties:** **(aot, Angstrom)**
  - **derived properties:** **(absorption, size)**
  - **value-added properties:** **(forcing, lidar ratio)**
- **locally – aerosol is completely defined !**
  - **limitation: column data, no info on 'components'**


Properties at GSFC
urban
aot .55um
Angstrom
w_vap /10
eff.radius
absorption
lidar /100
-(F,toA) /10
absorption:
10*aot*(1-ω0)
lidar ratio:
for spheres
⇨too small for
non-spheres
ToA Forcing:
clr-sky [W/m2]
0.0
0.5
1.0
1.5
J F M A M J J A S O N D


Properties at Mongu
biomass
2.0
1.5
1.0
0.5
0.0
J F M A M J J A S O N D
aot .55um
Angstrom
w_vap /10
eff.radius
absorption
lidar /100
-(F,toA) /10
30% PDF value
70% PDF value
absorption:
10*aot*(1-ω0)
lidar ratio:
for spheres
⇨too small for non-spheres
ToA Forcing:
clr-sky [W/m2]


Properties at Cape_Verde
dust
aot .55um
Angstrom
w_vap /10
eff.radius
absorption
lidar /100
-(F,toA) /10
absorption:
10*aot*(1-ω0)
lidar ratio:
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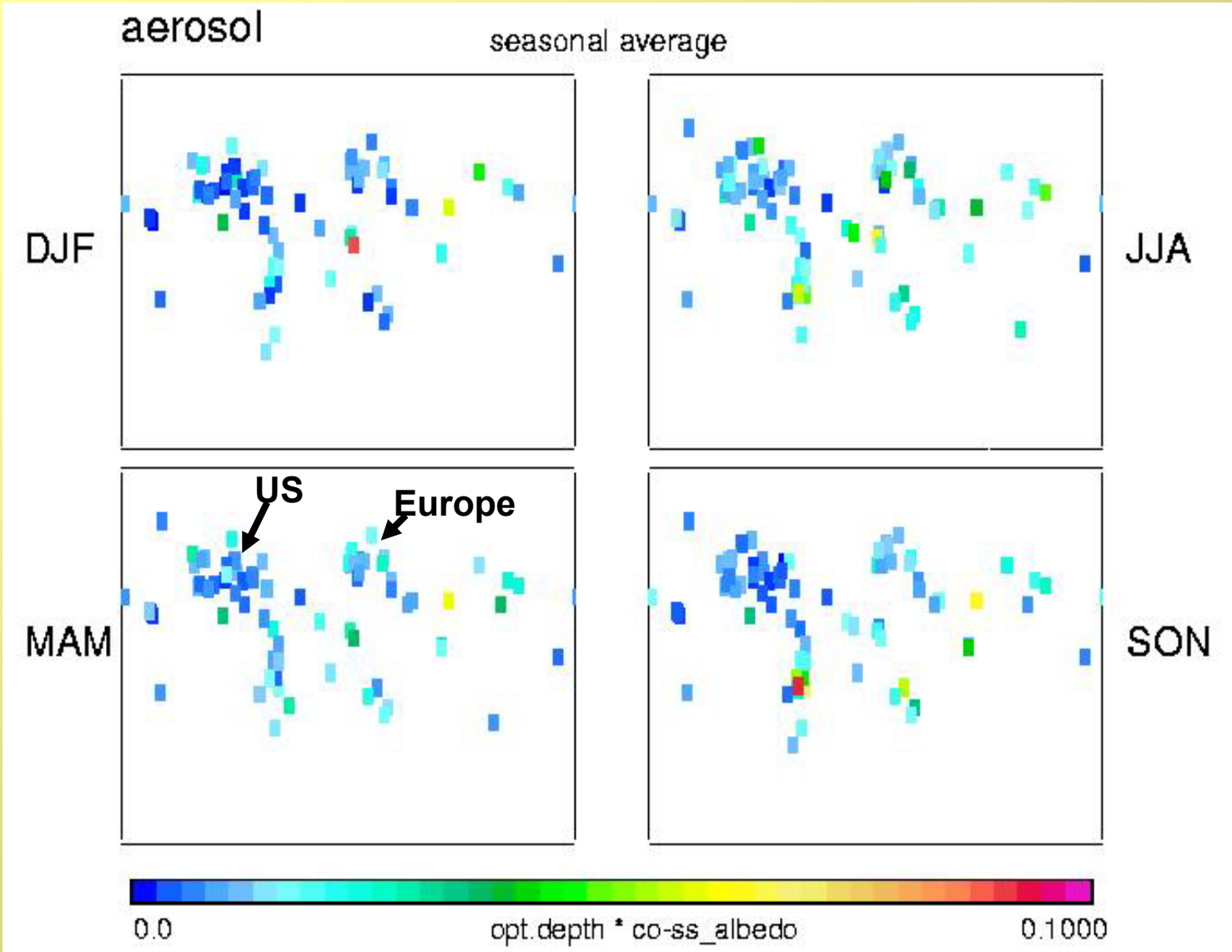
ToA Forcing:
clr-sky [W/m2]
2.0
1.5
1.0
0.5
0.0
J F M A M J J A S O N D

the consistency among data allows
combination for global assessment

this example:
seasonal avg. for aerosol absorption
[τ * (1-ω0)]

interesting…
… AERONET indicates more absorption by aerosol over Europe than over east- US



data harmonization

in search of the best possible data

best

- **in terms of accuracy**
- **in terms of detail**
- **In terms of consistency (different aerosol properties)**
- **in terms of resolution (temporal and spatial)**

- **AERONET and satellite retrievals**
  (similarly AERONET and modeling)
- **examples on**
  - **how AERONET data can 'help' (⇨)**
  - **how AERONET data can 'learn' (⇦)**

new generation of sensors

- high spatial resolution
  - as good as 1km * 1km
- more spectral detail
  - MODIS, MERIS (aerosol and cloud data!)
- multi directional
  - MISR, AATSR (land-retrievals, altitude info)
- polarization
  - POLDER (polarized signal for land retrieval)
- vertical profiling with lidar and radar
  - CALIPSO, CLOUDSAT (to be lauched next year)

AERONET ⇨ satellite data

satellite aot data *(aerosol optical thickness or depth)*

- **what is available ? what is best?**

Satellite	***Advantage***	**Disadvantage**
AVHRR	***historic record***	**calibration, not over land**
TOMS	***historic record***	**large (50km) pixel** **height or absorption assumed**
MODIS	***small pixel***	**failure over deserts**
MISR	***altitude info***	**temporally sparse**
POLDER		**short record, over land:** **less sensitive to large sizes**
SEAWIFS		**not over land, no IR channels**
GOES or MSG	***high temporal resolution***	**lack of detail with broad bands** **very limited over land**

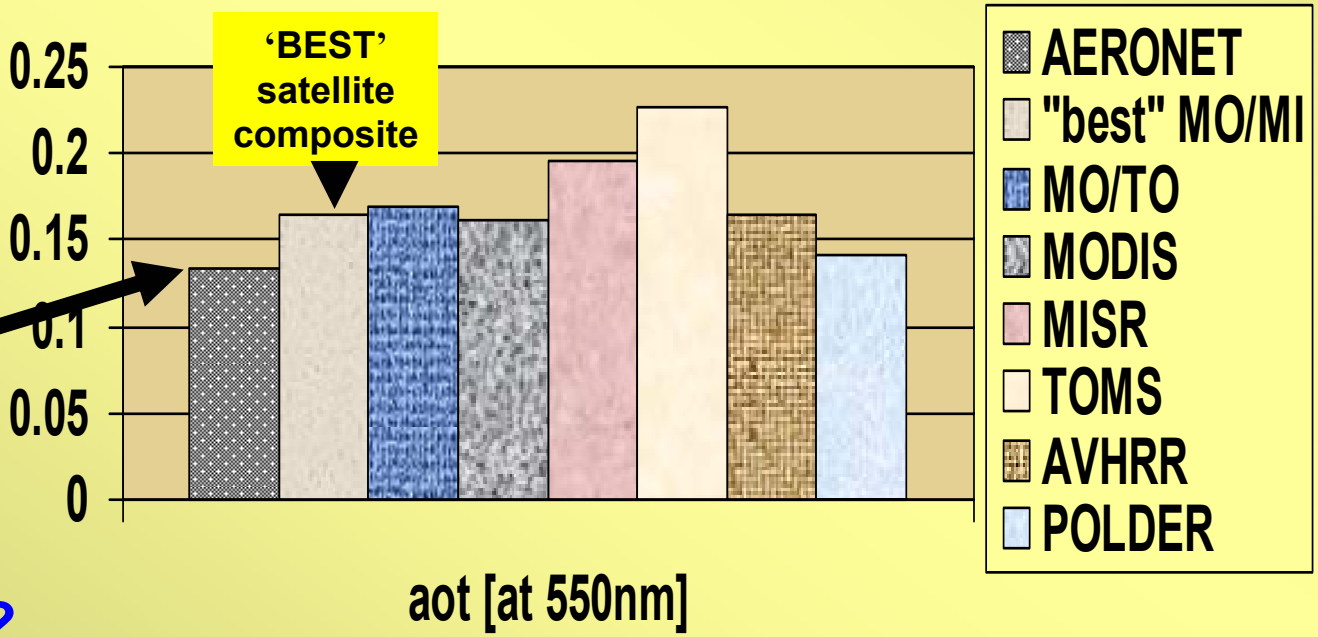
aot - global yearly averages

averaging over all available ⇨ data

normalized by model to offset sampling biases ⇨

AERONET has lower aots than satellites

a clear-sky bias?



comparisons or annual pattern

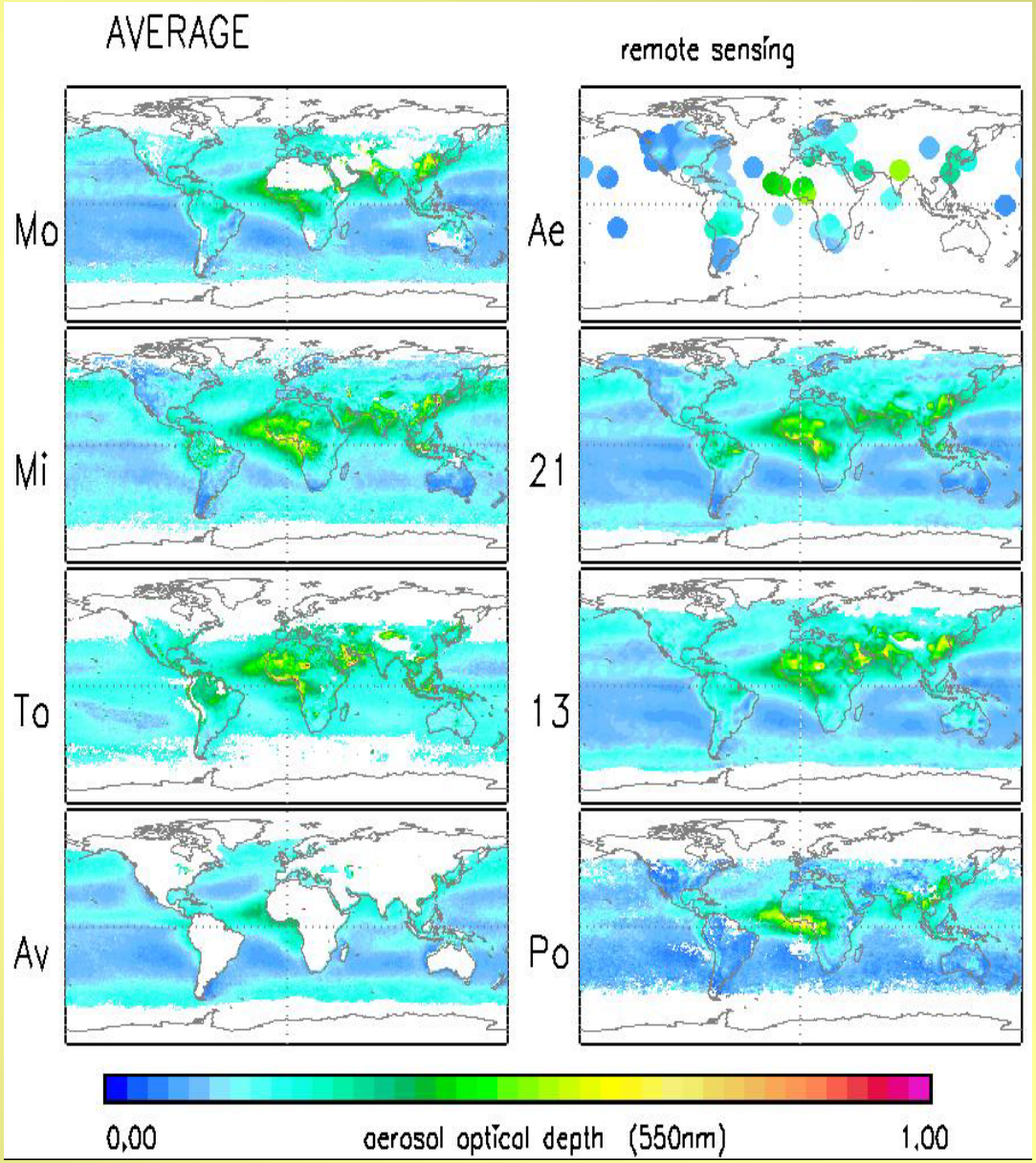
Mo: MODIS
Mi: MISR
To: TOMS
Av: AVHRR
Po: POLDER

composites:
12:Mo,Mi
13:Mo,To

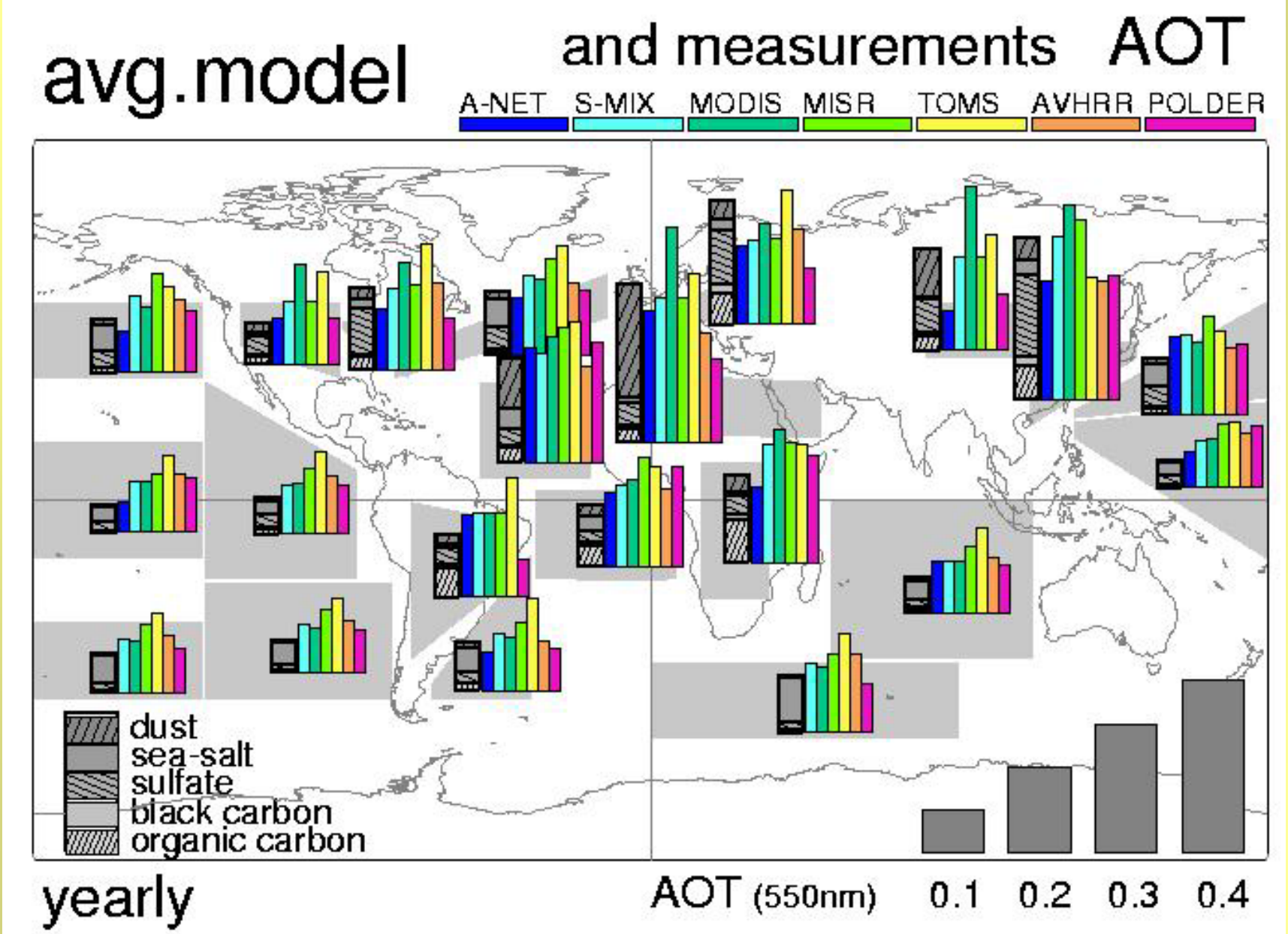
Ae:Aeronet

difficult to depict a best global retrieval
⇨composite needed

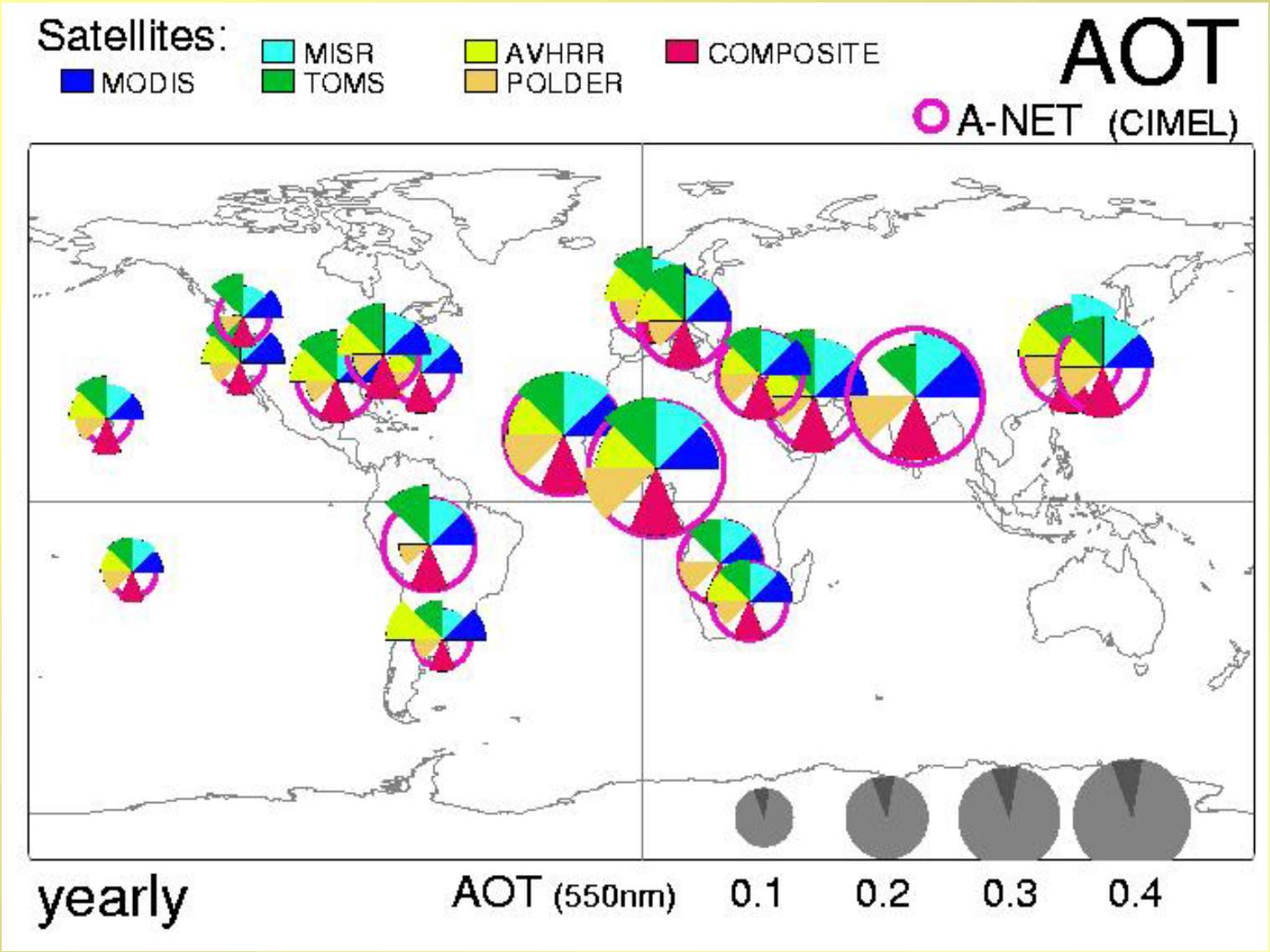
a MODIS *(ocean)* MISR *(land)* combination seems promising …
…but differences to AERONET still exist



regional avgs highlight differences



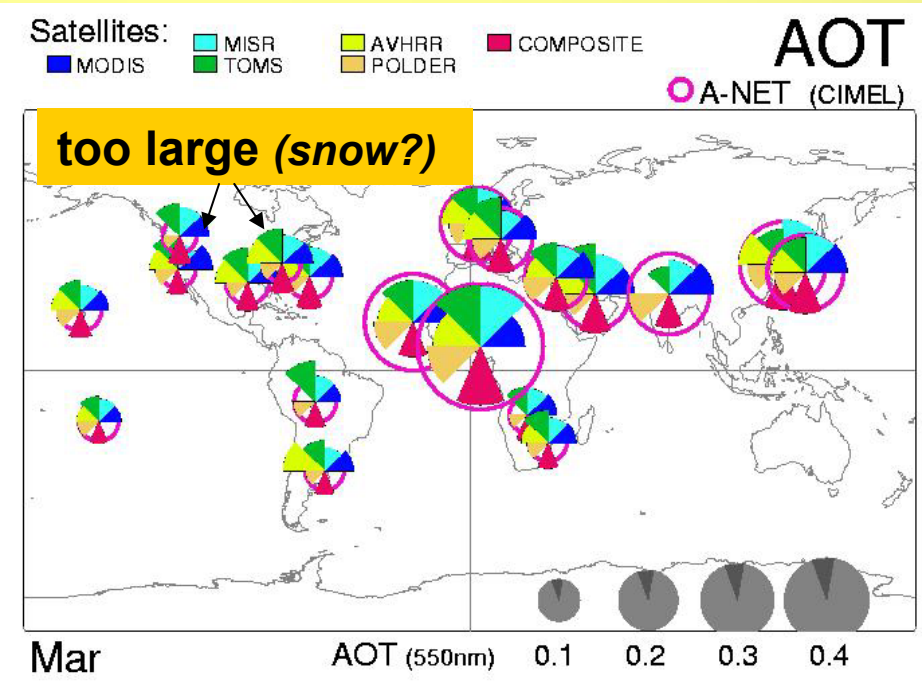
local comparisons to AERONET

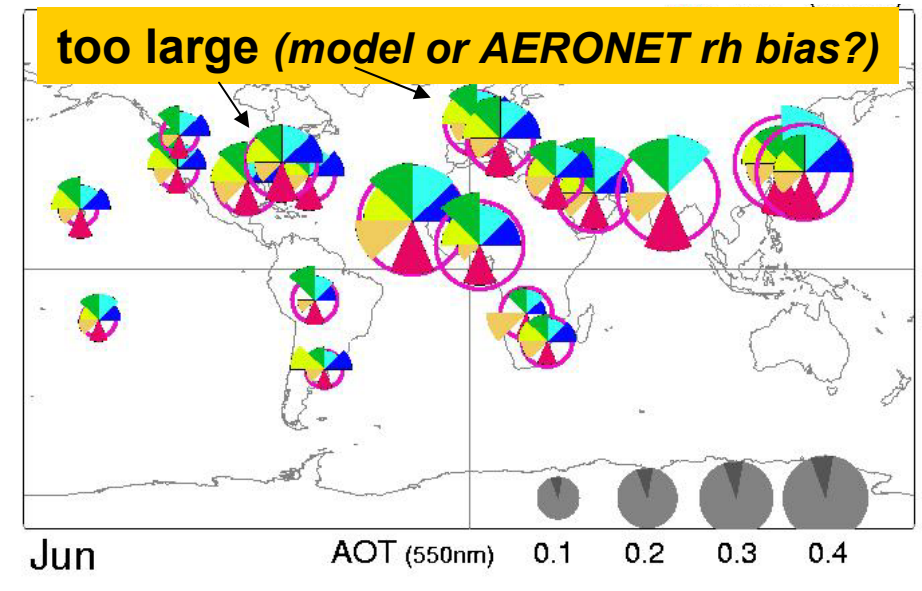


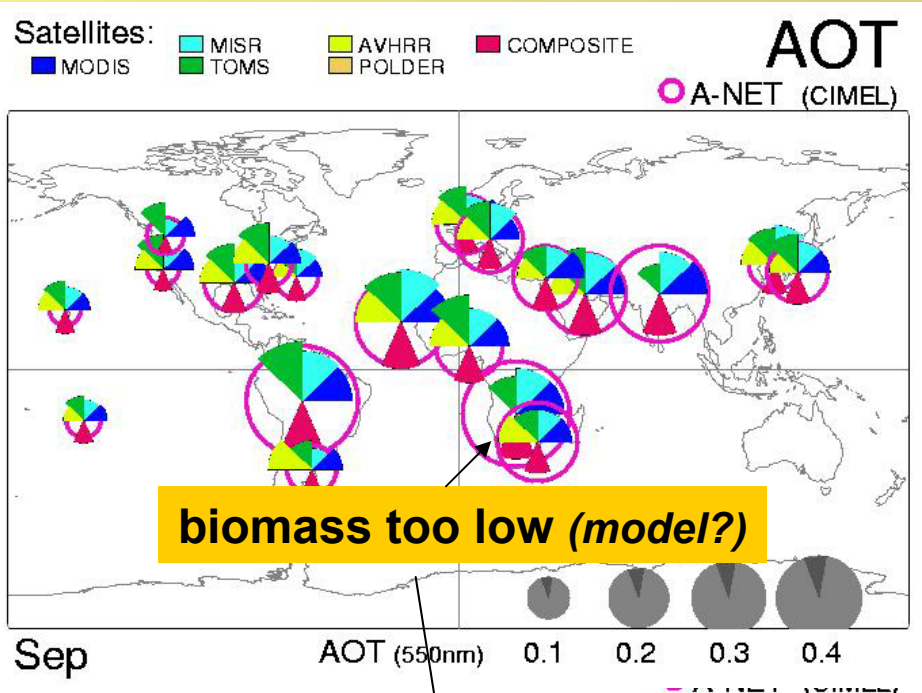
composite: MISR / MODIS

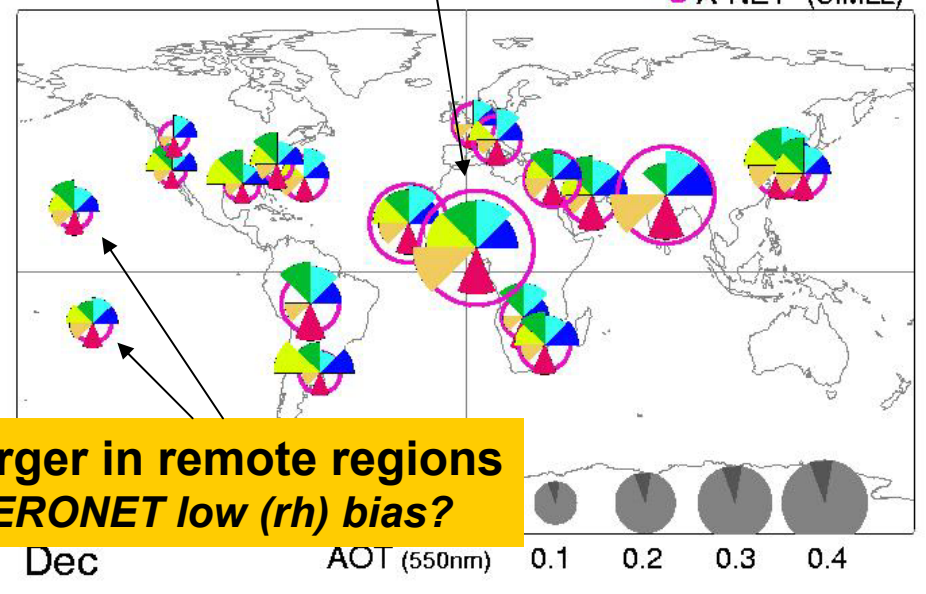
… still satellite data are generally larger than AERONET, particular in urban regions

seasonal comparisons at AERONET









first impressions

- **MODIS** best choice over the oceans … but too low in dust outflow regions *(high aot 'filtered as' clouds)*
- **MISR** most complete land cover … while biased high over oceans *(poor temporal sampling at ca 1/week)*
- **MODIS** *(ocean)* **/ MISR** *(land)* **combination** the 'best' satellite product is generally larger than AERONET … but too low during the biomass burning season

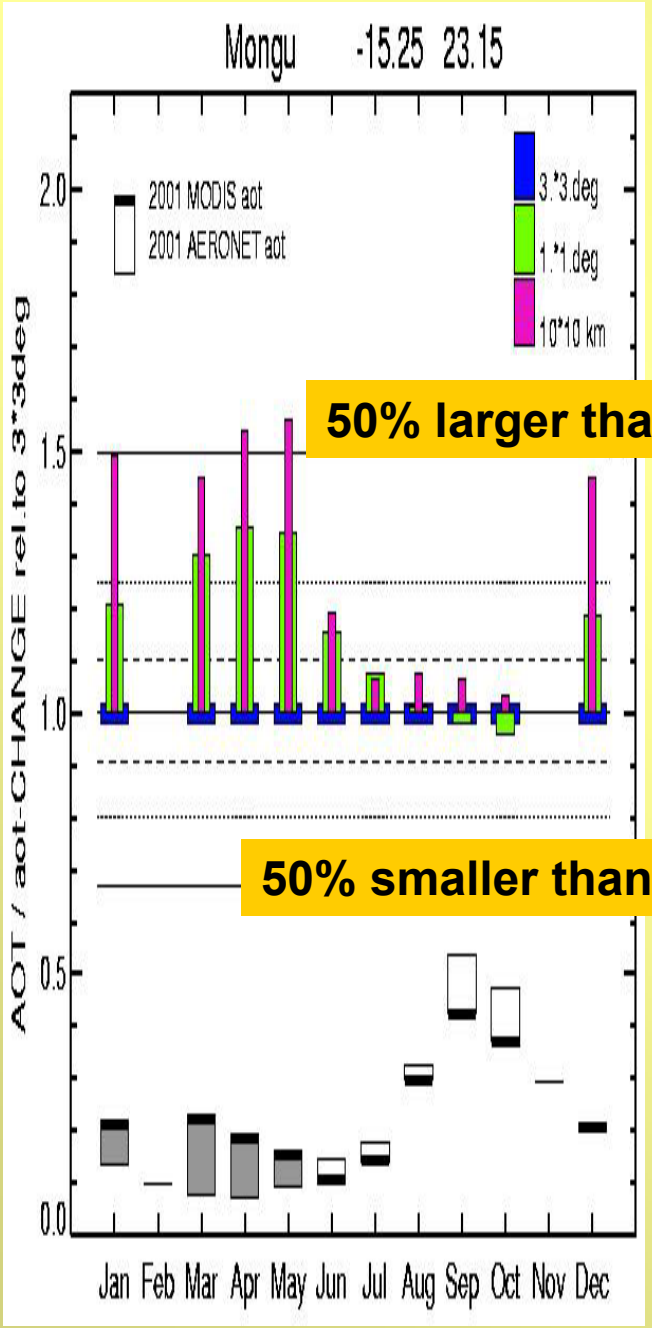
open issues:

- are AERONET aot smaller due to a clear-sky bias?
- what can be said about the quality of retrievals of low aot in remote regions (of no AERONET sites?)
- is it 'fair' to compare point data with regional data?

satellite data ⇨ AERONET

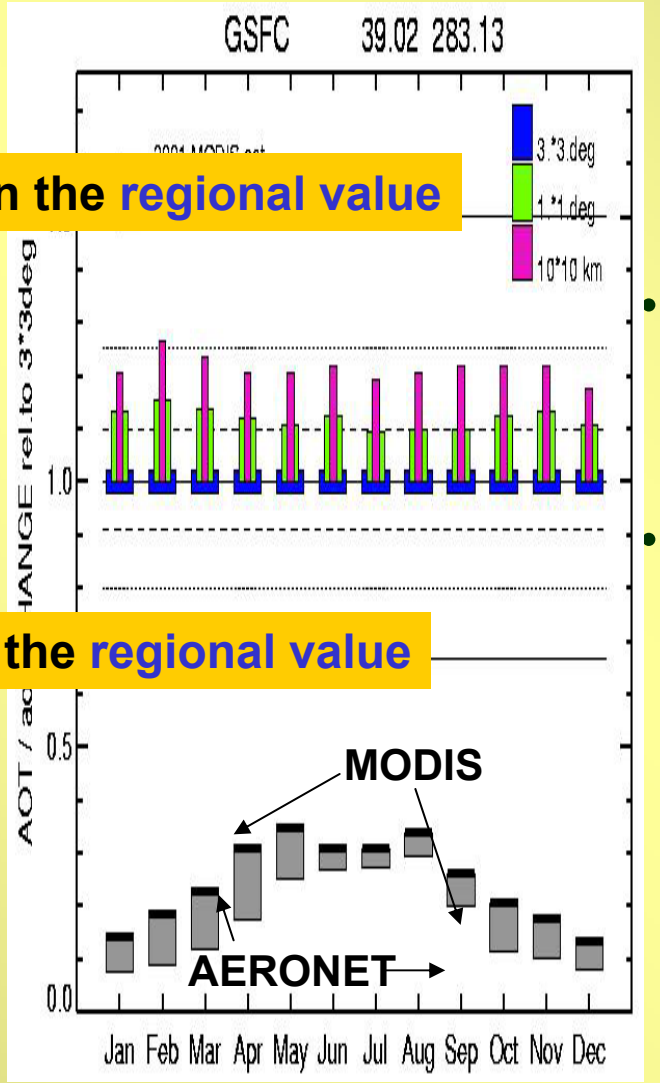
- use spatial information of satellite data
  - to relate local measurement detail to
    - coarse gridded data-sets
    - coarse resolution data in global modeling
- how ?
  - compare averages for different scales
    - agreement … indicates a ‘useful’ site
    - bias: ‘useful’ site after a bias adjustment
    - highly variable (season/years) : leave off comparison … unless secondary data exist

"scaling"



50% larger than the regional value

50% smaller than the regional value



- **Comparison of**
  - **300*300km data**
  - **100*100km data**
  - **10*10km data**
- ***GSFC (urban)***
  - **20% above the regional average**
- ***Mongu (biomass)***
  - **good match for the biomass season (Jul-Nov)**

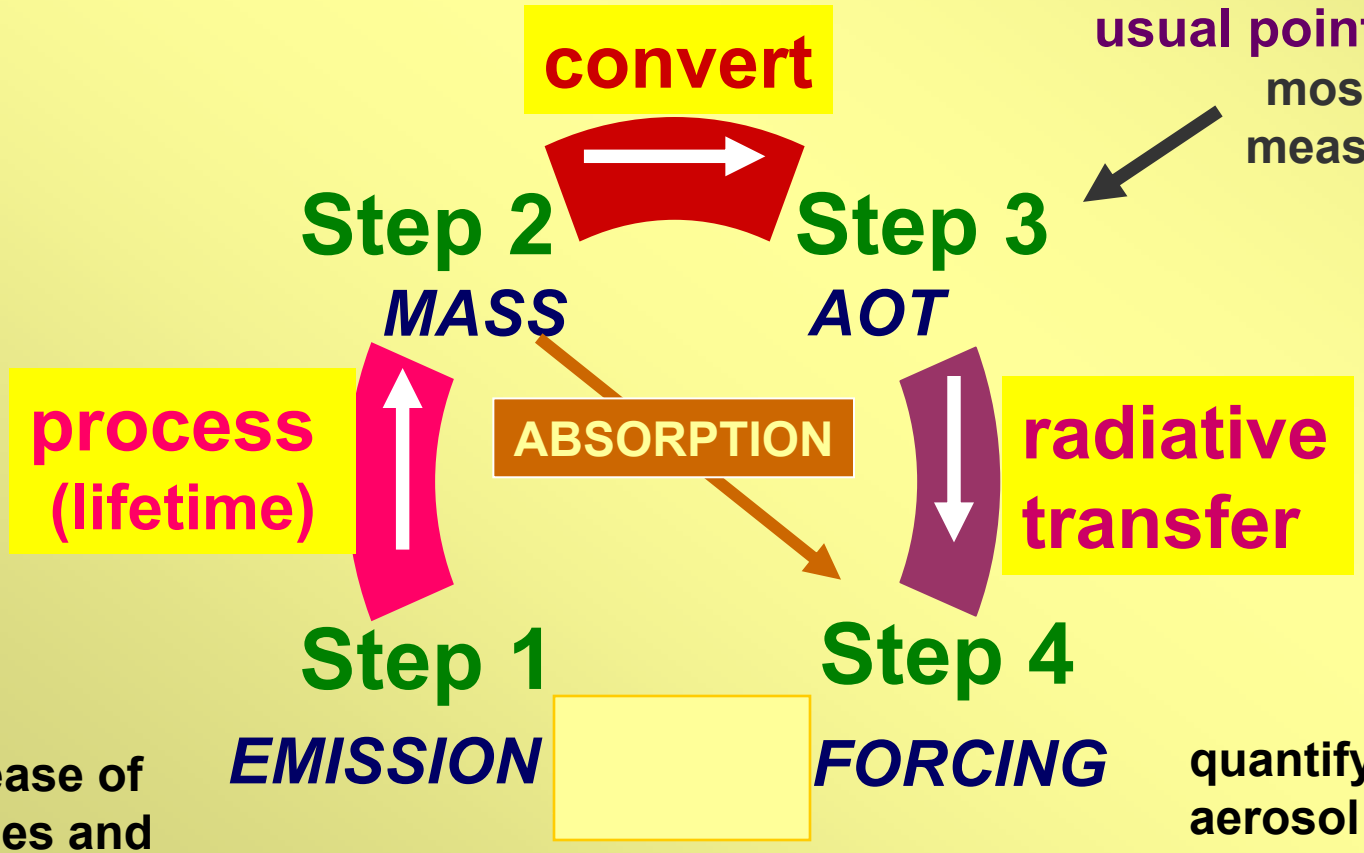
⇦ at the bottom are AERONET-MODIS comparisons (2001) ***note: MODIS statistics are very poor!***

needed scaling activities

- for different spatial domains a data-base of simultaneous satellite retrievals over AERONET sites is needed
- satellite requirements:
  - small (~1km) pixel retrievals at regional coverage
  - sufficient data (for seasonal /annual dependence)
  - coverage of all AERONET sites (incl. desert sites)

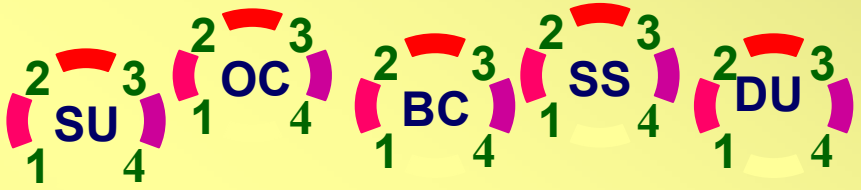
MODIS and MISR data are a start … although their smallest pixels size at 10.0 and 17.6 km is too large to represent 'truly' local characteristics

Aerosol (in global) modeling
a 4 Step process



Tuning opportunities !

- better aerosol modules in all major climate models distinguish SU, SS, DU, OC, BC
  - many processes and assumptions (⇨ new errors ?)



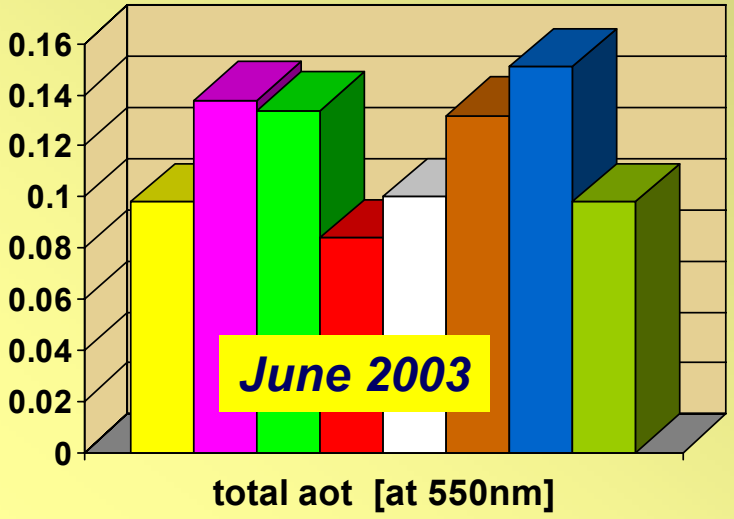
su-sulfate, ss-seasalt, du-dust, oc-org.carb, bc-soot

  - one bad error is sufficent to destroy a good effort

- there are always way to ‘adjust’ to the globally (annual) averaged aot of satellites

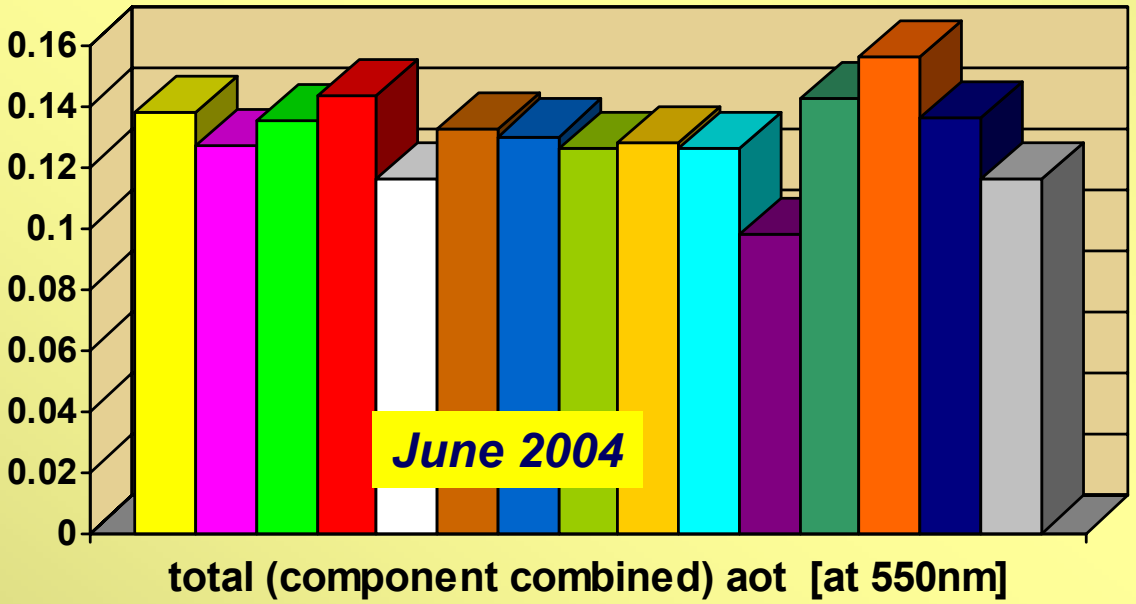
AOT

annual global average



8 models

- ECHAM
- GOCART
- MIRAGE
- GISS
- Sprintars
- Grantour
- ULAQ
- NCAR



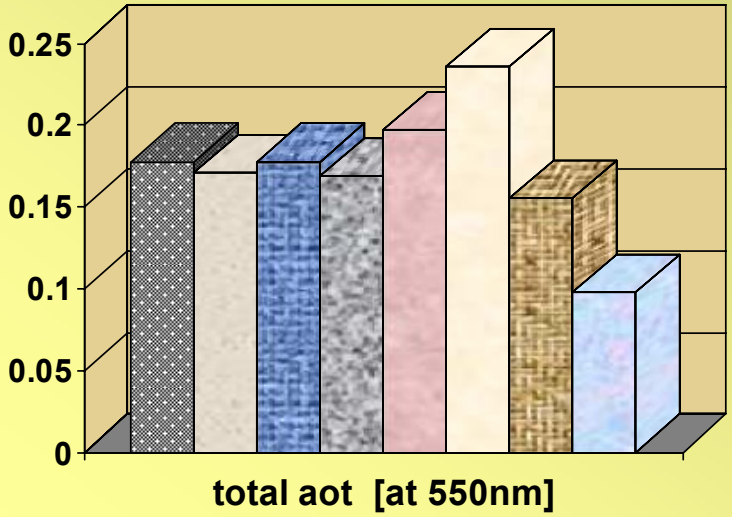
15 models

- ECHAM
- GOCART
- MIRAGE
- GISS
- Sprintars
- Grantour
- ULAQ
- NCAR
- LOA
- LSCE
- Canada
- NCAR-moz
- OSLO-ctm
- OSLO-gcm
- IMPACT

since the last year: more component models have appeared
models seem to converge towards one annual global average

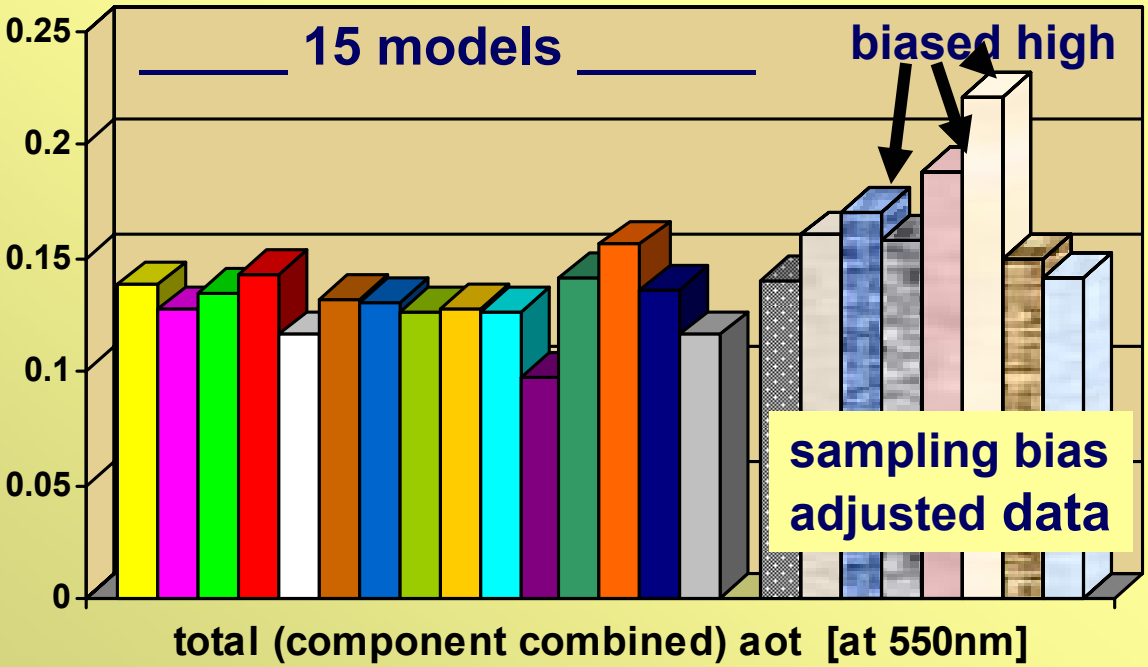
AOT

annual global average



8 data-sets

- AERONET
- "best" MO/MI
- MO/TO
- MODIS
- MISR
- TOMS
- AVHRR
- POLDER



models vs data

ECHAM	GOCART
MIRAGE	GISS
Sprintars	Grantour
ULAQ	NCAR
LOA	LSCE
Canada	NCAR-moz
OSLO-ctm	OSLO-gcm
IMPACT	
AERONET	"best" MO/MI
MO/TO	MODIS
MISR	TOMS
AVHRR	POLDER

this agreement is encouraging – are we making progress?

quantify global uncertainty

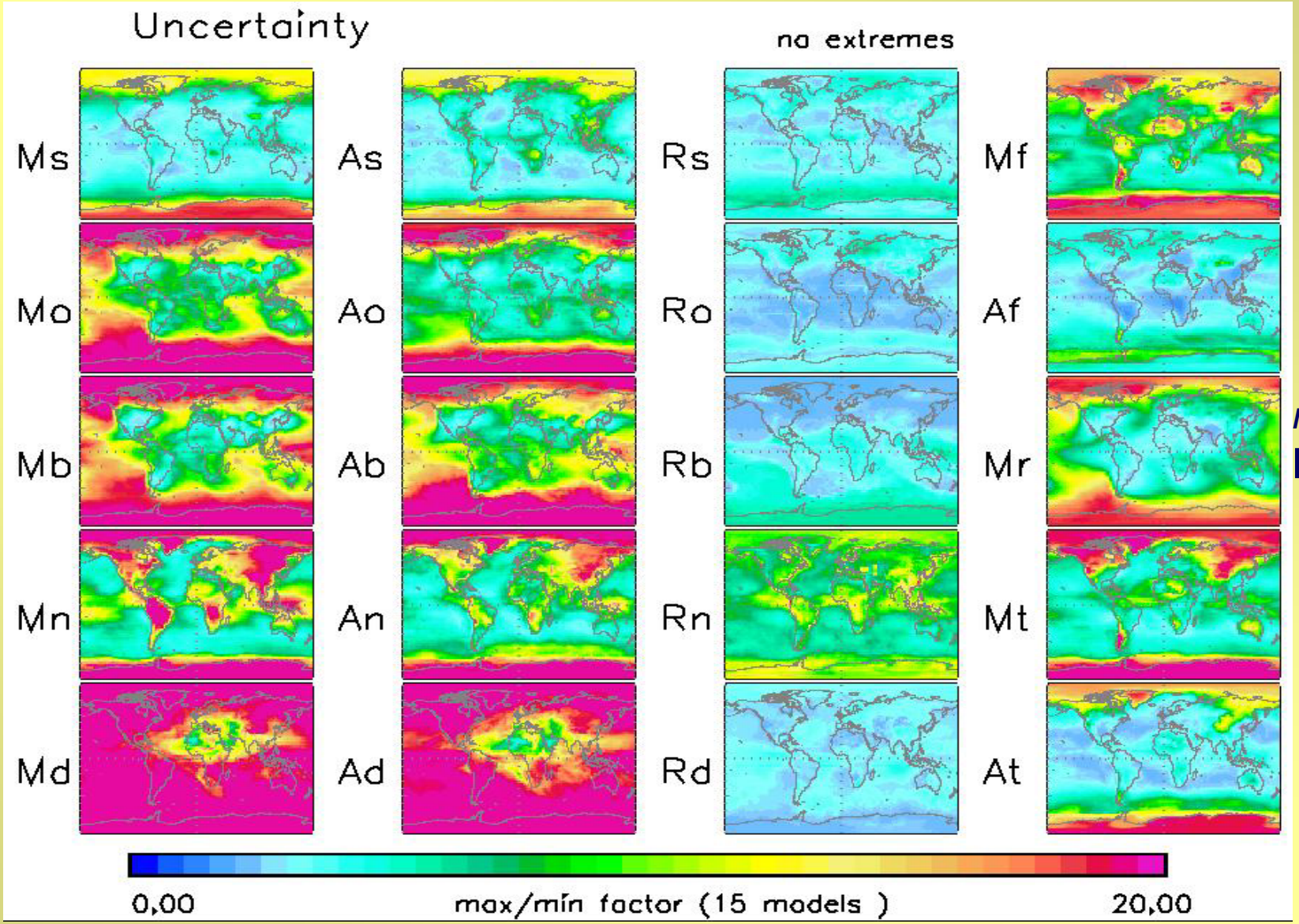
- max/min factors of 15 *(* 13 'no extremes')* models with aerosol component modules
- different min/max factors for aot and mass demonstrate MEE-differences
- these are still global annual averages!

	mass max/min	mass* max/min	aot max/min	aot * max/min
SU	2.4	1.9	3.8	2.1
BC	3.3	2.1	11	3.2
OC	3.5	1.5	4.0	2.1
DU	14	5.5	8.8	4.1
SS	6.0	2.6	7.4	3.6
TO	2.6	1.9	2.6	1.9
f_{frac}*	3.0	2.1	2.3	1.5

** f_{frac}: fine mode (sizes >1μm) fraction*

dust and sea-salt are associated with largest disagreements
good agreement for OC surprises ("if uncertain, look what others do")

dry mass optical depth mass ext. eff. ***Max/Min factors***



mass fract. >1μm aot

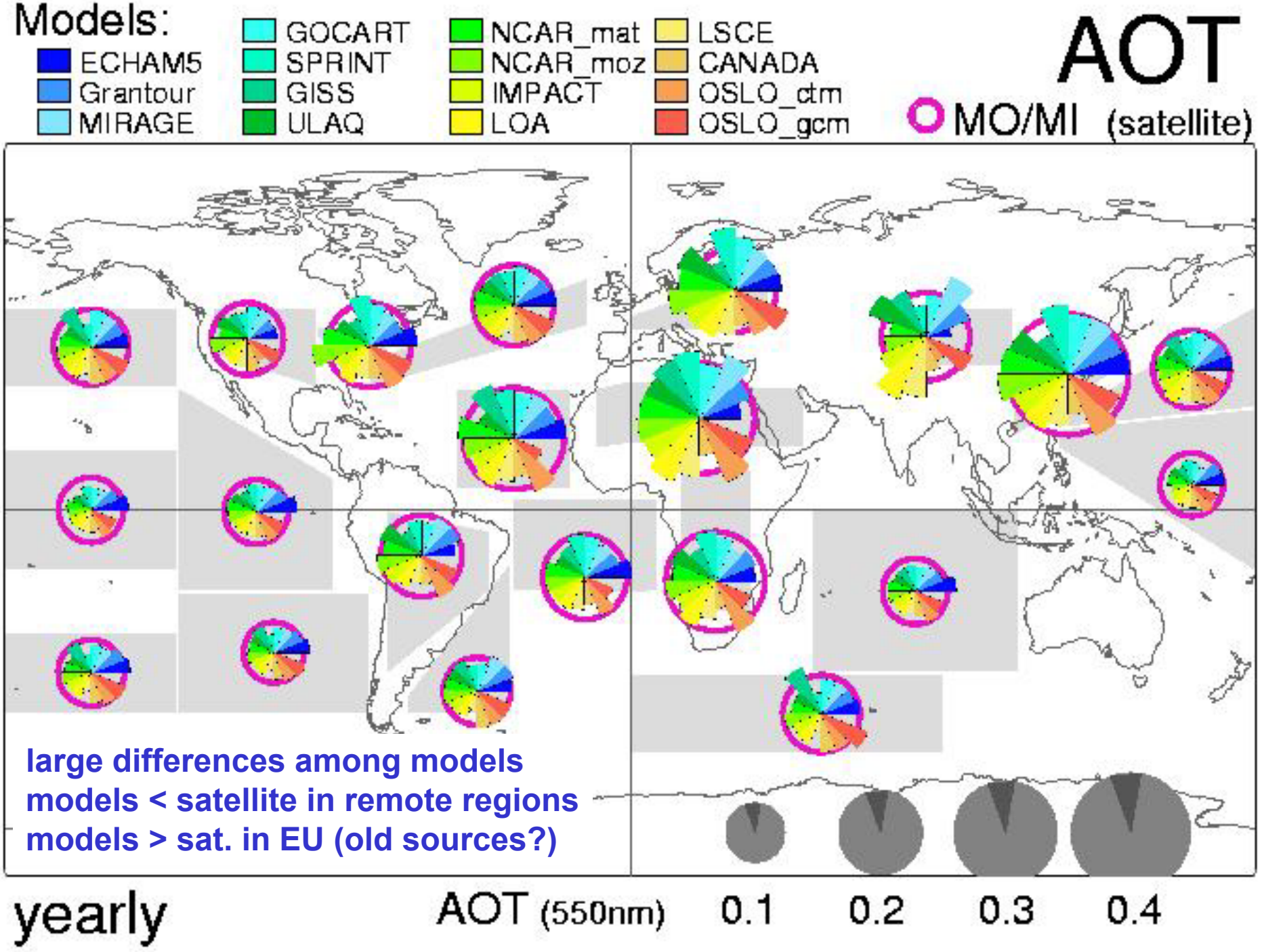
mass **BC/OC**

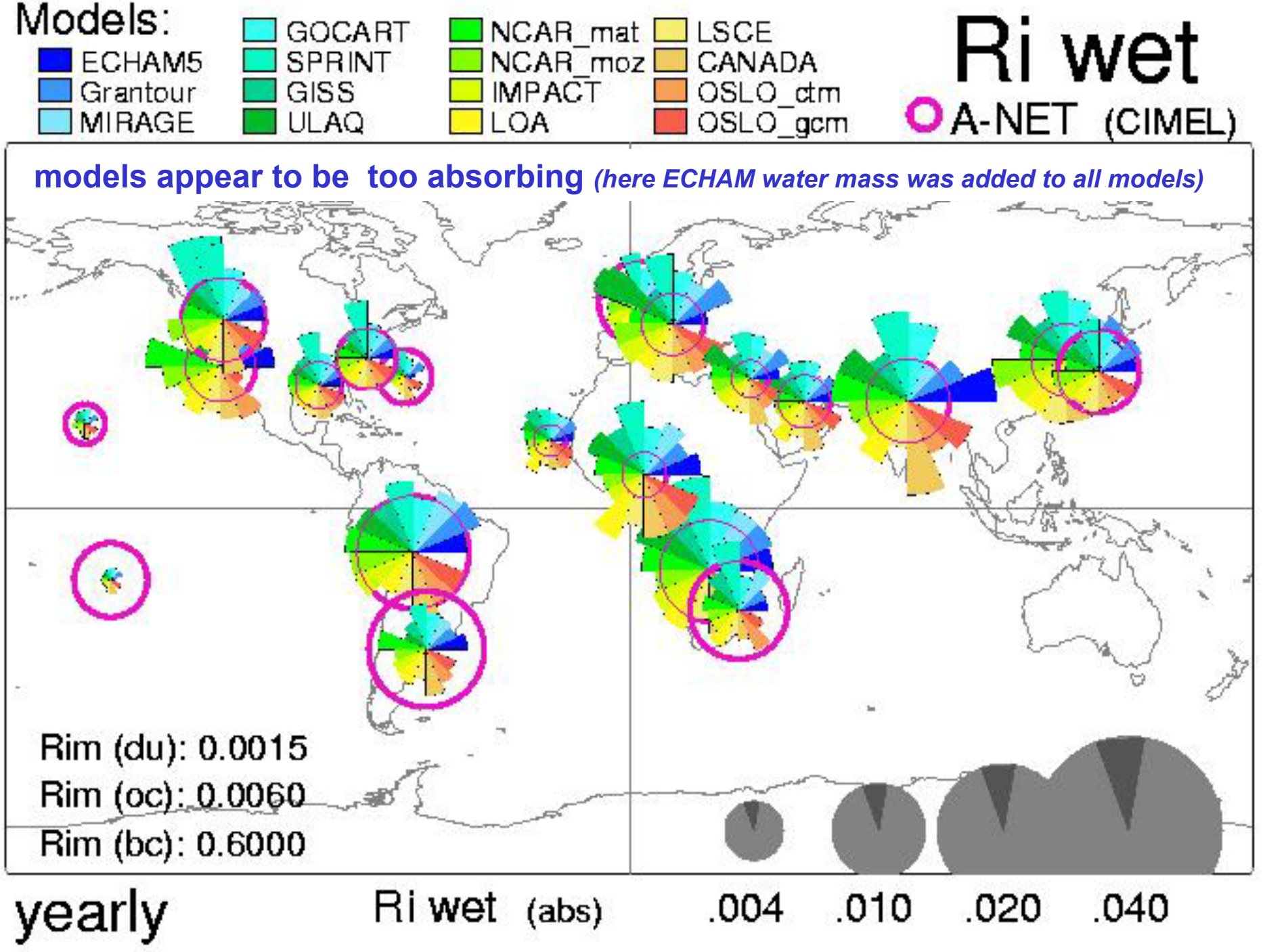
mass* total *aot

aerosol modeling uncertainty *(of 13 models, without the 2 extremes)*
illustrate the need for regional (and seasonal) assessments

let us take a break

- large differences among models discourage
  - who is going to believe any aerosol module?
- are there any data that can identify skill?
  - generally not at the required detail
  - if yes - how accurate are the data?
  - aerosol optical depth
    - compare on a regional basis to a MODIS / MISR retrieval composite *(possibly currently the most accurate data-set)*
  - aerosol absorption
    - compare mass weighted imaginary parts (a measure of absorption) to results of AERONET sky-data inversions


Models:
ECHAM5
Grantour
MIRAGE
GOCART
SPRINT
GISS
ULAQ
NCAR_mat
NCAR_moz
IMPACT
LOA
LSCE
CANADA
OSLO_ctm
OSLO_gcm
AOT
MO/MI (satellite)
large differences among models
models < satellite in remote regions
models > sat. in EU (old sources?)
yearly
AOT (550nm) 0.1 0.2 0.3 0.4


Models:
ECHAM5
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SPRINT
GISS
ULAQ
NCAR_mat
NCAR_moz
IMPACT
LOA
LSCE
CANADA
OSLO_ctm
OSLO_gcm
Ri wet
A-NET (CIMEL)
models appear to be too absorbing (here ECHAM water mass was added to all models)
Rim (du): 0.0015
Rim (oc): 0.0060
Rim (bc): 0.6000
yearly
Ri wet (abs)
.004
.010
.020
.040

we have a modeling problem !

- **why these differences ?**
  - **input *(emission data, meteorology)***
  - **aerosol processing! *(clouds, chemistry, transport*)**
  - **assumptions *(size, water uptake)* … lack of data**

- **what to do?**
  - **acquire quality data *(determine data accuracy)***
  - **diagnose models *(comparisons to data)***
  - **assure comparability *(same input)***

… in short AeroCom

AeroCom

an initiative of MPI and LSCE

- **AeroCom** *http://nansen.ipsl.jussieu.fr/Aerocom*
  - **validate against quality data!**
    - **surface concentrations (IMPROVE, EMEP, GAW)**
    - **surface remote sensing (AERONET, EARLINET)**
    - **remote sensing from space (MODIS, MISR)**
  - **15+ groups participate so far**
    - **A: 'best as you can' – simulation**
    - **B: yr 2000 simulation with prescribed emissions**
    - **C: yr 2000 simulation with pre-industrial emissions – to address anthropogenic 'forcing'**

AeroCom activities

- acquire and establish quality data ref.
- diagnose models (eliminate weak components) for a more harmonized model behavior
- test modeled cloud-aerosol interactions (processing, indirect) to observed correlations
- provide ‘more certain’ forcings for IPCC
- enhance model and data group contacts
  - regular meetings: NY-Dec04, Oslo-Jun05, …

2 way- correlations

aerosol and cloud interactions

A. pick a pair of co-located data-sets

B. rank data of the reference property

C. determine data averages of the reference property falling into the 5-30% and 70-95% PDF ranges

C. determine range associated data averages of the second property

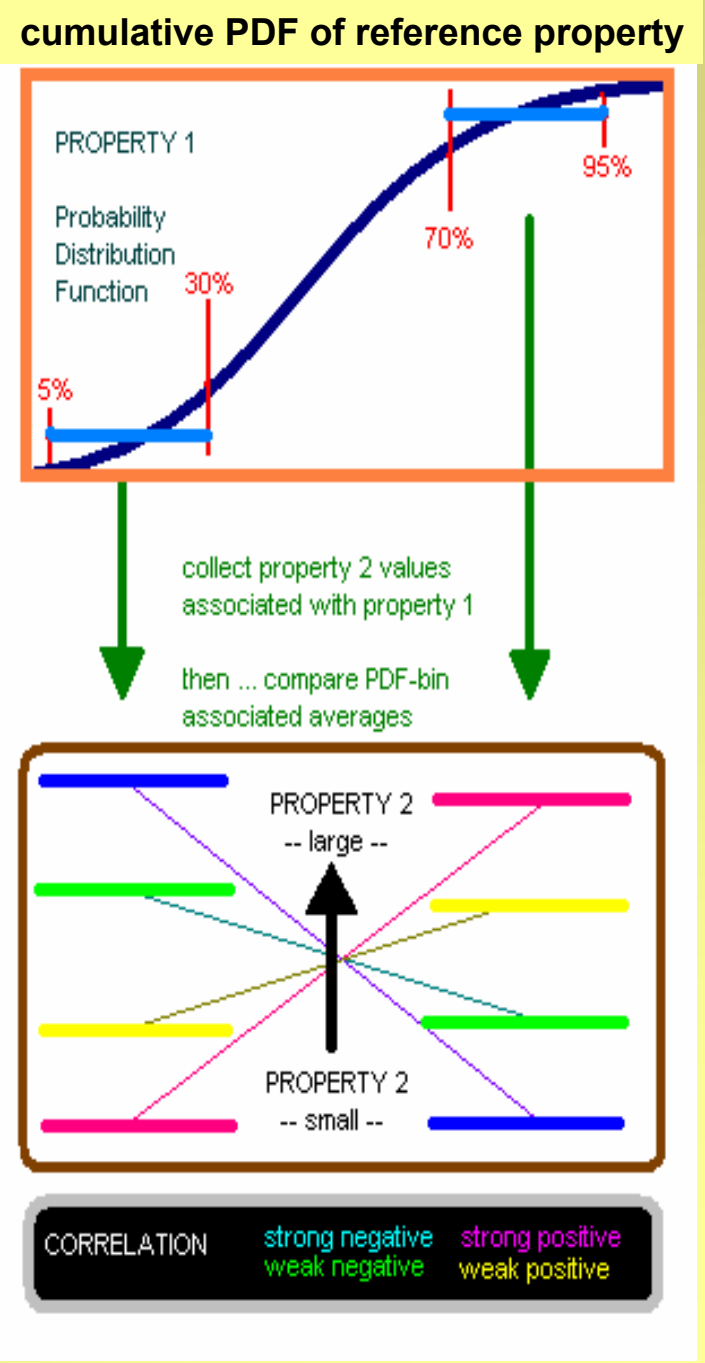
D. determine correlation:

+ slopes agree, - slopes disagree

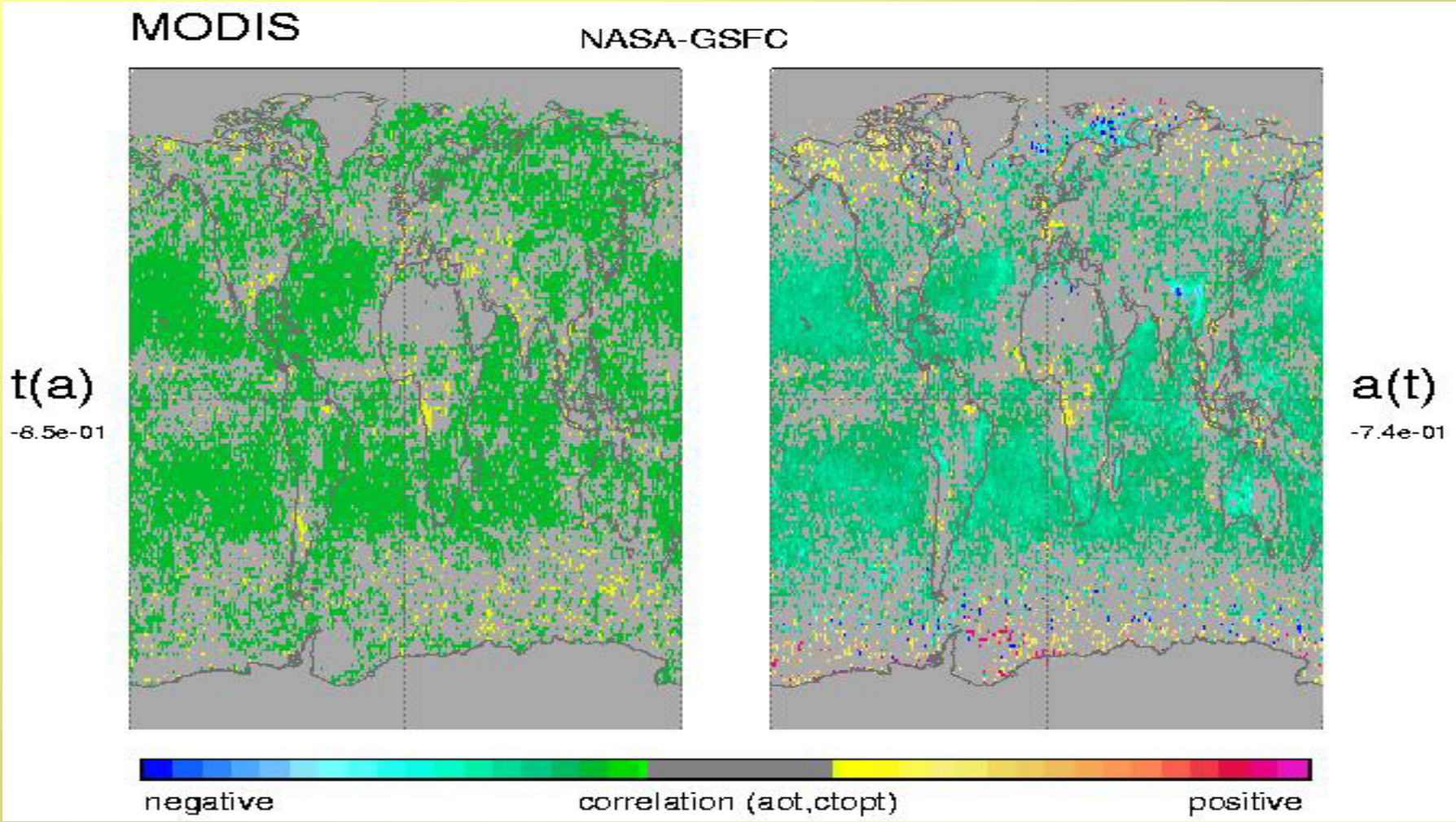
E. determine correlation strength:

use normalized slope steepness

F. repeat - by exchanging properties



aerosol - cloud

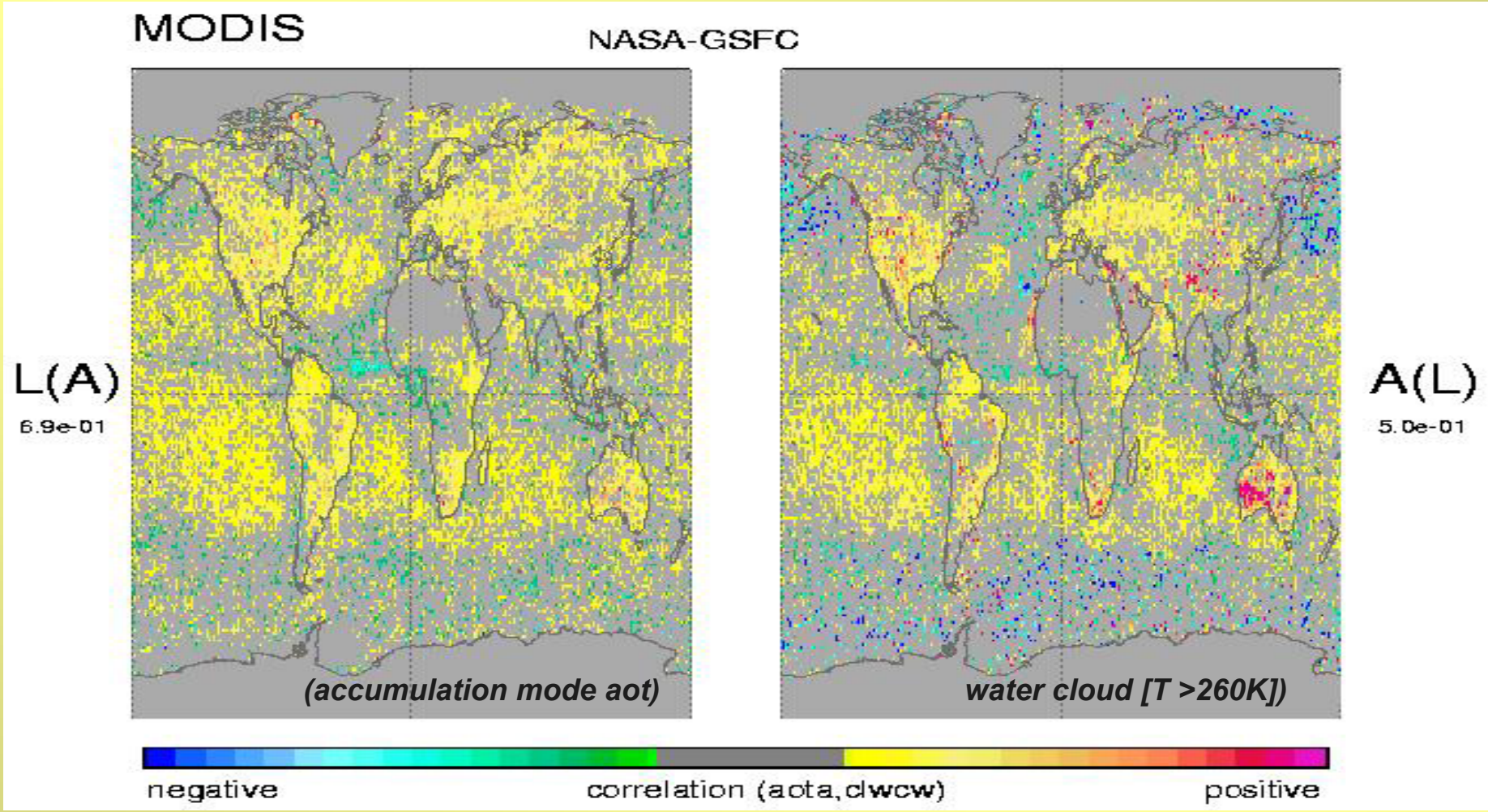


- **aerosol optical depth (A) – cloud top temp. (t)**

predominantly anti-correlated ***as higher cloud top reduce (IR) radiation losses to space … the expected solar albedo losses are to be partly compensated !***

anti-correlation is stronger with respect to changes in top temperature (right)

aerosol - cloud



- **aerosol optical depth (A) – cloud liquid water (L)**

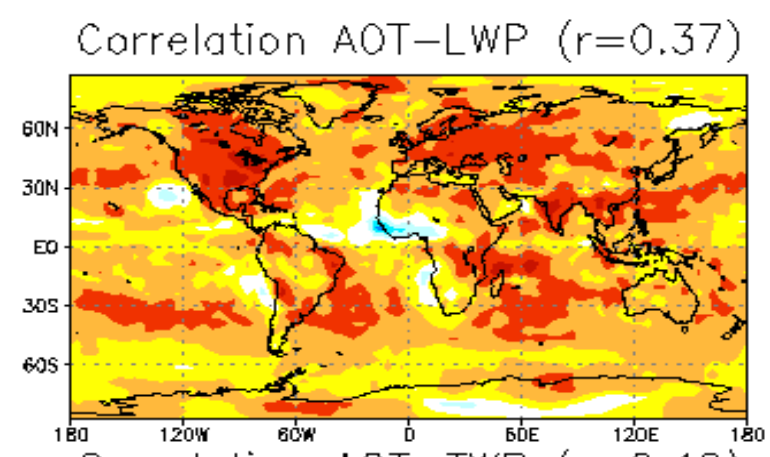
more specific choices can lead to stronger signals at the expense, explanations will remain a challenge and reasons for (anti-) and correlations are offered:

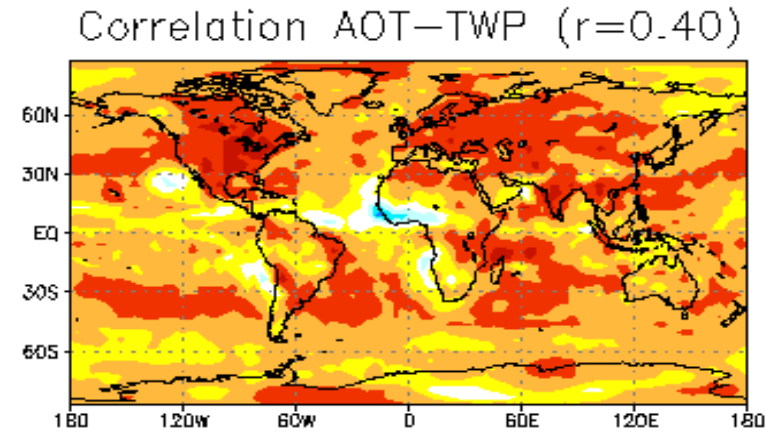
higher altitude dust signal disappears

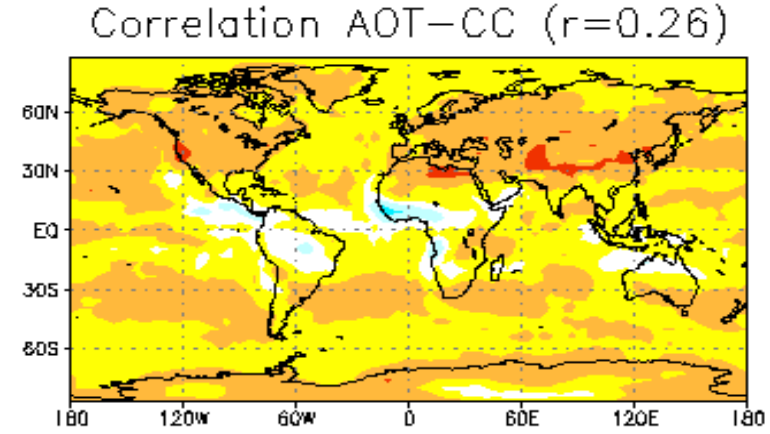
land signal increases (+ lifetime?)

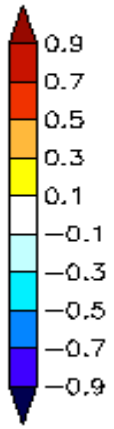
ECHAM 4 (U. Lohmann, ETH Zuerich)

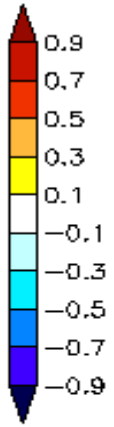
MODIS year 2000, all daily data

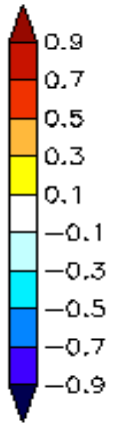


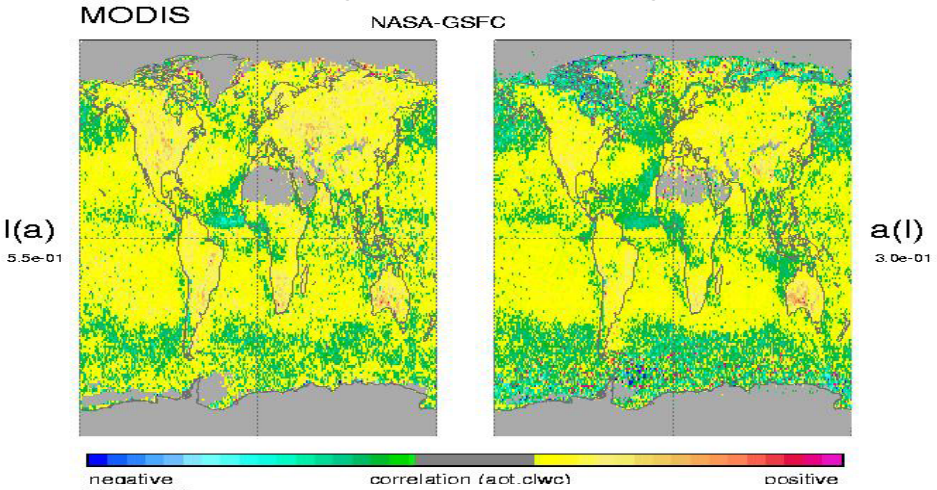


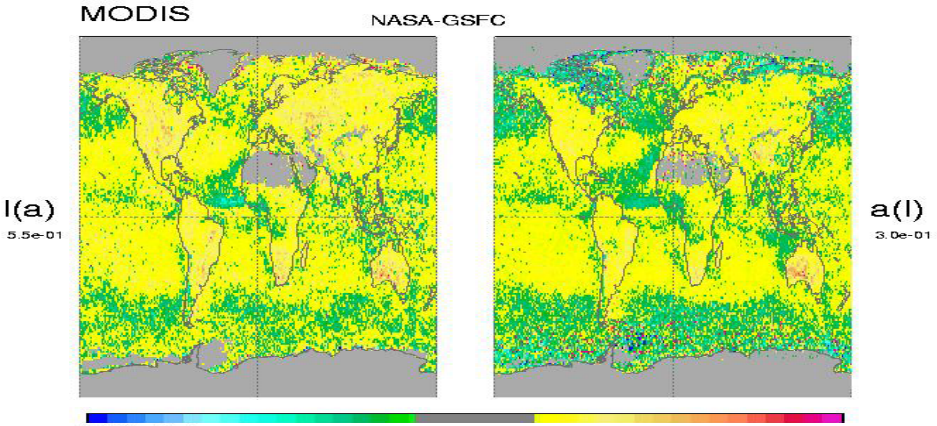


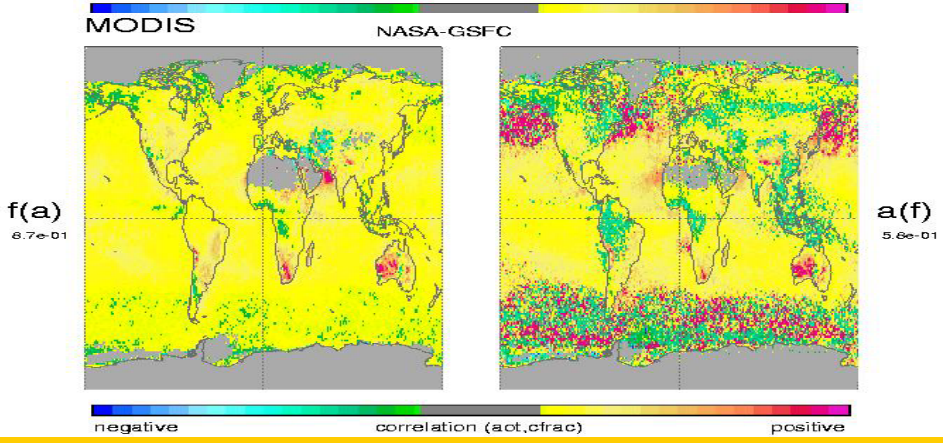












correlation patterns can be used to test aerosol-cloud interactions in models

Message

- **anthropogenic impact of aerosol on climate needs to be better quantified (reduce uncertainties)**
- **uncertainties in aerosol forcing (the end product in modeling) do not represent 'actual' uncertainties**
- **model differences at intermediate processing steps and on different scales are much larger**
- **quality data *(e.g. AERONET)* can provide at least a few constraints – data synergy helps**

…in turn data can benefit from modeling

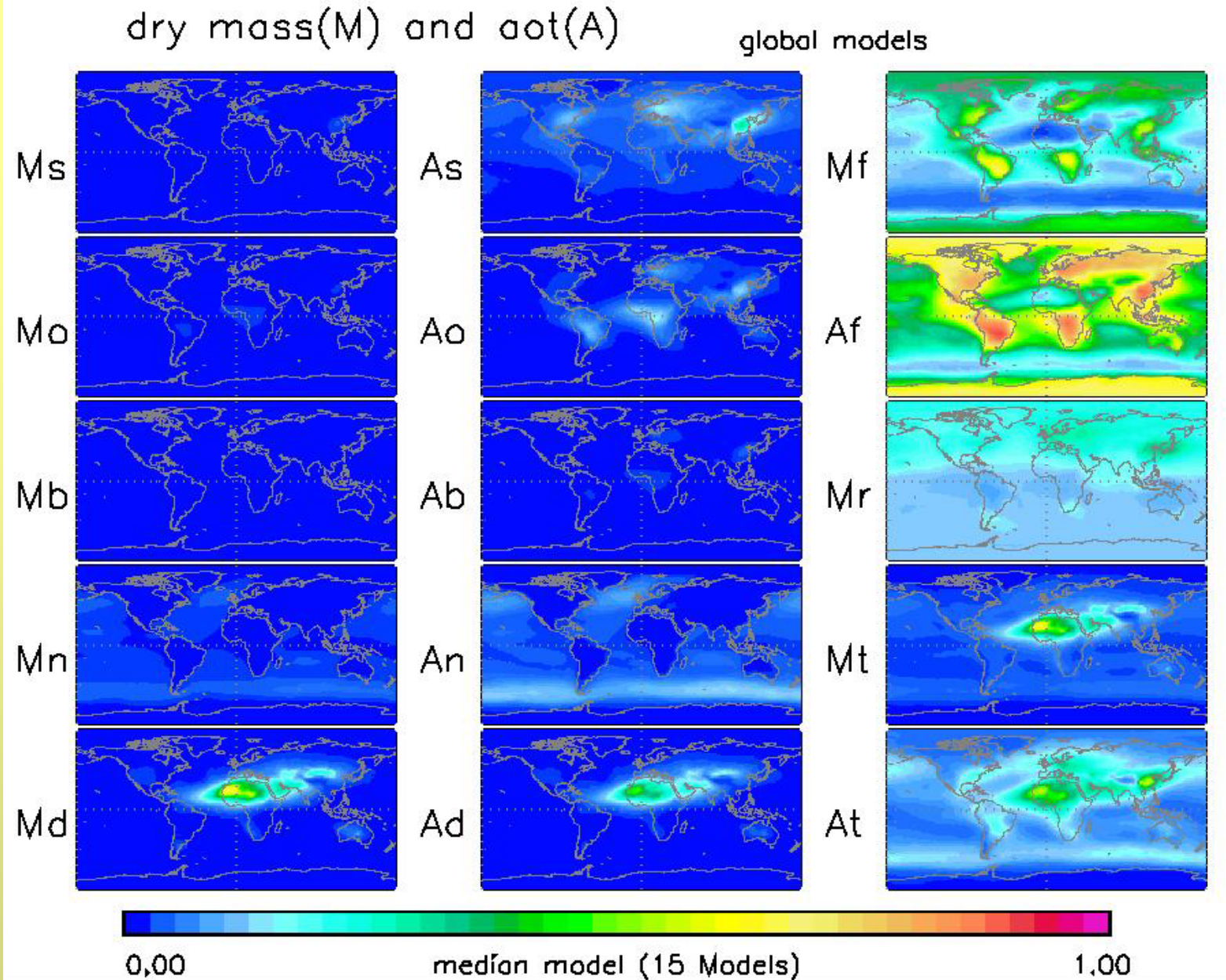
a reference? ‘median model’

modeling in return can help complete data-sets

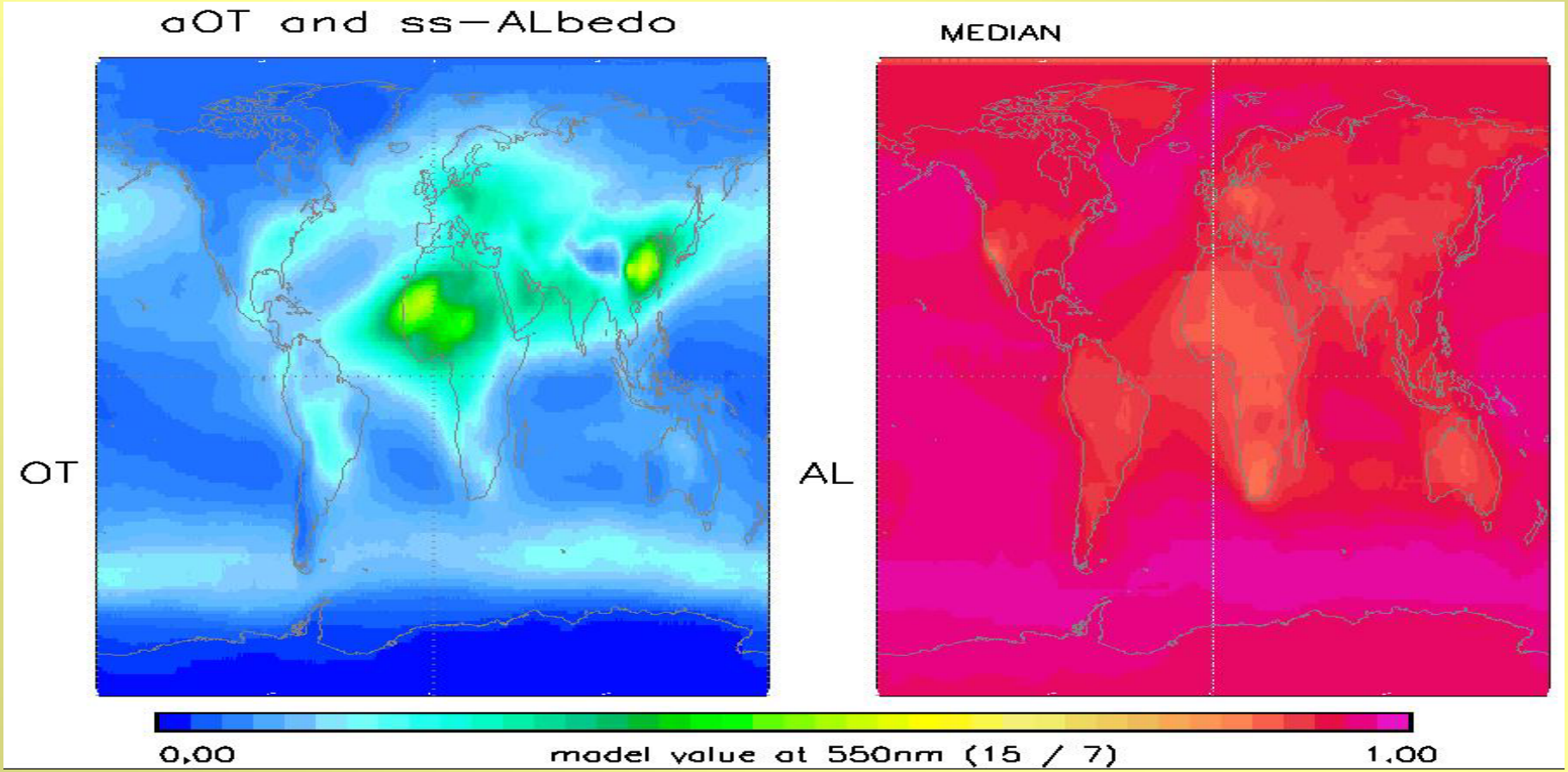
M_ mass
A_ aot

_s sulfate
_o org.carb
_b black c.
_n seasalt
_d dust

-t (s,o,b,n,d)
-f (s,o,b)
-r o/b-ratio



median *aot (aerosol optical depth) and*
median *ssa (single scattering albedo)*



essential aerosol optical properties when determining the aerosol forcing