Can AEROCOM help reduce uncertainties in direct radiative forcing of aerosols

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and AEROCOM aerosol modeling community

Special thanks to AERONET / MODIS / MISR / TOMS / AVHRR / EARLINET / IMPROVE / EMEP / GAW operators

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Laboratoire des Sciences du Climat et de l'environnement

AEROCOM
16 Contributing Global Aerosol Models:

Sprintars, *Kyushu University, Kyushu (KYU) Toshihiko Takemura et al. //* ***LMDzT-INCA***, *Lab Science Climat et de l'Enivonnement, Paris (LSCE) Michael Schulz, Yves Balkanski, Christiane Textor, Sylvia Generoso, Sarah Guibert, Didier Hauglustaine //* ***ECHAM5***, *MPI-Meterology, Hamburg (MPI) Philip Stier , Hans Feichter , Elisabeth Vignati, Julian Wilson, Michael Schulz //* ***GCM/CAM***, *ARQM Met Service Canda, Toronto (ARQM) Sunling Gong et al. //* ***MIRAGE***, *Battelle, Pacific Northwest National Laboratory, Richland (PNNL) Steve Ghan and Richard Easter //* ***CTM2***, *Univ. of Oslo, Oslo (UIO-CTM) Gunnar Myhre et al. //* ***ULAQ-CCM***, *Universita degli Studi L'Aquila (ULAQ) Giovanni Pitari, Eva Mancini and Veronica Montanaro //* ***CCM-Oslo***, *Univ.of Oslo, Oslo (UIO-GCM) Trond Yversen, Oyvind Seland,J.E.Kristjansson //* ***LMDzT***, *Lab Opt Atmos, Lille (LOA) LMDZ-GCM / Shekar Reddy and Olivier Boucher (LOA, Lille) //* ***MATCH***, *NCAR, Boulder (MATCH) David Fillmore, Phil Rasch, Bill Collins //* ***IMPACT/DAO***, *Univ Michigan, Ann Arbor (UMI) Joyce Penner et al. //* ***ECHAM-MADE***, *(DLR) Johannes Hendricks et al. //* ***GISS***, *Dorothy Koch und Susanne Bauer //* ***TM5*** *(IMAU) Maarten Krol, Frank Dentener //* ***GOCART***, *Mian Chin, Paul Ginoux* ***MOZART-GFDL-NCAR (MOZGN)*** *(NOAA-GFDL&NCAR) Larry Horowitz, Xuexi Tie, Jean-Francois Lamarque, Paul Ginoux*

GOALS

- Compare an **ensemble** of **global aerosol** models
- Eliminate weak components
- Reduce uncertainty in simulated radiative forcing

STRATEGY

- Multi-model evaluation with **observations**
  - From the surface (e.g., AERONET, IMPROVE, EMEP, GAW)
  - Vertical profiles (EARLINET)
  - From satellites (MODIS, AVHHR, TOMS, POLDER, MISR,…)
- Analyze and improve critical **parameters** and **processes**

BASIS

- Experiment A – models as they are
- Experiment B – with AEROCOM source y 2000
- Experiment PRE – with AEROCOM source 1750
- Experiments INDIRECT coordination J. Penner

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

Which strategy to reduce uncertainty in aerosol radiative forcing?

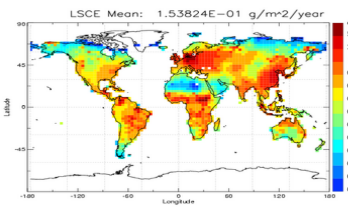
Can an intercomparison help?

- Models are complex expert choices with history
- Model parts are (unfortunately) not as modular as promised
- Too many sensitivity studies to be done

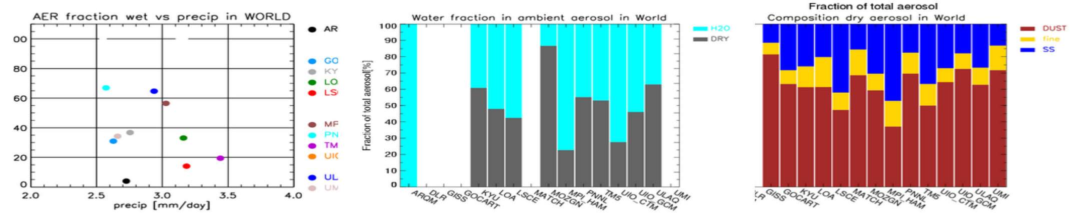
- Documentation of differences may lead to
  - Removal of errors in individual models
  - Understanding of differences
  - Specific sensitivity studies
  - Uncertainty range – if models behave reasonably well

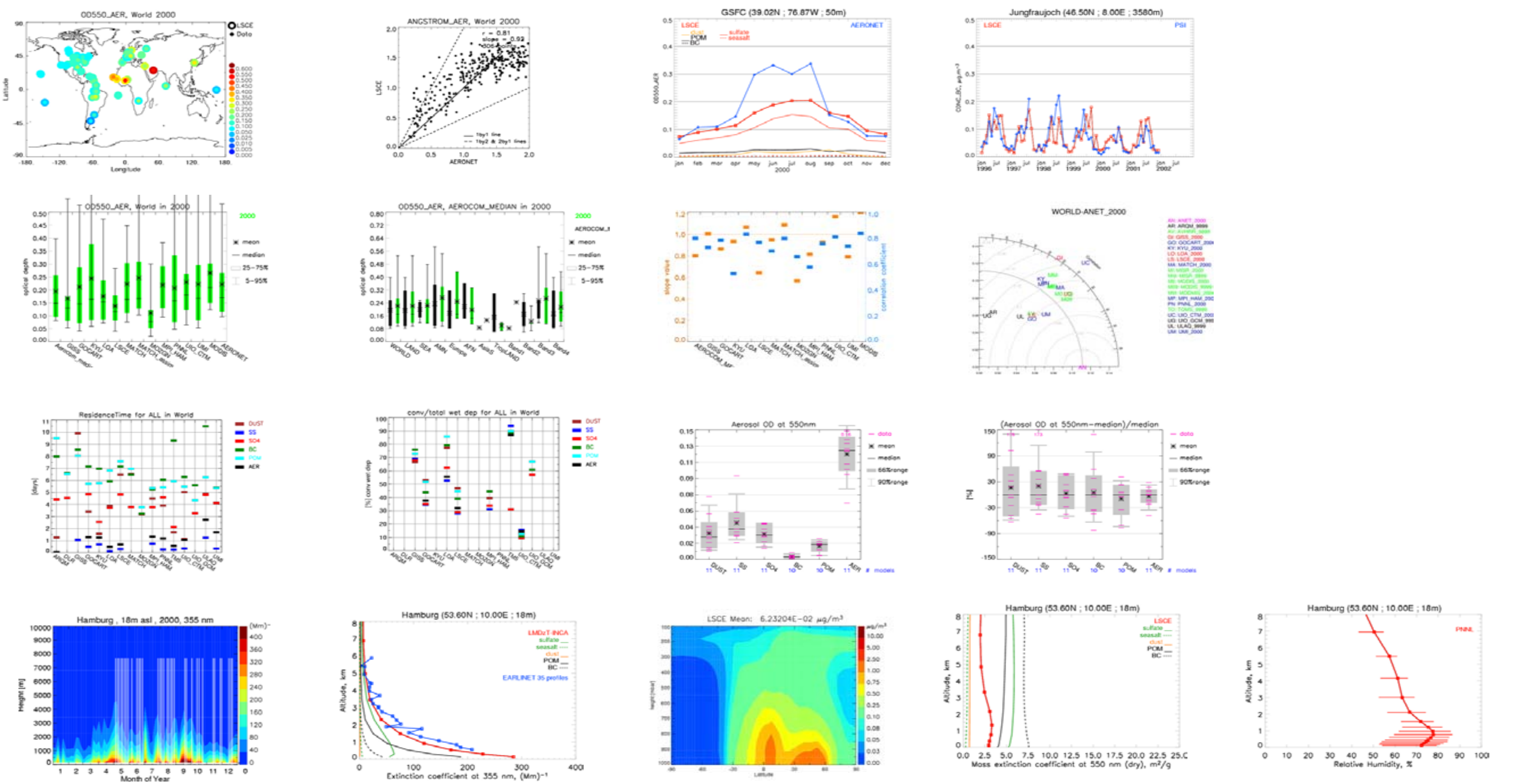
Documentation

What you may (*or may not*) find on the AEROCOM web interfaces



EMI	[Tg/a]	39.234
WET	[Tg/a]	59.669
WETCV	[Tg/a]	26.634
WETST	[Tg/a]	33.035
DRY	[Tg/a]	14.192
SED	[Tg/a]	0.177
SED+DRY	[Tg/a]	14.369
WET/(DRY+SED+WET)	[%]	80.593
LOAD	[Tg]	1.514
Sou-Sin	[Tg/a]	-34.804
(Sou-Sin)/Sou	[%]	-88.710
LIFE_Sources	[days]	14.084
LIFE_Sinks	[days]	7.463





Model	Type of model Name, Version	Horizont. Resolution (x y) (lon lat)	Vertical Resolution (# of levels) (type)	Type	number of bins or modes	aerosol mixing	Aerosol dynamics
ARQM	**CTM Canadian GCMIII**	128x64 2.81°x2.81°	32 hybrid sigma-p	bin	**17** (12 DU + 5 mixed)	DU + internal	none
DLR	**GCM ECHAM4**	96x48 3.75°x3.75°	19 sigma	modal, sigma fix	**2** nucl+acc	internal	aging of BC and POM SO4 microphysics
GISS	GCM modelE	46x72 5°x4°	20 sigma	bin	**10** 2 SS, 4 DU, 1BC, 1 POM,	external	aging of BC and POM
GOCART	CTM GOCART 3.15b	144x91 2.5°x2.0°	30 sigma	modal, sigma fix	**17** 8 DU, 4 SS, 2 BC, 2POM,	external	aging of BC and POM
KYU	GCM CCSR/NIES/FRSGC GCM / SPRINTARS /	320x160 1.1°x1.1°	20 sigma	modal, sigma fix	**17** 10 DU, 4 SS, 1 BC, 1 BCPOM, 1 SO4	external partly internal for BC/ POM	none
LSCE	GCM LMDzT 3.3	96x72 3.75°x2.5°	19 sigma	modal, sigma fix	**5** accum. sol+insol, coarse sol+insol,	external mixture of internally mixed modes	aging of BC and POM
LOA	GCM LMDzT 3.3	96x72 3.75°x2.5°	19 sigma	bin	**17** 2 DU, 10 SS, 2 BC, 2POM,	external	aging of BC and POM
MATCH	CTM MATCH v 4.2	192x94 1.9°x1.9°	28 sigma-p	bin	**8** 4DU, 1SS,1 BC, 1POM, 1SO4	external	aging of BC and POM
MPI HAM	GCM ECHAM5.2	192x96 1.8°x1.8°	31 hybrid sigma-p	modal, sigma fix	**7**	external mixture of internally mixed modes	Nucl., Coag., Condensation Thermodynamics
MOZGN	CTM MOZART v2.5	192x96 1.9°x1.9°	28 sigma	bin	**12** 1SU, 1OC, 1BC,5 DU, 4 SS	external	aging of BC and POM
PNNL	GCM MIRAGE 2 / derived from NCAR CAM2.0	144x91 2.5°x2.0°	24 hybrid sigma-p	modal, sigma fix	**8** aitken, accum., coarse DU, coarse SS,	external mixture of internally mixed modes	SO4 microphysics
TM5	CTM TM5	60x45 6°x4°	25 hybrid sigma-p	modal, sigma fix	**9** 3 SS, 2 DU, SOA, POM, BC, SO4	external	none
UIO_CTM	CTM OsloCTM2	128x64 2.81°x2.81°	40 sigma	bin	**20** 8 DU, 8 SS, BC, POM, biomass burn BCPOM,	external except biomass burning	aging of BC and POM
UIO_GCM	**GCM CCM3.2**	128x64 2.81°x2.81°	18 hybrid sigma-p	external: modal fix internal: bin	**55** 12 modes 43 bins	8 prescribed external 4 transported external 4 transported internal	aging of BC and POM
ULAQ	**CTM ULAQ**	16x19 22.5°x10°	26 log-p	bin	**41**	external	aging of BC and POM SO4 microphysics
UMI	GCM IMPACT	144x91 2.5°x2°	30 sigma	bin	**13**	external	none

The simple equation at the base of aerosol radiative forcing

Change in albedo due to aerosols

$$\Delta\alpha_p = [T_a^2(1-A_c)][2(1-R_s)^2\bar{\beta}f_b M\alpha_s f(RH) - 4R_s M\alpha_s f(RH)((1-\omega_0)/\omega_0)]$$

cloud fraction

surface albedo

upscatter fraction
+f(RH) for upscatter

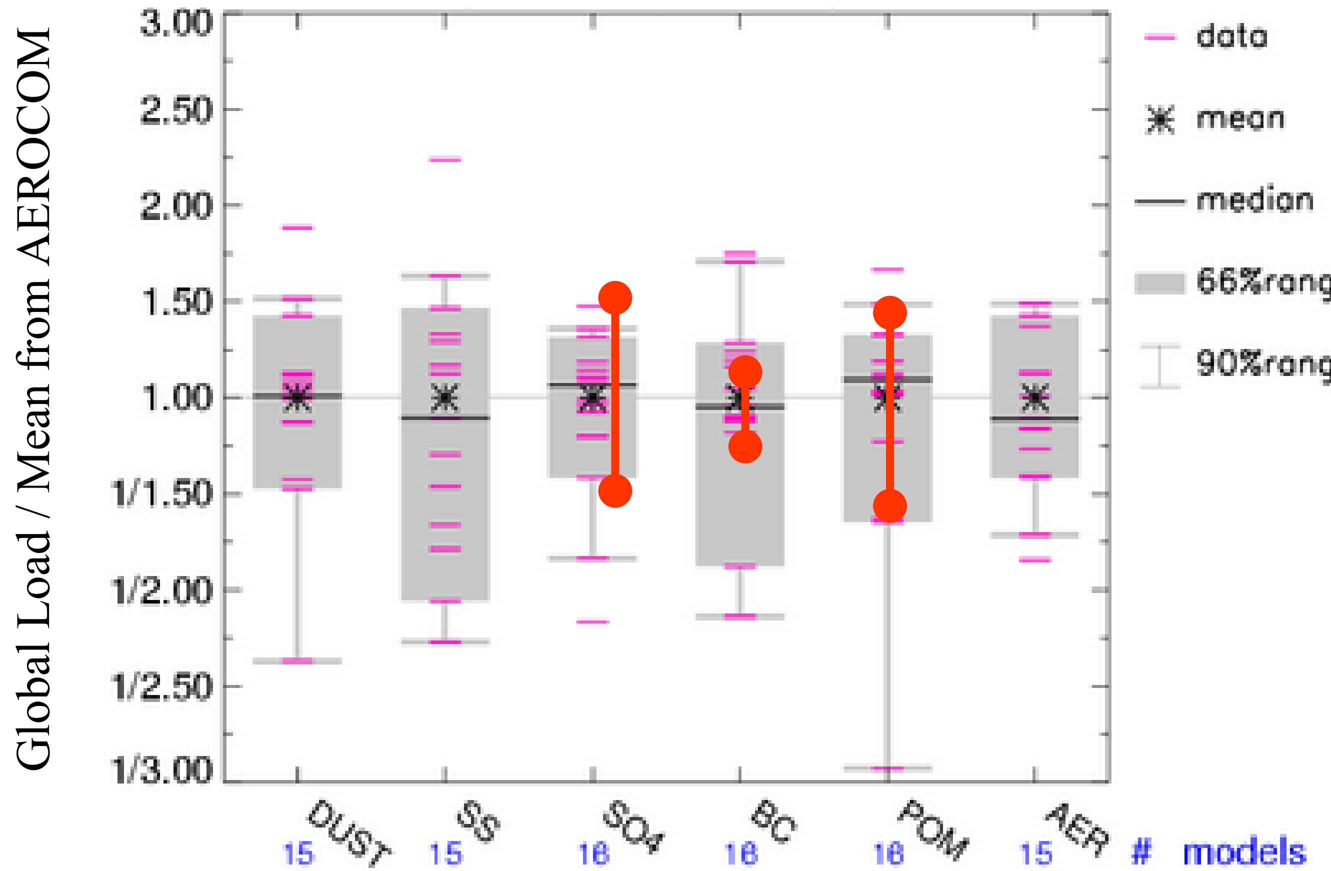
burden

mass extinction coefficient
hygroscopic growth factor mec

« absorption coefficient »

$$\Delta\alpha_p = [T_a^2(1-A_c)][2(1-R_s)^2\,\bar{\beta} f_s M \alpha_s f(RH) - 4R_s M \alpha_a f(RH)((1-\omega_0)/\omega_0)]$$

Range of burdens from 16 ***AEROCOM-A*** *models*



Mean Load [Tg]

Sulphate-S

old	→	new
4.1		3.9

POM→

2.1		3.2

BC →

0.26		0.41

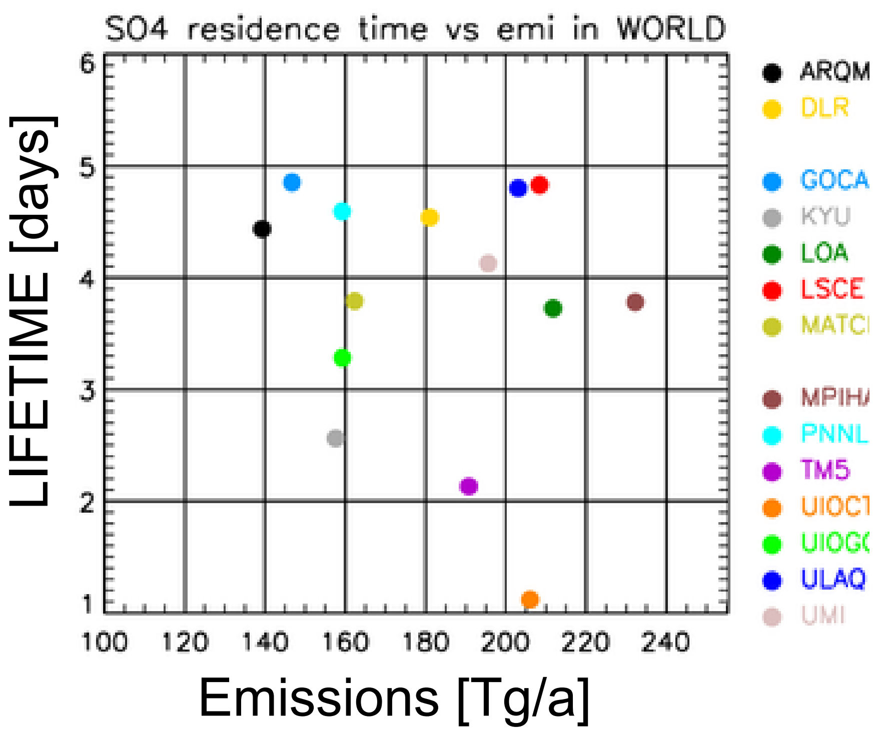
Value from individual model

2/3 uncertainty in last IPCC report 2001, chapter 5, Penner et al.

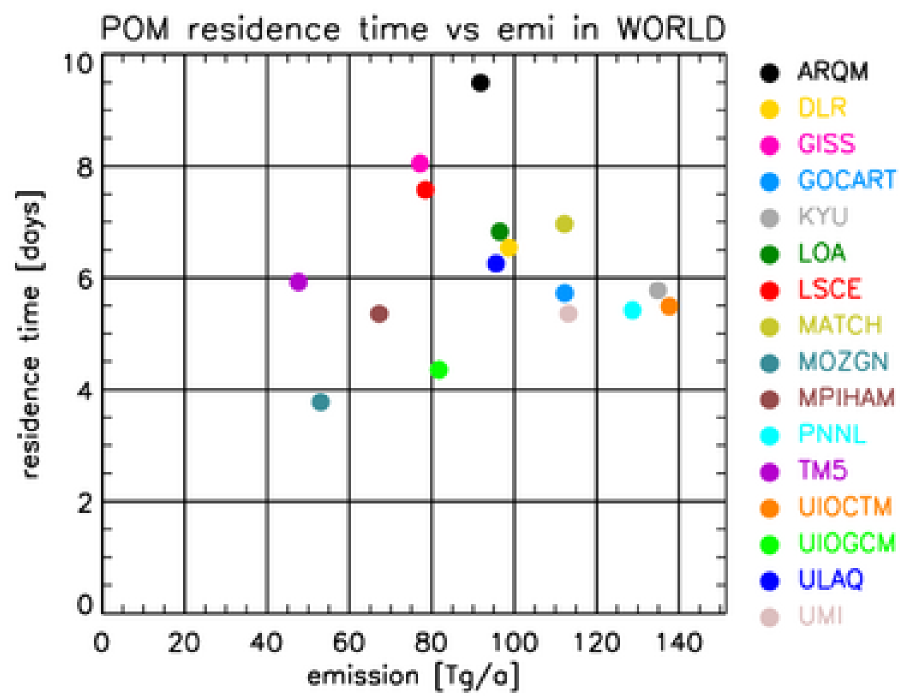
$$\Delta\alpha_p = [T_a^2(1-A_c)][2(1-R_s)^2\,\bar{\beta} f_b\, M\, \alpha_s f(RH) - 4R_s\, M\, \alpha_s f(RH)((1-\omega_0)/\omega_0)]$$

Burden = Emission x Lifetime

f(chemical reactions, removal, size, vertical mixing, regional distribution)

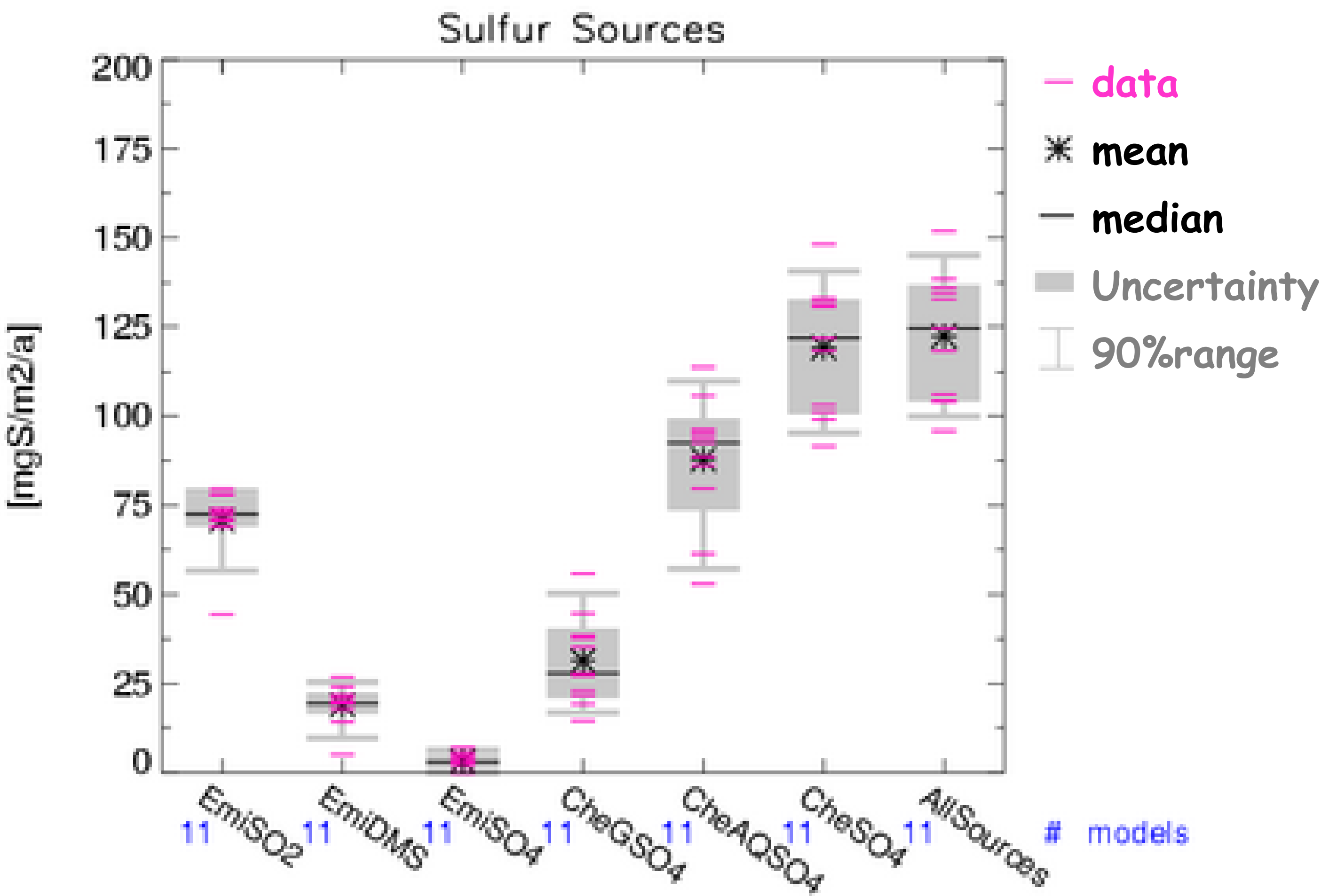


Sulphate



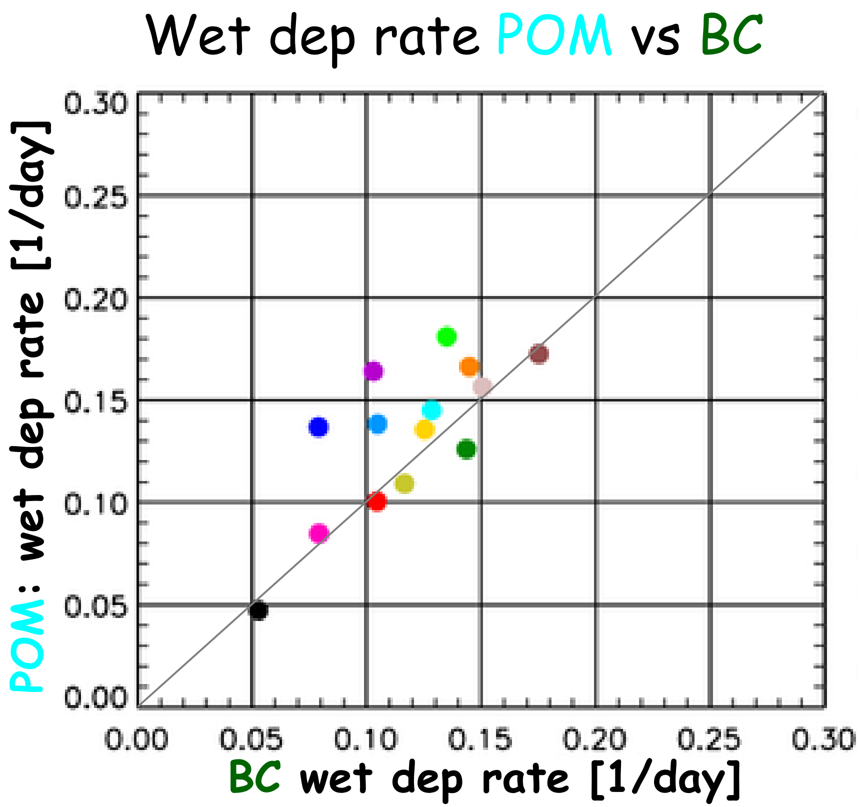
Particulate Organic Matter

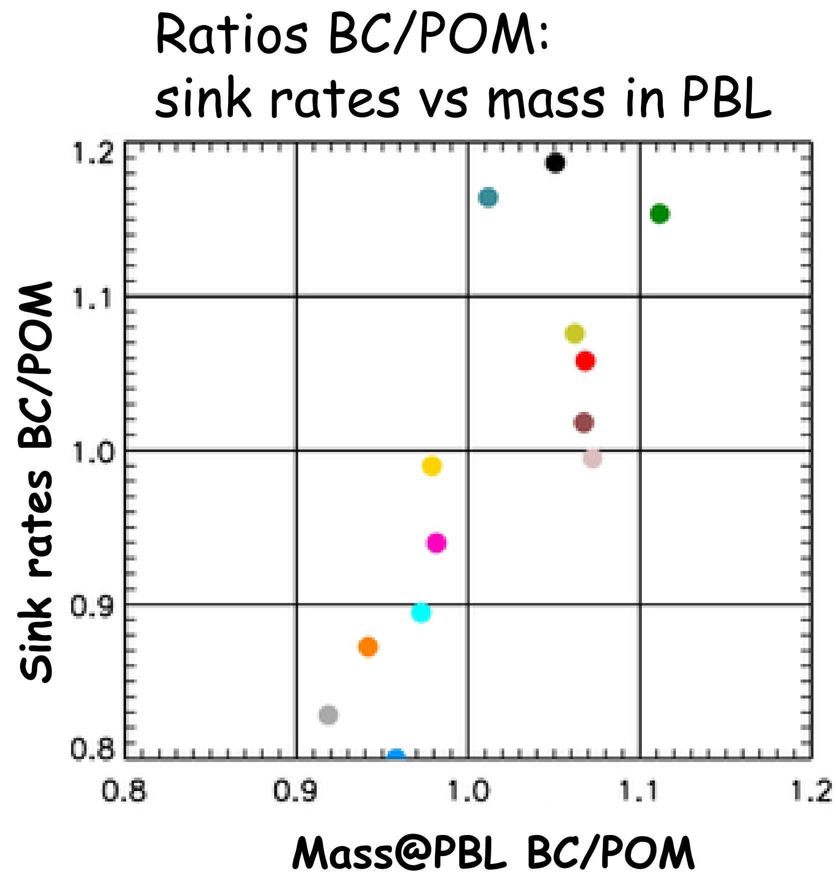
Sulfur sources/Uncertainty



The uncertainty of the sulfur sources is caused by chemistry, not by emissions.

Sink processes: Wet dep





- Sometimes faster removal for BC than for POM

More mass in the PBL ↔ Faster sink rates

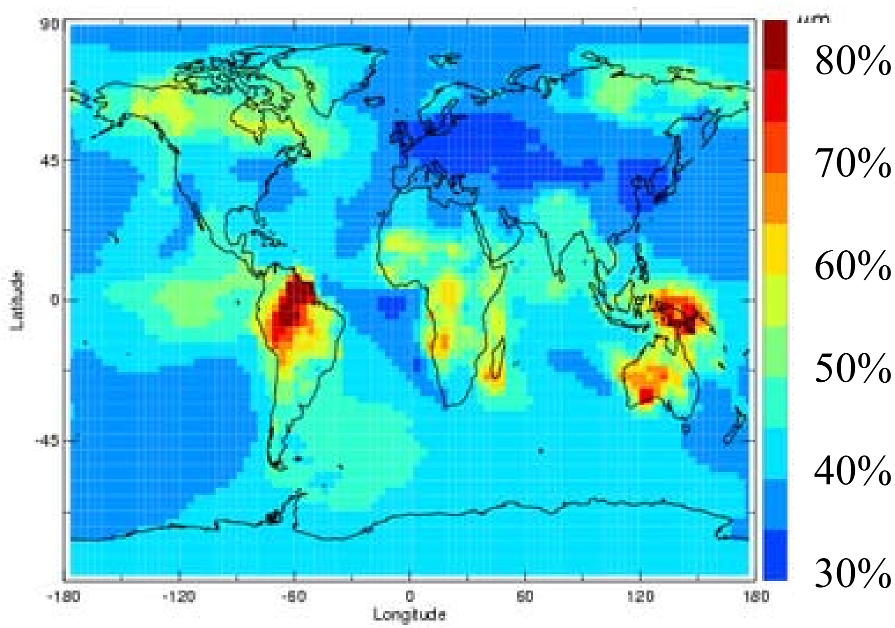
Lifetime differences are due to

-- removal velocity parameterisation

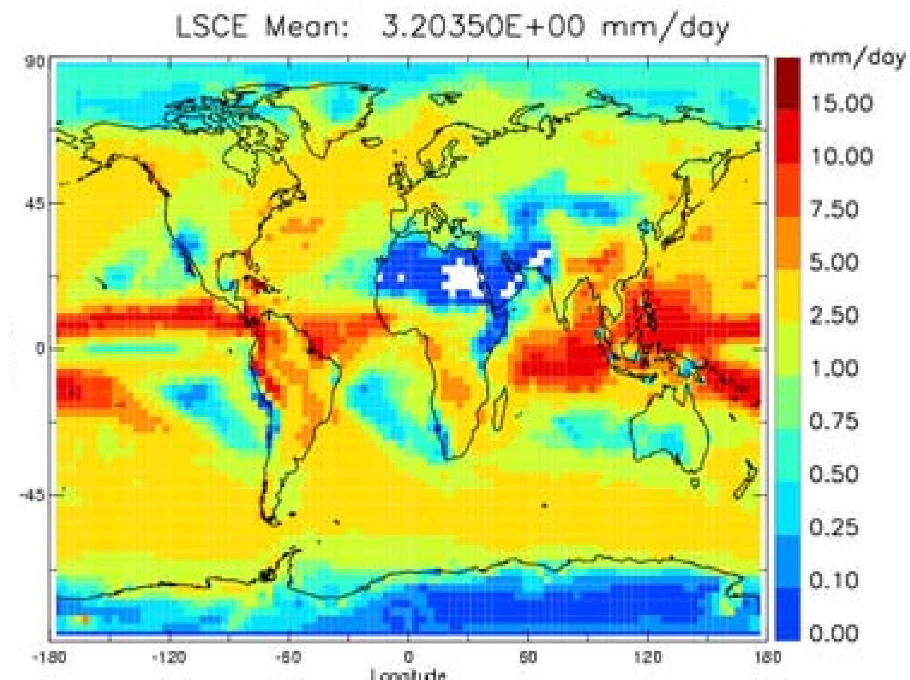
-- covariation of removal & transport & emission

- wet removal is height dependent
- emission in dry areas&seasons
- transport efficiency to upper troposphere
- mixing in the boundary layer

Example: Faction of POM emissions from total BC+POM

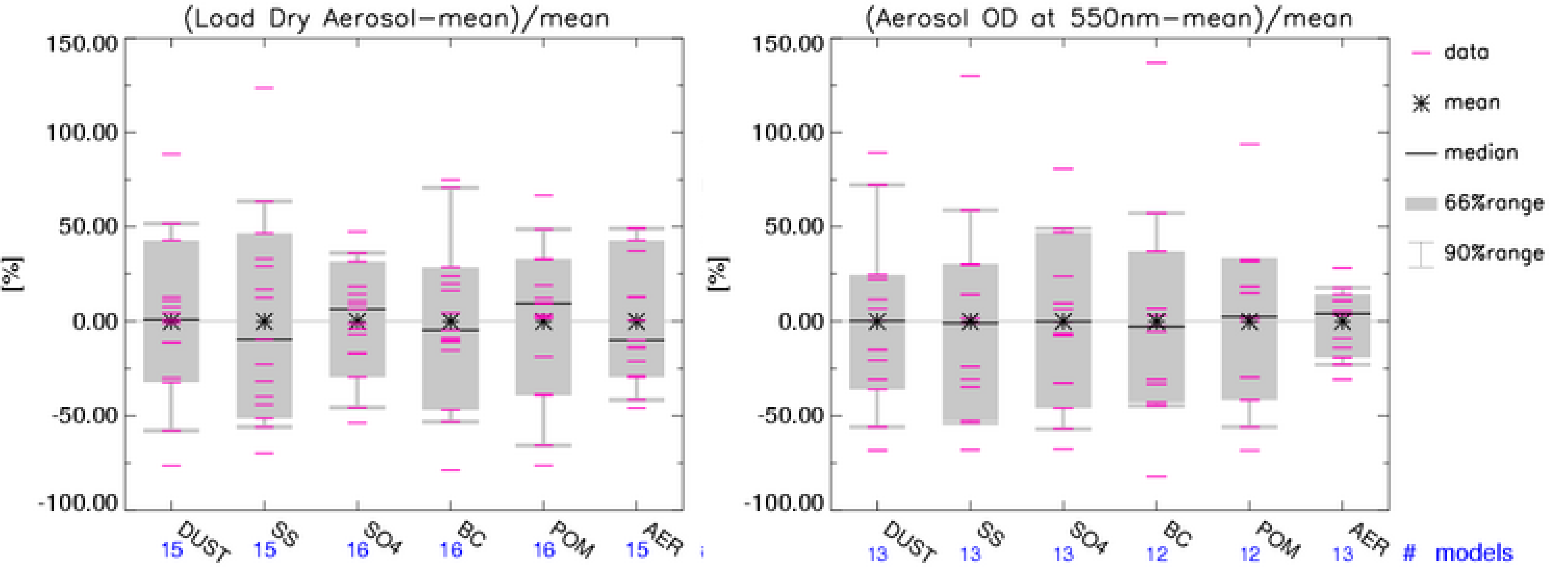


Precipitation



$$\Delta \alpha_p = [T_a^2(1-A_c)][2(1-R_s)^2 \bar{\beta} f_b M\alpha_s f(RH) - 4R_s M\alpha_s f(RH)((1-\omega_0)/\omega_0)]$$

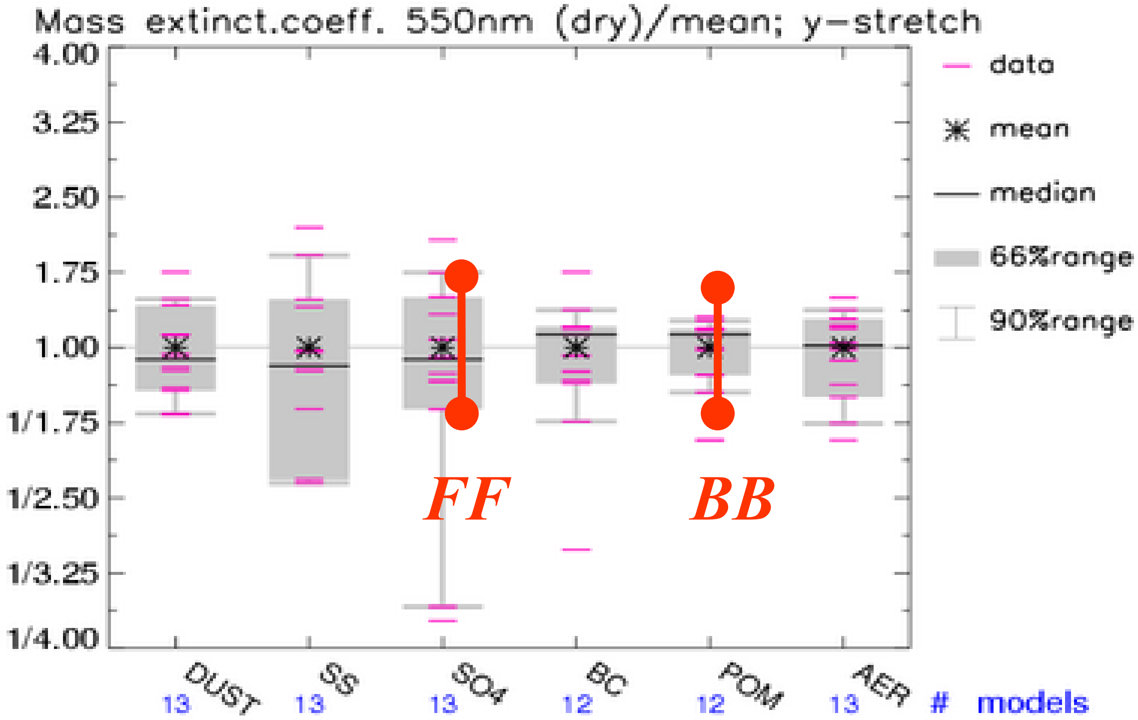
Load is not more certain than Aerosol optical depth ?



Total aerosol optical depth is more certain than components?

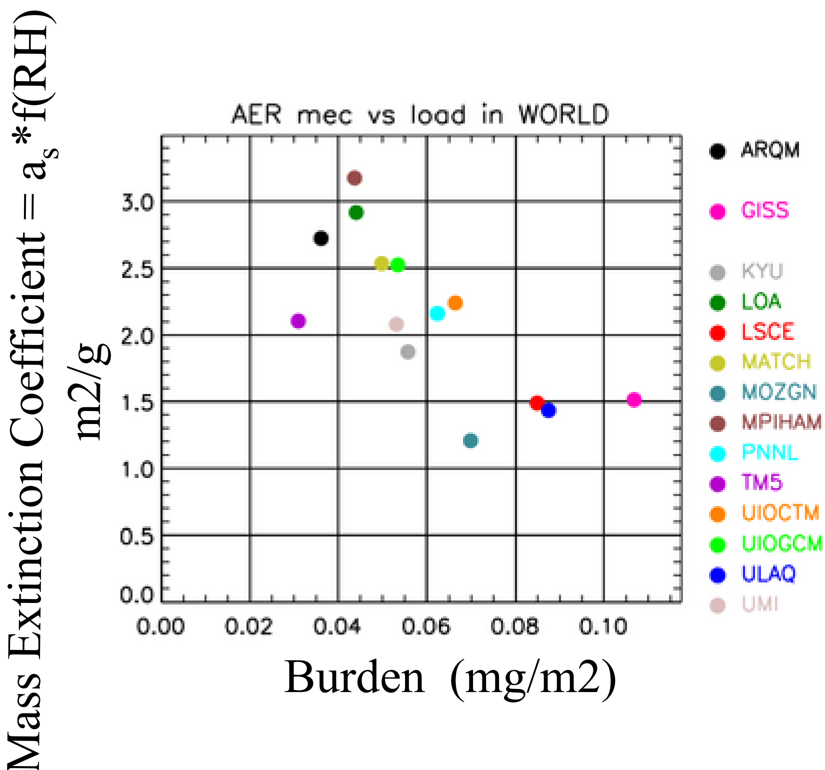
$$\Delta \alpha_p = [T_a^2 (1-A_c)][2(1-R_s)^2 \bar{\beta} f_b M_s \alpha_s f(RH) - 4 R_s M_s \alpha_s f(RH)((1-\omega_0)/\omega_0)]$$

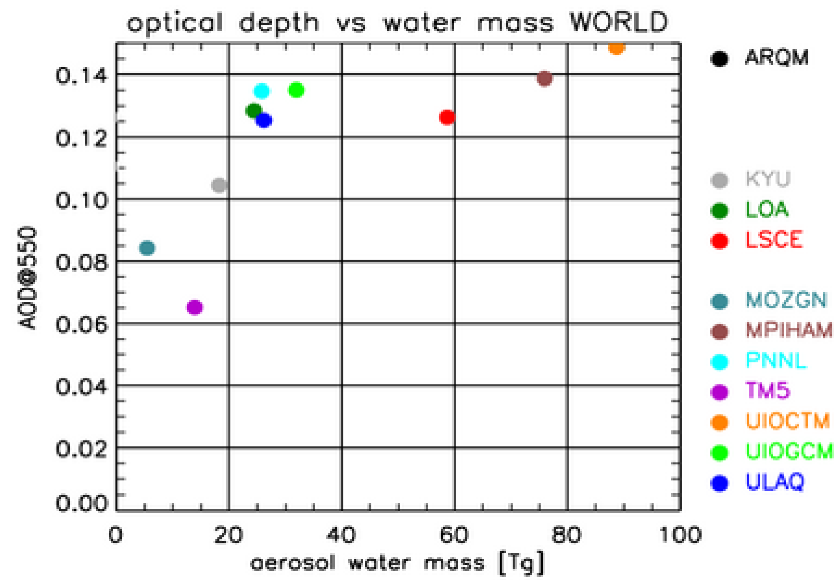
How uncertain is the conversion of Load to Aerosol Optical Depth



2/3 uncertainty in last IPCC report 2001, chapter 5, Penner et al.

Compensation effects?





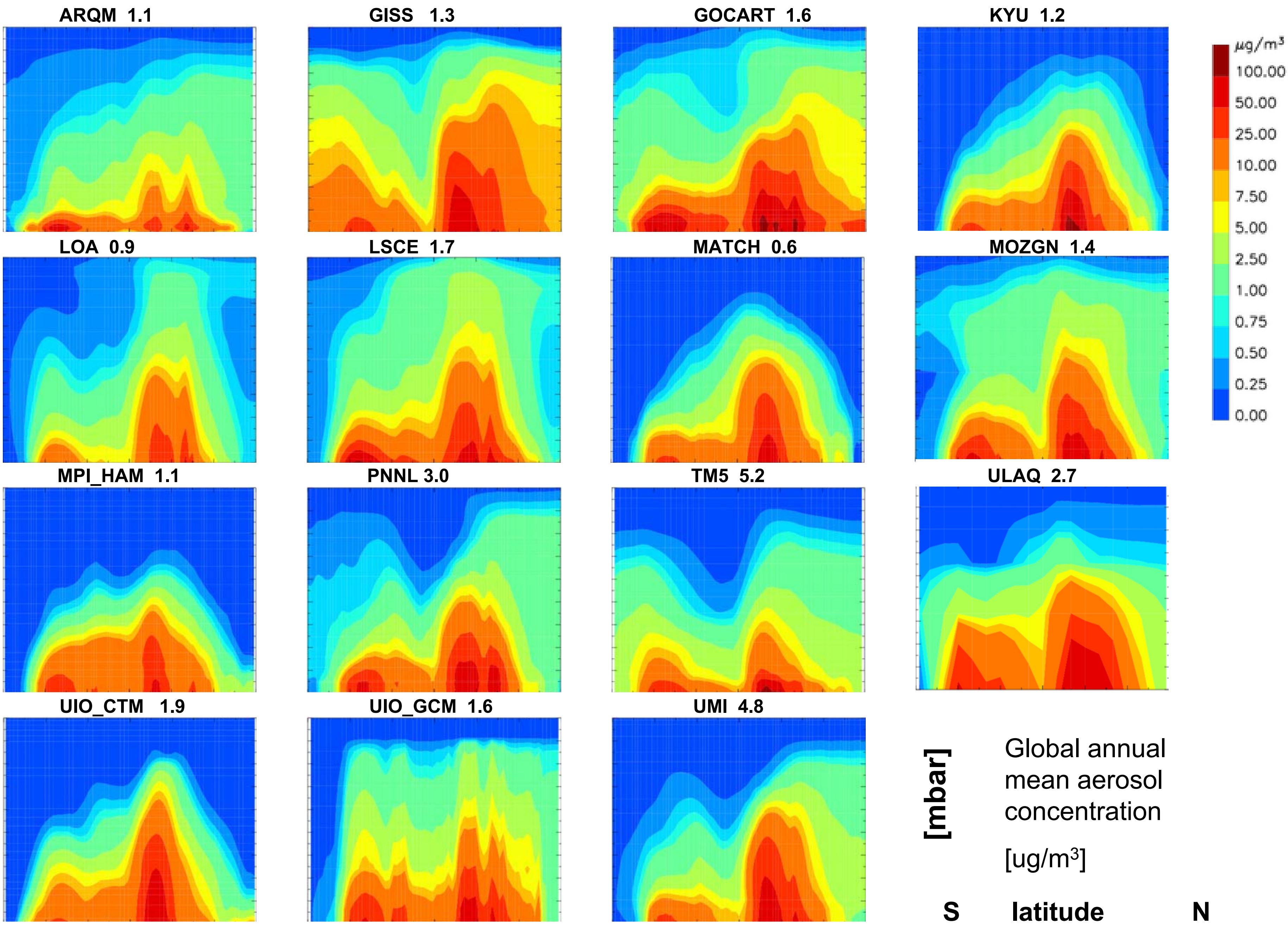
Covariations of

Humidity and Load ?

Load and Size ?

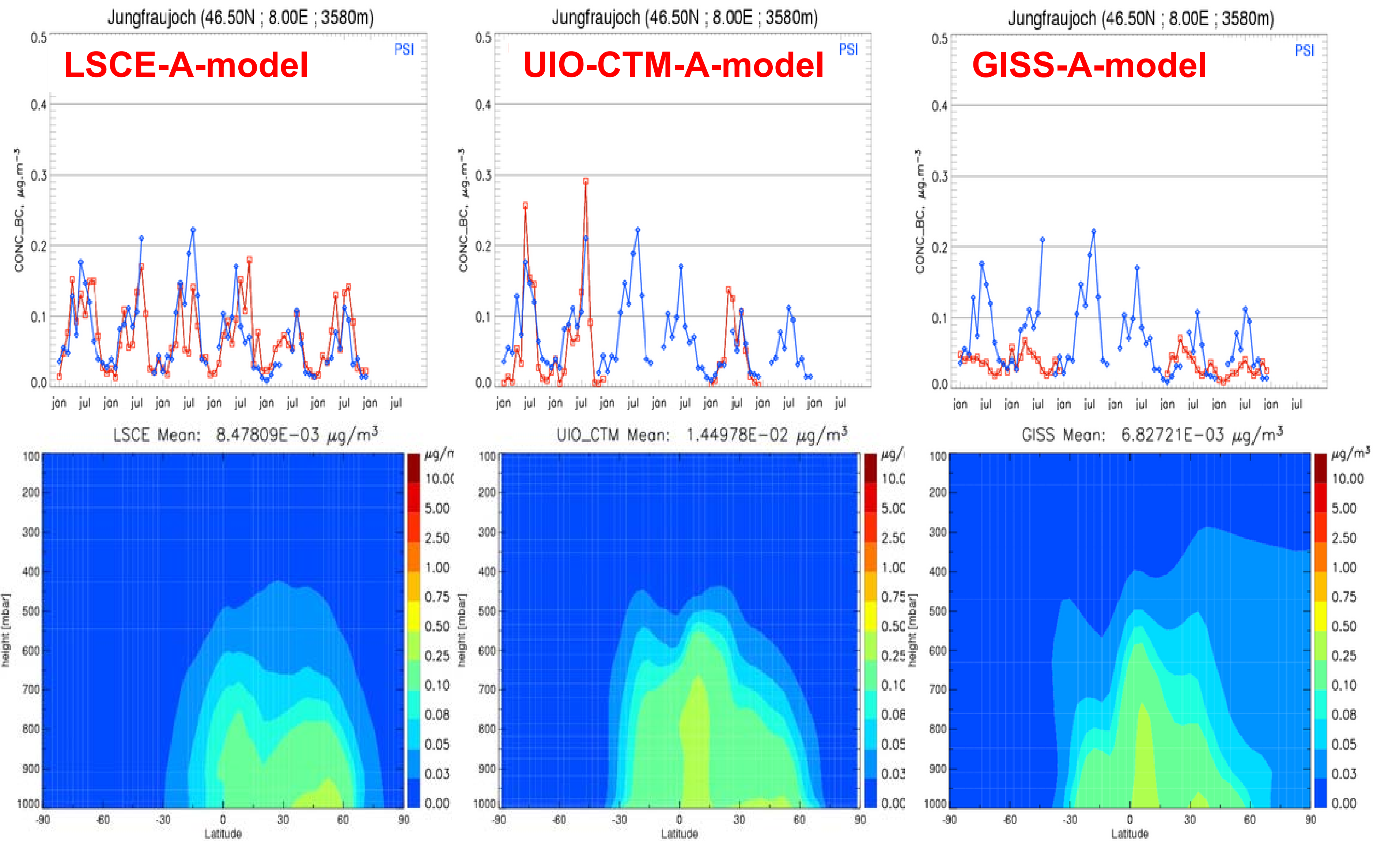
Humidity and aerosol profile ?

Annual mean zonal mean vertical aerosol concentration



$$\Delta \alpha_p = [T_a^2(1-A_c)][2(1-R_s)^2 \bar{\beta} f_b M \alpha_s f(RH) - 4R_s M \alpha_s f(RH)((1-\omega_0)/\omega_0)]$$

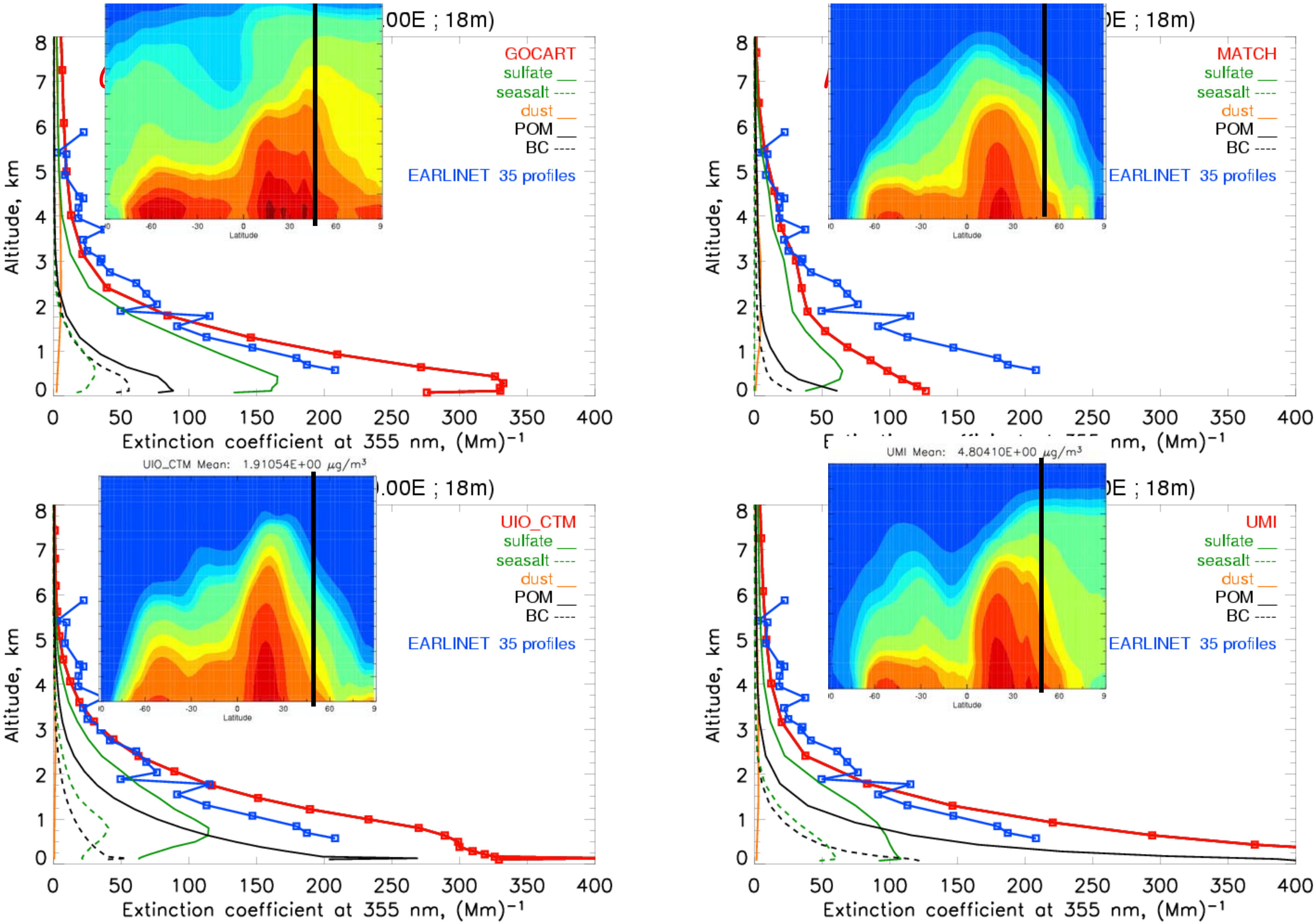
Black carbon vertical distribution? ***use observations from Mountains?***



Black carbon concentration Altitude versus Latitude

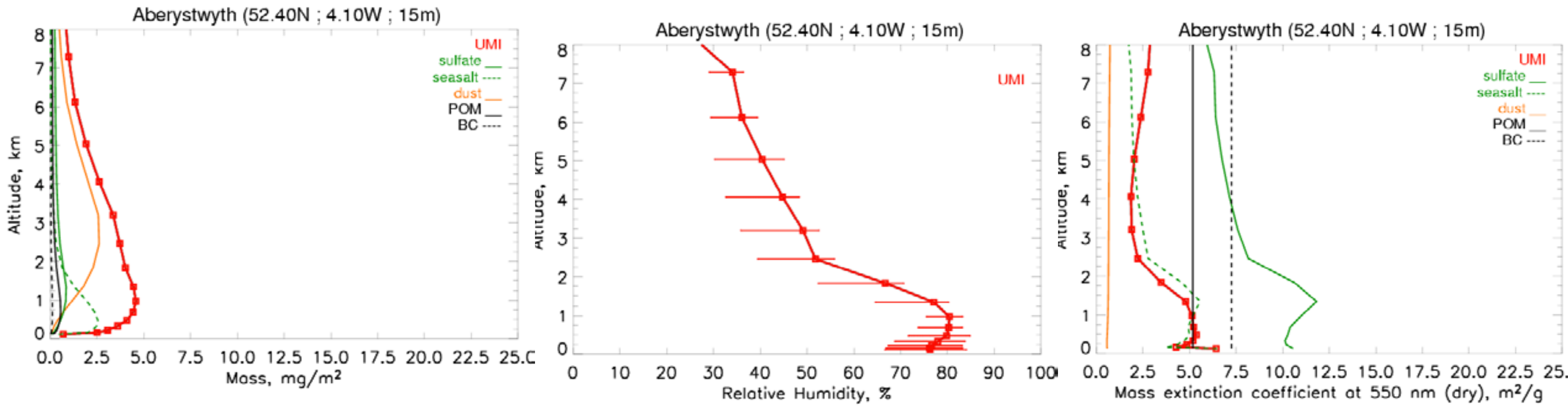
$$\Delta\alpha_p = [T_a^2(1-A_c)][2(1-R_s)^2\bar{\beta} f_b M\alpha_s f(RH) - 4R_s M\alpha_s f(RH)((1-\omega_0)/\omega_0)]$$

Year 2000 Mean LIDAR from Hamburg (MPI-M) against 4 AEROCOM models

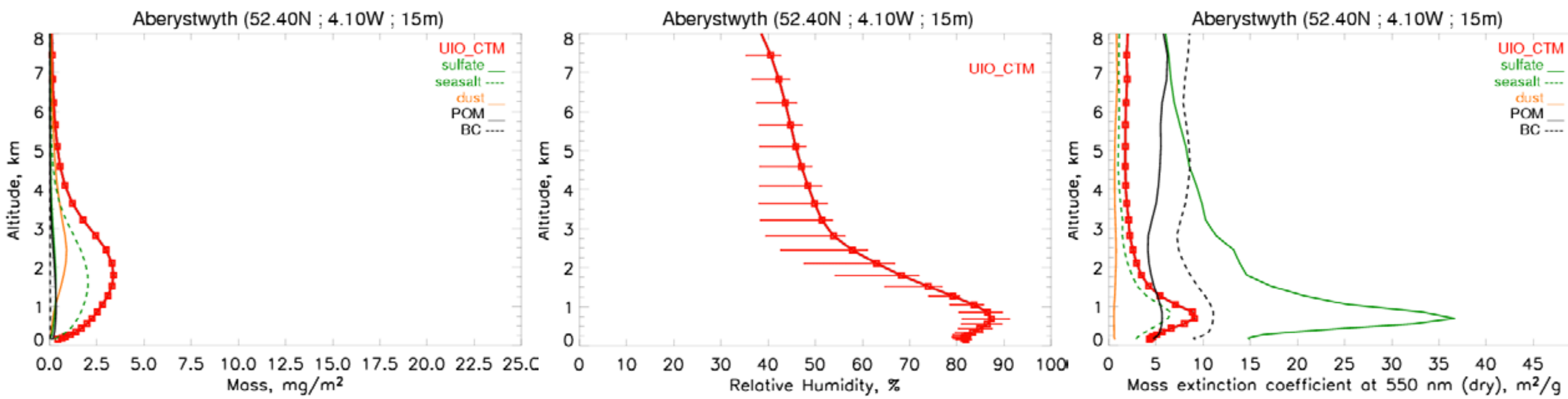


Lidar data Boesenberg/Matthias et al.

load + humidity + mass extinction

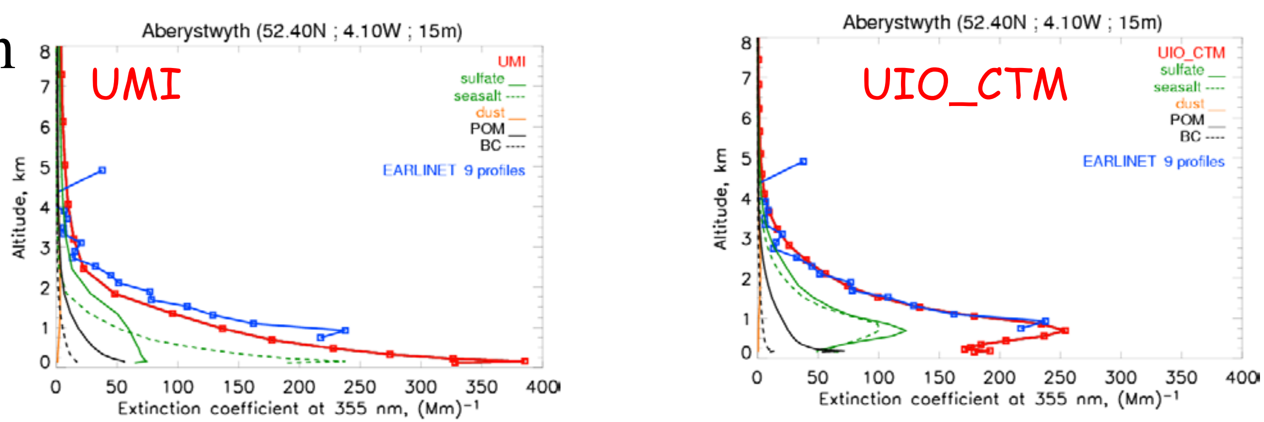


UMI



UIO_CTM

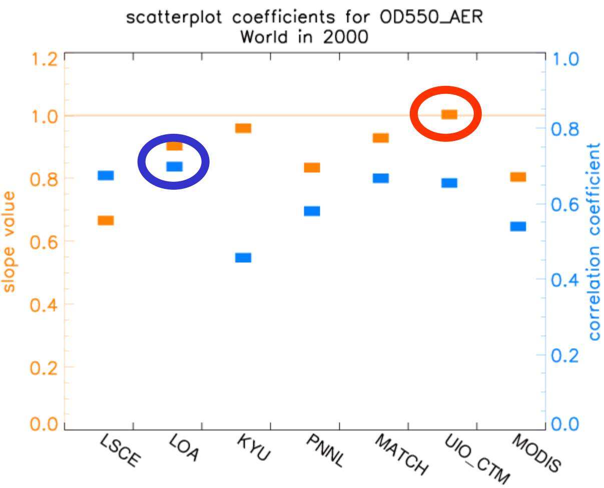
Extinction



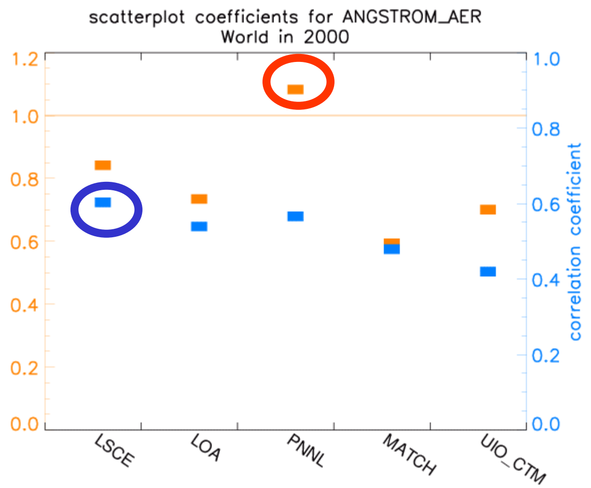
- Can we establish an overall error for each model?

CORRELATION AND *SLOPE* MODELS vs DIFFERENT DATA SETS

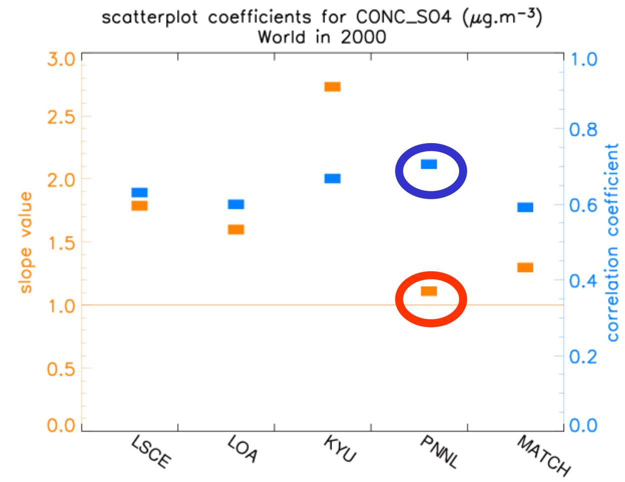
AOD@550nm



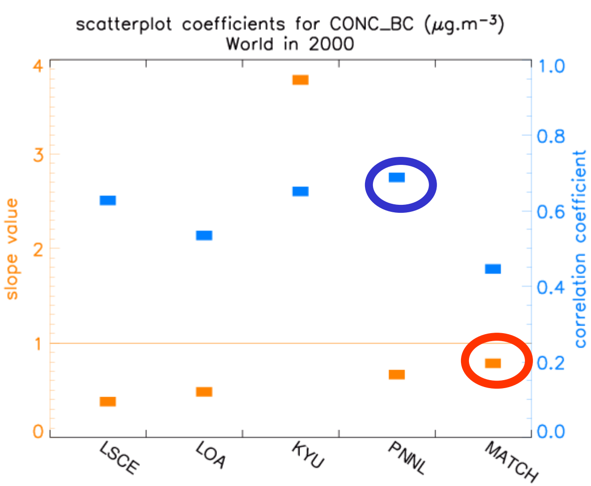
Angstroem Comp.



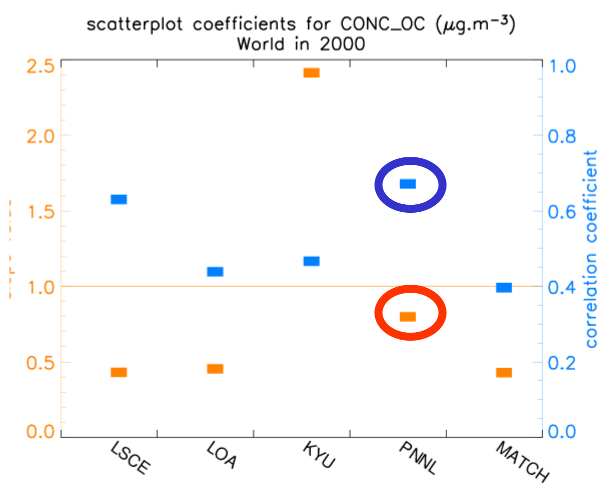
Sulphate Conc



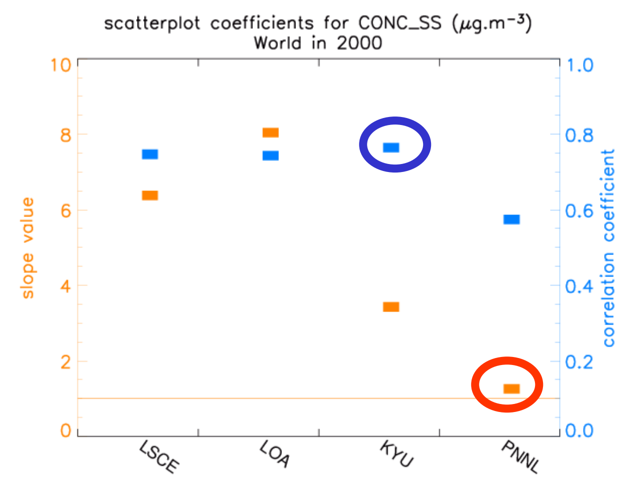
Black Carbon Conc.



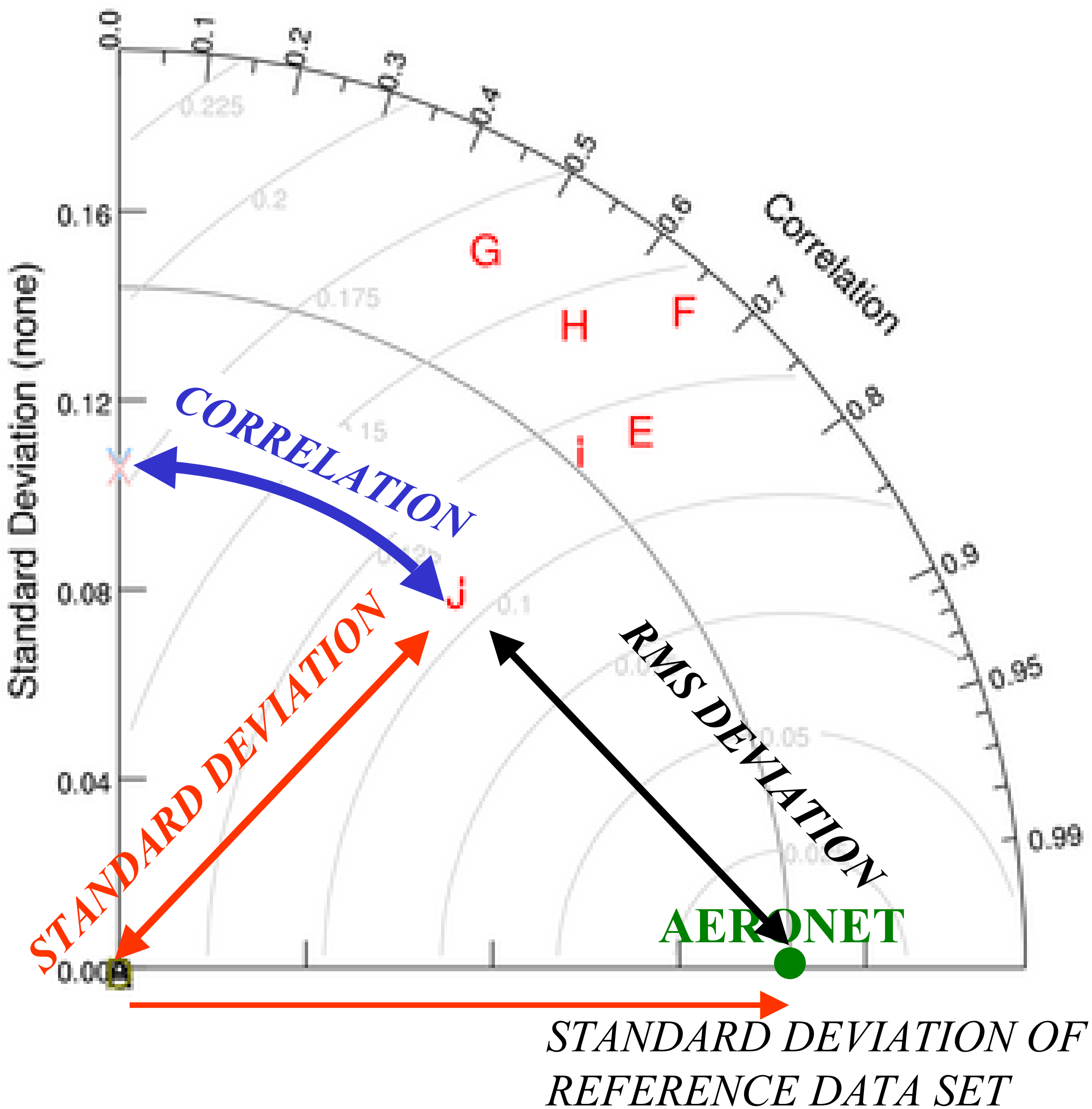
Organic Carbon Conc.



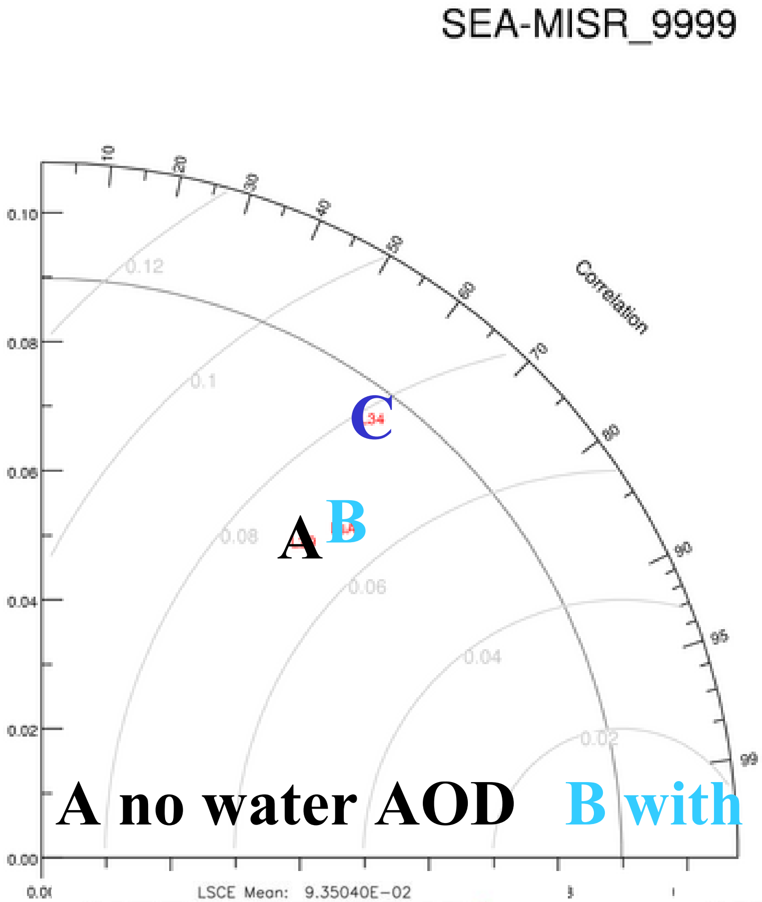
Sea Salt Conc.

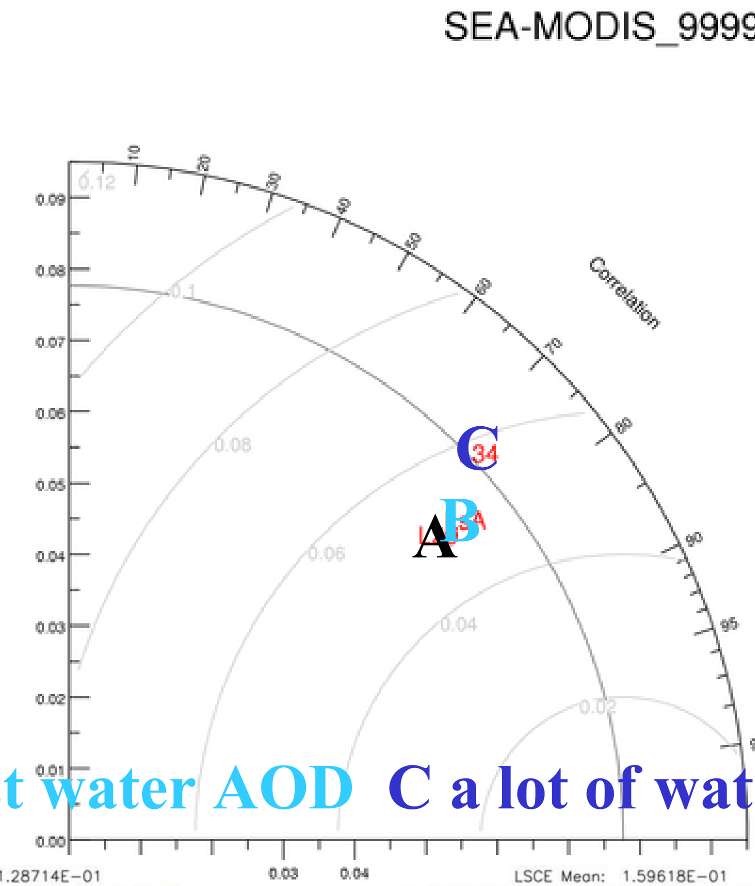


HOW TO SYNTHESIZE AEROCOM??
Taylor Diagrammes condense spatio-temporal varying fields

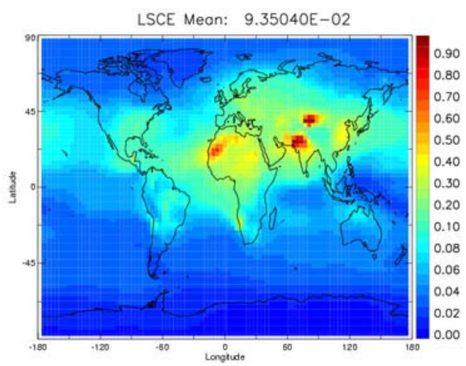


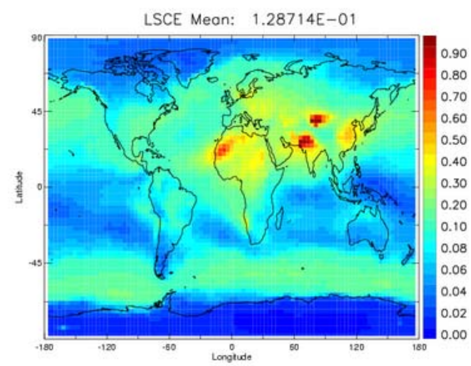
Example:
Follow up on changes in LMDzT-INCA model versions

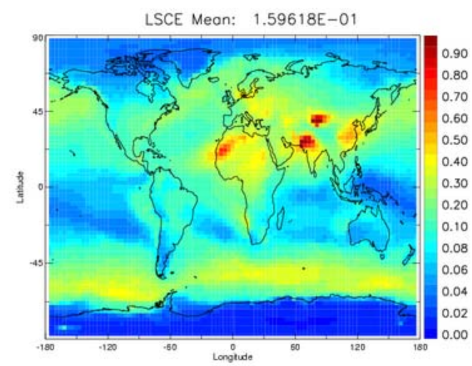




A no water AOD **B with modest water AOD** **C a lot of water AOD**







Statistics calculated for Taylor plots

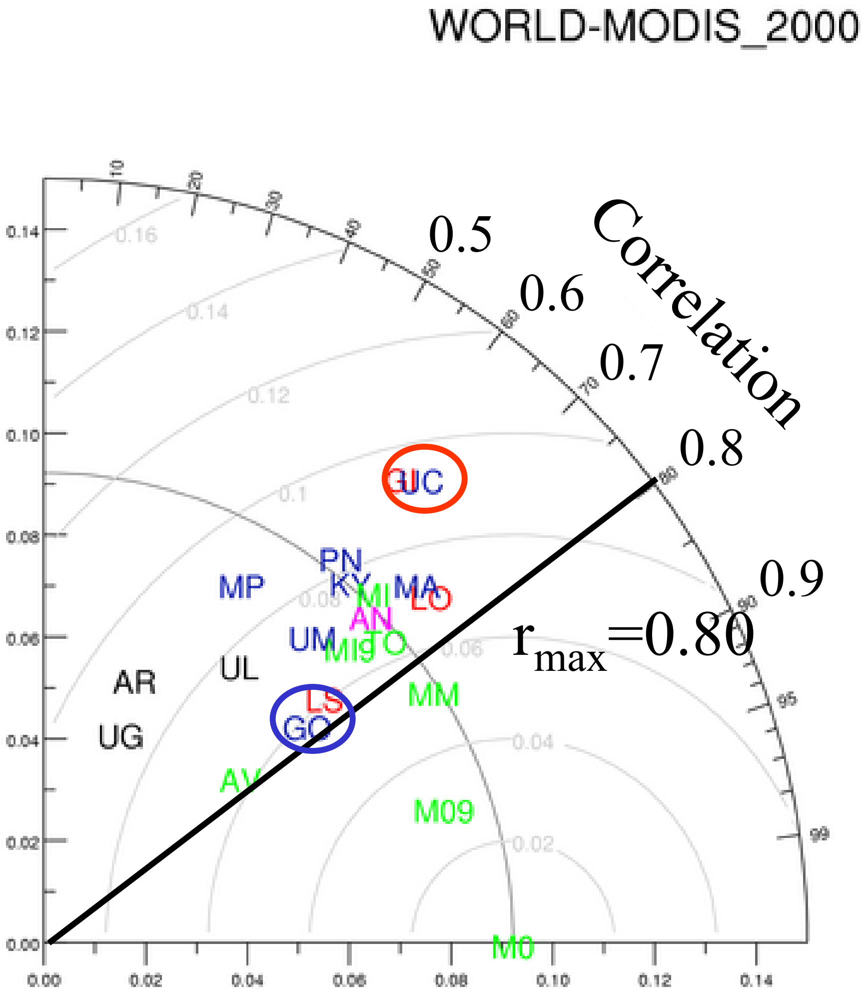
- 13 AEROCOM models output
- One year of monthly fields / 1x1 regridded

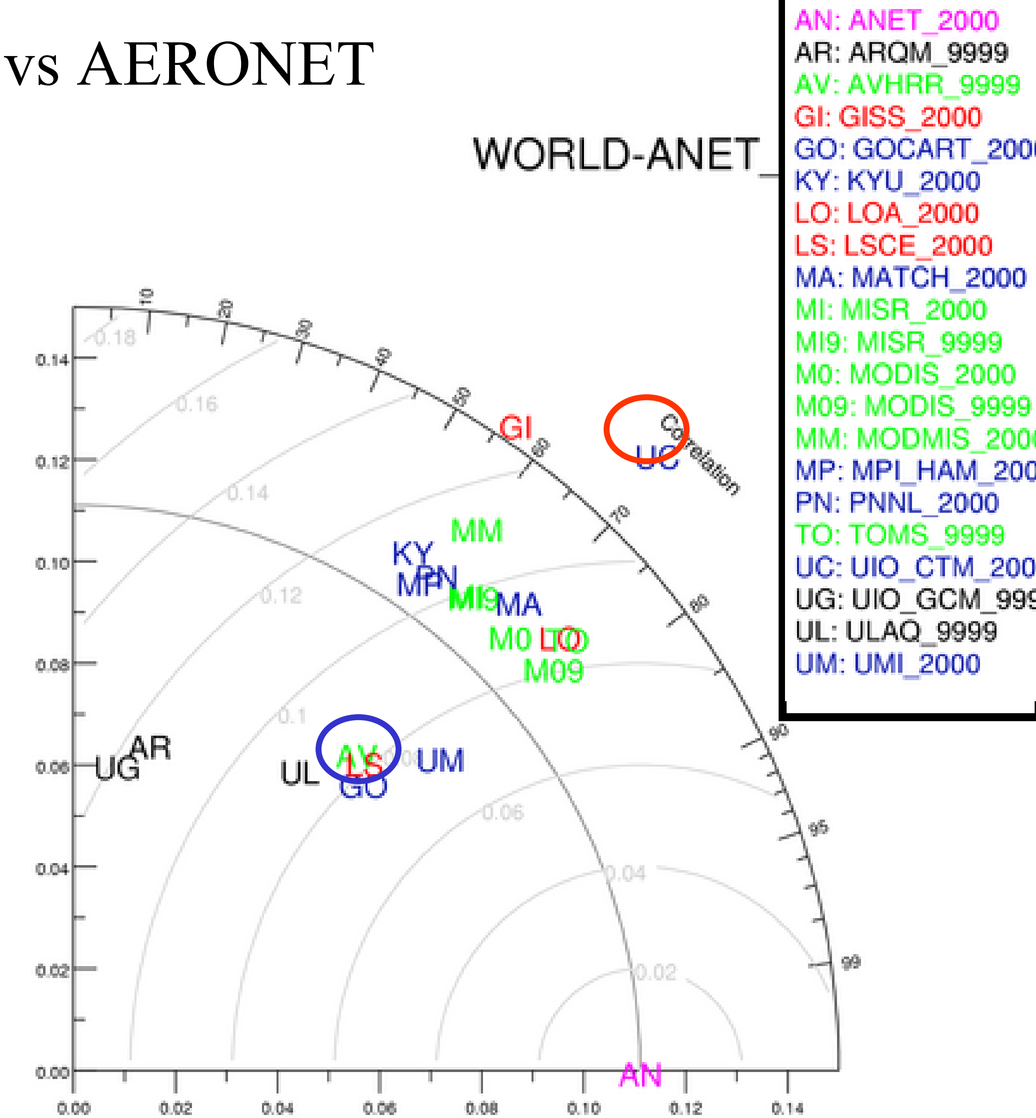
- Area weighted correlation / StdDev / RMS
  of spatio-temporal variation

- Reference data sets AERONET 2000 / MODIS 2000 / MODIS 00-03 / MISR 2000 / MISR 00-03 / TOMS 79-01 / AVHRR 83-01

- For satellite comparisons ca 300.000 data points

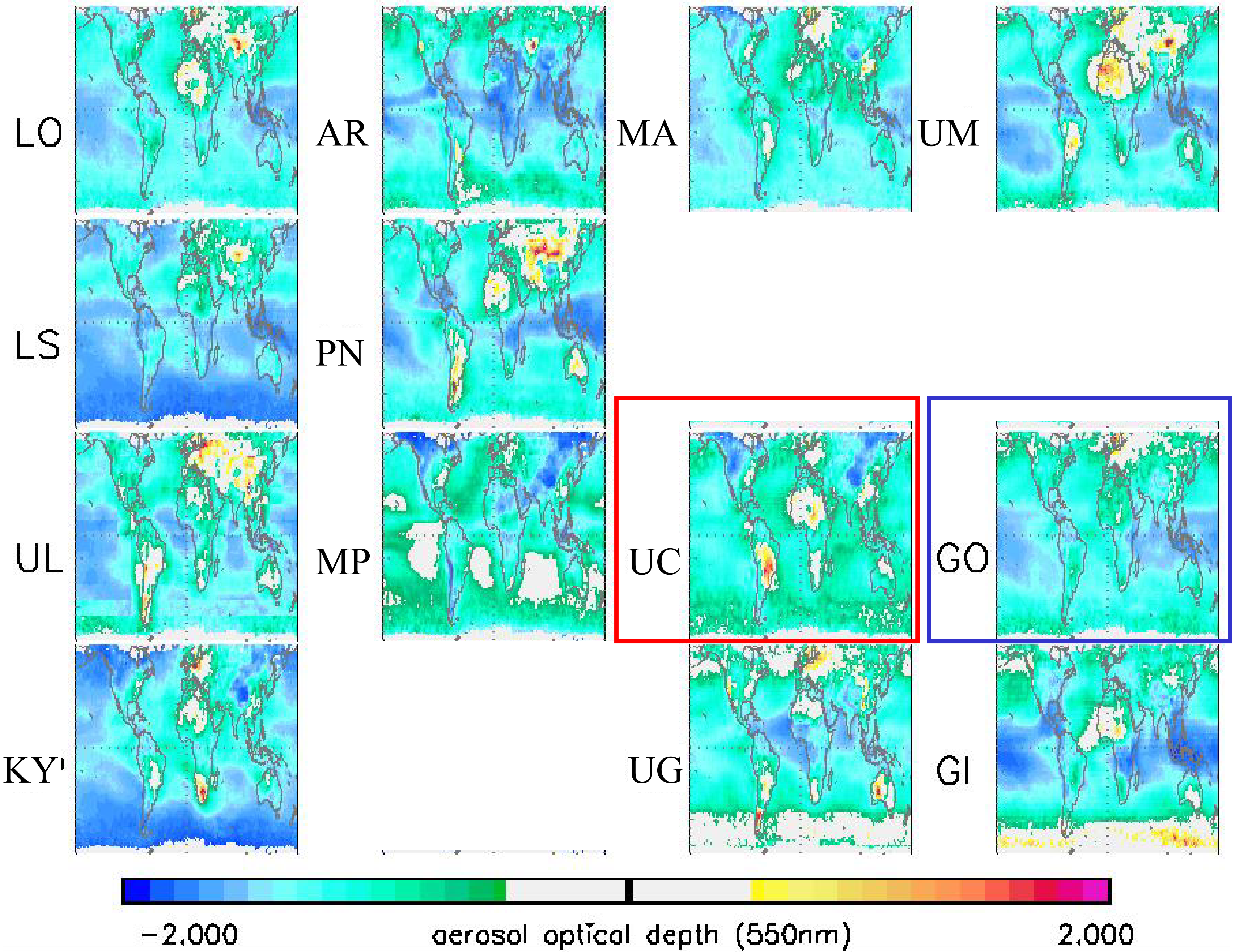
Global // year 2000 // MODIS vs AERONET



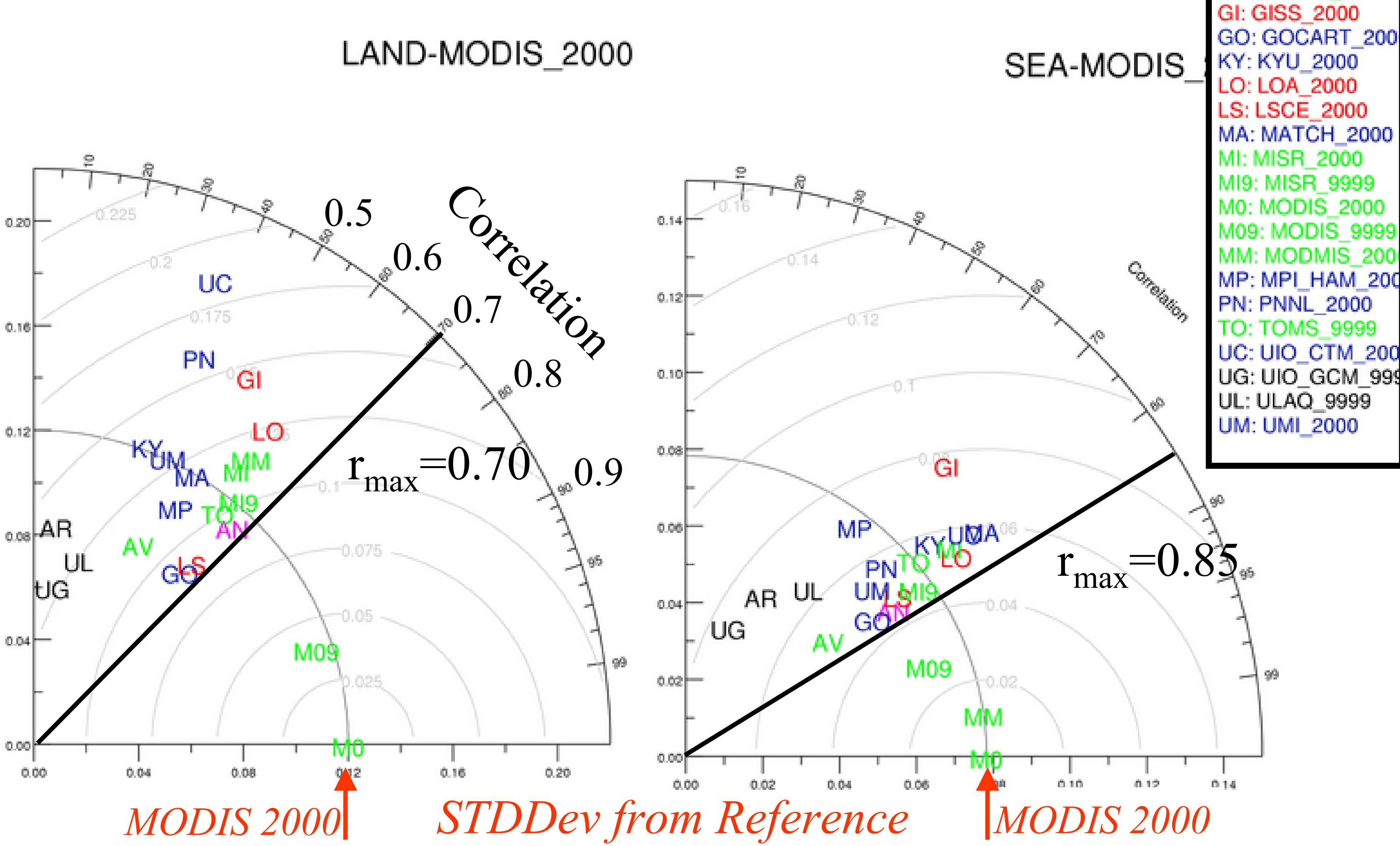


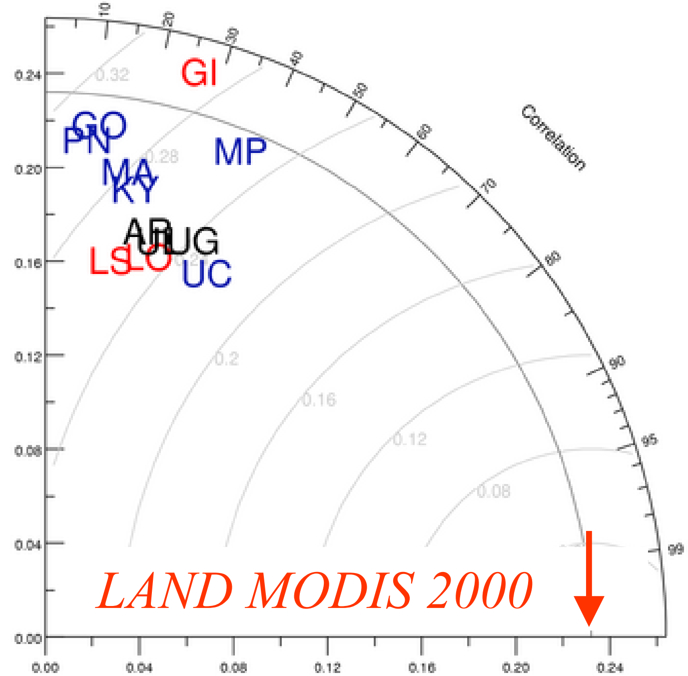
Green Satellites // Blue high resolution nudged GCMs or CTMs // Red lower resolution nudged GCMs // Black GCMs

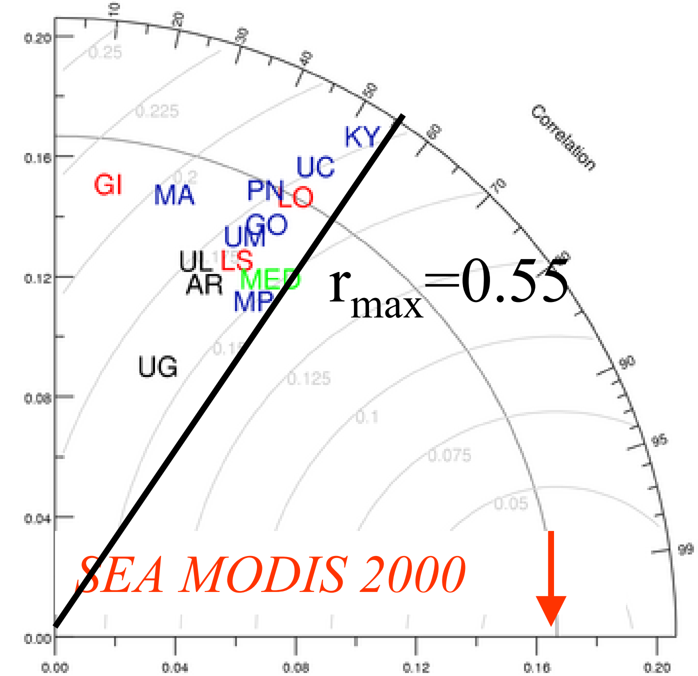
FACTOR DEVIATION to MODIS/MISR data



Land versus Sea // year 2000 MODIS





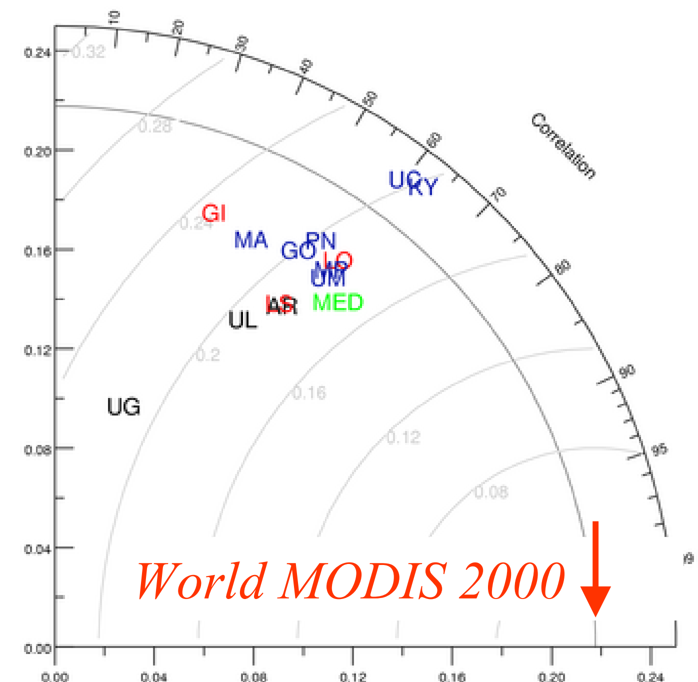


AN: ANET_2000
AR: ARQM_9999
AV: AVHRR_9999
GI: GISS_2000
GO: GOCART_200
KY: KYU_2000
LO: LOA_2000
LS: LSCE_2000
MA: MATCH_2000
MI: MISR_2000
MI9: MISR_9999
M0: MODIS_2000
M09: MODIS_9999
MM: MODMIS_200
MP: MPI_HAM_20
PN: PNNL_2000
TO: TOMS_9999
UC: UIO_CTM_200
UG: UIO_GCM_99
UL: ULAQ_9999
UM: UMI_2000

AOT fine fraction (0-1) MODIS 2000

Land vs Sea vs Global

Fine mode from models = sum(SO4+POM+BC)



Maximum correlation coefficients
of total spatio-temporal variation (12 monthly fields)

Reference	Sea	Land	World
AERONET	0.88	0.75	0.80
MODIS 2000	0.85	0.70	0.80
MODIS 00-03	0.85	0.75	
MISR 2000	0.80	0.60	
TOMS 79-01		0.60	
AVHRR 83-01	0.78		
MODIS fine fraction AOD	0.55	0.45	0.65

Conclusions from spatio-temporal variability analysis

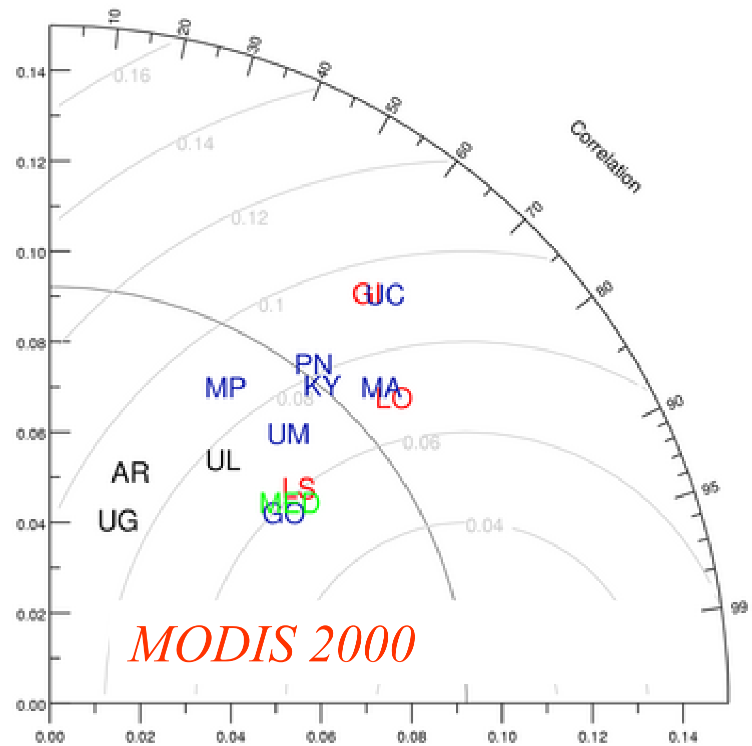
- Satellite/AERONET observations have similar standard deviation.
- Some models and satellites capture similar variablity of reference!
- Correlations are never better then ~0.85
- Agreement satellite and some models gives confidence

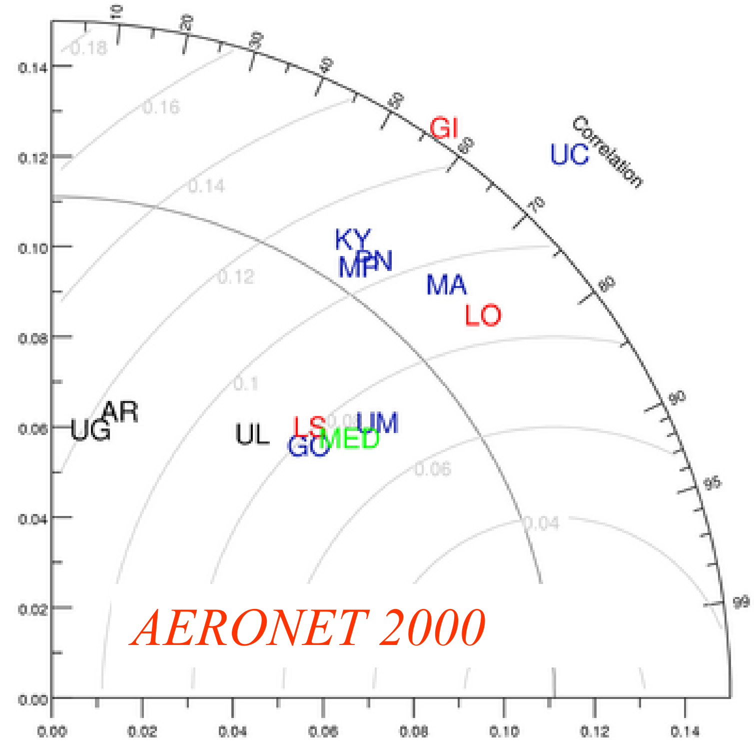
Significantly smaller correlation and larger RMS
over land and for fine aerosol fraction:

Why should a model “perform” better over sea?
- because - far away from sources
- but – sources need to be right
- but – dust and seasalt are more uncertain
- but – long range transport is more difficult to simulate

Can we rely on the fine mode satellite products to estimate
the anthropogenic component of the aerosol?

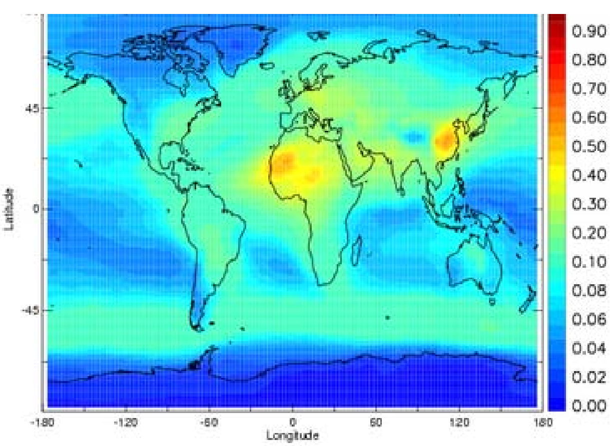
Stable and good: the MEDIAN from models



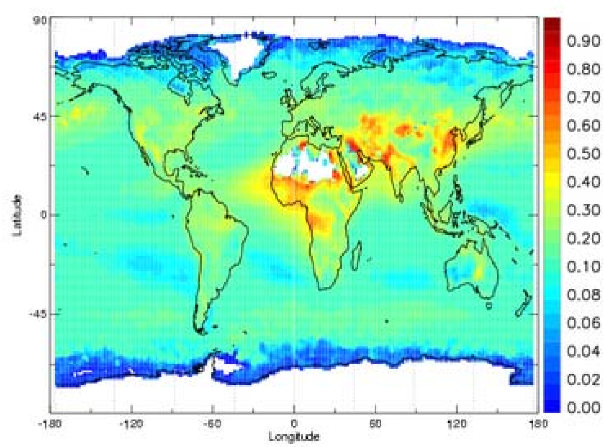


AN: ANET_2000
AR: ARQM_9999
AV: AVHRR_9999
GI: GISS_2000
GO: GOCART_2000
KY: KYU_2000
LO: LOA_2000
LS: LSCE_2000
MA: MATCH_2000
MI: MISR_2000
MI9: MISR_9999
M0: MODIS_2000
M09: MODIS_9999
MM: MODMIS_2000
MP: MPI_HAM_2000
PN: PNNL_2000
TO: TOMS_9999
UC: UIO_CTM_2000
UG: UIO_GCM_9999
UL: ULAQ_9999
UM: UMI_2000

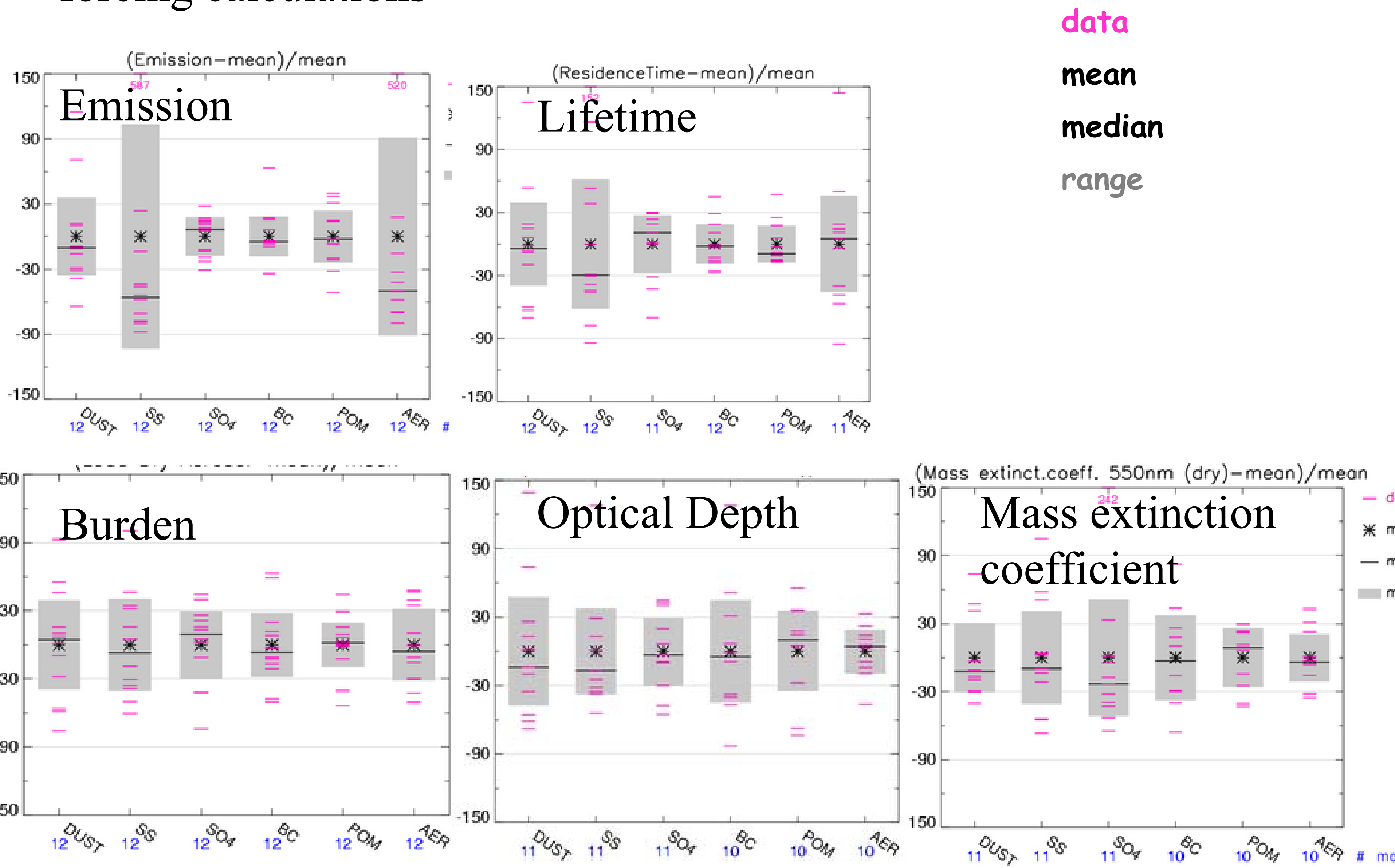
AEROCOM MEDIAN



MODIS



AEROCOM understanding of major parameters entering in forcing calculations

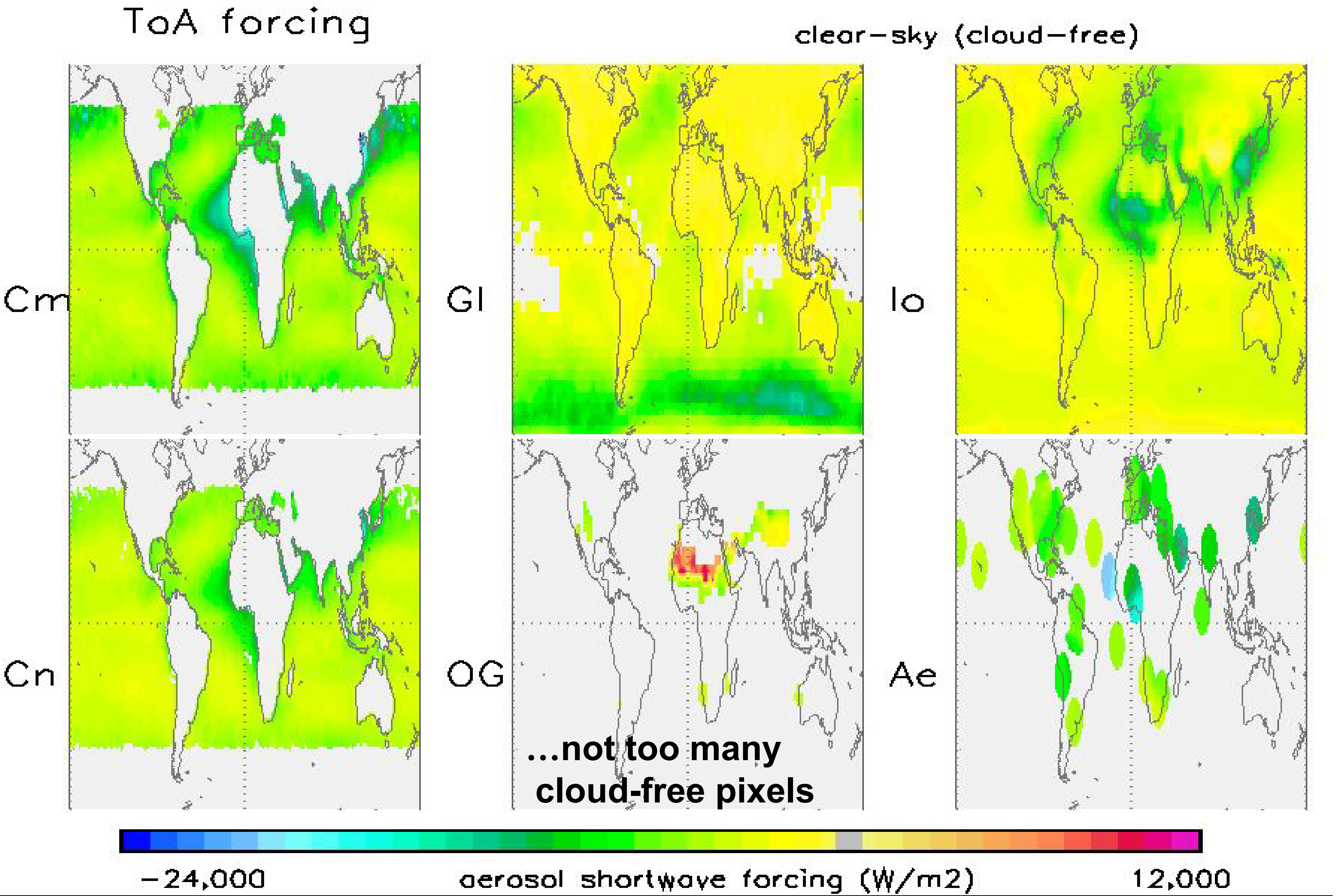


State of forcing estimate assembling

- forcing
  - clear-sky forcing (ToA comp. to CERES)
  - all-sky forcing
  - anthropogenic forcing and forcing efficiencies
- available data-sets
  - GI GISS, New York Koch, Bauer, Miller …
  - OG Oslo-GCM, Oslo Iversen, Seland
  - LO LOA, Lille Boucher, Reddy
  - SP Kyusho Takemura
  - EC MPI, Hamburg Stier, Feichter
  - Ae AERONET Holben, … , Kinne

yearly averages are shown *(yearly averages data required averages from all 12 months)*

CERES / clear-sky / cloud-free



clear-sky forcing *[- W/m2]*

ToA	C,m	C,n	GI	OG	LO	AE
global	5.7	4.2	2.7	2.2	2.8	6.4*
NH coast	8.5	6.7	1.5	3.8	5.8	7.5
EQ coast	6.1	4.9	1.4	3.2	2.9	7.6

surface			GI	OG	LO	AE
global			4.0	10.8	5.6	10.7*
NH coast			3.5	10.2	10.4	10.3
EQ coast			3.1	8.7	6.7	13.1

* **biased high due to sampling in areas of large aot**

- data suggest larger (neg.) ToA forcing than models
- data suggest biomass stronger surf forcing (+ ssa)
- larger ToA model differences on a regional basis

Conclusions

- AEROCOM comparisons obs/model bear still a treasure with respect to understanding model performance

- So far, it seems that the global anthropogenic aerosol forcing can not be established by observations ***alone***

- The ranges established for the different parameters can serve as a base for an uncertainty estimate of forcing
  - -Should we weigh model results with 1/RMS ?
  - -Should we establish pdf around Median model?
  - -How do we judge performance against different obs?