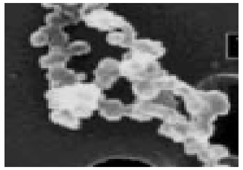
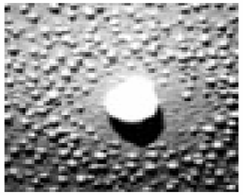
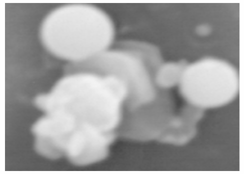
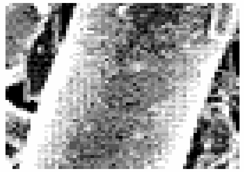


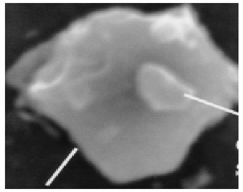
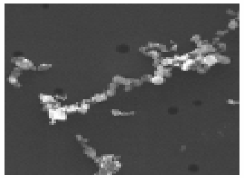
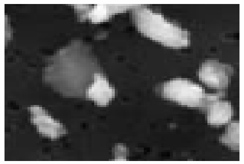
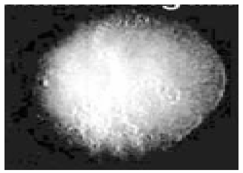




Aerosol modeling

Michael Schulz

Laboratoire des Sciences du Climat et de l'Environnement
CEA / CNRS / UVSQ - IPSL
Gif-sur-Yvette, France

Reading
2nd September 2008

Outline of talk

Why should we care about the aerosol?

How to represent the aerosol in a global model?

Current model quality with respect to observations?

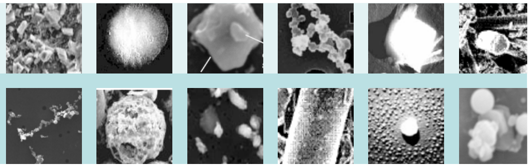
Model results used here

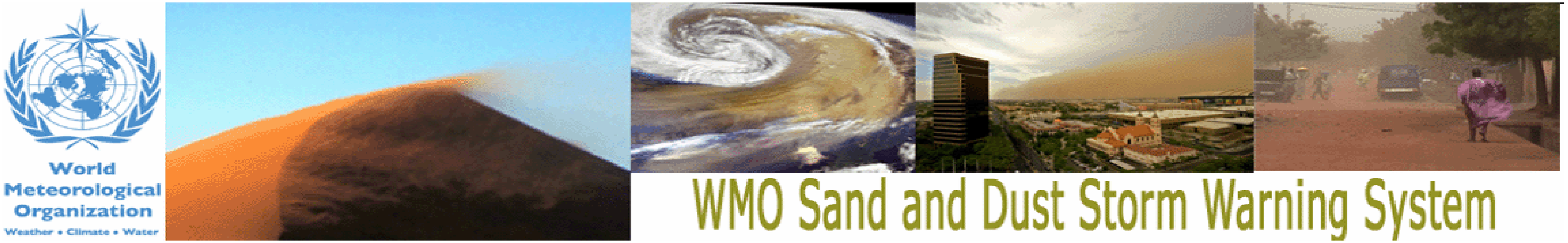
LMDzT-INCA
Atmosphere part of french IPSL climate model,
3.8°x2.8°x19 level resolution, nudged to ECMWF winds
With INCA chemistry and aerosol module,

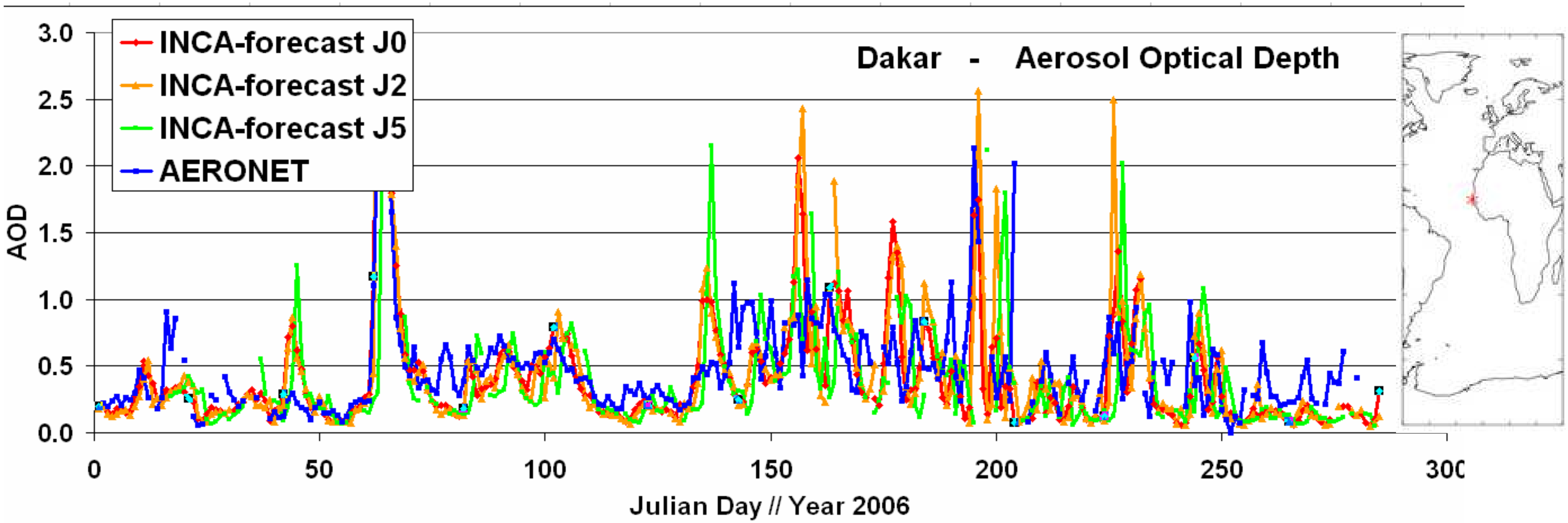
ECWMF-GEMS-AER
Forecast and Reanalysis, (MODIS AOD assimilated)

AeroCom models

Dust modeling

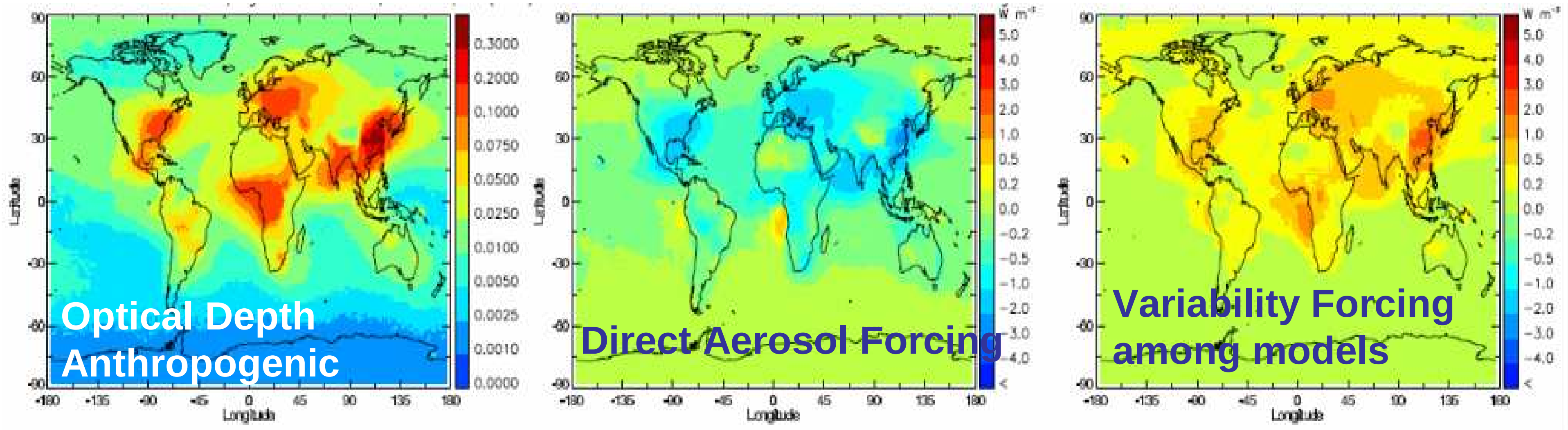






Dust forecast with LMDzT-INCA, nudged to ECMWF winds

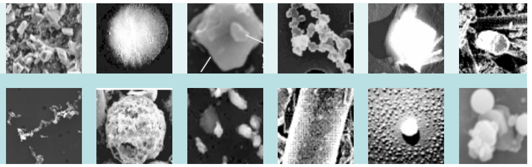
Mean aerosol direct radiative effect

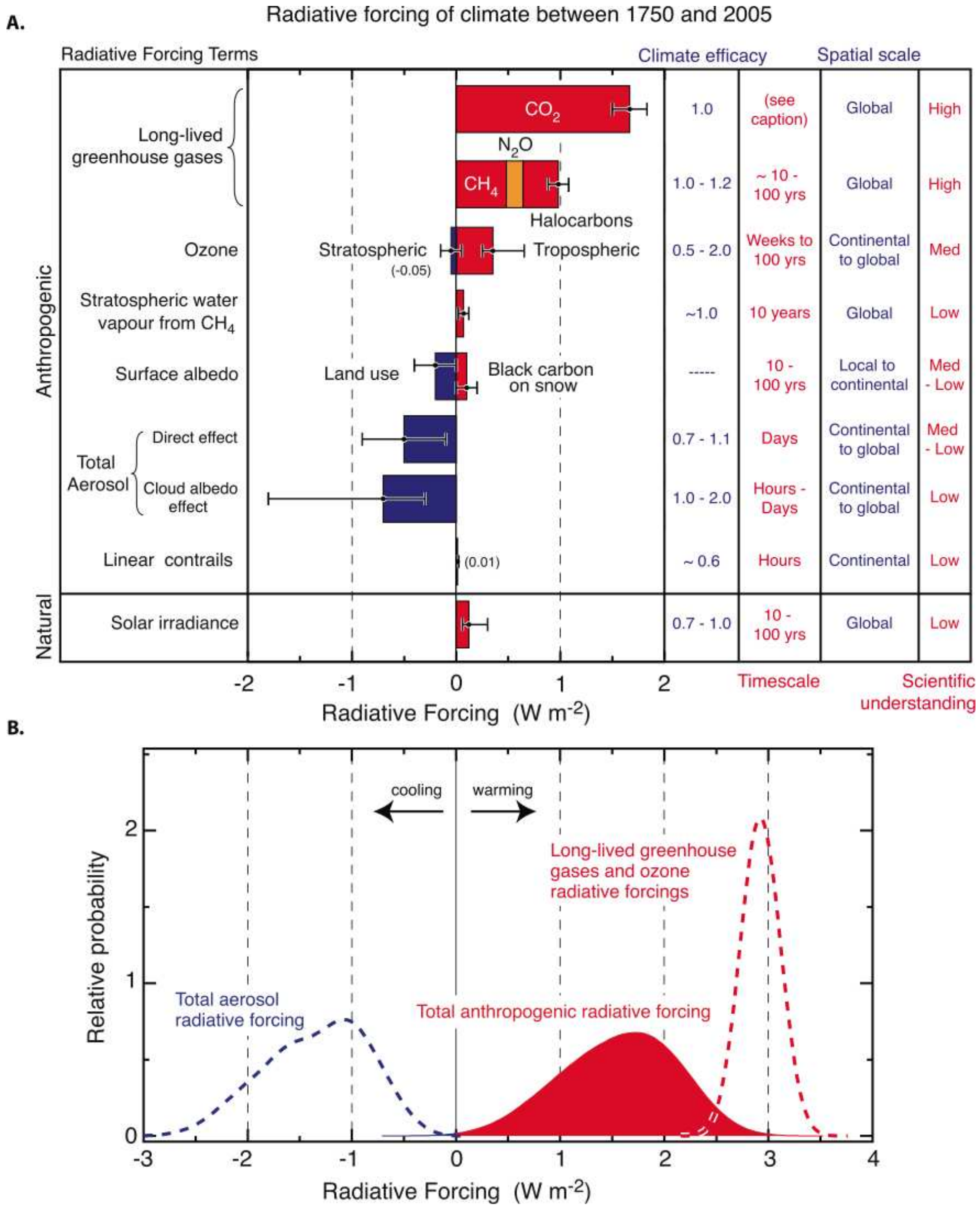


Based on multiple model simulations
Difference Current/Preindustrial emissions

4th assessment report IPCC 2007 / Schulz et al., ACP, 2006

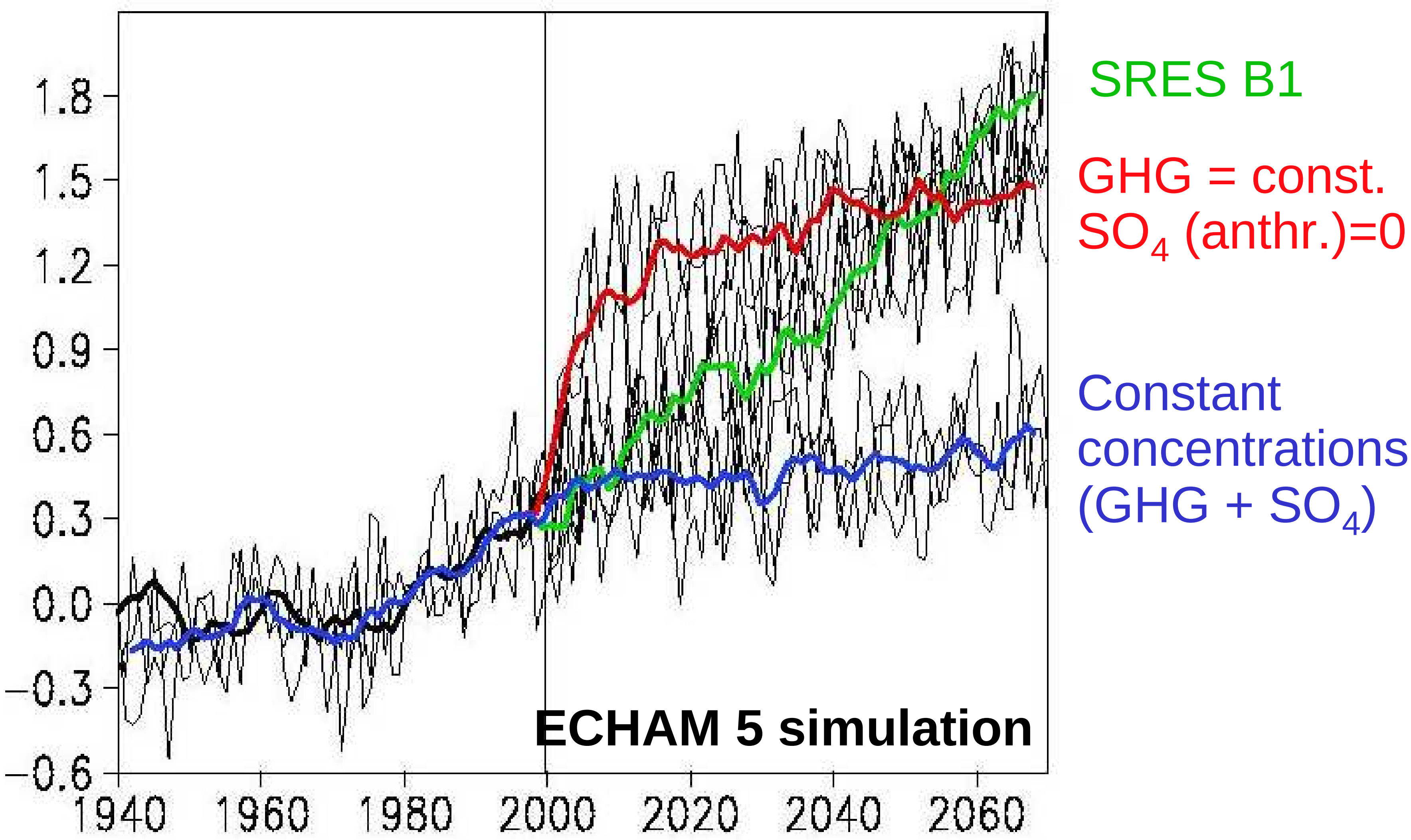
IPCC 4th assessment report





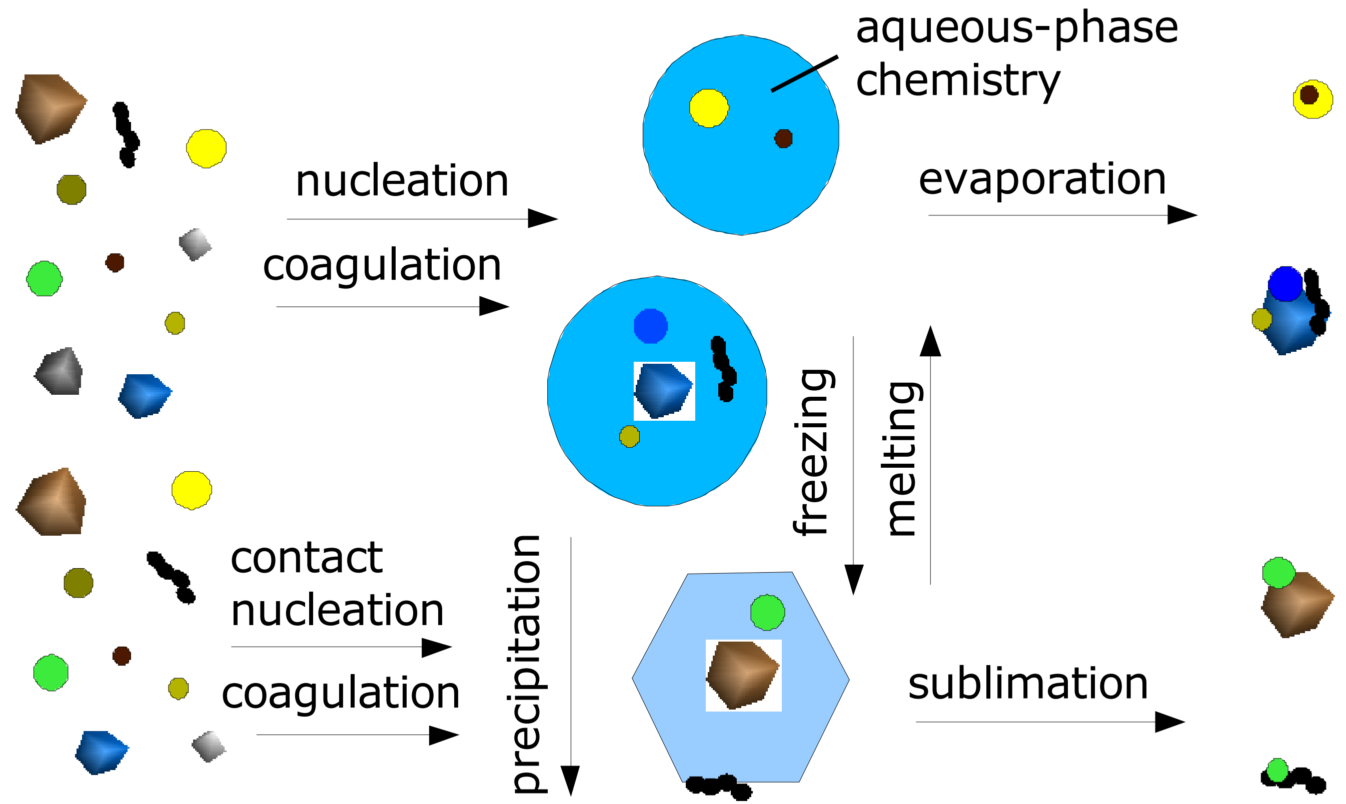
Foster et al. IPCC 2007
Haywood&Schulz, GRL, 2007

Aerosol Cooling Removed



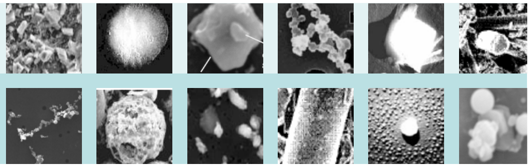
Brasseur and Roeckner, Geophys. Res. Lett., 2005

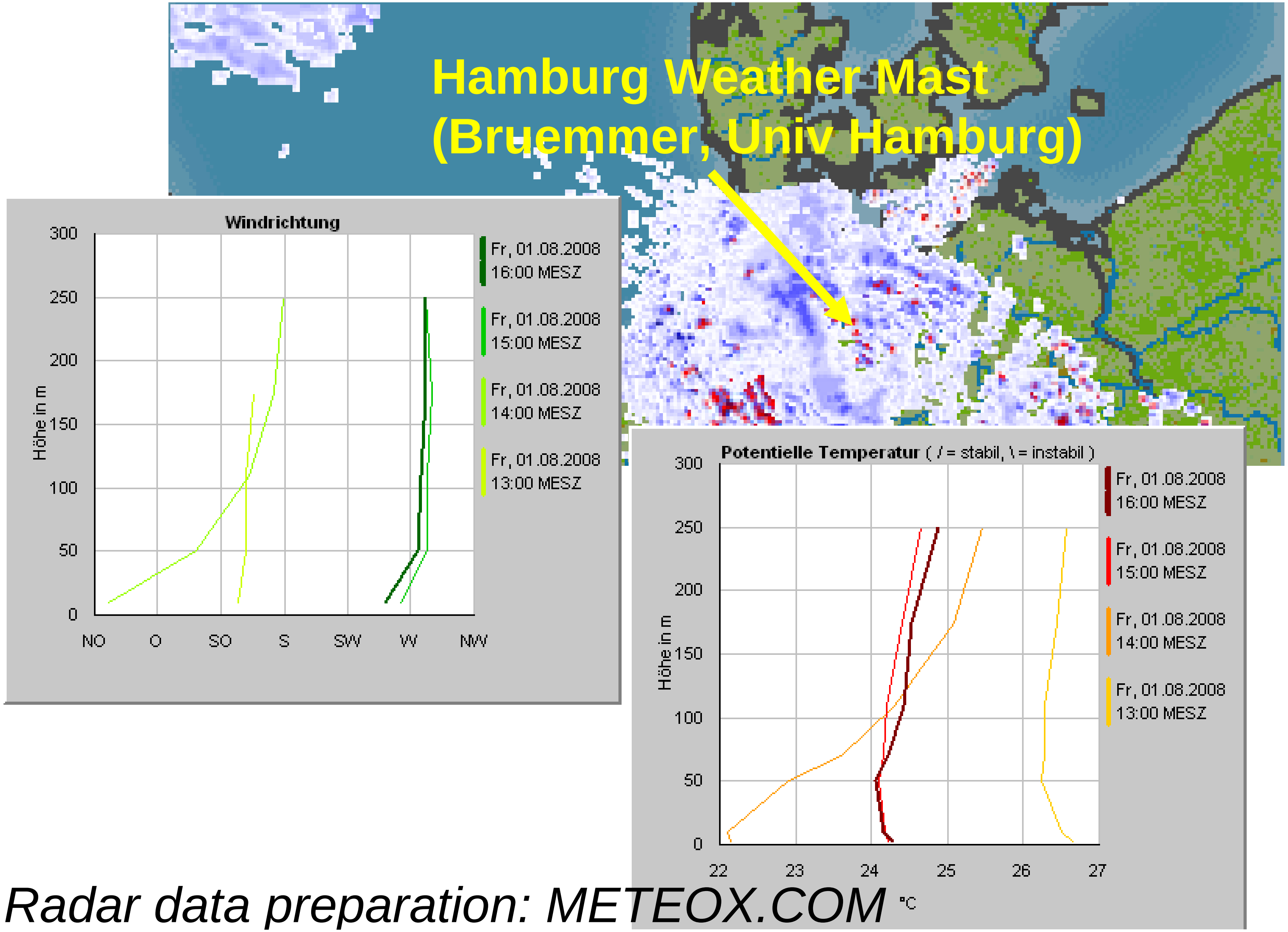
Aerosol-Cloud Interaction Processes



Lohmann et al., Atmos. Chem. Phys. Discuss., 2007

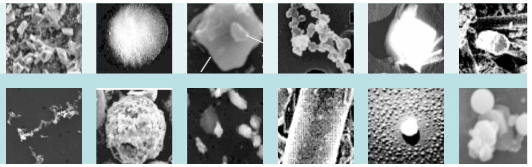
Aerosol-cloud interaction
Subjective example

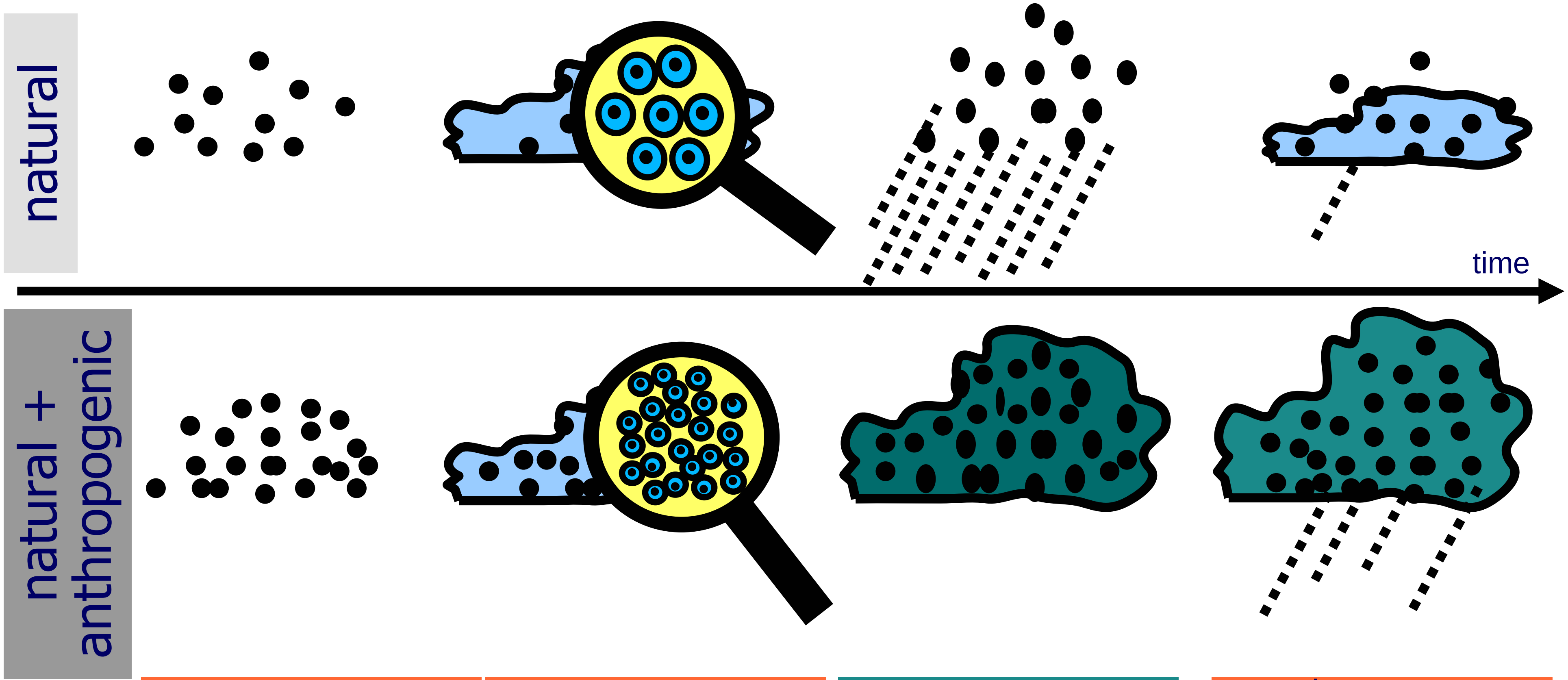




Radar data preparation: METEOX.COM

Direct and Indirect Effects of Aerosols





Direct

↑ aerosol number
↑ scattering/absorption
↑ planetary albedo

1st indirect

↑ condensation nuclei
↑ droplet number
↓ droplet size
↑ cloud albedo

cloud albedo

COD = 3/2 LWP / CDR

COD = cloud optical depth
LWP = liquid water path
CDR = cloud droplet radius

2nd indirect

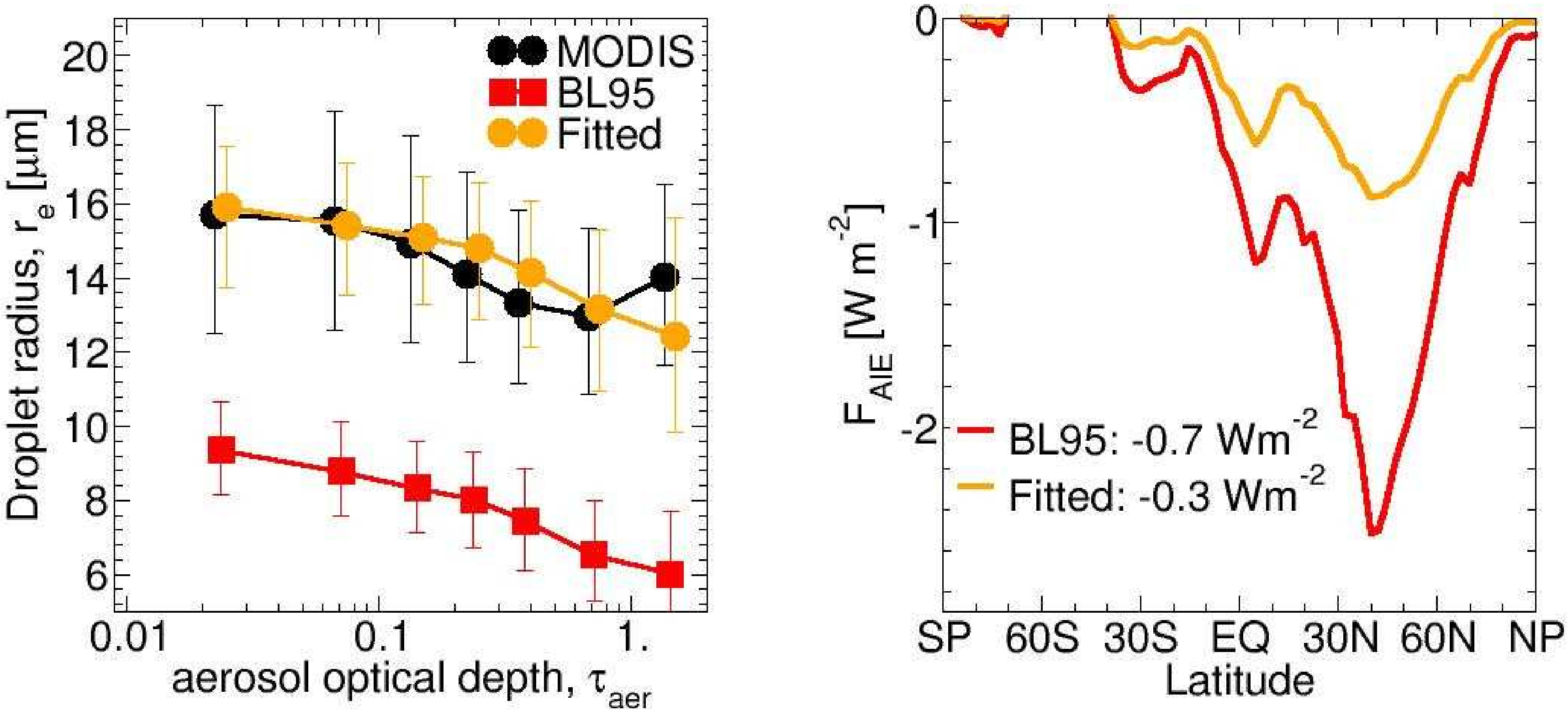
↓ droplet size
↓ rain formation rate
↑ cloud water
↑ cloud lifetime
↑ (mean) cloud albedo

Indirect Radiative Effects

Effect	Cloud type	Description
Indirect aerosol effect for clouds with fixed water amounts (cloud albedo or Twomey effect)	All clouds	The more numerous smaller cloud particles reflect more solar radiation
Indirect aerosol effect with varying water amounts (cloud lifetime effect)	All clouds	Smaller cloud particles decrease the precipitation efficiency thereby prolonging cloud lifetime
Semi-direct effect	All clouds	Absorption of solar radiation by soot may cause evaporation of cloud particles
Thermodynamic effect	Mixed-phase clouds	Smaller cloud droplets delay the onset of freezing
Glaciation indirect effect	Mixed-phase clouds	More ice nuclei increase the precipitation efficiency
Riming indirect effect	Mixed-phase clouds	Smaller cloud droplets decrease the riming efficiency

Lohmann and Feichter, Atmos. Chem. Phys., 2005

First Indirect Effect « Constrained »



LMDz simulation

MODIS satellite observations

Quaas and Boucher, Geophys. Res. Lett., 2005

Why should we care about the aerosol ?

Significant regional direct radiative effects

Alteration of the temperature profil due to absorbing aerosol

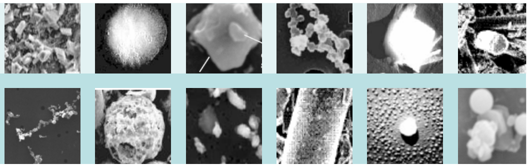
Modification of cloud structure and properties

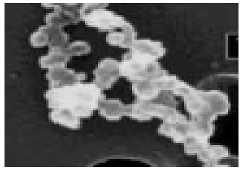
Climate effect of changes in aerosol emissions

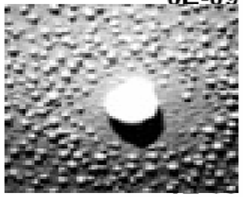
Visibility, regional pollution, health effects

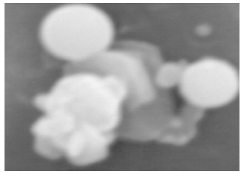
Large uncertainty in model simulation of effects

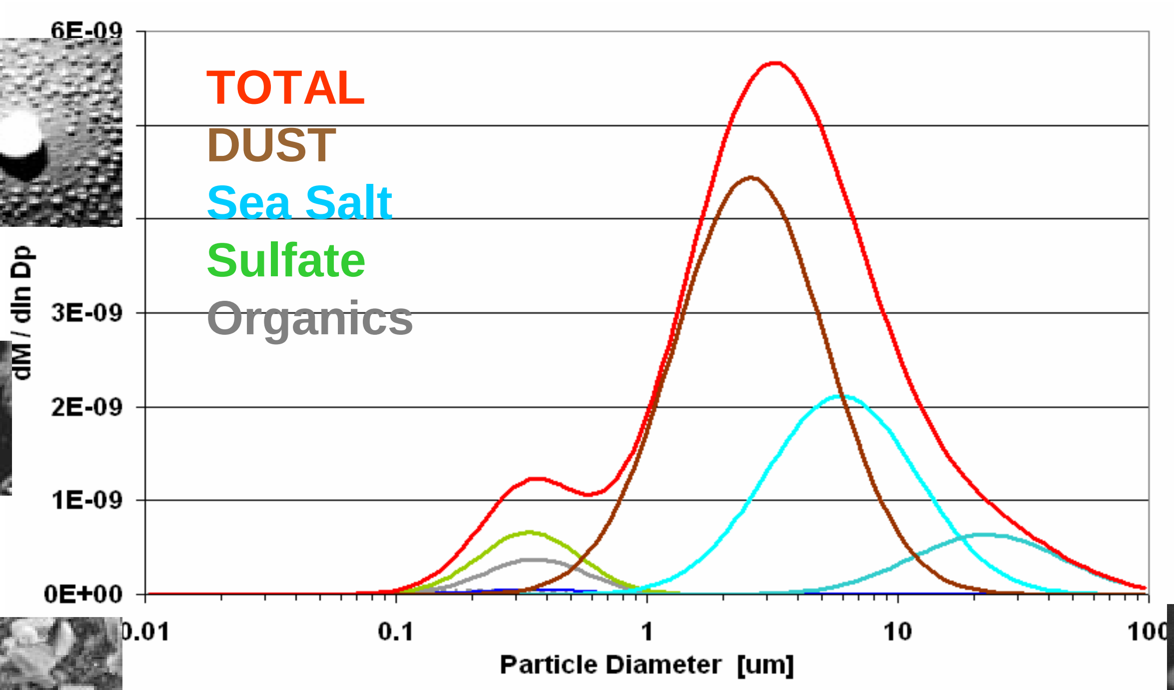
Representing aerosol in a global model

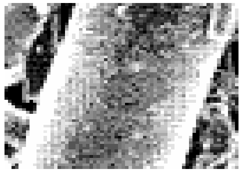


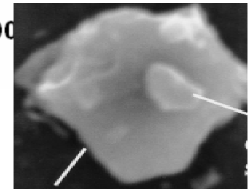


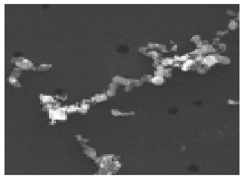


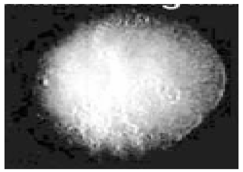


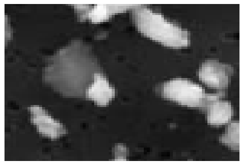




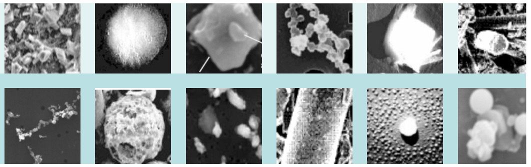








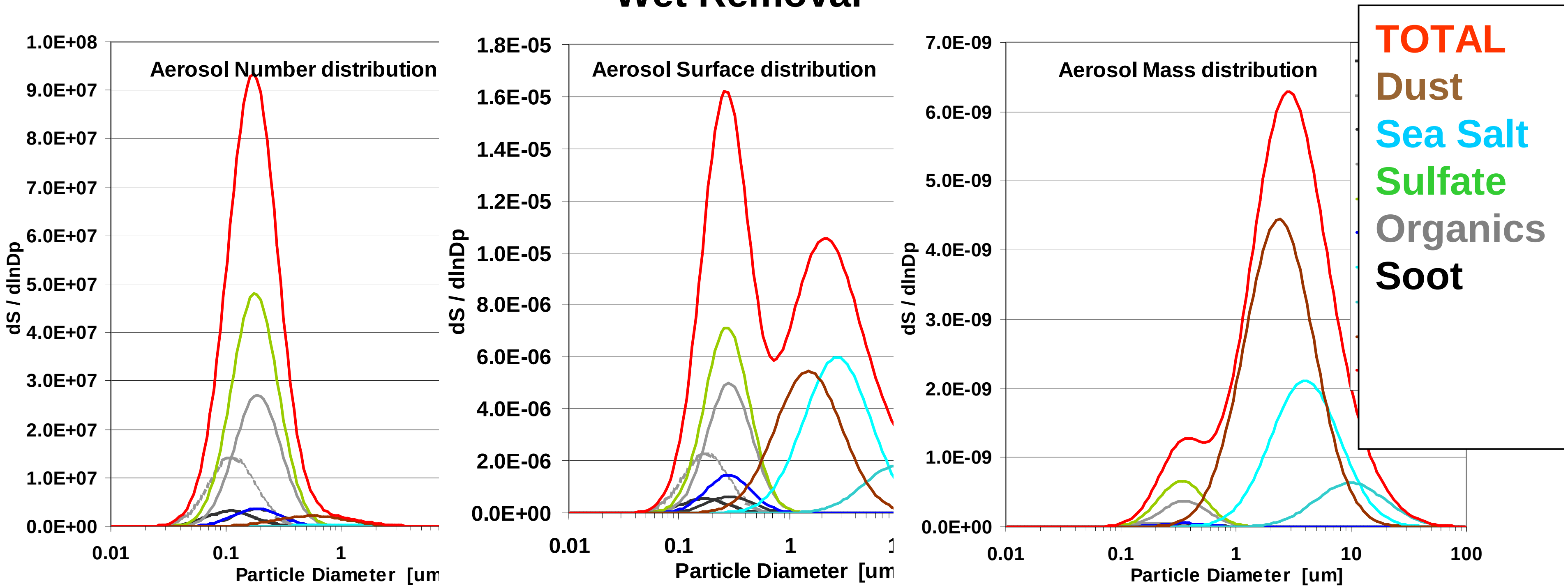
Only Size matters ! ?



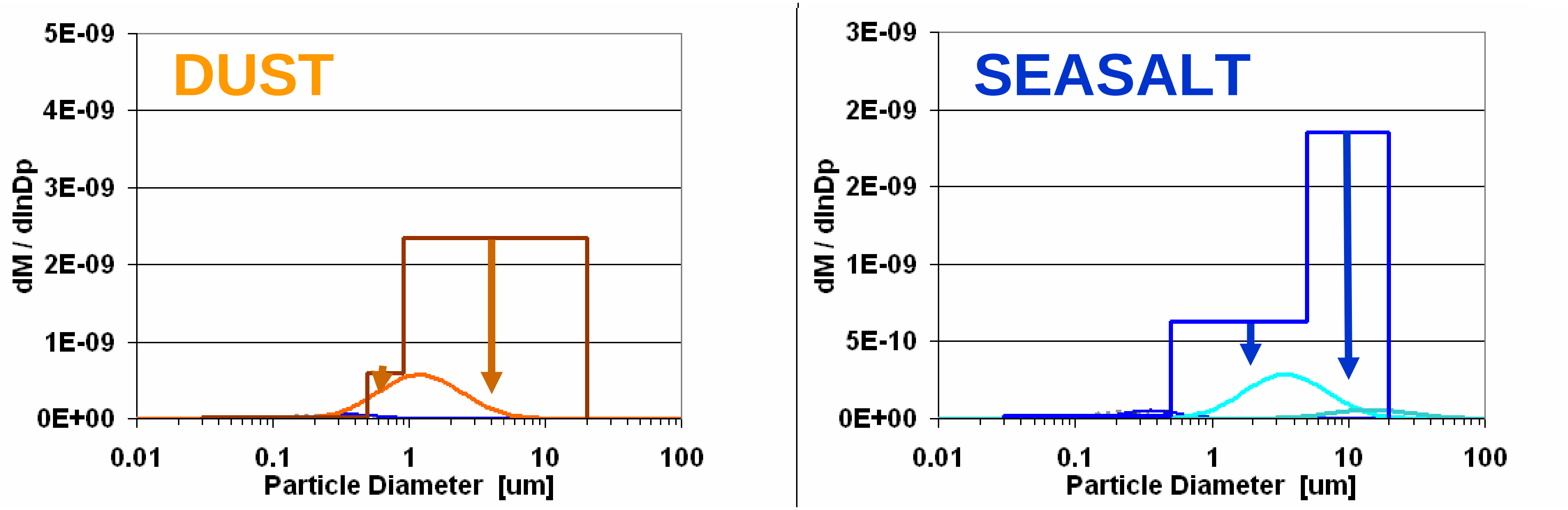
NUMBER =>
Cloud nuclei
Lung Infiltration

SURFACE=>
Scattering
Absorption
Het. Chemistry
Wet Removal

MASS=>
Sedimentation
Acidity



Bin versus modal size distribution

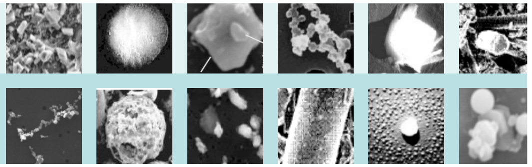


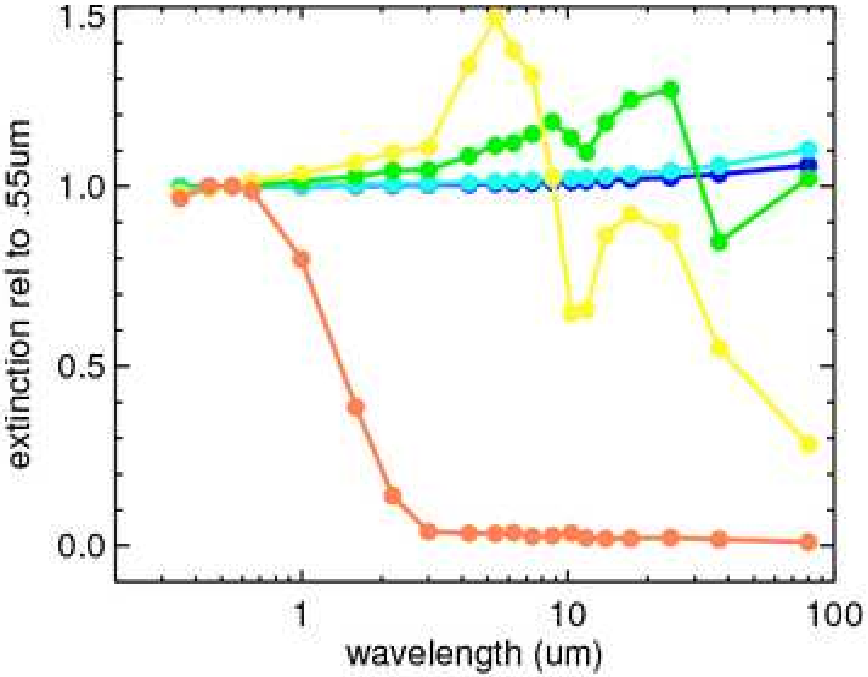
Bins=> | 1 |2| 3 | | 1 | 2 | 3 |

ECMWF aerosol model bin choices

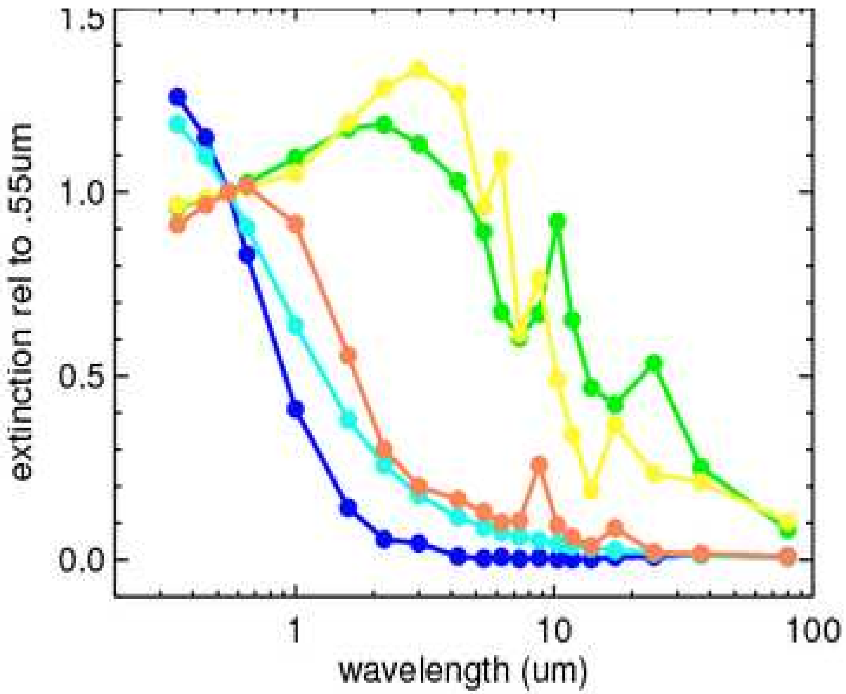
Lognormal Distributions as in LMDzT-INCA model

Extinction f(wavelength)



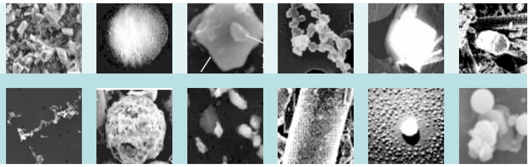


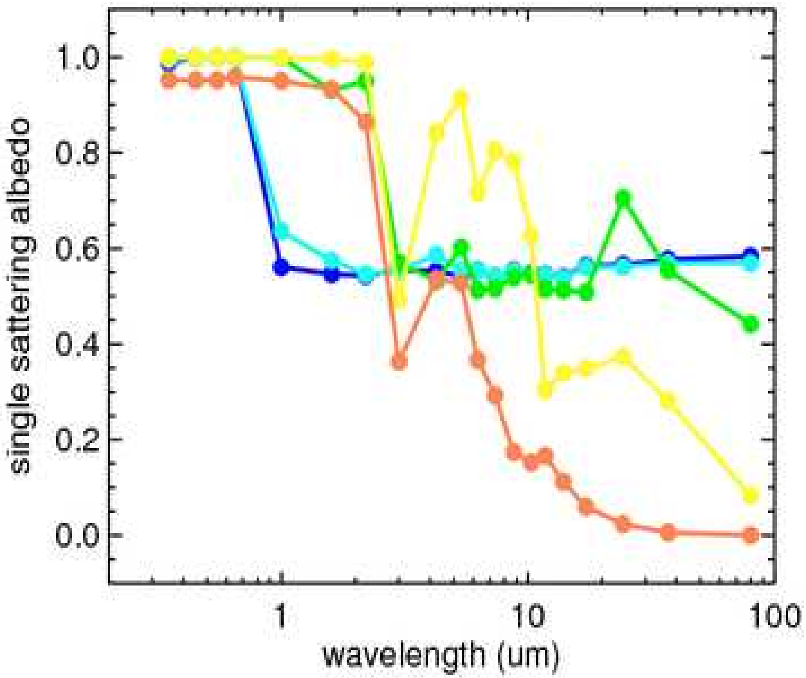
- heavy rain
- light rain
- ice cloud
- water cloud
- pollution



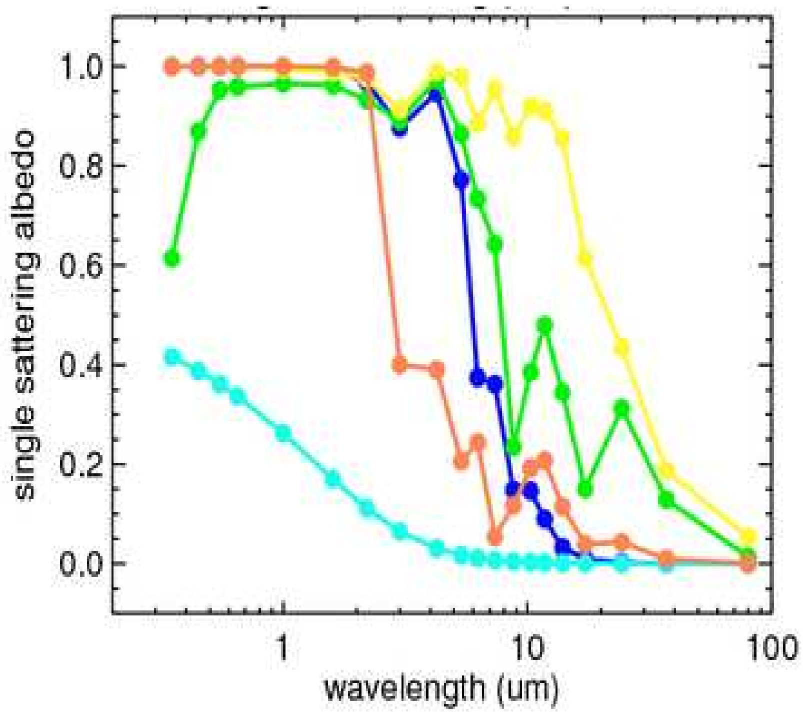
- sulfate
- black carbon
- dust
- sea-salt
- volcanic

Single scattering albedo f(wavelength)



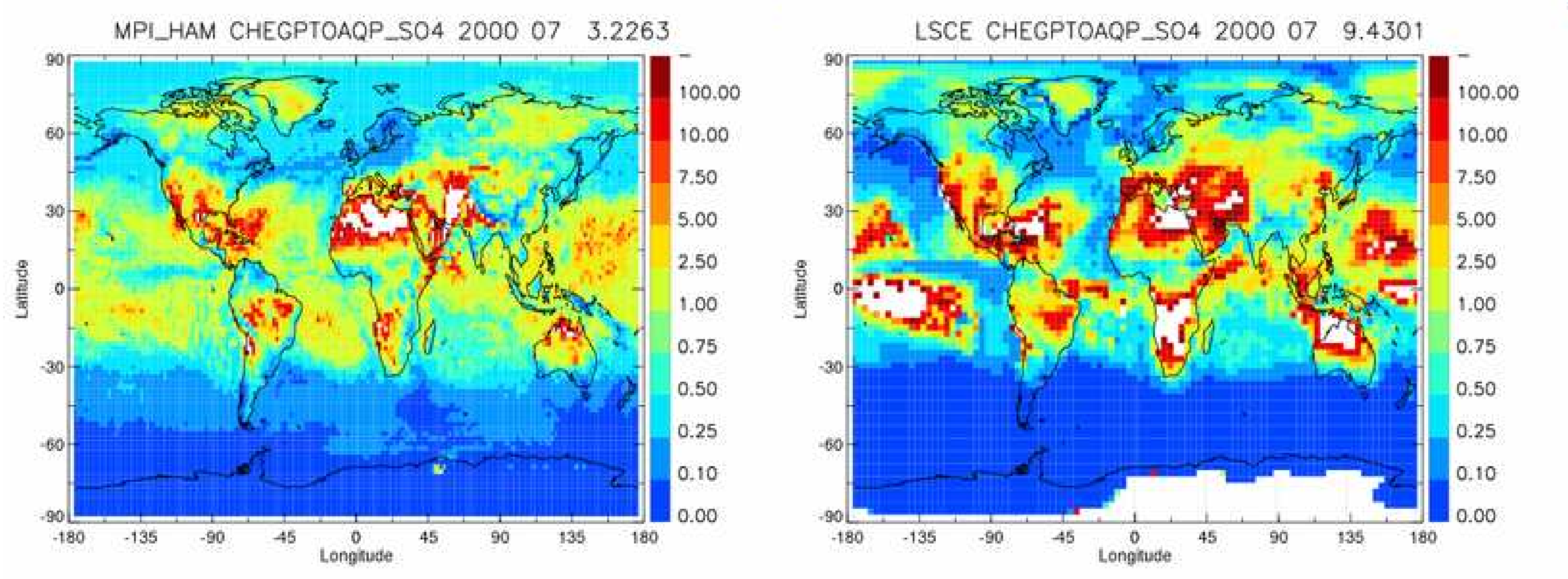


heavy rain
light rain
ice cloud
water cloud
pollution



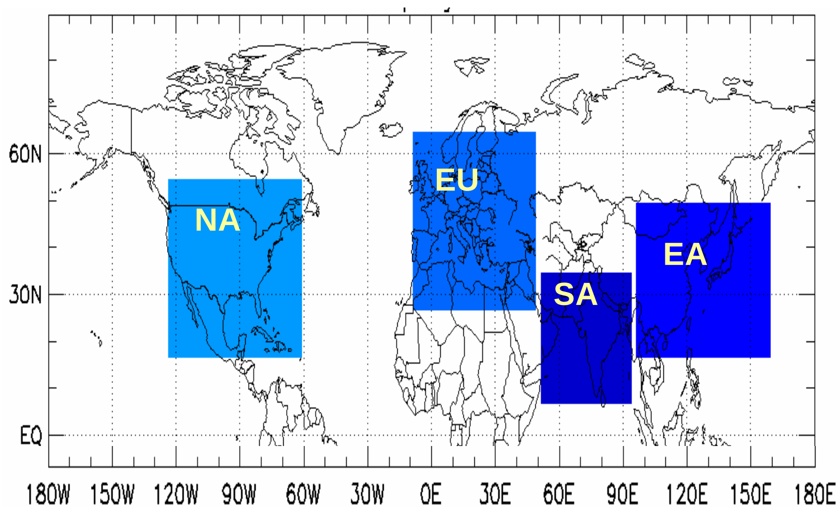
sulfate
black carbon
dust
sea-salt
volcanic

Ratio gas phase over aqueous phase production of Sulphate in ECHAM-HAM and LMDzT-INCA



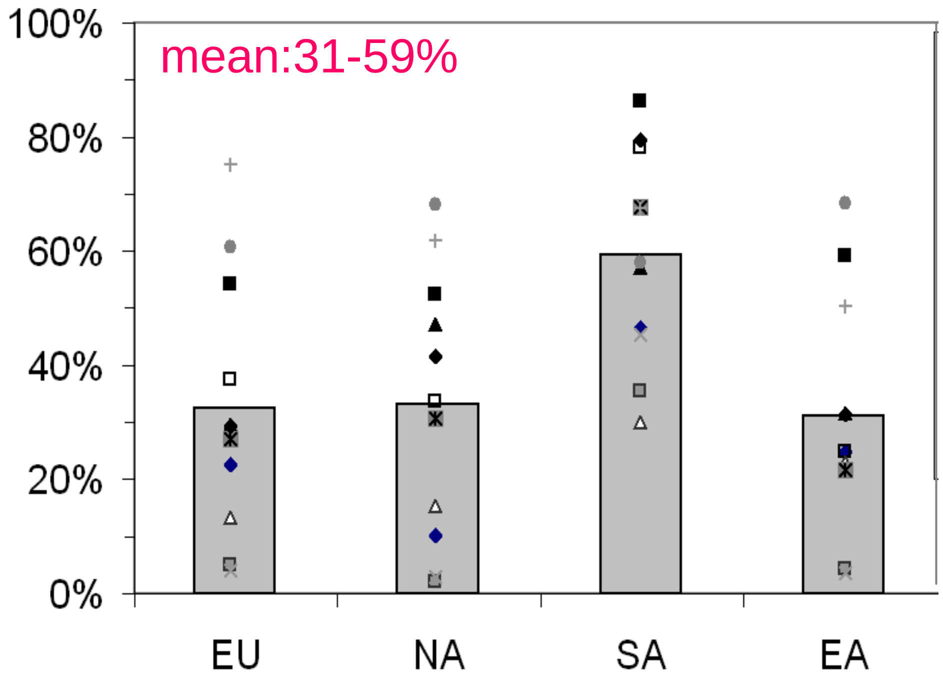
July 2000

UNECE Task force model experiments
Hemispheric Transport of Air Pollution

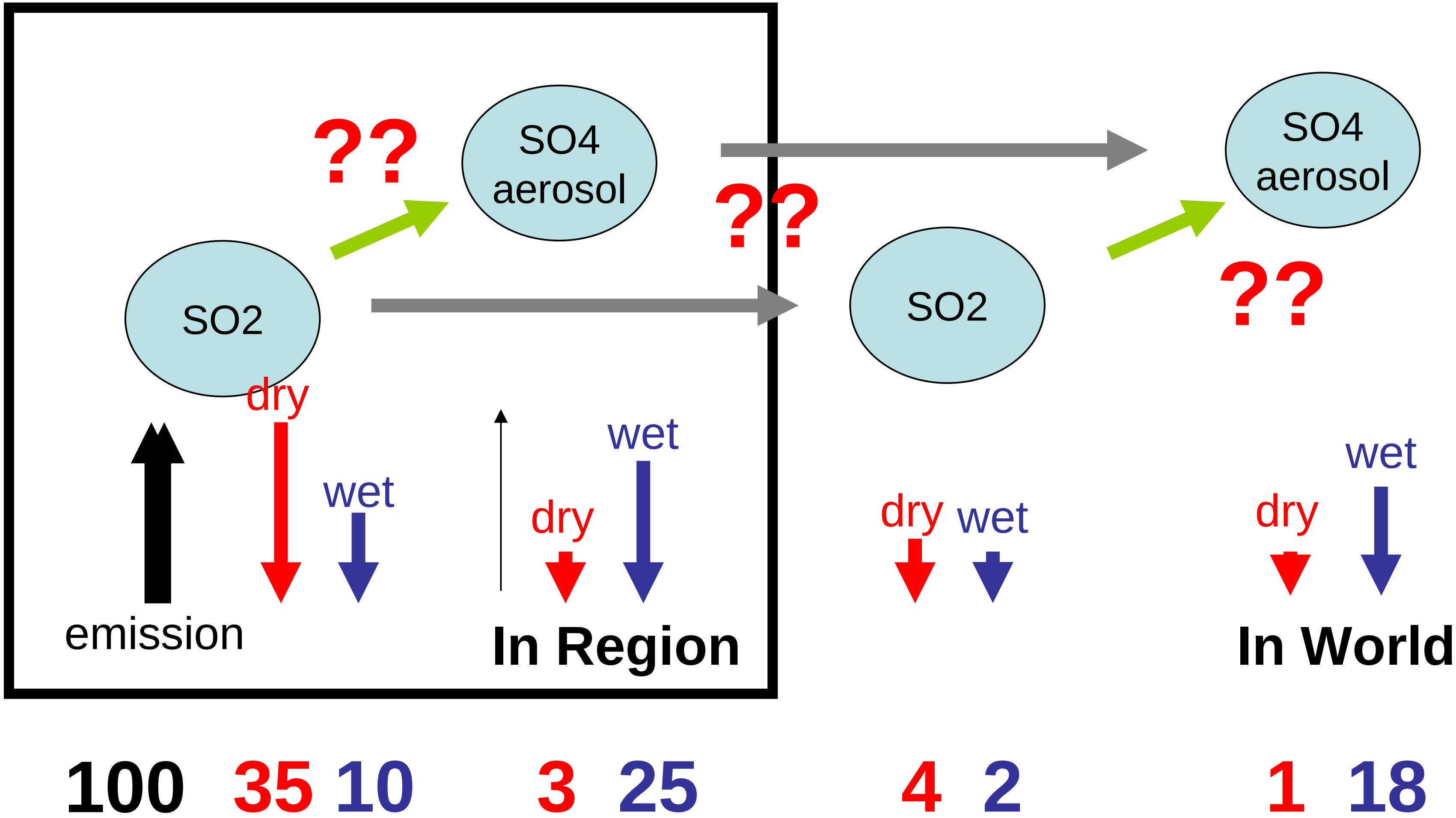


Source & Target Regions

Total sulfate column load imported into target region

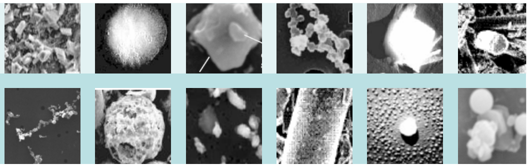


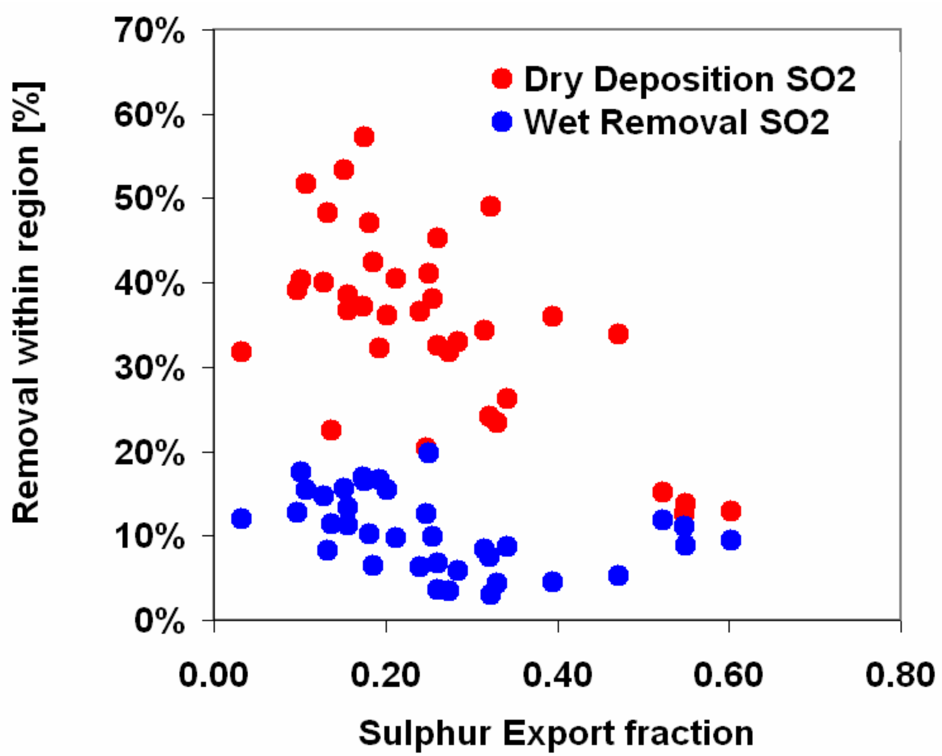
Average Sulphur Budget derived from HTAP model simulations

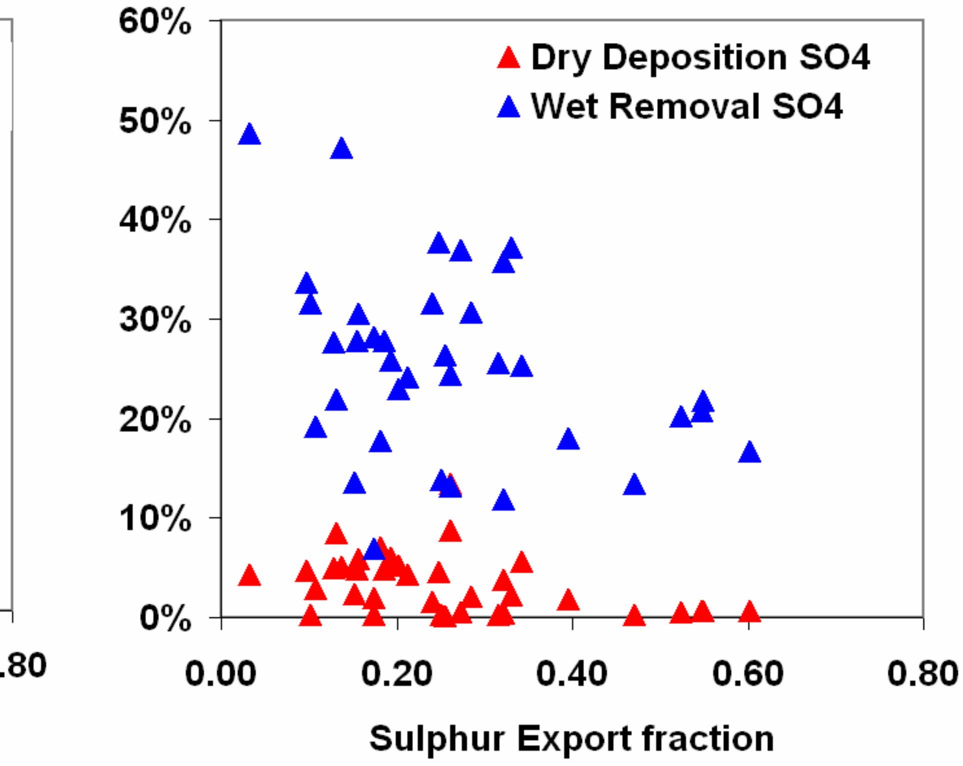


Sulphur Flux contributions [%]

Example for coupled processes within sulfate budget







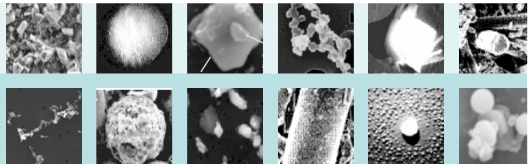
Why exhibits the removal of Sulphate and SO2 within region a relatively high scatter?

=> Differences in wet removal parameterization ?

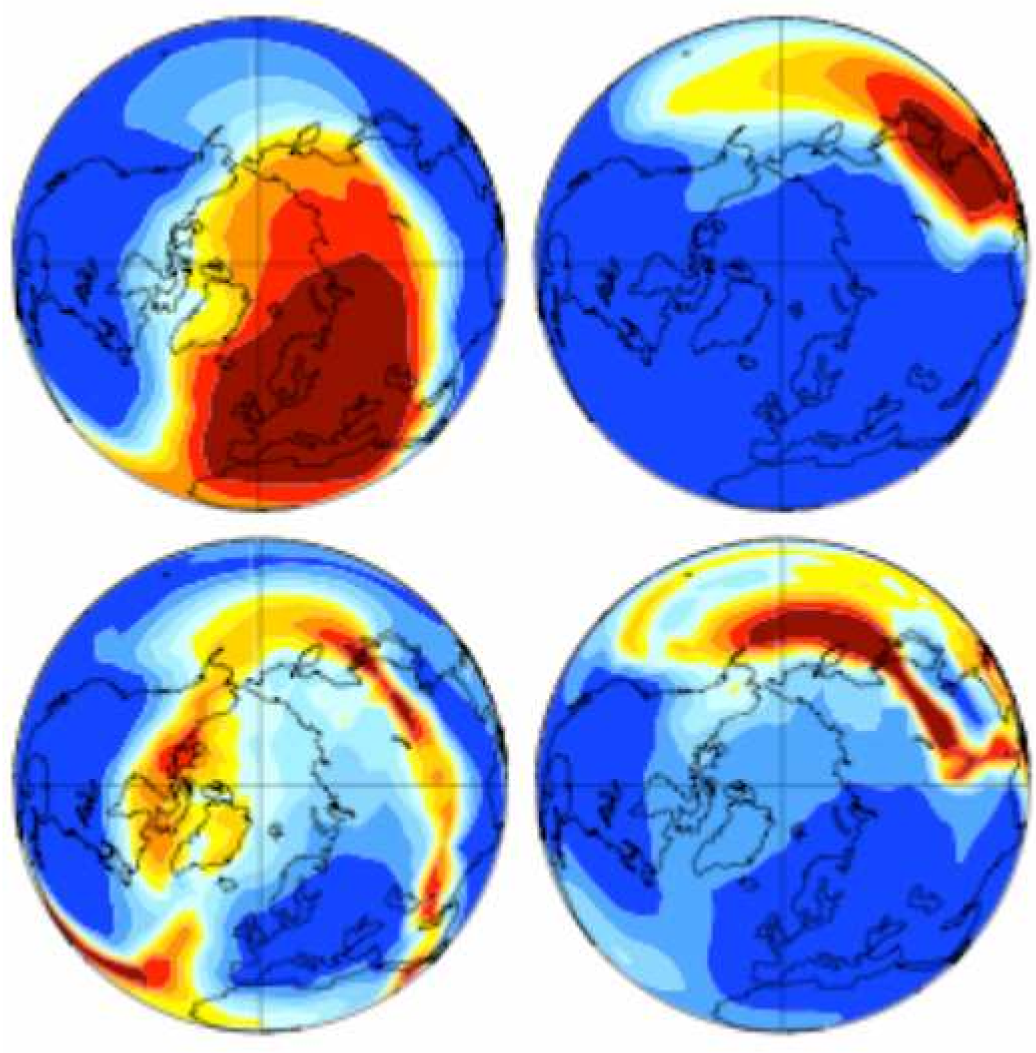
⇒ Differences in precursor SO2 dry deposition ?

⇒ Differences in SO2=> SO4 conversion ?

Winter Arctic surface concentrations



Europe **East Asia**

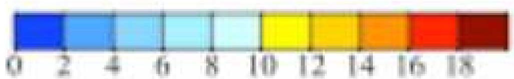


Mean contribution from region EU/EA to black carbon surface concentration

%

Standard Deviation among 8 HTAP model simulations

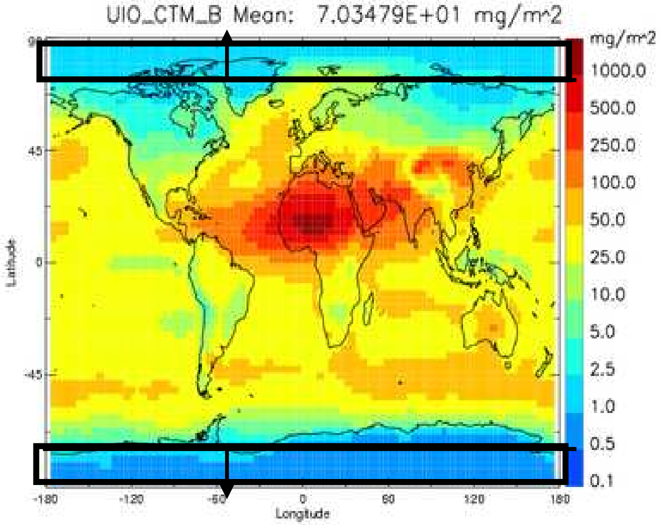
%



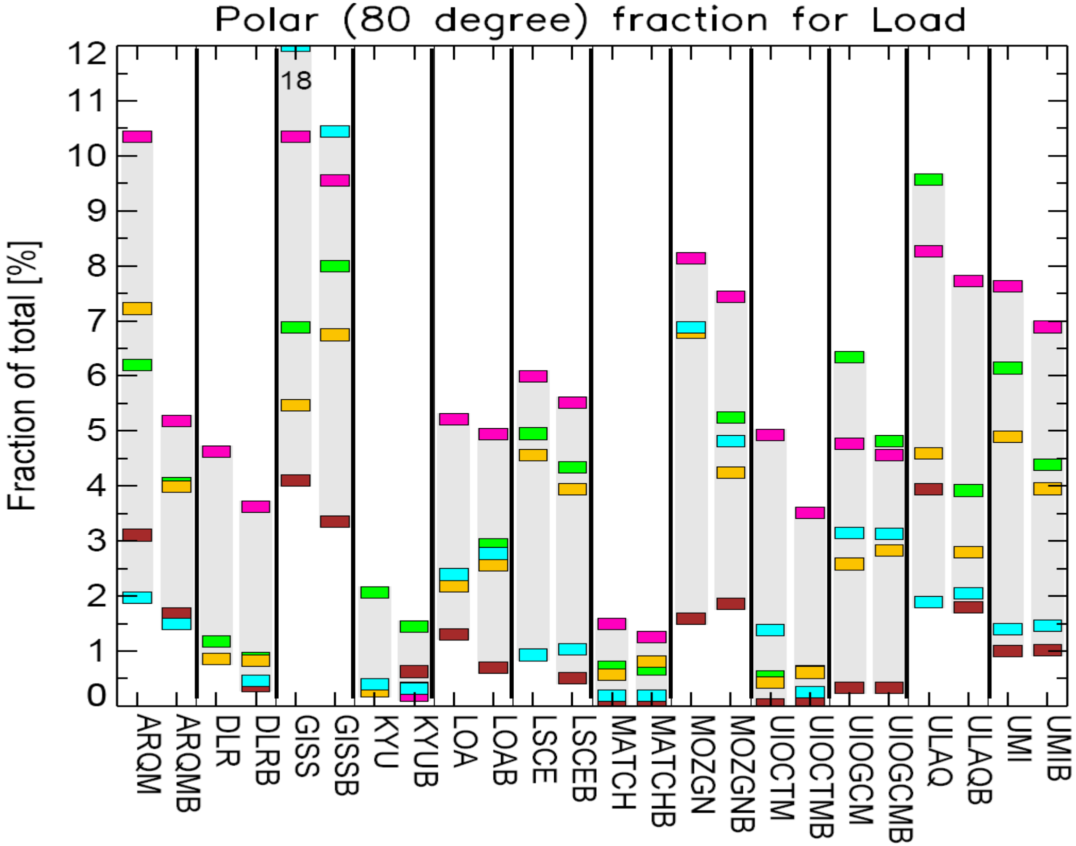
Shindell et al. ACP 2008

Meridional Aerosol Distribution

Aerosol Load



Mass fraction of components in polar region (>80°N+S) in two model experiments per model

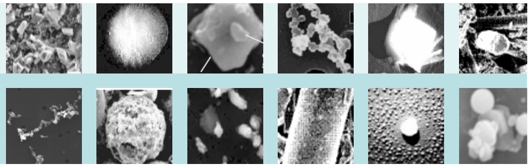


Sulfate
Partikulate Organic Matter
Black Carbon
Seasalt
Mineral dust

Experiment A model as is
Experiment B harmonized emission

Textor et al. 2006

Decomposing reasons for diversity in modelled forcing



Precursor emissions (SO_2, NO_x, VOC)

chemical production, condensation

Primary aerosol emissions (BC, POM, dust, sea salt)

↓ Residence times
Transport, dispersion, wet and dry deposition

Aerosol Loads

↓ Optical properties
Mass extinction/absorption coefficient

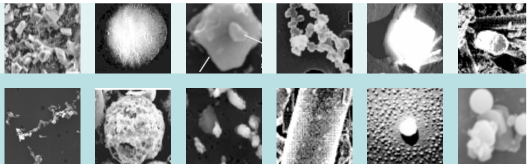
Aerosol Optical Depth

↓ Forcing efficiency per unit optical depth
Single scattering albedo
Hemispheric Backscatter
Vertical Distribution of aerosol
Cloud and aerosol position

Direct radiative forcing

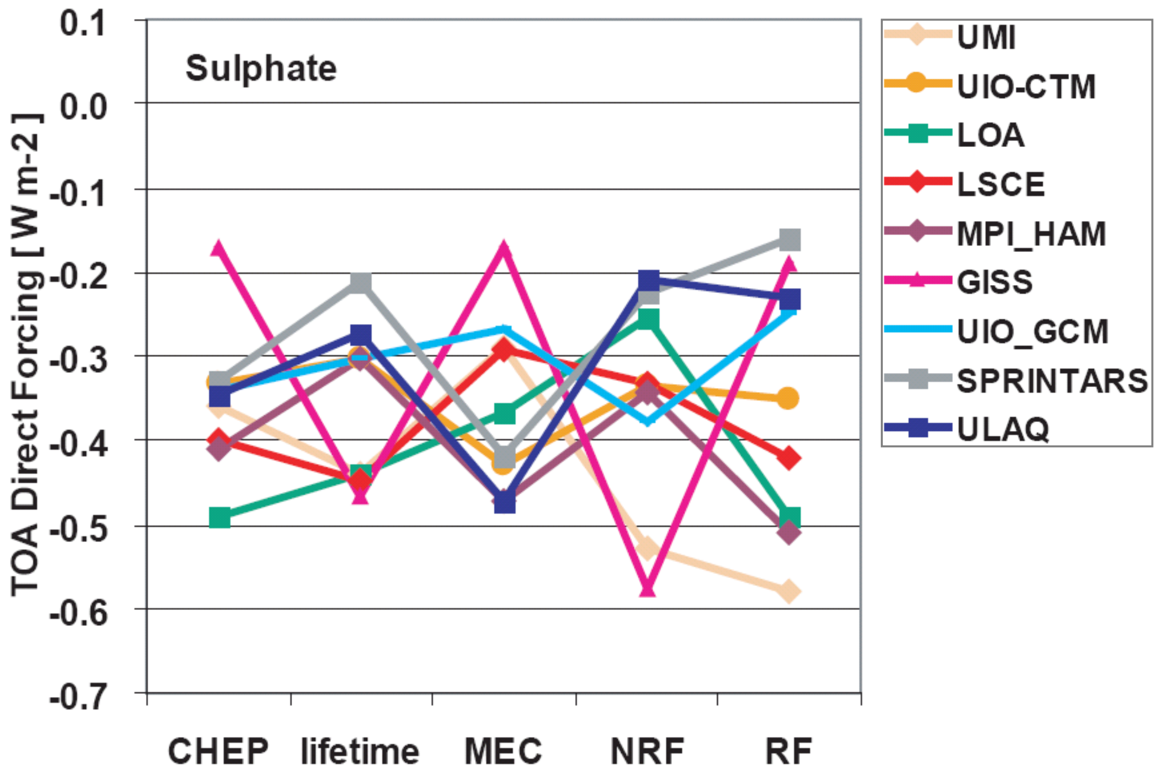
↕ Interdependence of processes ??

Partial sensitivity analysis of impact of different properties on forcing estimate



Forcing (RF)
= function (chemical production (CHEP) x lifetime
x extinction coefficient (MEC) x forcing efficiency (NRF)

How much would the simulated forcing vary,
if it depended on the variations of only one factor?

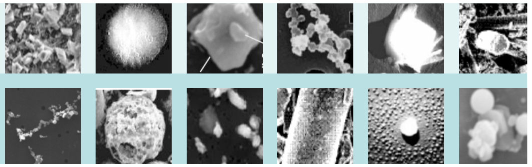


RF weighted with the relative deviation of the individual model results from the model mean for 5 factors

⇒ diversity (=uncertainty?) only ca. +- 0.2 W/m2

Schulz et al. 2006

Summary
How to represent the global aerosol in a model



We need to get it right for multiple problems

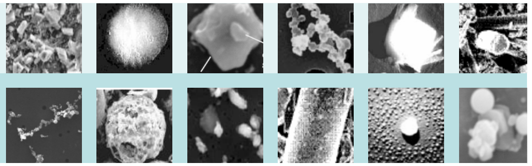
Emissions
Chemical Reactions
Size
Aerosol dynamics
Composition
Hygroscopicity
Optical properties
Aerosol-cloud Interactions (cloud properties, wet removal)
Dry removal
Transport

Evaluating aerosol models

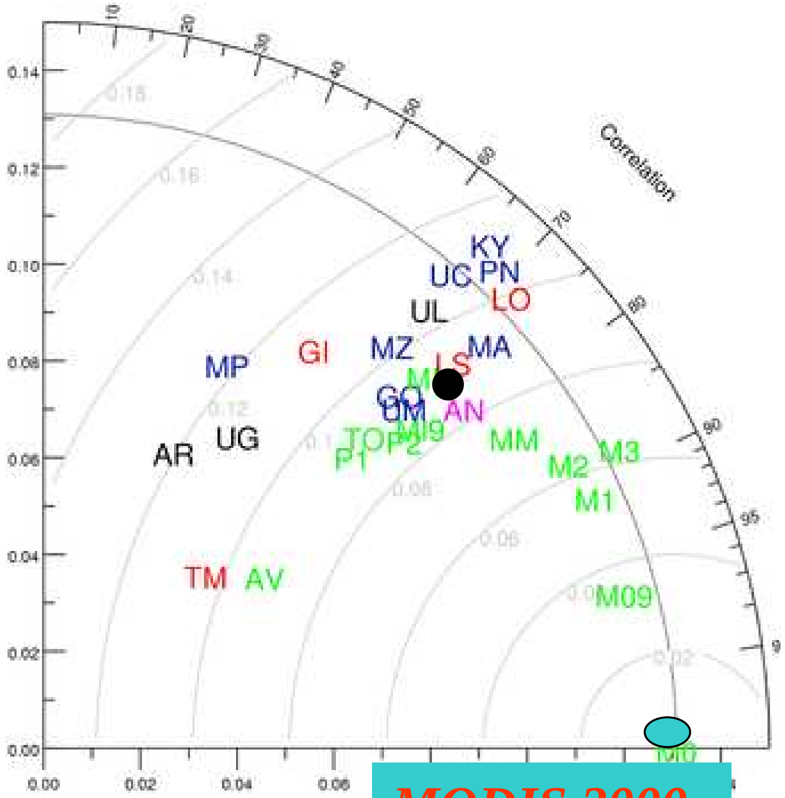
Methods to obtain observational records

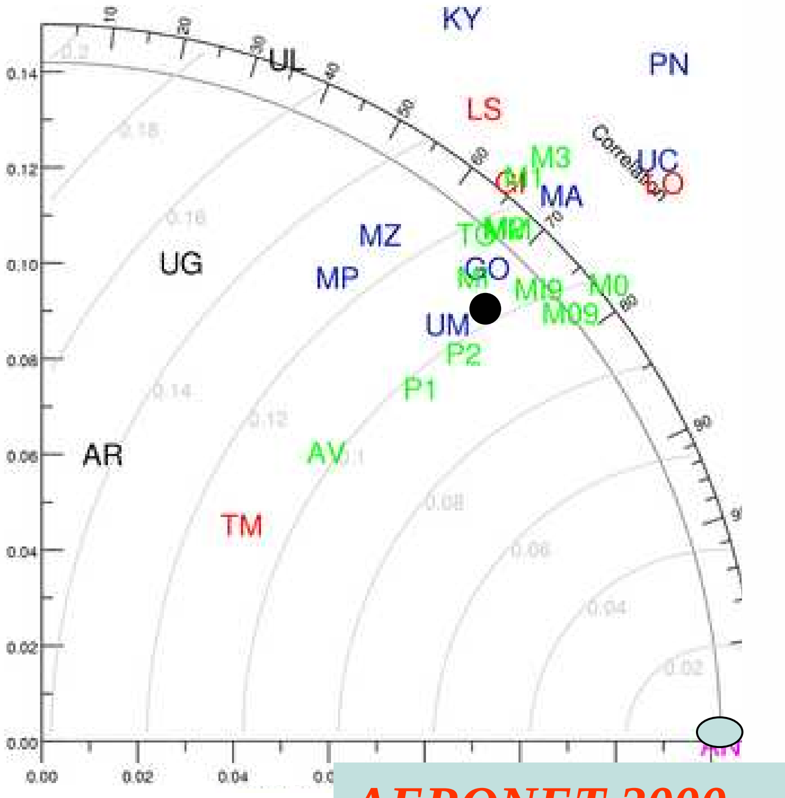
Chemical analysis of filter substrate, mass spectrometer
Size distribution by inversion of optical data
Electro+mechanical separation prior to detection
Condensation of vapour on particles prior to detection
Gravimetry of aerosol mass
Wet deposition collection and analysis
Light extinction & absorption measurement (sun light or lamp)
Satellite imagery and retrieval
Lidar detection of aerosol backscatter
Ice core chemical analysis

Models and Satellites against MODIS 2000 and Aeronet



- ● Median AeroCom model





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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
M1: MODIS_2001
M2: MODIS_2002
M3: MODIS_2003
M09: MODIS_9999
MM: MODMIS_2000
MZ: MOZGN_2000
MP: MPI_HAM_200
PN: PNNL_2000
P1: POLDER_1997
P2: POLDER_2003
TM: TM5_B_2000
TO: TOMS_9999
UC: UIO_CTM_200
UG: UIO_GCM_999
UL: ULAQ_9999
UM: UMI_2000

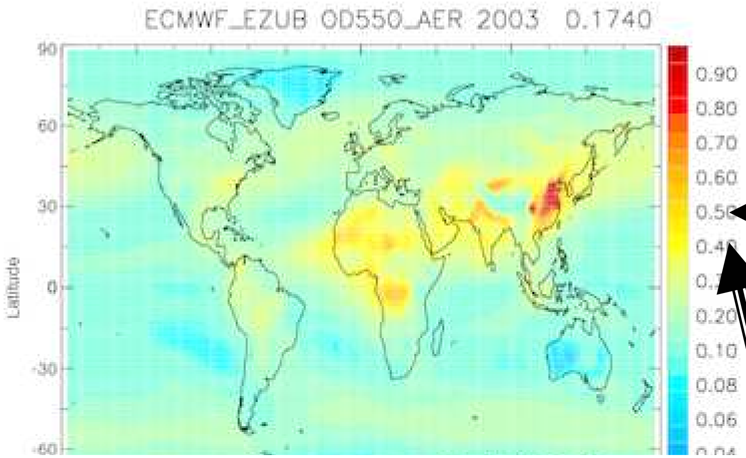
GREEN : satellite retrievals

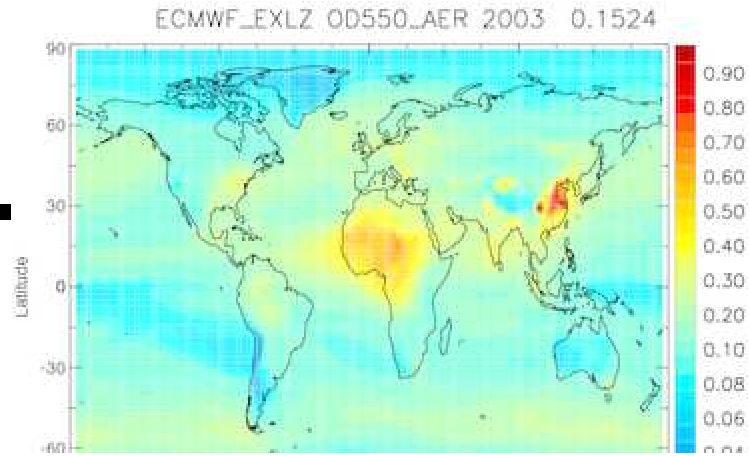
Blue/Red/Black : models

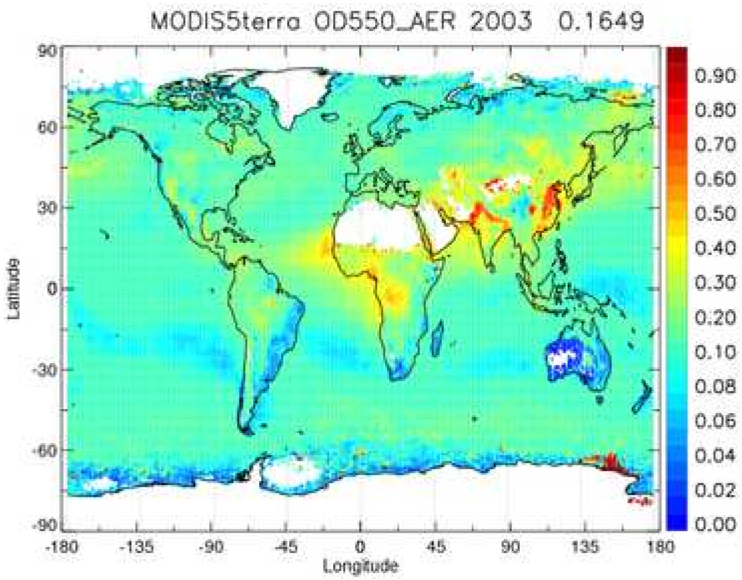
AOD fields by assimilation of satellite data

ECMWF Reanalysis
Modis AOD assimilation

ECMWF forecast 00h







MODIS satellite derived AOD

Annual averages 2003

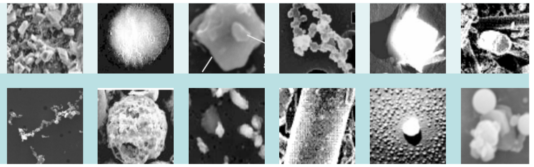
Acknowledgment Benedetti/Morcrette

Model Evaluation with Aeronet sun photometers

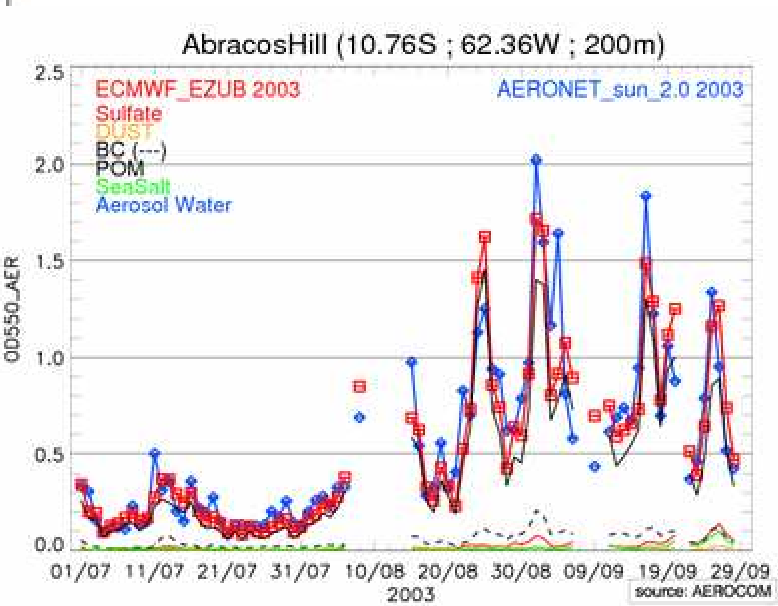
	Reanalysis	Forecast	Aeronet
Mean AOD	0.242	0.218	0.215
Correlation	0.86	0.71	
RMS	0.093	0.123	
Std Mod/Obs	0.79	0.75	
Month Bias	32%	39%	

Based on # 1280 monthly means in 2003
from worldwide Aeronet network
no mountain sites

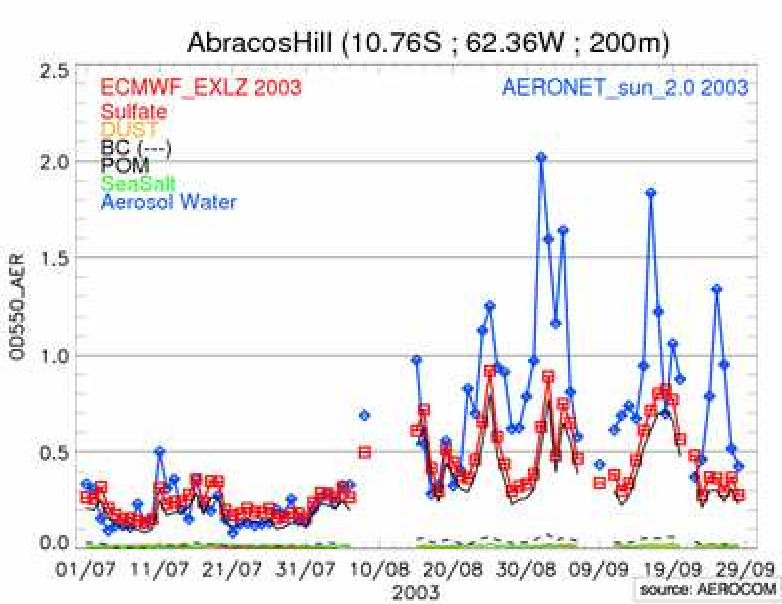
Model Evaluation with Aeronet sun photometers



Biomass burning aerosols



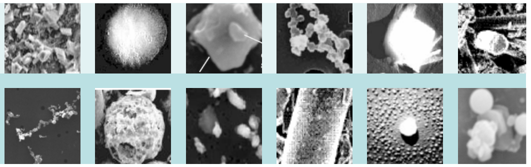
ECMWF Reanalysis
Modis AOD assimilation



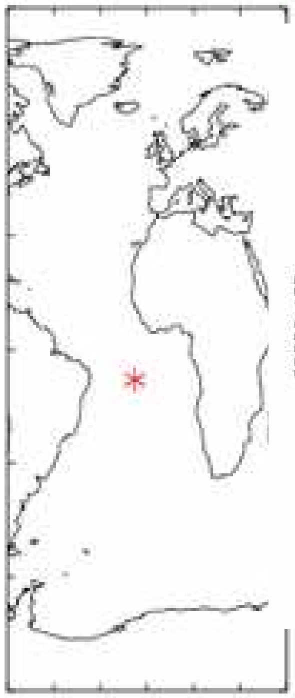
ECMWF forecast 00h

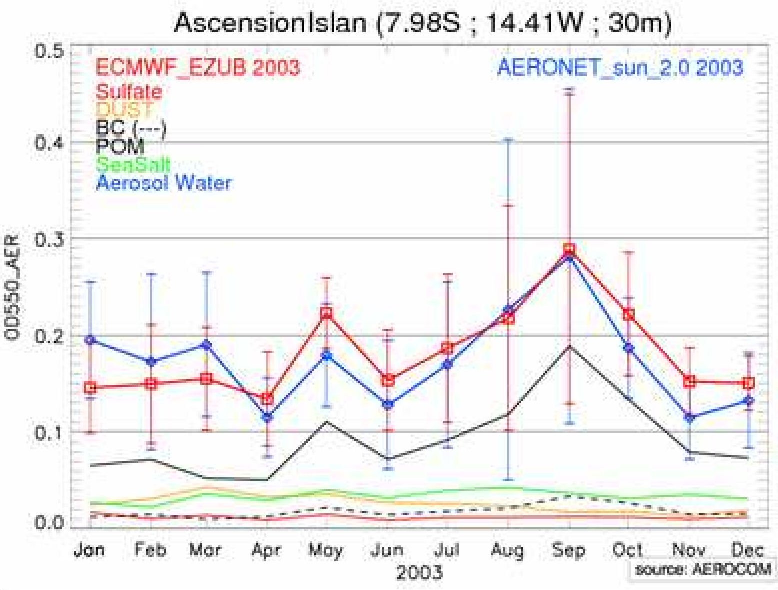
Against Aeronet sun photometer AOD obs

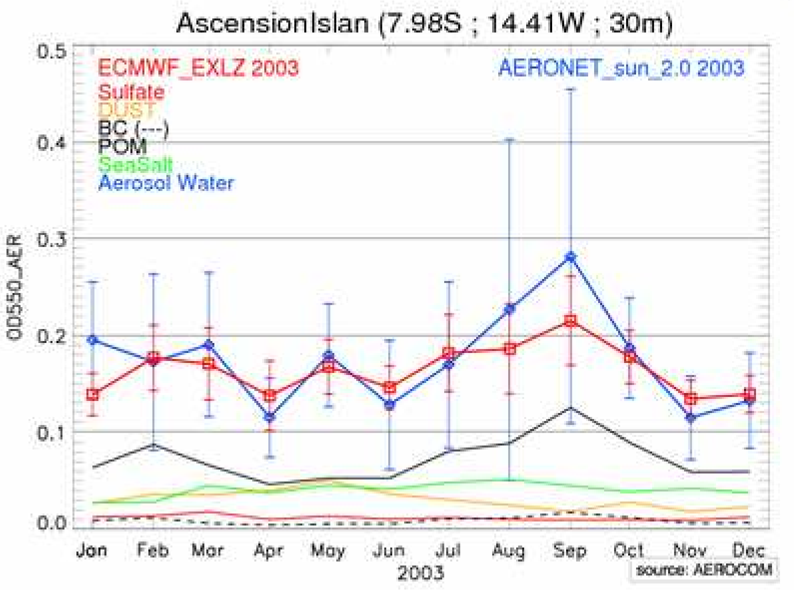
Model Evaluation with Aeronet sun photometers



Biomass burning aerosols





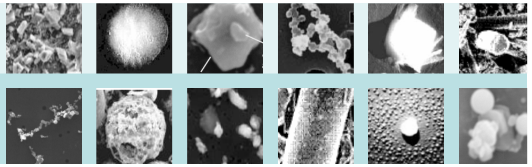


ECMWF Reanalysis
Modis AOD assimilation

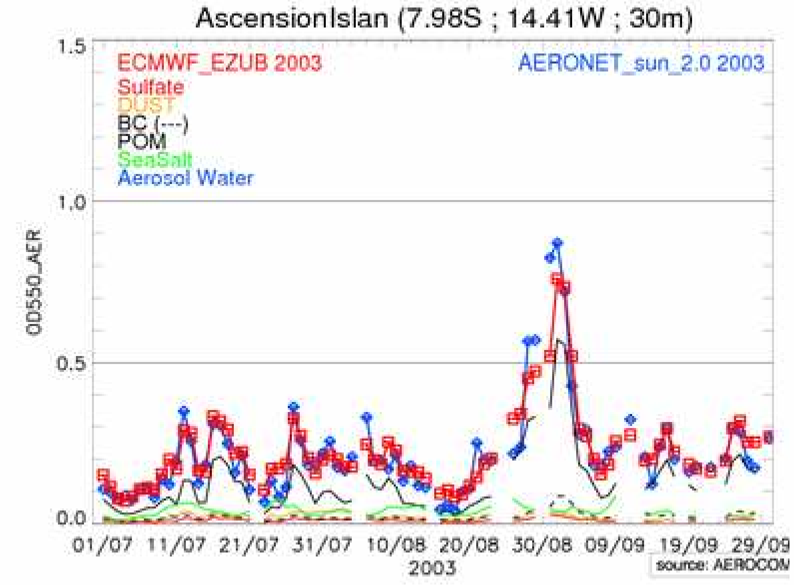
ECMWF forecast 00h

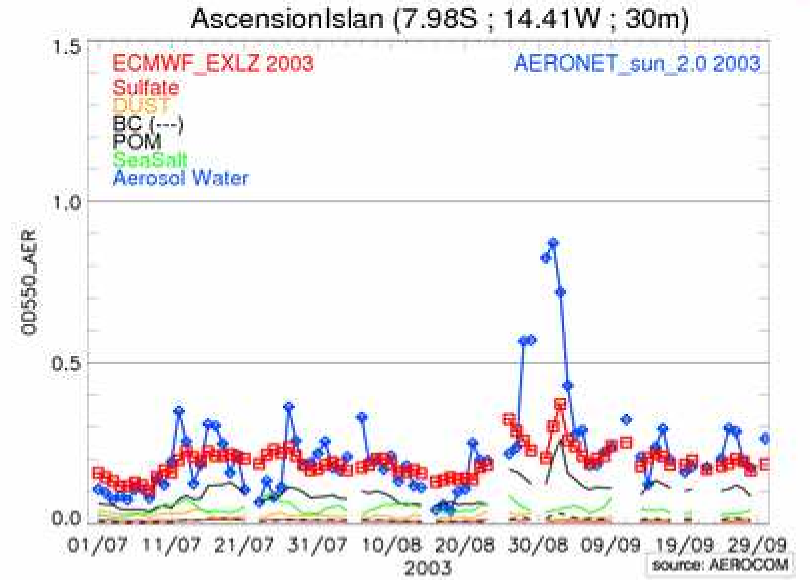
Against Aeronet sun photometer AOD obs

Model Evaluation with Aeronet sun photometers



Biomass burning aerosols



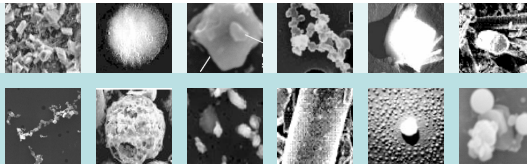


ECMWF Reanalysis Modis AOD assimilation

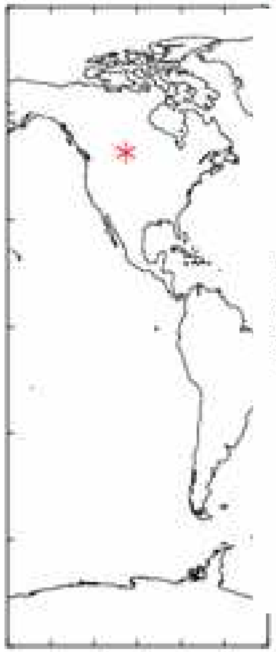
ECMWF forecast 00h

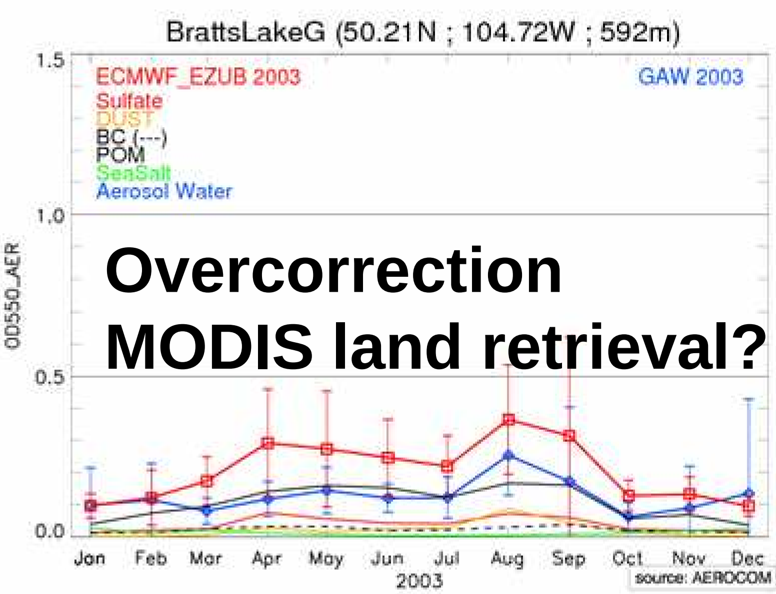
Against Aeronet sun photometer AOD obs

Model Evaluation with Aeronet sun photometers

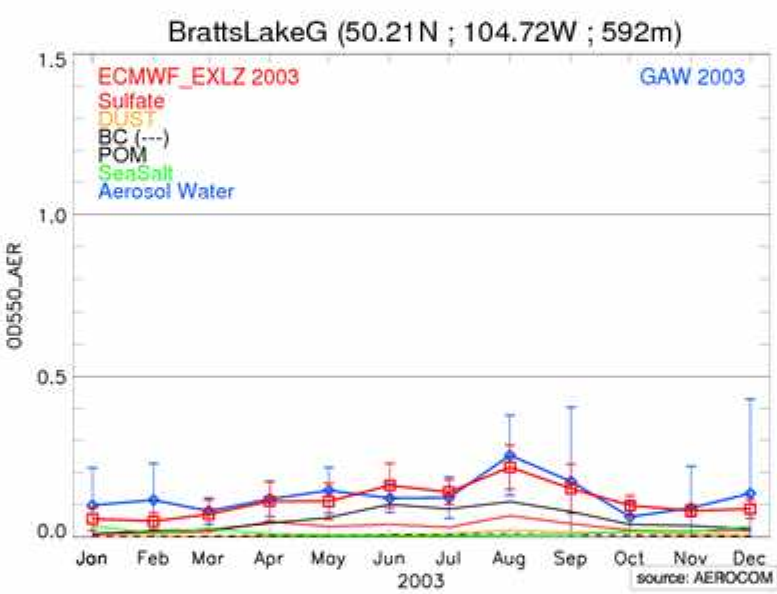


Boreal Forests / Fire aerosols





Overcorrection MODIS land retrieval?

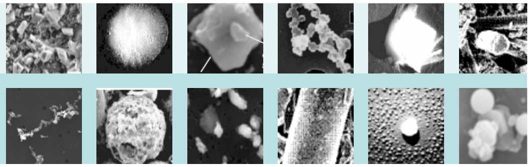


ECMWF Reanalysis Modis AOD assimilation

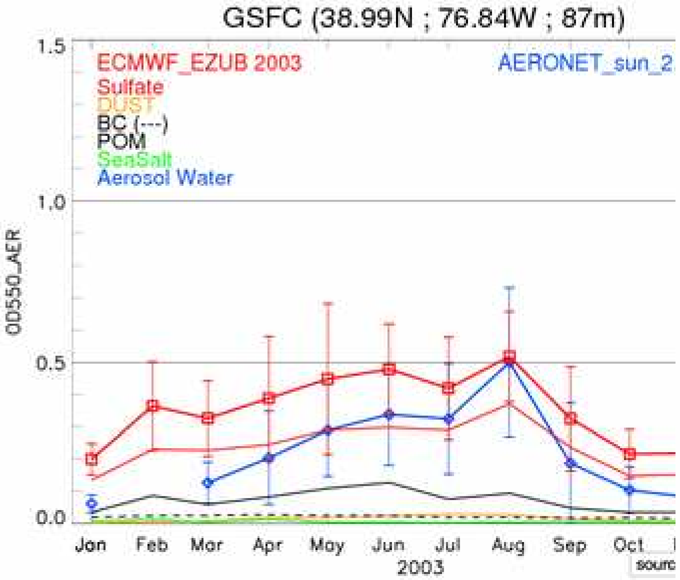
ECMWF forecast 00h

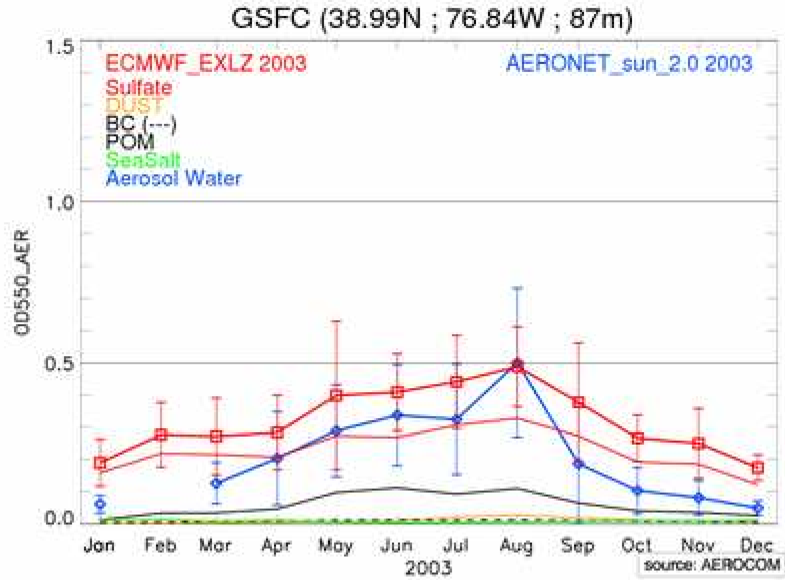
Against Aeronet sun photometer AOD obs

Model Evaluation with Aeronet sun photometers



North American pollution aerosol (Goddard)



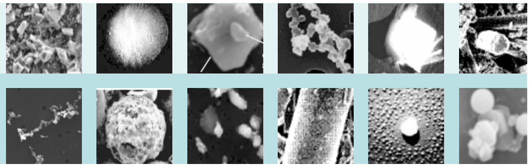


ECMWF Reanalysis
Modis AOD assimilation

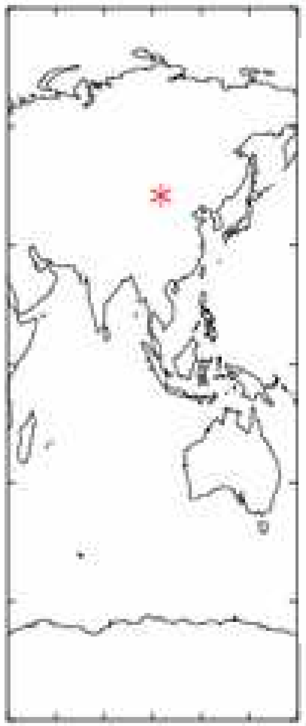
ECMWF forecast 00h

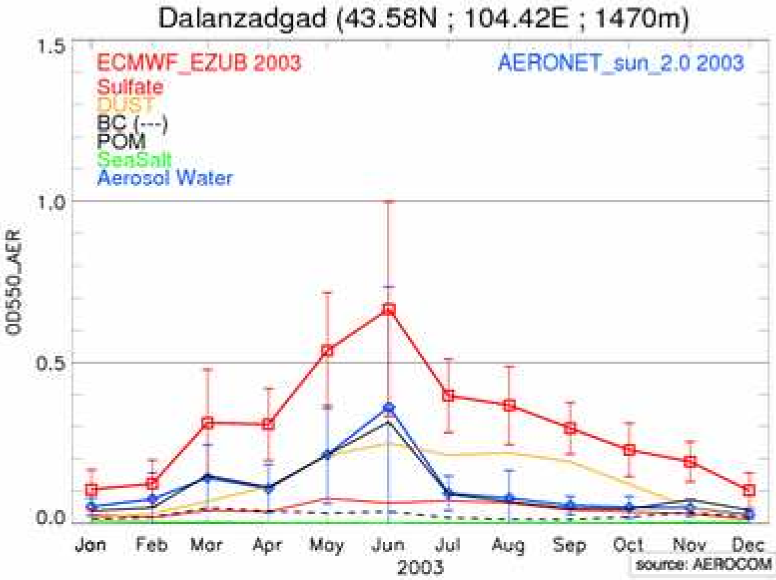
Against Aeronet sun photometer AOD obs

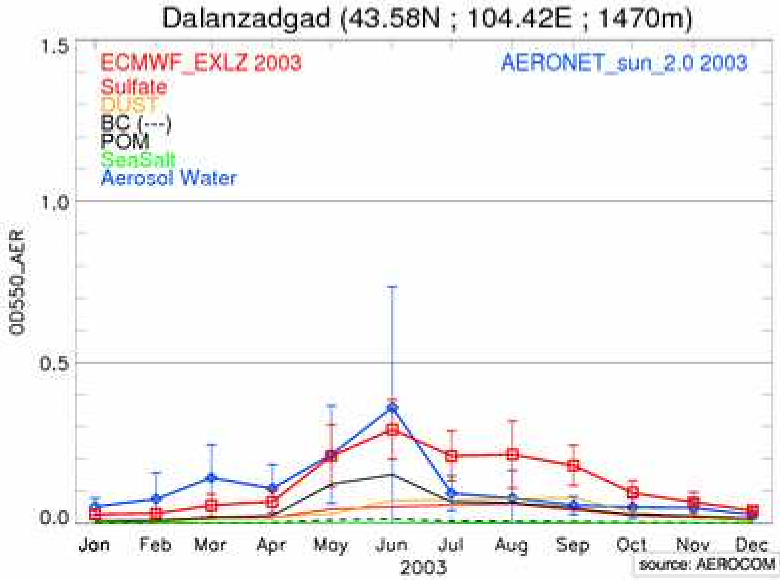
Model Evaluation with Aeronet sun photometers



Boreal Forests / Fire aerosols and Dust??





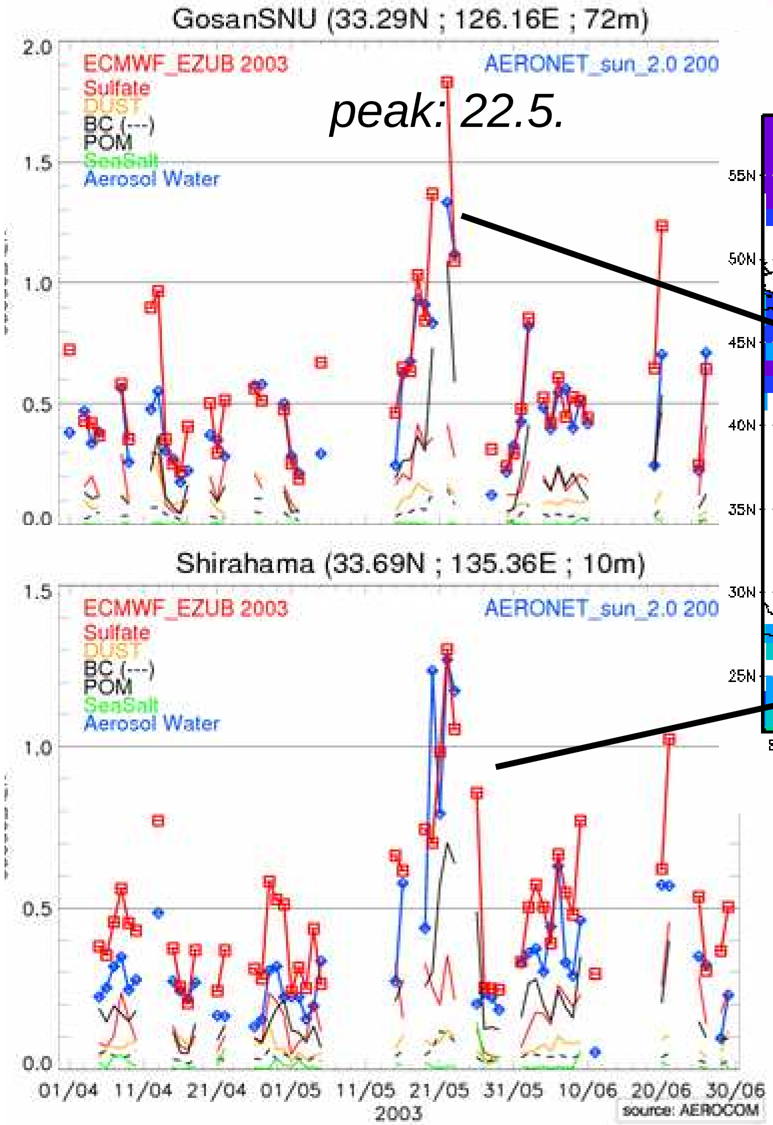


ECMWF Reanalysis
Modis AOD assimilation

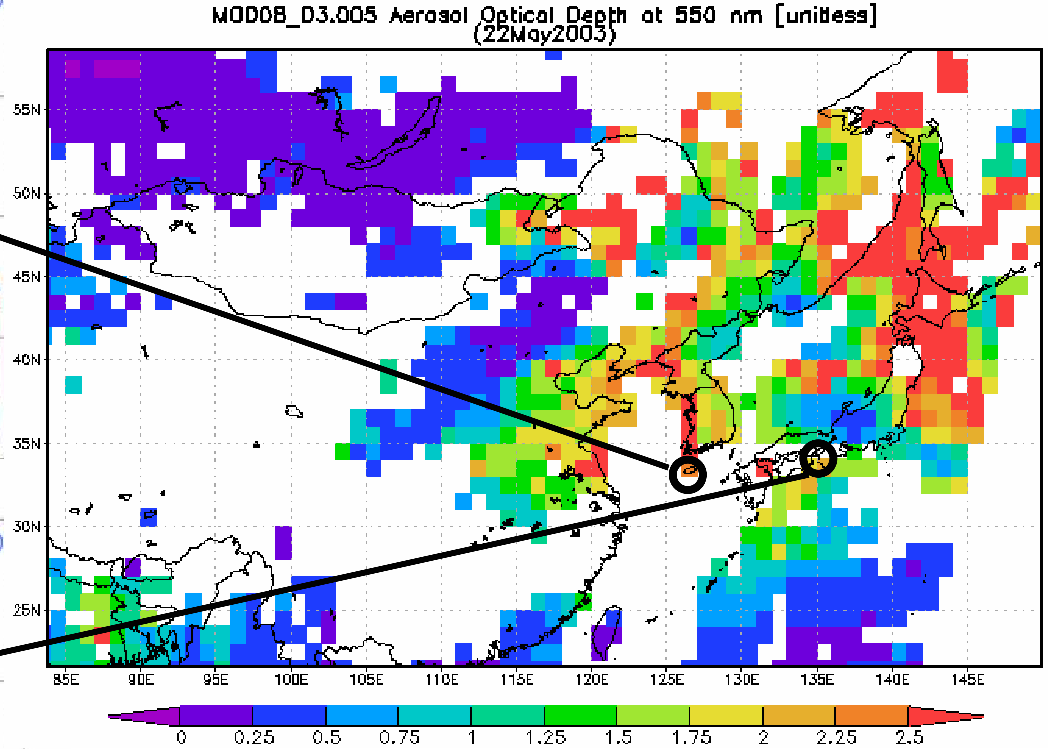
ECMWF forecast 00h

Against Aeronet sun photometer AOD obs

Model Evaluation with Aeronet sun photometers

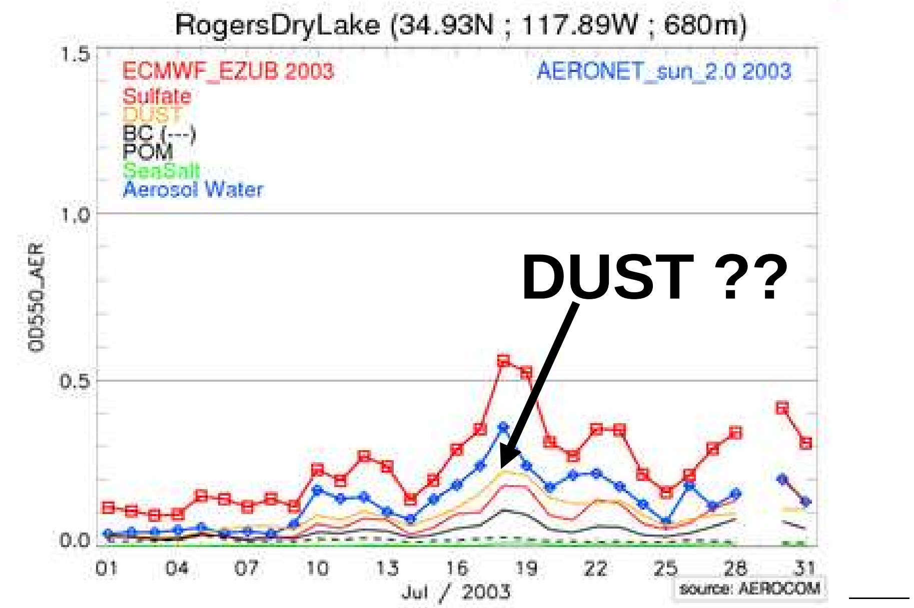


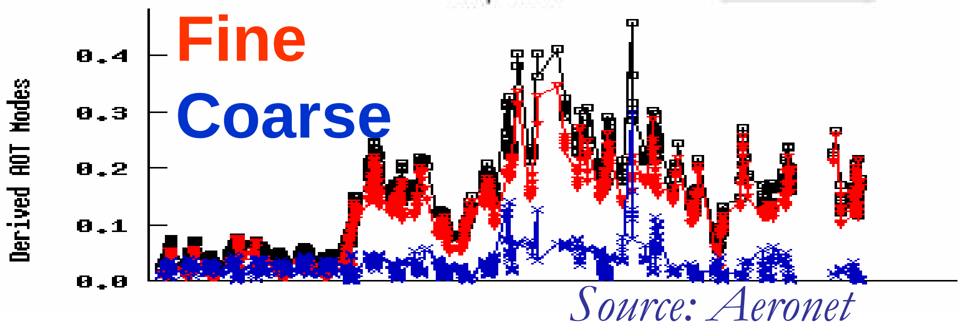
MODIS satellite AOD (20-22.5.03)

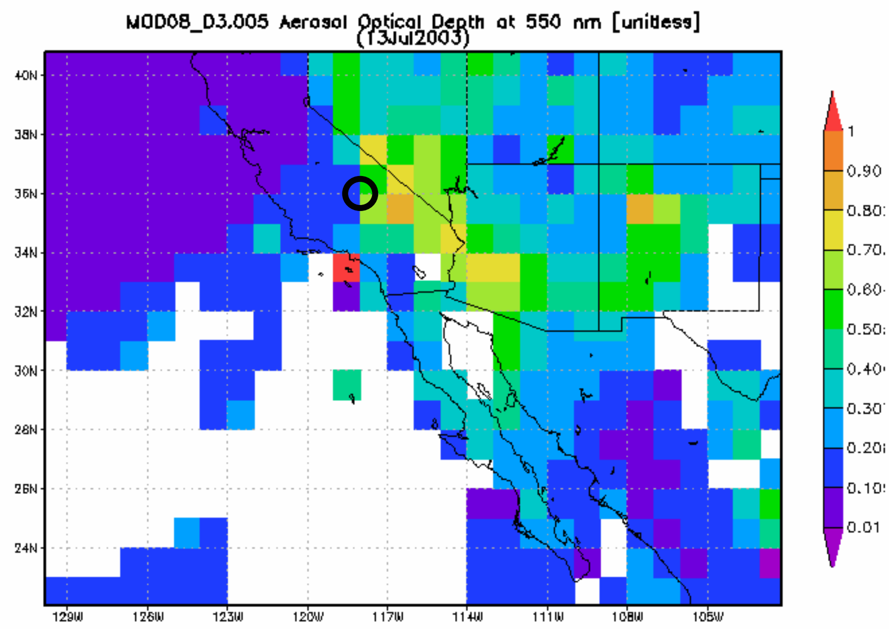


Asian pollution plume predominantly fine mode AOD confirmed by sun photometer inversion result

Model Evaluation with Aeronet sun photometers







North American pollution
California, July 03
False repartitioning
of AOD among species
by assimilation

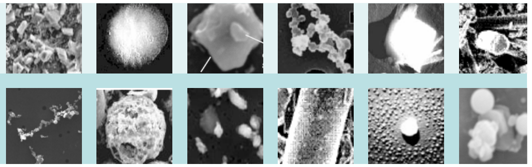
Natural aerosols

Source NASA

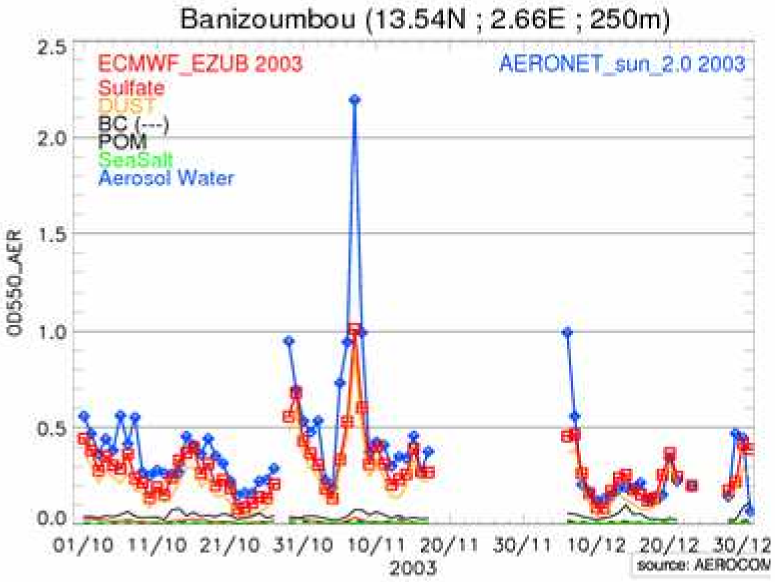
DUST:
Erosion due to high winds
Well defined transport events
Though localized emissions
Absorbing and Scattering!

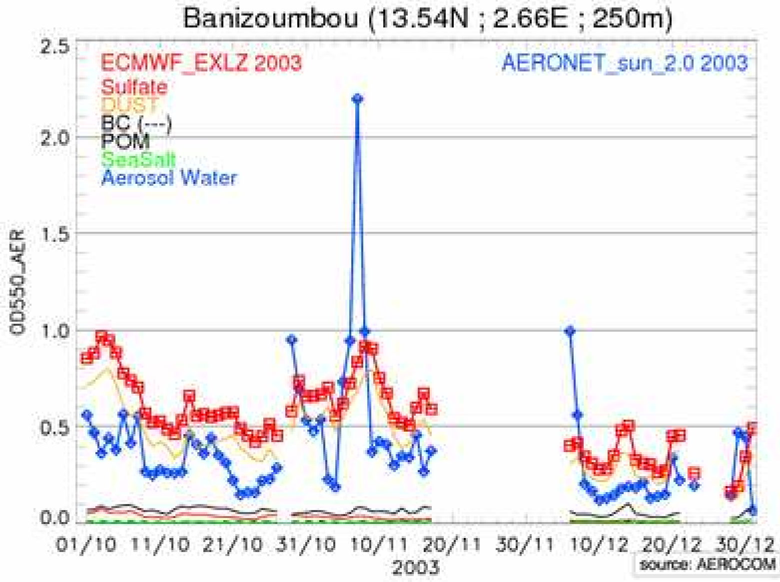
SEASALT:
Windy conditions
associated with high humidity
and cloudy conditions
AOD nonlinearly related to RH

Model Evaluation with Aeronet sun photometers



Dust aerosols (autumn OND, Sahel)



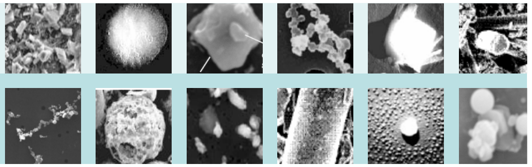


ECMWF Reanalysis
Modis AOD assimilation

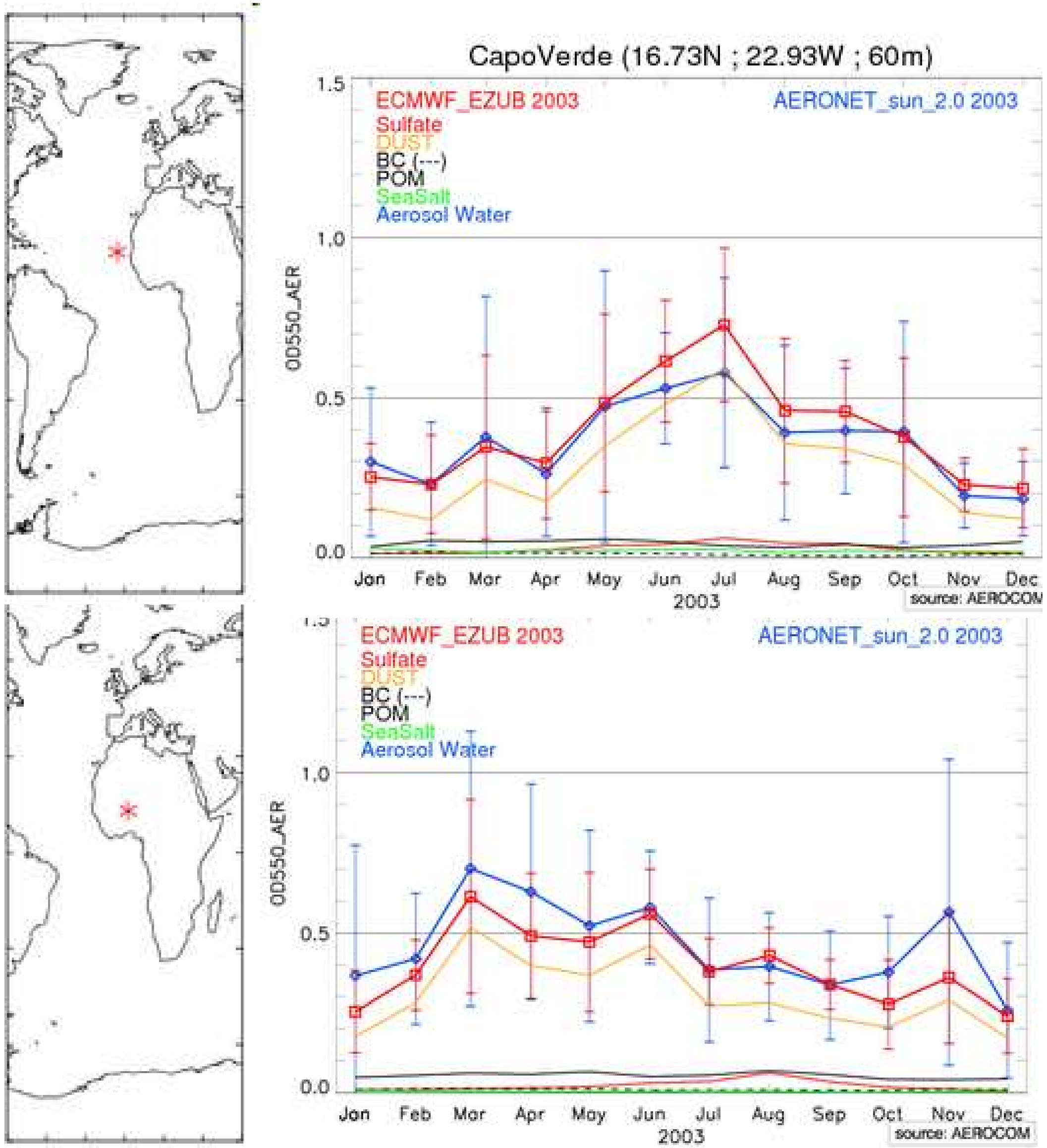
ECMWF forecast 00h

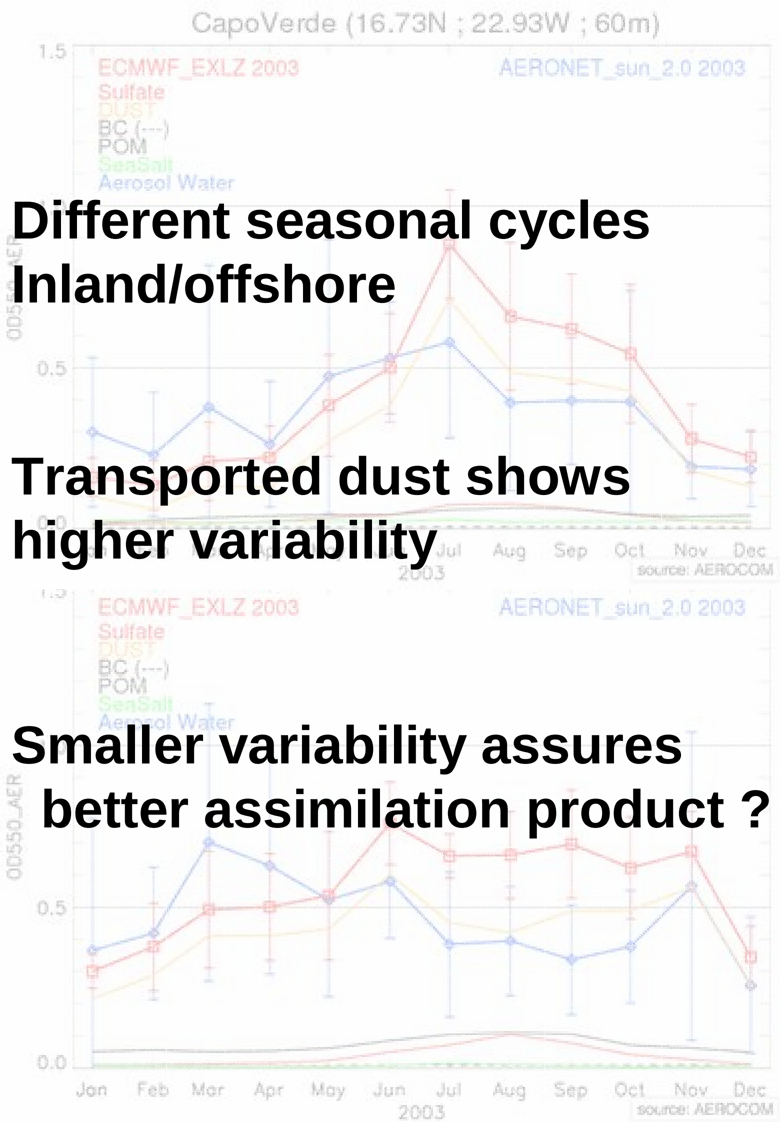
Against Aeronet sun photometer AOD obs

Model Evaluation with
Aeronet sun photometers



Dust aerosols (Sahel and Capo Verde)

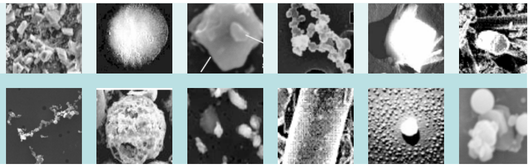




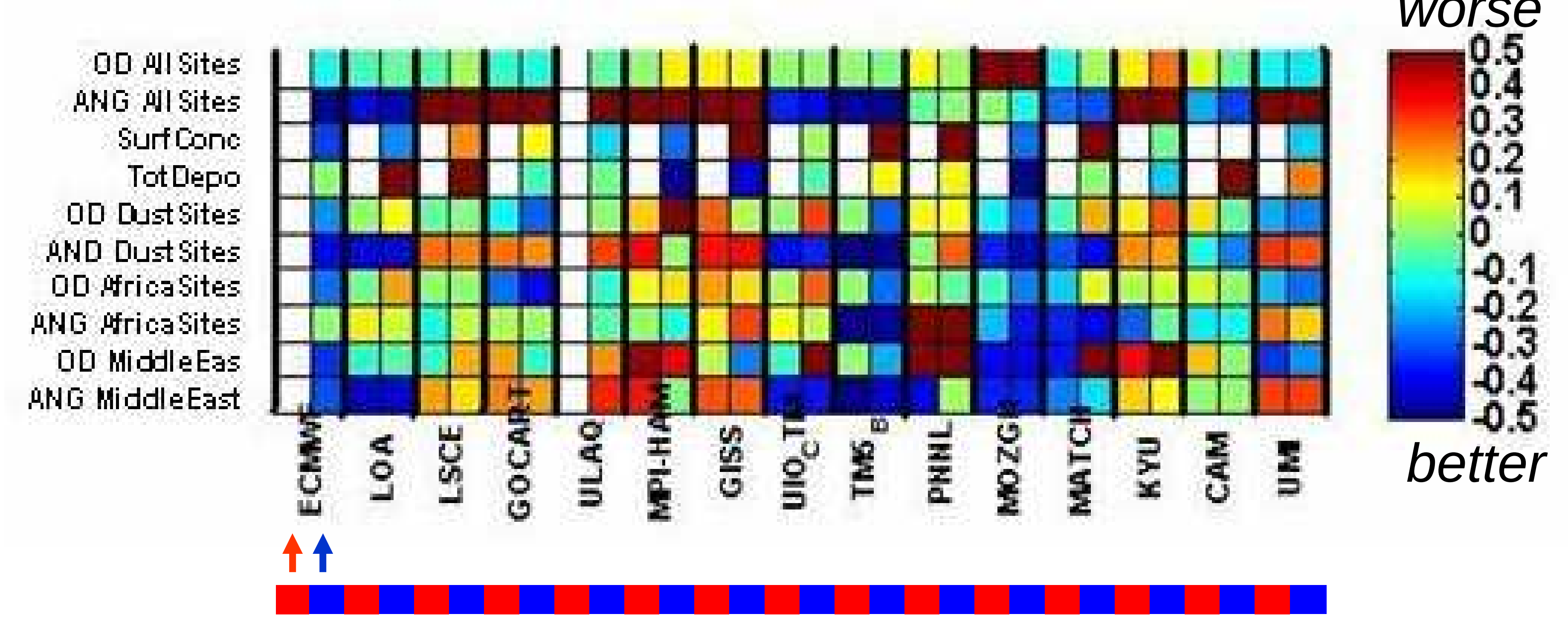
Different seasonal cycles Inland/offshore

Transported dust shows higher variability

Smaller variability assures better assimilation product ?



Error against different obs datasets normalized by mean error of AeroCom models



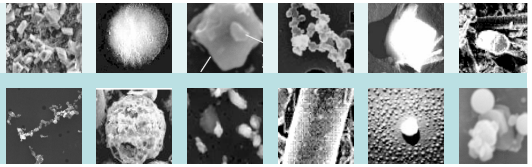
Year 2000

Climatological mean

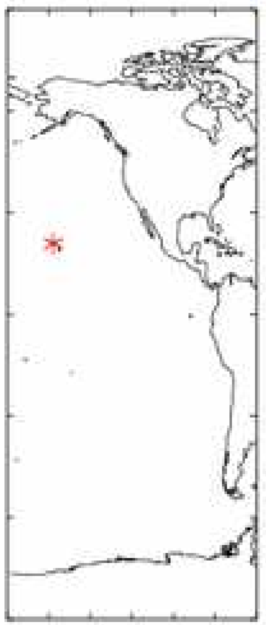
Two datasets to compare for each model

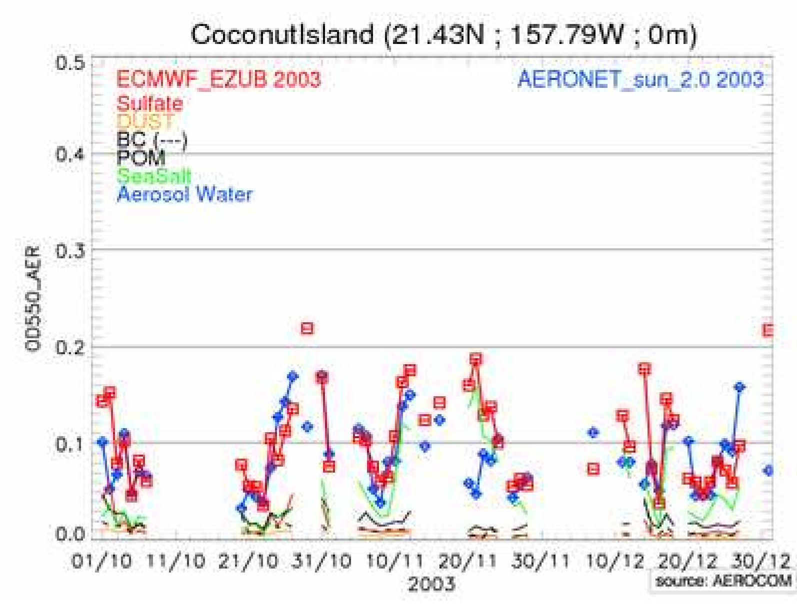
Acknowledgment Nicolas Huneeus / Jan Griesfeller LSCE

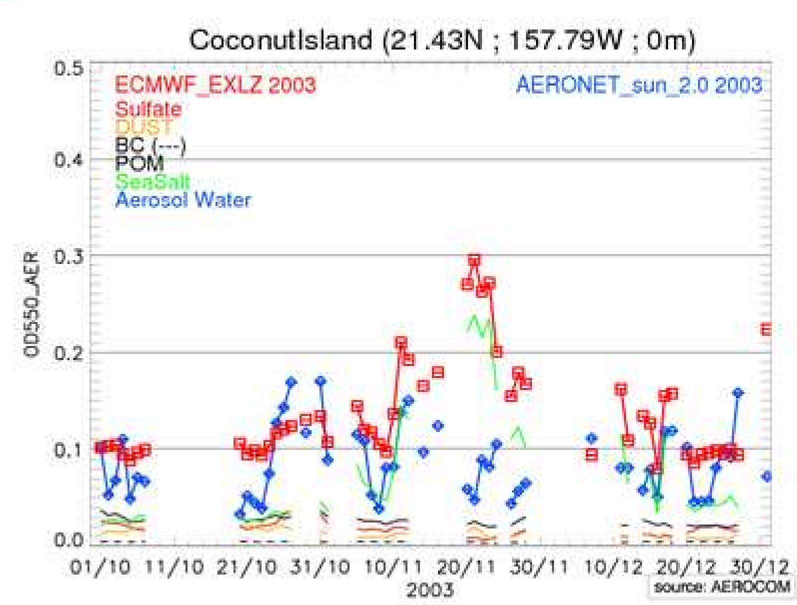
Model Evaluation with Aeronet sun photometers



Sea Salt aerosols (autumn OND, Central Pacific)





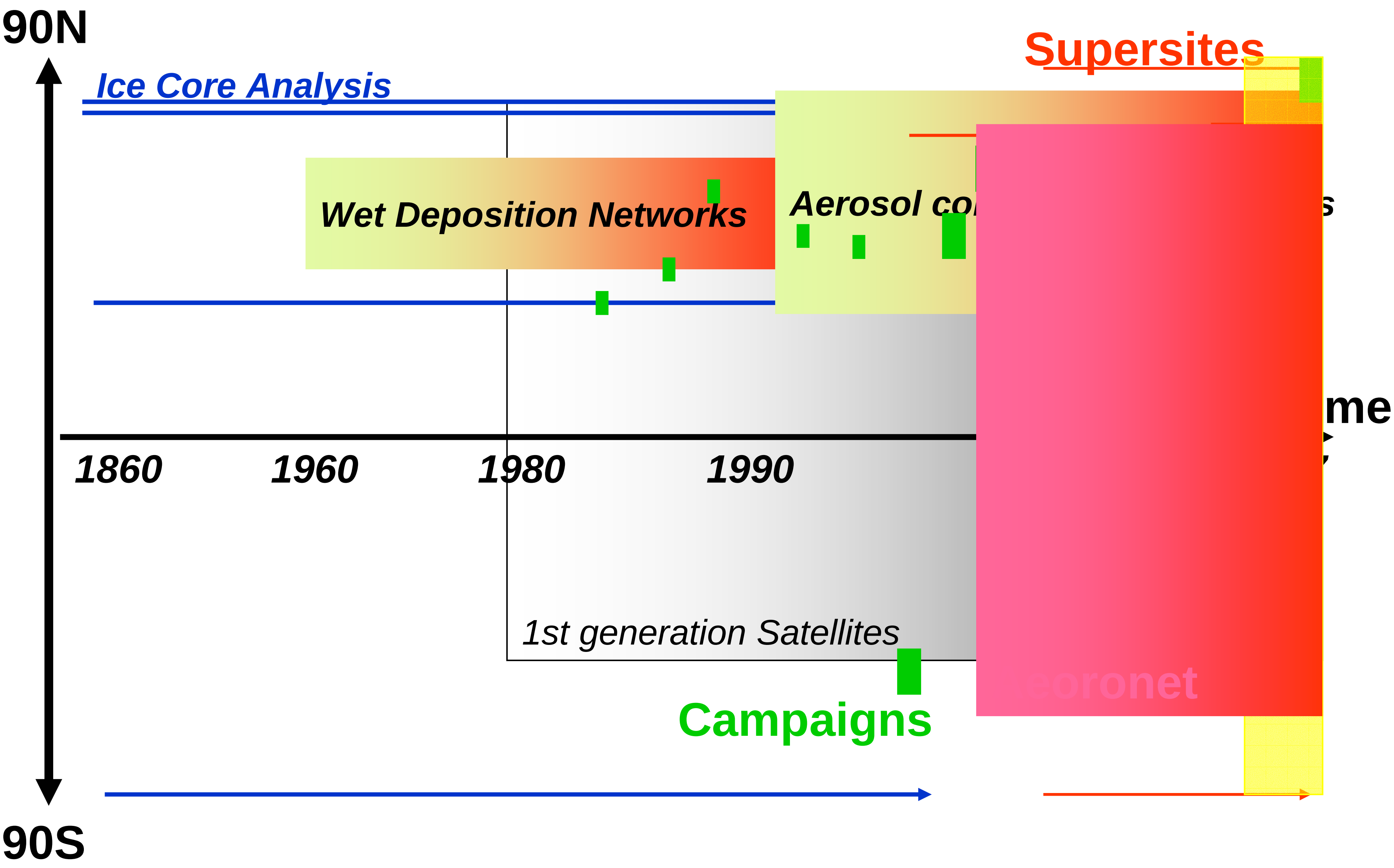


ECMWF Reanalysis
Modis AOD assimilation

ECMWF forecast 00h

Against Aeronet sun photometer AOD obs

Overview of long term records



Summary
Evaluation of aerosol models

Assimilation provides a significantly improved AOD

Different aerosol properties are matched with
Varying quality by different models

Future challenge:
Integrate in-situ & remote sensing observations
Link and exploit past campaigns & networks & A-train
Prepare hindcast simulations of the aerosol
Establish trends and regional/global climatologies

Acknowledgment

Thanks to contributions from
Stefan Kinne, Christiane Textor, Nicolas Huneeus, Johannes Quaas
Jan Griesfeller, Angela Benedetti, Jean-Jaques Morcrette,
AeroCom modellers,

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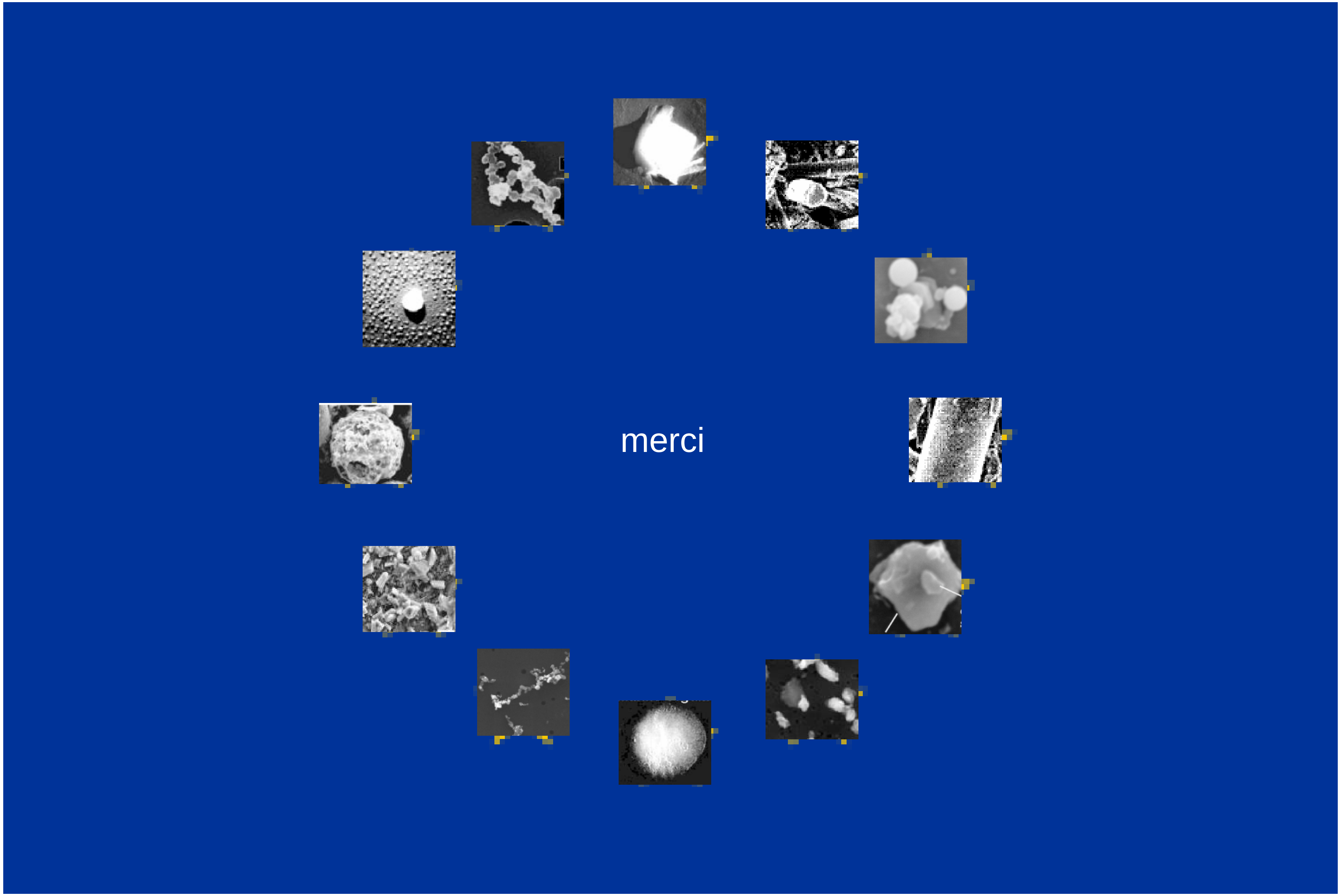
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