Internal mixing effects on the direct effect of aerosols

Øyvind Seland, Trond Iversen and Alf Kirkevåg

Acknowledgement: This research has been supported by the Norwegian Research Research Council through the NorClim project and through a grant of computing time

Aerocom meeting, Reykjavik, October 8-10th, 2008.

Norwegian Meteorological Institute met.no

Overview

- GCM-Oslo versus GCM-UIO
- Contribution of
- Verification of aerosol absorption

- Aerosol-climate interactions in CAM-Oslo

Major extensions to NCAR CAM3:

- Aerosol lifecycling and physical properties
  - Sea-Salt, Dust, SO_4, OM, BC
  - Size-modes of emitted primary particles are presumed
  - Concentrations are tagged to production and size mode
  - Process-specific mixing state (size dependent)
    - SO_4 gas phase production + nucleation or condensation on available particles
    - Clear-air and cloudy air coagulation
    - Wet-phase production in cloud droplets
    - Hygroscopic humidity swelling
  - Tables for modified size, optical, and physical properties
- Aerosol interactions with radiation
  - Refractive index according to mixing state and size
  - Optical Mie scattering and absorption
- Aerosol interaction with clouds
  - CCN activation by prescribed (old) or realized (new) super-saturations
  - Cloud droplet aging and influence on auto-conversion

Differences from GCM-Oslo

- CAM3 host model instead of CCM3
- Prognostic sea-salt and aerosol particles
- Not yet submitted to Aerocom main dataset
- Submitted to the EUCARII dataset (UIO-GCM ver2)

In RegClim Special issue, Tellus 60A, No.3

Tellus (2008), 60A, 459–491

TELLUS

Aerosol-climate interactions in the CAM-Oslo atmospheric GCM and investigation of associated basic shortcomings

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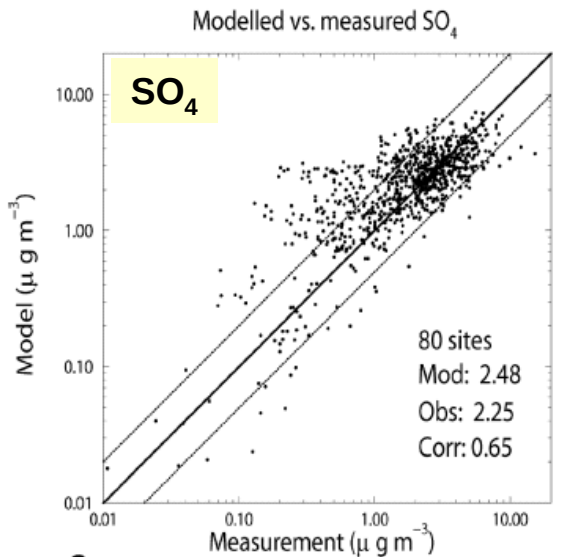
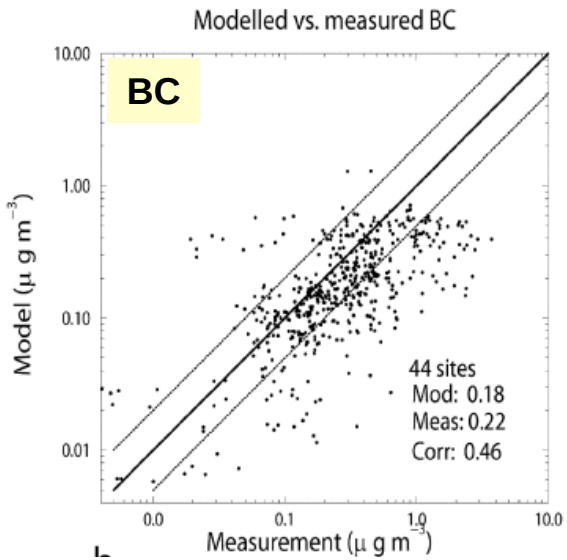
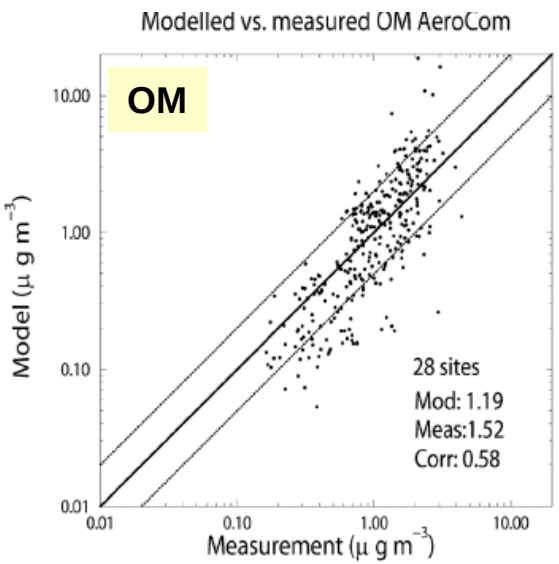
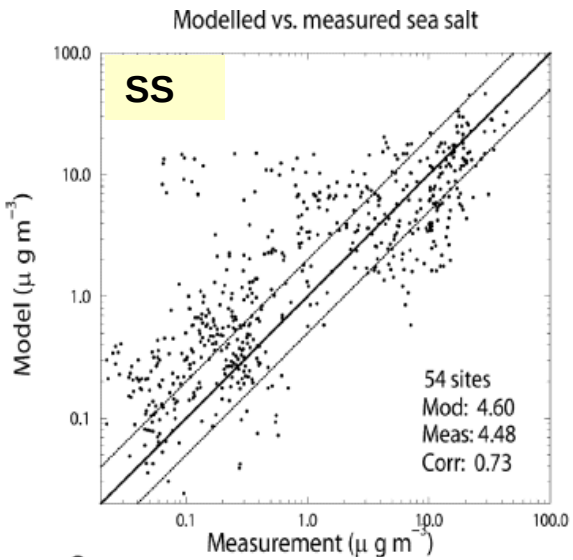
(Manuscript received 3 May 2007; in final form 7 January 2007)

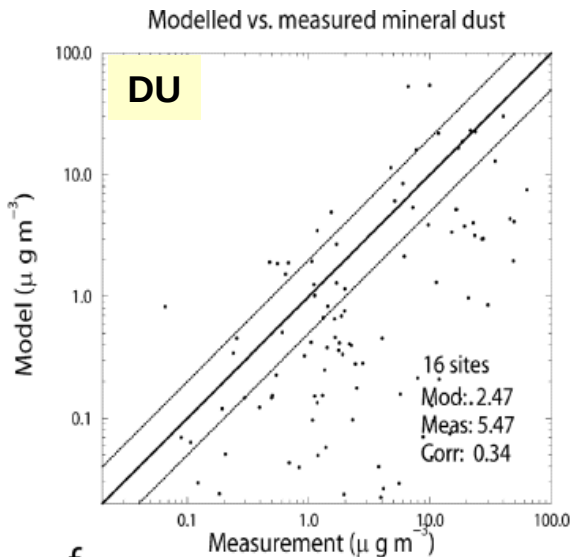
Modeled vs. measured annual surface concentrations:



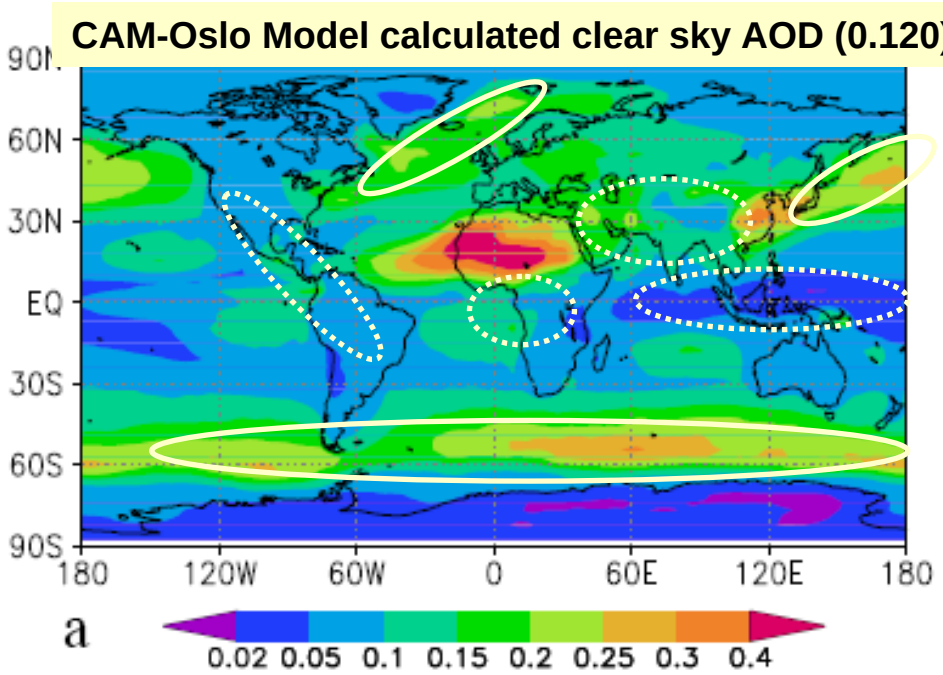


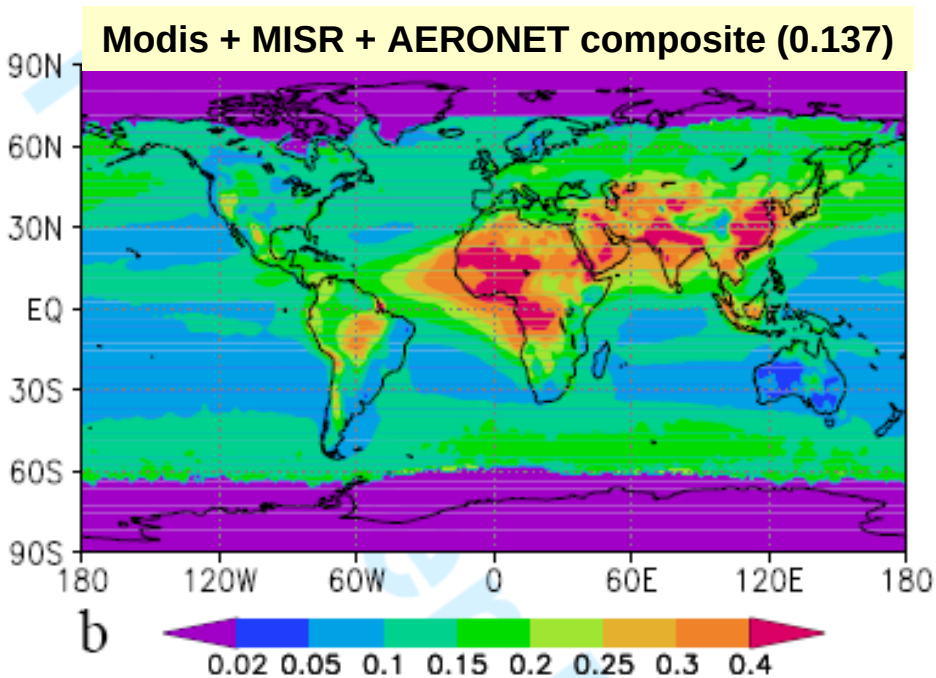




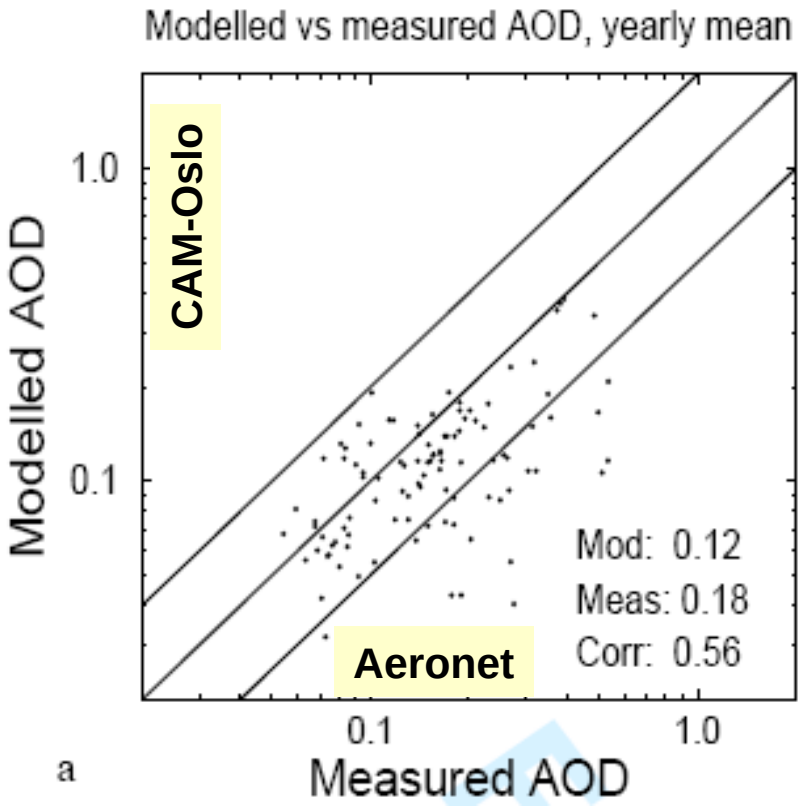


SO4: over-estimated remotely
BC: under-estimated
DU: under-estimated
SS: wide scatter



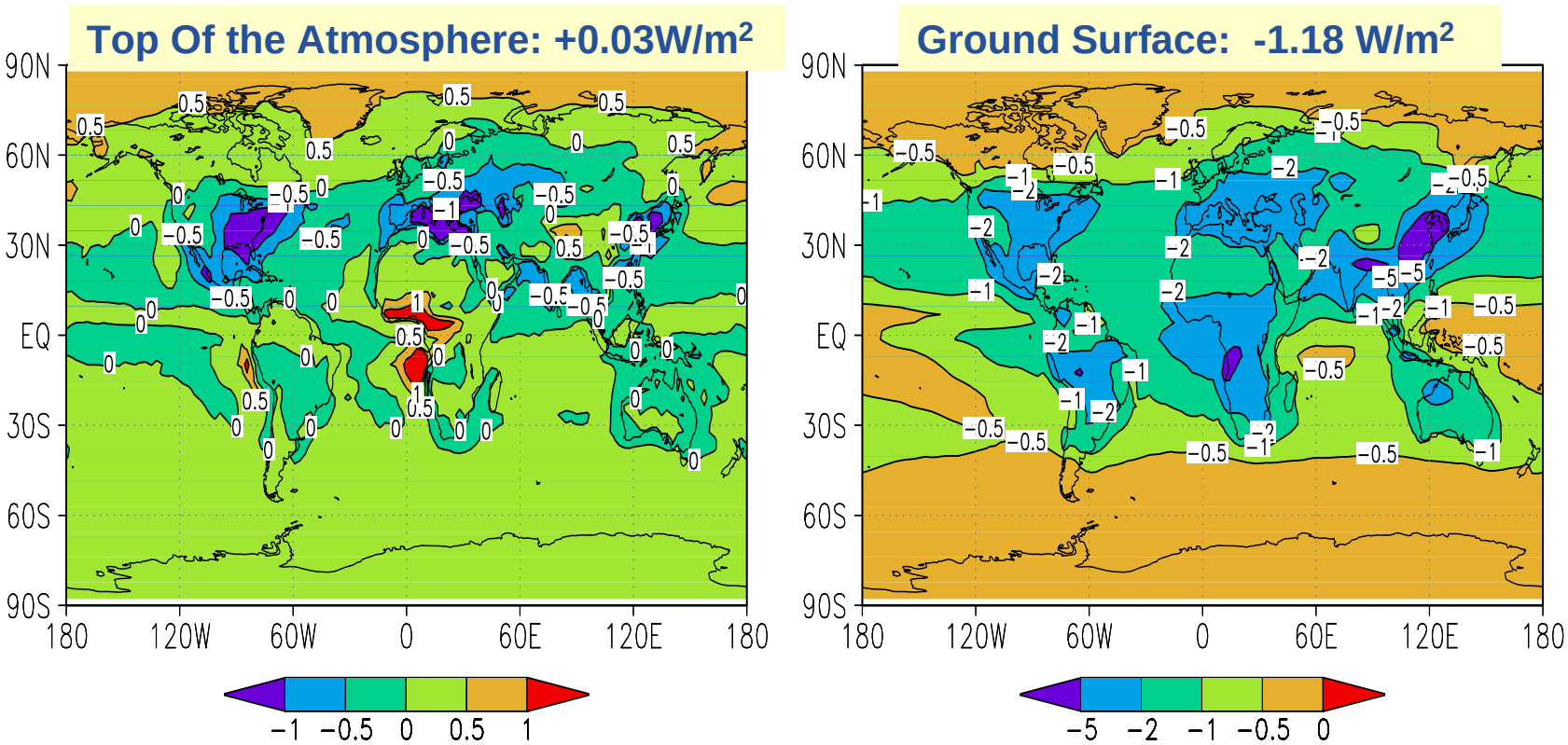


AOD = Aerosol Optical Depth:



- General tendency: under-estimate
  - ➢ especially in tropical biomass reg.
- Extratropics ocean: over-estimate

CAM-Oslo direct radiative forcing, DRF, Year 2000 vs. "pre-industrial" (1750)



TOA *global* annual DRF is approximately zero.

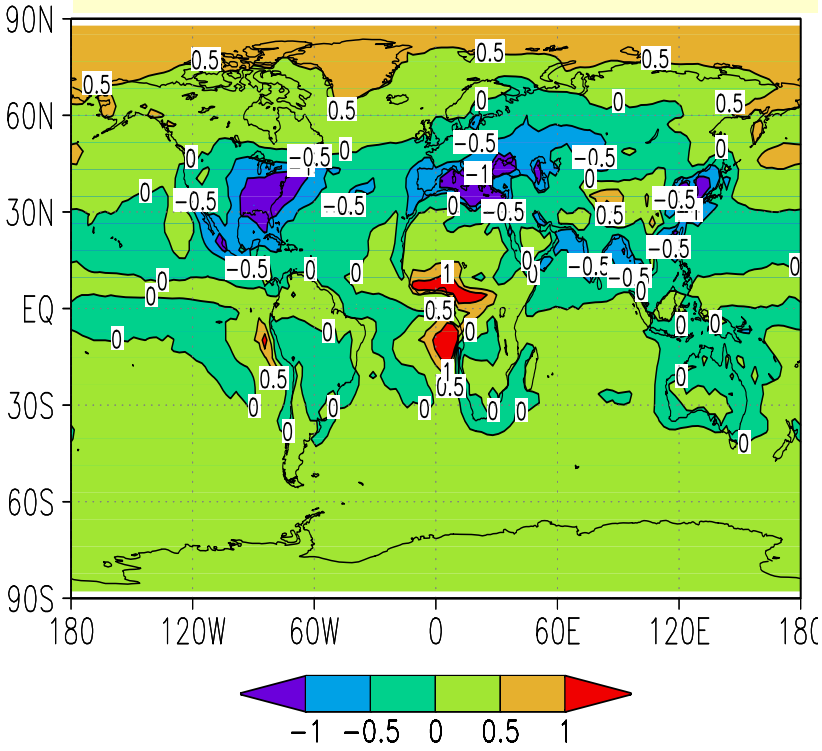
TOA Aerosol Direct Radiative Forcing (since 1750)

	AeroCom B mean DRF at TOA (W m^{-2})	CAM-Oslo DRF at TOA (W m^{-2})
Total	**-0.22**	**+0.031**
Contribution by SO4 only	**-0.35**	**-0.34**
Contribution by SO4 and OM	**-0.47**	**-0.50**
Contribution by SO4 and BC	**-0.05**	***+0.16***
Contribution by BC and OM	**+0.13**	***+0.38***

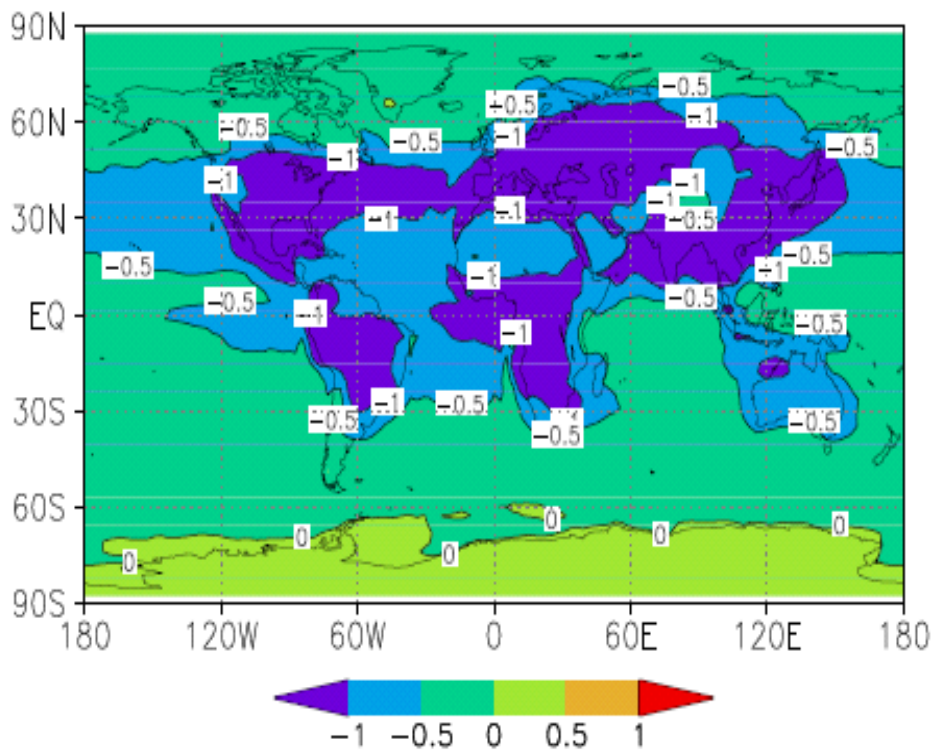
→ Our aerosol absorbs more light than many other models…

Direct radiative forcing TOA
Total vs. No black carbon

TOA, standard run: +0.03W/m²

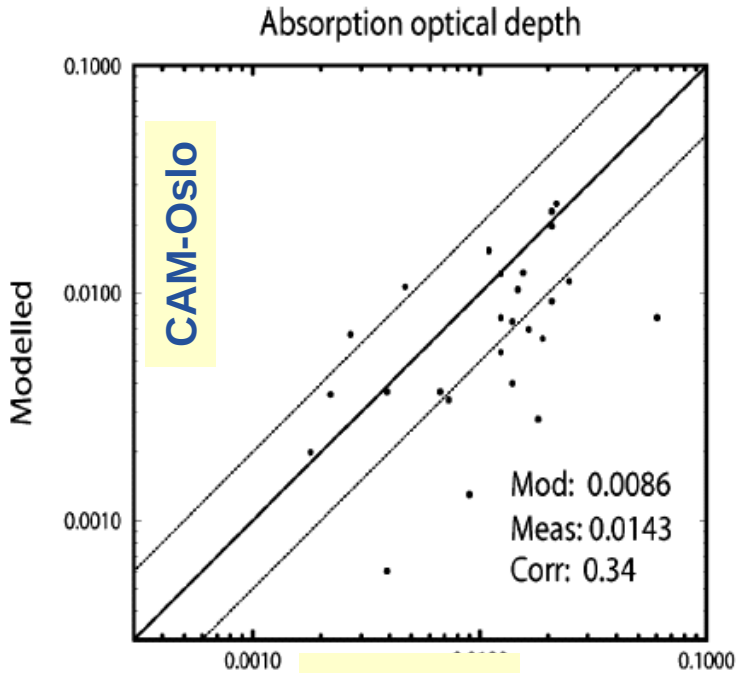


TOA , no black carbon -0.50 W/m²

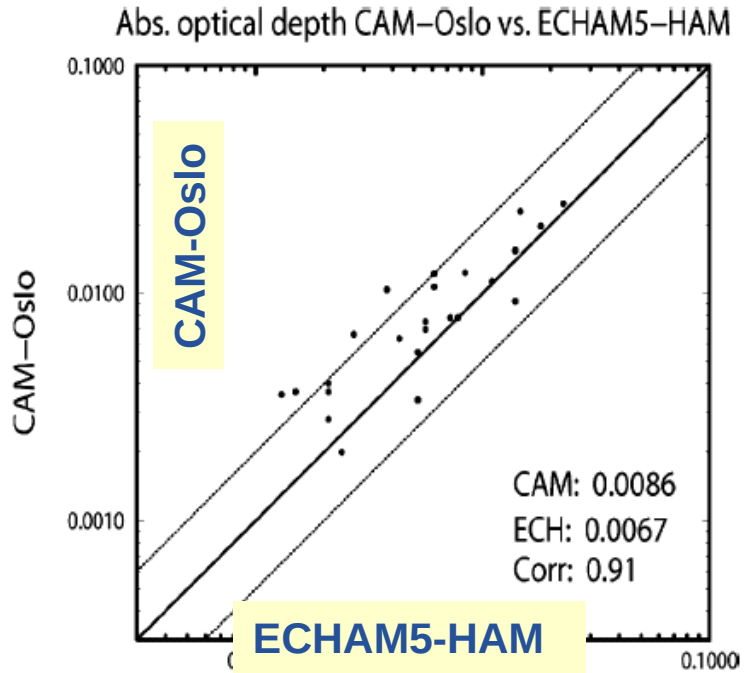


TOA *global* annual DRF is approximately zero.

… but is the absorption part of AOD abnormal?



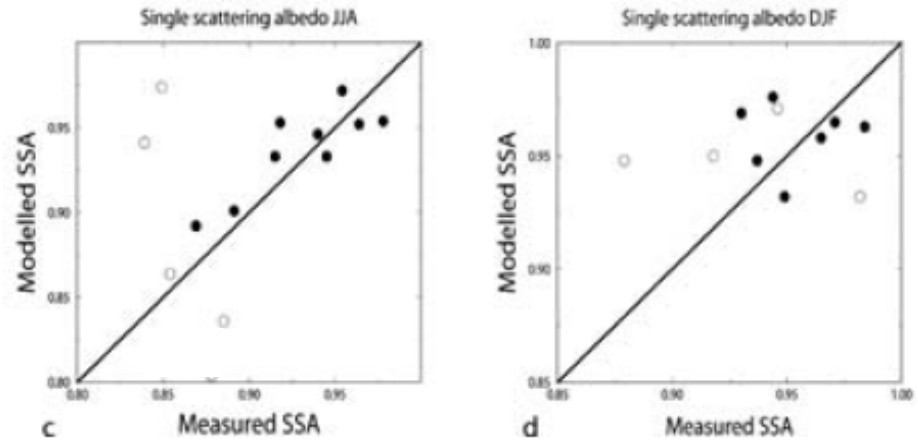
Aeronet



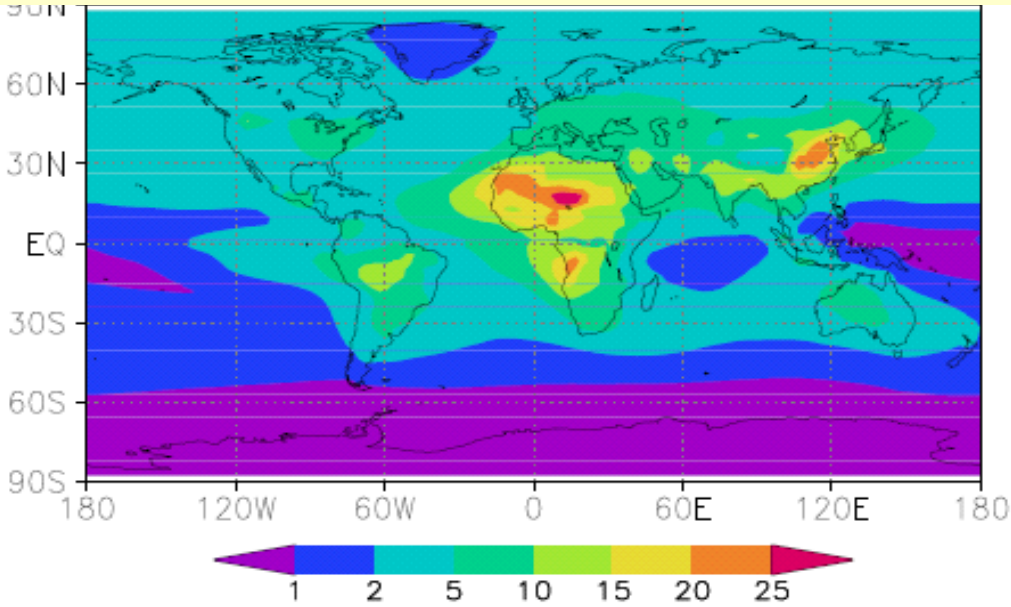
ECHAM5-HAM
Stier et al. 2005

The aerosol does not appear to be too absorptive
- if anything it absorbs too little.

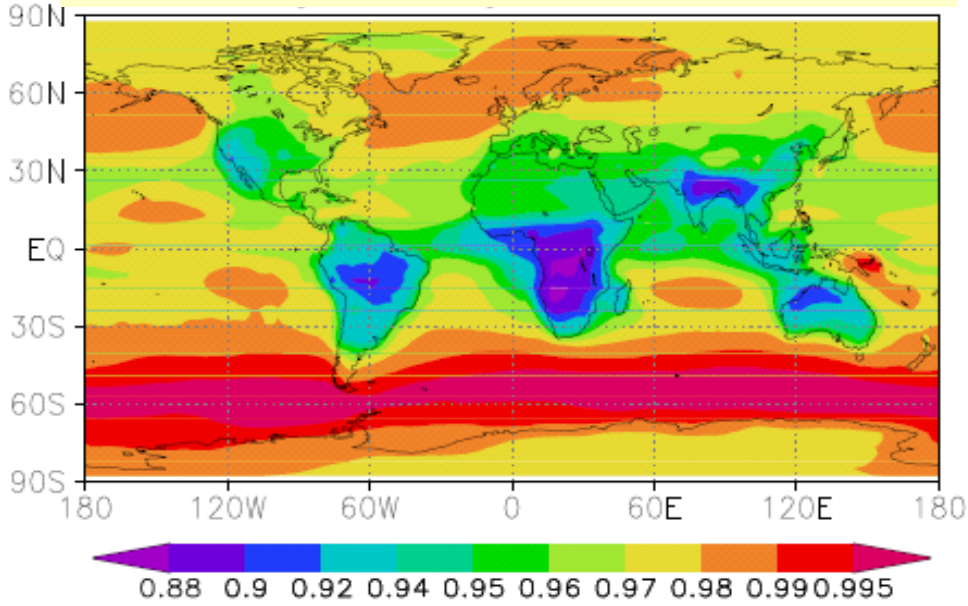
However, SSA = $(1\text{-}AOD_{abs})/AOD$ is ok, except in typical biomass areas (o)
→ reasonable representation of hygroscopicity and refractive indices



Absorptive optical depth *10^3 standard run (0.0040)



Single scattering albedo, standard run



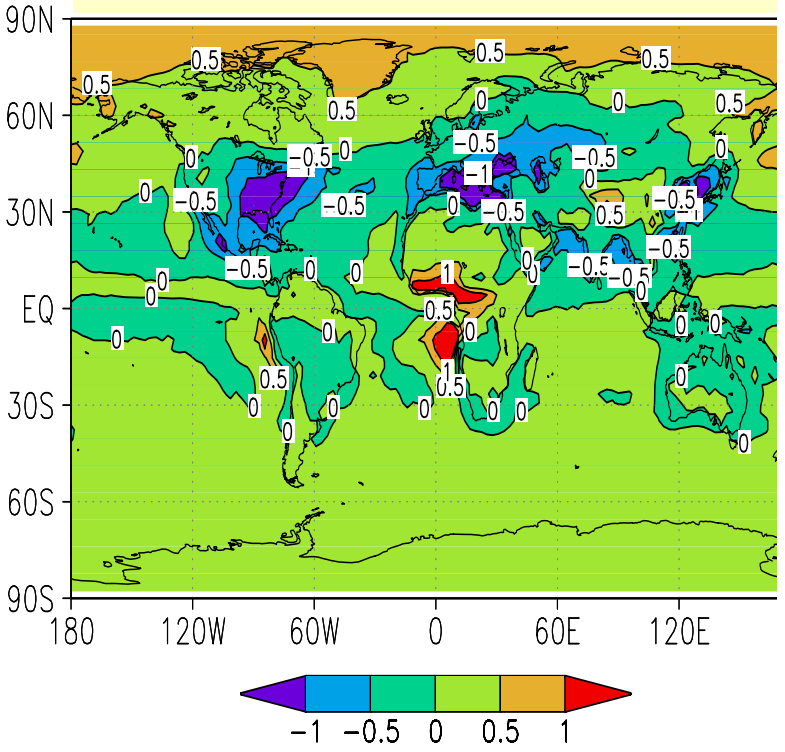
Assumptions influencing aerosol absorption…

TEST	CAM-Oslo DRF at TOA (W m^{-2})
Standard set-up	0.031
BC assumed externally mixed	**-0.175**
No OM absorption assumed	-0.018
No primary BC(ac) emitted (all in Nucleation / Aitken)	-0.021

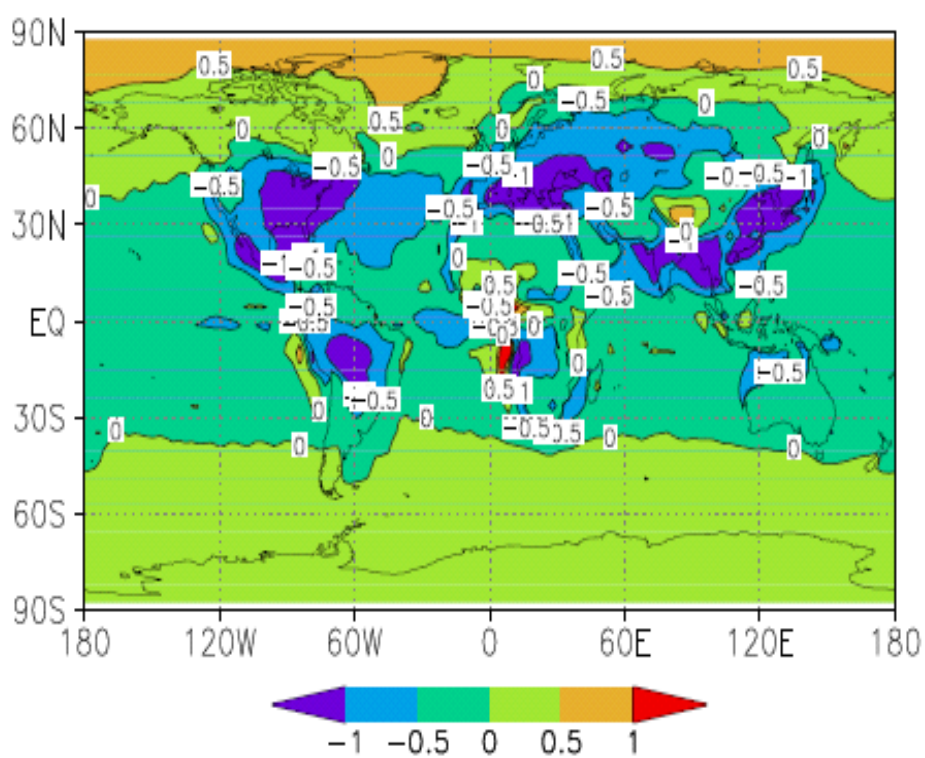
Assuming external mixing has implications for radiative forcing and hence also for climate impacts of BC (and possibly absorptive dust)

Direct radiative forcing TOA
Standard vs. External mixture

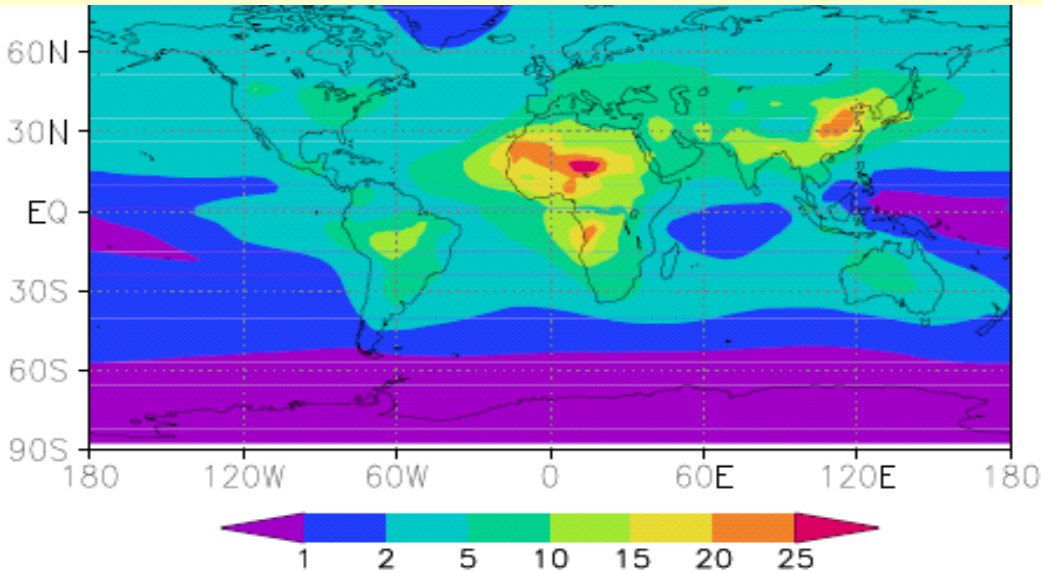
Top Of the Atmosphere: +0.03W/m²



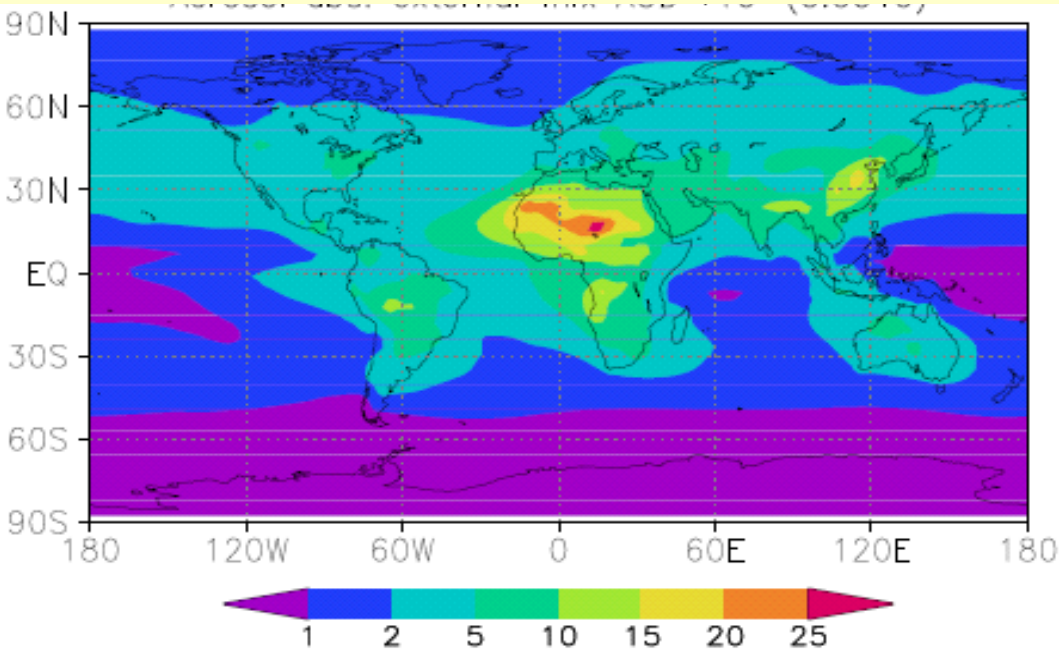
External mixture -0.18 W/m²



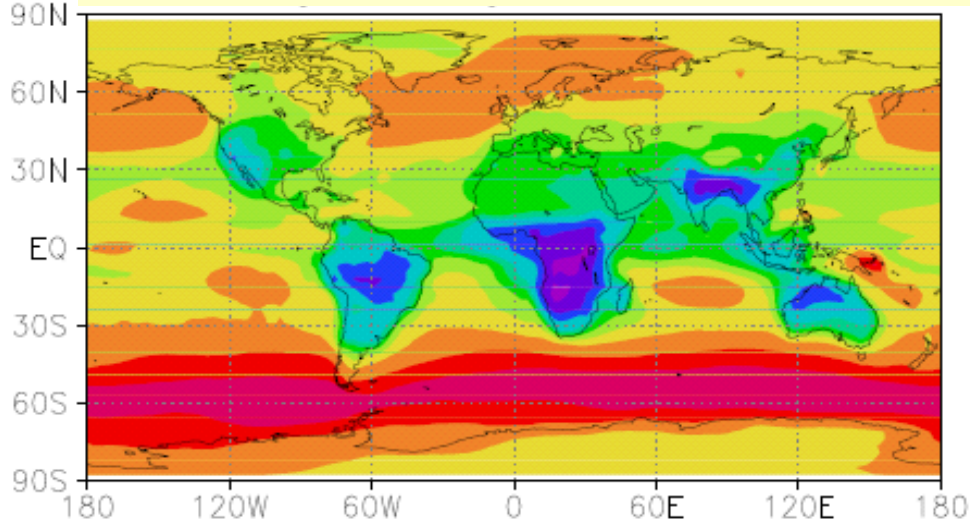
Absorptive optical depth *10^3 standard run (0.0040)



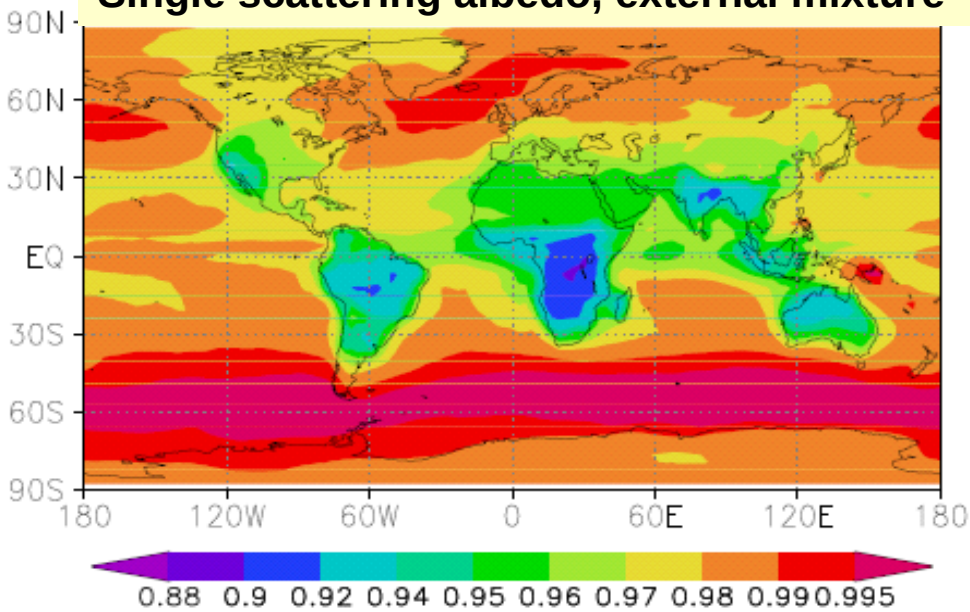
Absorptive optical depth *10^3 external mixture (0.0034)



Single scattering albedo, standard run



Single scattering albedo, external mixture



Summary on DRF:

- **Slightly positive direct aerosol forcing**
  - Internal mixing increases absorptivity non-linearly
  - Emitted BC-fractals (fluffy particles) from fossil fuel combustion
  - Biomass burning OM and BC emitted internally mixed.
  - Surface albedo and ABL cloudiness

Call for measurements:

- Aerosol absorption optical depth
- Mixing state
- Optical depth over clouds, in particular absorption
- Albedo

- **Models calculate "correct" AOD but miss aerosol components/processes**
  - "constraining" bulk quantities should be avoided


Thank you
NorClim

Extra Slides

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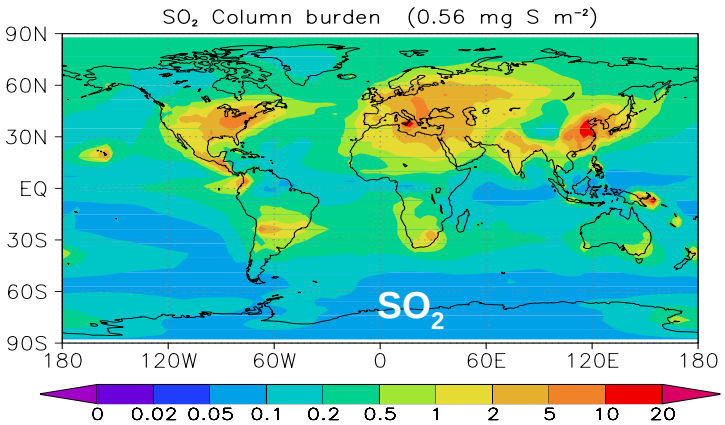
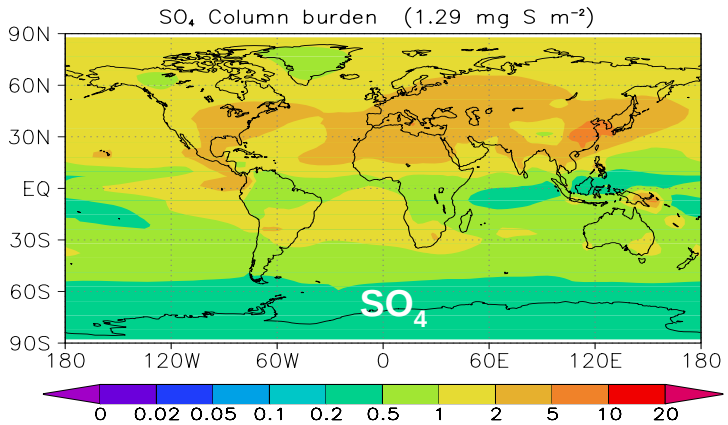
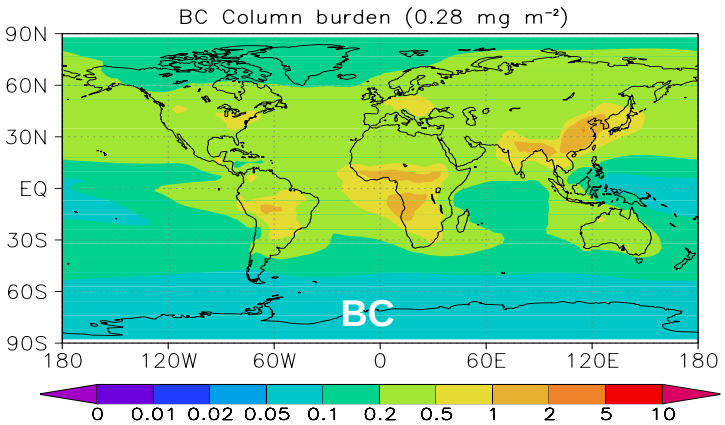
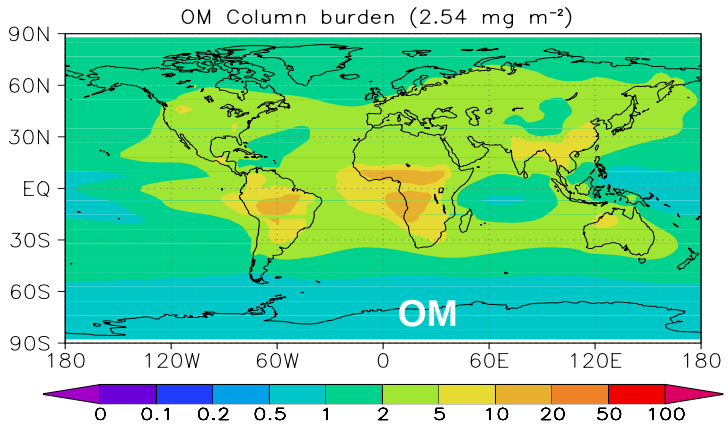
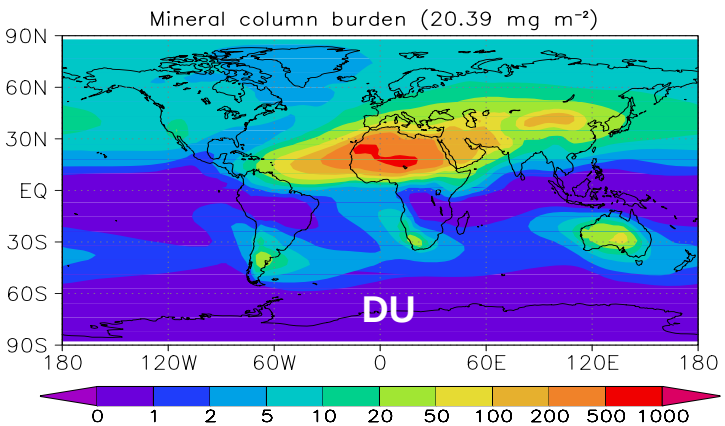
Aerosol column burdens:

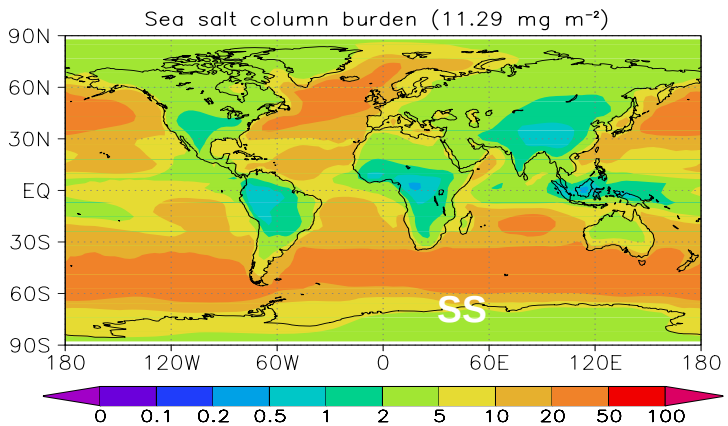


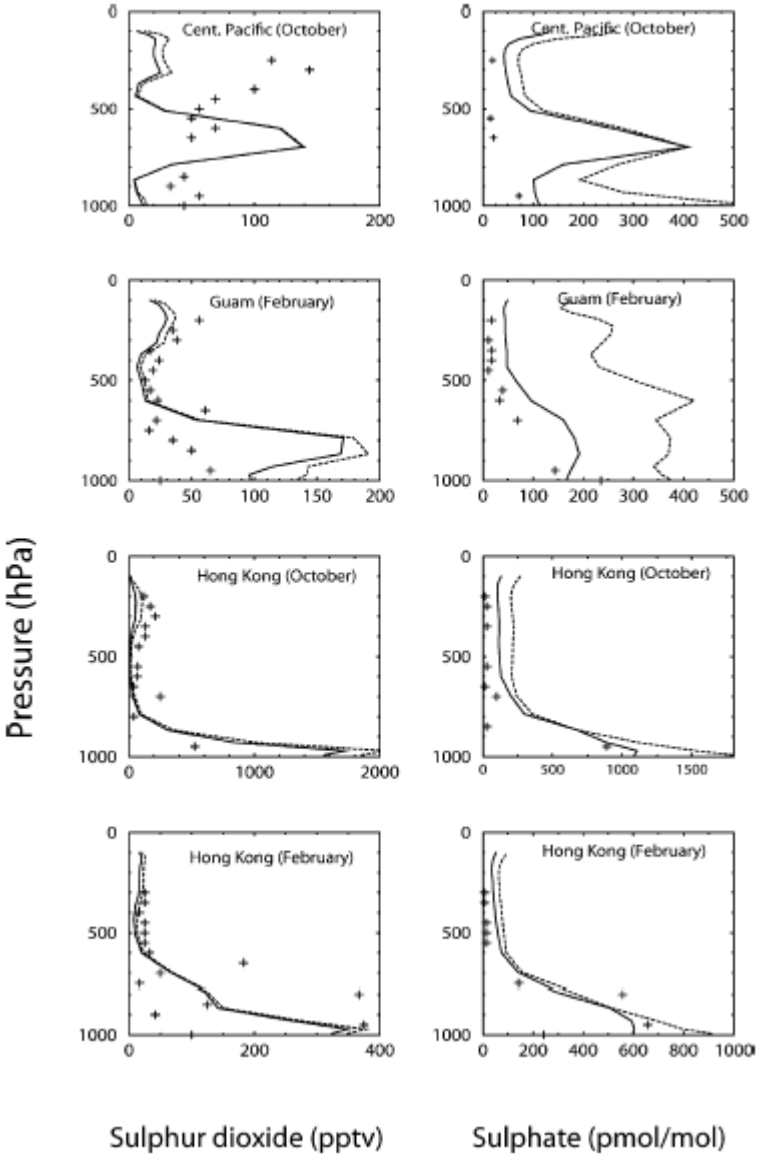












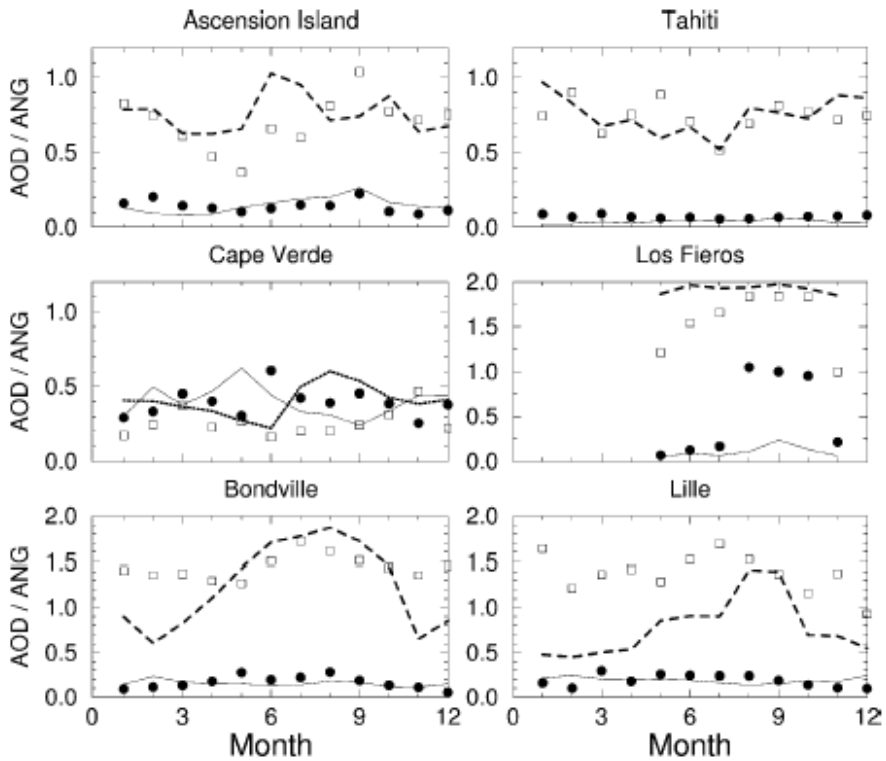


Fig. 13. Modelled and measured aerosol optical depth at 550nm (solid lines and black bullets) and Ångström exponent (ANG) (dashed lines and open squares) for a selection of AERONET stations for the period 1996–2002.

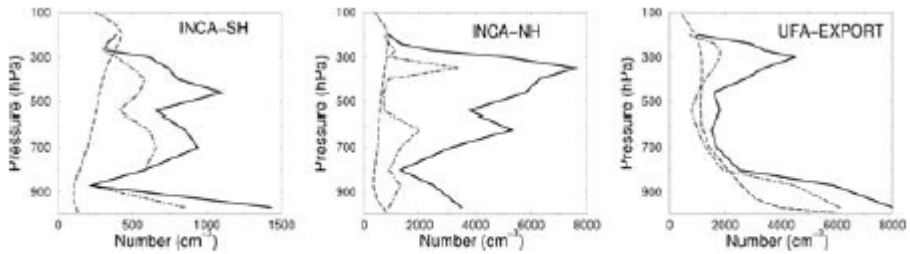
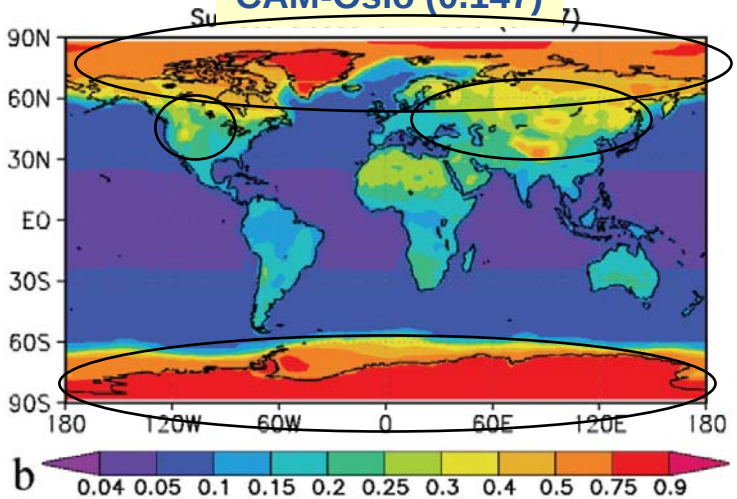


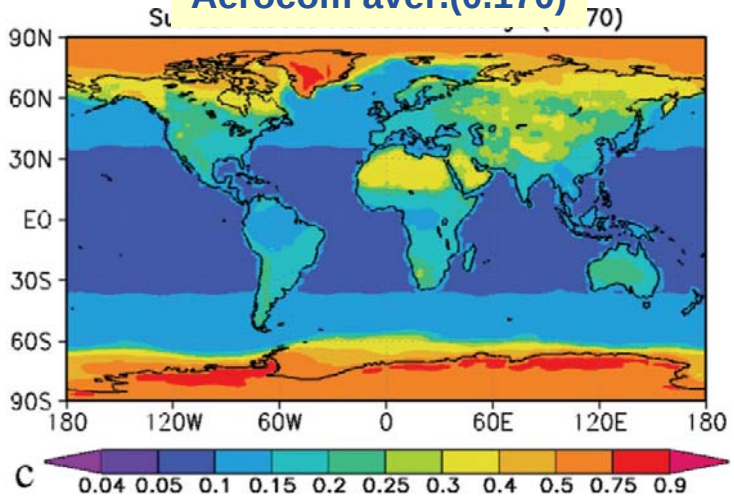
Fig. 10. Measured mean (solid lines), measured median (dash-dotted lines), and modelled mean (dashed lines) aerosol number concentrations for three flight measurement campaigns in the year 2000 over INCA-SH (Chile), INCA-NH (Scotland) and UFA-Export (Central Europe). Data are taken from Stier et al. (2005).

Additional influence on DRE: surface albedo

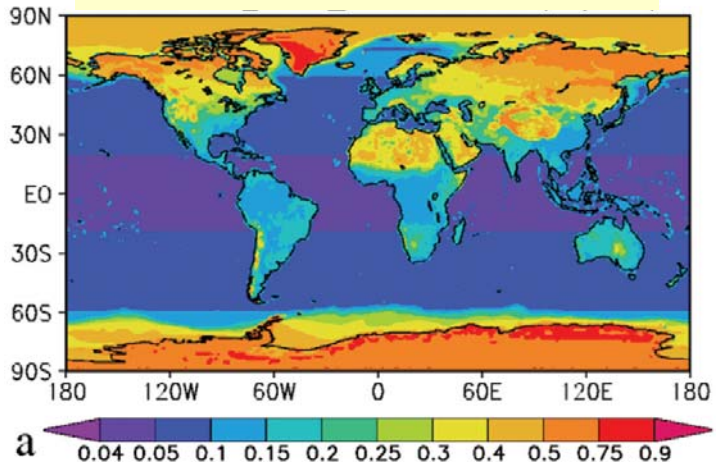
CAM-Oslo (0.147)



Aerocom aver.(0.170)



Modis + SSMI (0.153) (S. Kinne)



CAM-Oslo surface albedo is large at high latitudes and in some mid-latitude areas

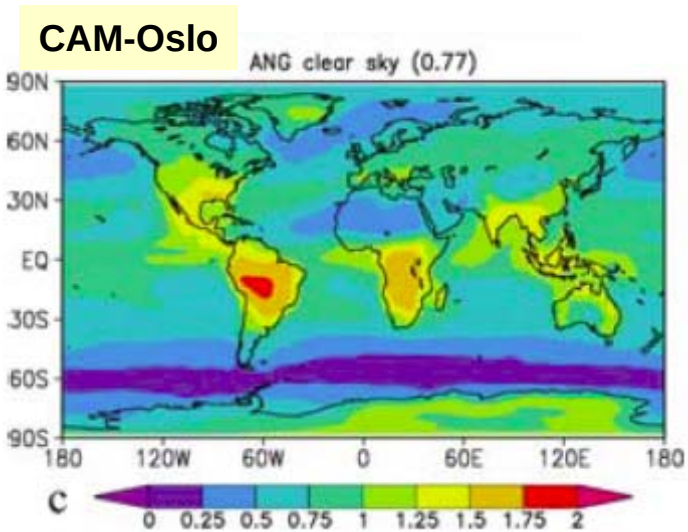
Ångström parameter:

$$\mathrm{ANG} = \frac{\ln AOD_1 - \ln AOD_2}{\ln \lambda_2 - \ln \lambda_1}$$

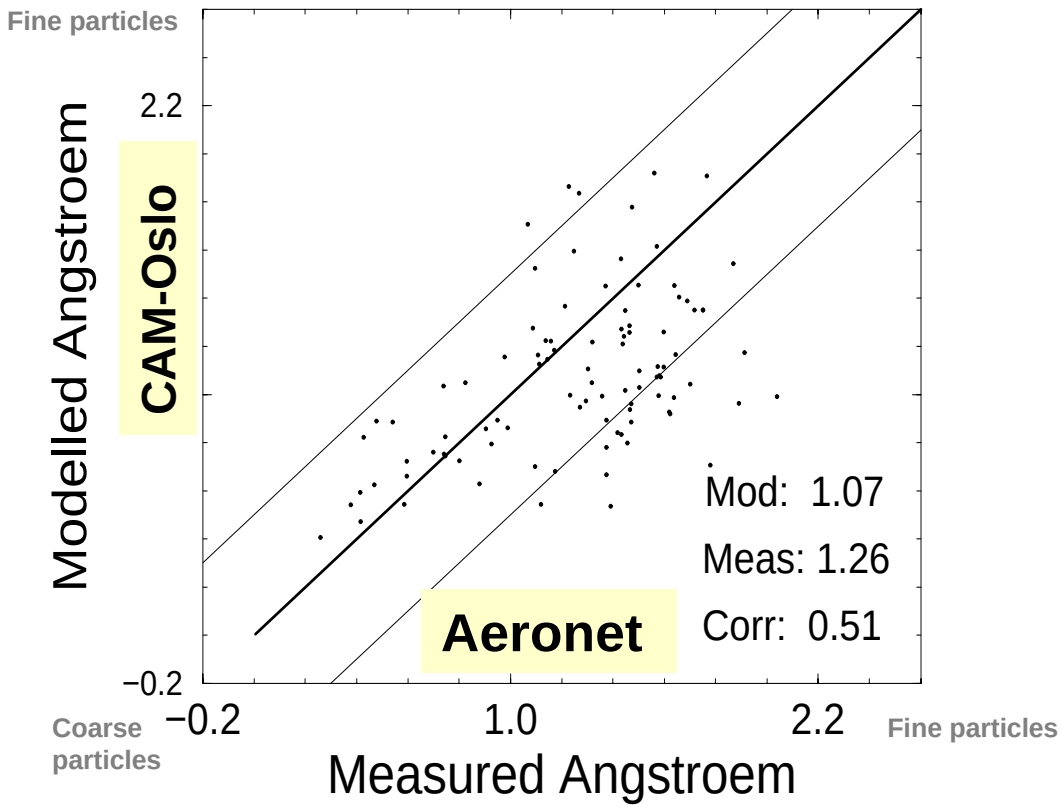
λ_1=0.55 μm

λ_2=0.865 μm

(indicator of dominant aerosol sizes)



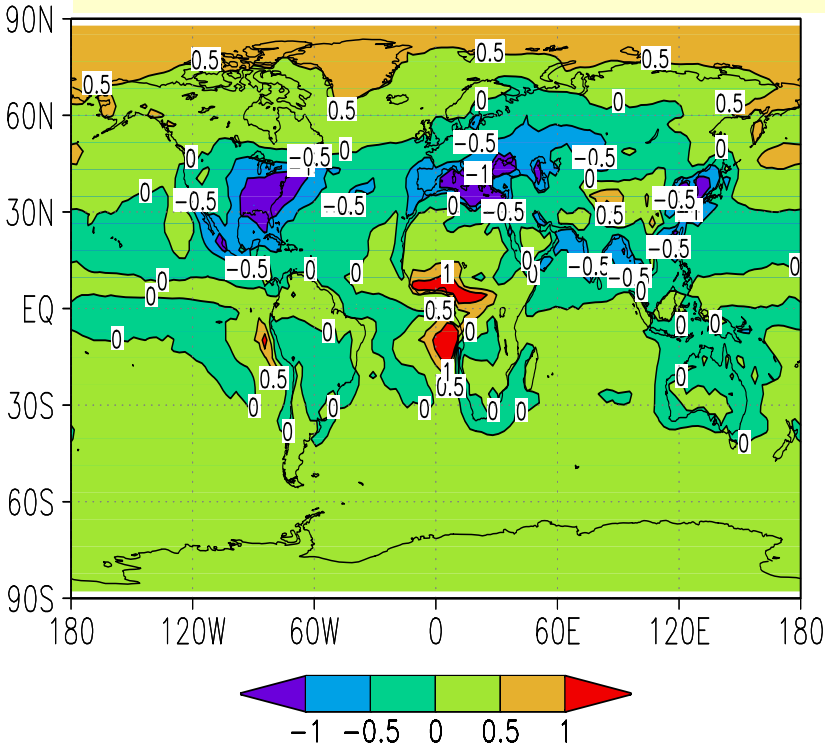
Modelled vs measured ANG, yearly mean



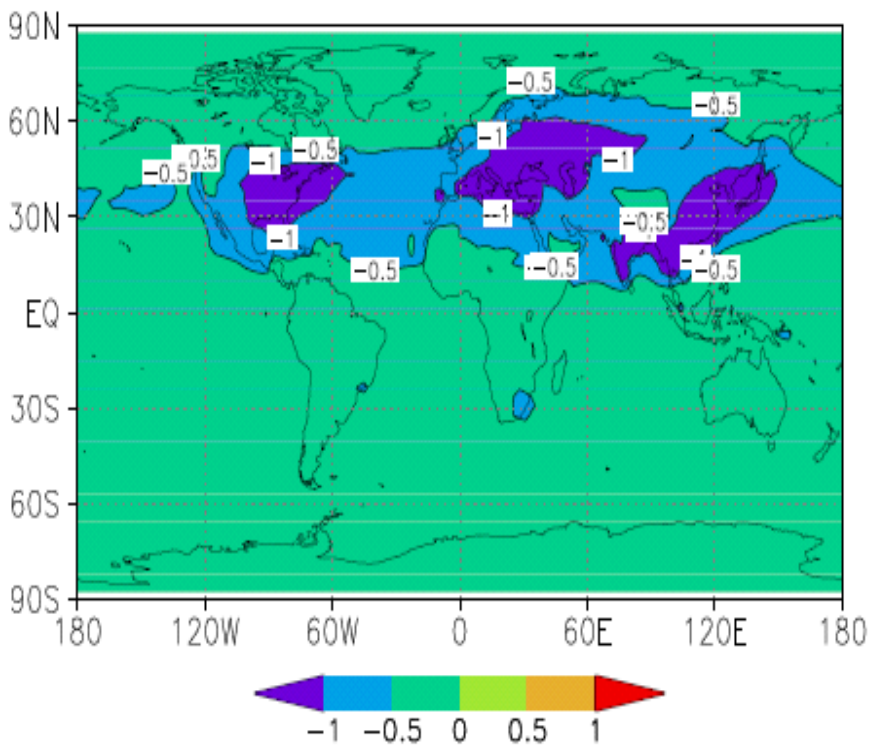
→ slight over-representation of large (relative to number of small) particles in CAM-Oslo

Direct radiative forcing TOA
Total vs. Sulphate only

Top Of the Atmosphere: +0.03W/m²



Sulphate only: -0.34 W/m²



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  - Biomass burning OM and BC emitted internally mixed.
  - Surface albedo and ABL cloudiness

Challenges :

- **AOD ~10-25% underestimated → Missing aerosols**
  - Non-desert mineral dust
  - Nitrate
    - Increased importance as sulphate emissions decrease
  - Anthropogenic SOA (+ some natural)
    - Speciation w.r.t. hygroscopicity and absorptivity
  - Bio-aerosols

- **Models calculate "correct" AOD but miss aerosol components/processes**
  - "constraining" bulk quantities should be avoided