Sensitivity of aerosol-climate interactions to assumed primary aerosol size (and other uncertainties)

Examples using CAM-Oslo

Trond Iversen, Alf Kirkevåg and Øyvind Seland

Mapping sensitive model parameters should be an aim for AeroCom Phase II

- **Examples:**

  CAM-Oslo used to study sensitivity of climate-relevant parameters w.r.t.:
  - **assumed size distributions of emitted primary particles.**
  - **parameters determining cloud influence on aerosols: convective clouds, below-cloud scavenging**

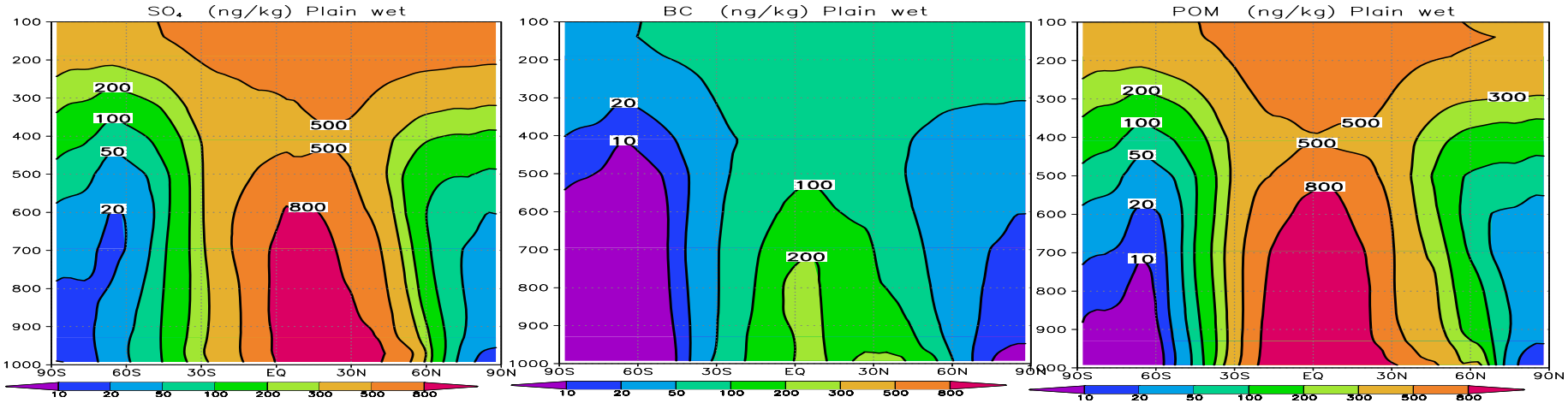
- **Short presentation of the new aerosol treatment in CAM-Oslo compared to CCM-Oslo (referred to in AeroCom Phase I as UiO-GCM)**

Convective processing / transport

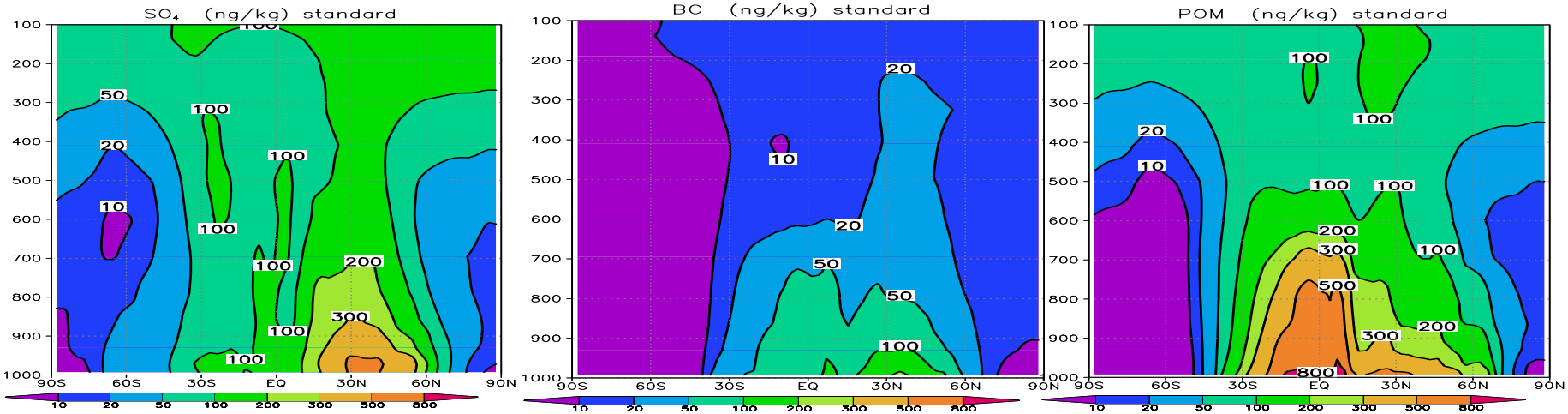
Reminder from earlier aerocom presentation

SO4 **BC** **POM**

Test: Below cloud convective scavenging in cloudy fraction only (no convergence effect)



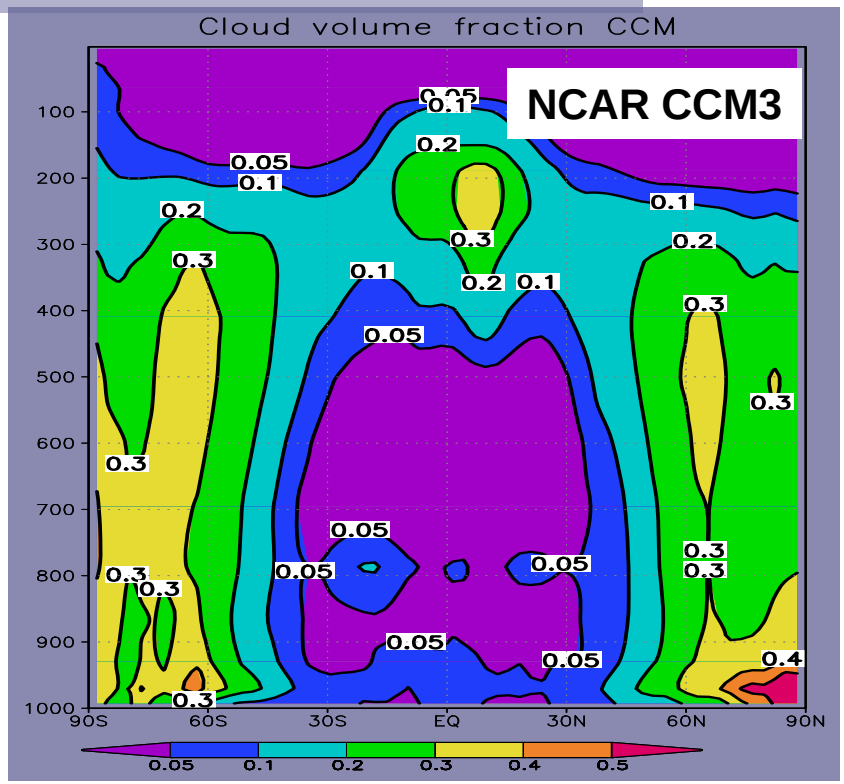
Standard: Increased below-cloud scavenging by convective precipitation in the ABL

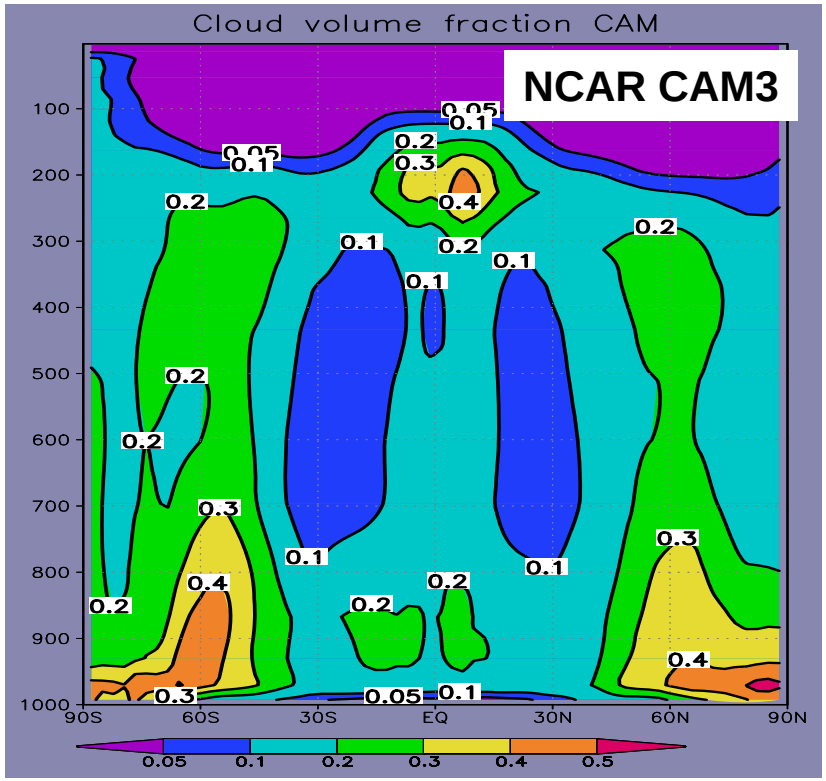


Cloud volume and liquid water:

an un-intended sensitivity test

Cloud volume fraction:





Cloud water: CCM3: 57 g/m2 ; CAM3: 128 g/m2

One reaction: reduced below-cloud scavenging;
Fraction of precip. clouds < total cloud fraction

Example of size influence: sea-salt modes

Pure sea-salt aerosol with a fixed mass concentration: the atmospheric lifetime, solar extinction, and CCN production vary strongly with particle size

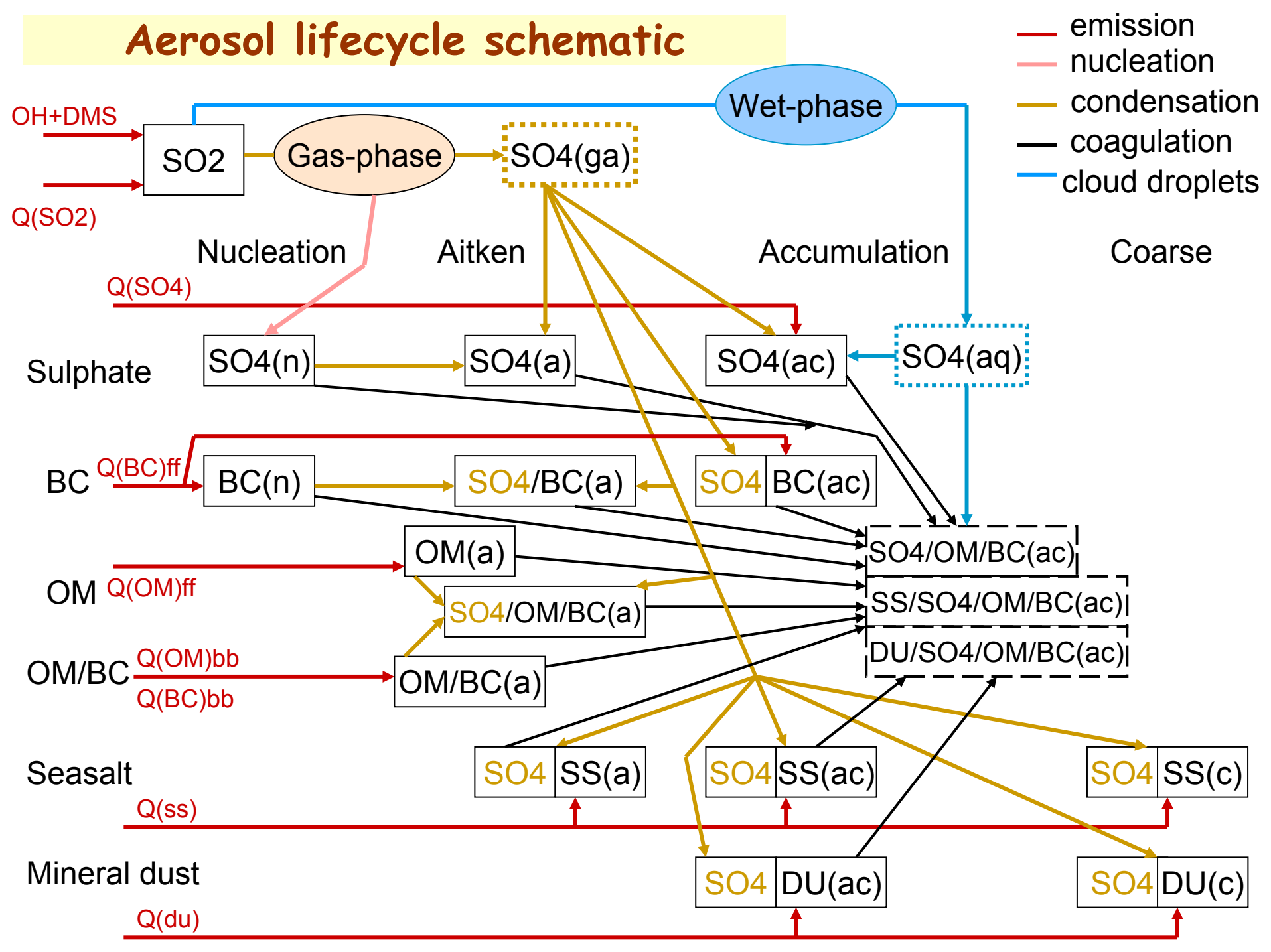
Mode	Modal parameters R(μ m)	σ	Life-time (d)	Wet dep (% of total)	Mass specific extinction, MEC (m^2/g ss) at 0.55μm **for RH =** **0%**	**80%**	**95%**	Mass specific CCN, CCN_m (cm^{-3}/(μg ss/m^3)) **for S =** **0.1%**	**0.25%**	**0.8%**
ss_a1	0.022	1.59	**1.30**	74	**0.25**	**4.1**	**17**	**59**	**744**	**3027**
ss_a2	0.13	1.59	**1.59**	88	**3.2**	**15**	**35**	**17.7**	**18.7**	**18.8**
ss_a3	0.76	2.00	**0.23**	24	**0.64**	**2.3**	**4.7**	**0.03**	**0.03**	**0.03**

CAM-OSLO

- **Basis: NCAR CAM3 extended with**
  - **aerosol lifecycling, production-tagged composition**
  - **Particle interactions with radiation**
  - **Particle interaction with clouds**
- **Sulphur and Black carbon (Iversen and Seland, 2002)**
- **Primary organic particles (Kirkevåg et al. 2005)**

New compared to CCM-Oslo (used in AeroCom B):

- **Re-runing of aerosol processes due to different cloud climatology**
- **Lifecycling of sea-salt and mineral aerosols**
  - **using emissions from aerocomB with some modifications**
- **Directly emitted sulphate allocated as accumulation mode**
  - **2.5% of emitted SOx-mass with 75nm modal radii**
- **Calculated nucleation/condensation fraction of gas phase sulphate**
- **Aitken size category included separatly:**
  - **All OM, and internally mixed biomass BC/OM, emitted as 40nm modal radii**


Aerosol lifecycle schematic
emission
nucleation
condensation
coagulation
cloud droplets
OH+DMS
SO2
Q(SO2)
Gas-phase
SO4(ga)
Wet-phase
Nucleation
Aitken
Accumulation
Coarse
Q(SO4)
Sulphate
SO4(n)
SO4(a)
SO4(ac)
SO4(aq)
BC
Q(BC)ff
BC(n)
SO4/BC(a)
SO4 BC(ac)
OM
Q(OM)ff
OM(a)
SO4/OM/BC(a)
OM/BC
Q(OM)bb
Q(BC)bb
OM/BC(a)
SO4/OM/BC(ac)
SS/SO4/OM/BC(ac)
DU/SO4/OM/BC(ac)
Seasalt
SO4 SS(a)
SO4 SS(ac)
SO4 SS(c)
Q(ss)
Mineral dust
SO4 DU(ac)
SO4 DU(c)
Q(du)

The standard simulation:

run for 5 years - the last 3 used for analysis.

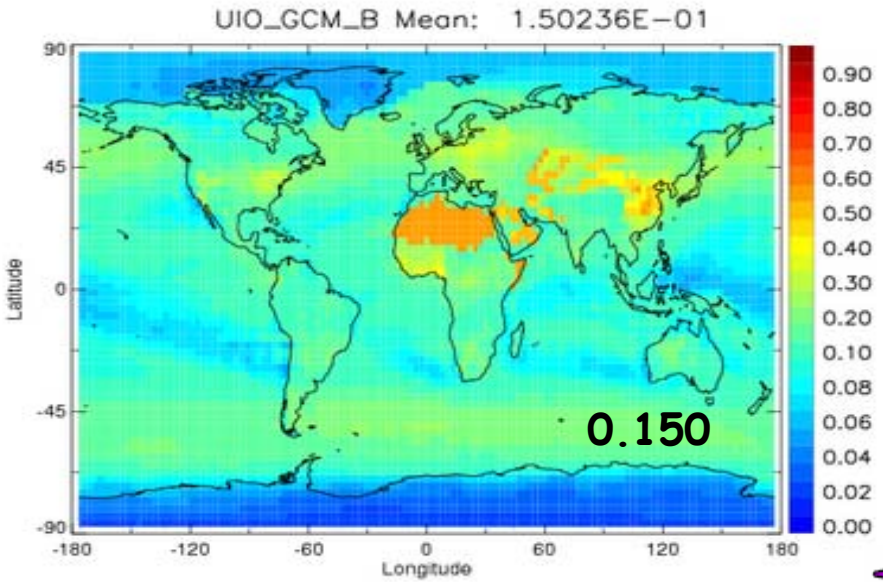
CAM-Oslo

vs.

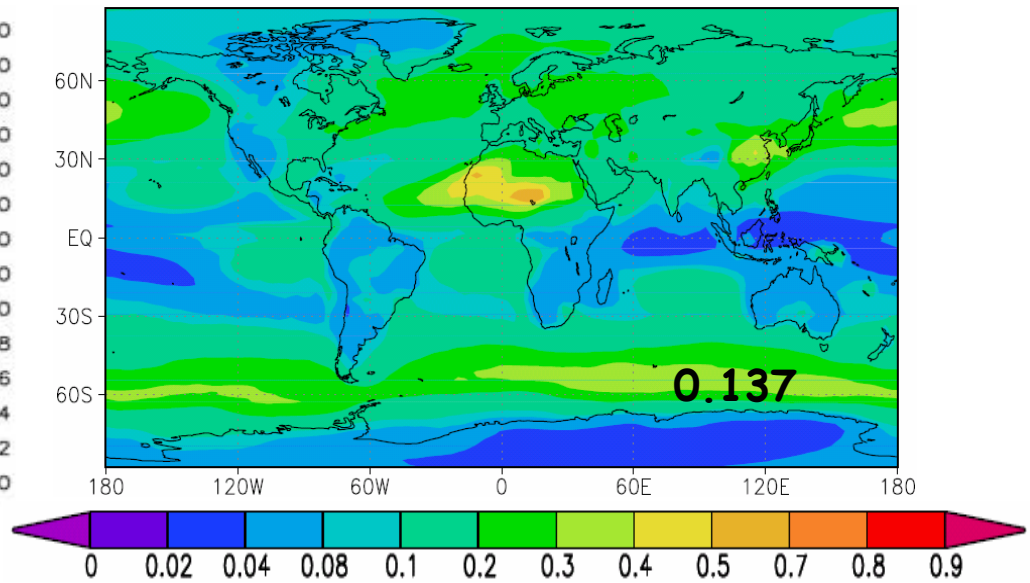
CCM-Oslo

Total Aerosol Optical Depth, τ_{550}

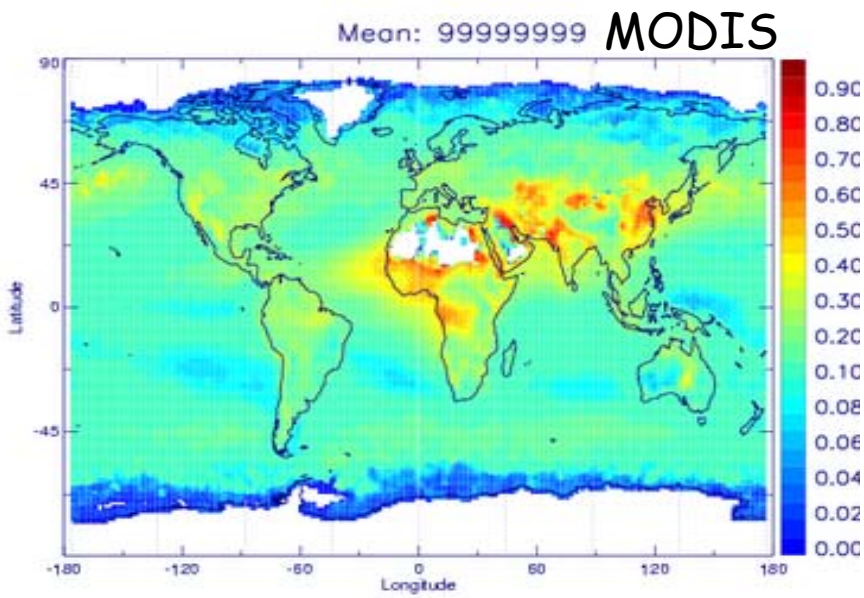
CCM-Oslo (B)

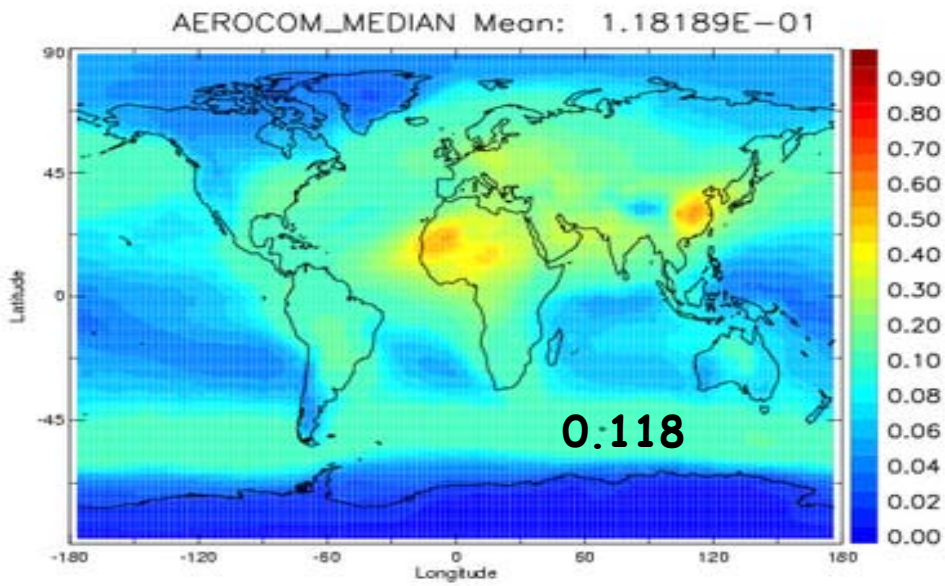


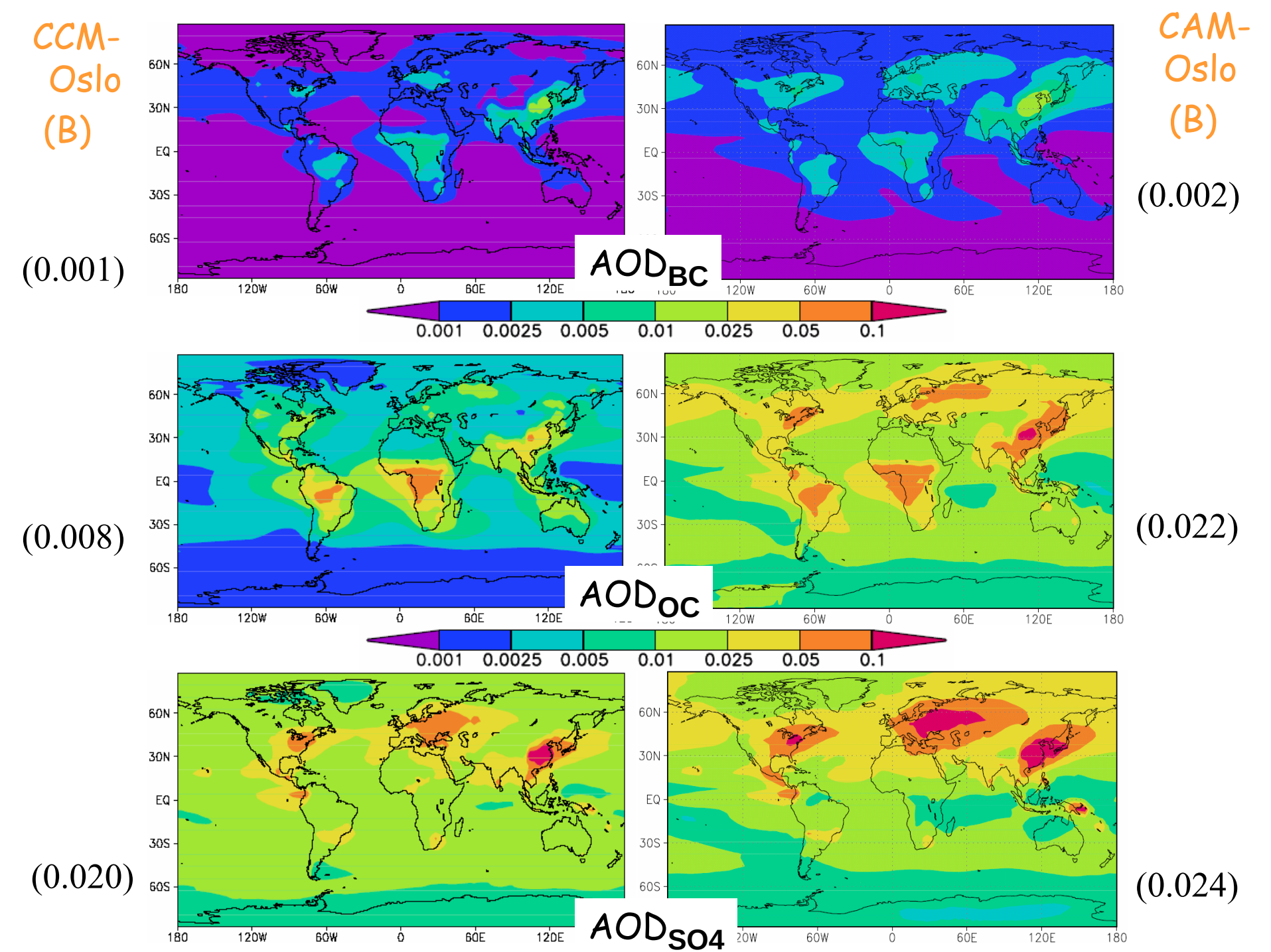
CAM-Oslo (B)



MODIS

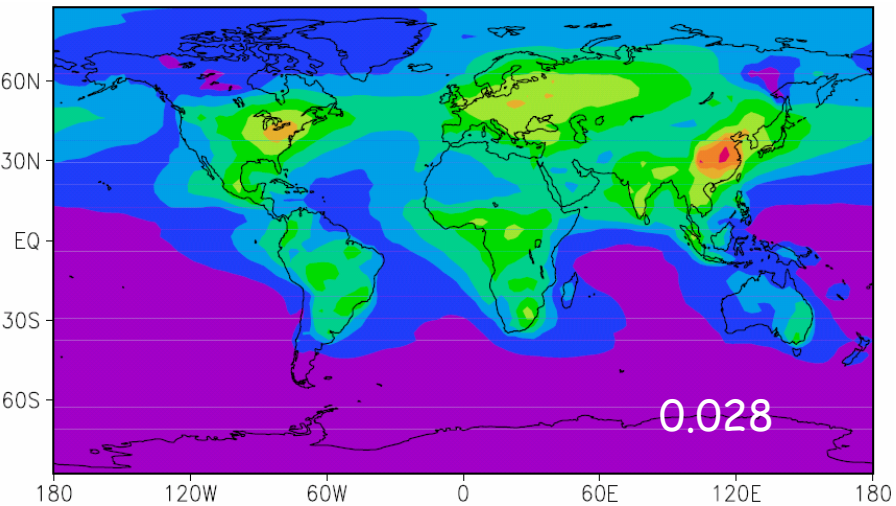




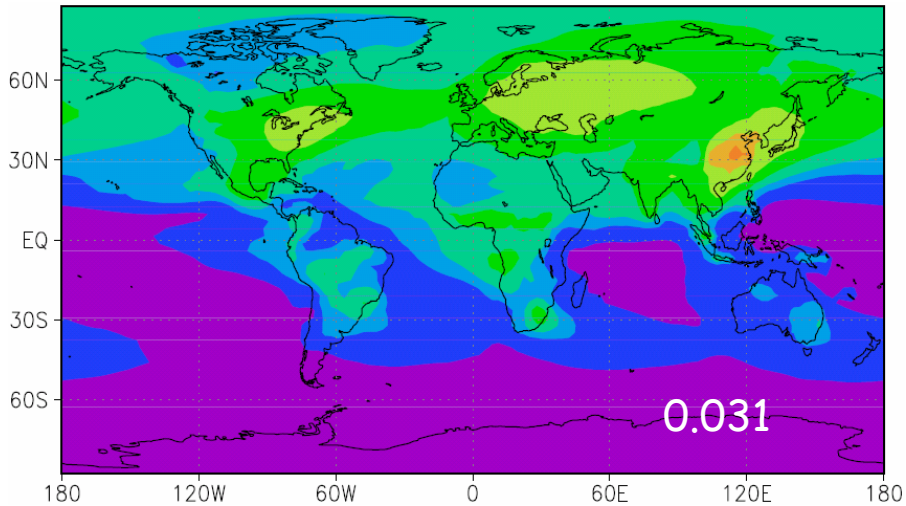

CCM-Oslo (B)
CAM-Oslo (B)
(0.001)
(0.002)
AOD_BC
(0.008)
(0.022)
AOD_OC
(0.020)
(0.024)
AOD_SO4
0.001 0.0025 0.005 0.01 0.025 0.05 0.1
60N
30N
EQ
30S
60S
180
120W
60W
0
60E
120E

AOD (τ_{550}), anthrop. SO4, OC and BC
Increment from Pre-industrial to aerocomB (2000)
(B – Pre)

CCM-Oslo



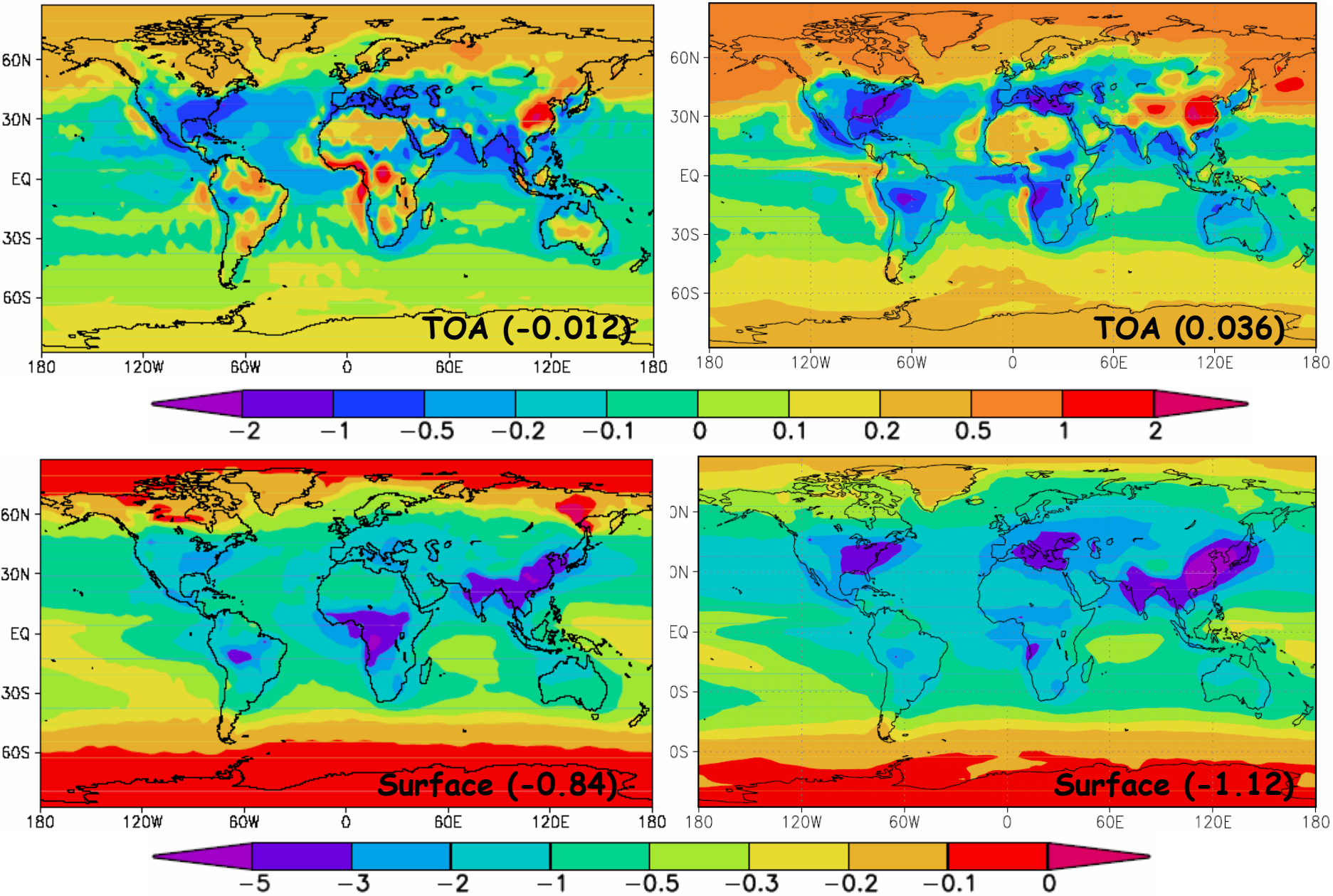
CAM-Oslo



CCM-Oslo

DRF (Wm^{-2}) due to anthrop. SO4, OC and BC (aerocomB – Pre)

CAM-Oslo

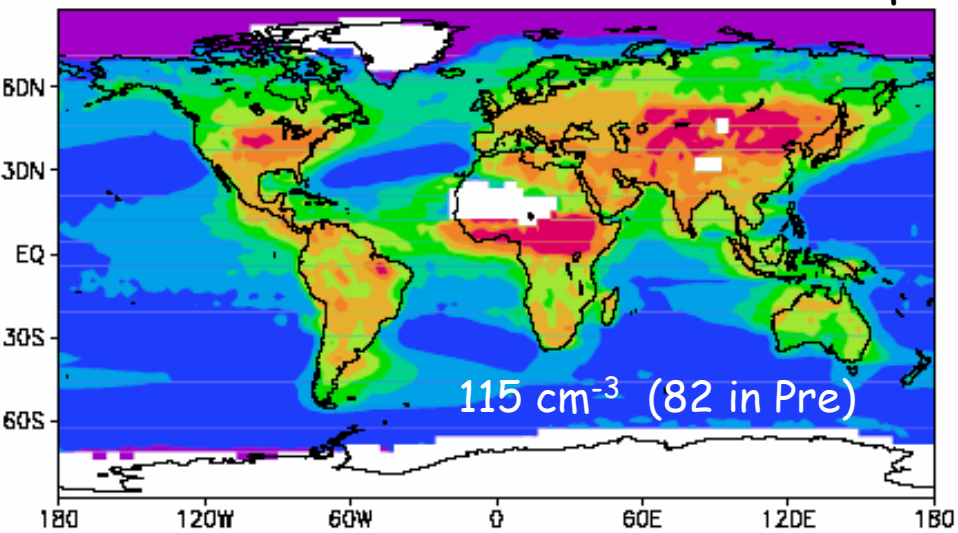


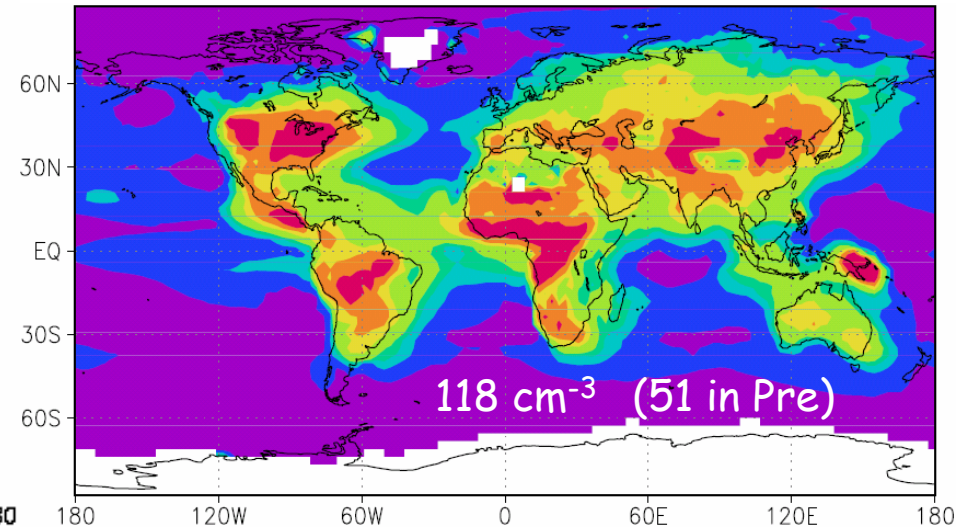
CDNC (cm^{-3}), Aerocom B

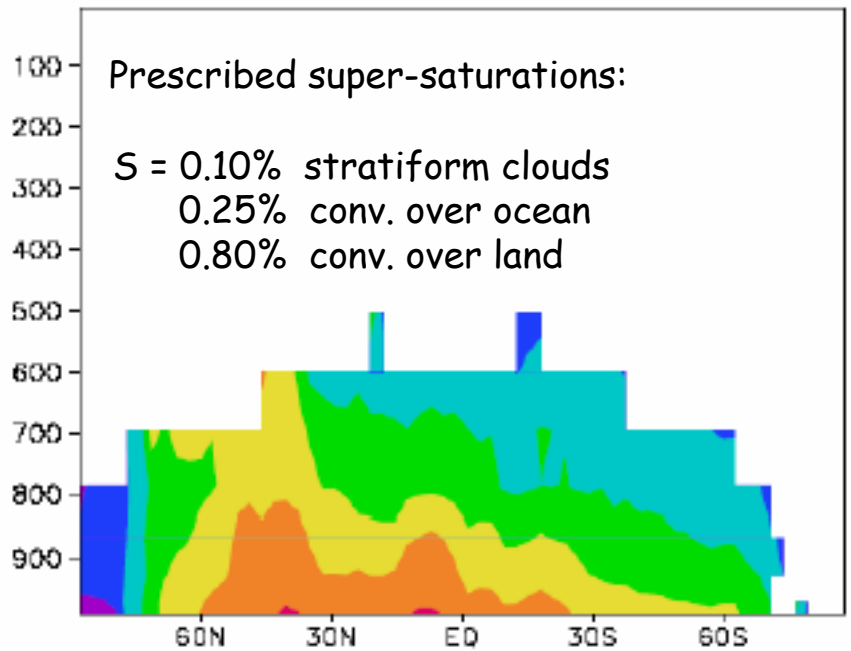
CCM-Oslo (B)

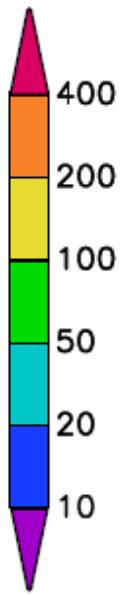
$\eta = 0.87$

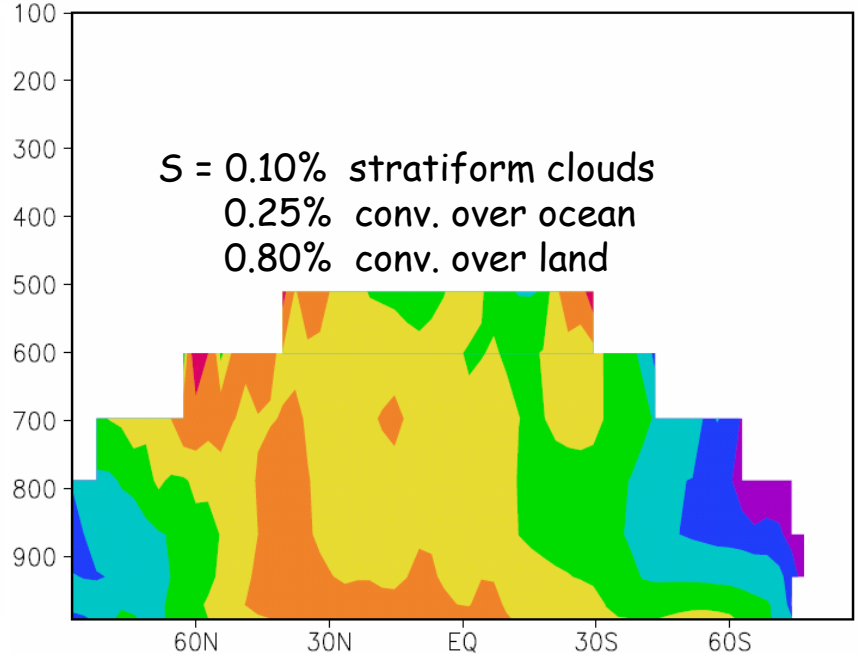
CAM-Oslo (B)





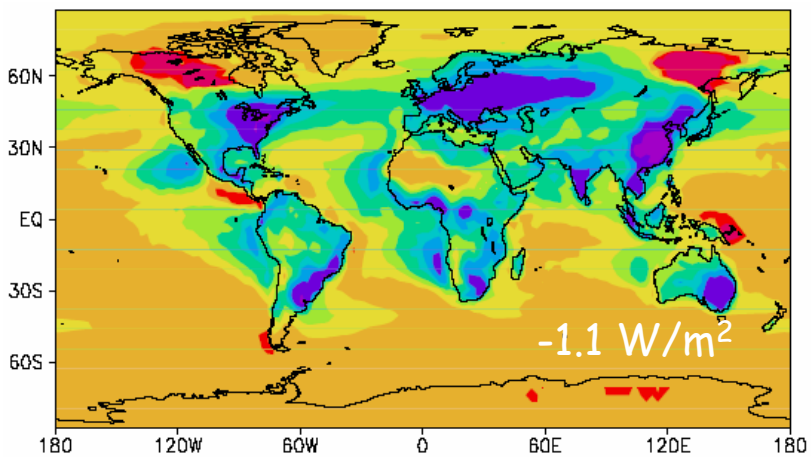




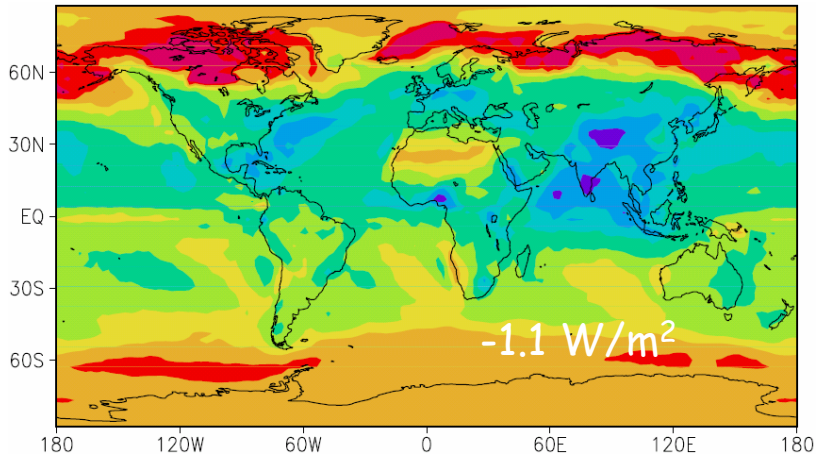


Change in Short Wave Cloud Forcing (W/m^2)(B-Pre)

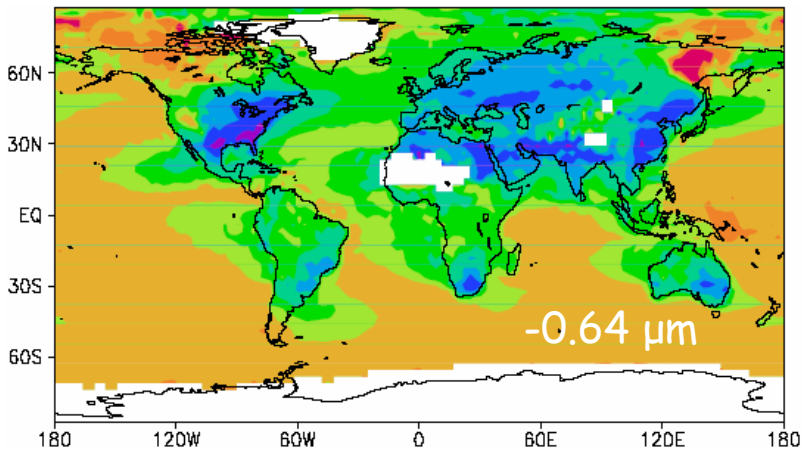
CCM-Oslo

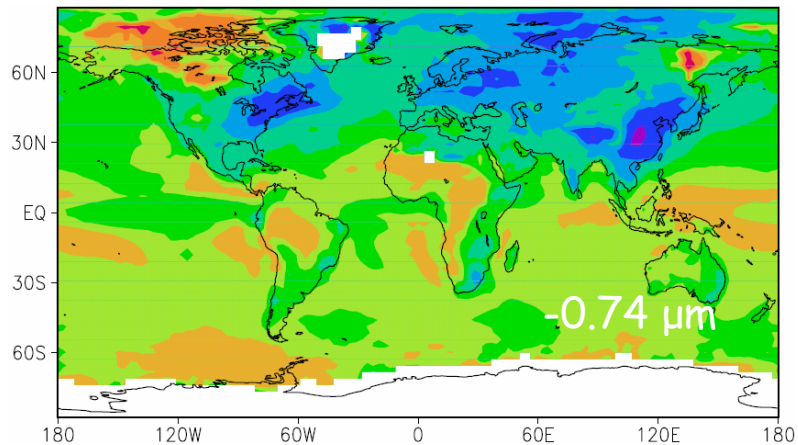


CAM-Oslo



Change in r_{eff}(μm) at η = 0.87, due to anthrop. SO4, OC & BC





Sensitivity tests

Influence of assumed particle size for primary particles

- Set up for year 5, starting with October the year before, and compared to year 5 of the standard simulation.
- E1: Base run: standard simulation but only for year no. 5.
- E2: Primary emissions of sulphate as H2SO4-gas (instead of 75nm modal radii primary particles)
- E3: Standard aerocom emissions for sea-salt (no re-allocation of coarse mode SS to accum. mode)
- E4: 0.1 % of emitted coarse mode (740nm) sea-salt mass re-allocated as 22 nm modal radii particles

Motivating tests E3 and E4: Re-allocation of sea-salt modal mass

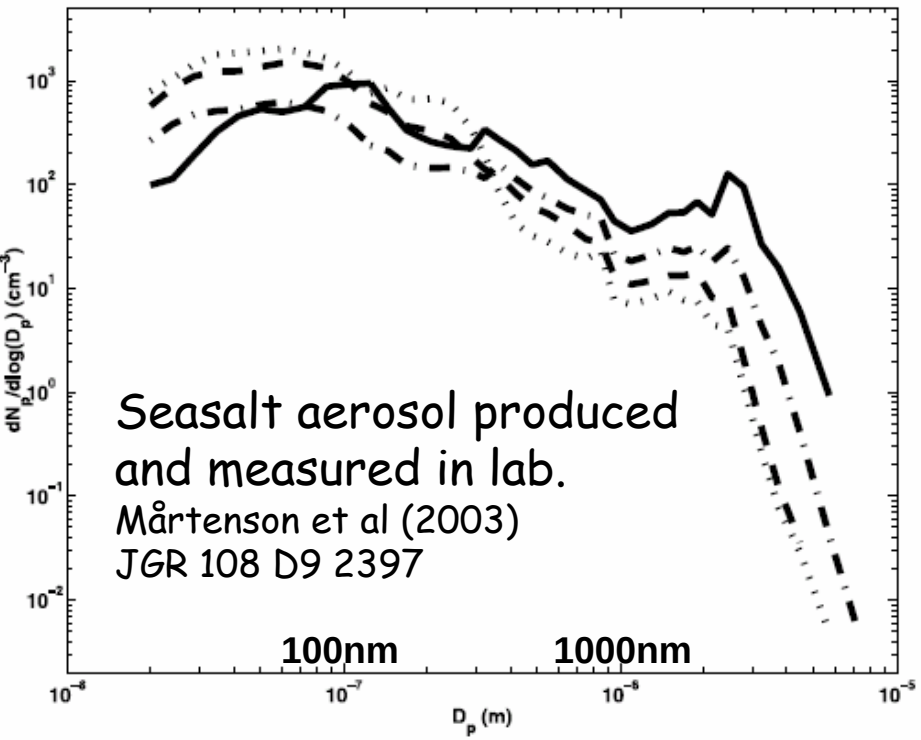
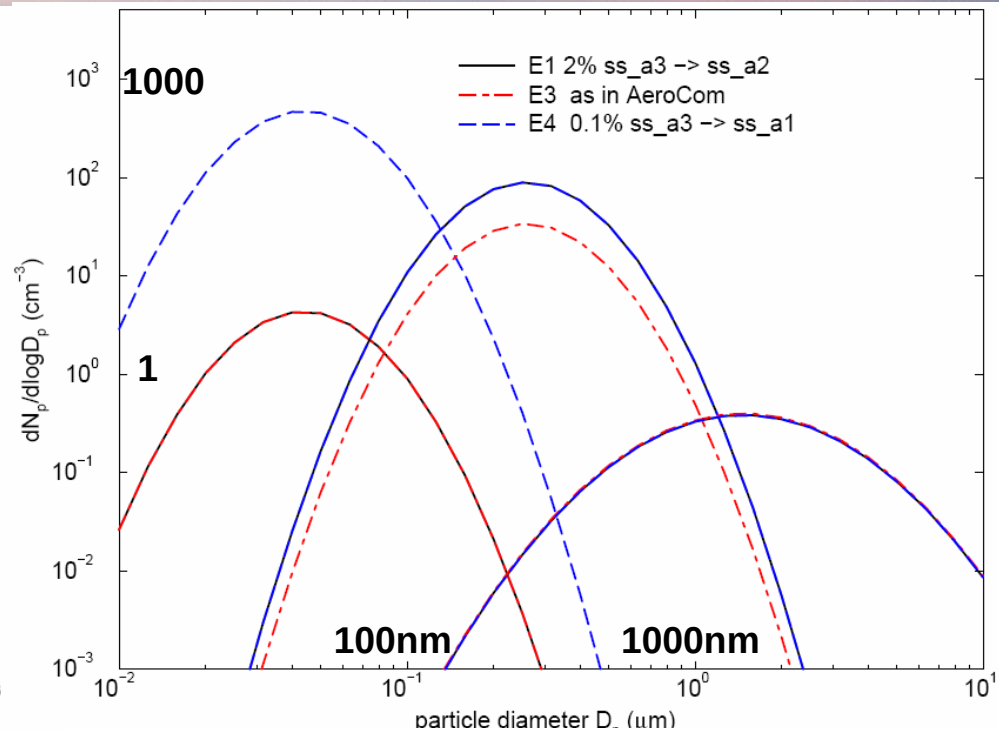


Figure 6. Number distributions of primary marine aerosol produced at water temperatures of −2°C (dotted line), 5°C (dashed line), 15°C (dot-dashed line), and 23°C (solid line) Here q_b was 13 mL min^{-1}, and the salinity was 33‰.



Average dry SS-aerosol number size distribution from CAM-Oslo for:
E1— , E3— , E4 —

Column burden and lifetime

E1: base run,

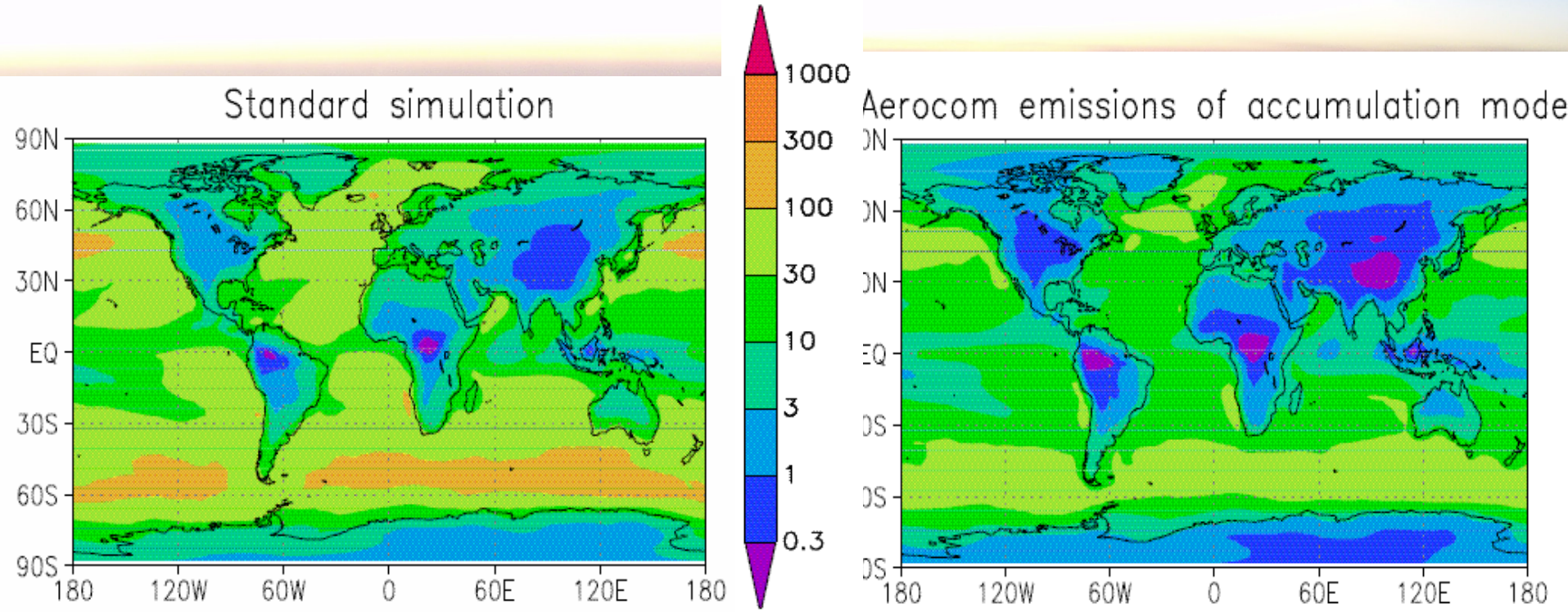
E2: no emitted primary sulphate accumulation mode

E3, unmodified aerocom sea-salt emissions,

E4, increased sea-salt aitken mode,

		SO4	Sea salt	POM	Mineral	BC
Burden (Tg)	E1	2.00	5.79	1.31	10.36	0.143
	E2	2.02	5.79	1.31	10.36	0.143
	E3	2.00	5.23	1.31	10.36	0.143
	E4	1.99	5.81	1.31	10.36	0.142
Lifetime (d)	E1	4.01	0.27	7.30	2.26	6.79
	E2	4.05	0.27	7.30	2.26	6.79
	E3	4.01	0.25	7.31	2.26	6.79
	E4	4.00	0.27	7.26	2.26	6.76
Wet.dep (%)	E1	92.2	26.4	80.3	35.7	75.2
	E2	92.0	26.4	80.3	35.7	75.2
	E3	92.2	25.2	80.3	35.7	75.1
	E4	92.2	26.5	80.5	35.7	75.3

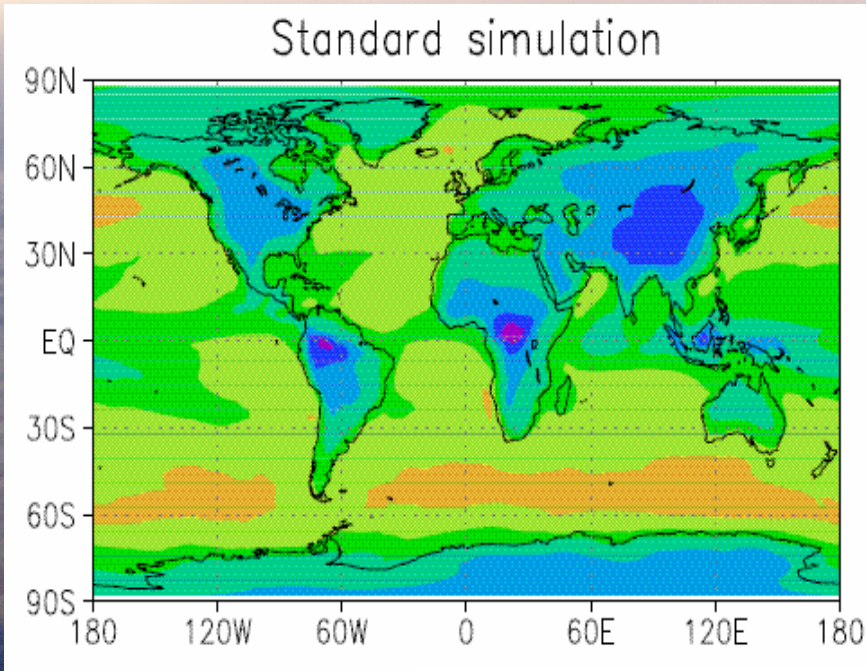
Sea-salt number concentration (1/cm^3) in E3 (aerocom original) compared to E1 (base run)

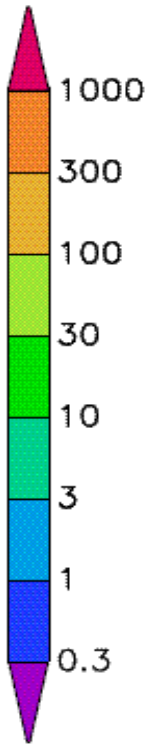


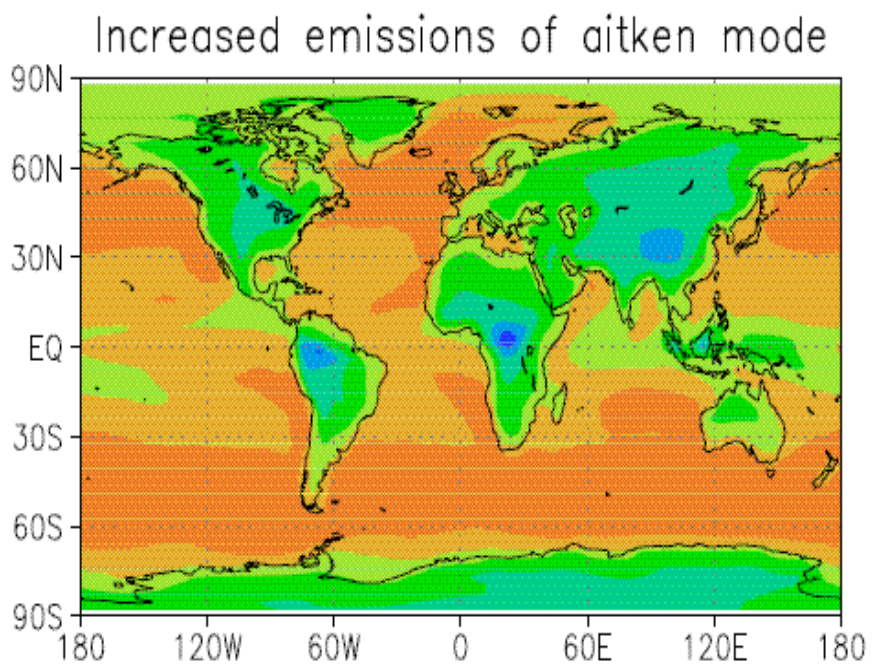
E1

E3

Sea-salt number concentration (1/cm^3) in E4 (incr. aitken SS) compared to E1 (base run)



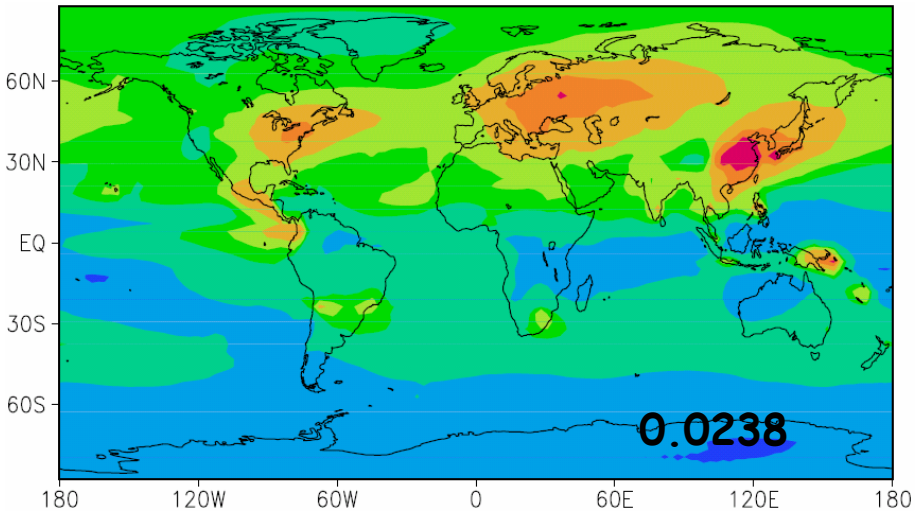




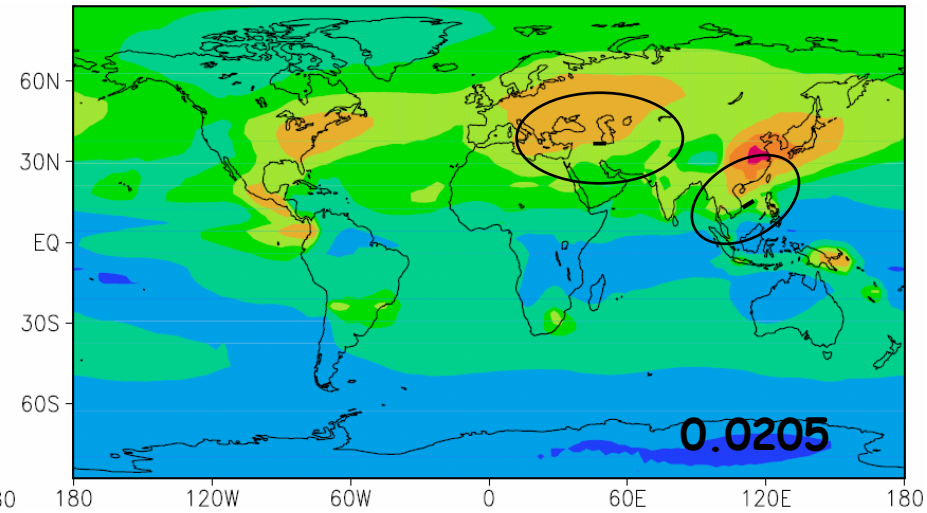
E1 **E4**

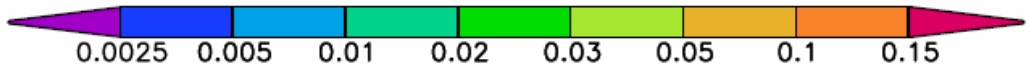
aerosol optical depth at 550nm CAM-Oslo, Aerocom B

E1: Base run, AOD SO4

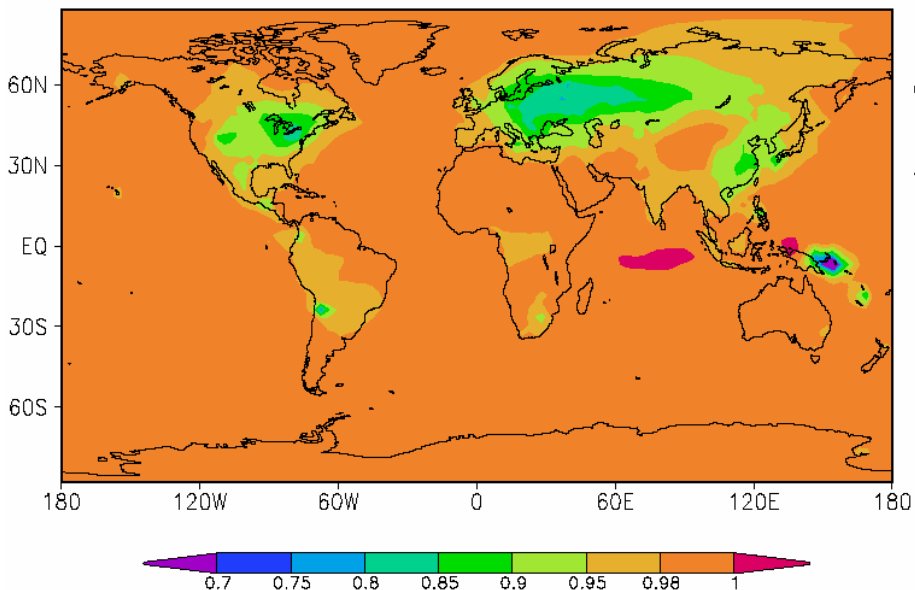


E2: 75nm SO4 primary acc. mode → H2SO4 gas

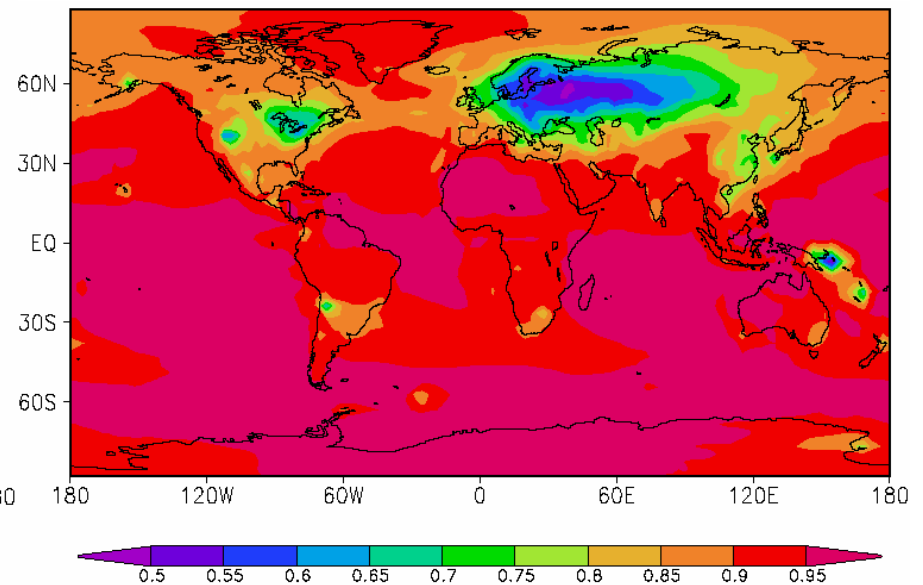




E2/E1: total AOD

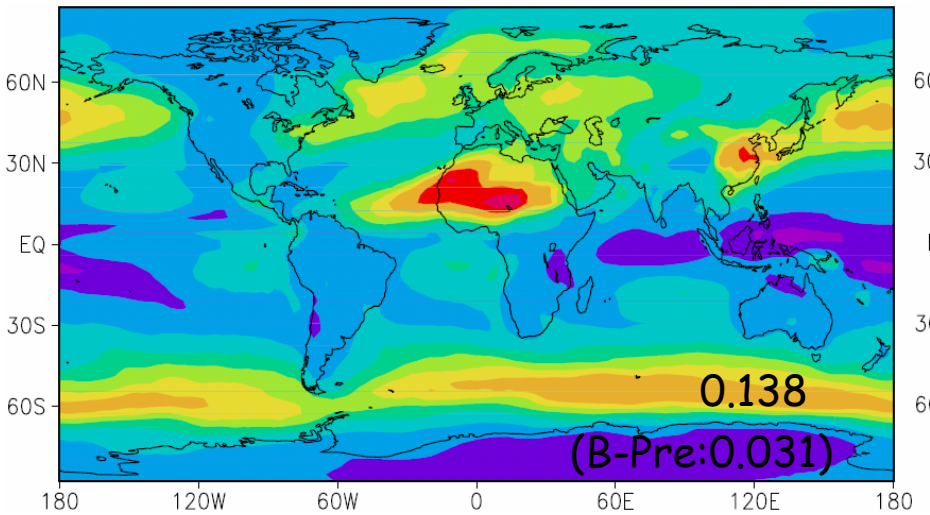


E2/E1: SO4 AOD

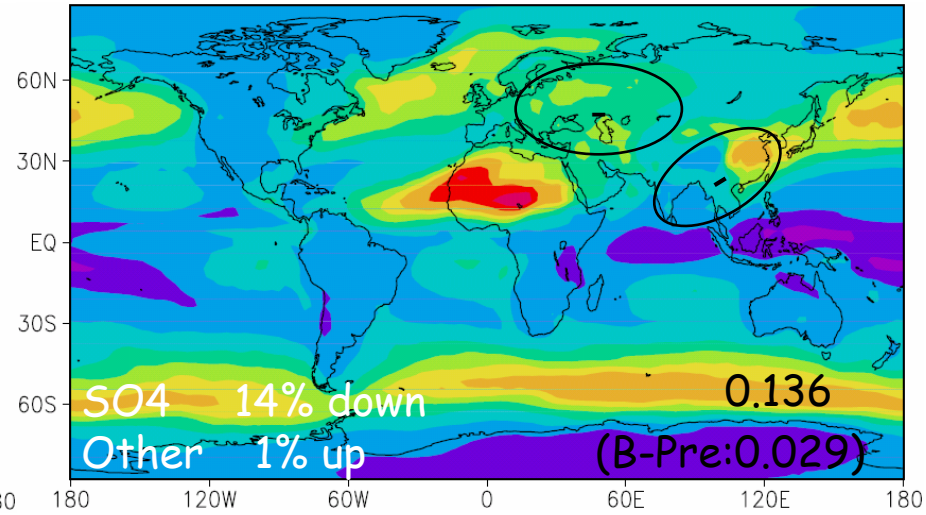


AOD (τ_{550}) CAM-Oslo, Aerocom **B**

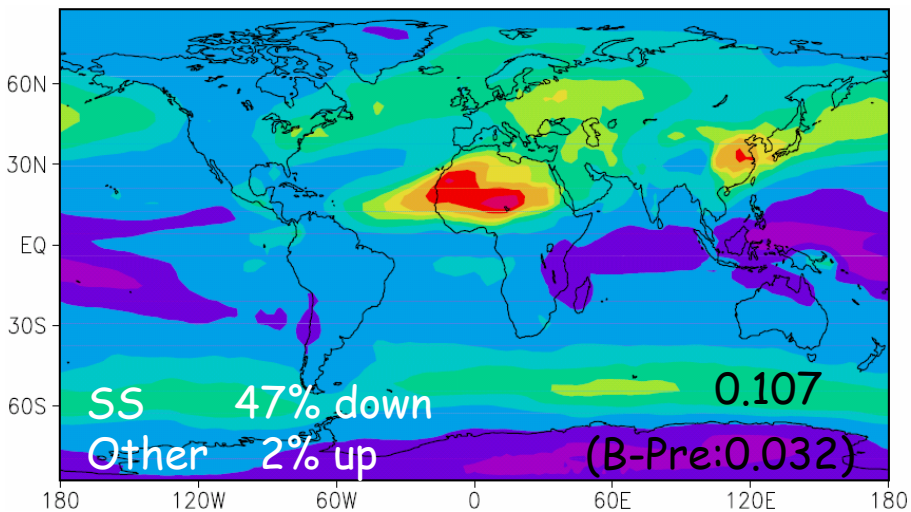
E1: Base run



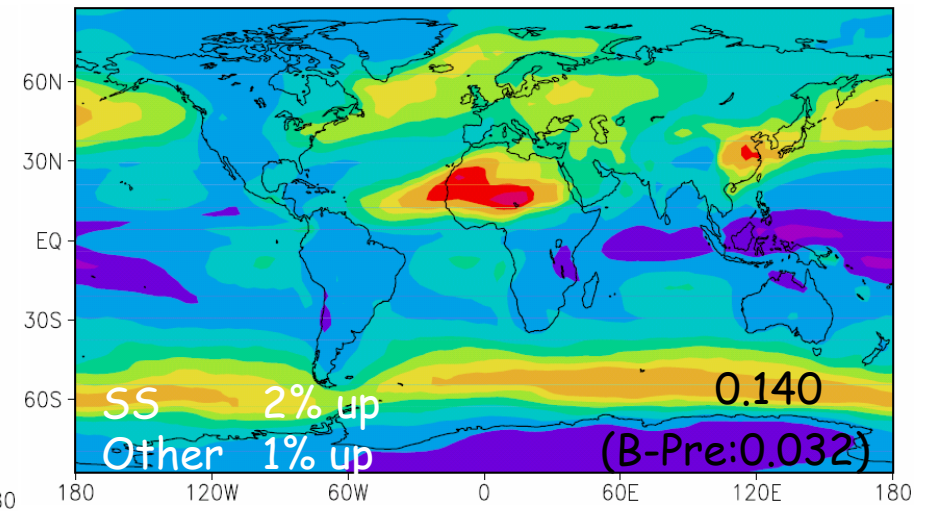
E2: 75nm SO4 primary acc. mode → H2SO4 gas



E3: standard Aerocom sea-salt



E4: 0.1% ss_coarse re-allocated to ss_aitken



Aerosol optical depth and direct radiative forcing:

Exp.	AOD (B)	AOD (B) SO4	AOD (B) POM	AOD (B) BC	AOD (B) Sea-salt	AOD (B) Dust	DRF (B-Pre) (W/m^2) Surface	TOA,
E1	0.138	0.0238	0.0217	0.0018	0.0704	0.0203	-1.13	0.036
E2	0.136	0.0205	0.0222	0.0018	0.0706	0.0206	-1.15	0.080
E3	0.107	0.0244	0.0224	0.0019	0.0375	0.0205	-1.15	0.027
E4	0.140	0.0248	0.0212	0.0018	0.0716	0.0203	-1.12	0.027

E1: Base run

E2: 75nm SO4 primary acc. mode → H2SO4 gas

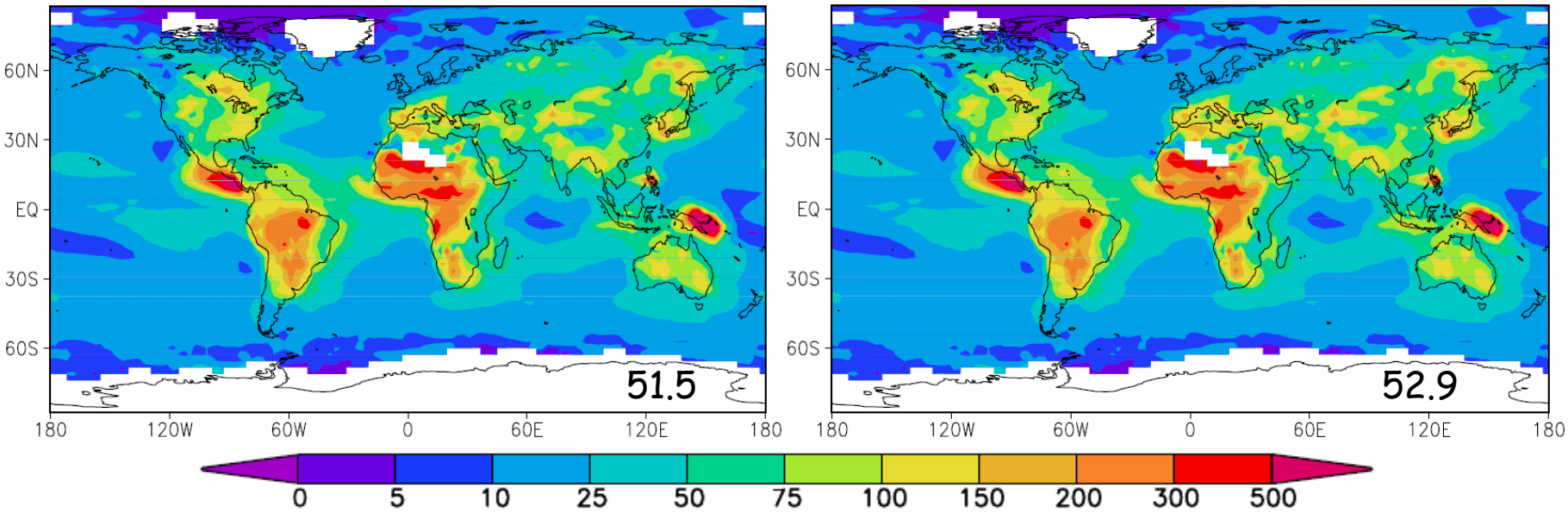
E3: standard Aerocom sea-salt

E4: 0.1% ss_coarse re-allocated to ss_aitken

CDNC (cm^{-3}) at $\eta = 0.87$ CAM-Oslo, Aerocom **Pre**

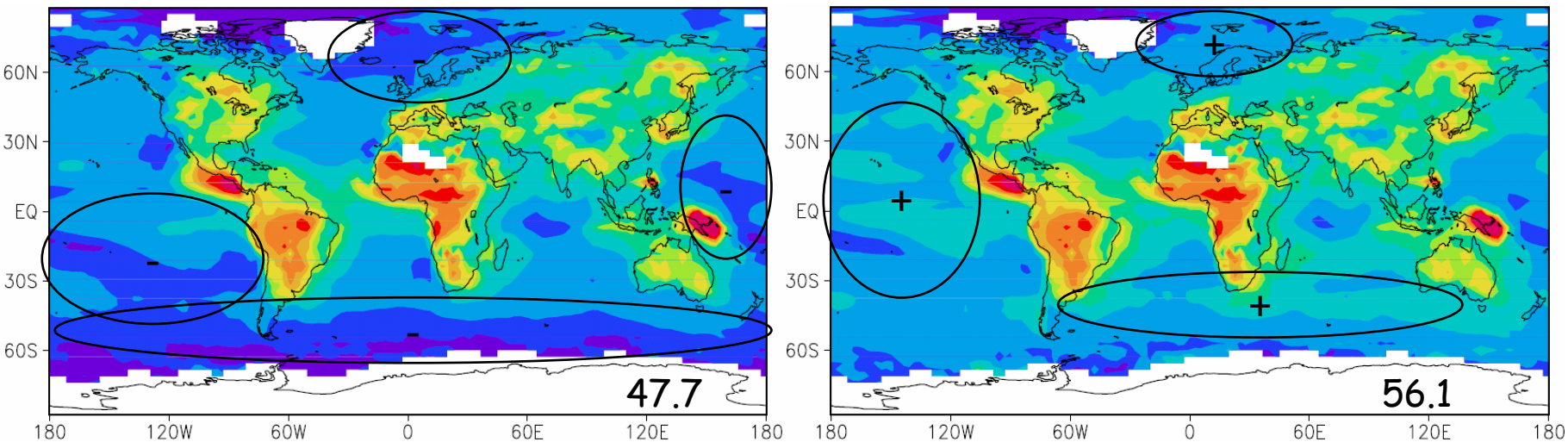
E1: Base run

E2: 75nm SO4 primary acc. mode → H2SO4 gas



E3: standard Aerocom sea-salt

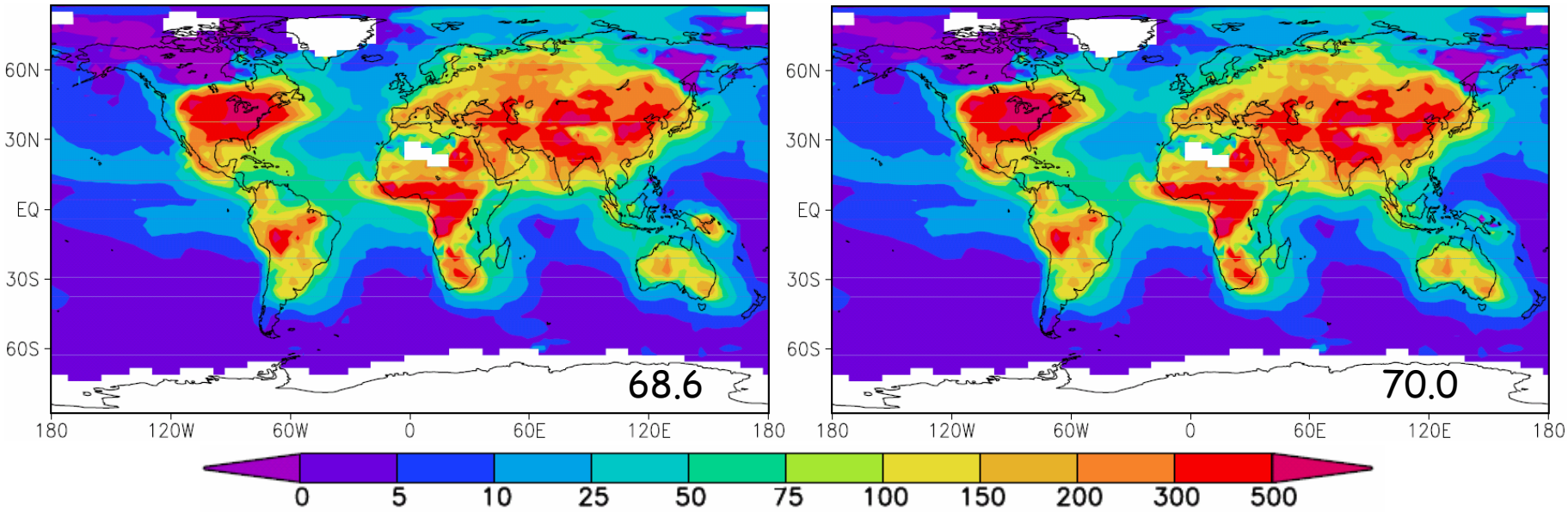
E4: 0.1% ss_coarse re-allocated to ss_aitken



CDNC (cm^{-3}) at $\eta = 0.87$ CAM-Oslo, Aerocom **B-Pre**

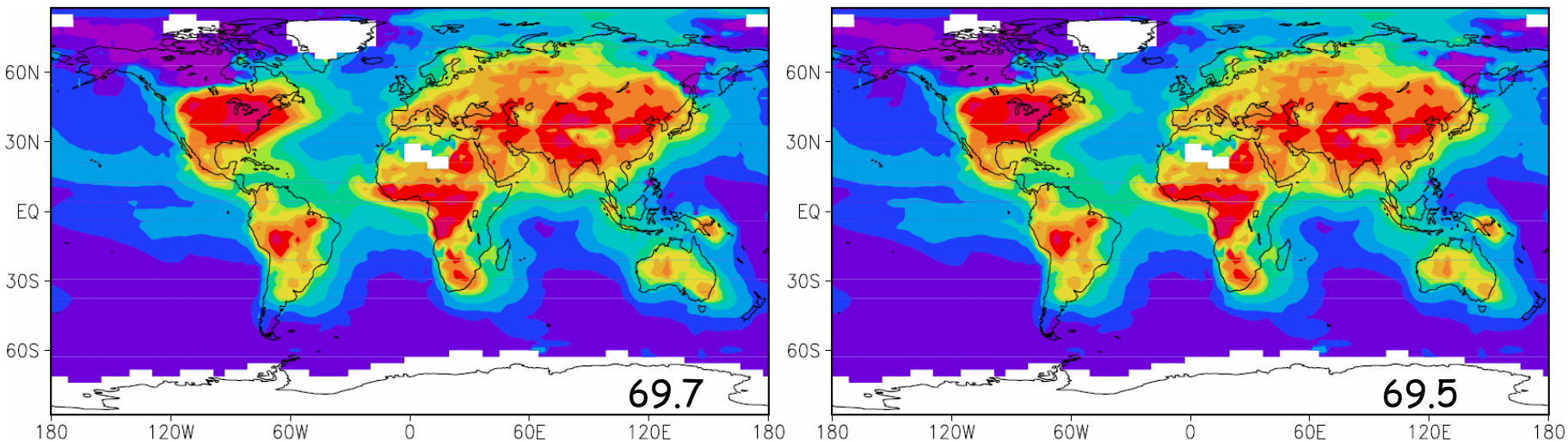
E1: Base run

E2: 75nm SO4 primary acc. mode → H2SO4 gas



E3: standard Aerocom sea-salt

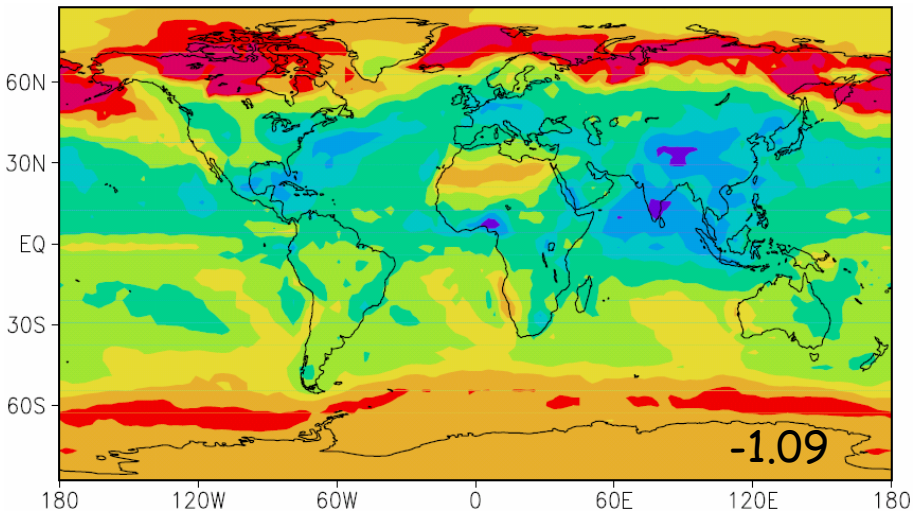
E4: 0.1% ss_coarse re-allocated to ss_aitken



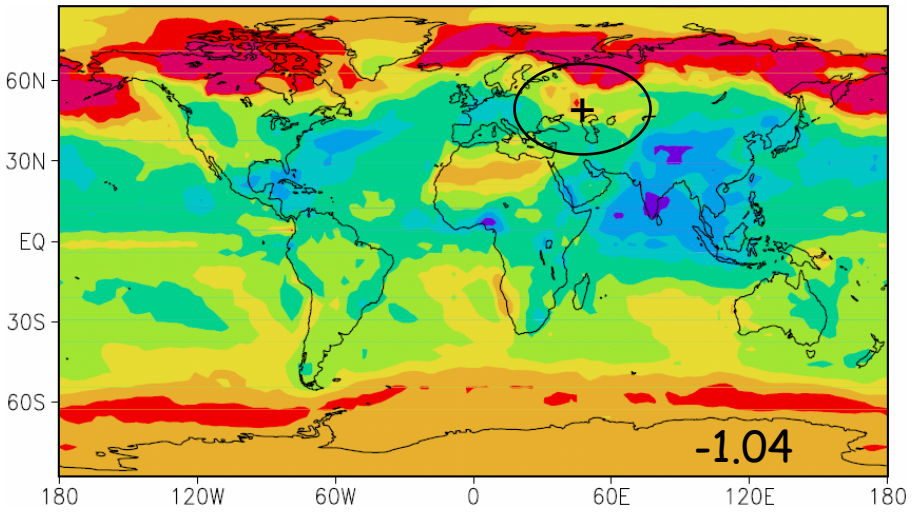
Change in SWCF (W/m^2)

CAM-Oslo, Aerocom **B-Pre**

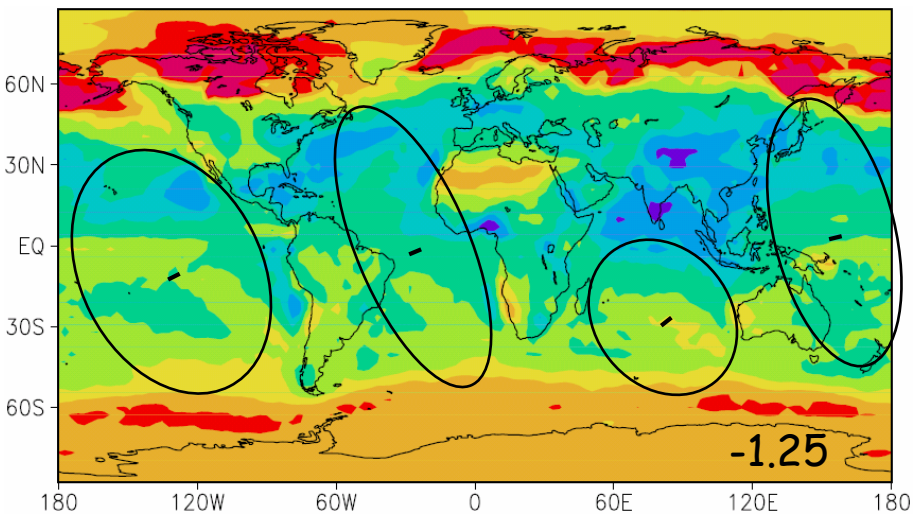
E1: Base run



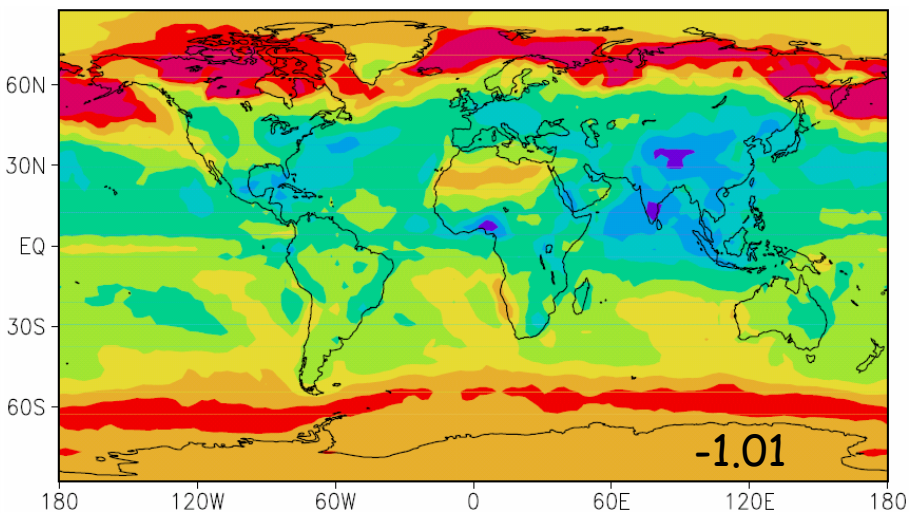
E2: 75nm SO4 primary acc. mode → H2SO4 gas



E3: standard Aerocom sea-salt



E4: 0.1% ss_coarse re-allocated to ss_aitken



Suggested questions for aerocom phase II

Are we able to produce correct clear-air and cloud properties from basic aerosol principles?

To what extent do are models tuned to achieve gross properties such as measured concentrations, total AOD, cdnc, etc.?

Is "constraining models" a healthy way of using satellite and aeronet retrievals?

Key issues: vertical distribution, particle size, composition, shape,…

Is there any role for neglected components/processes, such as:

- nitrate aerosols?
- biogenic aerosols?
- condensation of organics emitted in gas phase?
- influence of cosmic rays on new particle production?

How can we reduce uncertainties in vertical distribution and processes in deep convective clouds?

In designing inter-comparison, should AeroCom emphasize to what extent the spread of model results mirrors the level of understanding and the quality parameterizations?

Is spread between models a bad thing, or is it a strength?


AREA FUMATORI
VIETATO FUMARE
Thank You

Extra slides

CDNC & r_{eff} at $\eta = 0.87$, and indirect forcing:

Exp.	CDNC (Pre) (cm^{-3})	CDNC (B-Pre) (cm^{-3})	r_{effl} (Pre) (μm)	r_{effl} (B-Pre)/Pre (%)	SWCF (B-Pre) (W/m^2)
E1	51.5	68.6	9.52	-7.8	-1.09
E2	52.9	70.0	9.52	-7.4	-1.04
E3	47.4	69.7	10.10	-8.6	-1.25 (!)
E4	56.1	69.5	9.31	-7.4	-1.01

E1: Base run

E2: 75nm SO4 primary acc. Mode → H2SO4 gas

E3: standard Aerocom sea-salt
(few but large ss particles)

E4: 0.1% ss_coarse re-allocated to ss_aitken
(many but small ss particles)

Assuming same LWC in Pre and B:

$$\Delta SWCF \propto R_c(1-R_c)\cdot\frac{\Delta r_{effl}}{r_{effl}}$$

Acknowledgements and references

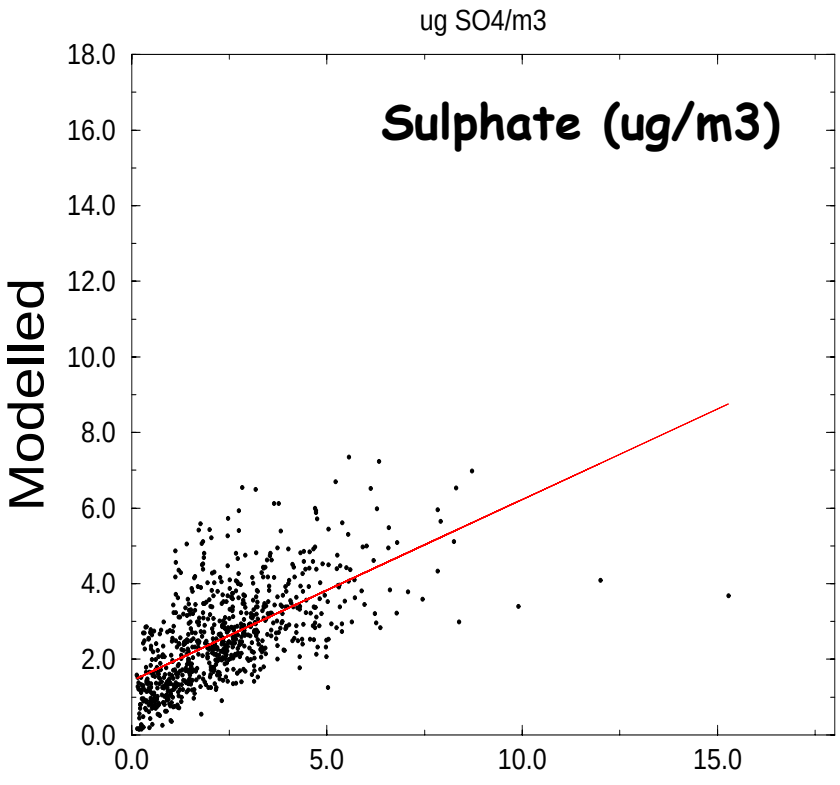
- Acknowledgements
  - The project is financed by the Norwegian Research Council through the project AerOzClim
  - The project has received support from NRC through a grant of computing time

- References

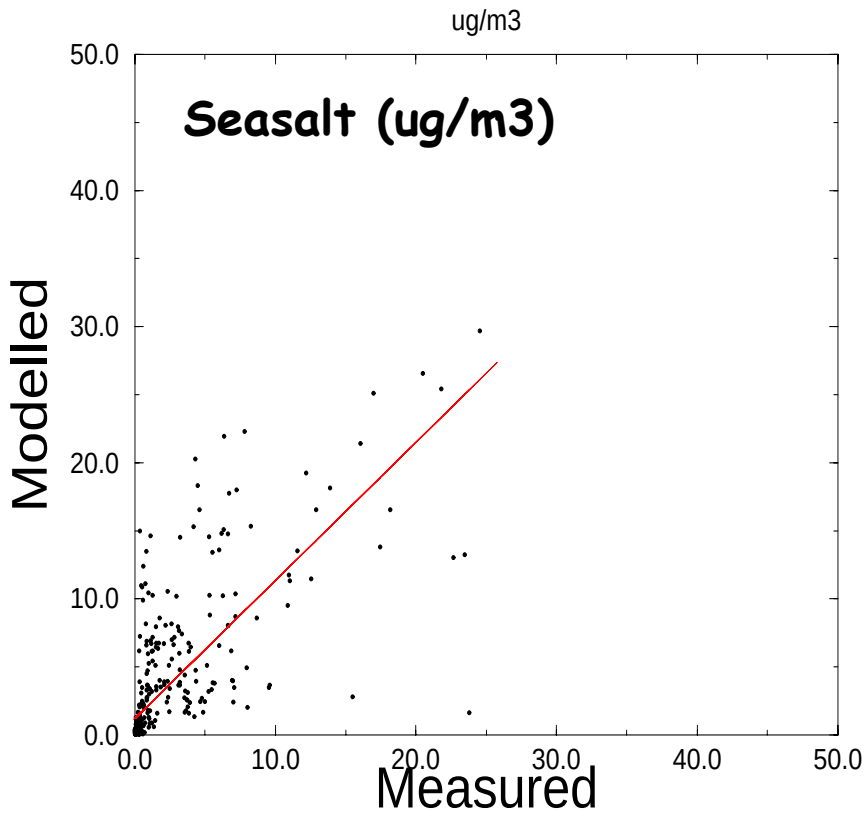
  - Kirkevåg et al (2005) Dep. Of Geosciences institute report No 128
  - Iversen and Seland(2002) JGR 107 D24 4751;
  - Mårtensson et al (2003) JGR 108 D9 2397
  - Ogren and Charlson (1983) Tellus 35B 241-254
  - Seinfeld and Pandis (1998) Atmospheric Chemistry and Physics. From air pollution to climate change
  - Stier et al (2005) ACP 5, 1125-1156
  - Textor et al. (2005) ACP 5 8331-8420;

Comparison with measurements
Standard simulation (3 years)

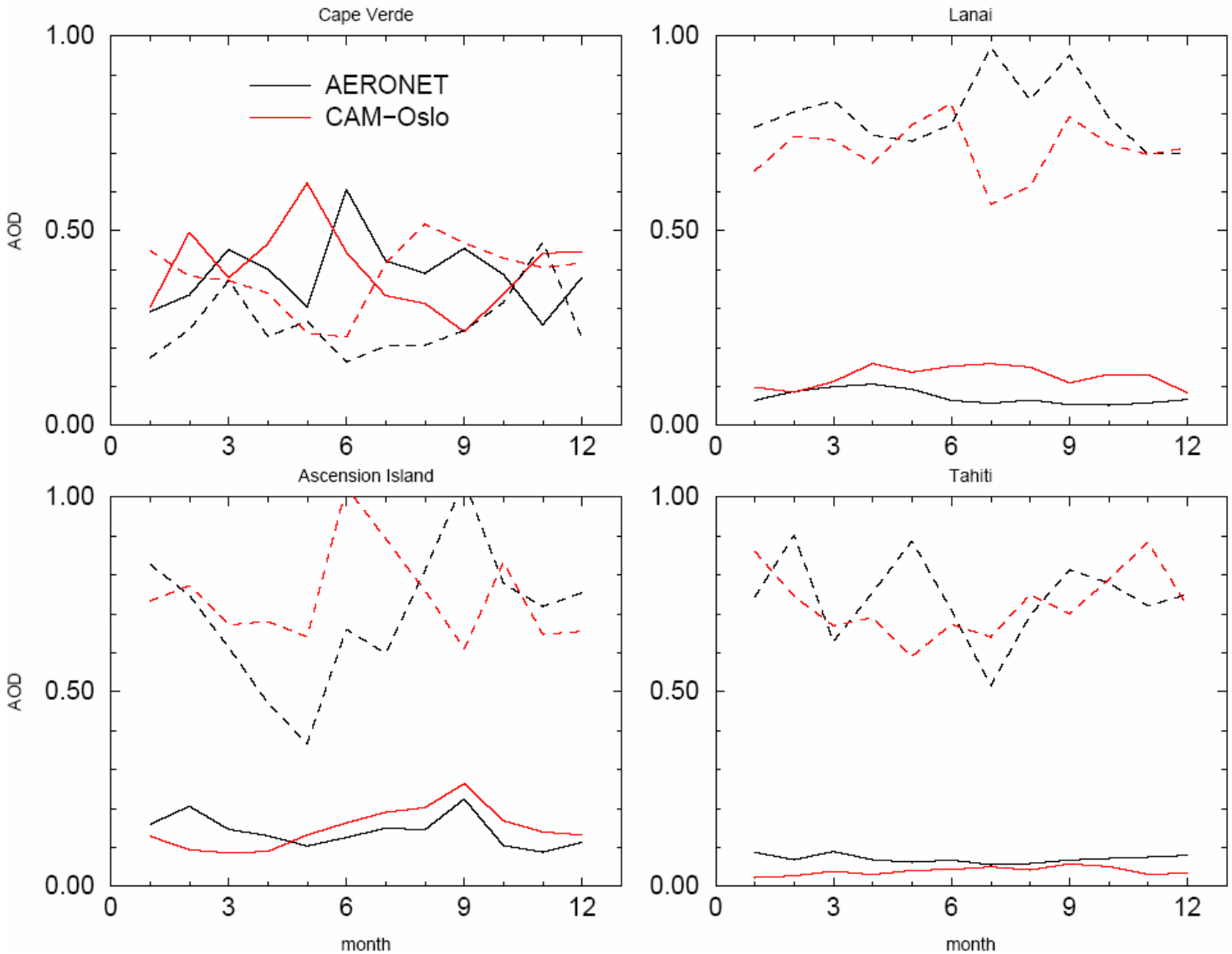
SO4 Model vs measurements



Modelled vs measured seasalt



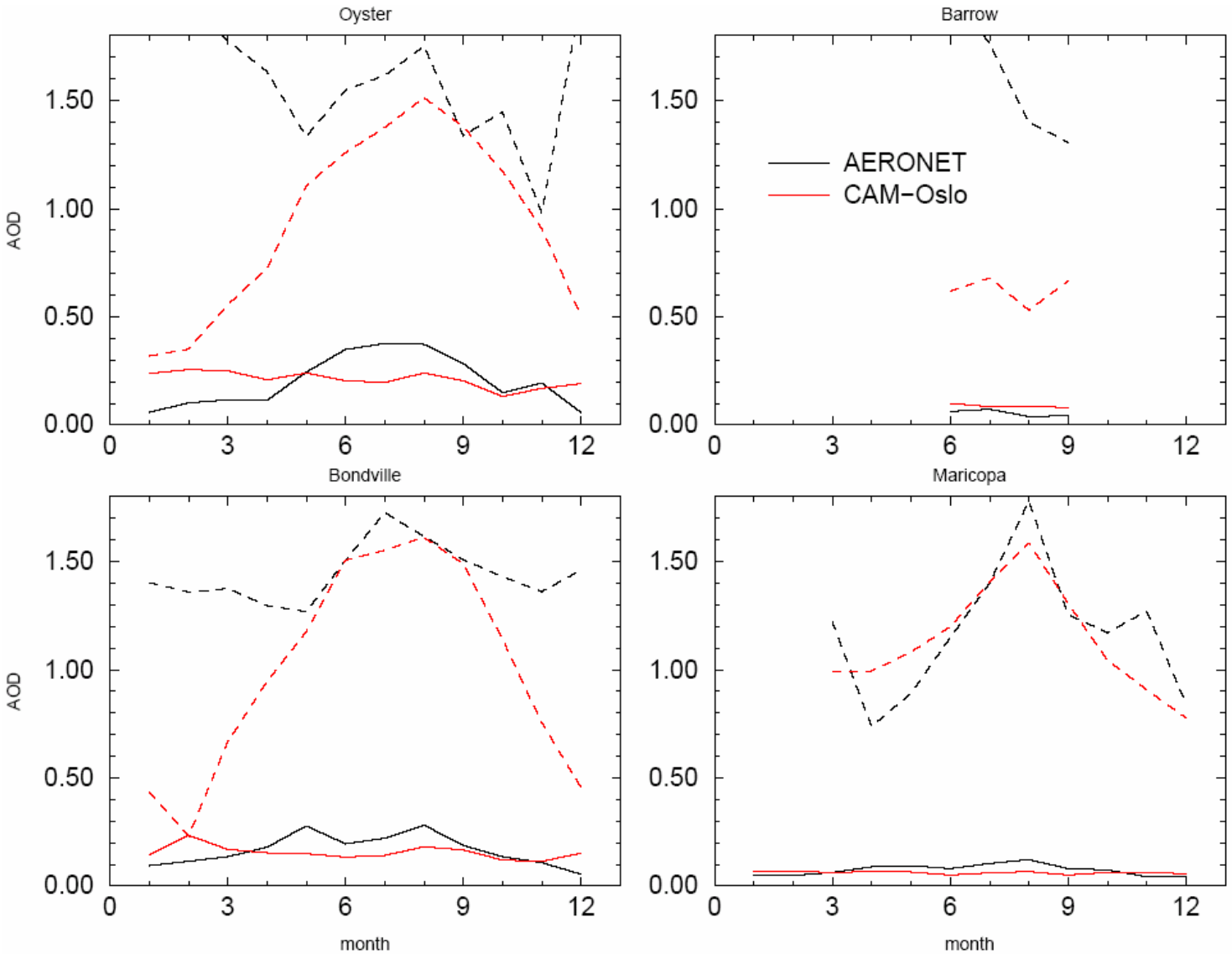
Comparison with AERONET
Examples from Standard simulation



AOD

Ångstrøm parameter

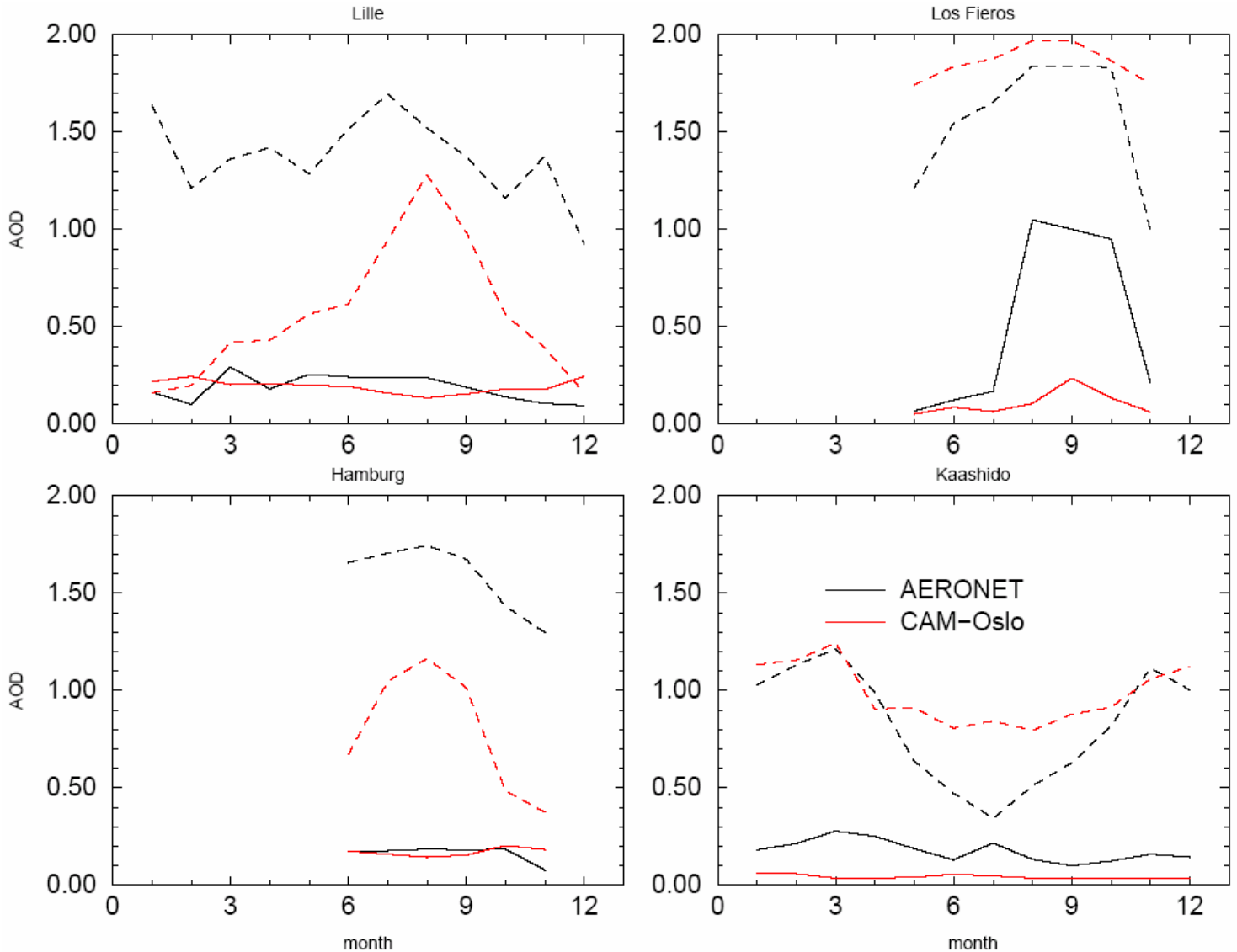
Comparison with AERONET
Examples from Standard simulation



AOD

Ångstrøm parameter

Comparison with AERONET
Examples from Standard simulation



Emission assumptions

- Primary sulphate emitted as accumulation mode (Stier et al, 2005)
- 2 % of aerocom sea-salt coarse mode mass re-allocated as aerocom accumulation mode (in accordance with Mårtensson et al, 2003)
- 10 % of fossil-fuel BC emitted as accumulation mode fractal particles (Ogren and Charlson, 1983) (as before)
- All OM emitted as aitken particles
- Biomass OM and BC emitted as internally mixed aitken particles