Aerosol modeling in the new Norwegian Earth System Model, **NorESM**, and comparisons with results from **CAM-Oslo** used for AeroCom.

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CAM3-Oslo:

Major changes to NCAR CAM3 (Collins et al., 2006, J. Clim. 19)

- Aerosol life cycling and physical properties

  (Seland et al. & Kirkevåg et al., 2008, Tellus 60A)
  - Sea-salt (**SS**), dust (**DU**), sulfate (**SO_4**), organic matter (**OM**), black carbon (**BC**)
  - Size-modes of nucleated and emitted primary particles are presumed
  - Particle size and mixing state after growth follows from process calculations
- Aerosol – cloud droplet interaction in warm clouds
  - New: CCN activation: by realized super-saturations and **prognostic CDNC**

    (Storelvmo et al., 2008, Env. Res. Lett. 3, Hoose et al., 2009, Geophys. Res. Lett. 36)
  - Old CCN activation: by prescribed super-saturations and **diagnostic CDNC**

    (Seland et al. & Kirkevåg et al., 2008, Tellus 60A)

NorESM

Norwegian Earth System Model, based on NCAR CCSM4

Atmosphere model:

based on a developement version of CAM4 (CAM3.6.15 in CCSM4 alpha 38)

with Finite Volume dyn. core, 1.9°×2.5° res., 26 levels:

- aerosol and cloud droplet properties as in CAM3-Oslo (+ updates)
- stratiform cloud microphysics as in CAM3
  (Rasch-Kristjansson inst. of Morrison Gettelman)
- radiative transfer scheme as in CAM3

Other NorESM components:

Ocean: MICOM, based on the Bergen Climate Model (BCM) version

Sea-Ice: CICE (NCAR)

Land model: CLM (NCAR)

Changes in aerosol and cloud droplet parameterizations from CAM3-Oslo to NorESM:

- Aerosol and precursor emissions: **AeroCom → IPCC** (AR5, prep. for CMIP5)
  - from ftp://ftp-ipcc.fz-juelich.de/pub/emissions/gridded_netcdf/

- New formulation for effective droplet radius w.r.t. radiation, **r_e**

Rotstayn & Liu (2009):

$$\frac{r_e}{r_v} \equiv \beta = \frac{\left(1+2\varepsilon^2\right)^{2/3}}{\left(1+\varepsilon^2\right)^{1/3}},$$

$$\varepsilon = 1 - 0.7\exp(-0.003 \cdot CDNC)$$

instead of constant β of 0.875 over land, 0.928 elsewhere

(only affecting 1. indirect effect)

And (later in the talk):

- Updated treatment of natural background aerosols
- Modified convective transport and scavenging
- Vertical distribution of biomass burning emissions

Results from 16 month offline simulations with

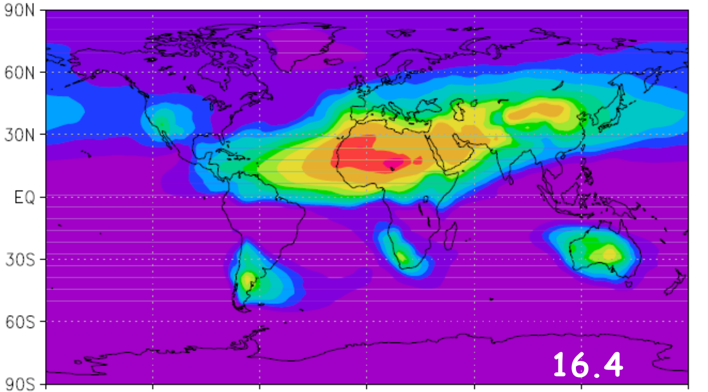
NorESM

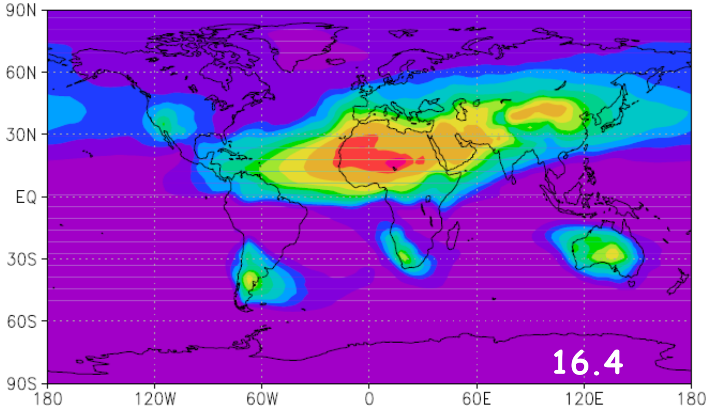
+ comparison with CAM3-Oslo

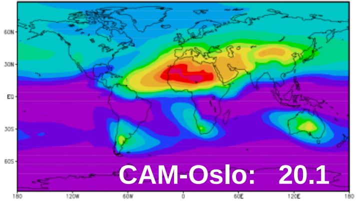
Aerosol column burdens (mg m^{-2}) with

AeroCom 2000 / 1750 and **IPCC** 2000 / 1850 emissions

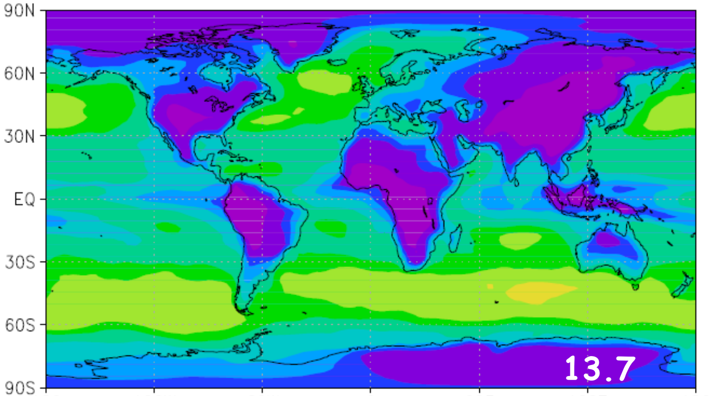
Dust

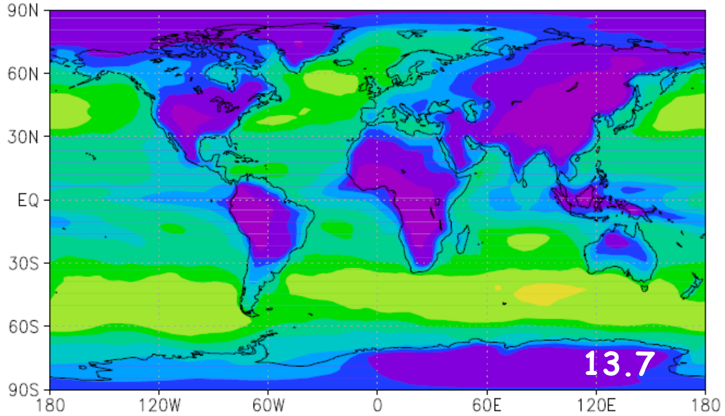


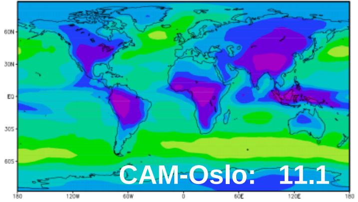




Sea-salt

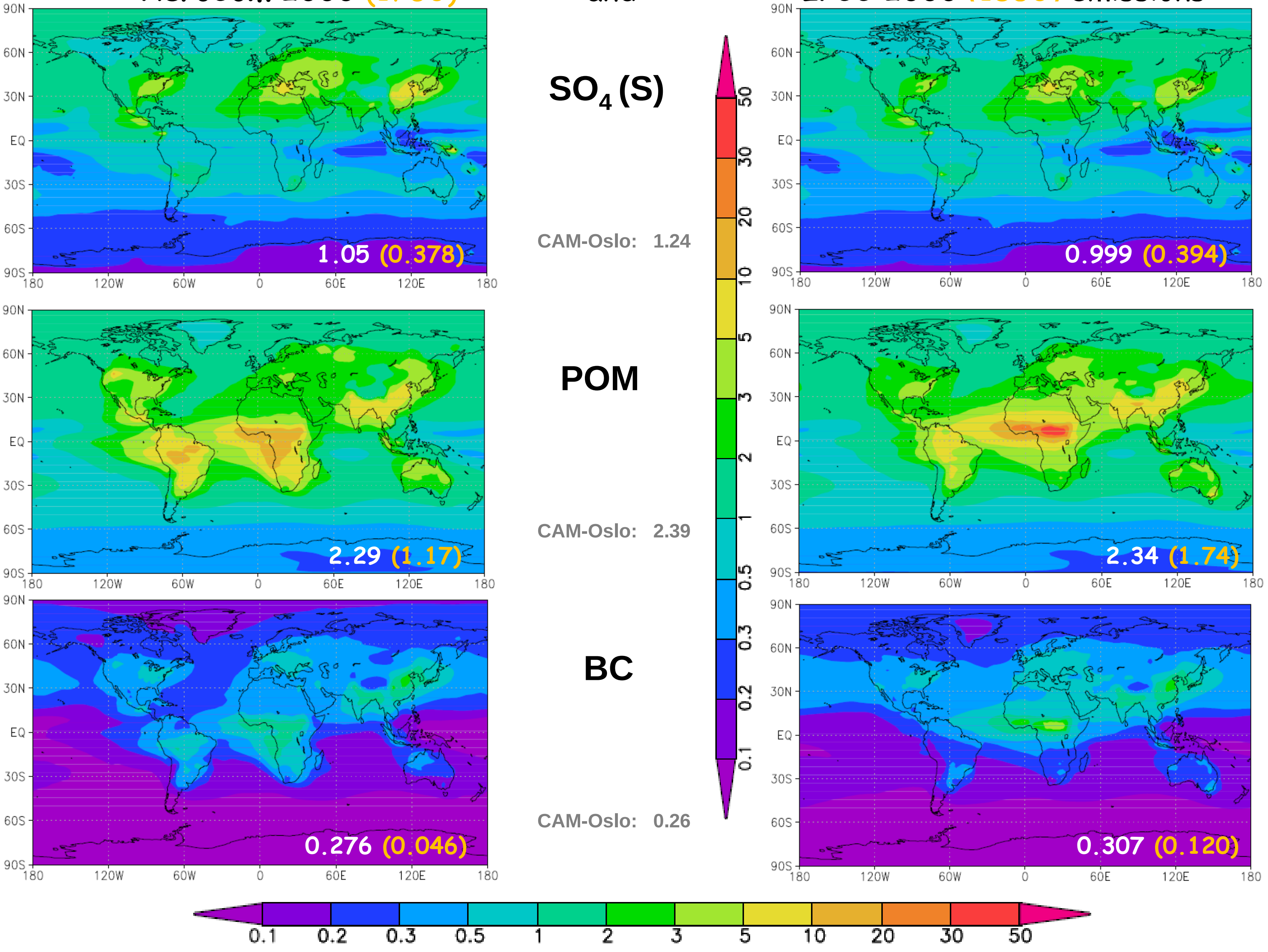






Aerosol column burdens (mg m^{-2}) with

AeroCom 2000 (1750) and **IPCC** 2000 (1850) emissions



SO_4 (S)

CAM-Oslo: 1.24

POM

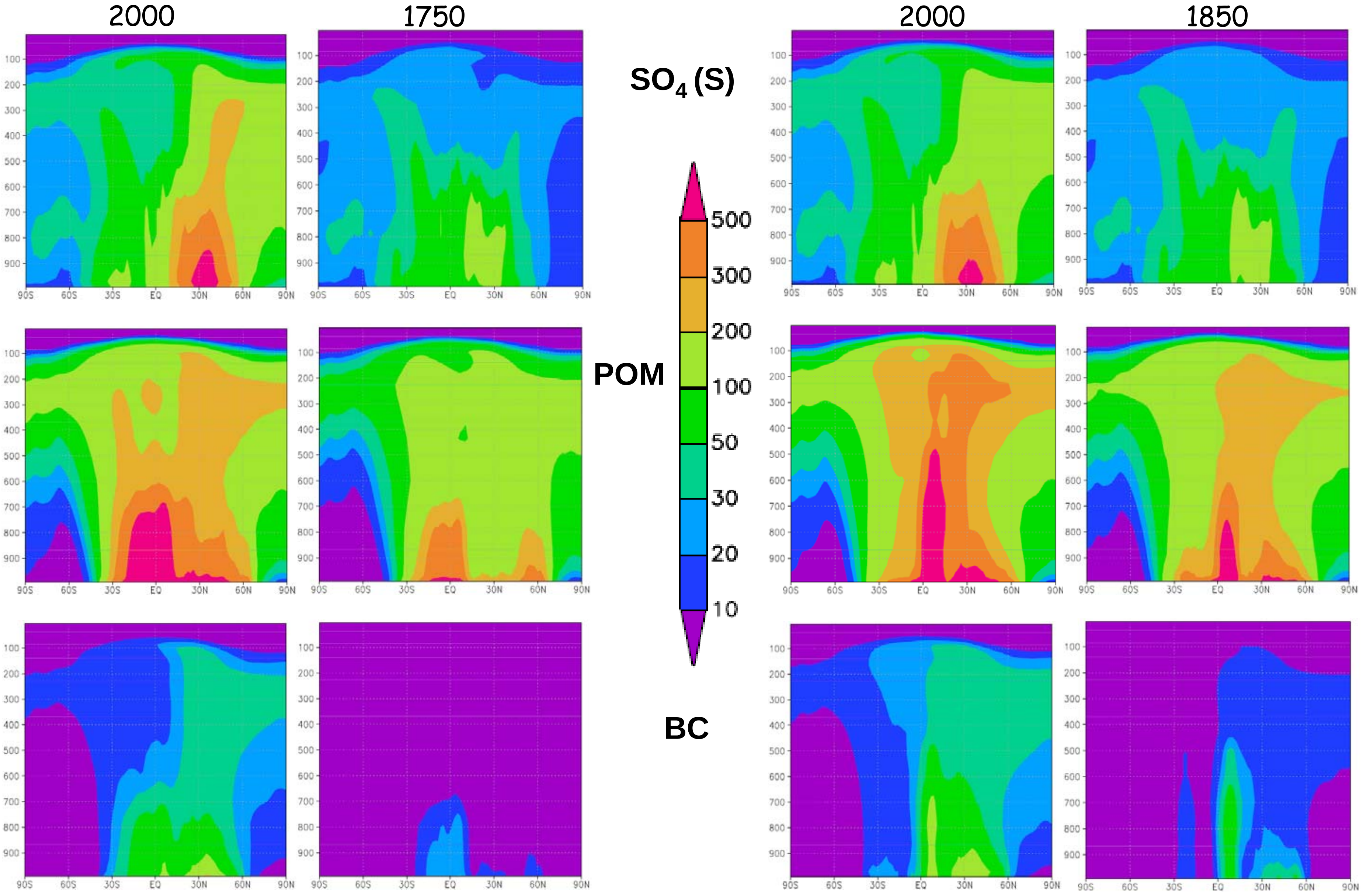
CAM-Oslo: 2.39

BC

CAM-Oslo: 0.26

Aerosol mass mixing ratios (ng kg^{-1}) with

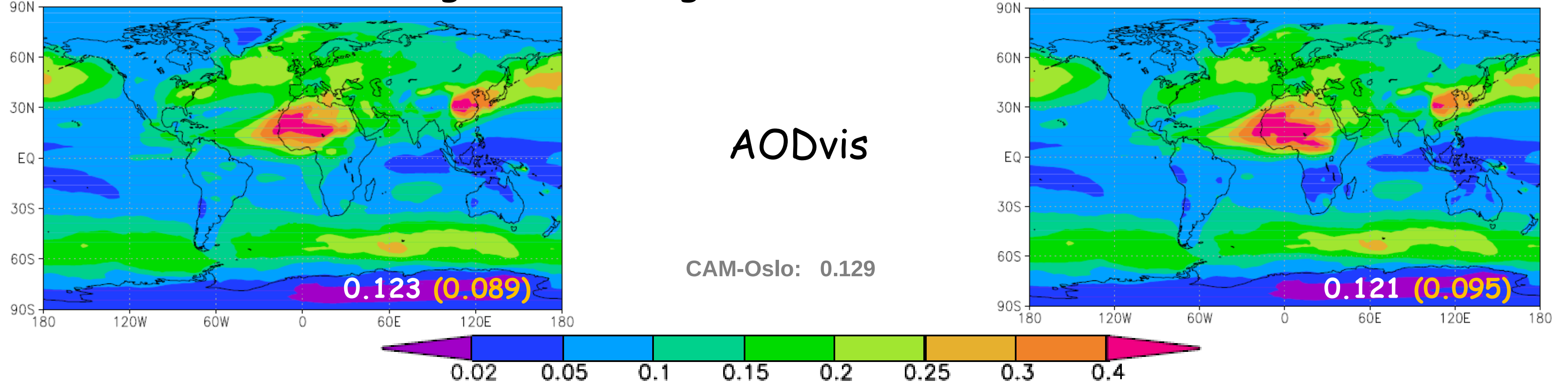
AeroCom emissions and **IPCC** emissions



Aerosol optical depth, AODvis, and single scattering albedo, SSAvis (0.35-0.64 μm)

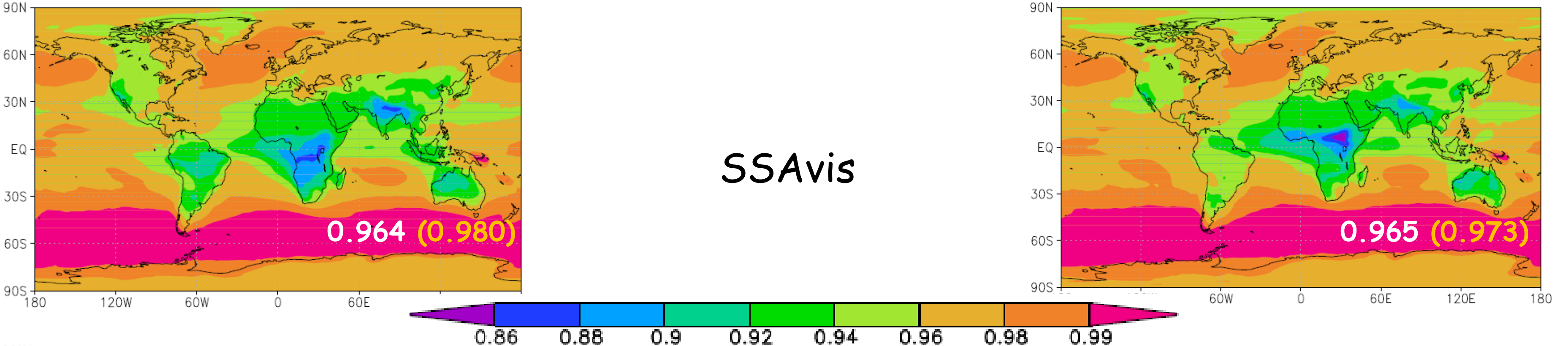
AeroCom 2000 (1750)

IPCC 2000 (1850)

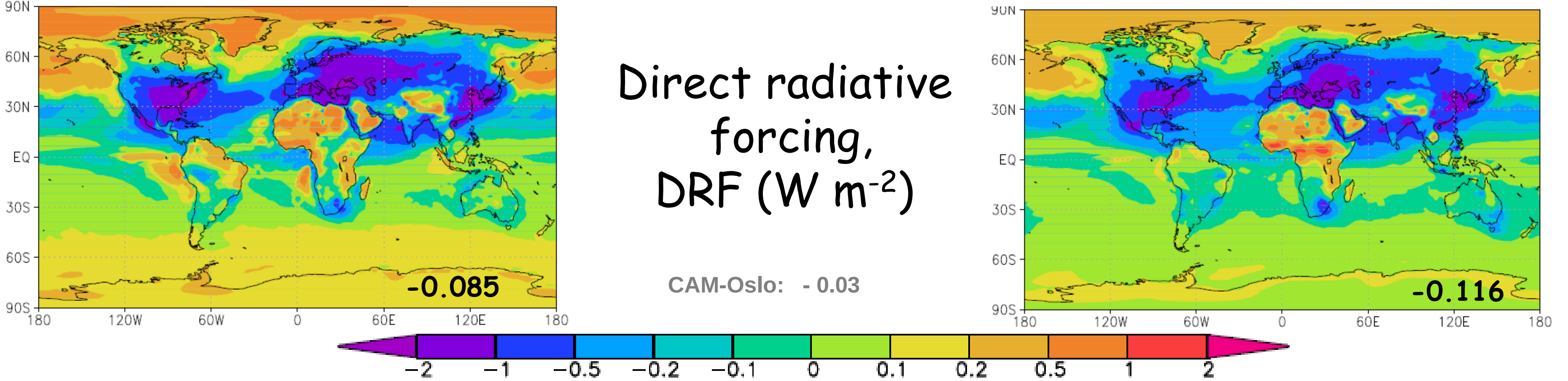


AODvis

CAM-Oslo: 0.129



SSAvis



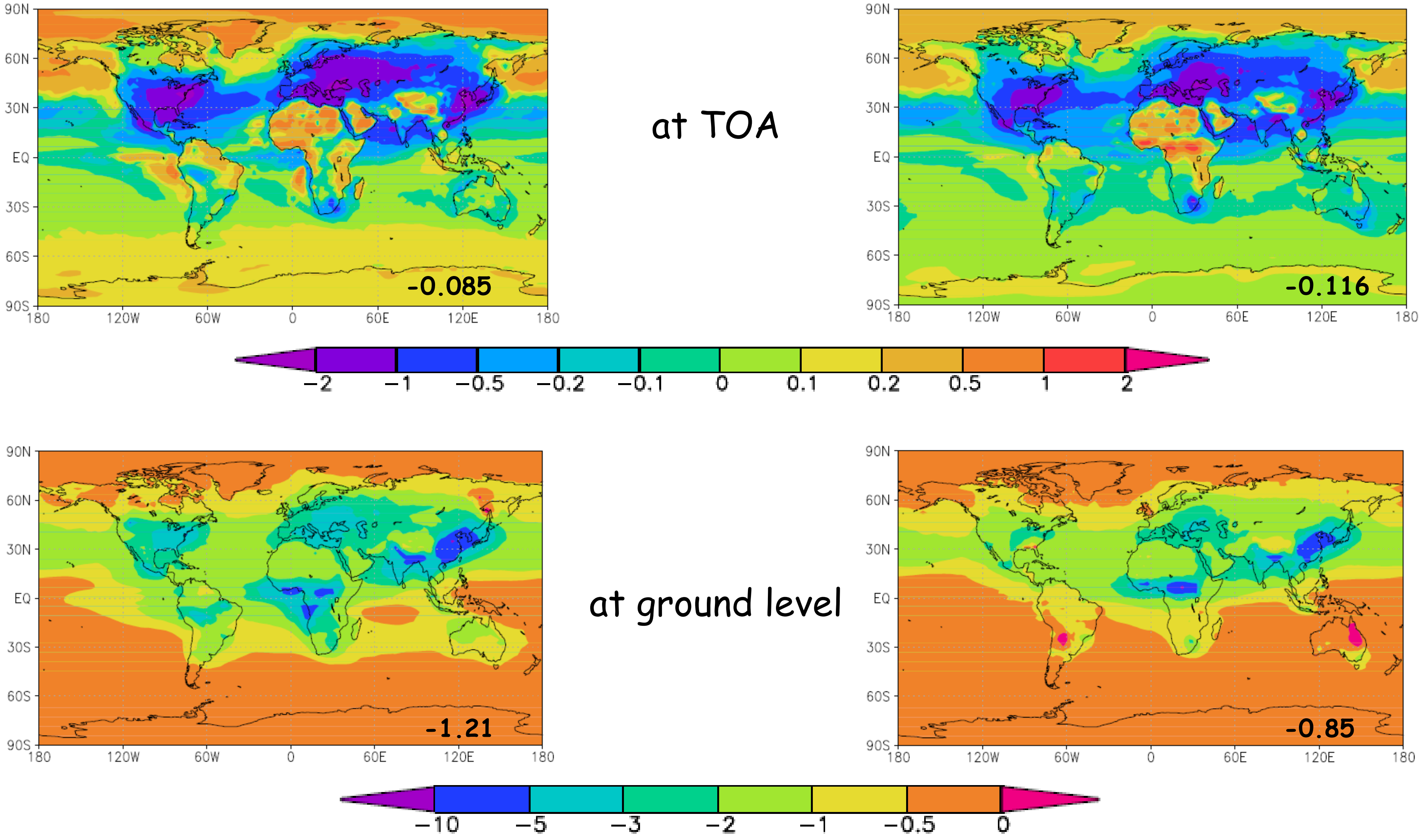
Direct radiative forcing, DRF (W m^{-2})

CAM-Oslo: - 0.03

Direct radiative forcing, DRF (W m^{-2})

AeroCom 2000 - 1750

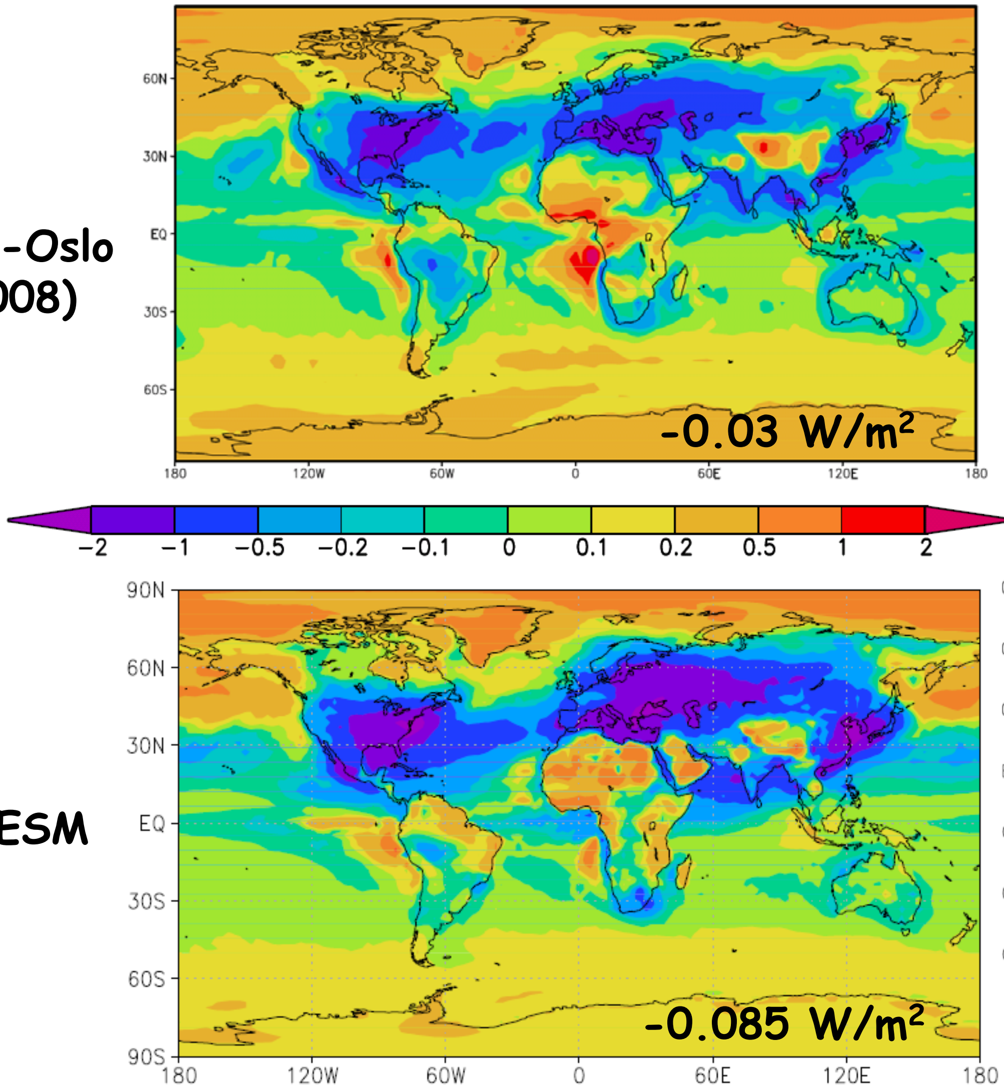
IPCC 2000 - 1850



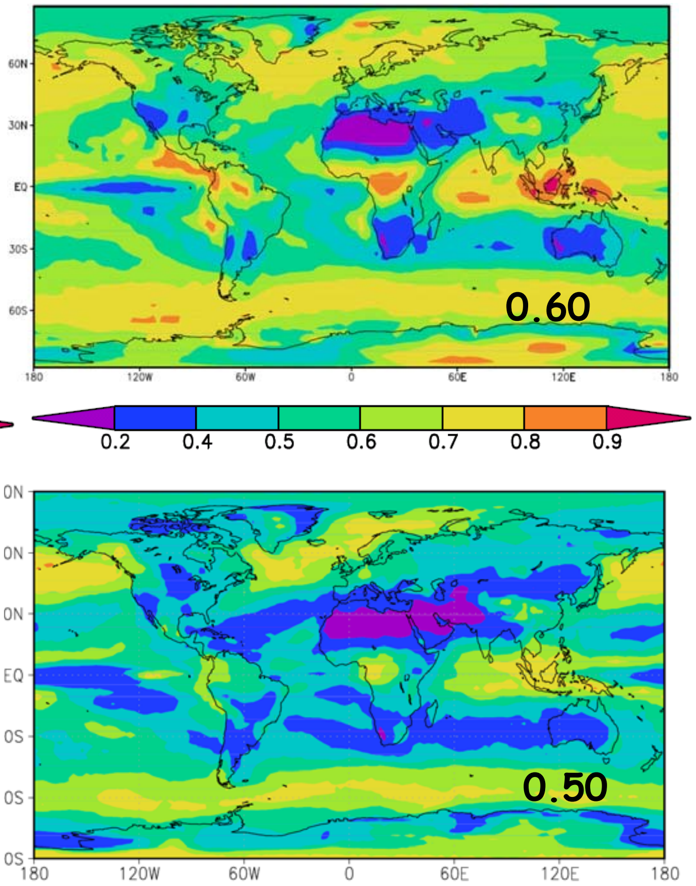
Direct radiative forcing, DRF, with AeroCom emissions

CAM-Oslo (2008)

NorESM

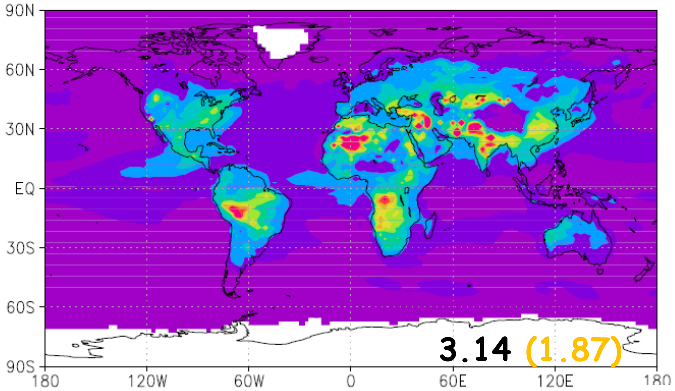


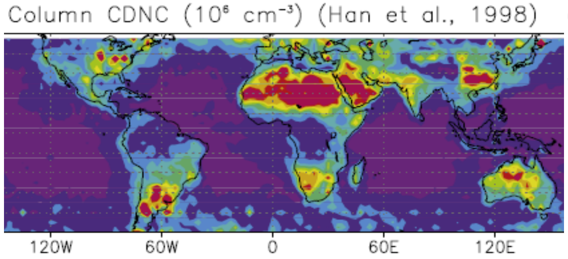
CLDTOT



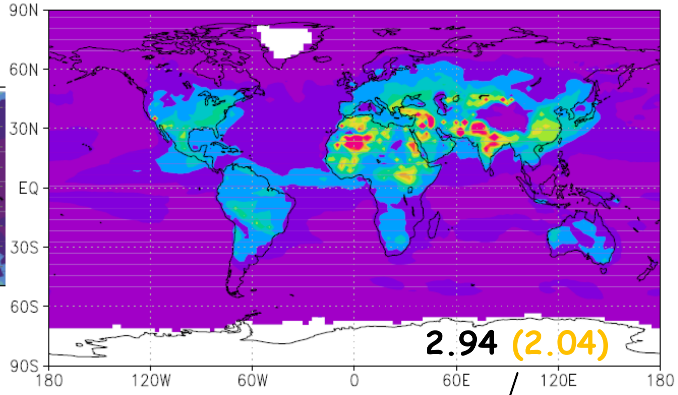
Vertically integrated warm cloud droplet number concentrations, CDNC (10^6 cm^{-2})

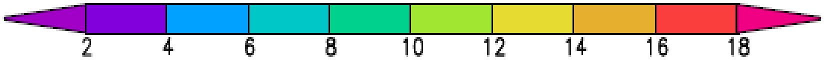
AeroCom 2000 (1750)





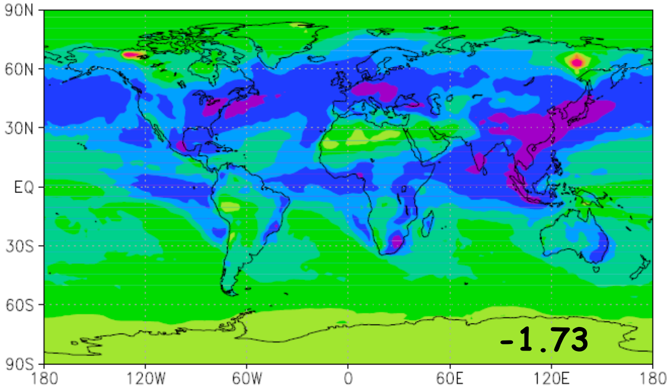
IPCC 2000 (1850)



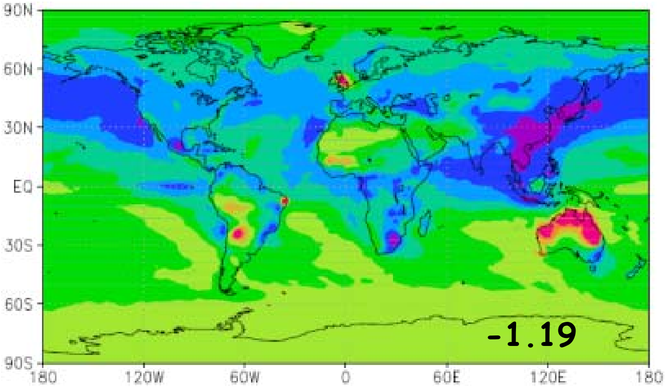


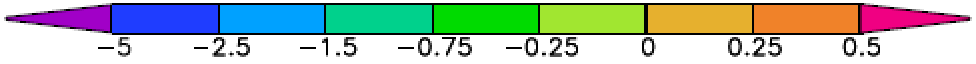
~ 30% lower "anthropogenic" CDNC

1.+2. indirect radiative forcing, IndRF (W m^{-2})

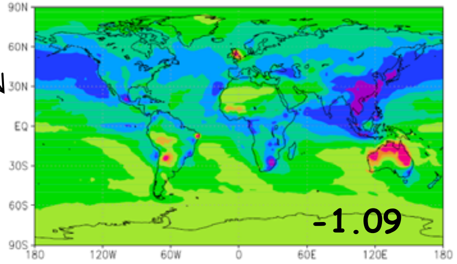


new emissions





new β



Changes in aerosol and cloud droplet parameterizations from CAM3-Oslo to NorESM:

- Aerosol and precursor emissions: AeroCom → IPCC
- New formulation for effective droplet radii w.r.t. radiation

- **Updated treatment of natural background aerosols**
  - sea-salt lumping: 0.1% coarse -> fine mode (Mårtensson et al., 2003)
  - added primary ocean-biogenic OM in Aitken mode
    - emissions horizontally distributed like sea-salt, and scaled to total of 8 Tg/yr (Spracklen et al., 2008)
  - increased SOA from vegetation: from 19.1 to 37.5 Tg/yr (Hoyle et al., 2007)

- **Modified convective transport and scavenging**
  - Reduced cloud base height for convective transport and wet scavenging in the tropics from 800 hP to 930 hPa (already 930 hPa elsewhere)

- **Vertical distribution of biomass burning emissions**

IPCC emissions are here assumed to have same vertical profile as in AeroCom

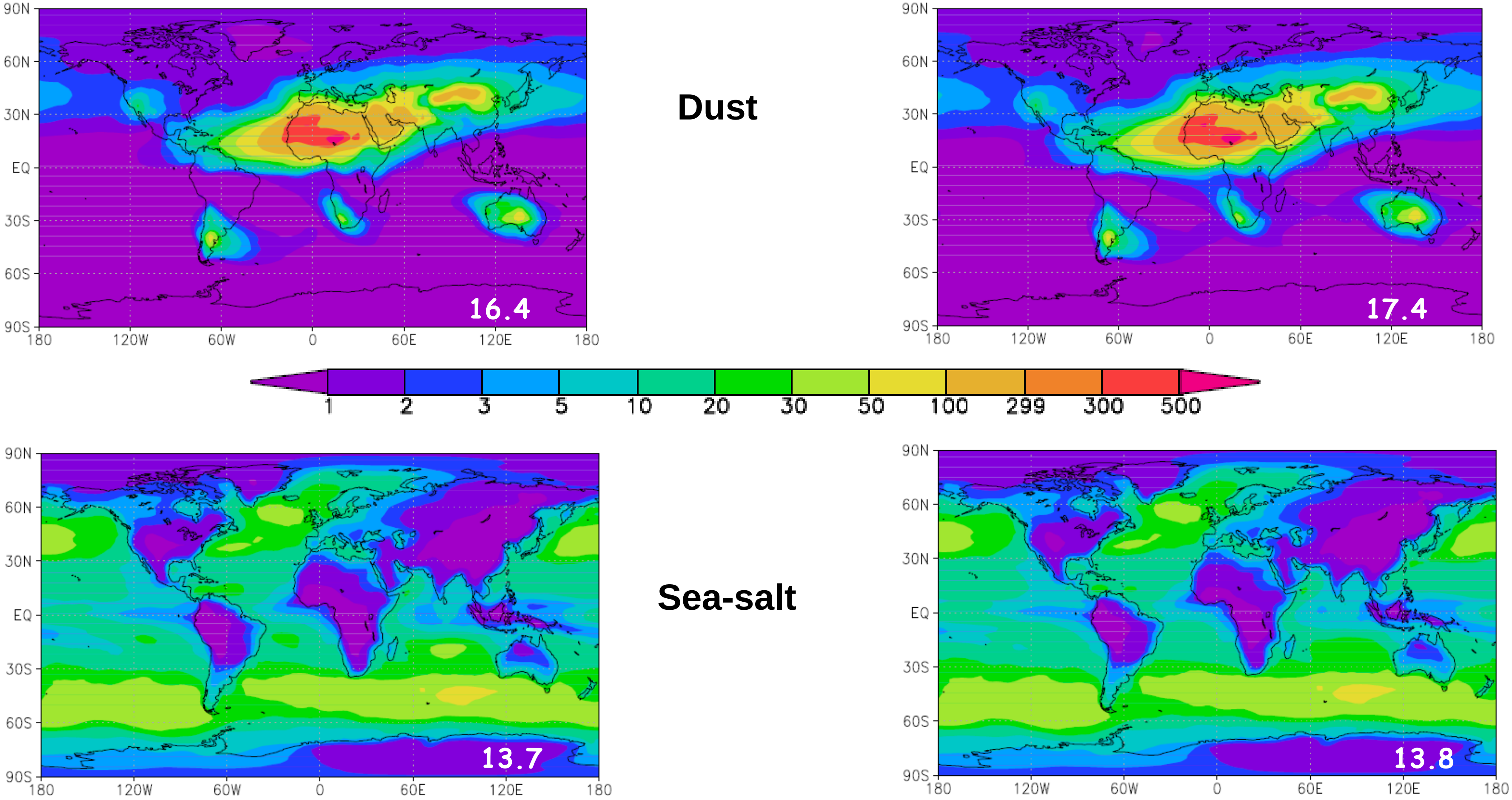
(Emissions are only given as 2D fields)

Tests: 16 months, off-line simulations

Test	AODvis	DRF (W m^{-2})	CDNC (10^6 cm^{-2})	1.+2. IndRF (W m^{-2})
-1. AeroCom emissions	0.123	-0.085	3.14	**-1.73 ***
0. IPCC AR5 emissions	0.121	-0.116	2.94	-1.19
1. Control simulation: IPCC emissions + new $\beta = r_e/r_v$	**0.121**	**-0.116**	**2.94**	**-1.09**
2. Seasalt lumping + added POM + increased SOA emissions -> new background aerosol	**0.129**	**-0.122**	**3.34**	**-0.823**
3. 2 + modified convective transport and scavenging	0.141	-0.146	3.64	-0.859
4. 3 + AeroCom vertical distribution for biomass burning emissions -> new aerosol scheme version	**0.144**	**-0.169**	**3.66**	**-0.909**

*** 2000 relative to 1750**
Else: 2000 relative to 1850

Aerosol column burdens (mg m^{-2}) with IPCC 2000 / 1850 emissions



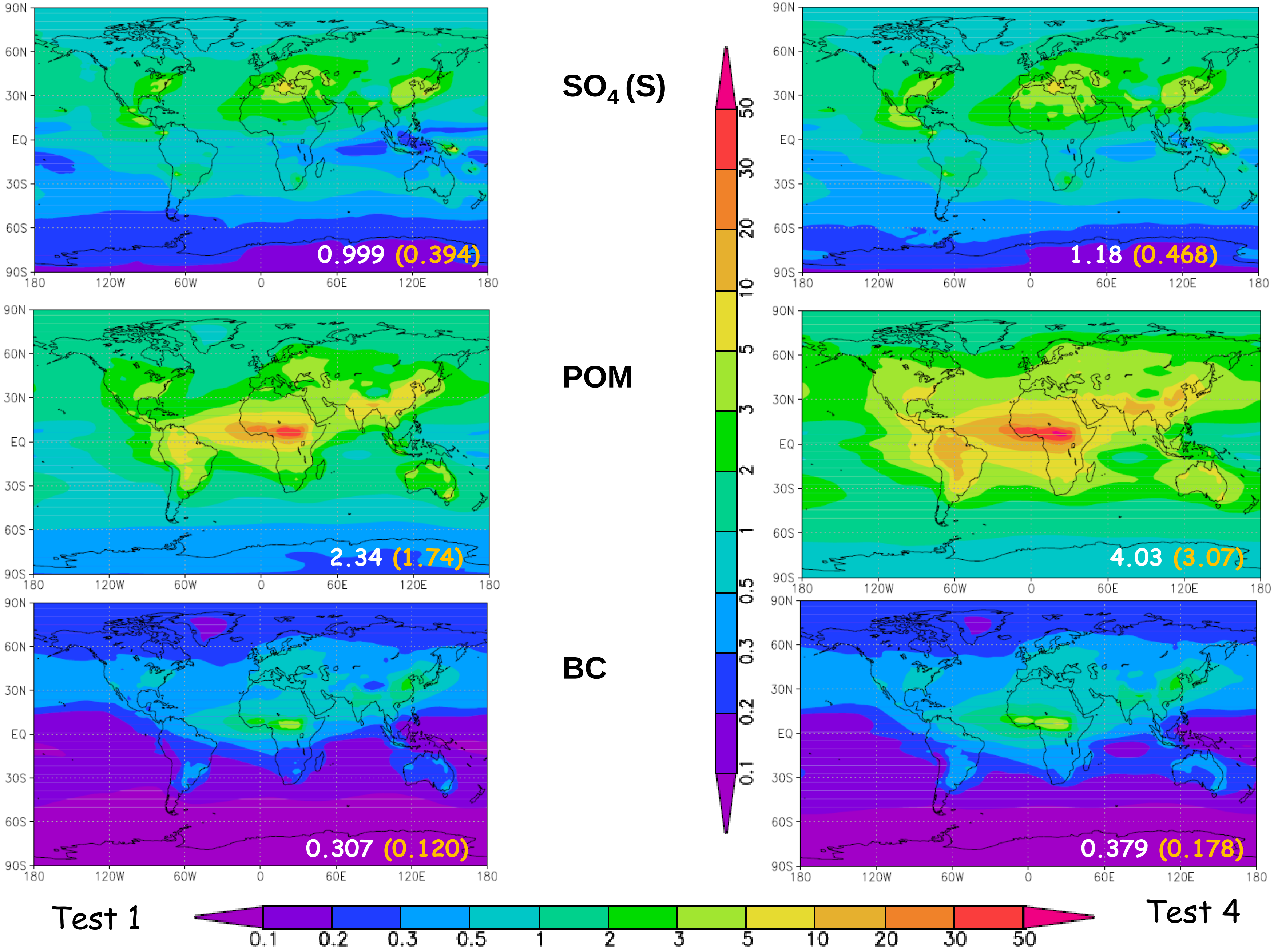
Dust

Sea-salt

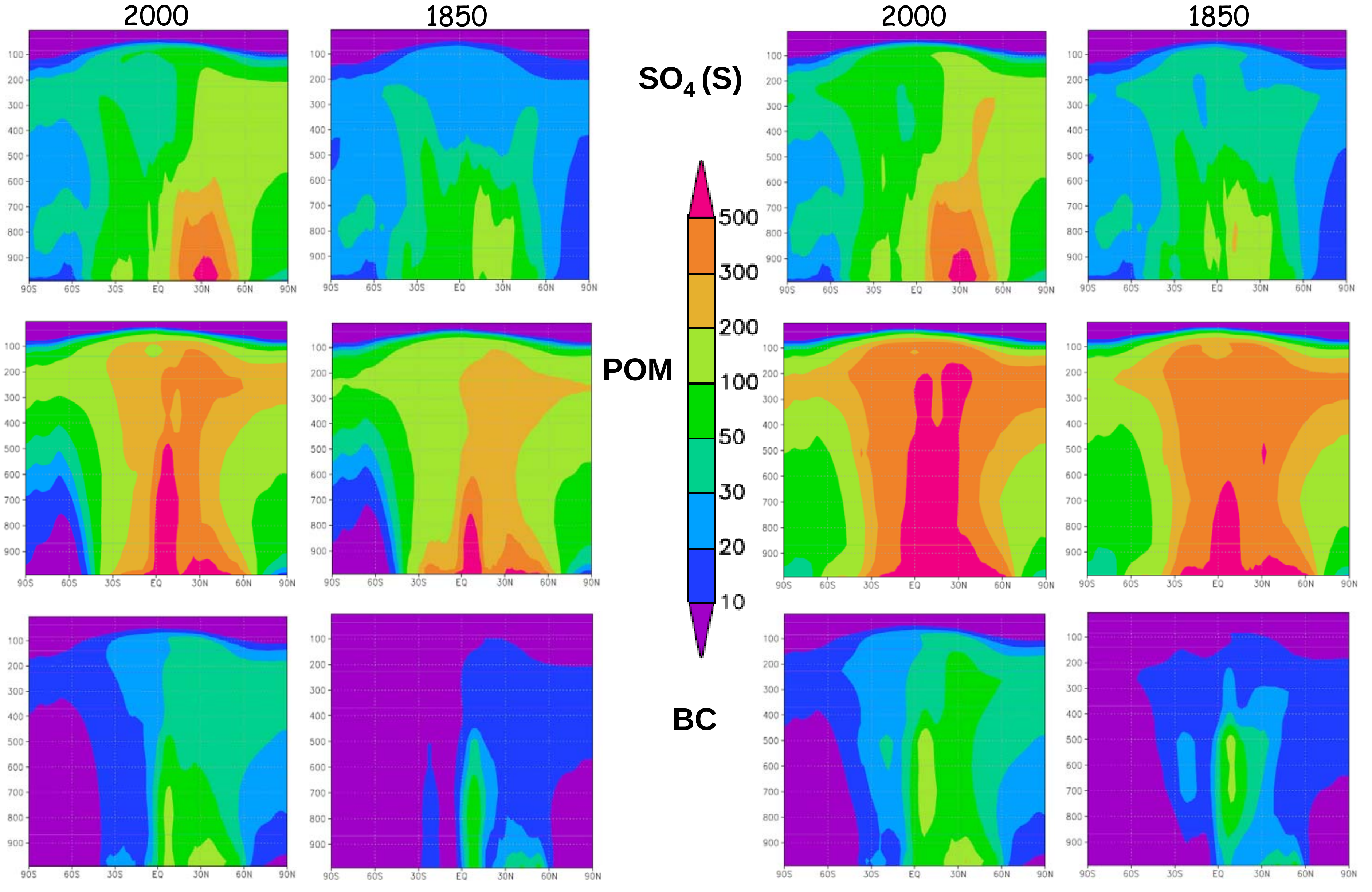
Test 1

Test 4 = new aerosol scheme

Aerosol column burdens (mg m^{-2}) with IPCC 2000 (1850) emissions



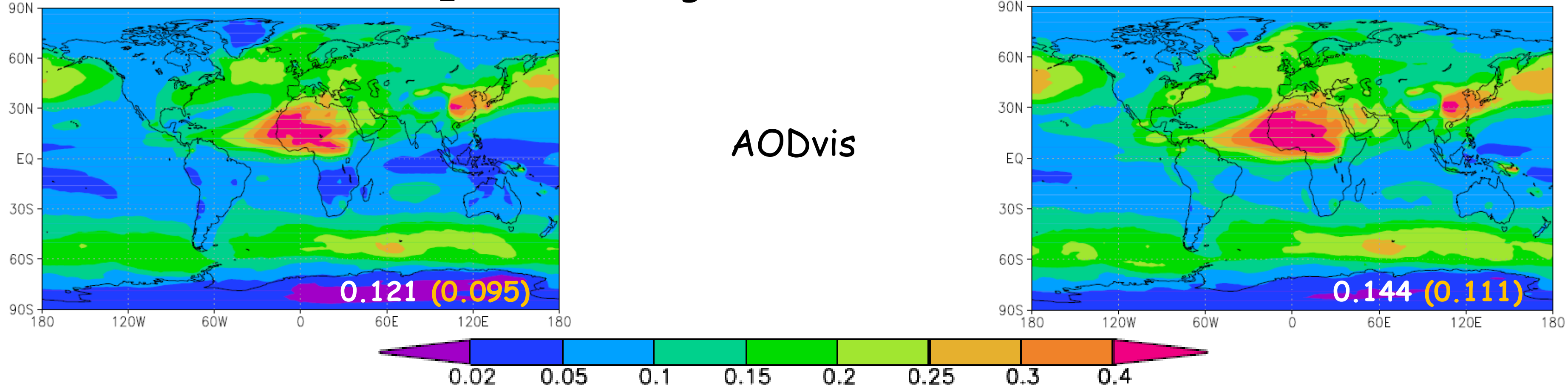
Aerosol mass mixing ratios (ng kg^{-1}) with IPCC 2000 and 1850 emissions

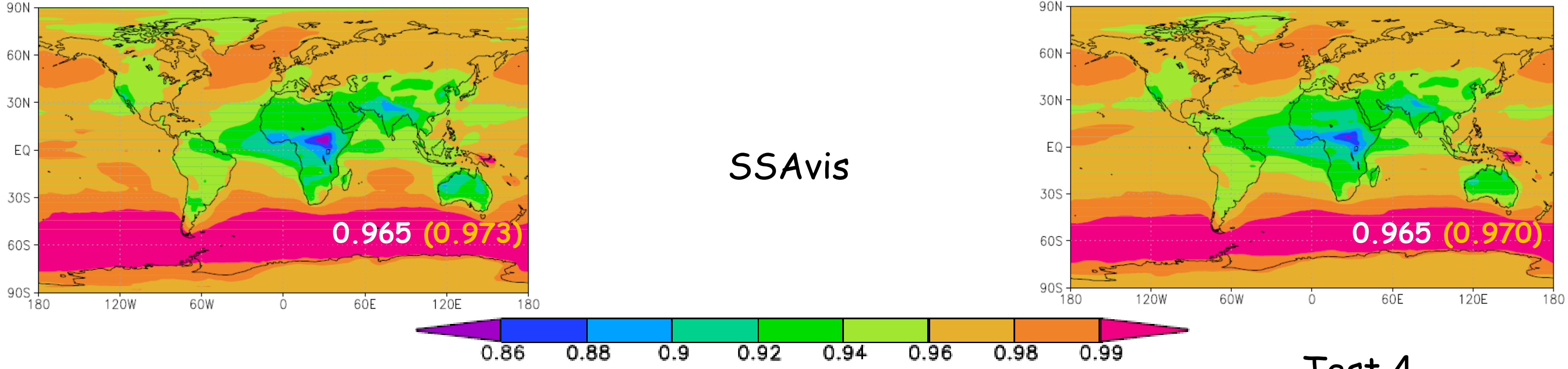


Test 1

Test 4 = new aerosol scheme

Aerosol optical depth, AODvis, and single scattering albedo, SSAvis (0.35-0.64 μm)



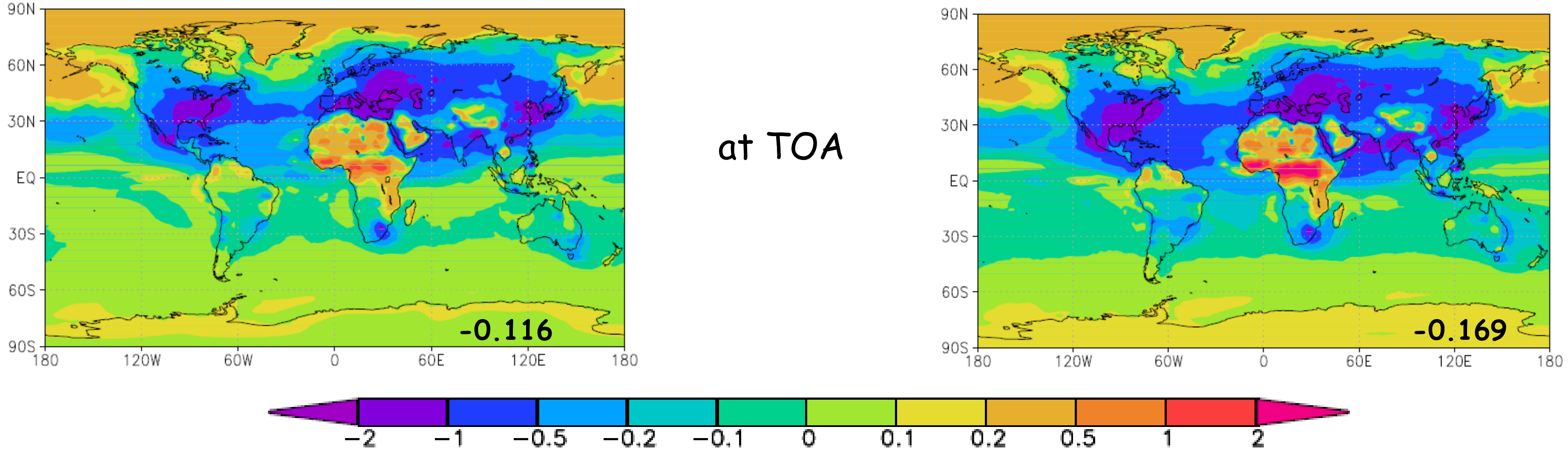


Test 1

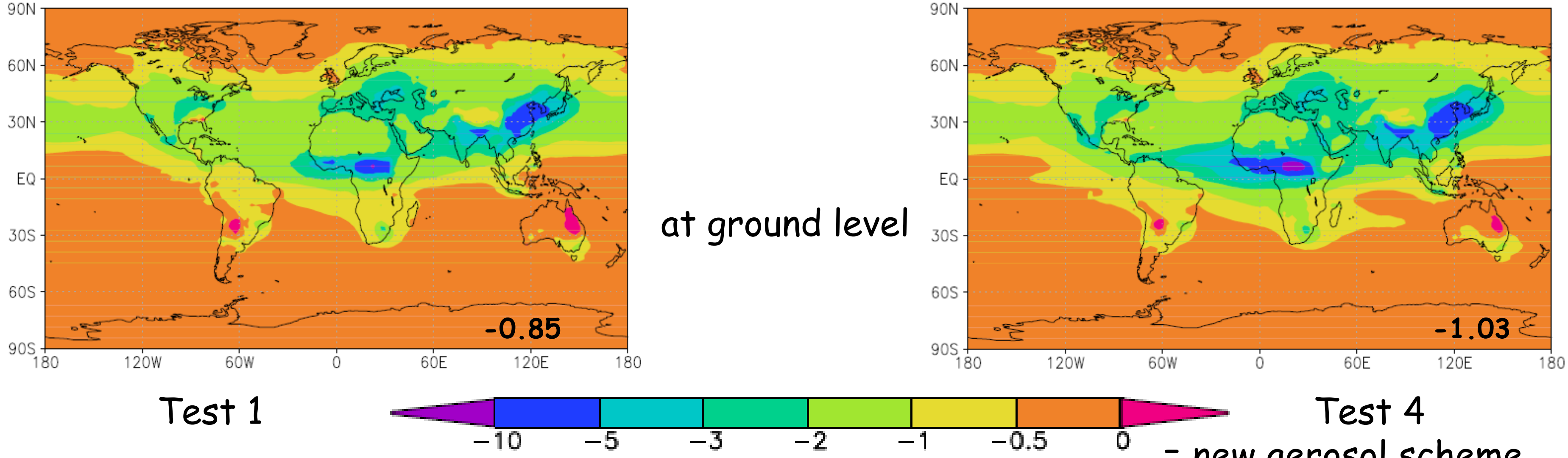
Test 4
= new aerosol scheme

Direct radiative forcing, DRF (W m^{-2})

IPCC 2000 - 1850



at TOA

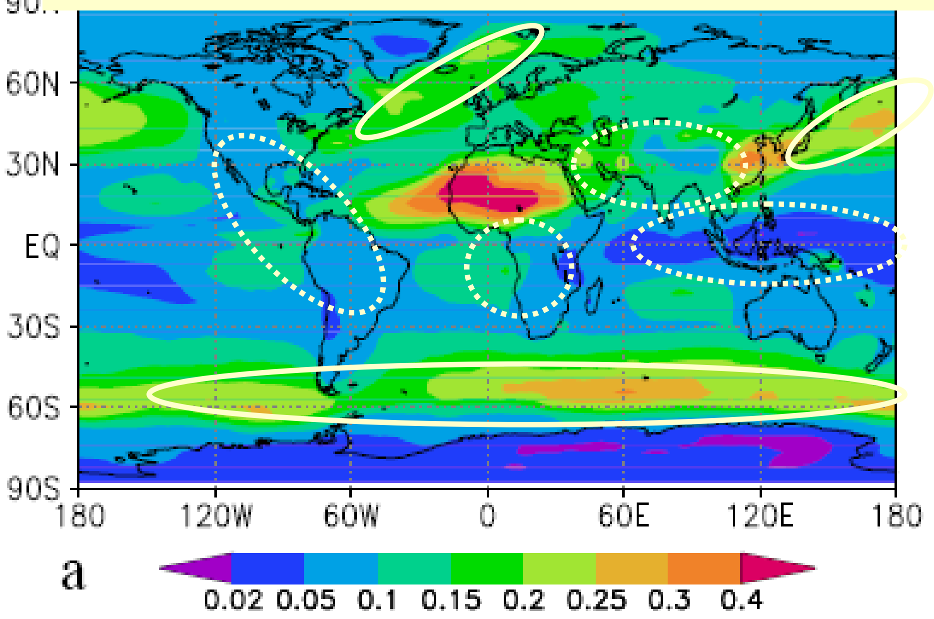


at ground level

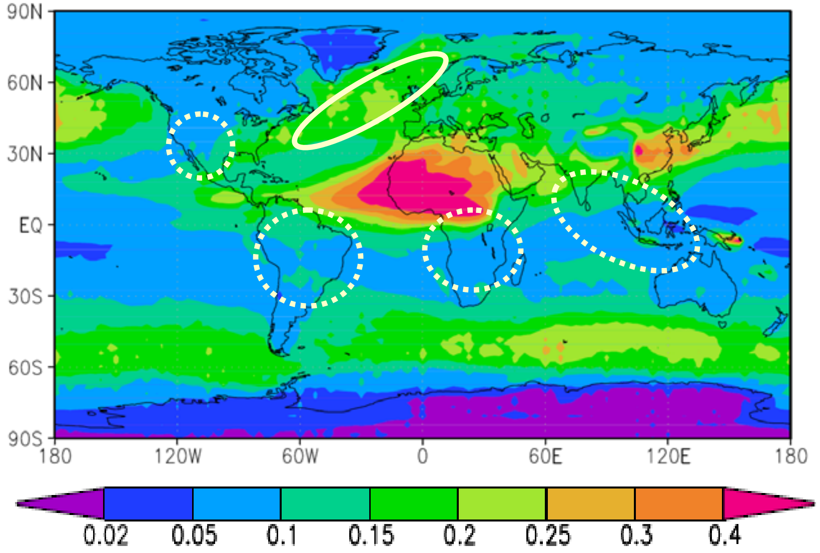
Test 1

Test 4
= new aerosol scheme

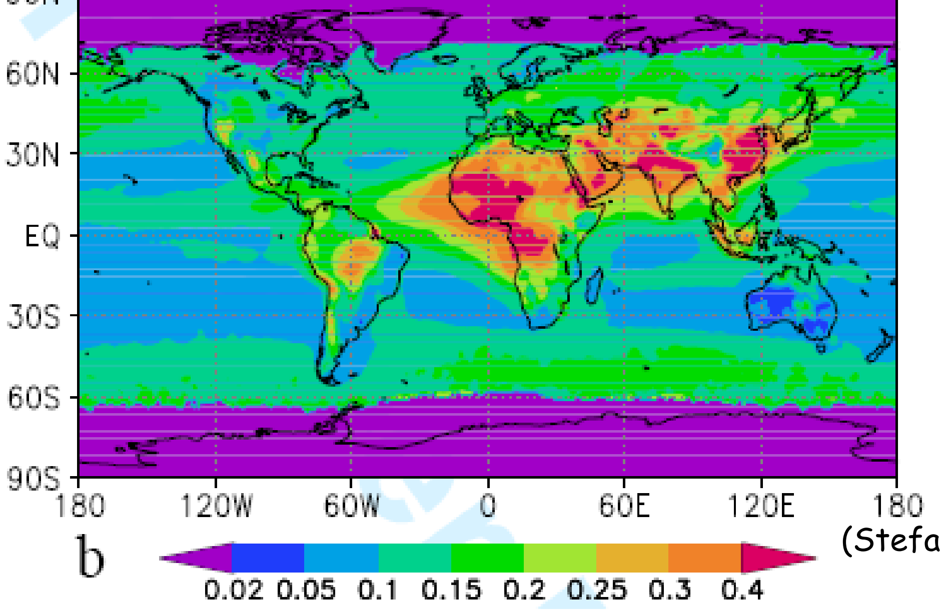
CAM-Oslo Model calculated clear sky AOD (0.120)



NorESM (Test 4 = new aerosol scheme), clear sky AODvis (0.136)



Modis + MISR + AERONET composite (0.137)



(Stefan Kinne, pers. comm.)

- General tendency: improved
  - ➢ especially over oceans
- Still too small over biomass burning areas

Summary and Conclusions

- CAM3-Oslo aerosol and cloud droplet schemes have been ported to CAM4 (CAM3.6.15) **-> basis for atmospheric part of NorESM**

- Important changes from CAM3-Oslo to NorESM:
  - New parameterization of effective cloud droplet radius -> 1. indirect effect
  - Change from AeroCom to IPCC AR5 emissions (+ new time span)
    - ***-> preparing for CMIP5 simulations***
  - Updated treatment of natural background aerosols
  - Modified convective transport and scavenging in the tropics
  - Vertical profile of biomass burning emissions as in AeroCom (Phase I)
- Effect on aerosols and aerosol radiative forcing:
  - Improved optical depth compared with observations
  - Stronger negative direct radiative forcing

    -> closer to results from model median in AeroCom Phase I
  - Increased cloud droplet numbers, especially for PI conditions, and a weaker indirect (cooling) effect
- Additional model tuning in preparation for CMIP5 simulations started

Thank you for your attention !

References

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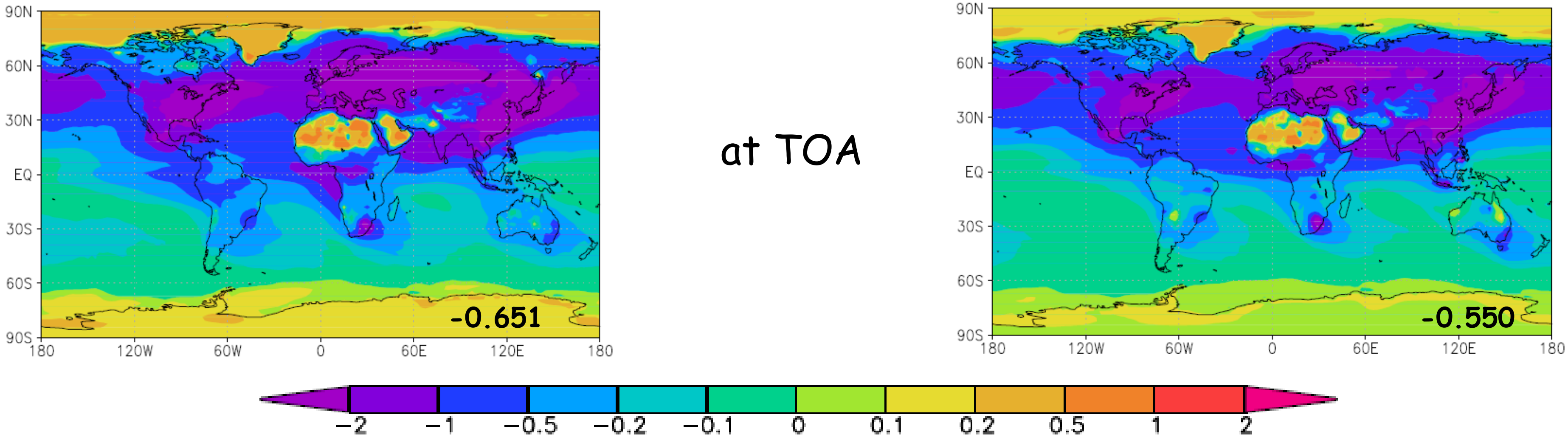
Extra slides

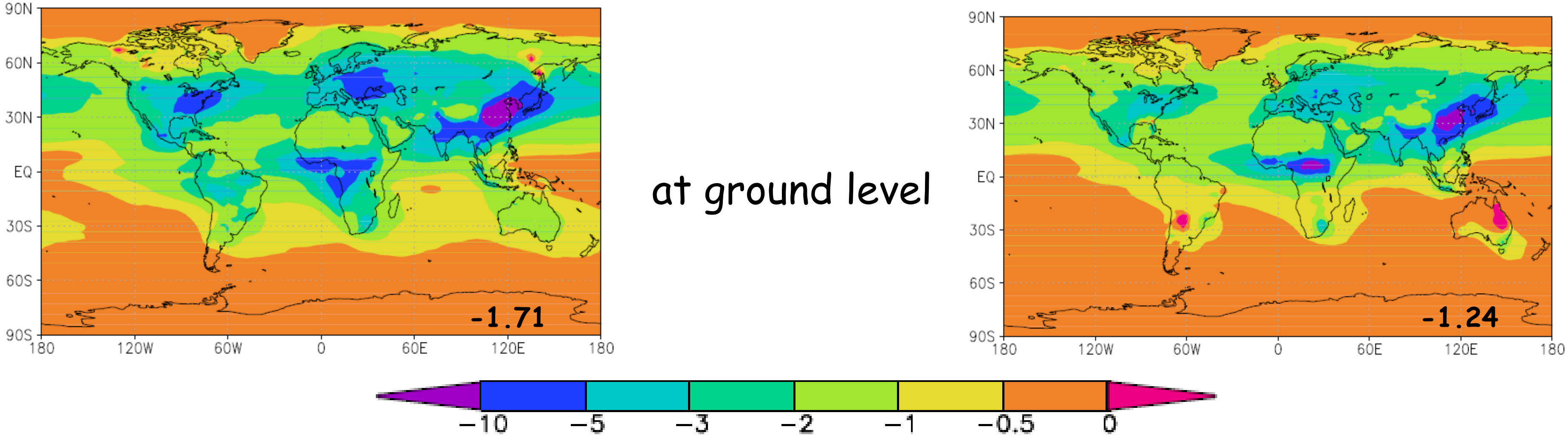
Clear-sky direct radiative forcing, DRFc (W m^{-2})

AeroCom 2000 - 1750

IPCC 2000 - 1850

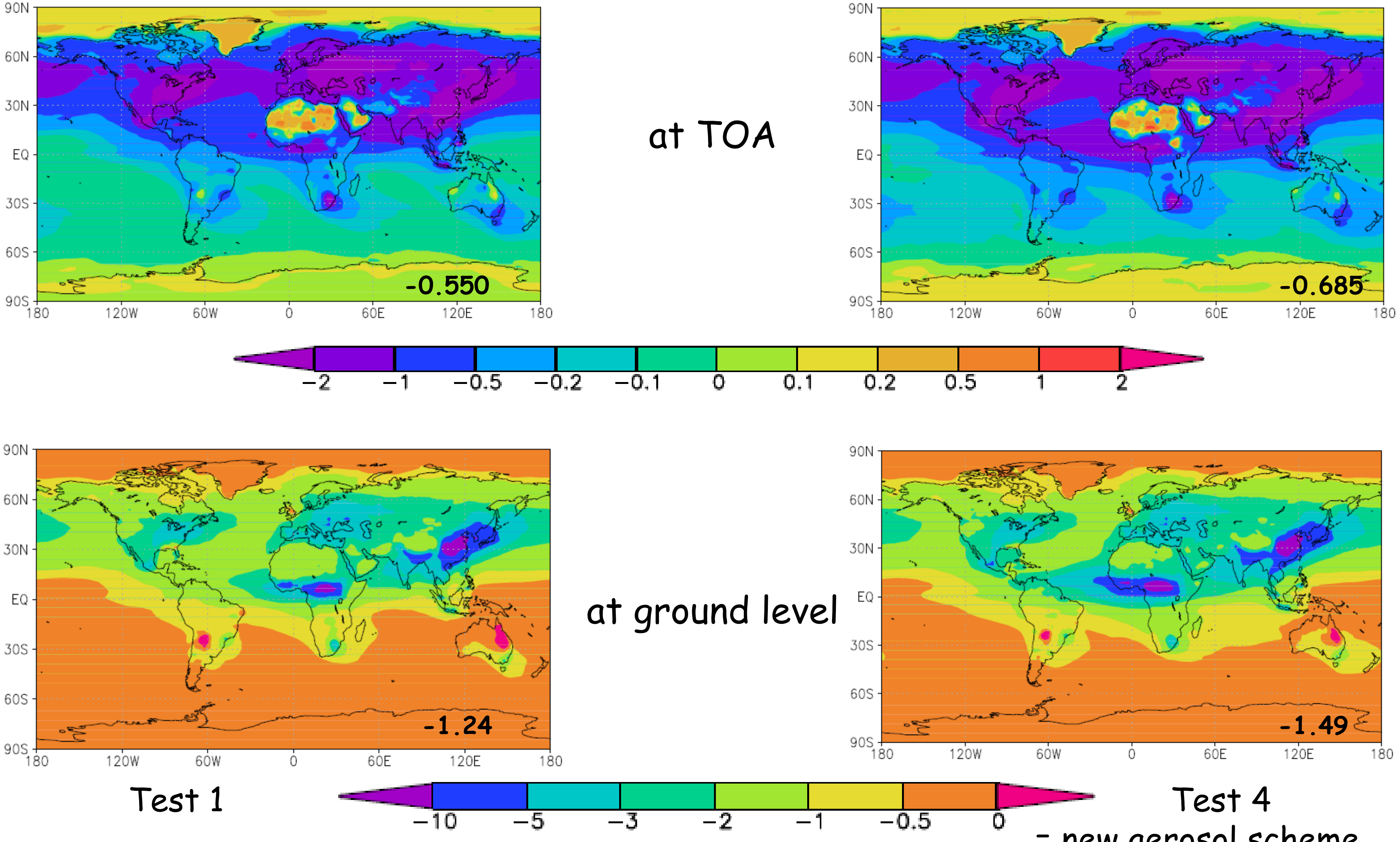


at TOA



at ground level

Clear-sky direct radiative forcing, DRFc (W m^{-2})



at TOA

at ground level

Test 1

Test 4
= new aerosol scheme

NorESM, Test 6 = new version (month 5-16)…

Spec.	Total sinks [Tg/yr]	Total Burden [Tg]	Life-time [days]	Wet dep. [%]	Chemical Loss [%]
DMS	18.1	0.11	2.17		100 (27.3)
SO_2	80.7	0.27	1.26	7.8	69.9 (85.6)
SO_4	58.1	0.60	3.78	94.5	n.a.
BC	7.7	**0.19**	**9.19**	82.2	n.a.
OM **(+SOA)**	**89.4+**	**2.06**	8.40	84.7	n.a.
SOA	n.a.	n.a.	n.a.	n.a.	n.a.
SS	7886	**7.02**	**0.33**	**47.5**	n.a.
DU	1672	9.02	1.97	30.9	n.a.

Increase > 20%

Increase > 10%

Decrease > 10%

… compared with CAM(3)-Oslo (Seland et al., 2008)

Spec.	Total sinks [Tg/yr]	Total Burden [Tg]	Life-time [days]	Wet dep. [%]	Chemical Loss [%]
DMS	18.1	0.10	2.09		100 (25.3)
SO_2	82.2	0.29	1.27	9.0	71.4 (85.2)
SO_4	60.4	0.66	3.96	92.3	n.a.
BC	7.7	0.14	6.74	75.0	n.a.
OM **(+SOA)**	65.6+	1.30	7.22	80.2	n.a.
SOA	n.a.	n.a.	n.a.	n.a.	n.a.
SS	7711	5.76	0.27	26.2	n.a.
DU	1671	10.40	2.27	35.9	n.a.

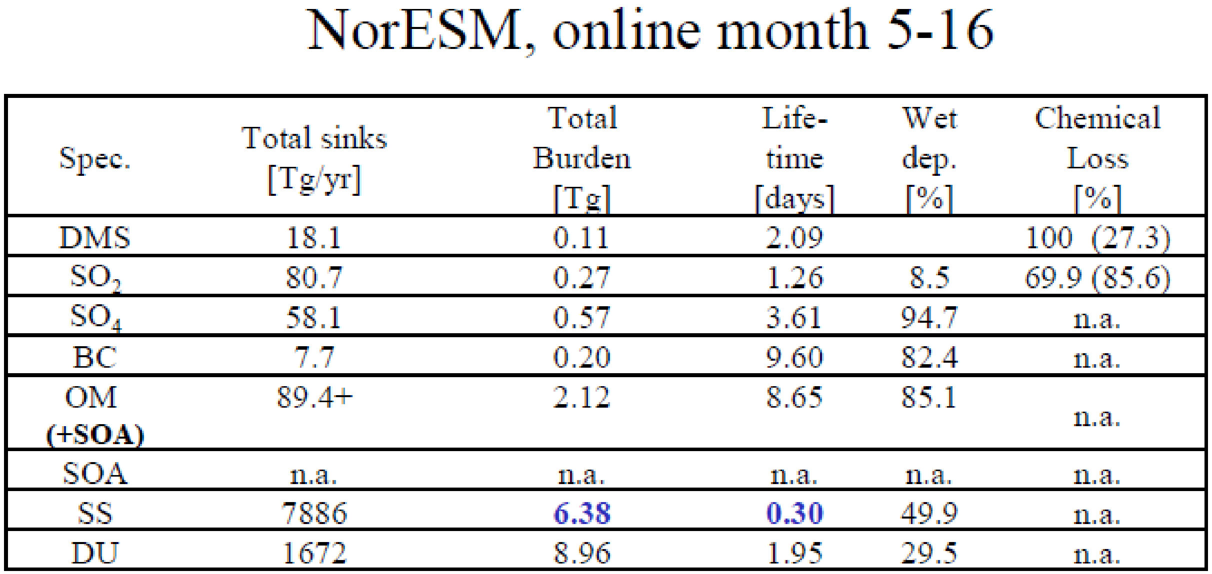
NorESM, Test 6 = new version (month 5-16)…

Spec.	Total sinks [Tg/yr]	Total Burden [Tg]	Life-time [days]	Wet dep. [%]	Chemical Loss [%]
DMS	18.1	0.11	2.17		100 (27.3)
SO_2	80.7	0.27	1.26	7.8	69.9 (85.6)
SO_4	58.1	0.60	3.78	94.5	n.a.
BC	7.7	**0.19**	**9.19**	82.2	n.a.
OM **(+SOA)**	**89.4+**	**2.06**	8.40	84.7	n.a.
SOA	n.a.	n.a.	n.a.	n.a.	n.a.
SS	7886	**7.02**	**0.33**	**47.5**	n.a.
DU	1672	9.02	1.97	30.9	n.a.

Increase > 20%

Increase > 10%

Decrease > 10%

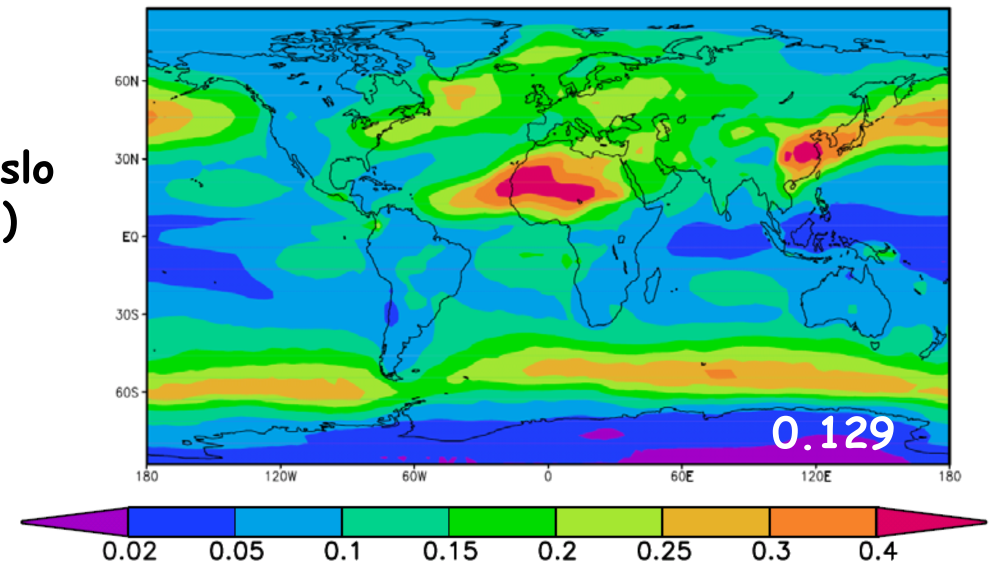


NorESM, online month 5-16

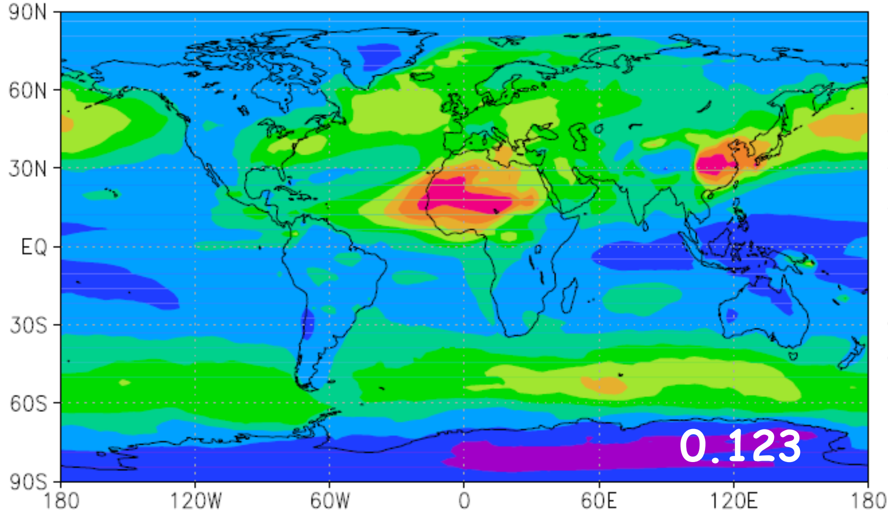
Spec.	Total sinks [Tg/yr]	Total Burden [Tg]	Life-time [days]	Wet dep. [%]	Chemical Loss [%]
DMS	18.1	0.11	2.09		100 (27.3)
SO_2	80.7	0.27	1.26	8.5	69.9 (85.6)
SO_4	58.1	0.57	3.61	94.7	n.a.
BC	7.7	0.20	9.60	82.4	n.a.
OM **(+SOA)**	89.4+	2.12	8.65	85.1	n.a.
SOA	n.a.	n.a.	n.a.	n.a.	n.a.
SS	7886	**6.38**	**0.30**	49.9	n.a.
DU	1672	8.96	1.95	29.5	n.a.

Present day AODvis (0.35-0.64 μm), with AeroCom emissions

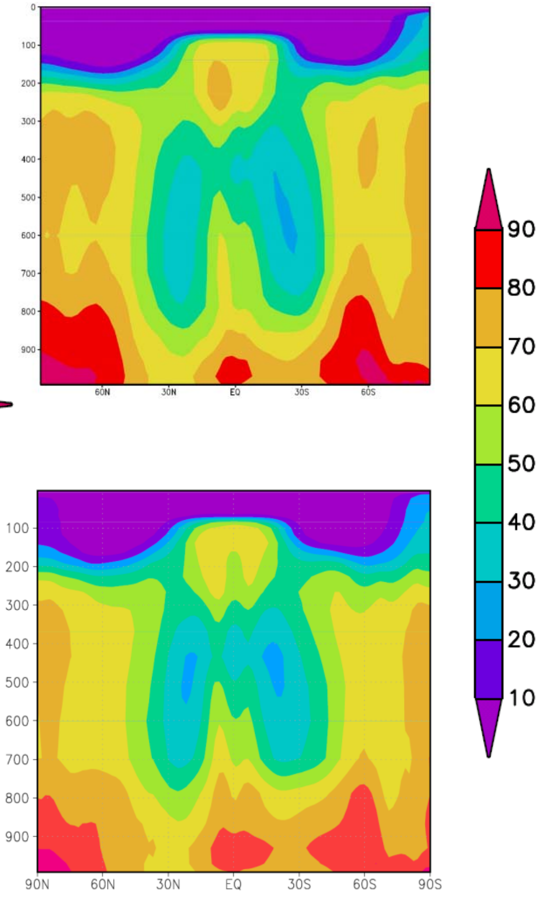
CAM-Oslo (2008)



CAM-Oslo / NorESM



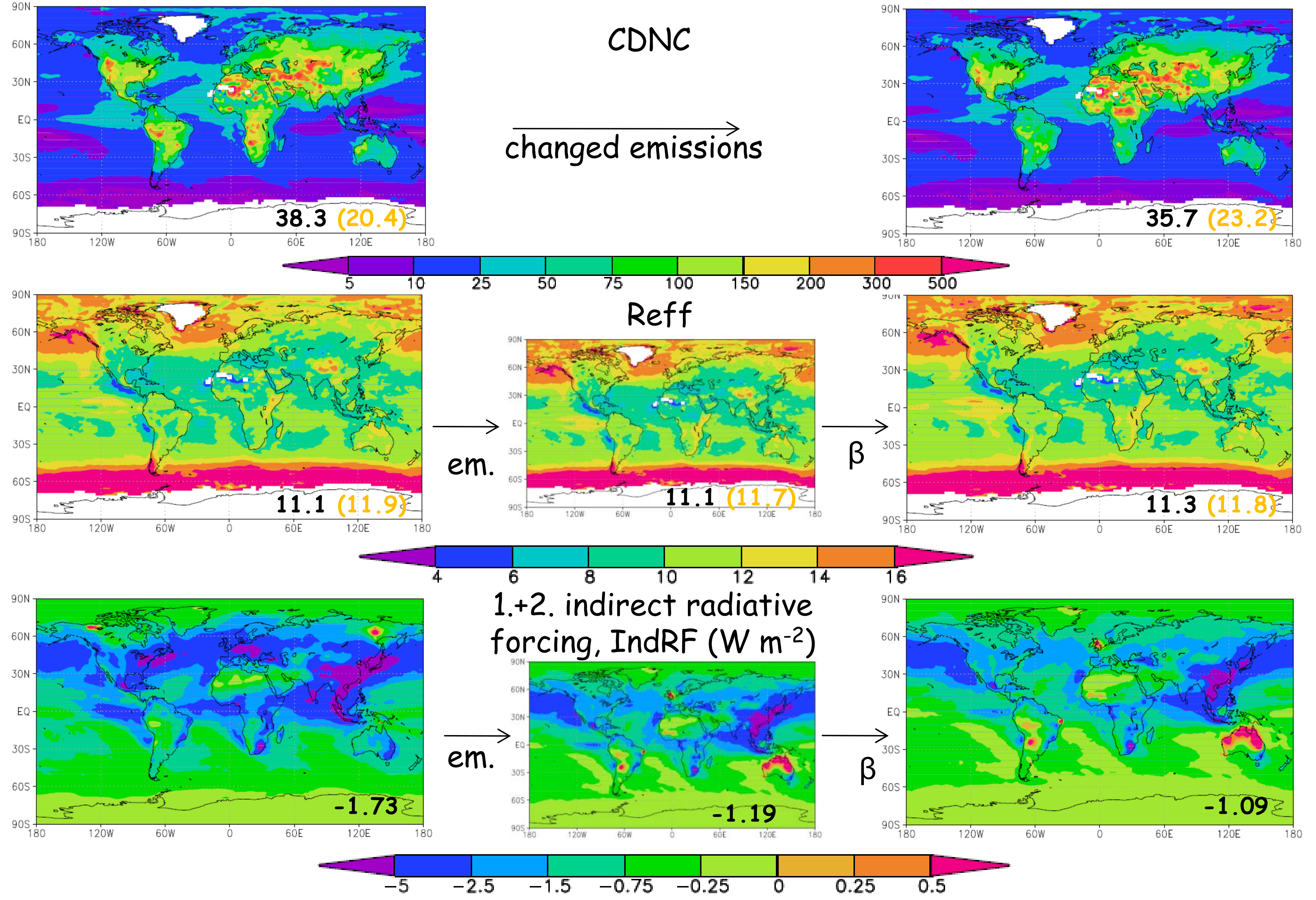
Relative humidity, RH



Cloud droplet number concentrations, CDNC (cm^{-3}) and effective cloud droplet radii, Reff (μm) (at 870 hPa)

AeroCom 2000 (1750)

IPCC 2000 (1850)



CDNC

changed emissions

Reff

1.+2. indirect radiative forcing, IndRF ($W\ m^{-2}$)

Cloud droplet number concentrations, CDNC (cm^{-3}) and vertically integrated CDNC (10^{6} cm^{-2})

AeroCom

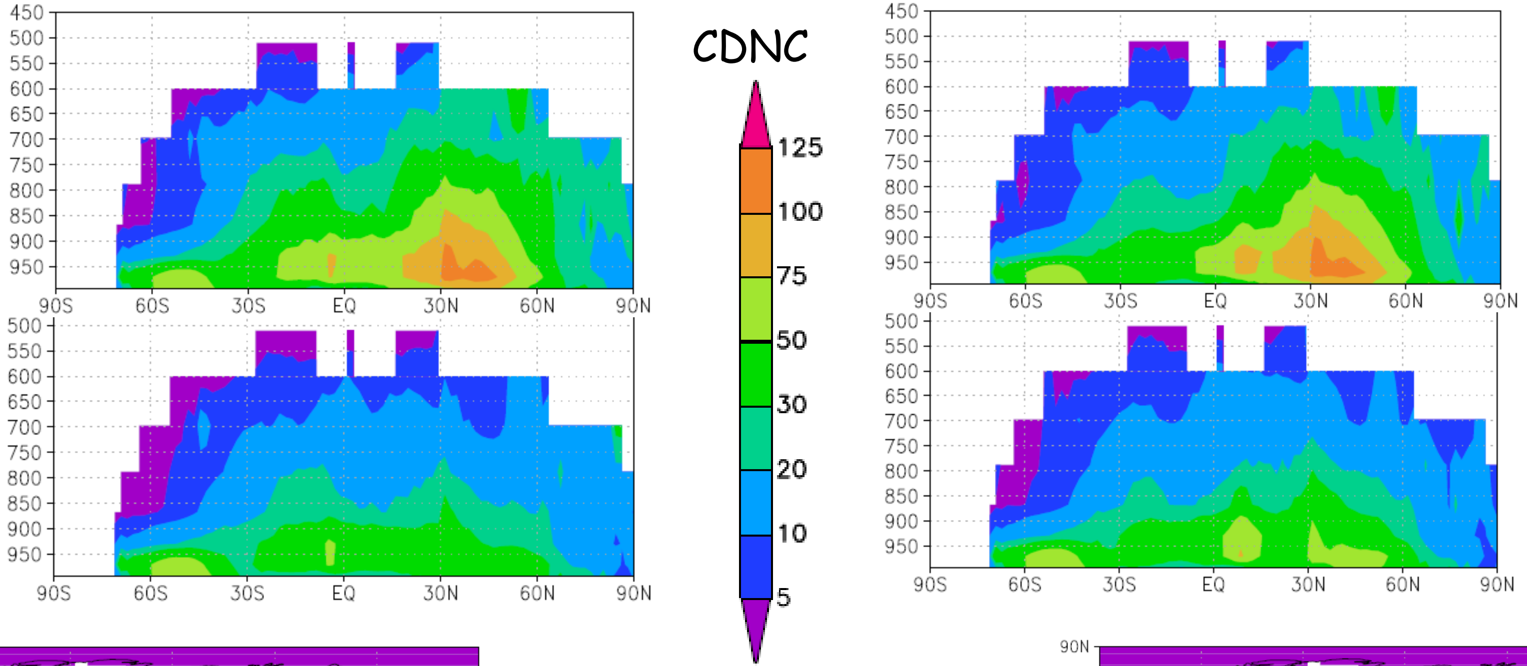
IPCC

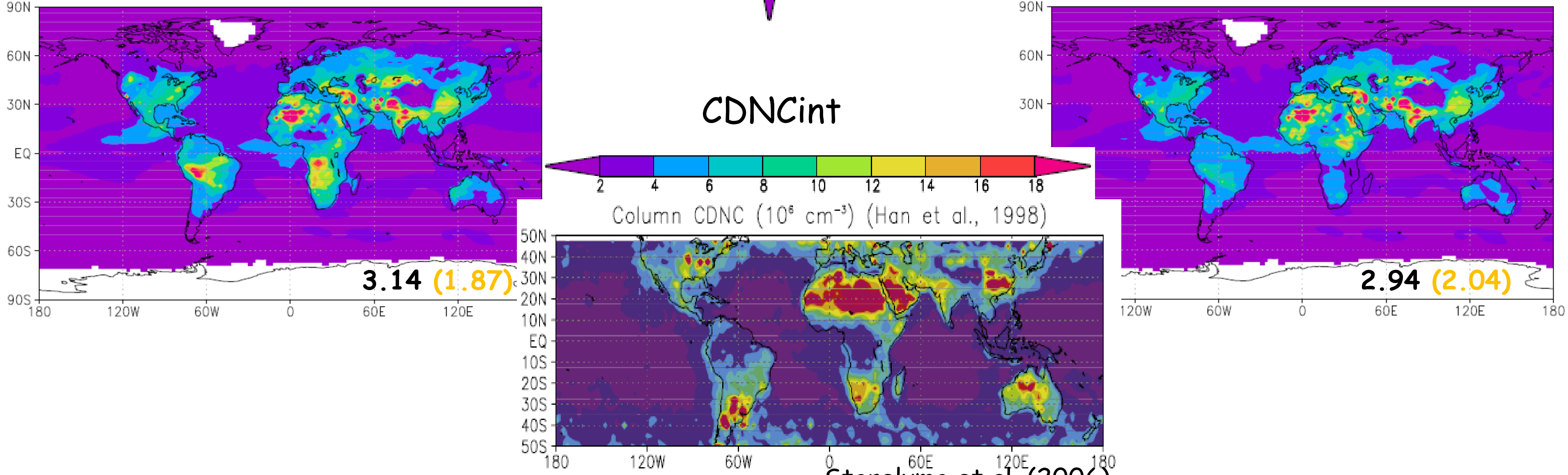
2000

1750

2000

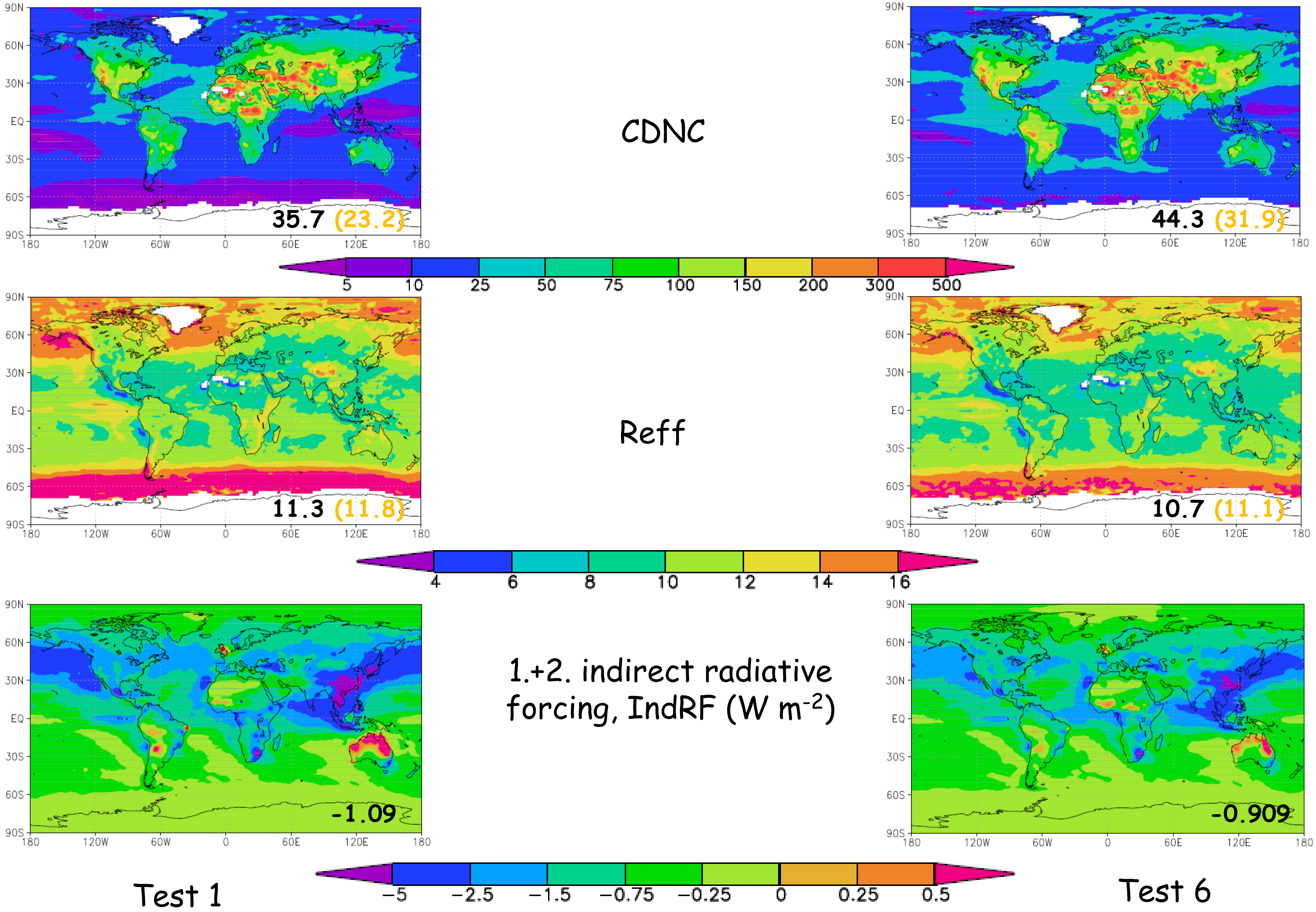
1850





Storelvmo et al. (2006)

Cloud droplet number concentrations, CDNC (cm^{-3}) and effective cloud droplet radii, Reff (μm) (at 870 hPa)



CDNC

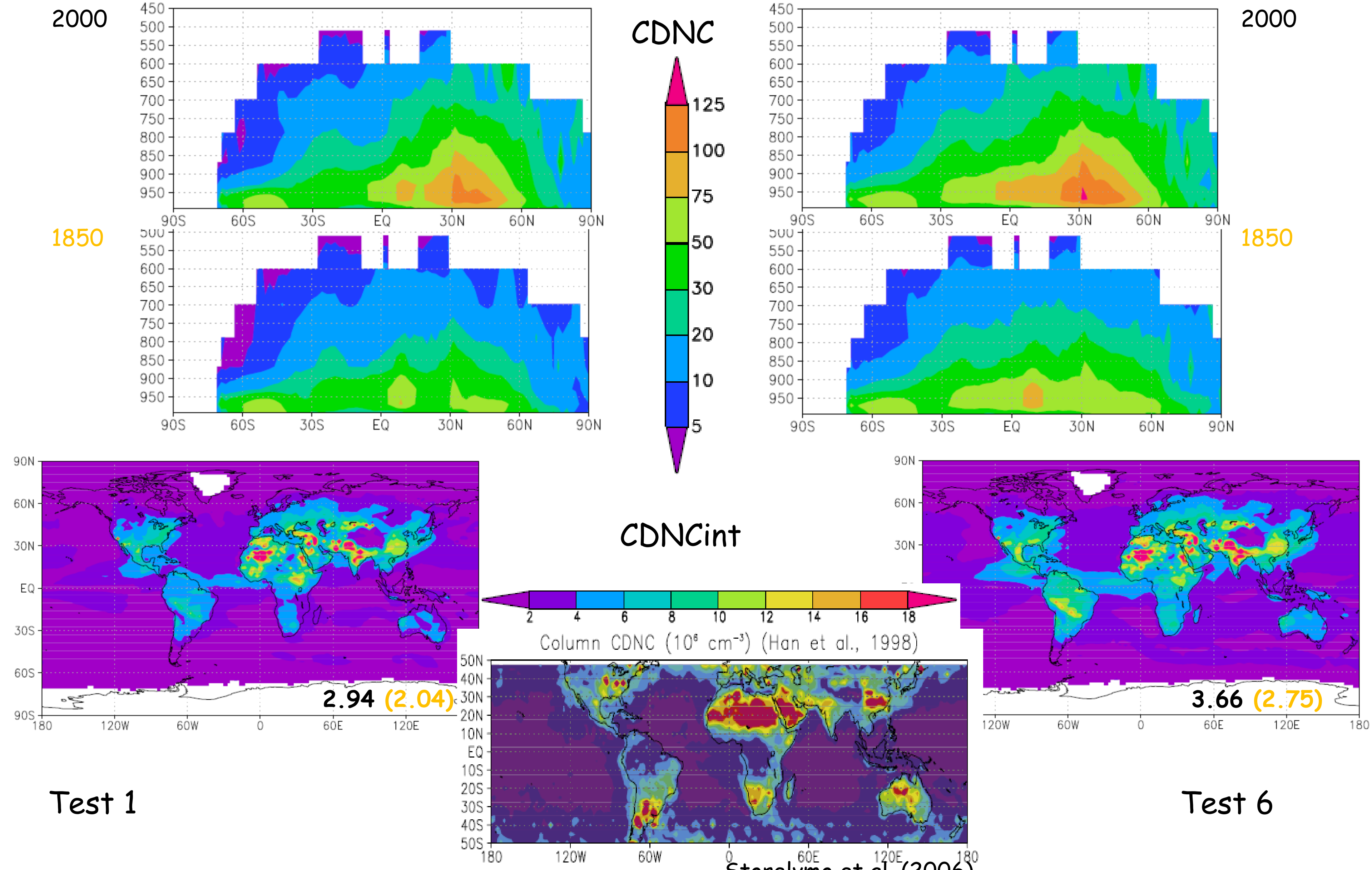
Reff

1.+2. indirect radiative forcing, IndRF (W m^{-2})

Test 1

Test 6

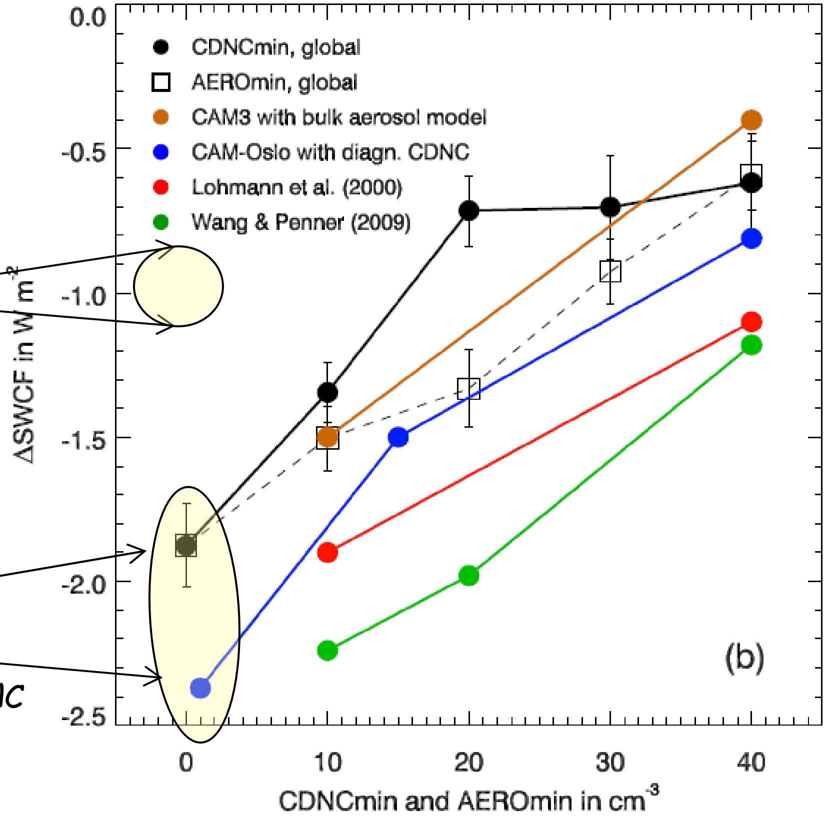
Cloud droplet number concentrations, CDNC (cm^{-3}) and vertically integrated CDNC (10^6 cm^{-2})



Storelvmo et al. (2006)

Indirect radiative forcing, IndRF (W m^{-2})

in two recent CAM-Oslo versions



NorESM/CAM(4)-Oslo

Prognostic CDNC

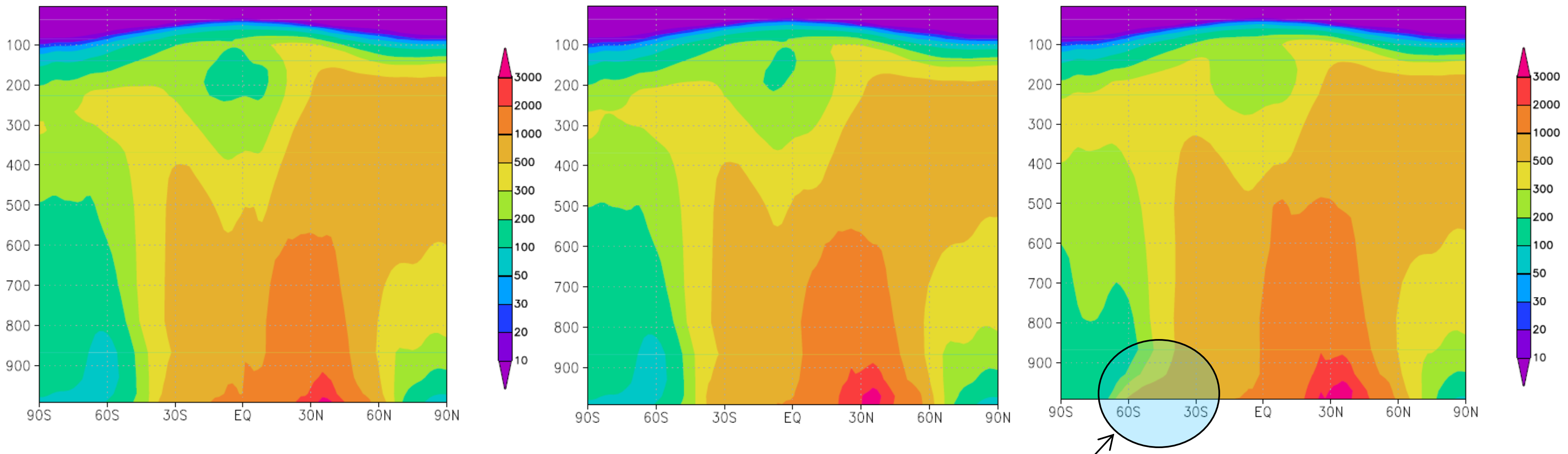
CAM(3)-Oslo

Diagnostic CDNC

Hoose et al. (2009)

Tests: 16 month off-line simulations	AODvis	DRF (W m^{-2})	CDNC (10^6 cm^{-2})	1.+2. IndRF (W m^{-2})
-1. AeroCom emissions	0.123	-0.085	3.14	**-1.73**
0. IPCC AR5 emissions	0.121	-0.116	2.94	-1.19
1. Control simulation: IPCC emissions + new $\beta = r_e/r_v$	**0.121**	**-0.116**	**2.94**	**-1.09**
2. Seasalt lumping 0.1% coarse -> fine mode	0.121	-	3.05	-
3. Adding primary OM ocean emissions	0.123	-	3.02	-
4. 2+3 + Incr. SOA em. -> new background aerosol	**0.129**	**-0.122**	**3.34**	**-0.823**
5. 4 + Increased convect. transport -> reduced deposition	0.141	-0.146	3.64	-0.859
6. 5 + use AeroCom vertical distribution of biomass burning emissions -> new aerosol scheme version	**0.144**	**-0.169**	**3.66**	**-0.909**

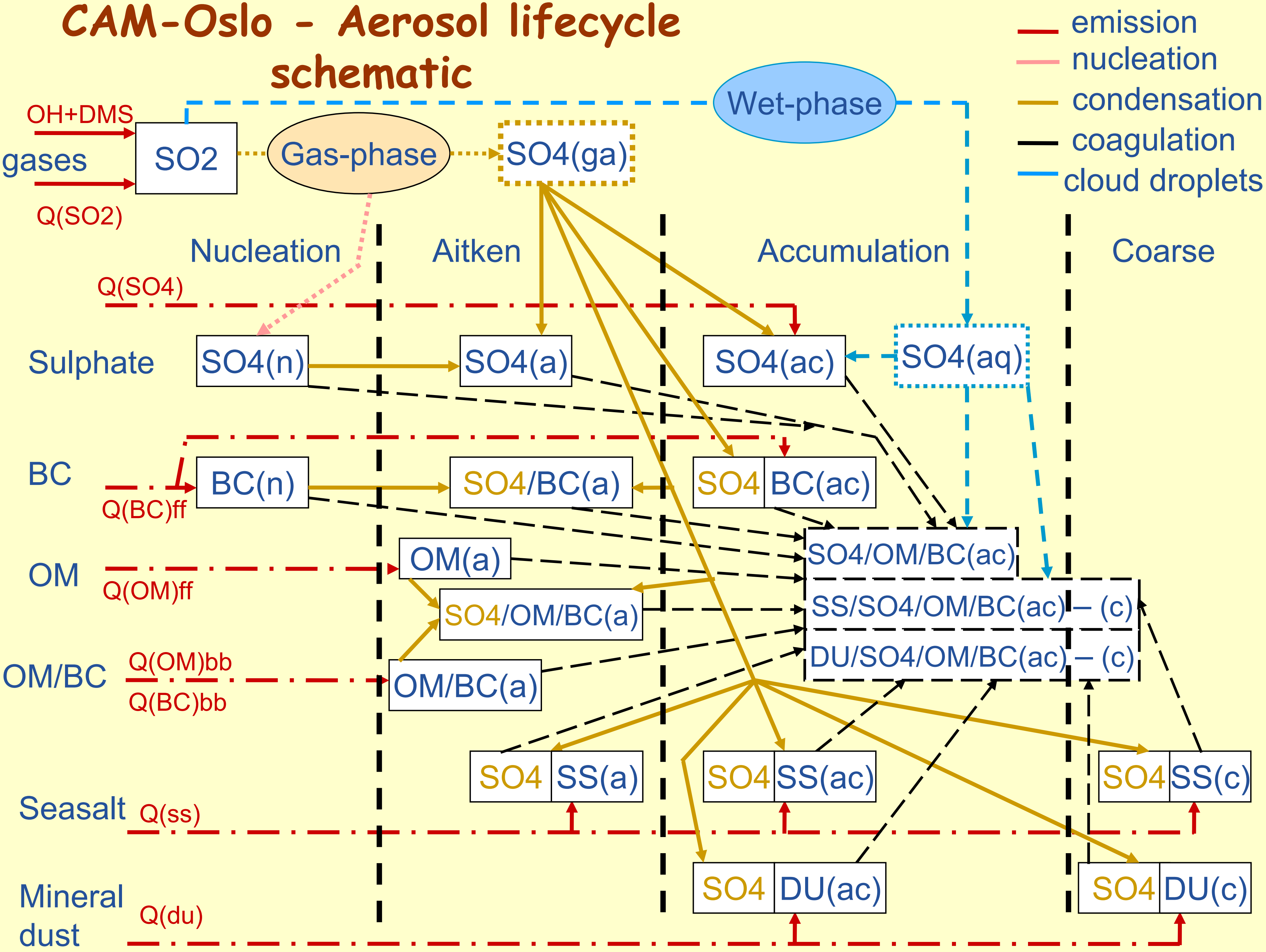
N_aer (cm^{-3}):



AeroCom → IPCC, test 1 → IPCC, test 4

SS(Ait)

CAM-Oslo - Aerosol lifecycle schematic

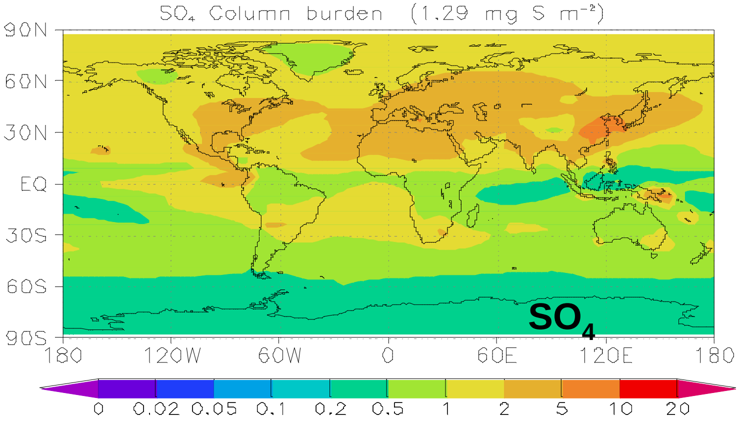


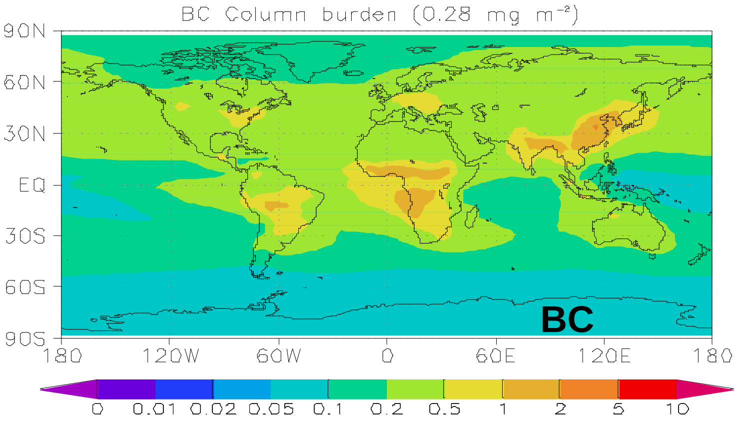
Prescribed lognormal externally mixed modes (before growth)

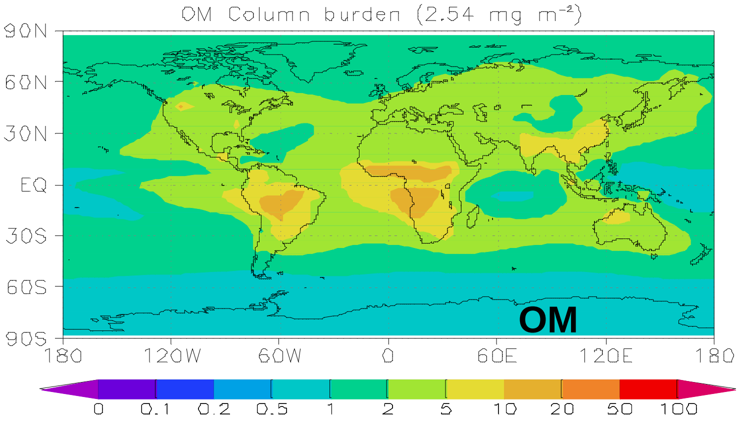
modes	modal median radius (μm)
SO_4(n/a) BC(n/a)	0.0118
BC(ac)	0.1
OC(a)	0.04
OC&BC(a)	0.04
SO4(ac)	0.075
MINERAL	0.22, 0.63
SEA-SALT	0.022, 0.13, 0.74

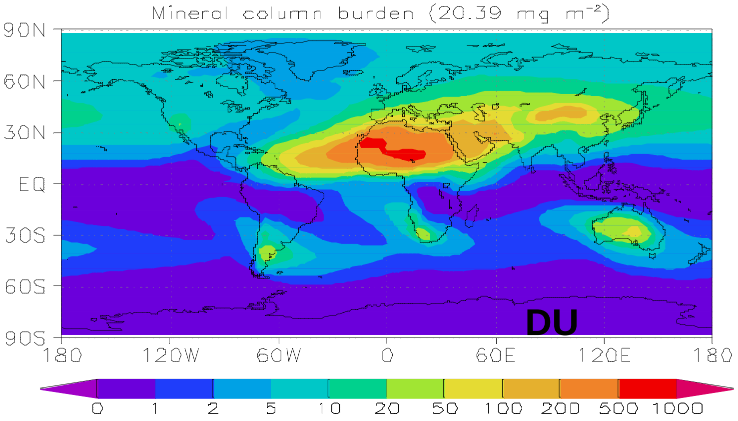
Results from 5 year simulations with CAM-Oslo

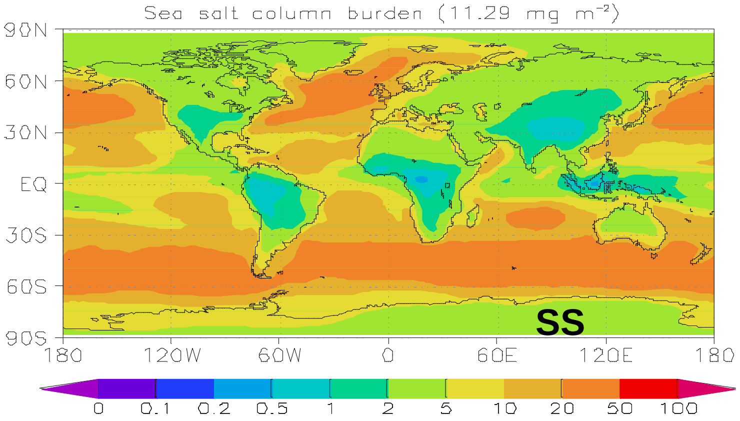
Modeled aerosol column burdens (mg/m²)


SO_4 Column burden (1.29 mg S m^{-2})

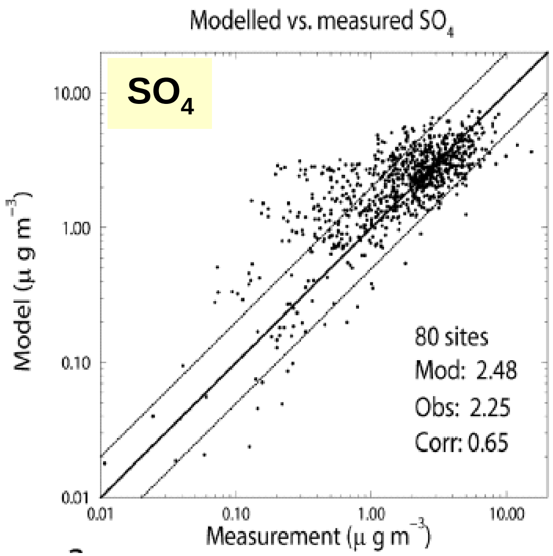

BC Column burden (0.28 mg m^{-2})

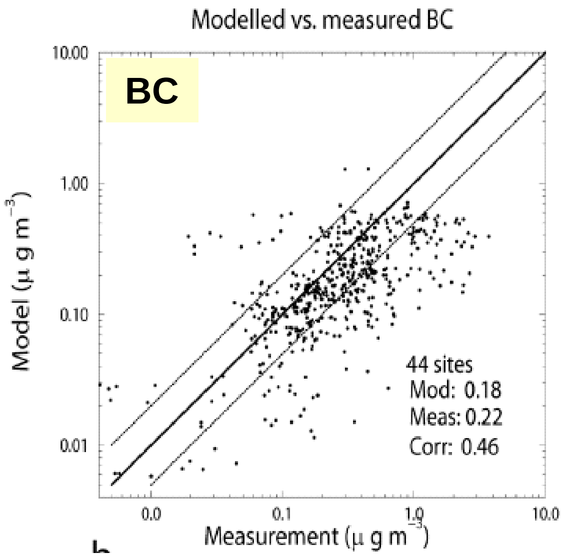

OM Column burden (2.54 mg m^{-2})

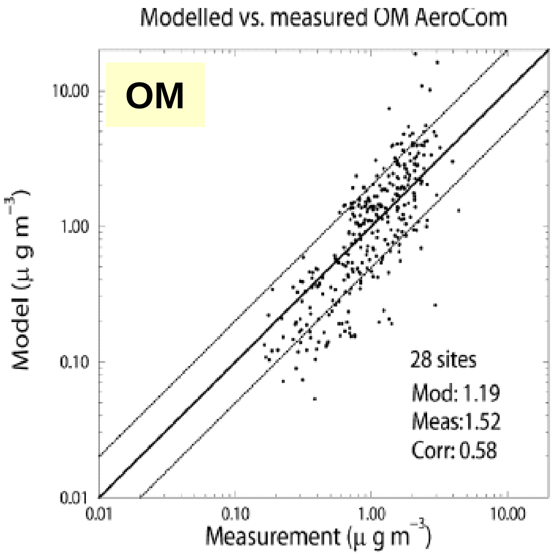

Mineral column burden (20.39 mg m^{-2})

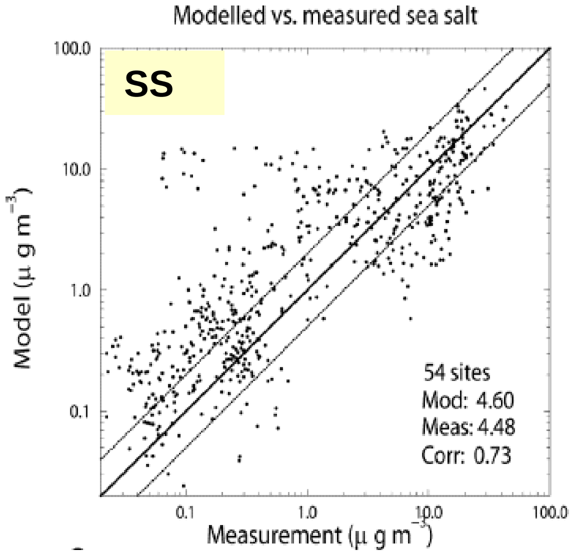

Sea salt column burden (11.29 mg m^{-2})

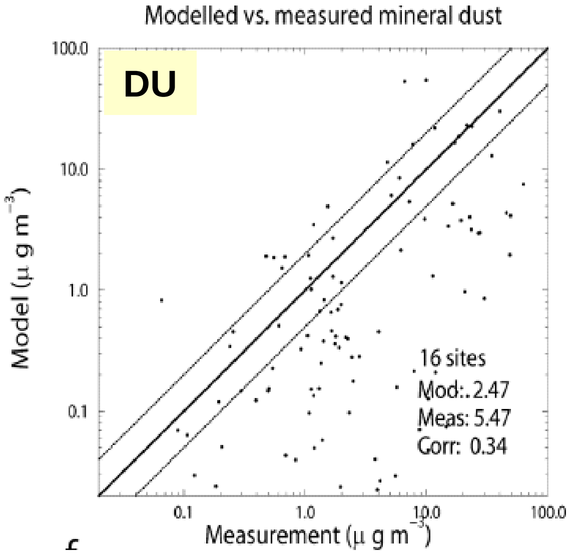
Modeled (CAM-Oslo) vs. measured annual surface concentrations


Modelled vs. measured SO_4


Modelled vs. measured BC


Modelled vs. measured OM AeroCom


Modelled vs. measured sea salt


Modelled vs. measured mineral dust

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