Aerosols in the CCSM4 based Norwegian Earth System Model – NorESM1-M:

the role of natural aerosols for estimates of radiative forcing by anthropogenic aerosols

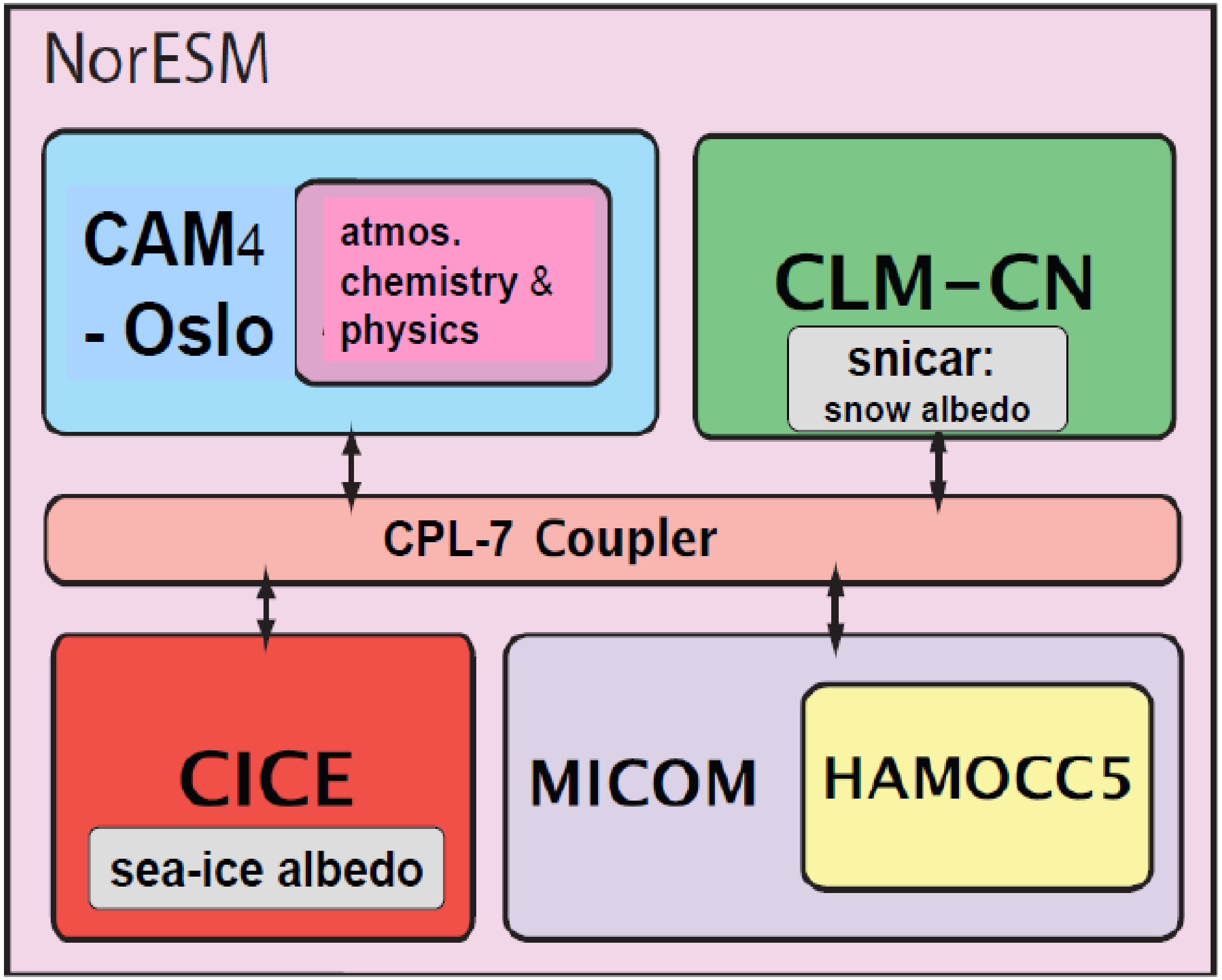
Alf Kirkevåg

with contributions from

Trond Iversen, Øyvind Seland, Corinna Hoose, Jon Egill Kristjánsson,
Hamish Struthers, Annica Ekman, Steve Ghan, Jan Griesfeller, Douglas Nilsson,
and Michael Schulz

CCWG meeting, NCAR,
February 11'th, 2013

NorESM
components and interactions



(FV dynamical core, 1.9°×2.5° res., 26 levels)

AMWG talk
by Trond Iversen:

NorESM fully coupled
→ CMIP5 simulations

This talk:

CAM4-Oslo with data ocean and sea-ice
→ forcing simulations

Most of the results are from:

A. Kirkevåg, T. Iversen, Ø. Seland, C. Hoose, J. E. Kristjánsson, H. Struthers, A. M. L. Ekman, S. Ghan, J. Griesfeller, E. D. Nilsson, and M. Schulz: Aerosol-climate interactions in the Norwegian Earth System Model – NorESM1-M, Geosci. Model Dev., 6, 207-244, 2013.

See also the NorESM special issue:
http://www.geosci-model-dev-discuss.net/special_issue21.html

New features in CAM4-Oslo / NorESM compared to CAM-Oslo:

Seland et al. (2008)
Hoose et al. (2009)
Struthers et al. (2011)

- **New and enhanced natural aerosol components** (vs. Seland et al., 2008):
  - Oceanic primary biogenic OM: emissions distributed as sea-salt and scaled to 8 Tg/yr globally (Spracklen et al., 2008)
  - MSA produced from the oceanic DMS included, treated as POM
  - Natural SOA produced from land vegetation and treated as POM is almost doubled (Hoyle et al., 2007)

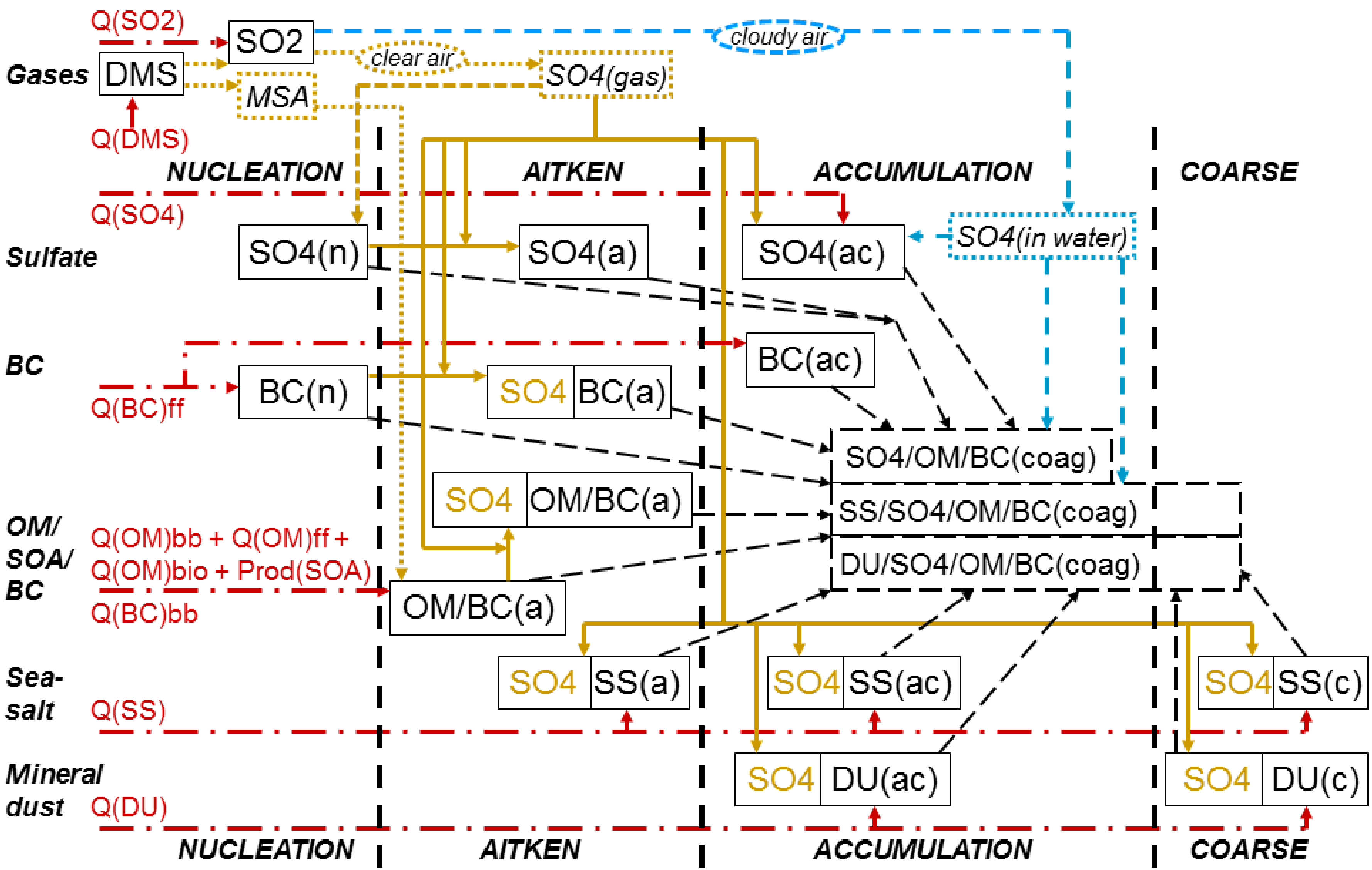
- **New processing of natural aerosols:**
  - Sea-salt emissions depend now on wind and temperature, *updated* Struthers et al. (2011)
  - In-cloud scavenging coefficient for dust is reduced from 1 (Seland et al., 2008) to 0.25

- **New treatment affecting both natural and anthropogenic aerosols** (vs. Seland et al., 2008):
  - OM/OC ratio for emissions of biomass burning POM: increased from 1.4 to 2.6 (Formenti et al., 2003)
  - Updated tropospheric oxidant fields from Oslo-CTM2 (Berntsen et al., 1997)
  - Rate of replenishment of H_2O_2 in cloud droplets changed from a fixed value of 1 h to 1-12 h, ~ $(1.1\text{-cldmax})^2$
  - Gravitational particle settling speed calculated at all heights

  - Pre-industrial emissions were AeroCom 1750, now: IPCC AR5 1850 for aerosols and precursors
  - Present-day emissions were AeroCom 2000, now: AeroCom 2006 or IPCC AR5 2000.

\+ **New cloud droplet spectral dispersion formulation** (vs. Hoose et al., 2009) (Rotstayn and Liu, 2009)

Schematic for aerosol processing in CAM4-Oslo



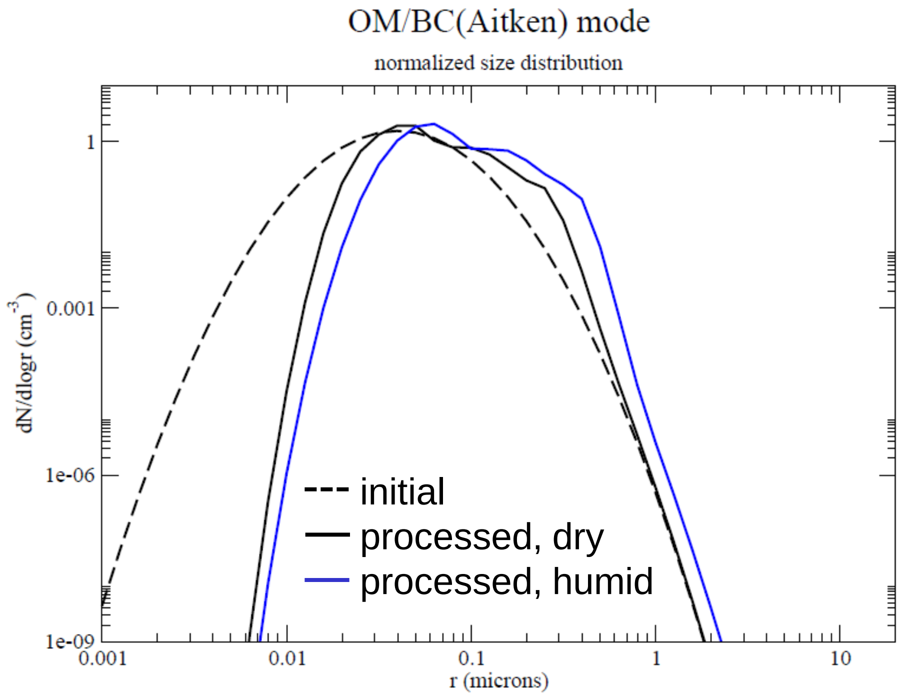
Aerosol growth by:

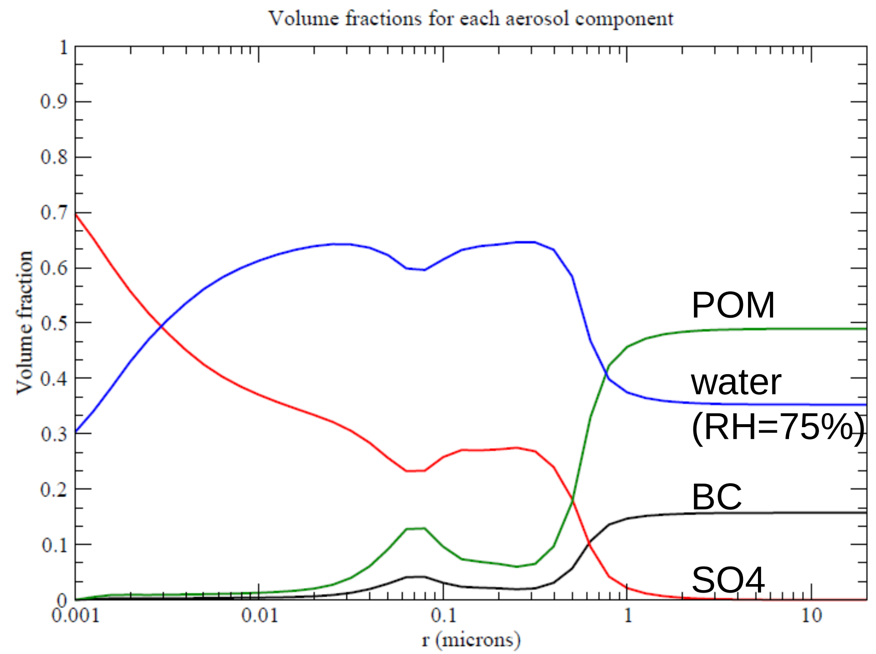
- condensation of H_2SO_4

- coagulation of Aitken particles
  onto larger pre-existing particles

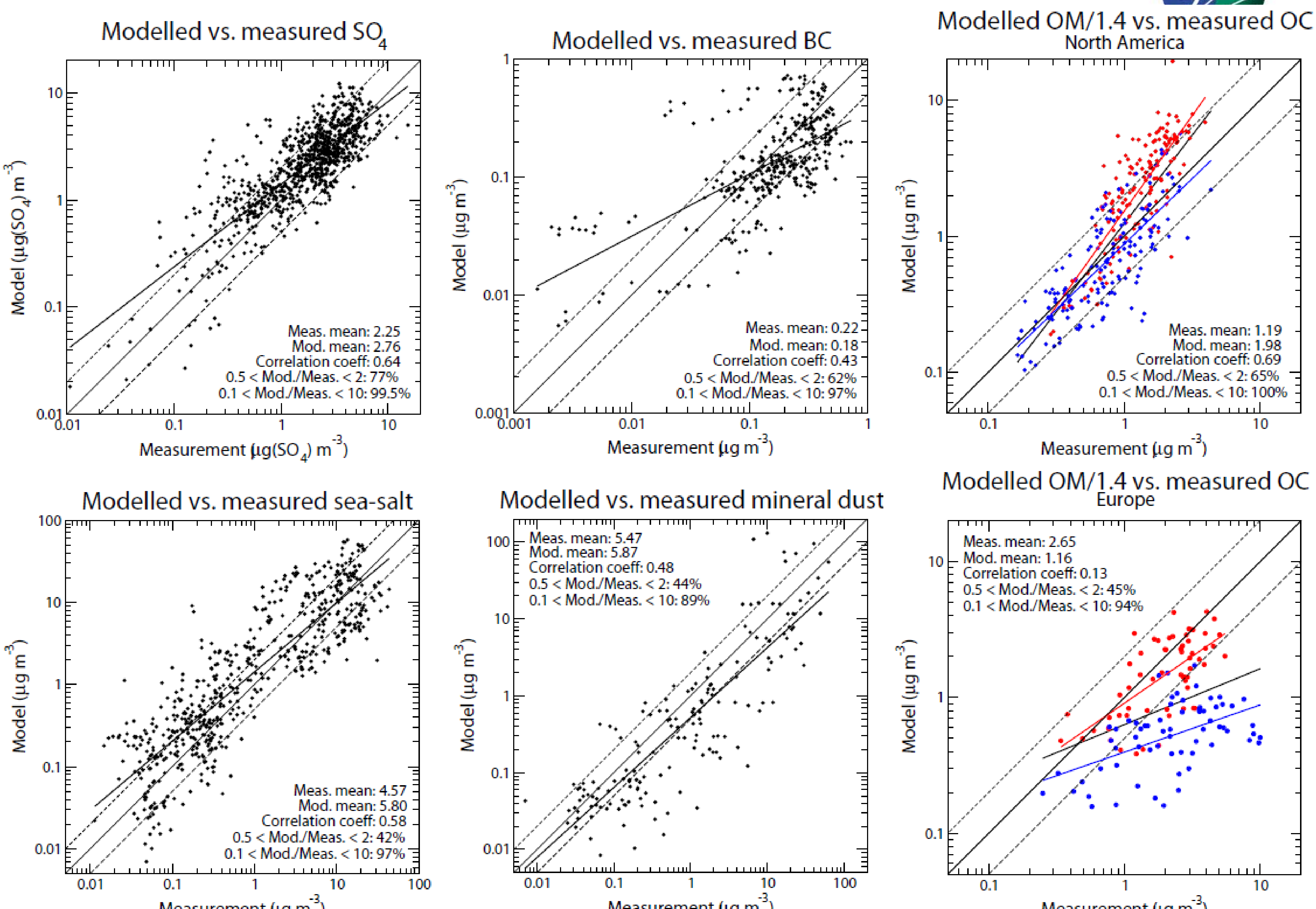
- cloud-processing/wet phase chemistry

- hygroscopic growth





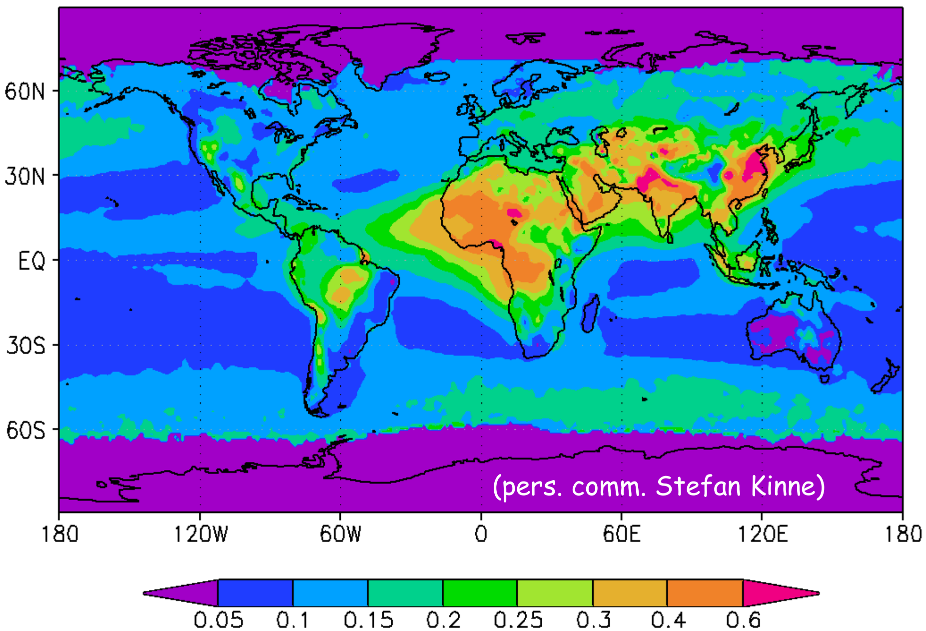
Monthly near-surface aerosol mass concentrations



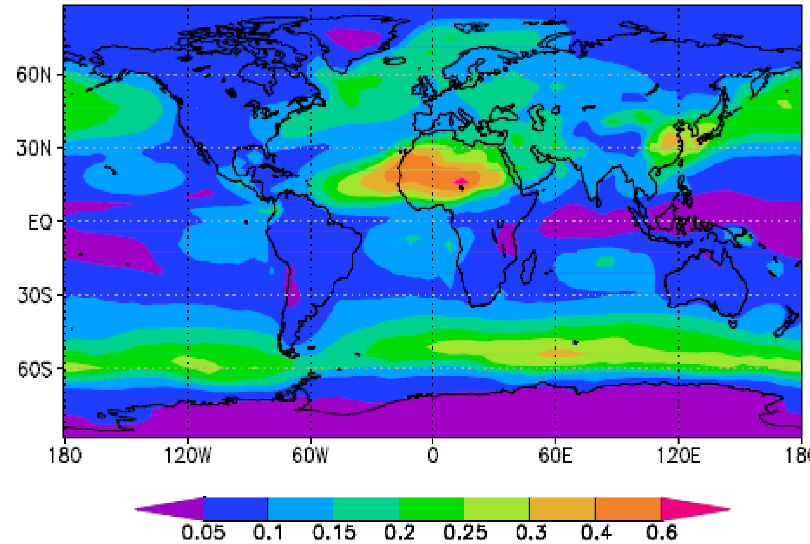
Clear-sky aerosol optical depth

Remote sensed data

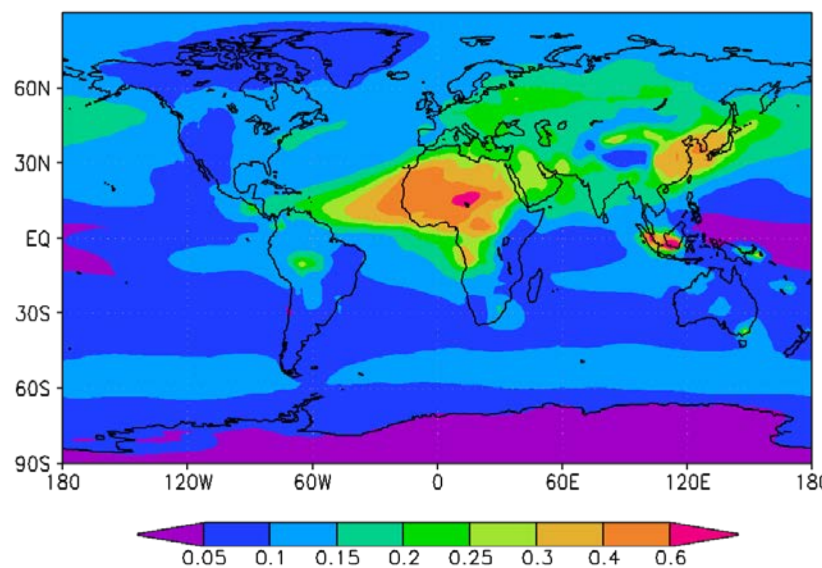
AOD composite, MODIS-MISR-AERONET



CAM-Oslo (Seland et al., 2008)

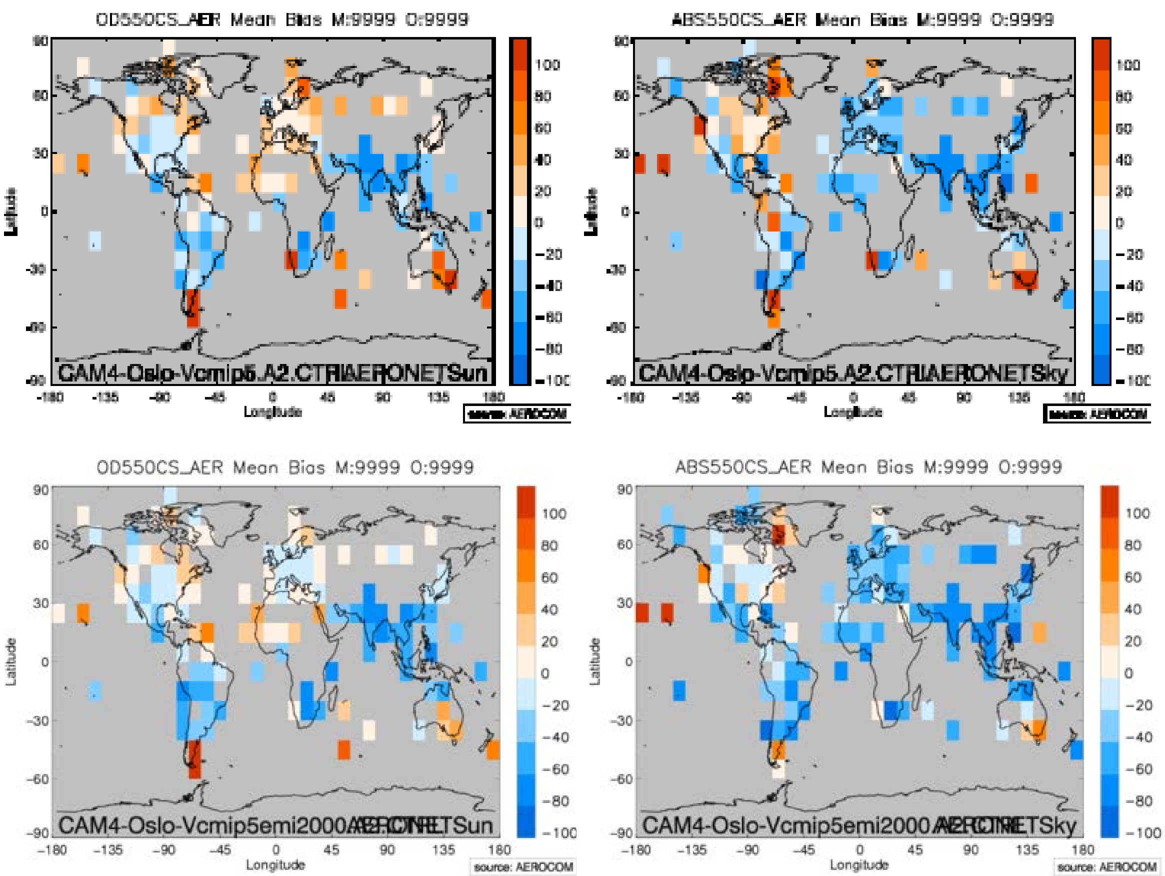


CAM4-Oslo



Bias (in %) compared to AERONET

clear-sky AOD | clear-sky ABS (absorption AOD)



Aerocom 2006 emissions

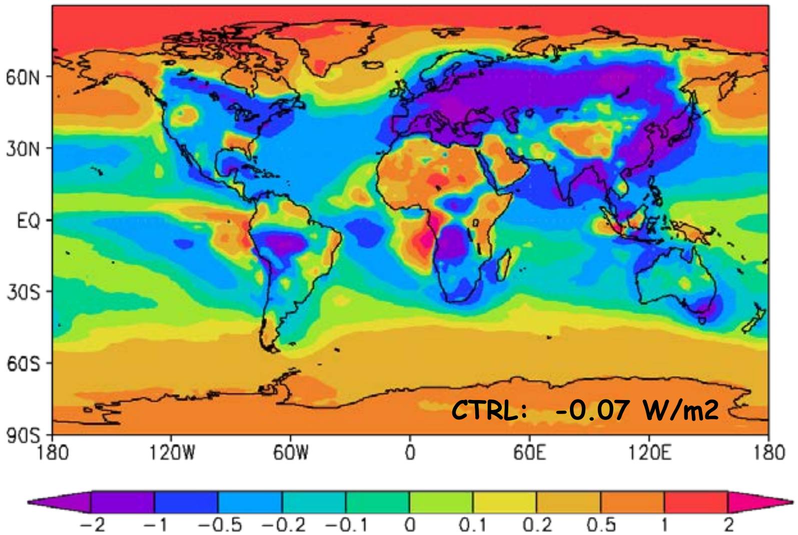
IPCC 2000 emissions (CMIP5)

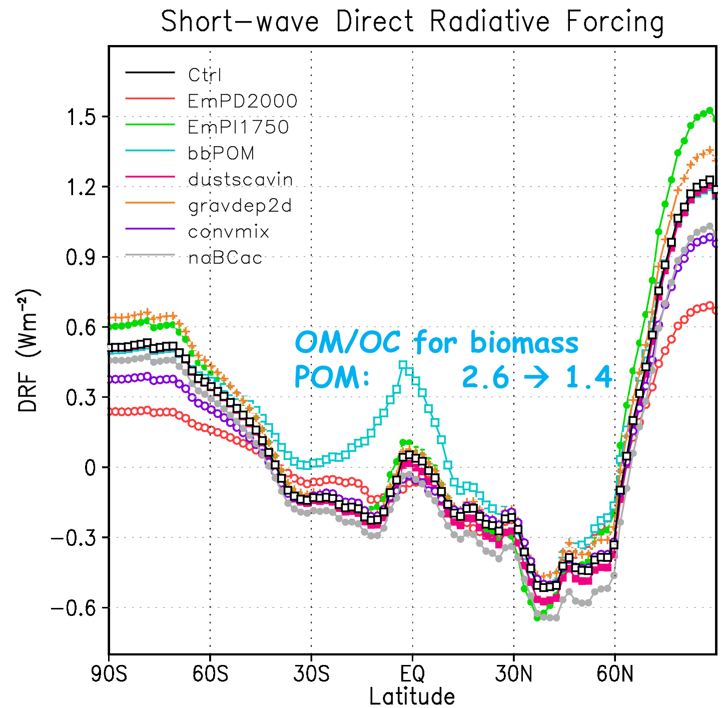
http://aerocom.met.no/

Sensitivity tests of mainly old versions of parameterizations in CAM4-Oslo coupled to *data* ocean & sea-ice models:

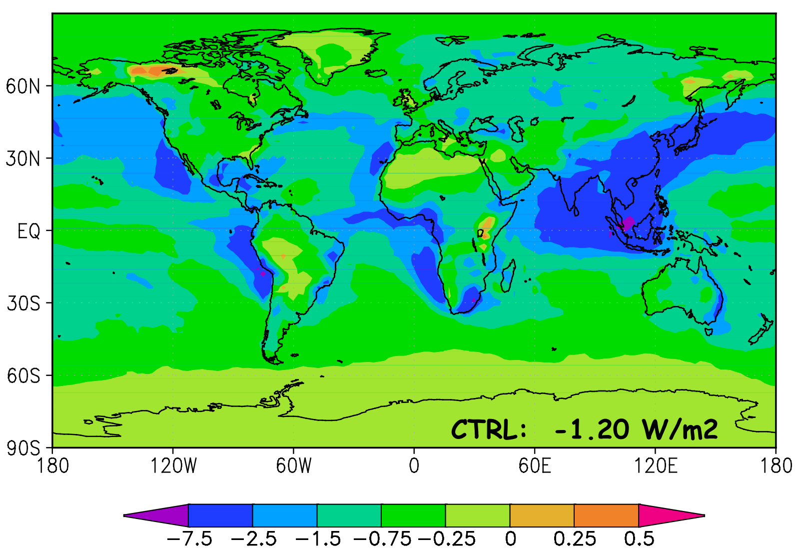
Identification	Short description (Se08=Seland et al., 2008)	
Ctrl	Standard Reference. All processes updated. Emissions years: PD = 2006; PRE = 1850.	
natOM	As *Ctrl*, but with natural OM as in Se08.	} nat.
natOMocn	As *Ctrl*, but no biogenic OM from oceans and MSA, as in Se08.	
bbPOM	As *Ctrl*, but OM / OC = 1.4, as in Se08.	} nat. & anthrop.
Struthers11	As *Ctrl*, but tuning of sea-salt emissions as in Struthers et al. (2011).	
dustscavin	As *Ctrl*, but in-cloud scavenging efficiency for dust = 1, as in Se08.	
cldtunorig	As *Ctrl*, but tuning of cloud microphysics as in NCAR CAM4 (Neale et al., 2010).	
gravdep2d	As *Ctrl*, but gravitational settling only in the lowest model layer, as in Se08.	
convmix	As *Ctrl*, but convective mixing of aerosols and precursors as in Se08.	
noBCac	As *Ctrl*, but no primary emissions of BC(ac), i.e. all BC is emitted as BC(n).	
replH2O2	As *Ctrl*, but replenishment time of H_2O_2 = 1 h, as in Se08.	
no coating	As *Ctrl*, but without coating of dust and BC in CCN-activation.	
prescrβ	As *Ctrl*, but effective cloud droplet radii parameterized as in Se08, Hoose et al. (2009), and Neale et al. (2010).	
EmPD2000	As *Ctrl* (all processes updated). Emissions years: PD = 2000; PI = 1850.	} nat. & anthrop.
EmPI1750	As *Ctrl* (all processes updated). Emissions years: PD = 2006; PI = 1750.	} nat. (PI in IPCC AR4)
Online	As *Ctrl*, but with online interactions between aerosol forcing and atmospheric dynamics.	

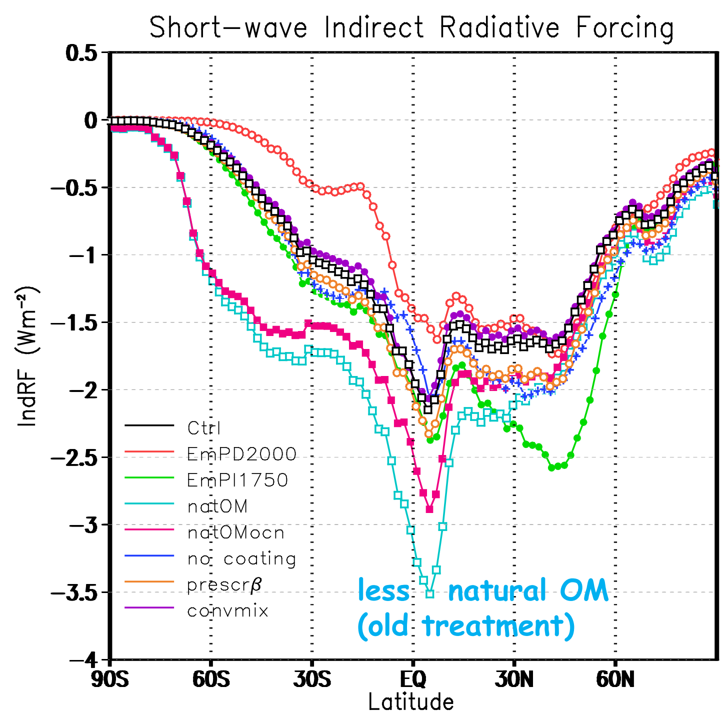
DRF at TOA

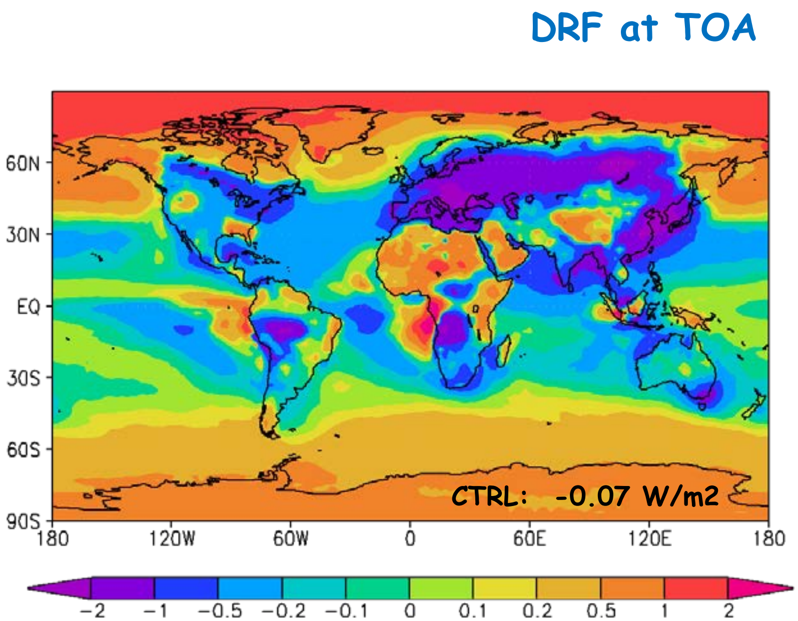


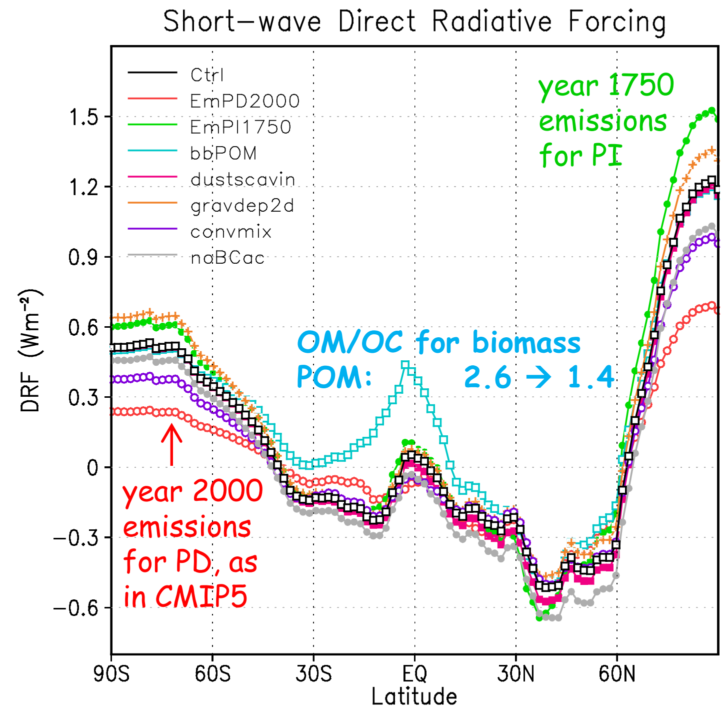


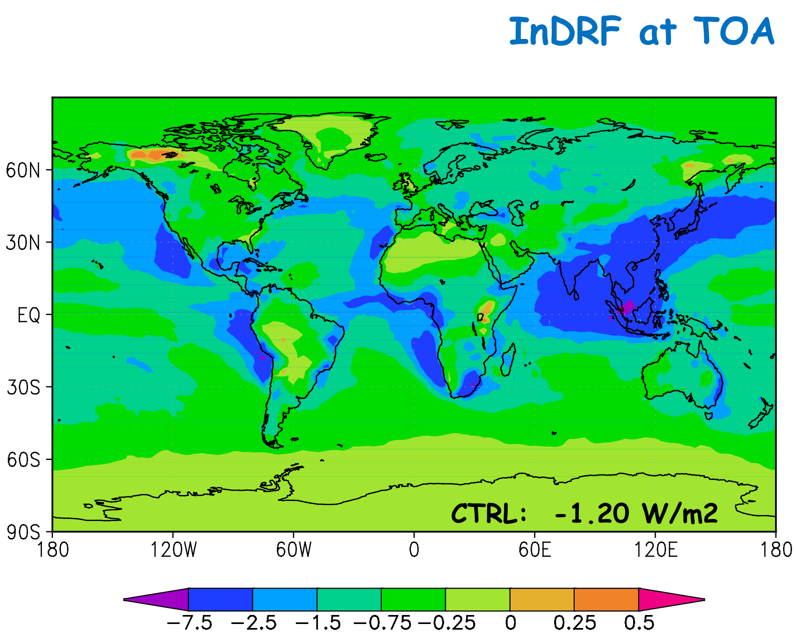
InDRF at TOA

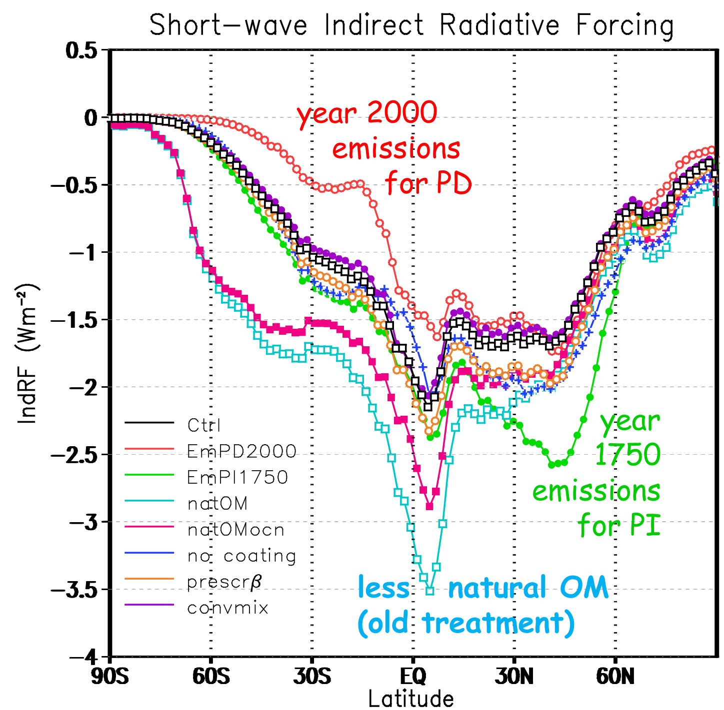





DRF at TOA
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
CTRL: -0.07 W/m2
−2 −1 −0.5 −0.2 −0.1 0 0.1 0.2 0.5 1 2

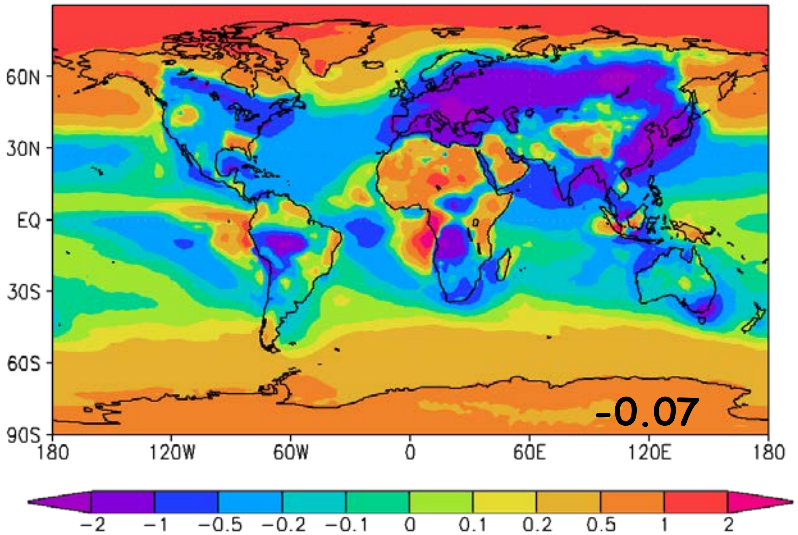

Short−wave Direct Radiative Forcing
Ctrl
EmPD2000
EmPI1750
bbPOM
dustscavin
gravdep2d
convmix
naBCac
year 1750 emissions for PI
OM/OC for biomass
POM: 2.6 → 1.4
year 2000 emissions for PD, as in CMIP5
DRF (Wm⁻²)
1.5
1.2
0.9
0.6
0.3
0
−0.3
−0.6
90S 60S 30S EQ 30N 60N
Latitude


InDRF at TOA
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
CTRL: -1.20 W/m2
−7.5 −2.5 −1.5 −0.75 −0.25 0 0.25 0.5

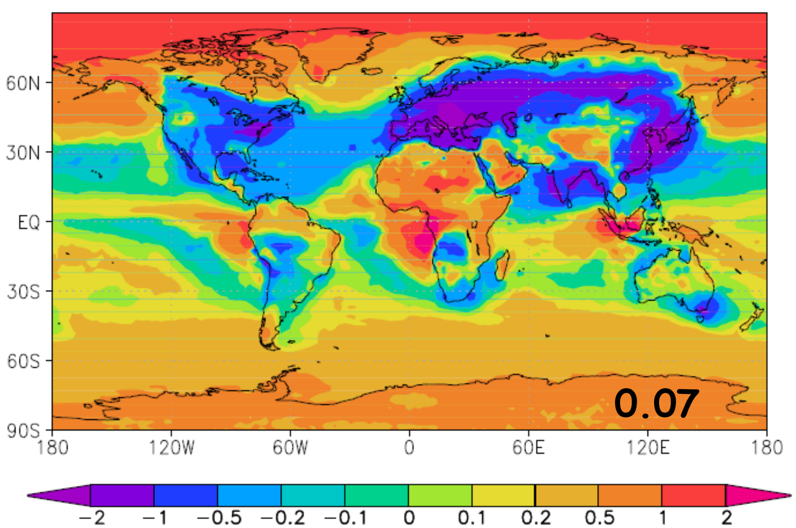

Short−wave Indirect Radiative Forcing
year 2000 emissions for PD
Ctrl
EmPD2000
EmPI1750
natOM
natOMocn
no coating
prescrβ
convmix
year 1750 emissions for PI
less natural OM (old treatment)
IndRF (Wm⁻²)
0.5
0
−0.5
−1
−1.5
−2
−2.5
−3
−3.5
−4
90S 60S 30S EQ 30N 60N
Latitude

DRF at TOA (W/m2)

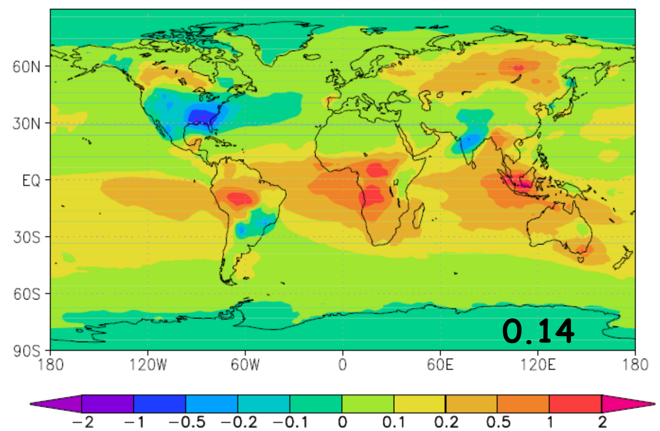
Ctrl



bbPOM (OM/OC=1.4)

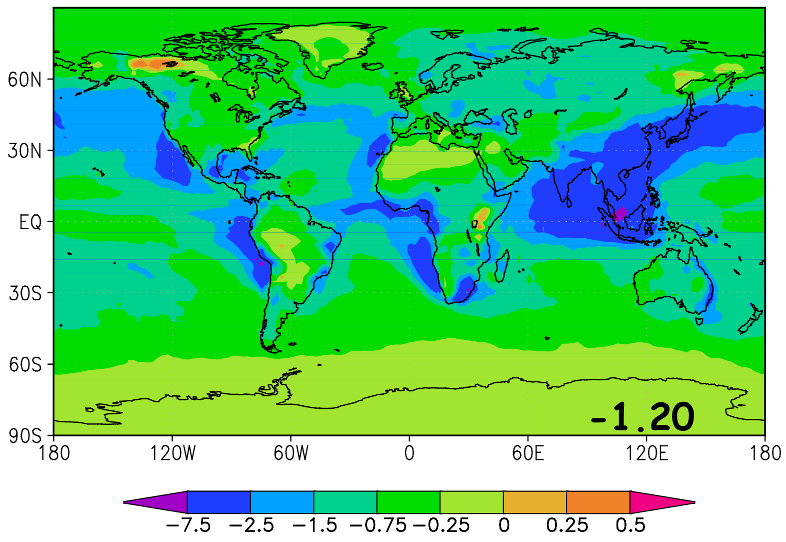


bbPOM - Ctrl

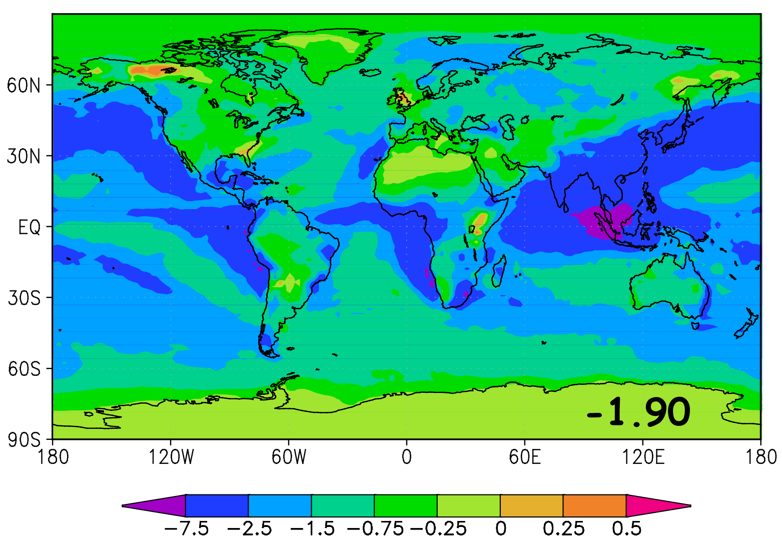


InDRF at TOA (W/m2)

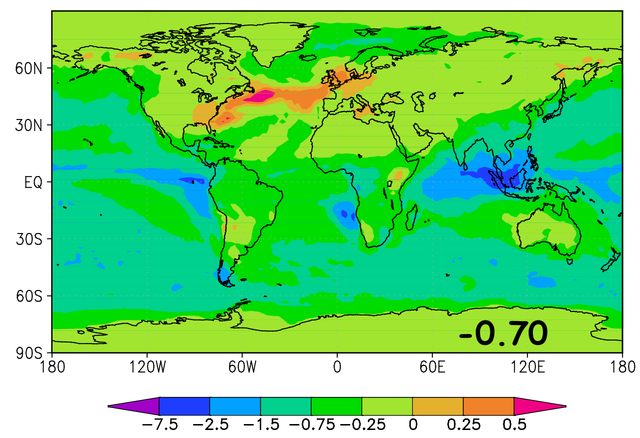
Ctrl



natOM (less natural OM)



natOM – Ctrl



Summary

Model validation:

Aerosol surface concentrations and optical properties compare reasonably well with observations, giving similar or (mainly) improved validation results compared to earlier model versions (but more over-estimated POM in N-America)

Direct and 1.&2. indirect SW forcing at TOA and near ground surface:

- **DRF** most sensitive to assumed OM/OC ratio for biomass burning POM:
  + 0.07 → – 0.07 Wm^{-2} when OM/BC is changed from 1.4 → 2.6

- Basic emission years / inventories also important, especially for surface forcing:
  -0.10 Wm^{-2} for year 2000 – 1850 (**CMIP5**) -1.04 Wm^{-2}
  -0.07 Wm^{-2} for year 2000 – 1750 -1.36 Wm^{-2}
  -0.07 Wm^{-2} for year 2006 – 1850 -1.89 Wm^{-2}
  -0.04 Wm^{-2} for year 2006 – 1750 -2.20 Wm^{-2}

- **IndRF** most sensitive to natural OM levels:
  - 1.90 → – 1.20 Wm^{-2} with the increased OM emission/production

- and basic emission years / inventories:
  -0.91 Wm^{-2} for year 2000 – 1850 (**CMIP5**)
  -1.23 Wm^{-2} for year 2000 – 1750
  -1.20 Wm^{-2} for year 2006 – 1850
  -1.53 Wm^{-2} for year 2006 – 1750

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  -1.23 Wm^{-2} for year 2000 – 1750
  -1.20 Wm^{-2} for year 2006 – 1850
  -1.53 Wm^{-2} for year 2006 – 1750

- **DRF** most sensitive to assumed *OM/OC* ratio for biomass burning POM: + 0.07 → – 0.07 Wm^{-2} when OM/BC is changed from 1.4 → 2.6

- Basic emission years / inventories also important, especially for surface forcing:

-0.10 Wm^{-2} for year 2000 – 1850 (**CMIP5**)	-1.04 Wm^{-2}
-0.07 Wm^{-2} for year 2000 – 1750	-1.36 Wm^{-2}
-0.07 Wm^{-2} for year 2006 – 1850	-1.89 Wm^{-2}
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  -1.23 Wm^{-2} for year 2000 – 1750
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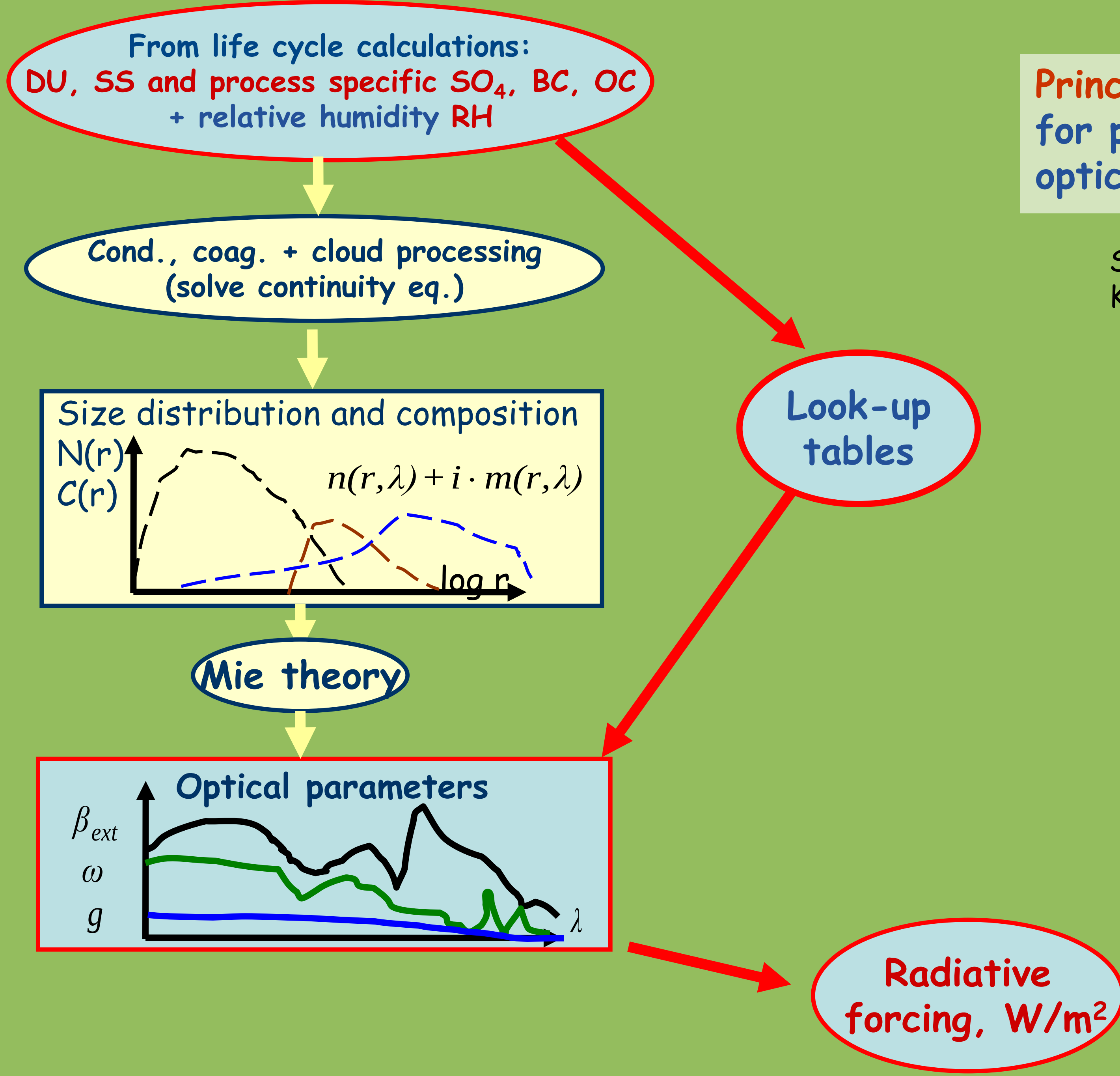
  -1.53 Wm^{-2} for year 2006 – 1750

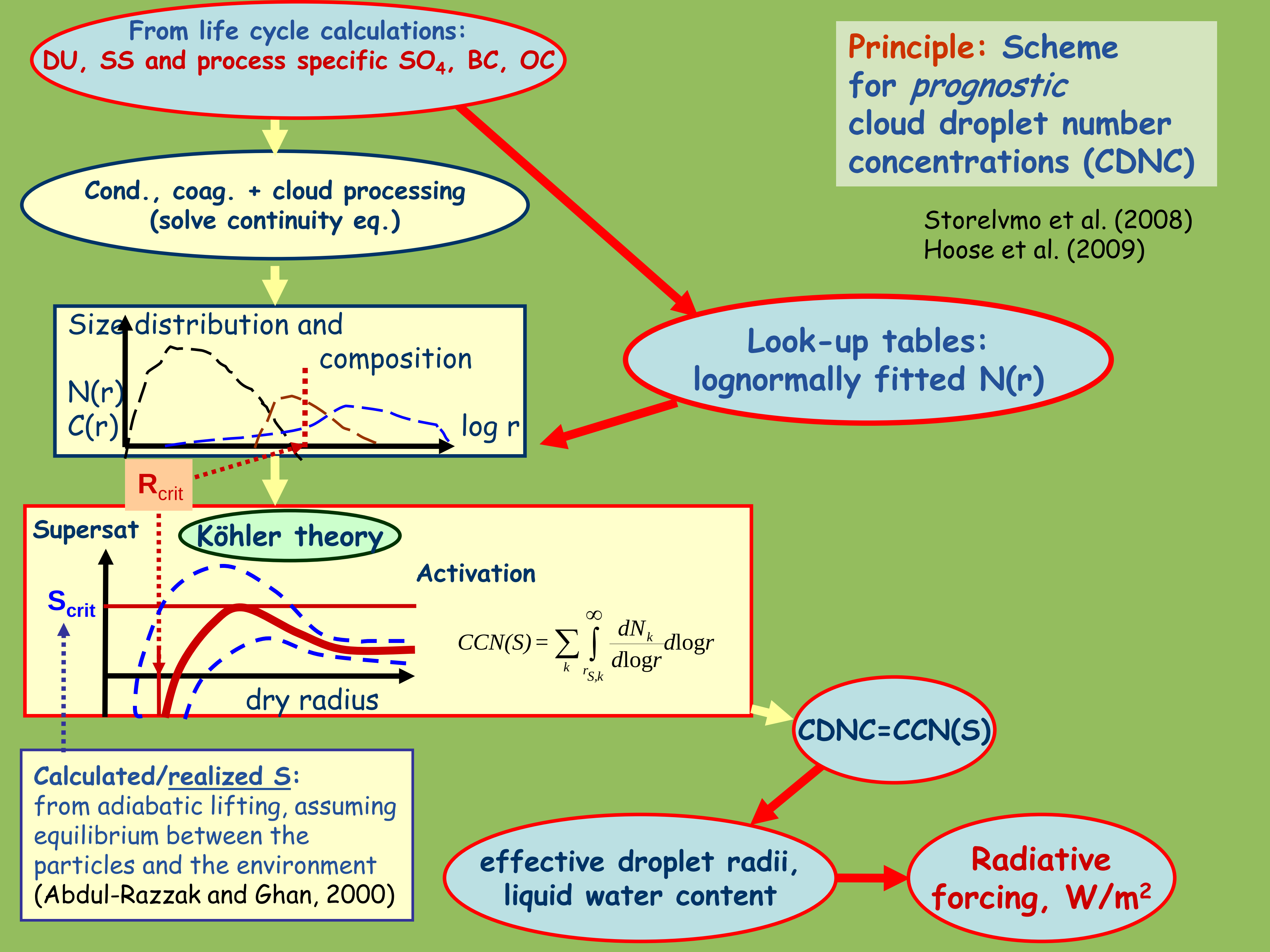
Thank you !

Acknowledgments:
The development of NorESM has been possible because of the granted early access by NCAR to the later public versions of the CCSM4 and CESM1. We are particularly grateful to P. J. Rasch, A. Gettelman, J. F. Lamarque, S. Ghan, M. Vertenstein, B. Eaton, M. Flanner, and others, for invaluable advice on numerous scientific and technical issues, and the support by the CESM program directors during the development period, P. Gent and J. Hurrel.

Principle: Scheme for parameterized optical parameters

Seland et al. (2008)
Kirkevåg et al. (2008)



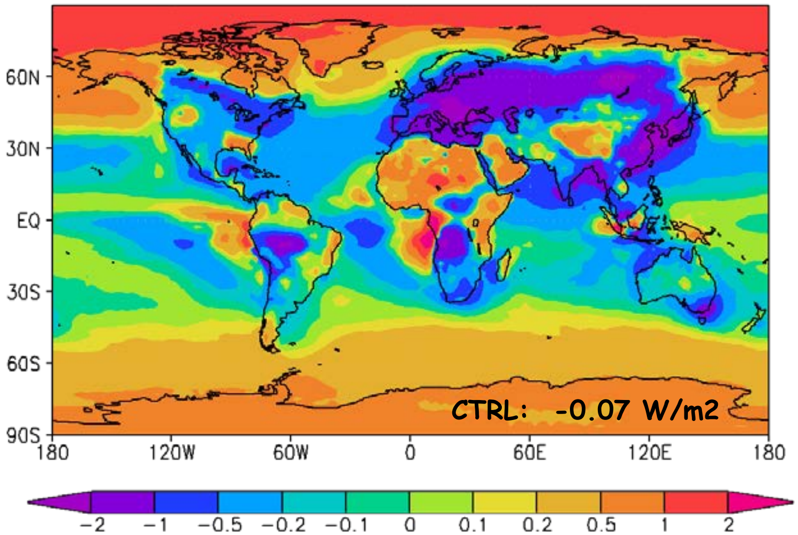


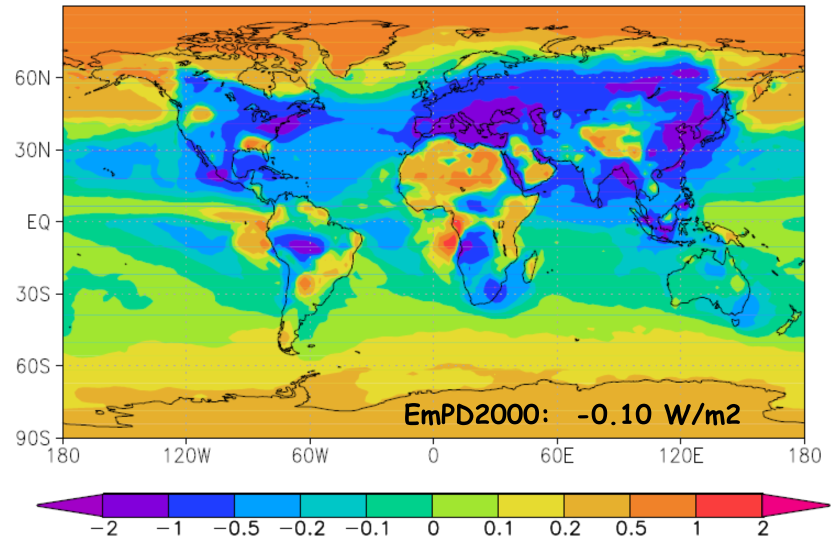
Principle: Scheme for *prognostic* cloud droplet number concentrations (CDNC)
Storelvmo et al. (2008)
Hoose et al. (2009)
From life cycle calculations:
DU, SS and process specific SO_4, BC, OC
Cond., coag. + cloud processing
(solve continuity eq.)
Size distribution and composition
N(r)
C(r)
log r
Look-up tables:
lognormally fitted N(r)
R_{crit}
Supersat
Köhler theory
Activation
S_{crit}
dry radius
$CCN(S) = \sum_k \int_{r_{S,k}}^{\infty} \frac{dN_k}{d\log r} d\log r$
CDNC=CCN(S)
Calculated/realized S:
from adiabatic lifting, assuming equilibrium between the particles and the environment
(Abdul-Razzak and Ghan, 2000)
effective droplet radii, liquid water content
Radiative forcing, W/m^2

AeroCom ←→ **IPCC (CMIP5)**

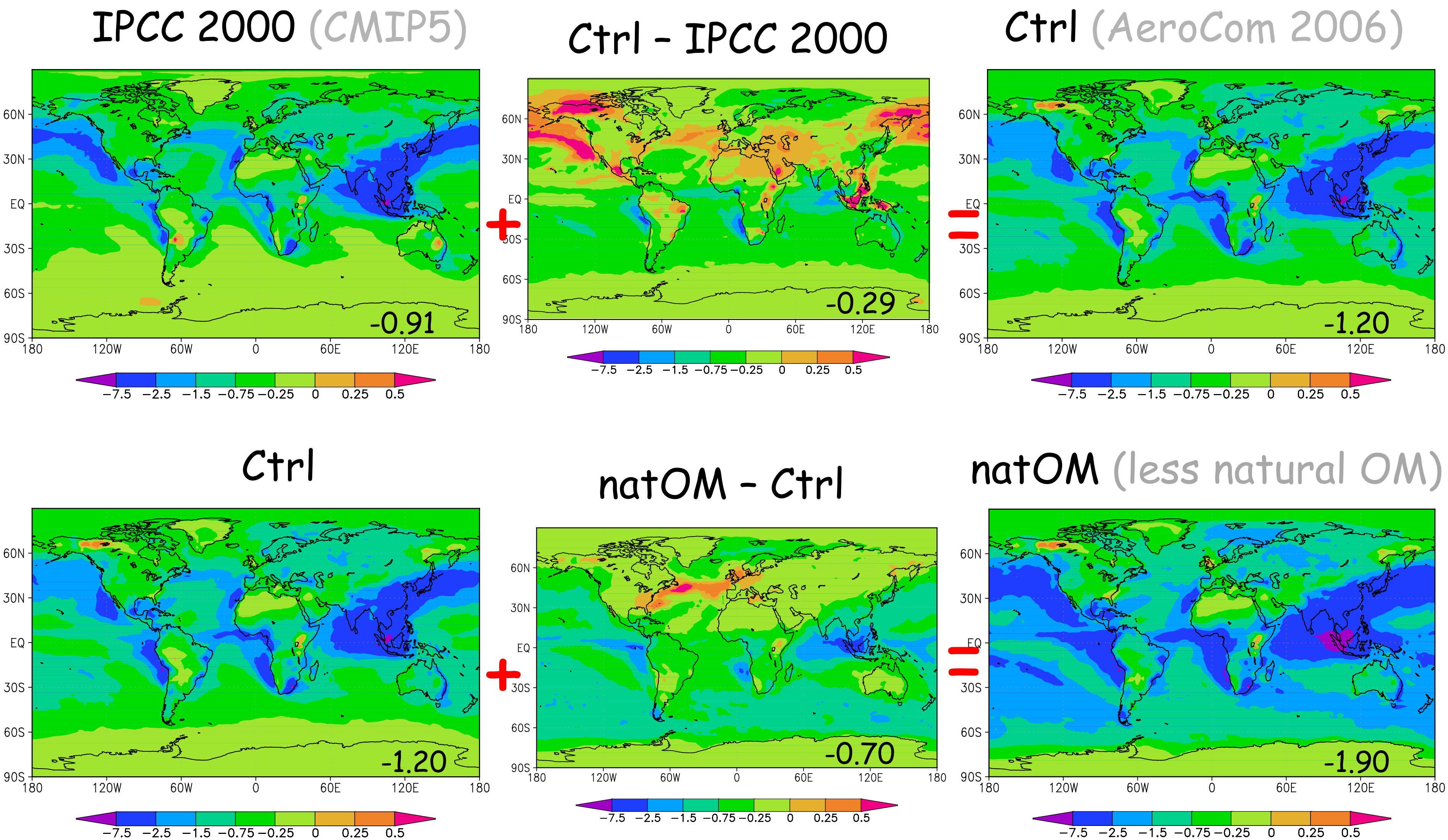
DRF at TOA

Emissions: **2006 - 1850** **2000 - 1850**



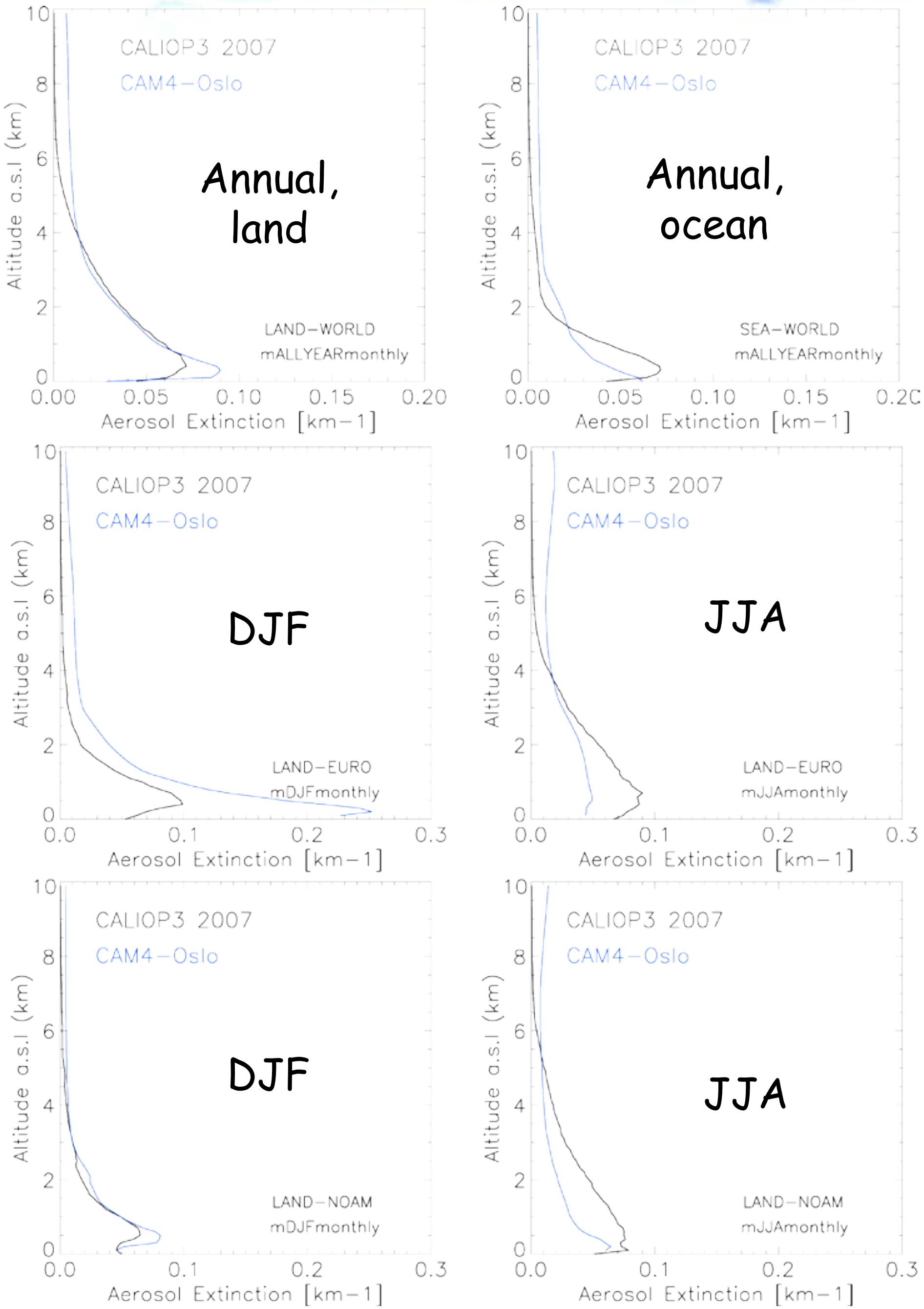


IndRF (W/m2)



IPCC 2000 (CMIP5)
Ctrl - IPCC 2000
Ctrl (AeroCom 2006)
-0.91
+
-0.29
=
-1.20
Ctrl
natOM - Ctrl
natOM (less natural OM)
-1.20
+
-0.70
=
-1.90
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
−7.5 −2.5 −1.5 −0.75 −0.25 0 0.25 0.5

Vertical distribution of aerosol extinction vs. CALIOP lidar



World

Europe, land

N-America, land

http://aerocom.met.no/

Experiment		AOD (550nm)	ABS (550nm)	DRF at TOA (W m^{-2})	DRF at Surface (W m^{-2})	CDNC (870hPa) (cm^{-3})	r_{eff} (870hPa) (μm)	LWP (g m^{-2})	IndRF at TOA (W m^{-2})
Ctrl	PD 2006	0.154	0.00632			52.4	9.41	130.5	
	PI 1850	0.101	0.00264			36.0	9.77	126.6	
	PD – PI	0.0535	0.00369	-0.0724	-1.89	16.4	-0.359	3.93	-1.20
natOM	PD 2006	0.143	0.00615			46.0	9.96	124.9	
	PI 1850	0.090	0.00245			28.3	10.48	119.0	
	PD – PI	0.0529	0.00370	-0.0673	-1.89	17.7	-0.528	5.94	-1.90
natOMocn	PD 2006	0.148	0.00623			48.5	9.85	126.1	
	PI 1850	0.094	0.00254			31.4	10.33	120.8	
	PD – PI	0.0532	0.00369	-0.0706	-1.89	17.0	-0.479	5.25	-1.66
bbPOM	PD 2006	0.142	0.00608			47.8	9.50	129.5	
	PI 1850	0.096	0.00254			32.0	9.87	125.6	
	PD – PI	0.0461	0.00354	+0.0722	-1.68	15.7	-0.370	3.96	-1.20
Struthers 11	PD 2006	0.159	0.00632			52.1	9.43	130.5	
	PI 1850	0.106	0.00264			35.7	9.79	126.5	
	PD – PI	0.0535	0.00369	-0.0694	-1.88	16.4	-0.362	3.94	-1.21
dustscavin	PD 2006	0.143	0.00597			52.5	9.41	130.6	
	PI 1850	0.089	0.00235			35.7	9.78	126.5	
	PD – PI	0.0536	0.00362	-0.103	-1.89	16.8	-0.372	4.06	-1.23
cldtunorig	PD 2006	0.147	0.00603			51.1	8.92	100.0	
	PI 1850	0.096	0.00255			35.2	9.25	97.9	
	PD – PI	0.0500	0.00351	-0.0855	-1.81	15.9	-0.330	3.09	-1.28
gravdep2d	PD 2006	0.168	0.00683			52.0	9.44	130.2	
	PI 1850	0.113	0.00298			35.6	9.80	126.3	
	PD – PI	0.0544	0.00385	-0.0263	-1.93	16.4	-0.364	3.96	-1.21
convmix	PD 2006	0.132	0.00518			53.4	9.40	129.1	
	PI 1850	0.089	0.00229			37.0	9.74	125.4	
	PD – PI	0.0429	0.00289	-0.0972	-1.48	16.5	-0.340	3.67	-1.15

Experiment		AOD (550nm)	ABS (550nm)	DRF at TOA (W m^{-2})	DRF at Surface (W m^{-2})	CDNC (870hPa) (cm^{-3})	r_{eff} (870hPa) (μm)	LWP (g m^{-2})	IndRF at TOA (W m^{-2})
noBCac	PD 2006	0.153	0.00585			52.4	9.41	130.4	
	PI 1850	0.101	0.00257			36.0	9.77	126.6	
	PD – PI	0.0529	0.00329	-0.164	-1.78	16.4	-0.358	3.91	-1.20
replH2O2	PD 2006	0.154	0.00632			52.3	9.41	130.4	
	PI 1850	0.100	0.00264			35.9	9.77	126.6	
	PD – PI	0.0534	0.00368	-0.0703	-1.88	16.4	-0.356	3.87	-1.19
no coating	PD 2006	0.154	0.00632			48.4	9.44	130.1	
	PI 1850	0.101	0.00264			31.2	9.87	125.5	
	PD – PI	0.0535	0.00369	-0.0724	-1.89	17.3	-0.426	4.52	-1.31
prescrβ	PD 2006	0.154	0.00632			52.4	9.14	130.5	
	PI 1850	0.101	0.00264			36.0	9.57	126.6	
	PD – PI	0.0535	0.00369	-0.0724	-1.89	16.4	-0.425	3.93	-1.34
Em-PD2000	PD 2000	0.135	0.00460			48.3	9.47	129.7	
	PI 1850	0.101	0.00264			36.0	9.77	126.6	
	PD – PI	0.0346	0.00197	-0.0997	-1.04	12.3	-0.296	3.10	-0.908
Em-PI1750	PD 2006	0.154	0.00632			52.4	9.41	130.5	
	PI 1750	0.095	0.00193			32.1	9.90	125.3	
	PD – PI	0.0589	0.00438	-0.0416	-2.20	20.3	-0.488	5.20	-1.53
Em PD2000 & EmPI1750	PD 2000	0.135	0.00460			48.3	9.47	129.7	
	PI 1750	0.095	0.00193			32.1	9.90	125.3	
	PD – PI	0.0399	0.00267	-0.0689	-1.36	16.1	-0.425	4.37	-1.23
Online	PD 2006	0.151	0.00725			49.0	9.50	130.3	
	PI 1850	0.092	0.00247			34.6	9.86	124.4	
	PD – PI	0.0588	0.00478	--	--	13.4	-0.342	5.89	--