Black carbon and climate warming

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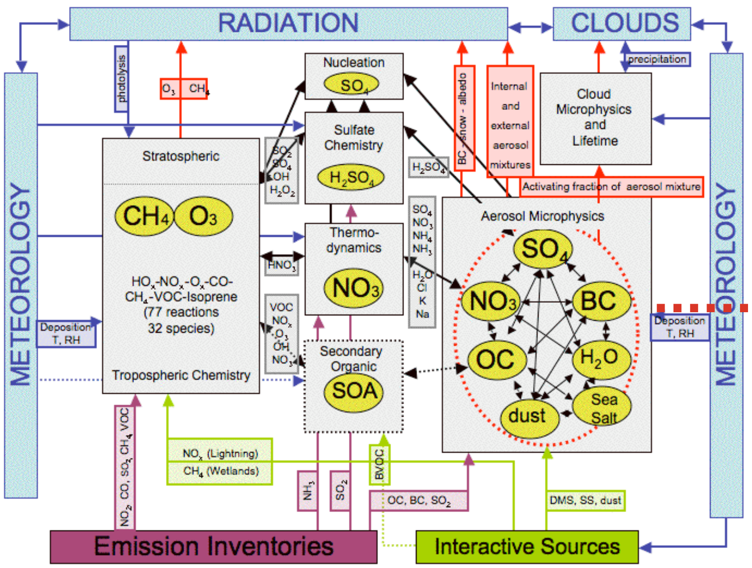
Overview

Microphysical GISS model:

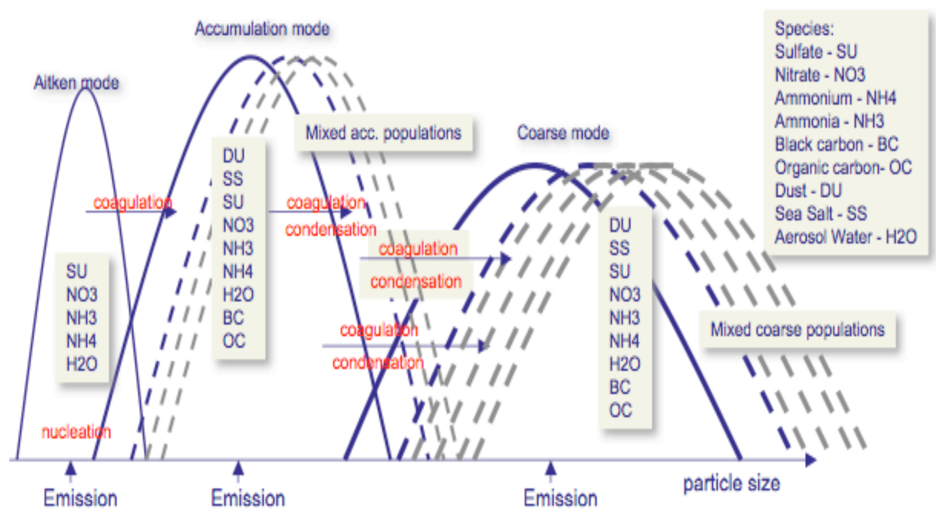
1. Forcing Results
2. Coagulation
3. Sensitivity towards particle size distributions
4. BC reduction experiments

Atmospheric Gas and Aerosol-phase Model as Part of the GISS Earth System Model



MATRIX

Aerosol Microphysical Model based on the Methods of Moments
Bauer et al. ACP 2008



Droplet activation: Adbul Razzak and Ghan (1998, 2000)
Cloud droplet nucleation follows prognostic treatment of Morrison et 2005, 2008

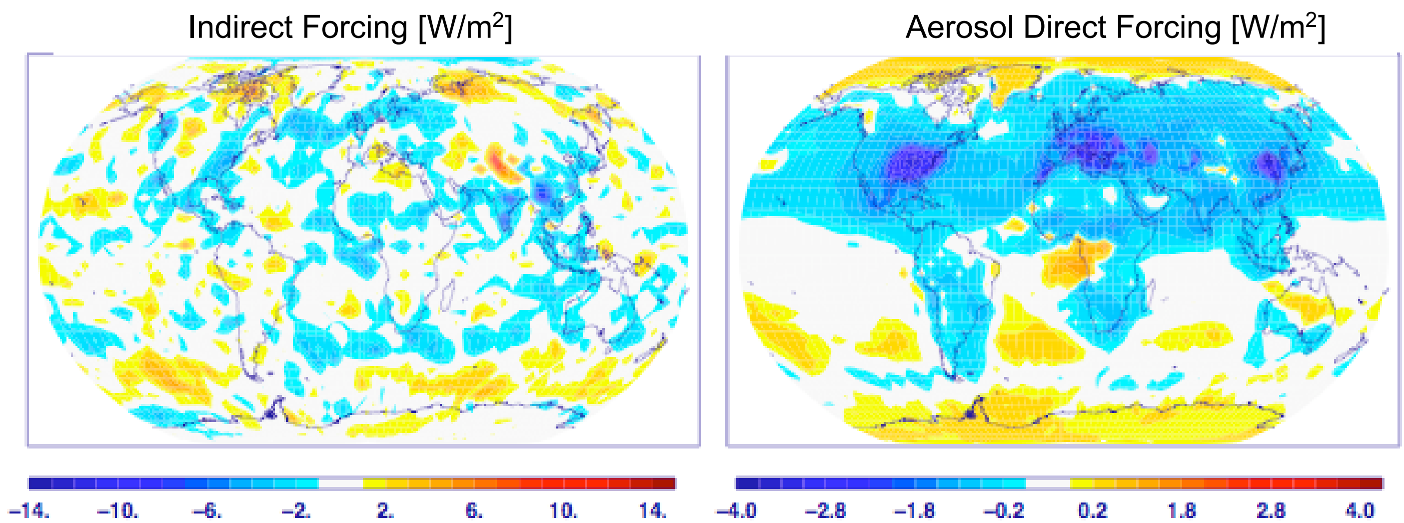
Aerosol Microphysics:

- Simulation of aerosol mass, mixing state and size distributions (1). Needed for:
- **Indirect effects**: Microphysical parameter. of aerosol - cloud activation (1,2)
- **Direct effects**: Radiation scheme coupled to aerosol shape and mixing state information (3)

1) Bauer et al., Atmos. Chem. Phys. 8, 6603-6635, 2008
2) Menon et al., Atmos. Chem. Phys, to be submitted
3) Bauer et al., Atmos. Chem. Phys, to be submitted

Pre-industrial to present-day

Radiative Forcing changes 1750 to 2000

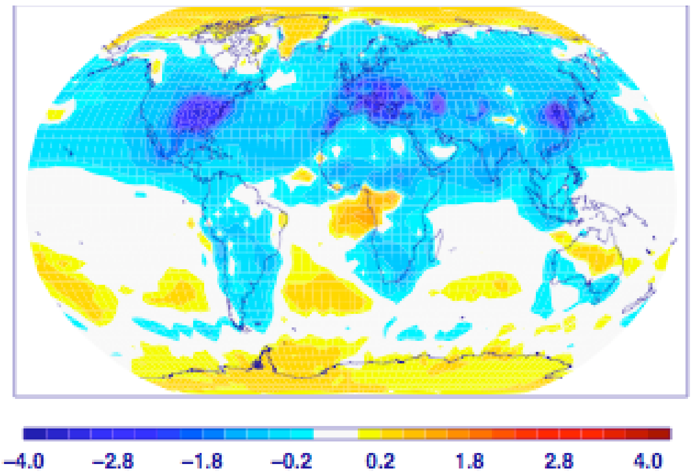


Indirect effect: -0.19 W/m^2
Direct effect: -0.27 W/m^2
Net Rad. change: -0.46 W/m^2

Pre-industrial to present-day

Radiative Forcing changes 1750 to 2000

Aerosol Forcing [W/m²]



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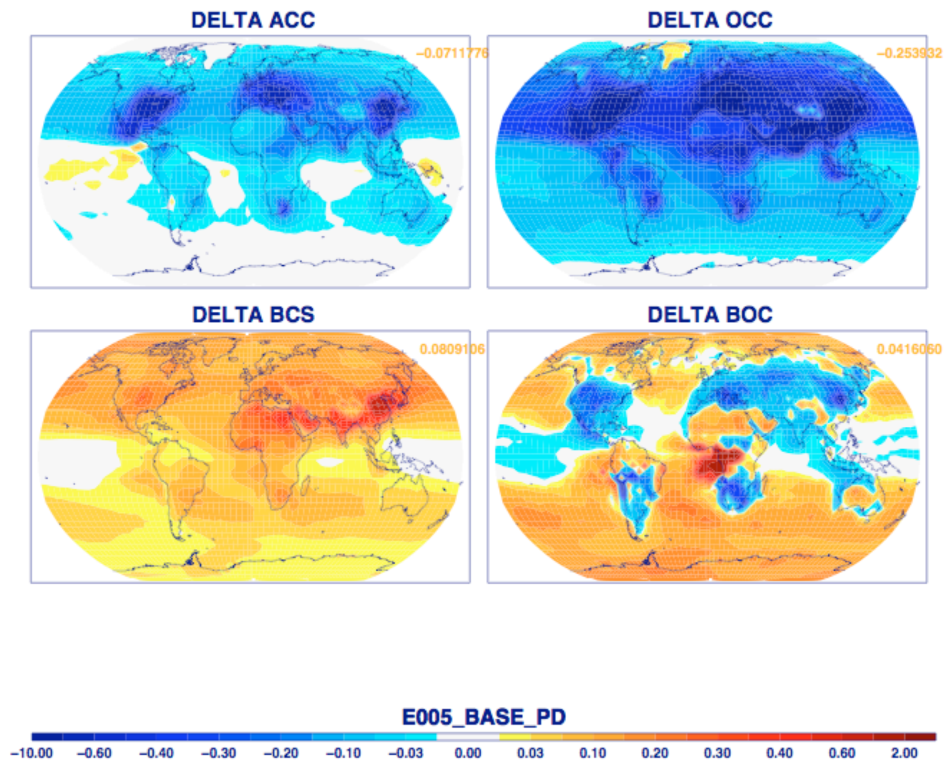
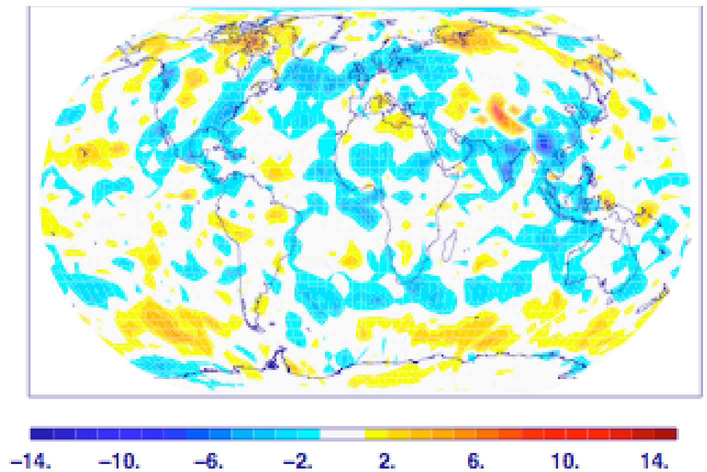
Radiative Forcing changes by species



Pre-industrial to present-day

Radiative Forcing changes 1750 to 2000

Indirect effect [W/m²]



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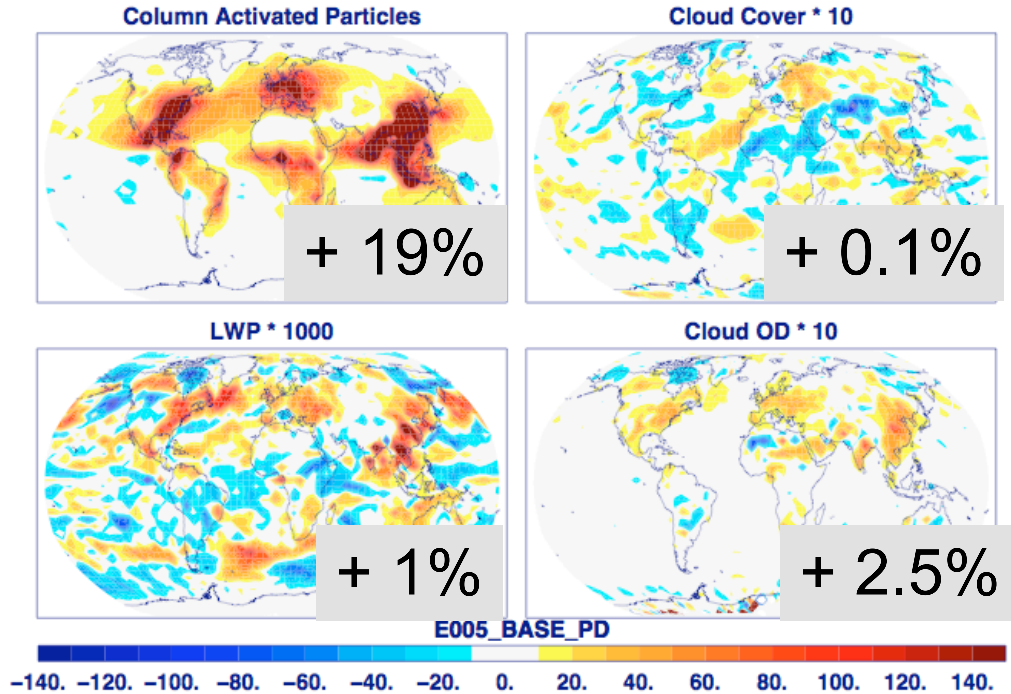


CRF is calculated from changes to the net cloud forcing obtained from differences between total and clear skies for each call to the radiation.
IE is calculated from the differences to the net TOA forcings

Summary

Radiative forcing smaller then in previous simulations!

MATRIX model: -0.46 (-0.27 ADE, -0.19 IE) W/m^2

Mass based GISS model: -0.94 (-0.15 ADE, -0.74 IE) W/m^2

- Direct Aerosol Forcing smaller due to stronger absorbing BC, less cooling sulfate as more present in internal mixtures

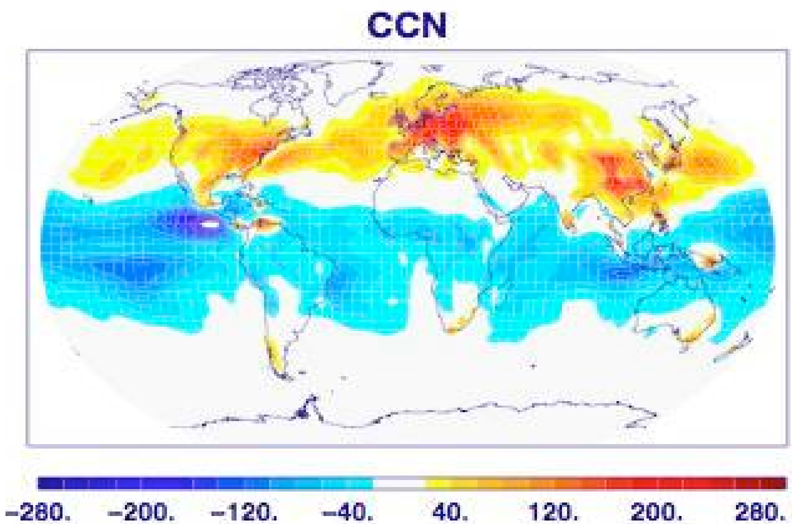
- Aerosol indirect effect reduced due to less CDNC.

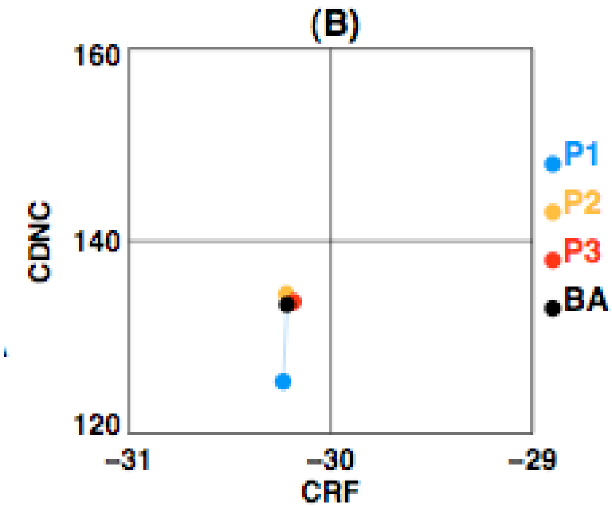
  CDNCs are reduced by more them 50% compared to the mass based GISS model, where aerosol mass is converted to aerosol number (Na) following *Lohmann et al. [2000].*

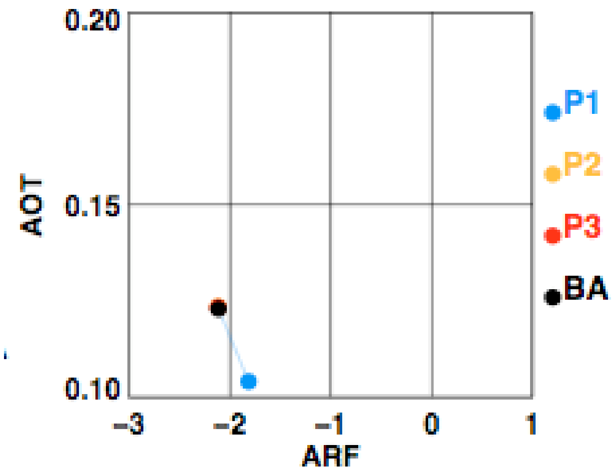
Coagulation

BA: all coagulation processes active
P1: no coagulation
P3: no coagulation btw. dry insoluble particles

Change in CCN concentrations BA - P1







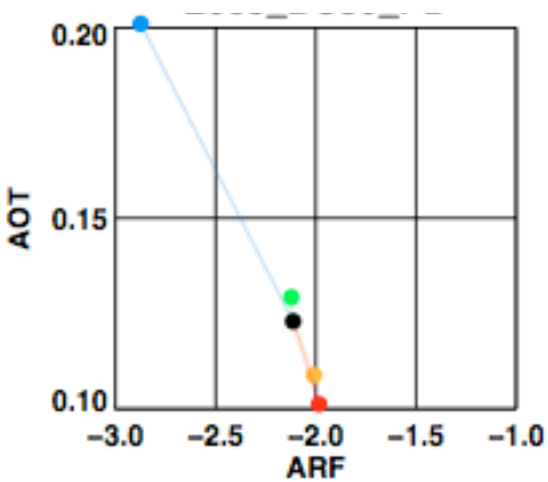
W/m^2

• P1: Increases CCN production from sulfate aerosols, and decrease production form carbonaceous particles. This is caused by more externally mixed sulfate in the NH mid-latitudes, and less sulfate coating, hence more externally mixed BC/OC particles in the tropical regions

BC/OC Particle Emission Size

Emission sizes of carbonaceous aerosols. Particle geometric mean diameters in [μm].

	OC [OCC] Fossil & biofuel	BC [BC1] fossil &biofuel	BC-OC [BOC] Biomass burning
BA	0.1	0.1	0.25
S1	0.01	0.01	0.025
S2	0.06	0.06	0.12
S3	0.2	0.2	0.5
S4	0.5	0.5	1



W/m^2

Direct Aerosol Forcing changes Yr 2000

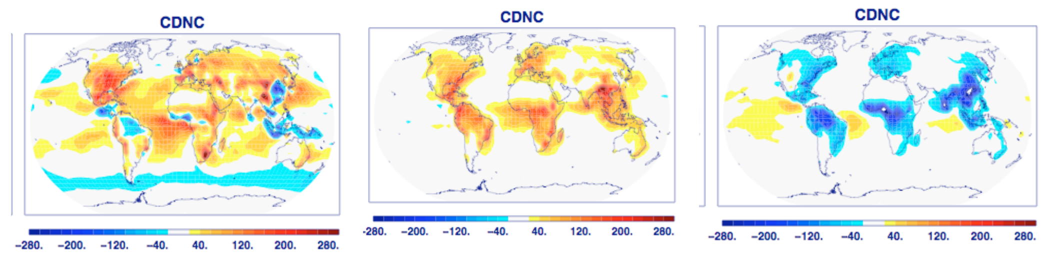
S1,S2: smaller BC/OC particles: enhanced mixing → stronger BC forcing (+ ARF over land), but coarse aerosol dominates cooling effect over the oceans (S1 enhanced mixing of pollution and coarse aerosols) → globally - ARF

S3,S4: larger BC/OC particles: reduced mixing → positive ARF

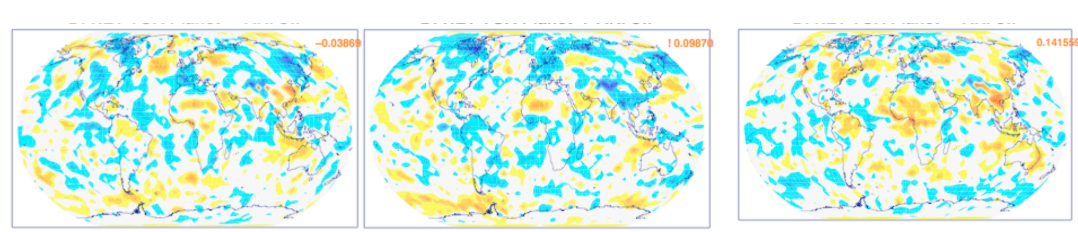
BC/OC Particle Emission Size

Aerosol Indirect Radiative Forcing (Yr 2000)

	S1 smaller	S2 smaller	S3 larger
CDNC	+15% 23 cm^{-3}	+15% 23 cm^{-3}	-8% -10cm^{-3}
LWP	+0.15% 0.001 kg/m2	+0.3% 0.02kg/m^2	-0.7% -0.005kg/m^2
Cloud cover	+0.34%	+0.1%	-0.1%
Cloud OD	+0.43% 0.05	+1.3% 0.2	-1.5% -0.2
IE	-8% -0.04 W/m^2	-25% -0.1 W/m^2	+22% 0.14 W/m^2



S1 smaller	S2 smaller	S3 larger

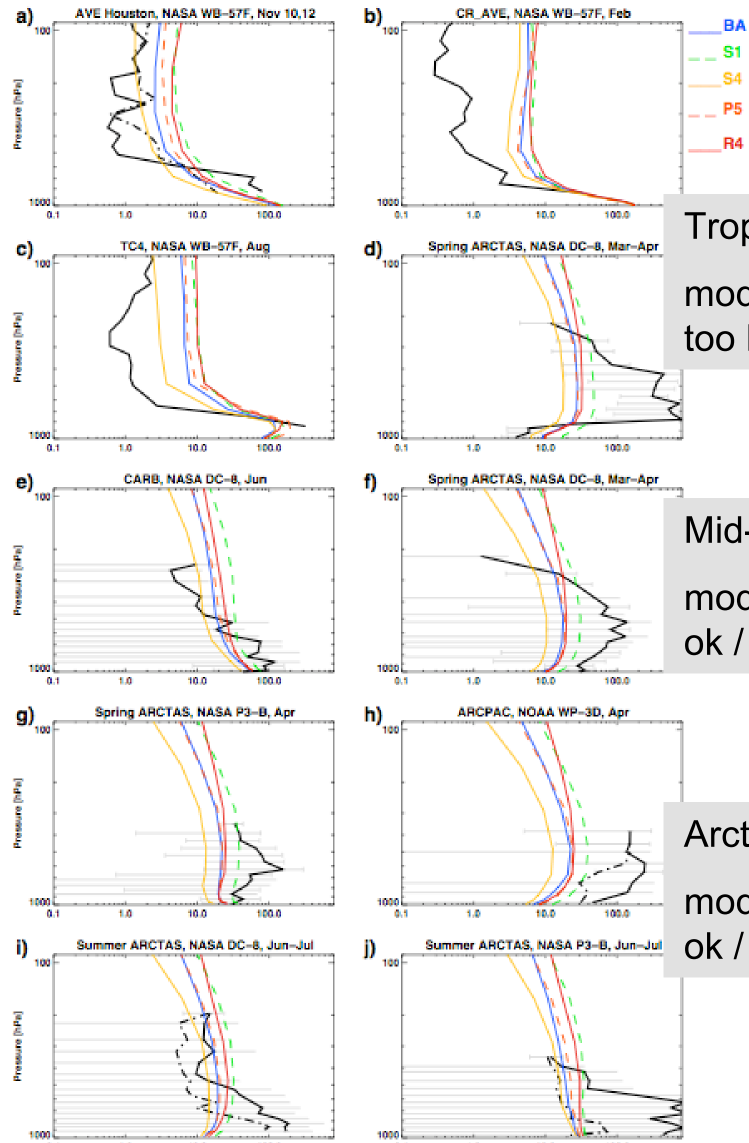


% and absolute differences rel. BASE

S1, S2 - similar CDNC changes lead to very different IE → regional differences and semi - direct effects

BC Mass, AOT and AAOT evaluation

	EMEP		IMPROVE		AERONET			
	BC mass at surface [μg/m³]				AAOT		AOT	
	r	M	r	M	r	M	r	M
Observation		**0.65**		**0.29**		**0.018**		**0.19**
BASE	0.22	0.37	0.53	0.14	0.49	0.012	0.62	0.16
S1	0.18	0.44	0.55	0.16	0.50	0.019	0.58	0.19
S2	0.18	0.41	0.55	0.15	0.50	0.013	0.61	0.17
S3	0.20	0.35	0.48	0.13	0.47	0.011	0.60	0.14
S4	0.20	0.30	0.45	0.11	0.45	0.010	0.57	0.13



Tropics:

model: too high

Mid-lat.:

model: ok / low

Arctic:

model: ok / low

- BC mass too low at surface
- Vertical profiles:

Too much BC in the tropics, ok/low in mid latitudes and Arctic.

- Best results for smallest OC/BC emission sizes, 0.01 μm
- AOT and AAOT excellent for S1

Koch ACPD 2009: *(previous generation of AeroCom models: without aerosol microphysics)*

- AAOT generally underestimated
- BC surface mass better simulated

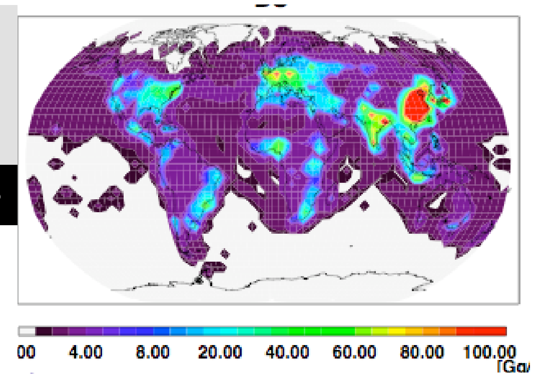
Summary

- BC / OC size distribution and mixing state information are crucial and those information need to be included in emission inventories.
- Project with Tami Bond and Nicole Riemer to develop such a module:

‘Bridging the last few kilometers: Accounting for subgrid mixing and spatial gradients in global aerosol models’

BC Mitigation

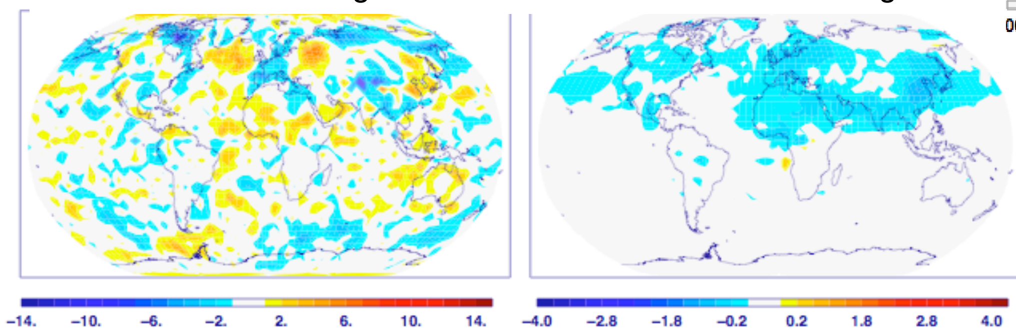
Reduction of 50% BC emissions from fossil fuel and bio fuel sources



IE:	0.03
ARF:	-0.06
NR:	-0.03

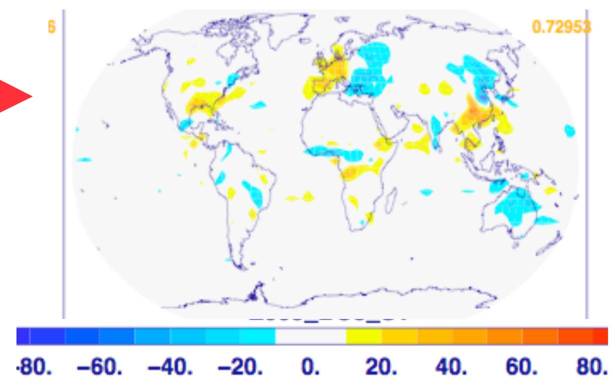
Change in Radiative Forcings [W/m^2]:

Cloud Forcing | Aerosol Forcing



CDNC: 0.5%
LWP: -0.4%
Cloud Cover: -0.1%
Cloud τ: -0.3 %
IE: 5 %

CDNC (BC50 - BASE)



Why does CDNC globally increase when BC emissions are reduced by 50%?

- less internally mixed BC-sulfate particles
- increase in the number concentrations of externally mixed sulfate particles
- pure sulfate very efficient CDNC

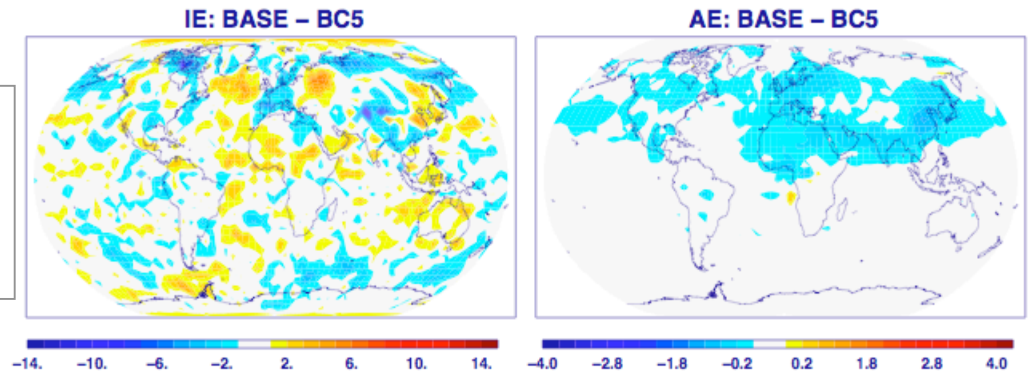
BC bio - fuel mitigation

Change in Radiative Forcings [W/m²]:

Cloud Forcing   Aerosol Forcing

BASE:

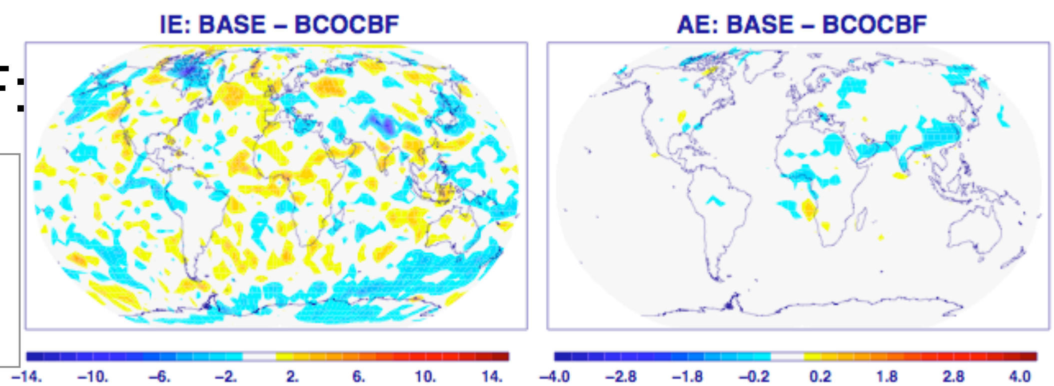
CRF: 0.03
ARF: -0.06
NR: -0.03



Reduction of BC and OC emissions from biofuel sources by 50%:

BC-OCBF:

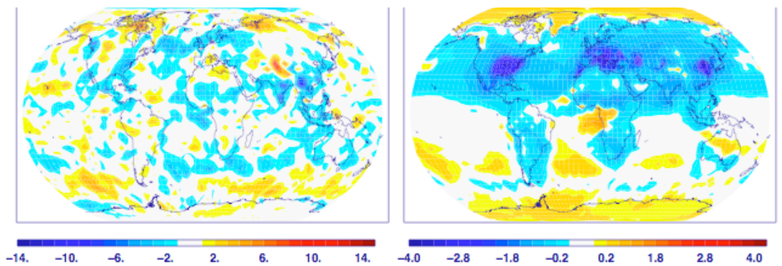
CRF: 0.00
ARF: -0.01
NR: -0.01



Black Carbon Mitigation Studies

Radiative Forcing changes 1750 to 2000

Cloud Forcing | Aerosol Forcing [W/m^2]



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Black Carbon Mitigation Scenarios:

(Forcing numbers show differences in respect to the Pre-industrial to Present day changes)

50 % of fossil and bio-fuel BC reductions (BASE)	Net Rad: -0.03 W/m^2
50 % of bio-fuel BC and OC reductions (BASE)	Net Rad: 0.0 W/m^2
50 % of fossil and bio-fuel BC reductions (smaller BC, S1)	Net Rad: -0.29 W/m^2

Summary

Benefits of BC mitigation highly depended on the microphysical characteristics of aerosols.

BC reduction always leads to less climate warming (due to the very small impact of the indirect effect), however the impact can range from insignificant to up to 50 % aerosol forcing reduction depending on the size and mixing state of BC particles.

(Aerosol - ice cloud interactions (cooling) and BC - snow albedo feedbacks (warming) were not included in this study)

Controlling only bio-fuel sources, due to the reduction of black and organic carbon, will have no beneficial climate impacts.

More modeling studies are planned within the AEROCOM project.

Conclusions

1) Anthropogenic Aerosol Forcing -0.46 W/m^2 (ADE: -0.27 IE: -0.19) smaller then in previous mass based model -0.94 W/m^2 (-0.15 ADE, -0.74 IE)

   S2 (0.06 µm) -0.22 W/m^2 (ADE: -0.09 IE: -0.13)

   S1 (0.01 µm) -0.47 W/m^2 (ADE: -0.21 IE: -0.26)

2) 'Mechanically' calculated coagulation works fine on the global scale, as insoluble aerosols mix strongly with soluble species.

3) Size and mixing state information must be included in emission inventories.

4) Success of BC mitigation, depends strongly on the carbonaceous particle size distributions and mixing state.

   Observations of those quantities are needed.

We acknowledge funding by the NASA MAP program