The Role of Soot Particles in the Climate System: Progress and Uncertainties in Modeling

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Aerosol and Climate:

HOTTER OR COOLER?

J. Gribbin, Nature, 1975

„the net climatological effect of industrial smoke could well be to heat and not to cool the earth"

Charlson and Pilat, 1969

In the 1990es cooling due to sulfate aerosol

change of the paradigm from the 1990es to the 2000es

aerosol warming due to black carbon

Press releases

•reducing soot emissions will slow global warming faster than will reducing carbon dioxide

• *one of the leading causes of rising world temperatures -- soot*

• diesel soot major global warming factor

• *black soot may be (is) responsible for 25 (50) % of observed global warming over the past century.*

Outline

- Hotter or Cooler?
- Impact of smoke on the aerosol population
- Mechanisms of climate impact
- Impact on climate – uncertainties
- Improvements

Analyses of cloud reflectance retrievals from AVHRR data over Central Europe shows that

- **in winter: soot-regime**

  decrease in cloud reflectance by 5% due to the semi-direct effect

- **in summer: sulfate-regime**

  when SO_2 oxidation is more efficient, the Twomey effect dominates

Krüger and Grassl, GRL, 2002

Equilibrium climate simulations

Model setup

- atmospheric GCM ECHAM4-T31

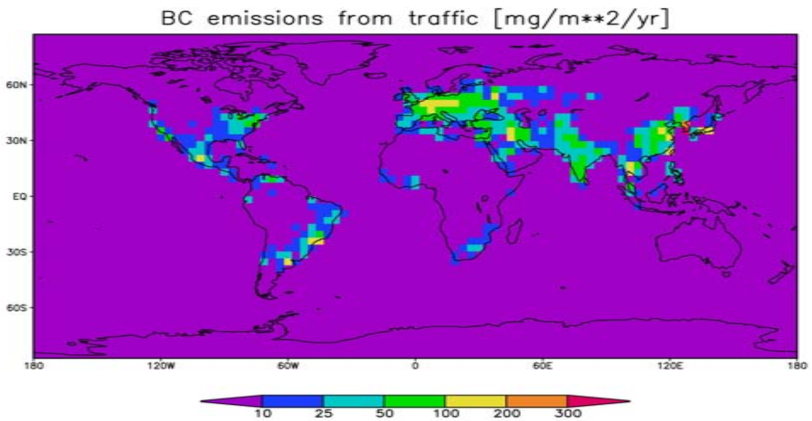
  including

  - Sulfur chemistry
  - Aerosol physics
    - compounds: sulfate, BC, OC (primary), seasalt and dust
    - external mixture
    - direct, warm indirect and semi-direct effects

25 years integration to reach equilibrium

further 50 year integration to obtain robust statistics

changes due to BC from car traffic

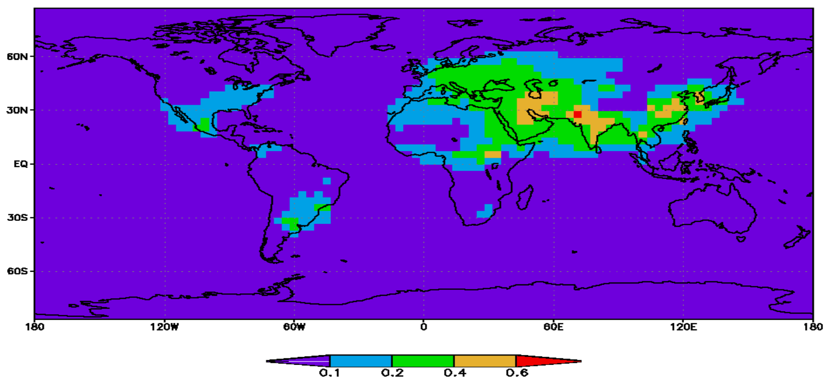


50-year average

emissions:
1.8 Tg C yr^{-1}

car traffic emissions ~ 12%

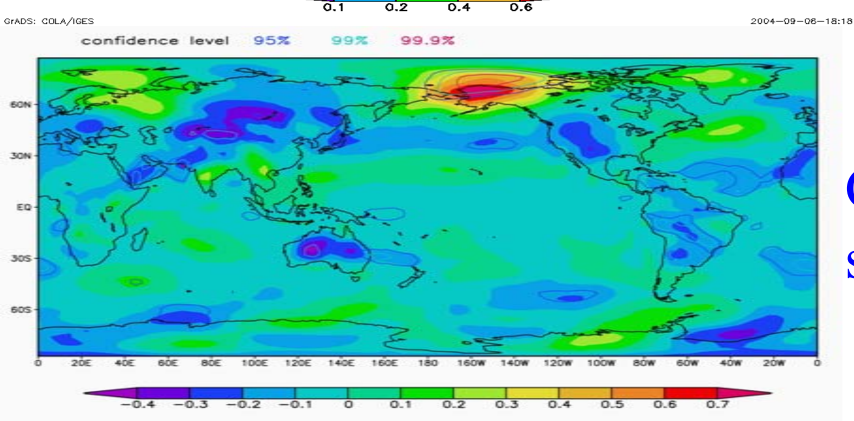
of total BC emissions



burden

0.03 Tg C

absorption in the
atmosphere 0.13 W/m^2



Change in
surf temp

+0.04 K

Note:

temperature response
is not significant

Extrapolation from traffic BC to total anthropogenic BC emissions (assuming linearity):

---------→>

absorption

Current work ~ $1.08\ W/m^2$ $\Delta T \sim +0.3\ K$

Koch et al. $0.91\ W/m^2$

Chin et al. $1.05\ W/m^2$

But

the response due to all anthropogenic aerosol emissions

is a cooling of –0.9 K

Model simulations show that BC may promote the GHG warming

BUT

- combustion aerosol does not consist of pure BC; combustion processes emit a multitude of primary particles, condensable species and greenhouse gases.
- the overall effect of combustion aerosol emissions from fossil fuel and biomass burning is a cooling

Combustion Aerosol (Smoke)

Product of combustion consisting of internal and external mixed aerosol with organic and inorganic components and elemental carbon

- small BC particles from the vapor phase
- larger particles from charring

Adding smoke to an existing aerosol population changes

size distribution and hygroscopicity

„a complete conceptual separation of elemental carbon and organic compounds is not possible“

Jacobson et al., Rev Geophys., 2000

„What is the climate impact of elemental carbon?“

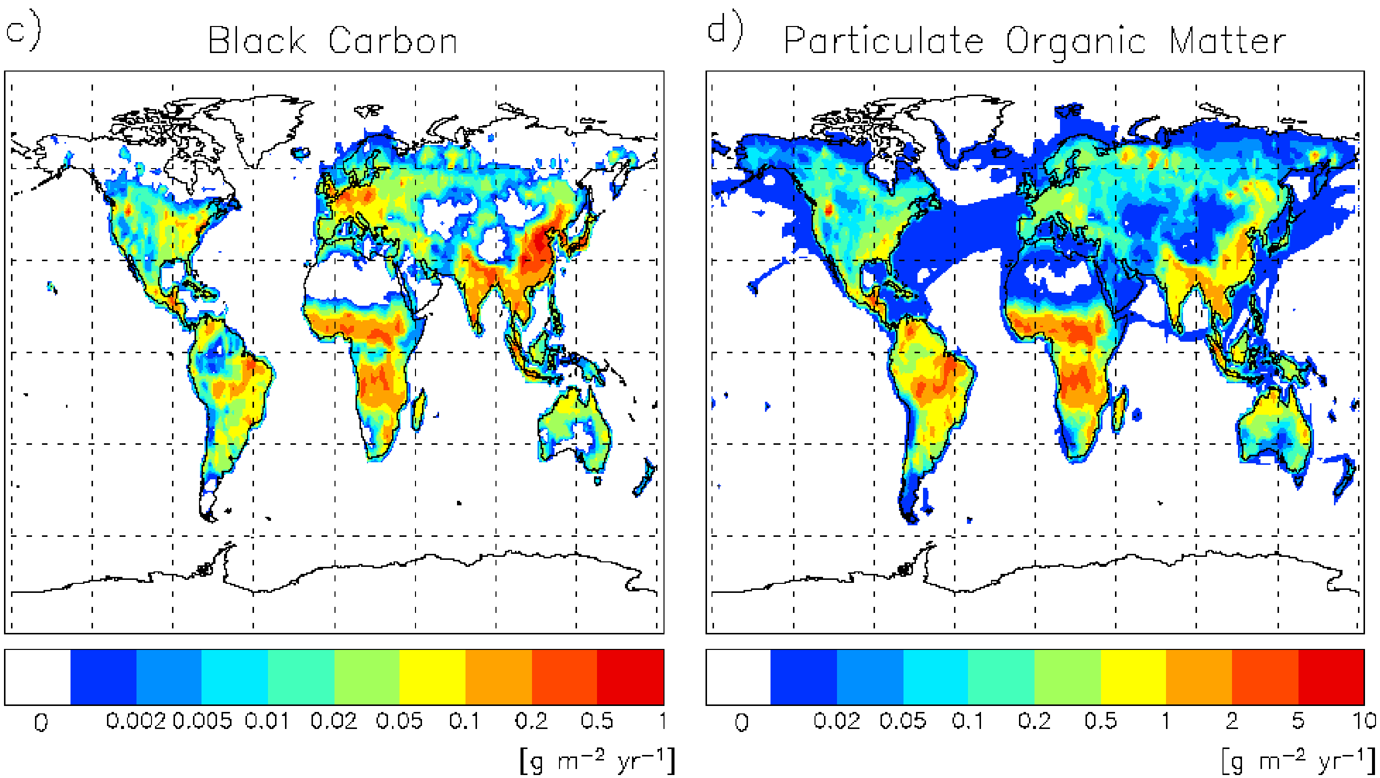
is not the right question

We have to raise the question:

How does the addition of combustion aerosol influence the existing aerosol population?

AeroCom year 2000 emission inventory

Dentener et al, in prep



Vegetation fires

Van der Werf et al., 2003

BC	3.0 Tg C/yr
POM	34.7 TgC/yr

Fossil fuel&biofuel

Bond et al., 2004

BC	4.7 Tg C/yr
POM	12.5 TgC/yr

source dependent specification of mixture and size distribution

is still missing!!

Biogenic

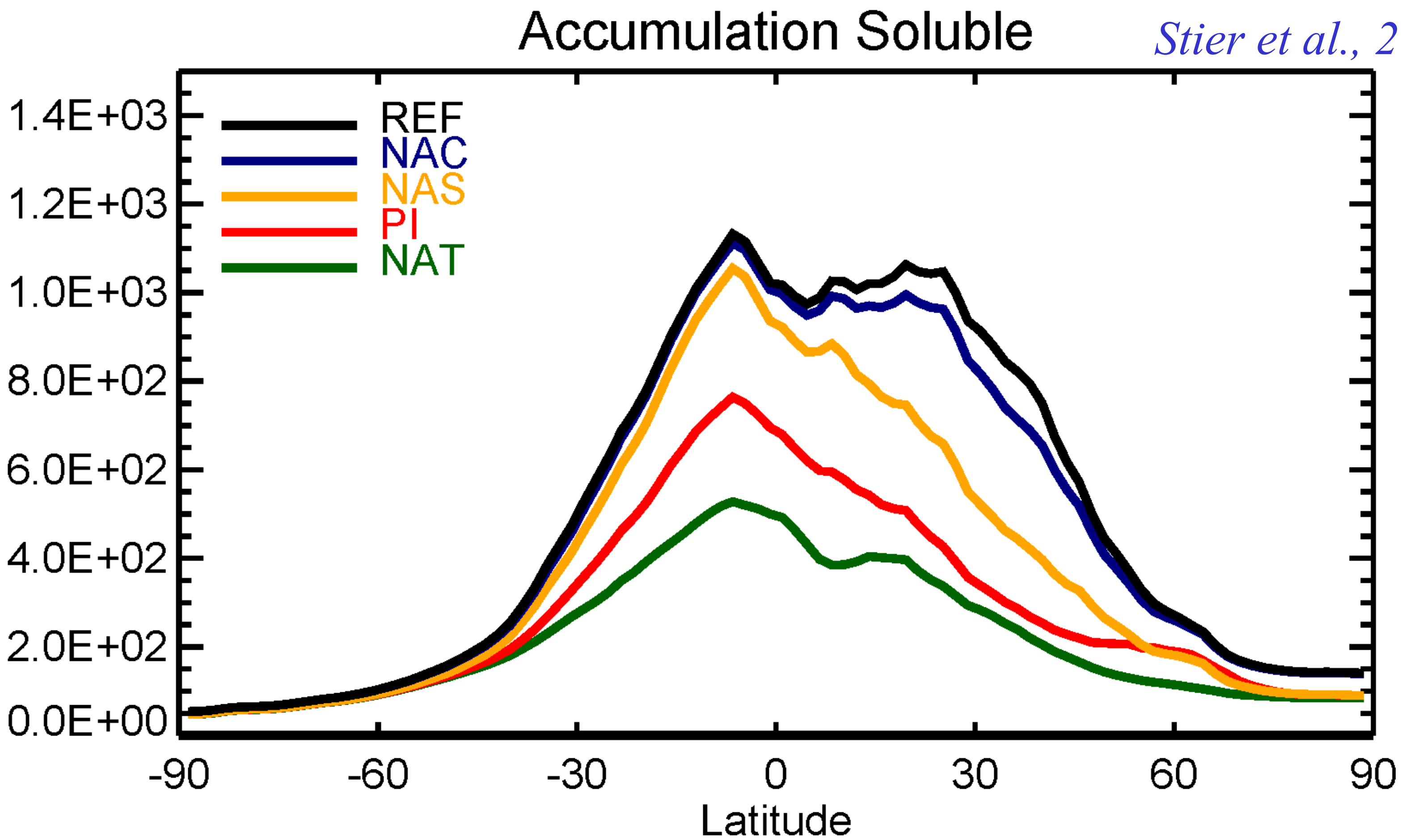
Guenther et al., 1995

POM	19.1 Tg C/yr

Model calculated number concentrations 10^9N [m^{-2}]

ECHAM5-HAM

Stier et al., 2004 ACPD

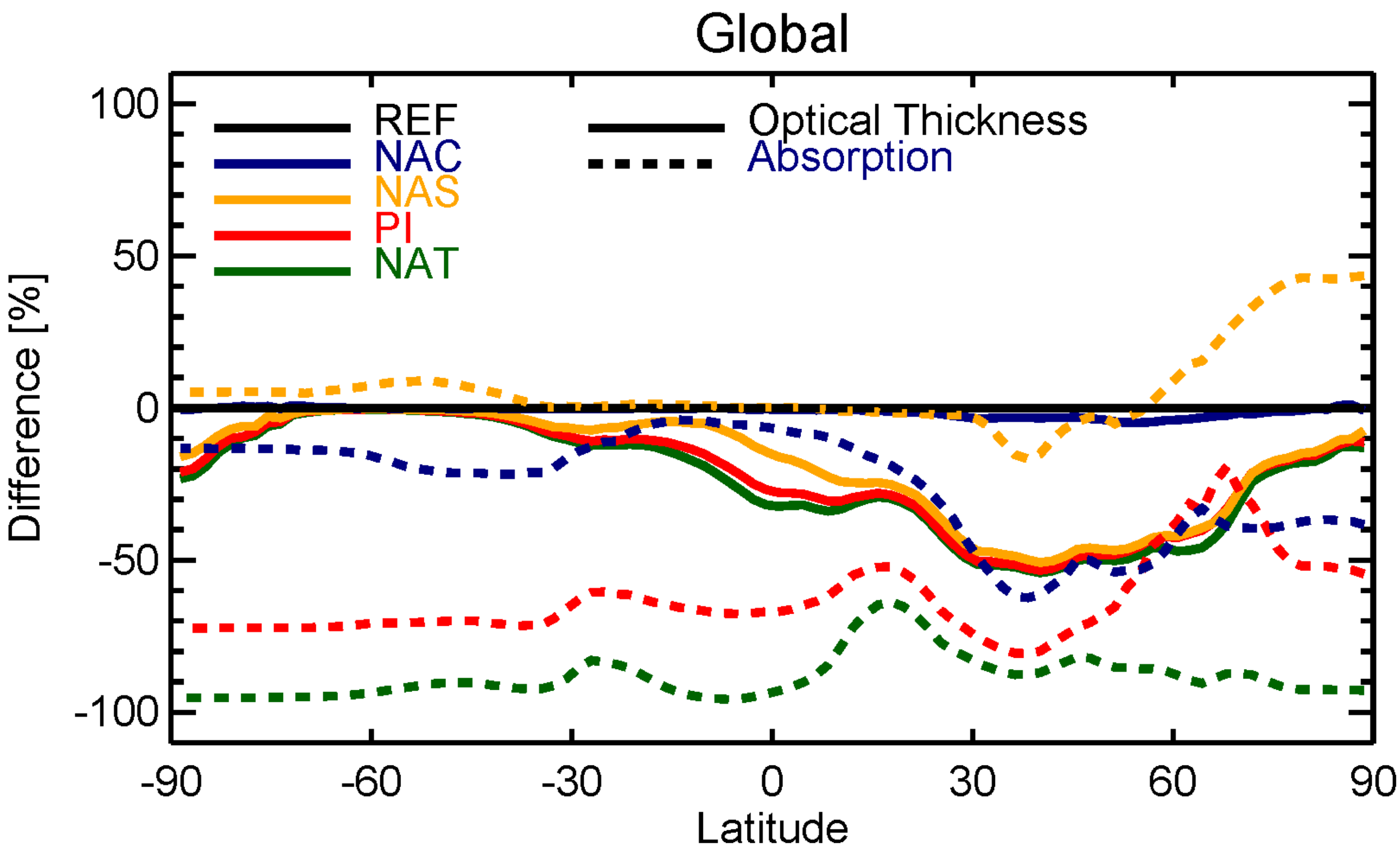


NAC ... no BC/OC from fossil fuel

NAT ... natural emissions only

NAS ... no anthrop. SO2 emission

PI ... yr 1750 emissions



NAC ... no BC/OC from fossil fuel

NAS ... no anthrop. SO2 emission

NAT ... natural emissions only

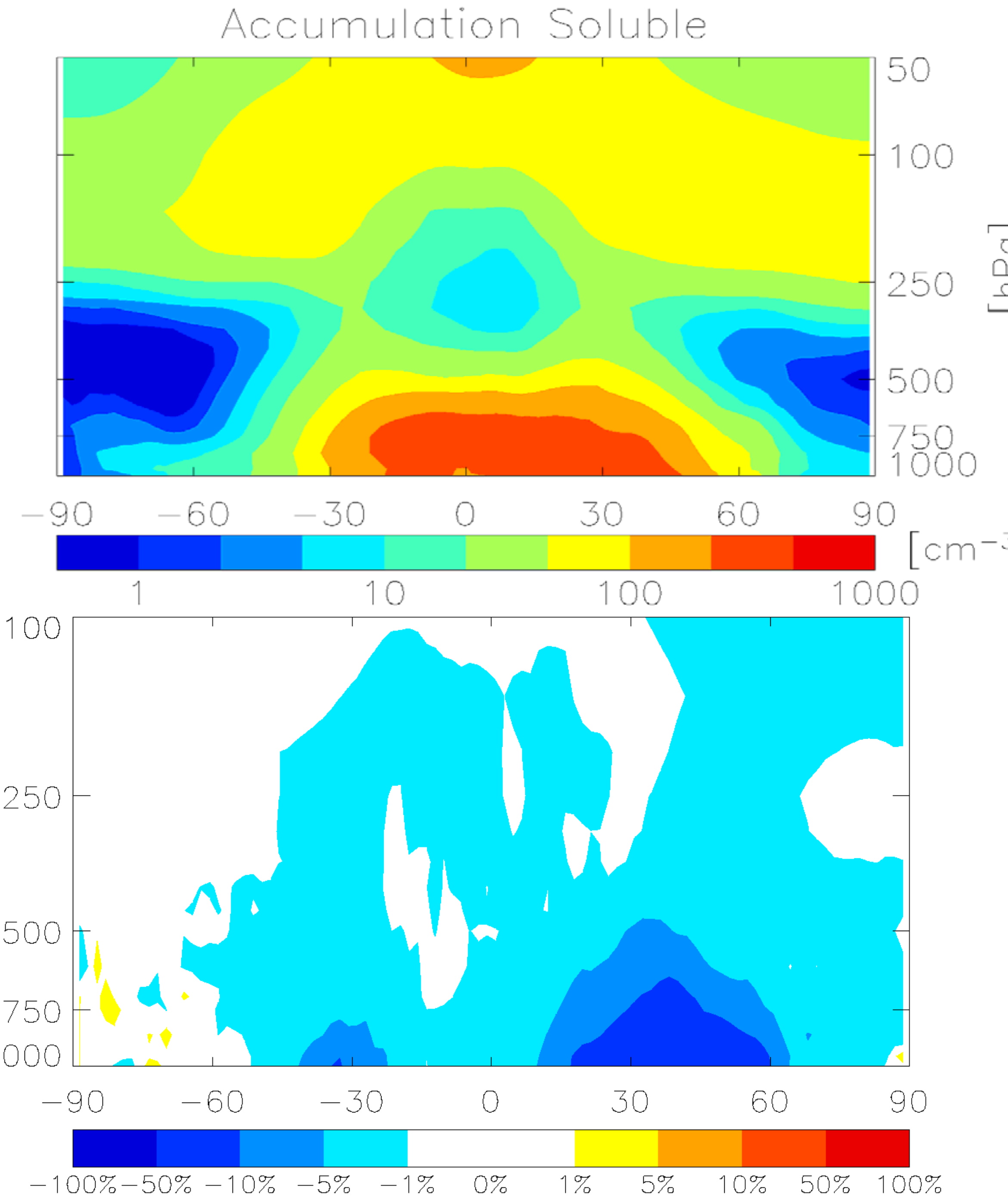
PI ... yr 1750 emissions

switch off ff BC&OC emissions ~

3 resp 4 TgC/yr

= less than 7% of total anthropogenic emission mass

10-50% decrease in particle number conc.



Direct Effect

direct forcing estimates has become

less negative since IPCC, 2001

- despite more BC warming still **overall cooling**

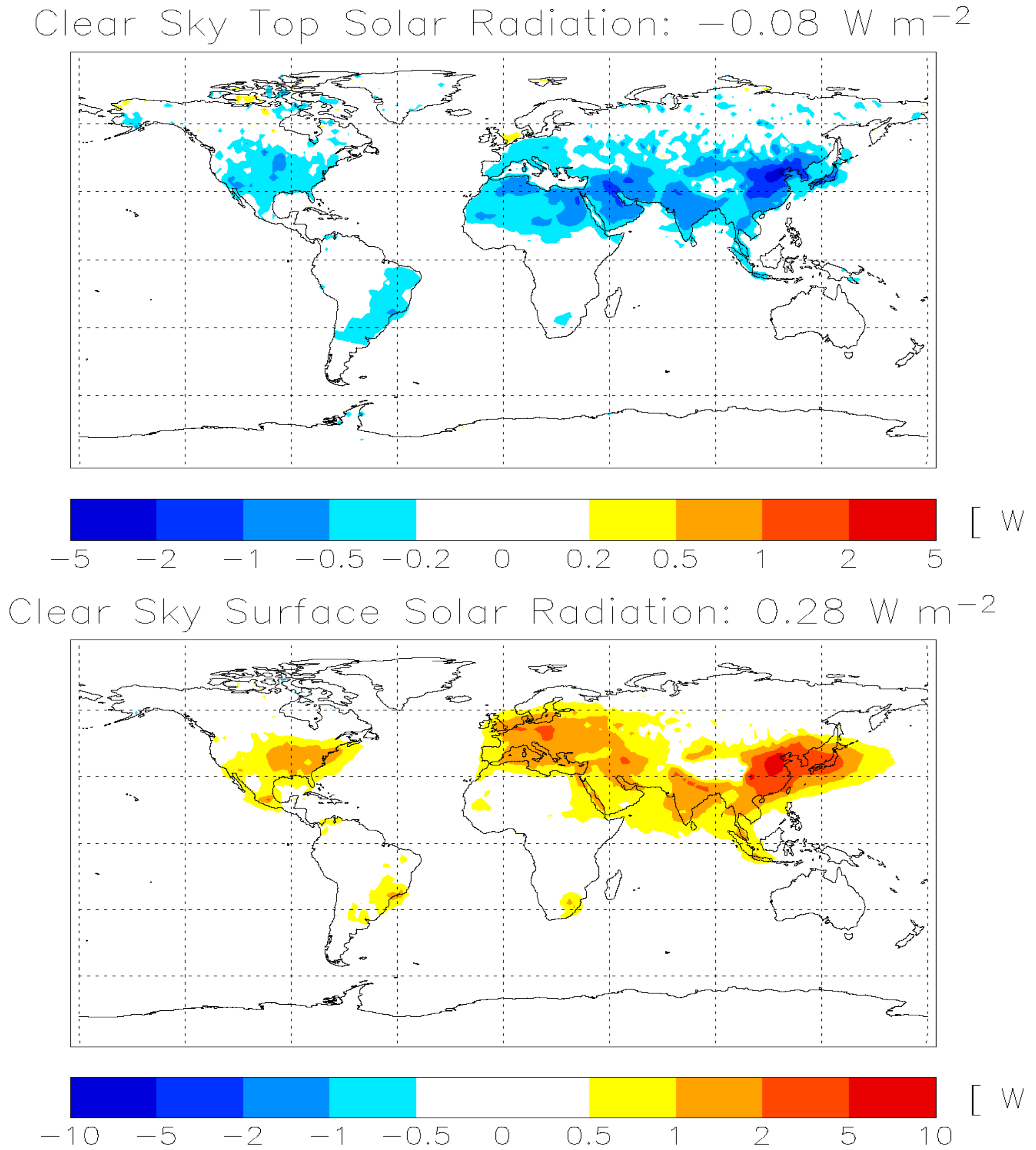
	LOA	GSFC	NCAR	Sprintars	GISS
SU	-.57	-.62	-1.08	-.27	
BC	+.42	+.35	BC and OC combined to:	+.42	+0.70
OC	-.46		+.01	-.33	
DU	-.46				
SS	-.30				

Forcing due to ff BC and OC

Note!

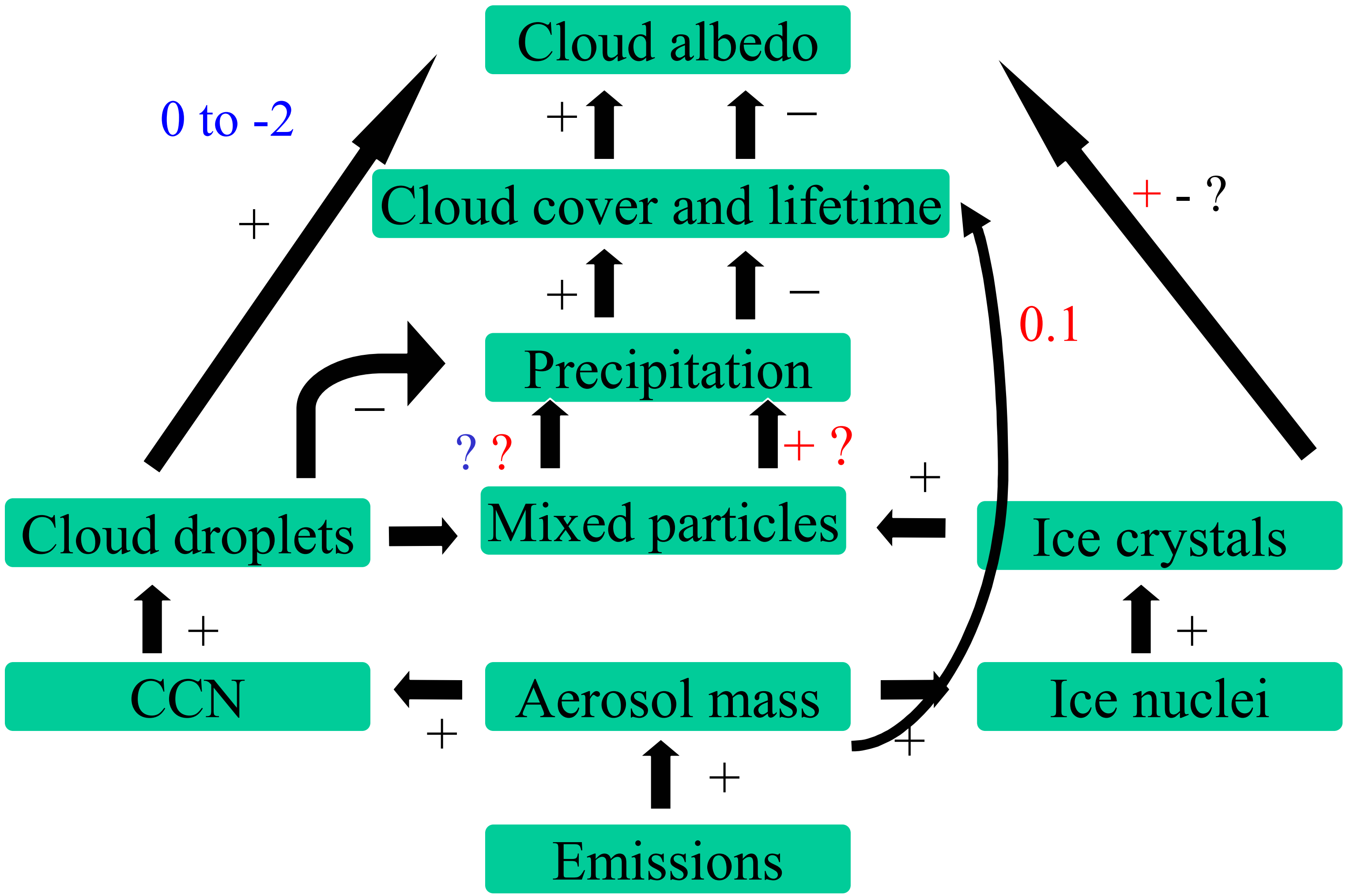
reversed sign

ECHAM5-HAM



aerosol-cloud interactions

(model estimates IPCC-2001 or later)



Effect of the vertical distribution of BC containing aerosol

- in the cloud – cloud dissolving (semi-direct effect)

  low level clouds – warming

  high level clouds - cooling

- above the cloud – strengthen the inversion – and Sc

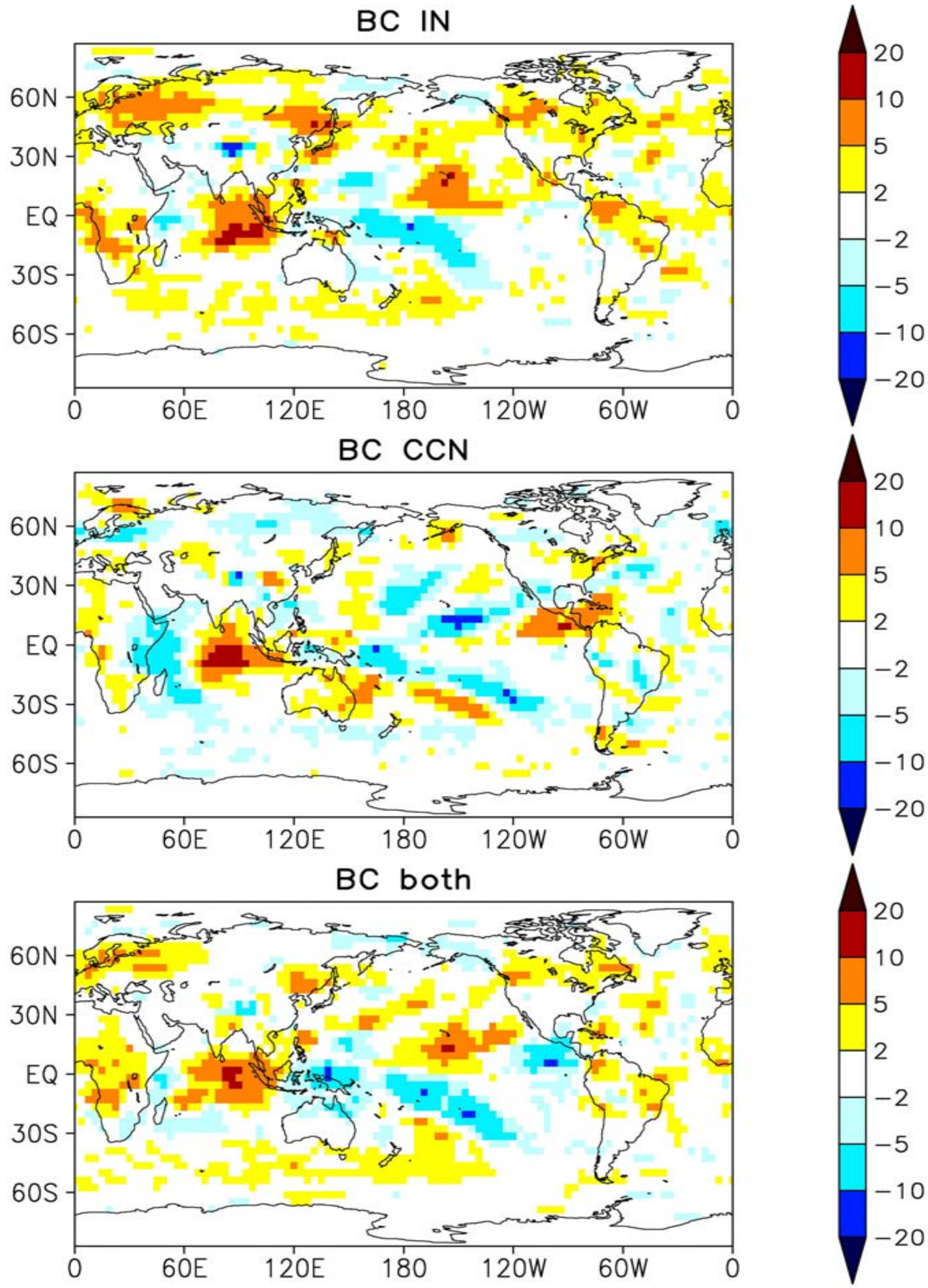
  enhances direct effect

- in the upper troposphere – acts as ice nucleus – warming

  enhances Bergeron-Findeisen process – cooling

Transport to the UT depends on source, size and hygroscopicity

Annual mean change in SW radiation TOA [W/m²]



+1.04 Wm^{-2}

-0.11

+0.55

BC particles

act only as ice nuclei

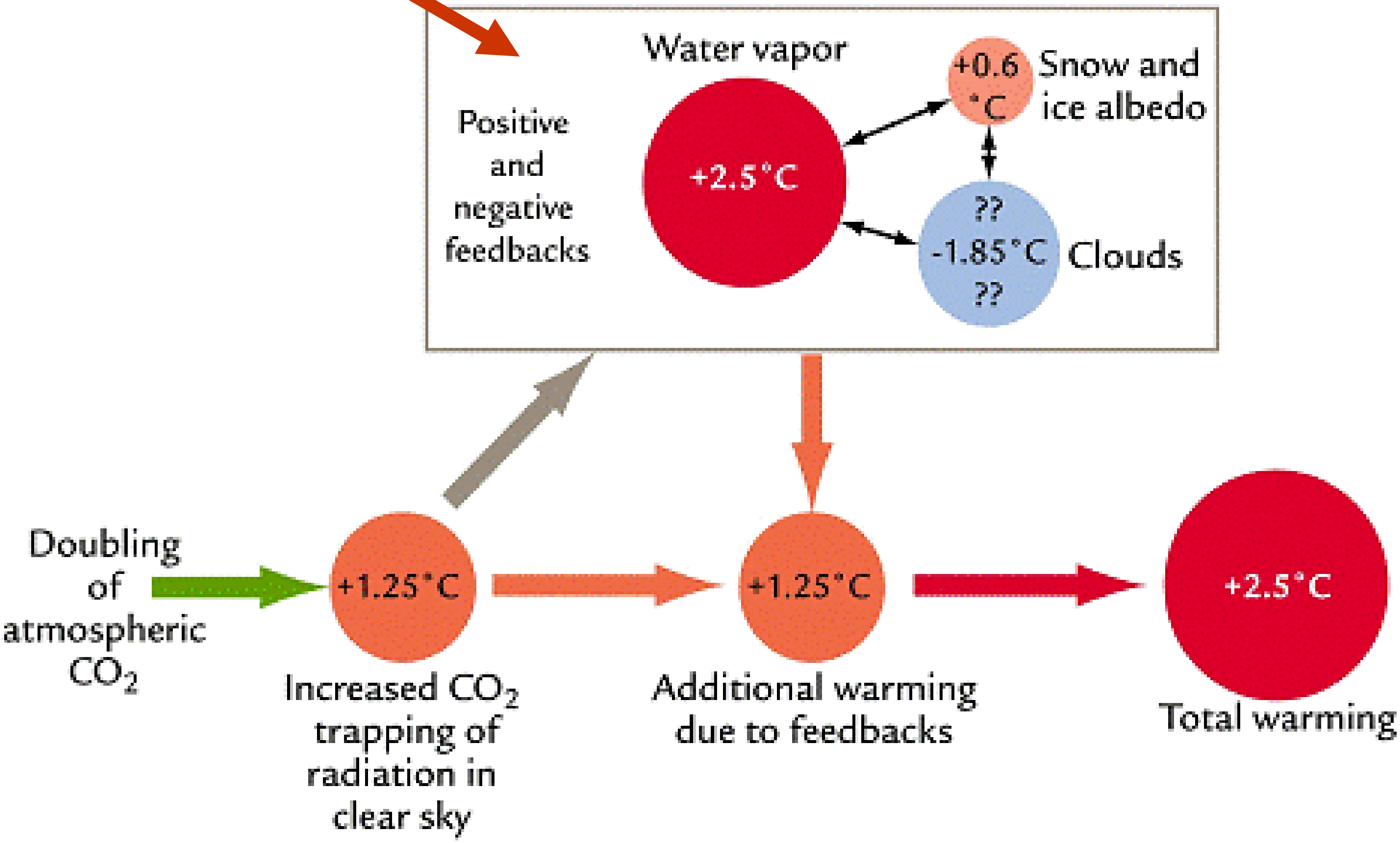
act only as cloud condensation nuclei

both CCN and IN

LW&SW forcing

0.37	0.04	0.16
IN	CCN	BOTH

Amount and composition of the aerosol influences the feedback processes



Equilibrium simulations

anthropogenic aerosol	**-0.87 K**
GHG (1985-1860)	1.72 K
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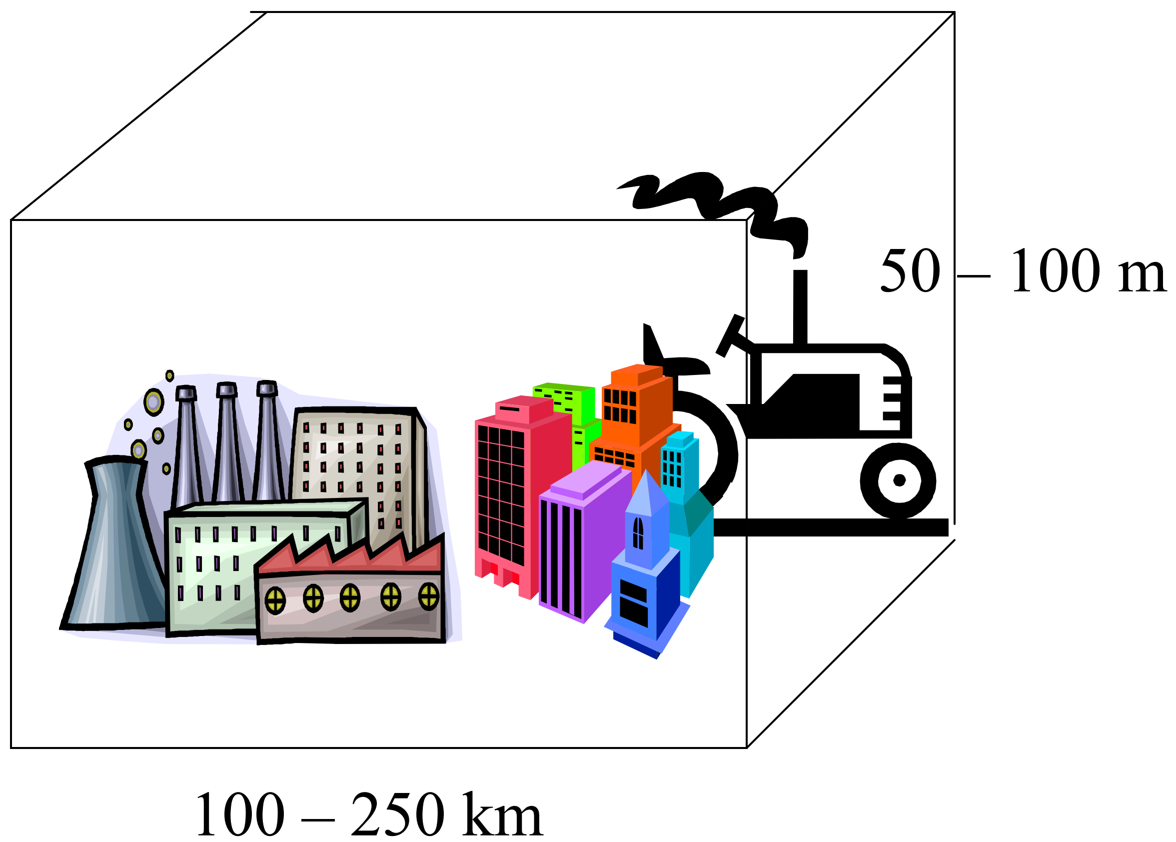
adds to	0.85 K
======================================	
GHG&AP	0.57 K

Treatment of aerosols as part of the water cycle affects the cloud-climate feedback and reduces the climate sensitivity

Outlook

• we need a better specification of the chemical and physical properties of combustion sources

we need informations about mixture and size distribution on the scale of a model grid-box



Outlook

- we need a better specification of the chemical and physical properties of combustion sources

- mechanistic treatment of aerosol and cloud processes

- the anthropogenic forcing may not be just the sum of the effects of single chemical compounds or single processes

Hotter or Cooler?

My guess:

combustion aerosols cool the atmosphere-Earth system