Biogeophysical and biogeochemical feedbacks involving aerosols

Olivier Boucher, Met Office Hadley Centre
Royal Meteorological Society's 2009 conference
2nd July 2009

Contents

This presentation covers the following areas

- Introduction
  - Feedbacks in the climate system
  - Aerosols
- Feedbacks involving natural aerosols
  - Marine aerosols
  - Dust
  - Biomass burning
  - Biogenic organic aerosols
- Aerosol-ecosystem interactions
- Conclusions

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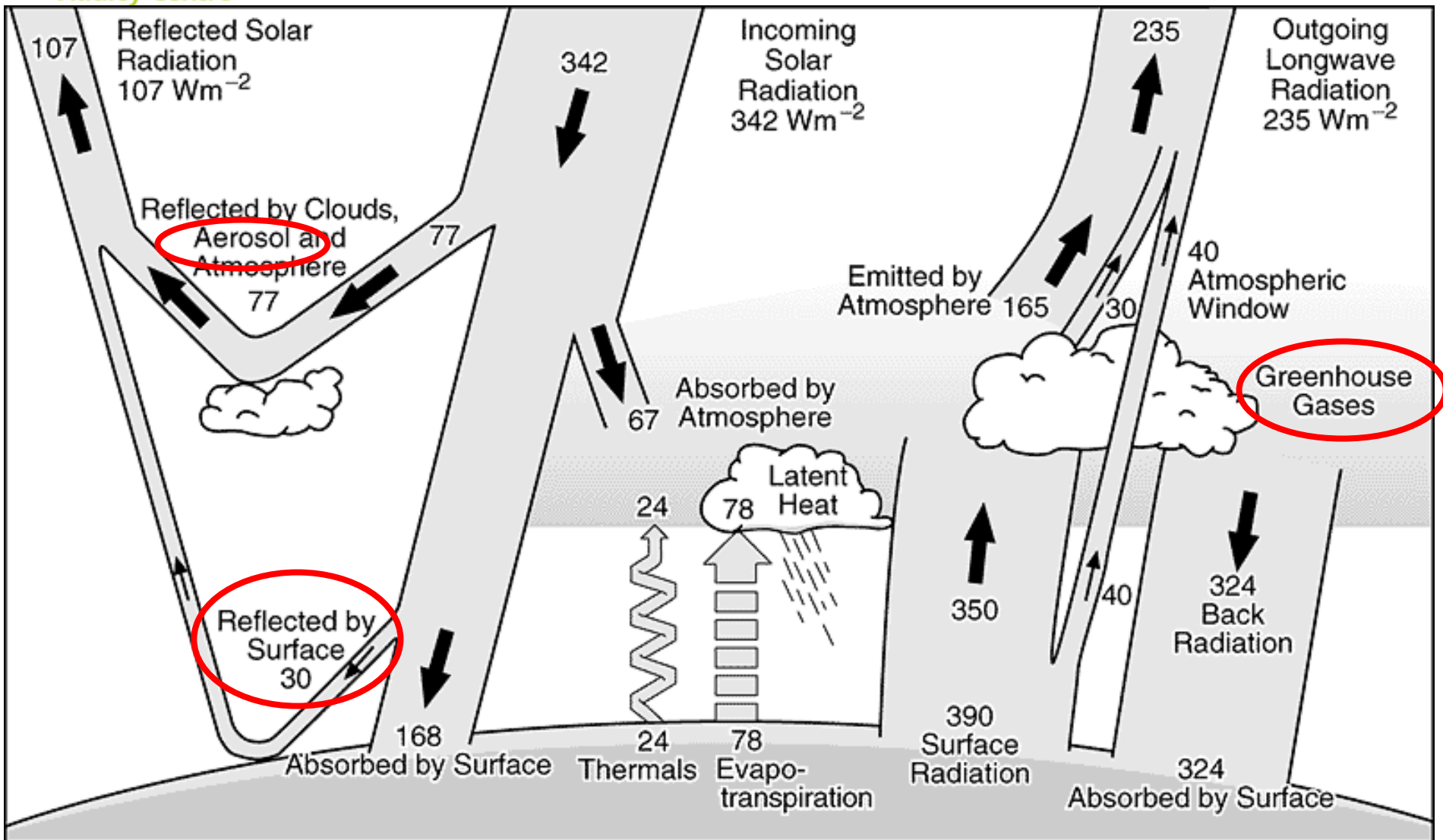
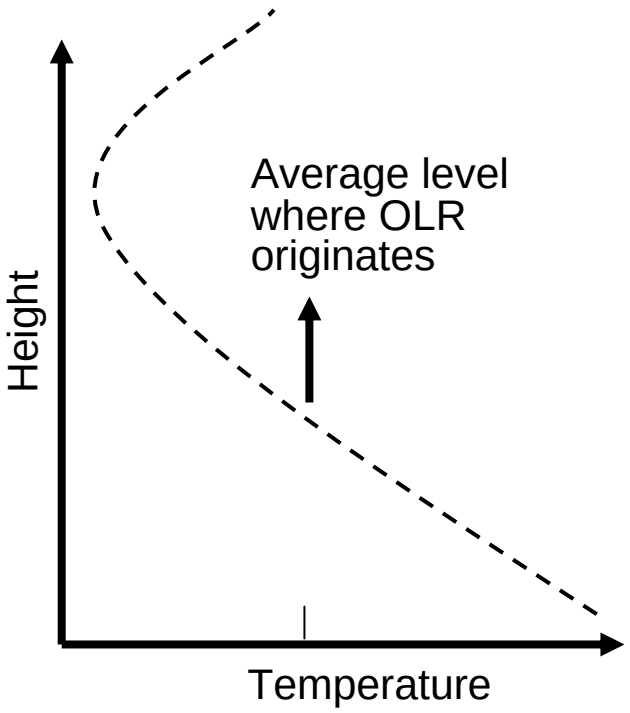
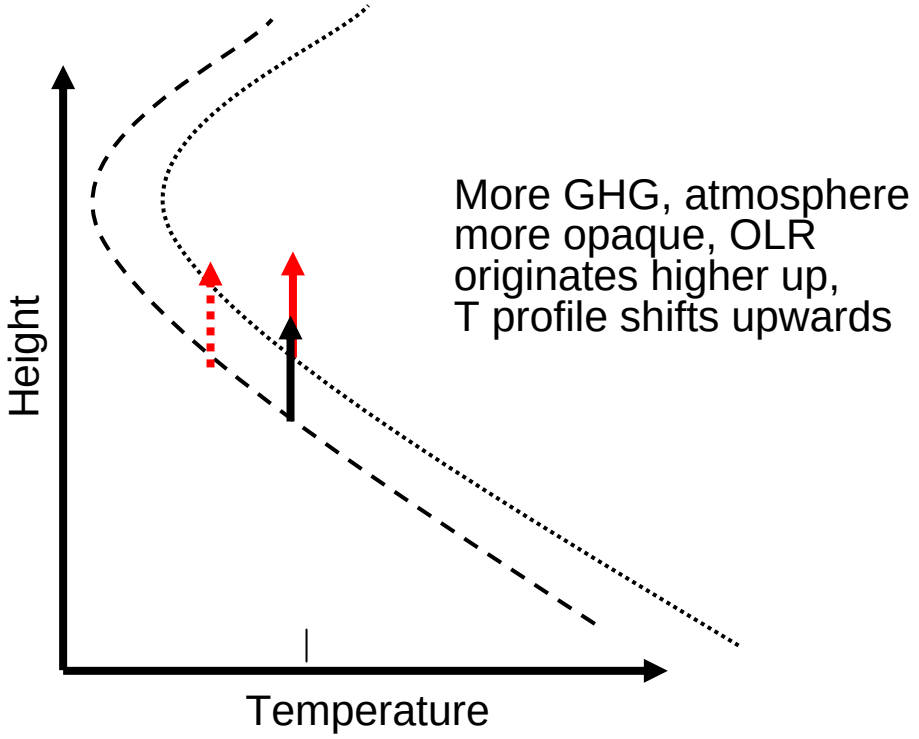
Energy budget



Forcing - Response



Reference Atmosphere



Atmosphere with enhanced greenhouse effect

What is a feedback? Examples

The water vapour feedback:

$$GHG \nearrow \Rightarrow T \nearrow \Rightarrow q_s(T) \nearrow \Rightarrow q \nearrow \Rightarrow GHG \nearrow \Rightarrow T \nearrow$$

The sea-ice feedback:

$$GHG \nearrow \Rightarrow T \nearrow \Rightarrow \text{sea-ice} \searrow \Rightarrow A \searrow \Rightarrow T \nearrow$$

Cloud, snow cover, lapse rate feedbacks …

What is a feedback? Examples

Carbon-climate feedback

$$\text{GHG}\nearrow \Rightarrow \text{T}\nearrow \Rightarrow \begin{matrix}\text{NPP}\nearrow \\ \text{Rh(T)}\nearrow \\ \text{stratification}\nearrow\end{matrix} \Rightarrow \text{carbon sink}\searrow \Rightarrow CO_2 \nearrow \Rightarrow \text{T}\nearrow$$

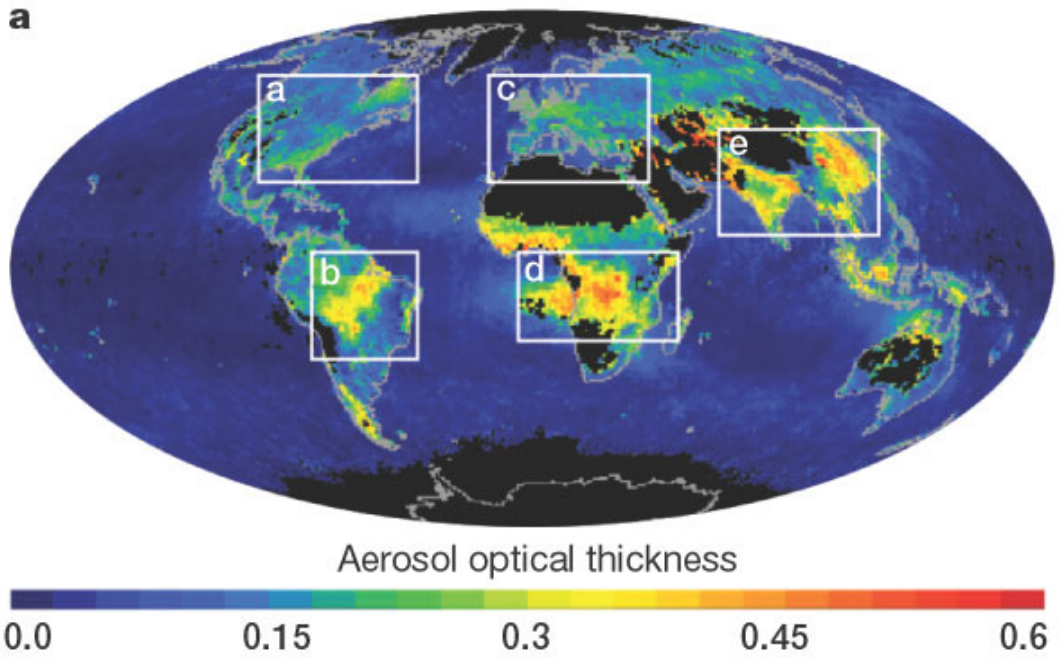
Permafrost

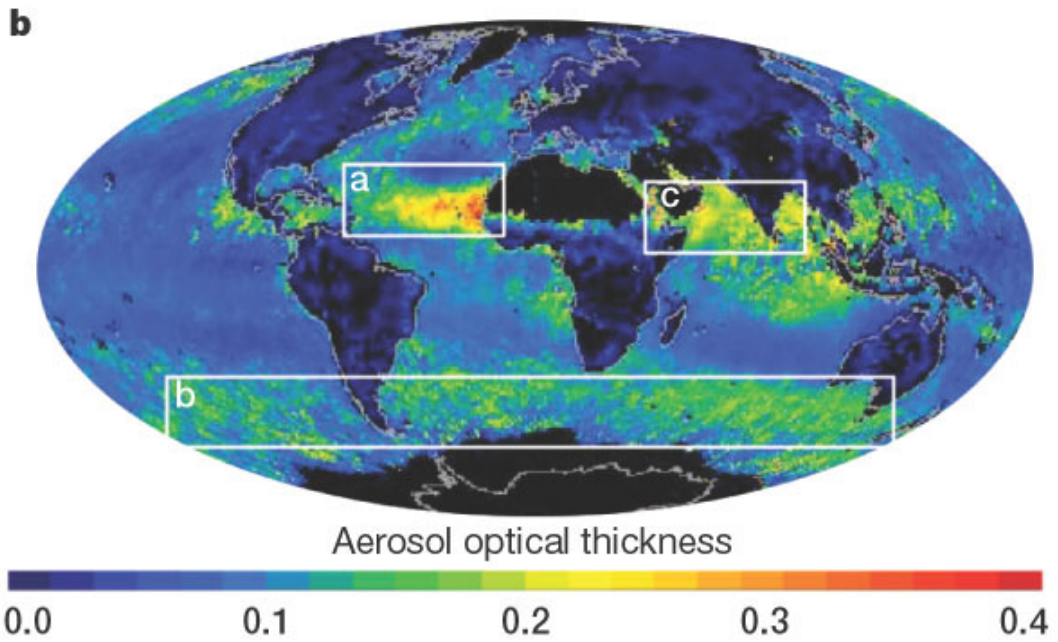
What about aerosols?

Met Office
Hadley Centre

Fine mode

Coarse mode





From Kaufman, Tanré & Boucher, *Nature*, 2002

HadGEM2, MISR and MODIS

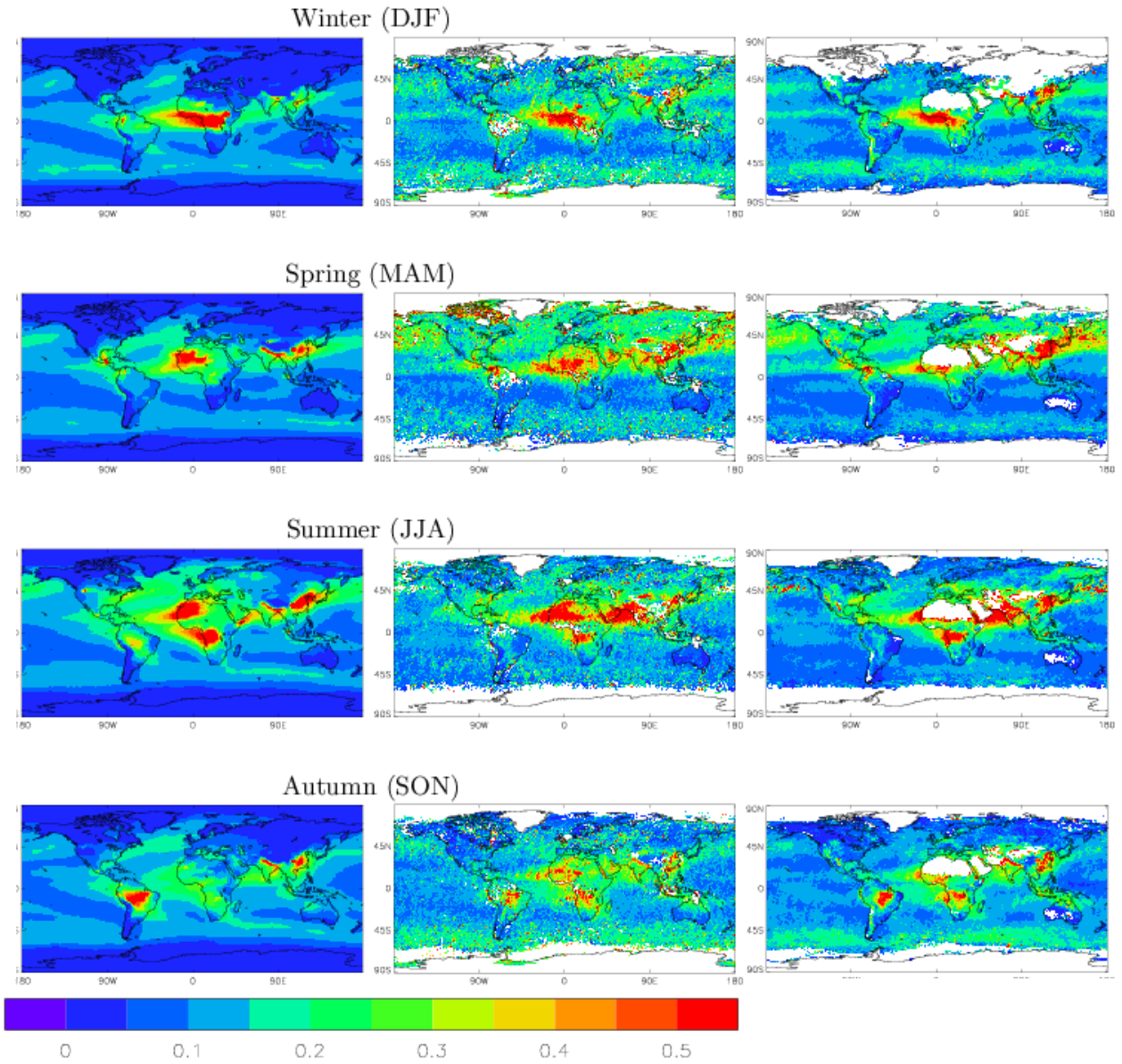
HadGEM1 HadGEM2 MISR MODIS

MODIS & MISR 2001

Main patterns are reproduced.

Continents are very clean in all seasons but summer (missing oxidation by O_3, nitrate).

African biomass burning seasonality too centred on summer.



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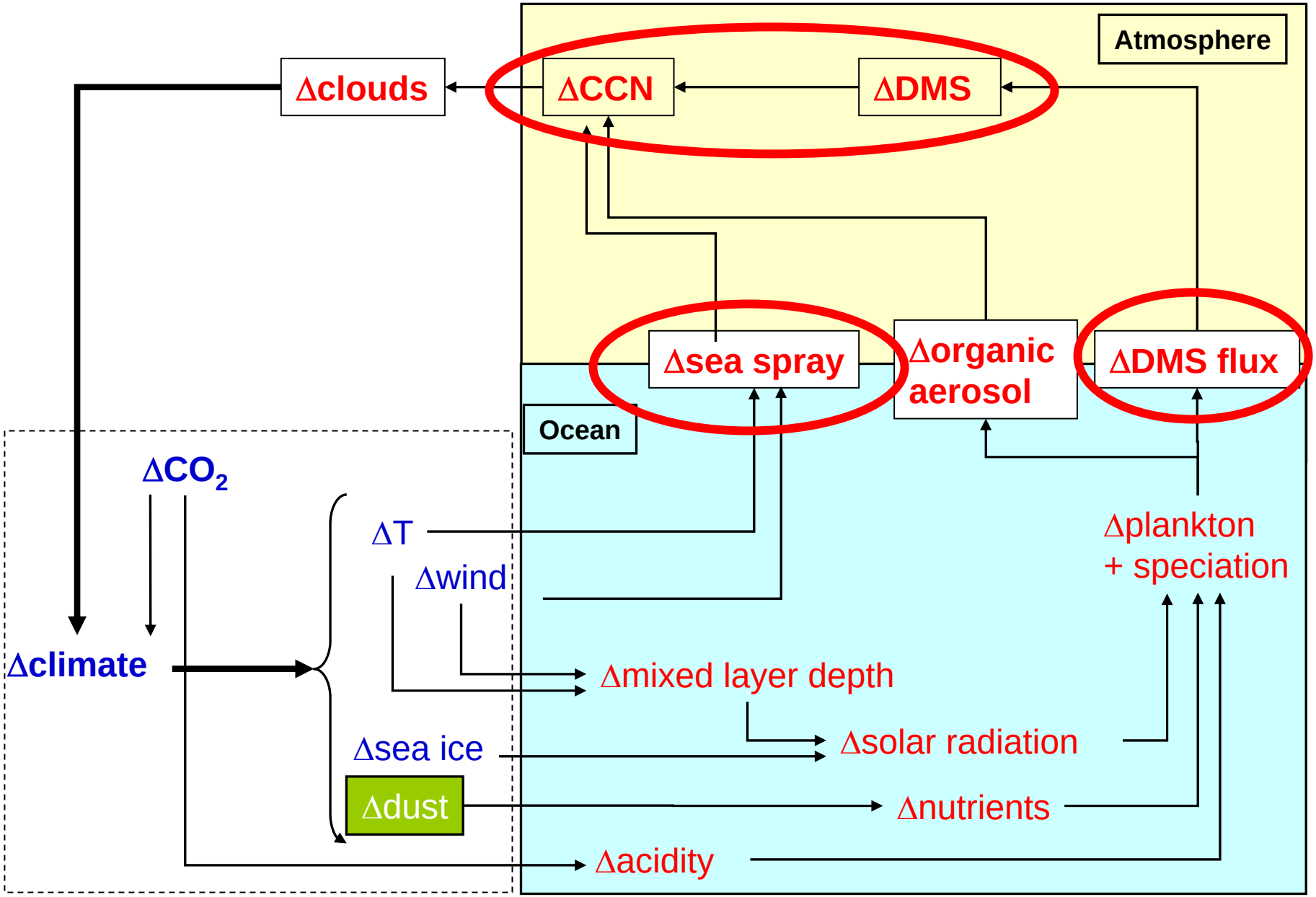
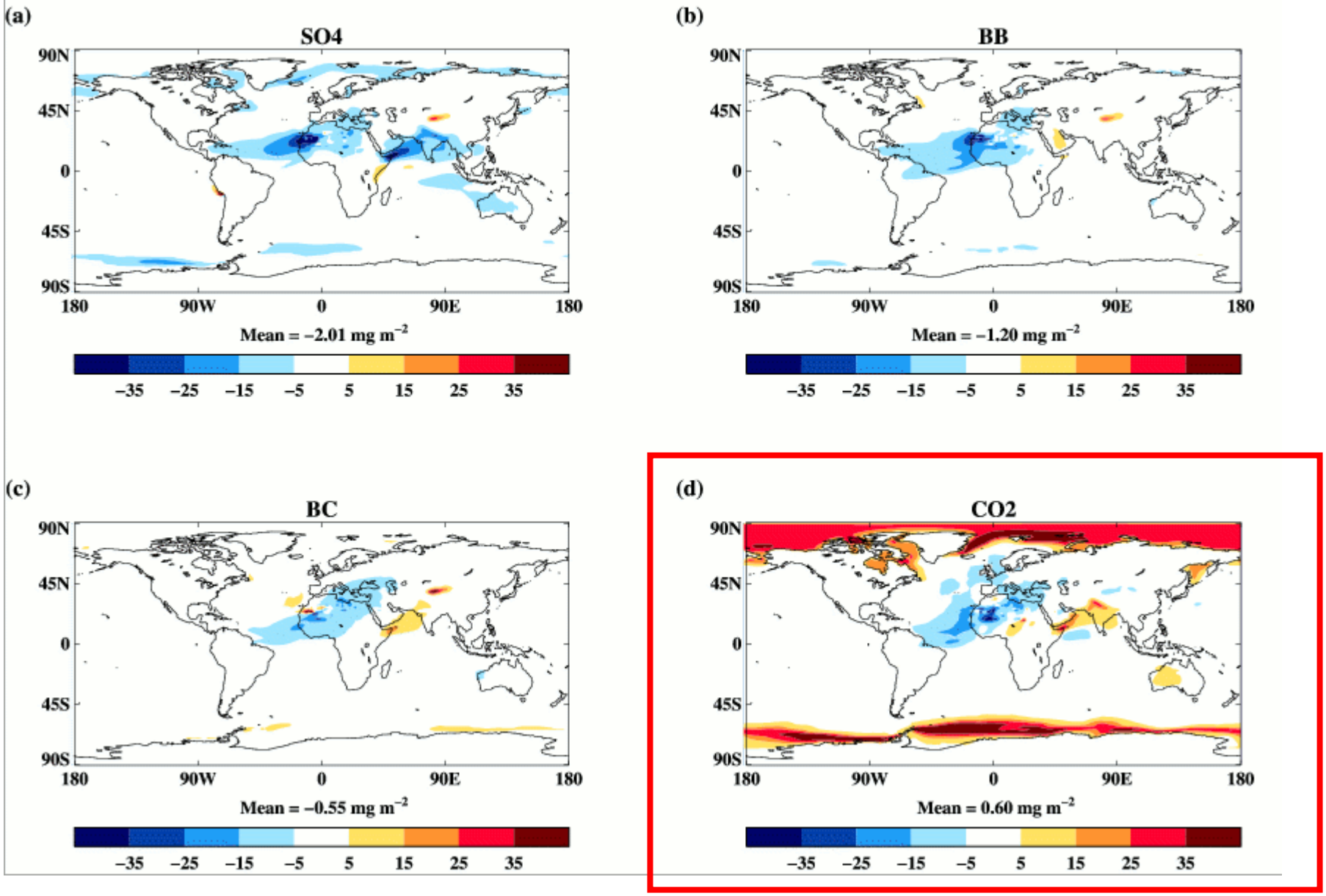
Feedback loops: marine aerosols



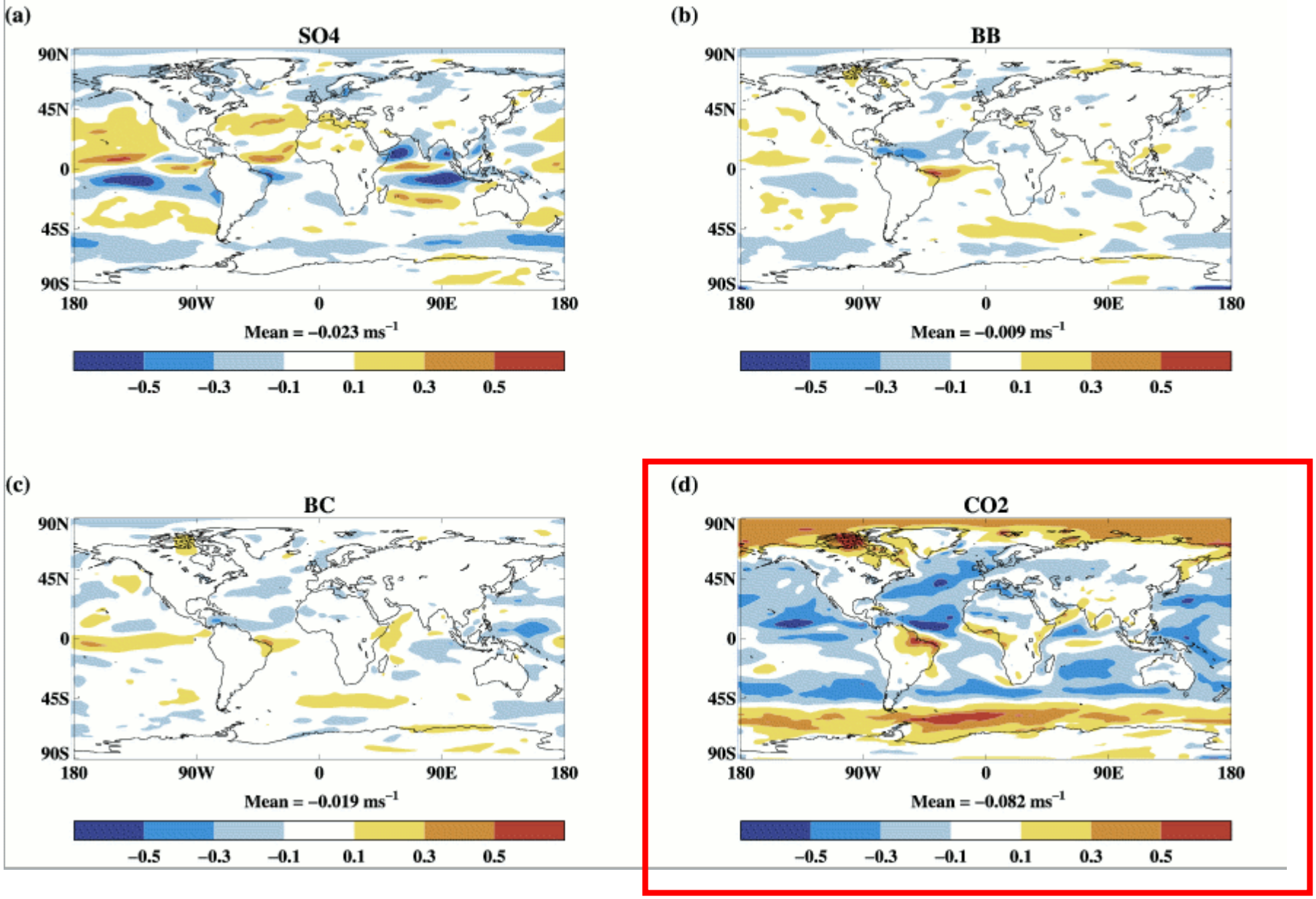
Carslaw, Boucher, et al., ACPD, 2009

Aerosol burden response to SO4/BB/BC/CO2 forcings



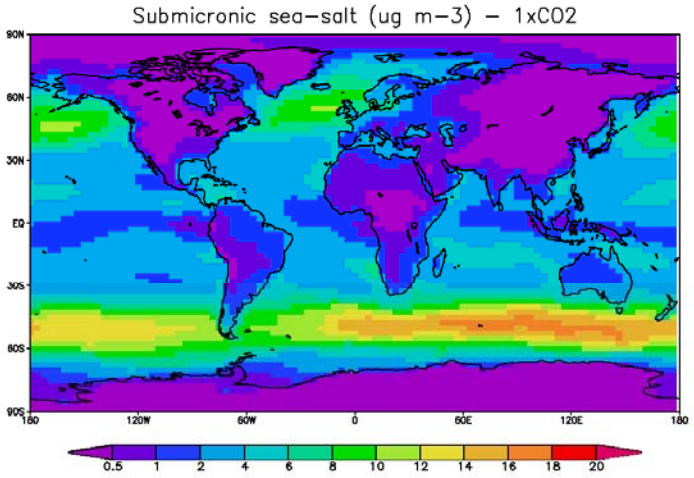
Jones, Haywood & Boucher, JGR, 2007

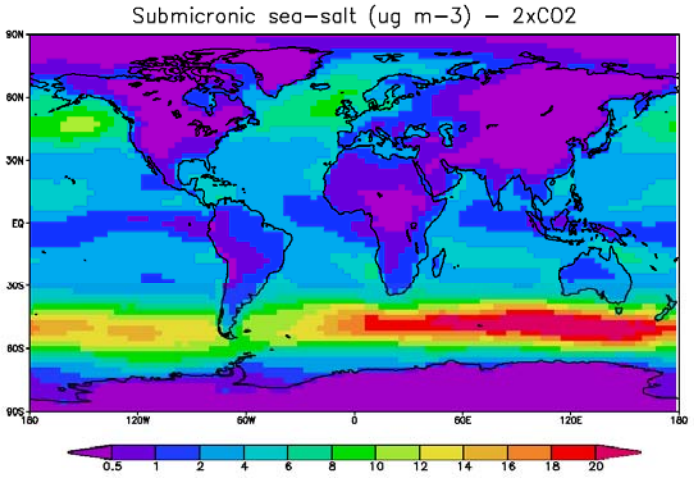
Wind speed response to SO4/BB/BC/CO2 forcings

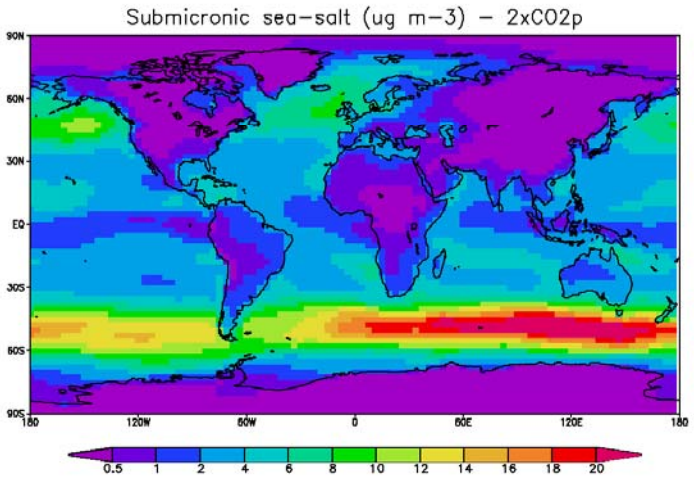


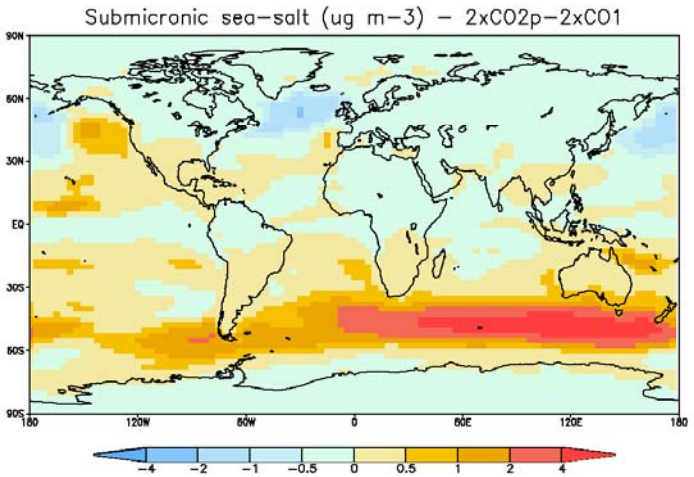
Jones, Haywood & Boucher, JGR, 2007

Change in sea salt cycle in a 2xCO_2 climate





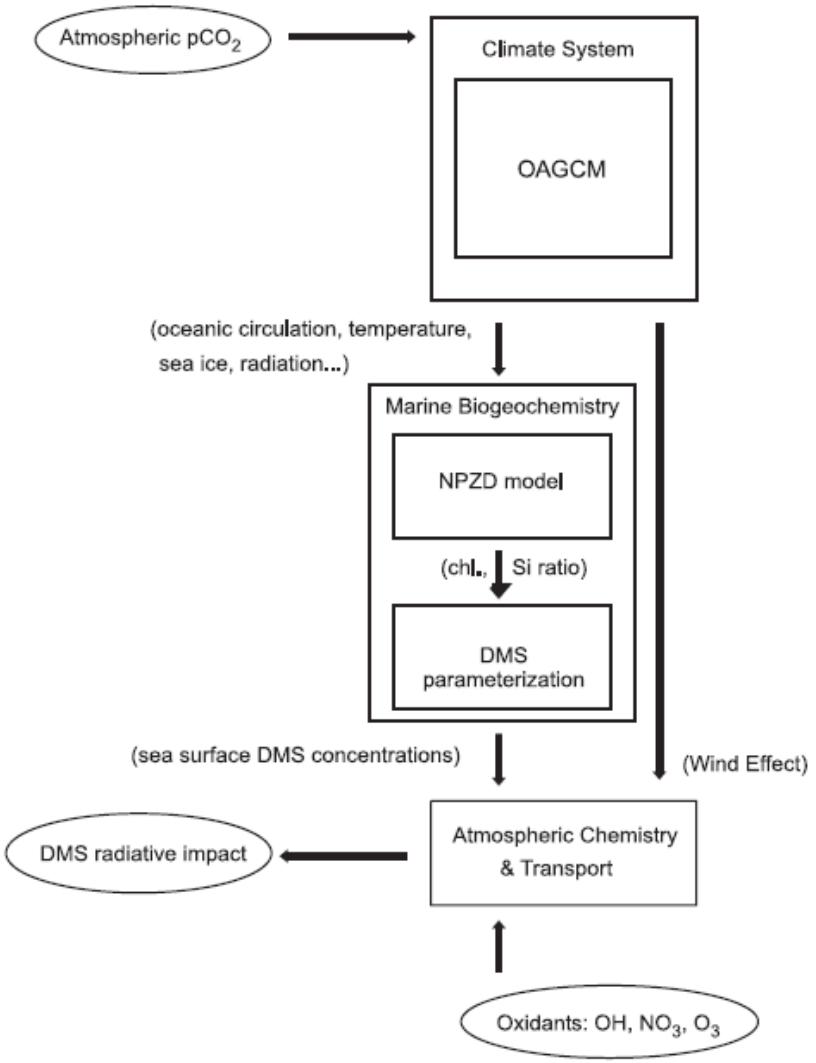


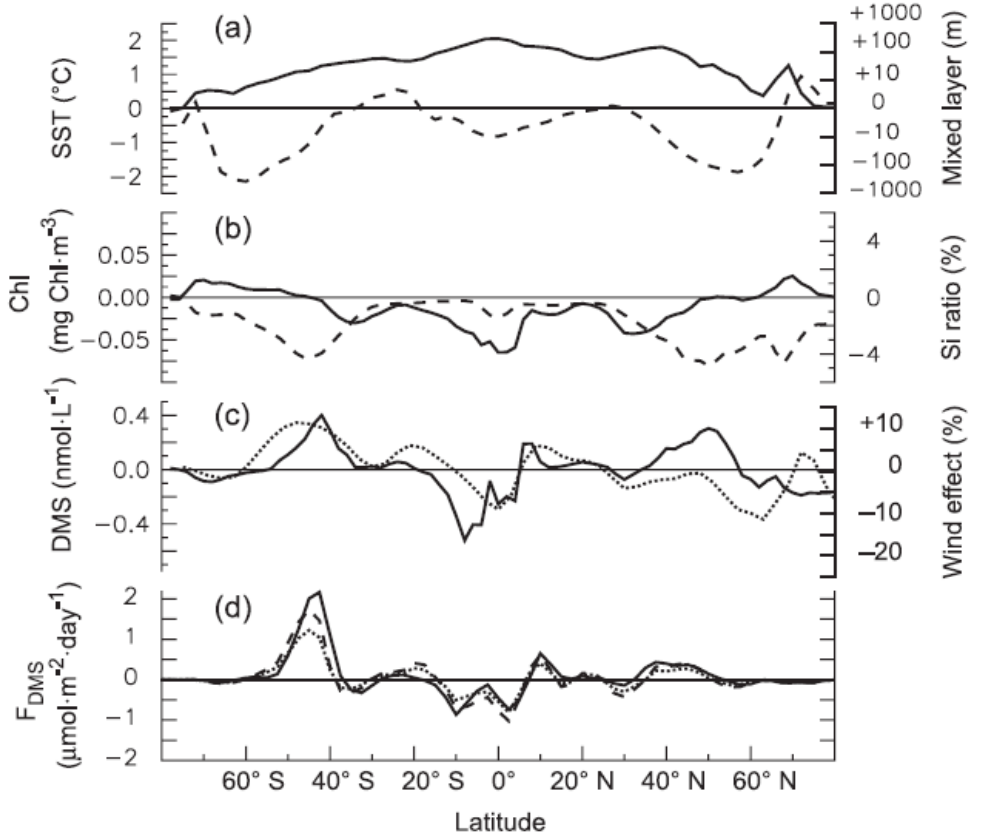


Emissions and sinks of sea-salt will respond to climate change through changes in wind speed, transport, and precipitation.

Less cooling in the NH, more cooling in the SH, leading enhanced hemispheric contrast.

DMS response to 2xCO_2 climate response

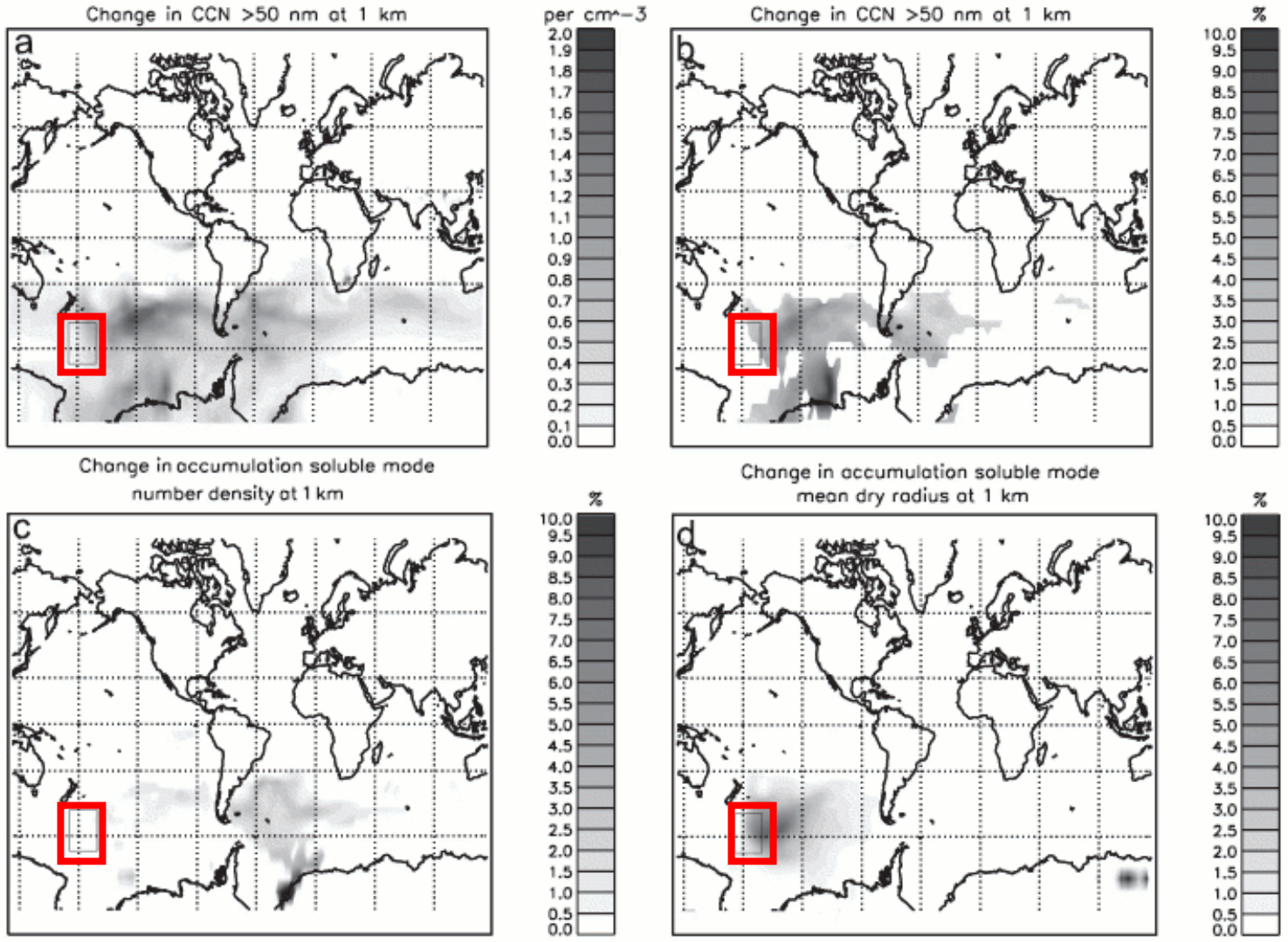




Bopp, Boucher, et al., 2003

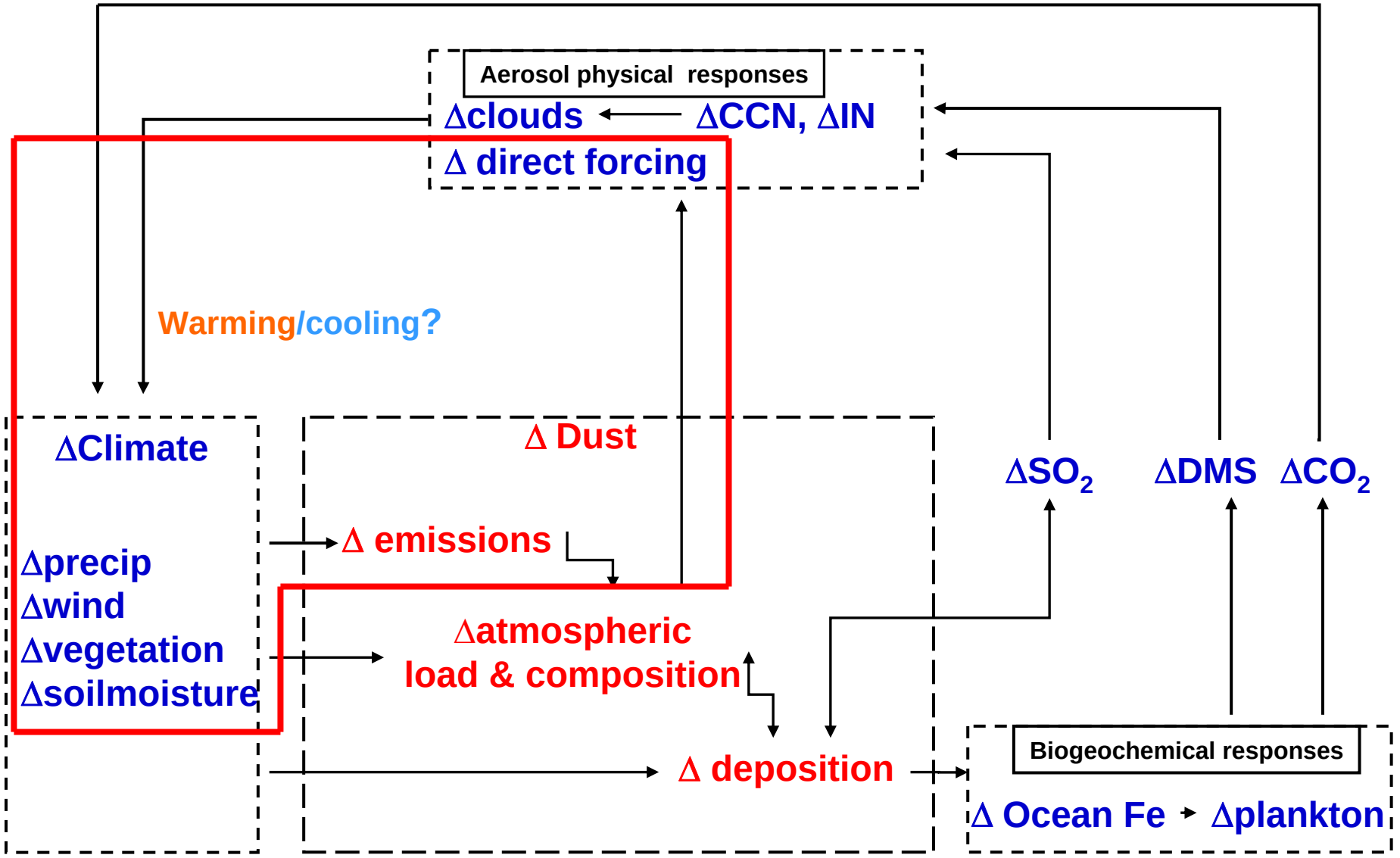
CCN sensitivity to change in DMS emission

Patch of 5xDMS emission, +8% increase in DMS emission in the Southern Ocean, but only +1.4% increase in CCN >50 nm



Woodhouse et al., *Atmos. Env.*, 2008

Feedback loops: dust aerosols



Carslaw, Boucher, et al., ACPD, 2009

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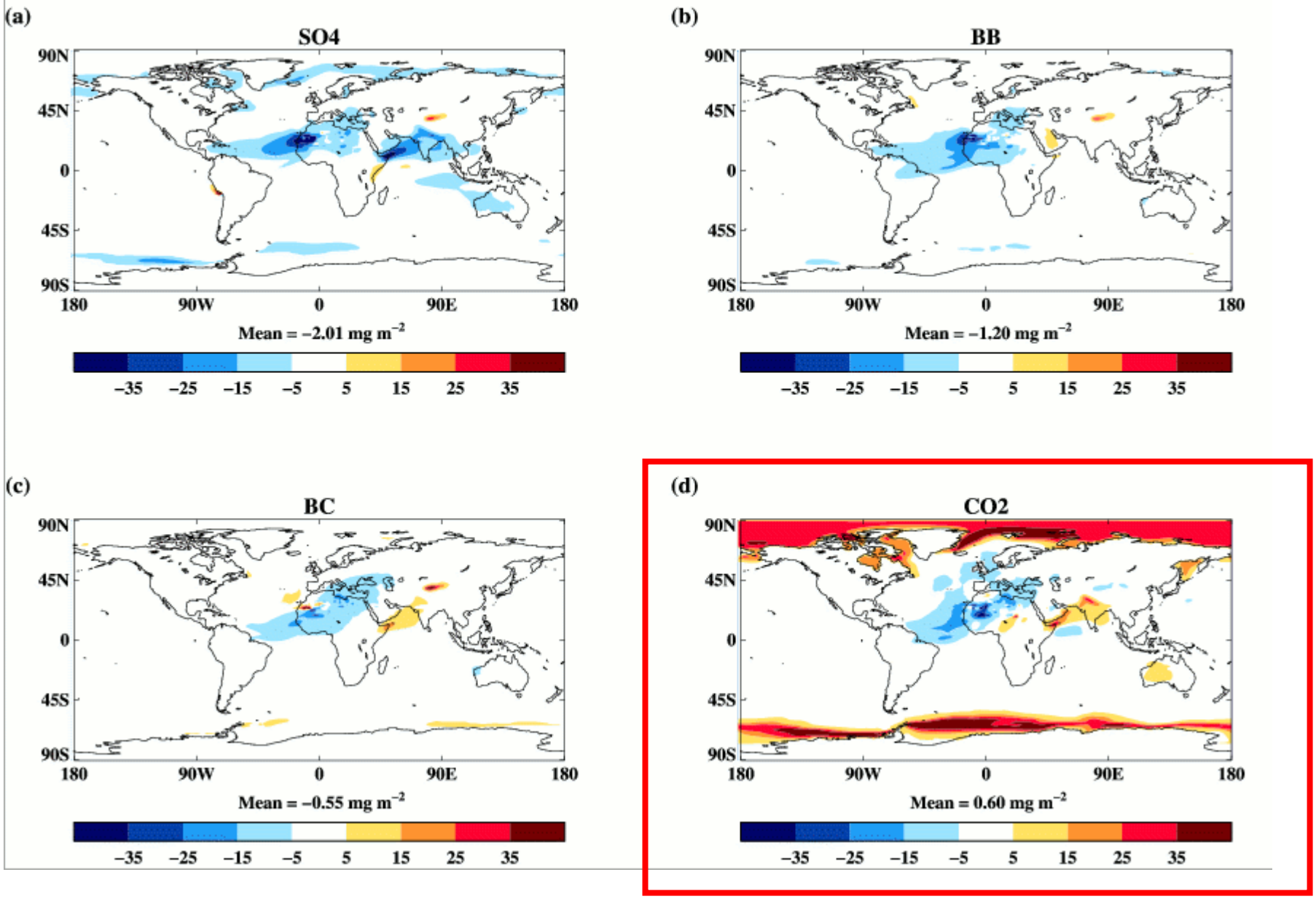
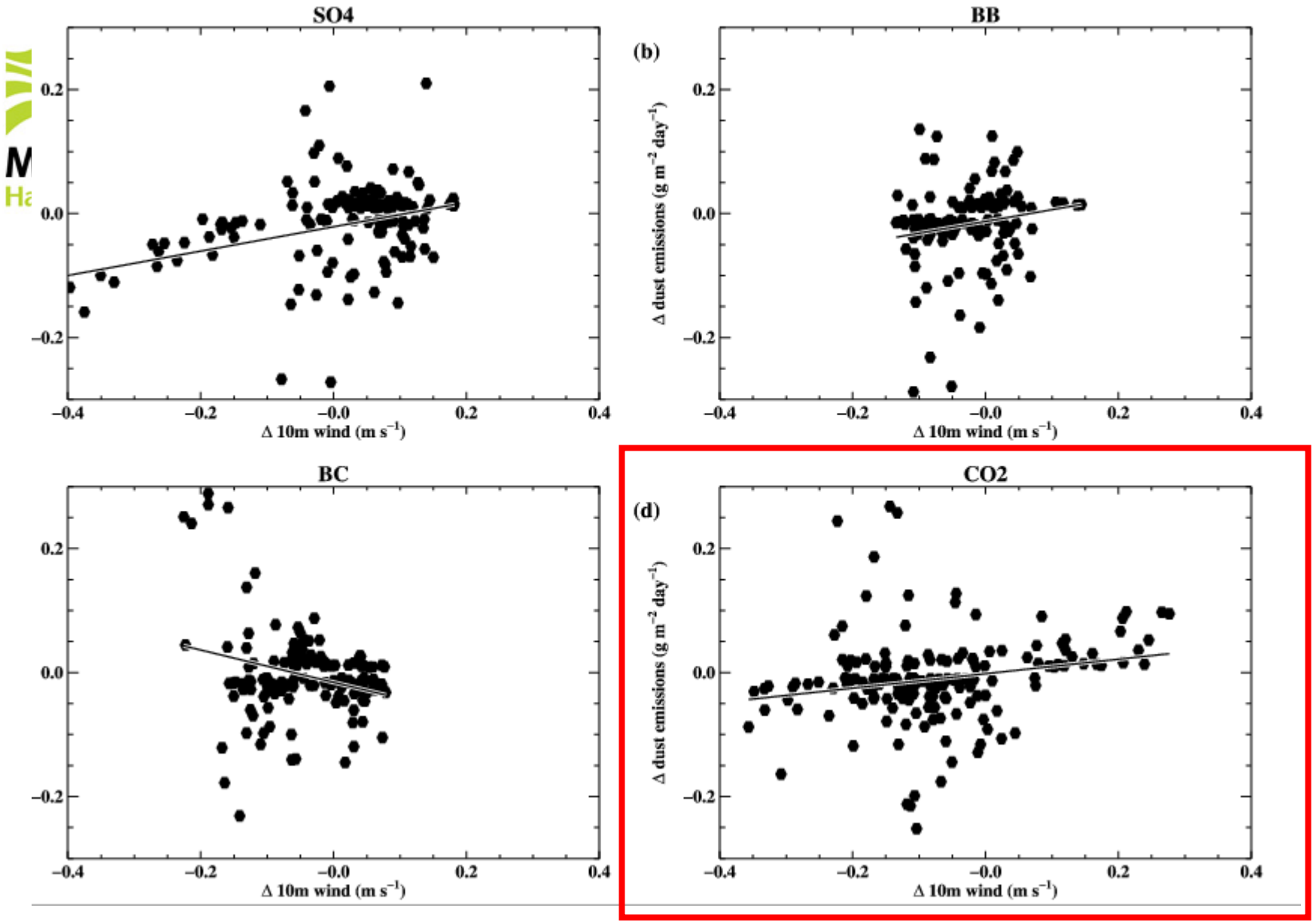
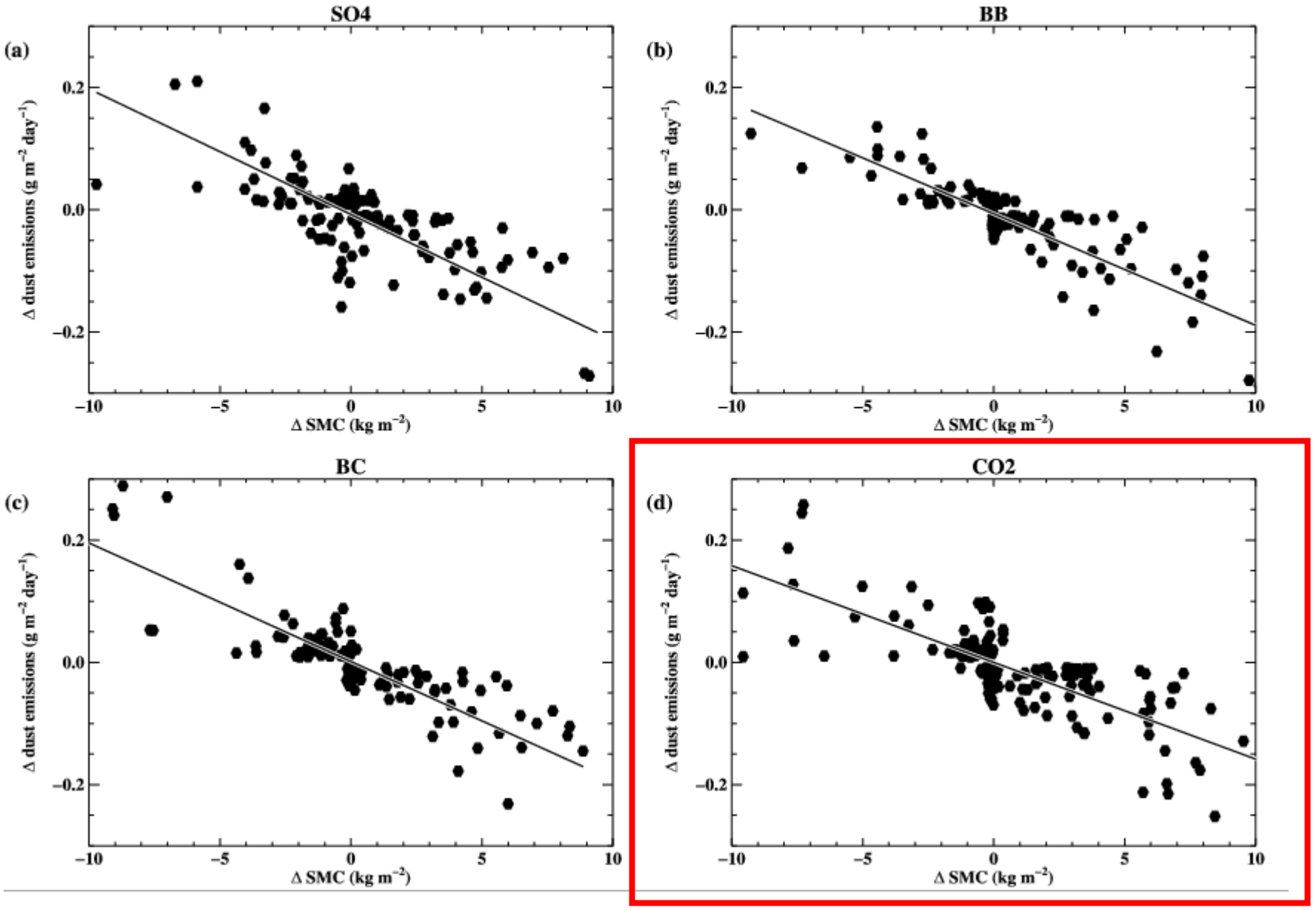


Jones, Haywood & Boucher, JGR, 2007

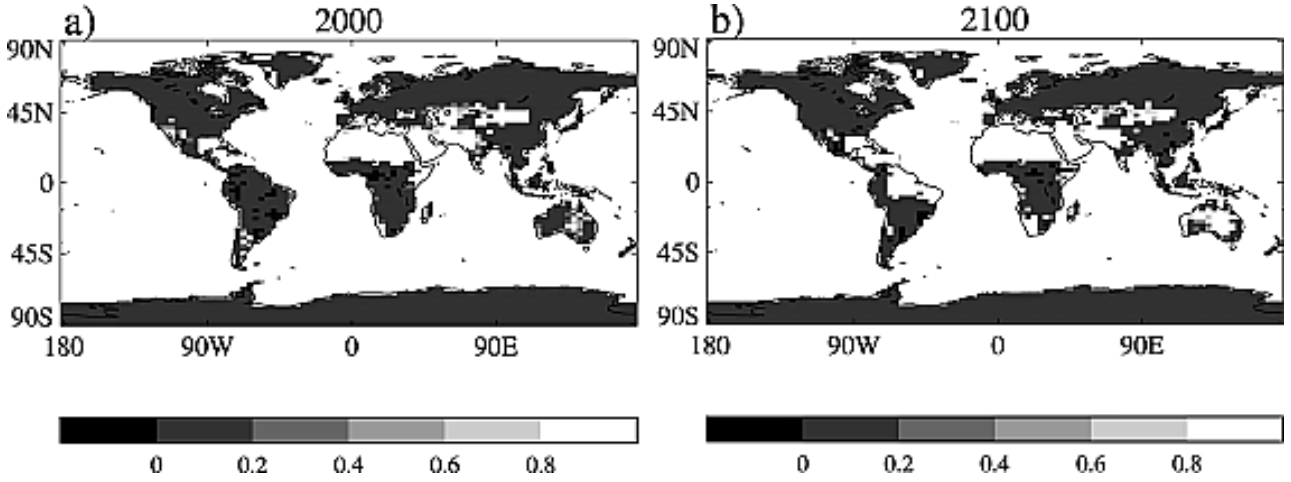


Jones, Haywood & Boucher, JGR, 2007

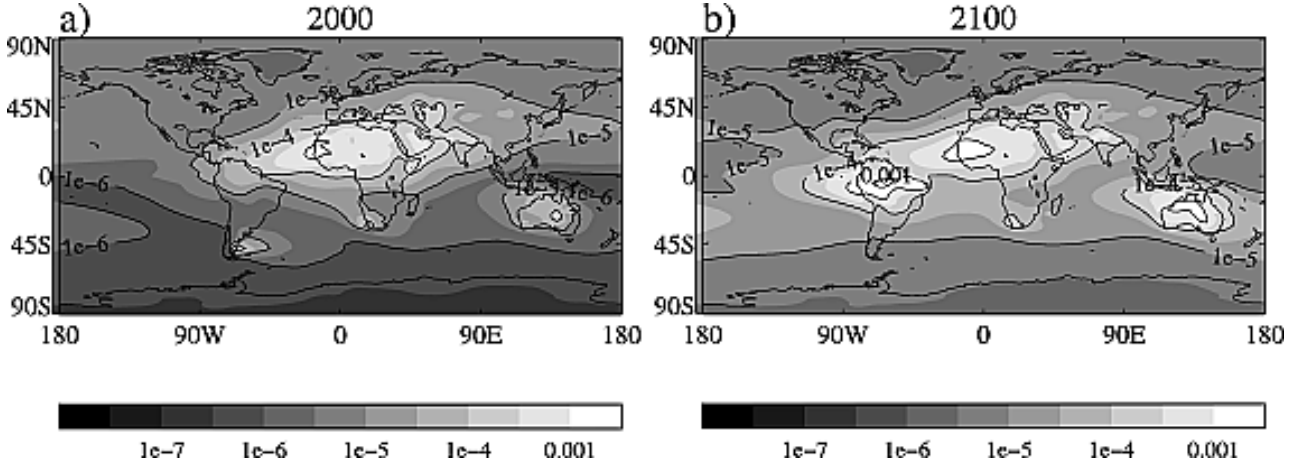


Jones, Haywood & Boucher, JGR, 2007

Changes in dust emissions from 2000 to 2100



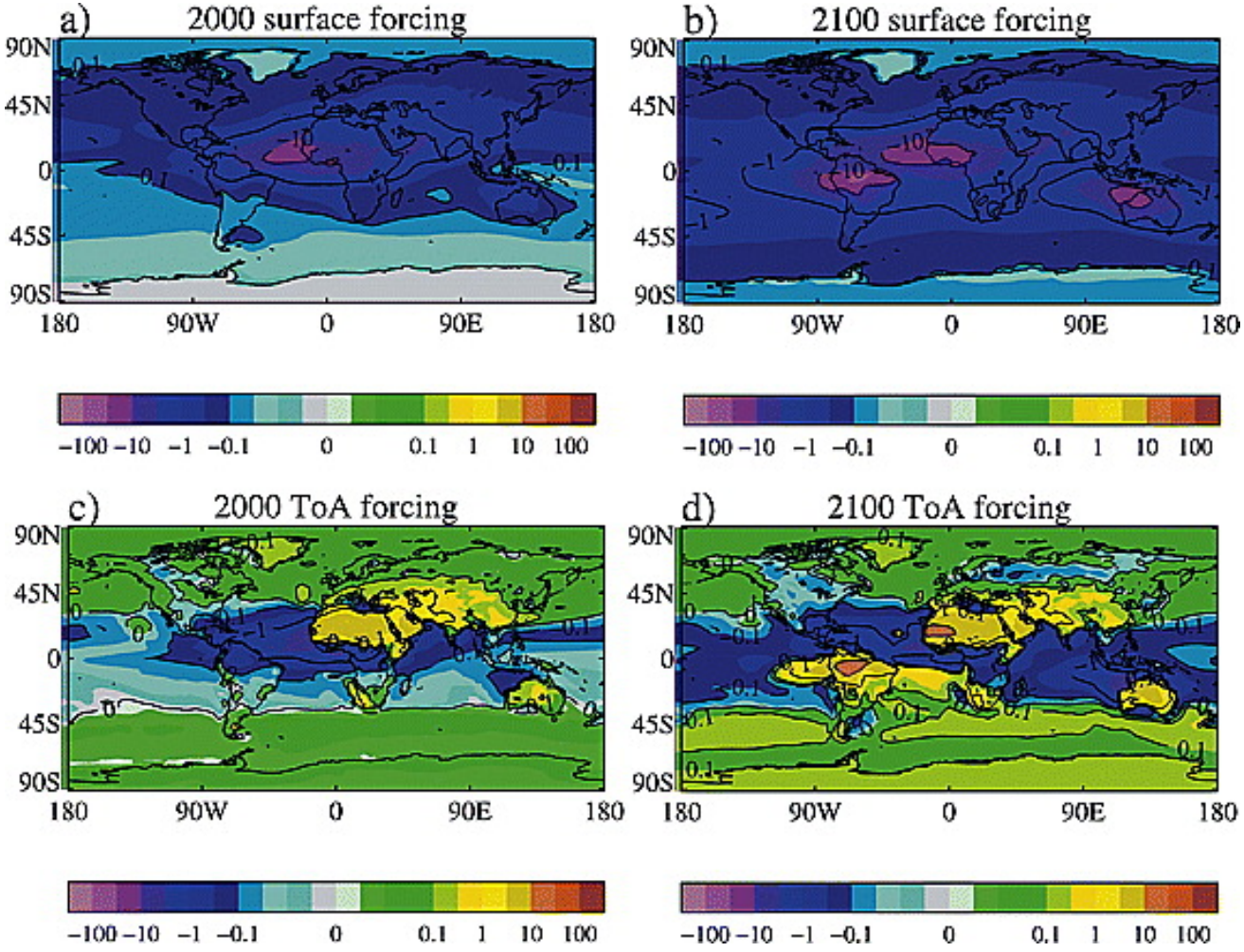
Bare soil fraction



Atmospheric dust load (kg m^{-2})

Woodward et al. *GRL*, 2005

Changes in dust RF from 2000 to 2100

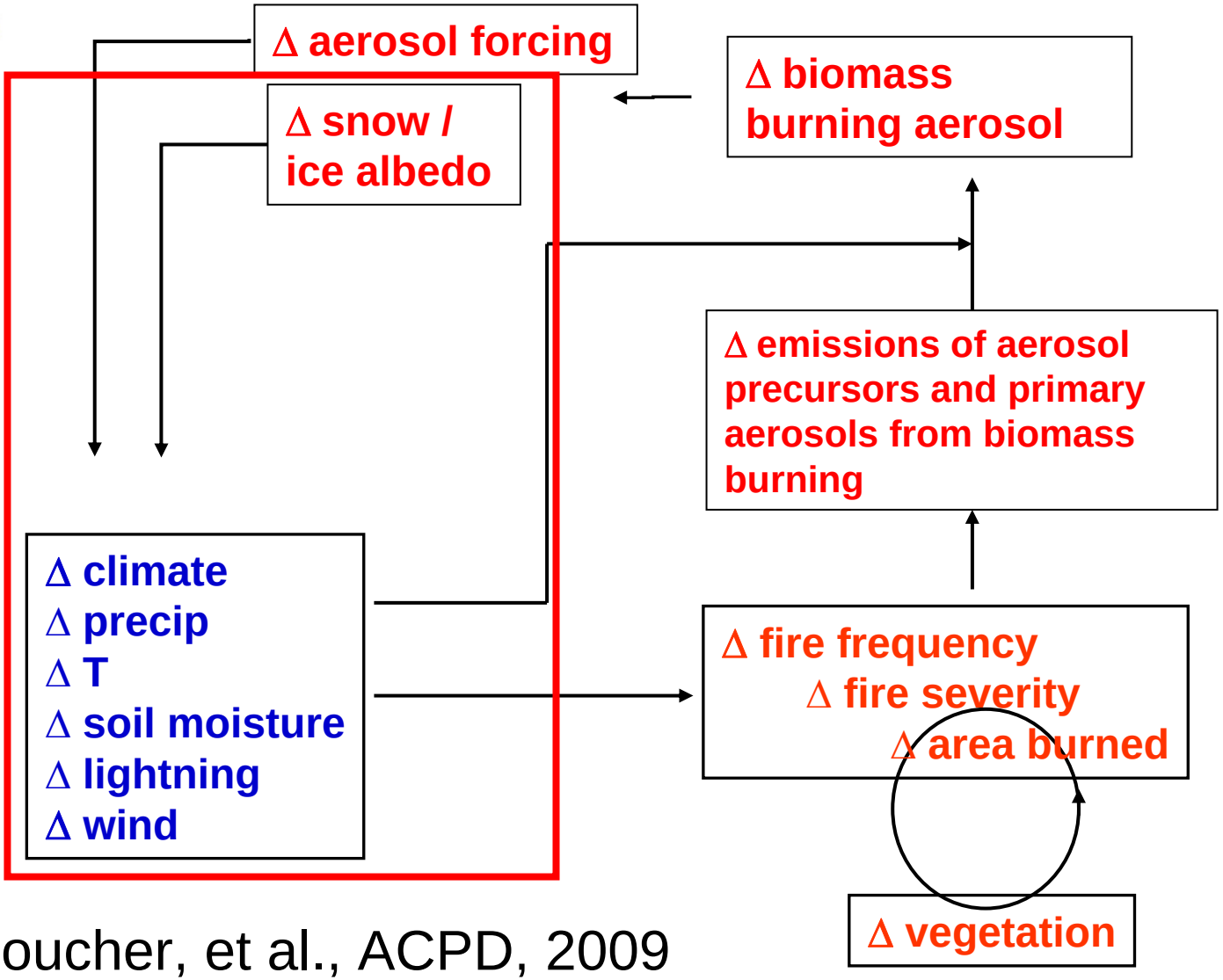


Surface forcing

ToA forcing

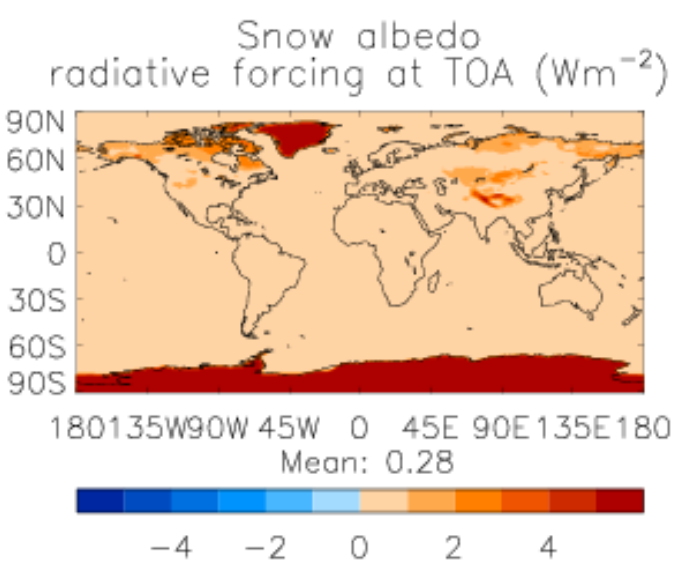
Woodward et al. *GRL*, 2005

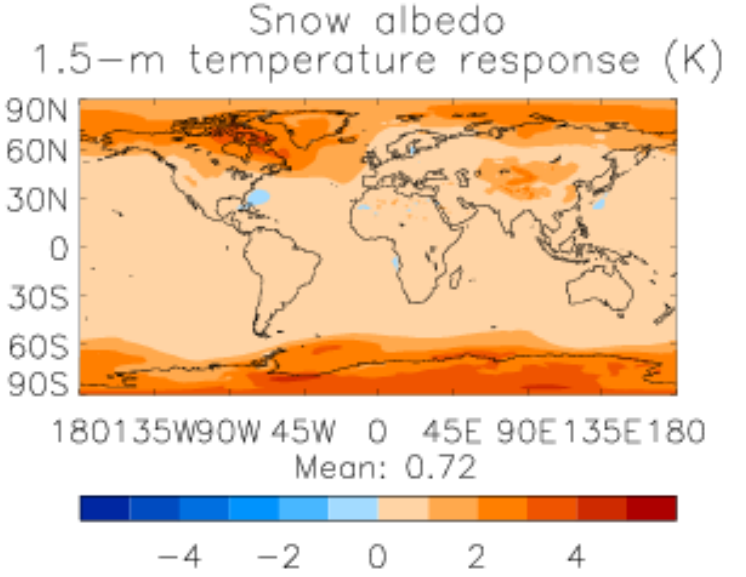
Feedback loops: biomass burning aerosols

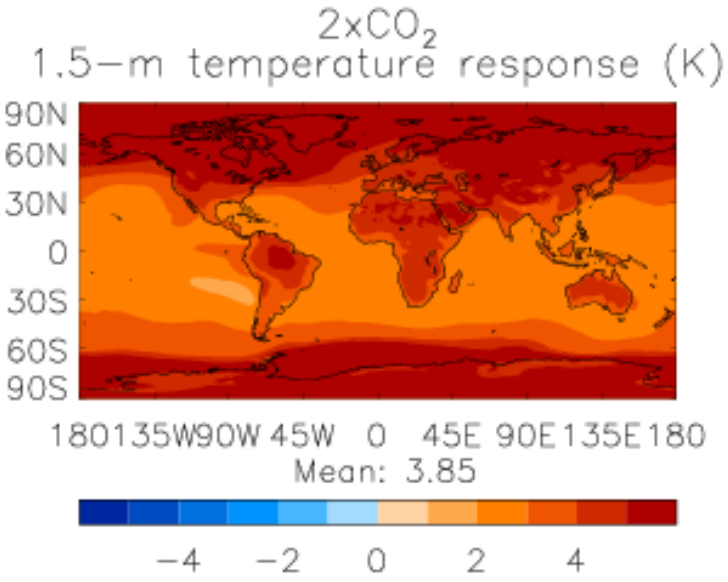


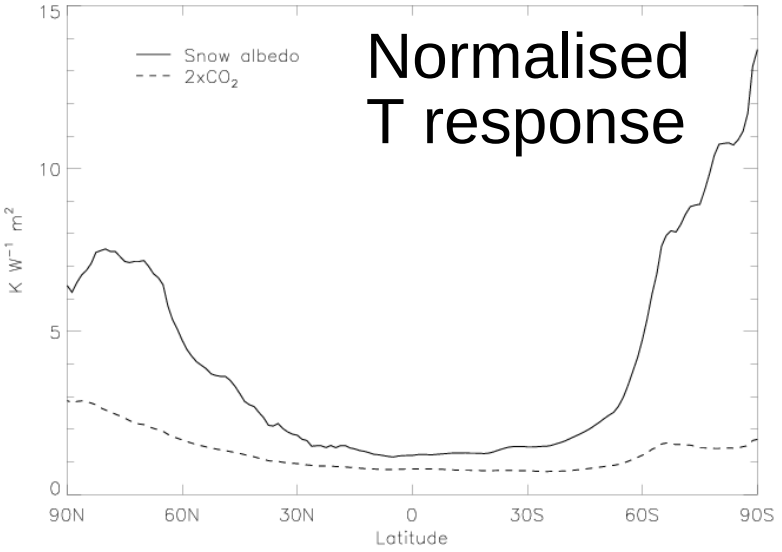
Carslaw, Boucher, et al., ACPD, 2009

Black carbon on snow



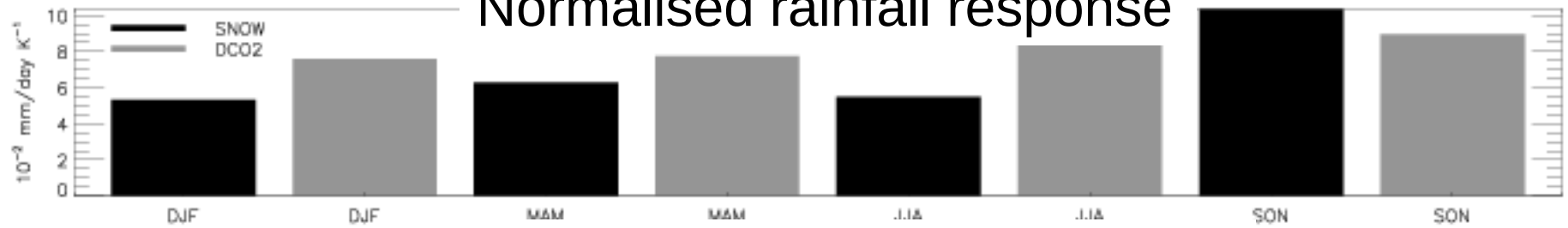




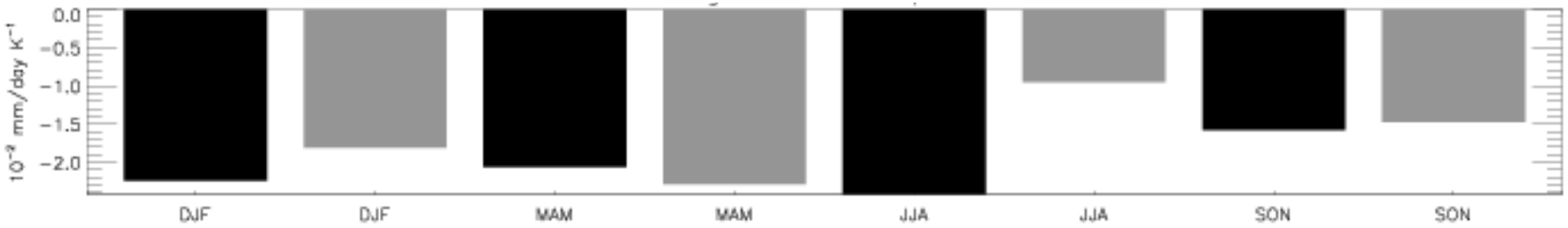


Bellouin and Boucher, 2009

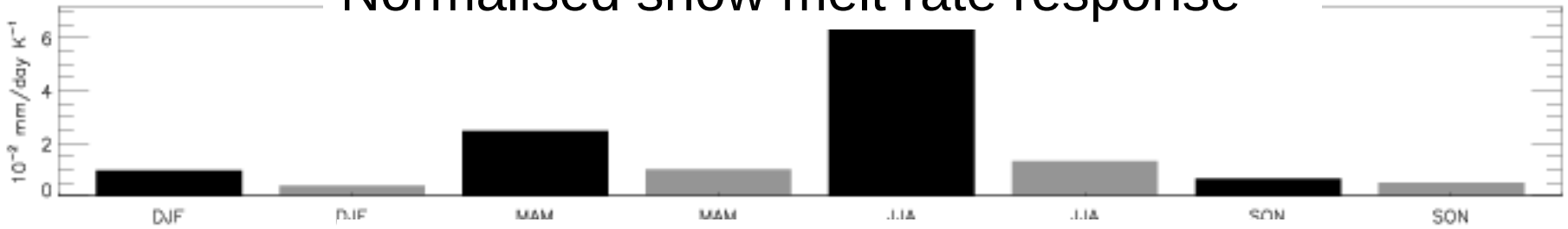
Normalised rainfall response



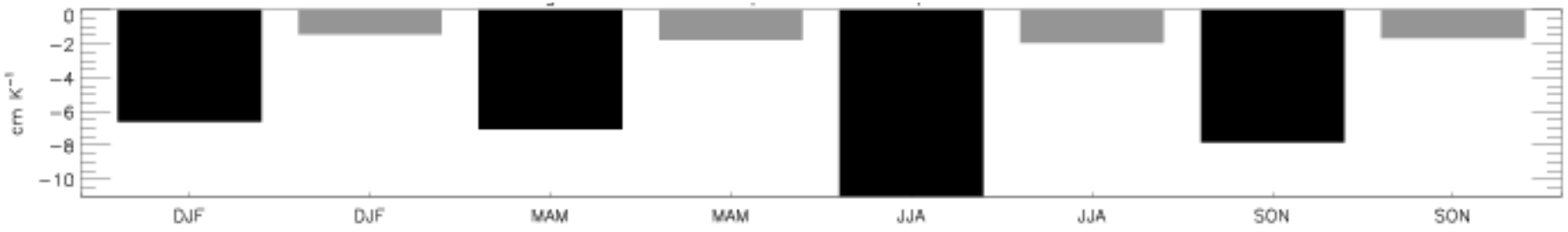
Normalised snowfall response



Normalised snow melt rate response

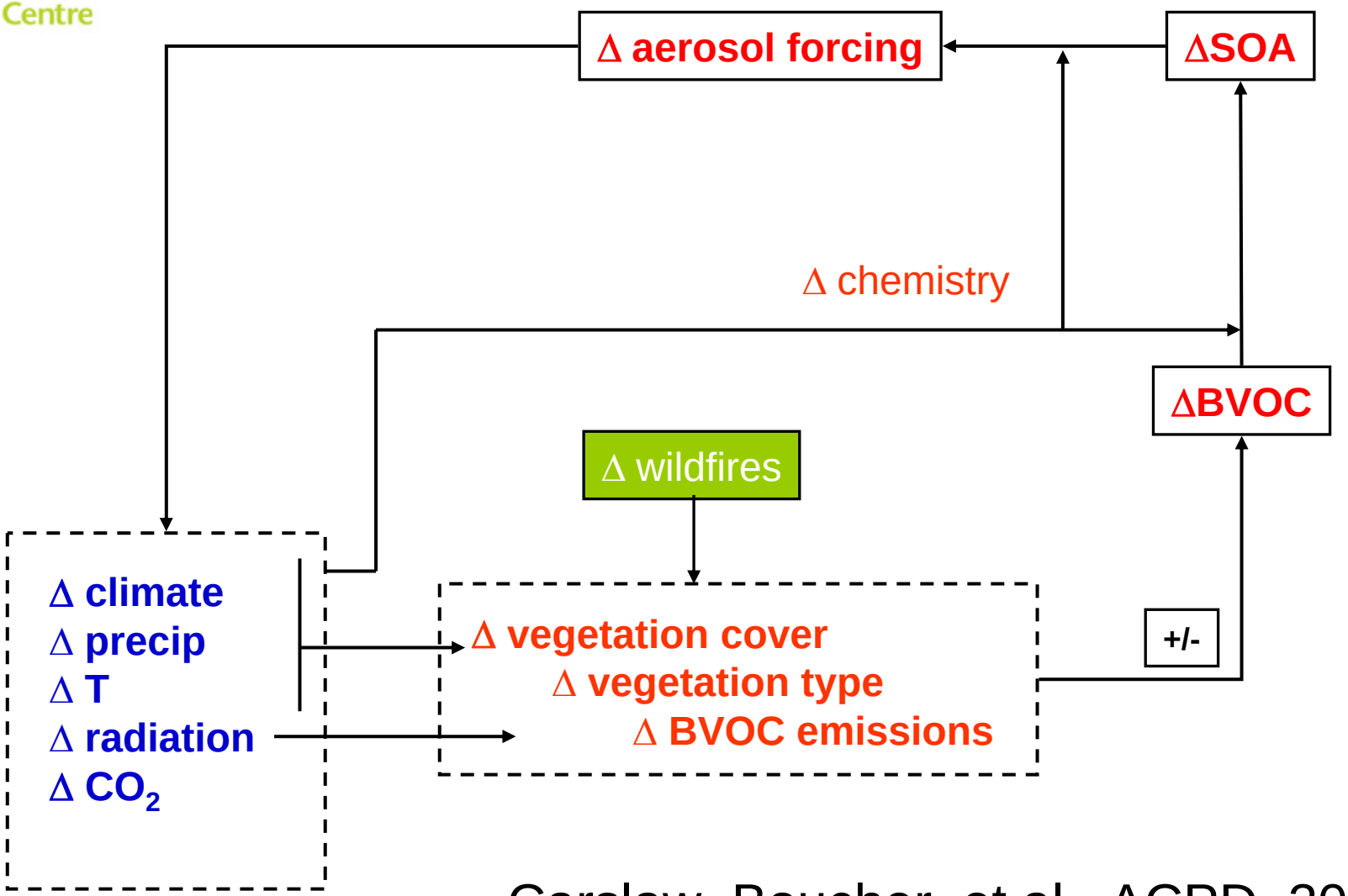


Normalised snow depth response



Bellouin and Boucher, 2009

Feedback loops: Secondary organic aerosols



Carslaw, Boucher, et al., ACPD, 2009

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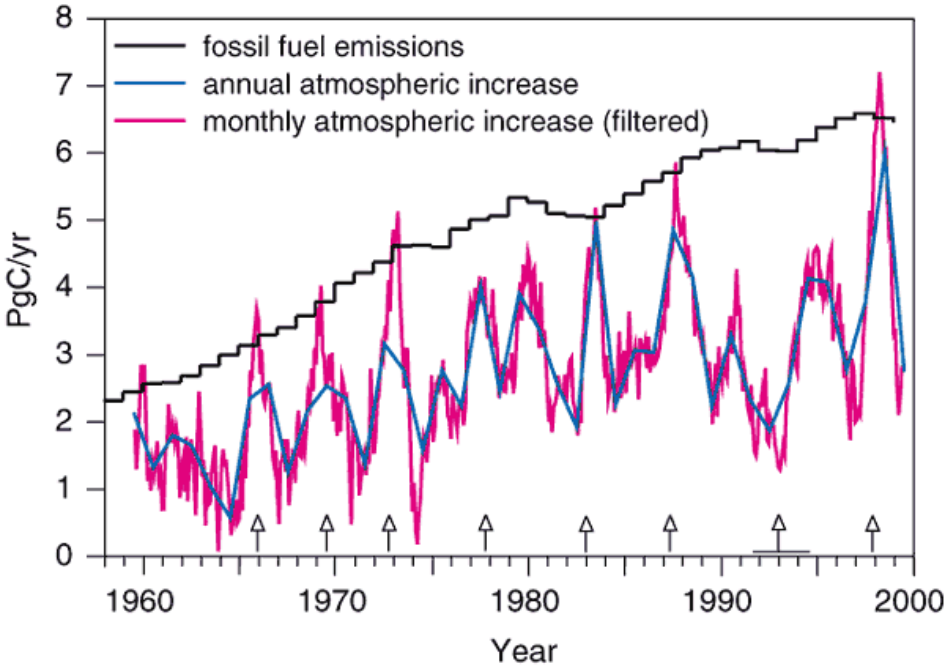
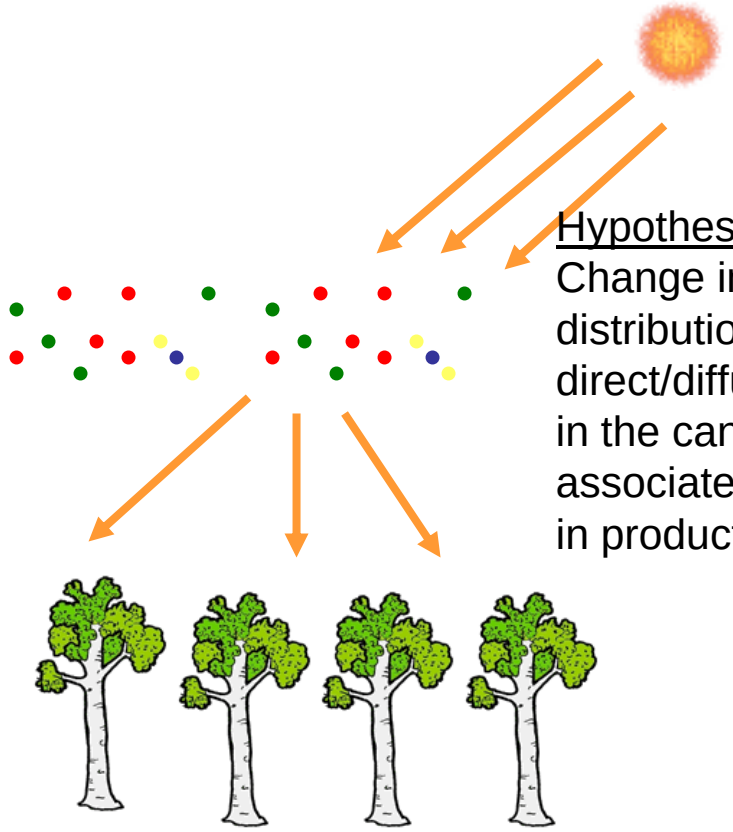
An aerosol impact on carbon sinks?

Interannual variability in the (land) carbon sink



<u>Hypothesis</u>: some of it may be caused by large events of stratospheric aerosols

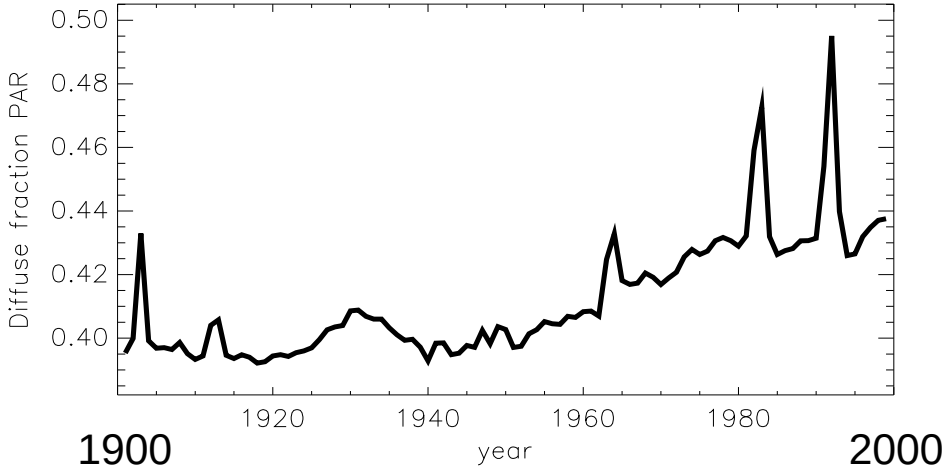


<u>Hypothesis:</u>
Change in the distribution of direct/diffuse light in the canopy with associated changes in productivity

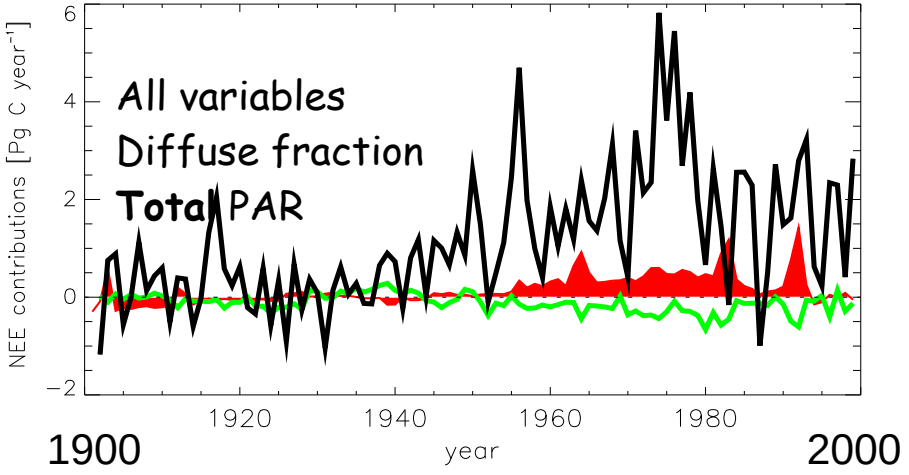
If true, there must have been a (transient) effect of tropospheric aerosols on the land carbon sink during the XX century.

Impact of changes in diffuse radiation on the global land carbon sink - 20th century

Diffuse fraction



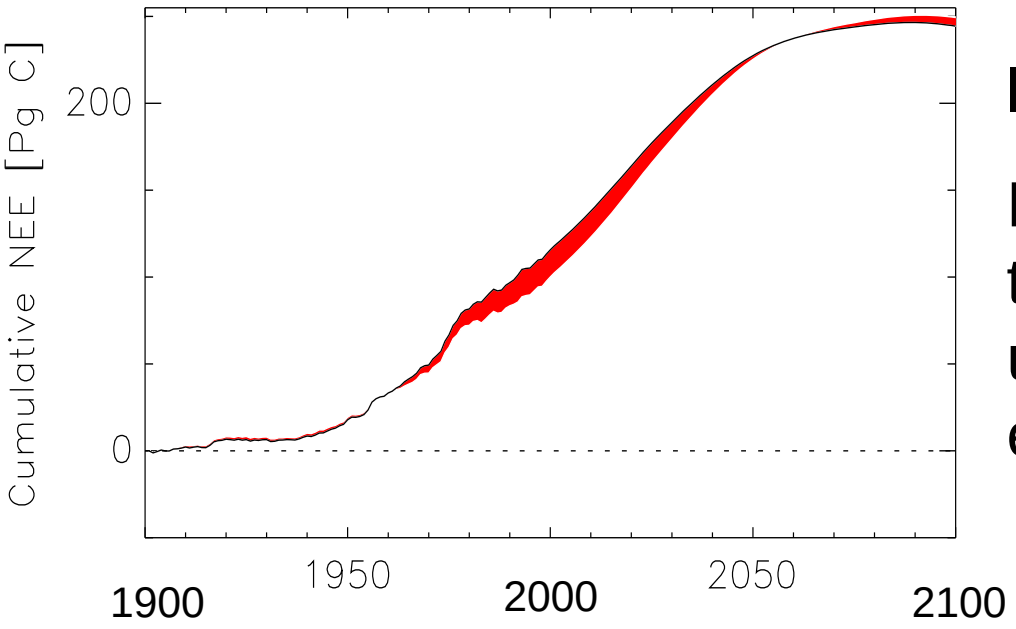
Contributions to C sink



Contributes 9% to terrestrial C sink over 1960-2000

Mercado et al., *Nature*, 2009
CEH-Met Office-Exeter Uni.

Impact of changes in diffuse radiation on the global land carbon sink - 21st century



In the future

Diffuse radiation contribution to land C sink will decrease under decreased aerosol emissions.

Mercado et al., *Nature*, 2009
CEH-Met Office-Exeter Uni.

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Summary

- Many potential feedback loops involve aerosols but only a few may be significant at the global scale
- Potential amplification mechanisms are
  - Change in vegetation (dust)
  - Change in vegetation productivity (aerosol diffuse radiation)
  - Change in snow albedo from boreal forest fires ?
- Earth system models can answer some of the questions
  - HadGEM2-ES (IPCC AR5)
  - QESM / HadGEM3-ES

Earth System Components in HadGEM2

Hadley Centre Global Environment Model 2

Fully coupled Earth System Model

- Atmosphere, ocean, sea-ice, land surface
- Land ecosystems: dynamic vegetation, soil carbon
  - TRIFFID, RothC
- Ocean ecosystems: NPZD, diatoms, non-diatoms, DMS
  - Diat-HadOCC
- Aerosols: Sulphate, BC, OC, dust, sea salt, nitrate?
- Tropospheric chemistry: ozone, methane, oxidants
  - UKCA

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HadGEM3-ES

Met Office Hadley Centre

Regional climate model

UKCA Troposphere & Stratosphere & Aerosols

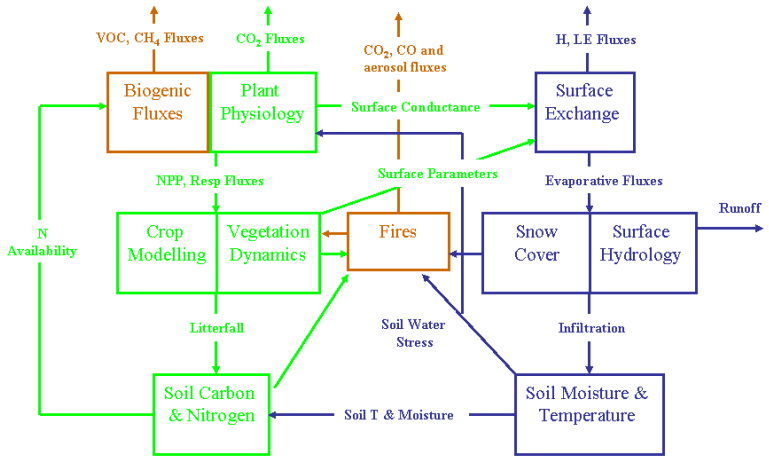
UM "atmosphere"

FLUME'd OASIS

CICE

NEMO

JULES



Land surface and impacts

Ice sheet model

Ocean biogeochemistry QPFT (TBC)

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Thank you for your attention

Questions?