The science of the Kyoto protocol

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with lots of help from Climate Chemistry and Ecosystem group

ECMWF seminar September 2005

Outline

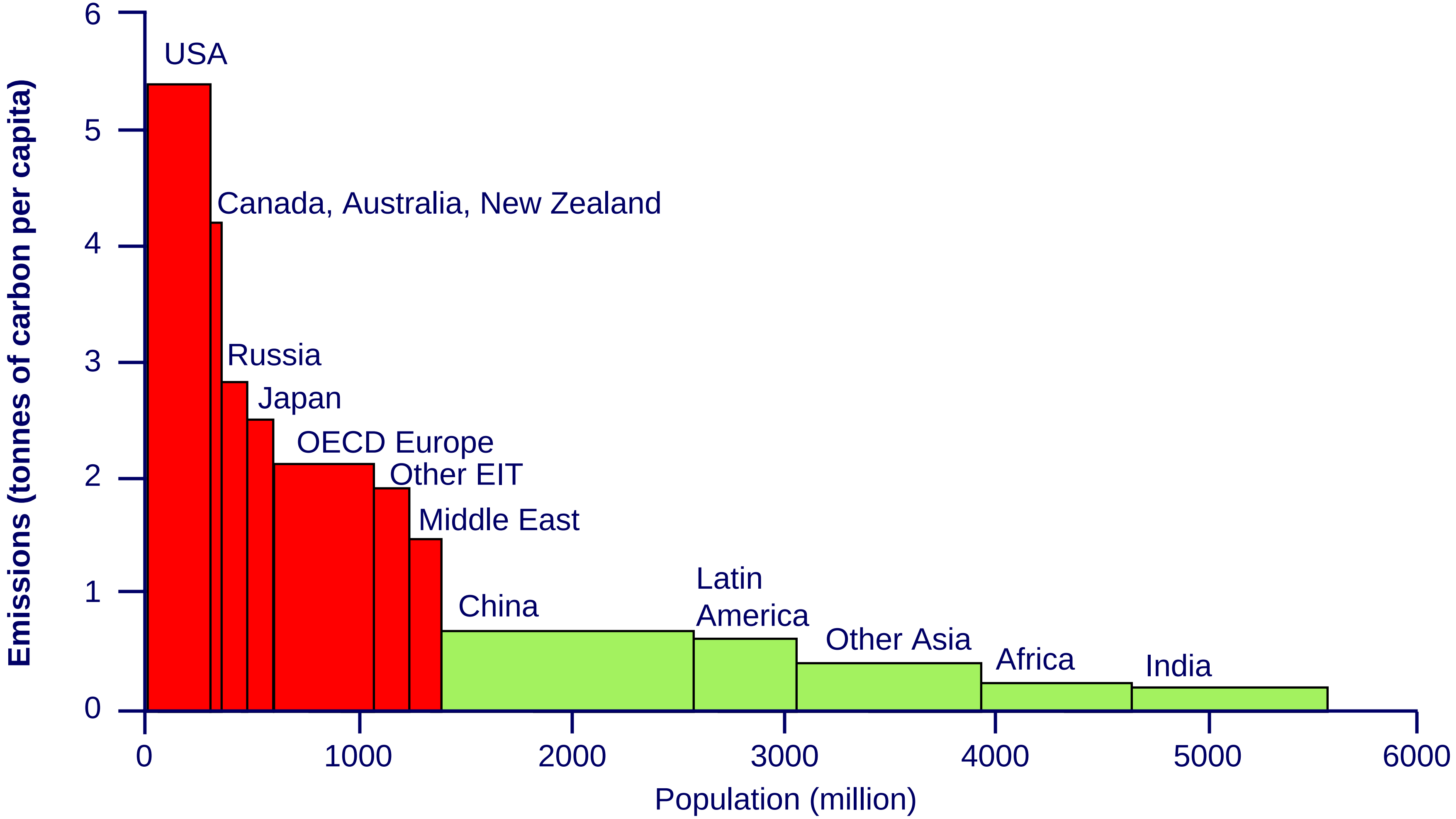
- Kyoto protocol
- Observations relevant to Kyoto
  - Baseline analysis
- Modelling relevant to Kyoto
  - Earth system modelling

Kyoto protocol

- The targets cover emissions of the six main greenhouse gases, namely:

  - Carbon dioxide (CO_2);
  - Methane (CH_4);
  - Nitrous oxide (N_2O);
  - Hydrofluorocarbons (HFCs);
  - Perfluorocarbons (PFCs); and
  - Sulphur hexafluoride (SF_6)

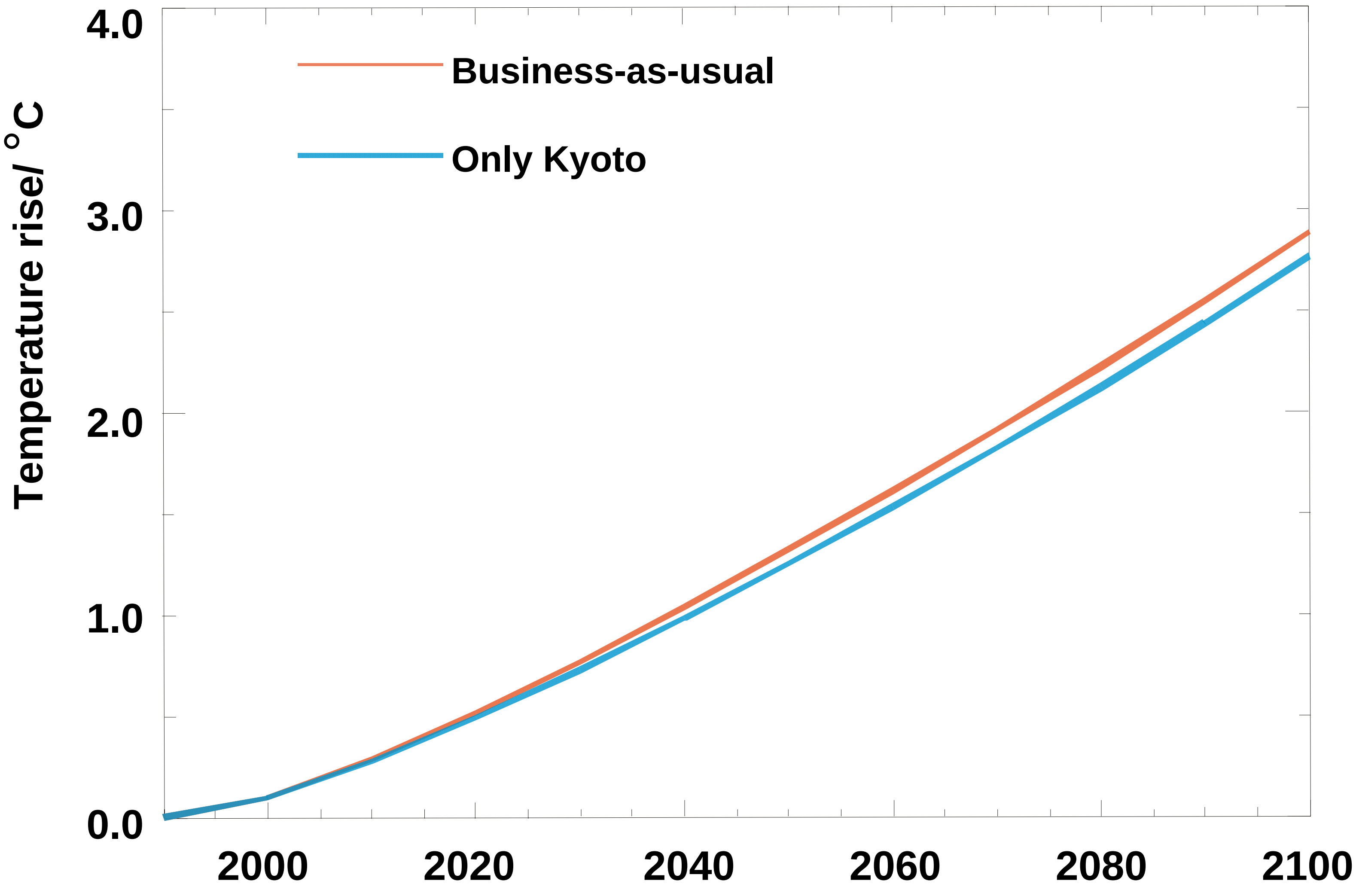
CO_2 per capita emissions and population (2000)



The 1997 Kyoto Protocol

- Developed countries (38) agreed to reduce emissions of greenhouse gases below their 1990 levels by 2010
- Reductions average 5% (UK reduction 12%)
- Planting trees can offset emissions by absorbing CO2
- Countries can buy and sell carbon emissions reductions
- Entry into Force: 16 Feb 2005. US has declined to ratify.
- Even if all countries ratify, reduction in warming will be small

Effect of Kyoto Protocol on global temperature



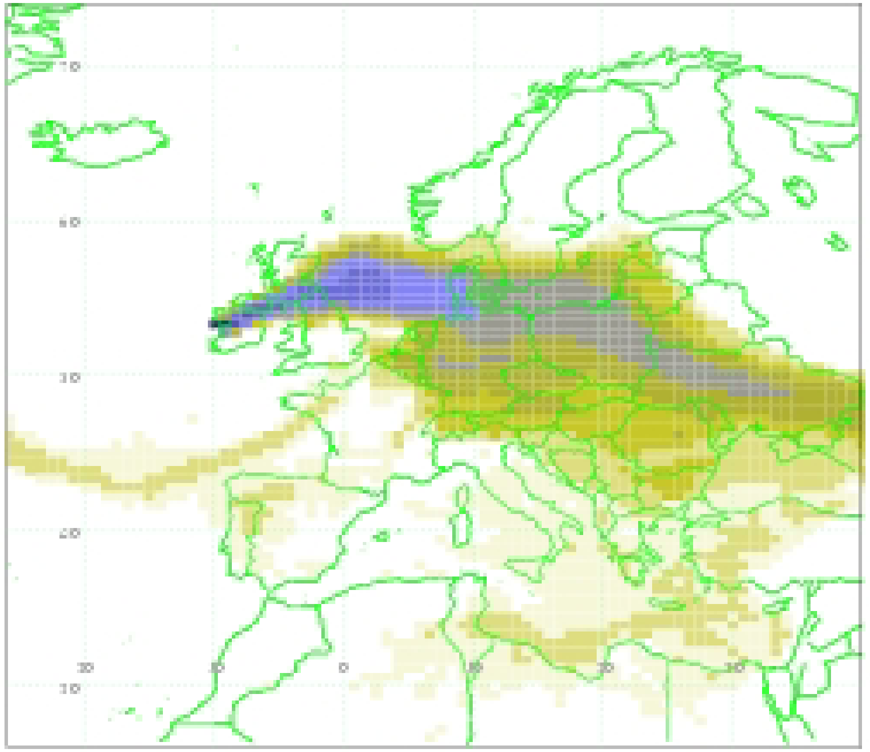
The 1997 Kyoto Protocol

- Negotiations on targets for the **second commitment** period are due to start in 2005, by which time Annex I Parties must have made “demonstrable progress” in meeting their commitments under the Protocol.

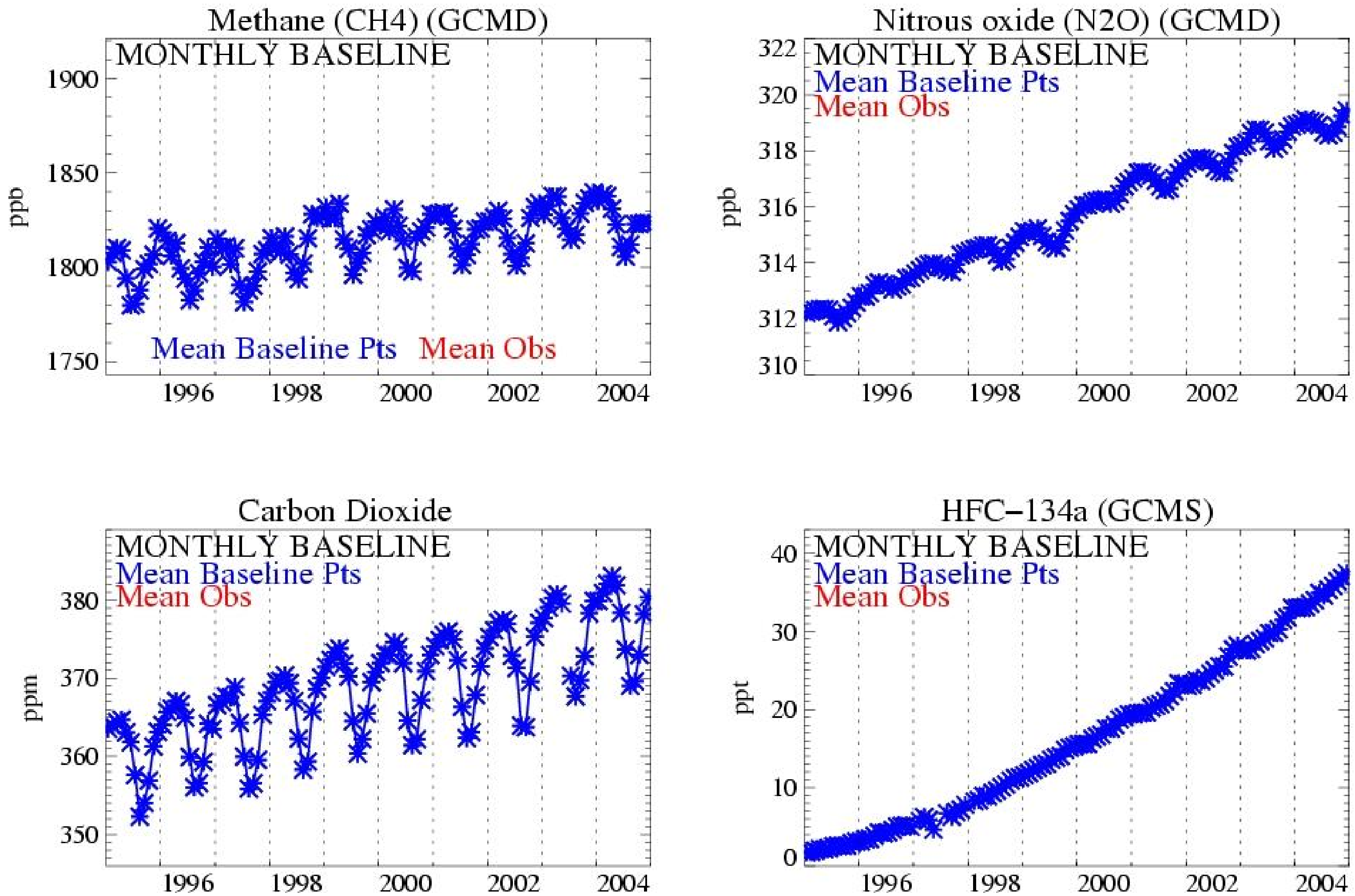
Baseline Analysis of Mace Head Observations

- Based on meteorological analyses
- NAME model derived air history maps - Darker shade means greater contribution from area
- All possible surface sources over previous 10 days
- Maps generated for each hour 1995-2004
- Sort Mace Head observations into ‘baseline’ (Atlantic) and ‘regionally polluted’ (European) based on air history maps
- Estimate Baseline trends of each GHG measured

0300Z 21/03/1996 to 04002 21/03/1996



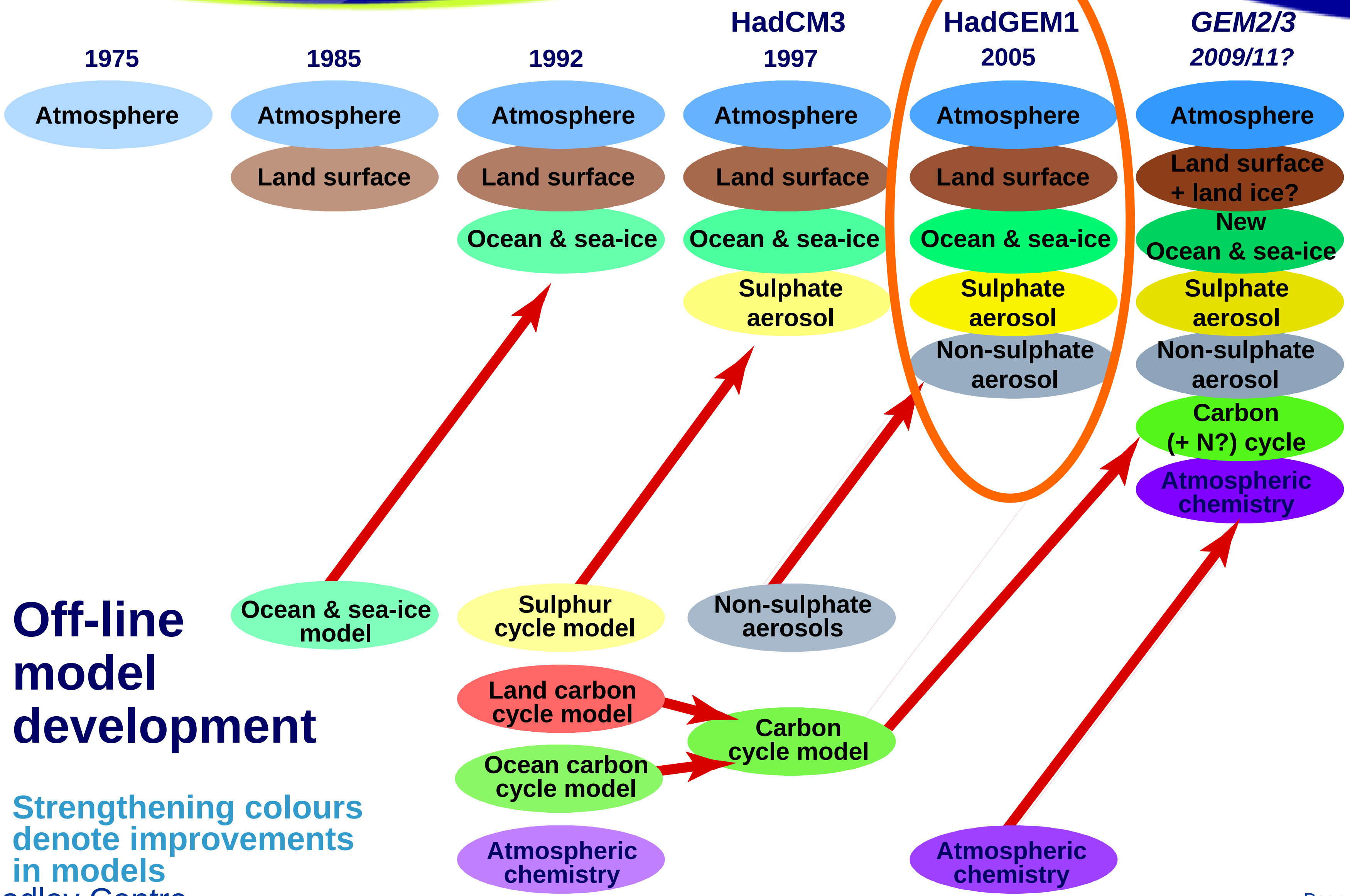
GHG baseline trends from Mace Head data



Reasons for building an Earth System Model

- climate-carbon feedback
- climate-chemistry interactions
- climate-aerosol interactions

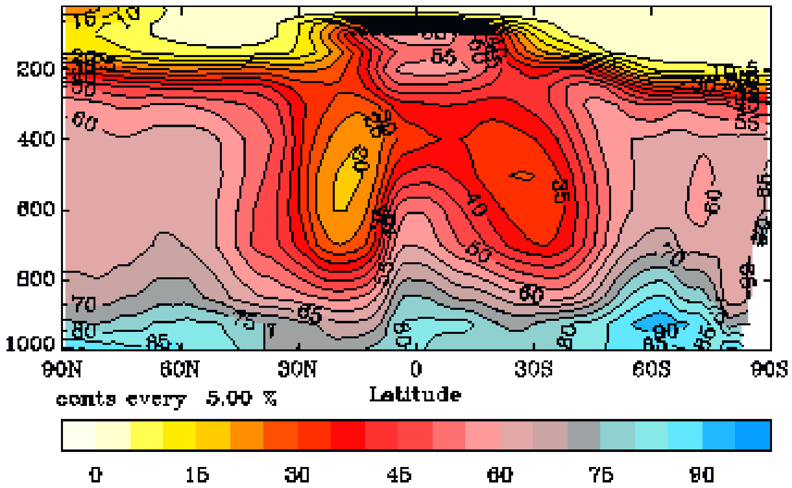
Development of the Hadley Centre Earth System Model
beyond HadGEM1



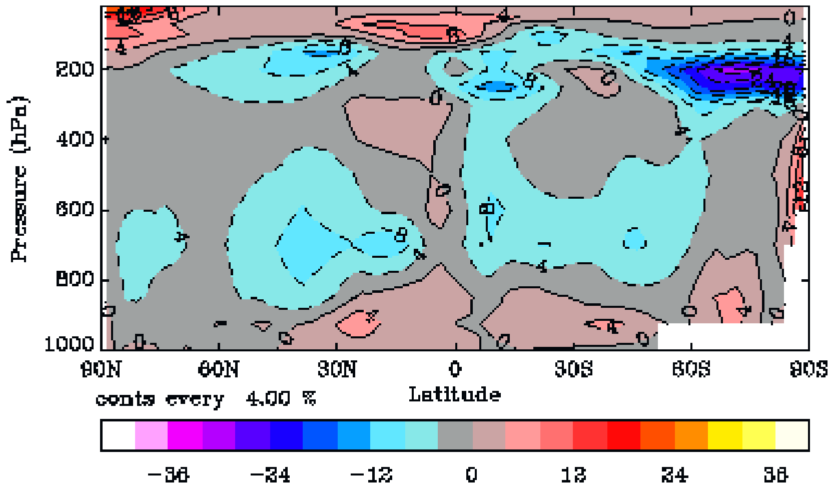
Importance of the baseline model

Relative humidity

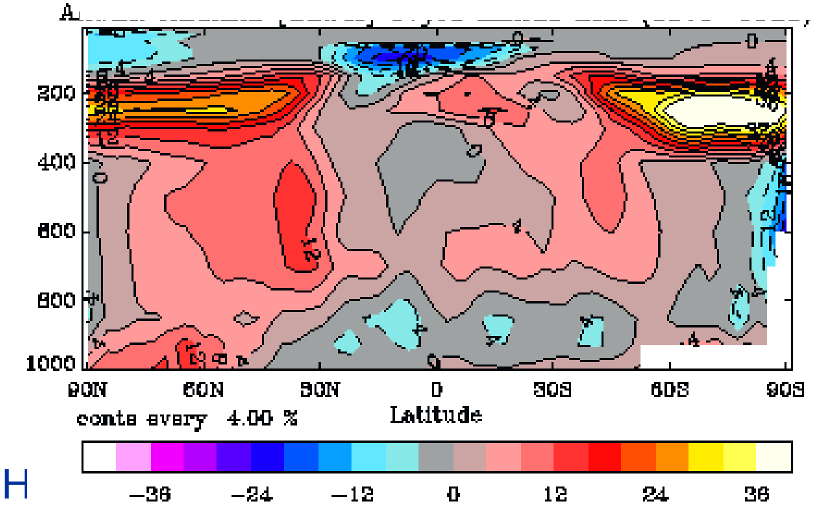
HadGEM1



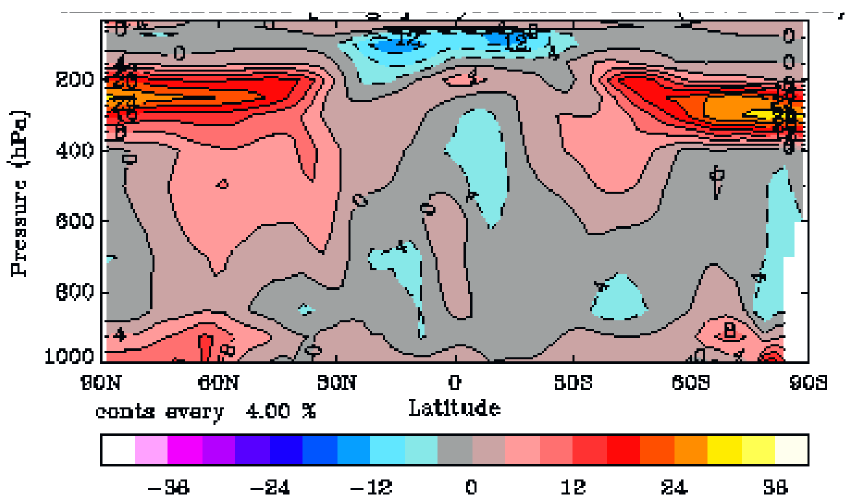
HadGEM1 – HadCM3



HadCM3 - ERA



HadGEM1 - ERA

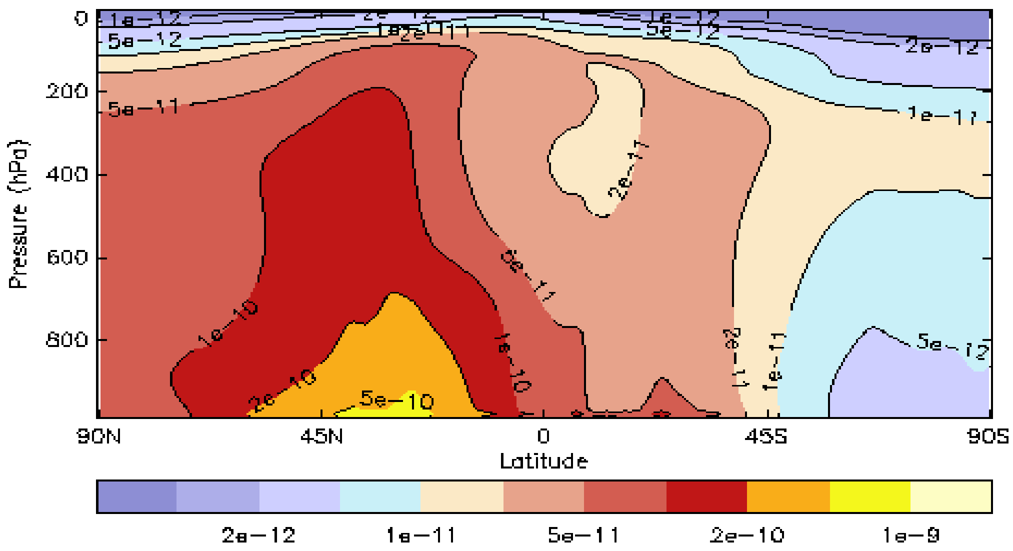


H

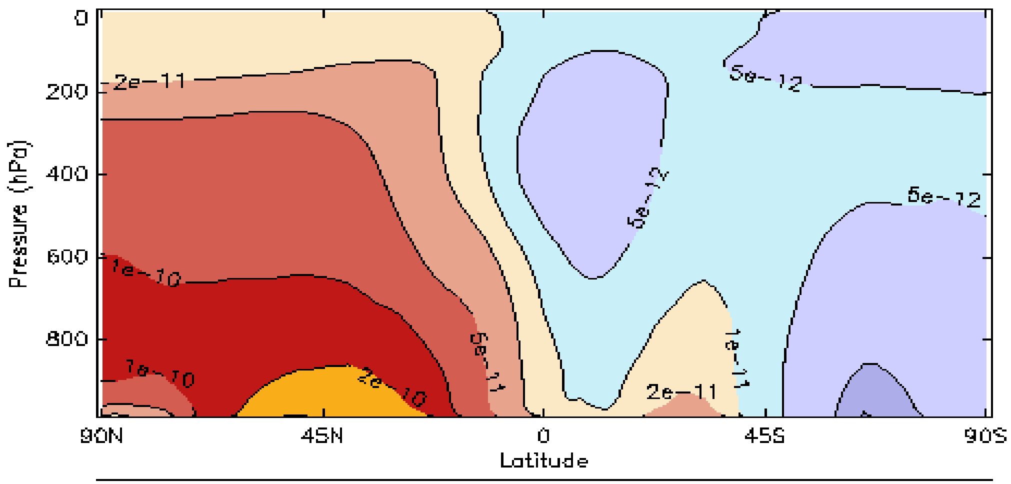
Transport

Black Carbon concentration (kg/kg)

HadGAM1

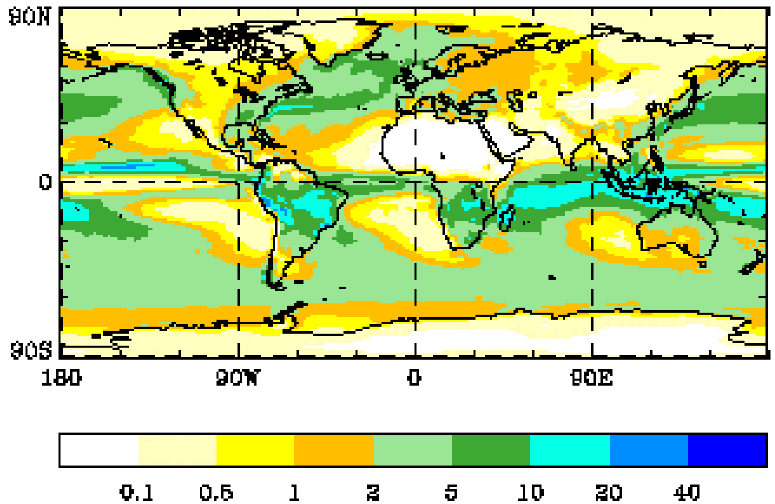


HadAM4

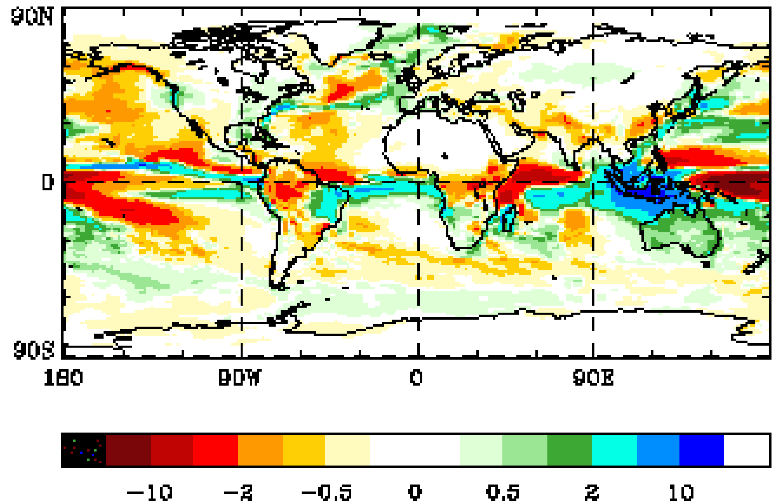


Precipitation – coupled feedbacks

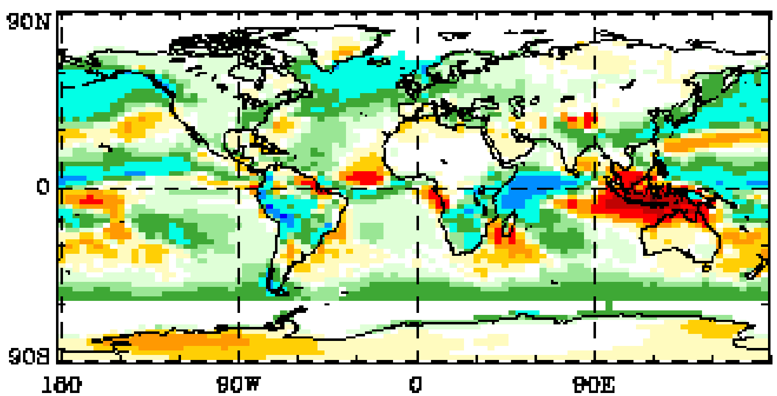
HadGEM1



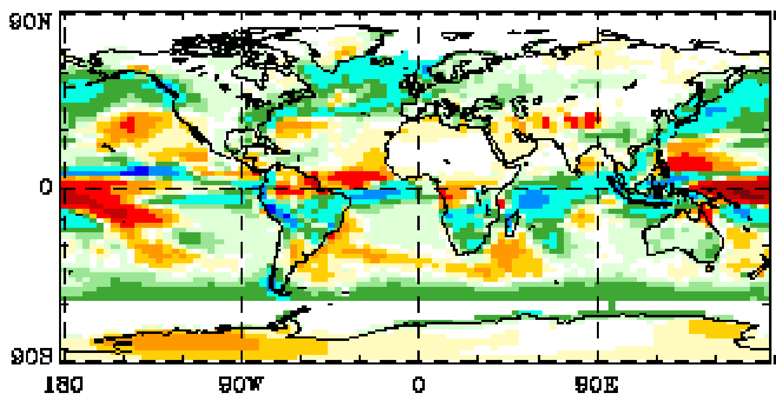
HadGEM1 – HadGAM1



HadGAM1 – CMAP

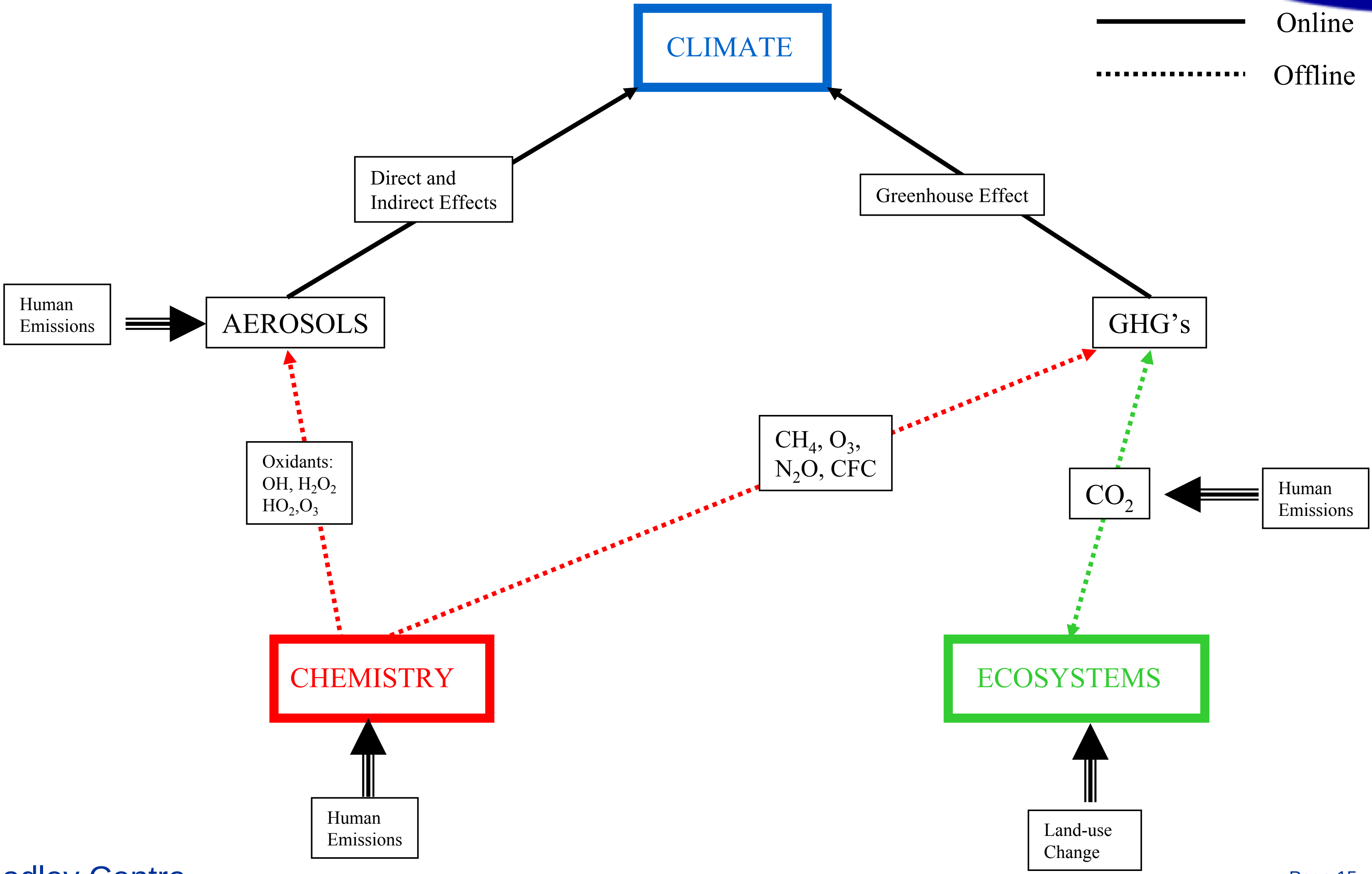


HadGEM1 – CMAP

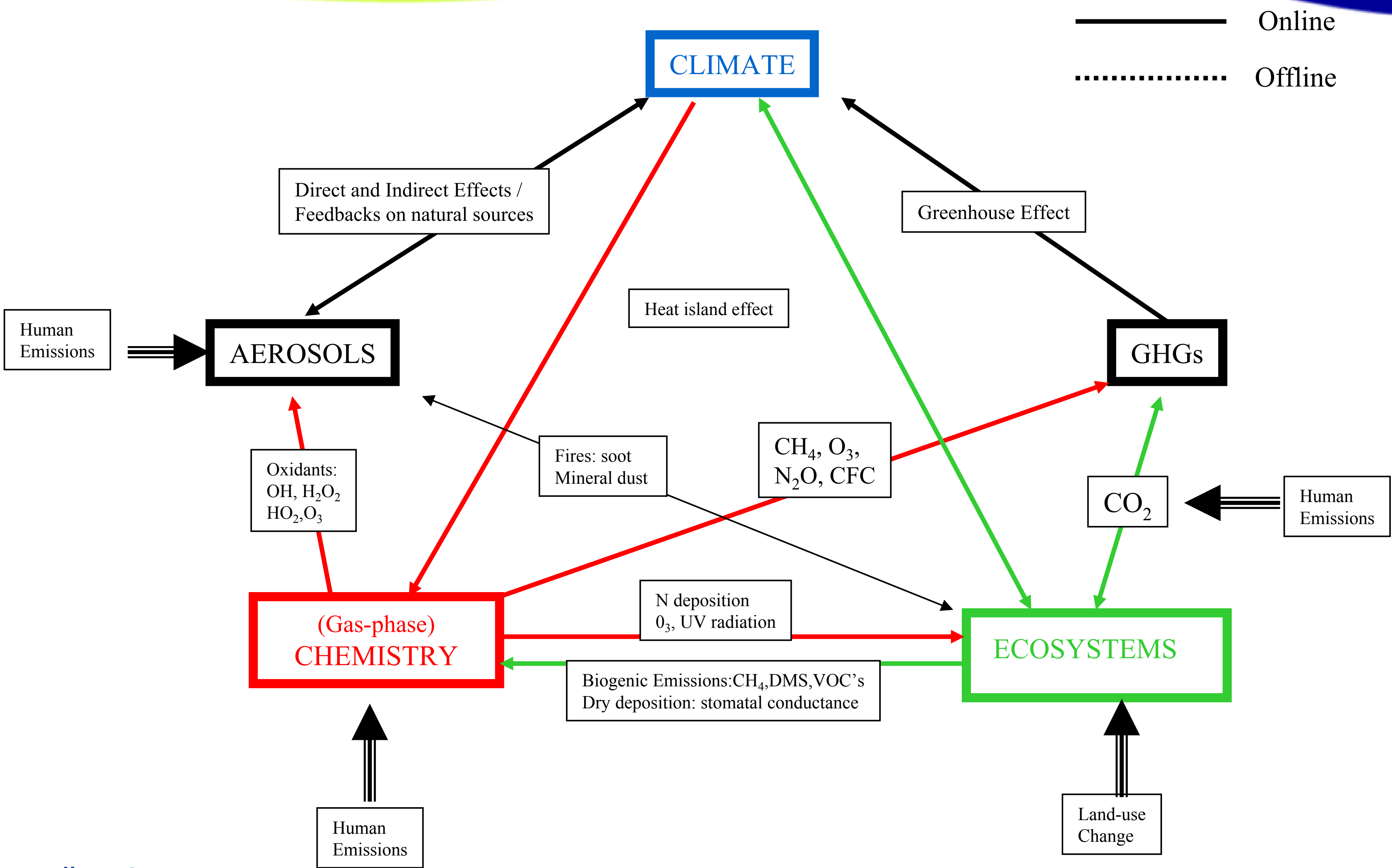


Earth system components

2005



Earth system models for climate 2009



HadGEM1 – Atmospheric Aerosols and Chemistry

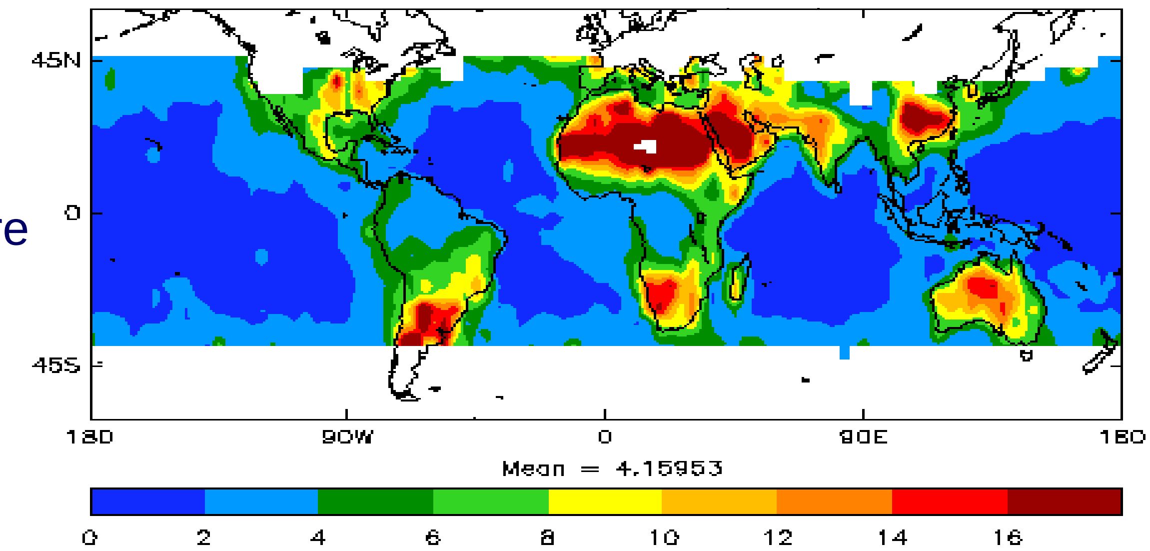
- Interactive, on-line aerosols scheme (replacing climatological background aerosols):
  - Sulphate, FF black carbon, biomass-burning aerosol (prognostic), sea-salt aerosol (diagnostic)
  - Some chemistry associated with atmospheric aerosols is included (oxidants are specified).
- Direct and indirect radiative forcings included.
- *Mineral dust scheme not yet included.*
- *No interactive carbon-climate or chemistry-climate coupling in the standard HadGEM1 model. However, a version of HadGEM1 with on-line coupling to STOCHEM has been developed (which is much more expensive).*

Column integrated droplet concentration

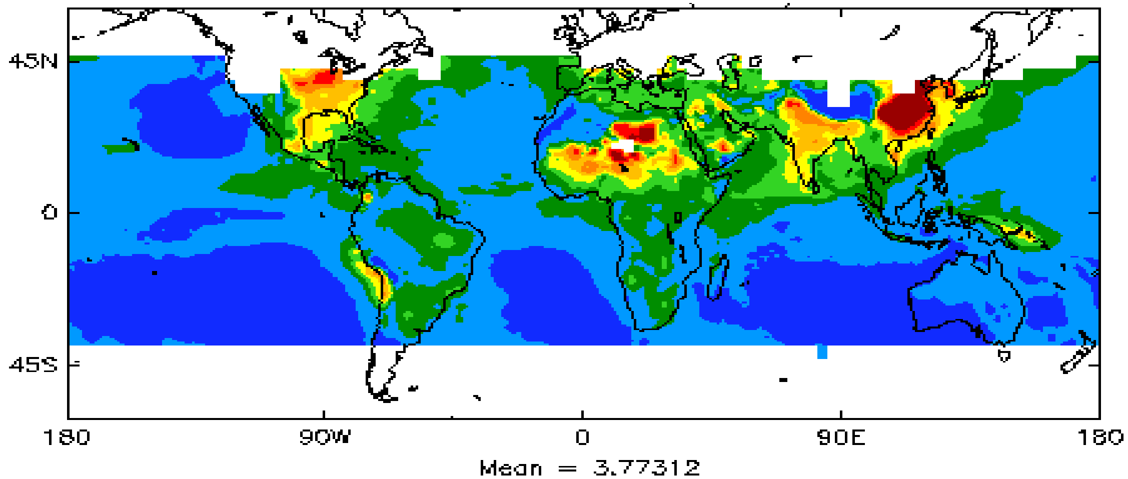
Column-integrated droplet numbers compare reasonably well with observations. (There is no mechanism for generating number concentration without aerosol.)

Droplet size is underestimated due to a lack of cloud water in sub-tropical oceanic regions.

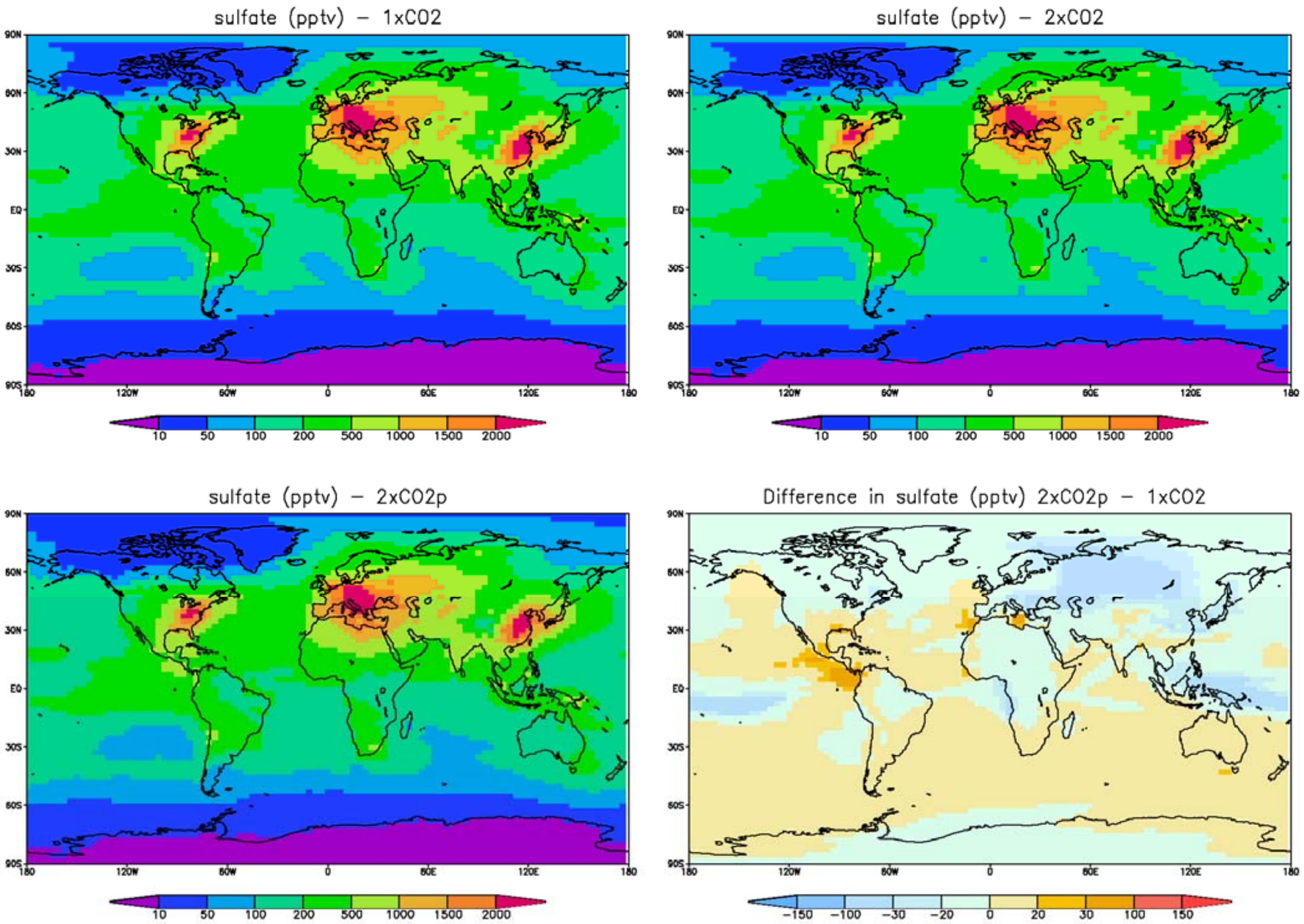
Han et al. ISCCP retrieval



HadGEM1 (transient run)



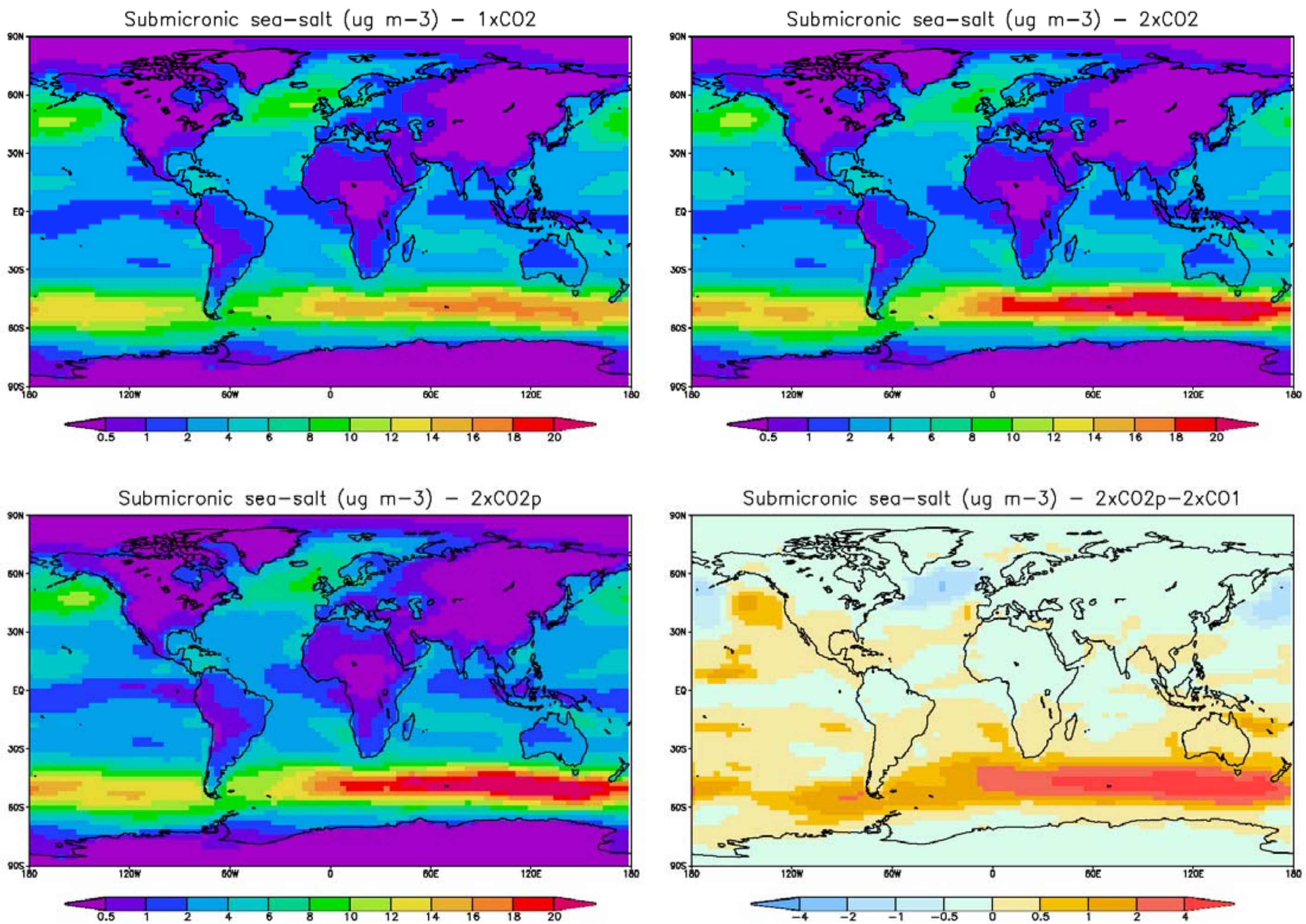
Change in sulfur cycle in a $2xCO_2$ climate



Emissions of natural sulphate precursors depends on wind speed (exp $2xCO_2$).

Both natural and anthropogenic sulphate responds to change in precipitation (exp $2xCO_2p$).

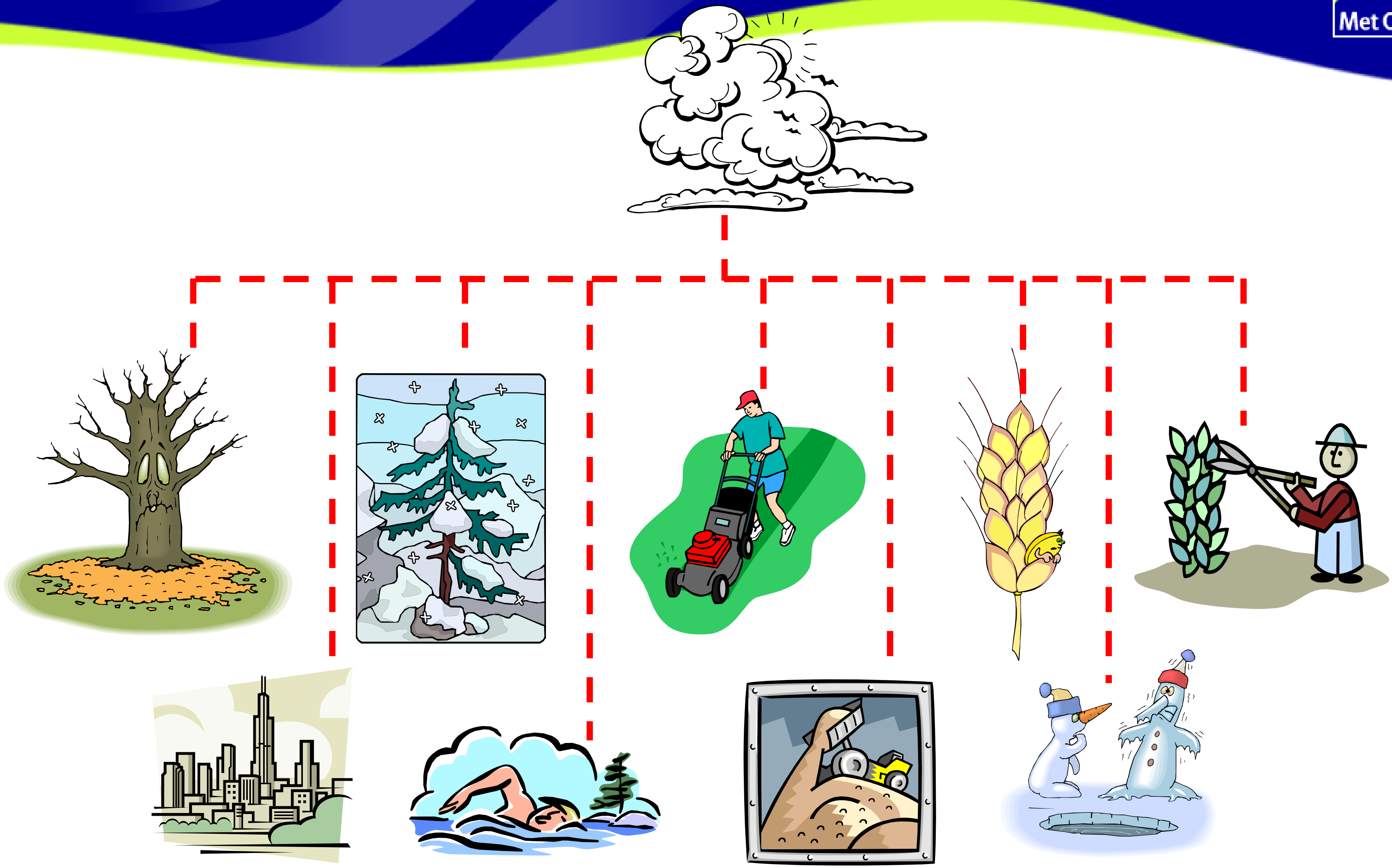
Change in sea salt cycle in a $2xCO_2$ climate



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

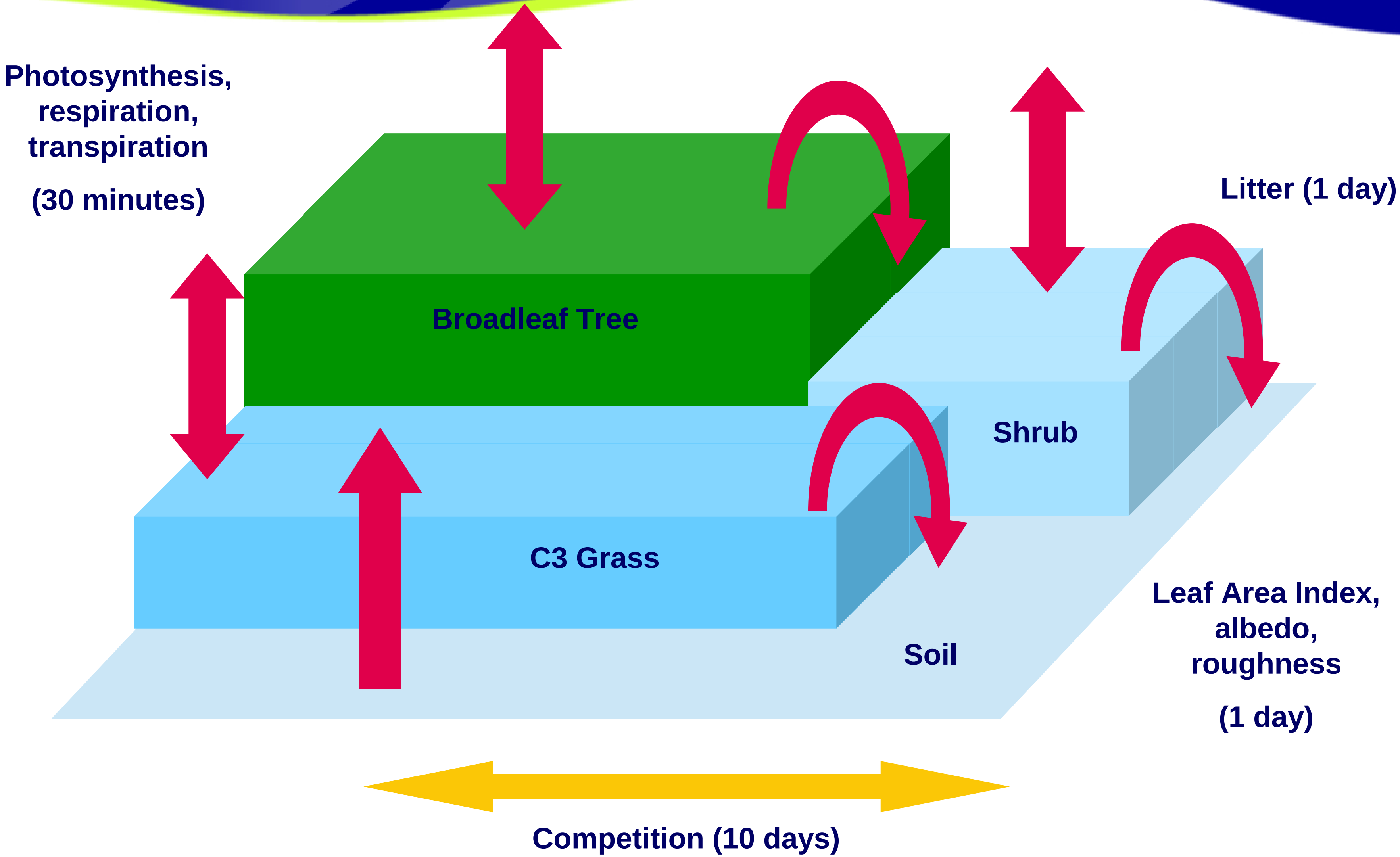
Less cooling in the NH, more cooling in the SH, leading enhanced hemispheric contrast.

Met Office Surface Exchange Scheme (MOSES)

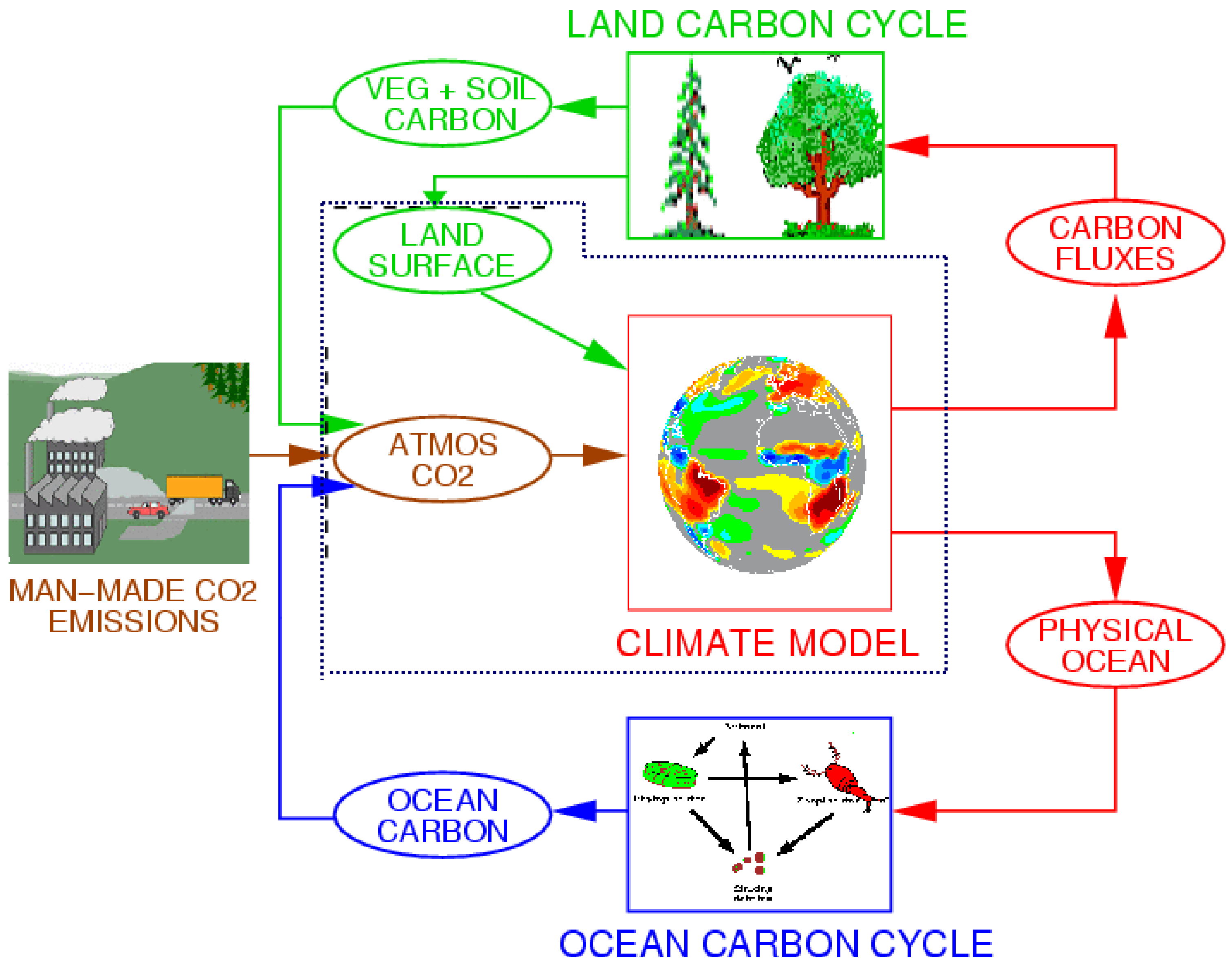


Land surface type prescribed – land use changes can be included

TRIFFID-GCM coupling

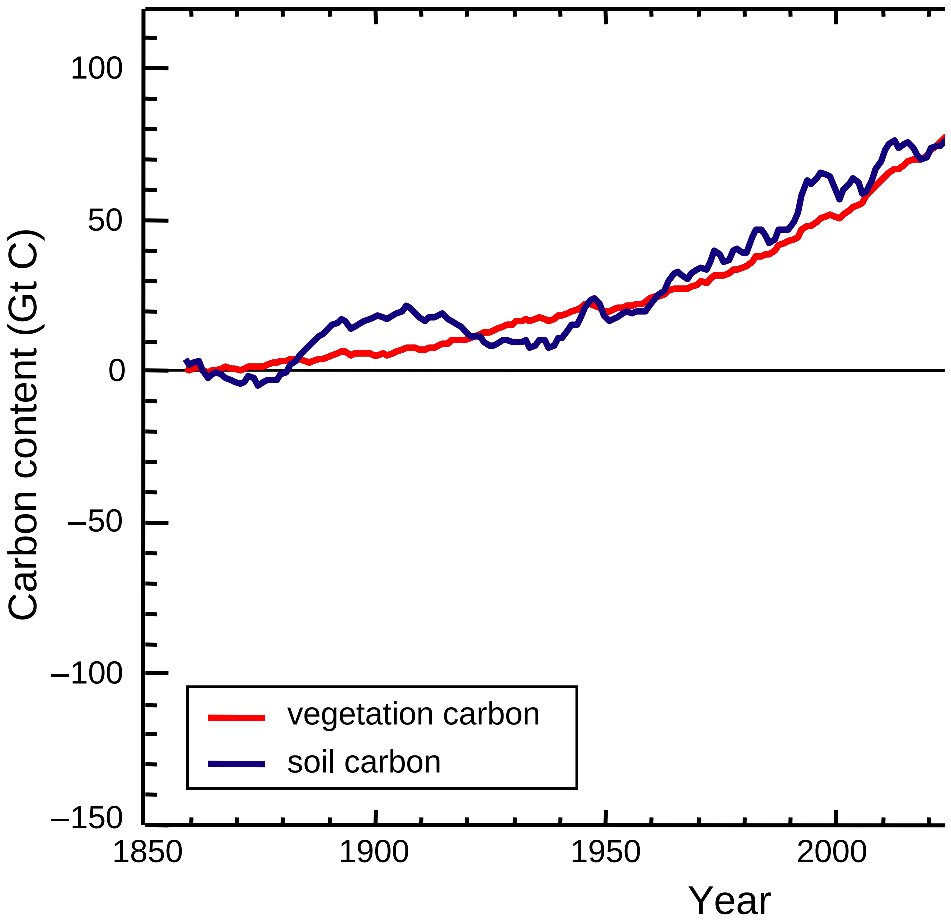


Hadley Centre Coupled Climate-Carbon Cycle Model



Can changes to the carbon cycle speed up climate change?

Simulated changes in the global total soil and vegetation carbon content



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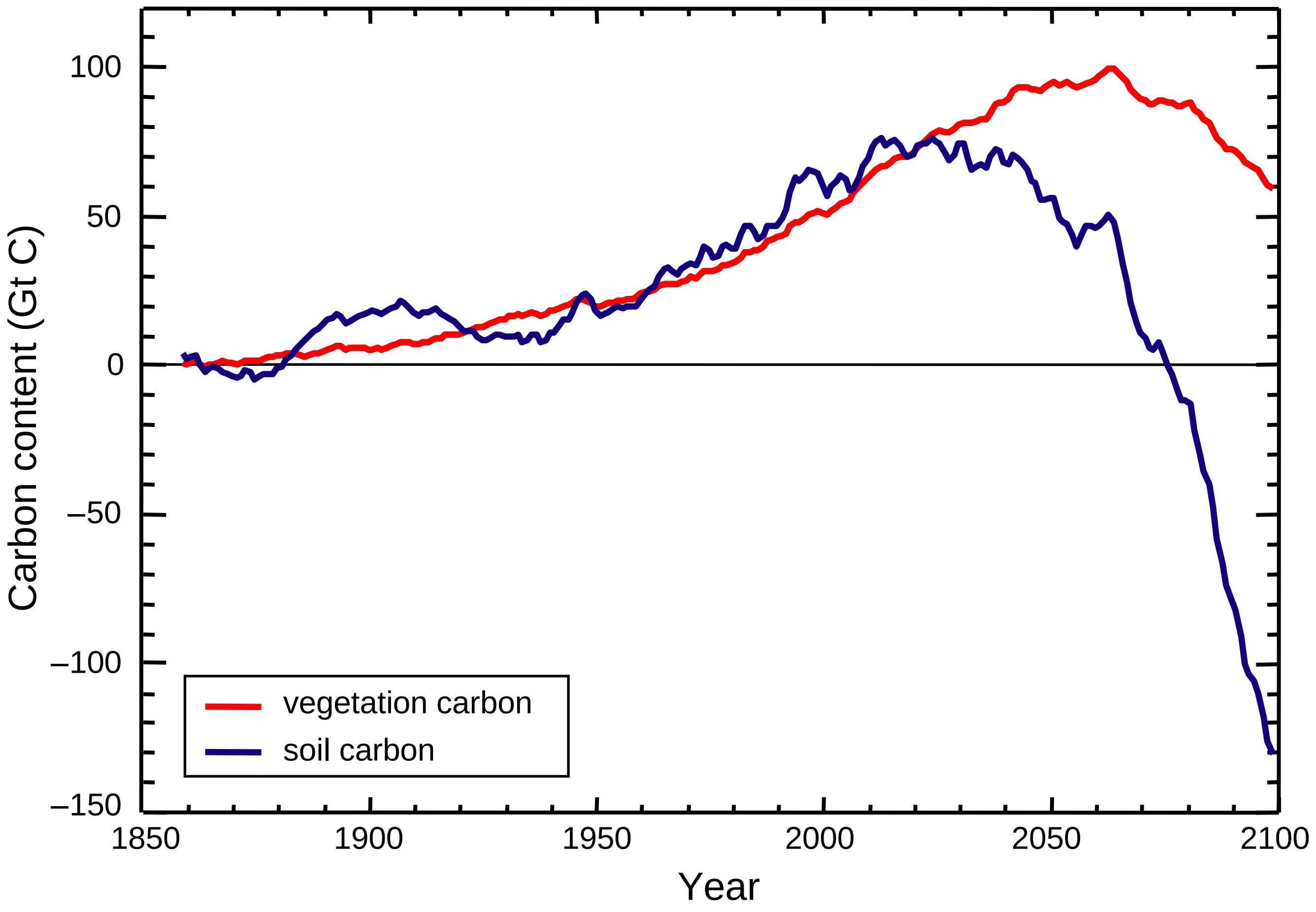
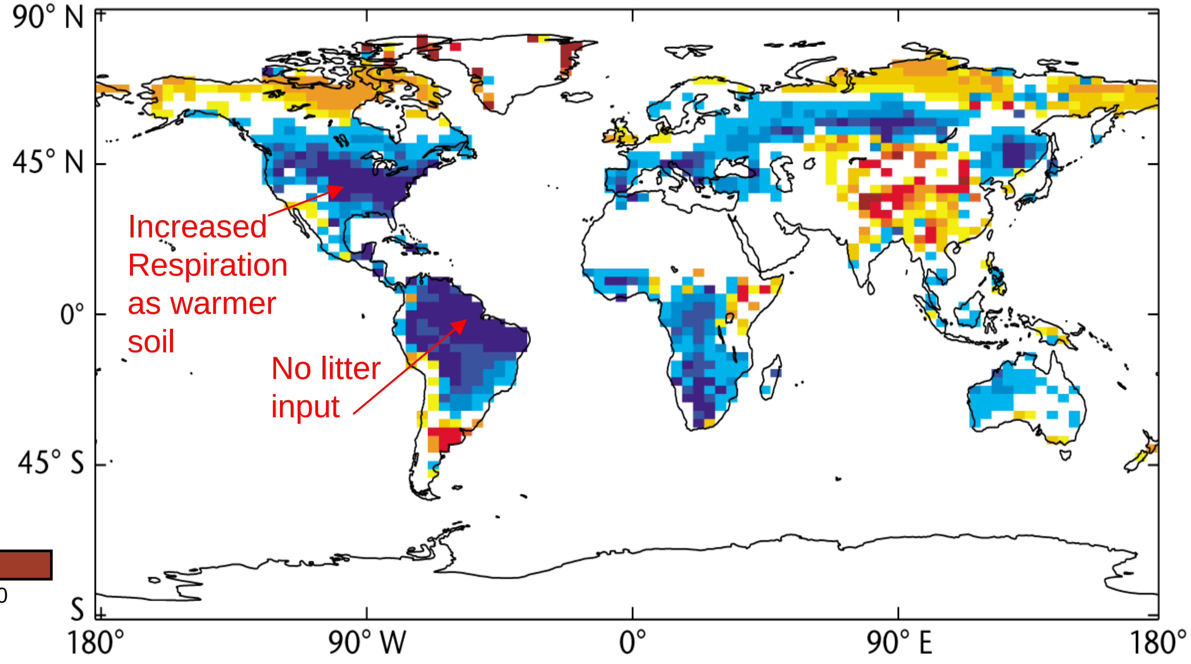
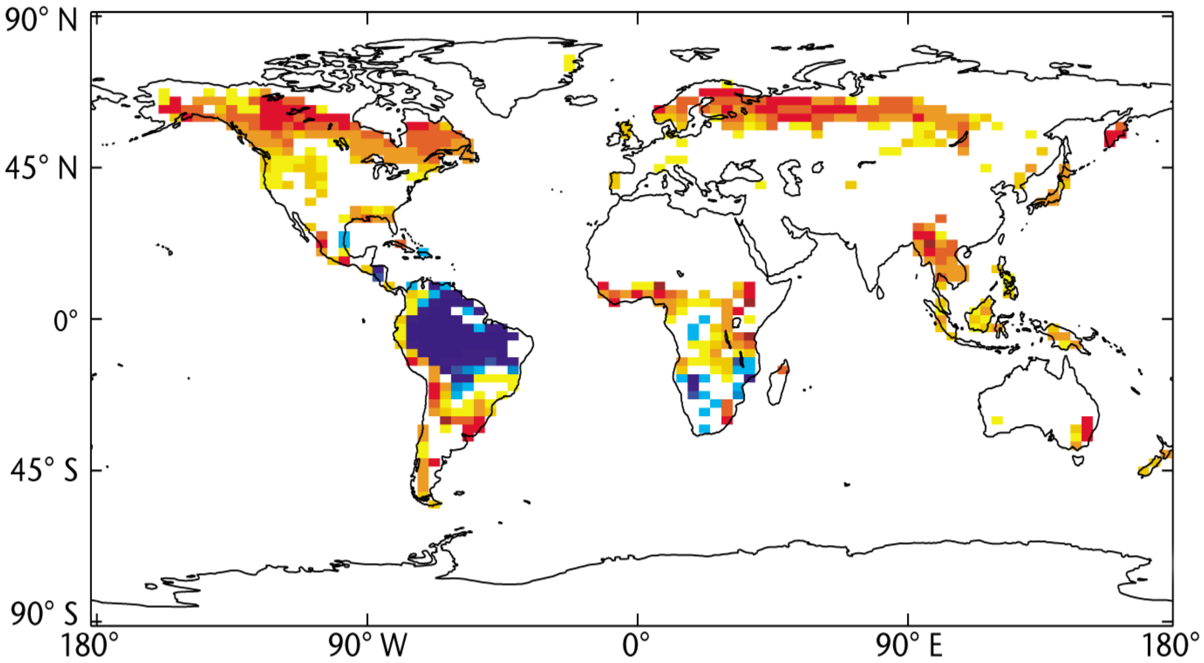


Change to carbon stored in soils (1860–2100)



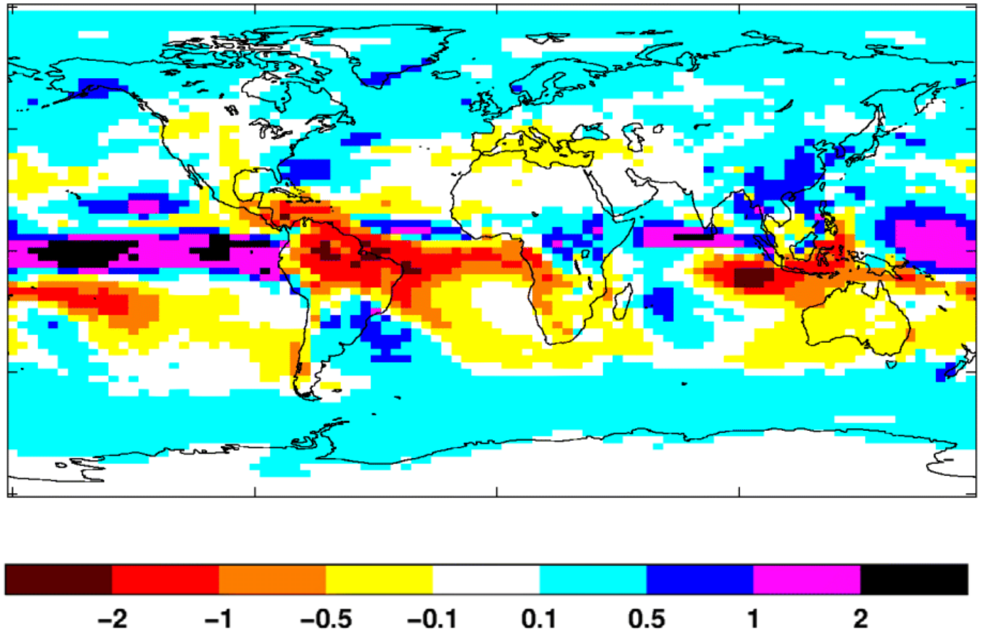


Change to carbon stored in vegetation (1860–2100)

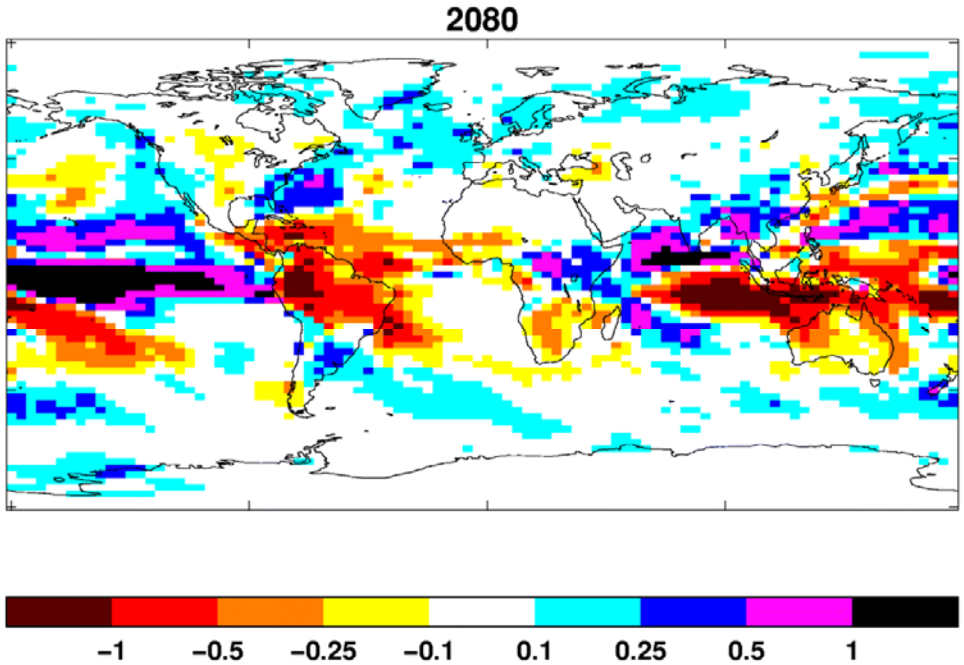
Local Feedbacks

Precipitation changes in 2080 relative to 2000

- Non-interactive CO_2



-Further precipitation changes with CO_2-climate feedback



mm day^{-1}

30-year means

Can changes to the carbon cycle speed up climate change?

The answer appears to be YES

- Climate-carbon cycle feedbacks significantly accelerate CO2 increase and climate change – **large positive climate feedback in HadCM3**

- Temperature rise over land
  - Without carbon feedback 5ºC
  - With carbon feedback 8ºC

- Land becomes source of CO2
  - Amazon dieback
  - Loss of soil carbon
- Ocean continues take up of carbon

WRE scenarios

- WRE are a family of scenarios of CO_2 level, stabilising at 450, 550, 650, 750 and 1000 ppmv

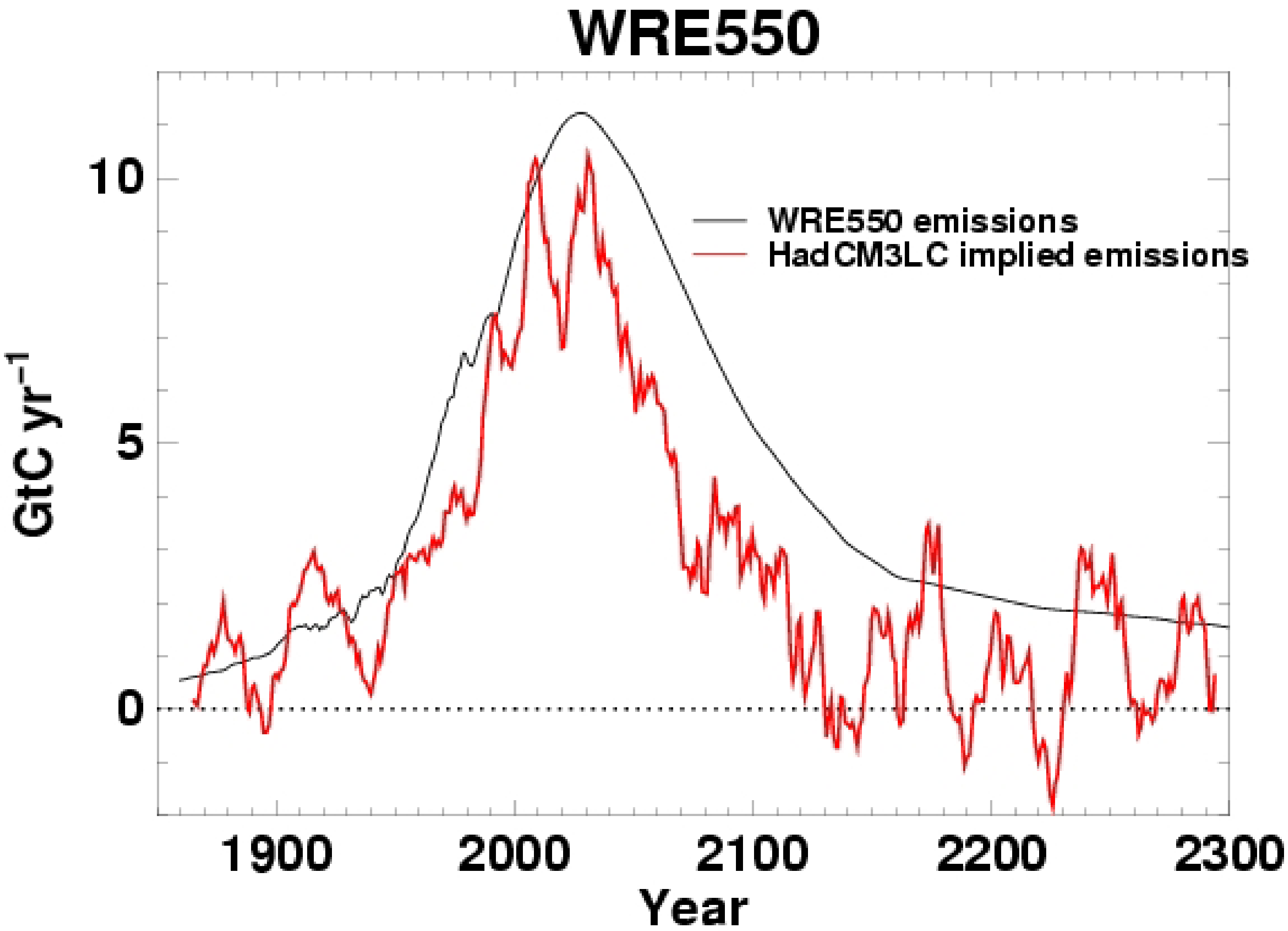
  Wigley, Richels and Edmonds. “Economic and environmental choices in the stabilisation of atmospheric CO_2 concentrations”. *Nature*, 1996.

- We run the carbon cycle GCM with these prescribed CO_2 levels and infer the emissions required to achieve them

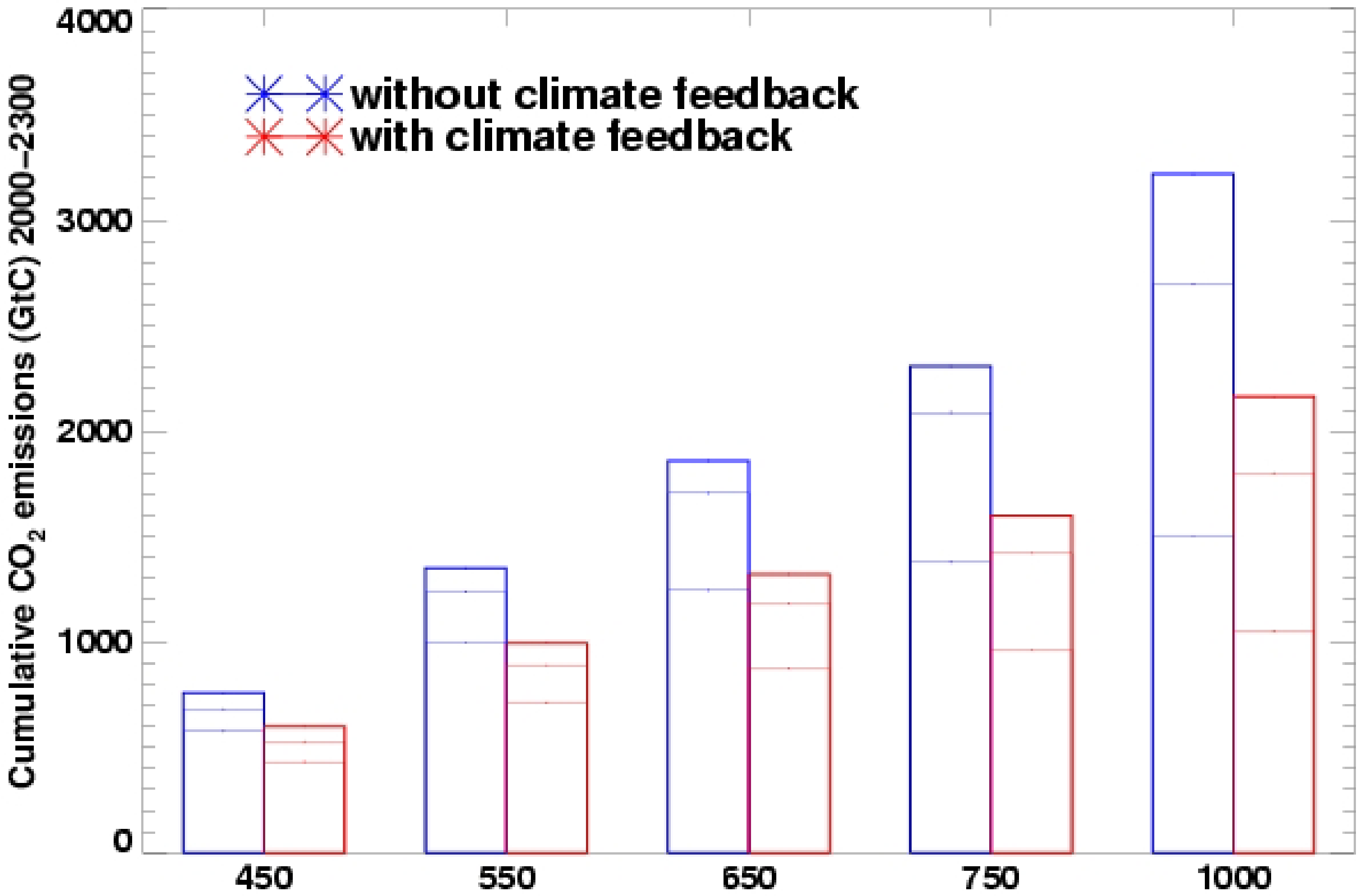
- Results shown in detail for 550 ppm

- Summary of results for all levels

WRE550 Carbon emissions



Other stabilisation levels

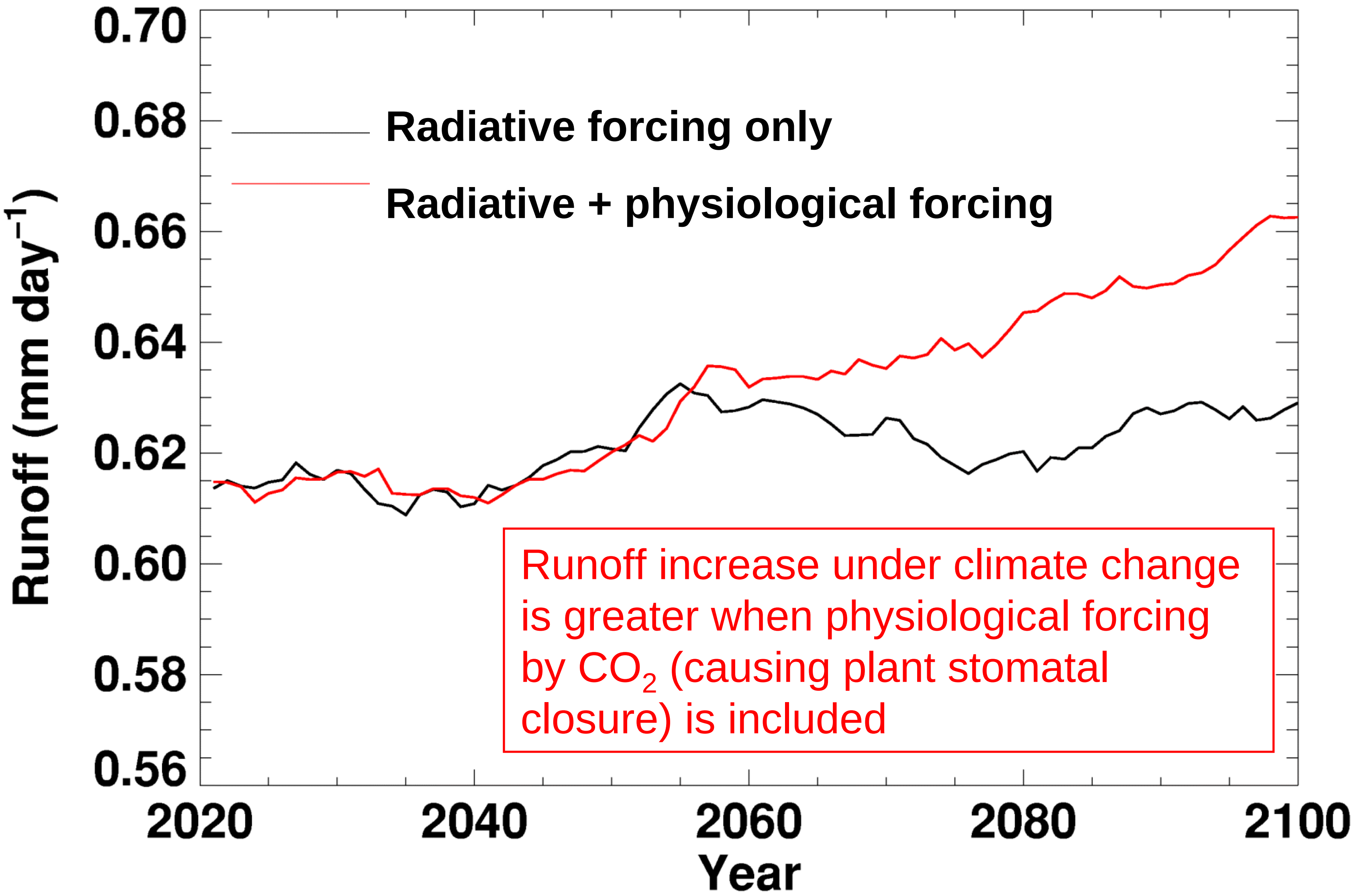


Net Effect of Reforestation - Importance of Albedo

- Forests are typically much darker than grasslands and croplands, especially in snow-covered areas.
- They therefore absorb more sunlight which tends to warm the climate.
- This warming effect offsets the cooling effect of carbon sequestration.
- Reforestation would have a net warming effect on climate in some (snowy) regions.

Global mean runoff (mm day^{-1})

TRIFFID, but prescribed CO2



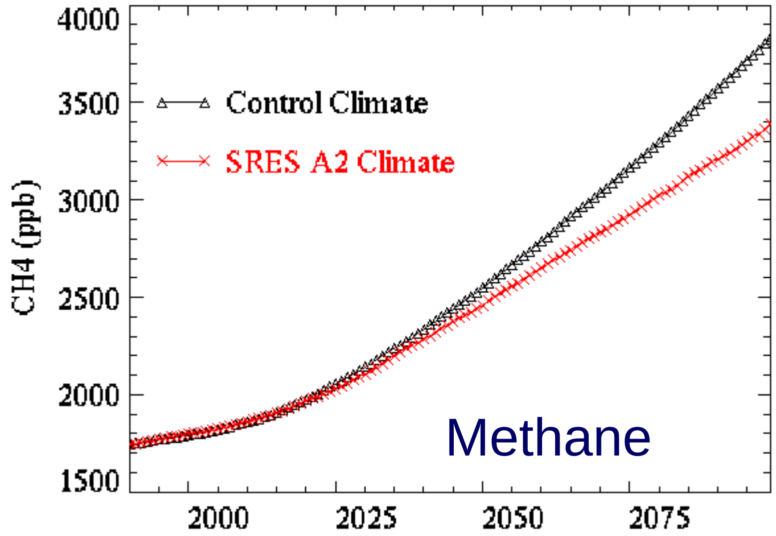
Climate impacts on chemistry

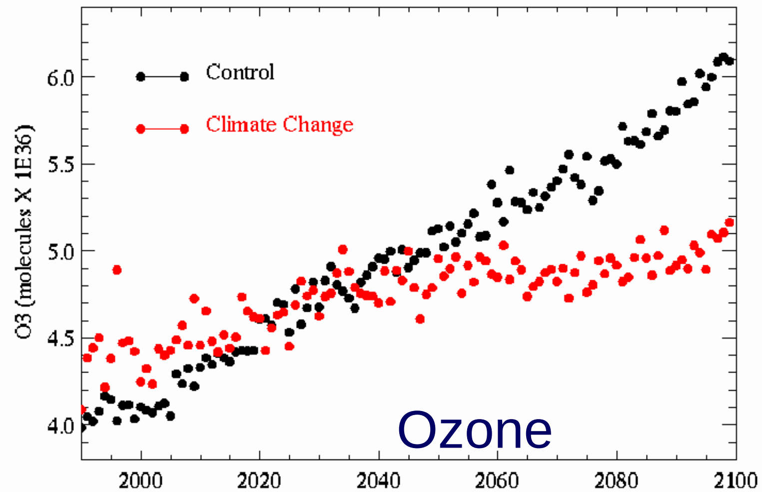
Only changes within troposphere included.

Increased water vapour and temperature in the future will lead to greater destruction of methane and ozone – red versus black lines

However this will be offset by increases in natural emissions

Not yet clear which will win.

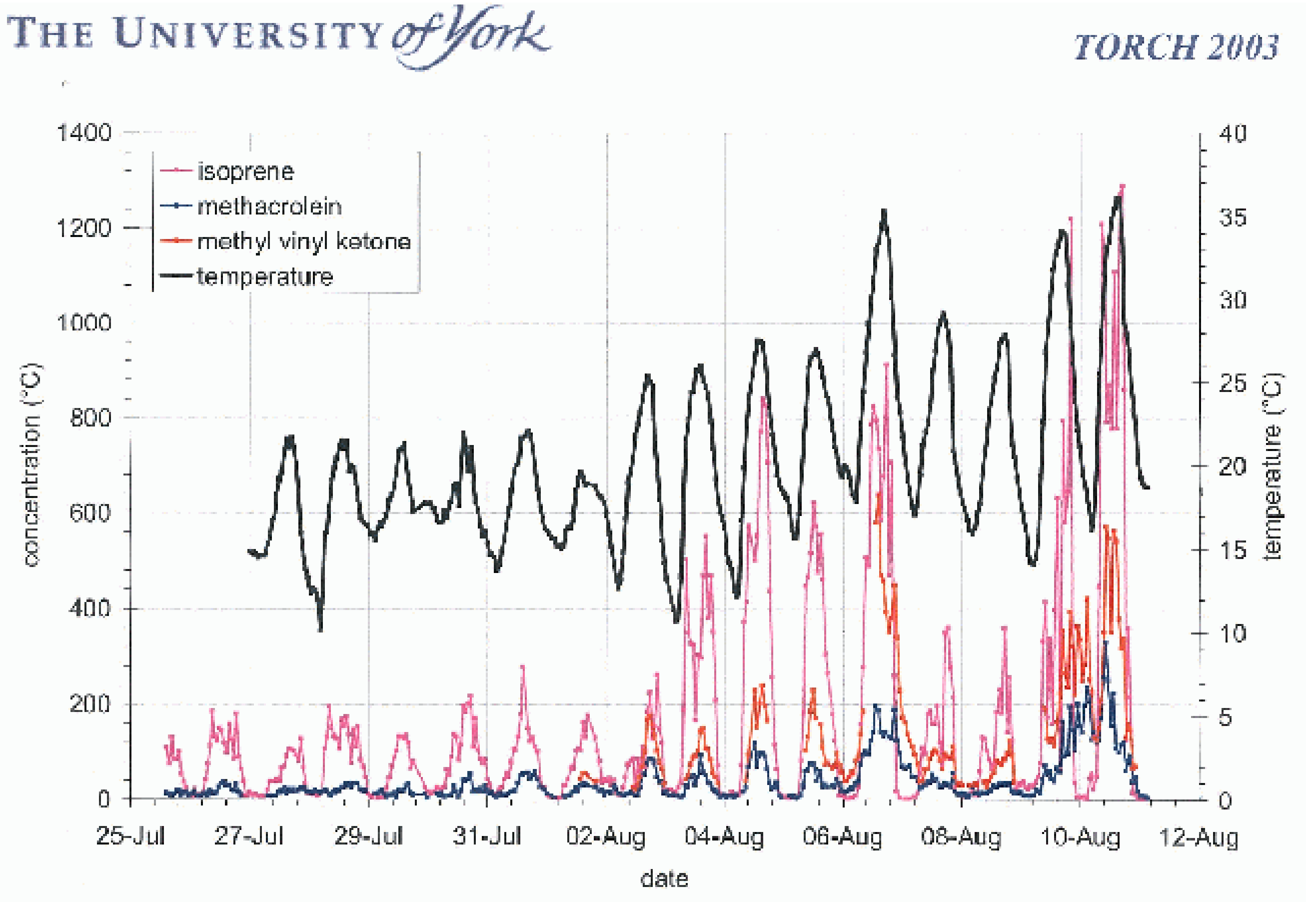




Johnson et al. GRL 2001

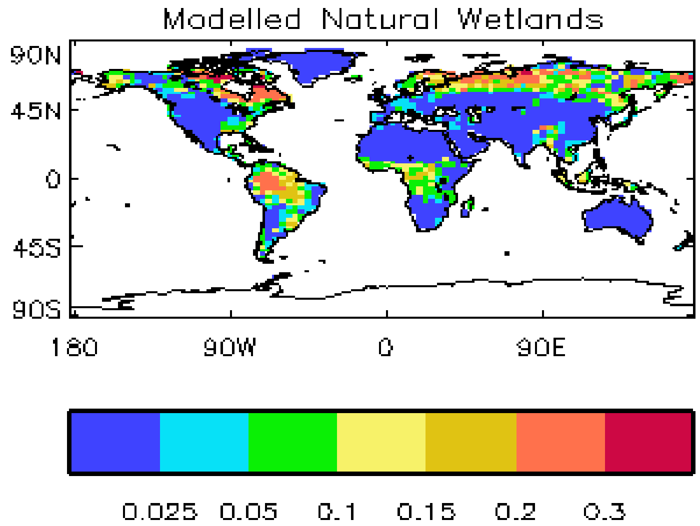
Climate impacts on biospheric emissions

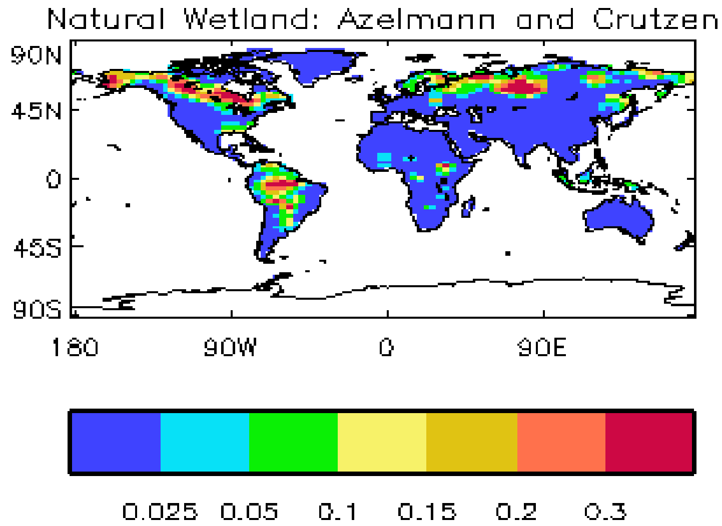
Increasing temperature increases hydrocarbon emissions from vegetation (e.g. isoprene)



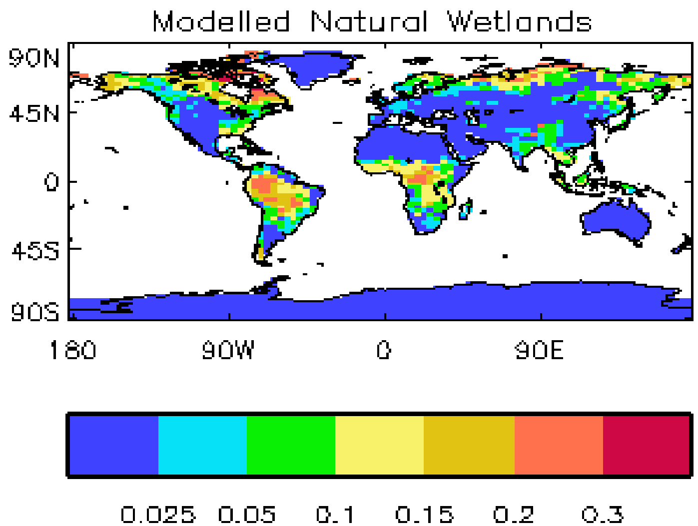
Simulated annual mean wetland fraction

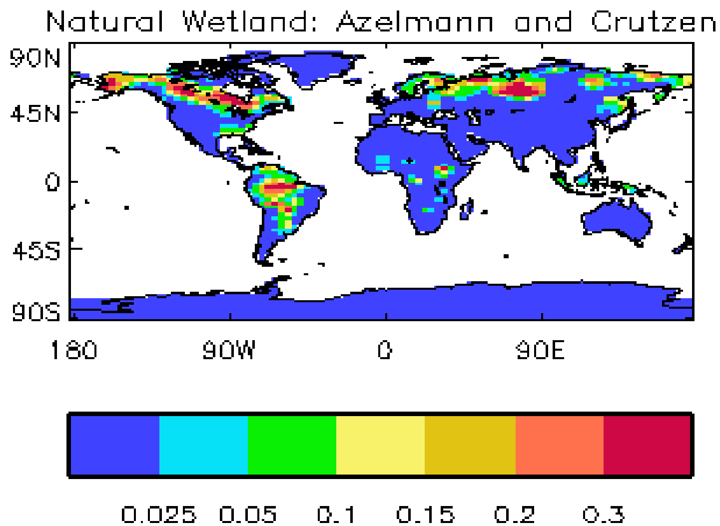
Off-line:



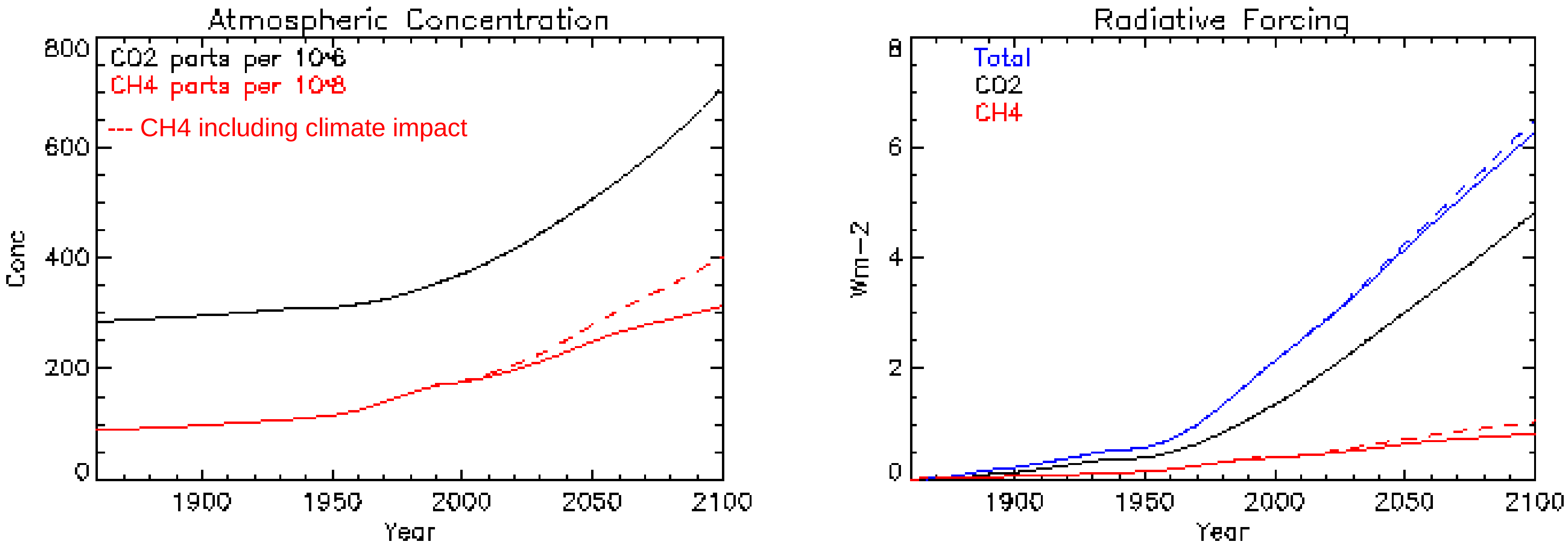


On-line:



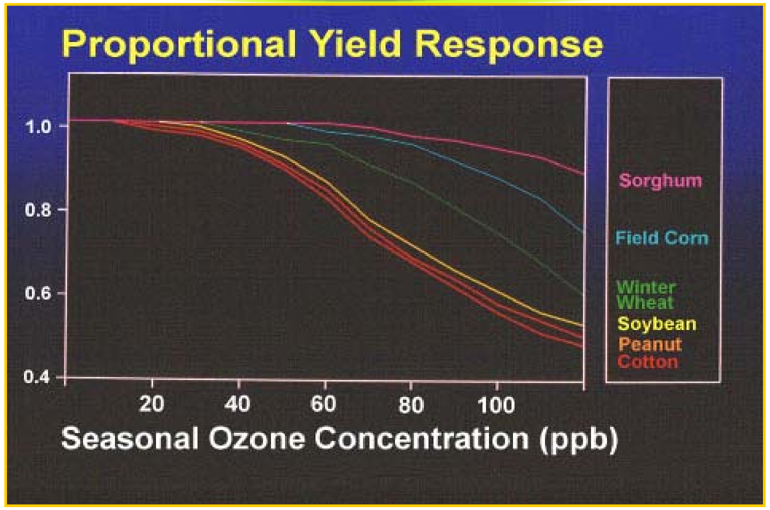


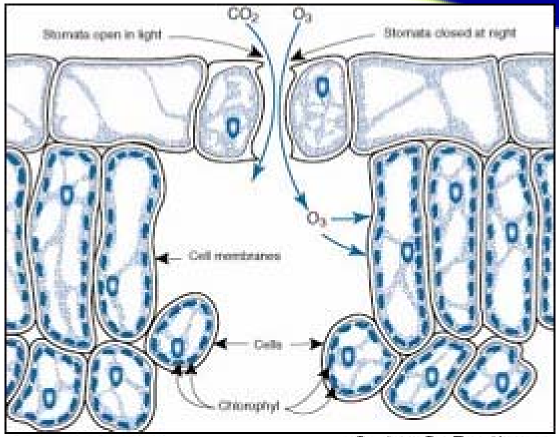
Effect of predicted wetland CH_4 emissions



1990→2100: 25% increase in CH_4
3-5% increase in total radiative forcing

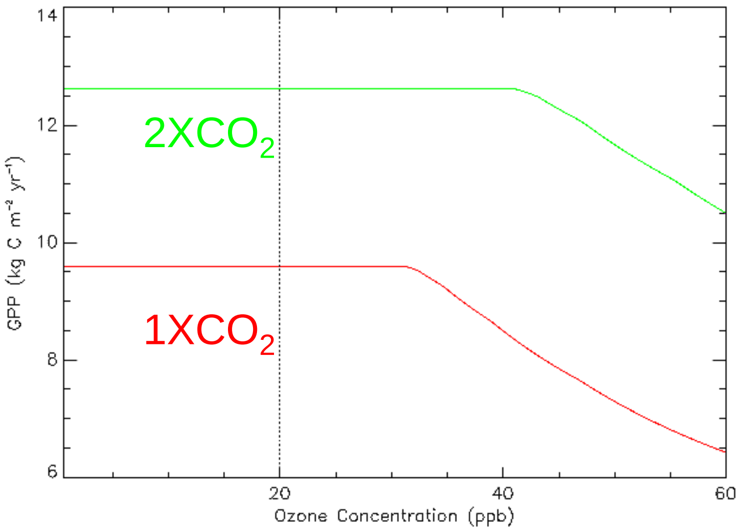
Coupling chemistry to ecosystems





Courtesy Gro Torsethaugen

Gross primary productivity

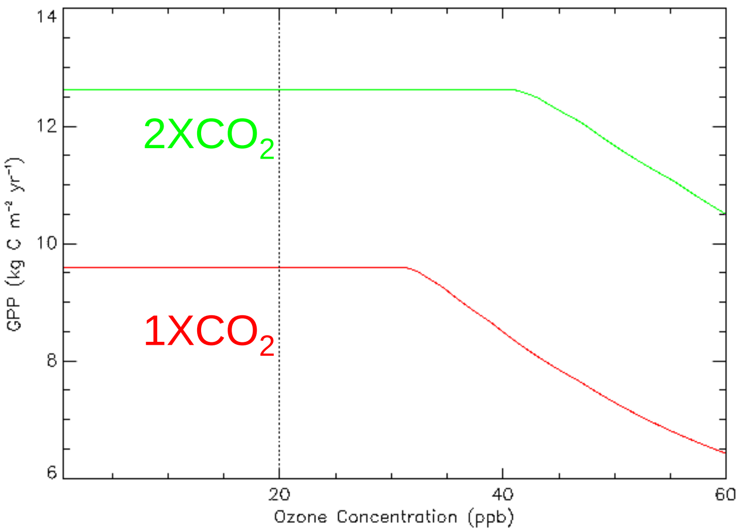


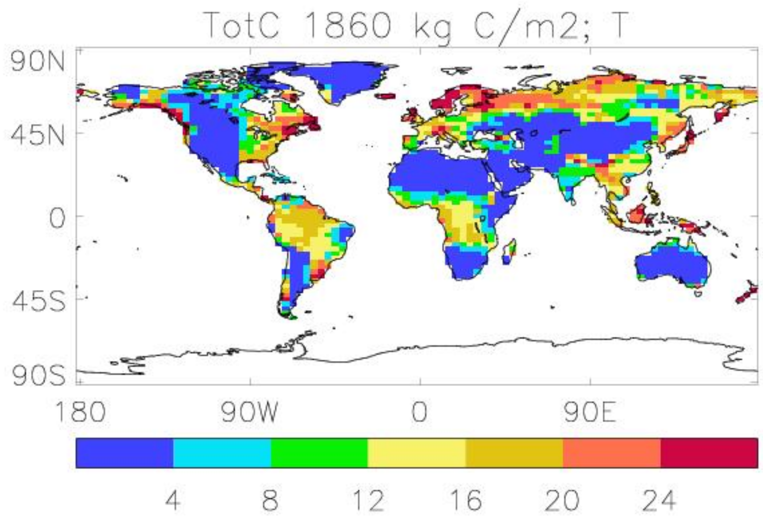
Ozone causes damage internally after passing through stomata

- By coupling chemistry and ecosystem models we can model the flux through stomata
- Increasing ozone will reduce the ability of plants to soak up CO_2

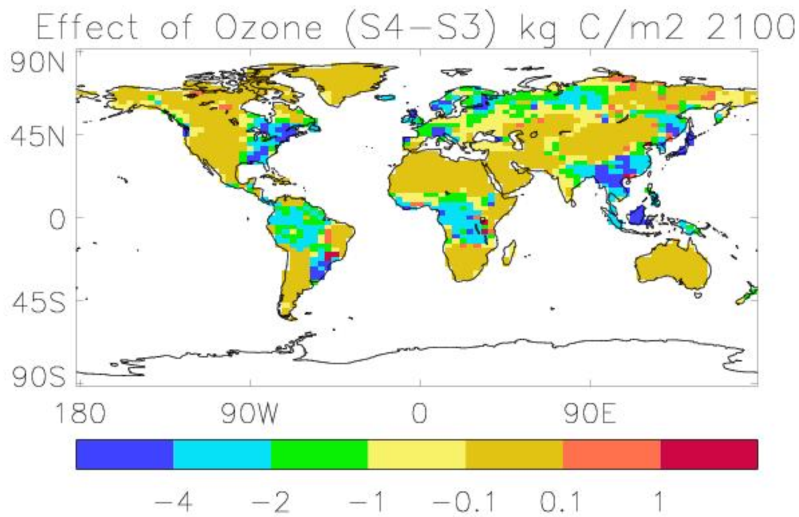
Coupling chemistry to ecosystems

Gross primary productivity





Ozone affects GPP. Ozone concentrations are expected to increase by 2100. Results indicate a potential loss of veg+soil carbon of 130 PgC (corresponding roughly to an extra 50 ppm in the atmosphere, to be compared to an increase of about 350 ppm due to CO_2 emissions – IS92a scenario, no carbon feedback)



Conclusions 1

Kyoto protocol

- Science?

Observations relevant to Kyoto

- Baseline analysis – results depend on method

Conclusions 2

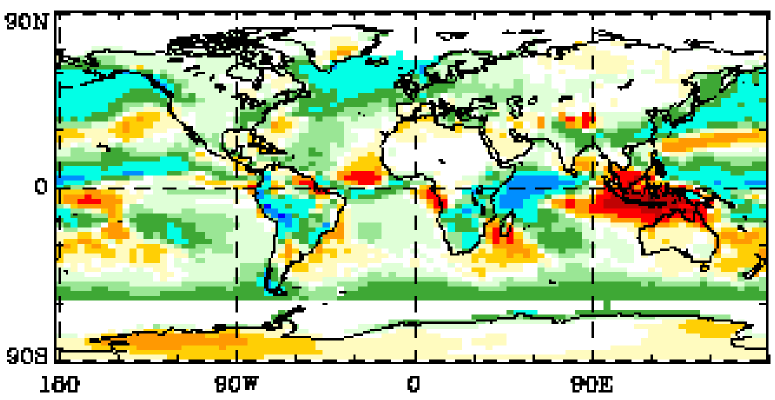
Modelling relevant to Kyoto

- Atmospheric concentrations depend on
  - Man-made emissions
  - Changes to natural emissions due to climate change
    - Isoprene etc
    - Methane from wetlands
  - Earth system feedbacks
    - Carbon cycle
    - Climate effect on methane, ozone
    - Ozone effect on plants/ carbon storage
- Are all greenhouse gases equivalent?
    - Physiological effects of CO_2
- Planting trees may not be an effective strategy

Precipitation – coupled feedbacks

- Lack of convection over Indonesian subcontinent allows SSTs to warm
- Excessive easterly wind stresses over the Pacific promote upwelling and cooling.
- New balance shifts rainfall over maritime subcontinent.
- Drives stronger Walker circulation alters wind stresses
- Similar process in HadCM3 and HadGEM1
- HadGEM1 bigger cooling error and very small warming error
- Locks in to a La Nina type phase

HadGAM1 – CMAP



HadGEM1 – CMAP