The role of science in the Kyoto protocol

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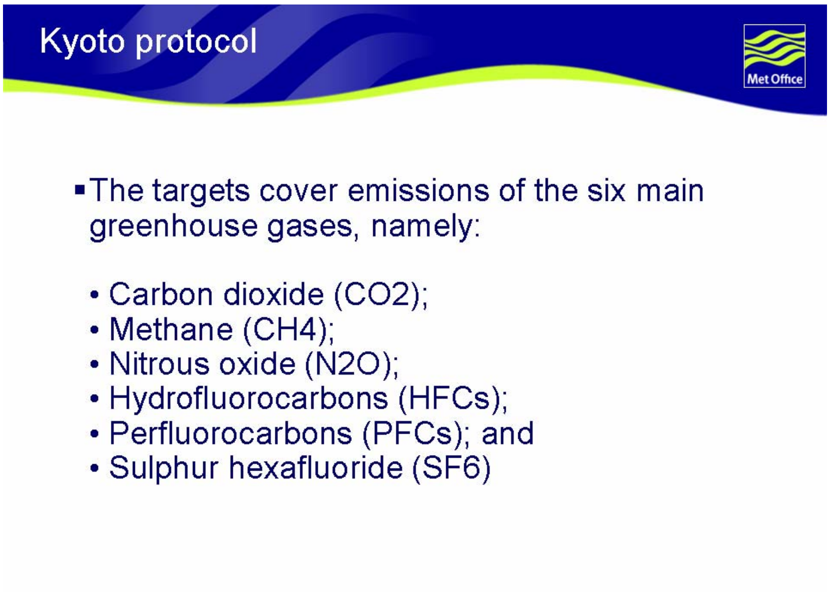
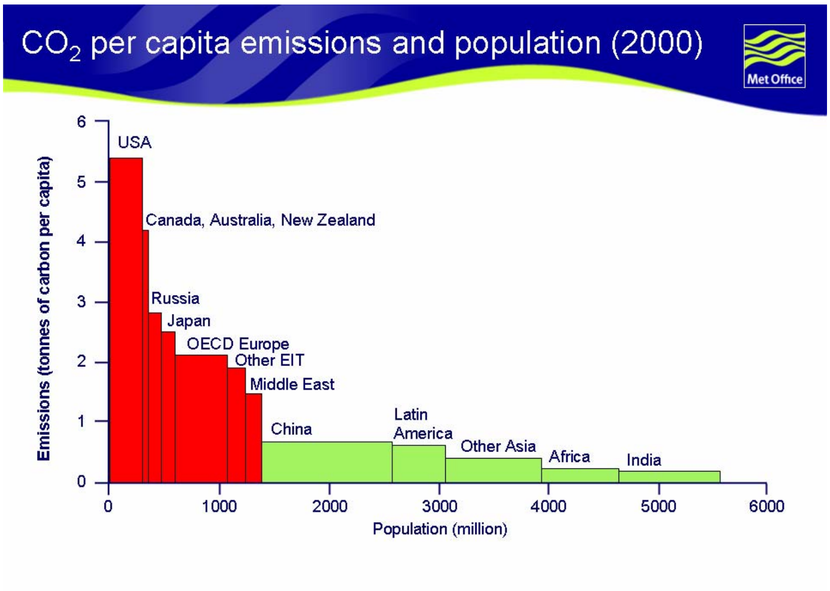
Exeter, UK





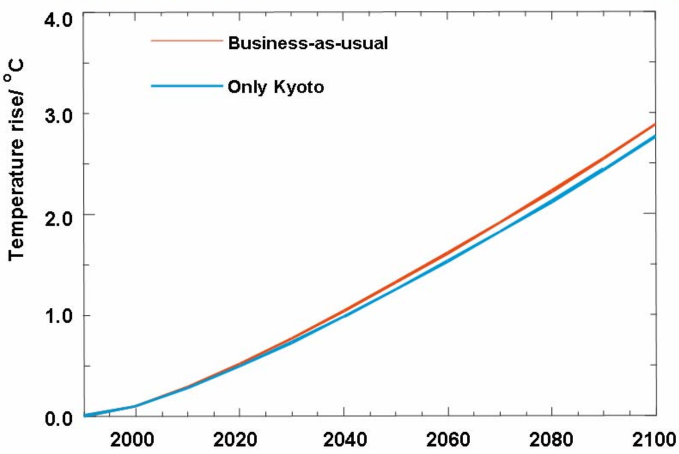
The 1997 Kyoto Protocol

Met Office

- 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

Met Office



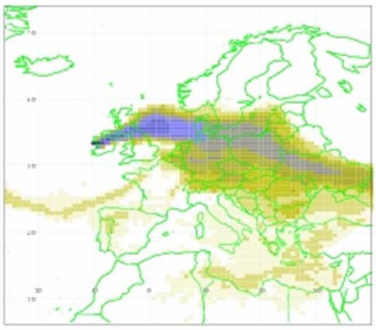
The 1997 Kyoto Protocol

Met Office

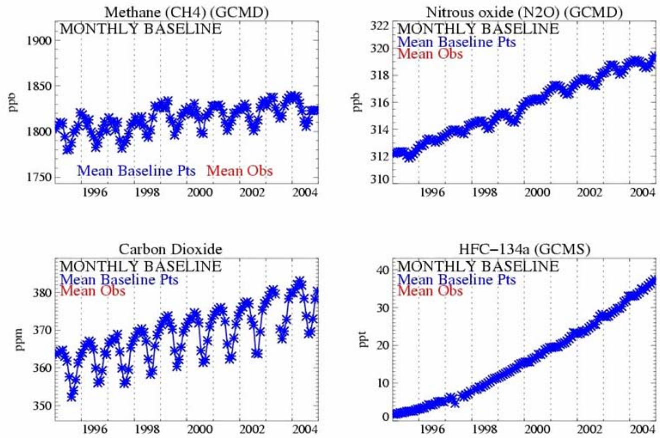
- Negotiations on targets for the **second commitment** period are due to start in 2005, by which time Annex I Parties must have made “demonstrable progress” in meeting their commitments under the Protocol.

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

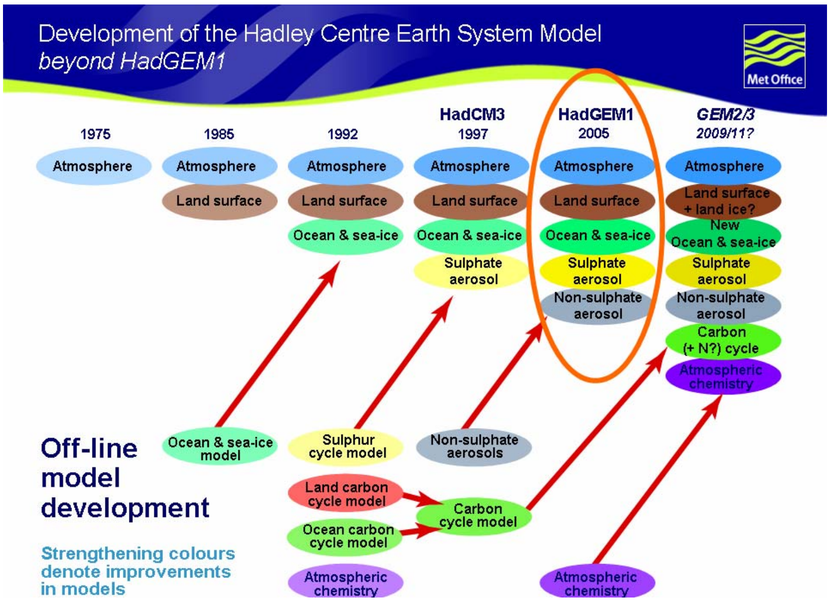


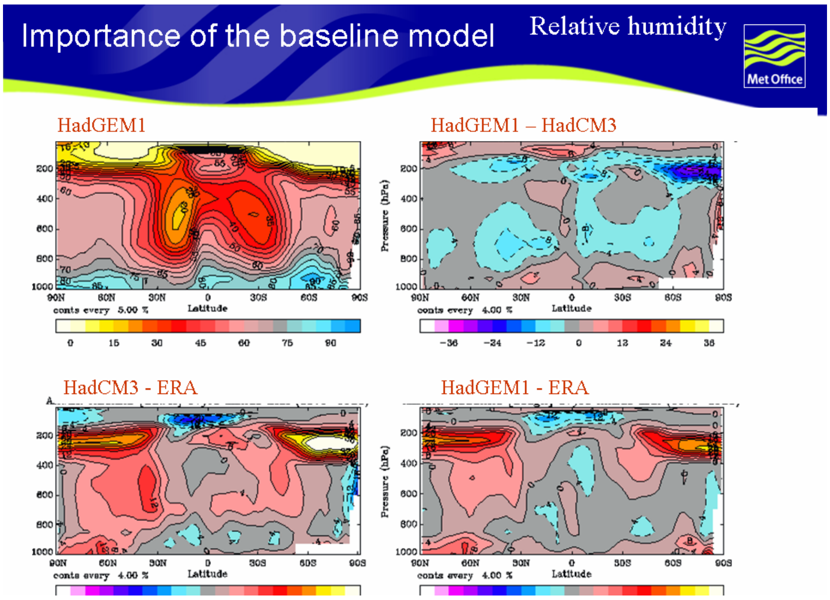
GHG baseline trends from Mace Head data

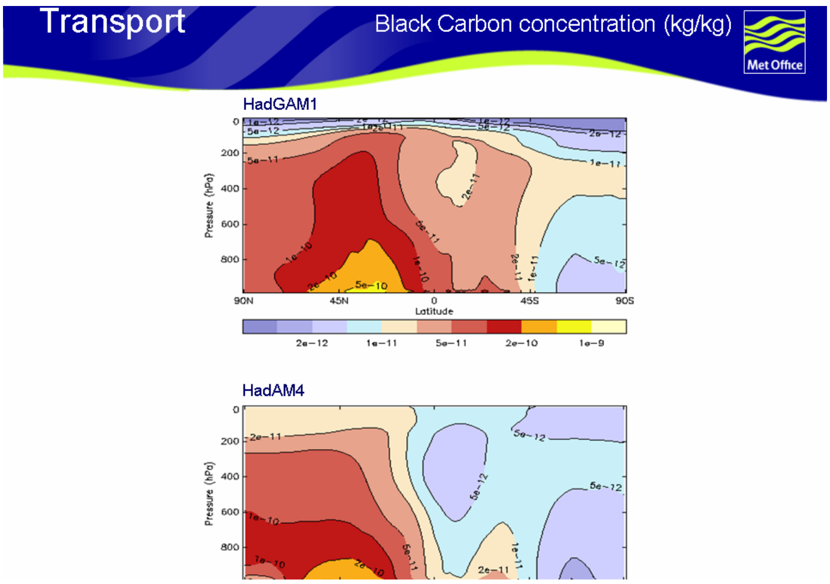


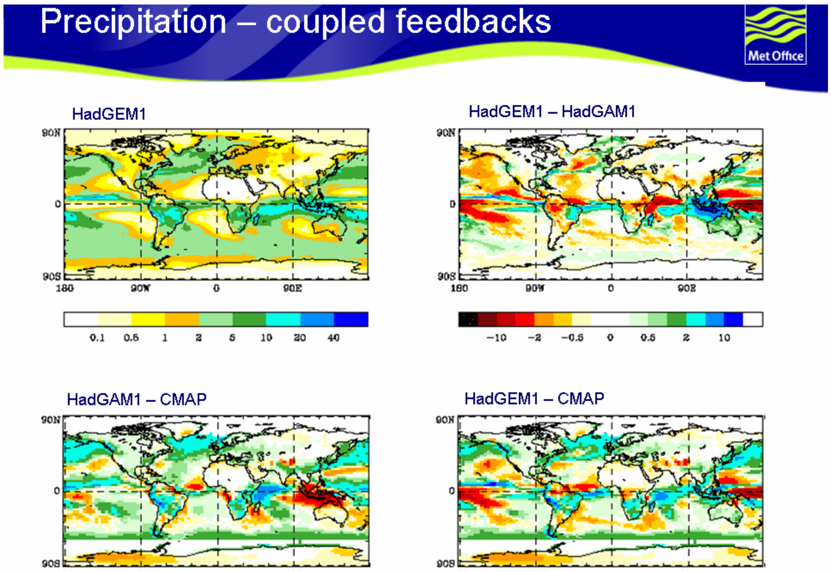
Reasons for building an Earth System Model

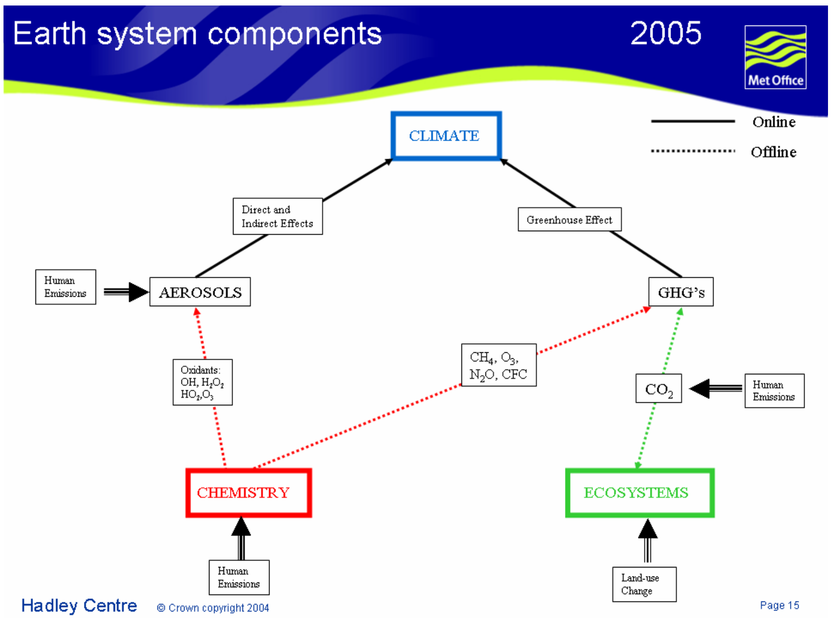
- climate-carbon feedback
- climate-chemistry interactions
- climate-aerosol interactions


Development of the Hadley Centre Earth System Model
beyond HadGEM1
Met Office
1975
1985
1992
HadCM3
1997
HadGEM1
2005
GEM2/3
2009/11?
Atmosphere
Land surface
Ocean & sea-ice
Sulphate aerosol
Non-sulphate aerosol
Land surface + land ice?
New Ocean & sea-ice
Carbon (+ N?) cycle
Atmospheric chemistry
Off-line model development
Ocean & sea-ice model
Sulphur cycle model
Non-sulphate aerosols
Land carbon cycle model
Ocean carbon cycle model
Carbon cycle model
Atmospheric chemistry
Strengthening colours denote improvements in models


Importance of the baseline model
Relative humidity
Met Office
HadGEM1
HadGEM1 – HadCM3
HadCM3 - ERA
HadGEM1 - ERA
Pressure (hPa)
Latitude


Transport
Black Carbon concentration (kg/kg)
Met Office
HadGAM1
HadAM4
Pressure (hPa)
Latitude


Precipitation – coupled feedbacks
Met Office
HadGEM1
HadGEM1 – HadGAM1
90N
0
90S
180
90W
0
90E
0.1 0.5 1 2 5 10 20 40
−10 −2 −0.5 0 0.5 2 10
HadGAM1 – CMAP
HadGEM1 – CMAP


Earth system components
2005
Met Office
CLIMATE
Online
Offline
Direct and Indirect Effects
Greenhouse Effect
Human Emissions
AEROSOLS
GHG's
Oxidants: OH, H_2O_2, HO_2, O_3
CH_4, O_3, N_2O, CFC
CO_2
Human Emissions
CHEMISTRY
ECOSYSTEMS
Human Emissions
Land-use Change
Hadley Centre
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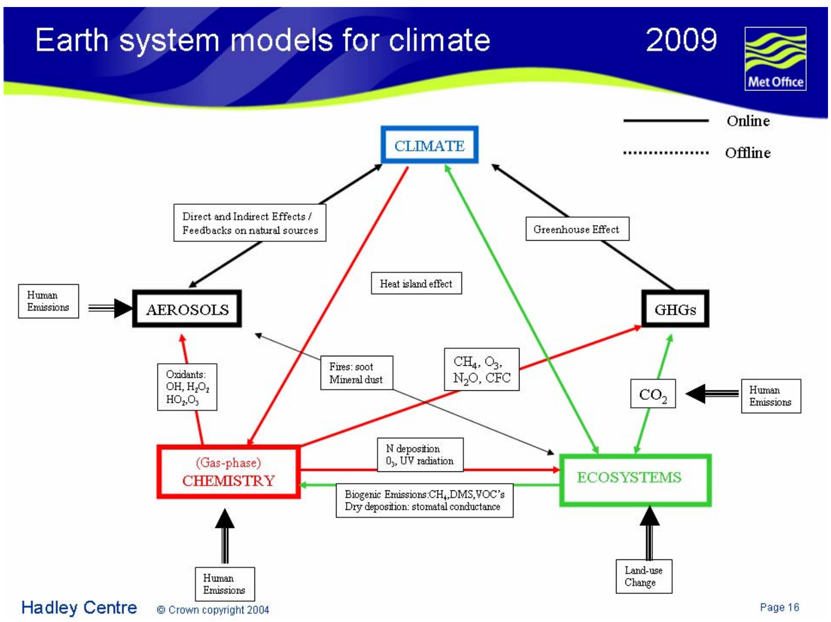
Earth system models for climate
2009
Met Office
CLIMATE
Online
Offline
Direct and Indirect Effects / Feedbacks on natural sources
Greenhouse Effect
Heat island effect
Human Emissions
AEROSOLS
GHGs
Oxidants: OH, H_2O_2, HO_2, O_3
Fires: soot Mineral dust
CH_4, O_3, N_2O, CFC
CO_2
Human Emissions
N deposition O_3, UV radiation
(Gas-phase) CHEMISTRY
ECOSYSTEMS
Biogenic Emissions:CH_4,DMS,VOC's Dry deposition: stomatal conductance
Human Emissions
Land-use Change
Hadley Centre
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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).*

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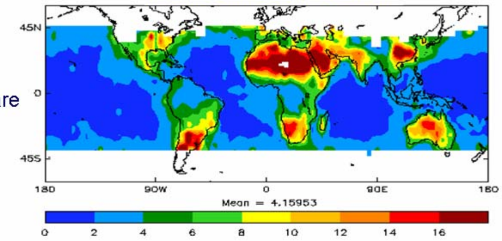
Column integrated droplet concentration

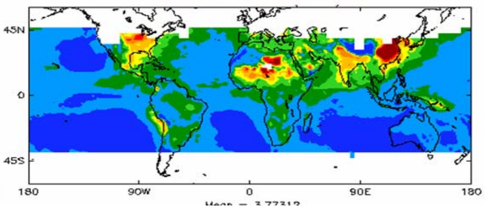
Han et al. ISCCP retrieval



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.

HadGEM1 (transient run)



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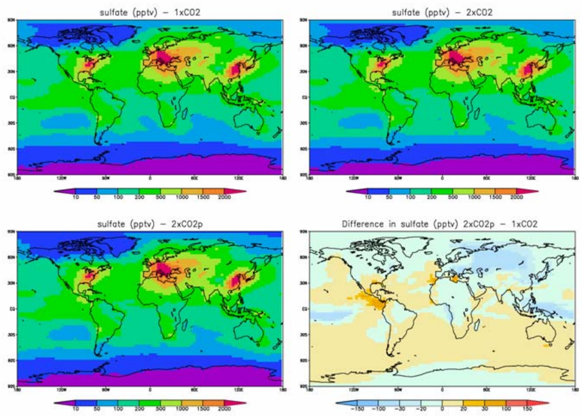
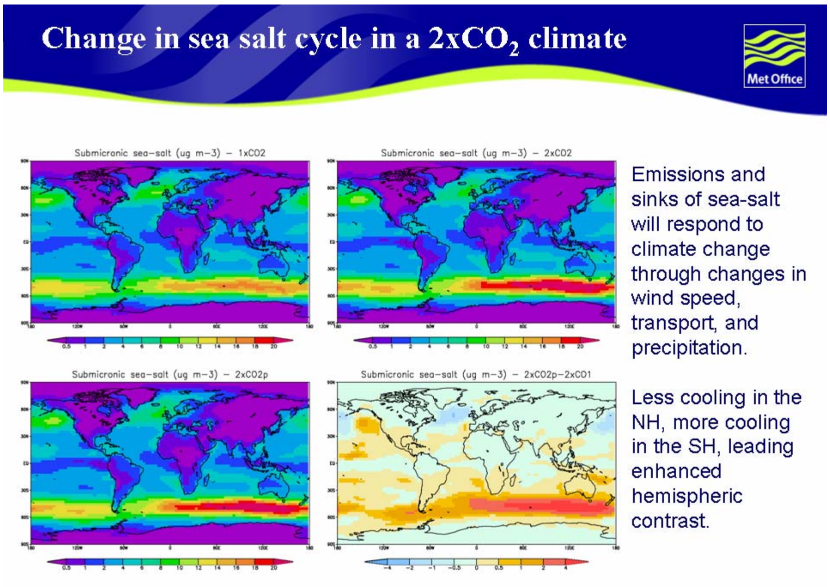
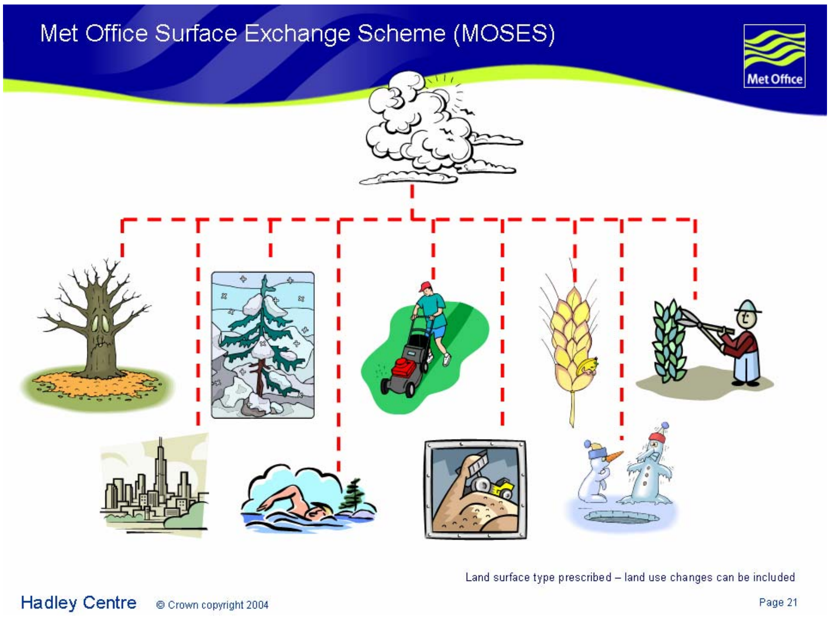
Change in sulfur cycle in a $2xCO_2$ climate



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 2xCO2 climate
Met Office
Submicronic sea-salt (ug m-3) - 1xCO2
Submicronic sea-salt (ug m-3) - 2xCO2
Submicronic sea-salt (ug m-3) - 2xCO2p
Submicronic sea-salt (ug m-3) - 2xCO2p-2xCO1
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)
Met Office
Land surface type prescribed – land use changes can be included
Hadley Centre
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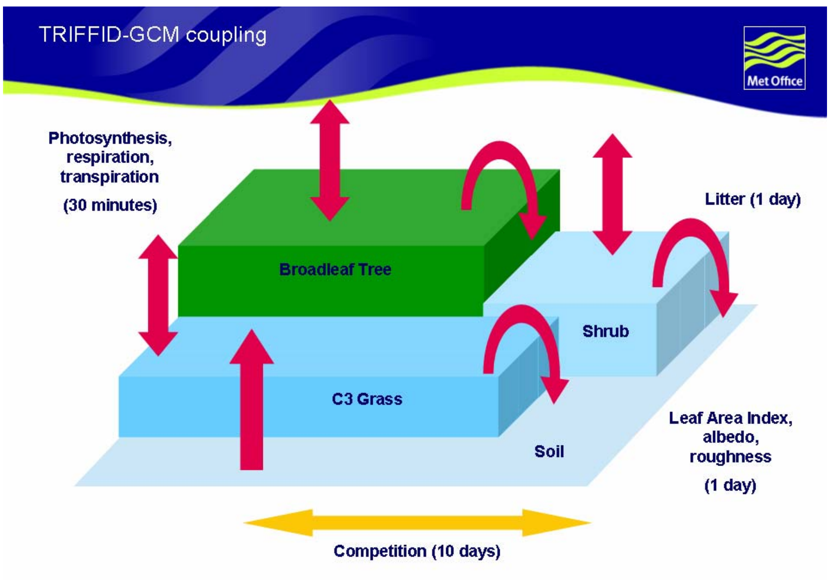
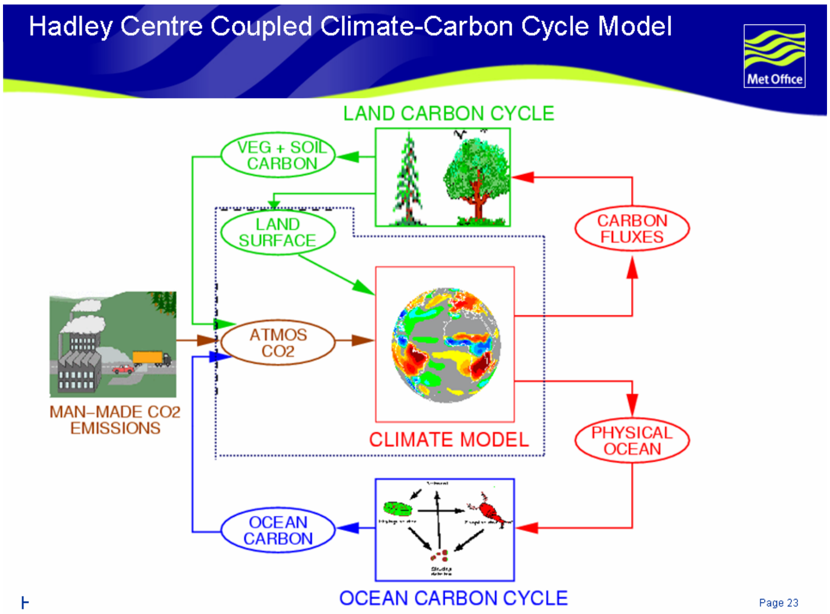

TRIFFID-GCM coupling
Met Office
Photosynthesis, respiration, transpiration
(30 minutes)
Litter (1 day)
Broadleaf Tree
Shrub
C3 Grass
Soil
Leaf Area Index, albedo, roughness
(1 day)
Competition (10 days)


Hadley Centre Coupled Climate-Carbon Cycle Model
Met Office
LAND CARBON CYCLE
VEG + SOIL CARBON
LAND SURFACE
CARBON FLUXES
ATMOS CO2
MAN-MADE CO2 EMISSIONS
CLIMATE MODEL
PHYSICAL OCEAN
OCEAN CARBON
OCEAN CARBON CYCLE
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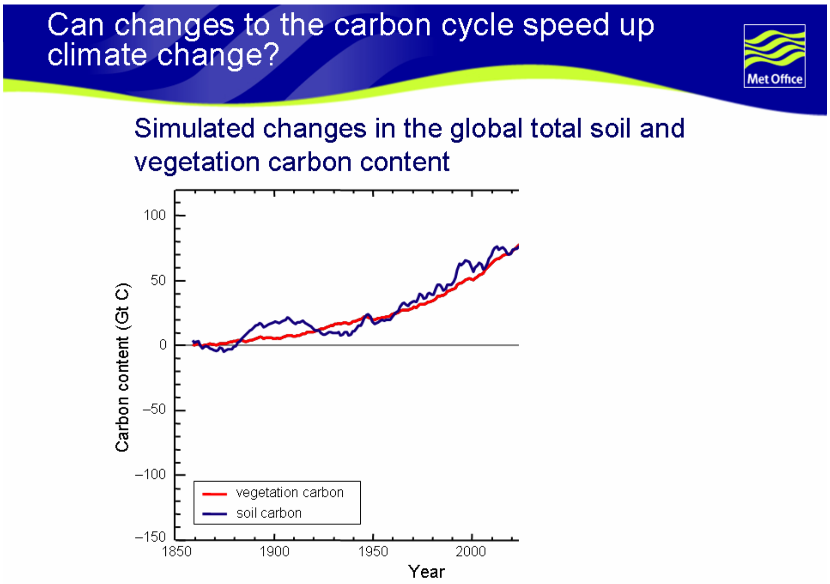
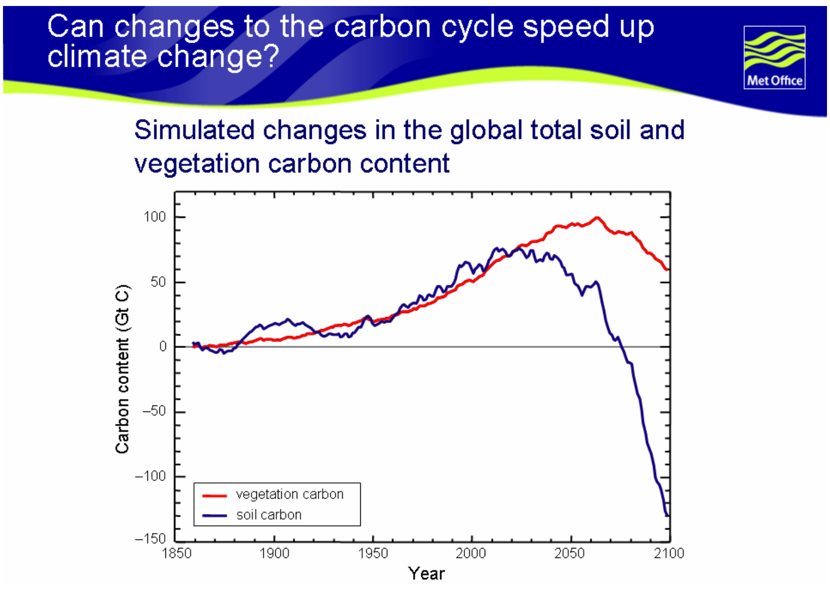

Can changes to the carbon cycle speed up climate change?
Met Office
Simulated changes in the global total soil and vegetation carbon content
Carbon content (Gt C)
100
50
0
−50
−100
−150
1850
1900
1950
2000
Year
vegetation carbon
soil carbon


Can changes to the carbon cycle speed up climate change?
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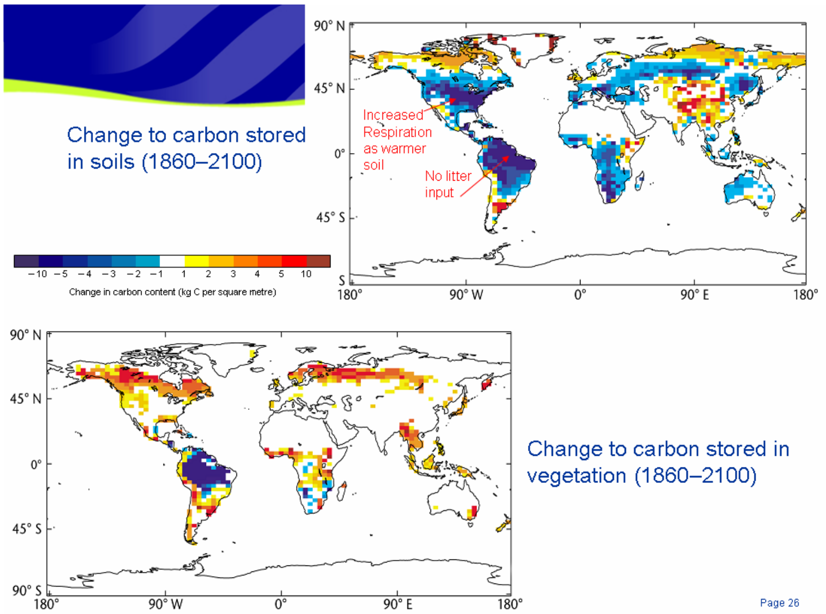
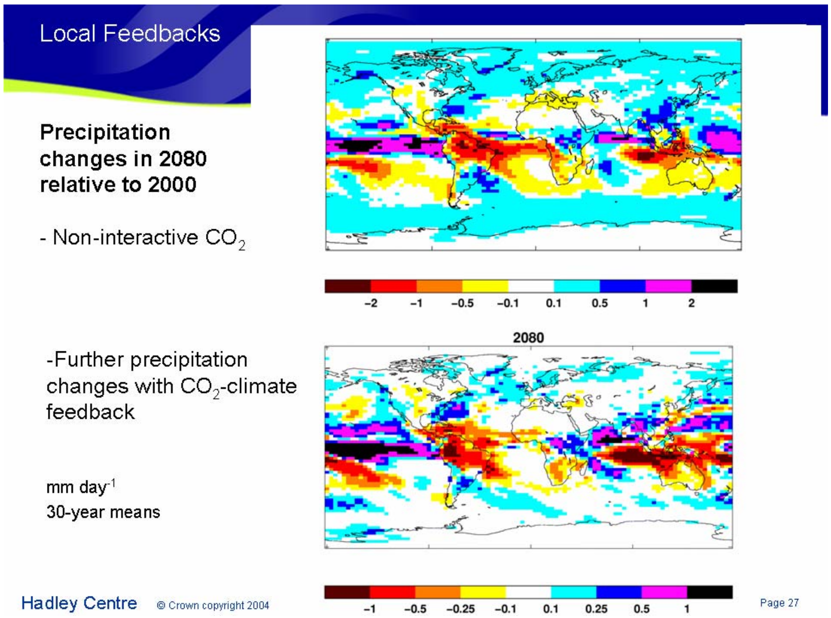
Simulated changes in the global total soil and vegetation carbon content
Carbon content (Gt C)
100
50
0
−50
−100
−150
1850
1900
1950
2000
2050
2100
Year
vegetation carbon
soil carbon


Change to carbon stored in soils (1860–2100)
Increased Respiration as warmer soil
No litter input
Change in carbon content (kg C per square metre)
−10 −5 −4 −3 −2 −1 1 2 3 4 5 10
90° N
45° N
0°
45° S
180°
90° W
0°
90° E
180°
Change to carbon stored in vegetation (1860–2100)
Page 26


Local Feedbacks
Precipitation changes in 2080 relative to 2000
- Non-interactive CO_2
−2 −1 −0.5 −0.1 0.1 0.5 1 2
2080
-Further precipitation changes with CO_2-climate feedback
mm day^{-1}
30-year means
−1 −0.5 −0.25 −0.1 0.1 0.25 0.5 1
Hadley Centre
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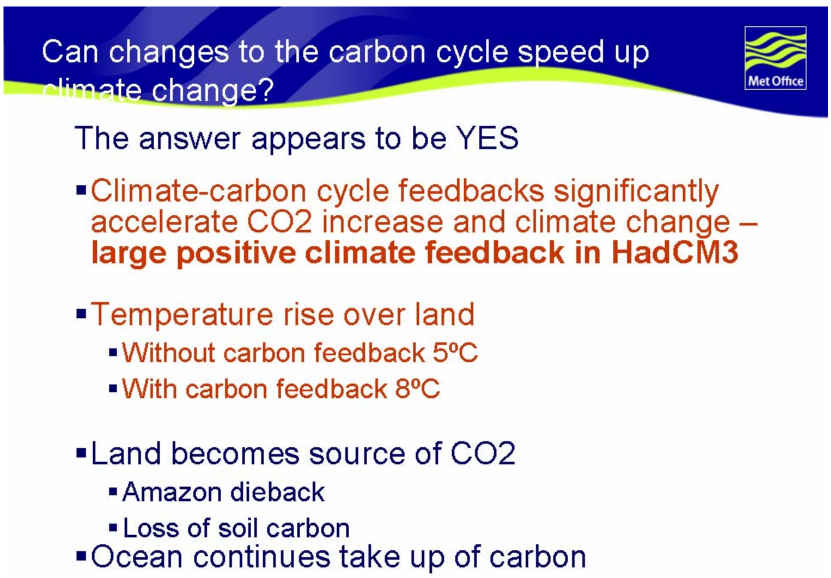

Can changes to the carbon cycle speed up climate change?
Met Office
The answer appears to be YES
▪Climate-carbon cycle feedbacks significantly accelerate CO2 increase and climate change – large positive climate feedback in HadCM3
▪Temperature rise over land
▪Without carbon feedback 5ºC
▪With carbon feedback 8ºC
▪Land becomes source of CO2
▪Amazon dieback
▪Loss of soil carbon
▪Ocean continues take up of carbon

WRE scenarios

Met Office

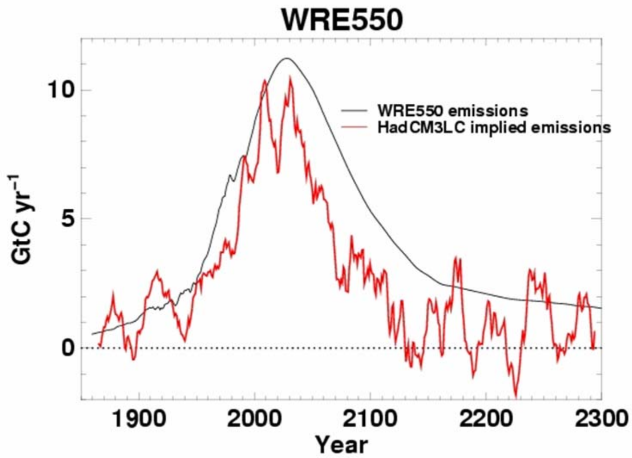
- WRE are a family of scenarios of CO_2 level, stabilising at 450, 550, 650, 750 and 1000 ppmv

  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

Met Office



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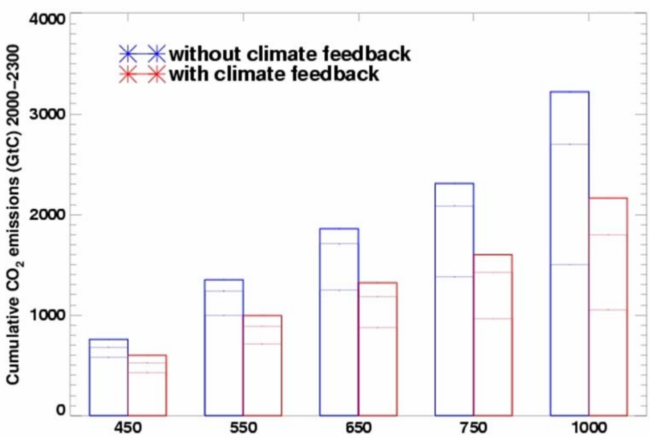
Other stabilisation levels

Met Office



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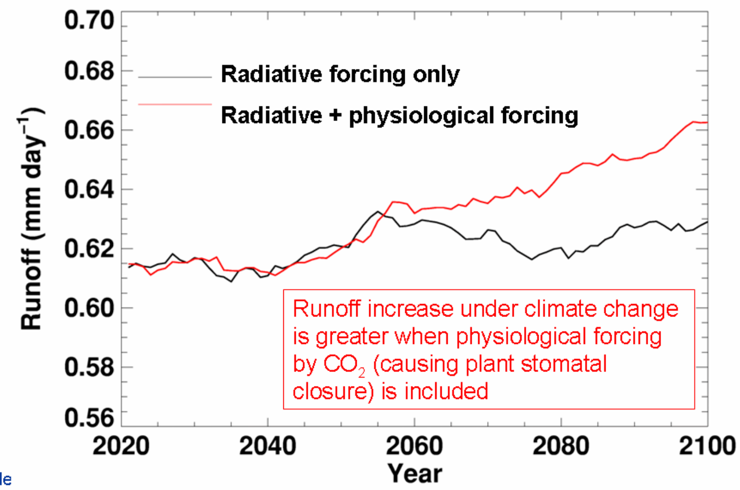
Net Effect of Reforestation - Importance of Albedo

- 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



Hadle

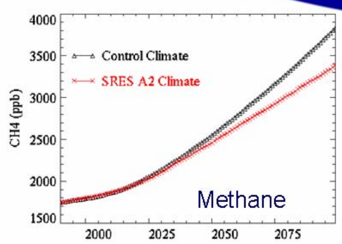
Climate impacts on chemistry

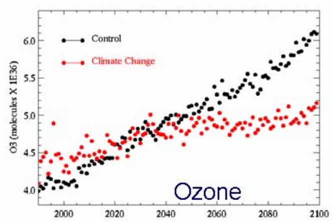
Only changes within troposphere included.

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.



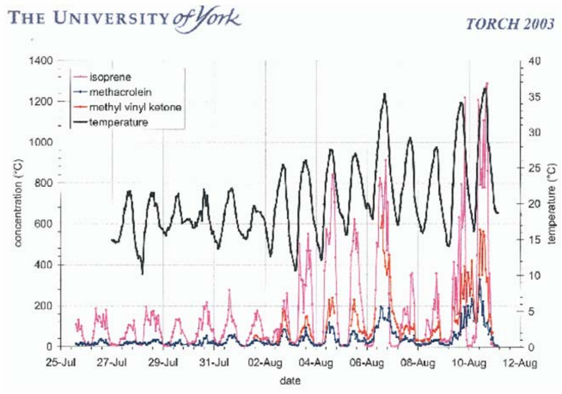


Hadley Centre

Johnson et al. GRL 2001

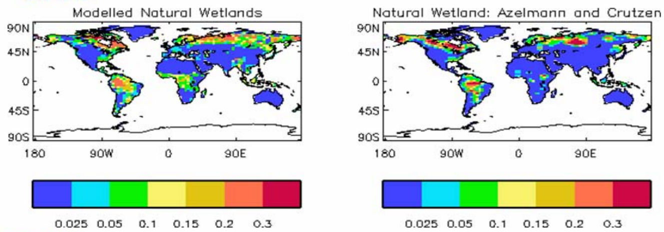
Climate impacts on biospheric emissions

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

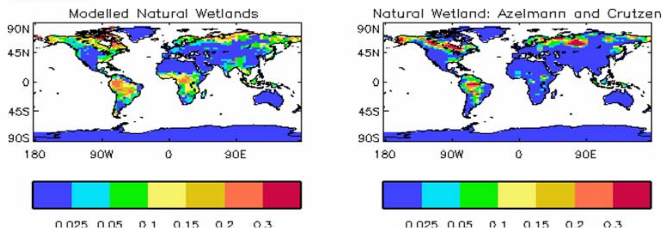


Simulated annual mean wetland fraction

Off-line:



On-line:



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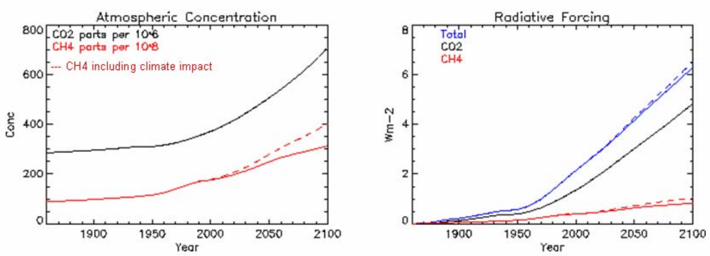
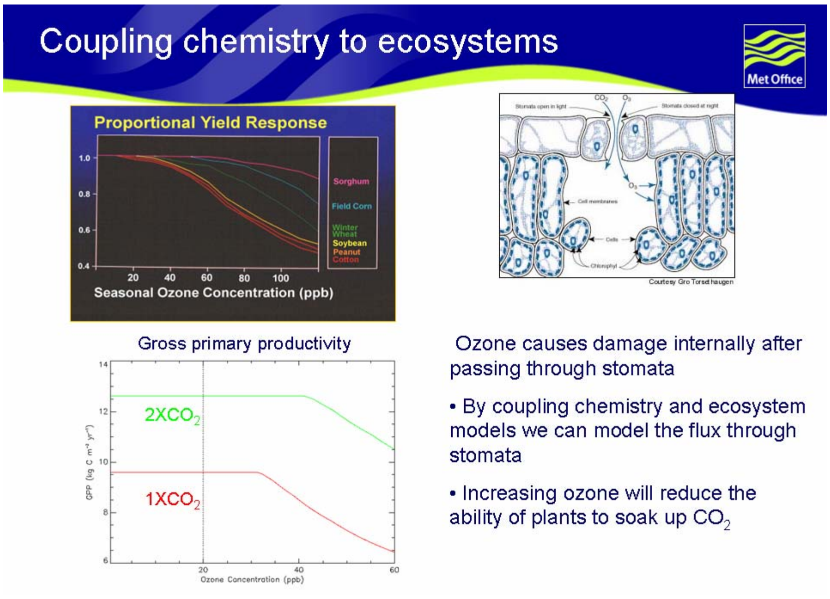
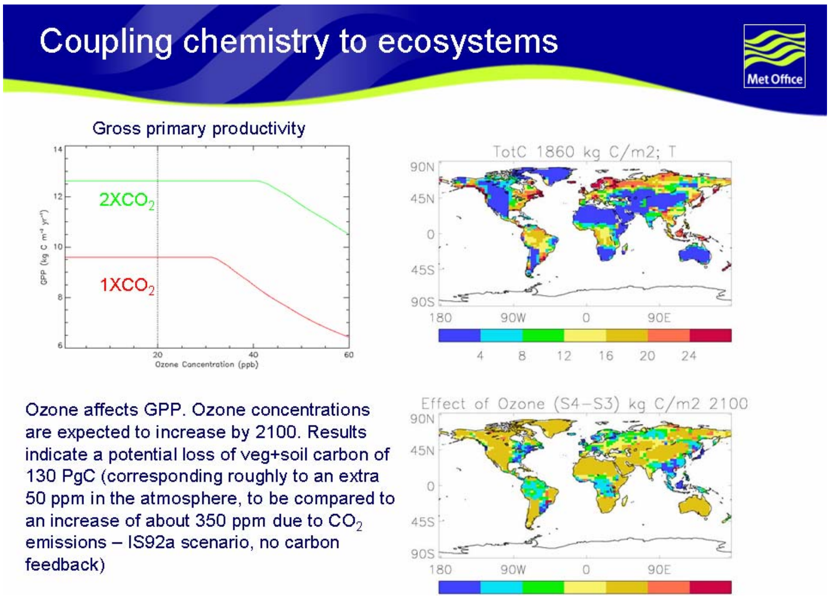
Effect of predicted wetland CH_4 emissions



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


Coupling chemistry to ecosystems
Met Office
Proportional Yield Response
1.0
0.8
0.6
0.4
20 40 60 80 100
Seasonal Ozone Concentration (ppb)
Sorghum
Field Corn
Winter Wheat
Soybean
Peanut
Cotton
CO2 O3
Courtesy Gro Torsethaugen
Gross primary productivity
2XCO2
1XCO2
GPP (kg C m-2 yr-1)
Ozone Concentration (ppb)
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 CO2


Coupling chemistry to ecosystems
Met Office
Gross primary productivity
2XCO2
1XCO2
GPP (kg C m-2 yr-1)
Ozone Concentration (ppb)
TotC 1860 kg C/m2; T
90N
45N
0
45S
90S
180 90W 0 90E
4 8 12 16 20 24
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 CO2 emissions – IS92a scenario, no carbon feedback)
Effect of Ozone (S4–S3) kg C/m2 2100
90N
45N
0
45S
90S
180 90W 0 90E

Conclusions 1

Kyoto protocol

- Science?

Observations relevant to Kyoto

- Baseline analysis – results depend on method

Conclusions 2

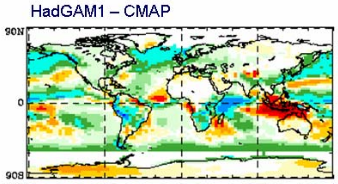
Modelling relevant to Kyoto

- 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