Earth System Modelling

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UKCA Training Workshop, Cambridge, January 2017

Overview

- What do we mean by the Earth System?
- Motivation for Studying ES Science
- Climate Models → Earth System Models
- The Earth System Model HadGEM2-ES
- Science Highlights involving HadGEM2-ES
- Next Generation ESM: UKESM1

What is the Earth System?

hy are we interested in ES Science?

imate Models -> Earth System Model

e Earth System Model: HadGEM2-E

ce Highlights involving HadGE

ation ESM: UKESM

What is the Earth System?

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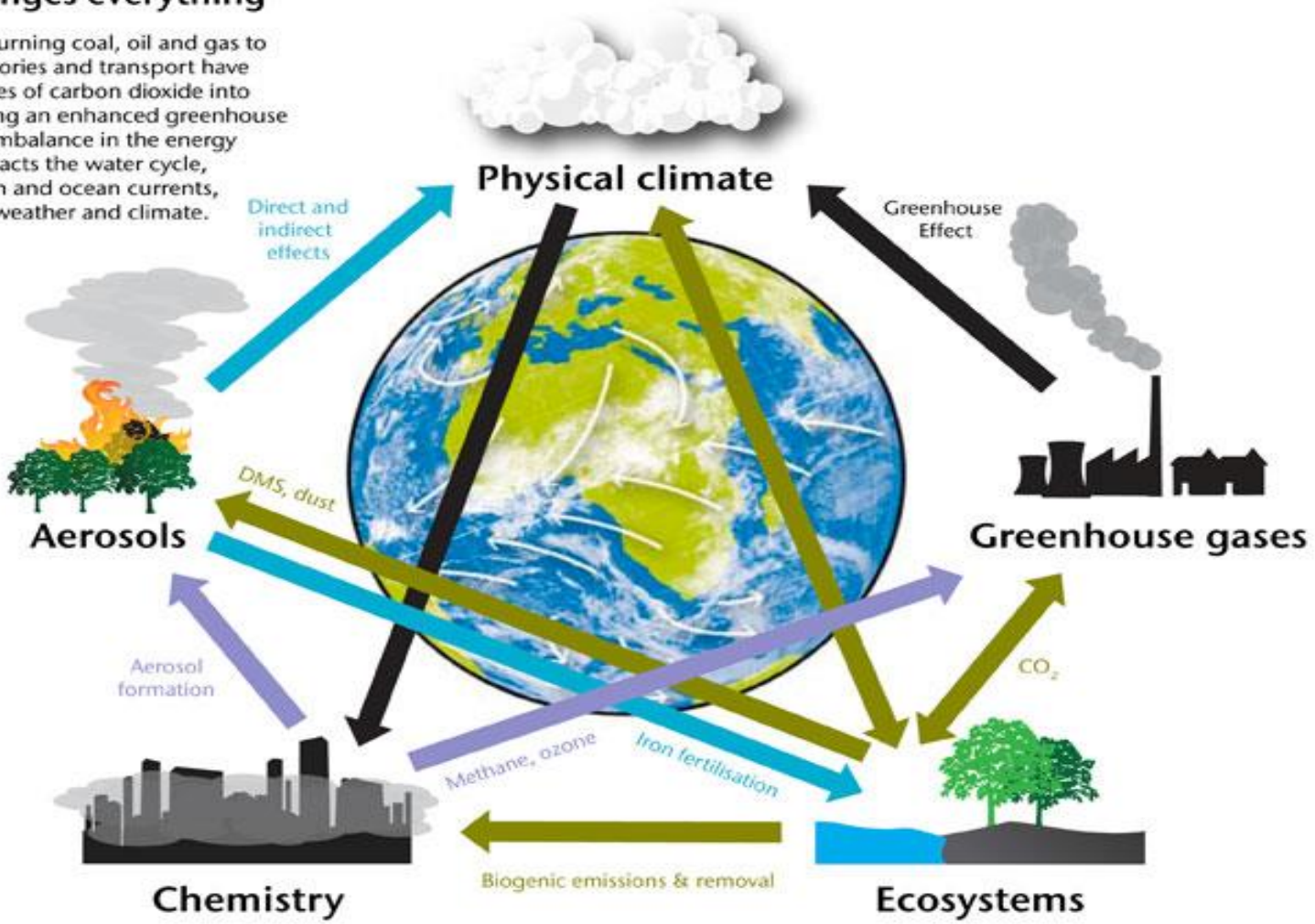
One thing changes everything

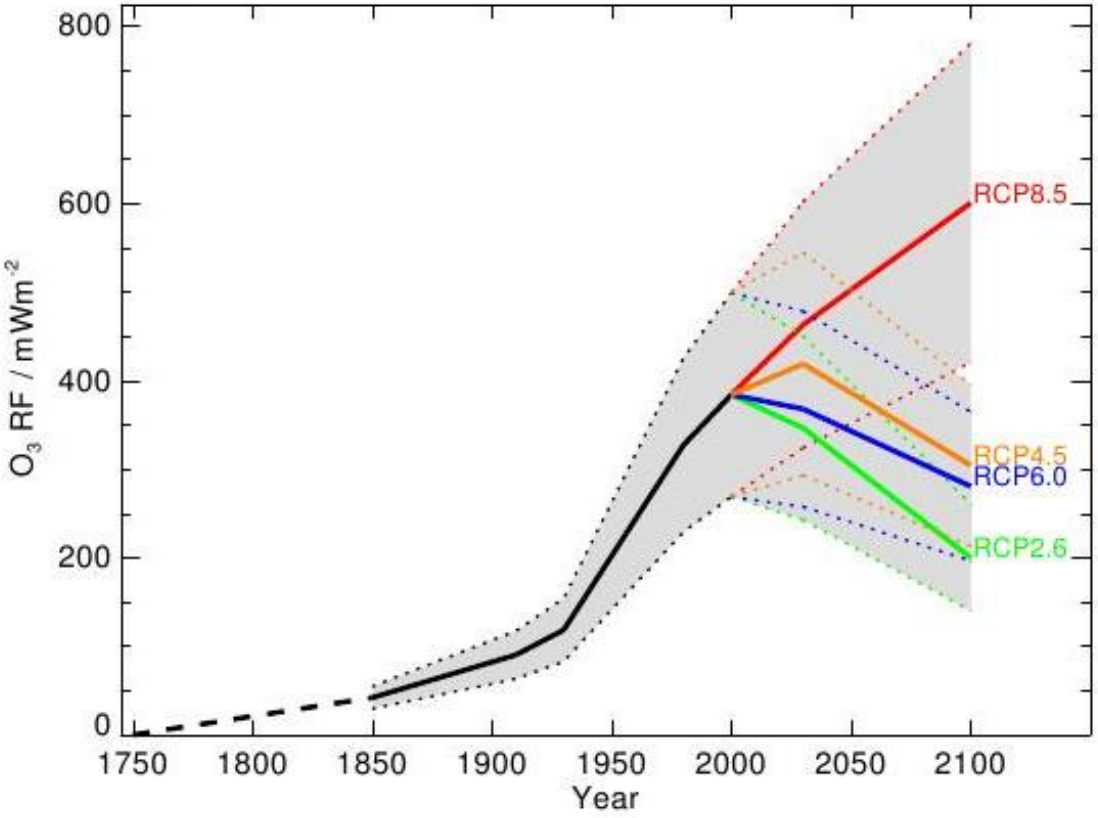
Human activities like burning coal, oil and gas to power our homes, factories and transport have released huge quantities of carbon dioxide into the atmosphere, causing an enhanced greenhouse effect. This causes an imbalance in the energy cycle that, in turn, impacts the water cycle, atmospheric circulation and ocean currents, leading to changes in weather and climate.



- Motivation for Studying ES Science

Why? – Climate Forcing (1)

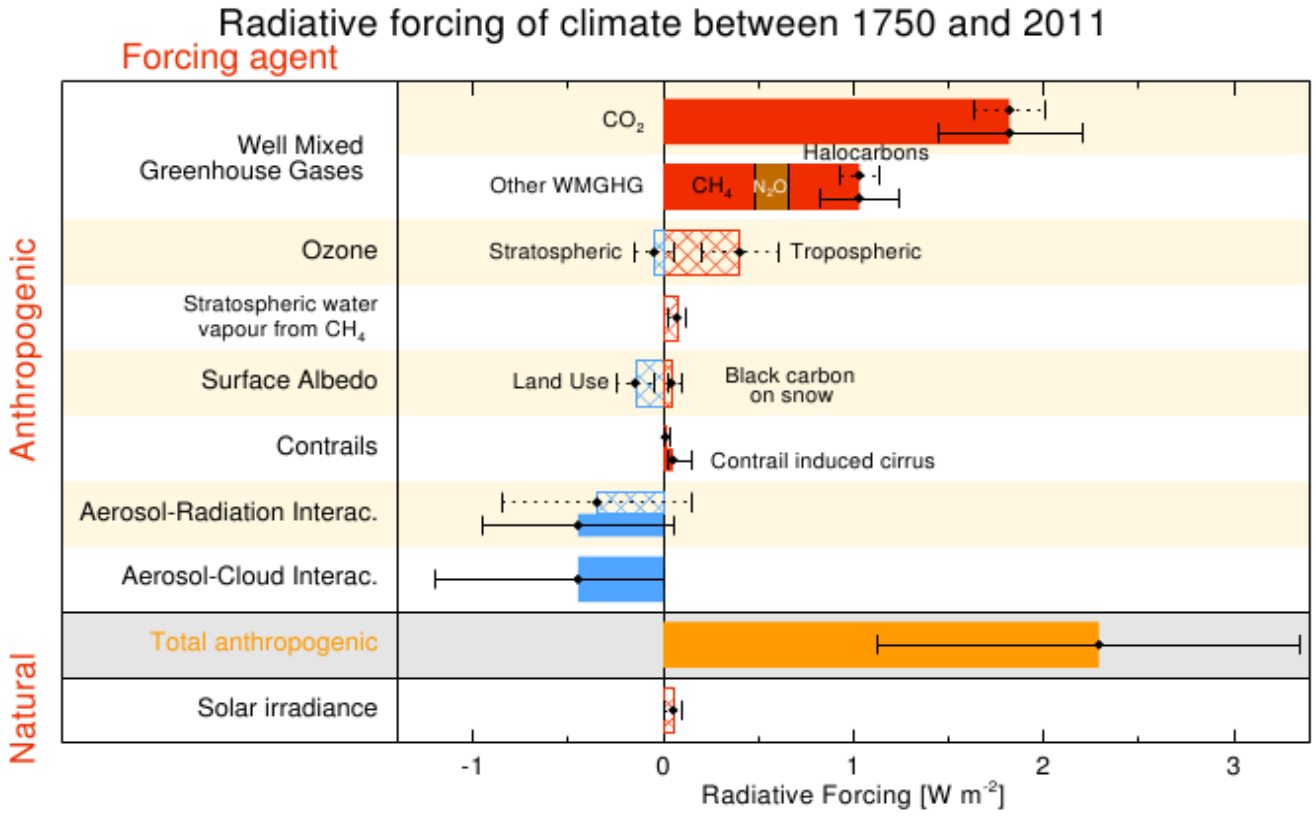
Tropospheric O_3 forcing



Multi-model study called Atmospheric Composition and Climate Model Intercomparison Project (ACCMIP) and included HadGEM2-ES

Stevenson et al., Atmos. Chem. Phys. (2013)

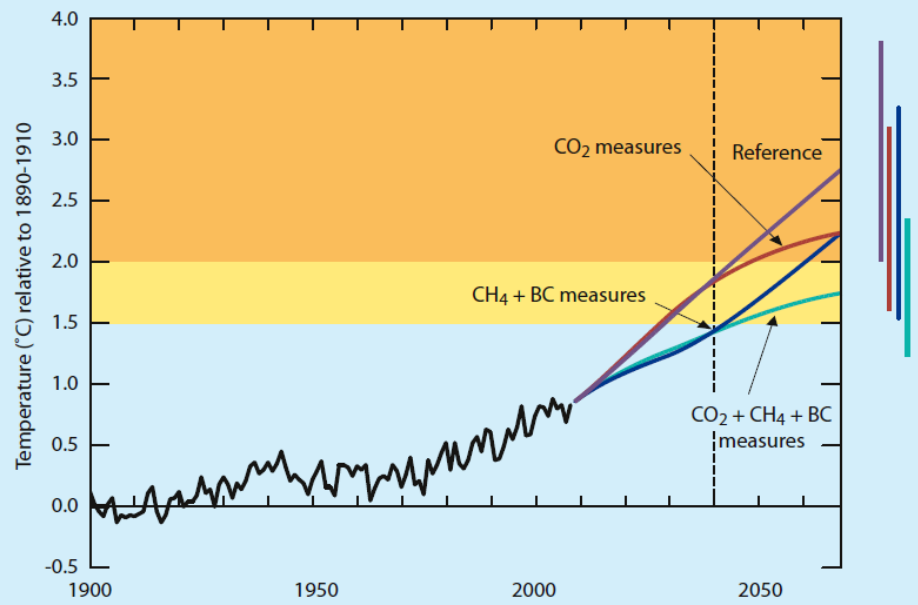
Why? – Climate Forcing (2)



5th Assessment Report (AR5), IPCC

Why? – Mitigation

Climate Change Mitigation refers to actions, which aim to reduce magnitude and/or rate of climate change



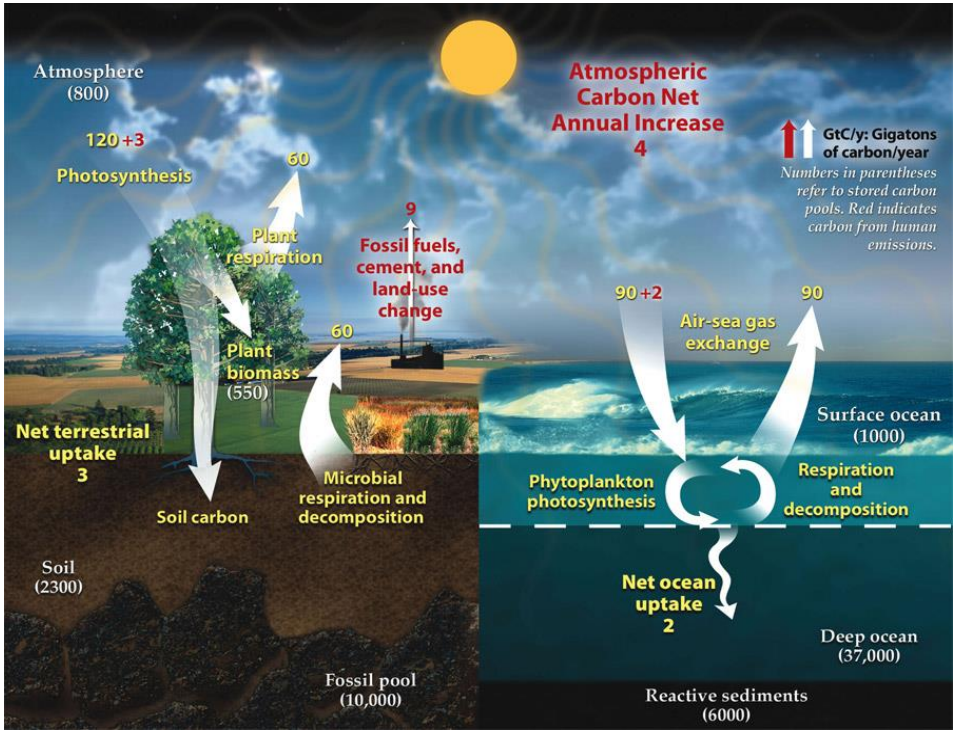
UNEP, 2011

CH_4 Emission Reductions:

- Technologically feasible although investment required
- Offer a near-term climate benefit
- Reduce tropospheric O_3 and improve air quality

Why? – Carbon Cycle Feedbacks (1)

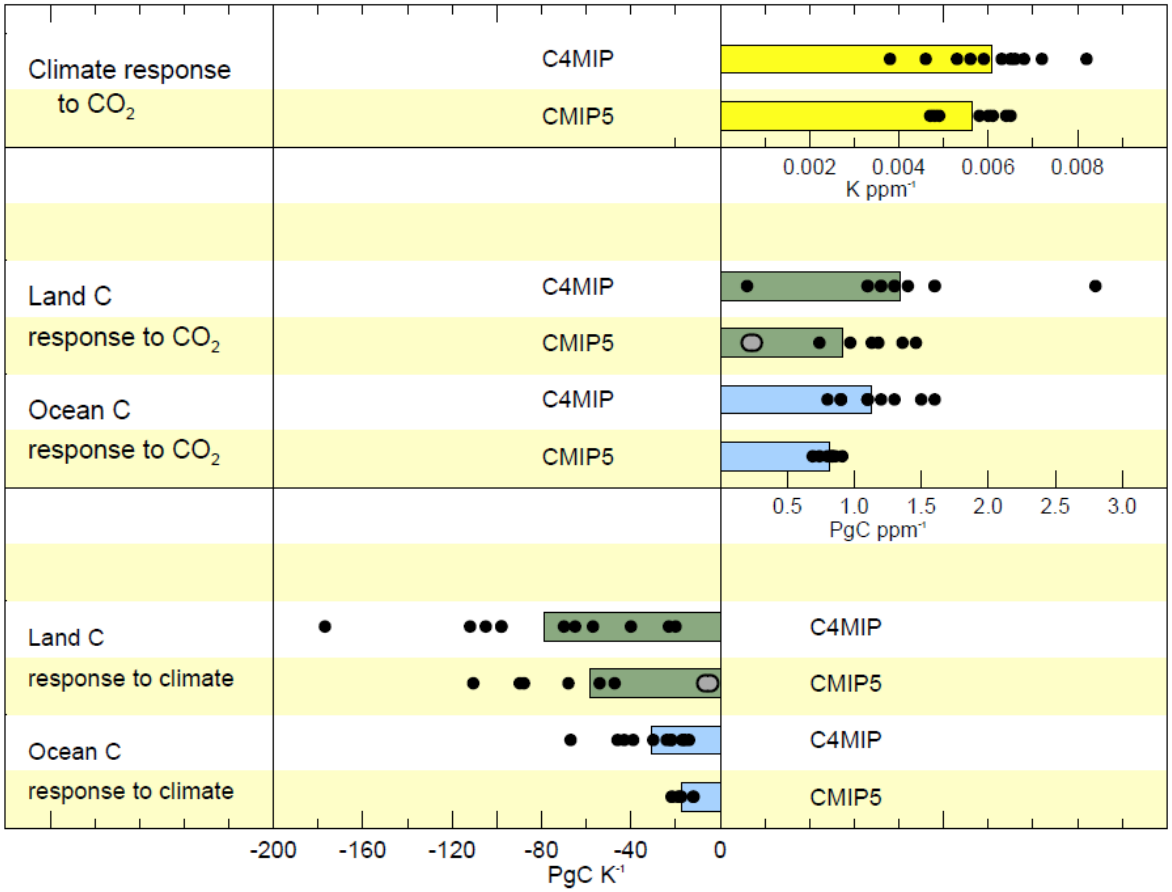
The carbon cycle is intimately linked to the physical climate system and requires an accurate simulation of associated biogeochemical cycles (e.g. H_2O, N_2, O_2)



Earth's carbon sources/sinks may be sensitive to climate change or increased CO_2 loading, changing the rate of uptake of (emitted) CO_2 from the atmosphere by the global biosphere

Why? – Carbon Cycle Feedbacks (2)

Response of C uptake to changing atmospheric CO_2 and climate — Large uncertainties, esp. in terrestrial carbon cycle



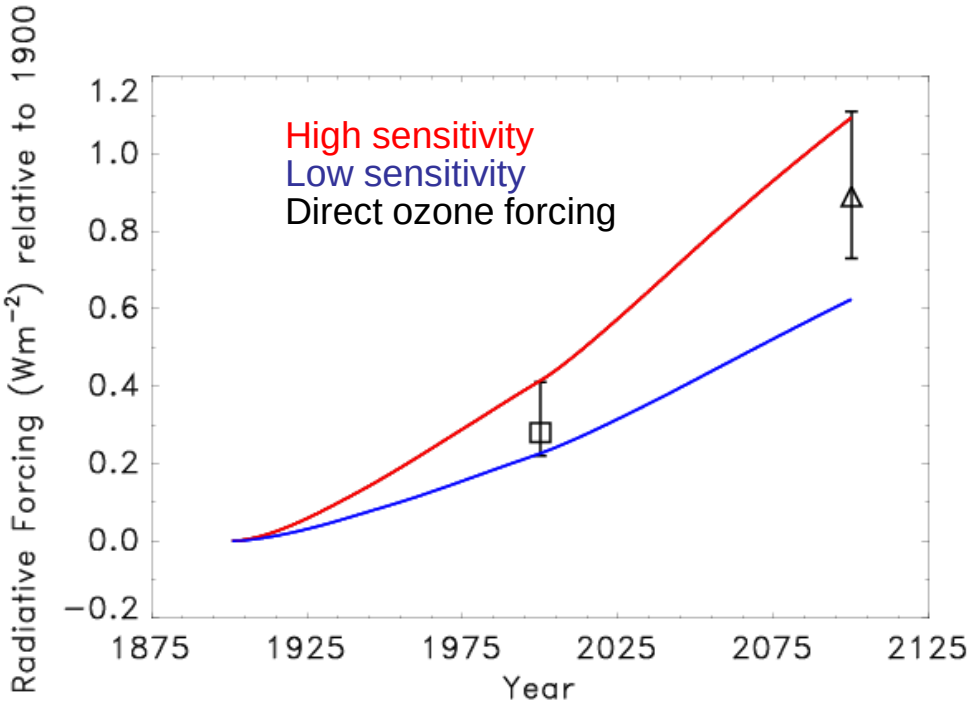
Models with a terrestrial Nitrogen cycle

Why? – Chemistry Climate Interactions (1)

- Ozone damage reduces the amount of carbon removed from the atmosphere by plants

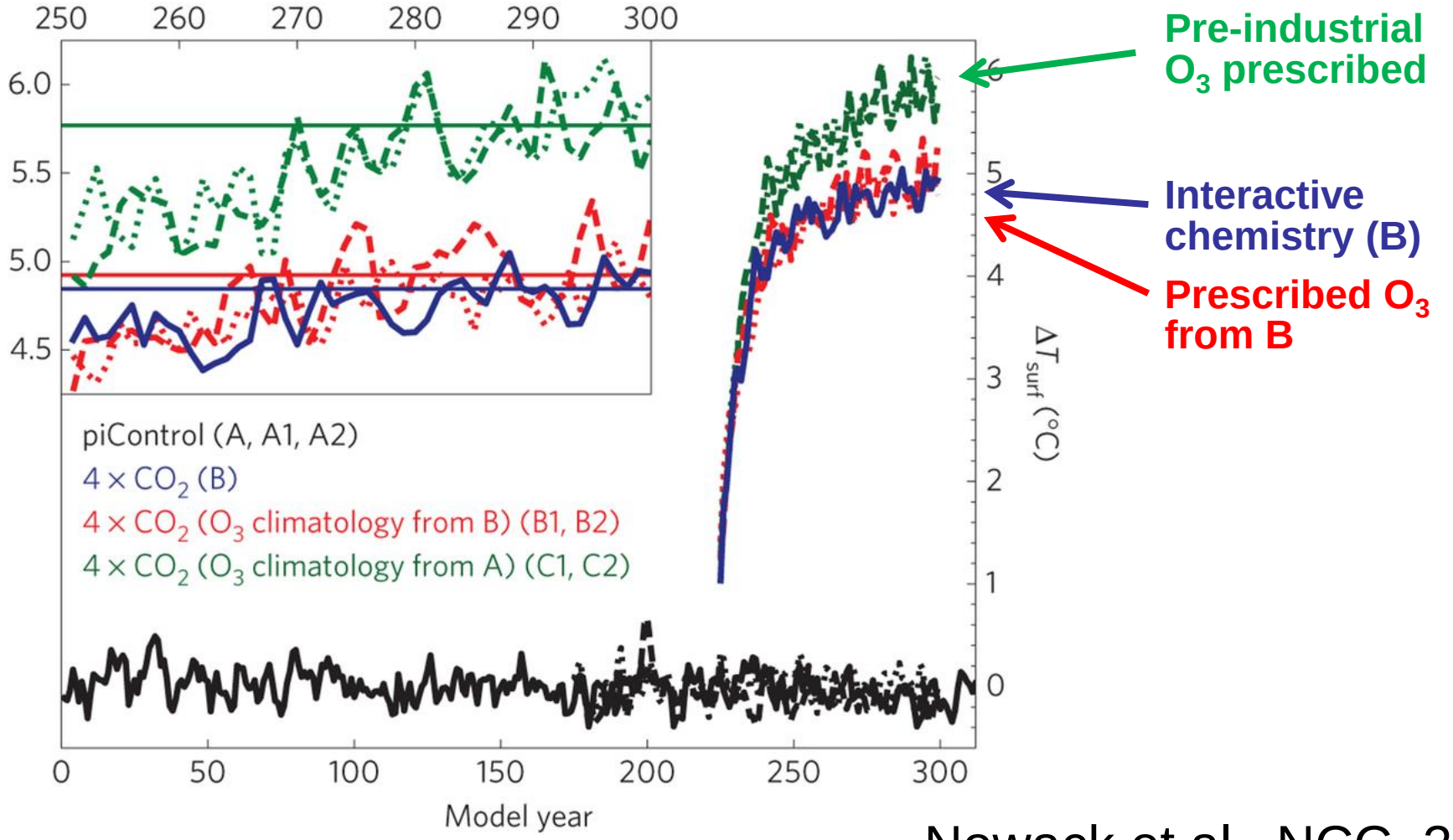
- Quantified RF over 20th & 21st Centuries

- Indirect forcing from the extra CO_2 is comparable to the direct radiative forcing from ozone



Sitch et al., Nature, 2007

Why? – Chemistry Climate Interactions (2)



Nowack et al., NCC, 2014

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- Climate Models → ES Models

Development of Models (1)

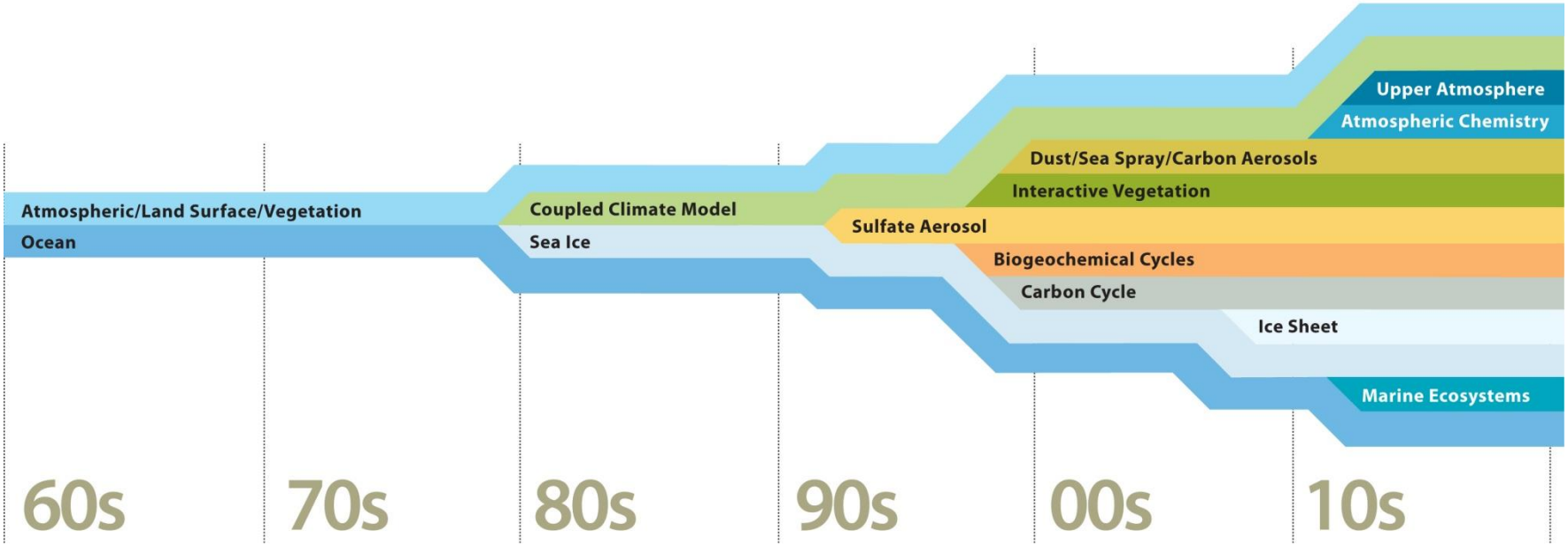
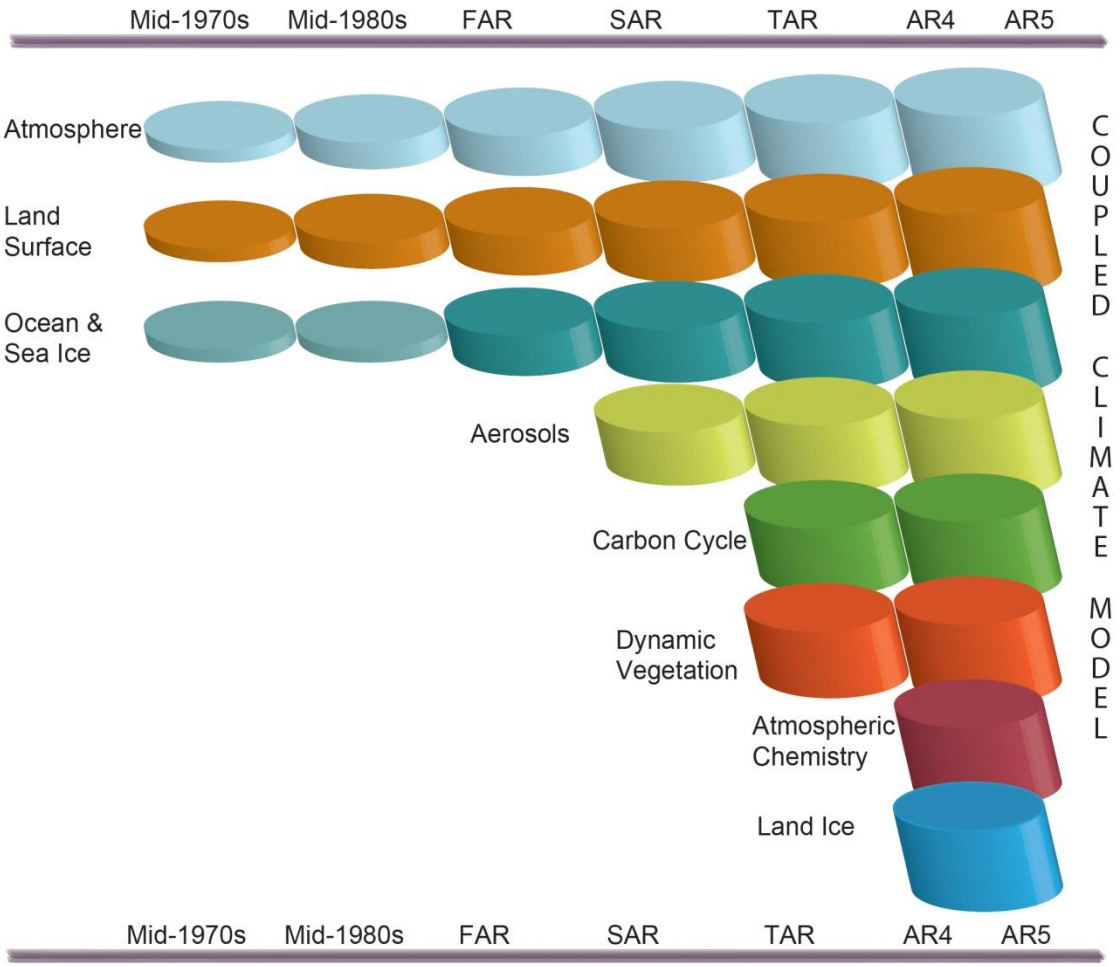


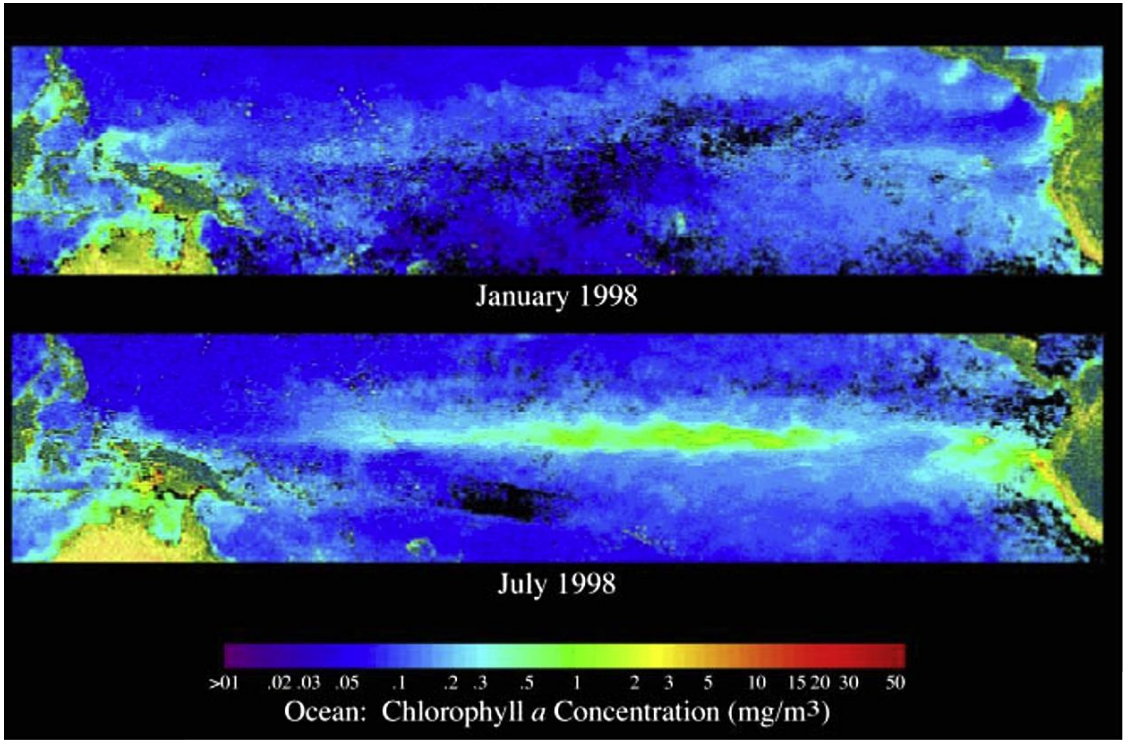
Figure courtesy of UCAR

Development of Models (2)

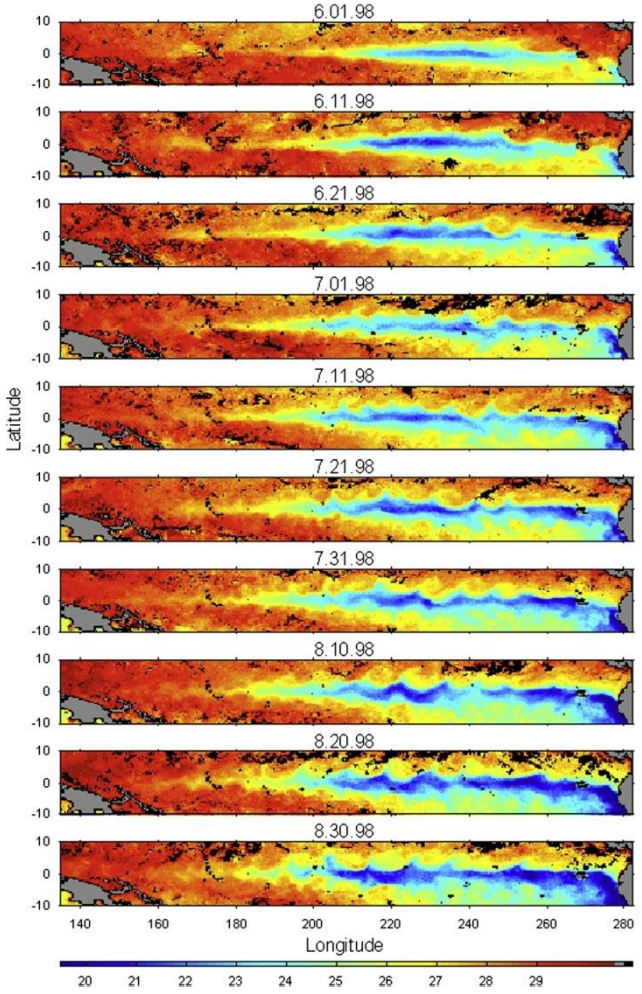


Physical climate variability and the carbon cycle interact strongly

Ocean biological activity, upwelling, carbon outgassing and nutrient transport



Evolution of summer 1998 La Nina



An Earth System Model is only as good as the core physical/dynamical climate model that is simulating underlying climate processes and variability

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Hadley Centre

- The ESM HadGEM2-ES

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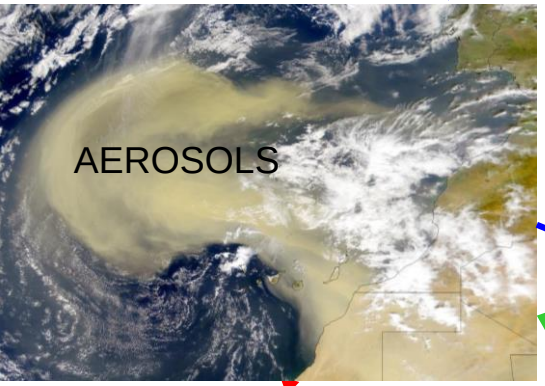
Collins et al., GMD (2011)

Radiation, cloud

Greenhouse Effect



HadGEM2-ES

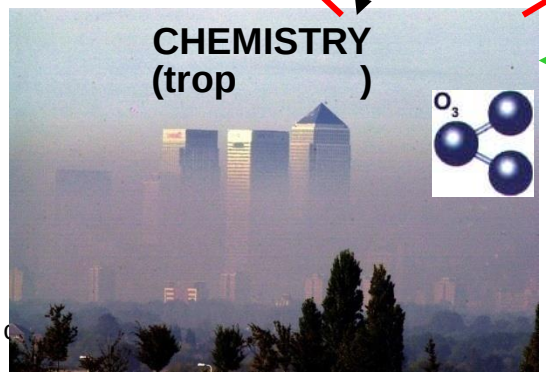
SO_4^{2-} formation

DMS, dust, emissions

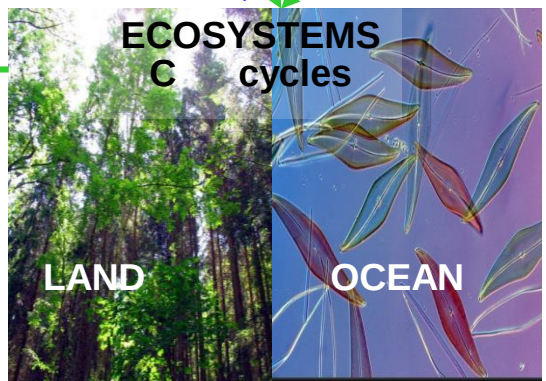
Iron, (NO_3^-) deposition

CO_2,

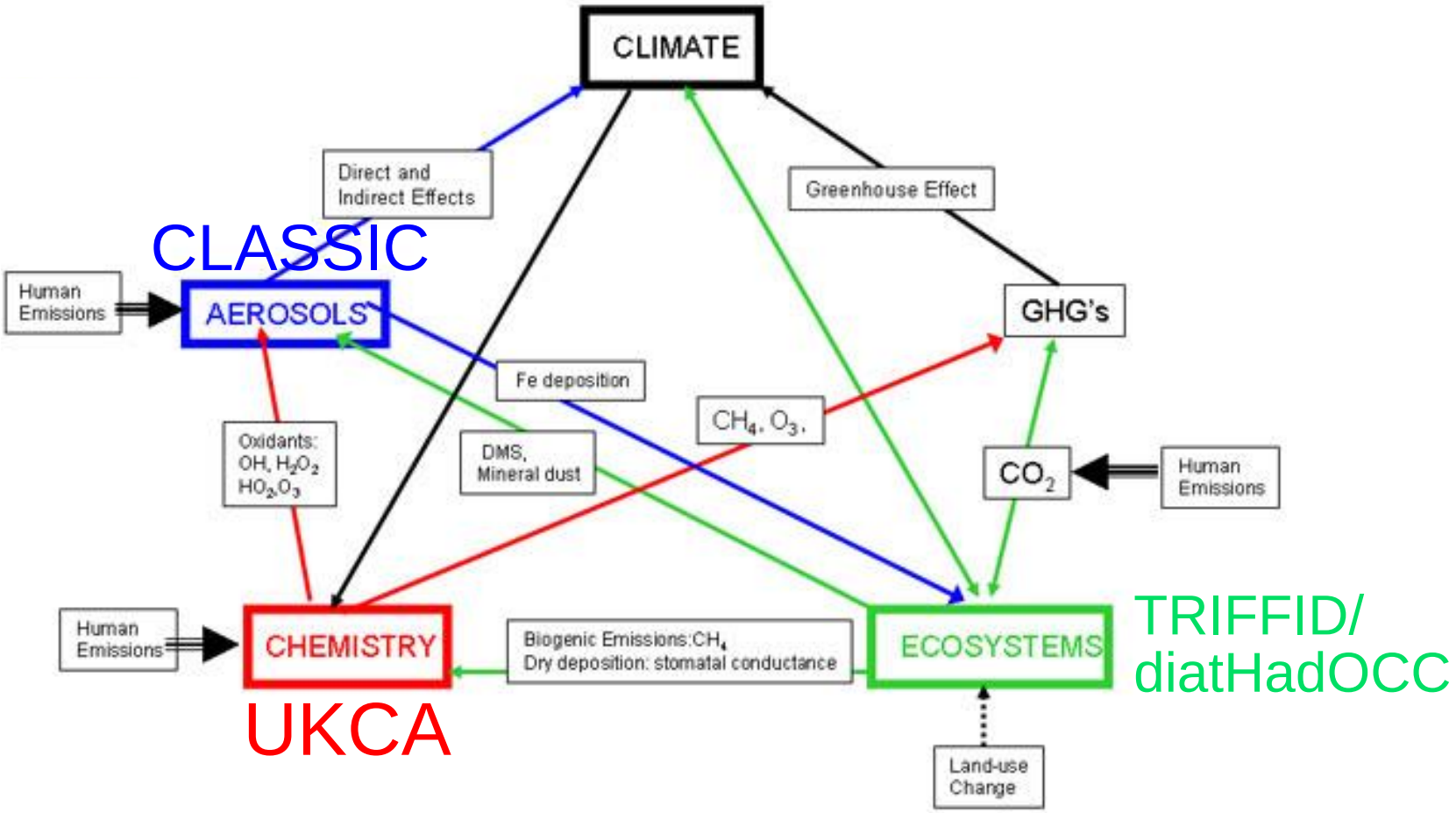
CH_4, trop O_3



Wetland CH_4, dry dep, stomatal uptake,



The Earth System Model, HadGEM2-ES



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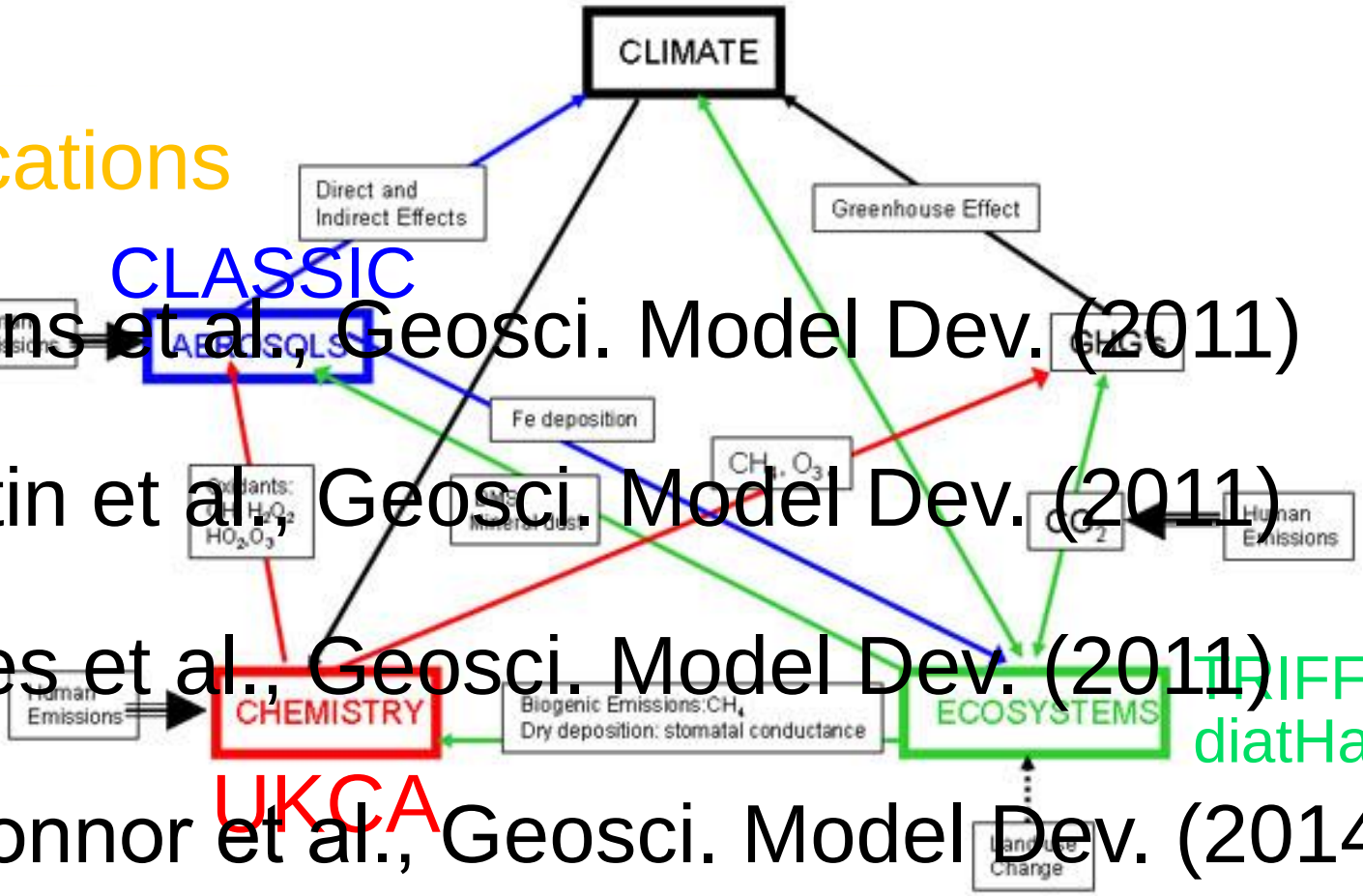

Publications

CLASSIC

- Collins et al., Geosci. Model Dev. (2011)
- Martin et al., Geosci. Model Dev. (2011)
- Jones et al., Geosci. Model Dev. (2011)

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UKCA

- O'Connor et al., Geosci. Model Dev. (2014)

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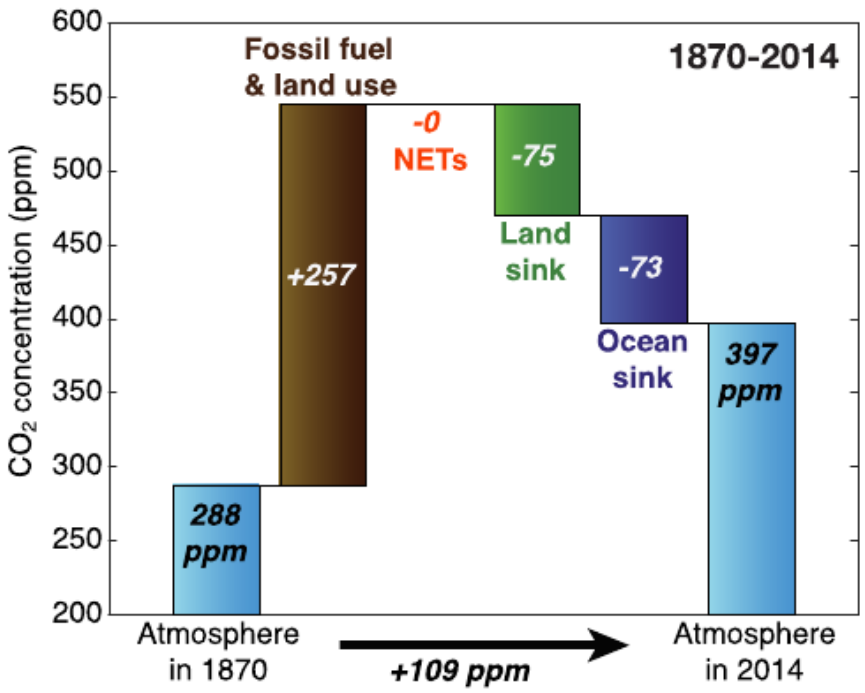
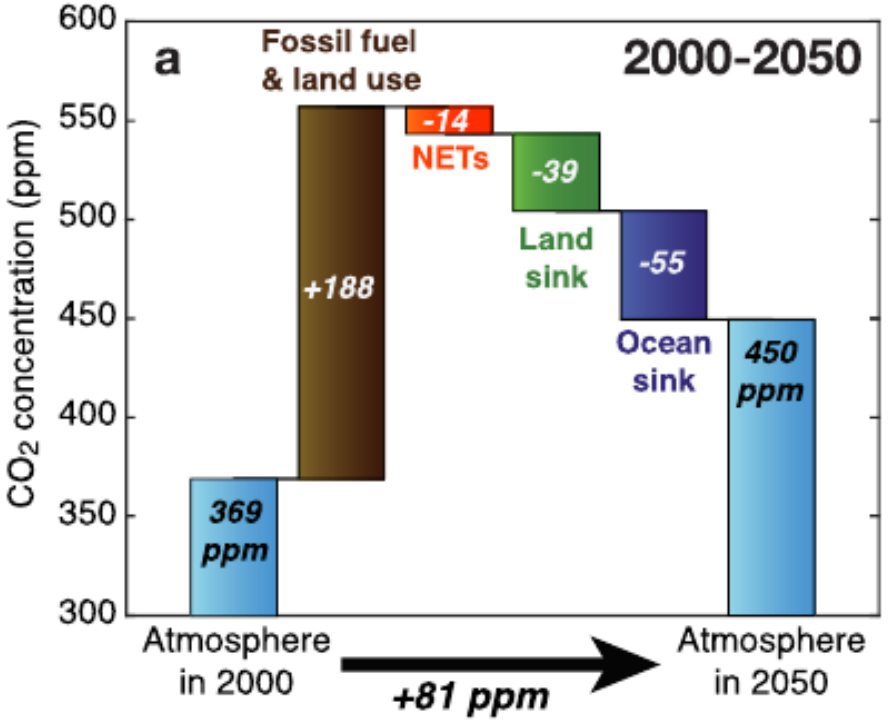
- Recent Science Highlights

ES Response to Negative Emissions (1)

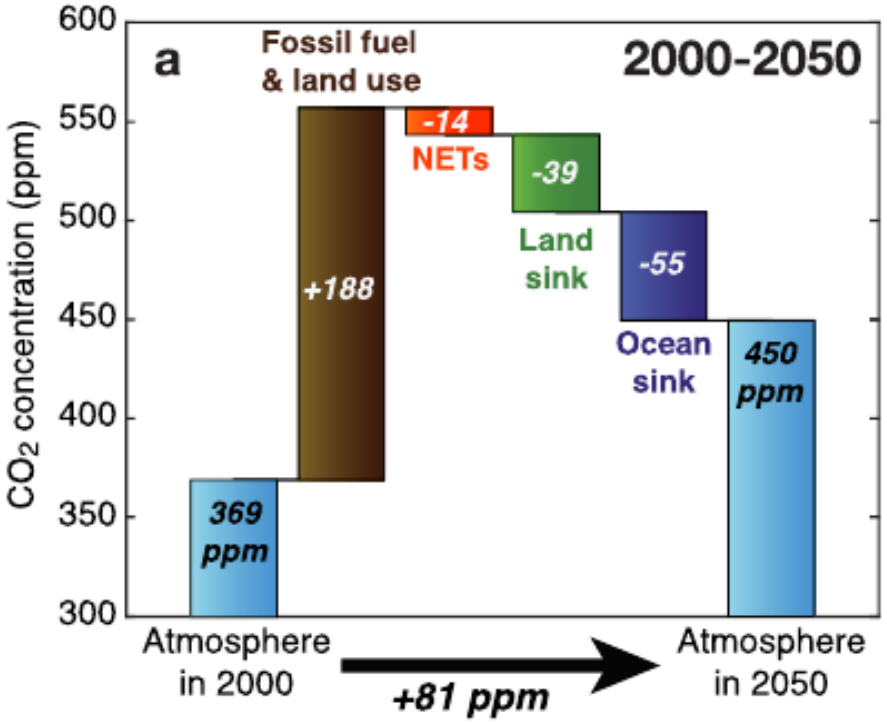


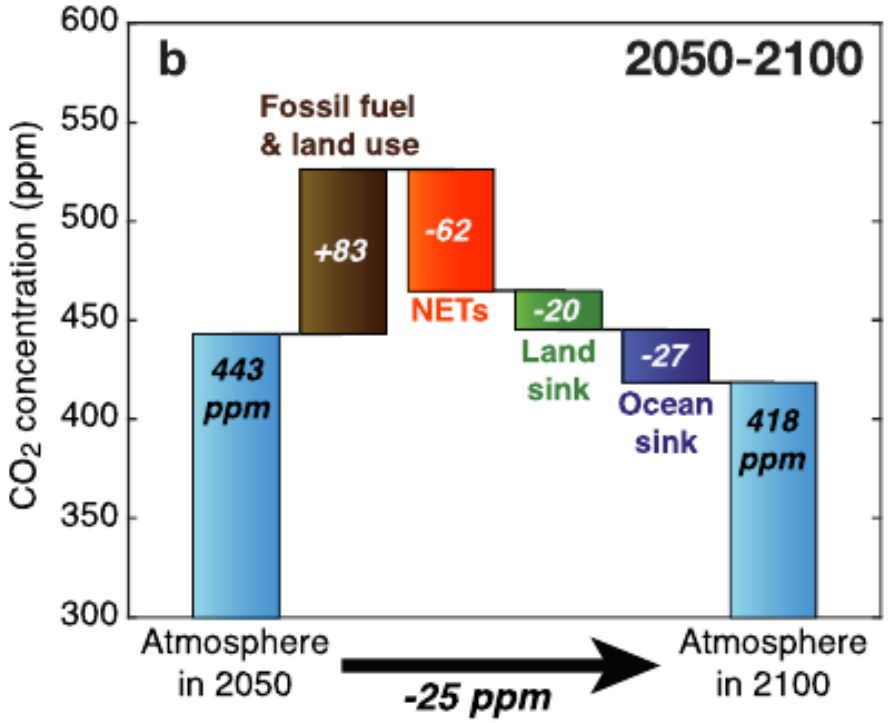


Historically, half of the anthropogenic CO_2 emitted by fossil fuel burning, cement production and land-use change was taken up by natural carbon sinks

Jones et al., ERL (2016)

ES Response to Negative Emissions (2)

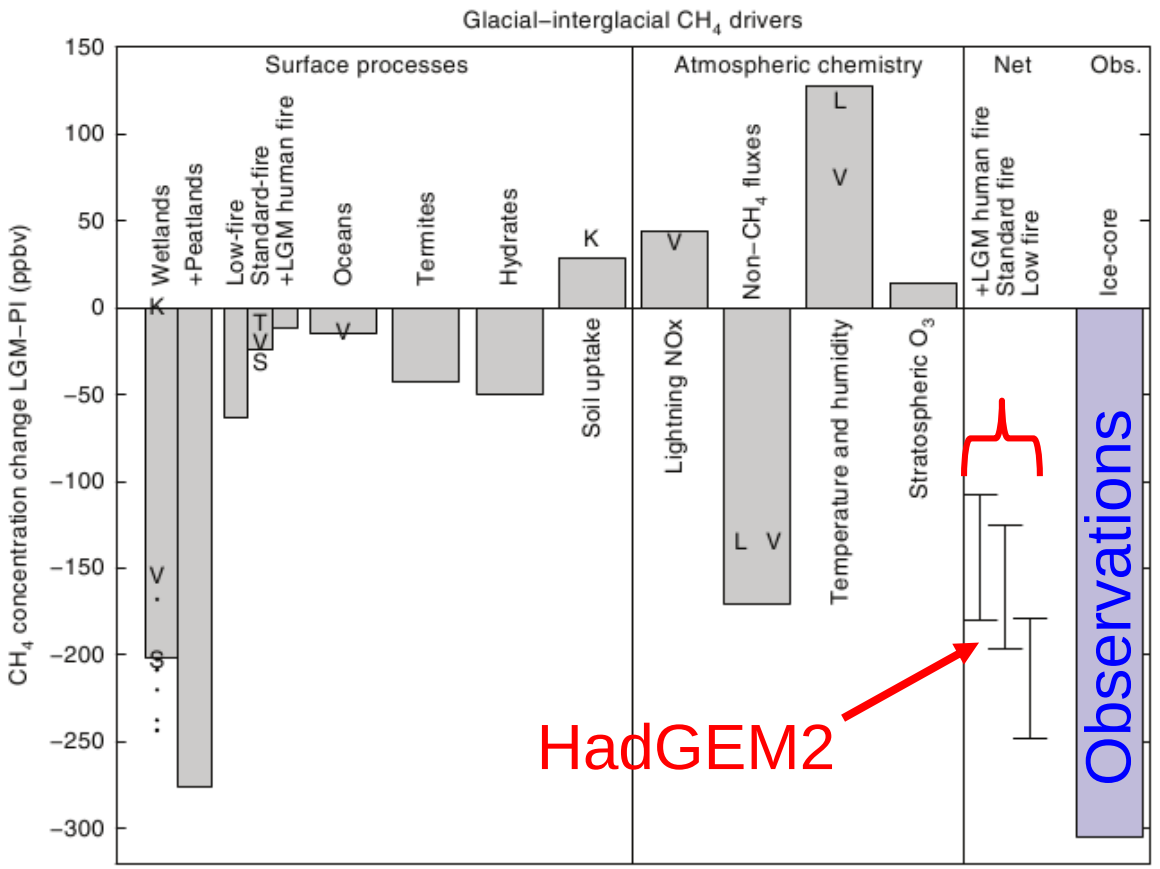




ESMs suggest significant weakening, even potential reversal, of the ocean and land sinks under future low emission scenarios may occur – will alter the effectiveness of negative emission technologies (NETs)

Methane budget at the LGM

Hopcroft et al., Nature Comm. (2017)



Cannot reconcile the observed change in CH_4 between the pre-industrial and the last glacial maximum (LGM)

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- Next Generation ESM: UKESM1

UKESM Core Group

NERC SCIENCE OF THE ENVIRONMENT

Met Office

Head

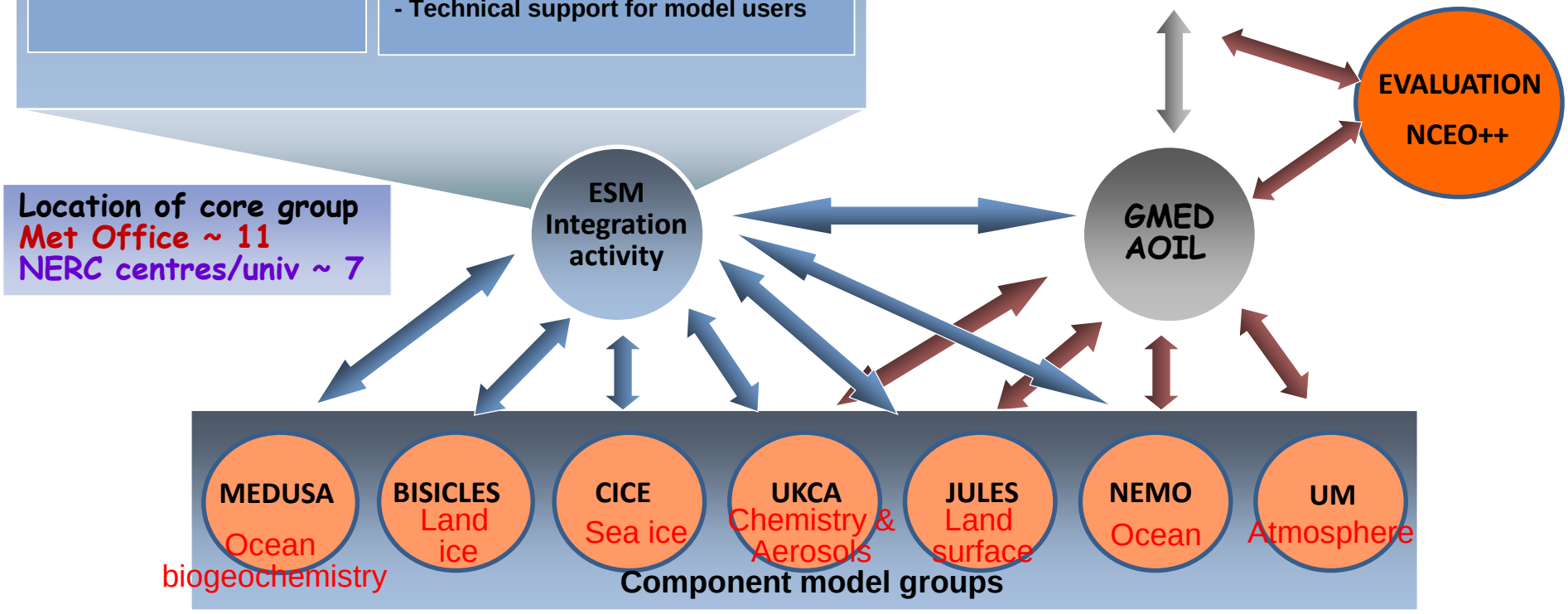
Integration team
-Core skills of integrating and running full ES models with mixed skills in component areas.
-Coupler skills.
-Configuration managers
-Spin up/initialization
-Evaluation
-Optimization

Community support
Diagnostic support
- Configuration files
- Porting

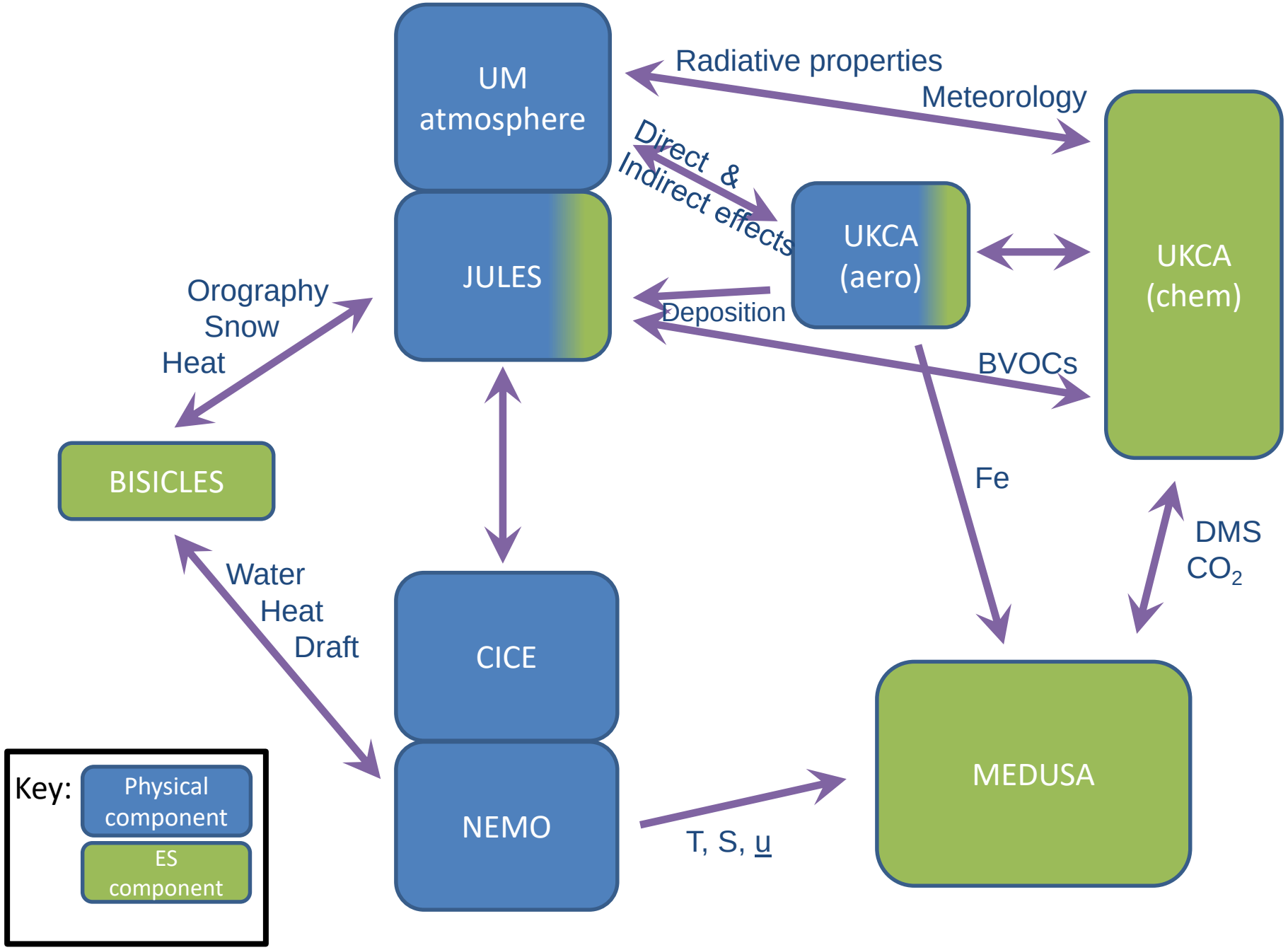
Tech. support
- Suite porting
- Community data access
- Community Evaluation tools
- Technical support for model users

UM systems and technical support
0.5 of Com. tech support is part of a larger international UM team

Location of core group
Met Office ~ 11
NERC centres/univ ~ 7



The core group integrates component developments into a full ESM

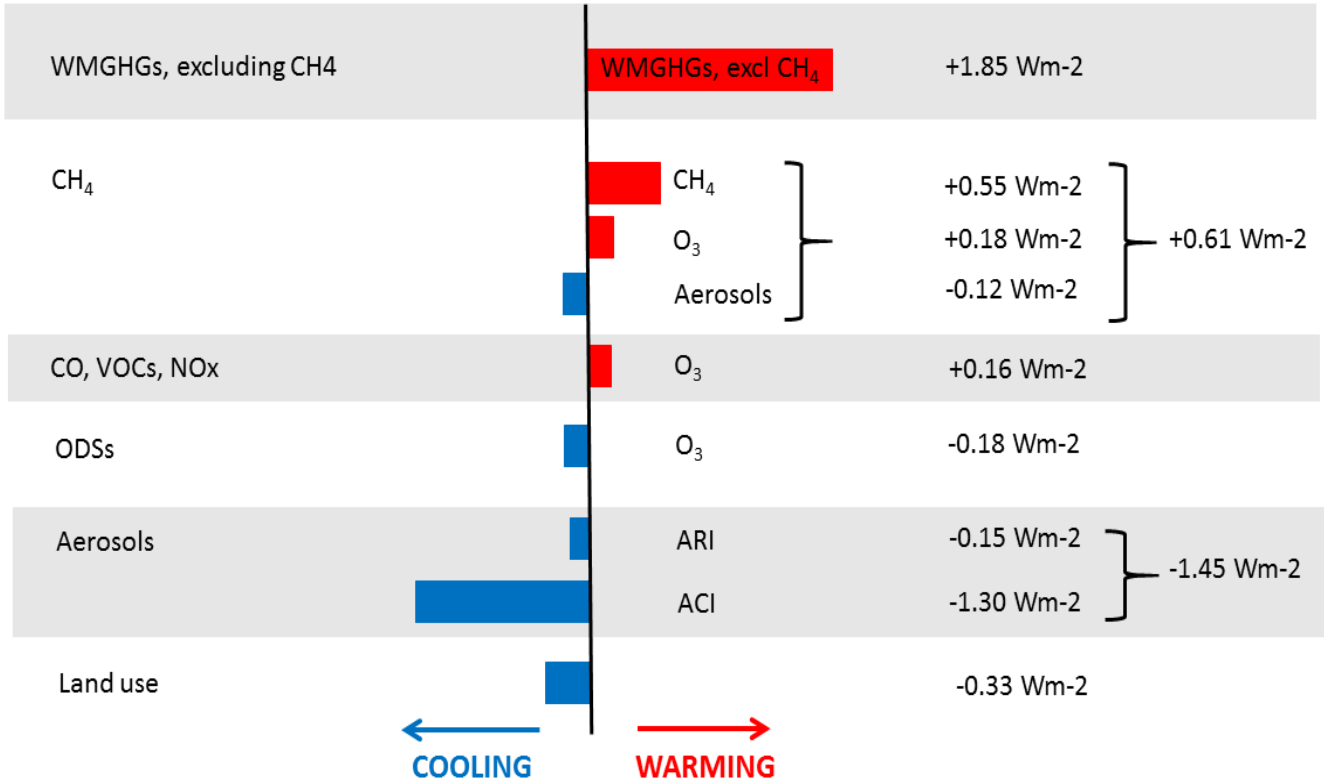

UM atmosphere
JULES
UKCA (aero)
UKCA (chem)
BISICLES
CICE
NEMO
MEDUSA
Radiative properties
Meteorology
Direct & Indirect effects
Deposition
Orography
Snow
Heat
BVOCs
Fe
DMS
CO_2
Water
Heat
Draft
T, S, u
Key:
Physical component
ES component

Planned resolutions & Timeline

- UKESM1-N96ORCA1: 130km atmosphere, 1° ocean
  - Used for many CMIP6 runs
  - Ready ~May/June2017
- UKESM1-N216ORCA025: 60km atmosphere, ¼ ° ocean
  - Some reference simulations, beginning mid-2018
- UKESM1-N216ORCA025hybrid: high-res physics, lower res OBGC advection and atmospheric chemistry/aerosol
  - Used for some CMIP6 runs

Effective Radiative Forcings

ERFs between PI & year-2000



Results from a prototype UKESM1-N96ORCA1 atmosphere-only model: O'Connor et al. (2016)

Conclusions

Concluding Remarks

- The Earth System and Climate Change Mitigation
- Motivation behind studying Earth System Science
- Development of Climate Models into Earth System Models
- The HadGEM2-ES Earth System Model
- Recent Science Highlights from HadGEM2-ES
- Brief overview of UKESM1

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Thank you for listening!
Any questions?