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Earth System Modelling

Fiona M. O'Connor

UKCA Training Workshop, Cambridge, January 2018

Overview

- What do we mean by the Earth System?
- Motivation for Studying ES Science
- Climate Models → Earth System Models
- Current UK ESM: UKESM1
- Recent ES Science Highlights

- What is the Earth System?
- hy are we interested in ES Science?
- imate Models -> Earth System Model
- rrent UK ESM: UKESM1
- ES Science Highlights

What is the Earth System?

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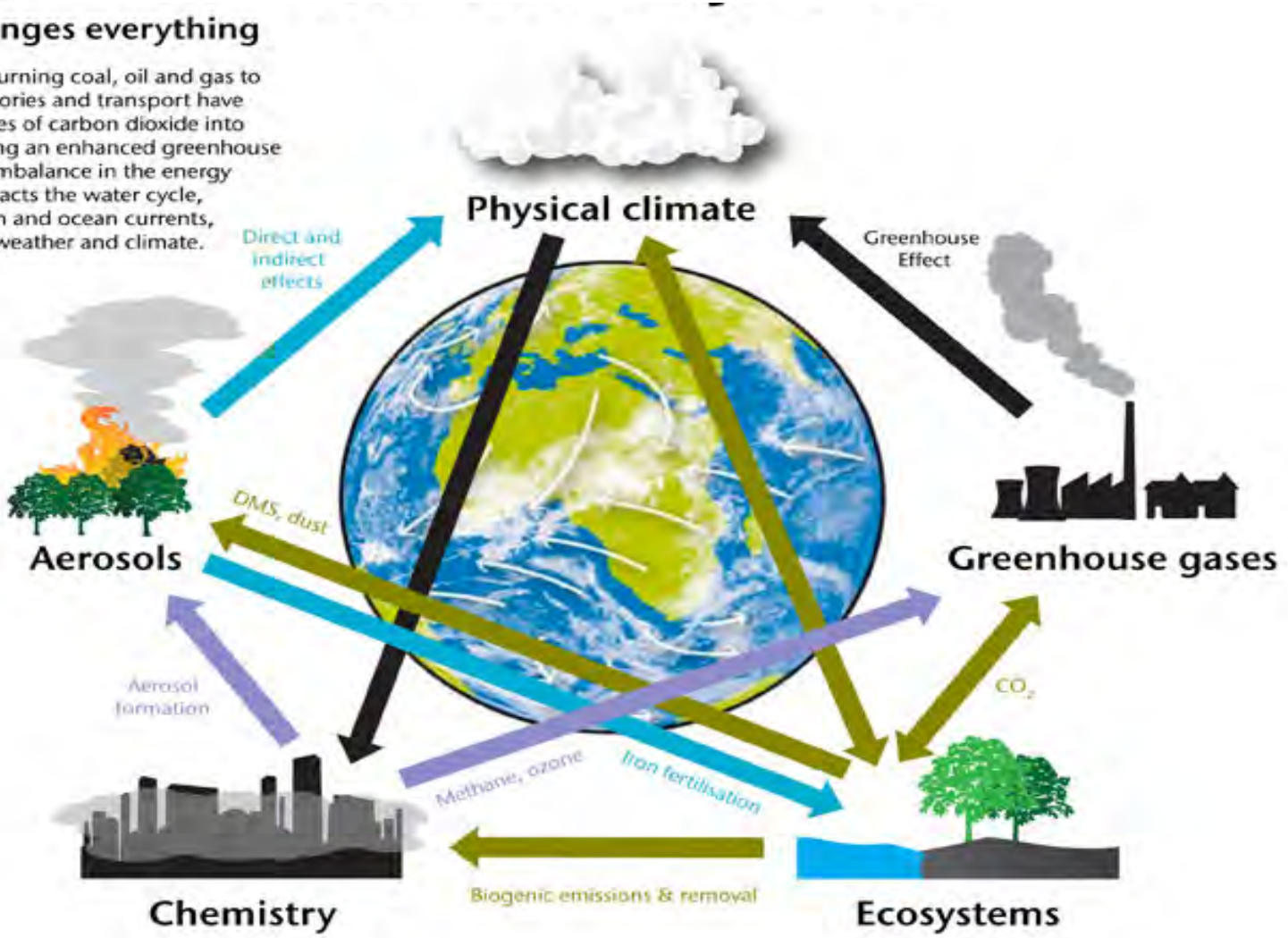
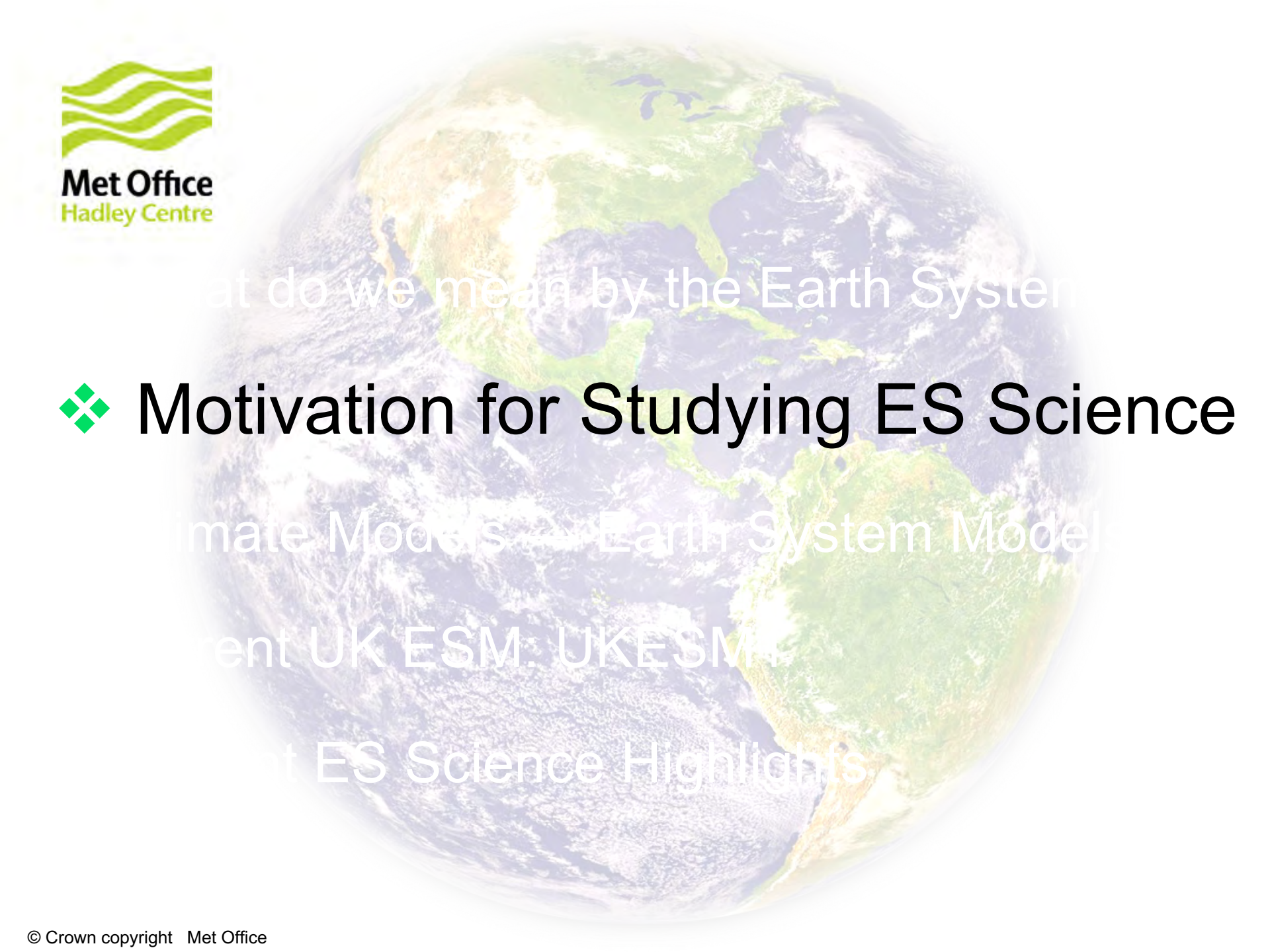
One thing changes everything

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.

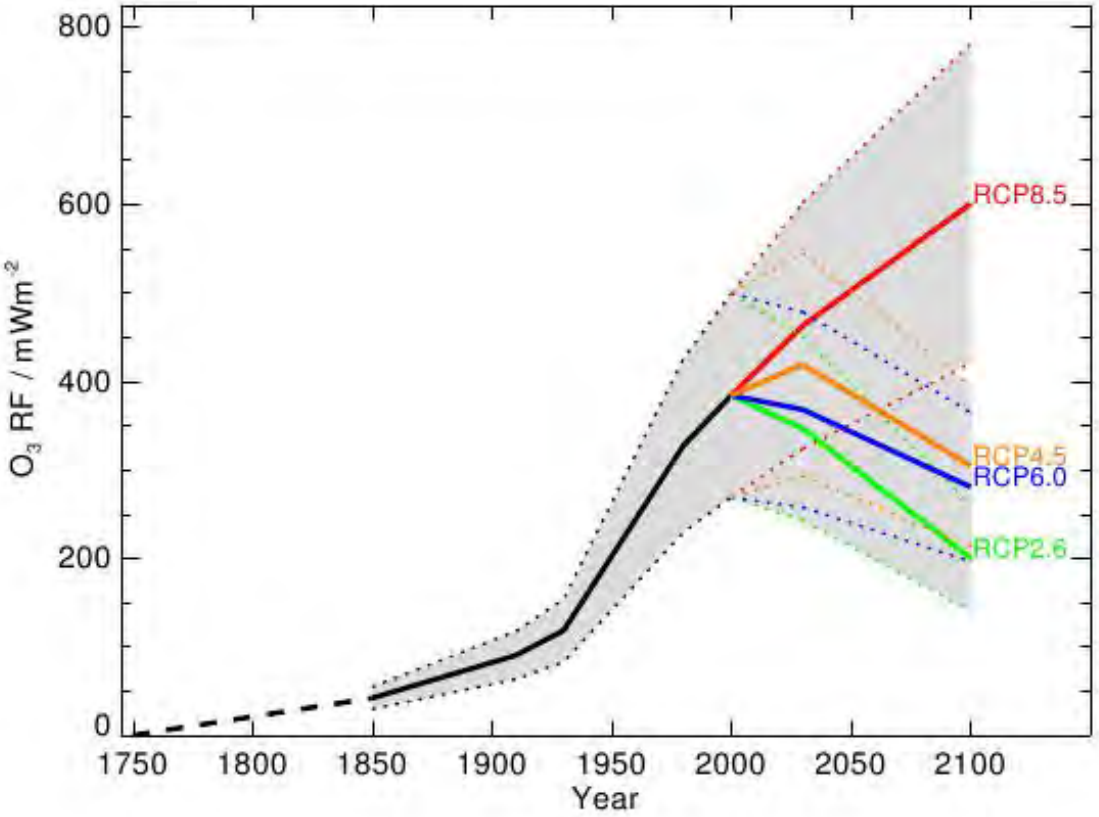




- Motivation for Studying ES Science

Why? – Climate Forcing (1)

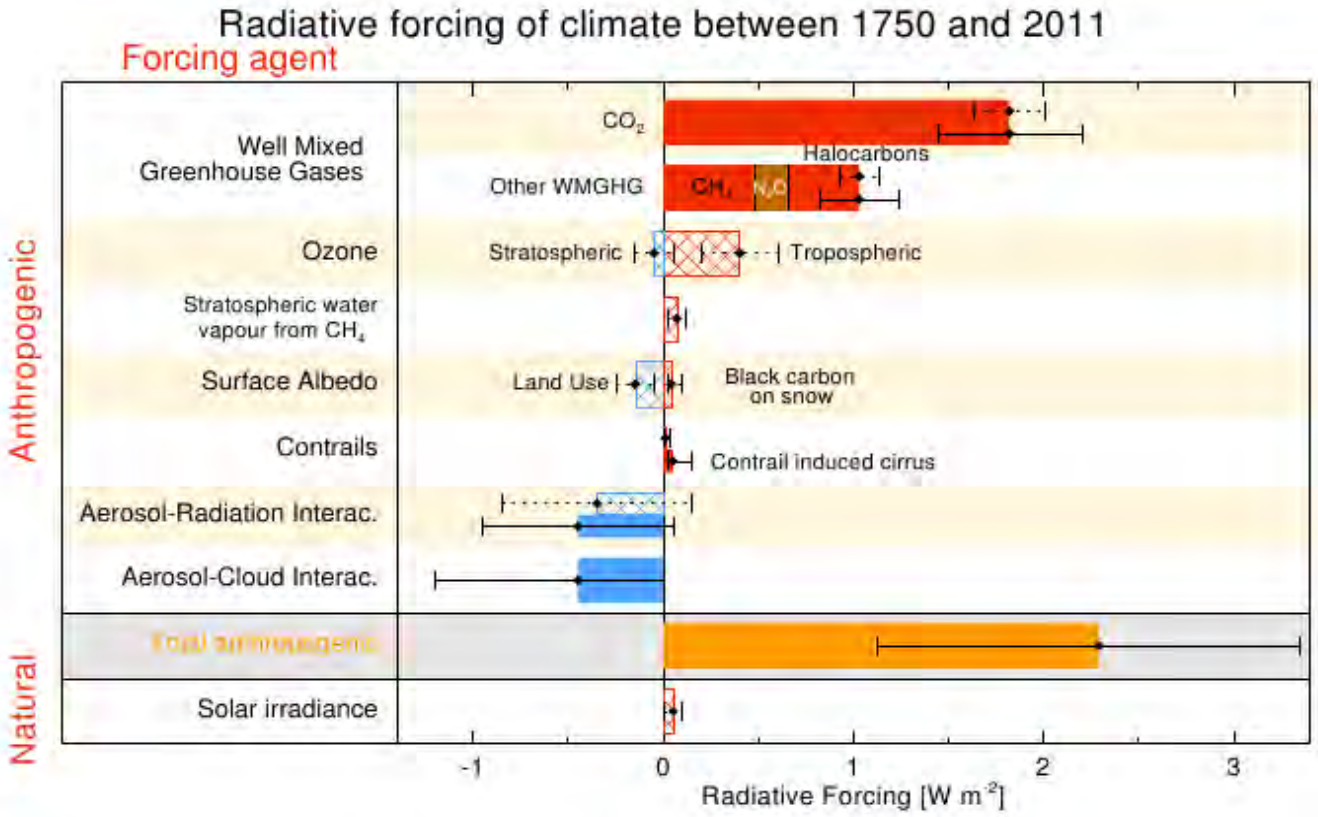
Tropospheric O_3 forcing



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

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

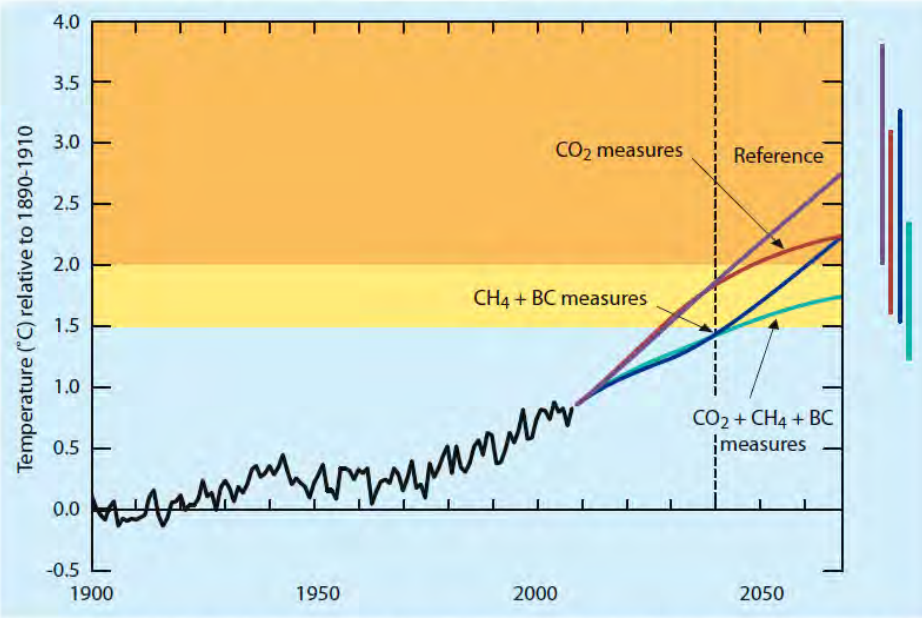
Why? – Climate Forcing (2)



5th Assessment Report (AR5), IPCC

Why? – Mitigation

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



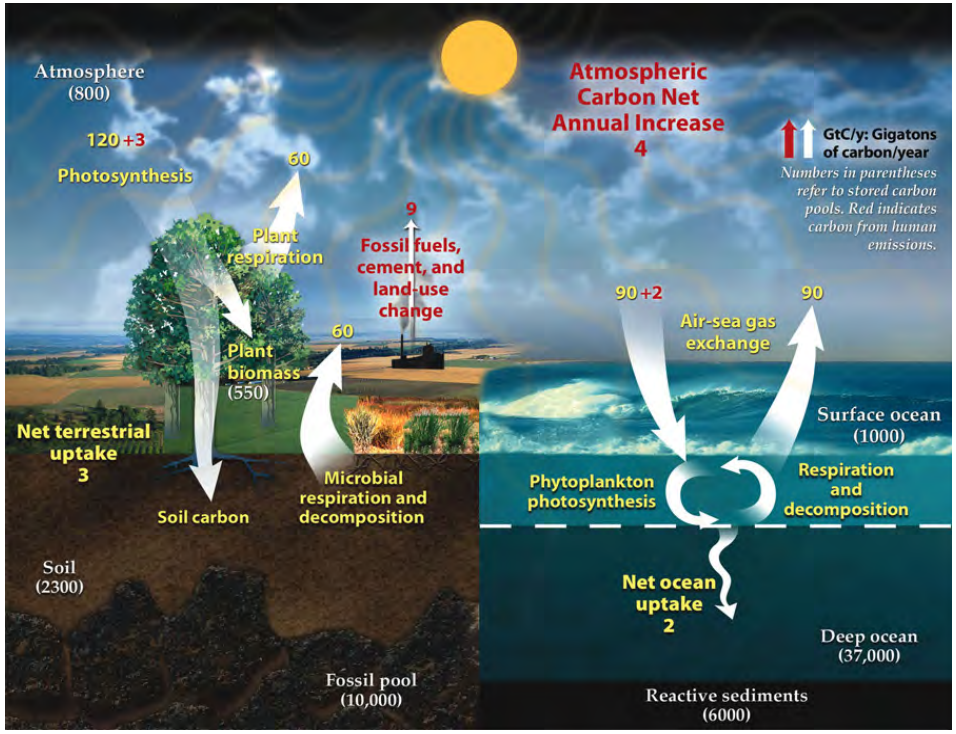
UNEP, 2011

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)

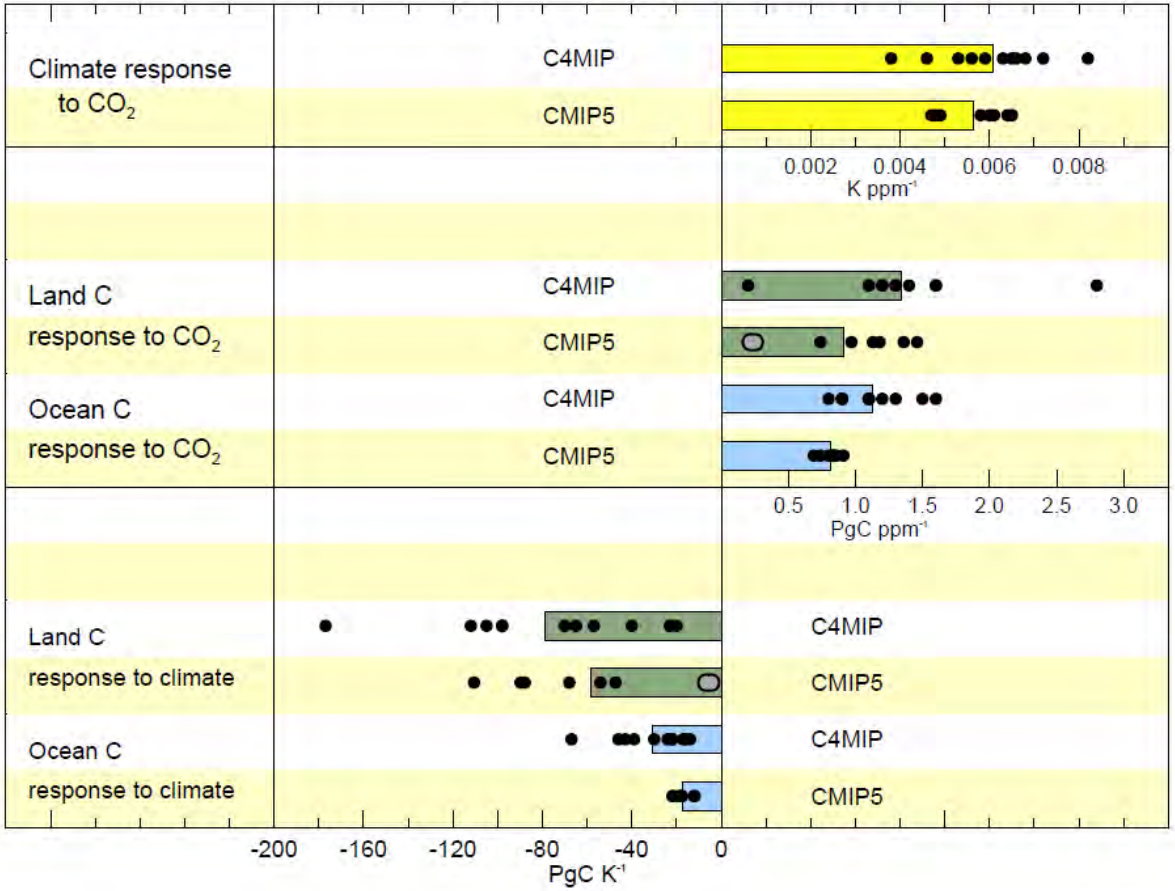
The carbon cycle is intimately linked to the physical climate system and requires an accurate simulation of associated biogeochemical cycles (e.g. H_2O, N_2, O_2)



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



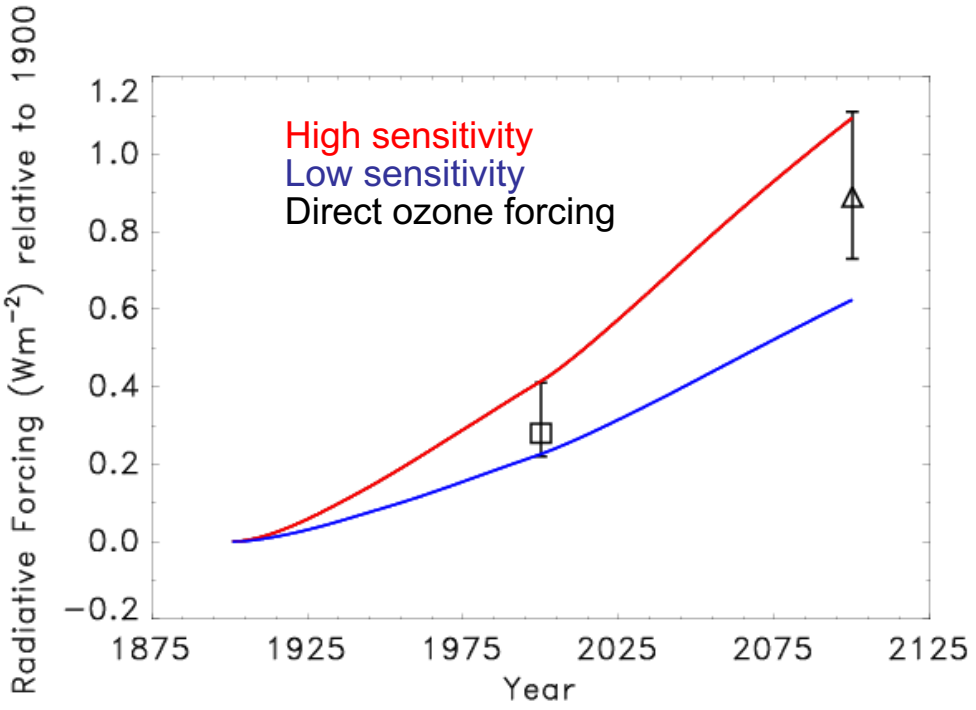
Models with a terrestrial Nitrogen cycle

Why? – Chemistry Climate Interactions (1)

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

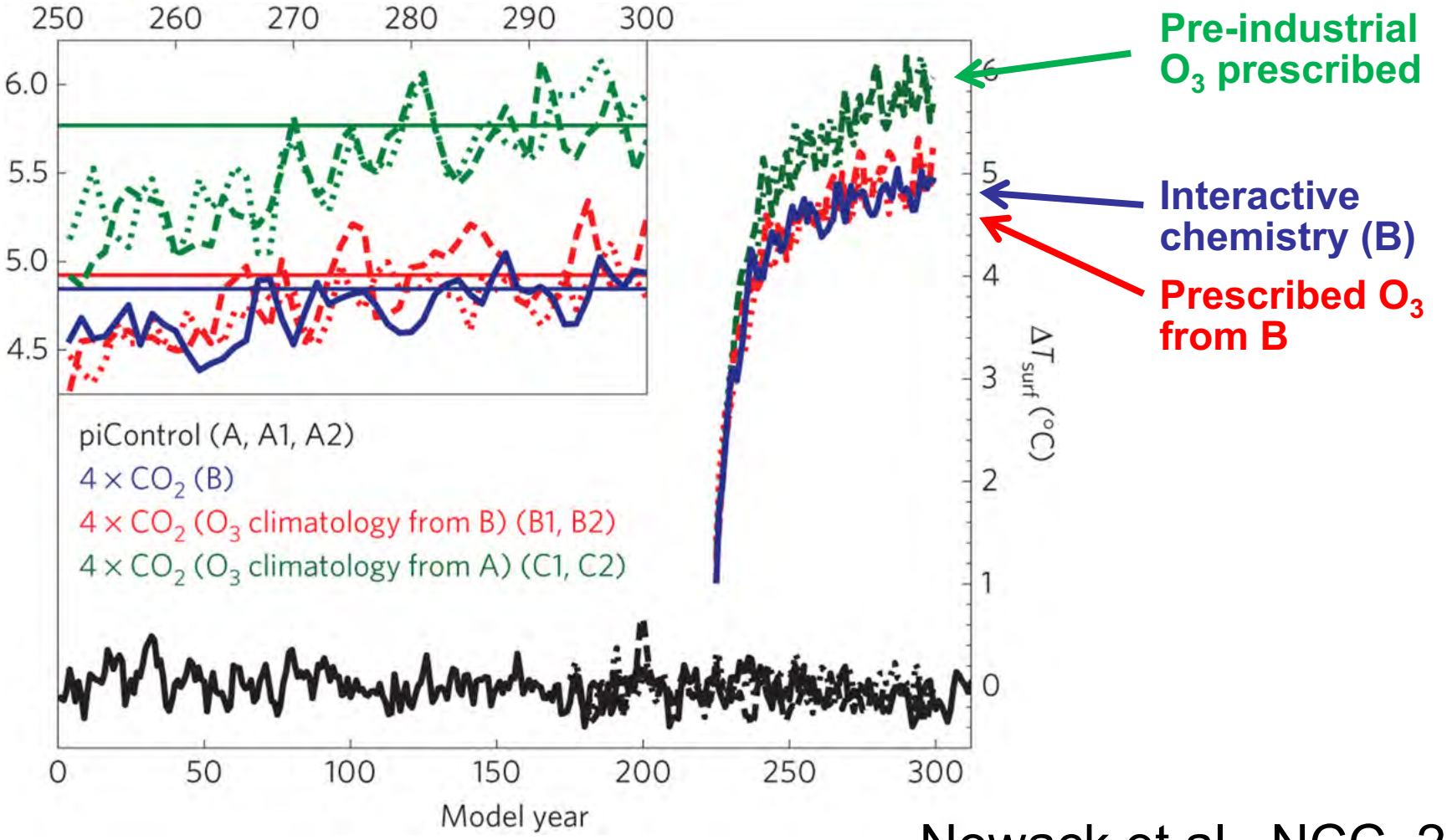
- Quantified RF over 20th & 21st Centuries

- 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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at do we mean by the Earth Syste

hy are we interested in ES Science?

- Climate Models → ES Models

t Generation ESM: UKESM1

ES Science Highlights

Development of Models (1)

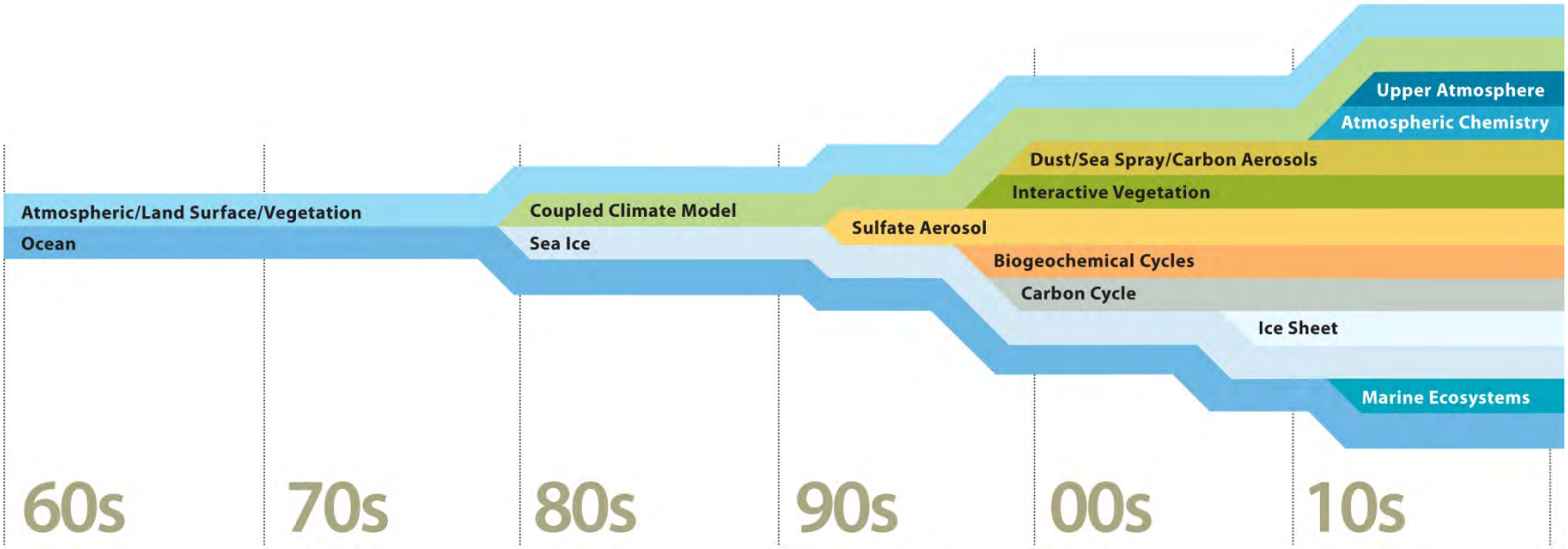
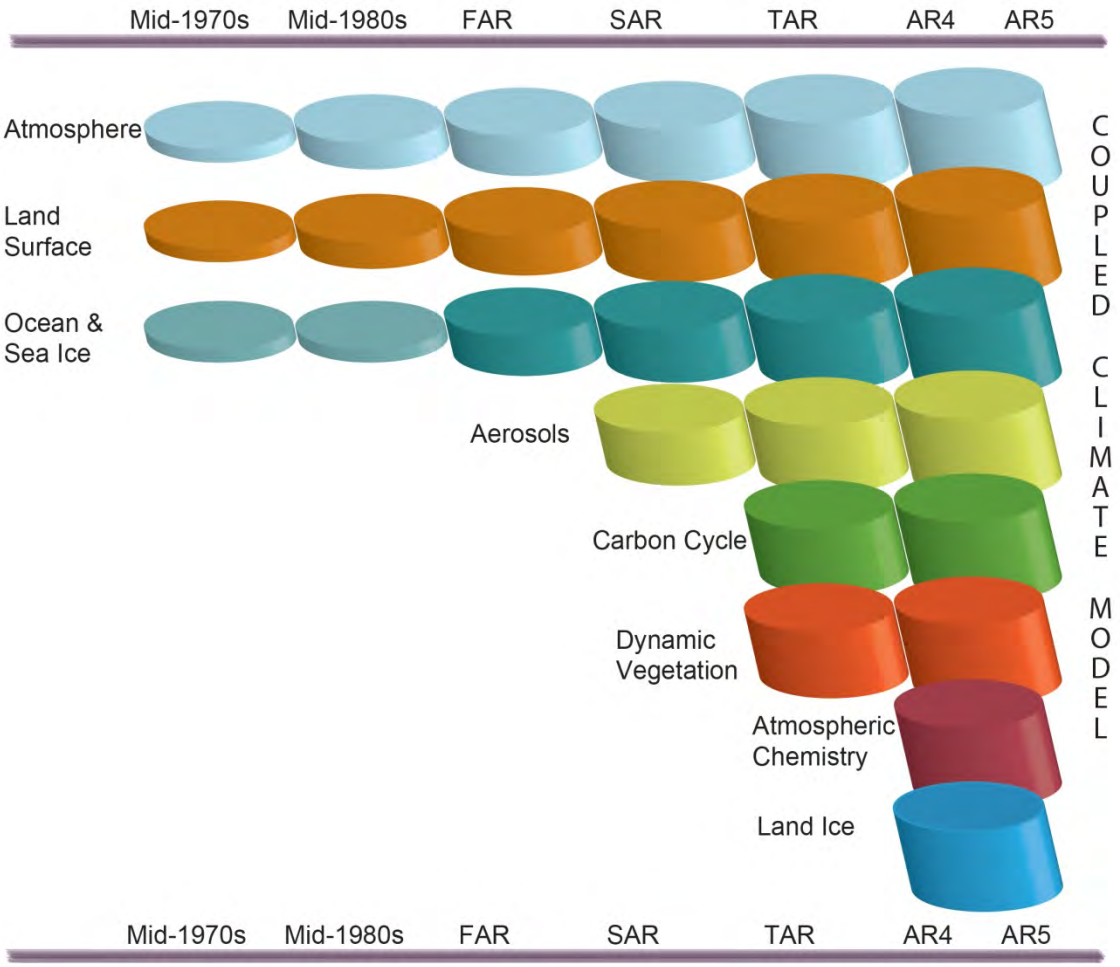


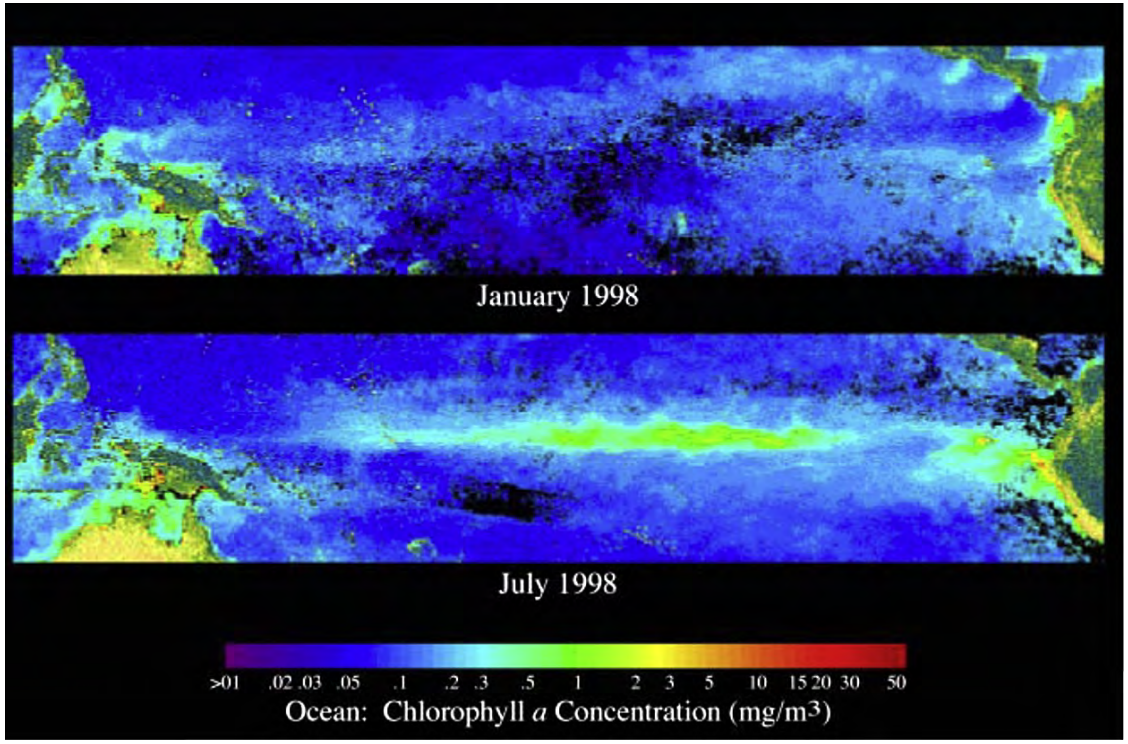
Figure courtesy of UCAR

Development of Models (2)

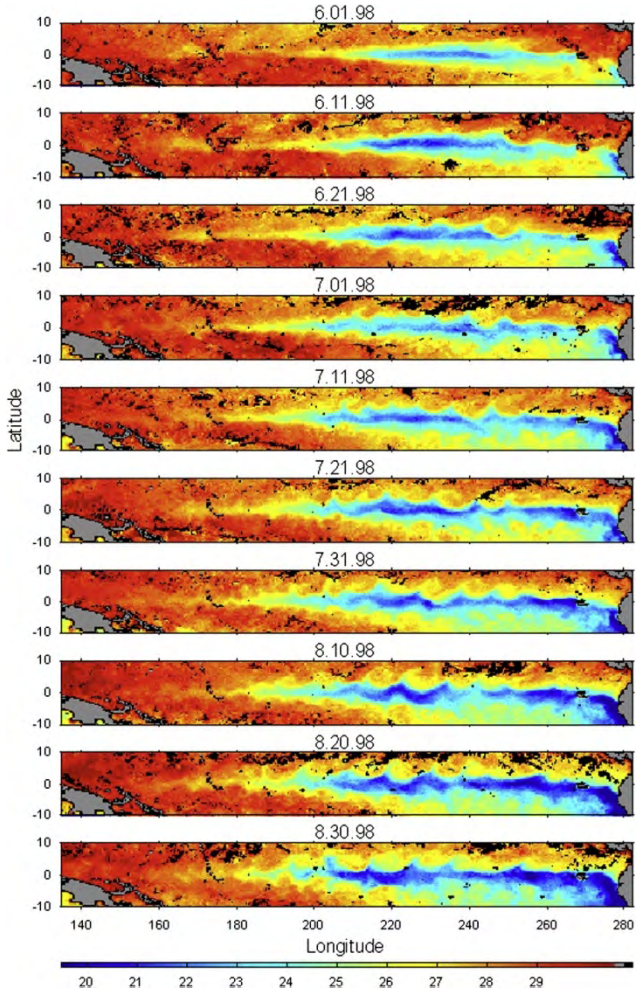


Physical climate variability and the carbon cycle interact strongly

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

- What do we mean by the Earth System
- Why are we interested in ES Science?
- Climate Models → Earth System Models
- Next Generation ESM: UKESM1
- Recent ES Science Highlights

UKESM Core Group

NERC SCIENCE OF THE ENVIRONMENT

Met Office

Head: Colin Jones

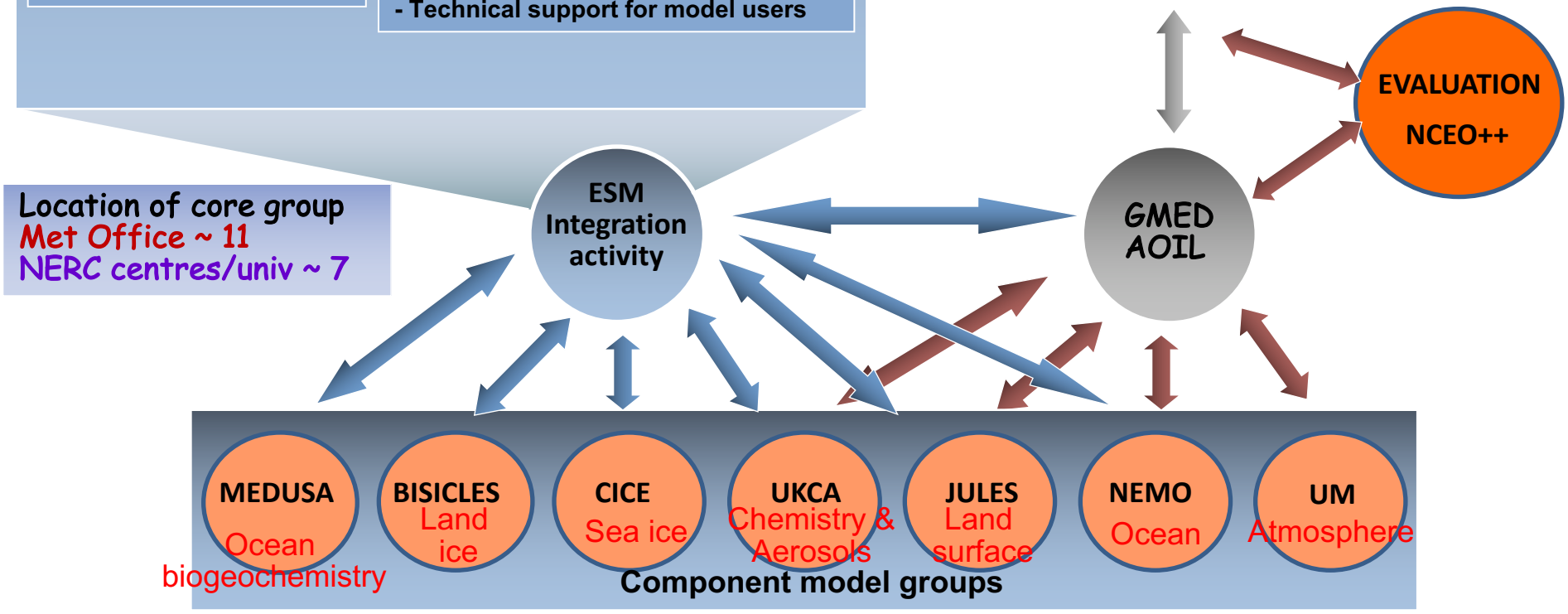
Integration team
-Core skills of integrating and running full ES models with mixed skills in component areas.
-Coupler skills.
-Configuration managers
-Spin up/initialization
-Evaluation
-Optimization

Community support
Diagnostic support
- Configuration files
- Porting

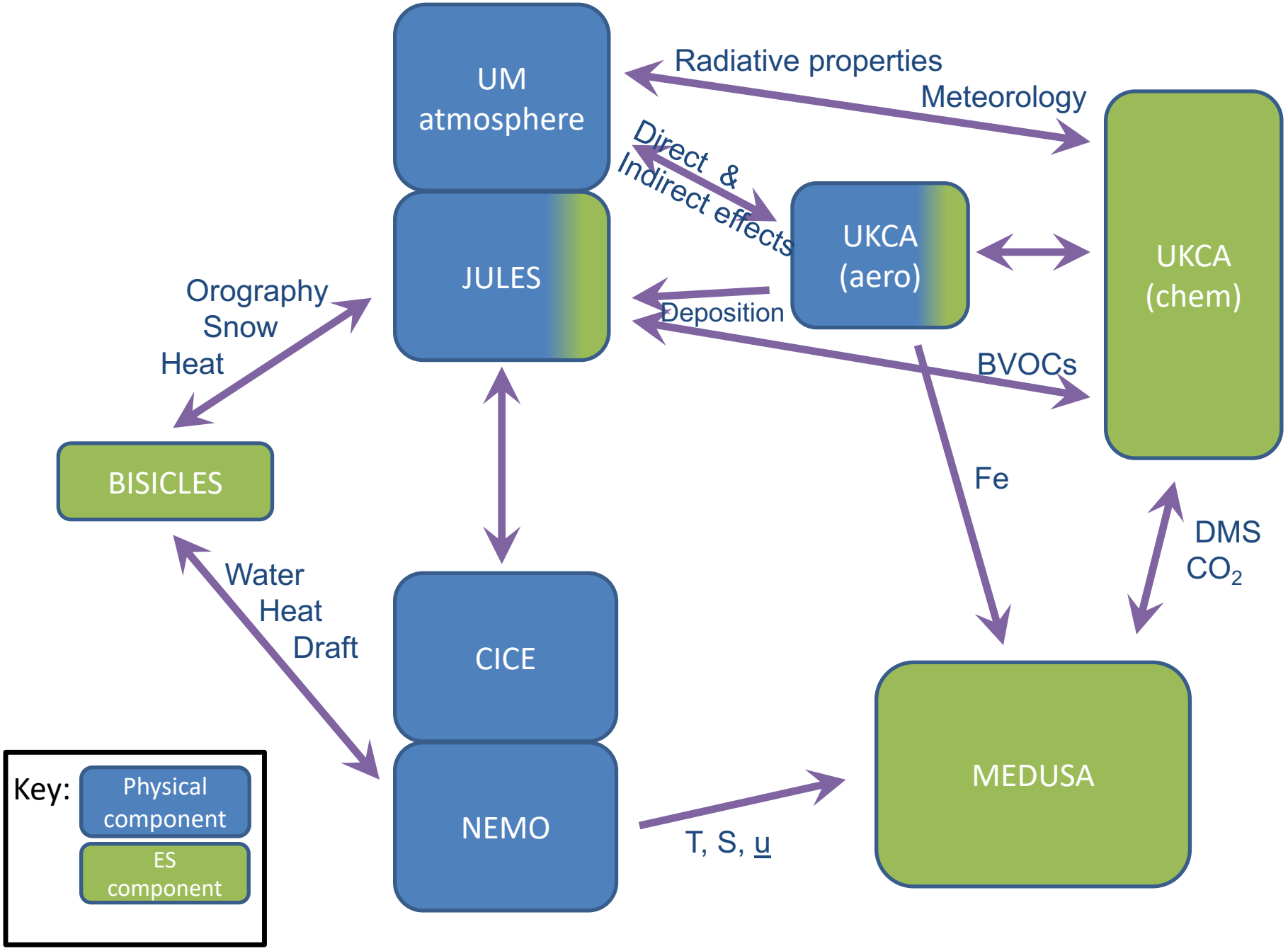
Tech. support
- Suite porting
- Community data access
- Community Evaluation tools
- Technical support for model users

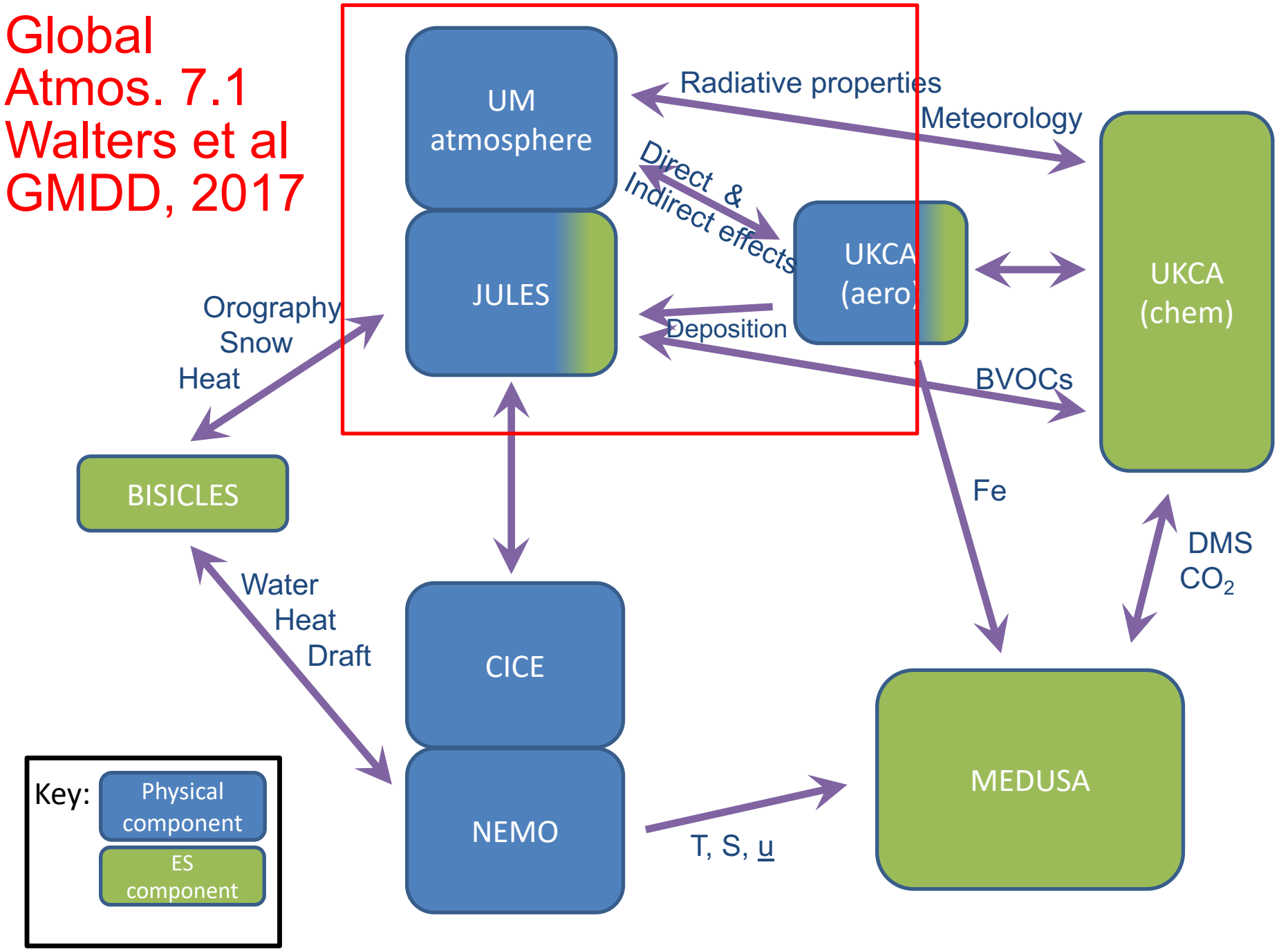
UM systems and technical support
0.5 of Com. tech support is part of a larger international UM team

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
Orography
Snow
Heat
Deposition
BVOCs
Fe
DMS
CO_2
Water
Heat
Draft
T, S, u
Key:
Physical component
ES component


Global
Atmos. 7.1
Walters et al
GMDD, 2017
UM
atmosphere
JULES
Radiative properties
Meteorology
Direct &
Indirect effects
UKCA
(aero)
UKCA
(chem)
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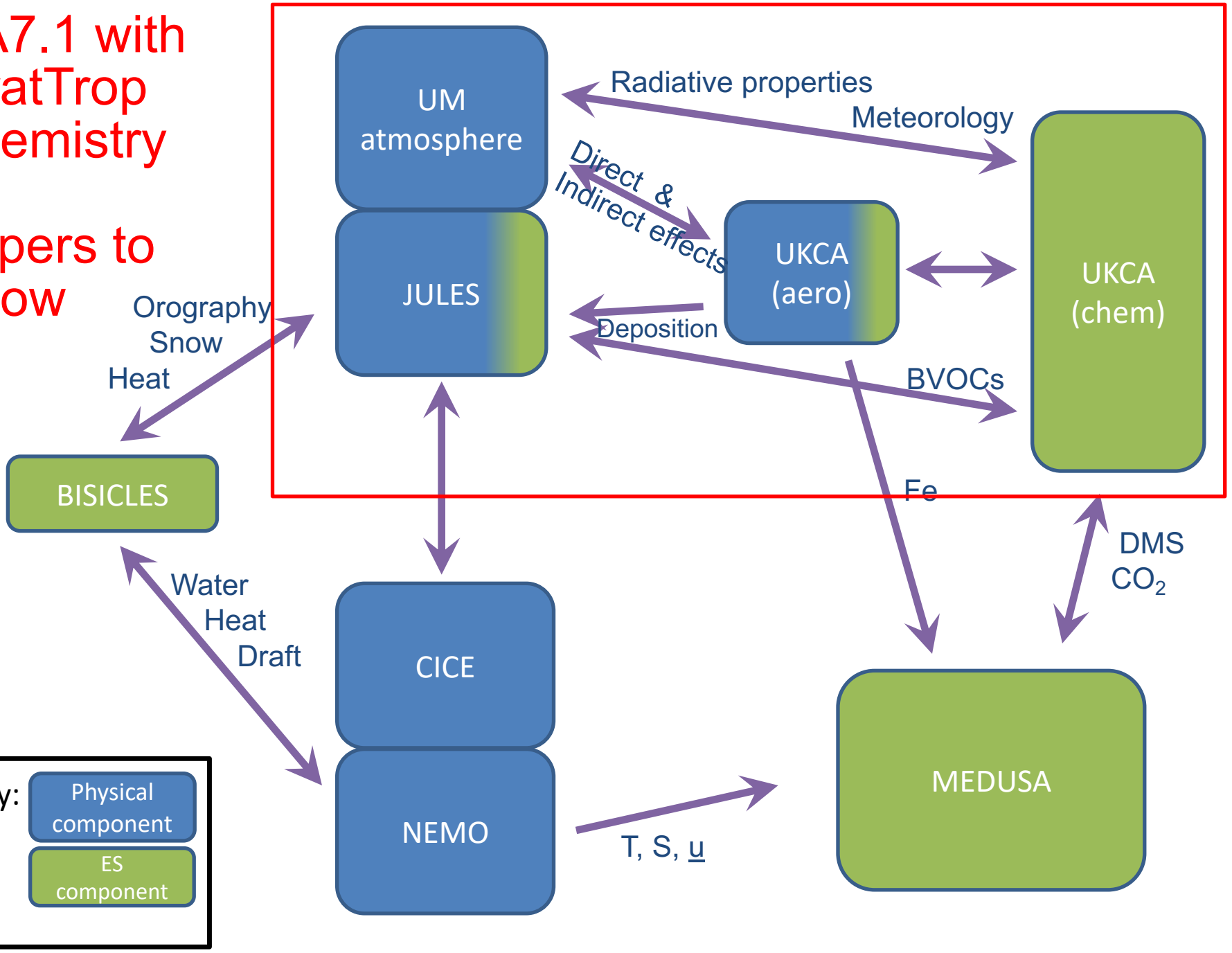
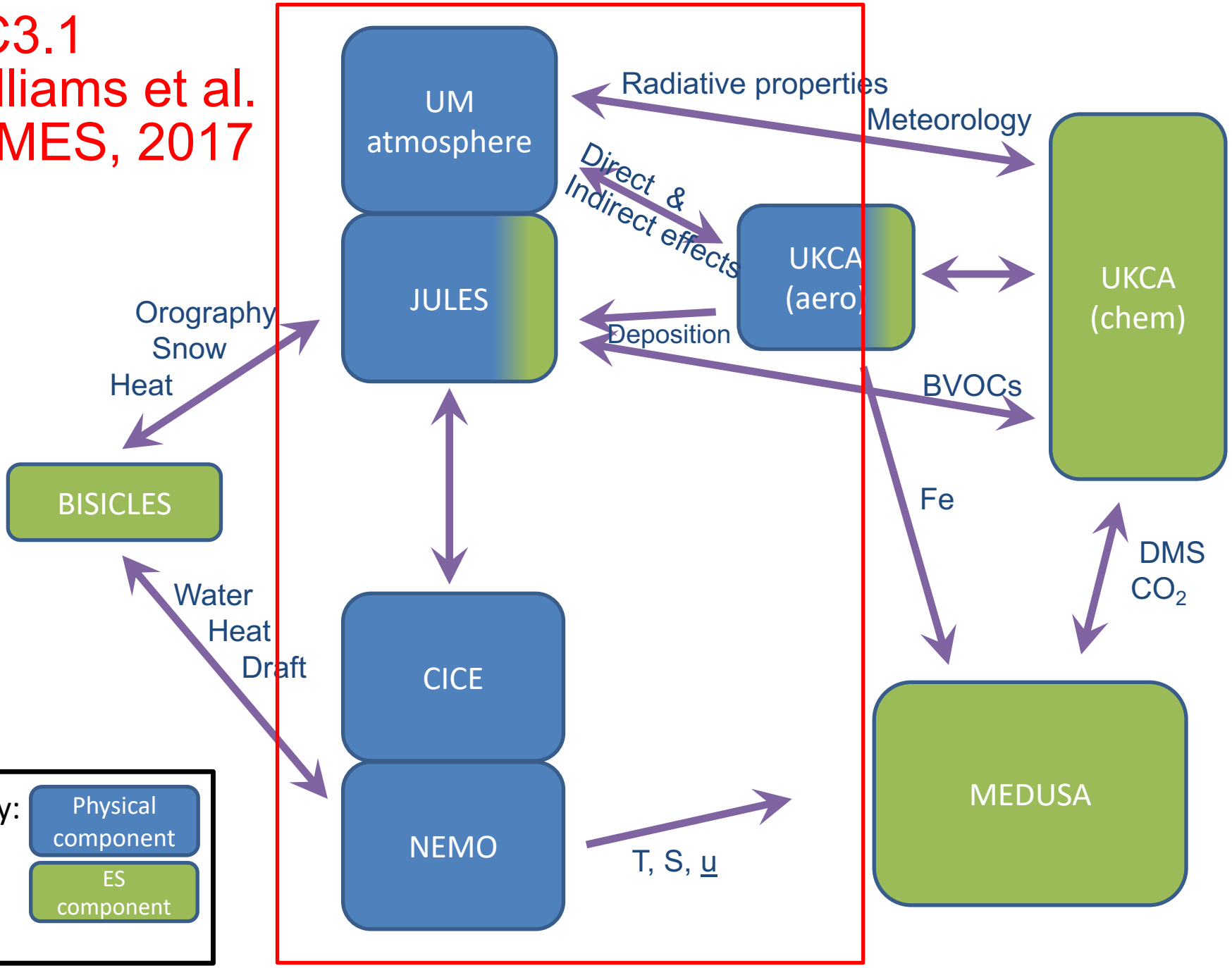
CICE
NEMO
MEDUSA
T, S, u
Key:
Physical
component
ES
component

GA7.1 with StratTrop Chemistry

Papers to follow

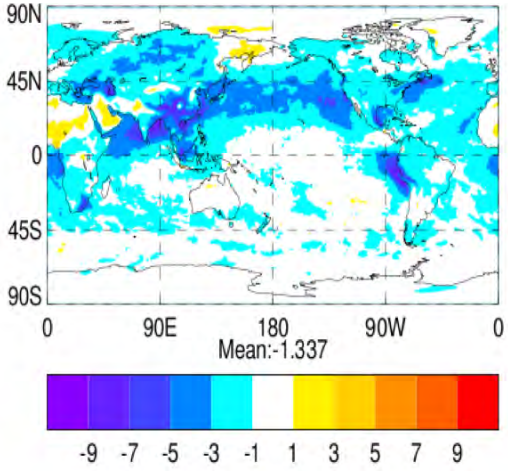


GC3.1 Williams et al. JAMES, 2017

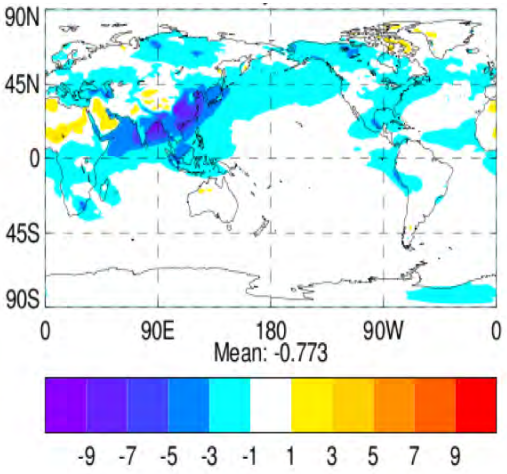


1. Aerosol ERF

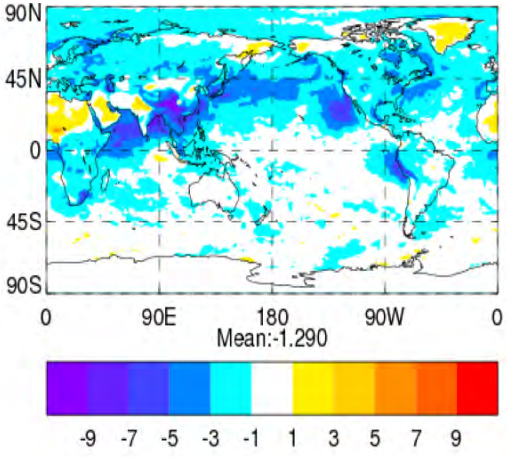
GA7.1 All Sky : -1.34 Wm^{-2}



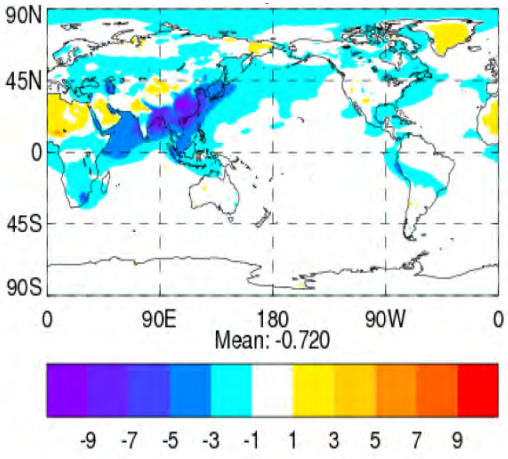
GA7.1 Clear Sky: -0.77 Wm^{-2}



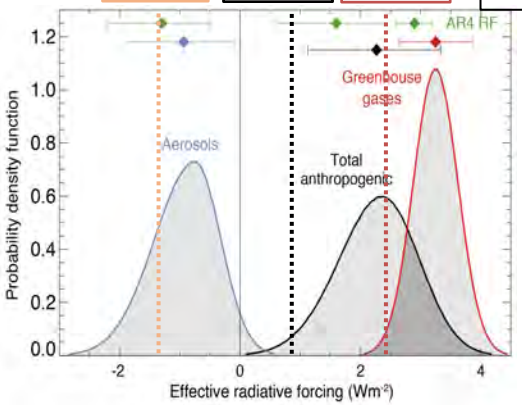
UKESM0.8 All Sky: -1.29 Wm^{-2}



UKESM0.8 Clear sky: -0.72 Wm^{-2}



HG2 | HG2 | HG2 | HadGEM2



IPCC AR5 ERFs
Myhre (2013)

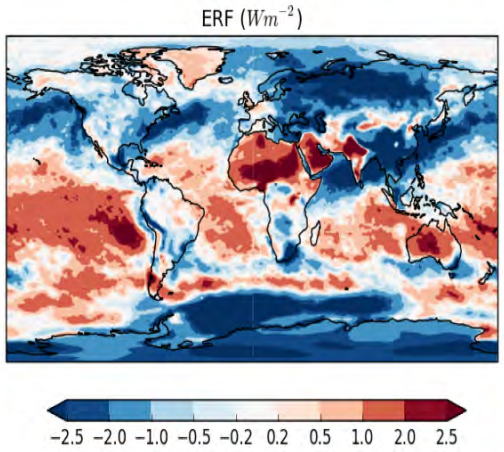
Changes in UKESM relative to GA7.1:

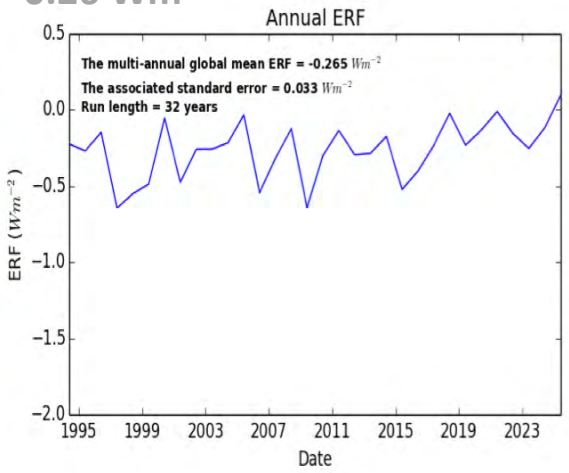
- Marine DMS emissions predicted from MEDUSA OBC, Unscaled (DMSx1)
- Representation of primary marine organic aerosol (Gantt 2012) : chl-a from MEDUSA
- MEDUSA sources from MEDUSA generated ancillaries in ERF tests
- Interactive vegetation → dust emissions

2. Total Composition ERF

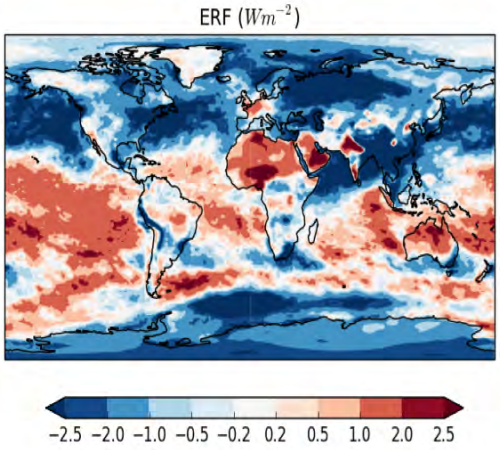
- Fully interactive UKCA StratTrop chemistry scheme used
- PD perturbs oxidants, aerosol, trop O_3 precursor emissions + CH_4 + N_2O + CFCs
- Water vapour feedback not included will add +0.12 Wm^{-2}
- Currently assessing most up-to-date chemistry config that improves low tropospheric O3 bias
- Cause of strengthening of ERF with CMIP6 trace gas emissions still needs investigating.

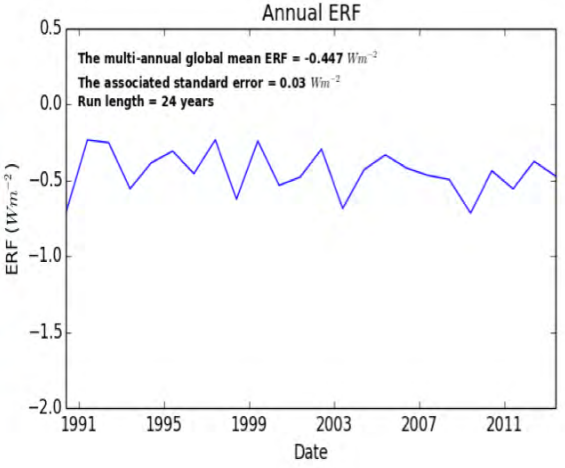
Total Composition ERF using CMIP5 trace gas emissions (Y2000): -0.26 Wm^{-2}





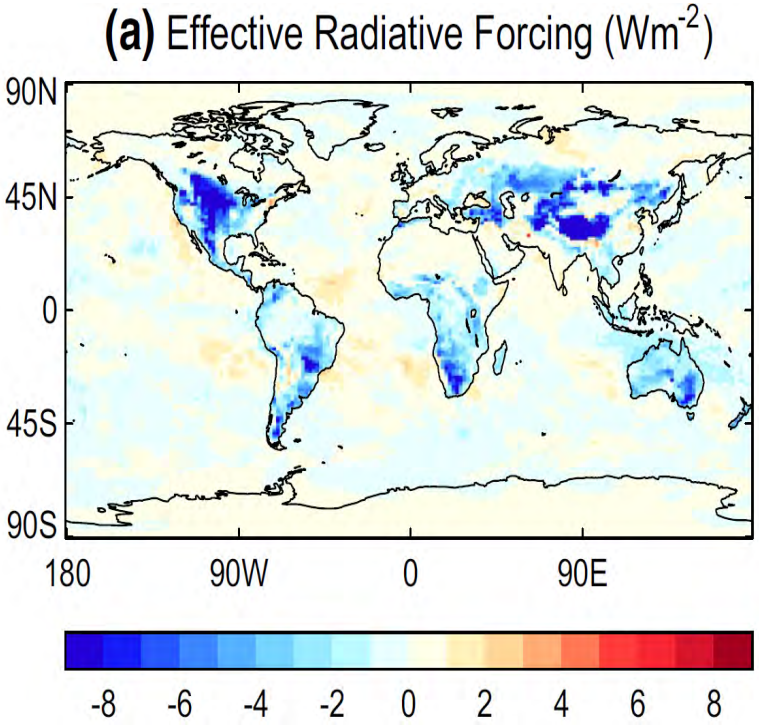
Total Composition ERF using CMIP6 trace gas emissions (Y2014): -0.43 Wm^{-2}



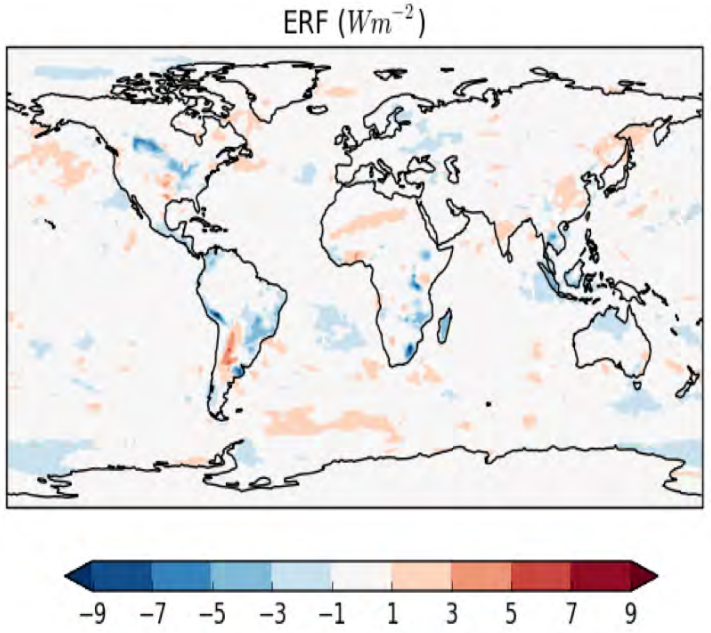


3. Land Use ERF (1850 vs present day)

HadGEM2-ES, Andrews et al (2016) : -0.4 Wm^{-2}



UKESM0.8 + albedo adj: -0.03 Wm^{-2}

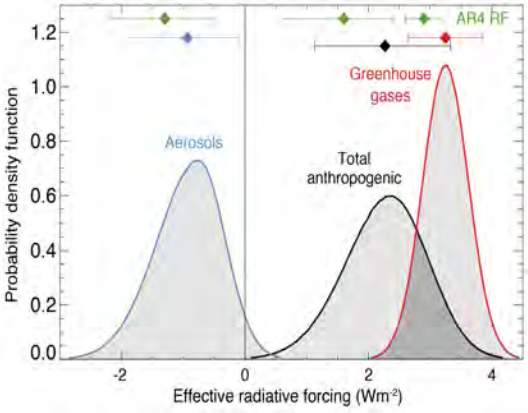


AR5 LU ERF: -0.25 to -0.05 W/m2 for 1750 to PD

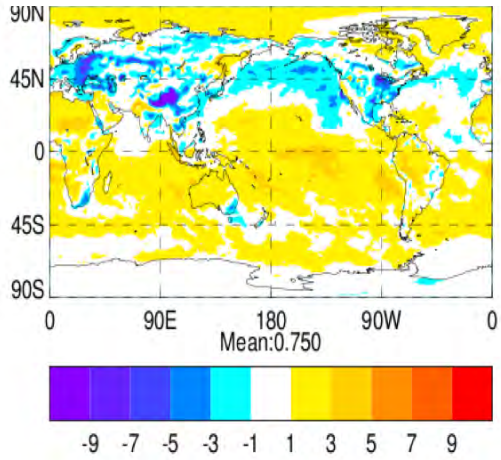
Expect the final LU ERF for 1750 to PD to be of ~ -0.05Wm2 to -0.1Wm2

4. Total anthropogenic ERF

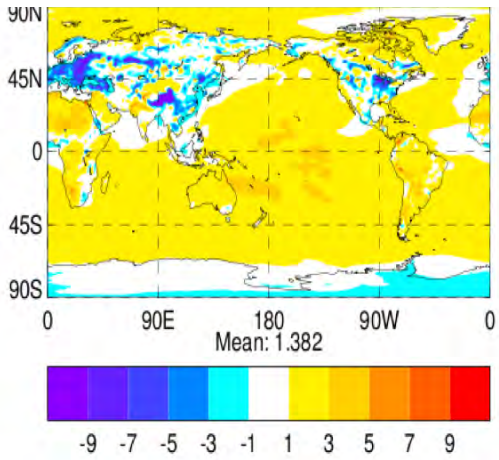
- GA7.1 total anthropogenic ERF based on CMIP5 forcings.
- GA7.1 *does not include* chemistry or TRIFFID
- UKESM with total composition + CO_2 + LU
- CMIP5 (1850/2000) trace gas emissions used
- Changing to CMIP6 trace gas emissions likely reduces positive total ERF by ~0.18Wm^{-2}.
- Inclusion of stratospheric water vapour feedback increases it by ~+0.12Wm^{-2}.
- LU ERF may be slightly more negative
- Hence final total ERF likely ~+1.7Wm^{-2}



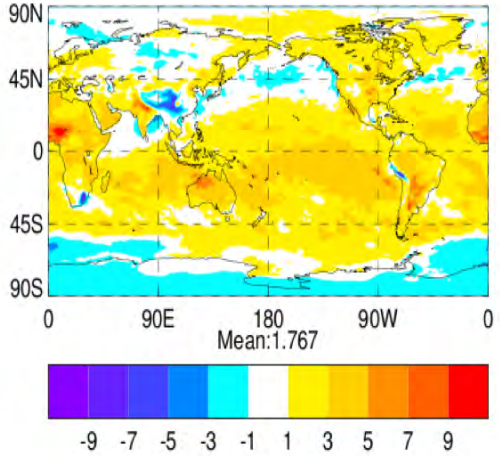
GA7.1 All Sky : +0.75 Wm^{-2}



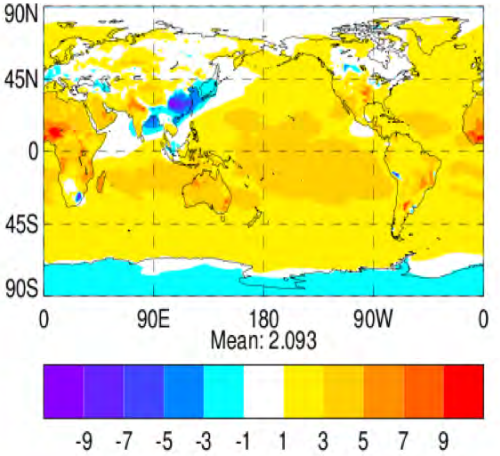
GA7.1 Clear Sky: +1.38 Wm^{-2}



UKESM All Sky: +1.77 Wm^{-2}

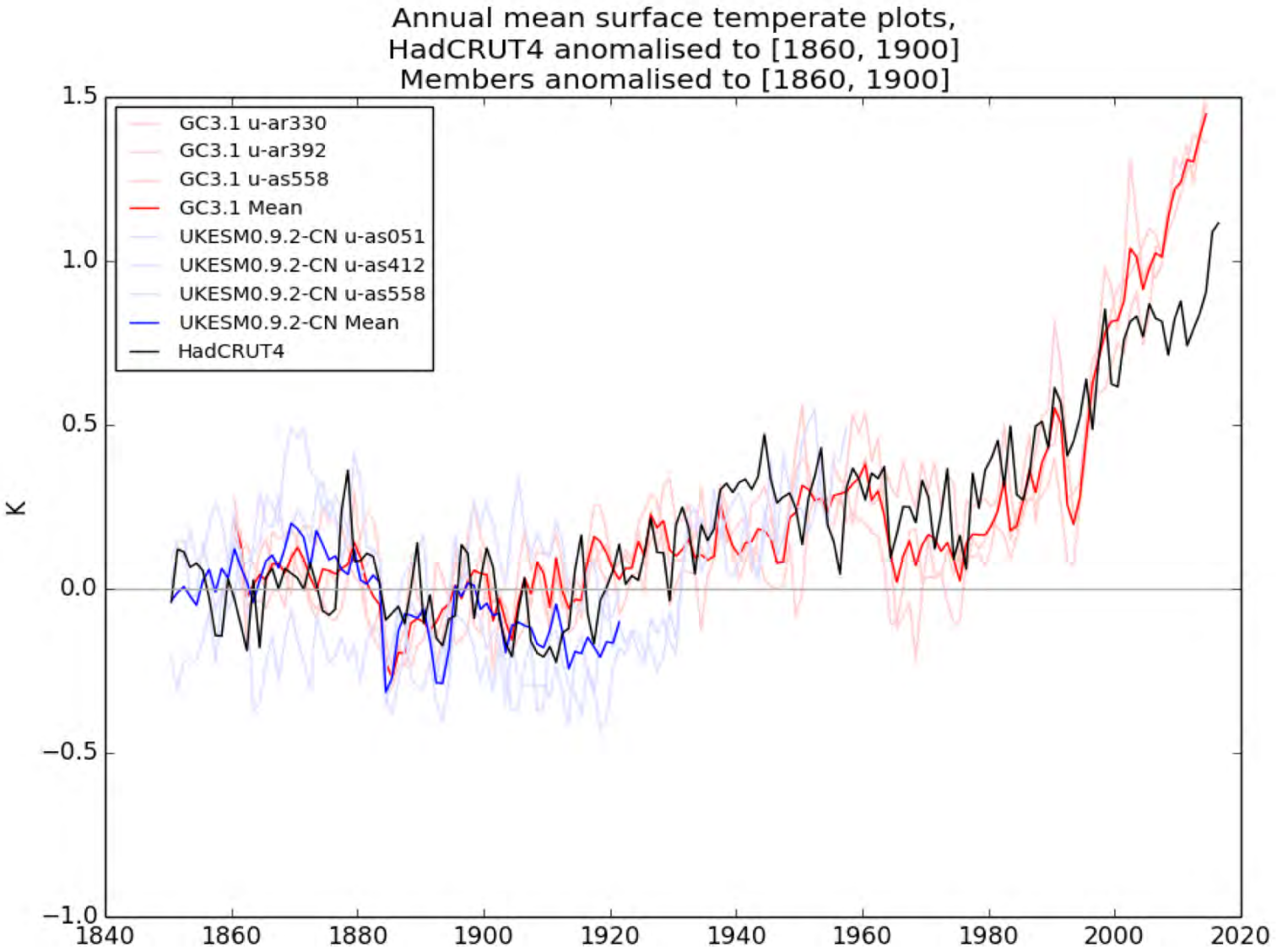


UKESM Clear Sky: +2.09 Wm^{-2}



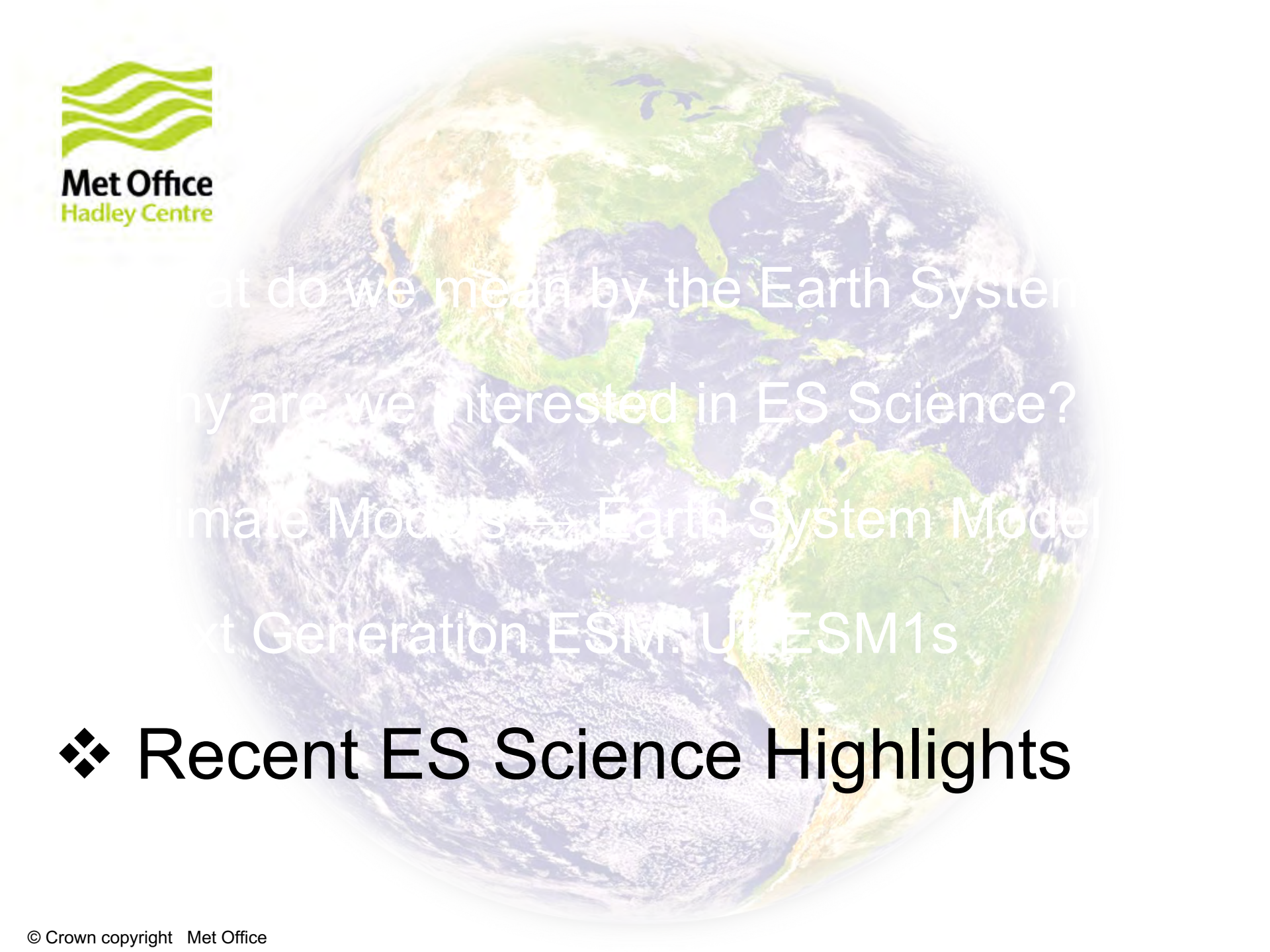
cf. HadGEM2-A (Andrews et al., 2014): **1.29 Wm^{-2}**

Started some historical test runs (3 members from a UKESM PI spin up run)
These are still progressing



Planned Resolutions & Timeline

- UKESM1-N96ORCA1: 130 km atmosphere, 1° ocean
  - Used for many CMIP6 runs (DECK, C4MIP, AerChemMIP)
  - Ready Feb 2018
- UKESM1-N216ORCA025: 60 km atmosphere, ¼° ocean
  - Some reference simulations
- UKESM1-N216ORCA025hybrid: high-res physics, lower res OBGC advection and atmospheric chemistry/aerosol
  - Still in development
  - Aim to use for some CMIP6 runs



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at do we mean by the Earth System

hy are we interested in ES Science?

imate Models → Earth System Model

xt Generation ESM: UK ESM1s

- Recent ES Science Highlights

Aerosol Indirect Effects

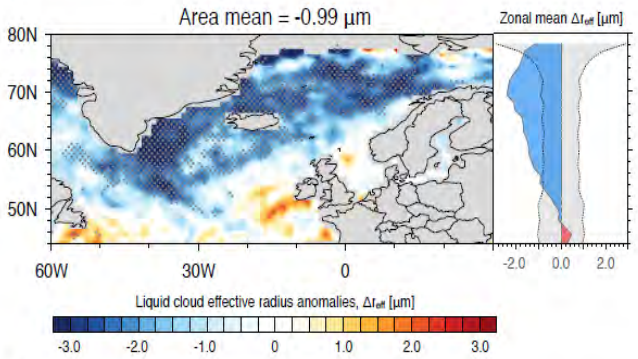
Cloud top droplet effective radius

Perturbation to cloud microphysics caused by emissions from Holuhraun volcanic eruption in October 2014.

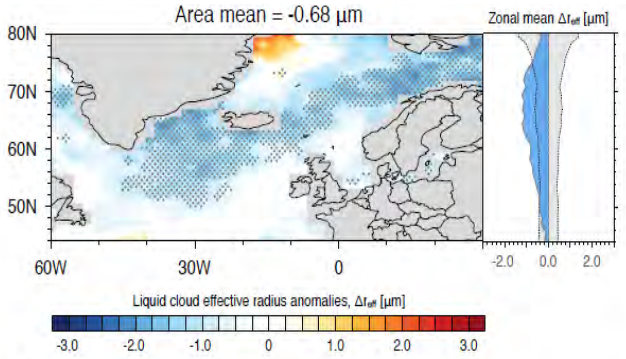
Cloud liquid water path

Malavelle et al., *Nature*, 2017

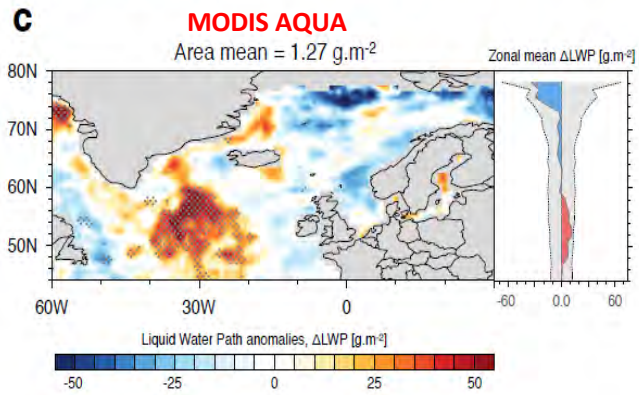
MODIS AQUA



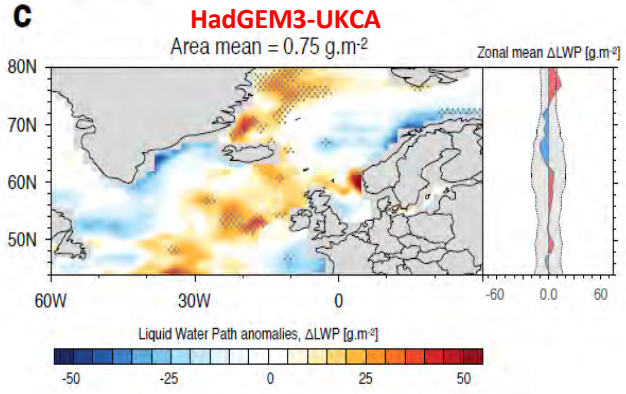
HadGEM3-UKCA



MODIS AQUA



HadGEM3-UKCA



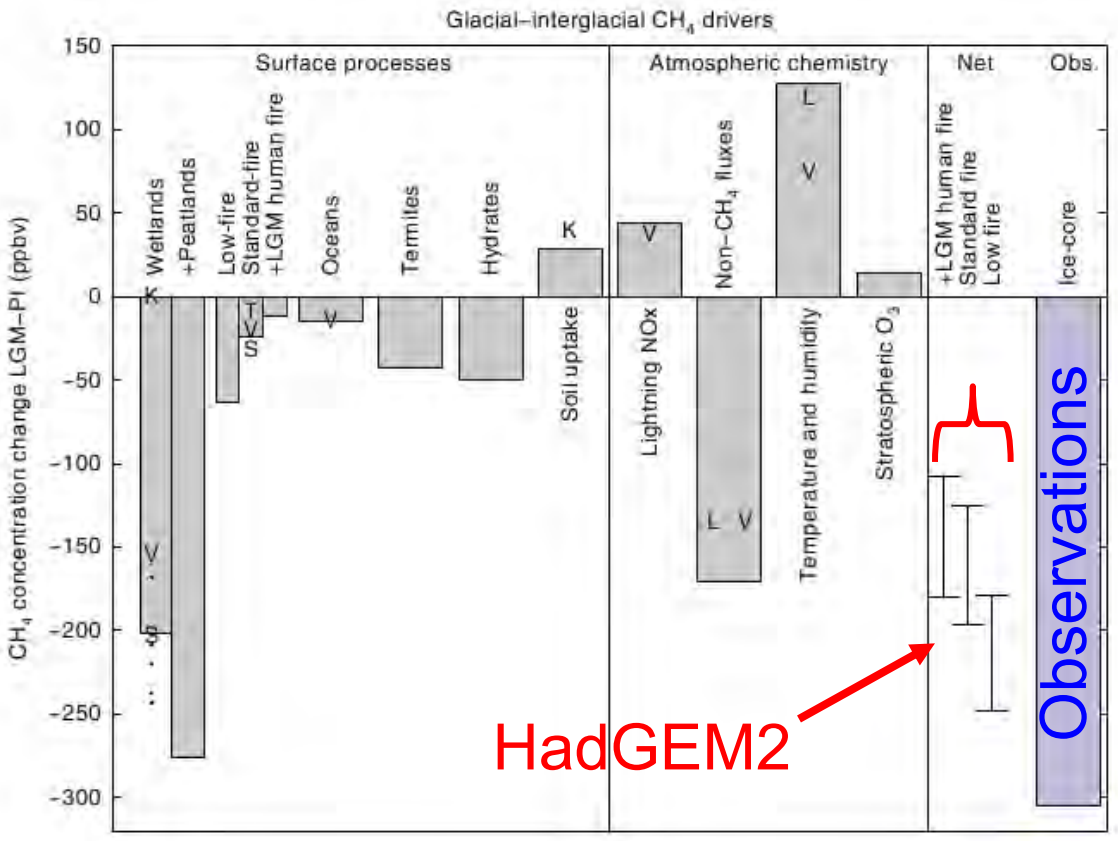
HadGEM3 with UKCA-MODE was able to represent the 'first' and 'second' aerosol indirect effects adequately. The second indirect effect is close to negligible; certainly much smaller in magnitude than some other models suggest.

Methane Budget at the LGM

Met Office Hadley Centre

University of BRISTOL

Hopcroft et al., Nature Comm. (2017)

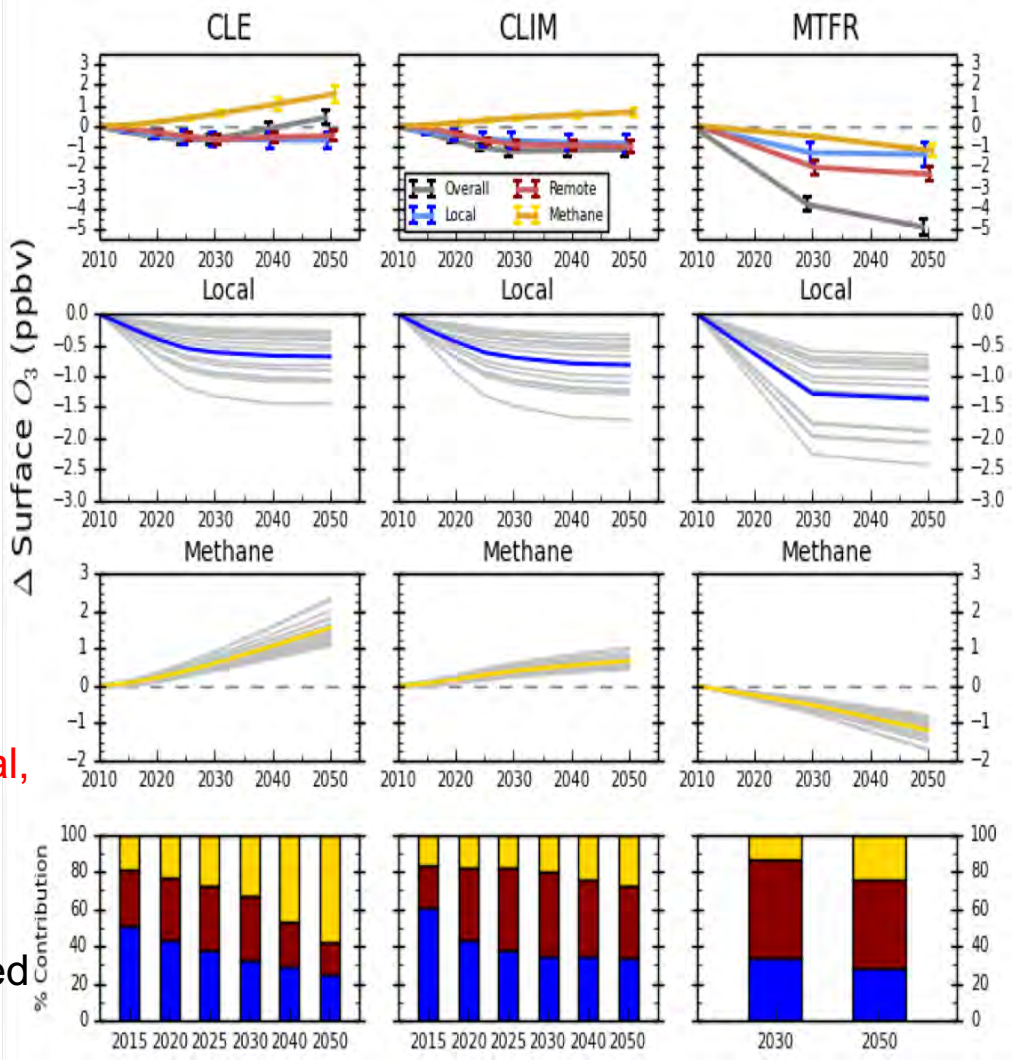


- The LGM-PI CH_4 difference is largely driven by emissions
- The ESM cannot reconcile the observed difference
- Current emission models do not show adequate sensitivity to changes in climate and CO_2

Climate & Air Quality

Ozone Parametric Model

- Parametric model developed to assess ozone response to emission perturbations based on inputs from multiple models
- Output is provided over 17 world regions,
- Total response can be attributed to the individual responses to local, remote and methane sources



Future O_3 response over Europe to different future scenarios, showing the influence of local, remote and methane sources from 2010 to 2050

Turnock et al., Atmos. Chem. Phys., Submitted (2017)

Conclusions

Concluding Remarks

- The Earth System and Climate Change Mitigation
- Motivation behind studying Earth System Science
- Development of Climate Models into Earth System Models
- Brief overview of the UK's latest ESM, UKESM1
- Recent ES Science Highlights

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Thank you for listening!
Any questions?