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Earth System Modelling: An Introduction

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UKCA Training Workshop, Cambridge, December 2022

Overview

- What do we mean by the Earth System?
- Motivation for Studying ES Science
- Climate Models → Earth System Models
- UK's Current Earth System Model & Plans
- 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
- t ES Science Highlights

What is the Earth System?

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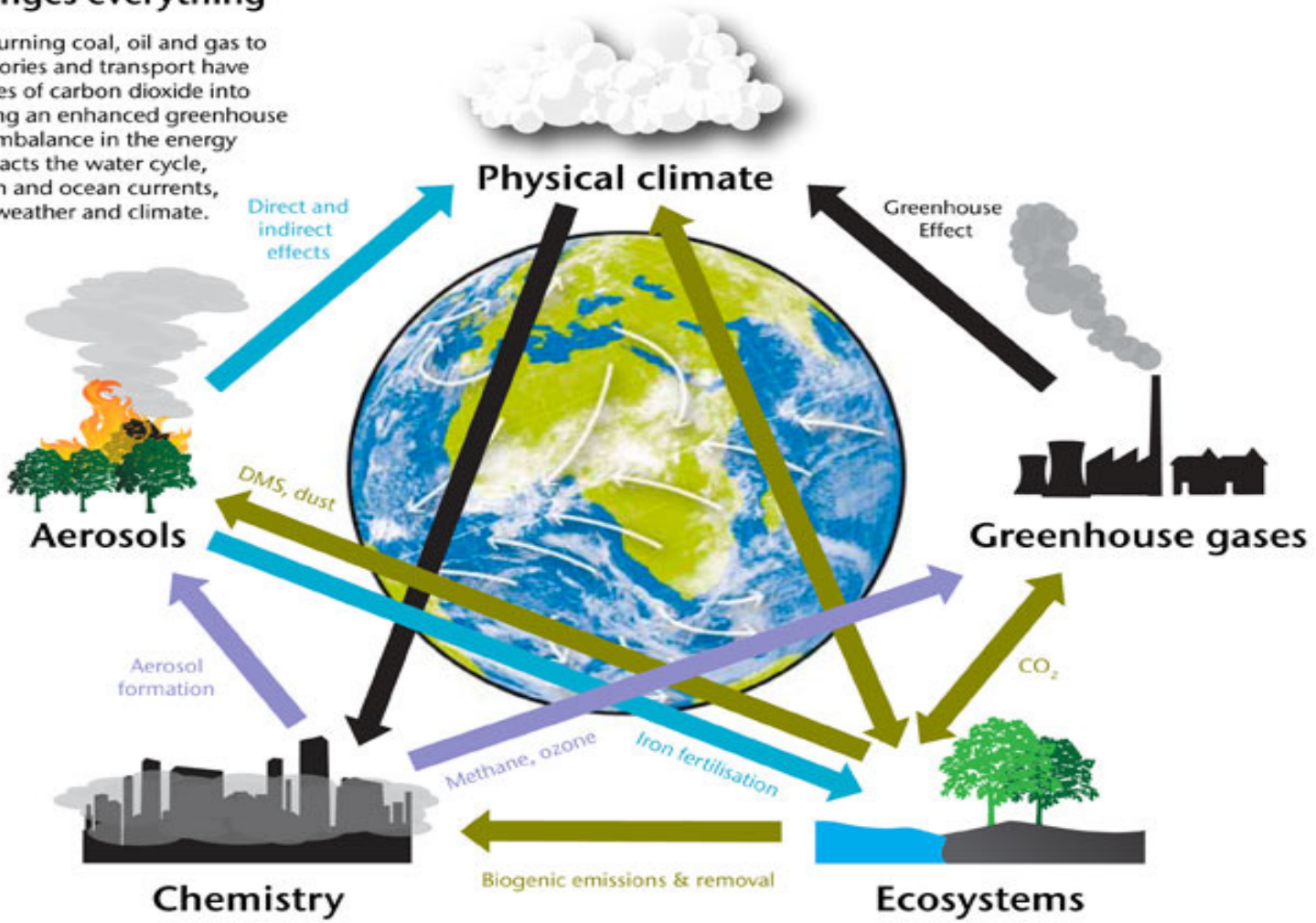
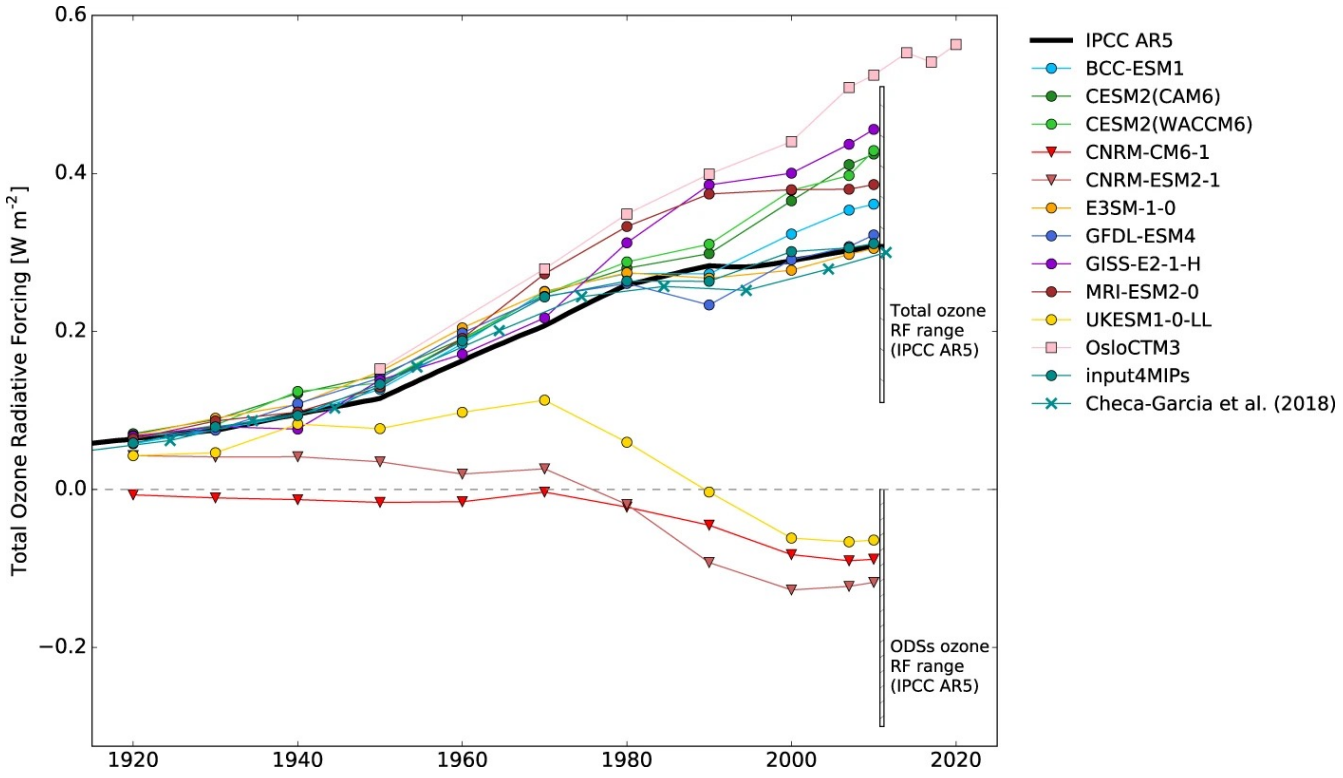
One thing changes everything

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

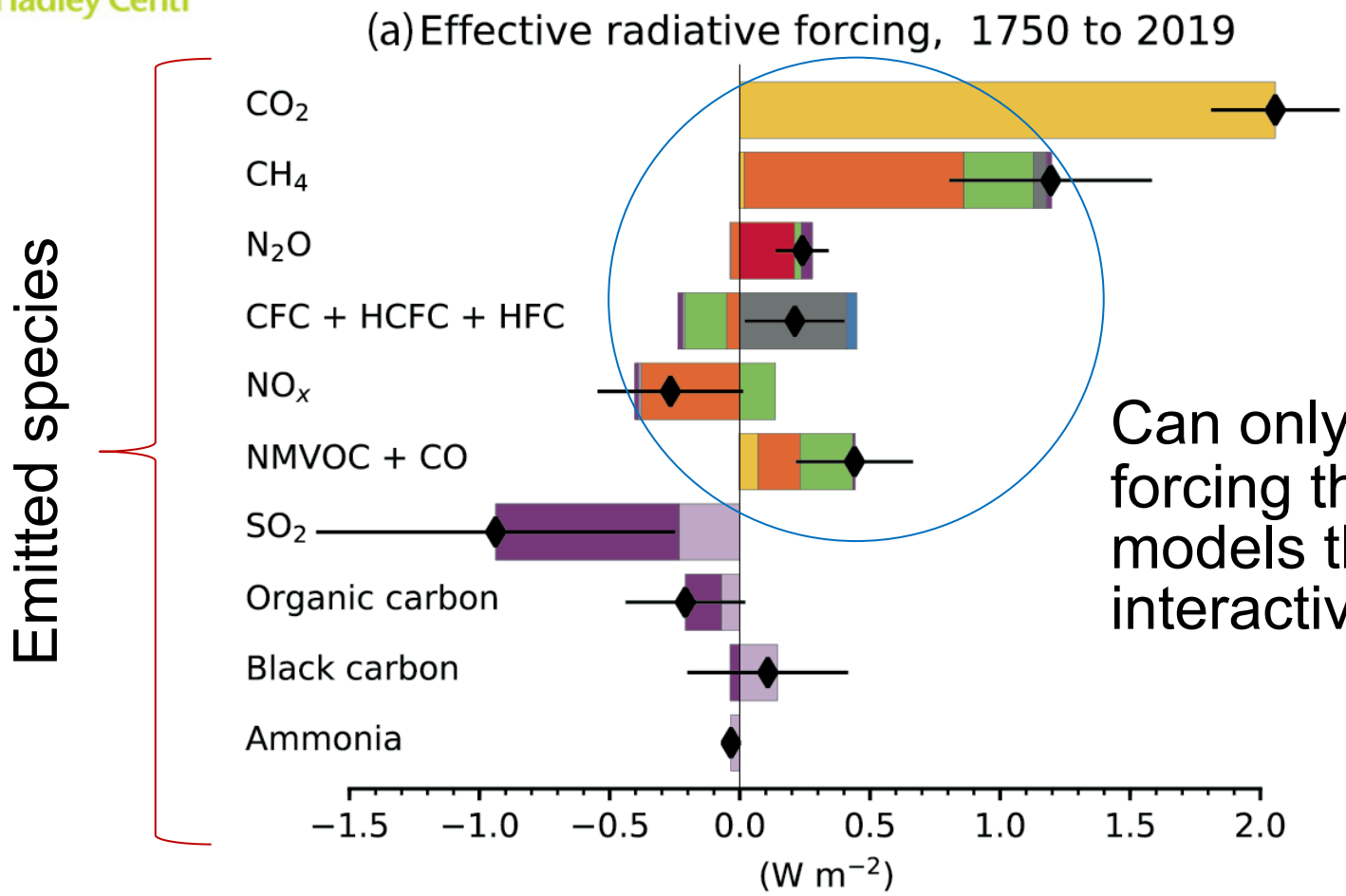
Why? – Climate Forcing (1)



Total O_3 forcing of 0.4 W m^{-2} at the present day … equivalent to a 3-bar electric fire running *all day every day* over the area of a football pitch!

Skeie et al., npj Climate Atmos. Sci., (2020)

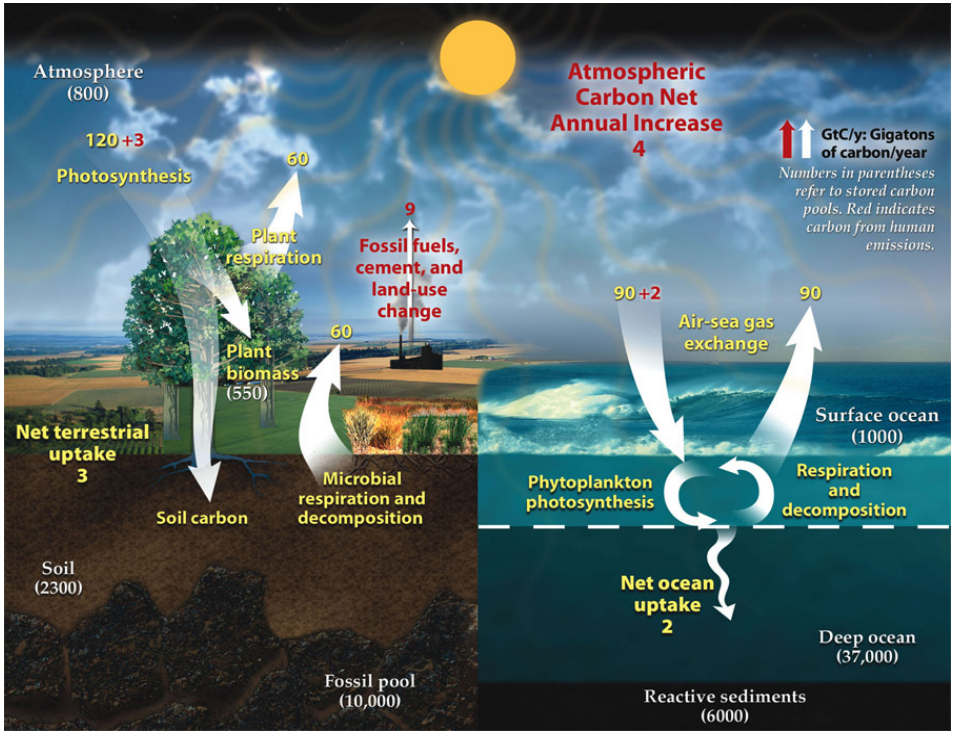
Why? – Climate Forcing (2)



Can only quantify this forcing through models that include interactive chemistry

IPCC 6th Assessment Report (AR6), 2021

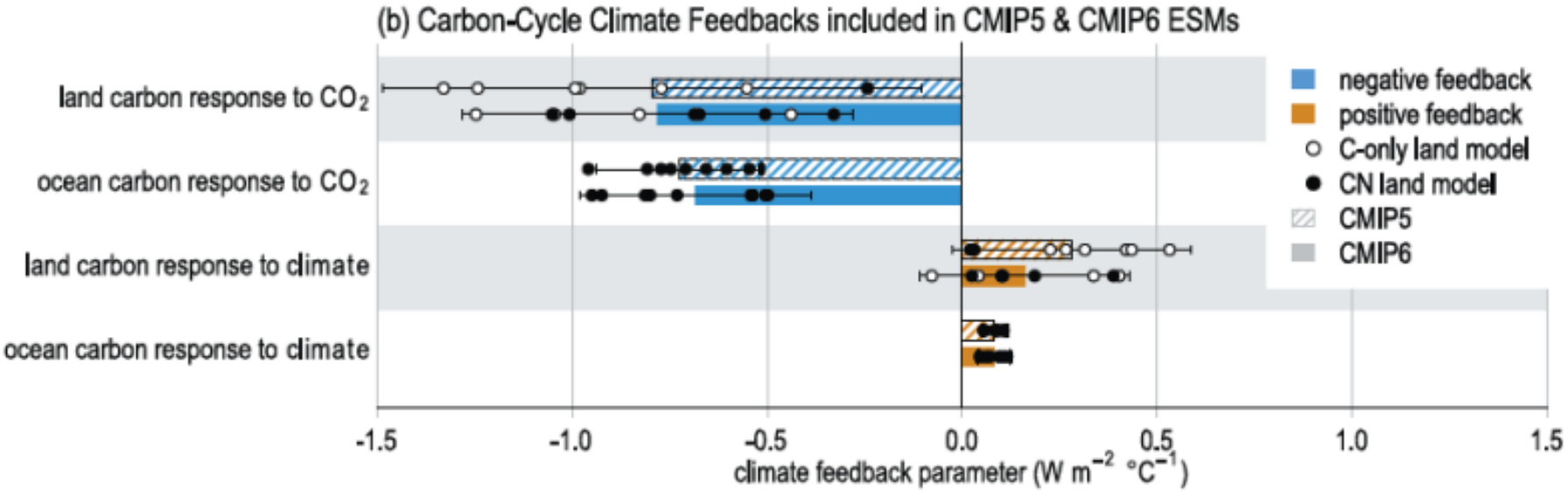
Why? – Carbon Cycle Feedbacks (1)



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



- Rising CO_2 increases photosynthesis & ocean uptake (-ve feedback)
- Rising temperature decreases both land & ocean uptake (+ve feedback)

IPCC 6th Assessment Report (AR6), 2021

Why? Mitigation & Policy Advice

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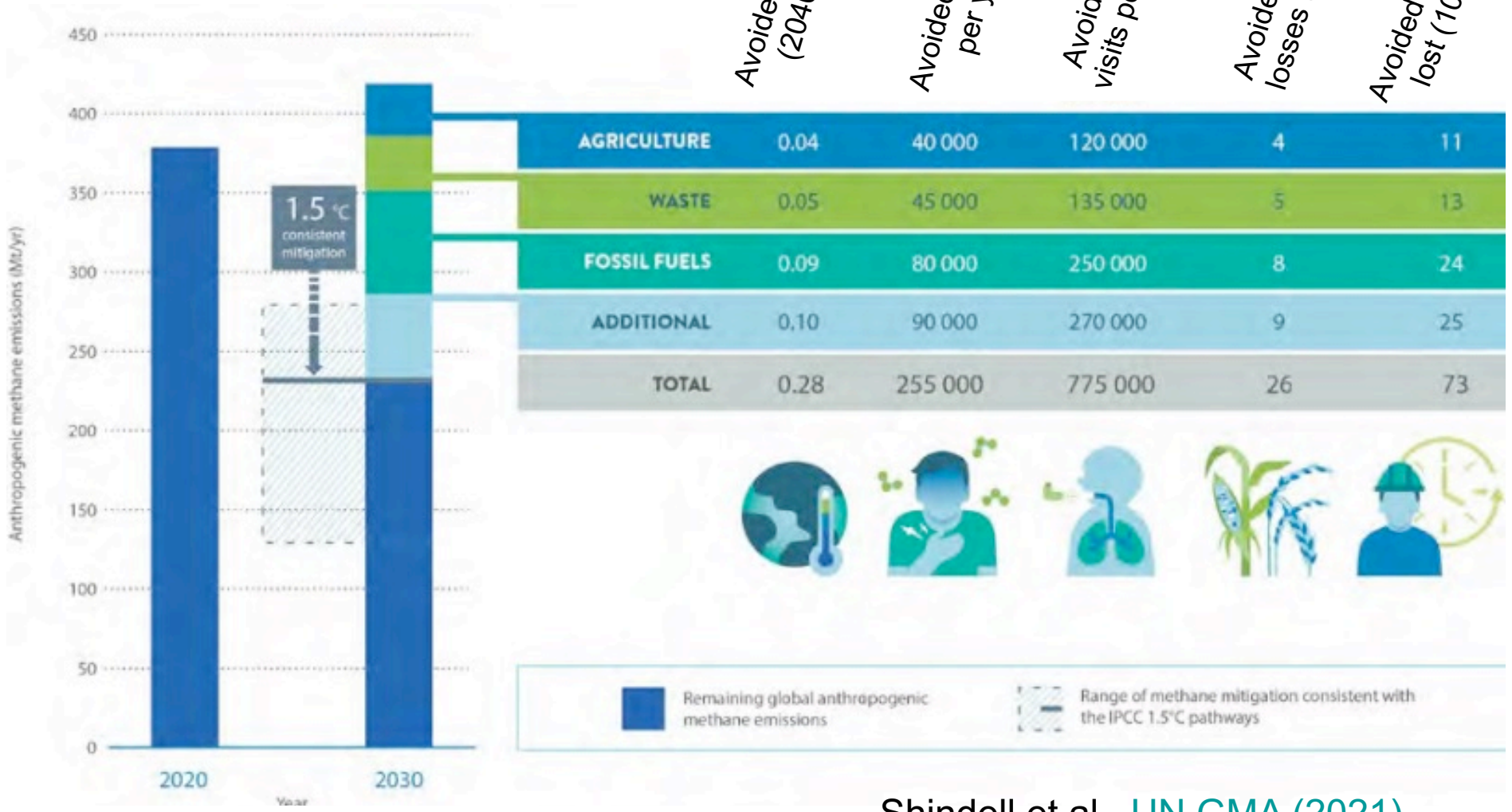

	Avoided warming (2040-2070)	Avoided deaths per year	Avoided ER visits per year	Avoided crop losses (Mt/yr)	Avoided work hours lost (10^9 hrs/yr)
AGRICULTURE	0.04	40 000	120 000	4	11
WASTE	0.05	45 000	135 000	5	13
FOSSIL FUELS	0.09	80 000	250 000	8	24
ADDITIONAL	0.10	90 000	270 000	9	25
TOTAL	0.28	255 000	775 000	26	73

Shindell et al., UN GMA (2021)

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at do we mean by the Earth System

hy are we interested in ES Science?

- Climate Models → ES Models

t Generation ESM: UKESM1

t ES Science Highlights

Development of Models (1)

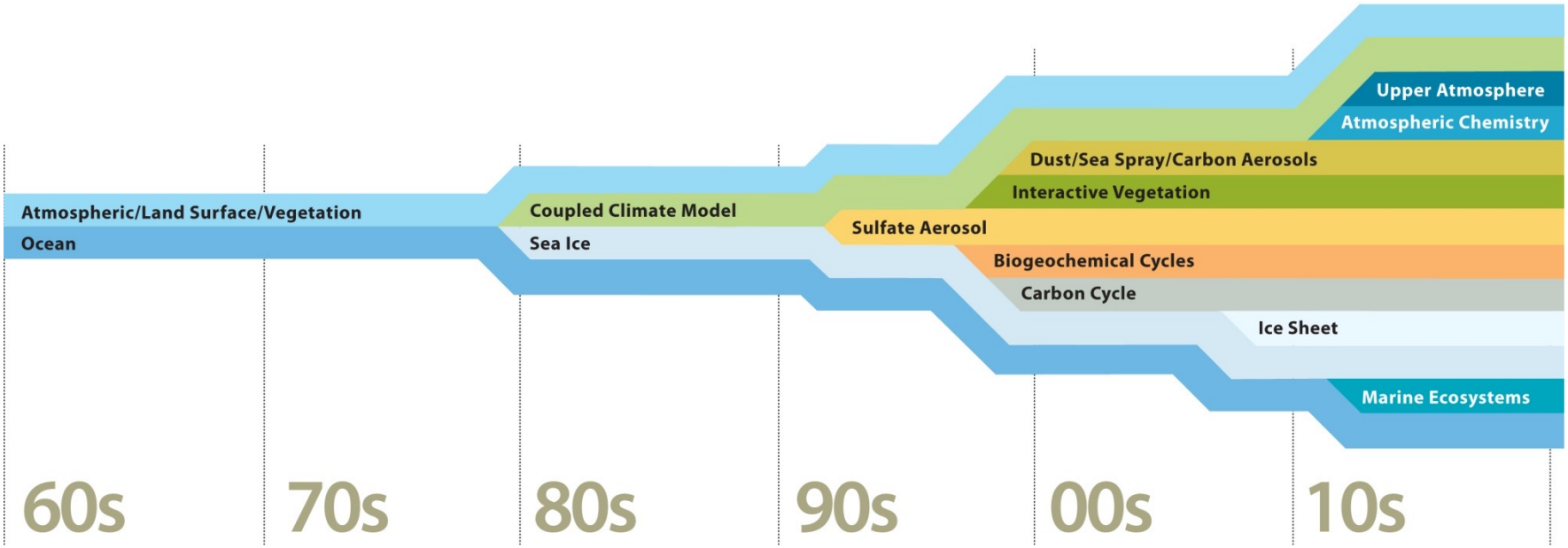
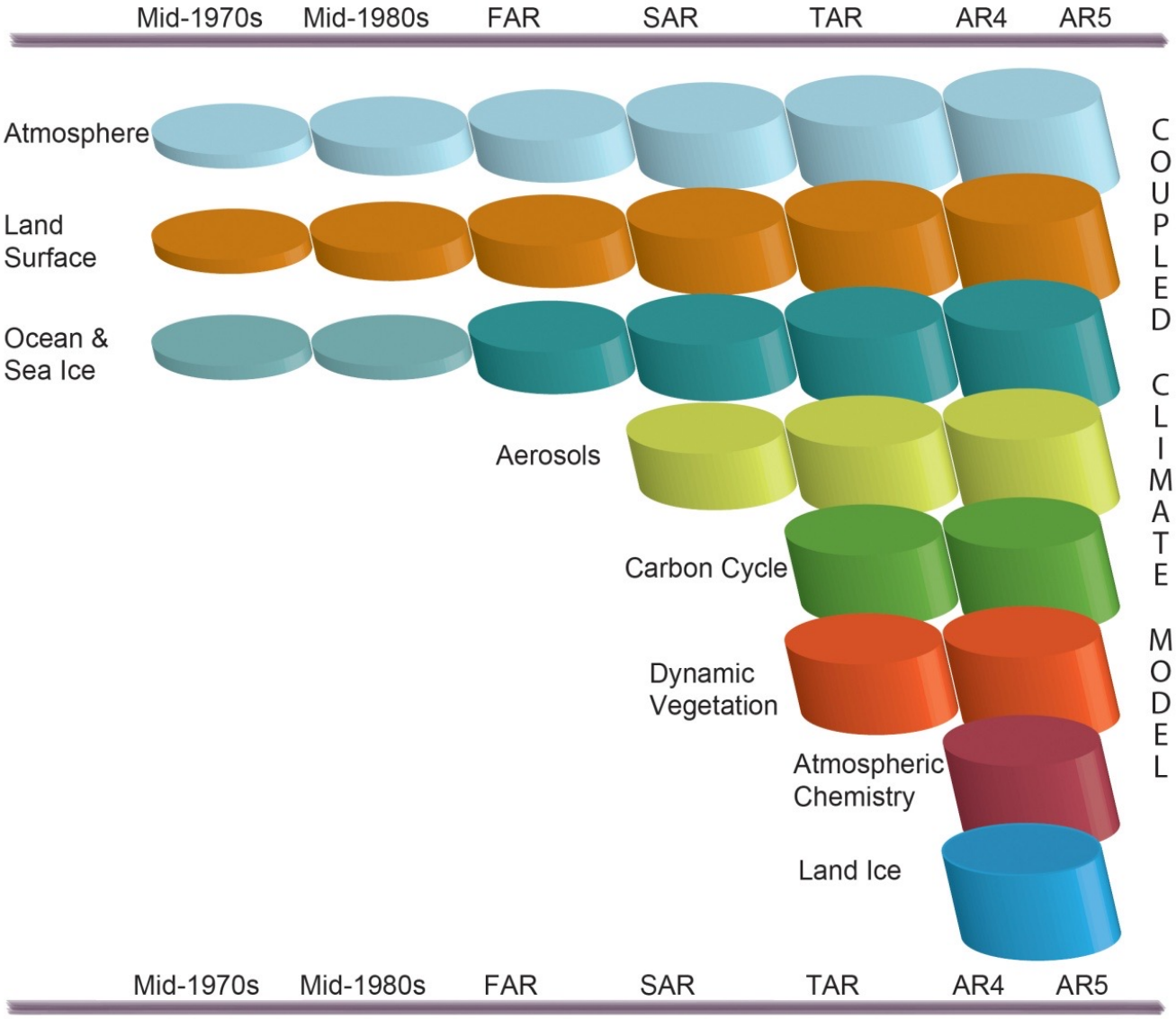


Figure courtesy of UCAR

Development of Models (2)



Types of Chemistry Models

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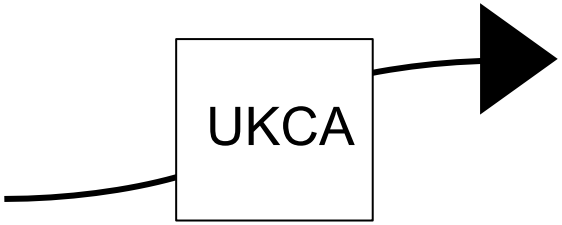
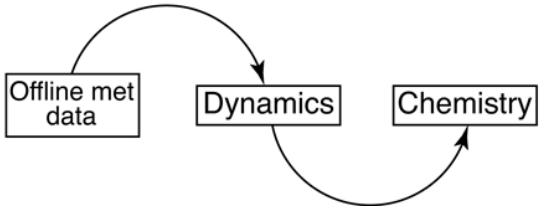
1. Box model

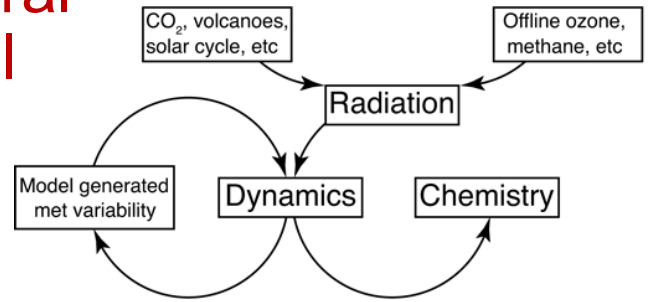
2. Lagrangian model



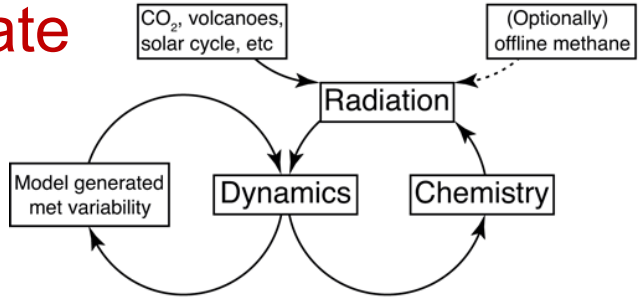
3. Chemistry transport Model (CTM)



4. Chemistry General Circulation Model



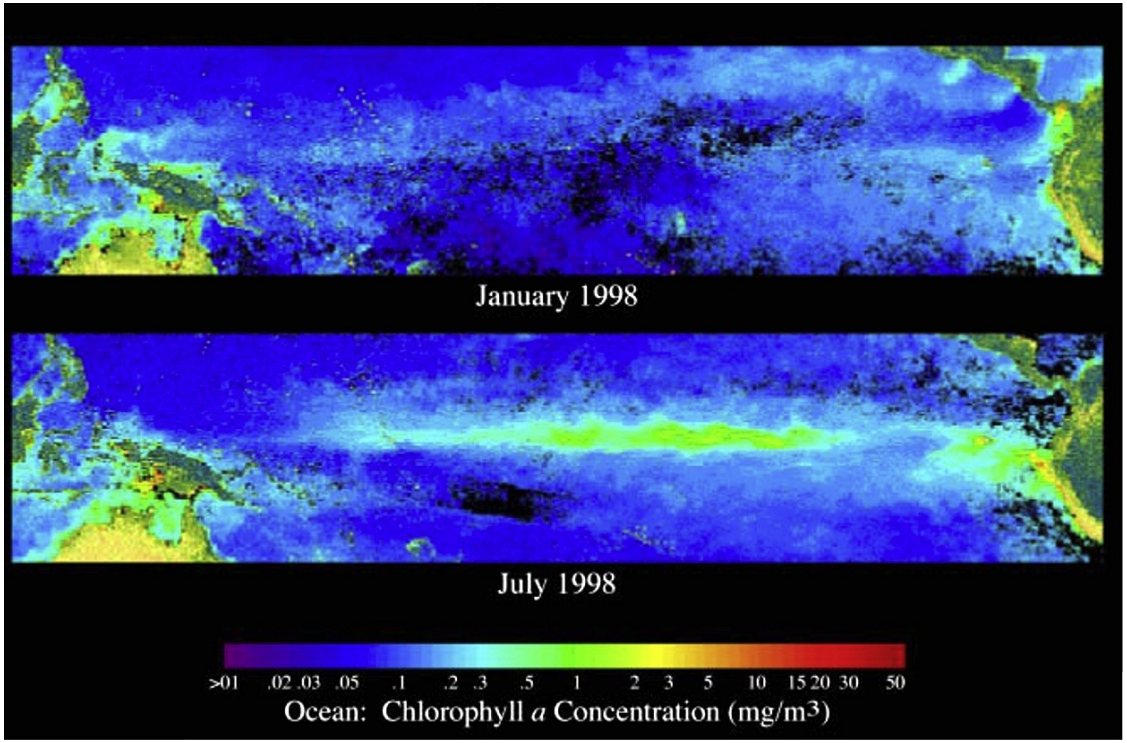
5. Chemistry Climate Model (CCM)



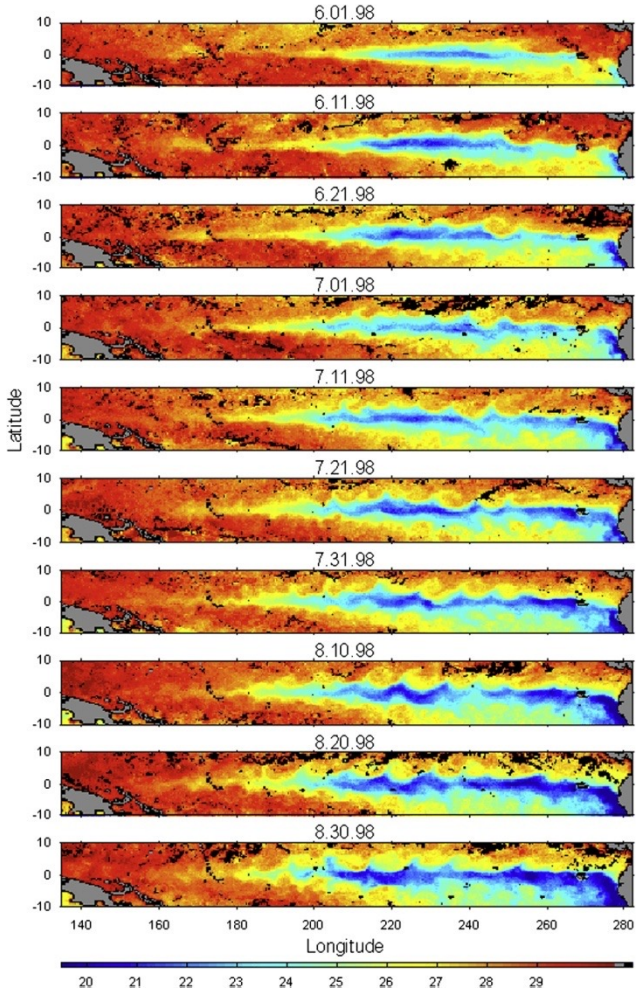
Young et al., Elementa (2018)

Physical climate variability and the carbon cycle interact strongly

Ocean biological activity, upwelling, carbon outgassing and nutrient transport

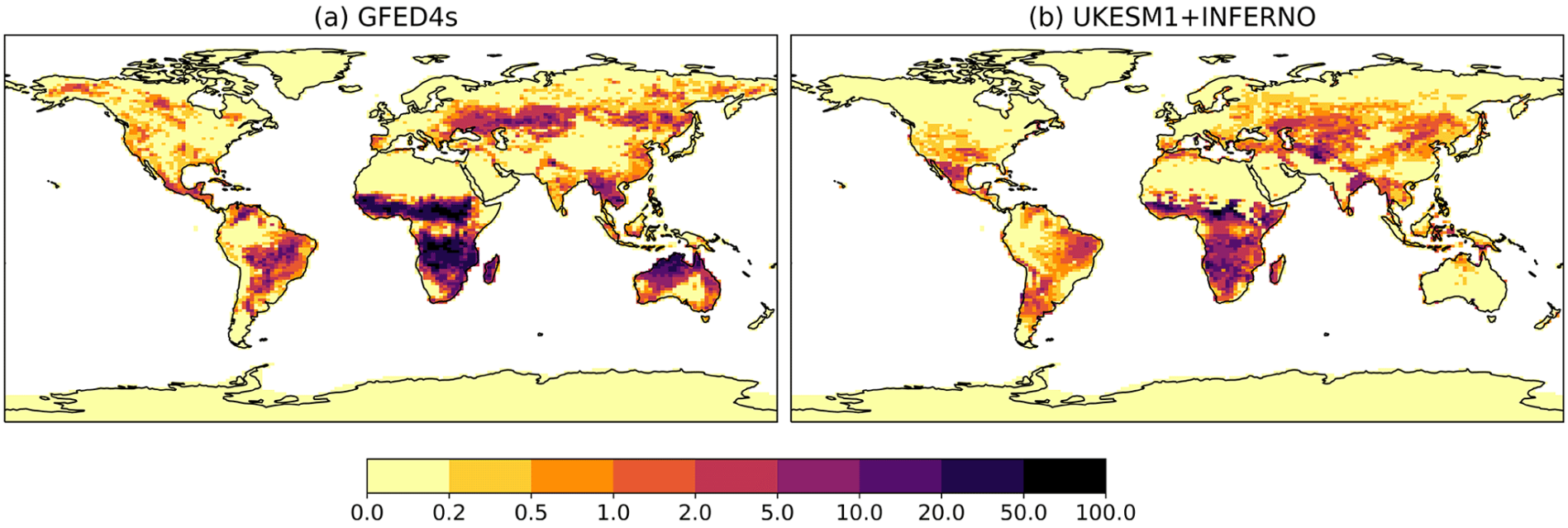


Evolution of summer 1998 La Nina



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

Modelling fire occurrence in the Earth System is sensitive to the underlying vegetation and meteorology



- Overestimation of tree fraction in savanna biomes
- Underestimation of fire size in these regions (e.g., SHSA)

Teixeira et al., GMD (2021)

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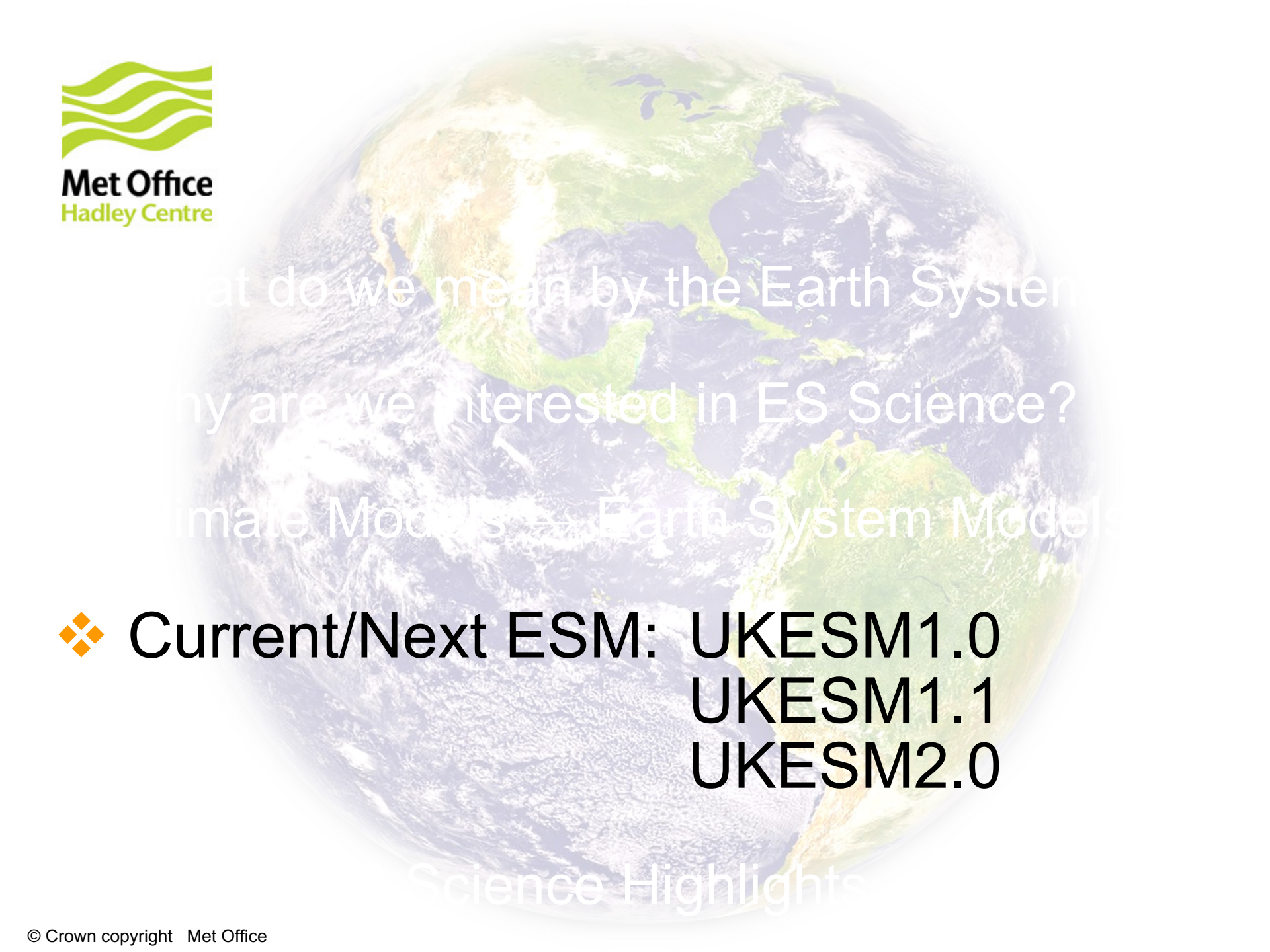


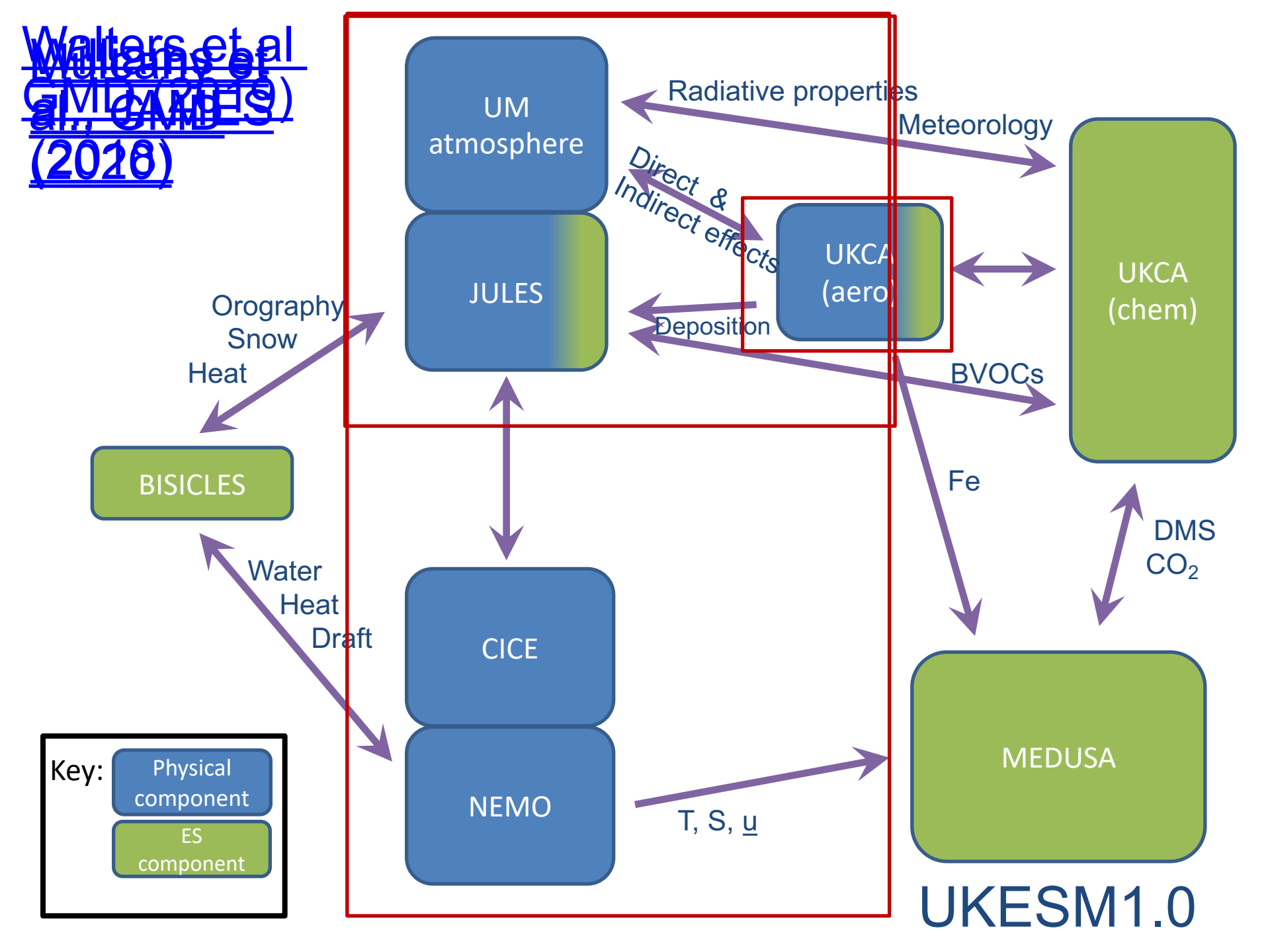
at do we mean by the Earth System

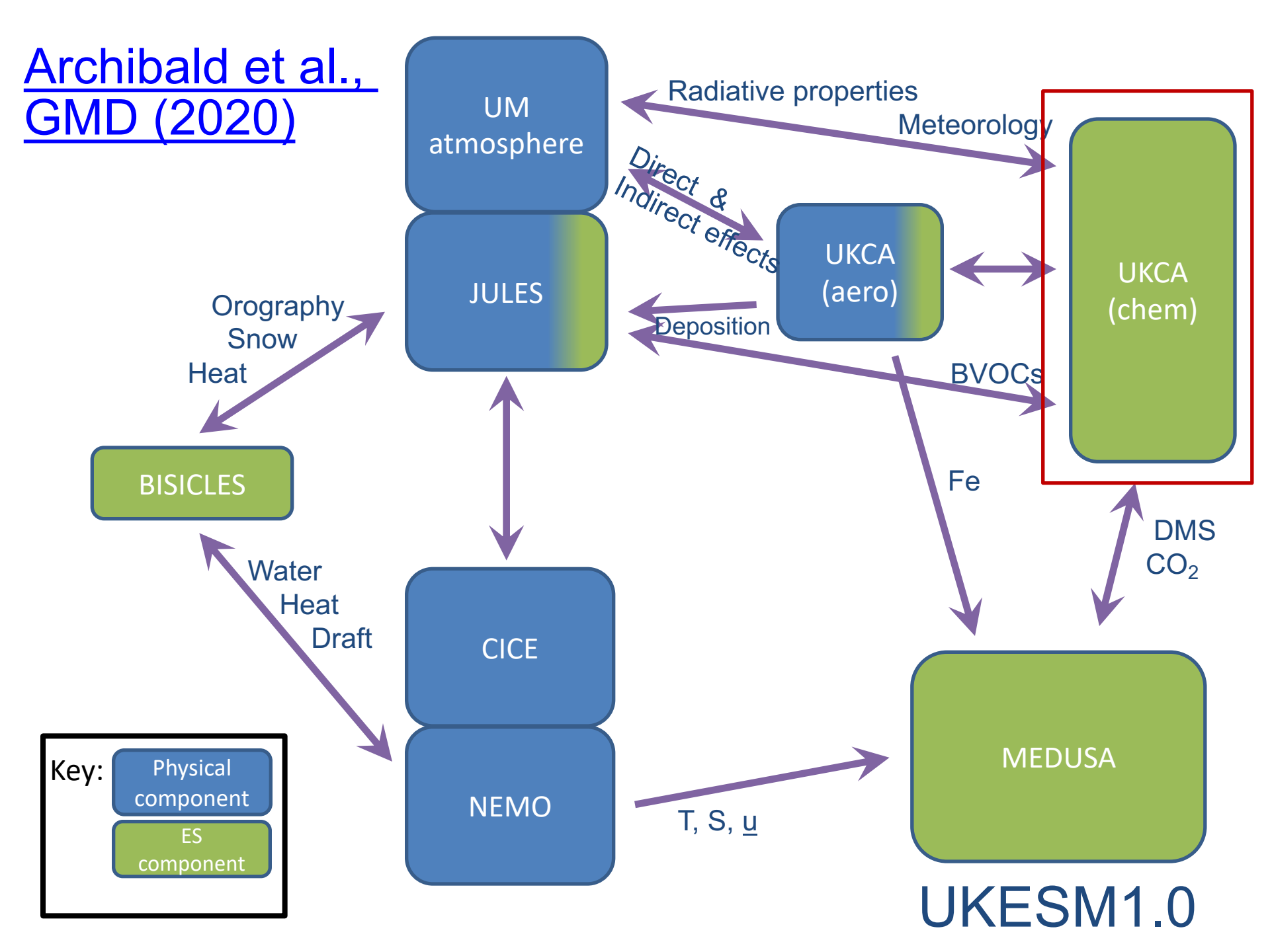
hy are we interested in ES Science?

imate Models → Earth System Models

- Current/Next ESM: UKESM1.0
  UKESM1.1
  UKESM2.0

Science Highlights


Walters et al (2018)
UM atmosphere
JULES
UKCA (aero)
UKCA (chem)
Radiative properties
Meteorology
Direct & Indirect effects
Deposition
Orography
Snow
Heat
BVOCs
Fe
DMS
CO_2
BISICLES
Water
Heat
Draft
CICE
NEMO
T, S, u
MEDUSA
Key:
Physical component
ES component
UKESM1.0


Archibald et al., GMD (2020)
UM atmosphere
JULES
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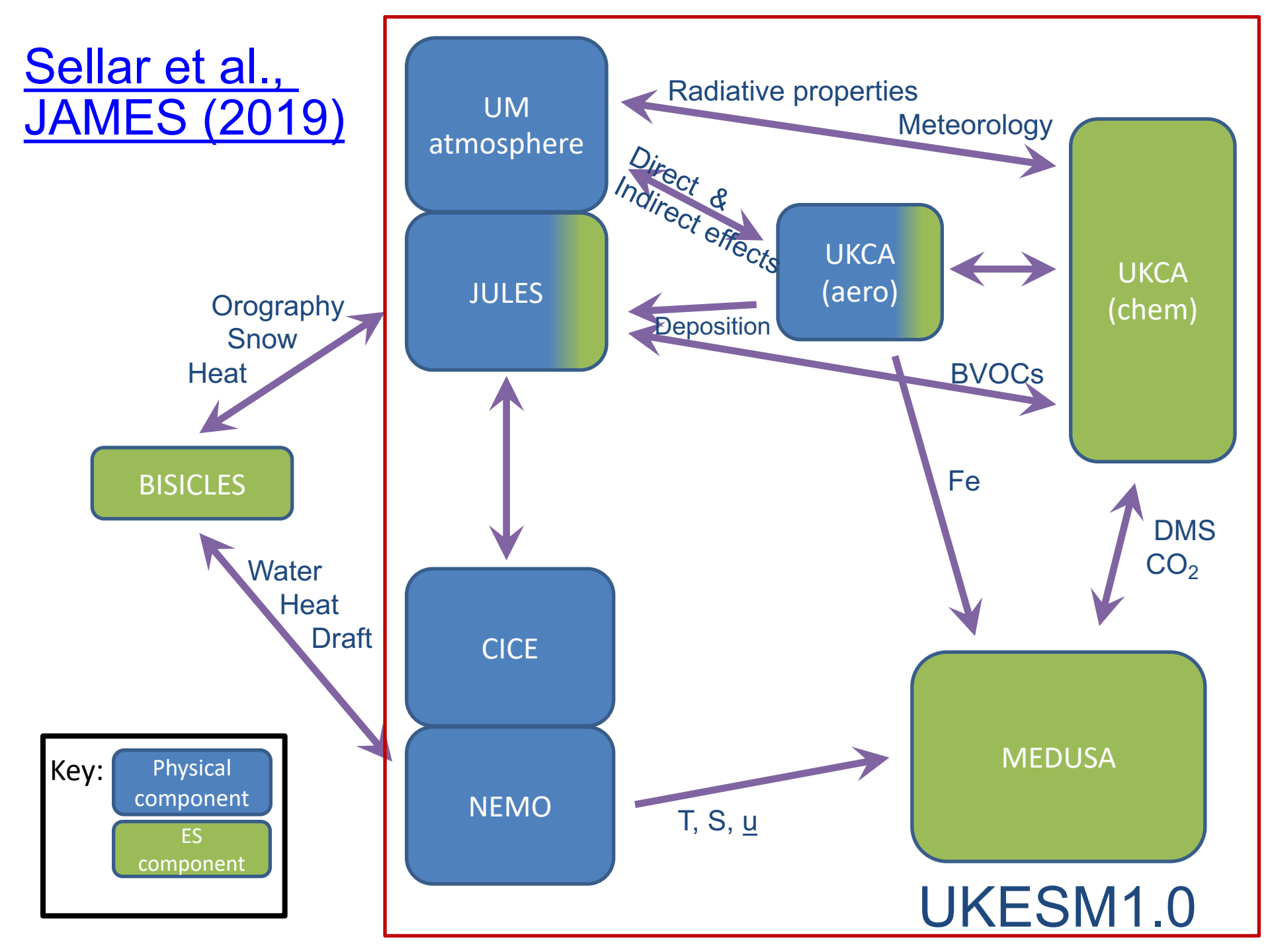
Sellar et al., JAMES (2019)
UM atmosphere
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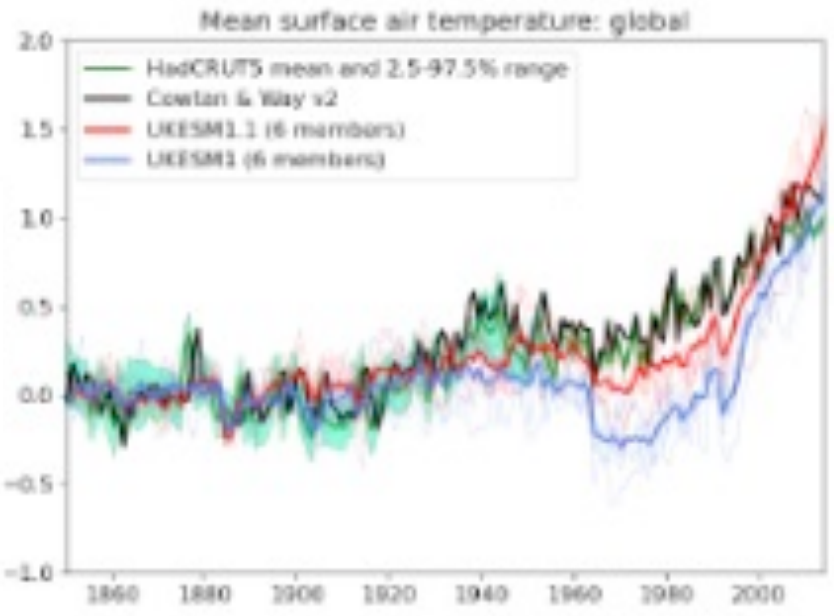
UKESM1.0

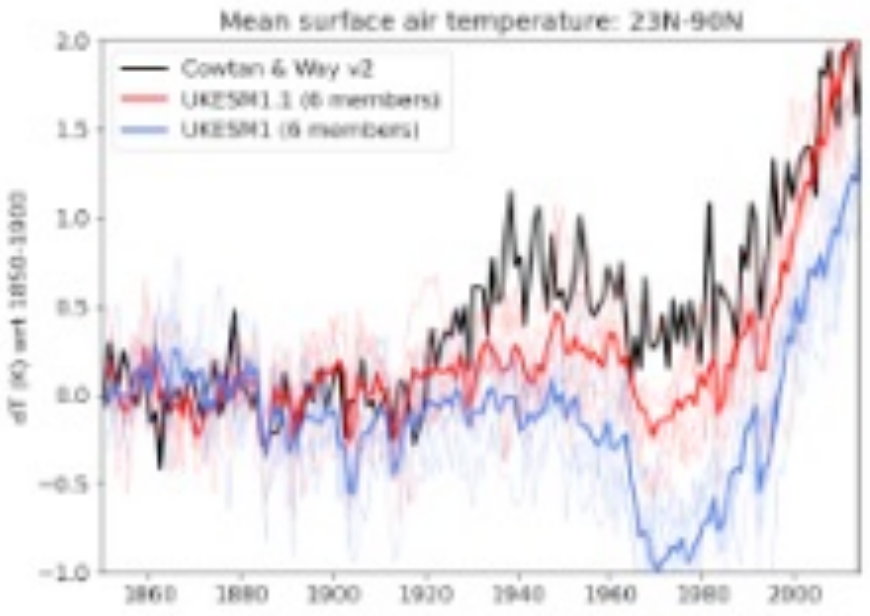
UKESM1.0 → UKESM1.1

Δtemp wrt 1850-1900

Globe



23-90°N



- Improved SO_2 dry deposition
- Reduced magnitude of aerosol forcing
- Bugfixes & re-tunings

UM-Based

Mulcahy et al., GMDD (2022)

UKESM1.1 → UKESM2.0

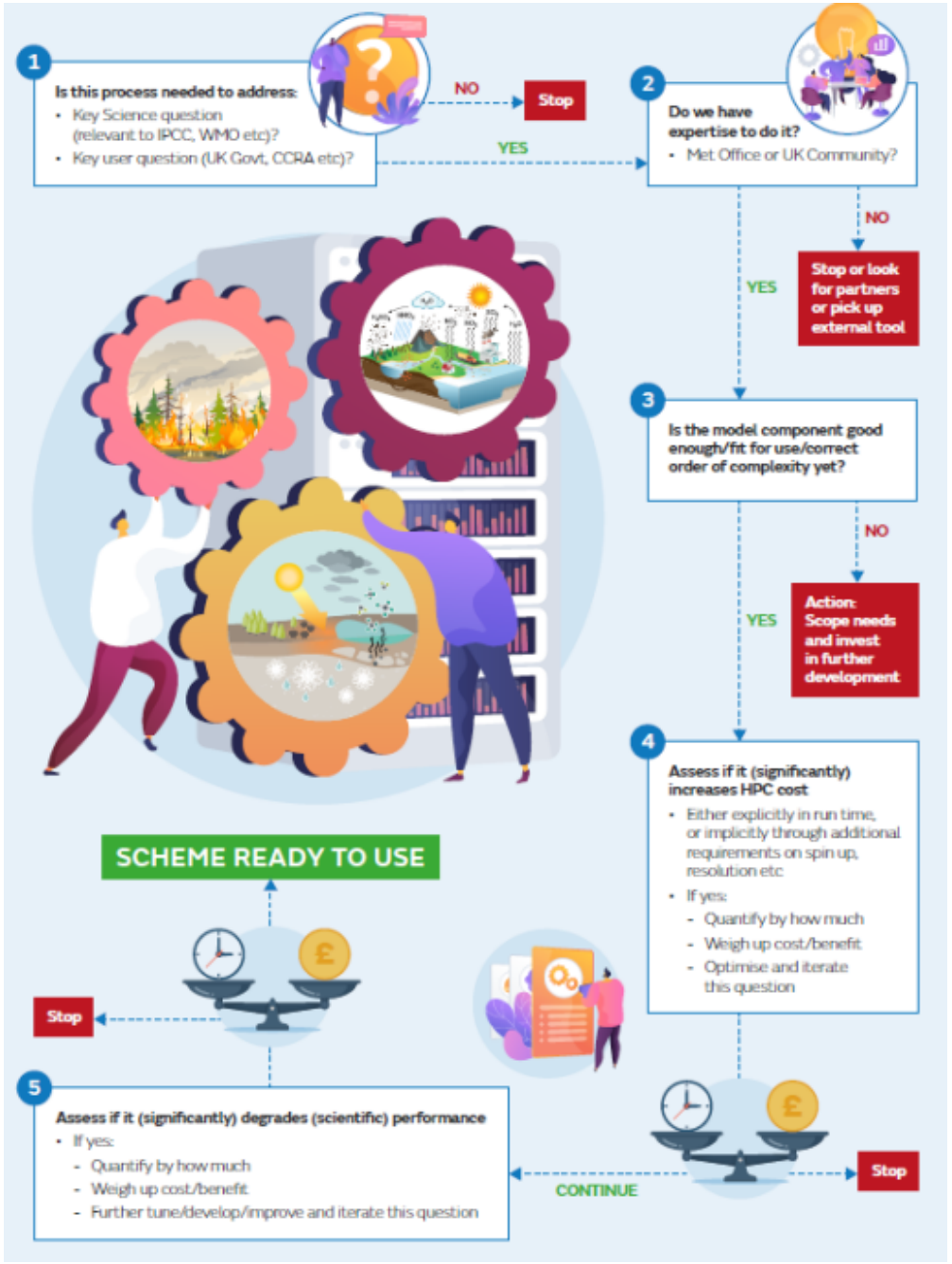
- Updated physical model (GC5)
- Improved stratospheric ozone
- Inclusion of interactive fires
- Methane emissions-driven capability
- Interactive pH parameterization
- Interactive ice sheets

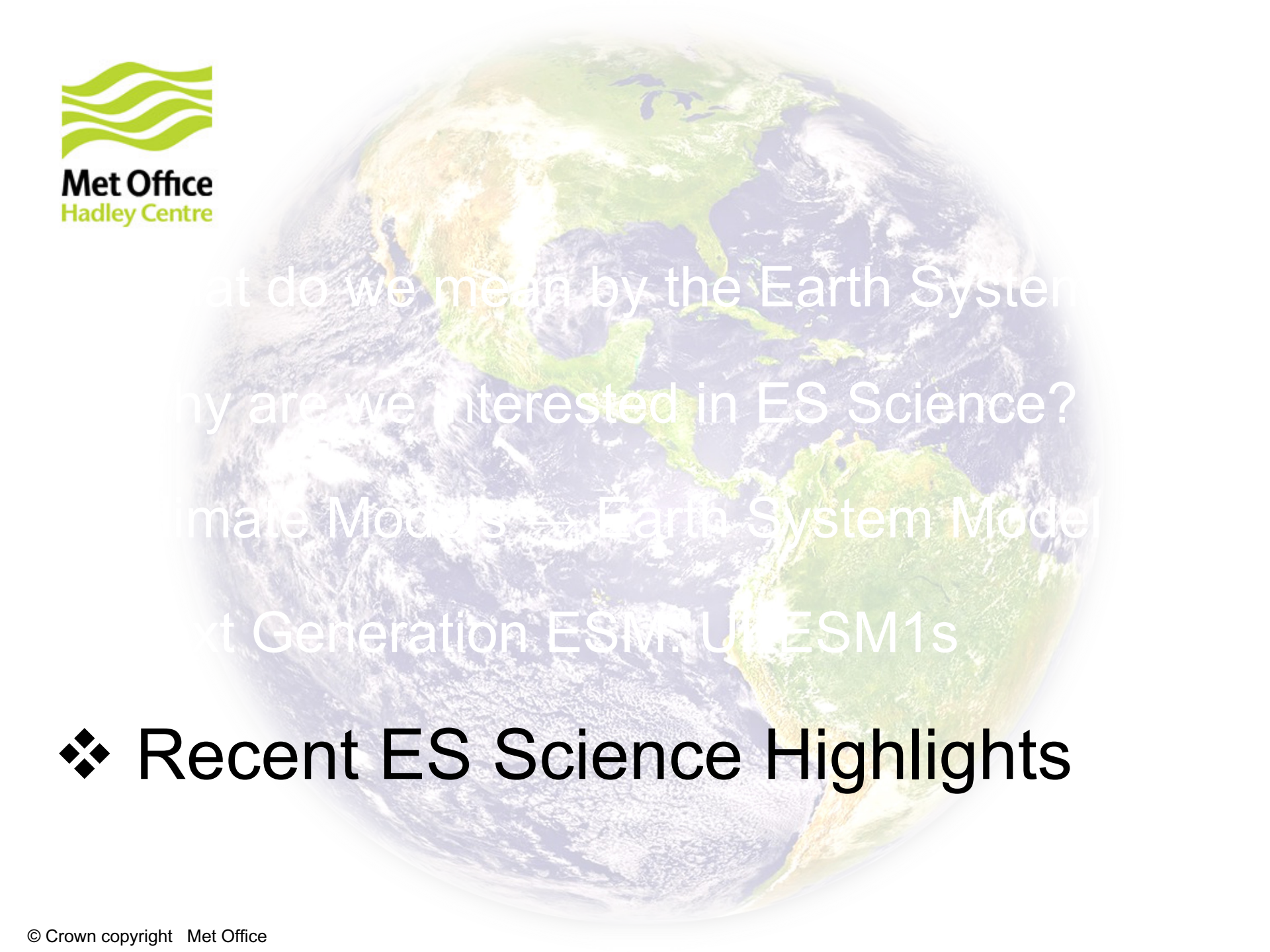
UM-Based

Due to be ready by 2024/2025

Decision making

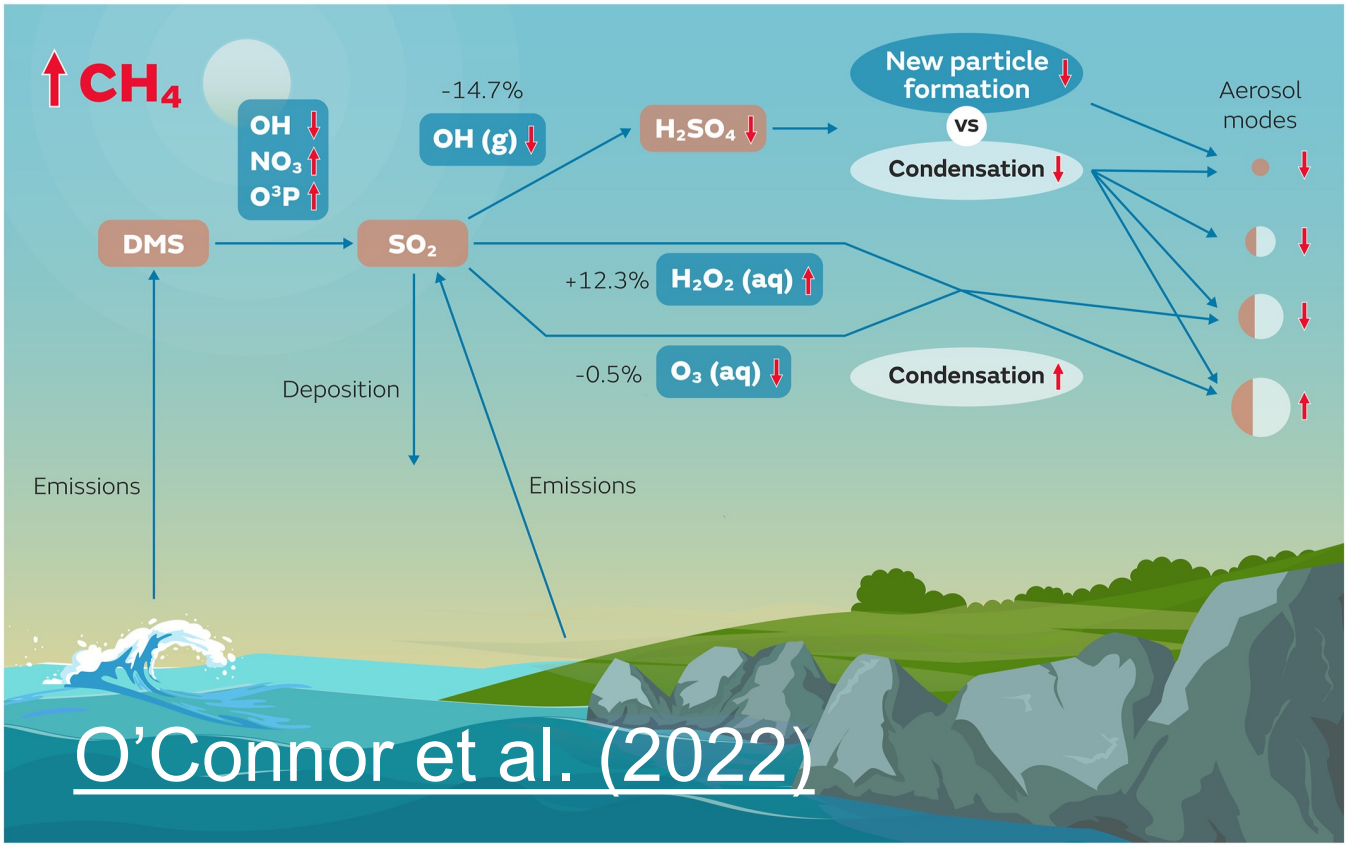
- Important?
- Expertise?
- Fit for purpose?
- Computational cost?
- Scientific performance?





- Recent ES Science Highlights

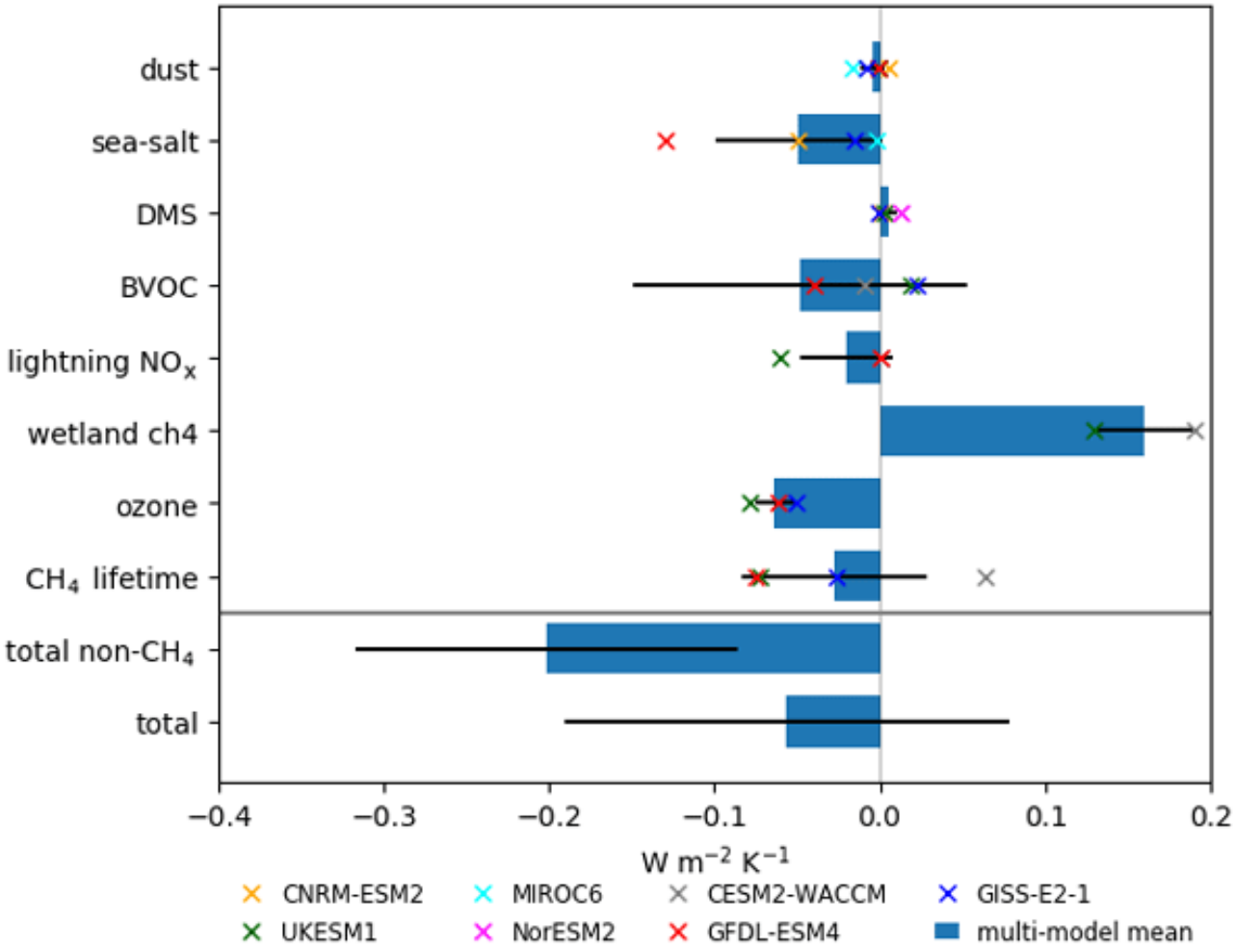
Methane Forcing



- Large uncertainty in methane forcing
- Partly due to chemistry representation
- Partly due to cloud forcing

Biogeochemical Feedbacks

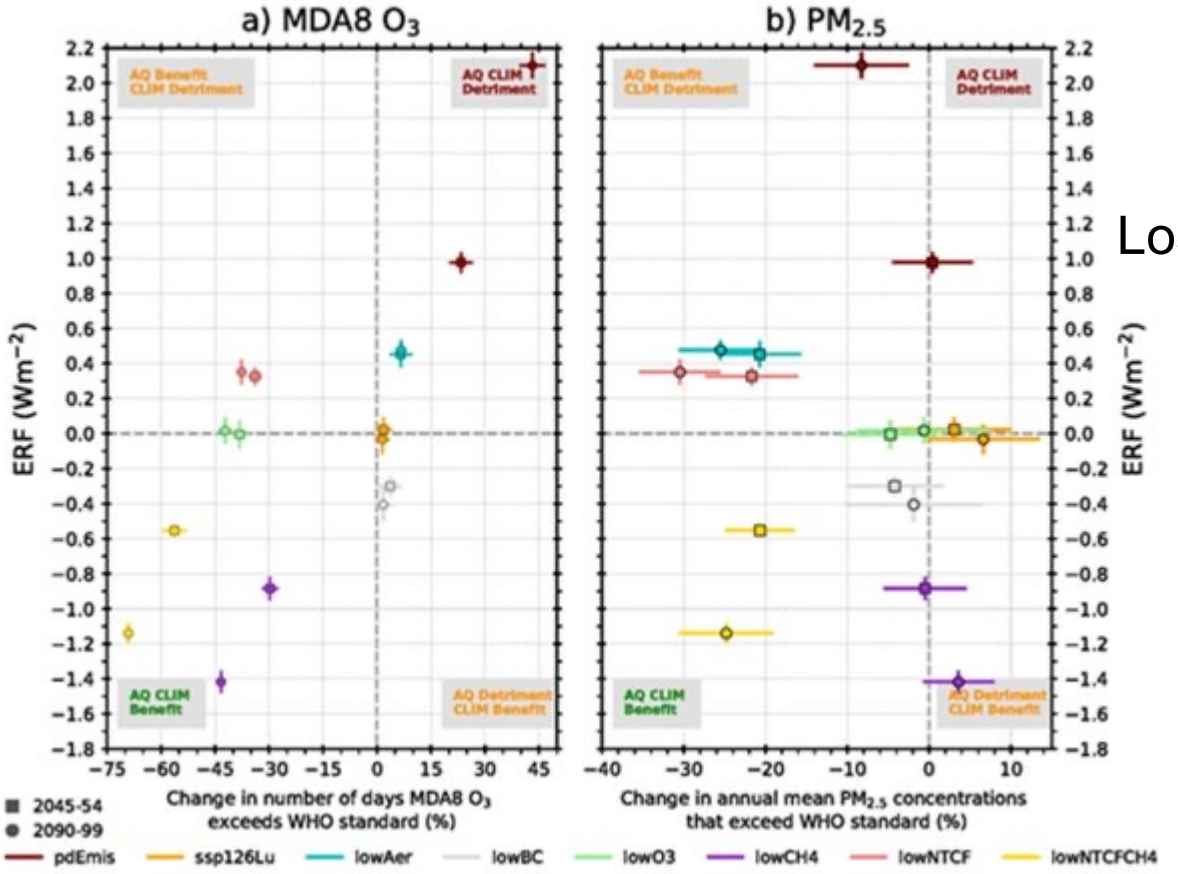
[Thornhill et al., ACP (2021)]



Quantify how different BGC processes respond to climate change & how their responses influence further climate change

Mitigation & Policy Advice

Lose-Lose



Win-Win

Assessment of climate & air quality impacts from different mitigation pathways, e.g., aerosols, land use, methane, etc..

Turnock et al., Earth's Future (2022)

Conclusions

Concluding Remarks

- The Earth System
- Motivation behind studying Earth System Science
- Development of Climate Models into Earth System Models
- Brief overview of UKESM1, UKESM1.1, & UKESM2
- Recent ES Science Highlights

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Thank you for listening!
Any questions?