

UKESM General Assembly 16-17 June 2020

Day 1 – Tuesday 16th June

| | |
|-------------|---|
| 09.30-10.30 | Introduction and review of progress over the past year |
| 10.30-11.00 | Break |
| 11.00-11.20 | Continued - review of progress over the past year |
| 11.20-11.30 | The 2 nd NERC Long Term Science Multi Centre (LTSM) programme. Rowan Sutton |
| 11.30-12.00 | Invited Talk 1: Investigating abrupt, potentially irreversible changes in the Earth system. Tim Lenton |
| 12.00-13.00 | Lunch Break |
| 13.00-13.30 | Invited Talk 2: Allowable carbon budgets for meeting key policy targets. Chris Jones |
| 13.30-14.00 | Invited Talk 3: The mitigation potential of non-CO ₂ Short Lived Climate Forcers and potential co-benefits for regional air quality. Fiona O'Connor |
| 14.00-14.30 | Invited Talk 4: Assessing aggressive climate mitigation strategies. Cat Scott |
| 14.30-15.00 | Break |
| 15.00-16.00 | International perspectives on future priorities for Earth system modelling and science. Olivier Boucher (IPSL) & Jean-François Lamarque (NCAR/CESM) |
| 16.00-16.15 | Summary of day 1 - Jane Mulcahy |

Day 2 – Wednesday 17th June

9.15 – 10.30 Science Talks (A)

1. Catherine Hardacre
2. Nicolas Bellouin
3. Gerd Folberth
4. Adam Povey
5. Paul Griffiths
6. Graham Mann
7. Lee de Mora

10.30 – 11.00 Break

11.00 – 12.15 Science Talks (B)

1. David Schroeder
2. Robin Smith
3. Victoria Lee
4. Antony Siahhaan
5. Joao Teixeira
6. Chantelle Burton
7. Douglas Kelley

12.15 -13.15 Lunch

13.15 – 14.30 Science Talks (C)

1. Jonny Williams
2. Marc Stringer
3. Till Kuhlbrodt
4. James Keeble
5. Leighton Regayre
6. Rob Parker

14.30 – 15.00 Break

15.00 - 15.45 Open discussion, summary, and outline of discussions for 1 year extension of UKESM project.

15.45 Meeting ends



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UKESM progress

- UKESM1 has been applied extensively in CMIP6
- A large amount of UKESM1 CMIP6 data is available on the UK ESGF node.
- UKESM1 Documentation and analysis papers have been published and a number are in preparation
- A configuration of UKESM1 with interactive Antarctic and Greenland ice sheets is now running
- A wildfire model (INFERNO) is close to running interactively in a configuration of UKESM1
- An update to UKESM1 (UKESM1.1) is under development (*for the end of 2020*)
- A computationally fast version of UKESM1 (UKESM1-fast) is under development
- UKESM1-hybrid resolution continues to be developed
- ESMValTool is increasingly being used for model analysis
- Project dissemination and communication is ongoing, being revamped. 2021 looks like it will be busy!
- With NERC centre reps we are planning our 1-year extension proposal (March 2021 – April 2022)

UKESM1 in CMIP6

- DECK : pre-industrial control (~1500 years & running), 4XCO₂, 1%CO₂, historical (19 members)
- MIPs : ScenarioMIP, AerchemMIP, C4MIP, CDRMIP, GeoMIP, ISMIP6, LUMIP, OMIP, PMIP, VoIMIP, ZECMIP
- ScenarioMIP; 5 members for ssp1-19, ssp2-45, ssp4-34, ssp5-85, ssp5-34-OS
13 members for ssp1-26 and ssp3-70
- CO₂ emission driven UKESM1 submitted to e.g. C4MIP
- UKESM1 selected as one of five core models for use in the ISIMIP project
Inter-sectorial Impact Model Intercomparison Project. The main international climate impacts project

UKESM1 documentation papers



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JAMES | Journal of Advances in Modeling Earth Systems

Special Issue: The UK Earth System Models for CMIP6 (*15 papers on UKESM1 & HadGEM3 in CMIP6 DECK*)

[Williams et al. 2017](#) : The Met Office Global Coupled Model 3.0 and 3.1 (GC3.0 and GC3.1) Configurations

[Mulcahy et al. 2018](#) : Improved Aerosol Processes and Effective Radiative Forcing in HadGEM3 and UKESM1

[Kuhlbrodt et al. 2018](#) : The Low-Resolution Version of HadGEM3-GC3.1 and Evaluation for Global Climate

[Sellar et al. 2020](#) : Description and Evaluation of the U.K. Earth System Model

[Senior et al. 2020](#) : UK Community Earth System modelling for CMIP6

[Yool et al. 2020](#) : Spin up of UK Earth System Model 1 (UKESM1) for CMIP6

[Sellar et al. 2020](#) : Implementation of U.K. Earth System Models for CMIP6

[Bodas-Salcedo et al. 2019](#) : Strong dependence of Atmospheric Feedbacks on Mixed-Phase Microphysics and Aerosol-Cloud interactions in HadGEM3 (*explains high ECS & cloud feedbacks in UKESM1*)

[Andrews et al. 2019](#) : Forcings, Feedbacks and Climate Sensitivity in HadGEM3-GC3.1 and UKESM1

Other UKESM1 documentation & evaluation papers



Description and evaluation of the UKCA stratosphere–troposphere chemistry scheme (StratTrop vn 1.0) implemented in UKESM1

Alexander T. Archibald^{1,2}, Fiona M. O'Connor³, Nathan Luke Abraham^{1,2}, Scott Archer-Nicholls¹, **GMD**



documents the interactive chemistry in UKESM1

Description and evaluation of aerosol in UKESM1 and HadGEM3-GC3.1 CMIP6 historical simulations

GMD

Jane P. Mulcahy¹, Colin Johnson^{1,2}, Colin G. Jones², Adam C. Povey³, Catherine E. Scott⁴,



documents the aerosol schemes in UKESM1/HadGEM3

Assessment of pre-industrial to present-day anthropogenic climate forcing in UKESM1

ACP

Fiona M. O'Connor¹, N. Luke Abraham^{2,3}, Mohit Dalvi¹, Gerd Folberth¹, Paul Griffiths^{2,3}, Catherine



Documents the historical radiative forcing in UKESM1

Coming Soon.....

Kuhlbrodt et al. 2020 : Ocean heat uptake in the UK model historical simulations

Yool et al 2020 : Evaluation of the ocean component of UKESM1 CMIP6 historical simulations

Kelley et al 2020 : Evaluation of the land component of UKESM1 in CMIP6 historical simulations

Ongoing analysis -> papers in prep in the UKESM core group



Smith et al 2020 : Coupling UKESM to dynamic models of the Greenland and Antarctic ice sheets

Lee et al. 2020 : Interactively simulating the Greenland ice sheet within an ESM: The impact of coupled climate-ice-sheet feedback processes

Siahaan et al 2021 : Interactively coupled Antarctic ice sheet in UKESM1: Climate change response

Hardacre 2020 : Evaluating the sulphur cycle in UKESM1

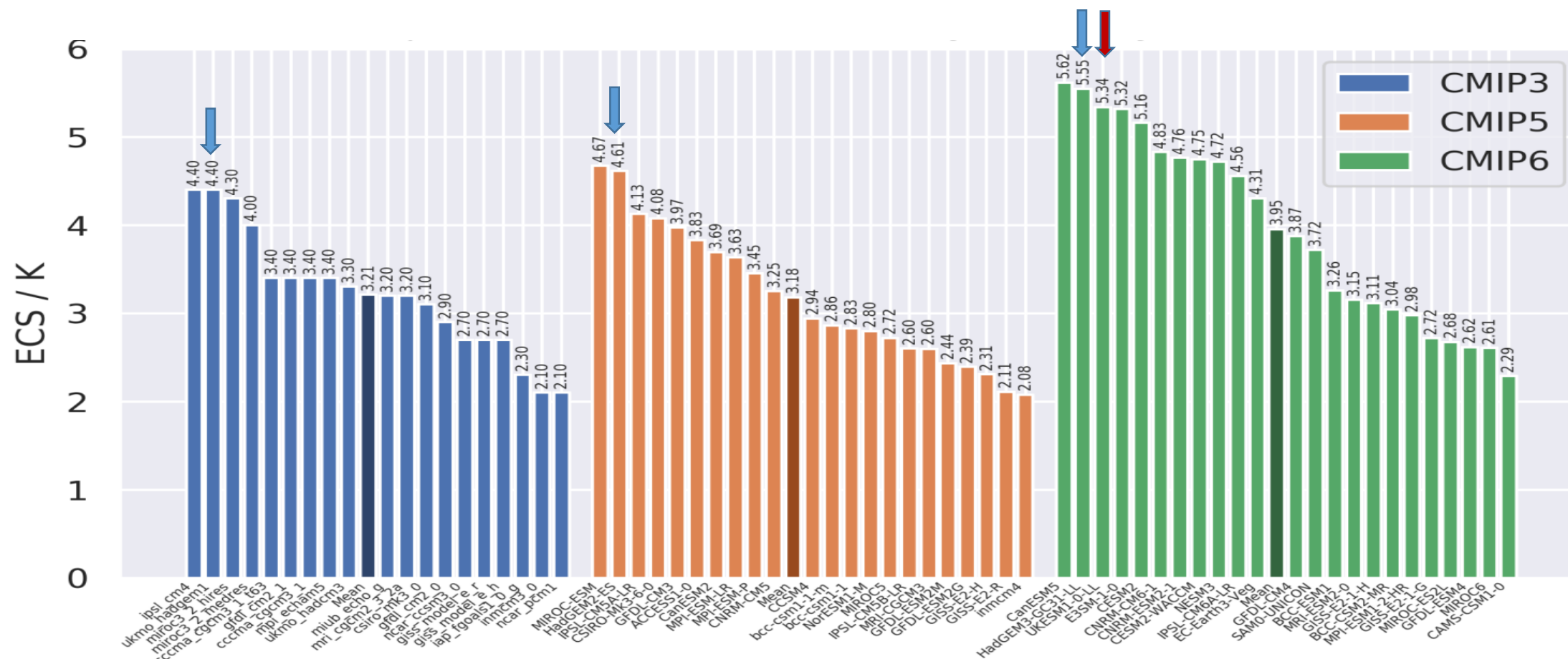
Also.....

Earth system change at different levels of global mean warming

- (i) Time of exceedance and seasonal to annual mean changes
- (ii) Higher time frequency changes -> impact relevant changes
- (iii) Regional analysis; co-variability of change across Earth system components.

The global carbon cycle at different level of global mean warming

CMIP6 is warmer than early CMIPs : UK models are warm in CMIP6



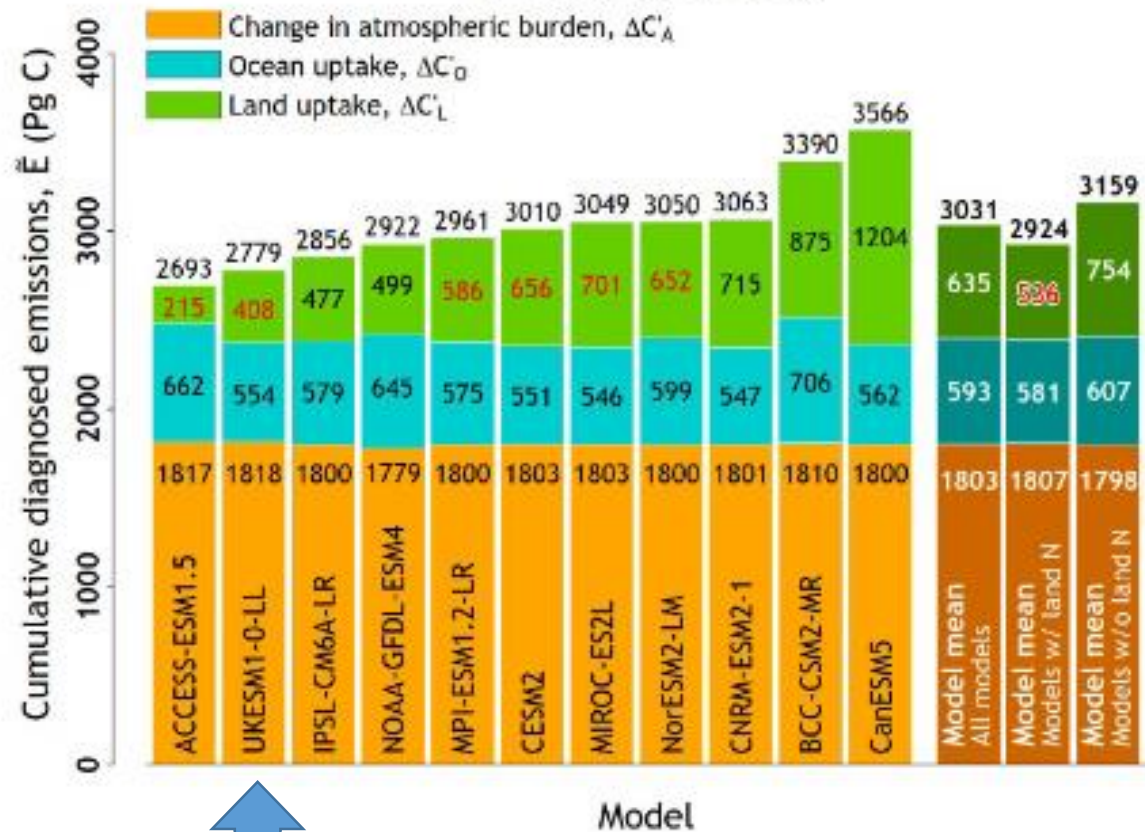
~0.3K of UKESM1 ECS = 5.3K comes from dynamic vegetation change (& surface albedo change) in 4XCO₂ run so with fixed veg UKESM1 ECS ~ 5K. i.e. 0.5K less than HadGEM3-GC31; difference due to interactive chemistry ?

UKESM1 CMIP6 simulation data is being actively used in numerous multi-model analysis studies around the world

Carbon – climate feedbacks In C4MIP

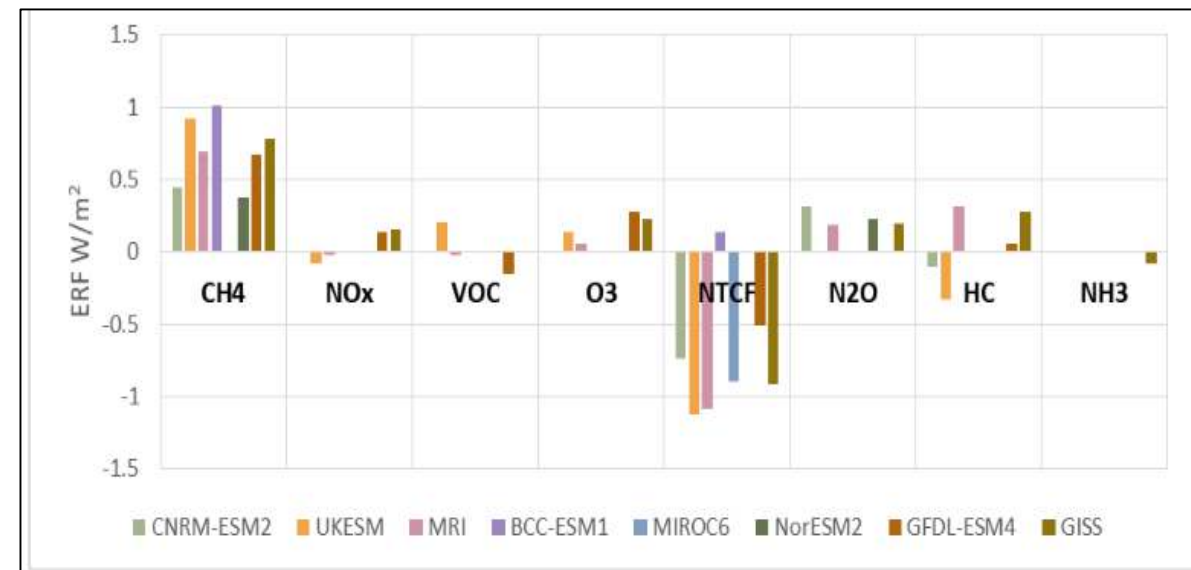
a) Carbon budget terms at 4xCO₂, CMIP6 models

$$\bar{E} = \Delta C'_A + \Delta C'_L + \Delta C'_O$$



Arora et al. 2019 Biogeosciences
<https://doi.org/10.5194/bg-2019-473>

Diagnosing trace gases and aerosol historical effective radiative forcing (ERF) in AerchemMIP



Thornhill et al. 2020 ACP
<https://doi.org/10.5194/acp-2019-1205>

UKESM CMIP6 data availability: An update

What / whence UK CMIP6 data?

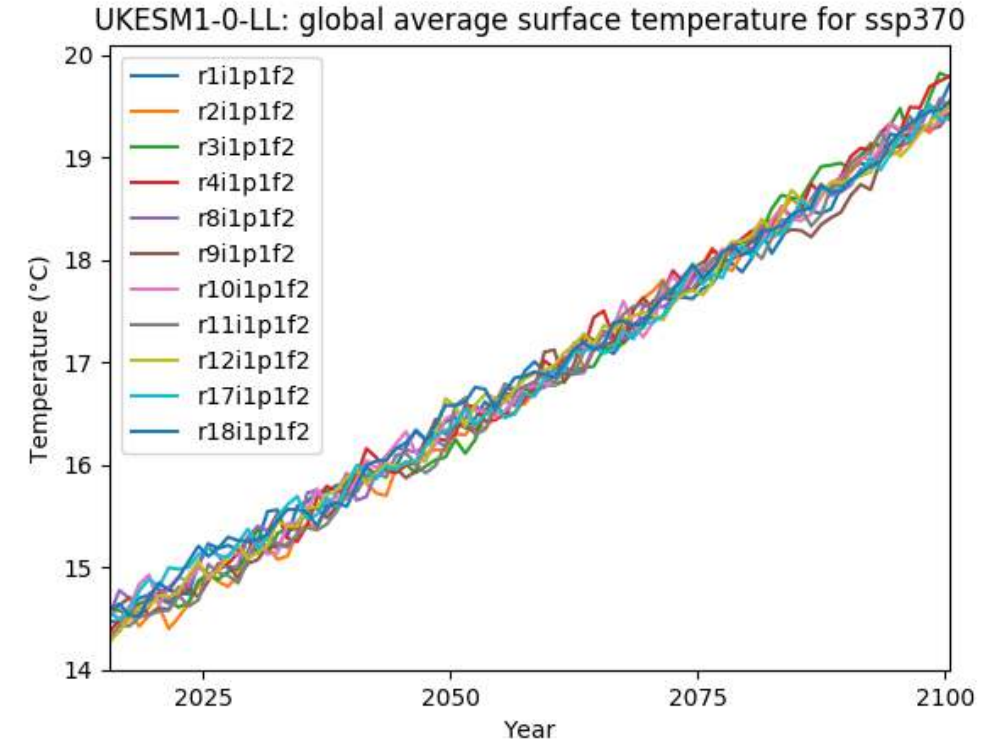
- Produced by converting model output into standard (cf-netCDF) file format, e.g.

`ta_Amon_UKESM1-0-LL_historical_r1i1p1f1_gn_185001-194912.nc`

- for selected **variables**, **frequencies** and **experiments**
- Uploaded to (CEDA node of) ESGF
 - <https://esgf-index1.ceda.ac.uk/search/cmip6-ceda/>
 - Searchable index, downloadable data
- Currently 48,279 datasets from UKESM1 (from MOHC/NERC, KMA & NIWA)
 - dataset* = **variable** on a **mip table** from a **model** run of an **experiment variant**
- CEDA node has UK data plus selected variables from other institutions
 - other UK data is from HadGEM3-GC31-LL (14,041), -MM (3,782), -HH (355)

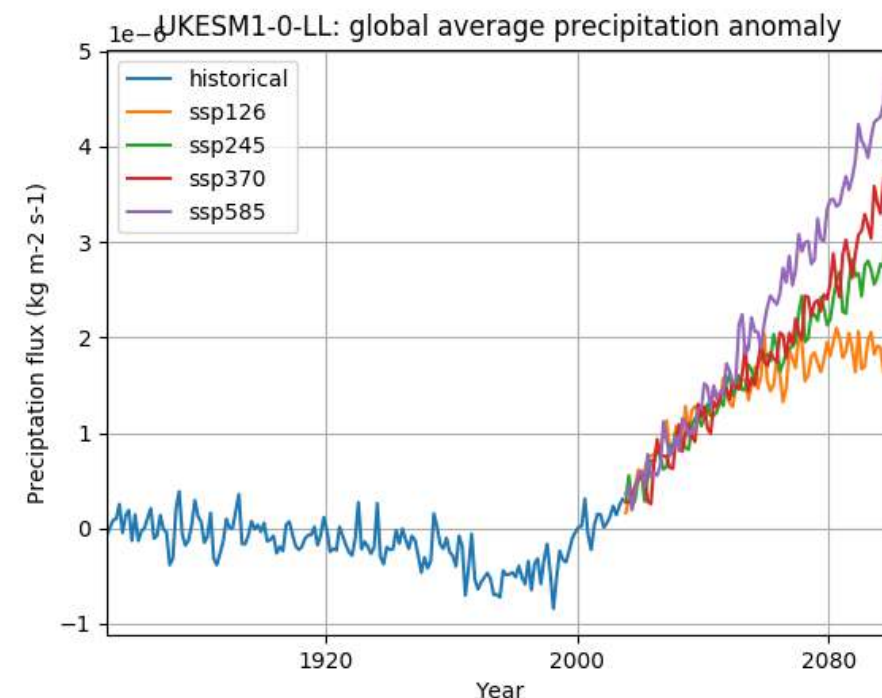
Which experiments?

- DECK
 - piControl (1100 years), 1%CO₂, 4xCO₂, AMIP
- Historical (1850-2014)
 - 19 ensemble members
- ScenarioMIP (2015-2100+)
 - Tier 1: ssp1-26, 2-45, 3-70, 5-85
Tier 2: ssp1-19, 4-34, 5-34-OS
 - 13 ensemble members for ssp3-70 (now), & ssp1-26 (end July 2020), 5 members for others
- Some experiments from AerChemMIP, C4MIP, LUMIP, GeoMIP, RFMIP



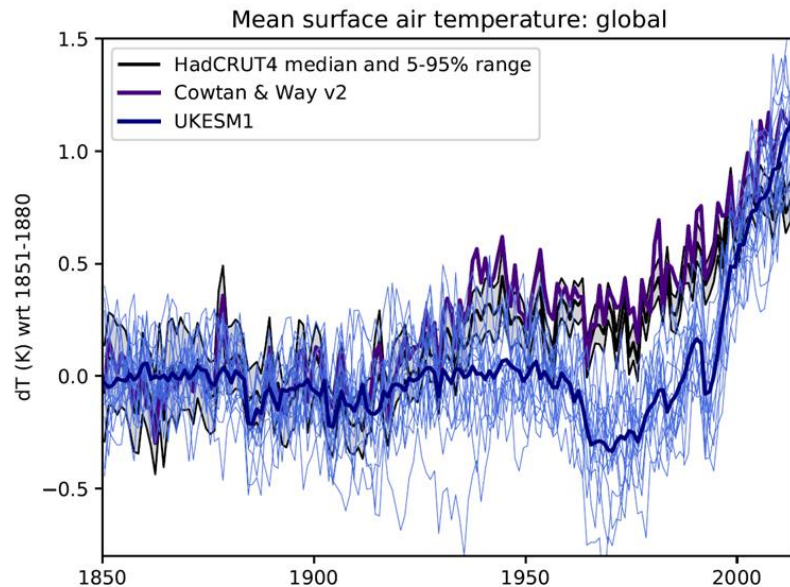
Which variables & frequencies?

- All variables that have been scientifically reviewed
 - No upload to ESGF without (successful) review
- Mostly monthly & daily frequencies
 - e.g., ~700 datasets for each historical ensemble member
- Plus sub-daily (6hr, 3hr, 1hr) frequencies for selected variables & experiments
- High priority (requested) variables
 - IPCC list: 97% available, with 8x 3hr variables to follow
 - ISIMIP3 list: 92% available, with 2x 6hr, 3x 3hr variables to follow
- Other variables available on request



UKESM1.1 Development Update

Motivation for updated configuration



- Investigations into role of aerosol forcing in the mid-late 20th Century cold bias in UKESM1 CMIP6 historical runs uncovered some issues (and bug) in the dry deposition of SO₂ (an important anthropogenic precursor of sulphate aerosol)
- A number of potentially important bugs came to light shortly after the release of UKESM1
- Opportunity to improve some of the more uncertain coupled tuning parameters in UKESM1
- NOTE: UKESM1.1 will not resolve all our issues with the historical temperature biases (that would have been too easy ... !)
- Rather than wait for UKESM2 (~2024) we feel its important to release this more technically and scientifically robust configuration to the community in advance

What's included in UKESM1.1



New Science:

Improved parameterization of SO₂ dry deposition accounting for land surface “wetness” (SO₂ highly soluble) following Erisman et al. 1994, [https://doi.org/10.1016/1352-2310\(94\)90433-2](https://doi.org/10.1016/1352-2310(94)90433-2) and [https://doi.org/10.1016/1352-2310\(94\)90126-0](https://doi.org/10.1016/1352-2310(94)90126-0)

Tunings:

- Albedo of snow on sea ice
- Burial of vegetation by snow
- Dust
- QBO
- Final tuning of net TOA

Bugfixes:

- Surface resistance constants for SO₂ deposition
- H₂SO₄/ystore bug in UKCA
- Correct DMS products in DMS chemistry in UKCA
- Fix CDNC vertical profile in UKCA-Activate
- Fix coupled sea-ice heat fluxes in NEMO

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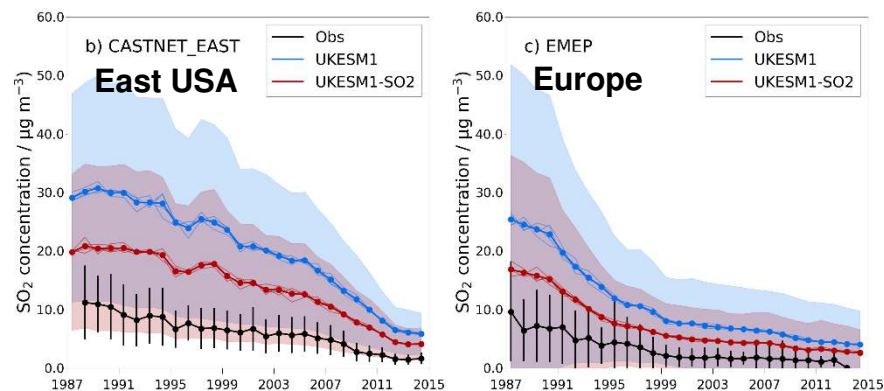
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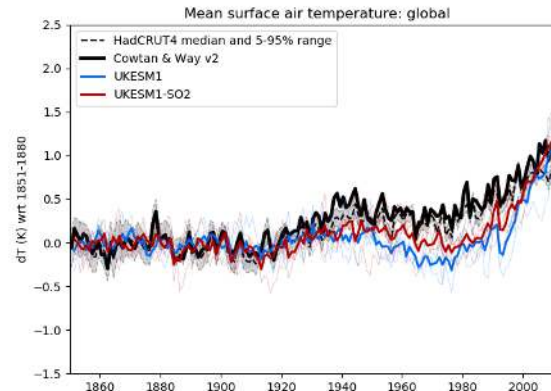
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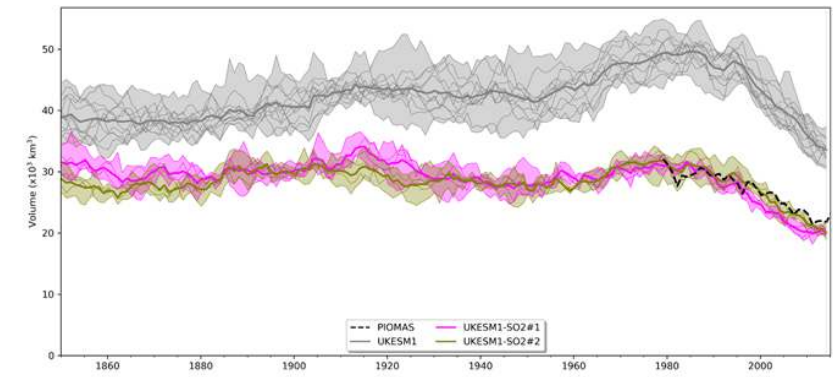
SO₂ evaluation



GMST

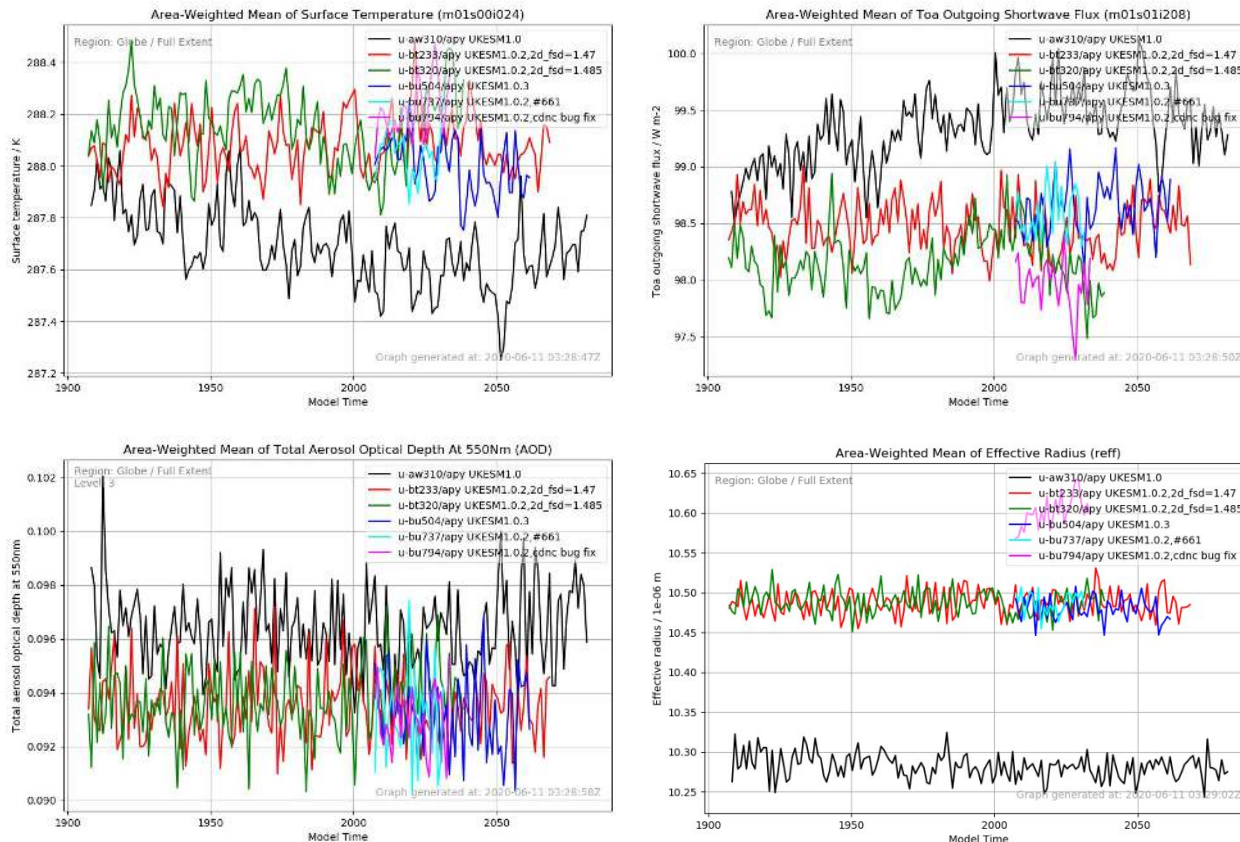


March sea-ice volume Arctic



Progress

Proto-type PI control simulations:



Timelines:

- Hope to have all elements included in coupled PI control simulation by ~July 2020
- We will run some coupled historical simulations later in the summer but currently do not plan to submit to CMIP6
- Aim to release UKESM1.1 to the community before end of 2020.

The interactive ice sheet configurations of UKESM1

UKESM1-ice: Background



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 UKRI
Natural Environment Research Council

- Two-way coupling to models of the Greenland and Antarctic ice sheets is available in special configurations of UKESM1
 - *Not* a standard option in release suites

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UKESM1-ice: Background



- Two-way coupling to models of the Greenland and Antarctic ice sheets is available in special configurations of UKESM1
 - *Not* a standard option in release suites
- Greenland-only suites have been run for CMIP6 via ISMIP6
- Antarctic coupling, including ocean<->ice shelf is unique in CMIP6 ESMs
 - technically and scientifically very challenging, still work in progress
 - many avenues to explore: ORCA1/ORCA025, coupled initialisation, sub-gridscale methods, parameter tuning...

UKESM1-ice: Current status



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 **UKRI** Natural Environment Research Council

- Greenland-only runs are being analysed
 - Paper ready by the end of the year
- ISMIP6 data ready to be CMORised on JASMIN for submission to ESGF
- Comparative work with other models in ISMIP6 being set up

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session B*

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 - Scenario runs to 2100 with ORCA1 ocean
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*Robin &
Antony's talks
tomorrow,
session B*

UKESM1-ice: Outlook



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 **UKRI** Natural Environment Research Council

- Shorter-term/LTSM1 extension
 - coupled initialisation
 - conservation
 - calving behaviour for Greenland
 - dealing with climate initial condition/internal variability in Antarctic projections
 - investigating higher resolution oceans

UKESM1-ice: Outlook



- Shorter-term/LTSM1 extension
 - coupled initialisation
 - conservation
 - calving behaviour for Greenland
 - dealing with climate initial condition/internal variability in Antarctic projections
 - investigating higher resolution oceans
- Longer-term/LTSM2?
 - interactive ice in standard UKESM release suites
 - marine coupling for Greenland
 - iceberg effects on marine biology
 - pollutant/biological darkening for ice sheet albedo
 - shelf collapse

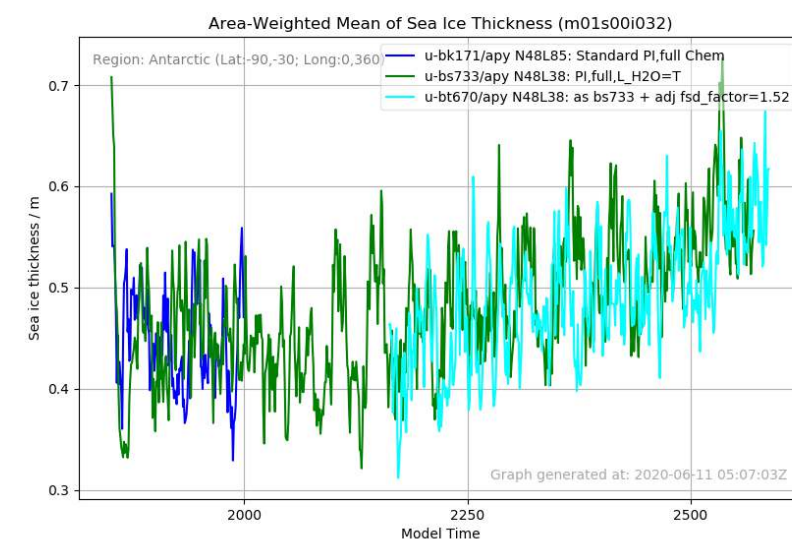
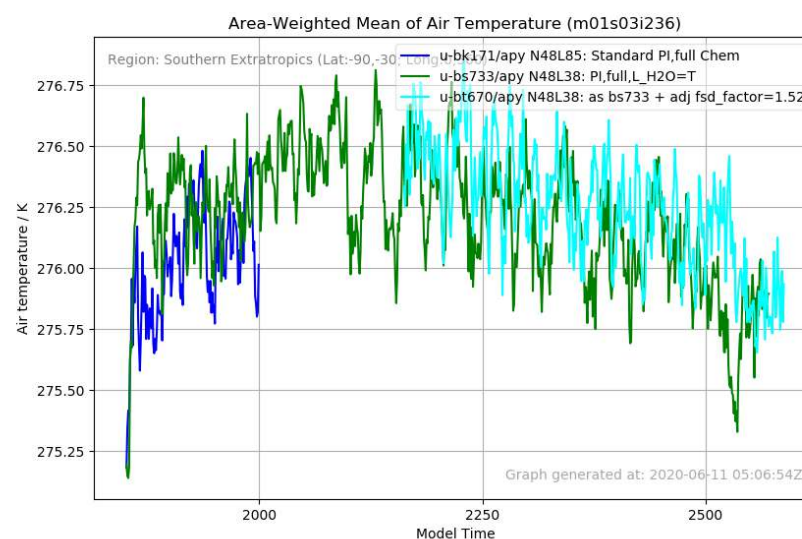
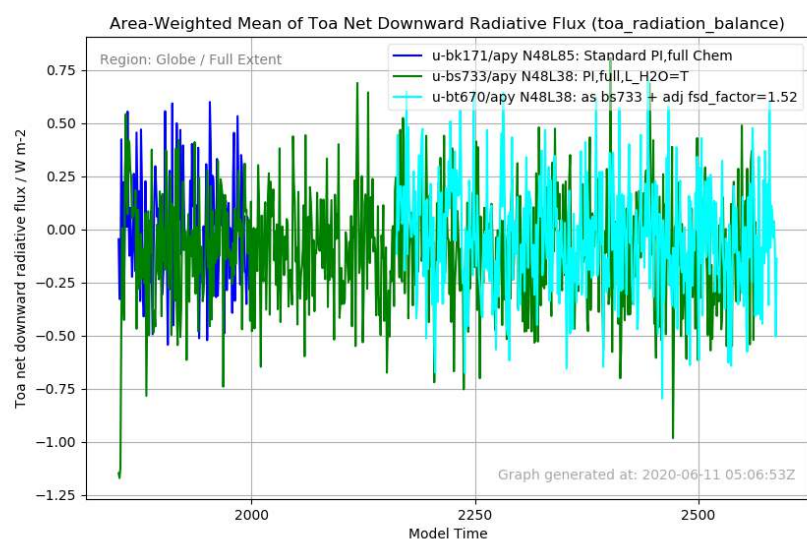
UKESM1-fast and UKESM1-hybrid

UKESM1-fast



- UKESM1-fast is at **N48L38** with all UKESM1 science components active
- L38 has a lower model top than L85 (41km compared to 85km) and coarser vertical layers.
- We developed this via an intermediate **N48L85** configuration.
- N48L85 runs at ~6.5 ypd on 40 nodes.
- N48L38 runs at 12.5 ypd on 33 nodes
- The standard UKESM1 **N96L85** runs at ~3 ypd on 37 nodes.
- The ocean is the same in all configurations (ORCA1L75 + MEDUSA)
- Some (modest, non-negligible) tuning was required in each step (N96L85 -> N48L85 -> N48L38)
- We have a version N48L38-CN (offline UKCA) that runs at ~19 ypd on 24 nodes (*currently shelved*)

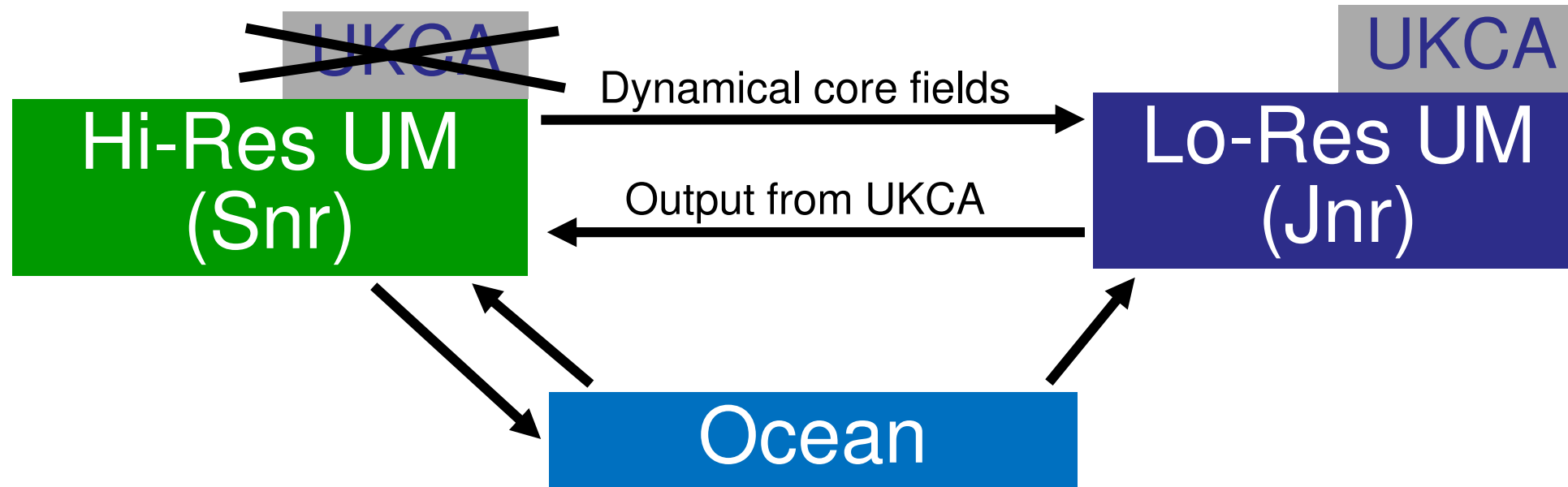
Despite a balanced nett TOA radiation UKESM1-fast wants to lose heat from the ocean



This is creating a trend in Southern ocean surface temperatures and sea ice

UKESM1-hybrid resolution atmosphere

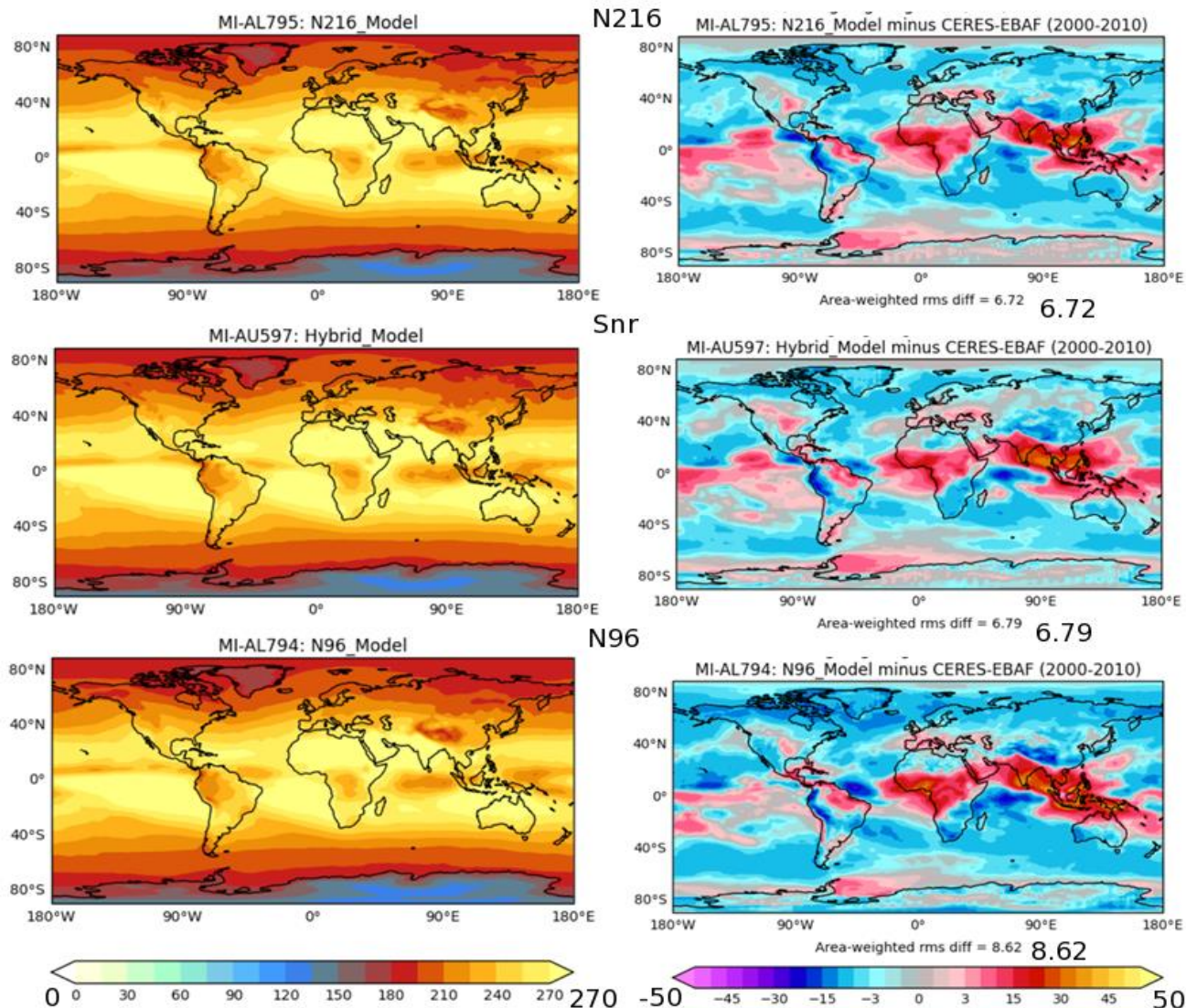
Chemistry & Aerosol (calculated in UKCA) are important, but computationally expensive



- Coupling executables with OASIS3-MCT
- We're running:
 - UKESM-hybrid N96 N48 ORCA1
 - UKESM-hybrid N216 N96 ORCA025
- For the same resources/nodes, UKESM-hybrid is ~65% faster than UKESM

Hybrid results and plans

Annual mean OLR (left column) and bias in TOA OLR against CERES observations (right column).



Planned runs

AMIP (1979-2014) and selected AerchemMIP/RFMIP runs for

- UKESM AMIP N216
- UKESM-hybrid AMIP N216 N96
- UKESM AMIP N96
- UKESM-hybrid AMIP N96 N48

Developments for UKESM2

Plans for UKESM2 (early days so still evolving)



UKESM2 will be built on HadGEM3-GC5 (available ~ mid 2022)

Aim for UKESM2 to be “operational” / science ready ~ mid 2024

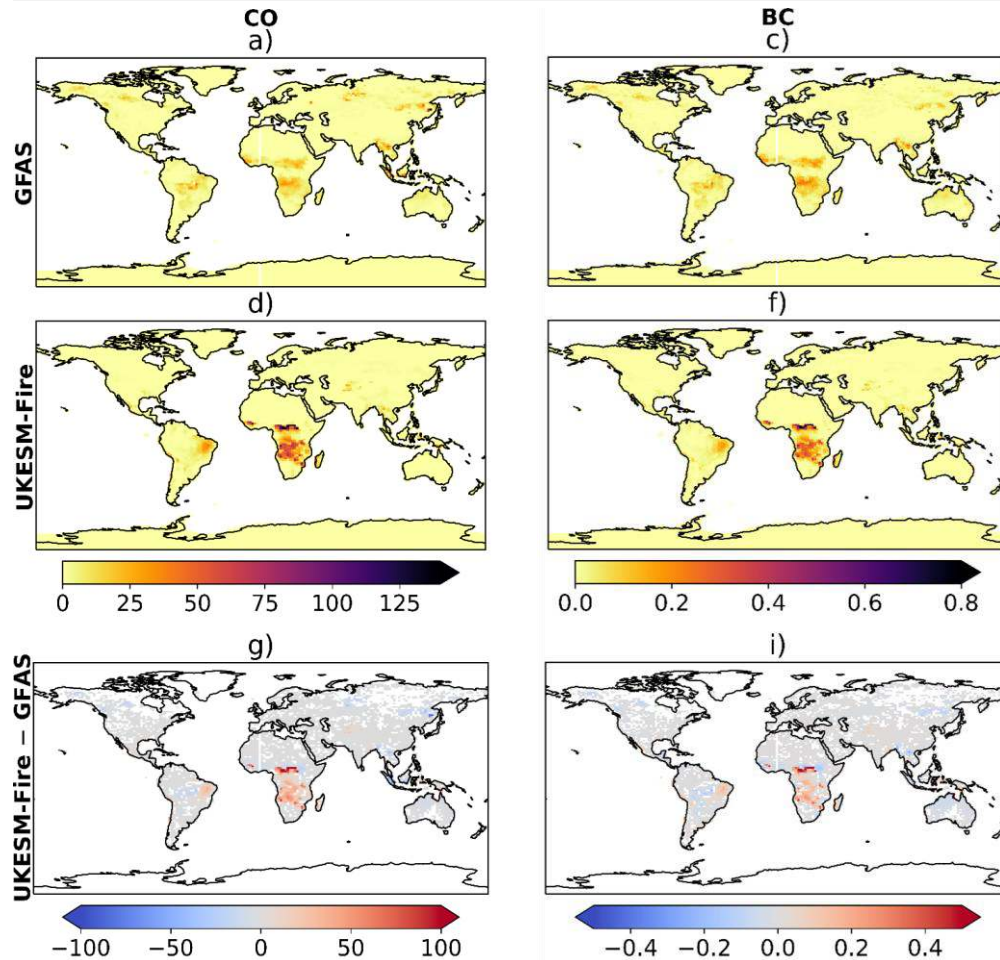
Primary developments:

- Workhorse model will stay at N96L85 – ORCA1L75
- Have an exploratory configuration at higher resolution (e.g. using hybrid approach)
- CASIM multi-moment cloud microphysics (if successfully adopted for GC5)
- Ability to run model with emissions of CO₂, CH₄ and Nr/N₂O
 - An initial CO₂ + CH₄ emission driven version of UKESM1 running (see Folberth et al. talk tomorrow)*
- Interactive Greenland and Antarctic ice as part of the standard model configuration.
- Wildfires fully interactive
- Improved representation of human land use
- Nitrate aerosol
- Modal dust
- Improved stratospheric ozone
- Develop a “fast” version (after main configuration is released)

Coupling a fire model into UKESM1

UKESM1-AMIP + INFERNO wildfires

Vegetation prescribed from UKESM1 historical run (without fires)
INFERNO fires coupled to and emitting into UKCA+GLOMAP



Errors in CO and BC emission in UKESM1-AMIP+INFERNO are collocated with biases in the vegetation prescribed from UKESM1 without fires

These vegetation biases are improved by including INFERNO in UKESM1 and allowing it to impact veg mortality and type

UKESM1 with INFERNO active and Impacting dynamic vegetation

