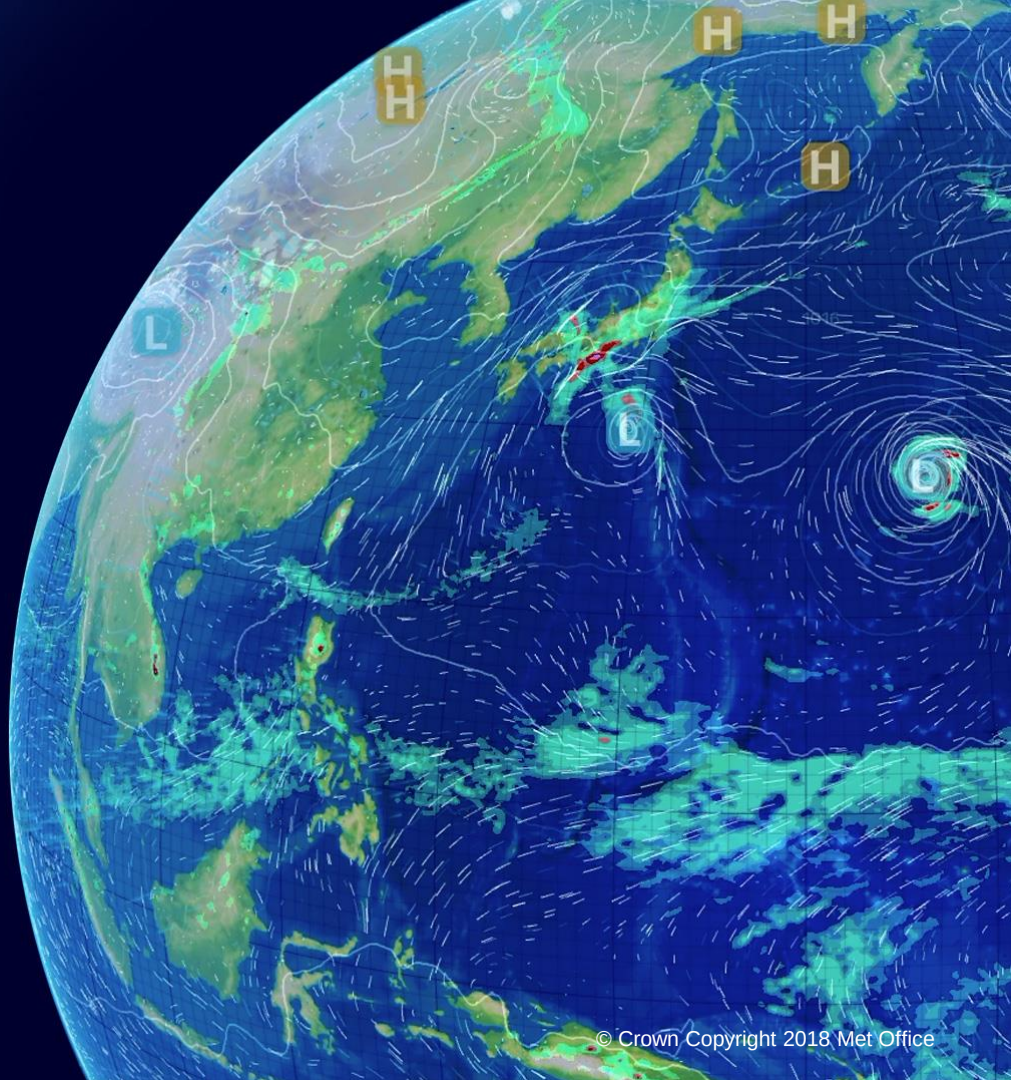
# JULES Earth System Configuration: JULES-ES

Andy Wiltshire + many others



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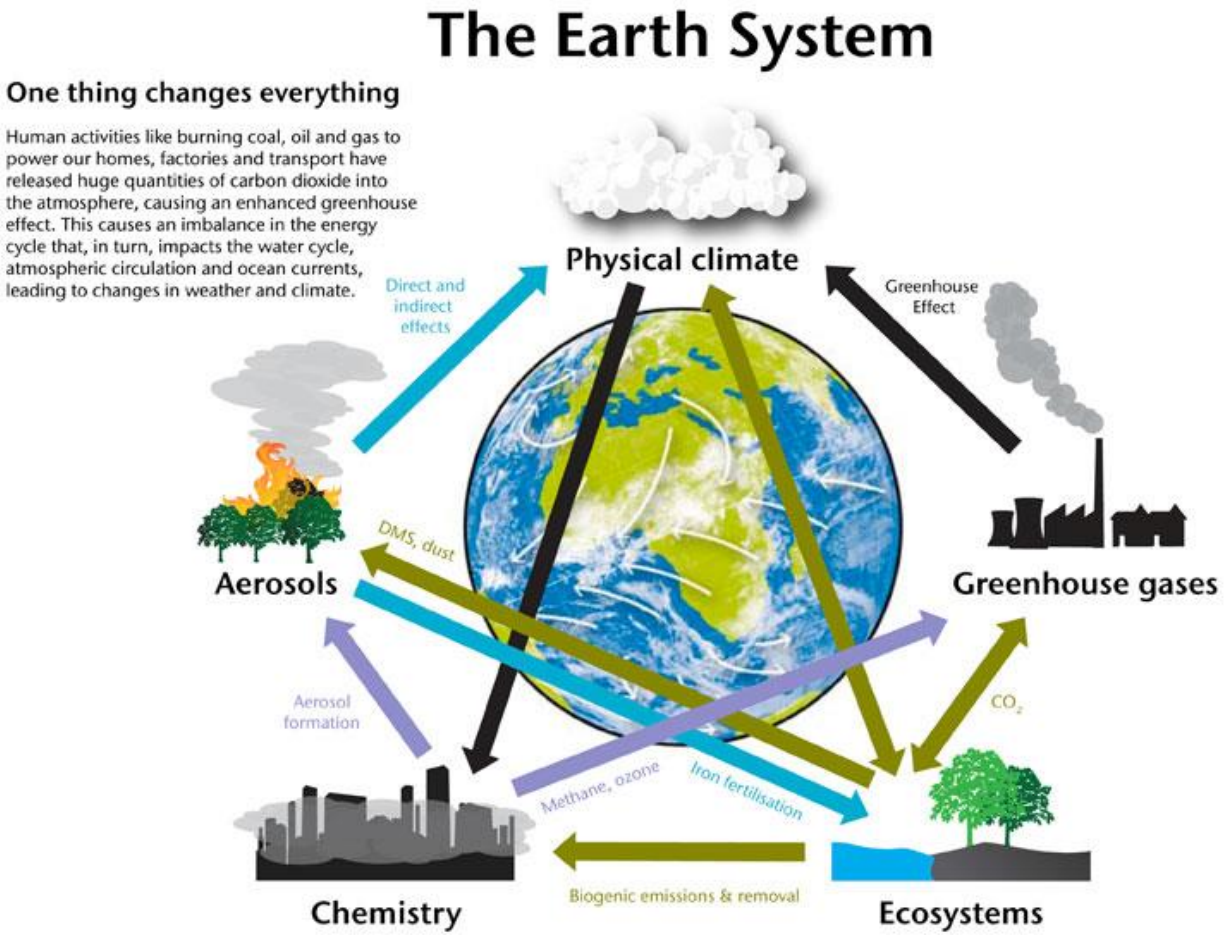
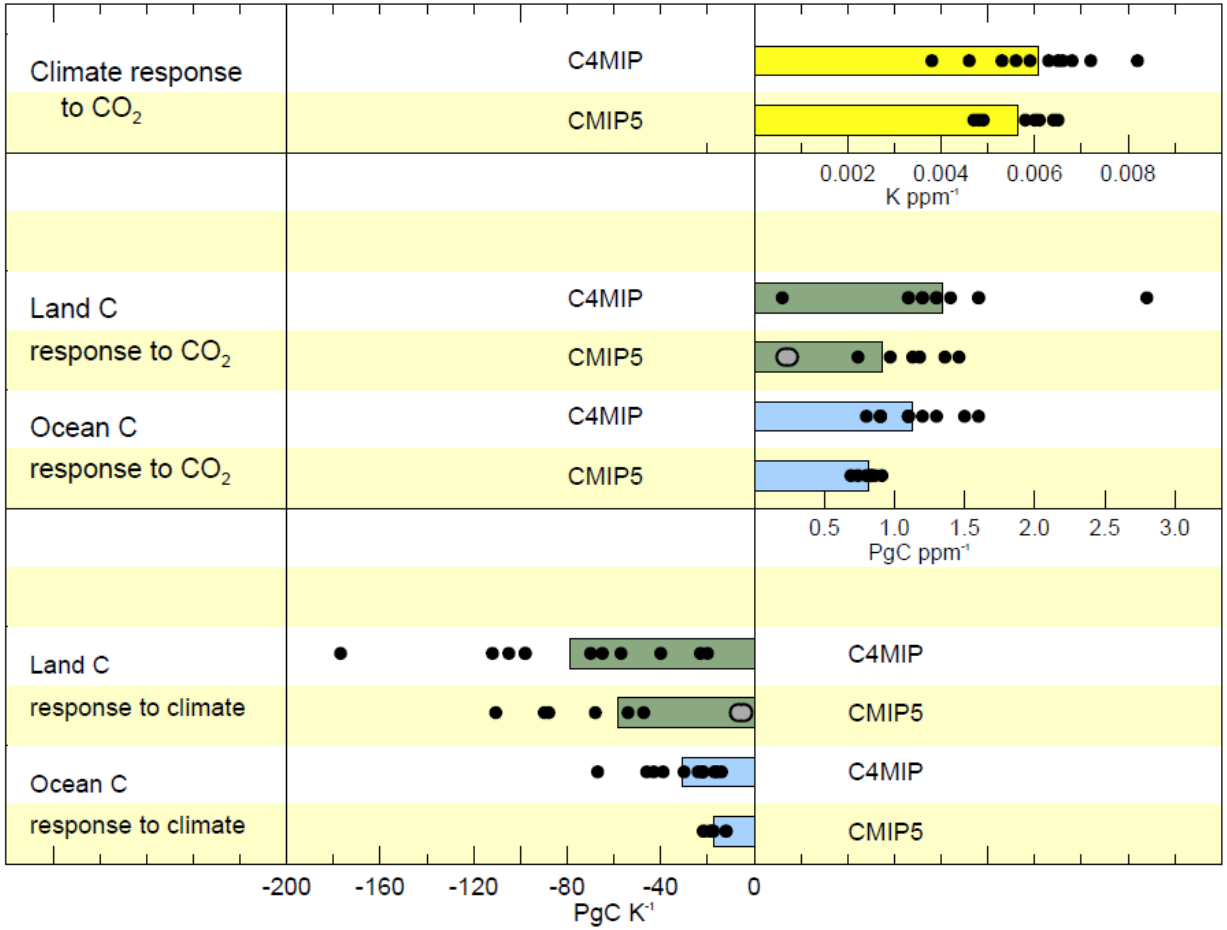
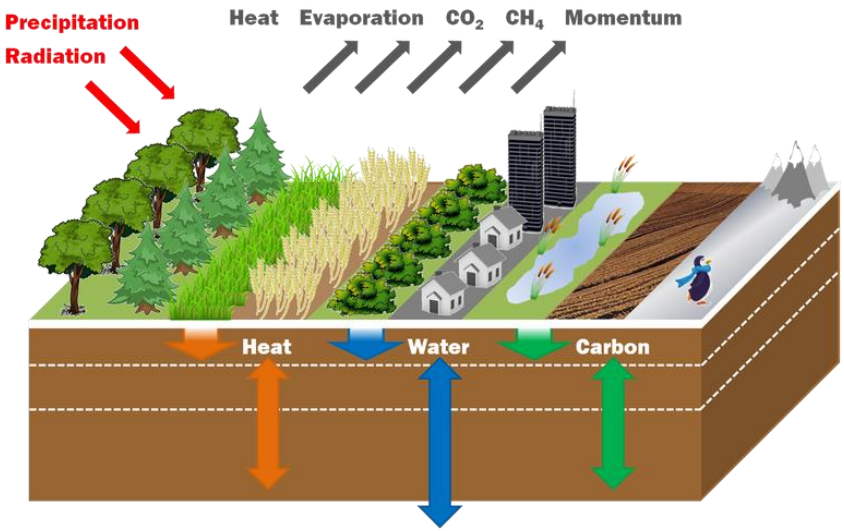
The ‘Earth System’ differs from the ‘Physical’ model in that includes amongst other things biogeochemical interaction and feedbacks.




Climate response to $CO_2$
C4MIP
CMIP5
0.002
0.004
0.006
0.008
K ppm$^{-1}$
Land C response to $CO_2$
C4MIP
CMIP5
Ocean C response to $CO_2$
C4MIP
CMIP5
0.5
1.0
1.5
2.0
2.5
3.0
PgC ppm$^{-1}$
Land C response to climate
C4MIP
CMIP5
Ocean C response to climate
C4MIP
CMIP5
-200
-160
-120
-80
-40
0
PgC K$^{-1}$

# JULES-ES

- JULES-ES is the terrestrial earth system component of UKESM (excluding ice sheets).
- JULES-ES simulates the exchange of heat, water, momentum, carbon, methane and BVOCs between the land and atmosphere
- At the core is the JULES physical land setup (JULES-GL7) with additional processes such as TRIFFID enabled which otherwise would be input from ancillary.



# JULES-ES

- JULES-ES has been developed over ~5 years as a partnership between Met Office and Exeter University, with CEH assisting with coupling and tuning of coupled model
- Anna Harper – updated plant physiology and TRIFFID veg dynamics
- Eddy Robertson – new land-management module
- Nic Gedney – improved CH4 scheme
- Gerd Folberth – improved BVOC scheme
- Andy Wiltshire – new Nitrogen scheme
- Spencer Liddicoat – undertook virtually all the coupling work

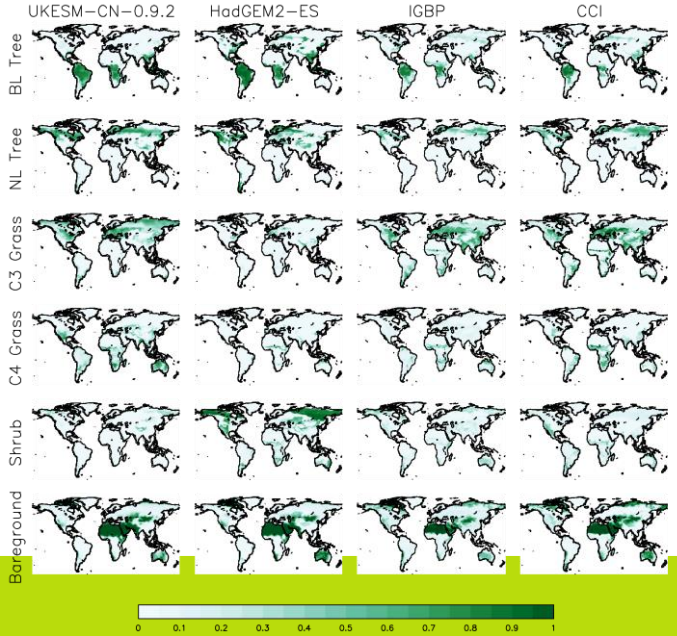
Met Office

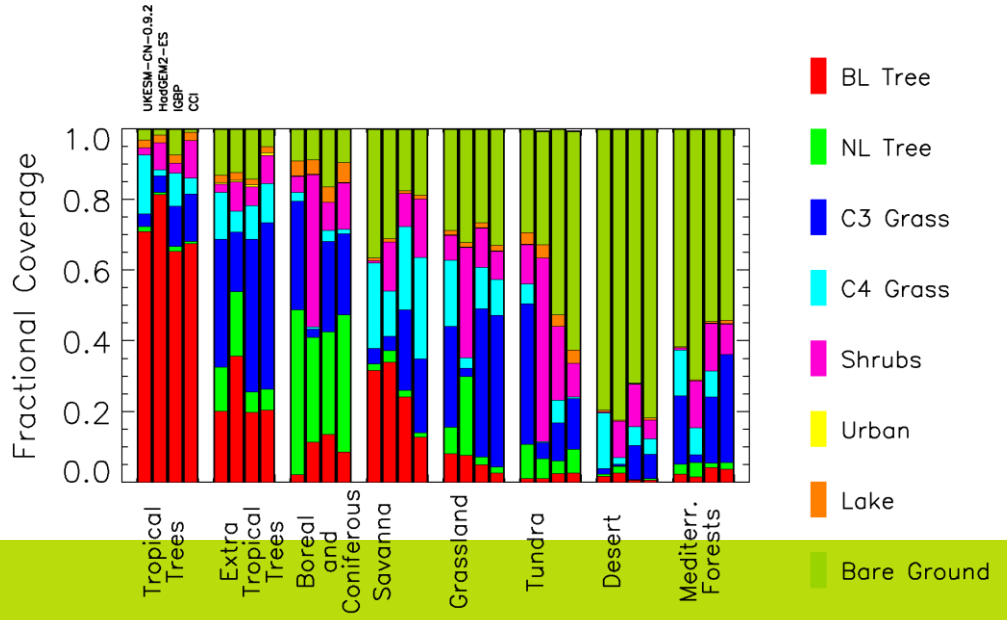
Huge number of people involved

- Alistair Sellar
- Chantelle Burton
- Chris Jones
- Doug Clark
- Doug Kelley
- Eleanor Burke
- Gerd Folberth
- Lina Mercado
- Peter Cox
- Pierre Friedlingstein
- Rich Ellis
- Sarah Chadburn
- Stephen Sitch
- T Davies-Barnard
- Sonke Zaehle (MPI)
- Stephanie Woodward

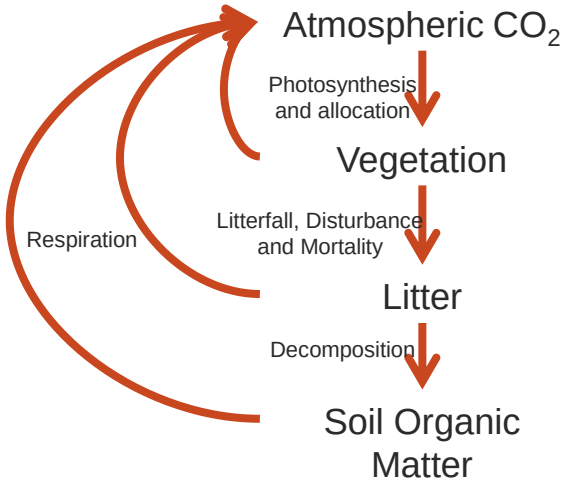
# JULES physiology

- Extended number of PFTs to 13 (5 trees, 2 shrubs, 2 grasses and 4 managed land classes)
  - Trait based physiology: parameterised based on huge datasets of measurements, classified in a way to capture the variation in functional trait
- Various improvements in Canopy processes, including a new canopy radiation module (CanRadMod 6)



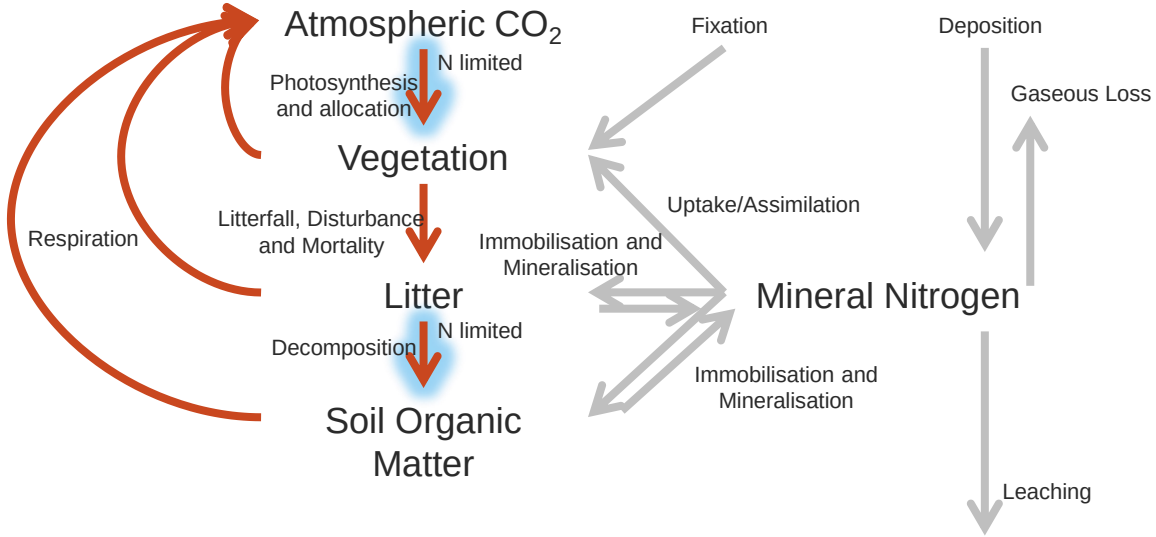



# New Nutrient Cycle




- TRIFFID Current Carbon Cycle Model
- Simulates Changes in Carbon Stores under Climate Change
- Missing the role of Nitrogen availability on carbon assimilation and turnover of soil carbon

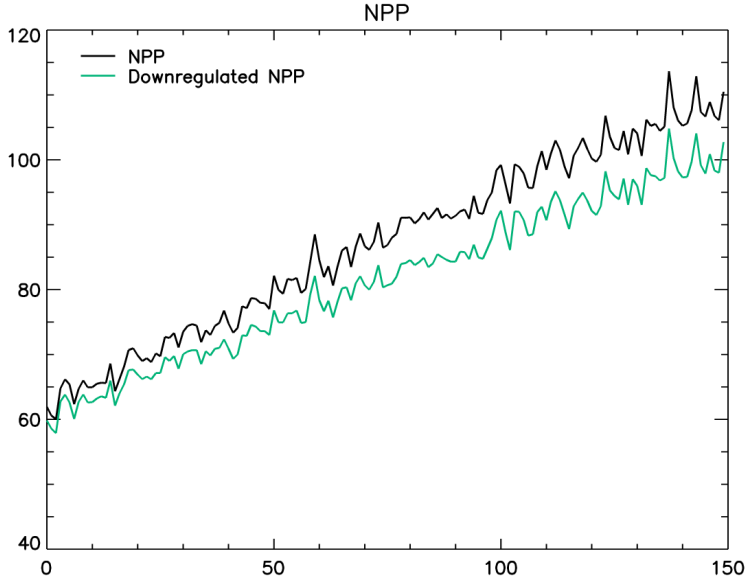
# Coupled Terrestrial Carbon-Nitrogen Cycle




- Extended to include terrestrial Nitrogen Cycle
- Availability of N limits assimilation of Carbon and Turnover of soil Carbon

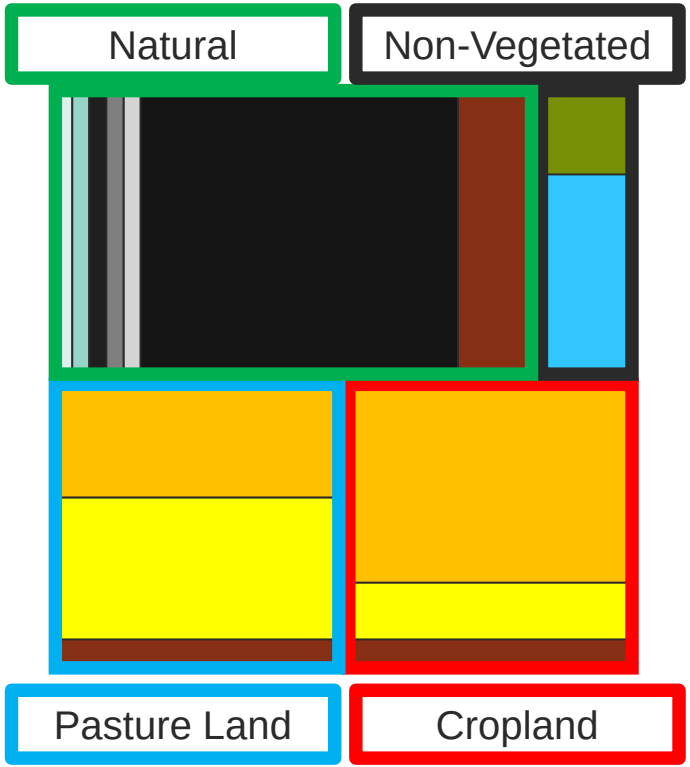
# Nitrogen Limitation

- Nitrogen in UKESM acts to modify the Carbon Use Efficiency – the fractional amount on acquired Carbon allocated to store (growth).




NPP is downregulated by approximately 10% at 4xCO2

# Land Use Scheme




*Schematic of sub-grid land surface tile areas in JULES-ES*

Non-ice grid-boxes can be considered as four “land units”:

- Non-vegetated: urban and lake tiles have constant areas
- Natural: 9 natural PFTs compete for space
- Cropland: 2 crop PFTs compete for space
- Pasture Land: 2 pasture PFTs compete for space

- PFT-competition does not result in total coverage. The sum of the uncovered areas in the three vegetated land units gives the area of the bare soil tile.
- When the area of a land unit is increased, the new area is initially bare soil and TRIFFID calculates the rate of expansion of PFTs into the newly available space.
- Crop harvest: 30% of crop PFT litter removed, preventing unrealistic accumulation of soil carbon. The crop harvest carbon flux does not affect vegetation structure or vegetation carbon.
- Perfect fertilizer application is assumed, where-by crop PFTs are not nitrogen-limited

Met Office

# Other developments

- New methane emission module
- BVOC emissions – new aerosol feedback in coupled model

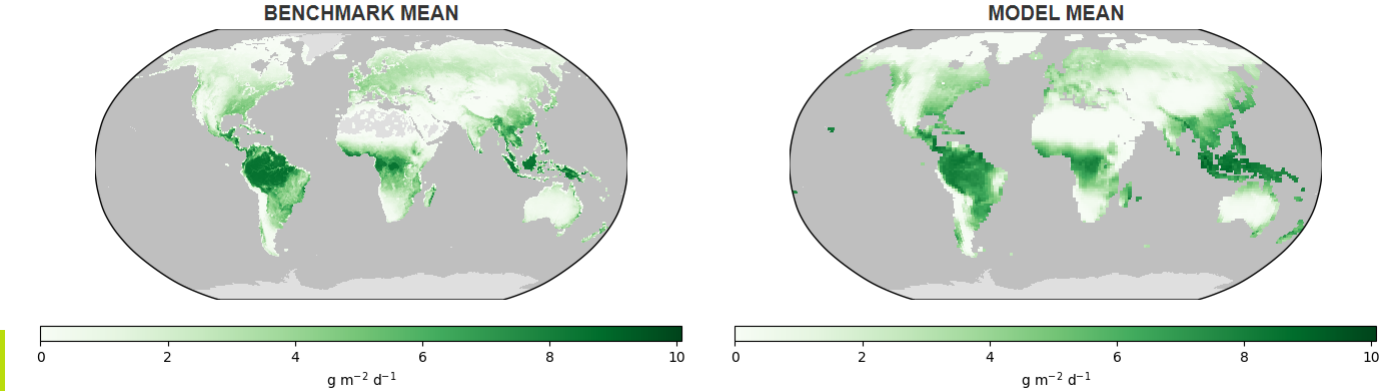
# What didn’t make it

- Interactive fire module (Chantelle Burton)
- Permafrost module (Eleanor Burke and Sarah Chadburn)
- Ozone damage

# GPP Benchmarking/Evaluation:

| | Download Data | Period Mean (original grids) [Pg yr-1] | Model Period Mean (intersection) [Pg yr-1] | Model Period Mean (complement) [Pg yr-1] | Benchmark Period Mean (intersection) [Pg yr-1] | Benchmark Period Mean (complement) [Pg yr-1] | Bias [g m-2 d-1] | RMSE [g m-2 d-1] | Phase Shift [months] | Bias Score [1] | RMSE Score [1] | Seasonal Cycle Score [1] | Spatial Distribution Score [1] | Overall Score [1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Benchmark | [-] | 119. | | | | | | | | | | | | |
| JULES-ES-1p0(u-aw650) | [-] | 124. | 123. | 27.7 | 118. | 0.623 | 0.108 | 1.44 | 1.18 | 0.50 | 0.39 | 0.81 | 0.95 | 0.61 |

Temporally integrated period mean

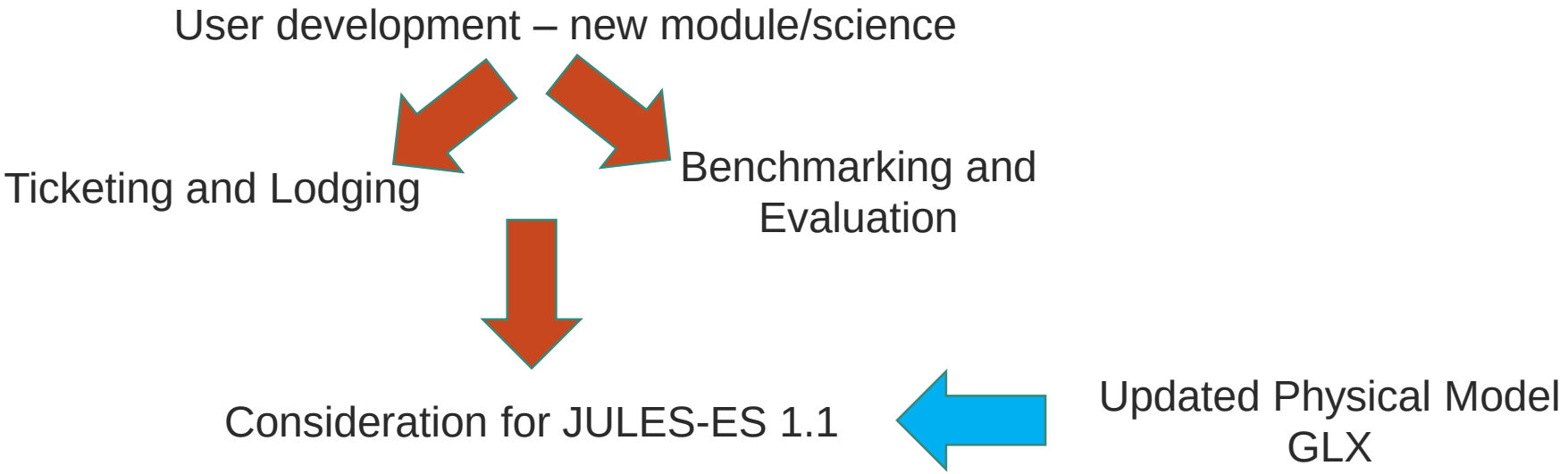


# Release Plans

- As part of JLMP the plan is that JULES-ES 1.0 will be released to the community in the coming months (waiting for freeze of UKESM1)
- It should be possible to:
  - check out the JULES-ES rose suite and submit either to the Met Office CRAY or JASMIN (both will have installed ancillaries and forcings).
  - In a secondary step produce ILAMB output
- JULES-ES 1.0 will be '***scientifically comparable***' between code releases – it therefore shouldn't matter which version of JULES you use. The answer should be the same.
  - This will be maintained for foreseeable code releases.

# Future development

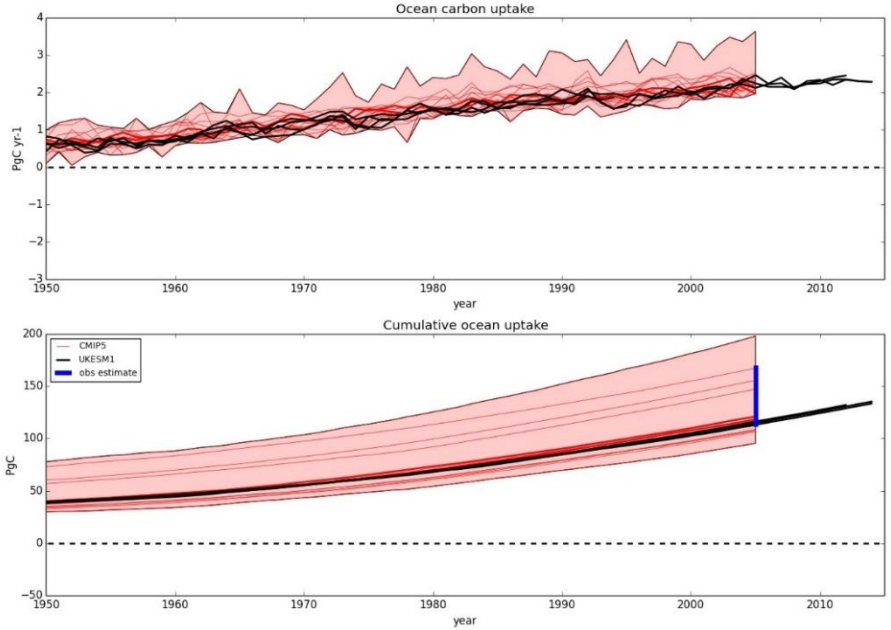
Future development will be open to the whole community, although there will be targeted development as well.



# Summary thoughts

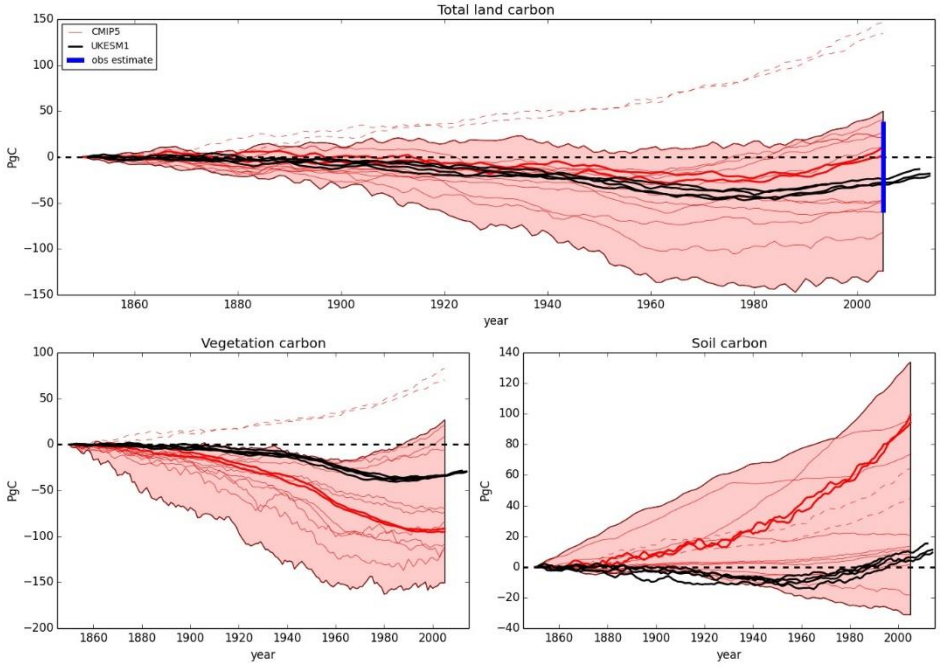
- JULES-ES is the biggest advance in terrestrial carbon cycling modelling since HadCM3C
- It would be great to build on this over the next years – potential to be truly world leading
- Doesn’t have to be just offline, opportunity to engage and use UKESM.
- Look out for the release and documentation papers coming soon

# Historical Scenario - C uptake : Ocean



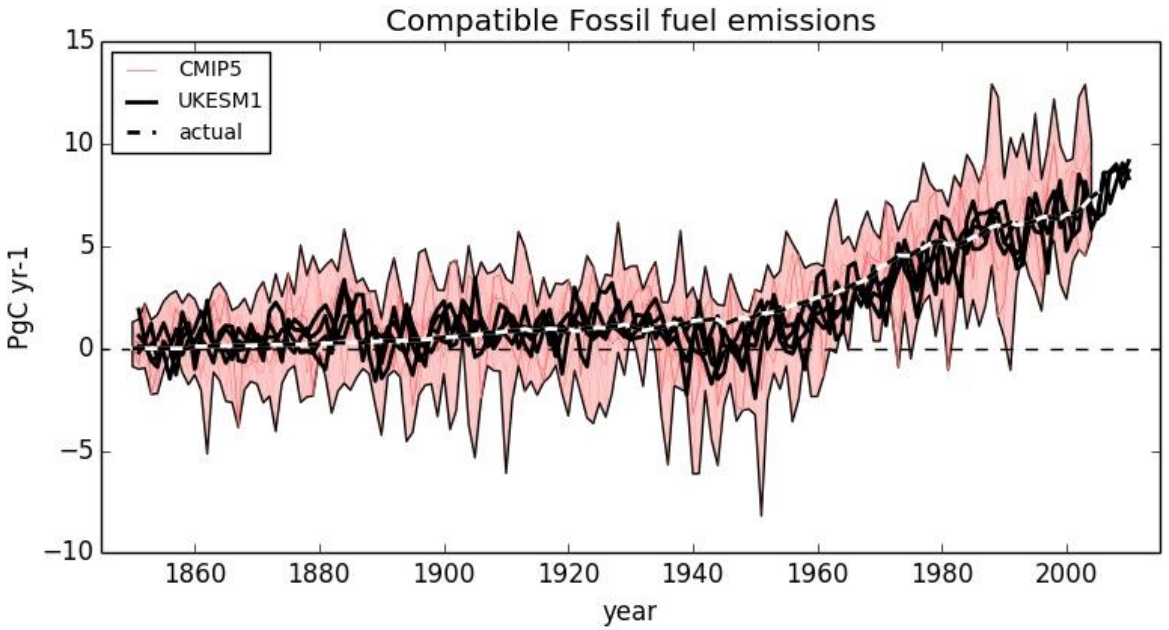

- The Ocean is important too!
- UKESM is incredibly similar to HadGEM2-ES.
- Ocean is towards lower end of observational estimates

# Historical Scenario - C uptake : Land




- Historical land carbon uptake is the net effect of two processes:
  - Land-use change: deforestation, regrowth
  - Climate and $CO_2$ impacts on undisturbed vegetation
- UKESM is doing a good job of getting the historical land sink within observational estimates

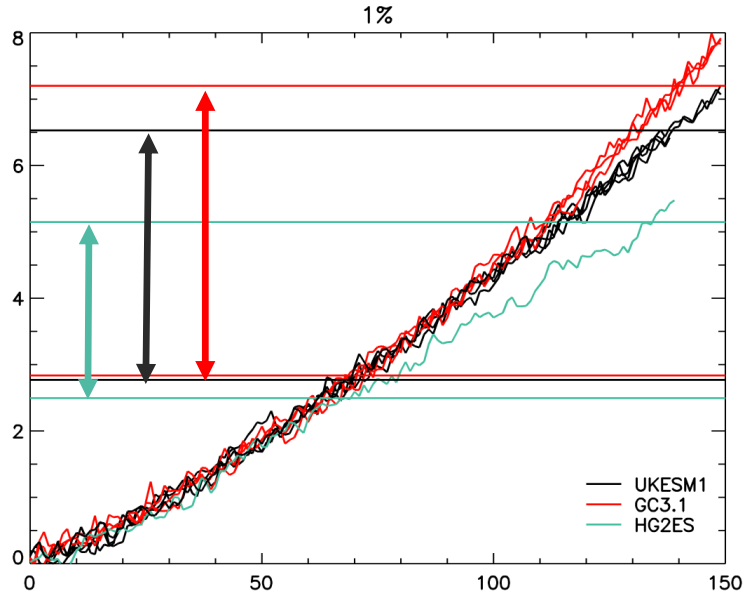
# Compatible Fossil Fuel Emissions




- Putting land and ocean sinks together allows us to work out what historical fossil fuel emissions would have been
- To use the model for carbon budget advice relies on us getting this right
- UKESM is doing a good job

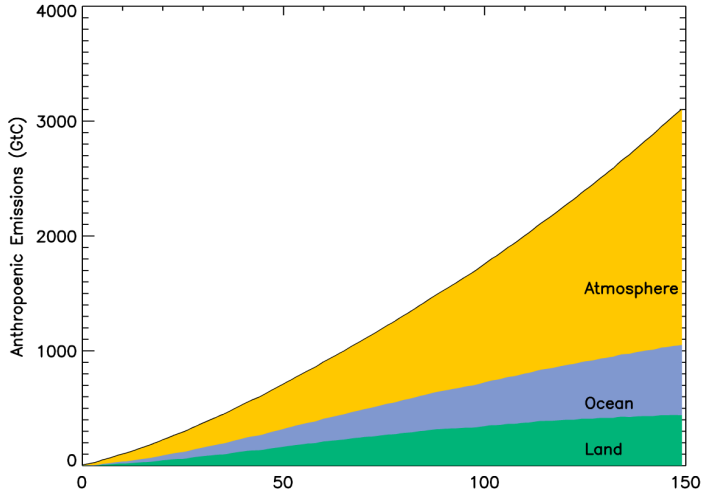
# Transient Climate Response

- Idealised 1% experiments
- UKESM has a TCR ~2.6K – slightly warmer than HadGEM2-ES and less than GC3.1
- However, the second doubling in UKESM is substantially larger than UKESM – indicating a stronger forcing/feedback combination in UKESM than HadGEM2-ES.



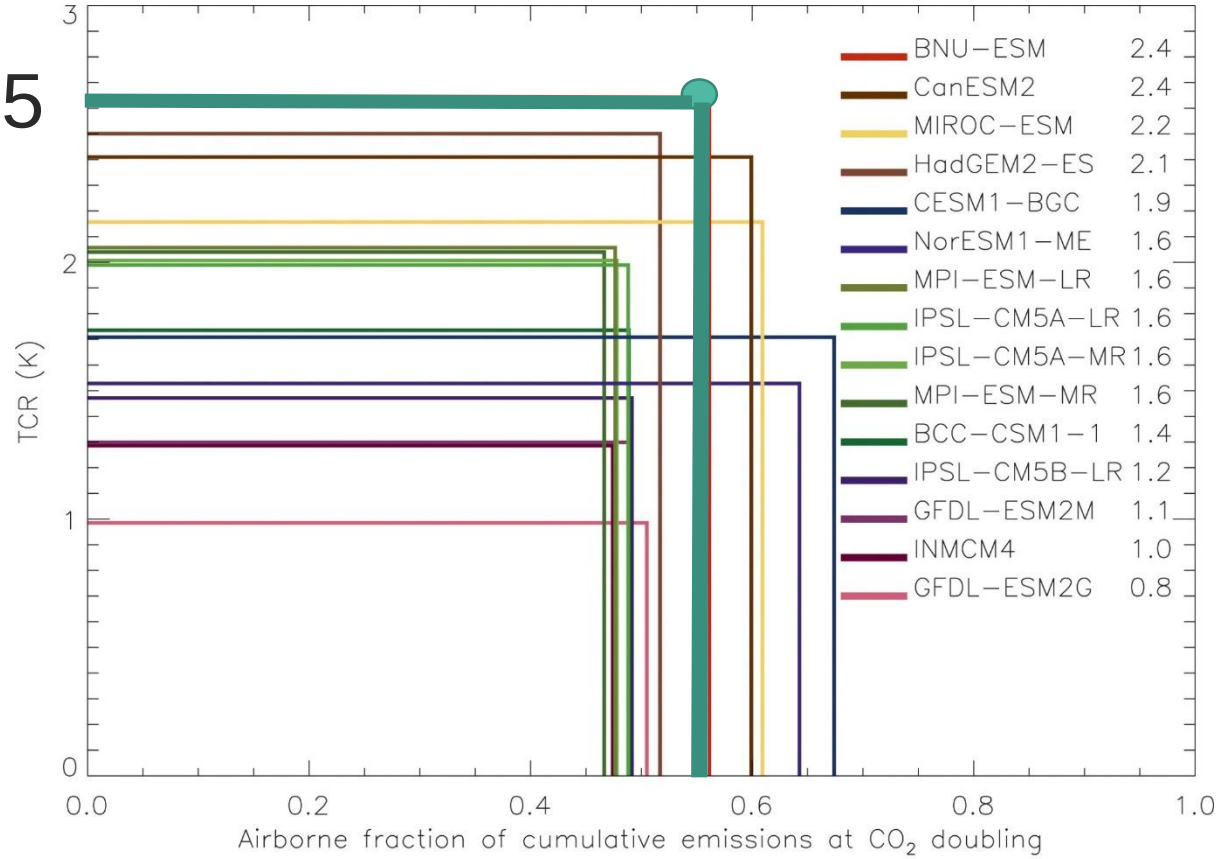
# Where does the Carbon go?

- Approximately, half of all emissions remain in the atmosphere – the other half is taken up by the land and oceans.
- However, under climate change the strength of the sink weakens. At 2xCO2 the airborne fraction (AF) is 55% at 4xCO2 AF is 62%
- This is mainly linked to the reduction in the land-borne fraction (LF) which reduces from 22% to 15%. This is partly related to the inclusion of Nitrogen nutrient limitation as well as other feedbacks in the model.



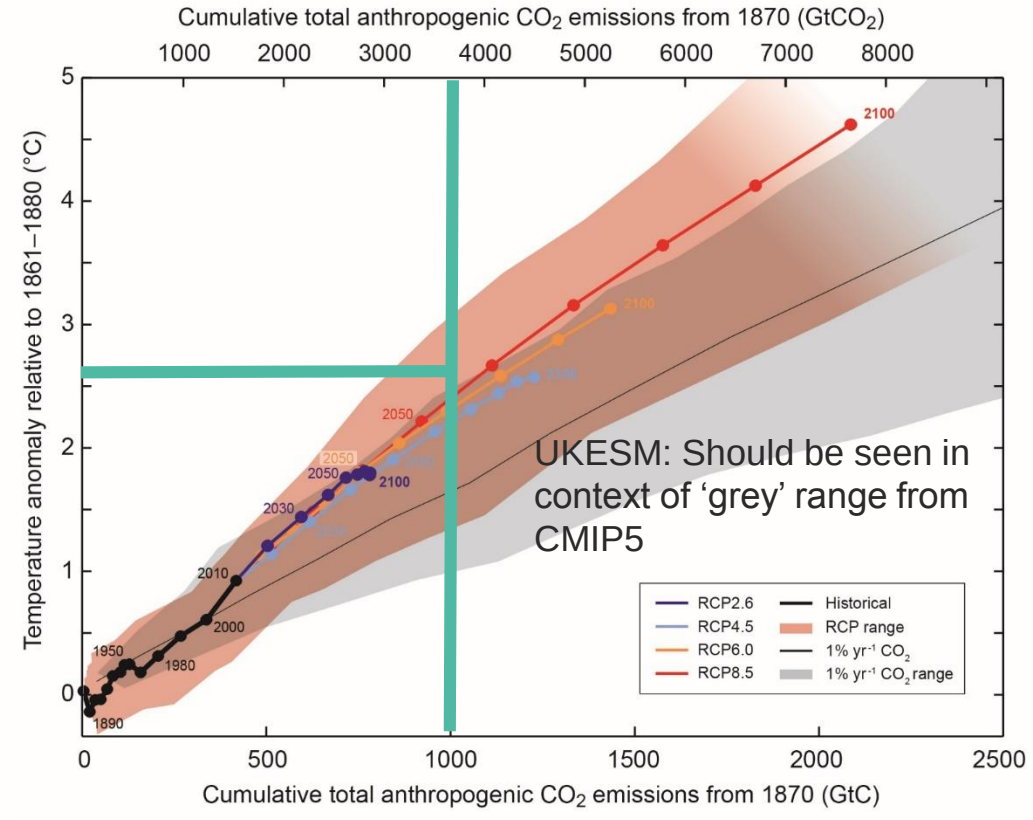
# UKESM cf. CMIP5

- UKESM has a high TCR – at the top end of CMIP5 models
- However, the AF is near the middle of the range.
- But what policy makers really want to know is how much warming is expected per unit emission accounting for Carbon Cycle feedbacks….



# TCRE

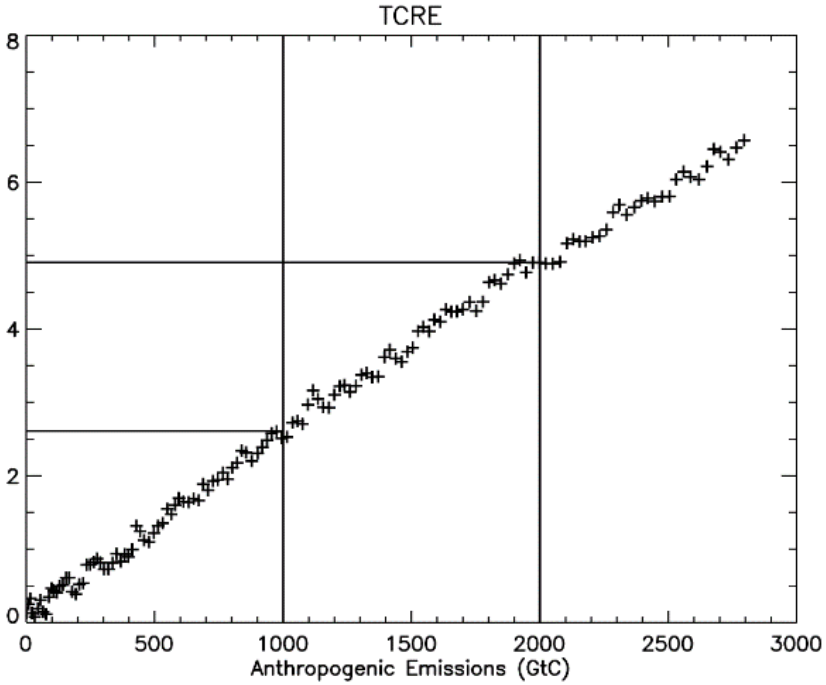
- … this is what is known as the Transient Climate Response to Emissions (TCRE). As standard is given as warming after 1000GtC of $CO_2$ emissions in a 1% per annum experiments.
- UKESM TCRE ~2.6 k/1000GtC
- HadGEM2-ES – 2.1
- UKESM is outside CMIP5 range primarily due to high TCR.



# TCRE

- Given the warming associated with the ‘second doubling’ is larger than the first does linearity in TCRE break down?

- No, warming at:
  - 1000GtC 2.6
  - 2000GtC 4.9



# Conclusions

- UKESM is a big step forward in modelling capability and provides a solid foundation for all future work.
- New functionality and process understanding built in particularly with the Nitrogen cycle.
- UKESM doing a job of capturing historical carbon budgets.
- Carbon cycle feedbacks are comparable with CMIP5. Ongoing work is quantifying these.
- UKESM has a moderately high TCRE compared with current estimates – a priority is constraining this number using observations and ‘emergent constraints’

# UKESM1 Terrestrial Biogeochemistry

- UKESM is a substantial upgrade relative to HadGEM2-ES.
  - Move to JULES rather than MOSES2.2 – although scientifically similar this was a massive technical change.
    - This provides the basis for ongoing developments from a common starting point.
  - Extended PFTs to 13 (5 trees, 2 shrubs, 2 grasses and 4 managed land classes)
    - Trait based physiology: parameterised based on huge datasets of measurements, classified in a way to capture the variation in functional trait
  - Various improvements in Canopy processes, including a new canopy radiation module
  - New interactive Nitrogen model downregulating growth during nutrient scarcity
  - New land-use scheme separating land-use into C3,C4 grasses for crops and pasture (see Eddy's poster).