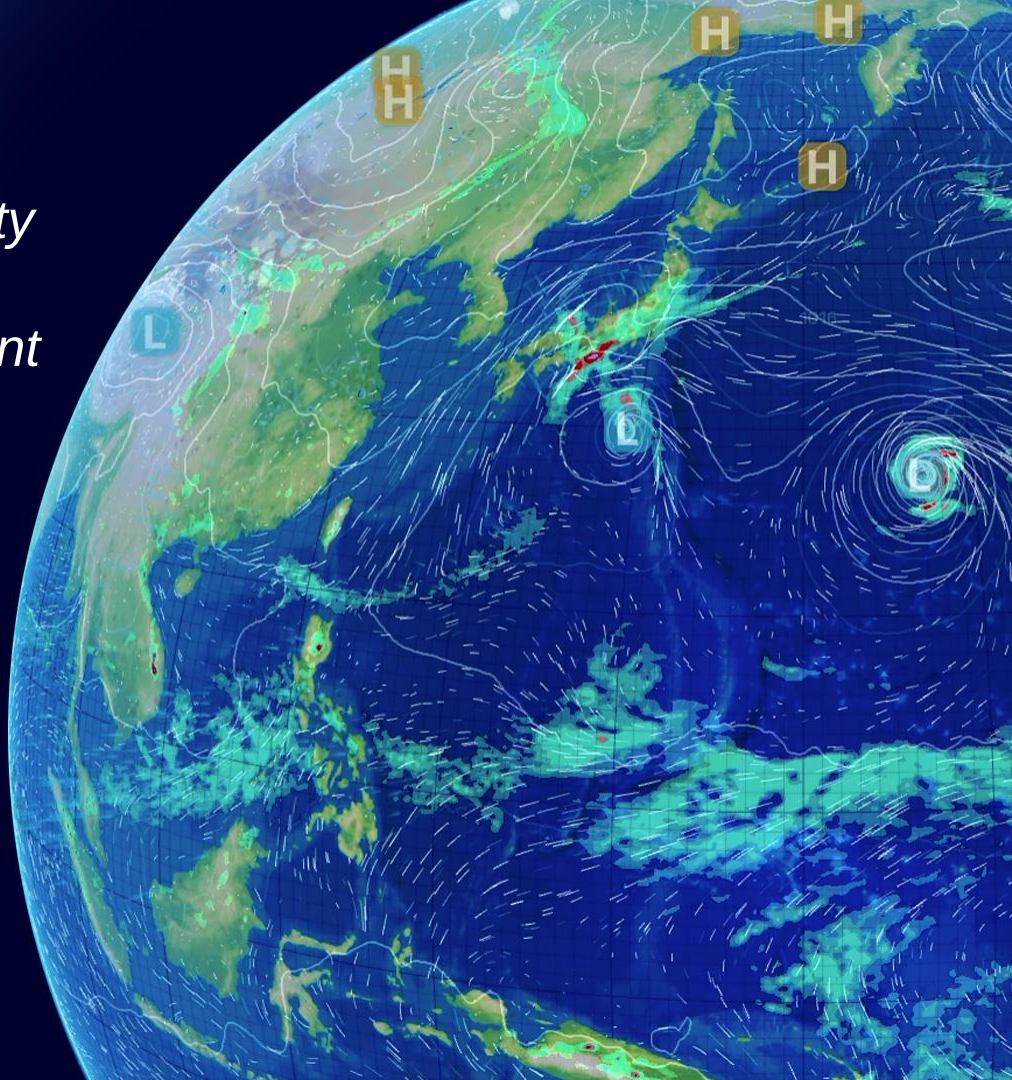
Met Office Hadley Centre

Quantifying process-level uncertainty contributions to TCRE and carbon budgets for meeting Paris Agreement climate targets



Chris Jones

CRESCENDO final GA

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www.c4mip.net

Contents

- IPCC AR5 introduced the concept of carbon budgets
  - The role of TCRE
  - SR15 framework for carbon budgets

- Carbon cycle feedbacks
  - Feedback metrics and uncertainty
  - CMIP6 vs CMIP5 results
  - Uncertainty – role of (partially) missing processes?

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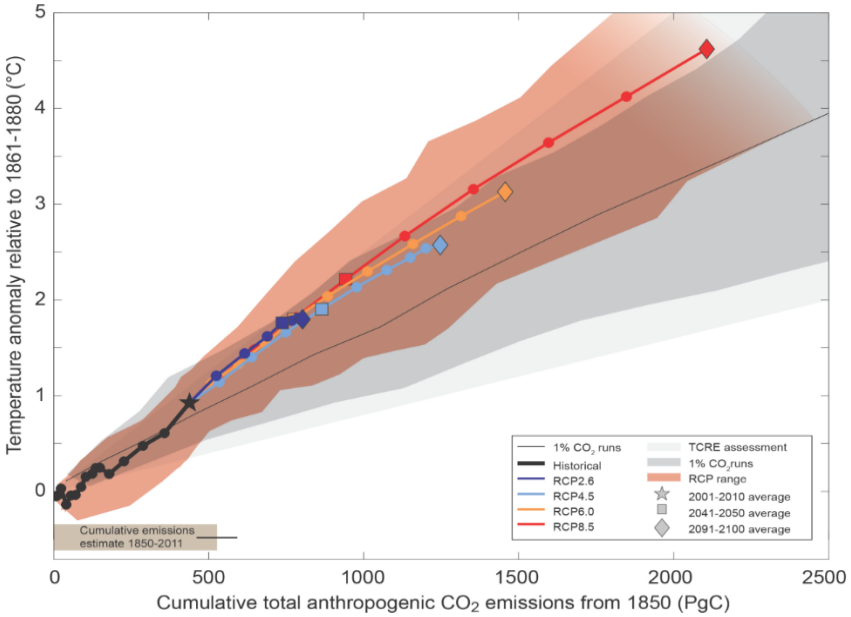
Total CO_2 emissions are strongly linked to total warming

- A key message from last IPCC report (AR5: 2013/14)
- Long-term warming is linearly related to total emissions of CO_2.
  - For a given warming target, higher emissions now imply lower emissions later.

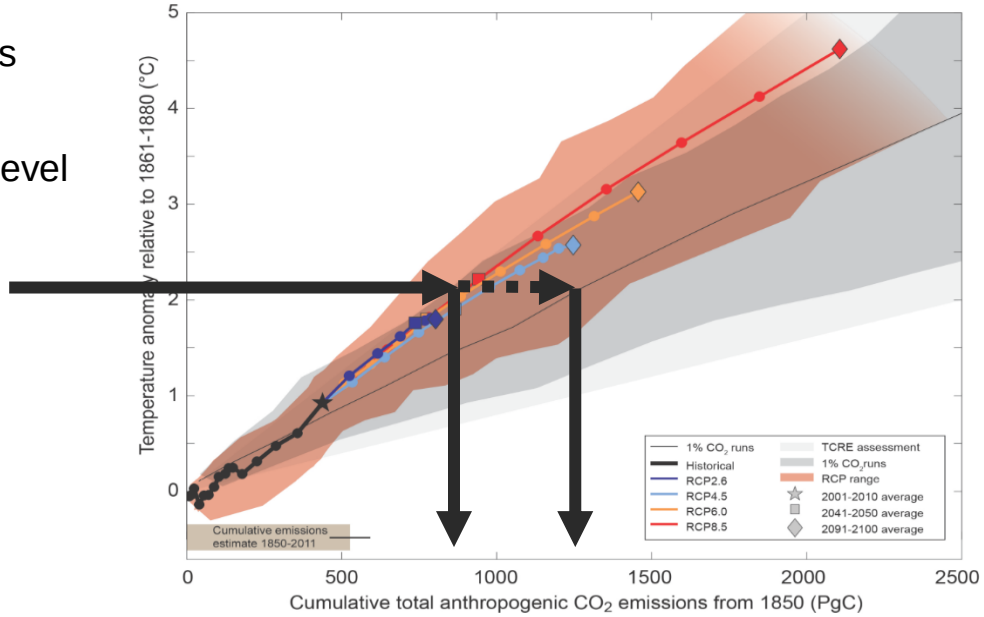


- Allows us to quantify exactly what we must do to meet targets
- Carbon “budget” we can spend
- Quantifying this drew together ***ALL*** of climate science into a single straight line!

TCRE: Transient Climate Response to cumulative carbon Emissions

Total CO_2 emissions are strongly linked to total warming

- But AR5 usage was fairly simplistic…
- Define a warming level
- Read off the total budget
- Subtract what's emitted already



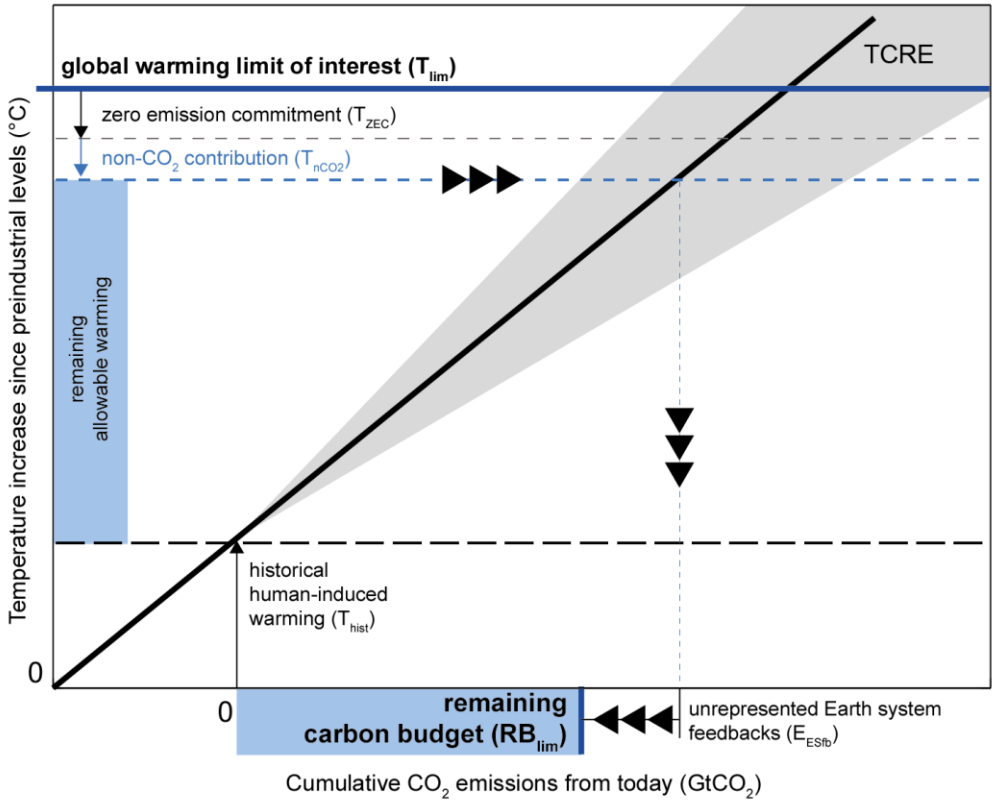
- No account taken of model errors/biases to date
- No account of climate variability
- Non-CO2 hard to consider
- No process understanding of where uncertainty comes from

TCRE: Transient Climate Response to cumulative carbon Emissions

The Remaining Carbon Budget Framework of the IPCC Special Report on Global Warming of 1.5°C

Five components:

- Historical warming to date
- Transient climate response to cumulative emissions of carbon dioxide (TCRE)
- Zero emission commitment (ZEC)
- Projected future non-CO_2 temperature contribution
- Unrepresented Earth system feedbacks



Rogelj et al., 2019

Carbon-cycle feedback metrics

- CO_2 affects climate:

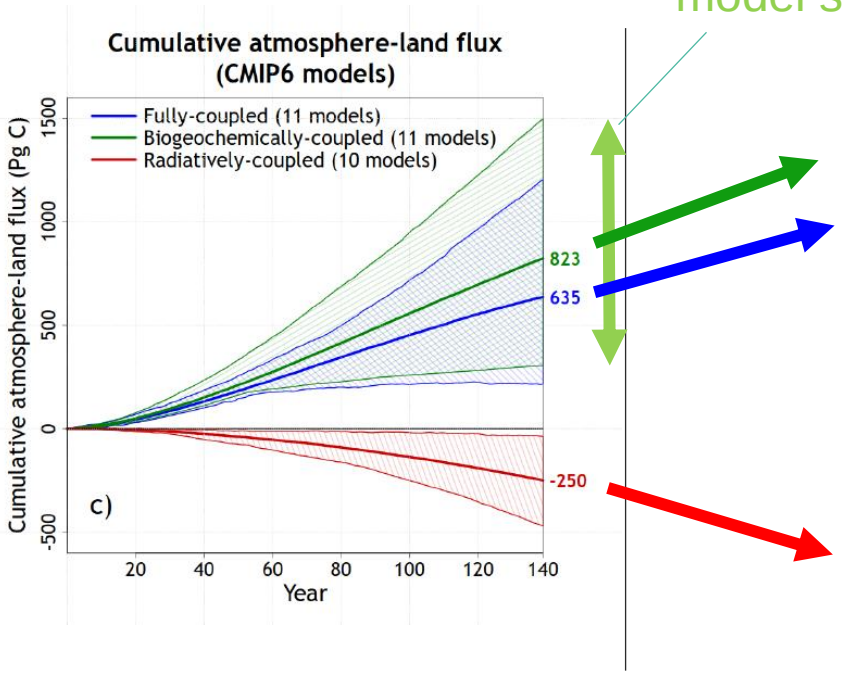
$$\Delta T = \alpha \Delta C_a$$

$$\Delta C = \beta \Delta C_a + \gamma \Delta T$$

- Carbon affected by CO_2 and Climate
- “COU” coupled runs vary both (CO_2 and climate)
- “BGC” biogeochemical runs – only vary CO_2, to diagnose beta

Carbon-cycle feedback metrics

Substantial model spread



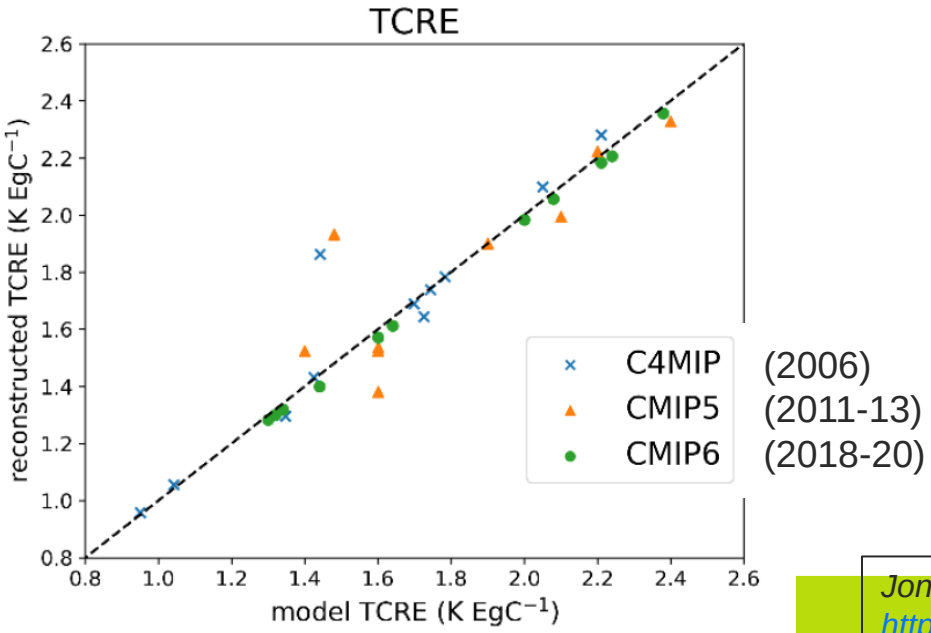
- Response to CO_2 (BGC) β
- Response to both (CO_2 and climate) (COU)
- Response to climate (RAD) γ

Arora et al., 2020

Using the feedback metrics

- TCRE can be calculated from the feedback metrics
- Airborne fraction determines how much CO2 stays in atmosphere, and TCRE brings in the climate response to this:

(k = unit conversion, 2.12 PgC/ppm)



$$AF = \frac{k}{k+\beta+\alpha\gamma}$$

$$TCRE = \frac{\alpha}{k+\beta+\alpha\gamma}$$

- Reconstructed quantities fit well

Jones & Friedlingstein, 2020, ERL
https://iopscience.iop.org/article/10.1088/1748-9326/ab858a

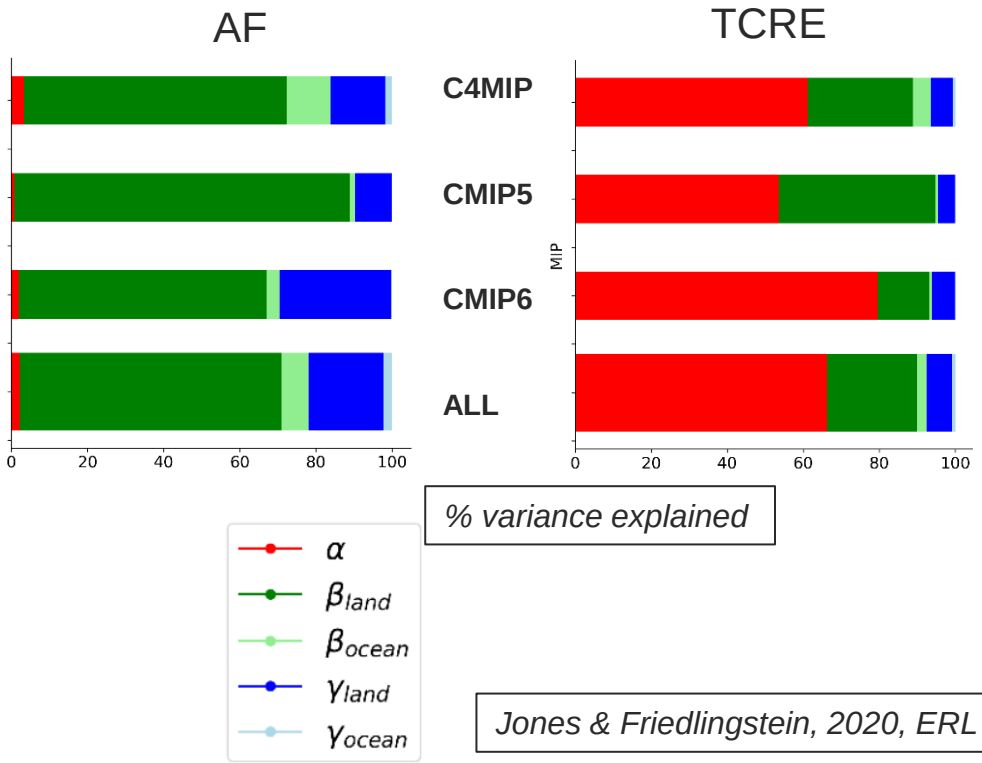
AF & TCRE: uncertainty

- This allows propagation of uncertainty from the feedback metrics to the quantity of interest

- **AF** – dominated by beta

- **TCRE** – jointly controlled by beta/alpha

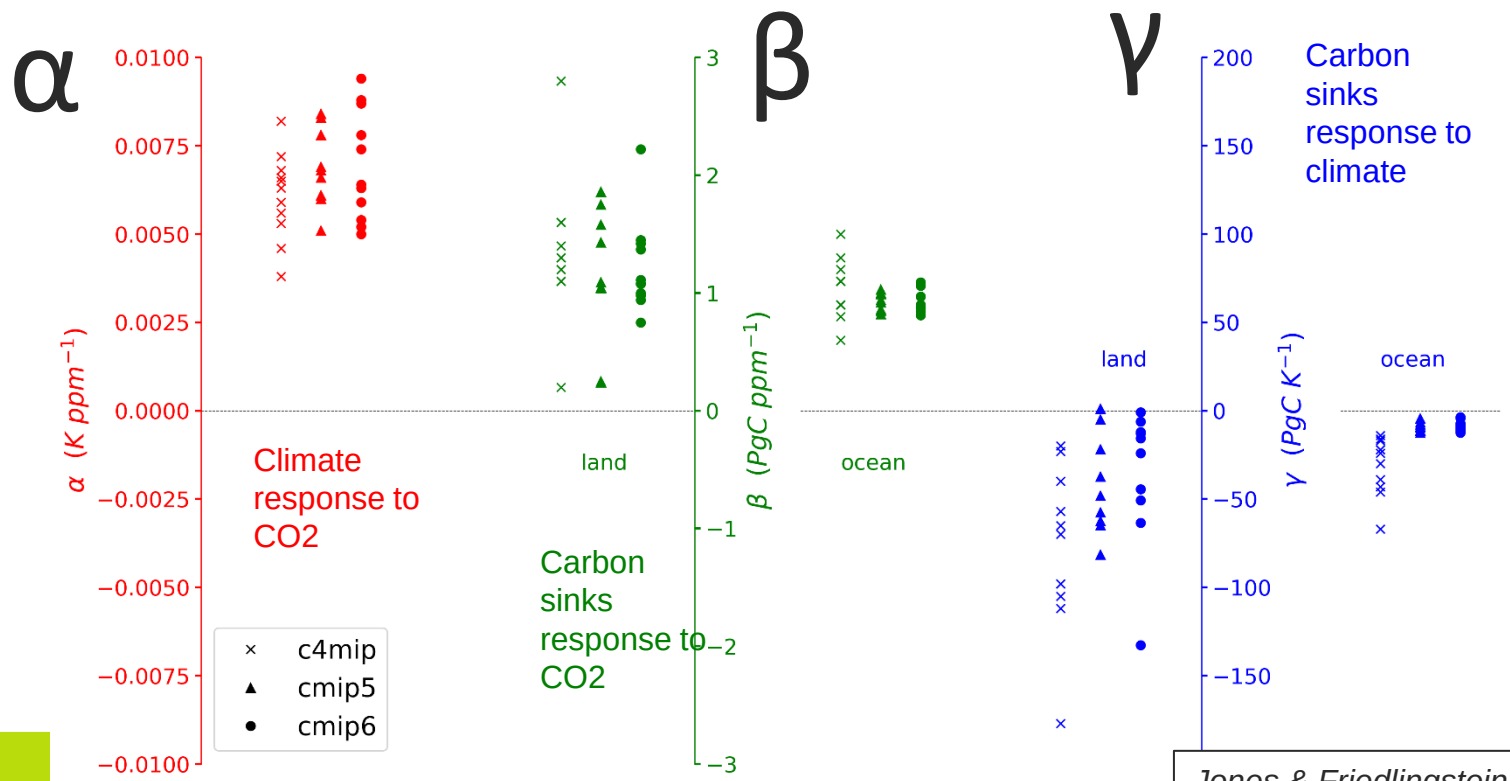
  - CMIP5: approx. 50:50 climate vs carbon cycle
  - CMIP6: move towards control by climate uncertainty



Jones & Friedlingstein, 2020, ERL

AF & TCRE: uncertainty

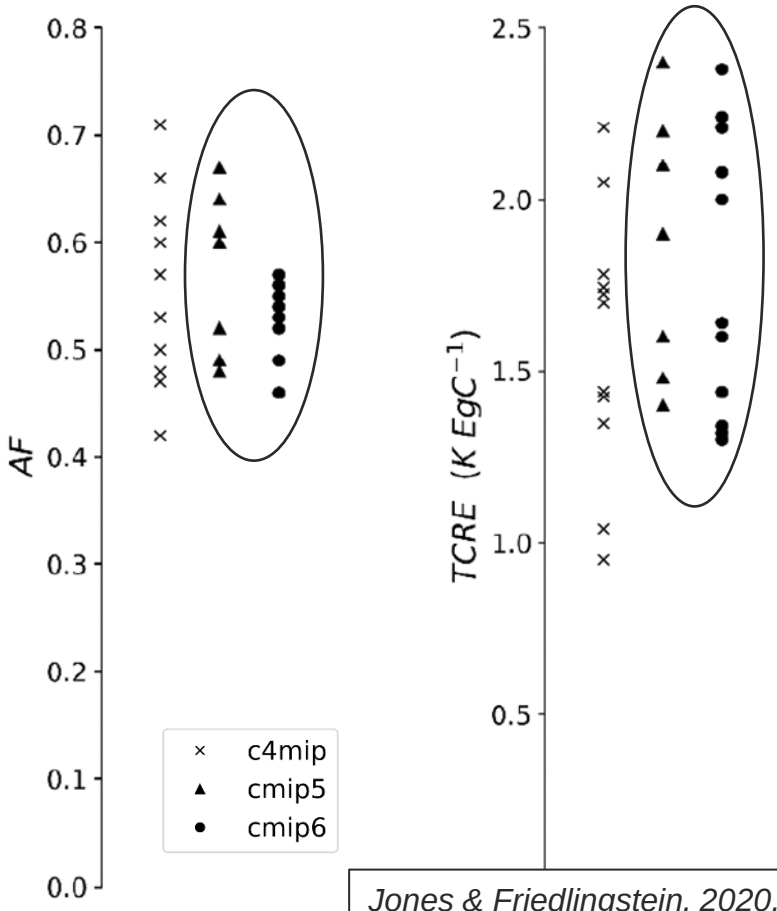
- This allows propagation of uncertainty in each term to the quantity of interest



Jones & Friedlingstein, 2020, ERL

AF & TCRE: uncertainty

- Now we can understand how CMIP6 differs from CMIP5
- **AF** – dominated by beta
  - CMIP6 spread <half of CMIP5
- **TCRE** – jointly controlled by beta/alpha
  - CMIP6 and CMIP5 very similar
    - mean and spread
  - But due to different combination in CMIP6 than CMIP5



Jones & Friedlingstein, 2020, ERL

C4MIP / ZECMIP synthesis

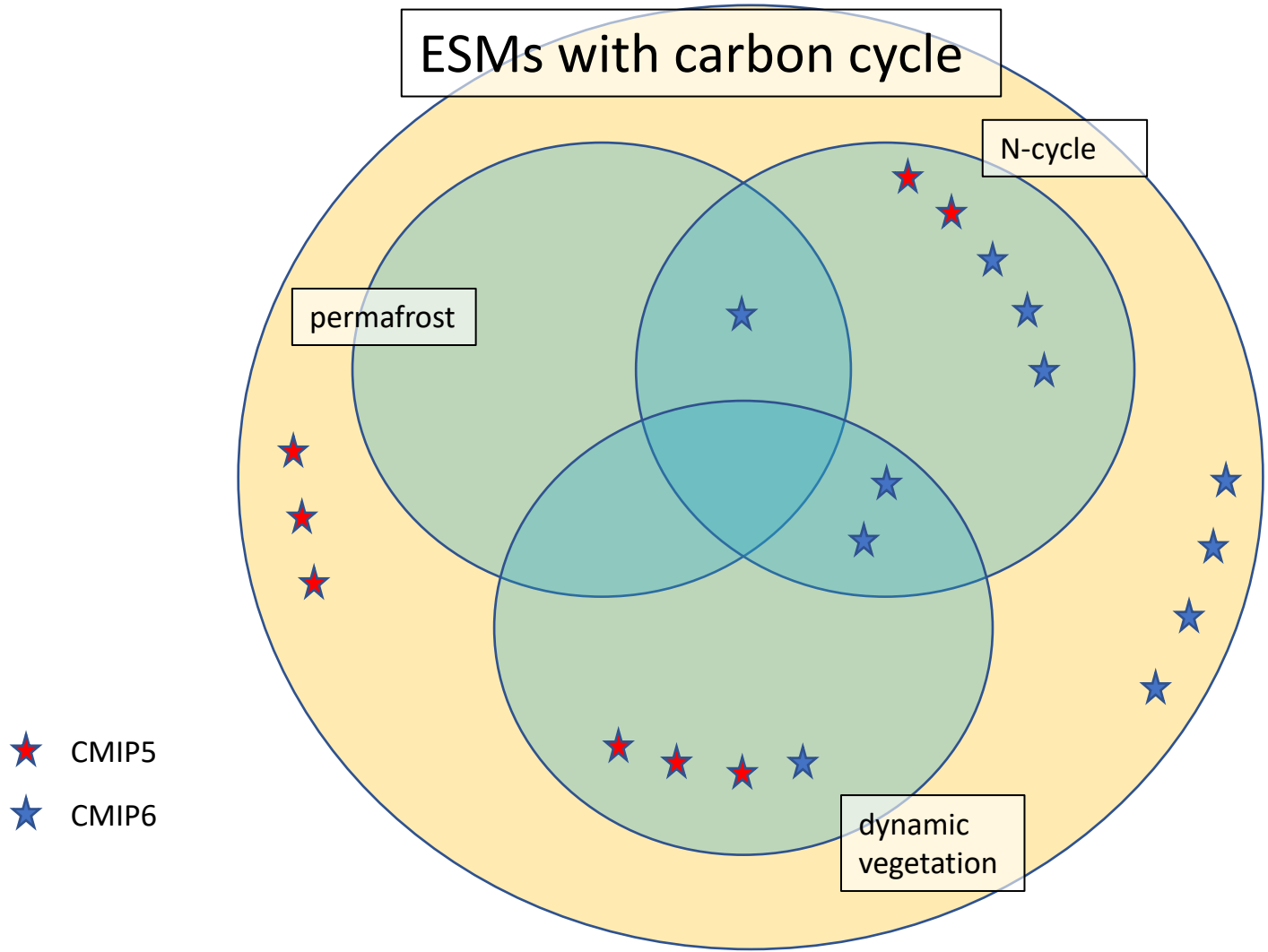
- So what does all this mean for carbon budgets?
- Three of the five components of SR15 carbon budgets:

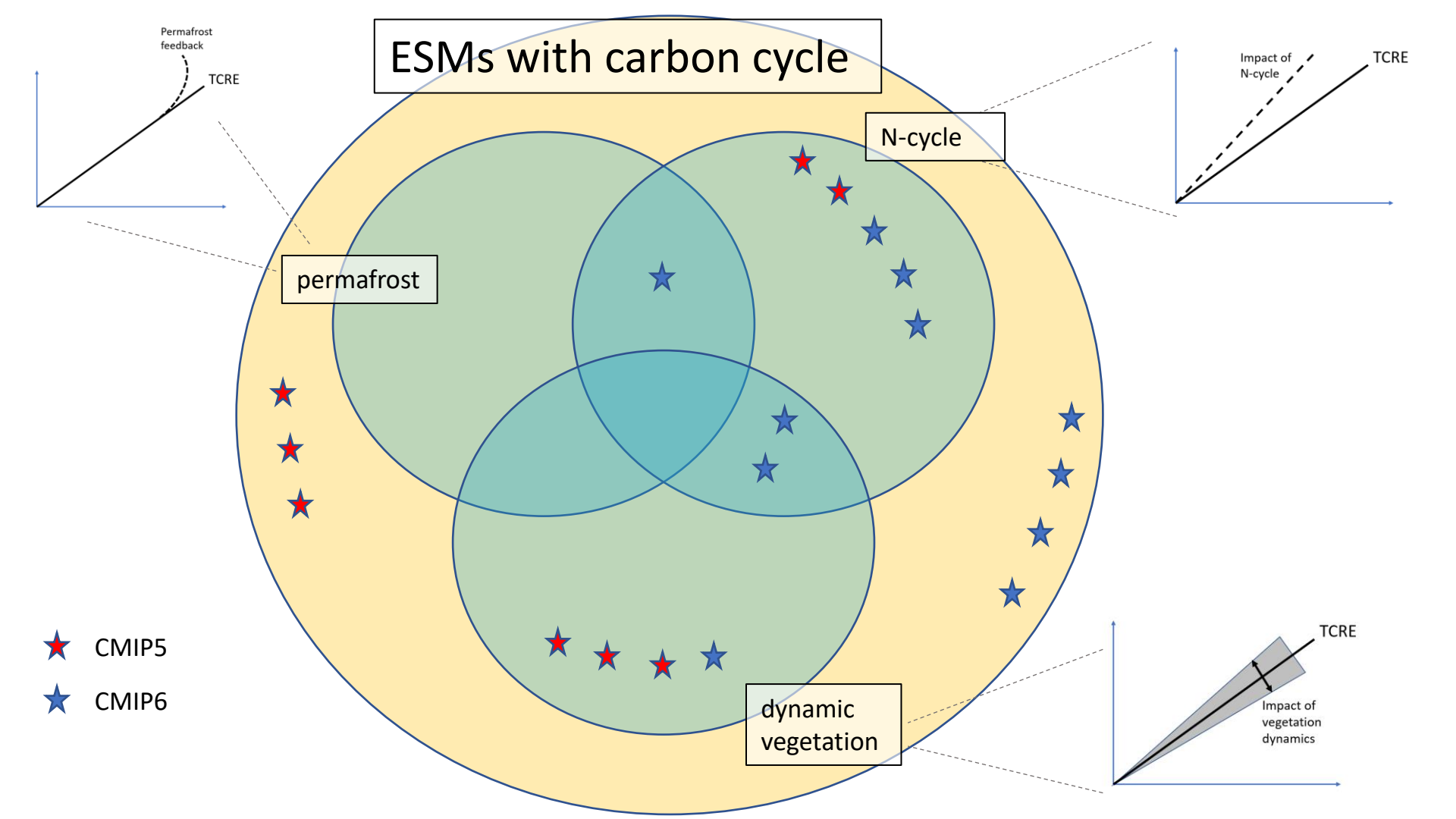
- ZEC ≈ 0
  - No change to our assumption, but now we can justify it
  - (Jones et al., 2019; MacDougall et al., 2020)

- TCRE
  - No change in TCRE magnitude or spread since CMIP5
  - BUT: change in _***source***_ of uncertainty
    - N-cycle has reduced spread in land-carbon, leaving greater role for climate response uncertainty

Next steps?

- SR15 framework includes adjustment for “un-represented processes”
  - But no treatment of mixed-complexity (“partially included processes”) in carbon budgets framework
  - What to do if half models have N-cycle and half don’t?
  - Can we do model-by-model adjustment for which processes it includes?
  - Role of emergent constraints?


ESMs with carbon cycle
N-cycle
permafrost
dynamic vegetation
CMIP5
CMIP6


ESMs with carbon cycle
Permafrost feedback
TCRE
permafrost
N-cycle
Impact of N-cycle
TCRE
dynamic vegetation
TCRE
Impact of vegetation dynamics
CMIP5
CMIP6

Concluding comments

- CMIP6 marks 3rd generation of coupled climate-carbon cycle ESMs
- Headline numbers not hugely different from CMIP5…
- BUT – there has been progress
  - Confirmation of ZEC=0, and understanding of mechanisms
  - Increased complexity (N-cycle) in land models has led to reduced spread of response
  - TCRE uncertainty now more controlled by climate sensitivity than carbon cycle feedbacks
- Need to be able to account for mixed-complexity ensembles

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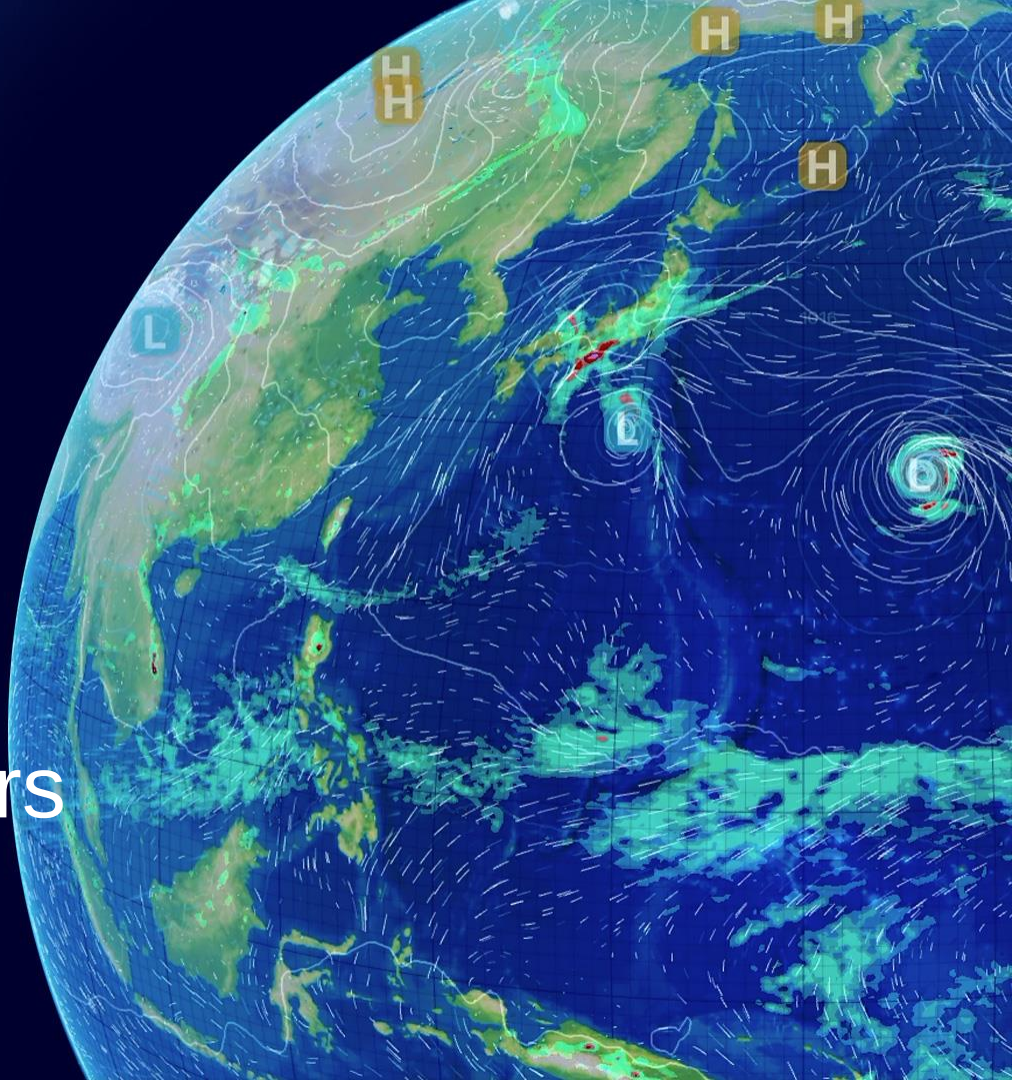
Questions and Answers



references

- C4MIP feedback definitions
  - Friedlingstein et al., 2006: https://journals.ametsoc.org/view/journals/clim/19/14/jcli3800.1.xml
- C4MIP experiments for CMIP6
  - Jones et al., 2016: https://gmd.copernicus.org/articles/9/2853/2016/
- CMIP5 and CMIP6 feedback results
  - Arora et al., 2013: https://journals.ametsoc.org/view/journals/clim/26/15/jcli-d-12-00494.1.xml
  - Arora et al., 2020: https://bg.copernicus.org/articles/17/4173/2020/
- TCRE uncertainty components (this talk)
  - Jones & Friedlingstein, 2020: https://iopscience.iop.org/article/10.1088/1748-9326/ab858a
- Zero Emissions Commitment (ZECMIP)
  - Jones et al., 2019: https://gmd.copernicus.org/articles/12/4375/2019/
  - MacDougall et al., 2020: https://bg.copernicus.org/articles/17/2987/2020/