Terrestrial Nitrogen cycle in JULES and it's impact in CMIP6

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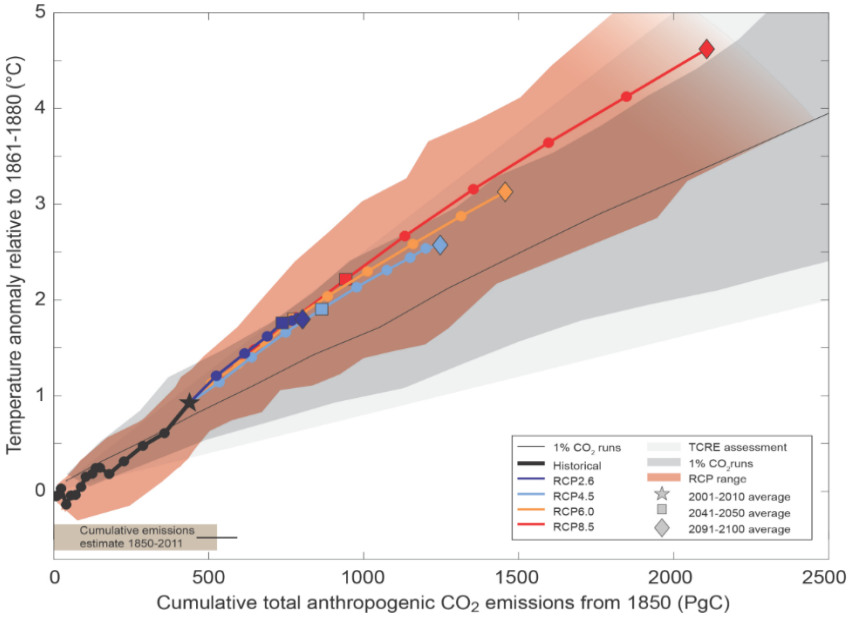
Contents

- Importance of N-cycle and it’s omission in land models

- N-cycle in JULES
  - structure
  - evaluation
- Impact in CMIP6
  - ESM complexity
  - Impact on feedbacks and carbon sinks

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.

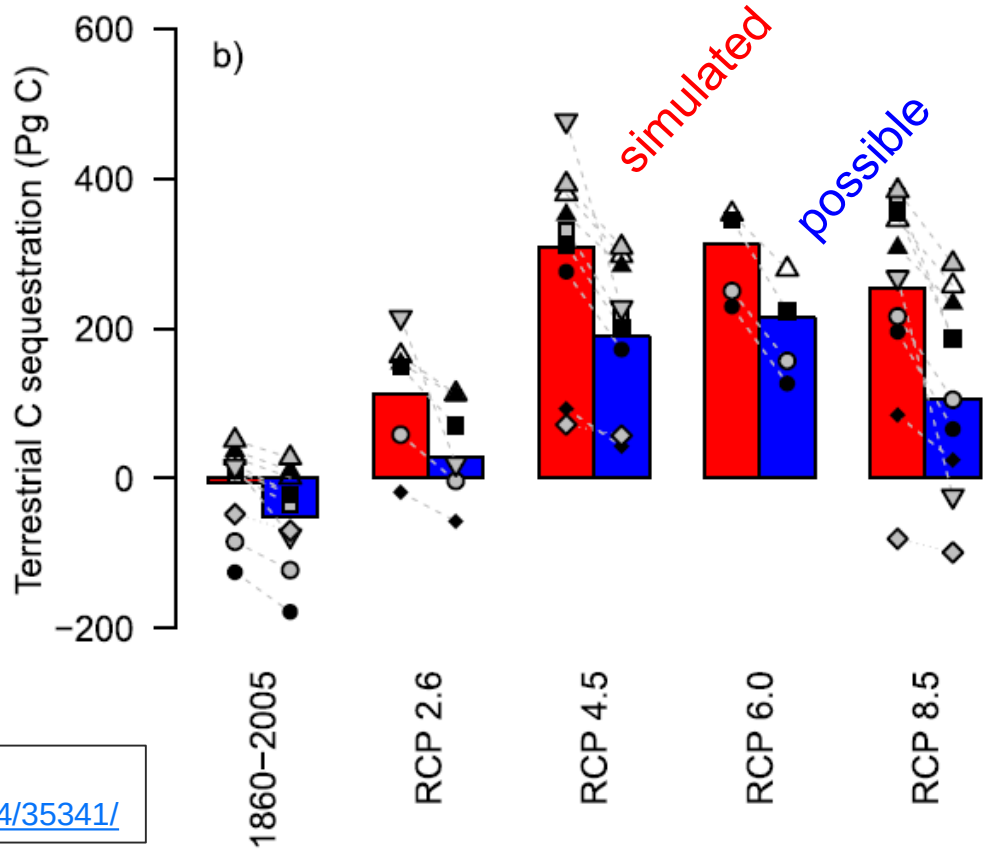


- Allows us to quantify exactly what we must do to meet targets
- Carbon “budget” we can spend
- Quantifying this drew together ***ALL*** of climate science into a single straight line!

TCRE: Transient Climate Response to cumulative carbon Emissions

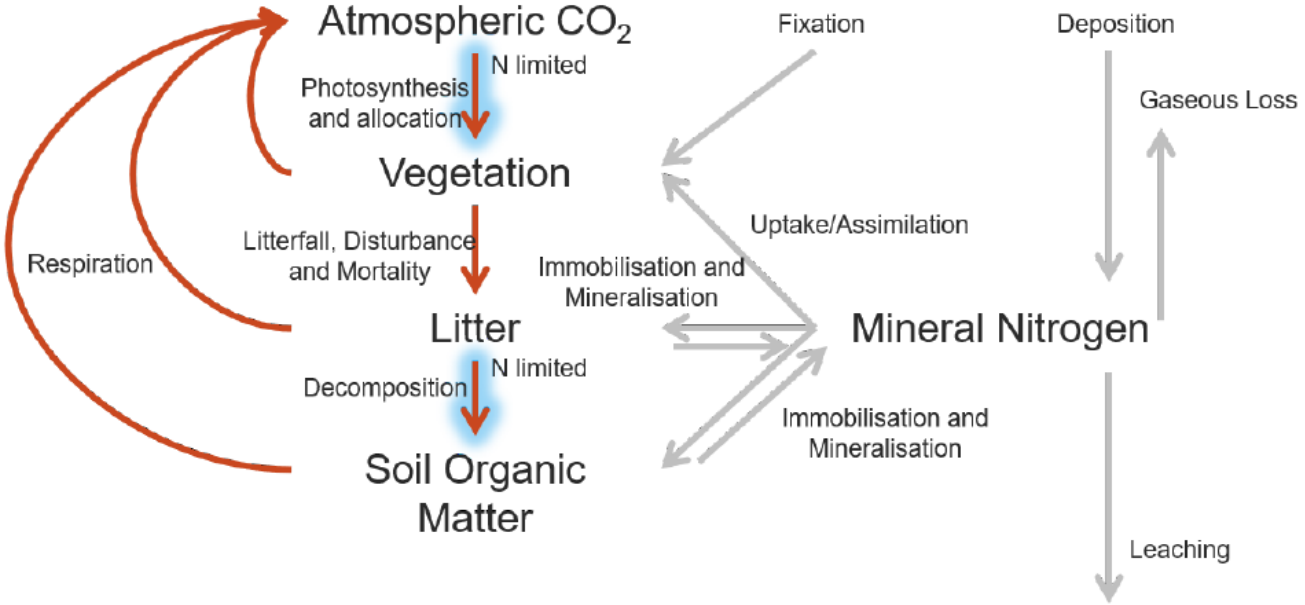
BUT… almost all models drastically over-estimated land carbon sinks

- Only one land-surface scheme in CMIP5 had N-cycle
- All other models simulated land carbon uptake much bigger than is physically possible
  - 100 PgC over 21st century
- Therefore our link from emissions to climate change is biased low* (all other aspects being correct)
  - In which case, we must cut emissions faster and sooner



Zaehle et al., 2014. J. Clim.,
https://journals.ametsoc.org/jcli/article/28/6/2494/35341/

JULES-CN structure



Designed from outset to be built on top of JULES carbon structure

Figure 1. Schematic of the nitrogen cycling within the JULES-CN model. Carbon fluxes are shown in red, Nitrogen fluxes in grey. Nitrogen limited carbon fluxes are highlighted in blue.

Wiltshire et al., 2020. GMDD, https://gmd.copernicus.org/preprints/gmd-2020-205/

JULES CN structure

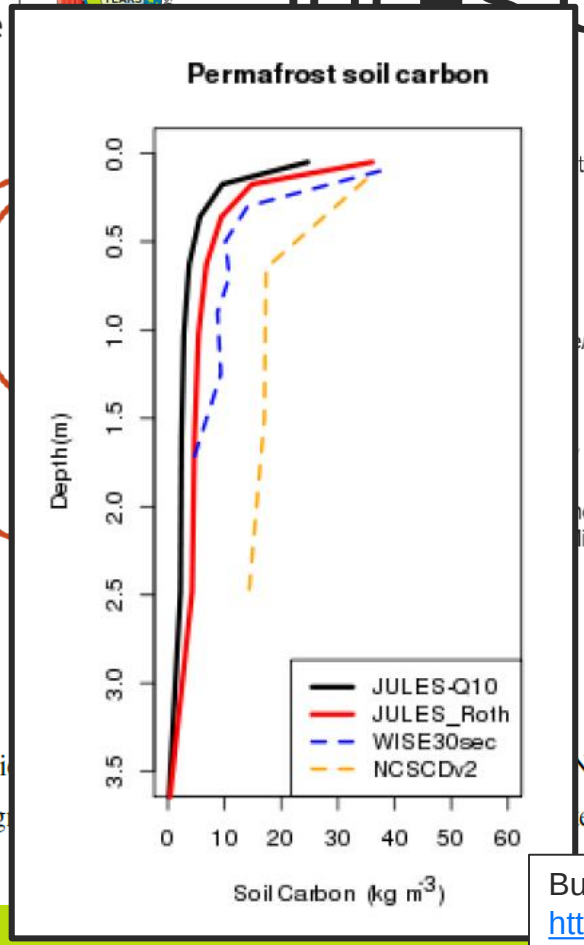


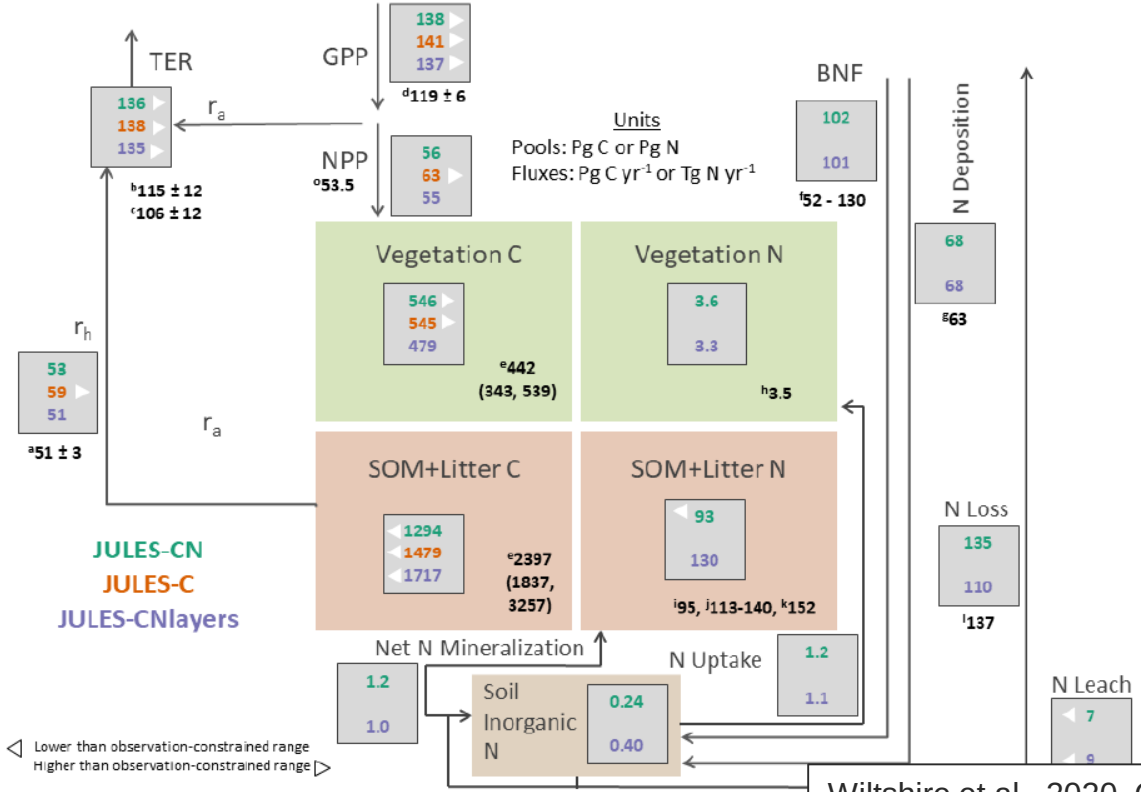
Figure 1. Schemati N model. Carbon fluxes are shown in red, Nitrogen fluxes in g ed in blue.

Designed from outset to be built on top of JULES carbon structure

Also implemented to be consistent with layered soil carbon /biogeochemistry

Burke et al., 2017. GMD, https://gmd.copernicus.org/articles/10/959/2017/

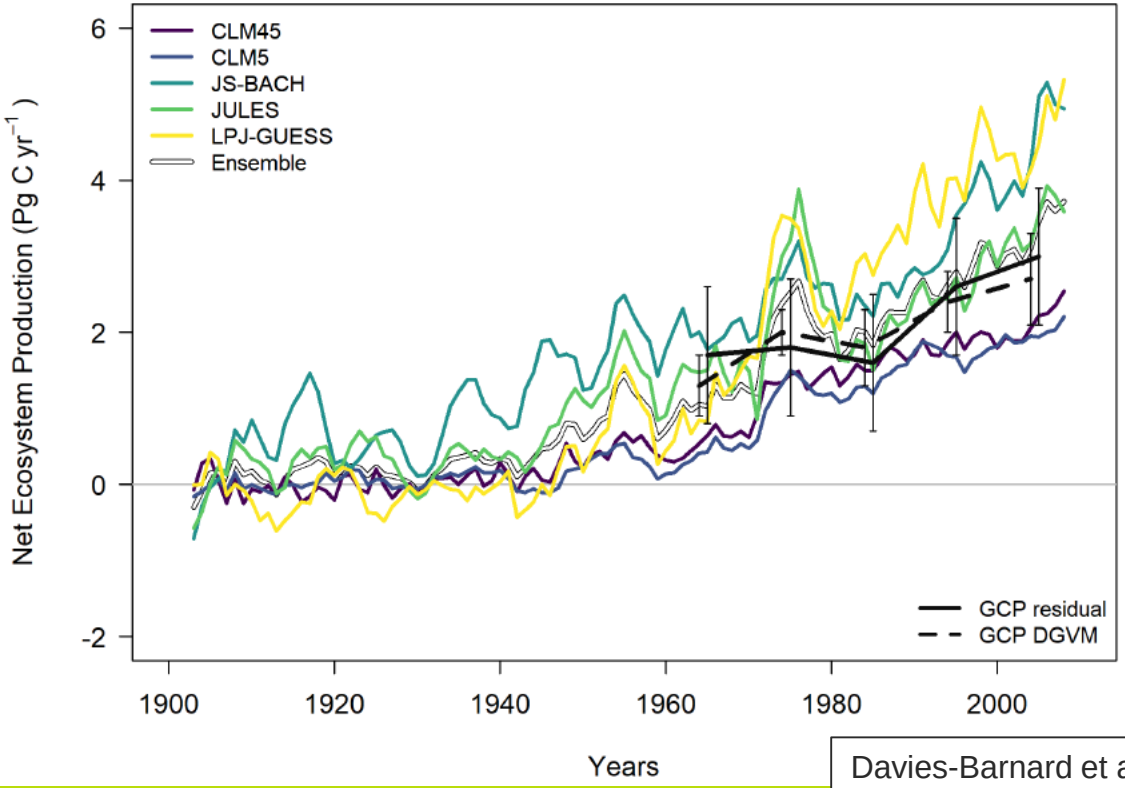
JULES-CN stocks and flows



C and N pools and fluxes compared with observational estimates

Wiltshire et al., 2020. GMDD, https://gmd.copernicus.org/preprints/gmd-2020-205/

Evaluation vs other LSMs

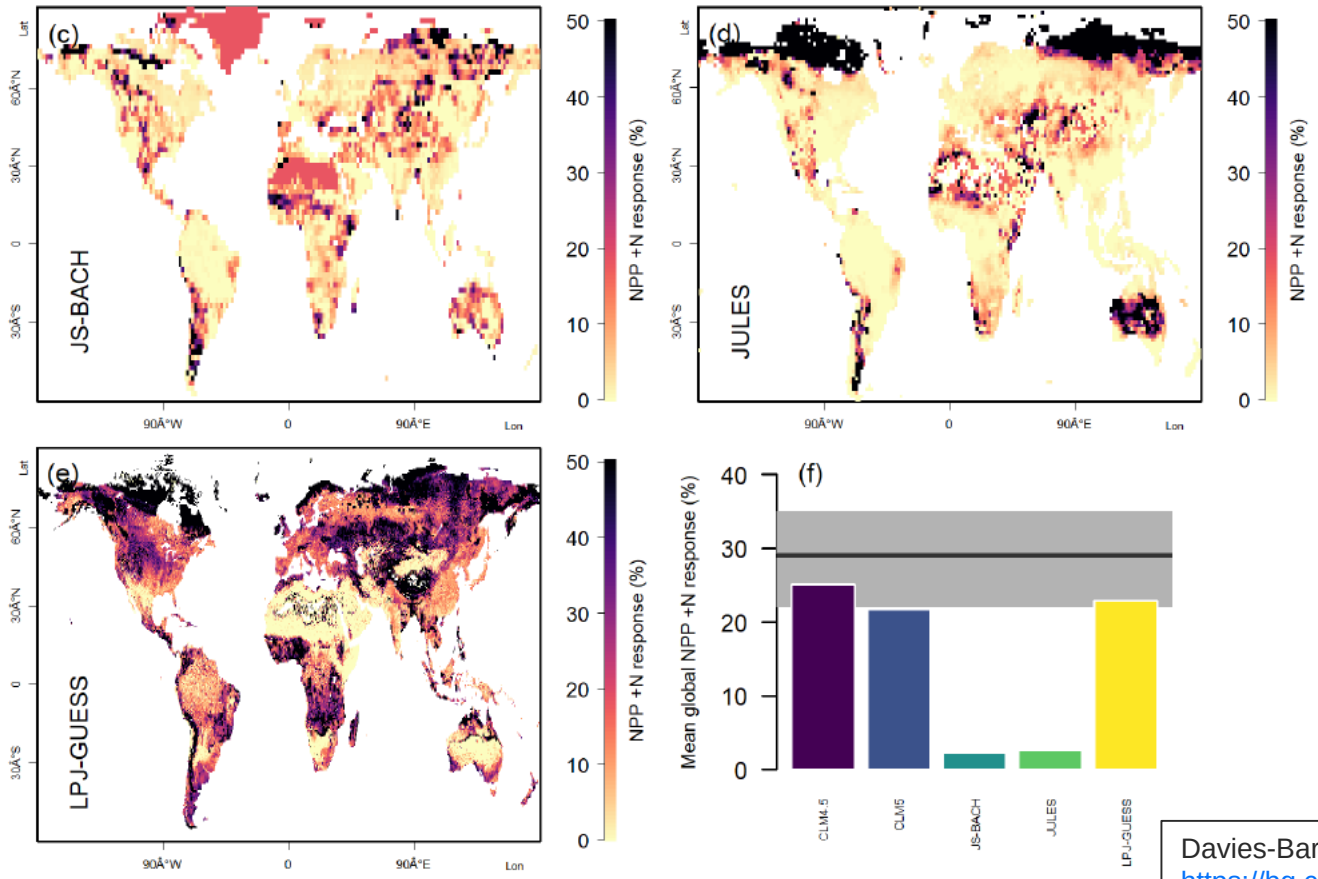


CRESCENDO EU project
5 EU land models from CMIP ESMs

JULES is good at 20th century land-carbon uptake

Davies-Barnard et al., 2020. BG (accepted), https://bg.copernicus.org/preprints/bg-2019-513/

Evaluation vs other LSMs

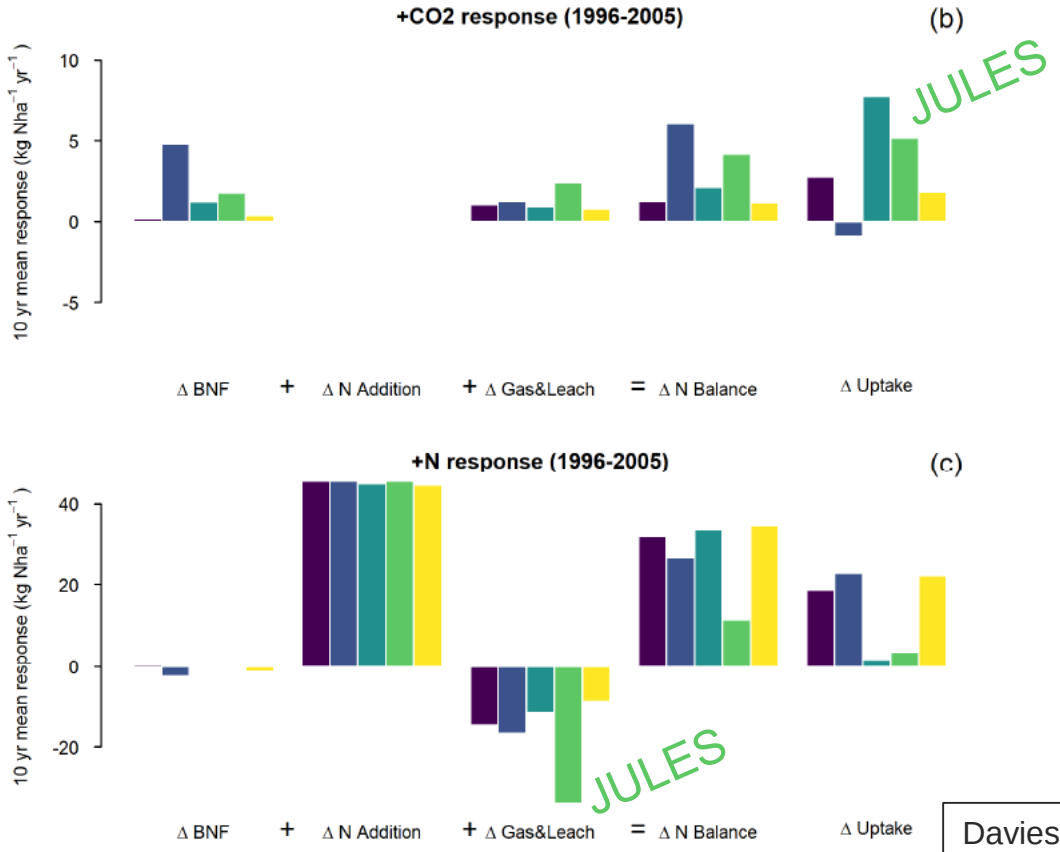


CRESCENDO EU project
5 EU land models from CMIP ESMs

JULES is less good at carbon uptake (here NPP) response to adding Nitrogen

Davies-Barnard et al., 2020. BG (accepted), https://bg.copernicus.org/preprints/bg-2019-513/

Process comparison with other LSMs



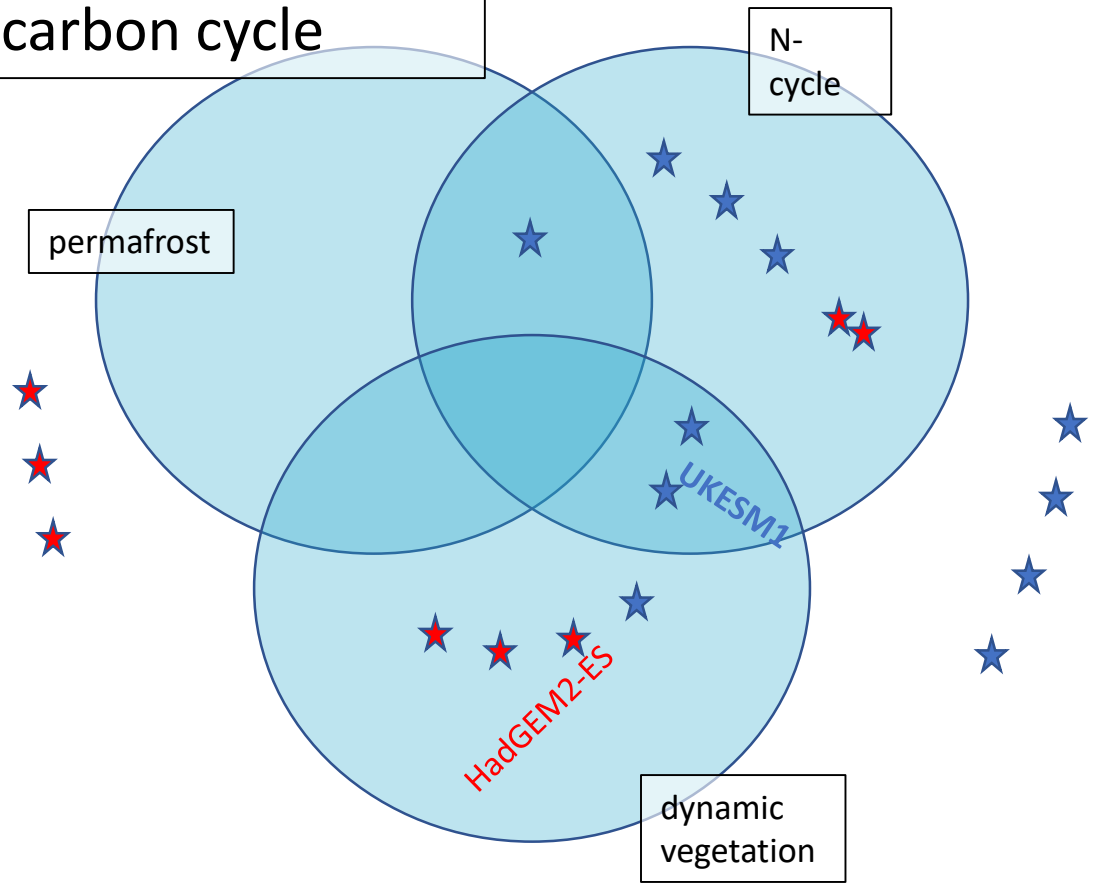
Differing responses to adding CO2 or N

JULES N uptake possibly too low?

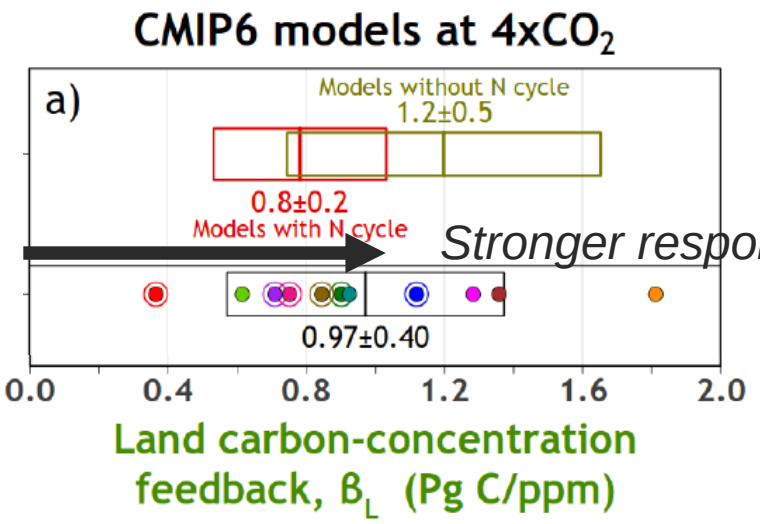
Evaluation ongoing…

Davies-Barnard et al., 2020. BG (accepted), https://bg.copernicus.org/preprints/bg-2019-513/

Process complexity of CMIP ESMs with carbon cycle

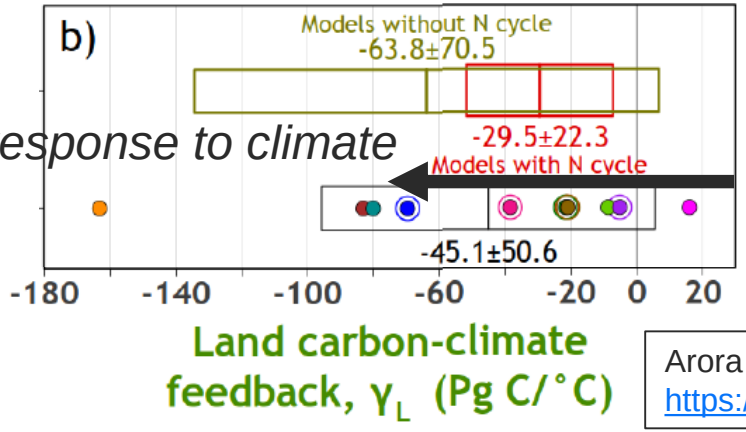


- 6 of 11 models include terrestrial N-cycle



Stronger response to CO_2

Stronger response to climate



- N-cycle models less sensitive than non-N
  - To CO2 and to warming
- Reduced spread in model response

Arora et al., 2020. BG, https://bg.copernicus.org/articles/17/4173/2020/

Concluding comments

- Terrestrial N-cycle has leading order control on land carbon sinks
- Previously neglected in CMIP models/IPCC assessments
  - Major over estimate of land carbon response
  - Vital that JULES and UKESM1 fill this gap
- JULES-CN now does so, and UKESM1 submission to CMIP6
  - Increased complexity (N-cycle) in land models has led to reduced spread of response
  - Enables more reliable carbon budget estimates

- Next steps
  - Development and evaluation – e.g. BNF, N-uptake response
  - Coupling to atmospheric composition – N-dep and soil NOx emissions
  - Interaction with other BGC – e.g. permafrost (see Eleanor's talk, Thursday)
  - Other (phosphorus) nutrient cycles