CARBON-CONCENTRATION AND CARBON-CLIMATE FEEDBACKS IN CMIP6 MODELS, AND THEIR COMPARISON TO CMIP5 MODELS

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Vivek Arora, Anna Katavouta, Richard Williams, Chris Jones, Victor Brovkin, Pierre Friedlingstein and the rest of C4MIP carbon feedbacks analysis team

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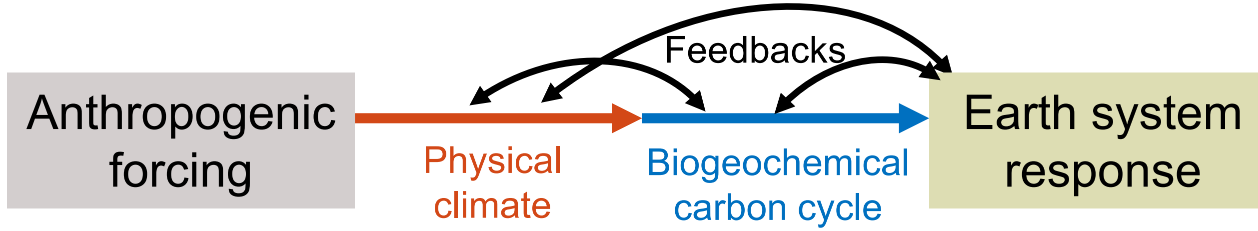
OUTLINE



- **Physical climate system:** the combined effect of changes in atmospheric water vapor, tropospheric lapse rate, ice/snow-albedo, and clouds is to enhance the initial climate signal via **positive feedbacks**.
- The combined effect of **feedbacks between the carbon cycle and physical climate system** is primarily to dampen the initial atmos. CO_2 perturbation via the dominant negative carbon-concentration feedback (β).
- The sub-dominant positive carbon-climate feedback (γ) enhances initial climate perturbation.
- The evolution of β and γ in comprehensive ESMs, from **CMIP5 to CMIP6**, is presented here.

METHODOLOGY

- Under the auspices of CMIP6, the **coupled carbon-cycle climate MIP (C^4MIP)** compares the interactions between the carbon cycle and climate.
- The analysis of feedbacks is based on 1pctCO2 runs in which **CO2 increases at 1% per year** from its pre-industrial value (~284 ppm) until quadrupling (~1140 ppm).
- C^4MIP has chosen to use 1pctCO2 simulation as a standard simulation from which to analyze feedbacks.
- Examine carbon budget terms and **feedback parameters** over **land** and **ocean**. For this CMIP phase we also delved into the reasons for differences among models.

CARBON BUDGET EQUATIONS

$$\frac{dC_G}{dt} = \frac{dC_A}{dt} + \frac{dC_L}{dt} + \frac{dC_O}{dt} = E$$

$C_G = C_A + C_L + C_O$: the **Global carbon pool** is the sum of carbon in the *A*tmosphere, *L*and and *O*cean components (PgC),
E: the rate of anthropogenic CO_2 **emissions** (PgC/yr) into the atmosphere.

Global carbon pool = Atmosphere + Ocean + Land

Integrating above equation yields change in atmospheric *C* burden (ΔC_A) and C uptake by land (ΔC_L) and ocean (ΔC_O), as **sum of cumulative *E***.

$$\Delta C_A + \Delta C_L + \Delta C_O = \int_0^t E\, dt = \tilde{E}$$

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FEEDBACK PARAMETERS

Assume linearity (feedbacks operate independenly) even if not exactly true!

$$\Delta C_X = \beta_X c + \gamma_X T$$

change in ocean or land carbon

changes in atmos CO_2

changes in surface T

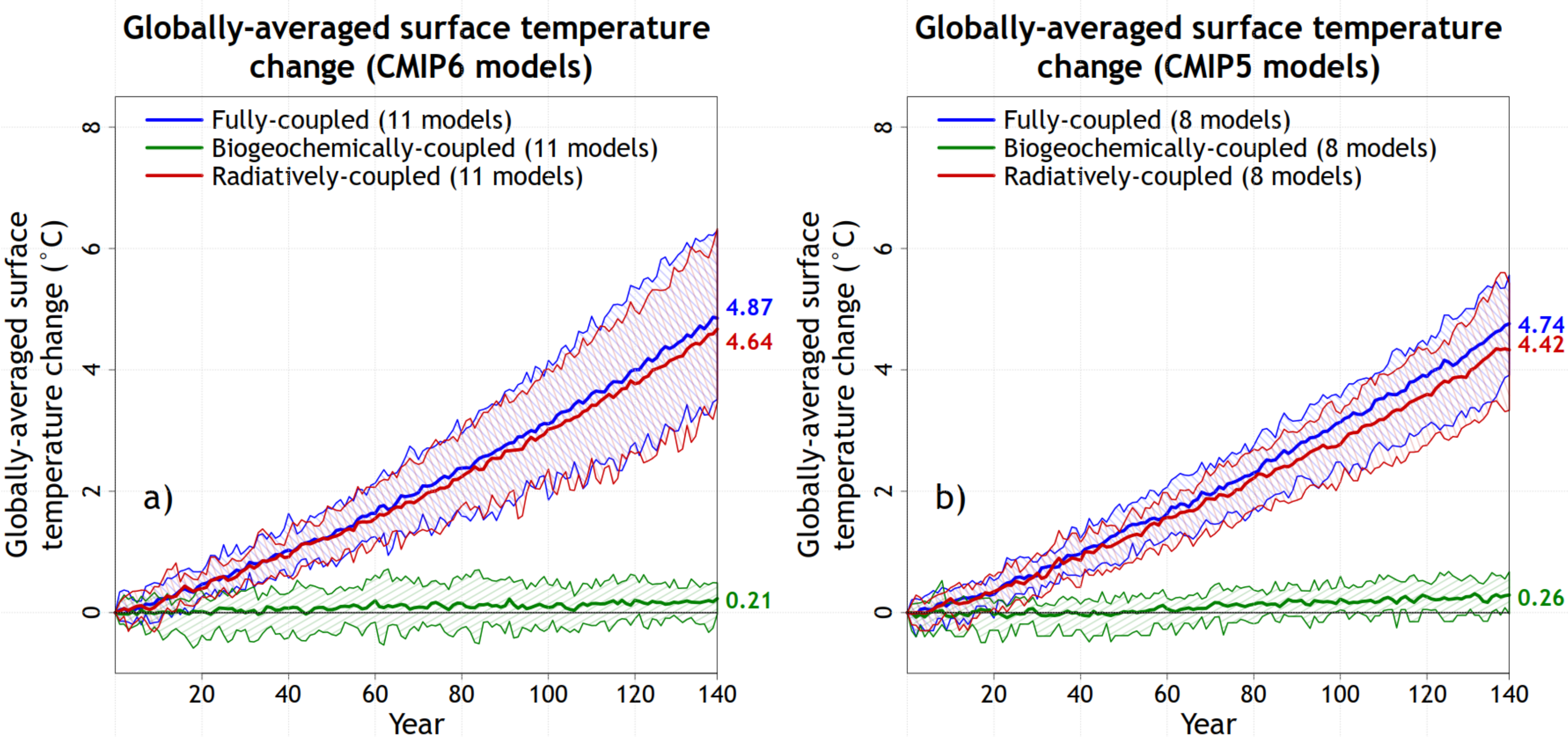
Use model simulations with **components switch on and off**:

Biogeochemically coupled simulation: $\Delta C_X^* = \int F_X^* \, dt = \beta_X c' + \gamma_X T^*$

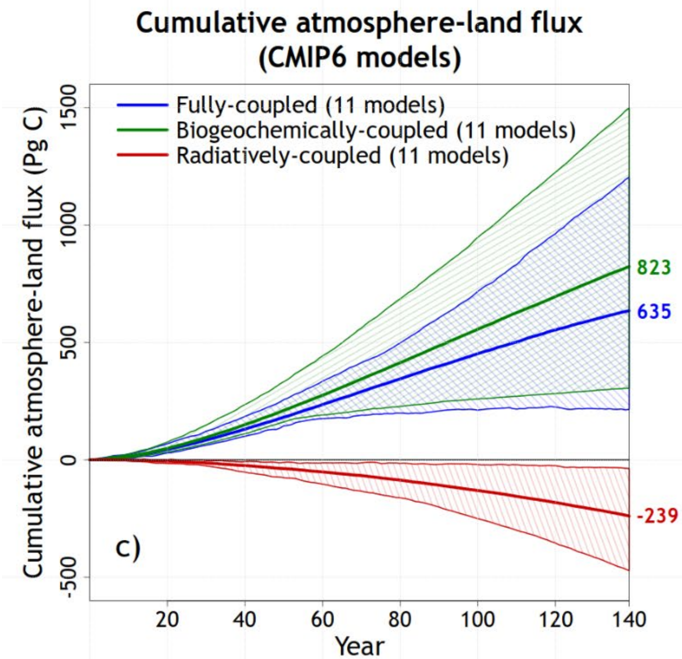
Fully coupled simulation: $\Delta C_X' = \int F_X' \, dt = \beta_X c' + \gamma_X T'$

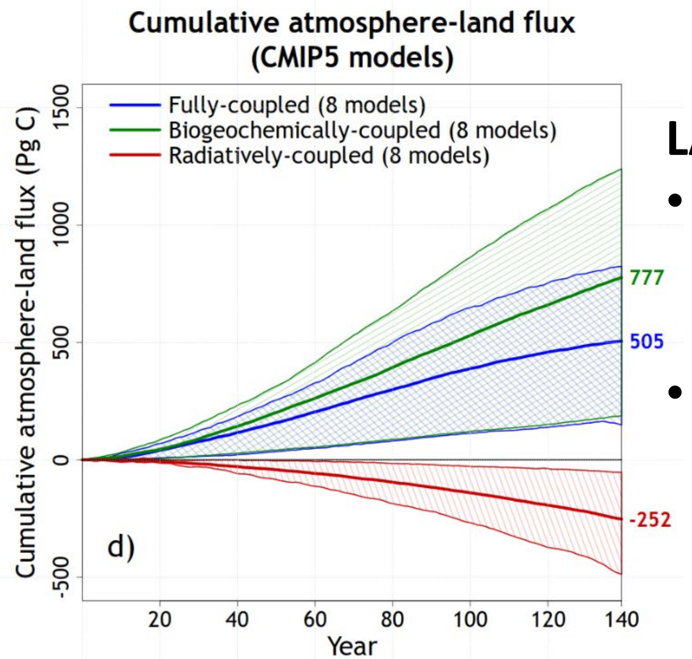
β and γ are found for land and ocean.

RESULTS



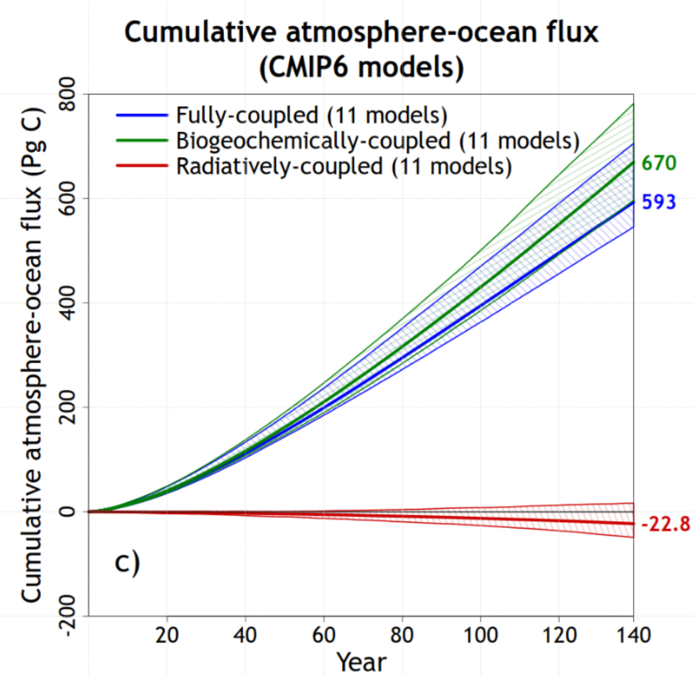
CMIP6 models are somewhat **warmer** than CMIP5 models.

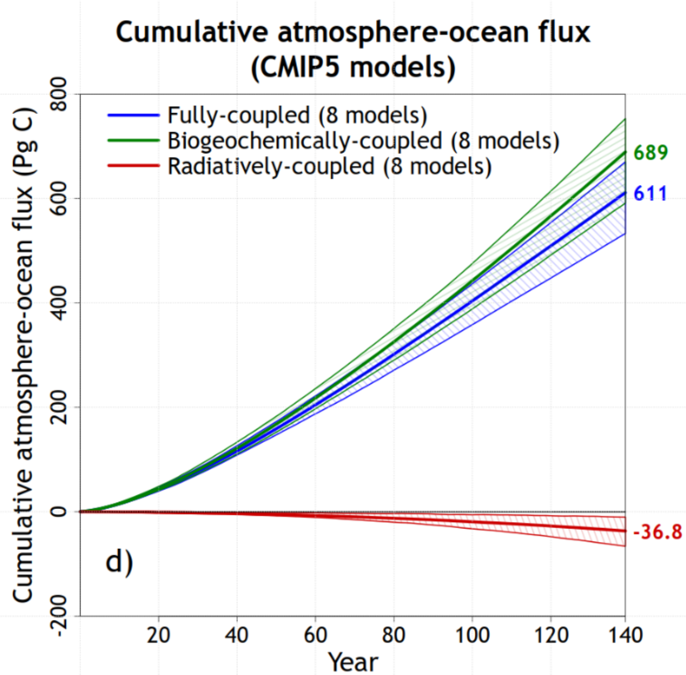




LAND :

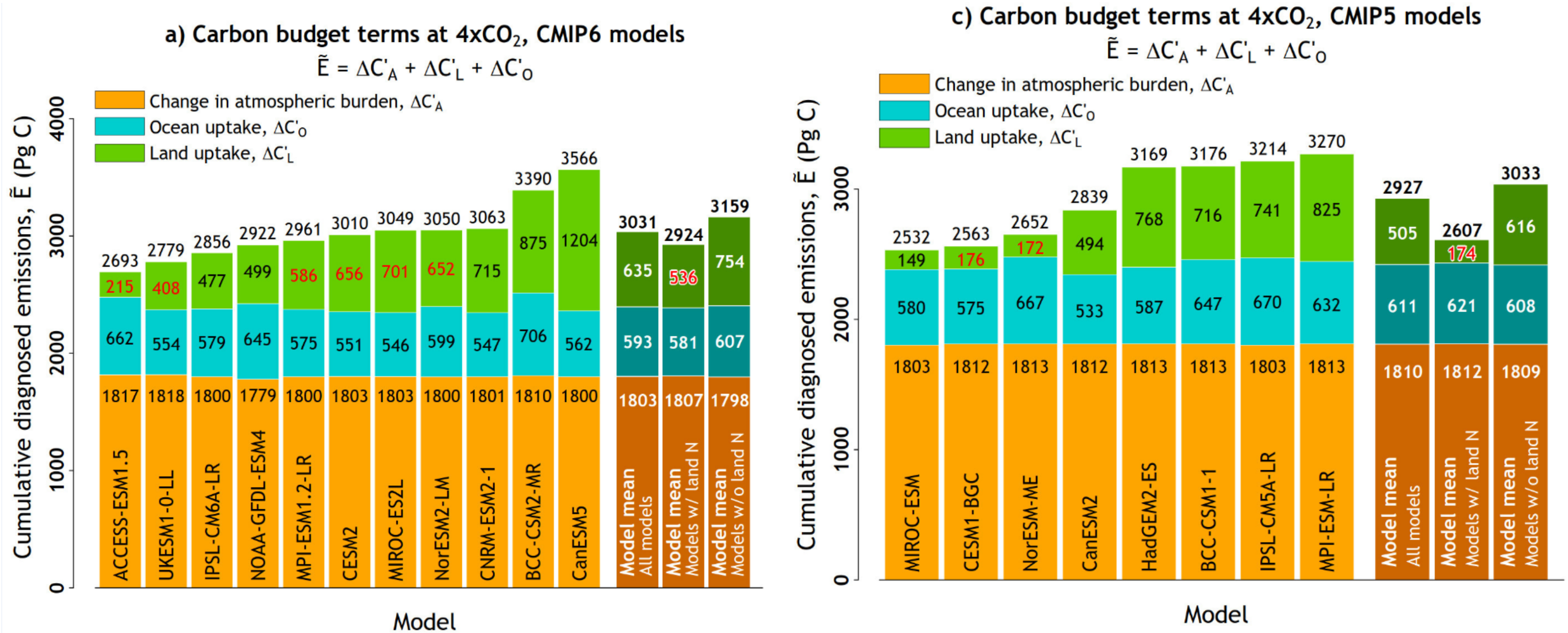
- C uptake higher in CMIP6 than CMIP5.
- Model spread also higher in CMIP6.





OCEAN :

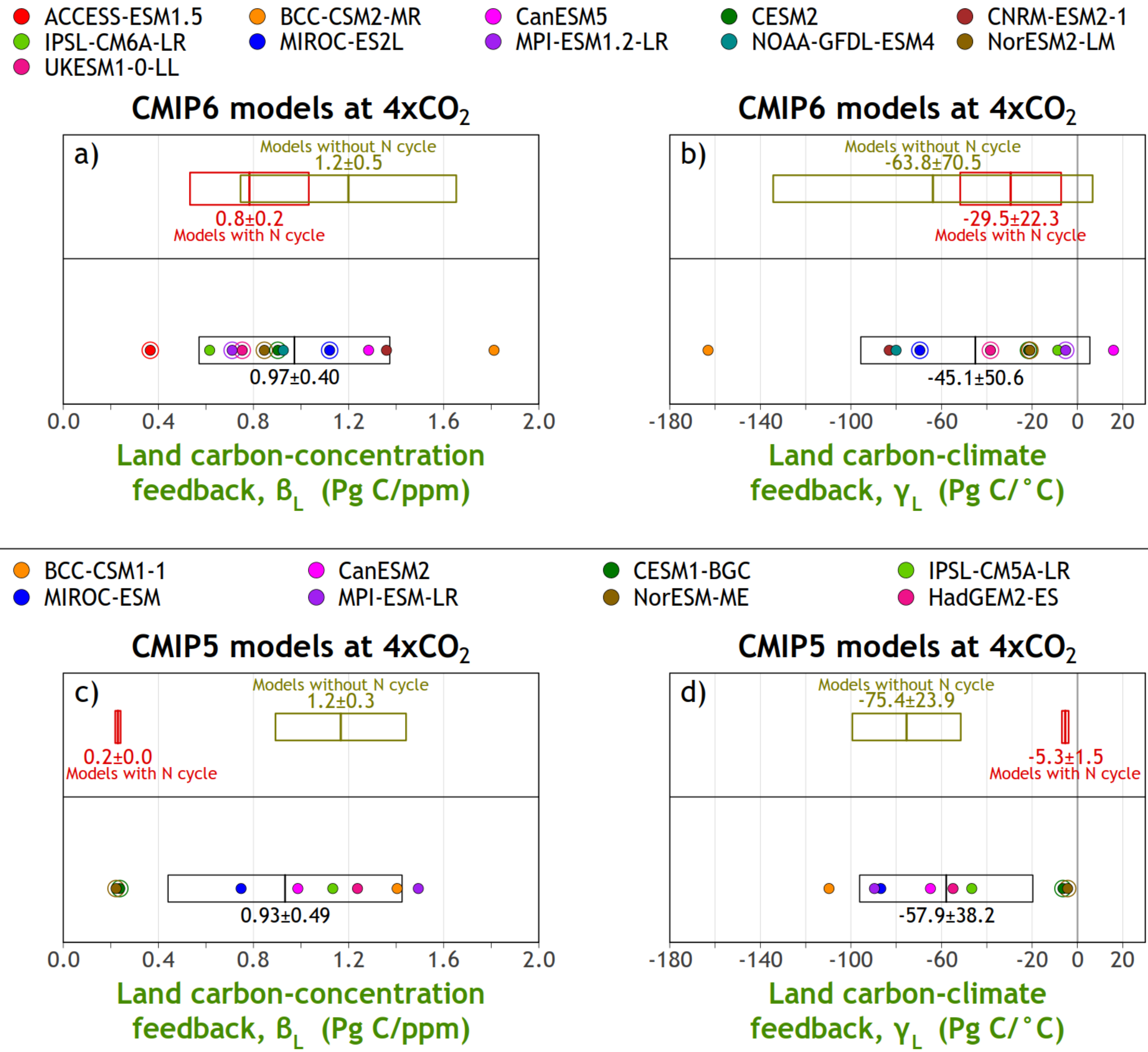
- C uptake similar in CMIP5 and CMIP6.



- More models with land **N cycle** (indicated in red) in CMIP6 (6 out of 11) than in CMIP5 (2 out of 8).
- Yet, **land C** uptake in 1pctCO2 simulations goes **up by ~25%** (although the increase is not statistically significant).
- Ocean C uptake in 1pctCO2 simulations similar in CMIP5 and CMIP6.

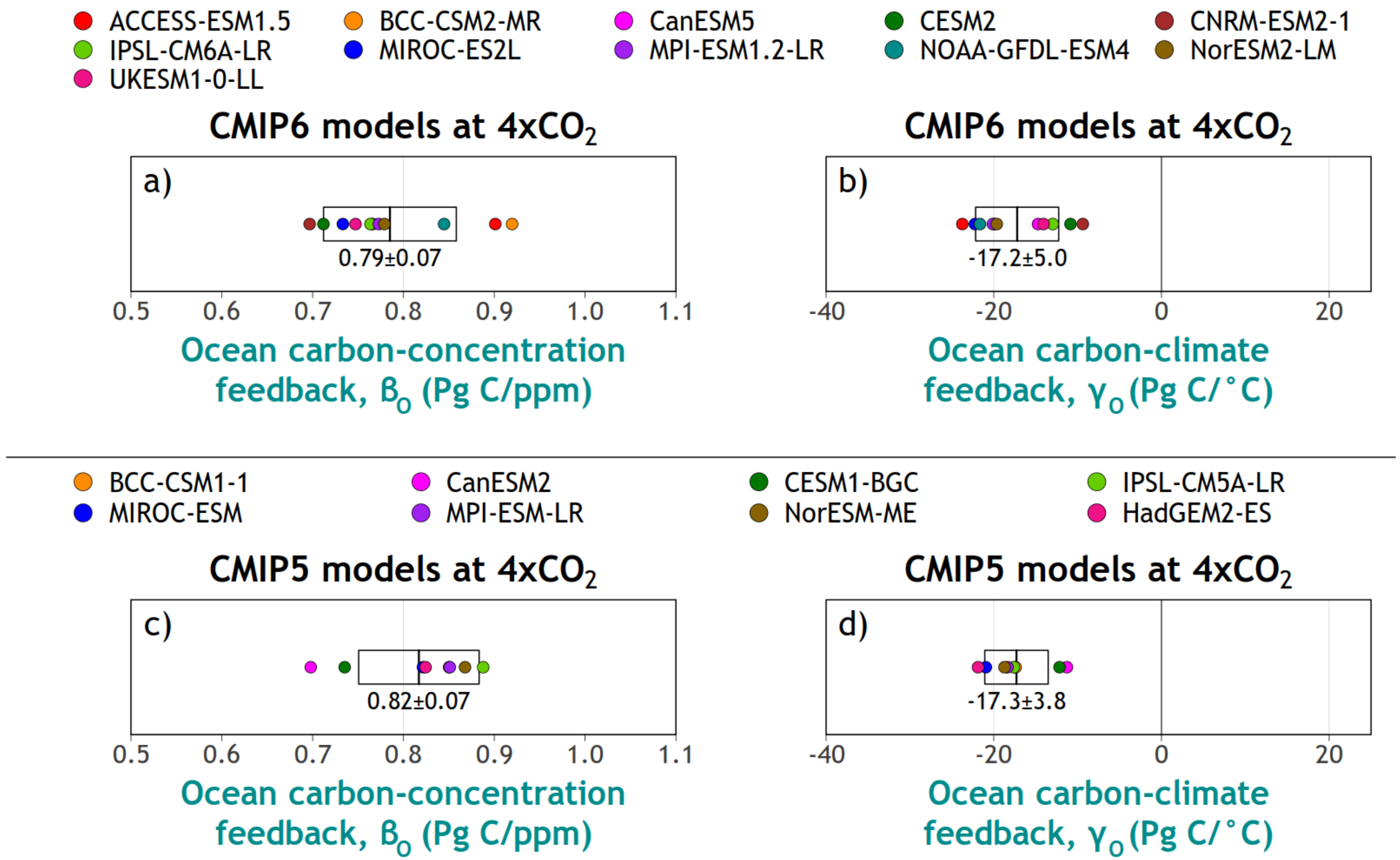
FEEDBACKS OVER LAND

- Models with land N cycle exhibit lower strength of feedbacks, and **less inter-model spread**.
- Carbon-concentration feedback β: **stronger** Carbon-climate feedback γ: **weaker** in CMIP6 compared to CMIP5 models.



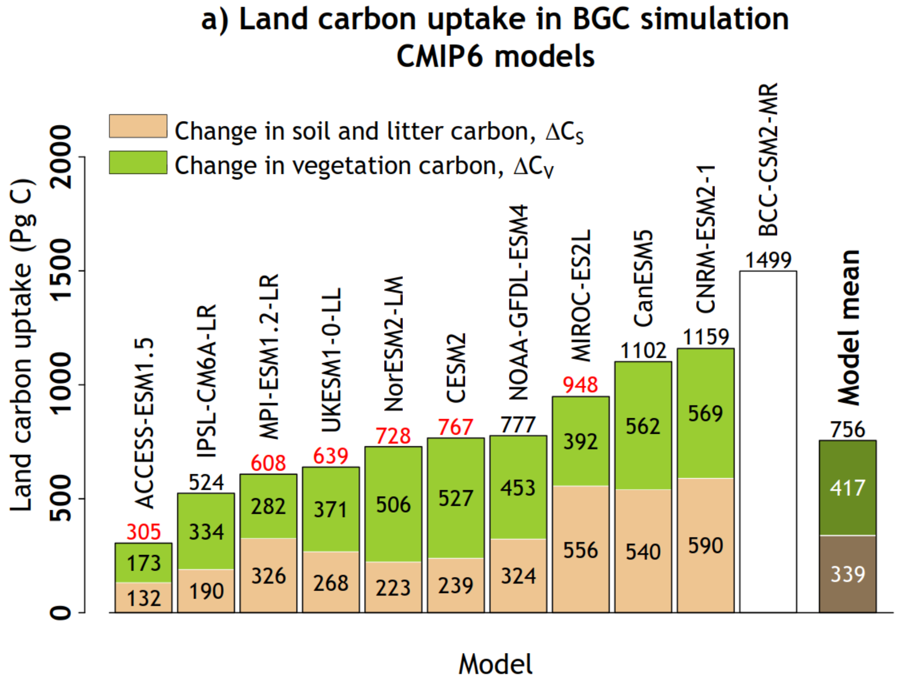
Feedbacks calculated using BGC and COU simulations (shown here) are preferred.

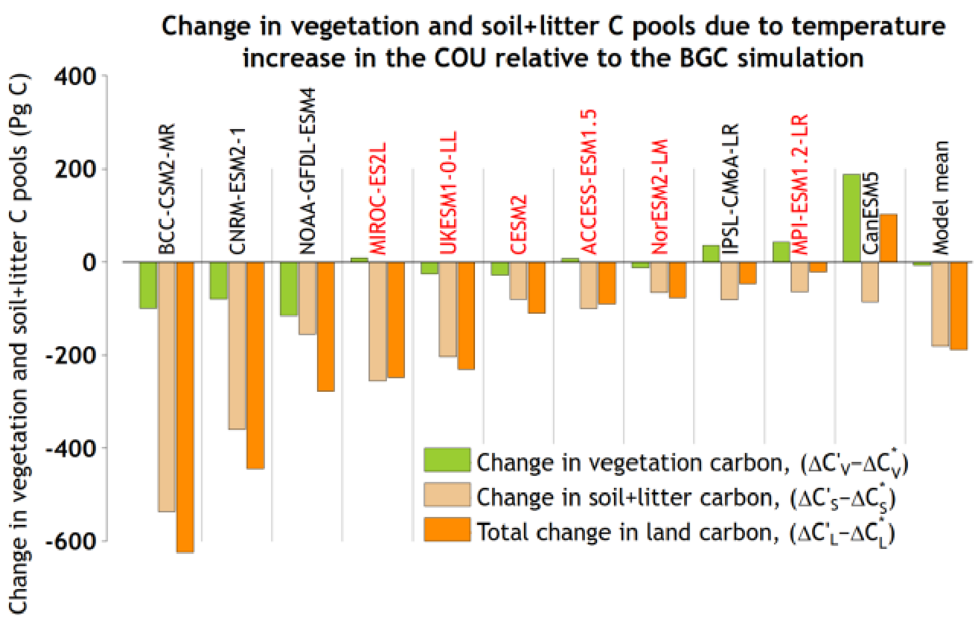
FEEDBACKS OVER OCEAN



- Strength of feedback parameters **similar** between CMIP5 and CMIP6.
- Less inter-model spread over ocean than over land

Feedbacks calculated using BGC and COU simulations (shown here) are preferred.

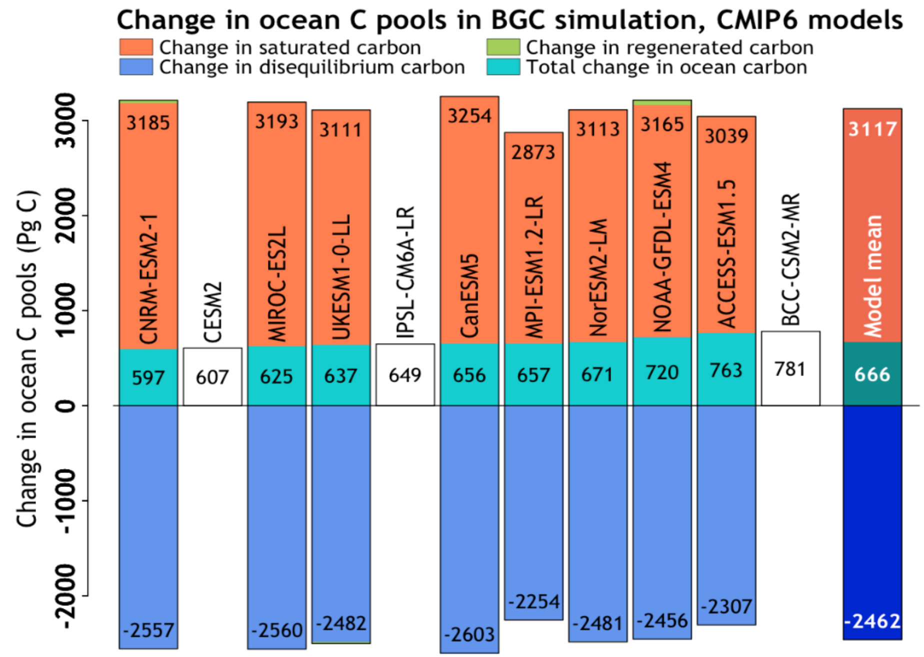


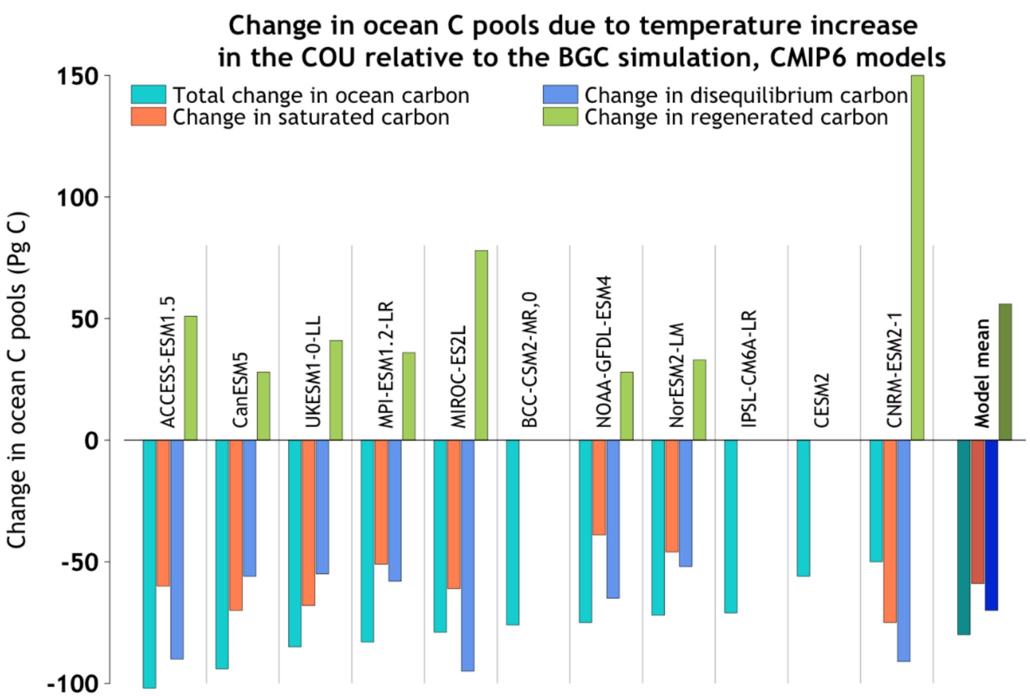


LOOKING DEEPER – WHY **LAND** MODELS ARE DIFFERENT?

- The split of land C uptake between **vegetation and soil carbon** is different across models.

- The model spread for both β and γ is due to a wide **range in the strength of processes across models**: CO_2 fertilization, conversion of GPP to NPP, and residence time in vegetation and soil carbon pools.





LOOKING DEEPER – WHY **OCEAN** MODELS ARE DIFFERENT? (BUT MORE SIMILAR THAN LAND)

- The split of ocean C uptake between change in **saturated, regenerated, and disequilibrium** reveals similarities and differences.
- For β: similar saturated and disequilibrium (regenerated is small in this case).
- For γ: larger differences from **disequilibrium** and regenerated

CONCLUSIONS

- Land C cycle models have always exhibited much larger inter-model spread than ocean C cycle models – **biology over land is much less understood than physics over oceans**.
- Introduction of **N cycle** in land models suggests inter-model spread can be reduced.
- **Ocean C** cycle behavior very similar in CMIP5 and CMIP6 models.
- The Biogeosciences paper attempts to delve into reasons for differences in land, and ocean, C cycle models

  Land: differences due to strength of CO_2 fertilization effect, fraction of GPP converted to NPP, and residence time in soil and vegetation pools.

  Ocean: relatively wider range in the disequilibrium and regenerated C changes with warming.

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