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MAKE OUR PLANET GREAT AGAIN

Carbon cycle response to temperature overshoot beyond 2 °C – an analysis of CMIP6 models

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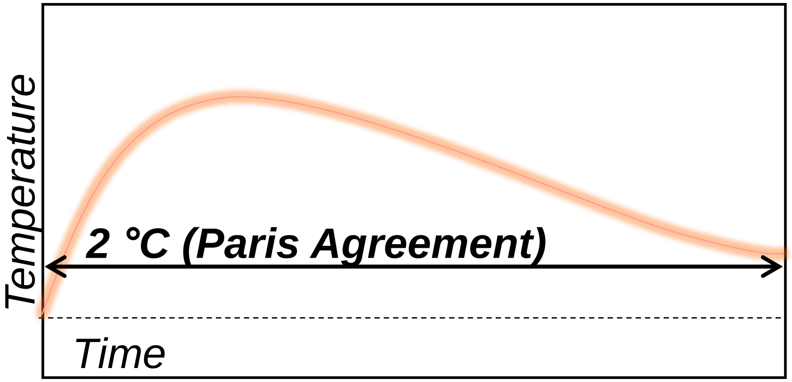
Motivations for Achieving the Paris Agreement Temperature Targets after Overshoot (PRATO) project



Converging?

End of the 21st century

- **Paris Agreement**
  - To limit warming below 2 °C (1.5 °C)

2050

- **Science (IPCC SR15)**: Net zero CO_2 emissions required to be on track for 1.5 °C (or by 2070 for 2 °C)
- **National policies**: Major economy countries adopted "net zero" targets by 2050-2060 (December 2020, Climate Action Tracker)
- **Hausfather & Peters, 2020 :** global warming is on course to 3 °C by the end of this century.

Gap

2030

- ***Science (IPCC SR15)***: *Net anthropogenic CO_2 emissions need to decline by 2030 up to 45% (25%) from 2010 levels for 1.5 °C (2 °C) target*
- ***National policies***: *NDCs indicate a slight increase in CO_2 emissions from 2020 levels (emission pledges need to be more than halved (Höhne et al., 2020))*

Overshooting the temperature target is becoming more likely

Background studies

Study	Model	Design	Results
Boucher *et al.*, 2012, Zickfield *et al.*, 2016	HadGEM2-ES, Uvic ESCM	572-1144 ppm CO_2, 2.0 to 5.5 °C warming (idealized)	**Ocean becomes a source** in a few decades, **land is sink** for long time
Tokarska *et al.*, 2019	UVic ESCM	480-620 ppm CO_2, 1.5 to 2.5 °C warming (idealized)	**Ocean and land** are **decreasing sinks** after ramp-down, more carbon is stored in the ocean
Palter *et al.*, 2018	GFDL-ESM2M	>580 ppm, ≈2 °C warming	**Land and ocean** become a **carbon source** nearly two to three decades after the peaks of CO_2 concentration and temperature
Schwinger & Tjiputra, 2018	NorESM	>800 ppm, ≈4 °C warming (idealized)	**Carbon source only after a strong reduction** in atmospheric CO_2

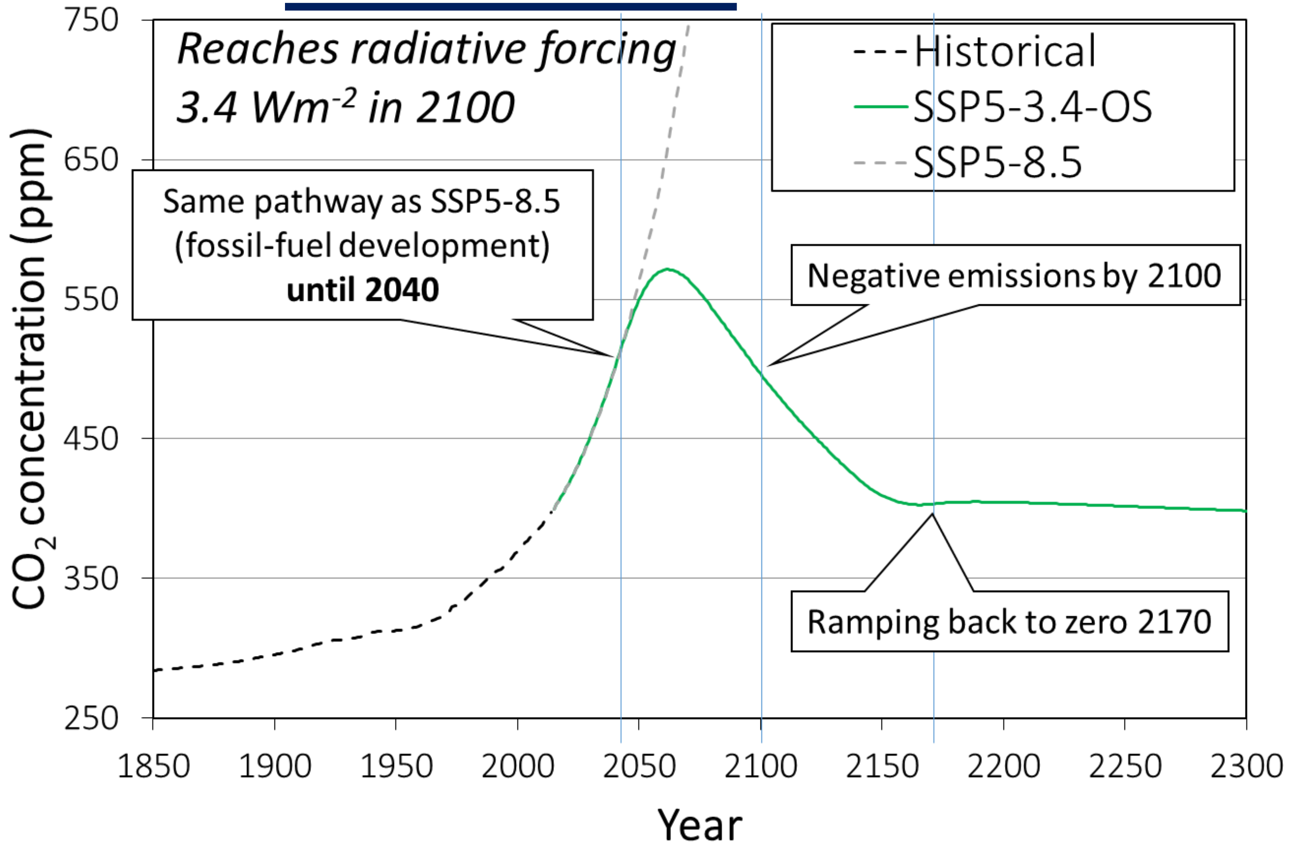
- Different, highly idealized scenarios
- Limited number of models, sometimes of intermediate complexity

What controls the response of the carbon cycle to the CO_2 and temperature overshoots is not well-known

Study purpose and methods

To explore the carbon cycle feedbacks over land and ocean under overshoot scenario

SSP5-3.4-OS



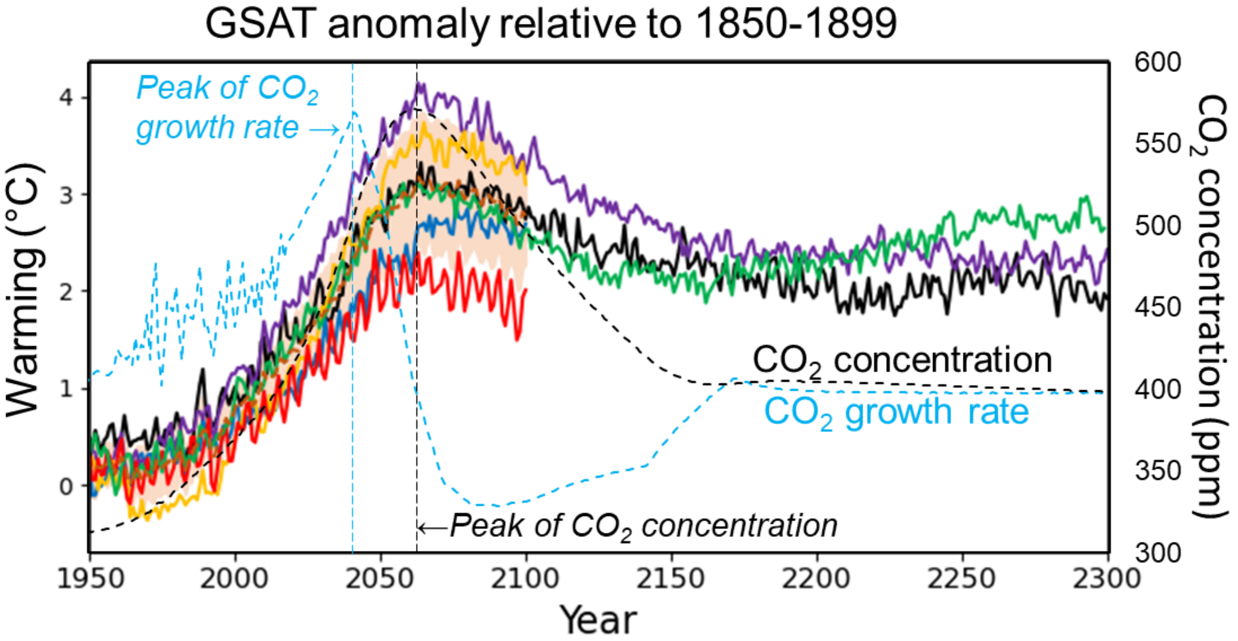
&

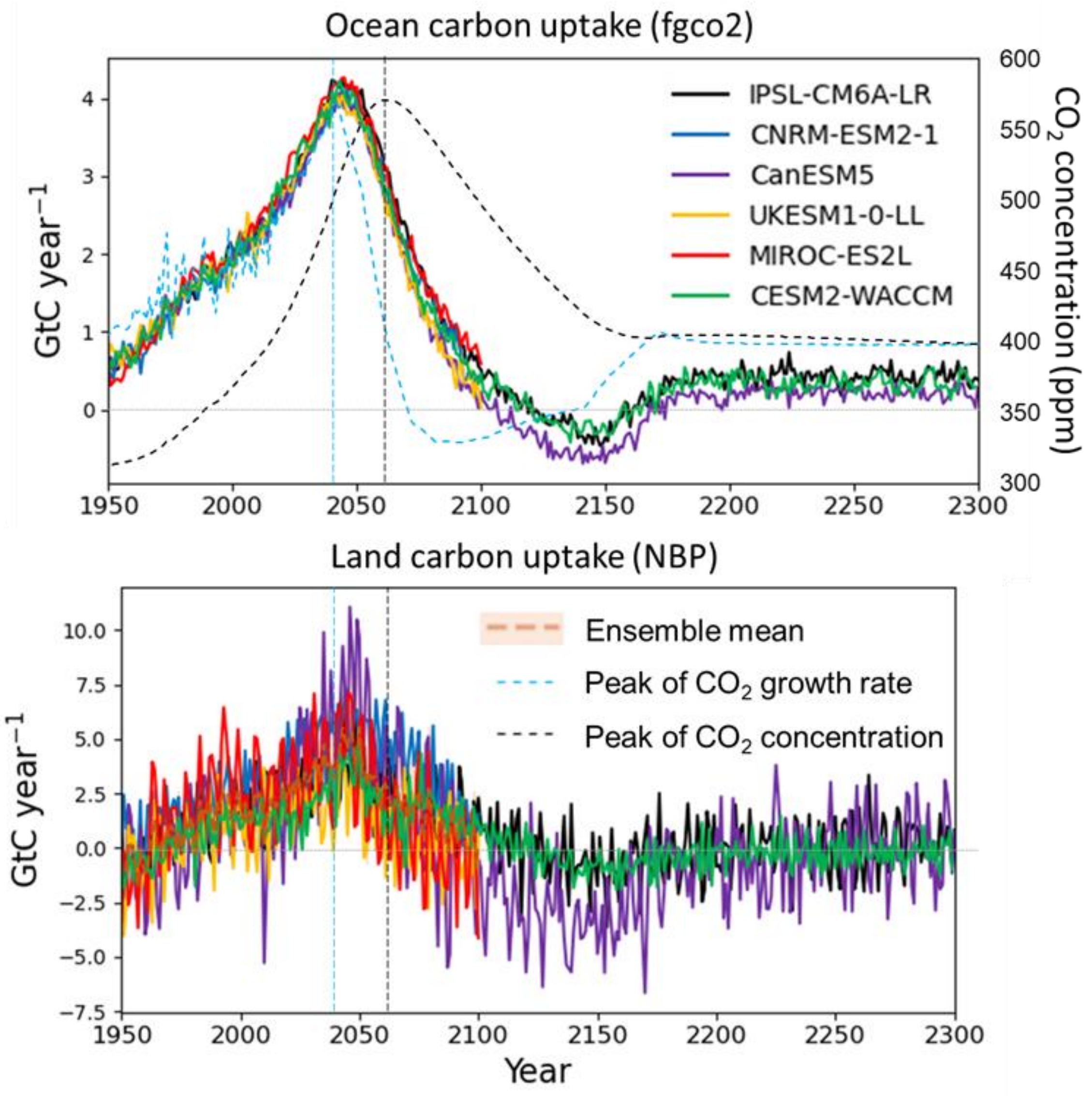
CMIP6 ESMs

1) IPSL-CM6A-LR
2) CNRM-ESM2-1
3) CanESM5
4) UKESM1-0-LL
5) MIROC-ES2L
6) CESM2-WACCM

- *We investigate temporal changes in carbon fluxes*
- *We apply* ***the carbon cycle feedback framework*** *to quantify the carbon cycle feedbacks*

Land and ocean carbon uptakes

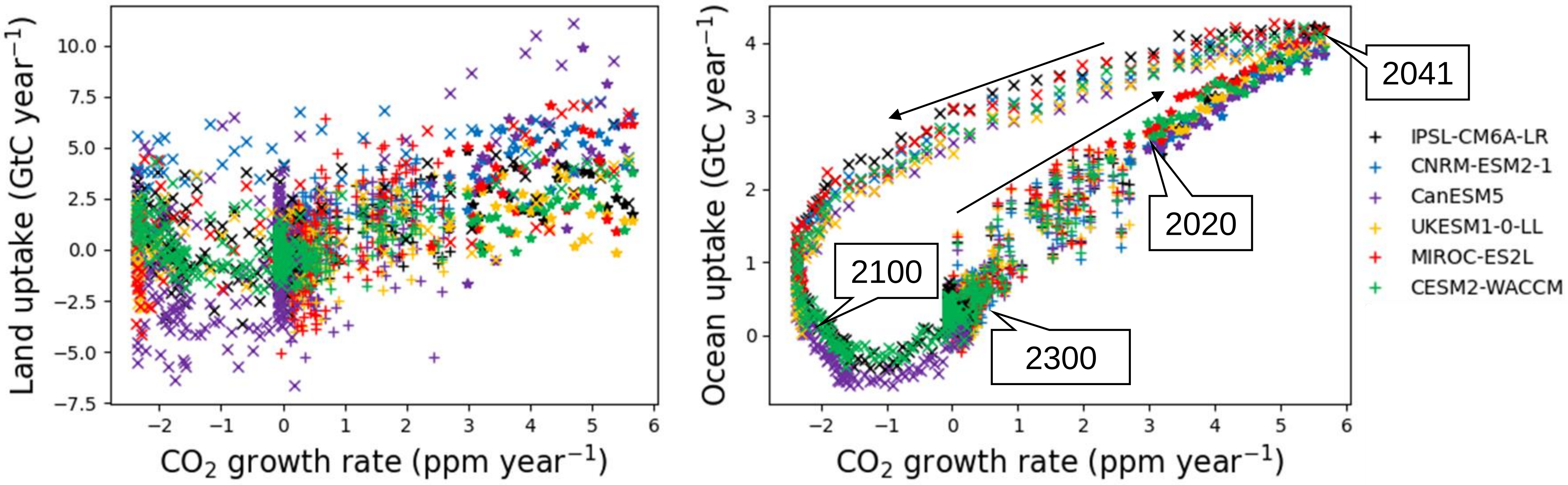




- CO_2 concentration peaks **two decades** after CO_2 growth rate
- ESMs differ in the response of **temperature** to the prescribed changes in CO_2 concentration, but all agree on a **delayed response**

- After the peak of CO_2 growth rate, **land and ocean take up carbon for at least 50 years** but at a declining rate
- In the 23rd century, **ocean is a weak carbon sink**, the response of **land** has a larger range of **uncertainties**
- Land and ocean carbon u**ptakes peak before the CO_2 concentration peak**

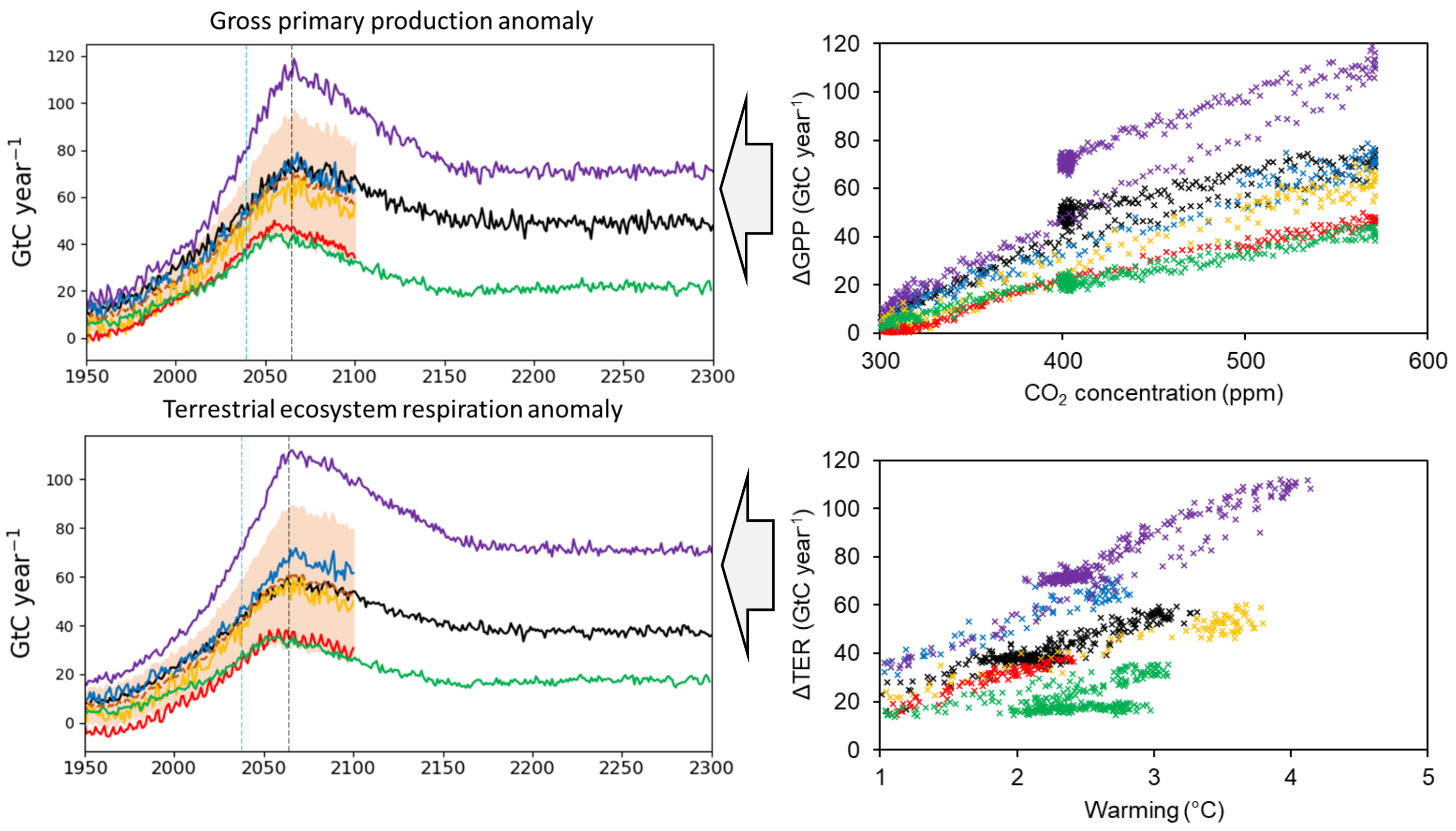
Peak of ocean carbon uptake

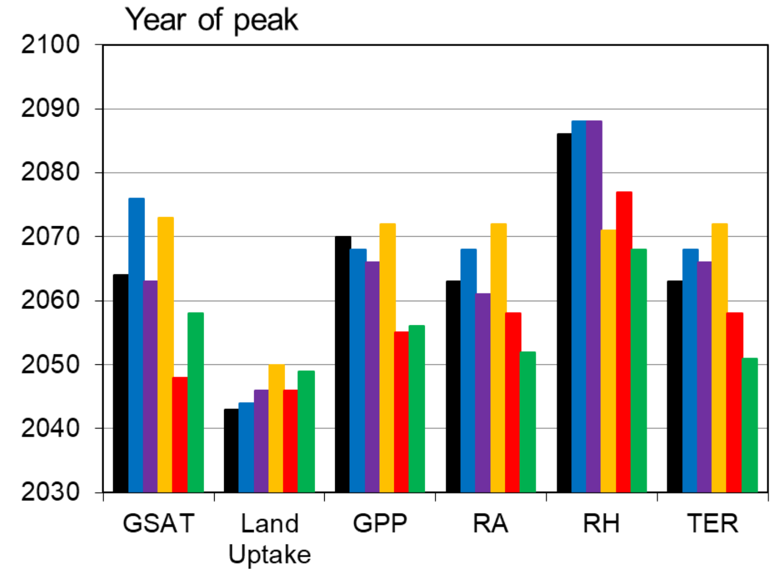


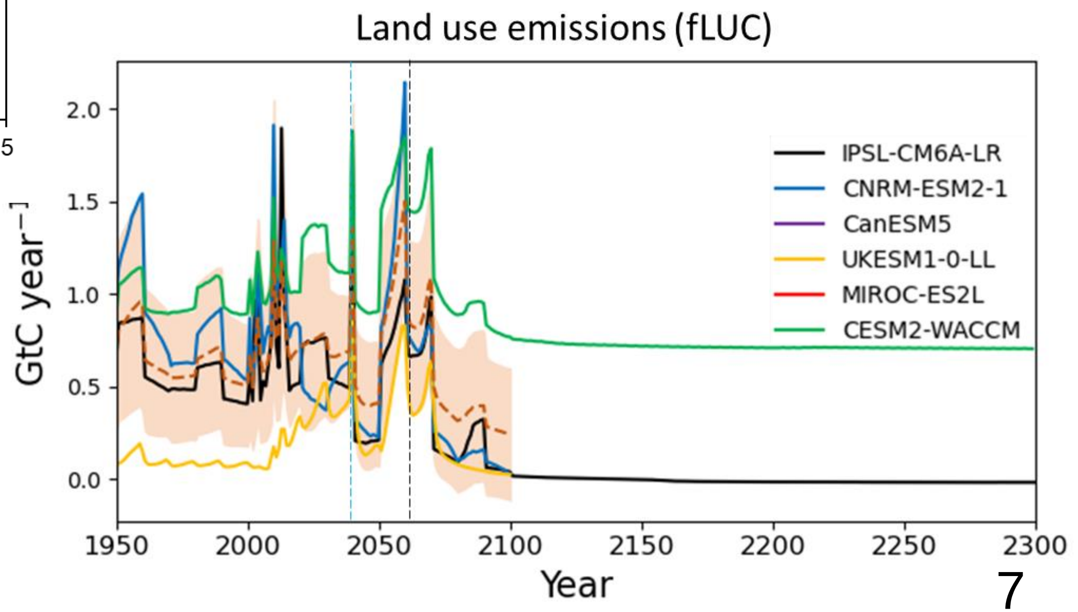
Global ocean carbon uptake has a nearly linear dependency on the atmospheric CO_2 growth rate with a hysteresis after the CO_2 growth rate peak

- McKinley et al. (2020) and Schwinger and Tjiputra (2018): the CO_2 growth rate dominates the variability in the global ocean on year-to-year timescales
- Additional analysis on the underlying reasons is needed
- A weaker linear dependency of the land carbon uptake on the CO_2 growth rate

Peak of land carbon uptake







The land sink decrease is due to the **larger growth of respiration than photosynthetic production** and concurrent **land-use change emissions**

Carbon cycle feedback framework (SSP5-3.4-OS)

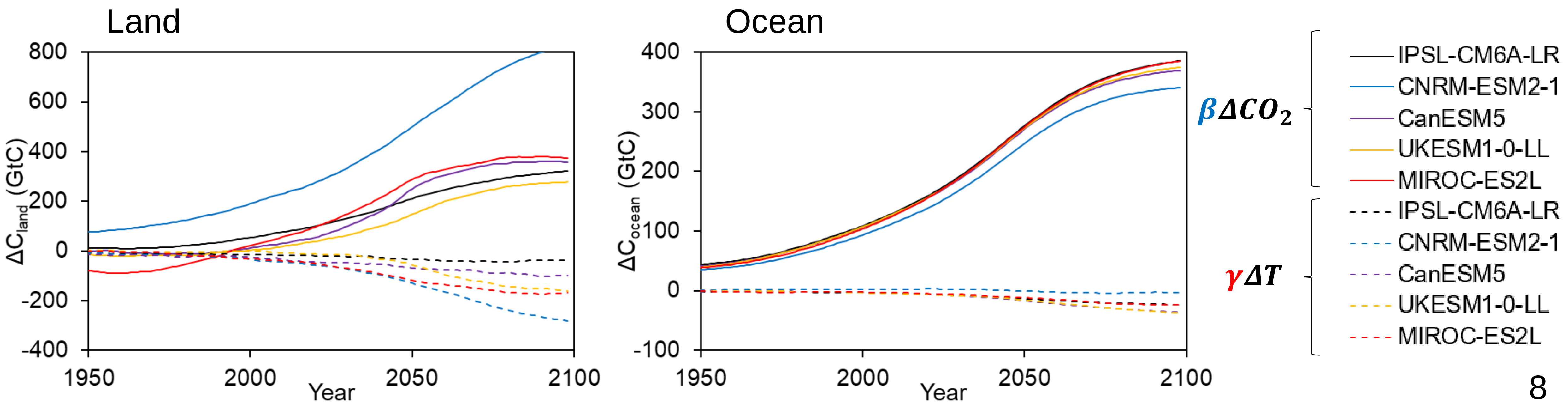
$$\Delta C = \beta \Delta CO_2 + \gamma \Delta T$$

Beta, β: carbon-concentration feedback (ΔC ppm^{-1})

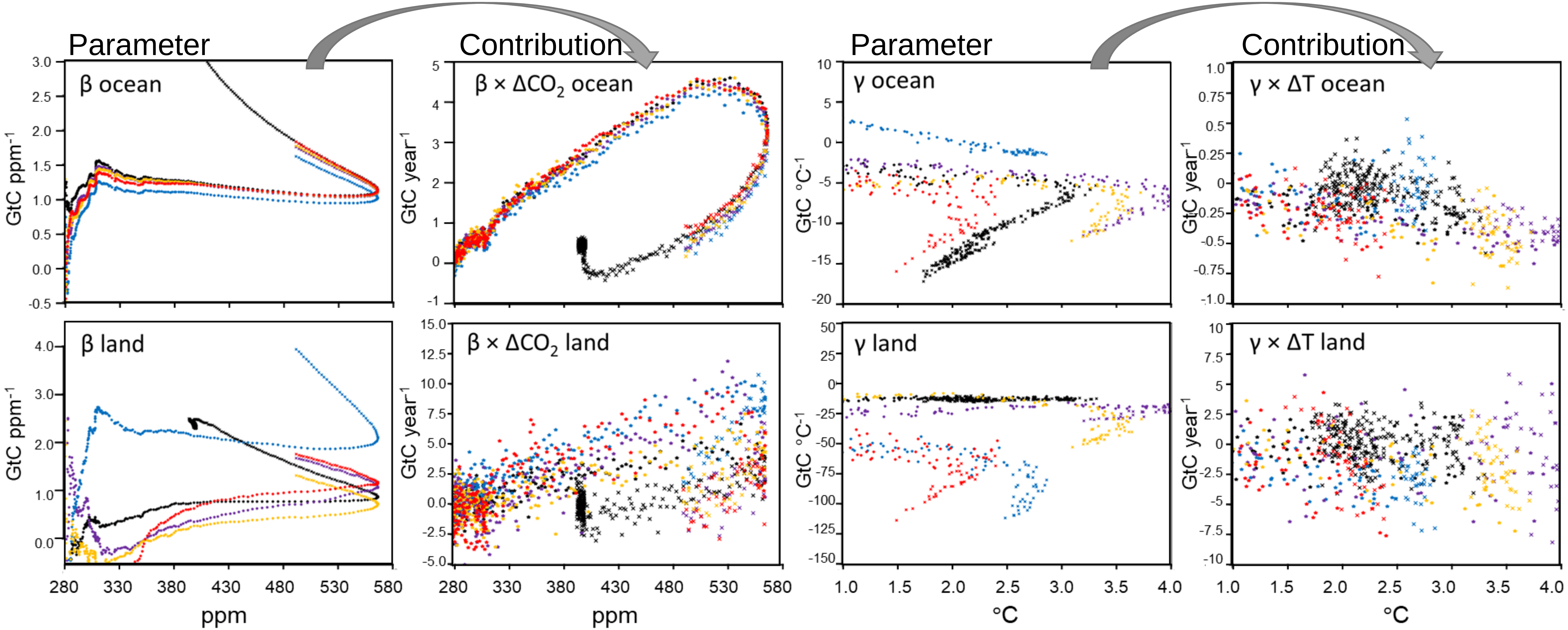
Gamma, γ: carbon-climate feedback: (ΔC $°C^{-1}$)

ΔC, ΔCO_2, ΔT are the changes of carbon mass (GtC), CO_2 concentration (ppm) and air temperature (°C) relative to their unperturbed preindustrial states

Gregory *et al.* 2009, Jones *et al.*, 2016



Carbon cycle feedbacks (SSP5-3.4-OS)



- Under declining emissions, both land and ocean continue to take up (via β) and lose carbon (via γ) at an asymmetrically larger rate
- The changes in the carbon cycle are dominated by β rather than γ till the end of the 21st century.

Conclusions

- In SSP5-3.4-OS, the land and ocean continue to remove carbon from the atmosphere at least for 50 years after the peak of the CO_2 growth rate. They turn to a source in the first half of the 22nd century for a short period and become a weak sink later, i.e., reach a new steady-state
- The ocean uptake decreases due to its dependency on the CO_2 growth rate
- The land uptake decreases due to a larger growth of respiration than GPP and concurrent LUC emissions
- The inertia in β and γ after their peaks causes amplification of carbon cycle feedback parameters.
- The total β carbon gain $\beta \times \Delta CO_2$ is larger than γ loss $\gamma \times \Delta T$, and, thus, land and ocean continue to uptake carbon during the CO_2 and temperature ramp-down periods.

Melnikova *et al.* 2021, under review in Earth’s Future