Project: **1446**
Project title: **AI4PEX: Ocean biogeochemistry and extremes**
Principal investigator: **Hongmei Li**
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Idealized simulations for process understanding

We have done a set of idealized simulations according to the esm-flat10 protocol with constant positive and negative CO2 emissions. These simulations, as part of the CMIP7 fast track, allow us to quantify the response of the carbon sink and climate under deep decarbonization. These simulations contribute to the reference paper (Sanderson et al. 2024) and other multi-model comparison studies. The MPI-ESM results are presented among the other Earth System models, together with simple climate models (Fig. 1). The climate and carbon cycle are irreversible even under the accumulation of zero emissions, featuring a lower global temperature and atmospheric CO2 concentration. An asymmetric response in the carbon uptake and release, and the ocean storage of carbon and heat, intervenes in the transient responses of climate to the cumulative CO2 emissions.

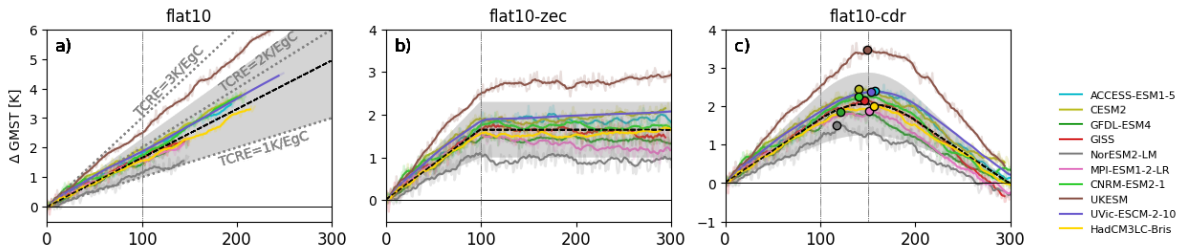

Fig. 1 Global mean surface air temperature from MPI-ESM flat10, flat10-zec, and flat10-cdr simulations in the context of results from simulations of other ESMs. The figure is taken from Sanderson et al. (2024).

We have done further simulations to isolate the influences of ocean carbon chemistry, ocean physics, and ocean biology to study the individual processes contributing to the global carbon cycle and climate under increasing emissions (Fig. 2).

Future projection of climate and carbon feedback

By leveraging extended large ensemble CO2 emission-driven simulations under diverse scenarios and idealized CO2 forcings, we investigated the transient climate response to cumulative emissions (TCRE) and the corresponding processes. The asymmetric carbon-climate responses to cumulative emissions lead to lower atmospheric CO2 of the emission-driven simulations relative to the IAMs, i.e., the IAMs largely overestimate the atm. CO2 concentration under the mitigation and negative emission. This emphasizes the necessity to use emission-driven models, especially for simulating the climate with carbon mitigation and decarbonization. The overlapping of the trajectory of carbon-climate feedback under different CO2 pathways implicates the independence of pathways. Deviation of climate response and hysteresis in flat10 simulations with only CO2 forcing from SSPs with all forcings indicates the contribution of non-CO_2 forcings to the climate and carbon cycle changes. These

simulations and results provide insights into the potential impacts of emission reduction strategies and the role of negative emissions in climate mitigation. We present the results at the EGU2025 General Assembly (Li et al., 2025).

Ocean compound extremes evolve with emission changes

Previous studies have demonstrated that the ocean extremes intensify with rising CO_2 levels. Ocean extreme events, e.g., marine heatwaves, low pH, and low oxygen extremes, can occur simultaneously and form compound extremes. The impacts of compound extreme events can intensify nonlinearly, and the response of individual and compound extremes to emission changes, especially under emission mitigation and decarbonization, remains less understood. We have extended the emission-driven large ensemble simulations under the SSP5-3.4 overshoot scenario, which follows along a pathway with a rapid increase of emissions followed by steep reductions, ultimately reaching net-negative and zero emissions. We explore how ocean compound extreme events evolve with the emission changes, focusing on the responses of the ocean extremes to negative emissions. This study provides a novel perspective on the implications of emission reductions and negative emissions for ocean extreme events. The changes of individual and compound extremes show different hysteresis behaviours, pinpointing the corresponding processes in the ocean surface and subsurface. We present the results at the EGU2025 General Assembly (Filippou et al., 2025).

Publications:

Sanderson, B. M., …Ilyina, T., …, Li, H., et al..: flat10MIP: An emissions-driven experiment to diagnose the climate response to positive, zero, and negative CO2 emissions, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-3356, 2024.

Filippou, D., Li, H., and Ilyina, T.: Ocean Compound Extreme Events Under Emission Reduction and Negative CO2 Pathways, EGU General Assembly 2025, Vienna, Austria, 27 Apr–2 May 2025, EGU25-1719, https://doi.org/10.5194/egusphere-egu25-1719, 2025.

Li, H., Ramme, L., Li, C., and Ilyina, T.: Asymmetric carbon-climate responses to cumulative emissions under different CO2 pathways, EGU General Assembly 2025, Vienna, Austria, 27 Apr–2 May 2025, EGU25-16501, https://doi.org/10.5194/egusphere-egu25-16501, 2025.