Project: **1446**
Project title: **AI4PEX: Ocean biogeochemistry and extremes**
Principal investigator: **Hongmei Li**
Report period: **2025-05-01 to 2026-04-30**

Climate-carbon feedback under deep decarbonisation

Simulations with an interactive carbon cycle are now standard in CMIP7, facilitating investigation of climate–carbon cycle feedbacks. While the climate and carbon cycle responses to rising CO_2 emissions have been widely studied, the responses to declining and negative CO_2 emissions remain unclear. We conduct CMIP6 overshoot scenarios and idealized esm-flat10 simulations to address the limited understanding of asymmetric climate–carbon cycle responses and underlying processes, especially in decreasing and negative CO_2 emission pathways. Results show that both the climate and carbon cycle exhibit hysteresis and irreversibility, even under net-zero cumulative emissions. Asymmetric patterns of storage of carbon and heat in the subsurface to deep ocean dominate the transient climate response to CO_2 emissions. Long-term carbon sequestration occurs in the deep South Pacific, likely driven by deep-ocean warming and enhanced remineralization. We present the results at the CMIP community workshop (Li et al., 2026) and the manuscript is in preparation. These simulations are included in further publications (Brovkin et al. 2025; Sanderson et al. 2025; Smith et al. 2026).

Ocean compound extremes, precursors and mechanisms with budgets

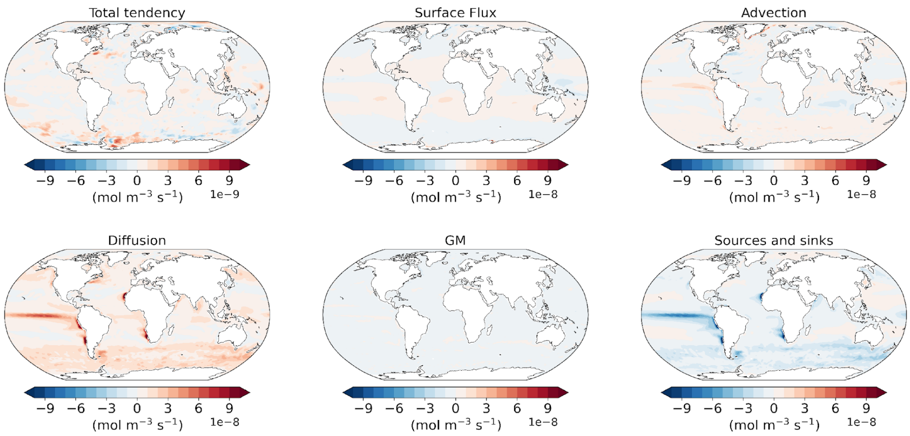

Fig. 1 Budget terms of dissolved inorganic carbon at the surface for the last year of the 100-year MPI-ESM flat10 simulation.

Ocean extremes, including marine heatwaves, low pH, and low oxygen extremes, and the compounds, evolve with emission changes. They show different hysteresis behaviours both in the surface and subsurface. We have presented the results at the Ocean Sciences meeting (Filippou et al. 2026) and the manuscript is in preparation. We have also applied ML and explainable AI to trace precursors of the ocean extreme events. The first results of ML-based prediction of marine heatwaves and identifying the precursors in the North Atlantic will be shown at EGU (Radin et al. 2026).

To further understand the mechanisms in regulating the changes in ocean extremes, we have extended the idealized esm-flat10 simulations with constant positive and negative CO2 emissions (Sanderson et al. 2025), including budget terms from individual processes. The newly implemented budgeting allows us to investigate the mechanisms of the changes in ocean extreme events and the responses under deep decarbonization. We have run the flat10 simulation with budgets for 100 years and checked the results. The shown plots are budget terms of the dissolved inorganic carbon (Fig. 1). With this established, we will run the simulations longer under decreasing, negative, and zero emissions to further understand the processes in regulating the extremes and related variable changes.

Neural network reconstruction of ocean heat and carbon

The ocean plays a crucial role in the climate system, taking up an estimated 89% of excess heat and 26% of annual CO_2 emissions resulting from anthropogenic activity in recent decades. However, there remains significant uncertainty around the magnitude and variability of ocean heat and carbon uptake due to the sparsity and uneven distribution of in-situ observations. Earth observations capture a more complete picture of the ocean's surface and, in combination with machine learning (ML) gap-filling methods, present an opportunity to advance our capacity to estimate ocean heat and carbon uptake and transport. Our 1° monthly temperature product uses exclusively Earth observations as input features to estimate ocean heat uptake and transport comparable with existing prediction methods such as optimal interpolation. Our 1° monthly DIC product uses a combination of Earth observations and observation-based data products to estimate ocean carbon uptake and transport, building on the previous MOBO-DIC product. Our results were presented at the Ocean Sciences Meeting 2026 (Burt, Landschützer & Olivelli, 2026).

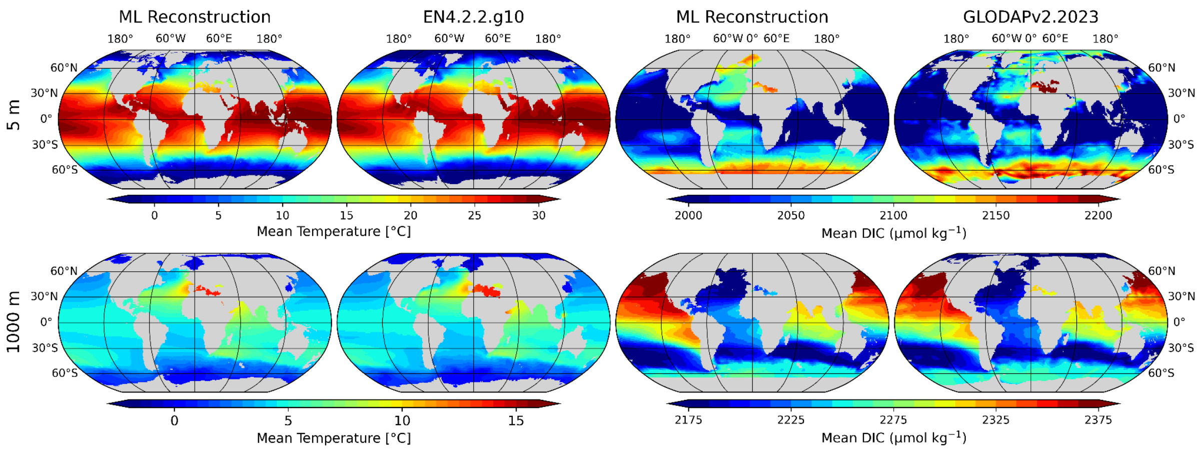

Fig. 2 Comparison of Machine Learning (ML) reconstructions of temperature and carbon against existing Optimal Interpolation temperature (EN4.2.2.g10) and carbon (GLODAPv2.2023) products at (top) 5 m and (bottom) 1000 m.

Publications:

Brovkin, V., Sanderson, B. M., Brizuela, N. G., Hajima, T., Ilyina, T., Jones, C. D., Koven, C., Lawrence, D., Lawrence, P., Li, H., Liddcoat, S., Romanou, A., Séférian, R., Sentman, L. T., Swann, A. L. S., Tjiputra, J., Ziehn, T., and Winkler, A. J., 2025. On a simplified solution of climate-carbon dynamics in idealized flat10MIP simulations, Earth Syst. Dynam., 16, 2021–2034, https://doi.org/10.5194/esd-16-2021-2025.

Burt, D.J., Landschützer, P. and Olivelli, A.: Estimating Ocean Heat and Carbon Uptake from Novel Earth Observation-informed Machine Learning-based Data Products, Ocean Sciences Meeting 2026, Glasgow, UK, 22–27 February 2026.

Filippou, D., Li, H., and Ilyina, T.: Ocean Compound Extreme Events Under Emission Reduction and Negative CO2 Pathways, Ocean Sciences Meeting 2026, Glasgow, UK, 22–27 February 2026.

Li, H., Choi, H.-J., Ramme, L., Liu, B., Li, C., and Ilyina, T.: Transient climate-carbon feedbacks under deep decarbonization pathways, CMIP community workshop, 9-13 March 2026

Radin, C., Mathis, M., Li, H., and Ilyina, T.: Explainable AI for Identifying Precursors of Extreme Oceanic Events in the North Atlantic, EGU General Assembly 2026, Vienna, Austria, 3–8 May 2026, EGU26-19617, https://doi.org/10.5194/egusphere-egu26-19617, 2026.

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, Geosci. Model Dev., 18, 5699–5724, https://doi.org/10.5194/gmd-18-5699-2025, 2025.

Smith, C., Ramme, L., Wells, C. D., Gjermundsen, A., Li, H., Ilyina, T., Muralidhar, A., Bourgeois, T., Schwinger, J., Romero-Prieto, A., Li, C., and Mauritzen, C.: Overshoot and (ir)reversibility to 2300 in two CO2-emissions driven Earth System Models, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2025-5292, 2025.