Project: **1124**
Project title: **CCiCC**
Principal investigator: **Tatiana Ilyina**
Report period: **2022-05-01 to 2023-04-30** (*Text: maximum of two pages incuding figures.)*

I. Reconstructions and predictions of the global carbon budget

Our study on the reconstructions and predictions of the global carbon budget with MPI-ESM based on nudging assimilation method was published in Earth System Dynamics (Li et al., 2023a). This is the first study investigating the GCB variations and predictions with an emission-driven prediction system. By assimilating physical atmospheric and oceanic data products into MPI-ESM, we are able to reproduce the annual mean historical GCB variations from 1970–2018, with high correlations of 0.75, 0.75, and 0.97 for atmospheric CO2 growth, air–land CO2 fluxes, and air–sea CO2 fluxes, respectively, relative to the assessments from the Global Carbon Project (GCP). Retrospective predictions initialized from the simulation in which physical atmospheric and oceanic data products are assimilated show high confidence in predicting the following year's GCB. The predictive skill is up to 5 years for the air–sea CO2 fluxes, and 2 years for the air–land CO2 fluxes and atmospheric carbon growth rate.

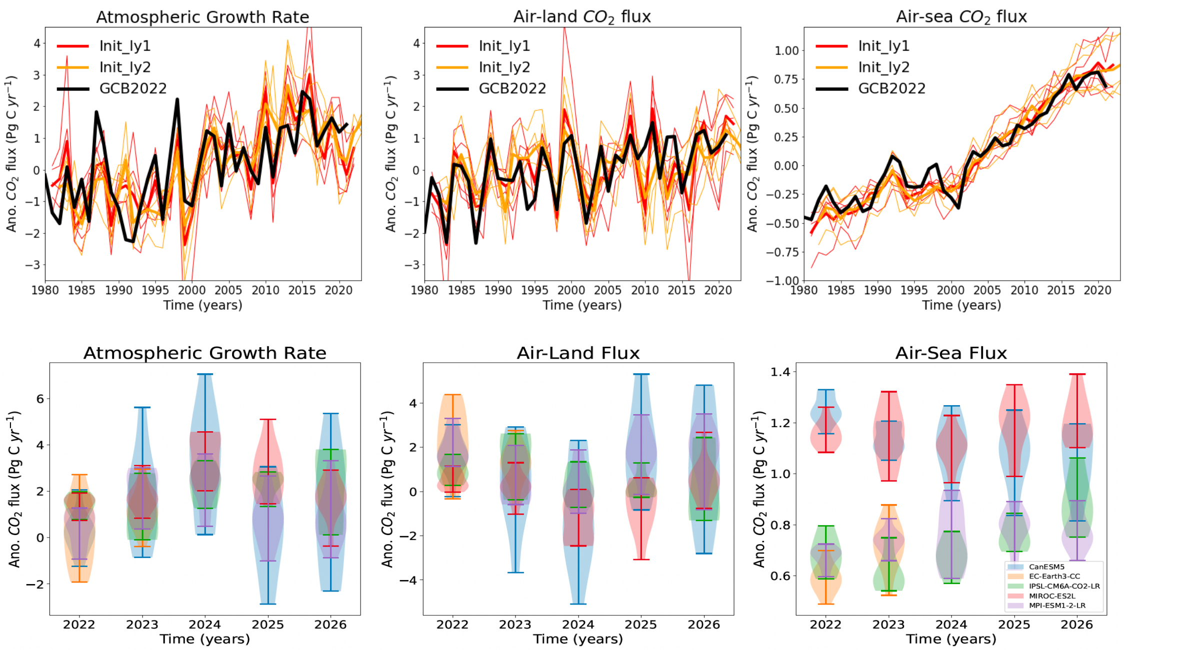

Figure 1. Upper panels: time series of anomalous atmospheric CO2 growth rate (left), air-land CO2 flux (middle), and air-sea CO2 flux (right) at lead time of 1 year and 2 years from multi-model predictions together with the recent global carbon budget estimates (GCB2022, Friedlingstein et al., 2022). The anomalous is calculated by removing the respective climatological mean for the time period from 1985-2014. **Lower panels:** Prediction of the corresponding CO2 fluxes in the next years, the colors show individual models' predictions with ensemble spreads.

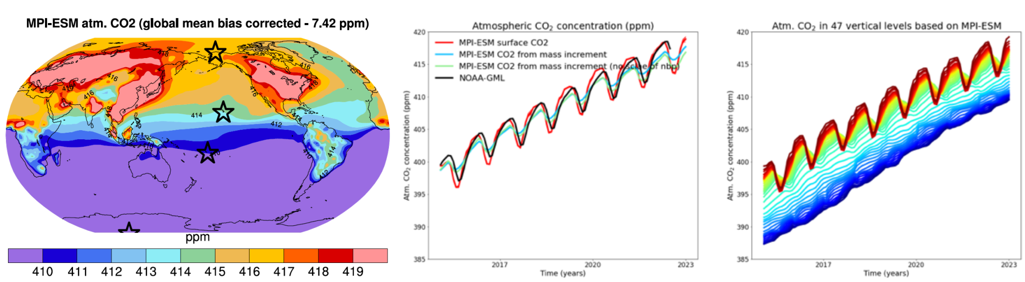

Figure 2. Left panel: Spatial distribution of atmospheric CO2 concentration in the year 2020. **Middle panel:** Time series of surface atmospheric CO2 concentration from MPI-ESM assimilation and hindcasts (red curve) together with NOAA-GML observations (black curve), the green and cyan curves show the vertical column integrated values. **Right panel:** Time series of atmospheric CO2 concentration from MPI-ESM simulation from all 47 vertical levels from the surface to top levels showing with different colours.

With a new assimilation method of the Ensemble Kalman filter of assimilating EN4 temperature and salinity profile data into MPI-ESM, we were able to maintain the reconstruction and prediction of the global carbon budget as found in the previous prediction system with the nudging method. Based on the predictions of the MPI-ESM system together with the other 4 ESMs from project partners (CanESM5, EC-Earth3-CC, IPSL-CM6A-CO2-LR, MIROC-ES2L), we investigated the reconstructions and predictability, and further make predictions for the next years in a multi-model framework as shown in Fig. 1. The spatial distribution and seasonal cycle from MPI-ESM simulations are shown in Fig. 2. A manuscript based on this study is in preparation (Li et al., 2023b).

II. Adaptive emissions scenario accounting for frozen soil carbon stocks

Our major objective was to quantify future CO_2 emission pathways over this century and beyond that are consistent with Paris agreement's temperature targets (that is reducing anthropogenic GHG emissions to stay well below 2°C above preindustrial levels), accounting for excess carbon that might become available for decomposition in the soil due to permafrost thaw in warming climate. We use an Adaptive Emission Reduction Approach (AERA) driven MPI-ESM, resulting in adapted future greenhouse gas emission pathways (Fig.3a). The frozen carbon stocks below the active layer are initialized using the recent observations. As the soil thaws additional carbon becomes accessible for decomposition, and gradually released into the atmosphere (Fig. 3b and 4).

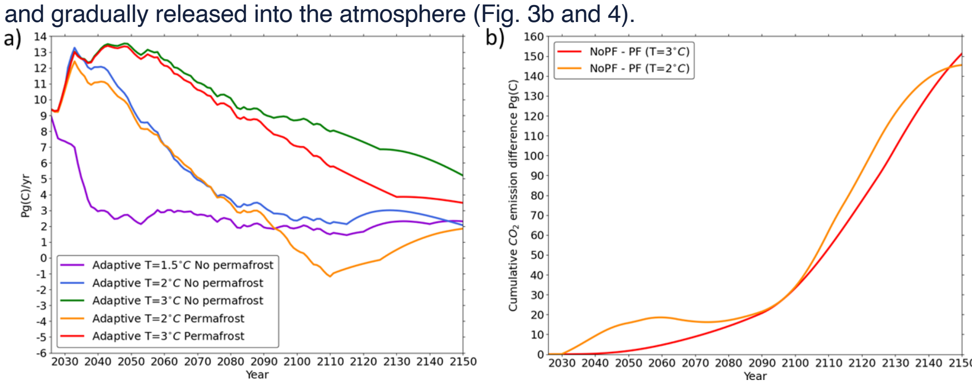

Figure 3: Time series of fossil fuel CO_2 emissions as calculated using AERA driven MPI-ESM simulations for various prescribed warming target including frozen carbon stocks in permafrost, and without (a). Cumulative deficit (due to release of frozen soil carbon) of available atmospheric carbon budget to keep below prescribed target warming (b).

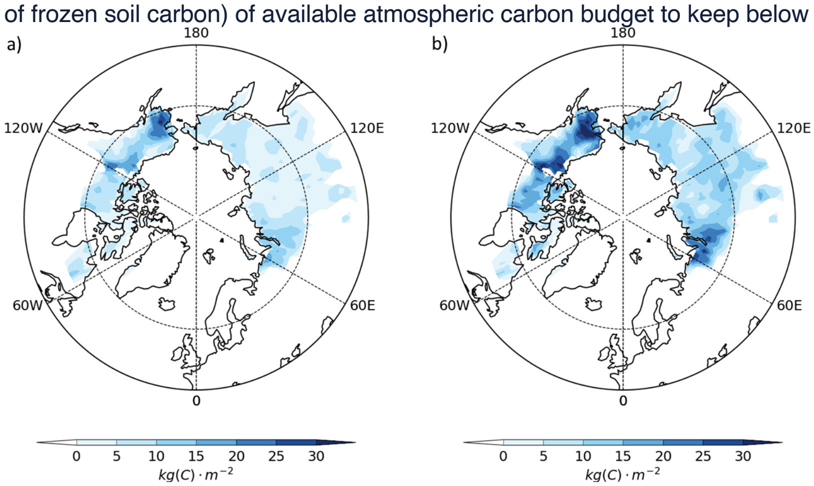

Figure 4: Carbon available for decomposition due to the thawing soil in period 2026 – 2150 for 2°C warming (a), and for 3°C prescribed warming (b).

Publications: Li, H., et al. (2023a). Reconstructions and predictions of the global carbon budget with an emission-driven Earth System Model. Earth System Dynamics, 14, 101-119. doi:10.5194/esd-14-101-2023.
Georgievski, G, et al (2022). Adaptive emission scenario simulations with MPI-ESM.GC13B-05 presented at 2022 Fall meeting, AGU Chicago (https://agu.confex.com/agu/fm22/meetingapp.cgi/Paper/1109537)
Li, H., et al. (2023b): Variations of the CO2 fluxes and atmospheric CO2 in multi-model predictions with an interactive carbon cycle, EGU General Assembly 2023, https://doi.org/10.5194/egusphere-egu23-14765, 2023.
Reference: Friedlingstein, P., et al (2022): Global Carbon Budget 2022, Earth Syst. Sci. Data, 14, 4811–4900, https://doi.org/10.5194/essd-14-4811-2022.