Project: **1124**
Project title: **CCiCC**
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I. Predictability of the global carbon cycle based on perfect model framework

Using perfect-model Earth System Model (ESM) simulations, i.e., the atmospheric CO_2 concentration is calculated prognostically instead of prescribed, we show that variations in atmospheric CO_2 are potentially predictable for 3 years. With the predictability of the isolated effects of land and ocean carbon sink on atmospheric CO_2 of 5 and 12 years respectively. This research indicates the potential of ESM-based predictions to forecast multi-year variations in atmospheric CO_2. A paper based on the results has been published on Geophys. Res. Lett..

Publication: Spring, A., and Ilyina, T. (2020). Predictability Horizons in the Global Carbon Cycle Inferred from a Perfect-Model Framework. *Geophys. Res. Lett.*, e2019GL08531.

II. large ensemble of emission-driven historical and scenario simulations

The aim of this large ensemble is to understand and to quantify the internal variability versus forced signal of the global carbon cycle and climate in the presence of interactive carbon cycle. The simulations are based on CMIP6 MPI-ESM-LR emission-driven configuration. So far 30 members of historical plus ssp245 and ssp585 scenario simulations have been finished, the other scenarios, i.e., ssp126 and ssp370 have 10 members each until year 2099. The emission-driven simulations show advantages in capturing the spatial pattern and temporal evolution of the atmospheric CO_2 concentration. As show in Fig. 1, the ensemble based on emission-driven simulations show large internal variability in the carbon fluxes and the atmospheric carbon increment. Further investigation towards attributing the variability to large scale circulation changes and climate oscillations will shed lights on near-term predictions. This set of large ensemble simulations is also contributed to the CMIP6 C4MIP, 10 members of these emission-driven historical and ssp585 simulation have been cmorized and published on ESGF.

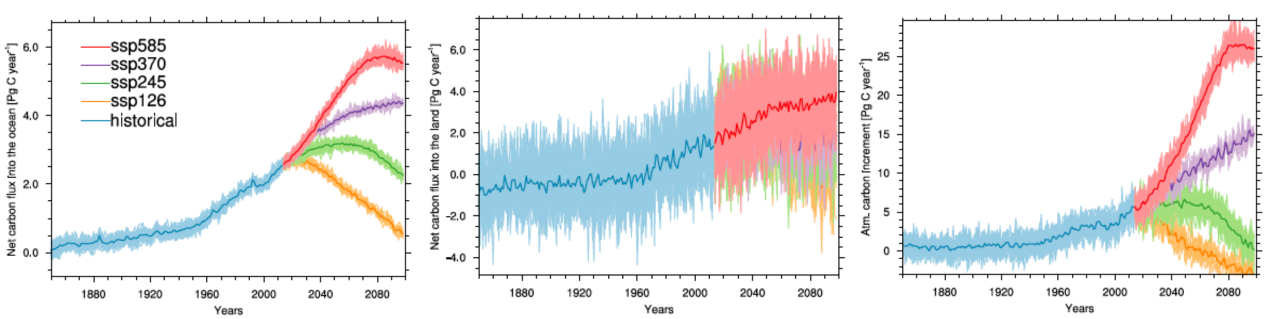

Fig. 1 Time series of carbon flux into the ocean (left), carbon flux into the land (middle), and atmospheric carbon increment (right) based on emission-driven large ensemble simulations.

III. Predictive skill of global carbon cycle based on assimilation and hindcasts

We have run three sets of simulations to quantify predictive skill for the global carbon cycle: (i) an assimilation simulation in which the three-dimensional (3D) atmospheric and oceanic physical states (ocean temperature and salinity, atmosphere winds and temperature) are restored toward ECMWF reanalysis data, (ii) an ensemble of 10 initialized hindcasts, i.e., 10-year-long prediction simulations starting from the assimilation run yearly from 1958-present; and (iii) an ensemble of 10 uninitialized simulations, i.e., continuous historical simulations, used as a reference to quantify the improvement of predictive skill of global carbon cycle due to initialization.

Here we show only the detrended time series to mainly focus on the multi-year variations (Fig. 2), which are more difficult for model to capture and to further predict than the linear trend. The assimilation shows consistent variations of carbon fluxes and atmospheric carbon growth as in Global Carbon Budget (GCB2018, Le Quéré et al. 2018) with high correlations. This coherence is also found in the initialized hindcasts at lead time of 2 years, especially for the air-land carbon fluxes. These results show potential of assimilation run in producing the evolution of carbon cycle as in the real world and also indicate skill in predicting the global carbon cycle in the next years. Furthermore, our assimilation provides a novel approach to quantify the global carbon budget in a fully coupled close system.

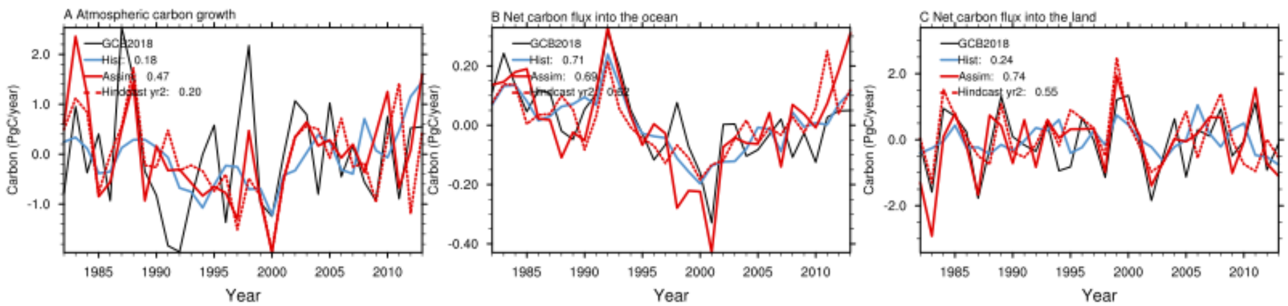

Fig. 2 Detrended time series of atmospheric carbon growth (left), carbon flux into the ocean (middle), and carbon flux into the land (right) from assimilation and hindcasts (in red) at lead time of 2 years together with the uninitialized historical simulations (in blue). The reference data used is Global Carbon Budget (GCB2018, in black), which is mainly based on stand-alone model outputs. The numbers in the legend show correlation coefficients of the respective simulations with GCB2018.

IV. Assimilation comparison in perfect-model framework

The goal of our perfect-model assimilation simulations is to estimate how well we can reconstruct marine biogeochemical fields by only directly assimilating physical variables. In the current state-of-the-art prediction systems for carbon cycle predictions no initial conditions from the carbon cycle are directly inserted into the model. This is mainly due to lack of data such as marine biogeochemical fields and also the occurrence of strong initialization shocks [Kröger et al. 2018, Toggweiler, 1989]. In a perfect-model framework, we have all output available and can test the benefit of having more or less variables nudged. Therefore, we reproduced atmospheric 6h output from CMIP6 esmControl and ran different assimilation type simulations (Fig. 2). With these we can compare how well initialized perfect-model simulations can predict the evolution of this control simulation and how well initial conditions need to be constrained by assimilation to do so with a focus on the global carbon sinks.

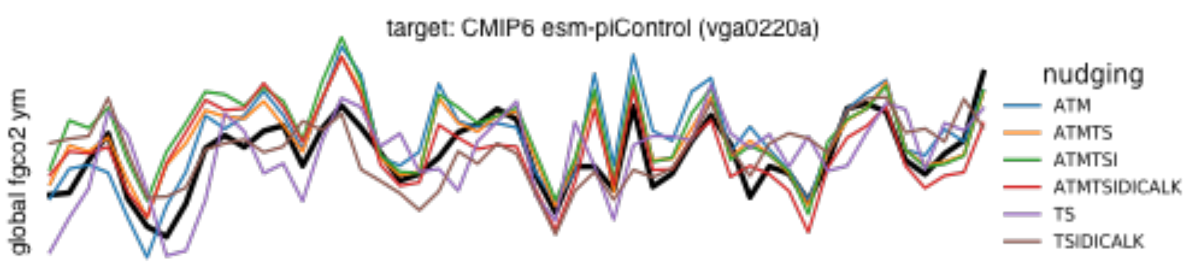

Fig. 3 Evolution of the global carbon fluxes into the ocean from assimilations with different combination of nudging quantities (in colors) in comparison with the reference run (in black).

References:
Le Quéré, C., et al. (2018), Global carbon budget 2018. *Earth Syst. Sci. Data*, 10, 2141–2194
Kröger, J., et al. (2018), *Climate Dynamics*, 51, 2593-2608.
Toggweiler, J. R., Dixon, K., & Bryan, K. (1989). J. Geophys. Res.: Oceans, 94(C6), 8217–8242. doi: 10/ffvkfj