Project: **976**
Project title: **EU H2020 CRESCENDO; Marine Biogeochemical Processes**
Principal investigator: **Tatiana Ilyina**
Report period: **2019-01-01 to 2019-12-31**

1 Project Overview

The EU Horizon 2020 project 'CRESCENDO' (Coordinate Research in Earth Systems and Climate: Experiments, kNowledge, Dissemination and Outreach) aims to improve the process realism to advance our understanding of the Earth System. By improving the representations of both physical climate and key biogeochemical processes, CRESCENDO advances the future climate prediction reliability of Earth System Models (ESMs) and fosters the assessability of Earth system changes and environmental responses of potentially significant socio-economic and ecosystem relevance.

In the present report period, we continued working on improving the biogeochemical processes in the model that control the biological pump, which is relevant for carbon, oxygen, and nutrients cycles. The model simulations in this project are **independent of DECK and scenario simulations of CMIP6**. We work in cooperation with the MARMA project (with Joeran Maerz) for continuous model development. We also worked in corporation with the OCTANT project (with Katharina Six and Anne Mouchet) exploring relevant physical processes in the model.

2 Report on Computational Time 2019

We aim to understand to what degree the ocean physical model and the biogeochemistry model can be utilized to gain insights on representation of carbon, oxygen and nutrient cycles. Here we report two on-going projects.

Ocean Physics: Sensitivity on horizontal and vertical resolution For the purpose of elucidating the fate of oxygen and nutrients in the Pacific Ocean (hosts one of the most largest Oxygen Minimum Zone (OMZ) in the ocean), we divided the model domain into several boxes and determined the age of these boxes (i.e. time past since the water of the box being in contact with the surface layer). Furthermore, we applied the method of partial ages [2] which keep track of the sub-regions visited by the tracer parcel along a flow path. The comparison of the ages obtained with different model resolution allow evidencing potential model shortcomings with respect to the ventilation (or renewal rate of water) in the equatorial Pacific Ocean and deep ocean.

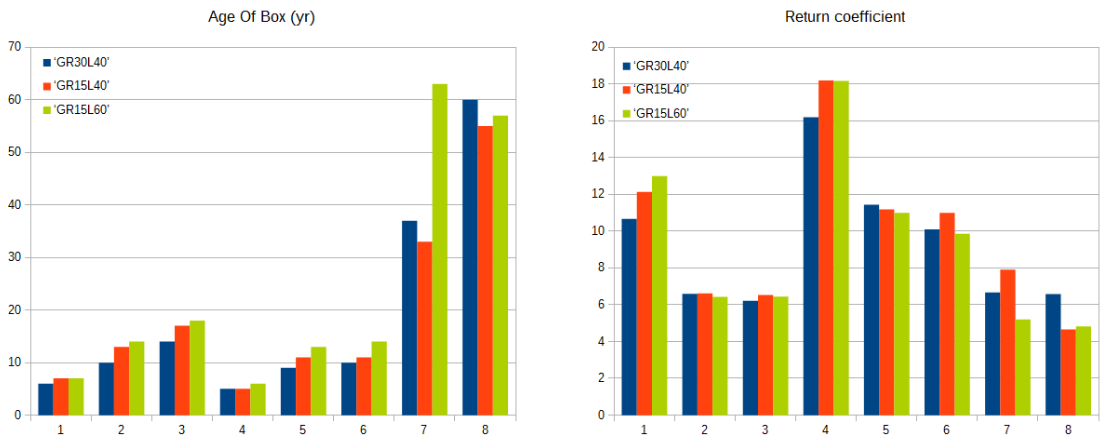

Figure 1: Ages of boxes in the Pacific Ocean (left) and return coefficient for the same boxes(right). Three model resolution are considered GR30L40 (blue), GR15L40 (orange), and GRL60 (green). These are preliminary results as the ages with GR15L40 and GR15L60 did not reach steady-state yet.

We base our analysis on three stand-alone set-ups of MPIOM; the two standard versions, GR30L40 and G15L40, as well as one newly designed set-up, GR15L60, which has an identical horizontal resolution as GR15, but 60 levels with a higher resolution at mid depth (38 levels between 0 -1000m instead of 24 as in L40). Preliminary results in Fig. 1 illustrate the potential of the method. At the exception of box 8 (at 100-2500 m depth of the western Pacific), there is a general tendency for the ages of boxes to increase with resolution (Fig. 1 left). Noticeable enough is the larger age value obtained with the best resolution (GR15L60) in box 7 (in the deep eastern Pacific). By combining partial ages with box ages we obtain an estimate of the mean number of transits through a specific box (return coefficient; Fig. 1 right).

The partial ages for the high-resolution set-ups (GR15L40/GR15L60) are still not in equilibrium. Thus, we are behind the schedule because of the longer spin-up requirement for further water mass diagnostics. Currently we are continuing on spin-up simulations with different model resolutions and targeting to explore ocean biogeochemical cycles on the model once we have simulations with sufficient amount of spin-up.

Ocean biogeochemistry: The biological carbon pump Sinking and remineralization of aggregates, formed from organic and inorganic matter produced in the sunlit upper ocean, determines the transfer efficiency and thus sequestration depth for particulate organic carbon (POC). In combination with ocean circulation, the transfer efficiency eventually determines the time scale at which carbon and nutrients reappear at the ocean surface. We advanced the representation of this biological carbon pump by explicitly characterize aggregate properties via the Microstructure, Multiscale, Mechanistic, Marine Aggregates in the Global Ocean (M^4AGO) sinking scheme in HAMOCC. With M^4AGO, we improved the representation of the POC transfer efficiency pattern. As a result of the tighter coupling of the carbon and nutrient cycles with M^4AGO, the tuning for particularly the phosphorus climatological state deserved more time than previously anticipated, which led us revise and modify our strategy for planned model runs. In the first quarter of 2019, we finalized the tuning of M^4AGO in a climatological OMIP forcing standalone setup [OMIP forcing; 3]. Based on the spun-up run, we performed three parameter sensitivity studies, where we studied the effect of aggregate structure, the size of aggregate constituents and the role of cyanobacteria growth on the transfer efficiency and the phosphorus climatology. Both, aggregate structure and constituents size, have a clear effect on the transfer efficiency, which has implications for the response of the biological carbon pump when considering potential adaptive organism size responses to climate warming. In combination with M^4AGO, cyanobacteria have a modulating effect on the subtropical gyres phosphate concentration. Further-

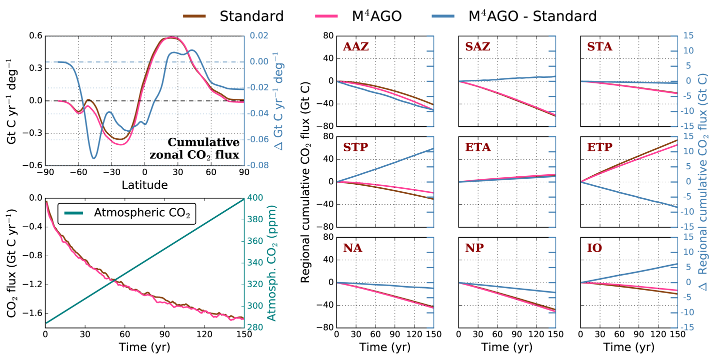

Figure 2: Climatological cumulative zonal CO_2 flux in the standard (Martin curve approach for POC fluxes) and the M^4AGO run. Global annual net CO_2 flux under linearly increasing atmospheric CO_2 concentrations. Regional cumulative fluxes under increasing atmospheric CO_2. Negative fluxes represent net-CO_2 oceanic uptake. AAZ: Antarctic Zone; SAZ: Subantarctic Zone; STA: Subtropical Atlantic; STP: Subtropical Pacific; ETA: Eastern Tropical Atlantic; ETP: Equatorial Tropical Pacific; NA: North Atlantic; NP: North Pacific; IO: Indian Ocean.

more, we performed uncoupled climatological OMIP forcing runs with increasing atmospheric carbon dioxide (CO_2) concentration to gain first insights into the regional consequence of the changed transfer efficiency pattern on CO_2 fluxes. Major effects were visible in the Antarctic zone and the Subtropical and Tropical Pacific, where CO_2 fluxes increased and decreased, respectively (see Fig. 2). This study is summarized, online available and in review [1]. At present, we are running coupled HAMOCC-MPI-ESM piControl-runs in grid resolution GR15 to tune M^4AGO to the coupled model physics state with the aim to gain insights into oceanic CO_2 uptake in a transient run. Sinking velocity of porous aggregates in stratified waters due to salinity gradients can be reduced by i) increased drag and ii) diffusion-limited buoyancy adaptation of interstitial pore water. The representation of these two processes in M^4AGO is underway and well advanced. We expect to start coupled HAMOCC-MPI-ESM runs to tune the advanced M^4AGO scheme in early November this year.

References

[1] Joeran Maerz, Katharina D. Six, Irene Stemmler, Soeren Ahmerkamp, and Tatiana Ilyina. Microstructure and composition of marine aggregates as co-determinants for vertical particulate organic carbon transfer in the global ocean. *Biogeosciences Discussion*, 2019.

[2] A. Mouchet, Deleersnijder E. Cornaton, F., and E. Delhez. Partial ages: diagnosing transport processes by means of multiple clocks. *Ocean Dynamics*, 66:367–386, 2016.

[3] F. Röske. Global oceanic heat and fresh water forcing datasets based on ERA-40 and ERA-15. Technical Report 13, Max Planck Institue for Meteorology, 2005.