Project: 1255
Project Title: ESM2025
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1 Preface

ESM2025 is an EU H2020 project aiming at developing the next generation of Earth System Models (ESMs). For 2022, only four work packages (WP2, WP3, WP4 and WP10) applied for computational resources, and thus their reports are summarized based on their work packages.

2 Resource usage

After the availability of Levante, the computation time planned for the second quarter of 2022 were not fully used due to the technical difficulties arising from the transition from Mistral to Levante as well as the instability of the system in the beginning. Furthermore, for WP3, the postdoc for ESM2025 was hired later than expected and started in June 2022.

	Allocated for 2022	Consumed (Oct 2022)	Projection of consumption by end of 2022
Computing time [nodehours]	137,957	53,928	71,000
Temporary storage [TiB]	144	150	150
Storage / arch [TiB]	97	0	70
Long term storage [TiB]	15	0	10

3 Outcomes and experiments

3.1 WP2

MPI-B tested a new version of ICON-Land, including the QUINCY model [1], as an alternative representation of biogeochemical land processes to JSBACH4. Initial tests revealed issues with the performance of the code, which we will address in the next year, using resources from the MPI-B (terrestrial biogeochemical cycles in the climate system) project. Using an offline R2B4 configuration driven by CRU JRA v2 forcing, the code currently requires 0.75 nh/myear on Levante, with approx. 100 GB/myear output (20 GB/myear + restart). We aim to further improve model performance and clean up the integration of the QUINCY code into ICON-L before engaging in operational model testing and coupled simulation in year 2024. The simulation results show that implementation of QUINCY results in a realistic present-day representation of the distribution of productivity. Isotope-tracers also agree well with the expected patterns (not shown here).

3.2 WP3

Extended N-cycle in MPI-ESM

The extended N-cycle has been successfully implemented within the MPI-ESM, which is no longer supported and why developmental efforts were focused on implementation and tuning within HAMOCC-ICON. We are currently tuning the extended N-cycle in a pre-industrial control simulation with the coarse-resolution of the MPI-ESM as a baseline for long-duration simulations. Developmental work here has focused on resolving bugs resulting from the effects of parameterisations inherent to coarse resolutions. These bugs were primarily due to mass non-conservation as a result of diffusive fluxes in the deep ocean, which were noted to have decreasing influence with increasing resolution. Furthermore, tuning the new processes and variables included within the extended N-cycle of HAMOCC is limited at coarse-resolutions due to the lack of comprehensive observations of NH_4 and NO_2 in the global ocean, where surveys are largely focused to oxygen minimum zones.

Extended N-cycle in ICON-O

The extended N-cyle has been successfully included in HAMOCC-ICON-O. We started working on creating pre-industrial control (piCtrl) simulations using the ICON-O 40 km configuration. Because the NCEP forcing resulted in poor AMOC results, we first spun up the ocean using OMIP forcing (spinOMIP). To avoid discontinuities when starting a historical transient from spinOMIP, we extended this spin-up with 200-year experiments using the ERA5 forcing (spinERA5). The spinERA5 experiments also served as a means to tune HAMOCC for the new ICON configuration using the default and the extended N-cycle. We have produced a stable piCtrl using the default N-cycling (piCtrl_defN) and are currently tuning the extended N-cycle to create a comparable piCtrl (piCtrl_extN). Both piCtrls use the explicit marine aggregate scheme M^4AGO which has not been used in combination with the extended N-cycle before. Therefore, we are currently working on producing two additional pre-industrial controls that employ the default sinking scheme for particulates in HAMOCC – the Martin-curve approach. The simpler Martin-curve approach should facilitate the tuning process of the extended N-cycle in the new configuration and enable comparison of our simulation results with previous models. The four piCtrls will serve as a baseline for our historical transient simulations and all future experiments. Figure X shows the spatial distribution of two new variables (NH_4, NO_2) that are explicitly represented in the new model using the extended N-cycle.

Finally, we did a first proof-of-concept run using the extended N-cycle in an ICON-ESM setup. For this, we used a lower-resolution configuration consisting of an R2B3 atmosphere coupled with an R2B4 ocean. For the spinup, the atmosphere is initialized from analysis files and uses constant pre-industrial boundary conditions for the year 1850. The ocean is spun up from a long tuning run (3000 years) using the default N-cycle. From this, we started an experiment enabling the untuned, extended N-cycle. The experiment ran stable for 100 years.

Vertical mixing schemes in ICON-O

We carried out sensitivity studies to test the effect of different TKE mixing parameters on the ocean biogeochemistry tuning parameters in the R2B6 setup of HAMOCC-ICON-O. The studies showed that optimizing the c_k parameter to decrease the ocean temperature bias in the mixed layer depth also decreases the ocean biogeochemistry bias. Specifically, the optimized setup lead to a simulated mean net carbon sink uptake of 2.08 GTC/yr for 2000-2009, which is well within the range of 2.1 ± 0.5 GtC/yr reported by the Global Carbon Budget. Previously, in the Ruby0 setup, with a lower vertical mixing diffusivity, the carbon uptake was simulated to be 1.61 GtC/yr, which is on the lowest range of CMIP6 models.

Phytoplankton feedback in ICON-O

The vertical profile of shortwave radiation absorption in the ocean is by default set to constant in ICON-Ocean. However, in the ocean, shortwave penetration depends on the concentration of phytoplankton and cyanobacteria. The temporal and spatial distribution of phytoplankton and cyanobacteria has, therefore, an effect on the vertical profile of temperature in the ocean. This biogeochemical-physical feedback was implemented in MPIOM [2, 3], but had so far not been tested in ICON. In a series of experiments with ICON-O in R2B6 (40 km), we were able to identify and correct bugs in the dynamic shortwave absorption routine, called when the phytoplankton feedback was switched on. We reproduce qualitatively the results from the original implementation of this feedback (Fig. 1). Not only does the shortwave absorption feedback change the temperature profile in sunlit regions, but also the vertical stability of the water column. Moreover, there is substantial subsurface warming in the tropics. The difference between simulations with and without the phytoplankton feedback reaches about 1°C with maxima at around 100 m depth, which deepens the mixed layer.

The differential distribution of ocean temperatures due to the phytoplankton and cyanobacteria distribution impacts surface heat fluxes with the atmosphere, having significant impacts on surface atmospheric temperatures, precipitation, and circulation [2]. Therefore, The successful representation of the phytoplankton feedback represents an important step towards the fully coupled configuration of ICON-ESM.

3.3 WP4

Work is progressing on integratng the parametrized emission-driven atmospheric methane sink into ICON-Art. The sink parametrization itself is implemented and currently tested with prescribed emissions. The implementation of interactive emissions driving the atmospheric chemical methane sink like lightning-NOx or biogenic emissions of VOCs (volatile organic compounds) is ongoing work. Especially the lightning-NOx source requires an interactive coupling with the hydrological cycle. All interactive sources furthermore need an online 3D-budgeting, i.e. the calculation of the integrated global emissions. The ICON interface for these task is also currently under development and testing.

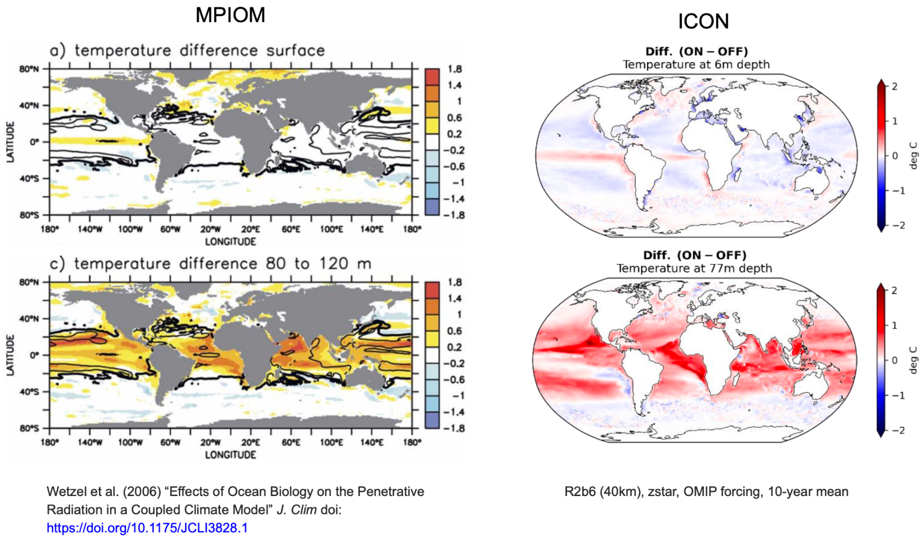

Figure 1: Left: long-term differences in surface and subsurface ocean temperatures, between simulations with and without the Phytoplankton Feedback in MPIOM from Wetzel et al. (2006). Right: the same, but for ICON-Ocean in the R2B6 configuration (40km resolution).

3.4 WP10

Work is progressing on integrating (i) forest age classes with a description of land-use change and (ii) a representation of herbaceous biomass plantations (HBPs) in JSBACH4. As basis for (i), the forest age classes of [4] are integrated in JSBACH4/ICON-Land with natural disturbances (wind, fire), while at the same time the land-use transition scheme, which describes land-use changes including sub-grid scale transitions between various natural and anthropogenic land cover classes, is being implemented in JSBACH4/ICON-Land. For (ii) we improved the flexibility of a previous implementation [5] in terms of restart capabilities and interactions with other land-use changes. For both strands of work, as anticipated, only test simulations have been performed during 2022, with work having been slowed down by the transition from mistral to levante. Operational runs are expected for 2023.

4 Publications and Presentations

Chegini, F., Ramme, L., Maerz, J., Casaroli L., Nielsen, D., Hülse, D., Ilyina, T., "The HAMburg Ocean Carbon Cycle model in ICON: Lessons learnt from tuning ocean biogeochemistry in a newly developed model", (Presentation, ESM2025 General Assembly)

Hülse, D., van de Velde, S., Pika, P., Bradley, J., Dale, A., and Arndt, S. "Global budgets of organic carbon degradation pathways in marine sediments", (Poster, ESM2025 General Assembly)

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