Project: **1102**

Project title: **SFB-Transregio (TRR181)**

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The previous and current phase of the DKRZ project were aimed at 1) performing ICON-o simulations with included tidal forcing, 2) preparing and performing high-resolved simulations with a horizontal and vertical resolution which is high enough to resolve submesoscale dynamics in the South Atlantic ocean (referred to as SMT-WAVE simulations) and 3) performing simulation to study the effect of upper-ocean turbulence on air-sea coupling. The goal of these simulations are to study energy transfers between 1) tides and mesoscale eddies, 2) mesoscale and submesoscale eddies, 3) the atmosphere and the ocean under the influence of upper-ocean turbulence like turbulent mixing and submesoscale dynamics.

A couple of technical developments are key for such high resolved simulations:

1a) implementation of tides into ICON-o

1b) tuning the model with respect to the tidal forcing
2a) implementation of the "zstar" vertical coordinate approach which is necessary to achieve the high vertical resolution we are aiming for
2b) testing the zstar coordinate and thin upper layers in numerous configurations

3a) implementation of "partial bottom cells" (PBCs) which allow the very last vertical grid cell which is filled with water to have a varying thickness. This assures that the total water depth is much closer to the actual bathymetry and not so much dependent on the vertical resolution in the deep ocean which is usually coarse.

4) develop sophisticated post-processing toolboxes to analyse these big data sets.

While the steps 1a, 2a, and 3a were successfully completed during last year's phase of the project, we were able to finish the testing and tuning phase of the tidal forcing and the zstar and PBC coordinates (1b, 2b, and 3b). Furthermore, we considerably expanded the python software module pyicon for analysing ICON data to also handle big data sets in parallel on many compute clusters.

The R2B8 spin-up for SMT-WAVE

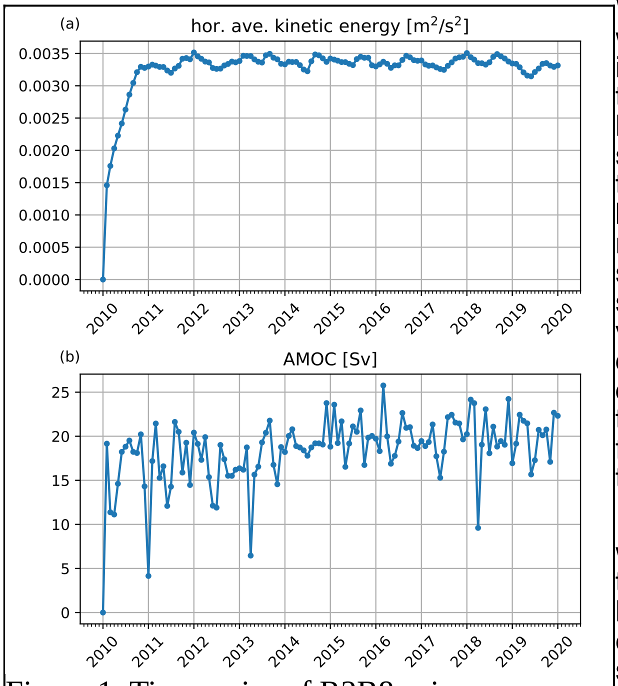

Figure 1: Time series of R2B8 spinup simulation as preparation for the SMT-WAVE simulation (a) for kinetic energy and (b) for the AMOC.

We were able to run a 10-year long simulation with a vertical resolution that corresponds to what is needed for the SMT-WAVE simulation (2m in the upper ocean) but which has a much coarser horizontal resolution (10km, R2B8). This simulation served on the one hand side as a testbed for the above mentioned developments but it will also provide the spin-up for the higher resolved SMT-WAVE simulations and other simulations outside of this project (e.g. R2B9 simulations used in NextGEMS Cycle1). The vertical resolution together with the zstar vertical coordinates and partial bottom cells which were developed and tested in this project will become the new standard vertical coordinate framework for ICON-o simulations for horizontal grids finer than 10km.

In Fig. 1, we show two important time series which indicate the R2B8 spin-up is long enough to fulfil the requirements of this project. The horizontally averaged kinetic energy has equilibrated already after 2 years of the simulation (Fig. 1a) which indicates that mesoscale eddy field has spun up and there is enough mesoscale variability and fronts on which submesoscale dynamics can grow on in the following SMT-WAVE runs. Furthermore, also the AMOC has equilibrated largely after 5 years (Fig. 1b) which indicates that no sever drifts in the circulation are to be expected for the SMT-WAVE simulation period.

SMT-WAVE simulation

From a snapshot in 07-01-2019 of this spinup we interpolated the velocity and tracer fields to the SMT-WAVE grid which here serve as initial conditions. It turned out that starting the SMT-WAVE simulation is very sensitive to the way of interpolating the data sets since the imprint of the coarse grid can cause instabilities. Furthermore, we detected a problem with one parameter of the partial bottom scheme which was recently resolved. This improvement will also be beneficial for other projects like NextGEMS. At the moment, we were able to run the full SMT-WAVE simulation for a whole day. The velocities seem to have equilibrated so that we are confident to successfully continue the simulation about the desired four month.

The 3D output is still a major problem which is not yet resolved. This output requires more memory then what is available on a single note and therefore needs to be written out in parallel. Technically, ICON-O should be able to do this using the cdi-pio library. However, this library does not seem to work properly for large grids. The DKRZ which is developing and maintaining this library is informed about the problem and will provide a solution.

The lack of 3D output makes debugging the simulation quite challenging. So far, we tackled this issues by two work arounds: 1) relying on high-frequent 2D output at the surface where we expect an important origin for instabilities to occur and 2) by developing a method to concatenate and visualize 3D restart files. This work-around helped to achieve some progress in the debugging, however, we are still in urgent need for the parallel output to successfully investigate the issues with the partial bottom cells, which are likely to cause problems over all depth.

Given the above problems, we are roughly five months behind our schedule regarding the SMT-WAVE simulation. However, we are still confident to achieve two of the three proposed four months long simulations in this remaining year. Due to this unexpected debugging time, we were not able to run the SMT-WAVE simulation as effective as we assumed in our previous DKRZ proposal. To not let the resources expire, we moved other tasks of the TRR181 project up in time. These tasks concern studying the effect of tides and developing new parameterizations for baroclinic tides and 2) the influence of upper-ocean turbulence on air-sea exchanges.

Tides

We completed a set of experiments examining the impact of various model features on the quality of the simulated tides. The tides in a control simulation performed with ICON-o in R2B6 resolution with z-coordinates is compared with the tides simulated using a) a telescope grid in Base-Camp resolution to study the impact of inhomogeneous grid, b) zstar-coordinates to study the impact of the new coordinates, c) a new self-attraction and loading parameterization, d) a new tidal dissipation parameterization, and e) an R2B8 grid to study the impact of increasing resolution. The work was mainly done by Eileen Hertiwig. Since Eileen has left MPI in May, it will take some time to further analyse this set of simulations and put the results in a form of a publication.

Air-Sea interactions

We run two four week-long coupled sensitivity experiments within the DYAMOND Winter framework (coupled ICON ocean and atmosphere models with a horizontal resolution of 5km) with modified vertical mixing. These simulations are reference studies for a later stage of the TRR181 L4 project, where the results of the SMT-WAVE simulations should be used to develop and improve parameterizations for submesoscale dynamics. These parameterizations should then be included into a DYAMOND-Winter-like setup. The reference simulations to these sensitivity tests were done during this DKRZ compute time phase instead of a later phase.

The following table summarizes the resource utilization as of 26th Aug 2021 of the above listed sub-projects:

	Node hours	Percentage
R2B8 (SMT-WAVE spin-up)	51,761	14.3
SMT-WAVE	106,964	29.6
Tides	173,106	48.0
Air-sea interactions	21,787	6.0
Post-processing	223	0.1
Expired	7,040	2.0
Sum:	360,881	100.0