Project 1239 - Collaborative Research Centre (CRC) "TRR 181" sub-project S2: Improved Parameterizations and Numerics in Climate Models

Principal investigator: Johann Jungclaus (MPI-M)
Project Participants: Nils Brueggemann, Oliver Gutjahr (MPI-M),
Sergey Danilov, Patrick Scholz, Nikolay Koldunov (AWI)

Report period: 2022-01-01 to 2022-10-31

In the reporting period, we have extended the ocean and sea ice models ICON-O (Korn, 2017; Korn et al., 2022), FESOM2 (Danilov et al., 2017) with additional tidal forcings for the IDEMIX closure (Olbers and Eden, 2013), which parameterizes internal wave energy in the ocean and the breaking of internal waves. The aim for the reporting period has been to provide a comparison of these models at a horizontal resolution of approximately 40 km, which are forced by 3-hourly JRA55-do reanalysis (1958-2019) (Tsujino et al., 2018), using the same bulk formulas from the CORE2 protocol (Large and Yeager, 2009). All other planned experiments with higher resolution configurations were postponed to the next reporting period. The reason for this postponement was the need for technical implementations prior to conducting model comparisons. For instance, in ICON-O a module had to be implemented to force the model with JRA55-do. Implementation and debugging took more time than expected, in addition to Levante's downtime. As a result, a large portion of the resources acquired could not be used in the reporting period. In addition to ICON and FESOM, IDEMIX was also implemented into the MITgcm (Marshall et al., 1997) at AWI. For this report, we only show results from ICON-O and FESOM, because an error in the configuration of MITgcm has been discovered and the simulations are currently rerun.

All models have been initialized from PHC3.0 (Steele et al., 2001) and were run for five cycles of the JRA55-do forcing. For analysis, we averaged 1979-2019 from the last cycle. For the reference simulation (REF), the TKE closure (Gaspar et al., 1990) was used to parameterize vertical mixing in the ocean. A minimum value of TKE was used to account for breaking of internal waves. In three sensitivity studies this minimum value was set to zero and the TKE

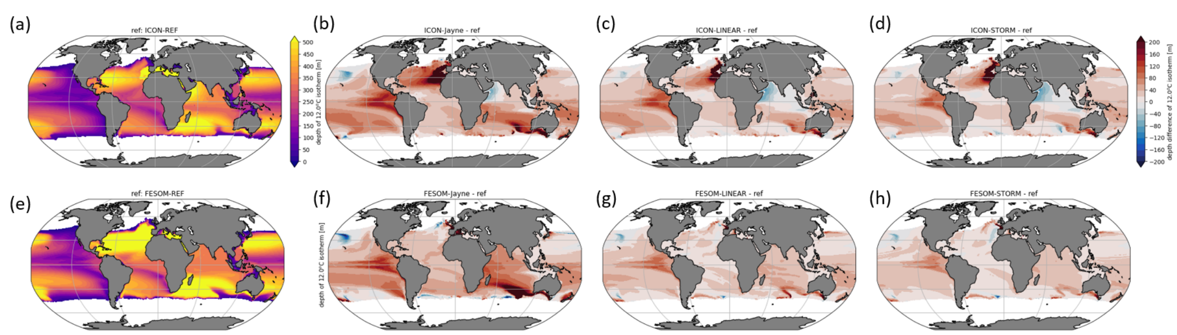

Figure 1: Depth of the 12 ° C isotherm as a proxy for the thermocline depth. The first row (a-d) shows results from ICON-O and the second row (e-h) those from FESOM. Absolute depths are shown in (a) and (e) and differences in the other panels.

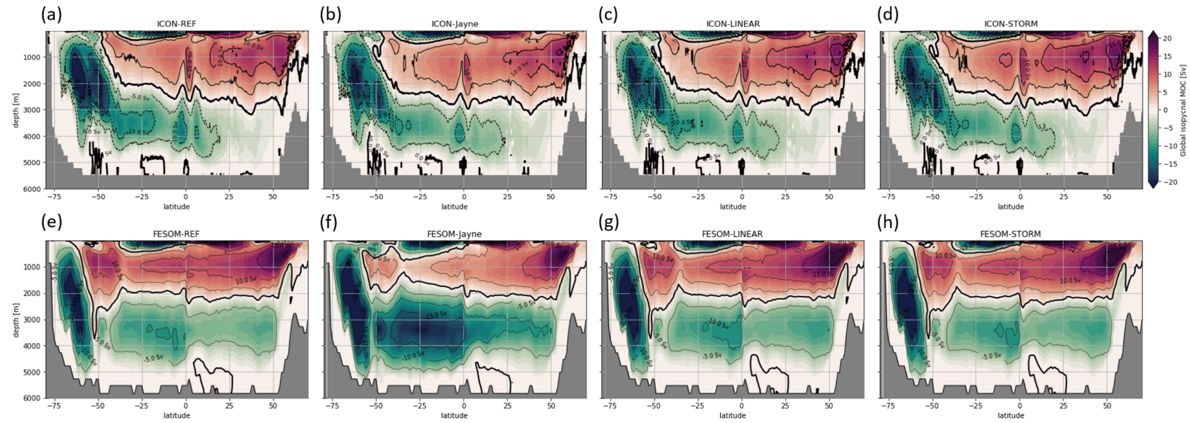

Figure 2: Global meridional overturning stream function calculated in density space and remapped to depth levels for (a-d) ICON-O and (e-h) FESOM.

scheme was used together with the IDEMIX closure to parameterize prognostically internal wave energy and the propagation and breaking of internal waves. The energy source for near-inertial waves at the bottom of the mixed layer is prescribed as a constant field, and so is the tidal energy that is transferred into the wave field. The three sensitivity simulations were run by prescribing three different tidal forcing: (1) scaling based on linear theory, used as parameterization of near-field tidal mixing (Jayne, 2009), which represents all tidal constituents (JAYNE), (2) linear theory calculations following (Nycander, 2005; Falahat et al., 2014), which uses 8 major tidal constituents (LINEAR), and (3) M2-tide generation from STORMTIDE2 simulation (Li and von Storch, 2020), with additional constituents from linear theory (STORMTIDE). Overall, we compare 12 simulations. Each simulation was forced by JRA55-do for five cycles. If not stated otherwise, we compare results averaged over the last 40 years (1979–2019) of the last cycle.

In all models, we find bottom-enhanced mixing above topography resulting from the IDEMIX closure, where internal waves are generated and propagate into the interior ocean and break. The explicit representation of internal waves in the interior of the ocean leads to more efficient downward mixing of the warmer surface water, increasing the depth of the thermocline (Fig. 1) on the order of 50 to 100 m in most parts of the (sub)tropical ocean. In general, this response is found in ICON-O and FESOM, with a noticeable deviation in the North Atlantic (Fig. 1a,b). Here the deepening of the thermocline is in particular strong in ICON-O when either of the tidal forcings for IDEMIX is used. In FESOM, however, the thermocline is already much deeper and therefore does not respond to increased mixing by IDEMIX (Fig. 1e,f). In addition, the increased mixing near the thermocline reduces a prominent cold bias in the tropical ocean in ICON-O (not shown), where the resulting eddy diffusivity from the default TKE scheme is not sufficiently strong.

Theoretically, mixing in the deeper ocean provides the return path of deep and abyssal water as denser water mixes with less dense water above, making it lighter and adiabatically upwelling in the Southern Ocean. Enhancing the mixing in the abyssal ocean should therefore increase this upwelling. By comparing the stream functions of the global meridional overturning circulation (Fig. 2), we find this response only for the JAYNE experiment with FESOM (Fig. 2f), which simulates a stronger Antarctic bottom water cell. In all other experiments, the bottom cell is not responding to the enhanced mixing. We have no final conclusions on this aspect, but the JAYNE tidal forcing is the strongest of the here used forcing options, resulting in a stronger response. The other tidal forcing are considered more realistic in terms of energy transfer from tides into the wave field, which is too large in JAYNE. It is therefore possible that the simulations are too short for the bottom cell to respond to IDEMIX closure.

The upper cell, on the other hand, responds more consistently to the use of IDEMIX in ICON-O and FESOM, and in the same direction for all tidal forcing options. There is an increase of the overturning in the subpolar North Atlantic (north of 50 ° N and a slight decrease south of the equator. We consider this effect as an indirect response by changed water mass properties that leads to stronger overturning in the high latitudes.

Overall, we find that ICON-O and FESOM respond similarly to the use of IDEMIX, with some deviations due to model-dependent features and biases. This consistent model response strengthens the confidence in the use of IDEMIX.

References

Danilov, S., D. Sidorenko, Q. Wang, and T. Jung, 2017: The Finite-volumE Sea ice–Ocean Model (FESOM2). *Geoscientific Model Development*, **10 (2)**, 765–789, doi:https://doi.org/10.5194/gmd-10-765-2017.

Falahat, S., J. Nycander, F. Roquet, and M. Zarroug, 2014: Global calculation of tidal energy conversion into vertical normal modes. *J. Phys. Oceanogr.*, **44 (12)**, 3225–3244, doi:https://doi.org/10.1175/JPO-D-14-0002.1.

Gaspar, P., Y. Grégoris, and J.-M. Lefevre, 1990: A simple eddy kinetic energy model for simulations of the oceanic vertical mixing: Tests at station Papa and long-term upper ocean study site. *J. Geophys. Res. Oceans*, **95 (C9)**, 16 179–16 193, doi:10.1029/JC095iC09p16179.

Jayne, S. R., 2009: The impact of abyssal mixing parameterizations in an ocean general circulation model. *J. Phys. Oceanogr.*, **39 (7)**, 1756–1775, doi:https://doi.org/10.1175/2009JPO4085.1.

Korn, P., 2017: Formulation of an unstructured grid model for global ocean dynamics. *J. Comp. Phy.*, **339**, 525–552, doi:https://doi.org/10.1016/j.jcp.2017.03.009.

Korn, P., and Coauthors, 2022: ICON-O: The Ocean Component of the ICON Earth System Model - Global Simulation Characteristics and Local Telescoping Capability. *Journal of Advances in Modeling Earth Systems*, e2021MS002952, doi:https://doi.org/10.1029/2021MS002952.

Large, W. G., and S. G. Yeager, 2009: The global climatology of an interannually varying air–sea flux data set. *Clim. Dyn.*, **33**, 341–364, doi:https://doi.org/10.1007/s00382-008-0441-3.

Li, Z., and J.-S. von Storch, 2020: M2 Internal-Tide Generation in STORMTIDE2. *J. Geophys. Res. Oceans*, **125 (8)**, e2019JC015 453, doi:https://doi.org/10.1029/2019JC015453.

Marshall, J., A. Adcroft, C. Hill, L. Perelman, and C. Heisey, 1997: A finite-volume, incompressible Navier Stokes model for studies of the ocean on parallel computers. *Journal of Geophysical Research: Oceans*, **102 (C3)**, 5753–5766, doi:https://doi.org/10.1029/96JC02775.

Nycander, J., 2005: Generation of internal waves in the deep ocean by tides. *J. Geophys. Res. Oceans*, **110 (C10)**, doi:https://doi.org/10.1029/2004JC002487.

Olbers, D., and C. Eden, 2013: A global model for the diapycnal diffusivity induced by internal gravity waves. *J. Phys. Oceanogr.*, **43 (8)**, 1759–1779, doi:https://doi.org/10.1175/JPO-D-12-0207.1.

Steele, M., R. Morley, and W. Ermold, 2001: PHC: A Global Ocean Hydrography with a High-Quality Arctic Ocean. *Journal of Climate*, **14 (9)**, 2079–2087, doi:10.1175/1520-0442(2001)014⟨2079:PAGOHW⟩2.0.CO;2.

Tsujino, H., and Coauthors, 2018: JRA-55 based surface dataset for driving ocean–sea-ice models (JRA55-do). *Ocean Modelling*, **130**, 79–139, doi:https://doi.org/10.1016/j.ocemod.2018.07.002.