Project: 944
Project title: EU H2020-project PRIMAVERA
Project lead: Jin-Song von Storch (MPI-M), Thomas Jung (AWI)
Allocation period: 01.01.2019 – 31.12.2019

Achievements since application for 2018:

MPI-M:

Towards the end of 2017, we have replaced the ocean vertical mixing scheme in MPI-ESM (KPP instead of PP). This indeed avoids the fresh bias in the subpolar North Atlantic and the subsequent shut-down of deep convection and keeps the AMOC stable without any flux correction for the XR configuration (T255/TP04) (Figure 1). Regarding the CMIP6 HighResMIP simulations, which will be made available to and be widely used within the climate research community worldwide, non-flux corrected simulations are highly desirable. Hence, in 2018 we have repeated the HighResMIP simulations (1950-2050 control, 1950-2014 historical) with MPI-ESM applying the KPP scheme (both low- and high-resolution version). We note that this effort has been supported by MPI-M shareholder account mh0033, as providing high-quality CMIP6 simulations is a major interest of MPI-M.

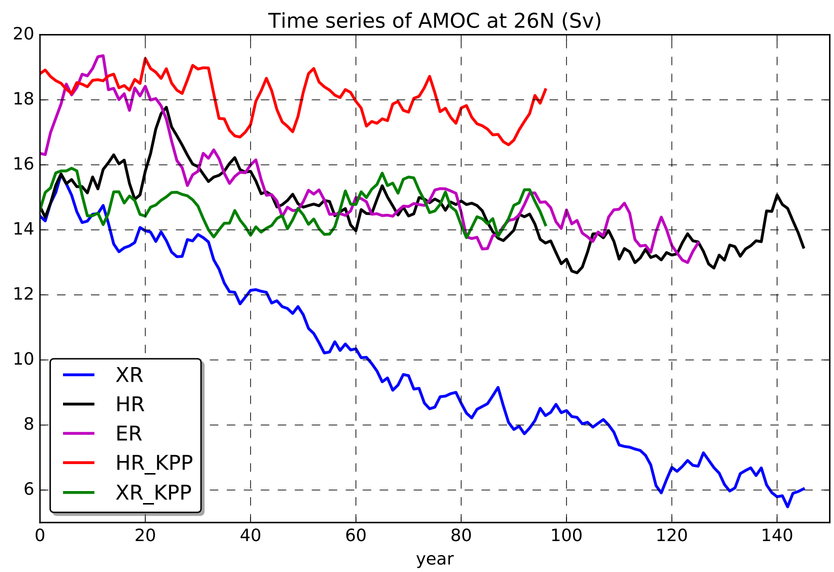

Figure 1: AMOC strength for various resolution configurations.

Thus far, only the atmospheric resolution has been enhanced. Yet in PRIMAVERA, there is great interest in evaluating the impact of an eddy-resolving ocean. Hence, a new configuration (ER; T127/TP6M) was set up for this purpose. In 2018, we have obtained a 100-year (+30 years spinup) ER control simulation. Also for this configuration, AMOC is stable (Figure 1). Ocean heat uptake and its response to strong greenhouse gas forcing is also a very relevant and contentious topic in climate studies that is to be addressed within HighResMIP and PRIMAVERA. In addition, it is unclear what the role of eddies will contribute to the heat uptake. Therefore, in 2018 we have performed a 100-year simulation applying 4xCO2 with both HR and ER configuration, which are to be compared with the respective control simulation. We note that the ER effort has been supported by MPI-M shareholder account mh0256. For the last 50-years ER simulations, we used an updated global solver for MPIOM, which helped us reduce CPU hour usage by ~15%.

Preliminary results indicate that there is a difference in the response of ER and HR to strong greenhouse gas forcing. From a general global perspective, ER provides greater ocean heat uptake (Fig. 2a) as a fast response, while careful inspection reveals a slow response that indicates a weaker warming in an eddying ocean. Regionally, the fast response from resolving ocean eddies shows that it uptakes more heat in eddy-rich regions and tropical Pacific (Fig. 2b). However, the difference seen in the tropical Pacific may be a symptom of ENSO variability rather than influence from eddies. Removal of the ENSO variability is essential for assessing the impact of eddies on ocean heat uptake. This can be done by running 2 more ensemble members for the 4xCO2, preferably for 100 years each to assess both fast and slow response. However, of immediate interest is the assessment of the fast response, which would require 30 years for each run.

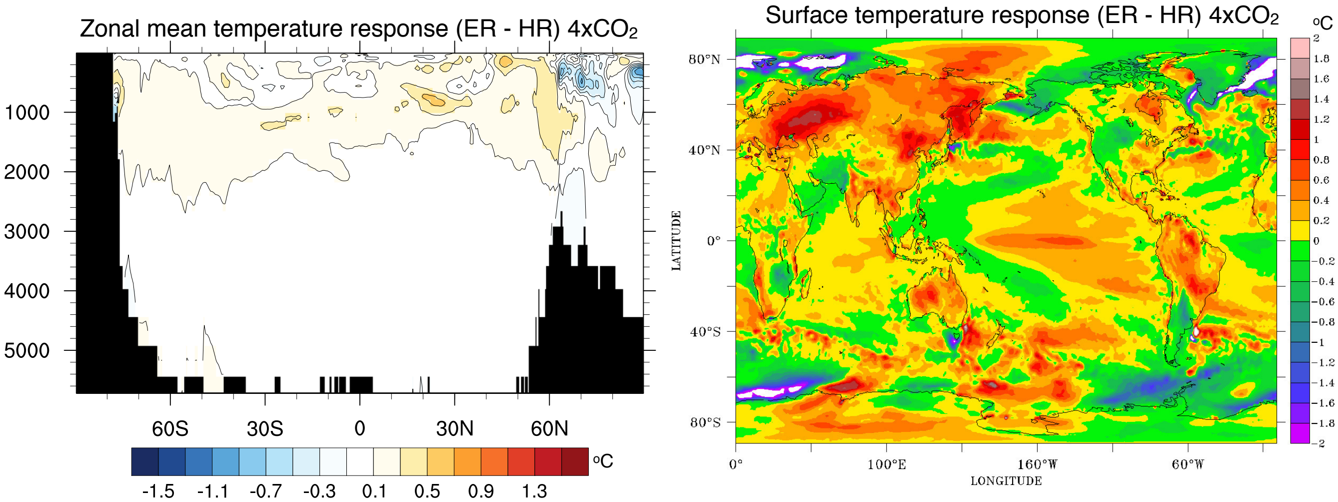

Figure 2: a) Global zonal mean temperature (^oC) response of eddies under strong CO_2 forcing [(ER_4xCO_2 – ER_control) – (HR_4xCO_2 – HR_control)]; b) surface temperature (^oC) response of eddies under strong CO_2 forcing.

In preparation for the planned stream 2 simulations of the PRIMAVERA project, we performed two test simulations with the MPI-ESM-HR model (1950-control), where we replaced the vertical mixing scheme by the newly implemented TKE scheme. Both simulations use the TKE scheme but one simulation uses a constant background diffusivity for the interior ocean (HR_{tke}), while the other simulation calculates the dissipation of internal waves prognostically with the IDEMIX scheme (HR_{ide}). First results show noticeable differences in the vertical mixing (not shown), which affect the large-scale circulation in the ocean. One area that is considerably affected is the northern North Atlantic (Fig. 3), which is an important area for the European climate. In HR_{ide}, the North Atlantic Current and later the Irminger Current transport less heat and salt (see Fig. 4) first into the Irminger Sea and further downstream into the Labrador Sea, resulting in much fresher and colder water masses in both basins. We further notice a stronger East Greenland, Baffin Island and Labrador Current, which indicates a stronger freshwater export from the Arctic Ocean (see Fig. 4b and Fig. 4d).

However, not only the near-surface circulation shows deviations in HR_{ide}, but also at intermediate depth (Fig. 3d). For instance, south of Cape Farewell (southernmost point of Greenland) HR_{tke} shows a southward path of the Irminger / Deep Western Boundary Current that is not simulated by HR_{ide}. Another deviation is found for the recirculating branch of the Deep Water Boundary Current, probably Labrador Sea Water, leaving the coast of Labrador (51°N, 45°W) and crossing the North Atlantic basin to the east via the Charlie-Gibbs Fracture Zone (~51°N, 35°W). This pathway is not present in HR_{ide}. The reasons for these circulation deviations are still under investigation and will be studied in more detail once the stream 2 simulations are finished.

Papers from MPI-M related to PRIMAVERA simulations:

- Putrasahan, D. A., Lohmann, K., von Storch, J.-S., Jungclaus , J. H., Haak, H., Gutjahr, O., 2018: Surface flux drivers for the slowdown of the Atlantic Meridional Overturning Circulation in a high-resolution global coupled climate model. In revision for *Journal of Advances in Modeling Earth Systems*
- Gutjahr, O., Putrasahan, D. A., Lohmann, K., von Storch, J.-S., Jungclaus, J. H., Haak, H., Brüggemann, N., Stössel, A., 2018: Max Planck Institute Earth System Model for HighResMIP. To be submitted to *Geoscientific Model Development*

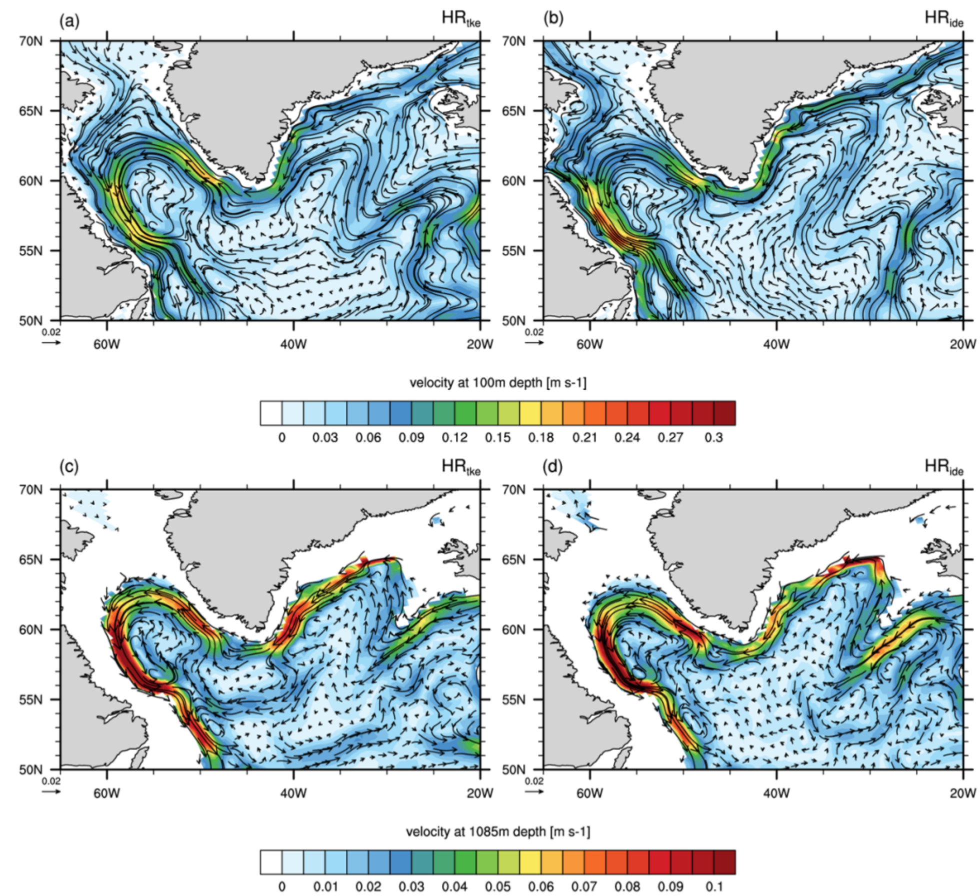

Figure 3: Velocity averaged over 50 model years (after 30 years of spin-up) at (a,b) 100m depth and (c,d) 1085m depth for (a,c) MPI-ESM-HR with TKE (HR_{tke}) and (b,d) MPI-ESM-HR with TKE+IDEMIX (HR_{ide}).

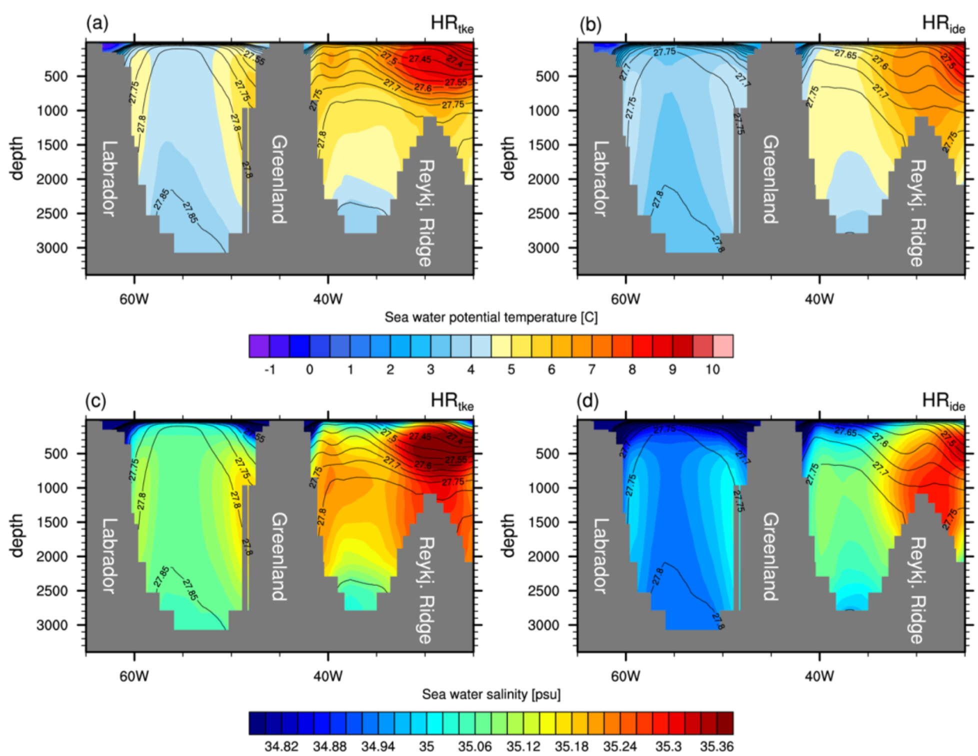

Figure 4: Potential temperature (a,b) and salinity (c,d) sections (colour shaded) averaged over 50 model years (after 30 years of spin-up) along 60°N for (a,c) MPI-ESM-HR with TKE (HR_{tke}) and (b,d) MPI-ESM-HR with TKE+IDEMIX (HR_{ide}). The black contour lines show the potential density (increment is 0.5 kg/m³).

AWI:

We investigated the effect of using different combinations of horizontal resolutions in atmosphere and ocean on the simulated climate in a global coupled climate model (AWI-CM). Particular attention is given to the Atlantic Meridional Overturning Circulation (AMOC). Four experiments with different combinations of relatively high and low resolutions in the ocean and atmosphere are conducted. We showed that increases in atmospheric and oceanic resolution have clear impacts on the simulated AMOC which are largely independent (Figure 5). Increased atmospheric resolution leads to a weaker AMOC. It also improves the simulated Gulf Stream separation; however, this is only the case if the ocean is locally eddy resolving and reacts to the improved atmosphere. We argue that our results can be explained by reduced mean winds caused by higher cyclone activity. Increased resolution of the ocean affects the AMOC in several ways, thereby locally increasing or reducing the AMOC. The finer topography (and reduced dissipation) in the vicinity of the Caribbean basin tends to locally increase the AMOC. However, there is a reduction in the AMOC around 45°N which relates to the reduced mixed layer depth in the Labrador Sea in simulations with refined ocean and changes in the North Atlantic current pathway. Furthermore, the eddy-induced changes in the Southern Ocean increase the strength of the deep cell.

In the PRIMAVERA general assembly in November 2017 a strong wish for more ensemble members of HighResMIP simulations has been expressed. We followed up on this wish and ran 3 ensemble members of our HR set-up with the official CMIP6 version comprising 200-year spin-up and control simulations each (50 years spin-up and 150 years control) and 63-year historical simulations from 1951-2013. We are still waiting for the greenhouse gas, aerosol, and ozone forcing for 2015-2100 to complete the remaining years from 2014-2100 according to the RCP8.5 scenario (year 2014 has not been run yet because 2015 concentrations are already used for 2014 when interpolating concentrations between years).

On our ensemble simulations we plan to publish a paper regarding the ensemble spread of the simulations. Furthermore, joint papers regarding specific aspects of the HighResMIP simulations from all project partners are in preparation.

Papers from AWI related to PRIMAVERA simulations:

- Sein, D. V., Koldunov, N. V., Danilov, S., Sidorenko, D., Wekerle, C., Cabos, W., et al. (2018). The relative influence of atmospheric and oceanic model resolution on the circulation of the North Atlantic Ocean in a coupled climate model. *Journal of Advances in Modeling Earth Systems*, 10, 2026–2041. Doi:10.1029/2018MS001327
- Rackow, T., Sein, D., Semmler, T., Danilov, S., Koldunov, N., Sidorenko, D., Wang, Q., and Jung, T. (2018). Sensitivity of deep ocean biases to horizontal resolution in prototype CMIP6 simulations with AWI-CM1.0, *Geosci. Model Dev. Discuss.* Doi:10.5194/gmd-2018-192, in review.
- Sidorenko, D., Koldunov, N. V., Wang, Q., Danilov, S., Goessling, H. F., Gurses, O., et al. (2018). Influence of a salt plume parameterization in a coupled climate model. *Journal of Advances in Modeling Earth Systems*, 10. Doi:10.1029/2018MS001291
- Koldunov, N.V., Danilov, S., Sidorenko, D., Hutter, N., Losch, M., Goessling, H., Rakowsky, N., Scholz, P., Sein, D. V., Wang, Q., and Jung, T. (2018). Fast EVP solutions in a high-resolution sea ice model. *Journal of Advances in Modeling Earth Systems*, in review.

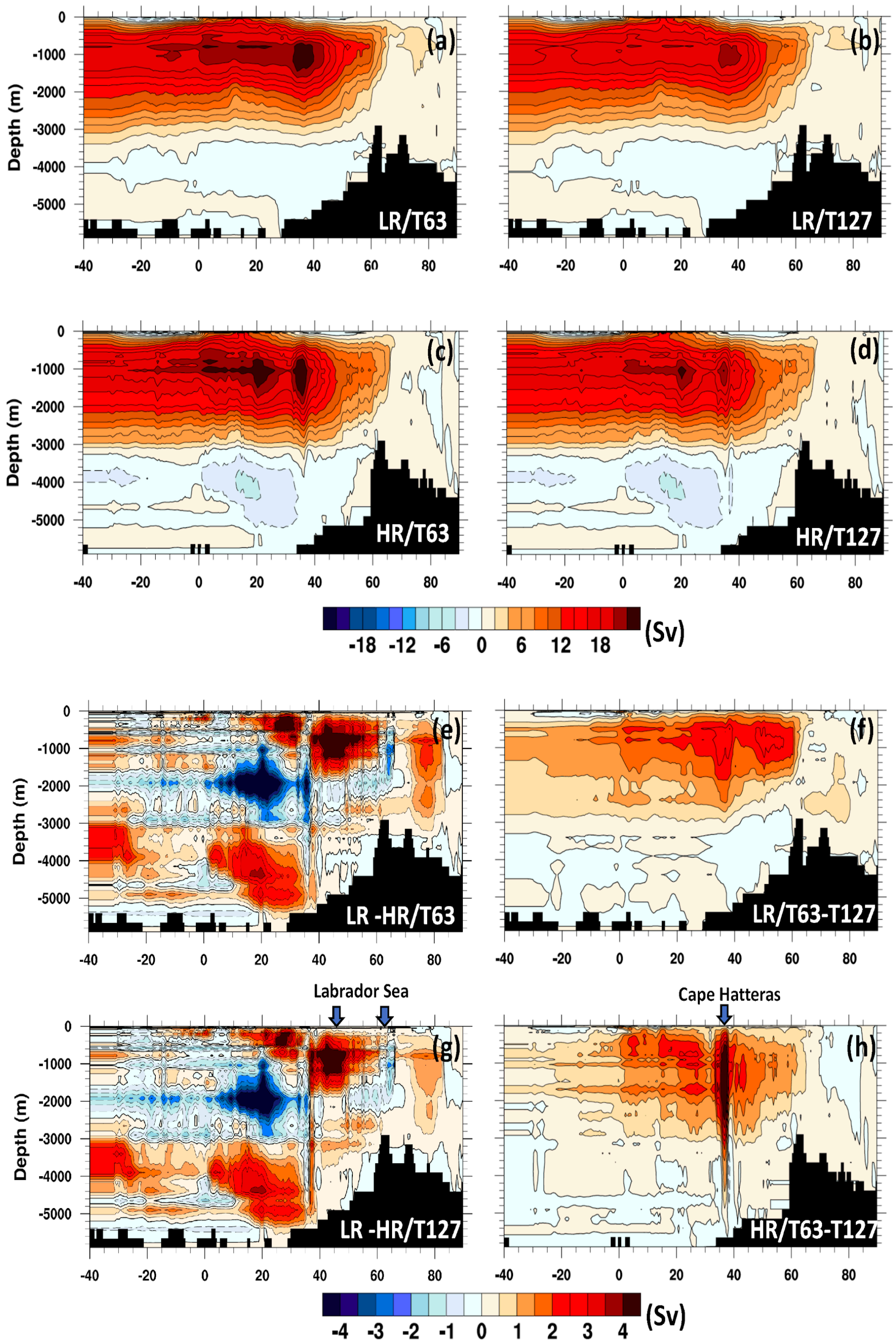

Figure 5: Mean (1980-2005) Atlantic meridional overturning circulation for different setups (a-d) and the difference between setups with the same atmosphere, but different ocean (f, h) and the same ocean, but different atmospheric resolution (e,g).