Project: 944
Project title: EU H2020-project PRIMAVERA
Project lead: Jin-Song von Storch (MPI-M), Thomas Jung (AWI)
Allocation period: 01.01.2020 – 31.12.2020

Achievements for 2019:

MPI-M:

HighResMIP simulations for stream 1 simulations of PRIMAVERA are now complete. With the computational resources afforded to us by DKRZ, we were able to complete 3 sets of 3 ensemble member simulations of 100-year long 4xCO2 simulations, with respective resolutions in NR, HR and ER. This allows us to study the impact of resolution and in particular the role of ocean eddies on the response of the climate system through their contributions on global ocean heat uptake. We find that global mean surface temperature does not rise as fast as with an eddying ocean (Fig. 1a) and is consistent with a larger ocean heat uptake by the eddying ocean (Fig. 1b). A keener look into the depth profiles of changes in ocean heat content suggests that differences in vertical eddy temperature flux convergence arising from varying resolution (Fig. 1c) contributes to greater deep ocean heat storage (depths below 2000m) in an eddying ocean relative to non-eddying ocean (Fig. 1d).

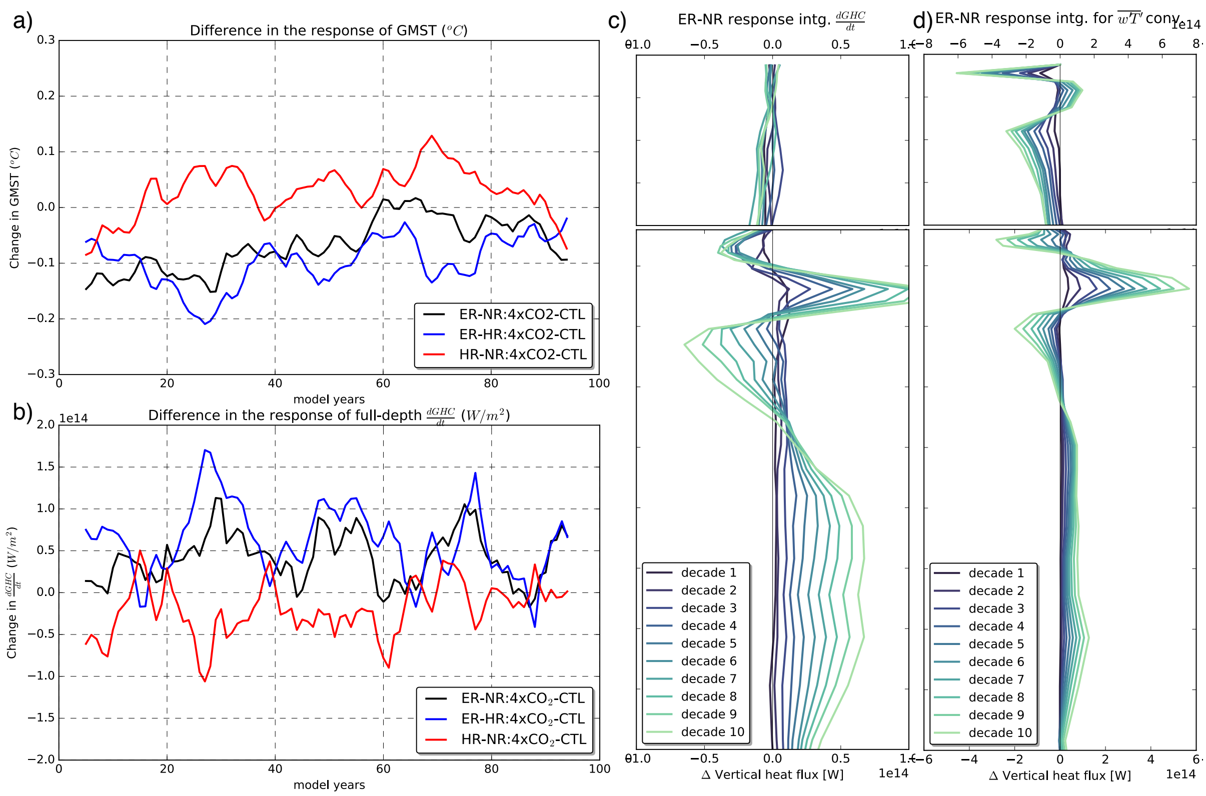

Figure 1: a) Difference in the response of global mean surface temperature by varying resolution; b) difference in response of ocean heat uptake by varying resolution; c) depth profile of difference (ER-NR) in response of rate of change of global ocean heat content, accumulated for each decade; d) similar to (c) but for vertical eddy temperature flux convergence.

Based on 100-year long control simulations with the MPI-ESM1.2-HR model, the effect on the ocean mean state of the newly implemented IDEMIX scheme was evaluated. In total, four HR simulations with different ocean vertical mixing schemes were compared. The reference simulation used the default PP scheme. Sensitivity simulations were run with the KPP scheme, TKE scheme, and TKE+IDEMIX scheme.

To a leading order, we conclude that the choice of the mixing scheme has minor effect in terms of model biases. The biases related to the TP04 grid dominate most regions of the World's Ocean. In particular, in the Atlantic we notice biases of too warm and saline water masses originating from the Mediterranean Overflow and from the Agulhas Current System. The bias in these water masses can be traced from the Atlantic over the GIN and Nordic Seas to the Arctic Ocean. Most of these biases diminish if an eddy-resolving ocean resolution is used, as in the MPI-ESM1.2-ER (Gutjahr et al., 2019). However, we notice improvements from IDEMIX that reduce the bias similarly as the eddy-resolving ocean does. The largest improvement is thereby the improved circulation and mixing in the GIN Sea and at Fram Strait that reduces the warm bias of the Atlantic Water layer in the Arctic Ocean (Fig. 2). Recently, it was shown that a high resolution, eddy-resolving ocean is needed in order to remove this bias (Wang et al., 2018; Gutjahr et al., 2019). Our results demonstrate, however, that the prognostic simulation of internal wave energy and its dissipation is crucial to improve the Atlantic water layer temperatures in Arctic Ocean. The reduction of this bias is not only important for the Arctic Ocean but might also impact the European climate, as the heat content of the Arctic Ocean influences the meridional temperature gradient and thus the west wind drift.

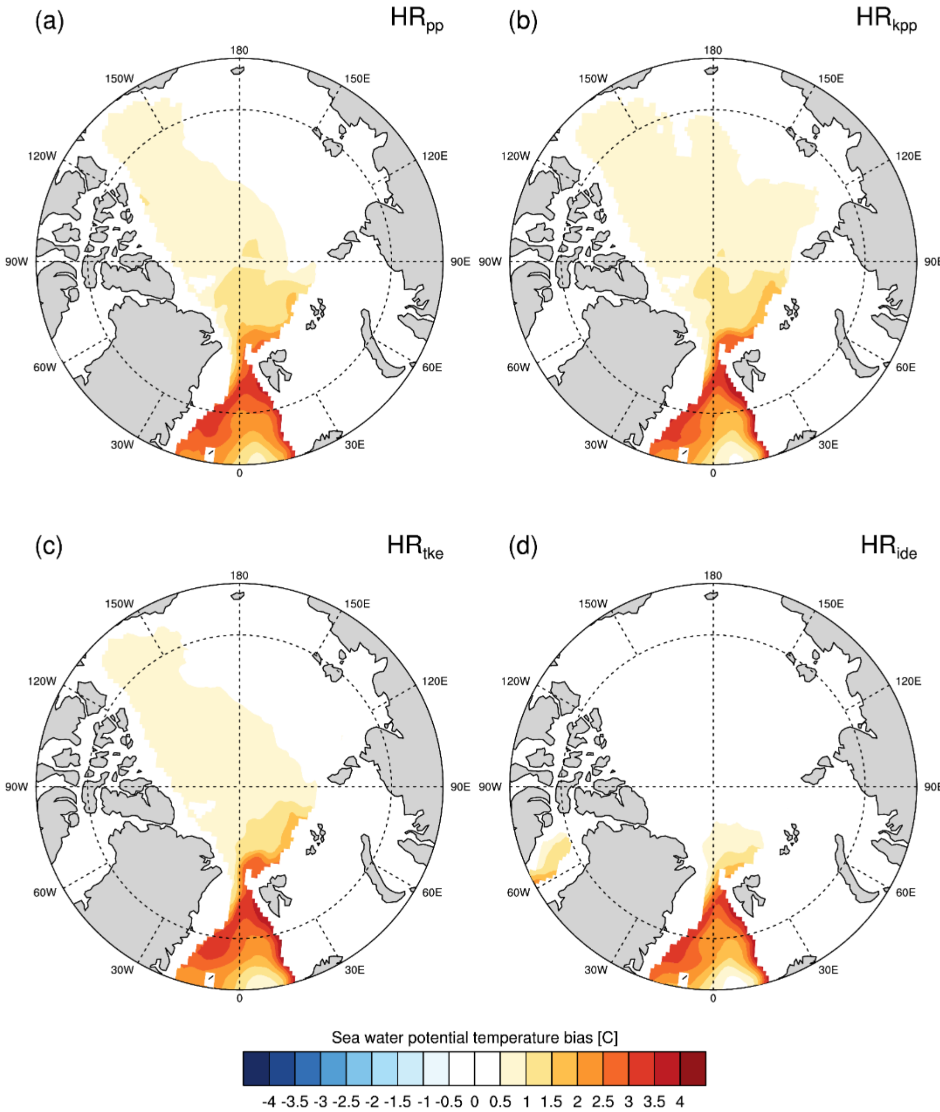

Figure 2: Temperature bias at 740m depth to EN4 for MPI-ESM1.2-HR (model year 80 to 100) with (a) PP scheme, (b) KPP scheme, (c) TKE scheme, and (d) TKE+IDEMIX scheme.

AWI:

We completed HighResMIP Stream 1 simulations for Low (LR) and High Resolution (HR) setups as well as 2 additional “mixed” runs (HR ocean with T63 atmosphere and LR ocean with T127 atmosphere). The simulations allowed us to analyze influence of ocean and atmospheric resolution on simulated climate. Fig. 3 demonstrates that, first, we can improve Gulf Stream position increasing atmospheric resolution only in case if ocean is properly resolved too. For LR ocean the increase of atmospheric resolution does not play significant role. Second, independent on atmospheric resolution we see significant difference in climate change signal in the North Atlantic for HR and LR oceans. Further details can be found in Rackow et al., 2019.

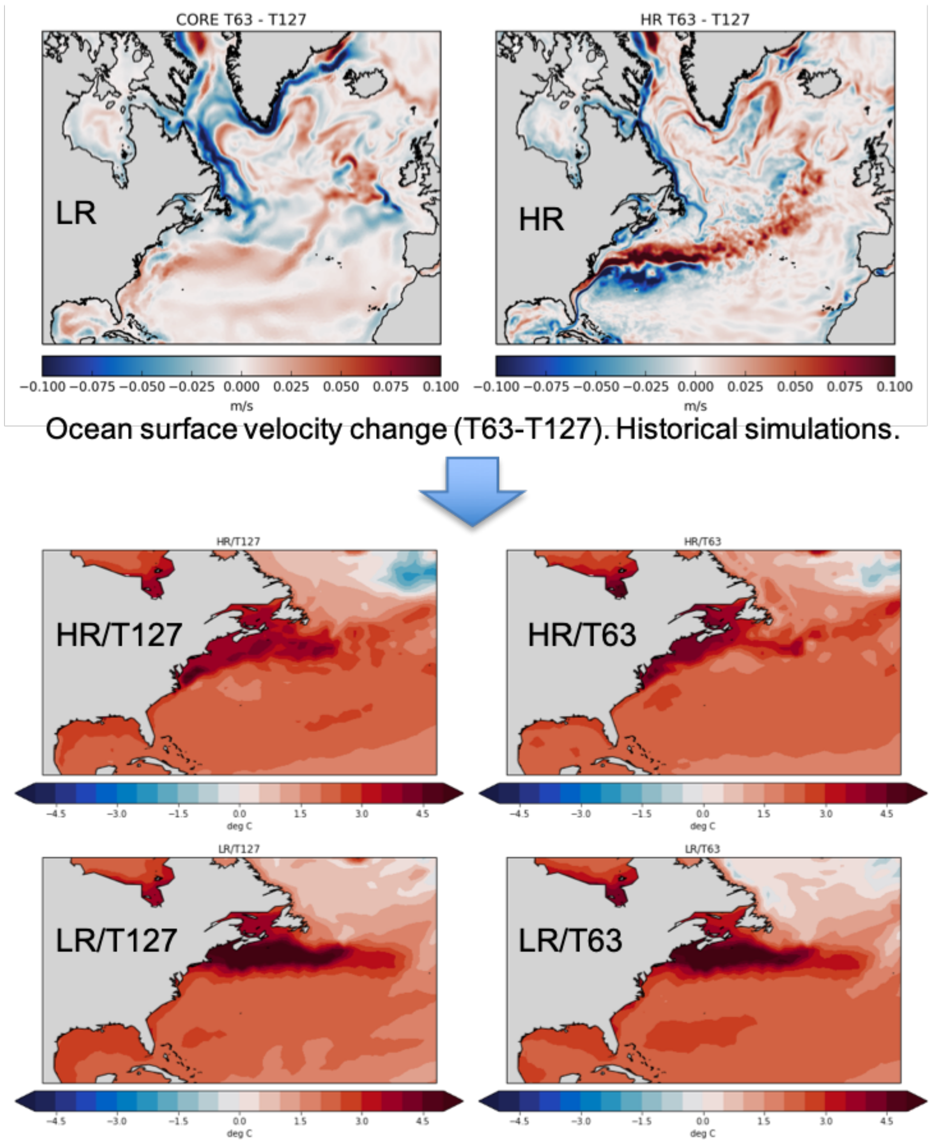

Figure 3: Upper: ocean surface velocity difference (T63-T127) for LR and HR ocean setups. Lower: SST change for spp8.5 scenario (2070-2099 – 1976-2005).

In parallel to Stream 1 simulations the frontier runs were carried out. Because of the development of finite volume version of FESOM (FESOM2) which is ca. 4 times faster than

FESOM1.4 (Koldunov et al., 2019b, Scholz et al., 2019, Sidorenko et al., 2019) we decided to increase resolution in our frontier ocean setup. Instead of our previous XR setup which was adjusted to the half of the baroclinic Rossby radius with 4 km minimal resolution, we created so-called Rossby4.2 setup which resolution is adjusted to ocean eddies activity, quarter of the Rossby radius and has 2km minimal resolution.

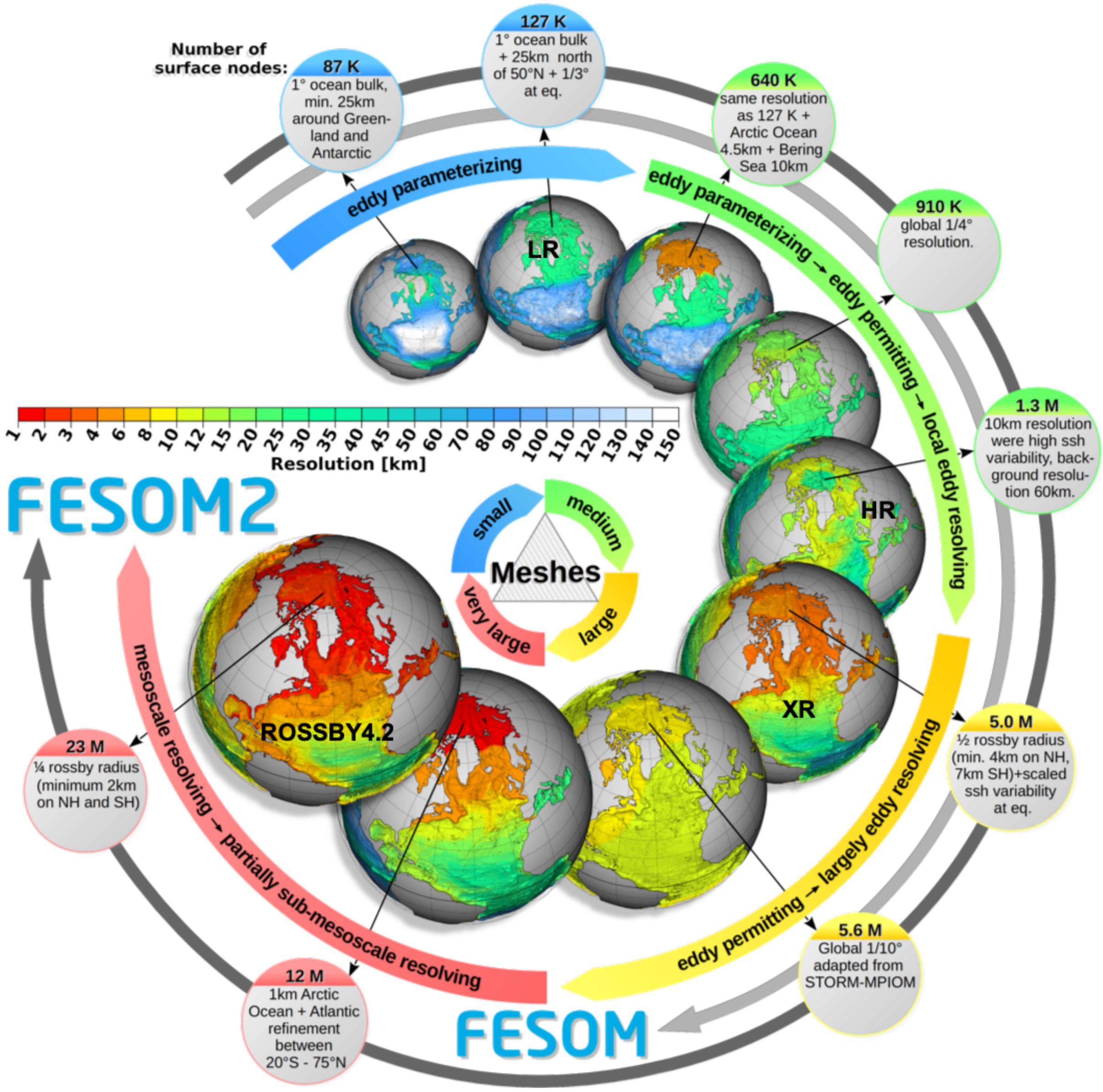

Figure 4: Hierarchy of FESOM/FESOM2 setups (Scholz et al., 2019). Setups which were used in PRIMAVERA framework are marked (LR,HR,XR,Rossby4.2)

Unfortunately because of the technical problems we were not be able to finish our frontier coupled simulations having at the moment only 40 years spin-up. But even at this stage we can see a big improvement in representation of ocean circulation in the North Atlantic, compared with our XR setup. For example, figure 5 demonstrates, that our new frontier setup is able to reproduce so-called Northwest Corner in Labrador Sea and shows very different eddy activity there.

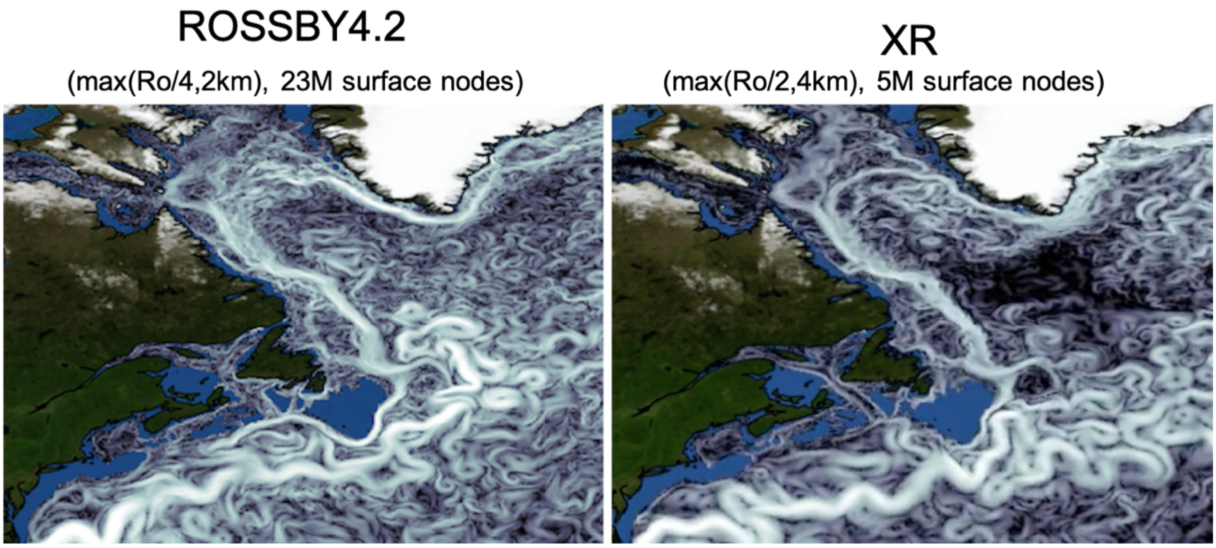

Figure 5: 100m velocity snapshot after 30 years of integration.

Further details of AWI activity during 2019 in the framework of PRIMAVERA project can be found n listed below publications

2019 publications related to the project:

Docquier, D., Grist, J. P., Roberts, M. J., Roberts, C. D., Semmler, T., Ponsoni, L., Massonnet, F., Sidorenko, D., Sein, D.V., Iovino, D., Bellucci, A. and Fichefet, T. (2019) Impact of model resolution on Arctic sea ice and North Atlantic Ocean heat transport, Climate Dynamics. https://doi.org/10.1007/s00382-019-04840-y

Gutjahr, O., Putrasahan, D., Lohmann, K., Jungclaus, J. H., von Storch, J.-S., Brüggemann, N., Haak, H., Stössel, A.: Max Planck Institute Earth System Model (MPI-ESM1.2) for the High-Resolution Model Intercomparison Project (HighResMIP), Geosci. Model Dev., 12, 3241-3281, https://doi.org/10.5194/gmd-12-3241-2019, 2019.

Koldunov, N. , Danilov, S., Sidorenko, D., Hutter, N. , Losch, M., Goessling, H., Rakowsky, N., Scholz, P., Sein, D., Wang, Q. and Jung, T. (2019a) Fast EVP Solutions in a High-Resolution Sea Ice Model, Journal of Advances in Modeling Earth Systems. https://doi.org/10.1029/2018MS001485

Koldunov, N. V., Aizinger, V., Rakowsky, N., Scholz, P., Sidorenko, D., Danilov, S., and Jung, T. (2019b): Scalability and some optimization of the Finite-volumE Sea ice–Ocean Model, Version 2.0 (FESOM2), Geosci. Model Dev., 12, 3991–4012, https://doi.org/10.5194/gmd-12-3991-2019

Putrasahan, D. A., Lohmann, K., von Storch, J.-S., Jungclaus , J. H., Haak, H., Gutjahr, O., 2019: Surface flux drivers for the slowdown of the Atlantic Meridional Overturning Circulation in a high-resolution global coupled climate model. *Journal of Advances in Modeling Earth System,* 11, 1349-1363, https://doi.org/10.1029/2018MS001447

Rackow, T., Sein, D. V., Semmler, T., Danilov, S., Koldunov, N. V., Sidorenko, D., Wang, Q. and Jung, T. (2019) Sensitivity of deep ocean biases to horizontal resolution in prototype CMIP6 simulations with AWI-CM1.0, Geoscientific Model Development, 12 (7), pp. 2635-2656. https://doi.org/10.5194/gmd-12-2635-2019

Scholz, P., Sidorenko, D., Gurses, O., Danilov, S., Koldunov, N., Wang, Q., Sein, D., Smolentseva, M., Rakowsky, N., and Jung, T.: Assessment of the Finite VolumE Sea Ice Ocean Model (FESOM2.0), Part I: Description of selected key model elements and comparison to its predecessor version, Geosci. Model Dev. Discuss., doi.org/10.5194/gmd-2018-329, accepted, 2019.

Sidorenko, D., Goessling, H. F., Koldunov, N. V., Scholz, P., Danilov, S., Barbi, D., Cabos, W., Gurses, O., Harig, S., Hinrichs, C., Juricke, S., Lohmann, G., Losch, M., Mu, L., Rackow, T., Rakowsky, N., Sein, D., Semmler, T., Shi, X., Stepanek, C., Streffing, J., Wang, Q., Wekerle, C., Yang, H., Jung, T. (2019). Evaluation of FESOM2.0 coupled to ECHAM6.3: Pre-industrial and HighResMIP simulations. Journal of Advances in Modeling Earth Systems, 11.

doi.org/10.1029/2019MS001696

Wang, Q., Wang, X., Wekerle, C., Danilov, S., Jung, T., Koldunov, N., Lind, S., Sein, D., Shu, Q., Sidorenko, D. (2019), Ocean heat transport into the Barents Sea: Distinct controls on the upward trend and interannual variability. Geophys. Res. Lett., 46. https://doi.org/10.1029/2019GL083837

Wang, Q., Wekerle, C., Danilov, S., Sidorenko, D., Koldunov, N., Sein, D., Rabe, B. and Jung, T. (2019) Recent Sea Ice Decline Did Not Significantly Increase the Total Liquid Freshwater Content of the Arctic Ocean, J. Climate, 32, pp. 15-32 . https://doi.org/10.1175/JCLI-D-18-0237.1

Publications in preparation:

Lohmann, K., Putrasahan, D. A., von Storch, J.-S., Gutjahr, O., Jungclaus , J. H., Haak, H.: Decadal-scale response of the Atlantic Meridional Overturning Circulation and the northern North Atlantic in general to reduced and increased wind stress forcing

Putrasahan, D. A., von Storch, J.-S., Lohmann, K., Gutjahr, O., Jungclaus , J. H., Haak, H.: Role of ocean eddies on the response of the climate system to strong greenhouse gas forcing. *Geophysical Research Letters*