Project: **1254**

Project title: **Global climate modelling on eddy-resolving scales with AWI-CM3**

Principal investigator: **Dmitry Sein**

Report period: **2025-11-01 to 2026-10-31**

During the reported period the following simulations and tasks were performed.

1. Kilometre-scale tide/no-tide twin experiment with FESOM2 (ocean–sea-ice, ERA5 forcing). Following the original project plan to first run the eddy-resolving ocean in stand-alone mode, we completed and analysed a 37-year (1980–2016) twin experiment on the global “jack” mesh: 30.0 million surface nodes, 57 z-levels, resolution of about 1 km on shelves, steep topography, high latitudes and in straits (Gibraltar, Bosphorus–Dardanelles), 10–20 km in the open tropics, median spacing 2.3 km (Fig. 1). After a common spin-up without tides (1948–1979), the run JON was continued with the full lunisolar tidal potential and scalar self-attraction and loading, and JOFF without tides. The final year 2016 was rerun with FESOM2 2.8.0 and XIOS parallel I/O to write 3-hourly 3-D output, together with a switch-off experiment (JOFFON) started from the JON state of 31 Dec 2015. To our knowledge this is the first multidecadal tide/no-tide twin at this resolution.

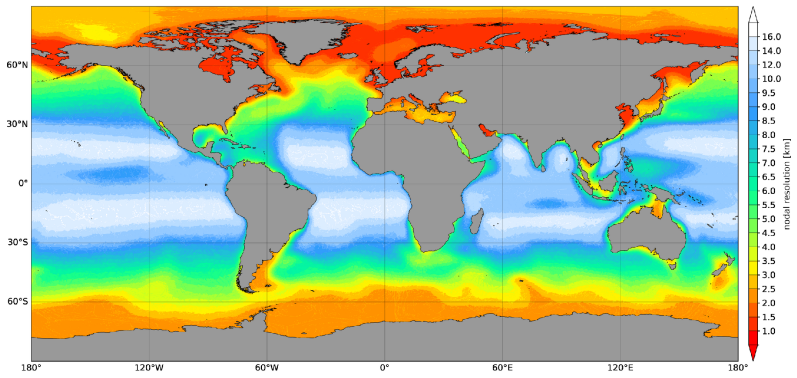


Figure 1. Horizontal resolution (km) of the 30-million-node FESOM2 “jack” mesh used for the twin experiments.

2. Main results (Fig. 2, Fig. 3):

- The simulated surface tide reproduces M2, S2, K1 and O1 of EOT20 altimetry (amplitude correlation 0.90–0.96); about 1 TW is converted into internal tides, whose surface signature has the observed geography but is ca. 1.4 times too strong (Fig. 2).
- With tides the ocean heat uptake doubles (3.6 vs. 1.8 W m^{-2}, Fig. 3). Below 1000 m the tidal-frequency heat covariance of the resolved internal waves is the largest term of the extra heating; its irreversible part is mostly numerical mixing of the advection scheme (effective diffusivity 2–3 times the Argo estimate). Together with the prescribed atmosphere this acts as a “numerical ocean heat pump”.
- Tides reduce the warm bias of the Mediterranean Outflow Water at 900–1300 m by 59–78%, make the Red Sea outflow lighter and shallower and weaken the Persian Gulf outflow by ca. 20%.
- Tides shift the northwest Atlantic shelf transport southwestward by 0.2–0.3 Sv (towards observations), drive a rectified gyre around Georges Bank, and change the transports through Luzon (+45%), Taiwan (−19%) and Tsushima (−14%) straits; no robust shift of the Gulf Stream or Kuroshio Extension can be attributed to tides.

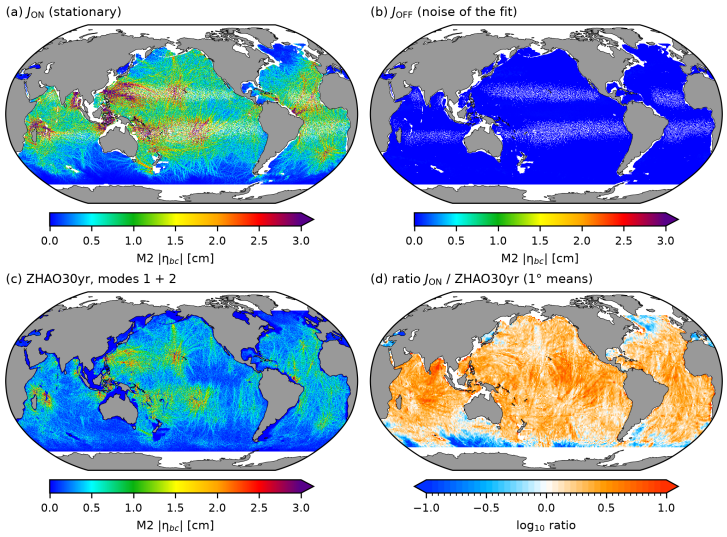


Figure 2. M2 internal-tide surface signature in 2016: (a) JON, (b) JOFF (noise of the harmonic fit), (c) ZHAO30yr altimetry (modes 1+2), (d) log10 ratio JON/ZHAO30yr.

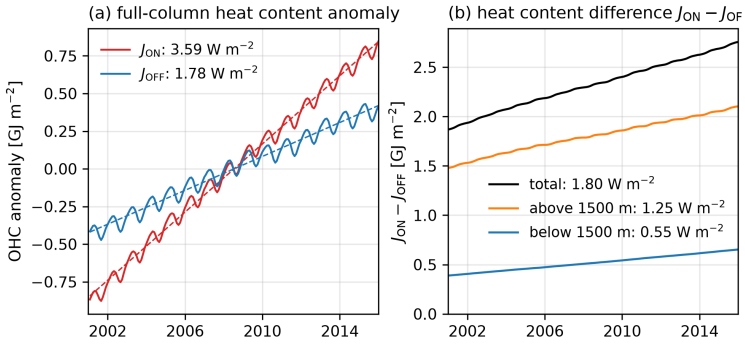


Figure 3. (a) Full-column ocean heat content anomaly in JON and JOFF, 2001–2016; (b) heat content difference JON − JOFF, total and above/below 1500 m.

3. AWI-CM3-XR. The analysis of the coupled eddy-resolving AWI-CM3 simulation (FESOM2 1.85–25 km, 13.2 million surface nodes, OpenIFS TCO639L137, 1950–2100, historical + SSP5-8.5) performed in the previous allocation periods was completed; compared with the previous version, the revised sea-ice thermodynamics reduced the strong overestimation of the Arctic sea-ice thickness, although the sea-ice extent is still too large (1985–2014: 8.2 vs. 6.1 × 10⁶ km² in September and 16.1 vs. 15.3 × 10⁶ km² in March, NSIDC). The high resolution reduces SST, precipitation and circulation biases in dynamically active regions. Present-day and future time slices with additional kinetic-energy and heat-budget diagnostics were used for the analysis.

4. Coupled AWI-CM3 with the 1-km ocean (jack mesh + OpenIFS TCO639) was set up and tested in short runs (19200 cores, ocean time step 144 s). The planned 50-year coupled spin-up was postponed: the twin experiment showed that resolved internal tides combined with the present advection scheme produce excessive numerical mixing and spurious ocean heat uptake, which has to be fixed before long coupled integrations at this resolution.

5. Visualisations of the tidal currents on the 1–10 km mesh were produced together with DKRZ (M. Böttinger).

6. All simulations described above were performed on Levante within project ba1254. Used resources (Slurm accounting, 2025-11-01 to 2026-10-29): 152,960 Levante node hours (121,086 for the jack twin experiment, 22,272 for runs on the XR (“next”) mesh in November 2025, ca. 6,200 for interactive and Jupyter analysis; the coupled AWI-CM3-palk runs P36/P37, 1950–2100, were shared with project ab0995), of which 102,191 of the 106,920 node hours granted for 2026 (96%, DKRZ accounting). Storage: 60.2 TiB of the 72 TiB /work quota; the tape archive was not used under ba1254.

Publications (manuscripts acknowledging DKRZ project ba1254)

- Sein, D. V., Danilov, S., Cabos, W., Izquierdo, A., Streffing, J., Scholz, P., Vázquez, R., Wang, Q., Böttinger, M., Mayer, B., Guillermo-Montiel, J. C., Harig, S., Limareva, N., Matseiun, A., Lohmann, G., and Jung, T.: Twin tidal experiments with FESOM2 on a kilometre-scale global mesh. Part 1: Resolved internal tides and a numerical ocean heat pump. J. Adv. Model. Earth Syst., submitted (2026MS006509).
- Sein, D. V., Danilov, S., Izquierdo, A., Cabos, W., Vázquez, R., Guillermo-Montiel, J. C., Limareva, N., Matseiun, A., and Jung, T.: Twin tidal experiments with FESOM2 on a kilometre-scale global mesh. Part 2: Tidal control of dense marginal-sea outflows. J. Adv. Model. Earth Syst., submitted (2026MS006519).
- Sein, D. V., Danilov, S., Izquierdo, A., Cabos, W., Vázquez, R., Guillermo-Montiel, J. C., Limareva, N., Matseiun, A., and Jung, T.: Twin tidal experiments with FESOM2 on a kilometre-scale global mesh. Part 3: Where do tides change the mean circulation? J. Adv. Model. Earth Syst., submitted (2026MS006531).
- Sein, D. V., Cabos, W., Vázquez, R., Guillermo-Montiel, J. C., Dvornikov, A. Yu., Li, J., Gou, R., Parras-Berrocal, I. M., Uchida, T., Koseki, S., Streffing, J., Andrés-Martínez, M., Akhtiamova, A. F., Sidorenko, D., Danilov, S., Wang, Q., Scholz, P., Fast, I., Böttinger, M., Kumar, P., Gupta, R. P., Limareva, N., Alekseeva, E., Stupak, D., Lohmann, G., and Jung, T.: Climate variability and change in the eddy-resolving global model AWI-CM3: a regional view. J. Adv. Model. Earth Syst., revised manuscript resubmitted (September 2026).
- Sein, D. V., Stupak, D., Neverov, R., and Cabos, W.: Effects of sea-ice averaging, thickness definition and ice evolution on projected Northern Sea Route accessibility. The Cryosphere, submitted (14 October 2026).
- Cabos, W., Vázquez, R., Sein, D. V., Guillermo-Montiel, J. C., and Koseki, S.: Atmospheric resolution sets the position of the Angola-Benguela Front in coupled climate models. Geophys. Res. Lett., submitted (2026GL127843).