Project: **1466**
Project title: **IOW-ESM — A regional earth system model for the Baltic Sea region**
Principal investigator: **Markus Meier**
Allocation period: **2025-11-01 to 2026-10-31**

Further development of the tuning library `tunelib`

One of the critical tasks when implementing a novel or modified climate model, regional or global alike, is the calibration of the model setup and the quantification of setup-related uncertainties. To that end, the analysis of uncertainties related to the choices for free parameters is receiving increasing attention in climate modeling (Hourdin et al. 2017). As an example, our coupled regional climate model for the Baltic Sea region, the IOW-ESM, exhibited a cold bias in the SST throughout the spring and summer months (not shown). Analysis indicated that the bias was partially caused by a bias in cloud cover, leading to a biased shortwave radiation at the ocean surface. To tackle this issue, we employed the method of Perturbed Parameter Ensembles (PPEs, Bellprat et al. 2012; Williamson et al. 2017; Hourdin et al. 2023). One important and not entirely unexpected result is that finding a single best parameter set fails due to the equifinality of the system. That is, different parameter sets deliver similarly improved results so that a best model setting cannot be derived uniquely. A manuscript summarizing our findings was submitted and is currently under revision in JAMES (Voelker et al. 2026a). Following the reviewers' suggestions and our own plans on extending our operational calibration techniques, a history matching scheme was implemented into the `tunelib` (Voelker et al. 2026b). Accordingly, a second wave of perturbed physics simulations containing 120 runs (i.e. 240 simulated years) is currently being conducted. Results will be added to the above-mentioned preprint. Furthermore, the developed library is actively used for the calibration of other components of the ESM, such as the biogeochemistry module ERGOM (Radtke et al. 2019).

Bias analysis of the ICON-CLM on the EURO-CORDEX domain (spice-2.4)

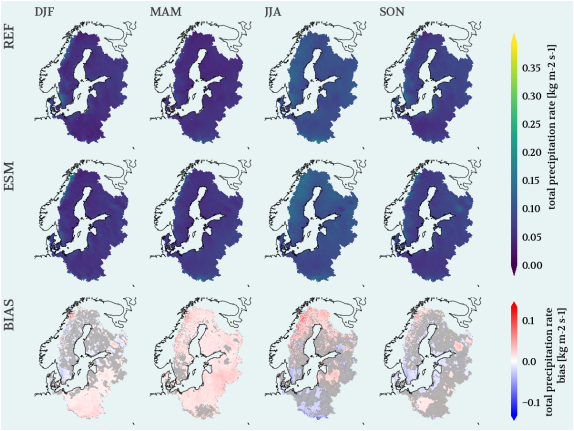


Figure 1: Seasonal bias of precipitation rate in ICON-CLM (EURO-CORDEX, settings from spice-2.4, second row) over the Baltic Sea catchment against the E-OBS dataset (v33.0e, first row). The uncoupled integration was performed for the climate reference period 1991-2020. Grey shadings in the bias mark non-significant differences.

Following the introduction of ICON (Pham et al. 2021) into the IOW-ESM infrastructure, we conducted a reference integration to identify possible biases of the model setup over the Baltic Sea and its catchment area. The uncoupled simulation with the up-to-date calibration recommendation by the CLM community (spice 2.4, Geyer et al. 2026) and driven by the ERA5 reanalysis, were set up for the climate reference period 1991 through 2020. Comparing the results to several reanalysis and observation-derived datasets (e.g. ERA5, E-OBS), we find that biases are much smaller relative to the COSMO-CLM setup used in the IOW-ESM (v1.0.5). What is more, in contrast to ICON-CLM/spice-2.3, precipitation biases are significantly reduced in the strong precipitation regime, leading to an overall improved performance (c.f. Fig. 1). Similarly, we find that most biases, where statistically significant, are within the disagreement of the various reference datasets. Hence, further investment of computation time into the calibration of ICON does not seem justified at this time. A potential need for the calibration of the coupled system is to be determined (see below). In addition to the model validation, diagnostics for the wind energy potential and the atmospheric water cycle were added for future analysis. In particular, the latter is to serve a better understanding of the atmosphere-ocean water cycle and its major drivers in the current and changing climate.

Expanding the IOW-ESM coupling interface for ICON

Building on the technical prototype of the coupling between ICON and MOM6 within the IOW-ESM framework, the flux calculation and coupling interface received a major revision. Most importantly, the flux calculator (c.f. Karsten et al. 2024) is now supplied with the atmospheric transfer velocities and follows the formulation of the ICON `turbtrans` module for matching fluxes on the exchange grid. Furthermore, the coupling fields were split into sea-ice and open water variables so that ICON's water and ice tiles are coupled to the ocean model MOM6 and the sea-ice model SIS2 directly (see coupling sequence diagram in Fig. 2). The revised coupling setup is thus consistent with the tile approach of ICON. Note that, even though the amount of communication increased accordingly, the consumed resources stay at approximately 20 node hours per simulated month (c.f. scaling test in proposal).

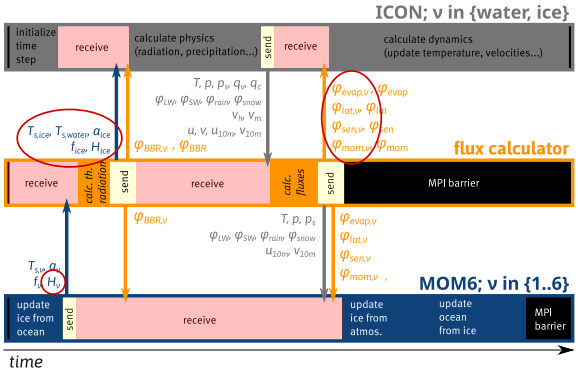


Figure 2: Adapted coupling sequence for the exchange with ICON in the IOW-ESM. Additionally required exchange fields are highlighted, c.f. Karsten et al. 2024.

Integration tests yielded good results, in particular for the relationship between the sea-surface temperature (MOM6), sea-ice concentration (SIS2), and the 2-meter temperature (ICON); see Fig. 3 for selected monthly means from a one-year integration. As one might expect, ocean and sea ice may warm or cool the atmospheric boundary layer depending on the current conditions. Similarly, the daily temperature variation is much reduced over open water with increased variation over sea ice and in coastal regions where advection can be locally dominant. The next steps will now include a reference integration serving the evaluation of the coupling effects on climate scales. For comparability, we will follow the ICON-A setup as utilized for the bias analysis described above.

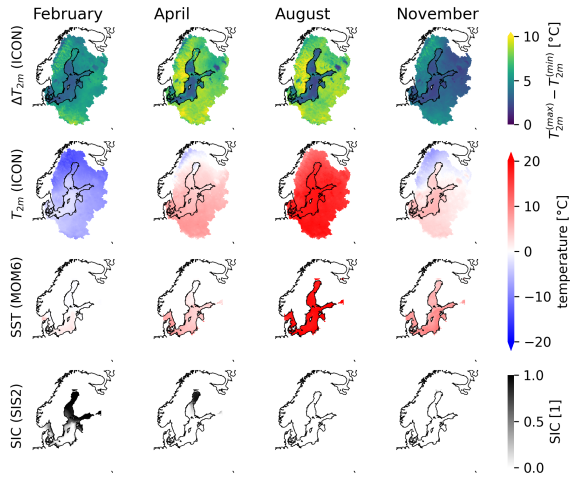


Figure 3: Amplitude of the diurnal cycle of 2m-temperatures (top row) and 2m-temperatures (second row) from ICON-CLM, sea surface temperatures from MOM6 (third row), and sea-ice concentrations from SIS2 (bottom row) for selected months (columns) in an integration of the coupled IOW-ESM through the year 1991.

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