Project: bm1344

Project title: Horizon EU-project EERIE [**E**uropean **E**ddy-**RI**ch **E**arth System Models]

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Allocation period: 2026-01-01 to 2026-12-31

Achievements in the previous allocation period

MPI-M

In 2025, we finished all ICON-EERIE (ICON-ESM-ER) phase 1 experiments as planned. This includes a 41 years long spin-up, a 101 years long control-1950 run, and a combined historical (1950-2014) and scenario (SSP2-4.5, 2015-2050) experiment. After having carried out several optimization steps of ICON-EERIE in and before 2025, the model now can be considered climate-ready, it operates in a slightly too cold climate state but shows a reasonable global warming signal as is illustrated in the time series of global mean surface temperature in Figure 1.

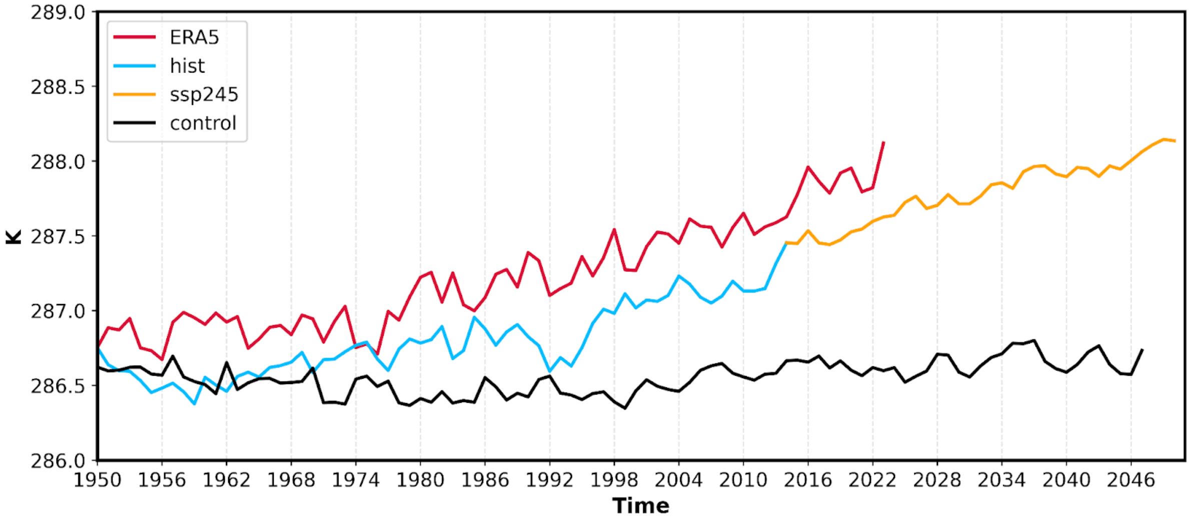

Figure 1: ICON-EERIE phase 1. Evolution of global mean surface air temperature in °K, time series of annual means in the control run (black), in historical (blue) and scenario (orange) runs and in ERA5 (red).

One remarkable feature of the historical run are realistic cooling trend patterns in SST in the southeastern tropical Pacific and the Southern Ocean between 1979 and 2014 (Figure 2). Such patterns that, so far, were typically not captured by climate models of coarser resolution indicate the important role of increasing spatial resolution in climate modelling. The link of increased model resolution to cooling trend patterns in SST in ICON-EERIE is being discussed in Kang et al. (2025)[1].

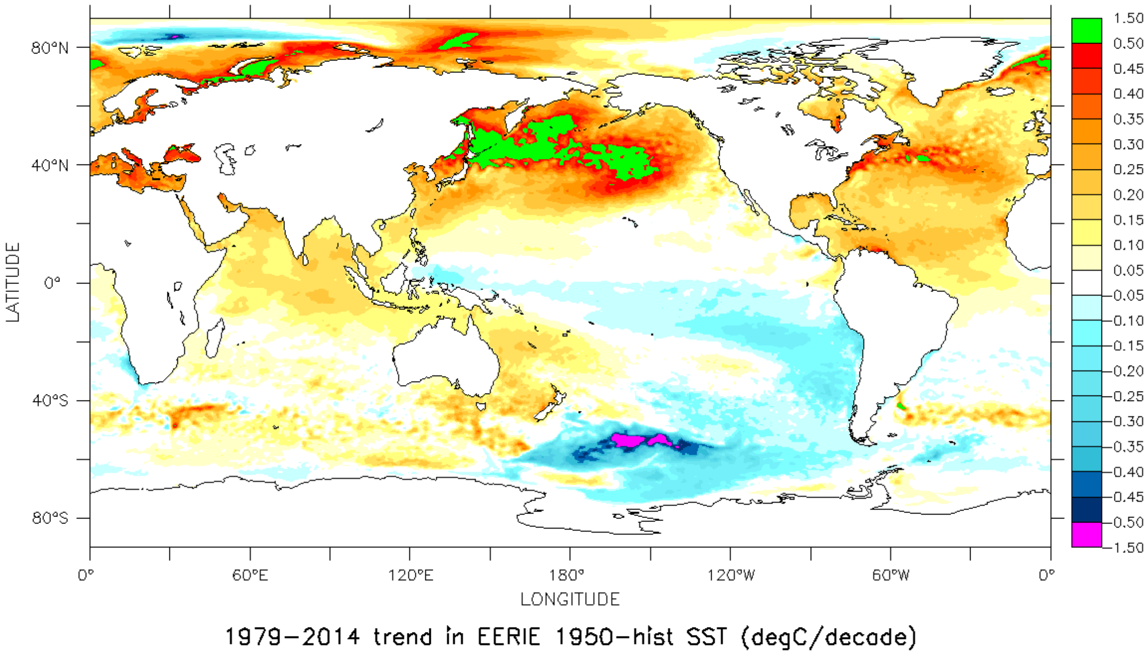

Figure 2: Sea surface temperature trend from 1979 to 2014 (ºC/decade) in the historical run.

Furthermore, resources also were used to develop, spin-up and begin integration of a forced configuration of the ICON ocean-only model at 5 km resolution which includes so-called boundary impulse response tracers. The outputs from this integration have been used to estimate the uptake of anthropogenic carbon by the ocean in an eddying regime over 70 years. This is the first time such calculations have been performed (Figure 3).

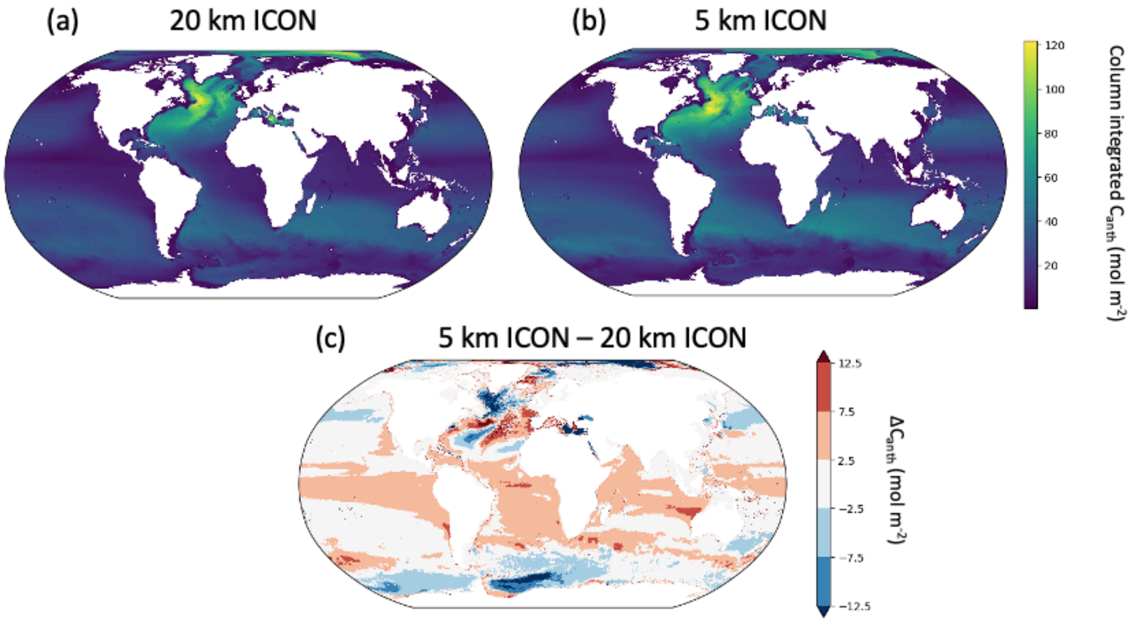

Figure 3: Average column integrated concentrations of Anthropogenic carbon for the period 2005–2014 in (a) the eddy parameterising and (b) the eddying simulations. (c) The difference in the column integrated anthropogenic carbon inventories.

AWI

During this reporting period, the primary objective was the completion of the Phase 1 simulation of IFS-FESOM. We successfully executed a 50-year coupled spin-up using 1950 radiative forcing, followed by two parallel simulations: Historical and Control. The 65-year historical simulation was finalized, and the control simulation, maintaining constant 1950 radiative forcing, was completed for 81 years and still continues to reach 101 years. Subsequent to the historical simulation's completion, it was extended with the SSP2-4.5 scenario forcing until 2060. The common aim for Phase 1 was to conclude by 2050; however, additional computing resources allowed for a continuation of 10 more years.

Figure 4 illustrates the global annual mean 2m temperature time series from the historical, control, and scenario simulations, compared with the ERA5 reanalysis. The historical simulation closely aligns with the ERA5 time series. The control simulation's time series exhibited minimal drift, suggesting that a 50-year coupled spin-up is justifiable for such a high-resolution simulation.

We encountered several technical challenges and identified the root causes of some issues. For instance, the initial condition generation process post-coupled spin-up introduced an error in snow depth, resulting in a significant temperature bias, particularly during the southern hemisphere summer over Antarctica. Although this bug has been rectified, the error was identified later in the simulation, and no mid-simulation corrections were made to keep consistency. Air-sea ice coupling remains problematic, especially over the Arctic, with a persistent and unrealistic increase in sea ice thickness centered over the Canadian Archipelago. This issue is under investigation and is believed to be primarily related to sea ice coupling. Aside from these concerns, the simulation exhibited no other major technical issues and demonstrated a close correlation with observed tendencies.

Due to the reduction in computing resources granted to this project, a substantial part of the IFS-FESOM simulations was necessarily executed on a different machine (JUWELS). All resulting data, however, have been hosted and archived on Levante in compliance with the data management approach established within the EERIE project.

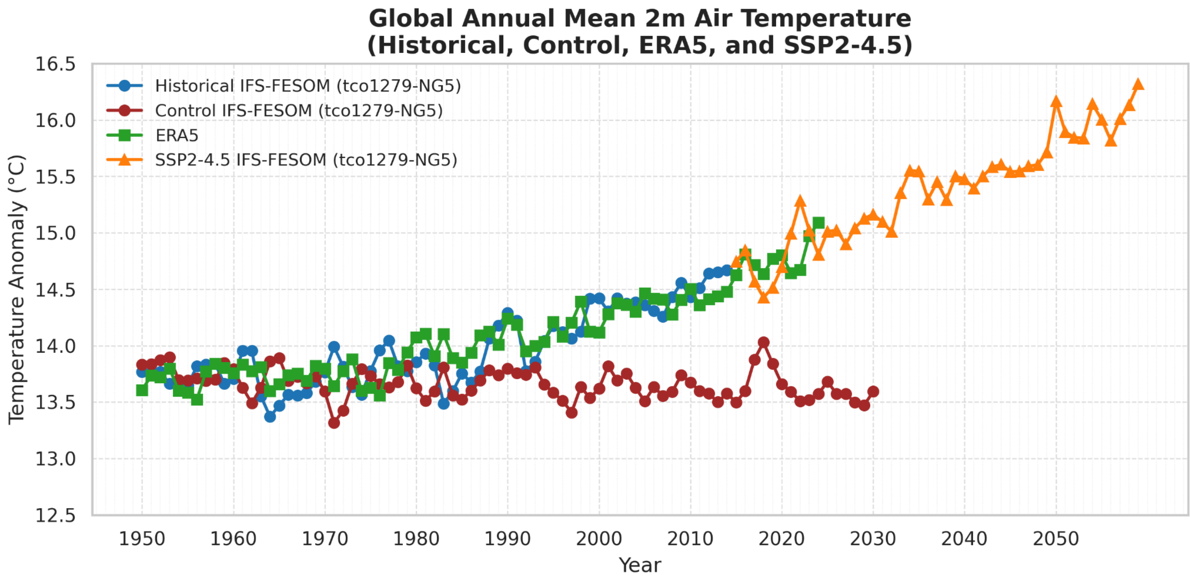

Figure 4 : Time series of annual global mean 2-meter temperature (in degrees Celsius) from ERA5 reanalysis (green), Historical simulation (blue), Control simulation (brown) under 1950 radiative forcing and Scenario simulation under SSP2-4.5 scenario forcing (orange) until 2059 in the IFS-FESOM model with a 9km atmosphere (TCo1279) and 5km ocean resolution (NG5) configuration.

DKRZ

We successfully applied and further improved the data workflows, originally introduced in the previous allocation request period, for all EERIE simulations carried out last year. The datasets are made available to all users through the central EERIE intake catalog as well as via the EERIE cloud. To ensure long-term accessibility and reliability, all datasets have also been, and continue to be, archived to the tape system (at the moment it is ~720 TB), which allowed us to free disk space for ongoing simulations. In addition, we regridded all datasets to a regular latitude–longitude grid and kept these regridded versions on Levante's Lustre file system, enabling users to use standard analysis tools designed for regular grids. The total volume of available data now exceeds the petabyte scale, underlining that a substantial share of the granted resources is openly accessible to all DKRZ users.

Phase 1 simulations, control run (1950–2050), historical run (1950–2014), and SSP245 scenario (2015–2050), have been recently completed for all EERIE models. For ICON alone, this corresponds to a data volume of approximately 3.2 PBs (raw model output is 16 TB per year) and it is 1.5 PB for IFS-FESOM (raw model output is 8.5 TB per year) The complete list of datasets available on Levante, along with further details, is shown in Table 1.

The standardized regridded datasets are highly valued by the users, as they greatly simplify data handling and intercomparison across models and observations. Therefore, it is crucial to maintain the regridded data on Levante's Lustre file system throughout the duration of the project. In total, this represents approximately 109 TB for ICON and 160 TB for AWI.

As part of the project's deliverable[5] requirements, a substantial portion of these regridded datasets has been CMORized and published on the ESGF DKRZ node, and also some on the World Data Climate Center (WDCC)[3,4], ensuring global accessibility and long-term reproducibility. This published data amounts to 42 TB for IFS-FESOM and 39 TB for ICON, both of which must also be kept on disk until the end of the project period to remain accessible. Furthermore, many users have expressed the need to access all regridded model outputs on a single HPC system to simplify the workflow. To meet this demand, it was necessary to transfer roughly 10 TB of data from the Met Office and the Barcelona Supercomputing Center (BSC).

We created a subproject 1377 and assigned a very small share (~ 2%) of the parent 1344 to it. This subproject is designated for EERIE partner scientists who aim to analyze the data produced in 1344. This separation ensures that only a limited amount of resources can be spent and it helps us to coordinate the system usage, especially for the hackathon activities. The storage space of 1377 is also used by EERIE partners to store additional simulation output important for other work packages.

The eerie.cloud data server provides access to the EERIE data catalog through the standard STAC interface as mentioned in last year's report. We have since expanded the system to include additional collections, making it part of a larger framework in line with the DKRZ services (https://discover.dkrz.de/?.language=en). With this broader scope, the platform now serves not only the EERIE community but also a wider range of users, showing its interoperability and potential for community-wide data sharing. Additionally, data from eerie.cloud is also made visible and accessible in DKRZ's data infrastructure hub gems.dkrz.de. This shows the well integration of development activities with other major projects around DKRZ.

As mentioned earlier, data archival (`slk list /arch/bm1344/`) is an ongoing process that serves two purposes:

- it provides a reliable backup and
- helps free up disk space by keeping only the most frequently used datasets on the Lustre file system.

Table 1 displays the amount of archived data for each run. We have also included these archived datasets in the EERIE Intake ESM catalog, so users can access and download the data on the native grid when required.

Importantly, until the archival of the native data is completed, these datasets must remain on disk, currently accounting for approximately 1.3 PB (including restart files) for ICON and 200 TB for AWI. Given the maximum archival throughput of 10 TB per day per person, we are able to free up roughly 50 TB per week. Consequently, to complete the cleanup of 2210 TB, we will require about 11 months, with an estimated 2 PB of disk space dedicated to the Phase 1 native data throughout this period. The compressed native data are kept on disk for future analyses, representing a total storage volume of 439 TB for the historical simulation.

Table 1: EERIE Production simulations archived in 1344 (October 2025).

Model	Run	Size (TB)
ICON-ESM-ER	eerie-spinup-1950	149.3
	eerie-control-1950	508.4
	hist-1950	300.9
	highres-future-ssp245	Not yet
IFS-FESOM-SR	eerie-spinup-1950	19.13
	eerie-control-1950	2.3
	hist-1950	130.6
	highres-future-ssp245	Not yet
Other		115.2

As part of the archiving process, we restructured the model output to ensure all files were compressed, conforming to storage quota requirements, and assigned human-readable names. The files were also rechunked to approximately 40MB chunk sizes for efficient handling. For sub-daily data and model-level daily data, we applied lossy compression techniques that preserve all bits necessary to cover 99.99% of the information content.

Additionally, we have generated a tree-like overview in text format to provide users with insight into the dataset's structure and expected data volume before retrieval. These files are hosted for easy reference. The subfolder hierarchy in the archive does not strictly follow a Data Reference Syntax (DRS) template, as it was deemed more practical to store daily output in multiple files compared to monthly output.

Reference:

1. Sarah M Kang, Dian A. Putrasahan, Noel G. Brizuela, Helmuth Haak, Jürgen Kröger, Jochem Marotzke, Bjorn Stevens, Jin-Song von Storch (2025) Km-scale coupled simulation reconciles model-observation SST trend discrepancy. PNAS, under review.

2. Ghosh, Rohit; Cheedela, Suvarchal Kumar; Wickramage, Chathurika; Wachsmann, Fabian; Beyer, Sebastian; Aengenheyster, Matthias; Becker, Tobias; Rackow, Thomas; Koldunov, Nikolay; Sidorenko, Dmitry; Jung, Thomas (2025). EERIE: Ocean Eddy-rich Kilometer-scale Climate Simulation with Integrated Forecasting System (IFS) - Finite volumE Sea Ice-Ocean Model (FESOM2.5): historical run. World Data Center for Climate (WDCC) at DKRZ. https://www.wdc-climate.de/ui/entry?acronym=EERIE_FESOM_hist

3. Ghosh, Rohit; Cheedela, Suvarchal Kumar; Wickramage, Chathurika; Wachsmann, Fabian; Beyer, Sebastian; Aengenheyster, Matthias; Milinski, Sebastian; Koldunov, Nikolay; Sidorenko, Dmitry; Jung, Thomas (2025). EERIE: Ocean Eddy-rich Kilometer-scale Climate Simulation with Integrated Forecasting System (IFS) - Finite volumE Sea Ice-Ocean Model (FESOM2.5): SSP2-4.5 scenario run. World Data Center for Climate (WDCC) at DKRZ. https://www.wdc-climate.de/ui/entry?acronym=EERIE_FESOM_s245

4. Rohit Ghosh, Suvarchal Kumar Cheedela, Sebastian Beyer, Nikolay Koldunov, Stella Berzina, Audrey Delpech, Stephy Libera, Chathurika Wikramage, Matthias Aengenheyster, Thomas Rackow, Patrick Scholz, Jan Streffing, Dmitry Sidorenko, Fabian Wachsmann, and Thomas Jung (2025). Ocean eddy-rich kilometre-scale global climate simulation with ifs-fesom. In Preparation for geoscientific model development, in preparation.

5. Wickramage, C., Wachsmann, F., Roberts, M., Iwi, A., AXNESS FERRANDO, M., & Bretonnière, P.-A. (2025). Publication of EERIE Phase 1 Simulations (2.0). Zenodo. https://doi.org/10.5281/zenodo.17465311