Project: 1344
Project title: Horizon EU-project EERIE [**E**uropean **E**ddy-**RI**ch **E**arth System Models]
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Report period: 2024-01-01 to 2024-10-31

Achievements in the previous allocation period:

MPI-M

New ICON configuration for EERIE in favor of ocean mesoscale eddies

Already in 2023, a change in the configuration for ICON in EERIE from R2B8L128-oce/R2B8L90-atm to R2B9L72-oce/R2B8L90-atm was made to better address the role of ocean mesoscale eddies on the climate. R2B8L128 for the ocean gives a nominal horizontal resolution of 10km, which technically does not resolve mesoscale eddies in the high latitudes like the Southern Ocean and subpolar/polar oceans. Since the project is about the role of ocean mesoscale eddies, we found it much more appropriate to go to R2B9L72, which has a horizontal resolution of 5km. We reduced the vertical levels and have it inline with EPOC, where vertical resolution of depths at which we are scientifically concerned about are still resolved, but we gain back computational throughput that would allow us to complete the long-integrations set forth in EERIE project goals.

New ICON code for EERIE in favor of climate readiness

Until the beginning of 2024, we used the coupled ICON, which has an energy leak of about 6 W/m2 at the top of the atmosphere. This version produced a cooler but stable climate. We obtained 40-years of control simulation output that was used for both EERIE and nextGEMS/EERIE hackathon. Recent model development at MPIM but through the nextGEMS project, produced an improved version of ICON atmosphere that we have decided to adopt and make them consistent with other projects like nextGEMS and DestinE. After spinning up the model again, this time with the improved version of the atmosphere, as of today, we have integrated a new control run for about 30 years. Application of the new ICON code delivered a much more reasonable climate but led to a decrease in computational throughput from peak values with the old code of about 1.33 SYPD to about 0.75 SYPD. Repeating spin-up and control run with a reduced throughput on top put us behind schedule for the production of EERIE phase 1 simulations.

Heterogeneous ICON configuration

Until mid-2024, we have worked on getting the coupled ICON model to run on a heterogeneous setup on Jülich SuperComputing machines (JSC). This heterogeneous setup employs GPUs for the atmospheric component and CPUs for the oceanic component. At that time the setup did not reach an optimized state, the throughput was similar to running fully on CPU-only (400 nodes) on Levante machines in DKRZ (but on noticeably much less nodes: 32 GPUs and 57 CPUs). Furthermore, we were not able to set up a workflow that would allow for proper production of EERIE experiments in the JSC environment. Currently, we (together with DKRZ and CIMD) set up a heterogeneous EERIE configuration on Levante in order to increase throughput and to reduce power consumption. A recent heterogenous setup for ICON (with a lower resolution configuration) showed promising results (work done by DKRZ).

Climate readiness of EERIE ICON simulations

EERIE continuously aims to adopt the NextGEMS setup to keep the number of configurations and settings between the various projects to its minimum, as well as to enable cleaner comparisons/analysis and more synergy between various projects (EERIE, NextGEMS, EPOC, DestinE, etc.) Also, an energetically consistent and energy conserving climate system would be desirable. Yet, EERIE has an added challenge to contend with, which is getting the simulations climate-ready. A climatically-stable (climate-ready) control simulation is crucial for having long-integration climate runs, and assessing changes in a warming world. As mentioned above, after implementing a new version of ICON atmosphere, we spun up the coupled system again followed by a new control-1950 (1950-forcing) run.

The global mean sea surface temperature (SST) in the new runs shows no more remarkable cooling tendencies (Fig. 1). Global SST went up to well beyond 18 degC in the spin-up followed by a slight drop below 18 degC just before the transition from spin-up to control run (in 1991). The drop most likely is the consequence of a bug fix in aerosol treatment in the model. In the old runs, cooling tendencies were also reflected in the evolution of total ocean heat content; here, the new runs reveal a warming trend instead, which moderates from 1991 onward (Fig. 2). Whereas in the old runs top of the atmosphere (TOA) short wave (SW) and long wave net fluxes were too low and out of balance by about 6 W/m2, in the new runs, those fluxes appear to be much better in balance by about one order of magnitude (Fig. 3).

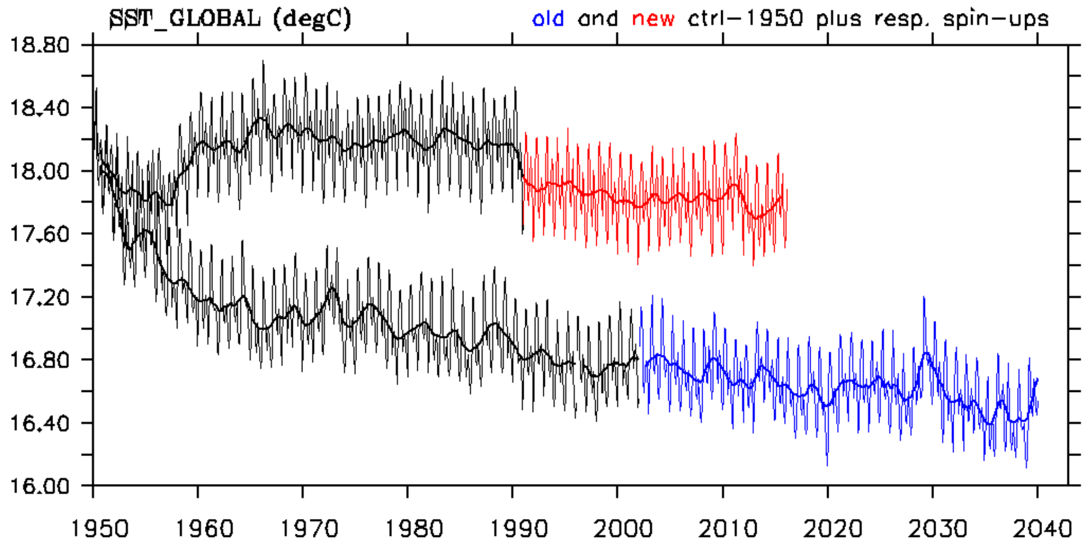

Figure 1: Evolution of global mean sea surface temperature in °C, time series of monthly means with (bold) and without (thin) smoothing by a running mean in the old (blue) and new (red) control-1950 runs with respective spin-ups up front (black).

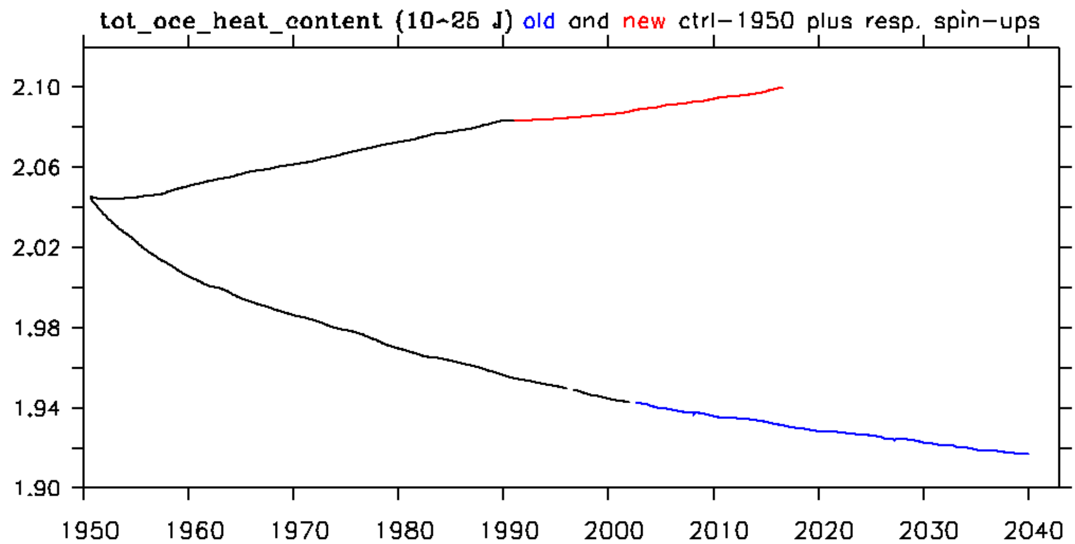

Figure 2: Evolution of global ocean heat content in 10^25 J, time series of monthly means with a smoothing by a running mean in the old (blue) and new (red) control-1950 runs with respective spin-ups up front (black).

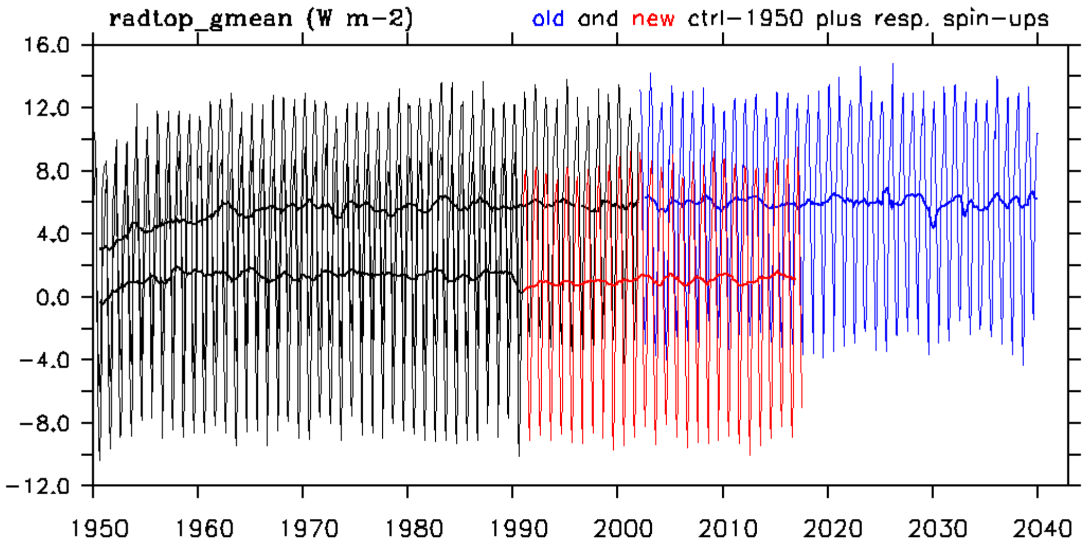

Figure 3: Evolution of top of the atmosphere (TOA) short wave (SW) and long wave net fluxes in W m-2, time series of monthly means with (bold) and without (thin) smoothing by a running mean in the old (blue) and new (red) control-1950 runs with respective spin-ups up front (black).

AWI

During this phase, one of AWI's primary tasks utilizing EERIE project resources on Levante was to execute the coupled spin-up of the IFS-FESOM model at kilometer-scale resolution (Tco1279-NG5). While the initial plan included performing simulations at high resolution, AWI prioritized the kilometer-scale simulations due to their importance and the limited available resources. Consequently, efforts were concentrated on the IFS-FESOM-SR setup.

We successfully configured the IFS-FESOM model and completed a 30-year coupled spin-up simulation with 1950 CMIP6 radiative forcing. The resulting data was utilized during the joint EERIE-NextGEMS hackathon in Hamburg earlier this year. To facilitate broader access and analysis, we have made this data available in a catalog format derived from the model's NetCDF output. Additionally, The data has been published in the long-term archive DOKU[1] (at DKRZ) to promote wider use and exploration by the scientific community.

Our coupled spin-up simulation was then extended until 50 years before starting the coupled control and historical simulations (which have been ongoing in Juwels cluster).

The primary aim of the EERIE project is to resolve the Ocean eddies and understand its potential impact in our climate system. The snapshot of ocean currents from the spinup simulations display the formation of Ocean eddies especially over the eddy-rich regions (such as Gulfstream regions), indicating that the model is able to perform and simulate eddies (Figure 1).

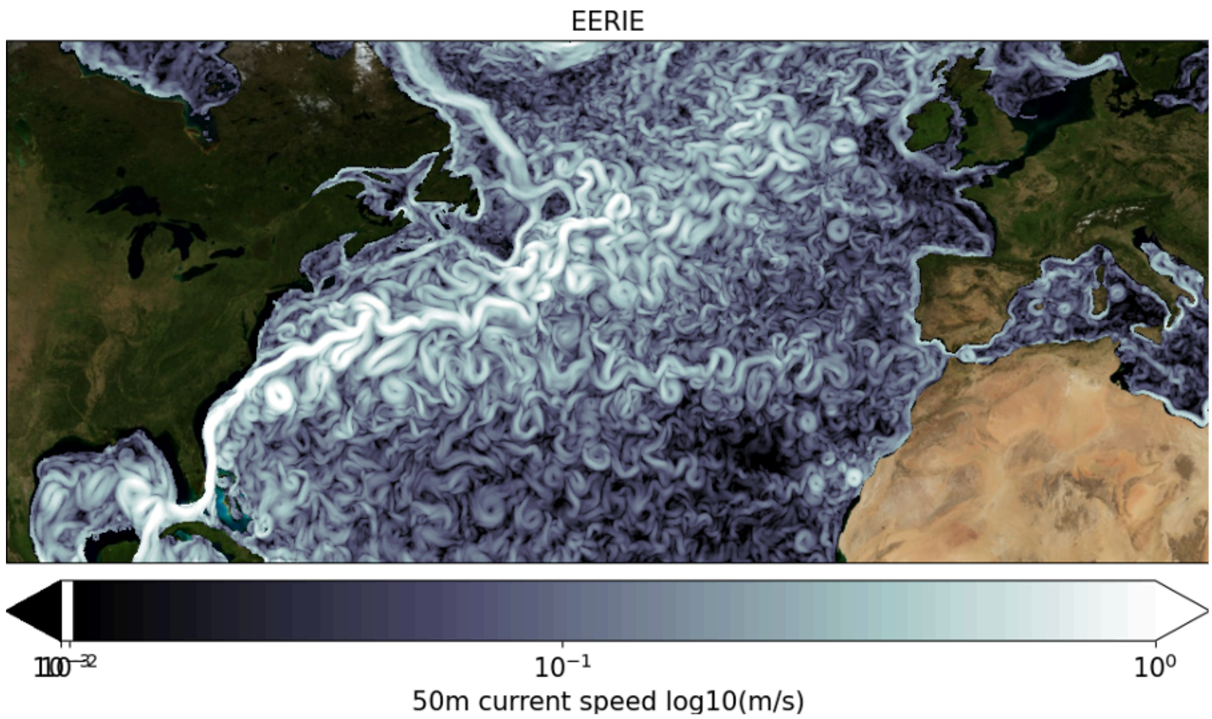

Figure 1. *The Ocean eddies in the EERIE IFS-FESOM simulation. Ocean current speed at 50m depth of the Ocean (in logarithmic scale) over the North Atlantic in a day of FESOM spinup simulation in NG5 ocean grid.*

Our coupled spin-up simulation has initially shown a drift towards colder global mean surface temperature (GMST) which apparently stabilized after the 10-15 years (Figure 2). As the simulations go on, this cold drift reduces and the global mean temperature almost returns to its initial state by the end of the simulation. This drift in GMST is mainly a result of excessive sea ice formation over the Arctic and over the Norwegian Sea (Figure 3). This excessive sea ice formation is potentially the result of the sea ice coupling in the model where the atmosphere model assumes a constant thickness of sea ice and drives the fluxes unrealistically. However, over a longer period this bias seems to get balanced and the sea ice amount seems to get back to the expected level. Though the long-term consequences of such bias on the climate system is still to be known when the entire centennial scale simulation would be ready. Nevertheless, this issue has prompted us already to implement a more realistic sea ice coupling in phase 2.

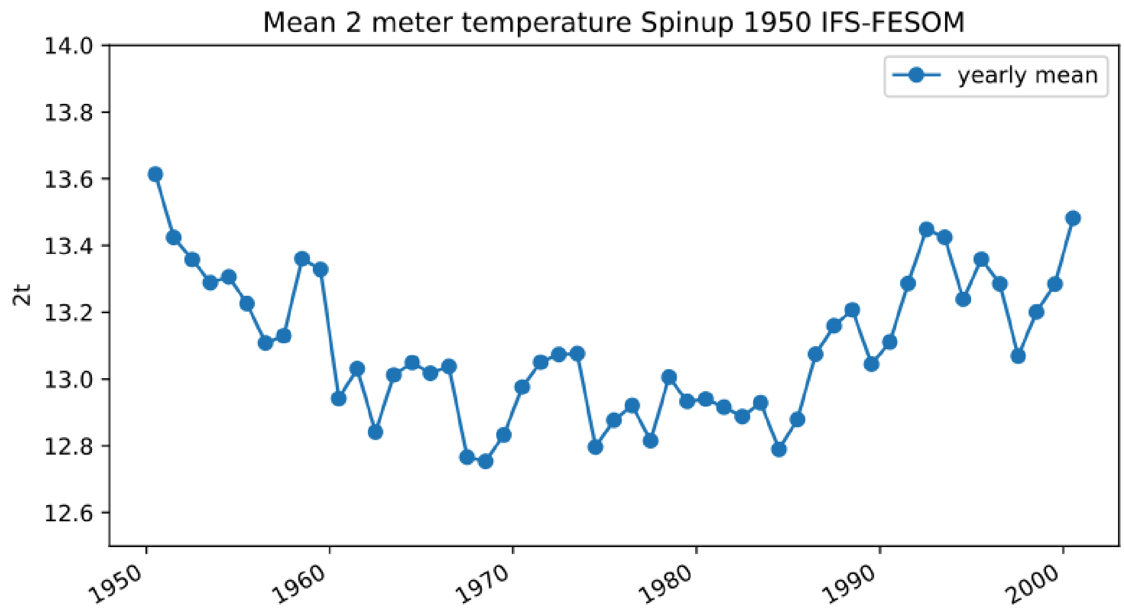

Figure 2. *The yearly global mean 2 meter air temperature time series for the entire period of coupled spin-up of IFS-FESOM at tco1279-NG5 atmosphere-ocean resolution and under 1950 radiative forcing condition. Each dot represents the yearly mean temperature of each year and the x-axis represents the number of years it has simulated starting from 1950. Units are in degree celsius.*

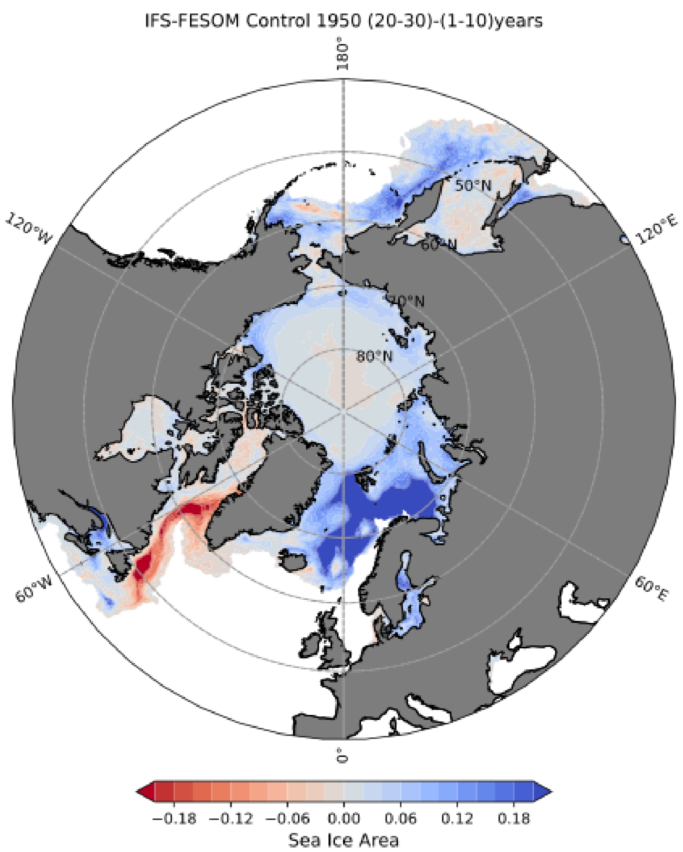

Figure 3. *The difference in sea ice area over the Arctic Ocean in the third decade (year20-30) and the first decade (year1-10) in the IFS-FESOM coupled spin-up simulation, indicating anomalous sea ice buildup over the Norwegian and Barents Sea.*

Regarding the overall Ocean eddy characteristic, the model seems to give promising results with almost identical representations of eddy-rich regions (Figure 4a,b). The main difference still remains over the Gulf Stream region where the eddy activity, although well captured, is still under-estimated. Although this has been not entirely a surprise as this region remains one of the toughest to simulate accurately. The overall Ocean circulation also shows remarkable similarity with the observed field (Figrue 4c,d). This results provides a promising start of the project where we will be focusing on what these eddies do to our climate system.

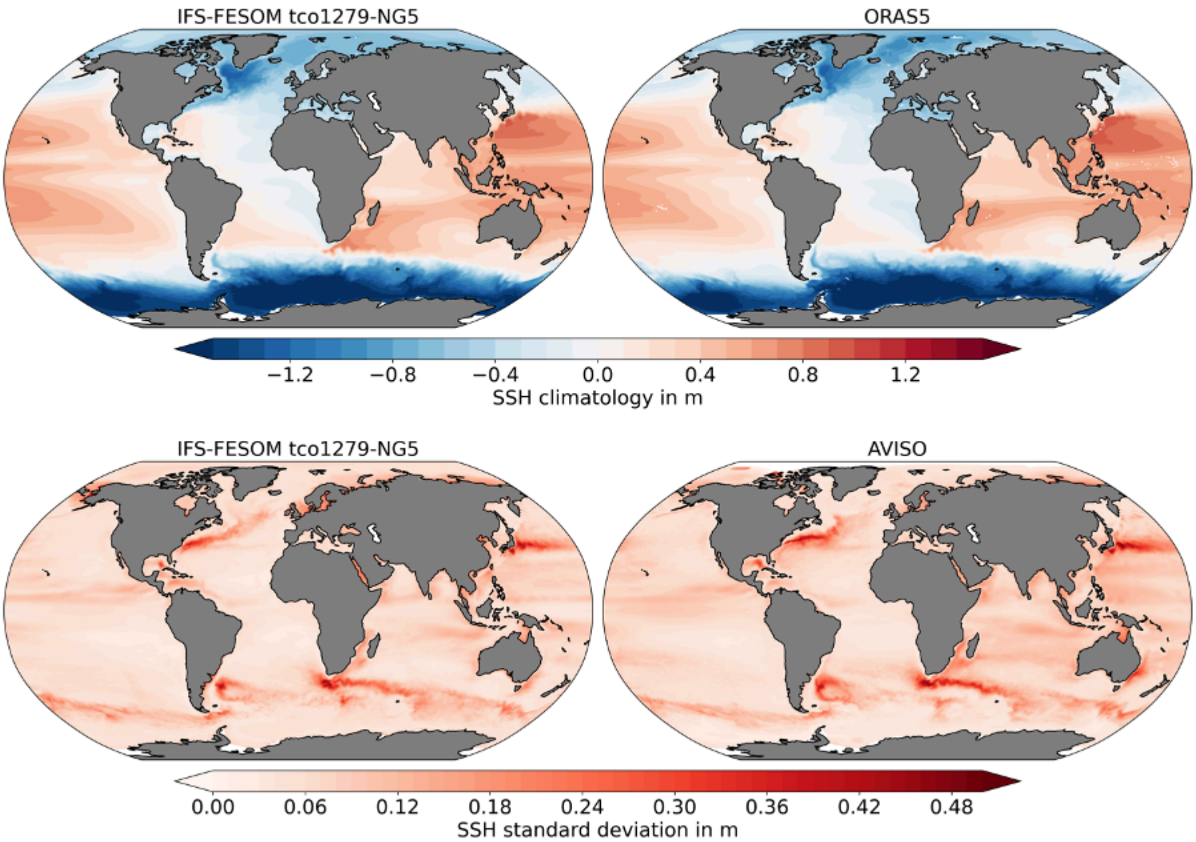

Figure 4: *20 year mean of sea surface height (SSH) in IFS-FESOM tco1279-NG5 coupled spin-up (top-left) and in ORAS5 reanalysis for the period 1950-1969 (top-right). The daily SSH standard deviation over the 20 year period in IFS-FESOM tco1279-NG5 coupled spin-up (top-left) and in AVISO (top-right) highlighting the ocean eddy-rich regions.*

DKRZ

We successfully applied and improved the data workflows, introduced in the report of the last allocation request period, for all EERIE simulations that were run last year. Through the central eerie catalog at https://github.com/eerie-project/intake_catalogues, we make the datasets available for all users (see Table 1). The total amount of available data of this resource project exceeds the Petabyte scale in size which highlights that a large share of our granted resources is made openly accessible to all DKRZ users. We continuously update the catalog and keep it synchronized with the Levante´s lustre file system.

We created a subproject 1377 and assigned a very small share 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 two hackathon activities. The storage space of 1377 is also used by eerie partners to store additional simulation output important for other work packages.

Table 1: EERIE Production simulations stored in 1344 and 1377 and made available through the intake catalog (October 2024). Green: started production in 1344 following the plan of last year's request.

source	**experiment**	**version**	**No of xarray datasets**	**No of variables**	**Size in memory [TB]**	**Simulation years**
ifs-fesom2-sr	eerie-spinup-1950	v20240304	11	79	29	30
ifs-fesom2-sr	eerie-control-1950	v20240304	21	220	226	30
ifs-fesom2-sr	hist-1950	v20240304	22	229	226	30
icon-esm-er	eerie-spinup-1950	v20240618	44	496	325	40
icon-esm-er	eerie-control-1950	v20240618	28	425	381	23
ifs-amip-tco1279	hist	v20240901	16	252	24	43
ifs-amip-tco1279	hist-c-0-a-lr20	v20240901	16	252	24	43
ifs-amip-tco399	hist	v20240901	16	252	21	43
ifs-amip-tco399	hist-c-0-a-lr20	v20240901	15	247	21	43
ifs-amip-tco399	hist-c-lr20-a-0	v20240901	16	252	21	43
hadgem3-gc5-n640-orca12	eerie-picontrol	latest	9	117	3	49
hadgem3-gc5-n216-orca025	eerie-picontrol	latest	9	115	1	129
Total			223	2.936	1.302	546

A newly developed plugin for eerie.cloud data server allows users to discover the EERIE data catalog with the industry-standard catalog tool STAC. The eerie.cloud.dkrz.de now forwards to a stac-browser´s view of a catalog which includes an EERIE collection. These new functionalities will be presented in the upcoming project assemblies in November and

January. The server also provides access to ERA5 and NextGEMs cycle 4 experiment data to showcase its interoperable field of application

The eerie.cloud is also being developed as a blueprint for a central element of the planned Warmworld data infrastructure. 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.

A lot of effort was spent on archiving EERIE simulations to be able to free disk space when needed. We improved the archival workflow for more accurate chunking and parallel application. Eventually, we fully archived the datasets

- ***icon-esm-er/eerie-spinup-1950/v20231106***
- ***icon-esm-er/eerie-control-1950/v20231106***
- ***ifs-fesom2-sr/eerie-spinup-1950/v20240304***

which sum up to about 300TB in total. These datasets were analyzed during the hackathons. When newer experiments become available, these datasets can conveniently be removed from disk. A subset of this post-processed dataset ***icon-esm-er/eerie-control-1950/v20231106*** is still available from disk and through the intake catalog, organized in 47 datasets, for 38 simulation years and 350TB in total when unpacked.

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.

We also re-gridded 10 years (1980-1990) of icon-esm-er/eerie-spinup-1950/v20240618 data onto EERIE´s regular quarter degree grid as per requested by users. For the same temporal subset, we interpolate model level hourly, daily and monthly data to pressure level and also re-grid it to the 0.25 regular grid. Both datasets can be accessed through the catalog.

EERIE Publications.

1. Ghosh, Rohit; Cheedela, Suvarchal Kumar; Wachsmann, Fabian; Wickramage, Chathurika; Beyer, Sebastian; John, Amal; Koldunov, Nikolay; Sidorenko, Dmitry; Jung, Thomas (2024). EERIE: IFS-FESOM TC01279/NG5 (9km, 5km): spinup-1950. DOKU at DKRZ. https://www.wdc-climate.de/ui/entry?acronym=DKRZ_LTA_1344_dsg0001
2. Fraser William Goldsworth. The fate of freshwater around Greenland: insights from an eddying coupled general circulation model. ESS Open Archive . July 25, 2024. DOI: 10.22541/essoar.172191625.54735141/v1