SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2023
Project Title:	EC-EARTH4: developing a next-generation European Earth System model based on ECMWF modelling systems
Computer Project Account:	SPNLTUNE
Principal Investigator(s):	Shuting Yang
Affiliation:	Danish Meteorological Institute
Name of ECMWF scientist(s) collaborating to the project (if applicable)	……………………………………………………………. …… ……………………………………………………………. ……
Start date of the project:	01/01/2022
Expected end date:	31/12/2024

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	100,000,000	0	115,000,000	2000
Data storage capacity	(Gbytes)	90,000	0	150,000	1000

Summary of project objectives (10 lines max)

The project aims at supporting the development of configurations of the next generation of the EC-Earth global Earth-system model: EC-Earth4, based on OpenIFS and NEMO4. In particular the project will allow model experiments to be used in the tuning process, including AMIP runs aimed at determining model sensitivity to parameter changes, validation and testing of the model following the integration of new component cycles, experiments aimed at testing new parameterizations and new configurations and long coupled equilibrium experiments at intermediate resolution to assess model biases and to tune ocean parameters. Experiments with different model resolutions and different component configurations are planned. The activity will include the implementation of a continuous testing, tuning and software validation framework.

Summary of problems encountered (10 lines max)

Due to a longer than expected development cycle, the release of a GCM version of EC-Earth4, suitable for tuning and a first evaluation of biases is now planned only after summer 2023. In particular EC-Earth4-GCM needs the implementation of CMIP6 forcings and of M7 aerosols in OpenIFS. This has led to an unforeseen delay in the planned schedule for tuning and diagnostics experiments in SPNLTUNE. Additionally, the participating institutions had (during last year and the first months of this) the availability of important external computing resources, which were used for developing and testing EC-Earth4 and, during most of last year, ECMWF's Atos BullSequana XH2000 (ATOS) usage was not billed.

Summary of plans for the continuation of the project (10 lines max)

The release of the EC-Earth4-GCM configuration (including a coupled and an AMIP configuration, CMIP6 forcing, simplified interactive aerosols and some tuning capabilities) is now planned after summer 2023. This version will be tested in SPNLTUNE by performing coupled runs (50y) under present-day conditions to identify the first major biases. We plan to use this version to perform a series of AMIP model runs (up to 20 years/run, 10 atmospheric parameters, at least 5 different parameter values, different model resolutions) aimed at determining model sensitivity to parameter changes to be used for tuning. The necessary workflow will be set up in the next months and, if EC-Earth4-GCM will be further delayed, run immediately also with EC-Earth4.0, to get a first estimate of the sensitivities and to obtain a dataset to develop tuning analysis software tools and workflow. We plan to implement a continuous testing workflow, including model diagnostics, allowing us to perform standardized experiments aimed at rapid tuning, with the goal of maintaining at all times a reasonably tuned version of the model in the main branch. A tagged version of EC-Earth4 including OpenIFS 43r3v2 and NEMO 4.2.0 is under development and is expected later this year. A transition towards OpenIFS 48r1 is being prepared and will occur as soon as that cycle becomes available.

List of publications/reports from the project with complete references

- None so far.
- The EC-Earth3 reference paper (Doescher et al. 2022) has been published in April 2022.
- Relevant porting and scaling of EC-Earth4 is reported in the ESiWACE2 deliverable Scalability on pre-exascale EuroHPC systems

Summary of results

The first months of 2022 were dedicated to developing a first technically working configuration of the model, and a first version 4.0 was released on 04 Feb 2022 and is available at https://dev.ec-earth.org/projects/ec-earth-4/repository/show/ecearth4/tags/4.0.
More recently, during the rest of 2022 and in the first half of 2023 model development has been entirely moved to a Gitlab platform hosted at SMHI, providing the advantage of a more efficient and flexible management of version control and the possibility of continuous integration.
The following EC-Earth components have been updated in the trunk version: OpenIFS 43r3v2, NEMO 4.2.0, XIOS 2.5+ (trunk), OASIS3-MCT 5.2. Implementation of CMIP6 forcings is underway and a modal aerosol scheme with either strongly simplified chemistry or

coupled to more comprehensive chemistry is being developed within the OpenIFS/AC project. A first version of the M7 aerosol implementation is currently being tested. Coupling of LPJ-GUESS to simulate dynamic vegetation in AMIP and GCM configurations is under development. Specifically the planned EC-Earth4-GCM release will include a coupled and an AMIP configuration, CMIP6 forcing, simplified interactive aerosols and some tuning capabilities. Fig. 1 reports a schematic overview of the model components. The currently available model version is based on a TL159L91 grid for the atmospheric component and an eORCA1L75 grid for the ocean component. An easy way to modify model tuning parameters from the runtime environment has been developed. EC-Earth4 uses the new ScriptEngine workflow software to handle the build and runtime environment scripts through simple YAML files. Full model documentation is available.

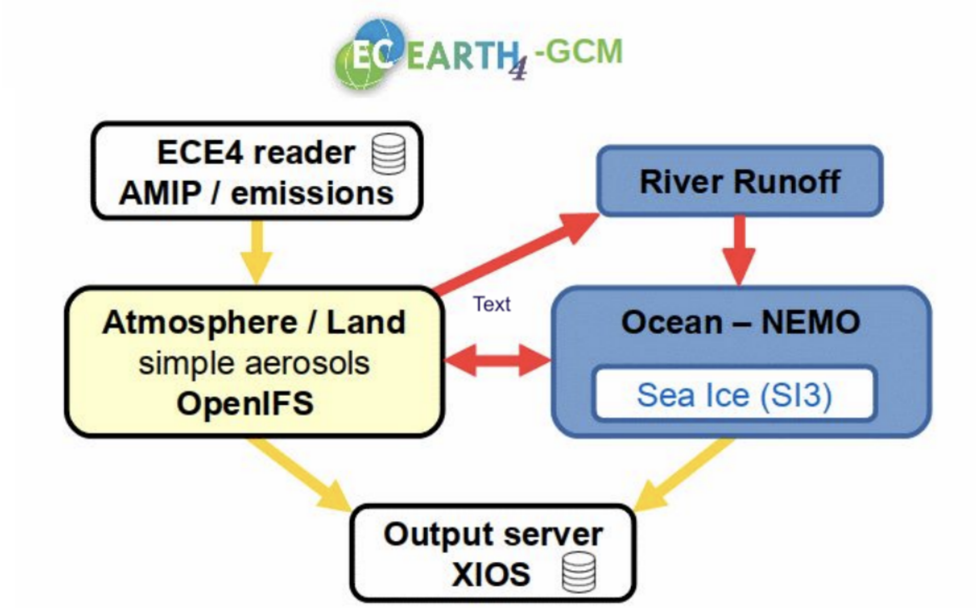

Fig 1. Schematic representation of the components included in EC-Earth4-GCM.

Model development included porting of the model to ECMWF Atos Sequana XH2000 HPCF, identifying the needed runtime environment and modules and adapting the model script engine configuration. The model has now been tested and successfully runs both in AMIP and coupled mode on ATOS at Tco95, TL159 and Tco199 atmospheric resolutions. Issues in EC-Earth4 development which have been addressed in the past year, also through targeted experiments, which are relevant for model tuning, include determination of an optimal time step for the TL159-eORCA1 configuration and the determination of the best resolution for EC-Earth4 development (TL159 has been preferred to Tco95 due to excessive Gibbs wiggles linked to orography). Testing and tuning of the NEMO 4.2 ocean component has started and a first evaluation of the main biases has been performed.

The release of the EC-Earth4-GCM configuration, a workable version of EC-Earth4 for GCM and AMIP configurations, capable of running a limited set of CMIP6 experiment configurations, represents an essential prerequisite for model tuning. In the meantime, model tuning activities have been focused on the development of a new suite of software tools needed for model monitoring, diagnostics and tuning, integrated in a complete model diagnostics workflow.

New tools developed specifically for EC-Earth4 tuning and monitoring include an updated version of a monitoring tool fully integrated in the model ScriptEngine scripting environment, with full documentation. The monitoring for each experiment is updated automatically after each simulated year, metrics are stored locally on disk and optionally uploaded automatically to the project Redmine as an issue. Atmosphere, ocean, sea-ice and technical metrics are included. An example of the output is reported in Fig. 2.

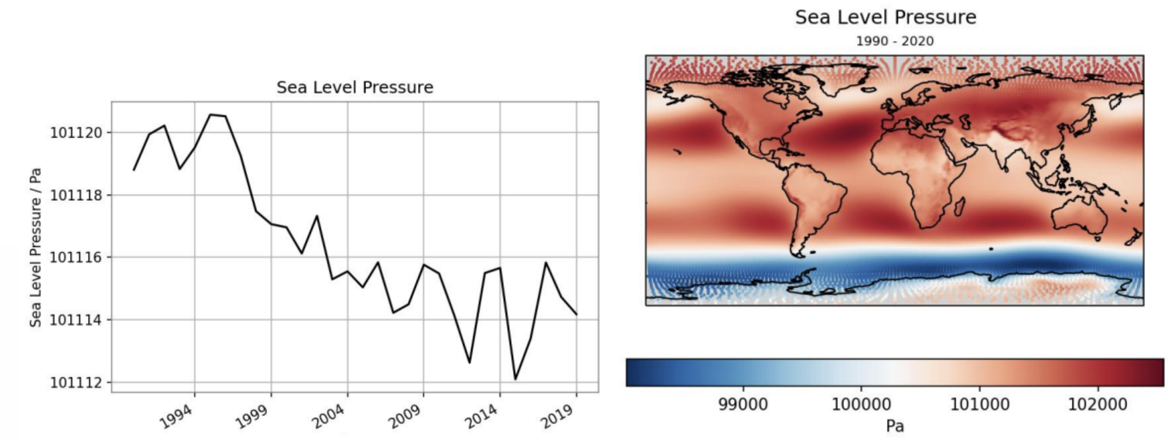

Fig. 2 Example output from the EC-Earth4 monitoring tool. This type of output can be pushed automatically to an issue on the EC-Earth development portal.

Specifically for EC-Earth4 tuning, in collaboration with the ARMAGNAC Special Project, we developed a new Python-based lightweight parallelized tool for evaluation of basic properties of the model, such as global mean and climate model performance indices, publicly available on Github (ECmean4, documentation). ECMean4 expands in a complete and publicly available software package from the simple ECmean script which was used for EC-Earth2 and EC-Earth3 evaluation, but it now uses Python3 and YAML configuration files. ECmean4 is built exploiting Xarray + Dask lazy calls which are executed in a single instance, exploiting parallelization on multiple variables with Multiprocessing. Working with YAML files allows for a more flexible usage, making possible expanding the support to new climate models or to include new reference climatologies. Scripts can be run from command line so that they can be easily integrated within an Earth System Model workflow. Additionally to EC-Earth4, interfaces for the analysis of EC-Earth3 and CMOR2 and CMOR3 CMIP5 and CMIP6 data are available, allowing an easy comparison across models. The development of EC-Mean4 was performed using test runs of EC-Earth4 performed on ATOS (mainly during the free billing period in 2022), including efficiency tests. ECmean4 is now publicly distributed as a PyPI package ("pip install ECmean4"). A new climatology making use of high-resolution data (e.g. CRU, ERA5, MSWEP, etc.) has been included and scripts are provided to possibly create new reference climatologies.

We report in Fig. 3 an example figure of the type of analysis which can be performed with ECmean4 (only one model year in this case), computing Reichler and Kim performance indices, globally, for latitudinal bands and seasonally. Fig. 4. shows instead an example of model biases which can be computed by the package. All diagnostics are produced both as figures and as machine-readable YAML files.

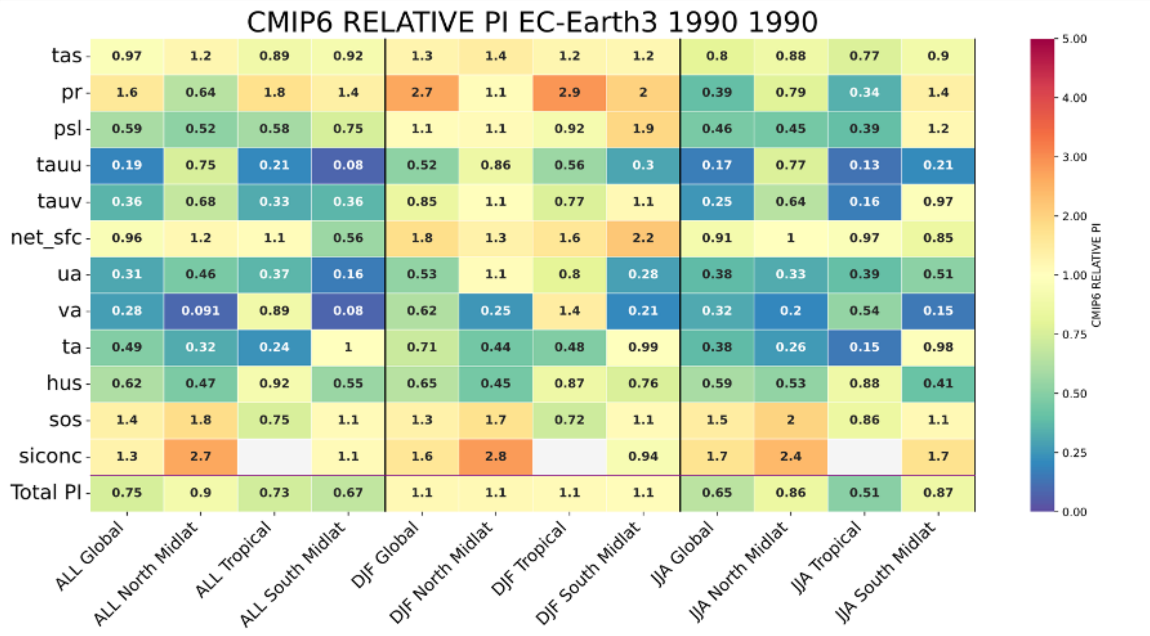

Fig. 3.: Sample performance indices computed by ECMean4 for an EC-Earth simulation. Values smaller than one imply better results than the CMIP6 ensemble average.

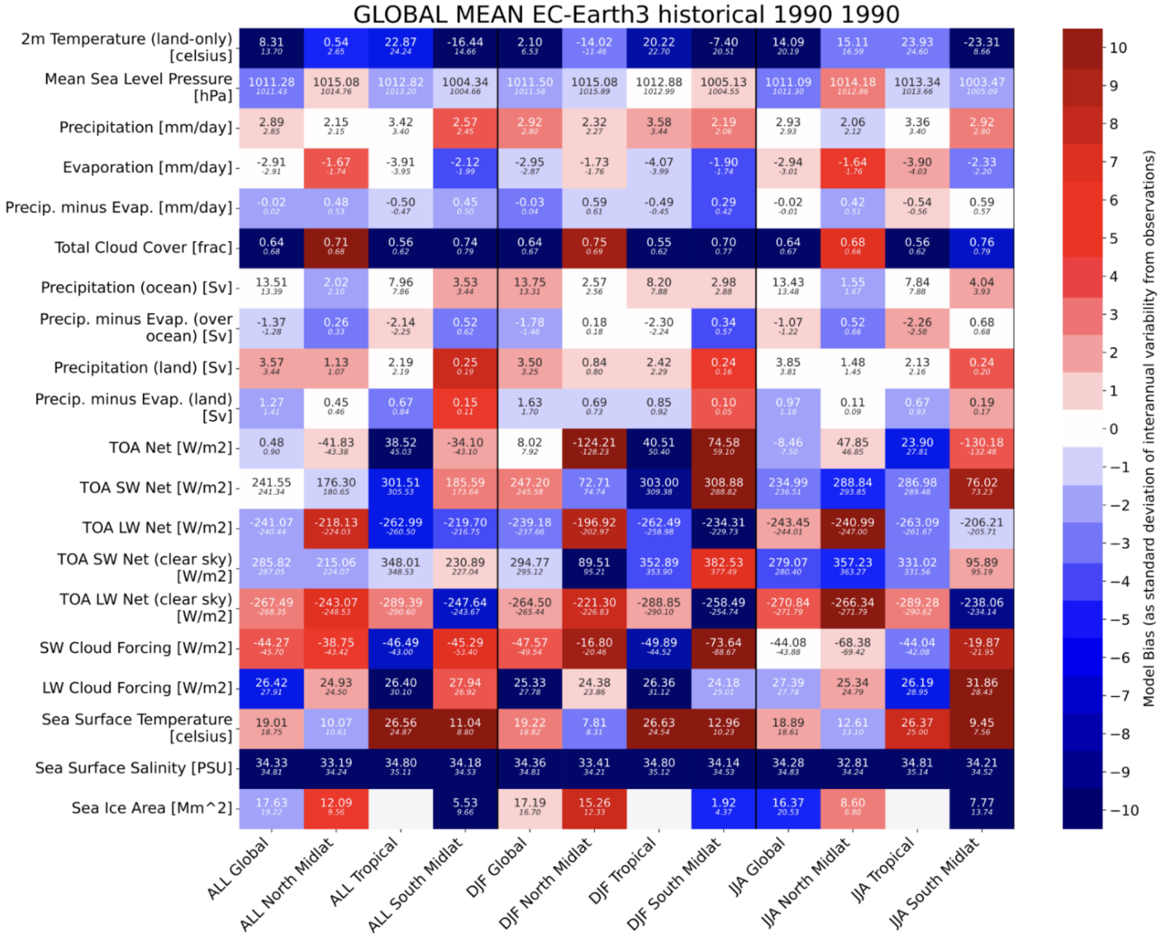

Fig. 4. Sample global mean bias calculation for an EC-Earth simulation. Colors indicate the model bias scaled with the standard deviation of the interannual variability from observations. Blue implies negative bias, red positive bias. In each of the tiles the larger number shows the model value, while the smaller one is the reference value.