SPECIAL PROJECT PROGRESS REPORT

Reporting year	2024 (1st year of the project)
Project Title:	Simulation of extremes of Arctic sea ice reduction with a rare event algorithm in EC-Earth3
Computer Project Account:	spberago
Principal Investigator(s):	Francesco Ragone (https://uclouvain.be/en/directories/francesco.ragone)
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Name of ECMWF scientist(s) collaborating to the project	/
Start date of the project:	01 January 2024
Expected end date:	31 December 2026

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

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	/	/	32,000,000	2,695,800
Data storage capacity	(Gbytes)	/	/	90,000	20,000

Summary of project objectives (10 lines max)

In this project we apply the Giardina-Kurchan-Lecomte-Tailleur (GKLT) rare event algorithm [1,2,3,4] applied to ensemble simulations with EC-Earth3 to increase the sampling efficiency of extreme Arctic sea ice lows. Taking advantage of the improved statistics provided by the algorithm, we estimate the probabilities of extreme sea ice lows and we investigate their physical drivers. The aim is to better understand the relative importance of winter-spring sea ice-ocean preconditioning vs. spring-summer thermodynamical and dynamical processes in favouring extremely low sea ice conditions during summer. Finally, we are interested in the probability of ultra-rare but high impact events, e.g. of a total disappearance of Arctic sea ice for one year under current climate conditions.

Summary of problems encountered (10 lines max)

A minor problem that we faced so far is related to the implementation of random perturbations to the model during the application of the rare event algorithm. The rare event algorithm involves a resampling procedure where at regular time intervals some ensemble members are cloned, while others are suppressed. After each resampling a small random perturbation is added to the clones to allow them to evolve differently from their parent trajectory. In previous applications of the algorithm with other models, for example CESM, this perturbation was added directly to the restart files taking advantage of the fact they were in netcdf format. As the IFS restart files are unformatted, in EC-Earth this is not practical. We decide to circumvent this problem by restarting the clones not from the restarts but from the IFS initial condition files, which are instead in GRIB format and therefore easy to handle. We have performed tests to verify that the difference between restarting the model from a restart file or from an initial condition file is indistinguishable from the difference between restarting the model from two perturbed initial condition files. This means that the use of initial condition files as substitutes for restarts is justified in our experiments, as we would add a random perturbation with a comparable impact anyway.

A more severe problem is that at the moment the computational resources required by the simulations with the rare event algorithm are larger than the original estimates. This is due to the fact that the rare event simulations includes additional operations related to the manipulation of the restarts/initial conditions files described above. The fact that simulations with the rare event algorithm are slower than regular ensemble simulations is expected, and the original estimates took this into account, based on the experience of the PI with the same method applied to a model of the same complexity (CESM). However, the current performances are nearly 3 times slower than the original estimates. This is likely due to a number of operations that are not yet performed in an optimal way. Issues that have been identified are: 1) likely avoidable rebuilding of NEMO restart files; 2) a too large output frequency of the IFS model; 3) inefficient tar-compression of output files; 4) redundant rearrangement of model code. We are at work on this in order to bring the computational performances in line with our original estimates. Given that we are at the beginning of the project, we do not forsee the need to modify the plan of the experiments yet. If in the next few months we will conclude that some of the problems are not solvable, we will refocus the project on experiments of Type 3 and 4, which are the most scientifically relevant. We do not think that it is necessary to take this decision right now however. Note also that a large part of the computational resources originally planned for the control run will be available for the experiments with the rare event algorithm, as the control run started before the beginning of the project and was completed using mostly the "regular" computational budget of RMI.

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

We recently finalized a first implementation of the rare event algorithm into the EC-Earth environment. In the next step of the project, we will optimize this implementation regarding the computational efficiency. This technical phase is planned to be completed in the next 1-2 months at maximum. Meanwhile we are analysing the EC-Earth control run (that we have already produced) in order to understand the time scales related to Arctic sea ice variability and sea ice lows in this specific model. These results and the results from rare event simulations that we already successfully performed with the intermediate complexity climate model Planet Simulator (PlaSim)-Large Scale Geostrophic (LSG) ocean [4] will provide the basis for choosing appropriate values for different parameters of the rare event algorithm and to construct a set-up of dedicated experiments with EC-Earth, which are expected to start from August-September 2024.

List of publications/reports from the project with complete references

Preparation of a first publication on experiments with EC-Earth is expected for Q4 2024-Q1 2025.

Summary of results

During the first six months of the project, the work with EC-Earth was primarily of technical nature. We produced a 150-year post-spin up control run (Figure 1) and finalized a first version of an implementation of the rare event algorithm into the EC-Earth environment. In this context, we tested to what extent the statistical properties of the simulated climate depend on whether the model is restarted from “IFS-restart files” vs. perturbed and unperturbed “IFS-initial condition files”. We found that the “IFS-initial condition files” can be used to implement small random perturbations required for the simulations with the rare event algorithm (see “Summary of plans for the continuation of project” for more details).

In parallel and as a preparation of our work with EC-Earth, we performed seven 600-member rare event algorithm and control ensemble simulations with the intermediate complexity coupled climate model PlaSim-LSG. These ensembles started from slightly perturbed identical initial conditions sampled from a control run. Such an ensemble design corresponds to the setup we are planning for experiments of Type 3 and 4 with EC-Earth3. We demonstrated the applicability of the algorithm to improve the sampling efficiency of extremely negative seasonal mean and August-September mean sea ice area anomalies. Likewise, the algorithm allowed us to generate ultra-rare sea ice lows that were not accessible with the control ensemble simulations. A separate publication on this is currently in preparation.

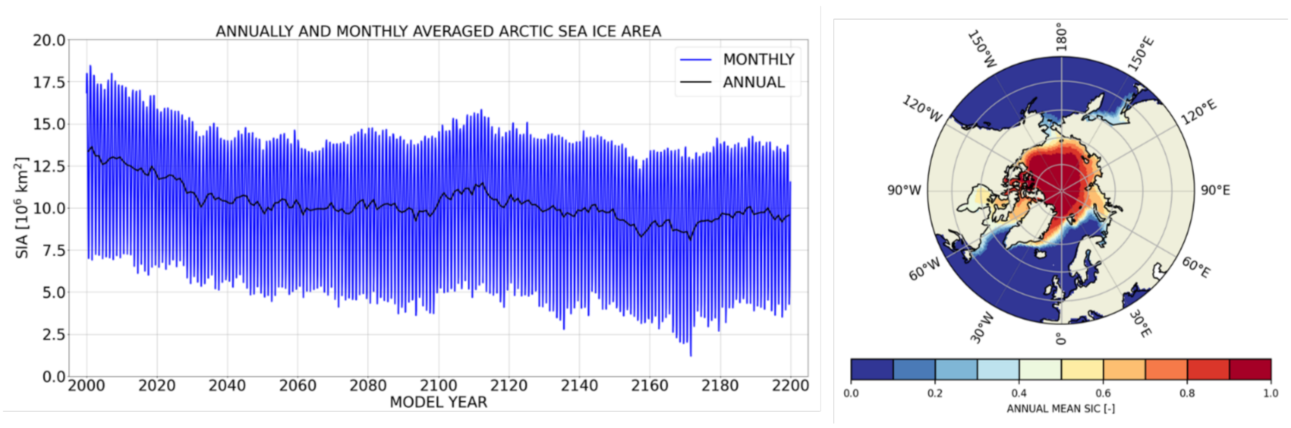

Figure 1:Control run with EC-Earth version 3.3.1.: (Left) Pan-Arctic sea ice area and (right) annual mean sea ice concentration. The annual mean sea ice concentration field is based on model years 2050-2199.

References

[1] Del Moral, P. and Garnier, J., 2005: Genealogical particle analysis of rare events, *Ann Appl. Prob.*, **15(4)**, 2496-2534, doi:10.1214/105051605000000566.

[2] Giardina C., J. Kurchan, V. Lecomte, J. Tailleur, 2011: Simulating rare events in dynamical processes, *Journal of Statistical Physics*, **145,** 787-811, doi:10.1007/s10955-011-0350-4.

[3] Ragone, F., J. Wouters and F. Bouchet, 2018: Computation of extreme heat waves in climate models using a large deviation algorithm, *Proc. Natl. Acad. of Sci.*, **115(1)**, 24-29, doi:10.1073/pnas.1712645115.

[4] Sauer, J., F. Ragone, F. Massonnet, G. Zappa, J. Demaeyer, 2024: Extremes of summer Arctic sea ice reduction investigated with a rare event algorithm, *Climate Dynamics*, 1-19, doi:10.1007/s00382-024-07160-y.