<u>LATE</u> REQUEST FOR A EMI R&D PROJECT 2026–2028

Country/Organisation: United Kingdom / University of Oxford

Principal Investigator[1]: Dr. Robert (Bobby) Antonio & Dr. Hannah Christensen

Affiliation: University of Oxford

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Dr Valentina Sicardi
Dr Michael Bareford

Project Title:

Speeding up ocean spin-up using stochastic parametrisations

To make changes to an existing project please submit an amended version of the original form.

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** GBCHRI	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2026	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Late EMI R&D Projects are normally approved for 1 year, but exceptionally can be approved for 3 years.

Computer resources required for project year:		2026	2027	2028
High Performance Computing Facility	[SBU]	3000000	3000000	
Graphics Processing Unit Cluster-A	[GBU]	1000000	1000000	
Graphics Processing Unit Cluster-B	[GBU]	500000	500000	
Accumulated data storage (total archive volume)[2]	[GB]	100	200	

[1] The Principal Investigator will act as contact person for this EMI R&D Project and, in particular, will be asked to register the project, provide annual progress reports of the project's activities, etc.
[2] These figures refer to data archived in ECFS and MARS. If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year etc.
[3] The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

EWC resources required for project year:		2026	2027	2028
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

Continue overleaf.

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Extended abstract

All EMI R&D Project requests should provide an abstract/project description including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

Following submission by the relevant Member State the EMI R&D Project requests will be published on the ECMWF website and evaluated by ECMWF and its Scientific Advisory Committee. The requests are evaluated based on their scientific and technical quality, and the justification of the resources requested. Previous EMI R&D Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

Requests exceeding 10,000,000 SBU should be more detailed (3-5 pages).

Project Overview:
The primary aim of this project are to use recent advances in machine learning (ML) to speed up the ocean spin-up in a coupled earth system model in order to improve the quality of climate simulations as part of the EERIE (European Eddie-Rich ESMs) project. Our approach to do this is by coupling a machine learning emulator of the atmosphere (ACE2) to a standard ocean model (NEMO), which will significantly reduce the compute time required per year of spin up. This also allows us to explore scientific questions about how the atmospheric dynamics affect the ocean, and the behaviour of machine-learnt emulators. Coupling a machine-learnt emulator to a physical ocean model is challenging and novel work, which to the best of our knowledge has not been achieved elsewhere.

As previously reported within the spgbchri project, we have created a scheme to couple ACE2 and NEMO to create ACE2-NEMO, and our 70-year historical and control runs using ECMWF's HPC system last year are documented in our recent preprint (https://arxiv.org/abs/2603.28704).

Spin-up Simulations Progress:

For the spin-up experiments, we have developed two protocols, where ocean restart files are created using ACE2-NEMO and passed to collaborators at Barcelona Supercomputing Centre who use these as initial conditions for EC-Earth3 simulations. The first is a 'Like-for-like' comparison, whereby the ocean is spun-up for the same amount of time using ACE2-NEMO and EC-Earth 3. The second approach ('Extended') makes use of the fact that ACE2-NEMO uses less than half the CPU resources of EC-Earth3, and so we can perform a longer spin-up using still fewer compute resources than for the EC-Earth3 spinup. In each case, the spun-up ocean state from ACE2-NEMO is provided as initial conditions to EC-Earth3 to investigate how much drift the post-spin-up periods present. It is also expected that there will be some 'shock' when providing EC-Earth3 with initial conditions from ACE2-NEMO, because feedback from the atmospheric model will not be identical to the IFS model in EC-Earth3: we therefore build in a 20 year buffer at the end of the ACE2-NEMO spin up to account for this adjustment. Results are compared against a spin-up using EC-Earth3 only ('Baseline'). The full spin-up protocol for these three runs (Like-for-like, Extended, and Baseline) is provided in Table 1.

Simulation name	ACE2-NEMO spin-up Length	EC-Earth3 spin-up length	EC-Earth3 evaluation period
Like-for-like	40	20	40
Extended	70	20	40
Baseline	-	60	40

Table 1: Summary of the spin-up experiments performed

Fig. 1 shows the globally averaged ocean potential temperature time series at six depth levels (0-100m, 100-500m, 500-1000m, 1000-2500m, 2500-4000m, and 4000m-bottom) for the three EC-Earth3 simulations. At the shallowest levels (0-100m and 100-500m), the ACE2-initialized experiments start the evaluation period considerably colder than the baseline and display substantially larger positive trends, confirming that they are still warming toward the baseline's thermal state. At intermediate depths (500-1000 m and 1000-2500 m), the simulations show diverging rather than converging trends, suggesting that different equilibrium states have been reached and that the spin-ups have not been long enough to reach convergence. Between 1000 and 4000m the trend magnitudes in the ACE2-spun up experiments are markedly weaker than at shallower levels, in contrast to the strong positive trends that persist in the upper ocean. This reduction in trend magnitude at intermediate depths in the ACE2-initialized simulations may point to a possible earlier stabilization of the intermediate ocean, but a longer evaluation is required to test this with any confidence. Below 2500m, the three simulations track each other more closely in terms of trend magnitude, but remain offset in absolute values; this offset between the Extended and Like-for-Like simulations suggests the spin-up period is not yet long enough to reach convergence.

Based on these results, our opinion is that longer spin-ups and evaluation simulations are necessary to ensure that the ocean initial conditions passed to EC-Earth3 are as close as possible to the model's coupled equilibrium, and to meaningfully assess convergence of ocean temperature at depth. We have also identified problems in the NEMO velocity fields, which reduce our ability to diagnose ocean current phenomena such as the AMOC; we have identified and tested a change in the NEMO namelist which deals with this but have not had the resources to rerun the experiments with this change.

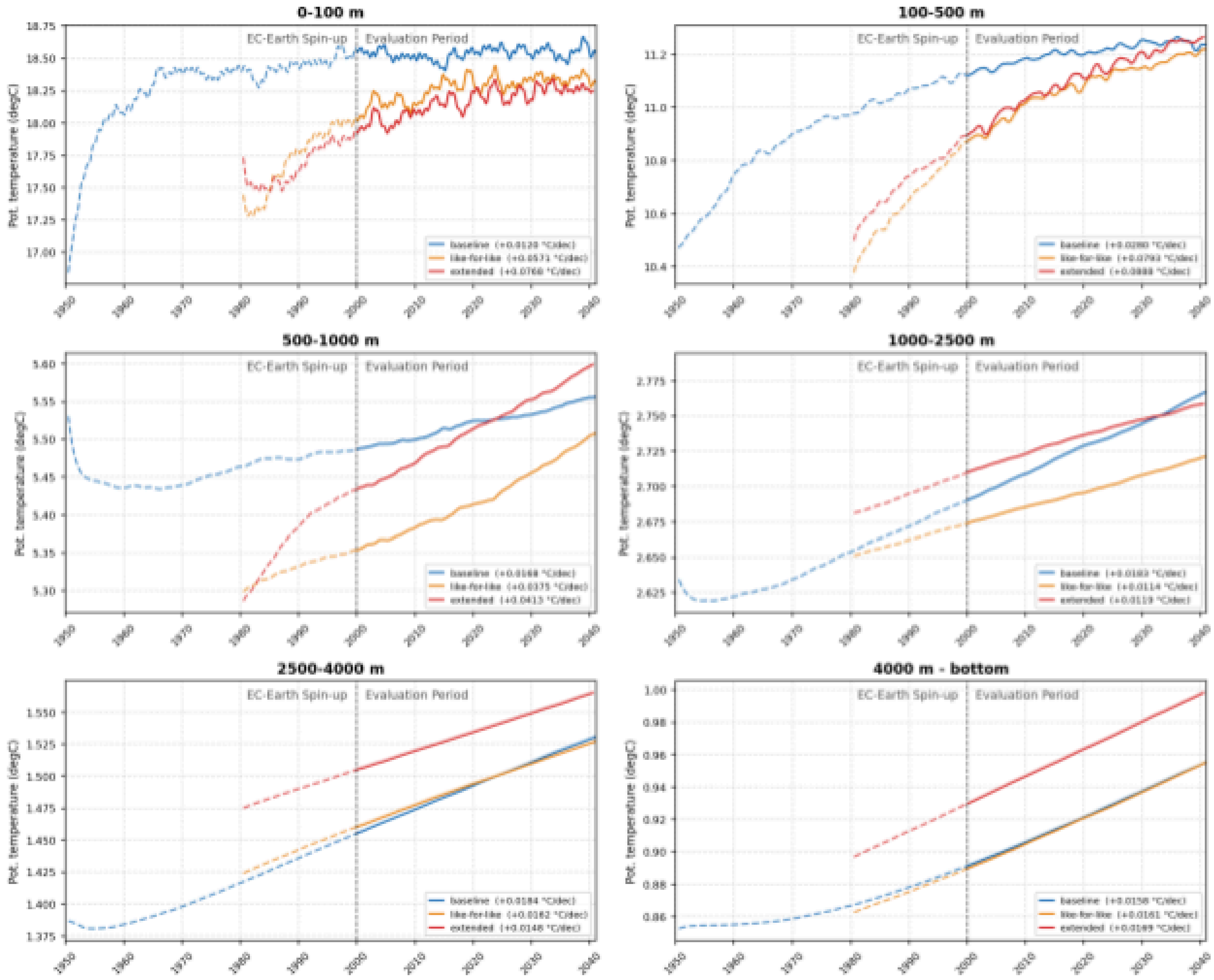

Figure 1: Timeseries of the globally averaged ocean temperature at different selected levels in the three EC-Earth simulations. The linear trends over the evaluation period are included in the legend.

Resource requirements:

We plan to run up to two additional 150 year spin-up simulations, using the adjusted NEMO namelist that improves the issues in ocean velocity fields. To run a 150-year simulation requires the use of 3 CPU nodes for running NEMO, and 1 GPU node for running ACE2, running for 15 days (1 day per decade). We therefore estimate that each 150-year simulation requires 2.5m SBU, and 1.3m GBU, rounded to 3m and 1.5 respectively to provide headroom for testing and analysis. Since we anticipate our new results raising more questions and hypotheses to be tested, including much longer spin-ups, we have incorporated two 150-year simulations into our plan, bringing the total to 6m SBU and 3m GBU, spread out over 2026 and early 2027. The compressed and monthly aggregated output from our simulations will be less than 100GB per 150-day simulation. Since our code with this config change has already been successfully run on ECMWF's HPC earlier this year, we do not anticipate any significant technical challenges that would prevent the simulations succeeding.

Technical Characteristics

We use the NEMO ocean model, which is written in Fortran and is written to be run in parallel over several nodes. For the atmosphere, we use ACE2, a recently developed machine-learnt emulator that has been demonstrated to be stable for 1000s of years, which is written in Python and requires a GPU to run. We communicate with NEMO using the OASIS and pyOASIS libraries, and utilise shared scratch storage and a polling mechanism to pass information from the CPU nodes to/from the GPU nodes (see Fig. 1 in https://arxiv.org/abs/2603.28704).