REQUEST FOR A SPECIAL PROJECT 2023–2025

MEMBER STATE: GB

Principal Investigator[1]: Beatriz Monge- Sanz

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Project Title: Alternative schemes to accelerate seamless weather prediction

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If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2023	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2023-2025: (To make changes to an existing project please submit an amended version of the original form.)		**2023**	**2024**	**2025**
High Performance Computing Facility	(SBU)	27,000,000	27,000,000	27,000,000
Accumulated data storage (total archive volume)[2]	(GB)	10,000	15,000	20,000

Continue overleaf

[1] The Principal Investigator will act as contact person for this Special 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.

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Extended abstract

All Special 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 Special 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 Special Project reports and the use of ECMWF software and data infrastructure will also be considered in the evaluation process.

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

Motivation and Project description

The new generation of Earth System Models (ESMs) required to answer pressing questions on weather extremes under climate change needs to be developed in ways that allow seamless prediction across a wide range of resolutions and timescales.

This requires a range of processes from different elements of the Earth System that influence surface weather to be realistically included in models. This often means parameterizing processes that cannot be resolved in current models, therefore using approximated approaches. It sometimes also means that emerging key processes are not so promptly included in models, slowing down our ability to address new questions.

Processes on relatively long timescales, like stratospheric processes, are being increasingly recognized as a potential source of predictability for surface weather on multiple timescales from days to decades (e.g. Scaife et al., 2022). How to efficiently incorporate appropriate descriptions of stratospheric processes, including stratospheric composition, in new ESMs is still an open question. Such descriptions need to exhibit the right compromise of realism and computational cost to be able to adequately perform across all timescales.

Due to computational costs, full-chemistry descriptions for the stratosphere are still mainly reserved for coarser resolutions than operational numerical weather prediction (NWP) models typically require, and such full-chemistry descriptions are not yet affordable for multi-ensemble long-range weather simulations.

Therefore, alternative stratospheric descriptions that are both realistic and affordable for all timescales and resolutions are key needs for emerging seamless systems.

With the increasing complexity in the number and variety of processes that future ESMs will include, from the high atmosphere to the deep ocean, from chemistry to clouds microphysics, from industrial emissions to vegetation processes, reducing the computational costs for the simulation of some of these elements will also allow for a wider constellation of processes to be included, and therefore for more comprehensive and realistic ESMs.

In this project we plan to assess feasibility and performance of alternative fast approaches for stratospheric key radiative species that can be implemented in an ESM at low computational cost, while providing quality comparable to key chemical fields from widely used full-chemistry models.

From our group at the University of Oxford we are developing new alternative approaches to emulate stratospheric composition options that allow interaction with atmospheric radiation and dynamics in ESMs, without the high costs of full-chemistry modules.

In collaboration with colleagues at ECMWF (see additional researchers named earlier in this document), we plan to assess the performance of these alternative approaches within the IFS system, with planned experiments both on medium-range and seasonal timescales.

In previous published work, we have shown how an improved description of stratospheric ozone improved meteorological fields and diagnostics in ECMWF experiments at different timescales (Monge-Sanz et al., 2022). For this, a fast linear ozone model was used (Monge-Sanz et al. 2011). We are continuing and expanding this line of research to include not only stratospheric ozone but also other species and processes key for stratospheric variability and evolution; for instance, promising results were presented for water vapour and methane by Monge-Sanz et al. (2013).

The new approaches we are developing in our group in Oxford are not limited to linear models but are also incorporating non-linear approaches and machine learning (ML) emulators. Thus, the implementation and assessment of our approaches in the ECMWF model also contribute to the ECMWF machine-learning strategy and to evaluate the feasibility and performance of ML-based descriptions to accelerate weather forecasting and ESM development (Dueben and Bauer, 2018).

The potential of ML-based emulators for ECMWF parameterization schemes has been successfully shown for the gravity-wave drag (GWD) parameterization scheme developed by Chantry et al. (2021). Experience and importing tools developed for this scheme will also contribute to this project.

For the implementation of linear fast models, we will build upon the experience and collaborations developed from previous work (Monge-Sanz et al., 2022). While for the implementation of ML-based models we will build upon the experience and coupling tools developed in the framework of one of our previous special projects for GWD and subsequently expanded by Matthew Chantry in the ESM Section at ECMWF (Chantry et al., 2021).

Our research will not only increase knowledge of stratospheric impacts on weather and climate prediction, showing potential ways to improve forecasts and predictability, but will also contribute to sustainable strategies to increase the complexity of processes included in the ECMWF model and guide model developments in other operational centres.

An additional benefit of implementing fast realistic approaches for key stratospheric species, is that we can then identify feedbacks and potential compensation errors that need to be addressed so that the ECMWF system is better prepared for an eventual operational use of interactive full-chemistry across different timescales.

While the focus of the main part of the project will be on stratospheric processes, we anticipate that later parts of the project will start to investigate other elements. Our research will therefore expand into other parameterization schemes contributing to a comprehensive development of Earth System Models at reduced computational cost compared to traditional approaches.

Experimental plan and justification of resources

The ML-based models we are developing offline will be coupled into IFS using routines created to import and run these ML models following the importing approaches developed by Chantry et al. (2021). To implement the ML-based models into the IFS system, we need to couple machine learning tools that are mostly written in python to the IFS Fortran code. The expertise of Matthew Chantry in importing and coupling ML emulators into IFS will contribute to the success of this project.

Once the coupling is successfully completed, then online IFS experiments are planned to compare the performance of these ML-based schemes to other linear schemes and to control simulations with default IFS configurations. We will run experiments for deterministic medium-range forecasts and for ensemble prediction runs on longer timescales.

Comparison of results from the online runs to improvements achieved by linear modelling options previously implemented in IFS (Monge-Sanz et al., 2022) will ideally be performed within one same IFS cycle version. The machine learning online coupling steps are being planned with the IFS CY47r3 cycle version, although this work is cycle-independent and can be adapted to a different cycle version as necessary.

The simulations we plan to carry out with IFS include:

i) Medium-range 10-day forecast experiments covering different periods of time, up to one year, allowing for assessment of the implemented approaches along the annual seasonal cycle, as well as under different atmospheric conditions and relevant meteorological patterns (e.g. polar vortex breaking events).

ii) Seasonal runs with 7-month integration range and typically two start dates. These runs will cover periods of between 10 and 20 years, allowing to assess the evolution of stratospheric interannual variability in a decadal framework.

A sufficient number of medium-range experiments will be performed and assessed prior to running the more costly seasonal experiments, to ensure optimal use of resources.

At least a subset of medium-range and seasonal experiments will be run at the same resolution to facilitate as much as possible the intercomparison of results on different timescales. We will aim to use a resolution of TCo399 and L137 for most of our experiments. The number of vertical levels is also chosen to match that of the ERA5 reanalysis for further comparison.

For this planned resolution, TCo399 and L137, the estimated cost of 10-day forecasts covering 1-year period is 140,000 System Billing Units (SBUs).

For a seasonal run with 2 start dates and 10 ensemble members covering 14 simulation months, the estimated cost is 800,000 SBUs.

The above estimates are based on the test experiments b2nj and b2nk.

The budget we propose, 27,000,000 SBUs per year, would allow us to carry out up to four simulation years of medium-range experiments and seasonal experiments covering up to 30-year periods, with the above configurations, each year. We allow for an additional 10% SBUs to account for initial tests and spin-up periods.

Our existing knowledge of IFS and of the ECMWF supercomputing facilities ensures we can start simulations in the first year and keep an analogous request of SBUs for the second and third years of the project.

References:

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