REQUEST FOR A SPECIAL PROJECT 2022–2024

MEMBER STATE: ……Italy……………………………………...…

Principal Investigator[1]**:** ……Federico Serva……………………….……

Affiliation: ……CNR-ISMAR…………………………………….……

Address: Via del Fosso del Cavaliere, 100
00133 Rome, Italy……………………….……

……………………………………………………….……

……………………………………………………….……

Other researchers: ……………………………………………………….……

……………………………………………………….……

Project Title: …Investigating the stratospheric dynamics of high-top climate model configurations …………………………………….……

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ITSERV______________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2022	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2022-2024: (To make changes to an existing project please submit an amended version of the original form.)		**2022**	**2023**	**2024**
High Performance Computing Facility	(SBU)	5 000 000	7 500 000	8 000 000
Accumulated data storage (total archive volume)[2]	(GB)	10 000	20 000	30 000

Continue overleaf

1The 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.

Principal Investigator: …Federico Serva………………………………………….

Project Title: ……………………………………………………………………

Extended abstract

The completed form should be submitted/uploaded at https://www.ecmwf.int/en/research/special-projects/special-project-application/special-project-request-submission.

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.

Following submission by the relevant Member State the Special Project requests will be published on the ECMWF website and evaluated by ECMWF as well as the Scientific Advisory Committee. The evaluation of the requests is based on the following criteria: Relevance to ECMWF's objectives, scientific and technical quality, and 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 asking for 3,000,000 SBUs or more should be more detailed (3-5 pages). Large requests asking for 10,000,000 SBUs or more might receive a detailed review by members of the Scientific Advisory Committee.

Current atmospheric models are able to simulate stratospheric processes with increasing accuracy and realism, leading to improved forecasts from the short to the seasonal time scale and beyond. Both numerical and physical aspects are very important for defining the model climatology and variability, but many physical processes are not well constrained and represented by schemes based on simplified assumptions. Since the cost of running simulations at high resolution or with more expensive schemes can be too high for longer experiments, it is important to know in detail the response of modelled processes under various possible configurations. For this project, we will focus on the stratosphere simulated by the Integrated Forecast System model in configurations including the upper atmospheric layers (up to 80 km heights).

Previous computational projects, such as SPHINX (*Davini et al., 2017*) investigated the sensitivity of the EC-EARTH model (v3.1) to horizontal resolution and perturbed physical tendencies, and results of these runs indicated a large spread in the stratospheric dynamics, such as in the properties of the equatorial quasi-biennial oscillation (QBO) in the stratosphere.

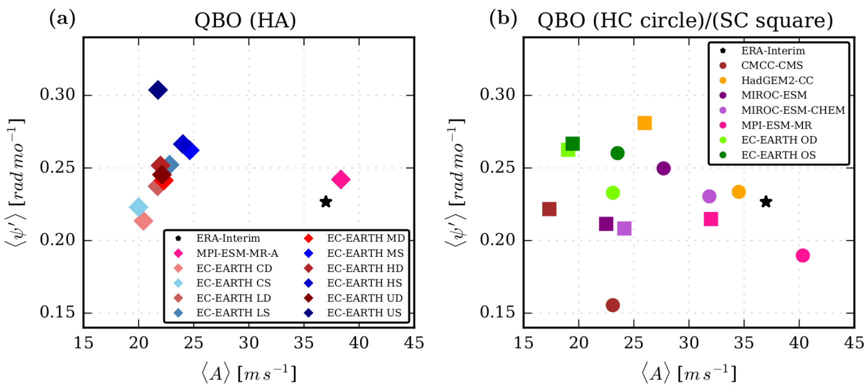

Figure 1: Scatter plots of the phase speed (radians/month) against the amplitude (m/s) of the modelled QBOs for the SPHINX set of simulations and a selection of high-top models from the CMIP5 generation. Historical, atmosphere-only

(HA) simulations in (a), historical coupled (HC, circles) and historical high-emissions scenario (SC, squares) in (b). Reproduced from *Serva et al. (2020)*.

From Figure 1 (a) we can see how there is a large spread for the QBO phase speed (on the ordinate) depending on the model resolution, whereas changes in the amplitude (on the abscissa) are more modest. Note moreover how the modelled phase speed is close to that observed (with a periodicity of about 28 months), but the amplitude is systematically underestimated by about a factor two. This is likely related to the driving of the QBO in the model, which is affected by changes in resolution and tuning of parameterized wave forcing. The lack of realism in the QBO driving also important for the climate scenario results, since while the amplitude is robustly predicted to decrease due to increased tropical upwelling, changes in the frequency remain highly uncertain (*Richter et al., 2020*), as also seen from the intermodel spread in a high emission scenario in Figure 1b.

Recently the EC-EARTH model (v3.2) has been used for producing the simulations for the Coupled Model Intercomparison Project – Phase 6 (CMIP6) activity. As seen from Figure 2, which compares aspects of the QBO simulated by the phase 5 and phase 6 model versions, both the phase speed and the amplitude of the CMIP6 model version are underestimated compared to observational references, probably since the model was not optimized for these aspects. The change of vertical resolution between CMIP5 and CMIP6 versions evidently improved the QBO realism, and similar improvements were reported for other aspects of the stratospheric climatology (*Doescher et al., 2021*).

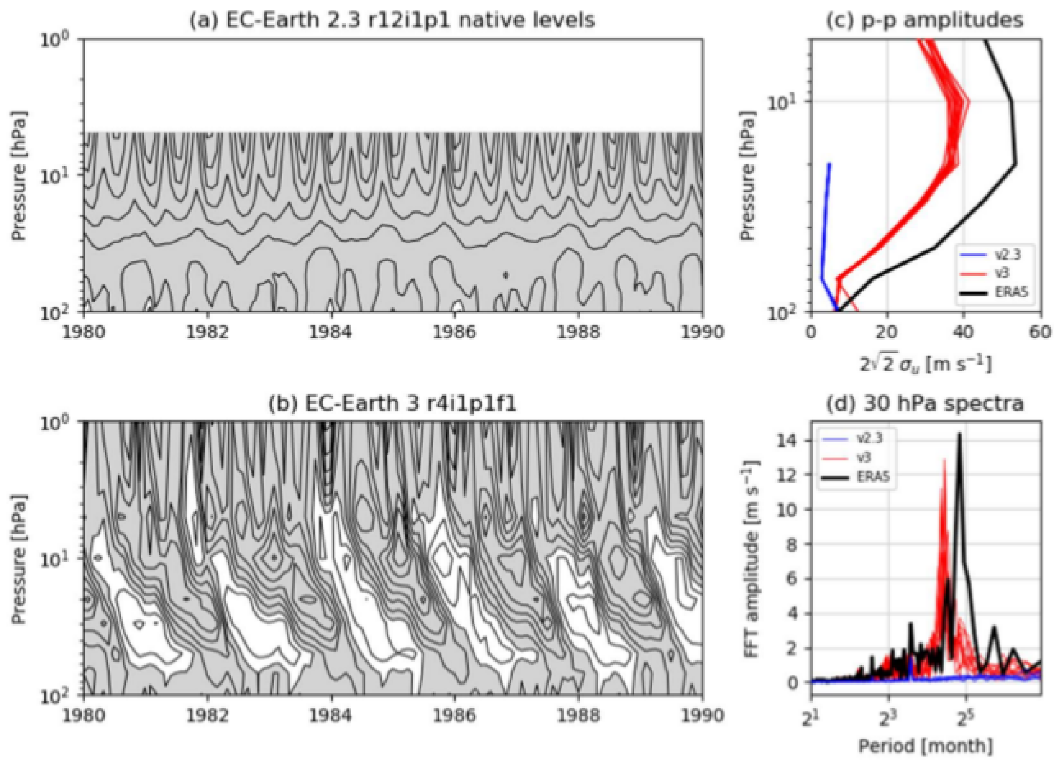

Figure 2: Panel with QBO winds as a function of time and pressure for EC-EARTH 2.3 (a) and EC-EARTH 3 (b), amplitude profiles (c) and Fourier spectra in the stratosphere (d), as simulated by a set of CMIP5 and CMIP6 integrations. Reproduced from *Doescher et al. (2021)*.

Some numerical aspects of the model were in fact not optimized with the stratosphere in mind, as for example the inclusion of a frictional drag term or other unsuitable conditions (suited for 'low-top' versions) in the physical drag schemes may deteriorate the realism of modelled processes. The variability of the upper stratosphere is still not realistic, due to an overall easterly bias (Fig. 2b, above ~5 hPa).

The objectives of this Special Project proposal are similar to the ones of a previous project (SPITSERV), and will benefit from the information derived from the runs performed with EC-EARTH3. The main interests are related with the circulation sensitivity and representation of stratosphere-troposphere coupling. In SPITSERV the OpenIFS model (Cy43r3) was proposed as the main tool to investigate the model response to changes in the configuration. However, due to a delayed release of the model, it was not possible to follow the original plan, since the available version (Cy40r1) was missing some required functionalities and updated schemes. Therefore in SPITSERV we considered the EC-EARTH model (v3.2), also shown in Figure 2b. The licence for OpenIFS was nevertheless obtained for preliminary work on the source code already during SPITSERV.

The design of the simulations would be similar to that already proposed for SPITSERV and depends on the progress in the inclusion of OpenIFS in the new version of EC-EARTH. Either OpenIFS, EC-EARTH3 or EC-EARTH4 could be used, with the latter more available likely after the second half of the project.

Assuming a multi-year project duration, the first year would be used to test a range of configurations, producing several 30-years runs (between 5 and 10) in an atmosphere-only setup. Shorter runs may be useful to investigate the effect of revising parameterization options in the model. For this the estimate is about ~150 simulated years and 5 MSBU (considering the time needed to adjust to the new HPC system).

In the second year, longer simulations could be carried out. At this point, the new version of the EC-EARTH model should be fully adapted to provide the required diagnostics. Comparison with previous simulations can be done, and coupled simulations carried out (provided that suitable initial states are available, in order to reduce spin-up times). Expecting higher costs due to the use of the coupled model, we expect around 7.5 MSBU for overall ~3 centuries of simulation.

Based on the results of second year, in the third year inter-decadal variability, initialized or nudged runs (supported by IFS) could be performed to further test the findings. A tentative estimate is similar to the second year, hence 8 MSBU.

For the archiving, retaining the full output may be unfeasible for higher vertical and horizontal resolution. Therefore the plan would be to retain postprocessed data and a smaller amount of higher resolution data for selected process-based studies (e.g., for equatorial or selected extratropical domains). Based on the EC-EARTH file size for CMOR-compliant files, we estimate cumulated 10, 20 and 30 TB of space throughout the duration of the project.

The investigation will only consider work on the new (Cy43r3) version of OpenIFS if only a one-year project is possible, given the possible usefulness of results in the course of the EC-EARTH update.

At this stage these numbers provided with this request are tentative, since both the new version of the model (with netCDF output capabilities, as recently documented by *Yepes-Arbos et al., 2021*) and the porting on the new HPC system may be beneficial leading to optimized use of resources. Timely updates will be provided to the Special Project support team to make the best use of the available infrastructure.

It is expected that the results of these activities will be useful in inform modellers on the response to changes in model configuration, hence ensuring the higher fidelity possible given the computational constraints and help increasing the reliability of the results.

References

Davini, P., and coauthors: *Climate SPHINX: evaluating the impact of resolution and stochastic physics parameterisations in the EC-Earth global climate model,* Geosci. Model Dev., 10, 1383–1402, https://doi.org/10.5194/gmd-10-1383-2017, 2017.

Döscher, R., and coauthors.: *The EC-Earth3 Earth System Model for the Climate Model Intercomparison Project 6*, Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2020-446, in review, 2021.

Richter, JH, Butchart, N, Kawatani, Y, et al. *Response of the Quasi-Biennial Oscillation to a warming climate in global climate models*. *Q J R Meteorol Soc*. 2020; 1– 29. https://doi.org/10.1002/qj.3749

Serva, F., Cagnazzo, C., Christiansen, B. *et al. The influence of ENSO events on the stratospheric QBO in a multi-model ensemble*. *Clim Dyn* **54,** 2561–2575 (2020). https://doi.org/10.1007/s00382-020-05131-7

Yepes-Arbós, X., van den Oord, G., Acosta, M. C., and Carver, G. D.: *Evaluation and optimisation of the I/O scalability for the next generation of Earth system models: IFS CY43R3 and XIOS 2.0 integration as a case study*, Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2021-65, in review, 2021.