REQUEST FOR A SPECIAL PROJECT 2022–2024

MEMBER STATE:	Italy
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Project Title:	QUECLIM - Quasi-equilibrium climates at increased greenhouse forcing

If this is a continuation of an existing project, please state the computer project account assigned previously.		
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**	
High Performance Computing Facility	(SBU)	28,500,000	28,500,000	
Accumulated data storage (total archive volume)[2]	(GB)	90,000	90,000	

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

The main goal of the project is to investigate the changes in the mean state and internal variability of the climate system at various temporal scales - from subseasonal to interannual and decadal - in quasi-equilibrium conditions with different levels of greenhouse forcing. This will be done performing 500-yr long simulations with the EC-Earth climate model with fixed greenhouse gases (GHG) and aerosol concentrations at the level of 1975 (from the historical), 2065 and 2080 (from SSP5-8.5). These 3 runs will complete a set of 6 + 1 (the CMIP6 pre-industrial control run) quasi-equilibrium climates, adding to three runs already performed with conditions fixed at 2025, 2050 and 2100. The new simulations have been planned to fill the large gaps in the mean global temperature between the simulations already performed.

The complete set will constitute a unique dataset to study the dependence of the state of the climate and the occurrence of climate extremes on different levels of warming in regions with large natural variability. Also, the stabilization pathways are of interest because they show how the committed warming - already implied by a given level of concentrations - will be realized in the next centuries.

Finally, the stabilized climates will be compared with the transient climate states from CMIP6 scenario simulations at the same global temperature, to understand how the impact of warming on precipitation and atmospheric dynamics depends on time.

In the second year of the project, we plan to extend 3 of the 6 simulations performed to 1000 years, to study the longest stabilization scales of the climate system and the impact of the mean state on multi-decadal oscillations.

Main Objective

The main goal of the project is to investigate the mean state and internal variability of the climate system at various time scales - from subseasonal to interannual and decadal - in quasi-equilibrium conditions with different levels of greenhouse forcing, by performing 500-yr and 1000-yr long integrations with the EC-Earth climate model. The simulated quasi-equilibrium worlds will be compared to the transient states at similar global mean temperature given by the CMIP6 scenario simulations, in order to disentangle the impact of fast and slow feedbacks on climate extremes.

Motivation

The projection of the future state of the climate under increased concentrations of greenhouse gases (GHG) is a key area of research in the climate community. This global effort is coordinated by the Coupled Model Intercomparison Project (CMIP) now at its sixth phase (Eyring et al., 2016), which describes a set of common protocols to be followed by tens of climate modelling groups around the world. The fundamental CMIP6 climate simulations are represented by the historical ones - which aim at reproducing the recent climate record given the observed concentrations of GHGs and anthropogenic/natural aerosols - and by the scenario simulations - which predict the future state of the climate during the XXI century depending on a set of GHG and aerosol concentration scenarios (O'Neill et al., 2016; Gidden et al., 2019).

The scenario simulations are of fundamental importance in studying the rate of change of the climate system in the next decades and the related impacts. However, one limitation is that these are all transient simulations, in which the external forcing varies from year to year and the climate state is rapidly changing to adapt to the additional energy absorbed by the system. This makes it difficult to disentangle the fast and slow feedbacks of the system, and gives only a partial account of the latter, since a significant part of the warming has yet to be realized in the coming centuries, due to the large thermal inertia of the global oceans. The fraction of warming yet to be realized is expressed for example by the difference between the transient climate response (TCR) (i.e. the warming at the time of a CO_2 doubling) and the equilibrium climate sensitivity (ECS) (i.e. the final warming at equilibrium after a CO_2 doubling) (Knutti et al., 2017).

While the scenario simulations well support the policy by identifying the consequences of different emission pathways for the next century, they miss the more fundamental question of which will be the state of the climate system after all the warming linked to a specific level of forcing has been realized. Of course, this also has a computational implication, since state-of-the-art climate models are computationally expensive, and the full stabilization of the climate system takes centuries or even millennia if slower components are considered (deep ocean, Greenland and Antarctic ice sheets).
Instead of performing a small set of very long simulations, the climate community has since now given priority to performing multiple ensemble simulations for each climate scenario, in order to assess the internal variability of the transient response. Nevertheless, some questions can only be asked performing a longer simulation towards the stabilization of the climate system:

- What is the long-term pathway towards stabilization of the climate system, starting from different forcing levels? Does the system cross some critical thresholds during the stabilization?
- How does the mean state of the climate and its internal variability change at quasi-equilibrium under different forcing levels? For example, recent research show that internal variability increases under climate change (e.g. Pendergrass, 2017). A long quasi-equilibrium simulation allows to better assess the climate variability at inter-annual and decadal scales, and the occurrence of climate extremes.
- Is there some non-linearity in the climate response to different levels of warming?
- How do a stabilized and a transient climate state at a given global temperature differ? It is known that the warming pattern changes with time (Rugenstein, 2019b; King et al., 2020) and this may influence other climate responses (e.g. dynamics and precipitation) and their variability.

2. Scientific project

The ideas introduced above are also behind the recent proposal of the LongRunMIP (Rugenstein, 2019a), which collects 1000-yr long climate simulations following an abrupt doubling or quadrupling of the CO_2 concentration. We here propose a different set-up: a set of 500-yr long simulations following an abrupt stabilization of the greenhouse gases and aerosol concentrations at three different years: 1975 (using historical conditions), 2065 and 2080 (from the SSP5-8.5 scenario). These simulations complete a set of three runs at 2025, 2050 and 2100 forcing conditions (from SSP5-8.5) that have already been performed, and will give a final set of 6 + 1 (the CMIP6 pre-industrial control run) quasi-equilibrium worlds. Note that this is different from a sudden cease in emissions at the chosen year, since we do not here consider carbon-cycle feedbacks (see for example the ZECMIP protocol, Jones et al., 2019). Figure 1 shows the mean global temperature increase with respect to the pre-industrial climate for the three 500-yr simulations already performed. The warming continues in all experiments well after the abrupt stabilization of the GHG concentrations, reaching very high values for the b100 run. Two new runs proposed in this project at 2065 and 2080 conditions are necessary to fill the gap between the extreme b100 and b050, and to properly study the variation of the climate state and variability in this temperature region. On the other side, the b025 simulation is already above the Paris agreement goals of 1.5 and 2 degrees warming above pre-industrial, and the 1975 simulation has been thought to fill this gap.

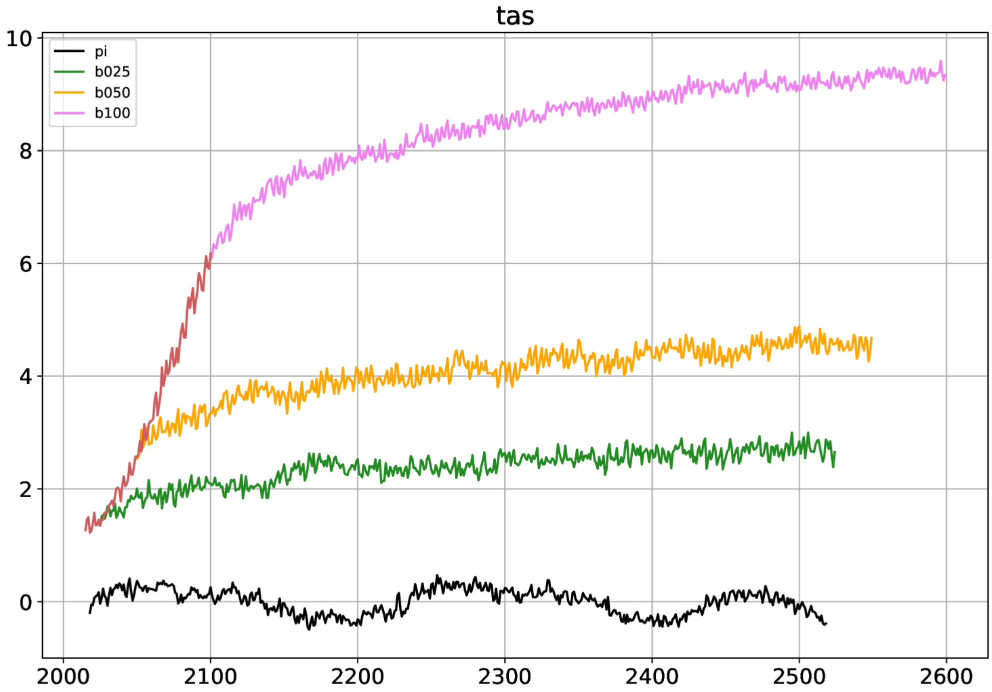

Figure 1. Mean global temperature at 2 meters (tas) difference to the pre-industrial simulation (pi, black), for the three stabilization simulations already performed at the 2025, 2050 and 2100 forcing. The red line shows the SSP5-8.5 simulation (member r4i1p1f1) of CMIP6, from which the runs have been initialized.

In the second year of the special project, we plan to extend 3 of the 6 quasi-equilibrium worlds to reach 1000 years and be included in the LongRunMIP ensemble.

The simulations will be performed with the EC-Earth model version 3.3.1.1, a state-of-the-art, high-resolution earth-system model, developed by a large consortium of European research institutions and researchers of which CNR-ISAC is a core partner (Hazeleger et al., 2010; http://www.ec-earth.org). EC-Earth includes advanced, robust and validated components for the atmosphere (the ECMWF IFS model cy36r4) the ocean (NEMO 3.6; Madec 2008), sea ice (LIM3; Fichefet and Morales Maqueda 1997) and land processes (H-Tessel; Balsamo et al. 2009). The model will be run in both atmospheric-only and coupled mode. It is worth to note that v3.3.1.1 is the same version currently used for the CMIP6 intercomparison project.

The model has been already implemented and tested on many supercomputing platforms, including CCA at ECMWF. The coupled model will be used in the standard CMIP6 resolution TL255L91-ORCA1, with a horizontal resolution of approximately 80 km and 100 km for the atmosphere and the ocean, respectively. In the vertical, the atmosphere uses 91 levels and the ocean 75 levels. The atmosphere-only model will be used in the corresponding TL255L91 resolution.

3. Justification of the computer resources requested

Scaling tests performed on CCA at ECMWF in the framework of the SPITDAVI project have determined that the optimal configuration for the EC-earth standard resolution (TL255L91-ORCA1) is obtained with 286 cores for IFS and 108 cores for NEMO, with one core each for the runoff mapper and the XIOS server. One year of integration with the coupled model in the above-mentioned conditions is completed in about 19,000 SBU on CCA.
Assuming the same number of SBUs are needed for one year on the new Atos machine, the amount of SBUs requested is 19,000 x 500 x 3 x 2 = 57,000,000 SBUs overall for the two years.

The following table summarizes the resources estimated.

#Year	Experiment	Model config.	Set-up	SBUs
Year 1	500-yr equilibration	TL255L91-ORCA1	3 coupled simulations with constant forcing, 500 yrs each	28.5 millions
Year 2	extension to quasi-equilibrium	TL255L91-ORCA1	extension of 3 simulations to 1000 yrs	28.5 millions

Considering 6-hourly output for IFS and monthly means for NEMO, the requirements for the storage are around 60 GB/model-year. Consequently, the total amount of required space at the end of the project is around 180 TB. Storage resources will be split in equal parts between the two years.

5. References

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