REQUEST FOR A SPECIAL PROJECT 2022–2024

MEMBER STATE: Sweden

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Other researchers:

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Project Title: Holocene climate variability in EC-Earth3 transient simulations……
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If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP**SEZHAN	
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)	20.000.000	20.000.000	20.000.000
Accumulated data storage (total archive volume)[2]	(GB)	10000	10000	15000

***An electronic copy of this form must be sent via e-mail to**:* *special_projects@ecmwf.int*

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 an annual progress report of the project's activities, etc.
[2] 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.

Principal Investigator: Qiong Zhang

Project Title: Holocene climate variability in EC-Earth3 transient simulations

Extended abstract

In our previous project, we have used EC-Earth 3 and run a few thousand years transient simulation in from early Holocene to late Holocene, using ECMWF HPC resource for 2019-2021. In the coming years we will continue the planned simulations in this project with new scientific focus. In this project, we will study the observed climate variability in the transient simulations. The scientific background, motivation, questions and simulation plan are described below.

Scientific background and aims

A crucial goal in climate research is to better understand the mechanisms of observed climate variability and change in order to assess the relative roles of internal variability and external forcing variations in explaining observed changes in the climate system. It is difficult to obtain an estimate of internal variability purely from the observational record, since observed climate variations arise both from internal variability and from changing radiative forcing agents, such as solar radiation and volcanic eruptions. The analysis of instrumental and proxy climate records has revealed important characteristics of multi-centennial scale climate variability but identifying the underlying cause of these variations remains difficult. To provide a further perspective on low-frequency climate variations that could arise solely from internal variability or driven by the external forcing, we can use the long climate model simulations. The analysis of these simulations is extremely useful in characterizing the internal variability in the climate system in the absence of changes in external forcing, as well as to estimate how the external forcing can modulate/alter these low-frequency variabilities.

In this project we focus on multi-centennial variability, defined as a time-scale of 200-500 years, which can also be approximated as a centennial to millennial time-scale. The main reason why there are few studies on the multi-centennial time-scale is that the length of instrumental observations is with some exceptions less than 200 years. There are no direct observations to confirm the existence of multi-centennial climate variability. It is instead inferred from information retrieved from paleoclimate proxy data including documentary historical sources. Another reason is that climate change caused by external forcing is easier to study (at least the ultimate cause is known), while internal variability or periodic oscillations are difficult to clarify the causal relationship (even for natural variability on inter-annual timescales). For example, there are many studies on the climate response to external forcings such as solar radiation, orbital forcing, volcanic eruptions, and changes in the concentration of greenhouse gases (GHG) on various timescales, but very few studies on variability on centennial timescale.

In order to have a foundation for reliable predictions of future climate change, we need to test the model's ability on reproducing past climate variability. The coupled climate model has been developed to earth system model by introducing more and more components, which can represent a more realistic climate system, and applied to future climate projection. At the same time, the rapid advance in HPC offers the opportunity to use such complex earth system model to conduct the simulations for several thousand years.

In this project, using the earth system model EC-Earth3, we will perform and analyse several-thousand-year-long simulations for different past periods, such as an unforced long pre-industrial control simulation, or forced transient Holocene simulation in which we have observed the existence of such multi-centennial variability. The length of these simulations allows to detect the mechanism of slow physical processes with robust statistical assessment.

Scientific question and hypotheses

This project intends to mainly answer the following two main questions:

Q1: Is multi-centennial climate variability primarily an intrinsic internal oscillation or is it caused by external forcing?

Our preliminary results from 3000-year PI control simulation have shown distinct 200-year cycles. The signal seems to originate from the high latitude north Atlantic according to the EOF analysis. A similar variability signal is seen in another PI control run with EC-Earth3-veg with standard resolution by our SMHI colleagues.

It indicates that the model resolution does not play a decisive role in generating this cycle. This PI control run with constant forcing (undisturbed) currently is in running and will have 5000 years of output and is expected to provide a solid basis for statistically robust results. We will perform an in-depth analysis on our 5000-year-long PI control run, to investigate whether the signal is (1) driven by the salinity, (2) associated with Arctic sea-ice, (3) or related to the hemispheric heat transport.

Q2: How does external forcing impact the multi-centennial climate variability?
Our Holocene transient simulation with varied radiation forcing (orbital forcing and GHG forcing) shows the presence of multi-centennial climate variability as those observed in PI control run with some differences in frequency. We will analyze the Holocene transient simulation where we imposed natural forcing. This simulation currently is in running, using our ECMWF HPC project SPSEZHAN (2019-2021), and expect to complete the planned simulation by the end of the year.

A recent article in *Science* (Mann et al. 2021) claimed that the Atlantic Multidecadal Oscillation (AMO) does not actually exist; instead multi-decadal oscillation would be modulated by the volcanic forcing. Indeed, a similar climate response to external forcing is found in our two last-millennium (850-1850) simulations with EC-Earth3-veg-LR. The simulation with volcanic forcing shows larger low-frequency variability than the one without volcanic forcing. Our first Holocene transient simulation does not include the time-independent volcanic forcing. To verify if the volcanic forcing has such an effect on multi-centennial variability, we will perform a second Holocene transient simulation by imposing the reconstructed volcanic forcing by (Zielinski et al. 1996) to identify the role of volcanic forcing on multi-centennial variability. This simulation will use the ECMWF HPC resource we applied here.

Earth System Model (ESM) EC-Earth3 configuration and simulation plan

We are using the CMIP6 version of EC-Earth3-veg-LR (Döscher et al., 2021) in this project for production run. This model version contributes to several PMIP4/CMIP6 experiments (Zhang et al., 2021).
Table1 lists the planned long simulations in this project. The scientific purpose for each simulation will be accomplished with specified forcings. The estimation on HPC is based on our current experience.

Table 1. Three long simulations planned in this project with specific scientific purpose. All the simulations will be performed with CMIP6 version of EC-Earth3-veg-LR. Data size is estimated from cmorised (ece2cmor) monthly mean.

Simulation	**Scientific purpose**	**Forcing**	**Simulation length in years and data size**	**HPC resource**
PI-control (PI)	Internal intrinsic variability	Fixed forcing as CMIP6 PI	5000 yrs Data: 20 TB Started from 2020-04	Use NSC HPC in Sweden
Holocene transient 1 (HT1)	Natural external forcing: orbital and GHG	Orbital forcing as (Berger 1978), GHG forcing as (Köhler et al. 2017)	spin-up: 1000 yrs Production: 8000 yrs Data: 35 TB Started from 2020-04	Use NSC and ECMWF SPSEZHAN (2019-2021)
Holocene transient 2 (HT2)	Natural external forcing: orbital, GHG and volcanic	Orbital and GHG forcing the same as HT1, plus volcanic forcing (Zielinski et al. 1996)	Production: 8000 yrs start from 2022-01 Data: 35 TB	**60,000,000 SBU** **35TB**

Justification of the computing resources

In the current setup for EC-Earth3-veg-LR, we used 128 cores for IFS, 256 cores for NEMO, 64 cores for LPJG-GUESS, 1 core for XIOS and 1 core for RUNOFF, in total of 450 cores for the coupled model. It cost 8500 SBU for one model year simulation.

The planned PI control and Holocene transient simulations has been running on Swedish NSC and ECMWF HOC resources since 2020. Here we apply resource mainly for Holocene transient simulation HT2. The total cost for 8000 years will be 68 million SBU, we use 8 million SBU from current HPC project (2019-2021) and request 60 million SBU for 2022-2024. The estimated monthly output (cmorised) is 35 TB in total, we will cmorise the model output to monthly mean data and transfer the processed data to local storage in Sweden, we apply 10T storage every year for data process and analysis.

Reference

Berger, A., 1978: Long-term variations of daily insolation and Quaternary climatic changes. Journal of the atmospheric sciences, 35, 2362-2367.

Döscher, R., et al., 2021: The EC-Earth3 Earth System Model for the Climate Model Intercomparison Project 6. Geosci. Model Dev.

Köhler, P., C. Nehrbass-Ahles, J. Schmitt, T. F. Stocker, and H. Fischer, 2017: A 156 kyr smoothed history of the atmospheric greenhouse gases CO2, CH4, and N2O and their radiative forcing. Earth Syst. Sci. Data, 9, 363-387.

Mann, M. E., B. A. Steinman, D. J. Brouillette, and S. K. Miller, 2021: Multidecadal climate oscillations during the past millennium driven by volcanic forcing. Science, 371, 1014.

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Zielinski, G. A., P. A. Mayewski, L. D. Meeker, S. Whitlow, and M. S. Twickler, 1996: A 110,000-Yr Record of Explosive Volcanism from the GISP2 (Greenland) Ice Core. Quaternary Research, 45, 109-118.