

REQUEST FOR A SPECIAL PROJECT 2023–2025

MEMBER STATE:ITALY.....

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Project Title:
Investigations of climate change in post-CMIP6 EC-Earth3 simulations over the Mediterranean Climate Regions
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If this is a continuation of an existing project, please state the computer project account assigned previously.	SP _____	
Starting year: <small>(A project can have a duration of up to 3 years, agreed at the beginning of the project.)</small>	2023	
Would you accept support for 1 year only, if necessary?	YES <input checked="" type="checkbox"/>	NO <input type="checkbox"/>

Computer resources required for 2023-2025: <small>(To make changes to an existing project please submit an amended version of the original form.)</small>	2023	2024	2025
High Performance Computing Facility (SBU)	4000000	5000000	11000000
Accumulated data storage (total archive volume) ² (GB)	13240	37200	67000

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.

Principal Investigator:Annalisa Cherchi.....

Project Title: Investigations of climate change in post-CMIP6 EC-Earth3 simulations over the Mediterranean Climate Regions

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).

The Institute for the Atmospheric Sciences and Climate at the National Research Council of Italy (CNR-ISAC) is member of the EC-Earth consortium (<http://www.ec-earth.org/>). The consortium is aimed at building a European community Earth System Model (ESM) combining efforts of different research institutes from 10 European countries. In the EC-Earth consortium, CNR-ISAC coordinates the *Land and Vegetation* working group and the *CMIP and Tuning* working group. Moreover, it contributes to the *Ocean* working group and the *Prediction* working group. CNR-ISAC is a partner in several international efforts including EU-funded H2020 and HE projects and WCRP activities in the framework of the sixth phase of the Coupled Model Intercomparison Project (CMIP6, <https://wcrp-climate.org/wgcm-cmip/wgcm-cmip6>), in new emerging initiatives, such as a proposal for a GEO (<https://earthobservations.org>) pilot initiative aimed at exploiting latest land observations to improve and better constrain Earth System predictions, as well as in the novel Lighthouse Activities, like Explaining and Predicting Earth System Change (<https://www.wcrp-climate.org/epesc>).

ISAC-CNR is also a partner of the EU Horizon Europe project OptimESM (“Optimal high resolution Earth System models for exploring future climate changes”, project ID 101081193). One aim of OptimESM is to investigate new scenarios that consider the most recent climate-policy decisions, including national pledges on emission reductions, e.g. realizing the Paris Agreements or overshooting the 1.5°C or 2°C global warming targets (Rogelj et al 2016). Extended to 2200, these new scenarios can be used to investigate and improve the understanding of processes and mechanisms at the base of recent climate change and projections for the coming centuries.

In this special project we will consider the newly available climate scenarios with the most recent climate policies to investigate the climate change response over the Mediterranean climate regions (MCRs), which are particularly sensitive and vulnerable to the process of subtropical drying and expansion. To this aim we will use the post-CMIP6 version of EC-Earth, hence exploiting the advantage of several corrections and developments that have been introduced after 2018, and contributing further to model developments of hydrological processes that improve the representation of climate feedbacks and the related risk of fast abrupt transitions, particularly relevant for MCRs.

The Mediterranean region as a climate change hot spot and other MCRs

The Mediterranean region is recognized as a climate change “hot spot” (Giorgi, 2006), both because of the unevenly large response of its regional climate to the global forcing and because of the socio-economic and environmental impacts of these changes in densely populated, vulnerable and extremely culturally and ecologically diverse areas. For example, the southern part of the region is dominated by agricultural activities and is particularly sensitive to prolonged water shortages and related consequences, like droughts or wildfires (Barcikowska et al 2020; IPCC, 2022). Diverse and updated CMIP simulations within the last decades project increases in temperature and reduction in precipitation, both in winter and summer, with potential increases in the aridity of the region and severe impacts on water and food security (Giorgi and Lionello 2008; Diffenbaugh and Giorgi 2012,

Alessandri et al 2014; Mariotti et al 2015; Lionello and Scarascia, 2018; Ukkola et al 2020; Vicente-Serrano et al 2020; Cos et al 2022). The frequency and intensity of extreme events has been found to increase in the Mediterranean region (Michaelides et al. 2018), both in observations and projections, with increasing likelihood of extreme heatwaves (Lelieveld et al. 2014). Observed increase in droughts is associated to deficit in precipitation but also to enhanced evaporative demand or decreased soil moisture, with a projected increase in aridity and fire weather conditions (Guion et al 2022). The mean climate characteristics of the Mediterranean region with temperate, wet winter and warm (or hot) dry summer is common to other regions of the world, like the west coast of North America, central Chile, the far southwest tip of Southern Africa and southwest Australia, which are all identified as Mediterranean climate regions (MCRs). They follow from the Koppen-Geiger classification of climates, and they share similar location, lie on the western edge of continents in the subtropics to mid-latitude thus being overall transition areas between wet and dry climates (Alessandri et al 2014; Seager et al 2019). Climate change caused by rising greenhouse gases is expected to reduce precipitation in all MCRs other than California (Polade et al 2017), which together with surface warming increases drought risk (Cook et al. 2014). With a probabilistic approach it has been possible to quantify the risk of a poleward shift of MCRs, mostly over the Mediterranean region and western North America, with the equatorward margins replaced by arid climate type in 21st century projections (Alessandri et al 2014). On top of this, the Mediterranean climate regions are prone to abrupt changes that may lead to tipping points, e.g. in land cover, vegetation, fires, and agriculture (Brovkin et al 2021), whose impact and degree of irreversibility are yet to be understood. To improve current understanding, land surface and hydrological processes improvements are needed in state-of-the-art ESM (Scanlon et al 2018; Condon et al 2020; IPCC 2021).

The post-CMIP6 version of EC-Earth

The EC-Earth3 model (Döscher et al. 2022) that contributed to CMIP6 has been frozen for production in 2018. In this special project, we will use the post-CMIP6 versions of EC-Earth that includes several corrections, bug-fixes and improvements that have been developed by the EC-Earth consortium since 2018. Novel ESM developments are included thanks to the coordinate effort of all partners and in previous and ongoing EU projects such as H2020 CRESCENDO, PRIMAVERA and CONFESS. The developments leading to post-CMIP6 versions (v3.3.x) of EC-Earth include improved process representation (improved treatment of aerosols and aerosol-cloud interactions, land hydrology, vegetation, permafrost) as well as the inclusion of novel components (such as dynamical ice sheets) that are relevant for the representation of climate feedbacks and the related risk of triggering fast and abrupt climate transitions. EC-Earth3 model components are routinely upgraded in order to benefit from improved numerical schemes or revised encoding leading to better HPC performances. The developments and improvements for the post-CMIP6 version of EC-Earth are evolving in time (version 3.4.0 is expected to be available in next months) and will be still on-going during this special project.

Planned experiments and analysis

For processes-based verification of EC-Earth over the MCRs we will run some offline (land-only and land-atmosphere) simulations not only to test the updates available at the time of this project but also to further contribute to the post-CMIP6 developments. A first set of offline simulations will consist of experiments where land surface and vegetation models (HTESSEL-LPJGuess) are forced by updated atmospheric reanalysis products (such as ERA5, Hersbach et al 2020) and verified versus the latest land surface and hydrological observational data (such as leaf area index, Verger et al 2014; vegetation fractional cover, Baret et al 2013; river discharge and other surface fluxes, Pastorello et al 2020, Jung et al 2019). These offline land simulations (OFF-land) are aimed at testing improved hydrological processes (related to groundwater, rivers, etc) and to investigate their effects in the representation of dry transitions, as expected for the Mediterranean climate regions. It is envisaged that around 500 years of simulation will cover the benchmarking of the planned HTESSEL-LPJGuess developments.

Following on from the analysis and improvements gained with the OFF-land simulations we will perform a small set of AMIP-type experiments (AMIP) to verify the effects of the updates in terms of land-atmosphere coupling and related consequences in the representation of the mean climate and

its variability over the MCRs. This analysis is designed to be propaedeutic to the evaluation of climate change signals in the fully coupled ESM setup. This set of experiments will be performed with IFS+HTESSEL+LPJG with the updates confirmed by the OFF-land simulations and forced with observed SST taken from PCMDI (Durack and Taylor, 2017), consistently with the CMIP6 protocol. We plan to perform about 108 years of AMIP-type experiments, corresponding to 3 members for the 1979-2014 reference period (as considered also in CMIP6).

Then the set of core experiments with the full ESM will consist of an historical simulation covering the period 1850-2014 with CMIP6 forcing (here identified as HIST), and two scenarios based on new sets of emissions following the latest climate policies, in phase with the release in the HE project OptimESM. One scenario, identified here as PA-REACH, reflects emissions that realize the Paris Agreement (i.e. that keep global warming below 1.5°C or 2°C relative to pre-industrial level), while the other, identified here as PA-FAIL, assumes delayed mitigation actions that overshoot the Paris target before returning to it at some later time (UNFCCC, 2015; IPCC, 2018; 2021). The scenario simulations will cover the 2015-2200 time period. Extended to the end of 2200, these new scenarios can help to improve the understanding of processes and mechanisms at the base of recent climate change and in the projections for the coming centuries. Because of the length obtained and the economic evolution included, they can be of help to improve current understanding about the risk of triggering abrupt changes on a global scale. These new scenarios performed with the latest improvements in EC-Earth (post-CMIP6) permits to identify the potential benefit or implications deriving from the implementation of the Paris Agreement, or delaying its achievement. Moreover, they can be compared with the SSP scenarios already produced within CMIP6 to explore the changes projected over MCRs and the related sensitivity to the different scenarios considered.

The analysis of the core set of experiments performed with EC-Earth ESM will be focused on the identification of differences in the climate response over the Mediterranean climate regions across different scenarios. We will investigate the attribution of changes in the occurrence of extreme events and shifts in MCRs to different global warming levels. In this respect, the effect of realizing the Paris Agreement vs. overshooting the global warming level targets will be assessed. Diverse drought indices will be evaluated and depending on how sensitive they are to rates of change in the land composition and the impact of different feedbacks, the assessment of their autocorrelation will allow to investigate the emergence of abrupt transitions in the scenarios considered (mostly, PA-REACH and PA-FAIL). In a meteorological framework, weather regimes and changes in their occurrence under different scenarios will be investigated. Dominant circulation patterns related to extreme events in MCRs will be identified, evaluating changes in their occurrence comparing the different scenarios considered.

A summary of the planned experiments, with details about the resources needed and how they are distributed within the duration of the special project are summarized in Table 1.

Configuration and justification of resources

For the OFF-land set we will use the offline version of HTESSEL-LPJGuess with an interface to prescribe meteorological fields from observations/reanalysis obtained from the latest OpenIFS release (<https://www.ecmwf.int/en/research/projects/openifs>). No parallelization of the code has been included so far in offline mode, therefore requiring 500 SBU per simulated year on Atos. For the AMIP set we will use IFS+HTESSEL+LPJG at T255 resolution with 91 vertical levels in the atmosphere. Using 256 cores (2 nodes), the estimated required resources on Atos are about 16000 SBU per simulated year. For the core set of coupled simulations, we will use EC-Earth3 in its full ESM configuration (with a closed carbon cycle) in a post-CMIP6 version, with updated components compared to the version previously used within CMIP6. The default resolution is T255 with 91 vertical levels in the atmosphere, and ORCA1 with 75 vertical levels in the ocean. Based on the evaluation performed in the framework of the EC-Earth consortium, the optimal configuration on Atos is obtained considering the following components and related dedicated CPUs: IFS (300), NEMO (with PISCES activated; 198), XIOS (2), LPJG (8), TM5_X(2), TM5_Y(2) by using 4 nodes (512 total cores). With this configuration, we estimate that the model requires on Atos about 29000 SBUs per simulated year. About 50 years of simulation with the full ESM are added to account for the need to test the updates and improvements as derived from the offline simulations. Overall, the

total resources estimated for the project is rounded to 20 million SBUs (Table 1), which includes a buffer of 5% to account for failing jobs or additional short tests needed.

In terms of storage, the requirement is about 100 GB per year of coupled simulations, considering raw data and monthly means for the different model components and higher-frequency (i.e. 6-hours or 1-hour) atmospheric variables. The “cmorization” procedure via the ece2cmor3 tool will be used to reduce the raw output volume in case of exceeding storage output. For the offline simulations the requirements are of about 10 GB per year for OFF-land and of about 30 GB per year for AMIP. Therefore, the total storage required for the project is 67 TB.

Experiment name	Description	SBU/year	Total years	Total SBU	Year 1	Year 2	Year 3
AMIP-type	Atmospheric model with prescribed SST	16000	108	1728000	1728000	0	0
Land-offline	Offline land surface model & vegetation model	500	500	250000	250000	0	0
Hist	Historical simulation (1850-2014)	29000	165	4785000	0	4785000	0
PA-reach	Future scenario with PA reached (2015-2200)	29000	186	5394000	0	0	5394000
PA-fail-OS	Future scenario with OS failed (2015-2200)	29000	186	5394000	0	0	5394000
Testing (ESM simulations)			50	1450000	1450000		
5% buffer				999000	572000	215000	212000
Total				20000000	4000000	5000000	11000000

Table 1: Experiment planned in this project, total years of simulation and details of the resources needed.

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