SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	……2024…………………………………………..……
Project Title:	Investigations of climate change in post-CMIP6 EC-Earth3 simulations over the Mediterranean climate regions
Computer Project Account:	……SPITCHER……………..……
Principal Investigator(s):	Annalisa Cherchi (Paolo Davini, Valerio Lembo, Susanna Corti, Jost von Hardenberg, Federico Fabiano, Virna Meccia, Alessio Bellucci, Giuseppe Zappa) …
Affiliation:	CNR-ISAC……………………………..……
Name of ECMWF scientist(s) collaborating to the project (if applicable)	……N/A………………………………………………..…… ………………………………………………………….……
Start date of the project:	……01/01/2023…………………..……
Expected end date:	……31/12/2025…………………………………………..……

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	5000000	4164889	5000000	5577550
Data storage capacity	(Gbytes)	14000	188	30500	3722

Summary of project objectives (10 lines max)

The main objective of this special project is to investigate the climate change response over the Mediterranean climate regions (MCRs), particularly sensitive and vulnerable to the process of subtropical drying and expansion, using the post-CMIP6 version of EC-Earth3 and considering newly available climate scenarios with the most recent climate policies.

Summary of problems encountered (10 lines max)

We ported on HPC2020 the EC-Earth3 post-CMIP6 version and we had some delays related to the availability of the PISM component provided by DMI to the EC-Earth community. Once the full ESM was ready, we started the simulations, but we realized that the SBU resources needed for one year experiment of the full model was underestimated. In fact, in 2024 we exhausted the allocated resources producing only a portion of the planned historical experiment. We submitted a request for additional SBU resources to complete the historical simulation by the end of the year as planned.

Summary of plans for the continuation of the project (10 lines max)

In the current year we intend to complete the historical simulation (we have submitted a request to add resources to SPITCHER to complete the simulation as we underestimated the resources needed to run the post-CMIP6 version of EC-Earth3, as also described above). In the meanwhile, we will also continue and expand the analysis of the simulations done so far and we will prepare for the scenarios experiments to be completed and analysed by the end of the project (in 2025).

List of publications/reports from the project with complete references

Cherchi A, Alessandri A, Lembo V, Gelsinari S, Possega M, Senigalliesi V, Renwick J (2024) Mediterranean climate regions in CMIP6 experiments: assessment of future changes and associated uncertainties. In preparation

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

1. **Configuration and porting of the post-CMIP6 version of EC-Earth3**

After the EC-Earth3 versions that have been used for CMIP6, several updates have been implemented within the Earth system model consortium. Among them, we consider here a post-CMIP6 version of the model where IFS and NEMO are the same as in CMIP6 (Doscher et al 2022), but where changes and specific updates are considered for the other components: an ice sheet model for Greenland, a freshwater emulator for Antarctica, an updated version of the LPJ-GUESS dynamic vegetation model and a new CO2 box model have been included. LPJGuess is used in its version 4 (Nord et al 2021). The ice sheet model PISM is coupled over Greenland. For the Southern Hemisphere, an emulator for mass loss of the Antarctic Ice Sheet (van der Linden et al 2023) has been coupled to EC-Earth3, rerouting the Antarctic meltwater flux to the Evaporation-Precipitation-runoff scheme of the atmospheric component for the surface layer, while adding the rest of the meltwater flux to the subsurface ocean layers surrounding Antarctica. The CO2 box model developed at BSC is a python-based component to track atmospheric CO2, considering CO2 emissions from CEDS (Hoesly et al 2018; Feng et al 2020) and CO2 fluxes with the land (LPJ-GUESS) and ocean (NEMO/PISCES) and sending surface average CO2 back to IFS, LPJ-GUESS and NEMO/PISCES realms.

Once all the components and the fully coupled version has been made available, we contributed within the EC-Earth consortium with help from KNMI, BSC and SMHI to the porting of the model configuration on HPC2020. Actually, the porting started in 2023 with some test experiments (mostly pre-industrial control) even if the full model has been available only at the beginning of 2024. A demanding step we had to work on has been the porting and compilation of the PISM component as we need to ask for ECMWF to install specific libraries on HPC2020. Then we prepared the full scripting chain to compile and run the model with the full configuration. The final step in the configuration has been the implementation of the historical experiment starting from initial condition and pre-industrial spinned-up experiments prepared from SMHI and Lund University.

2. **Preliminary analysis with CMIP6 simulations**

To investigate the climate change response over the Mediterranean climate regions (MCRs), we started some analysis with the CMIP6 experiments (historical and projections) to have a setup of analysis as well as a benchmark for comparison once the new simulations planned within the project will be available.

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). Following from the Koppen-Geiger classification of climates, they share similar location and lie on the western edge of continents in the subtropics to mid-latitude thus being overall transition areas between wet and dry climates. In a previous work, with a probabilistic approach, we have quantified 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 using CMIP5 21st century projections (Alessandri et al 2014). Internal atmospheric variability dominates winter precipitation variability in all MCRs, with a clear link with annular modes in the Mediterranean region (Seager et al 2019). All MCRs, except for North America, have dried and are projected to further drying in CMIP5 future projections (Seager et al 2019).

Following the above and using available CMIP6 simulations, we designed an update of the assessment of future climate changes in MCRs. We started from the identification of Mediterranean climate-type regions applying the Koppen-Geiger climate classification, as shown in Table 1. This classification is based on climatology and max/min of precipitation and temperature, as defined in Kottek et al (2006).

Type	Description	Criterion
A	Equatorial climates	$T_{min} \geq +18\ °C$
B	Arid climates	$P_{ann} < 10\ P_{th}$
C	Warm temperate climates	$-3\ °C < T_{min} < +18\ °C$
Cs	Warm temperate climate with dry summer	$P_{smin} < P_{wmin}, P_{wmax} > 3\ P_{smin}$ and $P_{smin} < 40$ mm
D	Snow climates	$T_{min} \leq -3\ °C$
E	Polar climates	$T_{max} < +10\ °C$

Table 1: Climate-type classification based on climatology and monthly max/min of precipitation and temperature (from Kottek et al 2006). Pth is an (empirical) dryness threshold based on annual mean temperature and the ratio between summer and winter precipitation over the annual amount.

We considered an ensemble of CMIP6 (Eyring et al 2016) historical and SSP5-8.5 experiments as listed in Table 2. The variables used for the classification are the temperature at 2 m and the total precipitation. All models' data have been regridded on a 1x1 regular grid. The climatology considered for the historical and SSP5-8.5 experiments are 1979-2000 and 2070-2100, respectively. For comparison, we considered 2m temperature (t2m) and precipitation (pr) from available reanalysis/observation. In particular, t2m is taken from the ERA5 reanalysis (Hersbach et al 2020), while pr is taken from GPCP (Adler et al 2018).

Model name	Institute/Country	Model name	Institute/Country
ACCESS-CM2	CSIRO-ARCCSS/Australia	HadGEM3-GC31	MOHC-NERC/UK
ACCESS-ESM1-5	CSIRO-ARCCSS/Australia	INM-CM4-8	INM/Russia
BCC-CSM2-MR	BCC/China	INM-CM5-0	INM/Russia
CESM2-WACCM	NCAR/US	IPSL-CM6A-LR	IPSL/France
CESM2	NCAR/US	KACE-1-0-G	NIMS-KMA/Korea
CNRM-CM6-HR	CNRM-CERFACS/France	MCM-UA-1-0	UA/US
CNRM-CM6-1	CNRM-CERFACS/France	MIROC-ES2L	MIROC/Japan
CNRM-ESM2-1	CNRM-CERFACS/France	MIROC6	MIROC/Japan
CanESM5	CCCma/Canada	MPI-ESM1-2-HR	MPI-M DWD DKRZ/Germany
EC-Earth3-Veg	EC-Earth Consortium/EU	MPI-ESM1-2-LR	MPI-M AWI/Germany
EC-Earth3	EC-Earth Consortium/EU	MRI-ESM2-0	MRI/Japan
FGOALS-f3-L	CAS/China	NESM3	NUIST/China
FGOALS-g3	CAS/China	NorESM2-LM	NCC/Norway
GFDL-ESM4	NOAA-GFDL/US	UKESM1-0-LL	MOHC NERC NIMS-KMA NIWA/UK

Table 2: List of CMIP6 models used in this analysis

Fig. 1 shows that in the CMIP6 ensemble mean used, in SSP5-8.5 projections toward the end of the century, Med climate-type regions expand and move poleward and are replaced equatorward from Arid climate-type (more evident in the Southern Hemisphere).
In Fig 2 future projections (SSP5-8.5) evidence an increased probability of having Mediterranean climate-type poleward and reduced equatorward (mostly evident in Northern Hemisphere MCRs and over South America). In MCRs over South Africa and Southern Australia a reduced probability to have MED climate-type is evident as well (the continents do not extend much poleward).
This is the preliminary set of diagnostics that will be applied to the new simulations (historical and future projections) as soon as available within SPITCHER.

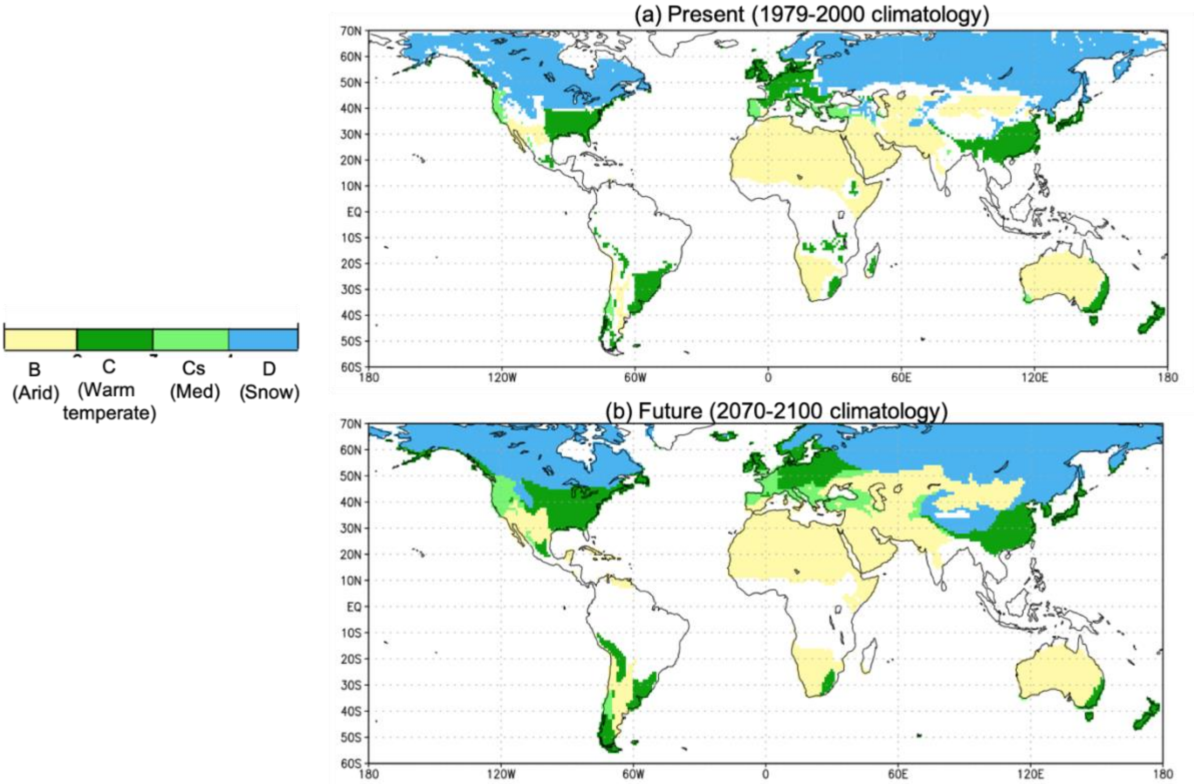

Fig 1: Climate-type classification as in Table 1 for the CMIP6 ensemble mean (a) historical experiments and (b) SSP5-8.5 projections. In (a) grid-points where the ensemble mean does not correspond to observations are not shown.

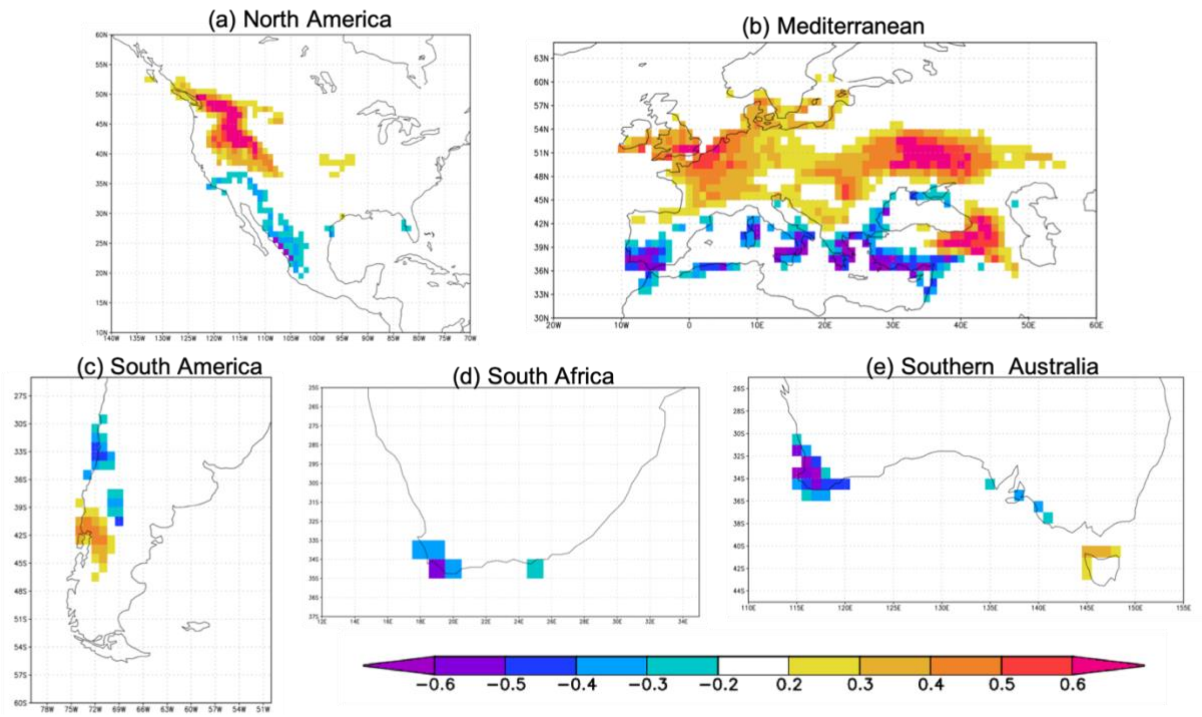

Fig 2: Change in probability to have a MED climate-type (SSP5-8.5 minus historical), zoomed over the different MCRs.

3. New historical simulation – preliminary results

The historical simulation covers the period 1850-2014, following the CMIP6 protocol (Eyring et al 2016) and it has been produced in emission-driven conditions. The simulation starts from initial conditions taken from long pre-industrial control simulation provided by SMHI in the framework of the HE OptimESM project. As mentioned above this simulation started and we currently have 96 years of simulation, covering the period 1850-1945. Some preliminary results are shown in the figures below and, where relevant, the outputs are compared with an historical simulation produced with a previous version of the EC-Earth3 model, specifically EC-Earth3-CC (Doscher et al 2022).
In this configuration, a co2box model coupled with the Earth System and Fig. 3 shows the timeseries of the mole fraction (*1.e-6) of carbon dioxide in air evidencing the transient behaviour of the emissions. Fig. 4 shows the evolution of 2m temperature globally averaged and compared with a previous EC-Earth3 simulation and with some atmospheric reanalyses (ERA5, Hersbach et al 2020; NCEP, Kalnay et al, 1996). The temporal evolution is comparable with previous simulation but warmer.

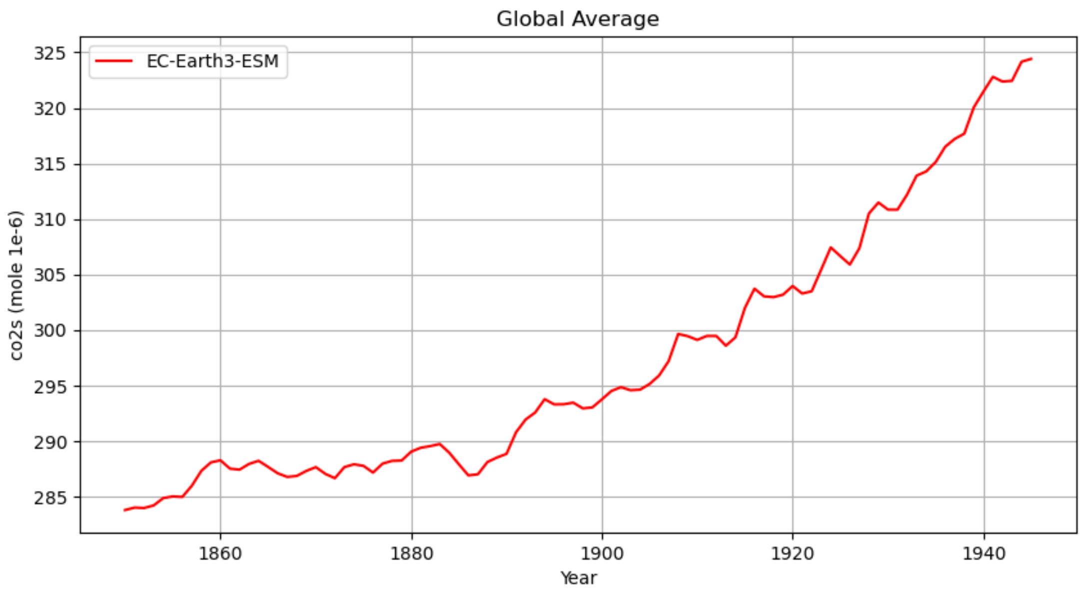

Fig. 3: Mole fraction (*1.e-6) of carbon dioxide in air (annual means) for the historical simulation with the post-CMIP6 version of EC-Earth3

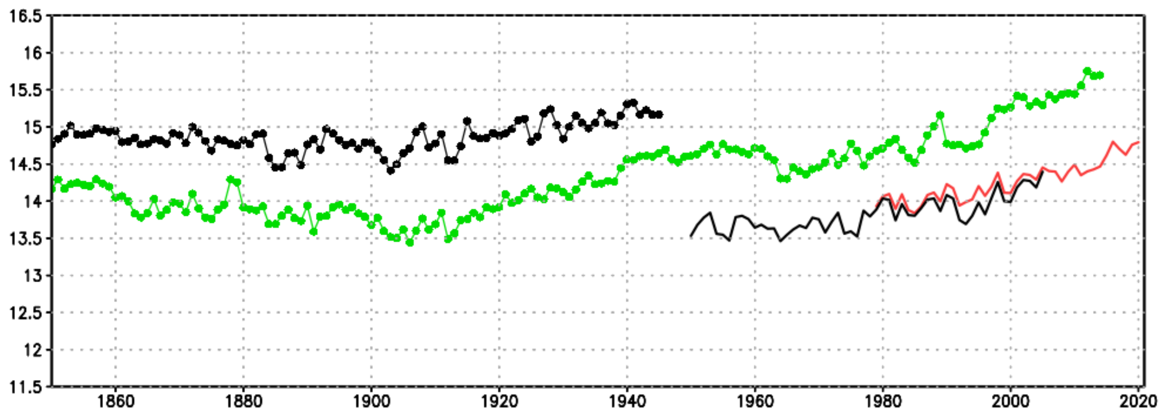

Fig. 4: Global mean surface temperature for the historical simulation with post-CMIP6 EC-Earth3 model (black line), for the similar simulation with previous version of EC-Earth3 (green line), and for three atmospheric reanalyses (ERA5, red line; NCEP black solid line)

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