REQUEST FOR A SPECIAL PROJECT 2023–2025

MEMBER STATE: ITALY

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Project Title: RegiOnal climate simUlations over ItaLy: a focus on futurE exTreme weaTher Events (ROULETTE)

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** ________________	
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2023	
Would you accept support for 1 year only, if necessary?	YES ☐	NO ☒

Computer resources required for 2023-2025: (To make changes to an existing project please submit an amended version of the original form.)		**2023**	**2024**	**2025**
High Performance Computing Facility	(SBU)	10 million	12 million	12 million
Accumulated data storage (total archive volume)[2]	(GB)	30000	30000	40000

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

Introduction

It is well known to the scientific community the position of IPCC (Intergovernmental Panel on Climatic Change) regarding the climate change for the future. The scientific body responsible for the study of climate changes on a global scale, and their impact on the environment and human life, even in the latest report published in 2022 (IPCC Sixth Assessment Report (AR6)) describes a general increase of the Earth's surface temperature in the next decades. It's also known as these climatic changes could lead to significant implications in other related environmental phenomena: extreme weather events and rainfall are becoming more common, and heat waves and droughts are expected to be more extreme, with possible important implications for the human health and for the safeguarding of property and infrastructure.
The topic assumes considerable importance, considering that in the last 40 years (1980-2020) climate-related extreme events caused economic losses of about EUR 487 billion in the EU-27 Member States, most of which mainly attributable to meteorological/hydrological events, in addition to more than 138000 fatalities, most of which mainly attributable to climatological/heat-waves events. (source: European Environment Agency-EEA; https://www.eea.europa.eu).

In the last years an increasing attention was devoted to the study of medicanes, intense Mediterranean cyclones with characteristics similar to tropical cyclones (e.g. Miglietta and Rotunno, 2019; Dafis et al., 2020), as well as to other fascinating and destructive phenomena, i.e. tornadoes and downbursts (e.g. Avolio and Miglietta, 2021; 2022). These work also demonstrated the ability of the modeling tools to better simulate the main synoptic patterns, and to forecast the high instability parameters mainly related to these events.

The main objective of the proposal is the reconstruction of the climate at the regional scale over Italy, with the principal aim of assessing the variations of the atmospheric parameters mainly related to the extreme weather events (e.g. convective available potential energy, helicity, wind shear, level of free convection, lifted condensation level, instability parameters/indexes, etc.).
To cope with is, regional climate simulations will be performed to provide detailed information on climatic conditions at local scale. The geomorphologic characteristics of the Italian Peninsula suggest that is not only desirable, but even necessary, the adoption of models with high spatial horizontal resolution, in order to better understand climatic variations between different parts of the Country.
Global climate models (GCMs) generate climate projections at coarse spatial resolution, failing to properly represent all the atmospheric features that have a big impact on local climate.
Several previous studies have shown how, for example, GCMs definitely under-estimate the number and the intensity of cyclones (e.g., Zhao et al., 2009; Zappa et al., 2013). At the same time, other studies have demonstrated that high-resolution RCMs are able to improve the simulation of various atmospheric fields, such as precipitation (e.g. Kendon et al., 2014; Nolan et al., 2017; Rauscheret al., 2010), surface temperature (e.g. Di Luca et al., 2016), strong Mediterranean cyclones (e.g. Cavicchia and Storch, 2011), and surface wind speeds (e.g. Kanamaru and Kanamitsu, 2007; Nolan et al., 2014).

The mesoscale model WRF (Weather Research and Forecasting) (Skamarock et al., 2019) at a maximum spatial resolution of 5 km will be used for the regional-scale simulations, through a dynamic downscaling from GCMs. This model represents the worldwide state of the art of numerical modeling and is used for many years also at CNR-ISAC for operational and research purposes; in the project activities we will reach a higher resolution (about halved), for the downscaled WRF model, respect to other similar initiatives, e.g. euro-cordex / med-cordex runs, also devoted to regional-scale climatic assessments.

Twenty years of simulations will be considered for the current climate (2001-2020) and for future climate (2081-2100).
The present climate will be simulated considering, as initial and boundary conditions for WRF, a state-of-the-

art atmospheric reanalysis dataset ERA5 (ECMWF) (Hersbach et al., 2020). For the future climate, a selected GCM (Global Climate Model) from CMIP6 (Coupled Model Intercomparison Project Phase 6) (Eyring et al., 2016) will be considered, and daily outputs of this GCM model will give initial and dynamic boundary conditions for the mesoscale atmospheric model runs.

The amount of simulations to be made will be noticeable, and the outputs (a selected number of variables) will be archived and will represent a unique high-resolution climatic database for the Italian Peninsula. This database will be used also in second stages, i.e. to perform further nested simulation at higher horizontal/temporal resolution in selected parts of the Country, and/or to produce different risk-related scenarios on the basis of peculiar needs.

Scientific plan

The Global Climate Models (GCM) have maximum spatial resolution of hundreds kilometers or slightly lower; these resolutions are not sufficient to describe climate change on a regional scale. Local studies are obtained through procedures of dynamical and statistical "downscaling" of global models. For dynamical downscaling, in particular, global model outputs are used as boundary conditions and as forcing for Regional Climate Models (RCM).
Numerical simulations for the study of climate and its variations are the main instruments available to the scientific community; these simulations are inevitably linked to different scenarios of greenhouse gas emissions and land use. Starting from atmospheric general circulation models, different scenarios with different temporal trends in emissions of greenhouse gases are defined, as a result of several hypothetical developments of human societies. Two main scenarios will be taken into account in our activities: SSP245, that represents a moderate socioeconomic-development path with medium-low radiation forcing, and SSP585, that represents the combined scenario of a high energy-intensive, socioeconomic developmental path with strong radiative forcing.

The objective of the project is to build a high-resolution database of present and future climate simulations, mainly devoted to the extreme weather events studies (flash floods, tornadoes, Mediterranean cyclones, heat waves, dust intrusions, etc.). Twenty years of simulations will be considered for both the current climate (2001-2020) and for the future climate (2081-2100); for the latter, both the scenarios defined above will be taken into account.
The present climate will be simulated considering, as initial and boundary conditions for WRF, the state-of-the-art atmospheric ECMWF reanalysis database ERA5 (0.25° resolution).
The global climate model adopted for scenario simulations will be a selected GCM from CMIP6. At this stage of the project proposal, the choice falls on EC-Earth model (EC-Earth Consortium, 2019) (0.7° resolution). This GCM model contributed to CMIP5 and CMIP6 projects, and consists of the ECMWF IFS atmospheric model, NEMO/LIM ocean and sea-ice model, a vegetation model and biogeochemistry model.
During the project activities, the possibility of choosing additional / different GCMs as drivers for the WRF simulations will be evaluated, considering the possible increased availability of data.

Dynamical downscaling, starting from daily outputs of the selected GCM, will be performed with WRF mesoscale model (Weather Research and Forecasting). Several scientific publications have demonstrated the ability of this numerical code to correct simulate, in Italy, weather conditions on a regional scale, particularly in complex orography regions. (e.g. Avolio et al., 2017, 2018; 2021; Miglietta et al., 2017).
WRF model will be configured to simulate the climate in Italy with a maximum horizontal resolution grid of 5 km (Figure 1).; an intermediate grid at 15 km resolution will be configured as parent domain (a resolution comparable with other RCMs, e.g. euro-cordex initiatives). 50 vertical levels will be adopted, with the vertical coordinates that follow the terrain. The parameterization schemes for microphysics, convection, radiation and turbulent processes will be activated. Model outputs will have 3-hourly temporal resolution and, for each run, 1 year will be simulated (considering 1 month of spin-up time that will be not involved in the analysis).

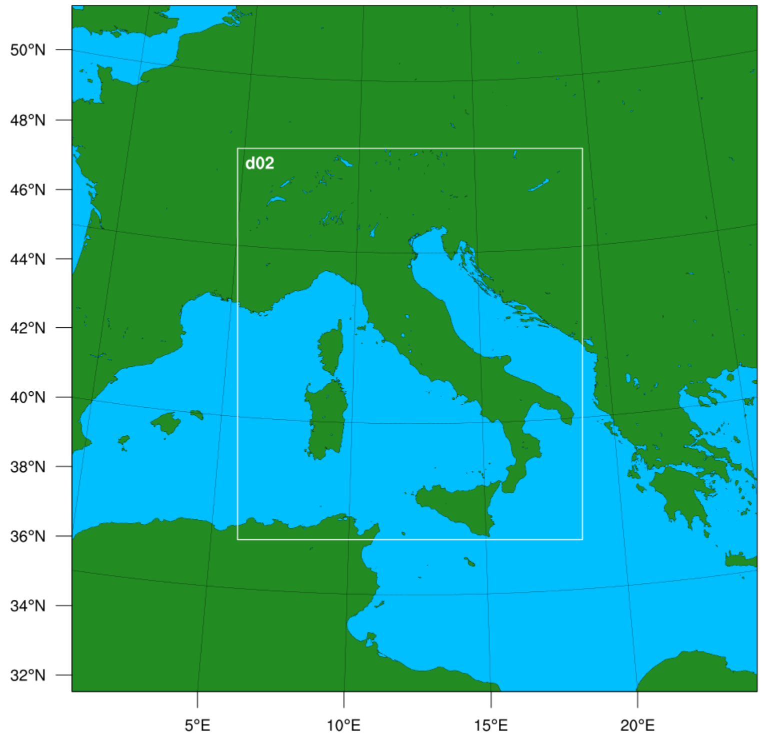

Figure 1. WRF domains.

The modelling actions will be divided into 2 main objectives:
1) WRF simulations for present climate using, as forcing, ERA5 reanalysis fields.
2) WRF Simulation for future climate using, as forcing, outputs by the selected GCM model.

For the present climate 20 years will be simulated: 240 months + 20 months of spin-up (non considered in the analysis). For the future climate, 20 years + 20 years (two scenarios) will be simulated. In this case: 480 months + 40 months of spin-up.
In total, 60 years of runs +5 (60 months) of spin-up will be simulated.
The final database, constituted of a limited number of variables, will be stored in netcdf format. Several post-processing routines will be developed to extract / organize / plot the main atmospheric fields.

Other important computational activities are clearly needed, both before and after the execution of all the simulations. In particular:
- Firstly, we have to download and store daily fields for the initial and boundary conditions: ERA5 reanalysis and GCM model, for the 2001-2020 (present climate) and 2081-2100 (future climate) periods, respectively.
- After consolidating the initial databases, will need to prepare appropriate procedures for re-reading the files, in order to make them compatible with the format required by WRF.
- Finally, specific post-processing procedures and analysis of the future climate outputs will be realized.

Justification of computational resources

The computational activities will be mainly devoted to the construction of the database. Despite this, other significant pre- and post-processing activities will be performed: i) for the preparation of the runs (i.e. download and preparation of the initial and boundary condition fields, model set-up, first test for the optimal WRF configuration, etc.); ii) for the extraction and the storage of the main simulated fields.
The RCMs are very computationally expensive. Thus, a preliminary estimation of the computational/storage resources has been accomplished considering the WRF configuration described in the previous section, to determine an optimal configuration and ensure an efficient use of computational resources.
This represents an approximate estimation since the effective computational cost will depend on physics options selected, on the compiler, on the WRF compilation options, on the adopted parallel libraries, etc..
This preliminarily estimation is performed based on Cray XC40 rules, and the results show that 20 years of a WRF simulations will request about 10 million SBUs.
So, for 65-years simulation, the total request is of 34 million SBUs.

The WRF simulations produce about 2920 GB of data per simulation year. Resulting in a total archive volume of 190000 GB (190 TB).
Since the outputs will be reduced, by extracting and storing the only meteorological parameters of greatest interest, it is believed to be able to require about half of the space theoretically identified: i.e. 100 TB for the entire project.
Some temporary files (full output to be reduced, initial conditions, pre- post-processing files, etc.) will be regularly deleted and the extracted outputs will be transferred to local storage resources as the simulations end.

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