LATE REQUEST FOR A SPECIAL PROJECT 2023–2025

MEMBER STATE: Italy

Principal Investigator[1]: Paolo Stocchi (p.stocchi@isac.cnr.it)

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Other researchers: Silvio Davolio (s.davolio@isac.cnr.it)

Project Title: *MOloch REanalysis (MORE):* High resolution (1.8 km) atmospheric reanalysis, obtained by dynamically downscaling ERA5 reanalysis with the italian convection permitting meteorological model MOLOCH

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 **X**	NO ☐

Computer resources required for the years: (To make changes to an existing project please submit an amended version of the original form.)		**2023**	**2024**	**2025**
High Performance Computing Facility	(SBU)	5 millions	15 millions	5 millions
Accumulated data storage (total archive volume)[2]	(GB)	20000	50000	20000

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: Paolo Stocchi

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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).

Scientific background

Climate reanalysis delivers a complete and consistent picture of the past weather relying on a numerical weather prediction model to assimilate historical observations (e.g., from satellite, in situ, multiple variables) that are not homogeneously distributed around the globe and represents a solution to ensure homogeneity and continuity of data for past and current climate, providing a comprehensive set of variables (in addition to traditional precipitation and temperature). Recently the European Centre for Medium Range Weather Forecast (ECMWF) has released a new generation of reanalysis data, acknowledged as ERA5, representing nowadays the most plausible description for current climate (Hersbach et al., 2020). It has a global coverage with a spatial resolution of 25 km and provides hourly outputs from 1950 up to now. The dataset benefits from a decade of advances in model physics and data assimilation methods. These features make ERA5 suitable for a wide range of applications such as monitoring climate change, research, education, policy making and business, in sectors such as renewable energy, agriculture and hydrology. Despite the authoritative relevance of ERA5, its coarse resolution could prevent a reliable adoption for characterizing localized events (e.g., extreme precipitation) particularly in complex areas (e.g., mountain or urban environments). This makes the use of ERA5 as direct input data for e.g., hydrological studies, not always adequate.

Dynamical downscaling with convection-permitting models (CPMs, resolution <4 km) (Berthou et al., 2018) represents a possible solution to partly cover this gap. CPMs provide information at finer grid scales than ERA5, more suitable for studies of regional phenomena and for application to vulnerability, impact, and adaptation assessments (Kendon et al., 2020)

Over the past decade, computational advances and updates of Regional Climate Models (RCMs) systems to non-hydrostatic frameworks has allowed the application of RCMs to continuous long-term simulations at very high resolutions, the so-called “convection-permitting” (CP) scale, i.e., with kilometer-scale grid spacing (order of 1–4 km) (Ban et al., 2014, Kendon et al., 2014, Weisman et al.,1997). CP-RCMs can provide a step change in our understanding of future changes at local scales and in the simulation of extreme weather events, that most impact society. Some European initiatives (e.g., H2020 EUCP, CORDEX-FPS convection) and many studies, have been exploring RCMs at so-called convection-permitting, convection-resolving, convection-allowing or kilometer-scale grid spacing (Ban et al. 2014; Kendon et al. 2014; Leutwyler et al. 2017; Liu et al. 2017; Berthou et al. 2018; Fumière et al. 2019) providing encouraging evidence about the ability of CP-RCMs to improve the representation of hourly precipitation characteristics (i.e., diurnal cycle, spatial structure of precipitation, intensity distribution, and extremes) towards dynamics matching reality. In addition, they have also demostrated the capacity of CP-RCMs to detect surface heterogeneities (e.g., mountains, coastal regions, and urban areas; Prein et al., 2015, Rowell P. and Berthou S., 2022), and a better representation of land–atmosphere feedback (Taylor et al., 2013) which is necessary to preserve/amplify other extremes such as droughts or summer heat waves. These improvements can also have a knock-on effect on other variables (e.g., energy fluxes such as latent heat and sensible heat, and soil moisture), usually scarcely monitored but of considerable interest for different types of applications.

Project-objectives

In this prospective the aim of our project is to bring the potential of ERA5 to the local scale with the aim of synergistically exploiting CP-RCM features and ERA5 reliability and creating a very-high resolution climate dataset for past/present climate, using a model setup specific for the areas of interest. This is the rationale adopted in this work: to create a new additional gridded dataset over Italy, labelled as MORE (MOloch REanalysis), derived from the dynamical downscaling of ERA5 reanalysis from their native resolution (25 km) to a resolution of 1.8 km for the period 1990–2020, more suitable for studies of regional phenomena and for application to vulnerability, impact, and adaptation assessments.

For example, the MORE dataset will be involved in a project, unveilINg pasT Events foR dROught risk mitiGATION (INTERROGATION), founded by the Ministry of University and Research. The goal of this project is to conduct a retrospective analysis of multi-year drought events by coupling high spatial/temporal resolution data like MORE dataset and advanced hydrological modelling. The framework will allow to investigate, both in space and time, the connection between natural variability of climate and human impact on drought development.

Theoretical and computational methods employed

The dynamical downscaling of ERA5 is carried out using the convection permitting model MOLOCH, a non-hydrostatic limited-area model that integrates the fully compressible dynamical equations with parameterized boundary layer turbulence, radiation, soil physics and cloud microphysics. The MOLOCH model is designed to be a flexible, state-of-the-art atmospheric simulation system that is portable and efficient on available parallel computing platforms. As a convection-permitting model, it is designed to operate at very high resolutions, with kilometer-scale grid spacing (order 1 – 4km) allowing for the explicit treatment of atmospheric convection (Malguzzi et al., 2006 and Davolio etal.,2009).

The MOLOCH model was developed for research purposes at the Institute of Atmospheric Sciences and Climate (ISAC) of the Italian National Research Council (CNR) and is currently implemented and used for operational forecasting and research activities at several national centres (e.g., ISPRA, LAMMA, ARPAL) and foreign institutions (e.g., Met Service of Catalunya, NOA Greece). Dynamical downscaling will be performed relying on a one-step nesting strategy in which the ERA5 data distributed over an European domain (Med-Cordex), are used as initial and boundary conditions for the convection permitting simulation performed with MOLOCH at the resolution of 1.8 km over the Italian territory (Figure 1).

The 30-year simulation will be divided into daily runs, where each MOLOCH run is initialized at 18:00 UTC by ERA5 atmospheric fields, while soil temperature, water content and snow height, are taken from the previous simulation; boundary conditions are provided every hour. The MOLOCH model produces outputs every hour over the domain of integration shown in Figure 1 (inner rectangle). The MORE dataset is then built using the last 24 hours of each model simulation, while the first six hours of integration, are considered as spin-up times and thus discarded. Such numerical simulations will be carried out for the period 1990-2020, and a scheme of the experimental design is shown in Figure 2

Atmospheric outputs will be with 1-hour frequency at full resolution and will be stored in raw format (and post-processed over a regular lat-lon grid in NetCDF format. All the model outputs for a total amount of 90 TB will be stored temporary for possible future analysis and use.

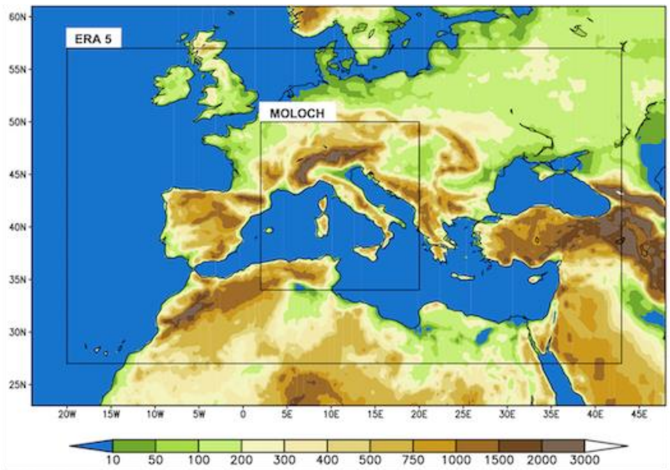

Fig. 1 Extent of the ERA5 and MOLOCH domains of integration with topography (m). The ERA5 domain, outer black box, approximately corresponds to the Med-CORDEX area; the MOLOCH domain, inner black box, covers Italy and surrounding.

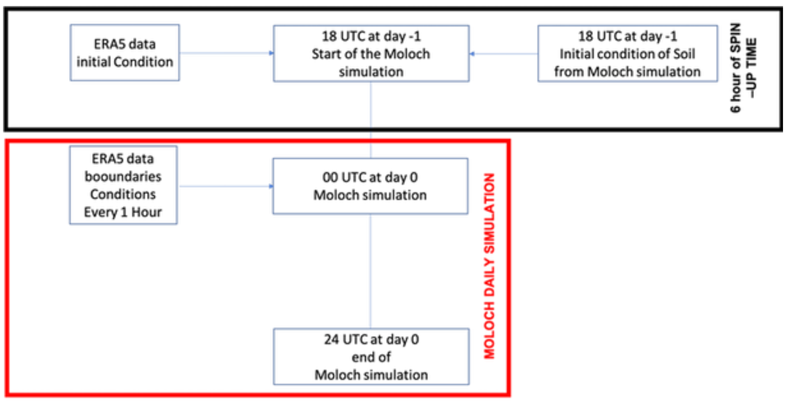

Fig.2: Modelling setup for the production of one single day of the MOLOCH downscaling.

Indicative Workplan and timetable of the activities

We will organize our workplan as follows:

Months 1-4: Collection of the ERA5 data. Installation and test of the model on the HPC platform and start of simulations for reanalysis production.

Months 5-17: Running the reanalysis

Months 18-14: Finish the reanalysis production

Computer Resource requirements

The computer-resource requirements have been estimated based on the previous experience where the model MOLOCH model and his pre and post processors have been already ported and tested on the Galileo100 (G100) platform (https://www.hpc.cineca.it/hardware/galileo100) at CINECA during previous ISCRA try projects..

We have also estimated the computer-resource requirements based on the computational information shared by the managers of a Special Project SPITCAPE (https://www.ecmwf.int/en/research/special-projects/spitbran-2018) where the Moloch model has been involved:

With the above experience the SBUs necessary using 3 nodes with 128 cores are :

~174269 SBUs for ~80 days of reanalysis (24 h of simulation), consequently the total amount of SBUs needed for 30 years of reanalysis are ~25 millions.

The total data storage required to store the whole 30-year period (1990-2020) is estimated in 90 TB

The research team Curriculum Vitae

PAOLO STOCCHI is permanent researcher at the Institute of Atmospheric Sciences and Climate (ISAC), National Research Council of Italy (CNR), Bologna, since December 2020. He has dealt with different topics of the atmospheric sciences and his main expertise include high-resolution regional climate modelling, analysis of the impact of climate change on ecosystems, extreme precipitation, convection, energy and water budgets, atmospheric moisture fluxes. His skills include model data analysis, running high-resolution climate models in HPC environments and good knowledge of several data manipulating softwares. He is coauthor of 17 peer-reviewed publications, among which 5 as first author (Orcid-id:0000-0001 7175-3294)

SILVIO DAVOLIO is permanent researcher at the Institute of Atmospheric Sciences and Climate (ISAC), National Research Council of Italy (CNR), Bologna, since April 2008. His main research topics include atmospheric dynamics, numerical modeling, data assimilation and meteorology. His skills include forecast verification, multi-model prediction, mesoscale meteorology, running atmospheric models in HPC environments and good knowledge of several data manipulating softwares. He is co-author of 65 peer-reviewed publications, among which 20 as first author. (https://orcid.org/0000-0001-9438-5439)

Relevant selected publications of the P.I. and the research team (about the topic proposed here)

Stocchi Paolo, Emanuela Pichelli, Jose Abraham Torres Alavez, Erika Coppola, Graziano Giuliani, and Filippo Giorgi. 2022. "Non-Hydrostatic Regcm4 (Regcm4-NH): Evaluation of Precipitation Statistics at the Convection-Permitting Scale over Different Domains" Atmosphere 13, no. 6: 861. https://doi.org/10.3390/atmos13060861

Coppola, E., Sobolowski, S., Pichelli, E. et al. A first-of-its-kind multi-model convection permitting ensemble for investigating convective phenomena over Europe and the Mediterranean. Clim Dyn 55, 3–34 (2020). https://doi.org/10.1007/s00382-018-4521-8

Paolo Stocchi, Silvio Davolio, Intense air-sea exchanges and heavy orographic precipitation over Italy: The role of Adriatic sea surface temperature uncertainty, Atmospheric Research, Volume 196, 2017, Pages 62-82, ISSN 0169-8095, https://doi.org/10.1016/j.atmosres.2017.06.004.

S. Davolio, R. Henin, P. Stocchi, A. Buzzi Bora wind and heavy persistent precipitation: atmospheric water balance and role of air–sea fluxes over the adriatic sea Q. J. R. Meteorol. Soc., 143 (703) (2017), pp. 1165-1177

Coppola, E., Stocchi, P., Pichelli, E., Torres Alavez, J. A., Glazer, R., Giuliani, G., Di Sante, F., Nogherotto, R., and Giorgi, F.: Non-Hydrostatic RegCM4 (RegCM4-NH): model description and case studies over multiple domains, Geosci. Model Dev., 14, 7705–7723, https://doi.org/10.5194/gmd-14-7705-2021, 2021

Pichelli, E., Coppola, E., Sobolowski, S. et al. The first multi-model ensemble of regional climate simulations at kilometer-scale resolution part 2: historical and future simulations of precipitation. Clim Dyn 56, 3581–3602 (2021). https://doi.org/10.1007/s00382-021-05657-4

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Berthou S, Kendon EJ, Chan SC, Ban N, Leutwyler D, Schär C, Fosser G (2018) Pan-European climate at convection-permitting scale: a model intercomparison study. Clim Dyn. https://doi.org/10.1007/s00382-018-4114-6

Davolio, S. et al. (2009). Orographic triggering of long-lived convection in three dimensions. Meteor. Atmos. Phys.,103, 35-44.

Fumière Q, Déqué M, Nuissier O, Somot S, Alias A, Caillaud C, Laurantin O, Seity Y (2020) Extreme rainfall in Mediterranean France during the fall: added value of the CNRM-AROME convection-permitting regional climate model. Clim Dyn. https://doi.org/10.1007/s00382-019-04898-8

Hersbach, H. et al. (2020). The ERA5 global reanalysis. Q. J. R. Meteorol. Soc., 146 (730)

Kendon, E.J.; Roberts, N.M.; Senior, C.A.; Roberts, M.J. Realism of rainfall in a very high-resolution regional climate model. J. Clim. 2012, 25, 5791–5806. https://doi.org/ 10.1175/JCLI-D-11-00562.1.

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Malguzzi, P. et al. (2006). The 1966 'century' flood in Italy: A meteorological and hydrological revisitation. J. Geophys. Res., 111, D24106

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Prein, A.F.; Langhans, W.; Fosser, G.; Ferrone, A.; Ban, N.; Goergen, K.; Keller, M.; Toelle, M.; Gutjahr, O.; Feser, F.; et al. A review on regional convection-permitting climate modeling: Demonstrations, prospects, and challenges. Rev. Geophys. 2015, 53, 323–361

Rowell, D. P., & Berthou, S. (2022). Fine-scale climate projections: What additional fixed spatial detail is provided by a convection-permitting model?, Journal of Climate (published online ahead of print 2022)

Taylor, C.; Birch, C.E.; Parker, D.; Dixon, N.; Guichard, F.; Nikulin, G.; Lister, G.M.S. Modeling soil moisture-precipitation feedback in the Sahel: Importance of spatial scale versus convective parameterization. Geophys. Res. Lett. 2013, 40, 6213–6218

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