REQUEST FOR A SPECIAL PROJECT 2026–2028

MEMBER STATE: Italy

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Project Title: **E-MOREMED – Exploring MOLOCH Reanalysis for the Mediterranean Domain**

To make changes to an existing project please submit an amended version of the original form.)

If this is a continuation of an existing project, please state the computer project account assigned previously.		
Starting year: (A project can have a duration of up to 3 years, agreed at the beginning of the project.)	2026	
Would you accept support for 1 year only, if necessary?	YES X	NO ☐

Computer resources required for project year:		2026	2027	2028
High Performance Computing Facility	[SBU]	**5 millions**		
Accumulated data storage (total archive volume)[2]	[GB]	**20000**		

[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.

[3]The number of vGPU is referred to the equivalent number of virtualized vGPUs with 8GB memory.

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

Extreme weather events, like heavy rainfall, heatwaves, and tropical-like cyclonesare becoming more frequent and intense due to global warming (Diffenbaugh et al., 2017). This trend poses serious challenges worldwide, raising concerns about the resilience of ecosystems and infrastructure under changing climate conditions (Calleja-Agius et al., 2021; Cramer et al., 2018). Europe, in particular, is warming faster than the global average, with land surface temperatures well above pre-industrial levels (Canadell et al., 2021). This rapid warming especially threatens vulnerable regions such as the Mediterranean basin, mountainous areas, and coastal zones.

These climate shifts have already led to significant impacts across Europe. Southern and central Europe face more frequent heatwaves and droughts (Rahmstorf & Coumou, 2011; Grillakis, 2019), while northern and northeastern parts experience higher risks of heavy rainfall and flooding (Alfieri et al., 2015; Vautard et al., 2014). The resulting socio-economic and environmental effects touch many sectors, from agriculture and energy to public health and transport and energy infrastructure (Bonanno et al., 2019).

To better understand and rapresent these extreme events, the scientific community has increasingly turned to convection-permitting regional climate models (CP-RCMs), which operate at spatial resolutions below 4 km, thus resolving key atmospheric processes at local scales (Kendon et al., 2021). These models have demonstrated improved skill in representing the intensity, timing, and spatial structure of extreme precipitation and heatwaves, compared with coarser global or regional models that parameterize convection (Ban et al. 2014; Kendon et al. 2014; Leutwyler et al. 2017; Liu et al. 2017; Berthou et al. 2018; Fumière et al. 2019). The capability of CP-RCMs to capture surface heterogeneities, such as orography (Dalla Torre et al., 2024), coastlines (Vannucchi et al., 2021), and urban areas (Reder et al., 2022), is crucial for precise simulations of extreme weather drivers and their impacts (Coppola et al., 2020).

Complementary to high-resolution modeling, state-of-the-art climate reanalyses such as ECMWF's ERA5 (Hersbach et al., 2020) provide detailed meteorological fields spanning multiple decades, essential for model initialization, validation, and downscaling. Dynamical downscaling of ERA5 data using mesoscale models like WRF (Skamarock et al., 2008) has enabled datasets such as CHAPTER, which offer 42 years of high-resolution meteorological simulations over Europe and the Mediterranean. These products represent a unique toolset to analyze long-term trends and variability in extreme weather at unprecedented detail.

However, long-term convection-permitting reanalyses covering large domains remain computationally prohibitive. Current convection-resolving datasets such as MERA (2.5 km over Ireland and the UK; Gleeson et al., 2017), LAMMA-HINDCAST (Capecchi et al., 2023), which employs the MOdello LOCale in Hybrid coordinates (MOLOCH, Malguzzi et al., 2006) at 2.5 km grid-spacing , and the Very High-Resolution Dynamical Downscaling of ERA5 Reanalysis over Italy (VHR-REA_IT) (Raffa et al., 2021; Adinolfi et al., 2023) using COSMO at 2.2 grid- spacing and COSMO-REA2 (2 km over Central Europe; Wahl et al., 2017), are limited in spatial extent. This gap motivates the need for targeted studies employing high-resolution convection-permitting simulations over broader domains and focused periods.

Project Objective:

Building on the experience gained from the special project **SPITSTOC-2023 (https://www.ecmwf.int/en/research/special-projects/spitstoc-2023)**, this initiative proposes the use of the **MOLOCH** convection-permitting model at an exceptionally fine horizontal resolution of **1.7 km** to simulate a targeted set of recent extreme weather events over the Mediterranean and surrounding regions. The selected events include **Mediterranean tropical-like cyclones (Medicanes)**, **severe rainfall episodes** such as those that impacted **Emilia-Romagna in May 2023** and **intense heatwaves**.

Unlike long-term multi-decadal reanalysis efforts, this project emphasizes **high-resolution, process-oriented simulations** of individual extreme events. This approach allows a detailed evaluation of MOLOCH's capabilities at 1.7 km resolution across an extensive and topographically diverse domain.

The primary goal is to **critically assess the added value of running MOLOCH at 1.7 km resolution over the full Mediterranean basin**, both in terms of physical realism and skill in representing local-scale convective processes and precipitation extremes. In addition, the project aims to **identify the most efficient and scalable configuration for running such simulations on ATOS**, in order to optimize resource usage without compromising accuracy.

This assessment will inform whether the significant computational cost associated with such high-resolution configurations is justified when compared to coarser (~3–4 km) grid spacings. The findings could directly support the **feasibility of conducting a multi-decadal, convection-permitting downscaling experiment** over the entire Mediterranean basin—extending the scope of the SPITSTOC project, which was previously limited to the Italian domain.

Beyond evaluation, these simulations will also serve as a foundation for **integrated research**, combining high-resolution output with **satellite-based observations** of hail and precipitation, as well as **machine learning algorithms**, to enhance estimation of rainfall associated with Medicanes and other high-impact events.

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-Mediterranean domain are used as initial and boundary conditions for the convection permitting simulation performed with MOLOCH at the resolution of 1.7 km over Mediterranean area (Figure 1).

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.

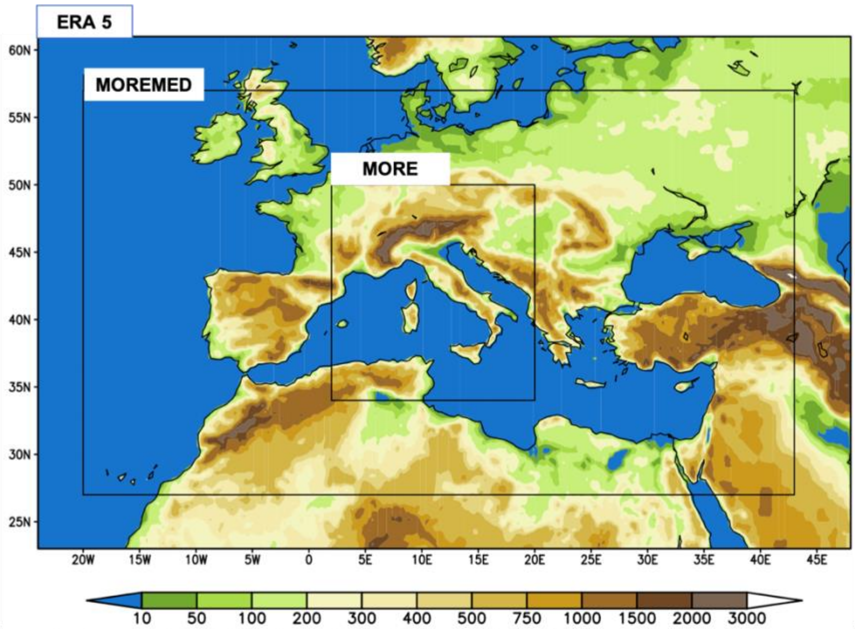

Fig. 1 DOMAINS: Geographical extent of the ERA5, MOREMED (1.7 km), and MORE (1.7 km) domains overlaid on topography (m). The outer black box indicates the ERA5 domain, which approximately corresponds to the Med-CORDEX area. The MOREMED domain, focused on the broader Mediterranean region, is nested within the ERA5 domain. The MORE domain, covering the Italian territory, corresponds to the 30-year high-resolution reanalysis developed within the previous SPITSTOC project.

Computer Resource requirements

The computational resource requirements have been estimated based on previous experience, during which the MOLOCH model—along with its pre- and post-processing tools, was successfully ported and tested (Special Project SPITSTOC-2023).

The simulation approach for the case studies will follow the same methodology adopted in the previous project, with the main difference being the spatial extent of the MOLOCH domain (MOREMED) (figure 1), which in this case will be approximately three times larger in terms of grid points compared to the domain (MORE) (figure 1) used for simulations over the Italian territory.

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