REQUEST FOR A SPECIAL PROJECT 2026–2028

MEMBER STATE: ITALY

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Project Title: Paleoclimate Evolution for Reconstructing Mediterranean Maritime Ancient Routes (PER MAR)

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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.	**SP**	
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 ☑	NO ☐

Computer resources required for project year:		**2026**	**2027**	**2028**
High Performance Computing Facility	[SBU]	15 mln	45 mln	21 mln
Accumulated data storage (total archive volume)[2]	[GB]	400.000	560.000	786.500

EWC resources required for project year:		**2026**	**2027**	**2028**
Number of vCPUs	[#]			
Total memory	[GB]			
Storage	[GB]			
Number of vGPUs[3]	[#]			

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

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Extended abstract

The Mediterranean Sea has long served as a cradle for human civilization, where maritime routes enabled the flow of goods, people, and ideas. Yet, the role of climate in shaping these ancient maritime routes (MAR) remains poorly understood.

PER MAR project aims at reconstructing the dominant Mediterranean Sea state conditions that influenced navigation pathways during antiquity through regional paleoclimate modelling (~12km and ~3km horizontal resolution). PER MAR will deliver a scientifically robust framework to explore how environmental variability influenced ancient maritime connectivity. This approach is new and never explored before in this context and at such highly resolved spatial scales.

Reconstructing the Mediterranean Sea climate in antiquity is not only an end in itself. Indeed, knowledge of the actual parameters of the sea conditions is crucial to determine the possible routes of ships. The modelling initiative of PER MAR is motivated by the funded ERC-Consolidator 2025 – 2028 project MarDepend (ERC-2024-COG, number 101170294). The research project is coordinated by prof. Pascal Warnking (Trier University, Germany), with the Italian National Research Council (CNR) has second beneficiary. In the context of MarDepend, CNR (with research scientists from ISMAR and ISAC) is aimed at providing the wind, wave and surface current conditions that characterized the Mediterranean Sea climate around 500 BCE, when the city-state of Syracuse controlled most Greek cities in Sicily and several in Italy.

Although PER MAR focuses on reconstructing past hydroclimate conditions rather than real-time forecasting, its methodological foundation—rooted in high-resolution dynamical modeling and downscaling—draws directly from numerical weather prediction practices (NWP). The project thus contributes to the advancement of NWP-derived modelling tools and reinforces their value for understanding atmospheric dynamics across timescales.

1.2 Background

Maritime navigation in the Mediterranean during antiquity was heavily influenced by prevailing wind systems, ocean currents, and seasonal weather patterns. However, our understanding of these physical drivers during specific historical periods—particularly around 500 BCE—is limited. Traditional reconstructions rely heavily on indirect archaeological indicators, such as shipwreck locations, harbor installations, or historical records, which provide spatially sparse and temporally ambiguous information. At the same time, the field of paleoclimate modelling has advanced significantly, offering dynamically consistent reconstructions of ancient atmospheric and oceanic fields across the Mediterranean. These datasets can now be leveraged to bridge a longstanding disciplinary gap: connecting modeled climate variability with archaeological reconstructions of maritime traffic and cultural exchange.

Previous studies have explored paleoenvironmental changes in the Mediterranean (Abrantes et al., 2010, D'Agostino et al., 2020), but few have explicitly linked wind regimes and ocean surface dynamics with seafaring routes. The potential to generate a paleo-navigational map—where ship movement potential is constrained or facilitated by reconstructed surface fields—offers a breakthrough in understanding how climate influenced human mobility, trade, and settlement dynamics.

PER MAR builds on recent methodological synergies between paleoclimate science, climate modeling, and maritime archaeology. It is particularly timely considering the growing interest in historical analogues for climate-driven migration and socio-environmental resilience.

2. Modelling strategy: the Regional Climate Model RegCM5

We will perform paleoclimate model simulation (atmosphere + land) at 12-km resolutions over the whole Mediterranean (Fig. 1) by using the publicly available Fifth Generation Regional Climate Modeling System (RegCM5, Giorgi et al. 2023) in parametrized convection setup. The atmospheric model is coupled with the Community Land Model 4.5 (CLM4.5) that is the land surface module (Oleson et al., 2013), which includes the carbon cycle, vegetation dynamics, and river routing. In the paleoclimate context, we attempt to run for the first time the coupled atmosphere/ocean version to simulate the ancient Mediterranean Sea condition and explore surface and deep currents. The ocean component coupled to RegCM5 is MITGCM (Marshall et al., 1997). The model uses a finite-volume approach to solve the incompressible Navier-Stokes equations on a sphere, making it suitable for studying ocean dynamics across various scales, from convective to global. The third setup will be focus on a much smaller domain centered over Southern Italy and will be run under convection permitting configuration at 3km horizonal resolution.

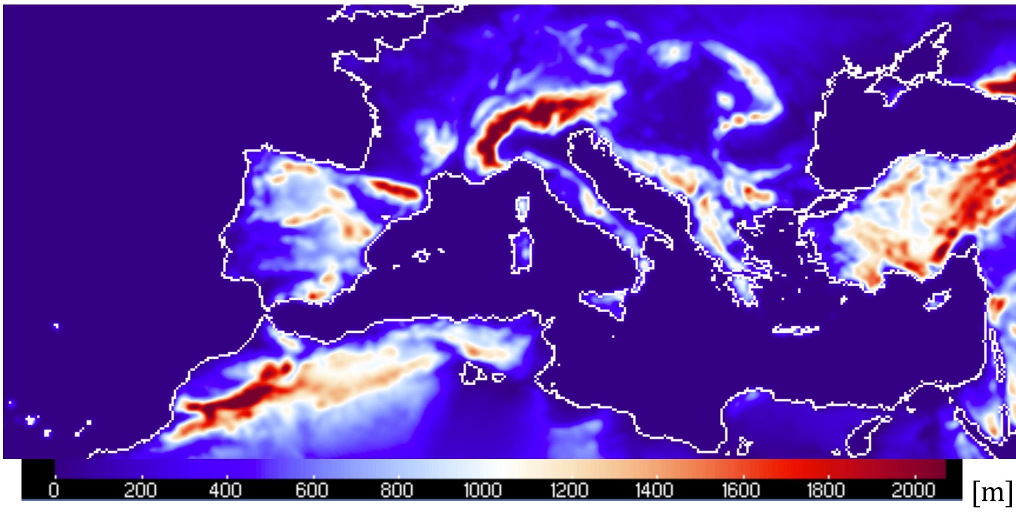

Figure 1: Topography (in meters) of the Mediterranean region (30N – 48N, 10W – 37E) from the paleoclimate simulation with RegCM5 at 12km horizontal resolution.

2.1 The Experimental design

2.1.1 ATMOSPHERIC PART – 1st year

We will be running 3 sets of two high-resolution time slices with RegCM5-CLM4.5 for 100 years:

- 1**) 2500 – 2400 years Before Pre Industrial (BPI).**
- 2**) Pre Industrial (PI): 1750 – 1850**, that would serve as the control run.

at 12km atmosphere+land, 12km fully coupled and 3 km atmosphere only convection permitting.

Under 12 km atmosphere+land configuration, the model runs according to values in table 1.

12-km Paleo Med	Sim Name	N. NODES	N. Tasks x	processor:	1 mon run time (sec)	1 mon run time (min)	1 year (h)
	paleo_001	4	48	192	5053	84,2	16,8
Buffer zone: 40							
	paleo_002	6	48	288	3576	59,6	11,9
Domain							
200 iy	paleo_003	8	48	384	2841	47,4	9,5
463 jx							
41 kz							

12-km Paleo Med	Sim Name	N. NODES	N. Tasks x Node		1 mon run time (sec)	1 mon run time (min)	1 year (h)
	paleo_011	4	24	96	10429	173,8	34,8
Buffer zone: 40							
	paleo_012	6	24	144	9427	157,1	31,4
Domain							
200 iy	paleo_013	8	24	192	4876	81,3	16,3
463 jx							
41 kz							

Table 1: RegCM5 over the Mediterranean (Fig. 1) scalability tests conducted on HPC Galileo100 machine at CINECA (Italy). Two series of experiments were conducted: changing nodes (4-8) and changing the number of tasks per node (24-48). Computing time is expressed in seconds and minutes for 1 simulated month time and in hours for 1 simulated year.

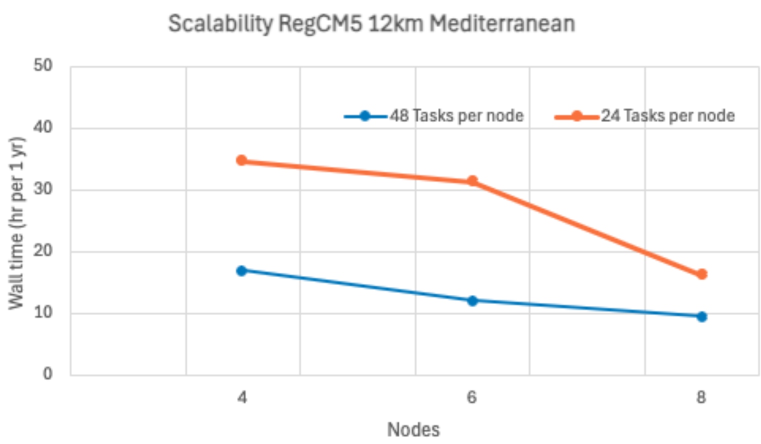

Figure 2: Scaling wall time as a function of nodes used for the integration values shown in Tab. 1.

Under the fastest configuration on Galileo 100 machine, 100 simulated years would need approximately 40 days to be completed. We believe that 100 simulated years for each time slice is a good climatology for the Mediterranean surface wind and current conditions. The atmospheric part of the simulation will need a short (in the order of months) spinup, however the land components will take much longer to adjust. We will perform ad hoc stand-alone simulation with the land component CLM4.5 for 200 to 500 years. It is generally faster than the atmospheric run and we believe that in 1 month we can let the nitrogen and other slower components of the soil at the equilibrium. Using 1 node and 112 tasks per node, we run 1 simulated year in 2 hours per year. This means that 500 years could be run in approximately 42 days.

This experiment series, simulating only the atmospheric conditions with land, will be performed during the first **6-12 months of the project.**

2.1.2 COUPLED SYSTEM PART – 2nd year

From months 12 to 24, we will attempt for the first time to run a paleoclimate experiment with the fully coupled RegCM-ES at 12 km. We plan to perform the same series of paleo experiments (2500 BPI and PI) with coupled ocean. Our colleagues at International Center on Theoretical Physical (ICTP) in Trieste, are running 1 simulated year of the coupled RegCM-ES in present-day condition with active biogeochemical cycles version over the Mediterranean domain at 12 km with 480 cores (96 tasks per

 This form is available at:
http://www.ecmwf.int/en/computing/access-computing-facilities/forms

node and 5 nodes) on Leonardo machine at CINECA in 24 hours walltime. We believe that in a similar configuration we could run 100 years in 100 days. However, the implementation and the pre-processing of the fully coupled RegCM-ES, requires much attention and dedication. The preparation of the spinup for the ocean model takes much time depending on our research target. As this would be the first time that RegCM-ES would be set up for paleoclimates, we aim at simulating the whole Mediterranean Sea, therefore, much longer spin-up is required (500 years at least) to let the ocean being at the equilibrium in the lower layers. We could try with acceleration technique to reduce the computation time to reach the equilibrium. In paleoclimate this is a common and accepted procedure. This means that 500 years of spinup could be tackled in 50 days, with an acceleration factor of x10. We believe that we could achieve this target by the end of the second year of the project.

2.2.3 3KM SOUTHERN ITALY PART – 3rd year

From month 24 to 36, we want to perform a very high resolution convection permitting (3 km) simulation over Central Mediterranean, including Southern Italy and Greece. Around 2500 BPI, the Southern Italy and Sicily (known as Magna Graecia) were extensively colonized by ancient Greeks, starting from the 8th century BC, with Syracuse fast emerging as a major power. This period saw the establishment of numerous Greek city-states in the region. The Greek colonization of Southern Italy was driven by factors like overpopulation in Greece, the search for new resources, and political instability. The high-resolution allows a precise climatological wind reconstruction of that period, eventually link anomalous surface winds with the Greek outbreaks in Southern Italy.

We have performed on Galileo100 several scaling tests with RegCM5 coupled with CLM4.5 at 3km, convection permitting over much smaller domain than in figure 1, centered over Southern Adriatic. Wall times are listed in table 2.

3km S. Adriatic	Sim Name	N. NODES	N. Tasks x	1 mon run time (sec)	1 mon run time (min)	1 year (h)
	test_002	3	48	10712	180	35
	test_003	4	48	7979	133	27
Buffer zone: 40	test_004	5	48	6186	103	21
	test_005	6	48	5476	91	18,2
Domain	test_006	7	48	4860	81	16,2
300 iy	test_007	8	48	4350	73	14,5
300 jx						
41 kz						
3km S. Adriatic	Sim Name	N. NODES	N. Tasks x	1 mon run time (sec)	1 mon run time (min)	1 year (h)
	test_012	3	24	30548	509	101
	test_013	4	24	16891	281	56
Buffer zone: 30	test_014	5	24	12735	212	42
	test_015	6	24	10540	175	35
Domain	test_016	7	24	8967	149	30
300 iy	test_017	8	24	4350	189	38
300 jx						
41 kz						

Table 2: RegCM5, 3km over Southern Italy scalability tests conducted on HPC Galileo100 machine at CINECA (Italy). Two series of experiments were conducted: changing nodes (3-8) and changing the number of tasks per node (24-48). Computing time is expressed in seconds and minutes for 1 simulated month time and in hours for 1 simulated year.

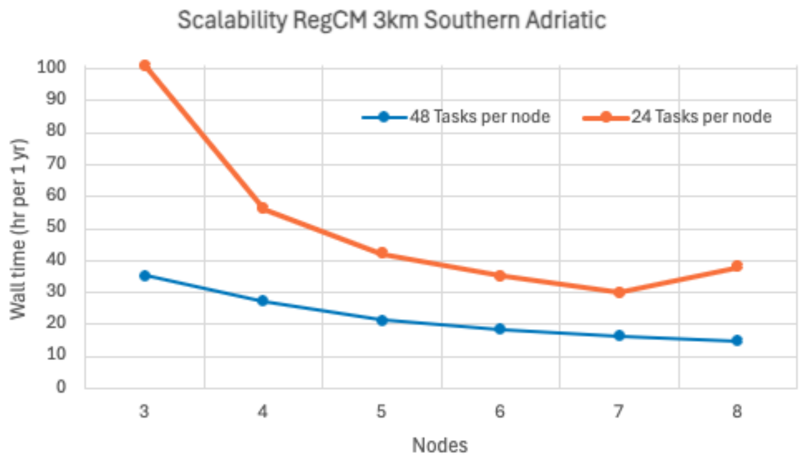

Figure 3: Scaling wall time as a function of nodes used for the integration values shown in Tab. 2.

3. Computational resources SBU and storage requests

	Task	Description	Sim. Years	Storage TB	Atos SBU
Year 1	3.1a	ICBC download	200	~ 250	
	3.1b	Spinup CLM + preproc	500	45	~ 2 mln
	3.1c	RegCM5 + CLM4.5 12km 2500 BPI sim.	100	41	~ 6 mln
	3.1d	RegCM5 + CLM4.5 12km PI sim.	100	41	~ 6 mln
TOTAL 1st year				**~380**	**14 mln**
Year 2	3.2a	Spinup MITgcm + preproc	50	~34	~ 10 mln
	3.2b	RegCM-ES 12km 2500 BPI sim.	100	67	~ 17 mln
	3.2c	RegCM-ES 12km PI sim.	100	67	~ 17 mln
TOTAL 2nd year				**~ 168 TB**	**44 mln**
Year 3	3.3a	Preproc.	100	~39	
	3.3b	RegCM5 3 km 2500 BPI sim.	100	80	9,5 mln
	3.3c	RegCM5 3 km PI sim.	100	80	9,5 mln
TOTAL 3rd year				**~ 200 TB**	**19 mln SBU**
TOTAL				**748 TB**	**77 mln SBU**
5% Buffer – TOTAL				**~38,5 TB**	**3,85 mln SBU**

3.1 Paleo MED 12 km RegCM5 – CLM4.5 (first year): Atmosphere + Land

3.1a) Download global model Holocene transient simulations provided by Institute Pierre Simon Laplace (IPSL) daily outputs ~ 250 TB

3.1b) Preprocessing + spinup ~500 yrs with CLM4.5 standalone computing time: 112 processors x 500 simulated years x 2 hours a year = **112000 core hours. Storage 17 TB + 18TB (input) + 10 TB = 45 TB.**

3.2c/d) Simulation computing time: 384 processors x 100 simulated years x 9,4 hours a year* x 2 simulations = **721900 core hours. Storage: 2 x 41 TB storage = 82 TB.**

3.2 Coupled MED 12 km RegCM-ESM (second year): Fully coupled

3.2a) Preprocessing + accelerated x10 ocean spinup (500 years -> 50 accelerated years): 480 processors x 50 simulated years x 24 hours a year = **576000 core hours. Storage: 56 GB x month x 12 x 50 ~ 34 TB**

3.2b/c) Simulation computing time: 480 processors x 100 simulated years x <u>24 hours a year</u>* x 2 simulations = **2304000 core hours. Storage: 67 TB x 2 ~ 135 TB**

3.3 S. Italy MED 3km RegCM5 – CLM4.5 (third year): Atmosphere

3.3a) Preprocessing: **Storage 39 TB (input)**

3.3b/c) Simulation computing time: 384 processors x 100 simulated years x <u>14,5 hours a year</u>* x 2 simulations = **1113600 core hours. Storage: 2 x 80 TB storage = 160 TB.**

*Note that the scaling tests have been performed on Galileo 100 machine at CINECA. It is likely that the performance on ATOS would be different.

References

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