REQUEST FOR A SPECIAL PROJECT 2024–2026

MEMBER STATE:	CROATIA
Principal Investigator[1]:	Iva Tojčić
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Project Title:	Adriatic Sea Climate: towards kilometre-scale biogeochemical modelling

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.)	2024	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for project year:		**2024**	**2025**	**2026**
High Performance Computing Facility	[SBU]	20,000,000	20,000,000	20,000,000
Accumulated data storage (total archive volume)[2]	[GB]	25,000	50,000	75,000

EWC resources required for project year:		**2024**	**2025**	**2026**
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

1) Motivation and problem identification

With ongoing and future global warming, it is anticipated that the frequency and intensity of extreme events will increase along the Mediterranean basin (Quintana Seguí et al., 2016; Cramer et al., 2018, 2019; Zittis et al., 2019; Molina et al., 2020). This is particularly relevant for coastal communities, which are experiencing rapid growth (SoED, 2020). Specifically, along the Adriatic coasts, local authorities are already facing and preparing for increasing hazards caused by (1) extreme storm surges, waves, land and marine heatwaves, floods, and heavy precipitation (Cramer et al., 2019; Lange, 2020), as well as (2) water quality issues associated with pollution, harmful algal blooms, hypoxia, over tourism, and rising sea temperatures (Zittis et al., 2019; Lange, 2020; SoED, 2020). To meet the increasing demand from decision-makers for more accurate long-term projections (climate hazards) of extreme events, the geoscientific community has developed and improved the global and regional Earth system models. Examples include the global European Centre for Medium-Range Weather Forecasts (ECMWF; Zsótér, 2006) and the regional Mediterranean Ocean Forecasting System (MFS; Pinardi et al., 2003), which offer enhanced products. These advancements aim to provide decision-makers with better tools for making informed decisions in response to the challenges posed by extreme events.

However, in terms of numerical modelling, the Adriatic region presents several challenges. Due to the complex geomorphology of the Adriatic basin, numerically expansive coupled atmosphere-ocean-wave kilometre-scale modelling suites are needed to reproduce the most extreme conditions likely to impact the coastal areas. Examples of such conditions include powerful bora winds, which generate the densest waters in the Mediterranean Sea, intense Sirocco events that cause flooding in northern Adriatic regions like Venice and the Gulf of Trieste, as well as atmospheric disturbances that trigger tsunami-like waves known as meteotsunamis, leading to flooding in vulnerable harbours along the eastern Adriatic coast. Kilometre-scale atmospheric models are essential to accurately capture these phenomena while (sub)-kilometre-scale resolutions in ocean models are necessary to accurately represent the coastal dynamics along the intricate Adriatic coastline which includes over 1200 islands.

Additionally, reliable biogeochemical climate models are of utmost importance for various activities such as tourism, shellfish or fish farming, and harbour maintenance. With about 3000 kilometres of coastline the Adriatic Sea is the main economic driver of the coastal communities that highly rely on tourism and maritime activities. However, the numerical complexity of coupled ocean-biogeochemical models, which provide crucial variables for assessing water quality such as pH, dissolved oxygen concentration, heavy metals, nitrates, phosphates, etc., is comparable to that of the coupled atmosphere-ocean-wave models in terms of computational requirements.

2) Previous Numerical Modelling Efforts

Recently, the Adriatic Sea and Coast (AdriSC) modelling suite (Denamiel et al., 2019) has been implemented to simulate the atmosphere-ocean dynamics of the Adriatic basin. This suite enables simulations at various scales, spanning from long-term coastal climate changes to minute-by-minute effects of extreme events, by using a modular approach (Table 1 and Figure 1): the AdriSC basic module provides hourly kilometre-scale atmosphere-ocean-wave dynamics while the AdriSC nearshore module only runs during atmospherically driven extreme events.

In the AdriSC basic module (Table 1 and Figure 1), the kilometre-scale coastal circulation over the Adriatic-Ionian basin is derived using the Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWST) modelling system (Warner et al., 2010). Hourly results are produced at resolutions up to 3-km for the Weather Research and Forecasting (WRF) model (Skamarock et al., 2005) in the atmosphere and 1-km for the Region Ocean Modeling System (ROMS; Shchepetkin & McWilliams, 2009) and the Simulating WAve Nearshore (SWAN) model (Booij et al., 1996) in the ocean (Table 1). Two 31-year long climate simulations have already been performed with the AdriSC climate component. An evaluation run for the 1987-2017 period was fully evaluated against a comprehensive atmospheric and oceanic observational and remote sensing dataset (Denamiel et al., 2021; Pranić et al., 2021) and already provided valuable insights of the long-term Adriatic Sea dynamics including the BiOS (Denamiel at al., 2022a), the dense water formation (Pranić et al., 2023) and the atmosphere-ocean trends and variability (Tojčić et al., 2023). The climate projection run under RCP8.5 climate warming scenario for the far-future 2070-2100 period was performed following the pseudo-global warming (PGW) method developed first in the atmosphere (Schär et al., 1996) and recently extended to the ocean (Denamiel et al., 2020a). The results of this simulation are currently under analysis.

The AdriSC nearshore module (Table 1 and Figure 1) further downscales the results of the AdriSC basic module and is based on the offline coupling between the WRF model at 1.5 km resolution and the Advanced CIRCulation model (ADCIRC-SWAN; Luettich et al., 1991) at up to 10 m resolution along the Adriatic coasts. Following the PGW method, the nearshore module has been used in short-term simulations in order to derive the impact of climate change on (1) extreme waves (Denamiel et al., 2020a), (2) extreme bora winds (Denamiel et al., 2020b) and (3) meteotsunamis (Denamiel et al., 2022b).

Table 1. Summary of the Adriatic Sea and Coast (AdriSC) modelling suite set-up.

Module	Coupling	Domain	Model	Horizontal resolution	Region	Initial and boundary conditions (frequency)
Basic	COAWST online	Atmosphere	WRF	15 km	Middle Mediterranean Sea	ERA-Interim (6-hourly)
			WRF	3 km	Adriatic-Ionian	Two-way nesting (30 sec)
		Ocean	ROMS SWAN	3 km	Adriatic-Ionian	MEDSEA (daily)
			ROMS SWAN	1 km	Wider Adriatic	One-way nesting (50 s)
Nearshore	Offline	Atmosphere	WRF	1.5 km	Adriatic Sea	WRF 3-km (hourly)
		Ocean	ADCIRC SWAN	up to 10 m	Adriatic Sea	ROMS-SWAN 1-km (hourly)

To our knowledge, the AdriSC climate suite is the first kilometre-scale coupled atmosphere-ocean climate model ever implemented. Despite encountering numerous challenges in the previous ECMWF special projects (e.g., slow performance of the AdriSC model), the AdriSC model has proven to greatly advance the scientific knowledge of the atmosphere-ocean Adriatic dynamics at the climate scale. The results of the AdriSC model are currently analysed to investigate a wide range of physical and biological processes in the past and project their behaviour within the context of future climate change scenarios.

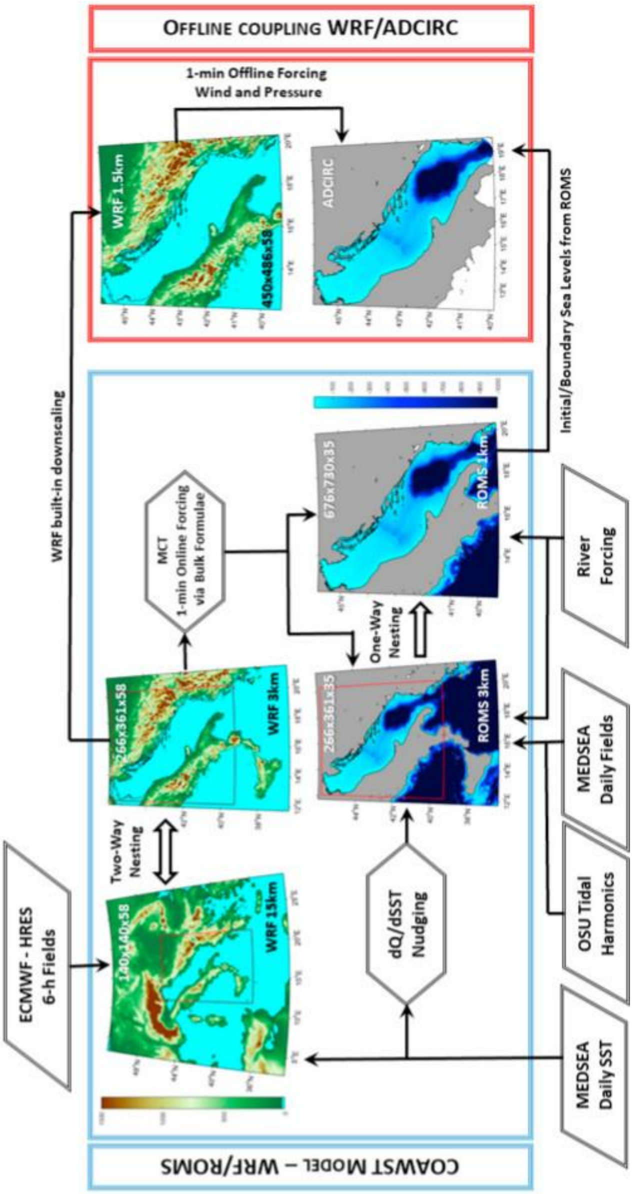

Figure 1 Numerical set-up of the AdriSC modelling suite.

3) Proposed Work

In this project, different biogeochemical models will be coupled with the AdriSC model and their performances, defined as the best balance between the result accuracy and the running time, will be tested for different configurations (i.e., different number of relevant variables). The main numerical implementation of the project will consist in the coupling of the AdriSC modelling suite with the chosen biogeochemical models. Then, the feasibility of producing kilometre-scale coupled atmosphere-ocean-wave-biogeochemical results at the climate scale in the Adriatic Sea will be tested with the ECMWF numerical resources.

As illustrated in Figure 2, the main objectives of the proposed work are thus: (1) to understand the importance and the added value of kilometre-scale water biogeochemical modelling for hazard assessments in the Adriatic Sea, (2) to study the impact of extreme events on the primary production in the Adriatic Sea both in the past and under extreme climate warming (RCP 8.5 scenario) with a coupled atmosphere-ocean-wave-biogeochemical model and (3) to assess the long-term changes in biogeochemical hazards due to extreme warming (RCP 8.5 scenario), and their consequences for the coastal communities living along the Adriatic basin, with a biogeochemical model forced offline by the already available AdriSC climate results.

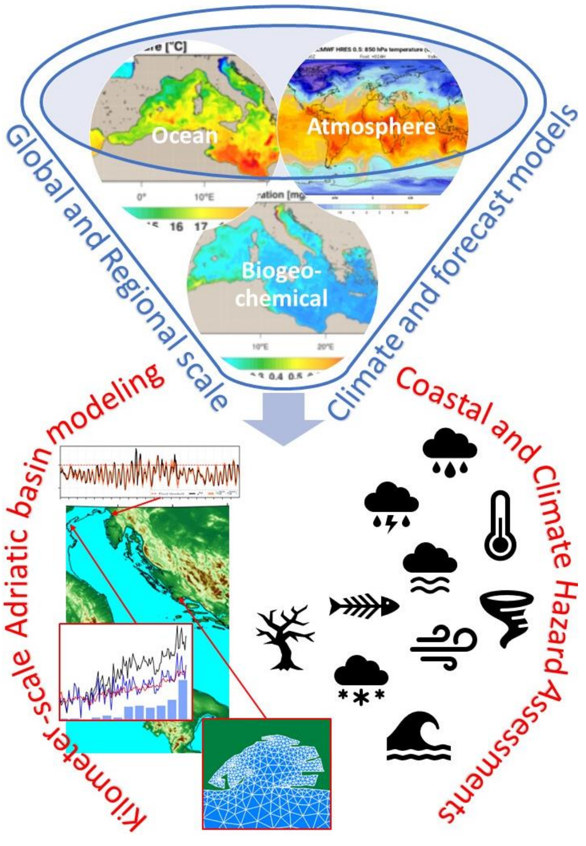

Figure 2 Conceptual design of the research in the framework of the special project. It consists in downscaling the available global and regional atmosphere, ocean, and biogeochemical forecasts or climate projections to targeted kilometre-scale results in the Adriatic basin and aims at providing to the local decision makers more accurate coastal and climate hazard assessments, particularly along the and Croatian coasts.

Computing resources needed: given the size of the grids (atmosphere: 140x140x58 + 266x361x58 + 676x730x58 – ocean: 266x361x35 + 676x730x35) and based on previous experience with the new

ATOS HPC at ECMWF, the following system should be run with 3 Cores in order to achieve reasonable time of execution of the coupled models. For the long-term simulations, 2 Cores should suffice to run the complex biogeochemical model alone.

The targeted use of the ECMWF resources is thus 20 000 SBUs and 25 000 GB of storage per year.

The modelling strategy of the project consists in the following points:

Setup and test/validation of different biogeochemical coupled with the AdriSC modelling suite

This task will focus on the evaluation of biogeochemical models (e.g., ERSEM, BFM, PISCES, SELMA, etc.) in terms of complexity, source code modularity, coupling feasibility and computational costs. Most of the more complex biogeochemical models allow for simplification by excluding parts of the code. Different ecological models will be installed and coupled with the AdriSC modelling suite. Their performances, defined as the best balance between the result accuracy and the running time, will be tested for different biogeochemical model configurations (i.e., different number of relevant variables). Depending on the performance of the models and configurations, two biogeochemical model setups will be chosen: (1) a simple configuration dedicated to the study of the primary production under extreme events and (2) a more complex configuration dedicated to the study of the Adriatic Sea ecosystem under long-term climate changes.

Computing resources needed: About **3 Cores * 10 days * 86400 s * P * 6 simulations = ~ 10 000 000 SBUs** and up to **5 000 GB** are planned to be used for this phase of the ECMWF special project.

Extreme event kilometre-scale atmosphere-ocean-wave-biogeochemical modelling

In this task, the impact of past and future extreme events on the Adriatic Sea ecosystem will be studied. First, short-term simulations coupling online kilometre-scale atmosphere-ocean-biogeochemical models will be implemented for extreme events during the 1987-2017 period with the chosen configuration of the coupling. The obtained results will be evaluated with the historical observations. Then, extreme events will be run under projected climate warming (RCP8.5 scenario) and the impact of climate change in terms of primary production will be derived during extreme events for the entire Adriatic Sea ecosystem.

Computing resources needed: Following our first estimate, **3 Cores * 10 days * 86400 s * P * 14 simulations = ~ 25 000 000 SBUs** and up to **35 000 GB** will be used in the framework of the ECMWF special project to fully cover these runs.

Climate kilometre-scale biogeochemical modelling

In this task, the chosen biogeochemical model will be coupled offline with the 31-year AdriSC hourly atmosphere-ocean climate results stored on ECFS. Both historical and future scenario will be run in parallel and the long-term impact of climate change on the Adriatic Sea ecosystem will be studied by comparing the biogeochemical model results of the 1987-2017 period with those obtained for the 2070-2100 period for the RCP8.5 future scenario.
Computing resources needed: Following our first estimate, **2 Cores * 110 days * 86400 s * P * 2 simulations = ~ 25 000 000 SBUs** and up to **35 000 GB** will be used in the framework of the ECMWF special project to fully cover these runs.

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