REQUEST FOR A SPECIAL PROJECT 2025–2027

MEMBER STATE: Portugal

Principal Investigator[1]**:** Gil Ramos Lopes Gonçalves Lemos ………………………………………………

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Project Title: IAMCOAST – IntegrAtive Multivariate Tool for Future Shoreline Evolution and COASTal Flooding Vulnerability Assessments in Portugal

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.)	2025	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for project year:		**2025**	**2026**	**2027**
High Performance Computing Facility	[SBU]	100.000.000	100.000.000	50.000.000
Accumulated data storage (total archive volume)[2]	[GB]	120.000	240.000	300.000

EWC resources required for project year:		**2025**	**2026**	**2027**
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

Introduction and Motivation

Climate change represents an existential threat to coastal areas worldwide [1], with potentially dire consequences for natural ecosystems, coastal communities, cities, and relevant infrastructures. The global coastlines have long been serving as vital hubs of economic activity, transportation, recreation, and cultural heritage [2-6], often developing faster than inland regions due to their unique and desirable attributes and location, making them increasingly vulnerable to climate change impacts [7]. Although the focus of the public and decision-makers tends to be mainly on the changes in mean sea levels, future episodic extreme coastal flooding resulting from severe weather synchronized with wave action and high tides in the context of rising sea levels, is expected to further endanger coastal communities [8-10]. Such a threat calls for comprehensive adaptation and impact mitigation strategies to safeguard coastal areas, based on reliable, long-term coastal vulnerability assessments.

The portion of total population living in coastal areas has rapidly increased in the last decades [11,12], being estimated that at least 10% of the current world's population lives in coastal areas less than 10 m above sea-level [13,14]. Such a trend is also verified in Portugal, since most of the Portuguese populational centres are located at the coast. According to [15], 14% of the national population lives within 2 km of the sea. In a recent update of the national census (CENSOS2021), it was shown that the population living in the Lisboa and Algarve regions increased by 1.7% and 3.7% relative to 2011, adding further pressure on the Portuguese coastal areas. Overall, the Portuguese coastline, extending for 987 km, is composed of sandy beaches, dunes, sandy rocky and soft cliffs, interspersed by river mouths, estuaries, lagoon systems, barrier islands and urbanized areas with maritime ports, sea walls, breakwaters, marginal roads and housing lots. Such a complex coastal setting poses enormous challenges in the definition of accurate and consistent coastal vulnerability and risk assessment methodologies.

Coastal management is becoming increasingly relevant in the context of climate change [2,16,17], as recent studies indicate significant projected changes not only in the mean sea levels [18], but also in storm surges (e.g.,[19,20]), waves (e.g., [21-27]), as well as in tropical [27-31] and extratropical (e.g., [32-34]) cyclonic activity. These changes are expected to increase coastal flood risk worldwide [35-37], enhancing the role of adaptation and impact management strategies. While [24] suggested that 48% of the global coastlines are at risk, from wave climate change alone, leading to increased property damage, loss of life and environmental degradation [38], sea level rise (SLR), sand mining and increasing human occupation are projected to accelerate local erosion mechanisms [39].

Coastal flooding is a relatively-well understood and widely modelled consequence of increasing total water levels (TWLs), which combine SLR, astronomical tides, storm surges and waves (wave set-up and run-up). Some of the most pressing challenges to coastal flood modelling include coherent approaches to obtain and assess total water level (TWL) components in order to produce adequate (and accurate) results. While the probabilistic combination of the TWL components should be considered the methodology of choice, the deterministic approach of combining all TWL components is still common. Furthermore, when dealing with wave climate simulations and projections, the additional efforts required to account for the waves' interaction with bathymetry near the coast are usually neglected. In fact, coherent and comprehensive methodologies combining SLR with tides, storm surges and waves are scarce [16,17]. Despite some exceptions [40,44], most studies focus uniquely on SLR, neglecting or considering the remaining variables stationary. Nevertheless, the combined impact of storm surges and extreme wave conditions, especially when synchronized with high tides, may produce variations in the TWLs greater than SLR, of up to a couple meters [17, 45].

Currently there are no consistent Coupled Model Intercomparison Project Phase 6 (CMIP6) assessments investigating the impact of climate change on the Portuguese coastal areas, focusing on SLR, wave action, tides and storm surges, and their impacts on shoreline evolution, extreme coastal flooding and permanent flooding of low-lying areas, directly related to loss of dry land. However, the continued rising sea levels along Portuguese coastlines, associated with the present scenario of coastal sedimentary imbalance, could result in unprecedented coastal flooding, if no additional coastal protection and risk-reduction or adaptation measures are implemented [46].

This project aims to provide, for the first time, a complete overview of the combined effects of SLR, tides, storm surges and waves' future climate projections along the 987 km of the Portuguese coastline, through high-resolution modelling based on a consistent methodology. The outputs are used to drive a coastal vulnerability assessment, based on probabilistic cartography, of the physical and socio-economic impacts of climate change, relying on a composed CVI, adapted to each type of coastal stretch, from natural (sandy to rocky) to urbanized (enclosed beaches or with adherent structures). The riskiest locations are identified and specific adaptation plans are built, considering both the local, regional and national projections.

The goal of this project is to ultimately provide clear and simple information for decision makers, yet based on rigorous and innovative scientific methodologies, to allow the implementation of strategic policies ranging through all sectors operating on coastal areas. This research follows the host institution strategy and mission, and it is linked to the UN 2030 agenda.

Objectives

This project aims to provide, for the first time, a complete overview of the combined effects of SLR, tides, storm surges and waves' future climate projections along the 987 km of the Portuguese coastline, through high-resolution modelling based on a consistent methodology focusing on small-scale phenomena and feedbacks usually neglected in similar assessments. The outputs are used to perform the most rigorous and accurate assessment of coastal vulnerability yet, due to climate change, along Portugal mainland's coastlines, based on CMIP6. The project seeks to produce high-resolution geomorphological data and probabilistic cartography of the projected erosion, exposure, vulnerability, and risk of flooding, which simply and pertinently highlight the areas for which adaptation and mitigation measures should be employed by the decision makers.

In summary, the objectives can be highlighted as: 1) promote, for the first time, a complete and coherent assessment of the impacts of climate change, determined by the changes in the water levels, along the Portuguese coastline; 2) produce CMIP6-based ensembles of dynamic wave climate and storm surge simulations and projections, at high-resolution, for Portugal; 3) assess how the return periods and overall intensity of extreme events is projected to change, for each component of the total water level: sea level rise, tides, storm surges and wave parameters; 4) implement an innovative streamlined methodology to better account for the necessary coupling between shoreline evolution, the three-dimensional changes in the terrain (through the modification of the digital terrain models), its impact on the nearshore bathymetry and wave characteristics, and finally, on future coastal flooding events; 5) produce new, CMIP6-based, feedback-considering, shoreline evolution projections for Portugal, and translate these projections into future projected modified DTMs; 6) project future coastal flooding along the Portuguese coastlines, distinguishing between permanent inundation (loss of territory) and extreme flooding (for long return periods of total water levels); 7) conduct a high-resolution vulnerability and risk assessment along the entire Portuguese coastline, proposing adaptation measures for better future coastal management, focusing on protecting the populations; 8) assess the projected inaction and adaptation costs for Portugal until 2100, highlighting the cost-benefit of these strategies.

Upon completion, long high-resolution datasets of tides and CMIP6-driven SLR, waves and storm surges will be made available, for further research, integrated in the COWCLIP global community, and amplifying the international role of the IAMCOAST project, its team and partners in climate change assessments.

Research plan and Methods

IAMCOAST consists of nine tasks, formally organized into five Work Packages (WP): 1) Forcing Data and Performance Evaluation; 2) Shoreline Evolution and Coastal Flooding; 3) Coastal Vulnerability, Exposure and Risk; 4) Economic Costs and Cost-Benefit analysis; 5) Stakeholder Engagement. WP1 encompasses TASK1 and TASK2, WP2 comprehends TASK3, TASK4 and TASK5, WP3 contains a subset of TASK7, as well as WP4, and WP5 encompasses TASK6, TASK8 and TASK9.

In TASK1 (WP1), CMIP6 GCM outputs will be used to obtain SLR, as well as to force the wave (WW3 [47]), storm surge (Delft3D-FLOW [48]), and then, the wave propagation, shoreline evolution and hydro-morpho-dynamic models (SWAN [49], ShorelineS [50] and XBeach [51]). Three time-slices and two scenarios will be considered: historical (1985-2014), mid- (2041-2070) and late-21st century (2071-2100), and the SSP1-2.6 and SSP5-8.5 [52] scenarios. All data will be archived for the entire 21st century. Tides will be numerically modelled based on harmonic analysis, considering long time-series of tidal observations [53]. The ERA5 reanalysis [54] will be used as benchmark, together with buoy observations and remote sensing altimetry measurements.

In TASK2 (WP1), both WW3 and Delft3D-FLOW models are used to generate wave and storm surge climate simulations and projections. WW3 will be setup with the ST4 parameterization, best suited for extratropical areas, and run on an adaptative grid with 6 km resolution. The Delft3D-FLOW setup will follow the WW3 as closely as possible (same forcing and grid). Deep learning bias correction methods [26,55] will then be employed, focusing on extreme wave and storm *surge events. 10 key-locations will be selected along the Portuguese coastline, considering historically critical areas considering SLR and erosion processes, and the ones disposing of previous studies and field data. Historical waves will be propagated nearshore, at each key-location, using the SWAN model and a high-resolution bathymetry from the COSMO project.*

In TASK3 and TASK4 (WP2), a streamline platform will be built, merging together two dynamical (SWAN and ShorelineS) and one empirical model (PaCR), to project future evolution of the shoreline, iteratively, accounting for small- and short-scale feedbacks (6 hours). High-frequency changes in three-dimensional topography and bathymetry are also quantified. The new bathymetry is used to modify waves from offshore to nearshore, using SWAN, at each iteration. These are then used as forcing for the next shoreline evolution iteration, and the cycle restarts.

In TASK5 (WP2), XBeach is setup and run considering total water level extreme events and permanent inundation instances. XBeach is forced by total water levels (or simply sea level rise for the permanent inundation) and the respective modified digital terrain models.

In TASK7 (WP3 and WP4), simplifications of the time- and computational-costly hydro- and morpho-dynamic modelling will be made for the national scale assessment, through adapted large-scale semi-empirical PaCR-based approach. Probabilistic cartography of flooding, exposure, vulnerability, and risk, considering different hazard levels, will be built at high-resolution (50 m) for the entire coastline, using a GIS platform. Finally, economic costs related to inaction and adaptation measures will be quantified.

The project will dispose of three moments for contact with stakeholders, integrated into TASK6, TASK8 and TASK9, all comprehended in WP5.

<u>Summary of TASKS:</u>

TASK1: Retrieve and process all CMIP6 forcings to the wave and storm surge models, upon evaluation by comparison with reference datasets (reanalysis, buoy observations and satellite altimetry measurements). Produce tidal projections using harmonic analysis.

TASK2: Running the WW3 wave and Delft3D-FLOW storm surge models to generate the required forcing data for the streamlined platform of hydro- and morpho-dynamic modelling. Application of bias correction methods and first wave propagation to shallow waters.

TASK3: Development and application of a streamlined modelling system to iteratively account for the contribution of high-frequency changes in the water levels on the evolution of the shoreline (besides wave contribution) as well as small-scale feedbacks.

TASK4: Creation of modified digital terrain models, at each iteration of the streamlined methodology, using the Parametric Coastal Retreat (PaCR) algorithm [56,57], based on the shoreline evolution projections obtained in TASK3.

TASK5: Running the XBeach hydrodynamic model over the modified digital terrain models considering extreme total water levels. Determination of permanently inundated areas at a yearly time-scale.

TASK6: Promotion and realization of a workshop aiming to put the results of the project into perspective and gather opinions from stakeholders and decision-makers.

TASK7: Definition of empirical transfer functions based on the PaCR to reproduce the results throughout the remaining Portuguese sandy coastlines. Mapping of the probabilistic exposure, vulnerability and risk composed indices. Economic cost analysis.

TASK8: Promotion and realization of a workshop aiming to reveal que proposed adaptation measures, inaction and adaptation costs, and gain final inputs regarding the results of the project.

TASK9: Incorporation of stakeholders and decision-makers perspectives from the previous workshop. Finalization of all reports, sharing of data and results through the dissemination means (media), promotion and realization of a final public event.

Resources

The resources are required for TASK2, TASK4 and TASK5.

The resources needed for TASK2 are as follows:

- *Approximately 150.000.000 SBU*
- *Total of 116 years of simulation for 8 ensemble members at high resolution (200 TB uncompressed).*
- *TASK2 will be performed in 1.5 years, accounting for approximately 100.000.000 SBU in the first year and 50.000.000 SBU in the second year.*

The resources needed for TASK4 are as follows:

- *Approximately 30.000.000 SBU*
- *Total of 86 years of simulation for 8 ensemble members at high resolution (20 TB uncompressed).*
- *TASK4 will be performed in 1 year, accounting for approximately 20.000.000 SBU in the first year and 10.000.000 SBU in the second year.*

The resources needed for TASK5 are as follows:

- *Approximately 70.000.000 SBU*
- *Total of 86 years of simulation for 8 ensemble members at high resolution (80 TB uncompressed).*
- *TASK4 will be performed in 1.25 years, accounting for approximately 30.000.000 SBU in the first year and 40.000.000 SBU in the second year.*

The storage will be managed to keep the relevant output of these simulations while temporary testing and extra output will be removed after the analysis.

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