EMI R&D PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2026……………………………………………………
Project Title:	IAMCOAST – IntegrAtive Multivariate Tool for Future Shoreline Evolution and COASTal Flooding Vulnerability Assessments in Portugal ……………………………………………………
Computer Project Account:	spptlemo / prt8438 ………………………………………
Principal Investigator(s):	Gil Ramos Lopes Gonçalves Lemos …………………… ……………………………………………………
Affiliation:	Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Pedro Matos Soares, Rita Margarida Cardoso, Daniela Lima, Virgílio Bento ……………………………………………………
Start date of the project:	01-01-2025 ………………………………………………
Expected end date:	31-12-2027 ………………………………………………

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	100.000.000	87.729.882	90.000.000	89.496.705
Data storage capacity	(Gbytes)	120.000	20.000	240.000	25.000

Summary of project objectives (10 lines max)

This project aims to provide a complete, comprehensive assessment of the combined impacts of changes in sea levels, tides, storm surge and wave climates, producing projections for the ~1000 km of the Portuguese mainland coastline, using high-resolution, CMIP6-based modelling. It is designed to capture small-scale processes and feedbacks often overlooked in similar studies. Its goal is to produce detailed coastal geomorphological data and probabilistic risk maps to inform targeted adaptation strategies. The project assesses future changes in extreme events (waves and total water levels), shoreline evolution, and coastal flooding risks, distinguishing between permanent inundation and episodic flooding. Outputs include shoreline projections, modified digital terrain models, vulnerability and risk analyses, and cost-benefit evaluations of adaptation measures. Results will support national planning and contribute to global climate modelling initiatives like COWCLIP.

Summary of problems encountered (10 lines max)

At the current stage of the project, TASK1 and TASK2 have been completed, and TASK3/TASK4 are underway. Several adjustments to the initially proposed methodology had to be conducted, namely regarding SWAN implementation (parameterization testing and running, which revealed to take longer than expected), and the choice of using the PCR method from Ranasinghe et al. (2012) (instead of the ShorelineS) to project the evolution of the shoreline based on the ~100 m resolution local dynamic downscaling. Data transfer and processing for the downscaled waves (totalizing 8166 years of simulation) provided a new source of delay, compensated by the testing of the XBeach (expected in TASK5) as soon as during the implementation of the PCR approach (TASK3).

Summary of plans for the continuation of the project (10 lines max)

The project is expected to continue following the proposed timeline and overall goals, with slight but necessary changes to the methodology. A ~1 km national-scale, and 9 ~100 m regional sub-domains (Ofir, Esmoriz-Furadouro, São Jacinto-Vagueira, Buarcos-Gova Gala, Nazaré-Peniche, Cascais-Fonte da Telha, Sines, Lagos-Portimão and Quarteira-Praia de Faro), integrate the 4-member CMIP6 ensemble of downscaled wave climate simulations (1985-2014) and projections (2015-2100), under the SSP1-2.6 and SSP5-8.5. The PCR has been successfully applied to simulate the evolution of the shoreline towards 2100. XBeach is configured to project coastal flooding once the reconstruction of the DTMs is finalized (TASK4). All sea level rise, tidal and storm surge data is collected, and ready to use in the coastal flooding projections. The first set of results have been presented at the "*Conselho Nacional do Ambiente e do Desenvolvimento Sustentável – Gestão Sustentável da Zona Costeira*" conference.

List of publications/reports from the project with complete references

Kumar, R., Lemos, G., Semedo, A., Li, J.-G. (2025). A global high-resolution CMIP6 ensemble of wave climate simulations and projections using a coastal multigrid: Configuration and performance evaluation. Ocean Modelling, 197, 102566. DOI: https://doi.org/10.1016/j.ocemod.2025.102566.

Kumar, R., Amarouche, K., Akpinar, A., Kamranzad, B., Lemos, G. (2025). Evaluating uncertainty in global wave storm characteristics using CMIP6-derived wave climate simulations with SWAN and WAVEWATCH III models. Global and Planetary Change, 257, 105214. https://doi.org/10.1016/j.gloplacha.2025.105214

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

During the first eighteen months of IAMCOAST, *i.e.*, from the project start in January 2025 to June 2026, the project moved from the conceptual and preparatory phase into a consolidated operational modelling framework for assessing climate-change impacts along the Portuguese mainland coastline. The work performed so far has established the data, modelling, downscaling, post-processing and coastal-impact components required to produce a coherent assessment of future shoreline evolution and coastal flooding risk under changing sea levels, tides, storm-surges and wave climate conditions. Although some methodological adjustments were required relative to the original proposal, the overall scientific objectives remain unchanged: to produce a high-resolution, physically consistent and decision-relevant assessment of future coastal hazard, vulnerability and risk for Portugal.

The first major result was the completion of the data retrieval, harmonization and pre-processing phase. The project assembled the necessary historical and future forcing datasets for the coastal impact modelling chain, namely global CMIP6-based wave climate simulations and projections, to provide boundary conditions for the downscaling, sea level rise projections along the Portuguese coastline, tidal projections (harmonic analysis), storm-surge data, bathymetric/topographic information, and observational datasets required for the performance evaluation of the results. The historical baseline remained centered on 1985-2014, according to the IPCC CMIP6 standard, while future projections cover the full 21st century (2015-2100), under the SSP1-2.6 and SSP5-8.5 scenarios. These data were organized into a consistent processing structure suitable for long-term simulations, 2-level nested downscaling with an ensemble approach, extreme-value assessments and subsequent forcing of shoreline evolution and coastal flooding frameworks/models. Particular attention was given to the treatment of variable naming, calendar conventions, time aggregation, spatial grids, file structure and output management, given the very large volume of simulations involved.

The wave climate downscaling component has been one of the most substantial achievements of the project to date. The SWAN wave model was implemented at a national-scale, along about 1000 km of Portuguese coastline, at approximately 1 km resolution, providing the intermediate coastal wave field required to bridge the gap between offshore/global wave climate information (from a CMIP6 ensemble of global wave climate simulations and projections leveraging a Spherical Multi-Cell (SMC) grid, up to 6 km near the shore), and very localized processes. In addition, nine high-resolution regional sub-domains were configured at approximately 100 m resolution, covering Ofir, Esmoriz-Furadouro, São Jacinto-Vagueira, Buarcos-Cova Gala, Nazaré-Peniche, Cascais-Fonte da Telha, Sines, Lagos-Portimão and Quarteira-Praia de Faro. These domains cover a representative set of highly exposed, geomorphologically diverse and/or socio-economically relevant coastal stretches of the Portuguese coastline, including sandy coasts, embayed systems, urbanized shorelines, barrier-island environments and historically vulnerable erosion/flooding hotspots.

The implementation of the SWAN modelling chain required more extensive testing than initially anticipated. Several parameterization, boundary condition and numerical-stability tests were performed before the production simulations were completed. These tests were necessary to ensure that the nearshore transformation of the offshore wave climate was robust across the different Portuguese coastal settings, including open Atlantic sectors, complex bathymetric transitions, embayed coastlines and areas affected by strong gradients in exposure and wave direction. The resulting configuration now provides a consistent basis for translating CMIP6-driven offshore wave

conditions into high-resolution coastal wave fields, which are essential for the subsequent assessment of shoreline retreat, total water level (TWL) extremes and coastal flooding.
All simulations were run in non-stationary mode, using spherical coordinates and nautical directional convention. The spectral grid used 36 directional bins and 23 logarithmically spaced frequency bins, ranging from 0.0373 to 1.1 Hz. The simulations included spectral propagation, quadruplet nonlinear wave-wave interactions, JONSWAP bottom friction, depth-induced breaking and Komen-type whitecapping/source-term formulations. In the implemented SWAN configuration, bottom friction was represented through the JONSWAP formulation with a coefficient of 0.038, and depth-induced breaking followed the constant breaker formulation.

Boundary spectra were generated using a JONSWAP formulation with a standard peak-enhancement factor $\gamma = 3.3$. While an alternative value of $\gamma = 2.0$ was tested, motivated by recent evidence that lower γ values may better represent many European coastal sea states (Mazzaretto et al., 2022; Alday et al., 2025), sensitivity tests showed that the lower γ configuration did not improve the overall representation of the wave climate in comparison with buoy observations. Hence, the standard $\gamma = 3.3$ was retained. Wind forcing was not included in the production configuration, since sensitivity tests showed a degradation of model skill against buoy observations, probably associated with biases in nearshore winds fields from coarse datasets.

The hyper-resolution (~100 m) nested simulations used boundary conditions extracted from the ~1 km fields. For the ERA5 downscaled hindcast (not the ensemble wave climate simulations and projections), bias correction was employed using the Empirical Gumbel Quantile Mapping method from Lemos et al. (2020a). Hyper-resolution nested simulations include historical mean sea-level variability, reconstructed from long-term tide-gauge measurements at Leixões, Cascais, Sines and Lagos, harmonised across datum changes and gap-filled using an XGBoost regression approach (Chen and Guestrin, 2016).

For the whole ensemble, plus the historical long-term ERA5 hindcast, the SWAN simulations include the period since 1940 (1985 for the CMIP6 simulations) and future projections up to 2100, for a 4-member ensemble. In total, the local dynamic downscaling represented 8,166 years of wave simulations, considering 5 main variables (significant wave height, mean wave period, peak wave period, mean wave direction, and wave energy flux), with approximately 489.960 spatial monthly files at 1- or 3-hour resolution, requiring substantial computational resources and extensive post-processing. Considerable effort was also dedicated to the development and verification of scripts for merging, selecting, aggregating and quality-controlling large volumes of results, allowing the computation of multiple statistics including monthly and annual statistics, maxima, percentiles, climatological averages and scenario/time-slice comparisons.

The performance-evaluation was conducted by comparison with reference datasets, including the original ERA5-based wave information, in-situ buoy observations and satellite altimetry measurements, where available. This allowed the assessment of the consistency of the SWAN implementation and identify systematic biases still present. These procedures are important because the subsequent shoreline and flooding assessments depend not only on mean wave conditions, but also on the representation of high-impact events, directional exposure and long-period swell components that can dominate coastal response in specific Portuguese coastal sectors.

In parallel with the wave downscaling, the remaining TWL components were consolidated. Sea level rise projections, astronomical tide information and storm-surge data were collected and prepared for integration with the nearshore wave climate outputs. This creates the basis for distinguishing between different mechanisms of coastal impact: permanent inundation driven primarily by mean sea level rise, episodic flooding associated with extreme TWLs, and erosion/retreat driven by the combined influence of sea level rise, wave climate, local morphology and sedimentary imbalance. The harmonization of these components is a central outcome of the first half of the project.

A second major result concerns the shoreline-evolution methodology. The original proposal envisaged a streamlined framework combining SWAN, ShorelineS and PaCR-type approaches to represent feedbacks between waves, shoreline change, topography and bathymetry. During implementation, however, it became clear that the direct use of ShorelineS in the proposed configuration would be computationally and methodologically less adequate for the full project workflow than initially expected, particularly when considering the number of simulations, scenarios, coastal sectors and terrain reconstructions required. The methodology was therefore adjusted towards the use of a PCR approach based on Ranasinghe et al. (2012), combined with the existing PaCR logic (Rosati et al., 2013) for translating projected shoreline retreat into terrain modification. This adjustment improves the robustness, transparency and scalability of the shoreline-evolution component, while preserving the central objective of estimating future retreat and its implications for coastal flooding and exposure.

The PCR-based shoreline-evolution framework has now been successfully implemented and applied to simulate shoreline evolution towards 2100. The method allows the projected response of sandy coastal stretches to be assessed under different climate scenarios and time horizons, using the high-resolution wave downscaling and sea level rise information as drivers. The resulting shoreline projections provide the basis for identifying sectors where retreat may substantially modify the coastal morphology, reduce beach/dune buffering capacity, increase exposure of built-up areas or change the boundary conditions for future flooding. The shoreline evolution results constitute an important intermediate product, because they convert offshore climate change signals into local geomorphological consequences.

TASK4, concerning the generation of modified digital terrain models, is now underway and directly builds on these shoreline evolution outputs. The project has advanced the workflow required to translate projected shoreline retreat into modified DTMs, allowing future terrain configurations to reflect the expected landward displacement of the shoreline and associated changes in coastal morphology. This step is essential because future flooding should not be estimated over present-day topography alone when the coastline itself is expected to evolve. The reconstruction of the DTMs is therefore being treated as a dynamic link between the shoreline evolution module and the coastal flood modelling module. Once finalized, these modified DTMs will become forcing for the XBeach model to project how coastal flooding may differ when future erosion, retreat and terrain lowering are explicitly considered.

The coastal flooding component has indeed been initiated earlier than originally scheduled. XBeach has been configured and tested for application to the selected high-resolution domains, using the available terrain, bathymetry, wave and TWL information. This early testing, within the PCR approach, was useful for identifying input requirements, checking model-domain consistency, defining boundary-condition formats and preparing the transition from shoreline-evolution outputs to hydrodynamic flooding simulations. Although the production coastal-flooding simulations depend on the finalization of the shoreline evolution projections and modified DTMs, the preparatory configuration of XBeach reduces the risk of later delays and ensures that TASK5 can proceed efficiently once the terrain reconstruction stage is completed. The modelling strategy remains focused on distinguishing between permanent inundation associated with sea level rise, and episodic flooding associated with extreme total water levels, including the contribution of waves.

The computational outcomes of the project are also relevant. A substantial part of the allocated ECMWF computing resources has been used to perform the SWAN implementation, testing and production simulations. The project used 87,729,882 units in the previous year and 89,496,705 units in the current year, reflecting the computational intensity of the high-resolution coastal downscaling and the near-complete use of the available allocation. The storage strategy was also adapted to retain essential outputs and generate a secondary backup while controlling the volume of intermediate files generated by the simulations. This is the reason why the actual stored data has not increased significantly in volume from the first to the second year of the project, despite the large number of new simulations. This, nevertheless, required careful post-processing, compression, selection of key variables and management of intermediate products, particularly because the local downscaling produced multi-scenario, multi-model, multi-domain datasets spanning historical and future periods.

The work completed so far has already contributed to scientific dissemination and international integration. Two publications/reports associated with the broader modelling framework and CMIP6 wave-climate ensemble have been produced during the project period. Other 3 (three) papers are currently being written, on the global wave climate forcing ensemble, the new hyperlocal resolution hindcast for the Portuguese coastal areas, and on the future wave climate projections for the Portuguese coastline. In addition, the first set of IAMCOAST results has been presented to stakeholders and decision-makers at the "*Conselho Nacional do Ambiente e do Desenvolvimento Sustentável – Gestão Sustentável da Zona Costeira*" conference, and in multiple meetings with stakeholders, contributing to the dissemination and policy relevance of the project. Furthermore, a MSc student is currently utilizing the hindcast simulations and projections for the Portuguese coastal areas, which will configure one of the main outputs of the thesis.

Overall, between January 2025 and June 2026, TASK1 and TASK2 have been completed, delivering the forcing data, SWAN configurations, downscaled wave-climate simulations and processing framework required for the coastal-impact assessment. TASK3 has progressed substantially through the implementation and application of the PCR-based shoreline-evolution methodology. TASK4 is underway, with the conversion of shoreline projections into modified DTMs now forming the key bridge towards flooding simulations. TASK5 has been anticipated through the early configuration and testing of XBeach. The next stages will therefore focus on completing the modified terrain datasets, running the coastal flooding projections, developing exposure/vulnerability/risk layers, and integrating these outputs into probabilistic coastal-risk cartography and adaptation-relevant assessments for mainland Portugal.

References:

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