BlueMath-Hub: A Cloud-Based, Open-Source, Python Framework with Interactive Notebooks for Statistical Analysis and Simulation of Coastal Climate Hazards in a Changing Climate

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Abstract. Addressing global challenges such as coastal hazards and climate change requires innovative tools capable of analyzing complex environmental drivers, including waves, storm surges, and cyclones, across varying scales. These tools are vital for predicting floods, assessing risks, and planning adaptive responses. BlueMath-Hub has been developed as a global collaborative initiative to provide accessible, customizable solutions for both researchers and practitioners. It aims to simplify the use of advanced statistical and numerical models, fostering creative and scalable approaches in coastal science and engineering.

BlueMath, the core of this platform, is an open-source repository of Python tools accessible via a cloud-based Jupyter Hub environment. It integrates statistical methods and numerical model wrappers within a modular framework. The system includes: (a) BlueMath-Toolkit, providing tools for data mining, interpolation, and model integration; (b) BlueMath-Statistical Downscaling, focusing on extreme events and generalized models; (c) BlueMath-Hybrid Downscaling, combining statistical and numerical approaches for optimized solutions; and (d) BlueMath-Climate Services, supporting integrated applications such as compound flooding assessments.

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BlueMath is continuously evolving, with its tools already applied in research, publications, and training. By lowering barriers to entry and enabling collaborative workflows, BlueMath-Hub supports the development of innovative solutions to mitigate the impacts of a changing climate.

Keywords: Coastal-hazards · Toolbox · Statistical Models · Repository · Collaboration

1 Significance and Motivation

In the face of increasing global challenges such as coastal hazards and climate change, the use of robust statistical and numerical analysis tools is essential. Tools that facilitate the analysis of multivariate met-ocean climatic drivers (e.g., waves, storm surges, tropical and extratropical tropical cyclones) acting at multiple spatial and temporal scales are key for predicting flooding events, producing risk assessments, or planning for adaptation measures. The development of applications for analyzing coastal hazards in a changing climate demands not only accessibility to such tools but also the flexibility to combine them seamlessly to generate valuable insights and creative solutions.

BlueMath-Hub arises in this context as a collaborative platform of many research groups and universities around the world working together to democratize the access to advanced models and services, empowering both researchers and non-specialists to generate customized, complex solutions. To the best of our knowledge, it is the first tool developed for this purpose in the field of coastal science and engineering. With ongoing contributions and the constant development of BlueMath, BlueMath-Hub promotes collaboration and innovation among scientists while enabling a more resilient future through easily accessible, customizable, and scalable solutions.

2 BlueMath Framework

BlueMath (https://geoocean.unican.es/bluemath.html) is an innovative, open-source repository of Python-coded tools. The repository is also accessible from the muti-user cloud-based Jupyter Hub environment, leveraging shared computational resources and the user-friendly interface of Jupyter Notebooks. BlueMath integrates state-of-the art statistical techniques and high-fidelity numerical model wrappers in a system framework that includes from standalone models with straightforward applications to hybrid model-tool combinations that produce comprehensive climate services (Fig. 1).

The individual modules of BlueMath (Fig. 2) are designed to be highly adaptable to a wide range of needs and applications:

a) **BlueMath-Toolkit**: Provides fundamental tools including data mining (e.g., dimensionality reduction, clustering techniques), interpolation (e.g., radial basis functions), and wrappers for numerical models such as SWAN, SWASH, Delft3D, and SFINCS. It also allows to generate statistical analyses of waves, tides, and tropical cyclones.

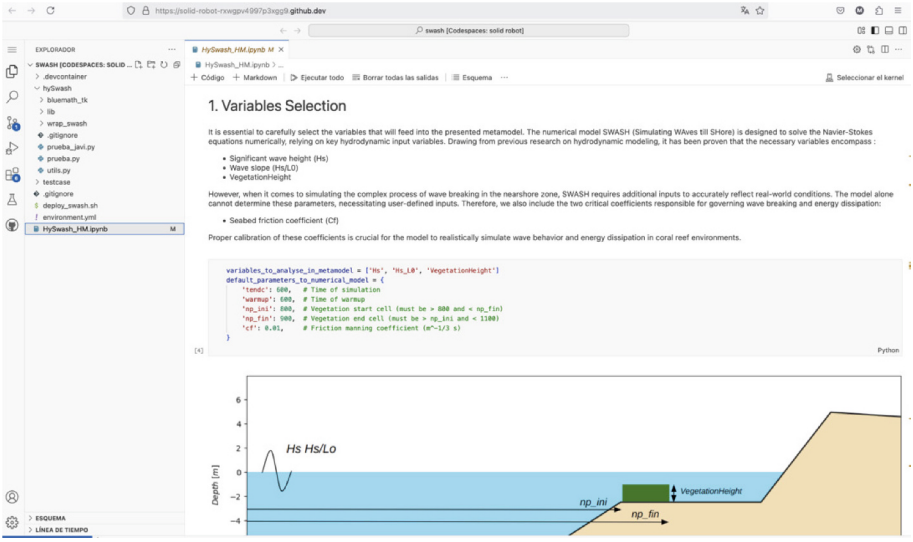

Fig. 1. Hybrid downscaling example implemented in BlueMath

b) **BlueMath-Statistical Downscaling**: Facilitates extreme value analysis, weather-typing, and generalized linear models. This allows to stablish simple downscaling methods as well as the ensemble of complex statistical models to build climate based emulators of metocean parameters in any location around the world (Anderson et al., 2019).
c) **BlueMath-Hybrid Downscaling**: Integrates statistical and numerical models to optimize computational efficiency. It includes the implementation of hybrid models like metamodels (e.g., HySwash (Ricondo et al., 2024)) and additive approaches (e.g., Binwaves (Cagigal et al., 2024), GreenSurge (Pérez-Diaz et al., 2025)).
d) **BlueMath-Climate Services**: Enables the creation of integrated climate applications by combining functionalities from previous modules. Examples include the TESLA climate emulator (Anderson et al., 2019), as well as detailed workflows of the integration of these tools on already implemented compound flooding and risk assessment projects.

The collaborative platform is undergoing continuous development and improvement. Notably, many of its tools have already been successfully applied in publications (e.g., Cagigal et al., 2024; Ricondo et al., 2024; Pérez-Diaz et al., 2025), the development of research projects, and the implementation of hands-on courses. The BlueMath framework aims to enhance collaboration among researchers by reducing the duplication of coding efforts and improving the replicability of published studies and methodologies. This is expected to significantly increase the potential influence of studies, facilitating easier and more transparent collaborations. Ongoing efforts will ensure that BlueMath remains a valuable and up-to-date resource for both researchers and practitioners, enriched by community testing, feedback, and contributions.

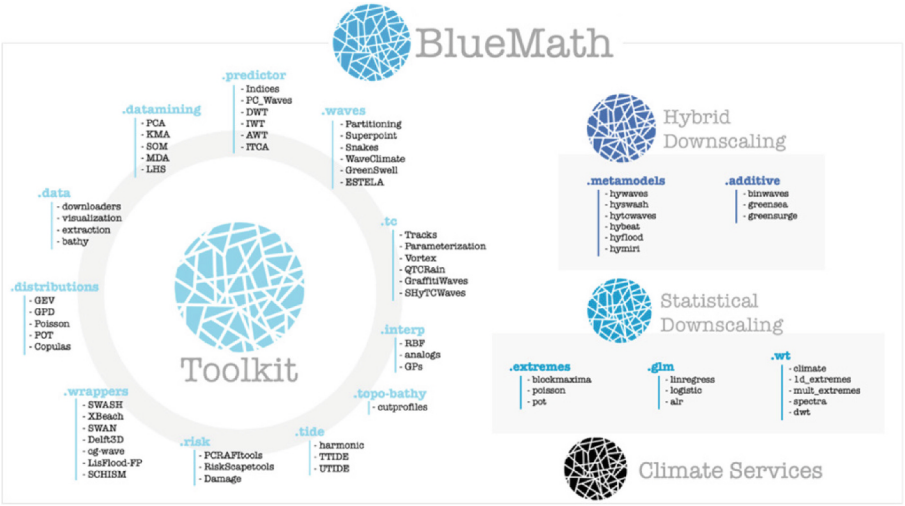

Fig. 2. BlueMath modules with functions to be implemented

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