HYBEAT: A HYBRID MODEL FOR SURF-ZONE HYDRODYNAMICS

Beatriz Pérez Díaz, Universidad de Cantabria, perezdb@unican.es
Laura Cagigal, Universidad de Cantabria, cagigall@unican.es
Manuel Zornoza, Universidad de Cantabria, zornozam@unican.es
Alba Ricondo, Universidad de Cantabria, ricondoa@unican.es
Sonia Castanedo, Universidad de Cantabria, castanedos@unican.es
Fernando Méndez, Universidad de Cantabria, mendezf@unican.es

INTRODUCTION

Climate change-induced sea level rise and increasing storm severity are important stressors that threaten the livability of coastal areas worldwide. In this context, it is crucial to be able to effectively predict coastal flooding and to provide the necessary tools to assist adaptation strategies to coastal communities and policymakers. These predictive tools should be able to forecast the local waves and water levels as well as their nearshore transformation to the shoreline. Commonly, phase-resolving numerical wave models have been employed for simulating complex nearshore hydrodynamics. Although they accurately reproduce the main physical processes, these models are computationally very expensive, posing a limitation on the ability to forecast future conditions. Alternatively, hybrid models have emerged to complement process-based wave numerical models by incorporating statistical methods that minimize the computational effort (Camus et al., 2011, Ricondo et al., 2023).

In this study, we introduce HyBeat, a hybrid model for efficiently reconstructing 2D hydrodynamic variables at a very High-Resolution scale (HR, 5 to 20 m) while accounting for non-linear nearshore wave transformation processes. Hence, HyBeat is a powerful method for forecasting wave conditions and reconstructing lengthy hindcast time series in a matter of minutes. In addition, the model permits to improve the understanding of extreme events, which are of paramount importance in complex bathymetry configurations, such as fringing coral reefs.

HYBEAT

The hybrid model is built on the combination of statistical techniques (i.e., sampling, clustering, and interpolation techniques), with the high-fidelity 2D hydrodynamic model Xbeach (Roelvink et al., 2015). The statistical techniques aim at overcoming the computational burden of dynamical downscaling by minimizing the number of needed numerical simulations. Figure 1 shows the methodological framework of HyBeat model.

The methodological steps outlined in Figure 1 are briefly detailed bellow:

1) Definition of the parameter space to generate the Hydraulic Boundary Conditions (HBC) of Xbeach model (significant wave height Hs, peak period Tp, wave direction θ, and still water level η) and the intervals of values for each variable.
2) Design of *N* synthetic cases based on previously selected parameters and their corresponding ranges of values using Latin Hypercube Sampling (LHS).
3) Selection of *M* cases from previous *N* cases using the Maximum Dissimilarity Algorithm (MDA) selection technique.
4) Numerically run the *M* cases with Xbeach model. This numerical model is applied in surfbeat mode, where the sort-wave variations on the wave group scale (short wave envelope) and the long waves associated with them are resolved.
5) Dimensionality reduction of the hourly mean output (y) spatial fields of selected hydrodynamic variables (e.g. Hs, Tp, θ, wave setup $\bar{\eta}_{wsetup}$, etc.) using Principal Component Analysis (PCA). The output Xbeach quantities $y(x;\ H_s, T_p, \theta, \eta)$ are decomposed into their Empirical Orthogonal Functions (EOF) and Principal Components (PCs) as:
$$y(x;\ H_s, T_p, \theta, \eta) \approx \bar{y}(x) + EOF_1(x)PC_1(H_s, T_p, \theta, \eta) + \ldots + EOF_C(x)PC_C(H_s, T_p, \theta, \eta) \quad (1)$$
6) Spatial and temporal reconstruction of selected output variables using a non-linear interpolation technique based on Radial Basis Functions (RBFs, Camus et al., 2011). The RBF allows to obtain the PCs of unmodeled cases that can be spatially reconstructed using Equation 1.

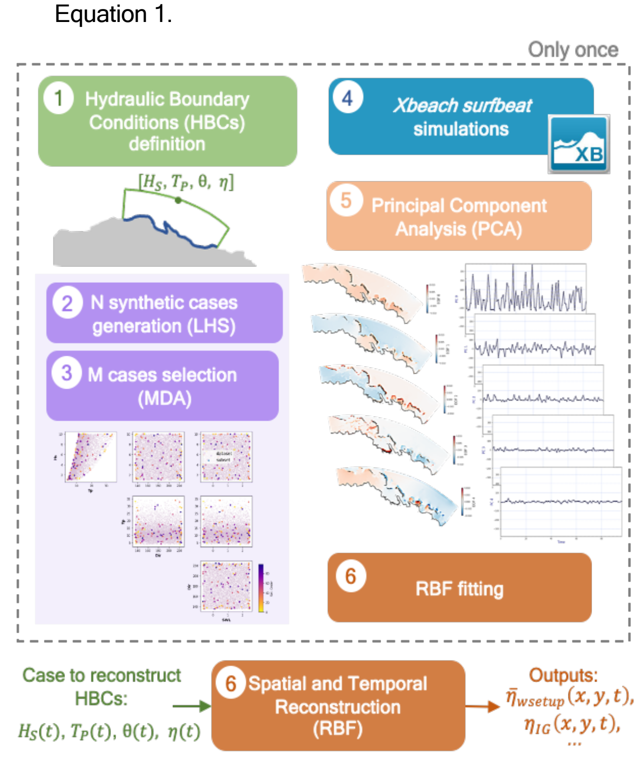

Figure 1 - Methodological framework of HyBeat model

APPLICATION AND VALIDATION

HyBeat model has been applied along the entire coral reef coastlines of Samoa and Tonga islands to obtain $\bar{\eta}_{wsetup}$ and the infragravity wave component η_{IG}, inferred from free surface standard deviation σ_η $(\eta_{IG} = 4\sqrt{m_{OIG}} = 4\sigma_\eta)$. Figure 2 shows, as an example, the computational domain to solve the capital of Samoa, Apia.

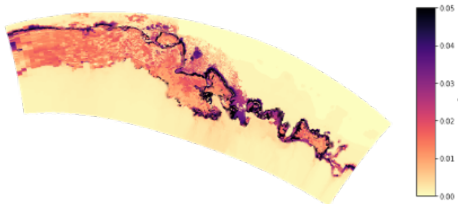

Figure 2 - HyBeat computational domain to solve the surf-zone hydrodynamics of Apia (Upolu, Samoa) together with the dimensionless flow friction coefficient *cf.*

The model has been numerically validated by comparing the results of a dynamic Xbeach simulation for certain events with the corresponding HyBeat results (PCA-RBF reconstruction using the first PCs explaining the 98% of variance). Figure 3 shows this comparison for two events. This numerical validation confirms the ability of the developed model to spatially reconstruct $\bar{\eta}_{wsetup}$ and η_{IG} in complex coral reef areas.

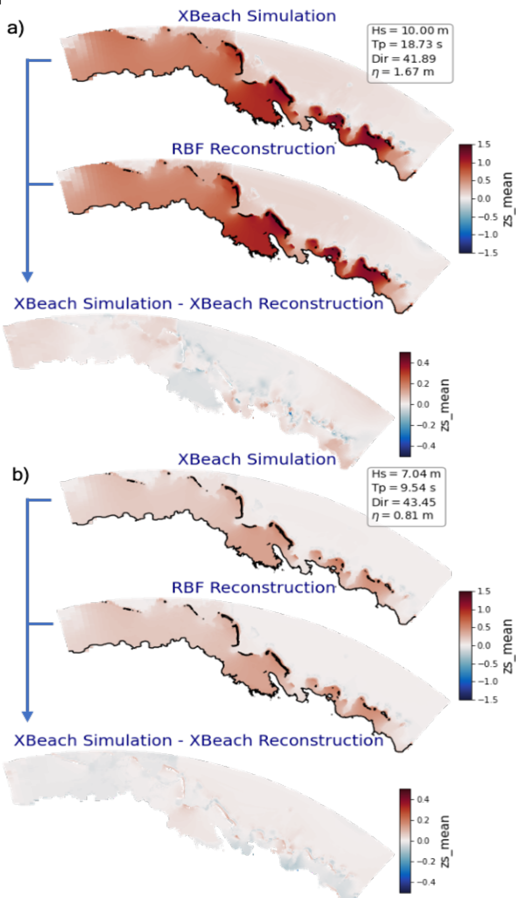

Figure 3 - HyBeat validation examples of $\bar{\eta}_{wsetup}$: Xbeach dynamic numerical results vs PCA-RBF reconstruction

REFERENCES

Camus, P., Méndez, F.J., Medina, R., 2011. A hybrid efficient method to downscale wave climate to coastal areas. Coastal Engineering 58 (9), 851-862.

Ricondo, A., Cagigal, L., Rueda, A., Hoeke, R., Storlazzi, C. D., & Méndez, F. J. (2023). HyWaves: Hybrid downscaling of multimodal wave spectra to nearshore areas. Ocean Modelling, 102210.

Roelvink, D., van Dongeren, A., McCall, R., Hoonhout, B., van Rooijen, A., van Geer, P., et al. (2015). XBeach Technical Reference: Kingsday Release. Model. Desc. Func. 77, 125-184