A MULTIVARIATE STATISTICAL MODEL TO SIMULATE STORM EVOLUTION

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INTRODUCTION

The design and management of a coastal structure must take into account not only the different levels of damage along its useful life but also the construction, reparation and dismantling costs. Therefore, it should be addressed as an optimization problem that depends on random multivariate climate variables. In this context it is essential to develop tools that allow the simulation of storms taking into account all the main maritime variables and their evolution (Borgman, 1969). In general, most studies focusing on storm characterization and evolution use geometric shapes like the equivalent triangular storm (Bocotti, 2000; ROM-1.0; 2009) to characterize individual storms. Actual storms have, however, irregular and random histories.

In this work, we present a simple and efficient methodology to simulate time-series of storm events including several maritime variables. This methodology includes the use of non-stationary parametric distributions (Solari, 2011) to characterize each variable, a vector autoregressive (VAR) model to describe the temporal dependence between variables, and a copula model to link the seasonal dependency of the storm duration and the interarrival time between consecutive storms.

METHODOLOGY

The methodology comprises the following steps:

a. *Storm definition*. For a given threshold value $H_{s,u}$, the storm events (duration, D) and the succeeding calm periods (interarrival times, I) are identified over the historical time-series of the significant wave height, H_s. The concomitant peak periods, T_p, and mean wave directions, θ_m are also obtained. Minimum values of D and I between consecutive events are set to ensure independency between events.
b. *Distribution functions*. H_s, T_p and θ_m are characterized using non-stationary marginal distribution functions. The dependence between the duration D *and* interarrival times I, is defined with a copula model by season.
c. *VAR model.* A vector autoregressive model was used to analyze the temporal dependence and interdependence of the variables and therefore characterize the storm evolution.
d. *Simulation.* A continuous time-series of maritime variables is obtained using the VAR model and the fitted distribution functions. A new threshold, $H_{s,u}'$, is set in order to define independent storms, maintaining the similarity between the CDFs of the storms' duration D.
e. *Storms' time-series simulation.* The simulated independent storms are then distributed throughout time by simulating the interarrival time from the distribution function of I conditioned to the corresponding duration, D (copula model).

RESULTS

A 50-year time-series of simulated storms in Granada, Spain was done using historical wave climate from the point SIMAR-2041080 (Puertos del Estado) with hourly data from 1958-2018. Using a threshold value $H_{s,u}$, corresponding to the 95th percentile, approximately 1500, storms were identified. H_s and T_p were fitted using Exponential and Lognormal distributions, respectively. The mean direction θ_m was fitted using a mixture distribution model of two truncated Normal distributions (Figure 1). A Clayton copula was used to study the seasonal dependence of D and I. (Figure 2). Figure 3 presents six simulations of the annual evolution of the significant wave height H_s.

As observed in Figures 4 and 5, the relation between the main maritime variables H_s, T_p and θ_m and the storms' duration D and magnitude M (defined as the area describing the storm) is kept between the data and the simulations. Therefore, the proposed model reproduces fairly well the joint stochastic character of the random variables of extreme events. Therefore, this is an efficient methodology that allows a multivariate description of maritime variables and their evolution in extreme events.

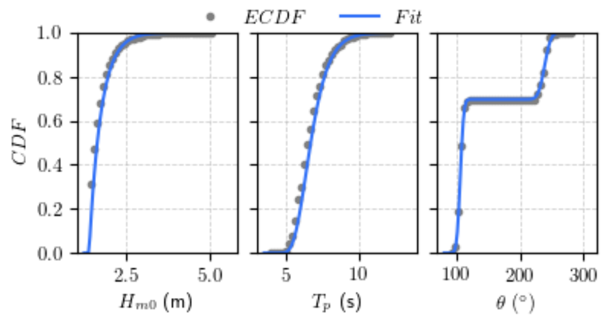

Figure 1 - Empirical Cumulative Distribution (ECDF) functions and fitted CDFs of H_s, T_p and θ_m

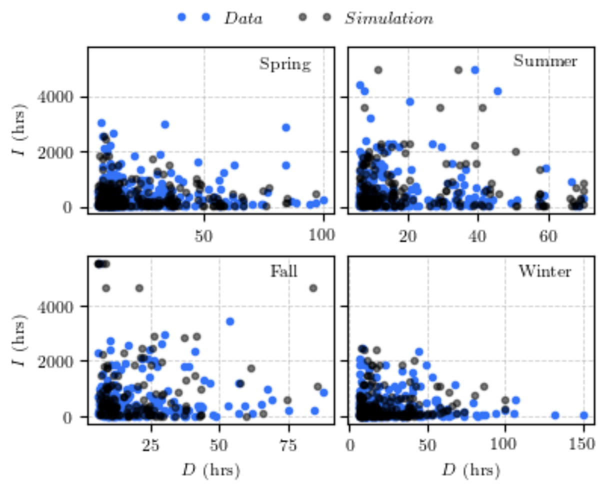

Figure 2 - D-I seasonal modeling with a Clayton copula

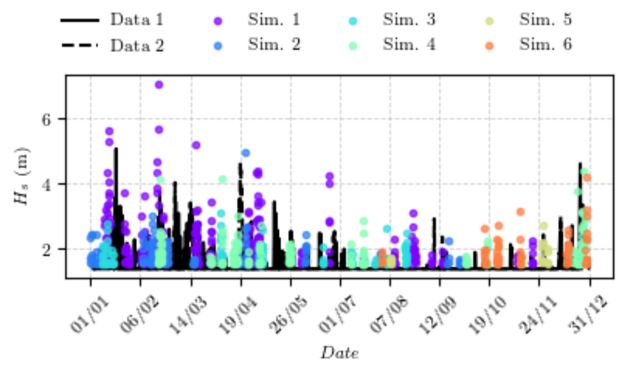

Figure 3 - Annual time-series of storms from data and simulations

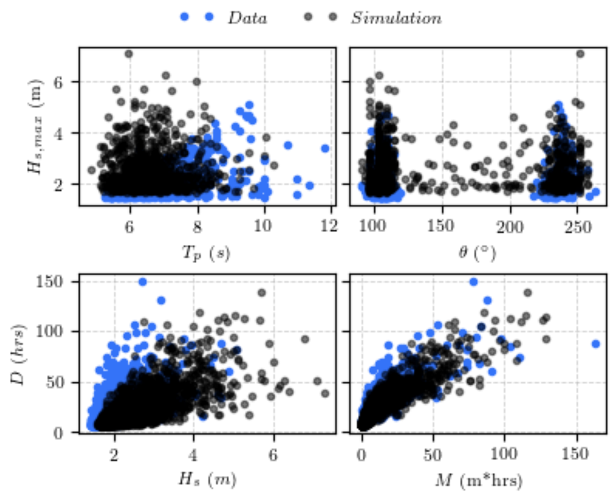

Figure 4 - Scatter plots of data and simulations

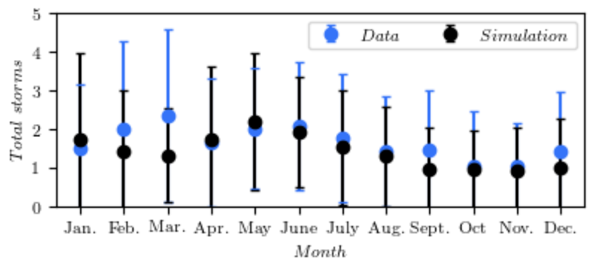

Figure 5 - Monthly average storm frequency

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