MULTIVARIATE ASSIMILATION METHOD FOR WAVE DYNAMICAL DOWNSCALING

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INTRODUCTION
Good quality, long-term wave series are a key aspect for the study of coastal problems and for the design of coastal and harbor works. Recent years have seen a significant improvement in the quality of global and local wave reanalyzes. They have increased their spatial and temporal resolution, as well as reduced errors, mainly in terms of total energy or Hm0 (e.g. Alonso & Solari 2020, Hersbach et al. 2020), although improvement in other parameters, such as direction and period, remains more challenging.

On the other hand, the emergence and popularization of low-cost, easy-to-handle wave buoys (e.g. Spotter by Sofar, Waverider DWR-G4by Datawell, or similar), as well as the popularization of ADCPs with wave measurement capabilities, makes it possible to collect wave data on site even for small-scale projects or for early stages of projects of any size. This on-site information can be used for point correction of data (e.g. Mínguez et al. 2011), or to calibrate wave propagation models used in downscaling global reanalyzes, which may include calibration of correction parameters for boundary conditions (see e.g. Alonso & Solari 2021); the latter case can be interpreted as a form of data assimilation (Wang et al. 2021).

This paper proposes a novel method for the assimilation of data measured on site when downscaling a wave reanalysis to the coast. The method is based on the use of multivariate bias correction (MBC) techniques to correct the boundary conditions of the numerical model. The proposed technique allows to: (a) incorporate the measured data to the entire computational domain (unlike the technique of Minguez et al, which allows for point corrections only), (b) to incorporate, in addition to wave height data, period and direction data, which usually present larger errors than the former (see e.g. Alonso & Solari 2020, 2021), and (c) to extend the correction (assimilation) to the whole period of the reanalysis, not only to the measured period, similar to what is achieved by parameter calibration (Wang et al. 2021).

METHODOLOGY
The iterative random projection method (IRPM), originally proposed by Pitie et al. (2005) for image processing, is applicable to *n*-dimensions to find the empirical optimal transport map that transforms one multivariate probability distribution into another (Zhang et al. 2023), which makes it a powerful method for MBC. The methodology proposed here uses the IRPM, in combination with Gaussian Process Regressions, to estimate the following functions:

$$f_{MBC\ (modeled \rightarrow measured)} \qquad [1]$$

which transforms the multivariate probability distribution of (H,T,D) modeled at the buoy/ADCP site into the multivariate probability distribution measured by the instrument at the site, and

$$f_{MBC\ (modeled\ at\ buoy \rightarrow moedeled\ at\ bc_i)} \qquad [2]$$

which transforms the multivariate probability distribution of (H,T,D) modeled at the buoy/ADCP site into the multivariate probability distribution of the reanalysis at each of the nodes used as a boundary condition for the downscaling.

Eq. 1 is used to perform a single-point MBC, and is responsible for assimilating the measured data. Eq. 2 transfers the assimilated information to the boundary conditions, from where it is propagated to the entire domain. Figure 1 presents an outline of the above.

The assimilation process consists of: (1) performing a first downscaling to estimate (or train) the above functions (Eqs. 1 and 2), (2) using Eq. 1 to correct the modeled time series at the measurement site, (3) using the corrected time series at the measurement site and Eq. 2 to correct the boundary conditions, (4) performing a new downscaling using the corrected boundary conditions.

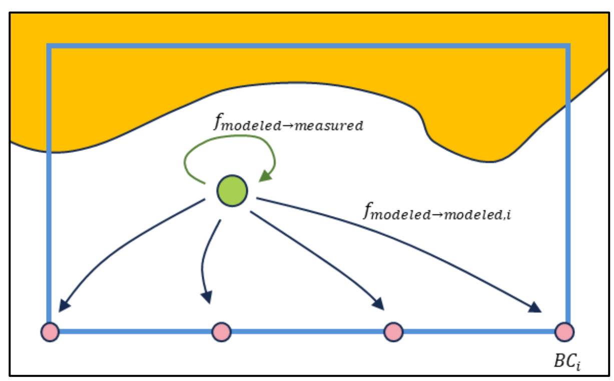

Figure 1 - Diagram of the MBC functions used in the assimilation process.

RESULTS
The proposed methodology is applied for the downscaling of the ERA5 wave reanalysis in a stretch of the Uruguayan coast. The downscaling is performed with the SWAN model, using two nested grids with step 500 m and 100 m respectively (see Figure 2 a). In this area, two wave series measured by two ADCPs at different depths are available (see Figure 2 b). ADCP01 data is used to apply the methodology described above, while ADCP02 data series is used to validate the results. The proposed methodology is applied only to the detail grid.

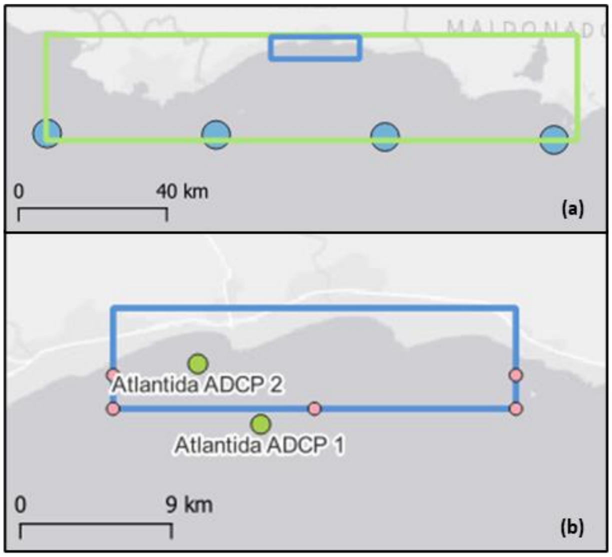

Figure 2 - Study site. (a) ERA5 boundary conditions (blue dots) and coarse grid domain (green line). (b) local grid boundary conditions (pink dots), ADCPs location (green dots) and fine grid domain (blue line).

Figure 3 compares the results obtained at the ADCP02 site, with and without data assimilation, with those measured at the site. The comparison focuses only on mean wave direction and period, as the significant wave height is well reproduced without the need for data assimilation and there is no room for significant improvements in this variable. It is observed that there is a significant improvement in the model's ability to represent the probability distribution of both analyzed variables. In particular, the correction obtained in the directions is such that it changes the direction of the net longshore transport at the coast from eastward to westward, which is consistent with the geomorphology of this stretch of coast.

The results obtained indicate that the proposed methodology allows for significant improvements when downscaling a global reanalysis. At the same time, the methodology is general, and can be applied to any site without modification, which makes it a valuable tool to take advantage of the information measured on site during relatively short periods.

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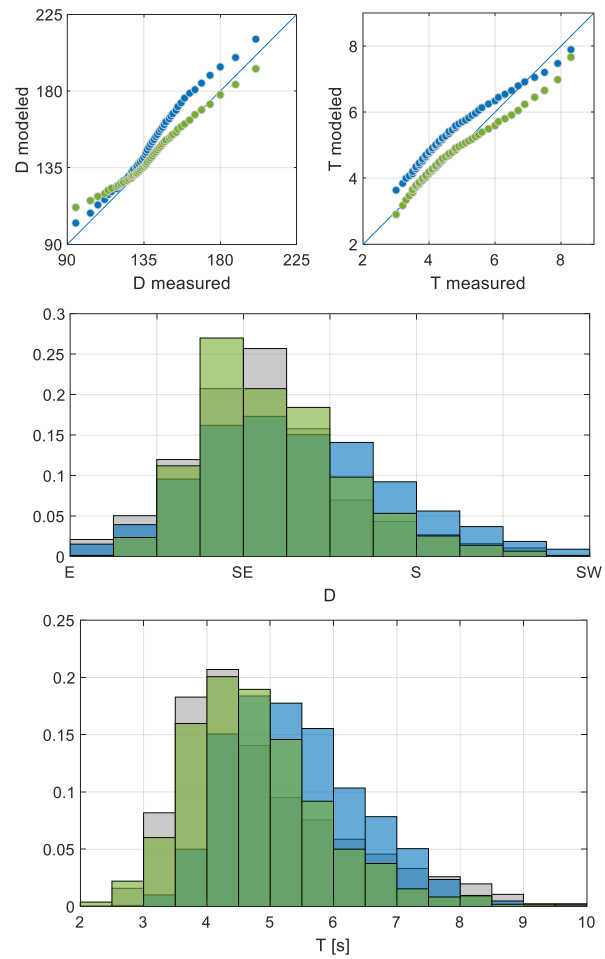

Figure 3 - Results obtained at the ADCP02 site. Top panels: qq-plots of mean wave direction (left) and period (right), for the downscaling obtained without (blue) and with (green) assimilation of the ADCP01 data. Mid and bottom panels: marginal PDF of the mean wave directions (mid panel) and periods (bottom panel): measured (gray), and downscaling without (blue) and with (green) assimilation of the ADCP01 data.