A predictive Data Driven Approach based on Reduced Order Models for the Morphodynamic Study of a Coastal Water Intake

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Abstract:

This work is motivated by the following question: How to deal with a dynamic physical problem when a numerical model is not an option (inexistent, unreliable or time consuming)? Specifically, when a fairly large data set is available, and the interest data are of different natures. In this context, we assess a dynamical data-driven model that links a two-dimensional state variable to scalar forcing variables.

The presented methodology is applied within the context of a power plant water intake monitoring. The intake channel is located in a coastal area, and must ensure enough water supply for the cooling process of the power plant, even though it is subject to massive sediment arrivals, which represents a clogging risk. One of the industrial challenges is therefore to predict the sediment dynamics observed in the channel, which can be deduced from the observed bed evolutions in the study area. The sediments outside of the channel can be stirred up under the waves constraint, and transported towards the channel by the tidal currents. This process can be amplified during low tide levels, resulting in a higher sediment volume entering the channel

Due to the monitoring needs, bathymetric measurements of the channel are performed on a regular basis, along with meteorological and hydrodynamic surveys (waves, wind, tidal levels, etc.) as well as management information (dredging data, pumping flowrates). The aim is therefore to establish a dynamical model that predicts the bed elevations state field, from the knowledge of the previous state and the several forcing parameters.

As the bed elevation is a two-dimensional field, it must be reduced to a representative vector of scalar variables by applying a Proper Orthogonal Decomposition (POD) [1]. The POD consists of decomposing a field that depends on both time and space variables into a finite sum of functions with separate variables. This allows first to isolate the spatial patterns, represented by the functions depending on space variables, called the POD basis. The POD basis terms, when added, explain the observed dynamic. The interest of this operation is that the deduced patterns can often be interpreted in terms of physical behavior. Another consequence of the POD is that the functions depending on time that are associated to each member of the POD basis, are simply scalar variables that vary in time. Their variability directly represents the variability of the original two-dimensional field, here the bathymetry. In a non-chaotic system, these functions, called "temporal modes", are often signals that can be explained by inputs, or even predicted by an adequate statistical model. This means that the temporal modes at future times can be predicted from previous times using the information on the forcing variables. A finite number **"K"** of modes can be selected as a reliable representation of reality.

A natural outgrowth of the analysis is therefore to propose a statistical model. In our study, we propose a Polynomial Chaos Expansion (PCE). The temporal modes are considered as random variables that can be linked to random forcing variables, considered as independent, via an orthogonal polynomial basis. The PCE is build using the Least Angle Regression Stagewise (LARS) method, which is a sparse PCE construction [2]. This allows to gain in fitting accuracy by increasing the polynomial degree with small amount of data.

The strength of the PCE is that the coefficients of the expansion are directly linked to the variance of the contribution of each variable and its interactions to the response. In other words, the Sobol sensitivity estimators deduced from the ANOVA decomposition can be calculated without further effort [3]. This allows to work both on the prediction model and on the quantification of correlation between the forcing parameters and the bathymetry response through its modes.

This analysis is done on each of the **"K"** chosen modes. The outcome of this step is therefore **"K"** dynamical prediction models linking each temporal mode to its future estimation.

The proposed prediction methodology is (see **Figure 1**):

1. Start from a new measured bathymetry: Project it on the constructed POD basis.
2. For each deduced temporal mode: predict the new value using the forcing variables and the previously constructed PCE models
3. Multiply each new temporal mode by its corresponding spatial mode (member of POD basis), and sum the all to reconstruct a new bathymetric state, that is physically consistent.

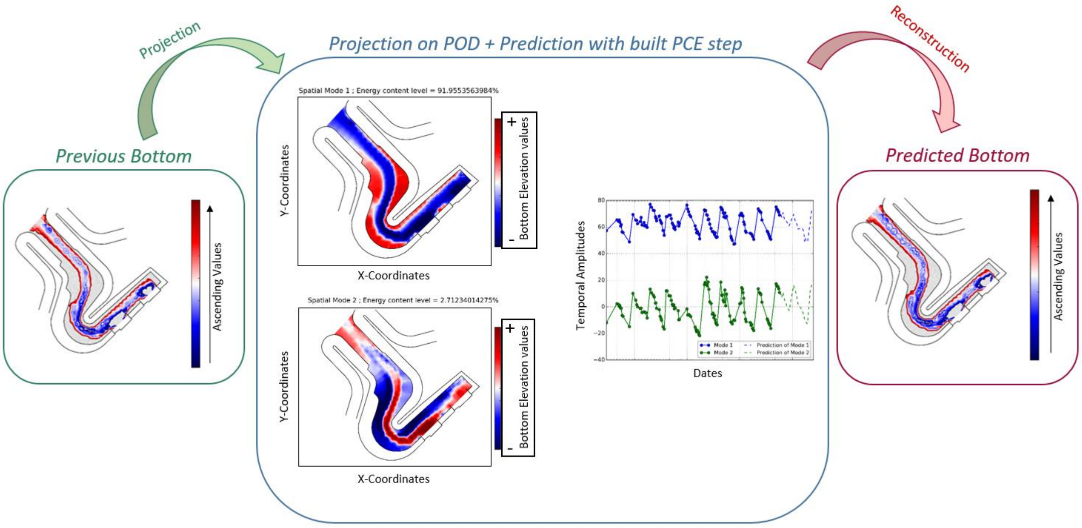

Figure 1 - Representation of the prediction algorithm

A number of uncertainty sources can be identified in this methodology, namely through the measurement errors, in the choice of the number of modes in the POD approximation, in the convergence of the POD itself, in the construction of the PCE and contribution of extreme events to the learning process, etc. This allows to characterize the prediction by a confidence interval and a density law for the residual errors.

As a perspective, the same procedure can be applied to evaluate the dynamics of a proposed process-based sediment transport model, and compare it to field observations. Furthermore, the decomposition of the numerical model response can make the calibration process (data assimilation) easier, by evaluating the temporal modes values instead of evaluating a complete two-dimensional field.

References

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Short biography – I studied mathematical and mechanical modeling, finishing on an internship about uncertainty quantification in sediment transport. My PhD results from the needs of a reliable prediction of bed movement in cooling intakes, which is one of EDF concerns, as dredging operations are costly. It is a PhD financed by ANRT and EDF R&D and directed in collaboration with CERFACS and INPT Université de Toulouse.