

Mixture of polynomial chaos expansions for uncertainty propagation in two-dimensional hydraulic models for flood forecasting

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Abstract:

Recent flood events have shown the devastating impact that flooding can cause in areas where security of people and infrastructures is at stake. With sufficient and efficient warning notice from national or international flood warning agencies, protection and evacuation can be organised to mitigate the excruciating effects of flooding. River hydraulic models are used to assess the environmental risk associated to flooding and consequently inform decision support systems for civil security needs. These numerical models are generally based on a deterministic approach based on resolving the Shallow Water Equations derived from the free surface Navier-Stokes equations [1].

Hydraulic parameters, such as the hydraulic roughness, upstream and lateral discharge as well as bathymetry, are usually described with considerable uncertainty [2] [6]. Indeed, no measurement are available for roughness; these parameters are classically set through a calibration procedure using observed stream flows over a limited range. Input discharge to the model stem from imperfect water level measurements that translate into discharge through a rating curve, usually extrapolated for high flow.

In order to overcome the limits of hydrodynamics deterministic simulations, uncertainties should be analysed; the knowledge of the type and magnitude of the uncertainties is crucial for a meaningful interpretation of the model results and a solid capacity of flow and water depth estimation.

A variety of statistical methods are reported in the literature to propagate uncertain inputs through the model. Non-intrusive approaches rely on the generation of an ensemble of simulations. The ensemble-based approach is favoured as it provides a statistical description of the output hydraulic variables, given statistical assumptions on the inputs. Appreciating and quantifying the dependency of the model outputs with respect to model inputs is possible using sensitivity analysis tools which rely on the classical Monte Carlo approach, known for its robustness but slow convergence and large associated computational cost [8]. The computational cost of the sensitivity analysis can be reduced using a surrogate model in place of the numerical hydrodynamic solver.

This strategy satisfyingly applies for moderate output dimensions [9] and when the relation between inputs and outputs is linear or weakly non linear. For instance, the polynomial chaos expansion (PCE) [4] [7] has proven useful in a wide range of applications, providing a low cost, yet accurate, metamodel to estimate sensitivity indices [10]. For mono-dimensional steady flow in hydraulics, [3] and [5] demonstrated that PCE surrogate model succeeds in representing the response in water level to uncertainties in friction and input stream flow, allowing for an efficient computation of Sobol' indices, water level probability density function and water level error covariance matrix, over a reach of the Garonne River in Southwest France.

However, for unsteady flow with a 2D hydrodynamics model that also represents the dynamics of the flood plain, strong nonlinearities occur when water overflows the minor bed of the river; especially near dikes and in areas where bathymetry is characterised by strong spatial gradients. In these regions, water level response shows strong nonlinearities with respect to roughness and input discharge. Classical PCE metamodeling is no longer adequate due to its inherent smoothness and leads to poor predictions. An advanced Mixture-of-Experts (MoE) approach is thus proposed, based on the divide-and-conquer principle. This methodology consists in, for a given mesh node, dividing the input space into sub-regions where input/output nonlinearities are weak, and building a PCE over each of these partitions of the input space. The merits of this approach over the classical PCE were demonstrated for the Garonne River.

In the continuation of the work, the single-node methodology should be extended to the entire two-dimensional mesh in order to predict the water level over the whole study area. As in this case the water height is of high dimension, it would be appropriate to combine the space reduction methodology with the MoE approach.

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Short biography – With a background in applied mathematics, I have two engineering degrees and I did a year-long exchange to study Big Data. The main goal of my research study is to improve the flood risk forecasting at low cost using reduced order models for operational needs in order to enable civil security system to take the necessary measures. This thesis is co-funded by CERFACS and the Occitanie Region.