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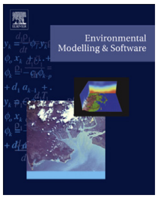

Spatial Global Sensitivity Analysis of High Resolution classified topographic data use in 2D urban flood modelling

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ABSTRACT

This paper presents a spatial Global Sensitivity Analysis (GSA) approach in a 2D shallow water equations based High Resolution (HR) flood model. The aim of a spatial GSA is to produce sensitivity maps which are based on Sobol index estimations. Such an approach allows to rank the effects of uncertain HR topographic data input parameters on flood model output. The influence of the three following parameters has been studied: the measurement error, the level of details of above-ground elements representation and the spatial discretization resolution. To introduce uncertainty, a Probability Density Function and discrete spatial approach have been applied to generate 2,000 DEMs. Based on a 2D urban flood river event modelling, the produced sensitivity maps highlight the major influence of modeller choices compared to HR measurement errors when HR topographic data are used. The spatial variability of the ranking is enhnaced.

Software availability

Name of software	FullSWOF_2D	Promethée
Developers	F. Darboux, O. Delestre, C. Laguerre, C. Lucas, M.H. Le	IRSN
Contacts	fullswof.contact@listes.univ-orleans.fr	Yann.richet@irsn.fr
First Year of Availability	2011	2009
Operating System	Linux, Windows and Mac	Linux, Windows and Mac
Software availability	https://sourcesup.renater.fr/projects/fullswof-2d/	http://promethee.irsn.fr
Cost	Free of charge, distributed under CeCILL-V2 licence (GPL compatible)	Free of charge

1. Introduction

In hydraulics, deterministic numerical modelling tools based on approximating solutions of the 2D Shallow Water Equations (SWE) system are commonly used for flood hazard assessment (Gourbesville, 2014). This category of tools describes water free surface behaviour (mainly elevation and discharge) according to an engineering conceptualization, aiming to provide to decision makers information that often consists in a flood map of maximal water depths. As underlined in Cunge (2012), good practice in hydraulic numerical modelling is for modellers to know in detail the chain of concepts in the modelling process and to supply to

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decision makers possible doubts and deviation between what has been simulated and the reality. Indeed, in considered SWE based models, sources of uncertainties come from (i) hypothesis in the mathematical description of the natural phenomena, (ii) numerical aspects when solving the model, (iii) lack of knowledge in input parameters and (iv) natural phenomena inherent randomness. Errors arising from i, ii and iii may be considered as belonging to the category of epistemic uncertainties (that can be reduced *e.g.* by improvement of description, measurement). Errors of type iv are seen as stochastic errors (where randomness is considered as a part of the natural process, *e.g.* in climatic born data) (Walker et al., 2003). At the same time, the combination of the increasing availability of High Resolution (HR) topographic data and of High Performance Computing (HPC) structures, leads to a growing production of HR flood models (Abily et al., 2013; Erpicum et al., 2010; Fewtrell et al., 2011; Hunter et al., 2008; Meesuk et al., 2015). For non-practitioner, the level of accuracy of HR topographic data might be erroneously interpreted as the level of accuracy of the HR flood models, disregarding uncertainty inherent to this type of data use, notwithstanding the fact that other types of above mentioned errors occur in hydraulic modelling.

1.1. High Resolution topographic data and associated errors

Topographic data is a major input for flood models, especially for complex environment such as urban and industrial areas, where a detailed topography helps for a better description of the physical properties of the modelled system (Abily et al., 2013; Djordjević et al., 2009; Gourbesville, 2014). In the case of an urban or industrial environment, a topographic dataset is considered to be of HR when it allows to include in the topographic information the elevation of infra-metric elements (Le Bris et al., 2013). These infra-metric elements (such as sidewalks, road-curbs, walls, *etc.*) are features that influence flow path and overland flow free surface properties. At megacities scale, HR topographic datasets are getting commonly available at an infra-metric resolution using modern gathering technologies (such as LiDAR, photogrammetry) through the use of aerial vectors like unmanned aerial vehicle or specific flight campaign (Chen et al., 2009; Meesuk et al., 2015; Musialski et al., 2013; Nex and Remondino, 2014; Remondino et al., 2011). Moreover, modern urban reconstruction methods based on features classification carried out by photo-interpretation process, allow to have high accuracy and highly detailed topographic information (Andres, 2012; Lafarge et al., 2010; Lafarge and Mallet, 2011; Mastin et al., 2009). Photo-interpreted HR datasets allow to generate HR DEMs including classes of impervious above ground features (Abily et al., 2014). Therefore generated HR DEMs can include above ground features elevation information depending on modeller selection among classes. Based on HR classified topographic datasets, produced HR Digital Elevation Model (DEM) can have a vertical and horizontal accuracy up to 0.1 m (Fewtrell et al., 2011).

Even though being of high accuracy, produced HR DEMs are assorted with the same types of errors as coarser DEMs. Errors are due to limitations in measurement techniques and to operational restrictions. These errors can be categorized as: (i) systematic, due to bias in measurement and processing; (ii) nuggets (or blunder), which are local abnormal value resulting from equipment or user failure, or to occurrence of abnormal phenomena in the gathering process (*e.g.* birds passing between the ground and the measurement device) or (iii) random variations, due to measurement/operation inherent limits (see Fisher and Tate, 2006; Wechsler, 2007). Moreover, the amount of data that composes a HR classified topographic dataset is massive. Consequently, to handle the HR dataset and to avoid prohibitive computational time, hydraulic modellers make choices to integrate this type of data in the hydraulic model, possibly decreasing HR DEM quality and introducing uncertainty (Tsubaki and Kawahara, 2013; Abily et al., 2015). As recalled in the literature (Dottori et al., 2013; Tsubaki and Kawahara, 2013), in HR flood models, effects of uncertainties related to HR topographic data use on simulated flow is not yet quantitatively understood.

1.2. Uncertainty and Sensitivity Analysis

To evaluate uncertainty in deterministic models, Uncertainty Analysis (UA) and Sensitivity Analysis (SA) have started to be used (Saltelli et al., 2000, 2008) and become broadly applied for a wild range of environmental modelling problems (Refsgaard et al., 2007; Uusitalo et al., 2015). UA consists in the propagation of uncertainty sources through model, and then focuses on the quantification of uncertainties in model output allowing robustness to be checked (Saint-Geours, 2012). SA aims to study how uncertainty in a model output can be linked and allocated proportionally to the contribution of each input uncertainties. Both UA and SA are essential to analyse complex systems (Helton et al., 2006; Saint Geours et al., 2014), as study of uncertainties related to input parameters is of prime interest for applied practitioners willing to decrease uncertainties in their models results (Iooss, 2011).

In 1D and 2D flood modelling studies, approaches based on sampling based methods are becoming used in practical applications for UA. For SA, depending on applications and objectives, different categories of variance based approaches have been recently applied in flood modelling studies (mainly in 1D) such as Local Sensitivity Analysis (LSA) (Delenne et al., 2012) or more recently, a Global Sensitivity Analysis (GSA) based on a screening method has been implemented in 2D flood modelling application (Willis, 2014).

1.2.1. Local Sensitivity Analysis

LSA focuses on fixed point in the space of the input and aims to address model behaviour near parameters nominal value to safely assume local linear dependences on the parameter. LSA can use either a differentiation or a continuous approach (Delenne et al., 2012). LSA based on differentiation approach performs simulations with slight differences in a given input parameter and computes the difference in the results variation, with respect to the parameter variation. LSA based on continuous approach differentiates directly the equations of the model, creating sensitivity equation (Delenne et al., 2012). The advantages of LSA approaches are that they are not resource demanding in terms of computational cost, drawback being that the space of input is locally explored assuming linear effects only. Linear effects means that given change in an input parameter introduces a proportional change in model output, in opposition to nonlinear effects. LSA approaches perform reasonably well with SWE system even if nonlinear effects occur punctually (see Delenne et al., 2012). Nonetheless, important nonlinear effects in model output might arise when parameters are interacting and when solution becomes discontinuous. LSA consequently becomes not suited (Delenne et al., 2012; Guinot et al., 2007) in such a context, which is likely to occur in case of 2D SWE based simulation of overland flow.

1.2.2. Global Sensitivity Analysis

GSA approaches rely on sampling based methods for uncertainty propagation, willing to fully map the space of possible model predictions from the various model uncertain input parameters and then, allow to rank the significance of the input parameter uncertainty contribution to the model output variability (Baroni and Tarantola, 2014). GSA approaches are well suited to be applied

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