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Global sensitivity analysis of complex numerical landslide models based on Gaussian-Process meta-modelling

J. Rohmer and E. Foerster
BRGM, Natural Risks Division, Orléans, France (j.rohmer@brgm.fr)

Large-scale landslide prediction is typically based on numerical modeling, with computer codes generally involving a large number of input parameters. Addressing the influence of each of them on the final result and providing a ranking procedure may be useful for risk management purposes, especially to guide future lab or in site characterizations and studies, but also to simplify the model by fixing the input parameters, which have negligible influence.

Variance-based global sensitivity analysis relying on the Sobol' indices can provide such valuable information and presents the advantages of exploring the sensitivity to input parameters over their whole range of variation (i.e. in a global manner), of fully accounting for possible interaction between them and of being applicable without introducing a priori assumptions on the mathematical formulation of the landslide model. Nevertheless, such analysis require a large number of computer code simulations (typically a thousand), which appears impracticable for computationally demanding simulations, with computation times ranging from several hours to several days. To overcome this difficulty, we propose a "meta-model"-based strategy consisting in replacing the complex simulator by a "costless-to-evaluate" statistical approximation (i.e. emulator) provided by a Gaussian-Process (GP) model. This allows computation of sensitivity measures from a limited number of simulations.

This meta-modelling strategy is demonstrated on two cases. The first application is a simple analytical model based on the infinite slope analysis, which allows to compare the sensitivity measures computed using the "true" model with those computed using the GP meta-model. The second application aims at ranking in terms of importance the properties of the elasto-plastic model describing the complex behaviour of the slip surface in the "La Frasse" landslide (Switzerland). This case is more challenging as a single simulation requires at least 4 days of calculation on a 2 GHz Pentium 4 PC. We demonstrate that valuable information on the sensitivity of the model can be achieved through GP-based methodology using a limited number of simulations performed on computing grid architecture of moderate size (of 10 computers).

Yet, one major limitation of is that the computation of sensitivity measures is associated with uncertainty as the simulator is approximated using a training sample of small size, i.e. a limited knowledge on the "true" simulator. This source of uncertainty can be taken into account by treating the GP model from a Bayesian perspective. This provides the full posterior probability distribution associated with the sensitivity measures, which can be summarized by a confidence interval to outline the regions where the GP model is "unsure". We show that this methodology is able to provide useful guidelines for the practical decision-making process and suggest further site investigations.