Combining spatial and thematic uncertainty and sensitivity analysis for mountain natural hazard assessment

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Abtract
This article presents an application of the Hybrid uncertainty propagation method to natural hazard assessment. It proposes a comparison with the usual probabilistic Monte-Carlo method, and propagates uncertainties related to both spatial and thematic variables.

Keywords
Uncertainty, sensitivity, Monte-Carlo, Hybrid.

I CONTEXT

Rockfalls and debris-flows are dangerous phenomena in mountains that cause severe damage to exposed assets and population (Figure 1). Risk assessment is based on both thematic and spatial information: physical phenomenon features such as height, speed, impact loads but also the extent of the phenomena is essential to be assessed (Figure 2).

Figure 1: Examples of debris-flows effects and extents.

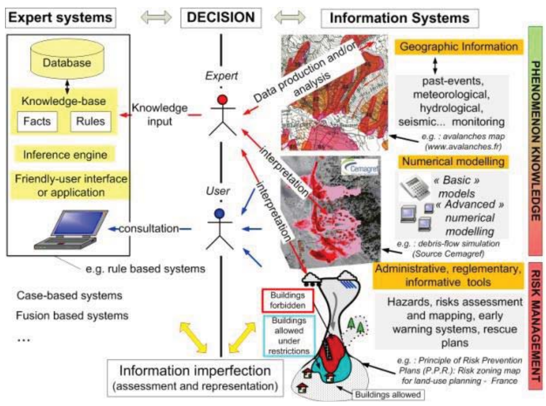

Figure 2: Spatial information is needed for natural risks assessment and management.

For both rockfalls and debris-flows hazard assessment, numerical models are used. In our case:

- For rockfalls, the code RockyFor3D described in Dorren et al. (2006) and Bourrier et al. (2009) simulates the 3D propagation of the rocks as a succession of free flights through the air and rebounds on the soil, modelled by a Digital Elevation Model (DEM). Using input thematic variables related to the falling rock characteristics, it provides spatialized outputs, namely kinetic energy, height, speed of the boulder.
- For debris-flows, Laigle et al. (2003) proposes the lave2D model, dedicated to the computation of the unconfined free-surface spreading of materials with complex rheology. It is based upon the steep-slope-shallow-water-equations which are solved using a finite volume technique which requires first to mesh the domain of interest. Equations are solved taking into account the material rheological behavior and the field topography represented by a DEM. Using input thematic variables related to the input hydrograph and rheological parameters, it provides spatialized outputs, namely flow height and speed.

Both thematic data and DEM can be affected by imperfection (imprecision, uncertainty) depending on the terrain morphology, data acquisition and processing methods. The main issues are therefore:

- To evaluate the quality of available DEM depending on its nature and acquisition process (Lidar, satellite, commercial maps etc.).
- To analyse and represent the effect of spatial information uncertainty on models' results.

This paper describes how innovative methods and tools are used to assess both thematic and spatial data uncertainties and to characterize the impact of the DEM uncertainties on the results of numerical modelling simulation.

II SPATIAL AND THEMATIC UNCERTAINTY PROPAGATION: SCIENTIFIC APPROACH AND MAIN RESULTS

The approach compares two uncertainty propagation approaches, to propagate both DEM and thematic uncertainty:

- The usual, probabilistic, Monte-Carlo method.
- A possibilistic, so-called Hybrid method proposed by Baudrit et al. (2006).

That last Hybrid approach considers the different aspects of information imperfection, especially its imprecision (lack of information, inaccuracy of measure…). It relies on the usual probability theory, the possibility theory as defined by Zadeh (1978) and Dubois et al. (2000), and the belief function theory detailed by Shafer (1976) and Smets et al. (1994). This method generalizes, under some restrictive conditions, the usual Monte Carlo method.

The DEM variability is modelled by a stochastic field using the new ModTer software developped by ProBayes under the ModTer project consortium, and detailed by Crimier et al. (2016) (Figure 3). It takes into account heterogeneity of DEM quality as an input of simulation model: it produces terrain simulations and confidence maps related to altimetric information.

Examples of results (quantile of rock passing heights) of a numerical simulation of rockfalls are proposed: they show the influence of data imperfection including those resulting from expert assessments on the simulation results (Figure 4). To demonstrate the effects of spatial data quality, a sensitivity analysis describes the contribution of the DEM uncertainty on the global uncertainty.

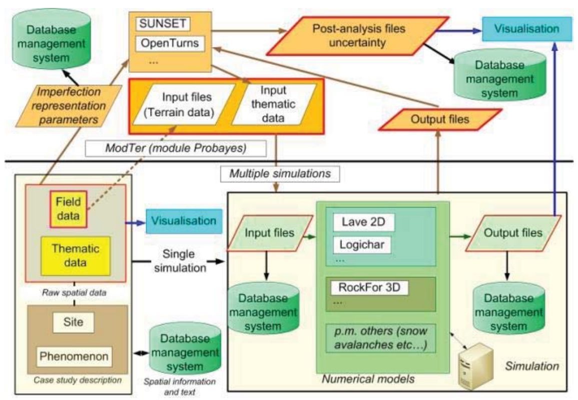

Figure 3: A global framework to evaluate and propagate both thematic and spatial uncertainties using new ModTer software

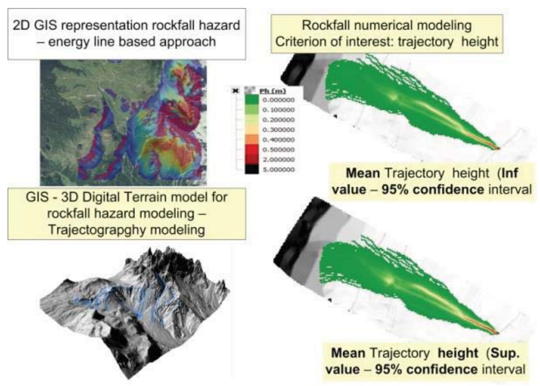

Figure 4: Example of rockfall simulation results

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