Cities on Volcanoes 9
November 20-25, 2016
Puerto Varas, Chile
'Understanding volcanoes and society: the key for risk mitigation'

Topographic uncertainty in models of geological hazards: a general statistical framework and application to a lahar hazard model using SRTM elevation data.

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Keywords: Uncertainty analysis, topography, surface mass flow model, digital elevation maps

Surface mass movements, such as lahars, debris flows, pyroclastic surges, and floods are extremely hazardous. Mathematical models are invaluable as predictive tools to assist in hazard planning and mitigation. To make robust predictions it is essential to characterize and quantify the uncertainty in the model. The local topography controls strongly the dynamics of surface flows. The topography is often represented by digital elevation maps (DEMs) that are interpolated to the spatial resolution required by the model. While it is possible to obtain DEMs at very high resolution the cost for large regions of interest is high. Therefore, many hazard models adopt freely available DEMs, such as those produced by the Shuttle Radar Tomography Mission (SRTM). Interpolation of the coarse SRTM DEM onto the computational grid introduces substantial uncertainty into the model predictions, which must be quantified. Here we develop a general statistical framework for quantifying the uncertainty in the topographic input into models of surface flows. Digital elevation data is treated as an imperfect observation of the true terrain, and is modelled as a Gaussian Markov Random Field (GMRF). GMRFs allow the neighbourhood structure of the DEM pixels to be encoded as a graph, and sparsity of the precision matrix (the inverse of the covariance matrix) leads to efficient computations that would otherwise be intractable for the large field. This allows us to generate a set of spatially coherent candidates for the true elevation, representing the uncertainty in the DEM, which can then be utilized in the mathematical model to characterize the effect on predictions. We demonstrate the application of the statistical framework to assess the uncertainty due to the topographic input in a lahar hazard model. We present a case study for lahars on Nevado del Ruiz, Colombia, using SRTM elevation data and observations from the lahars of 1985.