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# Probabilistic Volcanic Multi-Hazard Assessment at Somma-Vesuvius (Italy): coupling Bayesian Belief Networks with a physical model for lahar propagation

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Volcanoes are extremely complex physico-chemical systems where magma formed at depth breaks into the planet's surface resulting in major hazards from local to global scales. Volcano physics are dominated by non-linearities, and complicated spatio-temporal interrelationships which make volcanic hazards stochastic (i.e. not deterministic) by nature. In this context, probabilistic assessments are required to quantify the large uncertainties related to volcanic hazards.

Moreover, volcanoes are typically multi-hazard environments where different hazardous processes can occur whether simultaneously or in succession. In particular, explosive volcanoes are able to accumulate, through tephra fallout and Pyroclastic Density Currents (PDCs), large amounts of pyroclastic material into the drainage basins surrounding the volcano. This addition of fresh particulate material alters the local/regional hydrogeological equilibrium and increases the frequency and magnitude of sediment-rich aqueous flows, commonly known as lahars. The initiation and volume of rain-triggered lahars may depend on: rainfall intensity and duration; antecedent rainfall; terrain slope; thickness, permeability and hydraulic diffusivity of the tephra deposit; etc. Quantifying these complex interrelationships (and their uncertainties), in a tractable manner, requires a structured but flexible probabilistic approach.

A Bayesian Belief Network (BBN) is a directed acyclic graph that allows the representation of the joint probability distribution for a set of uncertain variables in a compact and efficient way, by exploiting unconditional and conditional independences between these variables. Once constructed and parametrized, the BBN uses Bayesian inference to perform causal (e.g. forecast) and/or evidential reasoning (e.g. explanation) about query variables, given some evidence.

In this work, we illustrate how BBNs can be used to model the influence of several variables on the generation of rain-triggered lahars and, finally, assess the probability of occurrence of lahars of different volumes. The information utilized to parametrize the BBNs includes: (1) datasets of lahar observations; (2) numerical modelling of tephra fallout and PDCs; and (3) literature data. The BBN framework provides an opportunity to quantitatively combine these different types of evidence and use them to derive a rational approach to lahar forecasting. Lastly, we couple the BBN assessments with a shallow-water physical model for lahar propagation in order to attach probabilities to the simulated hazard footprints. We develop our methodology at Somma-Vesuvius (Italy), an explosive volcano prone to rain-triggered lahars or debris flows whether right after an eruption or during inter-eruptive periods. Accounting for the variability in tephra-fallout and dense-PDC propagation and the main geomorphological features of the catchments around Somma-Vesuvius, the areas most likely of forming medium-large lahars are the flanks of the volcano and the Sarno mountains towards the east.