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Estimating conditional probability of volcanic flows for forecasting event distribution and making evacuation decisions

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In this study we propose a conditional probability framework for Galeras volcano, which is one of the most active volcanoes on the world. Nearly 400,000 people currently live near the volcano; 10,000 of them reside within the zone of high volcanic hazard. Pyroclastic flows pose a major hazard for this population. Some of the questions we try to answer when studying conditional probabilities for volcanic hazards are: *“Should a village be evacuated and villagers moved to a different location?"*, *“Should we construct a road along this valley or along a different one?"*, *“Should this university be evacuated?"* Here, we try to identify critical regions such as villages, infrastructures, cities, university to determine their relative probability of inundation in case of an volcanic eruption. In this study, a set of numerical simulation were performed using a computational tool TITAN2D which simulates granular flow over digital representation of the natural terrain. The particular choice from among the methods described below can be based on the amount of information necessary in the evacuation decision and on the complexity of the analysis required in taking such decision. A set of 4200 TITAN2D runs were performed for several different location so that the area of all probably vents is covered. The output of the geophysical model provides a flow map which contains the maximum flow depth over time. **Frequency approach** - In estimating the conditional probability of volcanic flows we define two discrete random variables (r.v.) A and B, where P(A =1) and P(B=1) represents the probability of having a flow at location A, and B, respectively. For this analysis we choose two critical locations identified by their UTM coordinates. The flow map is then used in identifying at the pixel level, flow or non-flow at the two locations. By counting the number of times there is flow or non-flow, we are able to find the marginal probabilities along with the joint probability associated with an event. **Logistic regression** - Here, we define A as a discrete r.v., while B is a continuous one. P(B) represents the probability of having a flow $\geq h_{critical}$ at location B, while P(A) represents the probability of having a flow or non-flow at A. **Bayes analysis** - At this stage of the analysis we consider only the r.v. A, where P(A) represents the probability of having a flow $\geq h_{critical}$ at location A. We are interested in observing how the probability of having a flow $\geq h_{critical}$ at location A is changing when data from the model is taken into consideration. We assume a Beta prior distribution for P(A) and compute P(A/data) using Maximum Likelihood Estimation (MLE) approach. **Bayesian network for causal relationships** - Here, we are interested in more than two critical locations and we are able to incorporate using a *directed acyclic graph* the causal relationship between all the chosen locations. Marginal probabilities along with the joint probability associated with an event based on the “causal links" between variables.