Forecasting natural hazards: scientific challenges and practical implications

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Owing to their scale, complexity, and openness to interactions within a larger environment, most natural systems cannot be replicated in the laboratory, and direct observations of their inner workings are always inadequate. As a consequence, the unavoidable and pervasive uncertainties in the formal representation of natural systems imply that the forecasting of emergent phenomena such as natural hazards must be based on probabilistic rather than deterministic modeling. The use of probabilities poses important scientific and practical challenges, and some of them are often overlooked, nurturing in the past well-founded criticism and pushing some scientists to claim that natural hazard analysis "is not science". Here I discuss the most important challenges that we have to face in the future with examples from seismology and volcanology.

From a scientific point of view, forecasting natural hazard is *per se* a formidable endeavor, with a lot of complexities that are often peculiar of each specific natural threat; however, I think that one of the most compelling challenges is that probabilistic forecasts are rarely rooted in a clear and coherent probabilistic framework. The definition of a proper probabilistic framework is not a mere philosophical issue; on the contrary, it has huge scientific implications. For instance, a reasonable merging of objective data and models, and subjective experts' opinion into a forecasting/hazard model, or the possibility to meaningful test the model against independent data (that is the cornerstone of science), cannot be made in any kind of probabilistic framework. Conversely, it is not unusual that forecasts and natural hazard assessments are based on incoherent probabilistic frameworks, where the probability is first considered as a "degree of belief", and then used as a "frequency" for testing the model.

From a practical point of view, probabilistic forecasts pose tough challenges to decision makers. "Decision making under uncertainty" implies that it is not possible to make decisions that are always the same that we would have made after the fact. I think that there are not "right" or "wrong" decisions, but decisions that can be rationally justified, or not. This can be achieved integrating in a proper way quantitative forecasts (deterministic predictions or probabilistic forecasts) and rationale decision making procedures. I show some examples in the seismic and volcanic context, emphasizing the need to clarify roles and responsibilities of the partners in the whole decision making process. This distinction allows each partner involved to protect the integrity of his/her specific assessment, and to establish clear, rationale and auditable decision making protocols. This is still far to be a common practice, but it is essential to use at best, rationally and ethically, scientific information to reduce the risk for society.