Event trees for eruption forecasting at Campi Flegrei caldera

Domenico Doronzo, Laura Sandri, Jacopo Selva, Mauro A. Di Vito

Istituto Nazionale di Geofisica e Vulcanologia

Abstract

Available studies for Event Trees at the Campi Flegrei caldera are based on the application of the Bayesian Event Tree model for eruption forecasting (BET_EF) and volcanic hazard (BET_VH). In this document we review such studies, which contain full implementation of the probabilistic eruption forecasting and volcanic hazard at Campi Flegrei, implemented both at long- (years) and short-term (hours to days) based on the current vs. past states of the caldera. In particular, we focus here on the eruption forecasting procedures. This review document has been developed within the WP11 of the European project EUROVOLC.

Keywords: Bayesian Event Tree; Campi Flegrei caldera; eruption forecasting; monitoring network; Osservatorio Vesuviano; EUROVOLC project.

1. Introduction

An Event Tree (ET) is a graphical representation of the possible behaviour of a volcano, starting from its restless condition to the spatial extension of volcanic hazards. It is built as a series of logical steps that follow each other as a sequence of branches of a tree. By using an ET, it is then possible to identify which hazardous behaviour we can expect from a specific volcano and, eventually, quantify the likelihood of its occurrence (probabilistic ET; Newhall and Hoblitt, 2002). In particular, probabilistic approaches, differently from deterministic ones, allow to account for temporal variability in eruption probability, uncertainty on eruptive style (effusive, explosive) and/or event magnitude (VEI), and spatial variability in the potential vent. These are all relevant factors in quantifying volcanic hazard (e.g., tephra dispersion, flow runout) (Newhall and Hoblitt, 2002; Marzocchi et al., 2004; Neri et al., 2008; Selva et al., 2010, 2012a, 2018; Tonini et al., 2015; Sandri et al., 2018). The sources of variability can be quantified by means of Event Trees and conditional probabilities (Newhall and Hoblitt, 2002). To better constrain uncertainty, different sources of information should be considered and integrated with each other: geological record, historical observations, monitoring activities, results from scenario modelling. The integration of the different data is important to provide a robust characterization of the state of Campi Flegrei over geological vs. historical times, also in light of its current state as inferred from monitoring data and conceptual models. Different techniques exist to carry out this integration. For Campi Flegrei, available studies are based on the application of the Bayesian Event Tree model for eruption forecasting (BET_EF; Marzocchi et al., 2008) and volcanic hazard (BET_VH; Marzocchi et al., 2010), and details are provided in Selva et al. (2010, 2012b, 2015, 2018), where the probabilistic eruption forecasting and volcanic hazard are implemented both at long- (years) and short-term (hours to days), based on the current vs. past states of the volcano. In the next sections, our focus will be on eruption forecasting procedures.

2. Formulation

The BET approach is adopted to integrate monitoring data, geological and historical data, and modelling results. The approach quantifies conditional probabilities for each pre-determined volcano state, by considering such probabilities as a random variable to model epistemic uncertainty. In other words, conditional probabilities are described by a probability density function that accounts for both the associated aleatoric (intrinsic unpredictability issue) and epistemic (lack-of-knowledge issue) uncertainties. The approach practically goes through fitting probability distributions to the available data and models, including the monitoring ones, toward a long- to short-term eruption forecasting (Marzocchi et al., 2004, 2008, 2010). In general, forecasting an eruption in the long- and short-term mostly requires information from past data and expert elicitations (Aspinall 2006, Marzocchi et al., 2008; Neri et al., 2008, 2015; Orsi et al., 2009; Selva et al., 2012b; Bevilacqua et al., 2015). On the other hand, forecasting a future eruption in the short-term will take advantage from the updated monitoring information. In the case of Campi Flegrei, these are collected by the INGV - Osservatorio Vesuviano and are summarized in weekly and monthly bulletins. A procedure for the short-term at Campi Flegrei was retrospectively tested by Selva et al. (2012b, 2015) during a 5-years long elicitation experiment, with the help of about 30 experts of the Campi Flegrei, through the lens of the experts' knowledge about historical and geological data, and numerical modelling. The aim was that of identifying the most informative anomalies and quantifying threshold values for the different parameters collected through the monitoring network to define anomalies, in order to forecast various states of the volcano.

3. Eruption forecasting and main hazards

The Event Tree reported in Fig. 1, and its application to the Campi Flegrei caldera for the long-term tephra fall, consist of two main parts, one focusing on eruption forecasting (up to node 5) and the other focusing on volcanic hazard (from node 6). In this document, the main focus is on eruption forecasting. This Event Tree encompasses all the general expected hazards at Campi Flegrei, which are new vent opening, tephra fallout, pyroclastic currents, and hydrothermal activity (Orsi et al., 2009; Selva et al., 2010; Neri et al., 2015).

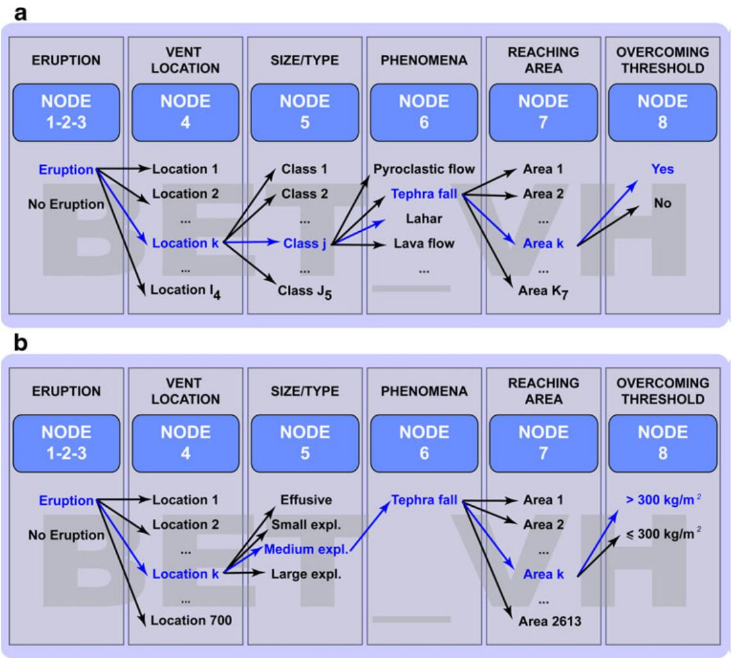

Fig. 1 – Event Tree of the BET model for a generic volcano (a), and for Campi Flegrei (b) (from Selva et al., 2010).

The adopted statistical model is BET for eruption forecasting (Marzocchi et al., 2008). The model is based on an Event Tree logic (Newhall and Hoblitt, 2002), in which branches are logical steps from a general starting event (the onset of unrest, node 1), through specific subsequent events (the presence of magma driving the unrest, node 2), to the final outcome (the onset of eruption, node 3), see Fig. 2A. The model assesses probabilities at all nodes through Bayesian inference, including any possible sources of information (theoretical beliefs, models, past data, and volcano monitoring), accounting for both aleatory and epistemic uncertainty. The probability of eruption is calculated by multiplying the probabilities at each node. A key feature of the model is that it automatically updates the forecast procedure, depending on the occurrence of relevant anomalies in the volcanic activity. In Fig. 2, it is shown the procedure adopted to integrate monitoring data into the BET model for eruption forecasting (Marzocchi et al., 2008). Whenever anomalies occur, the model makes its forecast based on the interpretation of the evolving monitoring measures (Fig. 2B). When only background activity is registered, the eruption forecast can address the expected long-term activity (Fig. 2C). The definition of what background vs. anomaly is, and the interpretation of anomalies represent the core of the analysis. The parametrization of this model for short-term eruption forecasting at Campi Flegrei caldera is discussed by Selva et al. (2012b, 2015). For Campi Flegrei caldera, the lack of previous pre-eruptive observations makes this analysis a necessary step that can be treated formally through expert opinion (Selva et al., 2012b).

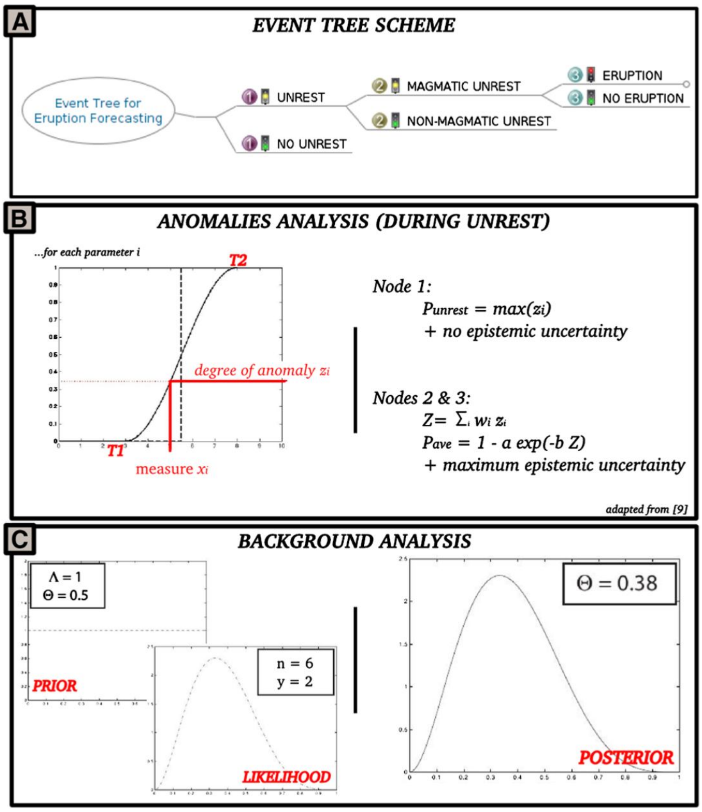

Fig. 2 – Schematic representation of the BET model. A, nodes of the Event Tree, in which a Bayesian inference scheme is performed; B, analysis of monitoring anomalies during unrest episodes; C, background analysis, in which theoretical models set any available past data (from Selva et al., 2012b).

In Fig. 3, it is shown a retrospective application of the BET model set on the first elicitation experiments (2005-2010) for eruption forecasting at Campi Flegrei, with the aim of tracking the unrest evolution at the caldera in the period 1981-2010. At the beginning of this time interval, the monitoring capability was not comparable to the present one, an inhomogeneity that poses some constraints to the resolution of the probability variations through time. Nonetheless, this example highlights the main features of the model when applied to a real case like the Campi Flegrei one. In Fig. 3, it is also reported the eruption probability distribution at three different times. Each distribution displays the estimated probability (central value) and the associated epistemic uncertainty (dispersion around the central value) (Selva et al., 2012b).

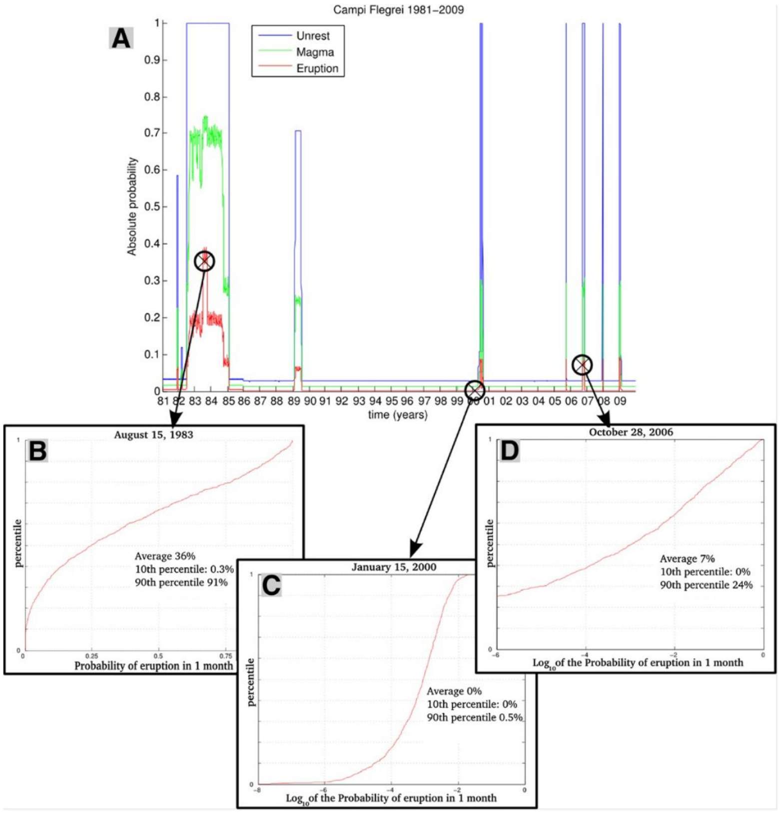

Fig. 3 – Retrospective application of the BET model to Campi Flegrei from year 1981 on. A, average probability of unrest (blue), magmatic unrest (green), and eruption (red); B, C, and D, cumulative distribution of eruption probability at three different times, with evidenced epistemic uncertainty (from Selva et al., 2012b).

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