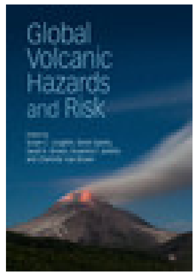

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Chapter

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Chapter 6

Tephra fall hazard for the Neapolitan area

W. Marzocchi, J. Selva, A. Costa, L. Sandri, R. Tonini and G. Macedonio

The Neapolitan area is one of the highest volcanic risk areas in the world, both for the presence of three potentially explosive and active volcanoes (Vesuvius, Campi Flegrei and Ischia), and for the extremely high exposure (over a million people located in a very large and important metropolitan area). Even though pyroclastic flows and lahars represent the most destructive phenomena near the volcanoes, tephra fall poses a serious threat on a wider spatial scale. Excess of tephra loading can cause building collapse, disrupt services and lifelines, and severely affect agriculture and human health. On a larger spatial scale, tephra fallout may cause a major disruption of the economy in Europe and in the Mediterranean area (Folch & Sulpizio, 2010, Sulpizio et al., 2012).

The volcanic *hazard* is the way in which scientists quantify such a kind of threat. The hazard is usually expressed in probabilistic terms in order to account for the vast irreducible (aleatory) and reducible (epistemic) uncertainties. In the past several papers focussed on the assessment of tephra fallout hazard from Neapolitan volcanoes (e.g. Barberi et al. (1990), Macedonio et al. (1990), Cioni et al. (2003), Costa et al. (2009)). These studies have combined field data of tephra deposits and numerical simulations of tephra dispersal (often considering tens of thousands of wind profiles to account for wind variability) to produce maps for the expected tephra loading in case of a specific scenario (e.g. considering one specific kind of eruption), or of a few reference scenarios at both Mount Vesuvius and Campi Flegrei.

This kind of map is still frequently used in volcanology, however, they do not represent the real volcanic hazard, because they do not consider the probability of occurrence of the specific scenarios considered, and they neglect a large part of the natural variability, such as the possibility to have eruptions of different size and from different vents. The latter is particularly important for the Campi Flegrei caldera, where the largest source of uncertainty comes from the forecast of the next eruption location. From a more technical point of view, these studies do not properly incorporate all known aleatory and epistemic uncertainties. This aspect is of primary importance in order to get a reliable volcanic hazard assessment.

The need to have a realistic volcanic hazard analysis is not only important from a scientific perspective, but it is of paramount importance for risk mitigation. Any sound (and defensible) risk assessment and mitigation plan has to be based on a reliable volcanic hazard analysis. In practical terms, the costs and benefits of any possible mitigation option have to be weighted and

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compared with the probability of occurrence of the wide range of possible threats, i.e. with the volcanic hazard. Any decision making based on single scenarios without considering their probability of occurrence cannot lead to any rational and defensible risk mitigation plan, in particular for high-risk areas.

The need to use the best available science for helping society to mitigate the high volcanic risk in the Neapolitan area pushed volcanologists to develop innovative tools for volcanic hazard analysis in probabilistic terms, the so-called Probabilistic Volcanic Hazard Analysis (PVHA). The attempt is to move toward hazard assessment formats that are similar to other kinds of hazards, such as, for example, the seismic hazard. Following the results of Costa et al. (2009), Selva et al. (2010) assessed tephra fallout hazard at Campi Flegrei attempting to overcome some of the limitations described above. In particular they accounted for the most important sources of uncertainty and natural variability in the eruptive processes due to many different possible scenarios (represented by a discrete number of eruptive scales, and vent positions), and statistically combining the contribution to the final PVHA from all the possible scenarios, making use of the law of total probability.

In order to provide information to the engineers to move from hazard to risk assessment we need to shape the hazard output in a way that can be easily combined with the fragility curves that represent how a building can be damaged as a function of the different intensities of the different volcanic threats (e.g. Spence et al. (2005), Zuccaro et al. (2008), Zuccaro & Leone (2011)).

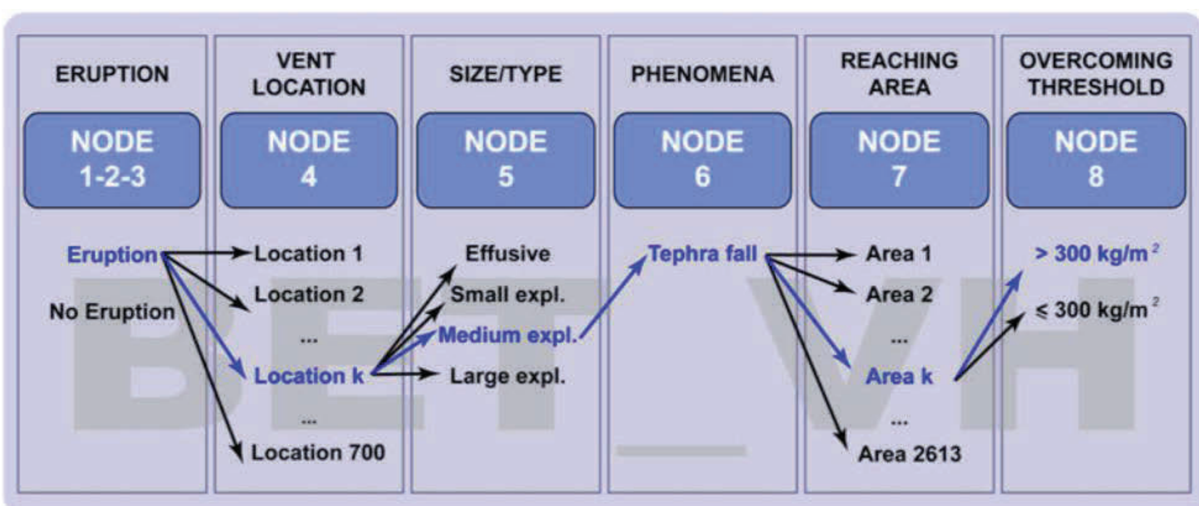

Figure 6.1 Event tree of the model BET_VH for a specific volcano to evaluate the PVHA for tephra fallout above 300 kg/m².

One of the currently adopted methodologies is based on the BET_VH tool (Marzocchi et al. (2010); https://vhub.org/resources/betvh) that performs a proper statistical mixing of the different possible scenarios, further extending the work made by Selva et al. (2010). Such an open source tool, being based on Bayesian inference modelling, properly accounts for the aleatory (intrinsic) and epistemic (linked to our limited knowledge of the eruptive process) uncertainty, propagating these two all along the different factors of PVHA. PVHA and related uncertainties are described by a probability density function instead of by a single value. This gives the interested stakeholders an idea about the confidence of the probabilities we are providing. The analysis for the volcanic hazard posed by tephra is based on an *event tree* (see Figure 6.1). An event tree is a branching graph representation of events in which individual branches are alternative steps from a general prior event, state or condition, and which evolve through time into increasingly specific subsequent events. Eventually the branches terminate in final outcomes representing specific hazards (or risks) that may occur in the future. In this way, an event tree attempts to graphically display all relevant possible volcanic outcomes in progressively higher levels of detail. Points on the graph where new branches are created are referred to as nodes. In BET_VH all uncertainties can be assessed at each level, namely on the eruption occurrence, on vent position, on the eruptive scale, on the production of tephra and on its transport, dispersal and deposition by the wind. The BET_VH tool has been used in other volcanic areas to produce a full PVHA for tephra fallout and other volcanic hazardous phenomena (Sandri et al., 2012, 2014).

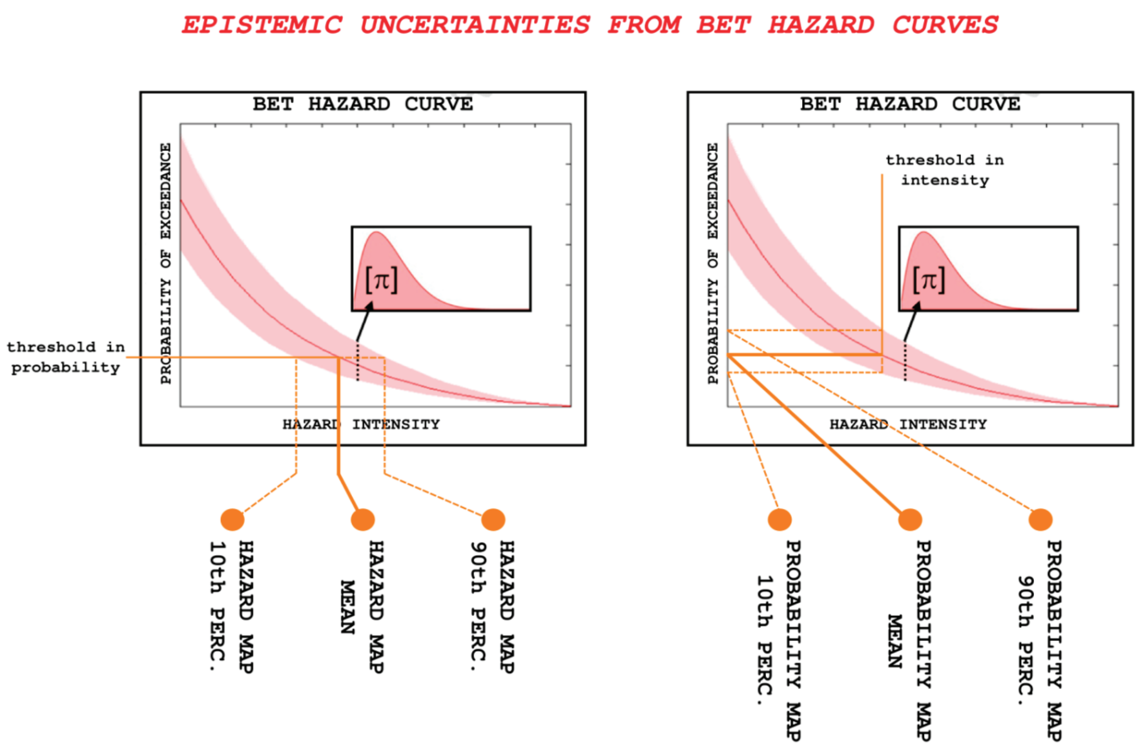

Figure 6.2 Example of hazard curve for a given target cell of the gridpoint. On the x-axis reports the different threshold of the intensity measure (tephra load in our case). On the y-axis reports, the computed exceedance probability of such intensity thresholds in a given time window and a given target position. The shaded area shows the 10 to 90th percentiles confidence interval of the hazard curve. Cutting the curves horizontally (left panels), we obtain the hazard intensity for a given exceedance probability value (basic ingredient of hazard maps). Cutting them vertically (right panel) we obtain the exceedance probability for a given intensity value (basic ingredient of probability maps). Given hazard curves at each position in a target area, maps can be produced at different levels of confidence (e.g. mean, 10th and 90th percentiles), showing the effects of epistemic uncertainties on either hazard (left panel) and probability (right panel) maps. (Modified from Selva et al. (2014).

An ongoing improvement of the method aims at performing the production of fully probabilistic hazard curves (see Figure 6.2), estimating the exceedance probability of a set of thresholds in tephra load, based on the method proposed for seismic hazard by Selva & Sandri (2013) Indeed, hazard curves represent the most complete information about the hazard, and they allow volcanologists to produce proper hazard maps at different levels of probability (SSHAC 1997), as shown in Figure 6.2. The proposed method can be used in both long (years to decades) and short (hours to weeks) perspectives (e.g. Marzocchi et al. (2008), Selva et al. (2014)). For the volcanoes threatening the Neapolitan area, several papers have already taken some steps in the direction of estimating some of the node probabilities reported in Figure 6.1 for both long- and short-term hazard. For Vesuvius, Marzocchi et al. (2004), (2008) estimated the factors probabilities of the first five nodes of the event tree of Figure 6.1, while Macedonio et al. (2008) provided an estimation of the best-guess probabilities for nodes 7 and 8. For Campi Flegrei, the probability distributions for the first five nodes have been respectively estimated by Selva et al. (2012a), Selva et al. (2012b) and Orsi et al. (2009), while Costa et al. (2009) provided an estimation of the best guess probabilities for nodes 7 and 8 in two possible vent locations (Eastern and Western parts of the caldera). Merging all these factors in a full comprehensive volcanic hazard analysis for tephra fall is one of the main goals of the ongoing research.

The results obtained so far include the PVHA for tephra fallout conditional to the occurrence of specific eruptive scenarios, i.e. the probability maps conditional to the occurrence of eruptions of specific sizes at Vesuvius (e.g. Macedonio et al. (2008)) and Campi Flegrei (e.g. Costa et al. (2009)). Figure 6.3 shows some of these maps. A significant improvement for Campi Flegrei was achieved by the proper mixing of all the possible eruptive sizes and vents, conditional to the occurrence of an eruptions, performed by Selva et al. (2010), computed by accounting for the different possible vent locations Selva et al. (2012b), eruption sizes (Orsi et al., 2009), and the probability distribution for the nodes 6, 7 and 8 (see Figure 6.4). In this respect, this kind of approach is particularly useful for large and potentially very explosive calderas, such as Campi Flegrei, for which the position of the vent is critical and it imposes a large uncertainty on the final PVHA.

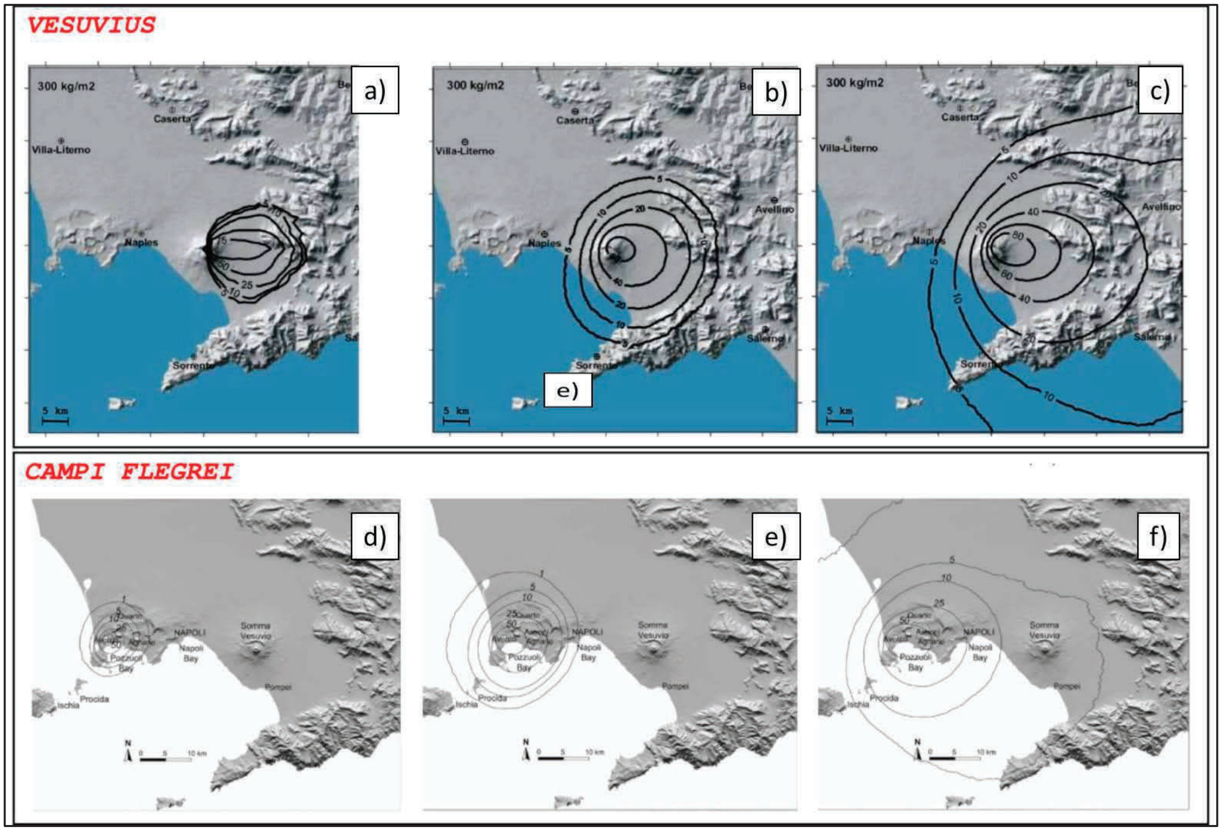

Figure 6.3 Results for tephra fallout probability of overcoming 300 kg/m² given the occurrence of an eruption of size a) Violent Strombolian, b) Subplinian and c) Plinian at Vesuvius (Macedonio et al., 2008), and of size d) low, e) medium and f) high explosive, from the eastern vent (Averno-Monte Nuovo) at Campi Flegrei (Costa et al., 2009). Each map shows the hazard footprint of the event, enabling the user to assess areas under threat.

Despite the recent significant steps ahead in achieving a full and comprehensive PVHA for tephra fall, much more work has still to be done. In two ongoing Italian projects (ByMur, 2010-2014, DPC-V1, 2012-2013), there have been attempts to provide further improvements in long-term PVHA for Vesuvius, Campi Flegrei and Ischia, by accounting for all the factors concurring to the full hazard. A preliminary merging of the full PVHA for tephra fallout posed by both Vesuvius and Campi Flegrei on the municipality of Naples is shown in Figure 6.5 (Selva et al., 2013). The variability of eruptive parameters within each size class must also be modelled, to evaluate its importance and impact on the final PVHA. The production of hazard curves, as mentioned above, is a necessary step if PVHA results are to be included into quantitative risk assessment procedures. The assessment of the epistemic uncertainty on the hazard curves represents the most complete results that we aim to achieve (Figure 6.4). The final PVHA for the municipality of Naples is planned to be ready for the end of the project ByMuR and it will consist of a hazard curves, at different level of confidence regarding epistemic uncertainties, for each cell of the grid covering the municipality of Naples.

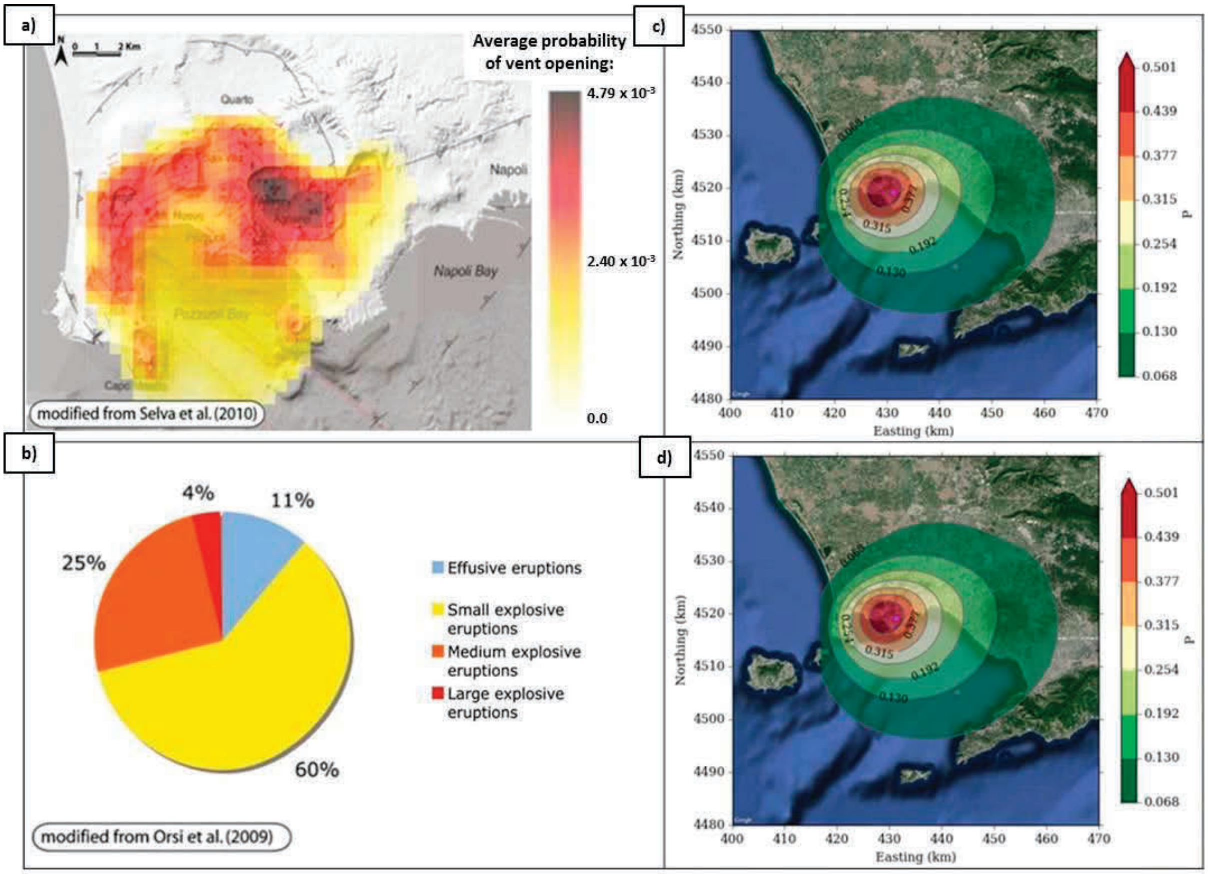

Figure 6.4 a) mean probability of vent opening at Campi Flegrei (the notation '4.7E-03' means 4.7 x 0.001=0.047); b) mean probability of possible eruptive sizes at Campi Flegrei; c) mean probability of tephra fallout and of tephra loading larger than 0 kg/m^2; d) as for c) but relative to a tephra loading larger than 300 kg/m^2. The maps reported in panels a) and b) have been obtained by Selva et al. (2010) integrating the outcome of all possible scenarios – all possible size (panel b) and all possible vent opening (panel a) – with their own probability of occurrence.

Regarding short-term PVHA in the Neapolitan area, two research projects (the Italian DPC-V2, 2012-2014, and the EC MEDSUV 2013-2015) aim at providing quantitative improvements for Vesuvius and Campi Flegrei in order to reach its operational implementation for tephra fallout. This would represent a tool of primary importance during potential volcanic unrest episodes and for ongoing eruptions, being able to be updated frequently and accounting for the rapidly evolving situation and providing crucial information for crisis management. Theoretically, short-term PVHA should be based on sound modelling procedures stemming from frequently updated meteorological forecast and information about the crisis evolution (Selva et al., 2014). In addition, the relevance of epistemic uncertainties arising from the forecast of the future eruption dynamics and wind conditions, and from the tephra dispersal model, should be estimated.

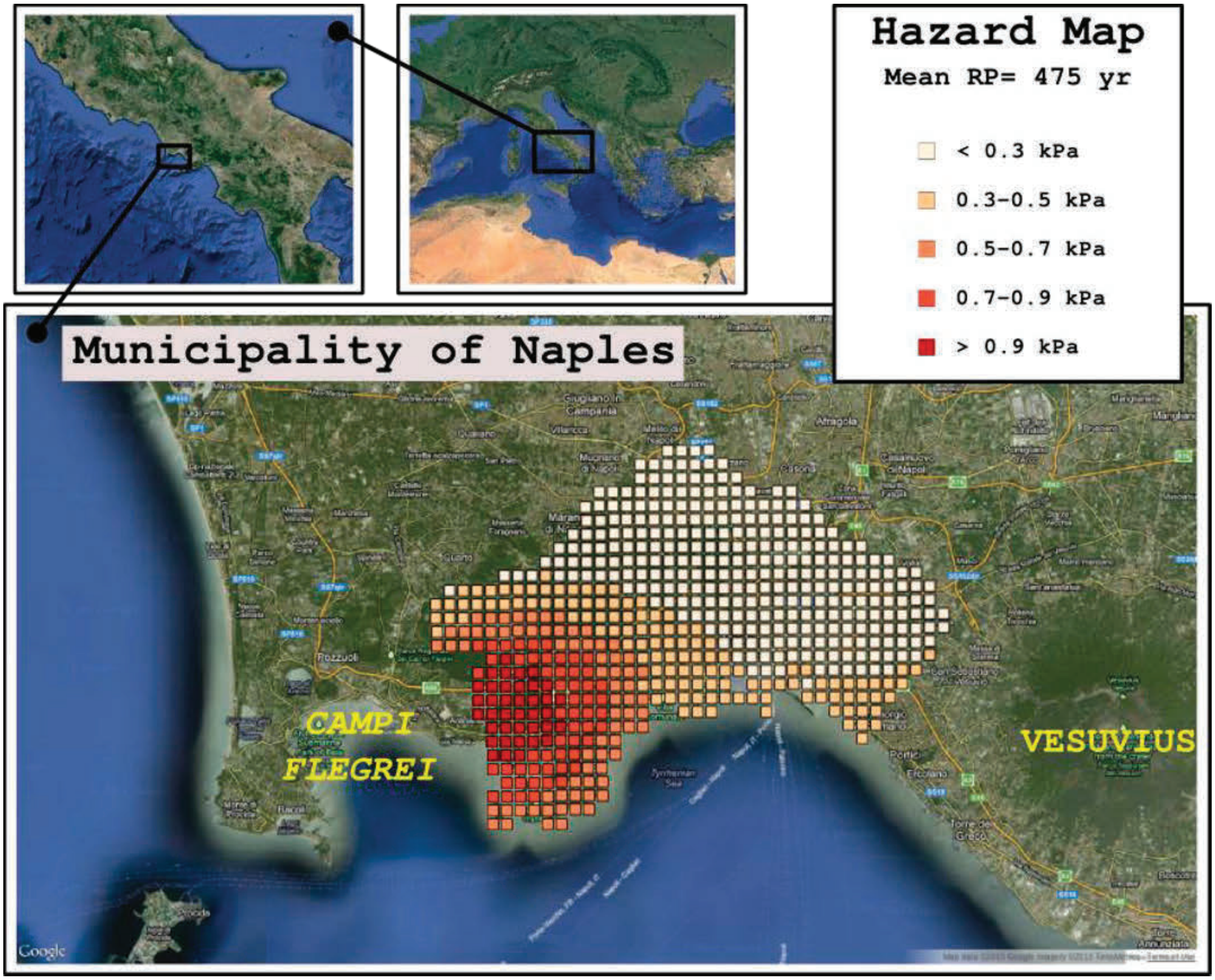

Figure 6.5 Hazard map (mean) for tephra loading with a return period of 475 years (exceedance probability threshold equal to 0.1 in 50 yr), considering both Vesuvius and Campi Flegrei on the municipality of Naples. In the legend 1 kPa stands for 1000 Pascal (or 0.1 bar).

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