A vent opening probability map for Somma-Vesuvio caldera with uncertainty quantification through Structured Expert Judgment

Alessandro Tadini[1,2], A. Bevilacqua[2,3], A. Neri[2], M. Bisson[2], R. Cioni[1], W.P. Aspinall[6,7], R. Isaia[8], G.A. Valentine[9], S. Vitale[10], P.J.Baxter[11], A. Bertagnini[2], M. Cerminara[2], M. De Michieli Vitturi[2], A. Di Roberto[2], S. Engwell[2], T. Esposti Ongaro[2], F. Mazzarini[2], M. Pistolesi[1]

[1]Università degli studi di Firenze, Dipartimento di Scienze della Terra
[2]Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Pisa
[3]Scuola Normale Superiore, Classe di Scienze
[4]Università di Pisa, Dipartimento di Scienze della Terra
[5]Università di Pisa, Dipartimento di Matematica
[6]Aspinall & Associates, Tisbury, United Kingdom
[7]University of Bristol, School of Earth Sciences, Bristol, United Kingdom
[8]Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Vesuviano
[9]University at Buffalo, Department of Geology
[10]Università di Napoli Federico II, Dip.to di Scienze della Terra, dell'Ambiente e delle Risorse
[11]University of Cambridge, Institute of Public Health

alessandro.tadini@ingv.it

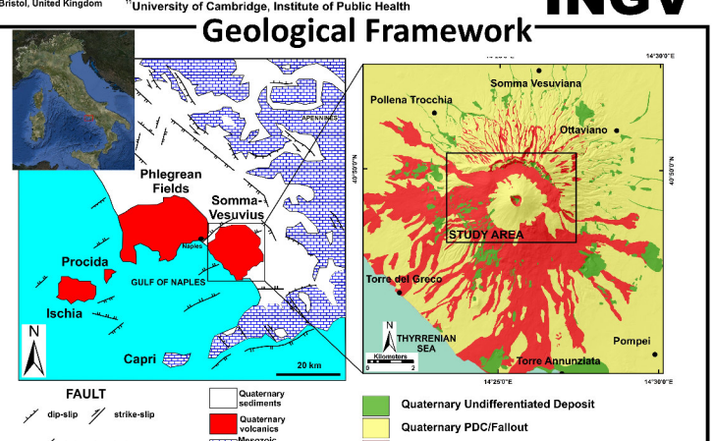
Uncertainty in the Geosciences: A Workshop on Hazard Analysis (Buffalo, March 15th-18th 2016)

Abstract

In this study we combine detailed reconstructions of volcanological datasets and inputs from Structured Expert Judgment (SEJ) to produce a first background (i.e. long-term or base-rate) probability map for vent opening location in the next Plinian or Sub-Plinian eruption of Somma-Vesuvius (SV).

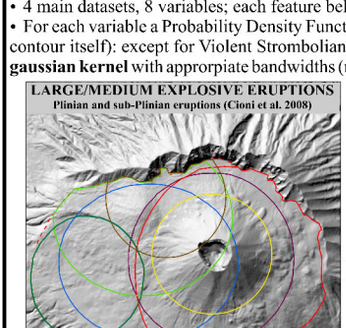
Thus far, we have focused on three main objectives: i) the collection and critical review of key volcanological features (position of past vents, distribution of faults, etc.) that could influence the spatial distribution of future vent locations, organized in a specific geo-database where epistemic uncertainties related to feature spatial distributions have been quantified; ii) developing spatial probability density maps with Gaussian kernel function modelling to use with our different volcanological and geophysical datasets, and iii) the production of a background probability map for vent opening position, using weighted linear combination of spatial density maps for the identified volcanological and geophysical parameters, with uncertainties (related to both epistemic and aleatoric uncertainties) explicitly included by using SEJ. Outcomes obtained during two elicitation sessions involving about 15 experts are reported for three expert judgment weighting and pooling models: (a) the Classical Model (CM) of ; (b) the Expected Relative Frequency (ERF) model of , and (c) the Equal Weights (EW) combination. The results of combining expert judgements with our spatial modeling of the identified variables illustrate that: a) vent opening probabilities are evenly distributed around the caldera with a peak in correspondence with the area of the present crater but with about 50% mean probability that the vent will open in other areas of the caldera; b) there is a mean cumulative probability of about 30% that the next vent will open west of the present edifice in the so-called "Piano delle Ginestre" area; c) there is a mean probability of more than 20% that next Plinian eruption will enlarge the present SV caldera and a not negligible probability (of almost 10%) that the next Plinian or sub-Plinian eruption will have its initial vent opening outside the present outline of the SV caldera. Robustness of results have been tested by considering the effects of alternative pooling methods, sub-groups of experts with different backgrounds and experiences and sub-groups of volcanological datasets. Uncertainty analysis also allowed identification of the most controversial issues and to have a first estimate of the associated ranges, which will be the focus of specific investigation to improve our basic knowledge to reduce uncertainty

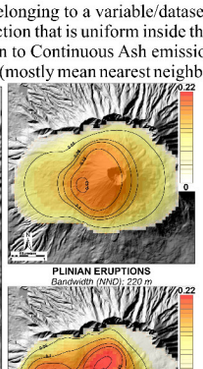
Geological Framework

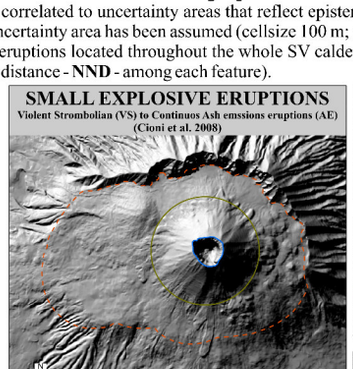


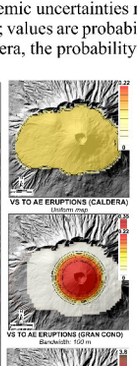
Datasets and density probability maps

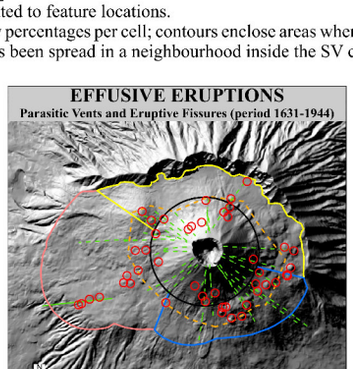
- 4 main datasets, 8 variables; each feature belonging to a variable/dataset is correlated to uncertainty areas that reflect epistemic uncertainties related to feature locations.
- For each variable a Probability Density Function that is uniform inside the uncertainty area has been assumed (cellsize 100 m; values are probability percentages per cell; contours enclose areas where the value is higher than the contour itself): except for Violent Strombolian to Continuous Ash emissions eruptions located throughout the whole SV caldera, the probability has been spread in a neighbourhood inside the SV caldera boundaries through a **gaussian kernel** with approrpiate bandwidths (mostly mean nearest neighbour distance - **NND** - among each feature).

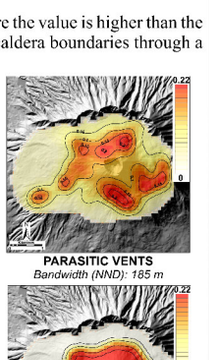


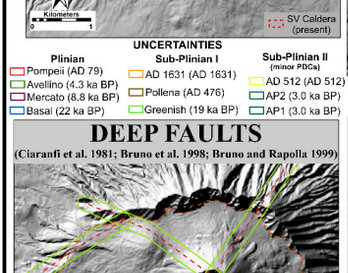


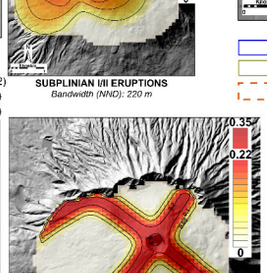








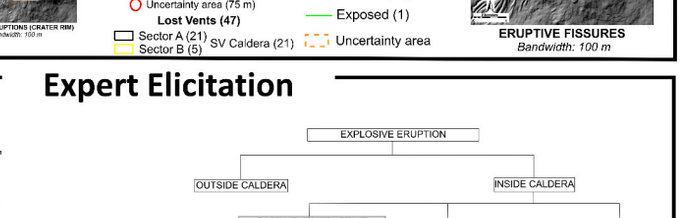




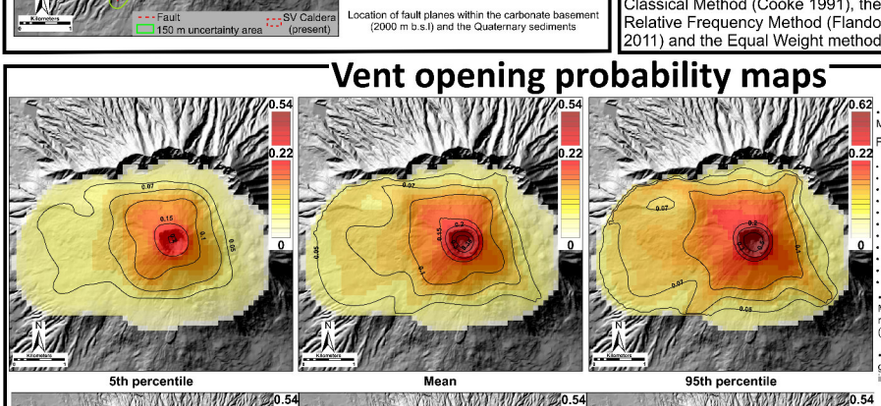
Location of fault planes within the carbonate basement (2000 m b.s.l) and the Quaternary sediments

Expert Elicitation

- Structured expert elicitation involving 15 experts
- 16 seed questions and 15 target questions, with the indication (for each question) of the 5th, 50th and 95th percentiles (uncertainty boundaries)
- Target questions according to the logic tree to the right (each branch is a question)
- 9 variables (8 above-mentioned plus a homogeneous map that accounts for neglected factors and missing informations) have been linearly combined (orange coloured boxes in the figure to the right)
- Results analyzed through the Cooke's Classical Method (Cooke 1991), the Expected Relative Frequency Method (Flandoli et al. 2011) and the Equal Weight method



Vent opening probability maps

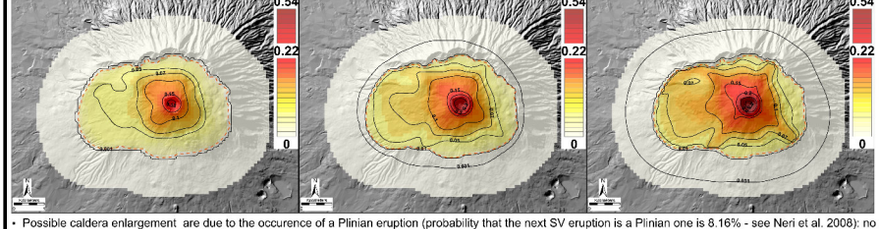


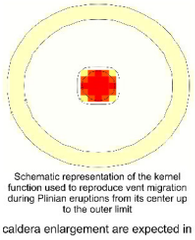
- Maps produced using Cooke's Classical Method

FINAL WEIGHTS (5th - Mean - 95th)

- Inside Caldera: (77% - 95% - 99%)
- Outside Caldera: (1% - 5% - 20%)
- Homogeneous map: (9,5% - 20% - 30%)
- Deep Faults: (1% - 11% - 22%)
- Plinian: (8% - 16% - 25%)
- Subplinian: (14% - 24% - 36%)
- VS to AE Crater: (1.5% - 6% - 12.5%)
- VS to AE Gran Cono: (1% - 6.5% - 13%)
- VS to AE Caldera: (2% - 8% - 16%)
- Parasitic Vents: (1% - 4% - 8.5%)
- Eruptive Fissures: (1% - 4% - 9%)

- General agreement between Classical Model, Expected Relative Frequency method and Equal Weight method (differences between weights <6%)
- Deep Faults effect on final maps generally tend to be slightly more evident in 95th percentile map





Schematic representation of the kernel function used to reproduce vent migration during Plinian eruptions from its center up to the outer limit

- Possible caldera enlargement are due to the occurence of a Plinian eruption (probability that the next SV eruption is a Plinian one is 8.16% - see Neri et al. 2008): no caldera enlargement are expected in case of a sub-Plinian or lower magnitude eruption
- CM maps previously produced has been applied a kernel function made by a circle with 1.3 km of radius (mean radius of past Plinian eruption collapsed areas): this function reproduces the migration of volcanic vent during Plinian eruption at SV from the INITIAL VENT of the eruption in the middle up to the limit of the collapsing areas
- The maps shown above have been obtained by combining CM maps without caldera enlargement (that accounts for 92.84% of the weight) with maps that have been applied a caldera enlargement (that accounts for 8.16% of the weight)

Conclusions and Future Work

- A comparative review of the SV data has been carried out with the aim of producing a first vent opening probability map of the caldera region
- A geodatabase containing the main dataset collected (where epistemic uncertainties have been represented through appropriate uncertainty areas) have been developed
- 4 datasets grouping 8 variables (plus a homogeneous map) have been used as proxies for the development of a vent opening probability map in the case of a future reactivation of SV with a Plinian/sub-Plinian eruption
- Gaussian kernels were applied to 7 variables for estimating the spatial density of future volcanic events based on the locations of past vents/feature. Appropriate bandwidths have been given to 7 variables
- A weighted combination of the relevant datasets have been carried out by using Expert Judgment techniques and different pooling methods to generate a preliminary vent opening probability maps. In particular the study allowed to consider and quantify some of the uncertainty sources affecting the system
- The maps show there is less than 50% of vent opening probability in corrispondence of the present edifice ("Gran Cono") and significant probability values are spread all over the caldera mostly towards west (almost 30% in the "Piano delle Ginestre" area)
- Results indicated also that there is at least 5% (up to 10%) of probability that next Plinian or sub-Plinian eruption will have its initial vent located outside the present SV caldera
- The extension of the map to consider the enlargement of the caldera possibly produced by caldera collapse generated by Plinian events has been implement by applying a specific kernel function (that reproduces vent migration during a Plinian eruption) to the above-mentioned map: cumulative proability of caldera enlargement in case of a next Plinian eruption is estimated around 20%
- Vent opening probability maps will be used as bases for the implementation of PDC and fallout probability invasion maps of the SV area

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Acknowledgments

We greatly thank IGM (Istituto Geografico Militare) for providing historical topographic maps
This project has been partially funded by 'Dipartimento Protezione Civile - Progetto V1: Valutazione della pericolosità vulcanica in termini probabilistici'