Dear Reviewer #3,

many thanks for your careful review that will definitely improve our manuscript.

In the following we try to comment (in italics) how we will respond to your comments in the revised version.

Abstract

Abstract should be overall re-written to emphasize the importance of good probability estimates of lateral eruptions.
The a priori assumption considered about how the past and present eruptive volcanic fissures can be used to estimate future spatial distribution of flank eruptions over long-term should be briefly described in the abstract to focus the work purposes as well as emphasize differences with previous works.
The difference of previous studies should be highlighted: time window extension that allows to increase the number of fissure (even the data incompleteness seems to not promote a substantial or change on forecasting capability) and therefore, to consider training and test sets to estimate density functions following a machine learning approach as well as the inclusion of the interconnectivity (induce stress) of flank fissures opening with deformation sources as the volumetric source that feeds eruptions and/or flank slip.
Before the training and test models description authors should describe that, for probability estimations, a kernel technique is used to obtain the unknown probability density function at the sampling points of the target area. For such a purpose different kernel functions are tested to construct probability maps (instead of directly talking about kernel functions) splitting data on to training and test sets.

This is a comment we have received from all three reviewers, so we will certainly need to do this. All the suggestions in the abstract given here will be taken into account carefully.

The term ‘unclamping’ should be removed from the abstract. Instead a brief introduction over induce stress should be included in the section 3.4.2.

We thank reviewers for raising the issue related with the use of these two terms. In geophysics, mostly in research in the field of earthquake triggering, inhibition, and clustering, the terms 'clamping’ and ‘unclamping’ are and have been widely used (at least in the last 20 years) to denote the effect of the changes in the normal stress resolved on predefined planes and associated with a determined source of deformation (see for example outstanding works by Lin and Stein 2004, and Toda et al., 2005). A similar terminology, to denote normal stress changes on fractures in volcanic environments (and due to volcanic sources of deformation) can be found in volcanological literature (see e.g., Walter et al. 2005 -for Etna-, Bonali et al. 2015, Dumont et al., 2024). However, we realize that such terminology is probably not well known in the volcanological literature in general; for this reason we definitely will introduce the topic and will fully clarify the meaning of these terms in the paper.

Nomenclature about ‘canonical map’ should be defined after first use (line 16).

We will also clarify what we mean with "canonical map".

Introduction

The power of the work should be enhanced in the introduction. I recommend a carefully rewritten, removing some parts that could be better merged onto other manuscript sections. Some suggestions the authors should take into account could be:

Focus lateral eruptions, main subject of the manuscript: paragraph containing line 25 would be better removed; the paragraph that starts on line 45 should be merged with the paragraph from lines 30 to 45. Then continue with the paragraph that starts on line 65 and the one that starts on line 74. The introduction should finish with a brief mention of the training and test procedure and the sensitivity analysis.

Paragraphs that start on lines 49, 82 and 89 have too much information for the introduction. I recommend cutting the methodological descriptions and merge such descriptions in the next sections.

These comments about the Introduction are generally similar to those we received from other reviewers, so we will need to restructure this section as well.) We agree that some parts are too detailed and should be moved to other sections (e.g. to the Data and Methods sections).

Data

This section should be the emplacement of the information presented in paragraphs that start on line 49 and 83 (subsection 2.1).

We will move some of the parts from the Introduction to the Data section.

Method

Unified notation should be used to name time windows: example, CE vs BP. CE is before/after 1971 or are the authors using the Gregorian Calendar?

We will move to a unique notation using CE (so for example 2500BP will become -500CE) throughout the manuscript.

Authors should describe here that assumption of the first stage of the analysis is that the past and present eruptive fissures can be used to estimate future spatial distribution of lateral eruptions over the long-term. The stochastic model they are using where a spatial point process where fissures are considered as random points within a set should be briefly described.

Ok

What is the role of the major and minor fissure sets classification for the computation of the spatial probability? I think they are used for train-test exercises because later on (lines 184-185) the authors refer to the assumption that future opening will be influenced by how close a point is from a fissure system.

No, this was not the case, we will better explain how we used the minor and main fissures in our analysis. In particular, in the presented analysis, we did not distinguish between main and minor fissures but we considered all fissures belonging to the same eruptive system, i.e. the same eruption.

I do not have a good understanding of the way authors estimate the rate of flank opening. My intuition is that the kernel function to estimate the rate of flank opening in a given cell point (every cell of the mesh assimilates to a point) of the domain (expression 1) takes into account the distance between the cell point of flank opening following expression 1. That is the way authors take into account the length and fissures orientation. However, they refer to the minimum distance between a point to a linear fissure element. Authors should define minimum distance. Is it the euclidean distance between two points on a plane? In this case the point of the linear fissure element is the one that accomplishes for the minimum euclidean distance. Is the elevation of the points taken into account? If not, what is the topography effect? From the physical point of view, the regional stress field caused by Etna topography could influence fissure opening. Maybe considering a topography zoning of the target domain given areas with different elevation and three dimensional euclidean distance could be a way to consider the topography effect.

Yes, we used Euclidean distance. We neglected the vertical coordinate (Z), and we actually had not thought of adding it. We have now tested (by using the Z coordinate from a DEM at 5m resolution) and, when adding the Z coordinate, the differences in distances among fissures are below 35 m, except in two cases when it is higher but less than 100m. So, for simplicity we neglect the Z coordinate in the computation of distances, as its addition leads to negligible differences in terms of Euclidean distance with respect to considering only the Easting and Northing coordinates. We will specify it in the revision.

3.2. Identification of the best kernel

The choice of kernel function with appropriate values of h has some consequences for the parameter estimation because it controls how expression (3) varies with distance from existing fissures. Gaussian and Cauchy kernels are based on the intuition that the next fissure to form will not be far from an existing one. What are the assumptions to consider exponential or uniform kernels? Do the authors choose a pair or just one kernel function to generate the probability map? How do the authors find the best? What kind of norm (measure) are they using?

The assumption in using the Exponential function is similar to Gaussian and Cauchy (it decreases -exponentially- with the distance). Instead for the Uniform we added it to consider an extreme case representing that the fissure location, at least in some instances, is also uncertain. So a Uniform function would represent the

case in which we do not rank points within a given distance from a fissure as more or less prone to a new opening, which in practice allows us to account also for the uncertainty on the fissure location.

3.4.2. Inclusion of stress changes due to different deformation sources

Lines 228-229: some reference should be included as Walter and Amelung (2004), Walter et al. (2005), Dieterich et al. (2003), Thatcher and Savage (1982), Stein (1999) or the classical King et al. (1994) (Static stress changes and the triggering of earthquakes, BSSA, 84 (3): 935–953. https://doi.org/10.1785/BSSA0840030935

Please, define clump or unclump through the sign of normal stresses to the plane of fracture.

Line 250 should be merged with the paragraph that starts on line 241 (in this way, there are more single sentences along the manuscript the authors should be take into account).

We will account for these suggestions in the revision.

4.1 Reference model on training data

Lines 271-274: How do you measure that the Exponential model is always the best?

Can the null hypothesis be rejected for the rest of the distributions? Visual inspection of Figure 5 for 1600 CE training subset does not allow to distinguish the Gaussian and exponential distribution.

We added a computation of the RMSE for each case.

1. **Discussion**

A flank eruption implies a fissure where magma is extruded as defined by the authors; however a fissure could be not related to a flank eruption. I think special attention should be given to this fact, including in the discussion a few lines about the effect of possible fissures not related to lateral eruptions. I assume there must be some kind of uncertainty on the fissure dataset consider by the authors.

We will better specify that we used only the fissures or portions of them that fed an eruption, i.e. those that correspond to eruptive products (lava flows or scoria cones). Dry fissures that do not correspond to any eruptive products were not included in the analyzed dataset.

Some lines about the fidelity or not of the probability map with the physic principles of the lateral eruptions should be included in the discussion.

We are not sure to understand what the reviewer means with fidelity. If the reviewer means to add some lines on the actual agreement between the probability map and the real fissure opening, what we can say is that in Section 5.2 (original Lines 371-379) we actually tested the probability of the vent opening in the most recent lateral eruption occurred after the setup of the model.

Lines 320-322: “10-5” should be replaced by 10^{-5} and so on.

Yes, right.

1. **Conclusions**

Instead of a canonical map, I would refer to a canonical cartography set that takes into account different future scenarios.

We prefer to keep the term "canonical map" for the main product of our work. Indeed as written by Lapaine et al. (2021): "A map is always the result of cartographic mapping. This is a process that associates a set of spatially related data with another set called a map, representation, or model, while preserving spatial arrangements and simplifying detail for specific purposes. Regardless of the definition of the map, cartography is the science, technology and art of cartographic mapping and using maps".

We will clarify that with the term "canonical map" we denote the probability map of future vent opening based on the longer set of data (the last 4000 years), still representative of the present behavior of Etna volcano. Further, this map is based only on the geological data, with the only assumption that future vents are more likely to open close to past eruptive fissures. The additional maps are based on less general assumptions. For this reason, we consider the canonical map as the main product of our work, keeping the other maps as additional sensitivity tests of the methodology.

Finally:

There are some missing single sentences across the manuscript that should be merged with paragraphs.

Ok.

In general, the quality of figures should be improved. Furthermore, I would merge Figure 2, 3 and 4; Figures 7 and 8; and Figures 9 and 10.

We will try to merge the figures in the suggested way and see if they are still readable.

Figure 6b seems cut.

Panel b has moved, you are right.

Data and figures on the Appendix are not properly cited on the overall manuscript instead of it is cited supplementary material.

We will check this carefully.

References:

F.L. Bonali, A. Tibaldi, C. Corazzato, Sensitivity analysis of earthquake-induced static stress changes on volcanoes: the 2010 Mw 8.8 Chile earthquake, Geophysical Journal International, Volume 201, Issue 3, June 2015, Pages 1868–1890, https://doi.org/10.1093/gji/ggv122

Dumont, Q., V. Cayol, and J.L. Froger (2024). Is stress modeling able to forecast intrusions and slip events at Piton de la Fournaise volcano? Earth and Planetary Science Letters, 626, 118494. https://doi.org/10.1016/j.epsl.2023.118494.

Lapaine, M., Midtbø, T., Gartner, G., Bandrova, T., Wang, T., and Shen, J. (2021) Definition of the Map, Adv. Cartogr. GIScience Int. Cartogr. Assoc., 3, 9, https://doi.org/10.5194/ica-adv-3-9-2021.

Lin, J., and Stein, R. S. (2004). Stress Triggering in Thrust and Subduction Earthquakes and Stress Interaction between the Southern san andreas and Nearby Thrust and Strike-Slip Faults. J. Geophys. Res. 109. doi:10.1029/2003JB002607

Toda, S., Stein, R. S., Richards-Dinger, K., and Bozkurt, S. B. (2005). Forecasting the Evolution of Seismicity in Southern california: Animations Built on Earthquake Stress Transfer. J. Geophys. Res. 110, 1–17. doi:10.1029/2004JB003415

Walter, T. R., V. Acocella, M. Neri, and F. Amelung (2005), Feedback processes between magmatic events and flank movement at Mount Etna (Italy) during the 2002–2003 eruption, J. Geophys. Res., 110, B10205, doi:10.1029/2005JB003688.