Interactive comment on "Assessing qualitative long-term volcanic hazard at Lanzarote Island (Canary Islands)" *by* Laura Becerril et al.

Laura Becerril et al.

laurabcar@gmail.com

Reply to JL Sophie Mossoux

Specific Comments:

How do you explain the difference that can be noticed between this manuscript and the susceptibility map published in 2013 by Bartolini et al.? Why did you had to produce a new version?

The previous susceptibility map created by Bartolini et al 2013 is only an example of the capabilities of QVAST. They used the geological information available at that time in the literature. In this work we have done a comprehensive analysis of the volcano-structural and additional geological information, adding new structural data and also

the stress field model for the island, therefore obtaining a most complete susceptibility map.

Explain why it has been decided to only focus, for some hazards, to specific scenarios instead of hazard assessment on the whole island. The ash fallout is in the paper limited on one specific scenario meanwhile the susceptibility map could be used to extent the analysis to the whole island. Lava flows have been simulated for the whole island.

The particularity of each process (hazard), as for example ashfall, forces to simulate individual scenarios. Ashfall process does not depend on the topography (DEM). Therefore, it is not possible to use the volcanic susceptibility map as base map for simulating ashfall. It would be necessary to do almost 150000 simulations that correspond to the number of pixels of the susceptibility model. All these simulations together would give us a superposition of many plumes that would cover the entire island...so not having much sense. For this reason we decided to simulate ashfall only in the highest probability vent assuming a Strombolian eruption similar to 1824 eruption. This approach has been used also in other long-term volcanic hazard assessment for ashfall hazard (see Cioni et al., 2003; Orsi et al., 2004; Rolandi 2010)".

How would you combine all the hazards together?

In this case we have preferred to show individual scenarios that can be useful during volcanic crises for Civil Protection, since each hazard has to be managed in a different way during an emergency. Nevertheless, if we have to combine all of them, we will follow the methodology that we used for El Hierro Island (Becerril et al., 2014). We combined the most probable scenarios to create a qualitative hazard map of El Hierro constructed from the combination of all them. We did map algebra and distinguished four levels of hazard, from very low to high hazard, depending on the number of individual hazards that overlapped on each point (pixel) of the map (Becerril et al. (2014); http://www.nat-hazards-earth-syst sci.net/14/1853/2014/nhess-14-1853-

2014.pdf). TECHNICAL CORRECTIONS/TYPING ERRORS

Title - wouldn't it more suitable to write "hazards". Three different hazards are studied in the paper. Correction done

Manuscript

L13-14: Lanzarote is an active volcanic island that has hosted the largest (>1.5 km3 DRE) and longest (6 years) eruption, the Timanfaya eruption, on the Canary Islands in historical times (last 600 years): - the largest and the longest compared to? It is referred to the rest of the Archipelago. It is written in the text: Lanzarote is an active volcanic island that has hosted the largest (>1.5 km3 DRE) and longest (6 years) eruption, the Timanfaya eruption, on the Canary Islands in historical times (last 600 years).

L14: the Timanfaya eruption - give the exact date of the eruption Correction done

L21: rational land planning - would you mean rational or national? Rational (Based on or in accordance with reason or logic)

L24: . . . the main aspects. . . - give more information about what you mean with "main aspect" We have added to the text the following sentence: such as the extension, the magnitude or the impact of hazards on an area . . .

L27: . . . in those places. . .: - is Lanzarote also included in the THOSE places? If not I would suggest to skip the "those" We have deleted "those"

L30: . . . due to the increase of exposition of most places . . . - due to urban sprawl . We have changed exposition by urban sprawl

L33: . . . despite having hosted 15 eruptions in historical times - you might refer to your table 1 and to add, in this table, information about the years of these eruptions. The 15 historical eruptions took place in the whole Archipelago, so none of the eruptions of table 1 correspond to any historical eruption in Lanzarote. Those of the table are pre-historical eruptions.

L34: . . . one of the most important touristic destinations - What is your reference? Wouldn't it better to be more general and say that "Lanzarote is an important touristic destination"? We are talking about the Canary Islands in this sentence. The reference has been taken from the fact that Teide National Park is the most visited in Europe (http://www.gobiernodecanarias.org/istac/jaxi-istac/tabla.do; http://dx.doi.org/10.1016/j.jnc.2016.03.001 see table 5)

L35: . . . has abandoned some traditional livelihoods - Was the traditional livelihood more adapted to the volcano to mention this in the paper? Not really, we have deleted this part of the sentence in order to not create confusion.

L35-38: Tourism has had a considerable economic impact on the region that has abandoned some traditional livelihoods and has suffered a tremendous demographic expansion. The latter, not always well planned and without considering potential natural hazards, may now interfere with the effective management of future volcanic crisis. - It would be great to support your statement of growth with some numbers or with a map where you would see the urban sprawl. So we can have an idea of the importance of the change (big/small change) We have added some numbers that indicate the total inhabitants of the archipelago in 1970 and in 2016.

L38-42: The last eruption, that occurred in El Hierro (Fig. 1 Inset) in 2011-2012, is a good example of the implications of not having conducted a previous hazard assessment. . . - The link with the demographic expansion is not clear enough. Could you please give us additional information: did the urban expansion mainly occur in the last eruption period? We have written additional information which is possible to compare the growth of the population in The Canary Islands during the last 50 years.

Did the eruption cause socio-economic disaster because no plan was existing? There was an emergency plan at that moment, but the management of the eruption was based on potential eruptive scenarios that may occur in similar volcanoes than those from el Hierro but not on a specific knowledge of the past volcanic activity on the island.

What was the human component/implications/problems of this eruption on the Island? One year before the eruption, the island was already severely impacted by a drastic drought that caused famine, and half of the population emigrated to other areas. When the eruption occurred, many of the Lanzarote inhabitants, who decided to remain there, finally emigrated too.

L55: Timanfaya type eruption - Define the Timanfaya type eruption We have added to the text the following sentence: (see the geological setting description to obtain more information about this eruption) to not describe again the Timanfaya type

L57: . . .the first susceptibility map - . . .the first volcanic eruption susceptibility map Correction done L59: . . . a spatial probability map: - Of what? We have written volcanic spatial probability map

L61: . . .these previous studies tackles a proper volcanic hazard - What do you mean with "proper" We have changed proper by thorough

L65: based on a review of these previous studies. . . - Did you only used the above mentioned studies or did you used also additional information. If so, I would suggest deleting the word "previous". We have added "new generate information" in order to clarify that we used previous and new information.

L66: Matri et al (2016a) - et al. Correction done

L68 : due to the scarce available information - Gives a "bad" impression. Wouldn't it more suitable to present the think like if there are out of the scoop of this paper for example We can change the adjective, but it is true that not much geochronological information, essential to obtain a right recurrence period and to evaluate volcanic hazard on the island, is available. We prefer to state the sentence that it is, due to if the paper is read in the future, perhaps someone decides to invest money for completing the dating catalogue.

L70 : recognised in the Holocene - recorded ? in the Holocene We have written "doc-

umented" instead of "recognised or recorded"

L84-L89: - Does this paragraph give an added value to this work? This paragraph contextualises the geological setting of the island. Since the volcanic hazard evaluation has as basis the geology, we consider that it is important to make a general framework of the island, and afterwards to go into more in detail.

L95: a really high eruptive rate . . .. L105: eruptive rates of 0.013-0.027 km^3/ka - Pay attention to the fact that the second eruptive rate is higher than the first one that you mention. Maybe it could be a good idea to avoid the use of "really high" for the first eruptive rate or to also give this impression for the second one. We have deleted "really"

L108: Tao, Nuevo Fuego and Tinguaton eruption - To keep as singular or to put as a plural? This is the name of the eruption because 3 cones were formed along a fissure during 1824. Nevertheless, we have deleted "the" to not create confusion

L115: Methodology - Isn't this paragraph more related to the data that you are using? In this first paragraph we are explaining the data and how we have used these data for conducting our analyses. For this reason we consider it is part of the methodology.

L116: the first step in any long-term. . . - Could you mention more precisely why you are collecting your data "to produce a volcanic susceptibility map"? We explain which kind of data and why we use them to produce the volcanic susceptibility map further in the text (lines 200-210 in the new manuscript).

L117: Holocene period - Justify the choice of this period in the frame of your work. We have added to the sentence that products are better preserved in the Holocene period. But also, and this is inherent to the meaning of Holocene, it is common to focus the volcanic hazard assessment during this epoch, since the volcanos from the Holocene are considered as active.

L120: "we" - It is a personal choice but may I suggest to use an impersonal form in

the whole manuscript. To avoid the use of "we" and to adapt the sentence like this "Previous geological ... have been taken into account". Correction done. In the rest of the paper we have preferred to use the active "we" form, due to NHESS has not the rule for writing in impersonal or passive style.

L127: ... in the computation of volcanic susceptibility - State clearly why the previous volcanic susceptibility maps that have been realized in Lanzarote have to be updated for this work. We have preferred to include a sentence in the susceptibility analyses section (lines 221-222) to state clearer why this new susceptibility map has been updated on the previous ones.

L129: previous information - Please, provide additional information about which previous information you are talking about We refer to all above mentioned information (maps, ortophotos, structural analyses, etc.). We have changed previous information by "all above mentioned information"

L132: for the spatial analysis (volcanic susceptibility). - Are you producing one susceptibility map or are you making a distinction between lava flows and explosive eruptions? I guess the probability to have these kind of eruption differ within the island (presence or not of water). The susceptibility map shows the probability of hosting new eruptions regardless of the type of the process such as: lava flows, ashfall, PDCs..... or other hazardous processes. Therefore, we have developed a susceptibility map that is the basis of the lava flow scenarios, since it is the most expected process on the island. For the other two processes, ashfall and PDCs, we have preferred to not use the susceptibility map, because our intention was to show how these processes would affect if there were an eruption from the highest probability area of the island.

L133:... to simulate lava flows, fallout and pyroclastic... - Use the same sequence as the one presented in the manuscript. Correction done

L115-L134: - When stating the data that you are using, I think you forgotten to mention the wind information you've collected. You are right!. We have added data wind

collection in this section.

L140: most sub-historical - What do you mean with this? It is the period of time before the Spanish conquer, that is, before 1405.

L141: Guatiza map) - No parenthesis needed Done

L146: Guatiza map) - No parenthesis needed Done

L140-L146 and L157-L166: - Clearly state the difference between both paragraphs. In the first paragraph we are talking about the sub-historical eruptions (before the last 600 years), meanwhile in the second one, we are talking about the historical ones (last 600 years). We have included before what means historical and sub-historical eruptions.

L163: 226km^2 of the Lanzarote's surface - Replace with 226km2 of Lanzarote surface Correction done

L165: Some of the stages... - Simply refer to these studies Correction done

L167: the consequences of 6 years - All number under 10 have to be completely spelled. Replace with "six years" Correction done

L173: 14km in length - Where is it on the map? We have added to figure 1, dashed lines to indicate the total length of the historical fissures.

L174: ...the SW coast - Isn't it the NW coast? We have changed SW by NW

L190: ...we obtained Miocene-Pliocene, Pleistocene - Give some arguments why are you here extending your time frame. Done - Be consistent with your figures and give the same terminology in your text and on your figures (table 2= mio-pliocene) Correction done

L199: ...eruption will start... - Replace "will" with "may". Susceptibility maps are still probabilities and some nuance has to be given to this sentence. Correction done

L201: This volcano-structural information... - Based on the premise that new vents

will not form far from the previous ones, this volcano-structural information is used... Correction done

L214: ...the distribution of volcanism... - Replace with: the volcanism distribution Done

L216: ... taking into consideration Geyer et al. (2016) - the contribution of Geyer et al. (2016) is not clear enough. If I'm right, they produced the regional stress field. Refer to them after mentioning the regional stress field or state clearly that they produced it: "the regional stress field produced by... " Correction done

L218: to generate quantitative ... in the island - to generate a quantitative... on the island Correction done

L219: ...method that uses the calculation of a ... - method that calculates a kernel function... Correction done

L220: The method is based on the distance... - rephrase your sentence. It has the exact same structure as the previous one. We have changed the previous sentence, therefore we have left this sentence as it was. L223: onshore and offshore - it is quite confusing, you are giving us the impression that offshore eruptive fissures may be observed and used but later on you state that they can't be used for the analysis (L315). The information present on line 315 has to be given before to clearly state that even though offshore eruptions are highly probable, they can't for the moment be included. We are talking about two different things. Volcano-structural information offshore (vents and eruptive fissures) have been considered for the spatial analysis but due to the fact that they have not ages (geochronological dates), it is not possible to conduct a temporal hazard assessment using such information.

L224: ...and reliability values - refer to table 3 Done

L225: GVB-CSIC - define the acronym Done

L227: LSCV: - define the acronym Done

L225 and L228: - avoid repetition of the same information or clearly state the difference between both panels. Elicitation of expert judgment procedure ... meanwhile a group of expert... We have deleted the sentence to avoid duplicity and rephrased the sentence

L217-239: - the sequence of the manipulation is not clear. It gives a repetition feeling. Restructure the paragraph. Done

L231: the bandwith parameter - could I advise to be consistent in the terminology that you choose. Pick up one word: smoothing parameter or bandwidth parameter. We have stated that there is the possibility to call this parameter in four different ways: smoothing parameter, smoothing factor, parameter h or bandwidth to make readers clear that commonly in the literature it could appear with different names. In the rest of the text we have called it as Bandwidth, maintaining this term throughout the text, even in Table 3.

L235: considering the regional stress field model - clearly state that the stress field is not use as input in QVAST. We have included a sentence to clarify this issue.

L249: ...size were inferred from data published from historical eruptions - replace with ... inferred from the historical eruptions published data. Correction done

L250: ... and references therein - please provide all main references you are using. We have provided the first three references as main ones, but inside the map's memories there are more that can be consulted.

L251: ...parameters of 1824 - replace with: "parameters as the 1824... " Correction done

L252: ...since this scenario can be... - since these parameters can be? We have slightly changed the sentence

L260-264: - wouldn't this be more suitable for a caption? We are describing the figure 5, but anyway we have changed a bit the sentence.

L258: . . . the entire wind rose directions and for the NE direction. . . - refer to the figures (Fig. 5b) and (Fig. 5a) Correction done

L260: figure 5A - Please provide, such as for figure 5B, the parameters that have been used. They are the same parameters. We have changed the sentence into the text to make it clearer.

L269: . . . as single vent scenarios reproducing lava flows of 1730 - I don't see the added value of showing these results. Where you calibrating the model using these lava flows? The overall map is more interesting. We wanted to show the extension of the lava flows from both historical eruptions. The 1730-1736 eruption was longer in time, and therefore more volume was emitted, invading a greater area than the 1824's eruption. If we only show the total hazard map, we are not giving the opportunity to the reader to see the extension differences between these two historical eruptions.

L273: . . .35km, since 1730-36 eruption poured out lavas. . . 25km. - Not clear which final length you are using for the simulation. Two lengths are mentioned. Which has been used to model the lava flows? The parameters used for the simulation could be added in the caption of the figure. We have clarify the sentence adding more information

L286: . . .in areas close to the previous - Are you still using the susceptibility map? In this case we are simulating only in areas close to previous eruptions that have generated PDCs, without considering the susceptibility map. We consider more interesting to show the reach of PDCs with different characteristics.

L295: in the range of around 5-29° - Be more precise We have added some more information to the text

L296: . . .areas with different Heim - Heim? We have change heim coefficients by collapse equivalent angles - Give the exact values that you used. We have added a sentence clarifying that each of the simulation is associated with previous occurred

PDCs on the island. Numbers in Figure 7 are related with those from Table 1.

L300: . . . has hosted important eruptive - Has hosted an important. . . Correction done

L321: . . . Timanfaya eruption - Reference to fig 4 We have reference fig 4

L322: . . .in this zone (Figs 1,4) - Reference only to figure 3 Correction done

L326-328: - The argument that is given is weak. Give more arguments. State clearly how does that method of Cappello et al. have been proved. We have preferred to use a method such as the one of Capello et al. (2013) as it has been successfully tested in volcanic fields similar to Lanzarote, rather than to develop a new method, whose the lack of testing could imply a higher uncertainty in the results obtained.

L329-333: - Keep in mind that the conclusion that is made is only valid for one case scenario. But this scenario has been done with the prevalent winds of the Canary Islands. In the model it is not possible to take into account all possible winds for one scenario.

L338: . . .National Park and Natural Park - Show these areas on a map We have included in Figure 2 two dashed lines to show the extension of these areas

L341: . . .would be practically unaffected by lava flows - Would have a lower chance to be inundated by lava flows. Correction done

L343: . . . to areas close to the coast - All areas in Lanzarote are close from the coast. Those closer areas to the coast are more suitable to the occurrence of hydromagmatic events, since the water from the sea can play an important role in eruptions located there. Nevertheless we have clarified the sentence adding "more".   TABLES: Table 1: add the starting and end year of each eruptions They are not historical eruptions; they have been recorded in geological times. They are not dating for any of them.

Table 2: Are the faults onshore or offshore We have modified the table to clarify they are onshore faults

Table 2-3: use similar names Correction done

Table 4: - The mean is usually associated with one value. Clearly state which is your mean length: 5 or 7.

- Put the table in the same sequence as the manuscript. We are not sure if you mean format. We have copied the format from previous tables. - Column height: which is the unit of it? km- added - Size particles: unit? Phi scale (φ)

FIGURES: GENERAL REMARQUES - Put the names of the islands, cities, volcanoes, parks that you mention on a map. Done - Use colorbrewer2.org to pick up colors that have a good contrast. Sometimes, some colors have not been selected properly provoking some confusion in the figure. - Writing "legend" as title of the legend is not really needed. People know that symbols are the legend. Ok

Figure 1 - The 2011-12 eruption is quite hard to see on your map. Make the symbol or the frame bigger. The triangle for the 2011-2012 was too small, we have enlarged the symbol. - colorbrewer2.org We have decided to leave figure as it is but we really appreciate your suggestion that will serve us for future figures. - "historical eruprions 1824" to be replaced with eruption. Correction done - Use in the sea the same blue as the one used in figure 2. The blue that is use for the moment make the message more difficult to see. The geological information is the message of this figure and not the sea. We have applied the same transparency to both figures. They show now the same blue sea colour. - Source: http. . .. : wouldn't it adapted to propose your own version of the map? We have clarified the source of the figure.

Figure 2: - Historical eruprtions 1824: to replace with eruption. Correction done - If a name is associated to some eruptions, I would suggest adding the names in the legend. We have placed the corresponding names - colorbrewer2.org - Some elements of the map are not present in the legend (the symbol of how the pictures have been taken for example). We have indicated in the figure the orientation in the figure. Therefore, we have not inserted the symbol into the legend. - Show only the elements you mention in

the text. Some cones and eruptions that are present in the figure are never mentioned in the text: remove them from the figure. All names of the figure caption have been referred in the text of tables at least once.

Figure 3: - colorbrewer2.org - Use similar colors for the vents and fissures of one same period. We had already done it.

Figure 4: - Susceptibility? Give more information: susceptibility of. . . . We have written "Volcanic Susceptibility" - "Value" can be removed. Done - The colors of the legend are not the same as the one in the figure. We have changed them - Timanfaya park: where is the park? We have changed in the caption Timanfaya Park by south of the Island.

Figure 5: - Scale: put everything to 10km and use the same extent for 5a and 5b. Done

Figure 6: - Remove the "legend" title and the "lava_35km", "lava_7km", "value", "lava flows.tif" Done - For a and b: place the eruption location you used for the simulation - Inform the reader the values are probabilities to be inundated by lava flows. Done - For c: Color choices: Look at Thompson et al. (2015). She is giving useful tips for the selecting the right color range for maps. Use the same color range as for a and b or adapt all of them based on Thompson et al. Green is usually considered as safe however, you have still some probabilities. You are right, therefore we have used the same colour for a, b and c figures.

Figure 7: - VEI: no additional information is given about that in your text. You are right. We have deleted it. - Give some extra information about all the symbols of your map. What are the lines for. Done (We have used different patterns to show the limits of all PDC scenarios).
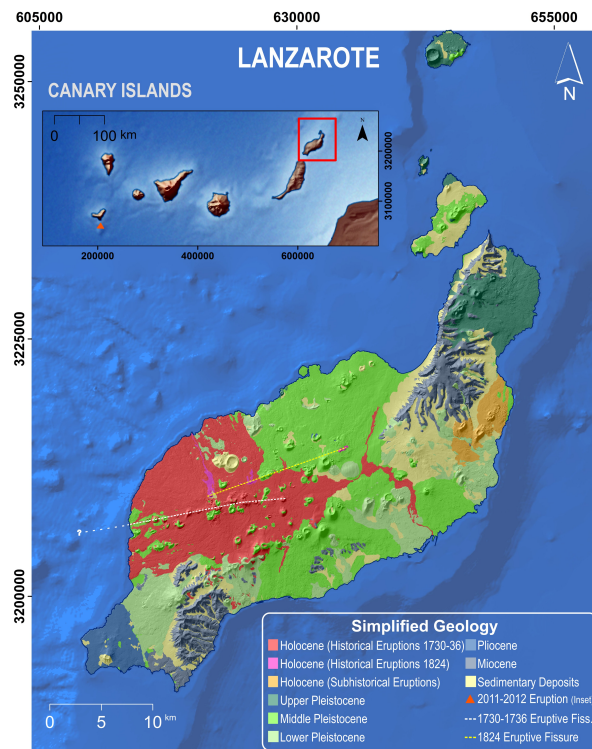
Fig. 1. Figure 1. Simplified geological map of Lanzarote Island. The top left inset displays the location of Lanzarote within the Canary Archipelago. (Original geological map can be found in: http://info.igme
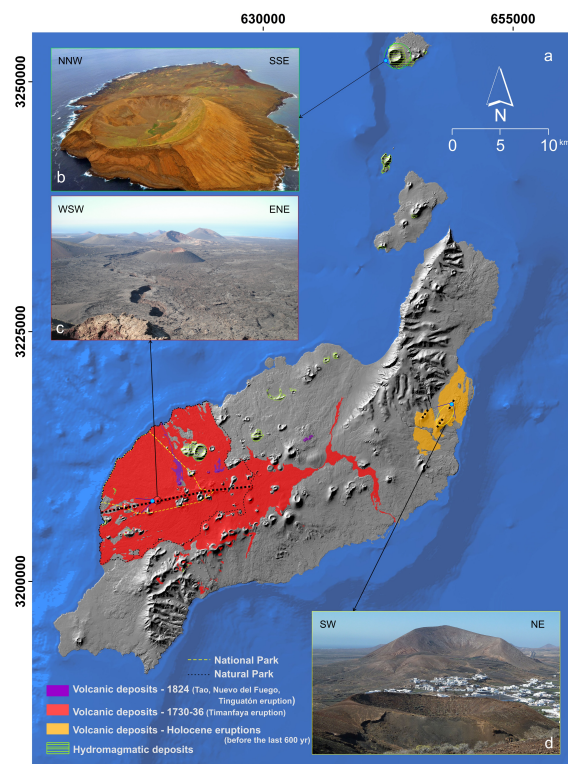
Fig. 2. Figure 2. a) Historical eruptions (red, pink and yellow), and hydromagmatic edifices (green) on Lanzarote; b) Alegranza hydromagmatic cone with a diameter of 1.2 km; c) Timanfaya cones; d) Mt. Guenia
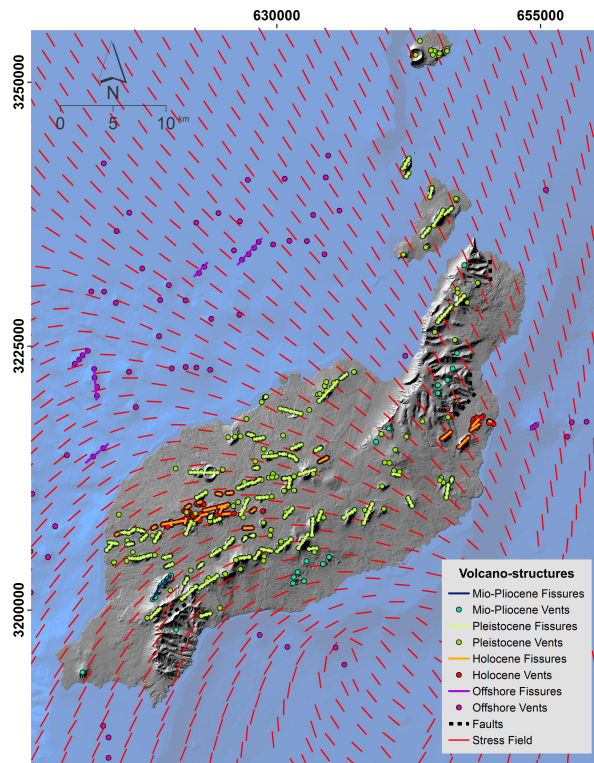
Fig. 3. Figure 3. Volcano-structural datasets defined for Lanzarote and used for evaluating spatial probability. Max-imum compressive horizontal stress trajectories are also indicated (red lines).
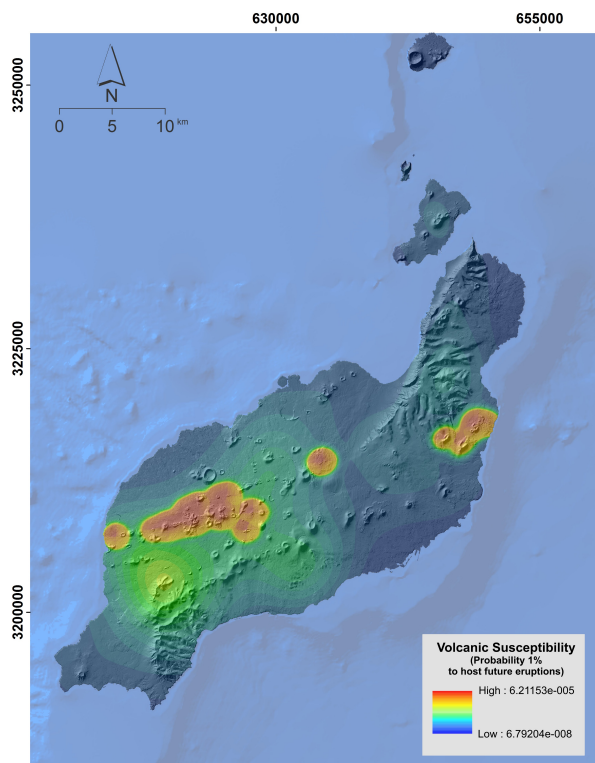
Fig. 4. Figure 4. Volcanic susceptibility map of Lanzarote Island. The highest probability (0.00006) of new vent open-ing is obtained along a NE-SW area. High probabilities are also observed in the South of
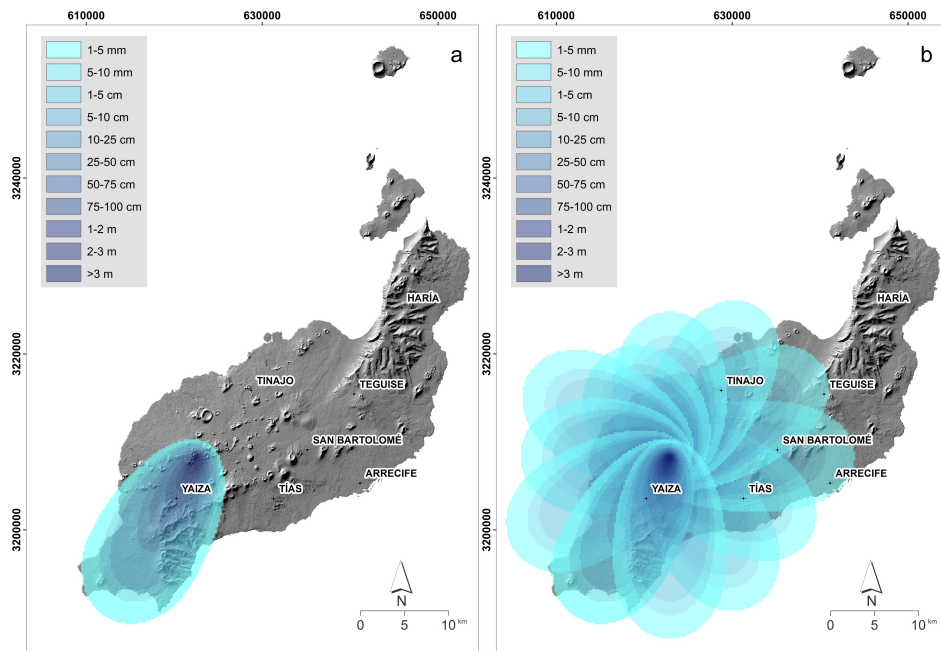
Fig. 5. Figure 5. Fallout scenarios at the highest probability vent for the NE wind direction and for the entire wind rose directions performed with VORIS 2.0.1. a) NE wind simulation assuming a Strombolian e
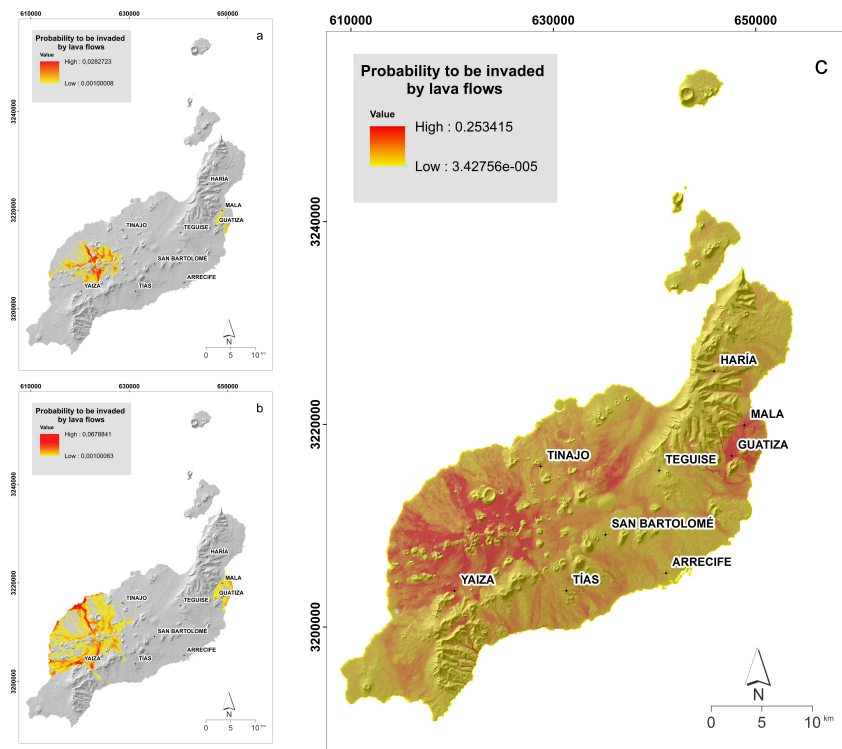
Fig. 6. Figure 6. Lava flow scenarios for Lanzarote performed with VORIS 2.0.1. a) Timanfaya scenario; b) 1824 eruption scenario; c) Total lava flow map. Red colours are those areas with the highest probabili
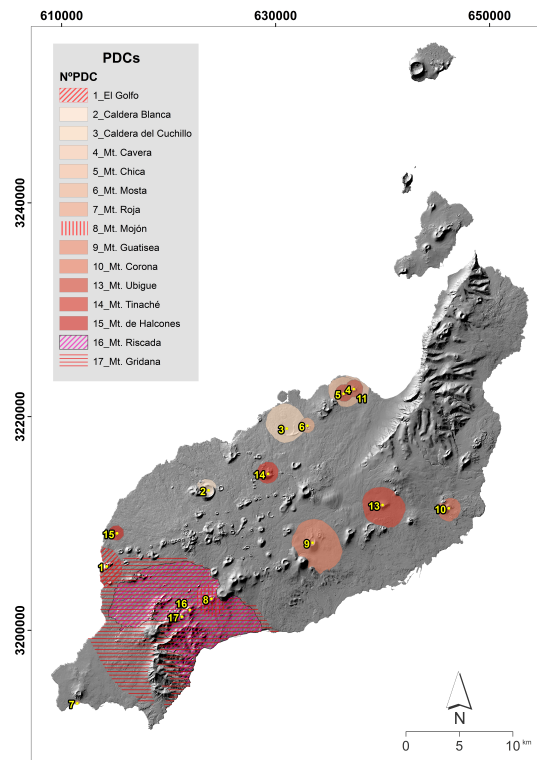
Fig. 7. Figure 7. PDC scenarios performed with VORIS 2.0.1. Covered areas with different collapse equivalent heights (Hc) and collapse equivalent angles (θ) (see the text for more detail). Different symbols (