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Natural Hazards and Earth System Sciences
Discussions
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Interactive comment on "A multi-scale risk assessment for tephra fallout and airborne concentration from multiple Icelandic volcanoes – Part 2: Vulnerability and impact" *by* C. Scaini et al.

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Dear Editor,

we hereby send you a revised version of our manuscript entitled "A multi-scale risk assessment for tephra fallout and airborne concentration from multiple Icelandic volcanoes – Part 2: vulnerability and impact". Here we answer to general comments raised by the reviewers (reported for clarity), and all changes are applied in the attached version of the manuscript.

Reviewer 1

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Reviewer I substantially agrees with the methodology and does not suggest substantial changes in the manuscript. We reviewed the document and ensure that all terms are explained and the reader is put in context. We also applied the required minor changes to the document.

Reviewer 2

Reviewer 2 pointed out some aspects of our methodology that needed to be clarified in order to avoid misunderstanding. In this work we propose and apply a simplified methodology that, although having many limitations, improves the current state-of-the-art and poses the basis for a wider risk-management action, focusing the attention on critical aspects and elements. We understand his/her concerns in ensuring that these results can support long-term decision making without misinterpretations. We thus include his/her suggestions in the manuscript, providing a wider background to this methodology and its results. Given that some aspects pointed out by the reviewer are related to both National and European scale, we add a part in the discussion that is common for both scales.

1) "The analysis of impact is essentially qualitative. This should be underlined in the different part of the analysis, since it may introduce important biases in the results, which may also affect the effectiveness of long-term mitigation actions. In particular, the vulnerability is not based on quantitative fragility assessments (e.g., Douglas 2007, NHESS), which assess the probability of damage for all potential intensities of the hazard. Only in this way a probabilistic risk assessment is possible (e.g., Cornell and Krawinkle 2000, PEER Center News), since both low intensities (with higher probability of occurrence, but low probability of damages) and high hazard intensity (with low probability of occurrence, but high probability of damage) may contribute to the probability of damage. To select a single critical value for the intensity, and report the probability of exceeding of this threshold is, in my opinion, limited and sometimes misleading (at very least). For example, in section 3.3 it is discussed: “The accumulation of 5–10 mm of ash can produce tephra-induced insulation flash-over, while a > 10 cm fine ash

fallout has a medium to high probability of causing electrical network failure ". How such a "medium to high probability" is accounted for here? How would this impact the results?"

As underlined by reviewer II, the assessment of vulnerability and impacts is essentially qualitative. The approach that he/she suggests, based on fragility curves, would allow to account for the probability associated with the occurrence of a physical damage due to low and high hazard intensities. The importance of fragility curves is commonly recognized, but their application in volcanology is quite limited (ENSURE, WP 1 – Del. 1.1.1. Fragility curves to tephra fallout are available for building typologies (associated to a given physical vulnerability), but are still under definition in case of ash fallout on main infrastructures, for which there are many factors (composition, humidity) that play an important role (Wilson et al. 2011). Thus, at the current state of knowledge is very difficult to adopt this approach. Moreover, a comprehensive assessment of physical vulnerability is beyond the scope of this paper, as we have further specified in the introduction and discussion of the reviewed manuscript. A comprehensive physical vulnerability analysis is in fact very difficult to perform due both to the scale of the analysis (the National scale) and to the limited availability of data (very few information are available on the features of exposed elements). At European scale, the main difficulty is that there is no agreement on ash concentration thresholds that cause damages to aircraft, and their performance in ash-contaminated airspace is still under definition. These motivations are also recognized by Douglas (2007), and between others he underlines that, while most impact assessment for earthquakes are focused on life losses and severe impacts on population, in case of other risks these procedures are performed to identify areas at danger and design risk mitigation actions (evacuation, intervention). Given that this is the aim of our work, we explicate our aim in the introduction. Moreover, we specify that our simplified analysis may put the basis for identifying specific areas on which to perform field/experimental work to gather specific information and perform quantitative risk assessment based on experimental data. The simplified impact assessment performed here is based on the choice of critical thresholds that lead to the verification of a damage condition. Reviewer II points out that the choice of a single critical value for tephra deposition that cause damages introduces strong assumptions. At national level we focus in particular on the potential impacts on critical infrastructures (electricity network and power plants), We integrated section 3.3 with more details on the choice of the critical value that cause expected damages on electricity network and power plants. Due to the importance of these elements, we account for their physical vulnerability hypothesizing a maximum vulnerability for all the elements that have suffered documented damage in past events, that is, hydroelectric plants and aerial sections of the distribution network. There are two main impacts of tephra fallout on the network: collapse/failure of network elements and flash-over of components. Wilson et al. (2012) propose the value of 10 cm as threshold for producing medium to high damages on network elements (towers, poles and lines). According to the authors, the values that can cause impacts to power plants are also in this order of magnitude. Moreover, Wilson et al. (2011) show that line collapses happened, for past events, for tephra fallout of this order of magnitude. But it is worth noticing that many impacts to transformers happen for lower tephra fallout values. Also, Wardman et al. (2012) show that lower values of tephra fallout (1-10 mm) can cause flash-over of components, providing a fragility curve for such phenomenon. Thus, in order to include all effects, and according to the fragility curve, we assume that 1 cm tephra fallout has a 60% probability of causing disruptions of components. It is worth noticing that we used a fragility curve for wet tephra, adopting a conservative approach, while dry tephra is not likely to produce flash-over. In the discussion, we suggest a differentiation of these two situations in future analysis. The underlying assumption is that, in case of failure of any component of the network, the network suffers a systemic damage. Thus, in order to account for both aspects (impacts on network and components), all parts of the network that are vulnerable to tephra fallout (section 3.2) and are covered by tephra fallout greater than 10 kg/m^2 (i.e. approximately 1 cm thickness) ash load are expected to suffer medium-to-high impact, and contribute to the calculation of expected impacts (Table 3). Impacts of lower tephra fallout values is not accounted here, also accounting for the fact that components are not necessarily directly exposed to tephra fallout, but we specify that this may be accounted in a comprehensive analysis (in particular, using a fragility function). We add an explanation on this point in section 3.3 and discussion. It is worth noticing that we partially account for the uncertainties related to the choice of the threshold value by varying the probability of occurrence between 5 and 20% (Table 3 and 4). In the discussion we stress the relevance of the thresholds choice and discuss how it can influence the usability of results. Moreover, we underline the need for specific studies to be performed in order to define quantitative thresholds that produce physical damages of elements. Note that this aspect is valid also for the analysis at European scale, as we underline it in the discussion.

2) "The potential applicability of the results is largely influenced by the fact that the hazard is essentially scenario based and limited to few potential volcanoes, neglecting most of the variability of potential sources (all the volcanoes) and potential eruptions (variability in eruption styles, volumes, etc., for all the volcanoes). This must be stressed, since it may greatly influence the results, and it must be discussed in all the parts of the manuscript in which the applicability of the results for long-term mitigation plans is proposed."

Eruptive scenarios considered here are a subset of the wide range of activities that happen at the (many) active volcanoes in Iceland, but account for different eruptive styles and in particular for the ash-producing scenarios more likely to happen according to historical record and volcanological studies. It is worth noticing that, for the hazard assessment, we use of statistically representative meteorological conditions at the European scale. Thus, given the small dimension of Iceland compared to the range of ash dispersal, it could be assumed the location of the vent do not strongly influence the outcomes of tephra dispersal hazard assessment. Our results for tephra dispersal may therefore be considered as valid for similar eruptions (in terms of eruptive source parameters) happening in the vicinities of the selected volcanoes, located in different parts of the island. Moreover, the robust statistical basis on which scenarios are built allows considering a wide range of possible outcomes for the same volcano and eruptive style, producing representative results of the expected ash fallout from the considered volcanoes. Nonetheless, we agree with the reviewer that it is worth reminding to the reader that outcomes of impact assessment are derived from probabilistic hazard assessment in order to avoid misunderstandings. Results of the impact assessment may therefore be used for a first-level impact assessment, but bearing in mind the influence of the scenarios choice. We add these considerations to section 2 and to the discussion in order to put the reader in context.

3) "In different part of the manuscript, it is underlined the “systemic” character of the analysis. However, the systemic vulnerability analysis here is, in my opinion, very limited. In particular, several systemic vulnerability assessments demonstrate that spatial correlations for damages (induced either by physical and/or functional inter- and intra-dependencies among components, or simply by the spatial correlation of the hazard) may lead to very important consequences in systems (e.g., Adachi and Ellingwood 2009, Computer-Aided Civil and Infrastructure Engineering). To model such spatial correlations, single realizations of the hazard (that is, single scenarios that, in this case, are represented by single eruptions and single wind conditions) should be systematically analyzed, and then aggregated considering the probability of occurrence of each of these scenarios (e.g., Cavalieri et al. 2012, Earthquake Eng Struct Dyn). If hazard curves (aggregating many potential single events) are considered as input, these spatial correlations are completely lost (e.g., merging all potential wind fields). To neglect this may introduce important biases, potentially strongly underestimating the expected losses. This is particularly important for the analysis of the road networks, as well as, the electric power network. On the opposite, in the manuscript, the “systemic” character is essentially related to the selection a priori of specific components that are important to the system performance, rather the identification of critical components a posteriori as a result of the systemic analysis. This choice is simpler, but again rather limited, and it should be stressed."

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Reviewer II points out an important aspect that is not directly considered in this work: the role of interdependencies, spatial correlations and other cascading effects that produce important consequences at a systemic level. In this work we consider only one aspect of the systemic vulnerability, that is, the a priori identification of elements and systems that are particularly relevant from a systemic point of view. We thus look for elements that play an important role for the system considered (i.e., the National socio-economic system and the European air traffic network) based on statistical data. The aim is to provide to the decision-makers a first-level assessment of expected impacts on these elements. Systemic impacts are, in this sense, impacts on the system due to the loss of functionality of critical elements, but without accounting for spatial and temporal interdependencies that may emerge during a specific volcanic event. It must be noticed that our work, the first example of scenario-based impact assessment for tephra fallout in Iceland, acts as an exploratory analysis that pose the basis for choosing both scenarios and areas for specific studies on cascading effects. The work proposed by the reviewer should therefore be performed in future and would complement this study and provide a wider perspective of expected impacts to decision-makers. But accounting for an effective analysis of interdependencies requires a specific scenario to be selected and its consequences to be described in detail, starting from the immediate physical impacts. This kind of analysis is beyond the scope of our work, but we agree with the reviewer in mentioning the important role that these effects they play for risk management purposes. In particular, we mention in the text the limitation of our approach with regards to road and electricity network disruptions, that may cause the failure of dependent services and infrastructures and lower the capacity of response of areas. Studies on electricity infrastructure vulnerability suggest that this analysis should start identifying where, how often and for how long electricity supply will be interrupted. This analysis should be performed by splitting the network at specific delivery points, implying a detailed knowledge of its structure (Kjølle et al, 2011). Similar considerations may be done for road and water supply network and many other services, but In order to be realistic and produce usable results, this kind of analysis require specific data on network structure and usage, not always easy to gather. Our intention with this work is to point out the critical aspects that should be covered in further work, and possibly promote new collaborations. s between involved stakeholders (infrastructure holders, service providers and end users). The same aspect can be underlined at European scale, at which only few studies on these aspects are available. Future developments should therefore include the analysis of cascading effects in respect to single scenarios in order to explore a whole chain of hazards, impacts and their propagation. We clarify these aspects in the introduction and discussion and propose further work that could enhance the current methodology.

4) "All the statements reporting probability must include the time frame and/or the conditions under which probabilities are assessed, otherwise they are meaningless. For example, sentences like “The electricity network is the most exposed element to an Askja OES 1875- type eruption, resulting in a 10 % probability of 655 km of the network being impacted” or “Based on all eruption scenarios, there is a 10 % probability of affecting 1–10 km2 of croplands. ” do not mean anything, without reporting either a time window (15 yr?, 10 yr?, 10000 yr?) or a condition (in case of eruption at Askja? In case of an eruption at Askja of 1875-type only? If so, what the the probability of an eruption of this type?). Essentially, this problem exists in many sentences of this kind throughout the manuscript."

Our probabilistic hazard assessment is based on scenarios characterized using the historical eruptive record and past studies (Part I). Given the rich historical record and high knowledge of Icelandic volcanic activity, it is possible for some volcanoes (e.g. Hekla) to associate scenarios with a “repose time”, while this is not possible for other volcanoes having a short documented eruptive history or not following evident evolution patterns. Thus, some scenarios used in this work are associated with a certain repose time, and other to a reference eruption, but we do not associate a probability of occurrence to each scenarios due to the high uncertainties of such approach. We explained this in session 2. In consequence of this, hazard and impact assessment results represent the expected situation conditioned to the occurrence of the scenario. We clarify this point in the text and accordingly all sentences in which probabilities are mentioned. For this reason, it is not possible to merge the outcomes of impact assessment for each scenario and produce a final map. Finally, given that decision-makers may want to compare expected outcomes from different scenarios, we introduce a qualitative impact assessment rating to classify impacts at European Flight Information Regions (FIRs). We specify in session 4 that this comparison is qualitative. Further work and current developments may provide a framework to enable the comparison of different scenarios on probability basis. We added this consideration to the new manuscript in the discussion section.

5) "(minor) Most (if not all) the results have a meaning only in a relative sense, since the qualitative character of the analysis makes practically impossible to compare the risk due to volcanic tephra with the one due to other hazards, in a multi-risk prospective (e.g., Grunthal et al. 2006, Nat Haz). Ultimately, the decision about mitigation actions should be based on multi-risk results, since we are not interested to damages due to tephra, but to damages due to whatever reason. This should be discussed case by case, whenever the applicability of the results for long-term mitigation plans is proposed."

The methodology proposed here is focused on a specific hazard caused by explosive volcanic eruptions (i.e. volcanic ash fallout and dispersal). But civil protection and other stakeholders will probably need to combine the outcomes of this work with other aspects of risk management. For this reason, our methodology has been developed referring to an integrated framework for vulnerability assessment which has been carried out in the European Project ENSURE (Menoni et al., 2012) and outcomes of this work, although qualitative, can be interfaced with other impact assessment results. We clarify this point in the discussion for the local part, but also in the introduction, as it is valid in general for the whole methodology. Moreover, we underline the importance of the multi-risk framework and propose its adoption in order to enhance interoperabil-

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ity between different branches of risk management. In particular, in Iceland volcanic eruptions are the hazardous phenomenon that pose the higher threat to population and socio-economic system, and their hazard comprise phenomena such as lava flow and Jökulhaups (glacial outburst floods), that can produce very strong impacts on populations and roads. In 1996, the eruption of Grímsvötn volcano triggered a Jökulhaups from Vatnajökull glacier, that destroyed parts of Route 1 (Ring Road) and a 880 m long bridge. In 2011, during a a small sub-glacial eruption from Katla, the bridge across the river Múlakvísl was destroyed as well as other parts of the Route 1. It is worth noticing that these events usually happen at very local scale, while ash fallout and dispersal have a wider spatial range. Moreover, for these events to be analyzed in a multi-risk framework, eruptive scenarios should be modified in order to include these events, accounting for their historical record, and the hazardous phenomenon should be modeled accordingly. Further work is therefore required in this field.

Please find attached the final manuscript in Latex format containing the updated tables and figures caption, and the SM in pdf format with updated captions. We modified the latest latex version of the manuscript in order to facilitate typesetting.

We would also like to add to the manuscript the following references: Menoni, S., Molinari, D., Parker, D., Ballio, F., Tapsell, S.: Assessing multifaceted vulnerability and resilience in order to design risk-mitigation strategies, Natural Hazards 64, pp. 2057-2082, 2012, DOI: 10.1007/s11069-012-0134-4. Jones, S., Bolivar, E.: Natural Disasters and Business : The Impact of the Icelandic Volcano of April 2010 on European Logistics and Distribution – A case study of Malta, Maastricht School of Management, Working Paper No. 2011/20, 39 pp. available at: http://web2.msm.nl/RePEc/msm/wpaper/MSM-WP2011-20.pdf, accessed June 2014. Kjølle, G.H., Utne, I.B., Gjerde, O.: Risk analysis of critical infrastructures emphasizing electricity supply and interdependencies, Reliability Engineering & System Safety 105, 80-89, 2011, DOI: 10.1016/j.ress.2012.02.006.

We hope that this revised version of our manuscript will meet the requirements to be

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published in your journal.

Best regards,

Chiara Scaini, Sébastien Biass, Adriana Galderisi, Costanza Bonadonna, Arnau Folch, Kate Smith & Armann Höskuldsson

Please also note the supplement to this comment:
http://www.nat-hazards-earth-syst-sci-discuss.net/2/C1406/2014/nhessd-2-C1406-2014-supplement.zip

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