Response to the referees' comments

Referee 1 (S. Tarquini)

The paper illustrates the calibration of the VORIS code (for the simulation of lava flows) to the 2010 eruption of Nyamulagira volcano. The work presented is an interesting premise of what could be done with the software and the data available to the authors. But beyond what is presented a significant amount of work is missing. The current discussion paper is too concise in places, and it is necessary to refer to other works for a proper assessment of what is presented here. Several concerns are listed below, starting from the title onwards.

1) Title. The title reads “sensibility analysis”, a wording which is of rather limited use in numerical modeling. Probably the authors meant what is usually called “sensitivity analysis” (e.g. Bilotta et al. 2012). But what is presented is not a sensitivity analysis, but a calibration of the code to a single case. A sensitivity analysis is usually performed after that a model has been already validated to a given test case (e.g. Bilotta et al. 2012, Tarquini and Favalli 2013), and the authors are willing to explore how the result changes upon moderate variations of input parameters (which are to be considered because of the intrinsic uncertainty in the system). But this is not the case.

We accept the comment made by the referee but we do not fully agree with it. Any mathematical model that is pretended to have a generalised use needs to pass a confidence test that implies two steps. The fist one is the quantification of uncertainty (uncertainty analysis) or calibration. The second step is the sensitivity analysis that aims at identifying how much of the input parameters required by the model influence the uncertainty of the results. In our case, VORIS has already been calibrated by the authors of the model (see Felpeto et al., 2007) and what we are looking for in our paper is to check if the model is applicable to the specific case studied, for which we need to quantify the degree of influence that the different input parameters required (DEM precision, lava thickness correction, …..) exert on the results (i.e.: sensibility analysis). A sensibility analysis does not really depend on the number of different examples we use, although it is accepted that a larger number of case studies provide better sensibility results. However, in our case we have only used one example as this is the only one from which we have full control of the parameters required to run the model. The work by Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, J., Gatelli, D. Saisana, M., and Tarantola, S., 2008, Global Sensitivity Analysis. The Primer, John Wiley & Sons, provides a very good description on sensibility analysis

2) Extent of the application. In the work presented the authors take as reference topography the SRTM1 DEM. This DEM was acquired during a survey carried out on February 2000 (Rabus et al. 2003). According to the very good map published by co-authors of the present work (Smets et al. 2010), there are additional 5-6 lava flows (beyond the one considered) that could be simulated on the SRTM topography, because they formed after the survey. These are the lava flows formed from eruptions in 2000, 2001 (probably two separate flow fields), 2002, 2004 and 2006. In addition, if older flows are actually so thin (consistently 3 m on average according to Smets et al. 2010), it is also possible that some lava flows older than the SRTM survey could be simulated in spite of the presence of the lava deposit (as it has been the case at Mt Cameroon, according to Favalli et al. 2012). It is also worthy to mention that, according to the cited map of the Nyamulagira volcano, it appears that the 2006 lava flow originated mainly from a vent very close (if not coincident) to the vent of the lava flow formed in 2010. The fact that the 2010 flow field coverage coincides to a large extent to the 2006 one (the cited map of Nyamulagira) appears to confirm that the 2006 lava deposit is thin, and hence it has only a minor effect on the paths of subsequent flows. Provided the above, the presented preliminary calibration should be followed by the simulation of other flows, to validate the preliminary calibration or to refine it. I have to say that, without this missing work, what already presented results to be a very light and incomplete work.

Again, we have to state that we have applied the model to the only lava flow from which we have good control on all the parameters that the model needs as inputs to run. Once we will have demonstrated (this paper) that VORIS works well and fulfils the needs of the Goma Volcano Observatory, we will be in the position to apply it to other eruptions less well known by us, but, anyway, such further studies will require first to undertake field work.

3) Geological setting. In the description of the geology of the volcano (current section 2) a wide spectrum of the past activity is mentioned, with SiO2 percent ranging from 43 to 56. But what is the (possibly more narrow) spectrum of the more recent activity? It is not even mentioned what kind of lava constitutes the 2010 lava flow which is being considered. Without a careful analysis of the spectrum of possible future scenarios any result is of limited significance, because lava flows between 43 and 56 percent emplace according to a very different dynamic, resulting (presumably) in a very different calibration of the VORIS parameters.
Despite this range of compositions appear in the whole record of the volcano, most of the Nyamulagira lavas are basic, SiO2-undersaturated and K-rich (Kampunzu et al., 1982; Aoki and Yoshida, 1983; Aoki et al., 1985), which form low viscosity flows able to travel for tens of kilometres. The lava from the 2010 eruption pertains to this type of lavas. Additional information will be added to the text to clarify this point

4) Code/methodology. 4.1) the authors highlight that lava flows are typically fed from eruptive fissures. Therefore, they should describe how the VORIS code copes with a similar feature (since they use only a single-point vent), or explain that the emission from a fissure is adequately approximated by a single-point vent in the case(s) considered.

VORIS allows both to simulate lava flow sources as single vents and as fissure vents of source areas. We tried bout of our simulations reproducing the size of the eruptive fissure of the modelled eruption, which was relatively short, obtaining very similar results. This is why we only present the simulations from single vent, which corresponds to the position of the main source area a short time after the eruption started. We will add new text to clarify this point

4.2) Tuning (or calibration) of the code and the relative presentation. The existing literature provides useful caveats regarding how to perform a calibration and how to evaluate the result of simulations (e.g. see references listed at the end and references therein). A very general consensus exists on the use of a specific index “i” to evaluate simulation results (e.g. Bilotta et al. 2012): i = (R intersection S) / (R union S) where “R” is the coverage of the real flow and “S” is the coverage of the simulation (in case, with an additional square root applied). The index i effectively summarizes in a single value the accuracy of the simulation (increasing from 0 to 1), and is much clearer than the multiple plots used by the authors (e.g. fig. 3). I encourage the authors in expressing their results by using the above index.

We agree with this comment and will add a new column in Tables 1 to 4 to include index “i” as suggested by the referee.

4.3) The authors should also discuss in more detail the point of the runout of lava flows. They show only a best-fit value in the calibration of a single case, but of course lava flow length can vary significantly, and this variation should be tackled as much as possible in the perspective of using the code in a volcano observatory (as specified in the conclusion). The existing map of recent lava flows provides a mean to explore flow length statistics and to check if some correlation holds with other parameters (e.g. vent elevation, see e.g. Favalli et al. 2009, 2012).

This is the purpose of a future work to be undertaken once this paper is accepted, but first we want to validate the model for its use on the Nyamulagira volcano

5) DEMs. In the DEMs section the authors simply state that it is necessary to perform a separate calibration for each DEM considered (which is rather obvious). I suggest to strengthen substantially this section or otherwise to substitute it with the above statement, specifying that the work is carried out using the best available DEM.
OK. However, it is worth mentioning here that in addition to the DEMs we have used we also know that there exist others with higher precisions, but also that computational requirements to download and operate with them are not necessarily available everywhere. So, we have developed this work using what was available to the scientists from the Goma volcano observatory at the time of writing, obtaining quite satisfactory the results.

6) Availability of the code and consequent application (this point is just a comment, not an issue). The authors highlight the benefit of the free availability of the VORIS code as opposed to other codes which "only exist in the literature". The free release of the code is undoubtedly a commendable option. I appreciate it. Maybe the ideal solution could be the sharing of a code through the establishment of a cooperation with the developers (supported by some project, hopefully), an option which should minimize misuse guaranteeing the accuracy of the critical data produced. I am not sure if the worst scenario is not having a lava flow simulation or instead having a poorly assessed one.

The main purpose of our paper is to test the applicability of VORIS model to the Nyamulagira volcano, particularly to its 2010 lava flow eruption, in order to see if this model, which is the only one freely available in internet, could fulfil the needs of the Goma Volcano Observatory for conducting long and short term hazard assessment on that volcano. We are aware about all other codes for lava flow simulations that have been published in the international literature, including that used by Dr. Tarquini. However, none of them are freely available, so they cannot be used by an external user, and in consequence not by scientists at the Goma Volcano Observatory. Establishing scientific collaborations could be an alternative option, but we prefer to insist on the need of an open and free sharing of information among scientists, not being obliged to establish selective collaborations that sometimes are not possible or not desired. This paper also wants to highlight the the real needs and difficulties that some colleagues have to develop their work, and convince all of us that the only way to help colleagues from less favoured countries is by freely shearing our work, making it fully open and accessible to the others.

7) Figures. See previous comment 4.2 for figures 3, 5 and 7. The multiple frames in figures 2, 4 and 6 are a good option. If you label each frame with a given letter, it would be easier to refer to a specific frame. To improve the readability please try also to use consistently the same scale factor in the different frames (e.g. fig 6), and use a bigger scale bar (I am not able to read the existing one). I have a further concern with figure 6: could you justify why in the first frame the runout is much shorter than in the second one while in the subsequent frames the runout monotonically decreases?. Consider current figures 8 and 9 according to comment 5. In figure 8, third frame, the number of iterations appear to be 50 times smaller than in previous frames (according to the labels).

Figures will be modified accordingly
8) final remark. The authors, in their conclusive section, state that the work presented illustrates that the VORIS code "is perfectly adapted for lava flow hazard assessment performed at Goma Volcano Observatory". The existing literature already showed that VORIS is a valid tool for hazard assessment purposes. But the novelty of the present work is only in the application presented (i.e. as a simple calibration to a single lava flow, so far), and this application is too light to demonstrate that the authors are using the code with the necessary care. I encourage the authors in undertaking a deeper and more comprehensive analysis to better exploit both the potential of the VORIS code and their substantial knowledge of the volcano.

We have already replied to this last point in the previous comments

References Bilotta, G., Cappello, A., Hérault, A., Vicari, A., Russo, G., Del Negro, C.: Sensitivity analysis of the MAGFLOW Cellular Automaton model for lava flow simulation. Environmental Modelling & Software 35, 122-131, 2012. Favalli, M., Tarquini, S., Fornaciai, A., Boschi, E.: A new approach to risk assessment of lava flow at Mount Etna. Geology 37, 1111-1114, 2009. Favalli, M., Tarquini, S., Papale, P., Fornaciai, A., Boschi, E.: Lava flow hazard and risk at Mt. Cameroon volcano. Bulletin of volcanology 74, 423-439, 2012. Rabus, B., Eineder, M., Roth, A., Bamler, R.: The shuttle radar topography mission: A new class of digital elevation models acquired by spaceborne radar. ISPRS Journal of Photogrammetry and Remote Sensing 57, 241–262, 2003. Tarquini, S., Favalli, M.: Uncertainties in lava flow hazard maps derived from numerical simulations: The case study of Mount Etna. Journal of Volcanology and Geothermal

When appropriate, these references will be added to the text

Referee 2 (anonymous)

This paper reports the results of a sensitivity analysis on the input parameters of the program VORIS for the simulation of lava flows, with application to the Nyamulagira 2010 eruption.

Comments and suggested corrections

• Page 7, line 11; page 8, line 21 and page 9, line 21: UTM Zone should be 35M (not 35S), please check.

OK, they will be corrected

• Figure 3, 5, 7, 9: The axis label of the top-left histogram should be “Simulated pixels” instead of “true lava flow pixels”. Please check.

OK, they will be corrected

• Results shown in Figure 6 need to be commented: increasing the lava flow thickness from 1 to 3m seems to increase the maximum distance reached by the lava flow, but from 3m to 8m it seems that this distance reduces. What is the reason of this behavior? Perhaps the path length (33 km) is not adequate?

OK. New text will be added to the Figure caption

• Figure 2 shows that the running time is almost constant when the length parameter and the number of lava flow pixels increase. Can you comment this not intuitive result?

There is some confusion here, as we do not show the running time in Fig. 2. We suppose that the referee refers to the running times indicated in tables 1 to 4. According to the algorithm that VORIS uses running time is highly dependent on the number of iterations, particularly when it goes above 5000, for a “normal” PC computer, but does not change significantly when length parameter or thickness correction change. However, accuracy of the simulation results also depend on the number of iteration improving considerably with it, but requiring a higher demand on computing resources. The best result was obtained with 10000 iterations. This is why it is necessary to look in each case for an acceptable balance between accuracy and computing resources, keeping into account that these last are not the same for all potential users. In this study, the accuracy of the results obtained (see tables 1 to 4 and Figures 3, 5, 7, and 9) are good enough for the purpose of the work but sure could be improved with better computing resources, unfortunately not available at the time of writing at Goma Volcano Observatory.

• Perhaps, to be uniform with the text, it is better to rename subsection “4.1 Total length”: “4.1

Length parameter”.
OK, it will be corrected

• Figures 2, 4, 6 and 8 report in the frames a distinction between “hazard < 0.1%” and “hazard # 0.1%”. Can you explain how this hazard is evaluated?
OK, this new text will be added to the Figure captions: As for the rest of Figures showing the results of simulations, we show here the simulated areas corresponding to a hazard > 0.1% when simulated result matches the real lava (well-estimated pixels), and to a hazard <0.1% when the simulated result falls outside the real lava flow (outside estimated pixels)

• Please, describe the effect of the “length parameter” in the “Discussion and conclusions” section.
OK. New text will be added to the Discussion and conclusions section: Concerning the length parameter our results indicate that a too small length value underestimates the probability of being covered by the lava flow, while a too large value tends to overestimate the maximum longitudinal or run-out distance, as well as the lateral extent of the lava flow, revealing the strong control that the highly irregular topography exerts on the final coverage of lavas

Bibliographic correction
• Page 2, line 25: “Tedesco, 2002, 2003” 7! “Tedesco, 2002/2003”.
• Page 3, line 4: Paper by Pouclet, 1976 is not reported in the bibliography.
• Page 4, line 17: Paper by Verhoogen, 1938 is reported in the bibliography as 1939. • Page 4, line 22: Paper by Pouclet, 1977 is not reported in the bibliography.
• Page 7, line 4: Leinartz 7! Reinartz
All suggested corrections will be made

• Page 7, line 5: Albino et al., 2014 is not reported in the bibliography
reference included

• Page 12, line 12: Chakrabarti et al., 2009 is not cited in the text
• Page 13, line 11: Head et al., 2012 is not cited in the text
• Page 13, line 19: Kasahara, 1983 is not cited in the text
• Page 13, line 32: Pouclet and Villeneuve, 1972 is not cited in the text
• Page 14, line 18: Tazieff, 1977 is not cited in the text
• Please check the official journals abbreviations, eg: “B. Volcanol” 7! “Bull. Volcanol.”; “J. Volcanol. Geoth. Res.” “J. Volcanol. Geotherm. Res.”, etc.
All suggested corrections will be made made

Typographic corrections
• Although “Nyamuragira” is equivalent to “Nyamulagira”, within the text, the authors should be consistent with the use of the name “Nyamulagira” as appears in the title of the paper (see page 10, lines 7, 9 and 25).
• Figures: 2, 4, 6, 8; all the frames. Please change “Km” to “km”. (According to the International System “k” is lower case).
• Page 2, line 24: Volcnaic 7! Volcanic
• Page 6, line 18: NSA 7! NASA
• Page 6, line 23: Felection 7! Reflection
• Page 10, line 21: Nyamunragira 7! Nyamuragira • Page 10, line 22: mush 7! must
• Page 10, line 23: stongly 7! strongly
• Page 12, line 6: Blegian 7! Belgian
All suggested corrections will be made