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Assessing the impact of lava flows during the 2020 unrest of the Svartsengi volcanic system on the Reykjanes peninsula, Iceland

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Abstract—**In January 2020, inflation up to 5 cm was detected in the volcanic system of Svartsengi, Reykjanes peninsula (Iceland). The inflation was probably linked to the movement of magma which was estimated to be at a depth of 3-5 km. Shortly after the detection of the inflation, the Scientific Advisory Board responsible for tackling the unrest deemed possible that the unrest could evolve into an effusive eruption. We used both the MrLavaLoba and the DOWNFLOW codes to simulate the area potentially inundated by lava flows in order to assess the hazard posed in case of an effusive eruption. The DOWNFLOW code was used to create a suite of 10,000 simulations which were used to derive maps of the lava flow hazards. These maps can be dynamically updated to account for ongoing modifications suggested by the geophysical signals of the monitoring system. The MrLavaLoba code, in turn, was tuned based on the historical lava flows in the area, so it would be ready to simulate potential lava flow fields if an eruption began. At the time of writing (April 2020), the area appears have experienced two intrusions and is currently in a waning phase. However, the lava flow modeling carried out constitutes an example of rapid response during an ongoing crisis. The post-processing of DOWNFLOW simulations can also allow for preliminary estimations of the time left before lava flow inundates given targets, providing effective support for stakeholders.**

I. Introduction

In mid-January 2020, inflation was detected in the south of the Reykjanes peninsula (Iceland), within the Svartsengi volcanic system. The inflation was accompanied by an earthquake swarm, and was centered close to Thorbjörn, a hill immediately to the North of the town of Grindavík (Fig. 1).

The collected geophysical data suggested that a magma body was moving upwards through the feeding system of Svartsengi, modeled to be at a depth of 3-5 km. The maximum deformation observed from the GPS stations was about 8 cm (as of end-April 2020; vedur.is). If the magma reached the surface, lava flows would have threatened inhabited areas (~ 3500 people), important facilities (e.g. a geothermal powerplant) and the main road linking the capital Reykjavík to the international airport. It was important to assess the possible impact from lava flows using models.

The present contribution summarizes how we used numerical lava flow modeling to prepare for a potential eruption and enhance mitigation planning during the crisis. At the time of writing the present abstract (end-April 2020), a second period of inflation has stalled and it appears that the unrest of Svartsengi is in a potentially temporary waning phase. However, we deemed useful to document the work carried out during the initial intrusion, which could be of use in the future.

II. Methods

Throughout the duration of the crisis, all the data collected by the monitoring system and the results provided by data post-processing were discussed during Scientific Advisory Board meetings. The board was formed by a team of scientists from Icelandic institutions and local stakeholders. The reports of the board meetings were rapidly published online (Icelandic Met Office website, vedur.is), to provide timely communication to the whole community. We carried out a series of lava flow numerical

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simulations to assess the hazard posed by possible lava flows in the area. As the computational domain, we used a digital elevation model of the Reykjanes peninsula from the Arctic DEM with a 10 m- grid-size, which is an adequate resolution for lava flow simulations [1]. Geological maps of the area and the relevant literature were studied to collect and analyze all the visible eruptive fissures, with the aim of getting information about possible future vents and about the eruption style. The last known eruptions in the area occurred in the time interval 1210-1240 AD. Within that period, three separate effusive episodes erupted from the Svartsengi fissure swarm. The largest eruption formed the Arnarseturshraun lava, estimated to be 0.3 km^3 in volume and to cover an area of 20 km^2. The duration of each historical eruption spans from a few days up to several weeks, with the entire eruptive episode lasting decades. Given the spatial orientation and the length of the historical eruptive fissures (up to 12 km long), it was necessary to consider possible vent opening in a large area around the ongoing inflation.

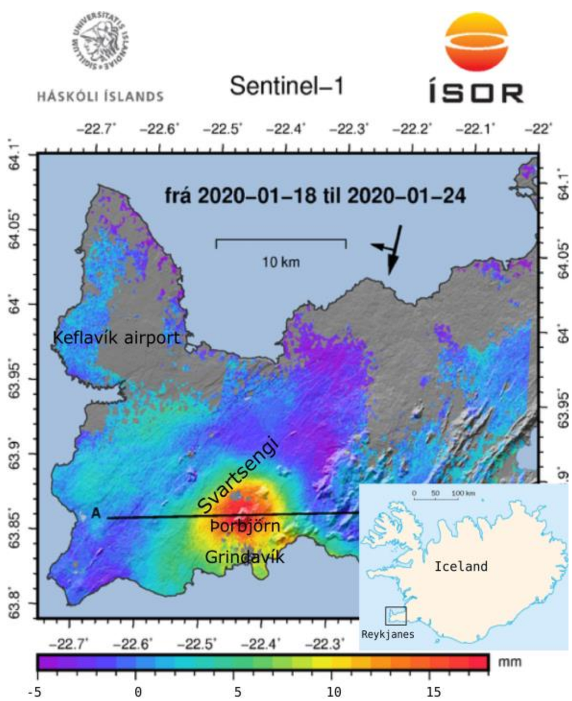

Figure 1. An InSAR measurement (InSAR: interferometric analysis of synthetic aperture radar images) based on satellite information showing the inflation during the period from Jan 18-24. The red colour indicates an inflation of around 15 mm during the period. (Vincent Drouin, ISOR). The inflation continued in the following weeks up to a maximum of about 5 cm. This figure has been downloaded from the Icelandic Met Office website during the crisis (vedur.is).

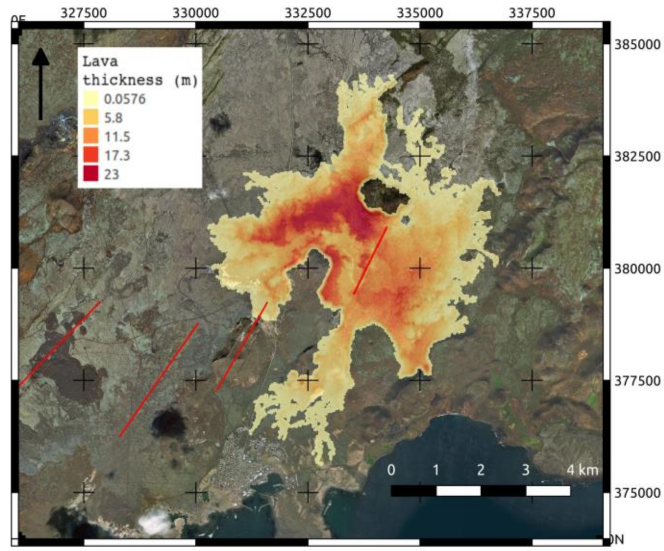

Figure 2. MrLavaLoba simulation from an eruptive fissure to the North-East of the Grindavík town. Red lines represent some of the possible eruptive fissures considered in the present work. 150 M m^3 of erupted lava considered.

A. Lava flow simulation codes

To perform numerical simulations, we decided to use both the MrLavaLoba code [2, https://github.com/demichie/MrLavaLoba] and the DOWNFLOW code [3]. Both codes are probabilistic in nature and provide an output area possibly inundated by the flowing lava. Both codes are essentially based on the computation of the steepest descent, but they differentiate in how the deviation from the bare steepest descent path is computed. MrLavaLoba can also explicitly account for the syn-emplacement modifications of the topography (i.e. it accounts for the erupted volume), and this capability can be specifically useful when the eruption promotes the formation of a thick lava deposit. The tuning of MrLavaLoba to a given scenario can imply several runs, because of the wide spectrum of possible combinations among the tunable parameters. A MrLavaLoba run can take minutes to hours on a PC, with the run time changing based on input parameter choices (for example, defining too many lobes to be generated leads to longer run times). In the present case, the preliminary tuning session lasted 4-6 hrs. Once the initial tuning is done, however, MrLavaLoba allows further additional calibration refinements which can potentially cope with the actual complexity of the lava flow emplacement process [4, 5]. The DOWNFLOW code, in comparison, does not explicitly account for the erupted volume, and takes only into account the pre-emplacement topography (details can be found in the Ref. [3]). In spite of its simplicity, DOWNFLOW has been demonstrated to be effective during several volcanic crises [1]. Additional characteristics of the DOWNFLOW code are that it is easy to tune (essentially only one parameter), and it is very fast (a few seconds for each run), making this code ideal for the creation of a large suite of simulations [6, 7].

III. RESULTS AND CONCLUSIONS

The two codes were used in parallel. MrLavaLoba was tuned to a spectrum of possible eruptive scenarios, in order to reproduce a range of lava deposit thicknesses and lava flow lengths based on given erupted volumes (e.g. Figure 2). We considered that, if an effusive event actually occurred, this code could have allowed to account for the specific emplacement style (e.g. a given thickening) by iteratively modifying the tuning of the code parameters on the basis of the available data from the monitoring system [8].

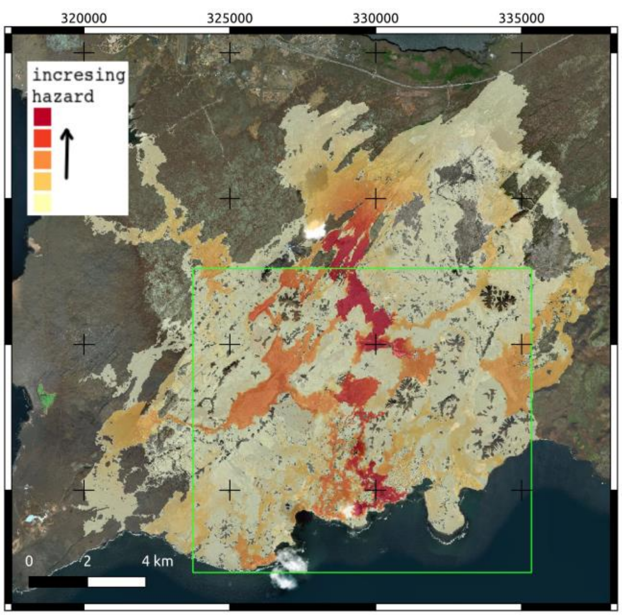

Figure 3. Lava flow hazard map of the area potentially affected by an eruption linked to the inflation in the Reykjanes peninsula. The map was derived by post-processing DOWNFLOW simulations triggered from a grid of about 10,000 computational vents (bounding box of the grid in green).

DOWNFLOW, instead, was used to derive a large database of lava flow simulations triggered from a regular 100 m-spaced grid of about 10,000 vents covering a wide area around Thorbjörn. This database was obtained in about 10 h by using a cluster for parallel computing hosted at the National Institute of Geophysics and Volcanology in Pisa (Italy). The database of simulations was then post-processed considering a given probability density function (pdf) of future vent opening (quantifying the opening probability of each vent), and a given probability of reaching a given maximum flow length.

We initially set a uniform pdf of vent opening, so that the opening probability is equal at each potential vent. The latter settings allow to highlight the effect of other factors than vent position, such as topography and flow length, in the resulting flow propagation. Based on the available geological mapping of this area, we set a uniform probability of reaching a flow length between 0 and 7 km, obtaining the hazard map in Figure 3. This map shows a maximum probability of lava flow inundation extending north from the south coast halfway through the green square (Figure 3).

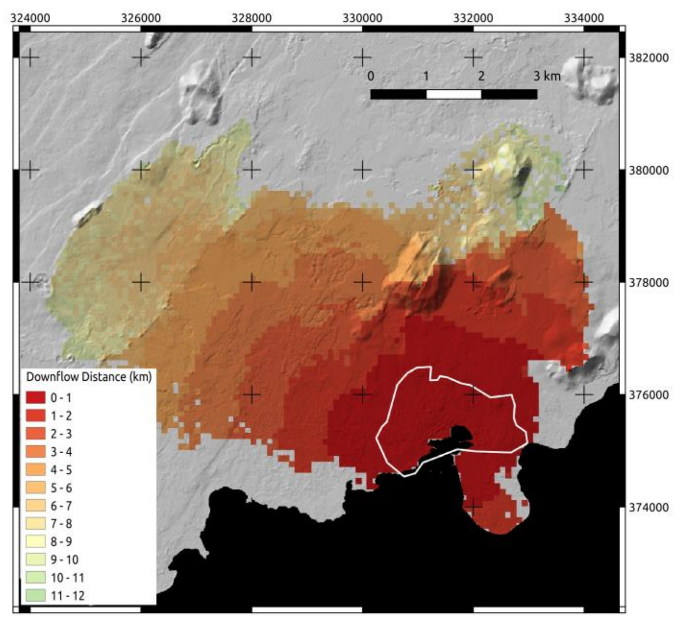

Figure 4. Map showing, at each point, the remaining down-flow distance to reach the town of Grindavík (enclosed by the white polygon). Down-flow distances are measured along the lava flow path computed by the simulations.

We derived additional hazard maps by considering different pdf of vent opening since the geophysical data (e.g. inflation, earthquakes) suggested that the probability of opening may be higher in certain areas than elsewhere. As an example, in the early days of the crisis, it was suggested that a more likely site of eruption was along the westernmost of the four possible eruptive fissures illustrated in Figure 2 (red segments), thus we created a pdf of vent opening assigning a uniform probability to all the computational vents laying within 100 m from the fissure, and 0 to all the other vents. From an operational viewpoint, we remind that a post-processing iteration of the described database takes about half an hour.

A different type of post processing of the same database of DOWNFLOW simulations allows to "invert" the map to visualize specific characteristics of the simulated lava flows with respect to given "targets", i.e. a given asset vulnerable to the potential lava flow [6, 9]. Figure 4 shows a map in which each point is attributed with the minimum distance a lava flow venting at (or reaching) that point has still to travel, along the simulation path, to reach the town of Grindavík (with a population of 3,300). During the present crisis, it was possible that an effusive vent could open quite close to the town. For this reason, stakeholders where especially interested in the assessment of the "time left" for possible evacuation. We note that the map of Figure 4 constitutes a significant step forward in that direction, because upon estimation of a range of possible average lava flow front advancement velocity, the down-flow distance can be easily translated into an estimation of the time left for evacuation. On the basis of a preliminary literature review [10 - 12] we believe a reasonable range of lava flow front advancement velocity is between 5 and 150 mh^{-1}, and we propose alternative color legends for Figure 4 providing the time left for minimum and maximum advancement velocities (Figure 5).

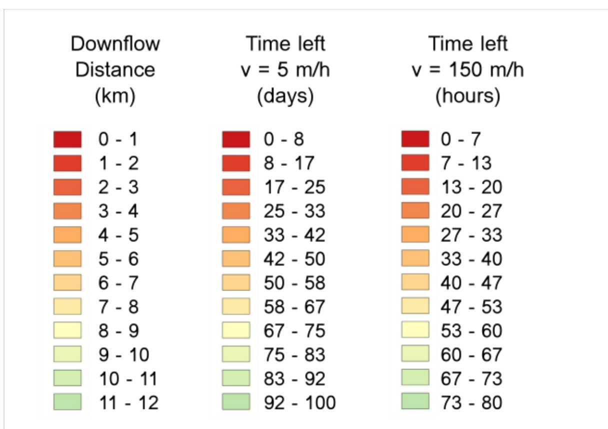

Figure 5. Alternative color legends for the map in Figure 4. From the left: The default legend showing the down-flow distance; the "time left" legend assuming a lava flow front advancement velocity (v) of 5 mh^{-1}; and the "time left" legend assuming a lava flow front advancement velocity of 150 mh^{-1}.

All the maps created during this work (including those showed in the present abstract) have been presented and discussed during Scientific Advisory Board meetings, and constituted effective support to the decision makers.

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