EUROPEAN SCIENCE FOUNDATION

Research Networking Programmes

Short Visit Grant ☒ or Exchange Visit Grant ☐

(please tick the relevant box)

Scientific Report

Application (one single document in WORD or PDF file) should be submitted online <u>at least two months in advance of the event</u>.

<u>Proposal Title</u>: "*Calibrating and testing a new code for the numerical simulation of pahoehoe lava flows in Icelandic scenarios*"

<u>Application Reference N°:</u> <u>6409</u>

1) Purpose of the visit

The proposal was initially based on two pillars: (i) the refinement of the existing embryo of a new code for the numerical simulation of pahoehoe lava flows, and (ii) the analysis of possible eruptive scenarios in Iceland joined with the morphological analysis of existing pahoehoe lava flow fields. The target would have been achieved through the lava flow modeling expertise of the grantee and co-workers from INGV Pisa (e.g. Tarquini and Favalli 2010; 2011; 2013; Tarquini and de' Michieli Vitturi 2014) combined with the field and geomorphological expertise of members of the Icelandic host institution, the University of Iceland/NORDVULK (e.g. Oskarsson and Riishuus 2013; Pedersen and Grosse 2014), with a further support by the Icelandic Met Office (IMO), which was already addressed in the proposal as a possible, interested end-user of the code for hazard and risk assessment purposes in Icelandic scenarios.

In spite of the above premise, as long as the development of the code progressed during the months following the application and preceding the grant (February-July 2014), it was evident that there was no reason to narrow the target of the simulation capabilities of the code to scenarios involving only pahoehoe flows, because the same approach allowed to tackle a variety of cases by simply tuning the input settings.

For this reason, the initial, narrow target was extended, with the aim of creating a comprehensive tool for the simulation of lava flows in Icelandic scenarios, whatever the involved emplacement dynamics (i.e. not only pahoehoe).

2) Description of the work carried out during the visit

The visit took place between 16 and 30 August 2014. By chance, it was exactly on 16 August that the seismic crisis started at Bardarbunga volcano. During the first days, the grantee had several interesting discussions and data sharing with the host institution's personnel (especially Gro Pedersend and Birgir Hoskarsson). This preliminary work allowed to define the link between the broad morphology formed by lava flows in several scenarios in Iceland and the possible dynamics responsible for the emplacement to be implemented and tuned in the code. At first, the grantee and local co-workers focused the analysis on the area nearby Reykjavic, where several relatively large eruptions occurred in the last thousands years. The morphology and the structure of the same lava flows have been analyzed and recorded directly in the field (Figure 1). In the meantime, the unrest at the Bardarbunga volcano progressed, and the attention of the grantee was focused on this exceptional activity. A long dyke propagated at very high speed towards NE-NNE (Gudmundsson et al. 2014), and during the week 25-29 August, it was evident that the occurrence of a "simple", subaerial (as opposed to subglacial) effusive activity was one of the more likely scenarios. Provided the above, it was a significant issue for the Icelandic Met Office (IMO), to tackle possible scenarios related to the effusion of lava flows from a fissure extending at the North from the *Dyngjujökull* glacier (Figure 2 and 3).

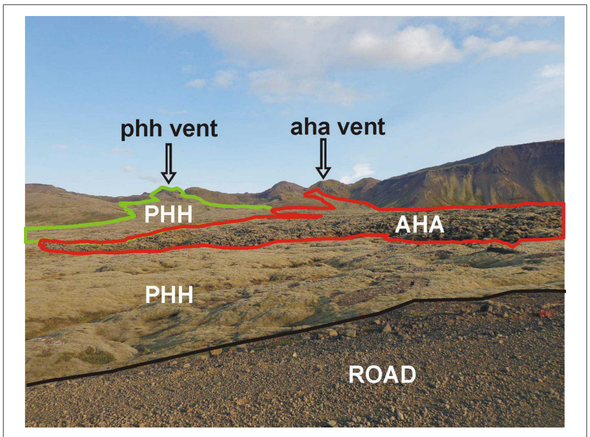

Figure 1. Post-glacial pahoehoe lavas (PHH in figure) partially covered by younger aha lavas (AHA in figure). Reykjaness peninsula. Details of the related emplacement structures and landforms have been studied in the field.

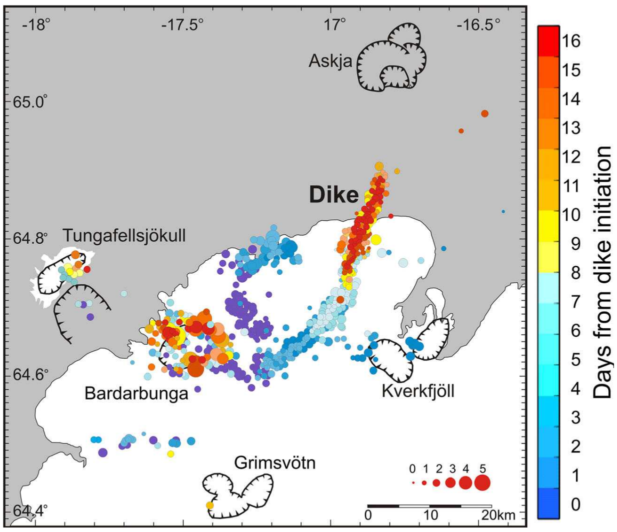

Figure 2. Earthquake map for the first 16 days of the dike-emplacement episode. The map is after Gudmundsson et al. (2014). Data has been provided to the scientific community by the IMO.

During the second week of the grant, the grantee and his co-worker at INGV-Pisa Mattia de' Michieli Vitturi (based in Italy at the time of the grant) were completely immersed into the tuning of the code to foreseeable scenarios linked to the propagating dyke. Therefore, the area of greatest interest was just "above" the dyke out from the rim of the *Dyngjujökull* glacier, NE of Bardarbunga volcano (Figure 3). The grantee participated at several meetings at the Department of Earth Sciences (University of Iceland) and at IMO organized for the sharing of news about the ongoing crisis.

During this phase, the grantee was mainly based at IMO (already identified in the proposal as a co-host Institution), to work in contact with the local responsible for the volcanic risk, Sara Barsotti (IMO) and other personnel from IMO responsible for GIS and lava flows (especially Esther H Jensen). Owing to this collaboration, it was possible to re-structure the code in agreement to the crucial issues which were highlighted during the evolution of the ongoing crisis.

Before the actual opening of the fissure, the site of possible eruption was identified out from the glacier, to the North (Figure 3), which is a site far from inhabited areas. Therefore, the risk due to direct impact of lava flows on farms, villages or facilities was null. Nevertheless, a non negligible risk was considered, due to possible explosions caused by lava-water interaction as the lava could have progressed towards the river *Jokulsa a Fjollum* to the North-East. For this reason, preliminary simulations of the potential propagation of (possibly) erupted lava were performed, by the IMO personnel, by using the VORIS code (Felpeto et al. 2007) on the basis of potential future vents (Figure 3b). These preliminary results, were compared with early tests obtained by using an initial version of the F-L code (Figure 4).

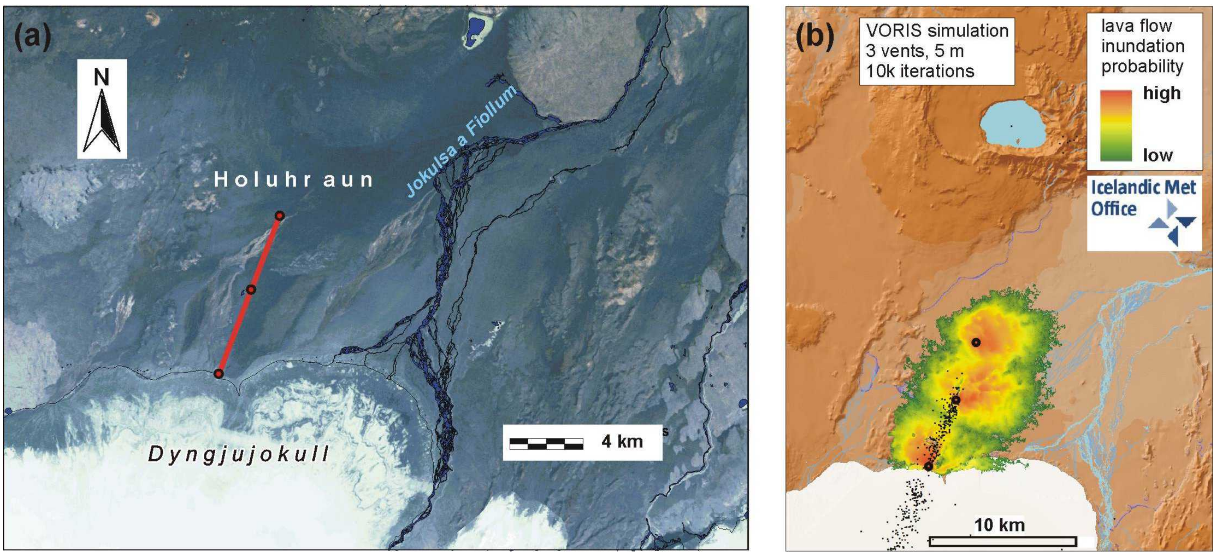

Figure 3. The area at north from the *Dyngjujokull* glacier identified as a site of possible fissure eruption (along the red line) prior to the actual eruption start. The 3 larger black-contoured dots in (a) and (b) represent the extremes and the middle point of the considered segment (the possible fissure), and have been considered as computational vents with the VORIS package (b) (Felpeto et al. 2007). Small black dots in (b) are the epicentres of recent earthquakes. Image in (b) is courtesy of Esther H Jensen (IMO).

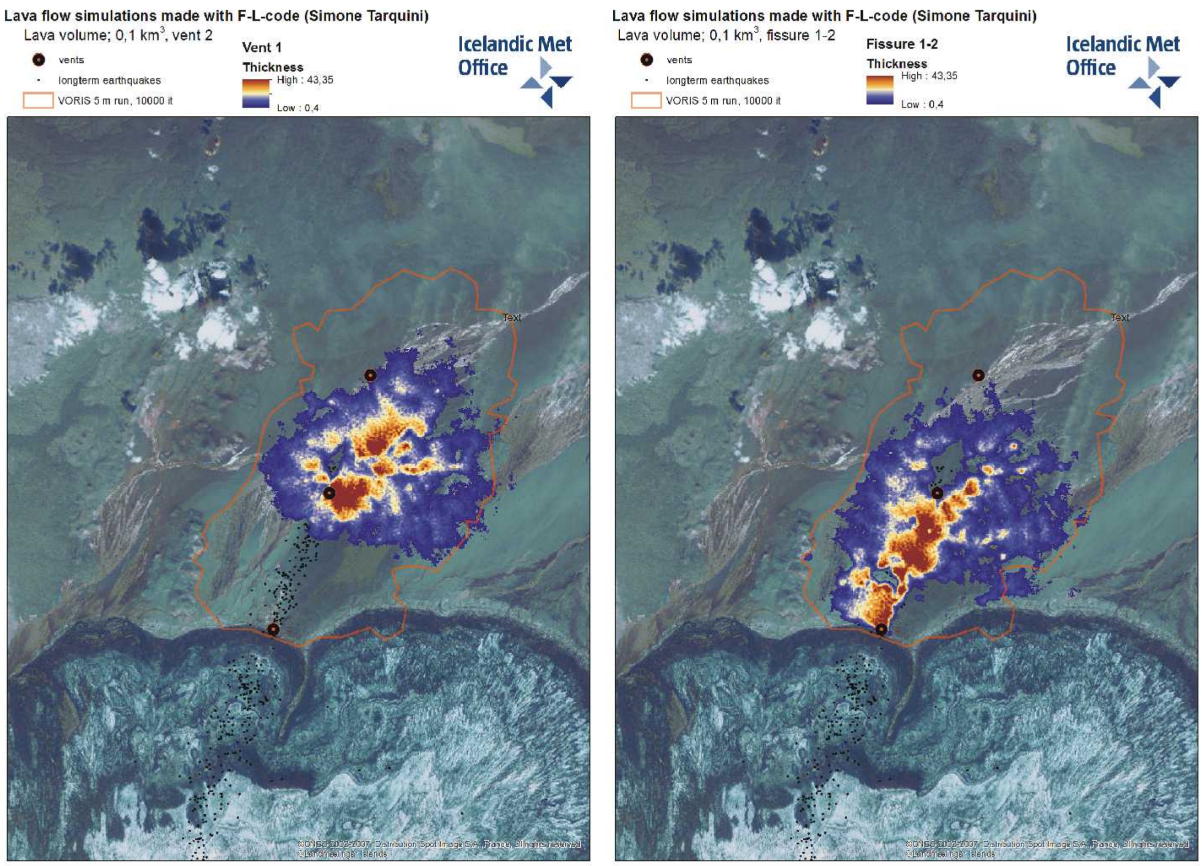

Figure 4. Preliminary simulations (before actual eruption start) obtained by the IMO personnel by using an early version of the F-L code. Results are compared with the ones obtained with the VORIS package (red contour, Felpeto et al. 2007). Large dots with a red core are the vents considered, small black dots are the epicentres of earthquakes. The central vent is considered on the left, a fissure joining the two southernmost vents on the right. Notice that the reference for the F-L code is incomplete in figure, the complete reference is in Figure 8. Whole figure is courtesy of Esther H Jensen (IMO).

As for the GIS work package, a significant effort was carried out to refine the existing DEMs of the Holuhraun area, the site of the lava flow emplacement (Figure 5). Different DEMs were available for testing, and comparison between different results has been quite instructive.

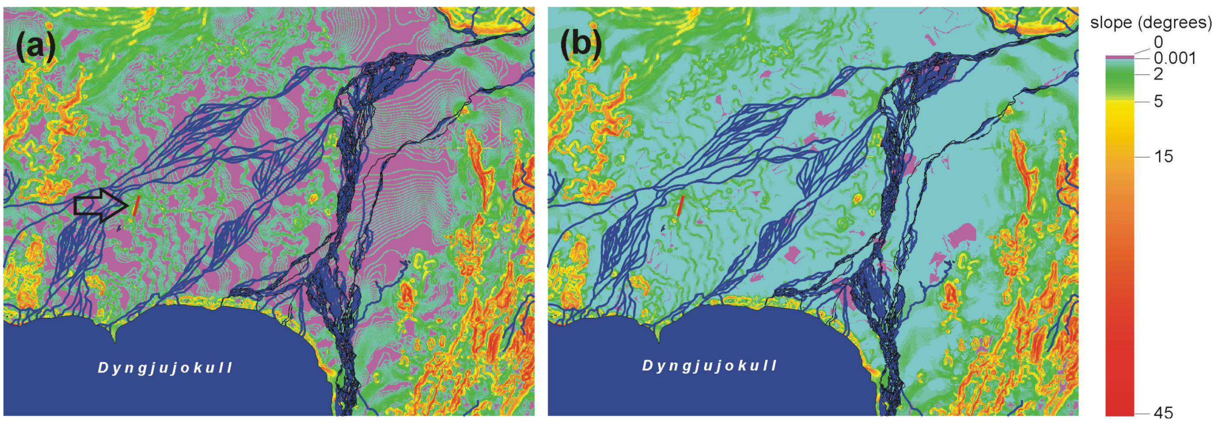

Figure 5 (above). Slope map of the DEM of the Holuhraun area prior (a) and after (b) correction. The input DEM (a) is the 25 m-cell size grid from ISOR (Skúli Víkingsson 2008). The magenta colour highlights a null slope (exactly zero degrees). The widespread presence of magenta in (a) indicates a poor interpolation between elevation contours, which are recognizable as the light blue to green rasterized lines. To fix this issue, contour lines have been re-derived, corrected and then used to create a new DEM in TIN format improved by the DEST algorithm (Favalli and Pareschi 2004). Then, a new grid (25 m cell size) has been re-derived from the TIN, obtaining an improved computational domain (with more realistic slopes). Black arrow in (a) points to the initial eruptive fissure (red segment).

3) Description of the main results obtained

The code was installed on a PC at IMO, to allow local personnel to run simulations of the flow according to the information collected in the field. Although the code has not been published yet, the grantee and co-workers carried out a preliminary validation in other scenarios where inputs and control data were available (e.g. Figure 6, see also Tarquini and Favalli 2011; Favalli et al. 2011; 2012).

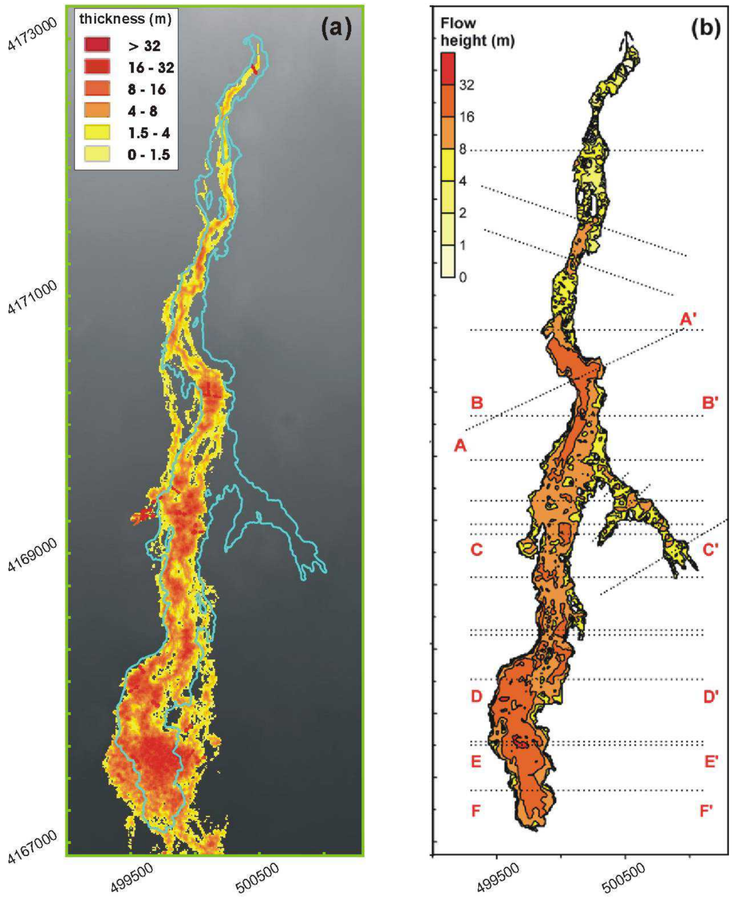

Figure 6. Application of F-L at Mt Etna. (a) F-L simulation of the lava flow LFS1 emplaced during the Mt Etna 2001 eruption. (b) analysis of the lava deposit formed by the same flow after Coltelli et al. (2007). Light blue contour in (a) indicates the actual contour of the final lava deposit, after Tarquini and Favalli (2011). Projection, UTM zone 32N; Datum WGS84. Tick marks indicate meter coordinates.

Owing to the variety of work carried out on different scenarios and thanks to the cooperation with colleagues from both the University of Iceland and the Icelandic Met Office, a critical amount of information was considered for the implementation and tuning of the F-L code. In the days immediately following the grant, repeated simulations of the evolving lava flow in Holuhraun were carried out by using increasingly refined versions of both the code and the input DEM (Figures 7, 8). Being data of general interest, IMO published simulations obtained by the F-L code on his website after the eruption start.

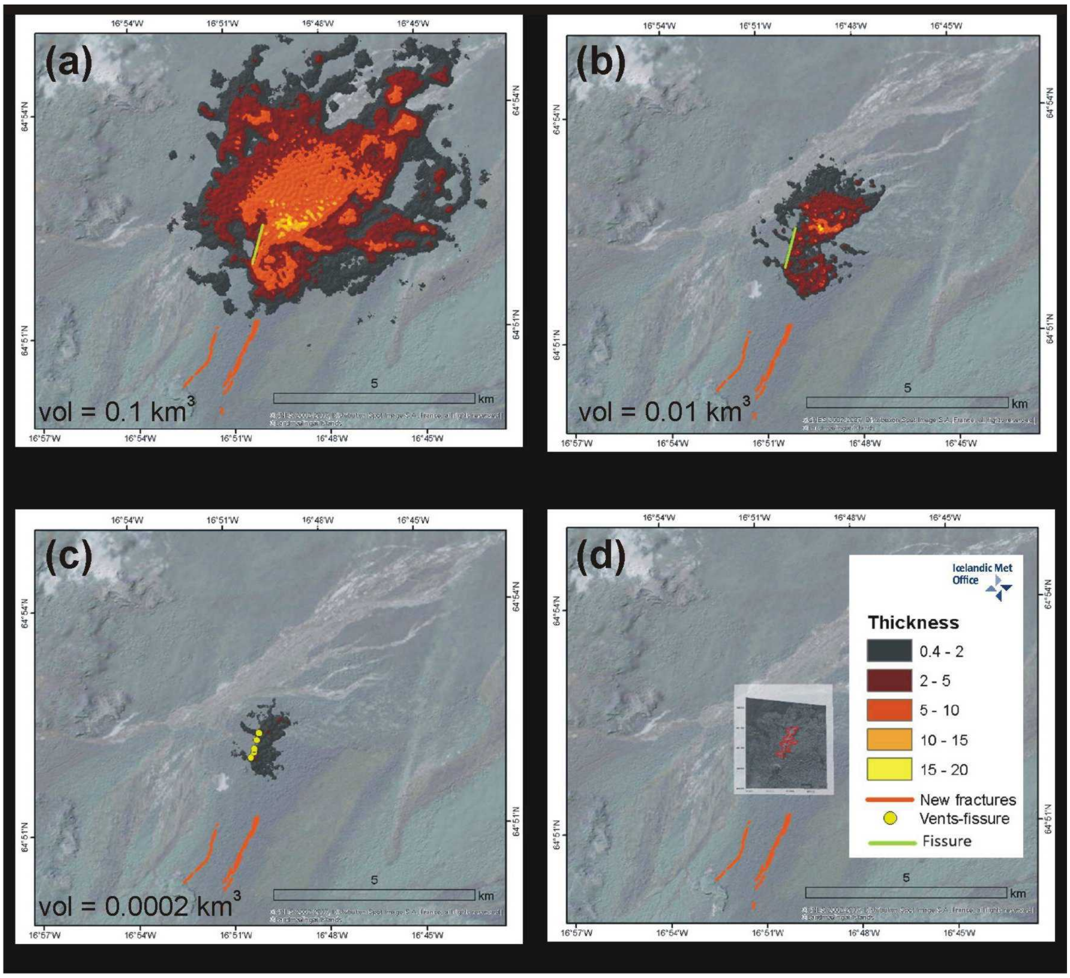

Figure 7 (above). Simulations obtained after the first, small effusive event occurred early in the morning on 29.08.2014 (mapped in (d)). The volume considered as output decreases from (a) to (c), and is indicated by a label in panels. The outline of the actual flow (d) has been obtained by the Institute of Earth Sciences (University of Iceland) from a radar image (central inset, courtesy of Icelandic Coast Guard). Whole figure is courtesy of Esther H Jensen (IMO).

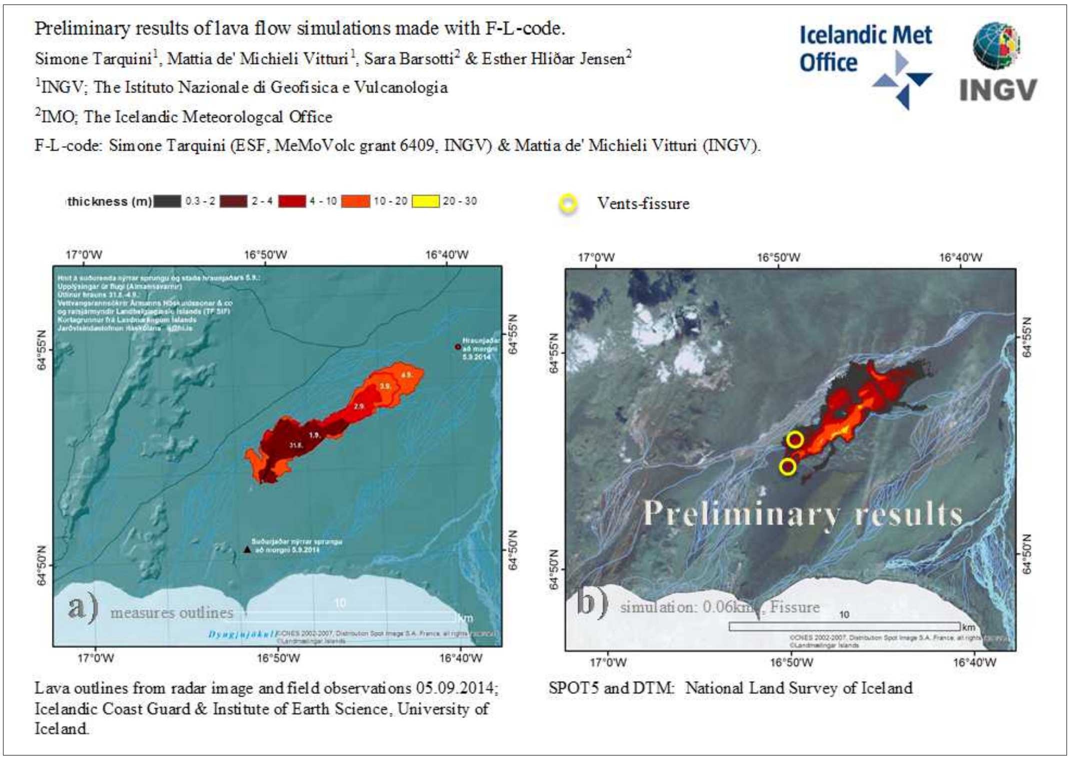

Figure 8 (previous page). Simulation obtained after the first days of the eruption, when the estimated cumulative erupted lava was about 0.06 km^3. (a) progression of the actual lava flow mapped by Icelandic Coast Guard & Institute of Earth Sciences, University of Iceland; (b) F-L simulation on the modified ISOR DEM (Figure 5). Notice that while in Figure 6 the lava propagation was somewhat dispersed in several directions, in figure above the propagation of the lava flow is basically consistent with the real one, heading to the North-East. Figure is courtesy of Esther H Jensen (IMO).

The initial version of the F-L code provided results quite similar to the ones obtained by using the VORIS package (Figures 3,4,7). Nevertheless, after the first days of the eruption, the code was modified to better fit the development of the actual flow, which, initially, advanced steadily towards the North-East (Figure 8). The effect of a very tiny morphological gradient in the early propagation of the lava flow was striking (about 0.4 degrees the average slope in the first 10 km), and this point highlighted the relevance of a detailed DEM when lava flows form on relatively flat areas. The code was substantially modified and several parameters were introduced to allow for a more detailed tuning. The relevance of this tuning is exemplified by the difference between initial and late simulations (Figures 7 and 8). The code is written in Python, is fast and very low demanding in terms of computational requirements. As an outcome, F-L is highly portable and ready to use in any platform.

4) Future collaboration with host institution (if applicable)

A collaboration is established with the personnel at IMO, because we are carrying out together repeated simulations of the ongoing fissure eruption and we are checking the fit with newly available field data over time. Field data are mainly provided by the local University (HI), with contribution from the Icelandic Coast Guard. As mentioned earlier, the F-L code is already installed at IMO and is currently used by the IMO personnel. Upon completion and publication (in the peer reviewed literature) of the work summarized in the present report, the F-L code will hopefully become one of the standard tools used at IMO to simulate lava flows.

5) Projected publications/articles resulting or to result or to result from the grant (ESF must be acknowledged in publications resulting from the grantee's work in relation with the grant)

The development of the F-L code benefited largely from the established collaboration with Icelandic colleagues, and the work carried out is now being completed and assembled to be submitted in the peer reviewed literature.

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