

Q-LAVHA 3.0: MANUAL

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1. Information about Q-LavHA

Accurate simulation of lava flow extent is essential information for scientists or stakeholders confronted with imminent or long-term lava flow hazard from basaltic volcanoes. Knowing what can be the area inundated by a potential or imminent lava flow can improve their understanding of the spatial distribution of lava flow hazard, influence their land use decisions and support evacuation planning during a volcanic crisis.

Q-LavHA (Quantum-Lava Hazard Assessment) (Mossoux et al., 2016) is a freeware plugin which simulates channelized 'a'ā lava flow inundation probability from one or regularly distributed eruptive vents on a Digital Elevation Model (DEM). It combines existing probabilistic and deterministic models (Felpeto et al., 2001; Harris and Rowland, 2001) and proposes some improvements to calculate the probability of lava flow spatial propagation and terminal length.

This user manual is provided to discuss the technical aspect of the plugin. We recommend you to carefully read the entire manual before starting any simulation. Make sure to prepare your input data such as described in the bellow section and fill correctly the required input parameters into the plugin before starting any simulation. For a more scientific description, please have a look at the related scientific paper written by Mossoux et al. in 2016 entitled "Q-LavHA: A flexible GIS plugin to simulate lava flows" (Computers and Geosciences).

2. Installation instructions

- Register on the Q-LavHA website (<http://we.vub.ac.be/en/q-lavha>): Download>Plugin>Register now. After registration, we will provide you a link to download the .zip file that contains the plugin.
- Install QGIS (<https://www.qgis.org/en/site/forusers/download.html>). The minimum required version of QGIS is 3.0.
- Install the Q-LavHA .zip file in QGIS: Plugins>Manage and Install plugins>Install from ZIP>...>Install Plugin. Do not unzipped the Q-LavHA file as QGIS required an .zip file to install a new plugin.
- Verify the plugin is well installed: Plugins>Manage and Install plugins>Installed>Q-LavHA checked. If needed, restart QGIS.

3. Prepare your data

DIGITAL ELEVATION MODEL (DEM)

The DEM is a **.asc** or **.tiff** file that has to be projected in **UTM**. To avoid simulations to be stuck in abnormal depressions, it is recommended to fill the nodata value and the sinks during a pre-processing manipulation.

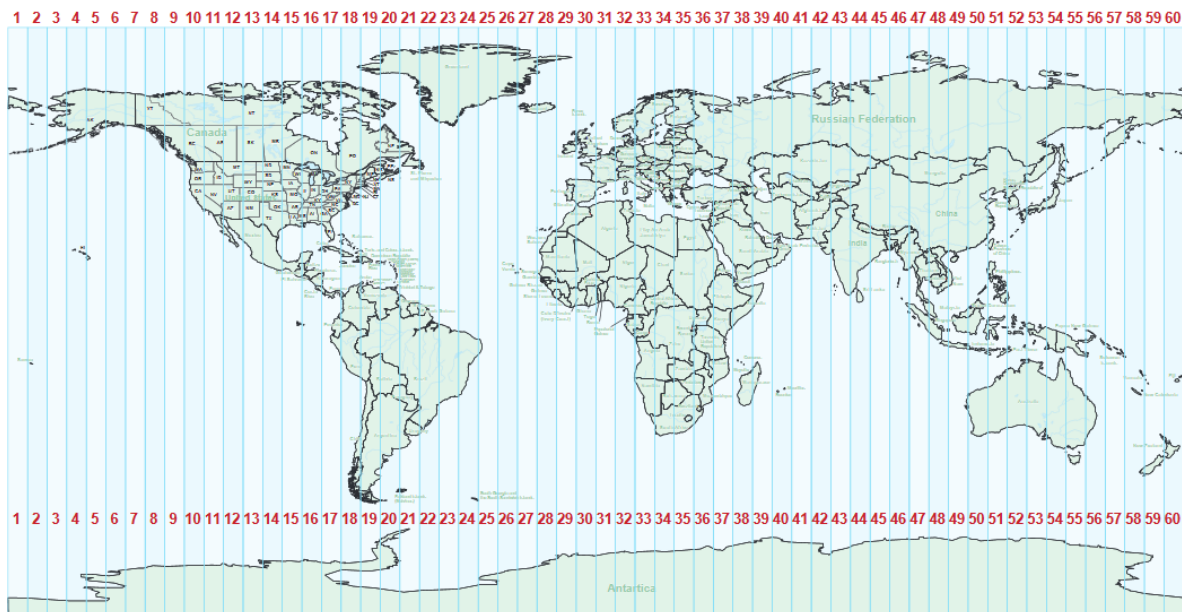
WHERE TO DOWNLOAD A DEM?

SRTM are Digital Elevation Model images of the year 2000 available for the entire world. The data are freely available on the following website: srtm.csi.cgiar.org/SELECTION/inputCoord.asp or <https://earthexplorer.usgs.gov/> after registration on their website.

REPROJECTION

Q-LavHA is working with DEMs projected in UTM. To reproject a DEM that has a geographic coordinate system (lat/lon) to a UTM projected coordinate system (m): QGIS>Raster>Projections>Wrap (Reproject):

- Input: the DEM with a geographic coordinate system (lat/lon).
- Source CRS: select>in the second panel select under Geographic Coordinate System WGS 84.
- Target CRS: select>in the second panel select under Projected Coordinate System the adapted WGS84/UTM zone of your study area.
- Resampling method to use: Bilinear
- Reprojected: Save to File> name of the new DEM that will be produced.



UTM zone map for the world

FILL NODATA

Fill in nodata values present in the DEM is important to avoid the simulation to stop:
QGIS>Raster>Analysis>Fill nodata:

- Input: the DEM.
- Filled: Save to File>Name of the new DEM.

FILL SINK

Fill abnormal depressions present in the DEM is important to avoid the simulation to be stuck:
QGIS>Processing>Toolbox>SAGA>Terrain Analysis – Hydrology>Fill sinks:

- DEM: the DEM.
- Filled DEM: Save to File>Name of the new DEM as a .sdatt

After running the plugin:


- Right click on the output layer>Export>Save as:
 - o Format: GeoTIFF
 - o File name: name of the new DEM





DEM EXTENT

Keep in mind that the total number of pixels of the DEM and therefore its extent and spatial resolution control the processing time of the simulation. Limit the extent of the DEM to avoid to over-load the plugin: QGIS>Raster>Extraction>Clip raster by extent.

VENT VECTOR LAYER


To make the simulations easier, the user can produce for each eruption vent a vector layer from which Q-LavHA automatically will extract the coordinates of its first object. To produce your own vent vector layer:

- ACTIVATE THE NEEDED TOOLBARS:
 - QGIS>Menu>View>Toolbars>activate
 - Manage Layers Toolbar
 - Digitizing Toolbar
- CREATE THE VENT VECTOR LAYER by creating a new shapefile: click on the new shapefile layer icon or Layer > Create Layer > New Shapefile Layer 
 - Geometry type: point, line or polygon.
 - Specify CRS: WGS84/UTM zone of the study area.
- DRAW THE VENT: Start editing the layer:
 - Select the layer you want to edit.
 - Edit the layer by clicking on the 'toggle editing' button (or right click > Toggle Editing).
 - Click on the 'add polygon feature' button and draw the polygon.
 - Left click to draw the polygon feature.
 - Backspace to erase a vertex.
 - Right click to end the drawing.
 - ID= 1
 - Click on the 'save layer edits' button.
 - Stop editing mode by clicking again on the 'toggle editing' button.

Toggle editing	Add polygon features	Save layer edits	New field
			

REAL LAVA FLOW

In order to assess the accuracy of the simulated channelized 'a'ā lava flow, a fitness index (FI) can be calculated. If the option is activated, the simulated lava flow will be compared to a real lava flow. The real lava flow has to be a **.asc or .tiff file** where a **'1' value** is assigned to all pixels corresponding to the real lava flow. The resolution of the real lava flow has to be the **same as the DEM resolution**.

- CREATE THE REAL LAVA FLOW by creating a new shapefile: click on the new shapefile layer icon or Layer > Create Layer > New Shapefile Layer 
 - Geometry type: polygon.
 - Specify CRS: WGS84/UTM zone of the study area.
 - New field: name=value/ type=whole number>add to fields list.
- DRAW THE REAL LAVA FLOW: Start editing the layer:

- Select the layer you want to edit.
 - Edit the layer by clicking on the 'toggle editing' button.
 - Click on the 'add polygon feature' button and draw the polygon.
 - Left click to draw the polygon feature.
 - Backspace to erase a vertex.
 - Right click to end the drawing.
 - ID= 1 and value= 1.
 - Click on the 'save layer edits' button.
 - Stop editing mode by clicking again on the 'toggle editing' button.
- CONVERT the shapefile to a raster
- Open the attribute table: select the layer>right click>open attribute table.
 - Verify that there is a field value=1. If not:
 - Start the editing mode of the attribute table by clicking on the 'toggle editing mode' button.
 - Add a column 'Value' to the attribute table: click on the 'new field' button.
 - Name: value.
 - Type: whole number (integer).
 - Length: 1.
 - Type '1' in the new field.
 - Click on the 'save layer edits' button.
 - Stop editing mode by clicking again on the 'toggle editing' button.
 - Convert the shapefile to a raster: Raster>Conversion>Rasterize:
 - Input layer: shapefile of the real lava flow (.shp).
 - Field to use for a burn-in value: the column 'value' in the attribute table.
 - Output raster size units: georeferenced units.
 - Width/Horizontal resolution: DEM resolution on which the simulations are realized. To know what is that value: open the DEM layer properties>properties>Pixel size.
 - Height/Vertical resolution: DEM resolution on which the simulations are realized.
 - Output extent: Use Layer Extent>Use Extent from>the real lava flow .shp
 - Assign a specified nodata value to output bands: the NoData value of the DEM that you are using. To know what is that value: open the DEM layer properties>transparency>No data value.
 - Rasterized: Save to file>name of the output file (.tif).

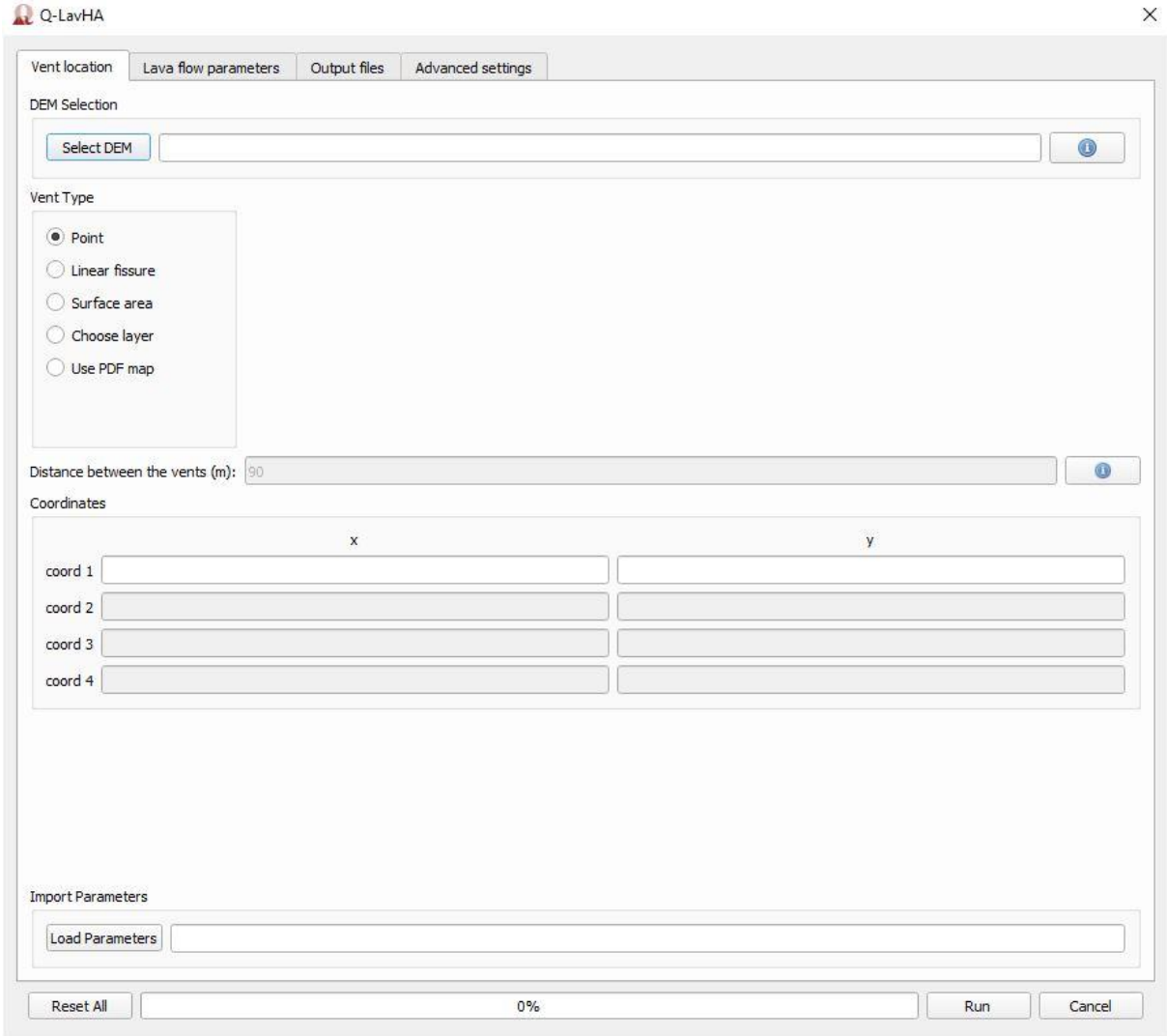
4. Open Q-LavHA

To open the plugin in the QGIS interface, press on the Q-LavHA icon in the QGIS tool bar.



5. Define the Q-LavHA parameters

FIRST TAB – VENT LOCATION: Provide information about the local topography and the eruption location.



DEM SELECTION

Topography plays an important role to determine where a lava flow front will propagate. Therefore, a Digital Elevation Model (DEM) must be implemented in Q-LavHA.

The DEM must be projected in **UTM** and it is recommended to **FILL THE SINKS** to avoid the simulation to be stuck in abnormal depressions present in the DEM. **LIMIT THE EXTENT** of the DEM to avoid to over-load the plugin (see above instructions on how to prepare your data).

Finally, Q-LavHA requires DEM in an **.ASC FORMAT**. The user can select a DEM .tiff file which will be automatically converted by the plugin to an .asc format. Do not use another software to produce the


.asc file. Leaving Q-LavHA to convert the .tiff file into an .asc format insure you to have the required file structure to run the simulations:

- Convert the .tiff file into an .asc format: Q-LavHA>FIRST TAB: Select DEM>Change the file type in the lower right corner of the window that pops up to GeoTiff>select the DEM.

VENT TYPE

The eruption source(s) can be defined in Q-LavHA as a point, a line or a surface area. The vent coordinates can be inserted manually or can be extracted from an already existing shapefile.

MANUALLY

- Base on the type of vent that must be simulated, add the UTM coordinates manually. For a **POINT**, select Point and fill in coordinate 1. For a **LINEAR FISSURE**, select linear fissure and fill in coordinate 1 to 2. For a **SURFACE AREA**, select surface area and fill in coordinate 1 to 4. For polygons, the code automatically recalculates the extent of the source zone to the largest-fit rectangle.
- If you do not know the coordinates of the vent: before opening Q-LavHA, install the plugin **COORDINATE CAPTURE**: Plugins>Manage and Install plugins>Not Installed>Coordinate Capture. When the coordinate capture plugin is installed: Start capture>point on the DEM to the desired location. The tool shows coordinates which remain displayed, even after moving  the cursor.

FROM AN EXISTING SHAPEFILE

- The starting coordinates can be extracted from an already existing shapefile (see above instructions on how to prepare your data). Select the option **CHOOSE LAYER** and choose the desired vector layer (point, line or polygon UTM projected) from the **LIST** of the layers opened in the working space or **BROWSE** through your directory to find the desired layer. This layer will automatically open in the working space. The coordinates of the first feature of that layer will be extracted.

PDF MAP

A probability density function map (**PDF MAP**) can be introduced and used to make simulations on a large area. A PDF map attributes a probability of vent opening to every pixel within the considered area between zero and one c). A PDF map can be produced with QVAST (Bartolini et al., 2013). Based on a specific threshold (**MINIMUM PDF VALUE TO SIMULATE**), the code analyzes successive pixels till encountering a pixel with a value higher or equal to the threshold and starts simulations. This minimum PDF value enables to avoid simulating lava for pixels with no or negligible chance to host an eruption site. 'No Data' pixels are ignored. Result of each individual simulation is weighted by the PDF value of the source pixel.

- If the "Use PDF Map" option is chosen, the user selects the probability density function map (.asc or .tiff file) and introduces the minimum PDF value for the simulation. Pay attention, the PDF file will be automatically transformed into an ascii file if a .tiff is uploaded. To choose a .tiff file, change the file type on the lower right in the lower right corner of the window that pops up to GeoTiff.

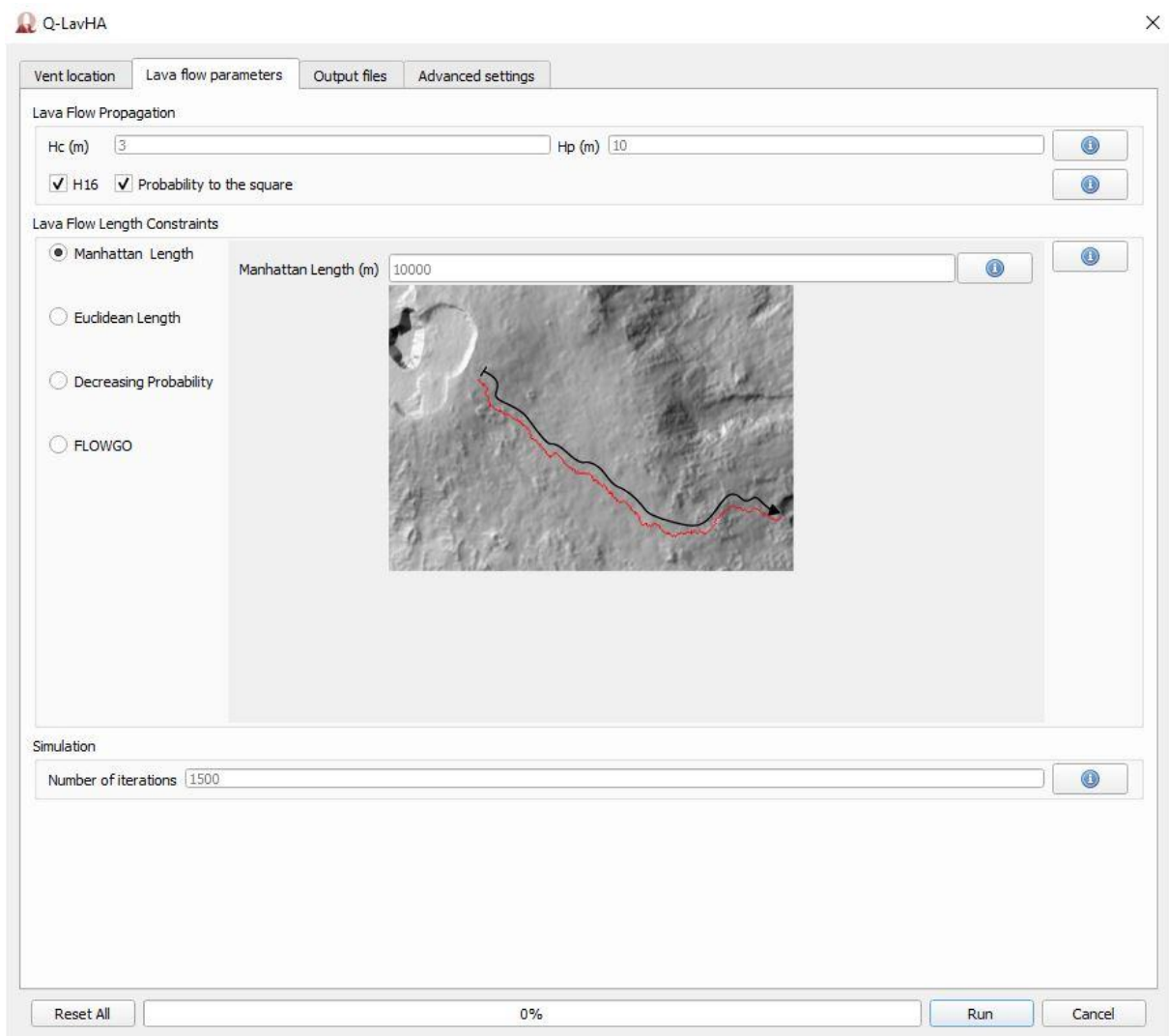
DISTANCE BETWEEN THE VENTS

For linear fissure, surface area and PDF map, simulations are not realized at each pixel. The user can define, in the **DISTANCE BETWEEN THE VENTS** (m) box, the spacing between successive punctual simulations. Provide a multiple of the DEM pixel size (e.g. 180 m or 900 m if the DEM resolution is of 90 m)

IMPORT PARAMETERS

The user can **IMPORT PARAMETERS** used during previous simulations if a parameter file has been previously saved (.qlc) (see third tab – output files).

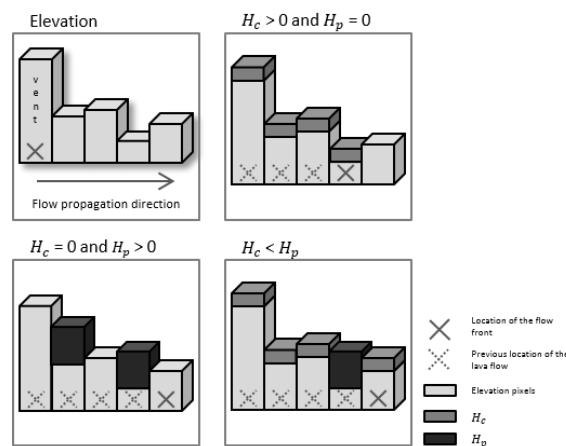
SECOND TAB – LAVA FLOW PARAMETERS: Provide information about the lava flow characteristics such as height and length.



LAVA FLOW PROPAGATION

A lava flow is a viscous fluid with yield strength. For that reason, it does not follow only the steepest path but is able to propagate laterally, fill depressions and overcome topographical obstacles. Corrective factors are included enabling the lava to overcome these small topographical obstacles or pits.

- **H_c** factor is always added to the elevation of the pixel at which the lava is located. This enable to simulate the lava thickness (Felpeto et al., 2001). It is a float number (m). See Q-LavHA scientific paper (Mossoux et al., 2016) for more details.
- **H_p** is also a topographical corrective factor that is only used when H_c is not enough. It replaces H_c (float number) (m). If both H_c and H_p are used, the H_p value needs to be larger than H_c to be effective. See Q-LavHA scientific paper (Mossoux et al., 2016) for more details.



(Mossoux et al. 2016)

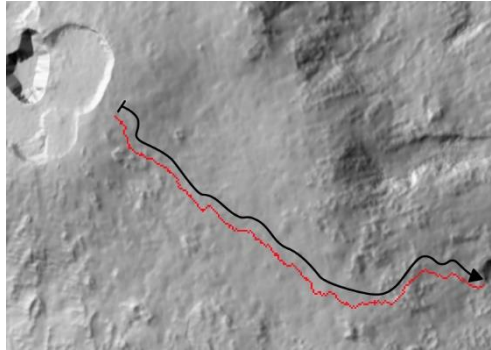
- **H₁₆**: If the lava flow line reaches a pit, which is too deep to be overcome by the corrective factors H_c and H_p , Q-LavHA includes the option to consider the 16 next surrounding pixels (H_{16}). If the lava flow line can propagate to one of the 16 surrounding pixels, it continues its path. If not, the simulation stops. It is recommended to activate this option. See Q-LavHA scientific paper (Mossoux et al., 2016) for more details.
- **PROBABILITY TO THE SQUARE**: this option narrows results spatially because the chance to take the steepest slope is increased. The second power induces that the pixel with the highest elevation differences gets a higher probability. Therefore, the flow line is more likely to follow the steepest slope path. It is recommended to use it, especially on gentle slopes. See Q-LavHA scientific paper (Mossoux et al., 2016) for more details.

LAVA FLOW LENGTH CONSTRAINTS

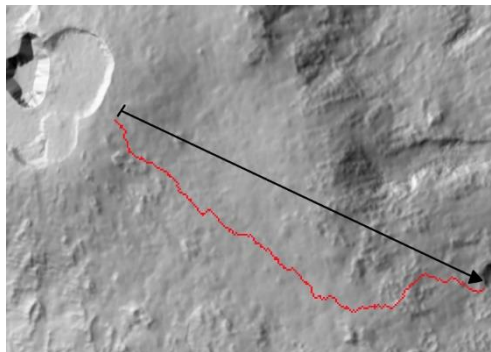
Lava emplacement is controlled by a complex interplay between mainly the effusion rate, underlying topography, lava viscosity, yield strength, cooling processes, morphology and propagation dynamics. However, many of these parameters are often not available or poorly constrained for a specific lava flow, they are difficult to predict and they vary between eruptions. To enable short-term forecasting,

alternatives must be found. In this context, Q-LavHA proposes four alternatives to terminate a flow line.

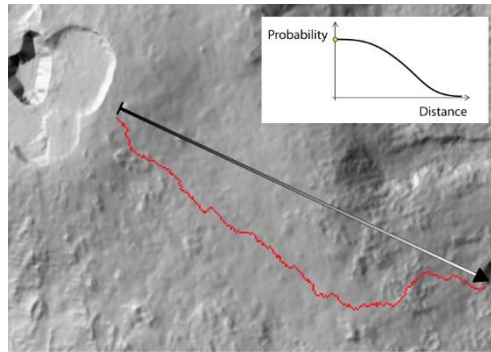
- **MANHATTAN LENGTH (m):** Q-LavHA consider the Manhattan length as the traveled distance covered by the lava flow line. It considers each visited pixel and loop realized by the flow line. The iteration stops when that distance is reached.



- **EUCLIDEAN LENGTH (m):** The Euclidean represents the crow-flies distance between the point where the simulation starts and the front of the flow line. The simulation stops when that distance is reached.



- **DECREASING PROBABILITY:** Because the length of each lava flow is not constant for a given volcano, it can be assumed that the probability of reaching a certain length can be expressed by a decreasing cumulative density function following a normal distribution (φ) (Bonne et al., 2008). This third option allows weighting the probability of lava inundation of each pixel along a lava flow line based on a decreasing cumulative density function. To use this equation, the user must to define the average length (m) and the standard deviation (m) of the historical lava flows of the volcano. The simulation stops when the flow line reaches a maximum Euclidean length equal to $(\text{mean} + 3 * \text{std})$. The final probability expressed by each pixel is a result of a calibration of the pixels with a decreasing cumulative distribution function.



- **FLOWGO** is a cooling-limited model. It is recommended to use this model only if the constraints of the lava flows physic-rheological properties are well defined. The pre-defined advanced parameters are from Harris & Rowland (2001) on Etna flows. The key parameters are effusion rate, lava initial viscosity, phenocryst content and channel ratio. The lava flow stops when at least one of the following conditions holds: (1) its velocity is zero, (2) the lava core temperature reaches the solidus or (3) the yield strength at the base of the channel is greater than the downhill stress.

Important to note that whatever the stopping length constraint selected, if Q-LavHA reaches an area surrounded by more or equal to four NoData pixels (a lake, a sea) or the edge of the DEM, simulations stops.

SIMULATION

The result obtained after a simulation is an integration of all the lava flow lines computed from one or multiple eruptive vents. The number of lava flow lines computed from one vent is defined by the **NUMBER OF ITERATIONS** that must be specified in Q-LavHA. After each iteration, a probability to be inundated ($1/\text{number of iterations}$) is attributed to each pixel that is part of the obtained flow line. This probability is added up to the output which allows defining the final pixel probability to be inundated.

A sufficiently high number of iterations (>1500 for a point simulation) is required to obtain stable and representative results.

With line or surface simulations, representative of fissure eruptions and clusters of closely spaced vents, simulations are produced for regularly spaced vent locations along the line or over the surface. All simulations are then combined and divided by the total number of vents simulated. Because for these simulations, the lava flow lines overlap each other, the **NUMBER OF ITERATIONS** can be reduced. This also enables to reduce the computation time of these computation demanding simulations.

THIRD TAB – OUTPUT FILES: Provide information about the generated output files

The screenshot shows the 'Output files' tab of the Q-LavHA software. The interface is divided into several sections:

- Lava Probability:** A section with a 'Threshold (%)' input field and an information icon.
- Fitness Index:** A section with a 'Calculate the Fitness Index' checkbox, a 'Real Lava Flow' input field, and an information icon.
- Save Results:** A section with 'Output Path' and 'Name' input fields.
- Export Parameters:** A section with a 'Save Parameters' input field.

At the bottom of the window, there are buttons for 'Reset All', a progress indicator showing '0%', a 'Run' button, and a 'Cancel' button.

LAVA PROBABILITY

THE THRESHOLD is the minimum probability considered in the simulation result (%). Only pixels having an inundation probability higher than the user defined threshold are displayed on the output map. Probabilities below that threshold, i.e. pixels that are flooded by a limited number of flow lines, are then considered as noise and are neglected.

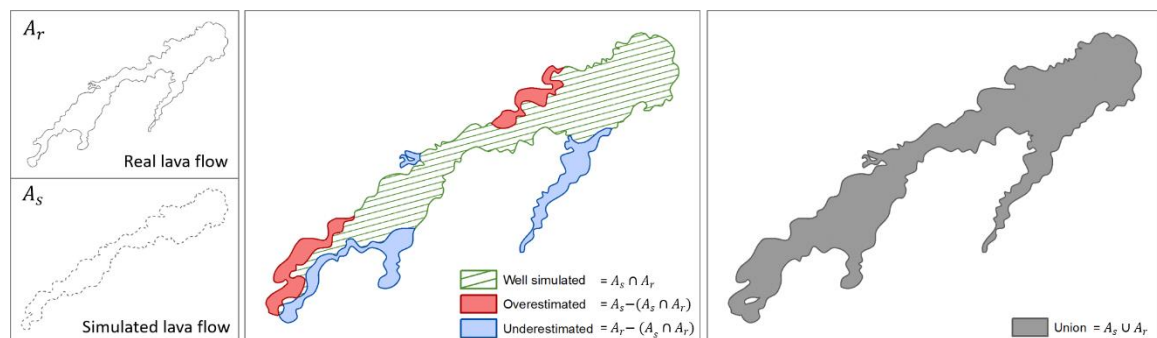
FITNESS INDEXES

To assess the accuracy of the simulated lava flow, fitness indexes can be calculated. The indexes compare the simulated lava flow to the real lava flow outline. To calculate these indexes, the user has to activate the Fitness Index option and to introduce a raster **.asc** or **.tiff** outline of the real lava flow (e.g. the lava flow of reference) (see above instructions on how to prepare your data). Pay attention, the file will be automatically transformed into an ascii file if a **.tiff** is uploaded. To choose a **.tiff** file, change the file type in the lower right corner of the window that pops up.

The fitness indexes are written in the -summary file at the end of the simulation.

- **TRUE POSITIVE (TP)**: corresponds to the overlapping area between the simulated and real lava flow. The TP varies between zero and one. The closer it gets to one, the more important is the overlap and the better the simulated lava flow corresponds to the real lava flow. See Q-LavHA scientific paper (Mossoux et al., 2016) for more details.
- **FALSE POSITIVE (FP)**: corresponds to the over-simulated lava flow area. The FP varies between zero and one. The closer it gets to one, the more important is the over-simulated area. See Q-LavHA scientific paper (Mossoux et al., 2016) for more details.
- **FALSE NEGATIVE (FN)**: corresponds to the under-simulated lava flow area. The FN varies between zero and one. The closer it gets to one, the more important is the under-simulated area. The closer the FALSE NEGATIVE gets to zero, the best as this means that a large part of the real lava flow has been well covered by the simulation. See Q-LavHA scientific paper (Mossoux et al., 2016) for more details.

The sum of these three indexes equals one and can be used to optimize the set of input parameters chosen to reproduce a lava flow. Based on the precautionary principle in a context of hazard assessment, we consider it less problematic to overestimate the future inundated area rather than to underestimate it. The true positive must be maximized and the false negative should be minimized.



(Mossoux et al. 2016)

- **COMPOSITE SCORE**: To compare results from the different simulations scenarios more easily, a weighted composite score was developed (CS). Using exponents, this index gives high importance to the presence of both high True Positive (correctly delineated) and very low False Negative (area underestimated), each index being crucial for effective use in risk management. When the area simulated matches perfectly the deposits mapped in the field, the composite score equals 100 (i.e. TP=1, FP and FN=0). When it mismatches the actual flow completely (i.e. TP=0 and FP + FN=1), the composite score equals 0.

$$CS = TP * ((1 - FP)^{1/2}) * ((1 - FN)^2) * 100$$

- **CUMULATIVE PROBABILITY WITHIN THE LAVA FLOW (CUMin)**: represents the cumulative probability of the pixels located within the real lava flow. Instead of focussing on the outline of the lava flow such as previous indexes, this index emphasis on the location of the inundation probabilities pixels. This index varies between zero and one. The higher the index, the best.

$$CUMin = 100 / \frac{\sum \text{lava flow inundation probability within the real lava flow}}{\sum \text{lava flow inundation probability of the entire simulation}}$$

- **CUMULATIVE PROBABILITY OUTSIDE THE LAVA FLOW** (CUMout): represents the cumulative probability of the pixels located outside the real lava flow. It is the opposite of previous index. The lower the index, the best.

$$CUMout = 1 - CUMin$$

OUTPUT FILE

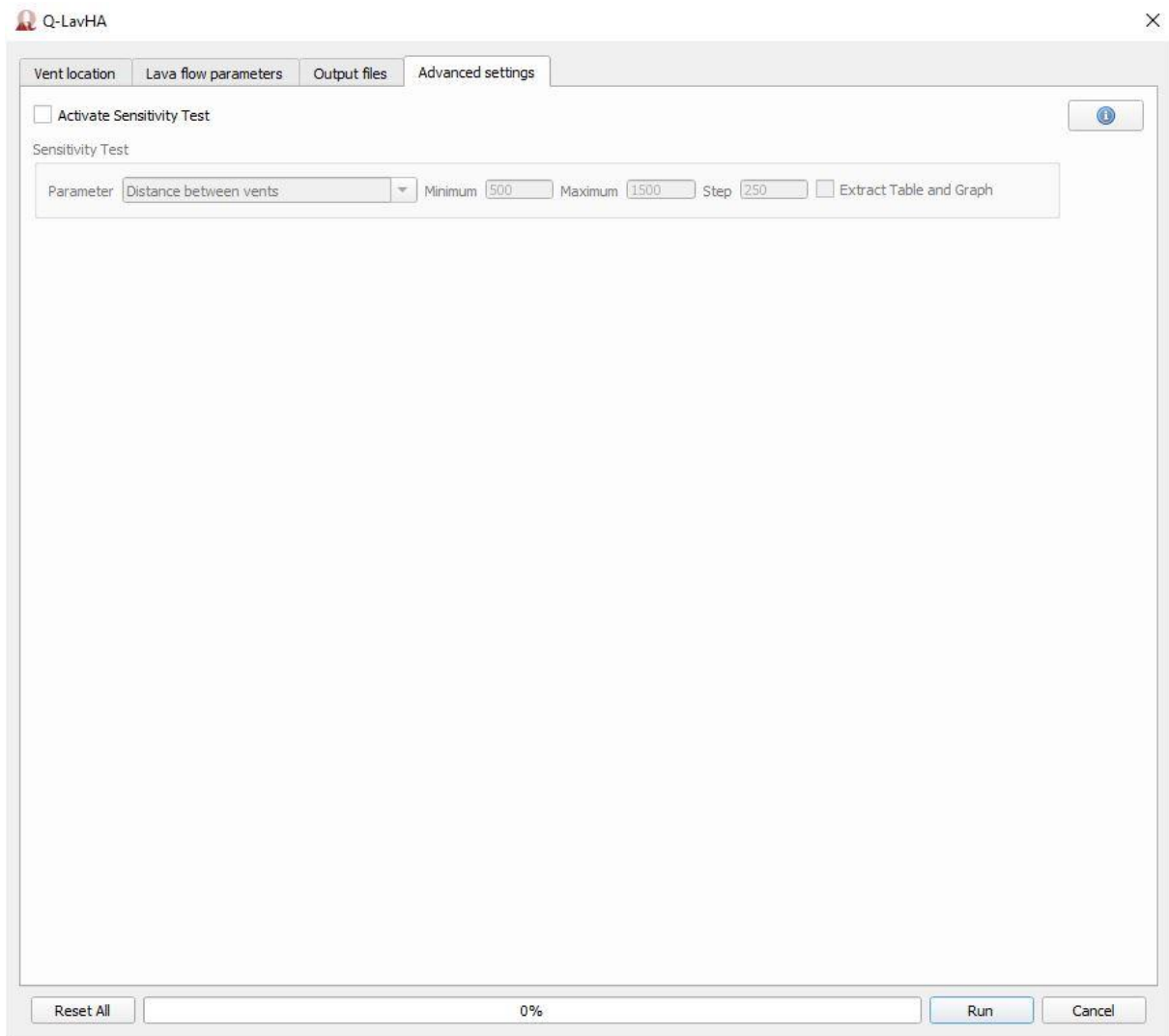
The output produced by Q-LavHA is a raster map expressing the probability of a pixel to be flooded by lava. It is presented in an .asc raster format and is added as a new layer to the active QGIS project. A summary file is simultaneously produced to recall the parameters used during the simulation.

- Define the **OUTPUT** path and name.

EXPORT PARAMETERS

To enable the user to reuse the input parameters of a simulation and to upload them more easily during a next simulation, the user can save the input parameters in a .qlc file which records all the input parameters of that specific simulation.

FOURTH TAB – ADVANCED SETTINGS: Realize if desired a sensitivity test on specific input parameters



If requested, the user can realize a sensitivity test of one parameter at a time. As for a standard simulation, the user is requested to fill in all the input parameters of the “vent location”, “lava flow parameter” and “output files” tabs. When completed, the user can:

- Activate the sensitivity test
- **PARAMETER:** Select the parameter on which to realize the analysis. A sensitive analysis can only be realized on a specific parameter when the corresponding option has been selected in the previous tabs. The value that is displayed on the tab will be overwritten by the start, stop and step parameters provided in the sensitivity test. All other parameters will stay constant throughout the sensitivity analysis.
- **MINIMUM/MAXIMUM/STEP:** Define the starting and stopping values as well as the step between the analysis. These values must be integer, except for the Hc, Hp, the FLOWGO-initial phenocryst mass fraction, the FLOWGO - Lava initial viscosity and the Threshold parameters where decimal

value up to four digits are accepted. The minimum value can not be equal to zero and must be smaller than the stop value.

If user defines the minimum = 250, the maximum = 1500 and the step = 250, Q-LavHA updates the tested parameter with the following values= 250, 500, 750, 1000, 1250, 1500.

- **EXTRACT TABLE AND GRAPH:** When the fitness index is activated in the “ouput files” tab, the user can activate the extract table and graph option. This automatically generates at the end of the simulates a .csv table and a .png graph within the output file. These visuals extract the fitness indexes of all the simulations to help the user with the parameter calibration (see fitness indexes to know how to interpret them).

Before starting a sensitivity analysis where the EXTRACT TABLE AND GRAPH option is activated, make sure to select an EMPTY FOLDER where to store the output files.

If the folder is not empty, the code will get in trouble and if the .csv file is not closed, Q-LavHA will not be able to write over the existing file.

6. Start the lava flow simulation

- Use the **RUN** button (or Ctrl + R) to start the lava flow simulation.
- Use the **CANCEL** button to stop the simulation.
- If you want to refresh all the tabs, click on the **RESET ALL** button.

7. Output

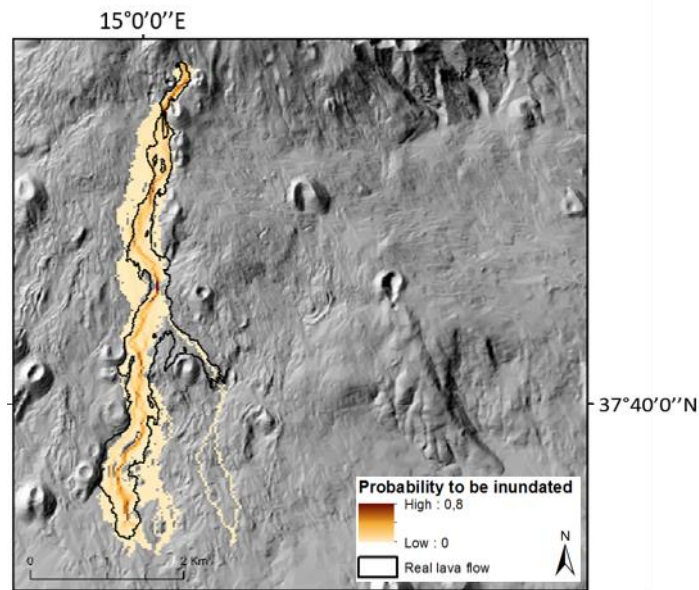
When the simulation is done, QGIS displays automatically the result expressing the probability of a pixel to be flooded by lava.

In the output folder tree files have been produced:

- The simulated lava flow (.asc)
- The projection information of the lava flow (.prj)
- ‘..._summary’ = summary of parameters used during the simulation (.asc)
- A fitness indexes summary table, if the extract table and graph has been activated (.csv)
- A fitness indexes summary graph, if the extract table and graph has been activated (.png)

To adapt the display of the lava flow:

- Right click on the layer > Properties>Symbology>Render type>Singleband pseudocolor>choose a color>Mode Continuous>Classify



$$FI_{true\ positive} = 0.48; FI_{false\ positive} = 0.39; FI_{false\ negative} = 0.13$$

Example of a simulation realized for the 2001 Etna lava flow (Mossoux et al. 2016)

8. Interpretation of the output

The probabilistic lava flow map produced by Q-LavHA should **be interpreted with care**. Q-LavHA is a plugin which attempts to approach the reality of a channelized 'a'ā lava flow inundation as accurately as possible. However, the outcome of the simulation depends on the quality of the DEM used and the selected simulation parameters. The probability of being inundated must be interpreted as having a higher or a lower chance to be inundated. We consequently recommend the users to interpret the results as the sum of the trajectories a flow can potentially follow if an eruption occurs.

9. Processing time

The time to compute the simulation using Q-LavHA is dependent of the size and resolution of the DEM, and the complexity of the simulation. Before starting any complex simulation, it is recommended to run simple simulations. If the user realizes that some simulations could be computer demanding, do not hesitate to reduce the DEM extent (QGIS>Raster>Extraction>Clip raster by extent), adapt the vent distance spacing, the number of iterations to realize, the minimum probability to simulation, ...

References

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