EUROVOLC

European Network of
Observatories and Research Infrastructure for Volcanology

Deliverable Report

D12.1 On-line searchable catalogue of pre-existing volcanic hazard assessment tools

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Work Package number:	*12*
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Task number	*12.1*
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CONTENTS

Summary

Deliverable 12.1 consists of an online **catalogue** of pre-existing tools for volcanic hazard assessment. It stems from the up-to date list compiled for Milestone MS25 at Month 6, and it has been implemented it in the following website

http://193.206.223.51:8081/software-list

The catalogue will be continuously updated throughout the course of the project, as soon as new tools will become available. It will be soon moved to the EUROVOLC website.

Introduction

Quantitative Volcanic Hazard Assessment has become one of the most rapidly developing topics in volcanology in the last decade. To reach the goal, a number of tools (either methodological or numerical) have been developed to help scientists apply quantitative methods at different volcanic settings.

In recent past, some efforts have been devoted to collect tools for volcanology in a reference platform, such as the V-Hub (http://vhub.org), or the effort by INGV team in Pisa (http://vmsg.pi.ingv.it/). In EUROVOLC, we have proposed to collect pre-existing tools assisting the quantification of volcanic hazard, so we have focussed on tools that either simulate hazardous volcanic processes, or on tools that use simulations and/or expert knowledge to provide probabilistic assessment of volcanic hazard.

To this end, we have first compiled a list (MS25 of EUROVOLC project) of pre-existing hazard tools that covers what we have found by scouting what is currently available online: either tools that are runnable online, or downloadable for free or upon request to authors, or listed already by previous efforts such as those mentioned above. For each tool, the list displays the website, a short description (mostly taken from the tools' web-pages or papers), authorship of tools, references, requirements and information on implementation, and link for download or online running (where these are available). Dedicated IAVCEI commissions (i.e., the Commission for Volcanic Hazards and Risk, Commission for Tephra Hazard Modelling and the Commission of Statistics in Volcanology) have been consulted in order not to miss relevant tools.

We have also implemented the list into an online catalogue that is the subject of the present deliverable.

We plan to continuously update the catalogue throughout the course of the project, as soon as new tools will become available. The catalogue is hosted on the Gateway of European Volcanoes, which will be maintained after the project on the EPOS platform.

We remark that the present collection complements the current effort made within the EPOS project to provide a catalogue of *numerical models* used in volcanology, which is still under testing and not yet public. As a future step, we suggest to homogenize the two catalogues into a unique webpage.

The catalogue

The catalogue can be found at http://193.206.223.51:8081/software-list

It lists the tools in alphabetical order (**Figure 1**). By clicking on a specific tool (**Figure 2**), information on the tool shows up: website, authorship, short description (mostly taken from the tools' web-pages or papers), references, requirements and information on implementation, and link for download or online running (where these are available).
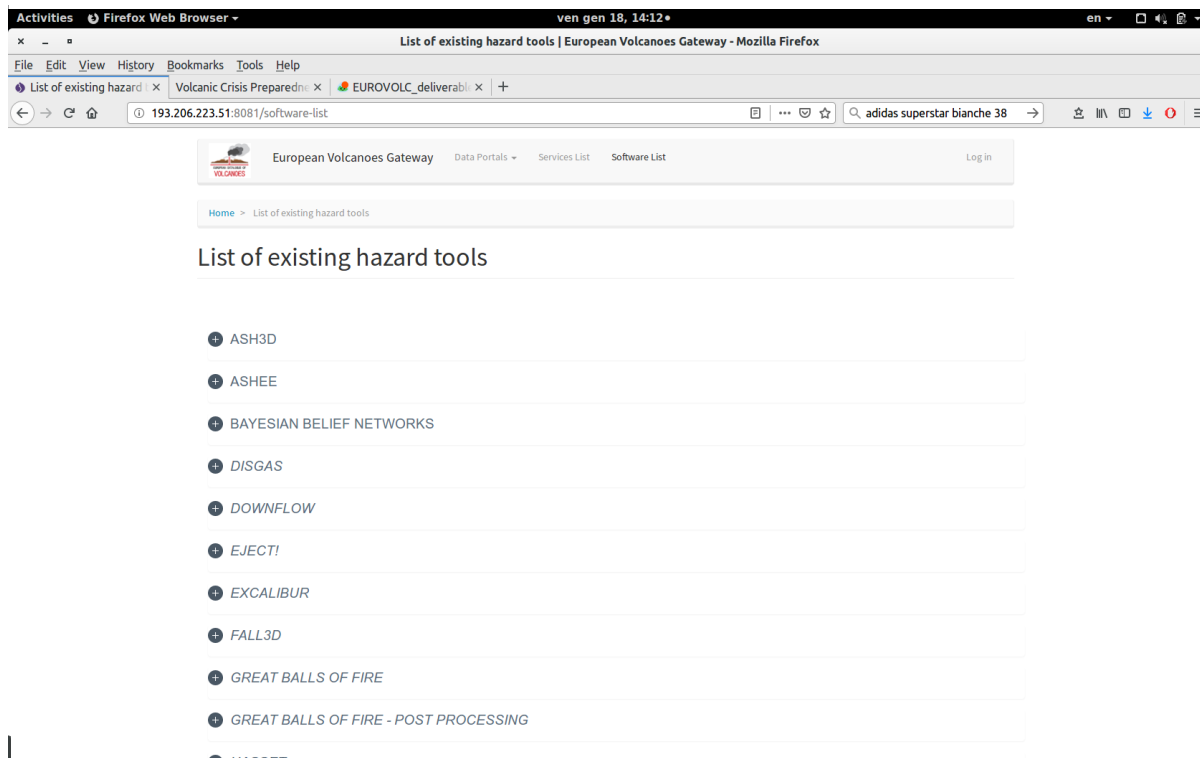
Figure 1: Screenshot of the catalogue webpage appearance
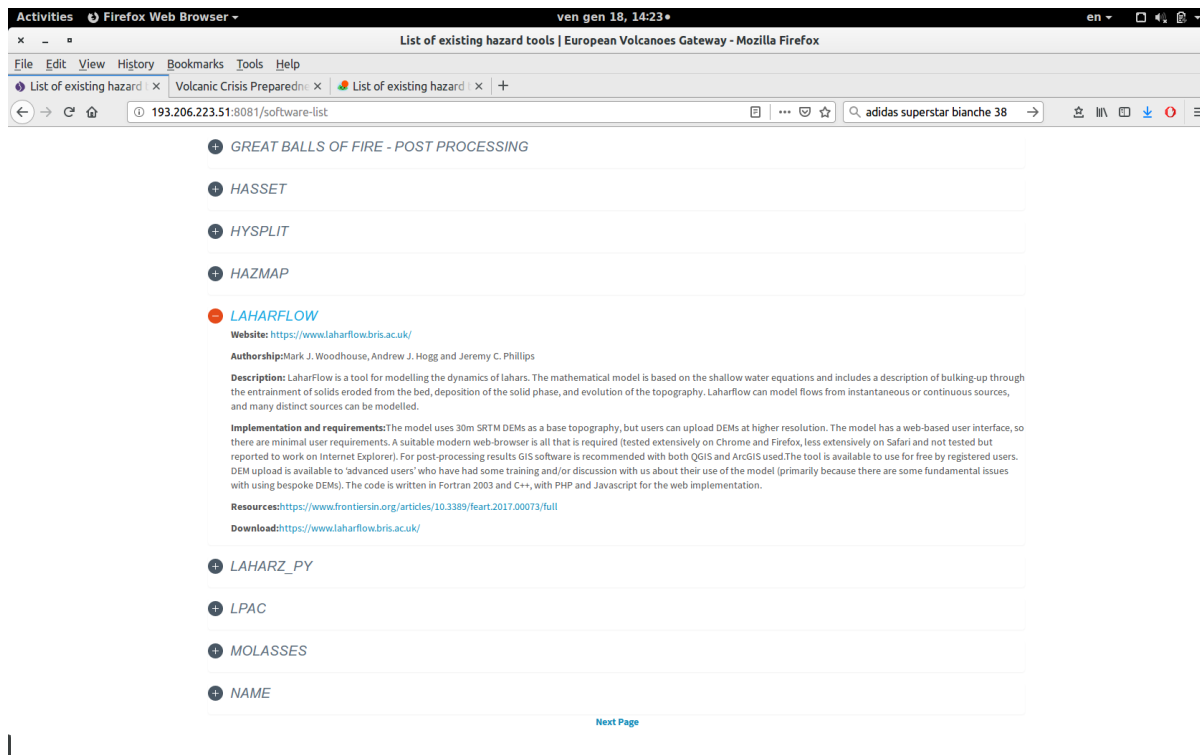
Figure 2: Screenshot of the information displayed when clicking on a specific tool (in this case, LAHARFLOW).

Catalogue searchability

In the web catalogue, it will be possible to browse the tools by "TOOL CATEGORY", and in particular the tools are divided according to their goal, i.e., according to what they serve for (HAZARD ASSESSMENT or EXPERT ELICITATION), or what they simulate (TEPHRA DISPERSAL, GAS DISPERSAL, BALLISTICS DISPERSAL, LAVA FLOW, PYROCLASTIC FLOW, LAHAR, SECTOR COLLAPSE, PLUME).

Alternatively, it will be possible to browse among the tools that are freely downloadable or that can be downloaded on request, or among those that can be run online.

The list of catalogued tools (MS25)

Ash3d

- **WEBSITE**: https://vsc-ash.wr.usgs.gov/ashgui/#/
- **AUTHORSHIP**: Larry G. Mastin, Michael J. Randall, Hans F. Schwaiger, Roger P. Denlinger
- **DESCRIPTION**:
  Ash3d is a three-dimensional Eulerian atmospheric model for tephra transport, dispersal, and deposition, written by the authors to study and forecast hazards of volcanic ash clouds and tephra fall.
  Ash3d uses three-dimensional, time-varying wind fields and other meteorological properties from numerical weather prediction models to calculate where airborne ash is transported under current or historical atmospheric conditions. Results are used in several ways.
- **IMPLEMENTATION AND REQUIREMENTS:**
  The code was written in Fortran 90/95. The program and associated scripts are executed on a Linux operating system.
- **PAPERS**:
  Denlinger, R. P., M. Pavolonis, and J. Sieglaff (2012), A robust method to forecast volcanic ash clouds, J. Geophys. Res., 117(D13), D13208, doi 10.1029/2012jd017732.

  Denlinger, R. P., P. Webley, L. G. Mastin, and H. Schwaiger (2013), A Bayesian Method to Rank Different Model Forecasts of the Same Volcanic Ash Cloud, in Lagrangian Modeling of the Atmosphere, edited, pp. 299-310, American Geophysical Union

  Mastin, L. G., A. R. Van Eaton, and J. B. Lowenstern (2014), Modeling ash fall distribution from a Yellowstone supereruption, Geochemistry, Geophysics, Geosystems, 15(8), 3459-3475, doi 10.1002/2014GC005469.

  Mastin, L. G., A. R. Van Eaton, and A. J. Durant (2016), Adjusting particle-size distributions to account for aggregation in tephra-deposit model forecasts, Atmos. Chem. Phys., 16(14), 9399-9420, doi 10.5194/acp-16-9399-2016.

  Mastin, L. G., M. Randall, J., H. Schwaiger, and R. Denlinger (2013), User's Guide and Reference to Ash3d: A Three-Dimensional Model for Atmospheric Tephra Transport and Deposition, U.S. Geological Survey Open-File Report 2013-1122, 48 pp.

  Mastin, L. G., H. Schwaiger, D. J. Schneider, K. L. Wallace, J. Schaefer, and R. P. Denlinger (2013), Injection, transport, and deposition of tephra during event 5 at Redoubt Volcano, 23 March, 2009, Journal of Volcanology and Geothermal Research, 259(0), 201-213,doi http://dx.doi.org/10.1016/j.jvolgeores.2012.04.025.

  Schwaiger, H., R. Denlinger, and L. G. Mastin (2012), Ash3d: a finite-volume, conservative numerical model for ash transport and tephra deposition, Journal of Geophysical Research, 117(B04204), doi:10.1029/2011JB008968, doi doi:10.1029/2011JB008968.

  Van Eaton, A. R., L. G. Mastin, M. Herzog, H. F. Schwaiger, D. J. Schneider, K. L. Wallace,

and A. B. Clarke (2015), Hail formation triggers rapid ash aggregation in volcanic plumes, Nat Commun, 6, doi 10.1038/ncomms8860.

- **WEB INTERFACE FOR ONLINE RUNNING**: login at https://vsc-ash.wr.usgs.gov/ashgui/#/
- *HAZARD: TEPHRA FALLOUT*
- *FREE DOWNLOAD or ON REQUEST: NO*
- *ONLINE RUNNABLE: YES*

- **ASHEE**
  - **WEBSITE**: http://vmsg.pi.ingv.it/index.php/en/software/show/sw_id/16
  - **AUTHORSHIP**: Matteo Cerminara, Tomaso Esposti Ongaro
  - **DESCRIPTION**:
    The ASHEE model is designed to simulate the transient dynamics of polydisperse turbulent mixtures of gas and particles in a three-dimensional domain. It assumes thermal equilibrium between gas and particles but allows description of the kinetic non-equilibrium through a first-order expansion of the compressible Eulerian multiphase flow equations. The model is valid for low concentration regimes (particle volume fraction less than 1e-3) and particles Stokes number (i.e., the ratio between their relaxat ion time and flow characteristic time) not exceeding about 0.2. It implements a variety of Large Eddy Simulation subgrid-scale models for modeling turbulent flows.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    The code and algorithm are based on the OpenFOAM opensource (Open Field Operation and Manipulation) Toolbox for Computational Fluid Dynamics (www.openfoam.org). OpenFOAM is written in C++ and has a highly modular design.
  - **PAPERS**: https://drive.google.com/open?id=0B4dLOcllyIYbU3NJb2JqZmtqWDQ, http://dx.doi.org/10.1016/j.jvolgeores.2016.06.018, http://www.geosci-model-dev.net/9/697/2016/
  - **CODE-REQUEST LINK**:
    http://vmsg.pi.ingv.it/index.php/en/software/showReleases/sw_id/16
  - *HAZARD: PLUME*
  - *FREE DOWNLOAD or ON REQUEST: YES*
  - *ONLINE RUNNABLE: NO*

- **BAYESIAN BELIEF NETWORKS**
  - **AUTHORSHIP**: various, see download links below
  - **DESCRIPTION**:
    Bayesian Belief Network (BBN) provide a formalism for determining a rational choice or for providing decision outcome solutions. They automatically perform the calculations involved in the application of Bayes' Rule. "The
    BBN itself is a graphical construct in which multiple uncertain variables are represented by separate nodes, and causal or infuence links between no-
    des are represented by arcs. Associated with each node is a set of conditional probability values, expressing the relationships of the states of that node to any others in the network to which it is linked. These relationships can be given in terms of statistical probability distributions, when data are plentiful, as discrete condition states when hard information is available, or as subjective probabilities or expert opinion when evidence is uncertain and sparse. Behind the graphical interface of a BBN lies the numerical means for computing possible Bayes' Rule outcomes, with whatever type of information is input." (Aspinall et al., JVGR, 2003)
  - **PAPERS**: https://www.sciencedirect.com/science/article/pii/S0377027303002609,

- **DOWNLOAD**:
  - NETICA SOFTWARE: http://www.norsys.com/download.html
  - OpenPNL: http://sourceforge.net/projects/openpnl/ ; https://github.com/crishoj/OpenPNL
  - GeNIe (Graphical Network Interface) software: http://genie.sis.pitt.edu
- *HAZARD: HAZARD ASSESSMENT*
- *FREE DOWNLOAD or ON REQUEST: YES*
- *ONLINE RUNNABLE: NO*

- **DISGAS**
  - **WEBSITE**: http://datasim.ov.ingv.it/models/disgas.html
  - **AUTHORSHIP**: Antonio Costa, Giovanni Macedonio
  - **DESCRIPTION**:
    DISGAS (passive DISpersion of GASes and particles) is an Eulerian model for passive dispersion of diluted gas and fine dust particles. Turbulent diffusion is based on the K-theory, and the wind field can be evaluated assuming either a wind profile based on the similarity theory or using a terrain-following mass consistent wind model. The model can be used to forecast concentration of gas (or dust) over complex terrains. The input to the model are topography, wind observations from meteorological stations, atmospheric stability information and gas flow rates from a discrete number of point sources.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    - **DISGAS 2.0:** Written in FORTRAN90. Package includes DISGAS-2.0 F90 source code, and a few examples. Requirements: a Fortran compiler. Makefile is provided only for *UNIX*, *LINUX*, and *MAC X* OS.
    - **DISGAS 2.0-win Characteristics** Binary files for Windows.
  - **PAPERS**: http://www.annalsofgeophysics.eu/index.php/annals/article/view/3236, https://www.sciencedirect.com/science/article/pii/S0377027313001443?via%3Dihub, http://www.ingv.it/editoria/rapporti/2016/rapporto332/,
  - **DOWNLOAD:** http://datasim.ov.ingv.it/models/disgas.html
  - *HAZARD: GAS DISPERSAL*
  - *FREE DOWNLOAD or ON REQUEST: YES*
  - *ONLINE RUNNABLE: NO*

- **DOWNFLOW**
  - **WEBSITE**: http://vmsg.pi.ingv.it/index.php/en/software/show/sw_id/9
  - **AUTHORSHIP**: Massimiliano Favalli, Simone Tarquini
  - **DESCRIPTION**:
    DOWNFLOW is a topography-based model for computation of lava flow inundation areas in short computational times. This code is optimal to compile high-resolution quantitative lava flow hazard and risk maps. Lava flows are relatively slowly gravity driven flows, therefore, as a first approximation, they follow the steepest descent path (SDP). The SDP is univocally defined by the underlying topography. Lava flows also tend to spread over topography, surmount obstacles, and branch in multiple directions. The DOWNFLOW model accounts for these complications in a probabilistic effective way without solving directly the physical equations. The lack of physical modeling for lava flow propagation does not allow a straightforward description of the time evolution of the flow nor the direct determination of the maximum runout distance. Maximum runout distances are input based on statistics from past eruptions.

- **IMPLEMENTATION AND REQUIREMENTS:**
  The code is implemented in C++ and the format of input and output data is compatible with ESRI softwares (e.g., ArcView, ArcGis). Compression of data is performed using the zlib library.
- **PAPERS**: http://www.agu.org/pubs/crossref/2005/2004GL021718.shtml
- **DOWNLOAD:** N/A
- *HAZARD: LAVA FLOW*
- *FREE DOWNLOAD or ON REQUEST: NO*
- *ONLINE RUNNABLE: NO*

- **Eject!**
  - **WEBSITE**: https://pubs.usgs.gov/of/2001/0045/
  - **AUTHORSHIP**: Larry Mastin
  - **DESCRIPTION**:
    It is a program that can be used for quick ballistics calculations
  - **IMPLEMENTATION AND REQUIREMENTS:**
    The code is written in Microsoft Visual Basic® and operates on any personal computer running Microsoft® Windows 95 or later.
  - **PAPERS**: https://pubs.usgs.gov/of/2001/0045/pdf/of2001-0045_v1-2.pdf
  - **DOWNLOAD:** https://pubs.usgs.gov/of/2001/0045/
  - *HAZARD: BALLISTICS DISPERSAL*
  - *FREE DOWNLOAD or ON REQUEST: YES*
  - *ONLINE RUNNABLE: NO*

- **Excalibur**
  - **WEBSITE**: http://www.lighttwist.net/wp/excalibur
  - **AUTHORSHIP**: Technical University of Delft; maintained by Lighttwist Software
  - **DESCRIPTION**:
    EXCALIBUR is a software package for structured expert judgement elicitation using Cooke's Classical Model. It is an old, but fully functioning application which was originally developed by the Technical University of Delft and is now maintained by Lighttwist Software.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    The code is operates on Microsoft® Windows only.
  - **PAPERS**:
    - Cooke RM: Experts in Uncertainty - Opinion and Subjective Probability in Science. Environmental Ethics and Science Policy. Series: Oxford University Press; 1991.
    - Cooke R, Kritchallo V, Solomatine D: EXCALIBUR v1.0 Delft University of Technology, The Netherlands. 2000.
    - Aspinall WP, Cooke R: Expert Elicitation and Judgement. In Risk and Uncertainty assessment in natural Hazards. Edited by: Hill L, Rougier JC, Sparks RSJ. Cambridge: Cambridge University Press; 2013
  - **DOWNLOAD:** http://www.lighttwist.net/wp/excalibur
  - *HAZARD: EXPERT ELICITATION*
  - *FREE DOWNLOAD or ON REQUEST: YES*
  - *ONLINE RUNNABLE: NO*

- **FALL3D**
  - **WEBSITE**: http://datasim.ov.ingv.it/models/fall3d.html, http://bsccase02.bsc.es/projects/fall3d/

- **AUTHORSHIP**: Antonio Costa, Giovanni Macedonio, Arnau Folch
- **DESCRIPTION**:

  FALL3D (version 7.3.1) is a 3-D time-dependent Eulerian model for the transport and deposition of tephra developed in collaboration with Barcelona Supercomputing Center (BSC). The model solves a set of advection-diffusion-sedimentation (ADS) equations on a structured terrain-following grid using a second-order Finite Differences (FD) explicit scheme. The model inputs are meteorological data, topography, vent coordinate, Eruption Source Parameters (ESP) such as column height, Mass Flow Rate (MFR), eruption duration, and Total Grain-Size Distribution (TGSD) which include particle shape and density information. Outputs are tephra ground load/thickness, airborne ash concentration and other related variables. Several parameterizations can be chosen to describe eruption source, particle terminal settling velocity, eddy diffusivity tensor, and ash aggregation. For the meteorological variables FALL3D-7.3.1 uses an off-line strategy, i.e. variables are furnished by independent meteorological models or datasets and interpolated to the FALL3D-7.3.1 grid as NetCDF files. The FALL3D-7.3.1 model can be used to reproduce features of past eruptions, short-term tephra dispersal forecasting, and for probabilistic volcanic fallout hazard assessment.

- **IMPLEMENTATION AND REQUIREMENTS:**

  The code, written in FORTRAN-90, is available for Unix/Linux/Mac X Operating Systems (OS) and can be compiled either as serial or parallel using MPI. A set of pre- and post-process utility programs and related scripts are also included in the FALL3D-7.3.1 distribution package.

  - **Package** includes FALL3D 7.3.1 F90 source code, few examples of application and the of utility programs needed for building input files for FALL3D 7.3.1: SetBsd (generates the FALL3D database files containing topography and meteorological data), SetTgsd (generates the total grain size distribution file needed by the utility program SetSrc), SetSrc (generates the source file and bulk granulometry file for FALL3D), Fall3d2GMT (utility program for visualizing Fall3d 7.3.1 output based on GMT).
  - **Requirements**: a F90 compiler, a C compiler and MPI for the parallel version, NetCDF libraries, and GMT for using Fall3d2GMT. Makefiles are provided for *UNIX*, *LINUX*, and *MAC X* OS.

- **PAPERS**: https://www.sciencedirect.com/science/article/pii/S0098300408002781
- **DOWNLOAD:** http://datasim.ov.ingv.it/models/fall3d.html
- *HAZARD: TEPHRA FALLOUT*
- *FREE DOWNLOAD or ON REQUEST: YES*
- *ONLINE RUNNABLE: NO*

- **Great Balls of Fire**
  - **WEBSITE**: https://e5k.github.io/pages/gbf
  - **AUTHORSHIP**: Sebastien Biass, Jean-Luc Falcone, Costanza Bonadonna
  - **DESCRIPTION**:

    Great Balls of Fire (GBF) is an approach for the probabilistic hazard assessment of volcanic ballistic projectiles (VBP). It contains a model describing ballistic trajectories of VBPs accounting for a variable drag coefficient and topography and is designed to model large numbers of VBPs stochastically. Associated functions come with the GBF code to post-process model outputs into a comprehensive probabilistic hazard assessment for VBP impacts. Outcomes include probability maps to exceed given thresholds of kinetic energies at impact, hazard curves and probabilistic isoenergy maps. Probabilities are calculated either on equally-

sized pixels or zones of interest. GBF can be downloaded as a suit of software for modeling the hazard posed by VBPs.

- **IMPLEMENTATION AND REQUIREMENTS:**
  GBF is executed on the Java virtual machine (version 8). It is then compatible with any OS which supports Java, notably GNU/Linux, Apple MacOSX and MS Windows. The computation is mainly CPU intensive, as each bomb trajectory is computed independently. Thus,
  only a limited amount of memory is required even for large simulations (1GB should be enough). Multicore CPU or multiprocessor machines will however greatly speed up the computation. The only external requirement is the Java Virtual Machine (JVM) version 8. A suitable version can be downloaded at Oracle website.
- **PAPERS**: https://www.sciencedirect.com/science/article/pii/S0377027316301317
- **DOWNLOAD:** https://github.com/unigeSPC/gbf
- *HAZARD: BALLISTICS DISPERSAL*
- *FREE DOWNLOAD or ON REQUEST: YES*
- *ONLINE RUNNABLE: NO*

- **Great Balls of Fire - Post Processing**
  - **WEBSITE**: https://e5k.github.io/codes/2017/10/09/ballistic-post-processing/
  - **AUTHORSHIP**: Sebastien Biass, Jean-Luc Falcone, Costanza Bonadonna
  - **DESCRIPTION**:
    It is an extended version of the Matlab post-processing function developed for the **Great Balls of Fire** model for the probabilistic hazard assessment of ballistic impact. This function has been modified so output files of virtually any model can be loaded and processed.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    Requirements are:
    - Impact coordinates must be defined in UTM WGS84
    - Files must be ascii and tab delimited
    - Columns in the output file should be organised as indicated in the table below. Note that adding extra columns is acceptable
  - **PAPERS**: https://www.sciencedirect.com/science/article/pii/S0377027316301317
  - **DOWNLOAD:** https://github.com/e5k/GBF-Post-Processing
  - *HAZARD: BALLISTICS DISPERSAL*
  - *FREE DOWNLOAD or ON REQUEST: YES*
  - *ONLINE RUNNABLE: NO*

- **HASSET**
  - **WEBSITE**: https://gvbcsic.wordpress.com/hasset/
  - **AUTHORSHIP**: Rosa Sobradelo, Stefania Bartolini, Joan Martí
  - **DESCRIPTION**:
    HASSET is A PROBABILITY EVENT TREE TOOL TO EVALUATE FUTURE VOLCANIC SCENARIOS USING BAYESIAN INFERENCE. IT IS PRESENTED AS A PLUGIN FOR QGIS. Event tree structures constitute one of the most useful and necessary tools in modern volcanology for assessment of hazards from future volcanic scenarios (those that culminate in an eruptive event as well as those that do not). They are particularly relevant for evaluation of long- and short-term probabilities of occurrence of possible volcanic scenarios and their potential impacts on urbanized areas. HASSET is presented as a free software package in the form of a plugin for the open source geographic information system

Quantum Gis (QGIS), providing a graphically supported computation of the event tree structure in an interactive and user-friendly way.

- **IMPLEMENTATION AND REQUIREMENTS:**
  The tool is downloaded as a zip file with the plugin for Qgis 2.0.1 and the User's Guide.
- **PAPERS**: https://gvbcsic.files.wordpress.com/2016/12/hasset.pdf
- **DOWNLOAD:** https://gvbcsic.wordpress.com/hasset/
- *HAZARD: HAZARD ASSESSMENT*
- *FREE DOWNLOAD or ON REQUEST: YES*
- *ONLINE RUNNABLE: NO*

- **HYSPLIT**
  - **WEBSITE**: https://www.arl.noaa.gov/hysplit/hysplit/
  - **AUTHORSHIP**: A. F. Stein, R. R. Draxler, G. D. Rolph, B. J. B. Stunder, M. D. Cohen, F. Ngan
  - **DESCRIPTION**:
    The **HYSPLIT** model is a complete system for computing simple air parcel trajectories, as well as complex transport, dispersion, chemical transformation, and deposition simulations. HYSPLIT continues to be one of the most extensively used atmospheric transport and dispersion models in the atmospheric sciences community. A common application is a back trajectory analysis to determine the origin of air masses and establish source-receptor relationships. HYSPLIT has also been used in a variety of simulations describing the atmospheric transport, dispersion, and deposition of pollutants and hazardous materials. Some examples of the applications include tracking and forecasting the release of radioactive material, wildfire smoke, windblown dust, pollutants from various stationary and mobile emission sources, allergens and volcanic ash.

    The model calculation method is a hybrid between the Lagrangian approach, using a moving frame of reference for the advection and diffusion calculations as the trajectories or air parcels move from their initial location, and the Eulerian methodology, which uses a fixed three-dimensional grid as a frame of reference to compute pollutant air concentrations (The model name, no longer meant as an acronym, originally reflected this hybrid computational approach). HYSPLIT has evolved over more than 30 years, from estimating simplified single trajectories based on radiosonde observations to a system accounting for multiple interacting pollutants transported, dispersed, and deposited over local to global scales.

    The dispersion of a pollutant is calculated by assuming either puff or particle dispersion. In the puff model, puffs expand until they exceed the size of the meteorological grid cell (either horizontally or vertically) and then split into several new puffs, each with its share of the pollutant mass. In the particle model, a fixed number of particles are advected about the model domain by the mean wind field and spread by a turbulent component. The model's default configuration assumes a 3-dimensional particle distribution (horizontal and vertical).
  - **IMPLEMENTATION AND REQUIREMENTS:**
    The model can be run interactively on the Web through the ARL READY system, or the code executable and meteorological data can be downloaded to a Windows or Mac PC. The web version has been configured with some limitations to avoid computational saturation of the ARL web server. The registered PC version is complete with no computational restrictions, except that users must obtain their own meteorological data files. The unregistered version is identical to the registered version except that plume concentrations cannot be calculated with forecast meteorology data files. The trajectory-only model has no restrictions, and forecast or archive trajectories may be computed with either version.
  - **PAPERS**: https://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-14-00110.1

- **DOWNLOAD:** https://www.ready.noaa.gov/HYSPLIT.php
- *HAZARD: GAS DISPERSAL*
- *FREE DOWNLOAD or ON REQUEST: YES*
- *ONLINE RUNNABLE: NO*

- **Hazmap**
  - **WEBSITE**: http://datasim.ov.ingv.it/models/hazmap.html, https://vhub.org/resources/hazmap
  - **AUTHORSHIP**: Giovanni Macedonio, Antonio Costa
  - **DESCRIPTION**:
    HAZMAP is a code for the solution of the equation of diffusion, transport and sedimentation of small particles in order to model the dispersion of ash generated by a convective column. The model simplifies the advection-diffusion-sedimentation equation for volcanic ash transport in the atmosphere from three to two spatial dimensions and uses a semi-analytical approach that greatly reduces the required computer time and memory. The model needs the definition of the physical system (spatial distribution of the point sources, total erupted mass, settling velocity model, wind velocity profile, atmospheric turbulent diffusion coefficients) and of a computational grid.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    HAZMAP 2.4.4 (F90 version. Release Jan 2016).
    - **Characteristics**: Written in FORTRAN90. Steady. Outputs total values of mass accumulation on the ground. Produces hazard maps. In this version settling velocities can be calculated directly as function of particle diameters, densities, and shapes. Supports GPU with CUDA.
    - **Package**: includes Hazmap 2.4.4 F90 source code and the utilitiy program haz2nc.
    - **Requirements**: a F90 compiler. Makefile is provided only for *UNIX*, *LINUX*, and *MAC X* OS.
  - **PAPERS**: https://vhub.org/resources/28/download/hazmap_paper.pdf
  - **DOWNLOAD:** http://datasim.ov.ingv.it/models/hazmap.html, https://vhub.org/resources/hazmap
  - *HAZARD: TEPHRA DISPERSAL*
  - *FREE DOWNLOAD or ON REQUEST: YES*
  - *ONLINE RUNNABLE: NO*

- **Laharflow**
  - **WEBSITE**: https://www.laharflow.bris.ac.uk/
  - **AUTHORSHIP**: Mark J. Woodhouse, Andrew J. Hogg and Jeremy C. Phillips
  - **DESCRIPTION**:
    LaharFlow is a tool for modelling the dynamics of lahars. The mathematical model is based on the shallow water equations and includes a description of bulking-up through the entrainment of solids eroded from the bed, deposition of the solid phase, and evolution of the topography. Laharflow can model flows from instantaneous or continuous sources, and many distinct sources can be modelled.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    The model uses 30m SRTM DEMs as a base topography, but users can upload DEMs at higher resolution.
    The model has a web-based user interface, so there are minimal user requirements. A suitable modern web-browser is all that is required (tested extensively on Chrome and Firefox, less extensively on Safari and not tested but reported to work on Internet Explorer). For post-processing results GIS software is recommended with both QGIS and ArcGIS used.

The tool is available to use for free by registered users. DEM upload is available to 'advanced users' who have had some training and/or discussion with us about their use of the model (primarily because there are some fundamental issues with using bespoke DEMs).
The code is written in Fortran 2003 and C++, with PHP and Javascript for the web implementation.

- **PAPERS**: https://www.frontiersin.org/articles/10.3389/feart.2017.00073/full
- **CODE-REQUEST LINK:** https://www.laharflow.bris.ac.uk/
- *HAZARD: LAVA FLOW*
- *FREE DOWNLOAD or ON REQUEST: YES*
- *ONLINE RUNNABLE: NO*

- **Laharz_py**
  - **WEBSITE**: https://pubs.usgs.gov/of/2014/1073/
  - **AUTHORSHIP**: Steve P. Schilling
  - **DESCRIPTION**:
    Primarily, **Laharz_py** is a computational model that uses statistical descriptions of areas inundated by past mass-flow events to forecast areas likely to be inundated by hypothetical future events. The forecasts use physically motivated and statistically calibrated power-law equations that each has a form $A = cV^{(2/3)}$, relating mass-flow volume (V) to planimetric or cross-sectional areas (A) inundated by an average flow as it descends a given drainage. Calibration of the equations utilizes logarithmic transformation and linear regression to determine the best-fit values of c. The software uses values of V, an algorithm for idenitifying mass-flow source locations, and digital elevation models of topography to portray forecast hazard zones for lahars, debris flows, or rock avalanches on maps. Laharz_py offers two methods to construct areas of potential inundation for lahars: (1) Selection of a range of plausible V values results in a set of nested hazard zones showing areas likely to be inundated by a range of hypothetical flows; and (2) The user selects a single volume and a confidence interval for the prediction. In either case, Laharz_py calculates the mean expected A and B value from each user-selected value of V. However, for the second case, a single value of V yields two additional results representing the upper and lower values of the confidence interval of prediction. Calculation of these two bounding predictions require the statistically calibrated prediction equations, a user-specified level of confidence, and t-distribution statistics to calculate the standard error of regression, standard error of the mean, and standard error of prediction. The portrayal of results from these two methods on maps compares the range of inundation areas due to prediction uncertainties with uncertainties in selection of V values.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    Laharz_py is written in the Python programming language as a suite of tools for use in ArcMap Geographic Information System (GIS). The Open-File Report document contains an explanation of how to install and use the software. The Laharz_py software includes an example data set for Mount Rainier, Washington. The second part of the documentation describes how to use all of the Laharz_py tools in an example dataset at Mount Rainier, Washington.
  - **PAPERS**: https://pubs.usgs.gov/of/2014/1073/pdf/ofr2014-1073.pdf
  - **DOWNLOAD:** https://pubs.usgs.gov/of/2014/1073/
  - *HAZARD: LAHAR*
  - *FREE DOWNLOAD or ON REQUEST: YES*
  - *ONLINE RUNNABLE: NO*

- **LPAC**
  - **WEBSITE**: http://vmsg.pi.ingv.it/index.php/en/software/show/sw_id/6

- **AUTHORSHIP**: Mattia de' Michieli Vitturi, Augusto Neri, Tomaso Esposti Ongaro
- **DESCRIPTION**:

  LPAC is a Lagrangian particle model able to describe the transport of pyroclastic lapilli and clasts during explosive eruptions. The model is based on a simplification of the Basset-Boussinesq-Oseen (BBO) equation, expressing the Lagrangian equation of a particle as the sum of the forces exerted on the particle along its trajectory. The Lagrangian equations accounts for drag and lift forces between fluid and particles, pressure gradients, and gravity and viscous forces.

  The simplified set of Basset-Boussinesq-Oseen equations are numerically integrated using a fourth order Runge-Kutta method. At each Runge-Kutta step the acceleration terms were evaluated explicitly inteprolating the output flow variables of the Eulerian code PDAC. A bicubic interpolation in space and a linear first-order or a nearest point interpolation in time are adopted.
- **IMPLEMENTATION AND REQUIREMENTS:**

  The code is written in Fortran 90 and is implemented for serial execution only.
- **PAPERS**: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2009JB007111
- **DOWNLOAD:** N/A
- *HAZARD: PYROCLASTIC FLOW*
- *FREE DOWNLOAD or ON REQUEST: NO*
- *ONLINE RUNNABLE: NO*

- **MOLASSES**
  - **WEBSITE**: http://131.247.211.166/tiki/tiki-index_raw.php?page=MOLASSES
  - **AUTHORSHIP**: Jacob Richardson, Laura Connor, Chuck Connor
  - **DESCRIPTION**:

    MOLASSES is an in-progress fluid flow simulator. MOLASSES stands for **MO**dular **LA**va **S**imulation **S**oftware for **E**arth **S**cience. MOLASSES is constructed with individual modules of files that each have a specific task, either carrying out the lava flow simulation, reading model input, or writing model output.
  - **IMPLEMENTATION AND REQUIREMENTS:**

    The code is written in C and requires the GDAL C libraries and a C compiler. To get the GDAL libraries, install gdal-devel on a UNIX machine. This program has been tested on computers that use the C compiler gcc.
  - **PAPERS**: https://appliedvolc.springeropen.com/articles/10.1186/2191-5040-1-3
  - **DOWNLOAD:** https://github.com/geoscience-community-codes/MOLASSES
  - *HAZARD: LAVA FLOW*
  - *FREE DOWNLOAD or ON REQUEST: YES*
  - *ONLINE RUNNABLE: NO*

- **NAME**
  - **WEBSITE**: https://www.metoffice.gov.uk/research/modelling-systems/dispersion-model
  - **AUTHORSHIP**: UK Met Office
  - **DESCRIPTION**:

    The Met Office's Numerical Atmospheric-dispersion Modelling Environment (**NAME**) is used to model a wide range of atmospheric dispersion events.

    NAME is a sophisticated tool capable of simulating many atmospheric dispersion phenomena and associated physical and chemical processes. NAME is capable of both forward and inverse (source identification) simulations.

    NAME is used by the Met Office to model a wide range of atmospheric dispersion events

including nuclear accidents, volcanic eruptions, chemical accidents, smoke from fires, odours, airborne animal diseases, as well as the provision of routine air quality forecasts. In inverse mode the model is used to investigate emissions of greenhouse gases and other atmospheric pollutants. The model is used for research activities and for emergency air pollution forecasts. NAME uses the Unified Model and ECMWF Numerical Weather Prediction (NWP) meteorology data. Both forecast and archived data are available, enabling forecasts out to 10 days and historic studies back to 1957. There is no limitation to the duration of a pollutant release or the time period covered by a NAME simulation. It is therefore possible to predict dispersion over distances ranging from a few kilometres to the whole globe and for time periods of minutes to decades.

NAME is a Lagrangian particle model which calculates the dispersion by tracking model 'particles' through the modelled atmosphere. These particles move with the resolved wind described by the meteorology, which can vary in space and time. The particles' motion also has a random component to represent the effects of atmospheric turbulence. A consequence of this is that no assumptions need to be made for the shape of the concentration distribution, such as are required in Gaussian plume models. Pollutants can also be removed from the model atmosphere by several processes: (i) fall out due to gravity, (ii) impaction with the surface, (iii) washout where the pollutant is 'swept out' by falling precipitation, and (iv) "rainout" where the pollutant is absorbed directly into cloud droplets as they form. In addition each model 'particle' can have its own characteristics; for example particles can represent different compounds or chemicals, and particles can have real particulate sizes.

- **IMPLEMENTATION AND REQUIREMENTS:**
  - FORTRAN 90/95 standard
  - Modular code design
  - openmp parallelisation
  - Compilers:
    - Supported: Intel
      - Unsupported but used: Sun Solaris, IMB XL FORTRAN, Compaq and Portland
  - Operating systems:
    - Supported: Linux, MS Windows
    - Unsupported but used: Apple Mac, Sun, IBM HPC

- **PAPERS**:

  Devenish B.J. et al, 2011, A study of the arrival over the United Kingdom in April 2010 of the Eyjafjallajokull ash cloud using ground-based lidar and numerical simulations, Atmospheric Environment, doi:10.1016/j.atmosenv.2011.06.033.

  Jones A.R., Thomson D.J., Hort M. and Devenish B., 2007, The U.K. Met Office's next-generation atmospheric dispersion model, NAME III', in Borrego C. and Norman A.-L. (Eds) Air Pollution Modeling and its Application XVII (Proceedings of the 27th NATO/CCMS International Technical Meeting on Air Pollution Modelling and its Application), Springer, pp. 580-589.

  Webster H.N. et al, 2011, Operational prediction of ash concentrations in the distal volcanic cloud from the 2010 Eyjafjallajokull eruption, Journal of Geophysical Research, doi:10.1029/2011JD016790.

- **USE-REQUEST LINK:** NAME is available for external research use under licence. Further information on how to apply for a licence can be obtained by contacting UK Met Office at https://www.metoffice.gov.uk/about-us/contact.

- *HAZARD: TEPHRA DISPERSAL*
- *FREE DOWNLOAD or ON REQUEST: YES*
- *ONLINE RUNNABLE: NO*

- **PDAC**
    - **WEBSITE**: http://vmsg.pi.ingv.it/index.php/en/software/show/sw_id/3
    - **AUTHORSHIP**: Tomaso Esposti Ongaro, Augusto Neri, Mattia de' Michieli Vitturi
    - **DESCRIPTION**:
    Transient, 3D multiphase flow model for the simulation of gas-particle mixtures. Solves the Eulerian transport equations for mass, momentum and enthalpy for a multiphase mixture made up of one gaseous phase (with up to 7 chemical components) and N granular phases. Constitutive equations describe the kinetic (gas-particle and particle-particle drag) and heat exchange between gas and particles, the equations of state, the stress tensor for each phase and the subgrid turbulent stress for the gas.
    Transport equations are discretized by adopting a Finite-Volume approach on a Cylindrical (2D) or Cartesian (2D/3D) grid. The temporal discretization of the momentum equation is semi-implicit, with explicit convection and diffusion terms and implicit pressure and interphase coupling. Mass transport equations are solved implicitly, whereas the enthalpy equations are fully explicit. The Finite Volumes spatial discretization scheme is based on an upwind treatment of the convection terms (with first or second order accuracy). Diffusive and pressure terms are discretized with a centered (second order) scheme. The solver is based on a iterative SOR (Successive Over-Relaxation) procedure together with a pressure correction algorithm suited for compressible, multiphase flows. The topography is described on the rectilinear mesh by means of an immersed boundaries method.
    - **IMPLEMENTATION AND REQUIREMENTS:**
    The code is written in Fortran 90 and implemented for both serial and parallel execution. Parallelization is achieved through a SPMD approach, by partitioning the physical domain among processors.
    - **PAPERS**: http://www.agu.org/pubs/crossref/2003/2001JB000508.shtml, http://linkinghub.elsevier.com/retrieve/pii/S0167819107000634
    - **CODE-REQUEST LINK:**
    http://vmsg.pi.ingv.it/index.php/en/software/showReleases/sw_id/3
    - *HAZARD: PYROCLASTIC FLOW*
    - *FREE DOWNLOAD or ON REQUEST: YES*
    - *ONLINE RUNNABLE: NO*
- **PLUMERISE**
    - **WEBSITE**: https://www.plumerise.bris.ac.uk/
    - **AUTHORSHIP**: Mark Woodhouse, Andrew Hogg, Jeremy Phillips, Steve Sparks
    - **DESCRIPTION**:
    PlumeRise is a tool for modelling the rise of volcanic plumes in a moist and windy atmosphere. The mathematical model is based on the fluid dynamics of turbulent buoyant plumes and includes a description of the thermodynamics of the heat transfer between hot pyroclasts and the surrounding magmatic and atmospheric gases.
    PlumeRise allows atmospheric controls on volcanic plume rise to be assessed and includes a description of the thermodynamics of phase changes of water.
    The model also accounts for the effect of cross winds on the rise of the plumes.
    - **IMPLEMENTATION AND REQUIREMENTS:**
    PlumeRise works best on recent web browsers. In particular, we do not recommend the use of

versions of Internet Explorer earlier than version 8, versions of Firefox prior to 4.0, or versions of Chrome prior to 6.0.

- **PAPERS**: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2012JB009592
- **DOWNLOAD:** https://www.plumerise.bris.ac.uk/
- *HAZARD: PLUME*
- *FREE DOWNLOAD or ON REQUEST: NO*
- *ONLINE RUNNABLE: YES*

- **puffin**
  - **WEBSITE**: https://vhub.org/resources/puffin
  - **AUTHORSHIP**: Marcus I. Bursik, Alejandro Uriel Carbonara, Sean Michael Zawicki, Abani Patra, Renette Jones-Ivey
  - **DESCRIPTION**:
    This program is a coupling of the programs Puffin (also known as Bent) and Puff. Both programs are described below. Puffin: Puffin is a theoretical model of a volcanic plume, based on applying the equations of motion in a plume-centered coordinate system. Puffin suggests that the interaction between a volcanic plume and wind causes enhanced entrainment of air and horizontal momentum, plume bending, and a decrease in plume rise height at constant eruption rate. Because of rapid dilution in the high wind speeds of the polar jet, plumes that vary over more than one order of magnitude in mass eruption rate ($10^$ to $10^$ kg/s), if injected into the polar jet, may all attain rise heights only slightly different from that of the core of the jet, ~10 km, as opposed to 17 – 33 km in a still atmosphere. The model outputs plume trajectories and rise heights, as well as pyroclast loadings as a function of height, and can therefore be used to produce input for advection-diffusion and volcanic ash transport models such as tephra2 or puff. Puff: Puff simulates the transport, dispersion and sedimentation of volcanic ash. It requires horizontal wind field data as a function of height on a regular grid covering the area of interest. Puff output includes the location (in 3 dimensions), size, and age-since-eruption of representative ash particles. Puff can also produce gridded data of relative and absolute ash concentration in the air and on the ground. Puff is a fast and efficient research and operational tool for predicting the trajectories of ash particles, which is essential for hazard assessment.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    For information on how to run puffin, check out the [https://vhub.org/resources/2641/download/PuffinDoc.pdf topics page].
  - **PAPERS**: N/A
  - **DOWNLOAD:** https://vhub.org/resources/puffin
  - *HAZARD: TEPHRA DISPERSAL; PLUME*
  - *FREE DOWNLOAD or ON REQUEST: YES*
  - *ONLINE RUNNABLE: NO*
- **PyBetUnrest**
  - **WEBSITE**: https://vhub.org/resources/betunrest
  - **AUTHORSHIP**: Roberto Tonini, Laura Sandri, Dmitri Rouwet
  - **DESCRIPTION**:
    PyBetUnrest implements the version of the probabilistic model BET (Bayesian Event Tree), called BET_UNREST, specifically developed to include the forecasting of non-magmatic unrest and related hazards, by adding a dedicated "non-magmatic" branch to the event tree's structure. Probabilities are calculated at each node by merging prior models and past data with new incoming monitoring data, and the results can be updated any time new data have been

collected. Monitoring data are weighted through pre-defined thresholds of anomaly, as in the previous only magmatic tool called BET_EF (BET for Eruption Forecasting, Marzocchi et al., 2008). PyBetUnrest is equipped with a Graphical User Interface aiming to create a user-friendly, open-access, and straightforward tool to support short-term volcanic forecasting.

- **IMPLEMENTATION AND REQUIREMENTS:**
  PyBetUnrest is an open and cross-platform implementation. The tool has been totally developed using Python programming language. It needs wxPython, NumPy and Matplotlib modules to be installed before usage.
- **PAPERS**: https://link.springer.com/article/10.1007/s00445-007-0157-y, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016GC006327
- **DOWNLOAD:** https://vhub.org/resources/betunrest
- *HAZARD: HAZARD ASSESSMENT*
- *FREE DOWNLOAD or ON REQUEST: YES*
- *ONLINE RUNNABLE: YES*

- **PyBetVH**
  - **WEBSITE**: https://vhub.org/resources/betvh, http://vmsg.pi.ingv.it/index.php/en/software/show/sw_id/17
  - **AUTHORSHIP**: Roberto Tonini, Laura Sandri, Jacopo Selva, Warner Marzocchi
  - **DESCRIPTION**:
    PyBetVH provides a graphically supported computation of long-term probabilities of volcanic hazardous phenomena (i.e., lava flows, tephra fall, pyroclastic flows, lahars, etc.) through the Bayesian Event Tree model for Volcanic Hazard (BET_VH, Marzocchi et al., 2010). This version introduces as main outputs the Hazard Curves (HC), showing the exceeding probability as function of the chosen intensity measure (e.g., the tephra load in kg/m2). The HC are provided together with their uncertainties (percentiles) through Bayesian inference and the user can explore the hazard results visualizing both Probability and Hazard Maps.
    The model is based on a Bayesian procedure, in order to quantify the aleatory and epistemic uncertainty characterizing the impact of volcanic eruptions in terms of hazard assessment.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    PyBetVH is an open and cross-platform implementation. The tool has been totally developed using Python programming language. It needs wxPython, NumPy and Matplotlib modules to be installed before usage.
  - **PAPERS**: https://link.springer.com/article/10.1007%2Fs00445-010-0357-8, https://www.sciencedirect.com/science/article/pii/S0098300415000515?via%3Dihub
  - **DOWNLOAD:** https://vhub.org/resources/betvh
  - *HAZARD: HAZARD ASSESSMENT*
  - *FREE DOWNLOAD or ON REQUEST: YES*
  - *ONLINE RUNNABLE: YES*

- **PYBOX**
  - **WEBSITE**: http://vmsg.pi.ingv.it/index.php/en/software/showReleases/sw_id/18
  - **AUTHORSHIP**: Tomaso Esposti Ongaro
  - **DESCRIPTION**:
    The model solves the box model equations for a polydisperse particle-laden gravity currents in Cartesian or Cylindrical coordinates. Particle settling velocities are computed with simplified correlations, depending on particle diameter and density. The Froude number, assumed as constant, must be provided as an input.
    Differential equations are solved by a RK algorithm.

- **IMPLEMENTATION AND REQUIREMENTS:**
  Input data: PDC volume, temperature, grain size distribution. Output data: front position and averaged particle concentrations as a function of time. Deposit distribution.
- **PAPERS**: https://www.sciencedirect.com/science/article/pii/S0377027316302347
- **CODE-REQUEST LINK:**
  http://vmsg.pi.ingv.it/index.php/en/software/showReleases/sw_id/18
- *HAZARD: PYROCLASTIC FLOW*
- *FREE DOWNLOAD or ON REQUEST: YES*
- *ONLINE RUNNABLE: NO*

- **PYFLOW_2.0**
  - **WEBSITE**: https://vhub.org/resources/4234
  - **AUTHORSHIP**: Fabio Dioguardi, Pierfrancesco Dellino, Daniela Mele
  - **DESCRIPTION**:
    PYFLOW_2.0 is a hazard tool for the calculation of the impact parameters of dilute pyroclastic density currents (DPDCs). DPDCs represent the dilute turbulent type of gravity flows that occur during explosive volcanic eruptions; their hazard is the result of their mobility and the capability to laterally impact buildings and infrastructures and to transport variable amounts of volcanic ash along the path. Starting from data coming from the analysis of deposits formed by DPDCs, PYFLOW_2.0 calculates the flow properties (e.g. velocity, bulk density, thickness) and impact parameters (dynamic pressure, deposition time) at the location of the sampled outcrop. Given the inherent uncertainties related to sampling, laboratory analyses, and modelling assumptions, the program provides ranges of variations and probability density functions of the impact parameters rather than single specific values; from these functions, the user can interrogate the program to obtain the value of the computed impact parameter at any specified exceedance probability.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    It requires a Fortran compiler and a text editor for creating the input file. A compilation script is made available.
  - **PAPERS**: https://link.springer.com/article/10.1007/s00445-017-1191-z
  - **CODE-REQUEST LINK:** https://vhub.org/resources/4235/download/PYFLOW_2.0.zip
  - *HAZARD: PYROCLASTIC FLOW*
  - *FREE DOWNLOAD or ON REQUEST: YES*
  - *ONLINE RUNNABLE: NO*

- **Q-LavHA**
  - **WEBSITE**: http://we.vub.ac.be/en/q-lavha
  - **AUTHORSHIP**: Mossoux S., Saey M., Bartolini S., Poppe S., Canters F., Kervyn M.
  - **DESCRIPTION**:
    Q-LavHA (Quantum-Lava Hazard Assessment) is a QGIS (Quantum Geographic Information System) freeware plugin which simulates 'a'ā lava flow invasion probability from one or regularly distributed eruptive vents on a Digital Elevation Model. 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. The spatial spread is constrained by the probabilistic steepest slope following the approach of Felpeto et al. (2001). Corrective factors are included to allow the lava flow simulation to overcome small topographical obstacles and fill pits. The terminal length of the lava flow simulation can be determined based on a fixed length value, a statistical length probability function or based on the thermo-rheological properties of an open-channel lava

flow following the approach of the FLOWGO model (Harris and Rowland 2001).
Q-LavHA is designed for scientists and stakeholders confronted with imminent or long-term lava flow hazard from basaltic volcanoes. Q-LavHA 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.

- **IMPLEMENTATION AND REQUIREMENTS:**
  Because of the diversity of its uses, Q-LavHA has been developed in Python in order to allow users to adapt the code to their needs. Its availability as a Quantum GIS plugin with a user friendly interface facilitates its distribution and its use by the community.
- **PAPERS**:
  https://www.sciencedirect.com/science/article/pii/S0098300416303715?via%3Dihub
- **DOWNLOAD:** http://we.vub.ac.be/en/q-lavha/download
- *HAZARD: LAVA FLOW*
- *FREE DOWNLOAD or ON REQUEST: YES*
- *ONLINE RUNNABLE: NO*

- **Sector Collapse**
  - **WEBSITE**: https://vhub.org/resources/sector
  - **AUTHORSHIP**: Chuck B Connor, Leah Michelle Courtland
  - **DESCRIPTION**:
    A simple model to calculate whether a site is impacted by sector collapse.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    N/A
  - **PAPERS**: N/A
  - **DOWNLOAD:** https://vhub.org/resources/sector
  - *HAZARD: SECTOR COLLAPSE*
  - *FREE DOWNLOAD or ON REQUEST: YES*
  - *ONLINE RUNNABLE: NO*

- **Swelava**
  - **WEBSITE**: http://datasim.ov.ingv.it/models/swelava.html
  - **AUTHORSHIP**: Antonio Costa, Giovanni Macedonio
  - **DESCRIPTION**:
    SWELAVA is a code for lava flow propagation based on depth-averaged equations solved by means of CLAWPACK routines.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    - **Characteristics** Written in FORTRAN77
    - **Package** in preparation
    - **Requirements**: a F77 compiler
  - **PAPERS**: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2004GL021817
  - **DOWNLOAD:** N/A
  - *HAZARD: LAVA FLOW*
  - *FREE DOWNLOAD or ON REQUEST: NO*
  - *ONLINE RUNNABLE: NO*

- **Tephra2**
  - **WEBSITE**: https://github.com/geoscience-community-codes/tephra2, https://vhub.org/resources/tephra2

- **AUTHORSHIP**: Costanza Bonadonna, Laura J Connor, Chuck B Connor, Leah Michelle Courtland
- **DESCRIPTION**:
  Tephra2 is a tephra dispersion model based on an analytical (closed-form) solution of the advection-diffusion equation. This initial version uses a plume model based on the beta function and incorporates a 2-D wind model that varies in speed and direction with changes in elevation.
- **IMPLEMENTATION AND REQUIREMENTS:**
  Perl scripts
- **PAPERS**: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2003JB002896
- **DOWNLOAD:** https://github.com/geoscience-community-codes/tephra2
- *HAZARD: TEPHRA DISPERSAL*
- *FREE DOWNLOAD or ON REQUEST: YES*
- *ONLINE RUNNABLE: NO*

- **TephraProb**
  - **WEBSITE**: https://e5k.github.io/pages/tephraprob
  - **AUTHORSHIP**: Sebastian Biass, Costanza Bonadonna, Laura J Connor, Chuck B Connor
  - **DESCRIPTION**:
    TephraProb is a toolbox of Matlab functions designed to produce scenario-based probabilistic hazard assessments for ground tephra accumulation based on the Tephra2 model. The toolbox includes a series of graphical user interfaces that collect, analyse and pre–process input data, create distributions of eruption source parameters based on a wide range of probabilistic eruption scenarios, run Tephra2 using the generated input scenarios and provide results as exceedence probability maps, probabilistic isomass maps and hazard curves.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    Matlab scripts
  - **PAPERS**: https://appliedvolc.springeropen.com/articles/10.1186/s13617-016-0050-5
  - **DOWNLOAD:** https://github.com/e5k/TephraProb
  - *HAZARD: TEPHRA DISPERSAL*
  - *FREE DOWNLOAD or ON REQUEST: YES*
  - *ONLINE RUNNABLE: NO*

- **Titan2D Mass-Flow Simulation Tool**
  - **WEBSITE**: https://vhub.org/resources/titan2d
  - **AUTHORSHIP**: Geophysical Mass Flow Group (GMFG), University at Buffalo, NY, USA
  - **DESCRIPTION**:
    The Titan2D toolkit is used for modeling of geophysical mass flows over natural terrain (volcanic flows, avalanches, landslides etc.). Titan2D uses an adaptive finite volume scheme, and assumes that a large class of granular flows of geophysical origin can be modeled with different rheologies modeling the interactions between the grains of the media and between the granular material and the basal surface. The solution is parallelized using the message-passing interface (MPI) and open multi-processing (OpenMP). Although simulations for difficult terrains can be relatively time consuming even on large computational clusters, many improvements have been incorporated into the new release of Titan2D including improved runtime performance. An essential input is the digital elevation model (DEM), since the flow simulation requires elevation, slope, curvature, and material information at every cell to be computed. This tool fronts a Titan2D simulation, but does not prepare the necessary DEM input, which is a prerequisite.

- **IMPLEMENTATION AND REQUIREMENTS:**
  The software is open source and is built using only other open source systems. It is designed for both low end single processor use and high end distributed/shared memory multi-processor use. The installation and use procedure is largely similar but there are small differences on each system.
- **PAPERS**: https://www.sciencedirect.com/journal/journal-of-volcanology-and-geothermal-research/vol/139/issue/1-2
- **DOWNLOAD:** http://www.gmfg.buffalo.edu/software.php, https://vhub.org/resources/titan2d
- **RELATED TOOLS AND LINKS:**
  - Titan2D View: https://vhub.org/resources/titanview
  - Titan2D Hazard Map Emulator Workflow: https://vhub.org/resources/testpegasus
- *HAZARD: LAHAR; PYROCLASTIC FLOW*
- *FREE DOWNLOAD or ON REQUEST: YES*
- *ONLINE RUNNABLE: NO*

- **Titan2F**
  - **WEBSITE**:
  - **AUTHORSHIP**: G. Córdoba, M. Sheridan, E. B. Pitman
  - **DESCRIPTION**:
    The Titan2F model develops a depth averaged "thin layer" model for geophysical mass flows that contain a mixture of solid material and fluid. Concepts from the engineering community are integrated with phenomenological findings in geo-science, resulting in a theory that accounts for the principal solid and fluid forces as well as interactions between the phases, across a wide range of solid volume fraction. A principal contribution here is to present drag and phase interaction terms that comport with the literature in geo-sciences. The program predicts the evolution of the concentration and dynamic pressure.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    N/A
  - **PAPERS**: https://www.nat-hazards-earth-syst-sci-discuss.net/3/3789/2015/nhessd-3-3789-2015.pdf
  - **DOWNLOAD:** N/A
  - *HAZARD: LAHAR*
  - *FREE DOWNLOAD or ON REQUEST: NO*
  - *ONLINE RUNNABLE: NO*

- **TWODEE-2**
  - **WEBSITE**: http://datasim.ov.ingv.it/models/twodee.html
  - **AUTHORSHIP**: Arnau Folch, Antonio Costa, Robin Hankin
  - **DESCRIPTION**:
    TWODEE-2 is a code for dispersion of heavy gases which has been derived from the optimization and improvement of a previous code. The model is based on the solution of a shallow water equations system for fluid depth, depth-averaged horizontal velocities and depth-averaged fluid density. The shallow layer approach used by Twodee is a compromise between the complexity of CFD models and the simpler integral models. The model can be used for forecasting gas dispersion near the ground and/or for hazard assessment over complex terrains. The input to the model are topography, wind measurements from meteorological stations and gas flow rate from the ground sources.
  - **IMPLEMENTATION AND REQUIREMENTS:**
    - **Characteristics**: Written in FORTRAN90.

- **Package** includes source codes, a run example and the source code for DIAGNO, a meteorological preprocessor.
        - **Requirements**: a F90 compiler. Makefiles are provided just for *UNIX*, *LINUX*, and *MAC X* OS. For *Windows* OS the binary executables are provided, so that the F90 compiler is not strictly necessary.
    - **PAPERS:** https://www.nat-hazards-earth-syst-sci.net/17/861/2017/, https://pdfs.semanticscholar.org/76d1/8ff9fe46d91da8f847384a1a7a0833ca13f1.pdf, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2007GC001762
    - **DOWNLOAD:** http://datasim.ov.ingv.it/models/twodee.html
    - *HAZARD: GAS DISPERSAL*
    - *FREE DOWNLOAD or ON REQUEST: YES*
    - *ONLINE RUNNABLE: NO*
- **VORIS**
    - **WEBSITE**: https://gvbcsic.wordpress.com/voris-2-0-1/
    - **AUTHORSHIP**: Alicia Felpeto, Joan Martí, Ramon Ortiz
    - **DESCRIPTION**:
    The GIS-based tools for Volcanic Hazard assessment developed by the Group of Volcanology of Barcelona are integrated on a single tool called VORIS (Volcanic Risk Information System).
    - **IMPLEMENTATION AND REQUIREMENTS:**
    VORIS 2.0.1 requires ArcGIS TM 9.1 by ESRI with Spatial Analyst extension.
    From the download site below you may download the tool (a mxd file and a compressed file with the simulation models) and the User's Guide.
    The authors intend to migrate VORIS to a Open Source GIS, probably gvGIS (http://www.gvsig.org/web/), so, no further developments are planned for VORIS 2.0.1 on ArcGIS
    - **PAPERS**: http://www.gvb-csic.es/GVB/VORIS/felpetoetalJVGR1662007.pdf
    - **DOWNLOAD:** https://gvbcsic.wordpress.com/voris-2-0-1/
    - *HAZARD: HAZARD ASSESSMENT*
    - *FREE DOWNLOAD or ON REQUEST: YES*
    - *ONLINE RUNNABLE: NO*
- **VOL-CALPUFF**
    - **WEBSITE**: http://vmsg.pi.ingv.it/index.php/en/software/show/sw_id/7
    - **AUTHORSHIP**: Sara Barsotti, Augusto Neri
    - **DESCRIPTION**:
    VOL-CALPUFF is a recently developed numerical code to simulate the non-steady-state dynamics of volcanic cloud in the atmosphere (Barsotti et al. 2008). It is a hybrid code for modelling tephra transport and deposition under the action of realistic 3D atmospheric conditions. Its main feature is the capability to couple an Eulerian 2D steady-state description of the column with a 3D Lagrangian description of ash dispersal. This approach allows to describe the effects on the dispersal process of column height variations due to wind action and atmospheric properties changes (as temperature, density and pressure profiles). The released tephra are then described as a series of discrete packets (puffs) that move independently in the atmosphere, experiencing advection by wind and the gravitational force. The fall of tephra to the ground is driven by a vertical velocity that is related to the puff altitude, particles Reynolds number and to the size and non-sphericity of particles. At each time step ash concentrations in a 3D domain and ground deposition are computed. In particular

the code produces outputs for each single granulometric size considered as well as for the eruptive mixture as a whole. Due to the Lagrangian description of the dispersal process, the execution time for a 48-hour forecast per single particle-size is of the order of few minutes on a common PC. VOL-CALPUFF derives from the widely-used air quality modelling code CALPUFF.

The steady-state plume theory equations of conservation of mass, momentum and energy are solved in a 2D Cartesian domain. A predictor-corrector scheme is adopted for the solution of such equations incrementing at each iteration the curvilinear coordinate and the computation stops when the rising mixture has no vertical momentum. At the exit, the emitted mixture composed by multi-particle solid phases and gaseous phases is assumed to be already at atmospheric pressure.

The tracking of emitted puffs is performed in a Lagrangian framework by following, within a temporal loop, the movement of puff centres. The displacement of each puff centre is explicitly computed by the simple space-velocity relationship that takes into account the meteorological variations occurring both in space and time. The material inside each puff is subjected to turbulent diffusion and is assumed to follow a Gaussian distribution.

- **IMPLEMENTATION AND REQUIREMENTS:**
  The code is made of one single source file written in Fortran77/90. It routinely runs on Linux platform. A trivial parallelization can be achieved allowing simultaneous runs for different granulometric classes (assumed to be not interacting).

- **PAPERS**: http://www.agu.org/journals/jb/jb0803/2006JB004623/, http://www.agu.org/journals/jb/jb0803/2006JB004624/

- **DOWNLOAD:** N/A

- *HAZARD: TEPHRA DISPERSAL*

- *FREE DOWNLOAD or ON REQUEST: NO*

- *ONLINE RUNNABLE: NO*

- **VolcFlow**
  - **WEBSITE**: http://lmv.uca.fr/volcflow/
  - **AUTHORSHIP**: Karim Kelfoun
  - **DESCRIPTION**:
    VolcFlow has been be used:
    - for determining the rheological behaviour of dense pyroclastic flows and debris avalanches
    - for visualizing deformations of the surface of debris avalanche and interpret or compare with field structures
    - for volcanic hazard mapping
    - for the the simulation of tsunami generated by volcanic flows
    - for reproducing the emplacement of fluidized flows in laboratory
    - for the simulation of lava flows
    - for the simulation of dense and dilute pyroclastic flows
  - **IMPLEMENTATION AND REQUIREMENTS:**
    VolcFlow is written in Matlab.
  - **PAPERS**: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2005JB003758, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2009JF001381, https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2010JB007622
  - **DOWNLOAD:** http://lmv.uca.fr/volcflow/
  - *HAZARD: LAHAR; PYROCLASTIC FLOW*
  - *FREE DOWNLOAD or ON REQUEST: YES*

- *ONLINE RUNNABLE: NO*

Activity meetings

In order to prepare MS25 and to implement it into the online catalogue, we have had the following internal meeting as Task 12.1:
1) during the WP12 meeting at the EUROVOLC kick-off meeting, in Keflavik, 5-7 February, 2018
2) during Cities on Volcanoes conference, in Naples, on 2nd September, 2018
3) GoogleMeet meetings in December 2018 and January 2019