EUROVOLC

European Network of Observatories and Research Infrastructure for Volcanology

Deliverable Report

D2.3 EUROVOLC standards and best practices

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Work Package leader:	*Kristín S. Vogfjörd*	
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Contents

Summary and introduction

This Task focused on developing standards and best practices in multidisciplinary data collection, analysis, modelling and communication with the aim of designing optimum multidisciplinary monitoring systems and technologies as well as of effectively communicating hazard to civil authorities and the public during volcanic crises.

Given the variety and multidisciplinary nature of the activities involved in such a Task, it was not possible to define an all-purpose EUROVOLC standards *sensu-stricto, i.e.* protocols and procedures valid for all of them. Instead, a number of common "*principles*" or recommendations were discussed, agreed and followed as much as possible in the carrying out of the researchers interested. In summary, such principles were:

- be ***comprehensive***: meaning collect, analyze and critically *review all existing* methods/tools/procedures developed worldwide for the specific aim. Possibly involve all researchers/groups who developed the different approaches;
- be ***transparent***: meaning make the methods/tools/procedures accessible, shareable and reviewable;
- be ***valid***: meaning identify good/best practices *based on empirical control*, i.e. based on the performance of their application to well-documented test cases or data;
- be ***quantitative***: meaning quantify the *accuracy* of the methods/tools/procedures developed as well as the main *uncertainty sources* associated to them;
- be ***modest***: meaning try to do the best that you can. Develop *guidelines, recommendations and checklists* (minimum requirements, etc.).

In the following Sections a detailed description of the activities carried out in this Task is given with specific reference to the following WPs and Tasks:

WP2 - *Task 2.2: Workshop on multidisciplinary collaboration and integration.*

WP4 - *Task 4.1.1: Tephra database implementation and instruments practice definition; Task 4.1.2 Remote-sensing database + catalogue of best practice for instruments use; Task 4.1.3 : Open access eruption dataset using Meteo/Volcano observations at specific targets; Task 4.2 - Connecting the volcanological community and Volcanic Ash Advisory Centres (VAAC).*

WP5 - *Task 5.1: Best practices for direct sampling techniques and analysis of fumarolic gases.*

WP8 - *Task 8.2: Near real-time detection of particle grain-size, ground mass load and sedimentation rate; Task 8.3 - Near real-time determination of mass eruption rate.*

WP10 - *Task 10.2.2: A review of petrological monitoring.*

WP11 - *Task 11.3: Toward a guideline for assessing monitoring level of the European volcanoes (EVMS).*

For each WP/Task, in the following sections a detailed description of activities aimed at developing standards and best practices is presented together with an outline of potential future developments.

Overall, most of Task activities have fully accounted for the above described "principles" favoring a wide involvement of the scientific community working on each topic and providing important indications and recommendations to improve available techniques, datasets/databases, procedures and protocols. As expected, each topic addressed has shown its own specific features and therefore outcomes need to always be referred to the specific context and range of conditions and systems considered. Nevertheless, the recommendations, checklists and guidelines provided appear extremely valuable to make volcanological sciences more accurate and robust as well as useful to society. Remarkably several of the Task outcomes are in the process of being published or have been already published in scientific papers or technical reports produced during the project.

Tasks contributing to the EUROVOLC common principles in best practices

WP2 - Collaboration and networking between VOs and VRIs, and with international initiatives

Task 2.2 Workshop on multidisciplinary collaboration and integration

Contributors: Laura Sandri (INGV Bologna), Paolo Papale (INGV Pisa), Eugenio Privitera (INGV Osservatorio Etneo)

Description of the activity

Analysis of the main outcomes from the VOBP#4 workshop (Volcano Observatory Best Practices), which was held in Mexico City in November 2019, with active participation, support and endorsement by EUROVOLC. In the workshop, the discussion to define best practices focused on how to get ready for a volcanic crisis, how to respond to volcanic crises, what can be told (and how) about the status of the volcano under study, and how academia can help in improving the responses at the Volcano Observatories (VOs). Also, some selected examples from different VOs' responses to past volcanic crises were analyzed.

Description of the standards and best practices developed

1) The importance of checklists (contribution by C. Newhall)

The importance of, and need for, checklists at VOs has been highlighted. Checklists must be intended as practical tools to avoid forgetting important tasks under the stress, fatigue and overload typical of volcanic crises management. Checklists should not be seen as a limit to the freedom in VO's actions.

Checklists for VOs should ideally span 3 different periods of time:

- *pre-crisis checklist*, to make sure that the VOs has collected all the available information on the volcano, prepared a response plan in quiet times, prepared a collaboration plan to work with non-observatory colleagues in a crisis, prepared hazard maps and event trees, and routinely exercises the practices (communication, monitoring, internal);
- *syn-crisis checklist*, to make sure to handle the correct functioning of the monitoring stations, to be able to plot collected data on a common timeline, to be ready to update hazard maps and event trees as new information comes in from monitoring, to activate crisis call-down lists, to keep track of the advises and products conveyed from the VO, to engage the media in a constructive partnership
- *post-crisis checklist*, to make sure to organize post-response discussions to capture key scientific lessons learned, and to use the opportunities of heightened political interest to advance VOs initiatives that need funding.

2) Recommendations on the link between forecasting and decision making (contribution by W. Marzocchi)

The importance of the separation between the domains in which scientists and decision-makers act is crucial. While sometimes hazard assessment is enough to make a decision (e.g. when a lahar is happening and we know everyone should be out of the path), most of the times a proper quantitative risk assessment is necessary to make a decision. However, there are no wrong or right decisions: rather, there are rational and defensible (or not) decisions. They should be taken on the basis of the associated risk to a natural event (such as the impact of an eruption) that can be acceptable or not: the probability itself is never "high" or "low". It is decision-making establishing when a probability is too high (or not) for a specific risk reduction action. This definition requires non-scientific competences. In this view, defining a threshold in exceedance probability implies defining a "reasonable acceptable risk", and again this requires non-scientific competences. Science provides the hazard forecast (by means of physics-based or empirical models, observations, probabilistic hazard models and expert judgement), while the associated risk analysis depends on the users and their needs (for example, a societal risk assessment is different from an individual risk assessment). In cascade, the possible risk mitigation actions depend on the user and related needs. In this light, the decision-makers and risk managers domain is separated from the scientific (hazard forecasting) domain.

3) Strategies for identifying and managing the challenges of legal scrutiny processes (contribution by R. Bretton)

This practice constitutes a link between the two above (points 1 and 2). In particular, the importance of identifying potential sources of legal scrutiny for VOs, and how can VOs be prepared or less vulnerable, is crucial. The work of VOs has sharply-defined time constraints, implies the use of incomplete datasets, and implies taking some practical actions during a crisis. However, it will be scrutinized before, during and after the crisis, and by many. "After-crisis" scrutiny will involve considering what happened (factual evidence) and what could or should have happened (counter-factual evidence): by comparing the two pieces of evidence potential shortfalls may arise. Possible strategies to protect VOs are to:

- Provide the best possible contribution to the management of societal risk.

- Avoid getting exposed by limiting roles.

- Get defensive by reducing vulnerability, e.g., by excluding or capping liability, getting insurance, indemnity and immunity, and keep good record of all the choices made and procedure followed.

4) Incident Command System (ICS) and Volcano Crisis Response (contribution by T. Murray)

This practice by the US Geological Survey (USGS) illustrates the use of their ICS scheme during the volcanic crisis of Kilauea 2019, and how it was adapted to VOs operations. ICS is a scheme that clearly defines roles and responsibilities, and how to shift and rotate roles. In the US, disasters such as eruptions are treated as INCIDENTS, and they are managed by the National Incident Management System, which requires the use of ICS. ICS establishes an IMT (Incident Management Team). Most of the incidents that occur commonly are handled locally, and if needed an IMT is established. If it cannot be handled locally, a regional or national IMT is established. The ICS is executed by the IMT. The Incident Commander leads the IMT. The structure of the IMT is fixed, and the various roles can be taken by rotation of staff. Roles and responsibilities are totally defined and *written down*. The rotation is typically every 2 weeks. The positions are not defined in terms of "names" or "qualification": a position may be filled by a seismologist, then by an engineer, but the person needs to be qualified for the role. One manager should have no more than 7 people working under him/her at a time. If so, the extra ones need to report to one of the 7 above, hierarchically.

The Commander is first briefed on the situation by the person calling for the IMT (e.g., the mayor). Then the commander writes down goals/guidance for the team.

The goals of the IMT are not the same as USGSs. The USGS supports the IMT in achieving its goals, but they do not have to reciprocate. VO interacts with the IMT by providing technical specialists to the Planning section, and Senior to the Liason section.

A challenge for VOs is to decide when to move into the crisis response mode. Written criteria may be needed; however, if it is debated, maybe it is time to move into such response mode.

5) How Much Monitoring is Enough? (contribution by S. Moran and J. Ewert)

This practice illustrates how in the US a rational procedure has been established to rank volcano monitoring gaps, that in turn identifies where to spend money to fill the high-priority gaps.

	Level 4 Well monitored	Level 3 Basic real time	Level 2 Limited	Level 1 Minimal	Level 0 No ground based
Very High Threat (N=18)	17%	33%	39%	11%	0%
High Threat (N=37)	0%	54%	22%	11%	13%
Moderate Threat (N=48)	0%	11%	29%	27%	33%
Low Threat (N=34)	0%	6%	9%	32%	53%
Very Low Threat (N=32)	0%	0%	0%	69%	31%

Figure 1. Procedure to carry out a gap analysis for volcano monitoring (from Ewert et. Al., 2005).

The procedure, illustrated in Figure 1, goes through 4 steps:

1) A systematic assessment of volcanic threat index (expressed as Hazard * Exposure) is carried out for all US volcanoes.
2) A definition of the minimum monitoring capabilities needed for different threat levels is performed.
3) A systematic assessment of current monitoring capabilities at each volcano is carried out.
4) A "Gap analysis" (what the volcanoes should have vs. what they currently have) is done.
5) On this basis, it is possible to rationally identify where to spend money to improve the monitoring level towards the minimum accepted.

Potential future developments

Future activities of the VOBP community will need to focus on the best practice to respond to the following open points:

- How to account for resuspended ash?
- When and how to issue a VONA? How to ask for cost recovery? Towards new recommendations from ICAO.
- Ideas and future steps to a new structure of WOVO.
- Parametric insurance for VOs?

Related products

- *Guidelines for volcano-crisis operations: Recommendations from the 2019 Volcano Observatory Best Practices meeting, by J.B. Lowenstern, K. Wallace, S. Barsotti, L. Sandri, W. Stovall, B. Bernard, E. Privitera, J.-C. Komorowski, N. Fournier, C. Baligizi, and E. Gareabiti, Journal of Applied Volcanology. (2022) 11:3;* https://doi.org/10.1186/s13617-021-00112-9.

WP4 - Networking atmospheric observations and connecting the volcanological community with VAACs;

Task 4.1.1 Tephra database implementation and instruments practice definition

Contributors Lucia Gurioli (OPGC-LMV), Simona Scollo (INGV)

Description of the activity

The objective of this Task D4.1.1 (Tephra_DB) was the construction of an informative data table (Figure 1) to list all the studied volcanoes and the main parameterized explosions/eruptions or periods of activity.

Bárðarbunga	x		x (IMO)	x (IMO)	x (IMO)			x (IMO;UNIFI)		x (IMO)							
BatuTara		x		x (INGV-RM1)													
CampiFlegrei		x	x (INGV-RM1)														
Copahue	x							x (UNIFI)									
Cordon Caulle		x	x (INGV-RM1)														
Etna	x	x	(INGV-OE; INGV-RM1; LMV-OPGC-UCA	x (UNIFI; INGVOE; INGV-RM1)	x (INGV-OE)			x (UNIFI)	x (LMV-OPGC-UCA)	x (UNIRM)	x(LMV-OPGC-UCA; INGV-CNT)	x (INGV-OE)		x (LMV-OPGC-UCA)			
Eyjafjallajokull		x	x (UNIGE, INGV-RM1; IMO)	x (UNIFI)	x (IMO)			x(IMO;UNIFI)		x(IMO)	x(IMO)	x(IMO)					x (IMO)
Fogo		x	x (CIVISA/IVAR)														
Fuego		x		x (INGV-RM1)													
Grímsvötn		x	x (IMO)		x (IMO)					x (IMO)	x (IMO)	x (IMO)					x (IMO)
Hekla		x	x (IMO; UNIGE)							x (IMO)	x(IMO)		x(IMO)				x (IMO)
Laacher See		x	x(INGV-RM1)														
Montserrat	x			x (UNIFI)				x (UNIFI)									
Nyaragongo	x			x(UNIFI)				x(UNIFI)									
Piton De Fournaise	x		x(OPGC-UCA)					x (UNIFI)			x (LMV-OPGC-UCA)						
Sakurajima	x		x(INGV-RM1)					x (UNIFI)									
Sete Cidades		x	x(CIVISA/IVAR)														
Stromboli	x		x(LMV-OPGC-UCA)	(LMV-OPGC-UCA; INGV-RM;UNIF	(LMV-OPGC-UCA; INGV-RM1;UNIF	(LMV-OPGC-UCA; INGV-RM1	x(OPGC-UCA)	x(UNIFI)	x(LMV-OPGC-UCA)		x(LMV-OPGC-UCA)			x(LMV-OPGC-UCA)	LMV-OPGC-UCA	x(OPGC-UCA)	
Teide		x	x(CSIC-IGN)														
Tungurahua	x							x(UNIFI)									
Vesuvio		x	x (INGV-OV)														
Yasur	x			x(INGV-RM1;UNIFI)		x(INGV-RM1)		x(UNIFI)									

Figure 1. *Summary table of the WP4-WP8_data_availability_survey table in* https://drive.google.com/drive/folders/1UE0S6m7giqO2sqqNJO3hh6QaWY4xlRWv?usp=sharing

Description of the standards and best practices developed

- *Twelve VOs and VRIs* (INGV-RM; INGV-OE; INGV-CNT; INGV-NA; IMO; UI; UNIRM; LMV-OPGP-UCA; UNIFI; UNIGE[1]; CIVISA-IVAR[1]; CSIC-IGN[1]) filled up the tables.
- *22 volcanoes* (Bárðarbunga, Batu Tara, Campi Flegrei, Copahue, Cordon Caulle, Etna, Eyjafjallajökull, Fogo, Fuego, Grímsvötn, Hekla, Laacher See, Montserrat, Nyaragongo, Piton De La Fournaise, Sakurajima, Sete Cidades, Stromboli, Teide, Tungurahua, Vesuvius and Yasur).
- *Ten parameters*: (i) plume height, (ii) mass eruption rate, (iii) volcanic particle content, (iv) temperature, (v) weather data, (vi) particle properties, (vii) volcanic gas composition, (viii) vertical distribution of gas and particles in the cloud, (ix) velocity, and (x) total grain size distribution, have been measured or derived through ground, airborne and space-based tools. Unprocessed data have also been listed.
- *Six main parameters related to the deposits* features have been listed as well: (i) deposit thickness and dispersion, (ii) density of the deposit, (iii) deposit grain size distribution, (iv) particle componentry, (v) particle shape, and (vi) particle density, connectivity and permeability.
- All the information has been organized in an open Google site: https://drive.google.com/drive/folders/1UE0S6m7giqO2sqqNJO3hh6QaWY4xlRWv?usp=sharing
- *Integration between WP4.1.1 and WP8* to collate metadata on available datasets describing volcanic activity across EUROVOLC.
- Figure **2** shows the number of events per volcano for which plume height information is available, and highlights that most information is available for the Italian volcanoes, Stromboli and Etna.

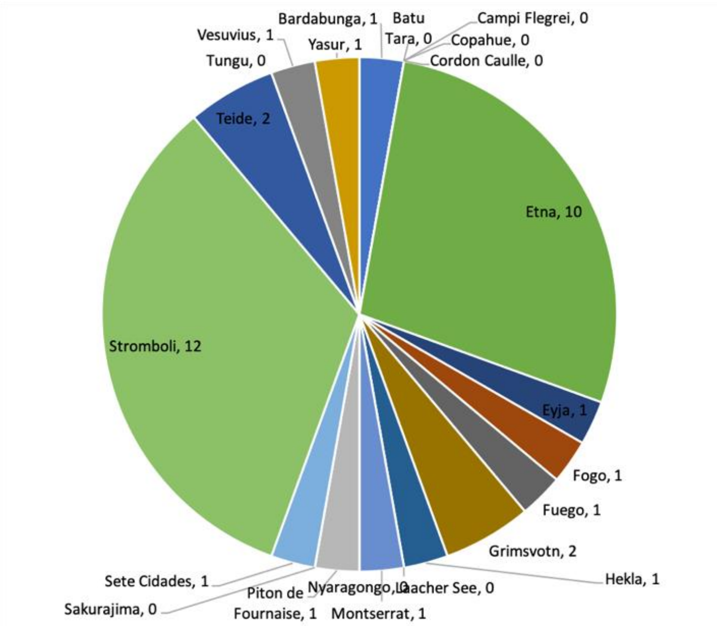

Figure 2. *Number of events according to volcano for which plume height information is available.*

In particular, the activities carried out have produced the following papers:

1) A paper in which source parameters from the deposits of a Plinian eruption at Sete Cicades have been used to constrain the modelling dispersions of the related fallout plumes:
2) A paper in G^3 which is related to the characterization of a weak ash plume at Piton de La Fournaise and the parameterization of the source parameters. Metadata are reported in WP4-WP8_data_availability_survey table. All the data are available at: http://opgc.fr/vobs/so_interface.php?so=dynvolc (DynVolc 2017);
3) A paper in Bulletin of Volcanology which is focusing on the capability of basaltic volcanoes to generate volcanic ash. Metadata are reported in WP4-WP8_data_availability_survey table. All the data are available at: http://opgc.fr/vobs/so_interface.php?so=dynvolc (DynVolc 2017).

Potential future developments

Future developments would be the maintenance of the Informative Table with a constant updating related to adding new eruptions and new measurements of source parameters and volcanic activities.

Related products

- *Kueppers U, Pimentel A, Ellis B, Forni F, Neukampf J, Pacheco J, Perugini D, Queiroz G (2019) Biased volcanic hazard assessment due to incomplete eruption records on ocean islands: an example of Sete Cidades Volcano, Azores. Front. Earth Sci. 7:122. doi: 10.3389/feart.2019.00122*
- *Thivet S, Gurioli L, Di Muro A, Derrien A, Ferrazzini V, Gouhier M, Coppola D, Galle B, Arellano S (2020) Evidences of plug pressurization enhancing magma fragmentation during the September 2016 basaltic eruption at Piton de la Fournaise (La Réunion Island, France). Geochemistry, Geophysics, Geosystems, 21. doi: 10.1029/2019GC008611*
- *Thivet S, Gurioli L, Di Muro A, Eychenne J, Besson P, Nedelec JM (2020) Variability of basaltic fragmentation efficiencies at shield volcanoes revealed by ash characterization: insights from historical and recent deposits at Piton de la Fournaise volcano. Bull. Volc. 82, 63, doi: 10.1007/s00445-020-01398-0*

Task 4.1.2 Remote-sensing database + catalogue of best practice for instruments use

Contributors: Lucia Gurioli (OPGC-UCA), Simona Scollo (INGV), Mathieu Gouhier (OPGC-UCA)

Description of the activity

The object of deliverable D4.1.2 (D4.2 Remote_sensing_DB) was the implementation of a Remote-sensing database to facilitate access and use of remote Sensing measurements and instruments to EUROVOLC partners. Because several databases already exist between the different Volcanic Research Institutes (VRIs) and Volcanological Observatories (VOs), we decided to use the informative Table of D4.1 to add all the instruments used and provided specific brochure for their description.

Description of the standards and best practices developed

- A *list of instruments* (Figure 4) was compiled (Infrared Camera, Visible Camera, High Speed Camera, UV Camera, Infrasound, Doppler Radar, Radar, Satellite sensors, Lidar, Airborne instruments, ASHER, Disdrometer, Radiometer, DOAS, Pilot Reports).
- A *brochure for each instrument* is given by each institute; this brochure is linked to the European Catalogue of Volcanoes of WP11.
- All the information has been organized in an open google site: https://drive.google.com/drive/folders/1UE0S6m7giqO2sqqNJO3hh6QaWY4xlRWv?usp=sharing

Figure 4*. Example of the brochure template to be filled with information related to ground, airborne and space-based tools, plus laboratory-based instruments.*

A paper on the ASHER (automatic ash collector, tested within WP8) has been accepted in Frontiers Earth Science. This paper focuses on the multiparametric field campaign on Stromboli in 2016 where very mild strombolian explosions have been observed, measured and sampled with an ASHER (Figure 5) - IR camera - SO_2 camera - DOAS. This paper is a contribution among some VOs and VRIs of WP4 and WP8 to present some best practice on instruments and deposits (including full methodological detail) (Metadata is reported in WP4-WP8_data_availability_survey table.).

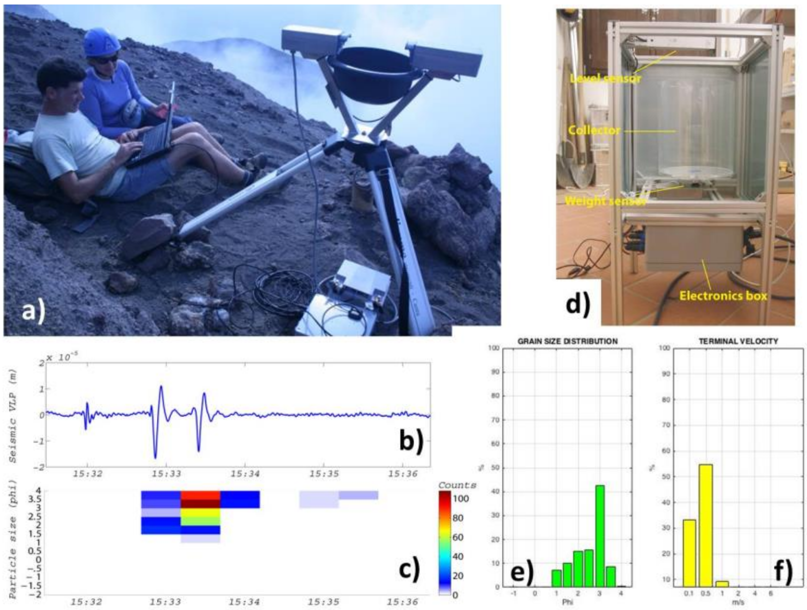

Figure 5. *a) Gurioli & Marchetti check ASHER data in real-time as ash falls past the optical barrier; (b) Seismic VLP data for the same event; (c) In-situ particle counting; (d) ASHER collector for accumulation rate measurement; (e) In-situ grain size distribution & (f) terminal velocity.*

Potential future developments

Future developments would be to keep the brochure updated with the upgrading of the instruments and the addition of new instruments as well. In the fall of 2021 (September to November 2021), we will try to cover more instruments already available at the VO and IR.

Related products

- *Gouhier M., Eychenne J., Azzaoui N., Guillin A., Deslandes M., Poret M., Costa A., Husson P. (2019). Low efficiency of large volcanic eruptions in transporting very fine ash into the atmosphere. Scientific Report vol.9, p.1449, doi: [10.1038/s41598-019-38595-7](10.1038/s41598-019-38595-7)*
- *Thivet S, Harris A, Gurioli L, Bani P, Barnie T, Bombrun M, Marchetti E (2021) Multi-parametric field experiment links explosive activity and persistent degassing at Stromboli. Front. Earth Sci. 9:669661. doi: 10.3389/feart.2021.669661*

Task 4.1.3: Open access eruption dataset using Meteo/Volcano observations at specific targets

Contributors: Bergrún Óladóttir (UI), Sara Barsotti (IMO), Lucia Gurioli (OPGC-UCA)

Description of the activity

The object of Task 4.1.3 was to develop an open-access eruption dataset for ash/tephra products, including a wide range of meteorological and other volcanological observations (e.g., plume height, initial velocity, mass flux, rates, etc.) from all VOs. The dataset was going to include information from recent Icelandic volcanoes. The idea was to provide a complete, official and multidisciplinary database and test-bed that could be used for benchmarking of all new/current models from 1D-column models to VATD (Volcanic Ash Transport Dispersion) forecast numerical models. The final product will represent a setup from previous initiative like the IAVCEI-Commission Tephra Hazard Modelling and VHUB.

Description of the standards and best practices developed

Within Task 4.3, information on 298 eruptions was gathered in the Eruption database. Out of the 298 eruptions (Figure 6), 116 eruptions are from French territories (Mt Pelée, Piton de la Fournaise and Chaine des Puys). We have 104 Italian eruptions (Etna, Stromboli, and Vesuvius), 34 eruptions from the Azores (Fogo, Sete Cidades), 22 Greek eruptions (Santorini), 21 eruptions from the Canary Islands (Teide Pico-Viejo) and one eruption from UK territories (Tristan da Cunha).

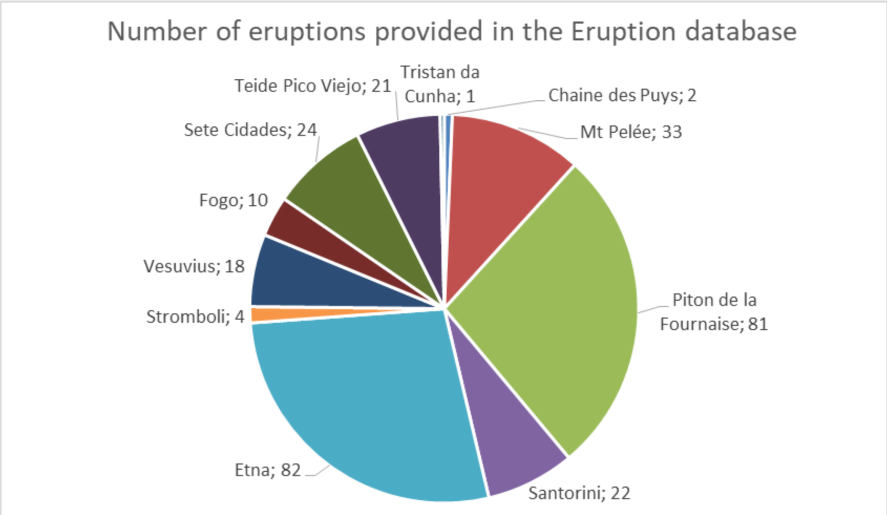

Figure 6. *Number of eruptions provided from each volcano in the Eruption database, information accessible through the Eruption search section on the European Catalogue of Volcanoes and Volcanic Areas (https://volcanoes.eurovolc.eu).*

The database includes 77 columns containing information that can be divided into seven categories:

1. Background information on volcano (e.g., country, volcano/volcanic system, eruption location, eruption scenario). Number of columns: 8.
2. Eruption type (explosive, effusive, external water). Number of columns: 3.
3. Event information (e.g., eruption ID, starting and ending time, dating method). Number of columns: 14.
4. Eruptive products (e.g., column height, VEI, magma composition, erupted volume, dispersal). Number of columns: 32.
5. Eruption impact (damage, evacuation, injuries, and fatalities). Number of columns: 12.
6. Data quality. Number of columns: 3.
7. Other/additional information (e.g., references, links to other data). Number of columns: 5.

The **Eruption database is published under the "Eruptions Search" section** (Figure 7, red box) of the ECV website (http://volcanoes.eurovolc.eu) that was initiated in WP11. Under the "Volcano" section (Figure 7, green box) background knowledge on the chosen volcanoes and their known behaviors and hazards can be accessed.

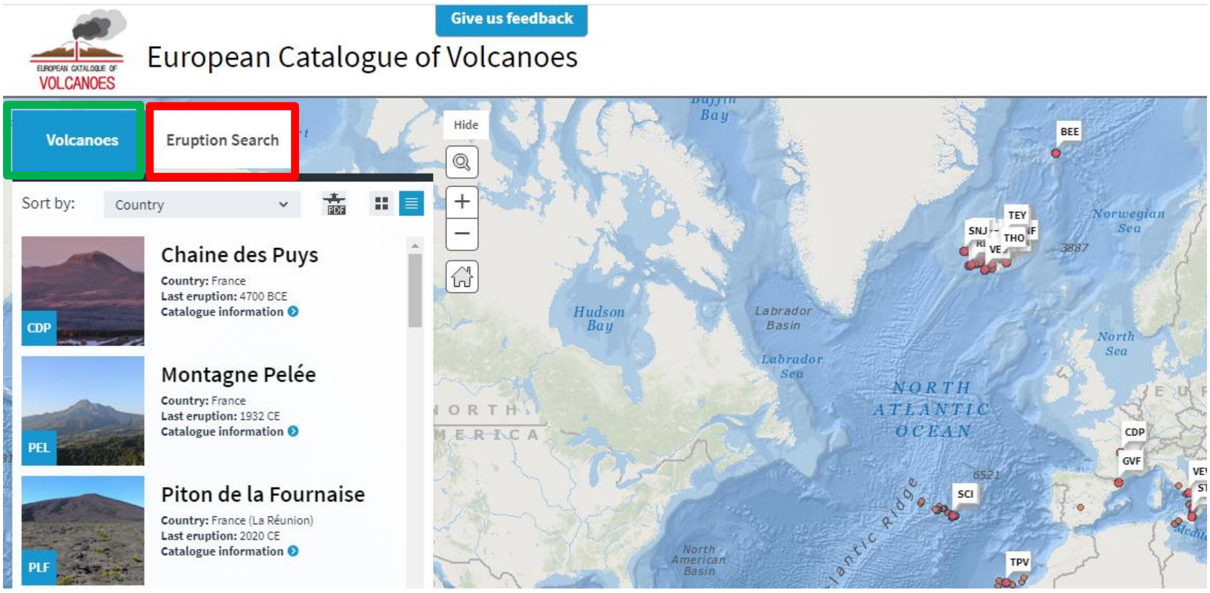

Figure 7. *Snap shot of the website https://volcanoes.eurovolc.eu indicating the two main search sections: Volcanoes and Eruption Search. Under the Volcano section (indicated with blue box) the readers can find background information.*

Potential future developments

Ideally, in the future, the eruption database should be constantly updated.

Related products

The eruption dataset is available online at https://volcanoes.eurovolc.eu.

Task 4.2 - Connecting the volcanological community and Volcanic Ash Advisory Centres (VAAC)

*Contributors**:** Claire Witham and Nina Kristiansen (Met Office), Lucia Gurioli (UCA) and all the participants of the workshop**.***

Description of the activity

A three-day workshop was held in February 2019 to bring together the Volcano Observatories (VOs), Volcanic Ash Advisory Centers (VAACs) and Volcanological Research Institutes (VRI) in Europe (Figure 8). The invited participants took part in a mixture of talks, discussions, and scenario-based activities to strengthen links and coordinate interactions for improved crisis response. The workshop identified how VOs, VRIs and VAACs currently communicate and share information, limitations within these procedures and positive ways these could be improved. Key recommendations for future improvements in the communication procedures and what best practices looked like were defined. These findings were summarized in a report and a series of actions.

Figure 8. *Participants of the EUROVOLC VAAC-VO workshop, hosted by the UK Met Office in February 2019*.

Description of the standards and best practices developed

The following best practices were identified or reinforced by the workshop through presentations, discussions, and case-study activities (Figure 9). These were summarized in the Task 4.2 report and used to derive a roadmap of actions that was shared with all the participants to be pursued during the rest of the EUROVOLC project.

The first list covers *items for volcano observatories* that can be considered at any time:

- All VOs should be familiar with the International Civil Aviation Organization (ICAO) International Airways Volcano Watch (IAVW) Handbook and, in Europe, the EUR/NAT Aviation document to ensure awareness of the ICAO procedures relating to volcanic eruptions. The production of the Volcano Observatory Notice for Aviation (VONA) is a mandated practice for State Volcano Observatories in these procedures.
    - VRIs that work and support the VOs should also be informed of these ICAO procedures and requirements so that there is a wider awareness and understanding across the community.
- All VOs should take part in aviation focused exercises, and VOs and VAACs should use the exercises as opportunities to test the implementation of best practices and revisions to procedures. This is particularly important for VOs with few real eruptions in order for them to train and maintain familiarity with the procedures.
- Regular summary reports on the current status of volcanoes should be supplied by the VOs to the VAACs to help improve knowledge. The frequency of these reports should be commensurate with the activity of the area.
- Eruption scenario information (e.g., likely plume heights, expected eruption duration) should be supplied by the VO to the VAAC both in quiet time and during activity.

Figure 9. *Mixed break-out groups were used to identify current avenues of communication and data-sharing and proposed Best Practice procedures for these interactions.*

The second list covers *best practices for volcano observatories (VO)* when an eruption is underway:

- The issuance of a VONA should be accompanied by a phone call from the VO to the lead VAAC. If there is a language concern, then construction and use of a template for this call is recommended.
- All VONA should be sent to both the lead and back-up VAAC for improved back-up response during events and for additional training opportunities.
- To enable easy access and review, all issued VONA should be displayed and archived on the VO's website and this should become a standard practice.
- During an event, the VO should feedback/report to the VAAC its difficulties in (i) communicating (due to language and/or the type of the eruption and/or local impediments), (ii) measuring the source parameters, and (iii) filling in the VONA and why.
- An observed or best guess estimate (e.g. from scenarios based on previous eruptions) of the plume height should always be provided in the VONA and ideally be accompanied by information about the level of uncertainty. If plume height observations are poor and/or with little confidence, additional information should be provided to highlight this.
  - In such a circumstance, it would be useful for VOs to provide a timeframe to VAACs within which they might expect to have better plume height information.

The third list describes *best practices for VAACs*:

- Each VAAC should be in contact with each VO in its region at least once per year. This is to test communications and also maintain familiarity and awareness.
- Two-way feedback between the VAAC and the VO is essential during an eruption, for example the VAAC should (i) report back on the usefulness and/or missing/inconsistent information in the VONA, (ii) provide additional information on plume height from e.g., satellite imagery or model techniques if available, and (iii) report if observation data (e.g., plume height) are differing from different approaches (e.g., observations vs. model/satellite).

- VAACs should include in their back-up procedures the notification of the VOs if a handover of lead responsibility occurs. Ideally this procedure should be practiced annually, possibly as part of an exercise.
- VAAC staff need to be educated about the limitations and sensible use of data in the VONA, in particular around uncertainties in the plume height.
- A debrief process between the VAAC and VO should be carried out after eruptive events to address any issues that arose and enhance links.

Potential future developments

The reports and recommendations from the workshop have been shared with the existing VAAC Best Practice and Volcano Best Practice initiatives and were presented at their respective meetings in November 2019. A key outcome from the activity was that there needs to be a continued focus on building relationships, trust and understanding between the VO and VAACs. A follow-up workshop wass held in Autumn 2021 to revisit the actions and questions from the first workshop and review the best practices identified above. This will be expanded to include a wider number of VAACs and observatories.

Since the workshop, the development and release of the European Catalogue of Volcanoes has provided new eruption scenario information for the VAACs, which is very valuable.

Related products

- *Kristiansen, N and Witham, C, 2019, Outcome of the VAAC-WS workshop, EUROVOLC Deliverable Report D4.4.*
- *Witham, C and Kristiansen, N, 2019, Roadmap for implementation of the recommendations from the EUROVOLC VAAC-VO Workshop in 2019, EUROVOLC Project Report.*

WP5 - Consolidation of geochemical gas monitoring across VOs.

Task 5.1 Best practices for direct sampling techniques and analysis of fumarolic gases.

Contributors: F. Viveiros, D. Matias, L. Moreno, C. Silva, S. Oliveira (CIVISA), F. Grassa, S. Caliro, C. Federico, M. Liotta, V. Prano, F. Salerno, V. Robert (INGV), R. Moretti, M. Bonifacie, A. Di Muro, S. Moune (IPGP), E. Ilynskaya (UNIVLEEDS), I. Iribarren, N. Luengo, P. Torres (CSIC),, P. Labazuy (UCA), M.A. Pfeffer (IMO).

Description of the activity

Direct sampling of fumaroles is challenging and several factors may interfere with the final variability observed in the datasets. Sampling using the so-called Giggenbach methodology is time consuming and requires a laboratory with several equipment and skills in order to obtain a complete chemical analysis of the gas sampled. Nevertheless, the volcanological community recognizes that this persists as the more accurate and complete technique to characterize gases emitted by fumaroles, including low and high temperature emissions. Several activities were carried out under the umbrella of EUROVOLC project and accounted with a joint sampling survey at the Azores archipelago, which involved seven partners, and posterior inter-laboratorial comparison of the results obtained. In addition, and due to the pandemic constrains, intra-laboratorial surveys were carried out by some partners and several web meetings and internal reports were shared to define strategies and implement discussion.

Description of the standards and best practices developed

The activities carried out showed that there is not a single "recipe" for the application of the so-called Giggenbach methodology and the selection of procedures is highly site dependent, essentially in what concerns the type and temperature of the gas emission. The consortium teams agreed that differences in the application of the above-mentioned methodology might derive from the pre-sampling preparation to the data analysis. Thus, the recommendations account with these different stages:

Pre-Sampling preparation

Preparation of the sampling has major importance and may control the success of the survey. The selection of the sampling material as well as the preparation of the gas bottles are essential for the results obtained and the data quality.

Checklists and protocols should be available in all the laboratories in order to avoid, for instance, lack of material in the field that can compromise the entire survey.

In the preparation of the Giggenbach gas bottles with soda solution, one of the crucial aspects is the efficiency of the stopcocks (that should have O-rings) to avoid leaking and to assure a good vacuum (*e.g.*, a rotary vane pump) of the gas bottle. Another recommendation relates with the volume of soda sample in the gas bottle, and a 40% volume seemed to accomplish with the binary data quality and sampling time. The type and dimension of the gas bottles did not seem to contribute to variability, however teams are recommended to use same type and volume of gas bottle (and stopcocks) within the same survey.

Sampling

Together with the natural variability of the fumarole during sampling, several factors may interfere in this phase, such as the human factor (experience on sampling and on selecting the site), the different apparatus and sampling line, or the sampling time, just to give some examples.

The selection of the sampling site is a major aspect and relies on the experience of the researchers with both the type of fumarole and the sampling site. The site should be the best representative of the gas emissions from depth and usually it corresponds to high flux zones and to the higher temperature spots. During sampling, metadata should be written in the notebook or in some forms previously prepared.

The sampling apparatus (*e.g.*, funnel, probe, tubes) is also highly site dependent (presence of boiling water, temperature) and needs to be set up assuring that atmospheric contamination is avoided.

Analytical procedures

Laboratories may use different techniques to analyze the gases collected from the fumaroles and the analytical procedures are even different depending on the gas species that are under analysis. *Table 1* shows the different techniques used by the consortium teams. Despite the different techniques used, the teams implement some general common strategies, such as: (1) the use of standards to calibrate the instruments and to be able to quantify the analyzed species, (2) preparation of protocols with the description of the analytical methodologies, standard and calibration procedures, (3) definition of metadata (*e.g.*, technicians involved, instruments used, analytical dates, standards), and (4) evaluation of the intra-laboratory variability for each gas species (limit of detection, accuracy and precision of the results).

Existence of pre-defined automatic forms to add the data and routinely obtain the total chemical analysis is crucial to avoid human errors in the insertion of data or estimation of the different parameters. We recommend, however, a careful review of the worksheets by at least two members of the teams (and an eventual external element) in order to avoid systematic errors. Double check of the final datasets is also crucial to avoid eventual typos on the data.

Inter-laboratory calibration procedures are also suggested to allow comparison of data between different teams.

Table 1. *Analytical methods applied by the different consortium teams to analyze the gases collected following the so-called Giggenbach methodology.*

Gas species	**Analytical methods**
H_2O	Weight
CO_2	Potentiometric Titration
H_2S	Ion Chromatography Colorimetric Titration
^{40}Ar, O_2; N_2, CH_4, H_2, He, CO	Gas Chromatography Mass Spectrometry
$^{40}Ar/^{36}Ar$	GC-IRMS
$\delta^{15}N$	GC-IRMS
$\delta^{13}C_{CO2}$	IRMS
$\delta^{18}O_{CO2}$	IRMS
$\delta^{18}O_{H2O}$	Laser Spectroscopy IRIS WS-CRDS
$\delta^{2}H_{H2O}$	

Data analysis

Application of potential statistical tests to the data obtained, or even plot the data in pre-defined diagrams, are some of the possibilities associated with the data analysis and depend on the aim of the team. Even though, all teams agreed that after obtaining the results, cleaning the datasets from the "gross errors" (air-contaminated samples or any other reported technical aspect) is mandatory.

Blind evaluation of the datasets is suggested when inter-laboratorial calibration is carried out. Data should be shared at the same time (sent to one person all at the same time). Two possibilities in this case: data would be reclassified by an external element and the samples shared between all the partners to allow a blind evaluation of the data, or, as second option, the reclassified samples would be sent to an external person that would make an evaluation of the data.

As conclusions, and even accounting for the differences between teams, common strategies were defined to help to accomplish best procedures namely:

- Elaborate check-lists;
- Create protocols;
- Implement routine use of metadata (in the field and in the laboratory);
- Use automatic forms to fill in all the information (preferentially following EPOS rules);
- Evaluate intra-laboratory variability for the different gas species;
- Implement inter-laboratory calibration strategies between laboratories;
- Ask for help and collaboration with other more experienced teams.

Potential future developments

This type of European network strongly contributes to the community building and open possibilities to maintain and strengthen collaborations even after the end of the project. The joint survey carried out in the Azores archipelago allowed discussions and definition of some best practices mainly in a hydrothermal environment. Further joint surveys in different fumarolic field with different characteristics (temperature, flux, composition, geological settings, …) would allow the complementation of the best practices considering other case studies and allow sharing of experiences and improvement between the teams, however the pandemic constrains prevented this possibility during the lifetime of this project.

As mentioned, and in order to reduce the pandemic effects, partners performed independently intra-laboratorial testing following commonly defined methodologies, which allowed to suggest some best practices especially in what concerns the pre-sampling and sampling strategies. In order to proceed with inter-laboratorial calibration tests, Giggenbach bottles (similar bottles with same type of stopcocks) filled with common standards (and with controlled amount of gas) will be shared between the four EUROVOLC laboratories (CIVISA, INGV-OV, INGV-Pa, IPGP-OVSG) with capacity to perform the analysis. The execution of this test is planned for September 2021. Invitation of additional teams, not involved in the EUROVOLC, is also one of the goals of the consortium partners.

Related products

- *Grassa, F., Viveiros, F., Burton, M., Federico, C., McCormick, B., Bonifacie, M., Brunet, C., Caliro, S., Di Muro, A., Donnadieu, F., Ilyinskaya, E., Iribarren, I., Labazuy, P., Lauret, F., Liotta, M., Liuzzo, M., Moreno, L., Moretti, R., Moune, S., Pfeffer, M.A., Silva, C. (2020) - Strategies to define best practices for geochemical gas monitoring across Volcano Observatories. EGU General Assembly 2020, Online, Viena (Austria), 4-8 May, doi: 10.5194/egusphere-egu2020-22138.*
- *Matias, D., Viveiros, F., Moreno, L., Silva, C., Oliveira, S. (2021) – Sampling fumaroles through the Giggenbach methodology: a contribute to understand intra-laboratorial variability, 1st CCVG Virtual Workshop, 24-26 May (oral presentation).*
- *Viveiros, F., Grassa, F., Moretti, R., Caliro, S., Bonifacie, M., Di Muro, A., Ilynskaya, E., Iribarren, I., Federico, C., Labazuy, P., Liotta, M., Luengo, N., Matias, D., Moreno, L., Moune, S., Pfeffer, M.A., Prano, V., Oliveira, S., Salerno, F., Silva, C., Robert, V., Torres, P. (2021) - D5.1: Best practices for direct sampling techniques and analysis of fumarolic gases. Deliverable Report EUROVOLC, 28p.*

WP8 - Characterization of grain-size parameters, determination of mass eruption rate and assimilation of geophysical data to initialize Volcanic Ash Transport and Dispersal Models (VATDMs)

Task 8.2 Near real-time detection of particle grain-size, ground mass load and sedimentation rate and Task 8.3 Near real-time determination of mass eruption rate

Contributors: Costanza Bonadonna (UNIGE-SUR) and colleagues of Partners BGS, IMO, INGV-OE, INGV-RM1, UNIFI, ITEM, IPGP, UCA-OPGC, UKMETOFFICE.

Description of the activity

WP8 has produced a variety of products that can be included in best practices for optimum multidisciplinary monitoring systems and technologies (e.g. Early-warning volcanic plume detection schemes – Task 8.1 / D8.1; Computational algorithm to derive VATDM source parameters from satellite – Task 8.4 / D8.2) and contributed to the design and compilation of the accumulation of ash/tephra datasets and databases to serve as testbeds for future testing of ash dispersion models (Task 4.1 / D4.3).

As part of Task 8.6 / D8.3, a survey was also carried out to identify the key inputs of VATDMs and to produce their probability density functions to be used to forecast future eruptive events; in particular, Plume height, Vertical Mass distribution and Mass Eruption Rate have been shown to be the most used Eruptive Source Parameters (EPSs) to run VATDMs. Finally, a new operational tephra fallout monitoring and forecasting system based on quantitative volcanological observations and modelling was also developed and implemented at the Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo (INGV-OE) (Task 8.3 / D8.2). Nonetheless, the main effort of WP8 for identifying "Standards and Best practice" is related to the determination of Total Grain-Size Distribution of tephra plumes and Mass Eruption Rate in near real-time (Task 8.2 and Task 8.3 / D8.2).

Description of the standards and best practices developed

Total Grain-Size Distribution (Task 8.2)

As part of the project FUTUREVOLC, Pioli et al. (2019) investigated the best sampling and empirical fitting strategies to better constrain the Total Grain-Size Distribution (TGSD) of tephra plumes. In particular, they used a statistical analysis to better evaluate the impact of sampling strategies, e.g. depending on number and location of tephra samples, on the representativeness of tephra deposit-based estimates. For example, they determined that the Rosin-Rammler equation is the best at reproducing both the field-based TGSDs but also the tail of very fine material that is rarely sampled on ground. They also found that TGSD medians and sorting coefficients were better reproduced when samples were collected either randomly or along the main dispersal axis of volcanic plumes. A first application of the Rosin-Rammler equation was made as part of the EUROVOLC project to combine ground sampling with satellite determination of Plume/Cloud mass and TGSD for the 29 August 2011 paroxysm at Etna. Rosin-Rammler grain-size distribution is shown to provide first order estimate of very fine material that is not sampled on ground but that is detected by satellite. Moreover, first estimates of near real-time TGSD have been computed for the 10 April 2011 and the 23 November 2013 paroxysms. These TGSDs result from the combination of weather radar and satellite-based infrared data and are based on a critical determination of the total erupted mass (TEM) obtained by each sensor. In particular, the TGSDs show a promising agreement with GSD derived from tephra-fallout deposit analyses (Freret-Lorgeril et al., 2021).

Mass Eruption Rate (Task 8.3)

The 10 April 2011 and 23 November 2012 paroxysms of Etna have been selected as part of Task 8.3 to test 6 different strategies for the determination of ESPs with a special focus on Mass Eruption Rate: tephra fall deposit analyses, ground-based and satellite infrared, visible imagery, infrasound and Doppler radars (Freret-Lorgeril et al., 2021). The comparison of the outcomes from all strategies (Figure 10) present discrepancies of several orders of magnitude that are due to the fact that all sensors record different phases of the paroxysmal episodes. In particular, infrasound, ground-based infrared and L-band Doppler radar are mostly sensitive to periods of unstable to sustained lava fountaining activity, whereas satellite-based infrared and microwave Doppler radar record the fountain-fed tephra plume activity and the end of the paroxysmal episodes. It is important, therefore, to consider that their retrievals are complementary.

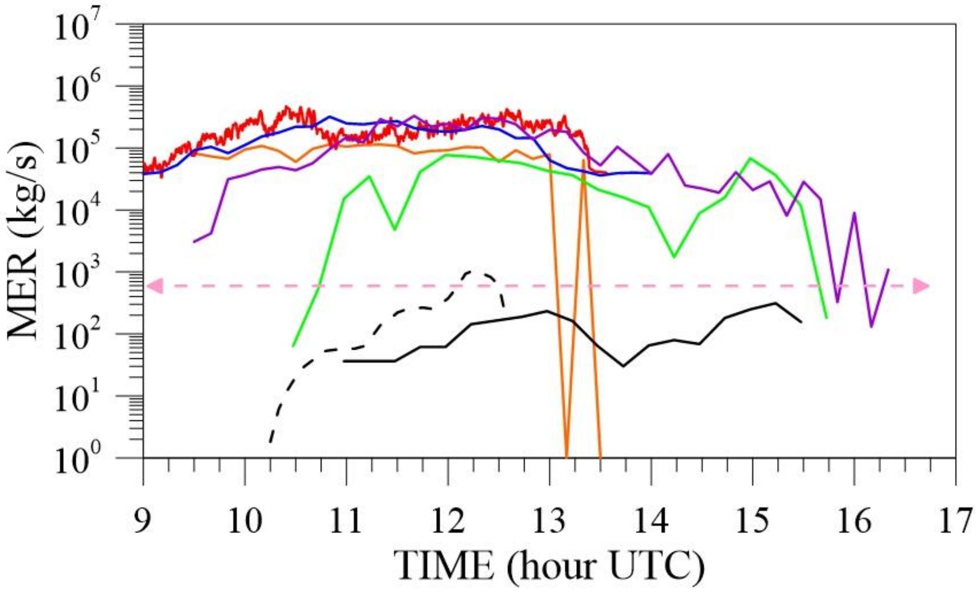

Figure 10: Mean Mass Eruption Rate time series from L-band (blue) and X-band (purple) Doppler radars, infrasound (red), ground-based infrared (orange), SEVIRI-based signal (black) and plume height measurements (green), MODIS (black dashed line) and from deposit analyses (pink) retrieved during the 10 April 2011 Etna paroxysm.

In addition, the REFIR package has been used to investigate the effect of plume height and Mass Eruption Rate uncertainties on Volcanic Ash Transport and Dispersal Model outputs based on three case studies at Etna: the 12th January 2011, 12th August 2011 and 23rd November 2013 paroxysms. In particular, it has been shown that plume height uncertainties strongly propagate in Mass Eruption Rate estimates and lead to large variations of simulated cloud dispersal and both tephra concentration in the atmosphere and tephra deposition.

Potential future developments

- Optical devices usually used to monitor rain, i.e. disdrometers, have been successfully tested for measuring tephra grain-size and sedimentation at Sabancaya (Peru), Sakurajima (Japan), Etna and Stromboli (Italy). Such instruments will be investigated further to provide near real-time TGSD in combination with the work already carried out as part of EUROVOLC (Pioli et al. 2019).

- Conclusions drawn from multi-method strategies at Etna will aim at making recommendations on how and when each remote sensing system should be used and combined depending on eruptive conditions.

Related products

- *Dioguardi, F., Beckett, F., Dürig, T., Stevenson, J.A., 2020. The impact of eruption source parameter uncertainties on ash dispersion forecasts during explosive volcanic eruptions. J. Geophys. Res. Atmos., under review.*
- *Freret-Lorgeril V. et al., 2021. Examples of Multi-Sensor Determination of Eruptive Source Parameters of Explosive Events at Mount Etna, Remote. Sens., 13:2097. doi:10.3390/rs13112097.*
- *Freret-Lorgeril V. et al., 2020. Ash sedimentation by fingering and sediment thermals from wind-advected volcanic plumes. Earth Planet Sci. Lett. 534:116072. doi:10.1016/j.epsl.2020.116072.*
- *Freret-Lorgeril V., et al., 2019. In situ terminal settling velocity measurements at Stromboli volcano: Input from physical characterization of ash. J. Volcanol. Geotherm. Res. 374:62-79.*
- *Freret-Lorgeril V., et al., 2018. Mass eruption rates of tephra plumes during the 2011–2015 lava fountain paroxysms at Mt. Etna from Doppler radar retrievals. Front. Earth Sci. 6:73. doi:10.3389/feart.2018.00073.*
- *Freret-Lorgeril V., et al., in prep. Tephra characterization and multidisciplinary determination of Eruptive Source Parameters of a weak paroxysm at Mount Etna (Italy).*
- *Marzano F.S., et al., 2020. Tephra Mass Eruption Rate from Ground-based X-Band and L-Band Microwave Radars during the 23 November 2013 Etna Paroxysm. IEEE Trans. Geosc. Remote Sens. 58, 5:3314-3327. doi: 10.1109/TGRS.2019.2953167.*
- *Pioli, L., Bonadonna, C., Pistolesi, M, 2019. Reliability of Total Grain-Size Distribution of Tephra Deposits. Sci. Report. 9:10006. https://doi.org/10.1038/s41598-019-46125-8.*
- *Scollo, S., et al., 2019. Near-Real-Time Tephra Fallout Assessment at Mt. Etna, Italy. Remote Sens. 11:2987. doi:10.3390/rs11242987.*

WP10 Integration and modelling of geophysical, geochemical and petrological monitoring data

Task 10.2.2 - A review of petrological monitoring

Contributors: Giuseppe Re (INGV Pisa), Rosa Anna Corsaro (INGV Osservatorio Etneo), Claudia D'Oriano (INGV Pisa), and Massimo Pompilio (INGV Pisa)

Description of the activity

A questionnaire to survey the common petrological monitoring procedures adopted by volcano monitoring institutions has been developed, aimed at identifying prevailing techniques and rating their suitability in terms of costs versus benefits. The collected information resulted from a sample of eighteen interviewed institutions, which include countries with some of the most important active volcanic provinces worldwide. The responding institutions also offer insights into volcanoes with a variety of volcanic activity, providing a comprehensive picture of the state of art of petrological monitoring. Starting from, how the petrological monitoring is performed by the different institutions worldwide, and what participants considered as the major problems, we identified the Best Practices in Petrological Monitoring as the best compromise between fast and easy analyses and the relevance of the acquired results.

Description of the standards and best practices developed

The survey provided a good representation of how petrological monitoring is performed by different institutions worldwide. To identify best practices for an efficient petrological monitoring the challenge is to find a balance between the analyses that are fast and easy to acquire (in terms of resources, equipment, and time availability) and the relevance of the results in terms of knowledge on the magmatic system and on the eruptive behavior.

To achieve this goal, we merge the answers on the time required for analyses and their relevance on an X-Y area, to detect faster and the more relevant investigations (Figure 11). The high priority analyses (green and blue fields) fall above an arbitrary threshold set at 75% on relevance (y-axes). All these analyses represent the hard-core practices of petrological investigations, as the data they produce supply the baseline for understanding the magmatic system and would be advantageous during any stage of volcano eruption. Similarly, on the right of another arbitrary threshold, set at 50% of the rapidity (x-axes), fall the faster analyses. These two thresholds identify the fast and highly relevant analyses, which are plotted into the green field. We suggest that the best practices for syn-eruptive petrological monitoring should necessarily include this set of analyses.

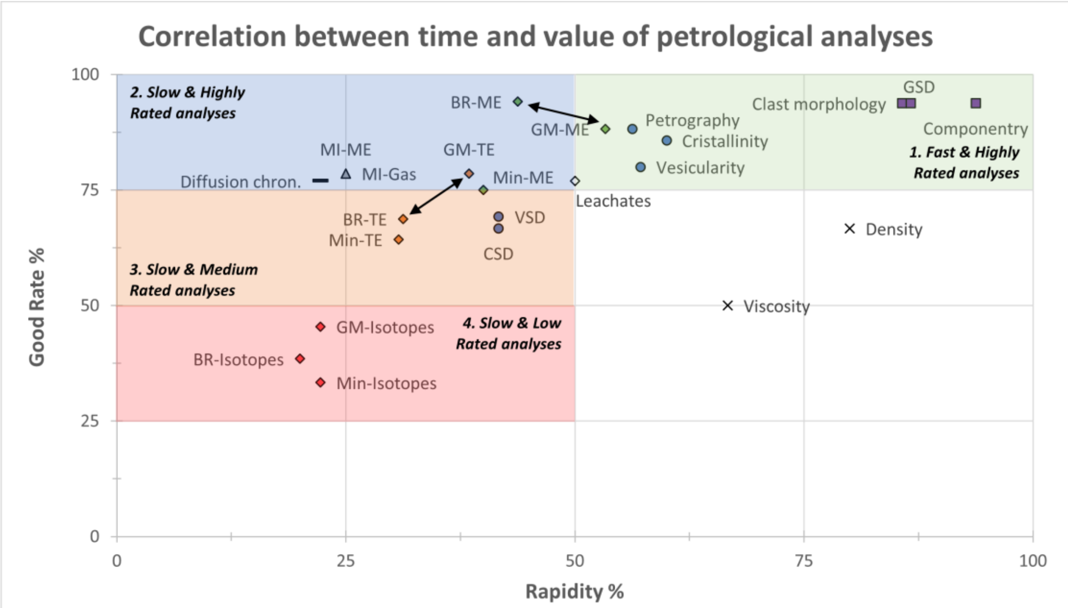

***Figure 11**. Representation of existing petrological techniques on a relevance (good rate) vs rapidity plot.*

In detail, the essential analyses include: litho-sedimentological (componentry, grain size distribution and clast morphology), petrographic and textural (petrography, crystallinity and vesicularity) investigations, together with major element groundmass glass composition (for pyroclasts) and bulk rocks (for lavas and coarse pyroclasts). Most of these analyses can be performed with basic and cheap equipment, such as sieves, stereomicroscopes and optical microscopes. With the exception of groundmass glass composition which requires a more expensive instrumentation (e.g. SEM-EDS), all these analyses can be performed within the observatory infrastructures and not far from monitored volcanoes even considering mobile labs. Major element bulk rock geochemistry, which falls in the blue field immediately outside the 50%-time threshold, deserve special mention: comparably to glass geochemistry, it requires expensive specialist instruments (e.g. XRF or ICP-OES and ICP-MS), and a little more time for sample preparation procedures, nevertheless it is sometimes the only option to gather chemical information (e.g. depending on the nature of the sample). Similarly, trace element geochemistry on glass is very promising since it can be performed in a short time without further sample preparation by means of LA-ICP-MS. The combination of the data extrapolated from the essential analyses provides some of the most powerful interpretations on the ongoing volcanic and magmatic processes. For example, the integration of litho-sedimentological and textural investigations can give insights on explosive eruptions. Variation of eruptive style, the mechanism of magma fragmentation or magma-water interaction, as well as the integration of textural and geochemical analyses, allow understanding magmatic processes occurring in the plumbing system, including events such as refilling, mixing of different magmas, disequilibrium conditions of minerals growth and the presence of different magmatic reservoirs.

The techniques that are not included in the high priority analyses still provide important petrological information, but they are generally highly resource and time consuming, as they require high-tech facilities and articulated post-sampling procedures that consist of multiple steps of sample preparations and analyses. For example, one of the main potentials of diffusion chronology is that it allows correlations between timescales of magmatic processes inferred from petrologic data and real-time monitoring signals. Melt inclusion geochemistry offers insights on processes occurring within the magmatic reservoir/s, such as estimation of volumes, depths, volatile contents, and injection of new magma. Also, the correlation of melt inclusions with the volcanic gases provides key constraints on degassing processes and saturation models. On the other hand, vesicle size distributions offer insights on volcanic degassing and fragmentation processes.

Moreover, measurements of crystal size distributions relate to crustal processes, namely magma storage, cooling rate and crystal nucleation and growth which can be completed by trace elements and isotopes geochemistry analyses in order to distinguish different batches of magma and so the processes occurring between the source and the deep feeding system. All these analyses are excellent for extended petrological investigations of an eruption or to assess the background conditions or long-term variations of the magmatic processes within the monitored volcanoes; if there are the conditions to accomplish these analyses in a short time, they will be very useful during syn-eruptive monitoring as well.

The above considerations are summarized in a flow chart diagram that describes the sequence of the entire petrological procedures (Figure 12). The flow chart has been divided into two branches based upon the nature of the sample, coherent or unconsolidated, as they require different preparation and analytic techniques. Moreover, the partition among coherent and unconsolidated volcanics also reflects (i) the sampling location, as the former are collected as near to the vent as possible, the latter at medial and distal locations, and (ii) the type of eruption, since the former (bombs excluded) represent effusive eruptions, whereas the latter are typical of explosive ones.

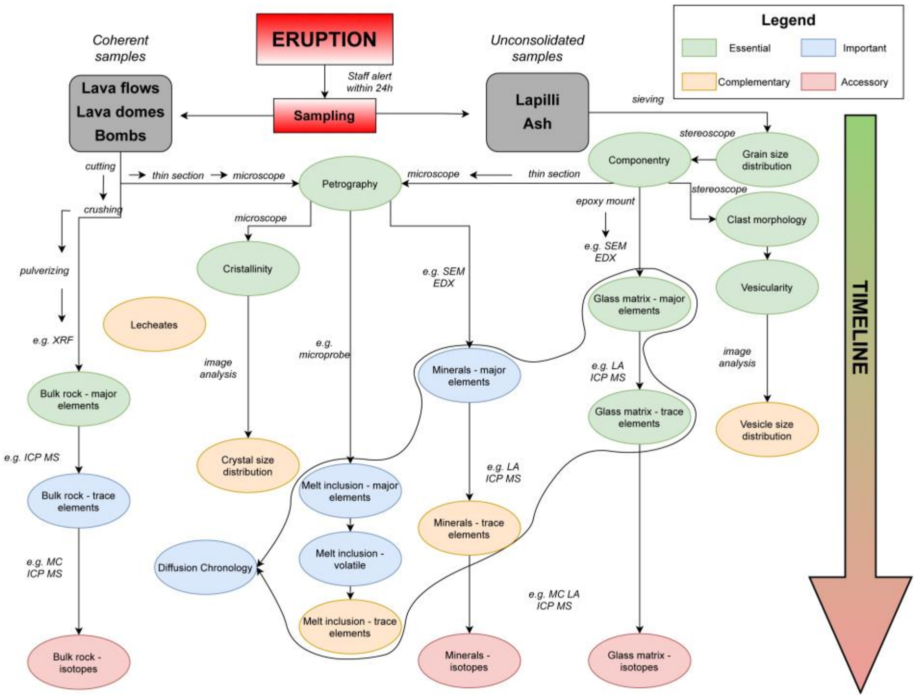

Figure 12. *Flowchart describing the procedures of the petrological techniques considered.*

Potential future developments

Organize a workshop between institutions performing petrological monitoring.

Related products

- *Re G., R. A. Corsaro, C. D'Oriano, M. Pompilio, Petrological monitoring of active volcanoes: A review of existing procedures to achieve best practices and operative protocols during* *eruptions, Journal of Volcanology and Geothermal Research, Volume 419, 2021, https://doi.org/10.1016/j.jvolgeores.2021.107365.*

- *Deliverable D10.4 : Best practice in petrological monitoring of eruptions in Eurovolc.*

WP11 – Version 1.0 of European Catalogue of Volcanoes and Volcanic Areas (ECV) and related volcanic hazards, and guidelines for a European Volcano Monitoring Status system

Task 11.3: Toward a guideline for assessing monitoring level of the European volcanoes (EVMS)

Contributors: Sara Barsotti, Kristín Vogfjörd (IMO), Mauro A. Di Vito, Stefano Branca (INGV), Adelina Geyer Traver (CSIC), Rita Silva Marques, Adriano Pimentel (CIVISA), Aline Peltier, Jean-Christophe Komorowski, Arnaud Lemarchand, Roberto Moretti, Anne-Marie Lejeune, Guillaume Carazzo (IPGP), Carmen López, Alicia Felpeto (IGN), Susan C Loughlin, Melanie Duncan, Charlotte L.Vye-Brown, Anna Hicks (NERC), Georges Vougioukalakis (IGME).

Description of the activity

The activity within this task is aimed at gathering basic information from the different European Volcano Observatories (VO) about existing criteria for defining monitoring levels for precursory detection at different volcanoes. The purpose is to compile an analysis by showing the different monitoring strategies and try to identify a common guideline or good practice to share for designing (and/or improving) a monitoring network for volcano surveillance.

The work relied on: An initial survey (to check the current monitoring strategy and criteria); the ranking of volcanoes monitored by European VO based on their hazard (to look for consistency between the volcanic threat and the level of monitoring); the definition of agreed statements regarding the concept of "good" monitoring network.

Description of the standards and best practices developed

The current monitoring setup for the different volcanoes, considered within WP11, were mapped into a matrix as the one shown in Table 2. The matrix spans over four monitoring level categories, characterized by increasing number and types of stations located at different distances (and directions) around the volcano. The categories are defined based on the three main types of geophysical/geochemical monitoring in common to all VOs in Europe, i.e. seismic, deformation and geochemical. However, the comparison between the different monitoring setup appears to be complicated and the working group recognized the need to begin by ranking the considered volcanoes by their threat and reviewing the level of monitoring in light of this scheme. VOs have then been asked to provide information about volcanoes to be capable to quantify the Volcano Hazard Index (VHI) as defined by Auker et al. 2015.

***Table 2**: The three main components of the monitoring network for different volcanoes have been compared by mapping them into the same scheme. Four monitoring categories are used from I (low monitoring) to IV (high monitoring level).*

SEISMIC	Minimum			Santorini Hekla Katla Bárðarbunga Grímsvötn	Mt. Pelée Piton La Soufríere Etna (minimum) Vesuvius (minimum) Fogo Teide (minimum)
	Optimal		Sete Cidades La Garrotxa (minimum)		
DEFORMATION		La Garrotxa (minimum)	Sete Cidades	Fogo Santorini Hekla Katla Bárðarbunga Grímsvötn	Mt. Pelée Piton La Soufríere Etna (minimum) Vesuvius (minimum) Fogo Teide (minimum)
GEOCHEMICAL	Continuous: Subaerial gases	Sete Cidades		Santorini Fogo Hekla Katla Bárðarbunga Grímsvötn	Mt. Pelée Piton La Soufríere Etna (minimum) Vesuvius (minimum) Fogo Teide (minimum)
	Continuous: gases which have been dissolved in H2O				
		I	II	III	IV

Fifteen volcanoes were ranked by following the same VHI approach. The VHI was then plotted against the Population Exposure Index as defined in the database available at the link https://data.humdata.org/dataset/volcano-population-exposure-index-gvm (which is an information valid country wise) The final matrix which includes the overview of selected European volcanoes ranked by their danger is shown in Figure 13.

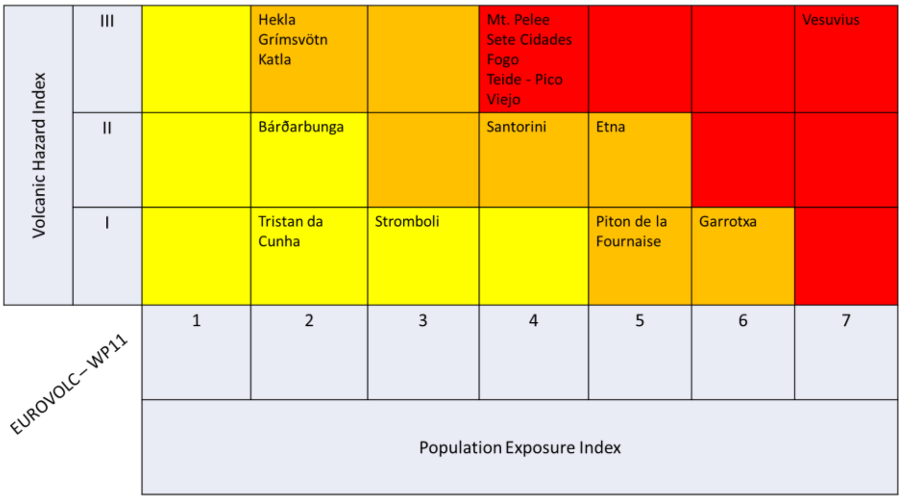

***Figure 13**: VHI/PEI matrix for those volcanoes monitored by European VOs and which are described in ECV obtained by using the information provided the VOs themselves as a WP11 product.*

The information on the relative volcanic threat for different volcanoes in Europe was then used to review the level of monitoring by confirming a general trend of an increasing level of monitoring for increasing danger at the volcano. However, some outliers are also present, and this should be investigated further.

The analysis and the initial comparison generated a good discussion within the WP11 group, which eventually helped in designing some important elements when we think about designing a "good volcano monitoring network". Some key aspects are summarized in the following points.

A good volcano monitoring network should be:

- dynamic and its setup should be reviewed with regularity;
- designed based on the volcano threat;
- designed based on the level of the current volcano activity;
- the minimal monitoring setup should guarantee the detection of the unrest, i.e. those geophysical/geochemical deviations from a known background level;
- in case of a volcano in unrest, the monitoring setup should improve the capability of interpreting and understanding the underlying processes;
- in case of escalation of the unrest, the monitoring setup should be functional in an early-warning system;
- ideally additional instrumentation should be moved and relocated in case of unrest.

Any good volcano monitoring network should be designed (and approved) by the scientists/technicians which "know" the volcano and have the expertise on its behaviour/activity.

Potential future developments

The current preliminary analysis provides a partial approach on how to assess a good monitoring network. In this sense, additional effort should be spent in extending the analysis and validating the applicability of the criteria. Specifically, some points regarding what to include in a more detailed analysis have been identified within Task 11.3.

In particular a complete review and ranking of monitoring levels should also account for:

- pre-eruptive monitoring needs;
- syn-eruptive monitoring needs;
- satellite based monitoring network;
- technical aspects like data quality, data transmission, reliability and resiliency of the network.

Related products

Only products related to milestones and deliverables have so far been released regarding this task.