EUROVOLC

European Network of Observatories and Research Infrastructure for Volcanology

Deliverable Report

D4.2 Remote_sensing_DB
Remote-sensing database & catalogue of best practice for instruments use

Work Package:	*Networking atmospheric observations and connecting the volcanological community with Volcanic Ash Advisory Centres (VAACs)*	
Work Package number:	*WP4*	
Work Package leader:	*Lucia Gurioli*	
Task (Activity) name:	*Remote-sensing data use/access for early warning & source parameters definition*	
Task number:	*4.1.2*	
Responsible Activity leaders:	*Lucia Gurioli and Mathieu Gouhier*	
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Type of Deliverable:	*Report X* *Prototype [ ]*	*Demonstrator [ ]* *Other [ ]*
Dissemination level:	*Public X* *Prog. Participants [ ]*	*Restricted Designated Group [ ]* *Confidential (consortium) [ ]*

Programme: H2020
Project number: 731070

CONTENTS

Summary

The object of the D4.2 deliverable (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 build up an informative data table to list all the studied volcanoes and the main parameterized explosion/eruption activities or periods of activities. Twelve VOs and VRIs (INGV-RM[1]; INGV-OE[2]; INGV-CNT[3]; INGV-NA[4]; IMO[5]; UI[6]; UNIRM[7]; OPGC-UCA[8]; UNIFI[9]; UNIGE[10]; CIVISA-IVAR1[11]; CSIC-IGN[12]) filled in the tables, for a total of 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). Several instruments have been listed among ground-, airborne- and space-based tools: 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 will be 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

Footnotes

1. INGV-RM: Istituto Nazionale di Geofisica e Vulcanologia, Roma
2. INGV-OE: Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo, Catania, Italy
3. INGV-CNT: Istituto Nazionale di Geofisica e Vulcanologia- Centro Nazionale Terremoti
4. INGV-NA: Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Vesuviano
5. IMO: Icelandic Meteorological Office
6. UI: University of Iceland
7. UNIRM: University of Roma 1
8. LMV-OPGP-UCA: Laboratoire Magmas et Volcans-Observatoire de Physique du Globe de Clermont-Ferrand-Université Clermont Auvergne
9. UNIFI: University of Florence
10. UNIGE: University of Geneva
11. CIVISA-IVAR: Centro de Informação e Vigilância Sismovulcânica dos Açores, Portugal- Instituto de investigação em Vulcanologia e Avaliação de Riscos
12. CSIC-IGN: Consejo Superior de Investigaciones Cientificas-Instituto Geografico Nacional

1. Introduction

On the 6–7 November 2012 a workshop entitled "Tracking and understanding volcanic emissions through cross-disciplinary integration: a textural working group" was held at the Université Blaise Pascal (Clermont-Ferrand, France). This workshop was supported by the European Science Foundation (ESF). The main objective of the workshop was to establish an initial advisory group to define measurements, methods, formats and standards to be applied in the integration of geophysical, physical and textural data collected during volcanic eruptions. This introduction is in part based on the geophysical section reported in the scientific paper realized by that group (Gurioli et al. 2015). The group agreed that community-wide, cross-disciplinary integration, centered on (i) defining the geophysical parameters that can be best measured and combined; (ii) the best delivery formats so that data can be shared between and easily used by different groups; is an attainable and key global focus.

A wide array of remote sensing and geophysical instruments can be used to parameterize an explosive event, both within and outside the volcanic conduit/dyke (e.g. Harris et al. 2013; Poret et al. 2018). Geophysical signals are generated by fluid and gas flow in the magma-filled part of the conduit and during fragmentation. Magma-gas ascent dynamics and conduit conditions extracted from geophysical data for this part of the system are particularly difficult to validate because the system cannot be directly observed. Measurements outside the conduit can be made of the emitted mixture of gas and particles as it (i) exits the vent, (ii) ascends above the vent as a plume and then (iii) drifts away from the vent as a cloud. Models and dynamic parameters extracted from geophysical and remote sensing data outside the conduit are a little easier to validate because they can be directly observed. The invisible part of the system is the realm of studies using seismic, pressure (infrasonic) and deformation data. All three data sets have long been shown capable of detecting the geophysical signature of explosive events, spanning weakly explosive Hawaiian to Strombolian through Plinian events. Seismic data sets are available, for example, for gas pistoning events, puffing, fountains and Strombolian eruptions at mafic systems (e.g. Goldstein and Chouet 1994; Ripepe et al. 1996; Sciotto et al. 2011; Ripepe and Braun 1994), as well as for events that generate somewhat larger plumes during silicic eruptions, such as at Santiaguito, Soufriere Hills and Redoubt. Associated pressure impulses (typically recorded by infrasound and barometers) have long been recorded for such energetic events, famous examples include the pressure response to the1883 eruption of Krakatoa and the 1967 caldera-forming eruption of Fernandina (Simkin and Howard 1970). Magma-gas ascent has also been shown to generate rapid, but recordable, deformation signals detected by tiltmeters (Aoyama and Oshima 2008; Genco and Ripepe 2010; Iguchi et al. 2008; Zobin et al. 2007). Velocities, masses and size distributions of particles leaving the vent have typically been measured by visible and thermal video (e.g. Chouet et al. 1974; Ripepe et al. 1993; Harris et al. 2012; Delle Donne and Ripepe 2012; Taddeucci et al. 2012; Bombrun et al. 2014; 2015; Gurioli et al. 2014; Gaudin et al., 2014a, b; Leduc et al; 2015) and Doppler radar (e.g. Dubosclard et al. 1999; Hort and Seyfried 1998; Vöge et al. 2005; Gouhier and Donnadieu 2008, 2011, 2016; Gerst et al. 2013; Freret-Lorgeril et al. 2018). Infrasonic array methods are also available to locate the emission in x, y space (e.g., Ripepe and Marchetti 2002). Plume front velocities, density and entrainment rates have also been successfully tracked using visible and thermal cameras, as well as radiometers, for a few stronger, ash-rich, buoyant plumes at Stromboli, Santiaguito and Eyjafjallajökull (Patrick 2007; Sahetapy-Engel and Harris 2009; Bjornsson et al. 2013; Valade et al. 2014) (see Chapter 9 of Harris 2013 for review).

Satellite remote sensing has long been used to track and measure properties of the eruption cloud as it drifts and disperses. These data are available for all cloud sizes, from those associated with small

Strombolian and fountaining events (e.g. Heiken and Pitts 1975; Dehn et al. 2002) to sub-Plinian and Plinian events (e.g. Holasek and Self 1995; Koyaguchi and Tokuno 1993; Holasek et al. 1996; Pavolonis et al. 2006 ; Spinetti et al. 2008; Corradini et al. 2008; Poret et al. 2018). Cloud dispersion dynamics are especially well revealed by geostationary satellite data with nominal imaging of one image every 15 min and higher (Prata and Kerkmann 2007; Labazuy et al. 2012; Gouhier and Paris 2019). Basic cloud properties that can be measured by satellite data include cloud dimensions, drift velocity and height (e.g. Robock and Matson 1982; Denniss et al. 1998; Aloisi et al. 2002; Zakšek et al. 2013; Gouhier et al. 2016). Prata (1989) and Wen and Rose (1994) introduced a method to extract particle size distribution and mass from split window (11–12 μm) thermal data. Multi-spectral and hyper-spectral ground-based thermal cameras can also be used to extract ash particle size and plume mass (Prata and Bernardo 2009; Smekens and Gouhier 2018). Newly available technology such as LiDAR and instruments such as PLUDIX were shown to be of value in detecting, tracking and measuring fine particles in the Eyjafjallajökull cloud (e.g. Bonadonna et al. 2011), as well as airborne measurements (Sahyoun et al. 2019).

Disdrometers and ash collectors, however, currently show greater potential for measuring particle size and terminal velocity (Marchetti et al. 2013; Shimano et al. 2013; Freret-Lorgeril et al; 2019) than PLUDIX, which was designed more for meteorological applications (Caracciolo et al. 2006; Prodi et al. 2011).

For the gas content of the cloud, many satellite-based sensors such as TOMS, OMI, AIRS, IASI, MODIS, SEVIRI, Sentinel-5, etc. have been used to obtain the SO2 content in the far field, once the gas cloud has decoupled from the ash cloud (e.g. Krueger et al. 1990; Carn et al. 2003, 2005; Watson et al. 2004; Yang et al. 2007; Prata and Kerkmann, 2007; Thomas and Prata 2011; Rix et al. 2012; Walker et al. 2012; Gauthier et al., 2016; Gouhier and Paris 2019), Ground-based sensors, such as COSPEC, FLYSPEC and DOAS (e.g. Caltabiano et al. 1994; Horton et al. 2005; Oppenheimer et al. 2011), have been used to measure SO2 fluxes relatively close to the source (see Williams-Jones et al. (2008) for full review). These approaches have recently been supplemented by SO2 camera systems, which allow 2-D images of SO2 concentrations to be collected at ~1-Hz rates (Mori and Burton 2006). Such studies have, though, tended to focus on passive degassing and gas puffing systems, because the presence of ash interferes with UV-light transmission on which the technique relies, making measurements problematic. Recently, SO2 cameras have been used to measure the gas masses and fluxes involved in discrete explosive events (Mori and Burton 2009; Holland et al. 2011; Barnie et al. 2014), as well as hyperspectral thermal infrared imager (e.g. Smekens and Gouhier 2018; Huret et al. 2019)

The raw signal of a remote sensing instrument is a voltage which, through calibration, can be converted to a higher level physical value, such as spectral radiant intensity or power. The conversion of this value to higher level and more volcanologically useful parameters (such as particle size distribution, mass flux or plume density) requires an increasingly complex system of assumption stacking. Thus, to adequately reduce geophysical data, a number of input parameters are required and many assumptions need to be made, all of which can be provided by the physical volcanological community. Data sets from this community, especially if provided simultaneously with geophysical data collection during an active event, or provided as a library typical of that event, can also be used to ground truth or check the precision and reality of the geophysically applied input or generated output (see deliverable D4.1). Therefore, even if remote sensing instruments are common tools used at VOs, the different methods and technical skills required for using the direct outputs or for processing raw data into high value-added EO products, make their utilization by researchers difficult. In task

4.1.2 the goal is to list existing instruments and allow researchers to gain know-how on existing techniques and their use, facilitate the access to related databases, and make associated data processing easier.

Geostationary satellite-based data from the HOTVOLC real-time monitoring system (http://hotvolc.opgc.fr, Fig. 1) is made available 24/7 through the UCA-OPGC partner. It allows 24/7 early-warnings and continuous monitoring of volcanoes at a rate of one image every 15 minutes (Gouhier et al. 2016). A large dataset of quantitative parameters retrieved from processed data is available to the partners following standardized data and metadata EO products (i.e., cloud top height (km) and velocity (m/s), very fine ash (1-15µm) grain-size distribution, MER estimation (Kg/s), or fine ash concentration (g/m^2) in the cloud). Data sets include, Eyjafjallajökull 2010, Grímsvötn 2011, Bárdarbunga 2014/15, Piton de la Fournaise and Etna eruptions. This system is now part of WP24 as a virtual access to remote sensing service (VA6).

Figure 1 Open access geostationary satellite-based HOTVOLC real-time monitoring system.The system provides radiance + temperature and lava flux, ash and SO_2concentration every 15 minutes.
•http://hotvolc.opgc.fr/www (PC version)
•http://hotvolc.opgc.fr/m (mobile version).

Ground based methods comprising high-speed visible and thermal infrared measurements of ash-rich eruptions of Etna (and other targets) represent an important dataset from INGV, while INGV-EO proposes several facilities for the detection of volcanic plumes and tephra deposits such as LIDAR system (UV-VIS), FTIR, as well as a video surveillance system able to give important data on explosive activity. Also a shared L-Band Doppler radar named VOLDORAD 2B (INGV-EO and UCA-OPGC) with databases of power spectra (http://wwwobs.univ-bpclermont.fr/SO/televolc/voldorad/index.php) for the continuous monitoring of volcanic ash and blocks is very useful. Access and data policy is regulated by the EPOS (the European Plate Observing System, https://www.epos-ip.org/) directives.

Portable instruments like ASHER and PLUDIX can be easily deployed during the course of an eruption. Many measurements have already been carried out and an important collection of tephra data is already available for recent Icelandic eruptions.

Unmanned Aerial Vehicles (UAV) are relevant tools for the study and real time monitoring of volcanic activity. UAV forms a natural bridge between spaceborn and ground measurements and is particularly relevant for in situ validation of remote measurements. These include time-series concentration measurements and sampling gas (e.g. SO2, CO2, H2S, HCl, HF), aerosols and volcanic ash from Optical Particle Counters (OPC) and Chemical Particle Counters (CPC).

2. Objective of WP4.1.2

Remote sensing instruments are common tools used at VOs, BUT the diversity of methods and the technical skills required make their utilization by researchers difficult. Therefore, the objectives of this task are:

- To list existing instruments and allow researchers to gain know-how on existing techniques and their use
- To facilitate the access to spatial databases (e.g., MSG-SEVIRI), make easier data processing such as for the OPGC-HOTVOLC system (http://hotvolc.opgc.fr)
- To share datasets from ground-based measurements of ash (INGV) and propose facilities for detection and monitoring (INGV-OE and OPGC-Voldorad)
- UAV (Drones) = natural bridge between spaceborn and ground measurements, useful for in-situ validation of remote sensing measurements

3. STEPS to reach the objectives with references to activity meetings

Discussions between several WP4 participants started at the *EUROVOLC kick-off meeting* in Iceland. We presented the two main Networking (NA) activities: (NA2.1) Networking atmospheric gas and aerosol observations and (NA2.3) Connecting the Volcanological Community with Volcanic Ash Advisory Centres (VAACs). Within NA2.1, the “WP4.1.2 remote-sensing data use/access for early warning & source parameters definition” activity was defined. It was decided to develop a questionnaire and send to the EUROVOLC WP4 and WP8 partners to identify all the remote sensing tools used by VOs and VRIs to observe/measure on-going activities on different volcanoes. The partners were asked to specify the instrument, the technical parameters, the methodology for using it, and whether the tools were open access.

After the kick-off meeting, several *Skype* and *email discussions* went on between the WP4 leaders and some components of WP8 to discuss, revise and correct the data collection list.

At the 11-16 April *EGU 2018 meeting in Vienna*, a common milestone between WP4 and WP8 was defined about the compilation of a Metadata table to be filled in by the participants of WP8 and WP4

On the 21 of May 2018: a first WP4-WP8 spreadsheet was uploaded in google drive document (Fig. 2): https://drive.google.com/file/d/1bhZ7KtRl5HS_rDnKWu_266a4BfSm-isQ/view?usp=sharing

Name of contact person	Institution	Email	Volcano	Eruption	Phase	Dates	Vent information		
							Location	Height	Geometry
							(e.g. coordinates)	*(e.g. m asl)*	*(e.g. radius)*

	Data	Data source	Data type	Sensor type	Sensor location	Sensor accuracy	Data published?	Time series	Notes
Eruption Observations	Plume Height	Radar	*(e.g. which radar)*	*(e.g. L band, X band)*				(e.g. Y/N)	
		Lidar							
		Webcam	*(e.g. which webcam)*						
		Satellite	*(e.g. which satellite)*						
		Pilot report							
		other ground based observations							
		Other e.g. deposit analysis							
	Mass flux	Infrasound							
		Radar							
		Satellite							
		Other e.g. deposit analysis							
	Volcanic ash concentration	Lidar							
		Satelite							
	Temperature	Infrared camera							
	Weather data	Radiosonde							
		Weather Prediction Model							
	Grainsize	Satellite							
		Radar							
	Gas species & flux	Satelite							
		FTIR							
		DOAS							

	Data	Sample location *(incl. number of samples per location)*	Method/Instrument/Strategy	Parameter	Data accuracy	Data published?	Notes
Deposit Information	Grainsize	*e.g. proximal*	*e.g. Hand sieving at 0.5 phi interval*	*e.g. median, sorting*			
		e.g. distal	*e.g. Coulter counter, ASHER, etc.*	*e.g. median, sorting*			
	TGSD		*e.g. Voronoi (also mention software used)*				
	Componentry		*e.g. Image Particle Analysis*	*e.g. median, sorting for each component*			
	Thickness/load						
	Volume						
	Density						
	Particle shape		*e.g. Morphologi*	*e.g. Sphericity*			
	Particle density		*e.g. pycnometer*				

Figure 2 First WP4-WP8 spreadsheet uploaded in Google Drive on the 21 of May 2018

At the 2-6 September *COV 2018 meeting in Naples*: a small WP4 + WP8 meeting was held to discuss the compilation of the different tables listed in the WP4 deliverables.

3-7 December 2018 *UCA-OPGC-LMV hosted the WP4.1.1 leader* allowing rich discussions between the WP4 leaders to work out new strategies for the Data table, to prepare the 9-month interim report and discuss all the deliverables.

Unfortunately we realized that the idea to make an electronic version of the table discouraged people and no-one at that point had filled in the table.

18-December 2018 a second WP4-WP8 Metadata_Collection table was sent again to the WP4 and WP8 participants. This time the spreadsheet consisted of 4 sections:

- Name and contact details of the Contact person(s) (top left)
- Eruption details (e.g. volcano name, location, etc.) (top right)
- Eruption Observations (e.g. MER, plume height) (center)
- Deposit Information (e.g. TGSD, componentry, thickness) (bottom)
- Instrument used to measure the data and instrument description (several columns)

Only a few VRIs sent us the filled tables.

4-8 February 2019 VAAC Meeting at Met-Office, Exeter (UK). During this meeting it was decided that an additional deliverable for WP4.2 was to set up a second VAAC meeting in Toulouse to discuss best instruments to use and best practices to measure and/or derive fundamental parameters required during a volcanic crisis.

At the 18-25 February 2019 *EUROVOLC 1st Annual Meeting in Ponta Delgada* (Azores Islands), a whole day was dedicated to the correction and reorganization of the WP4-WP8 informative table. We had then agreed to make it more detailed and include more explanations.

2 April 2019, the final **WP4-WP8_data_availability_survey table** was sent to both the whole WP4 and WP8 participants and personally to specific VOs and VRIs.

Since April 2019 we have been working to merge all the WP4_WP8_data_availability_survey tables that finally we received from almost all the VOs and VRIs

All this work has been done in collaboration with WP8 (Costanza Bonadonna, Samantha Engwell; Fabio Dioguardi, Matteo Cerminara). All the tables are available in an open access google drive:

https://drive.google.com/drive/folders/1UE0S6m7giqO2sqqNJO3hh6QaWY4xlRWv?usp=sharing

4. Explanation of the remote sensing informative tables and instruments brochures

The final WP4-WP8_data_availability_survey table was made with a first page of explanation and a second page for the survey table itself:
Below are the explanations provided for filling in the table.

1) Contact (Fig. 3 left): we asked for the contact information of the person responsible and/or in charge of the informative data, the relative institute and email. This information is crucial to allow the users to contact the source distributing the data

2) Volcano, activity and vent information (Fig. 3 right): for each volcano the responders were asked to provide the name and the corresponding identification number as reported by the Smithsonian Institute. Start time can refer either to the start of an eruptive activity, to the beginning of the data acquisition, to the beginning of a single phase or explosive event. Stop time refers to the end of the explosion/eruption or eruptive studied period, specifying the day (DD) month (MM) and year (YYYY) and the time in hours (HH) and minutes (MM) in UT, when possible.

For each instrument the following information is requested (Fig. 4):

1) Data source: Specify the kind of instrument used as listed in Figure 5.

2) Sensor name: Specify the name of the sensor, for example for the satellite it is SEVIRI or MODIS.

5) Sensor type: Specify the typology, for example for radar it is L band or X band; for camera it is visible or thermal.

6) Sensor location (Lat; Long): Specify the position of the instrument while making the measurement in the field.

7) Sensor accuracy: Specify the accuracy of the measurement.

8) Time series: Y/N

9) Methodology: Describe the measurement methodology.

10) Software/Codes (incl, web-site link from where they can be downloaded): Specify the code used, for example for the inversion algorithm etc.

11) Online repository [URL]: Add the link to a database or an online depository material (like a publication).

12) Reference: Add the reference published on these specific data, or on the use of the machine.

13) Notes: Add everything which is necessary to know about best practise or standards related to that machine.

Contact		
Name of contact person(s)	Institution(s)	Email
Person 1	*Institution 1*	
Person 2	*Institution 2*	
(...)	*(...)*	

Volcano	Start Time (1)	Stop Time (1)	Vent/crater information		
			Location	Height	Geometry
Name and Smithsonian Institute ID	DD/MM/YYYY (HH:MM)	DD/MM/YYYY (HH:MM)	*Lat-Lon*	*m. a.s.l.*	*diameter (m)*

Figure 3 WP4-WP8_data_availability_survey table: with contact information and Volcano, activity and vent information.

Data source	Sensor name	Sensor type	Sensor location [Lat, Lon]	Sensor accuracy	Time Series

Methodology	Softwares/Codes *(incl, web-site link where they can be download)*	Online repository [URL]	Reference	Notes

Figure 4 WP4-WP8_data_availability_survey table columns related to information required for the used instruments.

Tools	
Pilot report	FTIR
Webcam / camera array	DOAS/FlySpec
Visible camera	Multigas
Infrared camera / radiometer	Multispectral / Bispectral camera
Radar	IR Camera (H20 only)
Lidar	UV Camera (SO2 only)
Infrasound	Petrological studies
Satellite	Disdrometer
Radiosonde	ASHER
Weather Prediction Model	Deposit measurements

Figure 5 List of potential instruments used to observe/measure specific parameters.

Because the information reported in the Informative Tables were sometimes not so detailed, we decided to send to the WP4 group a form for a brochure to fill in for each instrument. This brochure allows a detail description of the instrument to be provided. The brochure will be used as an informative brochure to link with the European Catalogue of Volcanoes (WP11).

On the cover sheet of the brochure the following details are reported:

Instrument name: generic sensor system name

Model: manufacturer / model; or key sensor component or technical name with version number if more appropriate

Instrument location: institution where the instrument is held

Instrument contact: name/email of manager of institutional equipment pool for EUROVOLC

Responsible: name of person (NO email) responsible for instrument at host institution

Funding agency: funding agency/source of funds that secured initial instrument purchase

Instrument cost: Insured value

Insurance Required: Y/N

Instrument photo: insert a photo of the instrument

Caption: photo caption

On page two the specifications of the instrument are reported in terms of:

Description of the instrument: technical description of the instrument

Potential applications: parameters that can be measured

(i) *Base measurement*

Physical quantity measured, in sub-title field, with required pre-processing / calibration / corrections in text field.

(ii) *Higher order derivatives*

bullet point list of key parameters that can be calculated / derived from the base measurement, supported key source references for data processing / conversion methods.

Installation requirements:

Any requirements for installation, e.g., external power needs; line-of-sight required; positioning with respect to target; optimum distance to target / distribution of network; weather / environmental conditions; transport/shipping; on-site construction required.

Special requirements:

Check whichever of the following applies:

- □ Instrument is plug-and-play
- □ Instrument requires delivery by operator or collection at source (i.e., cannot be shipped)
- □ Instrument requires installation by specialist crew
- □ Instrument comes with users / operational manual
- □ Data acquisition requires installation and use of specialist software

Statement of accessibility:

Any qualifications regarding availability

References

Full references to support those cited in “potential applications” field

5. Some results of the remote sensing informative tables

Twelve VOs and VRIs (INGV-RM; INGV-OE; INGV-CNT; INGV-NA; IMO; UI; UNIRM; LMV-OPGP-UCA; UNIFI; UNIGE; CIVISA-IVAR; CSIC-IGN) filled in the tables, for a total of 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, Fig. 6).

The tables are grouped by the different volcanoes and divided according to the measurements performed as time series or as single eruptions. For each volcano the tables have also been divided according to the tools/methods used for the quantitation of the parameters. Two summary tables are produced, one related to the volcanoes, the instruments used for each volcano and the institutes involved (Fig. 6), the other just showing a list of all the ground, airborne and spatial tools named in the informative tables (Fig. 7). Brochures for each instrument are also reported by each VO and VRI.

Volcano	Time Period	Eruption	Deposit	Infrared Camera	Visible Camera	High Speed Camera	Infrasound	Doppler Radar	Radar	Satellite	Lidar	Airbone	Disdrometer	ASHER	Radiometer	Pilot Reports	DOAS	FTIR	Multigas	UV camera	Institutions
Bárðarbunga	x		x (IMO)	x (IMO)	x (IMO)		x (IMO;UNIFI)		x (IMO)	x (IMO, UNIFI)						x (IMO)	x (IMO)	x (IMO)	x (IMO)		IMO; UNIFI
BatuTara		x		x (INGV-RM1)																	INGV-RM1
CampiFlegrei		x	x (INGV-RM1)																		INGV-RM1
Copahue	x						x (UNIFI)														UNIFI
Cordon Caulle		x	x (INGV-RM1)																		INGV-RM1
Etna	x	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)								INGV-OE; INGV-RM1; UNIRM; UNIFI; LMV-OPGP-UCA; INGV-RM1; INGV-CNT
Eyjafjallajokull		x	x (UNIGE, INGV-RM1; IMO)	x (UNIFI)	x (IMO)		x(IMO;UNIFI)		x(IMO)	x(IMO)	x(IMO, satellite)					x (IMO)					IMO; UNIFI, INGV-RM1; UNIGE
Fogo		x	x (CIVISA/IVAR)																		CIVISA-IVAR
Fuego		x		x (INGV-RM1)																	INGV-RM1
Grímsvötn		x	x (IMO)		x (IMO)				x (IMO)	x (IMO)	x (IMO)					x (IMO)					IMO
Hekla		x	x (IMO; UNIGE)						x (IMO)	x(IMO)		x(IMO)				x (IMO)					IMO; UNIGE
Laacher See		x	x(INGV-RM1)																		INGV-RM1
Montserrat	x			x (UNIFI)			x (UNIFI)														UNIFI
Nyaragongo	x			x(UNIFI)			x(UNIFI)														UNIFI
Piton De La Fournaise	x	x	x(LMV-OPGC-UCA; IPGP-OVPF)				x (UNIFI)			x (LMV-OPGC-UCA)											UNIFI;LMV-OPGP-UCA;
Sakurajima	x		x(INGV-RM1)				x (UNIFI)														INGV-RM1; UNIFI
Sete Cidades		x	x(CIVISA/IVAR)																		CIVISA-IVAR
Stromboli	x		x(LMV-OPGC-UCA)	x(LMV-OPGC-UCA; INGV-RM;UNIFI)	x(LMV-OPGC-UCA; INGV-RM1;UNIFI)	x(LMV-OPGC-UCA; INGV-RM1)	x(UNIFI)	x(LMV-OPGC-UCA)		x(LMV-OPGC-UCA)			x(LMV-OPGC-UCA)	x(LMV-OPGC-UCA)	x(LMV-OPGC-UCA)		x(LMV-OPGC-UCA)			x(LMV-OPGC-UCA)	INGV-RM1;UNIFI; LMV-OPGP-UCA;
Teide		x	x(CSIC-IGN)																		CSIC-IGN
Tungurahua	x						x(UNIFI)														UNIFI
Vesuvius		x	X(INGV-NA)																		INGV-NA
Yasur	x			x(INGV-RM1;UNIFI)		x(INGV-RM)	x(UNIFI)														INGV-RM1; UNIFI
Volcano	Time Period	Eruption	Deposit	Infrared Camera	Visible Camera	High Speed Camera	Infrasound	Doppler Radar	Radar	Satellite	Lidar	Airbone	Disdrometer		Radiometer	Pilot Reports	DOAS	FTIR	Multigas	UV camera	Institutions
22	10	14	15	9	5	2	11	2	5	6	2	1	2		1	3	2	1	1	1	11

Figure 6 Summary table of the WP4-WP8_data_availability_survey table in https://drive.google.com/drive/folders/1UE0S6m7giqO2sqqNJO3hh6QaWY4xlRWv?usp=sharing

Instruments	Institution
Infrared Camera	IMO; INGV-RM1; INGV-OE; UNIFI; LMV-OPGC-UCA
Visible Camera	IMO; INGV-OE;LMV-OPGC-UCA; INGV-RM1;UNIFI
High Speed Camera	LMV-OPGC-UCA; INGV-RM1
UV Camera	LMV-OPGC-UCA
Infrasound	IMO;UNIFI
Doppler radar	LMV-OPGC-UCA
Radar	IMO;UNIRM
Satellite	LMV-OPGC-UCA; INGV-CNT
Lidar	INGV-OE; IMO
Airbone	IMO
Disdrometer	LMV-OPGC-UCA
Asher	LMV-OPGC-UCA; UI; UNIFI
Radiometer	LMV-OPGC-UCA
DOAS	LMV-OPGC-UCA
Pilot Reports	IMO

Figure 7 List of instruments and relative institutes.

6. Other deliverables

1) **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 1 (Fig. 8).

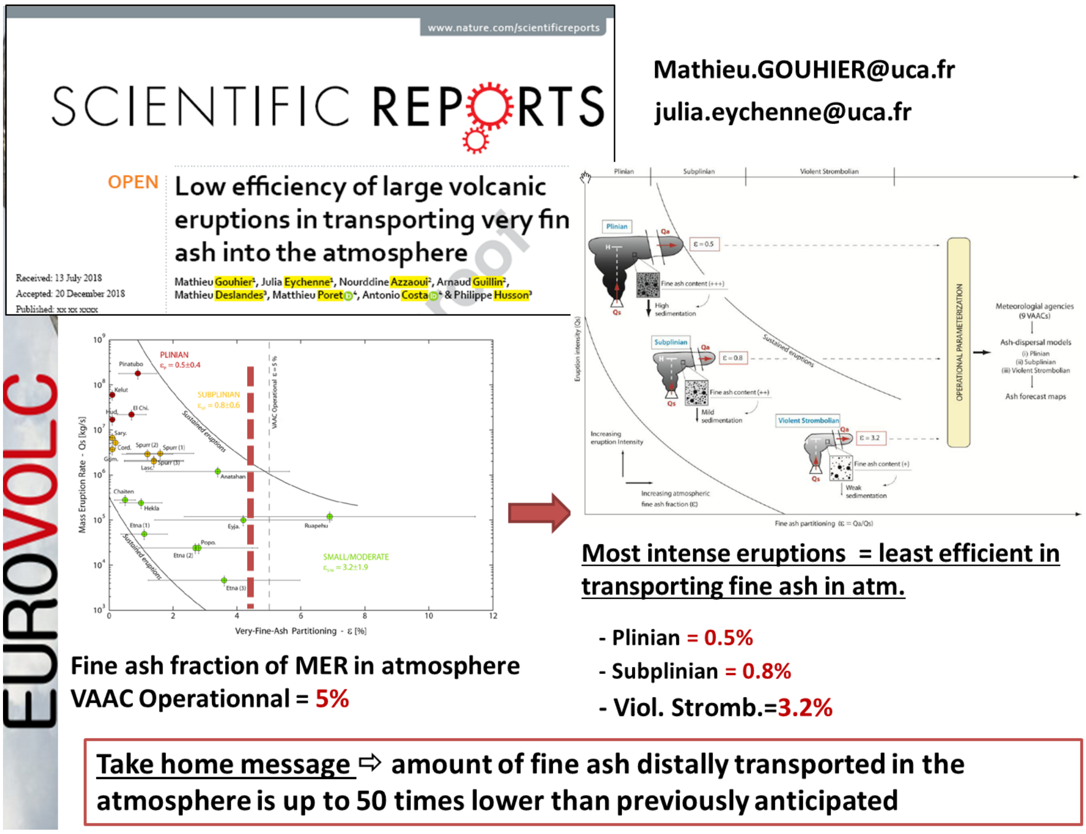

Figure 8 Scientific Report on the fine ash dispersion.

2) A methodological paper about the ASHER is in progress by participants of WP4 and WP8, to provide the description, validation and best use of this instrument.

3) A 4-month CDD supported by EUROVOLC (from January to April 2020) and supervised by Gurioli will finalize a second paper on the multiparametric field campaign on Stromboli in 2016 (see the Informative Table), with the ASHER - IR camera - SO2 camera - DOAS - Seismometer - acoustic - sample return about best practices on instruments and deposits. This paper will be a contribution among some VOs and VRIs of WP4 and WP8 to present some best practise case-studies (including full methodological detail).

4) The WP4.1.2 leader, Mathieu Gouhier (UCA-OPGC) and Philipe Hereil (leader of Toulouse VAAC) made preparations for a second VAAC meeting in Toulouse with the three VAACs in charge of monitoring the European Volcanoes + VOs + VRIs (scheduled 23-25 of June 2020, but postponed due to COVID-19). The meeting, which will be supported by WP4, EPOS-SP, OPGC and Meteo France, will provide additional contributions to best practices for instrument use during a volcanic crisis.

5) Finally, participation and discussions in the 2-day community workshop planned in connection with the Icelandic Summer school in August 2020 will also contribute to best practises in instrument use and standards. This workshop has also been postponed due to COVID-19.

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