EUROVOLC

European Network of Observatories and Research Infrastructure for Volcanology

Deliverable Report

Deliverable 2.2 - Forensic examination of multidisciplinary data from past volcanic crisis events

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Contents

1. Introduction

This deliverable describes several aspects related to state-of-the-art discussion and analysis of multidisciplinary data from past volcanic crisis events, including the response of volcano observatories to such events. Much of the content below comes from dedicated analysis 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; and it includes specific analysis of the December 24, 2018 eruption of Mt. Etna, with focus on aspects that emerge from that experience as being relevant in the organization of the observatory response and for the management of the scientific and technical aspects of the volcanic crisis.

2. Key points from VOPB4

In order to discuss and define best practices, at the workshop we put a focus on the following main topics:

- How can we get ready for a volcanic crisis?
- How can we respond to a volcanic crisis?
- What can we tell about the status of our volcano? How can we tell that?
- How can academia help in improving the responses at the VOs?
- How did Volcano Observatories (VOs) respond to past volcanic crises? Examples have been given at the workshop, and the most relevant outcomes are reported in Section 3.

2.1 The importance of checklists (contribution by Chris Newhall)

In this contribution, the importance of, and need for, checklists at VOs was 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 have 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 exercised the practices that should be in place during a crisis (communication, monitoring, internal);
- **syn-crisis checklist**, to make sure to handle the correct functioning of the monitoring station, 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 and notes of the advices 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.

2.2 Recommendations concerning the link between forecasting and decision making (contribution by Warner Marzocchi)

This contribution highlighted the importance of the separation between the domains in which scientists and decision-makers act.
While sometimes hazard assessment is enough to make a decision (e.g. when an event is happening, like a lahar, 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, we must have clear in mind that there are no *wrong* or *right* decisions: there are however rational and defendable (or not) decisions. They should be made on the basis of the risk associated with 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, it must be kept in mind that defining a threshold in exceedance probability implies defining a "reasonable acceptable risk", and again this requires non-scientific competences.

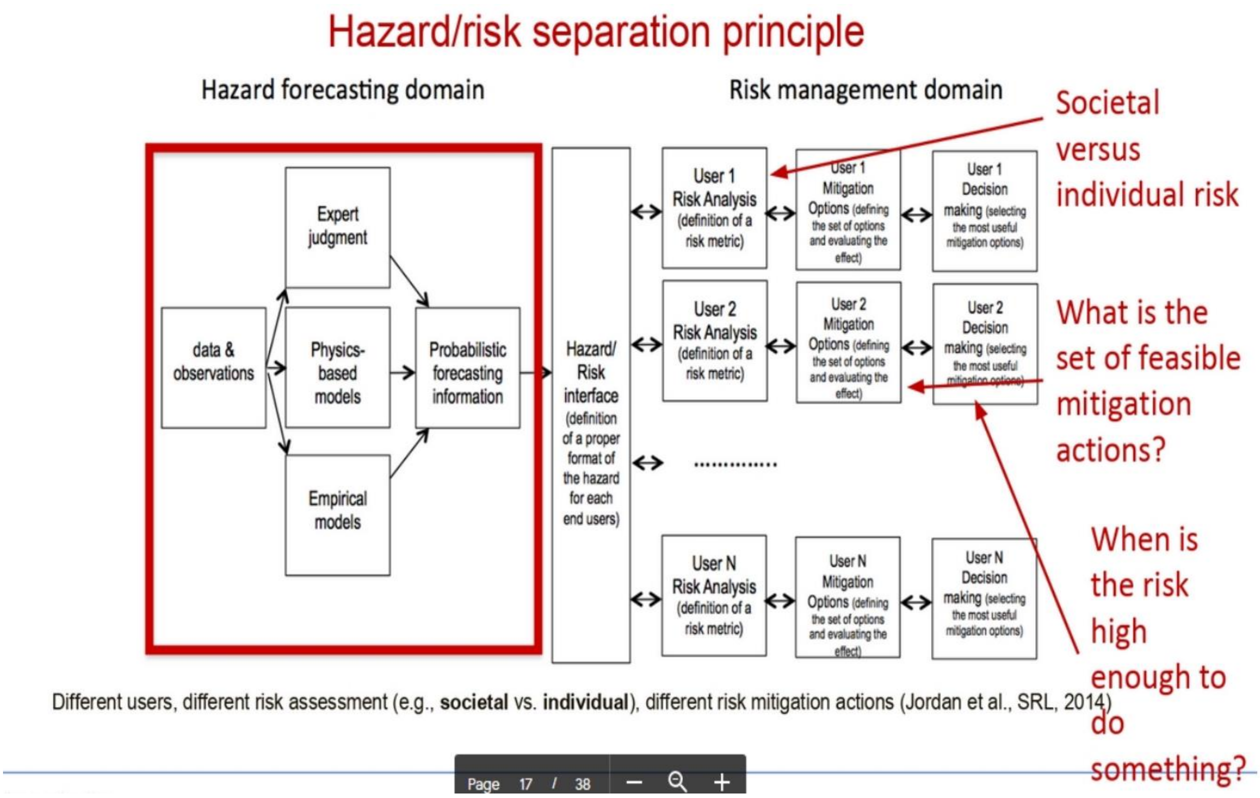

Figure 1. *Hazard/Risk separation principle*

Figure 1 illustrates the concept in more detail: 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 mitigating actions depend on the user and related needs, and when is risk high enough to take actions. In this light, the decision-makers and risk managers domain is separated from the scientific (hazard forecasting) domain.

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

This contribution constitutes a link between the two recommendations above (sections 2.1 and 2.2). In particular, it highlighted the importance of identifying potential sources of legal scrutiny for VOs, and how VOs can be prepared or less vulnerable. In particular, 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. In particular the "after-crisis" scrutiny will involve consideration of what happened (the factual evidence) and what could or should have happened (the counter-factual evidence), and by comparing these two pieces of evidence potential shortfalls may arise. In the light of this, possible strategies to protect VOs are:

- Provide the best possible contribution to the management of societal risk
- Avoid getting exposed by limiting roles (see 2.2)
- Be defensive by reducing vulnerability, e.g., by excluding or capping liability, getting insurance, indemnity and immunity, and keep good records of all the choices made and procedures followed (see 2.1)

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

This contribution explained the use of the ICS scheme by the US Geological Survey (USGS), reported in **Figure 2**, during the recent volcanic crisis of Kilauea in 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.

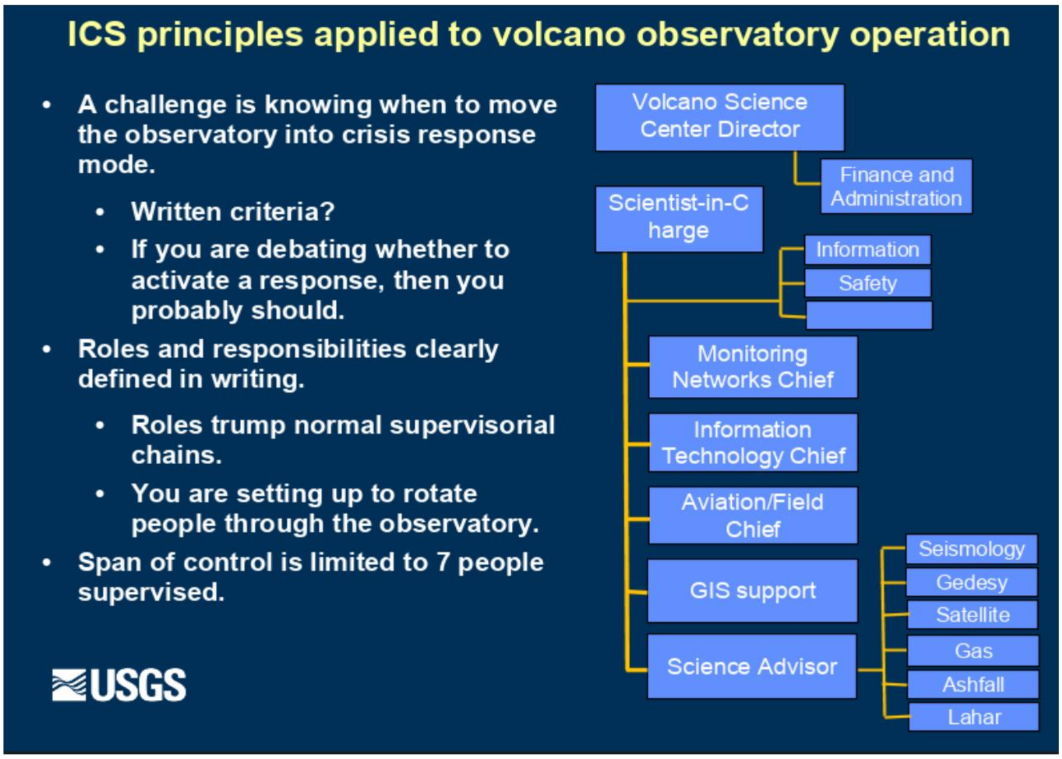

Figure 2. *ICS principles applied to VOs*

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 are commonly 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 there are more, then 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 the USGSs. The USGS supports the IMT in achieving its goals, but they do not have to reciprocate. The 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.

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

This contribution explained 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 3. *Procedure to carry out a gap analysis for volcano monitoring. From Ewert et al., 2005.*

The procedure, illustrated in **Figure 3**, 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

On this basis, it is possible to rationally identify where to spend money to improve the monitoring level towards the minimum accepted level.

3. Examples of unrest or crisis management

3.1 The technical and scientific management of the December 24, 2018 Mt. Etna eruption

On the morning of December 24, 2018, the first phenomena of unrest were observed, evolving quickly towards the opening of an eruptive fracture field from which lava fountains and lava flows originated. The eruption ended in the night between 26 and 27 December, a few hours after a strong earthquake that struck the Eastern flank of the volcano (see **Figure 4**, and **Table 1** for a synthetic history of the eruption).

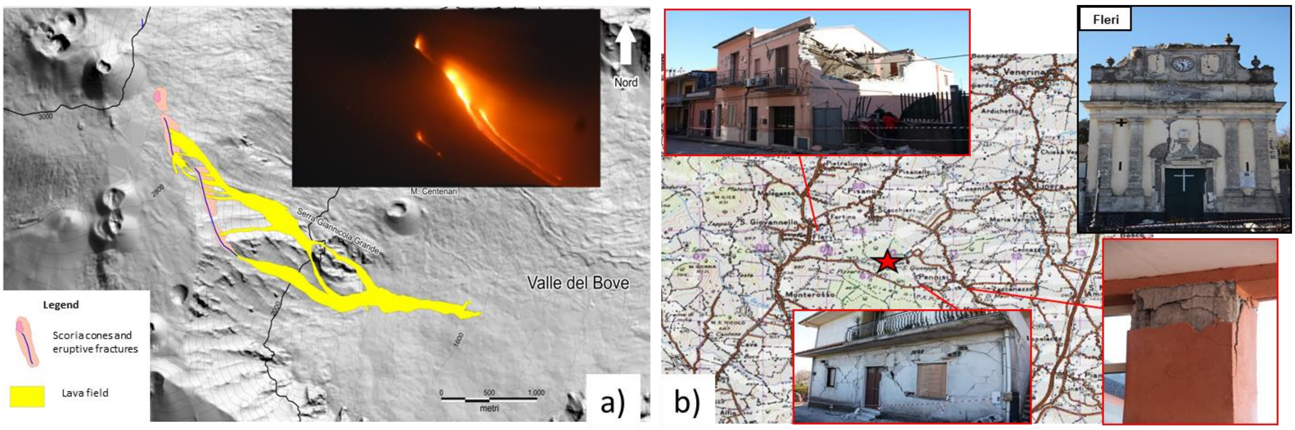

Figure 4*: a) map of the eruptive system showing the eruptive fracture and the lava field; in the inset: photo of the lava flow taken on the evening of 24 December 2018 (courtesy B. Behncke). b) epicentral location of the M_L4.8 earthquake on December 26, 2018 at 02:19; some of the observed macroseismic effects are shown in the insets (courtesy R. Azzaro).*

This lateral eruption displayed short duration of intense precursor phenomena, that began only about 1.5 hours before opening of the eruptive fractures. The precursory phenomena essentially consisted of energetic seismic activity (VT earthquakes and tremor) and conspicuous ground deformations detected by tilt and GNSS stations.

The Operations Room of the INGV-OE (Istituto Nazionale di Geofisica e Vulcanologia - Osservatorio Etneo) managed the communication flow with the National and Regional Departments of Civil Protection. In addition to dozens of phone calls, 120 volcanic activity notices and 2 extraordinary notices (bulletins containing hazard forecasts) were issued. In addition, five VONAs were issued to the aviation authorities. The communication flows respected the standards defined in the agreements between INGV and National Department of Civil Protection, in terms of both timing and content.

Table 1: *main phenomena observed during the December 24, 2018 Mt. Etna eruption. Summit craters abbreviations: BN = Bocca Nuova crater; NEC = North-East Crater; NSEC = New South-East Crater.*

Day	Time (UTC)	Phenomenology
December 24, 2018	07:38	Emission of white and dense steam from BN that in time became more constant and intense.
	08:30	A seismic swarm starts and heralds the imminent beginning of a lateral eruption.
	09:30	Relevant ground deformation was recognized by tilt and GNSS stations
	09:51 – 11:11	The BN produces a first puff of black ash that evolves in a diluted, continuous plume of pink ash (lithics), evolving further in a dark and continuous cloud. Dark ash emission occurred also from the NEC. The thermal images reveal that the ash cloud forms through a sequence of Strombolian explosions launching hot and pressurized material.
	11:11 - 11:40	The first eruptive vents open, and an eruptive fracture begins to spread from the Southern base of the NSEC in SSE direction, along the Western edge of the Valle del Bove. Lava flows and lava fountains are produced. The opening of the eruptive vents is accompanied by the production of a small hot debris avalanche that flows along the western wall of the Valle del Bove, and by abundant ash emission.
	11:48	The lava fountain activity at the fracture is no longer observed.
	12:00	End of the Strombolian activity at the higher altitude tip of the fracture.
	11:00 - 12:49	The BN and the NEC produce numerous discrete explosions, with a frequency of about one per minute and jets 500-600 m high.
	20:00	Termination of pre-existing activity from the NSEC, after a gradual reduction observed simultaneously to the beginning of the seismic swarm.
December 25, 2018		The effusive activity continues, fed from the lower part of the eruptive fracture, and feeding lava flows flowing in the Valle del Bove.
December 26, 2018	02:19	M_L = 4.8 earthquake strikes the Eastern flank of the volcano damaging some villages.
December 27, 2018	Early morning	The lava flows stop between December 26th late evening and morning of the following day.
January 9, 2019		The seismic swarm ends.

In two days the INGV-OE activated the 3 on-duty researchers to support the activities at the Operations Room, and involved about 30 researchers for data analysis, modeling, hazard estimation and interpretation of the phenomena. In addition, several field surveys were carried out, and the installation of mobile seismic and GNSS stations boosted the permanent networks. These activities involved 35 other technical-scientific staff. The overall managing of the technical and scientific aspects of the crisis included participation in two extraordinary video conferences, two ”Grandi Rischi” commission meetings (“Grandi Rischi” commission is the Scientific Advisory Board of the Civil Protection), a meeting of the Operational Committee (operational body of the Civil Protection bringing together every societal component with a capability of intervention during a crisis), and two encounters at the prefecture of Catania.

Direct communication to the general public through blogs and social networks was very intense and continuous, as was communication to local and national newspapers and televisions including several press releases, dozens of interviews and media reports.

The overall response to the crisis by INGV-OE has been adequate to the expectations. The key element lies in the organization of the Observatory, which results from countless experiences acquired from eruptive crises and events that have taken place during the last forty years. Still, some aspects, described below, clearly indicated the way forward for improvements in observatory response.

The first aspect concerns the need for better harmonization of the communication protocols regarding general seismic events in the Italian territory (managed by the INGV National Earthquake Observatory) and seismic events associated with volcanic phenomena (managed by INGV volcano observatories). In this respect, as the M_L4.8 earthquake caused damage to some villages on the Eastern side of Mt. Etna (Fig. 1), communication channels of both observatories were activated, generating some initial confusion: the results was that officials at the National Civil Protection Department initially understood that the eruption and the earthquake were not connected. The issue of multiple communication channels became the subject of internal discussion at INGV, which led, a few months after the eruption, to the adoption of a new communication protocol. This new protocol, in force from January 2020, establishes that the INGV volcano observatories are solely responsible for the communication flow for both volcanic events and earthquakes in the area of their competence.

A second notable aspect that emerged from the volcanic crisis, especially during the pre-eruptive phases, concerns the contents of communications established by the National agreement protocols. In the short time of intense unrest preceding the eruption, INGV-OE released 3 Volcanic Activity Notices, containing observations of volcanic, seismic and geodetic nature. These Notices do not have to include forecasts (they are conceived to represent fast communication on on-going phenomena). As a consequence, awareness by the scientific personnel at INGV-OV regarding the likelihood of an eruption may not have been communicated with due effectiveness to civil protection authorities. On one side, prompt response needs fast communication of the observations and records, whereas forecasts usually require internal discussion, data processing, code running etc., therefore take more time and bring about uncertainties that must be quantified; on the other hand, lack of forecasts in fast communication flows during rapid escalations may translate into partial and less effective information.

In conclusion, the following best-practice recommendations are suggested:

- Establishing in advance, and in agreement with civil protection authorities, the timing, frequency and content of notices and bulletins is essential for effective communication and in order to minimize the possibility of misunderstandings, which during the hectic times of crisis can be detrimental. Similarly relevant is that the observatory disposes of an internal emergency plan, prepared and tested during quiet periods, and that provides each involved personnel unit with a guidance on what to do, how to do it and when to do it. A minimum number of people must always be on duty, for rapid reaction to cope with emergencies even during holidays or in periods with reduced staff.
- The definition of quick procedures for hazard forecasts during the crisis is critical. Such forecasts should include an evaluation of their uncertainty, which would be larger for rapidly released forecasts, and can be reduced at a second time (as it is the case with protocols for quick communication following the occurrence of earthquakes). In any case, multi-hazard scenarios should be considered so to allow civil protection authorities to best calibrate their decision-making and response.
- The need for clear, univocal communication from volcano observatories to stakeholders, including the society, the media, and the decision-making bodies, cannot be overestimated. That communication should include a precise account of the observations and records, and an evaluation of the possible evolutions and their associated uncertainties. We found the use of 'Talking Points' very useful, as it allowed the many researchers involved in communication activities to spread a unique message representing the official voice of the Observatory.