HANDBOOK

for Volcanic Risk Management

PREVENTION, CRISIS MANAGEMENT, RESILIENCE

The MIAVITA project is financed by the European Commission under the
7th Framework Programme for Research and Technological Development,
Area "Environment", Activity 6.1 "Climate Change, Pollution and Risks".

Editorial Board:
Christian Bignami
Istituto Nazionale di Geofisica e Vulcanologia

Vittorio Bosi
Dipartimento della Protezione Civile

Licia Costantini
Dipartimento della Protezione Civile

Chiara Cristiani
Dipartimento della Protezione Civile

Franck Lavigne
Université Paris 1 Panthéon Sorbonne, CNRS

Pierre Thierry
Bureau de Recherches Géologiques et Minières

Art Director:
Maurilio Silvestri
Dipartimento della Protezione Civile

Graphic Design
Adriana Maria Tamborrino
Dipartimento della Protezione Civile

Editing:
Vittorio Bosi
Dipartimento della Protezione Civile

Licia Costantini
Dipartimento della Protezione Civile

Elena Lombardo
Dipartimento della Protezione Civile

Silvia Parisi
Dipartimento della Protezione Civile

Cover Photo:
Rosella Nave
Istituto Nazionale di Geofisica e Vulcanologia

Library of Congress Cataloging in Publication Data
Handbook for volcanic risk management: Prevention, crisis management, resilience. MIAVITA team, Orleans 2012

Printed in Orleans (France) by November, 2012

HANDBOOK for Volcanic Risk Management

PREVENTION, CRISIS MANAGEMENT, RESILIENCE

TABLE OF CONTENTS

Living with a volcano: increasing preparedness

4

Living with a volcano: reducing vulnerability

5

Means and methods for crisis management

Preface

A handbook for volcanic risk management: cause, objectives and target audience

Volcanic eruptions are one of the most impressive, violent and dramatic natural agents of change on our planet and represent a potential threat for hundreds of millions of people. Nevertheless, soil fertility, amongst other characteristics, often attracts populations, which settle on volcano flanks, creating, by the conjunction of hazards and population, high risk areas.

In 2007, the idea of building an integrated method to assess and efficiently manage volcanic threats rose among several volcanologists, social scientists and risk analysis experts from Europe and some countries in Asia and Africa. The idea was strongly supported by the French and Italian Civil Defence Agencies.

In response to this concern, the European Commission funded a four-year research project (2008 to 2012), called MIAVITA, which stands for "Mitigate and Assess risk from Volcanic Impact on Terrain and human Activities". This research project gathered a team of international experts covering most domains regarding volcanic risk management (academic/practical and operational). This team included the Italian and French Civil Defence Agencies, six national geological and volcanological surveys (France, Italy, Indonesia, Philippines, Cameroon and Cape Verde), the Norwegian air quality survey and five European universities and research centres from France, Germany, Portugal and the UK. The university and research centres include experts in volcanology and geosciences, social sciences, agriculture and civil engineering, information technologies and telecommunications.

With the contribution of such partners, the MIAVITA project constitutes a unique opportunity to identify useful guidelines for risk management in any geographical, geological and socio-economic contexts related to an active volcano. The above guidelines have been applied to our handbook, which has been designed to be easily consulted and provide quick answers for each topic, using a clear and non-technical language although sometimes scientific terminologies are required.

This handbook aims at synthesizing the acquired knowledge in a practical and useful way to cover the main aspects of volcanic risk management, such as prevention, preparedness, mitigation, intervention, crisis management and resilience. It promotes the creation of an ideal bridge between different stakeholders involved in risk management, improving and facilitating interactions among authorities and scientists. This work is based on current scientific research and the shared experience of the different partners as well as on international good practices previously recommended.

To manage volcanic risk, each country has set up its specific administrative and organisational frame. Therefore, names and roles of organizations in charge of volcanic risk management vary greatly from one country to another. Nevertheless, three major categories can be identified: political authorities and public services, civil defence agencies and specialists in crisis management and scientific institutions, possibly including universities.
This handbook addresses mainly the last two categories, especially in developing countries.

The rule is to present an overview of the main information needs to help decision makers to set up a technical and organisational frame for integrated volcanic risk prevention and crisis management. In particular, the goal is that any agency/person involved in volcanic risk management can identify within this handbook advice for tackling situations, whatever the country's economic level and even with little basic knowledge about volcanoes.
In particular, civil protection's agents or elected officials will find elements to better understand the methodologies, instruments and results that scientists can provide on volcano monitoring, together with some information about limitations, costs and future developments. In addition, civil protection stakeholders will also find some good practice and examples that could be useful both in prevention and crisis management and resilience phases. Scientists will find insights about what civil protection stakeholders usually need from them, and in which way their results will be used.

The authors are fully aware that authorities dealing with active volcanoes have already addressed this issue. Most likely the readers will recognize several elements but we hope that this handbook will provide a validation of their choices and some complementary ideas or concepts to improve their own situations.

It must be emphasized that advice and information presented in this handbook cannot cover all the aspects and cannot substitute local, national and international specialists and procedures. Moreover, as this handbook is based on current knowledge on volcanoes, further improvements in volcanic risk management may render some information obsolete.

Handbook structure and content: how to use it

The handbook has six sections. The first one briefly explains the global volcanic context and the principles of corresponding risk management. Section 2 contains a description of volcanic phenomena, damage and understanding size and effects that can be expected. Sections 3, 4 and 5 cover preparation and prevention and describe actions to be undertaken during the response phase of the volcano in order to develop preparedness of stakeholders and population and to minimize the effects of future eruptions. The last one, section 6, deals with crisis management and shows some recovery examples.

Each section is associated with a colour that allows the reader to quickly reach the topics of interest. The order of the six sections is also recalled in a sequence of coloured blocks at the bottom of each page.

An introduction page at the beginning of each section anticipates the main contents, followed by a list of the names of the authors who contributed to drafting the texts. A complete list of all the participating authors and indication of their affiliation can be found at the end of the handbook.

Boxes offering and in-depth analysis are included in the text; they allow the reader to focus on issues and analyze case studies mainly drawn from the experience gained in the project MIAVITA. A complete list of boxes is available at the end of the manual.

From the third section onwards, examples of good practice are inserted: they include action checklists or practical suggestions for volcanic risk management.

Pictures, charts and tables in the text were limited for easy consultation. Tables not included in the text are available in the appendix at the end of the handbook, and are colour coded according to the section they refer to. Footnotes were not included for the same reason.

Despite the enormous quantity of scientific papers existing related to the topics developed inside the handbook, the reference list has been limited to focus mainly on open data documents. All the references, which serve to broaden the content and simultaneously indicate their origin, were inserted at the end of each section, and are divided by publications and links to web pages.

A glossary providing a brief explanation of the scientific terms used in the text and a list of acronyms can be found at the end of the handbook.

1 INTRODUCTION TO VOLCANIC RISK

This section aims to present in a few pages the main features of volcanic risk management and proposes a global overview of this important domain: volcanoes main features, eruptions and their effects. Such a brief presentation corresponds to an over simplification of a complex reality which will be developed more in detail in the different chapters of the handbook.

Participating authors: Licia Costantini
Pierre Thierry

1. Some figures on the dimensions of volcanic risk

Volcanic eruptions are one of the most dangerous phenomena on Earth and some figures illustrate the catastrophic dimensions in terms of human and economic impacts.

It is estimated that the population directly at risk from volcanoes was at least 500 million in 2000. It represents as much as 7% of mankind. At a larger scale, volcanic emissions (gas and ash) can affect human health and the natural environment on the whole Earth and even modify the climate at least temporarily. During the 1990s, more than 2100 human lives were lost because of volcanic activity and 2 cities were completely devastated. In addition, during the same decade, volcanic eruptions and their effects directly affected around 2.8 million people and the economic losses reached several billions of Euros (€), causing tremendous disruption in entire regions and countries.

More recently, in April 2010, Western Europe faced major air-traffic disruption due to the Eyjafjallajökull eruption in Iceland. The economic losses were estimated at 1 billion € per day (almost 1.3 billion US$ per day). At the end of the same year, the eruption of the Merapi volcano in Indonesia, in addition to the tragic death of more than 380 persons, led to the displacement of more than 400000 people.

2. Volcanic risk management: main issues and integrated approach

Assessment and management of volcanic risks constitutes a crucial requirement for many countries. Before we start with the main issues, it is important to clarify and to give the right definition of terminology in use. In a volcanic environment, in fact, one commonly speaks inappropriately of hazard reduction instead of risk reduction. Briefly, natural hazard consists in the probability that a natural event occurs with a specific intensity (i.e., destructive power) in a given area within a specific time period. Elements at risk correspond to all kind of assets exposed to these natural phenomena. The level of potential damage (loss of value) of these elements at risk (exposure) is expressed by their vulnerability (resistance to the impact). Risk, then, is commonly defined by the probability of financial, environmental and human losses caused by natural phenomena. In addition to this definition, one has to consider coping capacities, i.e., community ability to recover after a disaster, which constitutes a major element in reducing, at least, long terms losses. Practically, risk in a given area can be expressed by the following expression:

Risk = (hazard) x (vulnerability) x (value at risk) / (coping capacity)

It is therefore clear that reducing volcanic risk implies to tackling all these aspects.

The presence of an active volcano constitutes a major concern for national and local authorities and the assessment and management of corresponding risks constitutes a crucial requirement. Difficulties relating to risk management are too often underestimated. Several possible reasons can be identified: first of all, people often congregate on volcano slopes, where land is available, fertile and sometimes cheaper even if the area is very dangerous because of high volcanic hazard. For those people, in fact, the main priority remains their daily sustenance and they tend to ignore all external advice. Second, available resources (budget or/and scientific capabilities) may be insufficient to ensure efficient risk management, especially in developing countries. Third, long return periods between eruptions or events may be perceived as a low risk threat by local authorities and the population. Forth and last reason, both the decision to live in volcanic hazard-prone areas and the lack of available resources are rooted in long term structural constraints linked to the political economy, such as unequal distribution of resources, patron-client relationships, debt burden, global trade policies and historical and cultural heritage.

Several gaps prevent human societies from efficient volcanic risk management: lack of knowledge about the hazard itself; lack of understanding of the vulnerability of exposed elements; lack of assessment of vulnerability and community resilience (i.e., capacity to recover after a catastrophe); lack of an integrated and multidisciplinary approach to manage and assess volcanic risk, in which communication plays a key role.

Assessing hazards and vulnerabilities of volcanoes falls under the responsibility of scientific bodies. It requires the combination and coordination of many capabilities and instrumental techniques, and involves field experts in volcanology, geology, meteorology, signal processing, data analysis, agriculture, civil engineering, human health social sciences, etc.

This assessment constitutes the basic knowledge essential to enable public authorities to take appropriate decisions in terms of risk management. Nevertheless, these decisions must involve other specialists:

- Emergency managers, specialists with skills and experience at tackling and managing all aspects of a crisis (i.e., preparedness, mitigation measures, evacuations, health and sanitary aspects, etc.)
- Telecommunication specialists, to ensure reliable information or transmissions instructions as well as scientific data exchanges
- Public and media communication specialists
- Information Technology (IT), specialists able to design an integrated information system which comprises data organisation and transfers

However, it must be pointed out that, in addition to all these stakeholders, the local population's and resident's role is fundamental in risk management.
Considering the multiplicity of stakeholders and domains, efficient action requires an integrated, seamless volcanic risk management strategy to be designed by public authorities and scientists. This approach focuses on three main objectives:

- Prevention tools based on hazard and risk assessment through risk mapping and creation of possible damage scenarios
- Reduction of people's vulnerability and development of recovering capabilities after an event occurs for both local communities and ecological systems
- Improvement of crisis management capabilities based, on one hand, on monitoring and early warning systems as well as secure communications and, on the other hand, on preparedness of stakeholders

This methodological frame for action can be summarized in the following scheme (Fig. 1). The design and set up of the above integrated seamless approach to managing volcanic risks in all its dimensions implies, before any evidence of volcanic activity, the cooperation in shared actions of scientists, national and local authorities, local communities and local people. This cooperation must integrate both top-down and bottom-up measures. Combining all the scales, covering all aspects and involving all the stakeholders is an essential step to effective risk and disaster management, shortcutting a link or a stakeholder from the risk and disaster management chain may introduce gaps and discrepancies leading to a real loss of efficiency.

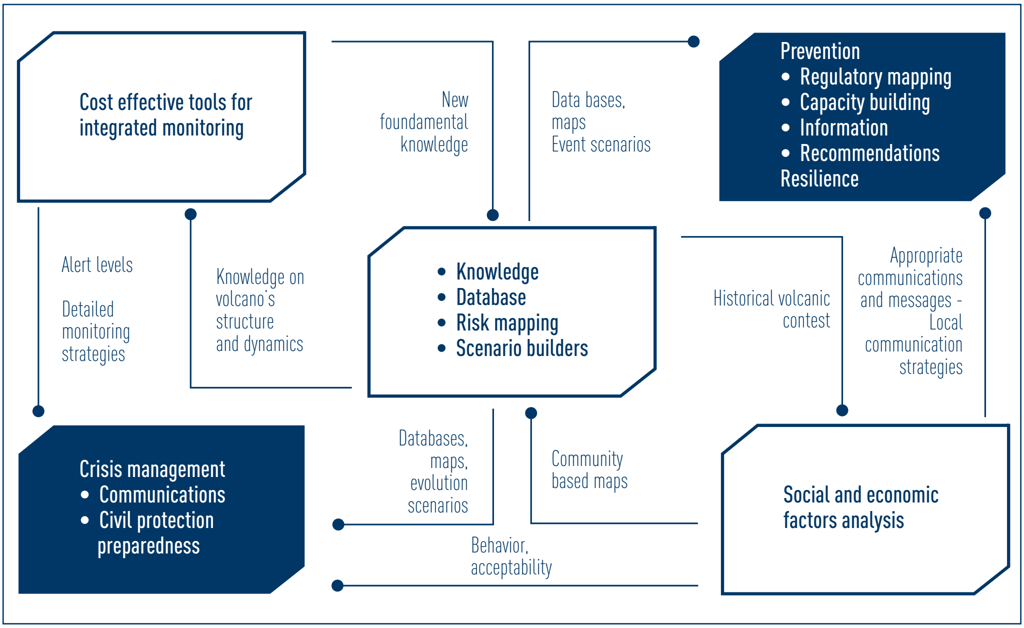

Figure 1: Methodological framework with related information flows for managing volcanic threat.

3. Volcanoes on the earth: main features

Volcanoes correspond to places where magma (molten rocks) reaches the Earth's surface. More than 1500 volcanoes are considered as "active" (i.e., with historical eruptions recorded). The above figure does not take into account the numerous submarine active volcanoes that are still to be charted. Of the 1500 active volcanoes, approximately 60 erupt each year.

Volcano distribution is anything but random. Their location corresponds to specific geological contexts described by plate tectonic theory. Fundamental characteristics of volcanoes are controlled by their geological setting, their geographical context and their own history. Consequently, this means that for many volcanoes, some specific phenomena will be more likely (explosive eruptions or effusive eruptions). To present a very simplified example: one volcano will essentially produce lava flows where another volcano, in a different context, will have a more explosive dynamic. Different types of eruptions have been defined by scientists (Hawaiian, Strombolian, Vulcanian, Pelean, Plinian, etc.). Each type corresponds to a different level of threat. It must be emphasized that not all of the possible dangerous volcanic phenomena will be expected from any volcano.

The direct effects of volcanic eruptions are more intense close to its proximity (e.g., within a 50 km radius). In some cases, however, volcanic eruptions may affect much broader areas with national and international impacts through dispersion of gas and ash by atmospheric currents. E.g., in 1991 the Pinatubo volcano (Philippines) produced enormous quantities of ash which reached the stratosphere and travelled several times around the globe triggering a decrease in ground temperature of 0.2 to 0.3 °C which lasted three years.

4. Rest and unrest of volcanoes

Geological time really differs from human time. Centuries sometimes represent the entire history for some countries but have little meaning for Earth's evolution and long-term process which may suddenly evolve in a catastrophic way.

Baring this in mind, volcanoes without known eruptions may become suddenly active. E.g., Pinatubo volcano in the 80s was considered an extinct volcano. Nevertheless, in 1991, after being dormant for 600 years, Pinatubo produced the major eruption of the 20th century.

In a geologically active context, the absence of any historical evidence of activity for a volcano cannot be considered as a proof of extinction. Actually, the difference between extinct volcanoes (i.e., not expected to erupt in the future) and dormant volcanoes (i.e., with no current activity but expected to erupt in the future) must be established. This statement needs detailed geological, geophysical and geochemical studies.

Authorities responsible for communities living around a young but supposed extinct volcano must be aware that it may only be dormant. For this reason if in doubt, one ought to get in contact with scientific authorities and verify the real status of the volcano. On dormant volcanoes assessment must be taken into account in detail for long-term land-use planning decisions.

Regarding time-scales, another specificity of volcanoes is that eruptions may last for extremely long periods. As an example, the Soufrière Hills volcano of Montserrat (English Lesser Antilles) began erupting on July 18th 1995. This was its first eruption since the 19th century. Since July 18th 1995 it has continued to erupt (17 years).

5. Main elements at the base of volcanic activity

Classically, the stages of a volcano is depicted, for the public, of molten rock rising up towards the ground surface (i.e., magma) from a deep storage chamber through an outlet (i.e., conduit) due to a difference in density with surrounding rocks.

Actually, volcanic mechanisms are much more complicated than this and different factors apply between the deep part of the crust (i.e., 20-30 km) and the surface. Indeed, in addition to the molten rock, two other components play a major role in volcanic activity. These are: magmatic gases and external water, such as ground water, lake water, rain, sea water etc. We must emphasize that this complexity is still not totally understood by scientists.

Magmas

Magma is a fluid, which is both multicomponent (i.e., contains more than one chemical species) and multiphase (i.e., comprises material in a variety of physical states). It usually constitutes a liquid phase (melt), a solid phase (crystals) and a gas phase (bubbles).

Characteristics of magmas significantly differ according to the different volcanic and plate tectonic contexts.

The two main parameters that have to be taken into account are temperature and viscosity (resistance to flow). Both are strongly influenced by the chemistry of the magma. Temperature commonly ranges from 650 °C to 1200 °C (for comparison purposes, the melting point of iron is 1538 °C). Magma viscosity can vary up to several orders of magnitude and is strongly controlled by the chemical composition of the magma and its temperature, as well as by the species and content of gas dissolved in the magma and by abundance of crystals. Magma viscosity is a fundamental parameter that strongly influences the eruptive style (e.g., explosive versus effusive style) and the rheology of a flow. Powerful explosive eruptions are in fact commonly associated with high-viscosity magma, whereas low-viscosity magma usually generates non-explosive (i.e., effusive) or at most weak explosive eruptions. As mentioned before, in the case of effusive eruptions, the rheology of magma flow is strongly dependent on viscosity. Low viscosity corresponds, in fact, to lavas able to flow at very high speed, faster than 10 km/h on steep slopes (speeds recorded up to 56 km/h). It must be noted that after cooling, the lava's speed decreases to a few meters per day. In contrast, high initial viscosity produces lavas, which do not flow significantly. This type of lava piles up to form domes, which may reach heights of several hundreds of meters above the initial ground surface. These lava domes, are extremely dangerous, and can easily explode or collapse producing glowing avalanches (pyroclastic flows), sometimes causing the surface collapse to bulge; these may also explode or even trigger the collapse of the volcanic edifice.

Gases

Taking into account gas components is crucial in assessing the danger of a volcano. At depth, magmas contain several species of dissolved gases: H_2O, CO_2, SO_2, H_2S, HCl, HF etc. These gases are released and form a separate vapour phase (i.e., bubbles) when pressure decreases as magma rises toward the surface of the Earth.

Most of these liberated gases (e.g., CO_2, H_2S) can represent a serious threat to people, especially when they are released instantaneously on the ground, after travelling through fractures or permeable rocks. These gases can also be very dangerous when they reach high concentrations, especially in depressed areas, being heavier than the air. In 1986, the sudden release of the CO_2 concentrated in Nyos Lake (Cameroon) killed almost 1700 people as well as 3500 livestock.

However, the most important characteristic is that gas constitutes, fundamentally, the major factor driving eruption explosivity by its sudden expansion, by fragmenting the magma. Eruptive style is, in fact, strongly dependent on the conditions of bubble formation and rise rate. If bubbles can escape from the melt, as usually happens in the case of low-viscosity magma, the remaining magma rises slowly in the conduit and generates effusive eruptions (lava flows). Such degassing is at the origin of photogenic lava fountains. On the contrary, when the bubbles do not decouple from the melt and escape, their expansion causes magma to accelerate upwards. The result is further decompression, volatile release, and magma expansion, perpetuating a feedback loop that culminates in explosive eruptions. Such behaviour is at the origin of some of the most dangerous phenomena such as pyroclastic density currents and tephra falls (see Chapters 8 and 9).

Surface and ground water

There is water dissolved in magmas, sometimes with a concentration of 1-5 wt%. But water of meteorological origin also plays a crucial role in volcanic activity. Rain water infiltrates in soil and concentrates in underground aquifers. When this water is heated by magma, it produces steam with possible overpressures leading to specific types of eruption, called phreatic and phreato-magmatic eruptions. The same type of eruptions can be produced if magma interacts with several kinds of surface water reservoirs, such as lakes, glaciers and shallow sea. For example, when an eruption occurs below a glacier and interacts with melt-water, the thermal shock increases the fragmentation of magma producing unexpected quantities of ash. This was the case for the 2010 Eyjafjallajökull eruption in Iceland. In addition water (in terms of rainfall, lakes or glaciers) can remobilize loose sediment and volcanic materials generating volcanic debris flows or mudflows, called "lahars" (see Chapter 11).

6. Phenomena and manifestations before eruptions

Usually before an eruption, some evidence (precursors) indicates that the volcano is changing its dynamic behaviour. This is true for dormant volcanoes but also for volcanoes known to be active. Such modifications of the volcano behaviour do not prove that an eruption will certainly occur (phenomena may become stable or even stop). Also, in the first phases of unrest, it remains extremely difficult to forecast any date of future eruption. But such evidence must be taken into account to raise awareness and, possibly, increase the level of monitoring, and prepare a future action plan for the safety of the population at risk.

Main precursor manifestations are:

Fumaroles

As stated above, rising magmas may release gases that reach the surface through fumaroles. Such a phenomenon may last for centuries indicating a stable basic activity. But increasing volumes or temperature, occurrence of new manifestations or changes in gas composition usually indicates that magma is present at depth within the volcano. These changes must be monitored and analysed by scientists in order to assess the new dynamic of the volcano.

Seismic activity

When rising towards the surface, magma and associated volcanic gases break rock and dilate fractures. The oscillations in the fluid phases, the chocks of magmas and solid blocs correspond to low magnitude earthquakes triggering an almost continuous shallow seismicity imperceptible for the public (i.e., seismic tremor). At a greater scale, the changes in the stress regime may produce significant earthquakes. These earthquakes may be strongly felt by the local population and cause damage to buildings (e.g., 1999 earthquake on Mount Cameroon) and ground deformation.

Ground deformation

The intrusion of large magma volumes at depth within the volcanic edifice may induce changes in the topography. Prior to any eruption, slight localized inflation happens. They can be associated with concomitant subsidence on other sides of the volcano. In some cases, these movements can trigger ground disruptions (appearance of new fractures) or slope instabilities as increasing volume and frequency of cliff collapses and landslides.

Changes in geophysical characteristics of the volcano

Associated with this intrusion of new material inside the volcano, other phenomena can occur. Two of them can be highlighted: change in the gravity field and modification in ground temperature. As previously stated, one of the main drivers for rising magmas from the deep chambers is the difference in densities i.e., lighter materials versus heavier ones. Therefore, magma rise may trigger local variations in the gravity. As a very simplified example, gas concentrations opening cracks will create some kind of cavities at depth. In addition, the rising up of hot magma is associated with local changes of the ground thermal gradient. Thermal anomalies are also a good indicator of unrest of the volcano. Moreover, the mapping of these thermal modifications may give indications of the magma (or gas) location.

Water table regime modifications

Topographical modifications, fracture openings, ground thermal gradient changes, increasing contents of gas, etc.; all these phenomena have possible impacts on the groundwater regimes. These impacts can be observed in springs or wells or monitored boreholes.

It is important to highlight that, even if in some case, especially when a large eruption becomes impending, people can perceive the changes and precursors mentioned above, in most cases analysis of monitoring data is the sole scientific basis for a short or mid-term eruption forecast. Therefore, the setting-up of appropriate instrumentations is needed to detect volcanic unrest. In addition, we emphasize the necessity of a multidisciplinary approach for a correct forecasting in order to get a reliable understanding of the different types of precursors.

7. Eruptions and their impacts

Volcanic eruptions are characterized by a set of various phenomena: lavas, ash fall, gas emission, etc. (see Section 2). Moreover, eruptions are also frequently associated with secondary geohazards such as earthquakes, landslides, cliff collapses, etc. This diversity creates a spectrum of impacts.

To summarize this complexity, dangerous phenomena on active volcanoes can be grouped into height categories; each of these poses a specific associated threat to the elements at risk, exposed on the volcano flanks and surrounding area (Table 1).

Considering all these potential impacts, it is clear that main elements of our human and natural environment are threatened:

- Human life, health and livelihood
- Vegetation including crops and agriculture
- Livestock and wild animals
- Water and storm water
- Buildings, infrastructures and all built facilities for agriculture, industry, transport, energy etc.
- Air traffic

Considering their difference in nature, these elements at risk will be more or less damaged by the different hazards. Resistance to impacts is expressed through their vulnerability. As an example, a banana plantation will not suffer during an earthquake unlike a building (low vulnerability to earthquakes). Conversely, the building will not be affected by 10 cm of ash whereas the banana plantation will be severely damaged (high vulnerability to ash fall).

Table 1: RELATIONS BETWEEN VOLCANIC PHENOMENA AND ELEMENTS AT RISK

	PHENOMENON	MAIN ASSOCIATED THREATS
VOLCANO HAZARDS	**Thepra fall/Ballistics**	Burns and burial Buildings and infrastructure destruction Disruption of road traffic and network systems (power lines, irrigation etc.) Disruption of air traffic Impacts on plant growth and livestock
	Pyroclastic Density Currents	Burns and burial Buildings and infrastructure destruction
	Lava flows	Burns Destruction of buildings by fire, lateral stress or burial
OTHER GEO-HAZARDS	**Lahars**	Drowning Buildings and infrastructure destruction and burial Impacts on crops
	Gas emissions	Toxicity for humans and livestock, acidity and corrosion Impacts on plant growth (especially roots)
	Sector collapses, landslides and rock falls	Impacts, scouring and burial
	Volcanic earthquakes	Burial under collapsed buildings Building and infrastructure destruction
	Volcano triggered tsunamis	Drowning Trauma by collision Buildings and infrastructure destruction

References and suggested readings

- http://pubs.usgs.gov/gip/dynamic/understanding.html
- http://www.ngdc.noaa.gov/hazard/stratoguide/glossary.html
- Blong, R.J., 1984. Volcanic hazards: a sourcebook on the effects of eruptions. Academic Press Australia, 424 pp.
- Marzocchi W., Mastellone M.L., Di Ruocco A., Novelli P., Romeo E., Gasparini P., 2009. Principles of multi-risk assessment Interaction amongst natural and man-induced risks. European Commission EUR23615 72 pp.
- Sigurdsson, H., Houghton, B.F., McNutt, S.R., Rymer, H., Stix, J., 1999. Encyclopedia of volcanoes. Academic Press, 1417 pp.

2 VOLCANIC EVENTS AND CORRESPONDING DAMAGE

Volcanic eruptions occur in a large variety of styles, magnitudes, and durations, and produce numerous phenomena that can be hazardous to humans, their property and their environment. The following chapters provide information on the most hazardous volcanic phenomena. It has to be noted that many of these processes can occur either together or in rapid succession during a single eruption at one volcano. Differences in eruptive styles are determined by a number of factors such as physical and chemical properties of the magma, magma ascent and eruption rate, vent location, volcano geometry, and volcano morphology.

Participating authors:

Boris Behncke
Jochen Berger
Susanna Jenkins
Marco Neri
Robin Spence
Karl Stahr

A widely accepted classification of eruption styles is the Volcanic Explosivity Index (VEI), which provides a relative measure of the explosiveness of volcanic eruptions based on the total erupted volume (Table I in Appendix).

8. Tephra falls/Ballistics

Tephra is a general term for fragments of volcanic rock, regardless of size, that are ejected into the air by explosive volcanism and carried upward by hot gases in eruption columns or fountains.
Such fragments can range in size from less than 0.001 mm to more than 10 m in diameter. Large tephra typically falls back to the ground on or close to the volcano and progressively smaller fragments are carried away from the vent by wind in the so called "volcanic plume" (Fig. 2). Volcanic ash, the smallest tephra fragments, can travel hundreds to thousands of kilometres downwind from a volcano.

Tephra consists of a wide range of rock particles in terms of size, shape, density, and chemical composition, which includes combinations of pumice, scoria, glass shards, crystals of different types of minerals, and all types of rocks forming the walls around the vent.

Pyroclastic materials are classified according to their size:
- Ash: fragments less than 2 mm
- Lapilli: fragments between 2 and 64 mm
- Blocks: angular fragments greater than 64 mm
- Bombs: rounded fragments greater than 64 mm

Tephra is also classified according to particle shape, composition, and mode of formation and travel. The most common terms are the following:
- Accretionary lapilli: spherical lapilli-sized particles that form as moist aggregates of ash in eruption clouds, usually by rain that falls through dry eruption clouds
- Bombs: formed from fluid magma, bombs are named according to shape, such as ribbon bombs, spindle bombs, cow-dung bombs, spheroidal bombs, and breadcrust bombs
- Lithics: dense rock fragments of a pyroclastic deposit

Figure 2: Volcanic plume generated by volcano Merapi (Indonesia) during the 2010 eruption. Photo taken by Anton Sulistio for CVGHM.

- Pumice: light, finely vesicular volcanic rock that forms during large (VEI >4) explosive eruptions
- Scoria: general term for a coarsely vesicular rock fragment ejected during an explosive eruption

Possible physical impacts and their effects

Tephra can be dispersed thousands of kilometres from source and impact communities in a number of ways, including: human and livestock health, disruption to aviation and critical infrastructure (e.g., transportation, power supplies, telecommunications, water and wastewater networks), damage to agriculture, buildings and structures (e.g., bridges, roads). Falls of fine volcanic ash can affect large areas and numbers of people during an eruption, with long-duration eruptions potentially causing repeated impacts. The level of building and infrastructure damage sustained by tephra falls depends upon structure type and ash fall characteristics such as chemical composition, moisture content and thickness, as well as distance from the volcano and wind direction. Thick tephra deposits (>100 mm) are capable of causing roof collapse and weakening walls, with possible death or injury to people or livestock inside. Roof failure occurs when the tephra load (a function of tephra fall density, gravitational load and tephra fall thickness) exceeds the capacity of the roof structure. Tephra clean-up actions can actually increase the impact of astatic tephra load, e.g., by people falling off or through roofs. Moderate to heavy falls of tephra can block out sunlight limiting emergency response. A large non-destructive tephra load may also adversely affect a building's resistance to other natural hazards, such as earthquakes. Thick tephra deposits can

overload and fail power lines, block drainage and irrigation systems, collapse embankments and weak bridges and render a road unusable; however, tephra falls are unlikely to cause significant structural damage to infrastructure.
The local and regional effects of volcanic ash on the soil, after volcanic events, are ambiguous. Depending on its chemical composition and thickness, ash can act either as a fertilizer or as a contaminant. Damage to crops and natural vegetation depends on the plant condition and morphology and ranges from complete, immediate loss, e.g., burial of small herbs, bending of shrubs, to minor damage such as defoliation and breakage of tree branches. The impact of tephra falls on local hydrological systems depends on the deposit thickness, grain-size distribution, geomorphology (i.e., the slope angle and degree of vegetation cover), soil permeability and climate, in particular the intensity of precipitation. Enhanced surface run-off and reduced infiltration rates cause higher stream discharges, higher flood peaks and deposit remobilisation and redistribution through erosion and re-sedimentation processes. Serious damage can be caused to sewerage and stormwater systems, as tephra is washed off roads, carparks and buildings into the systems.

The impact from thinner deposits farther from the eruption source will depend upon the physical and chemical properties of the volcanic ash. Injection of aerosols and fine material into the stratosphere can affect global temperatures, as happened following the Pinatubo eruption in 1991. Such changes can cause retarded plant growth and reduced productivity. In general, rehabilitation of agricultural land from tephra falls up to 100 mm may be expected with adapted land management, but it is difficult to foresee a quick recovery from deposits of over 500 mm without large technical input. However, even tephra falls of less than 5 mm can result in significant impacts for livestock and crops/natural vegetation if the ash is high in chemical species such as fluorine and acids. Topsoils containing fresh tephra are highly susceptible to aeolian erosion. Wind-blown tephra can cause abrasive damage to the recolonising plants or re-established crops and prevent soil cohesion; the erosional zone expands with time, similar to desertification.

Thin tephra falls of as little as 1 mm can also damage building components, infrastructure and lifelines because of their abrasive and conductive (especially when wet), properties, for example through short-circuiting electrical systems, contaminating water supplies and causing wear on mechanical parts. Thin tephra falls may also disrupt transportation systems; a tephra fall of 1 to 3 mm can reduce visibility and safety on highways, being resuspended by passing vehicles during and after deposition, reducing traction (especially if wet), damaging brake and belt systems and clogging air filters leading to engine overheating and seriously hampering any evacuation and rescue operation. A tephra fall of 1 mm will also obscure or completely cover markings on roads and can close an airport.
Thin tephra falls may improve soil fertility, particularly in the tropics where fertility would otherwise be reduced through nutrient leaching in the high rainfall environment. A positive impact of the 1995-1996 Ruapehu (New Zealand) tephra falls was to temporarily reduce the sulphur fertiliser requirement for all sheep, beef and dairy farmers within the fall area. Ash par-

ticles are especially destructive to insects and one advantage noted in agricultural areas that received small amounts of Mount St Helens ash was the destruction of insect pests.
While tephra is not toxic, it acts as an irritant affecting eyes and throats and exceptionally fine particles (<4 μm) can cause respiratory disorders. Deaths and injuries are more likely to result from secondary effects such as roof collapse, respiratory conditions or traffic accidents than immediate and direct trauma from the tephra fall.

Tephra bombs and blocks can potentially land more than 10 km from the vent but typically land within 5 km. Characteristics that determine a projectile's impact energy, and thus potential to cause damage, include the size, density and ejection velocity. The most damaging consequences of large tephra are from direct impact: large tephra can puncture holes in roofs, kill people or livestock and cause serious damage to crops. Tephra not large or dense enough to penetrate roofs can contribute to roof collapse through overloading or through repeated impacts that may seriously weaken a structure and leave it more vulnerable to future impacts or hazards. Hot tephra has been known to ignite fires upon impact: the ignition of flammable building components, furnishings or stock may cause more serious damage than through penetration alone.

9. Pyroclastic Density Currents

Flowage phenomena that involve various proportions of volcanic gas and fragmented volcanic rock are collectively called Pyroclastic Density Currents (PDCs); these are manifest as ground-hugging clouds moving down volcano flanks at tens to hundreds of kilometres per hour, and at temperatures that can reach more than ~700 °C (Fig. 3). PDCs are gravity-controlled, but their inception can be triggered by different mechanisms:

- Gravitational collapse of an eruption column (e.g., Vesuvius 79 AD, Italy)
- Gravitational collapse of a silicic lava dome, or of a steep-sided silicic lava flow (e.g., Merapi 2006 and Soufrière Hills volcano 2010)
- Phreatomagmatic explosions (interaction of hot volcanic rock with external water. E.g., Taal 1965, Philippines)
- Laterally directed explosions (Merapi 2010 and Mount St. Helens 1980, USA)
- Interaction of fast-moving lava flows with thick snow or ice on steep volcano flanks (Etna 2012, Italy)

PDCs can vary greatly in their density and are usually divided into diluted and concentrated PDCs. Rather dilute, gas-rich currents containing only 0.1-1% of solid rock material, often resulting from magma water interaction, are called surges and produce rather thin deposits (centimetres to decimetres). They are extremely mobile, generally travelling at tens to hundreds of km/h, but exceptionally reaching speeds of up to 1000 km/h.
Denser PDCs are referred to as pyroclastic flows; these are capable of travelling at similar speeds as surges to distances of many tens of kilometres. Dense PDCs are usually topographically controlled, generally following valleys or other low-lying areas. Surges can travel even across the sea (e.g., Krakatau 1883, Indonesia), and surmount conspicuous topographic obstacles, as documented

for eruptions such as the 1989-1990 eruption of Redoubt.

PDCs are significantly heterogeneous media that can vary their density depending on several factors such as mass eruption rate, influence of topography, segregation processes within the current (e.g., due to development of density stratification) and ingestion of air.

A dilute PDC (surge) can therefore become concentrated, for example in case of an increase of mass eruption rate or being channelled into a steep valley and vice versa.

PDCs are commonly associated with silicic magmas that produce either strongly explosive eruptions or very viscous lavas forming lava domes or rather thick, steep-sided flows whose partial collapse often generates pyroclastic flows and surges. However, basaltic eruptions are now known to generate PDCs.

Possible physical impacts and their effects

Through the 20th and into the 21st centuries, PDCs have caused the largest number of volcano-related fatalities worldwide among the various volcanic hazards. The devastating and deadly impact of PDCs are well known since the destruction of the city of Saint-Pierre near Mount Pelée volcano in the West Indies in 1902, where damage was a consequence of the high speed, volcanic clast load and high temperature of multiple currents. Most recently in October-November 2010 at Merapi more than 200 people were killed and more than 2200 buildings destroyed by PDCs (Fig. 4). Warning periods for PDCs are very short. People, animals or vegetation caught in the direct path of PDCs are likely to be instantly killed as a result

Figure 3: Pyroclastic flow generated by Merapi volcano. Photo by Franck Lavigne.

of trauma and burns, both external and internal (from inhalation of hot gas and ash). On the periphery, or in small dilute PDCs, people may survive and vegetation suffer heat damage but may not be destroyed.

Damage to buildings and other structures impacted by a PDC depends upon the dynamic pressure, temperature, duration of flows and amount of solid material it carries with greater damage expected with the increase of each variable. Failure of windows, generally the weakest component of a building, through elevated temperatures and dynamic pressures allows ingress of hot ash, which can cause combustion of furnishings and destruction of the building through fire. For relatively low temperature PDCs (<300 °C depending upon building construction type), or for areas with limited combustible material, the lateral dynamic pressures imposed on building surfaces by a PDC and the occurrence and nature of entrained projectiles becomes important to the level of damage sustained by buildings and infrastructure.

As with tephra falls, the impact of PDC deposits on local hydrologic systems depends on the deposit thickness, grain-size distribution, geo-

Figure 4: Kinahrejo village (Indonesia) strongly affected by pyroclastic flow during the 2010 Merapi eruption. Photo by Anton Sulistion.

Figure 5: Explosive and effusive activity at the South-East Crater of Mount Etna, on 24 April 2012. Photo by Marco Neri.

morphology (i.e., the slope angle and degree of vegetation cover) and climate, in particular the intensity of precipitation in triggering lahars. PDCs can also be destructive to road systems, to power and telecommunications networks, and to any other non-buried infrastructure elements in their area of impact.

10. Lava flows

Lava is molten rock expelled by a volcano during an eruption. The same term indicates the resulting rock after solidification and cooling. Close to the eruptive vent, lava is a fluid at temperatures from 650 °C to 1200 °C. Depending on its chemistry, temperature, effusion rate, viscosity, and on the topography, lava can flow great distances (from less than 1 km to several tens of km) at greatly varying speed (from a few meters to several tens of km/h) before cooling and solidifying (Fig. 5). A lava flow is generally created during effusive eruptions, which are characterised by low Volcanic Explosivity Index (VEI= 0-2, occasionally up to VEI 4, Table I in Appendix). Volcanic (extrusive) rocks can be classified into three chemical types; felsic, intermediate, and mafic. Felsic (or silicic) lavas such as rhyolite and dacite typically form lava spines, lava domes or "coulées" (which are thick, short lavas) and are often associated with pyroclastic (fragmental) deposits. Most silicic lava flows are extremely viscous, they do not flow far. Collapse of the steep sides of lava domes and "coulées" can generate gravitational landslide of hot materials, in same cases producing pyroclastic density currents (see Chapter 9). Felsic magmas can erupt at temperatures as low as 650 to 750 °C.

Intermediate (or andesitic) lavas form andesite domes and block lavas, and may occur on steep volcanoes, such as in the Andes. Commonly hotter than felsic lavas (in the range of 750 to 950 °C), they tend to be less viscous.

Mafic (or basaltic) lavas generally erupt at temperatures >950 °C. Viscosities are relatively low, although still thousands of times more viscous than water. Basalt lavas tend to produce low-profile shield volcanoes or "flood basalt fields", because the fluid lava flows for long distances from the vent. Most basalt lavas are characterised by a rough surface composed of broken lava blocks (i.e., 'A'a lavas) or characterised by a smooth, billowy, undulating, or ropy surface (i.e., pahoehoe type). Underwater they can form "pillow lavas".

Possible physical impacts and their effects

Lava flows will seldom threaten human or animal life because of their slow rate of movement. They will however cause complete destruction of buildings, infrastructure and vegetation in their path (Fig. 6). Any static element at risk, i.e., vegetation, buildings, infrastructure, within the area covered by a lava flow will be completely destroyed, as for example happened in Goma city (Democratic Republic of Congo) where lava flows up to 2 m deep destroyed at least 15% of Goma city killing around 150 people during the 2002 eruption of Mount Nyiragongo, and affecting part of the airport, greatly reducing the landing strip.

Low viscosity mafic (or basaltic) lava flows may cause the combustion of nearby flammables such as crops or buildings because of their higher temperatures and because of their

Figure 6: Etna, a house almost submerged by the1983 lava flow. Photo by Marco Neri.

low viscosity, and therefore relatively high speed, can occasionally threaten humans and livestock. The steep fronts of viscous felsic or intermediate lava flows may become unstable and collapse, causing small pyroclastic density currents; these are unlikely to cause more damage to infrastructure or buildings than the ensuing lava flow, although any humans and livestock impacted will be killed. If a lava flow becomes an object of tourist interest, there is of course the possibility for injury from getting too close, because of a limited understanding of the risk.

11. Lahars

Mixing of water and loose volcanic material produces volcanic debris flows or mudflows, called "lahars", the Indonesian word for volcanic mudflows (Fig. 7).

The formation of lahars requires water, abundant loose volcanic material, and slopes, conditions that exist in particular in rainy tropical climates, and in the presence of glaciers and lakes. Lahars can happen both during an eruption (i.e., primary or syn-eruptive) and after the end of eruption (i.e., secondary or post-eruptive). Syn-eruptive lahars can be generated by the explosive ejection of a volcanic crater lake along with tephra (e.g., Kelut, 1919 and 1966), by lava or pyroclastic flows melting snow and/or ice (e.g., Villarrica, 1971; Nevado del Ruiz, 1985), and by heavy rains mobilising freshly fallen tephra (e.g., Gamalama, 2011). Post-eruptive lahars can happen from a few hours to years or even millennia after the latest eruption. They can be generated by remobilisation of tephra deposits by heavy rain (e.g., Merapi and Pinatubo), failure of fumarolically altered volcano slopes during torrential rain (e.g., Casita), failure of volcanic material damming lakes (e.g., Ruapehu; El Chichón, Mexico).

Following large explosive eruptions that produce extensive sheets of pyroclastic (fall and flow) deposits, rainfalls can mobilise this loose material to transform it into post-eruptive or secondary lahars for many years; this is the case at Pinatubo, Philippines where lahars continue to occur more than 20 years after the major eruption of 1991.

Lahars usually travel along drainage systems on volcano slopes, and can reach distances of tens to hundreds of km from their source areas.

Possible physical impacts and their effects

People or animals caught in the path of a lahar have a high risk of death from severe crush injuries, drowning or asphyxiation. In terms of human fatalities, lahars rank as the second most deadly volcanic phenomenon after pyroclastic density currents in the 20th century and have caused the most injuries of any phenomenon. The single most deadly lahar disaster in history occurred in November 1985, when a relatively small explosive eruption of Nevado del Ruiz, Colombia, caused the melting of snow and ice on the volcano, generating lahars that travelled up to 80 km and inundated large portions of the town of Armero, with the loss of more than 23000 lives.

Lahars have characteristics similar to riverine floods and debris flows; however, even if their rheological characteristics have received much attention in the literature, detailed studies of their impacts on buildings, infrastructure and agriculture are rare. Their impact is potentially devastating due to the presence of large boulders being carried along in the flows. Historical eruptions, e.g., Nevado del Ruiz in 1985, Pinatubo in 1991, provide insights into potential building

Figure 7: Lahar at Kali Putih (Putih River, Indonesia). Photo by Moch Muzani.

damage resulting from lahars during the eruption and in the years following. Building damage includes burial, foundation erosion, debris impact, transportation due to soil erosion and liquefaction, failure from excessive wall or roof loads, collapse, undermining and corrosion due to the acidic nature of the flow. Depending on their densities and flow velocities, lahars may destroy or bury structures and machinery. Debris accumulation around bridges, particularly those with low clearance, can cause overtopping and flooding of nearby homes, businesses and agricultural land (Fig. 8).

12. Gas emissions

Volcanoes emit gas and solid rock. Prior to its release into the atmosphere, gas is dissolved in magma. The most abundant magmatic volatiles are water (H_2O) and carbon dioxide (CO_2), followed by sulfur (sulfur dioxide SO_2 and hydrogen sulfide H_2S), carbon monoxide (CO), halogens (HF and HCl), and Radon. These volatiles are released not only during eruptions, but also from volcanoes that have not erupted for thousands or tens of thousands of years. In such cases, gases may escape continuously into the atmosphere from the soil, volcanic vents, fumaroles, and hydrothermal systems (Fig. 9). Toxic volcanic gas is also released from flowing lava and so-called "lava haze" is released at the contact of lava with sea water. Hydrochloric acid forms when lava enters the ocean boiling and vaporizing the sea water. This is a short-lived local phenomenon but it represents a frequent nuisance for the population in Hawai'i.

Figure 8: Boyond brigde at Merapi volcano **a** on December 1994 and **b** on February 1995, after a series of lahars generated during the rainy season following the PDC of 22 November 1994. Photos by Franck Lavigne.

Possible physical impacts and their effects

Heavy gases such as CO_2, an odourless, invisible gas heavier than air, can accumulate in morphological depressions or flow considerable distances down valleys or slopes leading to the suffocation and/or poisoning of humans and animals. Such gases thus have the potential to collect in building basements and expose occupants to high, potentially fatal, concentrations. The sudden release of large quantities of CO_2 during phreatic explosions or the (non-eruptive) overturning of CO_2-charged lakes has resulted in disasters at Dieng, Indonesia in 1979, and Lake Monoun and Lake Nyos, Cameroon, in 1984 and 1986, respectively.

SO_2 has a pungent odour and is highly irritating to the eyes and respiratory organs. Acid rain resulting from oxidation of SO_2 with atmospheric OH has led to decades-long damage to crops and corrosion of metallic objects at Masaya, Nicaragua.

H_2S is known for its "rotten eggs" odour and long-term exposure at relatively low concentrations (50 ppm) can result in inflammation of the throat and, at higher concentrations (>250 ppm) in fluid buildup on the lungs; a number of deaths caused by H_2S are documented from various volcanoes in Japan.

If HF is released during eruptions it can cause the disease fluorosis, which may affect livestock which eat fluorine-contaminated grass even hundreds of kilometers from the source. Emission of an estimated 15 megatons of HF during the 1783 "Skaftár Fires" (Laki fissure) eruption in southern Iceland led to the death of more than half of Iceland's livestock. The resulting famine caused the death of one-fifth of the Icelandic population (then about 50000). The clouds of this gas and H_2SO_4 aerosol from the

Figure 9: Gas emission at Solfatara, Campi Flegrei, Italy. Photo by Antonio Ricciardi.

eruption affected northern Europe for months and possibly affected the global climate.
Exposure to gas and aerosols produced by eruptions can severely affect the health or lead to the death of humans and livestock, although direct exposure more commonly produces respiratory and eye irritation in humans and animals. Significant impacts are likely to be restricted to within about 5-7 km of the active vent/s and can occur independent of an eruption. Exposure to aerosols, particles less than 2.5 and 10 μm, can also have long-term health impacts.

The interaction between volcanic gas and the atmosphere can result in "dry fog" or "vog" (i.e., volcanic fog) and/or acid rain. Volcanic gases may attach to aerosol particles and ash, subsequently being dispersed downwind and deposited on livestock and crops. Chemicals in rain and volcanic ash have proved lethal to livestock in previous eruptions, e.g., Ruapehu 1995, Laki 1783, Hekla 1947 (Iceland). Aquatic life is also very susceptible to changes in water conditions such as increases in acidity, turbidity, temperature and concentrations of soluble elements. Acid rain and fog can cause considerable damage to farm plant/machinery (through corrosion) and crops, thus indirectly contributing to starvation and disease.

13. Sector collapses, landslides and rock falls

Volcanic edifices are the result of the repeated, rapid (usually $<10^5$ years) emplacement of magmatic products in a limited area. As a consequence of this relatively rapid construction, any volcanic edifice with significant height (on the order of ≥1000 m) can become unable to support its own load. This lack of support may result in the collapse of a sector of the volcano, which is a gravity-driven movement of a portion of a volcano, at scales ranging from minor rockslides and rock falls (<0.001 km^3) to giant megaslides and sector collapses (>5000 km^3), generally associated with large ocean-island volcanoes such as those on Hawai'i and in the Canary Islands. Sector collapse is observed at many volcanoes, independently of their composition (mafic and silicic), shape (stratovolcanoes, calderas and shield volcanoes) and geodynamic setting.
Sector collapses are characterised by very different velocities of the mobilised masses, ranging from slow movement (creep) to catastrophic fast-moving landslides. Collapse may occur abruptly or consist of accelerated movements within prolonged periods of creeping of the volcano flank.
Mobilised volumes vary enormously, even at the same volcano: from a few m^3 to huge flank movements (10^{12} m^3). Significant collapses commonly mobilise volumes of several cubic kilometres. Most sector collapses deposits extend to a distance roughly equal to the diameter of the volcanic edifice; nevertheless, in some cases, mud and debris flows produced by sector collapse can travel for significantly greater distances. The rapid entrance of large volumes of volcanic debris into major water bodies (lakes, oceans) may also trigger tsunamis, e.g., in Canary Islands and at Stromboli, Italy (last event in 2002, Fig. 10).

Sector collapse is facilitated by gravity and volcano height and steepness; it can occur when the basement on which a volcano sits is weak, when there is heightened magma pressure within the volcano, or when a volcanic edifice is weakened by acid fumarolic fluids and gases, and it can be triggered by tectonic and seismic processes.

Possible physical impacts and their effects

Sector collapses can pose an infrequent but significant risk to populations living close by and even at great distances, because of their sudden occurrence, extent and association with tsunamis (see Chapter 15). It is logical to assume total destruction for anything within the zone of impact of sector collapses and landslides, including humans and animals. The eruption of Mount St Helens in 1980 provides a recent, well-studied catastrophic collapse event that had significant impacts on the surrounding agriculture and forestry industries. Small rock falls may cause partial damage to infrastructure, for example by blocking roads or collapsing a retaining wall, and humans or livestock may survive being impacted by a small rock fall with trauma, i.e., broken limbs or head injuries.

14. Volcanic earthquakes

Different from tectonic earthquakes, which occur due to the rupturing of the Earth's crust along a fault, volcanic earthquakes are essentially related to the movement of magma. The movement results in pressure changes in the rock around where the magma has exerted a stress. At some point, the rock may break (triggering earthquakes) or move aseismically (through creep movements). The greatest number of earthquakes in volcanic areas is related to magma pushing into a volcano toward the surface, and often occurs in "swarms" of hundreds to thousands of earthquakes.

Figure 10: Stromboli, 30 December 2002. Landslide affecting the north-western flank of the volcano, triggered by the eruptive activity. Photo by Sonia Calvari.

There are two general categories end-member of earthquakes that can occur at a volcano: volcano-tectonic earthquakes and long-period earthquakes.

Volcano-tectonic earthquakes are produced by stress changes in brittle rock due to the injection (or withdrawal) of magma. During the last stage of an eruption, earthquakes can occur also as rock adjusts after withdrawal of magma. The magnitude of this kind of earthquakes is generally modest (<4 Richter scale M_L), but their shallow hypocenters can produce severe damage in limited areas around the epicenters e.g., at the village of Santa Venerina on Etna in 2002. The largest historical earthquake (Moment magnitude Mm >6.5) accompanied the 1912 Novarupta eruption in Alaska.

Long-period earthquakes are commonly seen as potential precursors to an imminent eruption. These earthquakes are a result of pressure changes within magma, magmatic gas or groundwater, during the unsteady transport of the magma toward the Earth's surface. Long period ground motion, is ground movement during an earthquake with a period longer than 1 second. The frequency of such waves is 1 Hz or lower, placing them in the infrasonic part of the audio spectrum. The magnitudes of these events are generally low (2-3 M_L), but their occurrence is important for hazard evaluations.

Possible physical impacts and their effects

Volcanic earthquakes can cause damage to buildings and infrastructure, trigger landslides and cause loss of life. Due to the shallow focus of a volcanic earthquake, typically less than 5 km, ground shaking will be particularly strong and damaging within a few kilometres of the vent however, the shaking will attenuate quickly with increasing distance. There is the potential for cumulative damage from earthquake swarms of smaller magnitudes; however, the limited available evidence suggests that the majority of the damage will result from the greatest magnitude earthquake. The most damaging impact of shaking is failure of masonry walls or the structural frame. Shaking of a building frame may cause large cracks in the walls, columns or beams and sever connections between the roof, walls and floor. Partial collapse of masonry walls in volcanic earthquakes could also cause the blockage of adjacent roads, creating problems for necessary evacuation and access for emergency services. Volcanic earthquakes, up to magnitude M_L 5 in some instances, can cause structural damage to some masonry bridges, with embankments and bridge abutments vulnerable to slippage. Major cracks may appear in roads or rail tracks making transport routes impassable. Reservoir, dam and water intake structures may be damaged allowing water leaks and wastewater pipes may be ruptured causing local contamination. The failure of telecommunication and electrical structures, such as power lines, can lead to disruptions in service and high rehabilitation costs. Fire and/or flooding following an earthquake, due to ruptured gas and power lines and/or water pipes, can also cause more damage to buildings than from the original structural failure, however occupants have a greater chance of escaping a fire or flood than a collapsed building as long as they are not trapped by debris. The main reason for human casualties and injuries in earthquakes is the collapse of buildings, contents and infrastructure.

15. Volcano triggered tsunamis

A tsunami is a series of generally catastrophic water waves generated by seafloor movement; that is the displacement of a large volume of a body of water, such as an ocean or a large lake. Periods of this "wave train" range from minutes to hours. The wavelength of tsunami waves is far longer than that of normal sea waves. The wavelength of volcano-triggered tsunamis is however shorter than that of earthquake-induced tsunamis.

Wave heights and run-up (maximum elevation reached by the tsunami on slopes) of tens of meters can be generated by large events. The run-up distribution of volcano-triggered or landslide-induced tsunami is characterized by high run-up in the axis of the collapse and lower run-up values on the margins, whereas co-seismic tsunamis display a more regular run-up distribution along the coast.

Although the impact of tsunamis is limited to coastal areas, their destructive power can be enormous and they can affect entire ocean basins. Volcanoes can trigger tsunamis through:

- Submarine volcanic eruptions
- Collapses of volcano flanks (see Chapter 13), either submarine or subaerial, entering an ocean (or a lake)
- Pyroclastic flows (see Chapter 9) or lahars (see Chapter 11) entering an ocean (or a lake).

These phenomena can occur individually or combined in a series of contemporaneous events. Explosive submarine volcanic eruptions can trigger tsunami waves. The power of significant submarine explosions can generate rapid movement in the water column located above the eruptive vent, and the following generation of water waves radiating from that point toward the surface of the sea.

The largest known tsunamis of volcanic origin were formed during the 1627-1628 BC Santorini (Greece) and 1883 Krakatau eruptions, when portions of the volcanic edifices – which were islands in the ocean – foundered into the large voids left by the rapid emptying of the magma reservoirs beneath these volcanoes (a process known as caldera collapse).

Submarine landslides along volcano flanks can generate tsunamis. These phenomena rapidly displace large water volumes, as energy from falling debris or expansion transfers to the water at a rate faster than the water can absorb. The rapid entrance of pyroclastic flows into the sea, or the rapid collapse of subaerial portions of a volcano flanks into the sea, can generate tsunami waves, as occurred at Krakatau in 1883 and at Stromboli in 2002. The rapid entrance of lahars into the sea has also triggered a tsunami a few days before the paroxysmal stage of the Mount Pelée (Martinique) eruption in 1902.

Volcanogenic tsunamis are one of the farthest-reaching volcanic phenomena, potentially impacting areas thousands of kilometres from source. For example, the caldera collapse of Krakatau in 1883 generated a tsunami nearly 40 m high at source, which remained large enough to strand small harbor boats in Sri Lanka, nearly 3000 km away and inundated the whole city of Saint-Paul on Réunion island. In the open ocean, volcanogenic tsunami waves can travel at speeds of 600-800 km/h although wave heights may be only a few centimetres. As the tsunami approaches shallow water and land, the waves travel more slowly, but their wave heights may increase to many metres, and thus they can become very destructive.

Possible physical impacts and their effects

From a damage and casualties perspective, important tsunami characteristics are the wave run-up height and velocity, inundation distance and the presence and size of debris within the tsunami that can cause localised damage. Drowning or trauma from collision with debris, infrastructure or trees, causes deaths and injuries. Damage to buildings and infrastructure may result from flooding, foundation erosion and failure, transport or failure through lateral dynamic pressures and missiles associated with the tsunami. The first tsunami wave to reach shore may not be the most destructive because of its relative size, velocity, inundation distance or debris content, and so the destruction of buildings and occurrence of casualties may be progressive. Rapid inundation of areas close to the volcanic source may prevent adequate warning, and associated evacuation, leading to significant loss of life.

References and suggested readings

- Bulletins of the Global Volcanism Program for recent historical eruptions: http://www.volcano.si.edu/reports/bulletin/
- GNS Science Volcanic hazards: http://gns.cri.nz/Home/Learning/Science-Topics/Volcanoes/Volcanic-Hazards
- USGS Volcano Hazards Program: http://volcanoes.usgs.gov/hazards/
  http://pubs.usgs.gov/circ/1990/1061/report.pdf

- Acocella, V., 2005. Modes of sector collapse of volcanic cones: Insights from analogue experiments. Journal of Geophysical Research, 110, B02205, doi:10.1029/2004JB003166.
- Beget, J.E., 1999. Volcanic tsunami. In: Sigurdsson, H., Houghton, B.F., McNutt, S.R., Rymer, H., Stix, J. (Eds). Encyclopedia of Volcanoes. Academic Press, pp. 1005–1013.
- Blong, R.J., 1984. Volcanic hazards: a sourcebook on the effects of eruptions. Academic Press Australia, 424 pp.
- Chouet, B., 1996. Long-period volcano seismicity: its sources and use in eruption forecasting. Nature 380, 309–316.
- Heiken, G., Wohletz, K., 1985. Volcanic Ash. University of California Press, Berkeley.
- Newhall, C.G. and Self, S., 1982. The volcanic explosivity index (VEI): An estimate of explosive magnitude for historical volcanism. Journal Geophysical Research, 87 (C2): 1231–1238.
- Roman, D. C., Cashman, K. V., 2006. The origin of volcano-tectonic earthquake swarms. Geology 34, 457–460.
- Sigurdsson, H., Houghton, B.F., McNutt, S.R., Rymer, H., Stix, J., 1999. Encyclopedia of volcanoes. Academic Press, 1417 pp.
- Spence, R.J., Kelman, I., Brown, A., Toyos, G., Purser, D. and Baxter, P., 2007. Residential building and occupant vulnerability to pyroclastic density currents in explosive eruptions. Natural Hazards and Earth Systems Sciences 7, 219-230.
- Thouret J.-C., Lavigne F., 2000. Lahars: occurrence, deposits and behaviour of volcano-hydrologic flows. In: Leyrit H. and Montenat C. (Eds.), Volcanoclastic rocks, from magma to sediments. Gordon and Breach Science Publishers, Amsterdam, pp. 151-174.
- Thordarson, T., Self, S., 2003. Atmospheric and environmental effects of the 1783–1784 Laki eruption; a review and reassessment. Journal Geophysical Research 108, 4011, doi: 10.1029/2001JD002042.
- Witham, C.S., 2005. Volcanic disasters and incidents: A new database. Journal of Volcanology and Geothermal Research 148, 191-233.

3 LIVING WITH A VOLCANO: SCIENTIFIC AND OPERATIONAL ASPECTS

Gathering scientific information about a volcano is one of the key requirements for the better comprehension of its past history and present behaviour. Indeed, volcano knowledge and understanding is a crucial aspect that strongly impacts on the management and organisation of territory and people living (and working) close to a volcano. The present section of this handbook is devoted to the analysis of what should be taken into account from the scientific and operational points of view. This section aims at focusing on the aspects of volcanic risk mitigation, which is the core of the present handbook. Moreover, it wants to give some suggestions derived from the lessons learnt during the four years of the MIAVITA project of cost-effective approaches.

Note that due to its intrinsic content, the section contains specific terminology and some principles of physics and mathematics. Nevertheless, the technical information are presented in a simplified way for easy reading. Limited scientific knowledge can help the reader in the understanding of the following chapters.

Participating authors:

Marco Bagni
Christian Bignami
Marie Boichu
Vittorio Bosi
Fabrizia Buongiorno
Licia Costantini
Bruno Faria
Joao Fonseca
Sri Hidayati
Susanna Jenkins
Philippe Jousset
Gonéri Le Cozannet
Emanuele Marchetti
Clive Oppenheimer
Ricardo Lopes Pereira
Fred Prata
Maurizio Ripepe
Fernando Silva
Claudia Spinetti
Sri Sumarti
Surono
Teresa Vazão

16. Necessary information that must be available

One of the fundamental requirements for living in harmony with a volcano is knowledge. Such knowledge can be obtained through the collection of many types of scientific information, which must be correctly analysed, elaborated and used to properly face the events which occur during the volcano's lifetime.

Some types of information can be gathered by studies on the past behaviour and history of the volcano (e.g., geological maps, morphology, historic records, field studies). Some others can be obtained by many monitoring techniques (e.g., seismic, chemical, deformation) that allow us to identify the base-line of volcano behaviour and thus changes that can predict an impending eruption. Moreover, other important information that must be available to those responsible for planning for and managing a future crisis are vulnerability data (e.g., physical, systemic) and exposure values (e.g., lives in danger). This information can be obtained using census data, and through an extensive and strong knowledge of the territory, buildings culture, civil protection system and other. This chapter lists the main resources that should be available to the scientific community and observatories involved in volcanic risk assessment and management.

Geological Maps

These maps describe geological features such as rock types, bedding planes, structural and stratigraphical characteristics of a certain territory. In a volcano area, a geological map will include the most recent and/or widespread volcanic deposits produced during the eruptions and their main characteristics (type of deposit, eruption style, chemistry, etc.), their absolute or relative ages and the main structural features. Geological maps are therefore fundamental for the knowledge of the volcano area, the type and dispersal of the main volcanic deposits and their ages.

The dating of volcanic rocks and deposits is particularly relevant especially in terms of the time gaps between eruptions. Dating of volcanic deposits is crucial to understand if the volcano is extinct, dormant or active. However, it is worth noting that only the largest eruptions are typically preserved whereas the smaller deposits (originated by less powerful eruptions) are easily eroded away. This is important to take into account in order not to misinterpret the volcano activity and underestimate the eruptive frequency (see Chapter 23).

Eruption history

The knowledge of the eruption history of a volcano is fundamental to characterize its past dynamics with the aim of understanding better its present behaviour and its possible evolution with time and of assessing the associated hazards.

The eruption history can be created by combining geological field studies and dating with historical records (when present). Field studies characterize of past volcanic deposits in terms of dispersal and possible vent location/s, internal stratigraphy (e.g., the number of short-lived eruptions that form the deposit) and erupted components. Past eruptions can be therefore defined in terms of eruption dynamics and style and their physical parameters (such as column height, erupted volume, mass eruption rate and eruption duration) can usually be estimated. These estimate necessarily contain a degree of uncertainty, which mainly depends on exposure and preservation status of deposits. Historical records can reduce this uncertainty. In addition, they can contain the description of eruptions for which deposits are no longer preserved and therefore they represent the only means that can prove the existence of relatively small, past eruptions.

Geomorphology

As described in Section 2, some volcanic phenomena (i.e., pyroclastic density currents, lava flow, lahars) are strongly dependent on topography, in terms of dispersal and flow properties (velocity, density, degree of turbulence, etc.). Valleys and river beds, for example, are the main places where volcanic flows are concentrated and deposit material. A detailed knowledge of geomorphology is therefore fundamental for hazard mapping and the correspondent definition of the hazard areas around the volcano. A high resolution Digital Elevation Model (DEM) is, in fact, usually required to develop hazard and risk maps (see Chapter 23).

In addition, a good knowledge of volcano geomorphology gives further information about the past volcano history and eruption phenomena. For example, the presence of a big depression like a caldera can be related to a large explosive eruption.

Vulnerability and exposure data

Knowledge of numbers and distribution of inhabitants, buildings, infrastructures and communication networks is essential for risk assessment and management. In addition, evaluation of the vulnerability (physical, social, economic, etc.) of the volcano territory is necessary for disaster prevention actions, informing mitigation actions such as building or infrastructure strengthening, preferential evacuation from vulnerable buildings or adaptable cropping patterns.

Vulnerability characteristics are typically determined through comprehensive field surveys and consider vulnerability with respect to the volcanic hazards thought likely to affect the territory, and their likely severity. For example, projectiles and tephra falls primarily affect the roofs and supporting structure of buildings, whereas pyroclastic density currents, lahars and volcanic earthquakes impact the foundations, and walls (see Section 2). Land-use planning in areas at risk should, amongst other mitigation measures, consider strengthening or relocating lifelines (e.g., roads, bridges, power and water supplies) and other key community facilities.

Monitoring System

The benefits of volcano monitoring are essentially twofold: first, observations provide essential input (evidence) on which to base (probabilistic) hazard assessment; second, observations are crucial for the validation and calibration of computational models for volcano behaviour. Of course, these two aspects directly reflect on the reduction in the death tolls and the physical impacts of volcanic eruption. Modern volcanology has advanced tremendously as a result of the synergy of theory and observation. Improved models for volcano behaviour naturally feed back into the first objective of monitoring: forecasting volcanic activity. In many observatories, this leads to a dual role of monitoring and research, often with fruitful, if sometimes complicated, collaborations developing between local scientists and colleagues in the wider volcanological community.

Generally speaking, the more sources of monitoring data that are available, the better the chances of constraining interpretations of volcanic hazard. Many volcano observatories employ multi-parameter monitoring strategies involving at least seismology, geodesy and geochemistry. These may be supplemented by routine visual observations, satellite data, thermal imaging, gravimetric and magnetotelluric surveys, and in the case of erupting volcanoes, petrological studies of lavas and tephra. The wealth of acquired information helps to build an evolving conceptual framework for the sources, storage, transport and rheology of magma, which can be continually re-evaluated and refined. One of the most difficult aspects of making short- to medium-range forecasts of eruptions is that the seismic, geodetic, geochemical and other signals emanating from a volcano prior to eruption can be difficult to distinguish from those signals observed in volcanic unrest that does not culminate in eruption. Other causes, such as hydrothermal activity, tectonic adjustments on faults, etc., may be at work. Or a magmatic intrusion may stall in the crust before reaching the surface. Presently, there are only a few clues known that help to discriminate between these various possible causes of unrest. This is a crucial point to bear in mind when considering uncertainties in forecasting volcanic activity.

Typically, a scheme for volcano monitoring requires:

- A general knowledge on volcano dynamics
- A series of instruments deployed on ground, possibly additional satellites data, and a series of techniques that probe the volcano and give observed signals
- Researchers, who analyse the signals and interpret them to issue adequate information to the authorities, and in some case, alert messages

The observed signals are compared with the baseline record obtained from data collected and analysed during the pre-eruptive phase. Any detected change in several observed quantities is compared to changes inferred from a general model of the volcano.

Main parameters to be monitored include:

- Displacement and movement of the ground at various frequencies (static to hundreds Hz), through a wide spectrum of

different instruments, such as seismometers, accelerometers, GPS, EDM, Radar, etc.
- Gravity to infer mass changes and displacements (gravimeters)
- Composition of rock, air, soil, volcanic gas, and plume, especially SO_2, CO_2, H_2O
- Temperature of gas, water, fumaroles, soil
- Environmental conditions such as rain, air temperature, air pressure, moisture variations, etc., because these parameters may affect other observations

It is important to remark that a multidisciplinary approach is the sole method, which allows an accurate eruption forecast.

The role of the observatories

Volcano observatories can be considered as the collectors of all the knowledge of a volcano. Among their main activities, observatories are important centres where most monitoring data are collected and can be transmitted in real time to different intervening partners (i.e., scientists, decision makers, civil protection authorities). Data can be analysed and interpreted directly by people working in the observatory or in other research centres. Usually the observatories are responsible for setting up and maintaining monitoring equipment and are also the place where instruments are stored and repaired. Generally observatories also have the authority to set the alert levels.

17. Geographic Information Systems

Utility

Organizing hazard and risk data is an important task for mitigation purposes. Indeed, once the necessary knowledge for assessing the threat and the associated risks has been acquired, the analysis of data and the dissemination processes are key points in order to maximize the chances of reducing potential disaster consequences. Geographic Information Systems (GIS) designed to organize and to disseminate hazard and risk information may improve the capability in reducing volcanic risk especially during prevention and preparedness phases. GIS allow the integration of heterogeneous data derived from different sources and enable their regular updating. They may also support the modulation and simulation of different scenarios for prevention and risk management. The exponential availability of geo-data layers challenges the ability of users and system designers to manage this data in a seamless way.

Principles

GIS are systems that enable storing, organising, manipulating and visualising georeferenced information. One application of GIS in volcanic risk management is for example the design of a map of potential adverse events and of their consequences in terms of damages. This can be done by crossing geographical layers describing a volcanic hazardous event with those depicting assets at risk (e.g., buildings) and their vulnerability to the considered events.
Advanced GIS solutions include browsing components developed to be executed within a Web browser. Such components are commonly addressed with the term "WebGIS" and are usually represented as a library of tools that can be assembled in order to create the desired user interface. In its simplest form, the WebGIS becomes a plain viewer, running within a Web Browser, like Firefox, Internet Explorer, Google

Chrome. This allows the seamless roaming inside a GIS data repository that, as stated before, can easily become extremely large and complex. More complex systems also enable analyses and geoprocessing of data. Distributed web-based systems can provide the users with flexible systems capable of managing heterogeneous data and services. The compliance of the WebGIS repositories to the Open GIS Consortium (OGC) standards allows a level of interoperability that increases with the availability of new OGC-compliant GIS repositories. For example, the availability of new data stored on a OGC-compliant GIS system can be immediately accessed by existing tools. This increases the sustainability of the systems. The development of a WebGIS component can be efficiently obtained using Open Source libraries like OpenLayers, GeoExt and ExtJS as well as proprietary products like ESRI or MapInfo.

GOOD PRACTICE FOR GEOGRAPHIC INFORMATION SYSTEMS

User requirements: assess users' expectations and their priorities in terms of requested or desired services during each phase of the disaster cycle. A well structured and written User Requirement Document (URD) is the first step to run a winning project.

Access policy and management: the organisation responsible for data access policy and the GIS or WebGIS management should get the exclusive right to restrict the access to certain sets of data to certain types of users only. This policy and the system management may be under the responsibility of either the national volcano agency, or the civil protection agency, or could be shared by both of them.

Information content of the data repository: it should be complete, up to date, and accurate. Authorities responsible for volcanic risk management have to base their decisions on easy and reliable information datasets.

Information and system reliability: the GIS system should be hosted on a high availability system to avoid service disruptions and grant access to the information whenever needed.

System flexibility: due to the particular strategic use of the GIS data, its availability must be guaranteed especially during emergencies. This can be achieved by tailoring system access privileges to exclude less important users in favour of those who most might need fast access to the information.

Personnel: it is important to employ highly qualified personnel to develop the GIS/WebGIS. Management of this type of technology requires expertise in Information Technology and Web mapping.

BOX 1

THE WEBGIS OF MOUNT CAMEROON

Within the MIAVITA project, a WebGIS was designed to enable users not used to GIS tools to visualize hazard and risk maps of volcanic and geological hazards in Mount Cameroon. User requirements were collected among local volcano observatories and civil security agencies involved within the MIAVITA project. Key users requirements were to develop a structured and flexible GIS-database, but also to manage user's privileges differently according to their profile, the status of the volcano and the capabilities of the system to manage queries. Finally, the need for different status for data was acknowledged, from data that can only be interpreted by experts (e.g., some complex remote sensing products) to data that can be disseminated to any users (e.g., a regulatory hazard map). The tool was based on open source resources. It encompasses a database management module and a visualisation tool. These modules comply with interoperability international standards. While the developed tool is able to provide users with enough flexibility to respond to the users' requirements, it is still necessary to own expertise in WebGIS to manage such tools. However, the WebGIS was transferred to the project partner in Mount Cameroon in order to explore the possibility to make this proof of concept an operative tool.

18. Scenario builders

Utility

Recently, authorities or agencies involved in risk management have required a tool to assess the potential consequences in terms of damage of an eruption. A scenario builder can provide a solution for the realisation of such tool. Scenario builders have twofold objectives: first, they can be used for emergency planning because they allow assessment of the potential consequences and permit a better preparation before the response; second, they can be used during an eruption to follow the eruption development and foresee the areas at risk.

Principles

A scenario builder can be implemented using some simple functions of a GIS. A scenario can be addressed by crossing a given succession of elicitated volcanic, seismic, landslides and hydro-geological events with the vulnerable elements such as road and telecommunications systems (infrastructures), buildings, agriculture and the exposed people.

For volcanic risk scenarios, three specific issues must be taken into account:

- A wide diversity of volcanic phenomena can affect a multitude of assets (see Section 2)
- The tool should be able to take into account a multitude of successive or simultaneous hazards that can succeed or simultaneously happen in the same eruption. The temporal extension of the hazard is thus very complex
- There are many features of damage to integrate into such a tool. Moreover, they are also very heterogeneous and poorly constrained by observations

However, despite the recognized importance of volcanic risk scenarios for improving civil security preparedness, in developing countries scenarios have been rather produced to generate possible volcanic event such as lava flows rather than for an assessment of the potential human consequences.

Automatic computation: implementation of scenario builder tools should automatically compute direct and tangible damage due to a given event, and should be linked to GIS/WebGIS.

19. Ground based monitoring

In this Chapter the reader will find described the three essential pillars of multiparameter, ground-based monitoring of volcanoes: seismology, geodesy and fluid geochemistry. In addition, two further techniques, acoustic systems and cameras, are described to complete this survey by presenting innovative approaches. For most instruments and techniques, information about the cost of the hardware equipment is reported. For some others there are no cost details because the technology changes rapidly and the related costs as well. It is worth noting that in addition to the cost for equipment, the reader should take into account that there is the cost concerning the processing of the data collected by instruments, and the expenses needed for training of staff. These amounts depend on many factors and cannot be easily estimated.

Seismic network, volcano seismology

Utility

Seismic monitoring is the basic approach for volcanic activity assessment. Earthquakes are due to sudden stress changes and mass movement in the crust that create waves propagating in the Earth. The associated seismic signal (the seismogram) is representative of the ground motion and is recorded at surface or in boreholes with seismometers. The frequency and time dependent signals are signatures of various processes taking place within the volcano.

Principles

Volcano-seismologists classify earthquakes into four basic earthquake types corresponding to main volcanic processes:

- Rock rupture produces Volcano-Tectonic (VT) high frequency (1-25 Hz) earthquakes
- Fluids movement produces low-frequency earthquakes (0.2-5 Hz), also called Long-Period events (LP)
- Explosion, Rock Fall, Pyroclastic Flows events produce signals with many frequencies (1 to 25 Hz); the seismogram signals are cigar-shaped and may last several tens of seconds to minutes
- Volcanic tremor is a sustained resonance of part of the volcano; frequencies can be harmonic (1 to several Hz)

This classification is not the only one possible, but it is the most widely used. Once seismograms have been analysed, the number of earthquakes and other parameters (frequency content, energy, magnitudes, earthquakes depth, etc.) are usually plotted in graphs as a function of time. These basic plots help to understand the chronology and development of volcano activity.

Instruments and techniques

Volcanic earthquake signals are recorded with seismometers, as seismic waves travel from their source to the sensor. A monitoring seismic station comprises the seismometer (sensor) and a transmission system to the main gathering information centre where data are processed and analysed. Data should be preferentially recorded continuously and digitally with a sampling rate of minimum 50 Hz (typically 100 Hz).

Two main types of sensor are available:

- Short-period sensors (1-100 Hz), which are cheap and easy to set-up; they are used at most volcanoes
- Broadband sensors, more expensive, can record frequencies in range of 0.005-100 Hz and are the state of the art instrumentation for top quality monitoring networks

The set-up of the latter is more demanding. Broadband seismometers allowed major progress in recent years in the understanding of seismic activity and its relation to associated volcanic processes. Borehole seismometers also exist, with high sensitivity, but their cost prevents their extensive use.

Volcano-tectonic earthquakes: the analysis of volcano-tectonic (VT) earthquakes can help in understanding the acting process. The sudden movement of two blocks of solidified rock along a fault under stress due to magma rise generates, in fact, VT earthquakes. One can estimate the orientations of the planes by analysis of the first motion (up or down) on the seismogram (fault plane solutions), and therefore identify the location of conduit and probable vents. The rotation of the fault plane solutions in fact indicate stress change which can been related to magma rising at depth. In addition, the spatial-temporal distribution of the events can be used to identify the storage and the conduit system in the volcano.

Basic analysis of VT seismic signals consists in:

- Detection of earthquakes (performed using classic algorithms). VT earthquakes comprises generally two types of waves: P- and S- waves
- Location of the earthquakes is the first important element to evaluate where the rock ruptures due to highest stresses occur in the volcano
- Earthquake magnitude or energy released. Once it is defined, its variation with time is more important rather than the absolute value
- Frequency content analysis to classify the seismicity. Frequency changes with time may indicate changing conditions in the fluids and stresses
- Shear-wave splitting within VT seismograms may also be observed, but this has not yet been fully exploited for volcano monitoring

Velocity model, tomography and earthquake locations: the determination of location, magnitude and source characteristics (e.g., full moment tensor solution) requires the knowledge of seismic wave velocities within the volcano, obtained using a technique called seismic tomography. Seismic tomography consists in minimizing the differences between observed travel times for P- and S- waves and computed travel times within a computer model of the crust velocities and earthquake location. We look for the best velocity distribution that explains observed travel times best. The velocity distribution is generally taken as specific locations on a 3D grid which approximates crust density and velocities. Because earthquake locations and velocity models are coupled, the search for the best velocity model and the earthquake hypocenters should be done at the same time. Modelling of wave propagation requires techniques like ray tracing, finite-difference, finite element modelling or stochastic modelling. As modelling is highly time-consuming, constant and simple velocity models are usually used for earthquake location and are sufficient for the monitoring needs.

Long-period seismicity: (frequencies between 0.2 to 5 Hz) has been recognised as a precursor of eruption in many instances (e.g., in Galeras and Merapi volcanoes). The location of long-period seismicity (LP, seismic tremor) cannot be assessed using the technique used for VT earthquakes, because it does not contain S-wave and the P-wave is emergent. Amplitude techniques may be used, which consist of estimating the best location from the evaluation of the signal amplitude decay with distance.

Most recent progress came from the determination of the propagation characteristics and the complete characterisation of the LP earthquake source. LP events supply fundamental information for understanding volcanic processes in relation to gas, as a driving force of magma. LP seismicity represents the best information from seismicity to predict volcanic activity. This is why volcano-seismologists deploy a great amount of effort to get this knowledge. The determination of the source characteristics in real-time is still challenging due to some limitations of the synthetic signal computation which is a very time consuming process (using finite-difference) and for a limited number of frequencies (low frequencies).

The similarities between low-frequency signals allow experts to define families of similar LP earthquakes, whose behaviour with time indicates different status of the volcano and the speed of magma flow. The analysis of complex frequencies can be used to estimate the nature of the fluids contained in fractures and therefore there is a future possibility to derive the size of the eruption.

The last element of great interest concerning volcano monitoring is the analysis of the seismicity triggered by non-magmatic processes, like surface waves issued from regional or remote earthquakes, earth-tide triggering, etc. It is difficult to identify in real time, but it has been recognised in an increasing number of cases.

GOOD PRACTICE FOR SEISMIC MONITORING

Seismic network: the minimal network should comprise of at least four short-period stations. A modern monitoring network should comprise at least of four to six broadband digital seismometers, with a reliable route for real time data transmission to a gathering centre where data is processed in real time.

Stations location: set-up at least one station far from the volcano, minimum distance of 20 km, or include other regional monitoring networks into the volcano monitoring system. This is particularly important when a large eruption takes place and networks close to the volcano become unusable.

Signal transmission: the most common way to transmit data is radio telemetry, but new networks use Wi-Fi transmissions. Rarely satellite transmissions are used, because they are too expensive (see Chapter 21).

Instruments installation: advise the population living in the network area and inform them about the usefulness of monitoring which causes no danger to them. Informing the population may avoid possible damage and theft from people that believe instruments make a "volcano spirit" angry.

BOX2

THE GEOPHYSICAL INSTRUMENT FOR LOW POWER DATA ACQUISITION (GILDA)

M.Orazi and R. Peluso

The geophysical data acquisition system named GILDA (Geophysical Instrument for Low power Data Acquisition) has been developed by the Osservatorio Vesuviano, a department of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Naples (Italy). The main goal of this project was to study, develop and produce a data acquisition system specifically devoted to multiparametric volcano monitoring. INGV policy is to share this instrument and the relative know-how in frameworks of collaborative activities with other institutions involved in geophysical monitoring and research.

The first step of the GILDA project has been the realization of a high-resolution seismic datalogger, with 4 channels, different possible sampling rates from 40 sps to 1000 sps, about 132 dB of dynamic range and a very low power consumption of about 840 mW at full performances. The GILDA datalogger is a multiboard system composed of a 24 bit sigma-delta ADC board, a central processing unit board based on an ARMv7 core, a timing board for GPS synchronization and a GPS board realized with a Trimble Lassen iQ unit. A module for remote GPS installation is also available allowing placement of the instrument in vaults and areas not covered by GPS signal. The last upgrade of the system is an external board for local data storage based on an SD/SDHC memory card allowing up 32 GB of data (in a typical usage this allows about 1.5 years of storage). At present other instruments are being studied for the GILDA project, in particular a multichannel acquisition system specially designed for array applications and another one designed for geochemical data acquisition.

The overall production costs of the datalogger system is of approx. 2500 € to date (2012), making it a very competitive solution for purposes of low budget experiments or seismic networks. It is a very good trade-off among performances, power requirement and costs. The multiboard approach of the datalogger further reduces running costs of the system because in case of faults it is always possible to repair or change only the broken board instead of repair or change the whole object.

Data acquisition of the system uses the Earthworm suite running a specialized home developed module. Both are open source software that may be used without any additional fees and they may be run on a GNU/Linux operating system. These conditions allow further cost reductions compared to some commercial solutions using proprietary and license charged software.

Ground deformation

Utility

As the magma reaches the shallow depths of the Earth (i.e., less than 20 km), it induces displacements, both in the horizontal and vertical directions of the ground surface, which is called ground deformation. These displacements may range between a few millimetres and tens of meters, and they may cover large areas. Their magnitude depends on the physical dimensions, the shape and the position (relative to ground) of the magma. Generally the ground deformation reaches an extreme value just before the beginning of an eruption. The time interval that it takes to reach this extreme value may span some hours, days, even months or years, and the interval depends on the evolution of magma accumulation or the progression of the intrusion and also on the physical and chemical properties of the magma. It is easy to understand that the ground deformation is an important volcanic signal precursor and its monitoring may be crucial to infer the state of the volcano and to forecast volcanic eruptions.

Principles

Volcano monitoring through ground deformation is performed generally by the measurement of at least one of the three quantities such as:

- Strain, which is the variation of the volume/length divided by total volume/length of deformed medium and expressed by parts per million - or microstrain
- Tilt, which is the variation of the angle (i.e., slope) of the Earth's surface and it is expressed in micro-radians
- Displacement of ground surfaces, both in the horizontal and vertical directions, and normally expressed in millimetres

Instruments and techniques

Several methods and instruments exist to measure each one of three quantities mentioned above (i.e., strain, tilt and displacement).

Strain: it can be measured by two kinds of instruments: linear and volumentric strain meters. The linear strain meters, usually called also extensometers, measure the length variation, with time, between two points at the Earth surface, whereas the volumetric strainmeters, also called dilatometers, measure the variation of a volume with time with respect to the original volume.

The resolution of a modern strainmeter is typically of the order of 10^{-9} strain, and it can reach the order of 0.02 nanostrain (0.02×10^{-9} strain), which means it can detect a variation of 2 mm over a distance of 1000 km.

Volcano strain monitoring is becoming a common tool and it has turned out to be very effective and successful for the prediction of eruptions of several volcanoes. However there are two main drawbacks on the use of the strainmeters. First, high-resolution strainmeters may not be commercially available and when available they are very expensive (e.g., the cost of a 0.02 nanostrain may be higher than 110000 € to date). Second, strain measurement may be very perturbed by environmental noise (see below) and therefore it is recommended to install strainmeters roughly at 200 m depth in boreholes, which leads to two additional considerations. First, it uses borehole strainmeters that are very expensive, although the cost of some strain instruments, of low resolution, may be the same order of a modern broadband seismometer; second, the drilling of boreholes is expensive and may be of the order of a thousand Euros per meter, but in general it depends on the considered site and country.

Tilt: it can be measured by two methods: dry tilt and tiltmeters.

The dry tilt method is based on the use of a level (roughly a telescope with a central cross-hair) and graduated vertical rods to measure with a high precision the variation of relative elevation of at least three permanent benchmarks deployed in a small array, usually an equilateral triangle of 50 m side and the level is installed at the centre. The tilt then is obtained applying some mathematical formu-

las to the results of the measurements. The tilt variation is obtained by comparing the measurements of successive campaigns with a regular time interval between each one.
Tiltmeters can be of different types, as for example the horizontal or vertical pendulums and the long base tiltmeters, also called water-tube tiltmeters. However, electronic bubble bi-axial tiltmeters are nowadays more used. These instruments are equipped with two perpendicular tiltmeters and can measure the rotation of the ground in the two perpendicular horizontal directions, with an accuracy of 1 micro-radian (i.e., the angle defined by 1 km long bar lifted up by 1 mm on its extremity). Tilt stations equipped with this kind of tiltmeter are very sensitive to the variation of environmental conditions. It is worth nothing that the cost of a suitable tiltmeters for volcano monitoring is of the order of few thousands of Euro (4500 € in 2012).
Strain and tilt measurements provide good information about the local deformation and both have the advantage of the telemetry in real time. On the other hand they share the same potential problem, because they do not provide any information about the vertical and horizontal displacements.

Displacements of the ground surface: it can be obtained using: Electronic Distance Measurement (EDM), Trilateration and Global Positioning System (GPS) receivers.
The EDM uses an electromagnetic wave emitter (usually infrared or visible) and a reflector installed on a benchmark to determine the distance between two points (the emitter and the reflector). The accuracy obtained with this technique is about 3 mm.
In the trilateration method, the angles between benchmarks combined with the distance are used to determine the three-dimensional changes of the position of the network of benchmarks. The angles are simply measured with a theodolite, whereas the distance is determined by EDM. This method may take a long time for a complete survey, and it is more useful for the monitoring of quiescent volcanoes. It should be stressed that this technique presents a high degree of danger at active volcanoes close to eruption since it requires the work of humans in the field.
GPS receivers (or briefly GPS) have become the most used technique for monitoring of ground displacements. GPS is a navigation system developed by the U.S. Department of Defence. It consists of a constellation of about 30 satellites, each one orbiting the Earth twice a day at a distance of about 20000 km. At the Earth surface, a receiver computes its distance to a satellite. With the distance to at least four satellites the receiver determines its position. However, due to military reasons, a civil GPS receiver does not have access to the full information carried by signals emitted by the satellites, therefore this method of location is affected by inaccuracies that may reach some meters to hundreds of meters. Nevertheless, this limitation is overcome on combining the measurements of at least two near receivers, and the relative position may be determined with accuracy of the order of 1 mm. This last technique, called differential GPS, is the one used for volcano monitoring. A GPS network may be permanent, called continuous GPS, or may be periodic, which means that periodic surveys are done with regular time interval between each one and using the same monuments (or pillars) to set up the GPS antenna. Anyway, permanent network and periodic campaigns require a long time for data acquisition (some

hours) and processing. As far as the cost is concerned, a GPS station including the monument construction, the power and data transmission equipment may cost few tens of thousands of Euros (about 18000 € in 2012).

Advices and remarks for setting up a network

Ideally at least two of the methods described above should be used to monitor a volcano. However due to budget limitations this practice is not always possible. Therefore in order to decide which method is the most suitable, several considerations should be taken into account. The first is to know if it should be a permanent monitoring network or a periodic campaign. The answer is not trivial, however if the volcano has infrequent eruptions or the objective is to test if it is still active, then probably the best practice should be to opt for a periodic campaign of GPS or dry tilt. If the volcano is known to be active and have frequent eruptions and with a small repose interval between each eruption, then a permanent network should be deployed. In this last case the choice of the instruments to install should be related to the nature or the geology of the volcano and also long-term cost. For example a volcano with a deep and small magma reservoir will produce very small vertical displacements at the Earth surface. In this case a GPS or a strain network would be better. On the contrary if magma storage is shallow then a tiltmeter network with an appropriate geometry will probably be better.

The environmental parameters also play an important role in the measured ground deformation quantities. In fact, the diurnal and seasonal variation of temperature has a strong effect on the local tilt and strain, which is called the thermo-elastic effect. Moreover, the water precipitation changes the mechanical properties of the soil, which also introduce noise to the measurement of those quantities. In addition, strain measurements are particularly affected by the pressure variation. These are the reasons why tiltmeters and strainmeters should be installed at depth. While GPS is reliable in all weather conditions, it may also be perturbed by environmental parameters. Indeed, the propagation of electromagnetic waves emitted by the satellites is significantly perturbed by the atmosphere and particularly by humidity. Particularly in tropical regions where its measurements may be severely affected by the seasonal variation of humidity, a GPS network may give some “unreal” deformation. This is especially true for periodic campaigns. Consequently, once a ground deformation network has been installed, it is crucial to have a long-term observation series recorded during a quiescent period of the volcano, in order to quantify the response of measurement to the variations of environmental parameters, and to identify, whenever is possible, the effect of each environmental parameter.

Opportunities for actions and future developments

In 2014 Galileo, the European navigation system similar to the GPS will be available. This new system will bring a lot of improvements since all users will have free access to all the codes emitted by the satellites, positioning will be much more accurate and the cost will also decrease. This new generation of GPS receivers are already configured to process the Galileo signals.

GOOD PRACTICE FOR GROUND DEFORMATION MONITORING

Strainmeters network: install at least three strain stations for an adequate volcano-monitoring network.

Site for tiltimeter deployment: when possible, use caves or lava tunnels, with stable temperature and soil, or install borehole tiltimeters at approximately 8 m deep. This last option is more expensive due to the cost of the equipment and also the cost of drilling boreholes.
Tiltimeters should be preferentially installed near a seismic station, as the same digitiser may be used for the tiltimeters and seismometer output signals. In addition, this practice enables sharing of the data transmission link and power infrastructures and, consequently, enables the reduction of deployment cost.

Tiltimeters network: tilt network should comprise of at least three stations and disposed in suitable geometry in order to cover a significant area around the volcano.

GPS network: the number of stations needed for a GPS network depends on the area that should be covered, but in general at least four stations are needed. One station should be installed, where it is not prone to suffer any deformation and the coordinates are well known, and the others in the region of activity.

Chemical monitoring

Utility

Volcanic gases have been described as "telegrams from the Earth's interior". Surveillance of gas composition and flux provides insights into how volcanoes work and valuable information for assessing volcanic hazards. Numerous methods to measure the gas mixtures and emission rates from volcanoes have been developed and gas geochemistry is widely recognized as an important and highly desirable component of multidisciplinary monitoring efforts. These include a range of spectroscopic instruments and sensors that can be operated at ground level, potentially autonomously. As well as offering a means for assessing volcanic activity, emission measurements can be relevant for exposure monitoring since a number of gas and aerosol species common in volcanic plumes are potentially harmful.

Instruments and techniques

This section briefly reviews the principal techniques for measurements of volcanic volatile emissions, which include: in situ sampling and sensing, ground-based ultraviolet spectroscopy (Correlation Spectrometer and successors), and ground-based infrared spectroscopy (Fourier transform spectroscopy and other infrared spectroscopic analysers).

Conventional analysis: conventional analyses of volcanic gases involve direct collection of samples from fumarole vents, and subsequent laboratory analysis. This approach typically uses the classic "Giggenbach" bottle, which consists of an evacuated Pyrex vessel partially filled with a solution of caustic soda (NaOH). Ammonia (NH_4OH) solution can be used as an alternative. The gas stream is passed through the solution via tubing inserted into the volcanic vent. Acid species such as sulphur dioxide (SO_2) and hydrogen chloride (HCl) condense and can be analysed by ion chromatography. The remaining gaseous species, including the noble gases, nitrogen (N_2), methane (CH_4), hydrogen (H_2), and carbon monoxide (CO), collect in the headspace. They are usually analysed by gas chromatography. The key benefit of this technique is that very detailed inventories of gas composition can be obtained. In addition, the measurement of isotopic compositions can be vital in identifying sources of carbon, helium, etc., in a volcanic emission. The disadvantage is that sampling can be laborious and hazardous, and suitable laboratory facilities are required.

An alternative and somewhat simpler strategy for acid gas sampling involves the use of base-treated filter papers (e.g., Whatman 41 ashless circles). The filters can be treated with 5% potassium carbonate (K_2CO_3) and 1% glycerol in distilled deionised water, and housed in a Teflon pack with a pre-filter to trap aerosol. They are typically connected to an air pump and deployed on crater rims or near fumaroles to sample volcanic plume diluted in air. They are easier to transport than Giggenbach apparatus and are suitable for in-plume measurements where the vent is inaccessible.

Electrochemical sensors: an alternative approach to volcanic gas surveillance is the application of electrochemical sensors, which can operate autonomously. These contain an electrolyte, which is exposed to ambient air (and volcanic gases) by diffusion, with or without the aid of an air pump. The ensuing redox chemistry generates a current that is proportional to the target gas abundance. Target gases include SO_2, H_2S and CO, which can be supplemented by non-dispersive infrared sensors for CO_2 and H_2O analysis to provide a useful suite of volcanic gas measurements. A valuable recent complement to these "multi-gas" sensing approaches is the availability of H_2 sensors, providing overall the potential to constrain the relative abundances of important redox pairs, namely CO_2/CO, SO_2/H_2S and H_2O/H_2. Long-term installations of such sensor units (using Wi-Fi or cell-phone networks, or satellite telemetry) are beginning to provide valuable and near-real time insights into the relationships between surface emissions and magmatic processes. Disadvantages of electrochemical sensors include sensor drift and imperfect specificity to target gases. Cross-sensitivities between different gas species represent a significant problem because of the cocktail of volatiles typically found in a volcanic plume; for example, most commercially available H_2S sensors respond also to SO_2. On the other hand, because they are mass-manufactured for a wide-range of industrial and consumer applications they are cheap. In any case, regular recalibration is required to ensure that data are reliable. Since they operate by direct exposure to volcanic gases, installations can quickly degrade through the action of acid species. Pumps used to circulate air to the sensors can also become clogged by aerosol.

Ultraviolet spectroscopy: optical sensing techniques have been increasingly used for volcanic gas and aerosol monitoring over the past four decades. Until around a decade ago, the Correlation Spectrometer (COSPEC), which was designed to sense ultraviolet light from the sky, was in routine use by volcano observatories worldwide for measurement of SO_2 fluxes. COSPEC saw active service in numerous volcanic crises, crucially helping to ascertain whether or not new magma pathways were opening up to shallow levels beneath the volcanoes concerned. Over the past decade, however, a new generation of ultraviolet spectrometers has taken over the role of COSPEC. The measurement of target gas abundances is typically (though not always) carried out via a procedure known as Differential Optical Absorption Spectroscopy (DOAS).

These new instruments are built around low-cost Charge-Coupled Device (CCD) detectors and mass-produced optical benches, and the first volcanological measurements were made at Masaya (Nicaragua) in 2001. There has been tremendous innovation in the application of these compact devices to volcanology, including their installation on unmanned aircraft and the development of scanning systems that rotate the field of view of the spectrometer around the sky (which enables SO_2 flux monitoring from fixed stations on the ground). A key benefit of scanning systems is their suitability for autonomous operation. In practice, plume scans can be made within a few minutes, providing 100 or more measurements per day. This can reveal rapid variability in source emissions, which might, for instance, relate to fluctuating magma flow to the surface. Even higher time resolution (of order 1 Hz) is possible with ultraviolet cameras (see ground-based camera later in this Chapter) since an entire plume can be captured instantaneously. In this case, spectral filters are used for SO_2 discrimination. Statistical means for tracking plume “puffs” provide estimates of the plume velocity, which is needed for flux calculations.

Similar high-temporal resolution measurements can be obtained using two spectrometers whose attached telescopes have parallel but offset optical fields of view. The use of cylindrical lenses provides an instantaneous view of the entire width of a volcanic plume enabling measurement of SO_2 flux at very high time resolution. Again, temporal correlation of the two spatially-offset time-series permits accurate estimation of the plume transport speed, otherwise seen as the largest source of uncertainty in SO_2 flux calculations.

Drawbacks of ultraviolet spectroscopy using scattered light from the sky include unresolved issues in validating measurements. It is also, of course, only possible to collect measurements during daytime. There are a number of potential artifacts and uncertainties in spectroscopic measurements of SO_2 that may have significant impact on retrievals. These include errors in plume transport speed estimation, but also radiative transfer issues, i.e., the way light is scattered behind, within and in front of the plume. Measurements are sensitive to meteorological conditions (including type and distribution of cloud) and viewing geometries (the position of the plume in relation to the observer and the Sun). These can result in substantial under-estimation or over-estimation of SO_2 burdens. Unfortunately, these effects can be very challenging to identify or quantify. Measurements made by scanning systems depend also on uncertainty in the height of the plume. While SO_2 monitoring using ultraviolet spectroscopy deservedly represents a key activity of many volcano observatories, caution has to be exercised in interpreting apparent changes in SO_2 flux. In addition, the quality of measurements can depend on the expertise of the operator in data collection and retrieval, more so perhaps than other means of volcano monitoring.

Fourier transform infrared spectroscopy: fourier transform infrared (FTIR) spectrometers are capable of simultaneously sensing several gas molecules of interest, including HCl, HF, CO_2, CO, OCS, SiF_4 and H_2O, as well as SO_2. Measurements are typically made of volcanic plumes as they are released from the vent or drift downwind. An observation geometry is required that places the plume in front of a suitable infrared source. This could be the Sun, an artificial infrared lamp, or indeed hot features on the volcano itself (lava domes, flows, lakes, or ground heated by fumaroles). The beauty of the technique is its flexibility: the observation strategy can readily be adapted to circumstances of volcanic activity, access and terrain. It can also furnish very accurate measurements of gas ratios and is little affected by instrumental drift.
Measurements of the relative abundance for different gases can be made with a sampling rate of around 1 Hz. Data can even be collected during more vigorous eruptive episodes yielding insights into the dynamics of magma transport and degassing of magma. Disadvantages of FTIR spectroscopy include equipment costs, typically in the range of a few tens of thousands of Euro, and the need for operators to have a reasonable background in spectroscopy.

The techniques discussed in this chapter are complementary (Table II in Appendix). Ultraviolet scattered light spectroscopy is well-suited to SO_2 flux measurements but other techniques (including electrochemical sensors, FTIR spectroscopy and Giggenbach bottles) are able to measure a wider range of volcanic volatile species. Integrating datasets (i.e., SO_2 flux from ultraviolet DOAS and CO_2/SO_2, HCl/SO_2, etc., from electrochemical or infrared sensing or direct sampling with filter packs) can thereby provide flux measurements for a suite of gas species. Some methods provide more detailed data for campaign measurements but are less suited to automated long term surveillance and vice versa. Flexibility and adaptability of field measurement strategy usually pays off.

Advices and remarks

Reliable measurements are the key to meaningful gas geochemical analysis. However, all the techniques for either compositional measurement or gas flux determination are subject to numerous sources of uncertainty, some of which can be very difficult to constrain. These include integrity of samples, suitability of calibration standards, measurement selectivity, dependence of spectroscopic retrievals on fitting parameters, applicability of wind speed measurements (for flux calculations), and the vagaries of atmospheric radiative transfer. The analyst thus needs a good appreciation of the way measurements are made and the extent to which they can be relied on to reach interpretations of volcanic processes or changes in levels of activity. For instance, in the case of ultraviolet DOAS measurements, a steady SO_2- flux from a crater could appear to change, simply due to varying meteorological conditions and time of day, reflecting the complexities of light propagation through the atmosphere.

Volcanic gases have invariably mixed with air prior to measurement, certainly in the case of plume sensing and sampling downwind from the vent. This allows time for chemical transformations to have occurred prior to measurement: typically, magmatic gases have been diluted in air by a factor of around 1000 by the time the plume drifts over a crater's edge. While some species are quite inert in the atmosphere, others are reactive in the presence of abundant oxygen and sunlight, and this is another reason why environmental conditions (e.g., atmospheric temperature, humidity, actinic flux) can modify the "primary" magmatic gas signature.

GOOD PRACTICE FOR GEOCHEMICAL MONITORING

Ancillary information: gas analysis should include careful recording of ancillary information during data collection. For instance, in the case of ultraviolet DOAS measurements of SO_2 flux, it is valuable to document atmospheric conditions (including cloud cover), viewing geometry, plume transport direction, etc.

Spectroscopic retrievals: care should be taken to characterise sensitivities of retrievals to fitting parameters (such as wavebands analysed), and to record chosen parameters.

Sample collection: it should always be accompanied by careful documentation of prevailing conditions and of laboratory analysis protocols and standards, etc.

Time-stamping and geocoding of data: establishing good practice in collecting appropriate metadata not only helps to standardise measurements, but in the longer run will support future data mining efforts (for instance evaluation of regional or global volcanic volatile fluxes).

Gas analysis approach: it should be flexible and use multi-gas monitoring instruments. The principal techniques for gas measurements are, in fact, complementary and therefore their contemporary use is desirable.

Opportunities for action and future developments

The greatest innovation ahead in volcanic gas geochemistry arguably lies in developments of laser-based techniques, notably laser spectroscopy and LIDAR (LIght Detection And Ranging). Laser spectrometers have the major advantages of sensitivity and selectivity to target gas species and even have the precision to enable measurement of isotopic composition. LIDAR instruments use a pulsed laser beam that is directed towards the plume. Recording the temporally-varying intensity of light scattered back to the instrument provides information on the atmospheric composition as a function of distance. LIDAR has been used to measure concentrations and fluxes (via traverses) of sulphate aerosol and ash. A variation on LIDAR known as differential absorption lidar (DIAL)

BOX3

GAS EMISSION DURING THE 2010 MERAPI ERUPTION

The 2010 eruption of Merapi was the largest for this volcano for more than a century. Fumarole gas sampling detected a significant increase in several volatile ratios (CO_2/SO_2, CO_2/HCl and CO_2/H_2O) in addition to increased CO_2 abundance in the months preceding the eruption. This suggested a stronger contribution to the surface emissions from a deep degassing magma source. Ground-based DOAS measurements were performed infrequently but nevertheless provided critical information, especially before the first explosive event in 2010, by revealing SO_2 fluxes that were high compared with those measured during previous eruptions of Merapi. This suggested a large input of gas and/or the arrival of a new volatile-rich magma body at depth. However, while ground-based DOAS observations were valuable in detecting anomalous pre-eruptive SO_2 emissions (that were below the detection limit of satellite sensors), they were difficult to sustain during the later paroxysmal explosive stage of the eruption. This was because of the wide exclusion area around the volcano, the quantities of ash in the plume, and adverse weather conditions (high humidity and frequent rainfall). At that stage, satellite remote sensing (using OMI, IASI and AIRS sensors) provided the best platform to observe SO_2 degassing.

This case study demonstrates that comprehensive monitoring of gas emissions through different stages of volcanic activity requires a combination of in situ gas sampling, ground-based DOAS and satellite remote sensing. In the Merapi case, the availability of these different tools allowed us to corroborate the magmatic unrest and to track, in near real-time, critical developments in the volcanic activity.

involves rapid switching of the wavelength of the laser to measure the spectral absorption of a gas of interest. By dividing the returned signals obtained at the two wavelengths and applying the Beer-Lambert law, range-resolved gas mixing ratios can be obtained. Scanning systems can even reveal the three-dimensional distribution of the target gas. This contrasts with measurements obtained from open-path FTIR or ultraviolet spectroscopy, which provide only limited information on the distribution of the target gas in the optical path. Currently, DIAL apparatus remains costly and bulky, and its operation and associated data analysis are complex. Thus it has only rarely been applied to measurements of volcanoes to date. With further innovation, however, it has great potential for improving the accuracy and frequency of gas flux measurements. In fact, as an active remote sensing technique it can be operated day or night unlike conventional ultraviolet spectroscopy using scattered light from the sky. In addition, measurements are also less affected by the kinds of radiative transfer uncertainties discussed above. Several engineering approaches can incorporate laser sources into spectrometers. Generally, these require pumping air (and plume) into an internal cell through which the laser beam is introduced. Thanks to very narrow spectral line-widths, lasers can make sensitive measurements of isotopic abundances. They can even resolve isotopomers that would be very difficult to discriminate by isotope ratio mass spectrometry. A few experimental systems have been constructed for measurement of the isotopes of CO_2 in the mid infrared region of the spectrum, while diode laser spectrometers have been demonstrated for measurement of water isotopes in the near-infrared region. In principle, laser spectrometers could be designed for measurement of chlorine and sulphur isotopes, too. Applications of nonlinear optics in volcanic plume measurements are emerging. They have the potential to revolutionise volcanic gas surveillance within the next decade.

Acoustic monitoring

Utility

Infrasound acoustics is used to measure pressure waves propagating in the atmosphere generated by volcanic eruptions and outgassing activity. Infrasound corresponds to the low-frequency component of sound and it ranges from 0.001 to about 20 Hz below the human threshold of hearing. Many natural phenomena, such as earthquakes, volcanic explosions, density currents (i.e., pyroclastic flows, surges, lahars, rock-falls, debris flows and avalanches, see Section 2), atmospheric processes (microbaroms, aurora, tornados, lightning), bolides, tsunami etc., generate infrasound in the atmosphere. Among them, volcanoes are quite a prolific radiator of infrasonic waves whenever a magmatic process becomes well coupled with the atmosphere, such as during an eruption. On active volcanoes, volumetric sources rapidly expanding in the atmosphere produce infrasound providing valuable insights into eruption dynamics and into the state of volcanic activity in general. Thus, infrasonic activity on volcanoes is the direct evidence that conduits are opened and that magma is outgassing.

On volcanoes characterized by dome growth, infrasound can be also generated by non-explosive sources related to dome collapses, such as pyroclastic flows, rock-falls and lahars. The ability to detect volcanic explosions and track pyroclastic flows in real-time is crucial to volcano monitoring operations and can positively impact risk management on many active volcanoes. Infrasound generated by density currents can be used to monitor in real-time the direction and the velocity of the flow. This makes monitoring the explosive activity more simple and infrasound is rapidly becoming widely used in volcano monitoring.

Principles

When the atmosphere is rapidly accelerated by a volumetric change it generates infrasound, which propagates as small perturbations ($<10^3$ Pa) of the atmospheric pressure (10^5 Pa). Unlike seismic waves propagating in the highly scattering ground media, infrasound propagates in the atmosphere, which at short distance from the source (<30 km) can be considered to be fully transparent to acoustic waves.

Given the large amount of natural and/or artificial sources propagating in the atmosphere, recording infrasound with a single station is not recommended because it makes signal interpretation more difficult. More commonly infrasound stations are deployed in a sparse network or in a specifically designed geometry (array, Fig. 11). The advantage of an array configuration is that it can provide the direction from which the sound emanates, and allows scientists to increase the signal-to-noise ratio and to reduce the ambiguity of infrasound signal detection.

Instruments and techniques

Early acoustic perturbations generated by volcanic activity were recorded with analog microbarometers capable of measuring only frequencies lower than 1 Hz. Despite the use of high sensitive microbarometers back in the 1960s, deployment of infrasonic sensors on active volcanoes is much more recent and started in the early 1990s. Nowadays, infrasonic sensors cover the whole frequency (1 mHz to 20 Hz) spectrum of volcano infrasound, from small amplitude outgassing (~10^{-2} Pa) to major eruptive episodes (>10^{3} Pa). This dynamic range (>100 dB) can be recorded by sophisticated microbarometers, such as those used in the Comprehensive Nuclear-Test-Ban Treaty Organization - International Monitoring System (CTBTO-IMS), sensitive from 100 hPa down to 0.5 mPa, far below the mean atmospheric noise level. However, the cost (few thousand Euros), the installation logistics and the power requirements, usually discourage the use in hostile volcano environment. In the last years low frequency microphones and differential pressure sensors sensitive in a quite broad frequency band are getting more and more common on active volcanoes. The frequency response of such sensors ranges from 0.001 to 50 Hz, which allows a complete analysis of volcano infrasound. Sensor's power requirements as well as installation logistics allow efficient monitoring and easy maintenance in the hostile volcanic environments. Prices vary from 2000-3000 €, for off-the-shelf sensors, down to ~800 € for sensors from piezo-resistivity pressure transducers, extensively used in industrial and medical application. These differential pressure sensors have however a limited (typically <100 dB) dynamic range, with reduced sensitivity at high pressure range.

The use of infrasound array monitoring can drastically reduce the ambiguity of infrasound signal detection. Here, multichannel correlation analysis among the different array elements allows signal detection and characterization, even at large source-to-receiver distances. The array processing applies multi-channel correlation method to identify signals from noise in terms of wave propagation back-azimuth and apparent velocity. The propagation back-azimuth indicates the direction where the signal is coming from and relates to the location of the source. The array design and dimension is strongly controlled by the specific application, frequency content and amplitude of expected infrasound signals, with apertures ranging from few tens/hundreds of meters for small source-to-receiver distances, up to several hundreds/thousands meters for high sensitive large aperture arrays operated within the CTBTO-IMS, specifically designed to identify nuclear explosions worldwide.

Infrasound array monitoring of volcanic activity at short source-to-receiver distances (<30 km) is best achieved with small aperture (<200 m) arrays (Fig. 11). This technique has proved the ability to detect both point sources, as explosive events, and non-point moving sources as pyroclastic flows and debris flows, in real-time. For a 100 m aperture array, the expected azimuth resolution is of ~1°, considering a frequency content of 3 Hz, typical of infrasound generated by volcanic activity, thus allowing real-time monitoring of different infrasonic sources within a single volcanic system. The use of small aperture infrasonic array is thus increasing the efficiency of volcano observatories during eruption crises, as it provides rapid assessment of eruptive activity and critical parameters to constrain with other geophysical parameters (mainly seismic signals, ground visible and thermal cameras, gas monitoring) the source models. Moreover, the efficient infrasound wave propagation in the atmosphere allows also monitoring large volcanic district with a single infrasound array with a direct impact in reducing the cost of the ground monitoring in large and remote areas.

Finally, it is worth noting that a full deployment of the array requires 24 hours of work by a team of 4 people. The approximate cost of the installation is comparable to one broadband three-component seismic station.

GOOD PRACTICE FOR ACOUSTIC MONITORING

Fibre optic technology: their use provides optimal signal-to-noise ratio (SNR) and the best network integrity against atmospheric agents such as lighting. This makes infrasonic arrays a robust and easy to maintain tool for long-term volcanic monitoring.

Instruments deployment: each sensor should be placed 1 m into the ground and it should then be connected to porous holes 2-3 m long radially distributed around the sensor in order to reduce the large noise contamination induced by strong winds. Pipes will provide the coupling to the atmosphere and prevent large wind noise contamination. This solution makes it possible to detect small pressure waves also in strong (15-20 m/s) wind environment.

Array deployment: to have the best array efficiency, locate the array in a low noise site, even if at a greater distance from the volcano, because of the low attenuation in the atmosphere of infrasound waves. Accordingly, a thick forest is a preferred site with respect to an open site.

Wind sensors: if possible, install a wind sensor coupled with the array. Wind, in fact, is the largest source of noise for infrasound.

Reliability of results: data from a single infrasonic station are often ambiguous. Better results can be obtained with an array or if this is not possible, with a combined seismo-acoustic observation that will help to identify seismic processes coupled with atmosphere.

Opportunities for action and future developments

Acoustic monitoring on a routine base is becoming increasingly well established on active volcanoes worldwide. Infrasonic arrays provide unambiguous information of ongoing volcanic activity that can be efficiently used as an early-warning monitoring tool to alert airports and the competent authorities. Unlike seismic waves, small (10^{-1} Pa) infrasonic waves related to ongoing volcanic activity can be detected hundreds of kilometers away from the volcano. Besides, infrasound propagation does not depend on weather conditions and is thus more efficient than other techniques such as satellite-based optical remote sensing. More infrasonic arrays should be deployed at local distances (<200 km) from active sources in volcanic districts. Data coming from these local arrays should be integrated in the CTBTO-IMS network to build a World-Wide Infrasonic System able to detect volcanic explosion.

3

a

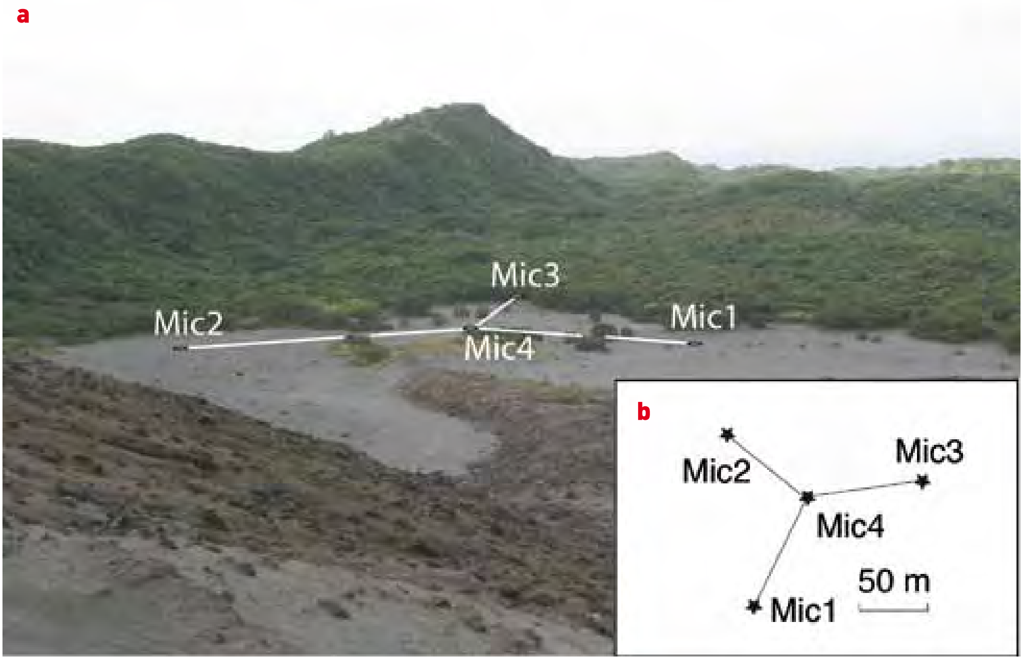

Figure 11: Sample picture **a** and geometry **b** of an infrasound array deployed at the base of a nearby volcano. Photo by Riccardo Genco - Yasur - Tannah Island - Vanatu.

BOX4

EXAMPLES OF ACOUSTIC MONITORING SYSTEMS

Acoustic technique is presently and efficiently used at several volcanoes, such as Stromboli and Etna (Italy), Soufrière Hills, Montserrat (West Indies), Tungurahua (Ecuador), Ejyafjallajökull (Iceland).

Soufrière Hills Volcano, Montserrat, West Indies: A volcano characterized by lava dome growth and collapse generating extremely dangerous density current such as PDCs, rock avalanches and lahars. This activity is responsible for nonstationary, extended infrasonic sources, which can be tracked in real-time using state-of-the-art technology. Thus, infrasonic monitoring, especially during severe weather conditions or when visual observations are precluded by the huge gas and ash columns towering above the edifice, is providing in real-time the onset of eruption and the direction and the velocity of the PDCs.

Ejyafjallajökull, Iceland: The 2010 ash-plume activity of Ejyafjallajökull volcano in Iceland was detected by the large aperture, high sensitive infrasound arrays in Europe, Russia and North Africa up to a distance of 3600 km, thus demonstrating the efficiency of the modern infrasound technology as a remote ground-based monitoring system, being able to detect small pressure perturbation (<0.01 Pa) generated by moderate (i.e., VEI >3, see Section 2 and Table I in Appendix) volcanic activity at distances of up to 9000 km.

Ground Based Cameras

Utility

Ground-based digital cameras can be effectively used for monitoring the volcanic environment and for providing hazard warnings. Since the early 1990s with the advent of cheap and durable CCDs, digital cameras have been deployed at many hazardous places, including at volcanoes, to indicate any change in conditions.

Instruments

The most common example of the use of digital camera technology is the webcam. Webcams consist of an affordable CCD camera, a power source (often derived from solar panels), a communications method and a display or monitoring device, often placed remotely from the camera. Wireless, IP (Internet Protocol) cameras are ideal for monitoring volcanic activity because of safety aspects and because continuous, autonomous operation is possible. An example of a webcam image from the eruption of Eyjafjallajökull is shown in Figure 12. Table III in Appendix provides a selection of current webcams at some important volcanoes.

A restriction of typical 'visible' webcam technology is that it is necessary to have good lighting conditions therefore its use is limited during the night. Webcam technology can be extended beyond and below the visible region by using CCDs that are sensitive to Ultra-Violet (UV), Near Infrared (NIR) and Thermal Infrared (TIR) radiation.

Near Infrared cameras operating above 1 μm and typically between 1.46–1.63 μm are commercially available, and have been deployed at several volcanoes in an effort to monitor activity and estimate heights of ash plumes.

Quantitative assessments of threats from volcanoes can be made with specialized cameras operating in the UV (280–320 nm) and TIR (8–13 μm) parts of the electromagnetic spectrum. Many of these ground-based systems owe their heritage to advanced space-borne sensors used to measure gases from volcanoes. UV cameras can be adapted for measuring SO_2 gas emission. These cameras measure SO_2 gas absorption with specialized CCDs and sample at frequencies between 1–10 Hz. They are usually used during field work for durations of 1 day to several weeks but so far have not been used for routine monitoring at volcano observatories, largely due to cost and labour requirements. Nevertheless, in the future as costs decrease and technology improves it is likely that these cameras will eventually supplant the UV spectrometers used in current volcano gas networks.

The limitations of relying on daylight and good visibility needed for webcams and UV cameras can be overcome by utilizing emitted radiation in the thermal regions. Thermal cameras have been used at volcanoes for many years to measure the radiant heat emitted by hot lavas and ash flows. The use of these types of cameras for measuring ash and gas plumes and associated hazards is relatively new, but offers some significant advantages over visible light and UV cameras. Notably the IR cameras may be used at night and in low visibility providing the opportunity to have continuous 24 hours/7days week surveillance of hazards from a safe viewing point. A spectral imaging IR camera may be used to quantify ash emissions from erupting volcanoes. The cameras may also be used to measure plume height and assess the motion of plumes by analyzing shapes in sequences of

Figure 12: Webcam image of the eruption of Eyjafjallajökull on 2 May, 2010 taken from Valahnuksbol. Image courtesy of the Icelandic Meteorological Office.

frames of images. An example of an IR camera image retrieval of SO_2 gas emissions from Turriabla volcano, Costa Rica on 18 January, 2011 is shown in Figure 13.

20. Satellite-based remote sensing monitoring

The availability of earth observation (EO) satellites in the last decades has offered the possibility to integrate ground surveillance with satellite derived information to characterise phenomena during natural disasters. Many countries worldwide are affected by at least one major natural hazard such as floods, fires, sandstorms, earthquakes, volcanic eruptions, landslides, rapid vertical ground displacements, and also by risks related to man-made activities such as chemical and nuclear accidents. These risks can be mitigated through better prevention and preparedness that includes provision and better use of space-based assets. In particular, satellite remote sensing has proved its potential as a reliable tool to monitor volcanic activity by developing dedicated applications. Remote sensing is a complex set of techniques requiring expertise in data processing and knowledge in the physics of the investigated phenomena.

Remote sensing sensors can be classified in two categories: passive and active sensors (Fig. 14).

Passive sensors measure the electromagnetic radiation that is naturally emitted and reflected by the Sun and by the Earth's surface and atmosphere. Passive sensors working in the spectral range from Ultra-Violet (UV) to Infrared (IR) are usually termed Optical sensors. The main spectral regions exploited for volcano monitoring are: the Visible (VIS), the Short Infrared (SWIR) and the Thermal Infrared (TIR) regions. There are also passive sensors working in the microwave region, but due to poor spatial resolution, there are no specific applications developed for volcanic area monitoring.

Active sensors: these measure the backscatter signal originating from the sensor itself. Since the source of energy is artificial, they can take measurements at any desired wavelength. In particular, in the microwave spectral range, these instruments are called RADARs and in the optical part of the spectrum they are called LIDARs. Among these sensors, RADARs, and in particular the Synthetic Aperture Radar (SAR) have proved to be valuable instruments for volcanic monitoring since they can operate night and day and in all weather conditions.

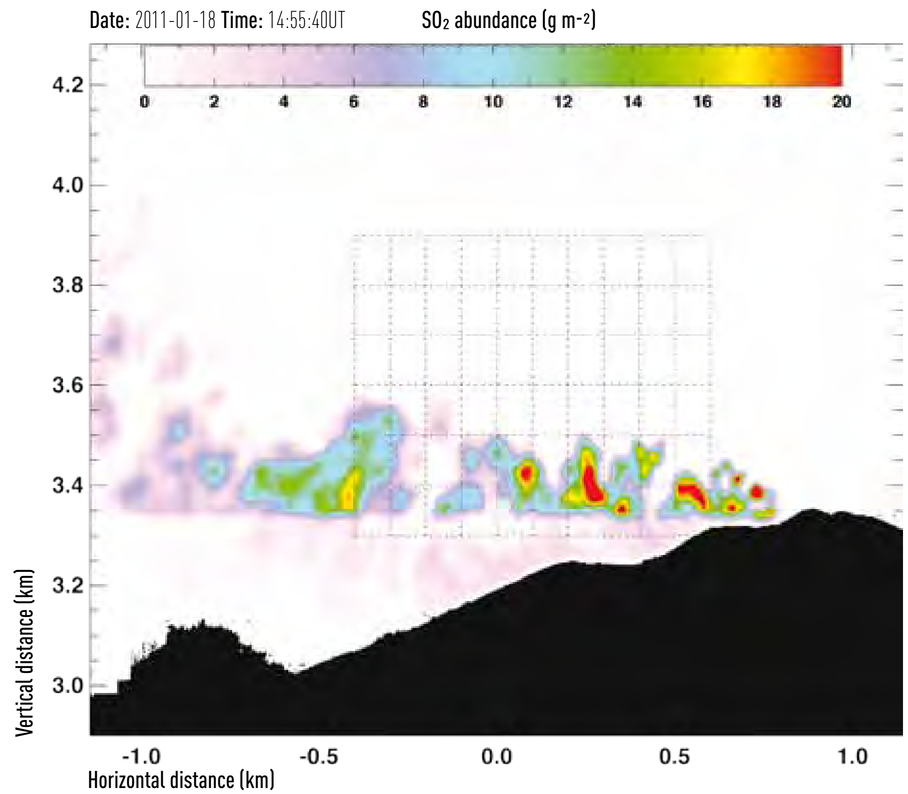

Figure 13: SO_2 gas emissions from Turrialba volcano, Costa Rica using a portable spectral imaging infrared camera.

Optical sensors and their applications

Utility

The availability of real-time EO data broadcasted directly to a user has allowed the possibility of using space-based measurements for monitoring active volcanoes. In particular, during volcanic crisis real-time data processing provides information concerning volcanic clouds, gas emissions, and lava flows to support the local observatories and decision makers. The use of EO satellite data to extract such information depends on:

- The spectral range covered by the sensor
- The available satellite sensors acquire images from the Visible to the Thermal

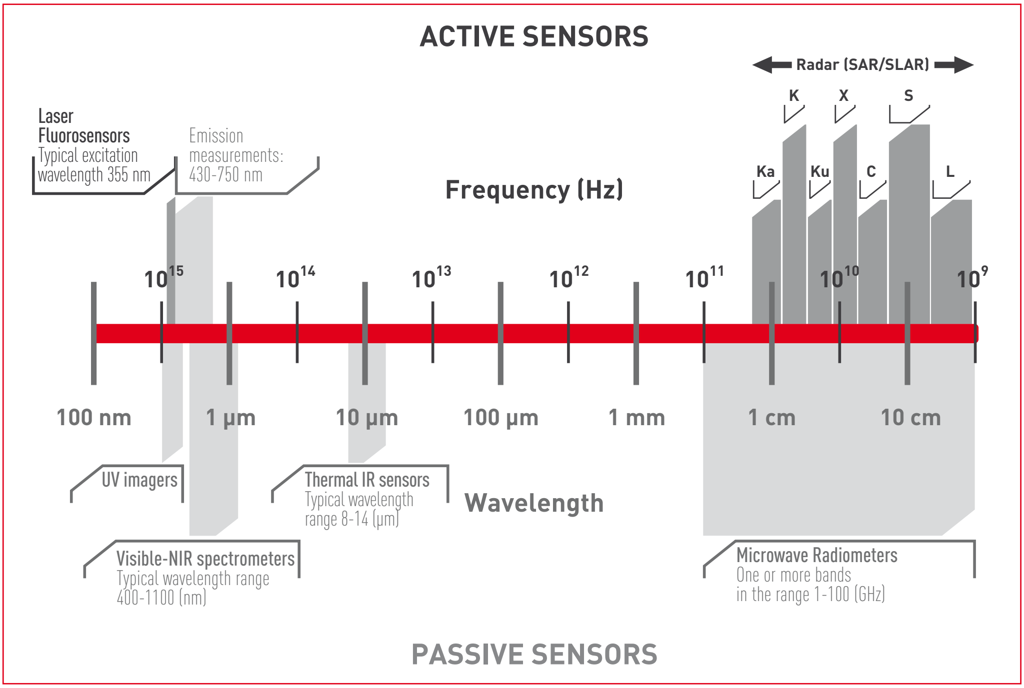

Figure 14: Electromagnetic spectrum and the working frequencies of EO sensors (scheme from http://www.seos-project.eu/).

Infrared spectral range

- The revisit time, which needs to be consistent with the duration of the monitored volcanic phenomena
- The area covered by the image and ground spatial resolution that defines the dimension of observed area needed to detect a specific volcanic phenomena

For example, in order to monitor an eruptive ash cloud that spreads at wind speed in the atmosphere over large areas (on the order of tens to hundred of km/h), the revisit time needs to be short while the area covered needs to be large. Alternatively, for slow eruptive phenomena, such as lava flows, the revisit time is less critical and more emphasis is placed on better spatial resolution, as lava flows spread over just a few km^2.

Instruments and techniques:

Remote Sensing algorithms have reached such levels of maturity to allow their use for volcanic monitoring. The information derived from EO data consists of geophysical parameters related to volcano status (i.e., quiescent, active) and to the type of activities, such as gas and particle emissions (in terms of column amounts), surface modification (e.g., radiant heat or 'hot' spot detection), and elevation change. If these parameters are mapped and updated they provide indications of change in the volcanic behaviour.

The current EO data used for volcanic activity monitoring are shown in Table IV (Appendix). It is important to remark that satellite missions have life-time nominal duration of about 5-10 years. Users may need to check the availability of the EO data by means of Space Agencies and data providers web portals.

During volcano quiescence, the most measurable parameters, with appropriate satellite spatial resolution, are: surface temperature, flux of gas and particles. During a volcanic eruption, the relevant measured parameters are: the velocity of active lava flows and the amount of volcanic ash and gas emitted in the atmosphere. All of these parameters when geo-referenced and combined become thematic maps. Thanks to this geographic approach minimum changes of such parameters is identified. Thematic maps are considered EO products to support the local observatories, emergency management and decision makers.
All the EO products are derived from data processing by applying specific algorithms

BOX5

EYJAFJALLAJÖKULL ERUPTION FROM OPTICAL SATELLITE IMAGES

Tremendous unprecedented impact on civil aviation in Europe was caused by the Icelandic Eyjafjallajökull volcanic eruption in April-May 2010. On 14th April at 8-9 UTC the eruption started to produce a pulsating column reaching a maximum 11 km height and a volcanic ash cloud spreading over Europe resulting in a billion Euro economic loss and large social impact. Satellite images, from which volcanic cloud quantitative parameters were estimated, came from many polar satellite and geostationary acquired data. Figure 15 shows an example of Aerosol characterization over Iceland area.

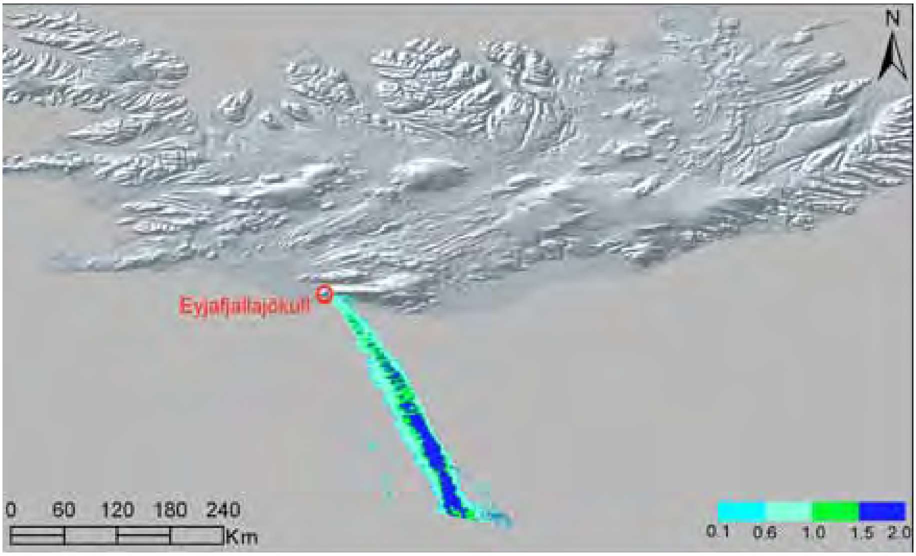

Figure 15: Example of EO product Aerosol characterization: MERIS derived AOT map on 11th May 2010 12.55 GMT over South Iceland. The figure shows the volcanic plume travelling in S-SE direction.

developed for each satellite sensor and described as follows:

- Thermal anomalies: heat flux and thermal features of active volcanoes
- Aerosol characterization: maps of volcanic aerosols optical thickness
- SO_2 characterization: volcanic SO_2 concentration maps and fluxes
- Effusion rate: active lava flow effusion rates
- Ash cloud characterization: ash presence in an explosive plume, ash loading maps, effective particle radius and infrared optical depth

The EO products are divided on the operative phases of the volcanic risk management as follows: knowledge and prevention, crisis management, post crisis (Table 2).

TABLE 2: EO OPTICAL SENSOR PRODUCTS AND RELATED PHASES APPLICABILITY

APPLICABILITY PHASE	EO PRODUCT	EO DATA
Knowledge & Prevention	- Thermal anomalies - Degassing plumes Aerosol characterization - Degassing plumes SO_2 characterization	ASTER, AVHRR and MODIS data ASTER, Hyperion, MERIS and MODIS data ASTER, MODIS, SEVIRI, AIRS, IASI, OMI data
Crisis	- Effusion rate - Ash cloud characterization	ASTER, AVHRR and MODIS data SEVIRI, AVHRR and MODIS data
Post Crisis	Change detection on surface characteristics due to: - Lava flow - Ash cover	Hyperion Very High resolution multispectral images (e.g., QuickBird, Pleiades)

GOOD PRACTICE FOR OPTICAL SENSORS APPLICATION

Systematic acquisition: during knowledge and prevention phase (Table 2) a systematic EO data acquisition allows the generation of time series to update images suitable for detection of changes in an eruption.

Acquisition frequency during crises: the acquisitions frequency of EO data should increase in order to cover the temporal window of an eruptive period.

Opportunities for action and future developments

Thanks to the improved space technologies, the next generation of EO missions is planned by the European Space Agency. The Sentinel mission will ensure the continuation of EO data time series with lower revisit time, higher spatial resolution and wider areal coverage. The new constellation of satellites will start in 2013. In Table V in Appendix, the new ESA-SENTINELs space missions characteristics are reported.

Synthetic Aperture Radar sensors and their applications

Utility

In addition to optical sensors, the Synthetic Aperture Radar (SAR), on board space platforms, can provide an alternative way to

3

monitor volcanic areas. SAR data can be exploited for useful products which can be used in volcano monitoring during prevention and crisis phases:

- Lava and pyroclastic deposits contours
- Areas affected by ash deposits
- Damage to buildings and infrastructure
- Crater modifications
- Syn-eruptive deformation map
- Surface velocity map and deformation history

Instruments and techniques

SARs are special RADAR imaging instruments. They are electromagnetic active sensors which can acquire a scene on the surface of Earth in any weather conditions, 24 hours a day, and without the need of an external source of energy (i.e., the Sun). Indeed, a SAR image is representative of the energy backscattered from the Earth's surface with respect to the emitted energy from SAR itself. The typical working frequencies of such sensors are the L band (1 – 2 GHz), the C band (4 – 8 GHz), and the X band (8 – 12 GHz) of the microwave electromagnetic spectrum. SAR data can cover a ground area that spans from 10 by 10 km to 200 by 200 km or more, depending on the specific characteristics of the SAR and its acquisition modes potentiality. One of the most important parameters of a SAR sensor is the resolution of the single image pixel, which is related to the capability for recognizing the objects on Earth surface. The most recent sensors, like the SAR onboard of the COSMO-SkyMed satellite mission or the one on TerraSAR-X, can acquire images with spatial resolutions that reach 1 by 1 m on ground. A second parameter that characterizes a SAR mission, is the revisit time, i.e., the time needed to acquire the same scene of the same area, and with the same geometry. The latter is a key point to perform SAR data analysis to derive the above mentioned products. Moreover, the revisit time is of course a very important factor especially in case of volcanic crises when information timeliness is crucial. Revisit times can be on the order of 25 days down to 1 day, which is the case of satellite constellations. This is of limited use during the crisis phase of the eruption. A synthesis of the main characteristic of the present and future SAR missions are listed in Table VI (Appendix).

Actually, two consolidated techniques can be used to extract information from SAR data: change detection and SAR interferometry.

The change detection method is based on the calculation of the per pixel backscattering difference between two SAR images, i.e., the difference of the amplitude of the SAR signal. The change detection can be exploited to obtain a map containing the surface changes (damage, lava flow, etc.) that occurred in the time span between the two images. An example of successful application of change detection, has been obtained during the October-November 2010 Merapi eruption (see Box 6). Thanks to SAR images, the MIAVITA remote sensing team gathered information about the opening of the crater and the extent of the large pyroclastic flow deposits (Fig. 16).

SAR Interferometry (InSAR), is a technique based on a particular signal processing of a pair of SAR images that acts on the phase component of the SAR signal. The two SAR images are combined to extract the per pixel phase difference which results in the so called Interferogram. This difference carries mainly information about the topography of the scene and measurements of surface deformations that occurred in the time window between the two SAR images. Therefore, it is clear that InSAR can be exploited to generate a DEM or terrain deformation and displacement. InSAR for deformation measurement is also called Differential SAR Interferometry (DInSAR), where the component related to the topography is removed from the Interferogram, allowing scientists to measure, with centimetric accuracy, deformation caused by earthquakes, volcanic activities, tectonic movements, landslides, etc. (Table 3).

During the last decade, advanced techniques based on DInSAR have been developed to provide a new product useful for geophysical risk monitoring. These techniques, called multi-temporal InSAR, exploit a series of SAR data, at least 20-25 images are required to obtain reliable results with millimetric accuracies, over a given area for a given period to detect slow terrain movements. The deformation caused by seismic or volcanic activities, slope instability, subsidence caused by natural compaction or ground water pumping, can be accurately measured. The final product is a map of points with their mean surface velocity, in mm/yr. Moreover, the deformation history, also called SAR time series, for each point is calculated with millimetre accuracy. The number and the density of the points depend on SAR sensor characteristics, mainly the working frequency, and on the land cover type. Many methodologies for multi-temporal InSAR are available. Among them, we can cite the most famous and pioneer techniques, which are the Small Baselines Subset (SBAS) technique, developed by CNR-IREA (i.e., the Italian Istituto per il Rilevamento Elettromagnetico dell'Ambiente, Consiglio Nazionale delle Ricerche), the Permanent Scatterers® (PS) technique, by T.R.E., and the Interferometric Point Target Analysis® (IPTA), implemented by GAMMA Remote Sensing.

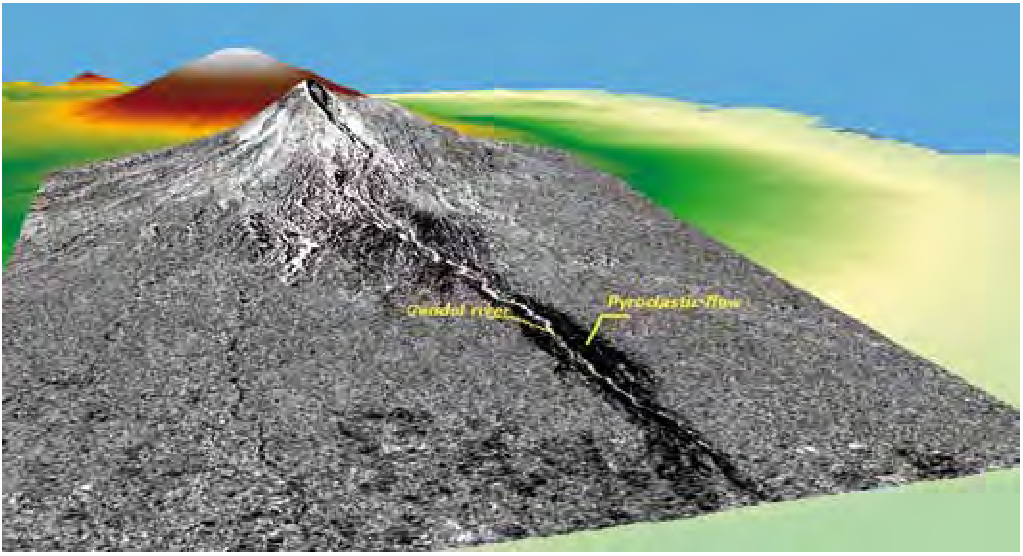

Figure 16: Example of SAR change detection analysis in 3D view. Black area corresponds to the 2010 pyroclastic deposits that blown out the buildings and vegetation surrounding the Gendol river. White pixels, inside the black area, correspond to deposits that filled up the Gendol river.

TABLE 3: SAR DERIVED PRODUCTS WITH RESPECT TO VOLCANIC PHASES AND SAR TECHNIQUES

PRODUCT	VOLCANIC PHASE	TECHNIQUE
Lava and pyroclastic deposit contours	Crises	Change detection
Areas affected by ash fall deposits		
Damage to buildings and infrastructures		
Crater modifications		
Syn-eruptive deformation map		DinSAR
Surface velocity map and time series	Knowledge and prevention	Multi-temporal InSAR

The main limitations that strongly impact on the usability and the reliability of SAR techniques, both DInSAR and time series are: atmospheric effects (wet troposphere) and dense vegetation cover, especially for C and X band sensors. Atmospheric effects can produce false signals that can mask or disturb the deformation pattern, while vegetation cover causes low SAR signal coherence hampering the calculation of the interferograms. These limitations have been observed during the MIAVITA project, where time series analysis by using ENVISAT SAR images (C band) did not provide useful data for Merapi volcano, and strongly limited the point density around Mount Cameroon. Concerning the cost of SAR data, a single very high resolution image can be expensive, reaching a few thousands Euro. Despite that, there are a number of possibilities for participating in international cooperative projects, to obtain data for free or at a very low cost, especially for research activities. It is worth noting that the European Space Agency (ESA), is going to launch a new mission, SENTINEL-1, in 2013, which will be able to make use of the data it provides free of charge (Table VI in appendix).

GOOD PRACTICE FOR SAR SENSORS APPLICATION

Systematic acquisition: during the knowledge and prevention phase (Table 3) the systematic acquisition of SAR data should be performed on a regular (at least monthly) basis. This approach from one side will allow the generation of SAR time series, from the other side will ensure updated images suitable for change detection products in case of an eruption.

Acquisition frequency during crises: when possible, increase the acquisitions frequency in order to closely follow the evolution of the eruption.

BOX6

A SAR APPLICATION DURING THE 2010 ERUPTION OF MERAPI

In the lifetime of the MIAVITA project, SAR monitoring techniques have been successfully used during the eruption of Merapi volcano. Soon after the beginning of the eruption, some SAR satellite missions had been tasked to acquire images, aiming to provide useful information to the Centre of Volcanology and Geological Hazard Mitigation of Indonesia (CVGHM), involved in the volcano monitoring. It is worth noting that the very cloudy conditions did not allow the use of optical images, therefore SAR was the only sensor able to access the Merapi volcanic area. Among the available data, we selected two SAR scenes, at X band, acquired by the Italian COSMO-SkyMed constellation. One pre-eruption image was taken on 1st May 2010, and one was dated November 8, 2010, after the explosion occurred on November 5. Both images are very high resolution data, with a pixel resolution of 3 m on ground. These SAR images have been exploited to detect and to evaluate the extension of the large pyroclastic flow deposit. For this purpose, the change detection methodology has been adopted and the resulting product clearly revealed the impact of the pyroclastic flow that hit the southern part of Merapi volcano.

Opportunities for action and future developments

Some studies are addressing the mitigation of atmospheric effects (e.g., by using meteorological data) and new procedures to derive new products will be validated in the future. For example, researchers are focusing on the possibility to detect and to estimate the amount of ash in the volcanic plume. Additional work concerns the evaluation of the lava and/or pyroclastic volumes.

Finally, thanks to the improved space technologies, the next generation of SAR system will increase the image availability, in particular with new satellite constellations, with higher accuracy, higher spatial resolutions and wider area coverage.

21. Data transmission

Utility and limitations: communications are a key element of volcanic disaster management. The high level of situational awareness required for effective emergency response requires the flow of critical information between intervening partners: scientists, civil protection agents, local and national authorities, media and public in general. In order to conduct routine monitoring for eruption forecasting, or to assist an emergency response effort once the eruption occurs, the teams need reliable data transmission links to gain access in real time to monitoring networks. Other data sets such as satellite imagery, acquired and processed in distant points of the planet, must be accessed and retrieved by the local scientists.

Nowadays, the Internet supports most of our communications needs (transmission of data, voice, images, etc.), and the current experience in developed countries may lead to the false impression that reliable Internet connectivity is available everywhere. However, the situation can be in sharp contrast when developing countries are considered. A volcanic monitoring network in a remote region is usually exposed to the "last mile" problem: given the increased capillarity of the distribution network, installation costs increase from the backbone to the end site, and investments in peripheral areas, where the ratio revenue/installation cost decrease, sharply are often avoided or postponed.

Principles

The infrastructure supporting information access near an active volcano is clearly exposed to the threat. Even when the infrastructure is not physically affected, a peak of demand following a disaster may disrupt the services. In this way, the efforts to capture and relay information to monitor the progress of the eruption may be compromised. Indeed, to be resilient, communications systems used for volcanic monitoring should be robust and interoperable, and careful planning is required, taking into account the weaknesses and strengths of the available technological infrastructure.

The following general principles apply to robust telecommunications for volcanic emergency management:

- Communications systems for emergency management should be used for routine operations; in this way the staff is familiar with the procedures, avoiding an additional factor of stress during a crisis and the working order of the communications channels is tested regularly
- Communications systems for critical data must be redundant and self-healing, including the support infrastructure, and in particular the power supply
- Communications systems, both for emergency and routine operation, must be cost effective (conflicting often with the previous requirement) in order to secure sustainability in the far-from-ideal funding conditions that as a rule characterize volcanic monitoring in developing countries

Example of bandwidth requirements for a volcanic monitoring network

The type of connectivity that best suits each particular monitoring network depends on the type and amount of data that is going to be transmitted, and a general recipe cannot be prescribed. But to have a rough idea of the bandwidth requirements we may consider the following typical configuration of a volcanic monitoring network:

- Eight seismic sensors sampling the three components of ground velocity at a rate of 50 samples per second, with 24 bits per sample
- Three continuous GPS stations at a rate of one sample per second
- 10 slow-rate environmental sensors (e.g., temperature or SO_2 concentrations measured at one sample per minute)

On the basis of the MIAVITA experiments conducted in Fogo Island, Cape Verde (see Box 7), it can be concluded that the amount of data produced by such a network can be transmitted satisfactorily in real time if a bandwidth of 84 kbit per second is permanently available for that purpose. The dominant contributors to this figure are the seismographic stations, where each of the three components of ground motion is sampled typically 50 times per second, each sample being composed of 24 bits (i.e., 3600 bits per second per seismographic station). This modest value, by comparison with modern public services, where data rates often reach several tens of Mb per second, hides an important fact: the total amount of data transmitted monthly will exceed 26 Gb, if the connection is continuous, as desired. The implication is that services with a monthly data volume limit, or with an extra cost for traffic above a certain monthly limit, are usually not cost effective. A flat rate with unlimited traffic over a limited bandwidth is a better choice for continuous transmission.

Commercially available services

When commercial services are available and reliable, they provide the most convenient way to transmit data. Telecommunication operators may be used to establish point-to-point connections, useful for private data transmission, or for connecting to the Internet. When transmitting sensitive data over public networks such as the Internet, encryption may be used to ensure privacy and integrity of data. Table VII (Appendix) compares some of the most common technologies for accessing the Internet.
Asymmetric Digital Subscriber Line (ADSL) is the most common of the xDSL technologies. The others, with higher upload rates, are usually geared towards business and as such command a price premium. The data rates of xDSL technologies are severely limited by the distance to the local exchange office. The presented data rates are only available up to 300m from it and Very-High-Data-Rate DSL (VDSL) only operates within 1.3 km while ADSL is capable of up to 5.4 km. FTTH (Fibre To The Home) technologies are still expensive to install and their roll out is being performed slowly.
These technologies offer data rates that are only guaranteed up to the local branch office. From there to the core of the operator's network, data are merged into a link with significantly lower capacity than the sum of all its tributaries. The ratio of the sum of the capacity of the links to the customer's premises and the capacity of the link to the operator's network is called the contention ratio. For ADSL connections, this often falls into the range 20:1 to 50:1. It is important to be aware that in this type of service the provider cannot guarantee a bit rate, which may fall temporarily to values much lower than the nominal value advertised. For this reason, residential-type services offered by commercial Internet Service Providers (ISP's), may be very unsuitable for the transmission of monitoring data.
A better quality of service, with stricter data rate assurances and uptime guarantees may be obtained by resorting to public switched networks, such as X.25, Frame Relay, Asynchronous Transfer Mode (ATM) or Ethernet. These provide data rates from 8 kb/s up to Gb/s. These networks allow Private Virtual Circuits to be established between two points (one may provide Internet access), providing Quality of Service (QoS) assurances. Their prices are usually much higher than those of the previous technologies.
When wired access is not possible or competitive, wireless technologies provide an alternative (Table VIII in Appendix). The most common are: Satellite networks, WiMax and Cellular Networks in their various versions: GSM (Global System for Mobile Communications), GPRS (General Packet Radio Service) and UMTS (Universal Mobile Telecommunications System) or CDMA2000 (Code Division Multiple Access).

Satellite networks have the advantage of providing worldwide coverage. However, satellites placed in Geostationary Orbit, present delays in the order of 250 ms. While they cover large regions of the globe, their capacity is shared over large areas, making their use very expensive. Also, large fixed antennas, with diameters of up to 3.8 m are required. Cellular networks use many radio stations, each covering a small area (a cell). This allows radio frequencies to be reused in non adjacent cells, greatly increasing the capacity. The same principle is used in Low Earth Orbit Satellites, where a constellation of satellites is deployed. While this increases their cost, their low orbit results in lower delays and enables the use of portable hand-held devices. However, transmission of large amounts of data remains expensive. A great advantage of satellite systems for volcanic risk management and emergency response is that the connectivity is not dependent on ground infrastructure exposed to hazard (other than the antenna and a power source). Experience often shows that satellite data transmission, currently quite cost-effective in regions such as Europe where it has to compete with land-based solutions such as cabled ADSL, has prohibitive costs in regions where it is the sole possibility, such as in remote parts of Africa. An example is that VSAT services with the adequate technical specifications for always-on data transmission are still too expensive to be sustainable. While WiMAX is still seen as a potential alternative in sparsely populated and/or under developed areas where cabled infrastructure is not available, its deployment world-wide is still very limited, and it will hardly be available in most places.

When commercial services are not available in the vicinity of the monitored area, Wi-Fi, or radio modems may be used to cover distances of up to a few tens of km, in order to reach a place with connectivity. These use unlicensed radio frequencies and may be privately established and run, being very inexpensive (only a few hundred Euro to setup). These may also be used to establish a redundant connection, which is more robust during a crisis, as public infrastructures will be exposed to the volcanic hazard and may be impaired during an emergency, with a very negative impact on response operations.

Advices and remarks

Ground-based infrastructures (cable, ADSL, CDMA, leased lines) are at present the most feasible options in most remote locations. However, these infrastructures will be exposed to volcanic hazard and may be impaired during an emergency, with a very negative impact on response operations. A peak of demand may affect strongly these (typically) high contention-ratio services during a crisis, even if the infrastructure is not affected. A private radio link connecting the LVL to a distant point of entry for the commercial services may be a good option, to create a redundant connection that is more robust during crisis.

The provision of Internet services is strongly market-driven, with little sensitivity to the potential social and cultural benefits behind these services. In Europe we are witnessing the inclusion of Internet access in the Universal Service definition, guaranteeing its availability everywhere. EU funded programs are also in place to bring FTTH solutions to economically unappealing areas such as rural areas. Satellite communication provides a good example of this problem: in theory it is available anywhere in the Earth's surface, with minimum local infrastructure, making it ideal for volcanic monitoring in remote areas. A satellite antenna, a modem, a PC and a power supply source are sufficient to establish a connection. However, access to satellite communications requires that a company be willing to provide the service at the specified location. Experience often shows that satellite data transmission, currently quite cost-effective in regions such as Europe where it has to compete with land-based solutions, has prohibitive costs in regions where it is the sole possibility. In fact, VSAT services with the adequate technical specifications for always-on data transmission are still too expensive to be sustainable.

BOX7

COMMUNICATIONS FOR REAL TIME MONITORING: THE FOGO VOLCANO EXAMPLE

In Fogo volcano, Cape Verde Islands, as in many other cases, the last stage of magma ascending towards the Earth's surface lasts typically hours to a few days. Thus, it is crucial to follow the precursor signals, and in particular the seismicity, ground deformation, gas composition etc., nearly in real time. For this purpose a network of broadband seismic stations was deployed by the Instituto Nacional de Meteorologia e Geofísica (INMG) in the vicinity of the volcano. Due to the scarcity of resources in Fogo Island the routine analysis of the data is conducted at the Geophysical Department of INMG in S.Vicente Island, where the data is recovered in real-time using Internet. We shall describe here the strategy adopted for data transmission.

To broadcast the data recorded by all six seismic stations of this network, it was not advisable to use a direct Internet connection to the stations, which are located in remote places where Internet is not available. Also, even if Internet access at the stations were possible, it would be too expensive to sustain, due to the high cost of Internet services in Cape Verde. Instead, the data transmission network of Fogo Volcano relies on a local Area Network (LAN). Each seismic station is equipped with a radio (FreeWave FGRPlus RE) supporting the TCP/IP protocol. The digitizer from each station feeds the data into the serial port of the radio, which is configured as TCP server with a specific port number. A data centre at a neighbour island (Santiago) is equipped with a similar radio, an embedded PC (CMG-EAM), a router (CISCO K 1921), a switch, a modem and a UPS. At the data centre, the data enters the Internet through a leased line, with a fixed public IP address. Because there is no line of sight from the different stations to the Santiago data centre, two repeater stations were set up at convenient locations. Each repeater station is equipped with an embedded PC (CMG-EAM), a switch, a UPS and FreeWave FGRPlus RE radios (one per station using the repeater, plus one to relay the data to the data centre). Each radio (stations, repeaters and data centre) has a LAN IP address. Network Address Translation (NAT) was set up at the router in the data centre to allow a computer outside the LAN to pull data directly from the embedded PC's at the repeaters, or even directly from the radios at the stations. This configuration allows the bypass of the repeater's embedded PC, in case of failure. It also allows the remote configuration of the equipment located at the stations (digitizers, radios) or repeaters (embedded PC's radios) from any point in the Internet. The solution provides total control by the end user (INMG) over the infrastructure between the monitoring stations and the Santiago data centre. From that point onwards, the infrastructure was deemed sufficiently robust to secure access to the data from any remote point.

22. Scientific-operational interface

Volcano monitoring is the key to increase the knowledge of a volcano's behavior and for short – term hazard assessment.

The last 20 years clearly demonstrate the importance of a multi-disciplinary approach for short-term volcanic forecasting. Many threads of evidence need to be analyzed and compared: direct empirical observations related to a variety of parameters (geophysical, geodetic, geochemical, gravity, petrology, etc.), modeling techniques and interpretations. Once parameters from different monitoring networks are acquired, it is fundamental to define how the analysis of the scientific evidence, derived from many sources on many timescales, can provide a short-term forecast for decision-makers and civil protection authorities. To be concise, the question is how and who should make the synthesis of results, when different scientific institutions exist, and where are the resources to do it. It is worth noting that in many countries

BOX8

SCIENTIFIC-OPERATIONAL INTERFACE: THE ITALIAN EXAMPLE

In the years from 2003 to 2006 the Italian Department of Civil Protection (DPC) actively managed at legislative level, to further upgrade and strengthen the national Civil Protection System. Over this time period improvements were made on the general architecture of the system and also of roles, responsibilities and ways of operating of the different components. One of the subjects to implement was how the scientific function could have been more effectively integrated into the Civil Protection System. In this regard the experience acquired at Stromboli represented a major source of knowledge and ideas, in Italy. The experience matured in the Advanced Coordinating Post (COA) in Stromboli, during the 2002-2003 volcanic crisis, where the real-time visualization of the main monitoring parameters as well as consultation procedures of scientists for the evaluation of the ongoing phenomena were in place. This was used as a reference for the creation, in Rome, of a volcanic branch named "Functional Centre (Centro Funzionale - CF)". During the Stromboli emergencies of 2002-2003 and 2007, in order to make the system able to react in real time, all the components of the civil protection system were sitting at the same table, especially during hazardous operational activities. Daily meetings were organized to establish day by day the procedures and actions to take. Now, in the CF of the national civil protection of Italy, the most relevant monitoring parameters concerning different hazards (meteorological, hydrologic, volcanic, wild fires) are visualized and eventually elaborated to generate scenarios of impending risk. The various Stromboli's monitoring parameters were the first real time parameters to be duplicated in the Civil Protection Department in Rome. Meanwhile the main institutions dealing with the scientific Stromboli's volcano monitoring (INGV and University of Florence) started daily routine procedures to report to the Volcanic Risk Functional Center the state of activity (seismic, volcanic and slope movement) of the volcano. To date, signals from different Italian volcanoes are duplicated and can be observed by the civil servants of DPC. The duplicated signals allow better comprehension of impending or occurring phenomena between scientists (who do monitoring and analyses) and DPC civil servants (who can represent the support to decision-makers in DPC).

different scientific institutions (research institutes, universities, observatories) perform different types of monitoring and analyses, but sharing of their analyses and interpretations in quasi real-time is often not included in their activities.
It is relevant to define how the information derived from monitoring (scientific function) could be more effectively integrated into the civil protection system. It is worth noting that this process should take into account the civil protection need to have short-term forecasting and to acquire alert levels and the need of scientists to have time and resources to continue to analyze data and to develop their investigations.

GOOD PRACTICE FOR DATA TRANSMISSION

Transmission of monitoring data: they should not be transmitted over public networks that are expected to suffer degradation of service during a volcanic event. The use of private radio links instead provides cheap service, either for primary or backup proposes.

Cost of services: an in-depth survey of available services is required to ensure adequate services at low cost. Telecommunication services availability varies wildly among locations.

Data stream: a good understanding of the characteristics of the data stream generated by the sensors is necessary, in order to build or hire the adequate telecommunication services.

Communication protocols: in many places, telecommunication services offers will evolve quickly during a sensor device lifetime. When possible, use standardized communication protocols because they will more likely be reusable with newer communication technologies as they become available.

GOOD PRACTICE FOR SCIENTIFIC-OPERATIONAL INTERFACE

Communication: shared protocols for communication between civil protection authorities and scientific institutions should be organised to establish, formally, when and how civil protection authorities will be informed about volcanic activity and relative responsibilities.

Data sharing: Organise a shared area such as web space with restricted access where to place all the real-time analyses, results and interpretations.

Projects funding: when possible, civil protection authorities may support scientific projects strictly related to civil protection aims. This would allow to have operative instruments always updated with respect to science development, to help researchers investigate volcanoes and encourage scientists and civil protection functionaries to work together, in order to be more efficient during emergencies.

References and suggested readings

Geographic Information Systems

- De Bélizal, E., Lavigne, F., Gaillard, J.C., Grancher, D., Pratomo, I., Komorowski, J.C., 2012. The 2007 eruption of Kelut volcano (East Java, Indonesia): Phenomenology, crisis management and social response. Geomorphology, 136, 1, 165-175.
- Felpeto, A., Martí, J., Ortiz, R., 2007. Automatic GIS-based system for volcanic hazard assessment. Journal of Volcanology and Geothermal Research, 166, 106-116.
- Martì, J., Spence, R., Calogero, E., Ordoñez, A., Felpeto, A., Baxter, P., 2008. Estimating building exposure and impact to volcanic hazards in Icod de los Vinos, Tenerife (Canary Islands). Journal of Volcanology and Geothermal Research, 178, 553-561.
- Pareschi, M.T., Cavarra, L., Favalli, M., Giannini, F., Meriggi, A., 2000. GIS and volcanic risk management. Natural Hazards 21, 361–379.
- Douglas, J., Usländer, T., Schimak, G., Esteban, J.F., Denzer, R., 2008. An open distributed architecture for sensor networks for risk management. Sensors 8, 1755–1773.
- Thierry, P., Stieltjes, L., Kouokam, E., Nguéya, P., Salley, M.P., 2008. Multi hazard risk mapping and assessment on an active volcano: the GRINP project at Mount Cameroon. Natural Hazards, 45, 429-456.

Seismic network, volcano seismology

- Aki, K., Ferrazini, V., 2000. Seismic monitoring and modelling of an active volcano for prediction. Journal of Geophysical Research, 105, B7, 16617-16640.
- Chouet, B., 1996. New Methods and Future Trend in Seismological Volcano Monitoring. In: Scarpa, R., Tilling, R. (Eds), Monitoring and Mitigation of Volcano Hazards, Springer-Verlag, pp 23-97.
- Chouet, B., 1996. Long-period volcano seismicity: its source and use in eruption forecasting. Nature 380, 309-316.
- Chouet, B., 2003. Volcano-seismology. Pure and Applied Geophysics, 160, 739–788.
- Jolly Roman, D.C., Neuberg, J., Luckett, R.R., 2006. Assessing the likelihood of volcanic eruption through analysis of volcanotectonic earthquake fault-plane solutions. Earth and Planetary Science Letters 248, 244-252.
- McNutt, S., 2005. Volcanic seismology. Annual Review of Earth and Planetary Science, 32, 15.1-15.31. www.aeic.alaska.edu/input/steve/PUBS/AR233-EA33-15_001-031_.pdf
- Saccarotti G., Chouet, B., Dawson, P., 2003. Shallow-velocity models at the Kilauea volcano, Hawaii, determined from array analyses of tremor wavefields. Geophysical Journal International, 152, 633-648.
- Surono, Jousset, P., Pallister, J., Boichu, M., Buongiorno, M.F., Budisantoso, A., Costa, F., Andreastuti, S., Prata, F., Schneider, D., Clarisse, L., Humaida, H., Sumarti, S., Bignami, C., Griswold, J., Carn, S., Oppenheimer, C., 2012. The 2010 explosive

eruption of Java's Merapi volcano – a '100-year' event. Journal of Volcanology and Geothermal Research, 241, 121-135, doi: 10.1016/j.jvolgeores.2012.06.018.

Ground deformation

- strainmeters: http://www.iris.iris.edu/pbo/instrumentation/bsm.html
  http://hvo.wr.usgs.gov/howwork/strain/
  http://www-odp.tamu.edu/publications/186_IR/chap_03/c3_3.htm

- tiltmeters: http://hvo.wr.usgs.gov/volcanowatch/archive/2002/02_05_30.html
  http://vulcan.wr.usgs.gov/Monitoring/Descriptions/description_tilt.html
- on GPS: http://volcanoes.usgs.gov/activity/methods/deformation/gps/index.php
  http://www.trimble.com/gps/whatgps.shtml

- Bruyninx, C., 1997. Modeling and methodology for high precision geodetic positioning with the Global Positioning System (GPS) using carrier phase observation, application to a GPS Network on the Mt. Etna Volcano. Flemish Journal of Natural Science, 76,2-4, p.127.
- Dvorak , J.J., Dzurisin, D., 1997. Volcano Geodesy: The search for magma reservoirs and the formation of eruptive vents. Reviews of Geophysics, 35, 343-384.
- Dzurisin, D., 2003. A comprehensive approach to monitoring volcano deformation as a window on eruption cycle. Reviews of Geophysics, 41, 1001, 29, doi:10.1029/2001RG000107.
- Hofmann-Wellenhof, B., Lichenegger H., Collins J., 1992. Global Positioning System, Theory and pratice. Springer-Verlag, New York.
- Heleno, S.I.N, Frischknecht, C, D'Oreye, N., Lima, J.N.P., Faria, B., Wall, R, Kervyn F., 2010. Seasonal tropospheric influence on SAR interferograms near the ITCZ – The case of Fogo Volcano and Mount Cameroon. Journal of African Earth Sciences, 58, 5, 833-856.

Chemical Monitoring

- Giggenbach, W.F., 1975, A simple method for the collection and analysis of volcanic gas samples. Bulletin of Volcanology, 39, 132–145.
- Guidelines on volcanic gas exposure for civil protection purposes are available at the website of the International Volcanic Health Hazards Network: http://www.ivhhn.org

- http://www.alphasense.com/environmental-sensors/pdf/Articles/Volcanic_Gas_Emissions.pdf
- http://www.alphasense.com/news_downloads/Volcanic%20Gas%20Emissions%20-%20CU%20-%20Alphasense.pdf
- http://www.iavcei.org/IAVCEI_publications/COSPEC/COSPEC_Cookbook.pdf
- http://www.novac-project.eu/
- http://srv1.rm.ingv.it/srv/srv/archive/ppt-catania/caltabiano-ppt

Acoustic monitoring

- Campus, P., 2006. Monitoring volcanic eruptions with the IMS infrasound network. Inframatics, 15, 6-12.
- Garces, M., Fee, D., McCormack, D., Servranckx, R., Bass, H., Hetzer, C., Hedlin, M., Matoza, R., Yepes, H., 2007. Prototype ASHE volcano monitoring system captures the acoustic fingerprint of stratospheric ash injection. Inframatics, 17, 1-6.
- Johnson, J.B., Ripepe, M., 2011. Volcano infrasound: a review. Journal of Volcanology and Geothermal Research, 206, 61-69.
- Matoza, R.S., Vergoz, J., Le Pichon, A., Ceranna, L., Green, D. N., Evers, L.G., Ripepe, M., Campus, P., Liszka, L., Kvaerna, T., Kjartansson, E., Höskuldsson A., 2011. Long-range acoustic observations of the Eyjafjallajökull eruption, Iceland, April–May 2010. Geophysical Research Letters, 38, L06308, doi:10.1029/2011GL047019.
- Moran, S.C., Matoza, R., Garces, M., Hedlin, A.E., Bowers, D., Scott, W.E., Sherrod, D.R., Wallace, J.W., 2008. Seismic and acoustic recordings of an unusually large rockfall at Mount St. Helens, Washington. Geophysical Research Letters, 35, L19302, doi:10.1029/2008GL035176.
- Ripepe, M., De Angelis, S., Lacanna, G., Voight, B., 2010. Observation of infrasonic and gravity waves at Soufriere Hills Volcano, Montserrat. Geophysical Research Letters, 37, L00E14, doi:10.1029/2010GL042557.
- Wilson, C.R., Olson, J.V., 2005. I53US and I55US signals from Manam Volcano. Inframatics, 9, 31-35.

Ground based cameras

- Bluth, G.J.S., Shannon, J.M., Watson, I.M., Prata, A.J., Realmuto, V.J., 2007. Development of an ultra-violet digital camera for volcanic SO_2 imaging. Journal of Volcanology and Geothermal Research, 161, 47–56.
- Kantzas, E.P., McGonigle, A.J.S., Tamburello, G., Aiuppa, A. Bryant, R.G., 2010. Protocols for UV camera volcanic SO_2 measurements. Journal of Volcanology and Geothermal Research, 194, 55-60.
- Kern, C., Deutschmann, T., Vogel, L., Wöhrbach, M., Wagner, T., Platt, U., 2009. Radiative transfer corrections for accurate spectroscopic measurements of volcanic gas emissions. Bulletin of Volcanology, 72, 233–247.
- Mori, T., Burton, M., 2006. The SO_2 camera: A simple, fast and cheap method for ground-based imaging of SO_2 in volcanic plumes. Geophysical Research Letters, 33(24). doi:10.1029/2006GL027916.
- Prata, A.J., Bluth. G.J., Werner, C., Carn, S., Realmuto, V., and Watson, I. M., 2012. Remote sensing of gases from volcanoes. In: Dean, K.G. and Dehn, J., (Eds.), Monitoring Volcanoes in the North Pacific: Observations From Space, Springer-Praxis Books, ISBN: 3540241256, in press.
- Prata, A. J., Bernardo, C., 2009. Retrieval of volcanic ash particle size, mass and

optical depth from a ground-based thermal infrared camera. Journal of Volcanology and Geothermal Research, 186, 91-107.
http://savaa.nilu.no/Portals/61/JVGR186_91_2009.pdf

- Ramsey, M.S., 2012. Temperature and textures of ash flow surfaces: Sheveluch, Kamchatka, Russia (4 June 2004). In: Dean, K.G., Dehn, J., (Eds.), Monitoring Volcanoes in the North Pacific: Observations From Space, Springer-Praxis Books, ISBN: 3540241256, in press.
- Sentman, R.D., Stephen R., McNutt, S.R., Stenbaek-Nielsen, H.C., Tytgat, G., DeRoin, N., 2007. Imaging Observations of Thermal Emissions from Augustine Volcano Using a Small Astronomical Camera. U.S. Geological Survey Professional Paper 1769, 1–9.
- Tupper, A., Kinoshita, K., Kanagaki, C., Iino, N., Kamada, Y., 2003. Observations of volcanic cloud heights and ash-atmosphere interactions. WMO/ICAO Third International Workshop on Volcanic Ash, Toulouse, France, September 29 -October 3.

Satellite optical sensors and their applications

- Harris, A.J.L., Flynn, L.P., Keszthelyi, L., Mougins-Mark, P., Rowland., S.K.J., Resing J.A., 1998. Calculation of lava effusion rates from Landsat TM data. Bulletin of Volcanology, 60, 52-71.
- Lombardo, V., Buongiorno, M.F., 2006. Lava flow thermal analysis using three infrared bands of remote-sensing imagery: a study case from Mount Etna 2001 eruption. Remote Sensing Environment, 101, 141–149.
- Prata, A. J., Kerkmann, J., 2007. Simultaneous retrieval of volcanic ash and SO_2 using MSGSEVIRI measurements. Geophysical Research Letters, 34, L05813, doi:10.1029/2006GL028691.
- Pugnaghi, S., Gangale, G., Corradini, S., Buongiorno, M.F., 2006. Mt. Etna sulfur dioxide flux monitoring using ASTER-TIR data and atmospheric observations. Journal of Volcanology and Geothermal Research, 152, 72-90.
- Spinetti, C., Colini, L., Buongiorno, M.F., Cardaci, C., Ciminelli, G., Corradini, S., Guglielmino, F., Musacchio, M., Pace, G., Pellegrino, D., Perelli, S., Pietranera, L., Puglisi, G., Soddu, P., 2010. Volcanic Risk management: the case of Mt. Etna 2006 eruption. In: Altan. O., Backhaus, R., Boccardo, P., Zlatanova, S. (Eds), Best Particles Booklet on Geo-information for Risk and Disaster Management. United Nation UNSPIDER (Abstract Accepted after selection 2009; conference press at UN 4 July 2010). UN web site: http://www.un-spider.org/about/portfolio/publications/jbgis-unoosa-booklet.

Synthetic Aperture Radar sensors and their applications

- InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation. http://www.esa.int/esapub/tm/tm19/TM-19_ptA.pdf
- Oliver, C., Quegan, S., 1998, Understanding Synthetic Aperture Radar Images, Artech House, Boston-London.

- Massonnet, D., Feigl, K.L., 1998. Radar interferometry and its application to changes in the Earth's surface. Reviews of Geophysics, 36, 441–500.
- Richards, J.A., 2009. Remote Sensing With Imaging Radar, Springer.
- Zebker, H.A., Goldstein, R.M., 1986. Topographic mapping from interferometric SAR observations. Journal Geophysical Research, 91 (B5), 4993-4999.

Data transmission

- Endo E.T., Murray T., 1991. Real-time seismic amplitude measurement (RSAM) - A volcano monitoring and prediction tool. Bulletin of Volcanology, 53, 533-545.

4 LIVING WITH A VOLCANO: INCREASING PREPAREDNESS

Despite the commitment of the international community to reduce the impacts of natural hazards, the efforts of national and local emergency managers are still largely "reactive" (i.e., based on intervention after a disaster). Several experiences have clearly indicated that prevention and preparedness actions greatly contribute to a successful response effort, and to reduce human and economic losses. Effective risk-reduction strategies require a multidisciplinary knowledge and effort that involves the whole system of civil protection (scientists, economists, technicians, media experts, civil protection professionals, etc.). Based on this knowledge it is possible to set up better prevention and mitigation measures, to improve volcano monitoring, to improve the disaster management plans, to raise awareness both in public and authorities, to plan for better recovery policies and actions. All these activities are fundamental to reduce victims, damage, the relief effort and the impact on society.

Participating authors: Louis Bonfils
Vittorio Bosi
Licia Costantini
Melanie Fontaine
Sri Hidayati
Gonéri Le Cozannet
Sri Sumarti
Surono
Pierre Thierry
Paolo Vaccari
Amélie Vagner

23. Hazard and risk assessment and mapping

The identification, analysis and evaluation of risk comprise the basis for timely and well-oriented disaster prevention and the essential key for successful disaster management. Such studies make people and authorities aware of the existing risks in the country and the relative probability of occurrence.

It is clear that reducing risk for volcanoes requires many steps (hazard, vulnerability, exposure, coping capacity) to be tackled. Nevertheless, one has to consider that it is often very difficult to reduce the hazard. Attempts at lava flow diversion (trenches and barriers) and removals of sediments from lahars (Sabo dams) have been made in the past with some positive results, but these are expensive measures. Therefore, the focus will have to be put on both limiting the exposure and reducing vulnerability through proper risk management.

In this respect, risk assessment and mapping is one of the most crucial points and a pre-requirement for any land-use planning. Once high risk areas are mapped, it is possible to reduce risk by applying prevention measures in those areas, such as to forbid or to discourage the construction of new buildings, to reinforce infrastructure when possible with sustainable cost, to set different types of cultivation in relation to their vulnerability with respect to the existing hazard, etc. It is also possible to prepare all necessary measures to manage risk, such as evacuation, interdiction of some areas, delocalization of villages and infrastructures, mitigation measures for transportation, health care, communication, etc. The reader can find useful insights on those measures and land-use planning in Chapter 27.

Two different concepts regarding volcanic hazard assessment are often present: either long or short-term hazard assessment.

A simple and short explanation of these two concepts follows:

Long-term hazard assessment: it represents the background (basis) for the behaviour of a volcano. Once the background is well known, it is possible to compare it with observations through time in order to identify anomalies, which can lead to a possible eruption. Historical and geological data are fundamental for a correct long term hazard assessment: it includes mapping of volcanic deposits, dating of volcanic products, assessment of explosivity and of the intensity, magnitude and duration of previous eruptions. These data become crucial in the case of dormant volcanoes, where no historical data exists and where monitoring data, if present, cannot be checked against background analysis (see Box 9).

Short-term hazard assessment: it is the human surveillance and instrumental monitoring of the volcano (precursory phenomena). Most volcanic eruptions are preceded by a variety of environmental changes ('precursory signs'), which accompany the rise of magma towards the surface (seismic activity, ground deformation, hydro-thermal phenomena, chemical changes, gravimetric anomalies etc.). The analysis of these data, compared with the background activity (long-term hazard assessment), gives the short-term hazard assessment (e.g., probability that a specific area is reached by a lava flow during the upcoming eruption) which is fundamental to prepare response. Monitoring information may be very helpful to forecast the time of onset and the location (point of origin or vent) of an eruption, but they are not sufficient to forecast the size of the next eruption even after unrest begins. Presently, the method to forecast the size of an upcoming eruption is related to the behaviour of the volcano in the past (frequency, size, chemistry of past eruptions), and on data coming from other studies about similar volcanoes around the world. This is a major concern for a reliable forecast and it's development in terms of probability of occurrence, with large uncertainty.

BOX9

THE IMPORTANCE OF GEOLOGICAL FIELD STUDIES FOR HAZARD ASSESSMENT

The knowledge of the eruption history of a volcano is fundamental to characterize its past and present behaviour and to assess the associated hazards. The eruptive history is usually constrained combining historical records (when existing) with geological field studies. Field studies allow the characterization of past volcanic deposits in terms of dispersion and possible vent location/s, internal stratigraphy (e.g., the number of short-lived eruptions that form the deposit) and erupted components. In addition they can be easily performed for all the exposed volcanic deposits, and therefore even significantly old eruptions (thousands - tens of thousand years old) can be constrained.

Field studies, together with subsequent lab analyses of eruptive products, are fundamental for the estimation of credible eruptive physical parameters (e.g., erupted volume, column height, mass eruptive rate and eruption duration) and for understanding eruptive dynamics as well as the volcano's behaviour.

However, it is worth noting that the stratigraphic record typically preserves only the largest events, the smaller deposits being easily eroded away. This is important in order not to misinterpret the volcano activity (which cannot be only characterized by big eruptions) and underestimate the eruptive frequency. In addition, the stratigraphic record only represents a small sample of all possible eruptive scenarios and wind directions, the latter being fundamental for tephra fall dispersal (see Chapter 8).

All these considerations do not minimize the high value of geological studies but, on the contrary, underline their importance and how to use them at best. A successful hazard assessment would in fact combine the knowledge and understanding of volcanic history with the development of numerical and empirical models and probabilistic techniques.

Short and long term hazard assessments should be always carried out as a priority input for correct planning of the territory and for scenario builders.

Principles and concepts in hazard and risk mapping

As stated above, a volcanic eruption consists of a combination of several dangerous adverse events (i.e., phenomena) each of them triggering physical impacts that may affect more or less different features. The scheme showed in Figure 17 is a theoretical and simplified example that illustrates the complexity, which ought to be taken into account in all hazards and risk mapping exercises.
Hazard mapping is used for land use planning and is a prerequisite for risk mapping. Considering that, for the same eruption, various adverse events will have different extensions and impacts, they have to be processed separately. This distinction between adverse events and their potential physical impacts is particularly important for hazard mapping in volcanic areas, since these areas can be affected by multiple adverse events, each one associated with several possible physical impacts (Fig. 17). Nevertheless, it is worth noting that the public's understanding of the situation may be hampered by a presentation of multiple maps indicating different kinds of threat (e.g., one map for lava flow, one other map for pyroclastic flows). Presentation of a single synthesis map will favour a better transfer of the hazard assessment into prevention policies. The map must be as clear and understandable as possible. For this purpose, it should indicate the possible extent of threatened zones with few, one to five, hazard classes.
For risk maps, the problem is even more complicated considering the multiplicity of possible physical impacts combined with the diversity of elements at risk. The risk maps must be drawn in order to highlight the "hot spots" where exposures of high values (e.g., concentration of population, strategic roads) are put at risk. Identification of such hot spots will help authorities to prioritize among prevention options.
In addition to hazard and risk maps, another tool deserves to be highlighted: the scenario builder, which describes the effects of hypothesised eruptions (see Chapter 18).

From methods to practical realisation of hazard and risk maps

Classically, most hazard maps (either global or specific to adverse events) are designed with a "naturalist" approach on the basis of historical and geological evidence of past eruptions, completed by a morphological analysis of the volcanic edifice. The identification and characterisation of historical and geological evidences need both extensive fieldwork (geological mapping, description of past eruptions in terms of intensity, etc.) and desk work (bibliography, aerial photographs or remote sensing image analysis, geochemical analysis, rock dating, etc.). In the past, geomorphological analysis used to be run by drawing on topographic maps. Nowadays, DEMs are widely used. Calculated from satellite images or aerial photos, DEMs are numerical grids where each mesh is represented by three values (X and Y coordinates plus elevation Z). They allow representation of topographic 3D models on computers and a better understanding of relief. It is worth noting that some DEMs (such as the NASA SRTM which covers the whole Earth) are freely available on the Web.

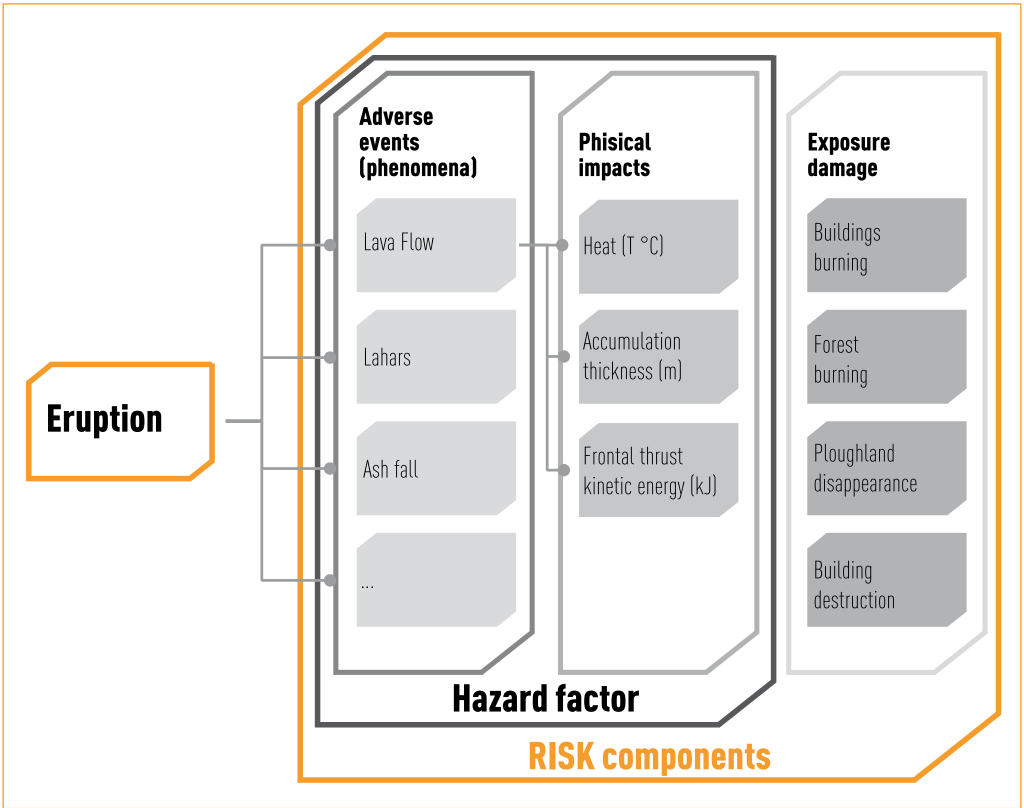

Figure 17: Theoretical scheme showing an example of the possible factors that have to be taken into account for hazard and risk mapping.

The results of such mapping usually present the sectors prone to different phenomena i.e., the possible extension of expected eruptions. It is probably more correct here to speak of "susceptibility maps" more than of "hazard maps". Indeed, these maps aim at identifying and delineating dangerous areas and, then, constitute a crucial tool, if not the main tool, for any natural risk management. These susceptibility maps correspond more particularly to the long-term hazard assessments.
It must be emphasized that, clearly, no prevention can be considered without having, at least, the susceptibility maps.
Nevertheless, these maps present two important limitations:

They do not properly take into account the return period of phenomena i.e., they make no distinction between a catastrophic event unlikely to occur at short term and a low or medium intensity event most likely to occur during the next few years. Consequently, they do not identify, within the prone areas, sectors most likely to be affected.

They do not differentiate among different types of physical impacts associated with the phenomena, making it difficult to quantify intensities and to undertake detailed vulnerability analysis. Hazard maps are actually expected to represent the probability of occurrence of physical impacts of a given intensity.

Beyond classical methods based on expert's judgement, two recent methods enable to map the hazards.

Scientific research is presently developing assessments based on numerical modelling. More or less sophisticated software are developed by different teams to simulate the progression on DEM of different kinds of events (lavas flows, pyroclastic flows, lahars, ash emissions and dispersion). This kind of simulation needs development of algorithms, based on physical properties laws (viscosity, wind currents, etc.) and therefore study of these physical laws including volcanic behaviour numerical modelling. Then, multiplying simulations, with different ranges of characteristics (emitted volume, viscosity, etc.) and from thousands of possible vents, allow the identification of preferential paths or extensions. Examples can be found in literature.
On the other hand, scientific teams develop methods to quantitatively estimate return periods of different types of eruptions. These studies, using statistical tools, are based on the design of event trees relying on a fuzzy approach to manage all kind of data (geological, historical as well as monitoring observations). Different event trees can be established for different sectors of the volcano.

The theoretical example of Figure 18 highlights that when unrest begins, it leads in 80% of cases to an eruption. When it occurs, the eruption is effusive in 25% of cases and explosive in 75% of cases. Given a return period for unrest (e.g., the volcano presents some activity evidence every 20 years), this method allows assessment of the probability of occurrence for different types of eruption in different sectors of the volcano. However, it must be noted that probabilities within event trees are often poorly constrained, because of lack of evidence on the volcano's behaviour. The role of the analyst here is to generate an up to date event tree and update it whilst new data or knowledge on the volcano is collected.

These two approaches (numerical modelling and event tree design) are well fitted for both long term and short-term hazard assessments. Results of these researches are now becoming operational.
It is worth noting that risk mapping is currently much less developed than hazard mapping. It consists generally in overlapping assets with previously existing hazard maps. Many of these attempts led to the production of numerous maps, which were difficult to interpret and therefore exploit for decisions.

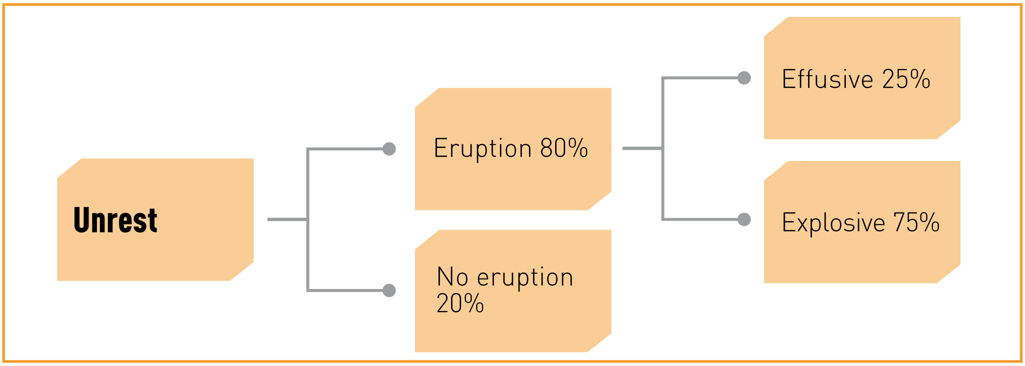

Figure 18: Schematic example of event tree.

Proposal for a unified approach

A new hazard and risk assessment method can be recommended integrating elements from these development and research results as well as multi-risk approaches previously developed by the MIAVITA team on Mount Cameroon and Merapi volcanoes. The main purposes of this applied methodology are:

To draw different hazard maps (at a scale of 1:25000, possibly 1:50000) each dedicated to one specific hazard (e.g., lava flow, ash fall or volcanic earthquake). These maps enable to describe the local maximum level of threat presenting the "worst" combination of frequency and intensity given the potential physical impacts (i.e., the combination generating the largest amount of damage for a relevant period).
These maps can constitute the basis for short time hazard assessment and scenario designing (assessment of damage and calculation of losses for a given eruption).

To draw a global hazard map for the volcano and its surrounding (1:25000 to 1:50000). It should integrate and combine all hazards. This map, suited for long-term hazard assessment, is mainly useful for land use planning and regulation as well as communication purposes (e.g., to provide recommendations for the population at risk).

To draw exposure maps with the location and characteristics of elements at risk. It allows scientists to assess the dimensions of exposure as well as, when possible, the values (this point will be extremely important for scenario designing).

To draw a risk map that highlights the critical zones in terms of probabilities of losses (conjunction of high hazard, whatever the considered phenomena, and concentration of elements at risk and exposures with high vulnerability and value). Therefore it is a valuable tool for stakeholders to elaborate mitigation measures and/or disaster risk reduction plan.

Multihazard mapping

The steps of the proposed volcano hazard mapping method are presented in the following scheme (Figs 19 and 20). Four main phases are identified before drawing final global and comprehensive hazard maps:

A first phase aims to build baselines (intensity/frequency) consistent for all types of phenomena (these baselines and their meaning are presented in more detail below).

A second phase aims to study the volcano as a whole, which includes:

- Geological fieldwork to build a better understanding of the volcano and its past and present dynamics. This corresponds to the essential work needed to build "susceptibility maps". In addition, numerical modelling of the volcano's behaviour may prove to be of major help
- The acquisition of a high resolution DEM
- The identification of some reference eruptions with their characteristics (i.e., intensities of the different adverse events associated with the eruption) and possible dimensions of these adverse events. The intensity is given for each adverse event by the maximum from its various physical impacts. These reference eruptions must be representative of the volcanic history

- The mapping of potential vent zones (i.e., zones where the likelihood of activation of eruptive vents in a future eruption remains almost similar everywhere), the design of event trees based on the reference eruptions for the different vent zones. These event trees allow estimation of the frequencies of the corresponding adverse events

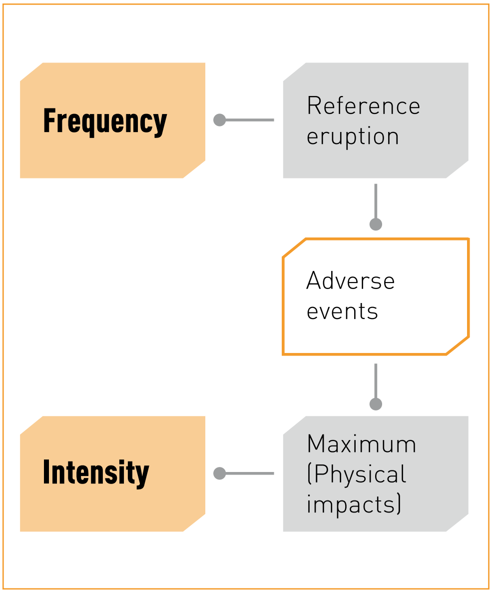

Figure 19: Scheme presenting relations between eruption frequency and intensity for adverse events hazard mapping.

A third phase aims to map roughly the different hazards: for each adverse event and for each vent zone, the dimension of adverse events is taken into account for each reference eruption to draw a rough hazard zoning. At any point, the hazard is then given by the worst case in terms of intensity/frequency between the different reference eruptions. It is worth noticing that, although such a method implies drawing a multiplicity of maps, the use of IT tools like GIS is efficient and time saving.

A fourth phase aims to refine maps for each adverse event hazard: at this stage, numerical modelling, as stated above, constitutes a most valuable tool. A very important point is that the range of parameters (volume, physical characteristics like viscosity, etc.) for the numeric calculations will be deduced from the preceding phase.

At the end, a single comprehensive hazard map will be produced by the superposition of the different hazard maps taking once more the worst case.

Hazard and risk mapping: common baselines

This sub-chapter explains how common baselines can be defined for hazard assessment in volcanic area. As examples, buildings might primarily be affected by peak ground acceleration induced by volcano-tectonic earthquake, prior or during an eruption, or by the tephra fall thickness and static loading on roofs. Agriculture is instead impacted by tephra fall in a larger extent than by other threats, while human health may be affected by pyroclastic flows, lahars, ballistics, flank collapses but also by SO_2 and CO_2 concentrations in the air (see Section 2). Combining all these different elements represents a real challenge for risk mapping. Here, a difficulty arises from the multiplicity of possible adverse events and physical impacts that may affect each asset. As a consequence, there is no common quantified scale that can express all these physical intensity. One solution can be to use baseline only in regards of human being (e.g., social or psychological dissatisfaction, financial losses, important economic losses and first injuries, first deaths, numerous deaths, see Table 4).

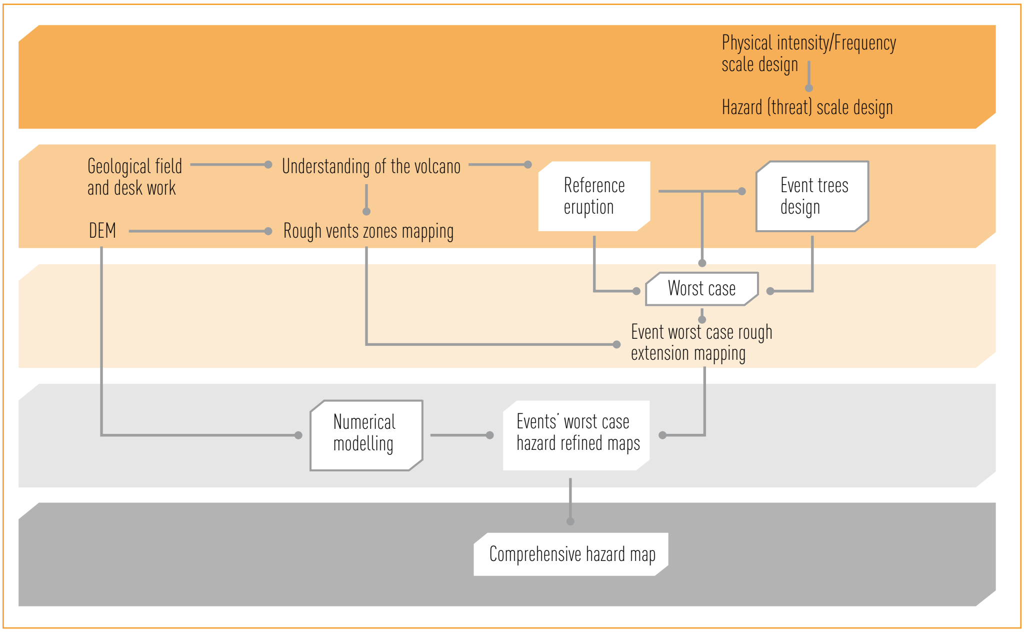

Figure 20: Steps of the proposed hazard mapping methodology.

The analysis of adverse events and their various physical impacts will allow identifying the "worst damage". As an example, an expected thickness of 50 cm of ashes will lead to health problems to affected people (low or moderate intensity) but also to the collapse of many roofs leading to possible deaths (high intensity). This last evaluation will be kept for assessing the global intensity of the adverse event. In order to translate this qualitative judgement into numerical equivalent, damage cost analysis can be used. For example, in Table 4, the value breakdown is based on a survey of global relative costs for road accidents in France that addressed human life's economic value as well as severe injuries' costs.

Then, a common frequency baseline for all adverse events must be defined (Table 5). Here, the probability of occurrence (or frequency or mean estimated return period (T) between two events of the same characteristics in a given sector) is evaluated using historical records, geological evidence and expert judgement. A numerical equivalent, Q_f, can then be established by calculating the inverse of the maximum time return period for each class: $Q_f = 1 / T_{max}$. For a better visibility of the result, Q_f might be multiplied by 100. While analyst often can not quantify precisely the mean return period of given events, it can be noticed that the accuracy required in Table 5 is very rough. Therefore, geological evidences and analyses of historical events often provide sufficient knowledge to relate a given event with a frequency class. This task is however highly dependent of field observations.

Finally, cross-referencing intensity and frequency of events leads to the definition of a common hazard scale, which can be expressed through practical recommendations in terms of human settlements.

TABLE 4: PROPOSED INTENSITY BASELINE AND NUMERICAL EQUIVALENT

INTENSITY CLASS	QUALIFICATION OF THE HAZARD INTENSITY	DEGREE OF DAMAGE (reference maximum human impact)	NUMERICAL EQUIVALENT (E_I)
I_1	very low to negligible	Social, psychological and economic dissatisfaction	0.5
I_2	Low	Some slight injuries in the population financial losses acceptable by individuals	2.5
I_3	moderate	Severe injuries in the population High financial losses	15
I_4	High	Severe injuries potentially leading to deaths	60
I_5	very high	Numerous deaths	100

The multi-hazard map can be produced by keeping the maximum threat index at each location. In other words, for each location, the worst intensity-frequency combination is kept. For example, let's consider a thalweg located near to the crater and possibly affected to pyroclastic flows with a return period of 50 years. Even if the same location can be affected by tephra fall with the same return period, that threat level in the global hazard map will still remain that defined for the pyroclastic flow event.

TABLE 5: : PROPOSED FREQUENCY SCALE

FREQUENCY CLASS	QUALIFICATION OF THE EVENT FREQUENCY	RETURN PERIOD FOR THE TYPE OF ACTIVITY OR PHENOMENON (Order of magnitude)	QUANTIFICATION OF THE PHENOMENON FREQUENCY (Q_i)	NUMERICAL EQUIVALENT (QF=100 x Q_i)
F_0	very low to negligible	5000 to 10,000 years	10^{-4}	0.01
F_1	very low	1000 to 5000 years	2.10^{-4}	0.02
F_2	low	500 to 1000 years	10^{-3}	0.1
F_3	moderate	100 to 500 years	2.10^{-3}	0.2
F_4	high	50 to 100 years	10^{-2}	1
F_5	very high	10 to 50 years	2.10^{-2}	2
F_6	quasi-permanent	1 to 10 years	10^{-1}	10

The threat matrix, obtained crossing intensity (expressed as numerical equivalent E_I) and frequency (expressed as numerical equivalent Q_F) baselines can be used to define hazard classes (Table 6).
In order to be most effective for disaster risk management, these threat level should directly refer to recommendations to people at risk:

- Negligible hazard (grey threat values in the table below, under 0.1): no associated recommendation for normal permanent human settlements
- Low hazard (yellow threat values, between 0.1 and 5): no specific associated recommendation, but vigilance required
- Moderate hazard (orange threat values, between 5 and 100): permanent human settlement possible but with specific recommendations
- High hazard (red threat values, between 100 and 500): permanent human settlement inadvisable unless major precautions taken
- Very high hazard (darkened threat red values, over 500): permanent human settlement should be avoided

TABLE 6: : THREAT MATRIX RESULTING FROM CROSSING INTENSITY AND FREQUENCY BASELINE SCALES

FREQUENCY (Q_F) \ INTENSITY (E_I)	0.5	2.5	15	60	100
0.01	0.005	0.025	0.15	0.6	1
0.02	0.01	0.05	0.3	1.2	2
0.1	0.05	0.25	1.5	6	10
0.2_3	0.1	0.5	3	12	20
1	0.5	2.5	15	60	100
2	1	5	30	120	200
10	5	25	150	600	1000

First applications of this hazard assessment method in Mount Cameroun and Kanlaon show that the method is sufficiently flexible to be applied in a variety of contexts, particularly in poorly known volcanoes. However, when little knowledge on the volcano exists, it is necessary to undertake extensive field geological survey, with a particular focus on dating of deposits and interpretation of the volcano structure and geomorphology.

Multirisk mapping

Beyond hazard mapping, the second step for risk mapping is the inventory of elements at risk, in the volcano's human, social and natural environment including:

- Population (urbanized areas and sites of periodic concentrations of people such as schools, main centres of worship, markets, stadiums, etc.)
- Strategic buildings for crisis management

and networks (governance, army and security, health centres, etc.)
- Buildings, infrastructures and lifelines (housing, transport, water and food supply systems, power networks, roads and bridges, telecommunications relays, etc.)
- Natural environment and farmland (vegetation and hydrography, food crops and industrial plantations)
- Main centres of economic and financial interest (banks, factories, tourist centres, etc.)

The methodology consists of acquiring the relevant data by census, field visits, questioning relevant people, analysing remote sensing data and aerial images as well as any relevant pre-existing maps or data. In case of lack of enough information, available data can be extrapolated by statistical methods.
Vulnerability assessments imply specific surveys conducted by scientists specialized in the different domains (social sciences for population vulnerability, architects and structural engineers for buildings, agronomists for cropping and agriculture, etc.). Usually, these specialists identify different classes of assets presenting a similar vulnerability. The mapping and localisation of these different classes permit weighing of elements at risk in terms of level of damage.

Finally the risk mapping methodology consists of crossing hazard, vulnerability and exposure indices taking into account the coping capacity index, which contributes to decrease the level of risk. In the approach proposed, the realization follows three steps:
- Generic bases on the risk components to take into account
- Collection of information by surveys and questionnaires, including information for the determination of hazard, vulnerability, exposure and coping capacity indexes

Risk analysis and mapping using Analytical Hierarchy Process, a "theory of measurement through pair wise comparisons" relying on the judgements of experts and stakeholders
The use of Analytical Hierarchy Process helps to derive priority scales measurement of intangibles in relative terms, and weighted indicators which allow scientists to weight a given community with respect to all sub-criterion that are components of the risk. Limits of risk classes can then be defined from the risk scores obtained previously and the map drawn.

As an example, this analysis has been created for Merapi by MIAVITA Indonesian partner CVGHM/BBPTK (before and after the 2010 eruption). For each community at stake, the hazard, vulnerability, exposure and coping capacity indexes have been evaluated and weighted in order to obtain risk scores that can be compared and used to scale the risk and then draw a risk map. The vulnerability index included three major components: demographic pressure (density, unsafe settlement, access to basic services, etc.), social (poverty level, diffusion of literacy, attitude and community participation) and economic (diversification and accessibility). The exposure index included three major components: structures (number of houses and lifelines), population (total population) and economy (local domestic product). The coping capacity index included four major components: land use planning, society (public awareness program, public participation, emergency response drill, local risk management and school curricula), economy (local emergency fund, access to national emergency fund and reconstruction capacity) and management (risk management, hazard mapping, early warning systems, emergency plans, institutional capacity building and communication). The resulting map syntheses the risk in administrative entities around Merapi.

24. Stakeholders' preparedness

Preparedness is the development of activities and measures that are planned and implemented to prepare the necessary measures to respond and cope with the effects of a volcanic eruption. Among the main activities the following are of great and strategic importance:

- Assessment of hazard and risk
- Definition of alert levels
- Evaluation of possible scenarios and their probability of occurrence
- Setting up of early warning systems
- Design of emergency plans (including validation, exercises and dissemination)
- Development of people's information and awareness about risk, education about the correct behaviour and actions to take in case of emergency
- Establishment of policies and standards
- Securing of resources
- Training of experts
- Planning and scheduling of exercises

People who live in active volcanic areas should implement a coherent, multi-risk approach for civil protection that integrates scientific research and technological expertise into a structured system for forecasting and early warning of natural disasters.

The following chapter aims to reinforce the concept of "civil protection system", which includes and enhances the scientific community role by setting up established agreements and protocols, depending on social-economical consideration and with regards to ordinary time activities.

The role of players

During the preparedness phase, the definition of roles for all the players involved is of primary importance. This organization of roles must avoid duplication and lead to the assignment of clear responsibilities. We present here, in a schematic way, the main roles which have to be assumed by the three main components of the civil protection system: national authorities, local stakeholders and the scientific community. The information about roles of other bodies are concerned, like operational corps such as fire fighters, Red Cross or Non-Governmental Organizations (NGOs) is well beyond the scope of this handbook and it can be easily found on Internet.

National authorities

They are responsible for civil protection actions at a national level (Civil Protection Agencies, Ministries, National Risk commissions or committee or observatory, etc.). Their main roles are to:

- Foster an accurate perception of risk and organize adequate resources to minimise those risks. A community with a proper, proportionate perception of risk is able to respond properly in case of a disaster and, consequently, to reduce the

devastating impact of disaster events
- Inform and educate the public on a regular base
- Develop emergency plans at national level and give relevant guidelines to develop the regional and local emergency plans
- Define the civil protection actions for each alert level
- Attribute clear roles and responsibilities to each actor
- Organize the response to a future eruption (means, strategies, rescue teams, etc.)
- Give the relevant guidelines to the other players involved (local stakeholders, operational forces, etc.)
- Identify and share information with all the stakeholders involved in volcanic threat on a regular base
- Organize an extensive training at national level and guide the training at regional and local level
- Carry out studies on civil protection measures
- Foster relations with national and international organizations on civil protection in order to be able to efficiently request and use international support in case of crisis
- Deal with media regularly and not only during or after an eruption event

Local stakeholders

Regional, provincial and municipality administrations have to be informed, organized and trained to produce the strongest effort to cope with the emergency in the initial phase. During volcanic crises, local authorities usually lead the first part of the response (it is the opposite for earthquake emergency). Their main roles are to:

- Increase the public perception of risk and promote appropriate behaviour (see Chapter 26)
- Update annually the census of the whole population living in areas potentially at risk (special care would be devoted to disabled and elderly persons)
- Update regularly all needed cartographic information on the area (roads and infrastructure, private and public buildings, strategic buildings, workplaces where a great number of people stay at the same time, land use, etc.). The transfer of this information to national authorities is fundamental for the development of national emergency plans
- Participate in the choice of emergency evacuation areas, entry points, allocation of resources and in all activities for developing national, regional and local emergency plans
- Draw up local evacuation procedures and test them with exercises on site
- Share information among all operational forces and administrations
- Inform the public about their activities, in collaboration with national authorities. Everybody should know what local administration is working on
- Plan every activity in a sustainable way and act constantly. Sporadic activities lead the public to a general sense of abandonment
- Train personnel and give a multidisciplinary view

Scientific community

It may include universities, observatories and research institutes involved in evaluating the behaviour of volcanoes. Only ap-

BOX 10

THE CIVIL PROTECTION SYSTEM OF CAMEROON AND THE ROLE OF NATIONAL RISK OBSERVATORY

The Directorate of Civil Defence (DCD) is one of the main structures in the central service of the Minister of Territorial Administration and Decentralization (MINATD). It is organized in two main groups, which include the unit in charge of studies and prevention and the unit in charge of coordination and intervention. A special and strategic role is assigned to the National Risk Observatory (NRO), which has the responsibility and the duty to collect, analyse, store and disseminate all the information about natural and anthropic risks. The NRO convenes every three months, under the coordination of a National Focal Point belonging to the DCD. The NRO is composed of the delegates of Ministers, regional authorities, Red Cross, fire fighters, scientific institutions and civil protection civil servants. During meetings, impending risk is analysed to supply to the National authority the needed information to take protective measures.

plied sciences are considered here. Upstream research on physics, chemistry, structural engineering, etc., are out of the scope of this handbook, even if they constitute the basis for future improvements. The main roles of the scientific community are to:

- Develop studies and research in order to increase knowledge about volcanoes and their behaviour
- Monitor the volcanoes, developing interdisciplinary monitoring and considering the possibility of building integrated networks (service and research). The aim of a service network is to give real time data and indications to the national community in terms of eruption forecasting (see Section 3)
- In countries where scientists are responsible for alert levels, they should define the alert levels and they should submit to the authorities the transitions to different levels of alert as soon as the situation demands it
- Inform the public about monitoring activities and acquired knowledge. When possible, give some information before the beginning of every event (see Box 11)
- Share information continuously with scientists of other disciplines. Only an interdisciplinary approach can improve the forecasting of a volcanic event. Established relationships, well tested in advance will work properly during emergencies
- Inform the authorities about the volcano activity recorded. This can be obtained by agreement between scientific institutes devoted to volcano monitoring/analysis and the main civil protection stakeholders using robust and shared procedures (see Chapter 22)

Forecasting

Available data on historical eruptions show that they are often preceded and accompanied by a phase of physical and geochemical variations (volcanic unrest) with respect to the normal state of activity (base level). This has been clearly indicated and demonstrated by analysis of information obtained through the last decades thanks to the development

of monitoring networks (ground or space based) and during past volcanic eruptions (e.g., the 1991 Pinatubo eruption or the 2006 and 2010 eruptions of Merapi).
Volcano monitoring comprises different branches of science and several techniques (e.g., seismicity, geodesy, geochemistry) and constitutes the unique scientific approach allowing short-term forecasting of volcanic eruptions. The simultaneous analysis of data, produced by these different monitoring networks leads to a certain level of probability to forecast an event. Volcanic monitoring systems are continuously improving and they have become more and more sophisticated, accurate and effective. In addition, new tools based on satellite observation are offering new possibilities, allowing the acquisition of a great amount of data, which were not available a few decades ago (see Section 3).
Nevertheless, it must be emphasized that even with a good knowledge of long-term hazard assessment and the availability of monitoring data (short-term forecast), the outcomes of volcanic unrest still remain largely unpredictable. The size, the time of occurrence and the duration of the impending eruption are still extremely difficult to forecast with precision.
It is relevant to underline also that each volcano has its own history and behaviour. Even if comparisons between eruptions of volcanoes with similar behaviour are often possible, they can sometimes be misleading if applied to short-term forecasting for civil protection

BOX11

DAMAGE TO MONITORING NETWORKS

In many developing countries, for people living on the slopes of active volcanoes, various popular beliefs often exist about the nature of volcanic eruptions. Many people believe there are the gods that cause disasters (see Chapter 26), and that monitoring stations perturb the rest of the volcano and cause eruptions. These beliefs can induce people to damage monitoring stations positioned by scientific institutions, even though they are fundamental for evaluating volcanic behaviour and short-term forecasting.

It is obvious that these cultural beliefs should be taken into account and communication should be planned before, during and after the installation of a monitoring network on a volcano. It is strongly recommended to inform people about the monitoring activity: what is its scope, what are the costs, why stations are important, where the stations are set up and so on. Sometimes this information can be disseminated directly to the public whereas in other cases it would be more appropriate to transmit information through chiefs of villages or other persons that have high credibility in the community. The effort and time consumed in these preliminary actions would be repaid twofold: it ought to ensure that the community will pay attention to the instruments (and cause no damage to them), which would imply that monitoring would be more economically sustainable and that measures of parameters would be continuous (no interruption due to maintenance), and increase people's awareness and volcanic risk culture, which would be crucial for a better response in case of volcanic activity.

aims. Such comparisons are more applicable for scientific researches, especially for understanding of volcanoes monitoring results.
In the current state of art, it is possible to estimate a certain probability of occurrence for an impending eruption, when an operational multi-disciplinary monitoring network exists, but it is not possible in any way to guarantee that an eruption will occur or not, nor to assess the dimensions of the event.
Civil protection authorities, Government as well as public, have to be fully aware that there are, most of the time, large uncertainties in eruption forecasting. Nevertheless, keeping this uncertainty in mind, many actions can be taken in order to protect people.

"False alarm" or alarm without a following eruption

Since it is not possible to forecast precisely the onset and size of a volcanic eruption, even in the case of well monitored volcanoes, it is always possible to create what is generally called "false alarm" (an alarm launched that is not followed by an eruption). When the scientists advise the civil protection authorities that the probability of eruption is over a certain threshold, the authorities should call for an evacuation or take alternative actions. This point must be considered in any public communication strategy. Efforts must be made to avoid the possibility that, after repeated false alarms, people will ignore them. People should know that forecasting volcanic dynamics and eruptions always implies a certain amount of uncertainty with respect to vent location (often low uncertainty), to time of occurrence and duration of an expected eruption (medium-high uncertainty) and to its magnitude (high uncertainty).

Scientists, civil protection authorities and more generally authorities responsible for public education, should disseminate this concept of "probability/uncertainty", to make people aware about it. This will lead to an easier emergency management, based on this concept. In this regard weather forecasting is a very good and understandable reference. When people know and assimilate the concept of "probability of occurrence", the duty of the authorities is highly simplified. This requires a strong effort in public education and communication, but it will contribute to the decrease in loss of life, in a volcanic crisis.

Time window for action

Considering the uncertainty in forecasting, it is worth noticing that, in the case of escalating unrest, the time window dedicated to decision on counter-measures is often really narrow. It is then fundamental to be able to react fast, with a pre-established and flexible (dealing with unexpected events) table of planned actions. A validated procedure to enlarge the time window for decision-making consists of setting up common work meetings gathering a chosen group of scientists, usually those responsible for the monitoring network and expert volcanologists, with public officials of civil protection authorities. This enables assessment of the volcanic unrest evolution and the subsequent development of eruption, when it occurs. The meetings guarantee that civil protection authority will know exactly what is happening (including the level of uncertainties), and allow the scientific community to know the measures that will be taken on the basis of their suggestions. This is fundamental for crisis management.

Alert levels

Each volcano has specific dynamics and behaviour. It is therefore very difficult to define a general number of alert levels relevant for every case. Furthermore, definition of alert levels depends on the monitoring network capability to measure and record variations of geophysical and geochemical parameters, on the knowledge of the volcano's behaviour and on the capability of scientists to discriminate variations in volcano state of activity. The international trend is to have simple consistent alert levels across all volcanoes. The application of the same alert scale to multiple hazards, e.g., hurricanes, floods, eruptions, and tsunamis simplifies people's understanding. Huge confusion would exist amongst the public if two neighbouring volcanoes, threatening the same civilian population, had separate alert scales involving different numbers of steps. Nevertheless, it has to be considered that the same number of alert levels cannot match always with all the behaviours of every volcano. Sometime, in fact, it is not effective to define the same number of alert levels for all the volcanoes if the monitoring network and the knowledge on volcano's behaviour are not able to distinguish one level from another, with respect to physical or geochemical variations. Choosing the most appropriate number of levels is fundamental to taking the right and effective counter-measures, to develop emergency planning (see Chapter 25) and to allow the authorities to draw up standard procedures. The alert level can be established using probabilistic approach.
The majority of well tested alert levels systems range from three to six levels and they consist of progressive scales such as:

- Normal (or Base) level is the background, non-eruptive state
- Attention (or Advisory) level indicates "starting unrest" (i.e., a change from the stability state)
- Pre-alarm (or Watch) level means rapid increase of precursors and on increased potentiality of eruption. It has sometimes been used to inform that an eruption is imminent but with limited expected hazards and consequent damage
- Alarm (or Warning) level means that the eruption is imminent or happening

It must be emphasized that the application of international "standards" from alert levels is a reasonable basis for the definition of alert levels in a country or for a volcano (same number of alert level in the country) but that this basis could be changed or modified if knowledge of the volcanic behaviour allows to do so.
Each one of the different alert levels must be associated with planned actions and procedures. These situations must be previously defined and are absolutely necessary.
All these levels might include probabilities, when the knowledge is sufficient to calculate them. For public communication, each level can be associated with a colour.
Every decision regarding changing the levels of alert is usually based on variation of geophysical, geodetic and geochemical parameters, often using threshold values (e.g., the appearance and the number of very long period seismic events, or changes in CO_2/SO_2 value, or the appearance of strong ground deformation). This is true for increasing the level as well as for reducing it (see Box 12).
Then each established alert level should be associated with:

The definition of the expected geochemical and geophysical changes: for volcanoes that display significant reliable monitoring data and knowledge on historical eruptions, threshold values can be defined for some of the monitored parameters. These values are sometimes very difficult to establish, due to both the scarcity/uncertainties of data and the usual and correct cautiousness of scientists on this topic. Nevertheless, when it is possible, it is easier to consider two threshold values: under a certain value the parameter that can be considered "normal" (low) and over another number the parameter can be considered "unusual" (high), leaving the interval between the two chosen values not well defined. The synthesis of the experts opinions about a specific parameter or even all parameters (elicitation) is a very useful procedure, which has already been validated and used in a lot of different organizations.

The description of expected phenomena for each level of alert: the description can be related to phenomena felt by instruments or/and people.

BOX12

RAISING OF ALERT LEVELS DURING THE 2010 ERUPTION OF MERAPI

Prior to the 2010 eruptions of Merapi volcano, Indonesia, a significant number of VT earthquakes were observed the previous year. One month before the eruption, swarms of VT earthquake frequently occurred. Increases in ground deformation and gas suggested that a magma or fluid was moving towards the surface. Based on those data, the alert level was declared to the public. On September 20, 2010, the alert level was increased to indicate that the volcano was in a serious unrest state (raised from Level I to Level II) following a dramatic increase in all monitoring signals. On October 21, 2010, the state of activity was raised to Level III when, aside from the number of volcanic earthquakes continuing to increase, the rate of deformation inflated 17 cm. The seismic activity kept increasing, SO_2 flux reached 249 tons/day and the rate of deformation increased to 42 cm in a day causing a rise of the alert level to its highest, Level IV on October 25, 2010. The CVGHM declared that the area within 10 km radius from the summit of Merapi volcano needed to be evacuated. The first of a series of eruptions occurred on October 26, 2010 generating pyroclastic flows, which travelled 8 km into Gendol river, in the south-eastern flanks of the volcano. On November 3, 2010 at 16: 05 (local time) CVGHM declared the area within 15 km radius from the summit of Merapi volcano needed to be evacuated since continuous and overscale seismic tremor occurred and SO_2 flux attained 500 tons/day. At 17:30, a pyroclastic flow travelled down to 9 km in the Gendol river. On November 4, 2010 at 23:00 due to overscale seismic tremor continued and SO_2 emission in the air increased to 100 kilotons, CVGHM declared that the area within 20 km from the summit needed to be evacuated. This activity reached its peak on November 5, 2010 at 00:02 when an explosion and subsequent collapse of the lava dome generated pyroclastic flows that reached more than 15 km from the summit into the Gendol river. The series of eruptions claimed many lives, more than 200 directly through contact with pyroclastic flows and surges, 277 injuries and the official evacuation of 410388 as well as significant damage to infrastructure, houses and agricultural areas.

The recommendation for additional monitoring equipment: it aims to ensure better forecasting of the possible impending eruption (temporary seismic network, satellite monitoring, frequent levelling or temporary GPS campaigns, etc.). These improvements should be mainly planned on 'normal' time (no alarm), especially in case of poorly monitored volcanoes, where the infrastructures are not well developed. This can be the time to ask for deployment of temporary networks as the level of alert rises; in fact, it becomes impossible to set up new equipment on the volcano during the alert phase (high risk for scientists).

The civil protection measures: they include all the measures that have to be taken at each alert level. Measures can include phases of different level of information and socialization (see Box 13) to people, administrators and the media, the establishment of commissions of scientists and institutional stakeholders, the opening of command posts, the preparation of means and logistics able to respond to future event, the evacuation etc.

Updating of alert levels

Knowledge of volcanoes increases continuously due to a better understanding of volcanic phenomena, analysis of new eruptions and technological developments allowing measurements of new parameters and quantities with greater precision (e.g., new possibilities for satellite analyses, cost of instruments decreasing with time), etc.
As a consequence, alert level determination will certainly change with time especially from a scientific point of view (increase in the capability to discern relevant information among confusing physical signals). It is therefore important to update the alert levels on a fixed schedule (e.g., every five years). This review can represent a major task because this updating has to be shared and disseminated to all the players, including the public.
This revision also contributes to maintain the focus on alert levels and preparedness in general.

BOX13

SOCIALIZATION PHASE IN INDONESIA

Among all the other relevant actions that need to be carried out during the various phases corresponding to different alert levels, the ¨socialization¨ phase in Indonesia seems to be particularly interesting and effective. Socialization phase is a period of time, corresponding to the pre-alarm phase, during which a great effort is put into informing people about the situation, discussing with people the problems arising from a probable imminent eruption, clarifying doubts and fears and assuring people about looting and disorders. It is in this time-frame that a large portion of the public's response efficiency can be improved. During a socialization phase, community meetings can be used to share experiences of past eruptions, thanks to people who lived them, to re-assign roles in the community, to ensure that everybody knows the emergency plan (especially regarding the alert system), how to be evacuated, where the meeting points are, etc. For dormant volcanoes, it is difficult to build a strong program on education and training because the perception of risk is usually very low. Socialization for people living close to dormant volcanoes is therefore crucial. It is important to highlight that socialization is possible and effective only when a program on risk perception and education has previously been carried out.

Early warning

Early warning systems aim at informing a community about an impending danger. They should trigger actions by designated agencies or community members to prepare this community to a hazard event and/or assist the evacuation of an area at risk. These systems can be built using modern technology (messages on telephone, radio and television, etc.). The definition of early warning procedures needs, on one hand, to bring together scientific and technical communities to forecast volcanic events with effective communications, and, on the other hand, to communicate the warning to the community using well-known standard procedures, with the active participation of local communities. The elaboration of a well shared early warning communication flow makes the dissemination of correct behaviour easier and quicker. In this context, it is fundamental to unequivocally designate who can authorize the release of warnings to the public, what organisations should be notified, and the procedures that should be followed.

Many types of early warning systems usually exist for different hazards in a volcanic environment. These systems can be traditional or modern, with respect to culture, economical sustainability, presence of power supply, etc. (Fig. 21).

Nowadays there is a great discussion about the manual activation of early warning systems or total automatism of them. It is relevant to highlight that, for well-trained and informed communities, automatic warning systems can present a great advantage in terms of speed. In developing countries, especially for lahars, sometimes volunteers, trained on purpose, can easily monitor the arrival of lahars from a safe location. From a radio or different communication device the early warning system can easily be launched.

Figure 21: Example of different early warning systems in Indonesia: traditional and modern. Photo by Vittorio Bosi.

GOOD PRACTICE FOR AN EARLY WARNING SYSTEM

Preparedness: appropriate means or equipment should be prepared in advance and should be determined based on the nature of the imminent hazard. Roles, responsibilities, procedures and signals used for launching the alarm to the public should be clear, well known and tested (i.e., command chain, bells, sirens, loudhailer, traditional equipment).

Signal response practices: the means of communication, the signal used and the correct behaviour with respect to the given warning should be effective and well known by the whole community before an eruption. People should know where to go and what to do, when detecting these signals.

Testing: the alarm signals should be tested regularly (weekly or monthly) in order to check their proper functioning, and to keep people well aware of the sound and its associated meaning. After a long period of inactivity, people cannot easily associate the sound to the necessary personal safety precautions.

Target: early warning systems should reach the entire population, including remote areas and seasonal population. Tourists should also be advised about early warning procedures and signals.

Reliability: it could be greatly improved by setting up a two-way communication systems in order to allow confirmation that the warning has been received. It is fundamental to receive confirmation that people and authorities are advised.

Information and training

Information and training are fundamental for all the players involved in volcanic risk management: scientists, civil protection authorities at national and local level, journalists and, above all, the population. Thanks to information and training, every component of the civil protection system can be efficiently prepared to cope with a disaster in every moment. Money spent for information and training will be totally reimbursed by the drastic reduction of the number of victims and economic losses during future eruptions.

Information and training are commonly considered as two different concepts:

Information is usually related to transmission of messages, signs or signals to someone.

Training prepares someone to react properly to given information.

In the middle of these two relevant step, it is often underestimated the concept of "sharing", which corresponds to supplying simultaneously the same information to different stakeholders.

These three phases should be undertaken consecutively, and no phase should be deleted. From now on, we will refer globally to all three phases as "training".

A general rule is that training cannot be a sporadic initiative. Training, in civil protection matters, implies constancy and sustainable programs. The frequency of training depends on many factors that are related to the cultural and socio-economic contest and to risk.
An example could be the billboards containing useful information (e.g., volcanic risk, recommended behaviour in case of eruption), which are useful methods and increase the public's risk perception. Nevertheless, if these informative billboards are not given sustainable maintenance, some problems can appear. Nothing, in fact, is more discouraging than an abandoned billboard on risks. It can be interpreted as a sign of carelessness, neglect or, even worse, of risk decreasing. After an eruption, in fact, the level of awareness to volcanic risk remains high for some years. During this first period many preventive actions are performed. Then, some years later, the level of awareness usually decreases giving a false sense of safety, which can be unfortunately reinforced by the abandonment of some of the prevention related activities (e.g., training, meetings, billboards), which were previously led.

Meanwhile, training methods and goals have to be adapted to specific targets. A brief presentation of these different types of training, addressed to the main players of volcanic risk prevention, is detailed below.

Training of national, regional and local authorities

Information normally follows a top-down direction, from national authorities to regional and local authorities. Usually national authorities give relevant guidelines to regional and local ones; unfortunately, sometimes, national guidelines and plans are not fully enforceable at local level, because of regional and local specificities and difficulties that are not taken into account. This can be avoided using mutual cooperation, which needs a two-way communication or cross-communication and a common "training", with information flowing from top to bottom and bottom to top, in a shared system. In this spirit, table-top exercises (see below) are very effective. Training of Majors is recommended.

Training of scientists

We are not dealing here with specific scientific and technical training but instead the training needed in order to help scientists to know how to react and communicate with civil protection, social agencies and media. In other words this means to understand civil protection concerns, to understand how to address the population, how to speak with the media, to define ways of sharing data with scientists of other disciplines, etc. One of the main difficulties is the mutual understanding between scientist and civil protection authorities. A common training on the main concepts is therefore recommended. Once this training is performed, it becomes easier to train scientists in efficient communication with the media, setting up a collaborative approach with the media itself, with the civil protection authorities, and with the public. It will allow tackling issues related to the possible generation of "false alarm" or panic. Training can be organized with the collaboration of journalists, as is the case for civil protection experts' training in the Monitoring Information Centre (European Civil Protection).

Training of volunteers

Volunteers represent added value to every system of civil protection. People who have the aptitude and are willing to act for the safety of the community may be trained to learn how to act in a coordinated approach with other civil protection organizations, monitor physical phenomena in order to participate in early warning systems based on observations, learn how to intervene in civil protection operations and learn how to disseminate the culture of civil protection to the population. Volunteers' training is also useful to reach their families and remote parts of the community. The transmission of civil protection culture by volunteers is always strongly recommended.

Training of media

The Media can represent one of the most strategic and useful ways to help the authorities to cope with a disaster, but they can also have an important role in dissemination of civil protection culture. The media is well known for being one of the interfaces with the public. A well informed journalist represents a chance to communicate correct information to the public. Training of journalists simply means to share with them experience, knowledge and strategy in communication in order to avoid panic and false alarms. If relationships with media are set and trained in advance (i.e., before the crisis), communication in the moment of an emergency will be effective. A clear liaison from a civil protection point of view would help especially in crucial periods.

Training of pupils and students

In many countries training of pupils and students is fundamental, because it is the sole training that involves the majority of people, in a very active phase of their life. Training of young people in schools has twin objectives, firstly it teaches them the correct behaviour in case of eruptions and helps them understand civil protection concepts and secondly, through a natural course of action, this knowledge is transferred to their family. One may find in literature numerous excellent examples that can be applied in different contexts.

GOOD PRACTICE FOR TRAINING OF PUPILS AND STUDENTS

Civil protection "role games": they are modern and attractive games that could be performed, for example, simply organizing a table-top exercise at school, where students take the role of different stakeholders and public.

Monitoring equipment in schools: a cost effective monitoring equipment deployed in schools is a good educational tool. In case of seismic station, usually it cannot be used as a real element of a monitoring network because of high instrumental noise.

Give lessons and make exercises in schools: lessons should be organised with a certain frequency (e.g., once per week, once per month), possibly twinning the lessons and/or exercises with cultural and sport events. The organization of movie screenings, etc., , at the end of a lesson or events such as concerts, after a planned exercise are, in fact, particularly effective and offers the advantage of inducing scholars to associate lively events with civil protection preparedness that ought to become a part of the cultural background, and involve a maximum number of people.

Training the public

Many pages could be written on this topic (see Chapter 26), and examples can easily be found on Internet. It is important here to underline that a diffuse training in the public and private sector, allows the public to be correctly informed. Governments all around the world are taking many initiatives regarding fire risks (e.g., information boards in elevators, single houses, offices, stations), but training on volcanic crises or earthquakes appears less developed. Public training can also be organized with the help of citizens' associations. Training the public is also an effective system to have a constant feedback on people preparedness.

Exercises

Exercises are fundamental for testing procedures, preparedness, and emergency plans, already prepared, and to maintain the attention on the spot. Exercises should be scheduled frequently and the frequency depends on several factors (e.g., behaviour of the volcano, social-economic context, level of risk perception, demographic trend). They clearly become ineffective and not useful if they are limited to isolated events.
There are many types of exercises but here we shall only bring three to your attention, which can represent many others:

Table-top exercises: they involve the command and control chain of emergency response (at national, regional or municipality scale, depending on the exercises). They are simulated interactive exercises that help to validate, consolidate and test the command and control chain, testing multiple functions of an organization's operational plan, focusing on the coordination, integration, and interaction among the different components, procedures, roles, and responsibilities before, during, or after the simulated event. The key for success stands usually in the clear attribution of roles and responsibilities. Each player should be clearly identified with details such as name, telephone, position, role, etc. This exercise helps to test the capability of an organization to respond to an event. The table-top exercise involves civil protection stakeholders including the scientific community at different levels (national, regional, local). It is cost effective because it does not require means, volunteers, etc. It also allows to test situations that would be impossible to run on the field in a full-scale exercise (e.g., 300000 people evacuated in an emergency following a tsunami). Table-top exercises can be used to identify weak points and means to remediate some of them. They can help people to learn how to work together, and it can also be very useful to use communication equipment and test protocol and procedures at every level of administration.

Full-scale exercises: they are actually more appropriate to test the delivery times and implementation of capacity on the field. But the corresponding costs, and personnel problems that can result from its use of resources, are not negligible. To make a full-scale exercise realistic and credible, it is necessary to commit relevant resources. Nevertheless, full-scale exercises are fundamental to test the whole civil protection response. Usually, once an emergency plan is issued and some table-top exercises and reduced exercises (see below) have already been performed, full-scale exercises contribute in a large part to validate the plan, and to consolidate all the procedures (road access, traffic problems, enforced evacuation, communication systems, etc.).

Reduced exercises: they are the most common ones. They are exercises that can be organized in public buildings, schools, universities, etc. They can be table-top (just at the level of command and control chain) or full-scale exercise (e.g., involving dwellers or students). They are relatively easy to organize and can be prepared once a week, a month or a year, depending on the different contexts and players.
If the notion of "thought" is often associated with table-top exercises, whereas "training" of men and materials (means of transportation, early warning systems, capability of people to move quickly, telecommunication systems, etc.) is more related to full-scale field exercises, the reality is more complex.

Exercises can be unannounced or announced, depending from the objectives.
Usually full-scale exercises are announced largely in advance to inform all the players and the whole community. This is because a clear and detailed program should be shared and approved by all the involved players, before the exercise. The organizers have to give a motivation to all participants to act promptly. Usually, without clear motivation, the exercises fail.
Unannounced exercises are instead suitable for reduced exercises and for table-top exercise. The use of unannounced exercise is necessary to verify the real strength of the system and the level of preparedness, when people do not expect to have a test.
In order to help choose the type of exercise, some reasonable constrains are:

- Clear objectives. It is important to write down an overall goal and some intermediate or specific objectives (Fig. 22)
- Type of hazard (ash, lava flow, lahar etc.), or multi-hazard
- Scale (national, regional or local)
- Players involved
- Budget
- Duration. The time you have at disposal

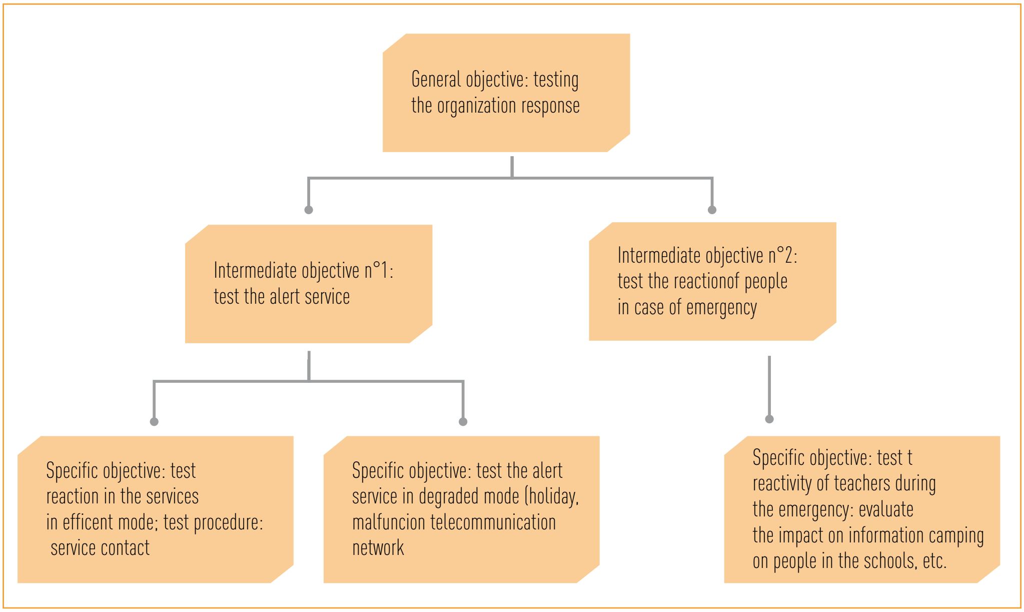

Figure 22: Example of the specific objectives of an exercise.

A form as the one in Table IX (Appendix) can help in the general organization of each exercise.

When these constraints are well defined, it would be possible to carry out the exercise in a positive and fruitful way.

GOOD PRACTICE FOR EXERCISE

Organisation: it should be based on the regulations and laws of the country.

Coordination: a steering group should be in charge of coordination and leadership of the various preparatory activities.

Scenario: a scientific-technical group is needed to modify the scenarios in a timely manner, even reflecting the reactions of the participants.

Work plan: an exercise work plan should be performed to determine the overall goal and some intermediate or specific objectives, as well as the list of participants, the command chain, the strategy, etc. A detailed agenda is also needed.

Exercises in degraded mood: They should be also planned to test system level capabilities of response when some parts of the system are not fully operative (holiday, malfunctioning of telecommunication network, blocked escape routes, snow, etc.).

Time required: Announced exercises preparation needs time. This should be considered during exercises planning. Usually, six to twelve months are necessary to prepare a full-scale exercise. If the promoted exercises are repeated on a fixed schedule, three months can be sufficient.

Debriefing: organize an on the spot debriefing straight after the exercise with the players, and another one approximately one month later with the exercise organizers, evaluators, observers, and a representative of the general public.

Communication: a communication plan is fundamental in the preparation of exercises, especially for full-scale ones. The media could contribute to inform the public about the approaching exercise.

Players: exercise preparation should involve all players from the beginning.

Reduced exercises: the organisation of entertainment is very effective to promote the participation of people in the exercise. Entertainment activities should always follow the end of the exercise and not precede it.

The role of sponsors (if needed)

The need and function of sponsors in exercises is generally debated. In general, private companies could sponsor exercises. This allows the Government to have more exercises on a reduced budget. Sponsors can be chosen among alarm system companies (who work on sirens for example), reinforced building companies, and any company working on categories related to civil protection purpose and risk reduction. As a general suggestion, when sponsors support exercises, it is recommended to vary sponsors from one exercise to another.

Dealing with media during the exercise

Relationships among participants (operational forces, scientists, civil protection authorities and media) during an emergency strongly depend on how these relationships have been built in advance. Exercises allow establishing and testing of good relationships with media, as such relationships are crucial during a real crisis. To improve them, it is highly recommended to involve the media in the earliest phases of exercise planning. This can help to understand how and when it is the most appropriate to start communication with the public. The media can be trained on technical aspects, which is often fundamental to let them have a sincere and valid criticism if something fails.

Preparedness for possible International aid

In the event of a major crisis, the affected country may request international support. Lack of preparedness in the request and in receiving international assistance will affect the effectiveness of the coordination of an emergency. Waste of resources and delay in implementation are the most evident negative effects in the first phase.

Requests for assistance have to be evaluated carefully in order to be sure that the support provided can respond usefully to the emergency management needs.
International assistance can be provided by Governments, UN agencies and/or NGOs. The latter can intervene even without a formal request. The management of these reinforcements, even if fundamental, usually occurs through UN and/or EU and are coordinated locally adopting OSOCC (On-Site Operation Coordination Centre) guidelines.

In parallel, the country affected has to activate its Host Nation Support Plan (HNSP).
A HNSP consists of a document listing all the activities that the country puts in place in order to remove foreseeable obstacles and to facilitate the delivery and use of international assistance. HNSP is a document that has to be adopted as part of the National Emergency Plan.
An HNSP will have to:

- Ensure the best possible use of the capabilities of an international support team from their arrival
- Integrate team operations with the ongoing rescue effort
- Support the team in all logistics' needs including fuel, transport, food and accommodation
- Assist the team in all contacts/relations with population or administration
- Facilitate the liaison between the team and local/national operational centres

In order to ensure proper HNSP in case of a major disaster, the country should consider setting up/integrating national arrangements to allow international emergency support within its territory.

All emergency management players should be identified and made aware of their responsibility in the different phases in the process of HNSP. In particular:

The country should make arrangements at all levels of its existing emergency command, control and coordination structure to facilitate the coordination of international assistance. At the same time, incoming teams should be aware of the country command, control and coordination structure and should report to the on-site commander at least on a daily basis.

The country should establish entry points, Reception and Departure Centre (RDC), a base of operations (BoO), a HNS team.

The country should pre-identify points of entry for incoming teams and should make all necessary arrangements to receive the incoming teams and modules at chosen points of entry (provide Liaison Officers, instructions, etc.). Entry points can be any type of border crossing (at roads, rivers, railroads, airports and seaports).

The country should be responsible for route planning and providing the necessary transport arrangements (transport means, escorts, maps, material handling equipment, fuel, food, etc.) for incoming teams starting from the point of entry and throughout the entire operation.

The country should provide logistics support for incoming teams and general maintenance of their equipment and should be responsible for take-over, storage and distribution of any kind assistance received. Moreover, the country should be responsible for the identification of an operation base, located as close as possible to the existing infrastructure. The HNSP should take into account the basic operation requirements such as access to water, electrical power, and sewage, access for cars and trucks, closeness to the disaster site.

The country should facilitate the use of telecommunication and the possibility to establish the necessary arrangements/facilities required to maintain communications with and within the locations of the international assistance operation and should also provide radio frequencies at the latest upon entry.

Twinning: A possible solution for pre-coordinated effective actions

Twinning among different territorial administrations (regions, provinces, municipalities or communities) leads to a stronger coping capacity in case of emergency and to a mutual learning in ordinary time. In the case of an emergency the affected territorial administration can receive a pre-coordinated aid from the twin one, which has not been affected. Protocols can be previously established between territorial administrations in order to plan mutual help in case of emergency and for daily activity. It is strongly suggested that common exercises are carried out in ordinary time. This is a very effective solution, which allows communities to stay in contact, to exchange expertise and experiences and support one another in case of emergency, as a stable agreement.
The main advantages of this partnership are: better coordination, cultural exchanges, sharing of resources.

25. Emergency planning

Generally speaking, for an effective response to an emergency, which is usually coordinated at different levels (national, regional and local), procedures, actions, roles, responsibilities and resources have to be clarified in advance. It is fundamental, in fact, to assess the ability to transmit an alert to the population of an area at risk, to improve coordination of emergency activities by maintaining connections among different institutional levels and to ensure an effective emergency preparedness, which includes preparation of emergency plans, assessment and finding means and resources. The involvement of the local level and residents is fundamental and indispensable for a correct emergency planning. This chapter is focused on the main and essential actions that should be undertaken in order to build an effective emergency plan.

The starting point: Identification of hazard areas in a multi-risk approach

Commonly an emergency plan starts with the definition of hazards and the identification of prone areas. During this initial phase, identification and mapping of main hazards (direct and indirect) are the main activities to perform. In addition, risk maps are generally drawn. It is important to emphasise that risk maps are very useful for urban planning, regulation and building codes, but they do not represent the main basis for emergency planning. Actually, robust emergency planning depends essentially on the knowledge of probability of occurrence for different scenarios.

A volcanic scenario represents a possible situation that is taken as representative of the expected volcanic event. It can be the most likely, the largest historically recorded, the most dangerous, etc. On this basis, using physical or numerical modelling and considering the data gathered for risk maps (e.g., different types of vulnerability, different types of exposure) on the targeted region, it is possible to establish the direct and indirect consequences related to the chosen scenarios. It is worth noticing that, in this regard, strong differences may exist between developed and developing countries. In developing countries, the main difficulties are related to the choice of the best scenario, especially for dormant volcanoes (because of the frequent scarcity of scientific data, etc.), to the evaluation of physical vulnerability (usually high) and to the impact on people, culture and livestock. On the contrary, in developed countries, risk assessment and scenario's evaluations are usually better constrained, and physical vulnerability is usually lower. Nevertheless, for both developed and developing countries the vulnerability of the socio-economic system, transportation and communications is often underestimated.

The identification of the best scenarios

The emergency planning design starts right after evaluation and choice of different scenarios. The choice of a single scenario is always challenging, because many factors can be poorly assessed, even for well-monitored volcanoes. For frequently erupting volcanoes, it is reasonably possible (even if not easy) to choose a scenario corresponding to volcano eruption type with recurrence time shorter than a decade or two. In this case, in order to understand the eruptive style of the volcano and to assess the probability of different types of eruption, in addition to geological records, scientists can also have

at their disposal many historical event descriptions and accounts and instrumental data, when monitoring network systems are effective. It is instead more difficult to choose a scenario when the time-recurrence of eruptions is longer. It depends strongly on the information available about its historical eruptions and on the availability of geological and geophysical data. It is even more difficult and usually controversial to choose scenarios for a dormant volcano that did not erupt for decades, centuries or millennium, which means that none or very few historical eruptions are known. In that case, only geological and geophysical data may exist.
For this reason, in general, it is good practice to build different scenarios, assigning a certain probability of occurrence to each (probabilistic scenarios).
Following this approach, it is always more advisable to develop some emergency plans, each based on different specific volcanic scenarios. Then, each emergency plan takes into account the corresponding relative probability of a scenario's occurrence. This will allow authorities to act properly in every situation. Emergency plans have to be prepared during the rest phase of the volcano. In fact, during this period, two essential resources are available: time, because there is no stress due to an evolving situation, and money, which will be allocated on other priorities during unrest or, even more, during eruption. The funding spent to draw emergency plans based on the choice of different scenarios is usually well repaid in terms of reducing number of casualties, effective emergency management and recovery. Scientists also have shown that stressed situations generate highly unfavourable conditions to take the right decisions.

Time scales for intervention

The relation between the time-scale of volcanic events and the time needed to put various protective measures (i.e., on-site protection and/or evacuation) constitutes a crucial parameter of good crisis management. Experience has shown that the interval between the onset of an eruption and its most violent peak may range from a few hours to several days, weeks or even months. On the other hand, the time required to react and to set up effective emergency measures depends on the size of the eruption (usually poorly known), the dimension of the area at risk (population density and settlement dimensions), the availability of transport and communication facilities and the general level of technological development. This can generally be measured in hours or days.

In practice, it will usually be appropriate to plan two main types of action:

Gradual phased response: when a progressive development of a volcanic crisis is expected. During this phase one may expect to have a warning of potentially dangerous volcanic events at least a few days before they occur, but more often a few weeks or months.

Immediate response: when the volcanic crisis is strongly accelerating, which calls for an immediate evacuation of the population with whatever means are available.

In both cases the following actions should be undertaken:

Communication means and strategy: efforts must be made to create a clear and understandable formulation and communication of public warnings. This means to prepare procedures for communication in case of emergencies. Media broadcast can be used to give information about the changes of alert levels and information about the impending evacuation.

Personnel at disposal: a procedure detailing the availability of personnel has to be prepared in order to guarantee the real-time receipt of alerts. It will include a list of the personnel (name, family name and contacts) and identify their respective roles and responsibilities.

Effective alert system (modern or traditional): effective alert system and clear procedures triggering the launch of the alert should be in place. Bells, sirens and/or traditional means of communication can be used to alert people about hazardous phenomena such pyroclastic flows, lahars, etc. In this case the means of communication should be well known and tested before, the sound should be different for each phenomenon and they should be robust and reliable (see Chapter 24).

Identification of operational centres on site: these centres should be located in safe areas, and their activation in case of need should immediate. When possible, the operational centres must be supplied with telecommunication systems.

Telecommunication systems: it is relevant and often essential to deal with means of communication and methods to restore possible communication networks that are malfunctioning due to an eruption (communication and systemic vulnerability).

Emergency or evacuation areas: the choice of emergency or evacuation areas is always debatable. In general, the reception areas (shelter camps) should be settled in safe sectors as close as possible to the affected areas, given that usually people are reluctant to be relocated far from their homes and regions. The identification of emergency areas is subdivided into:

- Waiting areas, where people can find first aid. These areas often represent the meeting point where information is available and where people can give information to the authorities
- Reception areas where shelter camps can be erected
- Gathering areas, where means and resources (human and technical) can be located. When possible, these areas are generally close to operational centres, but not close enough to hamper the work in the operational centres. Good practice consists of mapping unequivocally emergency areas (using GIS when it is possible, in a standard form).

Emergency areas should be well known to the authorities and the public. It is worth noticing that, if emergency areas are at risk from ash falls, tents cannot be an effective shelter during a volcanic eruption. In any case, ash removal plans should be prepared. Areas enabling relocation of animals, previously evacuated, should also be identified. In most developing countries without livestock evacuation plans, people will refuse to leave their houses, and will therefore not be evacuated, or they will try to go back home to feed the cattle, after the evacuation.

Road-system plan: it is fundamental to identify and indicate escape routes, accessibility routes for aid service, and preferred routes to reach the reception areas. Alternative routes should also be identified and these possibilities communicated. Finally, ash removal plans should be prepared in order to let the road system function.

Means of transportation: they consist of means to evacuate the evacuees (evacuation, dislocation etc.). It is fundamental to prepare all necessary means of transportation in order to evacuate people when needed. Military forces are usually the main corps able to do it properly. Different strategies can even be planned using private trucks, especially when evacuation starts in a rapidly escalating situation. Transportation means should remain as close as possible to emergency areas in order to transfer evacuees when needed.

Means and methods to assist affected people: in case of evacuation, the assistance offered to affected people when they arrive at meeting points in reception areas is fundamental. This assistance must last the entire time they spend in camps, and ensure means of transportation and means to feed and assist people in the first few days after the eruption, during which communication and transportation can be severely affected by the eruptive phenomena and deposits. In this case, the health function is mainly required to work on the psychological impact on evacuees, to assist people with physical and mental handicaps and the elderly, who are more fragile and at risk. In developing countries, the total amount of casualties during an eruption is generally obtained by summing up life losses due to people directly affected by the event and life losses due to elders and children unable to survive during evacuation and during the time spent in camps or provisional houses. The health function should be planned even in case of "immediate response" or when the eruption occurred during or before the evacuation of a certain sector of the hazard zone. In this case, a part of the population can be seriously affected (see Chapter 29).

Temporary houses (Fig. 23): a volcanic eruption can often last months, sometimes even more. The a priori identification of sites to build temporary houses is crucial, because the management system will be too stressed during the emergency phase to allow sound evidence-based decisions. Projects for provisional houses should be prepared a long time in advance to allow easy building and in order to shorten the building period. When possible, facilities should be included to assist people for long periods.

International aid: the emergency plan should take into account the possibility that the Government may request international assistance. This is something often poorly considered, although it can be of great importance, especially in developing countries (see Chapter 24). The emergency plan should take into account all aspects (logistics, communications, etc.) to ensure a good integration of foreign assistance with local assistance.

Figure 23: a Provisional houses built in Indonesia after the 2010 eruption of Merapi volcano; **b** water supply system for the provisional houses. Photo by Vittorio Bosi.

Dissemination of an emergency plan

An emergency plan becomes an effective plan only when it has been disseminated to the whole community. Civil protection authorities sometime underestimate this simple but strategic final step. The difficulty in applying an emergency plan without an effective contribution of all stakeholders and of the entire community is extreme for any country. Three main concepts illustrate why it is so important that information about emergency plan reaches the public:

- Perception of the risk (awareness)
- Knowledge of the plan (people should know what they have to do, where they have to go, what they can bring with them, who they will find at the meeting point, why they should evacuate and so on)
- Practicing (doing exercises on the emergency plan).

These three concepts do not work without a broad dissemination and sharing of an emergency plan at every level. The dissemination of the emergency plan constitutes an opportunity to train and increase the culture of the public for a better response in case of a disaster. Nevertheless, it has also to be considered that some part of the plan, for example, the detailed countermeasures to avoid or limit looting, or where resources are, should not be disseminated to the public. For the first example, the public should only know that emergency plans include the protection of its houses and belongings from looting and defines countermeasures. For the first example, the public should only know that emergency plans include the protection of its houses and belongings from looting and defines countermeasures. For an effective emergency plan it is fundamental to involve the local population from the start, in order to understand the cultural environment, which is necessary to plan adequate protection measures. Exercises are very useful to disseminate the emergency plan. There are of course many methodologies that can be used to achieve this relevant aim and it is beyond our goal to examine all of them. However, some methodologies that can be effective, depending on the degree of development of the countries, are listed below.

In developed countries, websites and WebGIS (see Chapter 17), are probably the easiest and cheapest methods to disseminate an emergency plan. The possibility of feedback on the dissemination is strategic in order to evaluate to what point dissemination methodology is really effective and successful. To improve this feedback, it would be useful to include a statistical software in the website, enabling monitoring not only of the number of visitors, but also the trends of access and where the attention is mainly focused. Newsletters and booklets sent to every family can reach directly the most concerned people, who are the final users of the emergency plans. The use of mobile phones SMS (Short Message Service) can be useful to explain where to find the national, regional, municipality plans, but this necessitates working with the mobile phone companies to access people's phone numbers. Meetings among stakeholders and the public are always welcome. The use of information plaques, which can be located in every private and public building, as is usually done for fires, is strategic, cheap and economically sustainable. Elements that should be addressed on these plaques are the behaviour to have in case of emergency, a map of the building, a telephone number to call in case of emergency, the location of the closest meeting point where first aid can be set up, when not trapped or seriously injured, or get or give information about the situation. Seminars and role-games in schools are useful to get children's and teenagers' attention, and to reach indirectly the whole family. Questionnaires can also be addressed to schools, private and public companies and institutions.

In less developed countries, Internet can sometimes be a challenge. It often can be used but, since it is not always reliable, it should not be considered as a major means of dissemination, till now. Therefore, meetings are probably more useful, especially when held by an expert or competent authority or a charismatic role player. Role games played in schools often have a very good feedback too. Useful suggestions for evaluation of risk perception are presented in Chapter 26.

Plan updating and validity

An emergency plan should not be considered as a static document but it should evolve from time to time on the basis of new information acquired through scientific research, updates about volcanic behaviour, increase or decrease of population, new technological possibilities, changes in local attitudes and perceptions etc. The evaluation and the review process will require a well-established schedule, which depends on the above mentioned factors.

A reasonable schedule for updating can be the following:

- Standard review at Year 3
- Major review at Year 5
- "Hot spot" reviews can also be solicited if the on-going situation is dramatically accelerating

During these review phases, civil protection authorities should collect and share with the stakeholders all the new information and insights produced after the latter review. This information will be elaborated to implement the original plan.

Each modification of the original plan, once approved, should be applied and given to the community by means of communication used for dissemination of the original plan, taking into consideration the updated possibilities due to increase in technology.

The review process requires a similar transparent and shared process the same way as the planning effort involved interactive workshops and consultative meetings.

The review process also represents for scientists a great advantage, as they are no longer obliged to produce "the best" hypothetical scenarios, but simply to describe the scenario, which represents the most updated state of the art. Updating emergency plans maintains the focus on the problem.

If timing of the scheduled review is delayed whatever the reason, this should not affect the validity of the current plan. The emergency plan will remain valid until it is revised, but the delay in reviewing the plan cannot exceed a certain period of time.

Plans should also be carefully reviewed immediately after the event, because in many cases the expected scenario probably has changed substantially compared to the state of information used for the original plan. As an example, during Merapi's 2010 eruption, pyroclastic flows exceeded the forecast length and the morphology of the top of the volcano significantly changed (Fig. 24). These two new situations should be taken into account in the update plan, because the modelling of pyroclastic flows will give different results with respect to those performed in the past. Consequently the most dangerous areas (red zone) will change in extension, including a different number of people living around the volcano. Also it has to be considered in the plan that some areas may have been abandoned and some people may have been relocated.

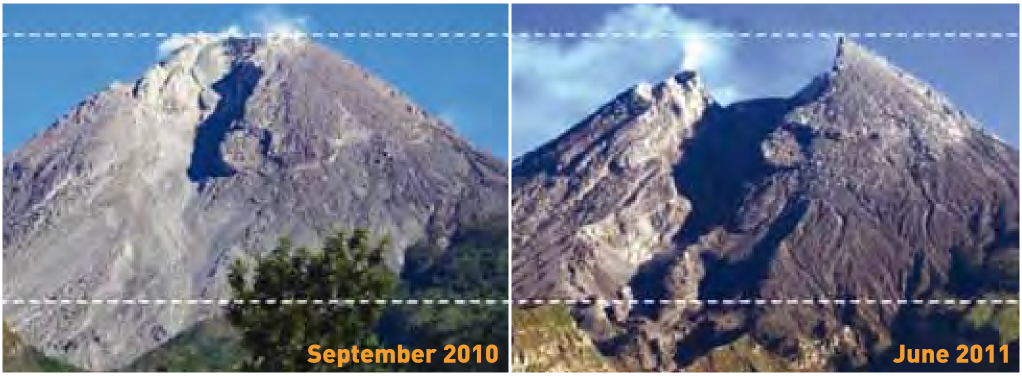

Figure 24: Photos of Merapi summit: the left picture was taken before 2010 eruption whereas the right one was taken after eruption. The morphological changes demonstrate the importance of scenario revision after eruption. Photo courtesy of CVGHM.

References and suggested readings

Hazard and risk assessment and management

- Cappello, A., Neri, M., Acocella, V., Gallo, G., Vicari, A., Del Negro, C., 2012. Spatial vent opening probability map of Mt. Etna volcano (Sicily, Italy). Bulletin of Volcanology, doi: 10.1007/s00445-012-0647-4.
- Marzocchi W., Mastellone M.L., Di Ruocco A., Novelli P., Romeo E., Gasparini P., 2009. Principles of multi-risk assessment Interaction amongst natural and man-induced risks. European Commission EUR23615, 72 pp. http://ec.europa.eu/research/environment/pdf/multi-risk_assessment.pdf
- Neri, A., Aspinall, W.P., Cioni, R., Bertagnini, A., Baxter, P.J., Zuccaro, G., Andronico, D., Barsotti,S., Cole, P.D., Esposti Ongaro, T.,Hincks, T.K.,Macedonio, G., Papale, P., Rosi, M., Santacroce, R., Woo, G., 2008. Developing an event tree for probabilistic hazard and risk assessment at Vesuvius. Journal of Volcanology and Geothermal Research 178, 397–415.
- Rongo R., Avolio M. V., Behncke B., D'Ambrosio D., Di Gregorio S., Lupiano V., Neri M., Spataro W., Crisci G.M., 2011. Defining High Detailed Hazard Maps by a Cellular Automata approach: Application to Mt. Etna (Italy). Annals of Geophysics, 54, 5, 568-578.
- Saaty, T. L., 2008. Decision making with the analytical hierarchy process. International Journal of Services Sciences, Vol. 1, No. 1.
- Thierry, P., Stieltjes, L., Kouokam, E., Nguéya, P., Salley, M. P., 2008. Multi hazard risk mapping and assessment on an active volcano: the GRINP project at Mount Cameroon. Natural Hazards 45(3), 429-456.

Stakeholder preparedness

- http://unocha.romenaca.org/Portals/0/Docs/Disaster-Preparedness-for-Effective-Response[1].pdf
- http://www.geonet.org.nz/volcano/alert-level.html
- http://www.avo.alaska.edu/color_codes.php
- http://volcanoes.usgs.org/activity/alertsystem/icons.php
- http://www.adv-geosci.net/14/3/2008/adgeo-14-3-2008.pdf
- http://www.iavcei.org/documents/newhall1.pdf
- http://www.unocha.org/what-we-do/coordination-tools/osocc-rdc/overview
- Tilling, R.I., 2008. The critical role of volcano monitoring in risk reduction. Advanced Geosciences, 14, 3-11.

Emergency planning

- http://www.crid.or.cr/cd/CD_Volcanes/pdf/eng/doc2802/doc2802.htm
- http://www.disastersrus.org/emtools/volcano/volcano_emergency_plan.htm
- http://fema.gov/pdf/plan/slg101.pdf

5 LIVING WITH A VOLCANO: REDUCING VULNERABILITY

To reduce the risk and to increase the response and coping capacity during a volcanic crisis, a fundamental aspect is to reduce the vulnerability of the multiple elements at risk (people, infrastructures, buildings, agriculture, etc.). Traditional response towards disasters acknowledge the complexity of human response and provide better understanding of the community's point of view on the disaster management process. Using top-down institutional responses to volcanic crisis is not sufficient in regions with a highly cultural perception of risk. In order to create locally adapted crisis management, both institutional and traditional responses have to be merged through active participation of the community and institutions. This section deals with reduction of vulnerability in different fields, including the human, physical and the functional vulnerability.

Participating authors:

Jochen Berger
Vittorio Bosi
Jake Rom Cadag
Noer Cholik
Floriane Chouraqui
Edouard De Belizal
Melanie Fontaine
Jean-Christophe Gaillard
Delphine Grancher
Susanna Jenkins
Franck Lavigne
Marco Leonardi
Emmanuel Kouokam
Etsuning Tyas Wulan Mei
Maria Ilaria Pannaccione Apa
Ricardo Lopes Pereira
Adrien Picquout
Dewi Sri Sayudi
Karl Stahr
Pauline Texier
Pierre Thierry
Joao Trinidade
Tereza Vazão

26. Human vulnerabilities and capacities

Risk perception has drawn the attention of many scientists interested in people's behaviour in the face of volcanic hazards. Risk perception is the estimated probability people have that hazards will affect them. The factors that may affect risk perception are threefold:

- The nature and features of the natural hazard involved including its magnitude, duration, frequency, and temporal spacing
- The frequency and intensity of personal experience of past, similar, events
- Personality factors like fate control, different views of nature and the tolerance of dissonance-creating information

Among these factors, the cultural context plays a key role on risk perception, independently from the socio-economic environment. Risks linked to volcanic hazard cannot therefore be dissociated from their cultural and socio-economic context.

The role of hazard knowledge and social structure on risk awareness

The common assumption that hazard knowledge, risk perception and people's behaviour are closely related and conditional on volcanic activity is debatable. Factors that play a role in hazard knowledge, e.g., basic knowledge of volcanic processes, personal experience of volcanic crisis, time elapsed since the last volcanic eruption are not always similar to those that influence risk perception.

In some way, communities in volcanic environments often have a good knowledge of risk perception of volcanic threats through direct experience, legends, tales and pedological soil composition. However, in some places especially when volcanic eruptions have not occurred for decades, little knowledge of unfamiliar natural phenomena can lead to low volcanic risk perception. There are several reasons for the common gap between actual hazards and known hazards:

The source of information on hazard and risk: hazard knowledge is transmitted through different media, either outside or within the community at risk. External stakeholders involved in the knowledge transfer are teachers, journalists or local authorities. Internal players include the elders, who have more chance than young people to have witnessed a volcanic eruption in the past or to have heard about previous eruptions by their ancestors. However, basic knowledge that teachers, the elders and the media transmit to the local people at risk is insufficient to anticipate the consequences of a volcanic eruption.

The personal experience of the local people: the volcanic processes may vary between two eruptions of a single volcano. The local people may not be aware that future pyroclastic flows may affect some valleys that have not experienced events in the past. Therefore risk perception of local communities that live in zones that have not been affected by volcanic events for just tens of years is poor. It gets even lower in the case of dormant volcanoes.

The poor knowledge of volcanic process: it is closely linked to the distance between their location and the volcano. Therefore risk awareness is low for people living far from the volcanoes, even in towns that can be affected by ash problems. However, the current development of Internet in urban areas like Yogyakarta, at the foot of Merapi volcano, contributes to a better knowledge about volcanic hazards.

The geographical origin of the villages/towns: it plays an important role as well in people's differing knowledge of volcanic hazards. People living in their birth village usually have a better knowledge of their environment, especially if they have already experienced previous eruptions or other natural hazards. In contrast, new migrants coming from a relatively safe area have a low perception of risk. For example, sand miners working in the valleys of Merapi are often trapped by lahars because most of them come from outside the area.

An excessive trust in countermeasures: it may reduce the risk perception of the public. The feeling of safety of the local communities is enhanced by technical countermeasures against volcanic hazards, e.g., drainage tunnels out of crater lakes, concrete dykes along river banks prone to lahar overflow, protection dams, etc. Technical mitigation measures may lead to overconfidence and risky behaviour.

The social structure of the village: it is an important factor in shaping hazard knowledge and people's behaviour in the face of volcanic hazards. The elders have retained a memory of the effects of the last eruptions, whereas younger residents have no such knowledge.

GOOD PRACTICE FOR RAISING HAZARD KNOWLEDGE AND PUBLIC AWARENESS

Hazard information: it should be widely disseminated, not only within the hazard zones of active volcanoes but also involve villages and cities located tens of kilometres away from the vent. These far areas, in fact, can be affected by an eruption (e.g., ash fall). Moreover, hazard information should also be disseminated around dormant volcanoes, where volcanic risk perception is usually low.

Information on volcano-related hazards: it needs to be disseminated through the members of hazard mitigation offices from regional to local levels.

However, educational programs at school may provide an academic basic and theoretical knowledge of volcanic hazard to children. Almost everywhere, hazard knowledge is poor among women. When facing a volcanic eruption, people will tend to not react individually only in relation to their age or gender. In traditional societies, the decision to evacuate or to come back to a hazardous area is usually taken as a community decision, where the chief of the village plays a more important role than the one played by the authorities.

The role of cultural factors on people's awareness and risk perception

Without excluding modern institutional mitigation measures, local knowledge and beliefs play an important role in disaster management, particularly in traditional societies (see Box 15 on Merapi). Communal perceptions of an event may be altered into myth-like stories and explanations. In volcanic regions, thus, it is important to examine both hazards and culture in order to develop more resilient communities. Anthropologists have emphasized the role of cultural factors in shaping

GOOD PRACTICE FOR DISSEMINATION METHODS AND TOOLS FOR COMMUNITY PARTICIPATION

Socioeconomic factors: it should be better integrated from daily life to strengthen livelihoods.

Context: adopt context-appropriate measures to develop local communities' capacities in facing risks.

Collaboration: it should be based on real collaboration between the different scales of action (institutional and upper level stakeholders, local stakeholders, and communities) to merge scientific, technical, political and local knowledge.

Even if things are theoretically well-established, practically speaking difficulties remain to develop this collaboration and to find a research methodology which could combine all knowledge to help practitioners to find better solutions in DRR and in resources management. Several approaches can be taken in order to gain more traditional knowledge of and responses to volcanic disasters, in the framework of a bottom-up disaster risk reduction programme. It is crucial to promote ownership of knowledge through participatory methods accessible to everyone. Participatory methods and tools include:

- Participative volcanic hazard mapping
- Community evacuation simulations
- Training of stakeholders, e.g., public health personnel shall be trained on disaster management
- Rural appraisal (PRA)
- Focused group discussion (FGD)
- Participatory three dimension mapping (P3DM), etc.

GOOD PRACTICE FOR AN EFFICIENT COMMUNICATION

Sharing of information: efficient communication between authorities, researchers, the media, local NGOs, and the population should be enhanced to improve crisis management. It should set an appropriate mechanism to collect and share information.

Language: information should be provided to people on time and using simple and clear language. In this respect, the use of traditional language during communication is crucial.

Feedback: for every dissemination, education or information activity it is recommended to assess if people have received and understood the information.

Dissemination of information: continuous media slots on risk prevention, preparedness and management taking into account geographical specificities may improve the risk awareness of the population. This is just one method to improve dissemination to the public.

GOOD PRACTICE FOR INTEGRATING LOCAL PEOPLE IN DISASTER RISK REDUCTION PROCESS

Community Based Disaster Risk Reduction (CBDRR): it should be considered in integrating top-down and bottom-up approaches and as a channel of information and actions between stakeholders (see Box 14 on Kanlaon example).

Community-Based Disaster Risk Management (CBDRM): it should be developed and strengthened as claimed by the Hyogo Framework of Action (HFA) adopted by 168 governments at the World Conference on Disaster Reduction held in Kobe, Japan, in January 2005. CBDRM, in fact, fosters the participation of threatened communities in both the evaluation of risk (including hazards, vulnerability and capacities) and in the ways to reduce it. CBDRM eventually empowers communities with self-developed and culturally acceptable ways of coping with crises due to natural hazards.

Accountability: it should not just be limited to the responsibility of the funding agency, but most importantly to the real needs of the local communities. Therefore, the need for community participation and involvement in raising hazard awareness is crucial, especially among specific stakeholders: recent immigrants or daily workers coming from outside the hazard zones; people living close to countermeasures, or women. Women are usually at home in lots of poor countries looking after children. They usually have a poorer knowledge of hazards than their husband or children for a variety of reasons.

BOX14

COMMUNITY-BASED DISASTER RISK REDUCTION ACTIVITIES AT KANLAON VOLCANO

50000 people, from three major ethnic groups, namely Llonggo, Cebuano and Bukidnon, live on the verge of poverty with numerous social problems on the slopes of Kanlaon Volcano. Most are marginalized people who had to escape the greater and everyday risk of livelihood insecurity. People decided to face volcanic hazards in order to plant food sustenance needed for daily living. The long history of poverty and political upheaval among mountain communities has created an atmosphere of mistrust between locals and the government.

Political, social, economic, and geographical marginalization characterizes the lives of the local people. Being marginalized, the resources at the household and community levels necessary to protect themselves from hazards are limited. Livelihood and other daily survival strategies are more urgent matters making disaster preparedness the least priority even if they are capable of doing it. In addition, being far, literally and politically from the city centre, the mountain communities are usually the lowest priorities of the government when conducting DRR programs. Thus, significant information such as hazard maps is normally inaccessible to the local people who are actually the most in need of that information.

In the frame of the MIAVITA project, recent DRR activities conducted around Kanlaon Volcano in collaboration with local stakeholders such as NGOs and authorities and local communities tried to integrate bottom-up and top-down strategies. CBDRR activities were implemented in four local communities considered as most vulnerable and most exposed to volcanic hazards. Participatory methods have allowed local people to express their knowledge. Livelihood issues were tackled and included. Local authorities and outside scientists had the opportunity to share and integrate, not substitute, their knowledge. Government DRR programs were also promoted to make people conscious that these activities have an institutional basis and are mandated by the law. In other words, trust and dialogue between stakeholders was established. The project fostered local ownership and sustainability. There is also an ethical question in terms of accountability on that extractive nature of research. It seems that the research is accountable only to the funding agency and not to the local communities. In the MIAVITA study, on the other hand, people own the knowledge they produced and outside stakeholders have access to it. Outputs such as the results of action planning, 3-dimensional maps, and other important documents produced by the people were left in the communities and are accessible to everyone.

people's behaviour in the face of natural hazards. Cultural theorists emphasise that individual's decisions to face hazards of various origins are embedded in social and cultural values. Both anthropological and sociological perspectives assert that people's behaviour is disconnected from the single threat posed by the hazard to which the individual is exposed. The danger is rather filtered by an individual's perception of the world, which varies according to social values, religious beliefs, community traditions and attachment to place. Risks are here ranked according to the value given to threatened assets by a particular society. Objective risks may therefore differ from perceived risks. A significant set of studies has highlighted the role of those cultural factors in the face of volcanic hazards mostly in Southeast Asia and the Pacific.

In many remote regions, people living on the

GOOD PRACTICE FOR INCLUDING CULTURAL FACTORS IN PEOPLE'S AWARENESS AND RISK PERCEPTION

Integration of wider culture and society: revise the current approach to volcanic risk management in order to integrate a wider culture and society. The Merapi case suggests that religion is an essential element of culture and must be carefully considered in the planning process, and not simply dismissed as a symptom of ignorance, superstition and backwardness. Local and cultural factors should be considered in risk and crisis management.

Active participation: promote active participation of the community and institutions in order to create locally adapted crisis management. Participatory risk management involving community leaders and their populations is most appropriate to bridge tradition, local realities and the implementation of risk management policies and strategies.

Redirection of risk perception from traditional beliefs to a more realistic interpretation: traditional leaders who are custodians of tradition shall be particularly considered in this step/stage. This step/stage/exercise may follow the standard anthropological process of integration in order to reduce the problem without causing social disruption or cultural strife that could broaden the gap between the traditional leaders, the civil protection agents or researchers.

slopes of active volcanoes often perceive disaster management measures as inadequate. Many people believe that the gods cause the disaster. This belief is more pronounced among the less educated people and the traditional leaders, who are the main custodians of the tradition. This perception can therefore disturb the implementation of risk management strategies if they are not fully integrated and if the mechanism is not conducted in a participatory approach. Prayers to God and ancestors are the most highlighted response of the population when faced with natural hazards. This response is most likely due to a lack of concrete alternative action to face the problem, because the majority do relate these hazards to natural phenomenon.
In Indonesia, the link between the Javanese people and their volcanic environment is very strong. The village where they live and the land they cultivate are also those of their ancestors. The local people are therefore strongly attached to their birth village. For that reason, people are often reticent to evacuate and/or in a hurry to come back home after having being moved by the local authorities. This attachment to a place is also conditioned by deeper beliefs related to the mental representation of volcanoes.

The role of socio-economic environment on people's awareness and behaviour

People's behaviour in the face of natural hazards is often constrained by social, economic and political forces beyond an individuals' control. Disasters are viewed as the extension of everyday hardships wherein the victims are marginalized in three ways:

- Geographically, because they are forced to live in marginal hazard-prone areas

BOX 15

ASSESSING RISK PERCEPTION AT MERAPI BEFORE AND DURING THE 2010 ERUPTION

Merapi volcano is one of the most active volcanoes worldwide. Approximately 1.3 million people live within a radius 20 km from the summit. The volcanic crisis management is organized in each district and based on the recommendations of the CVGHM, in charge of assessing and monitoring volcanic activity. In the framework of the MIAVITA project, people's behaviour, hazard knowledge and risk perception were assessed before and after the 2010 major eruption of Mt. Merapi. The volcanic activity of Merapi has been totally integrated into people's daily lives. In Javanese perspective, Mount Merapi is personified: "Mbah Merapi" (Mbah means grandparent) belongs to the human world. Instead of being considered as a source of danger, the volcano embodies the common patriarch respected by all the villagers. Local people put their trust in the spiritual guardian of the volcano appointed by Yogyakarta Palace, namely Mbah Marijan. The presence of the Juru Kunci's house at Kinarhejo partly explains the refusal of the inhabitants there to evacuate before the 2006 eruption of Mt. Merapi, although the evacuation had been ordered by the authorities. The feeling of safety is enhanced with the presence of concrete structures like Sabo dams, and by the distance of the village from the crater. This feeling of safety the local communities living further than 15 km from the Merapi crater was enhanced by the extent of the pyroclastic-flow hazardous areas delineated by CVGHM, which did not take into account the possibility of a major explosive eruption. Since 2006, several programs on volcano-related disaster management were conducted in villages located close to the summit, e.g., participative volcanic hazard mapping, community evacuation simulations, and compulsory training programs for hazard mitigation. However, there was a lack of community awareness and education for villages located between 10 and 20 km from the summit, where the evacuations were unplanned. More than 80% of the victims of the November 4th 2010 eruption were living in villages located outside the 10 kilometres radius. Most of the villagers decided to evacuate just after the first explosion on 26 October, when the pyroclastic flows reached Kinahrejo. Twenty five people were killed, including Mbah Maridjan who refused to evacuate. Even though the volcanic activity was already level IV, most of the people preferred to stay in the village. They opted to evacuate when they felt imminently threatened by pyroclastic flow or ash fall, as exemplified during the night of 4 to 5 November 2010.

72% of the interviewed people in the refugee camps have returned to their village during the evacuation period, some of them at a daily frequency, mainly in order to feed the livestock or to see the condition of their house. Nevertheless, their returns to the villages were not caused by the lack of trust in government and volcanologists. Such response emphasizes the need to consider in the contingency plans the option to evacuate the cattle during a crisis period.

- Socially, because they are poor and cannot protect themselves from natural hazards
- Politically, because their voices are easily ignored

This perspective emphasizes people's vulnerability or their susceptibility to damage. Vulnerability thus stresses the condition of a society, which makes it possible for a hazard to become a disaster. People's vulnerability in the face of natural hazards is highly dependent on their wellbeing and strength, their livelihood resistance, their ability and willingness to protect themselves, the societal protection and the social capital among other things. Access to livelihoods appears to be the main non hazard related factor in developing countries (see Boxes 16 and 17). Density of population marginal or within dangerous areas is often very high (e.g., in Java or Mount Cameroon), due to the pressure of poverty and food security. With the aim of increasing their income, the farmers have expanded their fields within endangered zones and accept the risk. In time of crisis, people's behaviour is similarly constrained by economic pressure. Villagers often come back daily to their evacuated village despite the ban from the authorities. They felt that the threat from looting was worse than the risk of being killed by the volcano. When financial or other limitations restrict livelihoods in order to reduce or avoid this risk, people sometimes live with a higher risk level than those they usually find acceptable.

People's behaviour in the face of volcanic hazards varies according to their livelihoods and resources. Indeed, although aware of an ongoing hazard, the poorest farmers or stockbreeders will sometimes be more reticent to evacuate than the other villagers because they may lose access to their only daily resources. The villagers do not ignore or deny the importance of the

BOX16

SOCIO-ECONOMIC INFLUENCE ON PEOPLE'S RISK AWARENESS: A VIEW FROM FOGO VOLCANO

Chã das Caldeiras is located in the 9 km-wide caldera of Fogo volcano. It lies within the Fogo Natural Park, which was created in 2003. In 2010, 1700 people lived in Chã against 1010 in 2004. Population growth is attributed to high birth rate. The population permanently exposed to volcanic hazards is around 710.

The community of Chã has both weaknesses and strengths in facing volcanic hazard. Socio-economic factors have been identified as more important compared to hazard-related factors, in explaining risk behaviours during an eruption. People have a good knowledge of volcanic hazard. Based on the MIAVITA database, 77% of people who experienced the last eruption in 1995 fled from danger. Others waited until the last moment (paroxysm of eruption) to leave the caldera (12.5%), while some stayed in the village. Cultural factors may explain the strong attachment of people living in the caldera with the volcano, which is considered as a friend despite the absence of local beliefs.

People's response is more likely due to economical assets and constraints and lack of alternatives for access to livelihoods outside the caldera. The volcanic soils within the caldera are fertile, the climate conditions are better than in the lowlands, and the volcano is a source of additional income since 1995 with the development of geotourism. However, livelihoods are fragile for many reasons: climate-dependent farming, absence of land registration, limited alternative resources, growing dependence on volatile national and international economies, lack of communication facilities and of public services, etc. Economic pressure can also explain people's behaviour during crisis, since they first refused to evacuate in order to cultivate their crops, take care of their animals and protect their goods.

Even if socio-economic vulnerability is strong, people can rely on strength and opportunities, which provide them with capacities to face volcanic hazard and recover, e.g., diversity of farming products, double sources of income and remittances flowing from overseas, permanent monitoring of the volcano. These results highlight that DRR should focus on measures aimed at reducing vulnerability by addressing socio-economical deep causes, linked to difficulties of access to livelihoods.

GOOD PRACTICE FOR INCLUDING SOCIOECONOMIC ENVIRONMENT IN PEOPLE'S AWARENESS AND BEHAVIOUR

Evacuation of livestock: in a period of crisis, specific fields are needed to evacuate livestock, which is the only source of income for farmers. This will reduce the number of villagers that come back daily to their village during an eruption in order to feed their livestock and protect their goods against thieves. However, an important stock of fodder is needed to feed livestock in their new sites.

Public services: they should be significantly improved, such as communication facilities, public roads, local health centres, etc.

BOX17

ASSESSING PEOPLE VULNERABILITY AND COPE CAPACITY AT MOUNT CAMEROON

The south-west region of Mount Cameroon has been studied in the framework of the MIAVITA project. This study aimed to assess factors of vulnerability and capacity to face the volcanic hazards of Mount Cameroon, focusing on cultural issues in this multi-cultural country. 38 indicators were selected and data were collected through questionnaires, interviews, FGD, etc. Both community leaders and the general population living in this region have pointed out that their livelihoods are endangered by the destruction of animals, forests, water and soil by various threats. The main reactions to natural hazards include: people run out of their houses and relocate temporarily, some stay back to protect property, people protect their nostrils from ash and gas using common material found in the environment, traditional medicine is used to prevent the inhaling of gas, women protect and provide food and equally take care of children, and men assist in rescue operations, perform rituals to appease the gods and prayers for divine intervention.

In relation to resilience, there is no significant difference in the perception of threat years after the occurrence of a disaster. Gas and acid rain were pointed out as the main cause of crop destruction years after eruption. The community members adapted to this problem by shifting from Colocasia and other tuber crops such as cocoyam to banana/plantain, though this was generally assessed not sufficient to curb the problem of low food production. Several years after the 1999 eruption, the population complained of reduction in food production, increasing poverty, unemployment, and in people settling continuously in disaster prone areas. The high fertility of the soil around Mount Cameroon which favours the development of large scale and small scale farming, the proximity of the sea that enhances fishing activities, natural resources like petrol, mineral water, and quarry sites are all natural potential factors which help the population to recover from a hazard. This natural resilience is more pronounced, because other predictors of resilience such as the economic status, the local policy or assistance in relation to disaster recovery are lacking.

The major findings of this study were used to develop a community-based disaster risk management scheme, which could be used to develop a model to reduce people's vulnerability and enhance community resilience.

volcanic threat; they merely do not consider it sufficiently important to justify moving away from the mountain. Implicitly, they do not consider (especially the elders) the volcanic risk to be greater than the threats they would face in an alternative place of residence. This crucial point is supported by the fact that living conditions in shelters are often very bad, and casualties sometimes occur in shelters after an evacuation.

27. Land use and urban planning

Whereas some volcanoes are characterised by continuous (i.e., Stromboli, Kilauea etc.) or very frequent activity (e.g., Etna), others are characterized by very infrequent activity (e.g., Pinatubo). While neighbouring communities are often well aware of the risks in the first case, it is more difficult to maintain people, whose lives are at stake, in a state of awareness in the second case, despite the fact that they are potentially large-scale spatial phenomena. This is the reason why we mainly refer here to volcanoes with infrequent activity. When the time scales are so different, one may think that integrating volcanic threat in urban planning seems not financially relevant. Unfortunately, without correct land planning, the cost of damages that will occur (direct from buildings, infrastructures and crops destruction, direct losses of life, indirect cost to economy and lives, etc.) can be tremendous and lead to the multiplication of ghost settlements in those areas. Therefore, the vulnerability of communities exposed to volcanic risk has to be reduced, particularly through the use of land use planning. In order to reach that goal, the first step is to assess the expected risks in a region and then to turn these scientific documents into regulatory maps and mitigation solutions.

Scientific information and risk mitigation methodologies

Generally speaking, mitigation policies aim at reducing hazard (when possible), exposure or vulnerability. In the case of volcanic risk, it is seldom possible to reduce the hazard, but when observations and scientific outputs provide enough information, mitigation can efficiently be focused on land use policies.
Traditionally, authorities manage volcanic risk through volcano monitoring and emergency services' planning, mainly focused on evacuation, aid and rehabilitation. In EU countries, volcanic risk management is tackled through scientific knowledge and monitoring: volcano hazard assessment and zonation maps are the main tools to address the questions of long-term planning and mitigation of volcanic hazards. Since mitigation and preparedness policies during the pre-emergency phases require information on populations or infrastructures' exposure as well as information on hazards, there is a need to move on some more integrated approaches of risk reduction including long-term land use planning. It is worth noting that for developing countries this goal can often be difficult to achieve due to the lack of regulations and the fact that they mostly focus on maintaining life support systems.
Besides the scientific risk maps and zoning, the basic elements required for town planning of municipalities are information documents (at regional and more local scale) gathering all the knowledge on hazard, elements at stake, prevention and emergency measures, urban master plans or simplified zonation of risk (see Box 18).

BOX18

URBAN PLANNING FOR RISK REDUCTION IN FRANCE

As an example, in France, there is a multi-level governance approach to natural hazards. Whereas the emergency side of risk management is a national responsibility, the preventive side of risk management is a local responsibility and is integrated in general land use and town planning with the help of regulatory area planning documents. Still, decision processes regarding land use are also under national State supervision and control since both municipalities and the State have to approve communal maps. One of the mayor's main obligations is to keep citizens informed of the risks they are dealing with (law n°2003-699, 30th July 2003), which also means that he has to take into account the risk issues in urban planning documents, sometimes with the help of legal constraints. He is also in charge of defining the assistance and emergency system with the help of a municipal safeguard plan aiming at organizing crisis management at local scale.

In France, town planning is ruled by two documents:
The urban master plan, that concerns several municipalities and sets fundamental tendencies on territory organization. It controls the balance between urban, industrial, touristic, farming or natural areas. From a risk assessment point of view, it sets strategic axes for prevention and characterizes sensitive territories.
The "Plan Local d'Urbanisme" (Local Plan for Urbanism - LPU), that tends to limit urban sprawling and improve spatial organization for a single municipality. It sets the general rules of land use on the considered territory and is constituted by: an introduction / presentation report (diagnosis and explanations of the different choices); a project of urban planning and sustainable development (general orientations of urban planning and rules) and maps documents to define the nature of the different areas (urban, to be urbanized, natural etc.). Additional annexes can be attached to this last document, among which is the "Plan de Prévention des Risques" (Risk Prevention Plan - RPP). The RPP is not a document of municipal land use planning but servitude of public utility. The Mayor has the authority to request one RPP for his town and is implied in its elaboration. But only the upper authority State representative (prefect) can approve and order its elaboration for one or several risks. The RPP relies on a scientific study of the related hazards and aims at reducing citizens' vulnerability. It is composed of rules (building constraints, area planning, etc.) and zoning maps (informative hazard maps). It can then be reviewed and updated with the progress of knowledge.

Possible content of a Risk Prevention Plan for volcanic risk management

A volcanic Risk Prevention Plan (RPP) has to consider all direct and indirect phenomena. It is built on hazard zoning and the vulnerability of the region and two types of needs can be considered in the generated maps: before (reducing the vulnerability) and during the volcanic crisis (evacuation, immediate protection measures, assistance to undertake, etc.). It allows identification of constructible areas, non-constructible areas (restriction of urban development in the most exposed areas) and restricted construction areas (under conditions). In that last case, it has also to define the protection measures, the construction type and the prevention measures to be taken in each area. Prevention measures meant for buildings and infrastructures are modulated depending on their degree of exposure and the phenomena involved.
Three types of measures can be recommended depending on the level of threat:

General measures of protection and prevention: preventive information of population, industries or technical services exposed.

Protection measures for buildings: reinforcement and protection of buildings exposed to ashes, structural reinforcement of strategic buildings against lateral dynamic and static pressures, recommendations for roof characteristics (high slope and metallic cover), use of refractory materials, recommendations aimed at reducing the exposure to dynamic overload generated by shock waves and pyroclastic density currents (buildings' orientation within the slope, openings, etc.).

Protection and prevention measures for infrastructures and networks: reinforcement and protection of infrastructures exposed to ash, reinforcement and burying of infrastructures and networks against lateral dynamic and static pressures in zones exposed to pyroclastic flows and heavy ash fall, planning the relocation of infrastructures in order to find them as quickly as possible in case of burial.

GOOD PRACTICE FOR VOLCANO RISK PREVENTION PLAN

Regulations and construction recommendations: vulnerability of the built environment can be decreased with the help of regulations (municipal land use planning and RPP, building permit, protection works, etc.) and of construction recommendations (roof slope, non-flammable materials, etc.).

Regulations and emergency planning: vulnerability of the productive environment (industry and agriculture; see Chapter 28) can be decreased via regulation and emergency plans.

Vulnerability of the socio-cultural environment: it can be decreased with the help of preventive information (risk zonation maps, RPP, safety instruction, etc.), evacuation plans and exercises. In this regard, beyond the organisation of exercises in real conditions, which are always a good way to train people to react correctly, lessons and experience from both exercises and real crises can and must be used to improve policies. A real crisis can generate new constraints for urban planning and must therefore be used to review the existing local plans and policies.

Training and education: Training and education from a very early age is also a pillar of risk prevention and is strongly recommended.

28. Reducing physical vulnerabilities

Physical vulnerability is defined here in the engineering sense as the probability of damage expected from a given hazard intensity (e.g., ash fall load); reducing physical vulnerability is clearly only one aspect of reducing overall community vulnerability. Reducing the physical vulnerability of infrastructure, agriculture and buildings may be undertaken for three primary reasons:

- To improve the safety of inhabitants (or livestock) who may be trapped during a volcanic eruption
- To protect the integrity of a building and its contents, so that occupants can return to the area as rapidly as possible after the eruption
- To prevent disruption to on going livelihood (e.g., agricultural), community or rescue activities

Where there are risks to the structural integrity of buildings in a threatened eruption, evacuation is always the preferred option, and none of the following vulnerability reduction measures should be taken to imply that occupants may safely remain in their dwellings and ignore evacuation orders or recommendations.

Agriculture/cropping patterns

In general, the vulnerability of a specific agricultural system is made up of the distinct vulnerability of several, interrelated components, e.g., cultivated crops, soil fertility, management practice and market-orientation.
Agricultural vulnerability is mainly related to tephra fall, lava flows, pyroclastic density currents and lahars (see Section 2). Ash fall is the most far-reaching and therefore often the most destructive agent to agriculture. It is known that the tephra impact mainly depends on the deposited thickness of ash and the level of adhering, particularly of toxic aerosols. But the prediction of tephra dispersion, deposition and its spatial extent is difficult. This uncertainty and the varying and complex vulnerability constrain generally applicable suggestions for pre-eruptive mitigation actions to areas affected by reoccurring minor tephra falls, summed in Table X (in Appendix). In addition, tephra fall is the only volcanic event that shows damage gradient in contrast to lava flows and PDCs, which end in the total devastation of the affected arable land and vegetation.

Table XI (in Appendix) gives a general overview of crop vulnerability. It has to be stated that this classification is mainly observation-based and damages can remarkably be different in individual cases. The vulnerability of a specific crop is, in fact, highly dependent on its development stage and affected by additional ash properties as well. For example, small amounts of ash affect more seriously the leaves if the ash is loaded with high concentration of acids and/or the ash texture is very fine and adheres much better to the leaf surface when wet.
Vulnerability of soils can be generalized as follows. Deep, highly productive soils (i.e., with a pH-value around 6.5 and rich in organic matter and nutrients) can buffer a moderate ash deposition up to approximately 10 cm very well. The state of very unproductive soils will not decrease much. In contrast, ash addition can improve the water holding capacity and workability, e.g., for very clay-rich soil, and fresh nutrients are also supplied. If more than a 30 cm ash layer remains, the old soil is more or less "sterilised".
Another vulnerability parameter is crop management and market orientation. There are two end points of an intensification gradient between low-input, self-subsistence farming to high-input, cash-crop production for export. Both extremes are highly vulnerable in different ways. The subsistence farming is directly connected to the food security of the local population. During an eruption food stocks can be lost and arable land destroyed.

This will lead to an undersupply of food and external food import is needed, for a long time if rehabilitation means are lacking. For completely export-oriented farming a great economic loss can be incurred directly after the eruption, but if the financial and management conditions permit, even technical and financial demanding rehabilitation measures can be achieved in a short period and production can start again.
Post-eruptive measures after tephra falls up to 5 cm can be limited to removing the volcanic ash from plant leaves by shaking or washing off. Observations at Merapi show that these actions worked well only for some crop types and ash still adhered to leaves. Tephra is incorporated into soil by natural processes or normal management practice. Soil fertility state is marginally influenced and no adaption of fertilisation is needed. Even an improvement of soil fertility due to nutrient addition was observed. Only salt- or pH-sensitive crops can show a short-term interference if a high solute load adheres to the tephra.

If the ash fall thickness exceeds 5 cm up to 10 cm, normally the ash layer persists at the surface and won't be incorporated naturally, e.g., by animals or washed in. Deep ploughing and mixing old topsoil and ash has been shown to minimise the productivity decrease. Furrowing the ash and planting in a trench can result in unsatisfying yields or total failure as erosion won't speed up or even re-burial occurs. But even with good mixing, a depletion of nutrients and organic matter occurs and soil fertility drops. Also drainage conditions change remarkably. Therefore an adapted, higher fertilizer input is required and cultivation practice should be adapted after a post-eruptive land evaluation is done. For example, after Pinatubo eruption 1991 (Philippines), local farmers changed to highly valuable field crops as the higher profit margins compensated for the increased cultivation costs.

If more than 10 cm up to 30 cm of ash were deposited, rehabilitation will be more difficult. Since deep ploughing and mixing is impractical and won't lead to promising results for growing annual crops, the complete removal of the ash would be the best measure, but also very labour intense and costly. The cultivation of nitrogen-fixing legumes, like lupines or Lotus species, and intensified organic matter amendments over several years can rebuild soil fertility to a point to restarted low-output agricultural production. A change to perennial plants (woody shrubs, fruit trees) with a deep rooting system to reach the old topsoil is another way of re-establishing agricultural production.

For tephra deposits thicker than 30 cm removal is unfeasible. Besides that it is almost impossible for plant roots to penetrate tephra layers down to the buried soil. The thick tephra layer changes drainage conditions and hinders the gas-exchange between atmosphere and soil, leading to anaerobic conditions. Combined with only traces of nutrients and no organic matter in the tephra this leads to a sterile substrate for plant growth. This applies also to depositional areas of PDCs and lahars. Only adapted species, so called pioneer plants, are able to handle with these extreme conditions. Often these species include fast-growing trees and alternative land uses, e.g. forestry, can be considered. The most promising approach is the re-cultivation measures mentioned above, organic fertilisation and N-fixing plants. For PDC and lahar areas this is not recommended if the risk of a recurrence of the event is high. Lava flows lead to a complete loss of vegetation and arable land and the rehabilitation needs decades to centuries. Also PDCs and lahars will cause the immediate and more or less complete destruction of arable land even if rehabilitation of the affected areas is possible within several years to decades. The spatial extent of these three hazards is relatively limited compared to tephra falls and prediction of the potentially affected area is possible due to flow path modelling. This enables people to take pre-eruption mitigation measures based on land use planning (Table XII in Appendix). Strict exclusion zones for any agricultural activity seem only manageable and appropriate in high risk areas. For the other areas prone to the mentioned hazards, the possible loss has to be minimised. High technical input requirements and/or perennial crops, especially cultivated in plantations, should be omitted. This comprises e.g., paddy rice, all kind of fruit trees and palms, coffee and tea, etc. The focus must not be laid solely on economic loss but also on food security of the local population. If crops grown in medium to high risk zones contribute to a high percentage to local food production, alternative sites should be provided to farmers for cultivation of those crops.

Infrastructure (roads, water, power)

Infrastructure includes the road, power, water supply and irrigation networks. In reducing vulnerability, it is important that, prior to an eruption, vulnerable elements of the networks are identified and the skills and equipment to maintain and restore them to use after an eruption are readily available. Infrastructural vulnerability is related to the damaging mechanism of the volcanic phenomena. Thus mitigation measures differ for each hazard and in some cases may be incompatible: for example, strengthening a roof will reduce the vulnerability to tephra fall but may act to increase the vulnerability to earthquake and affect living conditions within the building by reducing ventilation. Proposed mitigation measures for buildings and the different infrastructure components are described in more detail over the following sections and are summarised, with their potential limitations and incompatibilities, in Table XII (in Appendix), as a function of volcanic phenomena.

Roads and bridges

The most important mitigation task for tephra fall is to have locally available machinery, equipment and a skilled workforce to begin road clearance as soon as the ash fall has ceased. Dampening of the ash with water can inhibit ash re-suspension and improve visibility; however this can reduce traction and requires large resources of water and regular and repeated actions. A pre-defined dump site should also be established so that ash is removed from the area and cannot be easily remobilised by wind or rain. At a lower level of probability, roads may also be affected by ground deformation or earthquakes and associated landslides and by PDCs, lavas and lahars; again, unless roads can be economically rerouted away from areas at risk, preparation for post-event repair programmes with locally available skills and machinery is the most appropriate mitigation measure.

Where hazard maps show that bridges on

crucial routes are at risk from either PDCs or lahars, assessments should be made to evaluate the ability of the bridge to withstand probable levels of flow and flow pressures, and either strengthened accordingly, or rebuilt, or if necessary the road should be rerouted. Mitigation actions for transport operating in or after ash fall include limiting vehicle use in ash-laden conditions where possible, and ensuring that local vehicle maintenance facilities and skills are available, and are well-stocked with replacement parts for the components at risk.

Power networks

Mitigation actions for power and telecommunications networks should include:

- Close examination of local power or telephone networks to identify points of possible ash accumulation, or risks from collapse of adjacent trees, and removing these
- Checking that where lines cross likely PDC or lahar flow areas that they are supported on strong piers or at points not at risk
- Preparing a general emergency plan for a volcanic crisis, including access to key system components, which may need repair
- Having back-up telecommunications for use by the emergency services

Water supply and irrigation

Little can be done in advance of an eruption to protect against infill of irrigation channels by PDC or lahar, or the contamination of water through ash fall or lahars; availability of skills and equipment for post event clearing of canals will therefore be a key element of mitigation. In areas close to the volcano (<5 km), damage to the physical structures that hold water (e.g., dams), caused by volcanic earthquakes, can be reduced by building to appropriate seismic codes. Mitigation actions for ash fall impact on water supply and irrigation systems include:

- Covering exposed equipment (pumps, storage tanks)
- Monitoring performance during and after an eruption
- Making provision for back-up generation in the event of power supply failure
- Preparation of emergency plans for repair of pumping equipment, pipework or clearing of irrigation canals
- Having available sufficient quantity of essential equipment and supplies (e.g., filters, water treatment chemicals)

A plan should be in place for how and where ash will be removed so that it cannot repeatedly affect water supplies. Draw down of some reservoirs in advance of a damaging eruption may in some cases be undertaken as a precaution against flooding, but the need for large quantities of water for subsequent clean-up should also be considered.

Buildings

Three categories of buildings, which will likely have differing vulnerabilities, should be distinguished in the at-risk area: community buildings; residential buildings; agricultural buildings. The extent of building damage and human casualties from a future volcanic eruption will depend to a considerable extent on the vulnerability of these different building types to the principal volcanic hazards (see Section 2).

Tephra fall/ballistics

A code of practice for the design of buildings in volcanic areas should require roofs (i.e., both the roof covering and the roof supporting structure) to be designed for a loading equivalent to the expected max tephra fall in the largest foreseeable eruption scenario (See Box 19). Such a code should apply to community buildings such as schools, hospitals and clinics and other critical buildings, which are the responsibility of central government, or may be important during a crisis as gathering points or evacuation shelters. It should also be applied for agricultural buildings where the contents are valuable and at risk of damage from a collapsed roof. For residential buildings in areas that are considered to be at risk from ash fall of 100 mm or more, depending on assumed ash fall density, the roof structure should be upgraded to resist a minimum loading of approximately 1.5 kPa.

In cases where an eruption is threatening or underway, existing vulnerable roofs can be propped using appropriately placed timber poles or metal props to protect against roof collapse during a period of evacuation. Inhabitants of areas at high risk of tephra fall will need to be given guidance about how to prepare and install such props.

Penetration of ash into a building can in principle be countered by ensuring that all ventilation openings are sealed; however in highly ventilated buildings typical of tropical regions this is unlikely to be achievable except where explicitly provided for in the design. Alternative mitigation measures may be to provide covers for valuable or sensitive electrical equipment, and facemasks for occupants.

BOX19

ROOF DESIGN LOADING

To determine required resistance for building structures in earthquake zones, an approximately 1 in 500-year earthquake scenario is normally adopted, which is roughly equivalent to a 10% probability of exceedence in 50 years. This level of resistance represents a compromise between the conflicting aims of achieving an acceptable degree of safety and not imposing large additional costs. If such a scenario tephra fall can be approximately mapped, it could form the basis for a zonation map to include in a Code of Practice for new buildings. For Vesuvius, where the foreseeable eruption scenario is a sub-Plinian one, maps have been prepared, showing the probability of exceedence of roof loads of 3 kPa and 4 kPa, given an eruption of that scale, which can be used to define the load which should be designed for in any location within reach of significant tephra fall.

Pyroclastic density currents

The deadliness of PDCs is so great that any area which has been subjected to or is known to be at risk from PDC should be included in a permanent building exclusion zone. Peripheral areas, which may be affected by less dense pyroclastic surges in the event of an eruption should have a very high priority for evacuation when an eruption is threatening. Some measures are however possible to protect buildings in areas at risk from pyroclastic surges, so that any remaining occupants (or livestock) may have an improved chance of survival, and protect the building from destruction by infiltration of hot ash carried by the surge and the resulting fires:

- Ensure that roof materials and wall

materials are non-combustible.
- Provide solid shutters (timber or metal) which can be closed to protect glazed or unglazed openings from thermal failure and invasion of hot ash and from missiles carried in the surge
- Seal all external cavities which have a potential to trap firebrands
- Remove all easily combustible material from the immediate vicinity of the building (including outhouses, fuelwood piles, and also gas canisters)
- Remove other potential missiles from the surrounding area

In any community in an area potentially at risk, one or more buildings which are strong and well-sealed should be designated as shelters to provide protection for any inhabitants unable to evacuate in time.

Lahars

Little can be done to protect buildings impacted by deep lahars (>0.5 m); however, the constructions of dikes, sand-pockets or dams are sometimes used to protect areas at risk and contain the flow path of the lahars. However, such structures are expensive, sometimes ineffective, and are of no long-term value once they have been filled. They can also offer a false sense of security to those apparently protected by them. These structures may be of value in particular circumstances, but should only be used in accordance with local scientific advice.

Measures sometimes adopted in areas at risk of lahars of moderate depth have been raising houses on stilts and the use of sandbags to prevent the flow entering the building. Few systematic evaluations of the effectiveness of these measures have been done, and some observers have questioned the value of both measures. Raising building on stilts would certainly not be appropriate in areas of deep lahar flows (unless they are very robustly built), and could have a negative impact on other risks such as that from earthquakes and windstorms, while sandbagging can also be counterproductive. Thus, general mitigation measures suggested for areas subject to lahars are:
- To encourage vegetation of upper slopes covered with fresh tephra
- To develop maps of areas likely to be affected by lahars at different depth
- To encourage those with houses or other buildings in these areas to relocate over time to safer areas
- To reinforce riverbanks at the outer and inner bends of meanders

For areas where only small-thickness dilute lahars may be expected, an alternative to relocating is to rebuild in the same location with a modest increase in the plinth height of the building, while ensuring that openings, especially doors, are sealed against infiltration.

Volcanic earthquakes

Careful consideration should be given to providing masonry or concrete buildings with an adequate degree of earthquake-resistance. For future construction this can be achieved by following an established Code of Practice or local guidelines for construction in earthquake areas. Retrospective upgrading to reduce vulnerability is possible, but will be quite expensive. Detailed investigation would be needed to establish whether the risk reduction achievable would justify the work involved.

29. Reducing functional vulnerabilities

Functional vulnerability is defined here as the probability of expected malfunctioning or failure (total or partial) of the response system during an emergency. During volcanic crisis, in fact, some of the systems that normally are considered robust and reliable can suddenly become fragile due to their intrinsic vulnerability with respect to volcanic phenomena, but also because of insufficient or not efficient planning.

This chapter provides some insights for actions to undertake in order to reduce the functional vulnerability of governance, transport, health care system and communications with respect to volcanic hazards.

Governance and security functions

At government level all the aspects of preparedness, prevention, emergency management and resilience should be taken into account. The governmental action requires transparency, accountability, responsibility, commitment, effectiveness, participation and democracy. If any of those fail, the vulnerability of the whole system tends to increase. In fact, regarding vulnerability, systems based on strict authority and hierarchy usually tend to increase and propagate vulnerability at every level due to the necessity to refer to the authority responsible for any decision. A clear prior distribution of responsibilities allows improvement of such a situation. Generally, during a volcanic emergency, like during any catastrophe, the governmental ability to decide and organise is deeply hampered by the stress and pressure induced by society and media who may have many expectations during the crisis period that will not be easy to fulfil. It is clear that all efforts have to be made to preserve the efficiency at each governmental level.

During volcanic crises, some main criteria for governmental vulnerability can be briefly identified:

Direct impacts on Government representatives in the disaster: in this case, particular attention should be paid in order to avoid concentration of main functions and functionaries in risky areas, night and day. Even if the hazard can be assessed as low in certain areas, one has to consider the uncountable damage if the responsible authorities are affected by the event and not able to fulfil their duty.

Mistrust of government measures and actions: this is clearly connected with past Government policies and actions. If they have lost their faith in their Government, people are likely to react in the wrong way, deeply hampering crisis management efforts. An effective crisis management allows a retrieval of credibility.

Lack of resources: this could lead people to mistrust the Government and the authorities. In this case, correct emergency planning and allocation of means can avoid the majority of the problems and allows moving resources on time and concentrating resources where they are needed.

Lack of planning at every level (management, mitigation, recovery, resources, etc.): it gives rise to additional internal vulnerability of the institutional systems. The probability of misunderstanding and communication difficulties between the different governmental bodies increase seriously. In the same spirit, coordination among agencies is another crucial component to reduce Governmental vulnerability. Again, correct planning decreases the possible vulnerability of the system.

Ineffective communication: incomplete, omitted or contradictory information given by the authorities and by the institutions (even scientific) are mistakes that can preclude the effectiveness of the response and can lead the public to mistrust the authorities. Transparent and effective communication should be planned, using the most effective and well-known means of communication.

Different skills and resources at national, regional and local levels: all the levels should be well prepared and mutual help should be planned among them. The failing of one of these levels could propagate the vulnerability to the other levels. Propagation of vulnerability from an institution to another and/or failures in communication may lead to further consequences following disasters.

Transport

We consider here only road transport in close proximity of the volcano, mainly in terms of evacuation. Nevertheless, long distance transports by boats, trains or planes have to be considered too by the institutions.

Evacuation of people must be considered in two phases: first gradual then immediate. Both these phases should be planned (preparedness). The means for evacuation (type, number, location, availability, etc.) should be stated clearly in the emergency plan as well as in the evacuation plan. Private cars can be used once evacuation is declared with certain anticipation, but traffic control should be planned contemporaneously. Normally, during an immediate evacuation, and especially in developing countries, military forces or civil protection agencies organize transport. Motorbikes are widely used in developing countries. One should keep in mind that volcanic crises can last month or years and that during a volcanic crisis many eruptions can occur. Therefore a certain amount of means of transportation should be always ready to be used.

Healthcare system

Although generally lava flows are considered by people as the most dangerous volcanic hazard for human society and environment, other phenomena are actually much more likely to affect public health and safety, such as pyroclastic flows, lahars, ash falls, bombs, etc. The health effects caused by volcanic phenomena were already mentioned in Section 2 and can be briefly resumed as follows:

- Volcanic projectiles: traumas, burns
- Lava flows: burns
- Lahars: trauma, drowning, dismemberment
- Pyroclastic flows: burns, asphyxiation
- Ash falls: eye and respiratory disorders, intoxications, traumas due to building collapses
- Gases: poisoning, asphyxiations
- Earthquakes, tsunamis: traumas due to building collapses, drowning

A reduction in the vulnerability of the health system requires a preparation by medical services, and effective coordination with the operational forces and governance response, during an emergency.

The following actions are needed to ensure the response in case of eruption:

To collect of information: firstly about the type of hazards expected in the area and, when feasible, about the health impacts of the previous volcanic events.

TRANSPORTATION GOOD PRACTICE

Transport plan: it should always be well prepared and effective (see Chapter 25) and it should also include alternative escape routes. An alternative transport plan is also necessary for larger evacuation, than expected. As stated in Sections 4, in fact, the size of an eruption is usually unpredictable.

Communications: a system to control effectiveness of communication (cross-check) has to be set to avoid the possibility that part of the population is not advised of the evacuation.

Indications: for both types of evacuation (gradual and immediate) it is crucial to have clear indications on where to go using private cars, vans or motorcycles, and what is the destination of the public transport. A family unit should reach the same place, if possible at the same time.

Means of transportation: when private means are not available, they are in general provided by private or public companies and by military forces. In this case, an effective communication about the real need is strategic to allow preparation of resources (number of people that should be transported, number of trucks or vans needed, where they are expected to depart and to go, number of trips and kilometres to cover, where the petrol stations are located, etc.). This implies a clear agreement about the payment, once needed, and who will refund in case of damage.

Capacity for fuelling: stocks should be refuelled whenever needed. The routes to transport the fuel from storage to petrol stations should be available and controlled. Temporary petrol stations can be set in strategic locations, but this has to be planned (emergency planning) to be effective. Communication on this issue is strategic.

Escape routes: a survey on escape routes is necessary. Alternative routes should be planned in order to avoid problems arising from the main road-system's interruption due to ash falls, debris on roads caused by earthquake, traffic jams, etc. Effective communication (broadcast, radio) should be prepared in order to inform operational forces in real time about every change of escape routes. Strict communication with the coordination centre is indispensable, especially during immediate evacuation. The socialization phase (see Chapter 26) and a good communication plan should reduce the development of circulation problems; ash removal plan should be effective. Weather forecasting and wind direction forecasting are effective tools to correctly allocate the resources.

Livestock evacuation: in some countries, transportation of animals can be crucial. People, who live of livestock farming, will not evacuate if transportation of their animals is not planned. An antedated evacuation of animals can avoid problems of reduced transportation capacity at the moment of evacuation.

To analyse on the probability of occurrence of the different hazards: this will allow reasonable adaptation of the health resources to the needs.

To improve the health operators' knowledge: this can be achieved releasing information about the health effects of volcanic events and training on proper treatment of patients.

To inform to the population living in the area at risk about the: health hazards and proper mitigation measures, such as masks, glasses, etc. The population must also be informed about the locations of emergency health centres.

To make a plan for sheltering and/or distribution of protective equipment: usually tents are not the most appropriate shelters in case of explosive eruptions, as they are vulnerable to ash falls. Nevertheless, if only tents are available in an initial phase of sheltering, plastic sheets placed over the tents and covering all the aperture of the tents can constitute a rough defence against ash. If masks and glasses are not available, pieces of textile can be adapted to provide a preliminary protection for eyes, nose and mouth. Purchase and storage of mask is relevant.

To make a plan for the organisation of medical services in case of volcanic eruption: this plan should include a relevant number of doctors and assistants with expertise for required treatments, the organization of shift work, medication and drug transportation. It is worth noticing that an eruption can last for several months, and this should be considered in order to also reduce the vulnerability of the health system in the long term.

In case of efficient and timely evacuation of the dangerous areas, the main health problem for the population is related to conditions during transportation (especially for elderly, disabled, and children) and to the time span of the stay in the camps. Health function in this case really depends upon the preparedness, with respect to this kind of assistance. Normally the vulnerability of the health system in camps is low. An exception should be considered for hospitals, even if located in safe areas with respect to the main possible events. The functionality of hospitals or other health facilities, in fact, can be reduced or compromised by partial or total collapses, due to earthquakes, which generally occur during and (mainly) before volcanic eruptions, or to the accumulation of volcanic ash.
Countermeasures to reduce this kind of physical vulnerability can be found in Chapter 28. Nevertheless, hazards can affect people even during their stay in camps, mainly thanks to ash falls that can affect large areas. In this case, preventive measures should be taken to ensure availability of protective equipment, such as masks, glasses and removal of ash in and around the camps. It is worth noticing that assistance in camps is strongly related to the possibility of transporting means and goods to help the population. This is the main reason why, in order to reduce the vulnerability of the health system, strict coordination must exist with the operational forces, which take care of road-systems (transport function), airports and ports. In this regard, supply of medications and drugs coming from abroad constitutes a key point in terms of health system vulnerability.

One of the main problems arising from an evacuation is the psychological impact on people who are forced to leave their properties and face problems related to their transportation (trauma and heart attacks). The availability of relevant assistance and expertise (psychologists and doctors with experience in these kinds of problems) is the main countermeasure to decrease the vulnerability of the health system. Particular care should be taken of the elderly and children.

In case of escalation of volcanic activity there can be a rapid evacuation, which can take place when the eruption has already started. In this case, the vulnerability of health response increases, and coordination becomes even more strategic. Three main conditions are changing with respect to the situation described above:

- Search and rescue operation are probably in place
- Volcanic phenomena are occurring
- People and operational forces are in a hurry

In addition to the above mentioned problems related to transportation of people, a number of people could be affected by the most dangerous volcanic phenomena and the need for medical assistance increases dramatically. The main health problems are generally related to burns, asphyxiation, poisoning, trauma, drowning, eye and respiratory disorders. A special expertise is needed to provide relevant medical treatment. The interaction and coordination between operational forces, which have the responsibility for Search and Rescue operations, transport function, and medical services become crucial. In this case, the road-system plan (see Chapter 25) should be well known by the personnel responsible for the health systems and all the possible variations should be shared in real time to give, as an example, an alternative escape routes to ambulances, or to search and rescue teams. It is worth noticing that information given by the scientific community and/or by an appointed group of scientists are, under these conditions, of great importance and should be issued in real time.

Communications

Efficiently responding to a volcanic eruption requires that all organizations working on-site have the correct communication equipment and possess the relevant knowledge to interact with this equipment. It is also necessary for supporting communication infrastructures to be able to cope with damage caused by several hazards triggered by an eruption, such as airborne ash, lahars, pyroclastic flows, heavy ash falls and lava flows. Disruption of the communications can bring all the crisis management workflow to a stop, as orders cannot be issued and information cannot be sent to the local coordinators. The general population also relies on communication infrastructures to receive warnings and evacuation orders.
This paragraph describes common vulnerabilities of communication infrastructures and provides recommendations to minimize their impact. According to the classification formulated in recent study, types of vulnerability are divided into four groups: direct damage, technological vulnerabilities, organizational vulnerabilities and security vulnerabilities.

Direct damage to equipment

Volcanic events may cause damage to communication's infrastructures, regarding both network operators' and the users' equipment. Resilience to volcanic events can be improved within the network by the network operator and achieved by the users thanks to the use of operator redundancy.
Wireless networks are one of the networks most likely to be used in volcanic areas, as

they provide teams with mobility (see Chapter 21). Operators build these networks taking into account factors such as cost, demographics (potential users) and signal propagation conditions. If risk or hazard maps are used to identify antenna (base stations) safe locations, these will be less likely to be destroyed. In addition, the number of antennae may be increased in order to provide some redundancy to the system. These techniques will increase set up and operational costs, and this will not be perceived by the operators as an advantage, but it certainly will increase the likelihood of the network being usable during a volcanic event.
Organizations working on-site can also take measures to increase their operational capability in the case of a volcanic event. A disaster recovery centre may be built outside of the risk areas, enabling coordination activities to carry on when the on-site coordination centre is destroyed. This site should provide all the communication interfaces required for the coordination task.
Since the probability of at least one network being available is higher, on-site personal can be provided with access to several networks. This is achieved by carrying several communication devices or e.g. by using dual-sim GSM mobile phones. Satellite telecommunications are an alternative to land-based infrastructures, albeit a more expensive one. Data and voice services are available worldwide, and hand-held devices enable their mobile use. There are also radio technologies which do not require a support infrastructure, such as classic two-way radios, or that take advantage of an infrastructure when available but continue to provide some service when the infrastructure is not available, such as Terrestrial Trunked Radio (TETRA).
Populations need to be kept up to date regarding volcanic threats and notified about evacuation orders. The most effective way is to use broadcast media, such as radio and television. However, should broadcast or electrical networks fail, alternative community-based channels should be in place (e.g., sirens) with support from local authorities.

Technological vulnerabilities

Regarding communication, the technologies used have their own limitations. Chief among these are: capacity limitations, blind spots, inability to send non-voice data and interoperability issues.
Communication networks are designed to provide a limited capacity. Volcanic events may cause this capacity to be exceeded, either by over-usage or due to the destruction of parts of the network, prompting a network crash. This is particularly true with public networks, to which users will resort to find out about their relatives. As a consequence, emergency response and coordination should not rely on public networks. Furthermore, when commercial networks are the only option available, capacity should be reserved for this purpose, avoiding contention with the general public. The use of public data or telephone networks to notify the population should also be avoided in favour of broadcast media, in order to avoid stressing the network in the most critical times.
Wireless networks may exhibit blind spots, areas where coverage is non-existent. These should be identified early. When possible, network operators should upgrade their networks to eliminate these blind spots. The use of several operators may reduce the number of blind spots as different operators provide different coverage. Finally, satellite phones will provide full outdoor coverage.

Voice communications are very important. However, other types of information such as maps, video and monitoring information also play an important role. Technologies such as GPRS, UMTS, 4G or TETRA provide the necessary data rates (see Chapter 21 and Table VIII in Appendix).
Voice communication is possible when all the participants speak the same language, are familiar with the same vocabulary and use interconnected networks. In the case of voice communications, several networks may be connected through the Public Telephone Switched Network (PSTN) although gateways may be necessary to connect to some closed networks.
Data communications also require a common language. This should be the IP. Also a set of common applications should be normalised among the several participants.

Organizational Vulnerabilities

Organizational vulnerabilities may appear during a crisis scenario. Adequate training and preparation may mitigate these. The most significant organizational issues are: untrained personnel and jurisdictional tensions.
Field personnel must be able to operate the communication equipment under stressful situations. They must also be able to cope with failures that may occur during the incident response. The knowledge required should be obtained through periodical training and simulation sessions.
When emergency communications rely on commercial network operators, these should be properly equipped to deal with infrastructure maintenance during a crisis. Networks operations should be involved in training and simulations in order to ensure that their personnel are capable of providing support during a crisis, instead of waiting for the crisis to end in order to re-establish critical components of the network that may be malfunctioning. Therefore, network technicians should be aware of their assigned role during a crisis.
Crisis management usually involves different organizations, each one of them having its own communication infrastructure. When the operations are not adequately coordinated, different teams may use incompatible technologies to support the relief operations. The role of each partner and the utility of each different communication infrastructure should be defined before hand in the emergency plan.

Security Vulnerabilities

Telecommunication networks are a critical component of the crisis management workflow. Therefore, it is necessary to ensure an adequate level of security of the systems and of the transferred messages, by preventing service attacks, securing data and preventing unauthorized access.
Service attacks render a system unusable due to too many solicitations for service. This may happen intentionally or involuntarily. Access should be denied to malfunctioning stations and the call rate for each station limited.
Controlling access to data might play an important role in preventing panic in the population. It is also important to ensure that data is not manipulated or agencies impersonated. Some networks, such as GSM, provide some confidentiality, integrity and authenticity guarantees. When IP is used, applications may provide these services too.
Physical access to equipment may provide a security breach or allow for vandalism or sabotage. Access to communication infrastructures should be adequately protected and granted to authorised personnel only.

References and suggested readings

People's vulnerabilities and capacities

- Chester, D.K., 1993. Volcanoes and Society. E. Arnold, London.
- Chester, D.K., 2005. Theology and disaster studies: the need for dialogue. Journal of Volcanology and Geothermal Research, 146, 319-328.
- Gaillard, J.-C., 2008. Alternative paradigms of volcanic risk perception: The case of Mt Pinatubo in the Philippines. Journal of Volcanology and Geothermal Research, 172, 315-328.
- Lavigne, F., De Coster, B., Juvin, N., Flohic, F., Texier, P., Morin, J., Gaillard, J.-C., Sartohadi, J., 2008. People's behaviour in the face of volcanic hazards; view from Javanese communities, Indonesia. Journal of Volcanology and Geothermal Research, 172, 273-287.
- Mercer, J., Gaillard, J.-C., Donovan, K., Shannon, R., Alexander, B., Day, S., Becker, J., 2012. Cultural awareness in disaster risk reduction: Lessons and opportunities. Environmental Hazards, 11, 2, 74-95.
- Wisner, B., Blaikie, P., Cannon, T., Davis, I., 2004. At risk: natural hazards, people's vulnerability, and disasters. 2nd ed., Routledge, London.

Land use planning

- Boiteux, M., Baumstark L., 2001. Transport: choix des investissements et coût des nuisances. Commissariat Général du Plan. Report. http://www.ladocumentationfrancaise.fr/var/storage/rapports-publics/014000434/0000.pdf
- Saaty, T. L., 2008. Decision making with the analytical hierarchy process. Int. J. Services Sciences, Vol. 1, No. 1. 2008.
- Thierry, P., Stieltjes, L., Kouokam, E., Nguéya, P., Salley, M. P., 2008. Multi hazard risk mapping and assessment on an active volcano: the GRINP project at Mount Cameroon. Natural Hazards 45, 429-456.

Local plan for Urbanism (LPU):

- http://www.legifrance.gouv.fr/affichCode.do;jsessionid=F96ACF1E8D3EB54A96F313A6173AB4D9.tpdjo03v_2?idSectionTA=LEGISCTA000006158551&cidTexte=LEGITEXT000006074075&dateTexte=20120307
- Urban Master Plan: http://www.legifrance.gouv.fr/affichCode.do;jsessionid=F96ACF1E8D3EB54A96F313A6173AB4D9.tpdjo03v_2?idSectionTA=LEGISCTA000006158550&cidTexte=LEGITEXT000006074075&dateTexte=20120307

Reducing physical vulnerabilities

- Blong, R.J., 1984. Volcanic hazards: a sourcebook on the effects of eruptions. Sidney: Academic Press Australia, pp. 424.
- Macedonio, G., Costa, A., Folch, A., 2008. Ash fallout scenarios at Vesuvius: numerical

simulations and implications for hazard assessment. Journal of Volcanology and Geothermal Research, 178, 366-377.

- Mendoza, T.C., Cabangbang, R.P., 1992. Effects of Mt. Pinatubo Eruption in Crop Production Systems. The Philippine Agriculturist, 75, 1-8.
- Neild, J., O'Flaherty, P., Hedley, P., Johnston, D., Christenson, B., Brown, P., 1998. Impact of Volcanic Eruption on Agriculture and Forestry in New Zealand. MAF Policy Technical paper 99/2, 88.
- Rees, J.D., 1979. Effects of the eruption of Parícutin volcano on landforms, vegetation, and human occupancy. In: Volcanic activity and human ecology. New York: Academic Press, 249-292.
- Spence, R.J., Kelman, I., Brown, A., Toyos, G., Purser, D., Baxter, P., 2007. Residential building and occupant vulnerability to pyroclastic density currents in explosive eruptions. Natural Hazards and Earth Systems Sciences, 7, 219-230.
- Stieltjes L., Arnal, C., Bour, M., Doulet, S., Imbault, M., Masure, M., Mirgon, C., Mouroux, P., Sedan, O., Terrier, H., Traineau, H., 2001. XIème CPER Martinique – Evaluation et prévention du risque volcanique à la Martinique. Report BRGM R 40492, pp. 512.
- Wilson, T.; Kaye, G., Stewart, C., Cole, J., 2007. Impacts of the 2006 eruption of Merapi volcano, Indonesia, on agriculture and infrastructure. GNS Science Report 2007/07, pp. 69.

Reducing functional vulnerabilities

- Volcanoes: protecting the public's health" published by WHO/PAHO. www.paho.org/english/ped/volcano_guide.htm
- Report to the Chairman, Subcommittee on Communications, Technology, and the Internet, Committee on Commerce, Science & Transportation, United States Senate, "Emergency Communications – Vulnerabilities Remain and Limited Cooperation and Monitoring Hamper Federal Efforts", June 2009.

6 MEANS AND METHODS FOR CRISIS MANAGEMENT

During an eruption many civil protection actions are carried out in order to rescue people, to assist displaced people in camps, to survey and assess weakened infrastructure, to fix buildings and damaged structures, to transport material from storage to the camps, to evacuate animals and people reluctant to move during the first evacuation, etc. But volcanic eruptions present a unique specificity in comparison with other natural disasters. One must always keep in mind the possibility that unexpected phenomena can occur and this requires that attention should be paid to the development/evolution of volcanic activity, especially during risky missions in dangerous areas, which sometimes are essential. Furthermore many scientific activities, such as the repair/maintenance monitoring stations and the analysis of volcanic phenomena, which are generally safe, require access to dangerous areas in case of volcanic eruption. In order to allow the safety and security for people and for all the scientific and civil protection operations, a strict collaboration between the scientific community and civil protection authorities is absolutely necessary, in a coordinated manner with the different emergency management sectors such as health, search and rescue, transport, etc.

This section addresses crisis management, once the alert level rises the alarm phase lasts right (evacuation) up to the end of the eruption. In particular, the role of scientists, civil protection authorities and the media is discussed. In addition, some recovery examples are also included.

Participating authors: **Louis Bonfils**
Vittorio Bosi

30. Scientific support and advice

Role of scientific community

The main roles of the scientific community during an eruption can be summarized as follows:

- To ensure regular information to the authorities about the evolution of the volcanic activity, updated on monitoring data in real time
- To give, whenever possible, short term forecasting about future activity, always considering the uncertainties that usually characterize any forecast
- To ensure real time warning to authorities, especially during risky missions
- To keep monitoring networks functioning, with limited risks for researchers
- To carry out the necessary survey at the volcano and approach routes (local authorities - police - observatory), which could be opened to the public

These activities are fundamental to allow the civil protection to act properly with a minimal risk, when the eruption has begun.

This can be done using pre-established protocols and procedures, tested during the preparedness phase for example, an appointed commission of the stakeholders involved (see Chapters 22 and 24). This commission should work at least from the phase preceding the impending eruption until the eruption ends. It should follow all the operational and scientific aspects in a coordinated approach to minimize the risk for people, operational forces and scientists.

Communication

The success of the emergency response strongly depends on how the information reaches the public before, during and after the eruption. For this reason, it is important to plan a correct and organized communication for the public (i.e., communication plan). In this respect, it is difficult to suggest a unique solution applicable to all countries, but some general principles and practice can be mentioned which may be of universal validity.

Firstly, only consistent and reliable data should be disseminated. The concept of "fear of panic" when people are well educated and prepared is out-dated. Panic is generated by the dissemination of unreliable information, or by controversial or even conflicting information released by different institutions and/or persons. When people are previously informed and educated, they may tolerate and accept information indicating the possible change of their personal life style, especially when the concepts are clear, simple and easily understandable. Starting with the concept of total freedom of all the players involved (media, scientists and civil protection stakeholders) as a guarantee of democracy, it is important to stress that communication to the public and to the media sometimes deviates from a correct and effective line. In fact, interpretations are often released in place of factual data while data are disseminated without a correct vocabulary (popularized speech) and without a clear plan of dissemination. In many cases uncertainties are not given their correct weight. This leads to public and media confusion and makes them suspicious of civil protection authorities and the scientific community. This is exactly the kind of mistake that can generate panic. In this regard the question that needs to be solved is how is it is possible to respect the principle of information freedom in relation to the necessity of information reliability and consistency. Actually, the main element of response is related to necessary scientific knowledge. It is considered here what is, by this time, well known: a forecast of eruption/volcanic activity is possible only with a multi-disciplinary approach (see Section 3), and with some uncertainties. Following this principle, correct information about volcano activity can be given only after scientific discussions among specialists in various disciplines: seismology, geochemistry, geodesy, gravimetric analysis and others. These discussions allow producing shared conclusions that lead to a single and consistent message. Uncertainties should be always defined.

Moreover the decision about the number and quality of personnel who are authorized to talk with the media is debatable. Many solutions are adopted in various countries (e.g., Indonesia, Philippines) and here three of them are reported with some relative values and warnings:

- Only one or a few speakers are authorized to talk with the media and the public. At National level the choice lays usually on the general manager of the Local Emergency Management Agency (LEMA), or a delegate of the general manager, and/or the director of the scientific observatory, responsible for monitoring and analysis of data, etc. At local level usually the major or one delegate is the speaking person
- The media choose the speakers. The authorities do not design speaking persons
- Press conferences are organized to inform the public and the media about the situation and about the counter-measures already taken or the ones to be taken soon

In the case of few authorised speakers, the value is the uniformity of language and the quality of information released (no confusion for the public and the media). The warnings are that many voices are neglected and that usually journalists from different media, even local media, get additional information interviewing other people in the field, such as scientists, local administrators, etc. This makes it very difficult to control the quality of the “alternative” released information. Furthermore it is not often a good choice to refuse interviews, once requested. When the media choose the speakers by their own, the value is the perception of a high degree of freedom. Everybody is authorised to speak. The warnings are that proven reli-

ability of information does not exist and that sometimes a political control conceals practical and technical information.
When press conferences are organized, the value is the same as in the case of only one or a few selected speaker, with the advantage of a potential interactive response to all questions raised by the attendance. Warnings are the same as for one speaker with the disadvantage that the participants can perceive possible conflicts within the crisis management team, if they exist.

GOOD PRACTICE FOR COMMUNICATION

Dissemination of information: define roles and responsibilities to inform the public and deal with the media.

Communication strategy: share and discuss a communication strategy between the scientific community and the civil protection authorities. In this respect a very important point concerns the identification of authorized speakers.

Collaborative agreement with the media: establish a permanent and collaborative agreement with the media during a crisis. This can imply the organisation of regular broadcast reports. The agreement can include, for example, where, when and how the media will receive updates related to volcano activity and operational aspects.

Never hide information: give most of it or all, following a reasonable pre-ordered list based on priorities (the public and the media plan). When information is not available, give an explanation and indicate when and where information will be available.

Probabilities: use the concept of probability during conferences/interviews. Forecasting of an eruption always includes probabilities.

Spokespersons, press conferences and press-packages: commissions or boards of emergency management (Chapters 22 and 24) can be accompanied by the choice of spokespersons (two/three at least) which should be selected among scientist, civil protection officer and operational forces. Common daily press conferences can be then organised to inform the public and the media about the situation and the counter-measures already taken or about the ones that need to be taken soon. The commission can prepare and disseminate a press package to civil protection stakeholders and scientists: this press package will represent the official voice. The press package will be also issued to the media, during or before press conferences or interviews. The press package has a twofold meaning: firstly, to help the speaker to give the right information, in a correct language, at the right time and in every locality and secondly to help the media understand the message with reduced margin of interpretation.

31. Civil protection activities during emergencies

A good response to a volcanic crisis necessarily implies well-developed preparedness. The majority of civil protection activities, in fact, need effective organization and well defined and shared procedures, which are generally difficult to prepare and test during an impending eruption. Even if a certain amount of time usually exists between the first precursors and the eruption itself, strong acceleration of events can significantly reduce the time to prepare an effective response. Therefore procedures both for rapid emergencies (few days) and for a slower evolution of the volcanic crisis have to be carried out (see Chapter 25).

One of the most important needs is to achieve a minimum standard of capacity at national level for civil protection activities in the entire territory at risk. As a general rule, in fact, the management of a volcanic emergency is usually at national level. The reason for this lies mainly in the fact that the area potentially at risk is usually too large to be managed uniformly using only local capacity (different municipalities, with different economies, sometimes different ethnic groups, etc.), even though only a part of the region would be seriously affected by the volcanic event. Furthermore the coping capacity at local level, especially in case of a large evacuation, is often not sufficient. Normally, mutual help is needed between municipalities and provinces (districts) and regions.

Civil protection actions before the eruption

It is possible here to outline the main aspects that need to be faced just before a volcanic eruption. As soon as the first signs of activity are perceived, and the volcano observatory records warning of a possible eruption, civil protection actions should follow the National emergency plan. In particular they have to be focused on:

- Ensuring operational management according to the National emergency plan. In order to have a permanent link between a volcano observatory and civil protection authorities, general agreement and standard procedures should be defined in the preparedness phase (see Chapters 22, 24 and 25)
- Gathering systematically with volcano observatory and scientific institutions in order to be informed on the real-time situation and to activate the alert procedures. This will allow to follow the volcanic evolution in real time and to take the necessary counter-measures as fast as possible
- Supporting the volcano observatory for deployment of additional tools for monitoring the current eruption, in case of necessity
- Disseminating alerts following procedures defined in the National emergency plan.
- Informing the public of the updated situation
- Activating operations centres, previously defined according to the National emergency plans
- Preparing and issuing orders to prohibit access to dangerous areas
- Preparing all necessary means for evacuation and for organization of shelter camps, based on the local, regional and national emergency plans

- Preparing all communication actions to evacuate people in case of need
- Alerting the aviation authorities about a possible future eruption and ash dispersal. This is fundamental because, as the last eruption of Eyjafjallajökull demonstrates, air traffic can strongly suffer, causing damage to the general economy
- Preparing an ash removal plan, when necessary
- Assessing the vulnerability to ash loading and earthquakes of buildings located close to the main escape routes. Major consequences can arise from disruption of escape routes caused by partial or total collapse of buildings
- Centralizing information in operational centres and from there providing all updated information to other civil protection stakeholders and media, with a press package (media release)
- Conducting joint recognition (local authorities - police - volcano observatory) to approach and escape routes
- Reporting the situation to the Government, on a timely basis
- Evacuating population at risk, when necessary, towards the emergency areas (people are preventively advised about the organization of evacuations, the self-safety to adopt during the evacuation or to use in case the evacuation is delayed for any reasons). The evacuation should include all permanent settlements in valleys around the volcano that can be affected by lahars. These areas can be even farther from the volcano, but represent a real danger for people living there. People may be allowed to return to the danger areas to work, but on condition that an effective warning system is established so that they leave the area immediately a lahar is detected or expected.

The cost of evacuation, temporary housing, feeding and eventual resettlement of the population always represents an additional loss to the economy, but nevertheless it is often the sole possibility to save lives of people living in the area at risk. The costs of large-scale evacuations also include the discouraging effects on individuals of being displaced from their homes and deprived of their normal family and social life. These considerations illustrate the necessity to inform and educate the population and to limit a forced evacuation (people would collaborate without resistance, see Chapter 25). In order to overcome the resistance of people to evacuate some general recommendations can list below:

- It is relevant to increase the perception of the degree of hazard and associated risks through assessments based on scientific study and observation of the volcano
- People should be conscious of the inconvenience, hardship and disruption of normal life that evacuation will necessarily cause; people should know the psychological, economical and social costs and the possible consequences
- During evacuation, depending from the country, the Government could include procedures to avoid or limit looting. The effort to limit looting should be well disseminated to people, to convince them to evacuate, while the procedures to do it should be restricted to the responsible forces
- The understanding of the real fear and

problems of people, before, during and after the evacuation permit to set appropriate countermeasures. The fear and problems varies from country to country and strongly depends from cultural and socio-economic aspects (see Chapter 26)
- The preventive evacuation of animals could be included in the evacuation procedures as suggested in Chapter 25, because often their abandonment can induce the farmers to stay in their homes. Insurance for farmers can represent sometimes a useful counter-measure

In case of an imminent eruption, local authorities should:
- Facilitate and coordinate the actions of the command posts that should be activated closer to the hazard area, in a safe location, when the situation requires it (cut roads through lava flows, management of public access and regulation of traffic flows, possible evacuation of the population)
- Give updates about territorial information, following the lines established in the emergency plan. In case the plan does not exist, they should draw an ad hoc plan for the main escape routes and the emergency areas for the population
- Decide on accommodation of evacuees, on the basis of the national emergency plan, when it exists, or, alternatively on the basis of the local emergency plan, and they should prepare the applications for assistance whenever required
- Disseminate information through local media (radio, television, newspapers) following the previously established strategy
- Gather information from the local operational command post and inform the regional level.

All these actions are generally broadly connected with transportation, communications, infrastructures and building assessment, fire fighting activities, public health and medical services, power supplies, agriculture and natural resources, public safety, media and external affairs. The consequence is a complexity in the relationship among stakeholders, which suggests a multi-functional system for emergency management. In particular, it is very effective to group civil protection stakeholders into a single safe place (command post) on site, where they can have a consistent awareness of developing situations and a better responsiveness. Stakeholders in the command post represent the organizations responsible for all aspects of emergency management. In this way the different representatives, which sit at the same table, are able to share information and take decisions in real time. Usually authorities (regional or local, according to the level of the meeting) led inter-departmental and inter-agency meetings, representing the government in order to have a natural legitimacy.

Civil protection actions during the eruption

Once an eruption takes place and the civil protection system is fully operative (i.e., evacuees already reached the emergency areas) one of the main rising problems is the duration of the eruption and, more generally, its evolution. Available data on historical eruptions indicates that they can have different patterns and only accurate and reliable monitoring data can help understanding of when the eruption will end. During this phase that can last weeks or months (sometime years), civil protection activities are mainly focused on:

Launching alerts for aviation authorities and maintaining strict collaboration with them for the entire duration of the eruption.
Search and rescue operations in case of unexpected events or when the evacuation of the population has partially or totally failed. In this case evaluation of environmental conditions, favourable or unfavourable to search and rescue operations, is necessary. Rescuers, in fact, need total assistance and very rapid forecasts for their safety. As an example, very fast (low viscosity) lava flows can interrupt the escape route for rescuers, bringing them into a very risky situation in case of the possible occurrence of other eruptive phenomena. They should know, as an example, that even very thin (<1 mm) pyroclastic deposit is extremely hot and it will burn the feet of rescuers, if thick boots are not worm.

Giving assistance to evacuees in camps and to injured people. It is necessary to plan the organization of assistance for people that can have renal, cardiac and respiratory diseases caused by ash, burns or traumatic problems.

Having continuous communication with people and with the media by using a well pre-established strategy.

Monitoring continuously the road system. It can be affected by various volcanic phenomena as pyroclastic density currents, lahars, lava flows, or ash fall, with strong consequences in case of fast dislocation. These factors should be analysed and ash removal plans and alternative routes are necessary.

Preparing the return of the population: this means to plan the actions necessary for a safe homecoming of the population.

Preparing the recovery measures to increase the resilience.

During all these activities it is fundamental the constant and intense collaboration among the components of the civil protection system, especially with the scientific community.
In case of a major crisis, when the eruption has created severe damage or it was stronger than expected, the Government of the affected country can ask for international aid and support, usually by bilateral agreement with neighbouring countries or with the UN or EU. Governments and/or NGOs usually provide the needed reinforcements. As stated in Chapter 24, this intervention has to be prepared in advance to be efficient. The international support can organize an On-Site Operative Coordination Centre (OSOCC) in order to facilitate the cooperation with LEMA, and coordinate the incoming teams and goods, in close coordination with LEMA, which lead the emergency management, and which lay out priorities and objectives to achieve. Figure 25 gives an example of this type of organization.

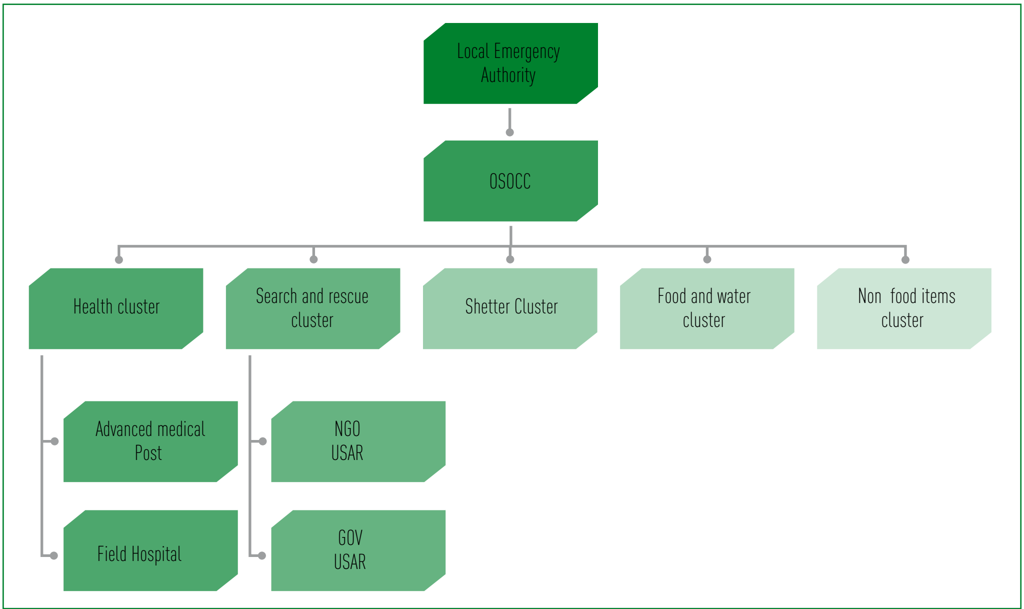

Figure 25: Example of command post organization in case of international aid.

Civil protection activities after the eruption

The following activities are the basis for an effective recovery:

- Assessing the damage
- Assisting people until the normal situation is restored
- Assessing the possibility to relocate the evacuated population permanently or to inhabit again the evacuated areas and villages
- Re-establishing the main functionalities for the systems that have been damaged (e.g., electric supply, water, roads, bridges, early warning systems, etc.) to allow the people to come back home in safe conditions (guarantee the safety and a possible new evacuation)
- Bringing people back to their homes when safe or assist people in temporary houses until the new houses will be built
- Assessing the state of the river-bed filled by lahar or pyroclastic deposits
- In case of damage, restoring the river beds and reinforcing embankments to diminish the risk of a future lahar breaching the embankment itself
- Consolidating all the numbers of casualties, injured, evacuees, number of tents used and costs

Post-emergency activities differ if permanent relocation occurs or not.

A permanent relocation means the building of new towns or villages, new grassland, new territory for agriculture, etc. Generally, after an eruption, the possible permanent relocation of people living in dangerous areas towards safer ones is slightly facilitated because of the damage and destruction of agricultural crops and grasslands, and because people, temporarily evacuated, are already experiencing a sense of abandon of their own properties. In many countries the relocation is sometimes very difficult, because of the density of the population (e.g., in countries as Indonesia or Japan), the extension of the areas at risk and the cultural and religious aspects (see Chapter 26). Nevertheless, effort to take this direction can be evaluated from the beginning of eruption, with the close collaboration of all the involved Government institutions, NGOs, and representatives of the communities. However, relocation should be planned in the safest nearby areas to maintain the cultural and the socio-cultural environment, and psychological and economical factors should be taken into account.

When relocation is hampered by many factors, the effort should be directed towards reestablishing livable conditions of life through the rehabilitation of farming, industries (developed countries) and housing. This implies a great amount of resources in terms of money, planning and hard work. The effort has to be Government-driven, but the role of individuals and private business companies is fundamental. In volcanic hazard areas a great contribution can be added when a business continuity plan exists. This allows recovery in a shorter time.

In this case some of the main efforts of the Government (national and local) are listed:

To construct alternative housing or restore the damaged buildings.

To create alternative jobs in order to provide occupation for the population that have been evacuated from the affected areas.

To support people from a technical and scientific point of view, in the individual recovery activity. Extremely important is for example:

- To assess the ash composition in order to plan cultivation of more adaptable crops
- To estimate the probability of ash dispersion in case of future eruptions in order to evaluate possible changes in the agricultural systems as changing of plantation type or shifting from outdoor crops to greenhouse-based production, as crops in greenhouses are protected from ash, etc. This forecasting will serve also to decide where livestock could live, if it is better to move them to other areas
- To assess the composition of soil after an eruption, to understand whether chemical changes in the soil would require a modification of crop type
- To evaluate the possible remobilization of the material deposited during the eruption (e.g., by future lahars). It is important, for example, to delineate where to avoid cultivation or to limit agricultural activities during the season where it is unlikely that remobilization can occur (e.g., dry season)

To ensure the continuity of traditions and the reestablishment of pre-eruptive conditions of life.

It has been proved that a national, coordinated cooperative effort is required to enhance national capacity to withstand and recover from volcanic emergencies. Disaster resilience, in fact, is the collective responsibility of all sectors of society, including all levels of government, business, non-govern-

mental sectors and individuals. Without this effort the recovery phase can be slow or can fail, causing economical difficulties to the whole region or country.
A remarkable example was the effort made by the Japanese Government (Prefecture of Nagasaki) in the case of the 1990-95 eruption of Mt. Unzen, when the recovery process was essentially government-driven, with extraordinary results.

It is worth noting that rehabilitation activities should be evaluated case by case, with strong differentiation from countries, in relation to the damage suffered, and the economical and cultural background. The reader can also find other useful insights in Chapter 26 and in references at the end of the section, given that good rehabilitation should be based on planning that aims to reduce vulnerability in the region.

Recovery examples

Recovery can be defined as the coordinated effort and processes to induce the medium- and long-term regeneration of a community after an emergency.
After a volcanic crisis, in fact, daily life for people can be totally changed, especially where effective urban and agricultural planning was not carried out before the event. Houses, crops, livestock, fertile soil, infrastructures can be totally or partially destroyed. Even though the eruptive activity can last a few weeks or months, the recovery can be hampered or postponed because of, for example, the occurrence of lahars for many years, especially in tropical regions.
The beginning of recovery starts during the emergency phase. The time allows preparation of the coordinated actions needed to bring about recovery. This will allow to anticipate actions that might be required in the recovery stage and wherever possible preparation can begin for these.

Japan

A large change in the type of crops and agricultural techniques took place after the 1990-1995 eruption of Unzen volcano. Dairy livestock, which mainly occupied the area, was relocated to neighbouring areas. The cultivation of tobacco, well developed before the eruption, was substituted with greenhouse horticulture, lowering the risk from ash fall. The rehabilitation of farming land was performed through a number of steps. First, soil was brought from other regions and was used to cover ash and pyroclastic deposits. Secondly, irrigation channels and drainage systems were built to guarantee crop irrigation and to minimise possible damage from future floods. In this case significant funding and technical assistance were provided in order to enable the farmers to start agricultural activities quickly. This solution required financial resources that very few countries can provide.

Indonesia

Indonesia used an interesting system to recovery the economy of affected people after the 2006 and 2010 Merapi eruptions. During the eruptions a lot of volcanic material was erupted and deposited along the slopes of the volcano (ash and pyroclastic flow deposits) and inside the riverbed (lahar and pyroclastic flow deposits). This caused damage to cultivation, buildings and infrastructures. Many people lost their jobs, with a strong reduction in their economy. Government created alternative jobs lending, for example, a certain amount of land inside the riverbed to affected family-units, with permission to mine and sell the extracted material. This allowed the Government to save money for the removal of filling material of the river bed, to increase the economy of poor people that lost their jobs because of the event and to increase the availability of material needed for reconstruction. As an example, material deposited into the riverbed was included in squared metal frames, which were used to strengthen the river embankment (Fig. 26).

Philippines

After the 1991 eruption of Mt. Pinatubo, in order to safeguard the lives of people relying on agriculture in areas at risk from lahars, the annual cropping pattern changed to seasonal crops that would grow outside of the rainy season. People working on cultivations did not suffer any risk from lahars. Supplementary activities were created, such as pumice-gathering used in the jeans industry to create the 'stone-washed' effect.

Figure 26: Strengthening of river embankment in Indonesia using volcanic materials deposited during the 2010 eruption of Merapi. Photo by Vittorio Bosi.

References and suggested readings

Recovery example

- Sylviane L.G.Lebon – Volcanic activity and environment: Impacts on agriculture and the use of geological data to improve recovery processes. Master thesis in Environmental Sciences and Natural Resources Management: http://skemman.is/stream/get/1946/3303/10384/1/Sylviane_Lebon_fixed.pdf

TABLE APPENDIX

TABLE I: CLASSIFICATION TABLE OF ERUPTIVE STYLE BASED ON VOLCANIC EXPLOSIVITY INDEX (SEE REFERENCES IN SECTION 2). THE TABLE IS FROM: http://en.wikipedia.org/wiki/VEI

VEI	EJECTA VOLUME	NAMES	DESCRIPTION	PLUME	FREQUENCY	TROPOSPHERIC INJECTION	STRATOSPHERIC INJECTION	EXAMPLES
0	<10,000 m^3	Hawaiian	Effusive	< 100 m	Constant	Negligible	None	Kilauea, Piton de la Fournaise
1	>10,000 m^3	Hawaiian/ Strombolian	Gentle	100-1000 m	Daily	Minor	None	Stromboli, Nyiragongo (2002)
2	>1,000,000 m^3	Strombolian/ vulcanian	Explosive	1-5 km	weekly	Moderate	None	Galeras (1993), Sinabung (2010)
3	>10,000,000 m^3	Vulcanian/ Peléan	Severe	3-15 km	few months	Substantial	Possible	Nevado del Ruiz (1985), Soufrière Hills (1995)
4	>0,1 km^3	Peléan/Plinian	Cataclysmic	10-25 km	≥ 1 yrs	Substantial	Definite	Mount Pelée (1902), Eyjafjallajökull (2010), Merapi (2010), Taal (1965)
5	>1 km^3	Plinian	Paroxismal	20-35 km	≥ 10 yrs	Substantial	Significant	Vesuvius (79 AD), Mount St. Helens (1980)
6	>10 km^3	Plinian/ Ultra Plinian	Colossal	> 30 km	≥100 yrs	Substantial	Substantial	Krakatau (1883), Mount Pinatubo (1991)
7	>100 km^3	Ultra Plinian	Super-colossal	> 40 km	≥ 1,000 yrs	Substantial	Substantial	Thera (Minoan Eruption), Tambora (1815)
8	>1,000 km^3	Supervolcanic	Mega-colossal	>50 km	≥10,000 yrs	Substantial	Substantial	Yellowstone (640,000 BP), Toba (74,000 BP)

TABLE II: COMPARISON OF GEOCHEMICAL TECHNIQUES DISCUSSED IN CHAPTER 19

TECHNIQUE	ADVANTAGES	LIMITATIONS	WHAT DOES IT MEASURE?	NOMINAL COST (€)	NUMBERS OF INSTRUMENTS REQUIRED	POWER AND MAINTENANCE
Ginggebach bottles	Very comprehensive measurements; including isotopic analysis	Laborious sampling; need for laboratory facilities; unsuitable for dilute plumes	Just about everything (depending on laboratory facilities available)	100	Several bottles required for sampling of multiple gas vents	Unpowered; care needed in transporting glassware
Filter packs	Cheap; suitable for dilute volcanic plumes	Only acid species; requires laboratory facilities	Acid gas species ratios (e.g., HCl/HF; HCl/SO_2)	100	Several filter packs; tubing, and at least two pumps	Usually a 12 V DC battery; sampling period about 1 hour
"Multihas" systems (comprising electrochemical and NDIR - non dispersive infrared sensors)	Comparatively cheap; can measure several species in real-time; good for dilute plumes; suitable for telemetry	Sensor drifts – needs regular recalibration (hence laboratory facilities); clogging of pumps and corrosion	SO_2, H_2S, H_2, CO (electrochemical): CO_2, H_2O (NDIR)	100	Ideally two or more per site; enabling one to be in operation while another is being recalibrated	Can usually be powered by solar panels or wind turbine, depending on telemetry duty cycles
COSPEC	Ease of operation and calibration; minimal training needed; sensitivity	No longer manufactured; a few systems still operational.	SO_2 flux (when combined with observation of plume transport speed)	10000	One instrument used in a daily, or weekly cycle	AC or DC (20 W)
UV spectrometers	Modest cost; versatility; readily adaptable for mobile or fixed station measurements		SO_2 flux (when combined with observation of plume transport speed); SO_2/BrO ratio	1000	Several instruments needed to build scanning network	1 W per spectrometer

TABLE III: SOME EXAMPLES OF CURRENTLY OPERATING WEBCAMS AT VOLCANOES. FOR A COMPLETE LIST SEE: http://bigthink.com/ideas/26619?page=all

VOLCANO	LOCATION	WEBCAM
Anatahan	Northern Mariana Islands	http://volcanoes.usgs.gov/nmi/images/webcam.php
Puu Oo	Hwai'i	http://volcanoes.usgs.gov/hvo/cams/POcam/
Sakurajima	Japan	http://webcam-svo2.pr.kyoto-u.ac.jp/local/camera.html
Bezymianny	Russia	http://data.emsd.iks.ru/videokzy/videokzy.htm
Cleveland	Alaska	http://www.avo.alaska.edu/webcam/Cleveland.php
Merapi	Indonesia	http://www.merapi.bgl.esdm.go.id/view-r.php?id=1
Piton de la Fournaise	Reunion	http://www.ipgp.fr/pages/03030807.php
Eyjafjallajokull	Iceland	http://eldgos.mila.is/eyjafjallajokull-fra-thorolfsfelli/
Turrialba	Costa Rica	http://www.ovsicori.una.ac.cr/videoturri.html
Popocatépetl	Mexico	http://www.cenapred.unam.mx/popo/UltimaImagenVolcanI.html

TABLE IV: EO OPTICAL SENSOR CHARACTERISTICS

SATELLITE SENSOR	SPECTRAL RANGE	SPATIAL RESOLUTION	REVISIT TIME
MSG-SEVIRI	12 bands VIS-IR	1.4 km (1 band) 3 km (2-12 bands)	Geostationary: 15 minutes
GOES	5 bands VIS-IR	1-4 km (VIS-IR)	30 minutes to 8 h
MTSAT	4 bands VIS-IR	1-4 km	30 minutes
NOAA - AVHRR	5 bands VIS-TIR	1.1 km	6 h
TERRA and AQUA MODIS	20 bands (0.62-2.155 µm) 15 bands (3.66-14.38 µm)	250 m (2 bands) 500 m (3-7 bands) 1 km (8-36)	12 h
ENVISAT – MERIS (mission ended April 2012)	15 bands VIS-NIR	300 m	4 days
ENVISAT – AATSR (mission ended April 2012)	2 bands VIS 1 bands NIR 2 bands Short Wave IR 2 bands TIR	1 km (nadir) 1.5 km x 2 km (forward)	6 days
TERRA-ASTER	2 bands VIS 2 bands NIR 6 bands Shortwave, IR 5 bands TIR	15 m 30 m 90 m	16 days
EO-1 HYPERION	224 bands VIS-Shortwave, IR	30 m	16 days
AIRS	>2000 bands (3–15 µm)	15 km	12 h
IASI	>2000 bands (3–15 µm)	12 km at nadir	12 h
OMI	(280–320 nm)	13 km × 24 km at nadir	1 day

TABLE V: THE ESA-SENTINEL'S SPACE MISSIONS CHARACTERISTICS

SENTINEL SENSOR	SPECTRAL RANGE	SPATIAL RESOLUTION	REVISIT TIME
Sentinel-2: Multi spectral imager	12 bands VIS-NIR-SWIR	10 m, 20 m, 60 m, depending on spectral range	5 days with 2 satellites
PSentinel-3: Ocean and Land Color Instruments	15 bands VIS, NIR	250 m, 1 km	< 4 days with 2 satellites
Sentinel-3: Sea and Land Surface Temperature	7 bands VIS-NIR-SWIR-TIR	1 km TIR, 500 m others	< 4 days with 2 satellities

TABLE VI: MAIN CHARACTERISTICS OF PRESENT AND FUTURE SAR MISSIONS

SATELLITE	WORKING FREQUENCY	RESOLUTIONS	REVISIT TIME
COSMO-SkyMed	X band	1 to 100 m	1 day (with 4 sat.)
Terrasar-X	X band	1 ti 16 m	11 days
Radarsat-2	C band	1.6 to 100 m	24 days
Envisat-ASAR	C band	25 to 100 m	30 days
Sentinel-1 (launch on2013)	C band	5 to 40 m	6 days (with 2 sat.)
Saocom-1 (launch on end 2012)	L band	10 to 100 m	8 days (with 2 sat.)

TABLE VII: MAIN CHARACTERISTICS OF THE MOST COMMON INTERNET ACCESS TECHNOLOGIES

TECNOLOGY	DATE RATE	COST	AVAILABILITY
Analogue PSTN (Public Switched Telephone Network)	< 56 kbps	Medium (call duration)	Urban areas
ISDN (Integrated Services Digital Network) PSTN	64 or 128 kbps	Medium (call duration)	Urban areas, some countries
ADSL	Upload 1 Mbps Download 24 Mbps	Low	Urban areas, some countries
SDSL	Upload 3 Mbps Download 3 Mbps	Medium	Urban areas, few countries
VDSL	Upload 16 Mbps Download 52 Mbps	Medium	Urban areas, few countries
HFC (Hibrid Fiber-Coaxial)u	Upload ~30 Mbps Download ~400 Mbps L band	Low	Urban areas, some countries
FTTH (Fibre To The Home)	Gbps	Low	Urban areas, few countries

TABLE VIII: MAIN CHARACTERISTICS OF THE MOST COMMON WIRELESS TECHNOLOGIES

TECNOLOGY	DATE RATE	COST	AVAILABILITY
Cellular – GSM	9.6 kbps	Medium (call duration)	Most countries
Cellular - GPRS	<171 kbps	Low – flat fee Medium – transmitted data	Many countries
Cellular - UMTS	384 kbps - 45 Mbps	Low – flat fee Medium – transmitted data	Some countries – urban areas
WiMax	<30 Mbps 1Mbps @ 50 km	Low	Few countries. Still being evaluated/ deployed
Satellite	kbps	High	Worldwide

TABLE IX: EXAMPLE OF A POSSIBLE SCRIPT FORM FOR EXERCISE

NAME OF THE EXERCISE			
Type of exercise: 1. Table-Top 2. Full scale 3. Reduced 4. Announced 5. Unannounced	Site address of exercise:		Scheduled date:
			Level of the players
	Type of hazard: Lahars, Ash fall, Health Hazard Earthquake		Time slot: 1. Day / night 2. AM / PM 3. Begin of exercise: 4. End of exercise
THEME			
Objectives	General Objective : 1.............. 2...............	Interim Objectives : 1 .... 2 .... 3	Specific Objectives : 1 .... 2 .... 3 ....
Players		Lower Animation	High Animation
	Private company Operators :	Electricity Railway company	CP of operators
	Public Institutions: Private Company:	e.g. Mayor	e.g. Regional Civil P
	Others	Students, Consultant, Scientists - Experts	
Kinetic	Speed?	Slow?	Compressed time?
Weather	Real?	Fictitious?	If fictitious : - Direction of wind - Hygrometry - Speed wind
Communication	yes	no	If yes, who, where and when?
	yes	no	Who and since when.
	yes	no	In case roles and number of figurants should be planned
Scenario and timetable	Outline and cutting time: Phase 1:.. Phase 2: .... Phase 3:..		
Logistics	Drinks, meals, blankets, etc.		
Evaluators	1....................., 2..............., 3.....................		
Observers	1.........................., 2..........................		
Hot feedback	What time, where and with whom? In general just after the end of the exercise or one day later.		
Cold	What time, where and with whom? In general 30 days after the end of the exercise		

TABLE X: SUMMARY TABLE OF PROPOSED MITIGATION MEASURES AND POSSIBLE LIMITATIONS (BASED ON NEILD ET AL. 1998, WILSON ET AL. 2006, AMENDED, SEE REFERENCES IN SECTION 5)

	MITIGATION MEASURES				
	Pre-eruption	Limitations	Post-eruption		Limitations
Tephra falls	Cultivation of less susceptible crops (erect habit, non-hairy leaves) and / or diversification of crops: spreading risk to different plant vulnerability and dependence on one harvest. Intercropping and agro-forestry: taller shrubs or trees shield subjacent crops during slight ash fall. Cultivation in hill beds and with organic mulch-cover: in case of crops are lost, a fast and easy removal of deposited ash from field is enabled (eventually already by rain). Focus on organic fertilization with manure, compost and harvest residues to increase soil organic matter pool and related soil fertility	Measures are feasible only to minor tephra fall events with a thickness <5 cm. Delineation of areas at risk to minor ash fall is difficult. Acceptance of adjusted management practices and crop types by local farmers	Tephra thickness		
			<5 cm	Tephra removal from plants and harvested crops. Natural processes (erosion, soil animals) will remove and/or incorporate ash layer into soil. Adjustment of fertilisation and pest management	Tephra removal from plants very time consuming and uneconomic for many crops Fine tephra adheres to leaves. Accessibility to fresh water for cleaning
			5 – 10 cm	Tephra removal from plants Mixing of ash with old top soil (deep ploughing) Increased input of fertiliser Change of cultivated crops	Machinery needed. Increased fertiliser costs. Possibility of marketing of newly introduced crops
			10 – 30 cm	Complete removal of ash layer. Re-cultivation measures similar to recovery of mining areas, introduction of lupines for nitrogen fixation	Very high machinery input and costs: only suitable for a limited area
			>30 cm	Re-cultivation measures: introduction of lupines for nitrogen fixation and amendment of organic fertiliser Alternative land use, e.g., afforestation by pioneer species	Long-term measures for several years to decades
Pyroclastic density currents Lahars	Proper land use planning with exclusion zones for agriculture in high hazard-prone areas. Substitution areas for crops supplying to food security		Mitigation measures of tephra fall >30 cm also applicable to PDCs and lahars		Cycles of repeated destruction possible. Long-term measures for several years to decades
Lava flows	Supplying to food security		Long-term loss of arable land		

TABLE XI: GENERAL OVERVIEW OF CROP VULNERABILITY BASED ON DATA OF BLONG (1984), NEILD (1998) AND STIELTES (2001), SEE REFERENCES IN SECTION 5

ASH (MM)	EFFECTS ON VEGETATION				
	Group 1	Group 2	Group 3	Group 4	Group 5
	Small herbaceous plants or creepers	Plants with tubers, vegetables	Graminoid plants, taller herbaceous plants	Small trees & shrubs	Trees & palms
		Manioc, sweet potato, yam...	Cereals, grasses, camellia, legumes, sugar cane...	Banana, citrus, tea, coffee, cacao, stone & pipe fruits	Coconut, rubber tree, oil palm,...
<10	Flowers and leaves are burned or pierced Risk of pests due to leaf damage				
	Some fruits growing at ground level, rot		Some damage to maize and wheat		
– 50	Some big fruits and flowers fall, flowering fails				
	Creepers and plants at ground level are damaged Some plants can't grow through the ash layer	Strong damage to growing vegetables Part in the open of plants with rhizome damaged	Cut hay is unusable 10% to 50% of grasses, cereals, legumes, are destroyed. Stem of camelina broken	Strong damage to citrus crops and fruit trees Branches of young trees break Fleshy fruits are damaged (cherries, peaches)	
- 150	Most of the plant cover is eliminated			- Severe defoliation	
				Banana plants are damaged Ripening of fruits is accelerated	Palm leaves break
– 500			Rice paddy destroyed	Coffee shrubs are strongly damaged	Branches break Trees are seriously damaged
– 1000	Most of the vegetation is destroyed but few plants survive				
>2000	Total destruction of every plantation or cultivation				

TABLE XII: SUMMARY TABLE OF PROPOSED MITIGATION MEASURES, WITH REFERENCE TO POTENTIAL INCOMPATIBILITIES AND LIMITATIONS

FACILITY	TEPHRA FALL	PYROCLASTIC DENSITY CURRENT (PDC)	LAHARS	EARTHQUAKES (EQ)	INCOMPATIBILITIES (LETTERS A) TO D) REFER TO PARTICULAR MITIGATION MEASURES IN IN COLUMNS 2 TO 5)	LIMITATIONS (NUMBERS 1) TO 5) REFER O PARTICULAR MITIGATION MEASURES IN COLUMNS 2 TO 5)
Buildings	Roofs resistant to projectiles (a,1) Roofs designed for ash load (a,1) Prop vulnerable roofs in event of eruption Seal openings (2) Cover electrical equipment Facemasks for occupants	Roof and wall materials non-combustible Solid shutters Seal cavities (2) Remove combustible material and potential missiles	Planting of upper slopes Relocation to safer areas Elevating building plinths (b)	Design or strengthen masonry buildings for expected quake intensity	a) Heavier roof may increase earthquake vulnerability b) Elevating building plinths may make buildings more vulnerable to either EQ or PDC	1) Increased thermal capacity not good in tropical areas 2) Reduced ventilation
Roads/ bridges/ vehicles	Prepare equipment, materials (including water) and skills for rapid road clearance (4) Define dump site for cleared tephra Limit vehicle use in ash-laden conditions (3) Ensure local maintenance facilities are well-equipped	Assess resistance of bridges on main routes to likely PDCs Strengthen or relocate vulnerable bridges (5)	Assess resistance of bridges on main routes to likely lahars. Strengthen or relocate vulnerable bridges (5) Keep bridges and engineered dikes clear of debris from past flows	Assess vulnerability of roads/bridges to ground deformation/ landslides strengthen or reroute (5		3) Reduced emergency capability 4) Use of water makes roads slippery 5) Possible longer evacuation route
Power and telecomms	Prepare emergency plan (c), including back-up telecoms for emergency services Investigate vulnerability of system components Identify points of ash accumulation or risk to overhead lines and remove	Check where lines cross likely PDC flows and strengthen or relocate supports as needed	Check where lines cross likely lahar zones and strengthen or relocate supports as needed		Check where lines cross likely lahar zones and strengthen or relocate supports as needed	
Water supply and irrigation	Prepare emergency plan (d) for maintenance/repair with adequate equipment/supplies Cover exposed equipment Cover water collection, storage and transport facilities (4) Provide for back-up power generation	Prepare emergency plan for post-eruption clearance of channels	Prepare emergency plan for post-eruption clearance of channels Keep irrigation channels clear of silt and debris	Assess vulnerability of irrigation channels or water pipes to EQ induced ground deformation	d) Emergency plan should allow for possible damage/ disruption to other lifelines	4) Reduces rainwater collection capacity

GLOSSARY

A

Active volcano
A volcano, which is currently erupting or has erupted in recorded history.

Aerosol
A mass of tiny solid or liquid particles suspended in air or another gas. See also volcanic gas.

Alarm
Signal giving warning of danger. Advisory that hazard is approaching but is less imminent than implied by warning message. See also warning and alert.

Andesite
Andesite is a gray to black volcanic rock with between about 52 and 63 wt.% silica (SiO_2). Andesite magma can commonly erupts as thick lava flows, or it can also generate strong explosive eruptions to form pyroclastic flows and surges and enormous eruption columns. Andesites erupt at temperatures between 900 and 1100 °C.

Aseismic *(Non-seismic); used to designate an area free from seismic activity or a tectonic deformation process not accompanied by seismic events.*

Ash
Volcanic ash consists of rock, mineral, and volcanic glass fragments smaller than 2 mm in diameter. Volcanic ash is created during explosive eruptions by the violent separation of magma (molten rock) into tiny pieces.

B

Basalt
Basalt is a hard, black volcanic rock with less than about 52 wt.% silica (SiO_2). Because of basalt's low silica content, it has a low viscosity. Therefore, basaltic magma usually generate lava flow or at most weak explosive eruptions. Basalt is erupted at temperatures between 1100 to 1250 °C.

Bombs
Volcanic bombs are magma fragments larger than 64 mm in diameter that were ejected while partially molten. Many acquire rounded aerodynamic shapes during their travel through the air.

Broadband
Data transmission system in which a wide band of frequencies is available to transmit information. Broadband systems allow more information to be transmitted in a given amount of time, i.e., they provide high speed information transmissions.

C

Caldera
A large, basin-shaped depression formed by the inward collapse of a volcano after or during an eruption.

Coping capacity
The ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters.

D

Disaster
A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts.

Disaster risk management
The systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts if hazards and the possibility of disaster occur.

Dome
Volcanic domes are rounded, steep-sided mounds built by viscous magma (intermediate to silicic composition). Such magmas are typically too viscous (resistant to flow) to move far from the vent before cooling and crystallizing. Domes may consist of one or more individual lava flows (i.e., lava dome).

Dormant volcano
A volcano with no current activity but expected to erupt in the future.

E

Early warning system
The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss.

Element at risk
All elements constituting the volcano's human, social and natural environment, such as: population, strategic buildings for crisis management, buildings, infrastructures and networks, natural environment and farmland, main centres of economic and financial interest, social functions (e.g., transports, water and food supplying).

Emergency management
The organization and management of resources and responsibilities for addressing all aspects of emergencies, in particular preparedness, response and initial recovery steps.

Eruption
The expelling of material including gases, ash, volcanic fragments and lava on Earth's surface due to volcanic activity.

Exposure
People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.

Extinct volcano
A volcano that is not expected to erupt in the future because it has not longer a magma supply.

F

Fault Fracture
A fracture zones in the Earth's crust along which one side moves with respect to the other. There are many types of faults (for example, strike-slip, normal, reverse, and thrust faults) ranging in size from a few tens of meters to hundreds of kilometres in dimension.

Forecast
Definite statement or statistical estimate of the likely occurrence of a future event or conditions for a specific area.

G

Geochemistry
Science that exploits the tools and the principles of chemistry to explain the mechanisms be-

hind major geological systems such as the Earth's crust and its oceans.

Geodesy
Branch of Earth sciences that deals with the measurement and the representation of the Earth, in a three-dimensional time-varying space, including its gravitational field and the study of phenomena such as crustal motion, tides, and polar motion.

Geomorphology
Branch of the Earth sciences related to the study of landforms and the processes that shape them.

H

Hazard
A dangerous phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Hazard assessment
Survey of a real or potential hazard to estimate the actual or expected damages and to make recommendations for prevention, preparedness and response.

L

Lahar
An Indonesian word for a rapidly flowing mixture of rock debris and water that originates on the slopes of a volcano. They form in a variety of ways, chiefly by the rapid melting of snow and ice by pyroclastic flows, intense rainfall on loose volcanic rock deposits, breakout of a lake dammed by volcanic deposits, and as a consequence of debris avalanches.

Land-use planning
The process undertaken by public authorities to identify, evaluate and decide on different options for the use of land, including consideration of long term economic, social and environmental objectives and the implications for different communities and interest groups, and the subsequent formulation and promulgation of plans that describe the permitted or acceptable uses.

Landslide *(volcanic landslides)*
Rapid downslope movements of rock, snow, and ice. Landslides range in size from small movements of loose debris on the surface of a volcano to massive failures of the entire summit or flanks of a volcano.

Lapilli
Rock fragments between 2 and 64 mm in diameter that were ejected from a volcano during an explosive eruption. Lapilli may consist of many different types of fragments, including scoria, pumice, lithics and crystals.

Lava
Molten rock erupted from a volcano. Lava can occur in flows, domes, fragments and as pillows formed underwater.

M

Mafic magma
Term used to describe magma with a low silica content (i.e., <52 wt.% of SiO_2). The low silica content makes the magma significantly fluid and with low viscosity. Mafic magma usually generate effusive or at most weak explosive eruptions.

Magma
Magma is molten or partially molten rock beneath the Earth's surface. Magma typically consists of (1) a liquid portion (often referred to as the melt); (2) a solid portion made of minerals that crystallized directly from the melt; (3) solid rocks incorporated into the magma from along the conduit or reservoir, called xenoliths or inclusions; and (4) a gas portion (bubbles).

M_L Local Magnitude
It is the scale used for the majority of earthquakes reported by local and regional seismological observatories.

N

Non-governmental organization
A private voluntary agency created to perform beneficial activities according to its statutes or constitution.

P

Plume
A long, feather-shaped cloud of steam, gases or ash (i.e., volcanic ash plume).

Preparedness
The knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions.

Prevention
The avoidance of adverse impacts of hazards and related disasters.

Pumice
Pumice is a light, porous volcanic rock that forms during explosive eruptions. It resembles a sponge because it consists of a network of gas bubbles frozen amidst fragile volcanic glass and minerals.

Pyroclast
rock fragments of volcanic origin generated by explosive eruption. The word derives from Greek. Pyro means "fire" and klastos means "broken"; thus pyroclast carries the connotation of "broken by fire".

Pyroclastic Density Current
Flowage phenomena that involve various proportions of hot volcanic gas and fragmented volcanic rocks. PDCs can vary greatly in their density and are usually divided into diluted (i.e., surges) and concentrated PDCs (i.e., pyroclastic flows). See also surge and pyroclastic flow.

Pyroclastic flow
A pyroclastic flow is a dense ground-hugging avalanche of hot ash, pumice, rock fragments, and volcanic gas that rushes down the side of a volcano as fast as hundreds of km/hour. The temperature within a pyroclastic flow may be greater than 500 °C, sufficient to burn and carbonize wood. See also pyroclastic density current.

Q

Quiescent volcano
A volcano, which is not active, but is still registering seismic activity. When there is no more seismicity, the volcano is dormant, but still capable of erupting. See also active, dormant, extinct volcano.

R

Recovery
The restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors.

Resilience
The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

Response
The provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected.

Rest
A volcano is in rest phase when it does not show any sign of activity or geophysical and geochemical anomalies See also unrest, dormant, quiescent.

Rheology
The science that studies the deformation and flow of matter; the ability of a fluid to flow or be deformed.

Risk
A probability or threat of a damage, injury, liability, disaster, loss, or other negative occurrence that is caused by a particular hazard for a given area and reference period and that may be neutralized or reduced through pre-emptive action. Based on mathematical calculations, risk is the product of hazard and vulnerability.

Risk assessment
A methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend.

Risk management
The systematic approach and practice of managing uncertainty to minimize potential harm and loss.

Risk Mitigation
The lessening or limitation of the adverse impacts of hazards and related disasters.

S

Scenario Representation
(quantitative or qualitative) of one or more adverse event during an eruption and of resulting damages on exposures. A scenario may be designed to describe a plausible although hypothetic eruption during the volcanic rest phase or to assess the likely running of a future eruption (unrest phase). In general every scenario usually contain a not negligible uncertainties.

Scoria
General term for a coarsely vesicular rock fragment ejected during an explosive eruption.

Seismogram
Record of the ground motion at a measuring station (the seismograph) as a function of time. Seismograms typically re-

cord motions in three Cartesian axes: x, y, and z, with the z axis perpendicular to the Earth's surface and the x- and y- axes parallel to the surface.

Sensor drift
The slow degradation of sensor properties over a long period of time.

Silicic magma
Term used to describe magma with a high silica content (i.e., >62 wt.% of SiO_2). The high silica content makes the magma more viscous and traps gases, tending to erupt explosively.

Spatial resolution
(remote sensing) the size of the smallest object that can be resolved on the ground. In a digital image acquired by remote sensing sensors, the resolution is limited by the pixel size, i.e. the smallest resolvable object cannot be smaller than the pixel size. Fine details can be seen in a high resolution image while only coarse features can be observed in a low resolution image.

Spectroscopy
The study of the interaction between matter and radiated energy as a function of its wavelength or frequency.

Stratovolcano
Steep, conical volcanoes built by the eruption of lava flows, tephra, and pyroclastic density currents, are called stratovolcanoes. Usually constructed over a period of tens to hundreds of thousands of years, stratovolcanoes may erupt a variety of magma types (i.e., mafic, intermediate and silicic magmas).

Surges
A turbulent, low-density cloud of hot rock debris and gases that moves at extremely high speeds. Because surges are low density, they tend to spread over large areas and jump ridge crests easily. See also pyroclastic density current.

T

Tephra
General term for fragments of volcanic rock, regardless of size, that are blasted into the air by explosive volcanism or carried upward by hot gases in eruption columns or lava fountains

Tomography
Technique for producing an image of a single plane (a slice) of a solid object excluding all other planes. Tomography allows to represent a solid object as a collection of slices.

Tsunami
Tsunami is a Japanese word meaning "harbor wave." A tsunami is a wave or series of waves that are generated in a body of water by a sudden disturbance that displaces water. They are typically caused by earthquakes and landslides in coastal regions. Volcanic eruptions can also caused tsunami in some particular cases.

U

Unrest
Volcanic unrest is indicated by variations in the geophysical and geochemical state of the volcanic system with respect to the normal state of activity (base level). Unrest phase can end with eruption, but not necessarily.

V

Value (at risk)
It measures the total potential losses due to an adverse event in a given area. It can be expressed through different units (human, social, monetary, economic, strategic, environmental)

Vent
Vents are openings in the Earth's crust from which molten rock and volcanic gases escape onto the ground or into the atmosphere. Vents may consist of a single circular-shaped structure, a large elongate fissure and fracture, or a tiny ground crack.

Viscosity
Resistance of a liquid to flow.

Volcanic Block
Solid rock fragment greater than 64 mm in diameter that was ejected from a volcano during an explosive eruption.

Volcanic Explosivity Index
The Volcanic Explosivity Index, or VEI, was proposed in 1982 as a way to describe the relative size or magnitude of explosive volcanic eruptions. It is a 0-to-8 index of increasing explosivity. Each increase in number represents an increase around a factor of ten. The VEI uses several factors to assign a number, including volume of erupted pyroclastic material (for example, ashfall, pyroclastic flows, and other ejecta), height of eruption column, duration in hours, and qualitative descriptive terms.

Volcanic gas
Dissolved gases contained in the magma are released into the atmosphere during volcanic eruptions. Gases may also escape continuously from volcanic vents, fumaroles, and hot springs.

Vulnerability
The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.. Vulnerability varies significantly within a community and over time. There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors.

(This glossary was built basing on: 2009 UNISDR Terminology on Disaster Risk Reduction, Australian Emergency Management Glossary, NOAA Teachers Guide to Stratovolcanoes of the World, USGS glossary of volcanic terms).

LIST OF ACRONYMS AND ABBREVIATIONS

A

ADSL
Asymmetric Digital Subscriber Line

C

CCD
Charged Couple Device

CBDRM
Community-Based Disaster Risk Management

CBDRR
Community-Based Disaster Risk Reduction

CDMA
Code Division Multiple Access

COSPEC
COrrelation SPECtrometer

CTBTO-IMS
Comprehensive Nuclear-Test-Ban Treaty Organization-International Monitoring System

CVGHM
Centre of Volcanology and Geological Hazard Mitigation (Indonesia)

D

DCD
Directorate of Civil Defence

DEM
Digital Elevation Model

DIAL
DIfferential Absorption Lidar

DInSAR
Differential SAR Interferometry

DOAS
Differential Optical Absorption Spectroscopy

DPC
Dipartimento della Protezione Civile

DRR
Disaster Risk Reduction

E

EDM
Electronic Distance Measurement

EO
Earth Observation

F

FGD
Focused Group Discussion

FTIR
Fourier Transform InfraRed (spectroscopy)

FTTH
Fibre To The Home

G

GILDA
Geophysical Instrument for Low power Data Acquisition

GIS
Geographic Information System

GPS
Global Positioning System

GPRS
General Packet Radio Service

GSM
Global System for Mobile Communications

H

HNSP
Host Nation Support Plan

I

INGV
Istituto Nazionale di Geofisica e Vulcanologia (Italy)

INMG
Istituto Nacional de Meteorologia e Geofísica (Cape Verde)

InSAR
SAR Interferometry

IP
Internet Protocol

IR
InfraRed (radiation)

IT
Information Technology

L

LAN
Local Area Network

LEMA
Local Emergency Management Agency

LIDAR
LIght Detection And Ranging

LP
Long Period (earthquake)

N

NGO
Non-Governmental Organizations

NIR
Near Infrared radiation

NRO
National Risk Observatory

O

OGC
Open GIS Consortium

OSOCC
On-Site Operation Coordination Centre

P

PDC
Pyroclastic Density Current

R

RPP
Risk Prevention Plan

S

SAR
Synthetic Aperture Radar

T

TETRA
Terrestrial Trunked Radio

TIR
Thermal Infrared Radiation

U

UMTS
Universal Mobile Telecommunications System

UV
Ultra-Violet (radiation)

V

VEI
Volcanic Explosivity Index

VT
Volcano-Tectonic (earthquake)

LIST OF AUTHORS
ACKNOWLEDGEMENTS

List of authors

Bagni Marco - *KELL srl. Rome, Italy*

Behncke Boris - *Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo. Catania, Italy.*

Berger Jochen - *University of Hohenheim, Institute of Soil. Stuttgart, Germany.*

Boichu Marie - *Institut Pierre Simon Laplace, Laboratoire de Météorologie Dynamique, Ecole Polytechnique, France*

Bignami Christian - *Istituto Nazionale di Geofisica e Vulcanologia, Remote Sensing Group. Rome, Italy*

Bonfils Louis - *Direction Générale de la Sécurité Civile et de la Gestion des Crises, Entente pour la Forêt Méditerranéenne, ECASC - Département Formation, Domaine de Valabre - RD 7 Gardanne, France*

Bosi Vittorio - *Dipartimento della Protezione Civile, Ufficio Rischio Sismico e Vulcanico, Servizio Rischio Vulcanico. Rome, Italy.*

Buongiorno Fabrizia - *Istituto Nazionale di Geofisica e Vulcanologia, Remote Sensing Group. Rome, Italy*

Cadag Jake Rom - *GRED, UMR Gouvernance, Risque, Environnement, Développement. Montpellier, France.*

Cholik Noer - *BPPTK (Balai Penyeledikan dan Pengembangan Teknologi Kegunungapian). Yogyakarta, Indonesia.*

Chouraqui Floriane - *Université Paris 1 Panthéon Sorbonne, CNRS, Laboratoire de Géographie Physique, UMR 8591. Paris, France.*

Costantini Licia - *Dipartimento della Protezione Civile, Ufficio Rischio Sismico e Vulcanico, Servizio Rischio Vulcanico. Rome, Italy.*

De Belizal Edouard - *Université Paris 1 Panthéon Sorbonne, CNRS, Laboratoire de Géographie Physique, UMR 8591. Paris, France.*

Faria Bruno - *Instituto Nacional de Meteorologia e Geofísica. S. Vicente, Cape Verde.*

Fonseca Joao - *Instituto Superior Tecnico. Lisbon, Portugal.*

Fontaine Melanie - *Bureau de Recherches Géologiques et Minières. Orléans, France.*

Gaillard Jean-Christophe - *School of Environment, University of Auckland. Auckland, New Zealand.*

Grancher Delphine - *Université Paris 1 Panthéon Sorbonne, CNRS, Laboratoire de Géographie Physique, UMR 8591. Paris, France.*

Hidayati Sri - *Center of Volcanology and Geological Hazard Mitigation. Bandung, Indonesia.*

Jenkins Susanna - *Cambridge Architectural Research. Cambridge, United Kingdom.*

Jousset Philippe - *Helmholtz Center GFZ, German Research Center for Geoscience, International Centre for Geothermal Research, Germany.*

Emmanuel Kouokam - *MINISTRY OF Industries, Mines and Technological Development (MINMIDT)*

Lavigne Franck - *Université Paris 1 Panthéon Sorbonne, CNRS, Laboratoire de Géographie Physique, UMR 8591. Paris, France.*

Le Cozannet Gonéri - *Bureau de Recherches Géologiques et Minières. Orléans, France.*

Leonardi Marco - *Dipartimento della Protezione Civile, Ufficio Gestione delle Emergenze, Servizio Emergenza Sanitaria e Assistenza alla Popolazione. Rome, Italy.*

Marchetti Emanuele - *Università di Firenze, Dipartimento di Scienze della Terra. Florence, Italy.*

Neri Marco - *Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo. Catania, Italy.*

Oppenheimer Clive - *University of Cambridge, Department of Geography. Cambridge, United Kingdom.*

Orazi Massimo - *Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Vesuviano. Naples, Italy.*

Pannaccione Apa Maria Ilaria - *Istituto Nazionale di Geofisica e Vulcanologia, Remote Sensing Group. Rome, Italy.*

Peluso Rosario - *Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Vesuviano. Naples, Italy.*

Pereira Ricardo Lopes - *INESC-ID. Lisbon, Portugal.*

Picquout Adrien - *Université Paris 1 Panthéon Sorbonne, CNRS, Laboratoire de Géographie Physique, UMR 8591. Paris, France.*

Prata Fred - *Norwegian Institute for Air Research. Oslo, Norway*

Ripepe Maurizio - *Università di Firenze, Dipartimento di Scienze della Terra. Florence, Italy.*

Sayudi Dewi Sri - *BPPTK (Balai Penyeledikan dan Pengembangan Teknologi Kegunungapian). Yogyakarta, Indonesia.*

Silva Fernando - *INESC-ID. Lisbon, Portugal.*

Spence Robin - *Cambridge Architectural Research. Cambridge, United Kingdom.*

Spinetti Claudia - *Istituto Nazionale di Geofisica e Vulcanologia, Remote Sensing Group. Rome, Italy.*

Stahr Karl - *University of Hohenheim, Institute of Soil. Stuttgart, Germany.*

Sumarti Sri - *BPPTK (Balai Penyeledikan dan Pengembangan Teknologi Kegunungapian). Yogyakarta, Indonesia.*

Surono - *Center of Volcanology and Geological Hazard Mitigation. Bandung, Indonesia.*

Texier Pauline - *Université Jean Moulin Lyon 3, Laboratoire Environnement, Ville et Société, UMR 5600. Lyon Cedex, France.*

Thierry Pierre - *Bureau de Recherches Géologiques et Minières. Orléans, France.*

Trinidade Joao - *INESC-ID. Lisbon, Portugal.*

Vaccari Paolo - *Dipartimento della Protezione Civile, Ufficio Relazioni Istituzionali, Servizio Relazioni Internazionali. Rome, Italy.*

Vagner Amélie - *Bureau de Recherches Géologiques et Minières. Orléans, France.*

Vazão Teresa - *INESC-ID. Lisbon, Portugal.*

Wulan Mei Etsuning Tyas - *Université Paris 1 Panthéon Sorbonne, CNRS, Laboratoire de Géographie Physique, UMR 8591. Paris, France.*

Acknowledgements

This handbook has been prepared and published in the frame of the MIAVITA project which was financed by the European Commission under the 7th Framework Programme for Research and Technological Development, Area “Environment”, Activity 6.1 “Climate Change, Pollution and Risks”. In this respect, we thank the EC Project Officer, Denis Peter, for his permanent support and advice during the project. MIAVITA benefited also from financial support by all the project’s partners: Bureau de Recherches Géologiques et Minières (BRGM), Istituto Nazionale di Geofisica e Vulcanologia (INGV), Instituto Superior Tecnico (IST), Centre National de la Recherche Scientifique (CNRS), Norwegian Institute for Air Research (NILU), KELL, Instituto de Engenharia de Sistemas e Computadores Investigação e Desenvolvimento em Lisboa (Inesc-ID), Hohenheim University (UHOH), University of Cambridge (UCAM), Direction Générale de la Sécurité Civile et de la Gestion des Crises (DGSCGC), Dipartimento della Protezione Civile (DPC), Instituto Nacional de Meteorologia e Geofisica (INMG), Ministry of Industries Mines and Technological Development (MINMIDT), Center for Volcanology and Geological Hazard Mitigation (CVGHM), and Philippine Institute of Volcanology and Seismology (PHIVOLCS). The cited authors are only a portion of the people who worked on this handbook, whatever their organization, and we apologise for not including everyone whose work and effort helped to form the foundation of this handbook. They deserve our full recognition for their enthusiasm and expertise. A special acknowledgement goes to Philippe Boullè, Bruce F. Houghton and Susan C. Loughlin who carefully reviewed the text and whose proved to be extremely valuable and helpful.

The MIAVITA project is financed by the European Commission under the 7th Framework Programme for Research and Technological Development, Area "Environment", Activity 6.1 "Climate Change, Pollution and Risks".

List of Beneficiaries

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

MIA VITA