
Volcano Crisis Communication: Challenges and Solutions in the 21st Century

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Abstract

This volume, *Observing the volcano world: volcanic crisis communication*, focuses at the point where the ‘rubber hits the road’, where the world of volcano-related sciences and all its uncertainties meet with the complex and ever-changing dynamics of our society, wherever and whenever this may be. Core to the issues addressed in this book is the idea of how volcanic crisis communication operates in practice and in theory. This chapter provides an overview of the evolution of thinking around the importance of volcanic crisis communication over the last century, bringing together studies on relevant case studies. Frequently, the mechanisms by which volcanic crisis communication occurs are via a number of key tools employed including: risk assessment, probabilistic analysis, early-warning systems, all of which assist in the decision-making procedures; that are compounded by ever-changing societal demands and needs. This chapter outlines some of the key challenges faced in managing responses to volcanic eruptions since the start of the 20th century,

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to explore what has been effective, what lessons have been learnt from key events, and what solutions we can discover. Adopting a holistic approach, this chapter aims to provide a contextual background for the following chapters in the volume that explore many of the elements discussed here in further detail. Finally, we consider the future, as many chapters in this book bring together a wealth of new knowledge that will enable further insights for investigation, experimentation, and development of future volcanic crisis communication.

1 Introduction: The Complexities of Volcanic Crisis Communication

With growing populations in volcanically vulnerable areas, it is likely that in the future more people will be affected by volcanic eruptions, most of whom will be busy with their daily concerns. The challenge today remains how to engage with a vulnerable population so that, when the time is right, appropriate actions are taken to mitigate loss of life and livelihood. If anything, the 21st century presents ever-increasing challenges to this goal. In part, this is demonstrated by the issues of mistrust and poor communication that emerged during the L'Aquila trial of five scientists and two emergency managers. These individuals were accused of making poor judgements on uncertainty that affected their communication to the public, and the risk-management actions the public took in response (Benessia and De Marchi 2017; Alexander 2014; Bretton et al. 2015). Whilst hugely complex, the L'Aquila case highlights the role that science plays within the broader field of crisis communication. As Sir Peter Gluckman, the Chief Science Adviser to the Prime Minister of New Zealand states (2014, p. 4):

Science advice is not generally a matter of dealing with the easy issues that need technical solutions. Rather it is largely sought in dealing with sensitive matters of high public concern and inevitably associated with uncertainty and considerable scientific and political complexity.

Over the last 100 years scientists and various stakeholders have made significant progress in

volcanic crisis communication. In this volume, *volcanic crisis communication* is the term used to encompass all forms of communication during a volcanic crisis: from the communication between monitoring equipment and scientists, to the interpretation and decision-making between scientists and, the communication between differing stakeholders on what actions to take and when, to name a few examples.

Volcano observation began in a structured way at the beginning of the 20th century. The earliest observatories were established in Asama, Japan and Hawaii, USA (Tilling 1989). As observations increased, the role of volcanologists in hazard management and mitigation grew. Progressive crises have imparted lessons to the volcanological community, helping to define different roles in these situations. While this led to great successes, in which volcanologists worked closely with civil-defence authorities, volcanic tragedies have also taken place, requiring reflection on how knowledge was communicated to stakeholders. For example, ineffective communication during the Nevado del Ruiz eruption in Colombia in 1985 resulted in the tragic catastrophe of over 23,000 deaths. This was not because of inadequate scientific knowledge or technology, but rather because local authorities and communities did not act on warnings (Hall 1990; Voight 1990). This was especially surprising as there had been a large effort to educate the population about the risks, and because an alert was issued in time. It is believed that a fundamental lack of understanding of terminology used in education campaigns

led the community of Armero to perceive the risk less significantly. The tragedy highlighted the role of scientists in crisis response, and the need to effectively engage with stakeholders. It is important that all information is presented clearly and with recognition that the audience may not possess the same understanding of jargon that scientists are comfortable with.

Effective volcanic crisis communication is a fundamental component of the concepts of mitigation, disaster management, and disaster risk reduction. As part of this communication process, a number of tools have emerged that are regularly employed in volcanic crises that assist in the structure and formulation of communicative processes. This chapter focuses on four vital lessons learnt from key crisis events. First, advocating the need for resources to develop knowledge surrounding dangerous volcanoes and establishing potential threats via risk assessments. Second, the need to communicate the inherent scientific uncertainties in managing volcanic hazards, which has led to probabilistic analysis playing an ever-increasing role in crisis communication. Third, the value of providing warnings, typically through networks commonly known as early-warning systems. Finally, the intricate role of decision-making, increasingly assisted by various tools such as digital maps, automated messaging and alerting tools, as well as new policies and procedures to communicate data and knowledge. Together these lessons have generated a diverse range of volcanic-crisis communication around the world, shaped largely by the crises experienced to date and by the capabilities of the people and institutions engaged in volcano hazard analysis and warning.

2 Learning from the Past: Key Events that Shaped Crisis Communication

The Nevado del Ruiz disaster prompted a significant paradigm shift within the global volcanological community towards developing a keener understanding of local contexts when issuing volcanic warnings. This event, however,

is not isolated. A number of other volcanic crises over the last 100 years have demonstrated the powerful influence of the social context on a crisis, and the need to continue to investigate crises where science and society come together in a pressured situation (see Table 1). Societal influence can be demonstrated by: the influence of political interference at Mt. Pelée, Martinique, 1902 (Scarth 2002); miscommunication between scientists and the media in Guadeloupe, 1976 (Fiske 1984); interactions between scientists and authorities in Montserrat, in 1995 (Druitt and Kokelaar 2002); differing levels of trust and understanding of the uncertainties and risks involved in volcanic crises (Haynes et al. 2008a, b); the importance of community leaders and past experience with volcanic crises (Andreatuti et al. 2017) and the ability for early warnings to successfully fulfil their purpose (Peterson and Tilling 1993), as key examples.

This volume addresses many key events that have shaped the paradigm of volcanic-crisis communication. Of the events listed in Table 1, three are especially noteworthy, well-studied case histories: La Soufrière (1976), El Chichón (1982), and Merapi (2010); for these, we have prepared detailed summaries from the many pertinent publications (see online supplementary materials). Acting as constant reminders, these events collectively have shaped practices around volcanic crisis communication.

One author of this chapter (Tilling) played a key role in many of these events in his capacity as head of the Volcano Programme at the United States Geological Survey (USGS). In 1989, Tilling identified five specific measures in volcano hazard mitigation to provide short- or long-term mitigation that collectively brings together the components required for effective volcanic management. He explored the relationships between these groups and their required actions in practice by identifying five key areas: (i) identification of high-risk volcanoes; (ii) hazard identification, assessment and zonation; (iii) volcano monitoring and eruption forecasting; (iv) engineering-oriented measures, and (v) volcanic emergency management (Fig. 1). It is important to note that the critical

Table 1 Overview of key events that have shaped volcanic crisis communication

Volcano, country	Date	Event	References
La Grande Soufrière, Guadeloupe	1976	Phreatic eruptions in Guadeloupe led to mass evacuations and very public disagreements between scientists	Fisk (1984), Komorowski et al. (2015)
Mount St. Helens, USA	1980	First successful implementation of volcano alert levels as a warning tool; first use of probabilistic event tree	Lipman and Mullineaux (1982), Newhall and Hoblitt (2002), Newhall and Pallister (2015)
Long Valley Caldera, USA	1980	First caldera unrest at Long Valley resulting in leaked news that eroded trust between the local communities and the scientists	Hill et al. (2017, Chap. “ Volcanic Unrest and Hazard Communication in Long Valley Caldera, California ”)
El Chichón, Mexico	1982	Eruption kills 2000 attributable to lack of monitoring, background information and mixed messages from scientists to military emergency managers	Macías et al. (1997), Espíndola et al. (2002), Tilling (2009)
Nevado del Ruiz, Colombia	1985	Lahars kill 23,000 people. The realisation that science is not enough, it needs to be effectively communicated and understood	Hall (1990), Voight (1990)
Pinatubo, Philippines	1991	Eruption of Pinatubo, daily use of Volcano Early Warning Systems (VEWS) to alert public and trigger evacuations that saved tens of thousands of lives. Use of IAVCEI sponsored video to demonstrate types of hazard, based mainly on films by Maurice and Katia Krafft	Newhall and Punongbayan (1996), Punongbayan et al. (1996), Newhall and Solidum (2017, Chap. “ Volcanic Hazard Communication at Pinatubo from 1991 to 2015 ”)
Galeras, Colombia	1993	Retrospective analysis suggests need for a more robust appraisal of hazards and introduction of Bayesian Belief Networks to aid decision making	Aspinall et al. (2003), Garcia and Mendez-Fajury (2017, Chap. “ If I Understand, I Am Understood: Experiences of Volcanic Risk Communication in Colombia ”)
Rabaul, Papua New Guinea	1994	Demonstrating the capacity for the public to self-evacuate and balancing the communication of uncertainty with safety	McKee et al. (2017, Chap. “ Instrumental Volcano Surveillance and Community Awareness in the Lead-Up to the 1994 Eruptions at Rabaul, Papua New Guinea ”)
Soufriere Hills, Montserrat	1995-present	Communicating uncertainty in long running volcanic crises; use of Science Advisory Committee, Expert Elicitation and links between Volcanic Alert Level System (VALS) and mitigation actions; trust and its influence on risk communication	Aspinall et al. (2002), Haynes et al. (2008a)
Huila, Colombia	2006–2007	Effective communication and use of VEWS and VALS by INGEOMINAS (now SGC) that saves hundreds of lives from lahars	Santacoloma et al. (2011, Pulgarin et al. 2011, 2015), Garcia and Mendez-Fajury (2017, Chap. “ If I Understand, I Am Understood: Experiences of Volcanic Risk Communication in Colombia ”)

(continued)

Table 1 (continued)

Volcano, country	Date	Event	References
Eyjafjallajökull, Iceland	2010	Demonstrating how volcanic ash can affect multiple countries and industries at once	Donovan and Oppenheimer (2012), Bird et al. (2017, Chap. "Crisis Coordination and Communication During the 2010 Eyjafjallajökull Eruption")
Merapi, Indonesia	2010	Preparedness and practice saves thousands despite rapid development of a major crisis	Surono et al. (2012), Mei et al. (2013)
Sinabung and Kelud, Indonesia	2010-present and 2014	Preparedness and differences in communication and culture at newly awakening vs. frequently erupting volcanoes; and the importance of local leaders and community engagement	Andreastuti et al. (2017, Chap. "Integrating Social and Physical Perspectives of Mitigation Policy and Practice in Indonesia")

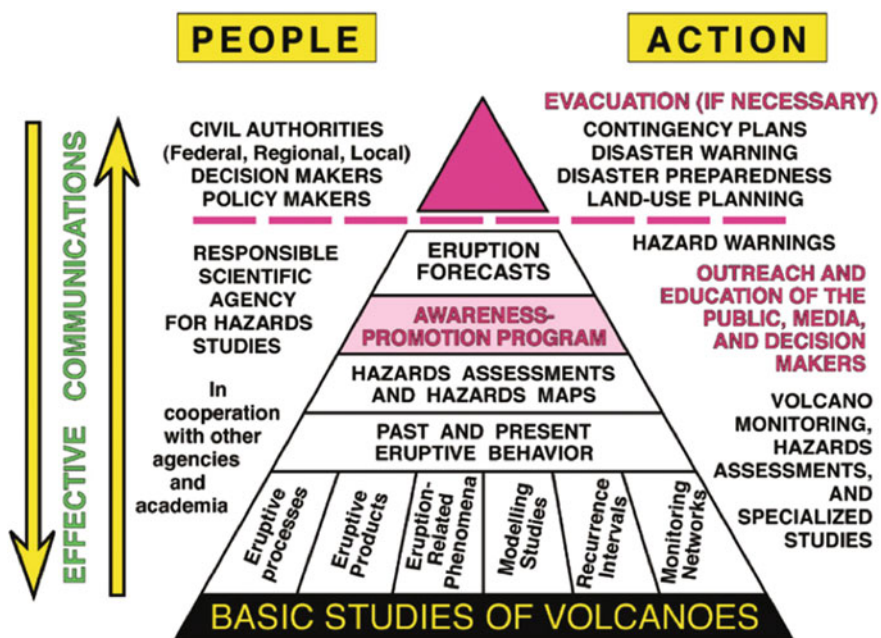


Fig. 1 Schematic diagram of an idealized program to reduce volcanic risk. The apex is separated from the rest of the triangle to emphasize that volcano scientists, while responsible for providing the best possible scientific information and advice, do not typically have knowledge

of other key factors (e.g., socio-economic, cultural, political) and rarely have the authority to make final decisions regarding mitigation measures, including possible evacuation (modified from Tilling 1989, Fig. 1)

role of volcanic emergency management was identified as being undervalued, partly because of the complexities of society. By 1993, Peterson and Tilling demonstrated that volcano warnings were largely hindered by institutional weaknesses in emergency-response procedures

and infrastructures, particularly the poor integration and sharing of critical information, as well as ineffective communications between scientists, decision-makers, and the affected populace. Communications clearly required more focus.

In the 1990s, there was significant focus on the communication of volcanic hazards for the aviation sector following two significant near-disasters and a major eruption that closed multiple airways: the first was the encounter of British Airways Flight 9 that encountered an ash cloud from Galunggung volcano in Java, the second was the near-loss of KLM flight 867 when it encountered the ash cloud of Redoubt volcano in 1989 (Guffanti and Miller 2013); and the eruption of Mount Pinatubo in 1991 that closed airports and airways across a wide region of the western Pacific (Tayag et al. 1996). In response to these crises, previous systems were refined and the schemes that are familiar today, such as the USGS Aviation colour code scheme, were devised (see Fearnley et al. 2012). However, even with variations of these systems now in place there are still questions as to their effectiveness and success globally (Winson et al. 2014; Papale 2017). Another key area of focus was the eruption of Soufriere Hills Volcano in Montserrat, extensively captured within Sparks and Young's memoir (2002). The ongoing eruption enabled significant exploration and experimentation, not just in volcanic monitoring and forecasting, but also in the governance of communication (Haynes et al. 2008a), the use of expert elicitation (Aspinall and Cooke 1998), and in generating maps and warning systems (Haynes et al. 2007). These events have closely shaped organisation and institutional practices within the volcanic and aviation sectors.

The publication 'Professional conduct of scientists during volcanic crises' emanating from the 1999 IAVCEI Subcommittee for Crisis Protocols provides guidance on what procedures and actions to take during a crisis (Newhall 1999). This simple yet powerful checklist is vital in minimizing communication pitfalls and is based on lessons identified by the committee's wealth of experiences during crises. The IAVCEI protocols seem to be standing the test of time, but society is dynamic and poses new challenges. This is particularly true in the context of: an ever-increasing population at risk, increasing pressures for global levels of warning, new forms

of technologies that aid scientific understanding, and communication—most recently via social media.

By the early 2000s, there was extensive focus around the interaction of volcanic events and cultures, wonderfully captured by Grattan and Torrance (2003, 2007). These two volumes explored a wealth of knowledge to better understand how culture is vital to the forms of communication that are fostered during volcanic crises, providing many a lesson learnt to shape future efforts. A surprising element of these books is the lesson that can be learnt from evaluating how early humans and civilisations 'sunk or swam' following volcanic crises.

Continuing the growth in key literature on volcanic crisis communication, in 2008, Barclay et al. (2008) explored the advances in understanding, modelling, and predicting volcanic hazards, and more recent techniques for reducing and mitigating volcanic risk. Providing valuable new insights, the article advocates the role of community-based disaster risk management (CBDRM) to aid effective risk communication. The article concludes with the following (p. 165):

Evidence suggests that the current 'multidisciplinary' approach within physical science needs a broader scope to include sociological knowledge and techniques. Key areas where this approach might be applied are: (1) the understanding of the incentives that make governments and communities act to reduce volcanic risk; (2) improving the communication of volcanic uncertainties in volcanic emergency management and long-term planning and development. To be successful, volcanic risk reduction programmes will need to be placed within the context of other risk-related phenomena (e.g., other natural hazards, climate change) and aim to develop an all-risks reduction culture. We suggest that the greatest potential for achieving these two aims comes from deliberative inclusive processes and geographic information systems.

Areas highlighted specifically for further research included: (1) effectively conveying uncertain information, (2) methods for making decisions in uncertain situations, and (3) methods for dealing with dynamic and changing uncertainty without losing credibility and trust. Since 2008, a majority of research within volcanic crisis

communication has focused on these three areas, and this work forms the foundations for this volume.

In an increasingly globalised world, recent volcanic disasters take on a new level of complexity. Whilst relatively minor loss of life may occur, particular events such as the 2010 Eyjafjallajökull eruption demonstrate the possibilities for significant global economic impacts. With ever increasing challenges to volcanic communities, ever more innovative solutions are needed to enhance crisis communication effectiveness for all sectors of society.

3 Key Solutions

Based on past events, we identify four key solutions to the challenges presented, alongside valuable lessons learnt: (i) assessing the threat; (ii) assessing and communicating uncertainty; (iii) establishing an early warning system; and (iv) developing and integrating decision-making tools.

3.1 Assessing the Threat

Attempts to assess the threat posed by volcanoes, relative to each other, began in the 1980s with three schemes created by: Bailey et al. (1983), Lowenstein and Talai (1984) and Yokoyama et al. (1984). The purpose of these was to identify the volcanoes most likely to generate destructive eruptions specific to the USA (Bailey et al. 1983) and Papua New Guinea (Lowenstein and Talai 1984) and, globally (UNESCO report, Yokoyama et al. (1984)). This would allow for preferential deployment of monitoring equipment for maximum threat mitigation. These three schemes were used as the basis for the U.S. National Volcano Early Warning System (NVEWS) (Ewert et al. 2005, 2007). NVEWS ranked 169 volcanoes in the USA in a combined assessment of 15 hazard and 9 exposure factors to generate a threat score. This scheme notably included a score for the potential exposure of aviation to an eruption of a specific volcano.

Threat scores allow volcanoes to be ranked against each other and thus enable recommendations for varying levels of monitoring (Ewert et al. 2005; Moran et al. 2008). Monitoring efforts are therefore focused on the volcanoes most likely to generate significant risk.

It is important to note that all authors of these types of ranking systems recognize that such comparisons are dependent on the existing quality and quantity of information. If little is known of a volcano, then it is difficult to accurately calculate its threat, except through global comparisons to analogue volcanoes and rapid investigations and monitoring installations during a crisis (i.e., playing “catch up”). For example, the global assessment prepared for UNESCO by Yokoyama et al. (1984) failed to recognize the potential for Pinatubo to produce a large, explosive eruption. This was not an oversight, but rather a reflection of what was known at the time. Less than a decade later, this volcano produced one of the largest recorded eruptions of the century, highlighting the need for vigilance and thorough assessment of any volcanoes near population centres, even if they have appeared dormant for hundreds of years. Although, there was a remarkably successful response that saved an estimated 20,000 lives (Newhall and Punongbayan 1996), it is now widely recognized that playing “catch up” is not the best solution, as it puts the response team in danger and it may not always result in a positive outcome. Consequently, the importance of developing a Volcano Early Warning System (VEWS) well in advance of a crisis, for all high-risk volcanoes, is now widely accepted as best practice. This was one of the major motivations for NVEWS that was first implemented in 2005, and is now used in a number of nations.

3.2 Assessing and Communicating Uncertainty

A principal challenge is that the degree of certainty in forecasting varies widely with time before (Newhall 2000). It is possible to forecast eruptions with relative certainty at an

intermittently active volcano over time scales of centuries, highly uncertain at intermediate time spans of months to a few years, and with greatly improved certainty at short time spans of days to hours. Yet, in spite of these restrictions, forecasts of eruptions have become relatively common. Volcano observatories worldwide issue alert levels, many of which include qualitative statements about the probability of an eruption (e.g., it is “likely”) within certain periods of time (e.g., “within days to weeks”). Repeated lava-dome eruptions were predicted successfully at Mount St. Helens (Swanson et al. 1983) and forecast at Montserrat (Voight et al. 1988) using changes in deformation and seismic rates. Similarly, based mainly on an escalation in seismicity and observations of physical changes at Pinatubo, the USGS-Philippine Institute of Volcanology and Seismology (PHIVOLCS) team estimated a 40% probability on 17 May 1991 for an eruption, 3 weeks before the eruption started. As levels and rates of unrest increased through early June, alert levels were used to warn that an eruption was likely to begin within 2 weeks and then within 24 hours (Punongbayan et al. 1996; Newhall and Pallister 2015). Based on seismic pattern-recognition during precursory activity and associated conceptual models of magma dynamics, successful forecasts have been made at many other volcanoes during the past several decades (McNutt 1996; Chouet 1996; White and McCausland 2016).

A problem with such forecasts, however, is that they typically use descriptive terms such as “likely” to convey the hazard (Doyle et al. 2014). This is a major shortcoming, because without a working understanding and effective communications of probability and uncertainty, emergency managers and the public may not be convinced of the potential hazard and urgency to take timely mitigation measures. In order to make forecasts more quantitative, probabilistic and statistical methods are now increasingly used. Probabilistic eruption forecasting typically utilizes Bayesian statistics, in which the probabilities of subsequent events depend on the outcomes of prior events; i.e., they are path

dependent and increase in magnitude as the path is realized and the volcano progresses toward an event. These methods typically assign initial (a priori) probabilities on the basis of historical statistics and then update them into a posteriori probabilities that are based on interpretation of monitoring data and on the physical and chemical processes that are thought to be controlling the system.

The Bayesian methods may be used in both long-term and short-term forecasting. The most common applications of statistics and uncertainty analyses in short-term eruption forecasting is the Bayesian Event Tree (Newhall and Hoblitt 2002), which considers probabilities and uncertainties of occurrence at each node in a tree-like time series leading to a potential eruption. Monitoring information is often combined with pre-determined patterns or thresholds and with conceptual models pertaining to the dynamics of magmatic systems to forecast outcomes of volcanic unrest. Current practitioners of Bayesian Event Tree (BET) analysis use either the Cooke-Aspinall method (Cooke 1991; Aspinall 2006) or the INGV (National Institute of Geophysics and Volcanology) method (Marzocchi et al. 2004, 2008), although there are other implementations (e.g., Sobradelo et al. 2014; Jolly et al. 2014; Newhall and Pallister 2015). In addition, Bayesian Belief Networks (BBN), another graphic method that does not require the same type of linear time progression as in BET systems, may be used effectively in some situations (e.g., Lindsay et al. 2010; Hincks et al. 2014; Aspinall and Woo 2014). All of these methods integrate some form of elicitation of opinions from a team of experts to assign probabilities and uncertainties based on monitoring data, past eruptive behaviour and conceptual models. They vary with respect to whether monitoring thresholds are defined in advance for the volcano in question and in how uncertainties are established. In comparison, the USGS/Volcano Disaster Assistance Programme (VDAP) team (Newhall and Pallister 2015) uses group discussion and consensus to assign nodal probabilities. In the INGV method, probability distributions are established for each node in the event tree

(Marzocchi et al. 2008). In this procedure, the parameters, weights, and thresholds are established through expert opinions, updated using data of past eruptions, and uncertainty is expressed as a probability density function for each node in the tree (Marzocchi and Bebbington 2012).

A daunting challenge for scientists who use any of these methods is to effectively communicate the results to emergency managers and the public; groups who are rarely well versed in statistics. A well-designed VEWS should utilize everyday terminology that is well-known to the population at risk, and be explicitly linked to any assigned numerical probabilities. For example, the USGS/VDAP team generally translates probabilities in terms of odds and rounds to the nearest 10%; e.g., “1 out of 3” or “9 out of 10” and terms such as “unlikely” are defined as <10%, “moderately likely” as 10–70% and “highly likely” as >70%.

3.3 Establishing an Early Warning System

Early-warning systems (EWS) are employed globally for a range of rapid onset hazards. The United Nations International Strategy for Disaster Reduction (UNISDR) recognises EWS as a core component of disaster risk reduction (DRR) measures both in the Hyogo Framework (2005) and the Sendai Framework for Disaster Risk Reduction (2015), stipulating the need to ‘substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030’ (UN ISDR 2015 p. 12). EWS can be defined as ‘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’ (UNISDR 2009, p. 12). This approach is comprised of four key sections: risk knowledge, monitoring and warning service, dissemination and communication, and response capacity (UNISDR PPEW 2006). This definition moves

away from a traditional approach to EWS, as merely technical warnings through a siren or other simple warning method.

According to Leonard et al. (2008), VEWS are composed of five key components (Fig. 2): the early warning system itself, planning, co-operation, education and participation, and exercises. It is widely accepted that VEWS are part of a broader framework of DRR measures including: scientific knowledge and limitation, education, technology capabilities, and policy. EWS are arguably the process by which many DRR measures are implemented, often within a broader mitigation strategy.

The process of developing a VEWS requires cooperation and communication not only across different cultures, but also different languages and political regimes. Garcia and Fearnley (2012) highlight that, whilst an EWS may have four key components as outlined by the UNISDR, it is often the links between these categories that are the focus of systemic failure. With multi-national volcanic events or hazards, these links are likely to be highly stressed. Whilst there are excellent studies on EWS (e.g., Mileti and Sorenson 1990; Kuppens and Zschau 2002; Basher 2006; Golnaraghi 2012), few look beyond the individual case study to focus on more international scale implications of a hazard event (Fig. 2).

It is possible to establish some of the complexities that VEWS have to deal with by applying the concept of classification of mitigation strategies to VEWS (Day and Fearnley 2015). This depends on how the VEWS has been designed. Responsive mitigation strategies prescribe actions after a hazard-source event has occurred, such as evacuations to avoid lahars, which require capacities to detect and quantify the hazard and to transmit warnings fast enough to enable at risk populations to decide and act effectively. Permanent mitigation strategies prescribe actions such as construction of SABO dams or land use restrictions: they are frequently both costly and “brittle” in that the actions work up to a design limit of hazard intensity or magnitude and then fail. Permanent warning systems exist on volcanoes, whereby a warning is

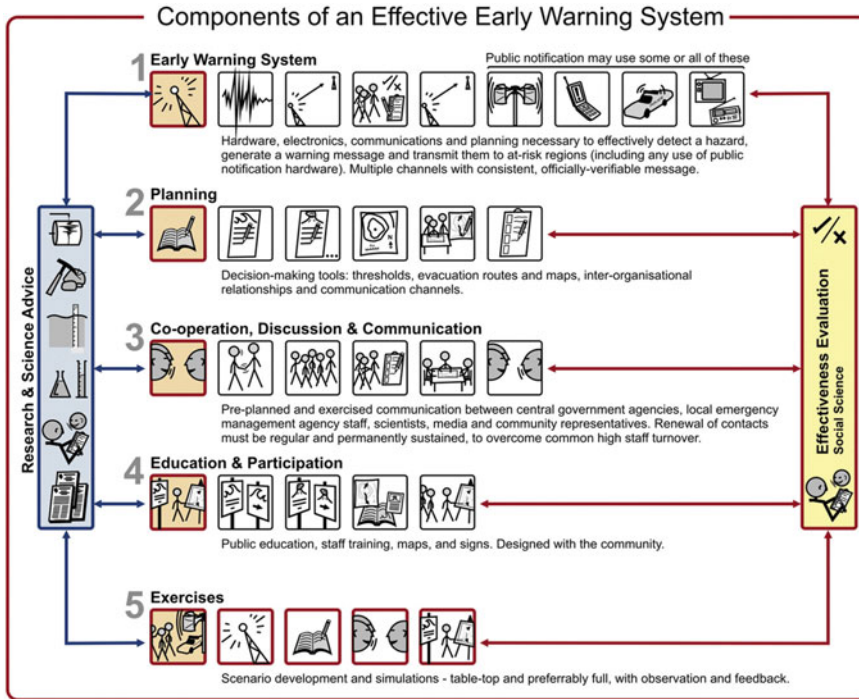


Fig. 2 Effective early-warning systems model with permission from Leonard et al. (2008, p. 204)

triggered, for example, by an automated lahar warning system. Anticipatory mitigation strategies, used in the mitigation of volcanic hazards more than for any other type of hazard, prescribe use of the interpretation of precursors to hazard source events as a basis for precautionary actions. However, challenges arise from uncertainties in hazard behaviour and in the interpretation of precursory signals. For example, evacuating vulnerable populations who live in areas susceptible to pyroclastic density currents prior to the onset of an eruption, pose hard questions about whether an early warning is based on forecasts, or on current activity and observations only, as well as our dependency on technology and statistical methods to make potentially life and death decisions.

Many countries operate so that their early warnings are based only and exclusively on scientific data and probabilistic forecasts. Other countries explicitly consider the social risks involved, alongside the scientific data and forecasts. There is potential for skewing of alert level

assignment, intentionally or unintentionally, when there is prior-knowledge of the risks involved, and when scientists rely upon non-probabilistic decision making (Fearnley 2013). Papale (2017) presents an argument that warnings may be flawed by implicit vested interests, and he recommends that observatories should rely on pre-established thresholds and communication of scientifically based probabilistic forecasts for hazard communication. Dependant on the context, differing approaches may be taken in either adopting a top-down (government led initiative) or bottom-up approach (driven by community based approaches).

What remains a challenge is to define whether a VEWS has been successful or not; this also depends on how success is measured. Paton et al. (1998) state that effectiveness of an integrated response can be constrained by communication and coordination across stakeholders, training experience, and organisational capabilities. It is imperative that all warning communication has one consistent message, with no contradiction to

cause confusion. This is essential to establish trust between the public and other users that the information is correct (Mileti and Sorenson 1990). Further challenges can arise from the accumulation of multiple disasters, e.g., the impact of Typhoon Yunya in the Philippines during the 1991 Pinatubo eruption significantly exacerbated lahars, ashfall distribution and loading (Newhall and Punongbayan 1996). It is also challenging to determine the cost benefit of a VEWS prior to the impact of the event and as a result, many disregard the value of the system, particularly for events with a long-return frequency.

Science is a necessary evidence base for making decisions and has become a key component in EWS or Incident Command Systems (ICS). In some cases, EWS have become 'hazard-focused, linear, top-down, expert-driven systems, with little or no engagement of end-users or their representatives' (Basher 2006, p. 2712). However, there are many examples where major efforts are being made to engage with end users via community outreach and educational activities such as PHIVOLCS (Philippine Institute of Volcanology and Seismology), the USGS, and CVGHM (Center for Volcanology and Geological Hazard Mitigation). Typically, government institutions that manage potential disasters use simple prescriptive policy. Within this they recognise that decision-making is more complex and that local practitioners and vulnerable populations are increasingly managing disasters relevant to them using community-based warning and emergency response systems (UN ISDR PPEW 2006). Such community-based warning and response systems are based upon local capabilities and technologies where communities can have ownership, generating a bottom-up approach. Although initially considered a radical approach when introduced by Hewitt (1983), community-based early warning and response systems have gained momentum and have been proven effective and empowering during crises (Andreastuti et al. 2017). Subsequently it is suggested by the UN ISDR PPEW (2006) that these community-based approaches

develop people-centric early warning and emergency response systems.

3.4 Decision-Making Tools

The way that people perceive information that has been communicated to them is vitally important, as it will shape how they frame problems and make decisions. There is significant progress in the role of various tools to assist in applying new knowledge making use of communicative products such as: map making, messages in preparedness products, infograms, and the simple verbal conveyance of crisis communication. Equally there are numerous new challenges and benefits to effective communication. For example there may be too little monitoring data, which increases the uncertainties in forecasts. In a few select cases where there are many different types of monitoring methods available, it may be difficult for scientists to synthesise all the information into a forecast in a timely manner. This suggests that there are optimal levels of monitoring and/or procedures for timely data processing and interpretation if the aim is to forecast future activity. Equally, the expansion of social media has opened lines of communication both to and from volcano observatories in new transparent and engaging ways, as seen via Twitter feeds, new citizen science apps, and community based monitoring (e.g., Stone et al. 2014), and in the sharing of knowledge. However, it also has placed pressure on the credibility of information, raising the risk of false data and interpretations that require careful management, and new levels of trust and engagement that must be built between the volcano observatories and the publics.

Maps are increasingly being used as a tool in conveying uncertainty, risk, and warnings. Volcano hazard maps are widely used to graphically portray the nature and extent of hazards and vulnerabilities and, in a few cases, the societal risk. Such maps may also be used to designate prohibited, restricted entry, or warning zones. They vary widely in style and content from nation to

nation, and from volcano to volcano. In the most basic form, a volcano hazard map consists of hazard zones based on the underlying geology and history of past eruptions to define the extent of past flows and tephra falls. More sophisticated hazard maps utilize detailed geologic mapping and modelling of potential flow paths, often using Digital Elevation Models (DEMs) and statistical or numerical models that simulate flows of varying volume and duration. Some new approaches use automatic GIS-based systems that incorporate numerical model results and display the results in a GIS format (Felpeto et al. 2007) or that display the results of spatial probability for potential vent locations and flow inundation (Bevilacqua et al. 2015; Neri et al. 2015). These automated methods provide the capability to quickly modify the hazard map during a rapidly developing crisis. In addition, a new generation of numerical models have enabled near-real-time probabilistic forecast maps of ash cloud and ash fall hazards (Schwaiger et al. 2012 and references therein). Regardless of their degree of sophistication, hazard maps are a fundamental means to convey the spatial distribution of danger zones to emergency managers and the public. Although not everyone can effectively read a topographic map, shaded relief and 3D oblique projections using DEMs provide more effective means to communicate map information (Newhall 2000; Haynes et al. 2007).

To date there has been little evaluation of the influence of institutional organisation and the flow of information between different actors in a crisis when deciding what to do with the 'threat'. Fearnley (2013) investigated the role of decision-making in the USGS when assigning a volcano alert level, which established that informal communication is essential to enable key user groups to determine the extent of risk and likelihood of events. This was commonly achieved via face-to-face meetings, workshops and exercises, and telephone conversations, alongside web resources. Interactions are conducted in a multi-directional manner as various stakeholders may discuss relevant issues, moving away from typical one or two-way communication models. Evidence suggested that the ability to develop dialogue enabled key decision-makers

to gauge the volcano's behaviour and forecast in terms relevant to their own geographical, and temporal relations to the hazard. Today, observatories have developed a number of institutional communication tools, whether they are simply telephone calls or meetings that enable dialogue, or a one-way tool of information from the observatory via standardised messages targeted to specific users, such as the Volcano Activity Notice (VAN) or Volcano Observatory Notice for Aviation (VONA). Information can be communicated via daily, weekly, or monthly formal updates, status or information reports, or via Tweets, social networking, and the Smithsonian Weekly Updates. With so many options available it is up to the observatory and their stakeholders to establish what tools best serve their purpose.

In addition, during times of crisis, most observatories also participate in National Incident Command systems, or other similar civil protection procedures. For example, the USGS volcano observatories contribute scientific information to the National Incident Management System (NIMS), which was developed over many decades in response to inter-agency responses to wildfires, and is now used for all types of crises and disasters. The fundamental element of NIMS is the Incident Command System (ICS) system, which is used to structure and organize responses by federal, state and local agencies with responsibility for responding to natural as well as man-made crises and disasters. Figure 3 shows how the USGS contributes to the ICS system during volcanic crises. For example, in a disaster response, USGS scientists serve as technical advisors in the Planning Section to provide information about hazards (e.g., forecasts regarding eruptive activity, information about areas likely to be affected, extent and duration of impacts, etc.). They may also have a role in the Operations Section (e.g., in helping coordinate aviation operations). During an ICS response, a Joint Information Center (JIC) and a Joint Operations Center (JOC) are established. Through the JIC, press briefings and other media events are planned and conducted (Dreidger et al. 2004). The JIC and JOC are places where representatives of all involved agencies meet to coordinate information and crisis operations.

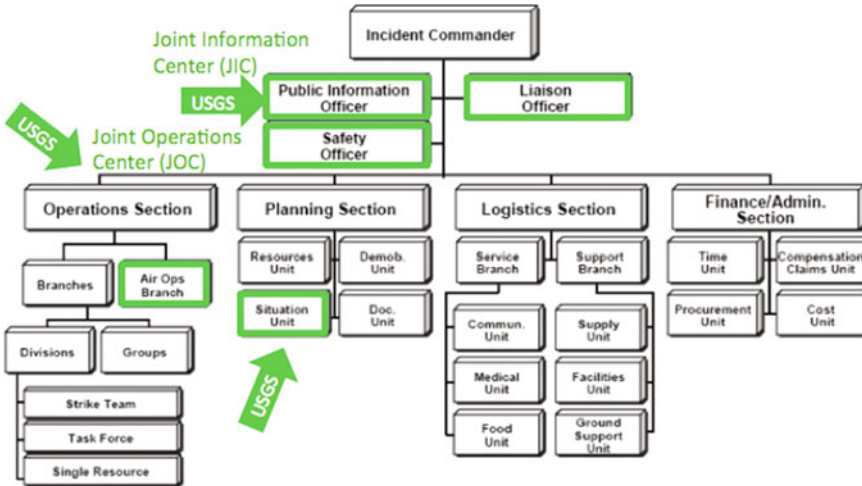


Fig. 3 USGS Volcano Observatories play a role as technical advisors in the U.S. Incident Command System (ICS). This is typically led by emergency-management

agencies. Coordinates response and communication among multiple agencies and jurisdictions. (Source USGS)

4 Where Are We Now and What Are the New Challenges?

The above solutions are four of many that exist but are those of greatest focus currently within the field. This volume have been specifically crafted to build on prior research in the field and case studies from over the last 100 years (and sometimes beyond), to show how multidisciplinary approaches can be used to successfully manage a volcanic crisis, and that core to this are the communication processes. It is the intention to enable the next stage of understanding of volcanic crisis management in the 2020s to help navigate strong, easy, and effective communication. To do this, the book has three parts focusing on various lessons surrounding volcanic crisis communication.

First, it is well established that due to the longevity of hazards and the uncertainties in lead-time, and because of their numerous primary and secondary hazards, volcanoes pose a particular challenge. Some may argue volcanologists make too much of this distinction of volcanic crises being ‘different’ from other hazards and that in terms of the complexities of societal impacts and recovery, they are similar to earthquakes, hurricanes, tsunami and flooding,

etc. However, it is the very challenge of providing warnings with great uncertainties that makes volcanoes one of the most complex phenomena to manage and communicate. Volcanic hazards vary in location, scale and duration as explored independently in Part 1 of the volume. Hazards range from: volcanic bombs within close proximity of a vent (Fitzgerald et al. 2017, Chapter “[The Communication and Risk Management of Volcanic Ballistic Hazards](#)”), to pyroclastic flows whose impacts can also be proximal (Lavigne et al. 2017, Chapter “[Mapping Hazard Zones, Rapid Warning Communication and Understanding Communities: Primary Ways to Mitigate Pyroclastic Flow Hazard](#)”), lahars that can travel extensive distances often into non-volcanic terrain (Becker et al. 2017, Chapter “[Organisational Response to the 2007 Ruapehu Crater Lake Dam-Break Lahar in New Zealand: Use of Communication in Creating an Effective Response](#)”), volcanic gas hazards (Edmonds et al. 2017, Chapter “[Volcanic Gases: Silent Killers](#)”) that can influence global climates (Donovan and Oppenheimer 2017, Chapter “[Imagining the Unimaginable: Communicating Extreme Volcanic Risk](#)”), and volcanic ash that can affect aviation (Lechner et al. 2017, Chapter

“Volcanic Ash and Aviation—The Challenges of Real-Time, Global Communication of a Natural Hazard”) as well as local populations (Stewart et al. 2017, Chapter “Communication Demands of Volcanic Ashfall Events”). Volcanic hazards often evolve over time, becoming more or less intense, or changing in character e.g., from Plinian to Hawaiian style eruptions. It is this diverse nature that poses significant challenges to the idea of creating a single VEWS to communicate unrest and danger. In fact, there are numerous VEWS in place for volcanoes globally; many tailored for the specific hazard of a particular volcano, e.g., hydrothermal activity at Yellowstone (Erfurt-Cooper 2017, Chapter “Active Hydrothermal Features as Tourist Attractions”), or lahars on Mt Ruapehu (Becker et al. 2017, Chapter “Organisational Response to the 2007 Ruapehu Crater Lake Dam-Break Lahar in New Zealand: Use of Communication in Creating an Effective Response”). Part 1 explores the specific nuances each hazard presents to developing effective volcanic crisis communication, for specific or for a combination of hazards that may occur during a crisis.

In Part 2, the chapters discuss some of the key challenges involved in developing communication procedures and tools, and how these processes have evolved through the development of volcano observatories during the last 100 years. This is done by sharing and analysing some key lessons identified/learnt and best practices to improve the development and implementations of crisis communication following a chronological order (some are highlighted in Table 1). In essence, we are asking how can we move forward and develop more robust and effective early warning and, volcanic hazard, and risk communication. Using a range of international examples, Part 2 considers: small island states (Komorowski et al. 2017, Chapter “Challenges of Volcanic Crises on Small Islands States”), politically contested areas including Mt Cameroon (Marmol et al. 2017, Chapter “Investigating the management of geological hazards and risks in the Mt Cameroon area using Focus Group Discussions”; Miles et al. 2017, Chapter

“Blaming Active Volcanoes or Active Volcanic Blame? Volcanic Crisis Communication and Blame Management in the Cameroon”), challenges of institutional and culturally different approaches to communicating during crises in the Canaries and Italy (Solana et al. 2017, Chapter “Supporting the Development of Procedures for Communications During Volcanic Emergencies: Lessons Learnt from the Canary Islands (Spain) and Etna and Stromboli (Italy)”), extensive work to protect the millions of people that live under the shadow of Popocatepetl (De la Cruz-Reyna et al. 2017, Chapter “Challenges in Responding to a Sustained, Continuing Volcanic Crisis: The Case of Popocatepetl Volcano, Mexico, 1994-Present”), and, challenges of representing those living by a volcano as seen at Colima in Mexico (Cuevas-Muñiz and Gavilanes-Ruiz 2017, Chapter “Social Representation of Human Resettlement Associated with Risk from Volcán de Colima, Mexico”) and at Eyjafjallajökull in Iceland (Bird et al. 2017, Chapter “Crisis Coordination and Communication During the 2010 Eyjafjallajökull Eruption”). There are old stories told with fresh eyes, old stories told for the first time, and some new stories that require humility to learn from.

Part 3 examines the numerous ways in which we communicate, not just across the science-society divide, but also across different disciplines including: religion (Chester et al. 2017, Chapter “Communicating Information on Eruptions and Their Impacts from the Earliest Times Until the Late Twentieth Century”), history and politics (Pyle 2017, Chapter “What Can We Learn from Records of Past Eruptions to Better Prepare for the Future?”). However we choose to communicate, whether via: oral histories (Procter et al. 2017, Chapter “Reflections from an Indigenous Community on Volcanic Event Management, Communications and Resilience”), social media (Sennert et al. 2017, Chapter “Role of Social Media and Networking in Volcanic Crises and Communication”), by drawing maps (Thompson et al. 2017, Chapter “More Than Meets the Eye: Volcanic Hazard Map Design and Visual Communication”), using

satellite data (Webley and Watson 2017, Chapter “The role of geospatial technologies in communicating a more effective hazard assessment: application of GIS tools and remote sensing data”); is vital is to be effective. To achieve this several tools can be adopted: education from children to adults (Kitagawa 2017, Chapter “Living with an Active Volcano: Informal and Community Learning for Preparedness in South of Japan”; Sharpe 2017, Chapter “Learning to be practical: A guided learning approach to transform student community resilience when faced with natural hazard threats”), developing tools such as role-play to enhance the learning process (Dohoney et al. 2017, Chapter “Using Role-Play to Improve Students’ Confidence and Perceptions of Communication in a Simulated Volcanic Crisis”), to practicing evacuation scenarios with emergency managers and communities (Hudson-Doyle 2017, Chapter “Decision-making: preventing miscommunication and creating sharing meaning between stakeholders”). Awareness of the challenges of communicating across cultures is also of great importance. Miscommunication is a frequent issue and there is a need to understand the psychological elements of decision-making and risk perception given these different cultural reference frames (Wilmshurst 2017, Chapter “There is no plastic in our volcano: A story about losing and finding a path to participatory volcanic risk management in Colombia”). Participatory methods have been highly successful to foster the participation of local communities (Cadag et al. 2017, Chapter “Participatory approaches to foster the participation of local communities in volcanic disaster risk reduction”), but there is often a need to find ways to bridge cultural differences between the scientists and end-users, often worlds apart (Newhall 2017, Chapter “Cultural Differences and the Importance of Trust Between Volcanologists and Partners in Volcanic Risk Mitigation”), or between the science and arts to explore differing understandings around volcanoes (Dixon and Beech 2017,

Chapter “Re-enchanting Volcanoes: The Rise, Fall, and Rise Again of Art and Aesthetics in the Making of Volcanic Knowledges”). Mistakes in managing these numerous complexities can restrict the maintenance of trust between the various stakeholders involved. We can negotiate these difficult interactions by developing tools to reduce the uncertainties and help decision making processes. Such tools include: statistical and probabilistic tools (Sobradelo and Marti 2017, Chapter “Using Statistics to Quantify and Communicate Uncertainty During Volcanic Crises”), establishing a robust EWS (Potter et al. 2017, Chapter “Challenges and Benefits of Standardising Early Warning Systems: A Case Study of New Zealand’s Volcanic Alert Level System”), and using insurance to offset the risks (Blong et al. 2017, Chapter “Insurance and a Volcanic Crisis—A Tale of One (Big) Eruption, Two Insurers, and Innumerable Insureds”). Core to the communication process is the ability to make decisions about what to do, when to do it, and who is affected, what can be done, what resources need to be made available to support these decisions. An exemplary set up is the co-ordination between the USA, Japan, and Russia in managing airbourne ash hazards for aviation (Igarashi et al. 2017, Chapter “International Coordination in Managing Airborne Ash Hazards: Lessons from the Northern Pacific”) where these three nations, at times politically and economically constrained, have managed to foster meaningful and successful coordination.

What all these chapters have in common, is that they demonstrate the value of communication and the open and timely sharing of knowledge, so finding a way to generate meaningful understanding; the need to keep both relationships and procedures strong and current; and the ability to cope with rapid changes in both society and volcanic activity. There have been many lessons learnt and many new tools are available to both volcanologists, emergency management practitioners, and the public; no doubt the future will present us with

new challenges to overcome. The ability to adapt and evolve before, during and after a crisis is of utmost importance and this can only happen through open, honest and robust communication. This sounds simple and this volume provides evidence that simplicity and clarity are often key to successful outcomes in volcanic crisis.

References

- Alexander DE (2014) Communicating earthquake risk to the public: the trial of the L'Aquila Seven. *Nat Hazards* 72(2):1159–1173. doi:10.1007/s11069-014-1062-2
- Andreastuti S, Paripurno ET, Gunawan H, Budianto A, Syahbana D, Pallister J (2017) Character of community response to volcanic crises at Sinabung and Kelud volcanoes. *J Volcanol Geoth Res* (in press)
- Aspinall WP (2006) Structured elicitation of expert judgement for probabilistic hazard and risk assessment in volcanic eruptions. In: Mader HM, Coles SG, Connor CB, Connor LJ (eds) *Statistics in volcanology*. IAVCEI Publications, ISBN 978–1-86239-208-3, pp 15–30
- Aspinall W, Cooke RM (1998) Expert judgement and the Montserrat volcano eruption. In: *Proceedings of the 4th international conference on probabilistic safety assessment and management PSAM4* (vol 3, pp 13–18)
- Aspinall WP, Woo G (2014) Santorini unrest 2011–2012: an immediate Bayesian belief network analysis of eruption scenario probabilities for urgent decision support under uncertainty. *J Appl Volcanol* 3(1):12. doi:10.1186/s13617-014-0012-8
- Aspinall WP, Loughlin SC, Michael FV, Miller AD, Norton GE, Rowley KC, Sparks RSJ, Young SR (2002) The montserrat volcano observatory: its evolution, organization, role and activities. *Geol Soc, Lond, Mem* 21:71–91
- Aspinall WP, Woo G, Voight B, Baxter PJ (2003) Evidence-based volcanology: application to eruption crises. *J Volcanol Geoth Res* 128:273–285. doi:10.1016/S0377-0273(03)00260-9
- Bailey RA, Beauchemin PR, Kapinos FP, Klick DW (1983) The volcano hazards program; objectives and long-range plans (No. 83–400). US Geological Survey
- Barclay J, Haynes K, Mitchell T, Solana C, Teeuw R, Darnell A, Crowweller HS, Cole P Pyle D, Lowe C, and Fearnley C (2008) Framing volcanic risk communication within disaster risk reduction: finding ways for the social and physical sciences to work together, vol 305, Geological Society Special Publication, pp 163–177
- Basher R (2006) Global early warning systems for natural hazards: systematic and people-centred. *Philos Trans R Soc* 364:2167–2182
- Benessia A, De Marchi B (2017) When the earth shakes... and science with it. The management and communication of uncertainty in the L'Aquila earthquake. *Futures*
- Bevilacqua A, Isaia R, Neri A, Vitale S, Aspinall WP, Bisson M, Flandoli F, Baxter P, Bertagnini A, Ongaro TE, Iannuzzi E, Pistolesi M, Rosi M (2015) Quantifying volcanic hazard at Campi Flegrei caldera (Italy) with uncertainty assessment: I. Vent opening maps. *J Geophys Res* 120. doi:10.1002/2014JB011775
- Bretton RJ, Gottsmann J, Aspinall WP, Christie R (2015) Implications of legal scrutiny processes (including the L'Aquila trial and other recent court cases) for future volcanic risk governance. *J Appl Volcanol* 4(1):18. doi:10.1186/s13617-015-0034-x
- Chouet BA (1996) Long-period volcano seismicity: its source and use in eruption forecasting. *Nature* 380:309–316
- Cooke RM (1991) *Experts in uncertainty: opinion and subjective probability in science*. Oxford University Press, New York
- Day S, Fearnley C (2015) A classification of mitigation strategies for natural hazards: implications for the understanding of interactions between mitigation strategies. *Nat Hazards* 79(2):1219–1238. doi:10.1007/s11069-015-1899-z
- Donovan A, and Oppenheimer C (2012) Governing the lithosphere: insights from Eyjafjallajökull concerning the role of scientists in supporting decision-making on active volcanoes. *J Geophys Res: Solid Earth* 117 (B3). doi:10.1029/2011JB009080
- Doyle EEH, McClure J, Johnston DM, Paton D (2014) Communicating likelihoods and probabilities in forecasts of volcanic eruptions. *J Volcanol Geoth Res* 272:1–15. doi:10.1016/j.jvolgeores.2013.12.006
- Driedger CL, Neal CA, Knappenberger TH, Needham DH, Harper RB, Steele WP (2004) Hazard information management during the autumn 2004 reawakening of Mount St. Helens Volcano, Washington. *A Volcano Rekindled: the renewed eruption of Mount St. Helens, 2006*, 505–519
- Druitt TH and Kokelaar BP (eds) (2002) *The eruption of Soufrière Hills volcano, Montserrat, from 1995 to 1999*. Geological Society of London
- Espíndola JM, Macías JL, Godínez L, Jiménez Z (2002) La erupción de 1982 del Volcán Chichónal, Chiapas, México. In: Lugo HJ, Inbar M (eds), *Desastres naturales en América Latina: Mexico, DF, Fondo de Cultura Económica*, pp 37–65
- Ewert JW (2007) System for ranking relative threats of US volcanoes. *Nat Hazards Rev* 8(4):112–124
- Ewert JW, Guffanti M, and Murray TL (2005) An assessment of volcanic threat and monitoring capabilities in the United States: framework for a National volcano early warning system (No. 2005–1164)
- Fearnley CJ (2013) Assigning a volcano alert level: negotiating uncertainty, risk, and complexity in decision-making processes. *Environ Plann a* 45 (8):1891–1911. doi:10.1068/a4542

- Fearnley CJ, McGuire WJ, Davies G, Twigg J (2012) Standardisation of the USGS Volcano Alert Level System (VALS): analysis and ramifications. *Bull Volcanol* 74(9):2023–2036. doi:10.1007/s00445-012-0645-6
- Felpeo A, Marti J, Ortiz R (2007) Automatic GIS-based system for volcanic hazard assessment. *J Volcanol Geoth Res* 166:106–116. doi:10.1016/j.jvolgeores.2007.07.008
- Fiske RS (eds) (1984) *Volcanologists, journalists, and the concerned local public: a tale of two crises in the eastern Caribbean*, National Research Council, Geophysics Study Committee, Explosive Volcanism, National Academy Press, Washington, DC, pp 110–121
- Garcia C, Fearnley CJ (2012) Evaluating critical links in early warning systems for natural hazards. *Environ Hazards* 11(2):123–137. doi:10.1080/17477891.2011.609877
- Gluckman P (2014) Evidence based policy: A quixotic challenge? Address given at the invitation of the science policy research unit. Brighton, UK: University of Sussex [January 21st, 2014; See http://www.pmcsa.org.nz/wp-content/uploads/Sussex_Jan-21_2014_Evidence-in-Policy_SPRU.pdf(Accessed 01 May 2016)]
- Golnaraghi M (ed) (2012) *Institutional partnerships in multi-hazard early warning systems: a compilation of seven national good practices and guiding principles*. Springer Science and Business Media
- Grattan J, Torrence R (2003) *Natural disasters and cultural change*. Routledge
- Grattan J, Torrence R (eds) (2007) *Living under the shadow: cultural impacts of volcanic eruptions*. Routledge
- Guffanti M, Miller TP (2013) A volcanic activity alert-level system for aviation: review of its development and application in Alaska. *Nat Hazards* 69(3):1519–1533. doi:10.1007/s11069-013-0761-4
- Hall ML (1990) Chronology of the principal scientific and governmental actions leading up to the November 13, 1985 eruption of Nevado-del-Ruiz, Colombia. *J Volcanol Geoth Res* 42:101–115. doi:10.1016/0377-0273(90)90072-N
- Haynes K, Barclay J, Pidgeon N (2007) Volcanic hazard communication using maps: an evaluation of their effectiveness. *Bull Volcanol* 70:123–138. doi:10.1007/s00445-007-0124-7
- Haynes K, Barclay J, Pidgeon N (2008a) The issue of trust and its influence on risk communication during a volcanic crisis. *Bull Volcanol* 70:605–621. doi:10.1007/s00445-007-0156-z
- Haynes K, Barclay J, Pidgeon N (2008b) Whose reality counts? Factors affecting the perception of volcanic risk. *J Volcanol Geoth Res* 172(3):259–272. doi:10.1016/j.jvolgeores.2007.12.012
- Hewitt K (1983) *Interpretations of calamity from the viewpoint of human ecology*. Allen and Unwin, Boston, p 304
- Hincks TK, Komorowski JC, Sparks SR, Aspinall WP (2014) Retrospective analysis of uncertain eruption precursors at La Soufrière volcano, Guadeloupe, 1975–77: volcanic hazard assessment using a bayesian belief network approach. *J Appl Volcanol* 3(1):3. doi:10.1186/2191-5040-3-3
- Jolly GE, Keys HJR, Procter JN, Deligne NI (2014) Overview of the co-ordinated risk-based approach to science and management response and recovery for the 2012 eruptions of Tongariro volcano, New Zealand. *J Volcanol Geoth Res* 286:184–207. doi:10.1016/j.jvolgeores.2014.08.028
- Komorowski JC, Hincks T, Sparks RSJ, Aspinall W, The CASAVA ANR Project Consortium (2015) Improving crisis decision-making at times of uncertain volcanic unrest (Guadeloupe, 1976). In: Loughlin SC, Sparks RSJ, Brown SK, Jenkins SF, Vye-Brown C (eds) *Global volcanic hazards and risk*. Cambridge University Press, pp 255–261
- Kuppens AN, Zschau J (2002) *Early warning systems for natural disaster reduction*. Springer, Berlin
- Leonard GS, Johnston DM, Paton D, Christianson A, Becker J, Keys H (2008) Developing effective warning systems: ongoing research at Ruapehu volcano, New Zealand. *J Volcanol Geoth Res* 172:199–215. doi:10.1016/j.jvolgeores.2007.12.008
- Lindsay J, Marzocchi W, Jolly G, Constantinescu R, Selva J, Sandri L (2010) Towards real-time eruption forecasting in the Auckland Volcanic Field: application of BET_EF during the New Zealand National Disaster Exercise ‘Ruaumoko’. *Bull Volcanol* 72(2):185–204. doi:10.1007/s00445-009-0311-9
- Lipman PW, Mullineaux DR (1982) *The 1980 eruptions of Mount St. Helens, Washington*. Geological survey professional paper 1250. US GPO, Washington
- Lowenstein PL, Talai B (1984) Volcanoes and volcanic hazards in Papua New Guinea. *Rep* 263:315–331
- Macías JL, Espindola JM, Taran Y, Sheridan MF, García PA (1997) Explosive volcanic activity during the last 3,500 years at El Chichón Volcano, México. In: *International Association of Volcanology and Chemistry of the Earth’s Interior, Puerto Vallarta, México, General Assembly, Field Guide, Excursion No. 6, Guadalajara, Jalisco, Gobierno del Estado del Jalisco, Secretaria General, Unidad Editorial*, 53 pp
- Marzocchi W, Bebbington MS (2012) Probabilistic eruption forecasting at short and long time scales. *Bull Volcanol* 74:1777–1805. doi:10.1007/s00445-012-0633-x
- Marzocchi W, Sandri L, Gasparini P, Newhall C, Boschi E (2004) Quantifying probabilities of volcanic events: the example of volcanic hazard at Mount Vesuvius. *J Geophys Res* 109:B11201. doi:10.1029/2004JB003155
- Marzocchi W, Sandri L, Selva J (2008) BET_EF: a probabilistic tool for long- and short-term eruption forecasting. *Bull Volcanol* 70:623–632. doi:10.1007/s00445-007-0157-y
- McNutt SR (1996) Seismic monitoring and eruption forecasting of volcanoes: a review of the state-of-the-art and case histories. In: Scarpa L.A., Tilling RI (eds) *Monitoring and mitigation of volcano hazards*. Springer, Berlin, pp 99–196

- Mei ETW, Lavigne F, Picquout A, de Bélizal E, Brunstein D, Grancher D, Sartohadi J, Cholik N, Vidal C (2013) Lessons learnt from the 2010 evacuations at Merapi volcano. *J Volcanol Geoth Res* 261:348–365. doi:10.1016/j.jvolgeores.2013.03.010
- Mileti DS, and Sorenson JH (1990) Communication of emergency public warnings: a social science perspective and state-of-the-art assessment. Oak Ridge National Laboratory
- Moran SC, Freymueller JT, LaHusen RG, McGee KA, Poland MP, Power JA, Schmidt DA, Schneider DJ, Stephens G, Werner CA, White RA (2008) Instrumentation recommendations for volcano monitoring at US volcanoes under the national volcano early warning system (no. 2008–5114), U.S. Geological Survey, Scientific Investigations Report, no. 2008-5114, pp 47
- Neri A, Bevilacqua A, Ongaro TE, Isaia R, Aspinall WP, Bisson M, Flandoli F, Baxter P, Betagnini A, Iannuzzi E, Orsucci S, Pistolesi M, Rosi M, Vitale S (2015) Quantifying volcanic hazard at Campi Flegrei caldera (Italy) with uncertainty assessment: 2. Pyroclastic density current invasion maps. *J Geophys Res* 120. doi:10.1002/2014JB011776
- Newhall C (1999) Professional conduct of scientists during volcanic crises. *Bull Volcanol* 60(5):323–334. doi:10.1007/PL00008908
- Newhall C (2000) Volcano warnings. In: Sigurdsson H, Houghton B, McNutt S, Rymer H, Stix J (eds) *Encyclopedia of Volcanoes*. Academic Press, New York, pp 1185–1197
- Newhall CG, Hoblitt RP (2002) Constructing event trees for volcanic crises. *Bull Volcanol* 64:3–20. doi:10.1007/s004450100173
- Newhall CG, Pallister JS (2015) Using multiple data sets to populate probabilistic volcanic event trees. Chapter 8 in Papale P., *volcanic hazards, risks and disasters*. Elsevier, Berlin, pp 203–227
- Newhall CG, Punongbayan R (eds) (1996) *Fire and mud: eruptions and lahars of Mount Pinatubo, Philippines* (p 1126). Philippine Institute of Volcanology and Seismology, Quezon City
- Papale P (2017) Rational volcanic hazard forecasts and the use of volcanic alert levels. *J Appl Volcanol* 6:13
- Paton D, Johnston D, Houghton B (1998) Organisational responses to a volcanic eruption. *Disaster Prev Manage* 7:5–13
- Peterson DW, Tilling RI (1993) Interactions between scientists, civil authorities and the public at hazardous volcanoes. In: Kilburn CRJ, Luongo G (eds) *Active Lavas*. UCL Press, London, pp 339–365
- Pulgarín B, Agudelo A, Calvache M, Cardona C, Santacoloma C, Monsalve ML (2011). Ch. 3 volcanic eruption and lahars. In: Breitzkreuz C, Gursky HJ (eds) *Geo-risk management—a German Latin American approach*, pp 69–80
- Pulgarín BE, Cardona CA, Agudelo AD, Santacoloma CR, Calvache MA, Murcia CA, Cuéllar MA, Medina EN, Balanta RE, Calderón YO, Leiva ÓM (2015) Erupciones Recientes del Volcán Nevado del Huila: Lahares Asociados y Cambios Morfológicos del Glaciar. Servicio Geológico Colombiano, *Boletín Geológico* 43:75–87
- Punongbayan RS, Newhall CG, Bautista MLP, Garcia D, Harlow DH, Hoblitt RP, Sabit JP, Solidum RU (1996) Eruption hazard assessments and warnings. In: Newhall CG, Punongbayan R (eds) *Fire and mud: eruptions and lahars of Mount Pinatubo, Philippines* (p 1126). Philippine Institute of Volcanology and Seismology, Quezon City, pp 67–99
- Santacoloma CC, Londono JM, Cardona CE (2011) Recent Eruptions of Nevado del Huila Volcano, Colombia after 500 years resting. In: AGU fall meeting abstracts, vol 1, p 2675
- Scarth A (2002) *La Catastrophe: Mount Pelée and the destruction of Saint-Pierre*. Dunedin Academic Press Ltd, Martinique
- Schwaiger HF, Denlinger RP, Mastin LG (2012) Ash3d: a finite-volume, conservative numerical model for ash transport and tephra deposition. *J Geophys Res: Solid Earth* 117(B4). doi:10.1029/2011JB008968
- Sobradelo R, Bartolini S, Martí J (2014) HASSET: a probability event tree tool to evaluate future volcanic scenarios using Bayesian inference. *Bull Volcanol* 76 (1):770. doi:10.1007/s00445-013-0770-x
- Stone J, Barclay J, Simmons P, Cole PD, Loughlin SC, Ramón P, Mothes P (2014) Risk reduction through community-based monitoring: the vigías of Tungurahua, Ecuador. *J of Appl Volcanol* 3(1):11. doi:10.1186/s13617-014-0011-9
- Surono, Jousset P, Pallister J, Boichu M, Buongiorno MF, Budi-Santoso A, Costa F, Andreastuti S, Prata F, Schneider D, and Clarisse L, Oppenheimer H (2012) The 2010 explosive eruption of Java’s Merapi volcano—a ‘100-year’ event. *J Volcanol Geotherm Res* 241–242. doi:10.1016/j.jvolgeores.2012.06.018
- Swanson DA, Fiske RS, Rose TR, Kenedi CL (1983) Predicting eruptions at Mount St. Helens, June 1980 through December 1982. *Science* 221:1369–1375
- Tayag J, Insauriga S, Ringor A, Belo M (1996) People’s response to eruption warning: the Pinatubo experience, 1991–1992. *Fire and mud. Eruptions and Lahars of Mount Pinatubo, Philippines*, University of Washington Press, 13
- Tilling RI (1989) Volcanic hazards and their mitigation: progress and problems. *Rev Geophys* 27(2):237–269. doi:10.1029/RG027i002p00237
- Tilling RI (2009) El Chichón’s “surprise” eruption in 1982: lessons for reducing volcano risk. *Geofísica Internacional* 48(1):3–19
- UN ISDR (2015) Sendai framework for disaster risk reduction 2015–2030, retrieved from: http://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf [accessed 14/02/17]
- UN ISDR PPEW (2006) *Global Survey of Early Warning Systems: An assessment of capacities, gaps and opportunities toward building a comprehensive global early warning system for all natural hazards*. In: *Platform for the Promotion of Early Warning (UNISDR—PPEW)* (ed.). UN, p 46

- United Nations, International Strategy for Disaster Reduction (UN-ISDR). Hyogo framework for action 2005–2015: building the resilience of nations and communities to disasters. In: World conference on disaster reduction, Kobe, Japan, January 2005. Accessed 12 May 2017
- United Nations Office for Disaster Risk Reduction (UN-ISDR) (2015) Sendai framework for disaster risk reduction 2015–2030. United Nations—Headquarters (UN) pp. 32 Retrieved from <http://www.wcdr.org/preparatory/post2015>. Accessed 12 May 2017
- Voight B (1990) The 1985 Nevado-Del-Ruiz volcano catastrophe—anatomy and retrospection. *J Volcanol Geoth Res* 42:151–188. doi:10.1016/0377-0273(90)90075-Q
- Voight B, Hoblitt RP, Clarke AB, Lockhart AB, Miller AD, Lynch L, McMahon J (1988) Remarkable cyclic ground deformation monitored in real-time on Montserrat, and its use in eruption forecasting. *Geophys Res Lett* 25:3405–3408
- White R, McCausland W (2016) Volcano-tectonic earthquakes: a new tool for estimating intrusive volumes and forecasting eruptions. *J Volcanol Geoth Res* 309:139–155. doi:10.1016/j.jvolgeores.2015.10.020
- Winson AE, Costa F, Newhall CG, Woo G (2014) An analysis of the issuance of volcanic alert levels during volcanic crises. *J Appl Volcanol* 3(1):1. doi:10.1186/s13617-014-0014-6
- Yokoyama I, Tilling RI, and Scarpa R (1984) International mobile early-warning system (s) for volcanic eruptions and related seismic activities: report of an UNESCO/UNEP sponsored preparatory study in 1982–84. UNESCO

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