Chapter 8

Improving crisis decision-making at times of uncertain volcanic unrest (Guadeloupe, 1976)

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8.1 Defining the problem

Scientists monitoring active volcanoes are increasingly required to provide decision support to civil authorities during periods of unrest. As monitoring techniques and their resolutions improve, the process of jointly interpreting multiple strands of indirect evidence becomes increasingly complex (Sparks & Aspinall, 2013). During a volcanic crisis, decisions typically have to be made with limited information and high uncertainty, on short time scales. The primary goal is to minimise loss and damage from any event, but social and economic losses resulting from false alarms or evacuations must also be considered (Woo, 2008). It is not the responsibility of scientists to call an evacuation or to manage a crisis; however, demands are increasing on them to assess risks and present scientific information and associated uncertainties in ways that enable public officials to make urgent evacuation decisions or other mitigation policy choices.

8.2 The 1975 - 1977 volcanic unrest at La Soufrière (Guadeloupe)

An increasing number of earthquakes were recorded and felt at La Soufrière one year prior the eruption, which began with an unexpected explosion on 8 July 1976. In the subsequent 9-month period, the volcano ejected about 2 million tonnes of old, cold volcanic ash and rocks in 26 explosions (Feuillard et al., 1983, Komorowski et al., 2005, Beauducel, 2006, Feuillard, 2011). Various volcanic gases (H_2O, minor CO_2, H_2S, SO_2) were also released during the eruption and led to moderate environmental impact with short-term public health implications (Figure 8.1), due to the presence of chlorine and fluorine in the vapour. A report that "fresh glass" was present in an ash sample, implying new magma was close to the surface, led to a major controversy among scientists that was widely echoed in the media (Fiske, 1984). With other evidence suggesting continued build-up of pressure in the volcano, this key observation – later found to be erroneous - and the uncertainty of possible transition to a devastating explosive

[1] https://sites.google.com/site/casavaanr/

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eruption, led the authorities to declare an evacuation of ca. 70,000 people on 15 August, which lasted 4 to 6 months. The evacuation had severe socio-economic consequences, which persisted long after the volcanic unrest had subsided. The costs have been estimated as 60% of the total annual per capita Gross Domestic Product of Guadeloupe in 1976, excluding losses of uninsured personal assets and open-grazing livestock. There were no fatalities, but this eruption stills ranks amongst the most costly of the twentieth century (De Vanssay, 1979, Lepointe, 1999).

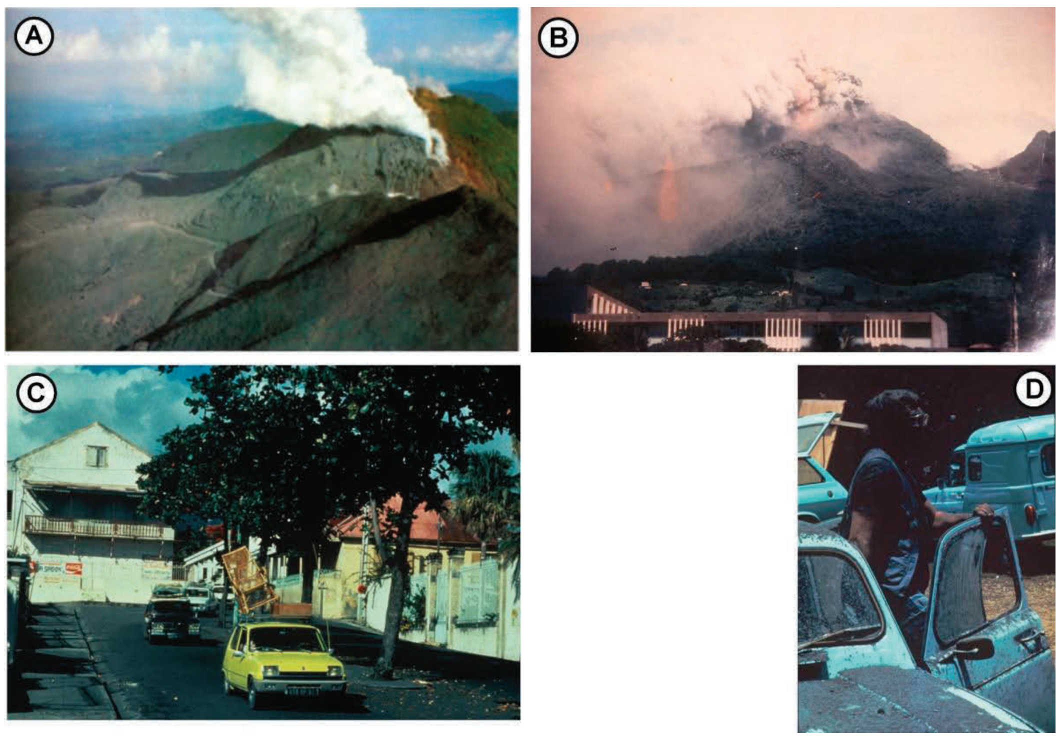

Figure 8.1 Eruptive phenomena and impact of the 1975-1977 volcanic unrest at La Soufrière (Guadeloupe). a) Gas and ash emitting fracture which opened on 8 July, photo taken before 30 August 1976 (copyright IPGP). b) Phreatic explosion and dense ash cloud, 4 October 1976 (copyright IPGP). c) People evacuating with their belongings from the towns of Saint-Claude and Basse-Terre in early September 1976 (R. Fiske). d) Ash and lapilli on car in the town of Saint-Claude from July-August 1976 explosions (R. Fiske).

8.3 Lessons learned

At La Soufrière, there was a lack of a comprehensive monitoring network prior to the 1976 crisis, limited knowledge of the eruptive history of this particular volcano, and a tendency towards caution exacerbated by the memory of past devastating Caribbean eruptions. These factors all contributed to major scientific uncertainty and a polemical publically-expressed lack of consensus and trust in available expertise (Komorowski et al., 2005, Beauducel, 2006). The combination of markedly escalating and fluctuating activity, and societal pressures, in a small island setting, made analysis, forecasting, and crisis response all highly challenging for scientists and authorities. Prior to the crisis there was no well-founded, and accepted, volcanic emergency response plan, so the authorities were compelled to resort to a "precautionary

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principle" approach in the face of the uncertain evidence and the absence of scientific consensus on the likely outlook.

Pre-eruption, there was a policy to move the banana export port facilities of Basse Terre to the more sheltered economic capital Pointe-à-Pitre, and the evacuation reinforced this policy. This, in turn, contributed to the ravaging of the economy of the administrative capital, Basse Terre, and to its population's bitterness and feeling of being forsaken. The evacuation is still perceived by some as having been unnecessary and an exaggerated application of the "precautionary principle". Even now, many hold to the view that much of the risk assessment was exaggerated for political reasons.

In its overseas territory context, the volcanic crisis in 1976 became a metaphor for many accumulated socio-cultural frustrations on island, and engendered a distrust of science as a possible contributor to solving such issues. The public debate at the time became polarised on issues of opposing "truths", served up and contrasted by a few strongly opinionated scientific experts, rather than focussing on how science could help constrain epistemic and aleatory uncertainty and foster improved decision-making in the circumstances. Thus this infamous crisis exemplified the need for a structured and transparent approach to evidence-based decision-making in the presence of substantial scientific uncertainty.

8.3.1 A probabilistic approach to quantifying uncertainty

Similarities of volcanic unrest interpretation with uncertainties in medical diagnosis suggest a formal evidence-based approach can be helpful, whereby monitoring data are analysed synoptically to provide probabilistic hazard forecasts. A probabilistic tool to formalise such inferences is the Bayesian Belief Network (BBN) (Bedford & Cooke, 2001). By explicitly representing conditional dependencies (relationships) between the volcanological model and observations, BBNs use probability theory to treat uncertainties in a rational and auditable manner, to the extent warranted by the strength of the scientific evidence. A retrospective analysis is given for the 1976 Guadeloupe crisis by Hincks et al. (2014), using a BBN (Figure 8.2) to provide a framework for assessing the state of the evolving magmatic system and the probability of a future eruption. Conditional dependencies are characterised quantitatively by structured expert elicitation (Aspinall, 2006, Aspinall & Cooke, 2013).

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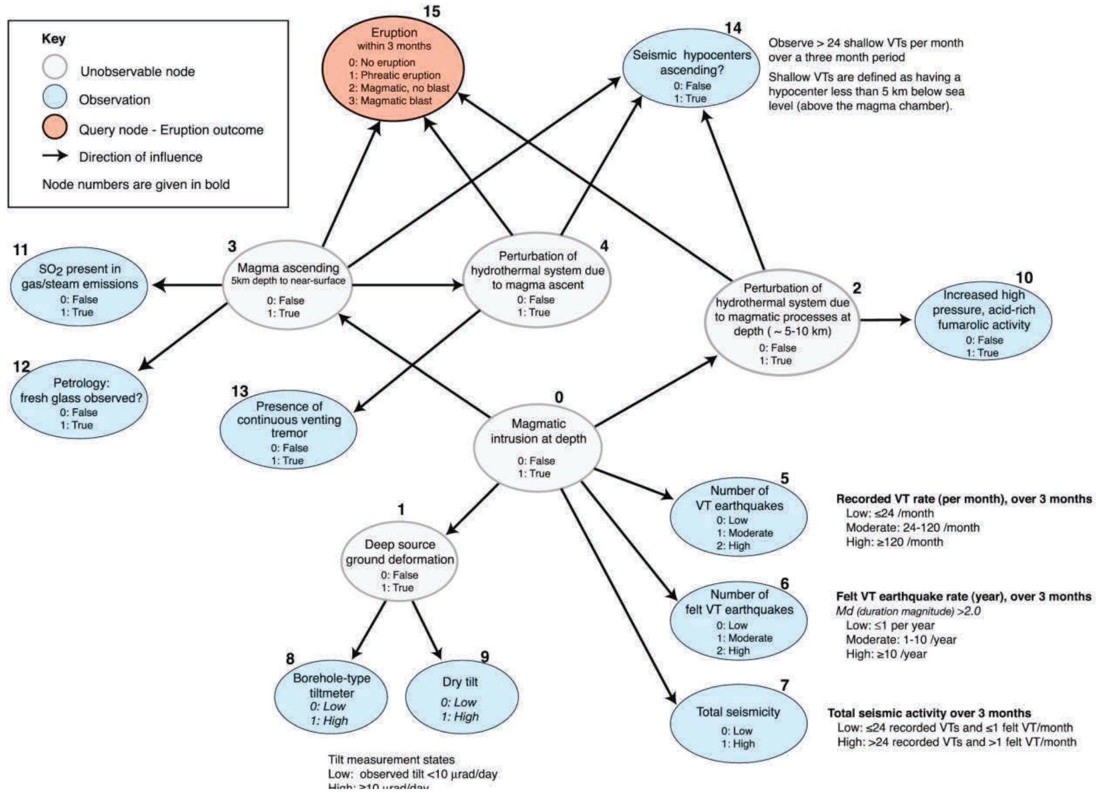

Figure 8.2 Retrospective Bayesian Belief Network (BBN) for La Soufrière (Hincks et al., 2014) showing the relationship between volcanic processes, states and observations available in 1976; used to make inferences about probabilities of future activity scenarios. Nodes represent both hidden (grey) and observable (blue) states. Arcs between nodes represent conditional dependencies (e.g. direct causal relationships or influence) and are characterised by conditional probability tables (CPTs). Arrows indicate the direction of influence. In this case, all conditional probability distributions (and associated uncertainties) were obtained by expert elicitation, the network structure being agreed by the group prior to elicitation.

Analysis of the available monitoring data suggests that at the height of the crisis the probability was high that magmatic intrusion was taking place, according with most scientific thinking at the time. Correspondingly, the probability of magmatic eruption was elevated in July and August 1976, and the signs of precursory activity were justifiably a cause for concern. However, as of 31 August 1976 collective uncertainty about the future course of the crisis was also substantial such that, of all the possible scenarios considered in the BBN, the marginally most likely outcome based on available observations was 'no eruption' (mean probability 0.5); the chance of a magmatic eruption, perhaps associated with a devastating volcanic blast, had an estimated mean probability of ~0.4 (Figure 8.3). There was, therefore, little or no evidential strength for asserting that one of these scenarios was significantly more likely than the other.

8.4 A path towards improved decision-making during crises

The analysis by Hincks et al. (2014) provides objective probabilistic expression to the volcanological narrative at the time of the 1976 crisis. Indeed a formal evidential case, such as this, would have supported the authorities concerns about public safety and their decision to evacuate. Revisiting the episode highlights many challenges for modern, contemporary decision-making under conditions of considerable uncertainty, and suggests that the BBN is a

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suitable framework for marshalling multiple, uncertain observations, model results and interpretations.

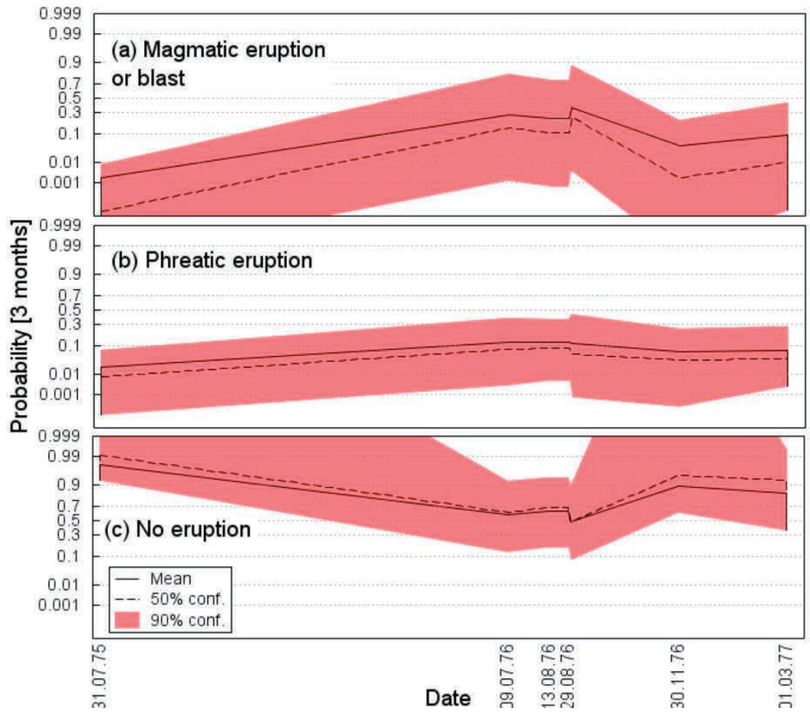

Figure 8.3 Temporal variations from July 1975 to March 1977 in BBN forecast probabilities for La Soufrière Volcano (Hincks et al., 2014), given observation states shown in the lower part of the figure: a) a magmatic eruption or magmatic blast; b) a phreatic eruption, or c) no eruption. The unbroken black line denotes the expected (mean) probability estimate and the dashed line the median, as determined by Monte Carlo re-sampling of BBN input distributions; the shaded bands show the corresponding 5-95 percentile ranges, indicating the uncertainty in the forecast probability.

More recently, mild but persistent seismic and fumarolic unrest since 1992 at La Soufrière volcano has prompted renewed interest in geologic studies, monitoring, risk modelling, and crisis response planning. Development of an advanced probabilistic formalism for decision-making could help quantify and constrain scientific uncertainty, and thereby assist public officials in making urgent evacuation decisions and policy choices should the ongoing unrest intensify in a lead-up to renewed eruptive activity.

The BBN formulation (Hincks et al., 2014) can be developed further as a tool for ongoing use in volcano observatories and can be combined with other probabilistic tools (Newhall & Hoblitt, 2002, Marzocchi et al., 2008, Marzocchi & Bebbington, 2012). This approach is complemented by a progressive quantitative hazard and risk assessment approach (CASAVA project: http://sites.google.com/site/casavaanr/home) that considers: (a) interdisciplinary determinations of infrastructural, human, systemic and cultural factors; (b) social vulnerabilities, capacity and resilience, and (c) includes also the influence of risk perception and governance issues on disaster preparedness. This new work has implications for the way monitoring should be organised for Lesser Antilles volcanoes, and for how risk-informed decision-making in crisis response and long-term strategies of volcanic risk mitigation should be formulated.

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