Institution: University of Bristol

Unit of Assessment: 7 – Earth Systems and Environmental Sciences

Title of case study: Volcanic Risk Reduction: Improved hazard management and emergency response planning leads to the reduction of volcanic risk worldwide

1. Summary of the impact

Novel methods in applied physical volcanology, such as expert elicitation, and hazard and risk assessment, developed mostly during the ongoing volcanic crisis at Soufrière Hills Volcano (Montserrat), continues to inform decision making, worker and public safety, and management of administrative hazard zones that control access. These methodologies have been adopted worldwide using Montserrat Volcano Observatory (MVO) as an exemplar by the World Organisation of Volcano Observatories (WOVO). Bristol researchers have advised on institutional programmes and informed international agencies, such as the United Nations and the World Bank, to reduce risk presented by volcanic hazards, and save lives. Such is the impact of Bristol's work at MVO it has been studied by up to nearly one million school children in the UK since 2008.

2. Underpinning research

World class research in volcanology has been conducted at Bristol University under the leadership of Professor Steve Sparks FRS (appointed Channing Wills chair in 1989) and Professor Willy Aspinall (appointed Industrial (now Cabot) Chair in 2005) in the School of Earth Sciences. Over the past 30 years, but particularly since the onset of the eruption of Soufrière Hills (1995), they have focused on understanding both volcanic processes and the development of methodologies to assess volcanic hazard and risk with applications and impacts at global, regional, national and local scales. The research has been supported through a number of large grants from both the academic and private sectors including NERC **[1,2]**, World Bank/UN **[3]**, and the EC **[4]**.

The breadth and depth of both Sparks' and Aspinall's research into both physical volcanology **[5,6]** and volcanic risk **[7-10]** is considerable. Sparks alone has produced 103 papers relating to the eruption of Soufrière Hills, with 4,361 citations to date (source: Web of Science 06/11/2013). Research methodologies applied at MVO include, but are not limited to, field observations **[5]**, numerical modeling of pyroclastic density currents **[6]**, analogue laboratory experiments, expert elicitation **[8]** and risk assessment **[7,9,10]**, and in all of these fields Sparks and/or Aspinall are world leaders. Under their leadership, volcanological knowledge at Bristol has been integrated into systematic modelling of risk and mitigation using event trees, expert elicitation and stochastic model ensembles **[7-10]** to characterise volcanic risk and hazards with attendant uncertainties.

Aspinall and Sparks served as chief scientists extensively between the most active period of the eruption of Soufrière Hills (1995-1998). During their tenure, a different, unique, approach to compiling scientific advice in the face of uncertainty was pioneered by Aspinall through a procedure of structured 'expert elicitation' **[8]**. This method pools the opinions of a group of specialists, using differential weights based on empirical testing of their abilities to judge accurately relevant uncertainties. The goal is to quantify these uncertainties for appropriate inclusion in decision making. Aspinall trialled this methodology at the start of the Soufrière Hills eruption - the first time a formal elicitation procedure was used in a live volcanic crisis **[a]**. Nearly twenty years on, volcano management in Montserrat stands as the longest-running application of the technique, which is now used by volcano observatories worldwide.

3. References to the research

Grants

[1] Sparks SAPPUR: (NERC) Scoping Study on the Analysis, Propagation and Communication of Probability, Uncertainty and Risk (2008-2009). £130K. http://www.bristol.ac.uk/brisk/sappur/

[2] Phillips STREVA: (NERC) Strengthening Resilience in Volcanic Areas (2011-2016). £3M. http://streva.ac.uk/

[3] Sparks VOGRIPA: (GFDRR/World Bank) Volcano Global Risk Identification and Analysis (2005-2014). £60K (initial). http://www.bristol.ac.uk/brisk/research/#vogripa

[4] Sparks VOLDIES: (EU) Dynamics of Volcanoes and their Impact on the Environment and Society (2009-2014). £2M. http://www.bristol.ac.uk/brisk/research/#voldies

References

[5] Roberston, R.E.A., **Aspinall, W.P.**, Herd, R.A., Norton, G.E., **Sparks, R.S.J.** and Young, S.R. (2000), The 1995–1998 eruption of the Soufriére Hills volcano, Montserrat, WI. *Philosophical Transactions of the Royal Society London A*, 358 (1770): 1619-1637. DOI: 10.1098/rsta.2000.0607.*

[6] Sparks, R.S.J., Barclay, J., Calder, E.S., Herd, R.A., Luckett, R., Norton, G.E., Ritchie, L.J., Voight, B. and Woods, A.W. (2002), Generation of a debris avalanche and violent pyroclastic density current on 26 December 1997 (Boxing Day) at Soufrière Hills Volcano, Montserrat. In: Druitt TH and Kokelaar BP (Eds.) *The eruption of the Soufrière Hills Volcano, Montserrat 1995 to 1999.* Geological Society, London. Memoir 21, 409-434. DOI: 10.1144/GSL.MEM.2002.021.01.18.

[7] Sparks, R.S.J. and **Aspinall, W.P.** (2004), Volcanic Activity: Frontiers and Challenges. In: *Forecasting, Prediction, and Risk Assessment. AGU Geophysical Monograph "State of the Planet".* IUGG Monograph 19 (150): 359-374. DOI: 10.1029/150GM28.

[8] Aspinall, W.P. (2006), Structured elicitation of expert judgment for probabilistic hazard and risk assessment in volcanic eruptions. In: Mader, H.M. et al. (Eds.) *Statistics in Volcanology,* pp 15-30. Can be supplied upon request.*

[9] Hill, B.E., **Aspinall, W.P.**, Connor, C.B., Godoy, A.R., Komorowski, J.C. and Nakada, S. (2009), Recommendations for assessing volcanic hazards at sites of nuclear installations. In: Connor, C.B., Chapman, N.A. and Connor, L.J. (Eds.) *Volcanic and Tectonic Hazard Assessment for Nuclear Facilities*. Cambridge University Press, Cambridge, pp 566-592. Can be supplied upon request.

[10] Sparks, R.S.J., **Aspinall, W.P.**, **Crosweller, H.S.** and **Hincks, T.K.** (2012), Risk and uncertainty assessment of volcanic hazards. In: Rougier, J., **Sparks, R.S.J.** and Hill, L. (Eds.) *Risk and Uncertainty Assessment for Natural Hazards*, pp 364-397. Can be supplied upon request.*

4. Details of the impact

In 1995, and almost overnight, Montserrat became dependent on volcanological expertise, with authorities needing advice to determine warning levels, travel restrictions and evacuations. Prior to this *"there were no contingency plans on Montserrat or with the UK Government*" for dealing with volcanic crises on the Island **[a]**. Sparks and Aspinall provided direct counsel, and it is their expertise and quality of research that continues to underpin the emergency management of the ongoing volcanic activity at Soufrière Hills. Nearly twenty years on, socio-economic impact is still being felt from both their early developmental work and in their subsequent roles, both on Montserrat and in the wider world.

Both Sparks and Aspinall contributed to the establishment of the MVO and were appointed as Chief Scientists from 1996-1998. Sparks and Aspinall were later commissioned in 1997 by the Governments of Montserrat and the UK to form a Risk Assessment Panel (RAP), which transformed into a Scientific Advisory Committee (SAC) in 2002, established by the Overseas Territories Department of the Foreign and Commonwealth Office **[a]**. The SAC is a group of independent international volcanologists whose role is to (i) evaluate evidence framed by the understanding of volcanic processes, (ii) forecast future activity, and (iii) assess hazards and risks with uncertainties by adopting a fully probabilistic approach. To do this, the SAC works with the MVO to provide advice to the UK and Montserrat Governments, and Civil Protection Groups, on long-term hazard and risk assessment and emergency management **[b]**. Sparks was the chair of both the RAP and SAC from 1997 until 2003 **[c]**, and later re-joined in 2011-present. Aspinall has been the facilitator of the risk assessment work by the RAP and SAC from 1997 until present **[c]**. Both Sparks and Aspinall "*have been in the vanguard of the scientific response and assessment of risk and both have provided invariably sound advice and calm professionalism on which GoM and UKG have based their decisions, initially for the protection of the community during the main eruptive stage (1995-98) and subsequently for the re-development of housing and key facilities to enable the community to remain on island"* **[a]**. For instance, their expertise has been used to quantify volcanic risk which "*enabled the UK and Montserrat Government to start a more rational plan for responding to the volcano, and in particular it assisted the early stages of planning longer term facilities in the North of the island to enable those who did not wish to evacuate to remain on* *island"* **[a]**. These decisions can be attributed directly to Bristol researchers and continues to have a *"profound impact on the safety of the island's inhabitants"* **[d]**. Indeed, the Head of Disaster Management for the UK Overseas Territories has stated; *"I have no doubt that the hazard maps, educational programmes, daily scientific reports in language that the community understood and close co-operation with the Government of the day, resulted in scores or more of lives being saved"* **[a]**.

There are multiple lines of evidence of how Bristol's research is linked to policy and decisions on Montserrat. One current example is sand mining **[d,e]**. In the last few years, sand mining has become an important source of income for Montserrat. However, these activities have caused some environmental concerns, including destruction of the main roads from truck movements, road safety, and noise and dust nuisance to residents. One solution is to develop the port at Plymouth for export, however this brings workers into a potentially hazardous region, despite volcanic activity being classified as 'low' for the last 2 years. Consequently, the SAC and MVO were commissioned by the Government of Montserrat National Disaster Preparedness and Advisory Committee to assess risks in relation to airport operations and commercial mining in order to establish whether or not various options were feasible. The SAC used knowledge of empirical pyroclastic flow models **[6]**, and statistical frequency-magnitude relationships of dome collapses to assess the risk and quantify attendant uncertainties **[5]**, using the formal expert elicitation methods developed by Aspinall **[8]**. Key research involving both current and former Bristol PhD students supervised by Sparks has also directly informed the estimates. From this work, occupational risk levels to workers were assessed and found to be 8-20 times higher than UK workers in the extractive industries, thus requiring additional efforts in monitoring and worker safety **[b,e]**. *"As a result, controlled export of volcanic sand now takes place from the jetty in Plymouth"* **[d]**.

The advice of Sparks and Aspinall through the RAP and SAC led to the permanent establishment of MVO with a dedicated building, employment of fifteen technical and scientific staff and also supports eight off-island administrative positions **[a]**. "*In a population of only a few thousand, MVO is a significant employer and a critical resource for the island and its long-term sustainability*" **[a].** Furthermore, the on-going monitoring and publicity around the Soufrière Hills eruption has led to this eruption being incorporated into the UK National Curriculum as a G.C.S.E Geography case study. The eruption and its mitigation policies have been studied by up to 962,238 school children between 2008 and present **[f]**.

The combination of volcanic process fundamentals (under Sparks), and modelling of risk (under Aspinall), provides the foundation of the risk assessment methodology that has been applied successfully on Montserrat since 1995. The MVO has established a testbed for new monitoring tools, including those that measure volcanic gases, deformation, seismology and strain. More than that, its management and decision making processes (designed and implemented by Aspinall), are still being used today, and tested and trialled worldwide in volcanic settings as diverse as Guatemala and Tristan de Cunha. This underscores the importance (and ethos) of knowledge sharing and risk reduction worldwide that is a leitmotif throughout the work of Sparks and Aspinall; "*the University of Bristol volcanology group have led some of the major research themes globally that feed into the day-to-day operations of volcano observatories. For example, the work of Professor Steve Sparks… has led to improved knowledge transfer on volcanic hazards and risk assessment tools"* **[g]**, and *"the research performed by the group has led to improved decision support and information transfer for the world's volcano community"* **[g]**.

To that end, as well as setting up MVO and facilitating its growth into a world-leading observatory, Aspinall and Sparks have co-authored a substantial report (2011) describing where this very knowledge is most needed, as part of the Global Facility for Disaster Reduction and Recovery (GFDRR) **[h]**. The GFDRR was launched in 2006 by the World Bank as a partnership between the UN, donors and developing countries. It was established to help developing countries, particularly those identified as the most vulnerable natural disaster 'hotspots', to build their capacity for disaster prevention, emergency preparedness, response, and recovery. The report **[h]** presents the results of a pilot study on the risk posed by volcanoes in the priority countries of the GFDRR and the World Bank and helps unveil how volcanic risk can impact the social and economic profiles of vulnerable countries; *"The aim of the study was to establish science-based evidence for better* *integration of volcanic risks in national Disaster Risk Reduction (DRR) programmes in priority countries, as well as regional cooperation in DRR programmes for all countries supported under GFDRR"* **[i]**. Since its launch, GFDRR has responded to the growing needs and demands of countries, currently funding more than 120 disaster risk reduction (DRR) and inter-related climate risk management programs in many disaster-prone low and middle income countries. GFDRR has, according to their website, spent over $197M in overseas programmes since its inception and this aid has been guided, in part, by the report **[j]**. The World Bank states, "*the findings of this study have been important in informing the continued development of the GFRDD country programs, which guide our interventions in 31 priority countries around the world. Through this study we have been able to more accurately reflect volcanic risk in our programmatic approach"* **[j].** The GFDRR report, specifically the methodology highlighted within it, has also shaped the thinking, and actions, of the United Nations itself; *"This evidence, and the method developed is study, has been critical for the development of the next Global Assessment Report (GAR15)…This, in turn, will have a direct impact to national governments, decision makers and practitioners, as well as implementation pathways for mainstreaming volcanic risk reduction into policies and practice"* **[i]**.

The work of Aspinall and Sparks in volcanic risk reduction has had impact worldwide. Through the MVO, they have developed an exemplar of both monitoring capability and, critically, effective decision making **[a,d,g]**. Through their work with the World Bank and the United Nations they have delimited the countries most at risk and, therefore, most in need of an understanding of the best-practices of an exemplary volcano observatory such as MVO **[i,j]**. The report **[h]** *"has been a timely contribution to our continuous efforts to reflect the latest scientific understanding of disaster risk n the programming of our funding to vulnerable countries. This supports our efforts to build increased capacity and expertise in understanding risks from natural hazards in countries around the world"* **[j]**. Through a better understanding of both risk and decision making, hazard managers are better armed to make good, effective choices that reduce exposure to volcanic hazards even during crises and in periods of great uncertainty.

5. Sources to corroborate the impact)

[a] Foreign and Commonwealth Office Overseas Territories Directorate. Factual Statement.

[b] SAC scientific reports (2002-present). Available from: http://www.mvo.ms

[c] IAEA (2012) *Volcanic Hazards in Site Evaluation for Nuclear Installations*. IAEA Safety Standards Series SSG-21. Available from: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1552_web.pdf

[d] Montserrat Volcano Observatory (MVO). Factual Statement.

[e] Montserrat Mining and Quarrying Industry Report. Available from: http://www.protectmontserrat.com/wp-content/uploads/2012/02/Montserrat-Mining-and-Quarrying-Report-FINAL.pdf

[f] Joint Council of Qualifications. Number G.C.S.E Geography candidates. Available from: http://www.jcq.org.uk/examination-results/gcses

[g] World Organization of Volcano Observatories (WOVO) Factual Statement.

[h] GFDRR Volcanic Risk Study: Volcano Hazard and Exposure in GFDRR Priority Countries and Risk Mitigation Measures (2011). NGI report 20100806. Available from: http://www.globalvolcanomodel.org/documents/Aspinall_et_al_GFDRR_Volcano_Risk_Final.pdf

[i] United Nations International Strategy for Disaster Reduction (UNISDR). Factual Statement.

[j] World Bank. Factual Statement.