Institution: University of Bristol		
Unit of Assessment: 7 – Earth Systems and Environmental Sciences		
Title of case study: Improved resilience, strengthened disaster response, and reduced human and financial losses to volcanic hazards for millions of people		
Period when the underpinning research was undertaken: 2010 - 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Juliet Biggs	Lecturer/Professor	2010 – Present
Sarah Brown	Postdoctoral researcher	2012 – Present
Helen Crosweller	Postdoctoral researcher	2009 – 2015
Susanna Ebmeier	Postdoctoral researcher	2012 – 2016
Joachim Gottsmann	Reader/Professor	2005 – Present
Steve Sparks	Professor	1989 – Present
Matthew Watson	Lecturer/Reader	2004 – Present
Period when the claimed impact occurred: 2014 - 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Globally, over 800 million people live within reach of potentially destructive volcanoes. The University of Bristol's (UoB) research into all phases of the Disaster Risk Reduction cycle has improved resilience, strengthened disaster response and reduced human and financial losses, enabling government agencies to move "*from managing geohazard crises to managing risks"*. Specifically, it has:

- Driven international policy through coordination and authorship of the United Nation's first and, so far, only global assessment of volcanic risk.
- Enabled governments (UK, EU and international), observatories, emergency responders and local residents to prepare for and to respond to volcanic emergencies in the 86 countries with active volcanoes.
- Built local and regional capacity for managing volcanic hazards, focussing on countries in Latin America and East Africa, where ~250 million people are exposed.
- Enhanced public understanding of volcanic risks by creating films viewed via social media in over 90 countries.
- Supported the accurate pricing of risk-based insurance policies and driven the development of novel insurance products.

2. Underpinning research

UoB's analysis of volcanic activity and risk on a global scale has shown that 800 million people (10% of the world's population) live within 100km of a volcano[3-1], and that there have been 280,000 volcanic fatalities in the last 500 years[3-2]. UoB's analysis further shows that only about 20% of volcanoes have any ground-based monitoring[3-1]. Few volcano observatories in developing countries have the capacity to utilise the latest technological developments in monitoring or conduct hazard assessments. Here we highlight UoB's research on global volcanic databases and remote monitoring methods, which has significantly extended the capacity to manage volcanic hazards, particularly in developing countries, and informed a step change in how hazard and risk are managed globally.

Global databases of hazard and risk

Bristol's Volcanology group and the British Geological Survey (BGS) co-developed the Global Volcano Model (GVM) Network in 2011. This international network brings together more than 30 partners from the global volcanological community to collect consistent and systematic global datasets of volcanic data and to develop uniform and open standards for calculating and communicating volcanic hazard and risk. Its achievements include the following:

Global eruption datasets. Understanding the magnitude-frequency relationship of eruptions is critical in characterising risk on a global scale. As part of GVM, UoB led the development and analysis of the LaMEVE database of Quaternary Large Magnitude Explosive Volcanic Eruptions[3-3]. Records of the largest eruptions are extracted from geological archives, which have substantial uncertainties in date and magnitude and may be systematically biased. UoB therefore developed new statistical methods to reduce these uncertainties and biases by accounting for magnitude rounding and under-recording and combined these with LaMEVE data to reassess the frequency of the largest eruptions. This demonstrated that the return period of 'super-eruptions' is ~17ka, an order of magnitude shorter than previous estimates[3-3].

Hazard and Exposure Indices. The GVM network were invited by the UN Office for Disaster Risk Reduction (UNISDR) to provide the technical background documents[3-1] for the UN Global Assessment of Risk (GAR). UoB conducted original research to develop a robust system of indices based on global volcano databases. UoB's volcanic fatalities database[3-2] was used to provide distance weightings for the population exposure index and the volcanic hazard index[3-1]. UoB researchers conducted a survey of monitoring capacity and found that less than 20% of volcanoes worldwide have formal monitoring and highlighted the lack of governmental and public awareness of volcanic hazards. These methodologies now underpin the assessment of risk for the 86 countries with active volcanoes and provide accessible and comparable profiles, enabling funding to be prioritised according to risk level.

Global volcano monitoring with remote sensing

At least 80% of the world's volcanoes lack ground-based monitoring, and researchers have turned to satellite data to collect baseline information. UoB's work on regional-global surveys, atmospheric corrections and machine learning has identified active deformation at more than 25 volcanoes previously considered inactive, including many in densely populated parts of the East African Rift and means that deformation can now be routinely detected in operational radar missions, such as Sentinel-1[3-4]. At erupting volcanoes, they have pioneered measurements of short-term deformation, lava effusion rates and changes in ice-cap morphology using high-resolution data. For instance, UoB were founder members of a Working Group[1] to analyse satellite data from the international Space Agencies and provide timely results to Volcano Observatories, which led to the real-time recognition and interpretation of unrest, and new insights into precursory activity[3-5]. UoB researchers have worked on quantifying volcanic ash and gas, developing innovative methods for 3-D imaging of ash clouds, and measuring SO_2 emissions from satellites and ground-based multi-spectral cameras[3-6]. This has led to a better understanding of the source strength and distribution of emissions to the atmosphere, including the first arc-scale estimate of SO_2 emission rate from the Central American arc and quantification of global emissions.

3. References to the research

3-1. Loughlin, S.C., **Sparks**, R.S.J., **Brown**, S.K., *et al*. eds., (2015). Global volcanic hazards and risk. Cambridge University Press. DOI: 10.1017/CBO9781316276273

3-2. **Brown**, S.K., Jenkins, S.F., **Sparks**, R.S.J. *et al*. (2017). Volcanic fatalities database: analysis of volcanic threat with distance and victim classification. Journal of Applied Volcanology, 6, 15. DOI: 10.1186/s13617-017-0067-4.

3-3. **Crosweller**, H.S., Arora, B., **Brown**, S.K., *et al.* (2012). Global database on large magnitude explosive volcanic eruptions (LaMEVE). Journal of Applied Volcanology, 1(1). DOI: 10.1186/2191-5040-1-4.

3-4. Anantrasirichai, N., **Biggs**, J., Albino, F., Hill, P., & Bull, D. (2018). Application of machine learning to classification of volcanic deformation in routinely generated InSAR data. Journal of Geophysical Research: Solid Earth, *123*(8), 6592-6606. DOI:10.1029/2018JB015911

3-5. Pritchard, M., **Biggs**, J., Wauthier, C. *et al* (2018). Towards coordinated regional multi-satellite InSAR volcano observations: results from the Latin America pilot project. Journal of Applied Volcanology, 7, 5. DOI: 10.1186/s13617-018-0074-0.

3-6. Holland, A.P., **Watson**, I.M., Phillips, J.C., *et al* (2011). Degassing processes during lava dome growth: Insights from Santiaguito lava dome, Guatemala. Journal of Volcanology and Geothermal Research, 202(1-2), pp.153-166. DOI: 10.1016/j.jvolgeores.2011.02.004.

[1] Committee on Earth Observation Satellites: http://ceos.org/ourwork/workinggroups/disasters/volcanoes/

4. Details of the impact

The Volcanology Group at UoB has a wealth of experience in responding to volcanic emergencies which has established UoB researchers in key leadership roles in collaborative efforts to reduce volcanic risk. The UoB researchers work with the public and private sector, through all phases of the Disaster Risk Reduction cycle, and have conducted knowledge transfer activities in 32 countries, including 19 ODA recipients. The Global Facility for Disaster Reduction and Recovery (GFDRR) have hailed UoB's "'*research prowess in volcanology and their convening power to engage and co-ordinate the international volcanology community*"[5-10]. The UK Department for International Development (DFID) state "*the research and datasets produced by … Bristol's Volcanology Group* [are] *valuable underpinning resources for our decision-making*"[5-4] and the US Volcano Disaster Assistance Program (VDAP) state that UoB's work has "*changed the way in which volcanic hazard and risk is managed on a global basis*"[5-5]. Further testament to their achievements, the Volcanology Group were awarded the Queen's Anniversary Prize in 2015 – an institutional award which honoured the outstanding importance and quality of UoB's work to reduce volcanic risks (www.queensanniversaryprizes.org.uk).

1. Informing international policy and aid. The Global Assessment of Risk (GAR) is the flagship report of the United Nations on worldwide efforts to reduce disaster risk. The 2015 report (GAR15) was the first to consider volcanic risk and, as co-leader of GVM, UoB co-ordinated scientists from 80 countries in the development of the report. UoB's scientists led or contributed to all four background papers on Global Volcanic Hazards and Risk[5-1] and UoB's system of robust indices[3-1] provided the foundation for the report's 86 Country Hazard and Risk Profiles. GAR15 produced *"the conceptual framing and evidence for the UN Sendai Framework for Disaster Risk Reduction"*[3-5] which provides UN member states with concrete actions to protect development gains from the risk of disaster and was adopted in 2015. The ability to assess volcanic risk on a global scale for the first time demonstrates how UoB's research has built the scientific foundation necessary for the UN to signal volcanic hazards as a policy priority to their member states[5-2].

UoB's risk metrics, developed for GAR15, have been widely adopted to advocate for funding and to inform authorities and decision-making. The insurance brokers Willis Towers Watson (WTW) describe them as "*a breakthrough in providing global volcanic risk metrics, which suit the needs of a variety of end-users, uniting academia, public sector, civil society and the private sector with a common language for risk … allowing for the cross-sector collaboration necessary to strengthen resilience."* The metrics underpin weekly assessments of volcanism for DFID and the European Response Coordination Centre (ERCC)[5-3]. DFID[5-4] explain "*We rely on the Bristol data … to allow us to rapidly start deploying resources (including people and aid) to the area affected".* During the 2018 eruption of Fuego, Guatemala, initial humanitarian reports indicated a large response from DFID was required, but "*By using the GAR data… we quickly understood that the number affected was far lower … thus saving man-hours and funds and allowing a more appropriate response"*[5-4]. The British Geological Survey state that the national risk rankings have been critical in "*drawing attention to volcanic hazard among government departments who in some cases were apparently unaware that such threats existed*"[5-3]. The volcanic risk component of GAR15 is openly accessible and has reached a wide audience: >46,000 downloads of open-access book chapters[3-1] (www.cambridge.org/volcano) and >3,900 downloads of risk data from UNOCHA Humanitarian Data Exchange (https://data.humdata.org/dataset/volcano-population-exposure-index-gvm).

2. Supporting crisis response. UoB's expertise in volcanic risk and remote monitoring has resulted in urgent requests for assistance from observatories, the UK government (BGS, DFID) and the US Volcano Disaster Assistance Program (VDAP)[5-5]. Here we select three recent volcanic crises which illustrate some of the ways in which UoB's research has been used operationally.
Institutional Disaster Response. The 2018 eruption of Fuego, Guatemala, is one of the deadliest eruptions of the 21st century and is thought to have resulted in up to 3,000 fatalities. UoB's satellite monitoring expertise and a 20-year collaborative relationship with Guatemala's national hazards agency, INSIVUMEH, meant UoB was selected to manage the International Disasters Charter response (https://disasterscharter.org) to the eruption, through which 17 space agencies make satellite data freely available to those affected by disasters. INSIVUMEH state that "*the information*

was used to manage the crisis by providing up-to-date information of the volcano's behaviour and also the location of buildings buried beneath the ash deposits"[5-7].

Reducing the impact of evacuations. In 2014, a series of seismic crises at the previously quiescent volcanic complex of Chiles-Cerro Negro, Ecuador, raised concerns of a possible large eruption. The Risk Management Ministry raised the volcanic alert level from Yellow to Orange on 21/10/14, triggering evacuation of about 3,500 families. UoB provided satellite InSAR data and analysis to the observatory (IG-EPN), which was fundamental in the decision to lower the alert level back to Yellow on 26/11/14[5-5,5-6]. This meant that "*evacuees could return home, and that disruption and socio-economic losses were minimised by avoiding a prolonged evacuation"*[5-6].

Safety of scientists and emergency responders. In 2018, New Zealand's research and monitoring institute, GNS Science[5-8], used UoB's volcanic fatality data[3-2] to develop the Volcano Life Risk Estimator (VoLREst), a world-first operational product and a key part of GNS Science's Health and Safety protocols. GNS state that UoB's fatality data provided "*key validation of the hazards considered in the VoLREst tool"*[5-8]. Following the 2019 Whakaari eruption, in which 21 people lost their lives, VoLREst was used to assess safety and aid decision-making in body recovery operations[5-8]. In the hours after the eruption, UoB's fatality data was used to brief Police and Fire and Emergency in support of their eruption response[5-8].

3. Improved monitoring capacity. UoB's research has been used to advocate for investment in capacity building and monitoring in several countries that the GAR15 identified as having high-risk active volcanoes and limited capabilities. Here we highlight two examples from Latin America and East Africa which demonstrate the ways in which UoB research has supported countries with dramatically different monitoring capabilities.

Latin America: According to GAR15, over 130 million people live within 100km of a volcano in Latin America. Following the 2018 eruption of Fuego, Guatemala, the work of international scientists led by the US Volcano Disaster Assistance Program (VDAP) and UoB was "*important in allowing Guatemala to secure a $200M loan from the World Bank to quickly mobilize resources in the aftermath of adverse natural events…"*[5-5]. Specifically, UoB researchers were "*instrumental in demonstrating the need for improvements in monitoring … using evidence from GAR15 comparing in country monitoring capacity and risk levels"*[5-7]. Guatemala's national hazard agency, INSIVUMEH, state that UoB's ongoing collaboration has enabled *"capacity building in both monitoring resources and the training of staff in cutting-edge monitoring techniques, which help us to respond to developing volcanic emergencies in the forecasting of activity and supporting decision-making, preparedness and emergency response"*[5-7]. In contrast, Ecuador has a relatively strong ground-based monitoring capacity. UoB's use of satellite data during the 2014 Chiles-Cerro Negro seismic crisis has inspired the volcano observatory, IG-EPN, to use satellite data for monitoring high-risk, physically inaccessible volcanoes[5-6]. IG-EPN state "*The training, workshop and exchanges with Bristol have inspired and helped to develop our processing of satellite data in house rather than rely solely on international collaborations*"[5-6].

East Africa: According to GAR15, over 120 million people live within 100km of a volcano in Africa and the Red Sea. UoB's work has been instrumental in communicating volcanic risk and building capacity within Ethiopian governmental organisations[5-9]. Since 2005, UoB have worked with the Institute of Geophysics, Space Science and Astronomy (IGSSA)[5-9] on a range of NERC-funded projects which IGSSA state have *"improved the knowledge of volcanism in Ethiopia and provided evidence and support for our national geohazard monitoring strategy"*[5-9]. Motivated by UoB's satellite surveys, the joint deployment of temporary seismic and geodetic networks has enabled IGSSA to develop their own volcano monitoring strategy. Since 2014, IGSSA have expanded Ethiopia's national network to include two real-time seismic and seven GPS stations specifically designed to monitor volcanoes. Exchange visits have increased capacity through the training of IGSSA staff members[5-9]. IGSSA state that "*a major change is an increased awareness of volcanic hazards and risk within the government and disaster risk reduction communities, culminating in the formation of a multi-organisational geohazard focus group"*[5-9]. This prompted the National Disaster Risk Management Commission to publicly announce in 2019 "*a paradigm shift from managing geohazard crises to managing risks*"[5-9]. The BGS describe this as *"a step-change in the understanding of volcanism and volcanic hazards in the Main Ethiopian Rift, greater awareness within the Ethiopian government and stakeholder groups, and valuable capacity building through instrumentation and training of personnel in satellite monitoring techniques*"[5-3].

4. Raising public awareness. UoB's research[3-1] identified significant gaps in public awareness of volcanic hazards, which led the Global Facility for Disaster Reduction and Recovery (GFDRR)'s Challenge Fund Program to fund UoB in leading the VolFilm project (https://vimeo.com/volfilm; USD200,000). VolFilm has produced 14 educational films on volcanic hazards and impacts in six languages. The Smithsonian Institution's volcano outreach specialist[5-10], often considered the world's leading media commentator on volcanology, explains that the films successfully improve people's understanding: "*I saw a clear reduction in the number of questions I was asked when I shared these films… a testament to how successful they are in relaying important information.. crucial to individuals and communities who need to make critical decisions*"[5-10]. The films have been viewed in over 90 countries. For example, Nuevo Mundo[5-11], a media group in Guatemala, shared VolFilm's pyroclastic flow video on Facebook to combat misinformation during the 2018 Fuego eruption. Literacy rates in the area are low and the press and public believed the hazard to be lava rather than pyroclastic flows[5-11]. The video effectively explained the impacts of pyroclastic flows and was subsequently viewed ~2 million times with >40,000 shares[5-11]. Nuevo Mundo state "*this video helped people help themselves*"[5-11], and one viewer commented, "*This is the information that people living around volcanoes need to know!*"[5-11].

5. New models of financing disaster relief. Financial losses from volcanic eruptions between 1980-2019 totalled about USD12 billion globally. Due to the challenges associated with assessing volcanic risk, only USD1.2 billion were insured[2]. UoB's development of volcanic databases and the quantification of global risk in GAR15 has driven the development of novel insurance products. The insurance brokers Willis Towers Watson (WTW) state *"Bristol's work has significantly advanced the potential for volcanic eruption risk modelling and supported the accurate pricing of risk-based insurance policies*"[5-2]. For example, following the publication of GAR15 and the Sendai Framework, the World Bank funded WTW to explore the feasibility of volcanic parametric insurance[5-2]. This insurance is a new product that would provide immediate financing to governments and vulnerable communities during volcanic emergencies. By linking the pay-out to event parameters rather than damage, finance can be released without the need for time-consuming impact assessments. UoB researchers formed part of the WTW-led project consortium and provided the expertise, datasets and risk metrics (e.g. 3.1, 3.2, 3.3) needed to build models for financial decision making. The project developed a Volcanic Risk Financing Roadmap[5-2] and, crucially, led to the development of a World Bank investment case. WTW comment this has significantly advanced "*the potential for parametric insurance policies to be developed by the World Bank and others*"[5-2].

5. Sources to corroborate the impact

5-1. United Nations (2015) Global Assessment Report on Disaster Risk Reduction
5-2. Willis Towers Watson, UK (2020). Corroborating statement – Head of the Climate and Resilience Hub, Science and Policy Practice
5-3. British Geological Survey (BGS), UK (2020). Corroborating statement – Head of Volcanology.
5-4. Department for International Development, UK (2020). Corroborating statement - Team Leader, Early Warning, Risk and Preparedness
5-5. Volcano Disaster Assistance Program, USA (2020). Corroborating statement – Director.
5-6. Instituto Geofisico Escuela Politecnica Nacional (IGEPN), Ecuador (2020). Corroborating statement – Head of Deformation Studies.
5-7. INSIVUMEH, Guatemala (2020). Corroborating statement – Sub-chief Geologist
5-8. GNS Science, New Zealand (2020). Corroborating statement – Volcanic Hazard & Risk Modeller and Volcanic Scientist
5-9. IGSSA, Ethiopia (2020). Corroborating statement – Director.
5-10. Smithsonian Institution Global Volcanism Program, Washington DC, USA (2019). Corroborating statement – Image collection and outreach specialist; Nuevo Mundo Media Group, Guatemala (2020). Corroborating statement (Spanish and English) – Social media manager; Global Facility for Disaster Reduction and Recovery (GFDRR), USA (2019). Corroborating statement – Senior Disaster Risk Management Specialist.

[2] https://www.munichre.com/en/risks/natural-disasters-losses-are-trending-upwards/volcanic-eruptions-the-earths-ring-of-fire.html#111129733