Institution: University of Sheffield

Unit of Assessment: 17B - Geography, Environmental Studies and Archaeology: Geography

Title of case study: More reliable, accurate and cost effective instruments to monitor volcanic activity

1. Summary of the impact

Andrew McGonigle's research is focused on the development of improved techniques for monitoring volcanic gases, data which are vital for assessing hazard levels and issuing pre-eruption evacuation alerts. The instrumentation derived from this research is considerably cheaper, more reliable and accurate and samples far more frequently than possible previously. These devices have been disseminated to at least 25 countries and are now used as internationally adopted standards by governmental agencies in monitoring and forecasting operations. McGonigle's work led to a Rolex Award for Enterprise in 2008, the Award citation stating that "*his combination of science and advanced technology has the potential to save thousands of lives*".

2. Underpinning research

Volcanoes release gases to the atmosphere from their summit craters. Measurements of these emissions are crucial to understanding and predicting volcanic activity. For instance, prior to the 1991 eruption of Mt. Pinatubo a tenfold increase in gas output (flux) was observed, prompting a mass evacuation that saved thousands of lives.

However, in recent years the applied instrumentation (the correlation spectrometer COSPEC) had become rather outdated and unreliable, as it was based on 1970s technology. Volcano monitoring personnel faced increasing costs and lengthy repair times to maintain these units in operation, creating particular issues in developing countries where volcanic risks are high, yet monitoring budgets are modest. The acquired data had very poor time resolutions and large errors (typically 2-3 data points per week, and > 50%, respectively) significantly limiting their usefulness for monitoring purposes.

McGonigle's research has been focused on developing improved instrumentation for monitoring volcanic gases, thereby overcoming the above limitations. In particular, he has defined novel hardware protocols and authored freely downloadable software to enable a compact state of the art commercially available spectrometer (the USB2000) to be used for measuring volcanic gases [R1, R2]. This instrumentation is considerably cheaper, more compact and reliable than the COSPEC (e.g. 1kg vs. 20 kg; $4k vs. $60k), hence is far better suited to volcanic field deployments. The device operates by measuring, at a safe distance from the crater, how much background skylight is absorbed by the released gases, from which emission rates are determined. He has also pioneered new measurement configurations using the USB2000, which significantly increase the time resolution and accuracy of acquisitions [R3].

He has subsequently developed an upgrade to the USB2000-based approach, using ultraviolet cameras [R4], which image the volcanic gas plumes, providing a step change improvement in sampling frequency (to once per second), whilst also delivering a direct and accurate measurement of the speed at which the gases are transported from the summit craters. The plume speed, a required component of the gas emission rate computation, was hitherto obtained using unreliable proxy data from anemometers, constituting the major component of measurement error. On the basis of the above developments flux errors have been reduced from > 50% for the COSPEC, to ≤ 15% for the USB2000 and UV camera approaches [R3, R5].

The above research was conducted by McGonigle at the University of Sheffield, firstly as a RCUK Academic Fellow (2005-2010), and subsequently a Reader, following on from preliminary work at the University of Cambridge where McGonigle was a RA (2001-2002) then NERC Postdoctoral Fellow (2002-2005), in collaboration with Prof. Clive Oppenheimer (Cambridge) and Prof. Bo Galle (Chalmers). This work was supported by a series of grants with McGonigle as PI, e.g. from the Royal Society (2007-2009), the Italian Istituto Nazionale di Geofisica e Vulcanologia (2008-2013), the AXA Research Fund (2010-2011) and the Google Faculty Research Awards program (2013-2014). Other researchers from Sheffield involved in this research include Dr Robert Bryant, two PhD students and a postdoctoral fellow: Dr Euripides Kantzas. In 2008 McGonigle was awarded a $100k Rolex Award for Enterprise for his "*vision, achievement and groundbreaking work*" regarding his volcanic gas instrumentation development work.

The quality and importance of McGonigle's work is further demonstrated by >1220 journal article citations (h-index of 22; Web of Science, October 2013), in fora such as *Nature*, by authors from 59 countries, and in governmental agencies such as NASA, the National Oceanic and Atmospheric Administration and the National Center for Atmospheric Research.

3. References to the research

R1. McGonigle, A.J.S., (2007), Measurement of volcanic SO_2 fluxes with differential optical absorption spectroscopy, *J. Volcanol. Geotherm. Res.,* 162, 111-122. doi: 10.1016/j.jvolgeores.2007.02.001

R2. Kantzas, E.P., A.J.S. McGonigle, G. Tamburello, and R.G. Bryant (2012), UVolc: A software platform for measuring volcanic SO_2 fluxes, *Computers & Geosciences,* 40, 194-199. doi: 10.1016/j.cageo.2011.07.011

R3. McGonigle, A.J.S., A. Aiuppa, M. Ripepe, E.P. Kantzas, and G. Tamburello (2009), Spectroscopic capture of 1 Hz volcanic SO2 fluxes and integration with volcano geophysical data, *Geophys. Res. Lett.,* 36, L21309 doi: 10.1029/2009GL040494

R4. Kantzas, E.P., A.J.S. McGonigle, G. Tamburello, A. Aiuppa, and R.G. Bryant (2010), Protocols for UV camera volcanic SO_2 measurements, *J. Volcanol. Geotherm. Res.*, 194, 55-60. doi: 10.1016/j.jvolgeores.2010.05.003

R5. Tamburello, G., E.P. Kantzas, A.J.S. McGonigle, A. Aiuppa, and G. Giudice (2011), UV camera measurements of fumarole field degassing (La Fossa crater, Vulcano Island), *J. Volcanol. Geotherm. Res.*, 199, 47-52. doi: 10.1016/j.jvolgeores.2010.10.004

4. Details of the impact

The USB2000 has had widespread international reach and is now considered "*the new de facto standard in measuring volcanic gas emission rates*", according to the former Director of the Montserrat Volcano Observatory [S1]. The unit has been deployed to almost every degassing volcano on the planet, in over twenty five countries and on every continent, for operation by volcano observatories, the governmental agencies responsible for volcano monitoring and eruption prediction. Since 2008, well over 10,000 survey days of service have been achieved, in countries such as: Costa Rica, Nicaragua, New Zealand, México, Colombia, Ecuador, El Salvador, France (Réunion), Vanuatu, the Democratic Republic of Congo, the USA, Italy, Russia, Japan, Indonesia and Chile. This technology has particularly expanded access to valuable volcanic gas data across the developing world. For instance, a volcanologist working within the Centre for Volcanology and Geological Hazards Mitigation in Indonesia states that the "*USB2000 is far smaller, lighter and cheaper than the Correlation Spectrometer previously used in this context and as such is far more*

suitable for field operation... For this reason these units have been used extensively now across South East Asia and Oceania, significantly increasing the volume of data we now have on volcanic degassing in the region" [S2].

The techniques devised by McGonigle have led to considerably more accurate and higher time resolution volcanic gas observations than available previously. The significance of this is confirmed by a scientist within the United States Geological Survey (USGS) who states that: "*volcanologists are now able to study far faster and subtler processes than possible previously*" and that "*This means we can monitor volcanoes in far more detail than in the past, with impact upon our capacity to forecast eruptions...These instruments have been used by USGS and extensively across the globe in monitoring operations and are a valued part of the surveillance we perform on the United States volcanoes in order to determine hazard levels in our efforts to ensure appropriate civil protection for US citizens*" [S3].

The former Director of the Montserrat Volcano Observatory further outlines the significance of this enhanced monitoring capability for civil protection measures: "*Hence we now have a far more robust means of constraining activity and the transitions from passive to eruptive behaviour with significant implications for our capacity in forecasting and in civil protection*" [S1]. In addition, a volcanologist within the Italian Istituto Nazionale di Geofisica e Vulcanologia indicates that the operation of these units on the Italian volcanoes has led to "*completely new insights into how these systems work*" and hence a "*far more accurate means of monitoring activity and forecasting eruptions*" [S4]. The USB2000 and UV camera approaches have therefore provided considerably improved models and data to inform monitoring and predictive efforts worldwide.

The international reach of these new methods has been expedited by McGonigle's authoring of a series of freely downloadable computer programs (VolcanoSO2.exe, Vulcamera and UVolc). The programs facilitate the use of the USB2000 (and the recent USB2000+ upgrade) and the UV cameras by volcanologists, the majority of whom are non-expert in the underlying science of spectroscopy and would not be able to benefit from this technology without such codes. A member of the Kamchatka Volcanic Eruption Response Team in Russia comments that: *"we have been using the UVolc software for controlling miniature USB2000+ spectrometers to measure the volcanic gas releases during a number of eruptions"*, and that the code is *"easy to use by non-experts" and "leads to far more accurate results than available previously. This approach to developing no cost software for wide circulation across the volcano community is a great help in ensuring the wide reach of these very helpful new technologies"* [S5]. Since 2008, these programs have been downloaded around 100 times (this corresponds to over 80% of the global user community, which numbers approximately 120), and McGonigle has personally trained volcanologists from Italy, the Philippines, Papua New Guinea, the USA and the UK in his novel hardware and software protocols for measuring volcanic gases.

This impact was recognised in McGonigle's Rolex Award for Enterprise and has led to extensive media coverage through outlets such as the *National Geographic* and *Discovery* channels, the BBC homepage (18 November 2008), and over 1,000 articles in 27 countries in print outlets such as: *The Telegraph*, *The Observer*, *El Pais*, *Le Monde*, *International Herald Tribune*, *Wired*, *Esquire* and *La Repubblica*. McGonigle's research has also been profiled in *Geographical* magazine (February 2009) and Italian *Vogue* where he is cited as "one of the world's foremost volcanologists" and as having caused "a minor revolution in the field".

5. Sources to corroborate the impact

S1. The supporting statement provided by the former Director of the Montserrat Volcano Observatory corroborates the broad international reach of the USB2000 and the significance of the approaches pioneered by McGonigle for improving volcano monitoring and forecasting.

S2. The supporting statement provided by the volcanologist working within the Centre for Volcanology and Geological Hazards Mitigation in Indonesia corroborates the broad international reach of the USB2000, in particular across the developing world, and the benefits of this approach over the predecessor technology.

S3. The supporting statement provided by the scientist within the United States Geological Survey corroborates the broad international reach of the technologies developed by McGonigle, in addition to the significance of them for improved volcano monitoring and forecasting efforts.

S4. The supporting statement provided by the scientist within the Istituto Nazionale di Geofisica e Vulcanologia corroborates the significance of the approaches pioneered by McGonigle in terms of improving the understanding of how volcanoes work and the benefits of this for volcano monitoring and forecasting.

S5. The supporting statement provided by the member of the Kamchatka Volcanic Eruption Response Team in Russia corroborates the user friendly nature of the UVolc code and the benefit this has been to their monitoring efforts.