Institution: The University of Edinburgh

Unit of Assessment: B7 – Earth Systems and Environmental Sciences

Title of case study: OPERATIONAL AND STRATEGIC POLICY FORMATION RELATED TO VOLCANIC HAZARDS IN NORTH-WESTERN EUROPE

1. Summary of the impact

Impacts: I) Operational decision making during the 2010 Eyjafjallajökull eruption, including that of the UK Civil Aviation Authority to relax airspace restrictions over Europe. II) Strategic planning for future volcanic hazards, including the 2012 classification by the UK National Risk Register of Civil Emergencies of Icelandic volcanic eruptions as a 'highest priority risk'.

Significance and reach: The relaxation of airspace restrictions over Europe affected up to ten million travellers and mitigated on-going airline industry costs of up to £130 million per day.

Underpinned by: Research into the size, frequency and dynamics of Icelandic volcanic eruptions, undertaken at the University of Edinburgh (2006 – January 2013).

2. Underpinning research

Numbered references refer to research outputs in Section 3.

Key researchers

The start and end dates of continuous employment in the School of GeoSciences, University of Edinburgh, are shown along with the most recent / current position of each researcher.

Thordarson, Reader in Volcanology (2006 – January 2013)
Stevenson, Royal Society of Edinburgh Research Fellow (2010 onwards)

Research overview and context

Research by the Edinburgh group led by Thordarson over the period 2006 - 2012 has investigated the processes involved in volcanic eruptions in Iceland and their atmospheric and land-surface impacts. This work has focussed on: the dynamics and effects of very large eruptions; the compilation of up-to-date records of historic and Holocene eruptions in Iceland; and the use of ground-based data to evaluate state-of-the-art atmospheric transport models. Taken collectively, the findings allow better understanding and quantification of the risks associated with Icelandic volcanism, in terms of both future eruptions and the real-time assessment of on-going eruptions.

Key research findings that underpin the subsequent impact

The release of volcanic gases during very large volcanic eruptions, of which the 1783-84 Laki eruption is an example, have large and widespread impacts both within the atmosphere and the land surface environment. Work published by Thordarson between 2009 and 2011 utilised computer modelling approaches to better quantify potential European mortality in response to any future Laki-style eruption **[1]** and the intricate system responses following such events, including impacts on cloud formation, which may double the atmospheric perturbation **[2,3]**. Thordarson has also compiled up-to-date records of historic and Holocene eruptions in Iceland, which forms the basis of a highly cited 2007 publication cataloguing the frequency, style, and magnitude of historical Icelandic eruptions and highlighting the need to understand why ash generation by explosive eruptions differs by several orders of magnitude between events **[4]**.

Thordarson led and participated in the fundamental responsive research to the Eyjafjallajökull April 2010 (E2010) eruption, including establishing key eruption parameters from ground-based measurements (funded through a NERC Emergency Grant with Thordarson as PI). These ground-based studies provided the benchmark data to verify and refine the remote sensing methods and atmospheric transport models used in real-time assessment and predictions of the atmospheric ash loading, all elements crucial to determining the restrictions placed on aviation by Icelandic

eruptions. Research findings published in 2012 by a team including Thordarson, Stevenson and colleagues from the University of Iceland showed that current remote sensing methods underestimated the atmospheric mass loading of ash during the E2010 eruption by an order of magnitude **[5]**. Parallel work by Stevenson in partnership with the British Geological Survey characterised the ash fallout within the UK and showed that ash deposition in the UK was dominated by grains too coarse to be recognised by satellite techniques **[6]**.

3. References to the research

Comments in bold on individual outputs give information on the quality of the underpinning research and may include the number of citations (Scopus, up to September 2013) and/or the 2012 Thomson Reuters Journal Impact Factor (JIF). The starred outputs best indicate this quality.

[1]* Peer-reviewed journal article, JIF: 9.7
Schmidt, A., Ostro, B., Carslaw, K.S., Wilson, M., Thordarson, T., Mann, G.W. and Simmons, A.J. (2011) 'Excess mortality in Europe following a future Laki-style Icelandic eruption', *PNAS* 108, 38: 15710–15715, DOI: 10.1073/pnas.1108569108

[2] Peer-reviewed journal article
Schmidt A., Carslaw, K.S., Mann, G.W., Wilson, M., Breider, T.J., Pickering, S.J. and Thordarson T. (2010) 'The impact of the 1783–1784AD Laki eruption on global aerosol formation processes / cloud condensation nuclei', *Atmos. Chem. Phys*. 10, 6025-6041, DOI: 10.5194/acp-10-6025-2010

[3] Peer-reviewed book chapter
Thordarson, T., Rampino, M., Keszthelyi, L. and Self, S. (2009) 'Effects of megascale eruptions on Earth and Mars', in Chapman, M.G., and Keszthelyi, L., eds., Preservation of random megascale events on Mars and Earth: Influence on geologic history, *Geol. Soc. Am. Spec. Paper*. 453, p. 37-53, DOI: 10.1130/2009.453(04)

[4]* Peer-reviewed journal article, >100 citations, JIF: 3.0
Thordarson, T. and Larsen, G. (2007) 'Volcanism in Iceland in Historical Time: Volcano types, eruption styles and eruptive history'. *J. Geodyn.* 43, 1: 118-152, DOI: 10.1016/j.jog.2006.09.005

[5]* Peer-reviewed journal article on the E2010 eruption, >10 citations in one year, JIF: 2.9
Guðmundsson, M.T., Thordarson, T., Höskuldsson, Á., Larsen, G., Björnsson, H., Prata, F.J., Oddsson, B., Magnússon, E., Högnadóttir, T., Petersen, G.N., Hayward, C.L., Stevenson, J.A. and Jónsdóttir, I. (2012) 'Ash generation and distribution from the April-May 2010 eruption of Eyjafjallajökull, Iceland', *Scientific Reports* 2, 572, DOI: 10.1038/srep 00572,

[6] Peer-reviewed journal article
Stevenson, J.A., Loughlin, S., Rae, C., Thordarson, T., Milodowski, A.E., Gilbert, J.S., Harangi, S., Lukács, R., Højgaard, B., Árting, U., Pyne-O'Donnell, S., MacLeod, A., Whitney, B. and Cassidy, M. (2012) 'Distal deposition of tephra from the Eyjafjallajökull 2010 summit eruption', *J. Geophys. Res*. 117, B00C10, DOI: 10.1029/2011JB008904

A further metric of research quality is given by the peer-reviewed grants from UK and Icelandic bodies that have contributed to the preceding outputs, which include:

- *Mapping and sampling of the tephra fallout from the 14 April – on-going eruption at Eyjafjöll volcano, S-Iceland* (2010-2011), sponsor: NERC Emergency Grant RA1339/NERC Ne/I00775x/1, value £64k, awarded to Thordarson.
- *VAST: Volcanism in the Arctic SysTem: Magnitude, Geochronology, and Climate Impacts* (2007-10), sponsor: Rannis Grant of Excellence, value: £250k, awarded to: Geirsdóttir (U. of Iceland) with Thordarson and others.
- *The 2004 eruption at Grímsvötn: A case study of energy fluxes, magma fragmentation and tephra dispersal in a subglacial phreatomagmatic eruption* (2006-08), sponsor: Rannis Grant, value: £80k, awarded to Guðmundsson (U. of Iceland) with Thordarson.

4. Details of the impact

Lettered references relate to corroboration sources in Section 5.

Operational decision making during the Eyjafjallajökull 2010 eruption (Primary Impact)

Pathway, significance and reach: Thordarson and Icelandic colleagues (Guðmundsson, Höskuldsson of U. of Iceland) led the team collecting samples and on-site observations during the E2010 eruption (funded by a NERC Emergency Grant, as listed in Section 3). The on-site results collected by Thordarson's team were delivered, via the U. of Iceland and the Icelandic Met Office **[A,B]**, to the London Volcanic Ash Advisory Centre (VAAC) based in the UK Met Office. The VAAC forecasts the movement of volcanic ash plumes in the UK, Iceland and the north-eastern part of the North Atlantic Ocean, aiding flight safety. The particular observations made by Thordarson's team on 21 April 2010 showed that the level of ash generation had diminished significantly **[A,B]** and hence provided material support for the decision by Civil Aviation Authority, informed by VAAC, to relax airspace restrictions over Europe on 23-24 April 2010. This led to a shortening of the period and extent of closed airspace, which independent sources estimate was affecting up to ten million travellers and costing the airline industry up to £130M per day **[C]**.

Strategic planning for future volcanic hazards (Primary Impact)

Pathway: Thordarson's research on historical Icelandic eruptions has underpinned advice to UK Government on the economic, health and environmental impacts that may arise from future events that are much larger than E2010. In particular, Thordarson was invited to join the UK Cabinet Scientific Advisory Group on Emergencies (SAGE), chaired by the Chief Scientific Adviser, during the E2010 eruption. As a member of the SAGE Volcanic Hazards Assessment Subgroup, Thordarson contributed to the indicative scenarios for the Volcanic Ash Planning Assumptions paper in April 2010 **[D]** and meeting minutes from SAGE in May/June 2012 evidence interaction with the Civil Contingencies Secretariat to develop planning assumptions **[E]**. Thordarson was also "a key person" at The Cabinet Office workshop on 'Effusive Eruption Source Characterisation' (May 2012), contributing to the evidence base for a 'Laki-type eruption' scenario **[F]**. The outcomes of this workshop led to the inclusion, later in 2012, of such eruptions in the UK National Risk Register of Civil Emergencies (NRR). Advice and data provided by the Edinburgh team has also influenced the work of specialists involved in hazard prediction, mitigation and health assessments.

Significance and reach:

- The 2012 NRR document states: "*Following consultation with geological and meteorological experts […] the assessment is that there are two main kinds of risk from volcanic eruptions. The first is an ash-emitting eruption, similar to that in 2010. The second […] which could have widespread impacts on health, agriculture and transport, is an effusive-style eruption on the scale of the 1783–84 Laki eruption in Iceland. This second type of eruption is now one of the highest priority risks in the NRA and the NRR*." **[G]**. This is the first time that the UK NRR of Civil Emergencies has included volcanic risks and the first instance of a European register ranking flood lava eruptions as the principal volcanic threat.
- Thordarson and Stevenson advised the Met Office on changes to the input parameters to their atmospheric dispersion model during the May 2011 Grímsvötn eruption **[H]**.
- Stevenson's work during E2010 paved the way for the development, with the British Geological Survey (BGS), of a citizen-science sampling programme, which was trialled during the Grímsvötn eruption and allows for much improved constraints on distal tephra dispersal, as can be corroborated by the Head of Volcanology at the BGS **[I]**.

Public engagement with, and understanding of, volcanic hazards (Secondary Impact)

Pathway, significance and reach: Between the onset of E2010 and May 2013, Thordarson provided >20 solicited media interviews and was cited in >60 on-line articles (>20 countries), with combined circulations >50M **[J].** Stevenson's popular science blog Volcan01010 (http://all-geo.org/volcan01010/) had 1,200 views per day (from 94 countries) during the Grímsvötn eruption, with content extensively used in news sources such as the *Economist* and *Guardian* **[J]**.

5. Sources to corroborate the impact
Where two web-links are given, the first is the primary source and the second an archived version.

[A] Syn-eruption report to the Icelandic authorities: Memorandum on changes in grain size in the tephra output from Eyjafjallajökull (27th April 2010)
http://tinyurl.com/B7-7-S5-A1 or available upon request. Provides evidence of information passed to the Icelandic Authorities from Thordarson's field-based work during the E2010 eruption, in particular the decline in ash production after 18th April.

[B] Project Manager at Civil Protection and Emergency Management in Iceland
Can provide corroboration that Thordarson's field-based work during E2010 contributed to real-time operational decision making.

[C] Online article in the Guardian (16th April 2010): *"Ash cloud costing airlines £130m a day"*
http://tinyurl.com/B7-7-S5-XC or http://tinyurl.com/B7-7-S5-C
Provides independent evidence of the daily costs for closed airspace to the airline industry.

[D] [text removed for publication]

[E] [text removed for publication]

[F] [text removed for publication]

[G] National Risk Register of Civil Emergencies, 2012 Edition (Cabinet Office)
http://tinyurl.com/B7-7-S5-XG or http://tinyurl.com/B7-7-S5-G Provides evidence of the inclusion of risk from both ash-emitting and effusive-style eruptions into the UK NRR of Civil Emergencies (Pages 8 and 9 for quote, see also Pages 19-21).

[H] Atmospheric Dispersion Research and Response Group Manager, UK Met Office
Can provide corroboration of Thordarson's and Stevenson's input to decisions about Grímsvötn 2011 modelling parameters and Stevenson's impact on the Met Office strategic planning.

[I] Head of Volcanology, British Geological Survey
Can provide corroboration of Stevenson's role in designing sampling methods and integration of data from multiple government agencies, as well as on-going collaboration with the BGS.

[J] Selected media coverage involving key researchers (2011 – January 2013)
I) Thordarson participated in *Doomsday Volcanoes* (January 2013, PBS, circulation 120million), *Birth of Europe – Fire* (April 2012, National Geographic), *Country file: Iceland special* (2012, BBC2) and *Kastljos* (RUV Iceland). The on-line circulation figures quoted are from a Meltwater News search, results from which are available upon request.
II) Examples of on-line articles in May 2011 citing Volcan01010 include one in *The Economist* (circulation >1.4M): http://tinyurl.com/B7-7-S5-XJ1 or http://tinyurl.com/B7-7-S5-J1
and two in *The Guardian* (circulation >300k):
http://tinyurl.com/B7-7-S5-XJ2A or http://tinyurl.com/B7-7-S5-J2,
http://tinyurl.com/B7-7-S5-XJ3A or http://tinyurl.com/B7-7-S5-J3.