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Redesigning hazard communication through technology: collaboration, co-production and coherence

Reconfigurer la communication sur les risques par la technologie: collaboration, coproduction et cohérence

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Redesigning hazard communication through technology: collaboration, co-production and coherence

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Introduction

1 The complexity of hazard networks has increased as technical innovation improves methods of communication between stakeholders. Iceland's network of agencies, designed to both monitor and respond to volcanic events, is an example of this trend. Hazard networks are entities within which stakeholders and agencies communicate at nodal points through the sharing of information (Kamal, 2015; Tucker, 2015). The nodal points in the Icelandic network have evolved in response to new communication practices, which have redefined the mitigation efforts of agencies such as the Icelandic Meteorological Office (IMO) and the Icelandic Civil Protection before, during and after eruptive events. This evolutionary process has repositioned where in the network communication takes place, leading to a redefinition of its configuration of agencies (Guffanti & Tupper, 2014). Iceland is an example of a hazard network within which transparency has led to greater coherence amongst stakeholders from different agencies, and where the co-production of knowledge from both scientific and social perspectives has resulted in information being conveyed in a manner that is reflective of the network

as a whole. Coherence and co-production have encouraged collaborative relations between stakeholders, largely by merging the practices of different agency clusters. Most academic research tends to focus upon the network's monitoring and response practices during a particular event, such as the eruption of Eyjafjallajökull in 2010, rather than explaining how the network evolves between crises. Temporality is significant as it shows how technology has enhanced communication and how stakeholders have become more attached or isolated as a result.

Research aims and intentions

2 Motivation for conducting this research emerged from both a desire to bridge the gap between social science and hazard management, and the need to shed light upon how technology sociologically transforms hazard and risk networks. The research conducted in Iceland questioned:

- How trusted interactions affect the sociology of different stakeholder communities in Iceland's volcanic hazard network?
- How advances in monitoring and response technology between volcanic events have reshaped channels of communication?

3 So, firstly, the research intended to identify and critique the methods through which trusted interactions are established, maintained and reinforced by monitoring and response agencies that have contrasting scientific and/or social interests. Secondly, it aimed to account for the impact of technical innovation and evaluate the extent to which this has affected patterns of communication between volcanic events. Identification of changes in the agency structure, and links to sociology, were the intended outcomes of the research, particularly highlighting developments in distributed decision-making, inter-agency trust, and the uses of social media and crowdsourcing. The research provides a processual narrative for its case study, documenting and evaluating both network and stakeholder changes. In so doing, it contrasts with previous academic critiques of management practices that often disproportionately focus upon the negative elements of stakeholder contestation, risk perception, and conflicts with science. Here, an understanding of the actual process through which hazard management practices evolve is researched. Past experience, and the frequent occurrence of eruptive events in Iceland, demonstrates the need for exhaustive research that accommodates both social and scientific interpretations. This study explores those evolving, technologically mitigated, practices that are changing the structure of Iceland's network, identifying inter-agency partnerships and the reorganisation of stakeholder communities.

Research context

4 A succession of catastrophic events, such as Iceland's Eyjafjallajökull eruption (Guffanti *et al.*, 2012; Bonadonna, 2014) and the Haiti Earthquake, have illustrated the need for greater sociological research on extreme natural hazards in developed and developing contexts. Hazardous environments are too complex for scientists to manage alone (Kendra & Nigg, 2014; De Marchi, 2015) and a multidisciplinary approach is required, potentially allowing for the incorporation of the "*Science and Technology Studies*" field (Jasanoff 2004, 2010), and within it, "*Social Constructivism*" (Stirling, 2008; Bijker *et al.*, 2012). Here, Latour's "*Actor-Network Theory*" (Latour, 1999, 2005) (ANT) appears to be of particular relevance as it

allows for a deconstruction of the network, illustrating the communication channels that exist between stakeholders, whilst also helping to explain and theorise the changes through which Iceland's hazard network has passed.

Key literature

Co-production and technology

5 The involvement of the public in scientific practises has furthered the potentialities of co-produced knowledge. Technical innovation has been a key to the reframing of knowledge emerging from scientists and the public working together to shape the understanding of an event or issue. According to Lane *et al.:*

> "Knowledge is co-produced through a process of dynamic, collective learning involving those for whom an issue is of particular concern." (Lane *et al*., 2011, p. 18)

6 Both Lane *et al.* (2011) and Landström *et al.* (2011) expand this definition by contextualising co-production through the knowledge, representation and outcomes of flood risk management, in the process repositioning the roles of scientists and the lay public. Outlining co-productive practices, such as participatory modelling, Landström *et al.* (2011) illustrate the bridging of knowledge gaps and the strengthening of communication processes that allow for a better transfer of both information and knowledge. Expanding upon the role of technology, Stirling (2008) implies that merging scientists and the public through co-production influences the cultivation of socio-technical knowledge. This study shows how practices that enhance co-production and lead to technical innovation have initiated evolutionary change in Iceland's approach to managing volcanic hazards.

Knowledge controversies

7 Jasanoff's explanation of "*techno-science*" (Jasanoff, 2010, p. 6), and Bijker's "*Social Construction of Technology*" approach (Bijker *et al.,* 2012) imply that knowledge cannot be coherently communicated when science, society or technology are assessed in isolation, as this leads to the transfer of partial knowledge:

> "Technological innovation would not be possible without scientific problem-solving; nor could scientific discovery be imagined without technological means to enable new experimental methods and approaches." (Jasanoff, 2010, p. 6)

8 However, the need for knowledge exchange to be scientifically true, reliable in a technical sense, and understandable to different social publics, means that the construction of coherent models, representations and systems is challenging, but can be furthered through the recognition of "*knowledge controversies*" following a disturbance to society (Whatmore, 2009, p. 587). Knowledge controversies are interpreted as "*generative events*" (Whatmore, 2009, p. 588) by scholars such as Callon and Latour since they can lead to greater public engagement with science, use of technology, and democratic forms of decision-making. Knowledge controversies facilitate the transfer of knowledge by leading to a redistribution of expertise, and by provoking collaboration between "*scientists (natural and social) and affected publics*" (Whatmore, 2009, p. 592). This paper explores the role of knowledge controversies in the evolution of Iceland's volcanic hazard network.

Hazard networks, nodes and evolutions

9 As hazard networks become more collaborative, the number of channels through which to communicate data and information expands. The network itself become so interconnected that nodes form, namely points that coordinate agencies providing and receiving data. Exchanging data through platforms such as a "*Sensor Network Server*" (Hart and Martinez, 2006, p. 178), and the conveyance of information at critical points, are processes through which hazard monitoring and response are managed. Seismic networks provide the best illustration as configurations of algorithms and wireless sensors dictate the positioning of data nodes (Pereira *et al.*, 2014; Fernandez-Steeger *et al.*, 2015), as evident in the networks of volcanic observatories in Ecuador (Welsh, 2006). Data nodes are rarely stable and can be repositioned in response to crises or technical innovation. In fact, changes in technology, media, stakeholders and data can lead to wholescale transformations within networks, integrating science and society at nodal points where information is transferred. An evolving network is influenced by participation, which allows for the "*flexibility to continuously modify goals as participants better realise their needs*" (Cronin *et al.*, 2004, p. 113). This study employs these ideas to outline the evolutions of nodes in Iceland's approach to mitigating risk during volcanic eruptions.

Actor-network theory (ANT)

10 ANT is a sociological approach to networked geographies; it establishes and deconstructs interconnections between actors, the material and conceptual components of a network (Law, 1999). ANT does not privilege a particular type of actor, human or technical. However, Latour views technology as an influential "*agent*" that can provide and enhance "*mobilized*" and "*connected lines*" of communication (Latour, 1993, p. 118). According to Latour, connections between actors are traceable:

> "Every branching, every alignment, every connection can be documented, since it generates tracers." (Latour, 1993, p. 118)

11 Technology directs interconnectivity, holds network's together, and also creates a trace, such as emails or messages that identify points of connection. As information is communicated, it becomes less pure as it is translated by the actors that connect with it:

> "Actors (1) construct common definitions and meanings (2), define representativities, and (3) co-opt each other in the pursuit of individual and collective objectives." (Bardini, 1997, p. 516)

12 Thus, a network evolves and adapts, depending upon the actors within it at any time; they cluster into agency structures, with information ideally bridging actors from scientific, social and technical backgrounds.

Study site: Iceland

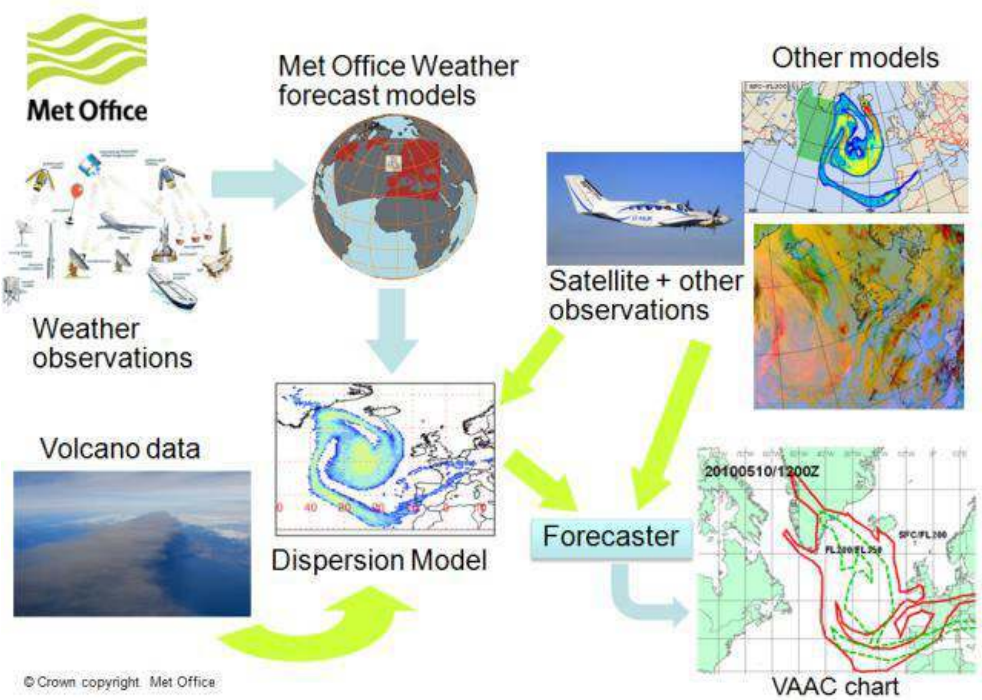
13 This study aims to analyse critically the evolution of Iceland's hazard network between different volcanic events. The study uses social theory to illustrate how trustworthy interactions influence the dynamics of monitoring and response agencies; and to evaluate

technology's impact upon communication channels between volcanic events, in a hazard and risk context that is continually evolving, both technically and socially.

Icelandic relations with the UK

14 Disruption caused by the Eyjafjallajökull eruption in 2010 (Budd *et al.*, 2011, Swindles *et al.*, 2013), and the global attention it received (Burgess, 2012), led to both the Icelandic network being reconfigured at different scales, and the development of collaborative practises that exploited new technical capabilities. The role and actions of UK based agencies, such as the London VAAC *(Volcanic Ash Advisory Centre)*, are of particular relevance (Parker, 2015). The London VAAC manage and distribute data that illustrates the dispersion of airborne ash from Icelandic volcanoes, using *"Numerical Atmospheric-dispersion Modelling Environment" (NAME)* technology (Jones *et al.*, 2007). As demonstrated in 2010, Europe is particularly vulnerable to volcanic activity in Iceland. The UK's National Risk Register recognises that both explosive and effusive hazards present significant natural threats, despite their non-domestic location (National Risk Register, 2015).

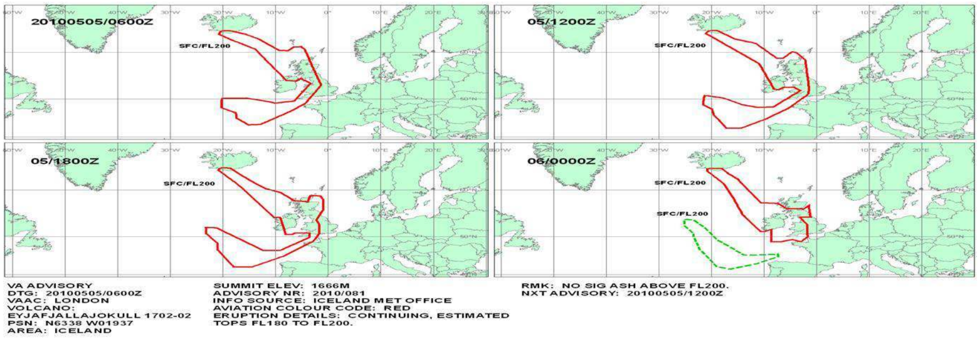
Figure 1. The Meteorological Office's (London VAAC, 2014) role in communicating hazard information with agencies in Iceland.



15 This vulnerability provided the political, social and financial incentive for the UK to take part in coordinated monitoring exercises, such as VOLCICE *(VOLcanic ash crisis exercise in ICEland)*, which was conducted jointly by the IMO (Icelandic Meteorological Office, 2014), London VAAC (2014) and Icelandic Aviation Service *(Isavia)*. Icelandic volcanoes present a regional hazard that, to be managed, requires collaborative engagement between Icelandic and UK based agencies (Reuter, 2014). Figure 1 details the role of the London VAAC.

16 Icelandic volcanoes continue to threaten European aviation. Even a medium scale eruption can have major socio-economic consequences when ash is blown in a southerly direction (Figure 2). The eruptions of Eyjafjallajökull in 2010, and Grímsvötn in 2011, highlighted hazard communication and management deficiencies and fostered the uptake of new technology (Johnson and Jeunemaitre, 2011).

Figure 2. Extract from a VOLCICE monitoring exercise, illustrating the modelled spread of projected movements of volcanic ash.



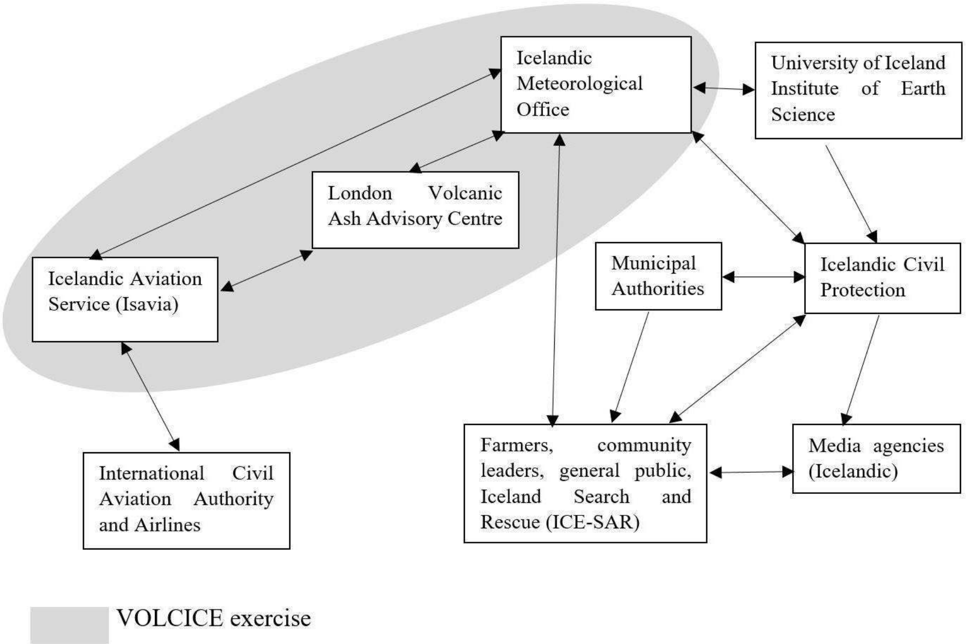
ICELANDIC METEOROLOGICAL OFFICE, 2014

17 The need for continual evaluation of the network set-up, and for maximising efficiency and communication, internationally became clear and, consequently, the network structure entered a phase of rapid change, designing, enforcing and enhancing monitoring and response procedures.

Partnerships and inter-agency trust

18 European-wide projects such as FutureVolc (2014) the Volcanic Ash Scientific Advisory Group (World Meteorological Organisation, 2015), and UK initiatives such as the Natural Hazards Partnership (2013), have worked to improve communication in response to the eruptions of Eyjafjallajökull (2010), Grímsvötn (2011), and Bárðarbunga (2014). One outcome has been an increase in "*inter-agency trust*" (Doyle *et al.*, 2015, 10), formed through the collaborative practices that coordinate actions between agencies, improve the distribution of co-produced knowledge, and enhance the provision of technical resources (Figure 3).

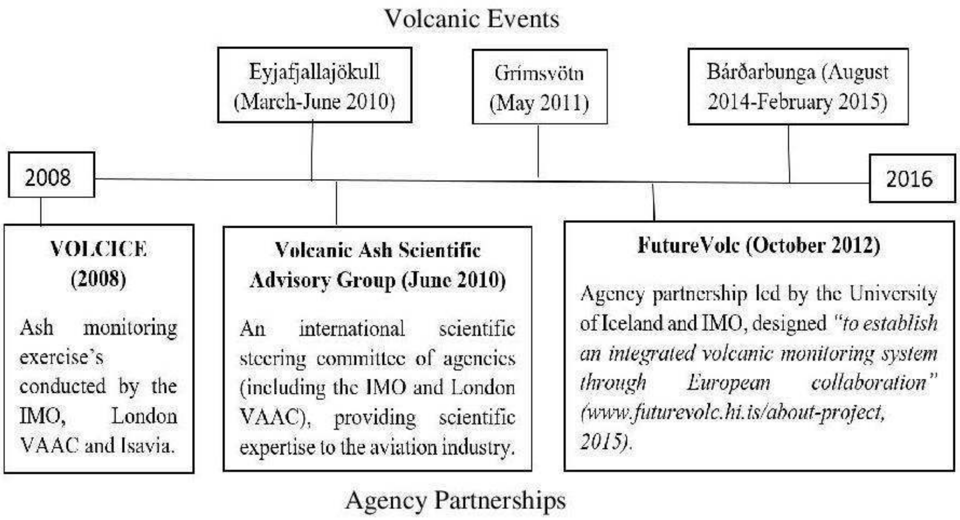
Figure 3. An organisational agency map visualising the knowledge networks and relationships between different agencies.



ARROWS INDICATE THE MAIN COMMUNICATION PATHWAYS FOR HAZARD DATA, INFORMATION AND ADVICE

19 Such continuing partnerships, and exercises such as VOLCICE, influence network evolution by developing trust, consolidating inter-agency relations, and changing the actions and responsibilities of individual stakeholders (Yates and Paquette, 2011; Doyle *et al.*, 2015). Iceland's resulting web of inter-agency connections emerged, largely, as a reaction to volcanic events (Figure 4); this network is a complex of emerging communication channels; these are tailored, locally, to a relatively small but interconnected society with rich understandings of science and high accessibility to hazard information and, internationally, to a plethora of agency partnerships and policies.

Figure 4. A timeline indicating the evolution of agency relationships in relation to volcanic events.



Methods

20 The study adopted a mixed methods approach, incorporating semi-structured interviews and participant observations, which provided scope to integrate an array of stakeholders from contrasting backgrounds across the network. According to Nightingale (2003) and Fielding (2012), mixed methods allow for greater flexibility in collecting and interpreting findings. This approach enabled exploration of both the scientific and social credentials of the network's structure, processes and evolutions. The research involved two fieldwork sessions:

21 • March-April 2014: Five weeks spent in Iceland, during which 37 interviews (Table 1) and 3 observations (Table 4) were conducted in Reykjavík, Vík í Mýrdal *(Vík)* and Höfn í Hornafirði *(Höfn)*.

Table 1. Interview Information Sources (Iceland).

Agency (Number of Interviews)	Location	Role within the Icelandic Hazard Network
Icelandic Meteorological Office (Veðurstofa Íslands) (8)	Reykjavík	Meteorological and natural hazard monitoring
Icelandic Aviation Authority (ISAVIA) (3)	Reykjavík Airport	Service provider for air navigation in Iceland
Institute of Earth Science (Jarðvísindastofnun), University of Iceland, (Háskóli Íslands) (6)	Reykjavík	Research institute for volcanic and earth science
Institute for Sustainability and Interdisciplinary Studies (Stofnun Sæmundar fróða), University of Iceland (Háskóli Íslands) (1)	Reykjavík	Institute coordinating research for advances in sustainable development
Icelandic Civil Protection (Almannavarnir) (4)	Reykjavík	Public service for emergency management and hazard response
Icelandic Red Cross (Rauði krossinn) (2)	Vík	Volunteer society assisting in hazard response
ICE-SAR (Search and Rescue) (3)	Reykjavík, Vík and Höfn	Volunteer Rescue Teams for Hazard Prevention and Response
Environment Agency of Iceland (Umhverfisstofnun) (1)	Reykjavík	Institute promoting public awareness of environmental risks
Reykjavík Metropolitan Police (Lögreglan) (1)	Reykjavík	Reykjavík-based police responsible for the Reykjavík Capital Region
Icelandair (1)	Keflavík Airport	National airline of Iceland with experience of flying during volcanic crises
Farmers, Community Leaders and General Public (7)	Vík and Höfn	Rural communities of stakeholders affected by volcanic activity

22 • August and October 2014: Two week-long periods spent in the UK conducting 13 interviews (Table 2) and 2 observations (Table 4).

Table 2. Interview Information Sources (UK).

Agency (Number of Interviews)	Location	Role within the Icelandic Hazard Network
London Volcanic Ash Advisory Centre (VAAC), Meteorological Office (7)	Exeter and Bournemouth Airport	Institute responsible for forecasting and modelling data of volcanic activity, and issuing advice.
Civil Aviation Authority (CAA) (1)	London	UK aviation regulator and policymaker
Cabinet Office (1)	London	Governmental department responsible for mitigating and overseeing the risk to the UK of volcanic gas
Academic Institutions (4) • Bristol University • University of East Anglia	Bristol and Norwich	UK-based academic institutes playing an active role in monitoring and studying volcanism in Iceland

23 • Between these fieldwork explorations, 14 Skype interviews were conducted online with stakeholders that could not be reached in person (Table 3).

Table 3. Skype Interview Information Sources.

Agency (Number of Skype Interviews)	Role within the Icelandic Hazard Network
Vísir News (1)	Icelandic media agency with coverage of volcanic crises
NetHope Consortium (1)	Alliance of NGO's with the intention of furthering the distribution of hazard information
Volcanic Ash Advisory Centre's (VAAC's) in Wellington, Washington & Montreal (4)	Institutions monitoring volcanic ash plumes, using modelling techniques to advise on airspace conditions in a defined geographical region
International Civil Aviation Organization (2)	Regulatory body for aviation Worldwide, policymaker for mitigating risks from volcanic activity
EasyJet (1)	European airline based in the UK
Academic Institutions (5) • Durham University • University of Cambridge • University of Oxford	Research institutes previously or currently conducting research that relates to Icelandic volcanism

24 Interviews and observations were not conducted in crisis settings, and largely took place at a time of relative quiescence in Iceland, when the only notable issue was media speculation about a potential volcanic event at the stratovolcano, Hekla. Of course, this study would have been difficult to conduct during a crisis as those involved would likely have been too busy to contribute. However, participant observations were conducted in the context of simulation exercises, which showed the patterns of communication upon which the network is constructed. The UK fieldwork was undertaken during the eruption of Bárðarbunga but this was considered largely irrelevant to UK based agencies at the time. Information was sourced from stakeholders with a range of scientific, social, political and economic backgrounds. The lens of interpretation was not dismissive of the natural sciences but analysis is positioned from a sociological perspective. The background of the researcher in using geographical and sociological frameworks, such as social constructivism (Stirling, 2008; Bijker *et al.*, 2012) and ANT (Latour, 1999, 2005), was not shared by most interviewees. However, the mixed methods approach provided the flexibility to account for these contrasts in positionality, understanding and focus (Hesse-Biber, 2010).

Semi-structured interviews

25 64 semi-structured interviews were conducted and were targeted initially at personnel within the IMO, Icelandic Civil Protection, Isavia and University of Iceland (UoI); the IMO

and UoI research and monitor volcanic activity, whereas the Civil Protection are more closely aligned with exchanging knowledge with the general public. Interviews were conducted with the leaders or coordinators of these agencies, with questions designed to encourage interviewees to identify further stakeholders who they regularly communicate with, or who play a significant role in the monitoring or response process. Networking with these stakeholders helped explore connectivity. The close-knit communities of stakeholders made networking relatively problem-free, but replicating this method in less transparent networks would be challenging. Agency headquarters in Reykjavík were the original research site, before extending to the communities of Vík and Höfn, and agencies based in the UK. Problems regarding interviewee availability resulted in the need to carry out some interviews via Skype. A Dictaphone was used to record interviews; if the interviewee objected, then notes were taken in a field diary.

26 Interviews were often carried out in academic or workplace environments, but also took place in public or domestic locations. For anonymity, only the agency to which the interviewee belonged was referenced. Interview durations varied from twenty minutes to two hours, when the semi-structured format provoked in-depth discussion of evolving stakeholder connections. Sensitivity sometimes needed to be exercised, particularly when discussing the political implications of Eyjafjallajökull. Interviews tended to begin with questions targeting the interviewee's roles, expertise and agency set-up. The second part asked more open-ended questions, which probed interactions, mitigation partnerships, opinions on the use of social media, links to agencies in the UK, previous experiences of volcanic crises, and uses of monitoring or response equipment. The final part drew upon how the network and the position of the interviewee within it, was likely to evolve.

Participant observation

27 Three observations were conducted in Iceland, with a further two in the UK (Table 4). Each observation involved shadowing stakeholders and noting their interactions and uses of technology. Icelandic observations took place prior to the Bárðarbunga eruption, with the UK-based observations taking place following its onset. The duration of observations varied depending upon the exercise or activity, for example, an observation of VOLCICE took place over seven hours at the IMO and Isavia, whereas an observation of seismic monitoring equipment at the IMO took only one hour (Table 4). Observations generally took place in agency headquarters and exercise settings, with the only exception being the Meteorological Office Civil Contingencies Aircraft *(MOCCA)* at Bournemouth Airport. Before an observation took place, each of the stakeholders known to be participating, were made aware of the research aims and intentions. During observations, informal exchanges with stakeholders were initiated, and, if given permission, these were recorded on a Dictaphone; questions were asked in order to penetrate the participant's thoughts, opinions and explanations of what was being observed, often in relation to understandings of how the network is shaped, or where communication takes place. Many observed actions could not be orally recorded, so timings, communications and uses of technology were noted in a field diary.

Table 4. Participant Observation Information Sources.

Observation	Location	Participating Institutions (Duration & Date)
VOLcanic Ash in ICEland exercise (VOLCICE), (and debrief).	Reykjavík, Iceland	Icelandic Meteorological Office (Veðurstofa Íslands); Icelandic Aviation Authority (ISAVIA); London VAAC (08.00-15.00, March 2014).
Seismic monitoring equipment and software	Reykjavík	Icelandic Meteorological Office (14.30-15.30, March 2014).
Media facilities and discussion	Reykjavík	Icelandic Civil Protection (Almannavarnir) (14.00-15.00, March 2014).
NAME (Numerical Atmospheric-dispersion Modelling Environment) Model (used in VOLCICE).	Meteorological Office, Exeter	London VAAC (9.30-11.30, October 2014).
MOCCA aircraft guide	Meteorological Office, Bournemouth Airport	Diamond Aviation, Meteorological Office (9.30-12.30, October 2014).

Methodology of analysis

28 Each interview and observation was transcribed from the Dictaphone or field diary following the fieldwork, and transcriptions were stored electronically. Transcriptions were forwarded to participants who requested a copy and they were given the opportunity to remove information deemed unsuitable. Before the data was assessed, a thematic analysis was carried out, using an NVivo software package (Bazeley and Jackson, 2013). Analysing the results proved challenging due to the large quantity of data but transcripts were coded according to interactions between stakeholder communities, opinions of emerging technologies, and representations of trust. Here, direct quotations from interviews and observations have been selected to illustrate stakeholder interactions, demonstrate communication processes and illustrate perceptions of network evolution. Further analysis involved the incorporation of theoretical frameworks such as ANT (Latour, 1993) and Social Constructivism (Bijker *et al.*, 2012) to explain inter-agency collaboration, the coherence of communication and the co-production of knowledge.

Results

29 Interviews and participant observations illustrated evolutions in the key trends and aspects of Iceland's hazard network. Findings show how partnerships and simulation exercises affect inter-agency trust, the use of social media and crowdsourcing, and the flexibility of the network's decision-making.

The development of partnerships and inter-agency trust since Eyjafjallajökull (2010)

30 Interviewees describe the Eyjafjallajökull eruption in 2010 as an event that caused agencies to interact to a much greater extent, encouraging the formation of domestic and international partnerships:

> "Before 2010 I had no idea who was working at the London VAAC, but everything changed and the UK are now our partners, they have several people within the government who are involved." (UoI, 2014)

31 Interviews with IMO coordinators confirmed how the eruption strengthened interactions and led to a closer binding of the IMO and the London VAAC (2014). They note how the lack of clear boundaries between, and flexible structures of, Icelandic agencies, such as the IMO and the Civil Protection, enabled them to collaborate and overlap their actions with others in the network, including the London VAAC and Isavia. Interviewees from the UoI claimed that *"in the aftermath of Eyjafjallajökull"* (UoI, 2014), interagency partnerships such as FutureVolc did more to incorporate UK agencies and bring them in from previously marginal roles. The FutureVolc project was a recurrent theme and interviewees from the IMO and the UoI were particularly keen to discuss its role in constructing a single repository from which stakeholders from social and scientific backgrounds could source hazard information:

> "FutureVolc is about merging information from different techniques, and coming up with a general model or dataset to bring that information forward to everyone." (UoI, 2014)

32 The vast scope of the FutureVolc project was emphasised to illustrate its relevance to the whole network. Interviewees from the UoI also argued that the provision of accessible information had enhanced inter-agency trust, both in Iceland and overseas. Observation of the VOLCICE exercise substantiated such improvements, when a participant was asked a question regarding teamwork, it became apparent that the repetition of these exercise had evolved new practises, cultures and interdependencies among the three participating agencies (IMO, London VAAC and Isavia):

> "We are trying to make sure that we are engaging with each other effectively and regularly so that we get the best results." (London VAAC 2014)

33 Experience and familiarity had been gained from the exercise, which became apparent in the debrief that followed. Occasional tensions may remain between the agencies involved, but the exercise played an important role in consolidating connectivity.

Impacts of social media and crowdsourcing prior to Bárðarbunga (2014)

34 Interviews with the IMO, and communities such as Vík, suggested that social media had enabled information to be communicated fluidly and transparently and many agencies feel that social media will continue expanding:

> "People are creating real-time blogs of earthquake's read by the IMO and tweeting them, I certainly think social media has a lot of potential." (Civil Protection, 2014)

35 Interviews with the public in Höfn also suggest an appreciation of the use of social media by the IMO, adding that it helped create a sense of empowerment. Whilst not referred to explicitly, it would appear that social media is perceived to shift the power-balance. For example, farmers in Southern Iceland claimed that, through social media, they were able, proactively, to distribute information to the IMO in the form of photographs and live updates. The eruption of Bárðarbunga in 2014 effectively illustrated this evolution of social media use:

36 "Social media has enabled us (IMO) to create connections between people and organisations that didn't exist" (IMO, 2014).

37 Many interviewees also referred to the unifying effect of the IMO and Iceland's Civil Protection's expanding use of "tools" (IMO 2014) such as Facebook. However, there are

concerns amongst some interviewees about the quality and excessive quantity of information shared via social media.

> "The problems are how you are going to deal with all that data coming in... if you get ten thousand pictures instead of one, how can you leverage that in a simple way?." (Civil Protection, 2014)

38 Despite such concerns, most interviewees felt that social media platforms were valuable tools.

39 Similarly, crowdsourcing has also expanded public involvement, with the Civil Protection describing it as *"a completely new reality"* (2014). Scientists from the IMO were eager to convey its positive impacts:

> "We are based in Reykjavik and barely in the field, we have people in the areas at risk, so we have started crowdsourcing to monitor what is happening, they send us photographs." (IMO, 2014)

40 Crowdsourcing allows agencies to access the expertise of affected communities and, interviewees claim, its use during Eyjafjallajökull has led to its expansion within Iceland. However, some interviewees at the UoI and the IMO cautioned against exaggerating its efficiency:

> "Crowdsourcing is dependent on how quickly those at the site of the hazard can share photographs with you, and how quickly you can convert the evidence into models." (UoI, 2014)

41 Many interviewees, while positive to the idea, acknowledged the limitations and dependencies associated with the increased use of crowdsourcing in Iceland.

Evolutions in decision-making practices influenced by Eyjafjallajökull (2010)

42 Most of the evolutionary changes outlined so far are linked to improvements in connectivity between scientific experts and end-users. However, the process of decision-making has also changed with many interviewees reporting an increasingly distributed practice since the eruption of Eyjafjallajökull, particularly within the aviation industry:

> "We (Isavia) are losing the responsibility of keeping the aircraft safe from volcanic ash, with decisions being taken by air traffic control and the airlines instead." (Isavia, 2014)

43 This transference of responsibility and decision-making was encouraged by the 2010 eruption, when flaws in the previous set-up became apparent. Subsequently, the role of both Isavia and the aviation authorities transitioned from decision-maker to advisor:

> "We (Isavia) are obliged to provide information, but we have less responsibility because the airlines make the decisions." (Isavia, 2014)

44 Beyond the aviation industry, decision-making has become further distributed as a result of community involvement, a process that began before Eyjafjallajökull, when some farmers in Southern Iceland were given the decision-making power to decide whether or not to evacuate before the eruption. The IMO acknowledge this transition:

> "The more people you include, the broader the system, and this is why any interpretation of decision-making should be viewed as a process built on open communication, it is very important for the people at the site to be a part of the decision-making." (IMO, 2014)

45 In general, the distribution of decision-making powers has changed the role of scientists, particularly in Iceland where, the Civil Protection, working with municipal authorities, acts as the main domestic decision-making agency.

Discussion

46 These results document the evolution of a hazard mitigation network through the construction of collaborative relationships and co-production of knowledge relating to volcanic events.

Trust in inter-agency response management

47 Joint exercises involving new technology have generally improved levels of inter-agency trust, constructing interactions that did not previously exist (Salas *et al.*, 1994). Following Jasanoff's (2004) approach to constructivism, partnerships, projects and advisories have provided an invisible fabric that consolidated inter-agency collaboration in Iceland. Similar evolutions are exemplified through "*community-based disaster risk management*" (Barclay *et al.*, 2008, p. 169) and the processes that created the Volcanic Science Advisory Group (Doyle *et al.*, 2015, p.2; London VAAC, 2014). In addition, the "*one trusted source*" (Doyle, 2015, p. 3) for hazard information, evident through projects such as FutureVolc (2014), has helped to cultivate a coherent approach. In Iceland, such sources have been the result of the Eyjafjallajökull eruption, referred to as a "*Black Swan event*" (Doyle *et al.*, 2015, p. 23). Connections had to be established, a process eased in Iceland by the network's high density of agencies, projects, partnerships and advisories. However, even in a highly interconnected network, disconnects can occur in a time of crisis, particularly between agencies constructed at different scales (Doyle *et al.*, 2015). The increasing contribution of UK-based agencies has meant increased flexibility, but also complexity in the network, so greater collaboration is required for trust to be maintained. The role played by technology in furthering communication and flexibility echoes Latour's interpretation of technical devices in ANT (Latour, 1993).

48 Temporality is also important in inter-agency trust since trust emerges from the construction of situational awareness amongst response agencies. Situational awareness is "*highly temporal in nature*" (Endsley, 1994, p. 32) and part of a "*temporally dynamic process*" (Companion, 1994, p.285). The creation of shared mental models is important in constructing inter-agency trust. There needs to be an "*understanding of each other's knowledge, skills, roles, anticipated behaviour or needs*" (Doyle *et al.*, 2015, p. 7), something that can only develop incrementally with time and regular contact. A final consideration in constructing inter-agency trust relates to the prominence of open access data, which has become a socially constructed expectation amongst response agencies and the wider community. Barclay *et al.* gives an example of the merits of open access data, by detailing the openness, transparency and trust that results from "*deliberative and inclusive processes*" *(DIPs)* (Barclay *et al.*, 2008, p. 172):

> "DIPs can help volcanic risk reduction efforts by increasing trust, by encouraging open deliberations of scientific uncertainty by those likely to be most effective, and by drawing attention to the issues." (Barclay *et al.*, 2008, p. 73)

49 Whilst there are conflicting definitions, the impact of open access data upon the reinforcement of trust among expert advisors, particularly scientists, is unquestionable.

The Icelandic network shows how open access data compliments inter-agency trust by widening access to hazard information, a process further encouraged here by the use of innovative technology.

Social media and crowdsourcing: translating hazard information

50 The key role of social media and crowdsourcing, in the evolution of hazard management practises in Iceland, has itself changed since Eyjafjallajökull. Previously, Sutton *et al.* (2008) and Yates and Paquette (2011) noted the enhanced connectivity of networks that resulted from the use of social media during and following the 2007 wildfires in Southern California and the 2010 Haiti earthquake. Others have highlighted the value of "Volunteered Geographic Information" (VGI) (Dransch *et al.*, 2013), and its use during hazardous events including the Haiti, Canterbury (Doyle *et al.*, 2015), and Nepal (Sanderson & Ramalingam, 2015) earthquakes, and the Tohoku tsunami (Peary *et al.*, 2012). Iceland's Bárðarbunga volcanic event presented a special opportunity to study the role of social media. Here, the collaboration between the IMO and Civil Protection, through the simultaneous use of Facebook to distribute hazard maps and daily update reports, illustrated greater coherence. As Sutton *et al.* suggested:

> "Agency and use of technology and the social structures that support them are mutually reinforcing." (Sutton *et al.*, 2008, p. 630)

51 The structure of the Icelandic network enabled social media and crowdsourcing to impact upon the sharing of knowledge between and beyond official agencies. Zook *et al.* (2010) illustrated the value of crowdsourcing in the relief effort that followed the 2010 Haiti earthquake, where VGI helped *"to bridge the gap between those on the ground in Haiti and those who are far away, but eager to help"* (Zook *et al.*, 2010, p. 18). This reasoning mirrors that in Iceland's IMO and the Civil Protection, who have begun using VGI to reduce the communicative distance between agency headquarters in Reykjavik and affected communities at the site of the hazard.

52 Social media and VGI improve the exposure of hazard information and establish common ground between agencies such as the IMO, UoI and Civil Protection. Social media can improve the *"knowledge management"* (Yates and Paquette, 2011, p. 7) of agencies in Iceland in the same way as it enhanced the coordination of response agencies and the US government after the 2010 Haiti earthquake. Communication has become both more diverse and extensive through the utilisation of *"backchannels"* (Sutton *et al.*, 2008, p. 624) that allow for the real-time distribution of photographic, cartographic and descriptive evidence of volcanic activity. This supports the claim by Zook *et al.* (2010) that hazard network's benefit from multiple means of effective communication. Co-produced knowledge has resulted from social media contributions that represent hazard information from both scientific and social perspectives. Once communicated, such information can be translated and mediated by different end-users, (cf. Latour, 1994). For example, during the 2014 eruption of Bárðarbunga, guidance notices posted on Facebook by the IMO and the Civil Protection represented knowledge that had been translated from models such as NAME. Translation removed the quantitative purity of modelled data, but its communication pathways are traceable through *"likes"* on Facebook and *"retweets"* on Twitter, making agency and stakeholder connections more identifiable (Bruns & Burgess, 2012).

Distributed decision-making: transforming knowledge and action

53 The evolving structure of Iceland's hazard network following Eyjafjallajökull has transformed decision-making by changing the position of nodal points, where hazard information is exchanged, and the responsibilities of agencies are determined. A constructivist interpretation could attribute such changes to the influence and innovation of technology (Jasanoff, 2004), such as the Google Crisis Response platform (Gibson *et al.*, 2015). However, an ANT approach could view changes in decision-making through the distinction between stakeholders with a mediating role (whereby their actions determine the decisions taken), and the intermediaries that communicate with them to provide or source information (Latour, 1994). Through coordination and teamwork, such distinctions can be blurred as the scale of the hazard is often ambiguous and actors are less clearly defined, challenging the boundaries of agencies such as the IMO and the Civil Protection. Paton *et al.* (1998, p. 6) claim:

> "The scale of hazard impact and its multi-jurisdictional implications also signal a need to explore the use of distributed decision-making procedures."

54 Recent transformations in the aviation industry exemplify the impact that scale and jurisdiction have had upon decision-making distributions. Latour's ANT approach suggests that, while aviation authorities such as Isavia in Iceland and the CAA in the UK were previously viewed as mediators, due to their responsibility to open or close airspace in response to volcanic activity, this role has since been renegotiated. Their decision-making responsibilities have been passed to individual airlines, resulting in the process becoming more distributed, and the aviation authorities being downgraded from decision-makers to intermediary advisors.

55 The process of translating hazard information has also energised the distribution of decision-making (Latour, 1999). For example, the UK based Scientific Advisory Group for Emergencies now translate quantitative data from the NAME modelling system into a summary representing the information in both qualitative and quantitative terms. Translation co-produces knowledge and aids a range of decision-makers with different decision-making needs, for example, airline personnel, risk management strategists, politicians, etc. Whilst a *"memorandum of understanding"* (Dash *et al.*, 2013, p. 57) can provide stability in decision-making, in exercises such as VOLCICE, changes in the responsibilities of external agencies show how network roles, connections and stakeholder positions can evolve (Latour, 2005). The ambiguity of decision-making is further highlighted through the significance of *"boundary spanners"* (Owen *et al.*, 2013, p. 9); in complex networks, the overlapping actions of different response agencies continually question the legitimacy of the attribution of decision-making responsibilities.

Conclusions

56 Iceland's volcanic hazard network lacks a clear boundary between society and science. It is characterised by the mergence of stakeholders from contrasting agencies, communities and technologies. The use of sociological narratives provides interdisciplinary frameworks that help assess the power dynamics and configuration of such a network and also highlight the role of technical innovation and trust in knowledge co-production, coherence and collaboration. This has been demonstrated through the evaluation of

changes in inter-agency trust, the use of social media and crowdsourcing, and the distribution of decision-making, between the eruptions of Eyjafjallajökull (2010) and Bárðarbunga (2014). Despite the size of Iceland's network, these conclusions remain case and context specific. They may not be reflective of networks in more politically and demographically challenging areas.

57 However, key conclusions are:

- The attention attributed to the Eyjafjallajökull eruption in 2010, and the flaws within the network, led to a greater distribution of decision-making power, particularly in the aviation industry. Technical innovation and enhanced levels of trust were contributing factors to this transformation thanks to improved situational awareness amongst agencies and the wider translation of data by stakeholders.
- The setting up of partnerships and expert advisories, following the Eyjafjallajökull eruption, and their continuation through the volcanic episode at Bárðarbunga, reinforced levels of inter-agency trust. This was abetted by technical innovation that improved the connectivity and communication between Icelandic and UK based agencies, with open access data being a significant factor.
- The rapid expansion and diversification of social media use and crowdsourcing between the Eyjafjallajökull and Bárðarbunga eruptions transformed communication channels and reduced the distance between affected communities and the agencies monitoring or responding to volcanic activity. Such emerging technologies continue to further VGI and mobilise different stakeholder communities, improving communication, whilst also enhancing trust and transparency.

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ABSTRACTS

Digital and virtual communication impacts increasingly upon the management of natural hazards in an uncertain world, challenging the boundaries between science and society. This study uses sociological theory to explore how technology reduces the mitigation failures and conflicts that scholars often disproportionately prioritise; it also evaluates the evolution of nodal points between communicating stakeholders in a complex hazard management network. Technical innovation has reshaped Iceland’s approach to mitigating risks associated with volcanic events; interconnections between stakeholders within the network evolve through technical innovation and the forming of collaborative engagements that renegotiate the roles and responsibilities of monitoring and response agencies. Interviews and participant observations, with agencies including the Icelandic Meteorological Office, evidence the impact of network evolution upon social media use, inter-agency trust, the expansion of crowdsourcing, and increasingly distributed decision-making frameworks.

La communication numérique et virtuelle impacte de plus en plus la gestion des risques naturels dans un monde instable, défiant les frontières entre science et société. Notre étude étudie, sous l'angle de la sociologie, comment la technologie contribue à réduire les défaillances et les divergences en la matière, auxquels se réfèrent trop souvent les scientifiques. Nous analysons également l'évolution des points nodaux entre les acteurs de la communication à l'intérieur d'un réseau complexe de gestion des risques. En Islande les progrès technologiques ont remodelé l'approche de l'atténuation des risques associés aux événements volcaniques. Les interconnexions entre acteurs du réseau évoluent en fonction des innovations techniques et du développement d'engagements de collaboration qui renégocient les rôles et les responsabilités des organismes de contrôle et d'intervention. Les interviews et les observations des différents organismes, y compris l'Office météorologique d'Islande, démontrent l'impact de l'évolution du réseau sur l'utilisation des médias sociaux, la collaboration entre organismes, l'extension du "crowdsourcing", et la répartition croissante des cadres décisionnels.

INDEX

Mots-clés: coproduction, réseau, risques volcaniques, réseaux sociaux, coopération inter-organismes, Islande
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