‘Riskscapes’ as a heuristic tool for understanding environmental risks: The Eyjafjallajokull volcanic ash cloud of April 2010

Running title: ANT and ash clouds

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Abstract

This paper looks at the 2010 ash cloud event associated with eruption of Eyjafjallajokull volcano in Iceland through the lens of actor network theory. Using this theory the shifting assignment of responsibility for the impact of the ash cloud can be traced amongst the various actors involved in the network focus on UK airspace. Mapping the relations between actors, in terms of their nature and strength, and how these change as the event unfolded can help to analyse the changing power relations and activation of relations to align the network. Understanding the activation of such links under the stress of an extreme environmental event and the network alignment it precipitates could have important implications for managing environmental risks.

Keywords: actor network, risk management, ash cloud, aviation

Introduction

Analysis of environmental risks and their management is an increasing pressing concern and one that requires an understanding of a multitude of complex responses of different human and physical agencies (Alexander, 2002, UNISDR, 2009 a, b). The complexity of understanding and integrating both the physical and human dimensions of risk have been addressed within the consultative framework emerging from the post-2015 Hyogo Framework for Action (HFA). HFA2 for disaster risk reduction explicitly aims to understand risk through '*understanding of the interaction of natural or physical and behavioural factors'* (UNISDR, 2013, p.6). Developing a conceptual framework that can help to address these issues is a key concern in risk management. This paper suggests that recent developments within actor network theory (ANT), particularly as outlined by Neisser (2014), could be of use in making these conceptual issues open to practical analysis.

This paper uses the impact on aviation of the ash cloud resulting from the April 2010 eruption of the Eyjafjallajokull volcano in Iceland as an illustration of how the conceptual or heuristic tool of actor network theory can be used to identify and illustrate the nature of risk to different actors and how the actor network is morphed through the event. The reshaped actor network then becomes the new riskscape upon which any future events and their management are played out. Through understanding the shifting topography of this new riskscape it should be possible to narrow down the range of likely scenarios that will be enacted in the next event thereby aiding the practical management of future risks.

Actor Network Theory and Visualization

The basic tenets of actor network theory have been discussed in depth by Latour (1987, 1996), Callon, (1986), Law, (1986; 1992) and Murdoch (1998) whilst Neiseer (2014) provides a detailed review of the key concepts of relevance to risk management and this paper will highlight those relevant to the issues dealt with in this paper.

ANT is more of a shifting conceptual framework for interpretation than an unified theory. It aids the researcher in identifying and interpreting the patterns and structures that emerge from the complex and dynamic relationships between changing entities. As noted by Latour:

'…*an actant can literally by anything provided it is granted to be the source of action'* (Latour, 1996, p.373).

ANT recognises that entities and relations co-evolve, stabilize and dissolve in a complex spatiotemporal ballet of flows and forms (Callon 1986, Murdoch, 1998). Within environmental risks this means that a seemingly stable entity such as a safety level is open to renegotiation when actors and their relations are stressed. The stable entity acts as an initial barrier to alignment of the network for powerful actors who use their influential position in the network to guide the course of negotiation, setting in motion the process and direction of dissolution of the stable entity towards their own interests. Such activity, however, does not necessarily require new relations or new actors; power may be exerted through the novel use of existing relations between actors and through existing procedures meant to produce stable entities such as safety standards.

The recognition that no single entity can operate without this complex and, in fact is defined and functional because of this complex of relations, means that the distinction between natural and social blurs as does the straight-forward assignment of causality to a single entity in the complex. This means that ANT rejects simple, deterministic explanation from both the natural an social sciences and instead focuses on the coproduction of knowledge that flows from the unfolding of the network.

Actors or actors within networks are '*any element which bends space around itself, makes other elements dependent upon it and translates their will into a language of its own'* (Callon and Latour, 1981, p.286). These elements are linked by relations through which they are both defined and which defines the actions of the network as a whole. This means that any element or entity in the network can not be conceptualised in isolation from all the other entities, elements and relations that enable it to function as part of that relational network. Within this network agency becomes the ability or capacity to affect other elements in the network, to guide, to determine their actions. Similarly causality becomes something spread across the network as causes relates to the actions of a particular set of configurations of the network rather than the simple action and effect of a single entity. This means that there will be no single cause for a risk, but rather that particular configurations of actors and relations will produce risk and so it is the identification and management of configurations that reduce risk rather than management of single actors that should the focus of risk management.

The actions of an actor network arise through the 'process of translation' (Latour, 1990, Murdoch, 1998) which involves the negotiation, transformation and assignment of identities and capacities. Through this process actors become mobilised as part of the network and form a functioning structure through which actions are co-ordinated. Interests of actors are aligned with a focal or focal actors and involves passage of actors through an obligatory passage point (Neisser, 2014) that makes these actors essential for the functioning of the network in that alignment or configuration. In this manner stable relations are established that enable the network to function as a seemingly 'natural' arrangement. 'Inscription' is an important part of the translation process and involves as the negotiated assignment of an actor to the prevailing script or behavioural patterns inscribed by the focal actors or actors (Inkpen et al., 2007). A successful actor network is one in which these processes are virtually invisible, where the network itself and the actors within it view the current configuration of relations as ‘natural’ and unquestioned. It is only when under stress that the ‘natural’ nature of the configuration of a network is questioned.

As Neisser (2014) notes, this approach provides a potentially powerful analytical tool for exploring issues central to risk management such as complexity, uncertainty and ambiguity. Analysing these networks is, however, a difficult task as although you can ‘follow the actors’ (Callon, 1986, Latour, 2005), there may be no set or convenient pattern to the analysis. Description of actions, outcomes and relations within a configuration and their changes as the configuration evolves may provide an insight into the functioning of the network but these descriptions need to be collated to provide a coherent framework for thinking about the actor network. In this respect Peuker (2010, cited in Neisser, 2014) outline of three key questions for actor networks is a useful starting point. Peuker suggests that initially research should focus on the stability and durability of relations at the local level before moving onto the issues of strengthening or weakening relations may strategically establish network structures or configurations. Lastly, the analysis should focus on issues concerning multiplicity difference and fractionality in the network of relations, issues that could fragment the network. In the context of risk management, Neisser (2014) points to this last aspect of analysis as capturing the characteristics of risk – complexity, uncertainty and ambiguity – that risk management of the network will endeavour to dampen or accommodate.

Analysis of actor networks are often undertaken through detailed descriptions of actors and their relations whilst recognising that networks are constructed and reconstructed though flows between actors. The detailed analysis of actor networks is often aided if the network comes under stress as at this time the often latent and unnoticed relations between actors become active and channels for co-ordinating actions. As Latour notes in relation to the practice of science: *'The impossible task of opening the black box is made feasible (if not easy) by moving in time and space until one finds the controversial topic on which scientists and engineers are busy at work. This is the first decision to make: our entry into science and technology must be through the back door of science in the making, not through the more grandiose entrance of ready made science'* (Latour, 1987, p.4). The ash cloud episode provides such an entry point for analysing risk management in the making and, in particular, a malleable network under stress.

Deploying the metaphor of topographies may help to visualise and interpret the dynamics of actor networks. Neisser (2014) notes that the term 'scape' has been used in the literature (e.g. Bickerstaff and Simmon, 2009, Appadurai, 1998, Muller-Mahn and Everts, 2013) but often in a vague sense that is not elaborated upon once the metaphor is mentioned. Given the central role of metaphor in driving understanding (Hofstadter and Sander, 2013) it is important to explore the use of a topographic metaphor in the actor network theory. Inkpen et al. (2007) noted that the landscape metaphor has been widely used in the natural and social sciences as well (e.g. Waddington, 1942, Kaufmann, 2000, Law, 1986, Murdoch, 1998). The metaphor enables the researcher to visualise two distant points or areas coming closer together by the enfolding of the intervening space. The topographic metaphor means that space can be viewed as distortable and dynamic across scales. Entities that form networks become closer to each other as they are inscribed and as their existence becomes increasingly a function of that network with the defining relations become ever more deeply entrenched (as illustrated in Figure 1). As in Inkpen et al. (2007), the metaphor can be used to visualise how the evolution of an actor network warps the topography. Within a relational landscape defined by the actor network strong relations that entrench and stabilize an entity could be thought of as producing deep, valleys within the landscape. As these relations become more entrenched they begin to distort the topography itself moving points and areas towards each other and dragging associated entities with them. Valleys in this topography become analogous to attractors as the network stabilizes relations that ensure the stability of the current entwrok configuration. Entities, howver, inhabit the landscape and deform it by the constant flows between them that are essential to their stability and continued existence. Latour (1997, p.197) suggests that *'time and space are the consequences of the way in which bodies related to one another'* in a topological framework.

Distances across this relational landscape are related to the power of the relations. The further from a valley (representing a set of stable relations) an entity is, the less likely it is to become fully entrenched into the established network. The evolution of this relational topography will result in the development of stable valley systems with flatter, plateau areas where relations are less well established and less constraining on entities. The plateaus represent zones where entities are relatively ambiguous in terms of their inscription into the actor network and can form sites that contest and challenge the prevailing network structure. As the actor network is a constantly evolving the stability of the valleys is not ensured but dependent upon the continued enrolment and inscription of their defining relations between actors. Mapping out actor networks in this manner is similar to the risk cartography used by Beck and Kropp (2011) in relation to identifying and mapping infrastructures of risk. In the context of the risk of the ash cloud, the initial safety standard of ash concentration appears to be well inscribed and located within a deep valley of relations define by the Civil Aviation Authority (CAA). As the crisis develops the seemingly fixed and technical nature of the standard emerges as a more contested entity. The safety standard becomes an entity on a plateau, suddenly open to relations that highlight and play upon its fluidity as a social construct. The technical standard performs what appears to be a minor task of summarising technological understanding of the relation between ash and engines into a simple safety level. As Latour (1991) notes, however, this delegation of the activities of many actors in the network to a single, technical entity is a social as much as a technological act and this entity begins to unravel as its nature is contested by the same actors who had delegated their authority to it.

Actor Network of Ash Cloud

Figure 2 outlines the actor network of the ash cloud at the beginning of the eruption on 14th April 2010. The time line of the eruption and its impact has been clearly documented elsewhere (Sammonds et al., 2010, Petersen, 2010, Schumann et al., 2010) including the tele-conferences held by the CAA during April with the various actors in Table 1. The ash cloud event (referred to as E15 by the CAA as noted in Hutter and Lloyd-Bostock, 2013) is a useful candidate for analysis using ANT as at its heart is the negotiation of the meaning of risk and safety within a physical entity, the airspace. The airspace is the focus of the actor network in Figure 2 as this is the physical and conceptual space within which the actions of all the actors are played out. Each actor has a different relation to the airspace which affects how they perceive the risk posed by the ash cloud. The volcano ejects ash into the airspace, so the airspace is a temporary store for the physical entity of ash. The ash, however, has specify physical characteristics as outlined by Sammonds et al. (2010) related to the physical characteristics of the volcano, the eruption intensity and the magma source feeding it. The specific volcano has a context of its own eruption history and the eruption history of Icelandic volcanoes which impact upon the predictability of eruptions of this type.

Ash in the airspace is also dependent upon the prevailing meteorological conditions of the airspace and its relation to the volcanic eruption. Sammonds et al. (2010) state that periods of north to northwesterly airflow from Iceland occur about 6% of the time although this may be considered a conservative estimate. Physically, the storage and transportation of this type of ash from this volcano into European airspace is an unusual although not unpredictable event (Sammonds et al., 2010). As long as the combination of volcanic eruption and prevailing meteorological conditions continued then the characteristics of the ash in the atmosphere would not alter.

The CAA has a legal and regulatory relationship to airspace whilst NATS provides air traffic control services for the airspace. Both are key actors in the closing of the airspace as this entailed the restriction of provision of air traffic services as stated within guidance provided by the ICAO (International Civil Aviation Organization) concerning airspaces affected by volcanic ash (Hutter and Lloyd-Bostock, 2013). The ICAO guidance of ash cloud was to avoid and a policy of zero ash concentration was the basis of the guidance. The implementation of the ICAO guidance changed the relation of the other actors to the airspace such as commercial airlines that could no longer fly through it, as well as throwing into sharper focus existing relations such as the monitoring and modelling of the airspace by the Met Office. In actor network terms, the regulation of airspace by the CAA and NATS is deeply entrenched and restricts, through their legal right to enforce safety, elimination of the use of the airspace by airlines.

The crisis evolved as the implications and impacts of the regulation of airspace on other actors became clearer. In this developmental process the risk present in the airspace became the subject of negotiation and the focus for competing perceptions of the risk (see Hutter and Lloyd-Bostcok, 2013, for a fuller discussion of the evolution and resolution of the regulatory issue as well as a discussion on the lines of funding for organisations). Actors in the network embark on actions that will activate latent relations to renegotiation their own and CAA/NATS relations to the airspace in order to align the network to their requirements with the key objective of opening up their pre-existing relations to the airspace, i.e. getting their commercial flights back in the air. The strategies of different actor can be analysed by following their actions and use of latent relations.

The commercial airlines were initially quietly compliant with the closure of the airspace. As the duration of the crisis increased this altered and they challenged the relationship of specific actors in the network to the airspace. The Met Office modelling of the airspace was challenged through the media (e.g. Guardian report, 2010, Telegraph report, 2010a and b) and through the use of special flights by airlines to illustrate the lack of ash risk within the closed airspace. The challenges focused on the scientific responsibility for the definition of the problem that seemed to lay with the Met Office. The challenges used a model of science as an accurate and fact-based process to question the modelling used by the Met Office to predict ash concentrations in the airspace. The inherent uncertainties in the modelling of physical reality were mentioned by the Met Office but were often interpreted as confirming the concerns of the airlines about the lack of rigour in the science. Challenging the privileged scientific relation of the Met Office to the airspace was a strategy employed to bring into doubt the physical reality of the ash risk and to put pressure on the Met Office though the public arena via the media and though the government as sponsor of the Met Office. The success of this strategy can be illustrated by the response of the Met Office in undertaking more intensive monitoring of the airspace as well as commissioning more flights to gather more data to confirm their modelling.

The impetus of the airlines to challenge the prevailing relations could be viewed in the context of their perception of the ash cloud risk relative to the economic risk imposed by the closure of airspace. The ash cloud, from their perspective, was a relatively small risk to any individual flight and one that was unquantifiable and abstract as well as being a risk over which they had no clear control or responsibility. The increasing and cumulative risk of economic damage that the day to day grounding of their aircraft caused would, however, be more visible to the airlines and one over which they had a clearer responsibility and ability to act upon. The cumulative economic impact of the ash cloud risk became a small but increasing risk to the airlines as the consequences of the grounding of planes produced actions that reflected the corporate responsibility of these actors. It provided the impetus to activate latent relations to try to align the network to alter the impact of the ash cloud risk. The physical nature of the risk could not be altered in the sense that the volcanic eruption and continued prevailing meteorological conditions were beyond the control of any agency. The definition of the risk as defined through a safety standard, was more amendable to negotiation hence the activation of the media and the questioning of the modelling of ash concentrations.

It is interesting to note that the airlines did not respond as a single actor but had differentiated access to the negotiation process as noted by Hutter and Lloyd-Bostock (2013). Low cost airlines such as Easyjet initially had no place or input into the tele-conferences with the CAA despite having the largest number of short-haul flights in the affected airspace. This reflects that, initially at least, the pre-existing network of relations between actors involved in the aviation sector, with privileged access for preferred airlines, was maintained in the network that developed to resolve the regulation crisis. Hutter and Lloyd-Bostock also note that the airlines involved in the negotiation process with the CAA were cooperative rather than confrontational, reflecting a difference in stance between their public and private approaches to activating and using relations to align the network to their ends. The airlines had different strategies for aligning the network depending upon the nature of the relations between themselves and other actors. In the case of the CAA a formal setting constrained or even defined the nature of acceptable actions that could be taken and so the form of negotiation.

The renegotiation of the risk of the ash cloud seems to have hinged on the ability of all parties to move the burden on responsibility away from challenges to the science and regulation of the risk to the engineering aspects of the aircraft. The involvement of aircraft and engine manufacturers from the first teleconference hosted by the CAA illustrates their central role in the redefinition of risk. It was not until 20th April, however, that these actors stated that aircraft and engines would tolerate operating in ash concentrations of $2x10^{-3}$ g/m^3. The joint statement released on 20th April (https://www.caa.co.uk/docs/1357/F0000977DisclosureLog.pdf) highlights the importance of attributing responsibility for the risk in the minds of the participants. The third point states the new safe limit for ash concentrations **and** the use of the Met Office scientific models that predict its locations. Preceding this point are two others that highlight the lack of available data for making any decision concerning safety and safety measures in place before the present crisis. The data upon which the new safe level were based, the detailed examination of past ash cloud encounters (particularly the aircraft encounter with the Mount Redoubt eruption in 1989 and the KLM B747-400 incident in the same year), are the same data that had been used to justify the zero concentration policy of the ICAO. The ICAO policy seemed to be based on precaution rather than known safety concerns at low concentrations of ash as was confirmed by the advisors from the FAA and US Weather Service.

The new standard represented the limit to which the aircraft and engine manufacturers were prepared to concede without further data or analysis of the impact of ash concentrations on airframe and engines. The timescale within which a decision was required were not sufficient to undertake any detailed scientific analysis or new experiments. Such analyses would be expected to form the scientific and empirical basis for defining operational limits. Importantly, such analyses would form the scientific basis for arguing that any adverse result of applying these limits was not the responsibility of these actors. The responsibility for such adverse effects would then have to be sought outside of the actions of these actors such as with the actions of the captain, maintenance schedules and the like.

Figure 3 outlines how the new limits were dependent upon a redefinition of responsibility by the actors and illustrated a change in the entrenched nature of relations between actors. The CAA retains its clear legal responsibility for the defining the risk in the airspace and hence deciding if the risk forces it closure. Aircraft and engine manufacturers had previously had a minor role in the responsibility for the decision as the zero tolerance level was based on a clear pre-cautionary principle from the ICAO. Demands, from different actors, to identify a specific tolerable fly limit has forced both these actors into having a share of the responsibility for defining the risk within the airspace. Willingness to participate in this negotiation is, like the airlines, based on the relative significance of the risk posed by a rare ash event relative to the increased economic risk of losing custom from the airlines should the no fly policy affect their economic viability. Aircraft and engine manufactures have therefore taken on an aspect of responsibility for defining the risk and so, potentially, the liability should this definition prove to be erroneous.

In the figure, the changing nature of relations between actors can be visualized. Aircraft and engine manufacturers have deeply entrenched relations to the airlines; their mutual dependence is clear. The relation to the CAA for assessing the ash risk is a new one but one that benefits from established relations from the safety context. The aircraft and engine manufacturers are taking on a new role by providing technical assurance of the risk associated with a specific concentration of ash. Ideally this assurance would be based on scientific analysis of data associated with real incidents plus appropriate experimental work. Such a framework of empirical and experimental data would mirror the existing approach to defining safety within this sector hence the detailed discussion of the lack of such data within the joint statement. The aircraft and engine manufacturers have now taken on a role in defining the safe level of ash through stating the technical standard, adding a further dimension to definition of this risk. Hutter and Lloyd-Bostock (2013) highlight the importance of this new responsibility for defining risk through the quote from the Chief Executive of the CAA, Andrew Haines in an interview on Radio 4 on 3rd May 2010:

'If we've had the assurances from manufacturers that we have now at the start of the crisis, the response would have been different …. I suspect that the manufacturers knew there *was an acceptable level of safety but what hadn't happened is that they were prepared to underwrite that and validate it'.*

The new relation between the CAA and aircraft and engine manufacturers in terms of responsibility also forces the forging of a change in the nature of the relations between the other actors. As noted in the joint statement, the Met Office retains responsibility for defining the presence of the ash risk but now has the additional requirement to identify and map different levels of ash concentration. The technical ability to do this plus the ability of the current modelling to undertake such detailed analysis are new requirements in the Met Office's relationship to the other actors. The CAA now has a different relationship to ash risk in the airspace as it now sees it as a spatially differentiated risk and a risk that is now more complicated to identify . The airlines have a more nuanced airspace for their aircrews to navigate through and so have changed the nature and risk of flying in relation to an ash cloud. In addition, the airlines may have resolved a short-term economic risk but may have to change their maintenance schedules to ensure that there is no cumulative damage to the airframe or engines caused by flying through low concentrations of ash. In this analysis the airlines perceive the longer term risk as acceptable and may even subsume it within their general concept of long-term ‘wear and tear’ and so remove it completely from their analysis of ash risk.

Entrenchment and Evolution

The evolution of the actor network means that the risk of an ash cloud evolves as well. As new relations are established and become entrenched then the potential evolution of the actor network becomes constrained. Since event E15 there have been a series of developments that highlight the continued entrenchment of the new relations and their incorporation and legitimation within existing networks of particular actors.

In the immediate aftermath of the incident the ICAO produced a number of working papers specifically to address issues concerning safe ash concentrations (e.g. IVATF, 2010a, IVATF 2010b and Volcanic Ash Contingency Plan, 2014). Working paper IVATF/1-WP/13 (IVATF, 2010a) produced at the first meeting of the International Volcanic Ash Task Force (IVAF) pointed out the lack of key scientific information and standardized testing concerning the airworthiness of aircraft in low ash concentrations. It also highlights the additional complexity in certification and operational complexity the specification of any low concentration limit would involve. This implies that the actor network needs to evolve throughout the whole aviation network to accommodate the change in ash risk definition. This is also seen by the ICAO issuing on 12th July 2010 a State Letter differentiating ash contamination into three levels of low ($2x10^{-3}$ g/m^3 or less), medium (more than $2x10^{-3}$ but less than $4x10^{-3}$ g/m^3) and high (above $4x10^{-3}$ g/m^3) thus moving away from its zero concentration policy (Working paper IVATF/1-WP/21- IVAFT, 2010b). This immediately means that the CAA is able to define the ash risk with reference to a new set of guidelines that provide more flexibility to keep the airspace open in a volcanic event. The new guidelines also put more demands on each VAAC to provide information on ash concentrations and cloud movements. The working paper is at pains to point out that the VAAC need to supply enhanced products capable of interpretation by operators and is concerned about the conservative nature of the models used but notes that since E15 there have been work to improve information on model parameters.

By the publication of the Volcanic Ash Contingency Plan: North Atlantic Region in 2014, the dissipation of responsibility for the identifying and defining the ash risk had filtered through the aviation network and specific roles assigned. Section 4 of the report outlines these with, for example, pilots now expected to provide as much detailed information as possible on the nature of the volcanic contamination and record this on a standardised form. This information is then disseminated through to relevant VAAC and meteorological organizations to aid in modelling. Likewise, similar standardised reports are to be completed by post-flight inspections, maintenance with all the data gathered and stored in a global data repository to aid in the analysis of the impact of ash on airframes and engines. These new procedures have not resulted from a change in the relations within the actor network but rather have used existing relations concerning pilot reporting, maintenance logs and the aviation organisations to provide a conduit for the collation of information deemed relevant to modelling ash cloud dynamics and to the impact of ash on aircraft. This has dissipated responsibility for risk identification and definition across the network through the formalization of data collection and collation, focusing on defining what is acceptable as data about ash events. On the basis of this information network the ICAO will review safety policy in relation to ash clouds, largely using the existing network of actors and relations.

Awareness of the risk associated with ash clouds now has a prominent place in the ICAO. Risk definition of ash has been dispersed across the existing actor network of the aviation industry. The CAA retain the regulatory authority for airspace closure but their responsibility is based on an underlying network of actors all with clear roles that feed information to other actors capable of defining tolerances of aircraft to ash as well as the modelling dynamics of the ash cloud itself. Closure of airspace may still reside with one organization but justification for that decision is now dispersed and fragmented so making it less clear where ‘blame’ lies. Redefining the ash cloud risk has slightly shrunk the CAA responsibility for air closure whilst the expanding the defining responsibilities for other actors which now occupy part of their normal operating conditions. The risk of an ash cloud seems to have been successful incorporated into the general risk management behaviour of the network. The event E15 seems to have generated little change in the network. The move from zero concentrations to identifying a ‘safe’ or ‘tolerable’ concentration of dust may, however, be viewed differently. Brannigan (2011), for example, views this movement as an illustration of an emerging paradigm within the aviation industry from one where air safety was focused on passenger safety to a new paradigm that privilege protecting airlines from disruption.

Conclusion

This paper outlines how mapping actor networks could be used to visualise the evolution of power relations as the impact of an environmental event unfolds. Using the metaphor of topography the establishment of a stable network of relations and entities provides a deeply entrenched valley which translates and inscribes practices and behaviour to maintain its existence. Getting out of the valley is difficult as it involves breaking away from the established relations that help to define the entity. The emergence of a safe level of ash for flying represents a negotiation over the definition of a safety level between different actors, representing a set of deeply entrenched by connected valleys in the landscape metaphor. Initially the safe concentration of ash was clearly defined and entrenched within the authority of the CAA.

For the ash cloud from the Eyjafjallajokull volcano, the interests of all the actors converge on the airspace where their relations became intertwined and, as the crisis evolved, relations were activated to renegotiate the definition of ‘safe levels’ in relation to ash concentrations. The CAA was the key actor with legal responsibility for the safety of the airspace but it began a process of diversifying the nature of this responsibility through active engagement with other actors such as airlines and engine manufacturers to redefine what was meant by the term ‘safe’ in the context of a crisis that was cumulatively impacting upon the stability of the actors. The inclusion of engine manufacturers was critical in this process of network alignment as their reinterpretation of existing information permitted a change in the strict definition safe ash levels. Although responsibility for declaring the airspace 'safe' still lay with the CAA, the negotiation process meant that any decision now had a clear line to evidence from engine manufacturers as its basis. 'Safe' ash levels is now a negotiated term defined by and aligned to the network and its powerful actors.

The redefinition of 'safety' in this context has become embedded within the existing protocols and practices of the different actors. Identification and monitoring of ash concentration is now part of the normal practice of reporting for pilots. Engine maintenance will now consider potential ash damage as a standard part of protocols. The Met Office will need to develop differentiated modelling for ash concentrations and the CAA will employ a differentiated protocol to closing airspace. The entity of 'safe levels' is still within the valley of the CAA responsibility, but its links to the other actors have been activated and more fully developed than before and this has resulted in the emergence of practices by other actors that not only link them more stronger to the entity but also are instrumental in defining it.

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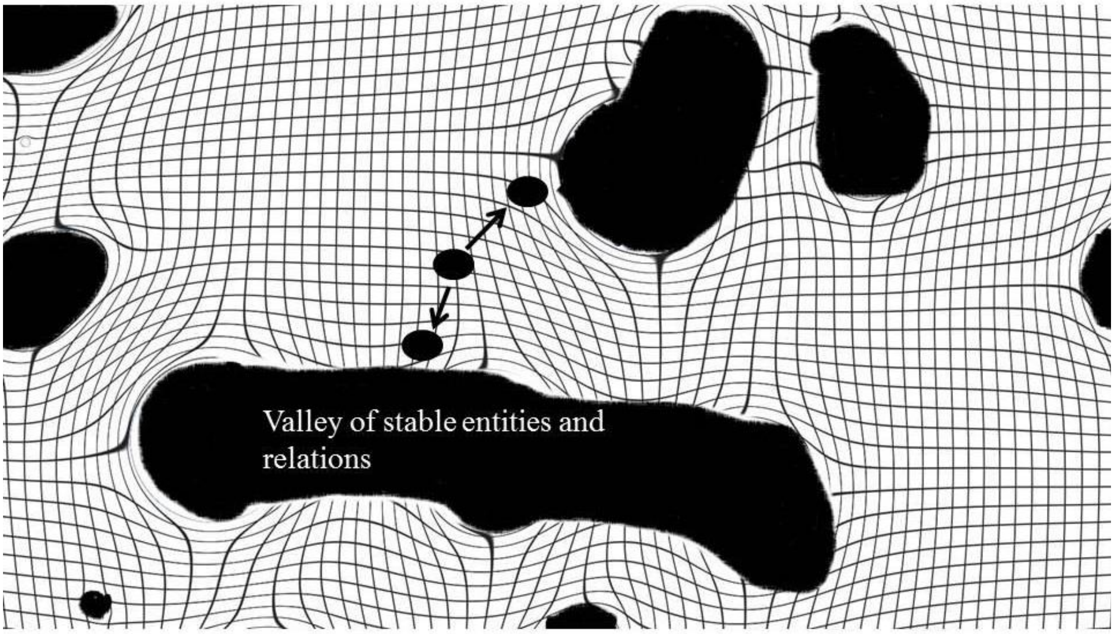
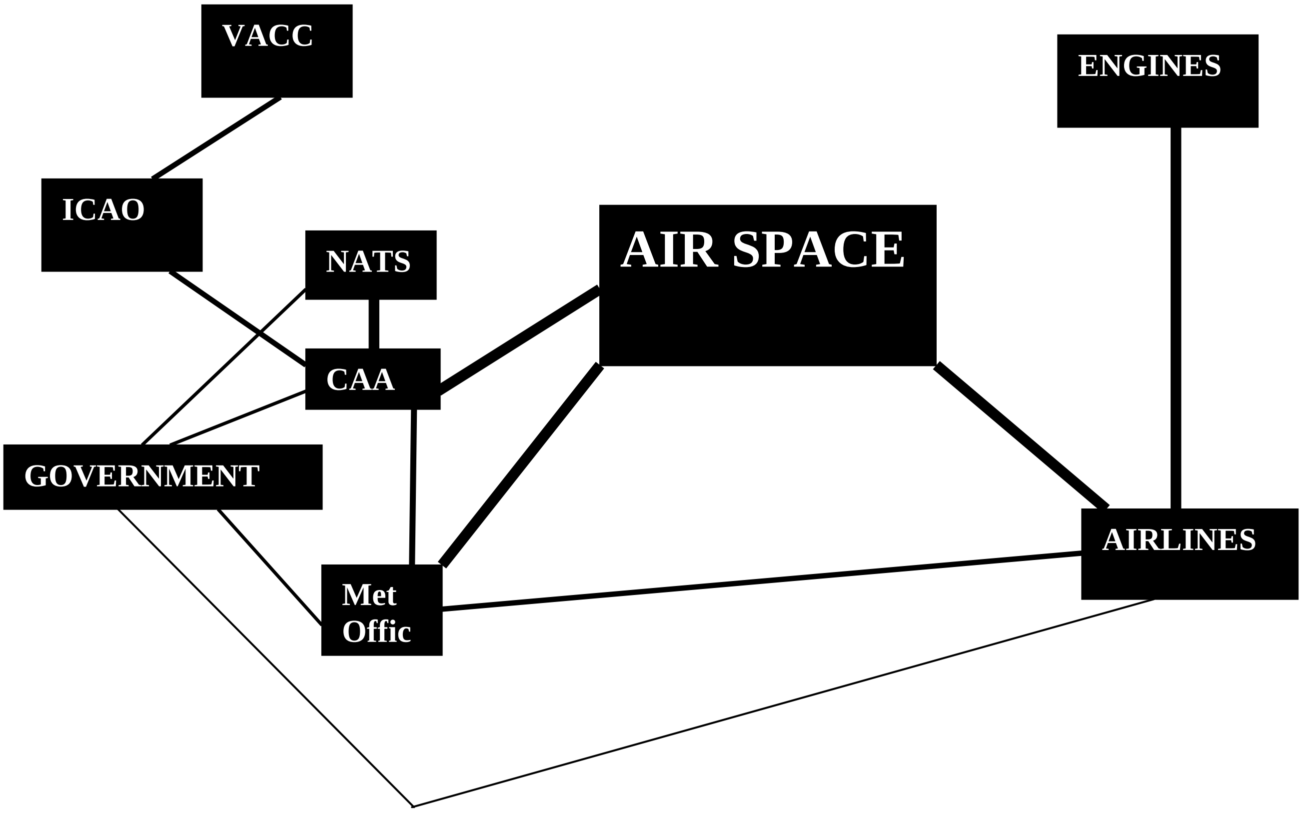
Figure 1 Visualization of topographic metaphor in actor network. The black valleys represent entrenched, stable entities and relations that define particular actors in the network. The black spot on the plateau region represents an entity whose definition is contested and which could move towards either valley depending on the negotiations and power relations s between the actors.

Figure 2 Representation of the actor network for the ash cloud event. The thickness of the lines represents the strength and activity of relations.

Figure 3 Representation of the actor network for the ash cloud event as the crisis evolved. The increased strengthening and activation of links between airlines, engine manufacturers and the CAA is observed as is their increased proximity representing their increased connectivity in negotiation the new safe level of ash concentration.


Valley of stable entities and relations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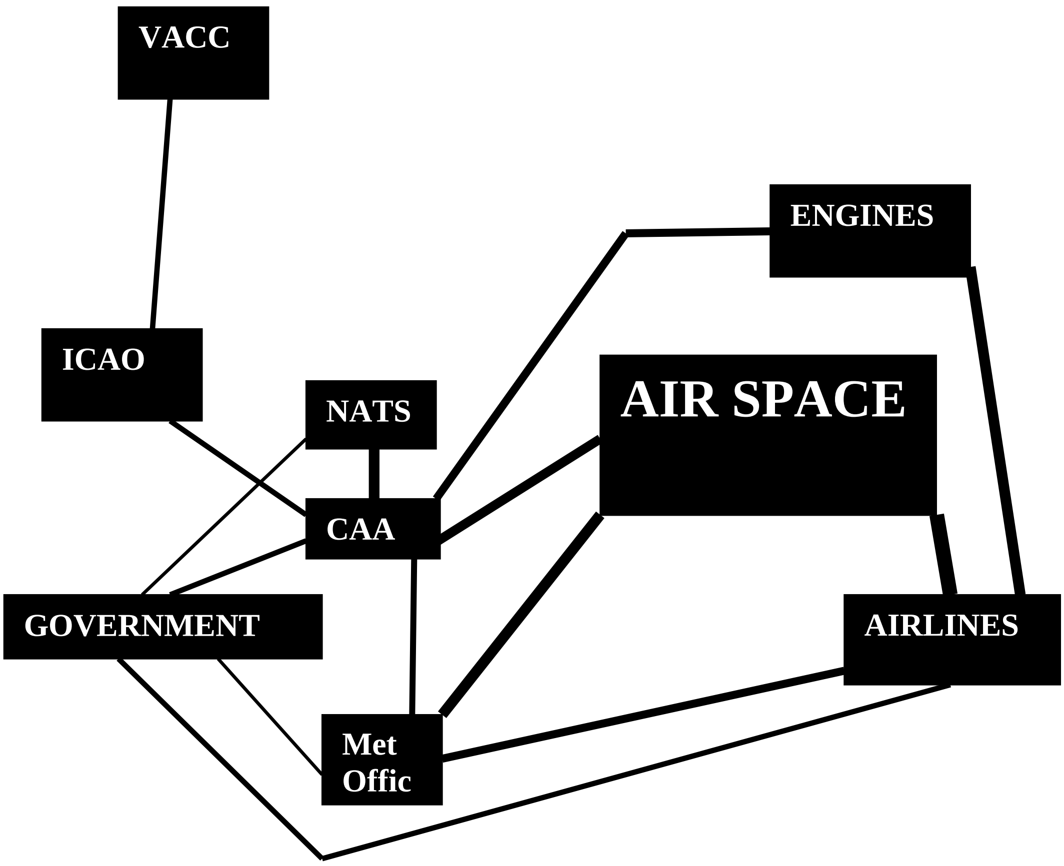
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Organisations	**Call 1**	**Call 2**	**Call 3**	**Call 4**	**Call 5**	**Call 6**	**Linked**
Airframe Manufacturers							
Airbus	X	X	X	X	X	X	
ATR							X
BAE Systems – Regional Aircraft					X	X	
Boeing	X	X	X	X	X	X	
Bombardier Aerospace				X	X	X	
Bombardier Shorts Brothers				X	X	X	
Cessna Textron							X
Dassault					X	X	
Embraer				X	X	X	
Gulfstream							X
Engine Manufacturers							
General Electric	X	X	X	X	X	X	
Honeywell International				X	X	X	
International Aero Engines						X	
Pratt and Whitney	X	X	X	X	X	X	
Pratt and Whitney Canada			X	X	X	X	
Rolls Royce	X	X	X	X	X	X	
SNECMA		X	X	X	X	X	
Williams International							X
Air Navigation Service Providers							
Eurocontrol	X						
FAA Air Traffic Control	X	X	X	X	X	X	
Metro France (Toulouse VAAC)		X		X			
Met Office, Iceland							X
Met Office, Netherlands		X			X		
Met Office, UK (London (VAAC)	X	X	X	X	X	X	
NOAA (Anchorage VAAC and Washington VAAC)	X	X	X	X	X	X	
NATS	X	X					
US Air Force Met Service						X	
Scientific Agencies							
CEV	X						
Chief Scientific Adviser, UK				X	X	X	
FAA Weather Group	X	X	X	X	X	X	
Facility for Airborne Atmospheric Sciences, UK (FAAM)	X	X	X	X	X	X	
NCAS		X	X	X	X	X	
NERC	X						
NLR, German Research Centre					X		

USGS						X	
Operators							
Air Canada						X	
Air France						X	
Astraeus							X
British Airways	X		X		X		
EasyJet							X
FlyBe				X	X	X	
Bmi					X	X	
Lufthansa				X	X	X	
Monarch				X	X	X	
Ryanair						X	
Thomas Cook				X	X	X	
Thomson Airways				X			
United Airlines						X	X
Virgin Atlantic					X	X	
Representative Bodies							
Aerospace Industries Association						X	
General Aviation Manufacturers Association						X	
Oil & Gas UK							X
Regulators							
AESA, Spain			X	X	X	X	
CAA, Netherlands	X	X	X	X			
CAA, Norway				X			
CAA, UK	X	X	X	X	X	X	
DGAC, France	X	X	X	X	X	X	
EASA	X	X	X	X	X	X	
FAA Airworthiness Certification	X	X	X	X	X	X	
Irish Aviation Authority			X	X	X	X	
MAA, UK Military Aviation Authority				X	X	X	
Transport Canada				X	X		
UK DfT		X	X	X		X	

Conference calls from Saturday 17 to Friday 23 April 2010 (no call on 21 April). Linked organisations were in contact with the proceedings.

Source: Kelleher, P. 2010. Volcanic Ash International Teleconference 17-23 April, 2010