Increasing resilience to natural hazards through crowd-sourcing in St. Vincent and the Grenadines

Information and Environmental Modelling Programme, Geohazards Programme

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SW corner 999999,999999
Centre point 999999,999999
NE corner 999999,999999

Map

Sheet 999, 1:99 000 scale, Map name

Front cover

The town at the end of the road: the remote village of Fancy, the northernmost settlement on St. Vincent, in the shadow of Soufrière St. Vincent volcano © NERC.

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Summary

In this project we aim to demonstrate how volcanic environments exposed to multiple hazards tend to be characterised by a lack of *relevant* data available both in real time and over the longer term (e.g. months to years). This can be at least partially addressed by actively involving citizens, communities, scientists and other key stakeholders in the collection, analysis and sharing of observations, samples and measurements of changes in the environment. Such community monitoring and co-production of knowledge over time can also build trusting relationships and resilience (Stone et al. 2014).

There are more than 100 institutions worldwide that monitor volcanoes and other natural hazards, contribute to early warning systems and are embedded in communities. They have a key role in building resilience alongside civil protection/emergency management agencies. In this report, we propose that such institutions are involved in big data initiatives and related research projects. In particular, we suggest that tools for crowd-sourcing may be of particular value. Citizen science, community monitoring and analysis of social media can build resilience by supporting: a) coordination and collaboration between scientists, authorities and citizens, b) decision-making by institutions and individuals, c) anticipation of natural hazards by monitoring institutions, authorities and citizens, d) capacity building of institutions and communities, and e) knowledge co-production.

We propose a mobile phone app with a supporting website as an appropriate crowd-sourcing tool for St Vincent and the Grenadines. The monitoring institution is the key contact for users and leads on the required specifications based on local knowledge and experience. Remote support is provided from the UK on technical issues, research integration, data management, validation and evaluation. It is intended that the app facilitates building of long-term relationships between scientists, communities and authorities. Real-time contributions and analysis of social media support early warning, real-time awareness and real-time feedback enhancing the response of scientists and authorities. The app has potential to facilitate, for example, discussions on new or revised hazards maps, multiple hazard analysis and could contribute to real-time risk monitoring. Such an approach can be scaled up to facilitate regional use – and is transferable to other countries.

Challenges of such an approach include data validation and quality assurance, redundancy in the system, motivating volunteers, managing expectations and ensuring safety. A combination of recruiting a core group of known and reliable users, training workshops, a code of conduct for users, identifying information influx thresholds beyond which external support might be needed, and continuing evaluation of both the data and the process will help to address these issues. The app is duplicated on the website in case mobile phone networks are down.

Development of such approaches would fit well within research programmes on building resilience. Ideally such research should be interdisciplinary in acknowledgement of the diversity and complexity of topics that this embraces. There may be funding inequality between national monitoring institutions and international research institutions but these and other in-country institutions can help drive innovation and research if they are fully involved in problem-definition and research design.

New innovations arising from increasing resolution (temporal and spatial) of EO products should lead to useful near-real time products from research and operational services. The app and website can ensure such diverse products from multiple sources are accessible to communities, scientists and authorities (as appropriate). Other innovations such as machine learning and data mining of time-series data collected by monitoring institutions may lead to new insights into physical processes which can support timely decision-making by scientists in particular (e.g. increasing alert levels).

1 Introduction

In this prototype project we aim to demonstrate how volcanic environments exposed to multiple hazards tend to be characterised by a lack of *relevant* data available both in real time and over the longer term (e.g. months to years). This can be at least partially addressed by actively involving citizens, communities, scientists and other key stakeholders in the collection, analysis and sharing of observations, samples and measurements of changes in the environment. Such co-production of knowledge over time can also build trusting relationships and resilience (Stone et al. 2014). We propose the use of a smartphone application (app), *myVolcano*, to promote citizen science, combined with real-time analysis of social media, a web-based version and a resource page. In combination, these will capture new data in real time, enable dialogue and provide redundancy.

In volcanic environments, the institution tasked with volcano monitoring has the primary role of working closely with civil protection organisations to keep populations safe by anticipating and forecasting hazardous events (e.g. Aspinall et al. 2002). There are more than 100 such monitoring institutions worldwide (see www.wovo.org) and some engage directly with local populations by raising awareness of volcanic and other natural hazards (e.g. earthquakes and tsunami) and discussing hazards and environmental changes that occur (e.g. PHIVOLCS in the Philippines www.phivolcs.dost.gov.ph). It was demonstrated in Montserrat, that scientists tended to be well-trusted by both at-risk populations and authorities (e.g. Haynes et al. 2007). The role of monitoring institutions as multidisciplinary scientific and technical centres of excellence embedded in communities is often overlooked.

In St Vincent and the Grenadines (SVG), an archipelagic state in the Eastern Caribbean, the active volcano (La Soufrière) sits in the north of the main island (St Vincent). SVG is a Small Island Developing State (SIDS) with an estimated population of 109,373 and GDP per capita of US$ 6515 in 2012 (GFDRR, 2014). Thirty percent of the population lives below the national poverty line (GFDRR, 2014). Public external debt relative to GDP ratio was 70 % in 2012, which results in St. Vincent having limited capacity to manage fiscal impacts of exogenous shocks (GFDRR, 2014). St Vincent is exposed to a number of hazards including hurricanes, earthquakes, landslides, tsunami and floods, and 97 % of the population live within 30 km of the volcano (Loughlin et al., 2015).

In SVG a number of different local, regional and international initiatives exist that are creating data and data products related to anticipating and responding to disasters. Many are research projects but they are rarely sustainable or operational and tend to pursue different agendas without interacting. Consequently, the methodology and proposed implementation of the app emphasises the importance of **identifying end-user needs, understanding the context** of the country, including its multiple hazard profile, **integrating and linking app users to operational resources, official sources of information and advice,** and other relevant resources.

The report begins by justifying the appropriateness of a citizen science approach and introducing the *myVolcano* app and our approach to applying it to different countries. The approach is then applied to St Vincent, identifying opportunities for and challenges to implementing the app. The report concludes with a short discussion of some of the key concerns identified during the study, how these relate to enhancing resilience, along with concrete recommendations for scaling up to other countries.

1.1 WHY USE CITIZEN SCIENCE IN VOLCANIC ENVIRONMENTS?

Volcanic environments are typically under-monitored, in part owing to the cost of equipment and maintenance (Brown et al. 2015a). Evidence suggests, however, that communities can participate, not only in the monitoring of their volcanic environment, but in discussions that raise awareness, understanding and preparedness, and also support early warning systems (e.g. Stone et al., 2014). Community observers can bridge the gap between scientists and the public, enhance the trust between the public and scientists as well as enhance social capital (Stone, et al., 2014; Stevenson et al. 2013). Previous eruptions have demonstrated the critical role citizens can have in collecting samples of volcanic fallout (Bernard, 2013; Stevenson et al., 2013), but citizens can also participate in observation and monitoring of volcanic environments by providing data and understanding that can be used to reduce community risk, rather than exclusively for the purpose of scientific research (Stone et al., 2014). The public can also help scientists and civil protection understand the evolution and impacts of complex events and provide information that may have immediate value in rescue, recovery and mitigation efforts (e.g. Loughlin et al. 2002). Two-way communication established through scientists' continuous engagement with volunteers can support the development of citizens' (volunteers) understanding of and trust in scientists, whilst at the same time enhancing scientists' understanding of the social, economic and cultural influences on individual decision-making in the face of volcanic risk (Stone et al., 2014).

Due to the dynamic nature of volcanic environments, there are opportunities to engage with citizens on an almost continuous basis (see Appendix 1) to assess flooding, landslides, felt earthquakes and so on. Appendix 2 describes a number of citizen science initiatives employed in volcanic environments around the world. The following section introduces the *myVolcano* app.

2 *myVolcano* – A crowd-sourcing app for natural hazards

During the eruptions of Eyafjallajökull and Grímsvötn volcanoes in 2010 and 2011, respectively, the British Geological Survey (BGS) asked the UK public to collect dust samples, which were analysed by microscope for the presence of ash and subsequently used to map the distribution of ash fallout in the UK (Stevenson, et al., 2012; 2013). These mapped distributions provided evidence of ash fall despite assertions from some that there was no ash (e.g. CEO Ryanair, see Daily Mail, 2011). The public, as potential airline passengers, were keen to contribute their own evidence to such a debate. In direct response to these experiences, the BGS, in collaboration with the Smithsonian Institution, Washington, developed a free mobile phone application for gathering observations of volcanic hazards and instructing users on methods for collecting volcanic ash samples in the event of a future eruption (Figure 1).

Figure 1 – Images from the *myVolcano* smartphone app (top) and the web-based interactive crowd map (bottom). Observations can be submitted and viewed through either the app or the web map.

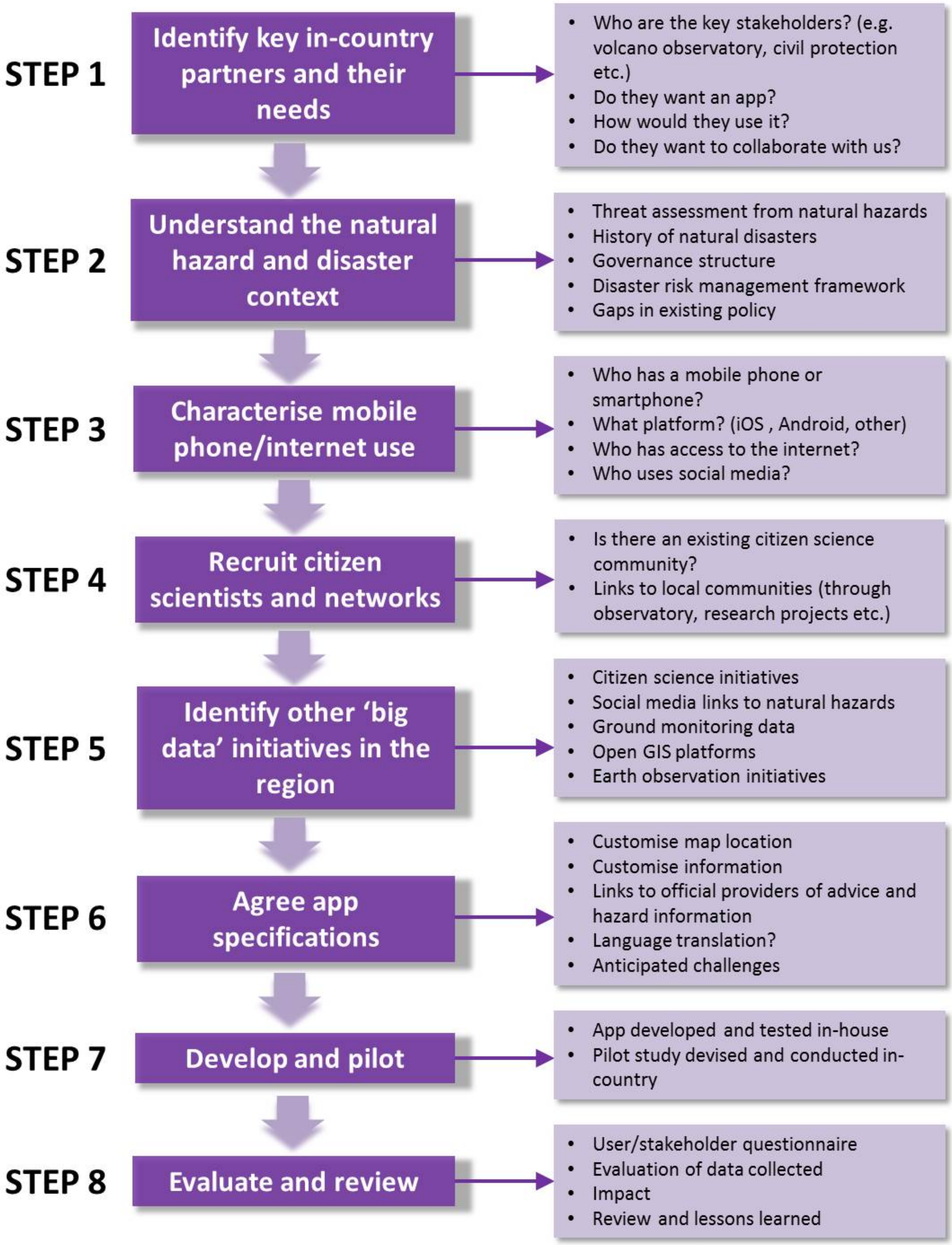

Figure 2 – Proposed methodology for assessing the potential of a citizen science app in any given country/region and steps for designing and implementing app use.

The app uses the device's in-built GPS to accurately record the location of observations and photographs, which can be accurate to a few metres. Observations are then made visible to other users via an interactive map built into the app so others can view them. A full specification of *myVolcano* is listed in Appendix 3. The existing version of *myVolcano* (Version 1.3 at the time of writing) has a UK focus in that it is geared towards collection of distal ash and gas observations (i.e. the principal volcanic hazards that could affect the UK). However, the map interface has global coverage and the data collection methods (free-text descriptions and photographs) are such that information about any natural hazard could be captured.

Through a number of collaborative, international volcanology projects, opportunities have arisen to investigate using the app in different countries and hazard settings (e.g. in SVG and Colombia as part of the STREVA project – see Appendix 4). We have developed a methodology for guiding its development and implementation by the BGS but in collaboration with key partners and with their identified needs as the focus (Figure 2). A more detailed description of each of these steps is presented in Appendix 5. In order to test this methodology and inform our prototype, we have addressed each of these methodological steps (within the bounds of this project) in the context of SVG.

3 St. Vincent and the Grenadines: A case study

STEP 1: IDENTIFICATION OF KEY PARTNERS

Several key stakeholders were contacted in connection with the app (Figure 3), including representatives of the National Emergency Management Organisation (NEMO), the University of West Indies Seismic Research Centre (SRC) based in Trinidad and Tobago and the University of West Indies Disaster Risk Reduction Centre (DRRC) in Jamaica. Monitoring of volcanic, earthquake and tsunami hazards in the Eastern Caribbean is conducted by SRC. SRC collaborates with a small local unit called the Soufrière Monitoring Unit (which operates from the Ministry of Agriculture in Kingstown). Key insight into the appropriateness and need for an app for monitoring environmental change, volcanic unrest and hazards in St Vincent was provided by Dr Richard Robertson (Director of SRC) and Dr Barbara Carby (Director of DRRC), who has extensive DRR experience in the country:

> "I think there is a place for crowd sourcing, it gives potentially wide coverage and encourages public participation, fosters an interest in DRM and builds awareness for the importance of research" (Dr Barbara Carby, email correspondence 2015).

In St Vincent, both seismicity and ground deformation (possible means of anticipating volcanic eruptions) are continuously monitored by SRC. These data are analysed in real-time by scientists at SRC and are used, in combination with any other available information, to inform decisions regarding alert levels at the volcano. SRC also produces hazard maps and are involved in a number of public engagement activities, focusing on engaging with school children and, more recently, institutions and governments that can enact policy to ready Caribbean nations to deal with natural hazards (Trinidad Daily Express):

> "In an environment of slow-moving policy changes, having such intimate knowledge of risk and the potential destruction of a geologic event can take a toll on some scientists. According to [Dr Richard] Robertson, it can either "frustrate or motivate." For the UWI-SRC Director—who admits that he reflexively identifies the exits when he's in any building—knowing the risks makes the outreach function of the SRC an even higher priority." (Trinidad Daily Express).

Collectively, SRC scientific staff has experience of volcano-seismic crises in several islands over the past three decades (SRC contribution to Brown et al., 2015b). Over half the present staff (60%) have experience of volcanic eruptions (SRC contribution to Brown et al., 2015b). They also monitor and advise on earthquakes and tsunami across the region. There are 35 full-time staff (19 scientific, 8 technical and 8 support staff) made up of seismologists, volcanologists and geologists, amongst many others (SRC contribution to Brown et al., 2015b). There exists, therefore, substantial regional knowledge and expertise, but also a huge demand on capacity, especially during volcanic unrest and hazardous events: SRC currently monitor active volcanoes on 8 territories (a total of 21 volcanoes) of the Lesser Antilles (SRC, 2011) where 12 of the islands have one or more active volcanoes (see Lindsay et al., 2005).

Challenges facing SRC

Scientists at SRC believe that by gaining a greater understanding of natural hazards and enhancing the centre's operational facility, they can provide much needed information that can be used in the development of policy for land use, building codes, volcanic contingency plans and other means of coping with the threats inherent in the environment:

> "We also need to make a greater effort to bridge the gap between science and policy and so move towards a state where the results of research by scientists are incorporated more seamlessly into the policy and plans for development plans in the Caribbean." (Dr Richard Robertson, Trinidad Daily Express)

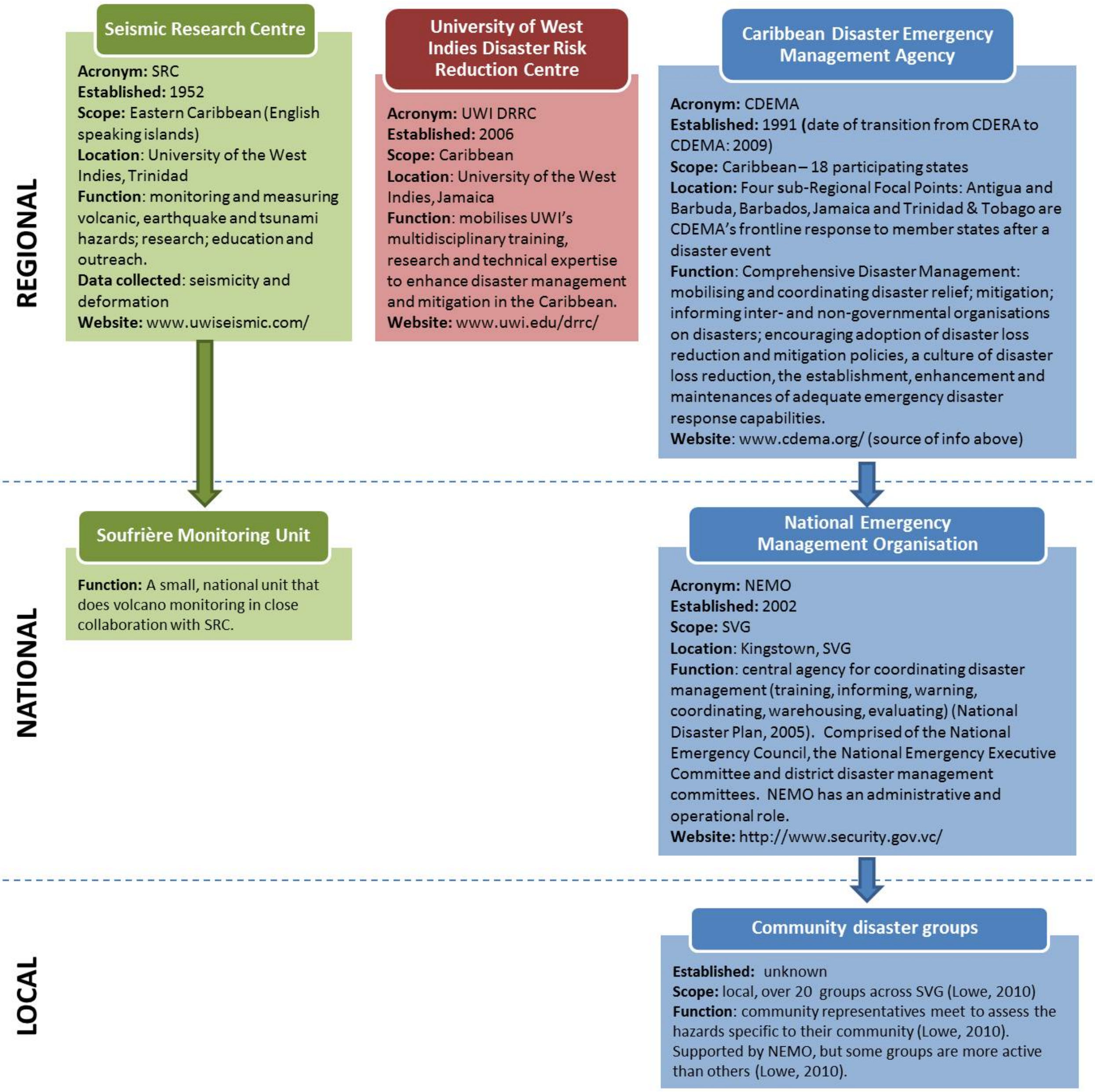

Figure 3 – Key organisations involved in volcano monitoring and DRR in St. Vincent and the Grenadines and the wider Caribbean.

SRC have the resources to respond to a developing situation at a volcano in the region (SRC contribution to Brown et al., 2015b), but a challenge is the timely installation of often costly additional monitoring equipment. Crowdsourcing could assist SRC in the identification of possible increases in volcanic unrest. Collected at a comparatively low cost, crowdsourcing ('big data') could be used to justify installation of additional monitoring equipment and/or personnel. As demonstrated in other volcanic environments, during times of heightened activity at the volcano, public observations can support/confirm interpretation of instrumental observations (Stone et al. 2014). Dr Robertson states that observations of environmental changes, geophysical hazards, hydro-meteorological hazards and impacts would all be of value because scientists and emergency managers cannot be everywhere at once (Appendices 6 and 7).

Communities have an existing role in monitoring the volcano:

> "Currently, the community have a role in monitoring partly through local staff in some territories, but otherwise through informal interactions in response to an elevation in activity levels." (SRC contribution to Brown et al., 2015b)

The app could enhance these existing relationships by providing a means of systematically and quickly recording this information and encouraging people to share their observations without SRC personnel needing to be available in country. It should also encourage the role and ownership of communities in monitoring their own environment (e.g. Stone et al. 2014).

Gaps in governance and disaster management

Any initiative for building resilience is only as successful as the underlying governance. In SVG, legislation for disaster management has existed for over sixty years (see Appendix 7). Since the implementation of the Hyogo Framework for Action in the Caribbean, there has been progress towards achieving, at least partially, some of the priorities for action although challenges still remain (GFDRR, 2010; Table 1). In the Caribbean as a whole, **limited resources, lack of political will, inconsistent enforcement of laws and the need for a shift in culture from a focus on hurricane preparedness to comprehensive all-hazards disaster risk management approach, are seen as the biggest obstacles to success** (Carby, 2011). Many of these shortfalls have also been recognised in SVG (Table 2).

SRC agree, that in order to reduce volcanic risk within SVG, there is a need to implement effective land use planning regulations to reduce vulnerability and exposure of the population and infrastructure (SRC contribution to Brown et al., 2015b). A major problem is that the long return periods of volcanic crises undermine response and mitigation efforts (SRC contribution to Brown et al., 2015b). The app is therefore designed to monitor not only volcanic unrest, but also other hazards that are often common in volcanic environments, particularly in the tropics, and that can interact with the volcano. Ensuring the monitoring of these additional hazards will be achieved by emphasising that the app monitors environmental change. Describing the app in these terms may assist in maintaining the awareness of the threat of volcanic eruptions during periods of inactivity.

STEP 2: NATURAL HAZARDS AND DISASTERS

Small island developing states (SIDS) face disproportionately high risks (UNISDR, 2015). They are particularly vulnerable to volcanic hazards with disproportionately high numbers of fatalities, probably due to the proximity of the population to the volcano and evacuation difficulties (Auker et al. 2013).

SVG has suffered a number of disasters over the past decades. Up to 1680 people were killed and 144 injured in an eruption of La Soufrière in 1902, and in 2013 there were 9 fatalities and over 500 affected by floods and landslides. Since 1990 most fatalities have been caused by floods and landslides and most economic losses are caused by cyclones (UNISDR, 2015).

Robertson (2005) described eruption scenarios at Soufrière St. Vincent and presents integrated hazard maps for effusive dome-forming and explosive eruptions. The maps show much of the north of the island as Very High Hazard, with decreasing hazard moving southwards. For the purposes of making national comparisons, a country volcanic threat profile for St Vincent was compiled by the 'Global Volcano Model network' in 2015 (Brown et al., 2015b, Appendix 8). A flashflood hazard map and landslide susceptibility map for SVG have recently been produced by the EO-RISC project (see Step 5; Appendix 4).

Table 1 – Successes made towards achieving the HFA Priorities in Saint Vincent and the Grenadines

HFA Priorities	Successes in Saint Vincent and the Grenadines
(1) Ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation	• New legislative act established in 2006 • NEMO established as a result of legislative act, with full-time staff dedicated to disaster response and planning • National Emergency Plan developed and operational • Line ministries are taking responsibilities for their functional areas during a disaster
(2) Identify, assess and monitor disaster risks and enhance early warning	• Volcano hazard maps have been produced and are regularly revised • Seismic monitoring is in place across the Eastern Caribbean, including the island of St. Vincent and Soufriere St. Vincent volcano. Local monitoring is carried out by the Soufriere monitoring unit • Meteorological hazards are monitored in SVG and early warning systems in place • Good communication network in place for disseminating information and early warning to meteorological hazards
(3) Use knowledge, innovation and education to build a culture of safety and resilience at all levels	• NEMO sponsors regular public risk-awareness programmes and the PM issues an annual public address at the onset of hurricane season • Volcanic hazard awareness has been boosted through public and stakeholder events (e.g. CaASHI workshop), STREVA • Introduction of disaster preparedness in the educational system
(4) Reduce the underlying risk factors	• Government-sponsored development and larger infrastructure projects generally include resilient design • DRR planning has been drafted for the tourism sector and there are plans to strengthen risk mapping
(5) Strengthen disaster preparedness for effective response at all levels	• NEMO has significantly raised public awareness to natural disasters • SVG is a member of CDEMA • Tourism sector is largely insured by commercial underwriters and is therefore relatively well-protected • 40 community disaster groups have been established and received training in damage assessment, shelter managements, relief supplies management, first aid etc. • Vulnerability assessments for the health sector infrastructure have been carried out, with some recommendations already implemented

Table 2 – Barriers to success in achieving HFA priorities in Saint Vincent and the Grenadines

HFA Priorities	Barriers to success
(1) Ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation	• DRR through policy and planning still in early development and not yet mandated as a development objective
(2) Identify, assess and monitor disaster risks and enhance early warning	• Hazard mapping not so advanced in other areas with limited GIS capability across some organisations
(3) Use knowledge, innovation and education to build a culture of safety and resilience at all levels	• Most efforts are focussed on preparedness and response, less so on risk reduction through effective planning and risk avoidance strategies
(4) Reduce the underlying risk factors	• Resilient design not employed on a widespread basis • Land use planning is not currently a factor for DRR in SVG
(5) Strengthen disaster preparedness for effective response at all levels	• SVG still relies heavily on outside assistance in the event of a major disaster • Whilst the tourism sector may be well insured other sectors, such as agriculture, transport and housing remain relatively vulnerable

SRC monitors regional earthquakes and has an alert level system for the volcano, there is also a regional tsunami and coastal hazards early warning system (CARIBE EWS). An app and associated tools can contribute significantly to the collation and sharing of information (including maps) on all hazards and environmental change not just during disasters but continuously. There are several Facebook and Twitter accounts (SRC and NEMO) that could provide useful information to *myVolcano* users, as well as useful information that people might post or tweet that could be 'pinned' to the map interface in the app.

The app can also support SRC and NEMO in managing community anxiety through provision of information. For example, in mid-February 2005, widespread sulphurous odours and haze on the island of St. Vincent and as far as the Grenadines (50-75 km S) led some people to conclude that the smells reflected increased output of volcanic gases from the volcano, there were fears that an eruption was imminent. SRC worked with the head of the local volcano monitoring unit, to first investigate the reports and later to quell fears that an eruption was imminent.

STEP 3: CHARACTERISE MOBILE PHONE AND INTERNET USE

Paramount to the success of any citizen science initiative is establishing that (a) a 'crowd' exists and (b) there is sufficient access to the necessary technology (see Polock et al.'s [2014] decision framework for citizen science). This step is necessary in understanding whether this infrastructure exists and, therefore, whether the use of an app would be appropriate. It also highlights any potential development needs (i.e. does the app need to be developed on another platform?).

Appendix 9 contains statistics compiled by the National Telecommunications Regulatory Commission (NTRC) of Saint Vincent and the Grenadines. In 2014, the number of fixed line telephone subscribers (19,176) accounted for only 17.5 % of the population, whereas the number of mobile phone subscribers (108,965) is equivalent to 99.6% of the population (some people have two phones). The percentage of users accessing the internet increased from < 20 % in 2007 to > 60 % in 2014. The dominant mobile phone platform according to the International Business Times (2013) is Blackberry, whilst Dr Robertson of SRC believes Android is most popular (Dr. Robertson, pers. comm.). Dr Robertson also stated that Facebook is very popular and both SRC and NEMO have well established Facebook pages through which they disseminate information and advice (Appendix 7).

The app is currently developed only for iOS devices (iPhone, iPad, IPod) although an Android version is being planned. Most modern Blackberry systems can use Android apps, since few people develop apps specifically for Blackberry. However, until an Android version is fully operational, a web version of the app has been developed. This is relatively cheap and quick to update and ensures that anyone with access to the internet is still able to contribute their observations.

STEP 4: RECRUIT CITIZEN SCIENTISTS AND NETWORKS

Motivating participants requires that we provide them with clear reasons as to why their participation is so important (Pocock et al., 2014). The motivation for engagement may relate to different socio-economic and cultural factors and will require understanding the country context where the app is being promoted. However, we can take lessons from existing studies. At Tungurahua volcano, the motivations of volunteer observers (vigías) are an important component of the network's success – all feel a sense of duty or moral obligation and want to help reduce risk to their family and community (Stone et al., 2014). Vigías stated that the voluntary nature of the role is very important to them. These volunteers were recruited through existing relationships with Civil Defence and scientists owing to the fact that monitoring equipment was located in their farmland. During the 2010 and 2011 eruptions in Iceland, UK citizens could relate to the hazard because it threatened something many of them do on a weekly, monthly or yearly basis – fly. Key entry points therefore include **in-country contacts, networks and cultural interests and perceptions of risk.**

Whilst *MyVolcano* would be freely available to anyone with access to the internet, Dr Robertson suggested that the app should target key individuals within communities who could be relied upon to regularly upload information. NEMO supports 20 community disaster groups that meet to assess and plan for the hazards specific to their community (Lowe, 2010). It is therefore envisaged that NEMO could assist with the identification of key individuals as well as highlighting the presence of the app for collecting observations and finding information. Likewise, building on SRC's existing public engagement activities should allow for the identification of key individuals and groups.

Both NEMO and SRC are already involved in many community outreach and schools projects. The BGS has also successfully engaged with schools for several years as part of the Schools' Seismology Project and has a network of schools across the British Isles who are equipped to collect ash samples when the next eruption occurs. In SVG, disaster preparedness is included in the educational curriculum (GFDRR, 2010) so there is a possibility of producing educational resources around the app to complement these targets. Schools would only require one computer with internet access to enable regular observations to be made and can be tasked with looking for specific changes depending on their location and hazard context. Staff and pupils can also be provided with additional instructions and guidelines on how to make and record observations, whereas such a level of detail on the app might be off-putting for casual users.

In addition to targeting specific users, the app could be marketed and promoted (through SRC and NEMO) across SVG and beyond to encourage individual users to download and contribute observations through the app. A simple way to elevate the presence of the app is to link through social media. *myVolcano* already has its own Twitter account which can easily retweet information coming from SRC and NEMO to help engage people with the app.

STEP 5: IDENTIFY OTHER 'BIG DATA' AND RESEARCH INITIATIVES

'Big data' can be used in a number of different contexts and with different objectives. Several 'big data' initiatives that specifically aim to increase resilience and support decision-making are active in SVG and the wider Caribbean region. According to Dr Robertson, research projects initiated outside the region can provide new knowledge that can contribute to DRR however, there is a need for greater linkages between some of these and existing regional institutions involved in similar research. International research projects provide opportunities for linkages with external agencies who may be better resourced and so are able to innovate and advance existing knowledge and understanding of regional systems. Dr Barbara Carby (DRRC) suggests that research should be solution-oriented and related to specific national needs but with potential regional benefits (Appendix 6). Thus, decision-makers should be involved in problem definition and research design, so that research builds national/regional capacity, complements previous work and encourages standardisation of methodologies where appropriate.

The SVG proposal was conceived partly because many projects were active on one small island but were not interacting in any way and because key in-country stakeholders and experts (e.g. SRC) were unaware of some projects (Appendix 3). International research investment can appear rather fragmented (see comments by Barbara Carby - Appendix 6) and rarely, if ever, connected or linked. The app can make connections between these independent initiatives that may fail to recognise all stakeholders.

Earth observation

Earth observation (EO) data products come in many forms including images, maps, time series plots, videos etc. Satellite **EO products are highly complementary to the traditional ground-based and airborne data** and information collected by volcano monitoring institutions. The EO needs of monitoring institutions are challenging to meet particularly in terms of spatial and temporal resolution). Often products that make the biggest difference are simple – for example those that detect change (temperature and topography), topographic mapping and visual images. Surono et al. (2012) documents the first time co-production of knowledge from ground (seismic, geodetic and gas observations) and space (near-real-time satellite radar imagery) was achieved to save lives and reduce economic losses during the 2010 eruption of Merapi in Indonesia (facilitated by the International Disaster Charter). A current EO project, EO-RISC (Earth Observation for Risk Information Services in the Caribbean) is an European Space Agency (ESA) 'eoworld' funded project to demonstrate the benefits of satellite earth observation (EO) technology (Appendix 4). The project has produced an improved land cover map, a flash flood hazard map, a landslide inventory map and a landslide susceptibility map for SVG (http://charim.net/stvincent/maps). These maps have been delivered to NEMO and other government departments in SVG.

Few EO projects begin with an analysis of user needs; however, the BGS have experience of a 'user-led' EO service that developed the required services and an interface for simple interaction with data products.

Unfortunately, the project could not be sustained much beyond the research project duration (EVOSS) (Appendix 4). We wish to develop an app that is sustainable, useful throughout the ‘risk management cycle’, and user-designed and led. The service would connect those on the ground with open access data products, operational EO resources and existing platforms that are most likely to build resilience and reduce risk.

Crowd sourcing

The Caribbean DEWETRA Platform created by the Caribbean Institute of Meteorology and Hydrology (CIMH) and partners is essentially a data fusion platform that manages and displays hydro-met hazard, exposure and impact data from various sources in a real-time, geo-spatial environment in support of improved decision making (Appendix 4). CIMH used the platform to capture impacts during an assessment of the floods in SVG in December 2013 (Dr Shawn Boyce, 2015, pers. comm. – see Appendix 6).

SRC has an existing ‘Did you feel it?’ template on its website for citizens to report their experiences. The University of the West Indies Disaster Risk Reduction Centre is also about to trial a crowd-sourcing project (Dr. Carby, 2015 pers. comm.). We aim to connect with all these initiatives which operate at a regional scale.

Due to time constraints, one aspect of crowd-sourcing that has not been fully explored during this scoping study is how the App could link to social media. There are several Facebook and Twitter accounts (SRC and NEMO) that could provide useful information to *myVolcano* users, as well as useful information people might post or tweet that could be ‘pinned’ to the map interface in the app. The BGS web tool ‘GeoSocial: Aurora’ is a crowd-sourcing tool that scours Twitter for tweets related to aurora sightings and maps them on an interactive map. The database archives tweets and therefore can be used for the purposes of evaluation. There is potential to have a similar function within *myVolcano* that displays tweets with certain hashtags on the interactive *myVolcano* map. The app could also create/suggest hashtags for people to use in their tweets so that the app is picking up the most relevant information. Whilst SRC should own the app, BGS can provide this data management support through the existing ‘GeoSocial: Aurora’ initiative with agreement from SRC and NEMO.

Open GIS

The World Bank’s Latin America and Caribbean Region (LCR) DRM team helped to implement open source, collaborative, geospatial, data-management platforms in nine countries, including SVG. This means that a wide range of practitioners (e.g. ministries of works and physical planning, academics and development agencies) have access to free GIS software (such as QGIS) and free data so that they can create their own geospatial resources, such as hazard maps.

Joining the dots

The app can act as an important link between these disparate data types and projects. The app can provide links to different projects and sources of data to ensure users are aware of different initiatives operating in SVG and the region. Data can also be served directly to another platform as a web service, which means up-to-date data from one platform is automatically displayed in another.

STEP 6: AGREE APP SPECIFICATIONS

Following discussions with key stakeholders (e.g. SRC, UWI Disaster Risk Reduction Centre) and the app developers, suggested additions/changes can be made to the app. These changes include additional information added to the map interface (e.g. sign-posting to monitoring and emergency management organisations relevant to SVG), data collection (what is collected and how), data and information dissemination and the underlying technology.

Table 3 lists the specific features relevant to SVG that can be incorporated into the app. These features include links to the websites of SRC, NEMO and CDEMA, incorporation of volcanic hazard and other maps, links to existing crowd-sourcing tools and other projects operating the area, including videos created by the STREVA project about the 1979 eruption of La Soufrière and volcanic hazard associated with the volcano (Figure 4). Social media, such as Facebook and Twitter, can also be linked into the app so people sharing information in the app can also share information directly to their own social media sites.

Table 3 – Suggested adaptations to the *myVolcano* app following consultation with UWI Seismic Research Centre.

App feature	Action	Solution
Map interface		
Functionality	Set to country/region	Either by choosing a pre-defined area (SVG, Caribbean) or zooming to a preferred extent and saving the view
GIS layers	Hazards information	Turn on and off hazard maps (e.g. integrated volcanic hazard map from SRC, landslide susceptibility maps from CHARIM?).
		Links to information about different hazards in the region
	Observatory information	Click on any volcano/country in Eastern Caribbean and brings up SRC's information (SRC website, Facebook, Twitter)
	Scientific advisories	Click on a volcano and any official scientific advisories (from the observatory) can be accessed
	National emergency management information	Click on any country and the corresponding emergency management organisation details are shown (e.g. NEMO for SVG – website, Facebook)
	Regional emergency management information	Click on any region and the corresponding emergency management organisation details are shown (e.g. CDEMA for Caribbean)
	Active projects in the region	Click on Soufrière St Vincent for links to the STREVA videos, CHARIM project, DEWETRA project
Data collection		
Simplify layout	Remove focus from ash collection to multi-hazards	Hide ash measurements from main view and give user option between taking a photo and written observation. If choosing 'observation', brings up a list of all different hazards from user to select from. Depending which they choose will depend what options they see (e.g. earthquake brings up SRC's form, ash brings up ash measurements, landslide brings up landslide measurements, etc.)
Disseminate information		
Push notifications	Ability to send messages to users via the app	Warnings, advice, alerts, scientific advisories, encouragement to collect data if something has happened
Technology		
Platform	Android version	In planning
	Web tool	Continue to develop the web version to support the iOS app until an Android version has been developed

STEPS 7 AND 8: DEVELOP, PILOT AND EVALUATE

Following consultation with one of our key partners – SRC – the next step will be to continue development of the app based on the agreed user requirements and to design a suitable pilot study in-country. Technical development of the app will continue to be led by BGS and we also anticipate assisting in managing and linking the data with SRC's systems. Training and workshops with the potential core users group will ensure data are collected consistently and that all ideas and opinions are included. Further innovation will be welcomed. For full implementation, BGS will continue to work with SRC providing technical and other support as needed. Evaluation of the app and its use will be conducted again when it is operational and has been used during a significant event.

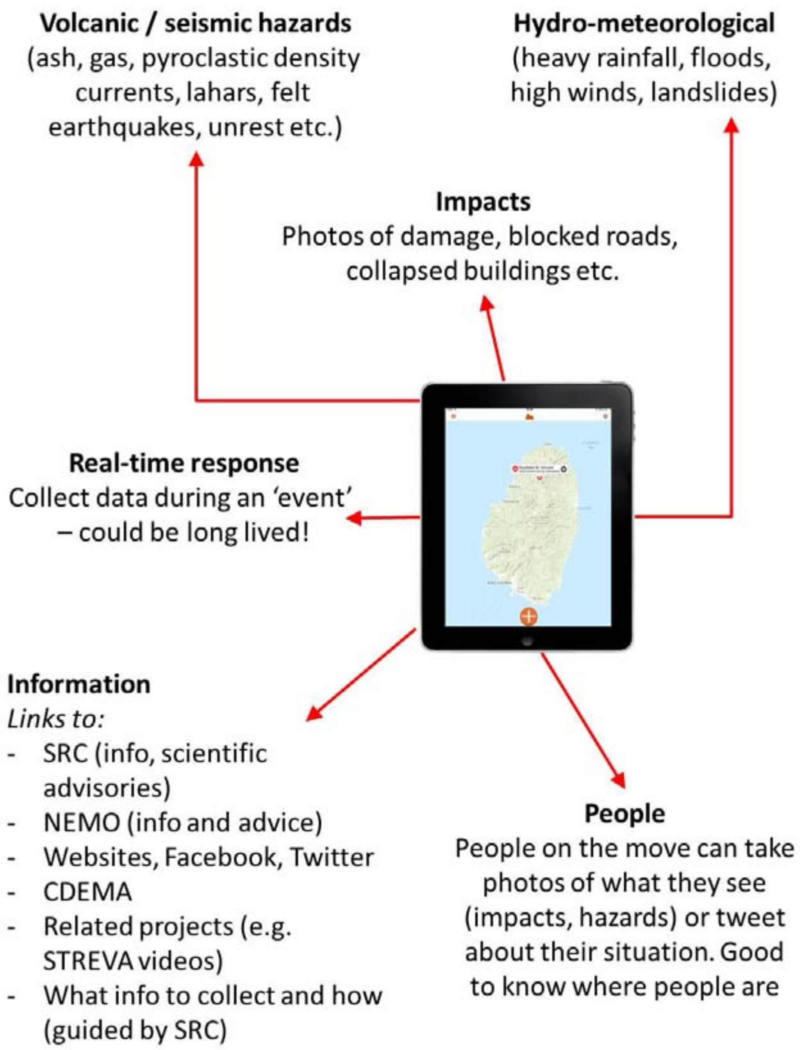

Figure 4 – Summary of the type of data that could be collected by the *myVolcano* app and the range of information it could provide to users, following consultation with UWI Seismic Research Centre, in the context of SVG and the wider Eastern Caribbean region.

ANTICIPATING CHALLENGES

Throughout the prototype development, we have anticipated and been made aware of several challenges that need to be overcome before the crowd-sourcing approach could be successfully implemented in SVG.

Data validation and quality assurance: A major challenge anticipated by key partners (Dr Roberston and Dr Carby) is how to validate the data and provide quality assurance, particularly if SRC and NEMO are to make decisions for issuing alerts and preparing for emergencies based on these data. SRC stated that they already actively engage in quelling rumours when members of the public make them aware of changes in activity on the volcano and thus suggested that they could take on the role of data validation. Managing large volumes of data will require dedicated time and staff and this is where a partner organisation, such as BGS, could provide support for data management. This support would not be to remove ownership from SRC, but instead to support their response. Dr Robertson also emphasised that a means of ensuring data validation would be to have a reliable base of dedicated volunteers, whose recordings could be compared with SRC monitoring (see Appendix 7).

Resilience of key systems: A key process of building resilience is ensuring backups in any system. The size and proximity of the population to the volcano in SVG mean that it is necessary to explore the resilience of mobile and home internet during an eruption (or other event), particularly given the role of the app in linking users to SRC's and NEMOs alert levels and advice. It is also necessary to anticipate how the volume of data recorded by the public may fluctuate over time. In Haiti, for instance, the volume of crowdsourcing data was overwhelming. A means of overcoming this would be for SRC to identify a threshold of information received that would trigger assistance from other agencies (e.g. BGS) for the purpose of data management.

Motivating volunteers, managing expectations and ensuring safety: Maintaining awareness of volcanic risk between eruptions is a notable problem in volcanic environments, however the means of overcoming this problem is to not separate hazards and risks but to emphasise their links. The fact that the app is designed to encourage monitoring of other hazards, e.g. hydrometerological events, under the umbrella of environmental change should help to maintain awareness. Managing expectations is also another anticipated challenge and lessons can be sought from other initiatives. For instance, a key element of our approach is the two-way exchange of information. However, as observed by Wallace et al. (2015) at the Alaska Volcano Observatory, there can be a time delay between citizens uploading information and it being displayed on the site due to the time it takes to validate the data. Their means of overcoming this was to include a disclaimer (Appendix 2). The importance of ethics and a code of conduct for users must also not be overlooked: Dr Robertson noted that the app should not encourage people to venture into dangerous areas, whilst NEMO recently emphasised on their Facebook page that images of fatalities are not appropriate for sharing. Developing such a code will be an iterative process involving key stakeholders, including SRC and NEMO.

Data sharing: An objective of the app is to link to different projects and initiatives and share data. Whilst the need for open access data is being increasingly acknowledged in building resilience and risk reduction, it continues to be a problem. In the context of the app itself, users are made aware that the information they share will be freely available, thus fostering a culture of transparency, openness and sharing.

4 Scaling up

In addition to the methodological steps identified in section 2, anticipated requirements for implementing the app and using it at a regional scale or in other settings include:

- Testing the resilience of the mobile network and internet in the face of an eruption
- Maximising the potential of the app: whilst we emphasised the importance of monitoring hazards, interviews with Dr Robertson (SRC) indicated the role the app could have in monitoring impacts upon people
- The iterative development of the code of conduct for users in collaboration with key partners
- Further testing of validation methods and protocols (e.g. for ash sample collection)
- Investigation of additional requirements for use throughout the Eastern Caribbean (with SRC remaining the key monitoring contact and each nation having a separate emergency management department).

Through existing collaborations, we have identified an interest in the app in Africa (via the RiftVolc project, Appendix 4), Colombia (via STREVA, Appendix 4), New Zealand (via GVM, Appendix 4) and Southeast Asia.

Apart from in the Democratic Republic of Congo (Goma Volcano Observatory) there are no institutions mandated to monitor volcanoes in the East African Rift. Nevertheless, our colleagues in national institutions (e.g. Tanzania Geological Survey, University of Addis Ababa) would certainly be expected to respond if there is an eruption or hazardous natural event. We anticipate that crowd-sourcing could be an excellent way of sharing information and data even though a mandate for these institutions is lacking.

Southeast Asia, in particular Indonesia and the Philippines, is home to a number of active volcanoes, which can generate hazards with local, regional and global impacts. In the Philippines, extensive use of social media (94% of internet users use Facebook according to On Device Research, 2014)[1], as well as the existence of initiatives for monitoring hazards (e.g. flooding in the Bicol River Basin) and platforms for integrating different data initiatives and local and international partners (e.g. the Nationwide Operational Assessment of Hazards, NOAH), points to the potential for a similar application (Appendix 10). Current smartphone usage is low, so our supporting web tool may be the appropriate point of engagement.

5 A road map for future research

Crowd-sourcing and citizen science can be powerful approaches, for real-time data collection to provide information to scientists and emergency managers and for signposting citizens to appropriate information and advice on how to reduce their risk. However, they are also not without their challenges including possible low uptake, the timeliness of validation and reliance on internet, mobile networks and technology. Problem-definition, co-production and subsequent research design with in-country partners helps to address such challenges. The emphasis on long-term relationship-building with citizens also mitigates some challenges.

In this report, we have particularly explored the possible role of crowdsourcing in the context of anticipating hazards, engagement and partnership and informing decision-making in SVG. We have presented evidence that our application designed initially for the UK has global applicability for both long-term and short-term hazard benefits. The app provides three key areas of real-time functionality (*cf.* Global Pulse, 2013): **early warning** (e.g. making civil authorities and monitoring institutions aware of long-term and rapid environmental change); **real-time awareness** (e.g. environmental reality, concerns and needs visible in real-time, impacts) and **real-time feedback** (e.g. more efficient and targeted official responses, as well as quelling rumours).

Over the longer term, our approach demonstrates that, in SVG and other regions, *myVolcano* can support five key processes of building resilience:

1. **Collaboration: Linking people, data and initiatives**
   The app can point people to different data sources and social media. It supports interaction between citizens, scientists and emergency managers.
2. **Decision making: Supporting the role of monitoring institutions, civil protection and communities in anticipating and responding to natural hazards**
   The app can support individuals, communities and authorities through increased awareness and knowledge to enhance decision-making.
3. **Anticipation: Supporting monitoring of volcanoes and their multi-hazard environments**
   Under-monitoring of volcanoes exists worldwide (especially in the Lesser Antilles, Africa, SE Asia). Community monitoring can provide useful data and has many benefits to communities, scientists and authorities.
4. **Capacity building of institutions and communities**
   In particular, supporting the role of monitoring institutions and attempting to use technology to address resource issues.
5. **Knowledge co-production: two-way exchange**
   The app provides a two-way movement of data and information: the crowd submits the data, the monitoring institution uses the data for their scientific purposes and information is fed back to the crowd. In other settings, this exchange has been demonstrated to help to raise awareness of hazards and risks and consolidate engagement with and confidence in the scientists (Stone et al., 2014).

Our project not only discusses the role of crowdsourcing (our chosen 'big data'), but also the process of taking an application designed for a particular country and applying it elsewhere. It is here that we begin to **question the concept of 'innovation'** and particularly the role we as the international scientists and

[1] Based on a survey of 900 mobile internet users (smartphone and feature phone users) and other publically available data sources (see https://ondeviceresearch.com/blog/philippines-mobile-internet-trends).

researchers play in forming a truly bottom-up, in-country owned approach. The key questions that need to be incorporated in future research include: who is the innovator and how does the innovation build resilience? What is the role of science and research in enhancing capacity at the local level?

Innovation should aim to support and work within existing risk governance structures where they are effective. To ensure that the design and functionality of the app is most appropriate to SVG, we devised **a user-centric methodology** that addresses key questions such as: who will benefit from an app, what do they want from it, how will it be used and by whom, and does the technological and citizen science framework exist for supporting the use of an app?

Future research also needs to emphasise the importance of understanding volcanic environments through an appreciation that volcanoes produce multiple hazards, exist within multi-hazardous settings (many in the tropics) and that citizen science is about observing environmental change – a holistic approach to monitoring, anticipating and analysing hazards and risk. This approach and the four areas of building resilience listed above require an **interdisciplinary approach**.

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Appendix 1 Citizen science before, during and after volcanic eruptions

Volcanic unrest

Volcanoes typically give multiple indications of unrest before an eruption, sometimes over several years, but these signals can be quite localised: changing groundwater levels, increased carbon dioxide emissions through soils, felt earthquakes, mudflows, increased hydrothermal activity, cracks in the ground, changing lake levels and smells of sulphurous gases (e.g. SVG in 2005). Citizens living around a volcano, familiar with the 'background state', may be among the first to observe these signals. Such observations are highly complementary to basic ground monitoring (seismometers and GPS stations in the case of SVG). Not all episodes of unrest lead to an eruption (e.g. Hincks et al, 2014) and SRC can compare observations to analysis of data produced by monitoring networks in order to assess a situation.

Volcanic eruptions

The onset of non-explosive eruptions can be quiet and observations may be the first indicator that an eruption has begun. Explosive eruptions require regular formalised observations to support aviation protocols. Once an eruption is underway, scientists and civil protection organisations need to know how an eruption is progressing but cannot be everywhere at once and hazards can occur anywhere, at any time. In addition, during an eruption, official responders will be busy dealing with the crisis and rarely have time to collect new or transient data. Some hazards are short-lived (explosions, ash deposits) so having community members ready to take specific photographs, make measurements or collect samples can help to gather data that would otherwise be missed.

During the long-lived eruption at Soufriere Hills Volcano, Montserrat (1995-ongoing), the volcano observatory installed cameras around the volcano to aid real-time observations but still wasn't able to see large parts of the volcano - the same would apply in SVG. In addition, the island was so small that assessing critical eruption parameters, such as ash plume height to communicate to the Volcanic Ash Advisory Centre in Washington, was often not possible because of the very steep line of sight, the same will apply in SVG. Distal observations from adjacent islands, or offshore were often better. An additional issue during eruptions is that during explosive eruptions, the ash cloud and falling ash can cause zero or limited visibility for hours at a time. If an observer is up-wind they can have a clear perspective on what is happening. An ability to capture observations from all angles and at different distances is particularly useful. Capturing quantitative data, observations and samples in areas outside any exclusion zone has significant scientific value and is something that community members in Montserrat embraced for many years and has recently been expanded to include use of kites and quadcopters to take photographs (Stone). Impacts of volcanic activity were also captured over time, for example environmental and agricultural impacts in different places at different times (e.g. Baxter et al. 2005). There is evidence of community resilience to extensive risks in volcanic environments such as volcanic ash fall (Sword-Daniels, 2014). Depending on settled thickness, volcanic ash fall can be a benefit or a hazard (Wilson et al., 2015; Wilson et al. 2015). In Ecuador, farmers change crops to more resistant varieties during eruptions (Teresa pers.comm.), and there are anecdotal reports of ash being collected from proximal areas to spread on fields in distal areas. Reliable documentation of such local mitigation measures is limited.

After eruptions

Many eruptions are long-lived, the average global duration is seven weeks and hazards tend to persist after an eruption has ended. Lahars can be a significant secondary hazard for many years and yet their documentation is minimal. Improving models of lahar initiation and flow depends on better observational data of transient phenomena. Windblown volcanic ash can be a health and aviation hazard long after an eruption. Recovery can be long and slow and again documentation of these issues and challenges could be much better.

Observations underpin much of science. Our experience in Montserrat, the UK, Iceland, Ecuador, Colombia and elsewhere has demonstrated that there is always a strong core network of citizens keen to participate and develop a long-term dialogue with scientists. The observations and information collated are also of value to civil protection and emergency management organisations. This can create a valuable ongoing dialogue between public-scientists-officials that builds trust, respect and co-produces knowledge. Another vulnerable group that can be overlooked are tourists (Bird et al 2011) but they can also use an App.

Appendix 2 Citizen science case studies

Detecting sulphur dioxide in Iceland

During the eruption of Bardabunga (August 2014 to February 2015) the Iceland Met Office (Veðurstofa Íslands) asked members of the public to fill out an online questionnaire asking them whether they could smell sulphur dioxide (SO_2) and had any ill effects from it. Respondents were also asked whether they could see the gas, what the weather conditions were and for their location. The Iceland Met office used the results from these observations in combination with their wind forecasts to make daily maps of SO_2 distribution predictions (see Figure 1), which they displayed on their website.

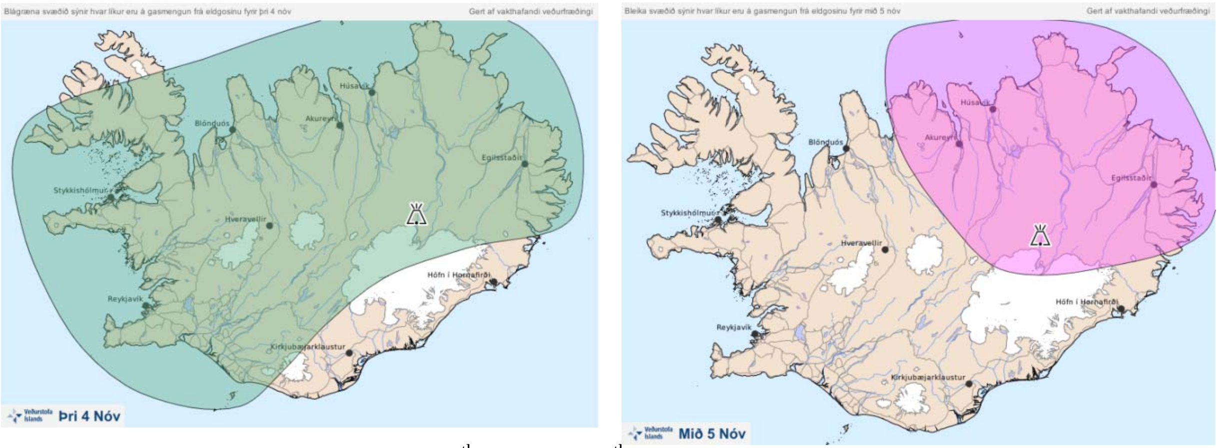


Figure 1: predicted SO_2 maps for the 4^{th} (left) and 5^{th} November (right) 2014 (Source: IMO website).

Link to the questionnaire (in Icelandic): http://www.vedur.is/skraning_brennisteinsmengun/

Ash fall detection in Alaska: "Is ash falling?"

The primary volcano hazard in Alaska is airborne ash, which endangers aircraft flying the busy North Pacific air routes and consequently affects global commerce. Downwind ashfall is also a significant threat to commerce, transportation and day-to-day activities in nearby Alaska communities (Wallace et al. 2015). The Alaska Volcano Observatory (AVO) have a web tool which people can be used to report any observations of ash fall. Importantly, the tool also allows users to submit records of no ash fall, which is equally as important to understanding the distribution of ashfall. Knowing the locations of ashfall reports provides 'on-the-ground' checks for ash dispersion and fallout computer models and satellite imagery interpretation, and consequently improves public ashfall warnings and forecasts (Wallace et al. 2015). Ashfall reports are shared with emergency management agencies and the wider public (Wallace et al. 2015). In order to overcome issues related to the time delay between validating the data provided by citizen scientists and displaying on the web, they included a disclaimer on the public map (Wallace et al. 2015). These reports also give scientists a more complete record of the amount, duration and other characteristics of ashfall (Wallace et al. 2015).

Link to the web tool: http://www.avo.alaska.edu/ashfall/ashreport.php

UK ash collection: the 2010 eruption of Grímsvötn

Source of the information below: BGS

http://www.bgs.ac.uk/research/volcanoes/icelandGrimsvotn.html;
http://www.bgs.ac.uk/discoveringGeology/hazards/volcanoes/grimsvotn2011.html

During the Grímsvötn eruption that began on the 21st May 2011, many schools and individuals (including the Met Office network of voluntary observers) across the UK collected samples of ash and sent these to BGS for analysis. Sample collection was relatively straightforward and samples included rainwater, pollen filters, sticky tape on paper, uncoated sticky tape and ash collected on tissue paper and sponges. Almost 200 samples had been submitted by the 10th June 2011 (Figure 2).

The BGS, the Met Office, Edinburgh University and other institutions in the UK coordinated sample collection during the Grímsvötn eruption in order, amongst many other reasons to further research on volcanic eruptions and volcanic ash clouds, as well as to help inform Met Office volcanic ash cloud advice.

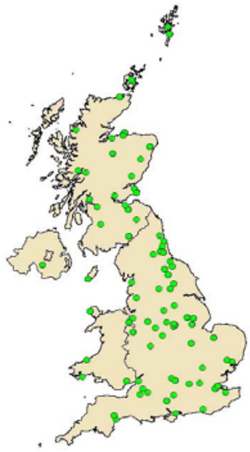


Figure 2: distribution of ash samples (Source: NERC)

The ash samples were collected for different types of analysis to show the extent of ashfall, the textures, chemical composition, sizes, shapes and other properties of the ash, in order to inform how ash forms, how it travels long distances and how it is removed from the atmosphere. Understanding the properties of different ash types helps us to choose instruments for research aircraft and satellites with the best ability to detect and monitor ash.

A much higher number of samples were collected and analysed than compared with the preceding Eyjafjallajokull eruption in 2010, resulting in some detailed scientific findings about the nature of the ash. However, data collection responses were still largely *ad hoc* meaning that the limited opportunity to collect volcanic ash samples through the entire duration of an eruption (and from both proximal and distal locations) was not fully taken advantage of. As a direct response to these eruptions, BGS, in collaboration with the Smithsonian Institution, developed *myVolcano*.

For more information see: http://www.bgs.ac.uk/research/volcanoes/icelandGrimsvotn.html

Did you feel it? Earthquake detection

Earthquake detection is a growing area of crowdsourcing and is of particular interest to this report since earthquakes are a common hazard in volcanic environments. The United States Geological Survey (USGS) has a crowdsourcing web tool that allows those who have felt an earthquake to record their experience. The questionnaire requires respondents to say where they were, what they felt, whether anyone else felt it, as well as how they responded. It therefore goes beyond a simple detection too, but also includes an assessment of responses and impacts. Such information could theoretically be used to explore whether strategies for awareness raising, preparedness and risk reduction have been effective. Reporting of earthquakes is also utilised by other institutions tasked with monitoring earthquakes, including the Seismic Research Unit (SRC) of University of the West Indies.

For more information see:

- USGS: http://earthquake.usgs.gov/earthquakes/dyfi/
- SRC: http://www.uwiseismic.com/EarthquakeFeedback.aspx

Community-based monitoring at Tungurahua volcano, Ecuador

Source: Stone, J., Barclay, J., Simmons, P., Cole, P. D., Loughlin, S. C., Ramon, P., Mothes, P. 2014. Risk reduction through community-based monitoring: the vigías of Tungurahua, Ecuador. Journal of Applied Volcanology **3**: 11.

Stone et al. (2014) provide a detailed description and analysis of a network of volunteers known as vigías that since 2000 has been engaged in community-based volcano monitoring around volcán Tungurahua, Ecuador. The following information is taken directly from their paper:

The network began as part of an initiative from several stakeholders. Civil Defence (at the time responsible for disaster management) needed to be able to communicate early warnings to communities in order to prompt timely evacuations. Concurrently, the scientists wanted to have more visual observations to complement their monitoring network. From the perspective of the vigías, they and their communities wanted information, and they wanted to have and be part of, some form of early warning system to enable them to live there with less risk. Initially the vigías maintained and managed sirens in communities on the volcano. The demand for such a network, from several stakeholders at once, which fulfilled multiple roles, contributed towards its success initially. The vigía network was a pragmatic solution to a real risk problem.

Vigías were recruited as Civil Defence volunteers; the first were recruited due to already being part of the Civil Defence and others were known to scientists as a result of monitoring equipment located on their farmland. Other vigías were recommended by each other, and the scientists along with Civil Defence commanders, visited locations to identify yet more vigías. The motivations for the vigías' initial and continued involvement are an important component of the network's success. All vigías in interviews stated that they felt a sense of duty or moral obligation and that they wanted to help reduce risk to their family and community. Vigías repeatedly stated that the voluntary nature of the role is very important to them.

The overall objective of the vigía network is to reduce risk to communities surrounding Tungurahua. It was initiated out of a compromise between citizens - who had forcibly returned to hazardous localities following an enforced evacuation - and the civil protection agencies attempting to ensure their safety. This pattern of evacuation and return, even against official advice, is a familiar one in volcanic areas, as well as in other settings (Bohra-Mishra et al. 2014). The network is therefore an adaptive compromise, requiring the cooperation of all stakeholders, which has enabled citizens to continue to live and work in hazardous areas by enhancing their capacity to respond quickly to escalating threats.

The vigías, many of whom were or have become community leaders, are able to make a transition between volunteer observer and community-level decision maker in times of crisis, and by communicating with each other using the network, communities can coordinate evacuations. The clear communication protocol of the network, requiring vigías to connect with each other, the scientists and authorities by radio at the same time every evening regardless of the level of activity, means that involvement is sustained during periods of quiescence at the volcano, continuing the development of relationships, thus preparing the network to respond to future crises.

In addition to the benefits of direct communication and monitoring, many of the vigías have a vital role in maintaining monitoring stations around the large volcano, without which the scientists' capabilities would be severely reduced. The upkeep of these stations has a secondary effect, in that when volcanic activity is low and thus there isn't much to report, the vigías still have an active and important role. During times of heightened activity at the volcano, their observations are deemed important by the scientists, as they confirm instrumental observations and are less affected by technical problems.

References

Bohra-Mishra P, Oppenheimer M, Hsiang SM (2014) Nonlinear permanent migration response to climatic variations but minimal response to disasters. Proc Natl Acad Sci 111(27).

Stone, J., Barclay, J., Simmons, P., Cole, P. D., Loughlin, S. C., Ramon, P., Mothes, P. 2014. Risk reduction through community-based monitoring: the vigías of Tungurahua, Ecuador. Journal of Applied Volcanology **3**: 11.

Wallace, K., Snedigar, S. and Cameron, C. 2015. 'Is Ash Falling?, an online ashfall reporting tool in support of improved ashfall warnings and investigations of ashfall processes. *Journal of Applied Volcanology* **4**(1): 1-10.

Appendix 3

Comprehensive list of all features and functionality in version 1.3:

1. English and Spanish versions
2. Worldwide maps and GIS layers (all can be turned on and off)
    a. ESRI topographic map
    b. ESRI satellite imagery
    c. Google maps
    d. Open Street Map
    e. Volcano locations
    f. Crowd source observations
3. Locations of world volcanoes
    a. Provided as a web service from Smithsonian Institution's Global Volcanism Program
4. Volcano information
    a. Provided as a web service from Smithsonian Institution's Global Volcanism Program
    b. Name
    c. Elevation
    d. Type
    e. Location (lat/long)
    f. Last eruption
    g. Images
    h. Link to SI GVP for further information
5. Locate user
    a. Zoom to current location using device's in-built GPS
    b. Manual search by panning/zooming around the map
    c. Search global gazetteer
6. Submitting observations
    a. Location
        i. Taken from current location on the map
        ii. From phone's GPS
        iii. Gazetteer search
    b. Description
        i. Free text
    c. Photo upload
        i. Upload photo from an album
        ii. Take a photo
    d. Ash collection
        i. Instructions and 'how to' videos
        ii. Only for UK samples – send to BGS
    e. Measurements
        i. Start and end date/time of collection period
        ii. Thickness (for volume calculation)
        iii. Area (for volume calculation)
        iv. Weight

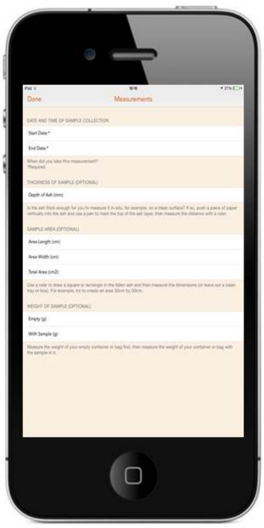
   f. Submission and verification
      i. New entries are ‘verified’ by BGS enquiries team – i.e. check for malicious content
      ii. Any unusual queries are referred to a member of the volcanology team – i.e. unsure whether content is relevant or not
      iii. Once verified, records are displayed on the map (on the app and web map)
      iv. Data is stored on BGS server
7. Crowd source map
   a. Submitted records are displayed on the map for anyone to view
8. Help and information
   a. Instructions on how to use the app
   b. Instructions on how to collect ash samples
   c. Information about volcanic hazards
9. Links
   a. BGS Volcanology team
   b. BGS myVolcano website
   c. Smithsonian Institution’s Global Volcanism Program
   d. Global Volcano Model (GVM)
   e. Strengthening Resilience in Volcanic Areas (STREVA)
   f. Volcanic Ash Advisory Centres (VAAC) – Met Office
   g. Iceland Met Office (IMO)
   h. World Volcano Observatories Organisation (WOVO)
   i. USGS Volcanic Hazards pages
   j. International Volcanic Health Hazards Network (IVHNN)
   k. International Association of Volcanology and Chemistry of the Earth’s Interior (IAVCEI)
   l. University of Iceland – Department of Earth Sciences
10. Feedback capability (report bugs/errors, suggestions, collaboration)
11. Terms of use

- Map interface
  - Topographic map
  - Satellite imagery
- Find location
  - Use device's in-built GPS
  - Manual search
  - Search gazetteer

- Location of all world's volcanoes
- Volcano information
- Provided by Smithsonian Institution's Global Volcanism Program

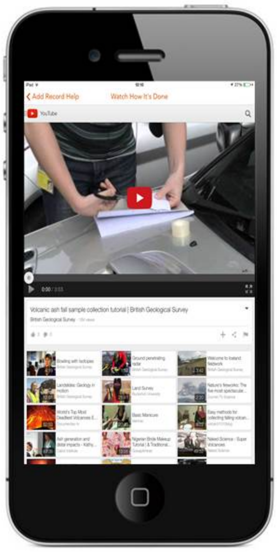
- Contribute data
- Upload photos
- Set location
  - Device GPS
  - Photo GPS
  - Manual/gazetteer search

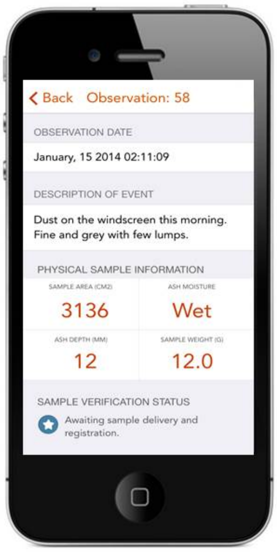
- Collect an ash sample
- Enter basic measurements
  - Start/end date of collection
  - Depth
  - Area
  - Weight

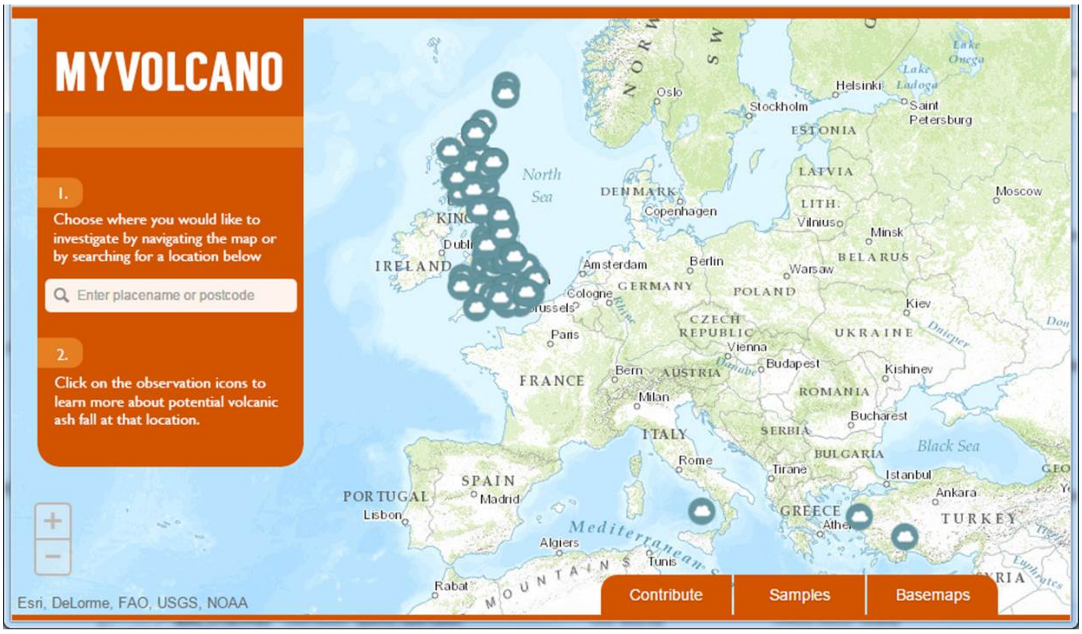


- Simple ‘how-to’ video for ash collection
- Several different methods features
- Submit record for verification by BGS

- View crowd-sourced data on the app
- Read other users’ comments
- View other users’ photos
- Lots of ‘help’ guides and further info about volcanic hazards





Web tool for non-iOS users:
http://mapapps.bgs.ac.uk/myVolcanoweb/home.html
App landing pages: http://www.bgs.ac.uk/myvolcano/
Available on Apple Store (free):
https://itunes.apple.com/gb/app/myvolcano/id774648897?mt=8

Appendix 4 Related projects

Strengthening Resilience in Volcanic Areas (STREVA)

STREVA is an interdisciplinary project that works aims to reduce the negative impact of volcanic activity on people and assets. The project works across disciplines to develop and apply a practical and adaptable volcanic risk assessment framework. This can be used to generate plans that will reduce the negative consequences of volcanic activity on people and assets. STREVA research focusses on six volcanic sites across the Lesser Antilles, Ecuador and Colombia. These countries are faced with multiple threats from volcanoes and associated natural hazards, often in close proximity to large towns and cities. However, by working across multiple sites, STREVA will identify common issues in volcanic disaster risk in these settings and consider how lessons could be applied worldwide.

In the Lesser Antilles, Soufrière Hills volcano on Montserrat was used as a 'forensic' volcano to learn lessons from previous eruptions which could be applied to Soufrière St. Vincent (SVG). The STREVA project has interviewed members of local communities in both locations to understand how people people who have experienced eruptions (i.e. Monserratians) respond, cope and adapt to long-lived eruptions and how those who have not experienced eruptions – or at least not for many years – (i.e. Vincentians), perceive the threat from the volcano and their own vulnerabilities.

STREVA is a collaboration between the BGS, UEA, University of Bristol, University of Oxford, University of Leeds and the Overseas Development Institute, along with several partners in-country. For more information on the STREVA project and its partners, visit http://streva.ac.uk/.

Earth Observation for Risk Information Services in the Caribbean (EO-RISC)

EO-RISC is an European Space Agency (ESA) 'eoworld' funded project to demonstrate the benefits of satellite earth observation (EO) technology as a standard tool in planning, implementing, monitoring and assessing for World Bank projects/programmes, and further to establish its use in World Bank operations on a sustainable basis. The project focusses on several countries in the Caribbean but with the specific task of producing land use/land cover mapping for St. Vincent. These maps, along with DEMs and landslide maps for other Caribbean countries, are being utilised through the **CHARIM** (below).

Caribbean Handbook on Risk Information Management (CHARIM)

CHARIM has produced an online 'handbook' (http://www.charim.net/) to support the generation and application of landslide and flood hazard and risk information to inform projects and program of planning and infrastructure sectors, specifically targeted to small countries in the Caribbean region. The methodology centres around a series of use cases, which are practical examples. CHARIM is a collaboration between University Twente (Netherlands), University of West Indies (Trinidad and Tobago), Asian Institute of Technology (Thailand), SSBN Flood Risk Solutions (UK) and Envirosense (UK) and is funded by the World Bank. Maps and DEMs produced by BGS as part of the EO-RISC project have been utilised by the CHARIM project in production of their hazard maps.

European Volcano Observatory Space Services (EVOSS)

The EU FP7 EVOSS project was a Copernicus 'Downstream Service' that began in 2010 with a '**user needs analysis**' for Volcano Observatories (VOs, including Seismic Research Centre, Trinidad) and Volcanic Ash Advisory Centres (VAACs). The project provided multiple near real-time data products (including thermal anomalies, volcanic ash and sulphur dioxide emissions) on an Information System (Virtual Volcano Observatory) that was applauded, particularly by users in Africa. The system could distinguish thermal anomalies from volcanic events and forest fires. The data products were relatively simple belying the complexity of algorithms, methods and infrastructure behind them. Unfortunately, sustainability beyond the project was a challenge. Global progress has been made on the needs of VAACs and the aviation sector and equivalent products are now available at different sites (progress has been supported by funding from ICAO, ESA and private sector among others). However, the identified needs of VOs which advise VAACs, national authorities and the public (and could be described as largely humanitarian), have still not been met in a sustainable way. The challenge to sustain EVOSS and similar services for landslides and forest fires was discussed at a ‘Supersites Coordination workshop’ in 2013:

https://www.earthobservations.org/documents/meetings/201306_supersites/20130610_11_supersites_coordination_final_agenda.pdf

Committee on Earth Observation Satellite (CEOS)

CEOS (i.e. the world’s space agencies) coordinates civil space-based EO programmes and comprises 30 space agencies responsible for the operation of 100 current EO satellite missions. The governments and agencies represented by CEOS have committed to increase the application of their investments in EO satellites to DRR. Several thematic pilot studies (Volcanoes, Earthquakes and Landslides) are underway providing free EO data to research projects working with in-country partners. The research project must provide evidence that free EO data can reduce disaster risk. One of the research projects benefiting from free EO data is the interdisciplinary STREVA (Strengthening Resilience in Volcanic Areas) project, which is partnering SRC and active in St Vincent, Ecuador and Colombia. Unfortunately, few research projects apply excellent science (including EO) in full iterative partnership with appropriate in-country institutions and with co-production of knowledge as STREVA does. The CEOS handbook (2015) admits that ‘obtaining the required spatial and temporal resolution of observations is a challenge on a global basis’. It describes international coordination efforts including the International Disaster Charter, Copernicus, GEO, CEOS and World Meteorological Organisation.

International Disaster Charter

The International Charter aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through Authorized Users. Each agency member has committed resources to support the provisions of the Charter and thus is helping to mitigate the effects of disasters on human life and property. BGS is a project manager for geohazard charter activations such as a recent Montserrat volcanic eruption. For the Japan 2011 Tohoku tsunami we utilised Charter data in the field to assist efforts on the ground.

In May 2011, BGS collaborated with scientists from Japan, Australia, the United States, Poland and Indonesia as part of the International Tsunami Survey Team (ITST) organised by UNESCO. They worked in the area around Sendai, in Miyage Prefecture, one of the most seriously damaged regions. In June 2011, BGS returned to Japan with EPOM colleagues funded by a NERC urgency grant. They again worked in close association with Japanese scientists, and worked in the Arahama area and farther southward in Shinchi. BGS is currently helping to produce landslide maps following the recent earthquakes in Nepal.

Global Volcano Model (GVM)

GVM is a growing international network that aims to create a sustainable, accessible information platform on volcanic hazard and risk. GVM will provide systematic evidence, data and analysis of volcanic hazards and risk on global and regional scales, and support Volcano Observatories at a local scale. GVM will develop capabilities to anticipate future volcanism and its consequences.”

The GVM project will develop an integrated global database system on volcanic hazards, vulnerability and exposure, make this globally accessible and crucially involve the international volcanological community and users in a partnership to design, develop, analyse and maintain the database system. The GVM project will aim to establish new international metadata standards that will reduce ambiguity in the use of global volcanic datasets. Vulnerability and exposure data will be integrated into the GVM and again new methods of assessment and analysis will be investigated and tested. The project also intends to establish methodologies for analysis of the evidence and data to inform risk assessment, to develop complementary volcanic hazards models, and create relevant hazards and risk assessment tools. The research will provide the scientific basis for mitigation strategies, responses to ash in the atmosphere for the aviation industry, land-use planning, evacuation plans and management of volcanic emergencies. Dr Sue Loughlin (BGS) is chair of GVM and part of the GVM Management Board.

Enhancing Resilience to Reduce Vulnerability in the Caribbean (ERC)

[Source: Dr Shawn Boyce, Chief Hydrologist, Caribbean Institute of Meteorology and Hydrology, personal communication – see full correspondence in Appendix 4)

The Caribbean Institute of Meteorology and Hydrology (CIMH) recently worked with other partners including the CIMA Research Foundation to implement a project entitled "Enhancing Resilience to Reduce Vulnerability in the Caribbean (ERC)". The project was funded by the Government of Italy and executed by UNDP Barbados & the OECS.

One of the activities included the adaptation and implementation of a disaster management platform, used to support civil defence in Italy, for use in the Caribbean. The platform, the Caribbean Dewetra Platform, is essentially a data fusion platform that manages and displays hazard, exposure and impact data from various sources in a real-time, geo-spatial environment in support of improved decision making. The platform has a reporting feature that allows the "crowd" to submit impact information related to the hazard of interest. The information is stored and can be retrieved later for post-assessment purposes. The crowd sourcing tool is based on Ushahidi (http://www.ushahidi.com/) and allows reports to be submitted to the platform using various methods including Twitter, email and the use of the Ushahidi smartphone application. Access to the platform allows users to load and visualize the impacts layer. Country specific profiles were created and distributed to disaster and met services.

The project closed early in 2014. Some persons have utilized the feature post project. The CIMH continues to sustain the platform post project. CIMH are continuing to build capacity and raise awareness of the benefits of the Caribbean Dewetra platform as a support tool applicable to all phases of the disaster cycle. This includes the use of the crowd-sourcing tool. The CIMH completed an assessment related to the December 24-25, 2013 event in St. Vincent. CIMH used the platform to capture impacts whilst in the field.

Rift Volcanism: past, present and future (RiftVolc)

BGS is part of a newly awarded NERC Large Grant to research past and current volcanism and volcanic hazards in the Main Ethiopian Rift. The £3.7 million, five year long project 'RiftVolc' starts in September 2014 and includes the universities of Bristol, Cambridge, Edinburgh, Leeds, Oxford and Southampton as well as Addis Ababa University and the Geological Survey of Ethiopia.

Along the East African Rift (EAR), there is a great variety of volcano types, from large silicic calderas to basaltic fissure swarms, monogenetic cones to off-axis volcanic fields. There is a wide variation in the styles of past volcanic eruptions as well as the frequency and magnitude of these eruptions. The project builds on previous NERC-funded projects including the Ethiopia Afar Geoscientific Lithospheric Experiment (EAGLE), the Afar Rift Consortium(ARC) and Airborne Research & Survey Facility (ARSF) data acquisition over Afar and Ethiopian rift volcanoes. These projects focussed on magmatism and rifting in the EAR. RiftVolc will focus on volcanoes and volcanic plumbing systems in three work packages to address fundamental questions, including:

1. What has driven eruptions over geological timescales?
2. What controls the active magmatic system and volcanic unrest?
3. What are the potential threats from future volcanic activity?

An improved understanding of the evolution of volcanic systems, gained from finding the answers to the first two questions, will provide the foundation on which new methods to assess and forecast volcanic hazards from high risk central volcanoes, active rift segments and volcanic fields will be developed to answer the final question.

GeoSocial - Aurora

GeoSocial is a tool currently being developed by the British Geological Survey for retrieving and displaying information relating to geoscience (initially geohazards) that people have posted on social media sites. Although still in its infancy, the aim of GeoSocial is to explore whether BGS can make use of the wealth of information, publically available through these sites, to help advance scientific understanding and provide better, or, more - timely, advice. GeoSocial employs both passive (i.e.

obtaining information which people have shared and which can be retrieved without requiring them to do anything beyond their normal behaviour and actions) and active crowdsourcing techniques.

Appendix 5 App methodology steps

Step 1: Identify key in-country partners and their needs

Citizen science is most effective when there are clearly defined aims or questions to be resolved (Pocock et al., 2014) and who better to determine these than the key in-country partners. This step is crucial in determining who key partners are, whether an App would be of use to them and the key issues it could resolve (and what it shouldn't do). The monitoring institution and civil protection/emergency management are likely to be key partners and their roles, governance and disaster risk management framework should be well-understood.

Statements of intended collaboration are also likely to be established at this point, if they do not already exist. During this step, it is also essential to consider how the use and impact of the App will be evaluated, in order to determine baselines for comparison.

Step 2: Understand the natural hazard threat and disaster context

The second stage is to understand the potential natural hazards, their likelihood of occurrence and threat to populations – this assessment is the role of a mandated monitoring organisation (if there is one) but researchers also contribute to this understanding. The key factors to understand are:a) the threat to the country from different natural hazards (volcanic and non-volcanic) and their interaction, b) the previous history of natural disasters and lessons learned, and c) likely future response actions and location of critical infrastructure.

Understanding these factors helps to determine what hazards the country is most at risk from, where communities are most exposed and key aspects of vulnerability.

Step 3: Characterise mobile phone/internet use

Paramount to the success of any citizen science initiative is establishing that (a) a 'crowd' exists and (b) there is sufficient access to the necessary technology (see Polock et al.'s [2014] decision framework for citizen science). A monitoring institution and civil protection/emergency managers will already have a good understanding of the communities they serve and will know whether engagement in data collection is likely to be successful or not. Nationally however, it is also useful to establish telecommunications trends such as: how many people have mobile phones/smartphones; what is the dominant platform; how many people have access to the internet; do people use social media and if so, which is most popular? These questions can help to determine whether a user community exists and whether technological changes need to be implemented in the App e.g. develop on another platform. If there are sufficient social media users, additional services can be developed e.g. to trawl sites for relevant information.

Step 4: Recruit a core group of citizen scientists and wider networks

The monitoring institution and authorities may know key individuals or groups in different communities, for example community leaders, local disaster groups, schools who would be interested in volunteering..

Motivating participants requires that we provide them with clear reasons as to why their participation is so important (Polock et al., 2014). At Tungurahua volcano, the motivations for volunteer observers (vigías) are an important component of the network's success – all feel a sense of duty or moral obligation and want to help reduce risk to their family and community (Stone et al., 2014). Vigías stated that the voluntary nature of the role is very important to them.

The motivation for engagement may relate to different socio-economic and cultural factors and will require understanding the country context where the App is being promoted. However, we can take lessons from existing studies. It is important that those recruiting citizen scientists make the purpose of the App clear, emphasise the benefits to those involved (the information they gather will be shared and there will be opportunities to engage with scientists) and guidance on how to safely monitor unrest and other hazards in volcanic environments.

Step 5: Identify other ‘big data’ initiatives in the region

There may be ongoing ‘big data’ initiatives or risk/resilience projects in the region that the App could link into. These activities may include existing citizen science initiatives, social media networks related to natural hazards, ground monitoring networks, early warning systems, open GIS platforms and earth observation projects. Since the App has the dual purposes of collecting and sharing information, it is critical to map out these existing resources to avoid duplication and to make connections where possible/necessary.

Step 6: Agree app specifications

A list of app specifications should be discussed and agreed between both the stakeholders (what is needed?) and the developers (what innovations are technically possible?). These might include developing the App on another platform, agreeing what extra data and information should be displayed on the map and establishing linkage to other ‘big data’ initiatives. It is also important to determine any anticipated challenges in developing the App to these agreed specifications.

Step 7: Develop and pilot

The App is ‘customised’ following agreement of what extra specifications should be added. As citizen science works best when small scale trials are undertaken to test the approach (Tweddle et al., 2012), a pilot study should be devised in-country with stakeholders and identified users, in order to gauge their response and identify local or social relevance, as well as the interests and motivations of potential participants (see Tweddle et al., 2012). Validation should be considered and tested at this stage. Such reflection will help to inform awareness raising campaigns and whether any demonstrations/training are required.

Step 8: Implement, evaluate and review

Following implementation, evaluation could be through user and stakeholder questionnaires, evaluation of quantity and quality of data collected or by reviewing the impact of the App. Evaluation should be a regular and ongoing research process.

Appendix 6 – Correspondence

Correspondence with Dr Barbara Carby, Head UWI Disaster Risk Reduction Centre:

Dear Katy

Please see my thoughts in text below - I am away from Jamaica on official travel at the moment.

From: Mee, Katy [katy@bgs.ac.uk]
Sent: Tuesday, May 12, 2015 7:18 AM
To: CARBY,Barbara E
Cc: Loughlin, Susan C.; Duncan, Melanie J.
Subject: Crowd-sourcing app for monitoring natural hazards

Dear Barbara,

I am a GIS specialist at the British Geological Survey (BGS), working with the STREVA project. My colleagues at BGS (Sue Loughlin and Melanie Duncan, copied in) and I are currently also working on a small pilot project (funded by NERC-ESRC-DfID) to explore the potential of 'Big Data' to support disaster and climate resilience in St. Vincent. This is part of a new Science for Humanitarian Emergencies and Resilience (SHEAR) programme.
http://www.esrc.ac.uk/funding-and-guidance/funding-opportunities/33546/big-data-for-resilience-realising-the-benefits-for-developing-countriesscoping-exercise-call.aspx

We're interested in two aspects of Big Data in particular: crowd sourcing and earth observation (satellite) data. We would be very grateful indeed if you could take the time to briefly answer a couple of questions. First some background:

BGS has developed an app for crowd-sourcing observations of natural hazards. It was initially designed as a tool for collecting observations about volcanic ash and gases in a distal setting (i.e. the types of things we might see/smell in the UK from Icelandic eruptions). The app enables people to upload descriptions and photos, geo-located by their phone's GPS, as well as showing users how to collect volcanic ash samples. The app could be developed further specifically for St Vincent. It enables the public to collect and share useful observations and such information might be useful for a range of organisations (e.g. NEMO, SRC). At a national scale, the app can also direct people to NEMO and other official organisations for advice and information. Richie Robertson also suggested, for example, that people use the app to take photos of things 'out of the ordinary', environmental changes that they might see or feel such as landslides, or felt earthquakes that might precede a volcanic eruption etc. It could be very valuable for recording impacts. We're interested in exploring exactly how such crowd-sourcing could increase resilience.

We're also interested in the very large number of projects that have aimed to increase resilience in the region using earth observation. For example, we were involved in setting up a platform to provide earth observation products to volcano observatories but sustaining the platform has been a challenge. BGS alone has been involved in a number of projects in St Vincent over the years funded by for example World Bank, EC, ESA, NERC, ESRC and others.

We appreciate that these are very big topics! Given your experience, particularly from a regional point-of-view, we'd be very interested in your brief views on the following:

1. What are the biggest challenges for St. Vincent in terms of increasing resilience to natural hazards?

A change in culture perhaps - thinking risk reduction instead of preparedness - and a concomitant change in planning horizons to medium to long term, where long term may now have be fifty - 100 years in order to accommodate CC

Ensuring coherence and synergy among govt policies which impact risk reduction and CCA

2. Do you think there is a place for crowd-sourcing through apps like ours – how could it help and what are the main limitations of such tools?

I think there is a place for crowd sourcing, it gives potentially wide coverage and encourages public participation, fosters an interest in DRM and builds awareness for the importance of research The main problem would e validation and quality assurance

3. Are there, or have there been any other crowd-sourcing initiatives in the region that you're aware of?

We are about to try it for a project out of DRRC

4. What are the challenges in using earth observation (satellite) data and products?

Don't do much remote sensing myself - the problem I suspect would be resources if the data/products are not open access. There may also be problems of downscaling in some cases

5. Do you have any other comments on these topics?

How can international research investment be more effective, supporting decision makers and really building resilience?

Should be solution-oriented - thus decision makers should be involved in problem definition and research design, related to specific national needs but with potential regional benefits, should build national/regional capacity, should complement previous work if at all possible, should encourage standardisation of methodologies

Many thanks
Katy Mee

Meeting notes from conversation with Dr. Richard Robertson, UWI Seismic Research Centre, Trinidad and Tobago:

(Our questions in black, notes from Dr Robertson's responses in red)

What data might be of use in St. Vincent and for whom?

- **Data collected by people during eruptions is key**
    - **Ash database – can compare the public's collection with SRC point of validation**
    - **Pyroclastic Density Currents (PDCs)– record locations of them**
    - **Data on people and impacts – of use to emergency management teams (call this 'other' data and information)**
    - **Collecting info like this would help NEMO etc.**
    - **Collect ash samples for SRC**
- **Focus on unrest – small changes in environment before an eruption – felt earthquakes/earthquake swarms, storms over the volcano (look for storm clouds)**
- **Link to hydro-meteorological hazards – landslides are under-measured**
- **Observatory at Belmont on west side of volcano – only staffed when an eruption is imminent and during an eruption – can only see one side of the volcano so having people take photos, observations on the other side would be useful**
- **Where flows (lahar, PDCs) might go**

Who will collect the data?

- **There might be key people in a community you could work with**
- **Need to avoid treading on toes of civil protection**
- **Avoid people going into danger areas to collect data – balancing understanding with risk taking**
- **People walk up the volcano all the time for leisure [when it's not erupting], people could take photos if they see something different**

Data validation – who would do this?

- **SRC are willing to work on this – rumour quelling**

What systems do most people use?

- **Most people use android and many people have more than one phone.**
- **Main cell providers are Digicell and LIME**

Current communication of data from monitoring – is it published?

- **SRC will send reports to NEMO and eventually these reports reach the web. But they only tell the public if there is unusual or concerning activity.**
- **Planning to put a bit of data out, but maybe not necessary, as people evacuate quickly on St Vincent.**
- **Probably would have regular web updates if eruption happened.**

Who is the App useful for/how is it useful?

- **Would need to build in something useful for the community – add education stuff.**

Other initiatives – does Richie know about these projects e.g. Colm's EO-RISC peroject to produce land-use maps:

- **Not heard of this – who are they working with in St. Vincent?**

Meeting notes from conversation with Dr. Colm Jordan, Team Leader Earth and Planetary Observation and Monitoring, British Geological Survey.

Who are the contacts in St. Vincent that the EO-RISC project is working with?

Colm to pass on a list of contacts but certainly NEMO know about the project and are involved. Chief engineer, SVG, NEMO, Ministry of Housing, Informal Human Settlements, Lands & Surveys & Physical Planning, Ministry of Transport, Works, Urban Development and Local Development

What happens to the end products (land use maps) and who can use them?

Essentially they will be made available to anyone. Maps/all data (maps or raw data or both?) will also be available through the Geohazard Exploitation Platform (https://geohazards-tep.eo.esa.int/#!pages/initiative). Some satellite imagery can only be provided to certain users due to license restrictions.

How is the charter activated?

Anyone who is an authorised user can activate the charter so would need to be registered but essentially anyone could do it i.e. for St. Vincent could be NEMO, SRC, BGS, USGS, CDEMA, St. Vincent Government etc. A new development in the Charter is 'universal Access' – any national disaster management authority can now submit requests for emergency response support to the Charter. Procedures have to be followed, but the affected country does not have to be a Charter member. In the UK, authorised users are the Cabinet Office and DfID. Once activated, the Executive will nominate a Project Manager, who has received specific training. The PM can also be the Value Adder, who processes/interprets the imagery and provides products to the Authorised User. The PM is normally someone/organisation with experience in that particular disaster e.g. BGS is a PM and VA for geohazards in the UK and overseas when appropriate.

How soon could the charter be activated? Could it be activated in advance e.g. of an eruption if it was thought an eruption was imminent but hadn't actually happened yet?

Can't really be activated unless a disaster has happened, but this has changed slightly so might be willing to agree to activate if an eruption was imminent, for example. Worried about activating the charter pre-emptively because could be setting precedence for others to use it irresponsibly. For example, BGS are trusted but then if it got activated and nothing happened that could affect the level of trust.

How long is the charter active?

At the moment there is just a short term response (~two week from initial event) but there is an argument for providing a longer term response [e.g. volcanic eruptions can last for months/years]. The Charter does not provide data to support rehabilitation, reconstruction, prevention, preparedness or scientific research. It also does not provide maps suitable for use in the field.

What is BGS' (Colm's) role?

Project Managers are the link between space agencies (data providers) and whoever has activated the charter (Authorised User). Coordinates the acquisition of data. We also act as Value Adder to processes and interpret data to make maps, provide data to users.

What happens to the data afterwards?

Can't be used after the event (see above) but in some cases it is possible to contact the space agencies individually to request non-commercial access – they may agree to continue letting you use the data but this is at their discretion.

Could you use crowd-sourcing?

Possibly – how would you ensure that you have experts looking at the maps and not picking up slides from before the earthquakes? Aside from the Charter, systems such as Tomnod use crowd sourcing. Crowd sourcing was used to identify infrastructure damage in the aftermath of the Nepal earthquakes but expertise is required to differentiate/delineate active landslides so this task was done by experts.

Other challenges with the charter?

Data volumes are huge – have 6 PCs running just to download the data [for Nepal]. The data is made available over a short period of time and there is a real urgency to create useful products. The data may not be ideal e.g. there can be significant cloud cover. Much is done on a best-endeavours basis so some flexibility is required/expected.

Appendix 7 Text boxes

Box 1: Is there a need for a monitoring App? A key stakeholder perspective

Biography of Dr Richard Robertson.

(Source: UWI SRC website http://www.uwiseismic.com/StaffProfile.aspx?id=20)

Originally from St. Vincent, Dr Richard Robertson joined the staff at the Seismic Research Centre in 1993 after serving for six years as Head of the local volcano-monitoring unit in St. Vincent (the Soufriere Monitoring Unit). Since joining the Seismic Research Centre he has been involved in a variety of projects including: the ongoing eruption of the Soufrière Hills Volcano on Montserrat; the establishment of volcano monitoring networks (mainly geodetic) and ongoing public education and outreach programs throughout the Eastern Caribbean. He served several tours of duty as Chief Scientist of the Montserrat Volcano Observatory during the period 1995-1999 and was its Director from October 1998 - March 1999. Dr Robertson served as Head of the Seismic Research Unit during the period 2004-2008 and as Director of the Seismic Research Centre from 2008-2011. For the period September 2011 to July 2013 Dr. Robertson served as a Geologist/Volcanologist at the SRC while on sabbatical, after which he resumed duties as its Director. In St. Augustine, Dr Robertson has assisted with the field supervision and lecturing of geoscience students. He was one of the editors of the Volcanic Hazards Atlas for the Lesser Antilles. Since 2008 he has been the main coordinator of the SRC and IPGP operations at the Montserrat Volcano Observatory.

Which data would be of use?

Dr Robertson emphasised that data collected by people during eruptions is key – we can compare the public's collection of ash with an SRC point of validation. Other data, such as that relating to people and impacts is also of use, particularly to the emergency management teams like NEMO. It would be of great interest to us for the app to encourage people to measure unrest, but to also link to other hazards, particularly hydro-meteorological hazards – landslides, for instance, are under-measured.

Who should collect these data?

There may be key people within the community to work with and it is important to discourage people from putting themselves in danger in order to collect data. There is a need to balance understanding with risk taking.

Who would validate these data?

SRC are willing to do this. They already see themselves in having a key role in quelling rumours.

Who is the App useful for/how is it useful?

It is necessary to build in something useful for the community, for instance education material including videos of hazards (SRC have existing videos). SRC are planning to share more data on their website, which the App could then link to.

Box 2: Volcanic alert levels for St Vincent

There exists an alert level system (based on seismic data) for St Vincent used to describe the state of activity at the volcano and is only communicated once a particular threshold is reached. However, during an ongoing eruption or a period of significantly elevated activity, the alert level would be regularly communicated. Information about the volcanic activity level is communicated by the SRC to the civil protection agency, which in the case of St Vincent is NEMO, after which the information is provided to the public through all available media.

What is the protocol if volcanic unrest increases?

Response is guided by an Alert Level Table, which outlines actions to be taken by Scientific Staff and Civil Authorities. Generally response to an unrest involves increased/intensification of monitoring with additional measurements and instruments deployed, increased site visits and providing of advice to civil authorities via regular Scientific Advisories. Response will depend on the signals derived from monitoring sites. Communications with local authorities is normally via the National Disaster Coordinator but there is allocation for contacting the highest office on the island if though necessary by the SRC monitoring team.

What is the protocol at the onset of an eruption?

Immediately prior to the onset of eruption a temporary observatory would be established on the island staffed by persons from the SRC and any local equivalent group that exists. Generally the Director of the SRC would be in charge of operations and staff and equipment will be deployed on island as deemed necessary to provide real-time monitoring and advice to local authorities.

Source: [Brown et al., 2015a]

[Additional info from our conversation with Richie: Probably would have regular web updates if eruption happened.]

Box 3: The History of Emergency Management in St Vincent

A summary of disaster management in the Caribbean is provided by Poncelet (1997) and outlined here. Throughout the 1960s and 1970s disaster management in the region was based on ad hoc response to disasters. This changed, however, after a number of destructive hazard events in 1979. First, the costly volcanic eruption on St. Vincent, in addition to Hurricane David which devastated Dominica and the Dominican Republic resulting in over 200,000 people being made homeless and more than US$1 billion in damage. On Dominica 56 percent of structures were damaged. These disasters led to a more regional approach to disaster management and the creation of the Pan Caribbean Disaster Preparedness Program in 1981 (later called the Pan Caribbean Disaster Preparedness and Prevention Program PCDPPP). The initiative lasted around 10 years under the guidance of a number of regional and international organisations including the Pan American Health Organisation (PAHO), the Red Cross, UNDRO, and the Secretariat of the Caribbean Community (CARICOM). However, the limited success of the PCDPPP became evident at the end of the decade when in 1988 Hurricane Gilbert devastated Jamaica and in 1989 Hurricane Hugo severely damaged Montserrat. In 1991 CARICOM states replaced the PCDPPP with CDERA – the Caribbean Disaster Emergency Response Agency - which had a stronger institutional position than the PCDPPP.

In 2009, CDERA was changed to CDEMA (the Caribbean Disaster Management Agency) with idea that it would both replace and advance the work of CDERA by adopting the principles and practice of Comprehensive Disaster Management – 'an integrated and proactive approach…[that] seeks to reduce the risk and loss associated with natural and technological hazards and the effects of climate change to enhance regional development' (CARICOM, 20110

Each island has a disaster management agency. Initially the role of disaster manager was a part time job undertaken by someone with additional duties in the government. On St. Vincent the disaster agency is called NEMO (National Emergency Management Organisation), which is staffed by full-time employees.

Other ministries such as transport and works, and telecommunications, are theoretically involved in national level disaster planning and management through several subcommittees, however, according to officials at NEMO they do not all recognize the importance of disaster planning and are not as active in the subcommittees as NEMO would like. At the local level disaster management is coordinated through community disaster groups across the island, of which there are over 20. These comprise of members of the community who hold jobs such as farmers, teachers, etc., that meet to assess the hazards specific to their community. In response to the risk from these hazards the groups create plans to respond to a hazard should it occur. These local groups are supported by NEMO, however in the same way as government ministries are not all active in disaster management; some community disaster groups are more active than others. Formally, the roles and responsibilities of the government ministries and community disaster groups and the structure for preparedness and response to disasters are outlined in the National Emergency and Disaster Management Act 2006, and the National Disaster Plan (NEMO, 2004).

Source: adapted from Lowe (2010) [mostly verbatim]

Appendix 8 Saint Vincent and the Grenadines country profile

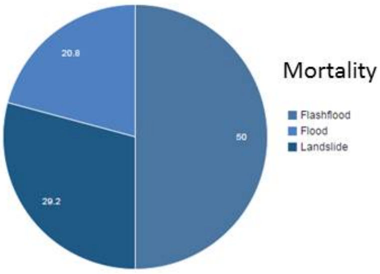
Country profile

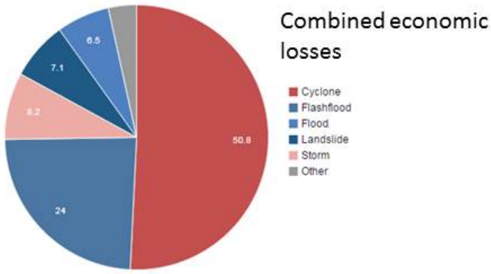
Population [1]:	109,400
GDP [1]:	US$ 709.4 million

Natural disasters 1980 – 2014 [2]

Disaster	Date	Affected
Flood	2013	16885
Storm	1980	2050
Storm	2004	1004
Flood	1987	1000
Storm	2005	530
Storm	1987	208
Flood	1992	200
Flood	1986	152
Storm	1999	100
Storm	2002	0

Nationally reported losses 1990 – 2014 [2]





Average Annual Loss (AAL) by hazard [2]

Hazard	Absolute [Million US$]	Capital stock [%]	GFCF [%]	Social exp [%]	Total Reserves [%]	Gross Savings [%]
Earthquake	2.79	0.105	1.587	7.490	2.065	-6.042
Wind	6.58	0.249	3.742	17.665	4.871	-14.250
Storm Surge	15.11	0.571	8.594	40.564	11.185	-32.722
Tsunami	0.01	0.000	0.006	0.027	0.007	-0.022
Multi-Hazard	24.49	0.926	13.928	65.746	18.128	-53.035

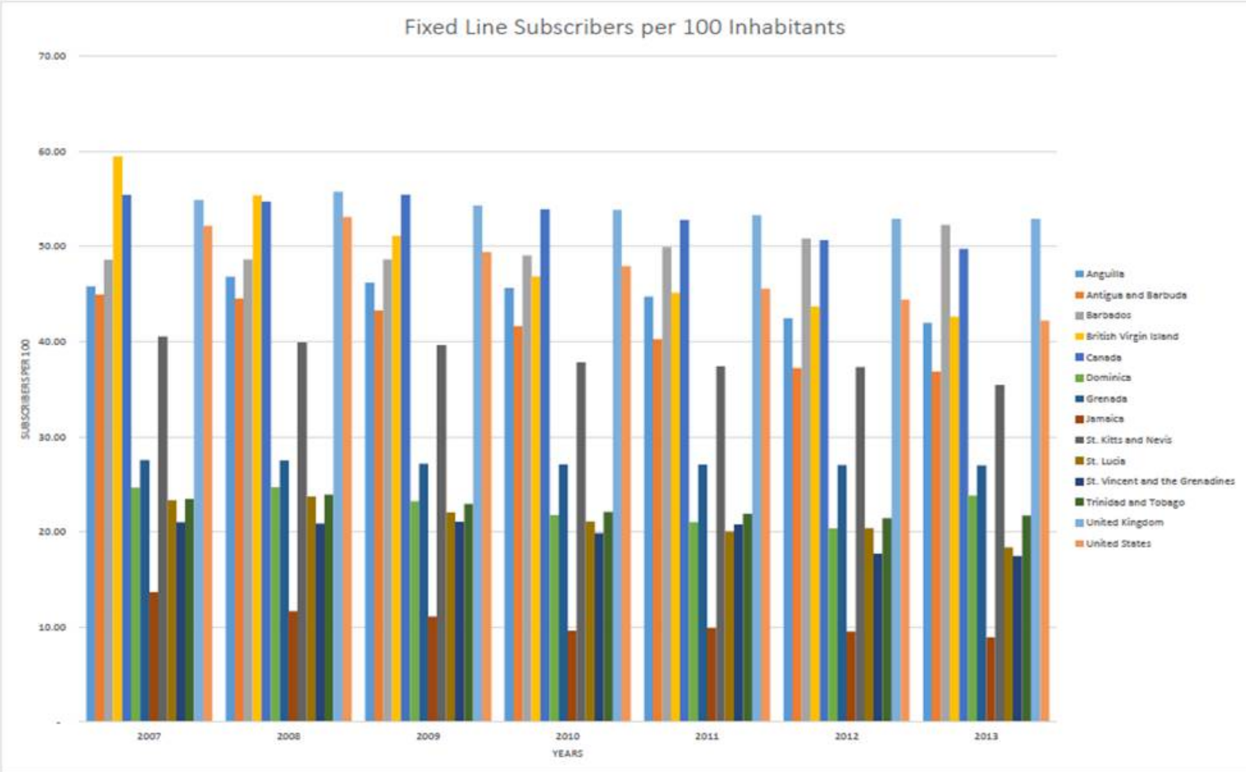
Exposure to volcanoes [2]

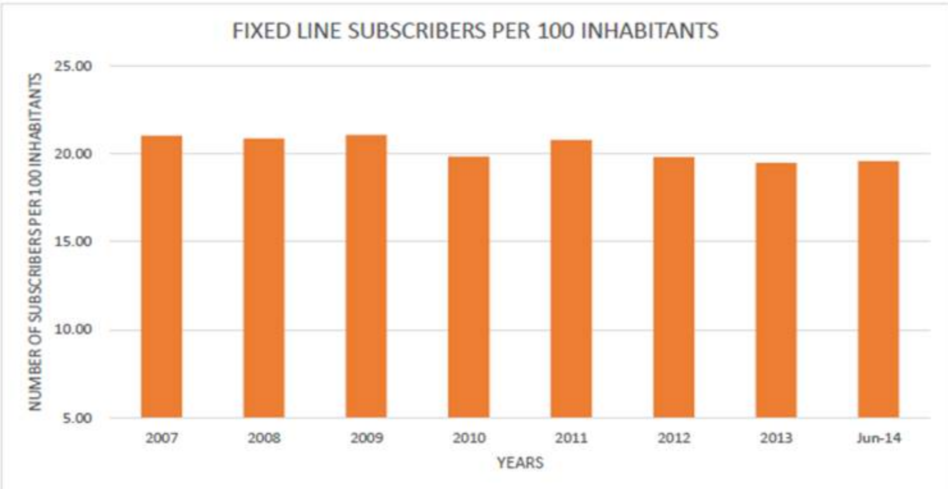
Number of volcanoes	1
Total population lining within 30 km from a volcano	100.414
% of population living within 30 km distance from a volcano	97 %

Source: [1] World Bank http://www.worldbank.org/; [2] Prevention Web http://www.preventionweb.net/english/

Appendix 9 Telecommunications and social media statistics

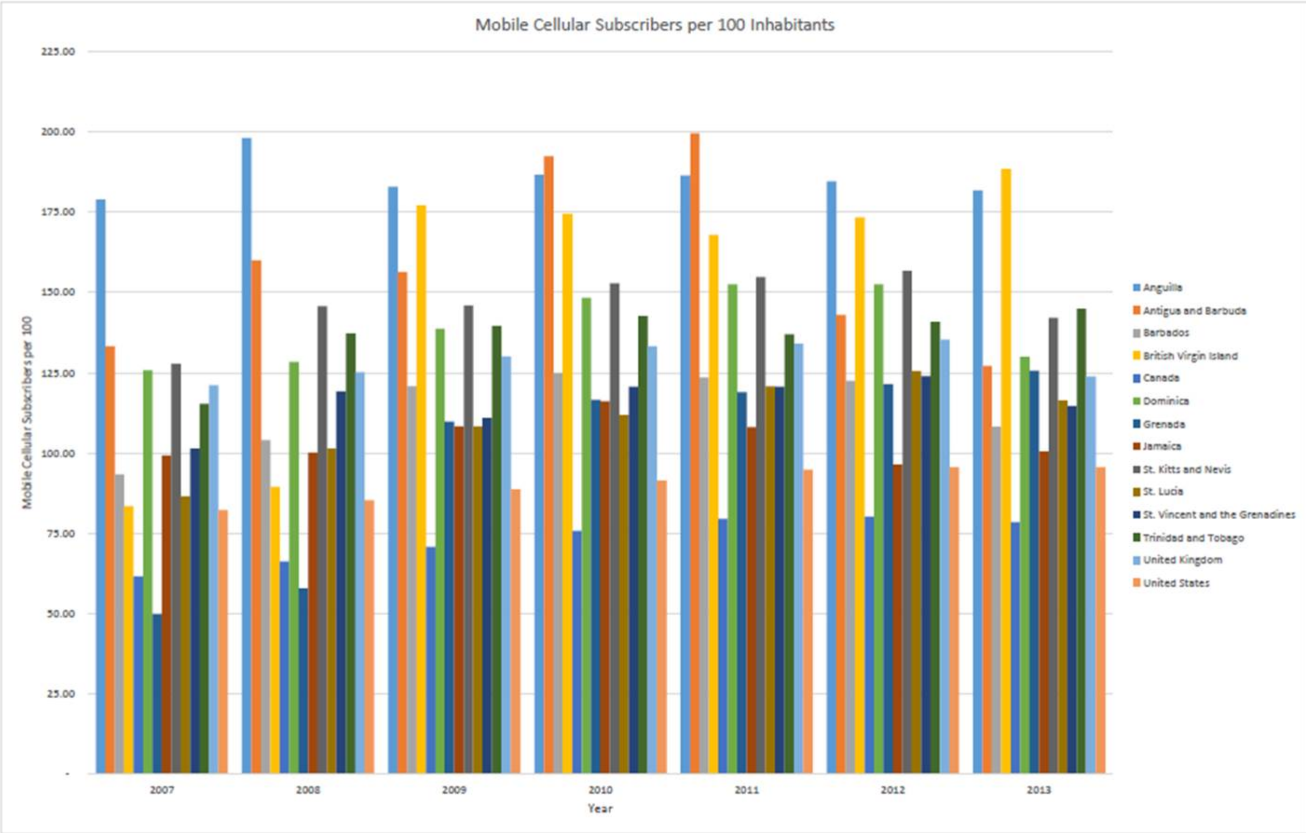
Data sources: The National Telecommunication Regulatory Commission of Saint Vincent and the Grenadines (http://www.ntrc.vc/index.php/telecommunications-statical-data)

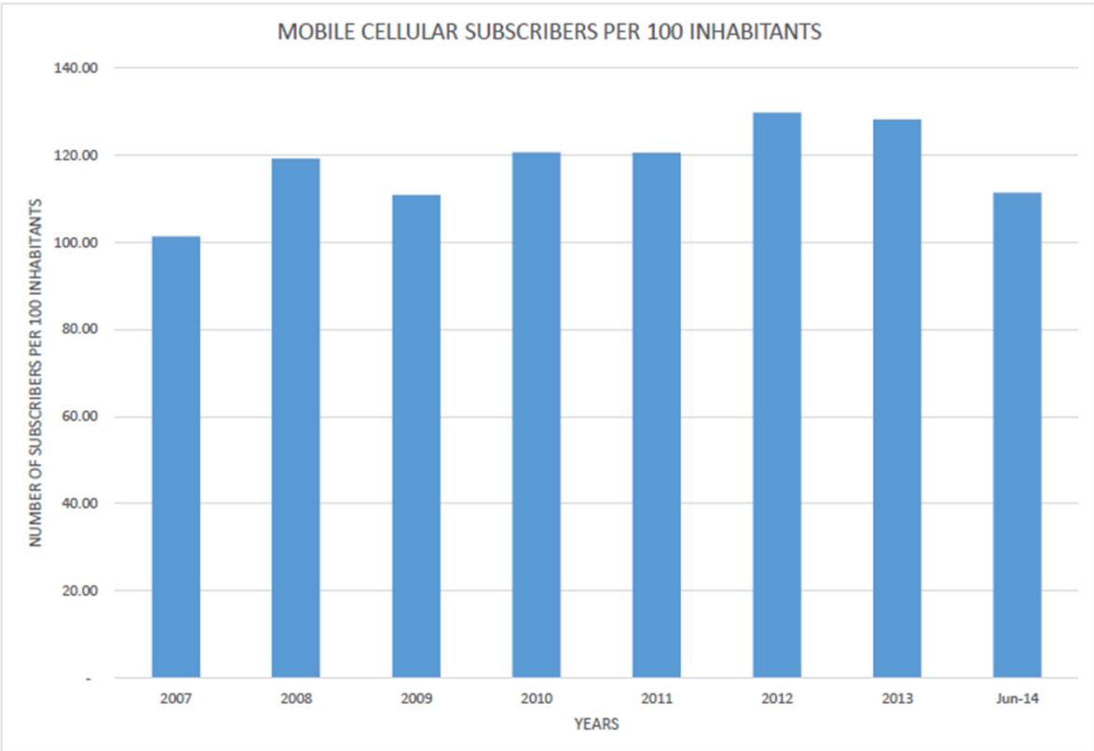


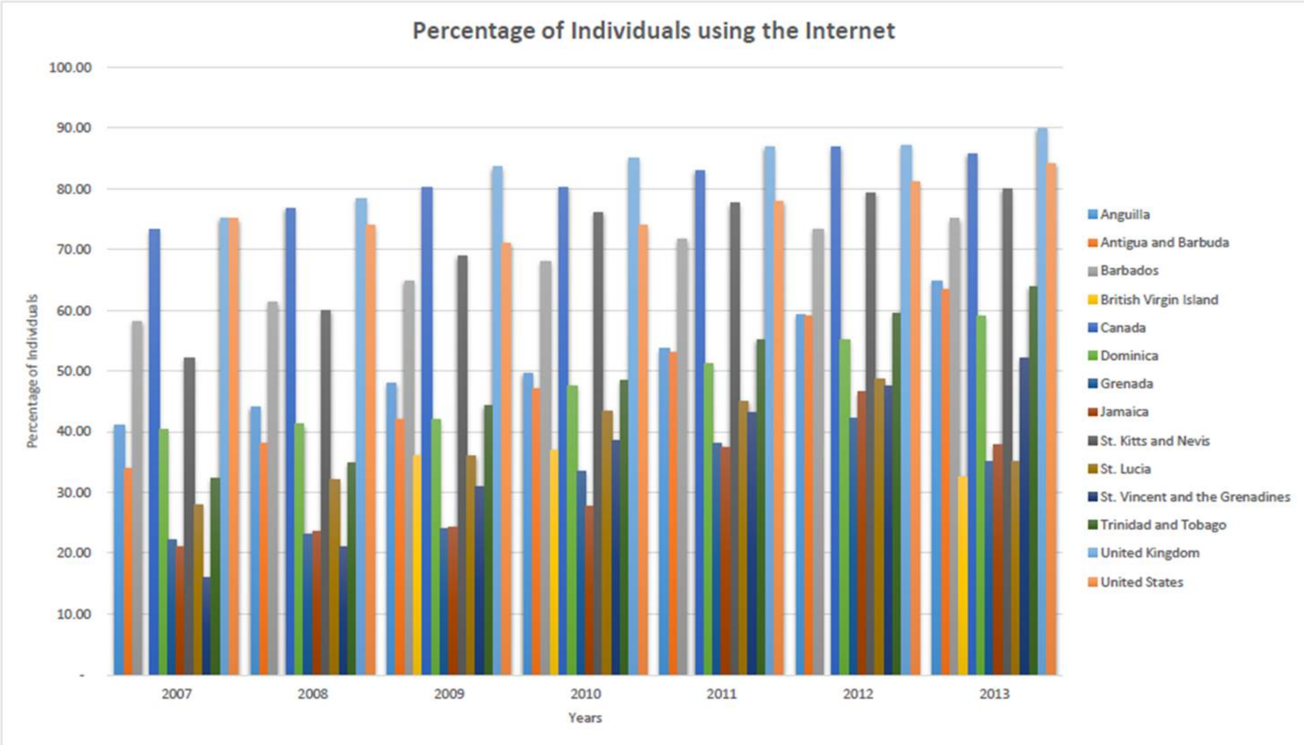


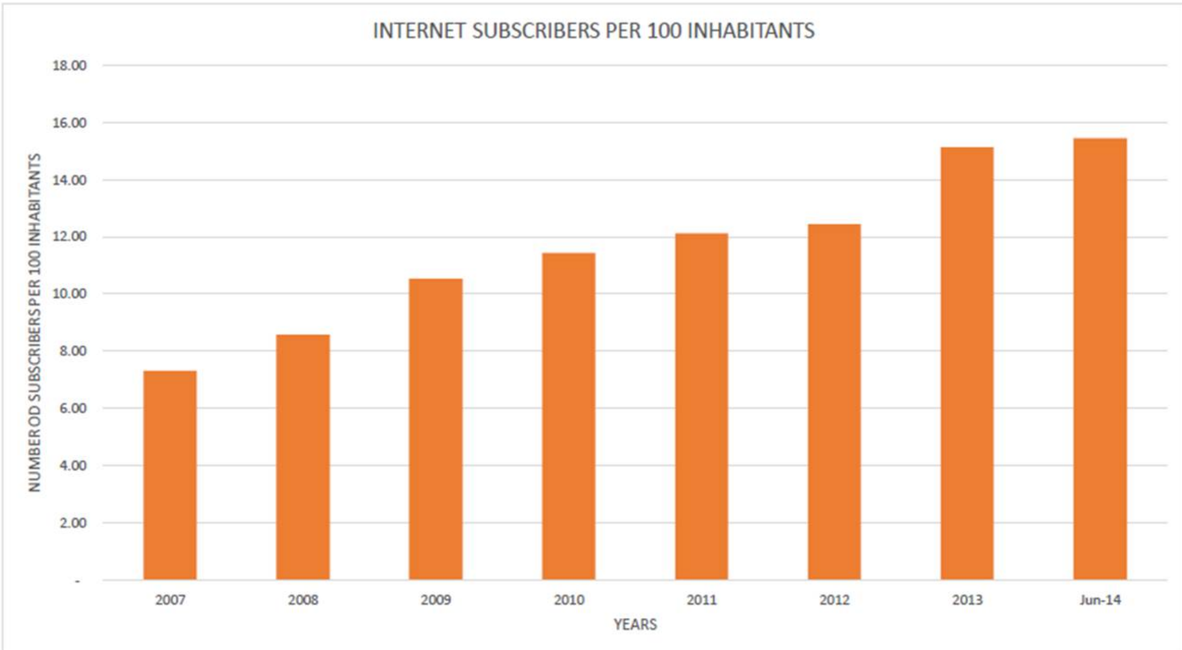
	FIXED LINE SUBSCRIBERS							
	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**June 14**
Residential	16,536	16,367	16,449	15,582	15,191	14,839	13,500	15,020
Business	6,391	6,410	6,540	6,121	7,521	4,540	5,569	4,156

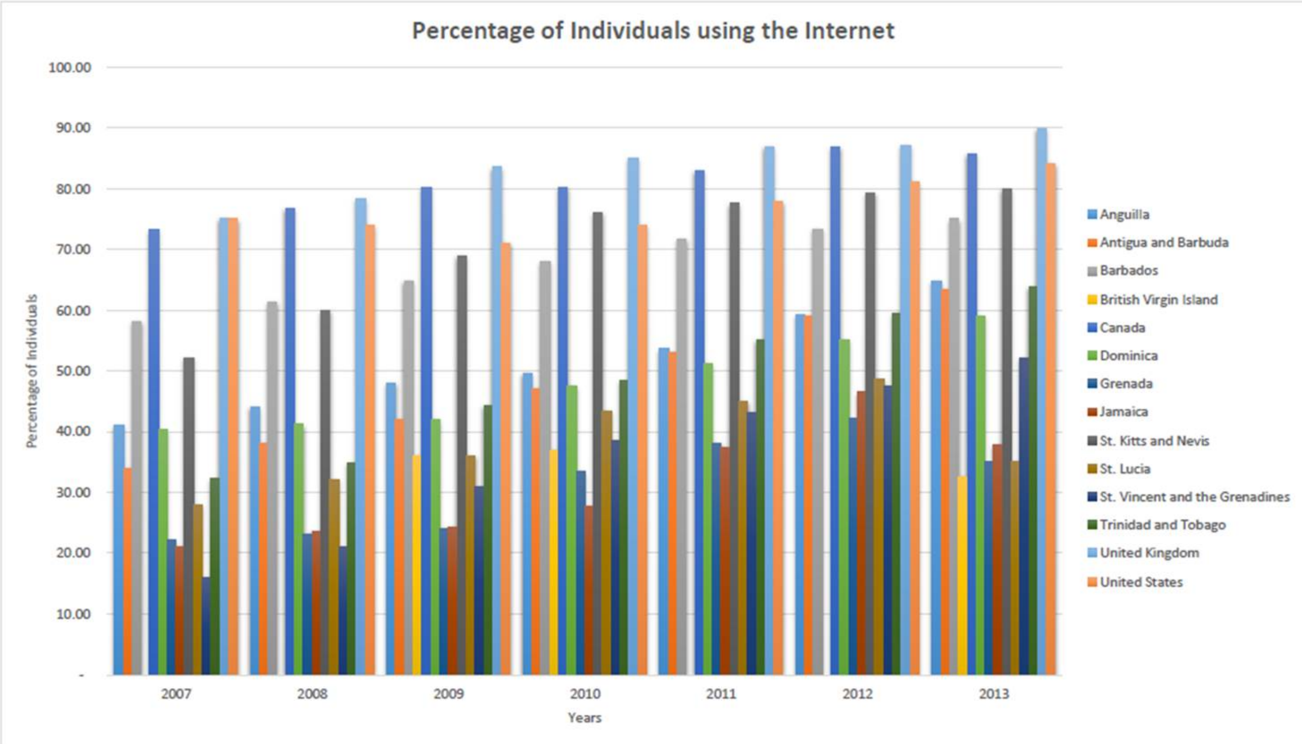
FIXED LINE SUBSCRIBERS PER 100 INHABITANTS							
2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**June 14**
21.03	20.87	21.07	19.85	20.78	19.80	19.48	19.59

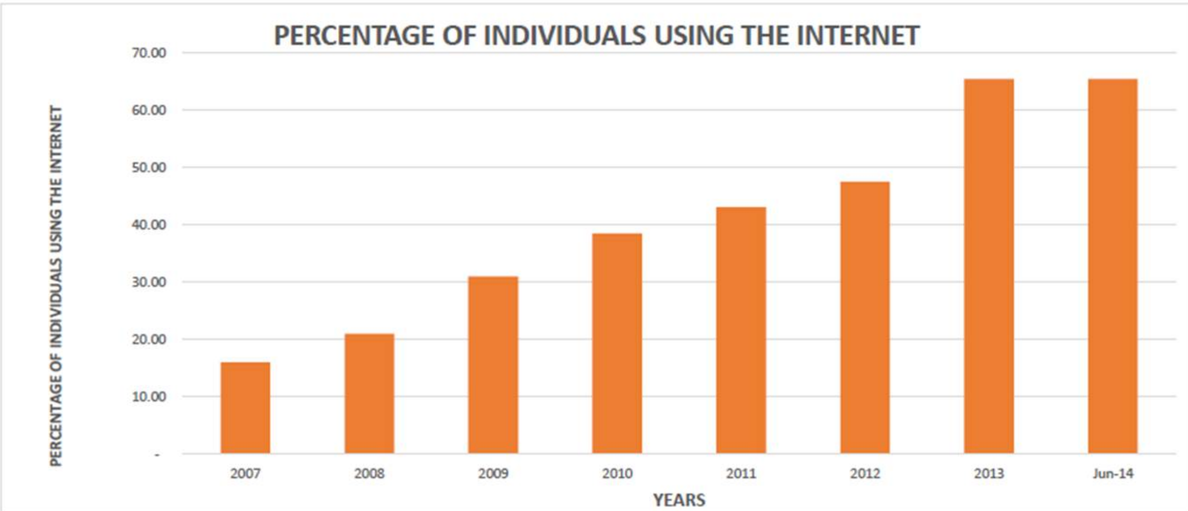

Mobile Cellular Subscribers per 100 Inhabitants
225.00
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
-
Mobile Cellular Subscribers per 100
2007
2008
2009
2010
2011
2012
2013
Year
Anguilla
Antigua and Barbuda
Barbados
British Virgin Island
Canada
Dominica
Grenada
Jamaica
St. Kitts and Nevis
St. Lucia
St. Vincent and the Grenadines
Trinidad and Tobago
United Kingdom
United States


MOBILE CELLULAR SUBSCRIBERS PER 100 INHABITANTS
140.00
120.00
100.00
80.00
60.00
40.00
20.00
-
NUMBER OF SUBSCRIBERS PER 100 INHABITANTS
2007
2008
2009
2010
2011
2012
2013
Jun-14
YEARS


Percentage of Individuals using the Internet
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
-
Percentage of Individuals
2007
2008
2009
2010
2011
2012
2013
Years
Anguilla
Antigua and Barbuda
Barbados
British Virgin Island
Canada
Dominica
Grenada
Jamaica
St. Kitts and Nevis
St. Lucia
St. Vincent and the Grenadines
Trinidad and Tobago
United Kingdom
United States


INTERNET SUBSCRIBERS PER 100 INHABITANTS
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
-
NUMBER OD SUBSCRIBERS PER 100 INHABITANTS
2007
2008
2009
2010
2011
2012
2013
Jun-14
YEARS





PERCENTAGE OF INDIVIDUALS USING THE INTERNET							
2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**June 14**
16.00	21.00	31.00	38.50	43.01	47.52	65.46	65.46

Smart phone and social media usage

http://www.internetworldstats.com/carib.htm

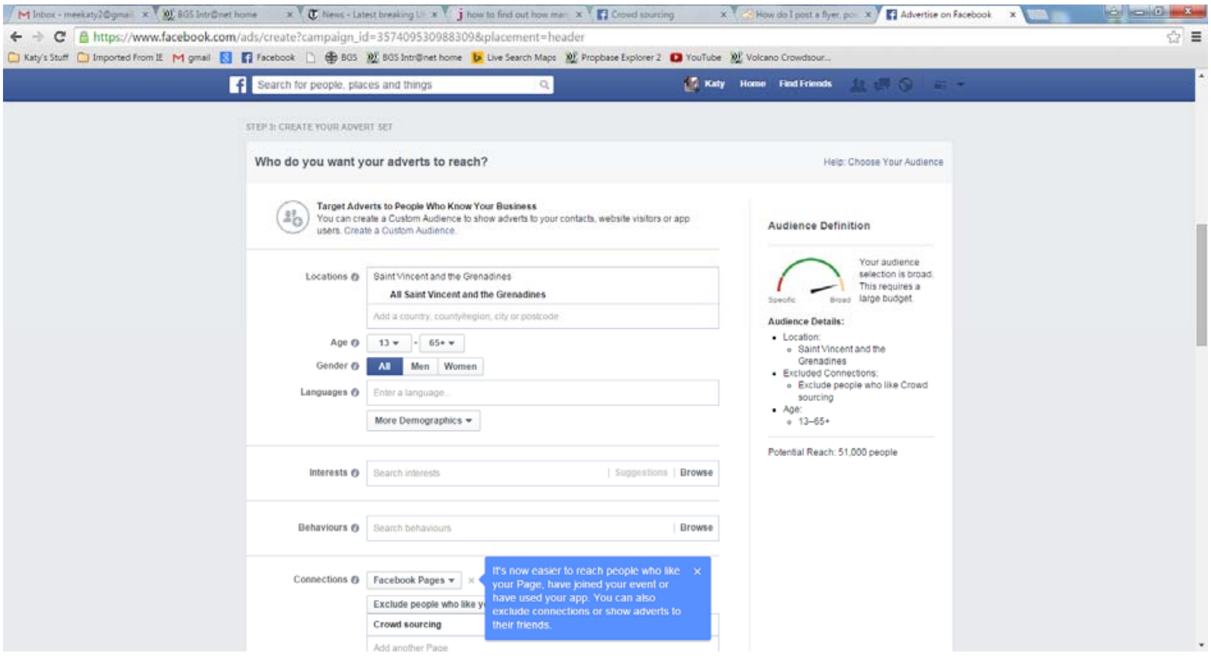
- Internet World Statistics
- 76,000 internet users as of December 2013, 73.8% penetrations, per IWS (Internet World Statistics)
- 38,640 Facebook users on Dec 31/2012, 37.5% penetration rate

http://data.worldbank.org/country/st-vincent-and-the-grenadines

- World Bank Data
- Access to the internet by percentage of population (number of people)
    - 2010 = 38.5% (42,086 of population 109,316)
    - 2011 = 43.0% (47,024 of population 109,357)
    - 2012 = 47.5% (51,952 of population 109,373)
    - 2013 = 52.0% (56,874 of population 109,373)

Facebook statistics

- 51,000 users in SVG – these figures can be found using the following method:
    - Can find out Facebook users in a particular country by creating an advert of one of your pages and choosing to distribute it in St. Vincent and the Grenadines (http://jilltxt.net/?p=2146)
        - Create a simple page on Facebook > go to drop-down menu in top right hand corner (next to padlock icon) > select 'create page' > create page (e.g. called crowd-sourcing) and publish the page.
        - Next, create an advert to promote the page > go to drop-down menu 'More' at the bottom of the advertising panel on the right-hand side and choose 'Advertising'.
        - Click on 'create and advert' > choose the page to promote (e.g. 'crowd-sourcing') > enter account info (you don't have to go through with creating an account as you can see the stats before finishing the page) >in the 'Who do you want the adverts to reach?' section, choose 'Saint Vincent and the Grenadines' (and delete US, which is the default) > select the largest age range 13 to 65+ and all gender.
        - On the right hand side, under 'audience definition' it gives the potential reach – in this case 51,000.
        - You can change demographics if necessary.



Relevant Facebook?Twitter pages

NEMO – 3274 likes Photos and up-to-date information (no Twitter?)
UWI SRC Facebook – 6329 likes
UWI SRC Twitter – 5788 followers
CaribWatch Twitter – 3356 followers
CDEMA Twitter – 211 followers
CDEMA Facebook – 268 likes
St Vincent News – 12400 followers
St Vincent and the Grenadines Red Cross Society Facebook – 1393
SVG Times Facebook – 2679

Global map of smartphone platforms:

http://www.ibtimes.com/android-vs-ios-whats-most-popular-mobile-operating-system-your-country-1464892

Appendix 10 Scaling up: crowdsourcing, citizen science and social media in Southeast Asia

Southeast Asia, in particular Indonesia and the Philippines, is home to a number of active volcanoes, which can generate hazards with local, regional and global impacts. The region has been the focus of recent assessments of the distribution of ash fall (e.g. Jenkins et al. 2012a, b), which is the volcanic hazard most likely to have widespread impacts since a single location may receive ash fall at different times from different volcanoes (GVM and IAVCEI, 2015a). Furthermore, given their tropical climate and long-coastlines, many Southeast Asian countries are exposed to multiple and interacting hazards, in **particular the Philippines.**

The Philippines is home to 47 Holocene volcanoes (Brown et al., 2015b). Volcanic, earthquake and associated hazards are monitored by the Philippine Institute of Volcanology and Seismology (PHIVOLCS), which is comprised of a number of volcanologists, geologists and other technical staff. With so many volcanoes to monitor with limited resources, the *MyVolcano* App could be of great utility to scientists and disaster managers, particularly given the frequency of disasters associated with different hazards in the country.

Social media: The use of social media is prolific in the Philippines – 94% of internet users use Facebook, and social media users spend four hours a day in all social channels, making them the most engaged in the Asia Pacific region (On Device Research, 2014)[1]. The weather bureau – the Philippine Atmospheric, Geophysical and Astronomical Services Administration – utilise Facebook (Dost_pagasa) and Twitter (@dost_pagasa) to enhance the reach of their weather warnings. They have 2.36 million Twitter followers and over 1.2 million Facebook 'likes'. In comparison, PHIVOLCS has 113,000 followers on Twitter (@phivolcs_dost) and just over 82,000 likes (PHIVOLCS-DOST). Citizen science and the App might be a means of encouraging interest and use of social media related to PHIVOLCS and volcanic hazards. Furthermore, PHIVOLCS already detail on their website how to spot signs of unrest.

Existing initiatives: There are existing interactive platforms related to hazard monitoring and warning. In the central Bicol River Basin, a community-based monitoring for flood early warnings systems attempted to combine SMS rain gauge monitoring from community volunteers with flood basin modelling (Abon et al., 2012). The results are used for flood forecasting and warning (Abon et al., 2012). the For instance, project Nationwide Operational Assessment of Hazards (NOAH) is a web platform designed to give people signed up to the service six hour lead times of weather warning, as well as enhance hazard mapping (Lagmay, 2012). Project NOAH embraces a collaborative approach by linking different datasets and different initiatives – NOAH's immediate task was to integrate current disaster science research and development projects and initiate new efforts within the DOST to achieve this objective. There are 43 national and international agencies in the project. At present the platform only deals with hydrological (mostly flooding) hazards; there is, therefore, an entry point for *MyVolcano*. Furthermore, although the website allows users to submit flood reports, there is no accompanying option on the Android app.

Mobile internet access: In comparison to these numbers of Twitter followers and Facebook likes (not all of whom may reside in the Philippines) the population of the Philippines is 98.39 million (as of 2013), 25.2% of whom live below the national poverty line (as of 2012; World Bank, 2015). A recent market research study found that despite mobile phone penetration being high at 101%, smartphones are only used by 15% of the population (On Device Research, 2014). In comparison, usage in Malaysia is 80% and in Thailand 49% (On Device Research, 2014).

However, in 2014 Oxford Business Group predicted smart phone penetration in the Philippines to reach 50% by 2015 (On Device Research, 2014). The user community is also particularly young – 88% of mobile internet users are below the age of 35 (On Device Research, 2014). In this case, emphasis should initially be placed on the delivery of the *MyVolcano* website, supported by the App for those with smartphone access.

[1] Based on a survey of 900 mobile internet users (smartphone and feature phone users) and other publically available data sources (On Device Research, 2014: https://ondeviceresearch.com/blog/philippines-mobileinternet-trends).