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The Geological Society 2017 YEAR OF RISK

Building Resilience to Geohazards in the Face of Uncertainty

7-8 September 2017

The Geological Society, Burlington House, London

ABSTRACT BOOK

Convenors

Susanne Sargeant (British Geological Survey, Increasing Resilience to Natural Hazards Knowledge Exchange Fellow)
Peter Sammonds (University College London, Increasing Resilience to Natural Hazards Strategic Advisor)
Anna Hicks (British Geological Survey, Strengthening Resilience in Volcanic Areas)

Building Resilience to Geohazards in the Face of Uncertainty
Geological Society of London
7-8 September 2017

Welcome to the conference!

We are pleased to welcome delegates working across research disciplines, from government, geoscience agencies and NGOs. We are also extremely grateful to those who have travelled from outside the UK to take part in this event.

During this meeting, we will share, discuss and celebrate results from major multi-disciplinary programmes involving researchers and other experts who are taking up the challenge to understand geohazards, manage risk and increase resilience. Our aim is to address the role that geoscience and geoscientists can play in building resilient communities and informing policymaking, into the future.

The programme includes around 40 posters and presentations sharing research across disciplines and geohazards, and given by researchers at all career stages. Keynote talks will be given by Dr Amod Mani Dixit (National Society for Earthquake Technology – Nepal), Prof. James Jackson (University of Cambridge) and Prof. Jenni Barclay (University of East Anglia). On each day, there will be a panel discussion exploring some of the challenges of building resilience to geohazards.

We will also produce a variety of outputs tailored for different audiences, both during and following the conference. Keep your eye out for Chris Shipton, our graphic artist, who will be producing live illustrations during the event.

Most of all, we hope you will enjoy the meeting, learn something new, make connections, and be inspired!

Thank you,

Susanne Sargeant
British Geological Survey
Increasing Resilience to Natural Hazards (IRNH) Knowledge Exchange Fellow

Peter Sammonds
University College London
IRNH Strategic Advisor

Anna Hicks
British Geological Survey

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Front cover photograph acknowledgements:

- *Debris flow disaster in China, 2010 (T. Dijkstra)*
- *Damage from the 2009 L'Aquila earthquake in Italy (S. Sargeant)*
- *A participatory mapping exercise with the vigías (volcano watchers) of Tungurahua volcano, Ecuador. Conducted as part of the Strengthening Resilience in Volcanic Areas (STREVA) project in 2013 (A. Hicks)*
- *Informal development on steep slopes at risk of failure, 2014 (J. Gill)*
- *Damage preserved from the 1999 Chi Chi earthquake in Taiwan (S. Sargeant)*

CONFERENCE PROGRAMME

Thursday 7th September 2017	
09:00	**Registration (tea and coffee available)**
09:30	**Welcome** Malcolm Brown, President of The Geological Society & Peter Sammonds, University College London and Strategic Advisor for the NERC-ESRC Increasing Resilience to Natural Hazards programme
09:45	**KEYNOTE ADDRESS** Amod Mani Dixit, Executive Director, National Society for Earthquake Technology – Nepal
10:30	**Advances and challenges to resilience efforts in the Eastern Caribbean** Richard Robertson*, University of the West Indies, Seismic Research Centre
10:45	**Adapting to changes in volcanic behaviour: formal and informal interactions for enhanced risk management at Tungurahua Volcano, Ecuador** Teresa Armijos, University of East Anglia
11:00	**Tea and coffee**
11:30	**Lightning poster presentations**
12:00	**Poster session**
13:00	**Lunch (STREVA film screening in the lecture theatre)**
14:00	**Panel Session – Stakeholder engagement and the role of science in decision making for resilience** ***Chair:*** John Twigg, Overseas Development Institute ***Panel members:*** Amod Mani Dixit, National Society for Earthquake Technology – Nepal; Colin Armstrong, UK Space Agency; Richard Robertson, University of the West Indies, Seismic Research Centre; Tom Newby, CARE International & Teresa Armijos, University of East Anglia
15:30	**Tea and coffee**
16:00	**The importance of geohazards for urban resilience: a study of Thessaloniki, Greece and its participation in the 100 Resilient Cities network** Vangelis Pitidis, University of Warwick
16:15	**Promoting safer building and improving support to self-recovery: Geohazards and the use of scientific knowledge** Susanne Sargeant, British Geological Survey
16:30	**In conversation with Prof. Maureen Fordham, University College London**
17:15	**Reflections on the day**
17:30	**Drinks reception**

Friday 8th September 2017	
08:30	**Tea and coffee**
08:50	**Welcome to Day 2**
09:00	**KEYNOTE**: **Re-thinking volcanic hazard analysis with communities at risk** Jenni Barclay, University of East Anglia
09:30	**Challenges of developing resilience to post-earthquake debris flows in China** Tristram Hales, Cardiff University
09:45	**Assessing hazard in inaccessible regions: the Makran subduction zone** Camilla Penney, University of Cambridge
10:00	**Historical Trajectories of Change and Disaster Risk Management in Small Island Developing States: Vanuatu and Dominica** Jenni Barclay, University of East Anglia
10:15	**Tea and coffee**
10.45	**Lightning poster presentations**
11:30	**Poster session**
12:30	**Lunch**
13:30	**KEYNOTE: Towards earthquake resilience in continental Asia: a perspective from the Earthquakes Without Frontiers project** James Jackson, University of Cambridge
14:00	**Panel Session – Innovation in interdisciplinary research** ***Chair:*** Peter Sammonds, University College London ***Panel members:*** Wendy McMahon, University of East Anglia; Eliza Calder, University of Edinburgh; David Pyle, University of Oxford; Katie Oven, Durham University; Tiziana Rossetto, University College London
15:30	**Tea and coffee**
16:00	**Calibrating seismic-instruments for lahar-warnings at Cotopaxi volcano** Daniel Andrade, Instituto Geofísico, Escuela Politécnica Nacional
16:15	**Reducing earthquake forecast uncertainty in the real world** Simone Mancini, British Geological Survey
16:30	**New insights into assessing buildings for earthquakes and tsunami** Tiziana Rossetto, University College London
16:45	**General discussion – led by Nic Bilham, Geological Society**
17:30	**Close of conference**

* *Speaker's attendance supported by the BGS ODA Programme*

POSTER PROGRAMME*
(alphabetical)

Thursday 7th; Friday 8th

Understanding structurally-controlled slope stability in the Bhutan Himalaya: implications for landslide hazard assessment Byron Adams, University of Bristol
Geohazards and Cascading Disasters – Theory, Methodology and Applications Gianluca Pescaroli, University College London
A SurveyPRISM': A tool to support people in assessing hazards, vulnerability and risks in Geohazard location Mike Andrews, University of Portsmouth
Linking the social sciences, physical sciences and the humanities to manage risk and build resilience to geohazards: innovative methods and approaches Maria Teresa Armijos, University of East Anglia
Dynamics of the pyroclastic density current formed during the 1902 eruption of La Soufriere, St Vincent, West Indies from analysis of the photographic archive Paul Cole, Plymouth University
The use of scientific evidence during the 2015 Nepal earthquake relief efforts Ajoy Datta, Overseas Development Institute
Monitoring volcanoes without humans: linking geophysics with drone imagery to understand South-Italian volcanism Luca De Siena, University of Aberdeen
An interdisciplinary approach to identifying potential natural hazard interactions in Guatemala Joel Gill, British Geological Survey
Developing a seismic hazard model for Sabah, East Malaysia using seismic and geodetic data Amy Gilligan, University of Aberdeen
Identifying volcanic and tectonic hazards in the Main Ethiopian Rift Tim Greenfield, University of Southampton
Risk Communication Films: Process, Product and Potential for Improving Preparedness and Behaviour Change Anna Hicks, British Geological Survey
Seismic Cities: An inter-disciplinary approach to understanding seismic hazard and risk in Santiago, Chile Ekbal Hussain, University of Leeds
Maintaining Credibility When Communicating Uncertainty: The Role of Communication Format Sarah Jenkins, University College London
An automated Bayesian fitting of macroseismic intensity data for isoseismal contours and epicentre estimation

Richard Chandler, University College London
Decision maker perspectives on scientific information at a volcanic simulation exercise David Litchfield, University of East Anglia
Resilience in practice – a comparative case study of structural and non-structural approaches Anna Lo Jacomo, University of Bristol
Multi-Hazard Vulnerability Assessment of School Infrastructure – The case of Cagayan de Oro, Philippines Arash Nassirpour, University College London
Landslide EVO: Citizen science for landslide risk reduction and disaster resilience building in mountainous regions Jonathan Paul, Imperial College London
Building Resilience in Lahar Hazard: hazard and susceptibility assessment at Volcán Cayambe, Ecuador Jeremy Phillips, University of Bristol
Assessing correspondence between volcanic activity and evacuation using time series and timeline data: forensic analysis from Soufrière Hills Volcano, Montserrat, 1996 – 2009 Jeremy Phillips, University of Bristol
The historical dimensions of volcanic hazards on St Vincent David Pyle, University of Oxford
Increasing Resilience to Environmental Hazards in Conflict Zones Peter Sammonds, University College London
Spatialising the interactions between people, animals, volcanic hazard and local perceptions and responses to Popocatépetl volcano, Mexico Mihaiela Swift, Kings College London
Building Resilience to Earthquakes in Bhutan: Probabilistic Seismic Hazard Assessment for a National Building Code Max Werner, University of Bristol
Developing interdisciplinary research to understand exposure to natural hazards in Small Island Developing States: Methodological reflections and implications for disaster risk management Carole White, University of East Anglia
Quantitative assessment of the earthquake moment magnitude (Mw) uncertainties Youbing Zhang, University College London

***please note that only poster presenters are indicated. Full author lists for the posters are shown with the abstracts towards the end of the booklet.**

ORAL ABSTRACTS
(in programme order)

Enhancing Disaster Resilience in Nepal –Dream Being Realised Against All Odds

Amod Mani Dixit
Executive Director, National Society for Earthquake Technology – Nepal (NSET)

Despite all adversities, Nepal is successfully enhancing disaster resilience and effectively conducting vulnerability reduction by implementing feasible actions that are effectively enhancing disaster knowledge, capacity, and creating better policy improvement. This is being done through innovative adaptation of applicable technologies, recognition of the need of combining social and technical approaches for disaster risk reduction, working with community centred approaches with inclusion of social mobilisers and local change agents such as teachers and social/political leaders in planning, design and implementers of disaster risk reduction and preparedness works.

Examples are the successful advocacy resulting implementation of disaster awareness and school earthquake safety program, and the Building Code Implementation program. The later has worked with more than a sample 30 largest municipalities among about 300 urbanizing settlements and a couple of rural settlements for improving seismic performance of new building constructions by ensuring compliance to the national building code. With a target indicator of 60 compliance to the national building code, the actual achievement is more that 70 % of compliance – it means more than 70 out of 100 new buildings in the municipalities will ensure life safety even in case of a design seismic loading of IX MMI of earthquake shaking intensity. More than 70 percentage of population in these municipalities have been provided with information and knowledge on earthquake hazard, social and physical vulnerabilities, and possible ways of achieving earthquake safety during an earthquake. These are sample demonstration achievements attained due to a close collaboration and understanding developed between civil society organizations government institutions at the central and local levels.

Such persistent effort over the past two decades focussing on linking the government policies to the last mile, linking academic scientific researches to solve practical problems on local construction materials and indigenous technologies, national and international networked effort for sophisticated laboratory testing for local building materials, and community capacity enhancement programs for developing local disaster risk management programs and their implementation, training of thousands of masons and engineers, innovative use of the network of community based and private FM radio stations throughout the country etc. have formed the foundation for enhancing disaster resiliency of our nation. And we have seen the expression of such resiliency during the last Gorkha earthquake sequence of 2015. The country was shaken, but the people were united to face the vagaries of nature and other unfortunate aftermath. A visible success was indicatively demonstrated when assessment found that over 275 seismically retrofitted school buildings stood intact even in the high intensity zones of the Gorkha earthquake, and these buildings provided safe havens for many search and rescue and relief organizations.

While disaster risk reduction approaches were done persistently at satisfactory levels, creating islands of successes, the process of positive change in the policy environment unfortunately couldn't keep pace due to several reasons, political, and consequently economic ones. The government was seriously engaged in revising the age-old disaster related Act and was developing the National Disaster Response Framework and the Gorkha earthquake stopped the process at its initial stages. As a result, the government had to spent the initial year and a half to developing policies and procedures for handling the initial

response and the early recovery and reconstruction. The slow process of reconstruction has been heavily criticised and has precipitated in several political consequences. But there is a silver lining – a closer look of reconstruction process confirms 92% compliance to the prescribed requirements of building back better, even of the rural reconstructions. The reconstruction process is picking up instilling hope and mutual thrust. More important is the learning in the process and realisation of the need scientific evidences for policy decisions and consequently the need to invest in science and technology for testing local materials and analysing local construction practices and building typologies, the need of capacity development of main actors in building construction – masons, engineers, bar benders and materials suppliers and producers.

Despite the gloomy statistics of the past 50 years of more than 70% of disaster-related deaths and more than 25% of disaster-related building damage taking place due to extensive risk disasters, and with a significant proportion of the national GDP being lost annually to natural hazard disasters, Nepal has been trying innovative and organized approaches for disaster risk management and progressing steadily in fulfilling her commitments to meet the Sendai indicators. The country unfortunately was caught in the middle by the massive Gorkha earthquake. The country could cope with the initial response and started reconstruction which has been difficult, and disturbed by political and several other endemic factors. However, there are indications that the country is learning fast and improving the reconstruction process, and also dealing with the long term needs for improving disaster risk management capability of the country, including mainstreaming DRM into all development sectors of economy including the design and construction of physical infrastructure and critical facilities.

NOTES

Advances and challenges to resilience efforts in the Eastern Caribbean

Richard Robertson, Lloyd Lynch, Joan Latchman
The University of the West Indies Seismic Research Centre, St. Augustine, Trinidad

The geologic setting of the Eastern Caribbean promotes topography that is prone to landslides and sediment flow triggered annually by hydro-meteorological events. The potentially high impact geohazards such as earthquakes, volcanic eruptions and tsunamis have a much lower occurrence rate. Within this multi-hazard environment, disasters resulting from natural hazards account for an average of nearly 20% of the variation in real GDP growth and have been identified by the Eastern Caribbean Central Bank as a key factor contributing to instability in foreign reserve earnings for the region. Current development trends are likely to increase exposure to natural hazards with continued negative impacts on development.

Over the past few decades, there have been concerted efforts throughout the Eastern Caribbean at building resilience and improving disaster management. The development of a comprehensive strategy to guide efforts towards disaster risk reduction (the CDM Framework and Strategy) has fostered and facilitated other activities. Hazard maps have been produced and advances made in developing capacity to undertake risk assessments at the national and regional level. There have been significant improvements in governance mechanisms with implementation of DRM legislation, development of Building Codes and use of ex ante insurance mechanisms. Equally important has been raising awareness through education and outreach.

Despite these advances civilian authorities within the region are still unable to strategically manage natural hazard risk. Resource constraints, distracted political will, inconsistent and sometimes non-enforcement of laws are some of the biggest obstacles. The challenging socio-economic and geologic environment and absence of an overall structure for analysing and integrating risks, cause agencies to operate in a relative information vacuum, with limited resources to guide the development process. This contributes to development plans often without the integration of disaster resilience in decision-making. There is still insufficient or no consideration given to risk transfers, recovery financing and incentives for mitigation efforts. In addition, within countries, responsibilities for action are diluted by being dispersed among various government agencies.

A number of urgent interventions are needed for meaningful change to happen. The region must develop the capacity to monitor and model natural hazards processes and make timely and accurate assessment of their full impact on society. An environment that fosters hazard resilient development planning and which makes full use of recent advances in Science and Technology to guide policies and action should be created. Scientific institutions must produce tools that enable better integration of natural hazards impacts into development planning. Countries in the sub-region rely heavily on the technical capacity of regional and global agencies for knowledge services and information regarding natural hazard risk. However, generating knowledge and information at a regional level that is useful for decision-making at a national level is challenging and requires simultaneous and sustained capacity building at both national and regional levels. Capacities already exist in some long-lived regional institutions and Caribbean governments must support and make full use of these existing, competent regional institutions with proven ability in their field and working closely with external collaborators, to generate this information.

NOTES

Adapting to changes in volcanic behaviour: formal and informal interactions for enhanced risk management at Tungurahua Volcano, Ecuador

Maria Teresa Armijos[1], Jeremy Phillips[2], Emily Wilkinson[3], Jenni Barclay[4], Anna Hicks[5], Pablo Palacios[6], Patricia Mothes[6], Jonathan Stone[7]

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[2]School of Earth Sciences, University of Bristol, Bristol, United Kingdom
[3]Overseas Development Institute, London, United Kingdom
[4]School of Environmental Sciences, University of East Anglia, Norwich, United Kingdom
[5]British Geological Survey, Edinburgh, United Kingdom
[6]Instituto Geofísico, Escuela Politécnica Nacional, Quito, Ecuador
[7]University of East Anglia/ British Geological Survey, United Kingdom

This paper provides an example of how communities can adapt to extreme forms of environmental change and uncertainty over the longer term. Combining methodologies from different disciplines, we analyse the interactions between scientists, communities and risk managers and examine the interpretation and communication of uncertain scientific information during a long-lived volcanic eruption in Tungurahua, Ecuador. This is complemented with a detailed study of the eruptions of 2006 and 2014, which exemplifies the complexity of interactions during periods of heightened volcanic activity. Our study describes how a 'shadow network' has developed outside of, but in interaction with, the formal risk management institutions in Ecuador, improving decision-making in response to heightened volcanic activity.

The findings suggest that the interactions have facilitated important adaptations in the scientific advisory response during eruptions (near-real-time interpretation of the volcanic hazards), in hazard communication, and in the evacuation processes. Improved communication between stakeholders and the establishment of thresholds for evacuations have created an effective voluntary evacuation system unique to Tungurahua, allowing people to continue to maintain their livelihoods during heightened volcanic activity and associated periods of uncertainty. Understanding how shadow networks act to minimise the negative consequences of volcanic activity provides valuable insights for increasing societal resilience to other types of hazards.

This work was conducted as part of the 'Strengthening Resilience in Volcanic Areas' (STREVA) project, under the 'Increasing Resilience to Natural Hazards' programme, funded by the Natural Environment Research Council (NERC) and the Economic and Social Research Council (ESRC): NE/J020052/1.

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The importance of geohazards for urban resilience: a study of Thessaloniki, Greece and its participation in the 100 Resilient Cities network

Pitidis V.[1], Tapete D.[2], Coaffee J.[3], Argyroudis S.[4], Kapetas L.[5]

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Urban Resilience has recently emerged as both a conceptual approach and directive agenda in an attempt to enhance the capabilities of cities to withstand and manage their environmental, economic or social pressures more effectively. Cities around the world are increasingly developing their own resilience policies to confront their uncertainty and exposure to several types of risks proactively rather than retrospectively. However, ground conditions and properties of the natural environment are often undermined in such policies primarily due to the propensity of local authorities to focus on other seemingly more pressing issues.

The City of Thessaloniki, Greece, is participating in the 100 Resilient Cities network pioneered by the Rockefeller Foundation, and in March 2017 published a Resilience Strategy for 2030. Therein, earthquakes and surface flooding are highlighted among the key natural hazards, with some consideration for the social and environmental elements that should be accounted for to develop programmes of risk mitigation and prevention.

In the 100th anniversary of the 1917 'Big Fire', which destroyed the historic centre of the city and triggered a major urban regeneration scheme, this study investigates the role that the knowledge of geological, geomorphological and topological properties of the physical environment and subsurface of Thessaloniki can play to shape future strategies of resilient urban design.

We focus on two specific neighbourhoods of Thessaloniki's metropolitan area that provide an interesting sample of: geological heterogeneity of the city's subsurface; exposure to the two most pressing geohazards; different stories of urban settlement, in one case millennial, recent urbanisation in the other. Implementing a multi-disciplinary approach combining geoscience and urban design, we make an assessment of the current level of susceptibility to earthquakes and surface flooding, and analyse where opportunities exist for effective policy-making.

In this regard, the case study of Thessaloniki can act as a test-bed to prove how an integrated approach of geoscience and urban planning can try to influence the implementation of a city's strategy in respect of building resilience to geohazards.

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Promoting Safer Building and improving support to self-recovery: Geohazards and the use of scientific knowledge

S. Sargeant[1], T. Dijkstra[1], A. Finlayson[1], B. Flinn[2], H. Schofield[2], L. Miranda Morel[2], A. Albuerne[3], V. Stephenson[3], E. Lovell[4], J. Twigg[4], T. Rossetto[3], D. D'Ayala[3]

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In the humanitarian shelter sector, 'self-recovery' (SR) refers to what households affected by disasters do to 'repair, build or rebuild their shelter themselves or through local builders' (Schofield and Miranda Morel, 2017). This process tends to be the predominant pathway to recovery after disasters and often happens with little or no external assistance (Parrack et al., 2014). In order that these communities build back safer and better, it is crucial that decisions are well-supported by scientific knowledge of geohazards and the environment. This paper focuses on two cases where the impact of the environment on SR and the role of science in supporting the process are explored.

However, recognising that the SR process will be shaped by a diverse range of interconnected factors, the cases were explored from a range of perspectives. Teams including humanitarian practitioners, engineers, social scientists as well as geoscientists undertook fieldwork together in rural communities in the Philippines and Nepal. Our methods included facilitating focus groups with community members, transect walks and interpreting the landscape, building surveys, carrying out semi-structured interviews and running roundtable discussions with representatives of humanitarian and development organisations based in the countries.

The Philippines research focused on groups of rural inland communities on the island of Leyte (severely affected by Typhoon Haiyan in November 2013) and on the island of Luzon (affected by Typhoon Haima in October 2016). Common to communities on both islands was a strong awareness of the environment. People's understanding of geohazards appears to come primarily from first-hand experience (typhoons occur regularly) and through transfer of ancestral knowledge, with more varying and limited direct input from scientific organisations. There is evidence that individuals' awareness of geohazards, and perceptions of event frequency, has influenced some rebuilding. However, many communities felt that challenges brought about by longer term patterns of environmental change (e.g. droughts associated with the strong 2015-16 El Niño) are creating a barrier to their sense of recovery by continually damaging livelihoods.

In Nepal, our focus was on rural communities in Dhading District that had been severely affected by the 25 April 2015 Gorkha earthquake and received varying degrees of assistance. Besides the direct impact of the earthquake and its aftershocks on shelter, many of these communities and the roads leading to them were, and continue to be, affected by landslides. Ongoing damage to roads is impeding the recovery process. As in the Philippines, people have a strong awareness of the environment but very little scientific knowledge compared with the Philippines. Rebuilding efforts focus on seismic resistance but it is clear that these communities are now exposed to a changed geohazard landscape with landscape instabilities occurring at places that were previously considered safe. There is very limited scientific input into the SR decision-making process although some information regarding safe siting of houses is given by the government.

The two cases show that the impact of the natural environment on SR goes beyond shelter and the limited extent to which scientific knowledge supports this process. Finding ways for geoscience to better support SR is therefore crucial.

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Re-thinking volcanic hazard analysis with communities at risk

Jenni Barclay
University of East Anglia

In common with many natural hazards, volcanoes have the most profound effect on the communities who live in their pathways. Yet, decisions to manage volcanic risk are usually taken on behalf of those communities by managers and decision-makers more remote from those effects. Does this contribute to stalled progress in reducing the impacts of hazardous events?

In an attempt to both increase knowledge of the hazard and understand how to reduce associated risk, the STREVA project set out develop new approaches that incorporated the experience and knowledge of communities at risk as well as scientists, managers and decision-makers.

Starting with a transdisciplinary analysis of past eruptions in Colombia, Ecuador, Montserrat and St. Vincent the team set out to understand the most important drivers of negative outcomes for the populations at risk. These 'drivers' usually transcend the usual compartmentalization of risk suggesting this integrated view of outcomes is important in anticipating and reducing future risk.

However, working this way can be complex and challenging. In reviewing progress this talk will consider some of the evidence for the new insights that can be generated, challenge whether this approach is always necessary and point out some fruitful new pathways that may help us work together to reduce the societal impacts of future hazardous events.

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Challenges of developing resilience to post-earthquake debris flows in China

Hales, T.C.[1.], Fan, X.[2.], MacGillivray, B. H.[1], Francis, O. R.[1.], Domenech, G.[2.], Ran, J.[1.], Hobley, D.E.J.[1.], Gong, Y.[1.]

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[2]State Key Laboratory for Geohazard Prevention, Chengdu University of Technology, Chengdu, China

In the nearly 10 years since the 2008 Wenchuan Earthquake, residents of the Wenchuan area have experienced multiple hazards (aftershocks, landslides, landslide dams, debris flows, and enhanced flooding and sedimentation) whose relative importance has changed through time, creating the so-called hazard chain. Each hazard presents a different challenge to developing resilience, in part, because each affects a different spatial location. For example, after the earthquake residents were resettled from the upper catchments that experienced co-seismic landslides onto debris fans, where flooding and debris flows are a significant hazard. Focussing on the debris flow problem, we quantify how hazard magnitude and frequency changes through time since the earthquake, then hypothesise how the structure and content of social networks affect resilience.

Post-earthquake debris flows initiate during intense rainfall creating highly mobile flows that damage infrastructure and endanger lives. Debris flows can mobilise from: (1) new shallow landslides on hillslopes without significant coseismic disturbance, (2) within coseismic landslide debris, and (3) remobilisation of sediment deposited in channels. In this region, mechanisms 2 and 3 are the most important, contrasting evidence from the 1999 Chi-Chi Earthquake. Through time, flows are more likely to initiate from landslide debris located at higher drainage areas, suggesting that the combination of throughflow and readily available sediment determines initiation propensity. Our data show that the location and frequency of debris flow initiations changes as sediment is redistributed through catchments, making it particularly challenging to apply empirical intensity-duration threshold analysis. Instead, we successfully apply a sediment cascade approach, defining a landslide probability as a function of the rainfall conditions and the state of sediment storage in upslope areas.

We consider how social vulnerability and social capital may influence the resilience of Chinese communities to this changing geophysical hazard. The current evidence base is limited. Social vulnerability measurement frameworks originated in advanced, western democracies, present challenges when applying them to China's unique cultural, economic and political context. Moreover, the drivers of social vulnerability are typically presumed, or derived based on "expert judgment," rather than being supported by rigorous empirical evidence. Finally, we question the widely held view that social capital is a core dimension of resilience. Rather, we highlight that the contribution of social networks to resilience is not merely driven by the strength and density of network ties but also by the *content* of the norms, perceptions, stories, and beliefs that are propagated through those networks. This implies that social networks - rather than social capital - is a more useful lens through which to analyse resilience. It also suggests that resilience may be best understood as hazard-specific. Thus in the context of a hazard chain, we may also need to identify a similar "resilience chain" – that incorporates a flexible view of how social networks co-evolve – whether adaptively or maladaptively - in response to changing hazard.

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Historical Trajectories of Change and Disaster Risk Management in Small Island Developing States: Vanuatu and Dominica

Jenni Barclay[1], Roger Few[2], Johanna Forster[1], Claire Jowitt[3], Irene Lorenzoni[1], Clare Shelton[2], Carole White[2], Emily Wilkinson[4]

[1] School of Environmental Sciences, University of East Anglia
[2] School of International Development, University of East Anglia
[3] School of History, University of East Anglia
[4] Overseas Development Institute

Small Island Developing States (SIDS) in the coastal tropics exposed to multiple hazards (storm surges, erosion, hurricanes, cyclones, intense rainfall and tectonic hazards) with high population density face extraordinary sustainable development and Disaster Risk Management (DRM) challenges. SIDS include two-thirds of the countries that face the highest losses as a consequence of natural hazards, and the costs are growing. Tropical cyclones alone cause an estimated $835 million of damage in the Caribbean and $178 million in the Pacific each year. Island States, often with large oceanic areas and mountainous volcanic landscapes are characterised by limited space on land for settlement resulting in their populations being particularly exposed to multiple hazards. Their exposure to hazards is multifaceted and can be traced to political, social and cultural processes rooted in colonial history.

Focusing on Vanuatu and Dominica, the underlying drivers and interacting factors that influence how multiple risks and shocks are managed are discussed. Both Vanuatu and Dominica, have experienced significant impacts from multiple hazards, including recently. In 2015, Cyclone Pam caused significant damage and displaced up to 70% of the ni-Vanuatu and Tropical Storm Erika caused damages estimated at US$483 million, equivalent to 90% of Dominica's GDP. To date, much research effort has focused on assessing the impacts of these recent events and developing technical solutions to reduce risk. However, little research has considered how historical legacies of tenure and exposure to hazards influence the effectiveness of present-day disaster risk management in these 'hazard hotspots'. This study posits that present day DRM has often been influenced by the colonial past on SIDS, which have left persistent legacies following independence.

Land tenure and use patterns in both SIDS have been profoundly shaped by legacies from French and British colonial powers, which governed the islands until their independence in 1979 and 1980. In Dominica, land tenure was shaped by colonisation, slavery and emancipation – especially in the 18th and 19th century - and this continues to limit where people can live and to determine their exposure to natural hazards. In Vanuatu, land tenure continues to be a contentious issue, historically with European settler and exploitation colonialism regarding land as a commodity, creating tensions with traditional views of land as integral to community well-being and identity. In both SIDS, this has led to housing development in hazardous areas where flooding, landslides and access issues are common due to a lack of planning and support. When evacuation or permanent relocation are considered, options are limited and consist of moving people from one hazard zone to another.

The findings presented from fieldwork at national and community level in Dominica and Vanuatu, in March and May 2017, demonstrate how a historical lens can shed light on the structural processes that magnify risk and undermine long-term risk reduction. Using the understanding that has been generated may encourage new approaches to current day DRM and building resilience.

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Towards earthquake resilience in continental Asia: a perspective from the Earthquakes Without Frontiers project

James Jackson
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Between 2 and 2.5 million people have died in earthquakes since 1900. Approximately two thirds of those deaths occurred in earthquakes in the continental interiors. Over that time interval, advances in the scientific understanding of earthquakes have been translated into impressive resilience in places where the hazard is well understood, particularly on oceanic margins, where the principal cause of death is now often from tsunamis. Comparable advances have not, however, taken place in most parts of the continental interiors, where the hazard is still much less well identified and poorly understood. The *Earthquakes Without Frontiers* project is a consortium funded by NERC and ESRC of natural-science, social-science and policy-into-science researchers from Cambridge, Durham, Hull, Leeds, Northumbria and Oxford universities and from the Overseas Development Institute and British Geological Survey. The project has three overarching objectives:

- To provide transformational increases in knowledge of the primary and secondary earthquake hazards in the continental interiors.
- To identify pathways to increased resilience in the populations exposed to these hazards.
- To secure these gains over the long term by establishing a well-networked, trans-disciplinary partnership for increasing resilience to earthquakes.

The project has made use of the close and trusted contacts the UK participants had built up with researchers in most of the countries of the Mediterranean-Asian earthquake belt between Italy and China (E-W) and Nepal and Mongolia (N-S) over the last few decades. Research has continued in all these countries, but has been focused on three regions in particular: north-east China; Iran and Central Asia; and the Himalayan mountain front. In each of these regions we have collaborated closely with local scientists, policy-makers and organisations, both government and non-governmental. This talk will summarize some of the lessons and experience we have gained over the lifetime of the project (2012-2018), particularly in transdisciplinary collaboration and research.

NOTES

Calibrating seismic-instruments for lahar-warnings at Cotopaxi volcano (Ecuador)

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Primary lahars from Cotopaxi volcano (Ecuador) are considered as a substantial hazard for large urban zones and infrastructures along three major drainage systems of Ecuador: Pita river (north), Cutuchi river (south) and Jatunyacu river (east). Several geological and sociological studies have focused on the last of these events, occurred in 1877, and have highlighted the disastrous consequences in the case it repeats in the near future. Since 2002, seismic instruments have been deployed in several of the drainages around Cotopaxi, with the aim of detecting lahars and delivering alerts for an early warning system (EWS) which is intended to trigger the execution of country-wide emergency plans. However, an issue arose regarding these instruments: seismic signals alone do not provide quantitative information about the size of a lahar, thus limiting their usefulness for the EWS. Additionally, even if the seismic signals could be related to “lahar size”, it is fundamental to define the specific thresholds that will be used to issue the alerts. So, the seismic instruments need to be calibrated in order to provide quantitative information (i.e. discharge rate) about flowing lahars.

Calibrating the seismic instruments installed at Cotopaxi volcano means that a relationship between seismic signal (S) and lahar discharge-rate (Q) needs to be established. The use of seismology concepts and theory in order to obtain a relationship $S = f(Q)$ inevitably leads to the use of physical parameters that are difficult to measure (or even unknown), thus introducing analytical and experimental complexity, as well as uncertainty in the results.

For the calibration of seismic instruments installed in Cotopaxi volcano, a different approach has been used, which is based on the following methodological steps: 1) a theoretical framework, based on the Buckingham Π-theorem on physically similar systems, provides a generalized calibration equation, that correlates the seismic signal (S) and the lahar discharge-rate (Q) in a simple linear system; 2) experiments performed with secondary lahars occurred in recent years at Tungurahua and Cotopaxi volcanoes validate the theory of the previous step and allow to calibrate all instruments installed at Cotopaxi volcano; and, 3) detailed geological fieldwork is performed in order to determine the peak discharges for the “biggest potential” and “smallest dangerous” lahars expected in the monitored drainages of Cotopaxi, and thus define the approximate threshold values for the instrumental alerts. This last step also allows to identify the instruments that would need to be installed elsewhere in order to provide optimal information.

The possibility to approximate in real-time the discharge rate of a flowing lahar, however, brings to questioning the operational details of the EWS for Cotopaxi volcano. For example, the possibility to have different alert levels (i.e. “big lahar” or “small lahar”) initially seems to increase complexity to an already complex situation.

NOTES

Reducing earthquake forecast uncertainty in the real world

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Several disastrous earthquakes occurred worldwide during the last years, as the 2015 M = 7.8 Gorkha earthquake in Nepal, the 2016 M = 7.8 earthquake in Kaikoura (New Zealand), the 2016 M = 7.0 earthquake in the Japanese prefecture of Kumamoto, and the 2016-2017 Central Apennines sequence in Italy, among others. These sequences underline two facts; first, fault network complexity controls the slip and aftershock distribution and second, aftershock damages can exceed the initial ones caused by the first event. In that context, predicting the spatial-temporal evolution of seismicity within unfolding earthquake sequences using stress model based on a realistic representation of the shallow crust is critical. Earthquake forecasts aim to support informed decision-making and increase resilience in a post-disaster environment while improving our understanding on fundamental earthquake physics.

The 2016-2017 Central Italy sequence presents a unique opportunity to investigate the limitations of our sequence forecasts and quantify the influence of real-time data products. On August 24th 2016 a normal faulting earthquake of M_W = 6.0 struck the Central Apennines near the town of Amatrice, leading to 299 fatalities and extended building collapses. The first large magnitude event was followed within less than one hour by a M_W = 5.4 aftershock. Another M_W = 5.4 event hit further north on October 26th followed by a M_W = 5.9 event close to the village of Visso, and a strong M_W = 6.5 earthquake that occurred near the town of Norcia on October 30th. From January 18th, the large-magnitude seismicity migrated to the southern extension of the fault zone with four events of M_W > 5 in the area of Montereale and Campotosto.

We develop and compare stress-based forecast models that build on laboratory confirmed laws and statistical models based on accumulated knowledge. We then provide a protocol for the development of each family model in real world conditions. We produce: (1) a “preliminary model” using data products available from minutes to hours after each large magnitude event of the sequence; (2) “intermediate models” with progressive refinements of data products, usually released from hours to weeks after a main event; (3) an “advanced model” making use of the best available science to date.

The preliminary physics-based forecast relies on uniform slip models with fault dimensions and amount of slip derived from empirical relations and on a wide range of fault constitutive parameters. On the other hand, the informed versions progressively incorporate more realistic source models and Rate-State parameters daily retrofitted on the evolving seismicity response.

The results reveal that during the early post-disaster phases, the preliminary forecasts are affected by a high associated error that reduces by an 8-fold factor once realistic source representations and geophysical parameter constraints are incorporated.

NOTES

Assessing hazard in inaccessible regions: the Makran subduction zone

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The Makran, along the southern coasts of Iran and Pakistan hosts one of the world's least studied subduction zones. A magnitude 8.1 earthquake in 1945, which triggered a tsunami and a series of submarine landslides, demonstrated that the eastern (Pakistani) part of the subduction zone can produce large earthquakes. However, in the western (Iranian) Makran no subduction-zone earthquakes have been recorded, which has led to suggestions that this half of the subduction zone may be aseismic. To the north of the Makran a series of right-lateral, north-south striking faults parallel the Iran-Afghanistan border, apparently separating these two regimes. However, no right-lateral offsets are seen in the folds of the Makran itself. We find that the question of how this motion is transferred across the Makran is related to whether the western Makran moves in earthquakes.

The motion of the Makran subduction zone has important implications for seismic hazard. A magnitude 9 earthquake in this subduction zone would threaten over 20 million people living in Karachi. Any associated tsunami would also pose a threat to populations along the rapidly urbanising Omani and west Indian coastal regions. However, the inaccessibility of the Makran has made it a difficult area to study, necessitating a multi-disciplinary approach. We combine results from seismology, GPS and satellite imagery with numerical modelling to gain insights into the behaviour of the subduction zone. We find that GPS measurements in the western, Iranian, part of the Makran are consistent with strain build-up, suggesting that the western Makran can move in large earthquakes. The timing of earthquakes on extensional faults to the north of the Makran may also be controlled by these large subduction zone earthquakes, presenting an additional hazard.

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New insights into assessing buildings for earthquakes and tsunami

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Currently, 8 out of the 10 most populous megacities in the world are vulnerable to severe earthquake damage, while 6 out of 10 are at risk of being severely affected by tsunami [1]. Preparing for major earthquakes and tsunami, through adequate disaster risk reduction (DRR) measures (e.g. design and construction of resistant buildings and evacuation/emergency protocols), is of paramount importance, because their timing and potential consequence are difficult to predict. To mitigate ground shaking and tsunami risks for coastal communities, reliable tools for simulating strong motion and tsunami are essential. Nowadays, computational methods are remarkably advanced, enabling accurate reproduction of main observations (e.g. peak ground motion amplitudes and tsunami waveforms) through detailed inversion analyses after a disaster. However, earthquake source information (e.g. slip distribution along fault plane and rise time) for future scenarios, which has significant impact on simulation results, is unknown and uncertain. Without adequate consideration of the uncertainty associated with earthquake sources, risk assessments are incomplete. In addition, from the tsunami hazard perspective there are large uncertainties regarding nearshore processes of tsunami, inundation prediction and tsunami loading on buildings.

This study brings together novel numerical and experimental work from the ERC-funded “URBAN WAVES” and the EPSRC-funded “CRUST “ projects and highlights advances made in (1) modelling uncertainty in the source characteristics of subduction type earthquakes and the resulting tsunami, and (2) assessing buildings for loading under tsunami only, as well as under successive earthquakes and tsunami. The ultimate aim of this work is to develop structural assessment methodologies and models of vulnerability for buildings that will inform the risk models used by governments to develop their DRR strategies. However, the results of the work demonstrate a conflict in the design targets and concepts for seismic versus tsunami-resistant design of structures, which raise questions on how to provide appropriate building resilience in coastal areas subjected to both these hazards.

NOTES

POSTER ABSTRACTS
(in programme order)

Geohazards and Cascading Disasters - Theory, Methodology and Applications

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In 2011 a tsunami caused a small landslide that cut off the last remaining power supply to the cooling plant of a nuclear reactor complex, which resulted in the melt-down of the core of three reactors and a massive nuclear release. The Fukushima Dai'ichi nuclear accident was a classic 'Na-Tech' event, caused by the interaction of overwhelming natural forces and failing technical equipment. It was also a cascading disaster, in which a primary impact, a magnitude 9 earthquake, gave rise to a chain of events. Only time will tell which of these leaves the most enduring legacy.

We contend that, such is the complexity of modern life, that all disasters above a certain threshold size are likely to be cascading events to a greater or lesser extent. Moreover, there is considerable scope for interacting, compound and interconnected risks to have concurrent impacts. For example, in January 2017 in central Italy, four shallow-focus earthquakes of magnitude Mw>5 occurred in a four-hour period, at a time when 80,000 customers were without electricity as a result of record snowfall. The tremors, which caused considerable damage to buildings, also led to a major snow avalanche that engulfed a hotel and killed 24 people, while snow accumulation made rescue of the survivors a very challenging and long-drawn out task. To cap it all, during the emergency a helicopter crashed in the area with the loss of seven live. All of this had to be managed as a single, polycentric emergency involving the coordination of varied forces in conditions that profoundly tested their mettle.

The study of cascading disasters reveals that natural hazards, including earthquakes, volcanic eruptions, landslides and tsunamis, can have effects that are far more profound and persistent than the primary impact would suggest. Our research begins with the investigation of escalation points, at which different vulnerabilities to hazard impacts combine to increase and propagate the effects of a disaster.

Critical infrastructure consists of those national or local systems that are indispensable to normal human life. It is usually divided into nine or ten categories. When critical infrastructure is put under stress by major hazards the tendency has been to consider the categories in isolation from each other. However, it is now clear that the interaction between them can be the most difficult problem and often presents the greatest response challenge. For example, if adverse environmental conditions lead to the progressive collapse of electricity generation and transmission, the main problems may come from water supply, sanitation, banking and communication, as these are all heavily dependent on electricity supply. Major wide-area black-outs (i.e. at the level of countries or very large regions) have occurred in at least ten places in the last 15 years.

This paper presents new work on the theory of cascading disasters and its applications when geohazards strike. We present a new magnitude scale for cascades, a classification scheme for connecting cascading, compound, interconnected and interacting risks (with an explanation of why it is helpful to do so), a methodology for understanding vulnerability to cascades in relation to escalation points, and a scenario-based approach to mapping cascades. The theory and methodology of cascading disasters is illustrated with examples from recent major natural hazard impacts.

NOTES

An interdisciplinary approach to identifying potential natural hazard interactions in Guatemala

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Here we combine physical and social science approaches to develop a multi-scale regional framework for natural hazard interactions in Guatemala. We gather and use five diverse evidence sources to organise and populate our framework: (i) internationally-accessible literature (total of 93 peer-review and 76 grey literature); (ii) civil protection bulletins (267 bulletins from 11 June 2010 to 15 October 2010); (iii) field observations (eight principal locations); (iv) stakeholder interviews (19 semi-structured interviews conducted from 28 February 2014 to 14 March 2014); and (v) stakeholder workshop results (16 participants, 06 March 2014). In the latter two, stakeholders consist of hazard and civil protection professionals from public and private universities, the private sector, and two government organisations.

These five evidence sources are synthesised to determine an appropriate natural hazard classification scheme for Guatemala (6 hazard groups, 19 hazard types, and 37 hazard sub-types). For a national spatial extent (Guatemala), we construct and populate a "21×21" hazard interaction matrix, identifying 49 possible interactions between 21 hazard types. For a sub-national spatial extent (Southern Highlands, Guatemala), we construct and populate a "33×33" hazard interaction matrix, identifying 112 possible interactions between 33 natural hazard sub-types. Interactions considered are those where a primary natural hazard can trigger and/or increase the probability of a secondary natural hazard. We also used evidence sources to identify 17 anthropogenic processes that could trigger natural hazards in Guatemala, and constrain possible networks of natural hazard interactions (cascades).

The outcomes of this approach are among the most comprehensive interaction frameworks for national and sub-national spatial scales in the published literature. Interaction frameworks can be used to support disaster risk reduction and civil protection professionals in better understanding natural hazards and potential disasters at a regional scale. The *Sendai Framework for Disaster Risk Reduction 2015–30* encourages multi-hazard approaches, with the UN Office for Disaster Risk Reduction defining multi-hazard to include hazard interactions. The identification and characterisation of natural hazard interactions are, therefore, important considerations in improving disaster risk reduction at a regional scale.

NOTES

Seismic Cities: An inter-disciplinary approach to understanding seismic hazard and risk in Santiago, Chile

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Seismic Cities is an inter-disciplinary research project funded jointly by NERC/ESRC/AHRC through the Building Resilience programme as part of the Global Challenges Research Fund (GCRF). The long-term aim of our project is to address the sustainable cities and communities challenge in urban regions prone to earthquake hazard by increasing resilience to such seismic shocks. We believe that bringing together diverse actors with a focus on a specific “Seismic City” has the potential to be a powerful mechanism to achieve this.

The urban population in 2014 accounted for 54% of the total global population, up from 34% in 1960, and continues to grow. The urban population growth, in absolute numbers, is concentrated in the less developed regions of the world. Many of these cities are located in regions with rapid tectonic strain, and thus are exposed to significant earthquake shaking in the future. These cities have grown rapidly over the past few decades, often under poorly regulated conditions; and with an economically poor demographic, the seismic risk is a very real concern for city planners and decision makers. In many cases the impact of urban expansion has been to build over and mask the evidence of faulting activity beneath and around cities.

The Seismic Cities project will develop a blueprint for focused inter- disciplinary research to tackle some of the key issues regarding seismic resilience in large cities exposed to significant seismic hazards. We present findings from our initial scoping project for the city of Santiago, Chile. The Santiago metropolitan region experiences shaking from regular offshore earthquakes, the most recent being the 2010 Mw8.8 Maule earthquake. However the recent discovery of the San Ramon fault by other researchers, located on the eastern margin of the city raises the question of increased risk from a much more proximal hazard compared to larger offshore earthquakes. We examine this risk through scenario calculations using the GEM OpenQuake-engine to explore the contrasting losses in terms of residential buildings and fatalities. We present preliminary findings from interviews with key informants and disadvantaged groups in the city to document the psychological impacts of the 2010 earthquake, understandings of preparedness, and how these relates to increasing social resilience during a disaster. We explore innovative methods to capture the multi-sensory experience of people and their environment, and investigate methods for documenting stories and personal experiences, with the potential to use these as mechanisms to share lived experiences across cities globally.

NOTES

Developing interdisciplinary research to understand exposure to natural hazards in Small Island Developing States: Methodological reflections and implications for disaster risk management

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Small Island Developing States (SIDS) are clear examples of 'complex social-ecological systems' where interactions and feedback mechanisms between ecosystem and governance processes shape responses and resilience to natural hazards. Therefore, interdisciplinary research including the social and natural sciences is necessary to more holistically understand their exposure and vulnerability to natural hazards. The governance of SIDS has often been influenced by their colonial past and legacies that have persisted to this day following independence. However, little research has considered how historical legacies of tenure and exposure to hazards shape the effectiveness of present-day disaster risk management in these 'hazard hotspots'. A research approach and methodology is presented which was used to think through historical trajectories of risk and DRM cultures today, drawing expertise from geologists, marine scientists, human geographers and historians. The methodology was applied in several case study settings including at community and national level in the Pacific and in the Caribbean. This approach helps to explore the underlying drivers and interacting factors that influence how multiple risks and shocks are managed, where current land and marine use patterns, location of infrastructure and DRM policies have been influenced by particular historical events and trajectories. Using results from fieldwork in Spring 2017, lessons learned from applying the approach are discussed and reflected on. What lessons from past interventions help frame multi-hazard interventions in the future? How can we integrate qualitative historical perspectives into other approaches to resilience that involve quantitative measures of risk? How do perceptions of disaster risk differ across disciplinary perspectives and across history, and what are the implications for modern-day risk management? Fostering a greater appreciation across disciplines of the role that different social, political and environmental factors play in generating risk, can improve and offer novel approaches to building resilience in SIDS and help address the longer-term impact of hazards on their development.

NOTES

Risk Communication Films: Process, Product and Potential for Improving Preparedness and Behaviour Change

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Film is a well-established medium for education and communication about hazardous phenomena; providing engaging ways to directly view hazards and their impacts. Empirical analysis can help to understand films' effectiveness in informing populations at risk and catalysing actions to reduce risk.

We present an evidence-based methodology to create, use, and track the outcomes of digital film tools designed to raise hazard and risk awareness and develop preparedness efforts. Experiences from two contrasting eruptions were documented (Nevado del Ruiz, 1985 and Soufriere St Vincent, 1979), with a secondary purpose of fostering social and cultural memories of eruptions, developed in response to demand from at-risk communities during field-based research. The films were created as a partnership with at-risk populations and local volcano monitoring scientists (Servicio Geológico Colombiano and the Seismic Research Centre), who consequently became the leading focus of the films, thus providing a contrast with other types of hazard communication.

We shared the final productions with communities at several local film screenings in both St Vincent and Colombia. Over 700 people attended local film screenings in at-risk areas around Nevado del Ruiz and seven screenings were held in communities located in the high hazard zones in St Vincent. These screenings were also designed to be fora for discussion about the films, so we surveyed the audience to evaluate immediate influence of the films on learning and affect. Results indicate that the use of local content and actors to share experiences and teach valuable lessons were impactful. Recognizable faces and spaces helped to convey the disaster risk reduction messages. They also motivated audiences to consider their ownership of risk and potential actions to reduce risk and strengthen resilience.

We present evidence of the effectiveness of co-production in the design and execution of these volcanic risk reduction intervention strategies. Co-production of films with local agencies resulted in products that are contextually appropriate, meaningful for audiences, and useful risk communication tools. For example, in St Vincent, they were used to support the roll out of 'household emergency plans' and have formed part of the communication strategy for the national emergency management organisation.

This research is part of the Strengthening Resilience in Volcanic Areas (STREVA) project.

NOTES

Landslide EVO: Citizen science for landslide risk reduction and disaster resilience building in mountainous regions

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We describe a major new international project, Landslide EVO, aimed at increasing local disaster resilience in remote mountainous environments by bringing together research on mountain hydrometeorology and landslide risk with citizen science, participatory approaches to knowledge generation, and risk governance. Our proposition is that maximum impact is created if end-users are involved from the start in this process, using a bottom-up and participatory approach. To this end, we leverage recent advances in in-situ and remotely sensed monitoring, risk modelling and forecasting, vulnerability assessment, and risk governance.

Landslides are one of the most damaging natural hazards worldwide. The high frequency of landslide occurrence in the Himalayan Arc (northern Pakistan to Nepal) is largely due to extreme and prolonged precipitation events, in particular related to the South Asian Summer Monsoon. However, in mountainous environments such as the Himalayas, hydrologically induced landslides occur within a wider context of multiple hazards; in particular, flooding and earthquakes. While natural hazards are widespread in mountainous regions, local resilience tends to be very low, often decreasing over time. The multi-dimensional nature of the hazards, acute data scarcity about the driving processes and vulnerability, and the high diversity and number of actors involved in disaster preparedness, response and recovery, makes disaster risk reduction in this environment a formidable challenge. Lack of scientific evidence is a major obstacle to improving local policy making to support resilience building, which is further hindered by the combination of acute poverty and weak governance structures.

We identify three major technological developments that strongly support our approach to resilience building in Nepal. First, distributed sensor networks, participatory monitoring, and citizen science hold great promise in complementing official monitoring networks and remote sensing by generating site-specific information with local buy-in, especially in data-scarce regions. Secondly, the emergence of open source, cloud-based risk analysis platforms supports the construction of a modular, distributed, and potentially de-centralised data processing workflow. Finally, linking data analysis platforms to social computer networks and ICT (e.g. mobile phones, tablets) allows tailored interfaces and people-centred decision- and policy-support systems to be built.

We draw upon recent scientific insights in the governance of natural resources; specifically on the use of polycentric approaches to data collection and knowledge generation. This acknowledges that socio-ecological systems are often characterised by multiple centres of decision-making across different scales, thereby relying on a distribution of responsibilities, multiple sources of information, and cogeneration of knowledge. We identify a strong potential in a polycentric approach to managing natural systems to reduce disaster risk in mountainous environments. In countries such as Nepal, governmental institutions tend to be strongly resource-constrained. This leads to other actors such as NGOs taking a more proactive and prominent role in preparedness and response. We hypothesise that this institutional diversity is key for resilience.

NOTES

The use of scientific evidence during the 2015 Nepal earthquake relief efforts

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The role that science can play in informing disaster preparedness and response is receiving increasing attention amongst the international community, with calls to make science more 'useful, useable and used.' However, how to do this in practice is less clear, particularly in high pressure, post-disaster situations. Focusing on the 2015 earthquakes in Nepal, this study explores the extent to which science (in particular geology, geomorphology and related scientific disciplines) fed into and informed the response effort. Specifically, the study set out to understand the information or evidence needs of the disaster response community, the scientific information that was produced, how this information was communicated, and how the science was used or not and why.

More than forty in-depth interviews were conducted with disaster managers within the Government of Nepal, the Nepal military, the UN agencies, international and national NGOs, and scientists. The findings highlight that demand for scientific evidence about the earthquakes was concentrated largely at the national level, within the UN-led Humanitarian Country Team and the wider humanitarian community, who often sought information from overseas experts; and within the Government's Central Natural Disaster Relief Committee, which sought information from government institutes within Nepal. District level Disaster Relief Committees (DDRCs), seen as one of the most influential groups in directing relief efforts, had no or little demand for scientific evidence. At the national level, Disaster response managers required information about the impact of the earthquake to target the response and to support logistical operations, and information about possible aftershocks and landslides which had implications for personal safety and security of staff. There was, however, a clear gap in understanding of what useful operational information scientists could provide and over what timeframes.

Relief efforts were initiated immediately, with needs assessments being conducted concurrently. It was therefore challenging to produce (and promote uptake of) robust scientific evidence within the timeframes required. In the absence of information, disaster managers relied heavily on their own experience and practical judgement. There were opportunities for scientists to feed into later needs assessments (which focussed primarily on beneficiary knowledge). However, a lack of understanding of the information needs of the response community, and the needs assessment process itself, together with limited knowledge amongst disaster managers about what scientists might offer limited the involvement of scientists.

In the weeks that followed, disaster managers were inundated with information (including maps) which was not always packaged in a way to facilitate its operational use. Information managers, a potentially important broker between the humanitarian and science communities, tended to be generalists rather than specialists, and did not always have the disaster specific knowledge and expertise required to access and communicate the scientific information produced. As a result, evidence in the form of expert advice from trusted scientists, brokered by disaster managers, committed to the use of science, was considered to be particularly useful. Even so, scientific information that did find its way into discussions amongst humanitarian teams tended to not be shared beyond the group reflecting the siloed nature of response operations. In light of our findings we set out a series of recommendations for scientists and disaster managers, with the aim of facilitating better

interaction between scientists and disaster managers with a focus on improving the latter's ability to 'improvise' during future emergencies.

NOTES

Maintaining Credibility When Communicating Uncertainty:The Role of Communication Format

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British Geological Survey

Preserving and cultivating the public's trust has never been more important for the scientific community (Nature, 2010). Unfortunately uncertainty – a common hallmark of science – is often perceived by the public as an 'indicator of ignorance', when in fact it should be seen as a source of actionable knowledge (Lewandowsky, Ballard & Pancost, 2015), which presents a challenge for risk communicators. Previous research has highlighted disparities between a communicator's intended meaning, and that understood by recipients of the communication. Recent work (e.g. Teigen, Juanchich, & Riege, 2013) suggests that people might have a tendency to expect terms such as 'unlikely' to refer to outcomes that will almost never occur, rather than occurring on around 20% of occasions (Theil, 2002). Such miscommunications could have negative implications for the perceived credibility of the communicator.

Firstly we present two studies, in which we examine the effect of using verbal ('unlikely'), numerical (point, '20%', and range, '10 – 30%') and mixed ('unlikely [20% likelihood]'/ '20% likelihood [unlikely]') communication formats on perceptions of credibility, as well as behavioural outcomes both before and after an 'erroneous prediction' (i.e. an 'unlikely' event occurred). Verbal formats consistently suffered sizeable reductions in credibility. These results support the use of numerical risk communications, though the benefits of using a range depended on the perceived predictability of the event (i.e. how precise an expert could be when describing its likelihood).

Secondly we present follow-up work which aims to try and explain why perceptions of credibility vary so widely between verbal and numerical expressions after 'erroneous predictions'. We speculated such disparities may have been due to people's awareness that numerical probabilities total 1. As such, if one communicates that there is a 20% likelihood of a gale occurring, people are more aware of the converse outcome too (that there is an 80% likelihood of the gale *not* occurring). However, in the verbal expression, this converse outcome is less apparent. We therefore present research in which we examine the effect of altering the framing of the verbal and numerical expressions by adding the converse outcome (i.e. it is unlikely the river will flood [it is likely the river will not flood]). By adding in the converse outcome, we see the differences between formats significantly reduce.

A greater understanding of the effects of different communication formats on the perceived credibility of the commuicator, and the mechanisms behind these effects is key to improving the effectiveness of communications of risk and uncertainty.

NOTES

Decision maker perspectives on scientific information at a volcanic simulation exercise

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Dominica is a Small Island Developing State (SIDS) in the Eastern Caribbean with one of the highest concentrations of potentially active volcanoes in the world. The last magmatic eruption occurred ~500 years B.P. with more recent phreatic eruptions and seismic unrest. Future scenarios include Montserrat-style dome-forming and Plinian-style eruptions from volcanic centres across the island. Uncertainty and incomplete knowledge around the location, size and style of a future eruption presents particular challenges to a nation whose hazard experience is dominated by hydro-meteorological events.

Here, we report perspectives of those responsible for managing the impacts of a future volcanic eruption through thematic analysis of participant observations, and semi-structured interviews with this group before and after a simulation exercise. This two-day event was run in Dominica in May 2015 by the EU-funded VUELCO (Volcanic Unrest in Europe and Latin America Consortium). Over three separate time steps spanning approximately 18 months of simulated time, injects of monitoring data created by the UWI Seismic Research Centre were passed to a team of regional and international scientific experts for analysis and discussion. They produced a report and briefing for local managers of risk and decision makers who then deliberated on the findings and determined a response.

Several themes were common to many participants including:

(1) The perceived role of experience. Interviewees contrasted their perceived lack of experience in dealing with volcanic activity with that of the scientists. Although few appeared to expect the scientists to make local decisions, many thought the scientists would offer insight into disaster management as well as the interpretation of scientific data. Most experienced difficulties understanding the scientific advice, but a number of these felt it reflected their lack of personal experience and knowledge of volcanoes. However, some noted improving ability to question the scientists over the course of the exercise.

(2) Type of information provided. Some felt the scientists focused too strongly on the 'why' (i.e. interpreting the volcanic system) rather than the 'so what' (i.e. how the information could be used). Having decided on evacuation, many felt the advice did not help to identify who to move and when. This highlights tensions familiar from retrospective accounts of past eruptions, and acknowledged in the community guidelines for volcanic crises: the desire for forecasting that predicts the location, timing and style of an event and the relationship between scientific advice and the decision to evacuate.

(3) Dealing with uncertainty. Many expressed an acceptance that the knowledge of what might happen next was inherently uncertain. They framed this in terms of nature being imperfectly predictable, reflecting on their past experiences of hurricane forecasts. However when asked about uncertainty in the data and analysis describing the ongoing state of the volcanic system, this was related back to scientific credibility and trust.

This analysis demonstrates that simulations uncover insights into plans for crisis management that could be used to divert problems during future crises. Dissecting these lessons and acting on them requires considerable effort, and long-term change in response to the findings is the focus of ongoing research.

NOTES

Resilience in practice - a comparative case study of structural and non-structural approaches

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If a hazard is predictable, then durable, fixed, structural measures can be designed with certainty to defend against the hazard. In reality, the time intervals between extreme natural hazard events are stochastic in nature, we lack long term data on their occurrence, and there are still gaps in our understanding of their physical processes. This difficulty in prediction is exacerbated by climate change and human activities. We also see that an increasingly complex coupling between the social and natural environment can lead to surprises, such as the Fukushima disaster which occurred despite the existance of a protective sea wall and of the security measures at the nuclear power plant. In this context, more flexible approaches are needed.

One approach which has been given a lot of attention recently is building resilience. We analysed a range of existing work on resilience and found pratical ways for measuring the long term resilience of cities through distance to thresholds, recovery capacity and adaptive capacity.

Based on this, we propose a conceptual model for comparing structural and non-structural disaster risk management options, based on a case study area in an earthquake prone mountain region of China. We demonstrate how by modelling failure and recovery in the long term, the model can be used for comparing between different disaster risk management options, such as building large scale protective structures, retrofitting existing buildings, implementing legislation to build-back-better, and increasing recovery capacity. The next steps will be to develop this model using data from collaborators at the Mountain Institute in Chengdu of China and from existing open source hazard models.

NOTES

Multi-Hazard Vulnerability Assessment of School Infrastructure – The case of Cagayan de Oro, Philippines

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The Philippines is one of the most hazard-prone countries in the world. It is regularly subject to various hazard-events, inflicting loss of lives and costly damage to the country's infrastructure. In particular, the Philippines straddles a region of complex tectonics at the intersection of three major tectonic plates (the Philippine Sea, Sunda and Eurasia plates). As such, the country is exposed to large and damaging earthquakes. For example, the most recent earthquake, the M 7.2 Bohol earthquake (2013), damaged more than 73,000 structures, of which more than 14,500 were totally destroyed, including several schools. According to the United Nations International Children's Emergency Fund (UNICEF), about 25,000 pre-schoolers and 275,855 school children in 1,200 early learning centres and 1,092 schools (931 elementary schools and 161 high schools) were affected by the earthquake. Similarly, several areas characterized by high wind and heavy rain exist along the northeast Philippine Sea coast. In 1991, a flash flood killed around 8,000 people and distracted many structure in Leyte Island. Furthermore, Typhoon Haiyan (2013), known as Super Typhoon Yolanda in the Philippines, was one of the strongest tropical cyclones ever recorded, which devastated several portions of the country, killing at least 6,300 people. According to the Philippine's Department of Education, Yolanda damaged 3,171 schools. The recent history of reported damage and destruction indicates the substantial vulnerability of the country's infrastructure, particularly schools, to different forms of natural hazards.

Schools play a critical role in the education of the next generation and one of the most vulnerable part of the society due to their age and their developmental stage. A safer school can save valuable lives of children, provide a safe haven for the local community, serve as a temporary shelter and help to bring normalcy back to society in times of disaster. However, like other infrastructure, public school buildings constructed prior to adequate building codes, share structural deficiencies common to other buildings of the same structural types in the same setting, but the above considerations set school buildings apart from their peers in terms of priority for assessment and retrofit. Taking into consideration the high probability of occurrence for any type of natural hazard in the Philippines, vulnerability of the school buildings should be of high priority for the governmental authorities and first responders. Considering the large number of existing school infrastructure and their geographical distribution, appropriate tools and approaches are required to address the prevailing vulnerabilities of Philippine's school infrastructure. Developing a comprehensive dataset of typical and systematically defined structural typologies for schools, including main structural and non-structural characteristics (e.g., age of construction, number of story, lateral load resisting system and materials, number of occupants), common defects, typical damage associated to multiple natural hazards, will also be beneficial for disaster management planning and decision making along with prioritization and resource allocation for strengthening program for such structures.

The main aim of this study is to develop a methodology for a rapid yet reliable visual vulnerability assessment of school infrastructures against the most common natural hazards of the Philippines. As part of this objective, a rapid visual survey form is proposed. In

addition, a mobile application has been developed to assist the surveyors for assessing the school building in a more efficient way. Furthermore, a preliminary investigation is conducted in the city of Cagayan de Oro to relate the collected data to vulnerability indices to swiftly determine the safety level of the considered buildings. Cagayan de Oro is the regional capital and the gateway to Northern Mindanao. It is a highly urbanized first class city with over 602,000 citizens and multi-hazard profile of earthquakes, floods, cyclones, tsunami, among others. The city has established a full-time unit in charge of disaster preparedness, response, recovery and mitigation.

To test the feasibility of the method, 115 school infrastructures have been surveyed and their vulnerability indices been estimated. The proposed method represents a first step toward a detailed multi-hazard vulnerability assessment of school infrastructure. This can allow decision-makers to quickly identify the most vulnerable structures among the surveyed stock, guide more detailed data collection and structural assessment procedures, and ultimately plan further rehabilitation measure or if necessary replacement.

NOTES

A SurveyPRISM': A tool to support people in assessing hazards, vulnerability and risks in Geohazard locations

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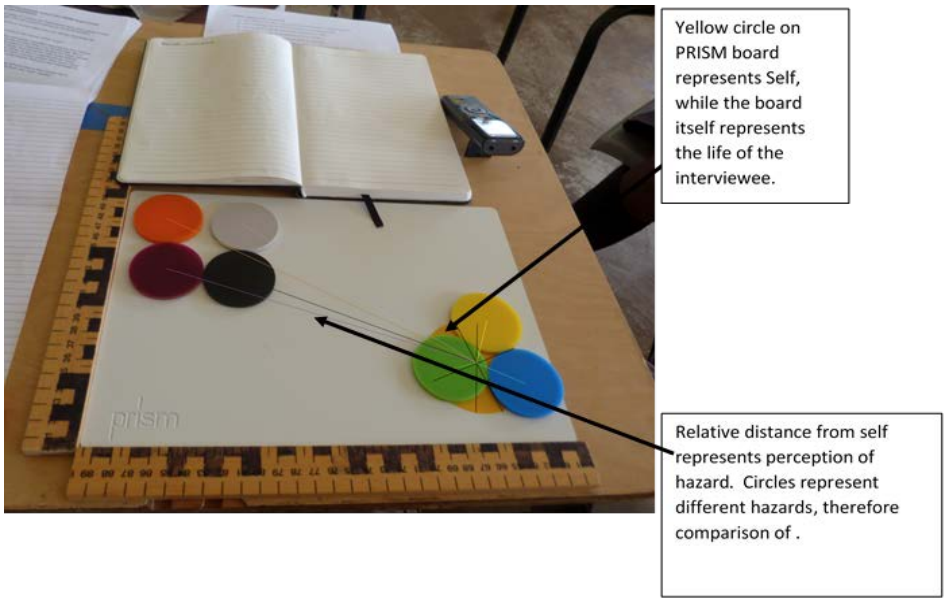
'Pictorial Representation of Illness and Self Measure' PRISM is a powerful tool used within medical studies to allow a person to ascertain their 'burden of suffering' as in how much impact did their illness have on their everyday life. Martin Parham and colleagues have been looking at the potential of using this tool to help people living in areas of high vulnerability due to Geohazards, such as in Dominica. Build on that novelty this project looks at moving from a paper based system to a digital version, and in so doing offers further novelty in both engaging young people in articulating their perceptions of risks and vulnerabilities, as well as providing a potentially new robust system and data collection covering self-reporting of perceptions of risks and vulnerabilities. Interestingly, the development so far indicates potential to also provide novel metrics on perceptions of risk and vulnerability that extends outside of the geohazards domain.

The PRISM technique is rooted in the work of Eric Cassel and his paper called 'The Nature of Suffering and the goals of medicine'. The paper reflects upon what constitutes suffering. Tom Sensky and Stefan Büchi have been key in developing PRISM as it is known today utilising a system of discs to represent the self and threats to the self-contained within a physical area representing the context of a patient's life (Sensky & Büchi, 2016). A typical paper version of PRISM is given in the figure below:



The paper based version required measuring the location of the various discs (representing a person's perception of a rick or hazard); the further away from the 'self' disc the higher the concern of suffering when used in the medical context, or the perception of risk and vulnerability in the geohazards context.

The developed digital version, SurveyPRISM, extends the paper version into a simple app that could be used by a wide selection of people from school children to adults in societies

affected by high levels of geohazards. The target sample for field trials is young people from the Island of Dominica where the paper version has been previously trialled.

Applying the PRISM tool, developed for specific purposes in health professions (treating cryonic illnesses), to a very different domain that of perceptions of risks and vulnerabilities within geohazards raised several challenges to ensure internal consistency within a cognitive lens. This entailed drawing upon literature from different domains. The development of the digital version entailed adopting an agile development approach with several iterations of prototypes and getting feedback from the research users.

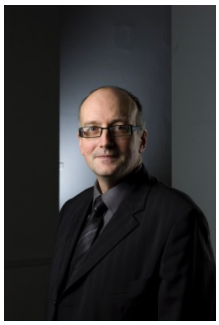
Developing the SurveyPRISM highlighted potential to capture other metrics relevant to perceptions of risk and vulnerabilities that would be useful to understand perceptions from people in locations with high level of geohazards. Some of the key possibilities include the potential to:

- collate together and compare input from whole communities and groups of people
- collate together different responses for the same individuals over periods of time, and in response to different stimulus (e.g. nearness of a disaster or hazard event)
- capture temporal elements of perception of risks and vulnerabilities for communities
- capture new response metrics such as speed and acceleration in responses to certain types of risk
- generating a data set capturing risk and vulnerabilities across regions, communities facing different types of geohazard and cultural differences

The research so far identifies many interesting avenues for further research exploring these possibilities. The potential to capture response metrics (e.g. speed and acceleration in responses to certain types of risk) has potential to provide novel metrics for self-assessment of risk and vulnerability assessment more widely (e.g. in crime, working environments). In addition, the work done on the SurveyPRISM has the potential to be feedback into the medial arena and provide further support in applying PRISM to help supporting cryonic illness sufferers.

NOTES

Increasing Resilience to Environmental Hazards in Conflict Zones



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Gareth Hearn (Hearn Geoserve)

This paper presents research from that focuses on building resilience in conflict zones subject to multiple environmental hazards. It is argued that resilience can be addressed through understanding the hazard risks and the heightened vulnerabilities of the people only in the context of knowledge of the history of disasters and analysis of the impact of conflict on social relations.

The Hindu-Kush Himalaya region is home to over 200 million people. The mountains are the source of the major rivers of Asia which support 1.3 billion people. The landscape of the Himalaya is a result of a continuing competition between on the one hand collision of tectonic plates, which has raised the Himalaya mountains, and on the other gravity, which causes erosion. Eroded sediments are deposited by glaciers and rivers. The high rate of these processes of uplift, erosion and sedimentation creates a highly dynamic environment which causes earthquakes, landslides, floods, excess temperatures, wind and snow storm and drought. This fragile environment is subject to rapid regional climate change and affected by uneven development (including high levels of seasonal tourism). These environmental hazards impact lives, livelihoods and critical infrastructure.

Within the region, Kashmir covers the Indian state of Jammu and Kashmir (subdivided into Jammu, Kashmir and Ladakh), the Pakistan state of Azad Jammu and Kashmir and the territory of Gilgit- Baltistan, and the Chinese-administered territory of Aksai Chin. The recent history of Kashmir is of over-lapping territorial claims of three nuclear powers, China, India and Pakistan (with the world's first, third and sixth largest armies), war and resolution (in 1947, 1962, 1965 and 1999), but with on-going internal conflict, border incursions and insurgency, which has led to communities divided across borders, militarised infrastructure and internal migration. These all have the potential to increase community vulnerability as they disrupt social relations.

The paper will focus on Ladakh. It was the scene of the most recent Indo-Pakistan war, the 1999 Kargil War, and has suffered cross-border infiltration from Pakistan and Afghanistan and incursions from China which have intersected with internal tensions between communities and mixed social and ethnic constitution of Ladakh. Population dynamics, economic growth and mass tourism are generating pressure on natural resources with migration and uncertain agricultural production modifying familial and village relationships and nomadic communities (i.e., the social capital).

We discuss the historical evolution of the landscape of the Himalaya, the drivers of hazards and the effect of human impact. We assess the vulnerabilities and social relations of communities in Ladakh, their cross- borders links, relations with other communities and migration. We analyse the history of disasters, in the broader Kashmir region, the cultural and political development of the region, and assess the impact of conflict on resilience and adaptation.

In the historical context of a border conflict zone, it is discussed how changing social relations increase or decrease social capital and vulnerability to environmental hazard risks.

NOTES

Building Resilience to Lahar Hazard: hazard and susceptibility assessment at Volcán Cayambe, Ecuador

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Minimising social and economic disruption from geohazards and building resilience requires a detailed understanding of a number of *dynamic* factors that in combination characterise disaster risk: the nature of the *hazard* itself, the *exposure* and *vulnerability* of people and assets, and the set of *capacities* in place to reduce, prepare for and recover from the impact. In this presentation, we explore the threat posed by lahars, or volcanic mudflows, which can travel very long distances from their source and can be very destructive. In particular, we focus on characterising their dynamics and inundation, and building capacity for hazard assessment, and to support planning and decision-making.

Lahars are complex suspension flows of particles and water that exhibit diverse characteristics. Despite substantial advancements gained through field observation and experimentation on large and small scales, the physical processes governing the dynamics of lahars are incompletely understood. Here we present a new model of lahar dynamics (LAHARFLOW) developed as part of the STREVA project, specifically as a tool for hazard assessment. As such, LAHARFLOW includes only the dominant physical processes and adopts bold parameterizations. We adopt a shallow-water framework, and model the transport of a mixture of water with entrained solid material. The flow of the mixture is resisted by basal stresses whose form evolves with composition of the flow, to model a wide range of observed behaviour. Erosion of the bed and deposition of the solid material alter the local topography that feeds back into the mobility of the flow. Uncertainty in model parameters can be readily propagated through the model, and we show the use of uncertainty quantified as part of model calibration as method for incorporating uncertainty estimates into rapid hazard assessments.

We present the use of LAHARFLOW and a similar research model, VOLCFLOW, for assessment of lahar hazard at Volcán Cayambe, Ecuador, which started showing signs of unrest in mid-2016. Both models were used in the production of the latest hazard map, which shows that Cayambe town (population c.85,000) is under threat from lahars travelling down the Rio Blanco ravine, passing through the town in very close proximity to housing and infrastructure. Model predictions for this setting require high resolution topography models, which were acquired from drone photogrammetry during a field campaign in March 2017. Additionally, future work will focus on the determination of the smallest lahar that constitutes a threat in Cayambe, through a susceptibility study that will identify the levels of volcanic ash accumulation and rainfall under which such a lahar could develop. That knowledge will be significant input to enhance both early warning and preparedness planning. We draw on experience of management of the threats from rain-triggered lahars at Volcán Tungurahua, Ecuador, and engagement with affected communities, to identify components that build resilience to lahar hazard.

NOTES

Understanding structurally-controlled slope stability in the Bhutan Himalaya: implications for landslide hazard assessment

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In the wake of the 2015 Gorkha earthquake in Nepal, many Himalayan countries have renewed concerns of earthquake preparedness and resilience. Failure cascades (e.g. loss of airports and roads leading to loss of fuel, food, and relief supply routes) after a significant seismic event can be difficult to foresee and can lead to disastrous circumstances long after the initial event. However, many failure cascades can be avoided if critical lifelines remain open after the shaking has stopped, or can be reopened shortly afterwards.

The significant shaking of the 2015 Nepal earthquake traveled a great distance along the Himalayan mountain range, damaging buildings in western Bhutan. This event has motivated ministries and communities within Bhutan to be better prepared for future seismic events. The urban population and infrastructure of Bhutan has grown rapidly over the past few decades, with much of the development carried out without adequate consideration of accurate seismic hazards. Though the seismic history of Bhutan is not as well-known as other sections of the range, new information is emerging that a Mw>8 earthquake is possible in this portion of the eastern Himalaya. Most goods come into the capital city, Thimphu, via ground transport from neighbouring India to the south. The Phuentsholing-Thimphu highway in western Bhutan is the most critical path for moving people and goods into the country. However, it is also one of the most difficult to maintain. This road is cut into very steep hillslopes, which can receive more than 6 m of rain per year, and weakly metamorphosed sedimentary rocks, which often have steeply dipping foliations and many complicating fracture sets.

This presentation will focus on our on-going efforts to better understand the driving mechanisms of the persistent landslide hazards along the lifeline roads in western Bhutan. We will present a methodology that incorporates high-resolution, remotely-sensed structural data (based on photogrammetry) into slope stability models in a way that is both easy to reproduce and inexpensive. This analysis and others like it, represent the critical first steps toward developing engineering solutions to stabilize slopes around cities and road cuts to mitigate failure cascades after seismic events.

NOTES

Developing a seismic hazard model for Sabah, East Malaysia using seismic and geodetic data

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Earthquakes may result in death, injuries, disruption to infrastructure, and significant economic loss. It is therefore crucial to assess the seismic hazards present in earthquake-prone regions to help mitigate against the risks posed. Most of Malaysia has low levels of seismicity. However the state of Sabah, in northern Borneo, has moderate levels of seismic activity. In June 2015 a magnitude 6.0 earthquake occurred near the town of Ranau, causing large landslides. 18 people were killed on Mt Kinabalu, and there was damage to buildings in nearby towns and villages. The region around Ranau is one of the main centres of seismicity in Sabah, the other being in the east of the state, around the town of Lahad Datu, where a magnitude 6.2 earthquake occurred in 1976. Despite rapid population expansion over the last 40 years, seismic hazard in Sabah remains poorly understood. Using seismic and geodetic data we hope to better quantify the hazards posed by earthquakes in this region, and thus help to minimize risk.

The Malaysian Metrological Department (MetMalaysia) has had a network of seismic stations located throughout Sabah since 2005. This part of the Malaysian National Seismic Network currently consists of nine broadband and six long-period instruments. We construct a new crustal model for Sabah using P receiver functions obtained from data recorded at the MetMalaysia stations and surface wave data (Tang et al., 2013). We (re)locate earthquakes that have occurred in Sabah since 2005 using this new crustal model and arrival times picked from data recorded at the MetMalaysia seismic stations. We use a probabilistic nonlinear earthquake location program, *NonLinLoc* (Lomax, 2001) to locate the earthquakes and then refine their relative locations using *HypoDD* (Waldhauser, 2001). The recorded waveforms are further used to obtain moment tensor solutions for these earthquakes. Earthquake locations and moment tenor solutions are then compared with the locations of faults throughout Sabah. Faults are identified from high-resolution IFSAR images and fieldwork, with a particular focus on the Lahad Datau and Ranau areas. Used together, these seismic and geodetic data can help us to better assess the seismic hazard in Sabah, to aid in the delivery of outreach activities regarding seismic hazard within local communities, and to understand the seismo-tectonic processes taking place in Sabah.

NOTES

Linking the social sciences, physical sciences and the humanities to manage risk and build resilience to geohazards: innovative methods and approaches

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It has been recognised that understanding hazards, managing risk and building resilience requires interdisciplinary research that engages with communities at risk. While the social and physical sciences have been working to bridge this gap, less attention has been paid to the role that humanities and arts can play in understanding risk to geohazards and empowering communities to respond and cope with these challenges. This presentation will introduce the methodologies used by two innovative projects funded by the UK Research Councils that are working across disciplines with the aim of engaging with communities vulnerable to hazards.

The first project, 'Moving with Risk: Forced Displacement and Vulnerability to Hazards in Colombia', combines qualitative social science methodologies with methodologies for both research and engagement in the humanities to understand the lived experiences, concerns and aspirations of Internally Displaced Persons who have resettled in hazard-risk areas. The project proposes to use the creative arts and music in particular, not just as a methodology for data collection but also as a channel for engagement of people and communities in managing disaster risk in their places of resettlement. The inter-disciplinary nature of the project also extends to inclusion of physical scientists who provide a deep understanding of the hazards to which these people are exposed to, such as landslides, volcanic hazards and floods.

The second project,' Explosive Transformations: Cultural Resilience to Natural Hazard on St Vincent and Montserrat' aims to understand the role that narratives of past volcanic events play in cultural life, community memory, and the shaping of island identities, and the ways in which this knowledge might usefully be employed to help with social response and readiness for future events. The project brings literary studies together with volcanology, international development, and the institutions responsible for future emergency response to volcanic eruptions to examine whether insights from literary, artistic and wider cultural expression (oral storytelling, poetry, song) can provide any new and useful ways to think about and implement programmes of resilience in the face of the natural hazard that volcanoes pose to communities.

The presentation will introduce the innovative collaboration and approaches applied by these two projects and explore how a combination of methodologies from the humanities, social sciences and physical sciences provides insights into responding to the challenges posed by the risk associated to geohazards.

NOTES

Spatialising the interactions between people, animals, volcanic hazard and local perceptions and responses to Popocatépetl volcano, Mexico

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Popocatépetl volcano in Mexico is one of the most active volcanoes in the world, and it is a source of multiple physical volcanic hazards. More than 20 million people are estimated to live within 70km of the crater. Those populations situated closer to its slopes have already been regularly affected by ash emissions and lahar formation since volcanic activity recommenced in 1994, and there is furthermore the potential for another Plinian-scale eruption.

Despite this, local drills and evacuation events have proven challenging, particularly those involving rural populations, where communities or individuals have either refused to leave or returned prematurely. In many cases, the need to feed and manage livestock is cited as a cause of this behaviour.

Beyond direct threats to life from hazards or as a result of starvation, the health and welfare implications of ongoing volcanic emissions exposure to pets and livestock, that these communities may also be responding to when making their hazard decisions, are poorly understood.

This interdisciplinary project builds upon two research approaches: i) participatory social volcanology; ii) the growing recognition of all species of managed animals not only as 'economic units', but as wider effectors upon people's risk responses and behaviour during disaster.

The impacts of animals during disaster gained recognition in the wake of the 2005 hurricane Katrina in the US, where a significant proportion of evacuation delays, refusals and deaths were attributed to a refusal to abandon pets and livestock to their fate. Multivariate studies have since confirmed that animal ownership is a 'risk factor' influencing human responses to hazards in a range of contexts.

Recent research not only frames animals as 'risk factors' for hazard response, but additionally asks whether animal ownership offers a pathway for targeted community engagement and disaster education. This project builds upon this trend, asking novel questions specifically about the spatial nature of how animals influence volcanic hazard responses.

We are presenting mapped historical volcanic hazard data and future hazard modelling output data for Popocatépetl volcano, alongside plans for qualitative interviews and a quantitative survey, to determine local knowledges of, and responses to, animals and risk. We aim: I) to undertake georeferenced, mixed methodology sociological fieldwork across the region from the volcano’s slopes to 45km east of Popocatépetl, including Puebla city; ii) to undertake participatory hazard mapping exercises to better understand these phenomena spatially, and engage local communities; iii) to map all fieldwork data, so it may be correlated with historical and modelled volcanic hazard data, and socioeconomic and land use data; iv) to perform multivariate spatial analysis upon these data to further understand the complex social-physical interactions.

All these data will allow us to spatially determine the influences of animals upon people's responses to volcanic hazards, and subsequently consider whether hazard resilience policy

could be spatially tailored and targeted for improved outcomes.

NOTES

The historical dimensions of volcanic hazards on St Vincent

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Jenni Barclay - School of Environmental Sciences, University of East Anglia, Norwich, UK

Maria Teresa Armijos - School of International Development, University of East Anglia, Norwich, UK

Analysis of the records of past hazard events can provide insights that are of value for disaster risk reduction today. Retrospective analysis of the contemporary colonial and scientific records of a major explosive eruption of the Soufrière of St Vincent from 1902-1903 reveals how this significant and prolonged event presented challenges to the authorities charged with managing the crisis, and its aftermath.

In a small-island setting vulnerable to multiple hazards, the spatial footprint of the volcanic hazard and the nature and intensity of the hazard effects were rather different to those of other recurrent hazards such as hurricanes. The eruption affected the same parts of the island that had been impacted by prior explosive eruptions in 1718 and 1812, with consequences that similarly and disproportionately affected those working in and around the large sugar estates. The official response to the eruption, both in terms of short-term relief and remediation, was significantly accelerated by the existence of mature plans for land-reform following the collapse of the sugar market, and ongoing plans for rebuilding in the aftermath of a destructive hurricane that hit the island in 1898. The picture that this analysis helps to illuminate provides insights both into the nature of the particular eruptive episode, and the human and social response to that episode. This not only informs discussion and planning for future explosive eruptions on St Vincent, but provides important empirical evidence for building effective responses in similar multihazard contexts.

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Dynamics of the pyroclastic density current formed during the 1902 eruption of La Soufriere, St Vincent, West Indies from analysis of the photographic archive

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The excellent contemporary documentation of eruption 7 May 1902 at La Soufriere, St Vincent provides a rare opportunity to study the impact and analyse the dynamics of a lethal pyroclastic density current (PDC). The photographic archive combined with these contemporary accounts reveals that the PDC formed was essentially a single, radially distributed short lived paroxysmal current occurring over the space of the a few minutes, and was not the result of multiple events. The PDC directly resulted in the deaths of around 1500 people, nevertheless a number of people survived inside buildings.

Dense high particle concentration scoria-rich PDCs moved down the main valleys to the NW, W, SW and SE, while the low particle concentration currents were continuous between these valleys. Dilute PDCs also travelled for several km over the sea on the western side of the volcano, emanating from several of the deep valleys.

In proximal areas, < 3km from source, tree felling was near total both in valley bottoms and on the top of narrow ridges. Such damage indicates high dynamic pressure (> 10Kpa) and likely high velocities. Whereas a near absence of damage or charring of wooden buildings reveals almost negligible dynamic pressures and low temperatures of the PDCs and in distal regions (6 – 7 km from source). Numerous human casualties occurring at these locations confirms the passage of a slow moving, dilute current in the final few km of runout.

This analysis indicates that the PDC rapidly attenuated in velocity and dynamic pressure over the course of its run out. Dynamic pressures decreased to <1 Kpa over only a few km. From a hazard point of view it is worth noting that despite the low temperatures and dynamic pressures these currents were lethal to anyone outdoors.

NOTES

Assessing correspondence between volcanic activity and evacuation using time series and timeline data: forensic analysis from Soufrière Hills Volcano, Montserrat, 1996-2009

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During a volcanic crisis, the usual response to an imminent and immediate threat to human life is to evacuate populations to safer areas. However, the scientific advice and civil authority decision-making processes are often complex, and improved understanding of their basis and interactions may help inform future crisis management. We explore the relationship between volcanic activity and evacuation of inhabited areas in order to investigate and characterise the drivers and timescales of volcanic crisis management during a prolonged period of escalating volcanic activity using examples from the eruption of Soufrière Hills Volcano, Montserrat, 1996 – 2009. An elemental time series approach is used to objectively quantify timeline relationships between the physical volcanic hazard and responses from risk-based decision making. Three representations of volcanic hazard are used: the total cumulative runout of pyroclastic density currents (a metric for the outcome of hazardous activity); the area evacuated (outcome of risk-based decision making), and seismic activity (an indicator of actual and 'potential' hazard). We compare time-series of these hazard expressions with an independent forensic analysis of available records of volcanic activity and response to risk by actions from decision-makers and the population.

Nine evacuations took place in the periods April 1996 - December 1997 and January 2007-December 2009. Our analysis of both these periods identified weaker correlations between observed *activity* and evacuation when there was less surface activity or the volcano was entering a new style of eruptive behaviour, such as rapid dome growth, with the latter changes more prevalent in early stages of the eruption. Although these findings show that both observed and potential hazard are likely to influence evacuation decision-making over timescales of a few days, our qualitative analysis shows that other social processes, such as the necessity to maintain livelihood, can also exert a strong influence.

NOTES

Quantitative assessment of earthquake moment magnitude (Mw) uncertainties

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To improve resilience to earthquakes and consequent triggered events, it is necessary: first to understand the hazard and associated risk; next to acknowledge that any such understanding must necessarily be incomplete due to multiple sources of uncertainty; and finally, to communicate both the understanding and the uncertainty to agencies responsible for planning and for emergency management, in a form that supports effective decision-making. The work reported here is part of a joint UK-China project, part of the Newton Fund programme “Increasing Resilience to Natural Hazards in Earthquake Prone Regions in China”, that seeks to address these issues with a focus on the Yunnan province in China.

As a first step in developing improved seismic hazard estimates for Yunnan, we aim to develop a single, long, homogeneous earthquake catalogue for the province by combining information from digital, analogue and historical records. This requires the development of calibration relationships between the various measurement and recording techniques that have been used over time, using techniques similar to those developed by Touati et al. (2017). To do this in a principled manner, and to ensure that uncertainties are represented appropriately in the final catalogue, it is necessary to attach uncertainty assessments, such as standard errors, to all of the individual data sources. Such assessments are not provided routinely for Chinese catalogues. A particular challenge is to derive uncertainties for estimates of the seismic moment magnitude Mw, obtained for modern events by inverting local seismograms. In Yunnan, the inversion is routinely carried out using the CAP method (Zhao and Helmberger 1994; Zhu and Helmberger 1996), which estimates earthquake source parameters by minimising an objective function which is a weighted sum of squared differences between observed and synthetic waveforms. In this poster, we show how to provide uncertainty assessments for any such inversion technique, using methods that are well known in the statistics community but have not received much exposure elsewhere. The methodology accounts automatically for epistemic uncertainties due to limitations of the models used to produce synthetic waveforms. For optimisation code that is well written, the approach can be implemented straightforwardly since it only requires the Hessian matrix of the objective function, together with contributions to its gradient from each station: these can be calculated numerically if necessary, at minimal additional cost after the optimisation is completed.

The method is illustrated for some events in Yunnan. The resulting uncertainties help to explain some of the differences between the Mw values reported in the Chinese catalogue and those for the same events from the global Centroid Moment Tensor (CMT) catalogue which is widely regarded as a reference.

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An automated Bayesian fitting of macroseismic intensity data for isoseismal contours and epicentre estimation

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In moderate to low seismicity areas such as the UK, earthquakes represent a small but not negligible risk to sensitive structures such as nuclear power plants and dams. As part of the safety case in the planning and regulation of such structures, seismic activity must be monitored and quantified to form a catalogue of past events. The catalogue can then be used to calculate the likelihood of ground shaking for any location in the UK, given a time period, highlighting vulnerable areas in seismic hazard maps. In addition, the assessment and communication of uncertainty involved in seismic hazard maps is becoming increasingly important in recent years.

The size of the earthquake source is often expressed in terms of moment magnitude, a logarithmic measure of seismic moment, which largely replaced the base 10 logarithmic Richter scale called local magnitude. The disadvantage of moment magnitude is that it requires digital data (available since around 1980) to perform the inversion. The catalogue can be extended back to around 1900 after calibration with analogue measures of local magnitude. However, historical events from the non-instrumental period do not have such measure available, hence it must be estimated through an alternative means.

Intensity is an ordinal measure of shaking and damaging effects of an earthquake, recorded in historical documents by contemporary observers. One possible way of extending the catalogue back in time is to derive an index, such as felt area at or above a given intensity, to build a conceptual model of how it might depend on moment magnitude based on the empirical relationship between the two measures for events from the instrumental period. Here we demonstrate a new method for constructing isoseismal maps objectively from intensity measures and their observed locations. It involves using mathematical expressions to represent concentric ellipses for the contours and estimating their optimal parameters and uncertainties in a Bayesian framework, using known constraints as priors. The resulting posterior distributions are used to calculate felt area at a given intensity, as well as the inferred epicentre.

We then describe another Bayesian approach for deriving moment magnitude from felt areas based on their relationship. The use of Bayesian inference allows us to quantify uncertainty inherent in the intensity measures and to propagate it through formally to a probability density function for the inferred moment magnitude.

NOTES

Monitoring volcanoes without humans: linking geophysics with drone imagery to understand South-Italian volcanism

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While geomorphology seeks to understand the origin and evolution of Earth landscapes and ocean bathymetry from surface observations, the aim of geophysical imaging is to unveil and monitor deep Earth structures directly. The link between these two disciplines is often too weak with respect to the benefits a true integration could lead. In a volcano, geophysics provides direct 4D information about magma, fluid, and gas movements, nevertheless making strong assumptions and using indirect observations. Geomorphology is able to observe directly the structural settings where these materials travel without providing immediate responses to monitoring questions.

In this study, we integrate recent seismological imaging with thermal analysis and geomorphological information collected at Stromboli volcano using drones. The correlation of geophysical data with drone imagery reduces uncertainties in the interpretation of the latters, and increases the understanding of biases between shallow manifestations and deep subsurface phenomena. Future applications to South Italian volcanoes, in cooperation with INGV, will allow the development of case studies for the most hazardous European volcanic area. The final technological deliverable is a system that any policy maker can integrate in risk assessment, operated by local officers in direct contact with communities, without the direct control of scientists.

The four volcanoes where the research will focus (Campi Flegrei, Mt. Vesuvius, Mt. Etna, and Stromboli) are among the most densely populated areas in the world. The interaction with scientists involved in everyday monitoring of the volcano provides the necessary background for the understanding of different eruptive scenarios. The possibility of monitoring the state of the volcano near volcanic vents, without humans involved in the measuring process, represents a step toward preventing life loss of during volcanic eruption. The applicability of the same technology to flank collapse and landslide events widens the scope of the research to volcanism across the Italian peninsula.

NOTES

Identifying volcanic and tectonic hazards in the Main Ethiopian Rift

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Identifying volcanic and tectonic hazards in developing countries is often difficult due to a lack of instrumentation and incomplete observations of historical activity. In particular, regions of the Earth which are slowly deforming and have long repeat times between events have hazards which are difficult to characterise. Ethiopia is an example of such a region. Here, rifting between the Nubian and Somalian plate is accommodated within an 80 km wide rift valley. Within the rift, the local population is exposed to both active volcanism around large, silicic and historically explosive central volcanoes and active tectonics expressed by large (at least 500 m high) border faults and significant intra-rift faulting. There is currently no continuously monitored seismic stations within the rift making this one of the most geologically hazardous and poorly understood regions of the world.

We present results from the NERC funded project RiftVolc, which aims to understand the hazard posed by earthquakes and volcanoes in the Main Ethiopia Rift (MER). To do this, we have deployed a dense seismic network around three actively deforming volcanoes in the rift: Bora, Aluto and Corbetti. An automatic detection and location algorithm is used to locate the seismicity around the volcano Bora. We detect more than 1000 earthquakes from the period February 2016 – February 2017. The seismicity occurs in swarms, striking north-northeast, possibly reflecting the activation of small faults, aligned with the regional trend, within the volcano. The depth of the seismicity is very shallow (<3 km below the surface), suggesting that the seismicity is induced by geothermal fluids circulating through the crust. This would infer the presence of a shallow heat source, possibly created by a small magma body which may or not of solidified.

Two tectonically induced earthquake swarms are also presented. One to the south of Aluto (Mw 5.3) and the other near the volcano Corbetti. Both events are quite deep (~8 km below sea level) and have normal faulting mechanisms. The Aluto event is poorly located by both teleseismic and regional networks. By using our local network, fortuitously located close to this earthquake, we can show that the earthquake was actually a double event. The aftershocks that follow the two main shocks delineate a fault patch on the eastern margin border fault near Aluto. This event highlights the close proximity of large faults and volcanoes in this area and the potential of events to be triggered. The Corbetti swarm is smaller (max Ml 4.0) but highlights the danger to the local population. It occurred beneath the large city of Hawassa (population 500,000), which is located less than 20 km from the volcano Corbetti and now also appears to be located near an intra-rift normal fault. The poor building quality in the city raises the potential for a large loss of life if there is even a relatively small earthquake.

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Building Resilience to Earthquakes in Bhutan: Probabilistic Seismic Hazard Assessment for a National Building Code

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The Royal Kingdom of Bhutan faces imminent seismic hazard and risk: The country lies in the Himalaya, directly above the Indian-Eurasian tectonic plate boundary, and to date no mandatory and enforced building code exists. Recent paleoseismic, geomorphological and historical evidence suggests an earthquake of magnitude 8.0±0.5 caused great damage to Bhutan in 1714. This laid to rest the hope that Bhutan is less exposed to earthquakes than other parts of the Himalayan belt. Bhutan is now developing a range of resilience-building strategies to cope with impending earthquake disasters, especially in light of the recent 2015 Gorkha, Nepal, earthquake.

The Bhutanese government is considering adopting a national mandatory building code for the design requirements of new buildings. Here, we present a preliminary probabilistic seismic and earthquake-triggered landslide hazard assessment for Bhutan. Our aim is to support the Bhutanese government in their decision-making process about building seismic resilience by providing a sound scientific framework.

The preliminary hazard assessment employs 1) an earthquake source model that comprises depth-dependent tectonic zones with associated frequency magnitude distributions from a regional earthquake catalogue, 2) a composite model of weighted ground motion prediction equations, and 3) an earthquake-triggered landslide prediction model. Preliminary results show spatial variations of expected peak ground motions across the country. We will compare the implications of the study for building design with those from extrapolating the Indian Building Code, which is under consideration for adoption in Bhutan, to understand whether the Indian code is fit for purpose in Bhutan.

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Burlington House Fire Safety Information

If you hear the Alarm

Alarm Bells are situated throughout the building and will ring continuously for an evacuation. Do not stop to collect your personal belongings.

Leave the building via the nearest and safest exit or the exit that you are advised to by the Fire Marshal on that floor.

Fire Exits from the Geological Society Conference Rooms

Lower Library:
Exit via main reception onto Piccadilly, or via staff entrance onto the courtyard.
Lecture Theatre
Exit at front of theatre (by screen) onto Courtyard or via side door out to Piccadilly entrance or via the doors that link to the Lower Library and to the staff entrance.
Main Piccadilly Entrance
Straight out door and walk around to the Courtyard.

Close the doors when leaving a room. **DO NOT SWITCH OFF THE LIGHTS**.

Assemble in the Courtyard in front of the Royal Academy, outside the Royal Astronomical Society. Event organizers should report as soon as possible to the nearest Fire Marshal on whether all event participants have been safely evacuated.

Please do not re-enter the building except when you are advised that it is safe to do so by the Fire Brigade.

First Aid

All accidents should be reported to Reception and First Aid assistance will be provided if necessary.

Facilities

The ladies toilets are situated in the basement at the bottom of the staircase outside the Lecture Theatre.

The Gents toilets are situated on the ground floor in the corridor leading to the Arthur Holmes Room.

The cloakroom is located along the corridor to the Arthur Holmes Room.

Ground Floor Plan of the Geological Society, Burlington House, Piccadilly