A Geographical and Statistical Analysis of the Relationship between Earthquakes and Volcanic Activity

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Summary: Understanding precursors to natural hazards is critical if we are to optimise emergency planning and reduce the impact of natural disasters when they strike. This paper presents preliminary results of research which aims to make a contribution to this field by enhancing our understanding of the possible relationship between earthquakes and volcanoes. Arguments that contribute to the speculation of this relationship will be discussed and a case study will be presented for an active volcano in South Asia. Overall, initial investigations are encouraging and it is hoped that with further research any relationship between earthquakes and volcanoes might be determined.

KEYWORDS: Earthquakes, Volcanoes, MODVOLC, Statistical analysis

1. Introduction

Earthquakes and volcanoes are both recognised to be manifestations of tectonic activity (Linde and Sacks 1998). In recent years, the interactions of these two natural hazards has attracted considerable interest (Tilling *et al.* 1976, Linde and Sacks 1998, Hill *et al.* 2002, Gresta *et al.* 2005, Manga and Brodsky 2006, Walter and Amelung 2007, Watt *et al.* 2009). Although a relatively new line of research, reports of these relationships date as far back as 1840 when Darwin reported volcanic activity in Chile following an earthquake (Walter and Amelung 2007:539). Furthermore, the early scientific papers of MacGregor (1949) and Latter (1971) presented ground breaking evidence of this relationship using statistical analyses (Alam and Kimura 2004:179). This was further confirmed by Yokoyama (1975) and Nakamura (1975) who collated a range of reports where instances of volcanic activity were reported following an earthquake (Linde and Sacks 1998:888).

More recently, papers such as Linde and Sacks (1998) and Hill *et al.* (2002) used historical records to identify patterns of volcanic response following an earthquake. However, it is only in the last decade that we have seen the most notable developments in the study of earthquake-volcano interactions. Continued improvements in computer science and remote sensing technology have seen the potential of satellites to produce remotely sensed imagery for volcanology, with papers now exploiting the use of satellite observations to study the relationship between seismic activity and volcanic eruptions (Tralli et al. 2005). An example of such an application includes the MODVOLC algorithm (Wright *et al.* 2002). Generated from MODIS data, captured by NASA's Terra and Aqua platforms (Wright *et al.* 2004), MODVOLC forms the basis of an automatic monitoring and detection system that maps the

magnitude of thermal anomalies, 'hotspots', at a 1 km resolution (Flynn *et al.* 2002, Wright *et al.* 2002, Wright *et al.* 2004). In particular, Delle Donne *et al.* (2010), recognise the utility of such data, substituting observational data for MODVOLC datasets to conduct a statistical analysis of earthquake-volcano interactions at both a global and regional scale.

Although informative in many ways, the reliability of these studies are limited due to their failings on the basis of scale, reliability of data and the distinct lack of unbiased. As a result, it is apparent that further research needs to be conducted in order to investigate any relationship. Here, preliminary results of such a study are presented. Using results from pilot studies, this paper will outline the approach that will be taken to investigate the interactions of earthquakes and volcanoes to help define and develop a statistical model.

2. Methodology

By extending the methodology of Delle Donne *et al.* (2010), this research will take a three stage approach to investigate the possible relationship between earthquakes and volcanoes. Most importantly, the response of volcanic activity to earthquakes will be evaluated to establish whether this pattern of activity can be recognised as the typical nature of the volcano or as a result of large seismic events. With further support of this relationship being provided by using a longer time series (11 years compared to 7 years), conducting further statistical analyses using unprocessed MODIS data and developing a statistical model of the relationships found. These stages can be defined as:

- Collection of earthquake (NEIC, courtesy of U.S. Geological Survey) and volcano (MODVOLC and MODIS) datasets to analyse for statistical relationships.
- Development of a statistical model based on the relationships found during preliminary investigations.
- Application of the model to examples to verify statistical significance.

Firstly, pre-processed MODVOLC data (Wright *et al.* 2002) are used to search for responses of volcanic activity to earthquakes within a 1000 km buffer zone. Within these results, thermal responses of volcanoes are compared to earthquake activity to help evaluate whether there is a relationship between the two occurrences. Based on these findings, unprocessed MODIS data will later be obtained in order to conduct a more detailed analysis. In particular, the ability of this MODIS data to detect lower radiances of thermal anomalies allows more sensitive investigations to be conducted recognising the subtle signals of lower level eruptions (Justice *et al.* 2002). Using a suite of computer packages, including IDL, ENVI and R, these anomalous patterns will be extracted for image processing and analysis, the results of which will then be used to define and develop a statistical model aimed at testing the potential for seismic activity to be used as a precursory indicator of

volcanic activity. Further justification for the validity of this model will then be provided by applying it to a range of case studies which include the recent earthquakes in Japan (2011) and Chile (2010).

Although this research will employ a range of techniques, the initial stage of research considered in this paper uses an unbiased approach to investigate the activity of volcanoes within 1000 km of the 2004 Boxing Day earthquake. Firstly, a query was run that produced a list of all volcanoes within this buffer zone. From this, each volcano was studied individually with MODVOLC data (Wright *et al.* 2002) being downloaded for the period 2000 – 2011. At this point, the activity of the volcano, Band 32 (11.770 – 12.270 µm, TIR band which detects temperatures up to 420 K), was plotted on a graph and compared to all magnitude 7 or more earthquakes (Wright *et al.* 2002). The results of this stage of research will now be examined which will help to determine if there is a potential relationship between earthquakes and volcanoes and to decide whether further analysis is warranted.

3. Results

Despite this research being in its early stages, initial investigations have provided positive results. Figure 1 presents preliminary results based on the volcanic activity of Barren Island, South Asia. From the graph, it is evident that there is a pattern of possible response between this volcano and large seismic events. Most notably, the largest earthquake (M9.1) appears to be the catalyst for activity at this volcano, before which the volcano was relatively inactive. Following this, the volcano appears to experience periods of activity, particularly following a large seismic event.

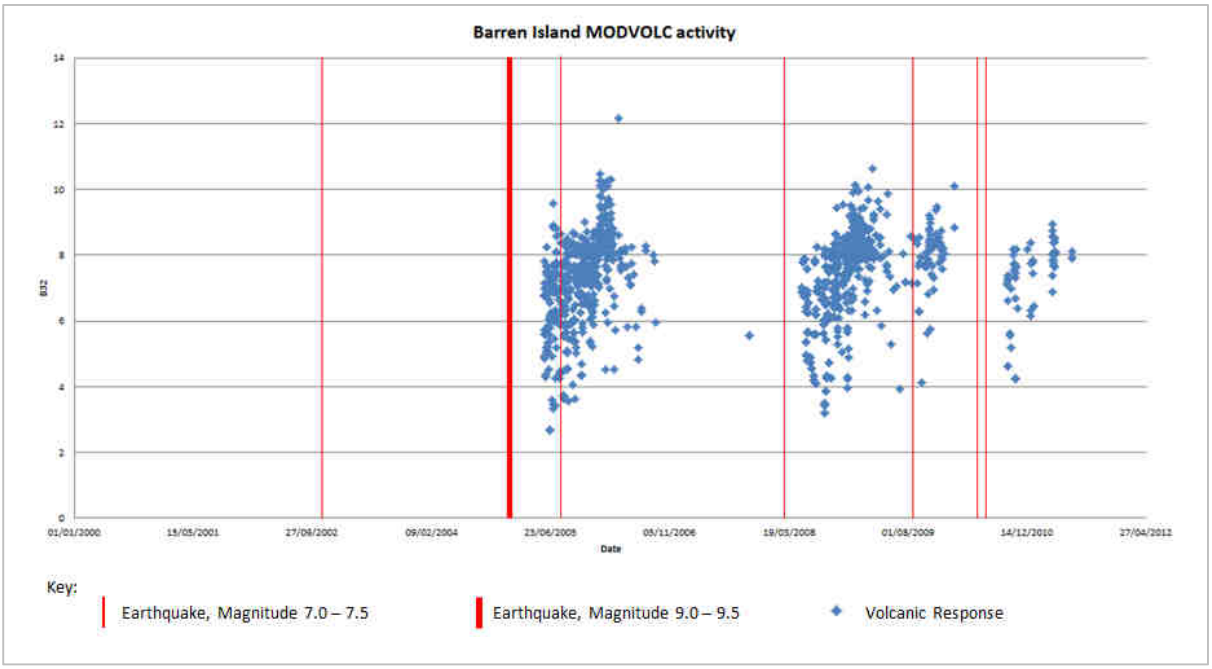

Figure 1: Band 32 (11.770 – 12.270 µm, TIR band which detects temperatures up to 420 K) volcanic hotspot data from Barren Island Volcano (as detected by the MODVOLC algorithm) compared to all magnitude 7 or more earthquakes within a 1000 km buffer zone, 2000 – 2011.

These preliminary findings are encouraging, suggesting that with further research the statistical significance of this possible relationship can be determined. Furthermore, the correlations of these findings with other studies suggests that this preliminary study is both successful and reliable (Magna and Brodsky 2006, Walter and Amelung 2007). With this in mind, further work will seek to analyse this pattern at a statistical level so that more distinct relationships between factors such as magnitude, size, location, volcanic state and eruption type can be determined.

Finally, it must be noted that the determination of a true relationship cannot be proven based on the limited findings we currently have. With the results of further studies still pending, conclusions are yet to be drawn on whether this possible relationship and the activity at Barren Island are of direct result of seismic activity or as the typical nature of the volcano.

5. Conclusion

Overall, the preliminary results presented in this paper prove promising. In particular, the pattern of response between seismic activity and volcanic eruptions at Barren Island suggests that there is a possible relationship between these two hazards. Furthermore, on review of the results presented, it is obvious that this research will provide valuable information on the interactions between earthquakes and volcanoes, ultimately determining whether there is a statistically significant relationship. Further research now aims to study this possible relationship at other volcanoes around the globe. By firstly identifying patterns of response using pre-processed MODVOLC data, further analysis aims to quantify this relationship using raw MODIS data to both determine if there is a statistically significant relationship and the factors that cause it.

6. Acknowledgements

Special thanks are extended to the USGS National Earthquake Information Centre (NEIC) and the University of Hawaii Institute of Geophysics and Planetology (HIGP) for the availability of MODVOLC and earthquake datasets used in this paper.

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8. Biography

Charley Hill-Butler is a Masters by Research student at Coventry University. After obtaining a fully funded studentship she is conducting her research on the use of remotely sensed data to study the possible relationship between earthquakes and volcanoes.

Dr Matthew Blackett is a senior lecturer in Geography at Coventry University. After obtaining his PhD from King's College London, he has pursued his main research interests which focus on using satellite remote sensing, largely for the monitoring of natural hazard events.

Dr Nigel Trodd co-directs the Environment, Hazards and Risk Applied Research Group at Coventry University. His research interests lie in environmental geoinformatics and the analysis of Earth observation data to extract land cover information. He is currently working on environmental studies in Botswana, The Gambia, Saudi Arabia and Tenerife.