Statistical methods for assembling and incorporating volcanic records in hazard estimation

A thesis presented in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

in

Statistics

at Massey University, Palmerston North, New Zealand.

Rebecca Green

2015

Abstract

The estimation of hazard arising from volcanic eruptions is a research topic of great interest to New Zealand, given the number and location of active and dormant volcanoes. Probabilistic temporal models are required to handle the stochastic nature of observed records. Such models are usually assembled using point process techniques or renewal theory and most are purely temporal in the sense that they only consider the distribution of event or inter-event times as predictors of further volcanic activity. I demonstrate using a high-resolution eruption record from Mt Taranaki (New Zealand) how geochemical data can be incorporated, using a proportional hazards type approach, to improve the performance of current renewal-type models.

Probabilistic forecasting relies on the accuracy and completeness of historical eruption records. This poses the question of how to establish a detailed record of past volcanic events. Multiple sites are needed to build a composite tephra record, but correctly merging them by recognizing events in common and site-specific gaps remains complex. I present an automated procedure for matching tephra sequences, using stochastic local optimization techniques. Implausible matches are eliminated through careful reasoning, while heuristically searching over the remaining alternatives. Possible matches are verified using known tephra compositions and stratigraphic constraints. The method is applied to match tephra records from five long sediment cores in Auckland, New Zealand. The correlated record compiled is statistically more likely than previously published arrangements from this area.

In addition to the matching of tephras found in the Auckland region, the algorithm is applied to stratigraphic records obtained from Mt Taranaki. With more detailed geochemical information available, matches are constrained further by considering principle component analysis of titanomagnetite compositional data.

Finally, after combining the amalgamated record of Mt Taranaki events with point thickness measurements, the eruptive volume of Mt Taranaki events is estimated. Utilizing isopach maps and individual point observations a model is formulated, in a Bayesian framework, for the thicknesses of tephra deposits as a function of the distance and angular direction of each location. The model estimates, in addition to eruptive volume, the wind and site-specific effects on the thickness deposits. The findings lead on to methods of incorporating eruptive volumes in hazard estimation.

Mt Taranaki. View from the North Egmont Visitor Center, April 2012.

Acknowledgements

First and foremost, I would like to give my sincere thanks to my primary supervisor Professor Mark Bebbington for his invaluable guidance and support during this entire research process. Without his time and care this PhD would not have been as successful. I started this PhD journey with limited knowledge of volcanology and Mark has been exceedingly patient as I explore this new field. I have enjoyed working under his supervision. His confidence in my ability and encouragement throughout the whole PhD process has made this experience very rewarding.

I am also very grateful to my co-supervisors Professor Shane Cronin and Associate Professor Geoff Jones. Shane has helped with interpreting many exciting results and has shown interest in my work even during the more 'statistical' supervision meetings. Shane has greatly assisted in developing my understanding of volcanology, for which I am very thankful. I also wish to express my thanks to Geoff, whose input has strengthened many aspects of this research. His attention to detail and his critical eye has enhanced the finer details of this PhD while his statistical expertise has resulted in many improvements to the more theoretical aspects of this research. As Einstein once said "it is the supreme art of the teacher to awaken joy in creative expression and knowledge." Mark, Shane and Geoff have succeeded in creating an intellectually stimulating environment, and it has been a very enriching experience working with such a spectacular supervisory team.

I want to acknowledge all those who have provided insightful comments on my research or otherwise helped me throughout my PhD. I recognize that this research would not have been possible without the financial assistance of a Massey University Doctoral Scholarship. I also give thanks to the postgraduate statistics students who have accompanied me throughout this journey; their friendships have been invaluable. My special thanks goes to Emily Kawabata. We have had many fruitful discussions which I have benefitted from. It has been fun discovering statistical volcanology with Emily, and I have enjoyed being able to exchange knowledge while curiously awaiting results together. I would like to give special mention to Dr Jonathan Godfrey whose support with many aspects of university has been a great help. I have gained a lot from his enthusiasm and willingness to teach. His approachability and encouragement has seen him act as another informal supervisor and mentor.

I would also like to give a very special thanks to my partner Leigh whose hope, optimism and humor have been a virtue throughout this roller coaster of a PhD. Lastly, I give the greatest thanks to my family whose love and support has known no bounds. To my sister Kim whose encouragement and company has been an immense help; and to my parents whose lifelong support and advice has helped me to achieve so many of my goals. xx

Publications arising from this thesis

- **Green, R.**, Bebbington, M., Cronin, S., and Jones, G. (2013). Geochemical precursors for eruption repose length. *Geophysical Journal International*, 193:855–873.
- **Green, R.**, Bebbington, M., Cronin, S., and Jones, G. (2014). Automated statistical matching of multiple tephra records exemplified using five long maar sequences younger than 75 ka, Auckland, New Zealand. *Quaternary Research*, 82(2):405–419.

Contents

List of Figures

List of Tables