Scale-model seismology: Forecasting failure in real time in the laboratory

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Project summary:

You will carry out laboratory experiments to quantify the quality of forecasts for catastrophic failure in rock samples in real time, using automated and state-of-the-art techniques of real-time data assimilation. The results are applicable to a range of natural and induced risks involving localized catastrophic failure of Earth materials.

Project background:

Many professional organizations have condemned the conviction of members of the Italian Grand Risks Committee for manslaughter (see for example Nature's editorial at http://www.nature.com/news/shock-and-law-1.11643) in the aftermath of the 2009 L'Aquila earthquake pictured above. One of the issues highlighted by the case is the unrealistic expectations by many public bodies and private individuals of certainty in quantifying and communicating risk in real time. In the absence of clear, reliable and diagnostic precursors, scientists have to weigh up many uncertainties, and also the negative consequences of issuing too many false alarms (Jordan et al., 2011). Much needs to be done at the interface between science and social science to ensure statements of probability and uncertainty are communicated and understood correctly, and there are likely to be no perfect solutions

This project will tackle a more fundamental scientific issue of relevance to this debate. You will examine the problem of quantifying the probabilities and uncertainties involved in forecasting catastrophic failure in real time by deforming laboratory rock samples in a 'scale-model' experiment. Experiments will be done under controlled conditions of slow loading, and mechanical and geophysical monitoring data will be streamed 'live' to a recently developed web-based portal so that forecasts can be done in real time, avoiding the potential retrospective selection bias that has plagued the literature on the predictability of catastrophic failure events. The results will then be scaled to those of realistic conditions for a range of natural and man-made hazards from catastrophic failure events, including earthquakes, volcanic eruptions and man-made seismicity due to fluid injection or withdrawal in the subsurface.

Key research questions:

(1) What is the best of several available models for the evolution of precursors to catastrophic failure in a laboratory setting?
(2) Given the best model, what are the uncertainties involved in forecasting future behavior, and how do they propagate into key metrics such as the failure time?
(3) Can prior information reduce this uncertainty in a Bayesian framework?
(4) What are the limits to forecast quality in this ideal scenario, and how might this scale to the uncontrolled and larger-scale processes occurring in nature?

Methodology:

Initially-intact rock samples will be deformed under pr*essure until they rupture (as described in Ojala et al., 2004*), and measurements of stress, strain, and acoustic emissions will be used to quantify the probability of failure at a given time using a number of metrics, including the best estimate of the failure time and its uncertainty. The data recorded will be transmitted ‘live’ to a web-based portal (see http://research.nesc.ac.uk/node/591) *designed to upload, analyze,* publish *and update* forecast probabilities in real time. The results will be used to quantify metrics of forecasting quality such as reliability, skill, accuracy and precision (nicely explained by Murphy, 1993) as a ‘best-case’ scenario for forecasting rock failure in real time. Examples of the methods of analysis applied to synthetic data, including how to handle errors of measurement, samplin*g and fluctuations in the data, are provided in Bell et al. (2013).* A suite of experiments will be undertaken to examine the effects of strain rate, stress and pore pressure on the probability of macroscopic failure, and used to inform the determination of risk at a larger scale, including induced seismicity and volcanic eruptions as well as natural earthquakes.

Training:

A comprehensive training programme will be provided, comprising both specialist training and generic transferable and professional skills. You will be trained in experimental laboratory rock physics and in automated data assimilation, including statistical seismology and the use of Python for data analysis and visualization. You will also acquire skills that can be applied to a range of natural and induced hazards, as well as to other applications of real-time data assimilation.

Requirements:

The project will suit a highly numerate geologist or geophysicist, or a physical scientist or mathematician with an interest in geoscience. The student must be highly motivated to undertake experimental work with appropriate training and guidance.

Further reading:

Bell, A. F., Naylor, M. & I. G. Main (2013). The limits of predictability of volcanic eruptions from accelerating rates of earthquakes, Geophys. J. Int., doi:10.1093/gji/ggt191

Jordan, T., Y. Chen, P. Gasparini, R. Madariaga, I. Main, W. Marzocchi, G. Papadopoulos, G. Sobolev, K. Yamaoka & J. Zschau (2011). Operational earthquake forecasting: State of Knowledge and Guidelines for Utilization. Annals of Geophysics, 54(4), 361-391. doi:10.4401/ag-5350

Murphy, Allan H., 1993: What Is a Good Forecast? An essay on the nature of goodness in weather forecasting. Wea. Forecasting, 8, 281–293. doi: http://dx.doi.org/10.1175/1520-0434(1993)008<0281:WIAGFA>2.0.CO;2

Ojala I O., I. G. Main & B. T. Ngwenya (2004). Strain rate and temperature dependence of Omori law scaling constants of AE data: implications for earthquake foreshock-aftershock sequences. Geophys. Res. Lett., 31, L24617, doi: 10.1029/2004GL020781.