Statistical Models for Earthquakes Incorporating Ancillary Data

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In memory of Professor Ma Li

Abstract

This thesis consists of two parts. The first part proposes a new model – the Markov-modulated Hawkes process with stepwise decay (MMHPSD) to investigate the seismicity rate. The MMHPSD is a self-exciting process which switches among different states, in each of which the process has distinguishable background seismicity and decay rates. Parameter estimation is developed via the expectation maximization algorithm. The model is applied to data from the Landers earthquake sequence, demonstrating that it is useful for modelling changes in the temporal patterns of seismicity. The states in the model can capture the behavior of main shocks, large aftershocks, secondary aftershocks and a period of quiescence with different background rates and decay rates. The state transitions can then explain the seismicity rate changes and help indicate if there is any seismicity shadow or relative quiescence.

The second part of this thesis develops statistical methods to examine earthquake sequences possessing ancillary data, in this case groundwater level data or GPS measurements of deformation. For the former, signals from groundwater level data at Tangshan Well, China, are extracted for the period from 2002 to 2005 using a moving window method. A number of different statistical techniques are used to detect and quantify coseismic responses to P, S, Love and Rayleigh wave arrivals. The P phase arrivals appear to trigger identifiable oscillations in groundwater level, whereas the Rayleigh waves amplify the water level movement. Identifiable coseismic responses are found for approximately 40 percent of magnitude 6+ earthquakes worldwide. A threshold in the relationship between earthquake magnitude and well–epicenter distance is also found, satisfied by 97% of the identified coseismic responses, above which coseismic changes in groundwater level at Tangshan Well are most likely.

A non-linear filter measuring short-term deformation rate changes is introduced to extract signals from GPS data. For two case studies of a) deep earthquakes in central North Island, New Zealand, and b) shallow earthquakes in Southern California, a hidden Markov model (HMM) is fitted to the output from the filter. Mutual information analysis indicates that the state having the largest variation of deformation rate contains precursory information that indicates an elevated probability for earthquake occurrence.

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Glossary

AMR	Accelerated moment release model
Craton	An old and stable part of the continental lithosphere
ETAS	Epidemic type aftershock sequence model
Declustered data	Earthquake sequences with aftershocks removed
Gutenberg-Richter law	The total number of earthquakes in a population that are larger than or equal to some magnitude M varies as 10^{bM}
HMM	Hidden Markov models
Hypocenter	The point within the earth where an earthquake rupture starts
LSRM	Linked stress release model
MMGLM	Markov-modulated generalized linear model
MMHPSD	Markov-modulated Hawkes process with stepwise decay
MMPP	Markov-modulated Poisson process
NHMM	Nonhomogeneous hidden Markov model
Relative quiescence	A significant decrease of earthquakes compared with the occurrence rate expected from a point-process model for ordinary seismic activity
Seismicity/stress shadows	Seismicity rate decreases
SRM	Stress release model