Title: Novel statistics for the evolution of seismicity: An Apennines Case Study

Supervisory Team: Naylor¹, Illian³, Lindgren² and Main¹
¹ School of GeoSciences, University of Edinburgh
² School of Mathematics, University of Edinburgh
³ Centre for Research into Ecological & Environmental Modelling, St Andrews

Summary
High resolution earthquake catalogues are enabling us to learn more about earthquake process and to discriminate between models that probabilistic forecast triggered earthquakes. Here you will develop and apply models of seismicity to a new dataset collected after the 2016 Amatrice earthquake in the Appenines, Italy (Figure 1).

Innovations in statistical methods need to keep pace. Here you will use an exciting state-of-the-art spatio-temporal point process code which has potential to transform the analysis of seismicity. Your work will have impact via improvements in operational earthquake forecasting - the probabilistic forecasting of earthquakes in the near future, based on recent seismicity.

You will interact with a wider funded project processing that data - a collaboration between the British Geological Survey, the University of Edinburgh, the National Institute of Geophysics in Italy, the US Geological Survey, Stanford University and Columbia University.

Background
Seismic sequences can be considered a self-exciting point process, in the sense that earthquakes trigger other seismic events within a decaying aftershock sequence. We are close to the point where earthquake sequences can be forecast in a routine manner using relatively coarse mean-field statistical observations that use arbitrary seismic zoning techniques or smoothed averages. As a consequence, there remain a range of competing physical hypotheses regarding information that may control the spatial distribution of events, for example the location of known faults and their deformation mechanism. 'INLABru' is a new statistical tool that allows this additional information to be incorporated, along with other prior knowledge, holding out the potential of more accurate and more precise forecasts of the locations of future earthquakes.

Research Aims:
- To develop new spatio-temporal methods to characterise seismicity, including
  - Methods to quantify the style of seismicity
  - Novel methods to model the seismicity as a spatial-temporal point process using the 'INLABru' method (https://sites.google.com/inlabru.org/inlabru)
- To apply these methods to case studies, including the Amatrice earthquake sequence
- To quantify the impact of catalogue quality by progressively stripping out the high resolution part of the Amatrice dataset and re-evaluating

Figure 1: Seismicity of the central Appenines highlighting the significant events within the Amatrice earthquake sequence and the Historic l’Aquila and Colfiorito sequences.
To identify lessons learned to inform Operational Earthquake Forecasting

**Method:** You will analyse a new, world leading earthquake catalogue recording the evolution of seismicity in the Apennines, Italy. The catalogue contains information on many more small earthquakes, along with their focal mechanisms (fault orientation and sense of slip) than a conventional one because it is produced using new cross-correlation techniques. You will develop and apply statistical methods to analyse this seismicity that are being developed by the group in Edinburgh to characterise and map the style of seismicity with the aim of better forecasting seismicity, and to incorporate other prior information such as the local map of faults (e.g. Figure 2).

This project will be tailored to suit the applicant – for example, a student with stronger statistical and/or computational skills might focus more on the development of clustering models in INLAbru. This is a flexible statistical modelling package based on the computationally efficient model fitting approach INLA (integrated nested Laplace approximation) along with a flexible representation of spatio-temporal structures through stochastic partial differential equations (SPDEs). INLAbru was originally designed to handle data structures common in ecology, but has become a package that makes INLA and SPDE methodologies accessible to a broad user community; it maps well onto the problem of aftershock forecasting.

![Random on faults – 93 events](image)

**Figure 2. Demonstration of how INLAbru can be used to trivially locate synthetic earthquake events onto an existing fault network.**

**Training:** In addition to generic transferable and research skills taught via the E3 program, you will receive specific training in statistical methods – including INLAbru. We encourage students to participate in at least one externally hosted summer school to gain a broader perspective. In addition, you will participate in our groups whiteboard discussion sessions.

**Applicant Requirements:** You will have a first degree in statistics, geophysics, physics, or applied mathematics, and be interested in the spatial and temporal evolution of seismicity. You will also be competent in computer programming, and be willing to learn more. Evidence of good communication skills in oral and written presentations would be a significant advantage.