Statistical Modelling of Induced Earthquakes

Thesis presentation

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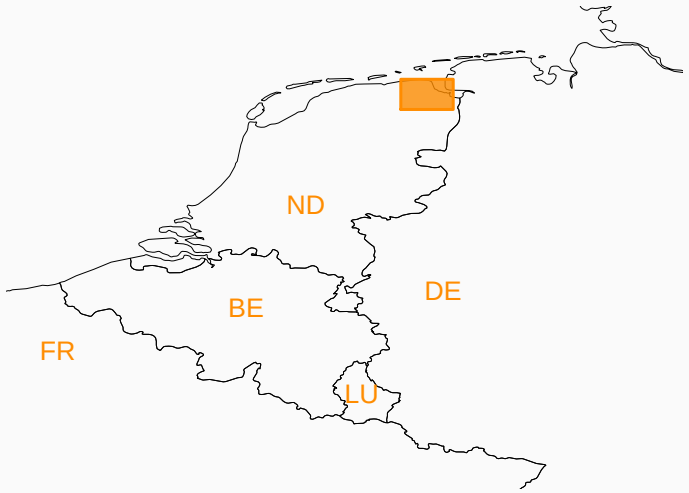
Motivation and Aims

Motivations



- Earthquakes caused by gas extraction in Groningen.
- Induced earthquakes: fewer, smaller, changing.
- Developing landscape: gas extraction, sensor network, opinion.

Aims

Scientific and Industrial

- 1| Better understand and describe induced earthquakes to inform policy.

Statistical

- 2| To make better use of the data that *are* available to us .

- 3| To improve and extend existing methodology used in seismology.

Contributions & Impact

Ch 4: Earthquake locations

Aim 1: Scientific and Industrial Impact

Contributions: Exploratory analysis of physiscal features included and missed from physically motivated model

$$\lambda(x, t; \boldsymbol{\beta}, \boldsymbol{s}) = \beta_0 \dot{s}(x, y)[1 + \beta_1 s(x, t)] \exp\{\beta_1 s(x, t)\}$$

- (+) Exp term dominant but linear simplifies interpretation
- (+) Evidence of spatial variability in effect of ICS
- (-) Insufficient evidence of: lag, shift, NFR or smoothing effects.

Ch 4: Earthquake locations

Outcomes:

Provided empirical evidence toward scientific debate: whose first principles are right?

Motivated funding for further work into more advanced spatial modelling.

Ch 5: Threshold selection

Aim 2: making best use of available data

Sensor network changing over time as well as gas extraction: can / should we use additional small EQs?

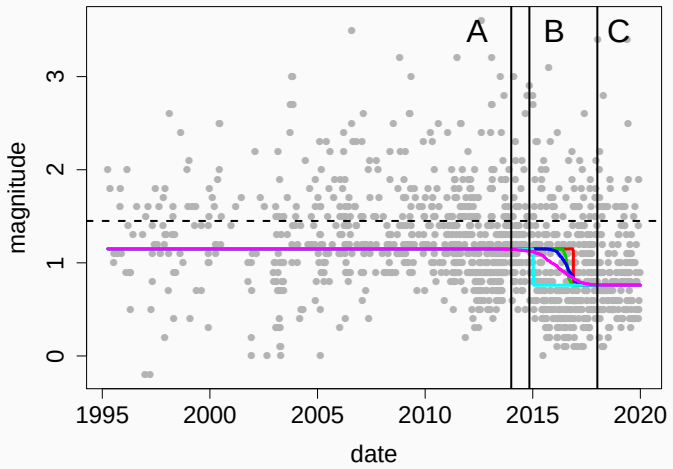
Contributions:

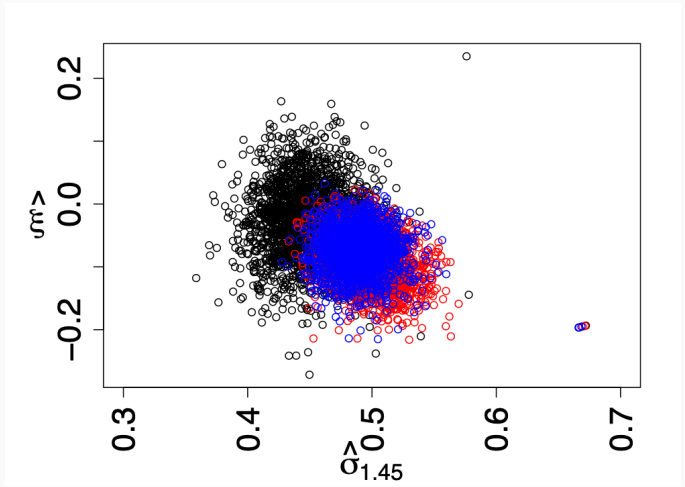
- Reframed G-R law as special case of GPD, extending model class;
- Novel method for selecting time-varying threshold for extreme value analysis;
- Addressing issues with rounded data and partial censoring of small values;
- Demonstrated inclusion of small events is beneficial to estimating distribution of large events.

Ch 5: Threshold selection

Outcomes:

- First method for selecting time varying modelling threshold;
- More than doubled data usage;
- Empirical evidence that $\xi_m < 0$;
- Justifies investment in EQ detection;
- Further work on stability and impact of choice of measurement scale.





Ch 6: Improving and extending ETAS

Aim 3: Improve and extend seismological models

ETAS assumes IID magnitudes and is difficult to fit directly. How can we improve using conditional inference methods?

Contributions:

- Empirical laws: really just a GPD or a GLM. Demonstrated that reparameterisation generalises and improves inference.
- Relaxing assumptions: Developed models, inference methods and testing for dual and correlated magnitudes.
- Investigated for the first time branching vector recovery.

Ch 6: Improving and extending ETAS

Outcomes:

- Motivated use of GPD and conditional inference in physical models;
- Nudged seismologists toward EVT methods;
- beta-version of R package to promote practitioner use;
- Lays foundations for further work exploring dual and dependent magnitudes .

Limitations and Further work

Limitations

Ch 4: in-sample testing, limited power, alternative models for same physical features.

Ch 5: Temporal only, computationally intensive, heuristic, application-methodology middle-ground.

Ch 6: (extensions) Temporal only, stationary background, Gaussian copula, accessibility to seismologists.

Further Work

I'm out of time but there is so much still to do!

- Draw together results from different chapters: e.g. include small events in physical models, spatial modelling threshold or ETAS extensions.

- Comparison to other threshold selection methods in standard EVT setting.

- Dual / corr model with non-constant seeding using, e.g. parametric or (thin-plate) spline model.

Thank you for your time,
any questions?