Induced Earthquakes: Challenges & Opportunities

Z Varty [1] J Tawn [1] S Bierman [2]

[1]Lancaster University, UK. [2]Shell Global Solutions, NL.

1| The Groningen Gas Field

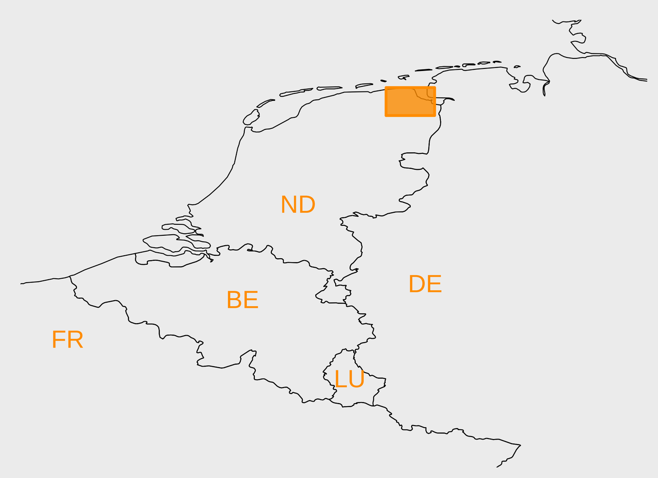

Figure: Location of Groningen gas field.

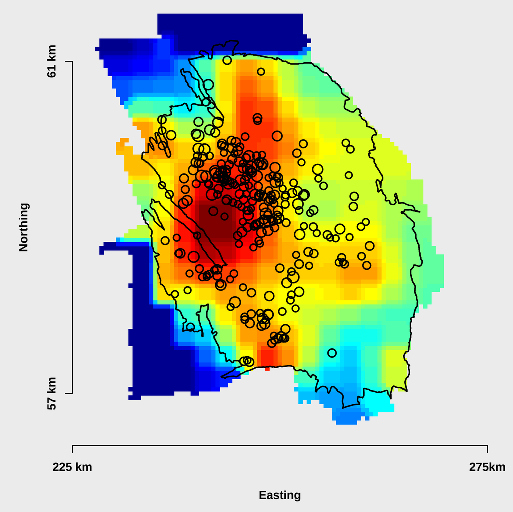

Figure: Reservoir compaction and earthquakes exceeding magnitude 1.5.

- The largest gas field in Europe, located in the North-East of the Netherlands.
- Gas extraction ∼3km sub-surface is linked to earthquake activity.
- The field supplies the Netherlands, Belgium, Germany and France.
- Appliances are adapted to gas from the field, so switching is not easy.
- Earthquakes are shallow and have an impact at low magnitudes.

Aim: **Use a point process approach to inform future gas extraction.**

2| Challenges

Challenges:

- Non-obvious how mainshock intensity $\mu(\boldsymbol{x}, t)$ should utilise extraction covariates $X(\boldsymbol{x}, t)$.
- Confounded effects of changing extraction and potential aftershock activity.
- **Parameters in the intensity model are highly correlated.**
- **The usable catalogue is small and the magnitude of completion M_c is both low and variable.**

$$\underbrace{\lambda(\boldsymbol{x}, t|X, \mathcal{H}_t, \theta)}_{\text{All earthquakes}} = \overbrace{\mu(\boldsymbol{x}, t|X, \theta)}^{\text{Poisson mainshocks}} + \underbrace{\sum_{i:t_i<t} \kappa(m_i|\theta) g(t - t_i|\theta) h(\boldsymbol{x} - \boldsymbol{x}_i|\theta)\,.}_{\text{ETAS aftershocks}}$$

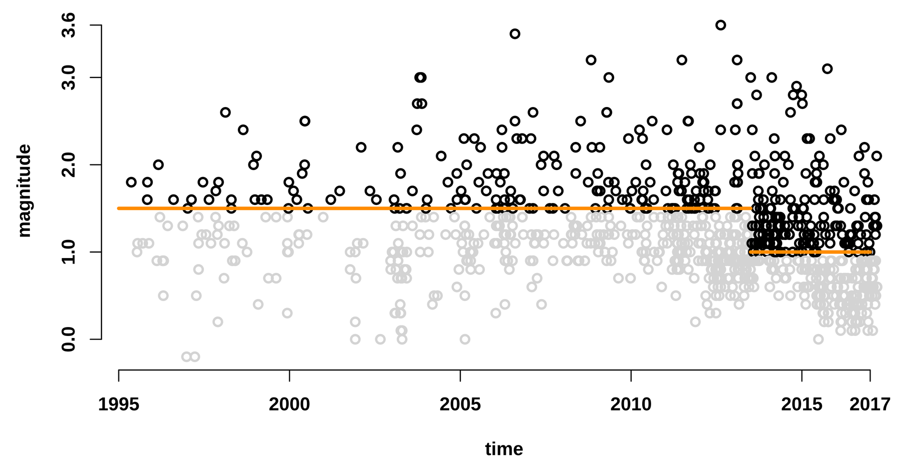

Figure: Earthquake catalogue and M_c

3| Proposal

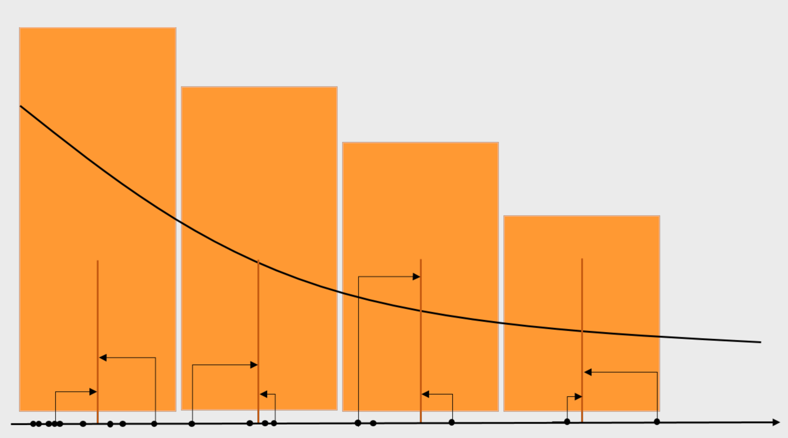

Figure: Multinomial-GPD magnitude model.

- Work in a Bayesian framework to simplify the propagation of uncertainty into seismicity forecasts.
- Condition on the latent branching structure leading only to within-block parameter dependence.*(G. Ross, 2016)*
- The Omori and Gutenberg-Richter laws are both restricted cases of the **Generalised Pareto Distribution** (GPD).
- Use the orthogonal GPD in place of empirical laws during modelling and centre the productivity effect in a Poisson generalised linear model.

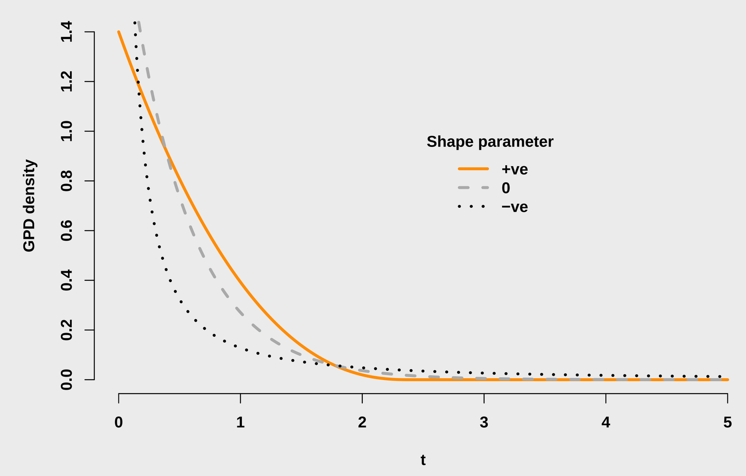

Figure: Density functions of $T \sim$ GPD$(\nu = 0.5, \xi)$

4| Results

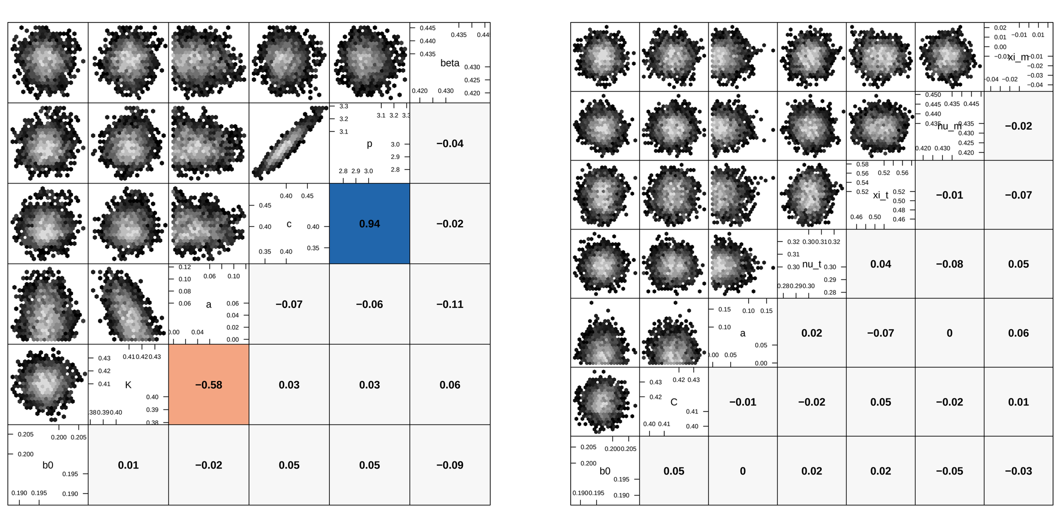

Figure: Posterior samples for empirical (left) and centred GPD (right) models. Proposed model reduces parameter dependence, simplifying inference and parameter interpretation.

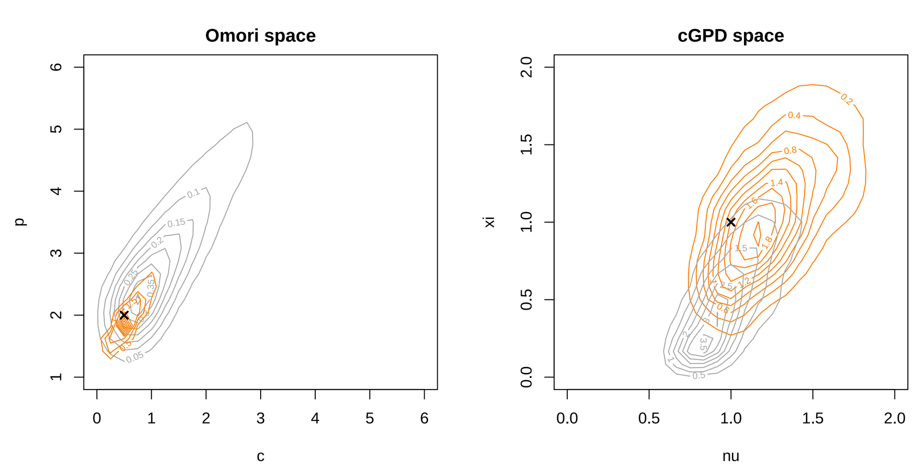

Figure: Posterior distributions of aftershock lag-times. Parameter recovery is improved by using the centred GPD model (orange).

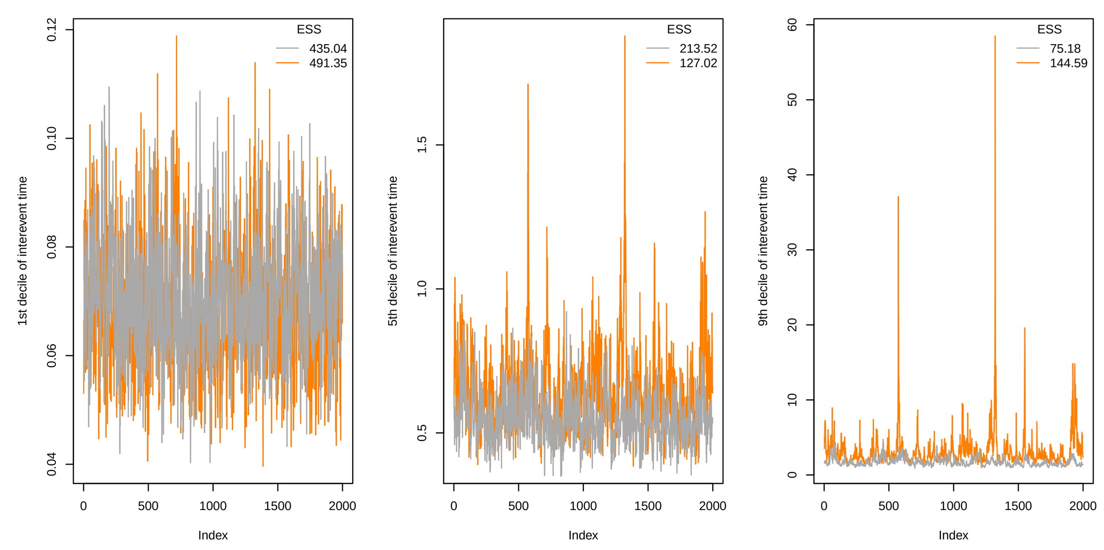

Figure: Sampled posterior quantiles of aftershock delay distribution. The centred GPD model (orange) has greater effective samples size in high quantiles.

5| Take-aways

Summary

1. Modelling induced earthquakes presents many unique challenges. These provide exciting opportunities for future research.
2. Commonly used empirical earthquake laws are special cases of (or are closely related to) the generalised Pareto distribution.
3. Using the GPD model in a Bayesian framework means that parameter estimation is more efficient and accurate.
4. Parameter uncertainty is properly propagated to the predictive distribution.

Further work

- Performance comparison in space and time, as well as on observed catalogues.
- Combining covariate and aftershock effects on the condition intensity function.
- Investigation of magnitude dependence on covariates and triggered status.

Contact

Twitter: @zakvarty
www.lancs.ac.uk/varty