Forward Induced Seismic Hazard Assessment - FISHA

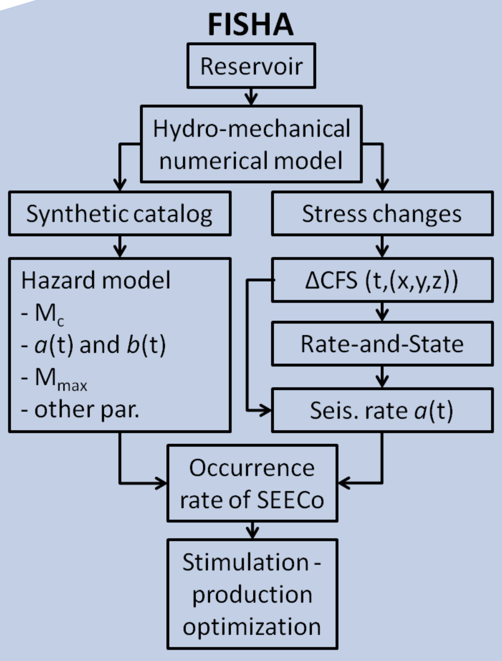
Application to the Synthetic Seismicity Catalogue by Discrete Element Hydromechanical Model of Multiple Fracturing

A. Hakimhashemi, J. S. Yoon, O. Heidbach, A. Zang, and G. Grünthal

Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Potsdam, Germany

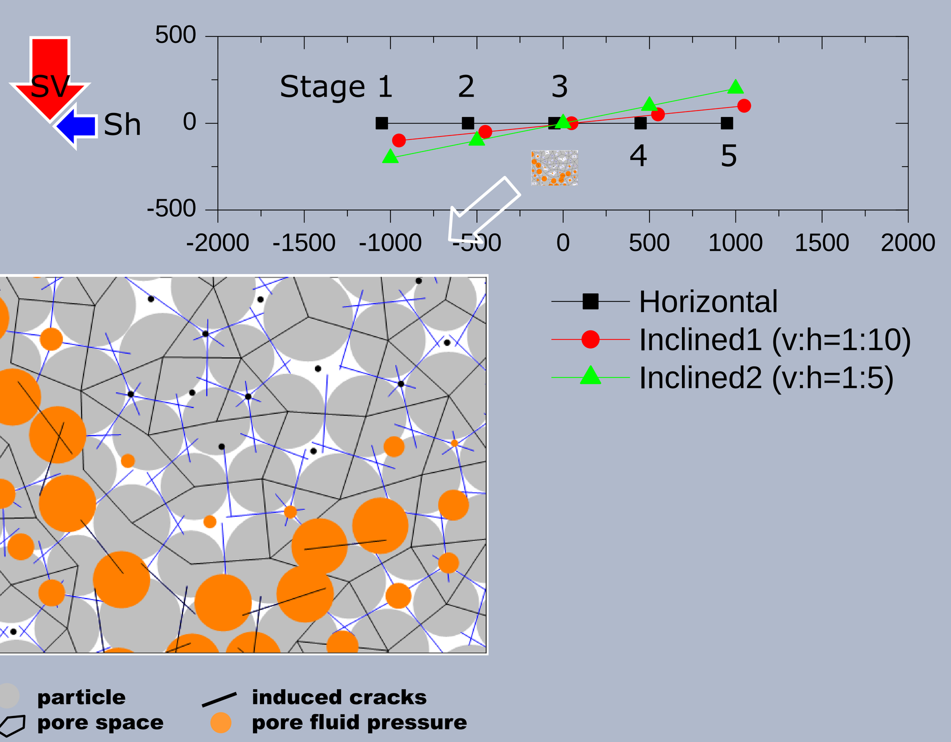
1. FISHA

The Forward Induced Seismic Hazard Assessment – FISHA (Hakimhashemi et al. 2014a,b) is a general workflow which links the output of hydromechanical-numerical models of geothermal reservoirs, either in terms of seismicity catalogue (Hakimhashemi et al. 2014a) or in the form of spatiotemporal changes in the stress field (Hakimhashemi et al. 2014b), to a time-dependent probabilistic seismic hazard assessment in terms of the time dependent occurrence rate of the Seismic Events of Economic Concern – SEECo (Grünthal, 2014).



2. Discrete element fluid injection model

- Discrete element fracture network model using the Itasca PFC-2D code with additionally implemented hydromechanical coupled routine (Yoon et al. poster presented in the workshop).
- Output of the model: Synthetic seismicity catalogues including occurrence times, x-y coordinates of hypocenters, and moment magnitudes of events.



- Model characteristics:
  2D (2 X 8 km²)
  Vertical section
  ΔSv / Δd = 10 Mpa/km
  ΔSh / Δd = 15 Mpa/km
- Three cases of multiple fluid injection in 4.5 to 5.5 km depth in 5 stages
- More details in poster from Yoon et al.

3. Hazard model

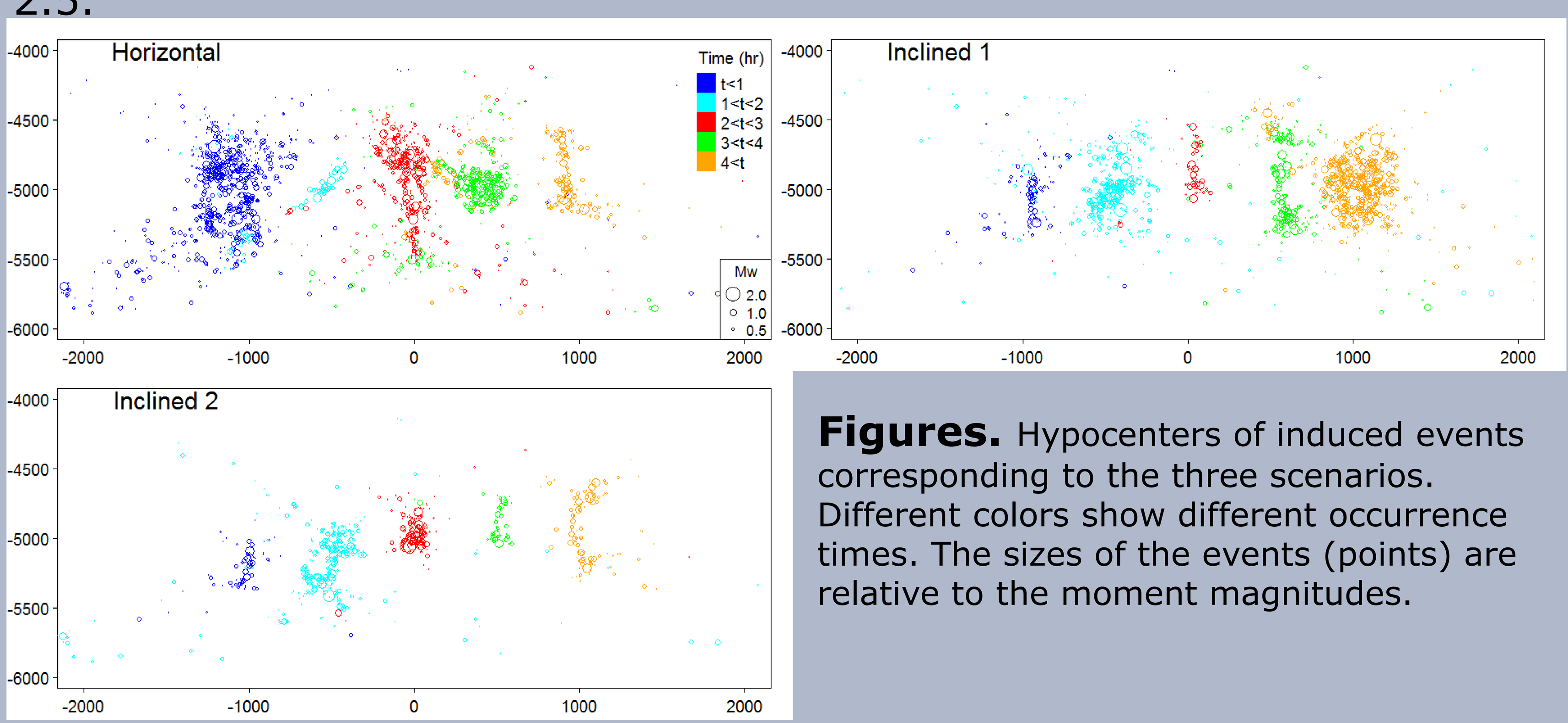
Here, the hazard is defined as the max. of time-dependent hourly occurrence rate of SEECo (Hakimhashemi et al. 2014a). First we estimate the magnitude completeness M_c for the given catalogue. Then the time-dependent parameters $a(t)$ and $b(t)$ of the frequency-magnitude relation are calculated using a maximum likelihood estimator on successive overlapping time-windows. Finally, the hazard is calculated as:

$$\vartheta(t) = a(t)\exp[-\beta(t)\,(M_{SEECo} - M_c)]\,,\ \ \beta(t) = b(t)\ln(10)$$

where $\vartheta(t)$ is the hourly occurrence rate of events with mag. ≥ M_{SEECo} at time t elapsed after the beginning of the injection and M_{SEECo} is the magnitude of SEECo.

4. Application

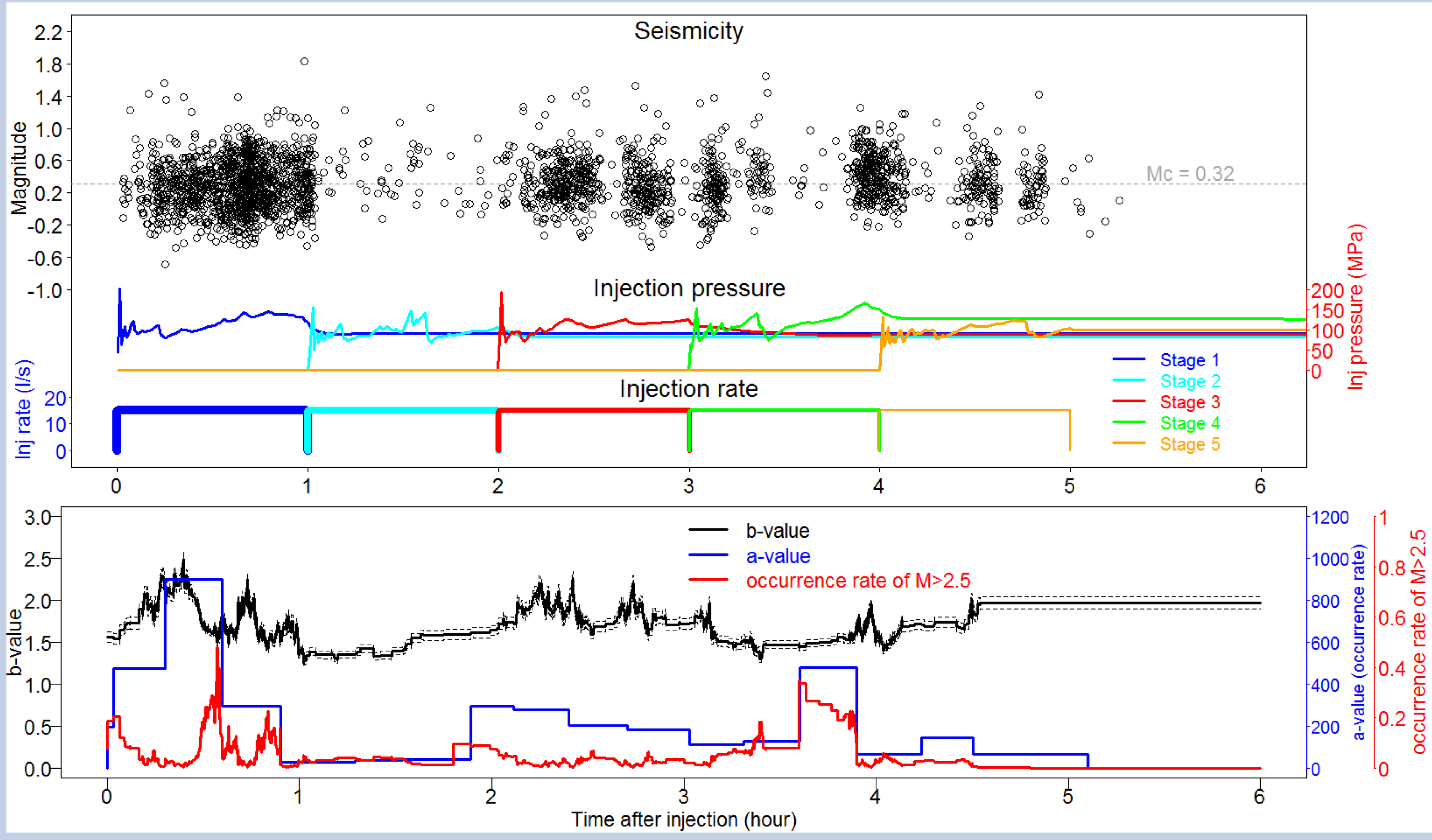
In this study, FISHA is applied to the synthetic seismicity catalogues of different scenarios of multiple injection to study the effect of the inclination of the injection points on the hazard. Scenarios are, 1) Horizontal injection, 2) Inclined 1 with v/h=1/10, and 3) Inclined 2 with v/h=1/5. The injection flow rates are 15 l/s and the duration is five hour, i.e. one hour for each stage starting sequentially from stage 1 to 5. M_{SEECo} is considered 2.5.



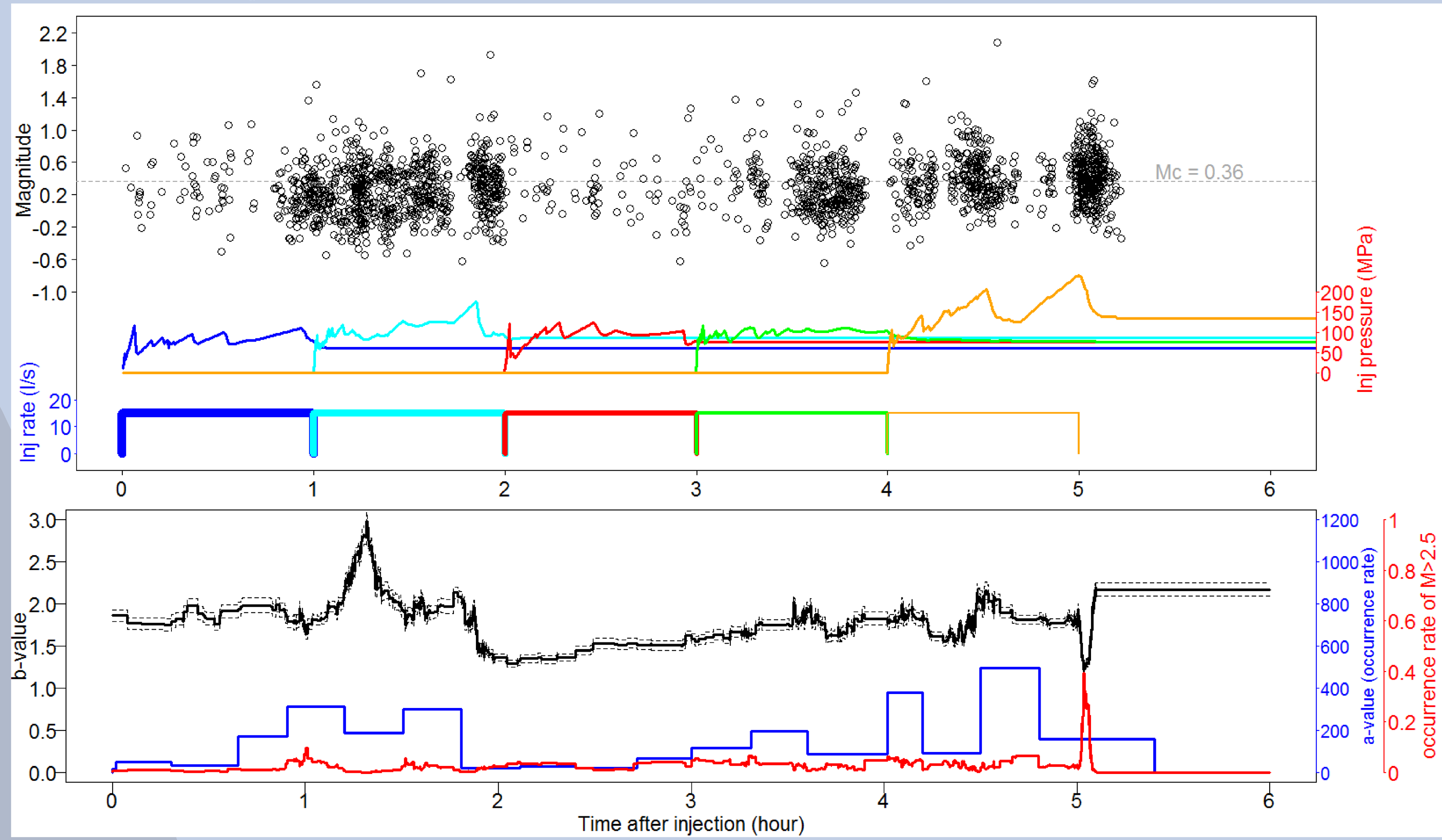
Figures. Hypocenters of induced events corresponding to the three scenarios. Different colors show different occurrence times. The sizes of the events (points) are relative to the moment magnitudes.

5. Results of different scenarios

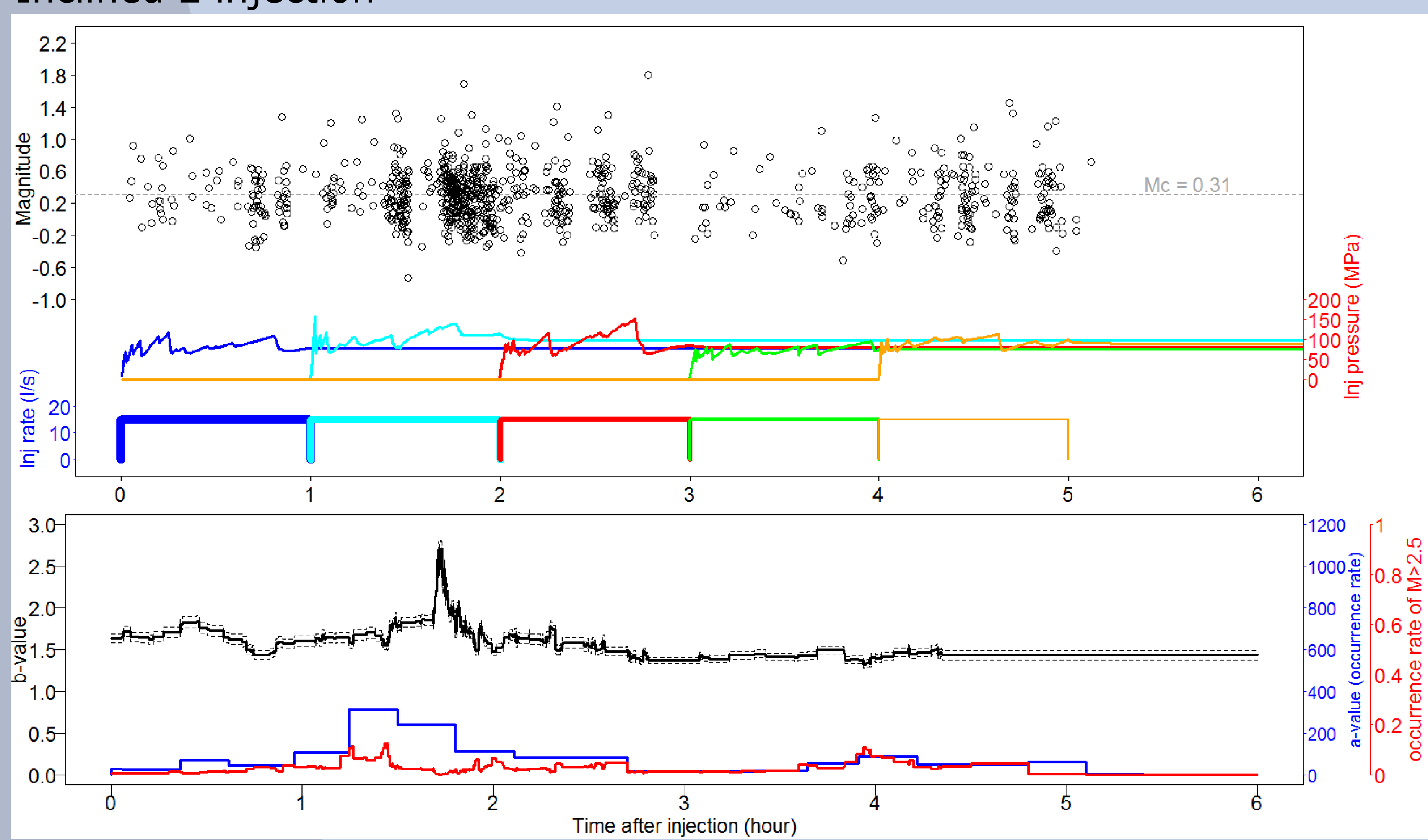
Horizontal injection



Inclined 1 injection



Inclined 2 injection



The estimated parameters as well as the estimated hazard corresponding to each scenario are given in the following table.

Scenario	$M_c \pm \sigma$	$a \pm \sigma$	min(b)±σ	hazard
Horizontal	0.32±0.01	1176+[-38,31]	1.246±0.037	0.48
Inclined 1	0.36±0.02	815+[-50,37]	1.218±0.038	0.39
Inclined 2	0.31±0.03	419+[-35,27]	1.320±0.045	0.12

6. Interpretation

- The time-dependent hourly occurrence rate of SEECo inversely responds to the *b*-value.
- The *a*- and *b*-values are reversely correlated.
- Inclination can result in reduced hazard in multiple fluid injection case, which we considered in this study.

References

Grünthal G. (2014). Induced seismicity related to geothermal projects versus natural tectonic earthquakes and other types of induced seismic events in Central Europe. *Geothermics*, 52, p. 22-35.

Hakimhashemi A., Yoon J.-S., Heidbach O., Zang A., Grünthal G. (2014a): Forward induced seismic hazard assessment: application to a synthetic seismicity catalogue from hydraulic stimulation modelling. *Journal of Seismology*, 18, 3, p. 671-680.

Hakimhashemi A., Schoenball M., Heidbach O., Zang A., Grünthal G. (2014b): Forward modelling of seismicity rate changes in georeservoirs with a hybrid geomechanical–statistical prototype model. - *Geothermics*, 52, p. 185-194.