Injection strategies for EGS: balancing seismic risk and stimulation efficiency

Vanille A. Ritz, Antonio P. Rinaldi, Stefan Wiemer

Swiss Seismological Service at ETH Zurich, Zürich, Switzerland

5 - 8 March 2019
DAVOS
SCHATZALP
3rd Induced Seismicity Workshop

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

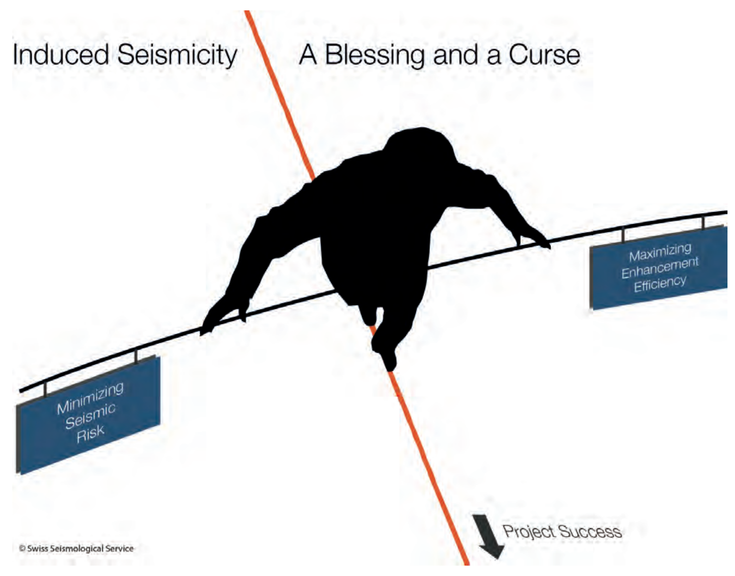
ETH zürich

induced seismicity

DESTRESS

Introduction

We propose a full 3D numerical modelling approach of hydraulic stimulation to test different injection scenarios, using TOUGH2-Seed. The fully synthetical hybrid model is first checked against observed seismological results in a classical setting, then used to test the seismic response to various injection tests and features. Multiple physical processes are added to the base model to assess their influence on the modelling, as these processes (static stress transfer, seismicity dependent permeability enhancement) can lead to better information for future forecasting work. The presence of a major fault zone is also investigated as it could increase the risk and affect the efficiency of the stimulation. The impact of different injection strategies is then evaluated for both efficiency of the stimulation and seismic risk, to determine more or less favourable trade-off options.



TOUGH2-Seed

A coupled hydro-geomechanical-stochastic simulator

- **TOUGH2**: full 3D multiphase fluid flow simulator
- **Seed**: stochastic geomechanical model
- Permeability changes dependent on pressure and seismicity
- Coulomb static stress transfer

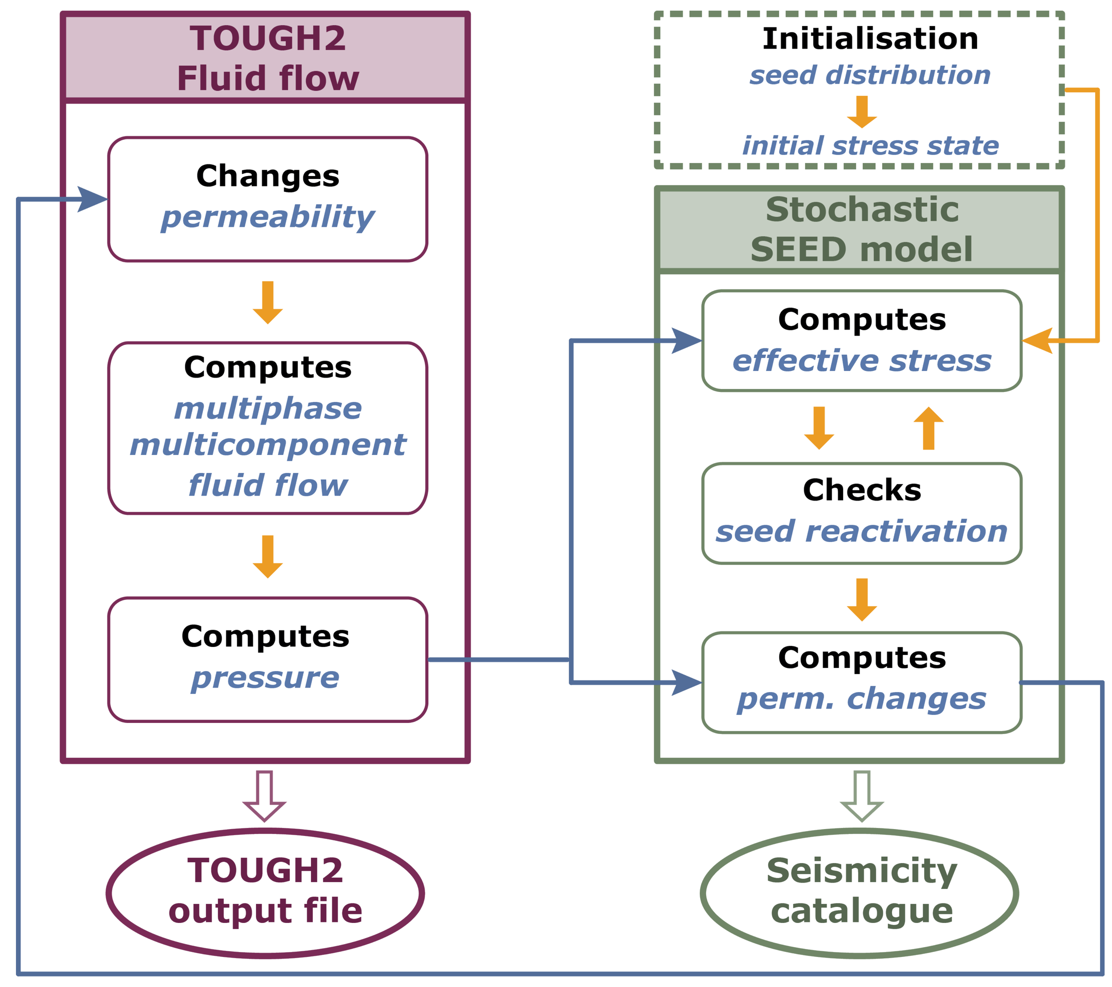


Figure 1: *TOUGH2-Seed coupling chain (adapted from Rinaldi and Nespoli, 2017)*

Influence of physical processes

Base case: Goertz-Allmann & Wiemer 2012 [2]

Step by step addition of:

- gravity
- permeability changes with pressure *(equation in [3])*
- permeability changes with P & seismicity *(eq. in [3])*
- Coulomb static transfer *(eq. in [1])*
- major fault zone

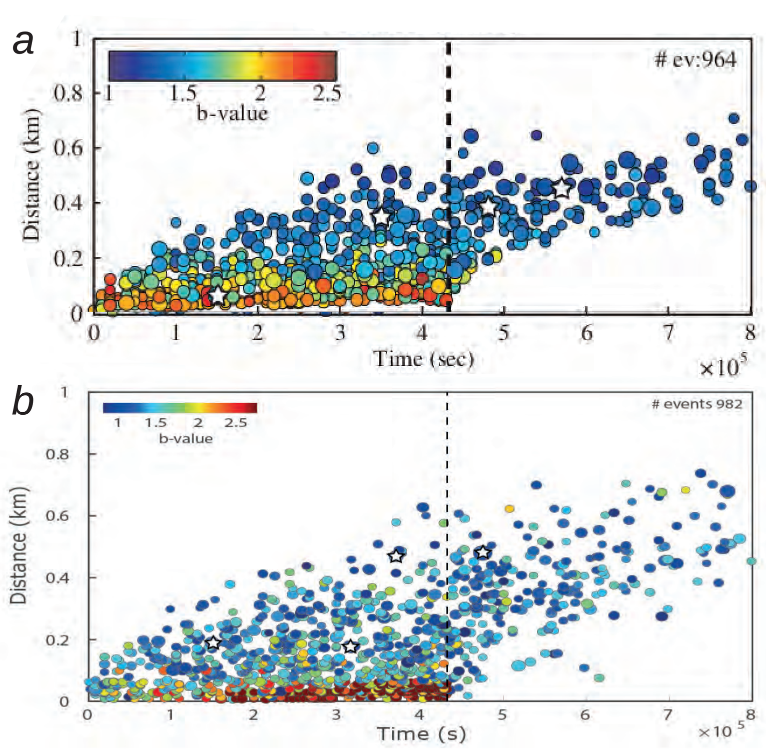


Figure 2: Simulated seismicity by [1] (a) TOUGH2-Seed (b)

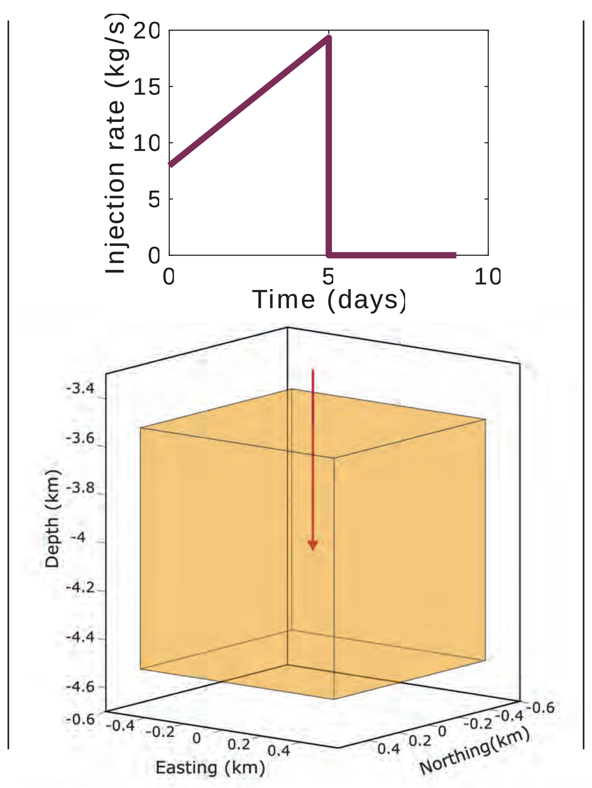


Figure 3: *Injection pattern and schematic view of the system*

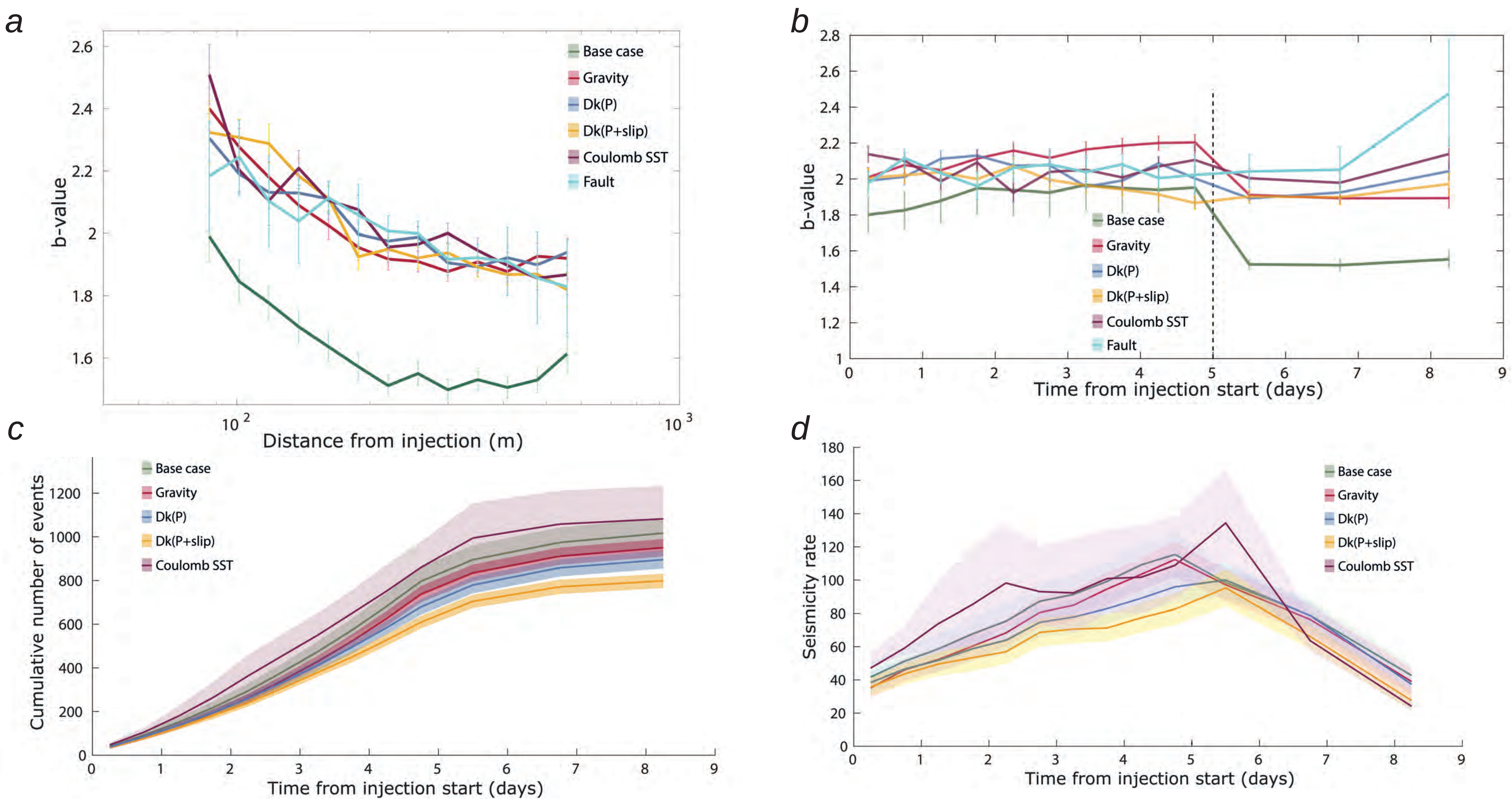


Figure 4: *Build up of physical processes*
a) b-value versus distance from injection b) b-value versus time from injection
c) cumulative number of events d) rate of seismicity

Injection strategies

Evaluation criteria

Reservoir stimulation efficiency

- Stimulation factor to quantify the volume of reservoir with enhanced permeability

$$SF_2 = \sum_{i=1}^{n} \frac{\kappa^i_{hm}}{\kappa^i_0} \frac{V_2}{V_{inj}} \left(\frac{\kappa^i_{hm}}{\kappa^i_0} > 10\right)$$

i (1 to n): index of the model blocks
hm: index of the current state

Induced seismic risk

- *Probability of occurence of an event of magnitude above M (Wiemer 2000; Tormann et al. 2014)*

Expected recurrence time:

$$T_r(M) = \frac{1}{10^{log(N \geqslant M)}}$$

Probability of occurence:

$$P_r(M) = 1 - e^{\frac{-1}{T_r(M)}}$$

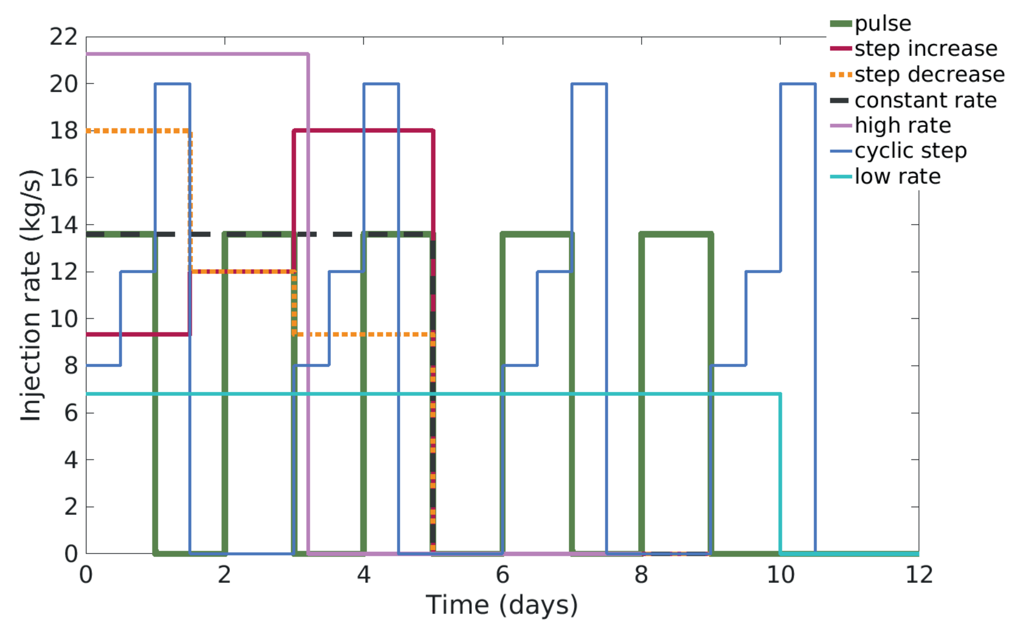


Figure 5: *Tested injection patterns*

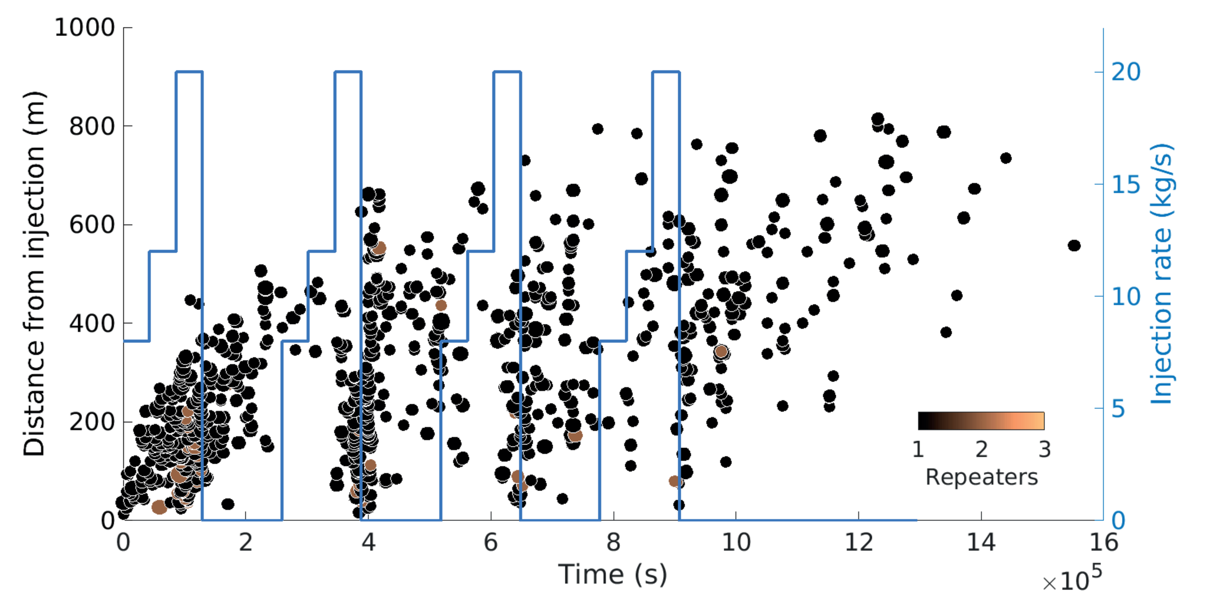


Figure 6: *Example of an R-T plot for the step inpulse injection strategy*

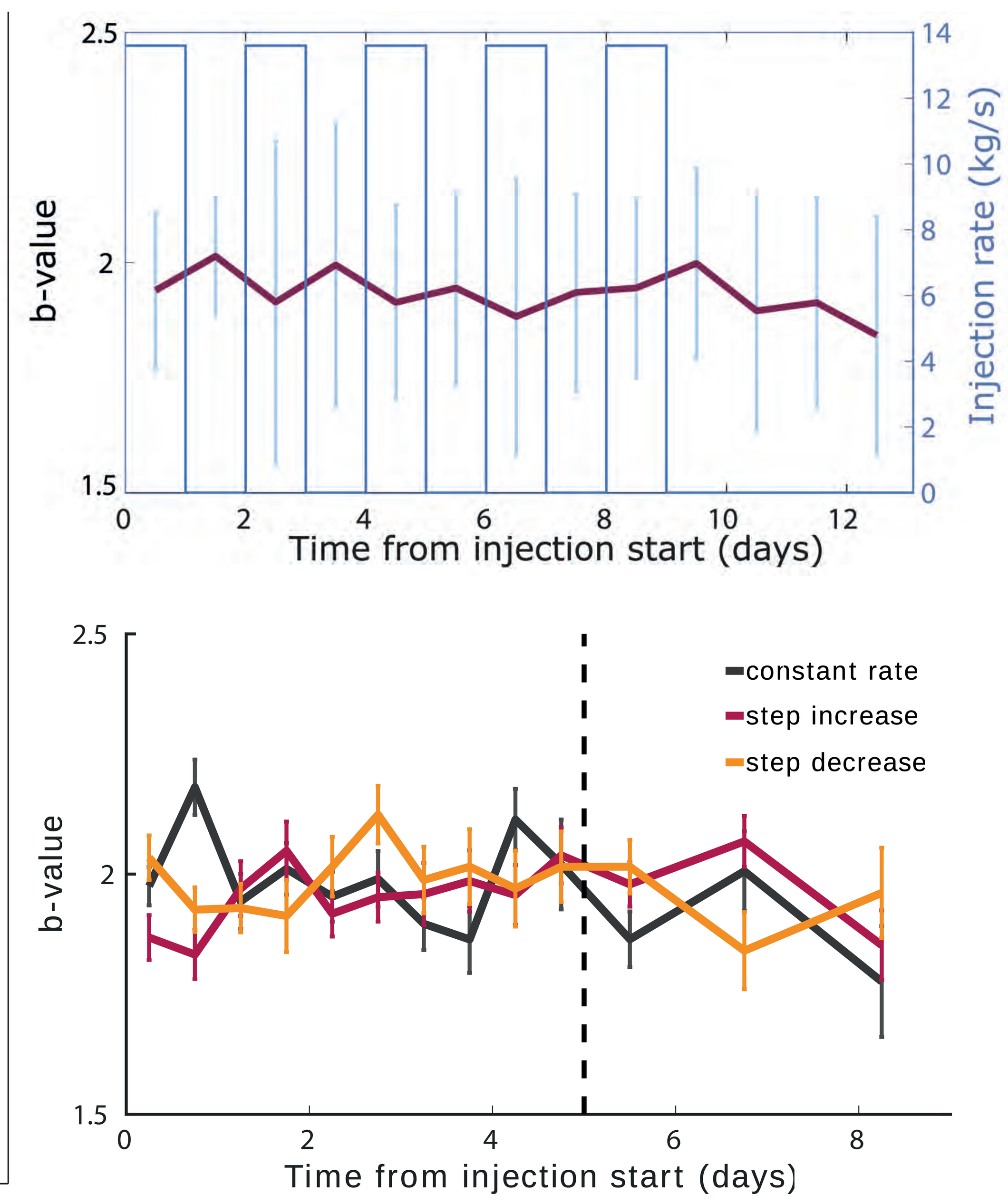


Figure 7: *b-value evolution in time for different strategies and same total injected volume of 8640 m³ a) cyclic pulse strategy b) constant intermediate rate, step-like decrease and increase (all three strategies with the same shut-in time)*

Strategy	Stimulation factor	Relative stim. Factor	Pr(M=3)
Constant rate ●	1.17E+06	100%	25.65%
Pulse short ●	1.15E+06	98%	34.14%
Step increase ●	1.38E+06	118%	25.64%
Step decrease ●	1.36E+06	116%	27.79%
Inpulse step ●	7.13E+05	61%	32.63%
High rate ●	1.50E+06	128%	43.34%
Low rate ●	6.17E+05	53%	29.95%

Table 1: *Efficiency and risk associated with the tested injection strategies*

Outlook

- Our hybrid model with full 3D is able to reproduce previously modelled base case for EGS
- The addition of physical phenomena does not change the behaviour of the b-value both in space and in time
- There is no clear trade-off between efficiency and seismic risk for the tested strategies
- Conservative injection rates yield poorly stimulated reservoir but without lowering the associated risk which remains comparable to a constant intermediate rate of injection

Next steps:

- Building of a comprehensive tool to assess seismic risk and stimulation efficiency
- Calibration of the stimulation factor on real EGS sites
- Investigation of the influence of a fault zone on injection strategies
- Forecast modelling of induced seismicity based on injection data and learning period

References

[1] Catalli, F., Rinaldi, A. P., Gischig, V., Nespoli, M., & Wiemer, S. (2016). The importance of earthquake interactions for injection-induced seismicity. Geophysical Research Letters

[2] Goertz-Allmann, B. P. and Wiemer, S. (2012). Geomechanical modeling of induced seismicity source parameters and implications for seismic hazard assessment. Geophysics

[3] Rinaldi, A. P. and Nespoli, M. (2017). Tough2-seed: A coupled fluid flow and mechanical-stochastic approach to model injection-induced seismicity. Computers & Geosciences

This research is funded by the European Union's Horizon 2020 research and innovation programme DESTRESS under grant agreement No.691728 and by the SNSF Ambizione Energy grant No.PZENP2_160555.