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Comparing strategies for stimulating and relieving an EGS reservoir with 3D Monte Carlo simulations

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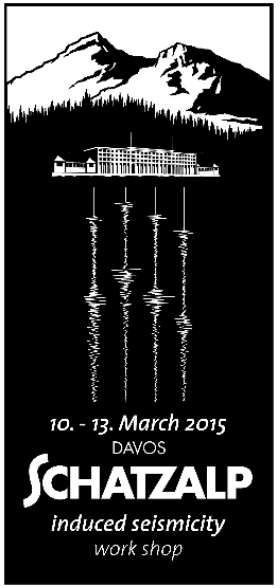
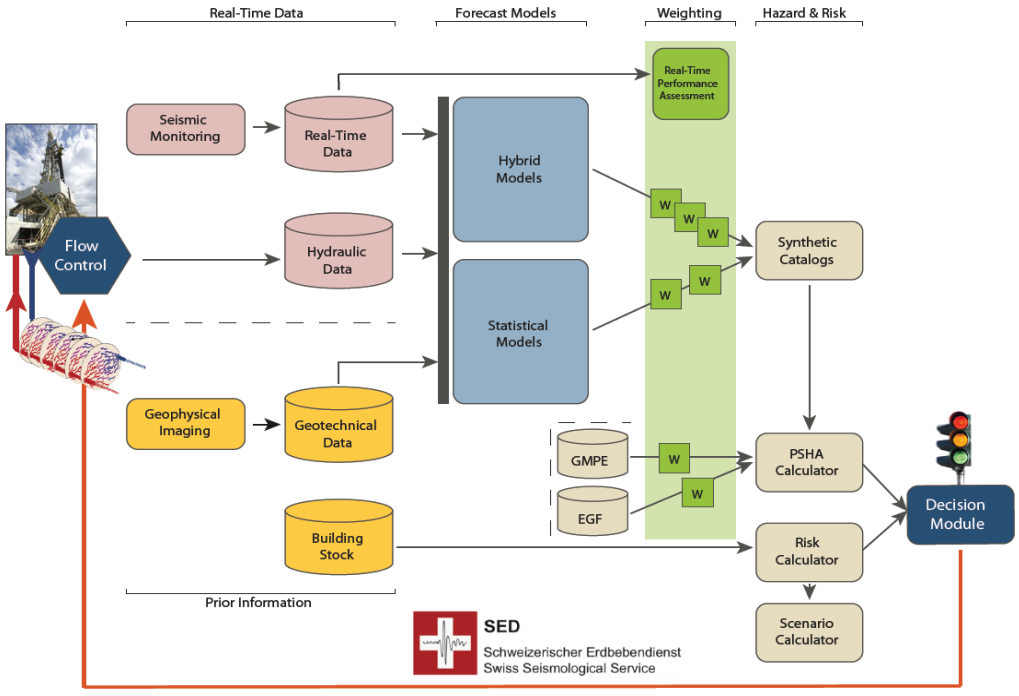


Introduction



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- The adaptive traffic light system (ATLS) is developed for projects with high risk.

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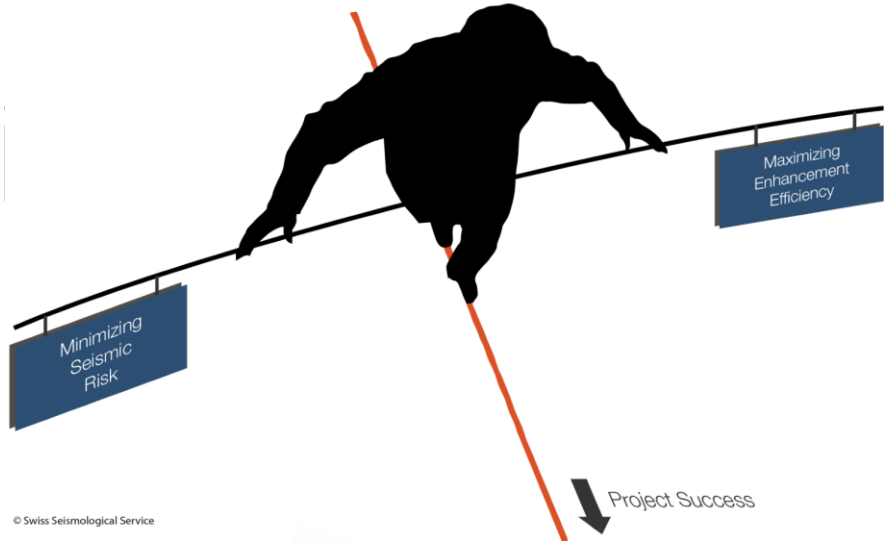

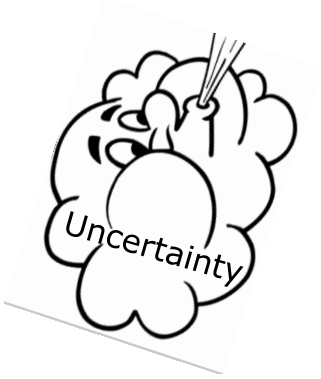

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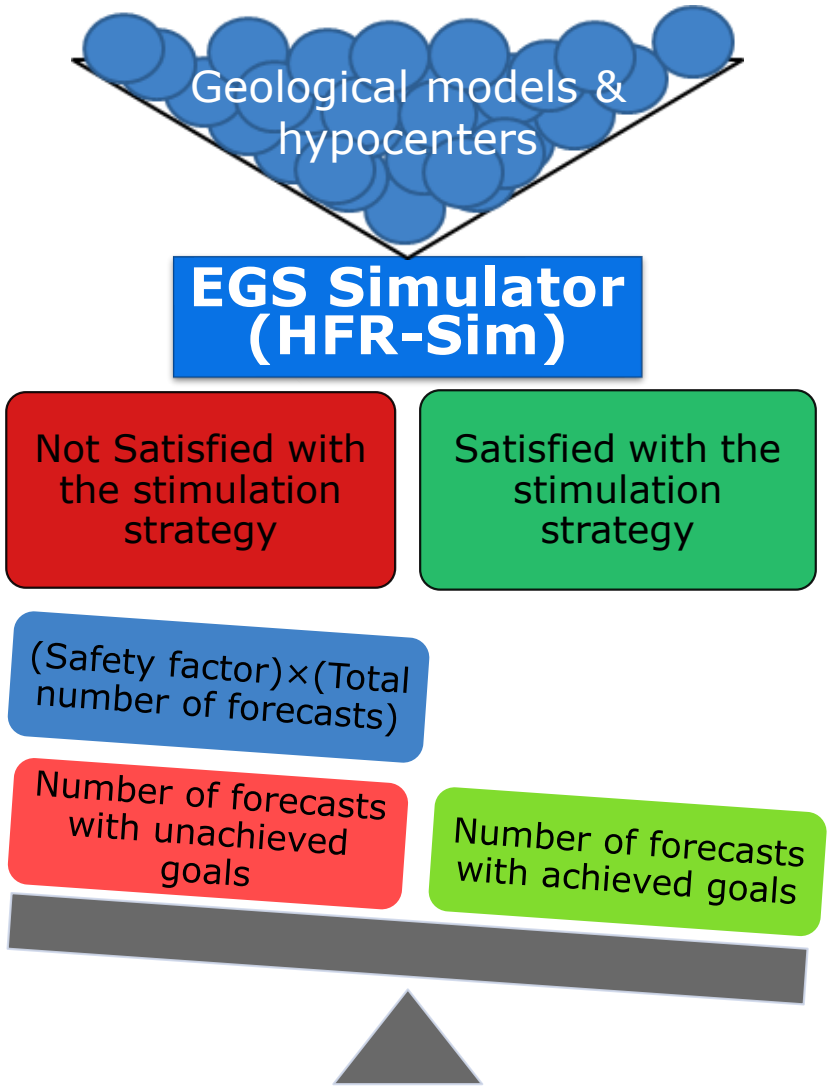

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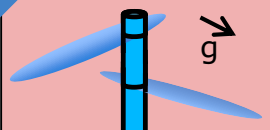
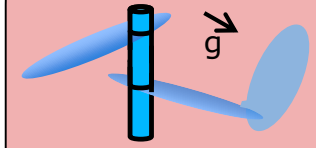
- Monte Carlo simulations with hybrid models are performed.
- Real time: not always the few days of injection.

Forecasting induced seismicity with HFR-Sim

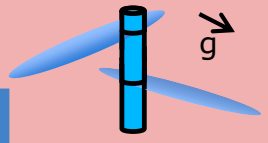
Start



HFR-Sim approximates the pressure field inside the EGS reservoir at each time-step.

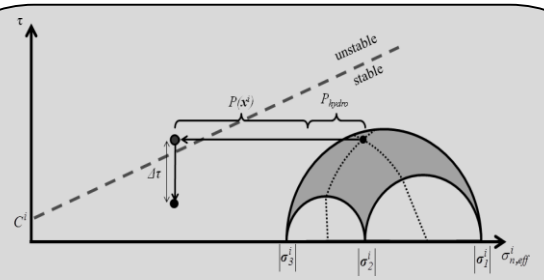


If M is larger than the threshold value, then a discrete fracture with high permeability is added in the HFR-Sim flow model and with the corresponding orientation size.



If M is smaller than a threshold value then the ruptured surface is not represented discretely but it is upscaled.

End



The Mohr-Coulomb failure criterion is applied at potential hypocenters. Observed statistics for the orientation, the stress conditions, the fracture density and the rate of seismicity are taken into account.

When the criterion is satisfied, a magnitude M of the corresponding earthquake is sampled according to the provided b-value. By sampling stress drop, the size of the ruptured area can be approximated.

Outcomes from one hybrid simulation with HFR-Sim

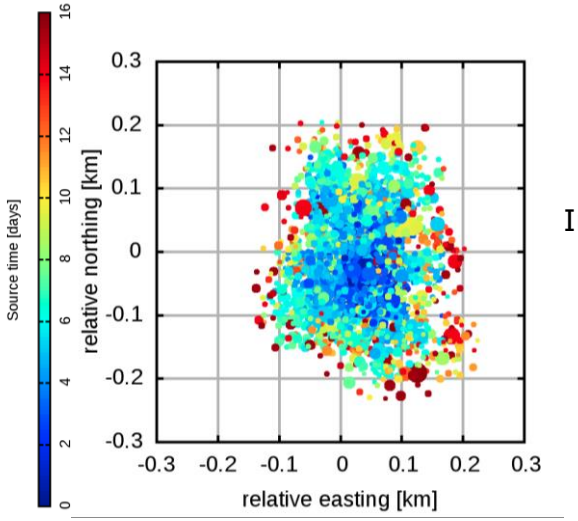
Each run with the hybrid returns:

a) A sequence of induced seismicity.

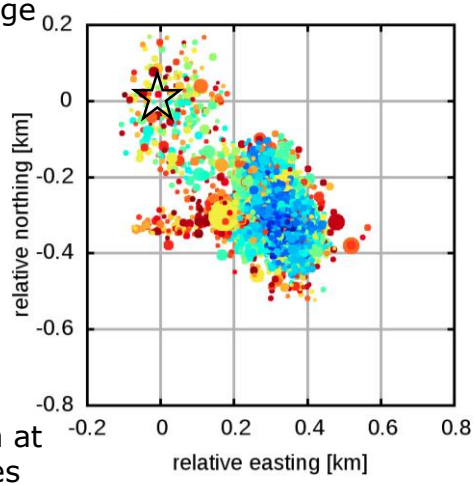
b) A network of discrete fractures with high permeability.

- Both outcomes are such that mass conservation is satisfied.
- They are the 'most' meaningful scenario for the sampled geological model.
- EGS simulations can be performed for the network of discrete fractures for many different scenarios.

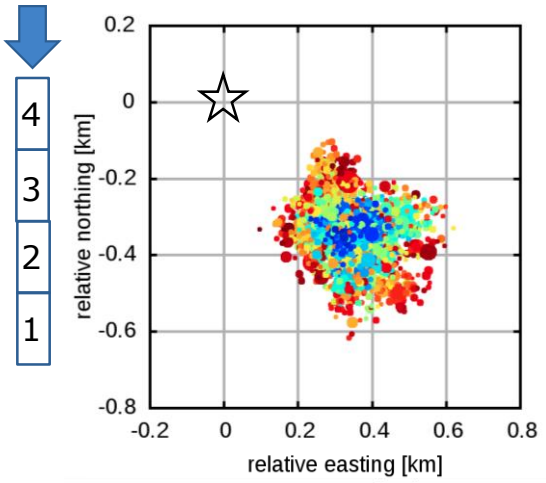
Predicting energy revenues from doublets

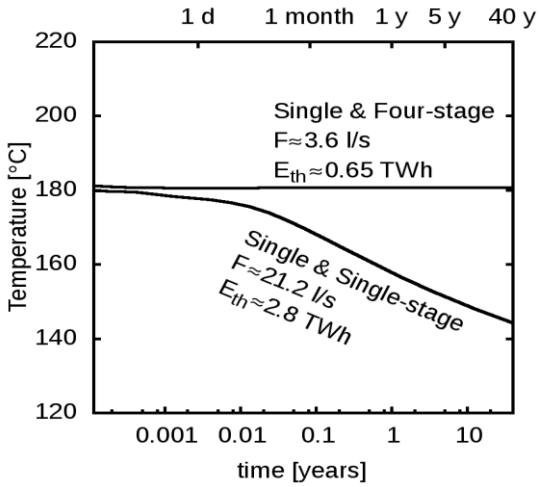


Injection at 1 stage



Injection at 4 stages

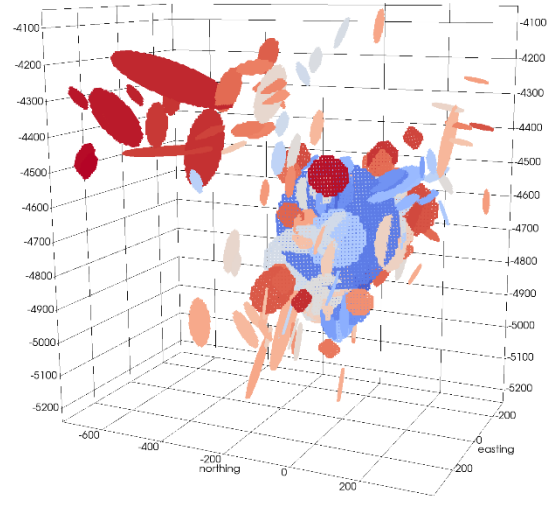


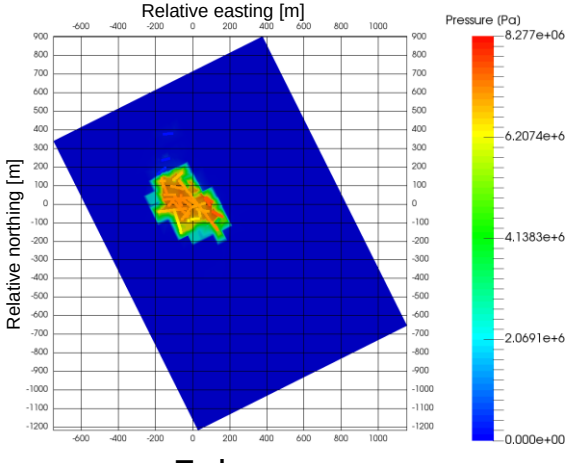


Understanding and processing field observations

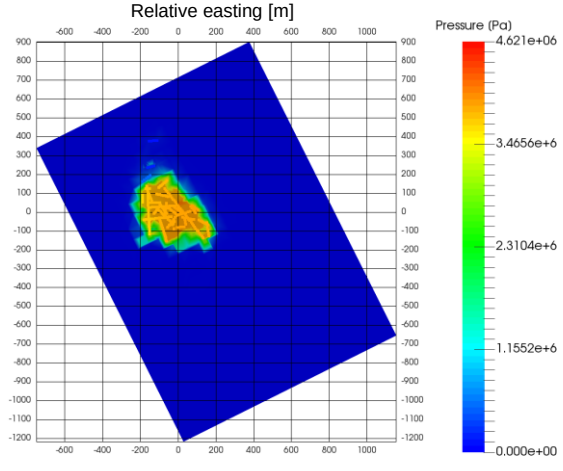
Observations considered:

- Cumulative volume of produced fluids
- Observed hypocenters and magnitudes (Kraft et al., 2015)
- Focal plane solutions and principal stresses (Terakawa et al., 2014)
- Cluster analysis (Deichmann et al., 2015).

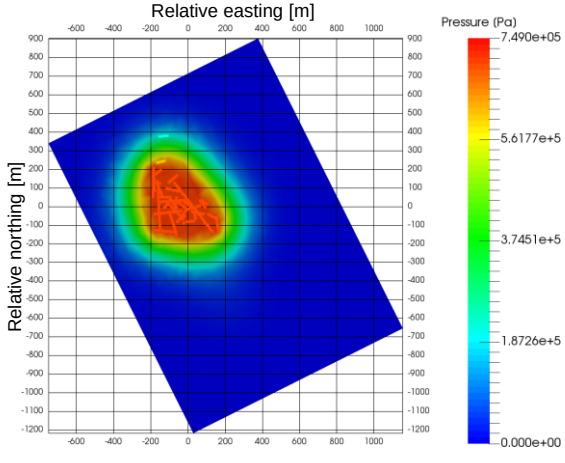




7 days



14 days



1 year

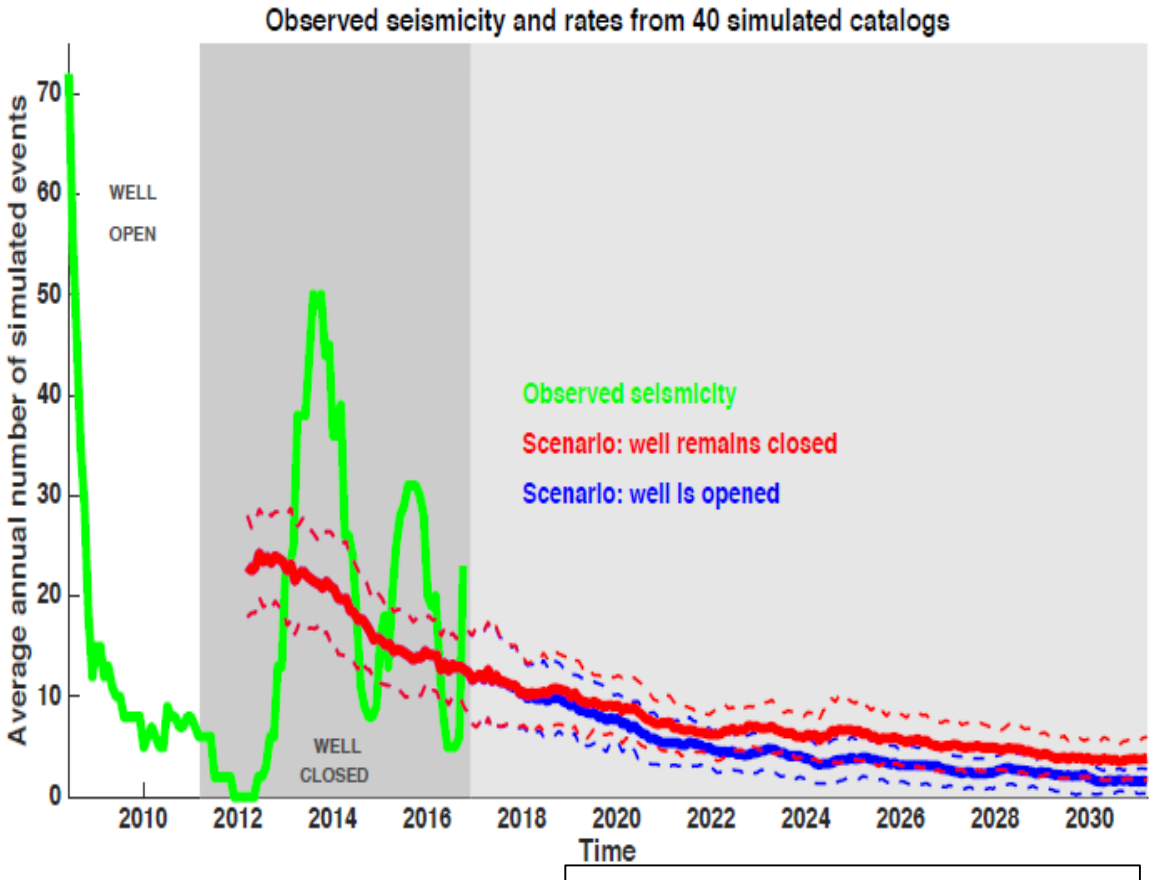
Assessing different risk mitigation strategies

Two scenarios are simulated for the next 20 years:

- Keep the well in Basel shut besides the increased seismicity
- Open the well in Basel because of the increased seismicity

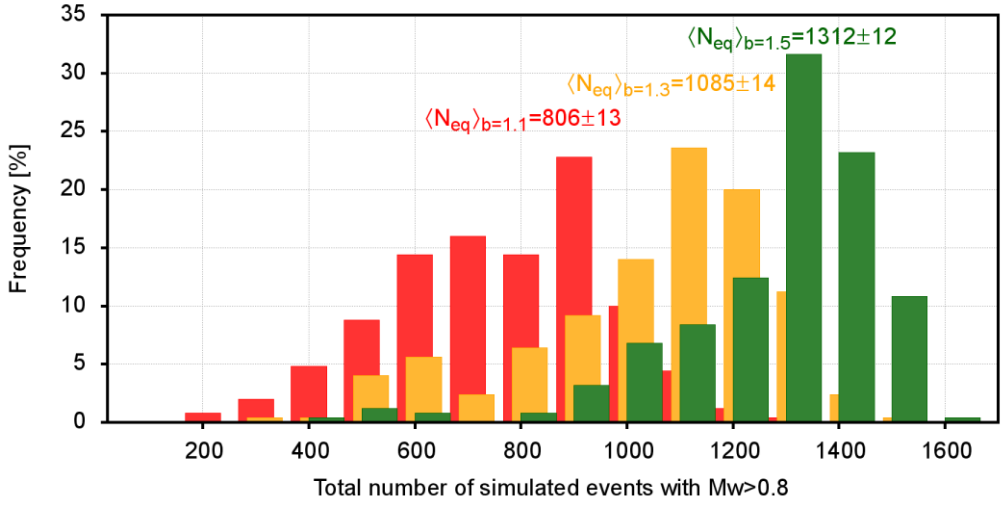
40 sets of seeds calibrated with the mean annual rate of observed seismicity since 2011.

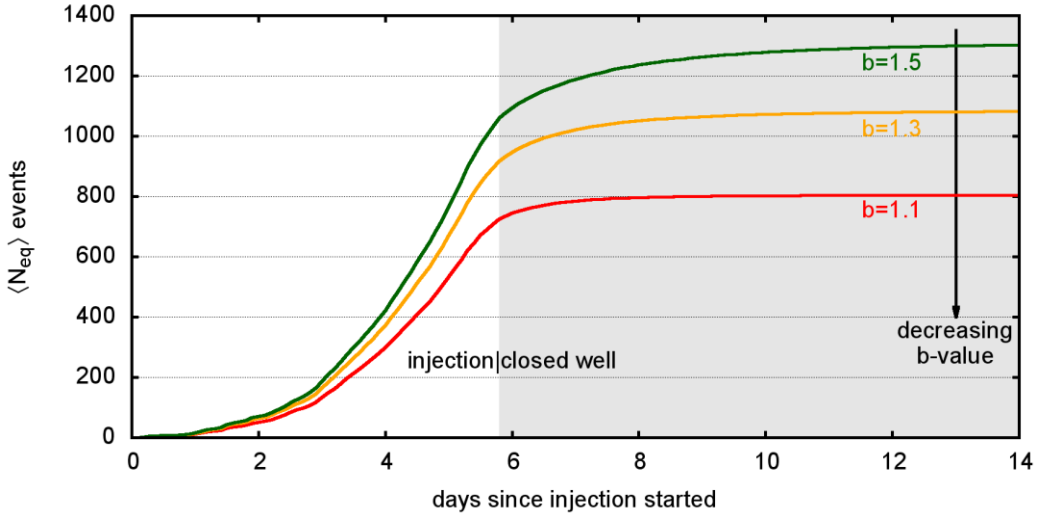
Prediction: The expected annual number of simulated events is expected to reduce faster if the well opens.



Wiemer et al., under preparation

Performing numerical experiments





- Three different b-values of the Gutenberg Richter (GR) law are considered for exactly the same injection.
- Non symmetric distributions obtained (negative skewness).
- Large variance of cumulative number of events → never a unique Seismogenic index

Mean	Normalized skewness	Frequency of max $M_w \geq 4$
1312	-1.55	3.2%
1085	-0.88	8.8%
806	-0.25	23.2%
	Total	**11.7%**

Conclusion

- The hybrid model returns sequences of induced seismicity and networks of ruptured surfaces that satisfy both pore pressure diffusion and observed statistics for the geological properties.
- The hybrid can assist in many important decision making situations both before and during the stimulation of an EGS reservoir.
- Thanks to its flexibility, the hybrid model can process field knowledge, which usually had to be neglected.
- The efficacy of different stimulation strategies can be probabilistically assessed with Monte Carlo simulations and numerical experiments can be performed.

Thank you

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