

Assessing Geothermal Reservoir Stability: A Machine Learning Approach to Induced Seismicity Forecasting

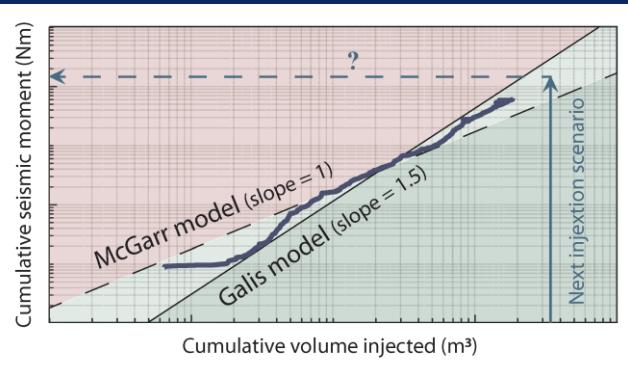


Photo: Karimpouli et al. GJI (under review)

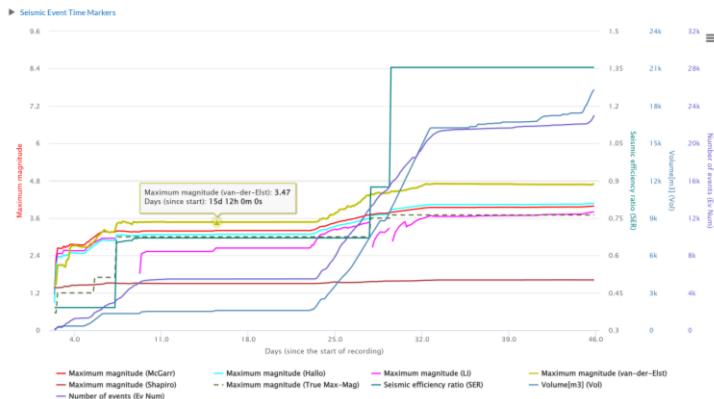
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Schatzalp, Davos, 18-21 May 2025

What is the problem?

- Forecasting of next largest magnitude event:
 - Deterministic and probabilistic models:
 - They are reliable when all assumptions are covered.



MaxMagMod

INFORMATION PAGE ACTIONS ▾

INPUTS

Catalog ⓘ Required 1 file **SELECT FILES**

Injection Rate ⓘ Required 1 file **SELECT FILES**

Chosen magnitude column: **ML**

Time window length [h] [min. 0]: **6**

Time interval [h] [min. 0]: **3**

Time window type: **Extending window from starting time**

End time of the computations [day] [min. 0]:

Minimum events count [min. 0]: **20**

Maximum magnitude model: **All models**

Completeness magnitude [2.0;3.7]: **-0.8**

HISTOGRAM CUMULATIVE HISTOGRAM LOAD VALUE FROM FILE

Friciton coefficient [0.2;0.8]: **0.6**

Shear modulus of reservior [GPa] [1; 100]: **35**

Static stress drop [MPa] [0.1; 100]: **3**

Geometrical constant [0.5; 5]: **0.95**

b-method

All
 b-value is 1
 MLE from Aki (1965)
 b-positive from van der Elst (2021)
 Tapered Gutenberg-Richter distribution Kagan (2002)

Confidence level [0..1]: **0.37**

Autorun **RUN** **RESET**

Usual run time: less than one minute
Max measured run time: 1 m

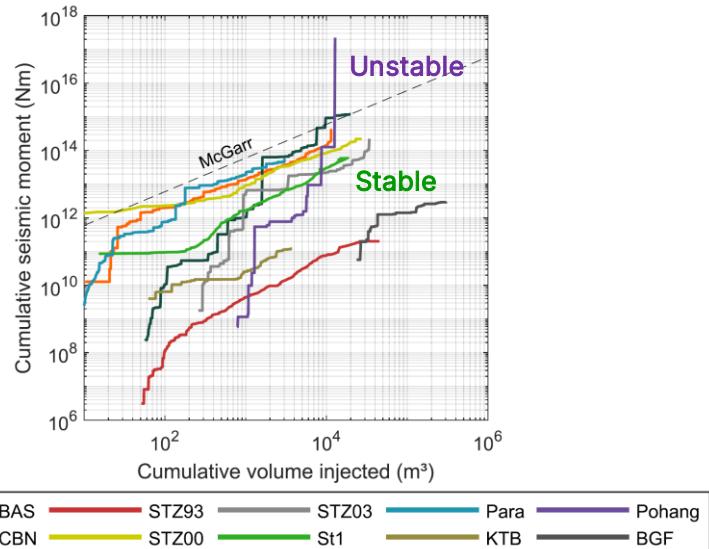
Autosave **SAVED** **RESET**

EPISODES PLATFORM

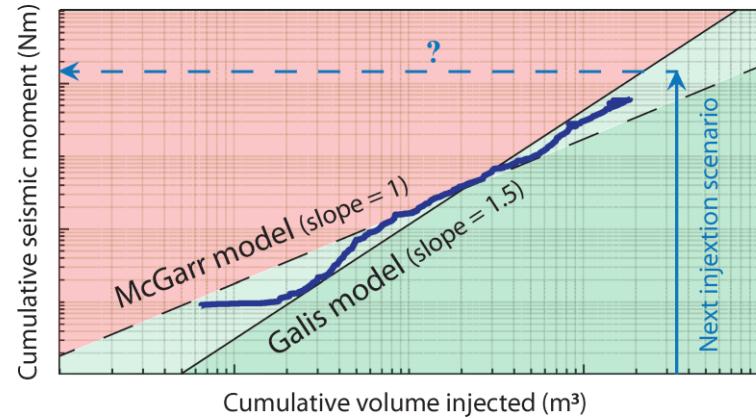
Karimpouli et al., SRL (under review)
MaxMagMod app is available on EPISODES platform

What is the problem?

- Assessing reservoir stability:



Bentz et al. (2020), GRL



New problem definition:
Monitoring stability of a reservoir

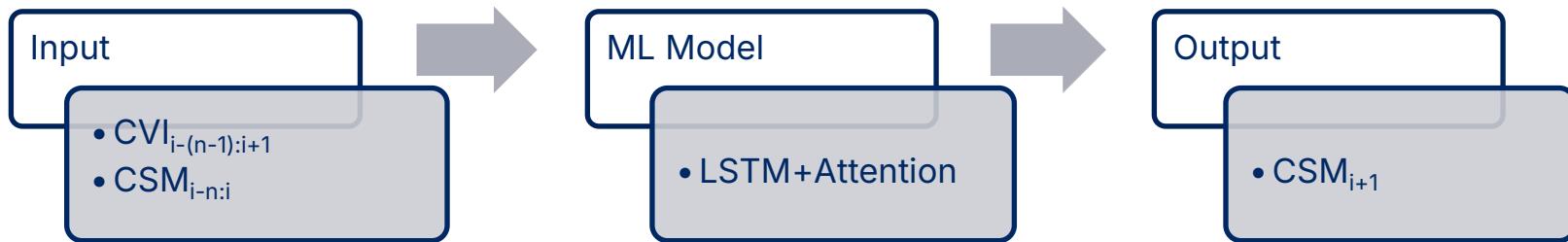
Target:

Prediction of cumulative seismic moment for the next injection scenario

Suggested solution

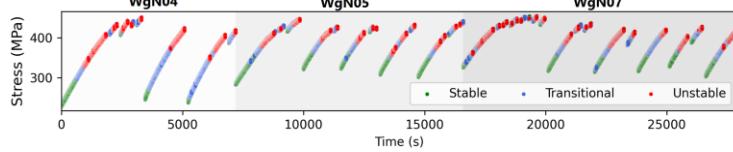
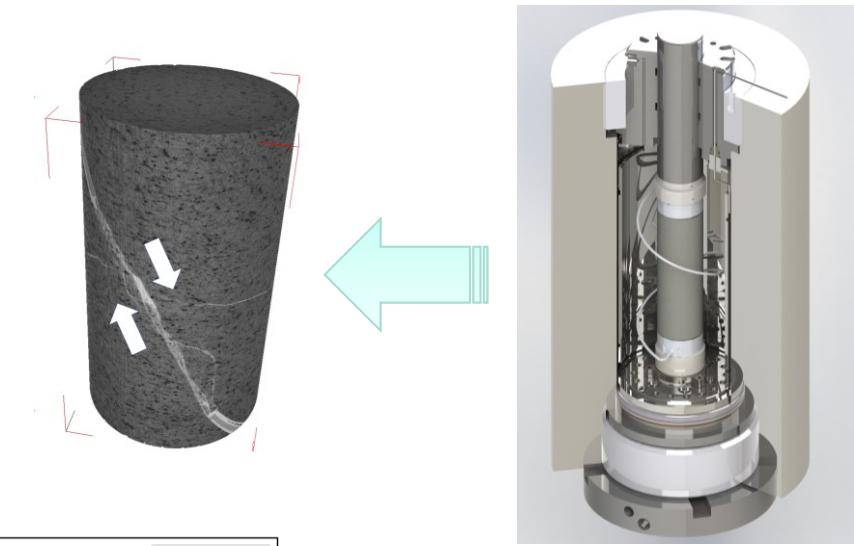
- ML to predict CSM_{i+1}

				$CVI_{i-(n-1)}$	.	.	.	.	.	t_{i-1}	t_i	t_{i+1}		
Cumulative volume injected (CVI)										CVI _i	CVI _{i+1}			
Cumulative seismic moment (CSM)			CSM _{i-n}	.	.	.	.	.	.	CSM _i	CSM _{i+1}			

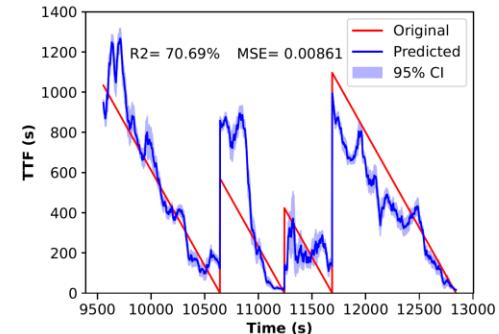


Lessons from lab-scale

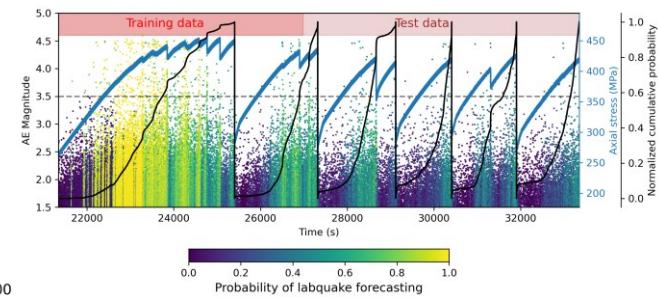
Triaxial stick-slip experiments (rough fault)



Unsupervised clustering of catalog-driven features
(Karimpouli et al. 2024- GJI)



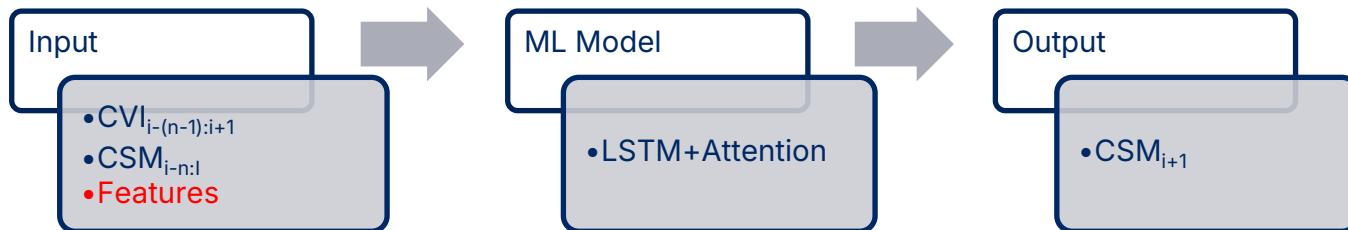
Time to failure prediction of labquakes
(Karimpouli et al., 2023- EPSL)



Labquake forecasting
(Karimpouli et al., 2024- JGR-ML)

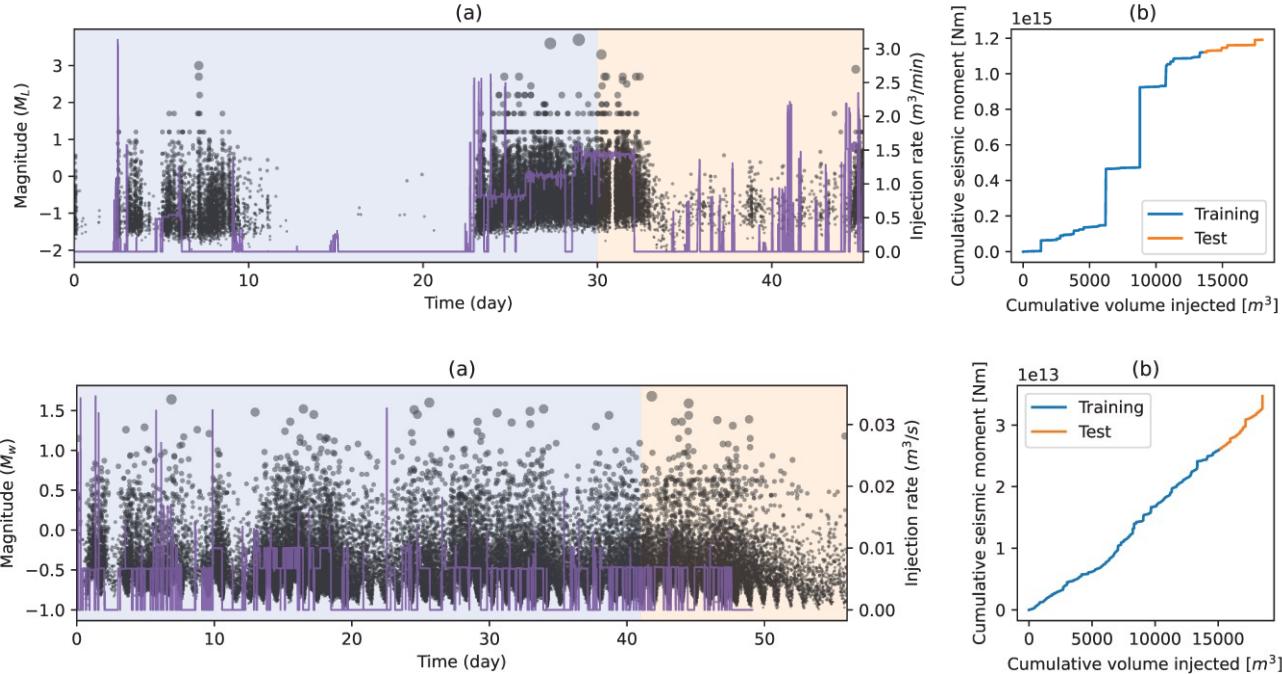
Suggested solution

				t_{i-1}	t_i	t_{i+1}		
Cumulative volume injected (CVI)			CVI _{i-(n-1)}	.	.	.	CVI _i	CVI _{i+1}
Cumulative seismic moment (CSM)		CSM _{i-n}	.	.	.	.	CSM _i	CSM _{i+1}
<i>b</i> -value (<i>b</i>)		b _{i-n}	.	.	.	.	b _i	
Correlation integral (C)		C _{i-n}	.	.	.	.	C _i	
Seismogenic index (SI)		SI _{i-n}	.	.	.	.	SI _i	
Seismic efficiency ratio (SER)		SER _{i-n}	.	.	.	.	SER _i	
Cluster to background ratio (CBR)		CBR _{i-n}	.	.	.	.	CBR _i	
Correlation with McGarr model (CMG)		CMG _{i-n}	.	.	.	.	CMG _i	



Case studies

Cooper Basin, Australia

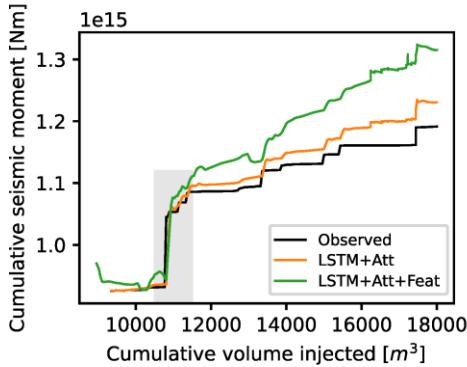


Results

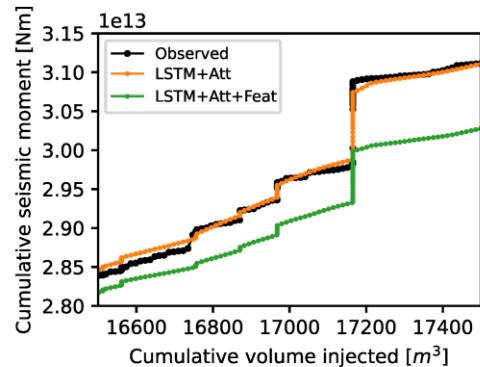
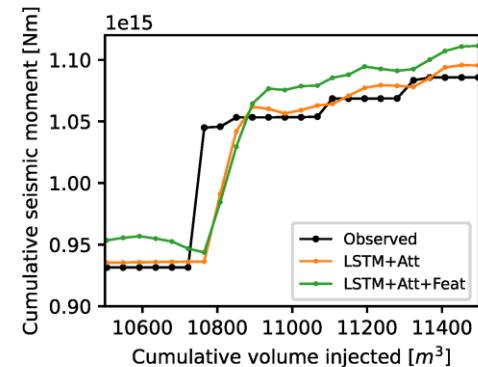
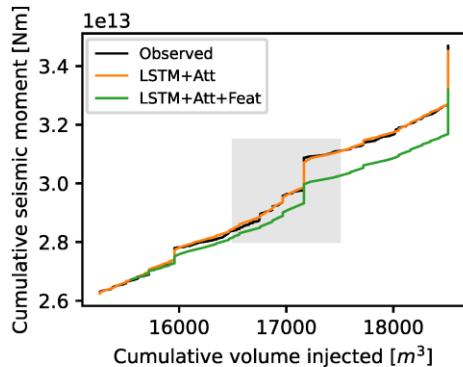
In this special problem:

- Underestimation is totally unacceptable, which means a low RMSE does not guarantee a valid estimation.
- Kwiatek et al. (2024)- SRL:
The best performing estimation is the one that produces minimal, yet positive deviation from the observed values.

Cooper Basin
Australia

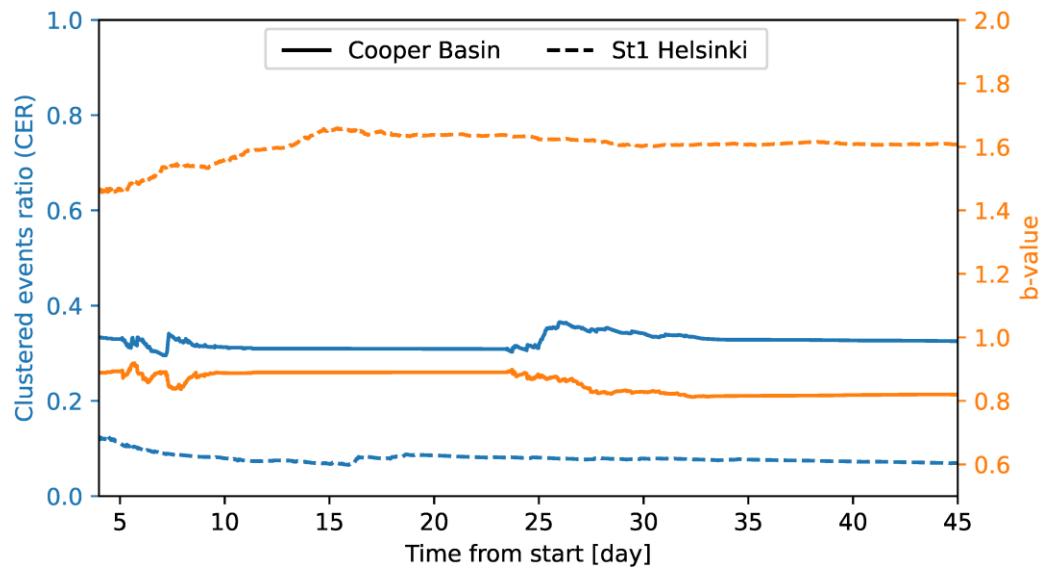


St1, Helsinki
Finland



Discussion

- Cooper basin:
 - High clustered seismicity
 - Low b-value
 - A planar fault zone
- St1 Helsinki:
 - Low clustered seismicity
 - High b-value
 - A network of distributed fractures



Key Messages

- Maximum magnitude prediction is complex, however, stability monitoring may be simpler yet efficient problem.
- Adding catalog features as input data works in cases that seismicity is promoted by earthquake interactions and fault reactivation.
- Augmentation of training data using numerical simulations may improve the predictions.