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

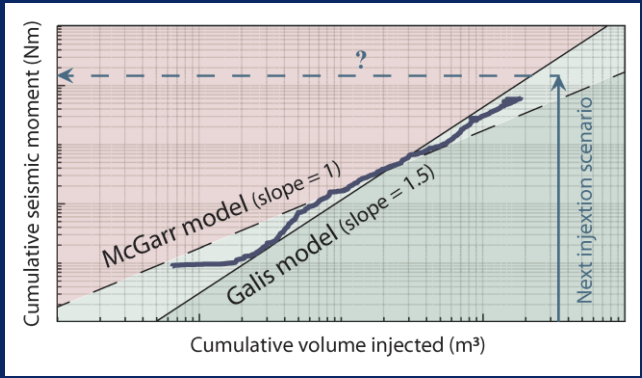

Photo: Karimpouli et al. GJI (under review)

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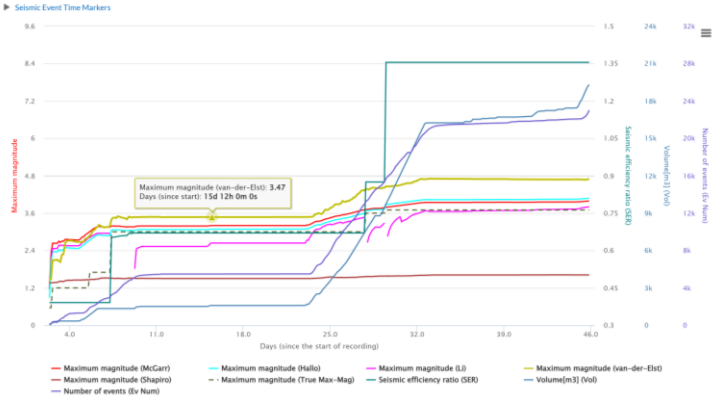
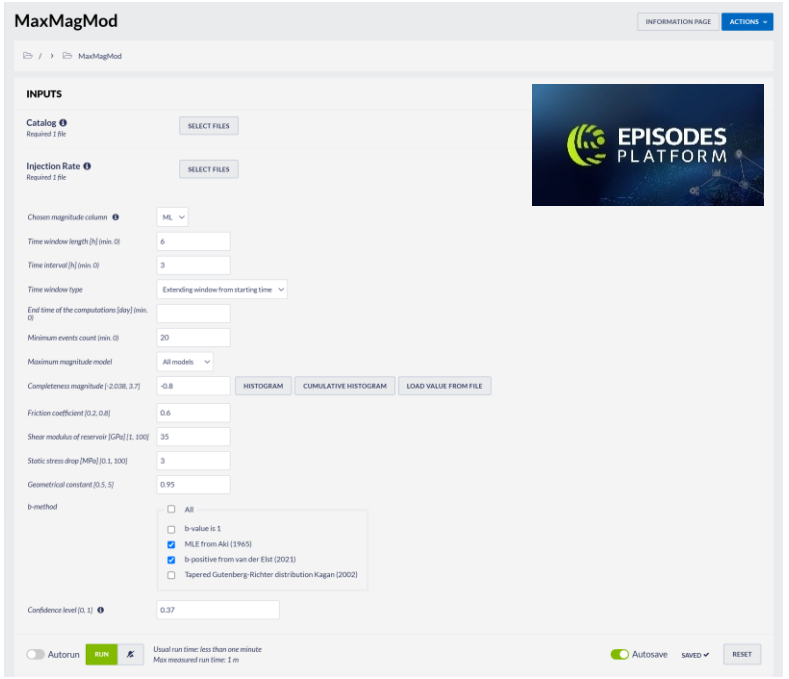
Schatzalp, Davos, 18-21 May 2025

What is the problem?

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





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

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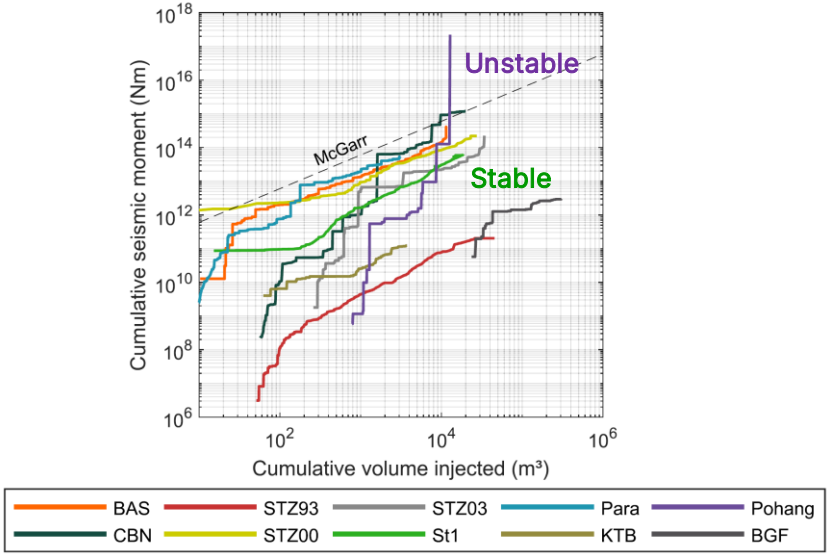
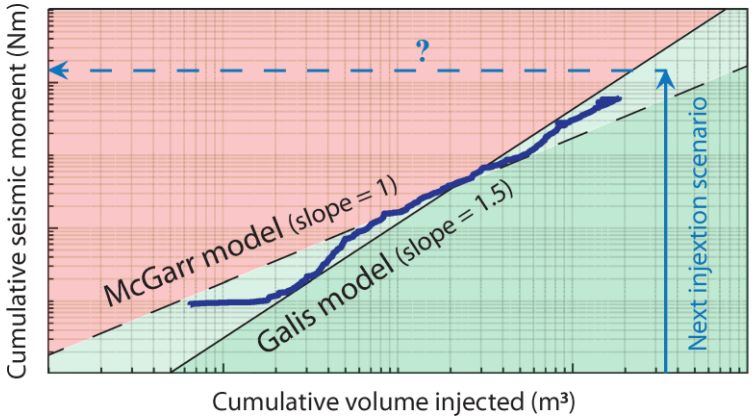
What is the problem?

- Assessing reservoir stability:



Bentz et al. (2020), *GRL*



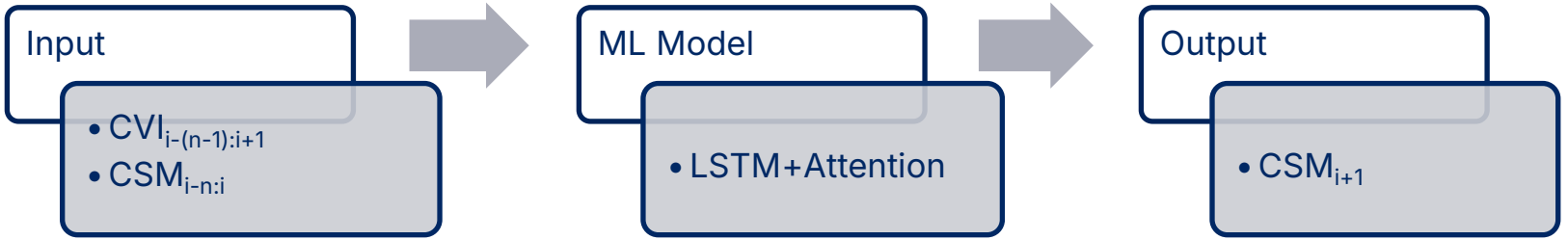
New problem definition:
Monitoring stability of a reservoir

Target:
Prediction of cumulative seismic moment for the next injection scenario

Suggested solution

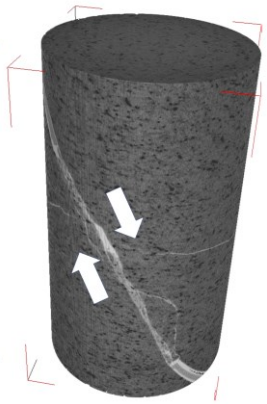
- ML to predict CSM_{i+1}

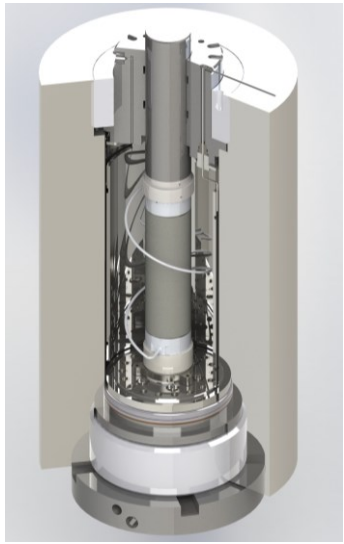
								t_{i-1}	t_i	t_{i+1}		
Cumulative volume injected (CVI)			$CVI_{i-(n-1)}$	.	.	.	.	.	CVI_i	CVI_{i+1}		
Cumulative seismic moment (CSM)		CSM_{i-n}	.	.	.	.	.	.	CSM_i	CSM_{i+1}		

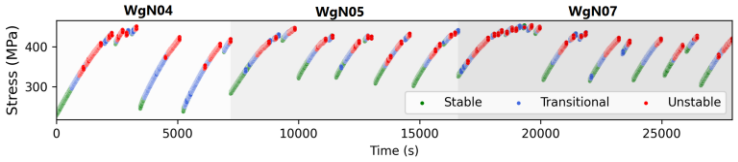


Lessons from lab-scale

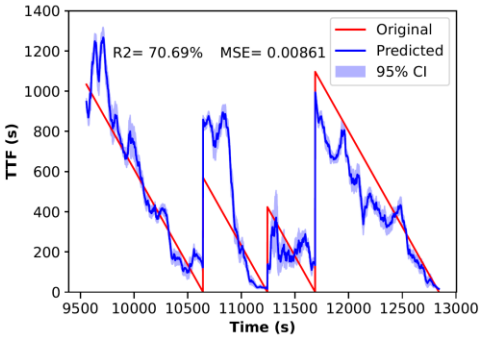
Triaxial stick-slip experiments (rough fault)



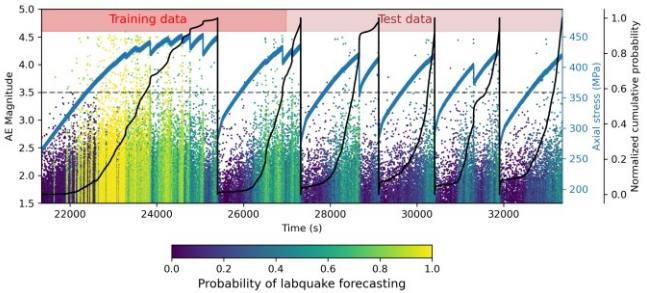




Unsupervised clustering of catalog-driven features (Karimpouli et al. 2024- *GJI*)



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



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

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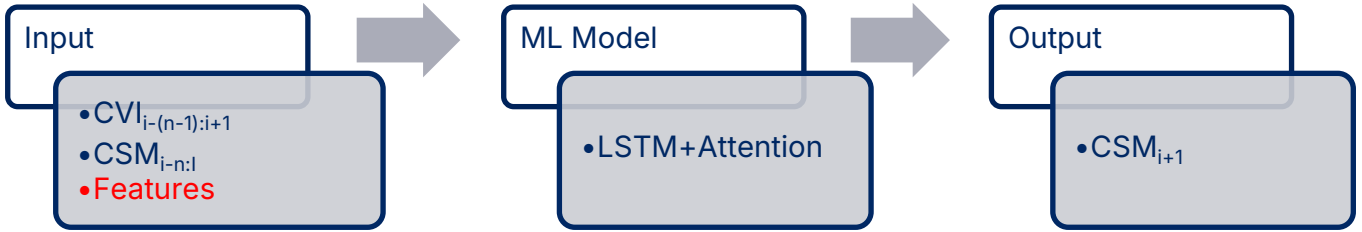
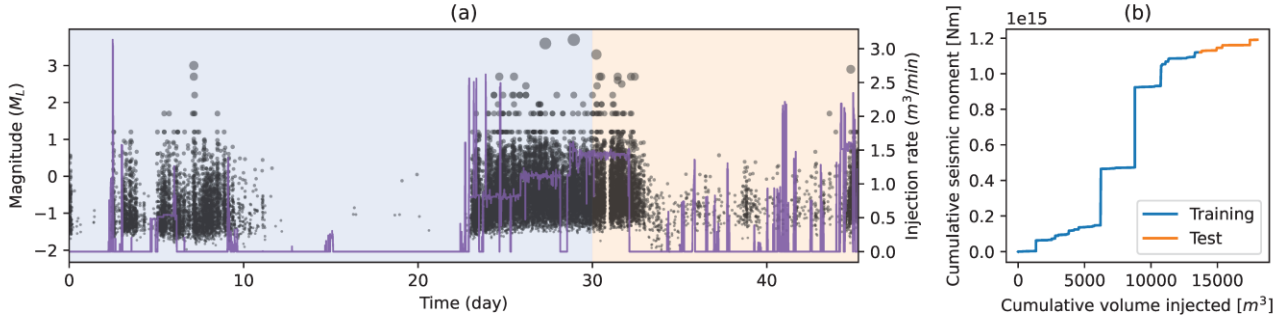
Suggested solution

						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}	
b-value (b)		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		

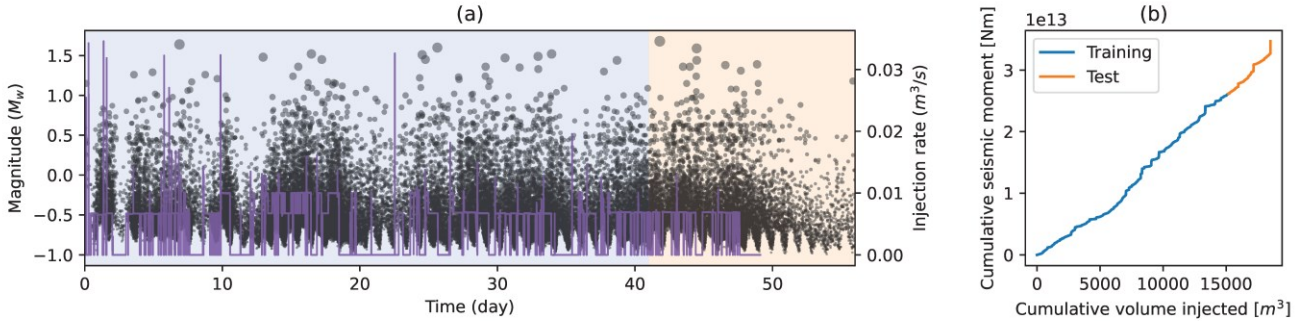


Case studies

Cooper Basin, Australia



St1, Helsinki, Finland



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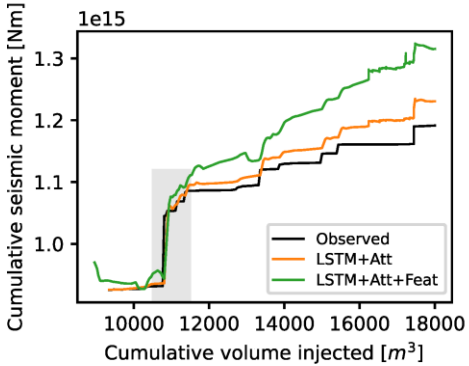
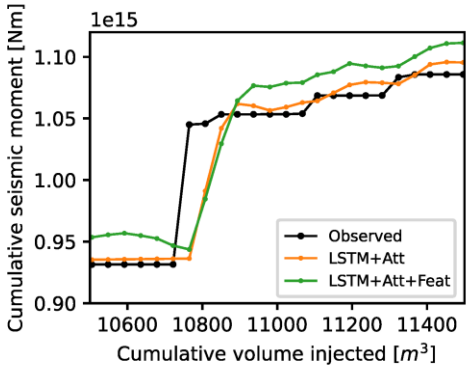
Results

In this special problem:

- Underestimation is totally unaccepted, which means a low RMSE does not grantee 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





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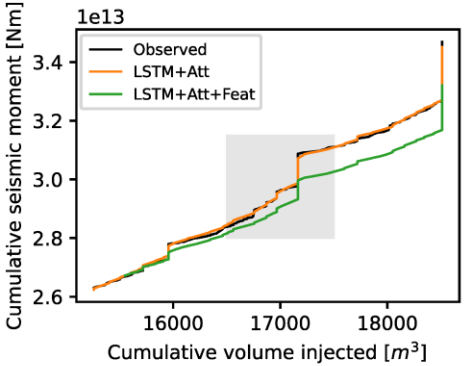

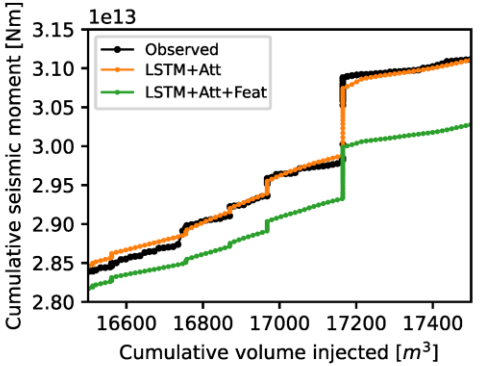

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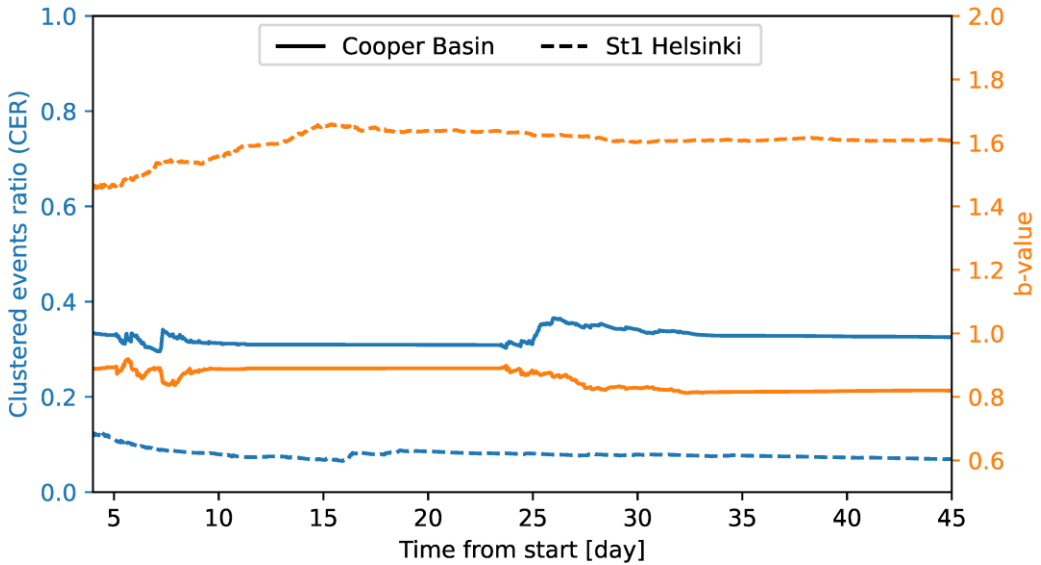
Discussion

- 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



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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.

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