Performance comparison of newly developed hydro-mechanical (hybrid) models for real-time induced seismicity forecasting

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Abstract

Introduction

Hybrid models have the potential to forecast induced seismicity accurately and in (near) real-time. Using hydraulic and seismic data from two recent hydraulic stimulations (Fig. 2) at the Bedretto Underground Laboratory in Ticino, Switzerland (Fig. 1), we performed pseudoforecasting tests applying two hybrid models currently being developed to evaluate and compare their forecasting and computational performances.

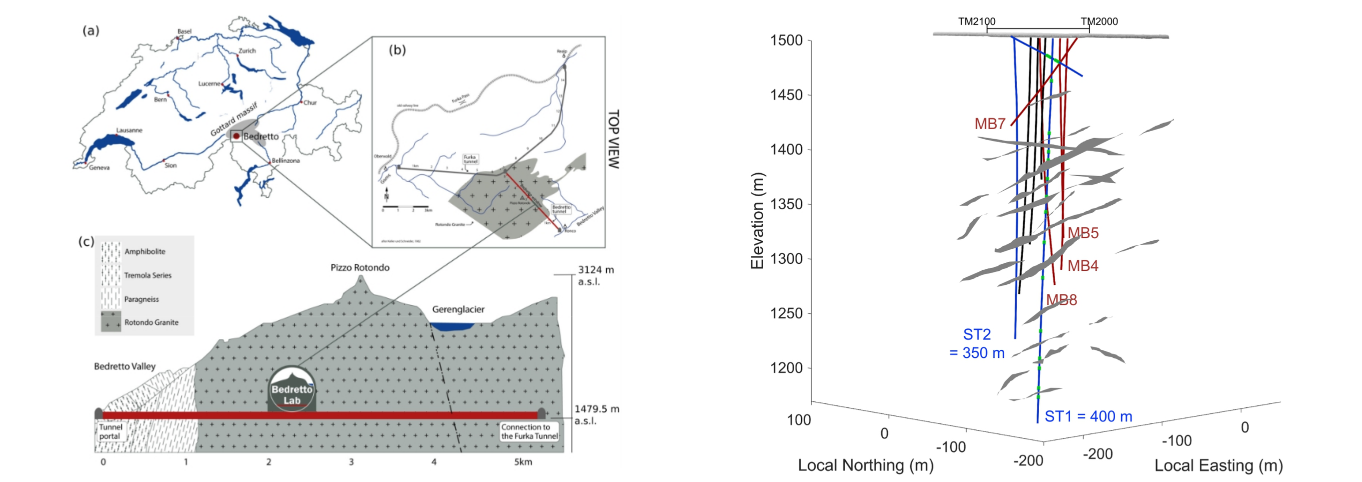

Fig. 1: Location and setting of the Bedretto Underground Laboratory (left panels a)-c); modified after Keller and Schneider, 1982) and borehole geometry representation of the Valter volume (right panel)
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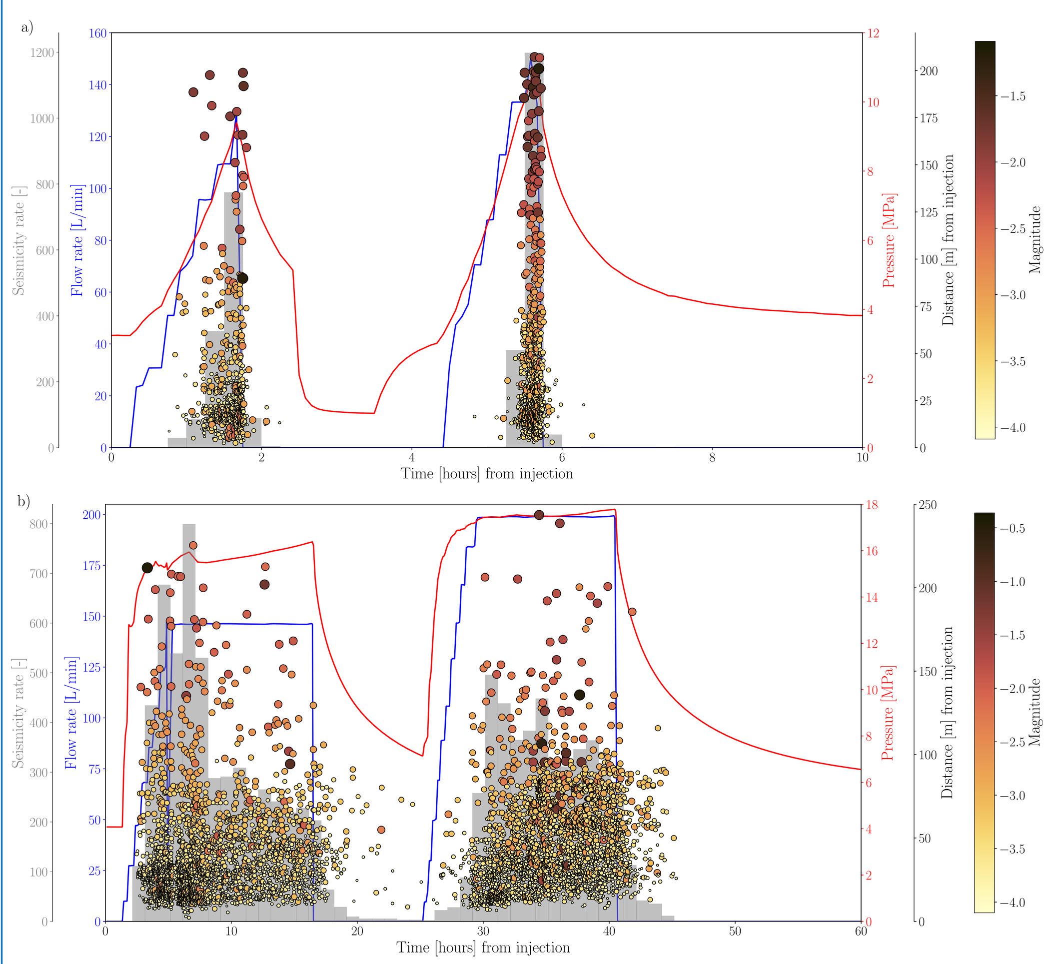
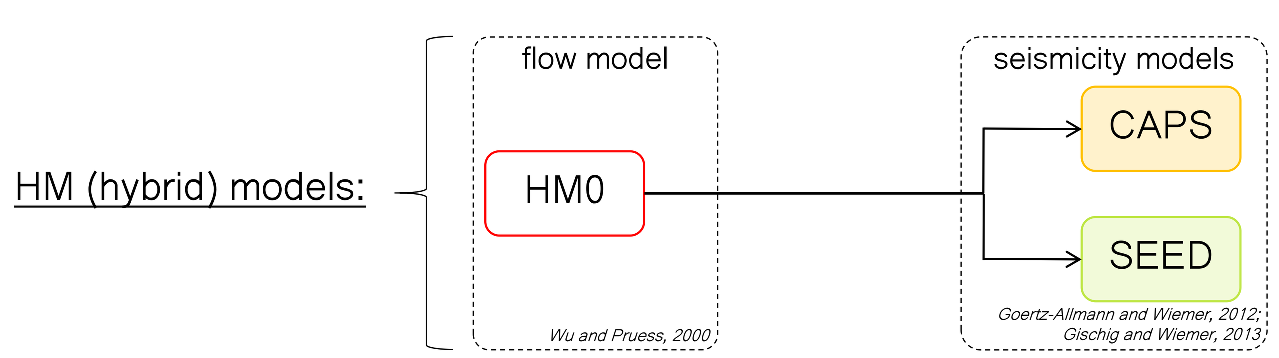


Fig. 2: Bedretto hydraulic stimulation data from: a) March 2022 (Valter phase 1 interval 13), and b) June 2022 (Valter phase 2 interval 8). Injected flow rate (blue), recorded pressure (red), seismicity rate (events per 15 min in a), events per hour in b)) bar plot (gray) and scatter plot of the events (above Mc) with time and distance from the injection point. The colors and the size of the scatter points indicate the magnitude of the events (dark red and larger scatter points for larger magnitudes).



Models' fit and pseudoforecast

- Flow and seismicity models are sequentially coupled, such that seismicity is triggered solely by changes in pressure (red in Fig. 3 a) and f)).
- Datasets are split into training and forecasting/validation phases at four time snapshots (Fig. 3, b) - e) and g) - j)).
- Calibrated model parameters serve as input along with the injection plan to issue pseudoforecasts.
- Fig. 3 shows overall a good fit for both models during the training phase, while the SEED model issues similar forecasts with narrower uncertainty distribution compared to CAPS.
- In terms of running time performance, the analytical solution performs better than the SEED model (Tab. 1).

***Tab. 1**: Running times (in seconds) for both models for the four different learning period (LP) durations/ snapshots (in hours) - shown for the Valter phase 2 int. 8 stimulation.*

LP	CAPS	SEED
8.0 h	48	190
16.0 h	59	334
24.0 h	73	428
32.0 h	82	445

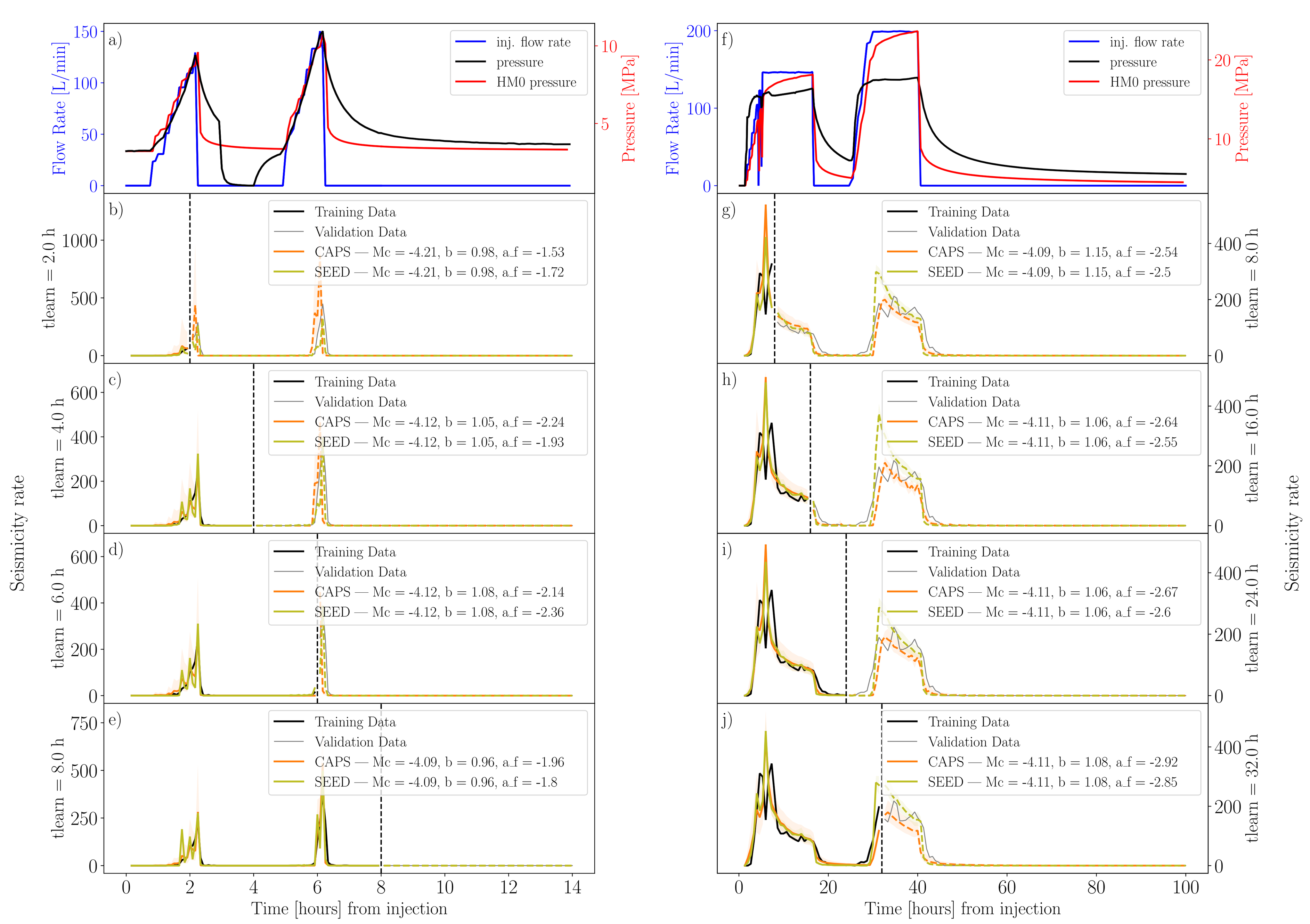


Fig. 3: Pseudoforecast results for both hydraulic stimulations: a) - e) for Valter phase 1 interval 13, and f) - j) for Valter phase 2 interval 8. The seismicity rate is shown for four learning times since the beginning of injection: 2, 4, 6, and 8 hours for phase 1 int. 13 (b) - e)), and 8, 16, 24, and 32 hours for phase 2 int. 8 (g) - j)). Continuous lines show the fit in the training phase while dashed lines show the forecasts in the forecast/validation phase for CAPS (orange) and SEED (green). The top subplots, a) and f) , show the flow rate (blue) and the pressure (observed in black, simulated in red) for both datasets.

Performance evaluation and comparison

- The forecast performance of any model is assessed computing the natural logarithm of the probability of forecasting the observed seismicity rate at a given time window.
- The average cumulative "Log-Likelihood" (LL) as indicator of how close the forecast is to the observation.
- We compare the performance of the SEED model with respect to CAPS via probability gain (PG) by taking the difference of their probabilities.

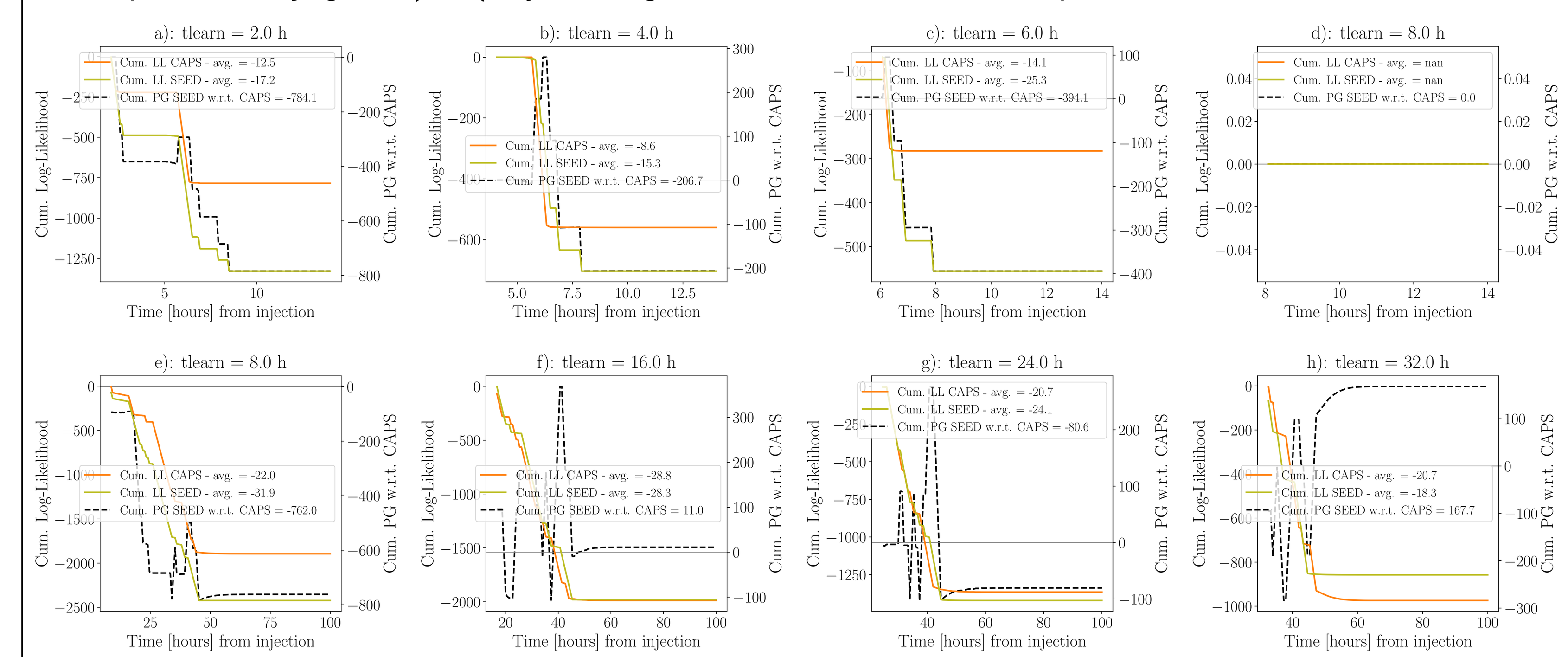


***Fig. 4**: Cumulative of the "log-likelihood" of the probabilities (continuous lines; left y-axis) for both models and cumulative probability gain (PG) of the SEED model with respect to CAPS (dashed line; right y-axis) for both hydraulic stimulations (a)-d) Valter phase 1 int. 13, e)-h) Valter phase 2 int. 8) since each snapshot.*

Conclusion and Outlook

- The added uncertainty distribution on top of the CAPS' direct solution is wider than the stochastic variability of the SEED model, which allows to capture the observed data better (see cum. LL in Fig. 4).
- The average cumulative LL can serve as an indicator at which stage into the stimulation the models robustly forecast the observations.
- The SEED model is computationally more expensive than the analytical solution. However, the former can give more information on the retirggering of seeds, b-value variations, differential stresses, etc.

References

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