Post-production seismicity forecasting for Groningen

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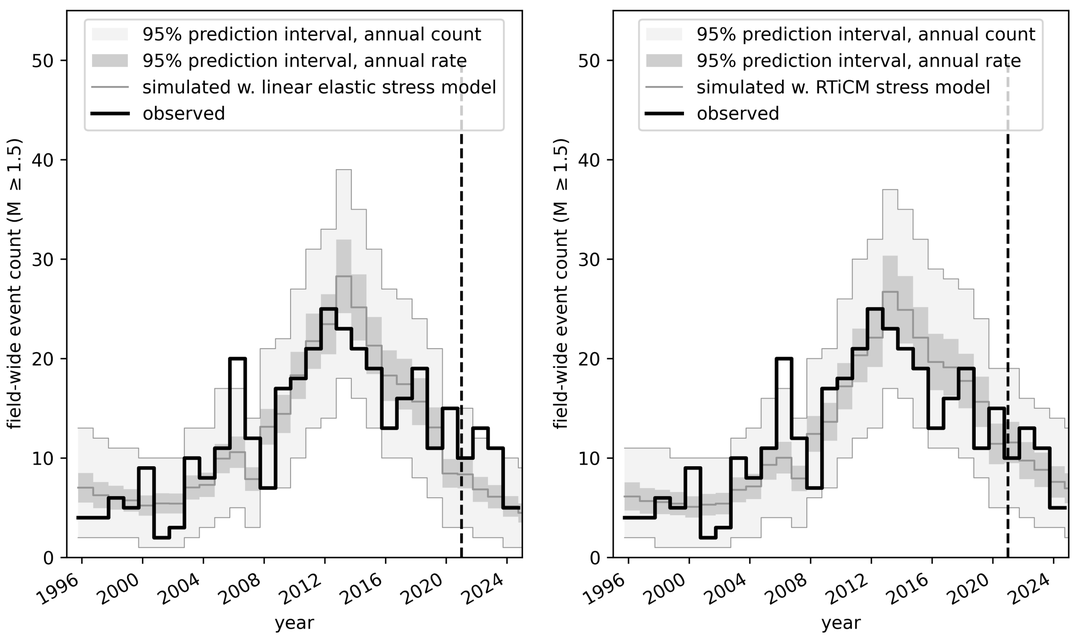
Background

After 60 years of gas production, the Groningen gas field ceased production on 1 October 2023, with approximately 500 billion cubic meters of gas remaining in place. As a result, the induced earthquake rate is expected to decrease. However, the observed seismicity appears to be declining less rapidly than expected based on the latest source model used in the *public Seismic Hazard and Risk Analysis* for Groningen (pSDRA23)[1]. This begs the question whether other models, which incorporate delay between the gas production and seismicity, may be more suited in the post-production era.



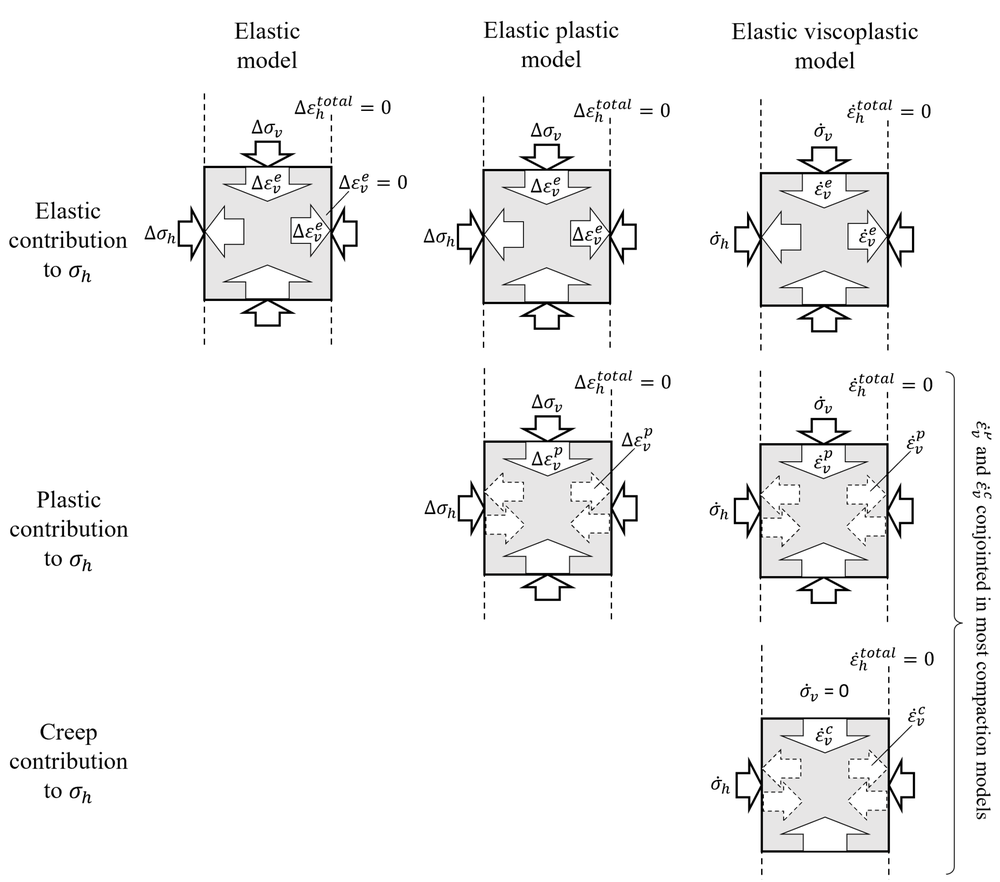
Approach

Most models source models for Groningen[2,3,4,5] compute seismicity in 2 steps:

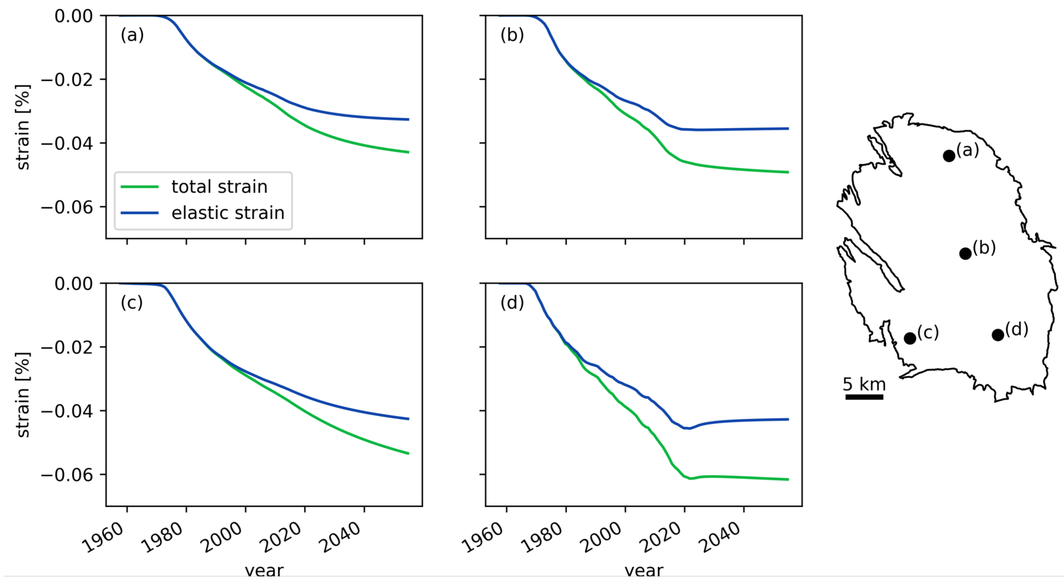
1. Gas production → stress changes on faults
2. Stress changes on faults → seismicity rate

The pSDRA23 uses a linear elasticity-based stress model, and a subsequent instantaneous failure model. Rate-and-state-based[6] models would provide temporal delay, but previous attempts[3] to apply such a model to Groningen found a poor temporal match to the data. Recently[5], a rate-and-state model with a threshold stress was proposed to improve the temporal match, but we find it fails to match spatio-temporally and is therefore unsuitable for forecasting earthquake activity in the Groningen field.

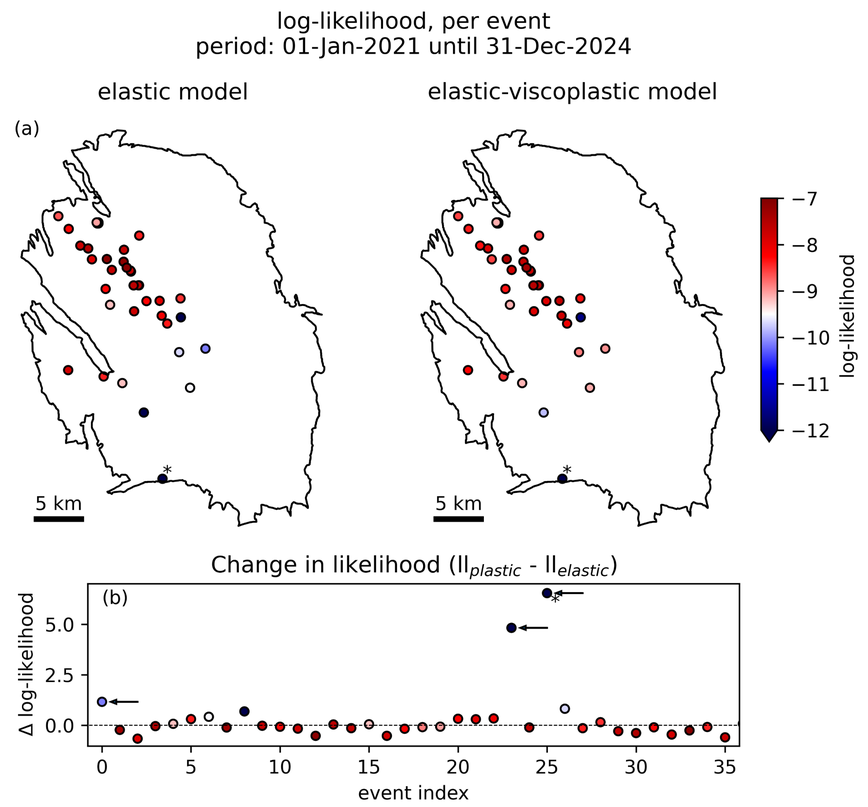
Here, we test an alternative approach for incorporating temporal delay, by implementing the Rate-Type isotach Compaction Model (RTiCM)[7].



Results



We find that the forecasting performance of the seismic source model that includes RTiCM improves for the evaluation period 2021-2024 for the forecast as a whole, and for almost every individual event.



Through leave-one-out-cross-validation (LOO-CV) we obtain model weights for the elastic and RTiCM-based seismicity rate models based on the entire seismicity catalogue from 1995-2024 which is approximately 40:60 (elastic : RTiCM). The elastic model performs better through earlier years, while the RTiCM model performs better in more recent years.

Discussion

Reliable and robust earthquake forecasting remains important for the Groningen region, even though the gas production has stopped. We have shown that the RTiCM model leads to a better seismicity forecast compared to the linear elastic model for recent years (when gas production was either extremely limited or completely stopped). As such we expect it to be a better forecasting model for the future. This has implications for the future seismic hazard and risk, as the RTiCM model forecasts seismicity rates to be ~2x higher than the linear elastic model through the years 2030-2050.

References

1. TNO 2023 R10682
2. Bourne and Oates 2017
3. Candela et al., 2019
4. Dempsey and Suckale 2017
5. Kaveh et al., 2024
6. Dieterich 1994
7. Pruiksma et al., 2015

full refs →