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A Stochastic Modelling Approach to Induced Seismicity Risk Mitigation

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Summary

Efforts to quantify induced-seismicity risk and to develop mitigation strategies are hampered by a dearth of numerical schemes that can accommodate realistic Earth models while capturing the full spectrum of applicable physics. Here we present a new approach to modelling induced seismicity, whereby the three principal models for induced seismicity triggering mechanisms are accounted for, and uncertainties in input parameters are addressed stochastically to provide a probabilistic assessment of induced seismicity risk.

Theory / Method / Workflow

Anthropogenic fluid injection into the subsurface is known to produce induced seismicity. Well-known examples include enhanced geothermal systems (Lee et al., 2019), wastewaster disposal (Ellsworth, 2013) and hydraulic fracturing (Bao and Eaton, 2016). Several models have been proposed to explain the mechanisms of fault activation by fluid injection. The most common is an increase in pore pressure within the fault zone, which leads to a reduction in effective normal stress acting on the fault (Bao and Eaton, 2016). Alternatively, poroelastic coupling between hydraulic fractures and the rock matrix is capable of altering fault-loading conditions without any hydraulic connection (Segall and Lu, 2015). However, a new model was recently suggested by Eyre et al. (2019) for hydraulic fracturing-induced seismicity whereby aseismic slip may play a major role. More specifically, distal, unstable regions of a fault are progressively loaded by aseismic slip on proximal, stable regions of the fault which is stimulated by pore pressure changes due to fluid injection. This model has significant implications for mitigation of induced seismicity. First, if we better understand the driving process, we can improve models that can be used to simulate injection scenarios. Additionally, the model suggests that there is a measurable slow slip/deformation signal that is present significantly (~ hours) prior to the nucleation of an induced earthquake, which may aid monitoring and mitigation efforts.

Our new modelling approach accounts for the three mechanisms above by assessing stress changes due to both pore pressure changes, poroelastic effects and slip-induced stress changes, while also acknowledging that not all slip induced by these changes is likely to result in seismicity. Simulations can be run a large number of times for input parameters that are assigned stochastically from distributions that can be based on the available knowledge of the area. Regions of modelled faults that exceed failure criteria (e.g. dark red region in Figure 1) are mapped and provide estimates for the magnitudes of any seismic events that may occur. In this manner, we can estimate the probabilities of generating an event of a certain magnitude based on the modelled injection scenario and parameter distributions. Figure 2 shows an example of the results of a model run for 10,000 iterations. Based on the obtained results, we can estimate that the probability of a magnitude 2.0 event is 0.0072 and a magnitude 4.0 event is 0.0002.

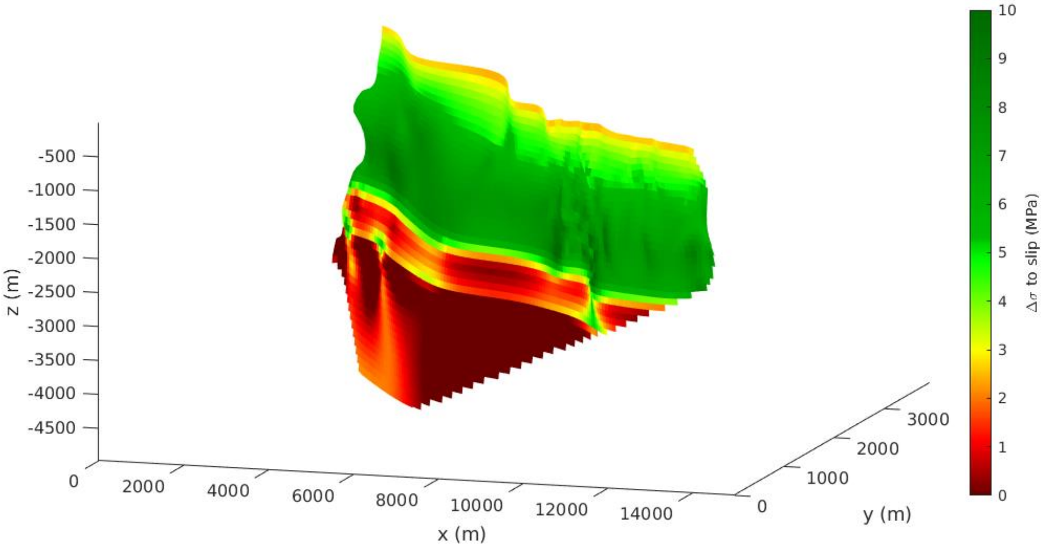

Figure 1. Example of the change in effective stress on a fault required to slip.

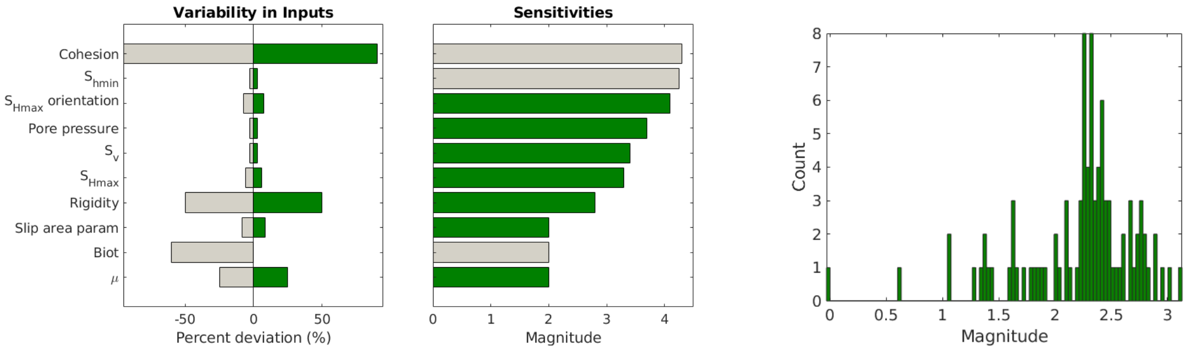

Figure 2. Example of the input parameter distributions and sensitivities of the results shown as tornado plots. Simulation results for 10,000 iterations are also shown (right).

Results, Observations, Conclusions

During the ongoing development, the modelling is being tested for various case studies from the Western Canadian Sedimentary Basin and also a number of other basins worldwide. We are developing this modelling into a user-friendly software package. Ultimately, our work aims to significantly reduce the financial, environmental and social risk of induced seismicity, as well as the potential to cause damage to local populations and infrastructure.

Acknowledgements

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