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Stochastic Modelling of Induced Seismicity in Enhanced Geothermal Systems using a Continuous Time Random Walk approach

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Enhanced Geothermal Systems (EGS) provide an alternative energy source that exploits geothermal energy stored into deep “hot” rock formations. Typically, the development of an EGS requires stimulation (permeability enhancement), which is achieved by massive fluid-injections under high pressure into the deep rock formation. Such fluid-injections can induce several small to larger magnitude earthquakes, posing a risk to nearby communities and infrastructures, as well as to the sustainability of the project. The efficient spatiotemporal modelling of such induced earthquake sequences in EGS is thus of primary importance in order to monitor operations, quantify the associated seismic hazard and gain information regarding the geometry of the stimulated reservoir. Injected fluids into the subsurface can migrate away from the well, reducing the effective normal stress along fracture zones and inducing earthquakes at distances that may vary from few meters to several kilometers away from the industrial site and at timescales that may vary from few days to months or even years. The diffusion process associated with the migration of pressurized fluids in the subsurface is fundamentally a nonlinear process, associated with the highly heterogeneous and multi-fractured crust that produce anisotropic diffusivities that vary both spatially and temporally by several orders of magnitude. Here we use data from the Cooper Basin (Australia) geothermal field to show that during fluid-injection induced seismicity migrates slowly away from the well characterized by subdiffusion, in contrast to normal (“Fickian”) diffusion. The spatiotemporal scaling properties of the induced earthquakes indicate asymptotic power-law behavior, which can well be approximated by a generalized statistical physics model (e.g., Vallianatos et al., 2016), indicating non-Poissonian behavior and correlations in the evolution of the induced seismicity. Taking in account these properties, we develop a Continuous Time Random Walk (CTRW) model to describe the nonlinear propagation of the induced seismicity in space and time. The results from the Cooper Basin geothermal field show that the CTRW model can efficiently be used to describe the complex (nonlinear) evolution of fluid-induced seismicity.

References

Vallianatos F., Papadakis G., Michas G., 2016. Generalized statistical mechanics approaches to earthquakes and tectonics. Proc. R. Soc. A, 472, 20160497.

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