Seismicity rate surge on faults after shut-in: poroelastic response to fluid injection

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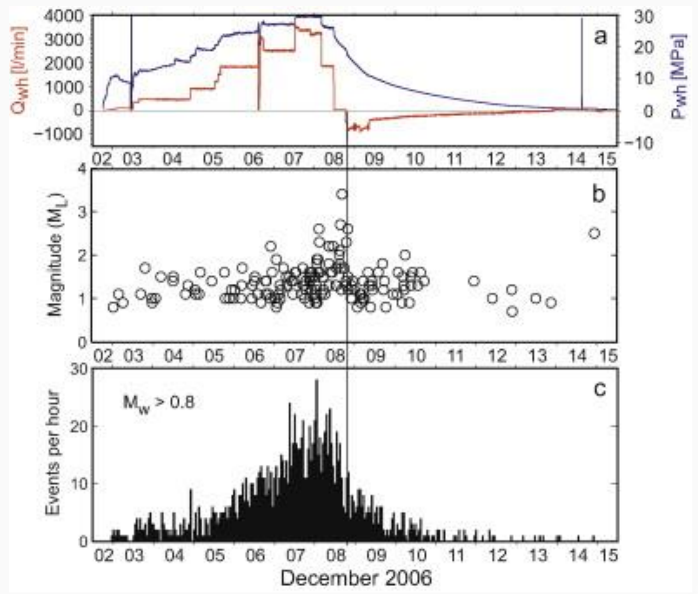
Motivations

- Injection of a large amount of fluids for subsurface energy activities can increase pore pressure and change the stress field, potentially inducing earthquakes.
- The increase in the seismicity rate has been observed even after shut-in of the injection well.
- Few mechanistic studies of the seismicity rate surge after shut-in have been performed

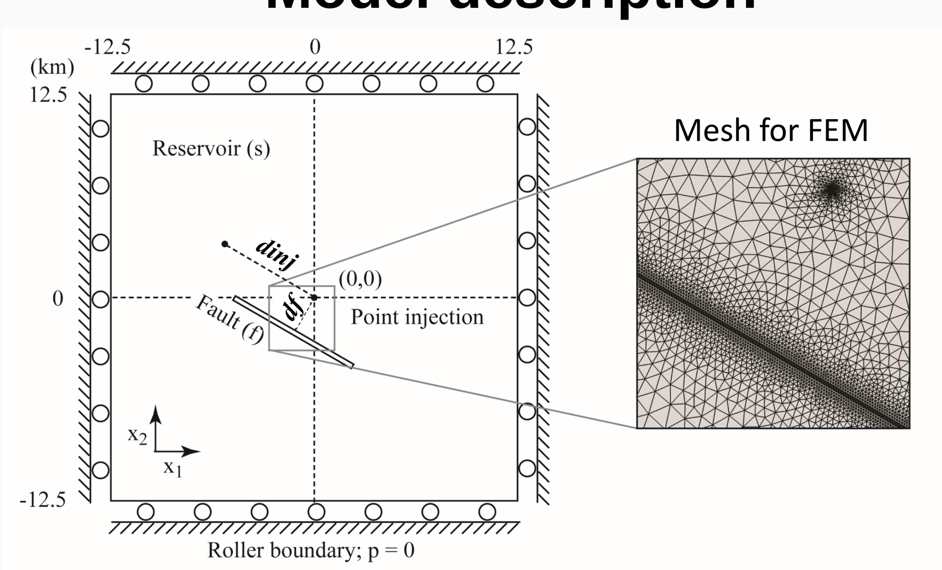


Basel EGS site, Deichmann (2014)

Objectives

- To understand the full poroelasic response of the faults to the fluid injection and perform the mechanical analysis along the fault zone.
- To evaluate the impact of injection-induced pore pressure buildup on the seismicity rate surge by a series of sensitivity tests
- To find a mitigation strategy (e.g. optimal well operations) to minimize the rate of post shut-in seismicity

Model description



- 2-D aerial view
- Poroelastic coupling system with the single-phase flow
- Injection for 10 days with the rate of 0.1 [kg/m/s], simulation runs for 20 days
- Looking at the perturbations from an initial state in equilibrium, such that
- Strike-slip fault(s)

$p(x,0) = \sigma_{ij}(x,0) = 0$

Coulomb stress change

$$\Delta\tau = \underbrace{(\Delta\tau_s + f\Delta\sigma_n)}_{\text{Poroelastic stress}} + \underbrace{f\Delta p}_{\text{Pore pressure}}$$

$\Delta\tau_s$ = shear stress change

$\Delta\sigma_n$ = normal stress change

Δp = pore pressure change

- (+) values of each quantity imply that the fault plane is moved closer to failure

Seismicity rate estimate

$$\frac{dR}{dt} = \frac{R}{t_a}\left(\frac{\dot{\tau}}{\dot{\tau}_0} - R\right)$$

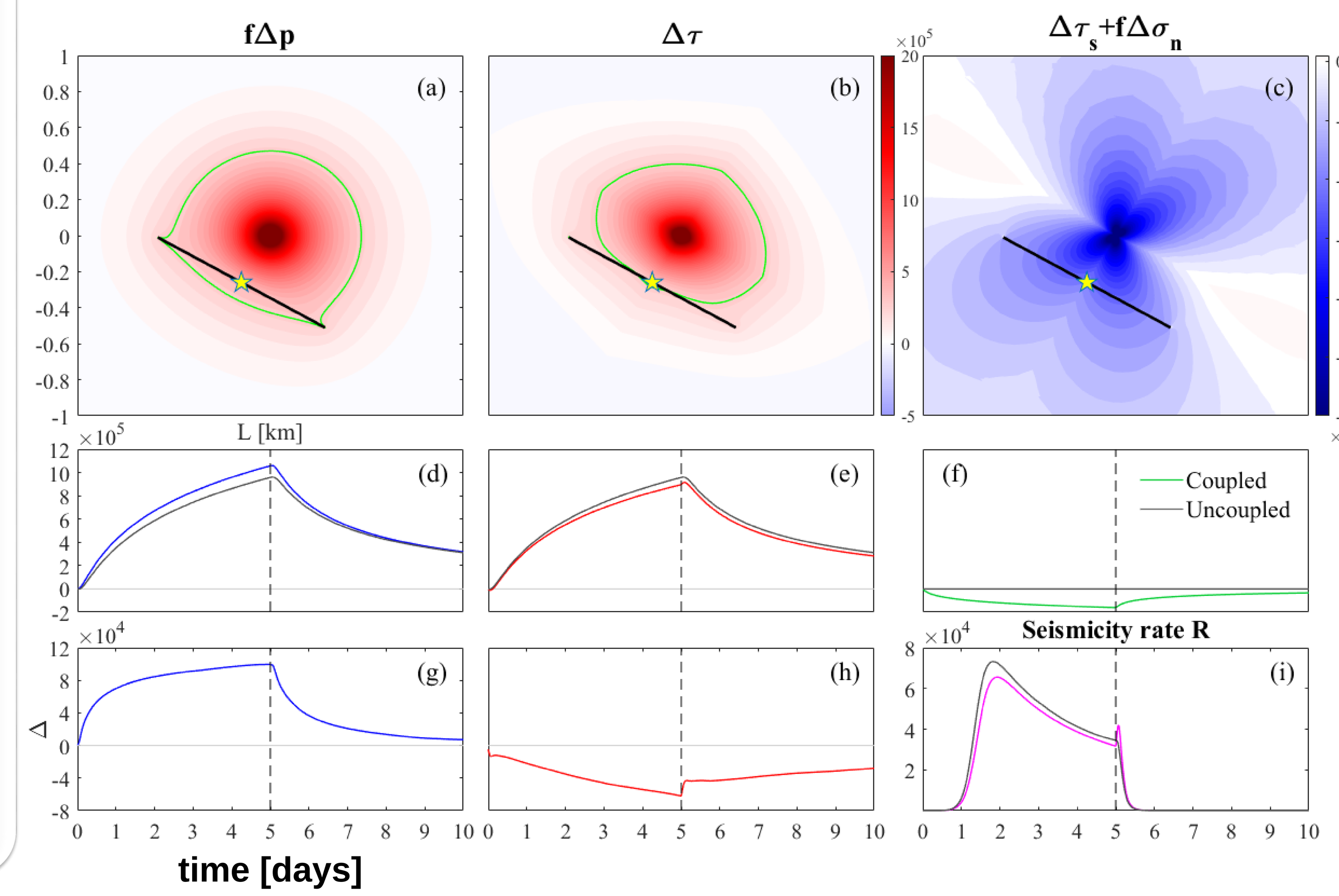
t_a = characteristic decaying time

- R is the seismicity rate relative to an assumed prior steady-state seismicity rate at a background stressing rate

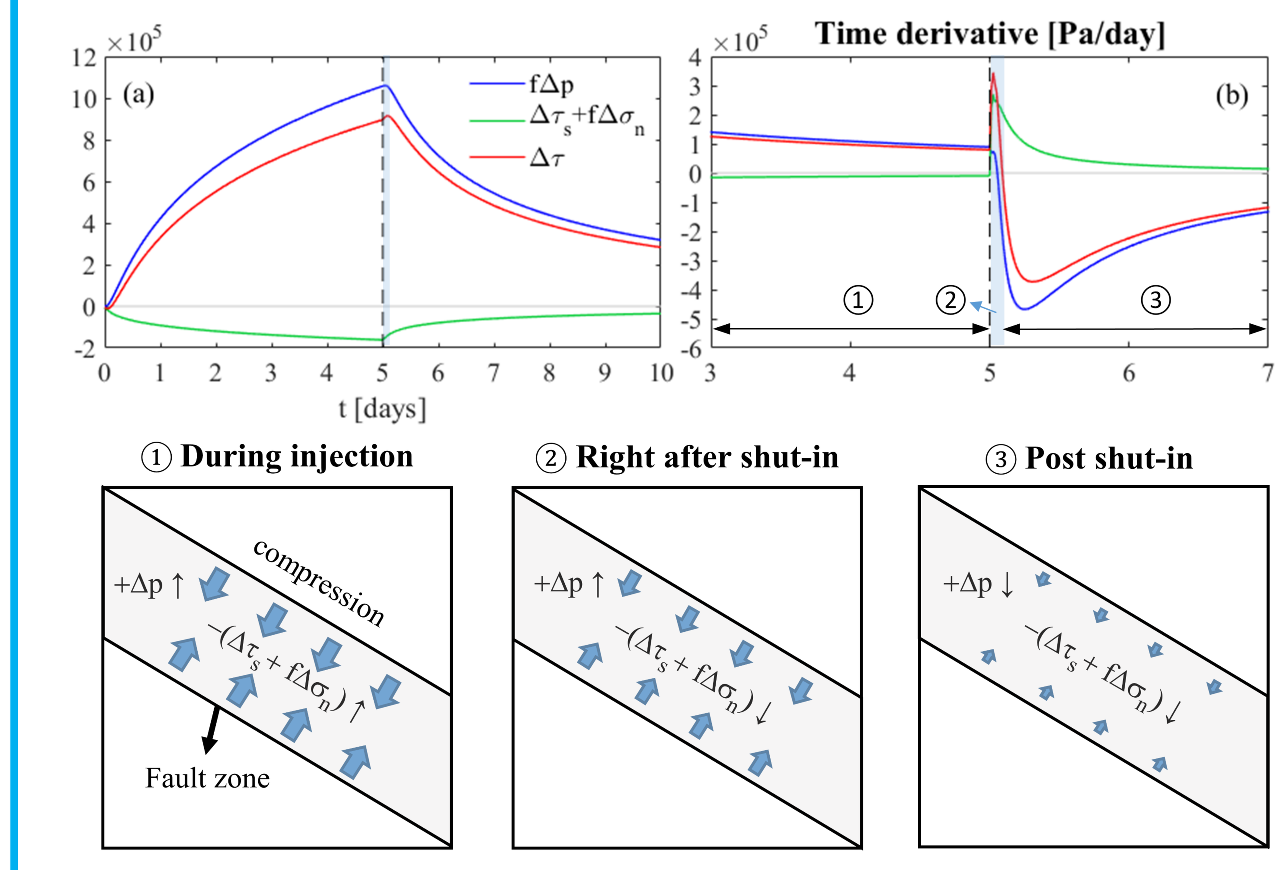
Simulation results

- Relaxation of poroelastic stressing causes seismicity rate surge after shut-in (**Case 1&2**).
- Closer to the injector, faster pressure buildup causes higher R (**Cases 3&4**).
- The permeability contrast causes higher R after shut-in due to poroelastic stressing and delayed pore-pressure diffusion (**Case 5**).
- The additional conductive fault acts as a mechanical/hydraulic cushion while the sealing fault confines pore pressure (**Case 6**).
- Gradual increases in injection rate before shut-in results in higher R (**Case 7**) and short-term injection with high injection rate generates higher R (**Case 8**).

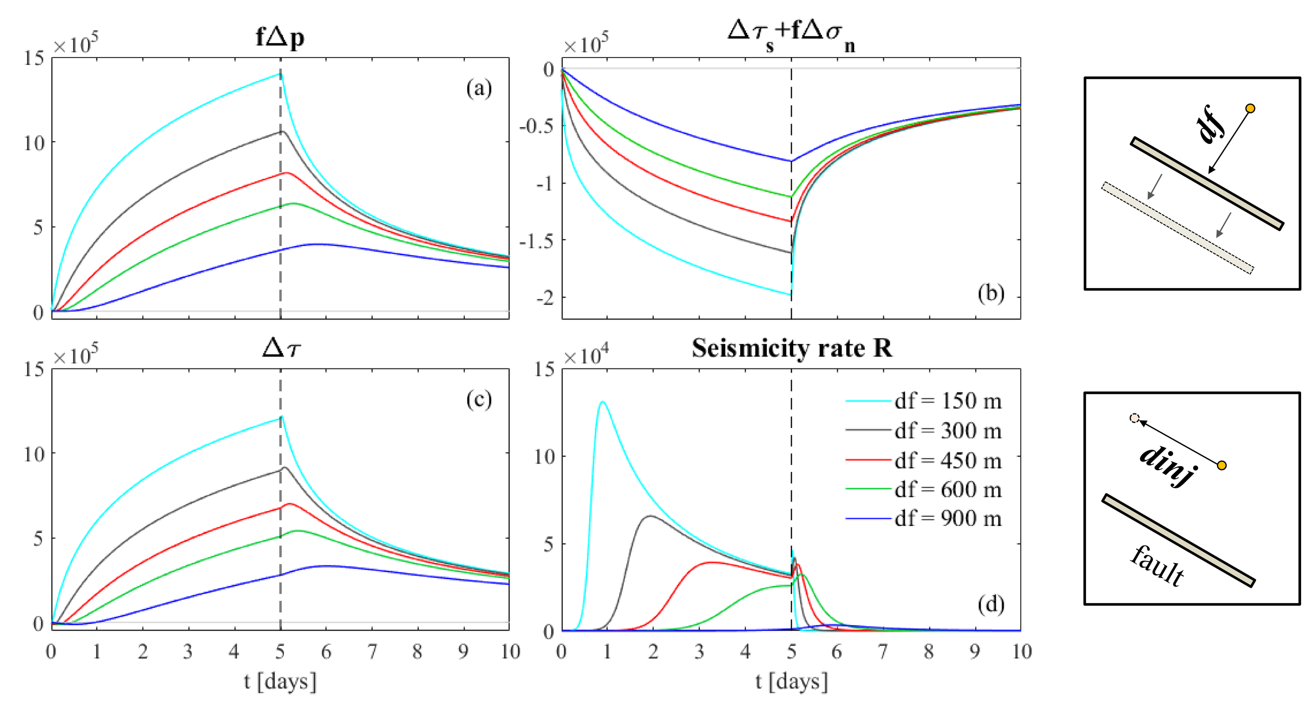
Cases 1 & 2: Coupled vs Uncoupled



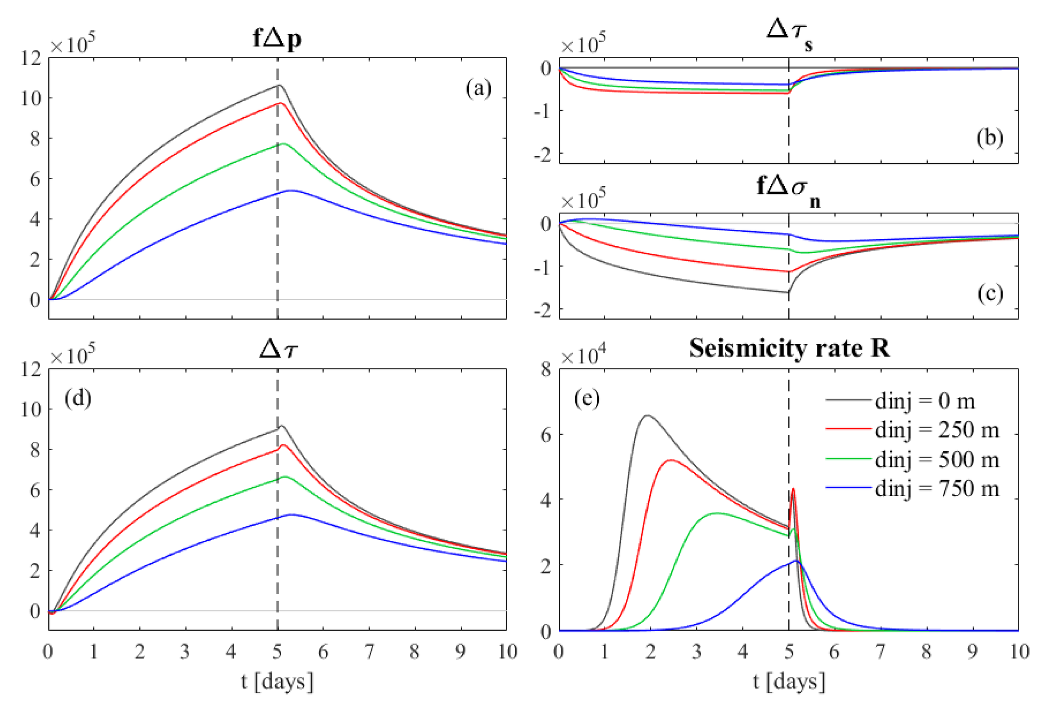
Mechanism of poroelastic behavior



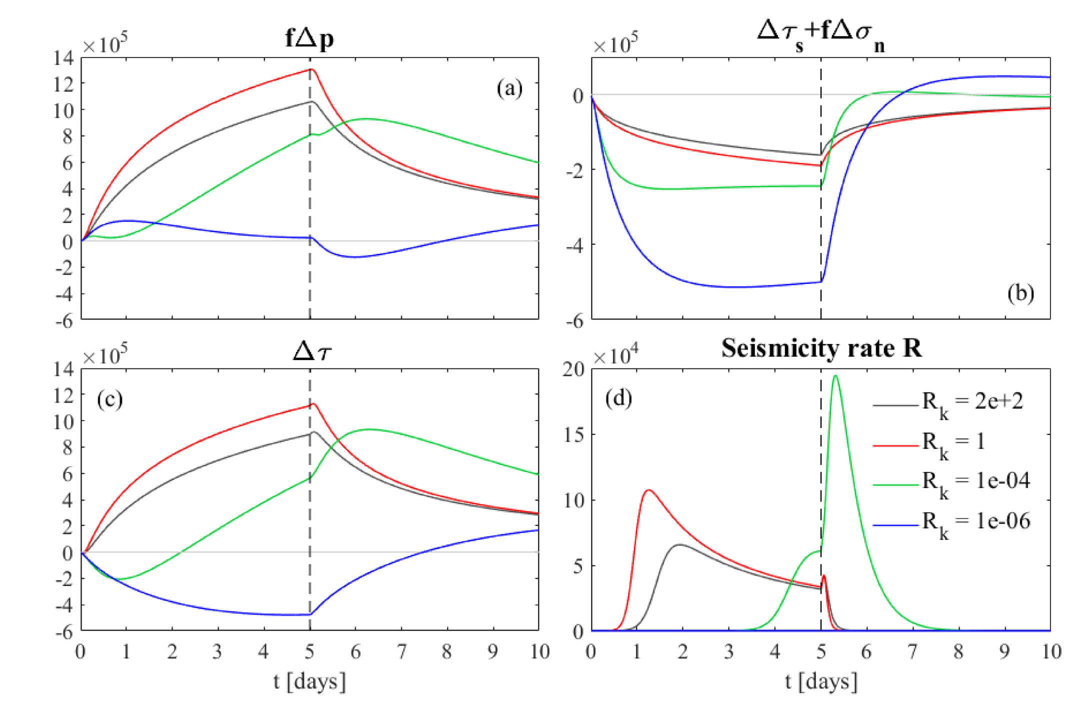
Case 3: Fault distance (df)



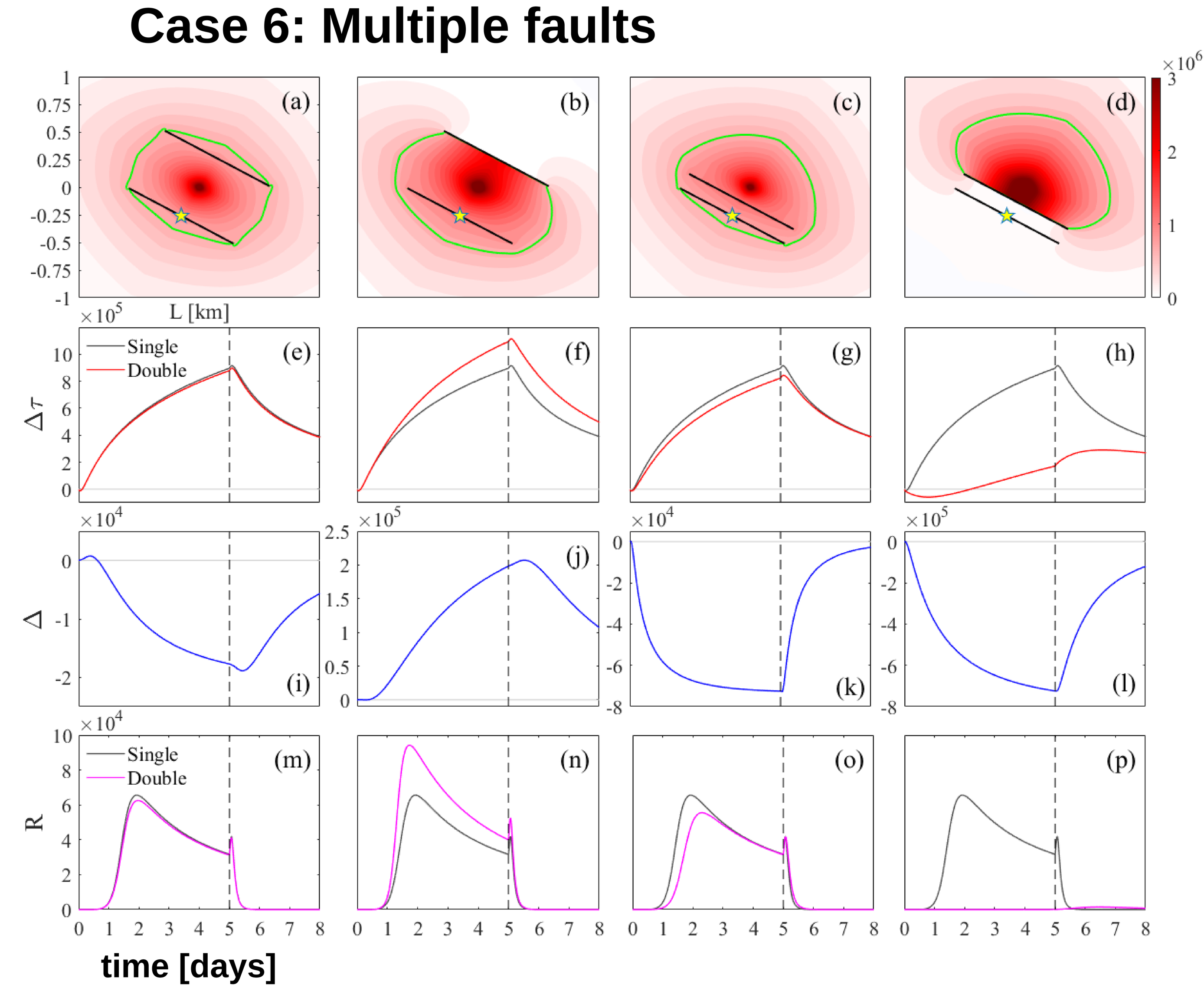
Case 4: Fault distance (dinj)



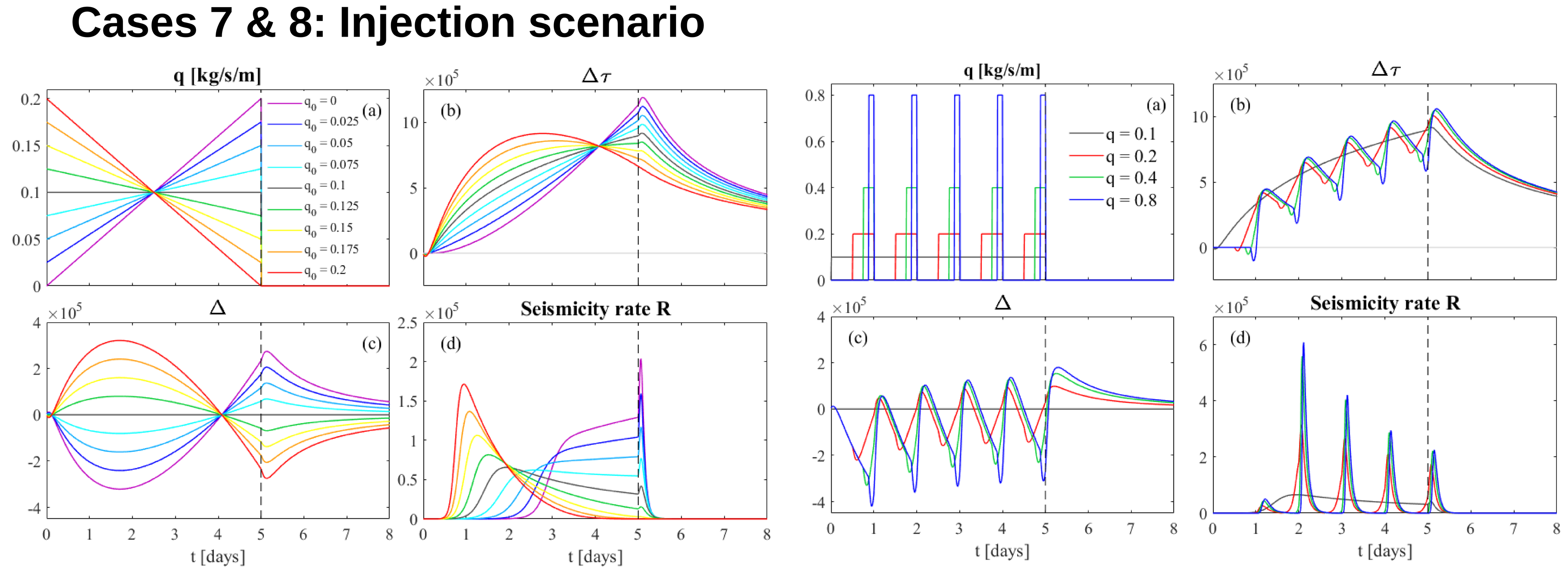
Case 5: Fault permeability



Case 6: Multiple faults



Cases 7 & 8: Injection scenario



Suggestion for optimal well operations

- Moderate injection with tapering operation can provide enough time for the relaxation of injection-induced poroelastic stresses that can minimize earthquakes after shut-in.

References

1. Deichmann et al. (2014), Geothermics, 52, 84-97
2. Chang & Segall (2016), JGR-Solid Earth, 121(4), 2708-2726
3. Segall & Lu (2015), JGR-Solid Earth, 120(7), 5082-5103

Acknowledgments

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