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Numerical Simulation Insights into the impact of tidal stress on seismicity

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Earthquakes result from the accumulation of stresses in the Earth's crust. Tidal stress is typically a few kilopascals, with primary components having periods of about 12 and 24 hours. Observational studies show that slow earthquakes are sensitive to tidal stress (Rubinstein et al., Science, 2008; Nakata et al., NG, 2008; Thomas et al., Nature, 2009), while the effect of tidal stress on ordinary earthquakes remains debated (Vidale et al., JGR, 1998; Tanaka et al., JGR, 2002; Ide et al., NG, 2016). Here, we investigate how small tidal stress can modulate seismicity (earthquakes and slow slip events) within the framework of rate-and-state friction.
We focus on two key questions regarding tidal modulation of seismicity: First, can tidal stress induce earthquakes on stable sliding faults? Second, how does tidal stress modulate the timing and magnitude of earthquakes on unstable faults with stick-slip behavior?
To explore these questions, we perform simulations using spring-slider model with rate-and-state friction and the aging law, considering typical tidal stress perturbations on normal stress for stable sliding faults (k = 1.1 kc) and unstable faults (k = 0.9 kc).
It has been found that for stable sliding faults, as the perturbation amplitude ratio increases, stable sliding transitions to single periodic oscillations. Further increase in amplitude leads to larger and more complex oscillations. In addition, resonance phenomena have been observed (Perfettini et al., GRL, 2001). At a perturbation amplitude ratio of 0.1%, the slip rate increases by about 5 times as the perturbation period nears the resonance period. At a perturbation amplitude ratio of 1%, slow slip events are generated, but no earthquakes occur. For unstable faults, the effect on earthquakes is very small at realistic tidal perturbation amplitude ratios. These results suggest that tidal stress may enhance slip rate, leading to local stress accumulation, which indirectly promotes slow slip events, or directly increase local stress, triggering slow slip events. However, under the given conditions, the effect of tidal stress on earthquakes is negligible.
We also further investigate the continuum two-dimensional fault model with a velocity-weakening zone surrounded by velocity-strengthening zones, focusing on the effect of tidal stress on the nucleation of both earthquakes and slow slip events, thereby extending and validating the results obtained from the spring-slider model above.

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