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Earthquake cycle (spring-slider) simulation with a modified slowness law including shear stress-dependent evolution

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It is well recognized that rate- and state-dependent friction (RSF) laws cannot capture all the aspects of friction observed in the laboratory, whereas its credential comes from the fact that it is based on laboratory data. Nagata [2009] has made two important corrections to RSF. First he has shown the value of direct effect coefficient "a" is much larger than the value obtained earlier, by using a novel experimental method to constrain the lower bound of "a" without using any evolution law that has been questioned. Second he has found a rather strong negative effect of shear stress, tau, on evolution and proposed a new evolution law in which the shear stress-dependent evolution has been added to the original Dieterich's slowness law. We refer to this revised law as "Modified Dieterich Law (MDL)".

MDL has been revealed by direct comparison of state variable values predicted by the original Dieterich law and the value obtained continuously from experiments by subtracting a*sigma*ln(V/V0) from the measured stress [Nakatani, 2001], where "sigma", "V" and "V0" are the normal stress, slip velocity and reference slip velocity, respectively. All types of laboratory experiments (quasi-static contact, slip resumption, and velocity step) on a typical rock friction setup (granite surfaces) were well reproduced by MDL with parameter values (a, b, L) = (0.005, 0.0056, 0.33 micron), where "b" and "L" are experimentally determined RSF parameters and "L" is especially denoted as a characteristic slip weakening distance in RSF. Although velocity step part can be also well reproduced by the original Dieterich evolution law with the traditional small sets of (a, b) = (0.017, 0.0225) and L (= 0.63 micron), this cannot be the true reproduction because such a small "a" value has been rejected independently of evolution laws. Nagata [2009] further pointed out that what has been compromised in traditional approach was the reproduction of state variable. He additionally demonstrated this point by monitoring the contact state during experiments by acoustic method [Nagata, 2008].

This is a major revision of RSF and we thus examine the outcome of this change in earthquake cycle simulations. As a first step, we present results with a simple spring-slider model. We compare the results with the both evolution laws with the parameter values mentioned above except that we suppose 10E+6 times larger values of L in order to scale them up to earthquake dimension. We adopt the loading velocity VL = 0.45 m/year, the spring stiffness k = 4.4 MPa/m, and the natural period of the spring-slider system Tn = 5 sec. The both models resulted in similar regular stick-slip cycles (Trecurrence = 158 year and Coseismic slip = 7 m for the original Dieterich law, Trecurrence = 136 year and Coseismic slip = 6 m for MDL). Both showed similar accelerating preslips (0.67 m for the original and 0.8 m for MDL), whose velocity exceeds VL, a few years before the mainshock, and reaching 1 mm/s just before the mainshock. However, state variable (defined as tau - a*sigma* ln(V/V0), natural extension of traditional frictional strength [Nakatani, 2001]), changed for 69 MPa for MDL, much greater drop than 26 MPa for the original Dieterich law under the assumed effective normal stress (100 MPa). This is due to the higher slip-weakening rate (b/L) in MDL, which is 5 times greater than that in the original Dieterich law.

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