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Macroscopic frictional work and energy partitioning during dynamic earthquake propagation.

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Geological observations and laboratory experiments indicate that slip in real fault zones is localized in a narrow slipping zone within a gouge layer. Ruptures propagate within such fault zones and the earthquake energy balance is certainly conditioned by various dissipative and anelastic processes occurring during dynamic failures. Propagation of earthquake ruptures along the principal sliding zone is accompanied by dynamic fault weakening. This weakening is represented by the dynamic traction evolution in which, as slip increases, traction drops from an upper yield stress to a residual kinetic stress level. One significant consequence of this complex fault structure involves the main observable physical quantities which characterize the rupture process. The shear stress, slip and slip velocity commonly used in numerical rupture models to describe dynamic fault weakening in various constitutive formulations should be considered to be macroscopic averages of complex processes occurring within the slipping zone (asperity fractures, gouge formation and evolution, etc…). For these reasons, we should regard these physical quantities as macroscopic variables. In this context, fault friction should also be considered in a macroscopic sense or as a phenomenological description of complex processes occurring within the fault core.

The fracture energy is one of the key ingredients required to describe the energy flux per unit area at the crack-tip. It represents the dynamic energy release rate required to allow the crack to advance in a fault zone, creating a dislocation. It is currently measured in a stress-slip plot as the area between the stress curve and the residual stress level. This parameter is of relevance to define classical fracture criteria and it has been estimated both through laboratory experiments and seismological investigations. For any real material fracture energy is not identical to surface energy (energy that goes into fracture of mineral grains and gouge formation). Even in a quasi-brittle cohe-

sionless crack the effective surface energy (Kostrov and Das, 1988, equation 2.3.1) contains contributions from different dissipative processes at the crack tip. Following the classic formulation of the earthquake energy balance proposed by Kostrov and Das (1988), we define the macroscopic frictional work either for the whole fault (global) or for a specific fault position (local). In order to identify the energy flux on the fault surface, we discuss the mechanical work and its partitioning into surface energy and heat at a single specific point on the fault plane. The evaluation of the fracture energy at a specific point on the fault plane is not a common procedure and relies on knowledge of the dynamic traction evolution. Tinti et al. (2005) have defined an alternative measure of work to be used instead of fracture energy to characterize traction evolution curves from kinematic models of real earthquake ruptures. These authors defined "breakdown work" at a specific point to be the excess of work over the minimum (magnitude of) traction experienced during slip. For real earthquakes breakdown work contains a relative proportion of heat and surface energy which is impossible to determine using only seismological data. We will present the distribution of breakdown work on the fault plane for several recent earthquakes; the average values range between 10^5 J/m^2 and 10^7 J/m^2 and agree with previous estimates available in the literature. Breakdown work density and its integral over the fault scale with seismic moment according to a power law with exponents 0.57 and 1.18, respectively.