



Fluctuation-dissipation Theorems for Granular Avalanches

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Fluctuation-dissipation theorems for avalanches flowing in a frictional / collisional regime are derived using work-energy concepts. These are: (i) the source of granular fluctuations is the basal slip volume (ii) random granular collisions can exert no resultant force in the mean against the downward motion of the avalanche when using a Gaussian distribution for particle fluctuations and (iii) the generation of fluctuation energy at the basal layer and destruction of fluctuation energy in the core of the avalanche must be in balance in steady state flow. These theorems require two complementary mechanisms, viscous shearing and inelastic collisions, to account for the dissipated energy. This suggests, in turn, that granular avalanches can be effectively treated as near-equilibrium thermodynamic systems. We demonstrate the usefulness of this approach by applying the theorems to construct constitutive relations to model the flow of real snow avalanches.