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Controls on the mass balance of earthquakes

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Large earthquakes deform the Earth's surface and drive topographic growth in the frontal zones of mountain belts. They also induce widespread mass wasting, reducing relief. The sum of these two opposing effects is unknown. We have constrained the mass balance of 12 earthquakes with a compressional component, ranging from Mw 6.5 to Mw 8.6, by comparing the volume of triggered landslides with the co-seismic uplifted volume computed with Okada's surface deformation theory. Landslide volumes were estimated from published landslide maps with a global area-volume relation and corrected for artifacts that have significantly affected some earlier studies. Combining our new data with older datasets we have determined a new empirical relationship between triggered landslide volume and earthquake moment, corrected for the peak slip depth of the rupture to account for seismic wave attenuation. Comparing this relationship with theoretical coseismic uplift we conclude that the destructive or constructive character of an earthquake does not depend on its seismic moment. Instead, the peak slip depth plays a key role in setting the attenuation of seismic wave amplitudes and thus how much shaking will occur at the surface. Only the shallowest earthquakes appear to have the potential to destroy topography, while other aspects of the earthquake source mechanism are only of secondary importance. Seismically induced mass wasting in the period after an earthquake may shift the mass balance towards erosion, but two well-constrained cases show that its effect on the total eroded volume is highly variable from one earthquake to another. The erosional effect of an earthquake further depends on the topographic sensitivity of the excited landscape as well as the mechanical properties of its substrate. Thus, seismic, geologic and geomorphic parameters together determine the mass balance of an earthquake, in a way that mostly leads to mountain building.