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The largest earthquakes on Earth: Comparison of magnitude-frequency distributions of tectonic and impact events

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There is an ongoing discussion about the maximum possible magnitude of tectonic earthquakes, and over which function best describes the magnitude-frequency distribution of the largest ones. Subduction zones have produced the largest observed earthquakes, up to magnitude ~ 9.5, and published geometrical constraints on earthquake rupture size suggest that the upper physical limit may be not more than one magnitude unit larger.

But indeed, the shaking due to the infrequent impacts of large asteroids or comets with Earth may reach even larger magnitudes. In impacts of the size of the Chicxulub event, previous modelling shows that the whole planet is affected by portentous shaking, and the lens-like focusing of seismic waves is expected to produce ground motions with amplitudes in excess of several metres even at the antipodes of the impact. Since there is not known upper limit for the energy of impacts on Earth, there may be a crossover magnitude above which impact earthquakes are more frequent than tectonic ones, for extremely rare but catastrophic events.

This presentation explores the contribution of impacts to the largest earthquakes on Earth. Direct observations are limited to atmospheric impact fireballs, especially detailed for the last decades. The measured shaking due to impact shock waves has been relatively modest so far. In the largest observed events (1906 Tunguska, magnitude ~ 5 and 2013 Chelyabinsk, magnitude ~ 4) the impactors disintegrated in the atmosphere, leading to a small coupling of shock waves to the ground. In turn, impactors larger than 50 m in diameter are expected to typically reach the surface and produce cratering, implying a larger conversion of impact energy to ground shaking. The rates of such large impacts are currently constrained by geologically-derived cratering rates and by the orbital modelling of the population of near-Earth asteroids.

The magnitude-frequency distribution of tectonic earthquakes is here in turn extrapolated considering several functional forms (either untruncated, truncated or tapered). For the truncated case, a potential maximum magnitude is assessed, based on the geometry of subduction zones and the extrapolation of updated empirical relationships between earthquake rupture dimensions and moment magnitude.

Seismic shaking is expected to be a minor hazard in large impacts compared to other effects (such as cratering, wind blast, overpressure shock, thermal radiation, and tsunami generation), but it potentially poses a non-negligible contribution to global seismic hazard in very long return periods.