Effect of the Sumatran mega-earthquake on the global magnitude cut-off and event rate

To the Editor — The great Sumatran earthquake of 2004 allows us to assess the statistics and statistical stability of the global earthquake catalogue from the digital era. A key question is: do such mega-earthquakes continue to follow the Gutenberg–Richter (G–R) trend[1], or is there an observable cut-off[2]? Physically, there must be a cut-off at a rupture length less than that of the planet circumference, but where exactly is it? Extreme events can also affect the whole magnitude range through aftershock generation[3,4]; so a second key question is how stable is the event rate for events of all sizes? Both these questions have significant implications for assessing uncertainties in seismic hazard associated with the relatively short duration of the current catalogue compared with the relatively long average recurrence period for such mega-events. The results may also have implications for the interpretation of other time-limited geophysical time series that exhibit power-law scaling.

The most commonly cited earthquake recurrence model is the G–R law, $\log F(m) = a - bm$, where F here is incremental frequency, m is magnitude, a is related to the total event rate dN/dt and the slope b is approximately 1. This implies a power-law distribution in scalar seismic moment[1] M: $F(M) \propto M^{-B-1}$, where M is the product of rupture area, average slip and rigidity modulus; $B = 2/3b$; and $\log M$ (in N m) = 9.1 + 1.5m. Finite tectonic moment release rates, dM/dt, have been used to show that the most likely form of truncation in the absence of other constraints is an exponential tail to the distribution of the generalized gamma form $F(M) \propto M^{-B-1}e^{-M/\theta}$, where the characteristic moment θ defines a gradual cut-off[2].

Prior to the Sumatra event, the simplest distribution consistent with the data from the Centroid Moment Tensor Catalogue (1 Jan 1977–30 June 1999) had been inferred to be a gamma distribution, using an appropriate statistical information criterion and assuming a conservative Poisson distribution of errors in incremental frequency[5]. We repeat this analysis for $m \geq 5.75$ and depths up to 70 km for the same time range, and compare it with a similar analysis of data up to end December 2006. The depth range is appropriate for shallow earthquakes, and the magnitude range is sufficiently high to ensure all events of this size have been recorded[6]. The gamma distribution is preferred for data up to 30 June 1999 (Fig. 1a, green line). For data up to 31 December 2006 the G–R law is now the best fit (Fig. 1a, black line): the great 26 December 2004 earthquake and its aftershocks have quantitatively straightened the line on Fig. 1a. This indicates that the cut-off moment is larger than previously thought, and in effect cannot be constrained accurately at present by the data.

In contrast, the total average monthly global event rate has increased from 14.3 to 14.7 since 1990, and has been more or less constant in the last decade or so (Fig 1b). The great Sumatra earthquake and its aftershocks perturb this trend by only ~1%, an amount limited by averaging over the 30-year length of the catalogue. Significant perturbation of the global event rate can now only be produced by events with a magnitude greater than the Sumatra event occurring in the relatively near future The standard deviation of monthly frequency for events of all sizes above the threshold has in fact increased systematically since 1990 and is now 5.2 events per month — some 36% of the event rate. We conclude that smaller magnitudes do have a much more statistically stable frequency of occurrence (at least within this relatively large standard deviation), but we will only be reasonably confident that statistical convergence across the whole magnitude range has occurred after the true cut-off for the global frequency-size distribution has been sufficiently sampled in time.

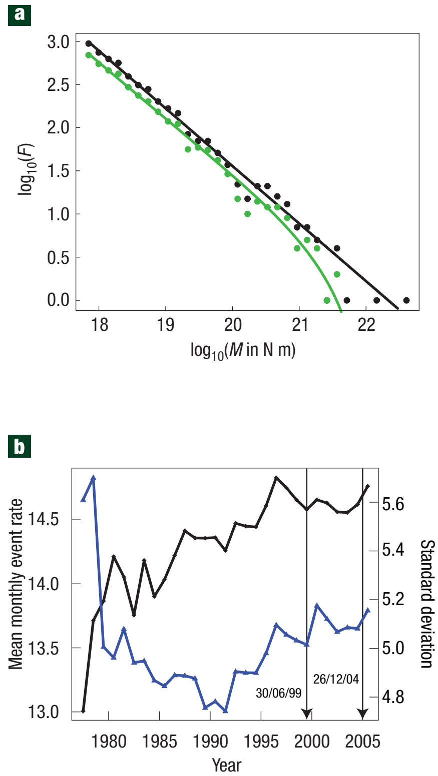

Figure 1 Results of statistical analysis. **a**, Incremental frequency F (summed over the time period of interest) versus seismic moment for the CMT catalogue up to the end of June 1999 (in green) and the end of December 2006 (in black), for events $m > 5.75$ at shallow (<70 km) depth since 1 Jan 1977. Best fit curves are shown as solid lines. For data used to fit the green curve, the difference in the Bayesian information criterion[5] ΔBIC of −3.5 implies that the gamma distribution is the best fit, with exponent $B = 0.637$ (±0.011) and cut-off moment $\theta = 2.18$ (+0.43, −0.60) × 10^{21} N m. For data used to fit the black line, $\Delta BIC = +1.0$, implying the G–R distribution is the best fit, with $B = 0.667$ (±0.010). **b**, Plot of the mean (black diamonds) and standard deviation (blue triangles) in the number of events per month for data between January 1977 and December in the end years shown.

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