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Fitting power-law distributions to geomorphological frequency-magnitude data: a good fingerprint for self-organised criticality?

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Frequency-magnitude analysis has long been a staple of geomorphology. However, in recent years increased awareness of self-organised criticality (SOC) has led geomorphologists to look at frequency-magnitude relationships in a new light. One fingerprint of SOC is a power-law frequency-magnitude relationship. Many geomorphological studies claim to have identified such a relationship, and thus suggest that SOC has a role in determining the dynamics of many kinds of geomorphological systems. If so, there are clear implications for the management of these systems, particularly with regard to extreme events.

But how conclusive is the evidence for SOC in geomorphological systems? This paper does not provide an answer. It does, however, question the methodology which is commonly used to determine whether geomorphological frequency-magnitude data are a good fit to a power-law distribution, and hence whether this SOC fingerprint is present.

The great majority of published studies which claim to have found a power-law in measured data have done so by fitting a straight line to the data as plotted on log-log axes. One of two techniques is invariably used to estimate the fit: simple visual inspection, or least-squares-based linear regression. Least-squares-based linear regression is of course more objective than visual assessment. Nonetheless, several studies point out that the use of least squares for linear regression in log-log cartesian space is problematic, giving rise to systematically biased estimates of the fit: e.g. Goldstein et al. (2004) calculated that the associated error could be as much as 36 %. This has implications for all studies which use linear regression to fit power-law lines.

A number of authors in the statistical literature (most notably Clauset et al., 2009) have recently proposed alternative, more robust, methods. These include logarithmic binning, linear fitting of only the first five points, least squares probability density function, least squares cumulative density function, and maximum likelihood estimation (MLE). Some of these approaches can be extended to determine whether a power-law is indeed the best fit, or whether the data would be better fitted by another tail-heavy distribution, such as the log-normal or the exponential. This paper presents the results obtained by fitting power-laws to Irish river flow data using MLE. Additional tests were also carried out to ascertain whether the power-law is a statistically appropriate model for the data. Results show that a power-law distribution cannot be ruled out for 19 of the 36 rivers in this study.