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E-MAIL CONTRIBUTIONS

One of this week's email contributors considers the consequences for earthquake predictions if they are indeed self-organized critical phenomena.

PER BAK

In order to understand the level at which we can expect to predict earthquakes, it is important to understand the dynamic nature of the phenomenon. Is it periodic? Is it chaotic? Is it random in space and time? Simple mathematical modelling, and comparison with empirical observations indicate that we are dealing with a self-organized critical phenomenon[1-4]. Using the notation of Pascal Bernard, these include **O5**, power law distribution of earthquake size and **O6**, fractal, power law distribution of fault segments, mimicking the highly inhomogeneous world-wide distribution of faults and fault-zones.

More interestingly, the earthquakes in SOC models are clustered in time and space, and therefore also reproduce the observation **O4**. This may give the strongest support for the SOC hypothesis, since no alternative models exhibiting this feature has been proposed. The distribution of waiting time between earthquakes of a given time is $T^{-\alpha}$. It is this feature that allows for prediction of earthquakes at level 2. and 3., beyond the level of chance, in Main's notation. Ito[5] has analysed a model previously introduced by Bak and Sneppen[6] in a different context. He found that the exponent α for actual earthquakes in California was well represented by a waiting time exponent $\alpha=1.4$, which compares well with the value obtained from the model, $\alpha=1.5$. This implies that the longer you have waited since the last event of a given size, the longer you still have to wait; as noted in Main's opening piece, but in sharp contrast to popular belief!.

For the smallest time-scales, this represents foreshocks and aftershocks. For the longest time-scales this implies that in regions where there have been no large earthquakes for thousands or millions of years, we can expect to wait thousands or millions of years before we are going to see another one. We can 'predict' that it is relatively safe to stay in a region with little recent historical activity, as everyone knows. There is no characteristic timescale where the probability starts increasing, as would be the case if we were dealing with a periodic phenomenon. The phenomenon is fractal in space and time, ranging from minutes and hours to millions of years in time, and from meters to thousands of kilometers in space. This behaviour could hardly be more different from Christopher Scholz's description that "SOC refers to a global state...containing many earthquake generating faults with uncorrelated states" and that in the SOC state "earthquakes of any size can occur randomly anywhere at any time".

Ironically, some real sandpiles[7] exhibit the oscillatory phenomenon depicted by Scholz but this has nothing to do with self-organized criticality! In fact, one of the independent arguments in favour of earthquakes as SOC is the relatively small stress drop (3 MPa), independent of earthquake size, compared to the absolute magnitude of the Earth's stress field at earthquake nucleation depths (300 MPa) (for review see ref. 8). Thus the stress change is sufficiently small that this type of oscillatory behaviour (for sandpiles with large changes in angle of repose) may be precluded.

Assuming that we are dealing with an SOC phenomenon, what can this tell us about the prospects of going on from statistical prediction towards the level 5 of individual prediction? Unfortunately, the size of an individual earthquake is contingent upon minor variations of the actual configuration of the crust of the Earth[8], as discussed in Main's introduction. Thus, any precursor state of a large event is essentially identical to a precursor state of a small event. The earthquake does not "know how large it will become", as eloquently stated by Scholz. Thus, if the crust of the earth is in a SOC state, there is a bleak future for individual earthquake prediction. On the other hand, the consequences of the spatio-temporal correlation function for time-dependent hazard calculations have so far not been fully exploited!

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