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How well do earthquake locations forecast future ones?

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It is debated whether the spatial distribution of past earthquakes is a good predictor of the locations of future ones. This is especially discussed for intraplate regions, where the few large earthquakes might alternate from one location to another, instead of recurring at the same sites where previous ones originated. This work points out that this debate may well have a geometric solution, and that the crucial issue would be how many earthquakes are available for analysis.

If earthquakes would reoccur exactly at the same locations, past epicentres would perfectly forecast the sites of future ones. In the opposite case, if epicentres were distributed with uniform probability over an area, past earthquake locations would be uninformative about future ones.

Reality lies in an intermediate case, in which earthquakes group in space (approximately in a fractal or multifractal way). So earthquakes in general tend to occur close to previous ones, but not necessarily at the same sites. The smaller the fractal dimension of this spatial distribution, the closer to each other earthquakes tend to occur, and the better past earthquake locations forecast future ones.

Here, a simple spatial forecast method is extensively used to test to what extent past epicentres forecast the location of future ones. The method calculates maps of spatial probabilities based on the empirical distribution of nearest-neighbour distances between epicentres. According to these maps, earthquakes are more likely to occur in the vicinity of past ones. As new earthquakes happen, the maps improve and self-sharpen. This method has no parameter, and assigns equal weight to the location of any past earthquake, regardless of its magnitude or origin time.

Tests are made with complete earthquake catalogues for different tectonic environments, and with up to tens of thousands of events, in:

- the whole Earth;
- Southern California (a transcurrent plate boundary);
- the Iberian Region (a “diffuse” plate boundary); and
- Australia (a stable continental region).

In all cases, the distribution of past epicentres forecasts well the location of the next one, but only after the first ~ 1000 events. The results show the same trend regardless of the tectonic region considered, and are very similar for all magnitudes. Similar results are obtained testing the method with points distributed at random on an artificial, fractal attractor.

This indicates that, for geometric reasons, a minimum number of earthquakes is required to constrain the spatial distribution of seismicity. Spatial probability maps may be unreliable if calculated with fewer epicentres. But, once this number is reached, the spatial distribution may potentially be extrapolated reliably (with improving resolution as more earthquakes take place), even in intraplate settings.

In consequence, a seismic hazard map may not be reliable if it is heavily influenced by the locations of just a few large earthquakes. To better constrain the spatial distribution of seismicity in hazard or forecast maps, the abundant small earthquakes would need to be considered with equal or similar weight as the few large ones.