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Robust estimation of seismogenic depths and their uncertainties

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Earthquakes occur in a depth range where the physical conditions allow rocks to behave as brittle and to deform in a stick-slip fashion. This range is limited by the so-called upper and lower seismogenic depths, which are input parameters for bounding seismogenic ruptures in models of seismic hazard assessment.

Usually, such limits are estimated from the observed depth distribution of hypocenters. An exact estimation is not possible, because earthquake locations (and particularly hypocentral depths) are uncertain. Also, the sample of observed earthquakes is finite, and shallower or deeper earthquakes than those so far observed at a site could eventually happen. For these reasons, the extreme values of the distribution (the shallowest and the deepest earthquakes in the sample) are weak estimators, especially if a small sample (with few earthquakes) is used.

A common, more statistically robust, proxy to those limits is a given percentile of the distribution of earthquake depths. For example, the 90%, 95% or 99% percentiles (named D90, D95 or D99, respectively) are frequently used as proxies to the lower seismogenic depth. But the actual uncertainties of such estimates are, so far, not properly assessed.

Here I present a method for calculating such percentiles with an unbiased estimator and quantifying their uncertainties in detail.

Earthquakes are more easily missed (more difficult to detect) the deeper they are. So earthquake catalogues preferentially contain shallow events. To avoid this bias, only those events with magnitude at least equal to the magnitude of completeness of the sample are regarded.

A mapping procedure is used in order to highlight spatial variations of seismogenic depths, considering, for each point in the map, the subsample of its closest earthquakes. Uncertainties arising from the finite sample size are dealt with by using bootstrap.

Each hypocentral location is randomized in space in a Monte Carlo simulation, to take into account the reported location uncertainties. Also, crustal earthquakes can be considered separately from deeper ones, by truncating the hypocentral depth distribution with a Moho model for which the uncertainty can also be taken into account.

This procedure allows calculating statistically robust maps of the seismogenic depths with a realistic treatment of their uncertainties, as exemplified with the analysis of a regional seismic

catalogue.