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Nonparametric estimation of seismic activity and seismic hazard

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To characterize seismic regime in an area it is important to determine seismic activity. It also can be used for seismic hazard estimation. It was suggested a new general method of seismic activity estimation for a certain point in space, time and magnitude. This method is based on nonparametric statistics methods.

Lets determine seismic activity A in an magnitude-spatial-temporal interval – $(M, \Delta M, X, \Delta X, Y, \Delta Y, Z, \Delta Z, T, \Delta T)$ as number of seismic events N in this interval normalized to the size of this interval:

$$A = \frac{N}{(\Delta X \Delta Y \Delta Z)\Delta T \Delta M} = \frac{N}{\Delta V \Delta T \Delta M}.$$

It means that $A = A(M, \Delta M, X, \Delta X, Y, \Delta Y, Z, \Delta Z, T, \Delta T)$ is a function of 10th parameters. Our goal will be estimation of seismic activity in a point, which is not depends on $\Delta V, \Delta T$ and ΔM.

Lets considered interval will be a subinterval of a big interval I_{tot} with a large number of seismic events N_{tot}. Then according to Bernoulli theorem ratio N/N_{tot} will be good probability estimation P for occurrence of next event in considered interval. In the same time the probability for small considered interval (when $\Delta V, \Delta T, \Delta M$ are small) can be estimated as:

$$P = p\ \Delta V \Delta T \Delta M,$$

where $p = p(M, X, Y, Z, T)$ is probability density function for occurrence of seismic event with magnitude M in time T and in point (X, Y, Z).

As a result seismic activity can be estimated as

$$A = \frac{N}{\Delta V \Delta T \Delta M} \approx \frac{N_{tot} P}{\Delta V \Delta T \Delta M} \approx N_{tot} p = N_{tot} p(M, X, Y, Z, T).$$

To estimate probability density function for occurrence of seismic event with magnitude M, in time T and in point (X, Y, Z) the methods of nonparametric statistics can be used. Lets use Parzen-Rozenblatt estimation. In general for m variables $x_1, x_2, ..., x_\mathrm{m}$ it is

$$\hat{p}_{Ntot}(x_1, x_2, ..., x_m) = \frac{1}{N_{tot}} \sum_{i=1}^{N_{tot}} [\frac{1}{h_1 h_2 \cdot ... \cdot h_m} K\left(\frac{x_1 - x_{1i}}{h_1}, \frac{x_2 - x_{2i}}{h_2}, ..., \frac{x_m - x_{mi}}{h_m}\right)],$$

where K is a kernel function, $h_1, h_2, ..., h_m$ are scaling parameters and $(x_{1i}, x_{2i}, ..., x_{mi})$ are coordinates of i-th experimental point.

There are some limitation for kernel function:

$$\int K(\xi) d\xi = 1, \quad \int |K(\xi)| d\xi < \infty, \quad \sup |K(\xi)| < \infty, \quad \lim_{\xi \to \infty} |\xi K(\xi)| = 0,$$

where ξ is multivariate value $(\xi_1, \xi_2, ..., \xi_m)$.

For good qualities of p estimation, the scaling parameters h_j must depends on N_{tot} and answer following requirements:

$$\lim_{N_{tot} \to \infty} N_{tot} h_1(N_{tot}) h_2(N_{tot}) \cdot ... \cdot h_m(N_{tot}) = \infty, \quad \lim_{N_{tot} \to \infty} \max_j (h_j(N_{tot})) = 0,$$

$$\lim_{N_{tot}\to\infty} N_{tot}[h_1(N_{tot})h_2(N_{tot})\cdot\ldots\cdot h_m(N_{tot})]^2=\infty.$$

Parameters $h_j=c_j(N_{tot})^{k/m}$, where $0<k<1/2$ and $0<c_j<\infty$ are suitable for this purposes.

As an example let use $\exp(-|\xi|/h)/(2h)$ as a kernel function. In this case probability density function for occurrence of seismic event with magnitude M, in time T and in point (X,Y,Z)can be estimated as

$$\hat{p}_{N\,tot}(x,y,t,M)=\lim_{\Delta x,\Delta y,\Delta t,\Delta M\to 0}\frac{\Delta P(x,y,t,M,\Delta x,\Delta y,\Delta t,\Delta M)}{\Delta x\Delta y\Delta t\Delta K}=$$

$$=\frac{1}{N_{tot}}\sum_{i=1}^{N_{tot}}\left[\frac{1}{16\pi h_{xy}^2 h_t h_M}\exp\left(-\sqrt{\left(\frac{x-x_i}{h_{xy}}\right)^2+\left(\frac{y-y_i}{h_{xy}}\right)^2}\right)\exp\left(-\frac{|t-t_i|}{h_t}\right)\exp\left(-\frac{|M-M_i|}{h_M}\right)\right].$$

This estimation of probability density function for occurrence of seismic event with magnitude M, in time T and in point (X,Y,Z) can be considered as a seismic hazard estimation. Seismic activity can be estimated as $A(x,y,t,M)\approx N_{tot}\hat{p}_{N\,tot}(x,y,t,M)$.

The results of the described approach application for investigation of seismic activity in Altay-Sayan region (Russia) are discussed.