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STATISTICAL INVESTIGATION OF THE SEISMIC PROCES ON SAME REGIONS IN THE WORLD

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ABSTRACT

The ideas about the discrete seismic phenomena and processes and the attempts for their quantitative study during the last few years have established themselves as a modern tendency with developing methods for its investigation. On the other hand, the chosen regions are of a high seismic activity and have a good contemporary network for recording of the seismic events along them. These are the two main motives that helped to select these regions for more detailed statistical investigation and establishment of quantitative relations, which can help the better understanding of the discrete process.

The purpose of this investigation is to describe analytically the seismic process in space at some active regions in the world. We consider the statistical distributions of the distances between each two consecutive earthquakes (so called pair analysis). The main aim of this approach is to create formal criteria for recognition of the different sources and strong earthquakes in different tectonic active areas.

Keywords: earthquakes, pair analysis

1. Introduction

The broad acceptance of the concept of discrete occurrence of seismic phenomena and processes recently has established itself as a trend of expanding methods and tools for their study. Investigating the time and spatial distribution of earthquakes if of fundamental importance for their forecast and understanding the underlying physics of the earthquake source including regional and local tectonic processes. Studying the parameters of the statistical distributions for regions differing in seismogenesis can help the separation of these regions by introducing statistical characterizing criteria or confirm the similarity of the seismic process in different regions, if such separation is possible.

Independent earthquakes from some seismogenic regions of Earth have been considered. Studies conducted on approximating the statistical distribution of the parameters of consecutive seismic events (e.g. the space and time separation) indicate the existence of characteristic functions that describe them best.

2. Methods of investigation

The objective discrimination between non-randomness and randomness is a major challenge in the application of statistical methods to study of earthquake occurrence. Statistical models describing the time distributions range from of a simple Poisson process to more elaborate models including clusterization. [1] In contrast, the statistical study of the earthquake spatial distribution seems to lag behind. At least two reasons for that exists. First, the two- or three-dimensional model needs to describe the spatial occurrence the earthquakes, which is done harder than in the case of a one-dimensional time model. Second, many researchers consider the characteristics represented as seismic maps and cross-sections to be sufficient and do not call for further proof. Some authors base the need to check the earthquake spatial distribution on statistical ground. The method of statistical moments has been applied for this purpose in a series of studies. [3,4,5 et al.] From a probability theory point-of-view the seismic regime is best described either as a stream of random events in a multidimensional phase space, or as a random point process, as considered in [4]. The structure of a random point process is given by its moments.

The first-order moment $M_1(\mathbf{x})$ of the process is simply the expectation value of the number of events with parameters $\mathbf{x};\ \mathbf{x_j} = \{x_j^k\}$ – five-element vector, represented *j*th earthquake, (k=1,2…5); x_j^1, x_j^2 specifies the epicenter; x_j^3 the depth; x_j^4 the magnitude; x_j^5 the origin time. For the point process the moment is discrete and is calculated by summation [3,4]. The first-order moment is a complete description of the distribution of the individual events in the catalog.

The-second order moment $M_2(\mathbf{x}_1, \mathbf{x2})$ is expressed as [3,5]:

$$M_2(\mathbf{x}_1,\mathbf{x}_2)= M_1(\mathbf{x}_1).\ M_2(\mathbf{x}_1 \,|\, \mathbf{x}_2)\ ,$$

$M_2(\mathbf{x}_1 \,|\, \mathbf{x}_2)$ is the conditional moment of the process, i.e., the expectation value of the number of events with parameter $\mathbf{x}_2$ given that another event $\mathbf{x}_1$ has occurred. The second-order moment is the two-point correlation function and describes the distribution of pairs of events in the catalog.

The distance between epicenter pairs was used to study the spatial distribution of earthquakes. The coordinates were taken from different catalogs published and available on the Internet [7]. The choice of these zones was determined by the availability of information, as well as the relatively diverse geodynamic space they belong to. Source data for different seismoactive areas were selected to contain commensurable number of events of commensurable earthquake parameter accuracy. Data after 1900 up to present days were used, which assures sufficient precision in determining epicentral coordinates. Besides, this is a relatively long period for accumulating information to describe the current seismic activity of the regions of interest.

The distances between epicenters were calculated for each pair of consecutive events from the source earthquake catalog. The corresponding spatial and time distribution histograms were constructed using initially processed data therefrom. The earthquake pairs were formed by taking the distance Δx between consecutive earthquakes only. Thus if N is the number of the events, (N-1) pairs are formed. The approximation of the empirical (observable) source data distributions with analytical expressions received greatest attention. The analytical form of the distance distributions for independent events is given by beta distribution. Its general form is:

$$f(x) = \Gamma(p+q)/\Gamma(p)\cdot\Gamma(q)\cdot x^{p-1}\cdot(1-x)^{q-1}$$

where $\Gamma(p) = \int\limits_0^\infty e^{-t}\cdot t^{p-1}\cdot dt$, is the Gamma function. [2] *p, q* where $p>0, q>0$ are parameters, and for the variable x holds - $0 \le x \le 1$. As the gamma-function containing coefficient is a normalizing factor, i.e. such that $\int\limits_0^\infty f(x)\cdot dx = 1$, for convenience the distribution density is presented by [2]:

$$f(x) = c_x \cdot x^{p-1}\cdot(1-x)^{q-1}.$$

To establish the statistical independence of the studied event pairs preliminary filtration of aftershocks using *Reasenberg's* spatial-time window in the Zmap package was carried out. [5, 6]

3. Results

The outlined method for serial source data processing enabled us to obtain the following results. Table 1 describes the selected zones. They were selected in rectangular windows for convenience and are described by both coordinates and area for comparison. The choice was made in accordance with the seismic mapping done by specialists in North America, Canada and Russia. Constructing the cumulative curves for the number of events from the catalogs with excluded aftershocks shows the apparent non-linear behavior of seismic activity in different regions. For that reason the catalogs were divided into separate time spans for which approximately linear activity curves could be observed, i.e. data subsets were extracted for which the method of earthquake spatial distribution was applied separately. Some of the studied regions received more than one such span. Calculated distribution parameter values are shown in Table 1.

Table 1. *Selected zones, space window, separate time spans and calculated distribution parameter values.*

region	window	area [km]	No.	time span	N	M_{min}	c_x	p	q
Coalinga, California	36.04-36.5° N, 120-120.59° W	53x 65.5	I	1926-1999	133	3.0	0.297	0.901	1.949
Imperial Valley, California	32.5-33.25° N, 115-115.75° W	70x 83	III	1930-1975	142	3.5	0.256	0.852	1.755
Calaveras fault, California	37.4-36.92° N, 121.42-121.75° W	29x 53	II	1942-1975	360	2.5	0.257	0.955	1.635
Cascadia, Canada	47.8-52° N, 120-129° W	645x 467	II	1964-1999	164	3.8	0.229	0.688	2.040
Lower St.Lawrence, Canada	46-50.2° N, 65-69° W	298.5x 467	II	1961-1979	89	2.0	0.171	0.667	1.279
			III	1981-1999	522	2.0	0.075	0.529	1.265
New Mexico, USA	32-37° N, 103-106° W	275.5x 554.5	II	1965-1986	89	2.6	0.122	0.609	1.089
Morgan Hill, California	37.1-37.4° N, 121.5-121.8° W	26.5x 33	II	1944-1974	346	2.0	0.840	1.431	4.390
West Quebec, Canada	44-47.5° N, 72.8-79.5° W	526.5x 389	II	1840-1929	105	2.4	0.400	1.194	2.357
			III	1930-1995	458	2.4	1.354	1.715	3.769
Garm, Asia	38.5-39.5° N, 70-71.6° E	139x 111	II	1962-1981	1245	2.8	1.512	1.830	3.427
			III	1982-1999	222	2.8	1.224	1.731	3.174
Offshore region, Canada	48-52° N, 127.5-133° W	394x 611.5	I	1917-1945	36	4.5	0.378	1.232	1.562
			II	1945-1960	79	3.0	22.458	2.560	6.820
			III	1960-1991	792	3.0	0.268	1.007	2.354
Toktogul, Asia	39.23-43.47° N, 69.23-76.98° E	652x 471	I	1929-1947	238	1.7	0.486	1.443	2.378
			II	1948-1957	631	1.7	1.889	1.579	2.739
			III	1965-1991	4648	1.7	16.584	2.180	9.515
Charlevoix, Canada	47.2-48° N, 69.6-70.5° W	68.5x 89	II	1925-1976	119	0.7	0.334	1.025	1.627
			III	1977-1993	780	0.5	2.437	1.850	4.805

It contains only those subset spans (designated by Roman digits) for different regions containing sufficient number of events to be amenable to analysis. All results were tested for statistical confidence. The hypothesis was tested for agreement between theoretical and experimental data according to the χ^2 - criterion and confirmed at the 95% level. The theoretical distribution curves for consecutive distances after fitting with empirical histograms are plotted in fig.1a and 1b. There the distances are in relative units. They were obtained by dividing the real by the maximal distance within each zone. The upper part of Table 1 contains the results from fig.1 a presented as falling curves (which have no clear maxima); the lower part contains the results plotted as unimodal curves in fig.1b. This is indicative of a tendency towards grouping (attracting) of earthquakes in different seismic zones. In the first case only about 20% of the registered events in the zone during the corresponding time span occur at distances exceeding 1/3 of the maximal. In the second case the greatest number of distances are observed within the 0.1 to 0.4 of the maximal in the zone.

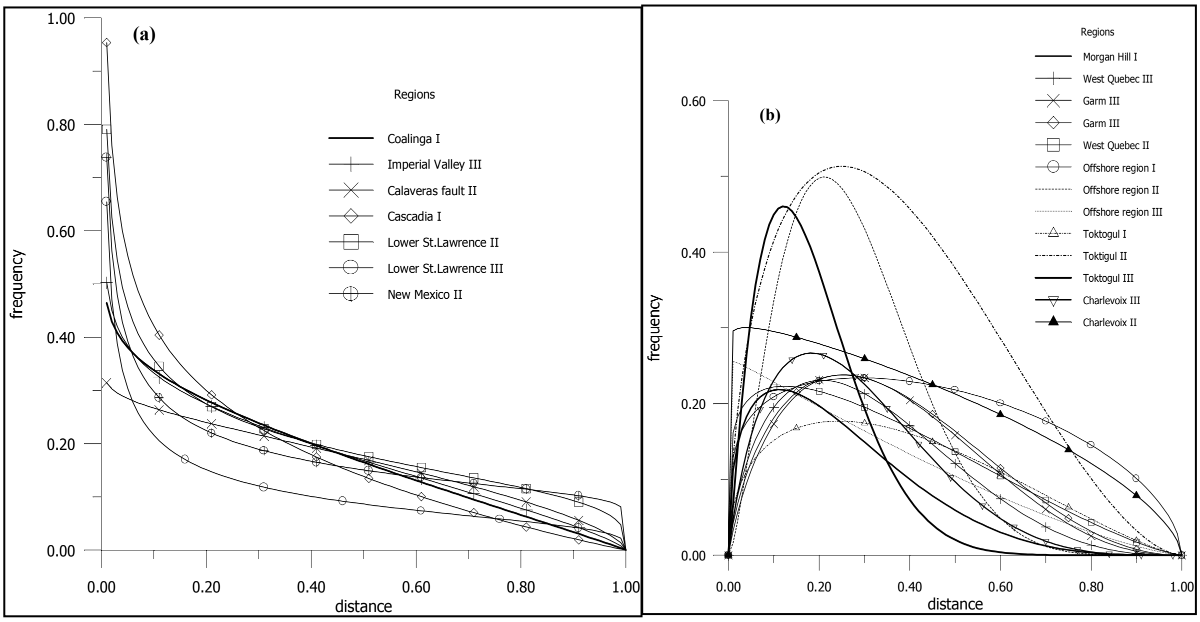

Fig. 1. ***Theoretical curves for distributions of distances for successive events on different regions.***

The results obtained confirm the rationality, usability and reliability of the approach adopted for delineating earthquakes belonging to different seismogenic zones on Earth.

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5. References

[1] Shlien S., N. Tokoz, A clustering model for earthquake occurences, BSSA, vol.60, No.6, 1970, pp. 1765- 1787
[2] Mosteller Fr., J. Tukey, Data analysis and regression, Addison-Wesley Pub.Co., 1982 (in russian)
[3] Kagan Y., L. Knopoff, Statistical search for non-random features of the seismicity of strong earthquakes, Phys. Earth Planet. Inter. (PEPI), 12, 1976, 291-318
[4] Kagan Y., L. Knopoff, Spatial distribution of earthquakes: the two-point correlation function, Geophys.J.R.astr.Soc., 62, 1980, 303-320
[5] Reasenberg P., Second-order moment of Central California seismicity, 1969-1982, J.Geophys.Res., 90, 1985, 5479-5495
[6] Wiemer, S., http://seismo.ethz.ch/staff/stefan/IntrotoZMAP6_online.htm
[7] CD от WDC-A , Denver, Colorado, http://www.seismo.nrcan.gc.ca, http://wwwneic.cr.usgs.gov, http://quake.geo.berkeley.edu/cnss, http://www.wdcb.rssi.ru/