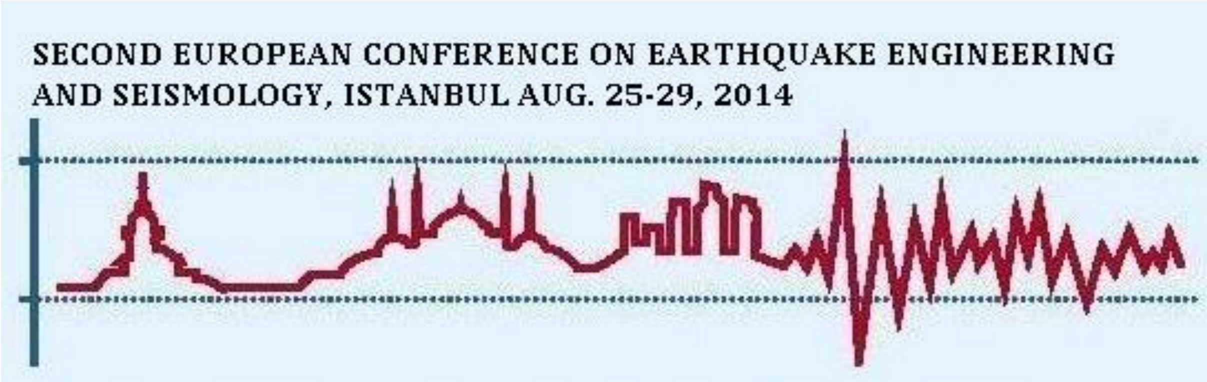

ANALYZING FEATURES OF EARTHQUAKE CLUSTERING

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INTRODUCTION

The cluster component of seismic flow consists of a sequence of seismic events obeys special spatial, temporal, and energy conditions. The possibility of earthquake cluster formation in the seismic flow (besides merely accidental bunch of events) follows from unstable-avalanche fault forming model (IPE Model) (Sobolev, 1993).

In this paper we propose a new method for the separation of the cluster component of the seismic flow. Properties of the cluster component are studied on the examples of the regions of Kamchatka and Japan.

MATHEMATICAL MODEL

Separation of a cluster component is based on the fulfillment of three conditions (Sobolev et al, 2003) Two events s_1 and s_2 are in the same cluster, if (1) their magnitude (or energy classes) m_2-$m_1 \leq \Delta$, where Δ– constant, (2) distance between events $\rho(s_1, s_2) \leq 3l(s_1)$, where $l(s_1)$ is length of the rupture in epicenter of event s_1, taken empirical relationship $\lg(s_1) = C_e \lg E(s_1) + C_l$, where C_e= 0.244 and C_l= -2,266 (3); in the paper Derendyaev et al (2011) it is shown that while taking into account the fractality of the seismity the time between events m_2 and m_1 $T(s_1) \geq (t_2 - t_1) \geq 0$ is defined on the catalog of earthquakes as follows

$$T(s_1) = -\ln(1-\alpha)\, A_{m_0}^{-1} 10^{b\left(-\frac{C_l + uC_e}{C_e v} - m_0\right)} \left(\frac{L_0}{3}\right)^{\frac{b}{C_e v}} (1 - 10^{-b}),$$

where: $\alpha$is level of significance that the events s_2 and s_1 belongs to one cluster; A_{m_0} is activity for magnitude m_0 and area S_0; L_0 is linear size for the area S_0; u and v are constants: energy class $k = u+vm$; b is b-value. This ratio shows that the average recurrence time of events within the focal zone is independent of the energy of an event (ie, reducing the number earthquakes due to the magnitude increase is fully compensate by increasing the area of each earthquake).

The model of cluster component separation of the seismic flow is probabilistic. Therefore, at any level of significance errors of target missing and false alarm are possible: events involved in the preparation of the earthquake doesn't fall into the cluster, and purely random events are fall into the cluster. We are not able to control the level of error of the target missing, but the error rate of false alarms can be monitored by conducting a clustering of a randomized earthquake catalog.

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RANDOMIZED EARTHQUAKE CATALOG

We use next algorithm for generating randomized catalog. Each event from the catalog is defined by three parameters: the coordinates (x, y), time t and the magnitude m. To determine the coordinates of events the whole area is partitioned into disjoint cells k=1, .., K with a side of g degrees. The probability π of the event is within the cell k is evaluated by real catalog. To determine the coordinates of a random event (x, y) firstly the cell number is selected with probability π, then the point coordinates within the cell are selected randomly with the uniform distribution. Time t of a random event is selected according to a uniform distribution of the temporal interval of real catalog. Magnitude m of a random event is selected according to the probability distribution of the magnitudes of all earthquakes in real catalog.

ANALYSIS

Thus, randomized catalog coincides with the real earthquake catalog by number of earthquakes, the duration of observation, as well as by the statistical characteristics of the spatial distribution of earthquakes and their magnitudes. Catalogs of earthquakes with cleared aftershocks for Kamchatka and Japan regions are taken for the analysis. For Kamchtka's catalog the strength of events are measured in the scale of energy classes K, but for Japan's one in the magnitude scale (see table 1).

Table 1. Parameters of experimental catalogs of earthquakes

Region	Observationinterval	Minimum class (K) or magnitude (m)	Numberof epicenters	b-value
Kamchatka	1987-2004	K=8	18191	γ=0.42
Japan	1985-2010	m=3	47165	b=0.75

Seismic activity was assessed by the earthquake epicenters in the circle moving window with radius of 30 km. Seismic activity values was assessed only if moving window contains more than 16 earthquake epicenters.

The quality of separation of cluster component of the seismic flow depends on the level of significance α. Three relationships were analyzed to determine α: (A) – the ratio of the number of clusters in randomized catalog to the number of clusters in real catalog, (B) – the ratio of the number of points in a cluster component of randomized catalog to the number of points in a cluster component of the real catalog, and (C) – the ratio of the average number of points in clusters of randomized catalog to the average number of points in clusters of real catalog. It was find out that for both regions the values of these characteristics are stabilized starting with $\alpha=5\cdot10^{-4}$. This level of significance was chosen for clustering.

Consider the results of clustering at a significance level $\alpha=5\cdot10^{-4}$. For Kamchatka region it was allocated 719 events in real catalog, which form 276 clusters containing from 2 to 16 events. It was allocated 245 events in a randomized catalog those form 117 clusters, which contains from 2 to 4 events.For Japan region it was allocated 6776 events in real catalog those form 1703 clusters containing from 2 to 132 events. In randomized catalog it was allocated 690 events which form 341 clusters containing from 2 to 3 events.

Figure 2 shows the dependence of the logarithm of the number of clusters on the logarithm of the number of events in the cluster for real and randomized catalogs. It can be seen that for a real catalog and number of clusters more than three this dependence is close to a linear one: $\lg N(n)=C_0-C_nN(n)$, where n – the number of events in the cluster (cluster size), $N(n)$ – number of clusters of size n. For real catalogs of Kamchatka and Japan coefficients C_n close to each other and take the values 3.627 and 3.775 respectively.

Figure 3 shows the dependence of the inclination angle tangent of the linear trend of dependency Lg$N(n)$ on α. It can be seen that the inclinations of the linear dependences are the same in different regions at different levels of significance, perhaps, indicative of the universality of this parameter.Analysis of the relationship between the selected clusters and the strongest earthquakes in regions demonstrates that for the areas of Kamchatka where seismic activity is defined, 3 of 6 epicenters are related to the cluster flow. In Japan, in the zone, which is defined for seismic activity, get all 14 of earthquakes, 8 of which belong to the selected clusters.

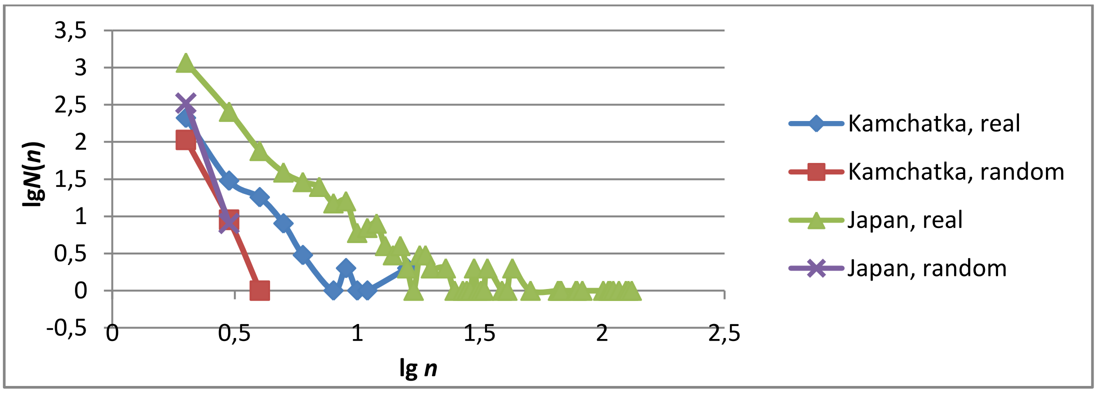

Fig. 1. The dependence of the logarithm of the number of clusters on the logarithm of the number of events in the cluster for regions of Kamchatka and Japan.

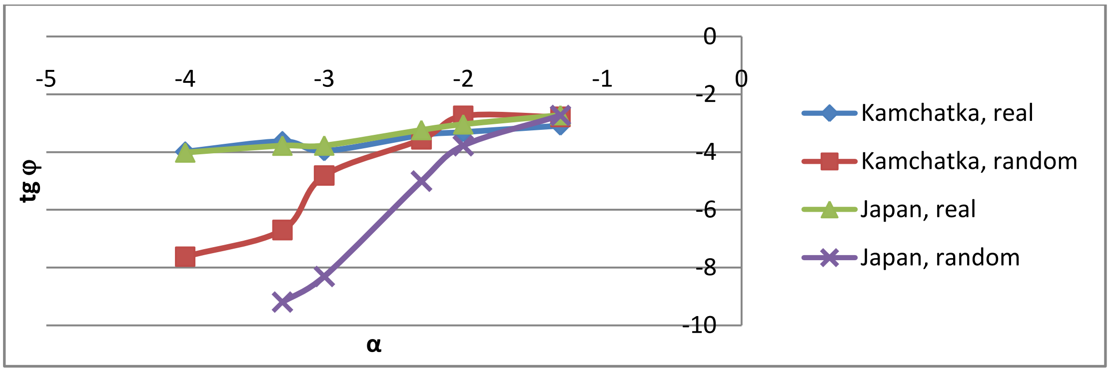

Fig2. The dependence of the inclination angle tangent of the linear trend of dependency LgN(n) on α for real and randomized catalogs of Kamchatka and Japan regions.

CONCLUSIONS

In this paper we proposed a new method for the separation of the cluster component of the seismic flow. It is shown that the dependence of the logarithm of the number of clusters on the logarithm of the number of events in clusters is linear. This is evidence of the self-similarity of cluster seismicity. In addition, the inclination of this linear dependence is the same in different regions at different levels of significance, perhaps, indicative of the universality of this parameter.

The analysis showed that most of the strongest earthquakes in regions relates to isolated clusters. This is an indirect confirmation of the unstable-avalanche fault forming model (IPE Model). However, not all strong earthquakes are preceded by the cluster component.

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