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Seismic catalog for Georgia

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A homogeneous reliable earthquake catalog is very important in seismic hazard assessment. The accuracy of earthquake location calculation, also accuracy of magnitude estimation influence on delineation and parameterization of seismic sources. In this work, we summarize all our attempt to obtain modern earthquake catalog for Georgia

In this work, there are two main goals: 1) Drafting a new catalog of historical earthquakes of Georgia and 2) Compilation of new instrumental seismic catalog of Georgia. In the process of compiling the level of the magnitude completeness was limited to: $M_S \geq 2.9$ or $M_W \geq 4.0$.

Catalog of historical earthquakes

The methods of interpretation of macro seismic data about historical earthquakes include:

- Collection and systematization of the whole available information concerning each historical earthquake.
- Parameterization of historical earthquakes on the basis of equalizing the macroseismic field
- Restoration of historical earthquakes with pure macroseismic data by using isoseist models of earthquakes with different magnitudes, built for the territory of Georgia.
- Complex analysis of macroseismic, archeological, seismotectonic and other kinds of data

More detail information about this work are presented in Varazanashvili et al. (2011) [1]. Here we just mentioned that about 47 historical earthquakes were studied. After investigation of data, three earthquakes had to be excluded from consideration because of the uncertain input data. This directory improves the accuracy of determining the basic parameters of historical earthquakes.

The final parametric catalog for 44 historical earthquakes includes the date and the location of the epicenter, magnitude and depth of focus, intensity epicenter (Fig. 1).

Instrumental seismic catalog

The second main task of this work is to refine the catalogue of instrumental earthquakes from 1900 to the present (Fig. 2).

In the Caucasus instrumental seismological observations started in the beginning of XX century. The lack of the instrumental data, particularly for the first half of the last century requires systematic recalculation of magnitude and location of earthquakes from the beginning of instrumental period since 1900 till 1962. The revision of macroseismic data and creation of reliable macroseismic databases is one of the important tools to achieve succeed in this work.

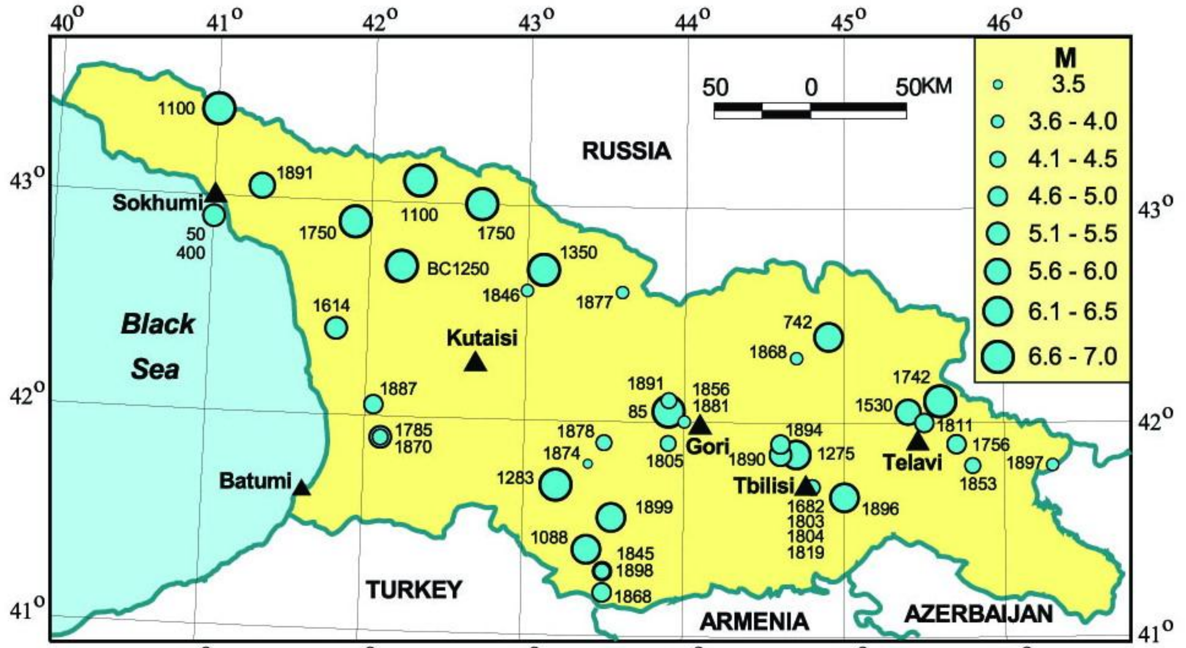

Fig. 1. Map of historical earthquakes (pre-1900) in Georgia.

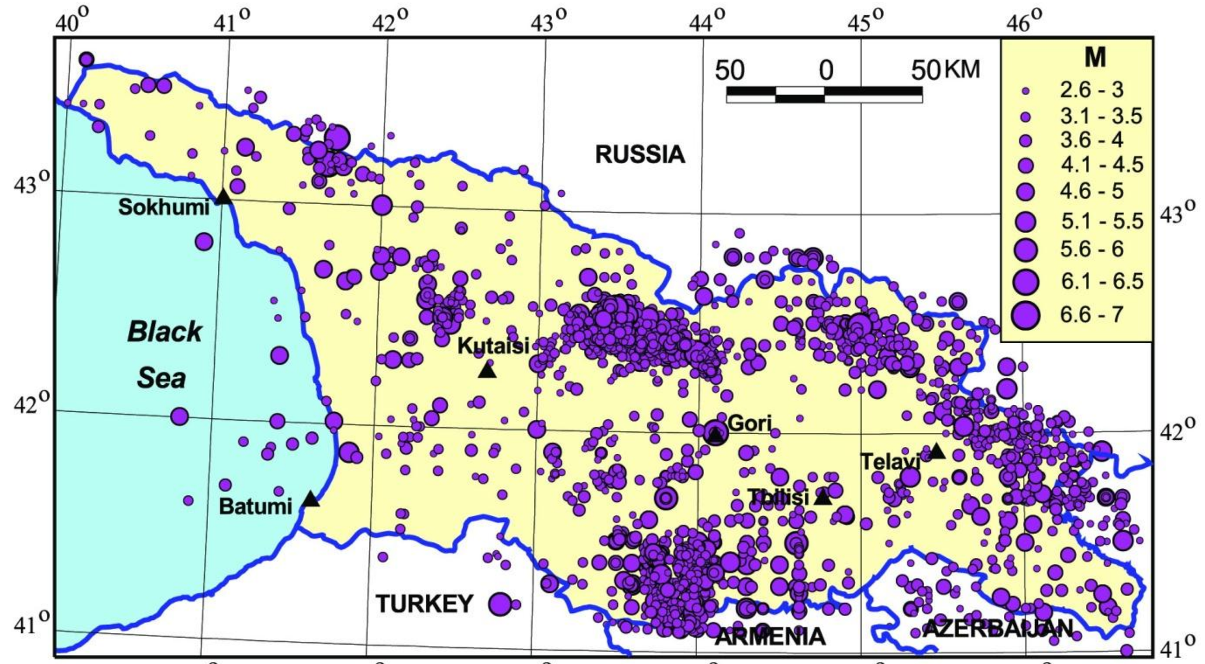

Fig.2. Map of instrumental earthquakes (1900-2009) in Georgia.

After 1962 the seismic network in the Caucasus and in Georgia began to improve, but inaccurate velocity models do not give good results. To reveal the best velocity model the hypocenter parameters of the earthquake were calculated, using the HYPO-71 program [2] for all existing velocity models of the Caucasus region, which were obtained by various geophysical methods [3, 4, 5, 6, 7]. The model obtained by the interpretation of the surface wave group velocity dispersion curves [8] gave a much higher accuracy in determining the hypocenters of earthquakes than the others. To be surer in our decision all velocity models were tested for explosions for which we directly know both the epicenter and the depth. Model [8] gives for explosions depth less than 2 kilometers, while others give depth more than 5 kilometers. The scatter of epicenter also was not high for this model. Thus we assume that the optimal crustal model consists of four layers (Table 1).

Table 1. Velocity model [8]

Layer thickness (km)	Vp (km/s)	Vp/Vs
0.0	4.2	1.71
4.0	5.5	
20.0	6.2	
30.0	6.9	
49.0	8.2	

During the period 1963-2002 for the territory of Georgia parameters of about 250 earthquakes were re-calculated. The difference between obtained and existing locations of individual earthquakes was sometimes more than 20 km (see Fig. 3, 4, 5).

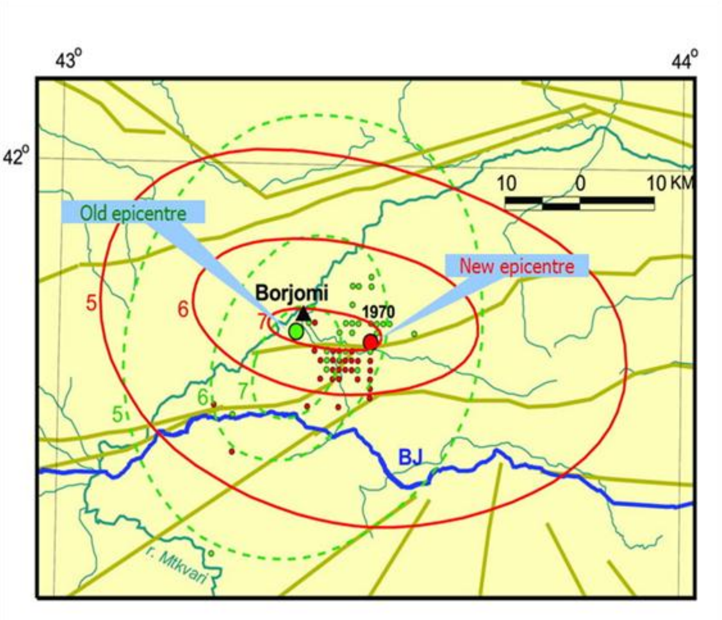

Fig. 3. Re-location of Borjomi earthquake, 1970.

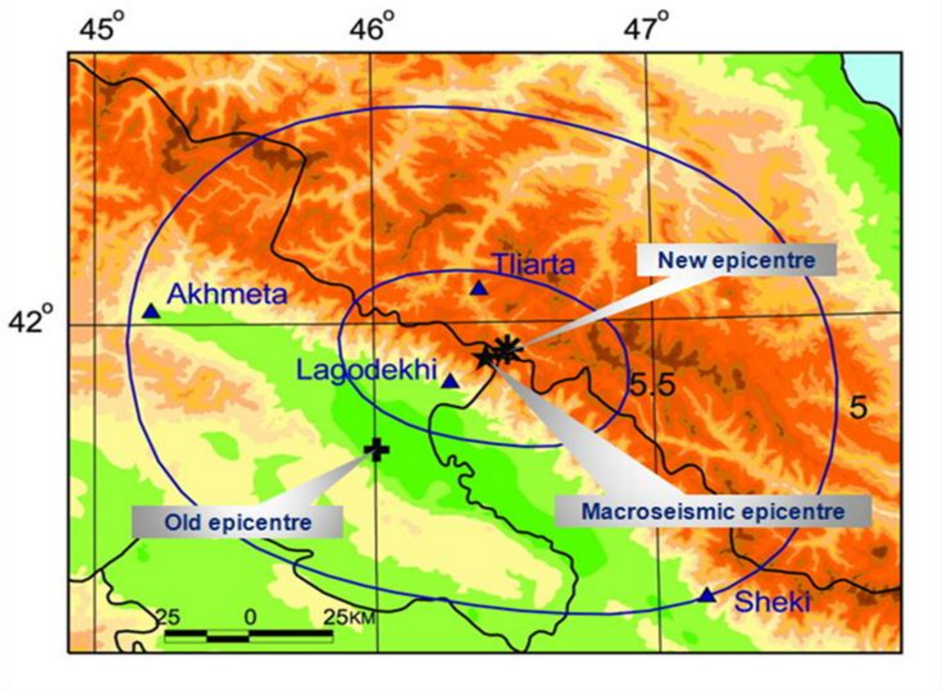

Fig. 4. Re-location of Tliarta earthquake, 1978.

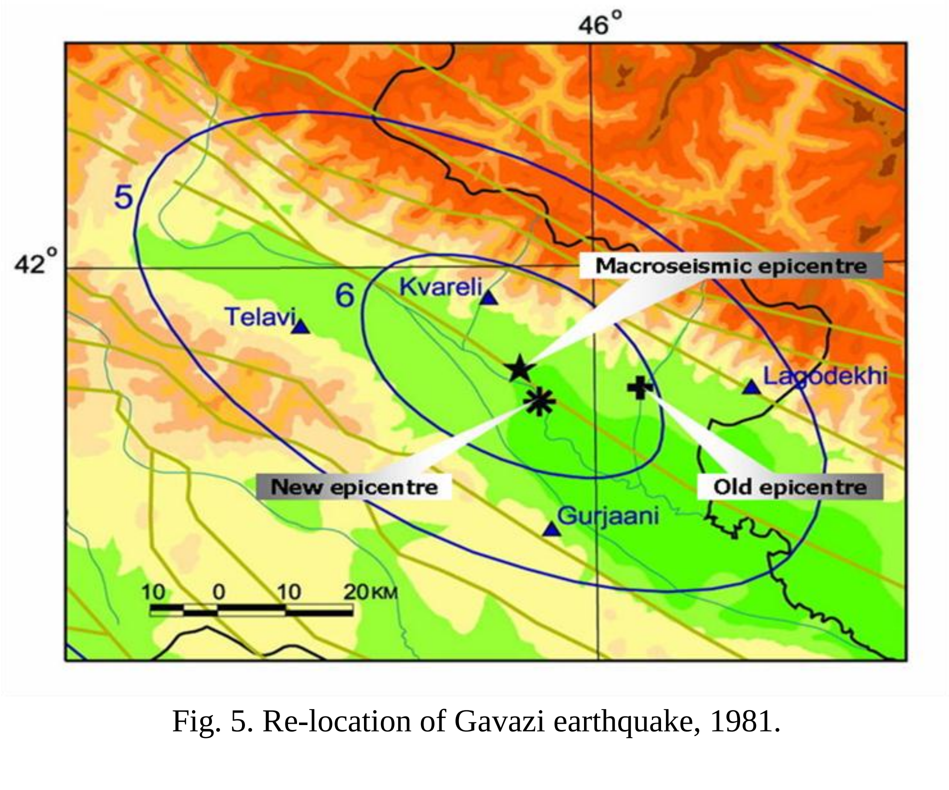

Fig. 5. Re-location of Gavazi earthquake, 1981.

In addition, it should be noted that in the catalog of earthquakes of Georgia magnitudes were categorized by surface waves (M_S). Since 1962 the accepted technique was to determine the energy class (K) of earthquakes, so in cases when the direct determination of the magnitude M_S was impossible, it was estimated mainly by the correlative dependence [9]:

$$K=1.8M_S+4$$

and sometimes following [10] we accept that $M_S \approx M_C$, where Mc is the magnitude estimated from the coda waves.

Since 2004, as a consequence of the reorganization of the network of seismic observation of Georgia, basically only local magnitude M_l was estimated for earthquakes and rarely magnitude M_d and M_b. In this case, the transition to the magnitude M_S was carried out by the correlation dependence given in Zare et al. (2014) [11].

Thus, after the determination or specification of the basic parameters of earthquakes, we present a new catalog of historical earthquakes (pre-1900) of Georgia and the refined instrumental earthquake catalog (1900-2015) of Georgia, complete for $M_S \geq 2.9$ or $M_W \geq 4.0$, in format (Fig. 6).

Year	Month	Day	Hour	Minute	Second	Lat	Long	Author	Depth	Engdahl	Mw	Author	Ms	Author
BC 1250	00	00	00	00	00	42.70	42.20	EDIG	15	362	6.9	EDIG	6.9	EDIG
0050	00	00	00	00	00	42.90	41.00	NC	10	360	5.8	EDIG	5.5	NC
0085	00	00	00	00	00	42.05	43.90	EDIG	15	362	7.0	EDIG	7.0	EDIG
0400	00	00	00	00	00	42.90	41.00	NC	10	360	5.8	EDIG	5.5	NC
0742	00	00	00	00	00	42.40	44.90	ShT	18	362	6.4	EDIG	6.4	NC
1088	04	22	00	00	00	41.40	43.40	EDIG	15	367	6.5	EDIG	6.5	EDIG
1100	00	00	00	00	00	43.10	42.30	EDIG	15	362	7.0	EDIG	7.0	EDIG
1275	04	14	00	00	00	41.85	44.70	EDIG	15	362	6.5	EDIG	6.5	EDIG
1283	00	00	00	00	00	41.70	43.20	EDIG	15	367	7.0	EDIG	7.0	EDIG
1350	00	00	00	00	00	42.70	43.10	EDIG	15	362	7.0	EDIG	7.0	EDIG
1530	00	00	00	00	00	42.05	45.40	EDIG	15	337	5.9	EDIG	5.7	EDIG
1600	00	00	00	00	00	43.40	41.00	EDIG	15	362	7.0	EDIG	7.0	EDIG
1614	00	00	00	00	00	42.40	41.80	EDIG	10	362	6.1	EDIG	6.0	EDIG
1682	06	13	22	30	00	41.70	44.80	EDIG	07	362	4.9	EDIG	4.2	EDIG
1742	08	05	00	00	00	42.10	45.60	EDIG	20	337	7.0	EDIG	7.0	EDIG
1750	00	00	00	00	00	42.90	41.90	EDIG	15	362	7.0	EDIG	7.0	EDIG
1750	00	00	00	00	00	43.00	42.70	EDIG	15	362	6.9	EDIG	6.9	EDIG
1756	00	00	00	00	00	41.90	45.70	EDIG	10	337	5.2	EDIG	4.7	EDIG
1785	05	00	00	00	00	41.90	42.10	EDIG	10	367	5.8	EDIG	5.5	EDIG
1803	10	29	00	00	00	41.70	44.80	EDIG	07	362	4.6	EDIG	3.8	EDIG
1804	10	11	17	00	00	41.70	44.80	EDIG	07	362	4.4	EDIG	3.5	EDIG
1805	02	21	19	00	00	41.90	43.90	NC	10	367	5.0	EDIG	4.4	NC
1811	01	01	05	00	00	42.00	45.50	EDIG	10	337	5.4	EDIG	5.0	EDIG
1819	02	28	00	00	00	41.70	44.80	EDIG	07	362	5.1	EDIG	4.5	EDIG
1845	05	24	01	00	00	41.30	43.50	EDIG	08	367	5.2	EDIG	4.6	EDIG
1846	04	23	21	00	00	42.60	43.00	EDIG	06	362	4.5	EDIG	3.7	EDIG
1853	03	18	00	30	00	41.80	45.80	EDIG	10	337	4.9	EDIG	4.2	EDIG
1856	02	13	04	00	00	42.00	44.00	EDIG	10	367	4.4	EDIG	3.5	EDIG
1868	02	18	17	00	00	41.20	43.50	EDIG	15	367	5.4	EDIG	4.9	EDIG
1868	12	09	16	30	00	42.30	44.70	EDIG	25	362	4.8	EDIG	4.0	EDIG
1870	07	19	14	30	00	41.90	42.10	EDIG	10	367	4.9	EDIG	4.2	EDIG
1874	02	25	19	30	00	41.80	43.40	EDIG	12	367	4.4	EDIG	3.5	EDIG
1877	08	08	06	30	00	42.60	43.60	EDIG	05	362	4.6	EDIG	3.8	EDIG
1878	11	26	23	00	00	41.90	43.50	NC	15	367	5.0	EDIG	4.3	NC
1881	08	24	20	00	00	42.00	44.00	EDIG	17	362	4.8	EDIG	4.0	EDIG
1887	07	16	17	45	00	42.05	42.05	EDIG	12	362	5.4	EDIG	4.9	EDIG
1890	10	28	19	00	00	41.85	44.60	EDIG	20	362	5.6	EDIG	5.2	EDIG
1891	00	00	00	00	00	43.05	41.30	EDIG	15	362	6.1	EDIG	6.0	EDIG
1891	03	27	18	30	00	42.10	43.90	NC	22	362	5.1	EDIG	4.5	NC
1894	11	29	10	30	00	41.90	44.60	EDIG	24	362	5.4	EDIG	5.0	EDIG
1896	09	22	03	53	00	41.65	45.00	EDIG	25	362	6.3	EDIG	6.3	EDIG
1897	02	03	02	00	00	41.80	46.30	EDIG	10	337	4.6	EDIG	3.8	EDIG
1898	08	13	00	00	00	41.30	43.50	EDIG	10	367	4.9	EDIG	4.2	EDIG
1899	12	31	10	50	00	41.55	43.55	EDIG	08	367	6.2	EDIG	6.1	EDIG
1900	01	01	19	00	00	41.60	43.50	EDIG	08	367	4.1	EDIG	3.0	EDIG
1900	04	17	02	25	00	42.20	45.10	NC	35	337	5.2	EDIG	4.6	NC
1902	02	21	03	06	00	41.70	46.60	NC	10	337	4.5	EDIG	3.6	NC
1902	03	20	06	10	26	42.60	43.40	NC	05	362	5.1	EDIG	4.5	NC
1902	06	18	23	53	10	43.00	42.00	NC	30	362	5.6	EDIG	5.2	NC
1902	07	03	00	00	00	42.80	44.20	NC	10	362	5.2	EDIG	4.7	NC
1902	07	06	19	33	00	42.80	44.20	NC	10	362	4.8	EDIG	4.0	NC
1902	08	19	02	26	00	42.60	43.40	NC	05	362	4.2	EDIG	3.2	NC
1902	10	03	23	05	43	41.80	45.60	NC	06	337	5.0	EDIG	4.4	NC
1902	10	04	01	46	00	41.90	45.60	NC	10	337	4.6	EDIG	3.8	NC
1902	10	17	07	21	00	42.10	45.80	NC	07	337	5.1	EDIG	4.5	NC

Fig. 8. New catalog of historical earthquakes (pre-1900) and the refined instrumental earthquake catalog (1900-2015) of Georgia, complete for $M_S \geq 2.9$ or $M_W \geq 4.0$.

Technique for declustering an earthquake catalog

Decluster process means to remove dependents events from seismic process and obtained independent events. This means to remove from earthquake catalog foreshocks, aftershocks and swarms. There are several declustering algorithms that applied by most users up to now [12, 13, 14, 15, 16]. However when we applied these methods for our catalog various number of earthquakes left (Table 2).

Table 2. Number of earthquakes in catalogue from various decluster methods

Reasenberg	Uhrhammer	Grünthal	Gardner and Knopoff
754	1433	674	929

As it is shown the number of independent events are very different that influence very much on seismic parameter estimations such as seismic rate and b value. That on his side influence very much on seismic hazard estimation. Moreover if obtained catalogs involve just independent events, they should follow stationary Poisson process. To be sure for it we calculated coefficient of scattering measure *R* that show us the nature of obtained process.

$$R = \frac{\sigma_{\overline{N}}}{\sqrt{\overline{N}}} \,(1)\,; \text{ where } \overline{N} = \frac{\sqrt{N_i}}{n}, \ \sigma_{\overline{N}} = \sqrt{\frac{\sum (N_i - \overline{N})^2}{n}}$$

n is the number of observed year, N_i is earthquake with *I* magnitude. When *R* equal 1 means events follow Poisson process. In table 3 are presented obtained results for R.

Table 3. Results for R obtained by various declustering methods

M	R Reasenberg	R **Uhrhammer**	R **Grünthal**	R **Gardner and Knopoff**	R **Tsereteli-Butikashvili**
3.5	2.28	2.87	1.67	1.56	1.38
4.0	1.06	1.26	1.03	1.11	1.0
4.5	1.25	1.25	1.25	1.25	1.0
5.0	1.0	1.11	0.8	1.0	0.9
3.5 – 7. 0	2.25	2.42	1.34	1.12	1.36

During investigation of clustering methods we pay attention on behavior of Racha earthquake on of 1991. This earthquake had unusual high number of aftershocks that continue during the very long period. We plotted the number of earthquakes for Racha region 10 years earlier and after events Fig. 9 (blue diamond). In the same figure we plot the Spitac earthquake of 1988 (brown dots). As we see Raca region was very active during the several years after strong earthquake, while the Spitac region was active during the one year. From the same picture we can see that seismic activity remain higher after Racha earthquake up to now, while Spitac region became calm. This gave us idea that strong earthquake should be consider individually during the clustering process. Based on this consideration we develop new methodology for declustering catalog. We consider earthquake with magnitude M_S more than 6 individually.

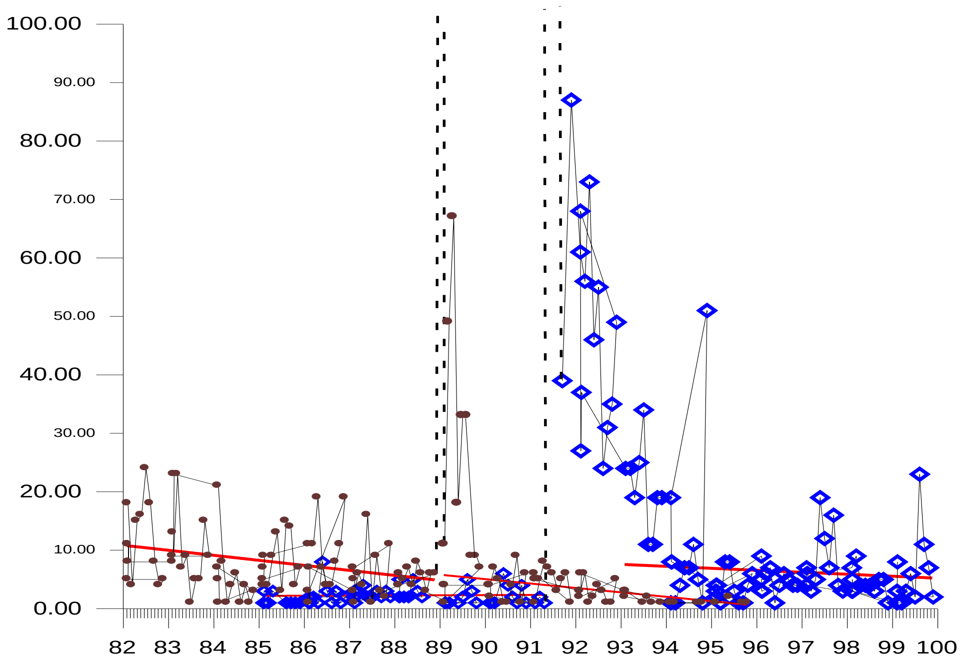

Fig. 9. The number of earthquakes for Racha earthquake of 1989 10 years earlier and after events (blue diamond). The number of earthquakes for Spitac earthquake of 1988 (brown dots). Redlines indicate the seismic level before and after earthquakes.

For the earthquake area [17] we investigate the number of earthquake before and after events during the 5 years. The average seismic level for each period is estimated. Comparison of these levels allow us estimate relaxation time period for this event. The earthquake source zone is divided by cells. The average numbers of earthquakes with various magnitudes are estimated for each cell by the seismic level that stabilized after strong earthquake. The same numbers with the same magnitude are left for each cell during the relaxation period. These increase numbers of earthquake during the relaxation period thought process anyway stay Poisson. Following this methodology total number of earthquake in decluster catalog is 2565. This is more then previous results show in table 2. The results of R are presented in table 3 as $R_{Tsereteli\text{-}Butikashvili}$.

For earthquake with magnitude less than 6 we use decluster methods described in [17] and in [18].

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საქართველოს სეიმური კატალოგი

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რეზიუმე

მიწისძვრების კატალოგების ერთგვაროვნებას და სიზუსტეს დიდი მნიშვნელობა აქვს სეიმური საშიშროების ამოცანების გადაწყვეტაში. მიწისძვრის ეპიცენტრიისა და მაგნიტუდის განსაზღვრისა და მათი ცდომილების შეფასების გარეშე შეუძლებელია მიწისძვრების სტატისტიკური კვლევა, სეისმური კერების ზონების გამოყოფა და პარამეტრიზაცია, გრუნტის მოძრაობის პროგნოზული განტოლებების შედგენა. ეს ყველაფერი თავის მხრივ გავლენას ახდენს სეისმური საშიშროების ალბათურ და დეტერმინისტულ გათვლებზე. აქ წარმოდგენილია მიწისძვრის პარამეტრების განსაზღვრის შეფასებები, როგორც ისტორიული, ასევე ინსტრუმენტული პერიოდის მიწისძვრებისთვის. ასევე განხილულია მიწისძვრის კატალოგების ფორ- და აფტერშოკებისაგან, გუნდებისაგან გაწმენდის სხვადსახვა მეთოდები, რომლებიც ფართოდ გამოიყენება სეისმოლოგიაში და შედარებულია ჩვენს მიერ შემოთავაზებულ მეთოდთან. ნაჩვენებია ამ უკანასკნელის უპირატესობა.

Сейсмический каталог Грузии

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Резюме

При решении задач сейсмической опасности очень важно однородность и точность каталогов землетрясений. Без определения эпицентра и магнитуды землетрясения и оценки их ошибок не возможно статистическое исследование землетрясений, выделение зон сейсмических очагов и их параметризация, составление прогнозстических уравнений двыжении грунта. Все это в свою очередь влияет на расчет вероятностной и детерминистической сейсмической опасности. Здесь представлены оценки определения параметров землетрясений, как для исторического, так и инструментального периода. Также обсуждаются различные методы очистки каталогов землетрясений от фор- и афтершоков, роев, которые широко используются в сейсмологии и они сравниваются с предложенным нами методом. Показан преимущество последнего.