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THE «ACTIVATION-LULL» METHOD FOR MEDIUM-STRENGTH EARTHQUAKES

Abstract. The analysis of the spatio-temporal patterns of the distribution of medium-strength earthquakes ($K \geq 9.6$) was carried out in order to determine the possibility of using them for the medium-term forecast for 2020. The territory of the Eastern Tien Shan and Dzungaria, encompassed by coordinates 41°40′ - 45°30′ of the north latitude and 74°00′ - 81°00 ′ of the east longitude, was adopted as a test site. The catalog of earthquakes with energy class $K \geq 9.6$ ($M \geq 4.2$) for 1951-2019 and strong earthquakes with $M \geq 5.6$-6.0 (total 16) that occurred during the indicated period was used. Based on a retrospective analysis of the time course of the annual values of the number of earthquakes (parameter N is the number of medium-strength earthquakes with $K \geq 9.6$), determined for the whole observation period with a shift of 3 months, anomalous changes in its behavior were revealed consisting in a successive alternation of activation periods ($N > N_{cr} = N_{av} \pm \sigma$), i.e. the parameter N exceeds certain critical level of N_{cr} and lull ($N < N_{cr}$), which are associated with the times of occurrence of strong earthquakes in the study area.

The fact of the existence of the "activation-lull" process for medium-sized earthquakes during periods of preparation of strong earthquakes is described in many studies on the theory of preparation and practice of forecasting and is used to predict strong earthquakes for various seismically active regions of Eurasia. According to studies, the distribution area of various precursors is so wide in size that it suggests the participation of large areas in the preparation of strong earthquakes.

A juxtaposition of the anomalous periods with the times of occurrence of strong earthquakes indicates the existence of a fairly close relationship between them. Indeed, before fourteen earthquakes out of 16 there was an anomalous lull in the number of earthquakes of medium strength, which is observed after activation. Three false alarms also occurred.

As a result of the study, 3 sites were identified, within or in the immediate vicinity of which earthquakes with $M \geq 5.6$-6.0 in the next one to two years are likely to occur.

Key words: catalog, medium-strength earthquakes, activation, lull, precursor, anomalous period, medium-term forecast.

In the article, the regularities (patterns) of the seismic mode of medium-strength earthquakes with $K \geq 9.6$ are investigated in order to clarify the possibility of using them for a medium-term forecast, which is understood as an assessment of the tendency of the seismic process for the next 1-2 years.

Many studies on the theory of preparation and practice of forecasting indicate the existence of a lull on the earthquakes of medium strength during the preparation of a strong event [1-4]. In [5-14], questions of using this pattern for forecasting purposes for various seismically active regions of Eurasia were considered. According to studies [4,13–16], the distribution area of various precursors is so large that it suggests the involvement of large territories in the preparation of strong earthquakes.

The territory of the Eastern Tien Shan and Dzhungaria, bounded by the coordinates of 41°40'-45°30'North latitude, 74°00' - 81°00 ' East longitude, is accepted as the test site. We analyzed earthquakes with an energy class $K \geq 9.6$ (without aftershocks) that occurred on the specified territory in 1951-2019. Figure 1 shows a time series of annual values of the number of earthquakes (N) with $K \geq 9.6$, determined in increments of Δt = 3 months, the data of which indicates the variability of the studied parameter over time.

The selection of abnormal periods of parameter *N* was performed by calculating errors in its definition. The calculation is based on the most homogeneous material since 1961 with the exception of intense aftershock sequences. The average annual value of N_{cp} was equal to 21 with a standard deviation of σ = ±5.1. The anomaly was considered to be a parameter value that goes beyond the corridor –σ with a confidence probability of 0.7 (the critical level).

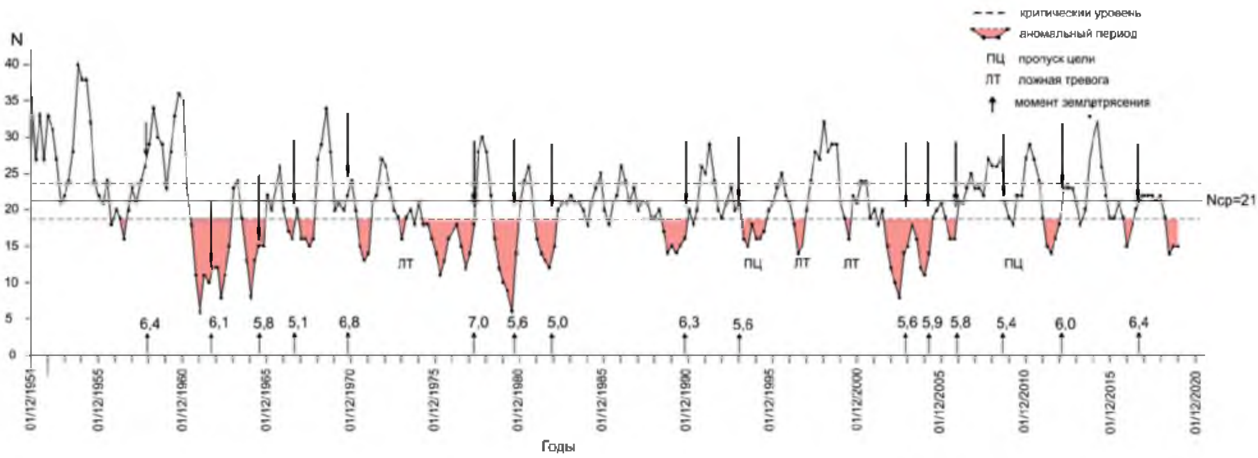


Figure 1 – Diagram of changes in the annual number of the earthquakes of medium strength ($K \geq 9.6$) in the territory of the Eastern Tien Shan and Dzhungaria

Strong earthquakes with $K \geq 15$ ($M \geq 5.8$-6.0) for 1951-2019 were studied, which occurred within the study area or in the immediate vicinity of it (no more than 30-40 km from its external borders). Also, the analysis involved earthquakes with $K = 14$ that occurred in the central part of the territory (figure 2). At the same time, if several strong earthquakes occurred in a short period of time (no more than a year), they were considered as a single event regardless of the epicentral distances. Such groups took place during the time periods from 12.1958 to 11.1959 (3 earthquakes), from 02.1969 to 06.1970 (2 earthquakes), and from 09.1979 to 07.1980 (2 earthquakes). Taking into account these circumstances, in the territory under consideration for the period of 1951-2019, a total of 16 strong earthquakes occurred (table 1), the time of their occurrence is shown by arrows (figure 1).

Table 1 – List of the earthquakes with $K \geq 14$ ($M \geq 5.4$) for the period of 1951-2018 that occurred within the study area or in the immediate vicinity of it

Earthquake name, year		Month	Day	Hour	Min	Sec	Latitude	Longitude	Depth	Energy class	*Ms*
1	Dzhungarian, 1958	12	21	5	46	29,0	44º48	80º 36	25	16,0	6,4
2	Dzhungarian, 1962	8	19	18	26	38,0	44º 46	81º 16	25	15,0	6,1
3	Kokshaal, I965	5	4	8	34	41,6	41º 44	79º 15	23	15,0	5,8
4	Saryjaz, 1967	8	20	2	2	5,0	45º 11	80º 00	18	13,8	5,3
5	Kokshaal, 1969	2	11	22	8	52,6	41º 30	79º 18	25	15,0	6,6
6	Sarykamysh, 1970	6	5	4	53	6,2	42º 28	78º 48	15	15,6	6,8
7	Zhalanash-Tyup, 1978	3	24	21	5	48,6	42º 52	78º 35	20	16,0	7,0
8	Bakanas, 1979	9	25	13	5	55,0	45º 00	77º 00	40	14,0	5,8
9	Kajisay, 1980	7	5	20	25	22,0	41º 46	77º 30	20	13,6	5,6
10	Novogodneye, 1982	12	31	19	46	46,4	42º 52	77º 22	18	13,7	5,6
11	Baysorunskoe, 1990	11	12	12	28	51,4	42º 56	77º 56	18	14,6	6,3
12	Tekeli-1, 1993	12	30	14	24	6,4	44º 49	78º 46	20	15,0	5,6
13	Syumbinskoe, 2003	12	1	1	38	32,6	42º 55	80º 33	-1	14,3	5,6
14	Kokshaal, 2005	2	14	23	38	9,5	41º 48	79º 11	5	14,3	5,9
15	Tekeli -2, 2009	6	13	17	17	37,9	44º 46	78º 49	15	13,8	5,4
16	Saryjaz, 2013	1	28	16	38	52,4	42º 31	79º 40	10	14,7	6,0

A comparison of the anomalous periods with the moments of the occurrence of strong earthquakes indicates the existence of a fairly close relationship between them. Indeed, before the fourteen earthquakes out of 16 there is an anomalous lull in the number of weak events that is observed after activation. It should be noted that the Tekeli earthquakes of 1993 (K = 15, M = 5.6) and 2009 (K = 14, M = 5.4) are poorly diagnosed and are marked as "missed targets" on the diagram, although a decrease in the number of earthquakes of medium strength is noted in front of them. There are also so called "false alarms".

The duration of the precursors was determined both from the moment of transition of the critical level and from the minimum value of the parameter. So, for the Baysorun earthquake of 1990 with M = 6.3, the duration of the precursor from the moment of transition of the critical level was 15 months, and from the minimum value of the parameter was 12 months.

A precursor is considered informative if P>Po according to [17], where Po is determined by the random forecast. Tabular values of Po at a confidence level of 0.975 for various values of the input parameters were carried out in [13,17]. According to [18], the forecast is statistically significantly different from random guessing if the value is J ≥ 2.0, and according to [19] the precursor is considered useful if q > 0.1-0.2 and very useful if q > 0.3-0.5 (n > 10-15).

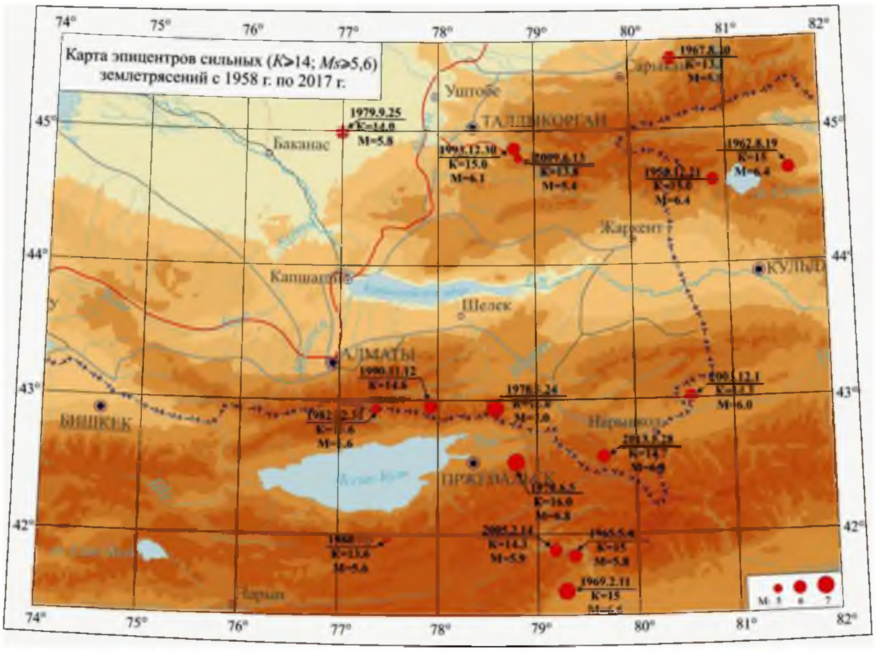


Figure 2 – Map of the epicenters of strong earthquakes for the period 1958-2019

A retrospective analysis of the diagram of changes in the annual numbers of medium-strength earthquakes ($K \geq 9.6$) on the territory of the Eastern Tien Shan and Dzhungaria allowed us to obtain the values of the informativeness coefficients of the method: P = 0.58 (Po = 0.36), J = 3.44, q = 0.66. In the calculations, the precursor duration, determined from the moment of transition of the critical level ($N_{cp} - \sigma$), was used as the most reliable.

Thus, the obtained data indicate that the coincidence of the time of occurrence of the considered strong earthquakes with the anomalous periods of the parameter N is not accidental.

To estimate the magnitude of the expected earthquake, we can use a generalized "image" of the behavior of the parameter under consideration for two magnitude groups (figures 3а, 3б), which is obtained by combining and averaging data for each earthquake depending on their magnitude [13].

As can be seen from figures 3а, 3б, the type of averaged time course of the parameter N for the considered magnitude groups is quite clearly different: for the magnitude group M = 5,6-6,1, it is shorter in time, and the level decrease occurs more sharply than for earthquakes with M = 6,3-6,8. To estimate the magnitude of the expected event, we can also use the dependence of the duration of the alarm time on the magnitude of the predicted earthquakes in accordance with the data in table 1 (figure 3в).

The dependence of the duration of the anomalous period (ΔT) on magnitude (M), for two options for determining the duration of the first, has the form:

$\lg\Delta T$ (month) = $0{,}55M - 2{,}3$ – from the moment the parameter N exceeds the critical level;

$\lg\Delta T$ (month) = $0{,}62M - 2{,}83$ – from the minimum value of the parameter N.

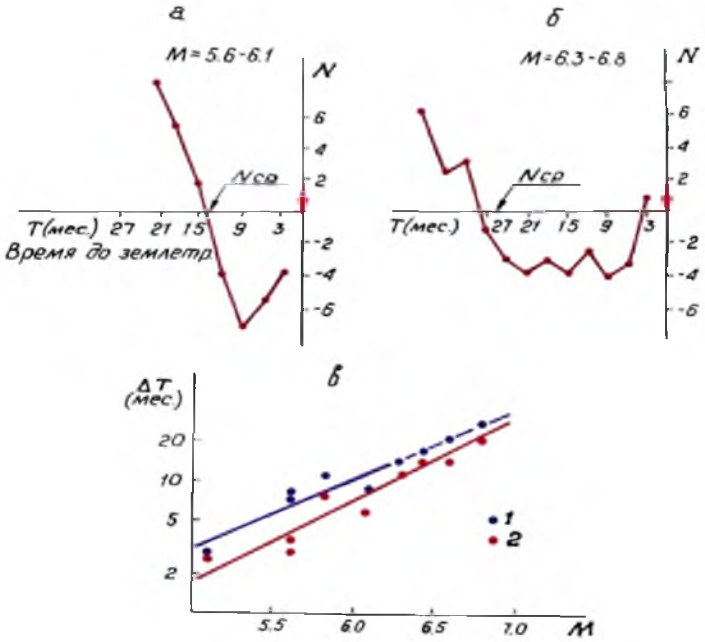


Figure 3 – The generalized time course of the number of earthquakes of medium strength for various magnitude groups (а, б) and the dependence of the duration of the anomalous period on the magnitude of earthquakes (в) [13]. 1 - from the moment of transition of the critical level; 2 - from the minimum value of the parameter *N*

An analysis of the maps of earthquake epicenters shows that in areas of future foci there is a complete lull ($N = 0$), or the number of earthquakes decreases sharply here. For less strong earthquakes ($K = 14$), such a pattern was not found. Thus, it can be stated that, according to the forecast of the place of occurrence of the earthquake, there is some uncertainty that can be overcome by using other methods. The graph (figure 1) shows that since the end of 2018, there has been a decrease in the parameter *N* - the number of the earthquakes of medium strength from $K \geq 9.6$ in the study area.

If we consider the seismic process in the near (R ≈ 100-150 km) and far (R ≈ 150 km) zones from the source of the future earthquake, then it proceeds differently. So, for 3-5 years before the earthquake in the near zone, activation prevails, and in the far zone lull prevails, and 1-2 years before the shock, the opposite picture is observed. This is clearly demonstrated in Figure 4, which shows the time diagram of the ratio of the number of earthquakes from $K \geq 9.6$ in the far zone (*N1*) to the near zone (*N2*). The area with coordinates 41°50'- 43°30' North latitude and 76°30'- 79°30' East latitude was considered as the near zone, within which the epicenters of strong earthquakes (1970, 1978, 1980, 1982 and 1990) occurred. The graph (figure 4) shows that before all the above-mentioned earthquakes, there is first a drop and then a sharp increase in the parameter *N1/N2*, which, in the vast majority of cases, goes beyond the confidence interval with a width of ±1.6 at a probability level of 0.7. Note that very low values of *N1/N2*, which are observed immediately after strong earthquakes, are associated with their aftershocks.

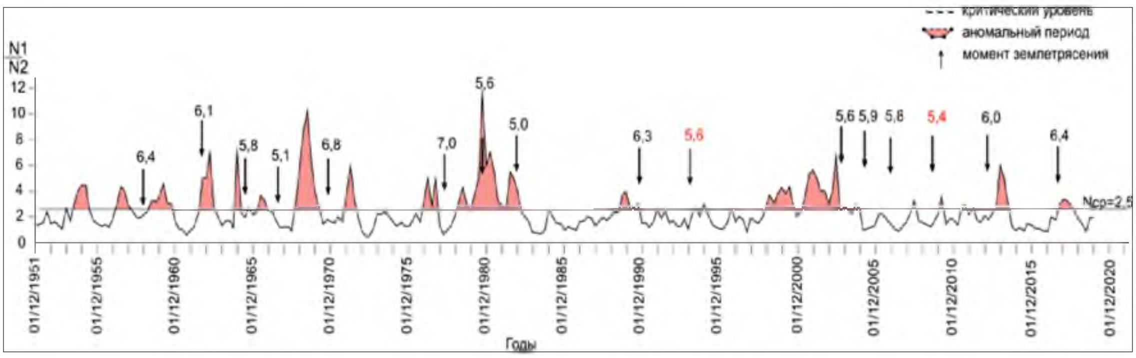
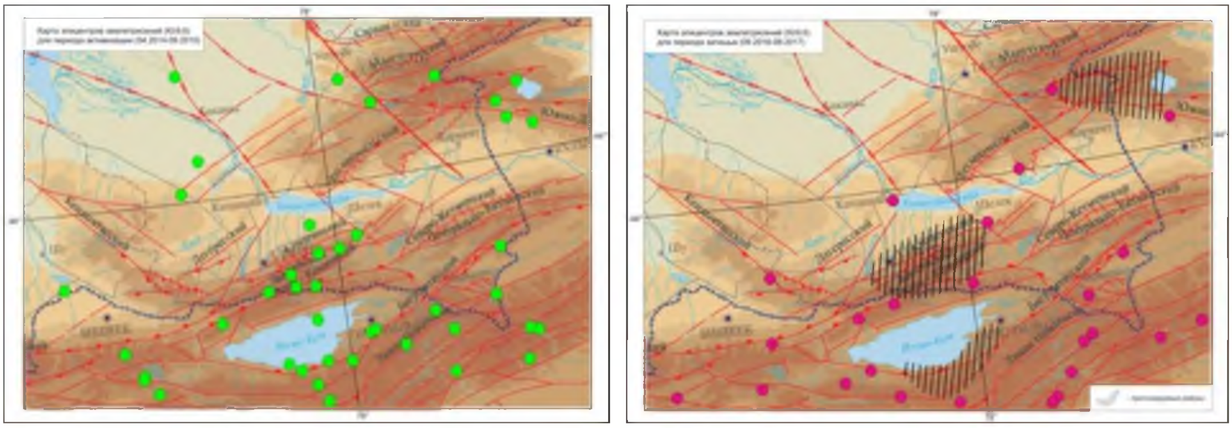


Figure 4 – Diagram of the time course of parameter *N1/N2*

To assess the places of possible occurrence of the expected earthquake, a search was conducted for areas within which the pattern of activation and lull in the number of medium-strength earthquakes is very clear. For this purpose, maps of earthquake epicenters were compared for two periods: for the activation period of 06.2014 - 06.2016, which, according to the data in figure 1, precedes the period of lull, and that for the anomalous period from 06.2016 to 05.2017.

Figure 5 shows that the seismic process under consideration (‘activation-lull’) occurred in three regions: in the central part of the Zailiysky and Kungei Alatau ridges, South-East of lake Issyk-Kul and in Dzhungaria.



a b

Figure 5 – Maps of earthquake epicenters with $K \geq 9.6$: (a) - for the activation period (06.2014 - 06.2016); (b) - for the lull period (06.2016 - 05.2017)

On August 8, 2017, an earthquake with M = 6.4 occurred on the territory of the Xinjiang Uygur Autonomous Region of China (the Dzhungarian section), and a significant number of less severe events (K = 9.6 - 11.6) in 2018 occurred on the other two sections (figure 6).

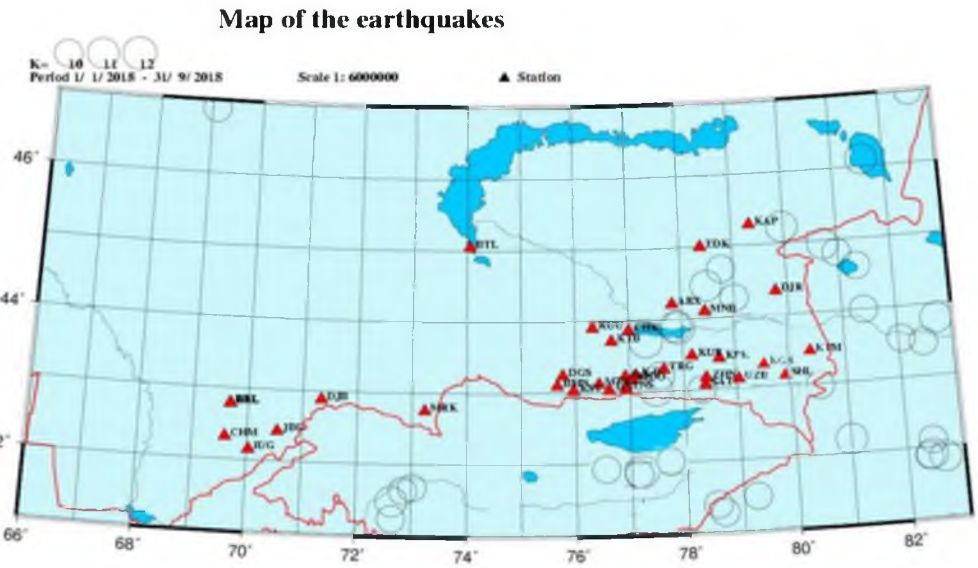


Figure 6 – Map of earthquake epicenters with $K \geq 9.6$ on the territory of South-East Kazakhstan and in its immediate vicinity for 2018

It should be noted that the graph of parameter N in 2019 begins to form a period of lull, which requires close attention to the further development of the time variation of parameters N and $N1/N2$.

The results obtained suggest that the proposed approach in combination with other methods can be used in the practice of medium-term forecasting of strong earthquakes in the Eastern Tien Shan and Dzhungaria regions.

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ОРТА КҮШТІ ЖЕРСІЛКІНІСТЕР БОЙЫНША «БЕЛСЕНДІЛІК-БӘСЕҢДІК» ӘДІСІ

Аннотация. 2020 жылдың орта мерзімді болжамын анықтауга қолдану үшін орта күші ($K \geq 9{,}6$) бар жер сілкінісінің кеңістік-уақыт заңдылыгымен таралу жагдайына талдау жүргізілді. Тәжірибелік полигон ретінде Шыгыс Тянь-Шань және Жоңгар аймагының солтүстік ендігі 41°40′- 45°30', шығыс бойлыгы 74°00′- 81°00′ координаттарымен шектелген аудан қарастырылды. 1951-2018 жылдар аралыгында магнитудасы $M \geq 5{,}6$-$6{,}0$ (барлығы 16) және энергетикалық класы $K \geq 9{,}6$ ($M \geq 4{,}2$) болатын жерсілкініс каталогы қолданылды. Ретроспектр талдау негізінде барлық бақыланып отырган жылдарда жер сілкінісі санының жылдық мәнінің (N параметрі – орта күшті жер сілкіністер саны) 3 ай сайын уақыттық жылжудан белсенділік кезеңінің ($N > Nкр = Nср \pm \sigma$) алмасуын көрсететін уақыттық жылжуы кезінде ауытқу өзгерістері байқалды, ягни N параметрінің кейбір критикалық деңгейі $Nкр$ жогарылауы және бәсеңдеуі ($N < Nкр$) зерттелін отырган аудандағы жер сілкінісінің болатын уақытымен байланысты.

Орта күшті жер сілкіністер бойынша жойқын зілзалаға дайындық кезеңі «белсенділік-бәсеңділік» үдерісінің болу фактісі жер сілкінісін болжау тәжірибесінде және жер сілкінісіне дайындық теориясына арналған көптеген зерттеулерде байқалады және Еуразияның түрлі сейсмобелсенді аудандарының күшті жер сілкіністерін болжау үшін пайдаланылады. Зерттеулерге сәйкес, түрлі алғышарттардың таралу ауқымы жағынан аса жоғары болуынан жойқын сілкініске дайындық көлемді территория алатыны байқалды.

Қатты жер сілкінісінің өту және ауытқу кезеңін салыстыру арқылы олардың арасында тығыз байланыс бар екені байқалды, шын мәнінде, 16 жер сілкінісінің ішіндегі он төрт жер сілкінісінің алдында белсенділік-тен кейін байқалатын орташа күшті жер сілкініс санының бәсеңділік ауытқуы байқалды. Сондай-ақ қатты жер сілкіністің өту және ауытқу кезеңдері сәйкес келмейтін үш жалған орын бар.

Бір-екі жылға жуық аралықта жер сілкіну магнитудасы $M \geq 5{,}6$-$6{,}0$ болуы ықтимал аумақтар, яғни тікелей жақын немесе зерттеліп отырған аудан шегінде орналасқан 3 аумақ көрсетілді.

Түйін сөздер: каталог, орта күшті жер сілкінісі, белсенділік, бәсеңділік, алғышарттар, ауытқу кезеңі, орта мерзімді болжам.

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МЕТОД «АКТИВИЗАЦИЯ-ЗАТИШЬЕ» ПО ЗЕМЛЕТРЯСЕНИЯМ СРЕДНЕЙ СИЛЫ

Аннотация. Проведен анализ пространственно-временных закономерностей распределения землетрясений средней силы ($K \geq 9{,}6$) с целью выяснения возможности применения их для среднесрочного прогноза на 2020 год. В качестве опытного полигона принята территория Восточного Тянь-Шаня и Джунгарии, ограниченная координатами 41°40′- 45°30' северной широты, 74°00′- 81°00′ восточной долготы. Использован каталог землетрясений с энергетическим классом $K \geq 9{,}6$ ($M \geq 4{,}2$) за I95I-2019 гг. и сильные землетрясения с $M \geq 5{,}6$-$6{,}0$ (всего 16), произошедшие за указанный период. На основе ретроспективного анализа временного хода годовых значений количества землетрясений (параметра N – количество землетрясений средней силы с $K \geq 9{,}6$), определенных для всего периода наблюдений со сдвигом в 3 месяца, выявлены аномальные изменения в его поведении, заключающиеся в последовательном чередовании периодов активизации ($N > Nкр = Nср \pm \sigma$), т.е. превышения параметром N некоторого критического уровня $Nкр$, и затишья ($N < Nкр$), которые связаны с моментами возникновения сильных землетрясений на исследуемой территории.

Факт существования процесса «активизация-затишье» по землетрясениям средней силы в периоды подготовки сильных землетрясений отмечается во многих исследованиях, посвященных теории подготовки и практике прогноза, и используется для целей прогнозирования сильных землетрясений для различных сейсмоактивных районов Евразии. Согласно исследованиям, площадь распределения различных предвестников столь велика по размерам, что позволяет предполагать участие крупных территорий в подготовке сильных землетрясений.

Сопоставление аномальных периодов с моментами возникновения сильных землетрясений свидетельствует о существовании достаточно тесной связи между ними, действительно, перед четырнадцатью землетрясениями из 16 имеет место аномальное затишье числа землетрясений средней силы, которое наблюдается после активизации. Также имеют место три ложные тревоги.

В результате проведенного исследования выделено 3 участка, в пределах или в непосредственной близости от которых вероятны возникновения землетрясений с $M \geq 5{,}6$-$6{,}0$ в ближайшие один-два года.

Ключевые слова: каталог, землетрясения средней силы, активизация, затишье, предвестник, аномальный период, среднесрочный прогноз.

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