ГЕОФИЗИЧЕСКИЕ ИССЛЕДОВАНИЯ, 2010, том 11, № 1, с.27-34

550.834

INVESTIGATION OF SEISMICITY IN WESTERN HIMALAYA

© 2010 г. Alexey A. Lyubushin[1], Baldev Raj Arora[2], Naresh Kumar[2]

[1] *Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, Russia*
[2] *Wadia Institute of Himalayan Geology, Dehra Dun, India*

Analysis of hidden periodicity of seismic records for Western part of Himalaya indicates a well defined precursors for the 29 March 1999 Chamoli earthquake of M_w=6.6 and for 19 October 1991 Uttarkashi earthquake, M_b=6.4, as statistically significant increasing of periodic component of main-shocks' sequence intensity estimated within moving time window of the length 4 years. The detailed analysis of new compiled seismic catalogue of the study region for a period of 1552 to 2004 highlight the importance of significant role of smaller magnitude earthquake for precursory study.

Keywords: seismic intensity, periodicity, earthquake precursors.

Introduction

Himalaya is the youngest mountain belt having complex geological setup, active tectonic discontinuities and zones of variable seismic density. The western part of Himalaya has experienced the catastrophe due to big Kangra earthquake of 1905 and the recently occurred M 7.8 Muzzafrabad earthquake of October 8, 2005. The Muzzafrabad earthquake (epicenter 73.5°E, 34.3°N) occurred to the north-west of our study region (74°E–82°E, 28°N–34°N) and therefore we are not able to analyze the precursor of this earthquake using the present catalogue for this methodology. The information of destruction due to historical earthquake is not available but it is clear from Fig. 1(a) that the region has experienced about 8 earthquakes having magnitude more than 7.0, while the reported earthquakes number of more than 6.0 magnitude is about 50.

In the eastern part of the study region two big earthquakes are happened during the instrumental records of the seismic events. The Chamoli earthquake occurred on March 28, 1991 having M 6.8 and epicenter while the Uttarkashi earthquake occurred on October 19, 1991 of 6.6 magnitude.

Geotectonic information

Himalaya is formed due to the continent-continent collision of Indian and Eurasian plates. The Indian plate is moving to the NNE direction and under thrusting with SSW moving Eurasian plate. The collision has started about 50 m.y. ago resulting the formation of high mountain belts extending to east-west direction for 2400 km with deformation of lithosphere with variable degree. It has resulted the complex geological setup from protorezoic to Quaternary age, the different tectonic discontinuities with increasing age from south to north and the occurrence of big earthquakes to recent age and release of increased stress due to occurrence of seismic events. The faults are of thrust, normal, strike slip. The thrust faults are extended for long length with east-west strike parallel along the mountain belt of Himalaya, dipping to the north from 5° to 15°. The normal and strike slip faults are mainly perpendicular to the thrust and the mountain belts and are of less length. These faults are dipping with variable degree.

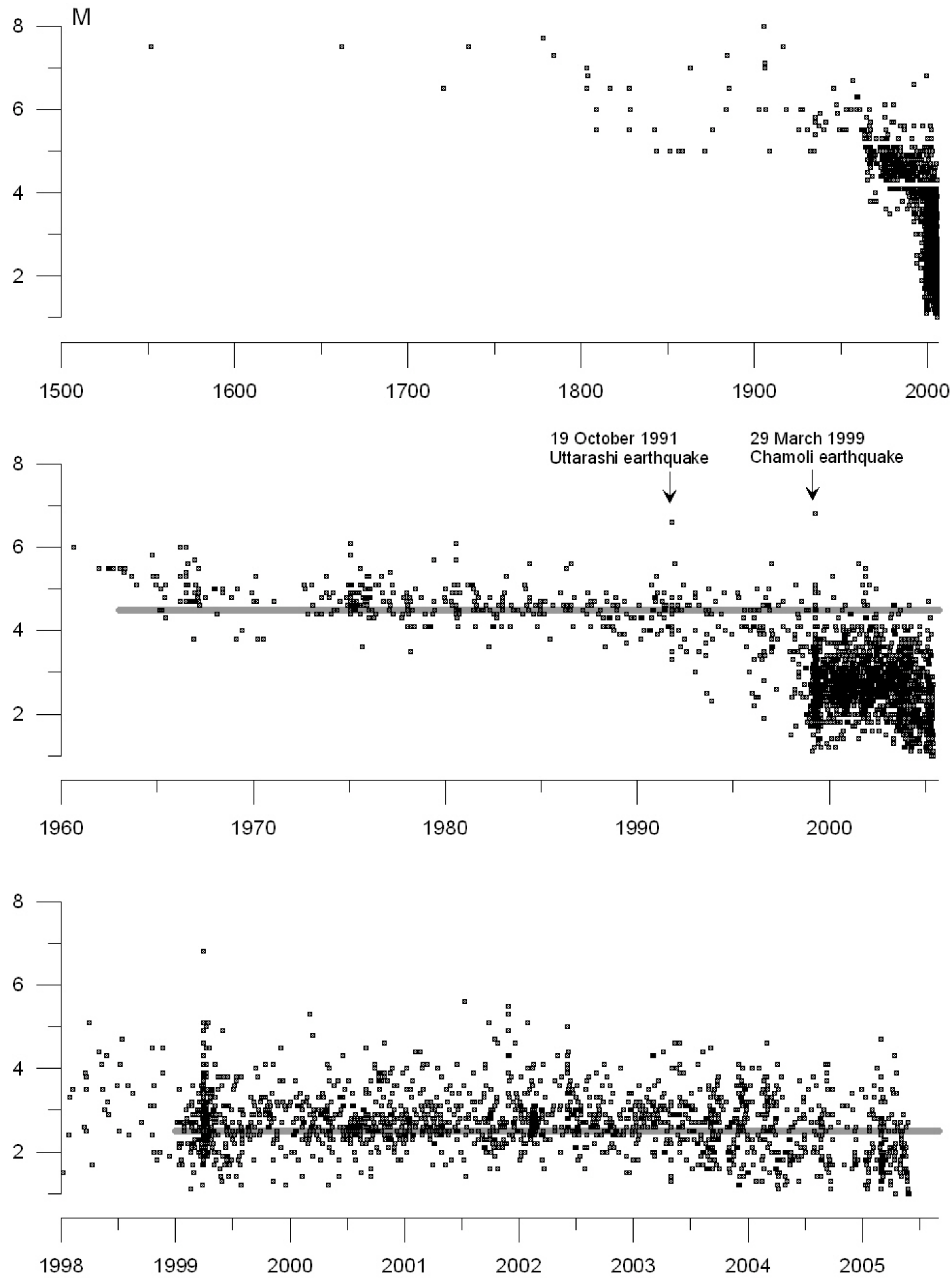

Fig. 1. Sequence of magnitudes values for different time intervals. Bold horizontal lines give statistically significant lower magnitude values

Seismic catalogue

The Fig. 1 presents a distribution of magnitudes values of seismic events in dependence on time. The catalog has 2 change points of essential increasing its quality: 1963 and 1999 – this could easily be noticed from the Fig. 1. The Fig. 2 presents empirical cumulative histograms for 2 time interval: 1963–2005 and 1999–2005. The value of argument for which the empirical distribution function has a straight line behavior till the maximum observed magnitudes gives statistically significant minimum value of magnitude: for 1963–005 intervals it equals 4.5 whereas for time interval 1999–2005 it equals 2.5.

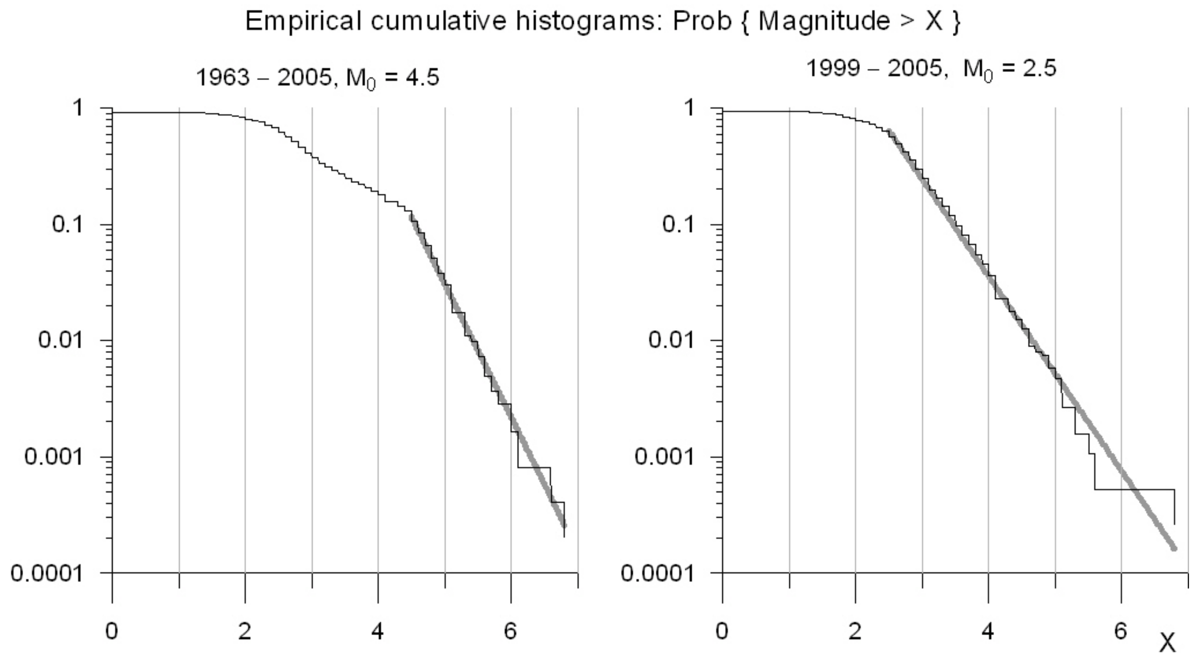

Fig. 2. Empirical functions of distribution of magnitudes values for periods 1963–2005 and 1999–2005. The values M_0 are statistically significant values of lower magnitude. Bold grey lines give best fit for magnitude values exceeding M_0

The Fig. 3 presents spatial distribution of earthquakes epicenters for all events within catalog and for events belonging to time interval 1963–2005 and having magnitudes not less than 4.5. Besides that Fig. 3(b) presents partition of the region into 2 polygonal parts: northern Q1 and southern Q2.

For further analysis it is necessary to exclude aftershocks. For this purpose the simplest method [*Gardner, Knopoff,* 1974] was used. The advantage of this method is that it is casual, i.e. does not use the future information for decision whether the considered event is mainshock or aftershock. This property is important for applications to earthquake prediction. Let t_j, M_j be the origin time and the magnitude of the mainshock. The seismic event t_k, M_k is considered its aftershock and removed from the catalog if it satisfies the criteria of $M_k < M_j$, $t_j < t_k < t_j + \tau(M_j)$ and the distance ρ_{jk} between epicenters of events *j* and *k* obeys the condition of $\rho_{jk} < r(M_j)$. Here $\tau(M) = \tau_0 \cdot 10^{a(M-M_0)}$ and $r(M) = r_0 \cdot 10^{b(M-M_0)}$. Following [*Gardner, Knopoff*, 1974] we used M_0=4, τ_0=30 days, r_0=10 km, *a*=*b*=0.5. The 1st event in the catalog is regarded as a mainshok.

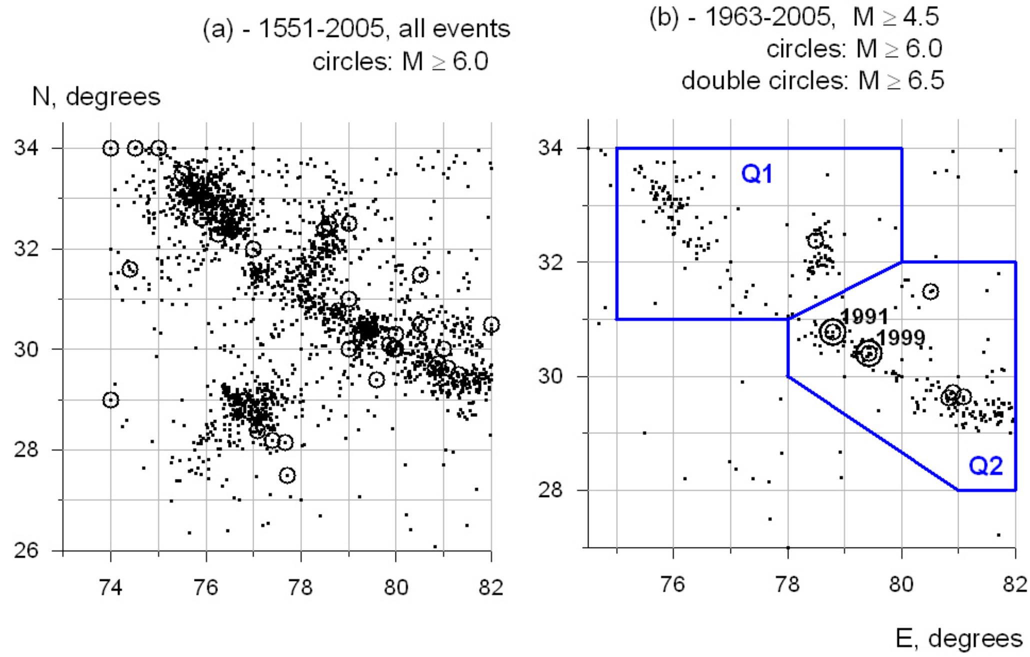

Fig. 3. (a) Distribution of epicenters for all events from historical to 2005; (b) Distribution of epicenters for time interval 1963–2005 for magnitudes ≥4.5, seismically active region is split into 2 parts (Q1 and Q2)

The next step of our investigation will be seeking for periodic components of main shocks intensity in the domains Q1 and Q2 for magnitudes ≥ 4.5.

Analysis of hidden periodicities within sequences of mainshocks

The method was proposed at the paper [*Lyubushin et al.,* 1998] and is intended for detecting periodic components within flow of events.

Let

$$t_i,\ i = 1,...,N \tag{1}$$

be a sequence of the time moments of occurrence of events that is observed within a time interval of $(0, T)$. Let us consider the following model of seismic intensity which has a periodic component:

$$\lambda(t) = \mu(1 + a\cos(\omega t + \varphi)), \tag{2}$$

where the frequency ω, amplitude a, $0 \le a \le 1$, phase angle φ, $\varphi \in [0, 2\pi]$ and multiplier $\mu \ge 0$ (which describe a Poissonian part of seismic process intensity) are parameters of the model to be identified. Thus, the Poissonian part of intensity is modulated by harmonic oscillation.

Let us fix some value of ω for which the Logarithmic likelihood function [*Cox, Lewis,* 1966] for the set of observations is equal to:

$$\begin{aligned} \ln L(\mu, a, \varphi \mid \omega) &= \sum_{t_i} \ln(\lambda(t_i)) - \int_0^T \lambda(s) ds = \\ &= N\ln(\mu) + \sum_{t_i} \ln(1 + a\cos(\omega t_i + \varphi)) - \mu T - \frac{\mu a}{\omega}[\sin(\omega T + \varphi) - \sin(\varphi)]. \end{aligned} \tag{3}$$

Taking maximum value of (3) with respect to μ, we can easily find

$$\hat{\mu} = \hat{\mu}(a,\varphi \mid \omega) = \frac{N}{T + a(\sin(\omega T + \varphi) - \sin(\varphi))/\omega} \ . \tag{4}$$

Substituting (4) into formula (3) we will have:

$$\ln(L(\hat{\mu},a,\varphi \mid \omega)) = \sum_{t_i} \ln(1 + a\cos(\omega t_i + \varphi)) + N\ln(\hat{\mu}(a,\varphi \mid \omega)) - N \ . \tag{5}$$

It should be noted that $\hat{\mu}(a = 0,\varphi \mid \omega) \equiv \hat{\mu}_0 = N/T$ is the estimate of the uniform Poissonian (pure random) part of intensity.

Thus, the increment of log-likelihood function due to introduction of the harmonic oscillation with given frequency value ω into the model of intensity with respect to zero hypothesis that seismic process is uniform pure random (Poissonian) equals:

$$\Delta \ln L(a,\varphi \mid \omega) = \sum_{t_i \in} \ln(1 + a\cos(\omega t_i + \varphi)) + N\ln(\hat{\mu}(a,\varphi \mid \omega)/\hat{\mu}_0) \,. \tag{6}$$

Let

$$R(\omega) = \max_{a,\varphi} \Delta \ln L(a,\varphi \mid \omega), \ 0 \le a \le 1, \ \varphi \in [0,2\pi] \,, \tag{7}$$

The function (7) could be regarded as the generalization of the spectra for the sequence of events. The graphic of this function indicates which probe values of the frequency provide the maximum gain in log-likelihood function increment with respect to a pure random model. Thus, the points of maximum of the function (7) detect periodic components of the seismic process.

The next generalization of this approach is estimating the function (7) not over the whole time interval of observation (0, *T*) but within moving time window of certain length T_W. Let τ be a time coordinate of the right-hand end of the moving time window. Then we have the function of 2 arguments: $R(\omega,\tau \mid T_W)$ which could be visualized as 2D map within the plane of (ω,τ)-values. The time-frequency diagrams allow describe the dynamics of periodic component within seismic process.

This time-frequency diagram allows to investigate the dynamics of occurring and development of periodic components within considered flow of events [*Lyubushin*, 2002; *Sobolev*, 2003].

For estimating statistical significance of the peaks of function (7) we can apply Wilks' theory [*Rao*, 1965; *Lyubushin et al.,* 1998] according to which in particular case of the model (2) in case when sequence of moment is pure random (Poissonian) an asymptotic relation for distribution probability function of (7) takes place:

$$\Pr\{R(\omega) < X\} = 1 - e^{-X}, \quad N \to \infty \,. \tag{8}$$

From formula (8) it follows that 90% probability threshold equals 2.3. Thus, if the peak values of (7) exceed the threshold 2.3 it means that we can regard these peaks as evidence for existing periodic component with probability not less that 0.9.

Results

Figures 4 and 5 present time-frequency diagrams of log-likelihood increments evolution within moving time window of length 1461 days (4 years) taking with mutual shift of 25 days for domains Q1 and Q2. For each diagram a corresponding sequence of mainshock is presented by a stick, whose length is proportional to the magnitude of the event. The time marks on the diagrams represent the right-hand coordinate of the moving time windows.

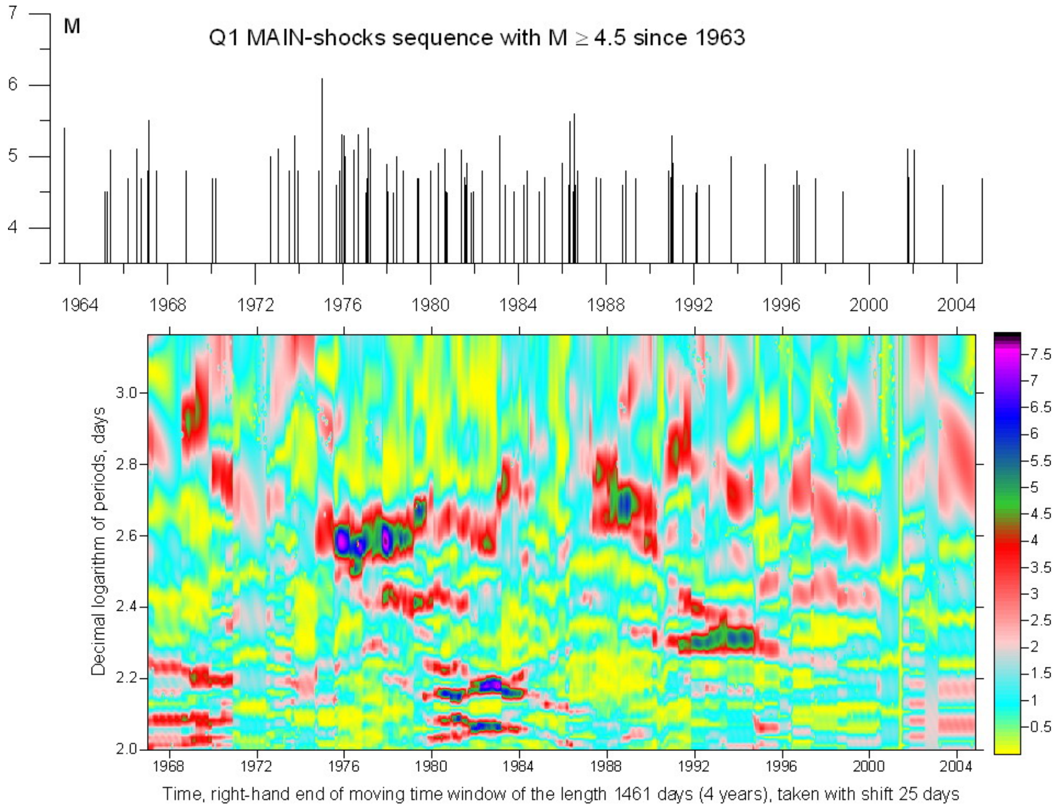

Fig. 4. Evolution of the increment of log-likelihood function for mainshocks in the domain Q1 within moving time window of the length 1461 days (4 years)

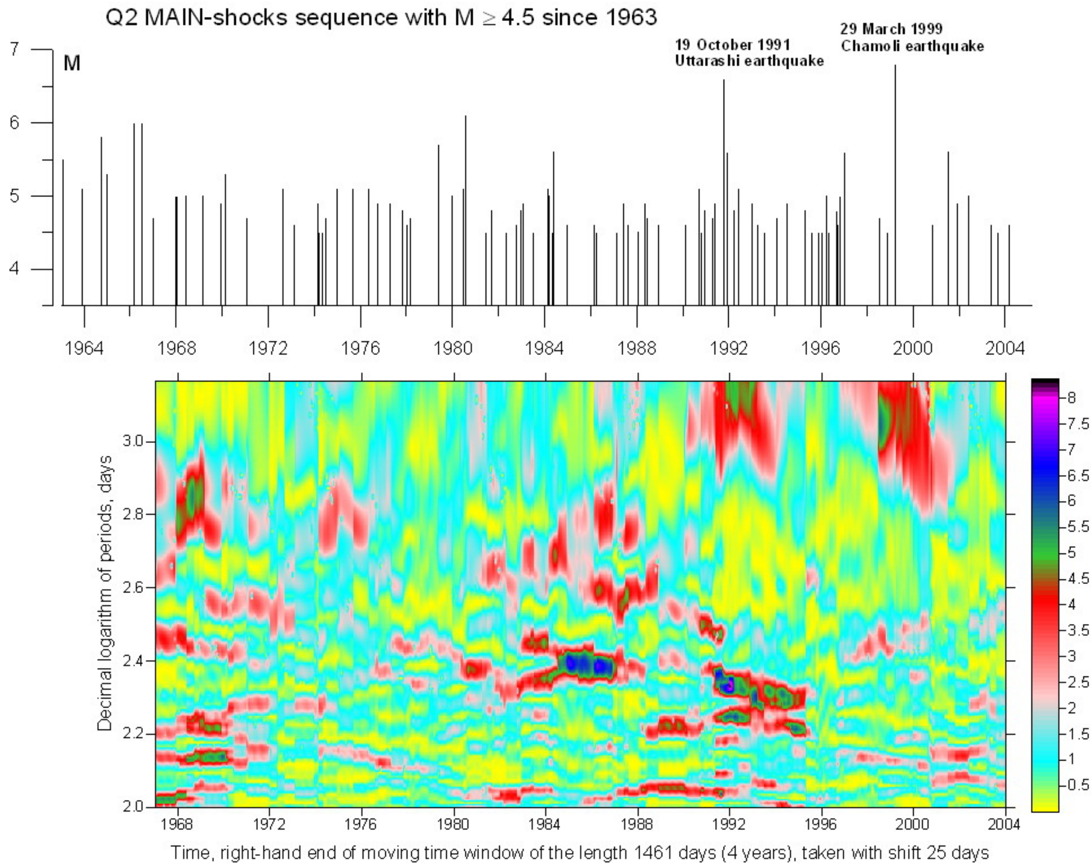

Fig. 5. Evolution of the increment of log-likelihood functions for mainshocks in the domain Q2 within moving time window of the length 1461 days (4 years)

The main difference between Fig. 4 and 5 consists in existing periodic components of intensity on the large periods (more than 1000 days) for the domain Q2. Domain Q2 contains two strong earthquakes, the first one is the Uttarkashi earthquake of October 19, 1991, M=6.6 with epicenter 30.77°N, 78.79°E and the second is the Chamoli earthquake of March 28, 999, M=6.8, 30.41°N, 79.42°E. For both theses earthquakes we noticed a significant increase in the periodic component of intensity for time windows having right-hand end approximately 0.5 year before the main shock. Domain Q1 (Fig. 4) has no long-periodic components of mainshocks sequence. This could be a consequence of absence of strong earthquakes in the domain Q1. Both diagrams have a number of peaks with periods less than 500 days but they reflect a stochastic structure of seismic process and it is difficult correspond them to any events directly.

The physical mechanisms for arising phenomena of increasing long-periodic component within seismic process before strong earthquakes is discussed in [*Sobolev*, 2003] and it could reflect the processes of consolidation of Earth's crust within the epicentral area of future shock.

Conclusion

The analysis of thin time-frequency spectral structure of main-shocks sequences using new method of detecting hidden periodicity within point processes allows detect precursory phenomena in the seismicity of Western Himalaya before the strongest earthquakes. This phenomena consists in increasing periodic component of intensity approximately 0.5 years before the shock on periods more than 1000 days.

References

Cox D.R., Lewis P.A.W. The statistical analysis of series of events. London: Methuen, 1966.

Gardner J.K., Knopoff L. Is the sequence of earthquakes in Southern California with aftershocks removed, Poissonian? // Bull. Seismol. Soc. Amer. 1974. V. 64. P.1363–1367.

Lyubushin A.A., Pisarenko V.F., Ruzich V.V., Buddo V.Yu. A New Method for Identifying Seismicity Periodicities // Volcanology and Seismology. 1998. V. 20. P.73–89.

Lyubushin A.A. Periodicities and Rhythms of Global Seismicity in the 20th Century // Joint Session of the OGGGGN RAN Seminar "Theoretical Problems of Geology" and the 10th Seminar "Planetary System of the Earth": Rhythms and Cycles in Geology as Evidence for General Laws of Development. February 7–8, 2002. Abstracts (OGGGGN RAN, Moscow, 2002) [in Russian]. 2002.

Rao C.R. Linear statistical inference and its applications. John Wiley & Sons, Inc. N.Y., London, Sydney. 1965.

Sobolev G.A. Evolution of Periodic Variations in the Seismic Intensity before Strong Earthquakes // Izvestiya. Physics of the Solid Earth. 2003. V. 39. P.873–884.

Authors:

LYUBUSHIN Alexey Alexandrovich – Dr. Sci., Chief research scientist, Institute of Physics of the Earth, Russian Academy of Sciences, 123995, Russia, Moscow, B. Gruzinskaya Str., 10. Phone: +7(499)254-23-50. E-mail: lyubushin@yandex.ru

ARORA Baldev Raj – Director of Wadia Institute of Himalayan Geology; 33, Gen. Mahadev Singh Road Dehra Dun - 248001. Phone No.: 0135-2625952, Fax No.: 0135-2625212.

KUMAR Naresh – Senior Scientist of Wadia Institute of Himalayan Geology; 33, Gen. Mahadev Singh Road Dehra Dun - 248001. Phone No.: 0135-2625952, Fax No.: 0135-2625212.

УДК 550.834

ИССЛЕДОВАНИЕ СЕЙСМИЧНОСТИ ЗАПАДНЫХ ГИМАЛАЕВ

А.А. Любушин[1], Б.Р. Арора[2], Н. Кумар[2]

[1] *Институт физики Земли им. О.Ю.Шмидта РАН, Москва, Россия*
[2] *Институт геологии Гималаев им. Вадиа, Дехрадун, Индия*

Аннотация. По результатам анализа сейсмического каталога Западных Гималаев, выполненного с целью обнаружения скрытых периодичностей, выделены предвестники землетрясений Чамоли 29 марта 1999 г. (*M*=6.6) и Уттаркаши 19 октября 1991 г. (*M*=6.4) – при оценке в скользящем временном окне длиной 4 года прослежено значимое увеличение периодической компоненты интенсивности главных толчков. Детальный анализ новых данных, полученных компилированием разных каталогов, подчеркивает важность для прогноза землетрясений регистрации землетрясений малой магнитуды.

Ключевые слова: сейсмическая интенсивность, периодичность, предвестники.