PRECURSOR OF SUMATRA, 26.12.2004, M=9, EARTHQUAKE AS INCREASING OF PERIODIC SEISMICITY INTENSITY COMPONENT AT THE PERIODS 250-320 DAYS.

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ABSTRACT

Retrospective statistically significant precursor of the Sumatra, 26.12.2004, M=9, earthquake was extracted as increasing of periodic oscillations of the seismic process intensity with the period values 250-320 days starting approximately 2 years before the shock within wide rectangular vicinity of the epicenter.

INTRODUCTION.

Unfortunately modern geophysics has no possibilities for real-time prediction of huge earthquakes. Representation about the modern state of art could be received from [1]. The retrospective analysis of the data after such events is the only way for seeking the probable ways for real prediction. After each huge seismic catastrophe a question arises: was there any premonitory information within available data, which could indicate the approaching of the event? For such event as Sumatra, 26.12.2004, M=9, earthquake no usual geophysical monitoring data (deformations, seismo-acoustic emission, geochemical time series, etc.) are available. The 1st reason is that the epicenter of the shock is placed at the ocean bottom. But the area of preparation of the earthquake of this scale is rather large and if it would be some geophysical monitoring stations on the shore of Indian Ocean there would be a hope to detect some precursory anomalies within geophysical monitoring time series. The 2nd reason is that there were no stations of such kind. Thus, the only information available is the series of seismic events detected by global net of seismic observations.

Below the method elaborated in [2] for investigating periodic components in seismic process will be modified for application in moving time window and will be applied for analyzing seismic process at the vicinity of the Sumatra, 26.12.2004, M=9, earthquake for time interval 1963-2004. Note that the applied method differs from previously proposed methods for point process periodic components estimating [3, 4] and is more simple, clear and straightforward. It preserves a “point process” nature of seismic process (i.e. is not based on reducing the sequence of events to usual time series with some uniform time step). Besides that the current realization is intended for estimating within moving time window for highly non-stationary flows of events what is very essential for investigating seismic process properties.

Seeking for some specific oscillations of different geophysical parameters before strong earthquakes is a well-known approach in earthquakes research [5, 6]. The method which is used in the article deals with flow of seismic events directly and does not need any preliminary transforms. The only free parameter of the method is the length of moving time window.

METHOD

Let

$$\mathbf{t_i, i = 1, ..., N} \qquad (1)$$

be a sequence of the events' time moments which was observed within time interval $(0,T]$. Let us consider the following model of seismic intensity which has a periodic component:

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

where the frequency ω, amplitude $a, 0 \le a \le 1$, phase angle φ, $\varphi \in [0,2\pi]$ and multipliers $\mu \ge 0$ (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 the frequency ω. Logarithmic likelihood function [3] for the set of observations is equal to:

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

Taking maximum value of (3) with respect to μ it is easily to find that

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

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

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

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:

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

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 the 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.

In papers [7, 8] the statistics (7) was used for seeking precursors of strong earthquakes at Kamchatka and for investigating a thin structure of micro-seismic oscillations before strong earthquakes.

CASE STUDY: SEISMIC PROCESS AT THE VICINITY OF THE SUMATRA, 26.12.2004, M=9, EARTHQUAKE FOR TIME INTERVAL 1963-2004.

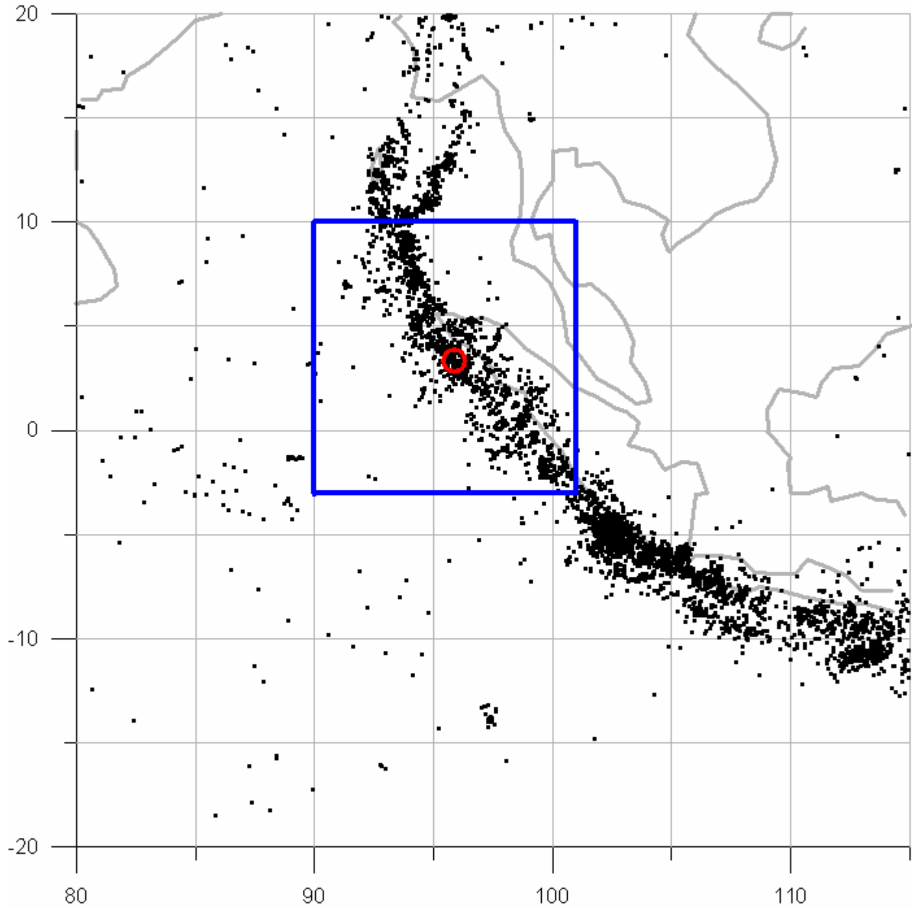

Fig.1. Distribution of earthquakes epicenters with M ≥ 4.5, depth ≤ 100 km in South-Eastern Asia, 1963-2004. Red cycle – epicenter of the Sumatra, 26.12.2004, M=9, earthquake. Blue rectangular domain is the vicinity of this shock to be investigated. Data were taken from http://wwwneic.cr.usgs.gov/neis/. Aftershocks were not removed.

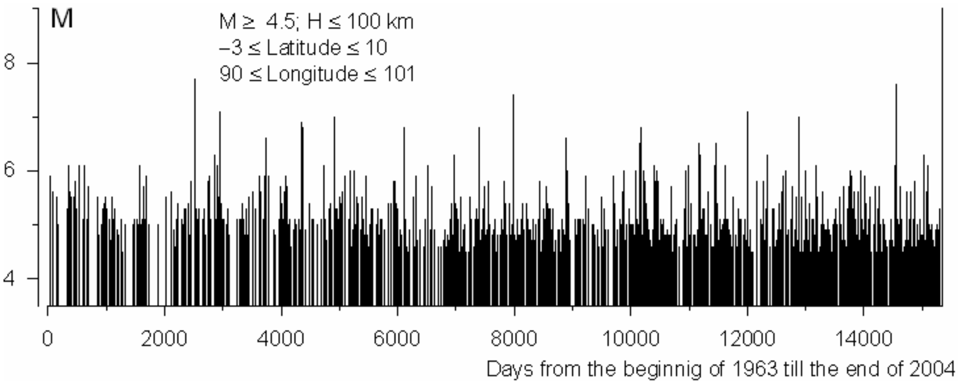

Fig.2. Seismic process within rectangular domain at the Fig.1. The general number of events before the 26.12.2004 shock equals 1387.

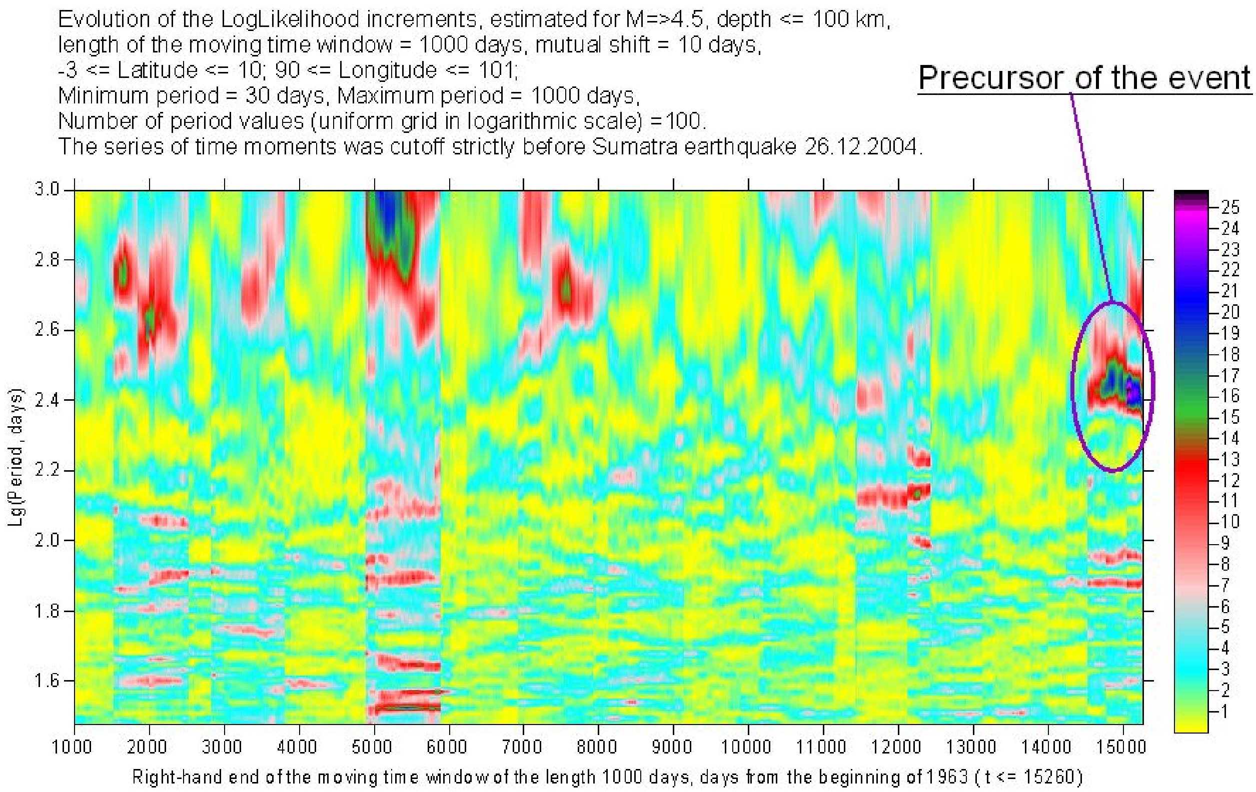

Fig.3(a). Statistics $\mathbf{R}(\omega,\tau\,|\,\mathbf{T}_W)$ for the length of moving time window 1000 days. The “strip-like” structure of the pattern is due to the influence of aftershocks series.

Conclusion

Increasing of periodic oscillations of seismic process intensity with the periods 250-320 days turns to be statistically significant precursor of the Sumatra, 26.12.2004, M=9, earthquake. Statistical significance of the result follows from the following experiment: the artificial Poissonian series of time moments of the same average intensity as for the sequence presented at the Fig.2 was generated. The length of this artificial time series was taken 10^5 events. Afterward the method of estimating statistics $\mathbf{R}(\omega,\tau\,|\,\mathbf{T}_W)$ was applied to this artificial series with the same parameters as at the Fig.3(a). The maximum value of $\mathbf{R(\omega,\tau\,|\,T_W)}$ for this experiment equals to 10.8. Thus, the precursory peak at the Fig.3(a) is statistically significant.

It should be underlined that aftershocks series were not removed before processing. The 2D diagram at the Fig.3(a) evidently contains characteristic strip-like structure because of the presence of aftershock series after rather strong earthquake. The main reason for leaving aftershock is that periodic component of seismic intensity can be most strong within these aftershocks series. The analogy with Earth's oscillations after strong earthquakes can be presented: although these oscillations take place at each time interval they could be reliably extracted after strong earthquakes only. The same situation seems to be with periodic component of seismic intensity: it became sufficiently strong within aftershock series of some moderate earthquakes. The precursor of Sumatra earthquake is a peak of periodic intensity within aftershock series of previous earthquake 02.11.2002, M=7.6, Latitude=2.82, Longitude=96.08. At this sense this earthquake could be regarded as generalized foreshock of Sumatra earthquake.

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