STATISTICAL MODELLING OF GLOBAL TECTONIC ACTIVITY AND SOME PHYSICAL CONSEQUENCES OF ITS RESULTS

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ABSTRACT
Based on the analysis of global earthquake data bank for the last thirty years, a global tectonic activity indicator was proposed comprising a weekly globally averaged mean earthquake magnitude value. It was shown that 84% of indicator variability is a harmonic oscillation with a fundamental period of 37.2 years, twice the maximum period in the tidal oscillation spectrum (18.6 years). From this observation, a conclusion was drawn that parametric resonance (PR) exists between global tectonic activity and low-frequency tides. The conclusion was also confirmed by the existence of the statistically significant PR response at the second lowest tidal frequency i.e. 182.6 days. It was shown that the global earthquake flow, with a determination factor 93%, is a sum of two Gaussian streams, nearly equally intense, with mean values of 23 and 83 events per week and standard deviations of 9 and 30 events per week, respectively. The Earth periphery to 'mean time interval between earthquakes' ratios in the first and the second flow modes described above match, by the order of magnitude, the sound velocity in the fluid (~1500 m/s) and in elastic medium (5500 m/s).

Keywords: earthquakes, statistical modelling, parametric resonance, tectonic activity.

Problem statement and input data
The study objective is to build statistical model of global tectonic activity as well as to provide analysis of possible formation mechanisms to result in its periodic and a periodic variability. To solve the problem, an earthquake database (DB) was created to cover earthquakes recorded by global seismic stations network [1] over the 1983 to 2012 period. The data base is arranged as an Excel 2010 spreadsheet workbook and consists of 92229 records each of which corresponds to individual earthquake (event) and contains the following record fields (entries): event time, the epicenter latitude, the epicenter longitude, and event magnitude. For the purpose of further analysis, the raw data were structured into 1509 records, each containing data to describe one week as represented by the following fields: mid-week timing, event number, mean magnitude, RMS magnitude error, maximum magnitude, and maximum and mean magnitude difference in RMS units. Input data are representative that is strongly illustrated by Figure 1 where points corresponding to the most powerful earthquakes of the week reliably indicate the global tectonic faults pattern well-known to experts in the field.

Simulation methods
Statistical modeling of Global Tectonic Activity (GTA) was performed using regression analysis. Event number, mean magnitude and maximum magnitude were tested for GTA indicator candidates. A regression model of the form:

$$I(t) = \sum_{k=0}^{n}[a_k \cos(k\omega t) + b_k \sin(k\omega t) + Rez(t) \qquad (1)$$

Was built for each assumed indicator where model coefficients(a_k,b_k,ω) were found using root-mean-square procedure followed by testing them for statistical significance using Student's test and evaluating the quality of the resulting regression model using model residuals to white noise similarity criteria.

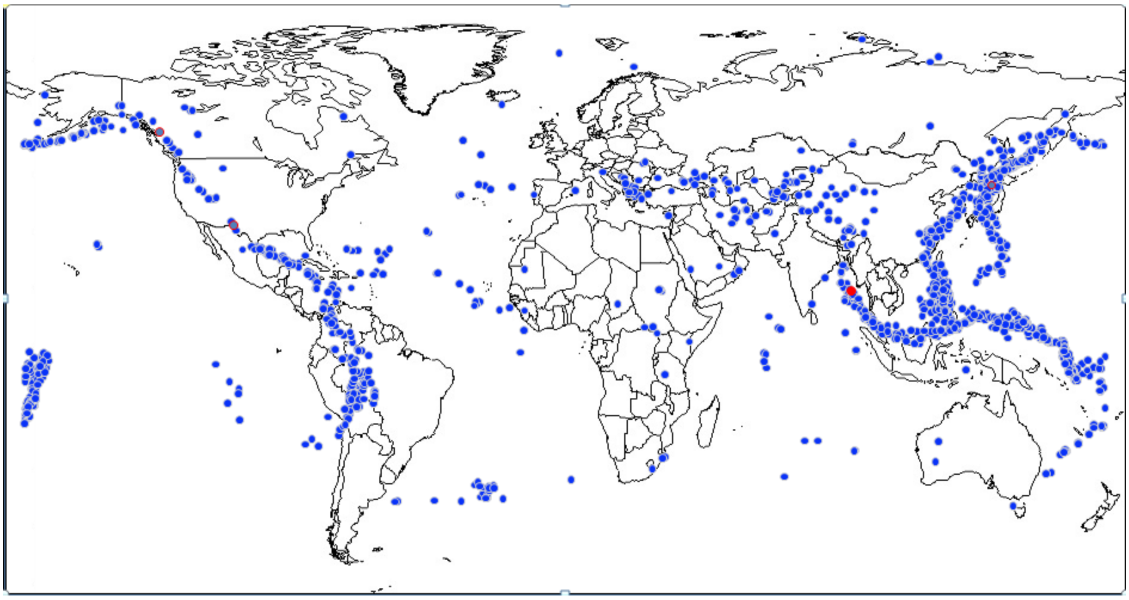

Figure 1: Visualization of faults resulted from the strongest earthquakes of the week

Model residuals similarity to white noise, in its turn, was quantified using Durbin-Watson statistic criterion closeness to 2 and the proximity criterion of integrated residual periodogram $Rez(t)$to the right line passed through zero (as judged by linear fitting determination factor value for integrated residual periodogram).

The flow of events (earthquakes) was modeled as a linear combination of Poisson and Gaussian streams with various intensity characteristics.

Simulation results

It is the first harmonic magnitude with a period of 37.2 years that has the highest determination factor (84%) of all tested indicators. Corresponding Fisher statistic value is 667. Figure 2 presents simulation results. Model vibration spectrum is represented by Table 1.

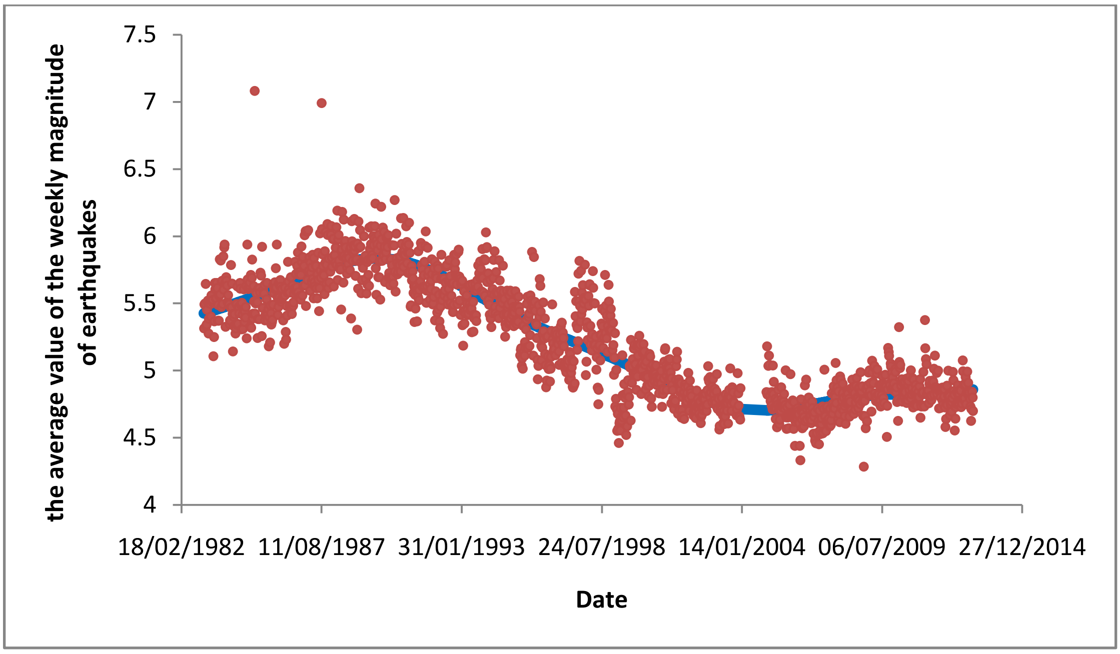

Figure 2: Indicator values (points) vs fitting curve (solid line)

Table 1

Harmonic	**0**	**1**	**2**	**3**	**4**
Amplitude	5.20	0.52	0.08	*0.01*	0.04
Error	0.01	0.01	0.01	*0.01*	0.01

The third harmonic discarded when building the model (significance less than 80%) is highlighted with smaller font italics. The rest values are significant at (100% - $4{\cdot}10^{-8}$) or higher significance level.

Straightforward residual testing of the model (1) $Rez(t)$for similarity to white noise seems unreasonable due to "aftershock" effect well-known to seismologists (the aftershock often lasts for a week or more). The effect is qualitatively confirmed by the high value of the mean magnitude autocorrelation function for a one-week lag, $B(1)$=0.44. It seems reasonably, therefore, that the model should be augmented with autoregressive term:

$I(t) = \sum_{k=0}^{n}[a_k \cos(k\omega t) + [b_k \sin(k\omega t)] + B(1)I(t-\tau) + Rezar(t)$ (2)

Where τ=1 week. For the model Eq. (2) residuals $Rezar(t)$, the Durbin-Watson statistic value is 2.16; Figure 3 is an illustration of energy spectrum scattering and its integral. When fitting the energy spectrum integral with right line passed through zero, the determination factor value is 99.6%.

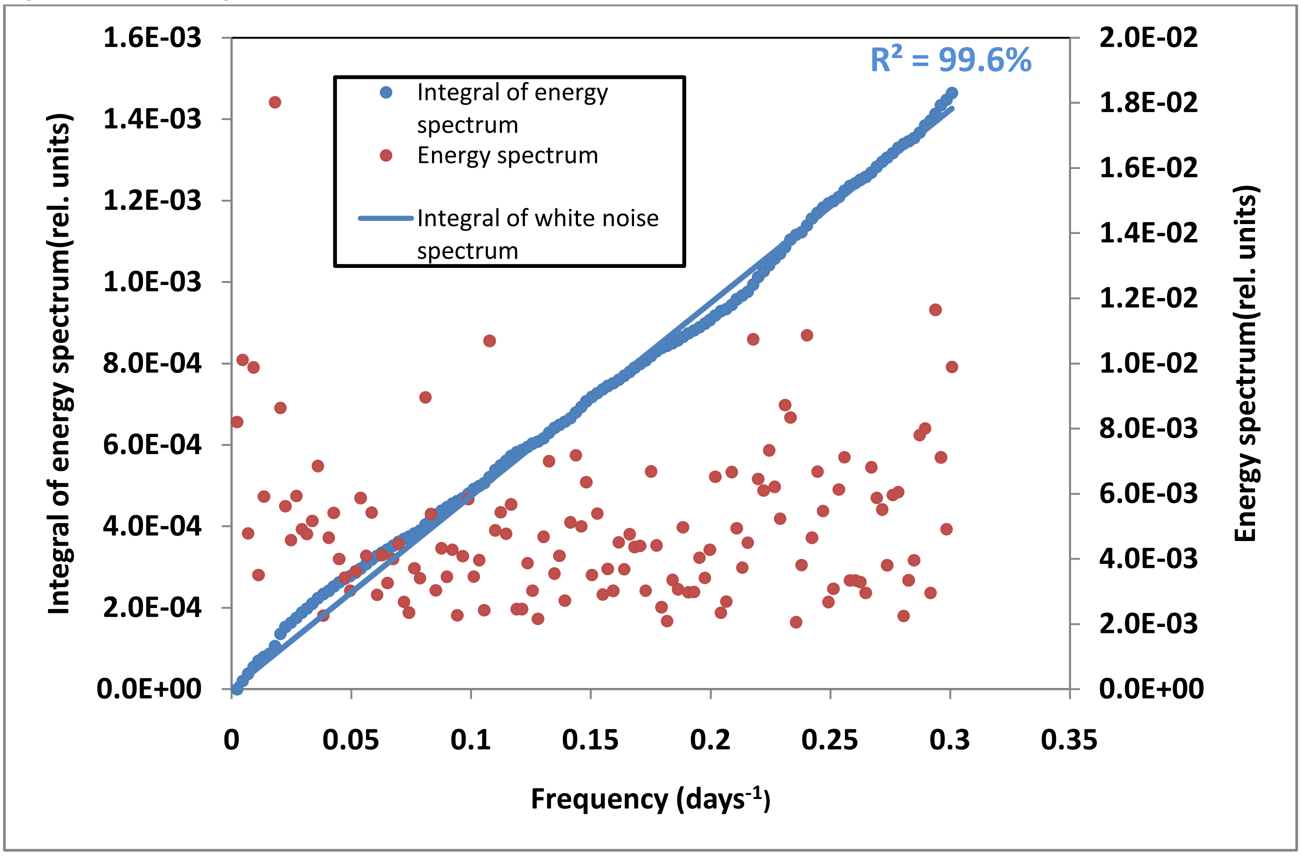

Figure 3: Testing the residual energy spectrum of the model (2) for similarity to white noise

The resulting global earthquake model with a determination factor of 93% (the Fisher statistic value being 8217) comprises a sum of two nearly equally intense Gaussian streams with mean occurrence values of 23 and 83 events per week and standard deviations of 9 and 30 events per week, respectively. Figure 4 is an illustration of the model. Interestingly, the Earth periphery to 'mean time interval between earthquakes' ratios in the first and the second flow modes described above match, by the order of magnitude, the sound velocity in the fluid(~1500 m/s) and in elastic medium (5500 m/s).

One more, and definitely worth mentioning, results of statistical modeling is the fact that the number of earthquakes per current week correlates with the mean earthquake magnitude over previous week with correlation coefficient W(1)=-0.68.This especially means that 46% (0.68^2) of the current earthquake number variability could be explained by mean earthquake magnitude variability over previous week.

Discussion of results

The principal outcome of model-based simulation is the oscillation with a period of 37.2 years. Such oscillations are well-known in atmosphere and ocean physics [2] to be a parametric resonance (PR) with the most low-frequency of tidal oscillations having a period of 18.6 years [3].

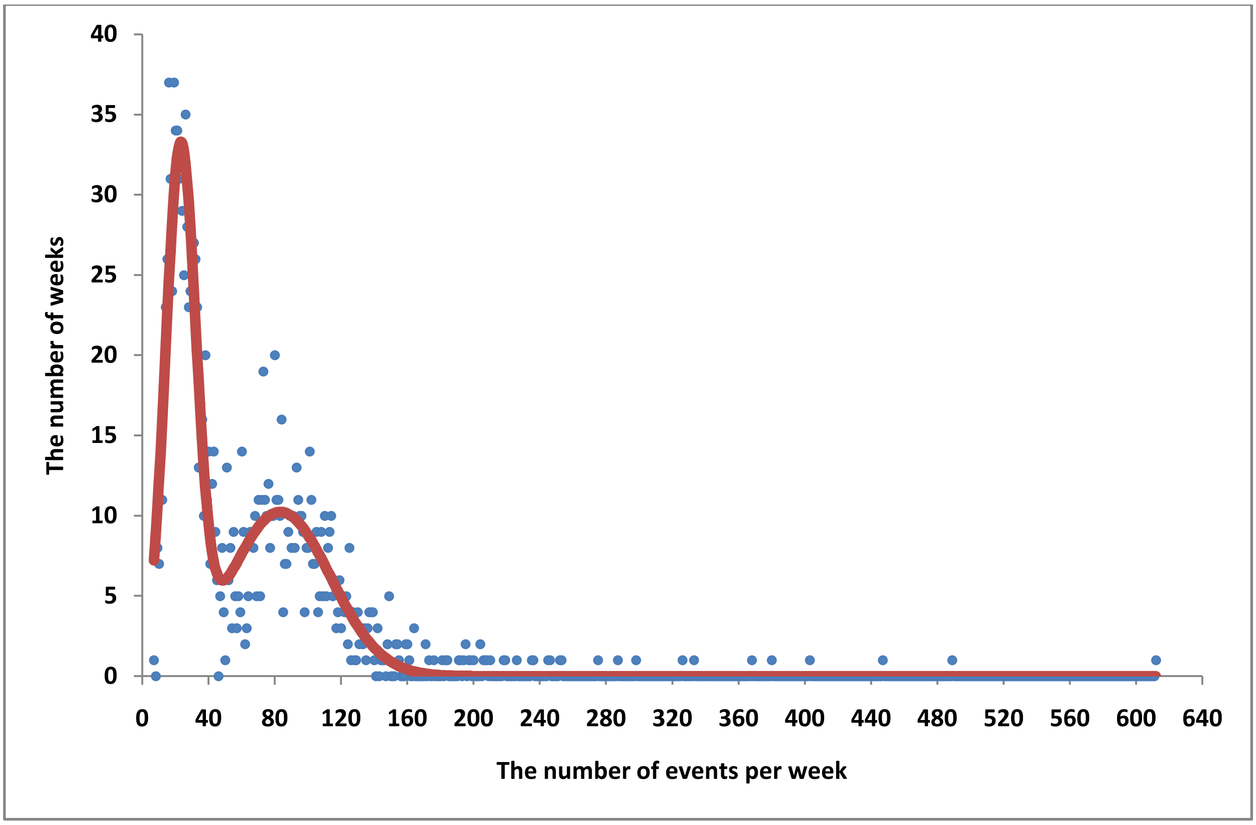

Figure 4: The flow of events (points) vs its model (solid curve)

Physical nature is well-established for PR. Tectonic activity variations are due to variable parameters of oscillating system, rather than to the Earth's crust strains induced by tidal forces. Tidal forces cause mass redistribution within the Earth and so redistribute the shock excitation redistribution conditions. According to general theory of parametric resonance [4], the result is the response at frequencies that are multiples of half the exciting frequency, with the resonant response being the most stable at half the frequency. It is appropriate to recall here that, apart from the conventional resonance, in this case the resonant response increases with time exponentially rather than linearly, so the system is highly sensitive to periodic variations of its own parameters. Furthermore, main constraints to forcing oscillation spectrum are imposed by inertia of the system – it is not mere chance that the most efficient PR occurs at an exciting frequency of the slowest of the tidal oscillation corresponding to a period of 18.6 years. Then again, the resonant response is still quite significant, although much smaller, at the next smallest tidal oscillation frequency of 182.6 days as well (see heavy red point in Figure 3).

The above conclusions suggest that the global tectonic activity is formed by responses to sporadic shock excitations through the Earth's crust stress relief due to waves induced by oscillations. That is why it is the propagation conditions of such waves modulated by tidal phenomena that mainly contribute (84%) to the global tectonic activity. Such an assumption is also confirmed by (far from being evident, at a first glance) negative CC value (W(1)=-0.68, see above) when correlating the number of earthquakes per current week with the mean earthquake magnitude over previous week. More powerful earthquake relieves greater number of developed strains so less number of them remains for relief on the next week.

Note that the PR so found is an evidence of geosphere interactions at low frequencies. In addition to the examples presented by [2] we point here to the existence of similar PR in ozonosphere (Figure 5).

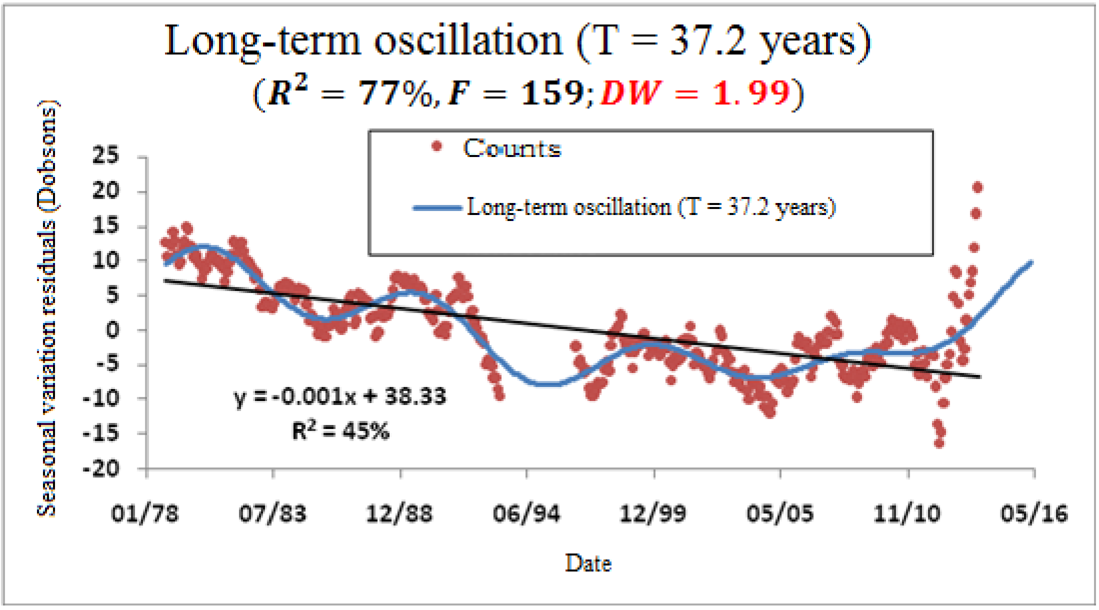

Figure 5: Model of long-term variability of global mean atmospheric ozone content (determination factor: 77%, Fisher statistic value: 177, Durbin-Watson statistic value: 1.99).

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