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Power spectra analysis for world-wide and North Africa historical earthquakes data in relation to sunspots periodicities

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Abstract

In the last three decades, the influence of solar activity on earth seismicity is one of the most important subjects in the field of long-term prediction of earthquakes.

In the present work, the autocorrelation and power spectra analysis were applied for the sequences of sunspots and earthquakes activity. The used data are the worldwide earthquakes of $M \geqslant 5$, and the sunspots number R_z, for the period 1903–1985. Both are available from the National Oceanic and Atmospheric Administration NOAA, Boulder, Colorado, U.S.A. Also, we restrict our attention to earthquakes in North Africa with two stations, one at Cairo (Egypt), and the other at Alger (Algeria) of $M \geqslant 4$ for the period (1900–1986).

The results indicated the presence of the eleven year cycles of the sunspots into the time of the earthquakes of the North Africa. Also, from the worldwide and North Africa earthquakes data a periodicities ranged between 1.01 and 5.5 years are revealed, which may be linked to a solar activity cycle.

1. Introduction

In the last three decades, many authors have suggested that, solar activity plays a significant but by no means exclusive role in the triggering of earthquakes. Simpson [1] found that maximum quake frequency occurs at times of moderately high and fluctuating solar activity. Sytinskiy [2–7] carried out a series of searches on the

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influence of solar activity on the earth seismicity. Lursmanashvili [8–10] and Lursmanashvili et al. [11] spoke about variations and position of the earth on its yearly orbit in correlation with the solar activity, and the regular changes of time of earthquake occurrences in some seismic regions, as in the Caucases. Ip [12] wrote about Chinese records on the correlation of heliocentric planetary alignments and earthquake activities. Forecasts were made on the basis of the correlation between the instants of occurrence of strong earthquakes and the time of passage of geoactive solar regions across the central meridian of the sun [13].

Anghel [14] estimated a new physical model for the earthquake triggering effect of solar activity and application to the Vrancea zone. Odinets [15] made an analysis for a sequence of earthquakes in the Far East and Central Asia; a cyclicity with a period of 5.5 years is revealed, which may be linked to a solar activity cycle. Relation of earthquakes in China and solar activity was reported by Xiufang [16]; also the great Wuqia earthquake of 1985 and its relation with sunspot cycles was discussed by Daoyi and Jianguo [17].

On the other hand, other authors said that most of the presumed correlations of earthquake occurrence with actual periodicities that have appeared in the literature can be shown to be spurious [18]; or due to the failure to apply proper statistical scrutiny [19, 20].

Allam and Mesiha [21] studied the short period seismic surface waves recorded at Helwan seismograph station. The earthquakes used in their study occurred in Greece, Mediterranean Sea, Turkey, Iran, Red Sea and Ethiopia in the period between 1965 and 1973; most of them were propagating through the northeastern region of the Mediterranean. It might be stated that the crustal structure of the region is continental. The same authors studied the surface waves and layered structure in Egypt [22].

Mesiha [23] found that the crustal thickness of the Northern African zone is 35 km, where the long period surface Rayleigh wave group velocity dispersion curves of selected earthquakes from Greece, recorded by Tunis, Algerian and Morocco seismic stations, were determined. Continental dispersion curves of group velocities for Love and Rayleigh waves have been determined using Helwan seismograph records for three earthquakes which occurred in the Aswan region. It was found that crustal thickness in the Aswan–Helwan region (Egypt) is about 35 km [24]. The structure of the crust and upper mantel under Northern Africa was studied by Mesiha [25]. The study depended on the analysis of the travel time of seismic body waves crossing Northern Africa.

In the present work, we applied a reliable statistical method for autocorrelation and power spectra analysis on sequences for worldwide and North African historical earthquake data to promote the notation that the statistical results of the earlier studies have a physical basis.

2. Data sources

The data used are the worldwide earthquakes of $M \geqslant 5$ and sunspots number R_z, for the period 1903–1985. Both are available from the National Oceanic and Atmospheric Administration NOAA, Boulder, Colorado, U.S.A.

We restricted our attention to earthquakes in North Africa with two stations Helwan–Cairo (Egypt) and Alger (Algeria) of $M \geqslant 4$, for the period 1900–1986. The coordinates of the two stations are:

$$\text{Helwan Lat. } 29^{\circ}52'\text{N}, \quad \text{Long. } 31^{\circ}20'\text{E}$$

$$\text{Alger Lat. } 36^{\circ}12'\text{N}, \quad \text{Long. } 5^{\circ}24'\text{E}$$

A monthly index for the earthquakes activity was designed to convert the unequal space data of earthquakes to equal spaced data that can be used for the autocorrelation analysis. The monthly index is the summation for the magnitudes of the earthquakes, which occurred during the month. The summation carried out for all earthquakes of $M \geqslant 5$ for the worldwide data, and for all earthquakes of $M \geqslant 4$ for Cairo (Helwan Station) and Alger.

3. Methodology

In the present work, there are four time series:

1. Sequence of the sunspot number R_z.
2. Sequence of worldwide earthquakes.
3. Sequence of earthquakes recorded at Cairo.
4. Sequence of earthquakes recorded at Alger.

In order to investigate the periodicity for these time series, the power spectrum analysis technique was used. The calculation of the power spectrum depends on the following steps:

1. Calculation of the autocorrelation function, $C(T)$, as a function in the lag number by:

$$C(T) = \frac{1}{N-T}\sum_{t=1}^{N-T}[X(t)-\bar{X}][X(t+T)-\bar{X}] \tag{1}$$

where N is the total number of months, T is the lag number ($T = 0, 1, 2, \ldots, T_m$), T_m is the maximum lag and $X(t)$ and $\bar{X}$ are monthly and the average observations.
2. The power spectra density $P(L)$ is computed from the following relation:

$$P(L) = \frac{1}{T_m}\left[C(O)+2\sum_{t=1}^{T_m-1}C(O)\cdot W(T)\cdot\cos\left(\frac{L\pi T}{T_m}\right) + C(T_m)\cdot W(T_m)\cdot\cos(L\pi)\right] \tag{2}$$

where $O < L < T_m$, $W(T)$ is known as the lag window.

The lag window may be considered as a cosine window in the following form:

$$W(T) = \begin{cases} (1/2T_m)[1+\cos(T/T_m)]; & O \leqslant T \leqslant T_m \\ O \quad ; & T > T_m \end{cases} \tag{3}$$

which is known as the Hanning window [26, 27].

The cosine lag window may be used in the following form:

$$W(T) = \begin{cases} (1/T_m)[0.54+0.46\cos(T/T_m)]; & O \leqslant T \leqslant T_m \\ O \quad ; & T > T_m \end{cases} \tag{4}$$

which is known as the Hanning window [26, 27].

Actually the general nature of the spectral windows in these two pairs is the same [26].

The consideration of the exponential form for the lag window given by the following form [27]:

$$W(T) = \begin{cases} (1/T_m)[1-6(T/T_m)^2+6(T/T_m)^3]; & O \leqslant T \leqslant T_m/2 \\ (2/T_m)[1-(T/T_m)]^3 \quad ; & T_m/2 \leqslant T \leqslant T_m \\ O \quad ; & T > T_m \end{cases} \tag{5}$$

Determination of the real frequencies in the input data depends on obtaining the power spectrum by the previous steps after filtering, using Kalman filter, given by the following mathematical model [28].

$$\begin{aligned} P_k^* &= e^{2(t_k-t_{k-1})}P_{k-1}+\sigma_h^2 \\ X_k^* &= e^{(t_k-t_{k-1})}\hat{X}_{k-1} \\ B_k &= P_k^*/(P_k^*+\sigma_v^2) \\ \hat{X}_k &= X_k^*+B_k(Y_k-X_k^*) \\ P_k &= (1-B_k)P_k^* \end{aligned} \tag{6}$$

Where σ_h^2 and σ_v^2 are the variances of the system and the measured noised respectively.

The estimated value of $\hat{X}_k$ at any time t_k can be evaluated once the prediction of that value is calculated according to the first two relations of eqn (6). The determination of σ_h^2 and σ_v^2 depends on the knowledge of the analysis after filtering, as well as, before filtering, indicating the reliability of these frequencies [29].

4. Results and discussions

The effect of the Kalman filter on the spectra of the monthly mean sunspot number R_z for the period 1903–1985 is given in Fig. 1. Before and after the filtration, the 11.1 year cycle is the large peak. There are some sub-periodicities of the values 3.97, 2.8, 1.98, 1.8, 1.36, 1.16 and 1.01 years.

Figure 2 shows the power spectra of the world-wide earthquakes of $M \geqslant 5$ that

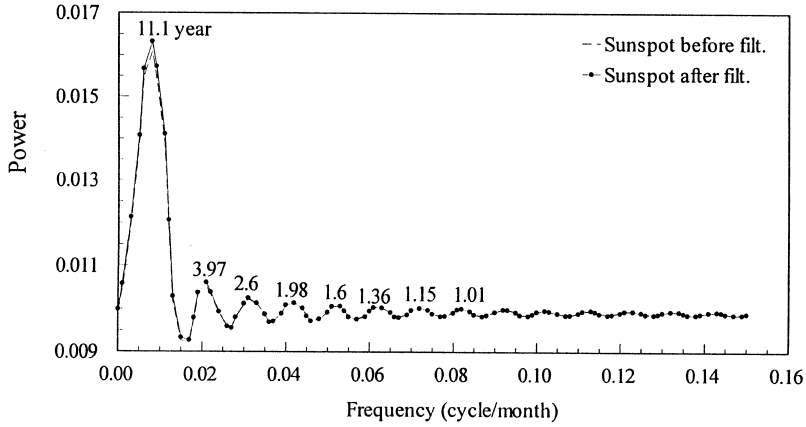

Fig. 1. Power spectra for the sunspot number R_z for the period 1903–1987, before and after the filtration by Kalman filter.

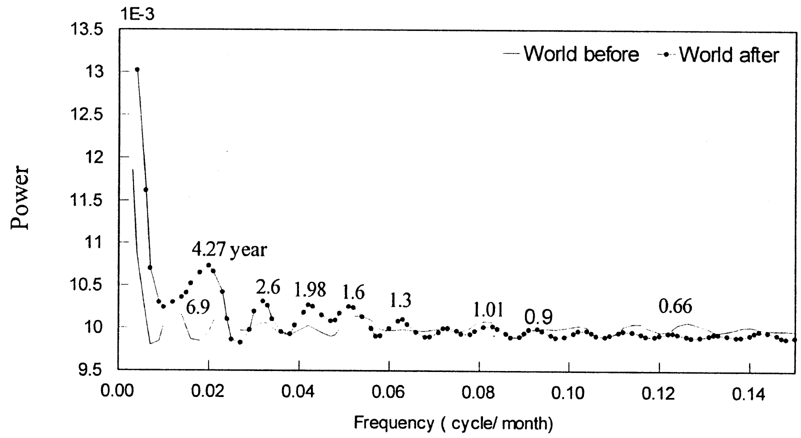

Fig. 2. Power spectra of the world-wide earthquakes of $M \geqslant 5$ for the period 1903–1987.

occurred during the period 1903–1985. After the filtration, there are periodicities of the values 4.27, 2.6, 1.98, 1.6, 1.3, 1.01, 0.9 and 0.66 years, where some of them are closed to the sub-periodicities in Fig. 1.

Figure 3 shows the power spectra for the body and surface waves of the earthquakes recorded at Cairo during the period 1900–1986. For the body wave, there are cycles of the values 11.1, 3.97, 2.5, 1.85, 1.26, 0.96, 0.89 and 0.64 years. After filtration, the prominent cycles are 4.6 years for the body wave and 5.5 years for the surface wave, as shown in Fig. 4.

Figure 5 shows the power spectra for earthquakes recorded at Alger during the period 1900–1986. There are periodicities of the values 13.9, 5, 3, 2.2, 1.7, 1.46, 1.2 and 1.1 years. The prominent peak is that of the 13.9 years periodicity, which is close

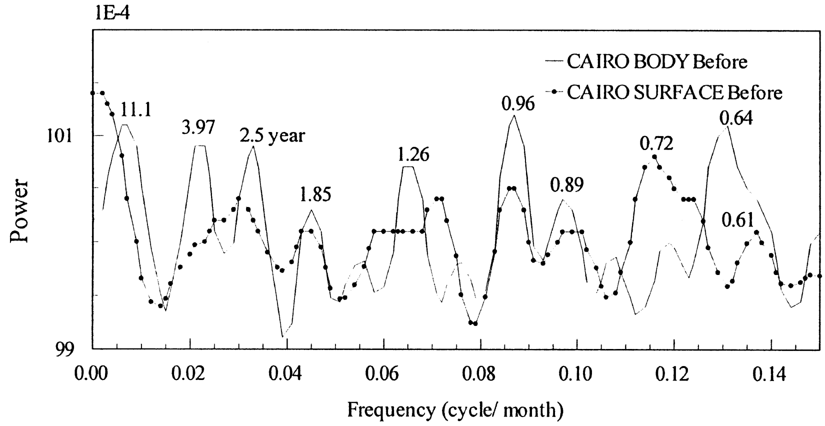

Fig. 3. Power spectra of body and surface waves of earthquakes recorded at Cairo (Helwan), for the period 1900–1986, before filtration by Kalman filter.

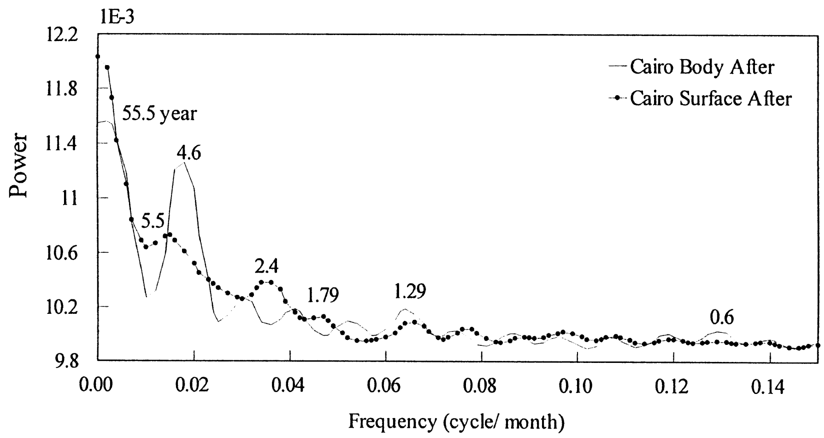

Fig. 4. Power spectra of body and surface waves of earthquakes recorded at Cairo (Helwan) for the period 1900–1986, after the filtration by Kalman filter.

to the 11 year cycle of the sunspot number R_z. Some of the sub-periodicities in Fig. 5 are close to the sub-periodicities of R_z in Fig. 1.

From the results, it is clear that there are close relations between R_z periodicities and earthquakes activity on the world-wide scale, or on the North African scale. In our opinion, this relation means that there are influences for the solar activity on the earth seismicity, but by no means an exclusive role in the triggering of earthquakes. Now, what is the mechanism of the influence of solar activity on seismic phenomena? The answer is one of the following possibilities:

(1) The variations in solar activity are responsible for the irregular variations in the

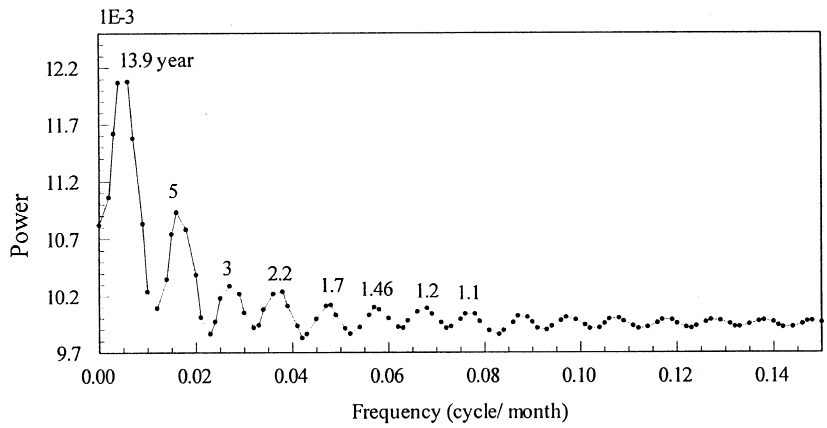

Fig. 5. Power spectra of earthquakes recorded at Alger (Algeria) during the period 1900–1986.

daily speed of rotation of the Earth and the Sun, for the seismic phenomena [16, 30, 31].

(2) Terrestrial-solar flare effects, which are the actual coupling mechanisms that trigger quakes appear to be either abrupt accelerations in the Earth's angular velocity or surges of telluric currents in the Earth's crust [1].
(3) The possible connection of volcanic eruptions with the Sun activity cycles [32] and the connection between volcanic and seismic cluster periods [33].
(4) Space-time correlation between solar activity and quasi-periodic gravity variations, where the latter affects the crustal structure and the earthquake energy [34, 35].
(5) It is established that the solar activity is the source for short and long term variation of the Earth's ionosphere, also it is the reason for the Sudden Ionospheric Disturbances SID (Mosalam Shaltout, 1980) [36]. Also, there is an ionospheric-seismic coupling, and there is a possibility of using it for earthquake predictions [37].
(6) Solar activity and irradiance affecting the atmospheric processes [38, 39]. Also Sytinskiy [6, 40] spoke about predicting the frequency and intensity of earthquakes and atmospheric processes.
(7) It is established that, solar activity affecting on the solar wind parameters [41]. Also, relations between strong earthquakes and solar wind parameters have been found by Sytinskiy [7].

5. Conclusions

From our analysis, results, and discussion we conclude that: solar activity plays a significant but no means exclusive role in the triggering of earthquakes. The mechanism of the influence of the solar activity on seismic manifestations is one of the seven possibilities, which are discussed in the previous section. The physical catalyst between the solar activity and earthquakes triggering is one of the following:

(1) Abrupt accelerations in the Earth's angular velocity (the daily speed of rotation of the earth).
(2) Surges of telluric currents in the Earth's crust.
(3) Volcanic eruptions.
(4) Quasi-periodic gravity variations, which affect the crustal structure.
(5) Variations in the Earth's ionosphere.
(6) Variations in the Earth's atmospheric processes.
(7) Variations in the solar wind parameters.

Where the seven phenomena are possibly affected by solar activity and possibly affect the triggering of the earthquakes.

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