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APPLIED RADIO PHYSICS: SPACE, ATMOSPHERE, AND EARTH'S SURFACE RESEARCH

ON THE RELATION BETWEEN GLOBAL SEISMICITY AND GEOMAGNETIC AND SOLAR ACTIVITY

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There are provided the results of investigation of the dependence of Earth seismicity upon geomagnetic activity during the periods of 43 strong magnetic storms and in the periods after 17 strong class X solar flares for two cycles of solar activity from the interval between the years 1974 to 2006. The investigations were performed on the basis of analysis of the Earthquake Catalog prepared by the National Earthquake Information Center of the United States Geological Survey (NEIS USGS) [<http://neic.usgs.gov>].

KEY WORDS: *Earth seismicity, strong magnetic storm, class X solar flare, the Earthquake Catalog, solar activity cycle*

1. INTRODUCTION

Seismic activity of the Earth can be referred to the sources of disturbances of natural origin, which, as it is shown by the investigations performed during the recent decades, often exert an essential influence upon the state of the ionospheric plasma. Main particularity of the above source is that in addition to the influence on the surface ionospheric plasma via generation of the wave processes having different types and modes, it results in significant and often substantial disturbances of the atmospheric this phenomenon electric field. In its turn, results in disturbances in the ionospheric plasma. A part of such disturbances is recorded using the radio physical and other methods.

Although many mechanisms of the influence of the earthquakes upon the state of the ionospheric plasma remain studied too little by now, it is already clear that at this type of disturbances the key role in the processes of the lithosphere-atmosphere-ionosphere-magnetosphere interaction is played by local and large-scale variations of the geo-electric fields and the geophysical phenomena related thereto (see, for

example, [1]). Despite a comparatively large number of publications the issues related to such influence upon the ionospheric plasma are studied insufficiently yet. It is related especially to the lowest part of the ionosphere – its D-region. Plenty of the issues, which are not clear, still remain in the mechanisms of the above relations presently. They require further theoretical studying and experimental research. Investigations of the disturbances within the “lithosphere-atmosphere-ionosphere-magnetosphere” system, which develop before and during the earthquakes, are of great importance primarily for development of the short-term and prompt prognoses of the powerful earthquakes.

Representation of the seismicity as a component part of a unitary physical process within the “Sun-Earth” system is used as the basis for studying the interaction between solar, geomagnetic and seismic activity of the Earth. At that, it is considered that the seismic activity (SA) and the phenomena properly are determined by the processes having both solar and terrestrial origin.

Analysis of the reference literature allows drawing the following conclusions:

- 1) There exists both global and regional statistically significant relation (a negative correlation) between the Earth SA and the phases of the 11-year cycle of solar activity;
- 2) Within the solar activity cycle the SA possesses the highest level during the period of the 11-year cycle minimum and during large solar flares (SF) occurring in the period of the increased solar activity;
- 3) There exist cyclic variations of the geomagnetic activity (GA) and the SA with the duration of three solar cycles;
- 4) Large solar proton flares occurring approximately once during three solar cycles initiate the transition of energy processes inside the Earth into the limit states, which states are preserved until the next large flares and determine the value of the energy release at the earthquakes (EQ) for the entire period concerned (see, for example, [2,3] and the links therein). However, as it turned out to be, no detail investigation was performed.

The relation between strong EQ and magnetic storms (MS) used to be detected long ago [2,4]. However, different modes of geomagnetic disturbances significantly impede detection of the attributes, occurrence of which is related to SA. Many researchers try obtaining the dependences between the GA and the EQ characteristics (probability, magnitude and depth) with the purpose of possible prediction of the earthquakes. The reference literature contains quite opposite opinions about the possibility of the EQ prediction on the basis of the geomagnetic data – from negation of the principal probability of the prediction to the possibility of providing for prompt prognoses.

Based on the analysis of the EQ Catalog prepared by the National Earthquake Information Center of the United States Geological Survey (NEIS USGS) [<http://neic.usgs.gov>] this paper provides the results of investigation of the dependence of SA upon GA during the periods of 43 strong MS and in the periods after 17 strong class X solar flares for two cycles of solar activity from the interval between the years 1974 to 2006.

The basis of our studies is formed by the following assumptions [5,6]:

- a) The Sun, the interplanetary medium, magnetosphere, ionosphere, and atmosphere of the Earth and the Earth properly including the processes occurring thereupon and resulting in the earthquakes, represent a single physical system that is the seismic phenomena are considered to be a part of the unitary physical process within the “Sun-Earth” system;
- b) The processes within the “Sun-Earth” system are interrelated; physical and biological processes depend on the state of each of the components of the above system;
- c) Seismic phenomena are determined by both the solar activity and the activity of the terrestrial origin.

2. ON THE RELATION BETWEEN THE GLOBAL SEISMICITY AND THE GEOMAGNETIC ACTIVITY (MAGNETIC STORMS)

In order to investigate the dependence of the seismicity upon the geomagnetic activity it is performed a search for the correlational relationship between the average monthly values of the geomagnetic activity index Ap and the number of EQ per month NQ for two cycles of solar activity (from 1974 till 2006).

Besides, daily distributions of the number of EQ were calculated from the Earthquake Catalog for the given period. The correlation analysis of the relation between the daily values of the number of EQ NQI with different intensities and the indices of Ap was performed on their basis.

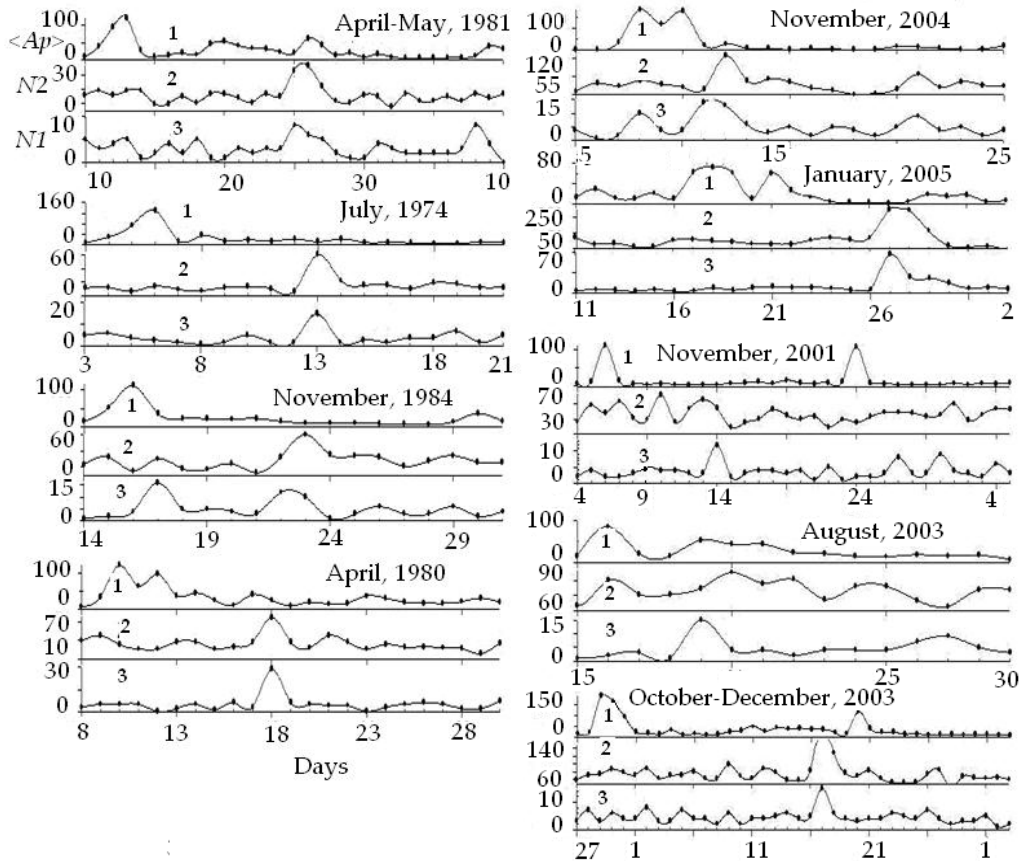
The analysis was performed for three samplings: there were separately considered the series of the data NQI including all the recorded EQ ($N2$), as well as for the EQ with the magnitude $M > 5$ ($N1$) and $M > 7$. On the basis of the above data it was also performed the analysis of relation of the seismicity with the periods of MS. For that purpose, 43 periods with the duration of 20...50 days (in some cases strong MS occurred after 15...25 days like, for example, in November, 2001, in August-September, 2005 etc.) were separated within the time interval concerned. Those periods included strong magnetic storms according to the generally accepted standard classification.

The MS with the value of $Ap > 100$ were considered. The behavior of the dependences $N1$ and $N2$ was analyzed during several days before the MS and during 15...30 days after the MS. Examples of dependences of the number of EQ with $M = 1...9$, with $M > 5$ and the GA indices Ap are shown in Fig. 1.

From the examples provided in Fig. 1 and from Table 1 it is determined and can be clearly seen that increasing of total number of the earthquakes by 1.5...3 times (and sometimes more) and the number of the earthquakes with $M > 5$ by 1.5...4 times in 2...3, 4...5, 6...7, 8...9, 12...14, 16...18 and 24...25 days after the earthquakes was observed in the considered cases with the probability of 0.2...0.6 (Table 1 provides the data about the increase of the number of EQ during the above periods: $N1$ and $N2$ are the numbers of EQ with $M > 5$ and $M = 1...9$ correspondingly).

TABLE 1: Distribution of the number of EQ during the typical periods after MS

Days	2...3	4...5	6...7	8...10	12...14	16...18	24...25
N1	25	14	17	18	18	11	3
N2	18	15	13	21	14	10	3

**FIG. 1:** Examples of the dependences of the number of the earthquakes with $M = 1 \dots 9$ (curves $N2$), with $M > 5$ (curves $N1$) and the geomagnetic activity indices Ap (curves 1)

3. ON THE RELATION BETWEEN THE GLOBAL SEISMICITY AND THE SOLAR FLARES

It is known that the large proton solar flares occurring approximately once during three solar cycles initiate the transition of energy processes inside the Earth into the limit states, which states are preserved until the next large flares and determine the value of the energy releases at the earthquakes during the period concerned. Besides, it was

noted that within the solar activity cycle the SA possesses the highest level in the period of the 11-year cycle minimum and during the large solar flares occurring in the period of the increased solar activity. However, apparently, no detail investigation was performed. Therefore, in order to investigate probable variations of global seismic activity of the Earth in the periods after 17 class X strong solar flares (of which the strongest and the mostly geo-efficient solar flares of 06.03.1989 X15.0/3b; 14.07.2000 X5.7/3b; 01, 04, 06, 09, 11 and 15.06.2001 X12.0/3b-4b; 28.10.2003 X17.2/4b; 04.11.2003 X17.4/3b (the peak value amounted to X28.0); 07.11.2004 X2.0; 10.11.2004 x2.5/3b; 07.09.2005 X17.0.) it is performed a search for the correlational relationship between the values of the geomagnetic activity index A_p and the daily number of EQ NQ for two cycles of solar activity from the interval of the years 1974 to 2006 [7].

To study the above variations, daily distributions of the number of EQ NQ were calculated from the Earthquake Catalog for the data representing all the given periods within the time interval of 10 days before and 30 days after each solar flare. There were analyzed the series of the data about NQ containing all the recorded earthquakes, as well as for the earthquakes having the magnitudes of $M > 5$, $M > 6$, and $M > 7$.

Examples of dependences of the number of EQ with $M = 1...9$, with $M > 5$ and the indices A_p are provided in Fig. 2 ($N1$ and $N2$ are the numbers of EQ with $M > 5$ and $M = 1...9$ correspondingly).

Table 2 represents the data about the increase of the number of EQ for the periods concerned.

TABLE 2: Distribution of the increase of the number of EQ during the typical periods after the solar flares

Days		2	5...6	7...9	10...13	17
Number of the increases of EQ	$N1$	12	9	11	8	9
	$N2$	14	12	13	11	10

It can be clearly seen from Table 2 and provided examples that in all the considered cases with the probability of 0.2 ...0.8 it was observed increasing of total number of the earthquakes by 1.5...3.5 times (sometimes even more) within approximately a day and the number of the earthquakes with $M > 5$ by 1.5...4.5 times in 2, 5...6, 7...9, 10...13 and 17 days after the solar flare. It is important that in 5...6, 10...13, 16...19 days after the strong flares there are recorded strong earthquakes with $M > 6$, and in 5, 17...19 and 21 days – with $M > 7$.

4. CONCLUSIONS

On the basis of the analysis of the seismic activity dynamics during the period of 43 strong magnetic storms and in the period after 17 strong proton solar flares during the years 1974 to 2006 there are determined typical particularities (periods) in the seismicity variations: 1) practically in all the considered cases during the periods of strong magnetic storms there occurred increasing of total number of the earthquakes by 1.5...3 times (and sometimes more) and the number of the earthquakes with $M > 5$ by

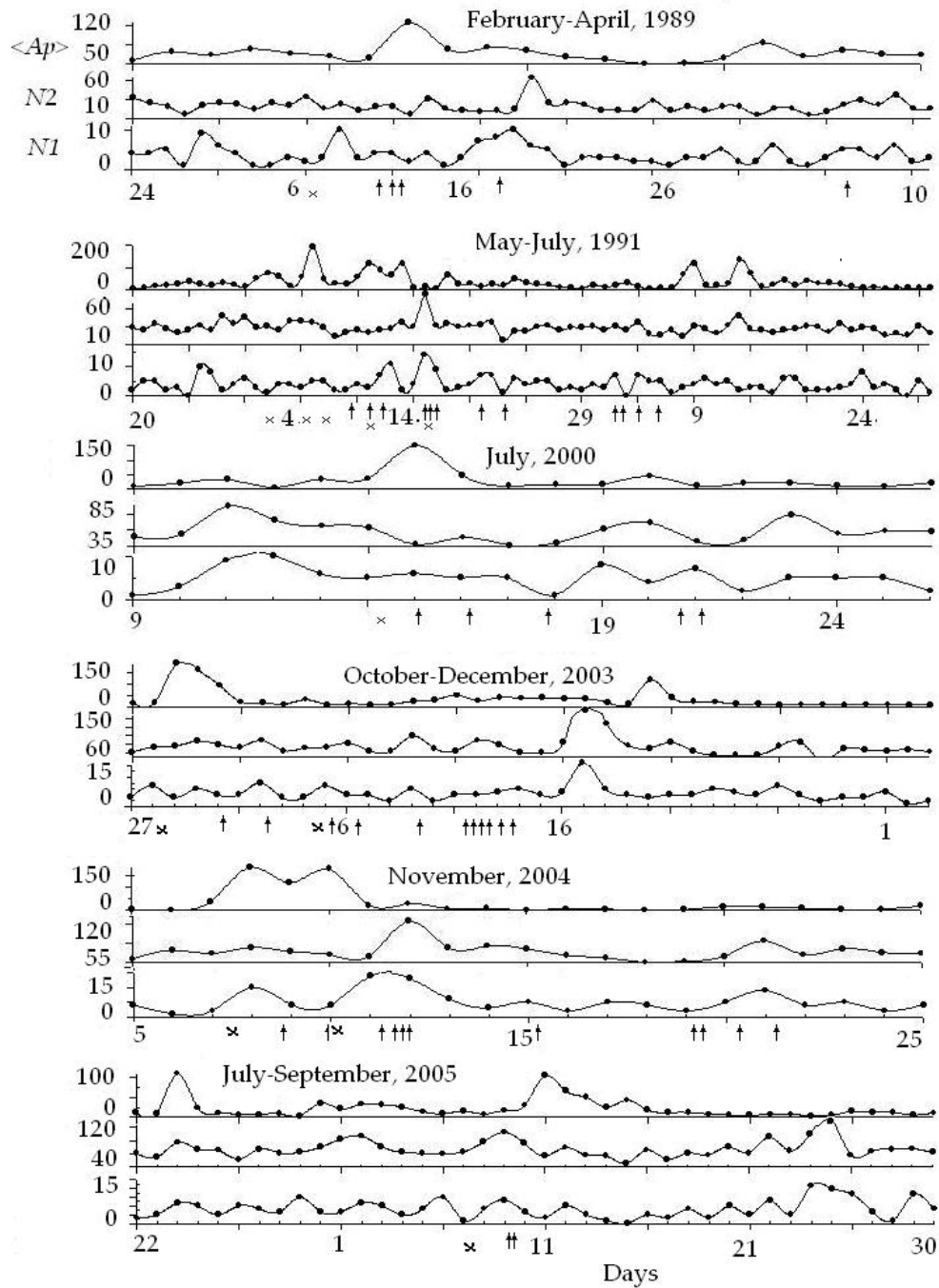


FIG. 2: Examples of dependences of the number of EQ with $M = 1 \dots 9$ (curves $N2$), with $M > 5$ ($N1$) and the geomagnetic activity indices Ap (curves 1). The arrows denote the moments of EQ with $M > 6$, the crosses depicts the moments of solar flares.

1.5...4 times in 2...3, 4...5, 6...7, 8...9, 12...14, 16...18 and 24...25 days after the earthquakes with the probability of 0.2...0.6; 2) in all the considered cases during the periods following 17 strong proton solar flares there occurred with the probability of 0.2 ...0.8 increasing of total number of the earthquakes by 1.5...3.5 times within approximately a day and the number of the earthquakes with $M > 5$ by 1.5...4.5 times in 2, 5...6, 7...11 and 17 days after the SF.

Based on the analysis of the reference literature there was made an assumption that the seismic activity on the Earth depends primarily on the internal processes inside the Earth. However, the obtained results show that there also exists a strong correlation between the seismic activity and the solar activity that is revealed in solar flares and geomagnetic disturbances. The mechanisms of the above relations can be assumed, as it is suggested in [5,6], as follows: the solar flares result in generation of the electromagnetic radiation and loaded particles, formation of the shock waves and coronal mass ejections into the interplanetary medium, geomagnetic storms and the Forbush-decreases in cosmic rays recorded both on the Earth and in the space. Based on the foregoing the processes that are typical for the Earth properly could be activated on the Earth and close to its surface. For example, increasing of the electric currents inside the Earth must occur during the geomagnetic storms that may result in variation of the seismic activity level. This process is characterized by appearance of the neutron flows on the Earth's surface.

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