Modified data on geoeffective solar flares and seismic noise variations

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Abstract. The problem of the relationship between strong magnetic swarms caused by solar flares and variations in seismicity is considered. The data on the temporal dependences of the parameters of seismic noise (average level, and standard deviation, RMS) recorded by the stations of the KNET seismic network have been used as the output data of monitoring the territory of the Bishkek geodynamic proving ground (Northern Tien Shan). The signatures of the influence of a magnetic swarm that occurred after an ultra-strong solar flare on September 6, 2017 have been established. The results obtained on the increase in seismic noise after this super-strong eruptive event are consistent with the results of studies on the influence of magnetic swarms on changes in regional seismicity.

1. Introduction

Although the influence of solar activity on the seismicity of the Earth is definitely to be established [1-5], it is of interest to search and analyze new examples of such influence signatures: seismic variations (if present) after geoeffective solar flares and magnetic swarms with an abrupt onset. For periods of several days, the influence is found for strong magnetic swarms with sudden onset (Swarm Sudden Commencement, SSC), developing within a few minutes. There are known works [3-7], where seismicity variations in seismically active regions of the Northern Tien Shan, Caucasus, Alaska, Northern and Southern California were considered as a reaction to magnetic swarms, are studied. It was shown in [7] that after strong solar flares, the first response of seismicity is a decrease in global seismicity; this effect is synchronized with the effect of the particle and energy flux (in the X-ray range). And the activation of regional seismicity occurs with a delay of several days, in particular, after magnetic swarms. So, does the magnetic field play a role?

A wider problem of the relationship between manifestations of seismicity (seismic noise level) and variations in the geomagnetic field was analyzed in [8]. In this work the existence of such relationship was confirmed according to the data of the geophysical observatory of the Institute of Dynamics of Geospheres of the Russian Academy of Sciences "Mikhnevo" (Moscow region). The Fig. 1 shows the relationship between the maximum value of ground velocity variations in the frequency range 0.01-0.1 Hz and the relative amplitude of sudden geomagnetic disturbances (in the form of sharp magnetic pulses). The results [8] reflect the transformation of the energy of geomagnetic variations on the earth's surface into the energy of seismic vibrations in the specific conditions of the «Mikhnevo»
The monotonically growing relationship between these values may indicate the influence of geomagnetic variations (the pulses relevant to induced currents in the ionosphere and associated telluric currents in the conducting layers of the Earth) on microseismic noise.

Figure 1. Dependence of the RMS amplitude of the background seismic noise variation \( v \), induced during the period of geomagnetic variations, on the amplitude of the horizontal component. Horizontal and vertical segments characterize the uncertainty of the measured values; circles - single measurements, solid curve - their averaging, according to materials [8].

In our previous work [9], 11 solar flares of the 23rd solar cycle, which occurred in the period from 2000 to 2006, were considered. An increase in the standard deviation of seismic noise (SDSN) was noted in 8 cases out of 11, and the correlation with a magnetic swarm is higher than with the preceding solar flare. On September 6, 2017. A flare of enormous power on the Sun (24 solar cycle) occurred in September 6, 2017. The flare was caused by the merger of the two largest sunspot groups. “Eruptive events of this power are the largest of that our star is capable to produce. They are formed only under very rare, unique conditions, as a rule, at the stage of the peak of solar activity” (Laboratory of X-ray Astronomy of the Sun of the PN Lebedev Physical Institute, https://lebedev.ru/ru). Such super-strong flares, accompanied by anomalous magnetic swarms, allows to verify the previously obtained results. The paper considers the effect of the 6.09.2017 flash on the level of seismic noise at the stations of the KNET network, Northern Tien Shan.

The goal is to continue studies of the influence of solar flares and magnetic swarms on the parameters of seismic noise (using the example of the Northern Tien Shan), with an emphasis on the verification of previously obtained results. An example of an anomalous flare on September 6, 2017 is a test case. Reanalysis has become especially relevant after recent publications [10-13] about the first response to flares - suppression of global seismicity, after which regional activations may occur, with some delay.

2. Data and method

The seismological network KNET was installed in 1991 on the territory of the Bishkek geodynamic proving ground (BGPG, Northern Tien Shan), which includes 10 digital broadband stations, each of which is equipped with an STS-2 seismological sensor (Figure 2, triangles). Various aspects of the operation of this network are described in most detail in [14]. Seismic noise records of KNET stations have been used as initial data.

To analyze the possible influence of solar flares and magnetic swarms on the seismic noise level, the current value of the standard deviation (SDSN) is used as indicative and reliable characteristic. 20-minute segments of seismic noise (vertical channel BHZ, 40 Hz) have been considered and the standard deviation is determined. As a result, 72 samples are generated per day. Study period: (41
days) ± 20 days relative to the day of the flare. Beside the change in the SDSN value during the noted period (2952 points), changes in Kp - the index of the Earth's magnetic field for every three hours have been considered. These data were obtained by the Laboratory of X-ray Astronomy of the Sun, P.N. Lebedev (https://lebedev.ru/ru). The characteristics of solar flares were given from the catalog “The Catalog of Solar Flare Events” of the Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation named after N.V. Pushkov RAS (responsible V.N. Ishkov, https://izmiran.ru/).

Figure 2. Position of KNET network stations (triangles) and repeaters (squares).

### 3. Result

As noted above, the seismic noise was considered during the period of solar flares that occurred from 2000 to 2006 [9]. It is worth reminder that, the seismic noise level was preliminarily studied in summer and winter in [9], and it was noted that the SDSN in summer months is lower than in winter: if in summer months its value fluctuates at a level of $0.2 \times 10^4$ nm/s, then in the winter months its level reaches $0.5 \times 10^4$ nm/s. Some parameters of three solar flares from [9] are presented in the Table, and the Figure 3 shows the distributions of the SDSN during these flares.

| №  | Date       | to  | te  | Class | lt       | lg  | L    |
|----|------------|-----|-----|-------|----------|-----|------|
| 1  | 24.09.2001 | 09:32| 12:17| X2.6  | S17      | E26 | 272  |
| 2  | 28.05.2003 | 00:17| 00:27| X3.6  | S06      | W20 | 182  |
| 3  | 28.10.2003 | 09:51| 14:20| X17.2 | S16      | E08 | 282  |
| 4  | 06.09.2017 | 11:53| 15:53| X9.3  | S08      | W33 | 117  |

Table. Parameters of some solar flares considered in [9] and the flare on September 6, 2017.

Notation: to, te – the begin, and the end times of the flare event; lt (heliographic latitude) - the distance in degrees from the solar equator; lg (central meridian) – the distance in degrees from a line extending from the north solar rotational pole to the south solar rotational pole through the center of the solar disk as viewed from Earth. L – (Carrington longitude) – the heliographic longitude of solar feature in the coordinate system that rotates with the Sun.
Figure 3. Time dependencies of the SDSN values at station AAK in a window of ±20 days before and after a solar flare (Table, № 1-3). The vertical gray rectangles mark the days of solar flares. Colored rectangles (the legend is in upper frame) indicate changes in the Kp index of the Earth's magnetic field.
Figure 4. The same as in the Fig. 3, but for the seismic noise at stations AAK and EKS2 in a window of ±20 days before and after a solar flare (Table, №4).

Each graph shows the distributions of SDSN (blue), the dates of the main solar flare (dark turquoise) and less powerful solar flares (turquoise), as well as changes in the Kp-index of the Earth's
magnetic field (colored columns, according to the legend presented in the inset to Figure 3). Let us consider the results for each of the presented SDSN in the period of ±20 days relative to the solar flare.

**24.09.2001.** (Figure 3, upwards). In this time interval, the standard deviation of the seismic noise shows small variations before the solar flare. As Fig. 5i shows, the SDSN’s amplitude somewhat increases on October 25, 2001, the day of the magnetic swarm, and continues to do so after the swarm ends. In the second half of the studied period, we can see abrupt SDSN spikes after the solar flare on October 1, 2001 and on the days of magnetic disturbances.

**28.05.2003.** (Figure 3, in the middle). There was only one flare in this period. As can be seen from the figure, the average level of the seismic noise was stable before the flare. The solar flare was followed by a magnetic swarm on May 29–31, 2003. The SDSN value considerably increased in the period of the magnetic swarm and returned near to the pre-swarm level after the swarm ended. It should be noted that namely this flare was considered in [15-16].

**28.10.2003.** (Figure 3, downwards). Besides this flare few more flares occurred in this time period such as that on October 28, (Table, №2). The SDSN value rapidly increased after the first flare (on October 29) and continued to do so until the end of the magnetic swarm, which began just after the flare on October 28, 2003. We note that the SDSN’s amplitude considerably increased during the magnetic swarm and started to decrease just after it. The next solar flares occurred on November 4–5, 2003 and caused a short-term growth of the SDSN value.

**6.09.2017.** (New super strong flare). Similarly with the cases of eruptive events studied previously we have built the distributions of the SDSN value for all seismic stations in a period of ±20 days from the flare date. After the main eruptive event, less powerful solar flares occurred. A sharp increase in the SDSN value after the magnetic swarm that occurred on September 8, 2017 and caused by a solar flare has been recorded at all stations of the network. The Figure 4 shows the results for two stations - AAK and EKS2. The top graph is plotted with a scale allowing visualization a sharp increase in the SDSN. The graphs of the SDSN on AAK and EKS2 stations are presented in the middle and bottom frames. These plots are built with a convenient scale to compare the distributions of SDSN and the Kp-index.

Solar cycle 24 includes several solar flares with class $M \geq 7.3$ and one flare with $X = 4.9$, which occurred on February 25, 2014 and caused an increase in the Kp index to level 4 (excited magnetosphere). Such a magnetic swarm practically did not affect the seismic noise level, as well as flares with class $M \geq 7.3$.

### 4. Conclusion

The analysis of standard deviation of seismic noise level allowed to confirm the results of previous studies of 2000-2006 on the solar flares and magnetic swarms influence on the Tien Shan territory seismicity characteristics. Increasing the values of seismic noise standard deviation can display a reaction of regional seismicity to these exogenous factors. A correlation of growth of seismic noise standard deviation with the period of magnetic swarm is more stable than that with the foregoing solar flare. The precedent of solar super flare of 06.09.2017 – is a serious argument in favor of eruptive events on the Sun to influence the seismic process.

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