Original Research Article

Electromagnetic Field Response to Impulsive Processes in the Earthquakes

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Abstract: Looking for electromagnetic effects of earthquakes, pulse signals are detected preceding the moment of the event or following it. The advance or delay is from 0 s to 200 s. The signals are observed as single or pair pulses in the frequency range 0-5 Hz. Dynamical spectra of the signals are presented and their characteristics are discussed. The signals impact actively on the magnetosphere and ionosphere. As a result of such impact a sharp change in the regime of geomagnetic pulsation excitation may occur. The detected response of the pulsations is considered and analyzed.

Keywords: Earthquake, Electromagnetic signals, Geomagnetic pulsations.

1. Introduction

The electromagnetic effects of earthquakes attract attention of specialists during the recent hundred years. This interest is due, first of all, to a potential possibility of revealing of real-time precursors of earthquakes. Their observations are also important for studies of the physics of seismic processes. There are separate observations of electromagnetic signals correlating to earthquakes [Belov et al., 1975; Breiner, 1964; Eleman, 1966; Gokhberg et al., 1989; Guglielmi and Levshenko, 1994; Moore, 1964; Yoshimori, 2002], and various mechanisms of transformation of the mechanical energy into the electromagnetic field energy were suggested [Gershenson et al., 1993; Guglielmi, 1986, 1992; Guglielmi and Levshenko, 1992, 1993; Guglielmi and Ruban, 1990]. Nevertheless, there is no common opinion on the reality of the relation between the detected signals and earthquakes. There is even a doubt in the principal possibility of observation of sesmomagnetic effects, at least by the currently available means. The main reason of this is irregular observations and, as a consequence, the absence of reliable repeatability of the results. In our opinion only detection at the analysis of a vast database of pulse signals in one frequency range with repeating shape of the dynamical spectrum and, evidently, with the determining criterion, i.e. with the fixed in time connection to the earthquake moment may be a proof of the existence of seismomagnetic effects.

Our assumption on the similarity of seismic processes leading to the transformation of one type of energy into another type and on the presence at the stage of earthquake preparation of time periods the most favorable for generation of electromagnetic signals indicates to this direction. Probably it is a close time vicinity of an earthquake (the first tens of seconds or minutes), when the tension reaches critical values and part of the energy stored in the site of origin is released in the form of electromagnetic emission.

To check this assumption we analyzed the records of the magnetic field variations in the SPO range (0-5 Hz) for several years. As a result, for approximately 300 events (earthquakes) pulse electromagnetic signals in the frequency range 0-5 Hz coinciding in time to the earthquake moment or close to it by time were found.

The aim of this paper is to give a description of the obtained up to this moment preliminary results of the analysis of the electromagnet signals tied by time to earthquakes. We describe first briefly the method of the analysis. Then we will present the dynamical spectra of the detected signals and give their general characteristics. Further we will consider the peculiarities of the signal observations for particular events. After that we will consider the detected response in the geomagnetic pulsations regime caused by the impact of seismogenic signals on the magnetosphere and ionosphere. In conclusion we will discuss the obtained results and formulate the results of the paper.

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2. Initial material the methods of the analysis

The initial material consisted of analog recordings to magnetic tape of the variations in the natural electromagnetic field in the frequency range 0-5 Hz obtained at the output of the induction magnetometer operating in the permanent regime at Borok observatory since 1973. The observatory is located in seismically inactive zone: the geographical coordinates of the observation point are: $\varphi = 58.06°$ N and $\lambda = 38.23°$. The analog records obtained at the Borok observatory were digitized and then subjected to spectral-temporal analysis with computer programs. Dynamic spectra of oscillations (spectrograms) were constructed. Information about the alternating electromagnetic field in the analyzed interval was reflected in the frequency time coordinates. During the initial visual review, the known forms of signals of magnetospheric origin were excluded from further analysis. .Impulse signals, which differed from the known types of geomagnetic pulsa tions in the form of the dynamic spectrum, were included in the analysis and compared (with a binding statistical significance of $P = 0.86$) with the closest earthquake in the catalog (International Seismologi cal Center, ISC Catalogues, (www.isc.ac.uk)) with specific geographic coordinates of the epicenter. The methodology of the analysis was described in detail earlier [Dovbnya et al., 2006] and additionally in [Dovbnya et al., 2019; Dovbnya, 2021, 2022]. The signal amplitudes were evaluated on the oscillograms with a sweeping time of 30 mm min^{-1}.

3. Observational results

As a result, we succeeded in finding in the period 1974-1976 of about 300 events of electromagnetic signals in the 0-5 Hz range in the chosen time vicinity of earthquakes. The signals were different by the form of the dynamical spectrum from already known types of geomagnetic pulsations. Their peculiarity was in a discrete form of the spectrum having its differences in individual events. Relative to the earthquake moment they were either preceding or following the earthquake pulses. Both the preceding and delayed signals were observed as single or pair pulses.

At the pair appearance the time between the first and second pulses varies from 40 s to 150 s. The advance time of the first pulse from the earthquake moment varies within the limit 100-220 s and the delay time varies from 25 s to 200 s. The amplitude and duration usually do not exceed values of 10 pT and 20 s, respectively.

Single pulses have the amplitude and duration up to 100 pT and 40-60 s, respectively, the time of advance and delay varies in insignificantly small limits.

We present here a few comments on the signal observations what may be useful at their search and interpretation. With remote monitoring, signals are recorded at significant distance from the epicenter of the earthquake (up to 10,000 km or more). It is natural to expect that the probability of their appearance at the observatory will depend on the conditions on the propagation path, which, in turn, are subject to diurnal and seasonal changes. Indeed, the analysis showed, the probability of observations of pulse signals from earthquakes under the same on the average seismic activity during equal time intervals was found considerably different on different days or even in different weeks. Periods of complete absence of seismomagnetic pulses suddenly were changed to periods of unexpectedly high electromagnetic activity. When the signals began to appear after the pause, the probability of their observation did not significantly depend on the event magnitude, however there was a preference to close (1-2 thousands km) earthquakes. The latitudinal, as well as daily and seasonal dependence in the appearance of the number of pulses at the Borok Observatory was considered in detail in [Dovbnya, 2021, 2022].

It is important to note that the single signals (at the preferable appearance in the vicinity of the earthquake moment) in a random way might be observed at the stage of the earthquake preparation and also in other time intervals. No pair signals were detected outside the preferable time interval. One should expect an earthquake after the appearance of a characteristic pair of pulses. The probable expectation time is 4-2 min after the appearance of the first pulse.

Now we consider examples of dynamical spectra of the electromagnetic signals observed in the vicinity of the earthquake moment. For illustration we will consider events with different magnitudes M occurred in different regions of the Earth surface. The earthquake moments are marked by arrows in the figures. Figure 1a shows the effect of the earthquake with $M = 3.0$ which occurred at 1158:21 UT on 24 August 1975 at a distance of 2500 km from the observation point.

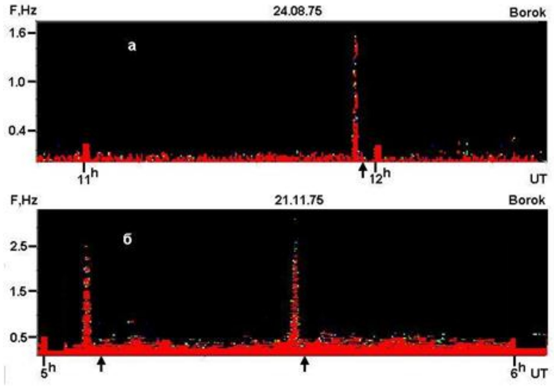

Figure 1 a, b Examples of dynamical spectra of single signals detected in the vicinity of the earthquake moments for the events: (a) on 24 August 1975 at 1158:21 UT (the epicenter coordinates were $\varphi = -37.4^\circ$, $\lambda = 21.6^\circ$); (b) on 21 November 1975 at 0507:04 UT and at 0532:25 UT (the epicenter coordinates were $\varphi = -34.32^\circ$, $\lambda = -116.36^\circ$ and $\varphi = -36.54^\circ$, $\lambda = 147.75^\circ$, respectively)

The signal in the electromagnetic field appeared approximately 2 min prior to the earthquake beginning. It was a single signal. In the dynamical spectrum in coordinates frequency—time the signal has a shape of a pulse with a discrete structure. The duration of the signal was about 30 s. And its amplitude in Borok was 100 pT and 150 pT for the H and D components, respectively. The frequency range was from 0 to 2 Hz. Figure 1b presents examples of observations of single signals from remote earthquakes. Two events with an interval of 25 min occurred on 21 November 1975 in different regions of the Earth surface. In both cases they were preceded by electromagnetic signals appearing 1.5-2 min before the earthquake moment. The signals have a shape with a discrete structure. Their duration and frequency range are approximately 60 s. and 0-2.5 Hz, respectively. The amplitudes are much lower and do not exceed 20 pT. The distance from the observational point to the epicenter of each event is not less than 10,000 km. It is worth noting that the signals in the considered case were observed also from week earthquakes.

Manifestation of the electromagnetic effects of earthquakes in the form of characteristic pair pulses is a rather rare event. It is observed in 20% of the total number of events. Figures 2a and 2b show examples of the dynamical spectra of pair signals from close and remote earthquakes.

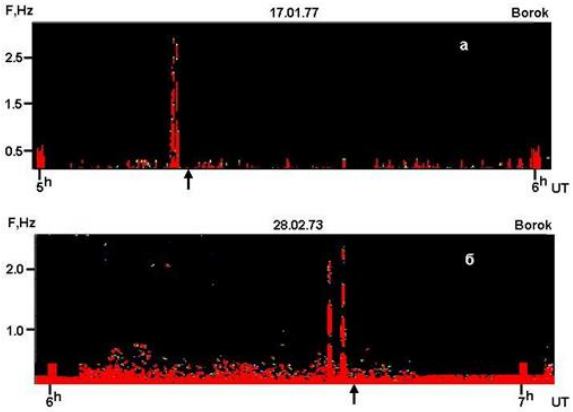

Figure 2 a, b Examples of dynamical spectra of pair signals observed in the vicinity of the earthquake moment for the events: (a) on 17 January 1977 at 0519:24 UT (the epicenter coordinates were $\varphi = -39.27^\circ$, $\lambda = 43.7^\circ$) and (b) on 28 February 1973 at 0637:54 UT (the epicenter coordinates were $\varphi = -50.514^\circ$, $\lambda = 156.58^\circ$).

Figure 2a shows the effect of the earthquake with a magnitude $M = 5.7$ which occurred in Turkey on 17 January 1977 at a distance of about 2000 km from Borok. The electromagnetic pulse appeared 3 min prior the main shock. Its amplitude and duration in Borok did not exceed 10 pT and 20 s, respectively. The second pulse of the same amplitude and duration was observed 35 s later. Both pulses have a discrete structure and the frequency range from 0 to 3.5 Hz.

Appearance of the discreteness as a peculiarity of the majority of the signals (pair and single) observed from earthquakes may have its own differences for individual events. There are differences in time between the first and second pulses. Figure 2b shows the advance electromagnetic effect from the strongest earthquake with a magnitude of $M = 7.4$ which occurred on 28 February 1973 at a distance more than 10,000 km from Borok. The signal appears 2 min prior the earthquake beginning. At the dynamical spectrum it presents two discrete pulses in the frequency range from 0 to 2 Hz with the interval between them of about 90 s. Their duration is not more then 30 s and the amplitude in Borok does not exceed the sensitivity of the registering equipment (10 pT mm^{-1}). It is worth noting that the character of the discreteness and time between the pulses differ from the case considered above.

Concluding we present one more example illustrating electromagnetic effects of earthquakes (Figure 3).

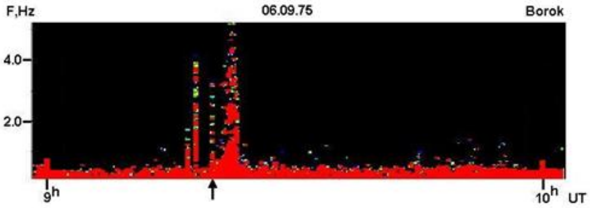

Figure 3 Electromagnetic effect from the earthquake on 6 September 1975 at 0920:11 UT (the epicenter coordinates were $\varphi = -38.513°$, $\lambda = 40.774°$).

On 6 September 1975 at 0920 UT in Turkey a destroying earthquake with a magnitude of $M = 6.9$ occurred. We consider now the sequence of the events using the figure for clearness. The advanced pair signal appears 3 min before the main shock. It consists of two pulses following each other with an interval of 1 min. The pulses passed along the H component of the geomagnetic field with an amplitude of 20 pT. In this example we are interested in the following effect. At 0920 UT one more pulse signal appears and after it there appears a splash of emission about 5 min long. By its dynamical spectrum the emission is similar to pulsations Pi1B [Guglielmi and Troitskaya, 1973]. Splashes of these irregular oscillations are observed during the precipitation of particles into the ionosphere and are typical for the evening time. In the considered case the event took place in the daytime (for Borok $LT = UT + 3h$). Below we will discuss appearance of typical pulsations in the untypical for them time. Simultaneously a strongest pulse of the bay-like shape about 5 min long (is not seen in the spectrum) is detected. Its amplitude in Borok was 15 nT and 9.5 nT in the H and D components, respectively, and was decreasing northward at the stations located in the vicinity of the Borok longitude.

Thus in all the considered examples the signals had similar dynamical spectra and the same frequency range, and they were observed within a fixed (relative to the earthquake moment) time interval.

We present below the preliminary results concerning distribution of the number of pair and single pulses over the time of their occurrence relative to the earthquake moment. Figure 4 shows histograms corresponding to the observation of the pulses prior and after the earthquake moment.

The ordinate shows the number of pulses, the abscissa shows time. It is worth drawing attention to the considerable asymmetry of the distributions. In our opinion it is an important argument in favor of the relation of the pulses to the earthquakes. The obtained asymmetry differs from a homogeneous distribution what should have appeared at occasional falling of the pulses into the considered time region.

During remote observation, signals coming from different places on the Earth's surface are recorded. This feature made it possible to analyze the geographical location of their generation zones. Figure 5 shows the distributions according to Borok observatory data. The green circle marks the location of the observatory on the map.

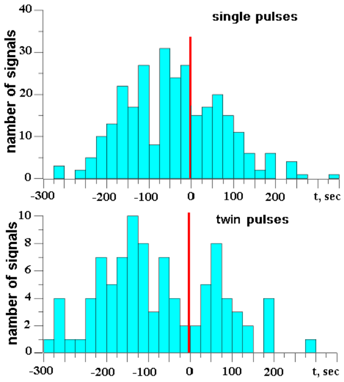

Figure 4 Distribution of the number of pulses over time and their connection to the earthquake moment

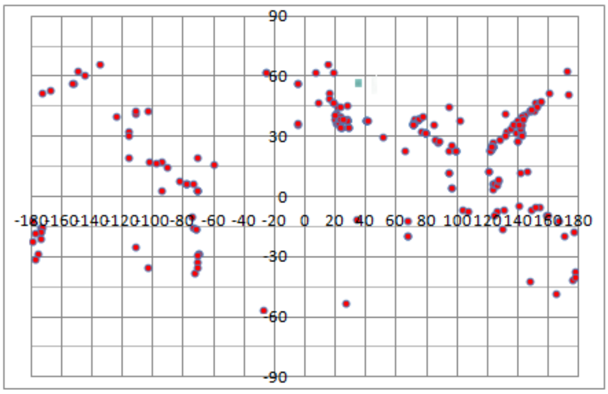

Figure 5 Distribution of sources of ULF-electromagnetic signals on the Earth's surface.

The analysis shows a wide spatial, and, at the same time, uneven, arrangement of radiation sources. They are grouped into separate zones and cells that highlighting regions on the map with manifestations of seismoelectromagnetic activity. The dynamic spectra of impulsive precursors were similar. They were repeated at different magnitudes and depths of the source and were observed in a selected time interval relative to the moment of the earthquake.

The electromagnetic signals from the site of origin of the prepared earthquake influence actively the ionosphere and magnetosphere. Analyzing the data we found a response in the geomagnetic pulsations to pulse processes of earthquakes with a clear connection in time to the moment of appearance of the electromagnetic signals. The response is manifested in the effect of stimulation or disappearance of the oscillations of the Pc1 type known in geophysics as “pearls”. At the stimulation the impact of the pulse emission on the magnetosphere leads to an excitation of a series of pearls with a close connection of the beginning of the oscillations to the moment of appearance of the signal (Figure 6).

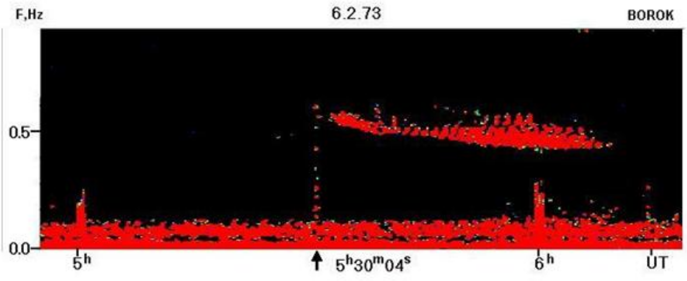

Figure 6 An example of stimulation of the pearl series. The beginning of the oscillations is closely connected in time to the appearance of the pulse signal in the vicinity of the earthquake moment. The earthquake with $M = 6.1$ occurred at 0530:04 UT on 6 February 1973 in the point with coordinates: $\varphi = -27.82°$, $\lambda = 127.797°$.

If a series of pearls already exists, the pulse impact on the environment may lead to a sharp break of the oscillations or to their quick attenuation (Figure 7).

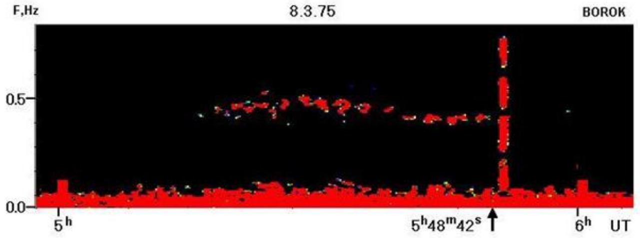

Figure 7 A break of the pearl series. The earthquake with $M = 4.0$ occurred at 0548:42 UT on 8 March 1975 in the point with the coordinates: $\varphi = -34.956°$, $\lambda = 23.305°$. A sharp break of the oscillations coincides in time to the appearance of the pulse signal near the earthquake moment.

The break of the pearls series after the electromagnetic pulse is related, apparently, to changes in the conditions of wave propagation through the ionosphere during the earthquake. One can assume that such change is caused by precipitation of particles into the ionosphere as a result of the resonance interaction of the pulse electromagnetic emission of the Earth to the particles of the radiation belts (at a coincidence of the signal frequency with the bounce-frequency of the particles). The addition ionization leads to changes in the reflection coefficient of waves in the ionosphere and, as a consequence, to the effect of rapid break or quick attenuation of the oscillations [Dovbnya and Zotov, 1985]. A sharp increase of the precipitating particle flux during an earthquake was actually registered in the experiment at the Salut 7 orbital station in 1985 [Voronov et al., 1989]. The above considered case of observation of pulsations of the Pi1B type (typical for particle precipitation) after the pulse signal also does not contradict to the above assumption (see Figure 3).

To explain the inverse effect (the effect of stimulation of Pc1 after the pulse, see Figure 5) one may assume the following. At the conditions in the generation region favorable for excitation of oscillations, the electromagnetic signals from earthquakes may play a role of an initiated pulse Pc1. A resonance frequency is cut away out of the continuous spectrum of the seismomagnetic signal and a series of pearls is developed, the beginning of the series being closely connected by time to the appearance of the electromagnetic signal [Dovbnya and Zotov, 1979].

4. Discussion

In this section we will try to provide a quantitative explanation to the obtained results. The detected signals may be considered as a manifestation of mechanically-electromagnetic transformations in the earthquake zones. Usually the induction and piezomagnetic mechanisms are considered as a possible cause of seismoelectromagnetic signals generation [Guglielmi and Levashenko, 1996]. However, the induction mechanism assumes sharp and considerable movements of the rocks for generation of pulse emission. These movements may be expected with high probability in the moment of the earthquake or at foreshocks and aftershocks and also at observations of co-seismic signals [Iyemori et al., 1996]. The possibility of generation of signals at a piezoeffect depends on piezomagnetic properties of the rocks in the earthquake site of origin. In our experiment the signals were observed from earthquakes of different by their geology regions of the Earth surface and mainly in the close time vicinity, i.e., prior of after the earthquake. Part of them may be explained by the action of the two these mechanisms, however for the explanation of the entire set of all observed signals, apparently, additional mechanisms should be attracted.

A special approach is required, apparently, for the explanation of the pair signals. No regime of such pair emission is known in geophysics. Appearance of two sequent pulses is, probably, a manifestation of two processes directly preceding the destruction of rocks in the earthquake site of origin.

As for the discrete structure, here one may explain that it is formed by the conditions at the radio signal propagation path. However in this paper we will not discuss possible ways and mechanisms of the detected signals.

On the basis of the analysis performed we conclude the following:

(1)The obtained results indicate that there actually exist seismoelectromagnetic signals.

(2)Observation of the signals is possible from both strong and week earthquakes and at large distances from the epicenter.

(3)The most probable time of appearance of seismoelectromagnetic signals of such form is the close time vicinity of an earthquake (the first tens of seconds or minutes). However the latter statement does not exclude a possibility of observation of the signals also in other time intervals.

(4)The seismoelectromagnetic signals actively influence on the magnetosphere and ionosphere As a result of such influence a sharp change in the regime of geomagnetic pulsation excitation may happen.

5. Conclusions

In this paper we tried to prove experimentally a possibility to observe seismoelectromagnetic signals and thus to reduce the skepticism in consideration of their real existence. In any case the obtained results make perspective further searches for electromagnetic effects of earthquakes. The experience in their search and forecasting is of a great importance because both these directions are mutually related.

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