

Effectiveness of electromagnetic monitoring in studying earthquakes

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Received 8 December 2020

Numerous researches conducted in connection with the study of earthquakes have shown that electromagnetic monitoring studies have led to some important results. From the Loma Prieta earthquake to the Guam earthquake, electromagnetic monitoring studies led to significant results. Since then, there have been numerous reports of possible electromagnetic precursors to earthquakes, some of which have involved frequencies covered by ELF/VLF (10—32 kHz) monitoring system Fraser—Smith et al. [1990]. Sometime later, they retrieved and started processing their ULF data. They had less reason to expect electromagnetic precursors in this latter data, because previous reports of precursory signals at frequencies below the ELF/VLF range have, with few exceptions, involved frequencies either below or predominantly below their ULF range (0.01—10 Hz) of operation. They found out that ELF/VLF data do not appear to show precursory activity, whereas ULF data contain a number of anomalous features that may prove to be earthquake precursors. The lack of observation of precursory ELF/VLF noise so close to the epicenters of several moderate to moderately-large earthquakes showed that ELF/VLF noise need not be a strong or obvious feature of every earthquake, as Fraser—Smith et al. [1990] reported in their paper.

At present, numerous studies have been conducted in this area and researches are being improved. From my experience as a young researcher, it became clear that electromagnetic monitoring research is necessary, and that more important and significant results can be achieved if continuous research is conducted in a certain area. Thus, these studies may play a significant role in the detection of earthquake precursors.

Key words: electromagnetic, precursor, earthquake, monitoring, MTS.

Introduction. Till now, numerous studies [Corwin, Morrison, 1977; Fraser-Smith et al., 1990; Park et al., 1993; Svetov et al., 1997; Uyeda et al., 2000; Balasco et al., 2004; Caldwell et al., 2004; Moroz et al., 2011; Kalisperi et al., 2013; Booker, 2014; Novruzov, Piriye 2015; Piriye, 2017, 2018] have been conducted to detect earthquake precursors and some positive results have been achieved. Among the researches carried out in the direction of detection of earthquake precursors, an example of a study conducted by researchers Y.F. Moroz and T.A. Moroz from the Institute of Volcanology and Seismology of FEB RAS and S.E. Smirnov from the Institute of Cosmophysical Research and Radio Wave Propagation

of FEB RAS in 2007—2008 assumed that the anomalous changes they discovered during the study could be related to earthquakes in the regions of the Paratunka and Magadan observatories. So that, in the time series of the magnetic tipper and tensor during 2007—2008 abnormal changes appeared that may be associated with strong earthquakes with $K \geq 6.3$ in the related regions [Moroz et al., 2011]. Before that, electromagnetic monitoring studies were also conducted in Azerbaijan to detect earthquake precursors and from that, important results were obtained. Thus, during 1997—2002, under the leadership of corresponding member of ANAS, Professor Kerim Kerimov, the Geophysics and Engineering Geology

Production Association monitored the Earth's naturally changing electromagnetic field for studying the changes in the cycle of electromagnetic fields and the acceleration of the propagation velocity of electromagnetic field variations as earthquake precursors were detected [Piriyev, 2017]. The territory of Azerbaijan is considered a tectonic territory, so it is very important to conduct electromagnetic monitoring there. The map presented in Fig.1 also clearly describes it, and the map points out that conducting electromagnetic monitoring research in the territory of Azerbaijan is one of the important issues. Because we know that electromagnetic monitoring studies are conducted in geodynamic active areas, and the main goal is aimed at detecting earthquake precursors.

Another example of that kind of researches is the Russian Trofimuk Institute of Petroleum Geology and Geophysics, Candidate of Tech-

nical Sciences, senior researcher V.V. Potanov and Doctor of Geological and Mineralogical Sciences, leading researcher E.V. Pospeeva in their investigations saw differences in behavior of apparent resistivity curves and geoelectric models obtained during 2007—2016 of instrumental observations. In their opinion those differences were quite significant and were probably related to changes in seismic activity of their studied territory [Potapov, Pospeeva, 2017]. Let's shortly analyze the electromagnetic monitoring studies conducted in Azerbaijan and Russia.

The study by [Kerimov, Agaguliyev, 2001, 2005; Kerimov et al., 2006]. During 1997—2002, under the leadership of the corresponding member of Azerbaijan National Academy of Sciences, professor Kerim Kerimov, «Geophysics and Engineering Geology» Production Union conducted monitoring of the Earth's natural changing electromagnetic field to stu-

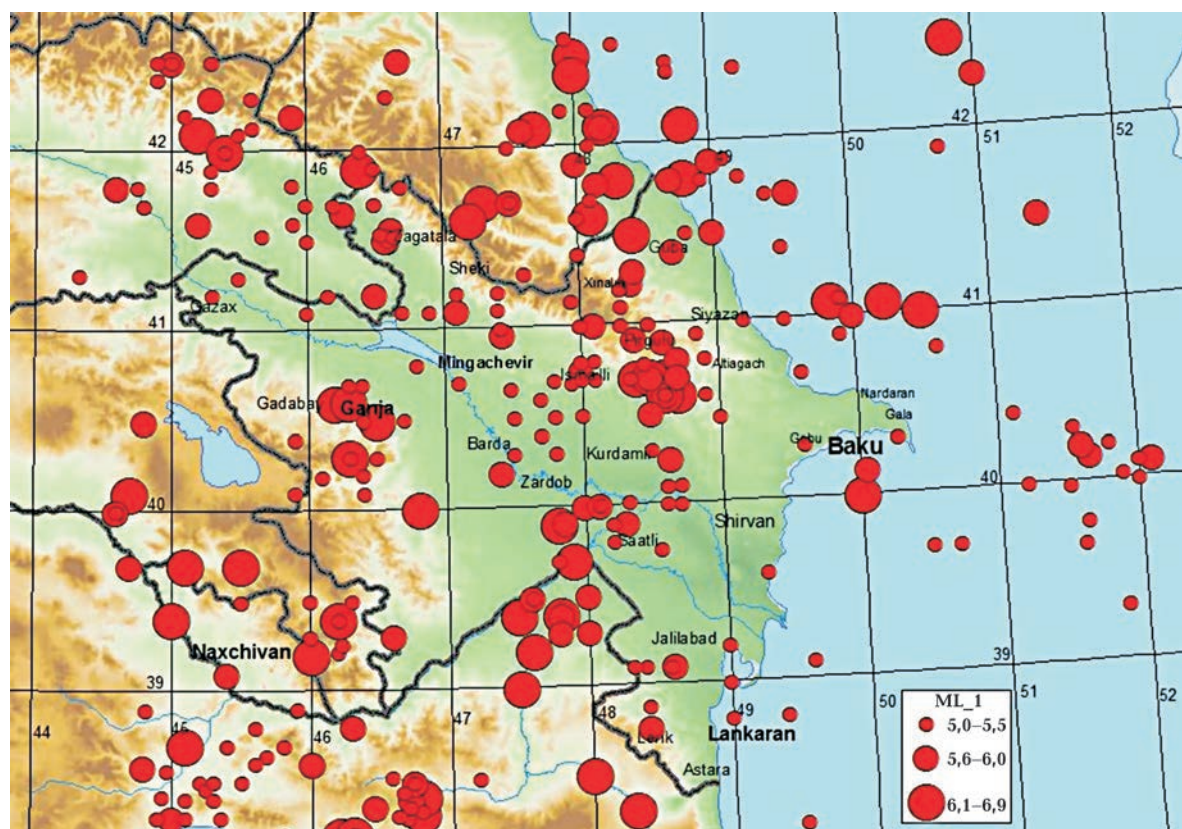


Fig. 1. A Map of epicenter distribution of strong earthquakes ($M \geq 5.0$ shown in red circles) occurred in Azerbaijan and near territories in the years 1942—2016 as reported by [Yetirmishli et al., 2017, Fig. 1].

dy earthquake precursors, and as earthquake precursors, changes in the life cycle of electromagnetic fields and the speed of propagation of electromagnetic field variations were detected. One Azerbaijanian and two Eurasian patents were obtained confirming the existence of these two precursors.

Kerimov and Agagulyev [2001, 2005] had shown that from the moment characterizing the time of change of the magnetic field cycle, magnetic field intensity vectors were directed towards the future earthquake center. On the other hand, as a result of Kerimov et al. [2006], it was found that the propagation velocity of electromagnetic field (magnetic components) in the direction of the zone in which geodynamic tension occurred and which may subsequently result in an earthquake was rapidly changing, and the coherence of the electromagnetic waves observed before this process was disrupted. In my opinion, the result of a joint study of both processes showed above as an earthquake precursor may lead to the detection of seismic activity and in the future, this could create conditions for the location of earthquake centers related to geodynamic stress zones.

Let's take a deep look at the explanation of the problems mentioned above. It is known that the period of life of the waves, which is connected with the internal magnetic field and is irradiated from the geodynamic stress zones depends on the geodynamics, dimensions, depth, and power of an earthquake center that generates these waves [Piriyev, 2016]. On the other hand, we know that a skin effect was characterized by the period of waves and there is an effective propagation depth of waves corresponding to each period. From that point of view, it becomes clear that geodynamic stress zones will only irradiate waves of the same type and the same period within a certain frame of error.

In 2000—2003, Kerimov et al. [2006] examined the results of electromagnetic monitoring conducted in the Fatmayi polygon, and they came into the conclusion that the violation of the circulation of waves occurred as a result of the superposition of natural electromagnetic waves of cosmic nature, reflected from that

depth by waves formed in connection with geodynamic stress zones and anisotropy.

The study by [Potapov, Pospeeva, 2017]. I briefly describe the way how they carried out electromagnetic monitoring. The recent report of Vladimir V. Potapov and Elena V. Pospeeva [2017] would like to provide relevant news in the search of earthquake precursors by method of MTS. Here I will discuss their significant results starting from the scientific literature before their study.

Possible views on earthquake precursors. Goldin et al. [2004] studied the area before and after Chuyskoe earthquake (or Altai earthquake) and came into the conclusion that seismic activity observed in the considered zone in 2002, according to the spatial distribution of the epicenters, differs significantly from the structure of the aftershock processes. Modern ideas about the geodynamic processes occurring in the interior of the Earth during the preparation of an earthquake give reason to believe that these processes are reflected in the data of electromagnetic soundings with artificial and natural sources. Among the methods that allow obtaining information about the deep structure of the Earth, magnetotelluric sounding (MTS) occupies one of the leading places, the main result of the interpretation of which is to reveal the spatial distribution of deep electrical conductivity, reflecting the thermodynamic conditions in the Earth's crust and upper mantle. At present, quite a lot of experience has been accumulated in prognostic regime magnetotelluric observations for studying the geodynamic processes occurring in the Earth's tectonosphere before and during an earthquake [Moroz et al., 2006; Rybin et al., 2009; Matyukov et al., 2010; Batalov et al., 2013]. When studying geodynamic processes using the electromagnetic field of the Earth, there are two approaches: identifying changes in the electrical properties of the geological environment and the structure of variations in the electric and magnetic fields. Electromagnetic monitoring using the MTS method in the Altai Mountains has been carried out for 10 years and based on the implementation of the first approach. The observations were carried out at four points located

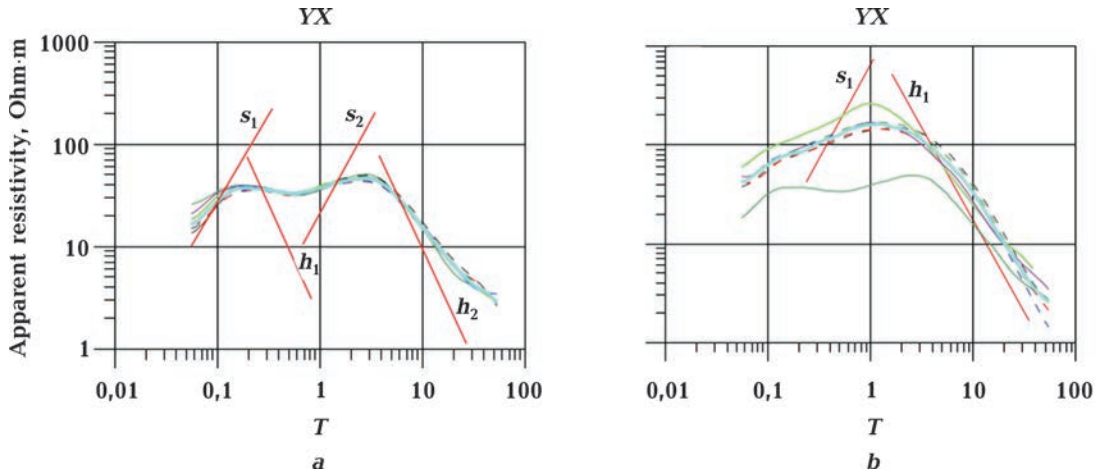


Fig. 2. Apparent resistivity at MTS observation points as reported by [Potapov, Pospeeva, 2017]: a — 1P1; b — 1P2. Individual colours are layers which show the differences in resistivity.

in the epicenter zone of the Chuiskoe earthquake. MTS works were carried out by fifth-generation equipment of the Canadian company «Phoenix Geophysics LTD» in the range of periods 0.003—10000 s. MTU-5 measuring modules were used, which made it possible to register five components (Ex, Ey, Hx, Hy, Hz) of the magnetotelluric field (MT field). A cross-shaped installation with an electric dipole length of 100 m was used. The components of the MT field were recorded for 22—24 hours. «Phoenix Geophysics LTD» software

was used to process field data; 1D and 2D inversion of experimental data was carried out using the «WinGLink» software package [Pospeeva, 2006].

The surveys were mainly conducted at points 1P1 and 1P2. From the conducted analysis it follows that the lowest deviation (2 %) from the average level is characterized by curved, obtained in the sounding point 1P1 (Fig. 2, a). It increases up to 5 % in the interval S1 due to significant variations in the level of curved resistance (from 12 to 30 Ohm · m). The

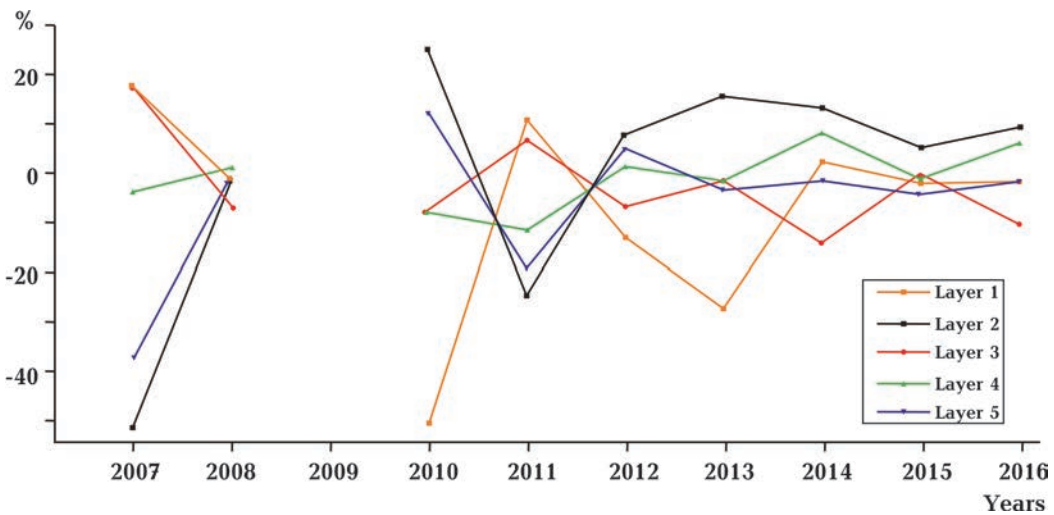


Fig. 3. Relative deviations of apparent resistivity in different layers (layers 1—5) of the geoelectric model in point 1P1 as reported by [Potapov, Pospeeva, 2017]. The layers 1—5 are coloured in order to show differences in apparent resistivity for the period 2007—2016.

Table 1. Precursory signatures before the earthquakes (1996 – 2015)

Earthquakes	Researchers [year]	Approach/Method: preearthquake changes	Electromagnetic precursor	Results
Before Guam earthquake	Hayakawa et al. [1996]	Electromagnetic monitoring: Polarization ratio time series of geomagnetic field data	Precursory signatures of the earthquake	Positive
	Hayakawa et al. [1999] Hobara et al. [2004] Ida et al. [2005] Ida, Hayakawa [2006] Smirnova et al. [2001]	Electromagnetic monitoring: Changes of ULF magnetic components before the earthquake	Precursory sign of the earthquake	Positive
	Thomas et al. [2009a, b] Masci [2010, 2011a,b, 2013a, b]	Electromagnetic monitoring: Changes of ULF magnetic components before the earthquake	No precursory sign of the earthquake	Negative
	Currie, Water [2014]	Electromagnetic monitoring: Polarization ratio time series of geomagnetic field data	Precursory signatures of the earthquake	Positive
	Surkov, Hayakawa [2014]	Electromagnetic monitoring: ULF disturbances of geomagnetic field data	Precursory signature of the earthquake	Positive
A month before Guam earthquake	Masci, Thomas [2015a]	Electromagnetic monitoring: Polarization ratio time series of geomagnetic field data	No precursory signatures of the earthquake	Negative
Between Peru earthquake 2007 and 2008	Takla et al. [2012]	Electromagnetic monitoring: long-term preearthquake changes in the amplitude of the geomagnetic field components, as well as polarization ratio time series of geomagnetic field data	Precursory signature of the earthquake	Positive
Before Peru earthquake 2007 and 2008	Masci, Thomas [2015b]	Electromagnetic monitoring: long-term preearthquake changes in the amplitude of the geomagnetic field components, as well as polarization ratio time series of geomagnetic field data	Precursory signature of the earthquake	Positive

Table 2. Anomalous behaviors of electromagnetic signals prior to earthquakes (1995–2016)

Name of earthquake	Date	Magnitude	Depth <i>h</i> , km	Researchers [year]	Approach/Method: preearthquake changes	Results
Kobe (or Great Hanshin) earthquake	January 17, 1995	7.3	14.3	Molchanov et al. [1998] Horie et al. [2006] Hayakawa et al. [2006]	Electromagnetic monitoring: Research data obtained before the earthquake was used. The differences in the time curve were graphically drawn and tested to see if they exceeded the 2σ	Some possible variations (exceeded the 2σ) before and after the earthquake
Leonidio, Southern Greece earthquake	January 6, 2008	6.2	75	Ulash [2011]	The data used in the study was obtained from measurements made over a period of 3 months	Variations of VLF signals before the earthquake
Erzincan earthquake	June 30, 2009	4.9	4	Büyüksaraç et al. [2015]	It was utilized the signals received from 5 different stations	Anomalous behaviors of VLF signals before the earthquake from only one station out of five different stations
Nepal (or Gorkha) earthquake	April 25, 2015	7.8	15	Phanikumar et al. [2018]	Continuous signals of 19.8 kHz frequency were recorded for 24 hours in the study	Anomalous behaviors of VLF signals 1 day before each earthquake
	May 12, 2015	7.3	15			
Haity earthquake	January 10, 2010	7.0	10	Hayakawa et al. [2011]	VLF amplitude data and the trend, distribution and changes in night divergence were analyzed for the data that were extensively studied during the period from the beginning of October 2009 to the end of March 2010	Ionospheric degradation 12 days before the earthquake
Ishinomaki earthquake (Japan)	November 11, 2016	6.1	42	Asano et al. [2017]	Two different receiver stations were used to observe signals. On November 2–3 and November 5–8, 2016, more prominent anomalies were identified	Anomalous behaviors of VLF signals several days before the earthquake
Fukushima earthquake (Japan)	November 22, 2016	6.9	11			

deviation of curves from the average in point 1P2 is 5 % in total, except for curves registered in 2010 and 2012, where it is more than 20 % (Fig. 2, b).

Significant variations in the level of the apparent resistivity curves cause differences in the determined parameters of the geoelectric section (resistivity and power). For example, in point 1P1, significant variations in resistivity values are noted in the interval S1, while in the interval S2, h1 and h2 are within the confidence interval (Fig. 3).

Potapov and Pospeeva [2017] found out that according to the electromagnetic monitoring by method of MTS in the epicentral zone of Chuiskoe earthquake (or Altai earthquake) this method allows you to see the differences in the behavior of the apparent resistance curves and geoelectric models obtained in different years of instrumental observations. These differences are quite significant and are probably associated with a change in the seismic activity of the studied territory. A technique has been developed for analyzing the behavior of apparent resistance curves and parameters of a geoelectric section, based on which further studies will be carried out.

The significant studies of other scientists.

The following table (Table 1) summarizes the electromagnetic monitoring studies conducted in different years. Most of the research conducted before the earthquakes in Guam and Peru was aimed at detecting earthquake precursors. As a whole, most cases have achieved

positive results with the correct approach. This shows that continuous research can lead to more positive results.

The significant studies to investigate the relationship between VLF signals and earthquakes by different researchers. The following table (Table 2) summarizes the electromagnetic monitoring studies conducted in different years. A lot of researches have been done on the relationship between earthquakes and the variations in very-low-frequency (VLF) signals that occur in the lower layer of the ionosphere before the earthquake.

Conclusions. In the world practice of electromagnetic monitoring research, there are many practical examples of positive results of magnetotelluric research for monitoring geodynamic processes in seismically active regions. The most promising results were obtained in the ULF/VLF range. One of the main problems is that MT signal observed on the surface of the earth is extremely weak, that makes magnetotelluric sounding susceptible to cultural noises. As one of the most common cultural noises during the acquisition of MT data, power line noise has plagued geophysicists for decades [Butler, Russell, 1993; Cohen et al., 2010]. To suppress power line noise, there are trap circuits designed in most of the acquisition instruments, however, the fundamental frequency of the power line noise is changeable with the fluctuate of the load current, hence the MT data are still seriously disturbed by the power line noise.

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Ефективність електромагнітного моніторингу при вивченні землетрусів

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Завдяки численним дослідженням методами електромагнітного моніторингу землетрусів, в тому числі близько Лома-Приєта і на Гуамі, отримані деякі важливі результати. З того часу з'явилося багато нової інформації про можливі електромагнітні провідники землетрусів, причому деякі спостереження зафіксовані на частотах ЭНЧ/ОНЧ (10—32 кГц) системою моніторингу Фрейзера та ін. [1990]. Пізніше була проведена обробка їх УНЧ-даних. Було мало підстав очікувати електромагнітних проявів провідників в цих пізніших даних, тому що попередні повідомлення про сигнали провідників з частотами нижче ЭНЧ/ОНЧ діапазону, за небагатьох винятків, включили частоти або нижче, або переважно нижче їх УНЧ-діапазону (0,01—10 Гц). Було встановлено, що ЭНЧ/ОНЧ дані не показують провідників, в той час як УНЧ-дані містять деяку кількість аномальних особливостей, які можуть виявитися провідниками землетрусу. Спостереження ЭНЧ/ОНЧ шуму передвісника близького до епіцентру від декількох середніх до великих землетрусів показало, що ЭНЧ/ОНЧ шум може не бути сильною або очевидною особливістю кожного землетрусу [Фрейзер-Сміт і ін., 1990]. В даний час проводяться численні подібні дослідження, а їх якість поліпшується. З мого досвіду, як молодого дослідника, стає ясно, що проведення електромагнітного моніторингу необхідно, і що більш важливі і значні результати можуть бути отримані, якщо такі дослідження будуть безперервними. Таким чином, вони можуть зіграти важливу роль у виявленні провідників землетрусів.

Ключові слова: електромагнітний провідник, землетрус, моніторинг, МТЗ.

Эффективность электромагнитного мониторинга при изучении землетрясений

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Благодаря многочисленным исследованиям методами электромагнитного мониторинга землетрясений, в том числе около Лома-Приєта и на Гуаме, получены некоторые важные результаты. С того времени появилось много новой информации о возможных электромагнитных предвестниках землетрясений, причем некоторые наблюдения зафиксированы на частотах ЭНЧ/ОНЧ (10—32 кГц) системой мониторинга Фрейзера и др. [1990]. Позже была проведена обработка их УНЧ-данных. Было мало оснований ожидать электромагнитных проявлений предвестников в этих более поздних данных, потому что предыдущие сообщения о сигналах предвестников с

частотами ниже ЭНЧ/ОНЧ диапазона, при немногих исключениях, включили частоты либо ниже, либо преимущественно ниже их УНЧ-диапазона (0,01—10 Гц). Было установлено, что ЭНЧ/ОНЧ данные не показывают предвестников, в то время как УНЧ-данные содержат некоторое количество аномальных особенностей, которые могут оказываться предвестниками землетрясения. Наблюдения ЭНЧ/ОНЧ шума предвестника близкого к эпицентрам от нескольких средних до крупных землетрясений показало, что ЭНЧ/ОНЧ шум может не быть сильной или очевидной особенностью каждого землетрясения [Фрейзер-Смит и др., 1990]. В настоящее время проводятся многочисленные подобные исследования, а их качество улучшается. Из моего опыта, как молодого исследователя, становится ясно, что проведение электромагнитного мониторинга необходимо, и что более важные и значительные результаты могут быть получены, если такие исследования будут непрерывными. Таким образом, они могут сыграть важную роль в обнаружении предвестников землетрясений.

Ключевые слова: электромагнитный предвестник, землетрясение, мониторинг, МТЗ.