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EARTHQUAKE PRECURSOR STUDIES WITH ELECTROMAGNETIC MONITORING: ULF SIGNALS AS POTENTIAL EARTHQUAKE PRECURSORS

Rahman H. Piriyev[1,2]

[1]*Baku State University, Acad. Zahid Khalilov Street, 23, AZ 1148. Baku, Azerbaijan*
[2]*Socar's Oil and Gas Research and Design Institute, Baku, Azerbaijan*

Changes in the electromagnetic (EM) field or EM phenomena prior to an earthquake (EQ) have been attempted to consider as precursors of an EQ by various scientists in different years. Among the studies in this direction, ultra-low frequency (ULF) signals are considered as potential EQ precursors. For this reason, in my research, I have tried to review different papers where ULF signals were considered as perspective signals. In order to do this I looked through the study by Currie and Waters [2014], the study of major EQs (Loma Prieta, and Guam), and the study of mega-earthquake (Tohoku) by different researchers (e.g. Hayakawa and Fujinawa, 1994; Hayakawa, 1996, 1999; Campbell, 2009; Fraser-Smith et al., 2011; Molchanov et al., 1992; Hobara et al., 2004; Ida et al., 2005; Surkov and Hayakawa, 2014). In the end, I came to the conclusion that the ULF EM approach should be considered as the best approach to studying EQs or to predict EQs (short-term prediction).

KEYWORDS: ELECTROMAGNETIC, EARTHQUAKE, ULF, PRECURSOR, SHORT-TERM PREDICTION

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INTRODUCTION

In the midst of the last century, Moore [1964] introduced disturbances in the EM field before the great EQ of magnitude 9.2 occurred in the Prince William Sound region of Alaska. Since then, there have been numerous articles showing anomalous changes in EM parameters in the natural geomagnetic fields before EQs. A relationship between changes in EM parameters and EQs has not been fully elucidated, but a disturbance in the EM field before an EQ is still considered as a candidate EQ precursor. So, EM phenomena, being statistically significant, can be used for short-term prediction of EQs. It is related to the generation of radiation in the atmosphere at the same time interval, but in a frequency range from several to tens of Hertz (Schekotov et al., 2013). Moreover, the majority of scientists consider ULF – ultra-low frequency (0.01–10 Hz) EM data investigations as the correct approach for studying precursory signs of EQs. Disturbances of EM signals (ULF/ELF) recorded near the epicenters of EQs at Loma Prieta (Fraser-Smith et al., 1990), Spitak (Kopytenko et al., 1990; Molchanov et al., 1992; Piriyev, 2017), Guam (Hayakawa et al., 1996), Tohoku (Kopytenko et al., 2012; Xu et al., 2013; Hayakawa et al., 2015; Ohta et al., 2013; Schekotov and Hayakawa, 2015; Hayakawa et al., 2012, 2013a,b; Schekotov et al., 2013a,b) gave significant data to researchers to interpret and make a conclusion whether there was a connection between those signals and EQs. My goal is to show examples to reveal that there were potential ULF EM precursors prior to an earthquake.

Rahman H. Piriyev, e-mail: rahmanpiriyev@bsu.edu.az

ФГБУ «ИПГ»
129128; Россия, Москва
ул. Ростокинская, 9.

1. THE STUDY OF EQ PRECURSOR BY CURRIE AND WATERS [2014]

The report of Currie and Waters [2014] searching for magnetic ULF precursors by means of polarization ratio analysis is very much impressive. According to their report, most researchers supported proposing possible ULF EM precursors of EQs or they had a positive view on the seismogenic origin of reported pre-earthquake ULF anomalies and only a few researchers had a negative view on this issue. (See Fig. 1.)

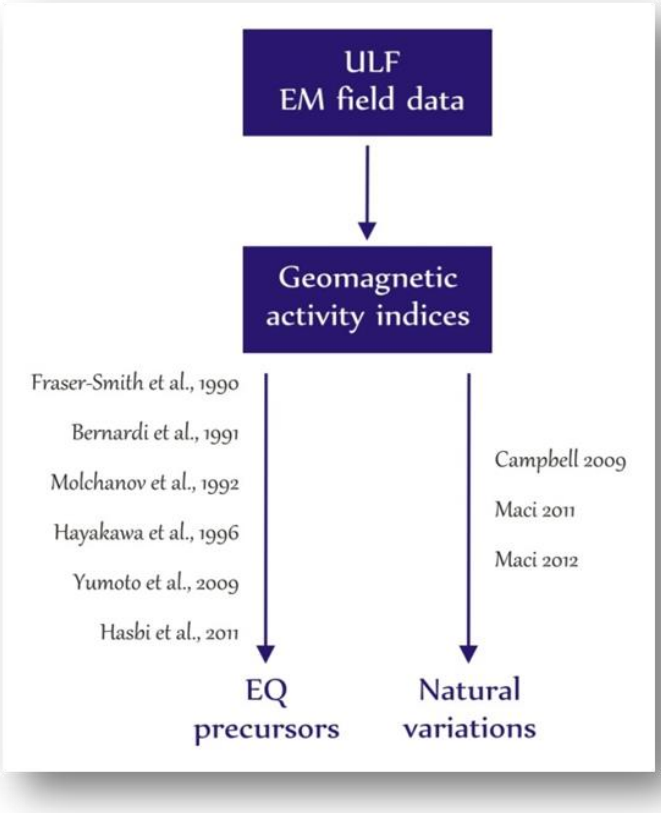

Figure 1. Summary of the use of ULF magnetic field and magnetic activity data sets and their relationship with EQ precursor research as reported Currie and Waters [2014, Figure 1].

2. THE STUDY OF EQS (LOMA-PRIETA, GUAM, AND TOHOKU)

As Hayakawa et al. [2000] in a paper published in *Geophysical Research Letters* reported EM phenomena were considered promising candidates for short-term prediction of EQ (e.g. Hayakawa and Fujinawa, 1994; Hayakawa, 1999). I absolutely agree with this statement. Because there are lots of papers that scientists showed promising results (See Tables below).

2.1. LOMA-PRIETA EQ

As I mentioned above in the introduction disturbances of EM signals (ULF/ELF) were observed near the epicenters of Loma Prieta EQ (Fraser-Smith et al., 1990). These disturbances were studied in the period of the last few decades by different researchers (e.g. Campbell, 2009; Fraser-Smith et al., 2011; Molchanov et al., 1992) (Tab. 2.). Molchanov et al., [1992] in a paper published in Geophysical Research Letters compared the characteristics of Spitak EQ (M=6.9; 7 December 1988; Armenia) with those of Loma Prieta EQ. The characteristics of the ULF EM field emissions of these EQs were apparently similar. The result of the comparison is shown in Tab. 1. On the report of Molchanov et al., [1992] a major difference in the ULF activity prior to the two above mentioned EQs was a contrast in amplitude, and this was easily explained as being caused by the different distances of the observation stations from epicenters.

Table 1. Characteristics of the ULF magnetic field emissions of two EQs

Changes in the EM field	Spitak EQ	Loma Prieta EQ	Difference/ similarity
Intensity of ULF background activity began to grow	3-5 days prior to EQ	12 days prior to EQ	Similar
Substantial ULF emission burst (that continued until the occurrence of the mainshock) commenced	4 hours before the event	3 hours before the event	Similar
ULF activity remained high	About 2 weeks after the EQ	Several months after the EQ	Similar
ULF noise bursts	1-6 hours before aftershock	No conclusive link	-
Amplitude in the ULF activity	0.2 nT before the EQ	5 nT before the EQ	Different

Table 2. The study of LOMA-PRIETA EQ

Natural phenomenon	Researcher [years]	Approach/Method: preearthquake changes	EM precursor	Frequency band
1989 Loma-Prieta EQ *(M=7.1; 17 October 1989; California)*	The study by Fraser-Smith et al. [1990]	EM monitoring: Preearthquake ULF magnetic anomaly identified a few days before the EQ	precursory signature of the EQ	ULF ELF/VLF
	The study by Molchanov et al. [1992]	EM monitoring: a large burst of ULF activity started a few hours before the EQ	precursory signature of the EQ	ULF
	The study by Campbell [2009]	EM monitoring: A detailed reanalysis of the anomaly: magnetic changes before the EQ observed	no precursory signature of the EQ	ULF VLF
	The study by Fraser-Smith et al. [2011]	EM monitoring: further independent evidence is required before the magnetic field fluctuations prior to the EQ	precursory signature of the EQ	ULF

2.2. GUAM EQ

According to the work of Hayakawa et al. [1996] and Miyahara et al. [1999] Guam EQ could have been predicted. They identified anomalous signals in the ULF range occurring before the earthquake. To give importance to EQ prediction, reports of EQ precursors and the need to be analyzed and checked for reproducibility Thomas et al. [2009] attempted to reproduce their results, made comparisons, and came to the conclusion that the signal which was seen in the data at about the time of the EQ was the part of normal global magnetic-field variation caused by solar-terrestrial interaction. But I think that the signal seen in the data prior to the EQ could be at the same time global magnetic-field variation caused by solar-terrestrial interaction and also partly could be caused by the preparation of the coming earthquake. These two processes were likely occurred at the same time. After Hayakawa et al. [1996] many articles (some of them are shown in Tab. 3.) using different approaches have reported ULF EM changes prior to the Guam earthquake. As stated by Surkov and Hayakawa [2014] this EQ is still considered as one of the seismic events that were accompanied by EM disturbances (ULF), which can be considered EQ precursors.

3. EM PRECURSORS FOR THE 2011 TOHOKU EARTHQUAKE

There are a lot of reports mainly from Japanese scientists (*e.g. Heki* [2011], Kopytenko et al. [2012], Hayakawa et al. [2012, 2013a,b], Xu et al. [2013], Ohta et al. [2013], Schekotov et al. [2013a,b], Kamogawa and Kakinami [2013], Chen et al. [2013], Nagao et al. [2014], Kamiyama et al. [2014], Hayakawa et al. [2015], Schekotov and Hayakawa [2015]) about the possible precursors of the Tohoku earthquake. These precursors include EM precursors, which are shown in Tab. 4.

Table 3. The study of GUAM EQ

Natural phenomenon	Researcher [year]	Approach/Method: preearthquake changes	EM precursor	Frequency band
1993 Guam EQ *(M=7.7; 8 August 1993)*	The study by Hayakawa et al. [1996]	EM monitoring: Polarization ratio time series of geomagnetic field data	precursory signatures of the EQ	ULF
	The study by Hayakawa et al. [1999] The study by Hobara et al. [2004] The study by Ida et al. [2005] The study by Ida and Hayakawa [2006] The study by Smirnova et al. [2001]	EM monitoring: Changes of ULF magnetic components before the EQ	precursory sign of the EQ	ULF
	Currie and Water [2014]	EM monitoring: Polarization ratio time series of geomagnetic field data	precursory signatures of the EQ	ULF
	Surkov and Hayakawa [2014]	EM monitoring: ULF disturbances of geomagnetic field data	precursory signature of the EQ	ULF/ELF

Table 4. The study of TOHOKU EQ

Natural phenomenon	Researcher [year]	Approach/Method	EM precursor	Frequency band
2011 Tohoku EQ *(M=9.0-9.1)*	Kopytenko et al. [2012]	Geomagnetic field data variations were observed over the 11-year period	Medium-term anomaly begins 3 years before the earthquake, and also a short-term ULF precursor observed less than 3 weeks before the EQ	ULF
	Xu et al. [2013]	Observation of geomagnetic field data variations	Anomalous daily variation of ULF data 2 months before the EQ	ULF
	Hayakawa et al. [2015]	Natural time analysis of the ULF data	Criticality conditions of horizontal magnetic field component several days before the EQ	ULF
	Ohta et al. [2013]	EM monitoring: observation of atmospheric radiation based on measurements at three different stations.	Extremely low-frequency pulsive radiation was reliably recorded a few days before the EQ	ELF
	Schekotov and Hayakawa [2015]	EM monitoring: extensively investigation of 5-year ULF data	Radiation in the vertical magnetic field component. ULF radiation data increased before the EQ, and decreased after the EQ.	ULF
	Hayakawa et al. [2012, 2013a,b]	EM monitoring: VLF/LF observation network data	Subionospheric VLF anomaly 5-6 days before the EQ	VLF/LF
	Schekotov et al. [2013a,b] Hayakawa et al. [2013b]	EM monitoring: the study of the depression of ULF horizontal magnetic field variations	ULF field depression 5 days before the EQ	

The similar pre-earthquake changes in the electromagnetic field during the study of the above-mentioned earthquakes indicate that studies in this direction should be continued.

CONCLUSION

The study by Curries and Waters [2014] showed us that most of the researchers (Fraser-Smith et al., [1990], Bernardi et al., [1991], Molchanov et al., [1992], Hayakawa et al., [1996], Yumoto et al., [2009], Hasbi et al., [2011]) who intended to search for precursors got positive results.
In the study of Tohoku EQ by Japanese scientists, we can easily see important results.
If we look at all the tables above (Tab.1, Tab.2, Tab.3, and Tab.4) we can easily see most of all positive results obtained from observation in the ULF band. For this very reason, I would like to notice that the ULF EM approach should be considered as the best approach to study EQs or to predict EQs (short-term prediction).
From all the above examples, it can be concluded that EM monitoring may be considered to be effective and potential in studying EQs.

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ИССЛЕДОВАНИЕ ПРЕДВЕСТНИКОВ ЗЕМЛЕТРЯСЕНИЯ ПУТЕМ ЭЛЕКТРОМАГНИТНОГО МОНИТОРИНГА: ИНЧ СИГНАЛЫ КАК ПОТЕНЦИАЛЬНЫЕ ПРЕДВЕСТНИКИ ЗЕМЛЕТРЯСЕНИЯ

Пириев Р.Х.

В течение последних лет неоднократно предпринимались попытки рассматривать изменение электромагнитного поля Земли, равно как и электромагнитные явления, предшествующие землетрясению, в качестве его предвестников. Как потенциальные предвестники землетрясения часто рассматриваются электромагнитные сигналы крайне низких частот (КНЧ). Поэтому особое внимание уделено тем статьям, где сигналы КНЧ рассматриваются как перспективные предвестники. Сделаны обзоры статьи Карри и Уотерса [Currie and Waters, 2014], исследования основных землетрясений Ломa-Приеты и Гуама [Loma Prieta, and Guam], а также исследования мегаземлетрясения в Тохоку (Япония) (напр., Hayakawa and Fujinawa, 1994; Hayakawa, 1996, 1999; Campbell, 2009; Fraser-Smith и др., 2011; Molchanov и др., 1992; Hobara и др., 2004; Ida и др., 2005; Surkov and Hayakawa, 2014). В качестве вывода, предлагается рассматривать подход, основанный на КНЧ, в качестве наилучшего подхода к прогнозированию землетрясений (краткосрочный прогноз).

Ключевые слова: электромагнитный, землетрясение, КНЧ, предвестник, краткосрочный прогноз.