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PRECURSORS OF EARTHQUAKES: VLF SIGNALS-IONOSPHERE RELATION

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Abstract: *A lot of people have died because of earthquakes every year. Therefore It is crucial to predict the time of the earthquakes reasonable time before it had happed. This paper presents recent information published in the literature about precursors of earthquakes. The relationships between earthquakes and ionosphere are targeted to guide new researches in order to study further to find novel prediction methods.*

Keywords: *Earthquake prediction, VLF, ionospheres*

1. INTRODUCTION

Earthquakes have been an important fact changing life of the living creatures throughout human history. People have increased the number of the studies carried out on earthquakes because of this importance. Every year around 120.000 people have died because of earthquakes [URL-1 , (2012)]. This is because, it is critical to predict the time of earthquakes before happens. There are many researchers tries to find fast and rigorous prediction methods in the literature. The main goal of this paper is to give detailed review on prediction of earthquakes studies published in the literature in order to guide further studies.

A lot of studies have started to focus on impacts of the earthquakes and the geological formation as well as on the issues like precursors [Molchanov et al. (1998)] [Pierce (1976)] [Muto et al. (2009)]. Probability of earthquake prediction is established on hypothesis of the existence of precursors. There have been a large number of earthquake precursors suggested since ancient times. However there has not been a precursor put forth yet fully proven and reliable [Molchanov et al. (1998)] [Hayakawa and Molchanov. (2000)] [Horie et al. (2006)]. It is observed that statistical analysis and signal processing techniques are applied on the methods identified as precursors and data sets from various VLF networks in all studies to define the relation between the ionosphere and the VLF signals.

There are studies carried out in two ways in order to improve reliability for existences of ionospheric perturbations in connection with earthquakes. One of them is the studies performed for large earthquakes on the characteristic changes in ionosphere [Molchanov vd. (1998)] [Shvets vd. (2004)] [Yamauchi et al. (2007)]. The second analysis method is to statistically analyze the relation between the earthquakes and the VLF/LF signals carrying the data of perturbations happening in the sub ionosphere [Molchanov et al. (1998)] [Muto et al. (2009)]. The earthquakes need to be on the surface in order sub ionosphere to be exposed to perturbations due to earthquakes. Furthermore the magnitude should be 6 or over to observe the impacts of the earthquakes on the ionosphere [Muto et al. (2009)]. There is an environment in the studies which are the receivers and transmitters. Electromagnetic waves from this transmitter are received by the receiver using reflection feature of ionosphere. What is observed here is that transmitted electromagnetic waves incur losses depending on the atmosphere which is the transmitting environment and ionosphere which is the reflecting surface [Yamauchi et al. (2007)] [Hayakawa (1999)]. These losses in fact are significant data. The losses are created by the impact of the factors in the environment. Defining these factors will give a meaning to data carried. Characteristic changes in electromagnetic waves include the data of the changes affecting ionosphere and occurring in the atmosphere thus on the earth [Muto et al. (2009)].

Amplitude and phase values of VLF signal sent by the transmitter and received by the receiver are examined in the studies. The changes on electromagnetic VLF signal depend on electric density of ionosphere's D layer and reflection height as long as the transmitter has a constant frequency and distance [Hayakawa et al. (2006). Using VLF signals is essential for analysis method due to reflection height [Molchanov et al. (1998)] [Gokhberg et al. (1989)]. The reason to use VLF signals as electromagnetic waves is because electromagnetic waves do not reflect on the ionosphere and, spread into other layers and the space in case of choosing a high frequency wave.

In the studies carried out by Russian and Japanese academicians they have found many clues proving that the earthquakes are related to propagation in the sub ionosphere [Molchanov et al. (1998)] [Muto et al. (2009)] [Shvets et al. (2004)].

The impacts on VLF signals are discussed in this study, one of the earthquake precursor methods. The environment of electromagnetic wave propagation is ionosphere. The purpose of the studies carried out is to work on a complete ionosphere model. However there has not been an ionosphere model presented yet. Because the ionosphere cannot be completely modeled, statistical methods have been suggested and some studies have been performed on this for determining precursors of earthquakes.

2. POSSIBLE FACTORS

There are various parameters set off by earthquakes. The whole course of the action should be comprehended in order to present possible factors.

The earthquake is a sudden and rapid shaking of the earth caused by the breaking and shifting of fault lines beneath the earth surface. This results in being able to observe the signs that are possible precursors of earthquakes by monitoring tension of the rocks [URL-2 (2011)] [URL-3 (2011)].

Monitoring emissions of excessive unexpected radon gas in the cracks or breaks in the fault lines can be defined as possible precursors of earthquakes [Saç and Camgöz (2005)] [Zmazek et al. (2002)]. Excessive emission of radon gas in the time frames prior to the earthquakes and the changing magnetic field of the earth present another method group of possible precursors [Liu et al. (2004)] [Hayakawa and Molchanov (2000)] [Yamauchi et al. (2007)] [Molchanov et al. (1998)] [(Karatay (2010)].

Magma movements setting off earthquakes and the movements of earth layers cause changes in magnetic field of the earth [[18](Sato et al. (2009)]. This change in magnetic field will have an influence on ionosphere height [Yamauchi et al. (2007)]. Height of ionosphere will determine reflection height of VLF sign and the unexpected changes in this will be able to be related to external factors. Changes in magnetic field of the earth will also have an impact on the ionization of ionosphere.

The propagation environment of electromagnetic signal is ionosphere. Electron density and ionization of ionosphere is directly related to losses on the signals. As presented in the studies change in electron density and ionization of ionosphere are in interaction with the earthquakes and ionizing effect of radon gasses is quite high [Zmazek et al. (2002)] [Karatay (2010)] [Muto et al. (2009)].

3. PREDICTION METHODS

This section gives details of prediction methods which use VLF signals and Ionosphere characteristics. There are also some predicted earthquakes examples published in the literatures.

3.1. VLF Signals-Ionosphere Relation Method

Different methods have been suggested considering all factors affecting earthquakes. There are tens of studies performed on these. The main issue to be emphasized here is the relation between ionosphere and earthquake. The theory of loading the data of possible earthquake and transmission of electromagnetic VLF waves by ionosphere with losses has been examined by several methods in the studies.

3.1.1. Termination Time

As observed in the studies VLF signs transmitted through ionosphere have certain characteristics in some time frames prior to the earthquakes [Molchanov et al. (1998)]. These characteristics start several days before the earthquake and go into amplitude several days after the earthquake.There are two prediction times in the day. One of them is sunrise prediction time (t_m) and the other one is sunset prediction time (t_e). These time frames are carried on electromagnetic waves with approximate 6-minutes accuracy. Prediction times are determined on the wave with constant amplitude transmitted by the transmitter and received by the receiver.
The time when the electromagnetic wave in the receiver initially reduces down to the lowest value in terms of amplitude defines sunrise prediction time. And sunset prediction time is when it secondly reduces down to the lowest value [Molchanov et al. (1998)]. There is a graphic shown in Figure 1 regarding to sunrise and sunset amplitude times.

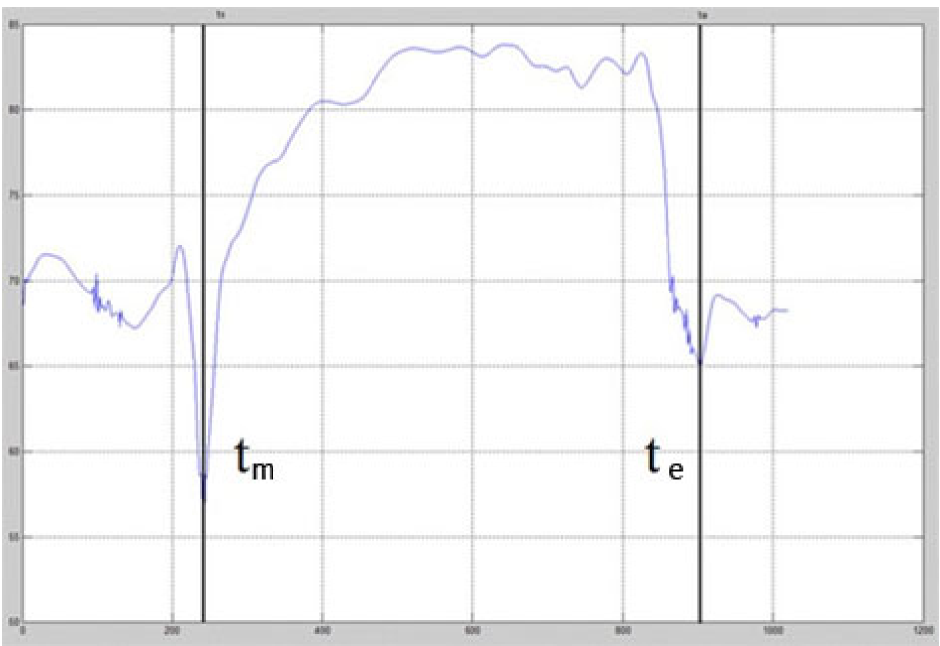


Figure 1. Detection of termination time on electromagnetic waves

Epicenter of the earthquake's being in Fresnel region will better reflect the impacts of sub ionosphere disturbances caused by seismic activities [Molchanov et al. (1998)].

As observed in various studies, reliability of the results obtained by using prediction time data is higher than other methods. Results obtained from studies performed on phase and amplitude are more difficult than prediction time method and have less accuracy [Molchanov et al. (1998)] [Hayakawa and Molchanov (2000)] [Muto et al. (2009)].

[Molchanov et al. (1998)], in his studies stated that there are certain changes in time frames prior to the earthquake which might be considered precursors. The data from 7.2 magnitude earthquake happened in Kobe Japan, happened in 17 Jan. 1996, were used in this study in [Molchanov et al. (1998)]. Prediction time method and data processing techniques in this study were used on VLF signals recorded during the earthquake [Molchanov et al. (1998)]. This earthquake happened on the transmission ways of the signals is also in Fresnel region which contains the effects in the best way possible. The region where the earthquake happened and electromagnetic wave network are shown in Figure 2. Fresnel region is an elliptic area for the focus of VLF transmitters and receivers [Molchanov et al. (1998)].

Figure 2. Receiver and Transmitter Stations, The Fresnel Area, The Earthquake Zone

Epicenter of Kobe earthquake is pointed in Figure 2 with a cross. Epicenter is at a 70 km distance to VLF sign propagation network. Seismic disturbances in Fresnel region will increase the impact of sub ionosphere on VLF signal propagation. As specified before and it has been presented in the study that a statistical analysis on prediction times provides more reliable results [Molchanov et al. (1998)].

As a result of examinations characteristic signs on VLF signals are observed that start several days before the earthquake and remain for a few days after the earthquake. The results obtained from this study shows parallelism with the fact that characteristic changing period is about 10 days. Ionospheric changes are likely to be caused by ionized effects of radon gases before earthquakes, changes in electric field, condensing waves of the earth, geomagnetic activities or disturbances by seismic activities. Phase and amplitude values of radio signals from horizontal VLF signals in the world wave guide have been monitored in the studies. VLF waves depend on reflection height h and electron density of ionosphere's D layer if the transmitter has a constant frequency and distance. VLF signals sent by Omega station and recorded Inubo station are used In this study [Molchanov et al. (1998)].

In Figure 3 phase amplitudes are provided on the graphic for the days before and after the earthquake. Prediction times indicate the lowest phase levels. Considering sunrise and sunset periods, shifting occurs in the prediction times when the signals have the lowest levels a few days before an earthquake. As seen in Figure 3 prediction times defining sunrise and sunset periods three days before the earthquake shift [Molchanov et al. (1998)].

When statistically examined the values of (t_m) and (t_e) and the equations in **Error! Reference source not found.** and **Error! Reference source not found.**, shifting in prediction time of (t_e) value is more significant [Molchanov et al. (1998)].

There will be some approaches indicating certain abnormalities occurred for the data obtained from Equation **Error! Reference source not found.** and days with values exceeding the level of the graphic. Prediction time exceeds the level of approximate 2 days before the earthquake in the study [Molchanov et al. (1998)].

As seen in Figure 3 where obtained values are presented, sunset prediction time presents more significant characteristics than sunrise prediction time.

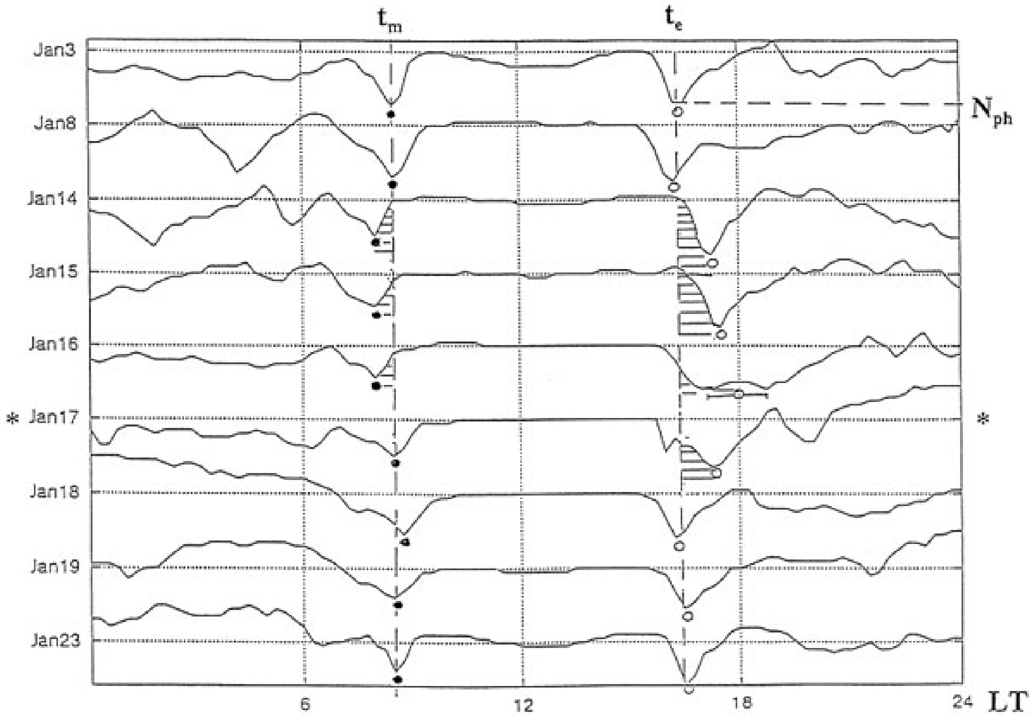


Figure 3. Detecting Termination time on signal phase data [Molchanov et al. (1998)]

3.1.2. 2 σ TEST

Practice of statistical data distribution is an easy calculation method and also has been a subject of successful studies performed on clarifying earthquake data on electromagnetic wave. Processes are carried out over electromagnetic waves selected as data set. The data used in the processes can be phases and amplitudes of VLF signs. If the differences between phase or amplitude values and mean value are higher than a certain level then this is accepted as a precursor. Furthermore as observed in the studies changes in prediction time or fluctuations in night periods are subjected to some tests by mean values)] [Hayakawa and Molchanov (2000)] [Muto et al. (2009)] [Yamauchi et al. (2007)] [Molchanov et al. (1998)].

Either (t_m) or (t_s) given in Figure 1 will be determined as data set. Mean values will be calculated through data set. A value based on instant differences will be obtained by mean value.

$$dt_a = t_a - t_{a-1} \quad (1)$$

It is the difference value given in equation **Error! Reference source not found.** and calculated by (2), prediction time values of phase or amplitude to mean prediction time. With this equation prediction time and prediction times in selected range where the earthquake happens are calculated as an average [Yamauchi et al. (2007)].

$$\sigma = \sqrt{(t_a - t_{a-1})^2} \quad (2)$$

There will be some approaches indicating certain abnormalities occurred for the data obtained from Equation **Error! Reference source not found.** and days with values exceeding the level of the graphic [Molchanov et al. (1998)].

As observed in Figure 1, 2σ level is drawn for the average of all periods of values obtained for amplitudes or phases of the waves. Prediction time differences are graphically drawn and some tests have been performed in order to understand whether 2σ level was exceeded or not. As a result of the studies it has been presented that the difference between prediction time and mean prediction time exceeds 2σ level a few days before an earthquake [Molchanov et al. (1998)] [Yamauchi et al. (2007)] [Horie et al. (2006)] [Hayakawa et al. (2006)]. Furthermore studies indicate that period of oscillation is about ten days. The graphic in Figure 5 obtained by sunset prediction time present significant abnormalities prior to the earthquake [Molchanov et al. (1998)].

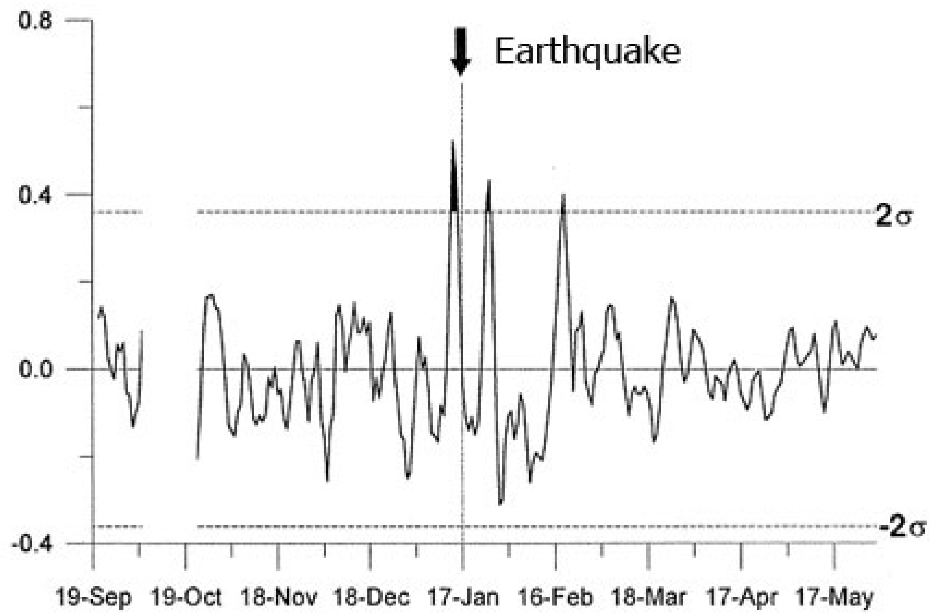
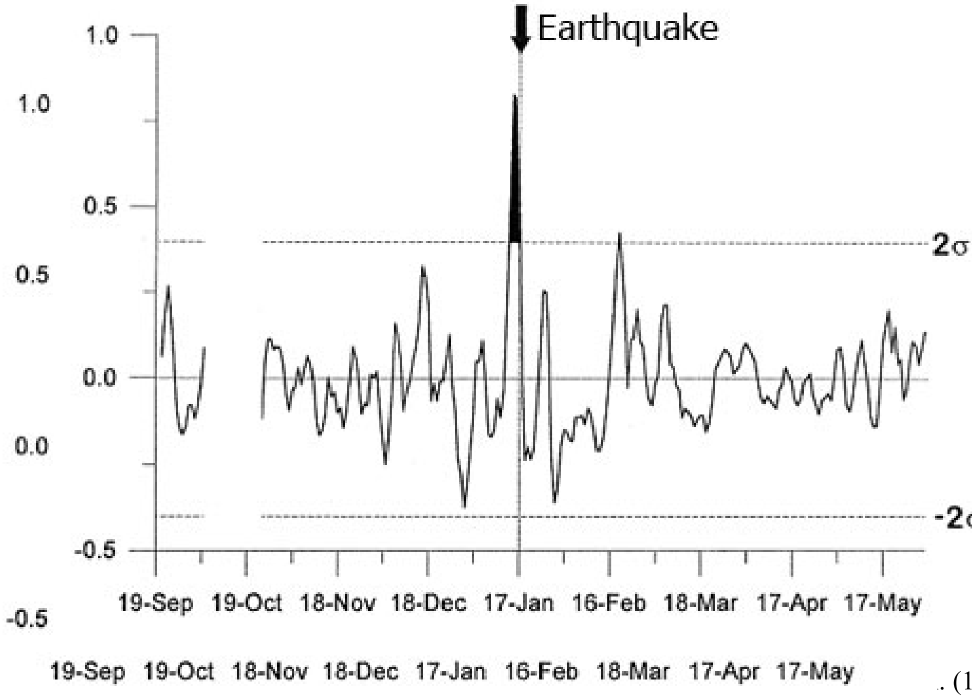


Figure 4. 2σ test for earthquake prediction with sunrise VLF data [Molchanov et al. (1998)]



. (1998)]

The evident increases in another study which indicates the relation between electromagnetic waves and the impacts of the earthquakes have certain characteristics. Various studies have suggested method in this study has calculating advantages from the structure of an integrated system. This is because any earthquakes happened in the large circle of receiver and transmitter has the influence changing the characteristic of VLF propagation. With using VLF data in complete scale studies about disturbances of seismic-ionosphere proceed in two ways. One of them is the study performed on the correlation between ionospheric disturbances and seismic activities. And the other one is about the relation between seismo-ionic disturbances and large earthquakes. With the combination of both methods more explicit knowledge should be presented about characteristic, structural features, formation mechanisms and dynamics of the relation between the earthquakes and the transmission of electromagnetic waves [Yamauchi et al. (2007)] [Hayakawa et al. (2006)] [Horie et al. (2006)].

We can see the influence difference between the sunrise and the sunset prediction times when we compare Figure 4 and Figure 5. is drawn up by the data of sunset prediction time.

been carried out in order disturbances in sub ionosphere to be detected by VLF electromagnetic wave propagation. The

This method is based on calculating amplitude and phase changes when sunrise and sunset periods and daily VLF signal reach the lowest level. Hayakawa in his studies and this change in prediction times indicate that abnormal prediction time shifting presents possible earthquake relation. The second method is analyzing of ascend and descend in ionosphere during the night [Yamauchi et al. (2007)]. The importance of atmospheric ground wave's role in Lithosphere – Ionosphere coupling has been mentioned in various studies [Molchanov (2001)] [Yamauchi et al. (2007)].

Ebino (JJI) transmitter signal data saved by Moshiri (MSR), Chofu (CHO), Chiba (CBA), and Kocki (KOC) recording station at Japan VLF Signal Networks, for analyzed earthquakes. Prediction time was used as analysis method. As clearly seen in the study carried out on Kobe earthquake sunset prediction time is more significant than sunrise prediction time in the morning [Hayakawa et al. (1996)]. Therefore we have focused on sunset prediction time. The data from transmitters are analyzed by MSR in terms of

And Figure 5 is prepared by the data of sunrise prediction time. Studies indicate that earthquakes create more significant impacts on sunset prediction time shifting [Molchanov et al. (1998)].

VLF Prediction Time Analysis Method; In the study performed on the 6.8 magnitude earthquake happened in Niigata on 23rd of October, Japanese VLF network and data from VLF network were analyzed [Yamauchi et al. (2007)]. Two different analysis methods were suggested to define seismo- ionospheric disturbances. The first is Prediction Time method.

day prediction times [Yamauchi et al. (2007)]. The results for time shifting of abnormal days are presented in Table 1. The abnormalities in Previous studies also present the same results [Hayakawa et al. (2006)]. 7-minute shifting of JJY-MSR means the contraction of day period. The same situation is seen in JJY-KOC data. In addition to this the situation of JJI shows 30-minute shifting in CBA. This decrease indicates extension of sunset prediction time and a longer period of a day [Yamauchi et al. (2007)].

Table 1. Observed shifting Termination Time

Transmitter	Receiver	Termination Time	Anomaly	Shift (Min.)
JJY	MSR	Sunrise	Before 7 days	+7
	KOC	Sunrise	Before 5 days	+6
JJI	CHO	Sunset	Before 6 days	-20
	CBA	Sunset	Before 7 days	+30

Prediction times define the lowest level that sign amplitudes reach during the day. Prediction times are shown in Figure 6. Sunset and sunrise happen in these time frames. The lowest level that the signal initially reduces is sunrise. The second lowest level shows sunset. Shifting in prediction times starting from several days before the earthquake occurs in amplitude characteristic of this signal used as precursor of an earthquake. This shifting may occur backward or onward in time. There might be several reasons why time shifting happens. One of the reasons is the shifting caused by earthquakes as it is the subject of

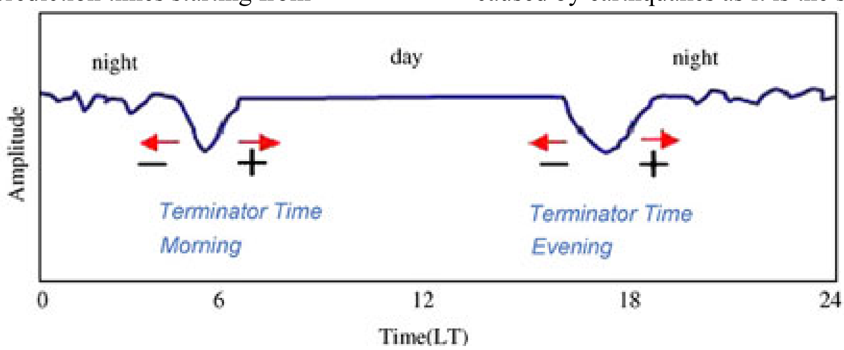


Figure 6. Sunrise and sunset Termination times [Yamauchi et al. (2007)]

this thesis. The studies performed indicate that there is shifting in prediction times during several days before the earthquake happens [Molchanov et al. (1998)] [Yamauchi et al. (2007)]. (t_m) and (t_e) moments defining prediction times can be observed for each day with 6-minute accuracy [Molchanov et al. (1998)].

3.1.3. Ionosphere Movement Analyze

Decrease in Ionosphere; Activity of ionosphere is one the reasons changing

C indicates the amount of shifting in sub ionosphere. Ionospheric activity indicated by parameter C varies between 1 and 5 km. The dependency of shifting in prediction times on perturbation parameters was examined in this study. Time shifting occurred depending upon parameter C is shown in Figure 7. The moment when the parameter C is 0 (C=0) is shown with bold straight line. It is observed here that 10-minute shifting time happens when C=5 km. Prediction time values examined here are for sunrise. As seen in Figure 7 solstitial occurs characteristic of VLF signal transmission. There are studies defining decrease and increase in ionosphere during day and night. Their impacts on the earthquakes were taken into account in these studies. Mathematical model used is two-dimensional finite difference time domain [Taflove (2002)]. It is known that FDTD method can be statistically solved by Maxwell equations. Electron density and ionosphere during day and night are shown in equation **Error! Reference source not found.**.

$$Ne(z) = 1.43x10^{13}\ e^{(-0.15H')}\ \ x\ \ e^{(\beta-0.15)(z-H')} \qquad (3)$$

The values in equation **Error! Reference source not found.** are for the daytime $H^{'} = 74\ km$ and $\beta = 0.3\ km$ and, for nighttime $H^{'} = 87\ km$ and $\beta = 0.6\ km$. Ionosphere transition between day and night was considered to be smooth. Furthermore ionospheric disturbance is considered to be as in the equation **Error! Reference source not found.** [Yamauchi et al. (2007)].

$$\Delta h(x) = C\ \ e^{\frac{(x-x_0)^2}{\Delta\sigma^2}} \qquad (4)$$

Depending on epicenter and location of the transmitter the equation is as follows: $x_0 = 250\ km$. The $\Delta\sigma$ horizontal scale is considered to be 200 km. Epicenter will be $(x = x_0)$ right above ionosphere. Parameter ten minutes earlier than its regular period. This results in extension of daytime. The exact opposite situation can be applied to increase in ionosphere [Yamauchi et al. (2007)].

Using traditional methods based on calculation of rock activity is quite common in prediction. However it can be concluded that the systems based on mechanical measurements are not very useful in short-term predictions. Thus a new prediction method has been presented through electromagnetic effects. A large number of evidence has been collected defining the relation between electromagnetic phenomenon and major earthquakes in large frequencies. While the data from mechanical effects provide long-term information on the earthquakes, electromagnetic waves give short-term information. It has been observed in the studies performed within the last ten years that seismic impacts unexpectedly have extremely sensitive effects on ionosphere [Hayakawa (2008)].

In the study performed by Hayakawa in 2008, amplitude values of nighttime were obtained by averaging 30-day data range including the earthquake.

The following conclusions have been reached in the studies [Hayakawa (2008)]:

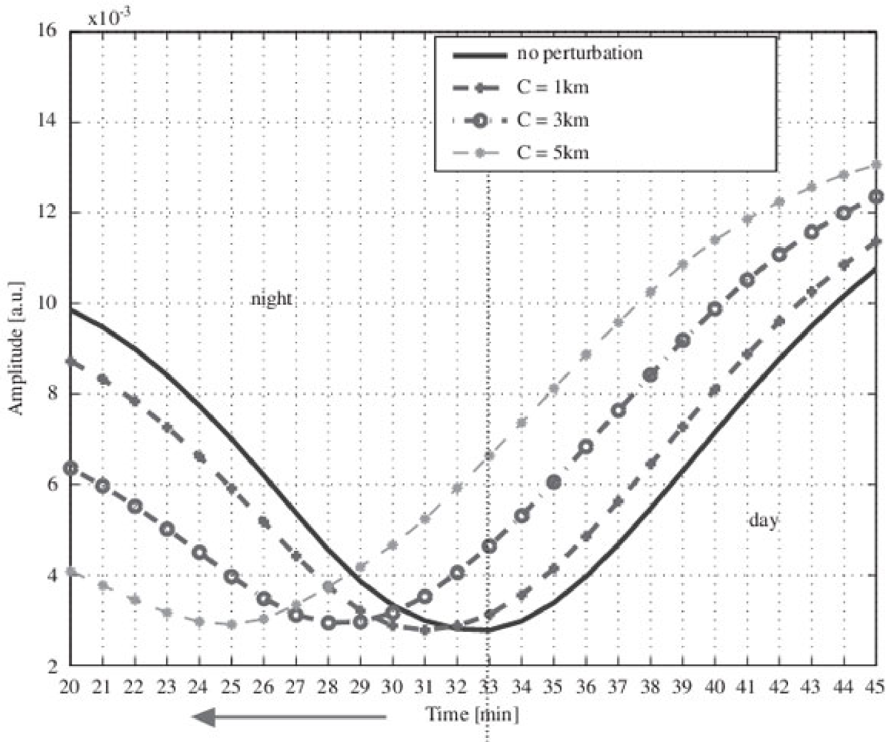


Figure 7. Shfting Termination time

- Nighttime amplitude presents significant decreases 2-5 days before the earthquakes. 6 magnitude or over earthquakes also exceed this decrease value.
- Excessive fluctuation in nighttime in seismic activities with 6 magnitude or over earthquakes can be observed.

The period of nighttime and the graphic drawn depending on amplitudes of signals transmitted at night are shown in Figure 8. The value in the graphic was exceeded in several days before particularly major earthquakes [Hayakawa (2008)].

The characteristic in Figure 8 can be put forth if it is applied on wavelet analysis *dA* and cross-correlation analysis is performed on VLF signals. The wave spreads outward from epicenter and wave speed is greater than 20 m/s [Hayakawa (2008)]. The earthquakes happened in Japan have been analyzed in another study based on characteristic changes in ionosphere caused by large earthquakes [Muto et al. (2009)]. There are several studies examining Lithosphere-Ionosphere connection on seismo-electromagnetic relations.

Target Earthquake and Analysis Period; Four-month period was analyzed for the 7.2 magnitude earthquake happened in 36 km depth in Miyagi-oki on 16th of August 2005. There were many aftershocks during the period of time after the main earthquake.

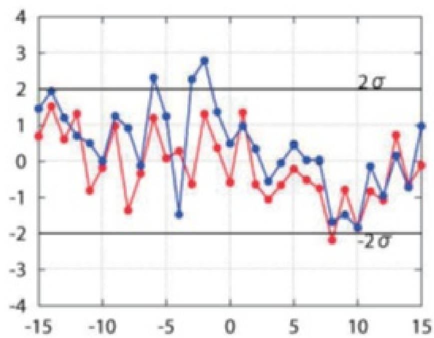


Figure 8. Exceed the 2σ level

The epicenter of these earthquakes is often on pathways of VLF signals [Muto et al. (2009)]. The amplitudes of VLF signals obtained every two minute were analyzed.

$$dA(t) = A(t) - A(t-1) \quad (5)$$

$A(t)$ given in the equation **Error! Reference source not found.** indicates amplitude value of the signal based on the time. $A(t-1)$ reference value is the signal obtained by

± 15 daily averages of t moments.

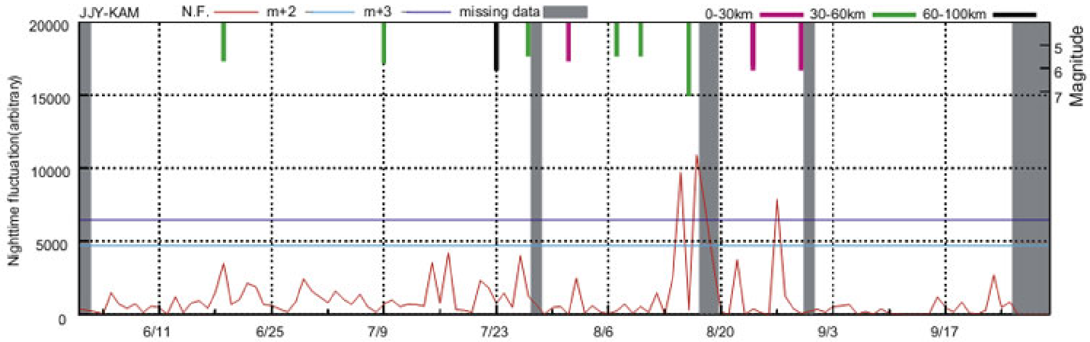


Figure 9. Observed perturbations before earthquakes

It is considered that characteristic disturbance can be prevented by this method instead of standard averaging. Data of nighttime were used considering prediction times. Amplitude value of nighttime was calculated as the average of all nighttime [Muto et al. (2009)].
As can be seen in the graphic in Figure 9 an observable disturbance is present prior to the earthquakes. Graphic indicated by red lines in Figure 9 is calculated dA(t) value. Vertical green and red bars on top of the graphic provide information on time and magnitude of the earthquakes happened. As can be observed light blue horizontal line is pushed when the large earthquakes happened. Likewise the dark blue line is exceeded at large earthquakes. It is seen in the statistical analysis the values and limits calculated several days before the earthquakes were exceeded [Hayakawa (2008)].

3.2. Earthquake – Total Electron Content Relations Method

Propagation environment of electromagnetic waves is ionosphere. It is known that ionosphere undergoes characteristic changes before earthquakes [Molchanov et al. (1998)]. We might be able predict earthquakes if we can characteristically monitor these changes. Being able to monitor ionosphere's electron content helps designate precursors of an earthquake. There are several methods to make a prediction based on Ionosphere's Total Electron Content (TEC).

3.2.1. Correlation Analyze

Correlation analysis is a method used to explain the impacts of seismic activities of the method is applied on electron density variable. The data obtained from ionosonde or GPS can be studied on the days which are geomagnetically still or complex. The data from ionosonde and GPS networks were used in the studies in the literature to find the change in electron density. There were two measuring points in the analysis. One of them is "receiving-sensor" in the area became affected by earthquake and the other one is "controlling-receiver" out of the area not to become affected by earthquake. The data of critical frequency and vertical total electron content (VTEC) were collected in equal time intervals for sample days. *(C)* Daily cross correlation coefficient was calculated by **Error! Reference source not found.** equation [Kouris (2006)] [Pulinets (2004)] [Karatay (2010)].

$$C = \frac{\sum_{i=0}^{k}[f_1(i) - af_1][f_2(i) - af_2]}{k[\sigma(1)\sigma(2)]} \quad (6)$$

Numbers 1 and 2 given in the equation **Error! Reference source not found.** represent the stations. Arithmetic mean of critical frequencies gives us *af* critical frequency. This equation is shown in **Error! Reference source not found.**. σ Standard deviation value is obtained in the equation **Error! Reference source not found.**.

$$af = \frac{\sum_{i=0}^{k} f(i)}{k+1} \quad (7)$$

$$\sigma^2 = \frac{\sum_{i=0}^{k}[f(i) - af]^2}{k} \quad (8)$$

earth on ionosphere layer. Correlation analysis

Russia active seismic zone several earthquakes were examined happened in Taiwan and Japan, Western Pacific region; the far east of Russia. For critical frequency autocorrelation coefficients were separately calculated and cross correlation coefficients of both stations were calculated starting from January 1974. It was monitored that cross correlation coefficients in two time intervals reduced under 0.9 for a 120-day interval within the days varying between 1 and 7 before the earthquakes [Kouris (2006)] [Pulinets (2004)] [Karatay (2010)].

3.2.2. Interquartile Range

Disturbances on the earth were analyzed by continually recording total electron content. Inclined Total Electron Content was calculated with electromagnetic waves recorded by receivers of Global Positioning System every 30 seconds [Liu et al. (2004)].
In the studies 20 earthquakes (M=6) happened in Taiwan between September 1999 and December 2002 were analyzed with interquartile range [Liu et al. (2004)]. VTEC value was calculated in 15-day time period before the earthquake.
The data used were obtained from Chung-Li ionosonde station and Yang-Ming-San GPS station (25.3° K, 120° D) [Liu et al. (2004)]. 5 days before the earthquake VTEC anomaly was observed in 16 earthquakes out of 20.

3.2.3. Total Electron Content (TEC) Differentiation Analysis

Kp-index and TEC changes depending on solar winds were analyzed in the study performed by TEC differentiation analysis [Plotkin (2003)]. Earthquake day and still-complex day analysis were done in the study.
These analysis were evaluated in parallel with the data of complex and still day and the impacts of the earthquake were examined. The sources of the deviations occurred on earthquake days were determined. Absolute TEC values from six receivers were used in this study [Plotkin (2003)]. Depending upon daily Sun cycle effective value was calculated for TEC time series in a few-hour time period.
With reference to the equation **Error! Reference source not found.** and with the data from Petropavloskna "receiving-sensor" and Magadan "controlling-receiver" located in

$$dTEC = (TEC)_i - (TEC)_{i+1} \qquad (9)$$

The data from two stations located out of impact area of the earthquake and four stations affected by the earthquake were used. Calculation dTEC in the equation **Error! Reference source not found.** was carried out for all stations. Daily variation curve was drawn for the differences of the stations located in and out of the impact area. Characteristic decreases in the stations located in the impact area were detected 2 days before the earthquake for both of the curves.

4. CONCLUSION

There are a lot of recent prediction methods, that use relationships between earthquake and ionosphere, presented to guide finding precursors of earthquakes.

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