

CHAPTER: 32

INVESTIGATIONS ON THE ULF BASED EMISSIONS FOR THE STRONG EARTHQUAKE (M 6.8) OCCURRED IN PAKISTAN REGION

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Ch.Id:-RBS/NSP/EB/RAASTTSE/2024/Ch-32

DOI: <https://doi.org/10.52458/9788197112492.nsp.2024.eb.ch-32>

ABSTRACT

In this paper we aim to study two significant earthquakes of high magnitude $M=7.4$ and 6.8 occurred in Pakistan in September 2013. We have examined the ulf data from the Agra station for September 2013 in order to study this. For this raw lemi 30i files have been analyzed and enhanced bursts have been found. In order to ascertain the lithospheric origin we have examined these bursts and electromagnetic bursts have been found of duration 10-15 sec and frequency range 0.06-0.1 Hz. Further to study these burst in detail we have used two analysis namely polarization parameter analysis and fractal analysis. Anomalous variations have been found 9-16 days before earthquake.

Keywords: ULF, fractal analysis, polarization parameter analysis.

INTRODUCTION

Earthquake prediction and seismo-electromagnetic techniques has been a relevant area of research for past few decades and significant results have been reported. The elegance of these methods lies in their ability to be utilized across an extensive frequency spectrum, spanning from DC to HF (Hayakawa and Fujinawa 1994; Ouzounov et al., 2021 and references cited therein). Ultra-low frequency (ULF) emission monitoring has recently yielded significant evidence supporting the lithospheric origin of

precursor signals. Some of the main justifications for selecting ulf methods are low attenuation, minimal contamination, large skin depth, and penetration beyond the magnetosphere and ionosphere. Both domestically (Singh et al., 2014, 2018 and references therein) and globally (Fenoglio et al., 1995; Hayakawa et al., 2007) there are a large number of researchers working in this direction. Numerous techniques have been used to analyze magnetic emissions for ultra low frequency (ULF) signals in an effort to identify anomalies that may be relevant to the study of earthquake precursors. Many researchers engage themselves in routine monitoring of ULF data at single as well as multi-station and prior report some informative findings. Availability of lot of data enables more convenient opportunity for statistical study which further ease to derive reliable conclusions about the precursor study. Numerous statistical methods have been used in this area, including principal component analysis, fractal analysis, polarization analysis, and inter-station transfer function. The direct method and the indirect method are two approaches that have been used extensively to research earthquake events. Direct emissions are defined as direct observations of electromagnetic emissions that begin in the lithosphere and manifest as ULF radiation. Indirect emissions are measurements based on the ionosphere and atmosphere's seismic influence. The DC geomagnetic fields measurements along with current associated with earthquakes have already completed a substantial amount of important work (Smith and Johnston, 1976). ULF data was first routinely monitored at the Agra station, and then at numerous other locations throughout India. In this work, we examine ULF data for September 2013, a month that had two significant earthquakes in Pakistan with magnitudes of $M=7.4$ and $M=6.8$. Significant precursors have been found 9-16 days before the earthquakes. Further to study these techniques we have employed techniques namely polarization parameter analysis and fractal analysis.

DETAILS OF ULF SETUP

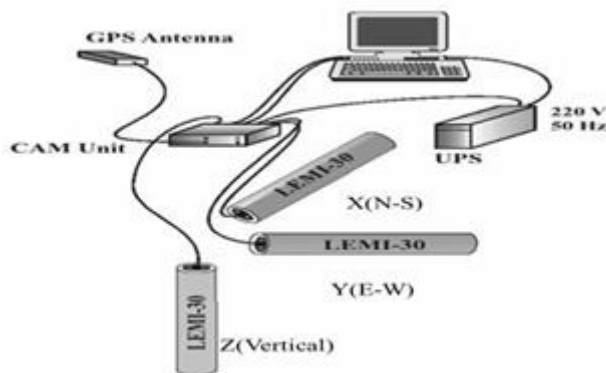


Fig. 1: ULF Measurement Setup

A three-component search coil magnetometer ($f=0.01-30$ Hz), a communication and data collection unit (CAM unit), and Lemi30i software, which was imported from the Institute of Space Research, Ukraine's Lviv center, make up the equipment. A whole arrangement is displayed in Fig. 1. The three sensors are positioned orthogonally 1.5 meters below the surface in the college's agricultural fields, an area with minimal electromagnetic and local noise. Every second at rate of 256 samples data from sensors is sent via wires to CAM unit kept in the room. An average of these samples is kept in the computer, resulting in 64 samples being retained every second. In 16 seconds, software analyzes 1024 data points at a sampling rate of 64 Hz. Here, the spectrum is obtained hourly by averaging 1024 data points throughout 450 spectrum. Similar experimental setups have been used by other researchers (Singh and Pundhir, 2014 and references therein).

DETAILS OF EARTHQUAKE AND GEOMAGNETIC ACTIVITY

Table 1 contains the specifics for earthquake data that were examined, which were obtained from the USGS website at <http://earthquake.usgs.gov/earthquakes/>. The geomagnetic data (Dst and $\sum Kp$) are derived from the following website: <http://omniweb.gsfc.nasa.gov/form/dx1.html>. Fig. 2 displays the fluctuations in the data throughout September 2013. Since Dst is always less than -25 and $\sum Kp$ is always less than 30, there isn't a significant magnetic storm at this time.

Table 1. Details of major earthquakes considered in this study

S.No	Date of earthquake	Time (UT)	Latitude (Deg.)	Longitude (Deg.)	Depth (km.)	Magnitude	Region	Distance from Agra (km)	Radius of the influence zone (km)
1.	24/09/2013	11.29.48	27.0N	67.7E	10	7.4	Pakistan	1217	1520.5
2.	28/09/2013	7.34.10	27.2N	65.9E	20	6.8	Pakistan	1196	839.5

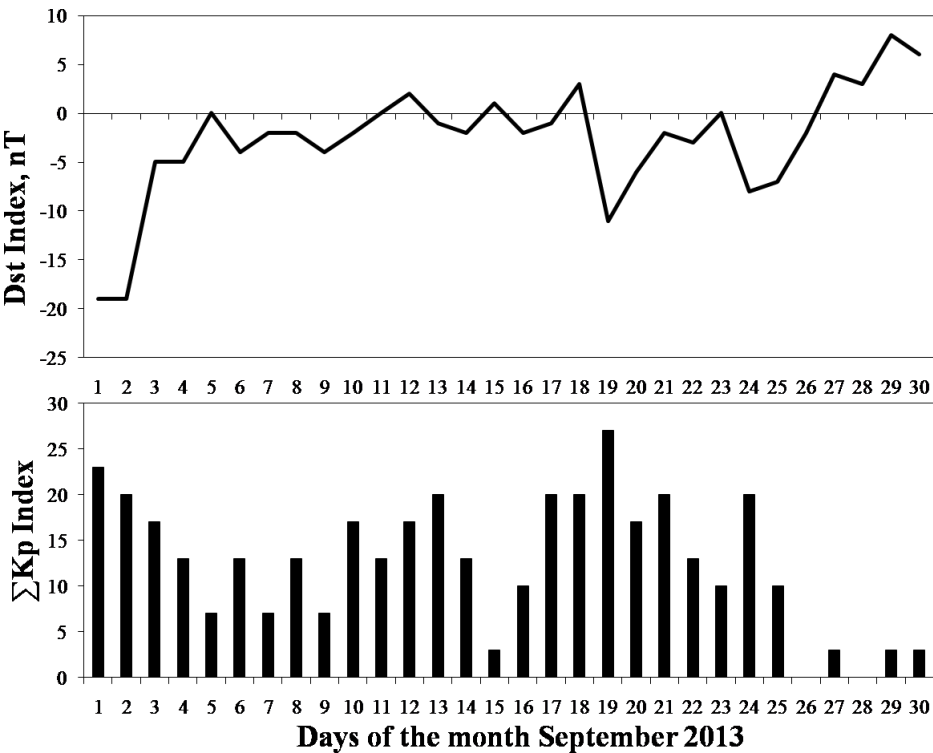


Fig. 2: Dst and Kp index variation for the month of September 2013.

RESULTS AND DISCUSSIONS

Both significant earthquakes with magnitudes of $M=7.4$ and 6.5 that struck Pakistan in September 2013 are taken into consideration in this study. Table 1 displays the day, time, location (latitude and longitude), depth, magnitude, and distance of the epicenter from the Agra station. Fig.3 shows a map with the locations of the observing station and earthquakes. We have examined Ulf data from the Agra station for this analysis because of its advantages, which include a high skin depth, low attenuation, and minimal contamination. Relation $R=10^{0.43M}$, where M be earthquake's magnitude, is used to compute the radius of influence zone (Dobrovolsky et al., 1979). According to Pullinets and Boyarchuk (2004), this formula can be used to calculate the radius of an earthquake's effect zone on the ground as well as in the ionosphere. To minimize the impact of daytime local noise interference, the six-hour night time data (12:00-18:00 UT, $LT=UT+5.5h$) in ULF time series data is procured for study. The observing station is well covered by the earthquake on September 24 but not by the one on September 28. One of the possible reason could be the second earthquake occurred just four days after the first one so it can be the aftershock. For the preliminary study we analyzed the raw for

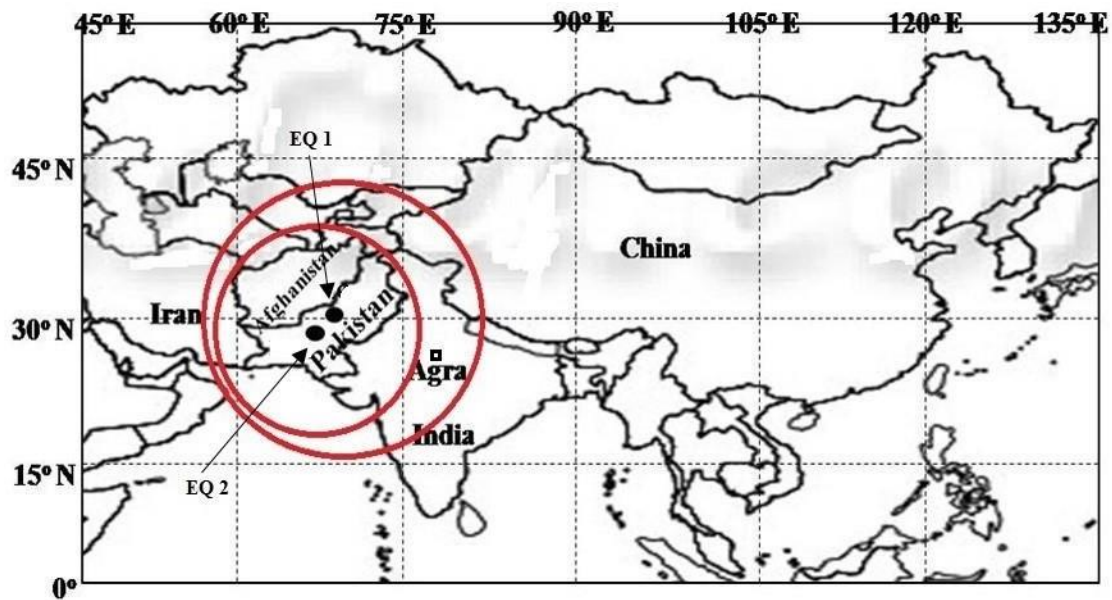


Fig. 3: Map of India and surrounding countries showing the location of earthquakes (solid circles) and observing station Agra (open square).

Each day and found that bursts occurred on multiple days before the days of earthquakes in both x and y component. In y component burst occurred on 8, 12, 13, 17, 25 September. The temporal expansion of the bursts has also been examined and electromagnetic pulses of periods has been found and is of duration 10-15 sec and frequency $f=0.06-0.1$ Hz. Fractal analysis is one technique used to investigate the crucial behavior of the approaching earthquake preparedness zone to ULF time series. The Burlaga Klein technique is used in this case. The length of the curve between time intervals $0 \leq t \leq T_0$ (where $T_0 = n\tau$) for a geophysical time series $B(t_k)$ ($k=1,2,3,\dots,n$) is as follows:

$$L_{BK}(\tau) = \sum_{k=1}^n \left| \overline{B(t_k + \tau)} - \overline{B(t_k)} \right| / \tau \quad (1)$$

where the mean value of $B(t)$ between $t=tk$ and $tk+\tau$ is represented numerically by $\overline{B(t_k)}$, which is the length of the curve Further it is used to calculate fractal dimension. Using the Berry equation fractal exponent is calculated:

$$\beta = 5 - 2D_o \quad (2)$$

The length of the curve is determined at six distinct periods using Eq. (1). The length and time are then plotted using hourly data for a day; this type of plot, known as a log log plot. The slope of this plot, or the fractal dimension (D_o), can be determined using a straight line. In a similar manner, the D_o is determined for the entire month. The fractal exponent is computed from this. The mean and standard deviation around the mean approach has been chosen for statistical analysis. Fig.4 shows daily variations in the fractal dimension and fractal exponent shown in the upper and lower panels. Here, the D_o reaches a peak above $m \pm \sigma$ on September 15, 2013, and its growing tendency becomes apparent due to its critical behavior in relation to two earthquakes following that. Below $m \pm \sigma$, a similar variation in β is readily observed. The complementary character of both parameters is further demonstrated by the fact that they both vary linearly and therefore one increases while the other declines concurrently. Large amplification and depletion are seen in both parameters nine to sixteen days before to the earthquakes. Lot of researchers have employed fractal analysis previously for earthquake precursor study. (Chauhan et al., 2010, Ida and Hayakawa 2006, Simirnova et al., 2001).

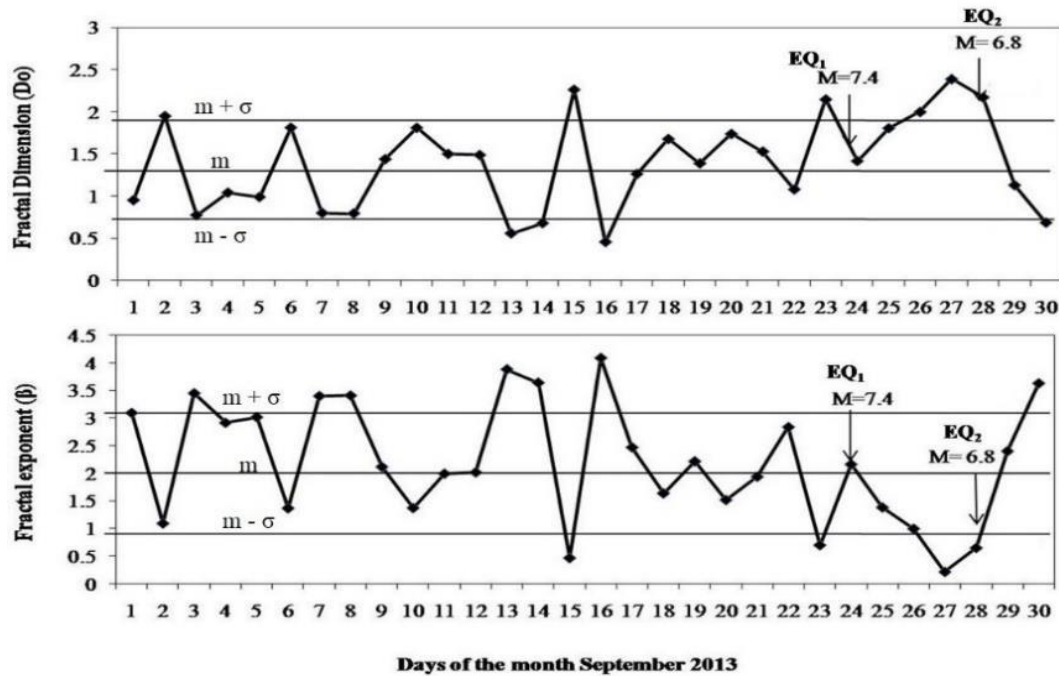


Fig. 4: Variation of fractal dimension and fractal exponent in the month of September, 2013. Arrows indicate the days of earthquakes.

Numerous experts have looked into the variations and bursts that occur before earthquakes. (Chauhan et al., 2009, 2012; Kushwah et al., 2005, 2007, 2009). They are not of magnetospheric origin and are not impacted by lightning activity because they occurred during a magnetically quiet era. We have examined x component ULF data for September 2013. In x component ULF bursts has been found on 8, 12, 13, 17 and 25 September. Bursts on these days have electromagnetic pulses of period ranging

between 10-15 sec and frequency ranging 0.06-0.1 Hz. Due to the overloading of input at the amplifier due to strong earthquake signal data has occurred in multiple files in both components. In order to ascertain the lithospheric origin of these bursts (Hayakawa et al., 1996, 2012) polarization analysis has been applied on the data. The condition polarization ratio (Z/X) illustrates the lithosphere or ionosphere/magnetosphere emissions. The produced linear current will have a large horizontal and weak vertical magnetic field if the earthquake happened close to the observing station, and the opposite will be true if it happened farther away. In this case, the horizontal magnetic field will be weak and the vertical magnetic field will be strong. $Z/X > 1$ would apply in our situation. As seen in Fig. 5, the ratios are larger either on the day of the earthquake or in the days preceding it. This demonstrates that these anomalies and the earthquakes are related.

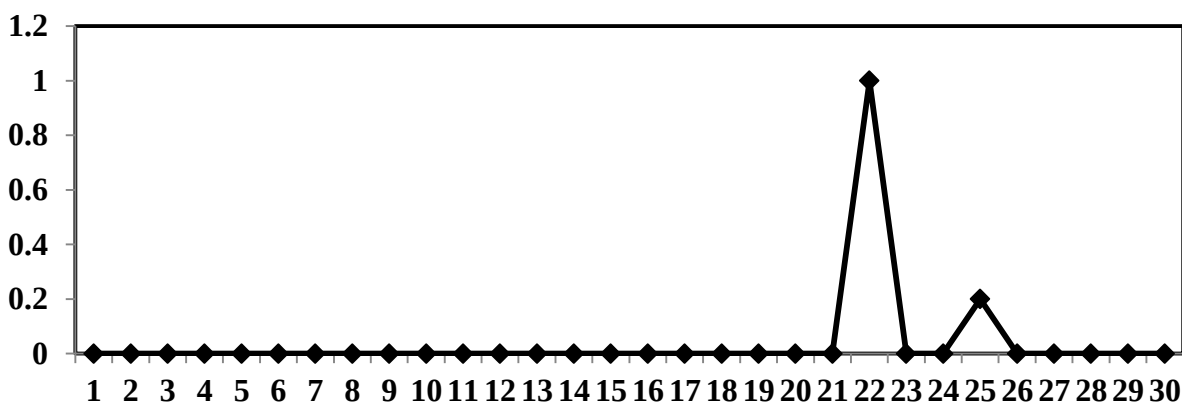


Fig. 6: Variation of polarisation ratio (Z/X) for the month of September 2013.

CONCLUSIONS

For a considerable amount of time, the emissions of the ulf magnetic field measurement at the Agra station has been routinely monitored. In this work, we examined the ulf data for September 2013, a month that saw two significant earthquakes with greater magnitudes ($M = 7.4$ and 6.8) on September 24 and 28. There is no geomagnetic activity this month. Round the clock observation of ulf magnetic field emissions measurement at agra station is running from a long period of time. In this study we have analyzed the ulf data for September 2013 where two high earthquakes of higher magnitude $M = 7.4$ and 6.8 occurred on 24 and 28 September 2013. This month is free from geomagnetic activity. Also we have noticed in the raw data occurred in multiple files on some days due to overloading of data at the input. Also the data on each day is analyzed bursts are found on some days and in order to study these in details the electromagnetic pulses are found and further periods and frequency are also calculated which matches very well with ulf range. Additional statistical techniques, such as fractal analysis and polarization parameter analysis, have been used to analyze the data. The distance between the epicenter and the observing center is taken into account for the polarization parameter analysis. In our situation, the requirement $Z/X > 1$ would apply as it pertains to the origin of emissions in the lithosphere or ionosphere/magnetosphere. Using the Burlaga Klien method, fractal analysis has also been used to examine the crucial behavior of approaching earthquakes. The relationship between both the parameters calculated using fractal analysis is complimentary. In both the studies enhancements have been found 9-16 days before the occurrence of earthquake.

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