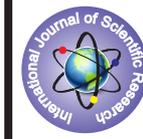


## Investigation of ULF magnetic field variations before a moderate Earthquake (M 4.8) in Kachchh, Gujarat, India



### Earth Science

**KEYWORDS:** ULF Magnetic Field, Earthquake Precursor, Polarisation ratio, fractal dimensions

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### ABSTRACT

In this paper, we carried out the study of power spectral density, polarisation ratios and fractal dimensions to study the seismo-electromagnetic emissions associated with a moderate earthquake on 29th July 2013 (M 4.8) using the data of 3-component Fluxgate Magnetometer installed at Desalpar, Kachchh, Gujarat. This earthquake occurred about 18 km from the observatory and is located within the preparatory zone. We found an enhancement in power spectral density at different frequency bands before this earthquake and this specific enhancement is found just 4-5 hours prior to this earthquake in frequency band 0.5-1.0 Hz. We examined the ULF variations with the polarisation ratios ( $Z/G$ ,  $\text{Sqrt}(Z)/G$ ,  $\text{Sqrt}(Z)/G$ ,  $Z/H$ ) in five frequency bands ranging from 0.001 to 1.0 Hz. We found an enhancement in polarisation ratio before this earthquake in all cases. We also found little enhancement of fractal dimension before the earthquake. Magnetic field intensity of ULF data is useful in understanding the earthquake preparation processes.

### INTRODUCTION

Electromagnetic anomalies from ultra low frequency (ULF) to very high frequency (VHF) have been emerged as good indicators for preseismic signatures before earthquakes. The ultra low frequency (ULF) signals are more prominent among all frequency bands. Several studies have shown positive correlation with earthquakes and electromagnetic field variations (Hayakawa et al 1996). ULF electromagnetic signals appear few days to several weeks before the earthquake occurrence (Hayakawa et al., 2000), whereas, the VLF-VHF signals appear just few hours before the earthquakes. There are several theories given for the generation mechanisms of seismo electromagnetic phenomenon such as piezoelectric process where they related opposite signs on the opposite faces of stress induced piezo electric rocks (Freund, 2000), electro kinetic process where active fluid flow in earth's crust is related to rock failure or volcanic activity (Draganov et al., 1991), triboelectric process related to electric spark on abrasion of rocks (Brady and Rowell, 1986) and microfracturing (Cress et al., 1987). Kachchh region of Gujarat is one of the highly seismic prone regions in India. This region falls under Seismic zone V. In order to carry out multi parametric geophysical studies for earthquake precursory signatures, we installed one Digital Fluxgate magnetometer which is in operation at Desalpar (23°.74 N, 70°.69 E). The image of this fluxgate magnetometer is shown as fig 1. It records the terrestrial geomagnetic field variations in three mutually perpendicular directions, two horizontal (H and D) and one in vertical direction (Z). The data is collected at one sample per second throughout the day continuously. Here, we used the magnetic data of Desalpar during 20th July-10 August 2013 in order to study the variations before the local earthquake on 29th July 2013 (M 4.8).

### METHOD

The following procedure of data analysis was adopted:

- 1) We used the data of 3hrs during the local midnight (18-21 UTC) with the sampling interval of 1 sec.
- 2) We applied a Fast Fourier Transform (FFT) procedure to determine the Power Spectral Density (PSD) at five different frequencies. By averaging over the 6 segments, we obtained the daily average spectrum.
- 3) The Polarization Analysis and Fractal dimensions were obtained.

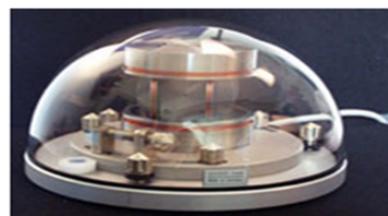
### Polarization ratios

It is ratio of magnetic vertical to horizontal component  $SZ/SH$  or  $SZ/SG$  ( $SG = \text{Sqrt}(SH^2 + SD^2)$ , H and D are two horizontal magnetic components) (Hayakawa et al 1996). The seismo-magnetic precursors can be considered as near-field effects. The method is based on the assumption that waves (natural EM field) from far-off

distances (several thousand kilometres) are planar and therefore do not have vertical component, whereas field of near source origin is non-planar and thus, has vertical component. Thus, this value is expected to be high ( $>1$ ) before and during strong seismic activity. The reason for high ratios can be an increased vertical magnetic field power which can be associated to direct mechanisms acting in the crust, so-called micro fracture electrification. Another possibility for a high polarization ratio is a decrease of the horizontal magnetic field power which can be related to indirect mechanisms like lithosphere-atmosphere ionosphere coupling effects.

### Fractal Dimensions

Earthquake dynamics can be studied based on the self-organized criticality (SOC) concept, where earthquake occurrence is considered as a critical stage. Earthquake preparation processes, leading to this stage, can be considered the intermediate stage of SOC evolution. Since the dynamics of such a system reflects power law distribution, studying the behavior of  $1/f$  characteristics with time can give information about different stages of the earthquake preparation process. We used two different methods like Berry's method and Higuchi method (Berry, M.V., 1979; Higuchi 1990). In the Berry's method, the hourly time series is divided into segments of 1024 data points, with 50% overlapping the previous segment. Each segment is subjected to Fast Fourier Transform. Power spectrum of five segments in 3 h is then averaged to obtain the most coherent and persistent spectral characteristics. Slope ( $\beta$ ) of averaged spectrum is then estimated using linear fit to the spectrum plotted on log-log scale in the frequency band 0.03-0.1 Hz. This slope can be linked with fractal dimension using Berry's equation ( $D = (5 - \beta)/2$ ) (Berry, M.V., 1979). In the Higuchi method, the original time series  $y(1), y(2), y(3), \dots, y(N)$  is subdivided into  $k$  new time series ( $y_{\tau m}$ ), each time series is defined as  $y_{\tau m} = \{y(m), y(m+\tau), y(m+2\tau), \dots, y(m+M\tau), m=1; 2; \dots, \tau$  where  $m$  and  $\tau$  are integers indicating an initial time and an interval time, respectively (Higuchi 1990). In order to discriminate the effect of geomagnetic storm activity, the planetary index ( $K_p$ ) and Disturbance Storm Index ( $Dst$ ) are also analysed in the corresponding period.

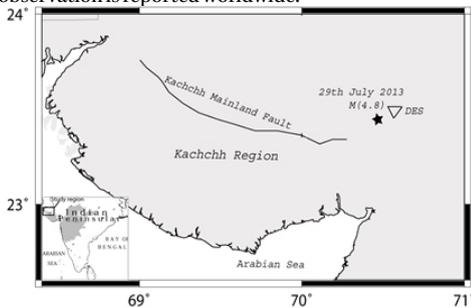


**Figure 1:** Image of digital fluxgate magnetometer

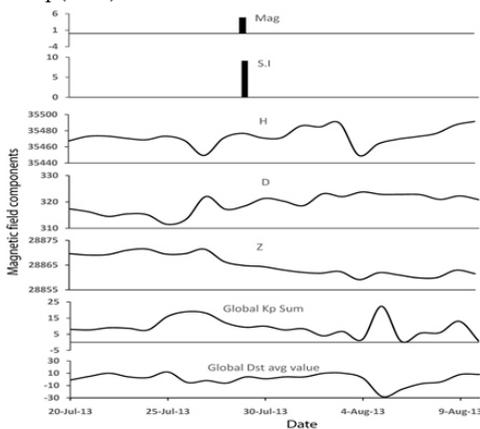
**RESULTS AND DISCUSSION**

**Power Spectral Densities**

The regular observation of magnetic field using DFM is in progress at Desalpar MPGO (geographic lat.23.74oN, long.70.68oE) since January 2010. The location of observing station and epicenter of earthquake considered in this study are shown as Fig.2. Daily night time 3 hours (18-21 UT) averaged magnetic field components (H, D, Z) from 20th July to 10th August 2013 are shown in Fig.3. We have also shown the earthquake magnitude, seismic index, Kp and Dst Values in this figure. The seismic index found to be 8.5. The Kp and Dst values are low during this period. We may assume that the influence of global magnetic field is less on the magnetic data during this period. We found a small rise in Z component just before this earthquake. Similar observation is reported worldwide.

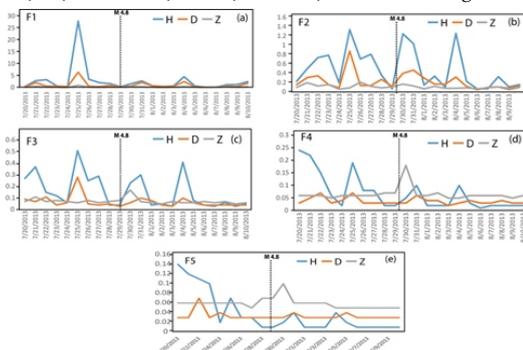


**Figure 2:** Location of Magnetic observatory (triangles) along with earthquake location (star). The study region is shown as rectangle in India map (inset).

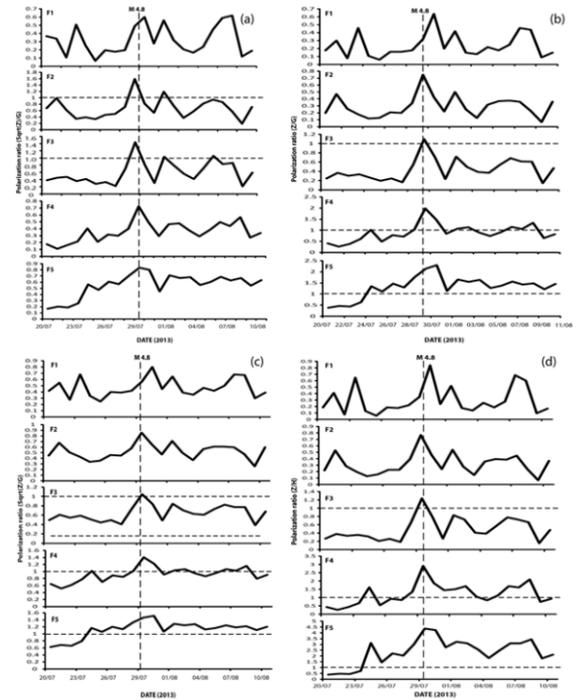


**Figure 3:** Time series of magnetic field components of H, D, Z during 20th July-10 Aug 2013

The Fast Fourier Transform (FFT) is a mathematical tool that can be used to analyse the frequency characteristics of a signal. Power spectral densities (PSD) are calculated using FFT technique in five frequency bands i.e. f1 (0.001–0.005Hz), f2(0.005–0.01Hz), f3(0.01–0.05Hz), f4(0.05–0.01Hz) and f5(0.1–0.5Hz) and shown as Fig 4.



**Figure 4:** Power spectral density in five frequency bands during 20th July-10 Aug 2013



**Figure 5:** Polarization ratios (a) Z/G, (b) Sqrt(Z)/G, (c) Sqrt(Z)/H, (d) Z/H during 20<sup>th</sup> July-10 Aug 2013

The PSDs are determined for all the three components separately. Here, the spectral densities with time are plotted for the period of 20th July-10th August 2013. This time period is chosen in such a way that it will cover few days before and few days after the earthquake on 29th July 2013. Emission intensity of the magnetic field was obtained for a particular frequency and time from the power spectrum analysis. In first frequency band (F1), there is high rise in H-comp and a small rise in D component. This rise started on 24th July and persistent till 28th July before this earthquake. After the earthquake, emission intensity of the magnetic field was quiet. Other frequency bands have shown small increase in signal as shown in F1. This observed enhancement in magnetic field intensity before the earthquake can be linked to the earthquake preparation phase. Based on the timing of rise, the possible rationale can be assumed that this signal was generated due to the electro-kinetic effect involving the active fluid flow in the earth's crust due to rock failure and micro fracturing processes in the rock.

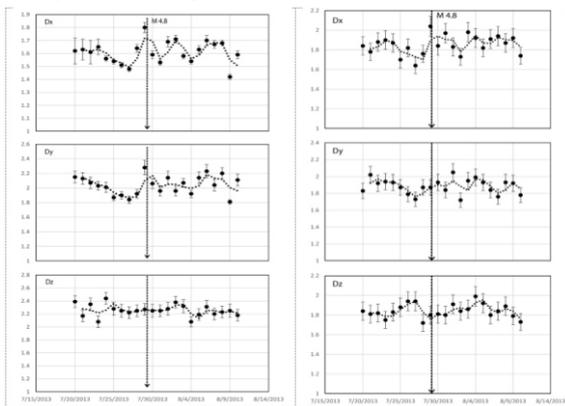
**Polarization Ratios**

We analyzed the signal by polarization ratio method. Here, we have taken the night time (18-21 hrs UT) geomagnetic field data to avoid diurnal variations and other day time cultural noise. The polarization ratios (Z/G, Sqrt (Z)/G, Sqrt (Z)/H, Z/X) in five frequency bands f1 (0.001–0.005Hz), f2(0.005–0.01Hz), f3(0.01–0.05Hz), f4(0.05–0.01Hz) and f5(0.1–0.5Hz) are determined and are shown in fig 5. Generally it is believed that if this ratio crosses 1 then there is a lithospheric influence, otherwise, there is a global magnetic influence on the signal. The vertical dotted line indicates the day of the earthquake and horizontal dotted line indicates PR value 1. The polarisation ratios are found to be crossed 1 in many cases before this earthquake. The minimum polarization reached values are found to be 0.2 in Z/H on 23<sup>rd</sup> July The polarization reached a maximum value around 29<sup>th</sup> July, i.e. on the day of earthquake. After the earthquake, the polarization value goes down to 0.5-0.8. It can be seen clearly from the figure that the polarization ratio of all frequency bands are high between 24 July and 29 July, 2013 when seismic activity is high. However, major enhancements appear in the Z/G and Z/H ratios in all frequency bands. The rise in PR is started much earlier (24<sup>th</sup> July onwards) in F5 band and but other frequency bands show enhanced ratios just 1-2 days before the earthquake. The most characteristic frequency of the

observed Seismo-ULF emissions is found in F3-F5 bands, similar to the results obtained by previous researchers (Kopytenko et al., 1990 and Hayakawa et al., 1996). The possible explanations for higher polarizations might be micro fracture electrification (Molchanov, O. and Hayakawa, M., 1998) and inductive seismo-electromagnetic effect (Molchanov, O. et al., 2001). We cannot exactly relate any one of these mechanisms in this case. However, it is expected that EM emissions generated from any of these mechanisms may propagate and observe very easily at observing station which is located at such a small distance from the epicenter of the earthquake.

### Fractal Dimensions

We calculated the fractal dimensions by using two methods such as Berry's method and Higuchi's method for the period of 20<sup>th</sup> July-10<sup>th</sup> August 2013 in order to look for any changes before the earthquake of M (4.8) on July 29, 2013. The fractal dimensions obtained from both these methods are shown in Fig.6. The dotted line is two days running average of fractal dimension variability. Fractal dimension variability of all the three components found to be different. The variability is more in Y and Z components and comparatively lesser in X component. Error bars in fractal dimensions are estimated from the errors obtained in the estimation of slope while fitting the straight line to spectra in least square sense.



**Figure 6: Fractal dimensions using (a) Berry's method (left panel), (b) Higuchi method (right panel) during 20th July-10th August 2013**

In Berry's method, the rise of fractal dimension in X and Y-comps started on July 25 from average value of 1.4-1.5 and reached a maximum value of 2.2 on 29th July just before the earthquake of M (4.8). The gradual increase in the fractal dimension, therefore, can be related to earthquake preparation processes. An increase in the fractal dimension before earthquakes is widely reported (Hayakawa et al., 1999; Rawat 2014). We have not seen much variation (1.6 to 1.8) in fractal dimension values obtained using Higuchi method. The difference in the fractal dimensions from both methods is primarily due to the difference in time series used. In Berry's method, fractal dimension is calculated for frequency band of 0.03-0.1 Hz, whereas we have used unfiltered time series with Higuchi method.

### CONCLUSIONS

The data resulting from a digital fluxgate magnetometer (DFM) employed at Desalpar MPGO in Kachchh region, Gujarat, India have been analysed for the period of 20th July-10th August 2013 to study the seismo-electromagnetic emissions associated with a moderate earthquake on 29th July 2013 (M 4.8). We applied various techniques such as power spectral densities, polarisation ratio and fractal dimension to this magnetic data. We found an enhancement in power spectral density at different frequency bands before this earthquake and this specific enhancement is found just 4-5 hours prior to this earthquake in frequency band 0.5-1.0 Hz. We examined the ULF variations with the polarisation ratios ( $Z/G$ ,  $\text{Sqrt}(Z)/G$ ,  $\text{Sqrt}(Z/G)$ ,  $Z/H$ ) in five frequency bands ranging from 0.001 to 1.0 Hz. We found an enhancement in polarisation ratio before this earthquake in all cases. We also found little enhancement of fractal

dimension before the earthquake. We conclude that the methods such as PSD, PR and FD are effective in precursory research. We attributed the rationale for increase of these parameters to the electro-kinetic effect involving the active fluid flow in the earth's crust due to rock failure and micro fracturing processes in the rock.

### ACKNOWLEDGEMENT

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