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Variations of Total Magnetic Field before two small magnitude Earthquakes in Kachchh, Gujarat, India

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ABSTRACT
In this study, variations of Total Magnetic field recorded in overhauser magnetometer at Multi Parametric Geophysical Observatories (MPGO) of Badargadh and Desalpar are analysed to correspond with small magnitude earthquakes occurred in 2014 in Kachchh, Gujarat employing different techniques such as power spectral density, fractal dimensions and principal component analysis. To reduce the effects of manmade and atmospheric perturbations magnetic data of mid night (i.e., 18-21 UTC) times were considered. Two small magnitude earthquakes occurred on 9th March 2014 (Mw 4.1, R=58 km) and 29th April 2014 (Mw 3.8, R=43 km) within the preparatory zone were studied in this analysis. In order to discriminate the effect of geomagnetic storm activity, the planetary index Kp and Dst were also analyzed in the corresponding period. These parameters are found to be normal during 9th March event and high during 29th April event. Total Magnetic field however, recorded considerable enhancement (10 nT for 9th March event and 30 nT for 29th April event) three days prior to these events. These enhancements persisted during the event and latter decreased exponentially. The difference between the total magnetic field data of the two MPGO Observatories (Badargadh and Desalpar), which is free of the secular trend of the geomagnetic field showed exponential increase prior to these events. We here by conclude that the observed magnetic anomaly prior to 9th March earthquake might be related to seismogenic origin while we cannot attribute the variations before 29th April with local earthquake activity as there was a record of global geomagnetic effects during this period.

Key words: Total magnetic field, Principal Component analysis, Fractal dimension, PSD, earthquake.

INTRODUCTION

The pre seismic anomalies related to electromagnetic effects are promising tools among the short term earthquake precursors. Various studies have shown that these pre-seismic electromagnetic emissions occur in a wide frequency band ranging from few Hz to MHz (Fraser-Smith et al., 1990; Hayakawa and Fujinawa, 1994). Pre earthquake anomalies are often observed in the magnetic observations close to earthquake epicentres (Hattori, 2004). Merzer and Klemperer (1997) suggest that geomagnetic anomalies are caused by induced electric currents flowing in the fault zone during the earthquake preparation period. All most all global pre-earthquake electromagnetic studies hither to conduct are based on large magnitude earthquakes. Efforts were little for similar studies in the case of small magnitude earthquakes. The purpose of the present paper is to apply modern techniques on geomagnetic data to see whether it is possible to identify any anomalies before small-magnitude earthquakes. Few such attempts reported in literature, unfortunately, did not show positive results. However, Seokhoon Oh, (2012), Bella et al., (1998), among others observed positive anomalies prior to local seismic activity. In the present paper we report the outcome of our study on the geomagnetic variations before small magnitude earthquakes (4.0 or smaller) occurred in Kachchh region of Gujarat that may probably be related to pre-seismic signatures. Here, we used the techniques of Fractal analysis, Principal component analysis and Power spectral densities for analysing the geomagnetic data.

Data and Method

The Kachchh basin is a western margin pericratonic rift basin of India and is considered to be an excellent site for studying pre-earthquake geomagnetic anomalies as this region is seismically active. Institute of Seismological Research (ISR) established three multi-parametric geophysical observatories (MPGO) at Desalpar, Badargadh and Vamka in this region. In order to monitor geomagnetic total field, one Overhauser magnetometer with a sample rate of 1sec is installed at each of these MPGO sites, which are located at remote places away from man-made noise and the electric field disturbances. The total geomagnetic data of Desalpar (DES) and Badargadh (BAD) during 25th Jan - 10th May 2014 are taken in this analysis. The locations of Badargadh (23^{0}.47 N, 70^{0}.62 E) and Desalpar (23^{0}.74 N, 70^{0}.69 E) observatories along with the two earthquake epicentres are shown in Figure 1. Details of the two local earthquakes being considered, which are within 50 km epicentre distance from our observatories are shown in Table 1.

Table 1. Details of local earthquakes being studied.

EVENT (Date)	TIME (GMT)	Mw	LAT. (°N)	LONG. (°E)	Epicentral dist (km) DES	Epicentral dist (km) BAD	Hy.Dist. (km) DES	Hy.Dist. (km) BAD	Depth (km)
09th Mar 2014	19:01	4.1	23.359	70.293	33	16	49	39	36.2
29th Apr 2014	05:55	3.8	23.491	70.281	32	15	34	19	12.5

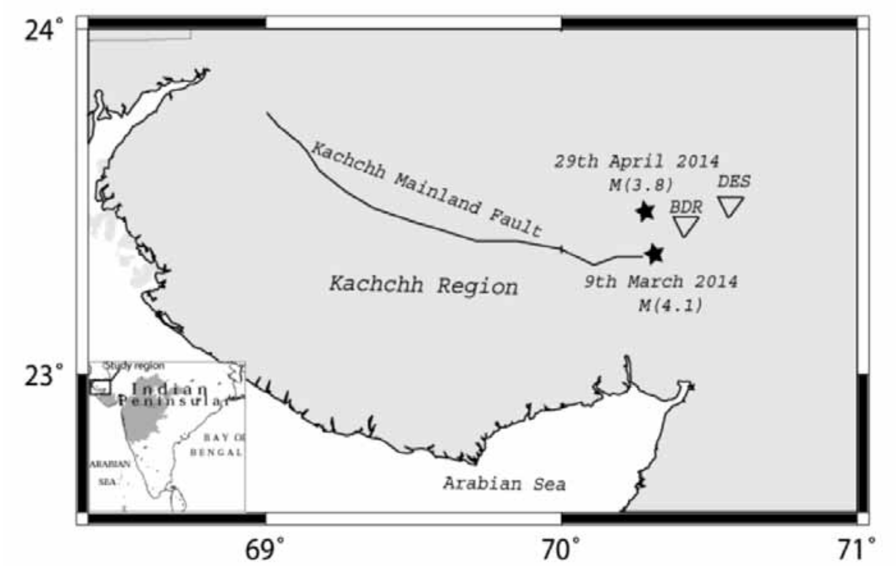

Figure 1. Locations of Magnetic observatories (triangles) along with earthquake locations (star). The study region is shown as rectangle in India map (inset).

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 performed the Power Spectral Density (PSD) at five different frequencies. By averaging over the 6 segments, we obtained the daily average spectrum.
3. The Principal Component Analysis and Fractal dimensions were obtained.

Principal Component Analysis

Principal component analysis (PCA) involves a mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components. The mathematical technique used in PCA is called eigen analysis: we solved for the eigen values and eigenvectors of a square symmetric matrix with sums of squares and cross products. In this Principal Component Analysis, we have to subtract the mean from each of the data dimensions; the mean is the average across each dimension. Then, we calculate the covariance matrix. Subsequently, we calculate the Eigen values and Eigen vectors of the covariance matrix.

Fractal Dimensions

We analysed the fractal dimensions which are based on self-organized critical (SOC) concept, using Berry's method (Berry, 1979). The concept of SOC was first introduced by Bak et al., (1987). 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 (β) 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, 1979).

RESULTS AND DISCUSSION

The local earthquakes in Kachchh considered in this study fall within the limits of Earthquake preparatory zone (Dobrovolsky et al., 1979) and Es parameter(Hattori et al., 2006). The Es parameter is found to be $0.6*10^8$ for

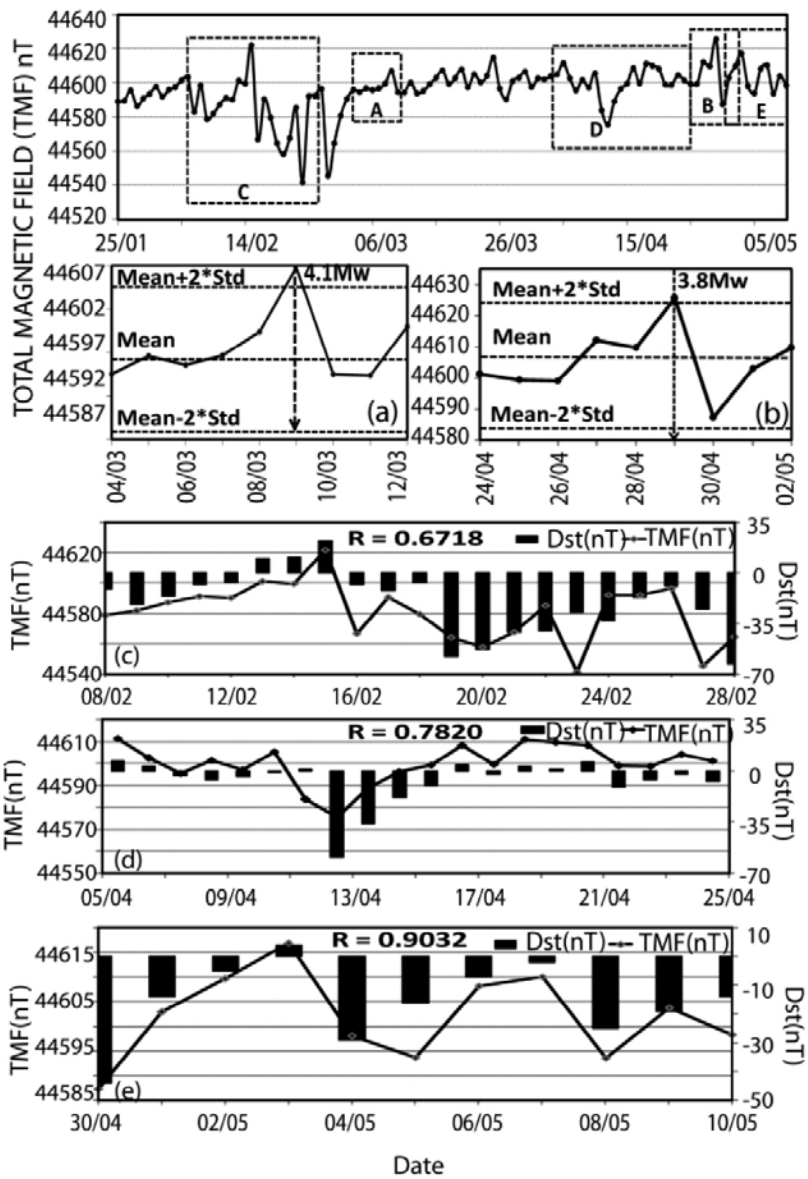

Figure 2. Total Magnetic Field of Badargadh site during 9th March and 29th April events. Panels a, b are 5 days before and 3 days after the local earthquakes respectively; panel c, d, e during the regime of high Dst. R is corr-coefficient between TMF and Dst.

the 9th March event and $0.8*10^8$for the 29th April event at Badargadh station.

Total Magnetic Field Variations

Daily night time 3 hours (18-21 UT) averaged Total Magnetic Field from 25th Jan to 10th May 2014 recorded at the MPGO sites of Badargadh and Desalpar are shown in Figures 2 & 3. These sites are situated within the radial distance of 50 km from each other. Total Magnetic Field values varied from 44540 to 46260nT at Badargadh and Desalpar sites respectively. We can clearly see the enhancement in the data series at few instances which are marked as a -e segments in these figures. The a, b segments are categorised as seismogenic and the c, d, e segments are categorised as global geomagnetic effects. This categorisation has been made based on timings of local earthquakes and global geomagnetic storms. The segments a & b represent 5 days before and 3 days after the earthquakes (Table 1). These segments clearly show considerable enhancement of 10nT for 9th March event and 30 nT for 29th April event. The enhancement started on 6th March from 44495 nT to 44605 nT on 9 th March. Similarly, the segment b is shown as middle panel, the enhancement started on 26th April from 44600 nT to 44630 nT on 29th April.

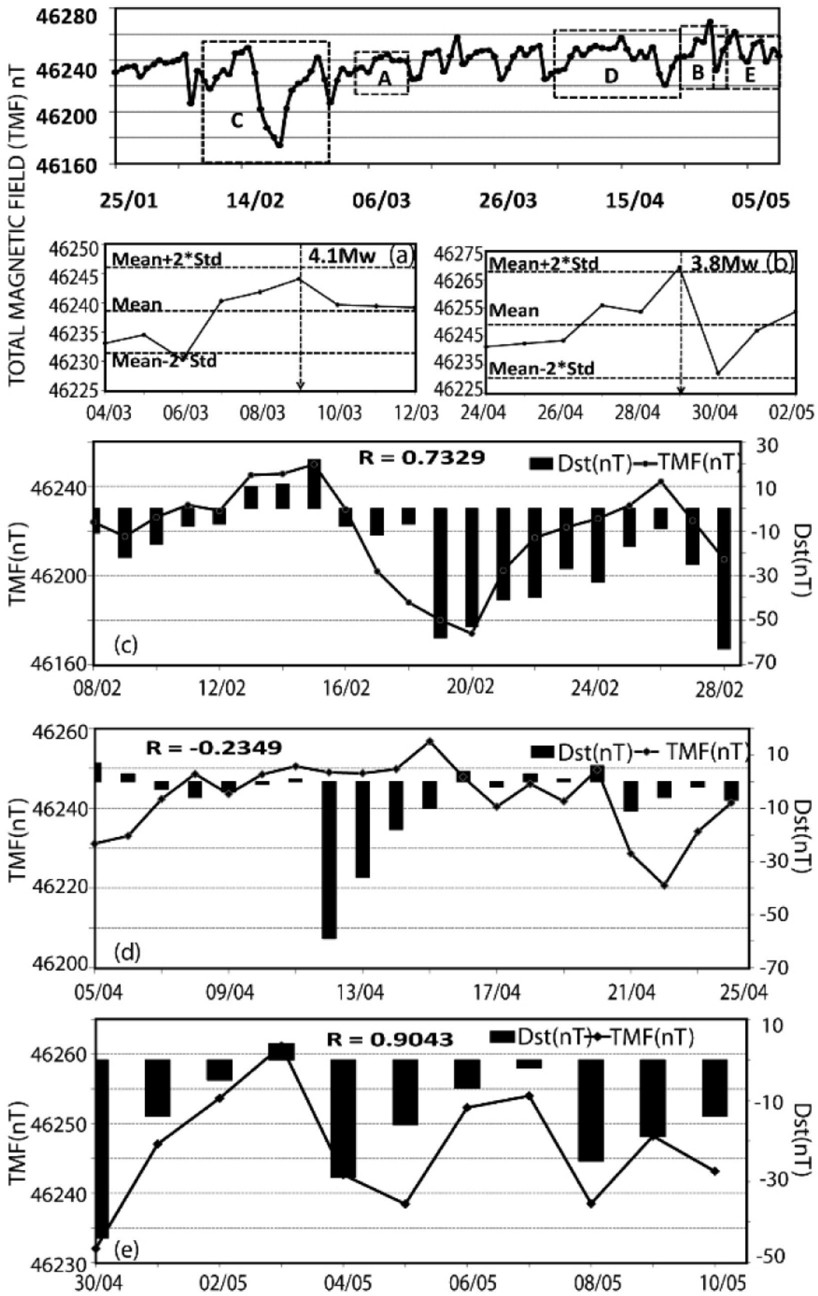

Figure 3. Total Magnetic Field of Desalpar site during 9th March and 29th April events. Panels a, b are 5 days before and 3 days after the local earthquakes respectively; panel c, d, e during the regime of high Dst. R is corr-coefficient between TMF and Dst.

The enhancement persists during the event and exponentially decreases after one day onwards. In order to identify the anomalies in the time series, statistical limits of Mean+2*sigma and Mean-2*sigma is computed for the 9 days regime during these earthquakes. The data series around 9th March event is found to be geomagnetic storm free data as it satisfies the conditions of $\Sigma Kp<10$ and Dst<-20nT during this period (Hayakawa et al., 1996). The other event on 29 April is not satisfying these conditions and fall in geomagnetic storm effect. We found that the signal crossed statistical limits just before these two earthquakes. It is generally believed that signal crossing this limit is anomalous. We can certainly attribute the anomalies before 9th March event as signatures of pre-earthquake geomagnetic variations. However, the data around 29th April event is influenced by storm, and therefore we cannot attribute this signal to local earthquake activity.

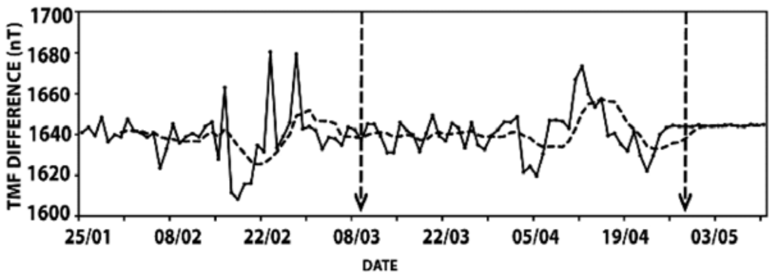

Figure 4. Difference plot of TMF of Badargadh- Desalpar.

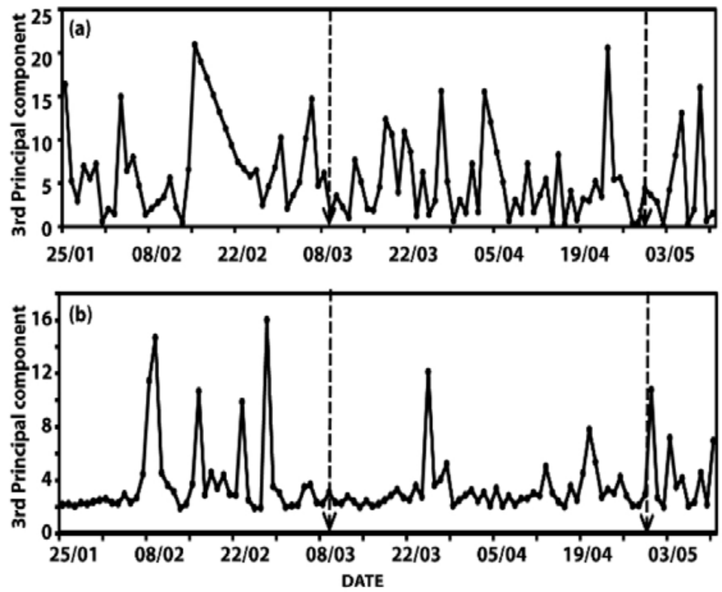

Figure 5. 3rd Principal Component Analysis of (a) Desalpar and (b) Badargadh.

Variation of difference of Total Magnetic Field of two stations

The main sources of Total Magnetic field are the earth's interior, localised stresses, currents in the ionosphere, magnetosphere and geomagnetic storms. It is essential to remove the effect of external sources from local stresses. So that we can retain the noise free signal and easily correlate with earthquakes. We first assume that the effect of external causes are similar to both the stations and therefore the difference between them will be free from the external effects. Figure 4 shows the differenced time series of TMF during 25Jan-10May 2014 of the two stations Badargadh and Desalpar. In order to see the trend, 10 days running mean is shown as dashed line in Figure 4. Many researchers reported that the differenced signal has shown anomalies in the form of offsets before earthquakes (Shapiro and Abdullabekov, 1982; Johnston and Mueller, 1987; Mueller and Johnston, 1990). In our case, the offset started on 25th February before 9th March event and on 5th April before 29th April event. The time series of differenced signal during these periods have shown linearly increasing trend with a rate of 1.04 nT/day for 9th March event and 0.41 nT/day for 29th April event.

Variations of 3rd Principal Component

We performed 3rd Principal component analysis on the time series of Total Magnetic Field data of Badargadh and Desalpar during 25th Jan-10th May 2014. The results of the 3rd PCA are shown as Figure 5.The peaks in 3rd principle component are observed on Feb 3, 15 and March 1 at Desalpar station and similar peaks on Feb 9, 16, 23 and 27are observed at Badargadh station before 9th March event. Eigen value increases from 3.5 on 1st March onwards to 16.67 on 7th March which is showing an enhancement of 88.68% in PCA signal at Desalpar. A sharp peak from 2 nT to 15 nT was observed on 1st March at Badargadh station. Similarly, we observed peaks on April 23 and April 20 before 29th April event with an increase of eigen values to 20.54 which is showing an enhancement of 78.67%.

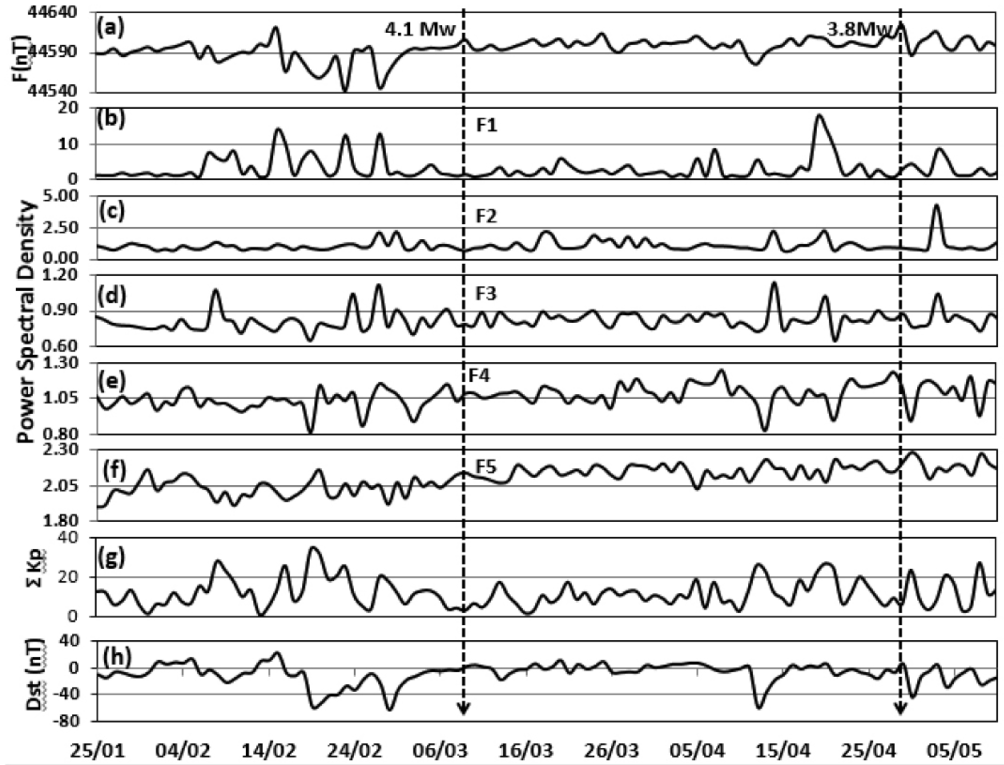

Figure 6. (a) night time (18-21UT) average value variations of total magnetic field (F) at Badargadh;(b-f) are PSD variations in five frequency bands f1-f5; (g) & (h) global kp sum & Dst values.

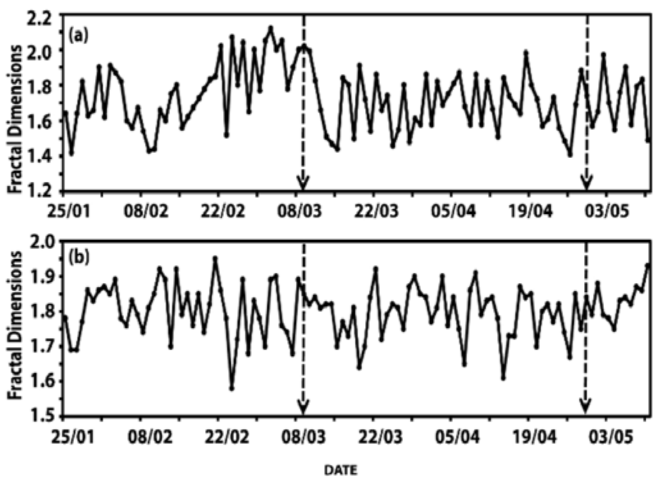

Figure 7. Fractal Dimensions of (a) Desalpar site (b) Badargadh site.

Variations in Power Spectral Density (PSD)

Power Spectral Density (PSD) is the frequency response of a random or periodic signal. The PSD analysis has been carried out in five frequency bands as f1(0.001-0.005Hz), f2(0.005-0.01Hz), f3(0.01-0.05Hz), f4(0.05-0.1Hz) and f5(0.1-0.5Hz) on TMF time series of both Badargadh and Desalpar. In Figure 6, Panel b-d shows the response of the frequencies (0.001-0.05 Hz). These frequencies responded more than other frequency ranges as shown in panel e-f in the frequency range 0.05-0.5 Hz. Hayakawa et al., (1996) have also reported the frequency band 0.005-0.01 is more responsive to seismogenic signal. There are few peaks in 20-25 February and 1-3 March before 9th March event.

There is a rise in Kp values during 20-25 February and we may relate the rise of PSD values during this period to global geomagnetic effects. The Kp values are quite normal during the time of 9th March event and the peaks during 1-3 March may be correlated with local earthquake activity. The Kp values during the 29th April event are high and the peaks observed in PSD around this time cannot be attributed to local earthquake activity. A rise of 40- 50% of the signal has been observed before the seismogenic effects. Similarly, 50-65% rise of the PSD values are observed before global geomagnetic effects. We can clearly see the distinct increase of signal in response to both global geomagnetic effects and local earthquake effects.

Variations of Fractal Dimensions

We calculated the fractal dimensions of TMF time series of both Badargadh and Desalpar observatories during 25th January - 10th May 2014using Berry's method and the same are shown in Figure 7. The fractal dimension D fluctuates from 1.4 - 2.1 at both the observatories. It increases gradually from 22nd February to reach a maximum of 2.1 just before 9th March event. Fractal dimensional values have shown good one –to –one variance with geomagnetic disturbance regime and seismogenic regime especially few days before 9th March earthquake. There is no prominent change in fractal dimensions observed during the time of 29th April event. An increase in the fractal dimension before earthquakes is widely reported in literature (Hayakawa et al., 1999; Rawat, 2014).

CONCLUSIONS

Two small magnitude earthquakes occurred on 9th March 2014 (Mw 4.1, R=58 km) and 29th April 2014 (Mw 3.8, R=43 km) and located near to Multi Parametric Geophysical Observatories (MPGO) of ISR at Badargadh and Desalpar in Kachchh region, Gujarat are studied. These two earthquakes are within the preparatory zone. The planetary index (Kp) and Dst are also analyzed in the corresponding period. These parameters are found to be normal during 9th March event and relatively high during 29th April event. An enhancement of 10 nT for 9th March event and 30 nT for 29th April event have been observed. The enhancement persists during the event and exponentially decreases after the event. Eigen value analysis (Principal Component Analysis) clearly showed enhancement of 88.68% in PCA signal before 9th March event and 78.67% before 29th April event. Fractal dimensions also showed 16-20% rise before 9th March event. Power Spectral Densities (PSD) in 0.001-0.05 Hz has shown good correlation with these events. The differenced signal of the total magnetic field data of Badargadh and Desalpar is enhanced exponentially prior to these events. These results facilitate us to conclude that the observed magnetic anomaly prior to 9th March event might be related to seismogenic origin. We cannot, however attribute the variations before 29th April event as seismogenic as there is high global geomagnetic influence during this period.

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Compliance with ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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More Frequent Glacial Quakes on Greenland Signal Ice Retreat

Between 1993 and 2011, the annual number of earthquakes caused by gigantic blocks of ice breaking away from Greenland's glaciers has increased; further evidence of accelerating ice loss.

Since the 1990s, researchers have seen a rise in the number of glacial earthquakes emanating from Greenland’s glaciers—earthquakes that stem from massive blocks of ice calving from glacier fronts. Nearly half of the glacial earthquakes in the past quarter century occurred between 2011 and 2013, a team of researchers has now found after digging through seismic data. These earthquakes could be a signal of a warming climate’s effect on the stability of the ice sheet itself.

“The rise in glacial earthquakes is part of the larger pattern of ice loss that is happening all over the Greenland ice sheet.” “The rise in glacial earthquakes is part of the larger pattern of ice loss that is happening all over the Greenland ice sheet”. Along with recorded ice loss and melt runoff, more frequent glacial earthquakes provide “another piece of evidence that Greenland is rapidly losing ice.” said Kira Olsen, Columbia University, New York, who led the new study. (**Citation:** Wendel, J. (2017), More frequent glacial quakes on Greenland signal ice retreat, Eos,98, doi:10.1029/2017EO065855).