Wavelet analysis of an IonosphericfoF2parameter as a Precursor of Earthquakes using Ground based Techniques

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ABSTRACT

Present study deals with the study of variations inhourly-mean value of F2-layer critical frequency (foF2) in association with three earthquakes occurred at New Zealand. In this work data observed at Christ church ionosonde station was used. The distance of earthquake epicenter form the ionosonde station was less than 1500 km. The data was processed by advanced wavelet based techniques. It was found that the foF2 increases significantly before the earthquakes and also show some anomalous behavior before the earthquakes. The observed effect is interpreted in terms of variation in electric fields between the ionosphere and quasi-neutral ion cluster. The generated electric fields penetrate the ionosphere and bring out structural changes in ionospheric parameters.

1. INTRODUCTION

The ionospheric effects produced due to seismic activity have attracted geophysicist's attention for few decades to the acute need for the prediction of earthquakes. Many paper validatevariousionospheric methods of earthquake prediction [Pulinets and Boyarchul 2004, Rishbeth, 2006, Dautermann at al., 2007; Namgaladze et al., 2009]. During earthquake generation process earth's lithosphere interact with the atmosphere and produced anomalous change in various ionspheric parameters. A significant decrease in the value of foF2 parameter before earthquakes was demonstrated by Hobara and Perrot (2005), Liperovsky et al. [1992], Rios et al. [2004], Sing et al. (2004). On the other side, Pulinets and Boyarchuk [2004] noticed an increase in value of foF2 parameter before an extremely strong earthquake. Liu et al. [2006] have analyzed the relationship between foF2 and 184 earthquakes (M≥5)occurred from 1994 to 1999 in Taiwan and found that the effect increases with magnitude but decreases with the distance from the epicenter to the ionospheric station.

The main concern of this work is to use wavelet based techniques to investigate the behavior of ionospheric foF2 parameter during the earthquake. The objectives are (1) Characterize the periodicity of ionospheric variation and (2) to explore the impacts of earthquake on foF2 parameter. Many researcher applied wavelet transform in atmospheric and oceanic sciences over a decade [e.g., Gamage and Blumen 1993; Liu 1994; Gu and Philander 1995; Kumar and Foufoula-Georgiou, 1997; Massel, S. R. 2001]; several useful reviews on this topic can be found in Meyers et al. [1993], Lau and Weng [1995], Torrence and Compo [1998], Domingues et al. [2005], and Labat [2005].

2. METHODOLOGY

A brief introduction of the methods used in this work was find in Torrence and Compo [1998] and references there in.The continuous wavelet transform of foF2 parameter time series $f(t)$ is defined as the convolution of $f(t)$ with a scaled and translated version of the mother wavelet [Torrence and Compo, 1998], which provide the wavelet coefficients as

$$W_f(a,b) = \sum_{n=0}^{N-1} f(t)\varphi^*\left(\frac{t-b}{a}\right) dt \quad \text{.......(1)}$$

Where φ^* is the complex conjugate of wavelet φ and variable a and b are the translation and dilation parameter respectively.

The squared magnitude of wavelet coefficients $\left|W_f(a,b)\right|^2$ providesthe energy content in time - frequency domain and known as wavelet power spectrum. The wavelet power spectrum describes the time series variance at a selected scale [Torrence and Webster, 1999]. The scaleaveraged wavelet power spectrum is used to examine fluctuations in power over a range of scales. It is obtained by averaging the local wavelet coefficients from s_1 to s_2 [Markovic and Koch, 2005]

$$\overline{W_f}^2 = \frac{\delta_j \delta_t}{C_\delta} \sum_{j=j_1}^{j=j_2} \frac{\left|W_f(a,b)\right|^2}{a_j} \quad \text{.......(2)}$$

where δ_j and δ_t depends on spectral-space of wavelet function, while C_δ is a constant for each wavelet function.

The average of wavelet power over all local wavelet spectra along the time axis is called global wavelet power spectrum [Torrence and Compo, 1998]

$$\overline{W_f}^2 = \frac{1}{N} \sum_{n=0}^{N-1} \left|W_f(a,b)\right|^2 \quad \text{.......(3)}$$

3. DATA SELECTION

In this work hourly data of ionospheric foF2 parameter during three earthquake occurred on New Zealand form 2006 – 2011 have been analyzed. The data is available online at National Geophysical Data Center (NGDC) data server. Characteristicsof the earthquake taken under considerationshould be given in Table-1. The selection of Ionosonde station has been done according tofamous Dobrovolsky Equation [1979], which is analytically written as:

$$\sigma = 10^{0.43XM} \quad \text{.......(4)}$$

Where M is the magnitude of earthquake

To eliminate the effect of geomagnetic activity on the analysis data of Dst index data have been taken form Kyoto geomagnetic observatory. This is available online at wdc.kugi.kyuto-u.ac.in. The variation of Dst index for all the three earthquake was illustrated in the Figure 1. It was noticed that geomagnetic conditions are quit during all three earthquakes.

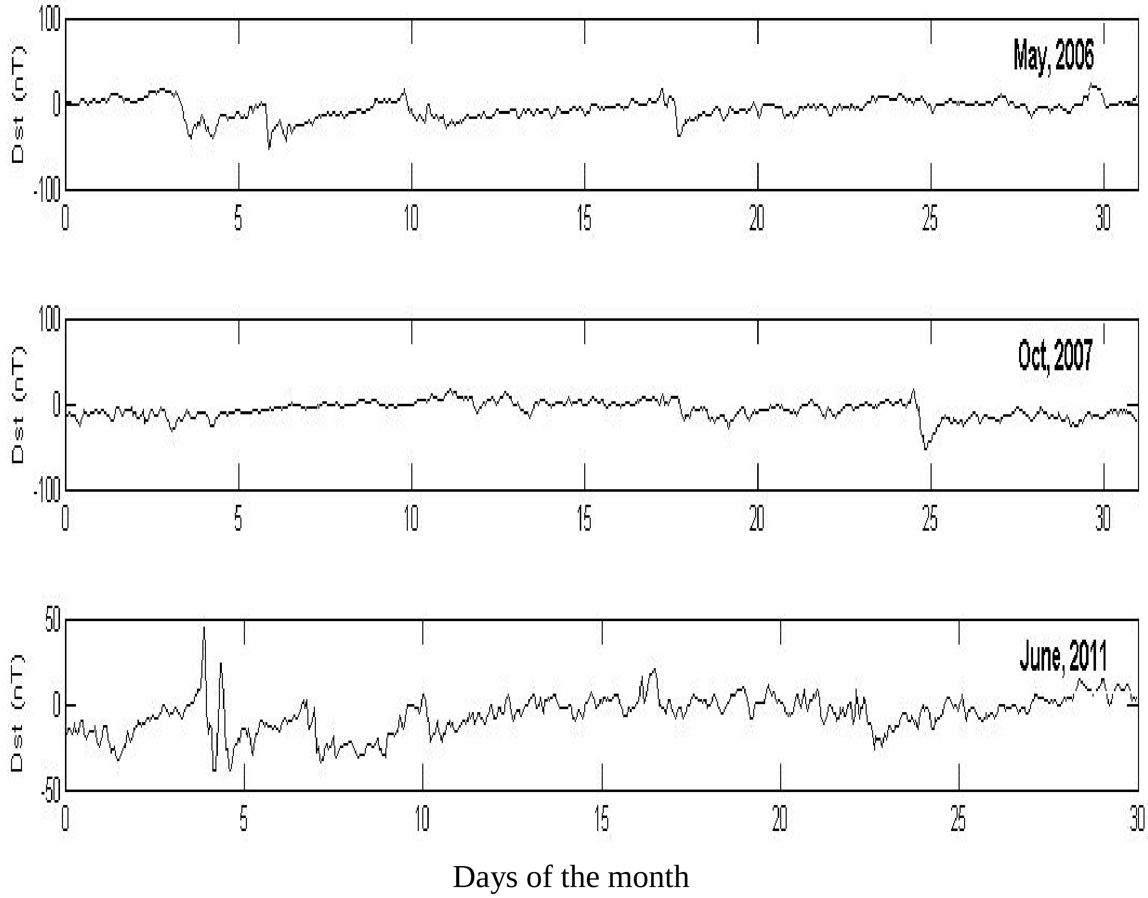

Figure 1. Variation in geomagneticDst index during the EarthquakesMay, 2006 (Upper panel), October, 2007 (Middle panel) and June, 2011 (Lower panel)

Table-1
Characteristics of Earthquake

S N.	Date	Time (UTC)	Depth (Km)	Mag (M)	Epicenter	Nearest Ionosonde Station	Distance form Epicenter (Km)	Precursor Found
1.	16/05/2006	10:39	150	7.6	Raoul Island, New Zealand $(31.56^0 S, 179.$	Christ church $(43^0 S, 172^0 E)$	1484	Before 4 days
2.	15/10/2007	12:29	5	6.7	George Sound, New Zealand $(44.72^0 S, 167.$	Christ church $(43^0 S, 172^0 E)$	416	Before 4 days
3.	13/06/2011	02:20	6.9	6.4	Cantenburg, New Zealand $(43.56^0 S, 172.$	Christ church $(43^0 S, 172^0 E)$	86	Before 6 days

4. OBSERVATIONS AND RESULTS

To perform the wavelet analysis of foF2 parameter non-orthogonal mother wavelet functions “Morlet” was used in the present work.

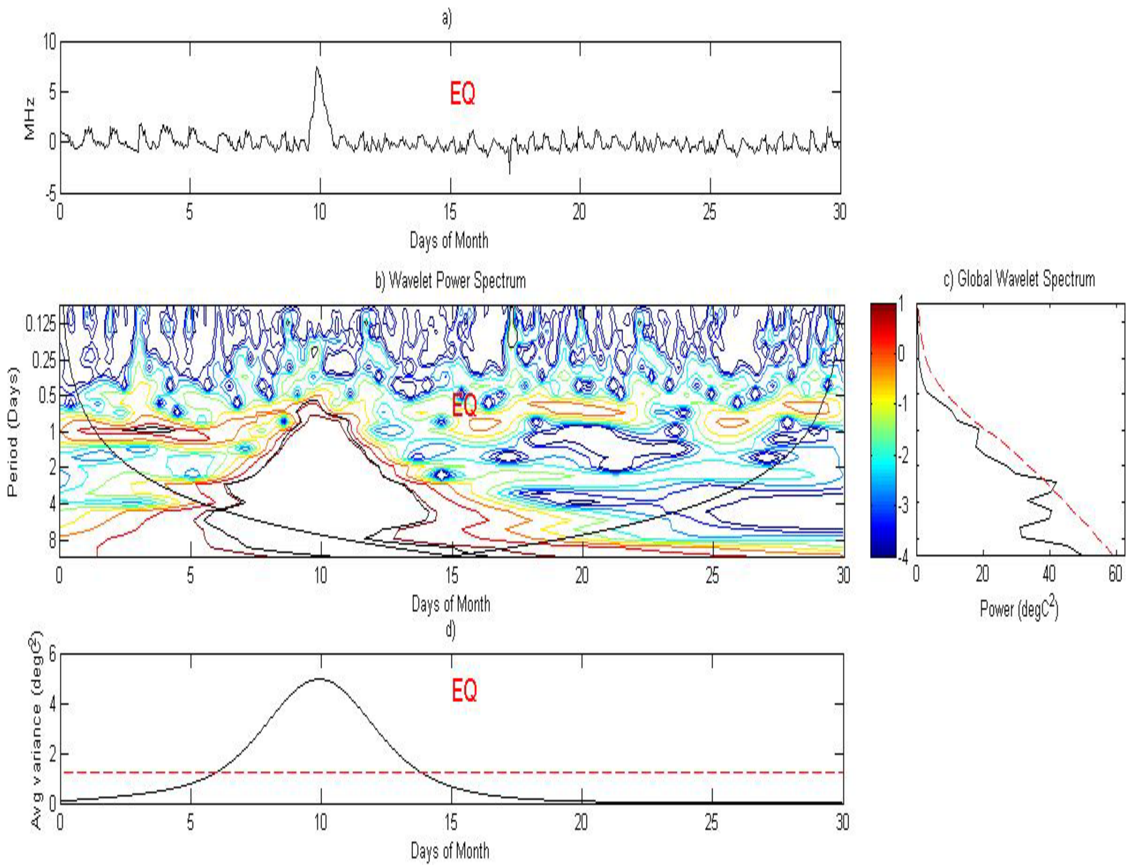

Figure 2. (a) Horulyvalue of Ionospheric foF2 parameter for May, 2006(b) The wavelet power spectrum using morlet mother wavelet. The cross-hatched region is the cone of influence, where zero padding has reduced the variance. (c) The global wavelet power spectrum. The dashed line is the 5 % significance level for the global wavelet spectrum; and (d) Scale-average wavelet power over the month band. The dashed line is the 95 % confidence

Firstly, we examine local dependence of the averaged foF2 parameter before the earthquake on May 16, 2006 in the vicinity of New Zealand with magnitude M=7.6 (The Raoul Island earthquake). The time of the earthquake is indicated by “EQ” in all the figures. One month data of foF2 parameter during earthquake were taken from Ionosonde located at Christ Church. Figure 2 (a) shows variations in ionospheric foF2 parameter for the entire month of the earthquake. It was found that value of foF2 parameter was suddenly increases 4 days before the main shock. Its normalized wavelet power spectrum is presented in Figure 2 (b). There exists a high wavelet power concentration at day 4 band, which can be attributed to seismic effects. Because we are dealing with finite-length time series, error will occur at the beginning and end of the wavelet power spectrum [Santos et al., 2001].

Figure 2 (c) presents the global wavelet power spectrum for the ionospheric foF2 parameter. The autocorrelation coefficients for foF2 parameter are estimated as a_{f0F2} = 0.84. Global wavelet spectra should be used to describe unusable changes in ionopheric foF2 data and these changes can be taken as earthquake precursors. It provides most highly significant peak (5 % level) centered at 4^{th} day band. It provides an unbiased and consistent estimation of the true power spectrum of the foF2 parameter and thus it is a simple and robust way to characterize the variability of foF2 parameter.

Figure 2 (d) presents the scale-averaged wavelet power spectrum over the identified statistically significant scales at 5% significance level (continuous line) for ionospheric foF2 parameter together with the respective 95% confidence levels (dashed line). It is made by the average of Figure 2 (c) over all scales between 4 and 8 days, which gives a measure of the average day variance versus time. The variance plot shows distinct periods when foF2 variance was low i.e form day 17 to 30, and an important peak in the scale-average time series can be identified for day 10 to 13.

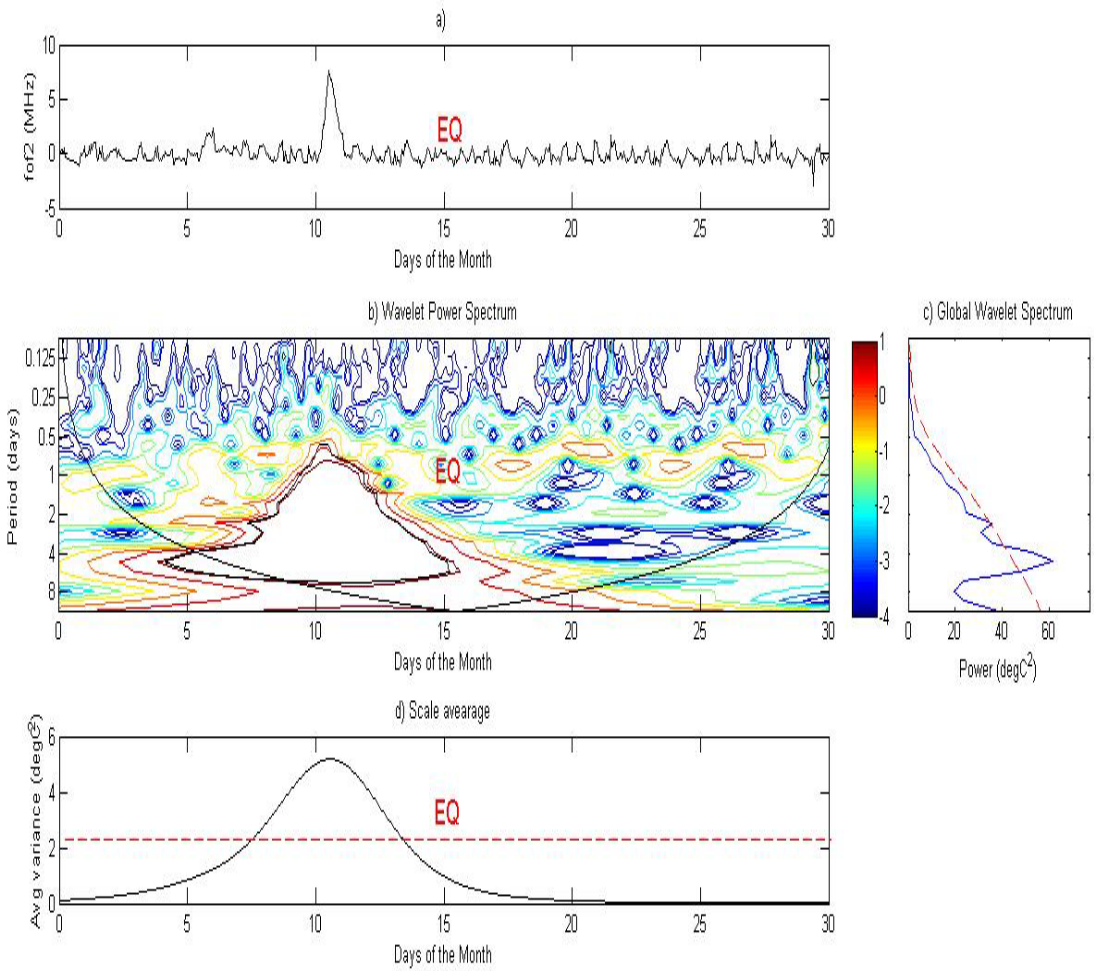

Figure 3 (a) Hourly values of Ionospheric foF2 parameter for October, 2007 (b) The wavelet power spectrum using morlet mother wavelet. The cross-hatched region is the cone of influence, where zero padding has reduced the variance. (c) The global wavelet power spectrum. The dashed line is the 5 % significance level for the global wavelet spectrum; and (d) Scale-average wavelet power over the month band. The dashed line is the 95 % confidence

Secondly, we analyze the local dependence of the hourly foF2 value around the area of the earthquake occurred on October 15, 2007 (the George Sound earthquake) in the vicinity of New Zealand, with the magnitude M=6.7 (the time of the quake is indicated by “EQ” in Figure 3 (a,b,c and d)). Figure 3 (a) shows variations in the ionospheric foF2 parameter for the month of October 2007. The anomalous increase in value of foF2 parameter is observed on October 11, 2007 (i.e. 4 days before the earthquake). Figure 3(b) shows its wavelet power spectrum with 95 % confidence level. It was found that significantly high power is concentrated between the 4 to 8 day bands. Using a_{f0F2}=0.84. The global wavelet spectrum was illustrated in Figure 3 (c). It shows significant peak centered at 4 – 8 days band; these oscillations are ignored in the rest of the analysis, because of the fact that most of the foF2 variability within this interval is included in the COI. Therefore periods in the range of 2 to 4 are considered statistically significant. Figure 3 (d) represents the scale-averaged wavelet power spectrum for ionospheric foF2 parameter. The variance plot shows an important peak in the scale-avearagefoF2 parameter for day 07 to 13.
As the third example, we analyze the local dependence of the hourly foF2 value around the area of the earthquake occurred on May 13, 2011 (the Canterburg earthquake) in the vicinity of New Zealand, with the magnitude M=6.4 (the time of the earthquake is indicated by “EQ” in Figure 4 (a,b,c and d)). Figure 4 (a) shows variations in the ionospheric foF2 parameter for the month of May 2011. The anomalous increases in value of foF2 parameter are observed on May 07, 2011.

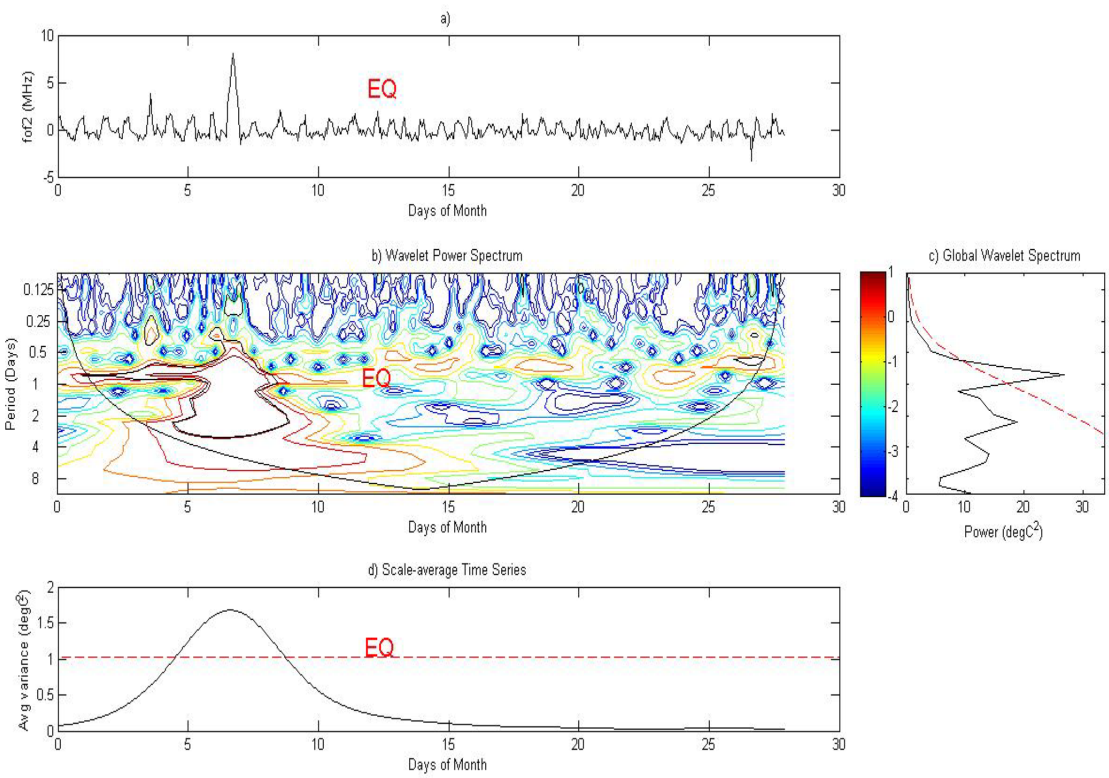

Figure 4 (a) Horuly value of Ionospheric foF2 parameter for June, 2011 during the June 13, 2011 (b) The wavelet power spectrum using morlet mother wavelet. The cross-hatched region is the cone of influence, where zero padding has reduced the variance. (c) The global wavelet power spectrum. The dashed line is the 5 % significance level for the global wavelet spectrum; and (d) Scale-average wavelet power over the month band. The dashed line is the 95 % confidence

It wavelet power spectrum with 95 % confidence level was illustrated in Figure 4 (b). The spectrumshows significantly high power concentrated between 1 to 4 day bands. The monthly frequency (periodicity at 30 days) of the time series is confirmed by an integration of power over time (Figure 4 (c)), which shows one significant peak above the 95 % confidence level for the global wavelet spectrum.It also shows a significant peak centered at 1 day band. Therefore most statistically significant peaks are found at 3 and 5 days band. Figure 4 (d) presents the scale-averaged wavelet power spectrum. The variance plot shows an important peak for day 04 to 08.

4. DISCUSSION AND CONCLUSION

In this work wavelet analysis was used to study the variability of ionospheric foF2 parameter during the earthquakes occurred at New Zealand. The wavelet power spectra showsconcentrations ofbig power few days before the main shock at various bands in the area of future earthquake caused by the enhanced seismic activity during earthquakes preparation process.This work verifies that the foF2 anomaly serves as a candidate precursor for short-term prediction of earthquake.

However, a proper monitoring of the precursors togetherwith a complete record of earthquakes in the same place for a long time are needed for establishing a precursory connection to earthquakes which may lead to skills in earthquake prediction (Jackson1999). The recorded foF2 data during 2006 - 2011 shows that the occurrence of the foF2 anomaly depends on the magnitude of relatedearthquake and the distance from the epicenter to the ionosonde station (Liu et al. 2003).However, to have a probabilistic earthquake prediction, we need to build an appropriate model for describing the relationship between well-defined precursory strength and themagnitude, occurrence time lag, and the epicenter of the related earthquake. All of these wouldbe the valuable future work based wavelet analysis on the seismo-ionospheric precursor.Another problem of real forecast is false precursors. Although they are not numerous but they exhibit thesame features as real ones and cannot be distinguished in themonitoring process. One may suppose that the false precursors are related to the same process of electric fields penetration from below, but these fields are not relatedto the earthquake preparation process. Anywaythe question of false precursors needs further considerationkeeping in mind its practical importance. Therefore more sophisticated methods are used to identify the true effect of earthquake.

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