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Satellite Based Precursor Observation Technique (SPOT) – A Study on Earthquakes Occurred During Jan – March, 2016 with Magnitude Greater Than 7.0

N VENKATANATHAN, W S VENKATESH AND V HAREESH
Department of Physics, School of Electrical and Electronics Engineering, SASTRA University, Thirumalaisamudram, Thanjavur, Tamil Nadu, India
Email: venkatanathan@eee.sastra.edu

Abstract: Prior to the occurrence of several devastating earthquakes like Sumatra earthquake 2004, China earthquake 2008, Haiti earthquake 2010 and Japan earthquake 2011, thermal anomalies were detected with the help of remote sensing technology. These results obtained have encouraged the scientists to correlate multi-parameter precursors to forecast earthquakes on short term basis. In this paper, the authors' approach is based on monitoring the outgoing longwave radiation (OLR), which is measured at the top of the atmosphere. The data is obtained from NOAA, which uses geo stationary satellites to record the OLR radiation. The authors have analyzed the earthquakes of magnitude above 7.0, which occurred between January and March of this year (2016). It is observed that outgoing long wave radiation anomalies begin to appear 3-30 days prior to the earthquakes, near the epicenter. This enables the authors to conclude that it is possible to forecast earthquakes of greater magnitude on a short term basis with reasonable accuracy by using anomalous outgoing longwave radiation.

Keywords: *Outgoing Longwave Radiation, Anomaly, Satellite based precursor technique (SPOT) and Lithosphere-Atmosphere-Ionosphere-coupling (LAIC)*

1. Introduction

Even though earthquake is a complex physical phenomenon, the devastation produced by the two great earthquakes, (the 2014 Sumatra earthquake and the 2011 Tohoku-oki earthquake) necessitated the scientists to explore the possibilities of forecasting earthquakes on short term basis. Scientists from various countries like India, Italy, China, Turkey, and Japan are exploring the possibility of using "Satellite based Precursor Observation Techniques" (SPOT) to forecast big earthquakes on short term basis. The probable reason for them to adopt this method is, monitoring a potentially vulnerable region round the clock at global level easier than using ground based observatories, since it is difficult to implement and also very expensive process.

From the retrospective analysis of OLR scenario in the seismically active region, it was found by many scientists across the globe that there were anomalous positive deviations prior to the various devastating large earthquakes.

In 1988, scientists started using satellite technology to identify the appearance of short lived thermal anomalies prior to the big earthquakes (Gorny et al, 1988). Five Days prior to the occurrence of the mega earthquake in Sumatra region (2004), anomalous appearance of OLR was recorded as 80 W/m^2 in Sumatra (Ouzounov et al, 2007). Similarly a change in OLR energy index (ΔE) was recorded above the $+2\sigma$ value, 4 days prior to the Japan 2011 earthquake (Ouzounov et al, 2011). Short lived anomalies were observed three times prior to the Pakistan earthquake that occurred on September 24, 2013 with the magnitude of M7.7 (Venkatanathan and Natyaganov, 2014). Vineeta Rawat et al., (2011) observed that the flux values of OLR recorded were 30-45 W/m^2 higher than normal values prior to the earthquakes in India and Italy regions. In recent years, prior to the occurrence of big earthquakes, the scientists have found that there are anomalous changes in 'total electron concentration' (TEC) in the F2 layer of the ionosphere (Pulinets 2012 & Liu et al. 2004). Analysis of wavelet maxima curves has shown prominent OLR singularities prior to the earthquakes that occurred in China (Xiong et al., 2009). For the earthquakes of 26 December 2003 and 21 February 2005 in the Iran region, 5˚C to 10˚C rise in temperature was observed near the epicenters of the earthquakes (Choudhury et al., 2006). Several scientists have reported the detection of thermal anomaly on the surface and in the atmosphere prior to the earthquakes in the recent past. (Gorny and Shilin 1992; Qiang et al. 1999; Tronin 2000; Choudhury et al. 2006; Saraf et al. 2009; Panda et al. 2007; Ouzounov and Freund 2004; Tramutoli et al. 2005; Filizzola et al. 2004). Outgoing Longwave Radiations (OLR) are reflected from the earth's surface to the atmosphere and it is measured at the top of the atmosphere. It is often influenced by cloud and surface temperature of the earth. (Pan Xiong et al, 2009).

The probable reason for the anomalous thermal spike in the atmosphere was hypothesized by Pulinets and Ouzounov in 2011. They proposed that the emanation of radioactive gases like radon gas induces the ionization of air in the atmosphere near the potentially vulnerable zones. The ionized air acts as active centres for the water vapours to condense, which releases latent heat to a larger extent in to the atmosphere. These ions induced nucleation process plays important role in the coupling between thermal and electric phenomena of the atmosphere. Thus Lithosphere – Atmosphere – Ionosphere – Magnetosphere Coupling is developed prior to the occurrence of devastating earthquakes.

In this manuscript the authors have chosen the recent earthquakes that occurred between January and March, 2016 with magnitude greater than 7.0 (Table. 1), in order to validate that the appearance of OLR anomaly is not region specific.

Table 1: *Earthquake Occurred from January to March 2016 with M>7.0*

Date	Latitude	Longitude	Depth	Magnitude	Place
2016-01-24	59.6363	-153.405	129	7.1	86km E of Old Iliamna, Alaska
2016-01-30	53.9787	158.5347	177	7.2	88km N of Yelizovo, Russia
2016-03-02	-4.9082	94.275	24	7.8	Southwest of Sumatra, Indonesia

2. Methodology

2.1. Anomalous OLR Flux Index Method

Outgoing Long wave Radiations are low frequency electromagnetic radiations reflected from the earth's surface and clouds, which can be measured above the cloud level. The basic data obtained from the satellite is processed using an algorithm to obtain the OLR data ranging between 10 and 13 µm, since atmosphere is most transparent in this wavelength range, and not influenced by other factors like water vapour, carbon dioxide and Ozone. Normally OLR anomaly was observed 3 to 30 days prior to the devastating earthquakes.

2.2 Space and time analysis

The OLR anomaly can be identified by finding variation in the anomalous signal level index (*AS_index*), which indicates the maximum change in the level of OLR flux (*Ouzounov et al, 2011*):

$$\overline{y^*(a_{i,j}, b_{i,j})} = \sum_{t=1}^{n} y^*(a_{i,j}, b_{i,j})$$

Where "n" is the number of predefined preceding years for which mean OLR flux is calculated for the selected spatial region and time.

$$AS_{index} = \left[\frac{\left(y^*(a_{i,j}, b_{i,j}) - \overline{y^*(a_{i,j}, b_{i,j})}\right)}{\sigma_{i,j}}\right]_t$$

Where,

AS_{index} $-$ *Maximum change in signal level in the form of OLR flux for time 't'*

$y^*(a_{i,j}, b_{i,j})$ $=$ *Current OLR flux for predefined time* (t) *and spatial location with latitude* $(a_{i,j})$ *and longitude* (b_{ij})

$\overline{y^*[a_{i,j}, b_{i,j}]}$ $=$ *Mean OLR flux for predefined preceding years of given time* (t) *and spatial location with latitude* $(a_{i,j})$ *and longitude* (b_{ij})

By using the above formula, the anomaly is localized and the time analysis for that particular location is carried out. The anomaly is effectively identified by comparing the daily mean OLR for the year 2016 ($\mu_{d(i,j)}$) against the averaged multiple year mean OLR ($\sum \mu_{d(i,j)}$) (calculated for the preceding 10 years of the OLR flux). If the value of daily mean OLR is more than +2σ confidence level of the averaged multiple year mean OLR, then the OLR flux representing particular space and time can be considered as an anomalous one.

$$If\ \left(\mu_{d(i,j)n} \geq \frac{(\Sigma\mu_{d(i,j)n} + 2\sigma)}{n}\right)$$

$$\alpha_{(i,j)n} = \mu_{d(i,j)n} - \frac{(\Sigma\mu_{d(i,j)n} + 2\sigma)}{n} \quad else\ \alpha_{(i,j)n} = 0$$

Where,

$\mu_{d(i,j)n} =$ *Daily mean OLR for the current year* (2016)

$\Sigma\mu_{d(i,j)n} =$ *Averaged multiple years mean OLR*

$\alpha_{(i,j)n} =$ *OLR flux index*

$\sigma =$ *Standard deviation calculated from mean OLR flux*

$n =$ *Number of predefined preceding years*

By using the above formula, the anomaly is localized and the time analysis for that particular location is carried out. The anomaly is effectively identified by comparing the daily mean OLR for the year 2016 ($\mu_{d(i,j)}$) against the averaged multiple year mean OLR ($\sum \mu_{d(i,j)}$) (calculated for the preceding 10 years of the OLR flux). If the value of daily mean OLR is more than +2σ confidence level of the averaged multiple year mean OLR, then the OLR flux representing

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Where,

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$\Sigma\mu_{d(i,j)n} = Averaged\ multiple\ years\ mean\ OLR$

$\alpha_{(i,j)n} = OLR\ flux\ index$

$\sigma = Standard\ deviation\ calculated\ from\ mean\ OLR\ flux$

$n = Number\ of predefined\ preceding\ years$

3. Results and Discussion

3.1. Iliamna, Alaska earthquake (M7.1)

On January 24, 2016, an earthquake with a magnitude of 7.1 occurred at the southwest of Anchorage, Alaska. The earthquake was due to strike slip fault at the depth of 129 km from the surface. The focal mechanism indicates that the direction of fault is either a north-westerly right-lateral fault or a north-easterly left-lateral fault (www.neic.usgs). The epicenter of the earthquake was at the latitude of 59.6363 N and the longitude of 153.405 W (Fig. 1).

***Figure 1**: Map showing epicenter of Alaska earthquake. Map not to scale.*

From the space and time analysis of the OLR prior to the occurrence of the earthquake, an anomalous increase in OLR was observed. Prior to the Jan 24, 2016 earthquake, the OLR anomaly was observed thrice during a period of 30 days, starting from Dec 23, 2015 (Fig. 2). The first anomaly was observed by the geostationary satellites on December 26, 2015, with "daily mean OLR flux" value of 239.005 W/m^2, which is 6.318 W/m^2 more than two sigma level of "averaged mean OLR flux" calculated from past ten years of OLR flux observed at the epicentral region. After four days (i.e.) on December 30, 2015 the second anomaly was observed. This is a stronger anomaly when compared to the first one.

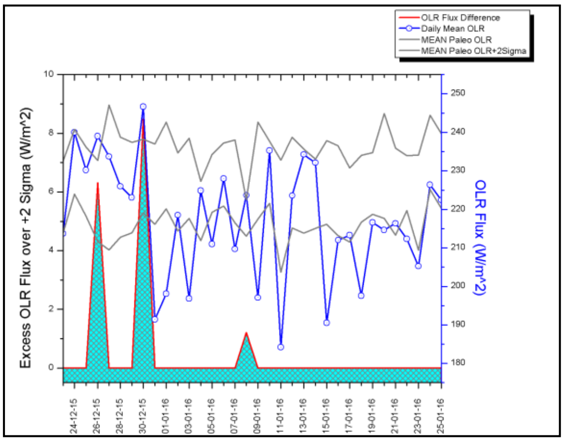

***Figure 2:** Graph showing excess OLR flux observed three times during one month prior to the earthquake*

The "daily mean OLR flux" observed was 246.711 W/m^2 and it is 8.481833929 W/m^2 higher than two sigma level of "averaged mean OLR flux", hence records the "Anomalous signal Index" of 2.8334 (Fig. 3). The third and final anomaly was observed on January 08, 2016, but the "anomalous signal index" was less, compared to the first two anomalies observed. The "anomalous signal index" of 2.2111 and excess OLR flux over +2 sigma of averaged mean OLR flux value of 1.211 W/m^2 was recorded.

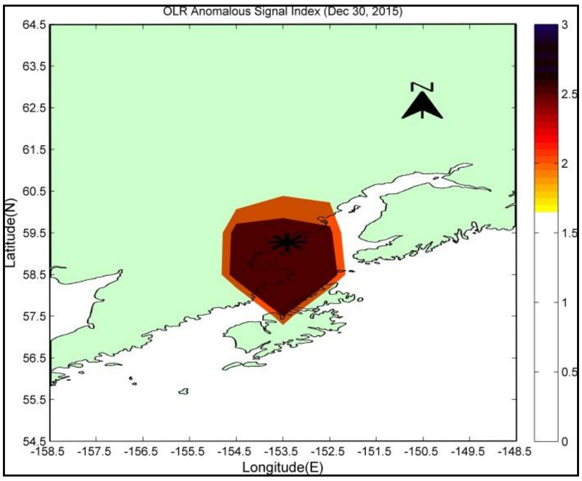

***Figure 3:** Map showing anomaly observed 25 days prior to the earthquake in the Alaska region. The asterisk symbol shows epicenter of the earthquake*

3.2. Yelizovo, Russia earthquake (M 7.2)

An earthquake with a magnitude of M7.2 occurred at Kamchatka Peninsula, Russia on January 30, 2016. The earthquake occurred at 53.9787 N latitude and 158.5347E longitude (Fig. 4). The earthquake might be due to the Oblique – Normal faulting at the depth of 180 km. From the depth and faulting mechanism it can be inferred that for this earthquake the ruptured fault is in the Pacific lithosphere, which subducts beneath the Eurasian plate (www.neic.usgs).

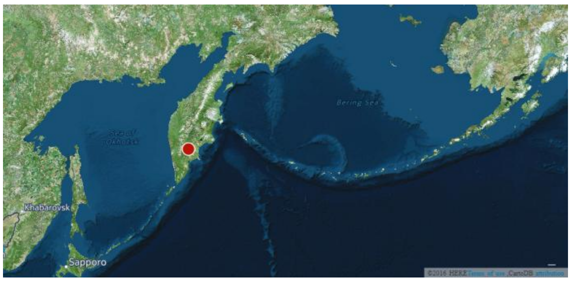

Figure 4: *Map showing Kamchatka Peninsula earthquake occurred on Jan 30, 2016. Map not to scale*

From the analysis of OLR scenario prior to the earthquake that occurred on January 30, 2016, it can be inferred that the anomalous spike was observed by the geostationary satellites on January 12, 2016 (i.e.) 18 days prior to the earthquake at Kamchatka Peninsula region (Fig. 5).

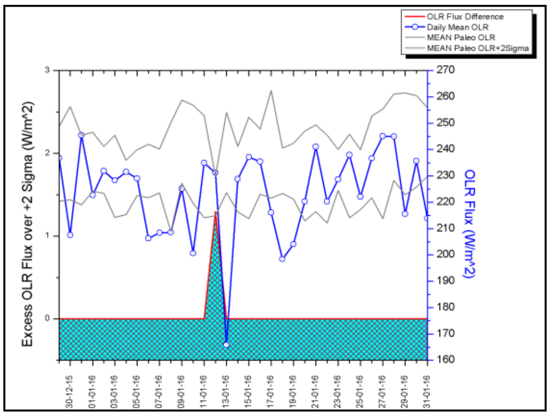

Figure 5: *Graph showing anomalous OLR spike observed on Jan 12, 2016, 14 days prior to the earthquake*

The "Anomalous signal Index" of 2.129 was recorded due to "daily mean OLR flux" of 231.194 W/m^2 (Fig. 6). The "daily mean OLR flux" was 1.295 W/m^2 in excess compared to +2 sigma level of averaged mean OLR flux value.

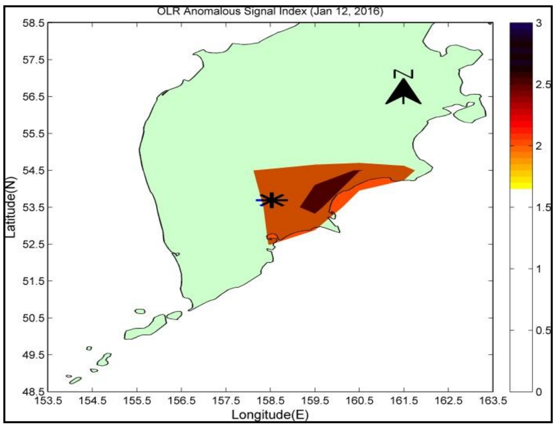

Figure 6: *Map showing epicenter of the earthquake (marked blue asterisk) and OLR anomaly observed on Jan 12, 2016*

3.3. Southwest of Sumatra, Indonesia earthquake (M7.8)

At the location 4.9082S latitude and 94.275E longitude, an earthquake with a magnitude of 7.8 occurred at a depth of 24 km on March 2, 2016 (Fig. 7). The earthquake occurred in oceanic lithosphere and is located approximately 600 km southwest of a major subduction zone where the Indo - Australian plates were subducted beneath the Sunda plate. At the earthquake location, the oceanic lithosphere deforms for broader region and thus it separates the India and Australia plates. From the preliminary investigation it was inferred that the fault may possess the dimension of 90 x 40 km. The fault models of this earthquake indicate that the rupture may be on the east – west nodal plane with right lateral slip (www.neic.usgs).

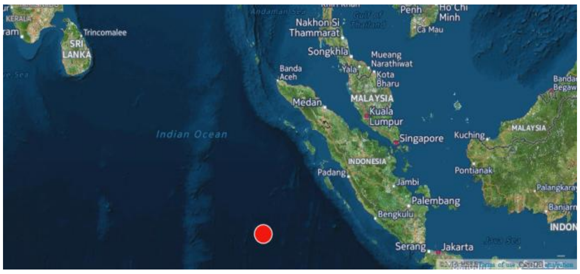

Figure 7: *Map showing epicenter of earthquake occurred in SW of Sumatra*

The anomalous OLR flux had started appearing 14 days prior to the earthquake in Southwest of Sumatra region and unlike other two earthquakes discussed in this paper, the anomaly appeared continuously for 4 days (i.e.) from February 17, 2016 to February 20, 2016. On February 17, 2016 the "daily mean OLR flux" of 275.339 W/m^2 was observed, 4.524 W/m^2 more than +2 sigma level of averaged mean OLR flux value. On the second day (i.e.) on February 18, 2016 the excess flux value over +2 sigma level of averaged mean OLR flux was much higher than that of first day (Fig. 8).

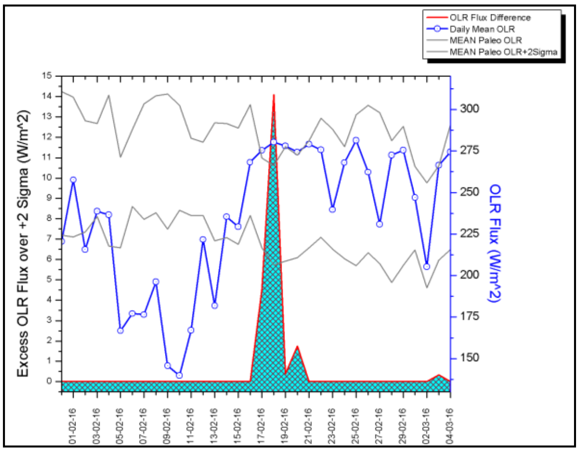

Figure 8: *Graph showing sharp spike observed on Feb 17, 2016, 14 days prior to the earthquake*

The flux value of 14.09 W/m^2 was observed in excess to the "averaged mean OLR flux + 2σ" value. The maximum "Anomalous signal index" of 2.421 was recorded for the second day (Fig. 9).

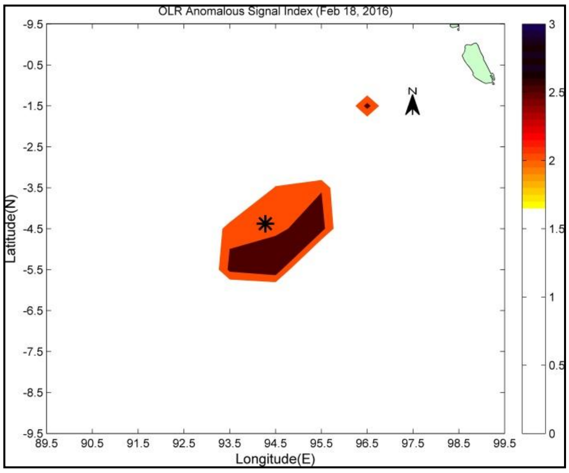

Figure 9: *Map showing anomaly close to the epicenter (marked in asterisk) on Feb 18, 2016*

On the third day the excess OLR flux value over "averaged mean OLR flux + 2σ" value decreased to 0.378 W/m^2, but finally on February 20, 2016 excess OLR flux value compared to "averaged mean OLR flux + 2σ" value increased to 1.754 W/m^2.

4. Discussion

From the above results it can be inferred that there is a definite possibility that the important parameters like location in terms of latitude and longitude, magnitude-depth and time of occurrence can be found. From the figures (3, 6 & 9) the OLR anomalies were observed very close to the epicenters of the earthquakes. The excess energy in OLR value has been observed to increase for higher magnitude earthquakes, but this relation is a complex phenomenon due to the influence of depth, where the seismic waves start propagating due to rupturing of rocks (Fig 10 (a&b), 11a & 12).

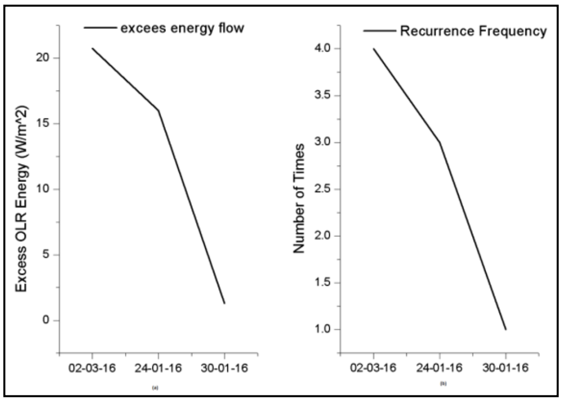

Figure 10 (a&b): *Graph showing correlation between excess OLR energy and recurrence frequency for the earthquakes discussed here*

The time of occurrence of the earthquake can roughly be calculated by using recurrence frequency of OLR anomaly, days prior to the earthquake event and excess energy flow in W/m^2. With the increase in excess energy flow, the reoccurrence frequency of anomalous OLR also increases, but the time gap between the OLR anomaly appearance and the earthquake event decreases and viz. (Fig. 10 (a&b) & Fig 11(b)).

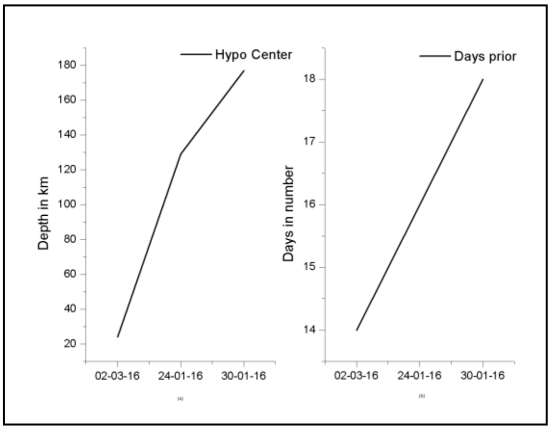

Figure 11 (a&b): *Graph showing depths and appearance of OLR anomaly prior to the earthquakes discussed here*

From the above results one can infer that as LAIC model hypothesized that the increased tectonic activity leads to the emanation radon gases from the seismically active region.

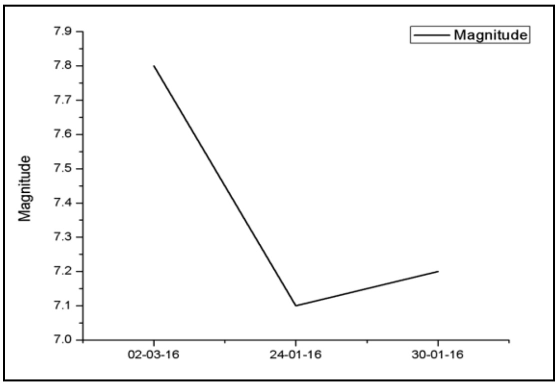

Figure 12: *Graph showing magnitudes of three earthquakes considered for the analysis*

Increased radon gas emission is the reason for the condensation of water vapour and increase in latent heat release. Thus the OLR fluxes were observed anomalously prior to the occurrence of big earthquakes.

5. Conclusion

Radon from the vicinity of the tectonically active region is the basis for the anomalous OLR variations. Normally these thermal variations were observed prior to the big earthquakes. The decay of radioactive radon leads to the ionization of atmospheric air molecules and these ionized molecules are acting as a condensation centers. During the condensation process, the water molecules releases enormous amount of heat energy due to the latent heat phenomenon. In this paper we have analyzed, the OLR flux prior to the earthquakes occurred during Jan – March period with the magnitude above 7.0. Even though anomalous OLR variations can provide vital clue about impending earthquakes, lot work need to be done in order to fine tune the earthquake forecasting research. Thus the authors propose interdisciplinary study of earthquake precursors to resolve the complex earthquake phenomena. In order to improvise the accuracy of earthquake forecasting studies, the authors proposed the multi-parameter and interdisciplinary precursory techniques by including the parameters like Total electron content, infra sound studies, radon gas emanation and EM emissions, then earthquake forecasting will no longer be considered as 'COMPLEX' phenomena.

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