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550.34 : 551.521.32 (540.41)

Diurnal variations of outgoing long wave radiation (OLR) *vis a vis* 4 January, 2016 Manipur earthquake (Mw: 6.7): An earthquake precursor?

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सार – 25 दिसम्बर 2015 से 5 जनवरी 2016 के दौरान इनसेट 3D और कल्पना उपग्रह से OLR के दैनिक और दिन में दोबार OLR की परिवर्तनशीलता का अध्ययन 4 जनवरी 2016 (Mw 6.7) मणिपुर भूकंप के अधिकेंद्र और अन्य क्षेत्र में किया गया। भूकंप के केंद्र से 30 कि. मी. दूर इम्फाल में रिकॉर्ड किए गए तापमान की भी जांच की गई है। यह पता चला है कि मणिपुर में भूकंप के आने से पहले OLR कम रही जबकि अन्य अनेक स्टेशनों पर यह काफी अधिक रही जहां से किसी भूकंप की विशेष रिपोर्ट दर्ज नहीं हुई। पहले हुए अध्ययनों से प्राप्त हुए परिणामों से यह जानकारी मिलती है कि OLR अथवा तापमान परिवर्तन मौसम वैज्ञानिक कारणों से संबंधित है और इसको केवल भूकंप के प्रागुक्तों के रूप में जानना भ्रम की स्थिति उत्पन्न कर सकता है।

ABSTRACT. Daily and diurnal variations of OLR from INSAT 3D and Kalpana satellites have been studied during 25 December, 2015 to 5 January, 2016 over the epicentral region of the Manipur earthquake of 4 January, 2016 (Mw 6.7) and other regions within the view of these satellites. The surface temperatures recorded at Imphal around 30 km from epicentre of this earthquake were also examined. It is found that OLR remained low prior to the occurrence of Manipur earthquake while much larger rise occurred over several other regions where no significant seismic activity was reported. The results corroborate inferences reported in earlier studies that OLR or temperature changes are related to meteorological causes and its sole identification as earthquake precursor may be misleading due to poor constraints.

Key words – OLR, Manipur earthquake 2016, Seismic intensity.

1. Introduction

Recent studies have demonstrated that Manipur region of northeast India lies in intricate seismogenesis because of its complex geotectonic settings and high degree of structural heterogeneities imaged in 3-D tomograms (Mishra, 2011; Mishra, 2014). Active seismicity of northeast India is attributed to the north north easterly movement of the Indian plate at the rate of about 5 cm/year and its collision with the Eurasian plate. This plate boundary takes a syntaxial bend towards Manipur-Myanmar border. Multiple collisions have caused several faults in this region called Naga thrusts which are seismically very active (Chaudhury and Srivastava, 1976). A number of other faults in northeast India called Kopili lineament, Dawki fault, Lohit and Mishmi thrusts are also seismically active. The Shillong plateau is also surrounded by faults all round where the great earthquake (Mw: 8.1) occurred in 1897 and microseismicity continues to be very high (Srivastava *et al*., 1996). Largest earthquake of magnitude (Mw: 8.4 - 8.6) occurred in 1950 near Assam Tibet border. Also several earthquakes of magnitude 7 or more have taken place in northeast India during 1900 to 2015 (USGS, Tandon and Srivastava, 1974). Regional plate tectonics suggests that this region will continue to be the source for major or great earthquakes (Srivastava and Chaudhury, 1979). However, Srivastava *et al*. (2013b) constrained the magnitude of the largest earthquake in the continent-continent collision zone of Himalaya (including northeast India) where it is expected to be less than in subduction zones. Fig. 1 shows the epicentral distribution of earthquakes ($M \geq 6.0$) over northeast India during the years 1975 to January 2016.

During the last four to five decades, attempts have been made to search seismological precursors which include seismic gaps, seismicity patterns, changes in

TABLE 1

Hypo centre parameters of Manipur earthquake January 2016

Date	Origin Time (UTC) Hh:mm:ss.s	Epicenter Lat (°N) / Long (°E)	Focal depth (km)	Magnitude and region	Source
3 January, 2016*	23:05: 16.0 (04:35:16.0)	24.8 / 93.5	17	6.7: Tamenglong (Manipur)	NCS

*4 January, 2016 at 04:35:16 IST

b-value in Gutenberg Richter relationship, P wave velocities and stress changes. The other geophysical methods are based on geodetic, geomagnetic and geoelectric observations (Srivastava, 2004). In the Indian region, several precursory studies have been undertaken using seismicity patterns, seismic gaps or b-values in Gutenberg Richter relation. In a recent study, Srivastava *et al*. (2013a) analysed the deficiencies in the very long Himalayan seismic gaps (Khattri, 1987) and delineated two types of seismic gaps with discriminatory characteristics. The new classification was validated by the recent 2015 Nepal earthquake (Mw: 7.8) which occurred in the seismic gap of type 1 (Prakash *et al*., 2016). This earthquake was preceded by seismic quiescence since 2008 similar to several other damaging earthquakes in Himalaya from Kashmir to northeast India as reported for 2005 Muzaffarabad (Singh *et al*., 2008), 1980 Jammu (Dube and Srivastava, 1983), 1974 and 1978 Himachal Pradesh (Srivastava *et al*., 1987), 1960 and 1966 India Nepal border (Srivastava and Gautam, 1987), 1991 and 1999 Uttarakhand (Prakash *et al*., 2004) and 1988 India Myanmar border (Srivastava and Rao, 1991). Decadal changes in the b-value in Gutenberg-Richter relation showed a decrease in the last decade preceding 2015 Nepal earthquake (Prakash *et al*., 2016). Of late geochemical, ionospheric, seismomagnetic (Schekotov and Hyakawa, 2015) and thermal anomalies have also been attempted (Zu-ji *et al*., 1991; Ouzounov *et al*., 2007; Zhang *et al*., 2011; Saraf *et al*., 2012; Wei *et al*., 2013). A closer examination of these results shows that they are controversial due to the influence of several atmospheric or other parameters (Srivastava, 2004; Prakash and Srivastava, 2015).

The 2016 Manipur earthquake (Mw: 6.7) provided an opportunity to understand the behavior of OLR anomaly using Indian satellite data. In the present study we attempted to examine the precursory potential of OLR data recorded from 25 December, 2015 to 5 January, 2016 by Kalpana and INSAT -3 D. An apt interpretation and discussion has been made to understand the physics of diurnal variations of OLR in the different parts of the regions available within the range of the satellites in this study.

2. OLR as a measure of thermal anomaly

OLR is the amount of emitted terrestrial radiation from earth (land and ocean) and clouds. It is affected by the earth's skin temperature, surface emissivity, atmospheric temperature, water vapor profile, cloud cover and dust in the atmosphere. Major deserts have largest OLR during summer due to solar radiations. Larger emission also occurs in the vicinity of the oceanic subtropical highs (30° N to 30° S). Due to persistent thunderstorms in the inter tropical convergence tropical zone near the equator, OLR is generally lowest. It may however migrate about equator in different seasons.

OLR is measured through infra red sensors in Advanced Very High Resolution Radiometers (AVHRR) of remote sensing satellites. The thermal infra red sensor in the earlier INSAT series used the band 10 to 12.5 μm. INSAT-3D is an advanced weather satellite of India with improved imaging system and atmospheric sounder. It is designed for enhanced meteorological observations over land and ocean surfaces and can generate vertical profiles of temperature and humidity for weather forecasting and disaster warning. The sounder spectral range in microns consists of visible (0.67-0.72 μm). short wave infra red (3.67-4.59 μm), medium infra red (6.38-11.33 μm) and long wave infra red (11.66-14.85 μm). In this satellite, data is collected in 4 × 4 km grid point and image is prepared. The OLR image is full disc and its resolution is about 14 × 14 km. In Kalpana satellite, data is collected in 25 × 25 km grid point. Both these satellites were launched by Indian Space Research Organisation (ISRO) India. OLR data is readily available in India Meteorological Department (IMD). The surface weather observations are needed to validate the OLR values whose units of measurement are derived in W/m^2. Shah *et al*. (2013) compared the maximum and minimum temperature data from MODIS satellite with that from the surface observations reported by IMD and found mean absolute error less than 2 °C and RMSE of about ±2.2 °C. For interpreting OLR or thermal anomalies, due weightage needs to be given to the meteorological factors such as land and sea breeze, orographic ascent or descent, troughs in westerly or easterly wind flow, western disturbances

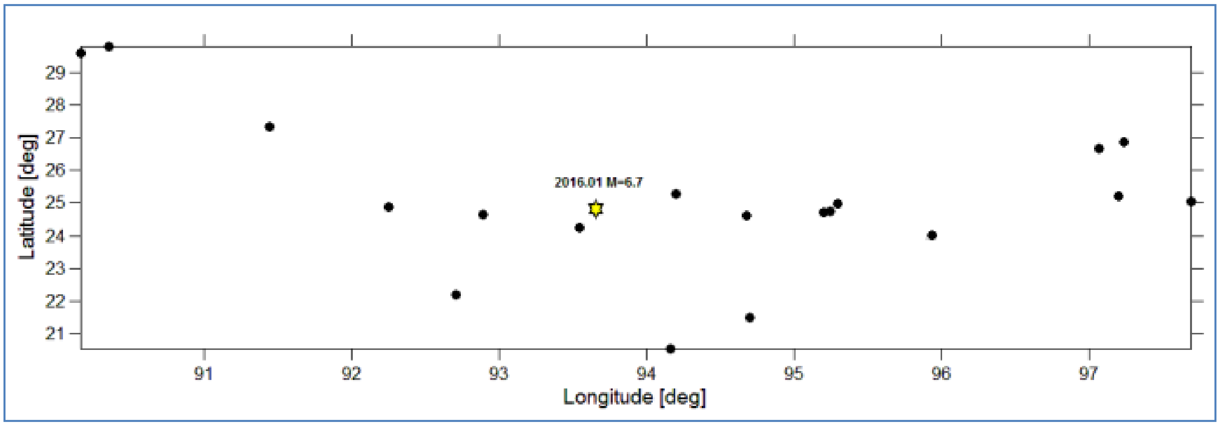


Fig. 1. Seismicity over northeast India during the years 1975 to January 2016 (M $\geq$ 6.0)

and or induced lows, monsoon depressions, position of axis of monsoon trough, cyclonic storms or persistence of high pressure areas, onset and withdrawal of monsoon, El Nino conditions over eastern Pacific ocean or warm ocean currents, air sea interaction, solar radiation, Southern and Madden-Julian oscillations. Also diurnal, seasonal or annual changes need to keep in view with respect to long term normal of temperatures at the place.

3. Seismic intensity and epicentral parameters of 4 January, 2016 Manipur earthquake

An earthquake of damaging intensity (Mw: 6.7) occurred on 4 January, 2016 in northeast India, about 30 km east of Imphal causing loss of human lives, injuring about 200 persons besides significant damage to property. The shock was widely felt in India, Bangladesh and Nepal. The maximum intensity was assessed as VIII on modified Mercalli scale. The hypo central parameters of the Manipur earthquake of January, 2016 are given in Table 1.

4. Observations

For studying thermal anomalies, OLR data from satellites and surface temperatures recorded by meteorological stations is used. OLR distribution from INSAT 3D and Kalpana satellites over Afro Asian and neighbouring countries is shown for representative days (28-31 December, 2015 and 1-4 January, 2016) during 25 December, 2015 to 5 January, 2016 [Figs. 2(a-h) & 3(a-d)]. Diurnal variations of OLR from INSAT 3D satellite at 00 and 10 GMT for two representative days (31 December, 2015 and 1 January, 2016) are also shown in Figs. 4(a-d). Daily variations of OLR as observed by the INSAT 3D satellite prior to the Manipur earthquake, 2016 from 25 December to 3 January, 2016 and after the occurrence of the earthquake are summarised below:

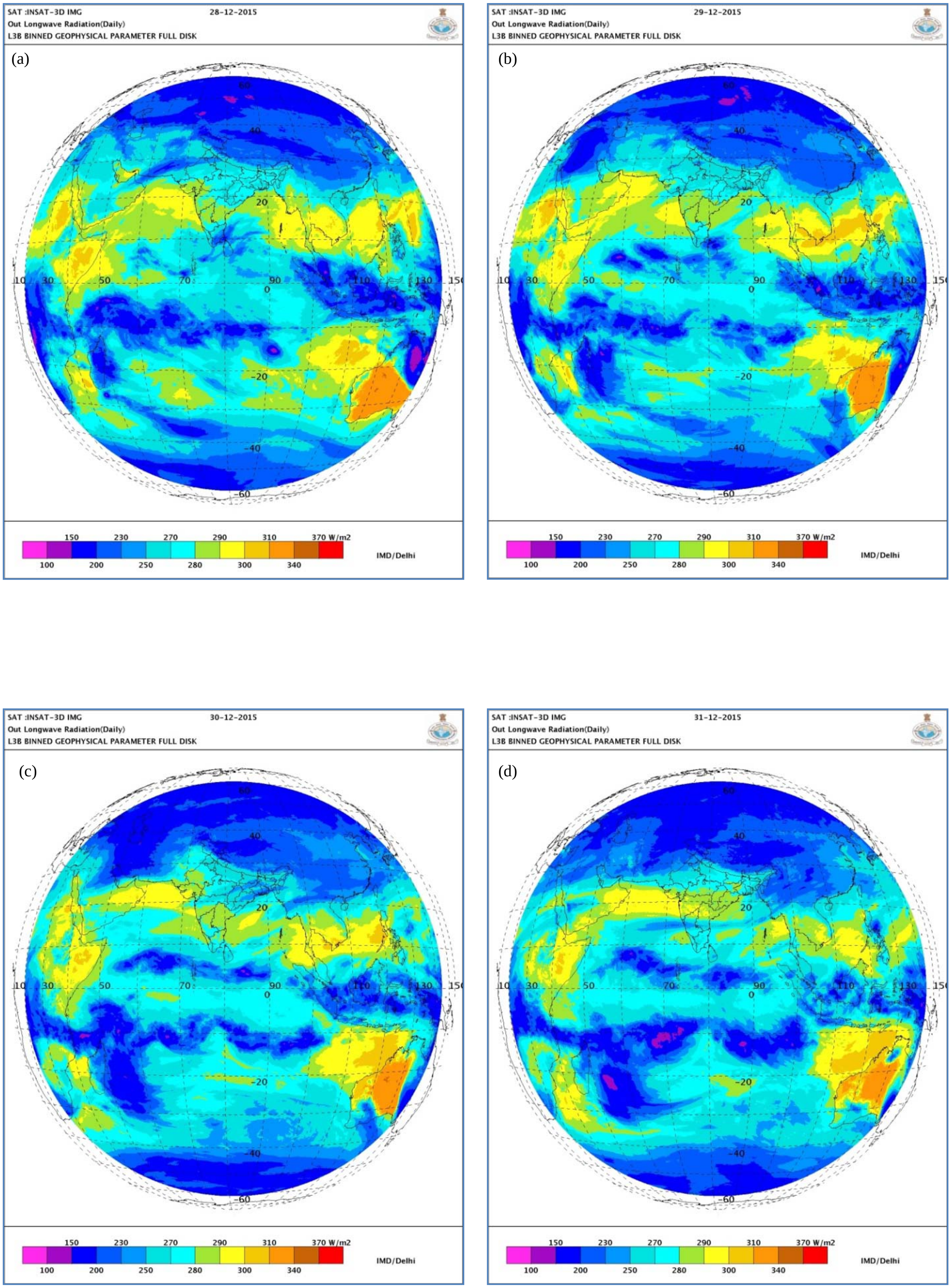
4.1. *Before the earthquake of January 3, 2016 (from 28 December, 2015 to 2 January, 2016)*

It may be noted that there are some persistent patches of high and low OLR values although minor variations in their locations occur during this period prior to earthquake. If we confine our attention to regions close to India, it may be noted that low OLR values of the order of 250 to 280 W/m^2 prevailed over northern parts of the country. Relatively larger values of 280 to 300 W/m^2 were observed from Africa, Arabian Sea to peninsular India, Bay of Bengal and thence to Pacific Ocean. Well marked rise in OLR was observed in the southern hemisphere mostly near northwest Australia with scattered patches in the Indian Ocean. On 30 and 31 December, 2015 a thin belt of lower OLR values of 150-250 W/m^2 developed over coastal Bengal, Manipur and Myanmar region which disappeared the next day. There was a slight rise in OLR values of 280 to 290 W/m^2 over Bangla Desh and Tripura on 1 January, 2016 which dissipated the next day [Figs. 2(a-h)].

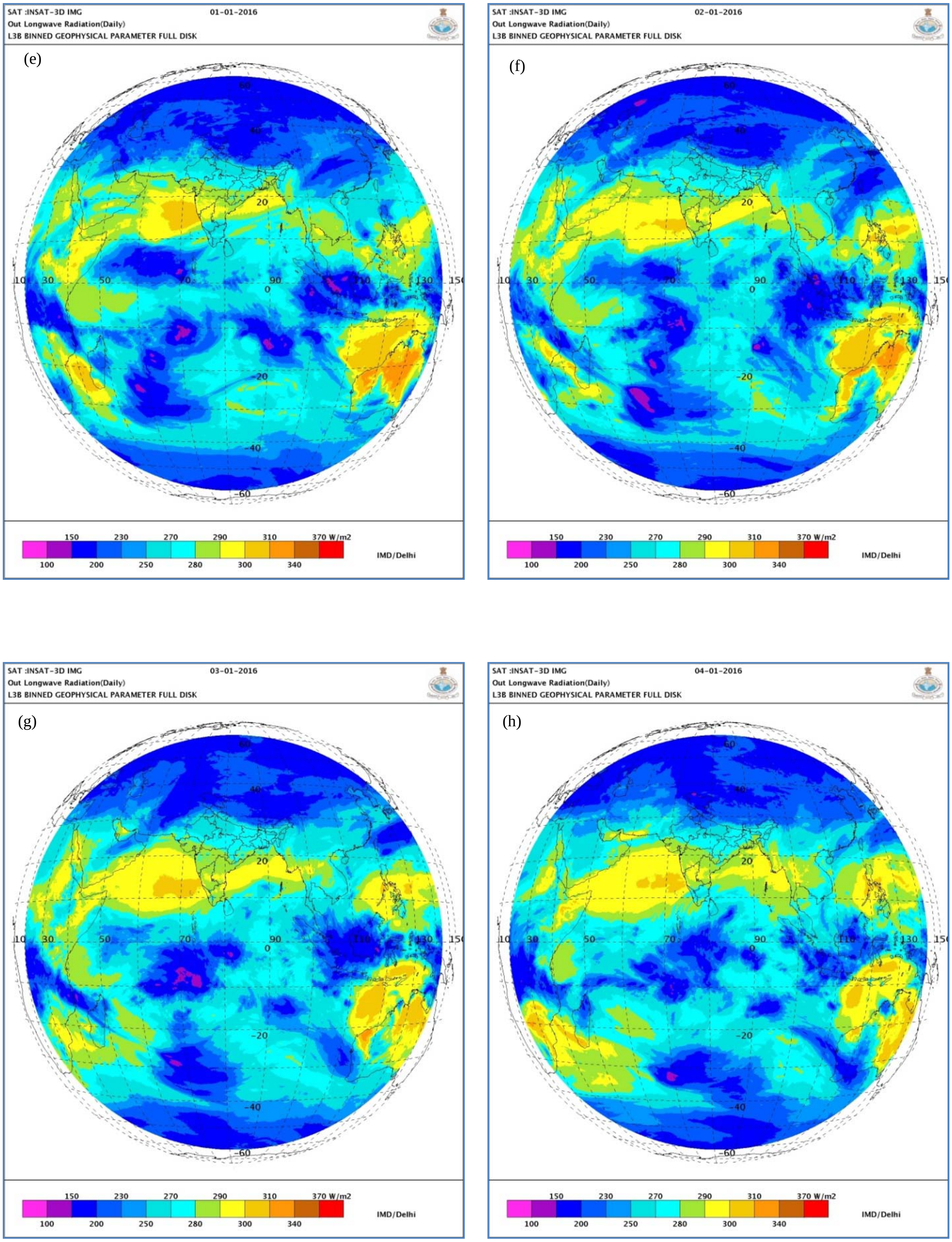
4.2. *After the Manipur earthquake, 2015*

Similar distribution of low and high values of OLR after the occurrence of Manipur earthquake, 2016 could be seen as observed prior to the earthquake, *i.e.*, lower values of OLR over north India and relatively higher values (280-300 W/m^2) from Arabian Sea, Bay of Bengal and thence to Pacific Ocean. Very high patches of OLR persisted over northwest Australia [Figs. 2(a-h)].

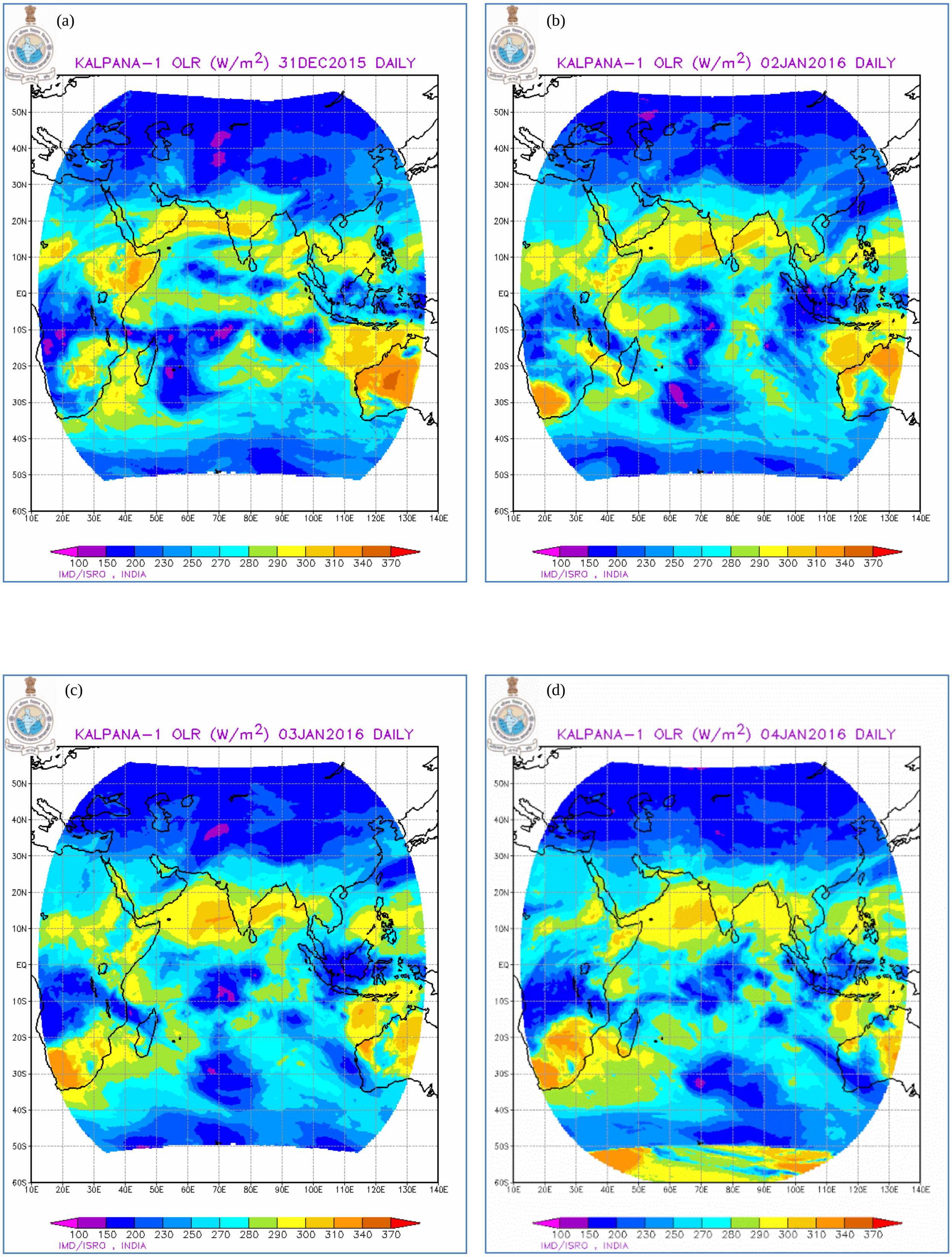
Similar results were found from Kalpana satellite as well for all these days [Figs. 3(a-d)].



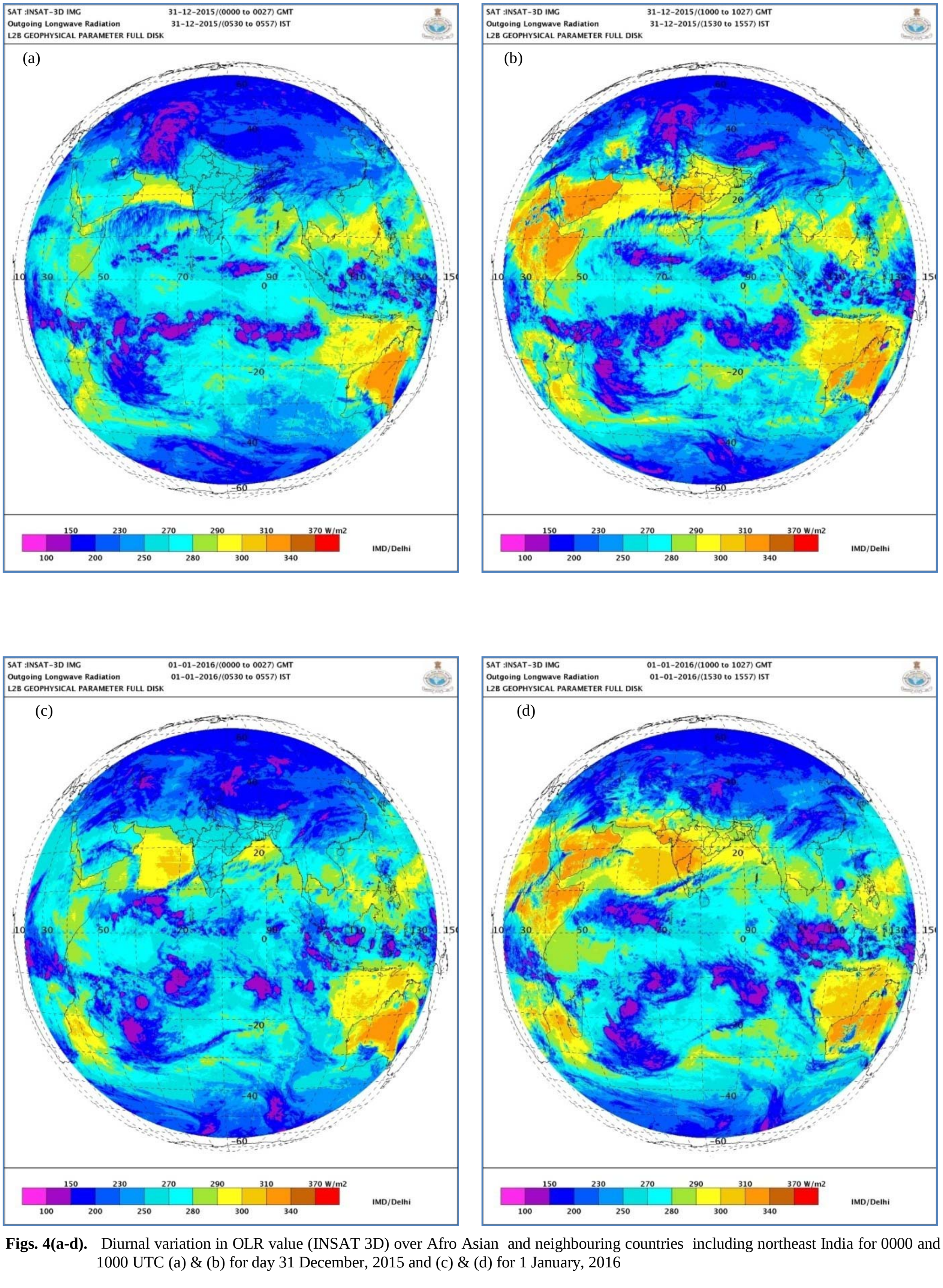
SAT :INSAT-3D IMG
28-12-2015
Out Longwave Radiation(Daily)
L3B BINNED GEOPHYSICAL PARAMETER FULL DISK
(a)
SAT :INSAT-3D IMG
29-12-2015
Out Longwave Radiation(Daily)
L3B BINNED GEOPHYSICAL PARAMETER FULL DISK
(b)
SAT :INSAT-3D IMG
30-12-2015
Out Longwave Radiation(Daily)
L3B BINNED GEOPHYSICAL PARAMETER FULL DISK
(c)
SAT :INSAT-3D IMG
31-12-2015
Out Longwave Radiation(Daily)
L3B BINNED GEOPHYSICAL PARAMETER FULL DISK
(d)
150 230 270 290 310 370 W/m2
100 200 250 280 300 340
IMD/Delhi



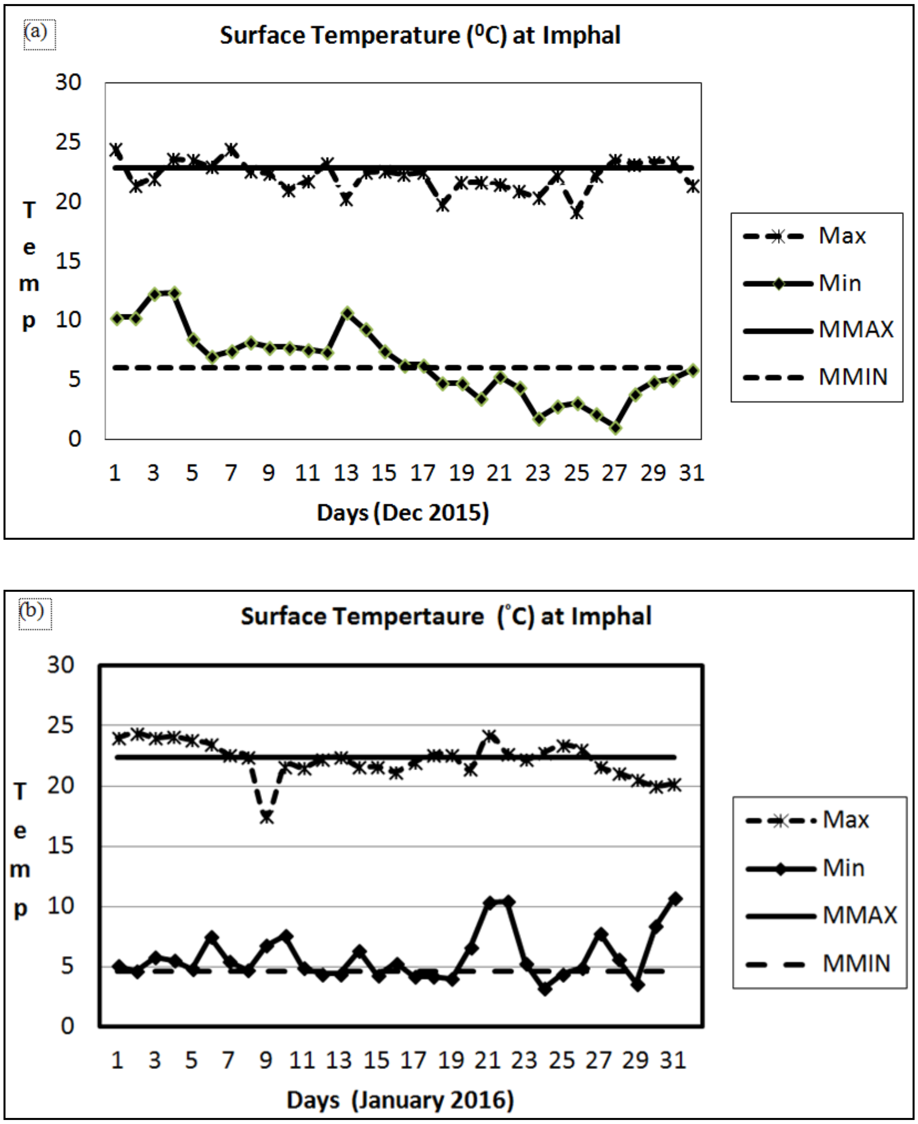
Figs. 2(a-h). OLR (INSAT 3D) over Afro Asian and neighbouring countries including region of northeast India [for day (a) 28, (b) 29, (c) 30, (d) 31 December, 2015 and (e) 1, (f) 2, (g) 3 and (h) 4 January, 2016]



Figs. 3(a-d). OLR (Kalpana satellite) over Afro Asian and neighbouring countries including region of North East India [for days (a) 31 December, 2015 and (b) 2, (c) 3 and (d) 4 January, 2016]



Figs. 4(a-d). Diurnal variation in OLR value (INSAT 3D) over Afro Asian and neighbouring countries including northeast India for 0000 and 1000 UTC (a) & (b) for day 31 December, 2015 and (c) & (d) for 1 January, 2016



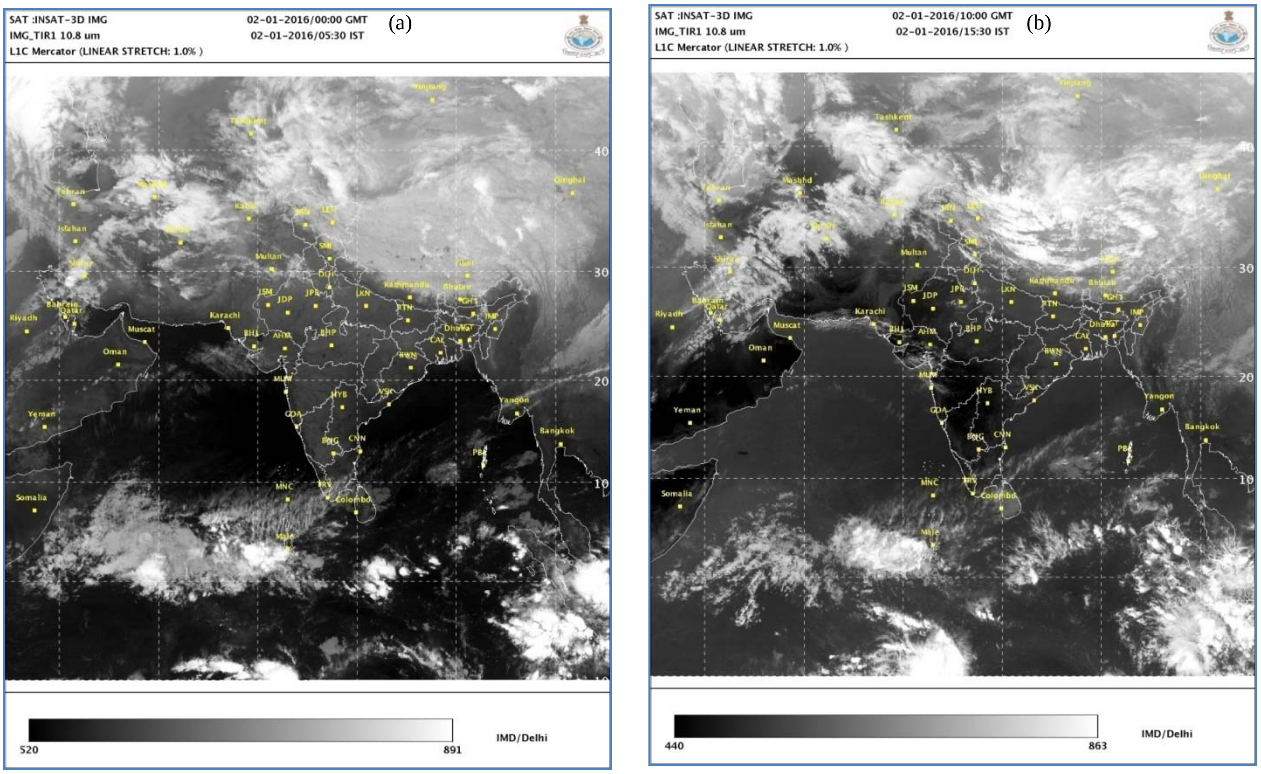
Figs. 5(a&b). Surface Temperature (ºC) variation at Imphal during (a) December, 2015 and (b) January, 2016

4.3. *Diurnal variations of OLR*

Diurnal variations of OLR as recorded by INSAT 3D were studied for two representative days namely 31 December, 2015 and 1 January, 2016 prior to Manipur earthquake 2016 at 0000 and 1000 GMT close to minimum and maximum temperature [Figs. 4(a-d)]. The differences in OLR over land and oceanic region is attributed to low and high thermal capacity of respective regions due to which much larger diurnal variations occur over land as compared to oceans. In the morning hour, the lowest values of OLR were recorded over north India where temperatures are lower as compared to the rest of the country. Highest values of OLR of 290-310 W/m^2 could be seen over north Arabian sea, parts of Bay of Bengal, Thailand, south China sea. In the afternoon, there was a general rise in OLR values over the land areas with still higher values over Gujarat and Maharashtra.

In order to corroborate the OLR variations with the surface temperatures, the temporal variations of maximum and minimum temperatures at Imphal (about 30 km from the epicentre of Manipur earthquake) were examined for the months of December 2015 and January 2016 [Figs. 5(a&b)]. The following inferences are drawn:

(*i*) In the month of December 2015, the maximum temperatures of 24.5 °C occurred on 1 and 7 December and slightly lower temperature of 23 °C to 23.5 °C on 4, 5,



Figs. 6(a&b). Cloud picture (IR1 band) over India and adjoining area including northeast India on 2 January, 2016 (a) 0000 UTC and (b) 1000 UTC

6, 12, 28 and 30 December. In the month of January 2016, the maximum temperature of 24 °C or more occurred on 1, 2, 3, 4 and 21 January. The slightly lower temperature of 23 to 23.5 °C occurred on 5, 25 and 26 January. The mean maximum temperatures at Imphal during December, 2015 and January, 2016 are 22.9 °C and 22.4 °C respectively. This implies that the maximum temperature at Imphal never rose by more than 2 °C during these two months.

(*ii*) The highest minimum temperature of 12.3-12.4 °C at Imphal occurred on 3 and 4 December, 2015 followed by 11 °C on 27 December. The lowest minimum temperature of 1.8 °C at this station was recorded on 23 December. The highest minimum temperature of 10.4 to 10.7 °C were recorded on 21, 22 and 31 January. The lowest minimum temperature of 3.2 °C occurred on 24 December. The minimum temperature on 4 January was 5.5 °C while the larger minimum temperatures of 7.5 °C and 7.6 °C occurred on January 6 and 10 after the earthquake.

INSAT cloud pictures given in Figs. 6(a&b) (2 January, 2016) shows that there were no clouds in northeast region prior to the earthquake of 4 January, 2016. This suggests that OLR values in the region were not affected by clouds.

5. Discussion

Synthesis of daily mean values of OLR based on satellite observations generally follows the temperature distribution over India during winter (Climatological Normal of India, IMD). Lower values of OLR were attributed to lower temperatures in north India during December 2015 and January 2016. High OLR over northwest Australia was attributed to prevailing summer season in southern hemisphere. Diurnal variations of OLR over Indian region also followed the minimum and maximum temperatures trend as expected from the thermal capacity difference between land and oceans. It would thus be seen that the causes for OLR variations are meteorological in origin.

Figs. 2(a-h) and 3(a-d) show that OLR values were much lower in northeast India as compared to peninsular India. There was a slight rise of OLR in Tripura and adjoining regions on 1 January, 2016 which decreased the next day. The earthquake of 4 January occurred in the zone of lower OLR while much larger values could be seen over peninsular India, Arabia and parts of Africa. If the rise of OLR southeast of earthquake on 1 January, 2016 is considered as precursory, it would be misleading because the OLR values decreased next day onwards to

TABLE 2

Number of earthquakes worldwide (Source: US Geological Survey)

Magnitude range	Year 2008	Year 2009	Year 2010	Year 2011	Year 2012	Year 2013	Year 2014	Year 2015
8 - 9	0	1	1	2	2	1	1	1
7 - 7.9	12	16	21	19	15	17	11	18
6 - 6.9	168	144	151	204	129	125	140	124
5 - 5.9	1768	1896	1963	2771	1412	1402	1475	1413
4-4.9	12292	6805	10164	13303	10990	9795	13494	13230

similar lower values as on 31 December, 2015 or earlier. Lower values of OLR (150-200 W/m^2) were also found prior to the Sikkim earthquake of 2011 (Prakash and Srivastava, 2015) and Nepal earthquake 2015 (Prakash *et al*., 2015). Contrary to these results, Baral *et al*. (2016) postulated the emission of green house gases, emitted from the fault zone region of Nepal earthquake 2015 but failed to explain why the consistent rise of temperature could not sustained till occurrence of earthquake and also did not explain similar study for its largest aftershock of 12 May, 2015 (Mw:7.3). Thus, precursory rise in OLR or thermal anomaly prior to earthquakes is not substantiated.

Table 2 shows a general frequency trend of earthquake occurrence in different magnitude range over the globe. About 5000 and 10000 earthquakes occur every year in the magnitude range of 5 to 5.9 and 4 to 4.9 respectively. However, Saraf *et al*. (2012) considered thermal anomaly before only one earthquake of magnitude 4.9 to 5 in Uttarakhand. They connected largest spatial extent of thermal anomaly away from the epicentre over elevated Tibetan plateau which is questionable when compared with much larger earthquake of Dalbandin (Pakistan) (Mw 7.2) in 2012 and many others. Simha *et al*. (2015) reported increase of OLR from 20 to 100 W/m^2 prior to a few larger earthquakes near Indian region but could not find any increase in three other cases. The OLR distribution over the countries within the view of the Kalpana and INSAT 3 D satellites [Figs. 2(a-h) & 3(a-d)] shows much larger variations on any day besides diurnal variations [Figs. 4(a-d)]. Higher OLR anomalies in the epicentral regions reported earlier prior to Latur (1993); Jabalpur (1997); Bhuj (2001) and Muzaffarabad (2005) and other earthquakes (Srivastava *et al*.,1997; Saraf and Chaudhury, 2005a&b; Panda *et al*., 2007; Saraf *et al*., 2012) were shown to be within the meteorological variability (Prakash and Srivastava, 2015).

Limitations in associating earthquakes with thermal changes have been pointed out earlier by several workers. Okyay (2012), surmised that LST anomalies observed by MODIS/Terra satellites are not always followed by an earthquake. Qu (2006) examined NOAA 16 satellite data prior to earthquake of 24 March, 2004 (Ms: 5.9) and concluded that such anomalies are probably caused by atmosphere temperature inversion phenomena instead of earthquake. Blackett *et al*. (2010) did not find convincing evidence of LST precursors to 2001 Bhuj earthquake (Mw: 7.6). Prakash and Srivastava (2015) found increase in the maximum temperatures for a longer time from January 11 to January 18 in 2014 as compared to 2001 at Bhuj observatory. Since no earthquake occurred in 2014, it was concluded that the anomalous rise in temperature in Gujarat prior to Bhuj earthquake, 2001 was not exceptional and cannot be considered as earthquake precursor (Saraf and Chaudhury, 2005a)

Saraf and Chaudhury (2005b) noted rise in temperature for 5 days prior to 26 December, 2003 earthquake but dropped on the day the earthquake occurred. If we assume that there is transfer of heat from the causative faults to the earth surface or by some mechanism (Pullinets *et al*., 2006), there should be a consistent rise in OLR or thermal anomaly at least till the occurrence of the earthquake. However, if dilatancy model is assumed to hold good, OLR or surface temperatures should rise consistently and then decrease for some time. Such anomalies again increase to at least the earlier values prior to main earthquake and remain high during the aftershocks (if any). Such a rise in temperature however cannot be distinguished from the synoptic and dynamic weather changes as observed on the globe. This is abundantly clear from the OLR distribution as measured by satellites imageries when patches of larger OLR occur in different regions without any seismic activity [Figs. 2(a-h) & 3(a-d)]. Also, any statistical technique however advanced may reduce the influence of diurnal, seasonal or annual changes (Wei *et al*., 2013) but cannot incorporate sudden and persistent changes caused by dynamical weather systems which may produce anomalies of 10 °C or more (Indian Daily Weather Reports, India Meteorological Department) besides very large ambiguity during heat or cold waves. Still larger changes occur in humidity in the atmosphere (Srivastava *et al*., 1994) under different weather situations. Such variations in temperature and humidity associated with plate interaction around the time of Michoacan earthquake 1985 (Pullinets and Dunajecka, 2007) are open to question. Rising trends in temperature over India has been reported since 1901 which is similar to other places in the world (Srivastava *et al*., 1992). The climate change is also causing unusual rise or fall in temperature over extensive areas in different parts of the world from time to time. Deeper understanding of dynamical weather systems and climatology would restrain geoscientists to use thermal anomaly as a precursor for tectonic earthquakes.

6. Conclusions

Analysis of OLR data obtained from Kalpana and INSAT 3D satellites over northeast India and neighbourhood from 25 December, 2015 to 5 January, 2016 showed that the Manipur earthquake 2016 occurred in the region where low values of OLR were found. This was corroborated through scrutiny of surface temperatures at Imphal, about 30 km away from the epicentre. High values of OLR were found far away from the epicentral region where no significant seismic activity occurred. Similar results were reported prior to Sikkim earthquake 2011 (Mw 6.9) and Nepal earthquake 2015 (7.8), suggesting that attempts to use thermal anomalies as earthquake precursor need to be discontinued due to larger changes caused by dynamic weather systems or climate change.

The seismogenesis is an intricate process and it is therefore very difficult to infer that diurnal or secular variation can provide authentic information on earthquake precursory signal keeping in view that OLR is a measure of thermal anomalies which is profoundly affected by several factors associated with physical processes over the earth surface and the atmosphere. In order to resolve such enigmatic issue there is a need of adopting integrated approach using a large volume of data collected over long duration.

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