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An analysis of the relation between precipitation and earthquake in the Indian region

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The paper aims to examine the relation between rainfall anomalies and occurrence of earthquakes (magnitude > 6.5) in the Indian region. For this purpose, earthquakes of Sikkim (18 September 2011), Gujarat (26 January 2001), Uttarkashi (20 October 1991) and Assam (15 August 1950) are considered. Anomaly in rainfall magnitude is calculated from the synoptic seasonal fluctuation of rainfall as the seasonal ambient level, considering gridded rainfall data from India Meteorological Department (IMD) (1°×1°), NECP/NCAR reanalysis (2.5°×2.5°), and monthly accumulated rainfall data from the Indian Institute of Tropical Meteorology (IITM). Monthly spatial rainfall distribution obtained from Tropical Rainfall Measuring Mission (TRMM) is also plotted over the epicenter zone of the earthquakes under consideration. In Sikkim, Gujarat and Assam earthquake cases, high positive anomaly (beyond ambient level) in rainfall is observed in the earthquake months, whereas no such association is detected for Uttarkashi event. Further, the rainfall anomalies are associated with earthquake induced heat flux and the results obtained are discussed in terms of the seasonal atmospheric variabilities and geographical features of the region near to earthquake epicenter.

Keywords: Earthquake, Precipitation, Rainfall anomaly, Spatial rainfall distribution, Seasonal atmospheric variability

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1 Introduction

The modifications in the normal atmospheric conditions around the epicenter are possible by the earthquake preparatory process[1]. Hence, efforts have been made towards understanding the association of the atmospheric anomalies in relation to earthquake. Changes in atmospheric water vapour, aerosol parameters have been observed around epicenter of the Gujarat earthquake[2,3]. Variation in air temperature and humidity, resulting anomalous changes in the surface latent heat flux (SLHF), is detected[4] around the epicenter of the coastal earthquakes. There are also reports of thermal anomaly around the epicenter region of earthquake[5,6] and those variations are attributed to the thermal flux deposited in the seismically active region[7] of earth's crust. The earthquake induced atmospheric disturbances are even reflected in the ionospheric height[8-10]. Detailed studies on atmospheric variables have been taken up over land, ocean and atmosphere to understand the possible mechanisms involved in the modification of the normal atmospheric profiles by an earthquake with an aim to collect precursory signatures, if any[11,12].

In the present study, an effort is made to examine the association between precipitation and earthquakes in the Indian region. For this purpose, four earthquake (M_w > 6.5) events are studied to find the possible contribution of the earthquake preparatory process to anomalous precipitation near the epicenter region. The association between rainfall and the occurrence of earthquake is discussed in terms of the thermal fluxes ejected during earthquake preparatory processes. The possible influences of climatic conditions and geographical environment of the epicenter are also discussed.

2 Event description

For this study, only those earthquake events are considered which have magnitude of 6.5 M_w and above. Location, date of occurrence, depth, magnitude, etc. of the earthquake events are presented in Table 1. Sikkim earthquake occurred on 18 September 2011 with a magnitude of 6.9 M_w. The earthquake centered within the Kanchenjunga conservation area (27.723°N, 88.064°E), near the border of Nepal and in the Indian state of Sikkim, at 18:10 hrs IST (12:40 hrs UT). Its depth was 19 km and duration was 30-40 second. Gujarat earthquake occurred on 26 January 2001 at 08:46 hrs LT (03:16 hrs UT) and lasted for over two minutes. The epicenter location was near 23.419°N, 70.232°E, with an intensity of 7.7 M_w and depth of 16 km. The Uttarkashi earthquake of magnitude 6.8 M_w and depth 10 km occurred on 20 October 1991. The epicenter was situated within the main thrust system of the Himalaya (30.78°N, 78.77°E). Assam earthquake occurred on 15 August 1950 with a magnitude of 8.6 M_w. The epicenter was located near Rima, in Tibet (28.5°N, 96.5°E).

3 Data and Methodology

For the study, the daily gridded rainfall data from India Meteorological Department (IMD), which were available for the period 1951–2007 with a spatial resolution of 1°×1° (lat /long), has been used. This data set is constructed by collecting rainfall data from 1803 stations all over India with minimum 90% data availability during the analysis period[13]. Reanalysis data sets of NCEP/NCAR (1948 - present) are also used for evaluating the rainfall anomaly near the epicenter regions before the earthquakes. These data (2.5°×2.5°) are available as four times daily format and daily averages. Monthly accumulated rainfall data from the Indian Institute of Tropical Meteorology (IITM) website (www.iitm.ac.in) and Tropical Rainfall Measuring Mission (TRMM) Online Visualization and Analysis System (TOVAS) (http://gdata1.sci.gsfc.nasa.gov) are also utilized for this study.

Considering a period of twenty years, including the earthquake year, the total monthly rainfall is evaluated for the earthquake month and then the mean (μ) of these twenty years (composite) is calculated. This composite has been subtracted from the individual years to get the composite rainfall anomalies (CRA) for each year. CRA is, then, normalized by dividing with the standard deviation (σ) of the anomalies to get the normalized composite rainfall anomaly (NCRA). The year-to-year rainfall variability also depends on the seasonal synoptic variation of atmospheric parameters over a region. To filter out these variabilities, μ plus 2×σ of the total rainfall is used as background seasonal ambient level over that region and any fluctuation beyond these limits are considered as an anomaly due to earthquake.

Surface temperature data for this study have been obtained from the NCEP-NCAR reanalysis of the IRI/LDEO Climate Data Library (http://iridl.ldeo.columbia.edu/). This is a global database centre of various meteorological and surface parameters. These data are generated by taking the measured values of variables from worldwide stations and also those retrieved from satellite data. These parameters are available from 1 Jan 1948 to 7 Oct 2012 and with resolution of global grid 1.8°×1.8°.

4 Results and Discussion

4.1 Sikkim earthquake on 18 September 2011

Here, the zone of 26°-28°N and 86°-89°E covering the epicenter location has been considered. For the month of September, the ambient level of rainfall, using 20 years (1992-2012) climatology, is 338.80 mm and NCRA is ±2.03 over the region under consideration. Figure 1(a) shows the spatial distribution of the surface precipitation rate for September 2011 where a very heavy rain rate is seen over Sikkim. It is also noted from Fig. 1(b) that the rainfall magnitude in 2011 was 420 mm, which was above the seasonal ambient level in contrast to other years. Monthly accumulated rainfall from TRMM satellite is also presented in Fig. 1(c) as a supporting data, which shows a maximum of 540 mm of rain near the epicenter. The spatial distribution of the composite rainfall anomaly for September 2011 is shown in Fig. 2(a) and the yearly variation of NCRA for the month of September 2011 is shown in Fig. 2(b). Here, the positive fluctuation of the NCRA was observed to be 3.31.

4.2 Gujarat earthquake on 26 January 2001

For this case, the rainfall for the month of January 2001 is computed for the grid box within 22.5°-

Table 1 — Earthquakes under consideration

S No	Date	Location	Epicenter position		Depth, km	Magnitude, M_w	Distance from sea, km
			Latitude, °N	Longitude, °E			
1	18 Sep 2011	Sikkim	27.72	88.064	19.7	6.9	440
2	26 Jan 2001	Gujarat, Bhuj	23.41	70.232	16	7.7	80
3	20 Oct 1991	Uttarkashi	30.78	78.77	10	6.8	1300
4	15 Aug 1950	Assam	28.5	96.5	*	8.6	650

**For Assam earthquake depth information is not available*

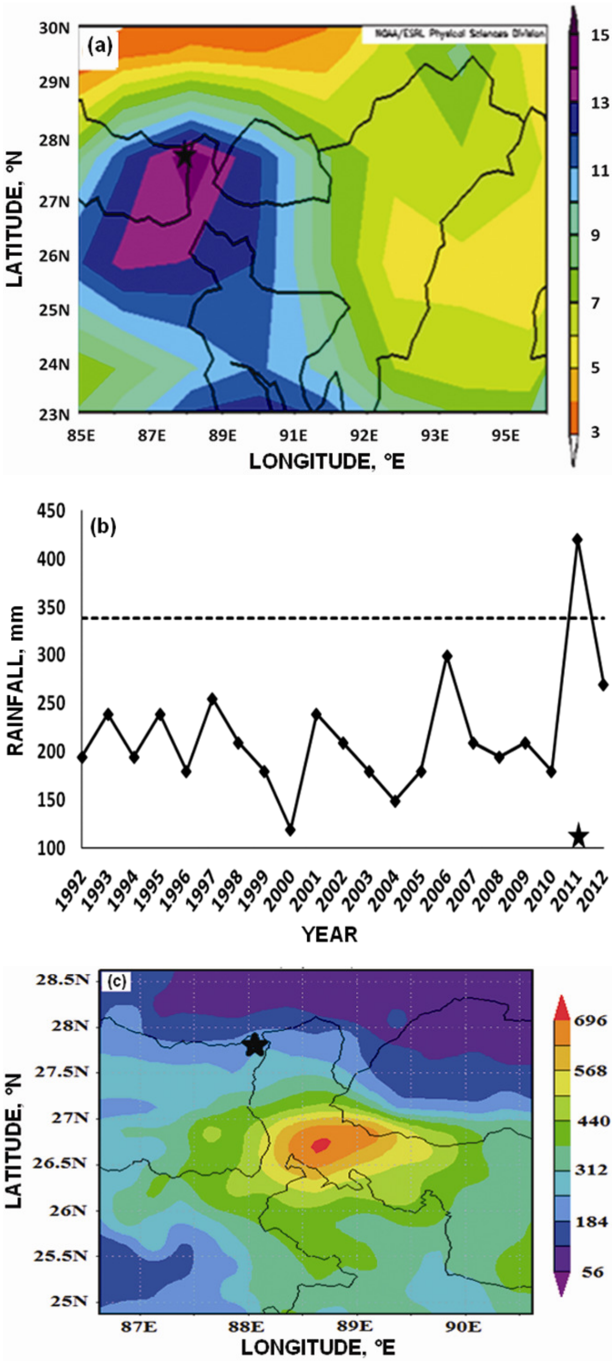

Fig. 1 — (a) Monthly surface precipitation rate over Sikkim for September 2011; (b) Yearly variation of September month total rainfall (1992-2012); and (c) Monthly accumulated rain from TRMM over Sikkim for September 2011 [earthquake year is represented by ★ symbol and dotted line represents ambient level]

24.5°N and 71.5°-73.5°E covering the epicenter. The seasonal background precipitation over Gujarat for the month of January is estimated to be 114.2 mm (based on 1988-2007 climatology). The monthly accumulated rainfall over Gujarat in January 2001

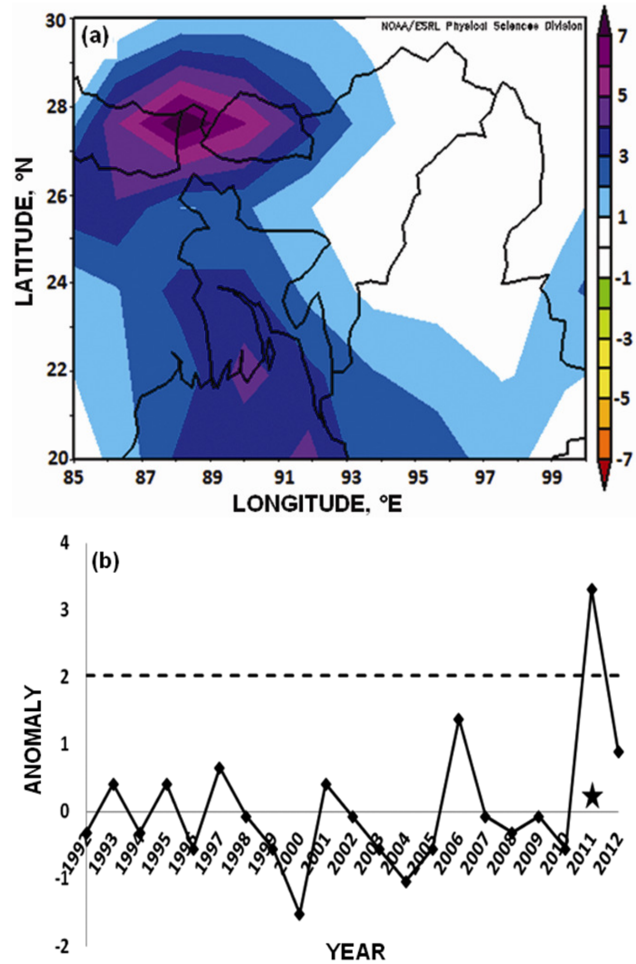

Fig. 2 — Composite rainfall anomaly over Sikkim (1992-2012 climatology): (a) Spatial distribution of CRA of 2011; and (b) yearly NCRA variation for September month

was observed to be 210 mm as shown in Fig. 3(a), which was far above the ambient level as demonstrated in Fig. 3(b). Spatial rainfall distribution from TRMM, for the January month 2001 is presented in Fig. 3(c). Some localized rainfall signature is observed near the earthquake zone during the earthquake month and in some areas, more than 220 mm of rainfall was observed in that month. Figure 4(a) shows the spatial distribution of CRA over Gujarat region for January 2011. From the climatology, it is seen that NCRA for the month of January over Gujarat used to fluctuate ±2, but from the results, it was seen that for the month of the earthquake it was +4.04, which was a positive excursion above the seasonal ambience.

4.3 Uttarkashi earthquake on 20 October 1991

For this case, the rainfall for the month of October 1991 is computed for grid box within 30°-32°N and

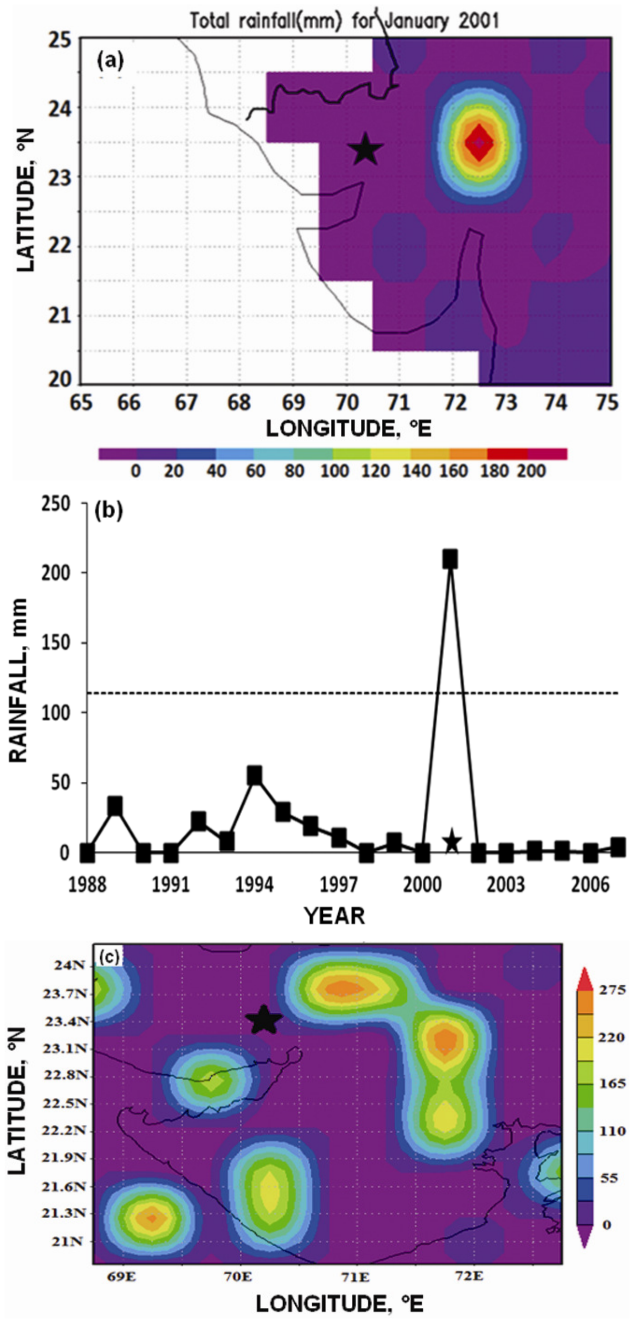

Fig. 3 — (a) Monthly accumulated rainfall for January 2001; (b) Yearly variation of accumulated January month rainfall over Gujarat; and (c) Spatial distribution of total monthly rainfall over Gujarat for January 2001

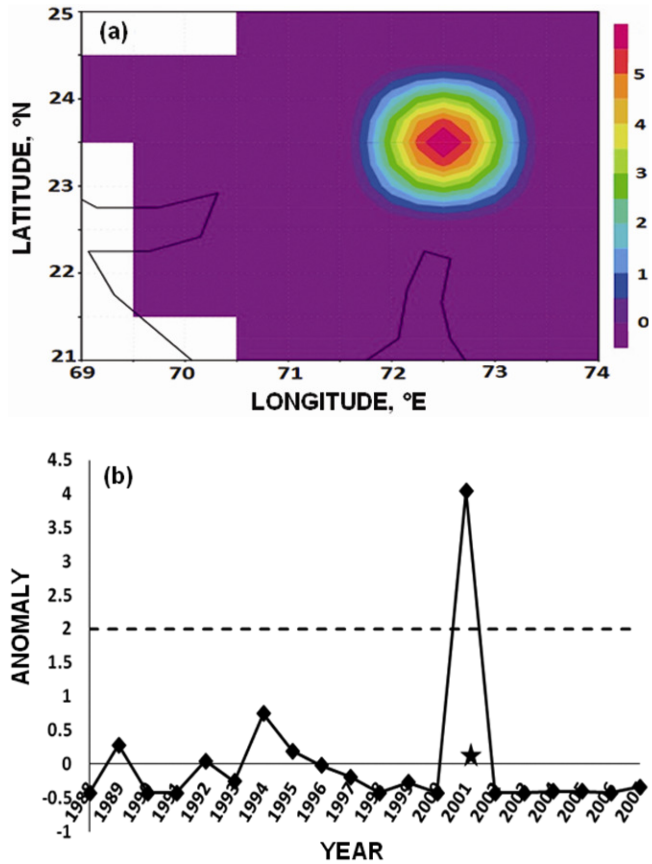

Fig. 4 — (a) January month CRA of rainfall over Gujarat for 2001; (b) Variation of yearly January month NCRA (1988-2007 climatology)

77°-79°E covering the epicenter location. The seasonal background ambient level over Uttarkashi for the month of October is estimated to be 125.43 mm (based on 1981-2000 climatology). Figure 5(a) shows accumulated rainfall of 12.4 mm for October 1991, which was far below the ambient level. Figure 5(b) presents the yearly variation of accumulated rainfall over Uttarkashi. In Figure 6(a), CRA over Uttarkashi for October 1991 is shown and NCRA over this region for the month of October is displayed in Fig. 6(b). From the climatology, it is seen that NCRA over Uttarkashi for the month of October fluctuates ±1.99, but from the result, it is seen that for the month of the earthquake it was -1.03, which was well below the set limit in the negative direction.

4.4 Assam earthquake on 15 August 1950

Assam earthquake is a past event and during those days there was a sparse availability of atmospheric data. To analyse this event, the data set, available on the IITM website (www.iitm.ac.in), which has been developed using high quality controlled data from well spread network of 316 rain gauge stations, has been taken. Using this data set, a time series analysis for the August month is done based on the 1939-1957 climatology. Following the procedure mentioned above, the composite rainfall anomaly for the period under consideration has also been calculated.

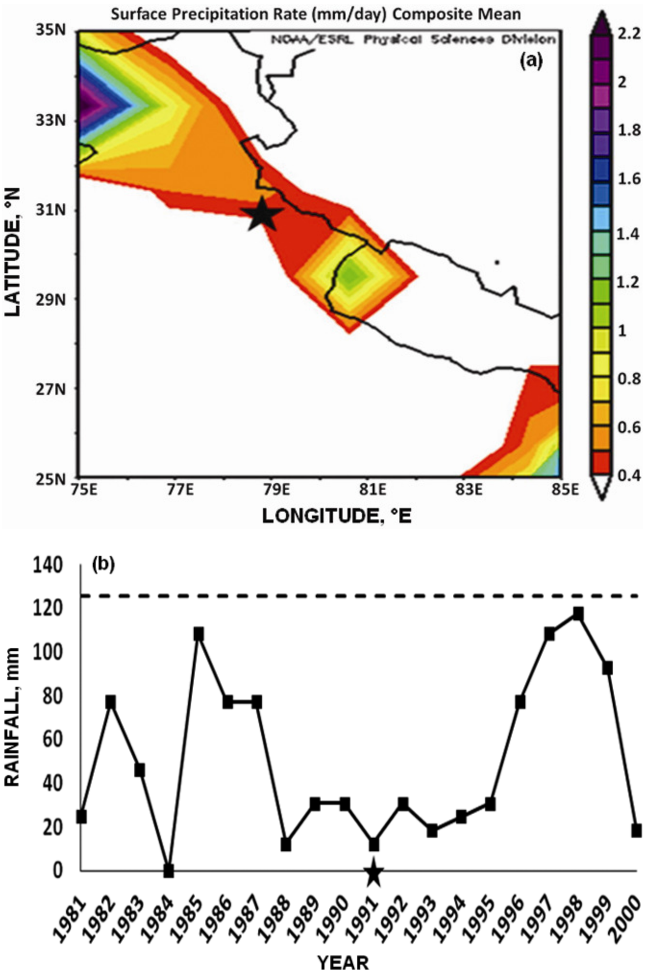

Fig. 5 — (a) Monthly accumulated rainfall for October 1991; and (b) Yearly variation of accumulated October month rainfall over Uttarkashi

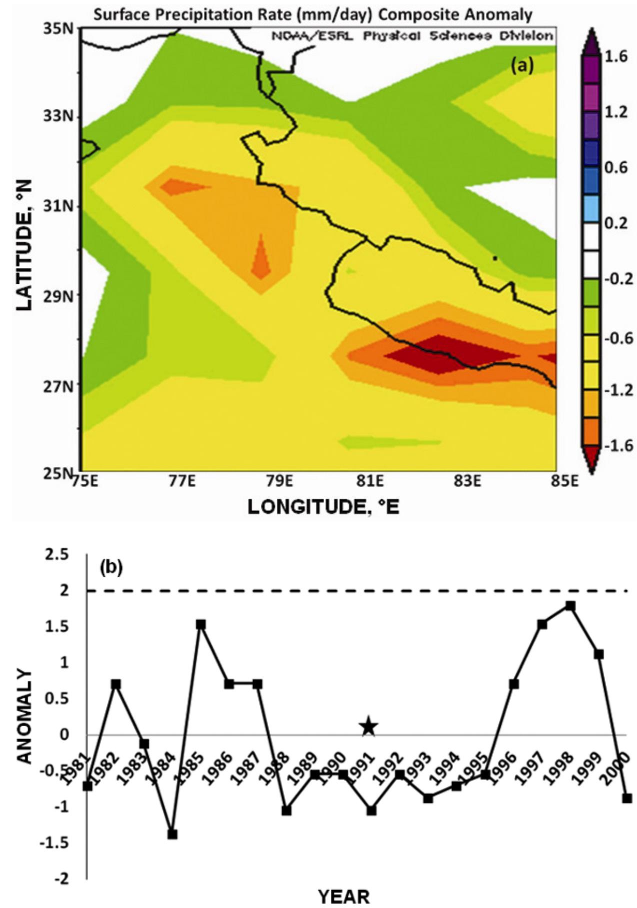

Fig. 6 — (a) October month CRA of rainfall over Uttarkashi for 1991; (b) Variation of yearly October month NCRA (1981-2000 climatology)

Here, the seasonal ambience for August month is estimated to be 436.22 mm and the NCRA fluctuation limit is ±2.26 (1939-1957 climatology). From Fig. 7(a), it is clear that the August 1950 received a heavy rainfall of 453.7 mm, which is quite high as compared to the other years under consideration. Figure 7(b) shows the NCRA over Assam for the month of August from 1939 to 1957, where a positive anomaly of 2.82 is observed for the earthquake year 1950.

In three of the above cases, a positive rainfall anomaly has been observed in the earthquake month of the particular year as compared to the rest of the years. To explain these anomalies, it is necessary to consider the energy fluxes released in an earthquake process. Geological observations in the earthquake region reveal that the total energy released in earth is divided into two parts: seismic energy and the frictional heat energy[14]. Hence, in this study, the efforts have been made to relate the release of heat energy to the changes in the land surface temperature (LST) of the Earth surface. For this, the LST anomaly profiles near the epicenter region of Gujarat and Sikkim earthquakes have been considered as examples. It is seen from the LST profile Fig. 8(a) that from 23 January, LST showed a positive anomaly with a maximum value of +5 on 25 January. In case of Sikkim earthquake, temperature started increasing from 10 September and the maximum anomaly (+2.10) was observed on 11 September [Fig. 8(b)]. For Uttarkashi earthquake also, anomaly in the LST was seen before the earthquake and the maximum anomaly was seen on 14 October (+1.54) [Fig. 8(c)]. Here, anomalies in LST were seen from three days to two weeks before the occurrence of the event. Similar results of anomalies in LST were also reported by different researchers[15-19]. Hence, rise in thermal fluxes in earthquake preparatory process may be attributed for anomalous rainfall as observed.

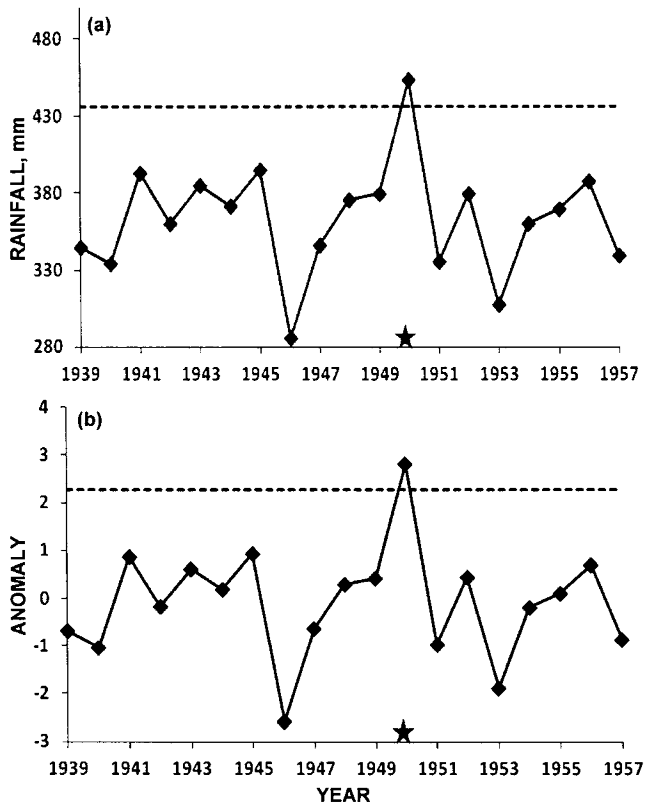

Fig. 7 — (a) August month total rainfall over Assam (1939-1957 climatology); (b) August month NCRA of rain over Assam (1939-1957 climatology)

But in case of the Uttarkashi earthquake, no rainfall anomaly was observed in the earthquake month like the rest of the cases. Hence, it is necessary to consider the influence of the season and surrounding environment on the rainfall anomaly related to earthquake. In case of the Gujarat earthquake, the distance of the epicenter was only 80 km from the sea coast. So, the thermal flux imbalance may create a pressure difference between the epicenter region and the sea region and hence, there is a possibility of moisture transport from sea to the region near epicenter. This anomalous change in water vapour around the epicenter was reported by Dey *et al.*[2] in the case of Gujarat earthquake. Sikkim and Assam earthquakes occurred in the month of September and August, respectively, i.e. just after the monsoon and water availability in those regions may contribute to the rainfall anomaly. But Uttarkashi is a land lock region and the distance of the earthquake epicenter in this case is about 1300 km. In addition, the earthquake occurred in a dry month (October) of that region. This may be the possible reason for no rainfall anomaly in the case of Uttarkashi earthquake.

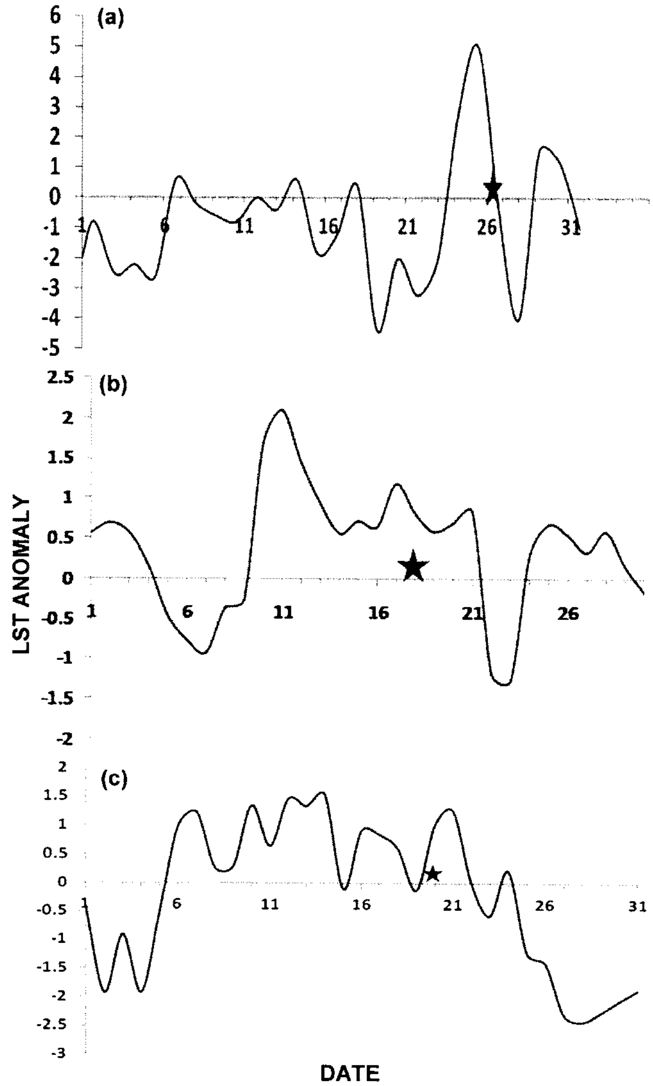

Fig. 8 — LST anomalies during: (a) Gujarat earthquake; (b) Sikkim earthquake; and (c) Uttarkashi earthquake

5 Summary and Conclusions

In the present paper, an association between earthquake and precipitation close to the epicenter is examined by considering four earthquake events in India, which are having magnitude of more than 6.5 M_w. This association is studied by evaluating the rainfall anomalies in the month of earthquake for different years.

From the results, it is observed that in the first event the monthly accumulated rainfall over Gujarat in January 2001 was 210 mm which was far above the ambient level of 114.2 mm. The NCRA value 4.04 is beyond the positive limit of 2 in the earthquake year. For the Uttarkashi case, no positive anomaly in rainfall is seen in the earthquake month. The earthquake month accumulated rainfall was 12.4 mm, which was well below the seasonal ambience boundary of 125.43 mm. NCRA in this case was negative (-1.03) as compared to the NCRA fluctuation limit of 1.99. In the case of Sikkim earthquake, the September month seasonal ambience level was 338.80 mm and the fluctuation limit of NCRA is 2.03, but the results show a monthly rainfall of 420 mm and NCRA of +3.31 in the year of earthquake. In Assam earthquake also, anomalous features are seen with NCRA value of +2.82. In this case, total rainfall of the earthquake year was 453.7 mm, which was higher than the seasonal ambience level of 436.22 mm.

From the earthquakes under consideration, it is observed that for the Sikkim, Gujarat and Assam cases, in the earthquake month, there is a high positive anomaly in the years of earthquakes compared to other years. In Uttarkashi case, no rainfall anomaly is observed. The physics behind this anomalous rainfall has been related to changes in the thermal energy of the earth surface due to earthquake preparatory processes, which may lead to the changes in the surface heat fluxes around the epicenter region. The sensible heat flux increases evapo-transpiration, which is one of the sources for water vapour transportation to the atmosphere. This, in turn, may trigger the cloud formation and hence, precipitation anomalies. Again, the season in which the earthquake occurred and the distance of the epicenter from the ocean may also contribute significantly for the observed rainfall anomaly. This physical relation of different atmospheric parameters with the earthquake will be carried out in future as a part of this work.

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