



# Long term (1975-2016) anomaly of surface latent heat flux (SLHF) over Indian subcontinent: Signatures of early warning of earthquake disasters

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A long-term anomaly study of 42 years (1975-2016) of surface heat flux (SLHF) from the epicentres of the earthquakes over the Indian subcontinent carried out. The results of study revealed anomalous behaviour. On an average, maximum surge of SLHF was found to be 10-15 days before the main earthquake events which were likely due to the ocean atmosphere interaction. This improvement of SLHF before the most earthquake events was considerably attributed to the surge in infrared thermal (IR) temperatures within the epicentral and near surroundings. The abnormal surge in SLHF provides associate early cautionary of a ruinous earthquake during a region, provided there's a decent understanding of the ground noise because of the zonal tides and regional monsoon in surface heat energy flux. A lot of effort has been put to have an understanding of the level of background noise within the epicentral regions of the 10 earthquakes over the Indian Subcontinent during the last 42 years. Latitudinal and longitudinal effects of SLHF anomaly for the ten earthquakes over Indian Subcontinent were studied, which showed that the anomalous behaviour of SLHF before the main earthquake events were somewhat associated only with the coastal earthquake activities.

**Keywords:** Latent heat, Hazardous, Earthquake, Atmosphere

## 1 Introduction

Earthquake events have close relationships with a number of geophysical and ionospheric parameters<sup>1-6</sup>. This has been proved by recent studies conducted on the earthquakes which occurred around the Globe<sup>7-8</sup>. However, earthquake prediction is still taken as a challenge<sup>9</sup>. The atmospheric parameters might prove to be the probable forerunners of an earthquake event if we understand their characteristic behaviour. In recent times, many catastrophic earthquakes have occurred frequently near the earth-ocean surface<sup>10-14</sup>. Recent earthquakes occurring near the ground surface have shown momentous fluctuations on the land and ocean parameters<sup>15-18</sup> which have prompted us to study the effects in atmospheric surface parameters associated with these earthquakes<sup>19</sup>. A study conducted on the multi-sensor satellite data of Gujarat and other earthquakes have shown anomalous behaviour of surface latent heat parameters in the atmosphere prior to the events and especially those occurred near the ocean with a focal depth 33 km<sup>20</sup>. In the present paper, we have taken into account ten such earthquakes with a magnitude >5 (Table 1), having comparable characteristics in view of their focal depth

(within crustal depth) and proximity to the oceans. In this paper, analysis is done of the behaviour of surface latent heat flux (SLHF) from the epicentral regions of coastal earthquakes and earthquakes which occurred faraway from coast over the Indian-subcontinent covering last 42 years (1975-2016) to study the SLHF behaviour both prior and after the earthquakes.

## 2 Surface latent heat flux (SLHF) of the atmosphere

The atmospheric surface latent heat flux, the heat released by phase changes due to thermodynamic process of solidifying or evaporation or melting<sup>21-22</sup>. The energy loss due to radiation processes which occur in the atmosphere is partly compensated by the energy transport in the atmospheric surface through the evaporation at the surface atmosphere interface<sup>23</sup>. The ground surface latent heat flux is greatly dependent on meteorological parameters, such as relative humidity, wind speed, ocean depth and proximity from the ocean<sup>24</sup>. Before an earthquake, the accretion of stress result in the thermal infrared emissions<sup>25-28</sup>, this enhances the rates of energy exchange between the surface and the atmosphere, resulting in surge of SLHF. Satellite data provides

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Table 1 — Earthquake sites with their magnitudes (M) and epicenters [8]. Average distance of place (in km) from ocean is also shown.

Date	Site	M	Epicenter	Focal Depth (km)	Intensity/Type of earthquake	Causalities/Deaths	Remarks
Jan 03 2016	North East India	6.7	24.83 N, 93.67 E	55	VII (Very Strong)	11	Regional event that affected India, Myanmar, and Bangladesh.
May 12 2015	Kodari, Nepal	7.3	27.79 N, 85.97 E	18.5	VIII (Severe)	218	Epicenter 17 km S of Kodari, Nepal; Felt in Delhi, West Bengal, Bihar, U.P.
April 25 2015	Lamjung, Nepal	7.8	28.14 N, 84.71 E	8.2	IX (Violent)	8,900	Epicenter 34 km of Lamjung, Nepal. Felt in eastern, northern, northeastern India and parts of Gujarat
Sept 18 2011	Gangtok, India	6.9	27.72 N, 88.06 E	19.7	VII (Intraplate)	118	Strong earthquake in NE India, tremors felt in Delhi, Kolkata, Lucknow and Jaipur
Jan 26 2001	Gujrat, India	7.7	23.60 N, 69.80 E	16	X (Oblique-slip)	20,000	Indian Republic Day Gujarat earthquake, thousands killed
March 29 1999	Chamoli, India	6.8	30.40 N, 79.42 E	21	VIII (Severe)	103	Moderate earthquake in Chamoli
May 22 1997	Jabalpur, India	6	23.08 N, 80.04 E	35	VII	39	Moderate earthquake in Madhya Pradesh
Sept 30 1993	Latur, India	6.3	18.07 N, 76.45 E	10	VII (Intraplate)	9,748	Major disaster in Latur of Maharashtra
Oct 20 1991	Uttarkashi, India	7	30.73 N, 78.45 E	10	VIII (Severe)	2,000	Moderate earthquake in Uttarkashi
Jan 19 1975	Kinnaur, India	6.8	32.46 N, 78.43 E	33	IX (Violent)	47	Moderate earthquake in Himachal Pradesh

accurate SLHF retrievals<sup>29</sup>, this in turn provide opportunities for long-term monitoring of the atmospheric parameters in order to develop forthcoming precursor models<sup>30</sup>. The energy loss at the bottom surface through coincidental exchange of vapour and warmth with the atmosphere is larger at the ocean surface than over the land; so, surface heat of transformation flux is larger at the ocean-surface and a pointy distinction is invariably discovered at the land-ocean interface<sup>31</sup>. There is decrease of Surface latent heat flux SLHF in land surface, when far from the land-ocean interface<sup>32</sup>. Change in surface temperature (ST), a precursor parameter during an earthquake<sup>33</sup> also controls variation in SLHF. Thermal infrared satellite data during the earth-quake in China (10 January 1998) and Kobe (Japan) on 17 January 1995 denoted surface temperature anomaly as a precursor<sup>34-37</sup>.

### 3 Methodology

The SLHF data of ten earthquakes over Indian subcontinent for the period of (1975-2016) was taken over the pixel which covered the epicentre of the earthquakes from the Earth Science Research

laboratory (ESRL). Table 1 contains detailed information of the earthquake, the epicentres of these earthquakes and focal depth of the earthquake sites are given. Figure-1 shows epicentre locations of the earthquakes considered in the present study. The coastal earthquakes that occurred in India during the past 42 years have been considered. Table 1 gives the approximate distance of the epicentre location from the Ocean. Gaussian grid of 100 lines from the pole to the equator, a regular longitudinal spacing and projected to 2° latitudes 2° longitude in a rectangular grid is used to represent the data set. The study of spatial distributions of the SHLF anomaly before the main event was done in a 10° by 10° area with the pixel which covered the epicentre of the earthquakes at the center<sup>38</sup>. Measured values from stations worldwide and also satellite retrievals are taken into consideration while generating this database<sup>12-15</sup>. Operational weather forecast models use fluxes which incorporate in-situ observation through an assimilation process<sup>39</sup>. A frequent change in assimilation methodology and in model resolution is one major downside of the data source, but using the re-analysis procedure by NCEP has solved the

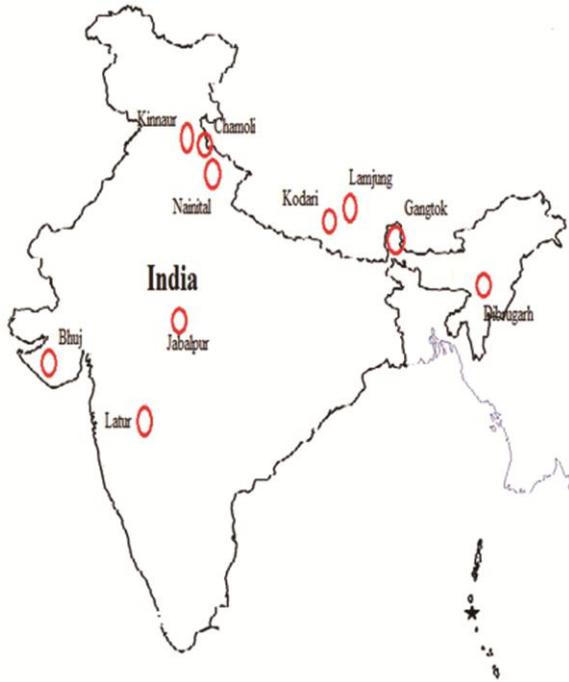


Fig. 1 — Geographic locations of India showing epi centres of different sites of earthquake events.

drawback, as it incorporates the whole archived data set into a sole frozen data assimilation system<sup>21</sup>. A detailed description and validation of re-analysis of the ESRL SLHF data have been given elsewhere<sup>24-29</sup>. SLHF values were considered daily for a time period of three months before and after the earthquake events. Seasonal effect is required, so the mean value of the period is taken. Study of the anomalous behaviour of SLHF occurring during the earthquakes is conducted by subtracting monthly mean from the daily values. Normalization of SLHF is done by dividing the daily SHLF value by the standard deviation ( $\sigma$ ) of the SLHF data for that day considering a 10-year data set. The maximum values for SLHF depends on month to month, season to season and location to location, and is affected by winds, tides and monsoon<sup>35</sup>. The background noise for each earthquake location is taken by adding 1.5 times standard deviation of SLHF to the mean ( $\mu$ ) value of SLHF<sup>16</sup>.

#### 4 Results and Discussions

Epicentre locations of the earthquake sites over Indian region for the period of 1975-2016 which were chosen for the present study are shown in Fig. 1. Distance of the epicentres of the ten earthquakes are given in Table 1. The variations in normalized SLHF for the period of 2001-2006 are given in Fig. 2, whereas the same variation for the period 1975-2000

is given in Fig. 4. Horizontal lines in each figure shows the monthly mean normalized value. The maximum values of background noise for given earthquakes are shown in Table 1. Variation in location to location and month to month causes difference in background noise. The red circle covers the nearby days of the key earthquake events. The daily behaviour of SLHF for the period 2001-2016 covering one month before and one month after the key earthquake events is shown in Fig. 3, whereas the same variation for the period 1975-2000 is shown in Fig. 5. The daily variation in the SLHF values during the month of the key earthquake events were found to be comparable in the non-earthquake years. The extreme enhancement in the normalized SLHF was observed 10-15 days before the key earthquake events. Prior to the key earthquake events the normalized SLHF was higher than the sum of the mean SLHF and 1.5 times the standard deviations, which indicate that only prior to the earthquakes, the normalized SLHF value became suggestively high. The normalized SLHF surged from the background noise by 204% 2 days before the earthquakes in North-East earthquake; Kodari of Nepal by 28%, 12 days before the key earthquake event; 34% in Gangtok, 20 days prior to the earthquake; 65%, 12 days before the earthquake in Gujrat; 8% , 30 days before the key earthquake event in Chamoli, Uttarakhand; 55%, 18 days before to the earthquake in Jabalpur, Madhya Pradesh; 40%, 28 days before the key earthquake event in Latur, Maharashtra; 34%, 15 days before the earthquake in Uttarkashi, Uttarakhand and 84%, 6 days before the earthquake event in Kinnaur, Himachal Pradesh (Fig. 6a). The percentage surge in the normalized SLHF value before the key earthquake events exhibited a slightly decreasing negative trend with the magnitude of earthquake intensity (Fig. 6a). Normalised SLHF decreased after the key earthquake event but increased after some days, before it acquired the average background values (Figs 2&4). SLHF shows a moderate contrast between ocean and the land in normal conditions<sup>31</sup>. Heat conduction through water and fluid present in the rock pores and soils is likely responsible for the migration of strong SLHF contrast zones over the ocean and in the epi-central regions<sup>23</sup>. Ocean water is suitable for faster heat conduction, because of which the SLHF contrast is likely to spread faster over the Arabian ocean, whereas there is low heat conduction through pore fluid in rocks and

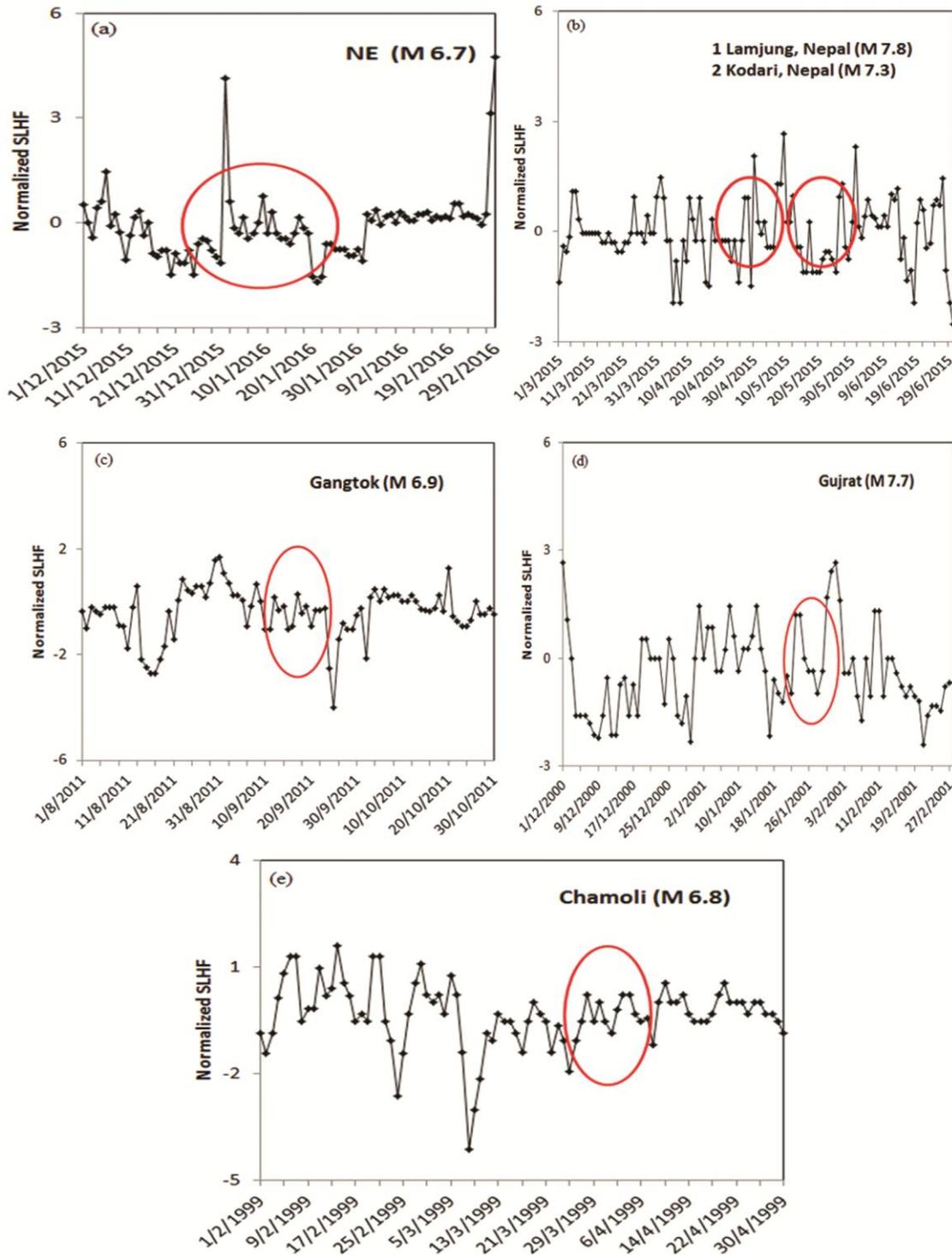


Fig. 2 — Variation of normalized SLHF over different earthquake sites of India for the period 1999-2016.

soils due to which the SLHF contrast observed over the land areas are smaller<sup>4</sup>.

However, after the key earthquake events the SLHF anomaly showed higher values in the case of Gujrat, Latur and Kinnaur earthquakes. This gives a

clear picture that the earthquakes occurring distant from the ocean takes a while; as a result, the strong SLHF anomaly observed before the coastal earthquakes shows a extended delay in establishing a strong SLHF anomaly, as a result of the strong

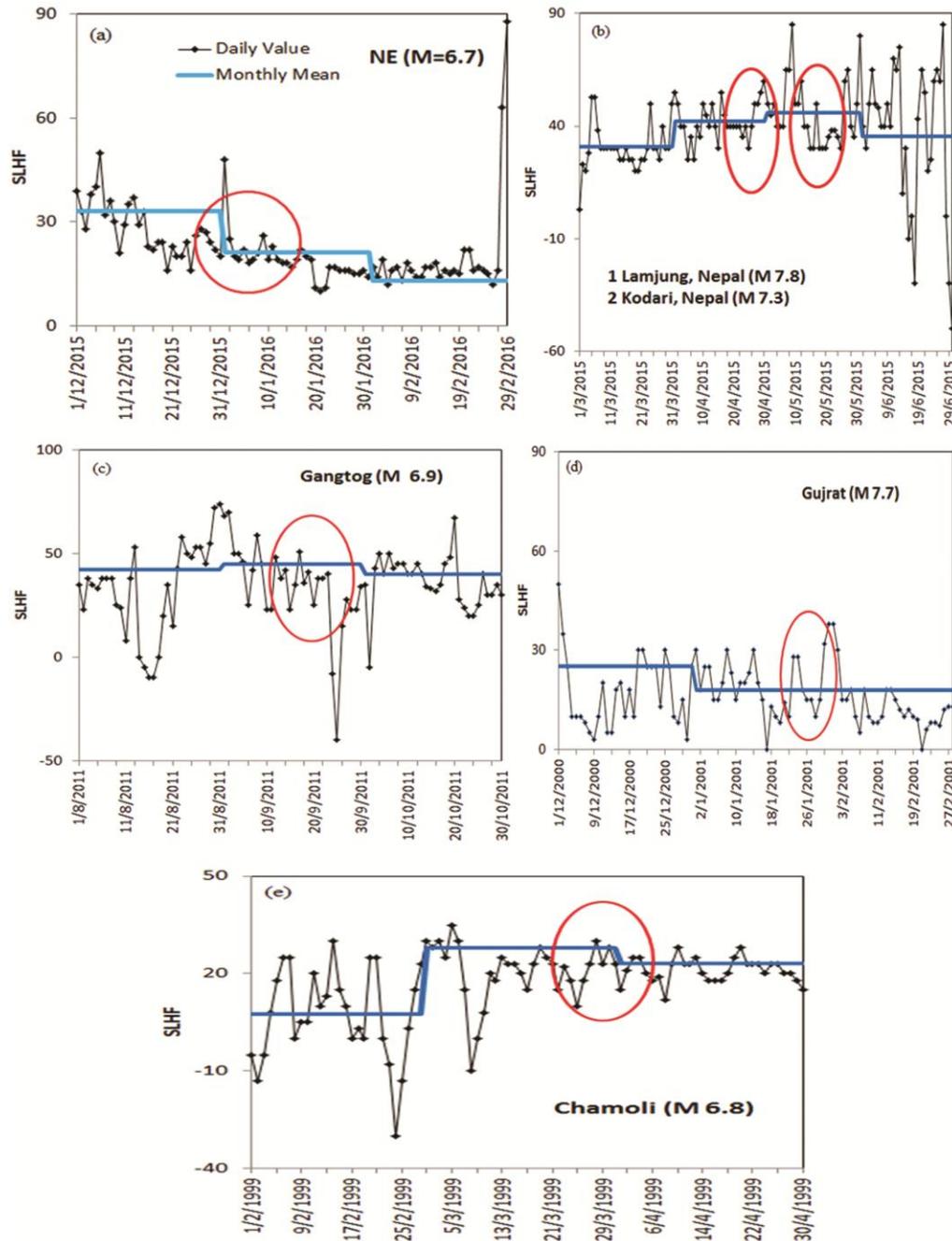


Fig. 3 — Variation of daily mean SLHF over different earthquake sites of India for the period 1999-2016.

interaction between the ocean-land-atmosphere (Figs 2 to 5). The magnitude of the fluctuations in the normalized SLHF related with these ten earthquakes are probably correlated with the prevailing meteorological parameters in the earthquake region, location of earthquakes, proximity of the epicenter to the ocean, season in which the earthquakes occurred and the coupling between the land-ocean-atmosphere<sup>6-7</sup>. The nature of such a coupling and the

hidden physical processes are yet to be explored<sup>16</sup>. Fig. 6 (c, d) shows the variations of the earthquake intensity with latitude and longitude over the Indian sub-continent. The surge in infrared thermal (IR) temperature epi-central region before the earthquakes leads to strong land-ocean-atmosphere interaction giving anomalous SLHF at that time<sup>26</sup>. The accretion of stress days before the earthquake in the epi-central region mainly considered to be responsible for the

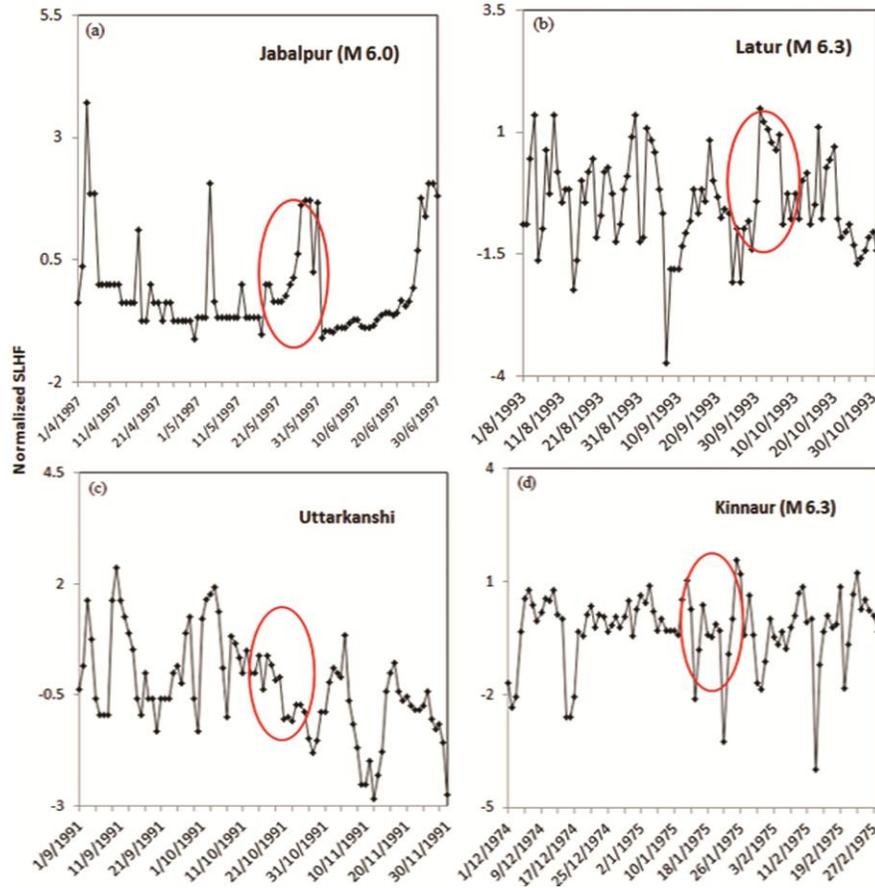


Fig. 4 — Same as Fig. 2 but for the period 1975-1998.

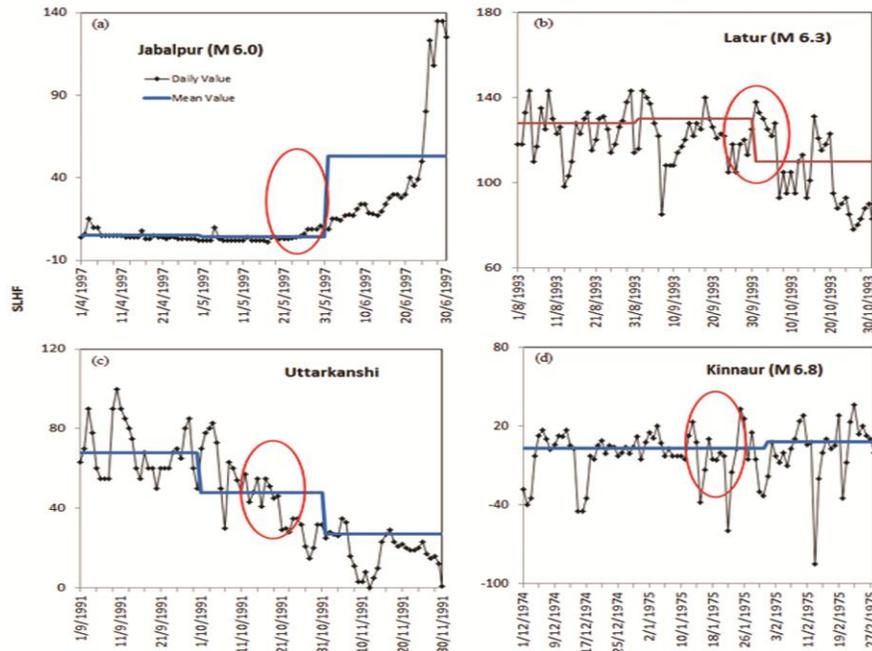


Fig. 5 — Same as Fig. 3 but for the period 1975-1998.

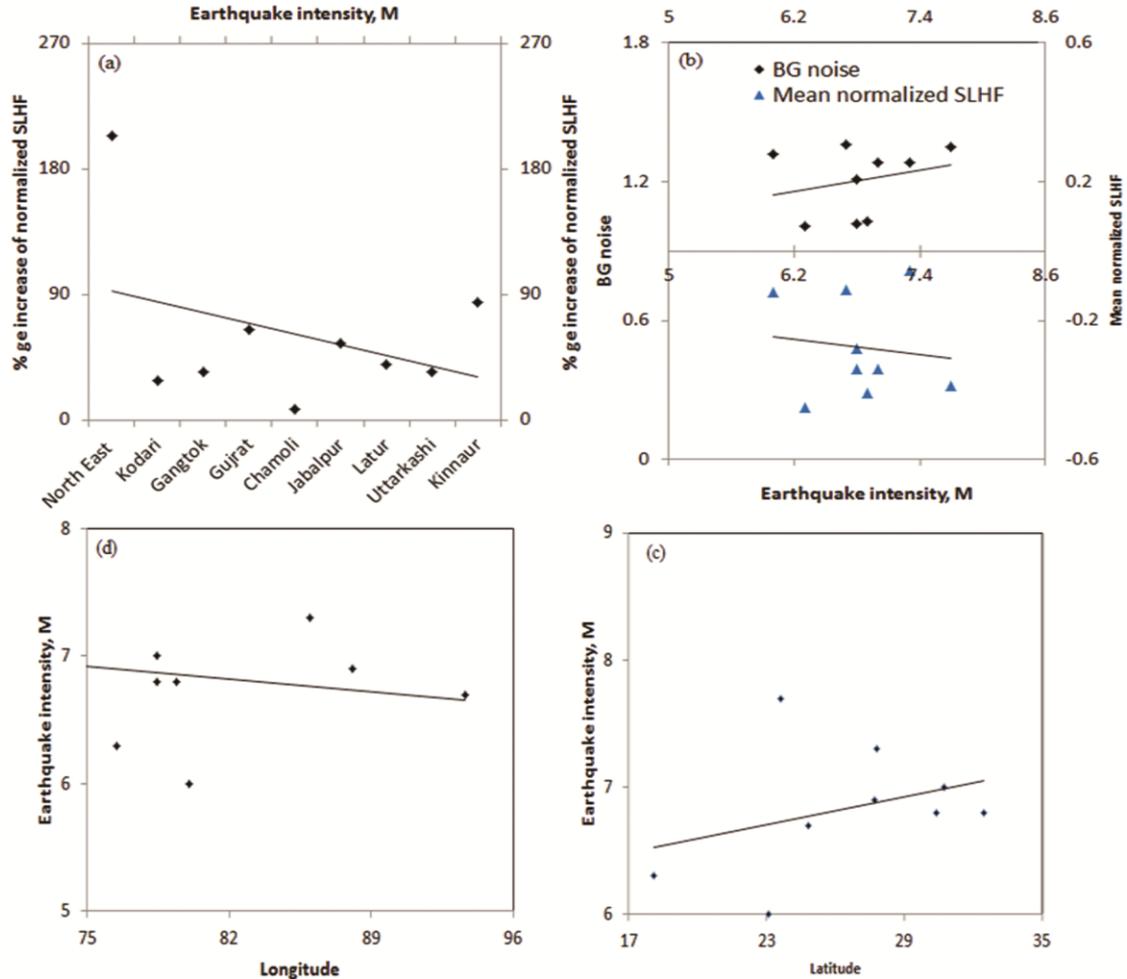


Fig. 6 — Variation of (a) Percentage (%) increase of normalized SLHF with earthquake events, (b) background (BG) noise and mean normalized SLHF with earthquake intensity, (c) earthquake intensity with latitude, and (d) earthquake intensity with longitude.

surge in IR temperature prior to the earthquake<sup>8</sup>. The manifestation of the stress accretion in terms of surface temperature and SLHF is distinct in case of shallow focal depth earthquakes<sup>32</sup>. The change in SLHF is likely to be attributed to a non-equilibrium in the mineralogical phase transformation due to the accretion of stress. It should be mentioned here that this effect is less prominent in the case of shallow-focus earthquakes<sup>22</sup>. The SLHF is heightened by the interaction of ocean and atmosphere in greater regions which depends on the proximity of the earthquake epicenters to the ocean in regulating the variations of SLHF<sup>19</sup>. The apex value of SLHF 10-15 days prior to the earthquakes are probably due to the characteristic fluids present within the Earth's crust and the increase in interaction between the atmosphere, ocean and land<sup>4-6</sup>. This interaction can be said to be governed by several parameters predominant in the earthquake

epicenters and neighboring regions<sup>32-35</sup>. The SLHF shows, exchange of water vapor in the atmosphere<sup>8</sup>.

The idea of land-ocean-atmosphere interactions occurring during an earthquake<sup>33-37</sup> was supported by the observation of anomalous behavior of concentration of water vapors in the atmosphere prior to the Gujrat earthquake. Water vapor, an optically active greenhouse gas, absorbs apart of the Earth's outgoing infrared radiation and contributes to the accumulation of heat near the Earth's surface. The exchange of energy is affected by the accumulated heat<sup>5-8</sup>; as a result, it was found that there is an increase of SLHF prior to the earthquakes<sup>1</sup>. SLHF immediately decreases as there is a release of accumulated stress after the main earthquake events<sup>3</sup>. The higher moisture content in the soil and humidity in the air facilitates the energy transfer to the atmosphere<sup>27</sup>.

## 5 Conclusions

This analysis of the surface latent heat flux (SLHF) data of recent ten earthquakes over the Indian sub-continent of the period 1975-2016 indicates anomalous behaviour preceding the earthquakes. This anomalous behaviour is found in earthquakes only in close proximity to the ocean. Following are the main conclusions of our findings.

1. The organized pattern of SLHF shows a potential precursor which provides with the information about catastrophic earthquakes occurring near coastal regions well in advance<sup>3</sup>.
2. The maximum increment in normalized SLHF was observed 10-15 days earlier to the main earthquake events. This normalized SLHF was established to increase from the back ground noise by 204%, 2 days before the earthquake in North-East; Kodari of Nepal by 28%, 12 days before the earthquake; 34% in Gangtok, Sikkim, 20 days before the earthquake; 65%, 12 days before the earthquake in Gujrat; 8%, 30 prior to a main earthquake event in Chamoli, Uttrakhand; 55%, 18 days before earthquake in Jabalpur, Madhya Pradesh; 40%, 28 days before the main earthquake event in Latur, Maharashtra; 34%, 15 days before the earthquake in Uttarkashi, Uttrakhand and 84%, 6 days before the key earthquake event in Kinnaur of Himachal Pradesh.
3. This percentage increment in the normalized SLHF value before the key earthquake event show slightly decreasing negative trend with the magnitude of earthquake intensity<sup>24</sup>.
4. After the main event, the normalized SLHF was first found to decrease and then after some days increase, before it acquires an average background value.
5. The maximum increase in SLHF 10-15 days before the earthquakes was most likely due to the fact that Earth's crust has fluid and the increased interactivity between the atmosphere, ocean and land.
6. The high-resolution remote sensing data also with better spatial and temporal resolutions may provide more reliable information about SLHF, which can be further easily used, for early warning of coastal earthquakes<sup>22</sup>.
7. The SLHF appears to exchange water vapor with the atmosphere. It is to be made clear that this water vapor, an optically active greenhouse gas

which is absorbing a part of the Earth's outgoing infrared radiation, is a contributing factor to the accumulation of heat near the surface<sup>32</sup>. This energy that is accumulated affects the energy exchange; which ends in a rise in SLHF before the earthquake<sup>7</sup>. Succeeding this main earthquake event, follows the discharge of accumulated stress implying a right away decrease in SLHF<sup>25</sup>. High water content in soil and humidness in air facilitates the energy transfer to the atmosphere.

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