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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Variability of lightning hazard over Indian region with respect to ENSO Phases" *by* Sreenath Avaronthan Veettil et al.

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Specific comment 1: How is calculated the anomaly for different parameters as LFR, graupel concentration at different seasons and in different regions.

Response to comment 1: The term Lightning Flash Rate (LFR) anomaly indicates the difference between the composite of LFR during a particular ENSO phase in a specific season and the composite of LFR during all the three ENSO phases in that particular season. e.g., LFR anomaly during pre-monsoon during La-Nina = (Composite of LFR during La-Nina in pre-monsoon) - (Composite of LFR during all the three ENSO phases in pre-monsoon). The anomalies of all other parameters used in this study are calculated using the same method. Thank you for the comment.

Major comment 1: The authors have to define the periods distinguished as premonsoon, monsoon and postmonsoon, because it is not made and it is a main information to well understand and interpret the values of the LFR provided in flash per day and per km2. What is the duration and the dates of each season? At line 64 the data beginning is given in July 1995 and in Table 1, a value is given for each season of 1995. Does it mean the premonsoon is in July?

Response to major comment 1: The pre-monsoon season includes the months of March, April, and May. The period June to September is the monsoon season. October, November and December months are taken as the post-monsoon season. The LFR data is available starting from July 1995 only. So the pre-monsoon season in our work starts from 1996 (March-April-May) and ends in 2013 (March-April-May). Due to data unavailability, the first monsoon season includes only three months (July, August, and September 1995). This particular season terminates in 2013 (June, July, August, and September). On the other hand, the post-monsoon season is prepared from 1995 (October, November, and December) to 2013 (October, November, and December). Since our work is based on the seasonal variation of LFR with ENSO Phases, the monthly average value of LFR from the LIS/OTD data product is used. The monthly average values outset from July 1995, and it concluded in December 2013. Perhaps our description in lines 64-65 may be a little confusing. The inclusion of the above information in the data and methodology section will provide better clarity for readers. Thank you for this suggestion. Table 1 provides the ONI index to show the pre-monsoon season in 1995 was the normal phase of ENSO, and it doesn't mean July is in pre-monsoon, and it doesn't mean the pre-monsoon started in 1995. In figure 3(a), (d), and (g), you can see that LFR values are absent during the 1995 pre- monsoon season.

Major comment 2: The LFR is calculated from the flashes detected by LIS or OTD. Is it estimated for the whole period by extrapolation of the flashes detected by the sensors? Indeed, the sensors were above the region for a short time according to the low orbit satellite location.

Response to major comment2: Combined OTD (Optical Transient Detector) + LIS (Lightning Imaging Sensor) monthly averaged flash rates expressed as flash rate density (flash km-2day -1) available from http://ghrc.nsstc.nasa.gov/ is used in this work. These products compute mean lightning flash rates by accumulating the total number of flashes observed and the total observation duration for each grid box (2.5° $\times$ 2.5°) from the thousands of individual satellite orbits. The lightning climatology derived from OTD / LIS (Cecil et al., 2014) provides a unique observational basis for the global flash distribution in monthly time series (Kamra and Athira., 2016), seasonal cycles (Christian et al., 2003), or diurnal cycles (Blakeslee et al., 2014). To produce the low-resolution monthly time series (LMRTS) data, LIS and OTD flash rates and view times are smoothed precisely and are extracted for the middle day of each month (Cecil et al., 2014). The lightning flash rates in an LRMTS have slightly over three months of temporal smoothing and 7.5°*7.5° spatial smoothing (Cecil et al., 2014). The data sets are described in greater detail in the following paper: Gridded lightning climatology from TRMM-LIS and OTD: Dataset description by Cecil et al. (2014).

Major comment 3: At line 100, can we talk about three hot spots during the premonsoon season? In southern India it is not really a hot spot and in NNWI no more. “Hot spot” needs to be very distinctly higher than around.

Response to major comment 3: Ahmad and Ghosh (2017) reported that compared to other regions of India, lightning activity is higher over the North-Eastern part and southern part of India during pre-monsoon season in India. They also observed that the maxima of lightning during post-monsoon is also lying over the southern and eastern regions of India. So previous studies indicate that we can take the southern peninsula as one of the hotspots of lightning over India. As you pointed out, the hotspot is not distinguishable in figure 1, probably due to the color scale we have chosen. Thank you very much for this useful remark. Accordingly, we have modified Figure 1 with an appropriate color scale to get a better view of the region corresponding to a higher

lighting occurrence (Please see the revised figure 1 given below). NNWI is the acronym for north of northwest India. You can also see a dominance of lightning over the same region during pre-monsoon, monsoon, and post-monsoon seasons in India.

Major comment 4: Figure 2 needs explanation, how is calculated the anomaly? Why it is so different at NEI between El-Nino and La-Nina? While it is not very different for LFR in Figure 1 and even it seems LFR is larger in NEI during La-Nina while the anomaly is negative there. By comparing Figures 1a and 1b, I do not understand the differences between Figures 2a and 2b? I do not understand the negative value of anomaly in Figure 2b for NEI? (It is even lower than in Figure 2C for the same region NEI. Anyway, the values of the anomaly are < 0.015 for LFR values of about 0.1.. Is it significant? At line 115, it is said "the cold ENSO phase suppresses LFR over NEI" but in Figure 1b the hot spot over NEI is not suppressed at all! The other comment at line 115 can be discussed on the same way. Clarification is necessary, especially to describe the anomaly estimation. Same at line 119, it is impossible to say "which firmly indicates that the cold phase suppresses the LFR over NEI," according to Figure 1b. Same for comment about "the warm phase enhances it over SPI".

Response to major comment 4: As explained in response to the specific comment 1, the LFR anomaly is calculated by taking the difference between the composite of LFR during a particular ENSO phase in a specific season and the composite of LFR during all the three ENSO phases in that particular season. e.g., LFR anomaly during pre-monsoon during LaNina = (Composite of LFR during LaNina in pre-monsoon) - (Composite of LFR during all the three ENSO phases in pre-monsoon). The disparity of LFR over north east India (NEI) during El-Nino and La-Nina may arise due to the difference in convective clouds’ intensity over that region. The hydrometeors (Snow and Graupel) and the latent heat profile support the higher LFR during the El-Nino phase during the pre-monsoon season (Figure 4 (a), 5(a), and 6(a)). In contrast, the hydrometeors concentration and latent heat release are less during the La-Nina period, which indicates suppression of convective clouds and hence the LFR. The contrast between figure1 (climatology of LFR) and figure 2 (Anomaly of LFR) must have evolved due to a plotting error that happened unknowingly while drawing figure 1. We are very much thankful to the reviewer for pointing this out. We have modified Figure 1 and given below. In our study, the LFR varies from 0.02 to 0.2 flash/km*2/day (Figure 1). A prior study by Kmara and Athira (2016) shows that LFR ranges between 0.01 to 0.2 flash/km*2/day over India. The main regions of lightning over India (e.g., NEI) shows an increase of more than 0.01 flash/km*2/day during El-Nino and a decrease of more than 0.01 flash/km*2/day during La Nina in pre-monsoon season (Figure 2). This indicates that the modulus of the anomaly over these hotspots regions is higher than the LFR climatology over many parts of India. Yuan et al. (2016) calculated the LFR anomaly (Unit: Flashes/Km*2/month) over Southeast Asia during El-Nino and La-Nina episodes. They found a similar range of LFR anomalies as in our study. Further, their analysis is based on this anomalous pattern of LFR. Hence, previous studies support that the anomalous values of LFR as shown in our study are sufficient to explain the contrast in LFR over northeast India, north of northwest India, and southern peninsular India during different ENSO phases. An examination of figure 1, along with figure 2 (a, b), is helpful. In figure 2 (a, b), one can notice that NEI shows reduced LFR during the La-Nina phase (cold phase) of ENSO, and the El-Nino phase (Warm phase) shows enhanced LFR over southern peninsular India.

Major comment 5: The same comments for the season “Monsoon” about the anomaly not obvious by looking at Figure 1d-e. They talk about increase of LFR along the coast of NWI at line 132 for El-Nino, not obvious in Figure 1d. At line 139: “The NEI is showing positive anomaly of LFR during both warm and cold phases of ENSO” this comment does not seem justified in Figure 2e, no increase.

Response to major comment 5: The anomaly figure suggests that (Figure 2(a)) LFR shows an increase (although small in magnitude (between 0.002 - 0.006)) along the northwest coast of India. The anomaly plot better serves this purpose of capturing small changes in LFR with different ENSO phases. At the same time, climatology

figure 1 is used to get an overall idea about the distribution of LFR. Small variations in LFR values are not discernible in the climatology figure 1. Anomaly plots are widely used as a tool to overcome this difficulty. In the present work, NEI is defined as the region between 20° - 30° N and 85°-95° E. Kindly find the anomaly plot in which NEI is marked inside a black box (Figure 2(e)), which shows that figure 2(e) can justify the comment we made in line 139: i.e., “The NEI is showing positive anomaly of LFR during both warm and cold phases of ENSO.”

Major comment 6: The profiles in Figures 4-5-6 show concentration anomalies for graupel, snow and latent heat, respectively. The values seem very small to explain something. Why to not display the concentration directly? The values could be used to explain the storm occurrence?

Response to major comment 6: Graupel and snow are the different forms of ice content inside the convective clouds. In situ airborne observations during the Cloud-Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) over various locations of India shows that convective clouds during the pre-monsoon and monsoon period have an ice water content of 10-4 to 1 g m-3 (Patade et al., 2015). Moreover, in situ measured ice cloud properties in the European Cloud Radiation Experiment (EUCREX) have reported a similar range of ice water content inside the clouds system (10-4 g m-3 to 1 g m-3) (Hogan et al., 2006). So the anomaly values of snow or graupel are significant compared to actual values of ice content inside the cloud system. As said earlier, anomaly values are used to catch the minute variations in the vertical distribution of hydrometeors during different ENSO phases, which will help better understand the variability in the hydrometeors profiles. Kumar et al. (2013) analyzed the contrast between cloud properties over India’s west coast and the Myanmar coast. They provide the vertical profile of latent heating over the two contrasting regions expressed in degrees/day, ranging between 0 to 0.3. The west coast of India is marked by shallow convection, while vigorous convective clouds dominate Myanmar coasts during the Asian summer monsoon. In the present work, anomalous latent heating exists mostly between +/- 0.01, and in some cases, it is extending up to +/-0.02 (Kelvin/hr). Hence, from prior studies, the anomaly values of latent heating are highly significant compared to the actual values of the same, and they can indicate modulations of convective cloud formation and storm occurrence along with hydrometeors profiles in different seasons of India with various phases of ENSO.

Major comment 7: Line 141:"The similarity in the LFR anomaly is noticeable in the distribution of graupel and snow during the two phases (Figure 4 (b), 5 (b))." The anomaly is close to zero in this case for graupel and snow. Does it can explain the positive anomaly for the LFR during the two ENSO phases commented at line 139? Line 142 : Where is it visible that the LFR is suppressed in NWI for the warm season during monsoon? In Figure 1d it is well visible there is a hot spot like in cold season (Figure 1e).

Response to major comment 7: During monsoon season, the anomalous snow and graupel distribution unable to provide strong evidence for the increase of LFR during the warm and cold phases of ENSO over NEI. We have used figure 3 to ensure the above observation by indicating that all the years under the warm phase and the majority of years under the cold phase (during the monsoon season) show an increase in LFR over NEI. In our study, the region between 25°N - 40° N and 65°E - 80°E is defined as north of northwest India (NNWI). From figure 2(d) (given inside a red box), you can see the suppression of LFR over this region in the warm phase during the monsoon season. As same as in figure 1 (d), you can see a hotspot like region of LFR over the same area in figure 1 (e) and figure 1(f). As mentioned earlier, these figures represent the climatology pattern of LFR. Its purpose is to provide an overall idea about the distribution of LFR in different seasons with various ENSO phases. To get the idea about the modulation of LFR with different ENSO phases during different seasons, we can use the anomaly plot.

Minor comment 1: The parameter LFR could be LFD as lightning flash density since it is a density (km-2 day-1). It is a daily density. Is it more consistent to talk about

density?

Response to minor comment 1:We have defined lightning flash rate as the number of flashes/km2/day in this work. Some earlier studies also expressed this parameter as the flash rate (Kamra and Athira (2016); Yuan et al., (2016)). Since the previous works define the term as the flash rate, we used the same term. Further, the term 'rate' is more appropriate as it appears to be more synonymous with 'the chances of occurrences for lightning flashes' rather than to the intensity of individual flashes. On the other hand, the term 'density' may imply the intensity or severity of lightning, which we do not intend to suggest in the present study.

Minor comment 2: Figure 1: The unit for the scale could more visible and written along the colored scale.

Response to minor comment 2: Correction included. Please see figure 1.

Minor comment 3: Line 72 : "seasons" -

Response to minor comment 3: Correction included.

Minor comment 4: Line 90: With such average values of CAPE (1500 J/Kg) all over India, we can think storms are produced everywhere over India during that season. However, Figure 1 shows the LFR is < 0.05 km-2 day-1 over a large part of India. Do they want to say the CAPE is 1500 in average during the whole season or just during a short period ?

Response to minor comment 4: A typing error occurred in line 90. Thanks for pointing out. Now the sentence is rewritten into "The seasonal average of convective available potential energy (CAPE) highest over the east coast of India, and the same is 1500 J/kg all over south India (Murugavel et al., 2014). At the same time, large regions of India, especially the central Indian region, show a seasonal average of CAPE less than 1000 J/Kg (Murugavel et al., 2014)." By including this correction, we can explain the existence of LFR < 0.05 km-2 day-1 over a large part of India.

Minor comment 5: Line 100: They could keep the same order for longitude/latitude in the definition of the regions.

Response to minor comment 5: To get more accurate results in our work, we have chosen the latitude and longitude for the regions around the maximum values LFR (we called it hotspots of LFR). Figure 1(a) shows that a hotspot of LFR over NEI lies exactly inside 20° N-30° N and 85° E- 195° E. NNWI is exhibiting maximum values of LFR between 25° N-40° N and 65° E-80° E (Figure 1(d)). The intense LFR activity over southern peninsular India (SPI) includes the region between 5° N-15° N and 75° E-80° E (figure 1(a)). Other areas around SPI have smaller values of LFR as similar to the majority of regions in India. We cannot consider those regions as a hotspot. The same is valid in the case of NEI and NNWI.

Minor comment 5: Line 103: Is it better to use "neutral" and not "normal"? Check for others.

Response to minor comment 5: Correction included. Thank you for this suggestion.

Minor comment 6: Line 105: I do not see a decrease of the LFR for El-Nino during the season premonsoon in NNWI (Figure 2a) while I see a decrease of LFR (negative anomaly) during La-Nina (Figure 2b). Can you check?

Response to minor comment 6: Please see figure 2(a), in which a decrease of LFR can be seen over NNWI, which is enclosed inside a green box, and this result is supported by the anomalous decrease of graupel conecntration during premonsoon season in El-Nino phase (Figure 4(d)).

Minor comment 7: Line 110: Is LH defined before? (Latent Heat I suppose?).

Response to minor comment 7: LH denotes latent heat. Correction included. Thank You.

Minor comment 8: Line 110: "decreases" since it is the amount?

Response to minor comment 8: Correction included. Thank You.

Minor comment 9: Line 111: "unable" or "unbaled"?

Response to minor comment 9: Correction included. Thank You.

Minor comment 10: Figure 3: Check the symbol of the variable on the graphs? It has to be LFR?

Response to minor comment 10: Correction included. The symbol is changed to LFR. Please see figure 3. Thank You.

Minor comment 11: Figure 4 caption: graupel and not groupel.

Response to minor comment 11: Correction included. Thank You.

Minor comment 12: Figure 4h "India"

Response to minor comment 12: Correction included. Please see figure 4(h). Thank You.

Minor comment 13: Figure 4 and Figure 5: Unit is g m-3 and not gm-3 but the values seem very low.. For graupel the maximum should be 0.0008 g m-3 i.e. 0.8 mg m-3 isn't that a little weak?

Response to minor comment 13: Cloud ice water content (IWC) is defined as cloud ice mass in the unit volume of atmospheric air. As we indicated in the response of major comment 6, convective clouds during the pre-monsoon and monsoon periods have an ice water content (graupel and snow are the ice forms inside the clouds) of 10-4 to 1 g m-3 (Patade et al., 2015). ie, 0.1 mg-1000 mg. So, the anomaly values are significant in comparison with actual values of ice content inside the clouds.

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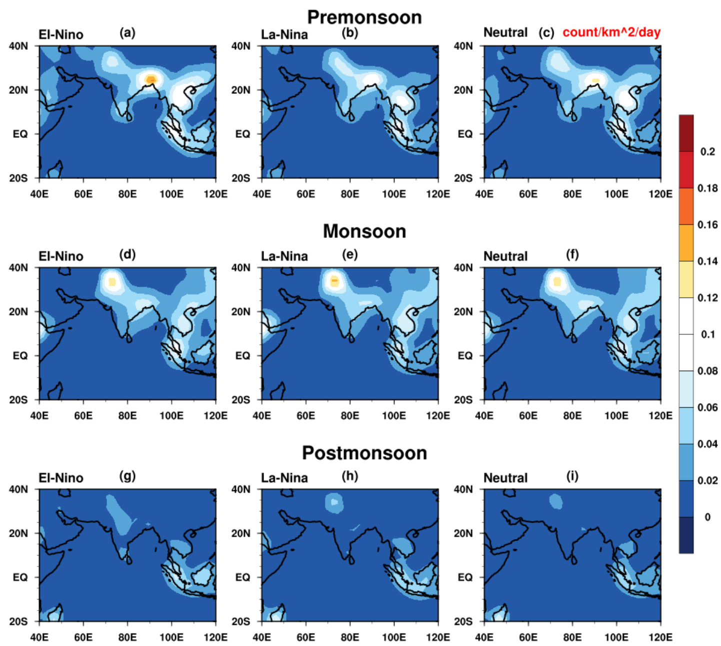

Fig. 1. LFR climatology during different ENSO phases

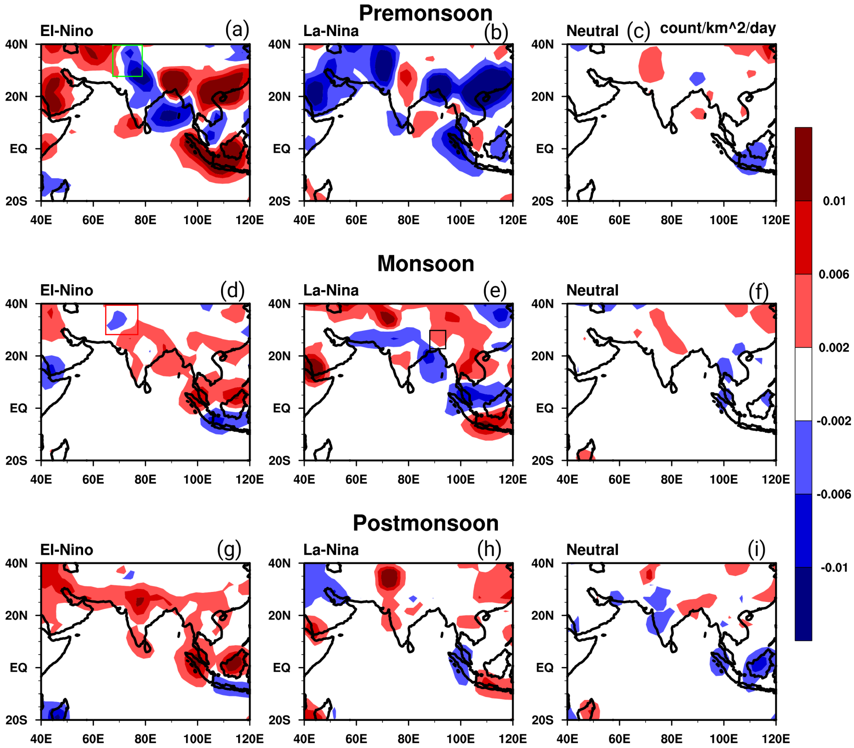

Fig. 2. Anomaly composite of LFR during different ENSO phases.

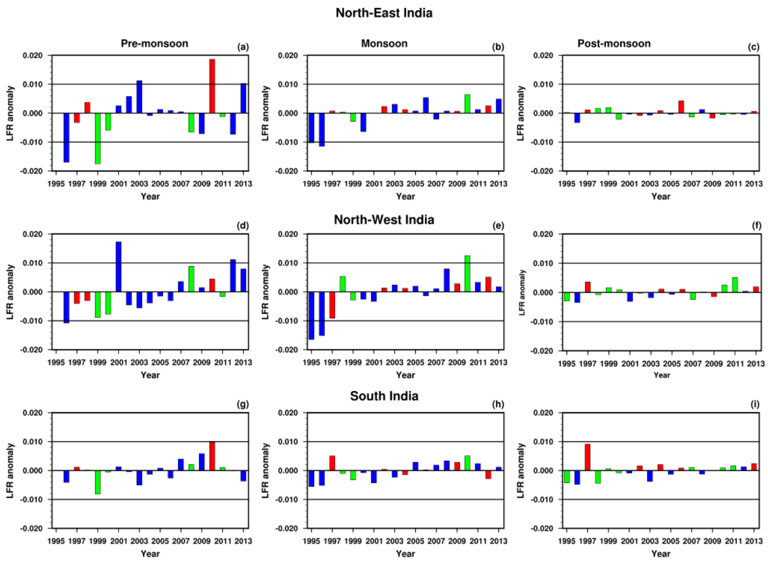

Fig. 3. The anomaly of LFR during the individual years with different ENSO phases. Red color label bar corresponds to warm (El-Nino); green one corresponds to the cold (La-Nina) and blue color label bar indi

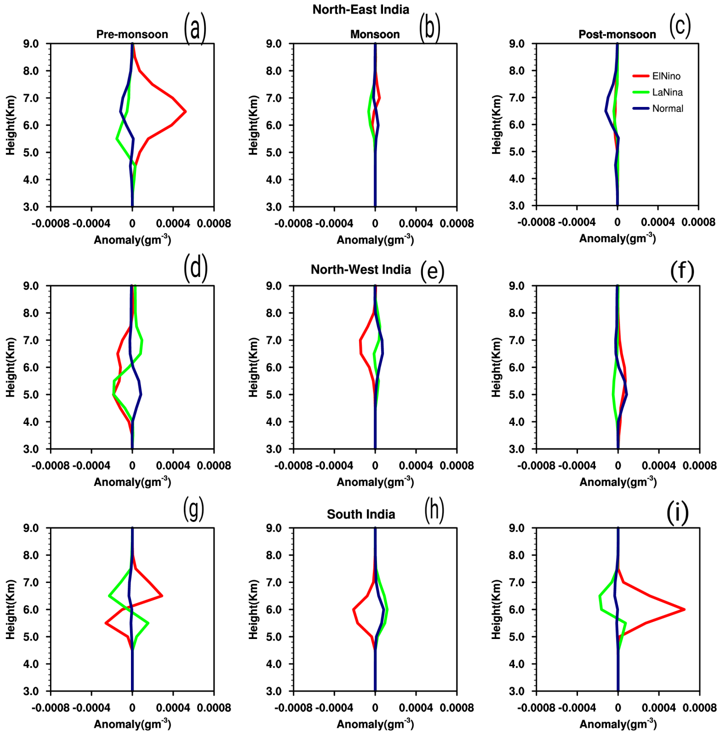

Fig. 4. Anomaly composite of graupel during different ENSO phases