Replies to Reviewer #2

General Comments: The distribution, causative factors and the trends of lightning activities in different parts of India are investigated comprehensively. The main question is that some evidence or more sentences should be added to explain why the author use the variable lightning radiance, and what's the relationship between lighting radiance and intensity of storm clouds. I recommend **minor revision.**

The authors wish to thank the reviewer for the comments/suggestions which significantly improved the content of the manuscript. The authors have addressed all the comments raised by the reviewer and incorporated them in the revised manuscript wherever necessary.

1, The main question is what's the physical meaning of lightning radiance? As I know, in terms of satellite lightning observation, lightning flash rate is most physically significant variable. I'm confused about the relationship between lightning radiance and the intensity of convections, please add some evidence or some more sentences to clarify under what conditions will lightning radiance increase.

Reply: At first the authors want to clarify that lightning radiance represents the amount of charges being neutralized at the ground which in turn also corresponds to the amount of electrical charges generated inside the thundercloud. Now it is well known that satellite observations sense both types of lightning events namely: intercloud and cloud to ground lightning. However, according to previous literature, the former type covers approximately 80-90% of the total events while none of them possess enough charges or energy to shatter the atmospheric insolation to reach the ground. But on the other hand, the remaining 10-20% events have much higher radiance or charges and hence only this type of strikes are capable of reaching the ground and causing enormous socio-economic damage. So, this explains the importance of the lightning radiance. A pertinent discussion on this aspect has now been added in the revised manuscript as follows.

"While utilizing the lightning radiance measurements from satellite observations, it may be best suited to explain the utility of this data towards the weather and climate as this attribute has never been extensively discussed in past research attempts unlike lightning frequency or flash rate. It is well known that lightning activities originate due to charge separation in mixed phase clouds, but they require a sufficient amount of electrostatic charge to shatter the insolation capacity of the atmosphere and descend to the earth surface further causing widespread damage to life and property. However, a majority of these lightning occurrences are not strong enough and hence they remain as intercloud lightning and hence have no real impact on the climate or socio-economy. On the other hand, according to some novel studies like Uman (1986) only 10-20% of the total lightning activities are strong enough to reach the ground and thereby inflict widespread socio-economic impacts. Thus, the climatological variation of lightning intensity or radiance also needs to be monitored very closely by present policy makers to prevent the chances of any impending catastrophises in future."

Now as far as the relationship between lightning radiance and its components is concerned, the authors have already cited various research attempts explaining the probable mechanisms responsible for the genesis of lightning. However, for further clarification, the authors would like to recall the non-inductive charging equation from Shi et al. (2015) where the amount of charges created by graupel-ice collisions are expressed in terms of the graupel or ice diameters and their number concentrations along with their relative velocities. The thermodynamic instabilities prevailing inside a thundercloud (denoted by CAPE) represent the relative velocities present between graupel and ice and this in turn impacts the charging rate thus explaining its relationship with radiance. Next, the concentration of graupel and ice particles inside a thundercloud depend on the existing moisture content or TCWV present in the atmosphere and this in turn dictates the number of collisions and hence the radiance associated with lightning. Finally, the diameters of graupel and ice particles determine the collision

area and charge transfer rates responsible for lightning and this in turn is controlled by the aerosol concentrations (AOD). So this explains how lightning radiance is related each of these factors.

$$\left(\frac{\partial Q_{eg}}{\partial t}\right)_{np} = \beta\delta q E_r (1-E_r)^{-1} \times \frac{1}{\rho_0} |\overline{V}_i - \overline{V}_g| \int_0^\infty \int_0^\infty \frac{\pi}{4} E_{gi} (D_g + D_i)^2 N_g N_i dD_g dD_i$$

Here the Left-hand side represents the charge formation rate, Er refers to the collision and rebounding efficiencies, V indicate the individual vertical velocities for each of the hydrometeors and finally D and N denote the weighted average diameters and number concentrations of both graupel, and ice involved in this process. Now, a detailed explanation on this aspect has already been discussed in the introduction section of the manuscript. Hence this clarification has not been inserted in to the text.

2. If the convection is much stronger, I think both lightning flash rate and lightning radiance should increase, but in this paper, the trends are not inconsistent. I think maybe it's related to different storm clouds. Such as lightning in stratocumulus clouds or thermal convections should be different. Authors can try to give more information about types of clouds in different regions and add more explanations.

Reply: At first, the authors would like to clarify that CAPE or the convective instability is not the major factor controlling both lightning frequency and intensity. Had that been the case, then lightning frequency would not be highest over land while the radiance values are much higher over BoB. Now it is a fact that having too many lightning strikes does not guarantee that all these events will also experience very high intensities (since they do not have an exact one-to-one correlation). Now, a weak lightning event can develop even with moderate instabilities and meagre amounts of hydrometeors; but, in case of intense lightning events a profuse amount of hydrometeor collisions is required (which in turn is not possible without ample moisture supply). Thus, sea regions like BoB always experiences stronger radiance values despite weaker lightning frequency thereby explaining the author's argument.

Now, in view of the reviewer's comments, the authors have gone through sufficient literature survey. A study by Subramanyam (2013) depicted the strongest deep convective clouds over BoB but only during the summer monsoon period. So, to get an overall idea about the impact of clouds, the authors have plotted the yearly averaged high, mid and low-level cloud covers over Indian region. As lightning events require interaction between mixed phase hydrometeors which are mainly found above 5 km; hence high clouds followed by the mid clouds are only expected to show a congruence with lightning.

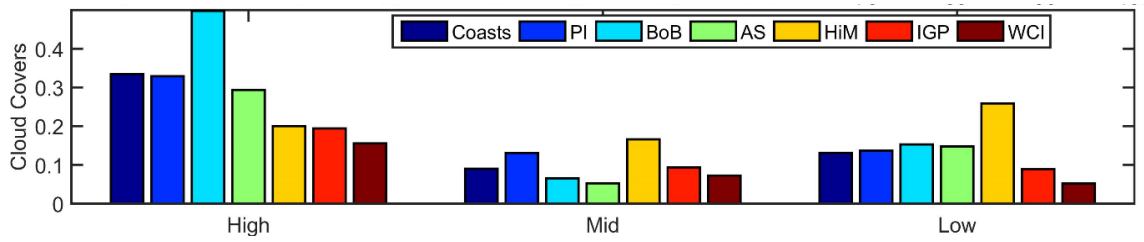

Figure: Average spatial variations of high, mid and low cloud cover over the Indian Subcontinent

The average spatial variation of cloud types over Indian region also supports this argument showing most frequent high-level clouds over the maritime regions. Also, the amount of high clouds are much higher than the mid-level ones throughout the country thereby implying the stronger role played by the ice clouds behind lightning genesis. However, this relationship fails drastically in a couple of cases. First, the average lightning frequency and radiance values over IGP, WCI or HIM are much higher than PI despite having half of its cloud cover. This facet can be addressed by considering the additional influences of either AOD and CAPE over IGP and WCI or using the concept of orographic lifting in HIM. Also, the contribution of clouds seems relatively useless over AS since it experiences minimum lightning. Hence the authors wish to reaffirm that it is not the clouds alone but a complex combination of CAPE, TCWV and AOD which ultimately determines the lightning properties over the Indian

region. In view of the above and for the sake of simplicity, the authors have decided not to include any discussion about the impact of clouds on lightning in the revised manuscript. However, in future a detailed study can be progressed to investigate the radiative and microphysical impacts of clouds alone on lightning over each Indian subdivision using observations and modelling.

The authors thank the reviewer once again for providing all the suggestions and sincerely accept that these have turned out to be indispensable in pushing and improving the standard of the current work.