Authors reply to reviewers' comments

Dear Anonymous Referees,

Thanks for your careful review of the manuscript. We read the reviewers' comments carefully, have considered and responded to all the reviewers' comments, and revised the manuscript accordingly. My detailed responses, including a point-by-point response to the review and a list of all relevant changes, are as follows:

Reviewer #1:

The authors stated that: "+CG flashes with currents less than 10 kA are not removed to make sure the comparison between +CG and -CG fair". However, a lots of studies showed that most positive discharges with peak current below 10 kA are cloud discharges. So, this should be taken to mitigate such misclassification, as to improve the quality of the CG dataset used in this paper.

Response: In fact, in our initial version of the submission, we filtered out +CG with peak currents below 10 kA. However, the third reviewer raised concerns that this filtering could lead to an overestimation of the average peak current for +CG flashes, resulting in unfair comparisons between +CG and -CG in Figures 4, 6, and 9. Therefore, in this revised version, we reprocessed the data and did not filter out +CG flashes with peak current below 10 kA.

2. Line 103, the authors stated that they used the first detected stroke to represent the entire flash. However, for comparing the peak current of different multi-stroke CG flashes, it is not enough to consider only the first detected stroke.

Response: We appreciate your insightful suggestion, and upon thorough deliberation among the authors, we concur that relying solely on the first lightning stroke to represent the entirety of a lightning flash could potentially introduce bias to the conclusions drawn. Therefore, the entire text has been reprocessed, shifting from analyzing lightning flashes to analyzing lightning strokes. Consequently, the focus is no longer solely on the location and current of the first stroke, but rather on the locations and currents of all lightning strokes.

3. Line 109, it is suggested to use the term "number of reporting sensors" instead of "the number of triggered stations".

Response: Thank you for your suggestion. The corresponding content has been modified, see line 126.

Reviewer #2:

The second version of the paper is more relevant in a generally speaking. The lightning data are analyzed in several aspects for the whole Chinese territory. It is a complex task to present the variability according to many parameters. However, some comments are not correct according to the figures. The terminology is still ambiguous and unusual. English language could be improved. The authors have improved the paper but it needs a revision, more than minor according to the number of corrections to do.

This article has three major changes. Firstly, based on the feedback from the first reviewer, the statistics on lightning flash have been modified to statistics on lightning strokes. Secondly, due to the long review period, new data for another year has been obtained, expanding the data collection period to seven years (2016-2022). As a result, the relevant statistical values have undergone slight fluctuations, and the figures have been adjusted accordingly. However, the main conclusions remain essentially unchanged. Furthermore, we have also improved the comments according to the figures to enhance the reliability of the results.

1. My comments about terminology in the first review are partially taken into account. The main which is still to be clarified is the “peak current” for the strokes and consequently for the flashes since the flashes take the peak current of the first stroke. The peak current is the characteristic provided by the detection systems. The authors employ often “intensity” or “current”. It is necessary to standardize in the text and as it is made in other works, with “peak current”, it will be clearer.

Response: Thank you for your suggestion. The phrase "discharge intensity" has been replaced with "peak current" throughout the paper.

On the other hand, for the proportion and ratio concerning the +CG flashes, in the abstract I read two different terms: line 21 “+CG proportion” and line 29 “the +CG ratio”. By using proportion, it is clear; by using ratio it is ambiguous! Is it +CG/-CG ratio or +CG/CG ratio? Again, it is necessary to use the same term (in the whole paper) to avoid ambiguity. When it is expressed in % it is clearly a proportion, when it is decimal number it is a ratio and it is ambiguous. I recommend to use the term “proportion” and the % for the values.

Response: Through a thorough text search, we found that there is only one instance of the term "ratio" remaining in the abstract. We sincerely apologize for this oversight even after the first round of revisions. We have now replaced the term "ratio" with "proportion" in the abstract. In fact, the intended meaning of the paper is the "+CG/all CG" ratio, so using the term "ratio" was incorrect

2. In a lot of comments, the authors use region names which are not well identified by the reader. For many comments, the geographical location (longitude, latitude) could help to understand. Maybe hen a region is cited and commented, a reference could be made also to Figure 1 with the initials? An example at lines 325-326.

Response: The geographical abbreviations in Fig. 1 have been replaced with their full

names, and the geographical names unfriendly for non-Chinese readers mentioned in the text have been labeled in Fig. 1 using the alphabetical labels (a, b, c, d, etc.).

3. The efficiency is commented in the conclusion (not before in section 2) as “relatively high” but it is not quantified. First, it could be made in section 2 with values or range of values according to the region. Secondly, in the first version of the paper it was given at 24.5 % for the national system, it is not high. It is not clear at that point.

Response: Indeed, the detection efficiency of CNLDN is relatively low compared to other internationally advanced systems, such as NLDN of America. Besides, there has been no research conducted to evaluate the detection efficiency across all regions covered by CNLDN.

Nevertheless, CNLDN remains the sole operational system employed by the Chinese meteorological department, serving as the most extensively deployed national lightning detection system in China. It should be noted that the term "relatively high" in the original conclusion refers to a comparison with other detection systems within China; however, this expression is imprecise. Therefore, it has been modified to “This paper utilizes the dataset from a ground-based lightning location system, CNLDN, which serves as the most extensively deployed national lightning detection system in China, to analyze the CG lightning characteristics in China over the past seven years.” at lines 404-407.

In addition, the current research progresses on the local assessment of CNLDN are added in the introduction at lines 87-100.

4. The term of complexity is often used in the paper. It is not clear what is signified by complexity, for example in the conclusion, at line 374. The complexity is a little vague. I think the interpretation have to be more accurate when it is possible.

Response: The sentences related to the term "complexity" in the text have all been modified. See lines 27,337,392-395,416-418.

5. The data used correspond with lightning flashes over 6 years. The total number of flashes could be given somewhere (in the abstract and in the text with more details according to the different regions. A table could summarize the activity by year and by each of the four regions, it would be welcome. I would say even it is necessary.

Response: Tab.1 has been added to the text displaying the statistics on the annual average numbers of return strokes, stroke densities, and peak current values of the four regions.

6. At lines 241-242 and Figure 3, the comment has to be revised, it is not true for all regions. For example, in region I (the most active), the +CG proportion is the lowest in months September and October! In other regions, it is also around September that it is the lowest, but in region II it is also low in March. It has to be revised in all the paper I think. At line 243, the value is lower than 10 % also, it has to be revised.

Response: After reprocessing the data, the corresponding descriptions in the document

have also been modified. Please refer to the highlighted sections at lines 273-280.

7. Figure 5: Maybe the scale has to be adapted in each panel? The comment at line 270 is not relevant, the lightning activity at midnight is not so strong compared to the beginning of the day (01h 00) for most regions. The sentence has to be revised. The maximum is around 16h for most regions. The sentence at line 279 is wrong, it is not true for regions II and III (both parts of the sentence). Furthermore, it is not consistent with the sentence at line 278.

Response: The scale has been adapted in each panel for Fig. 5. But after carefully checking, the maximum is around 15:00 CST in Region-I and Region-II in the east of China and 1-2 hours later in Region-III and Region-IV in the west of China as illustrated in the text. The other modifications have been highlighted in red in the text.

8. The comments of Figure 6 could be clearer and more correct (lines 292-300). For example, at line 295 "with a more intense change in -CG than in +CG.", I see the opposite! This part has to be more fluent for the language. At line 300 for the disparity, it is also large before noon, correct during noon by around noon maybe?

Response: Based on your feedback, we have made extensive revisions to the description of Fig.6 in this paragraph. See lines 330-341.

9. For the average peak current in Figure 8, some values are surprising (around 200 kA) for such a long period (6 years). Is it correct? Is it consistent with Figure 9 which does not show such large values in the distribution?

Response: Through meticulous examination of the data, we have discovered that over a span of seven years, there were indeed instances of strokes with exceptionally high current values. Approximately 5.1% of the stokes with peak currents exceeding ±100kA, while 0.7% of the strokes surpass ±200kA. The distribution range of peak current of +CG stroke is also consistent with the results inferred from the radiation electric field by *Nag, Amitabh, Vladimir A. Rakov, and Kenneth L. Cummins. "Positive lightning peak currents reported by the US National Lightning Detection Network."IEEE transactions on electromagnetic compatibility 56.2 (2013): 404-412.*

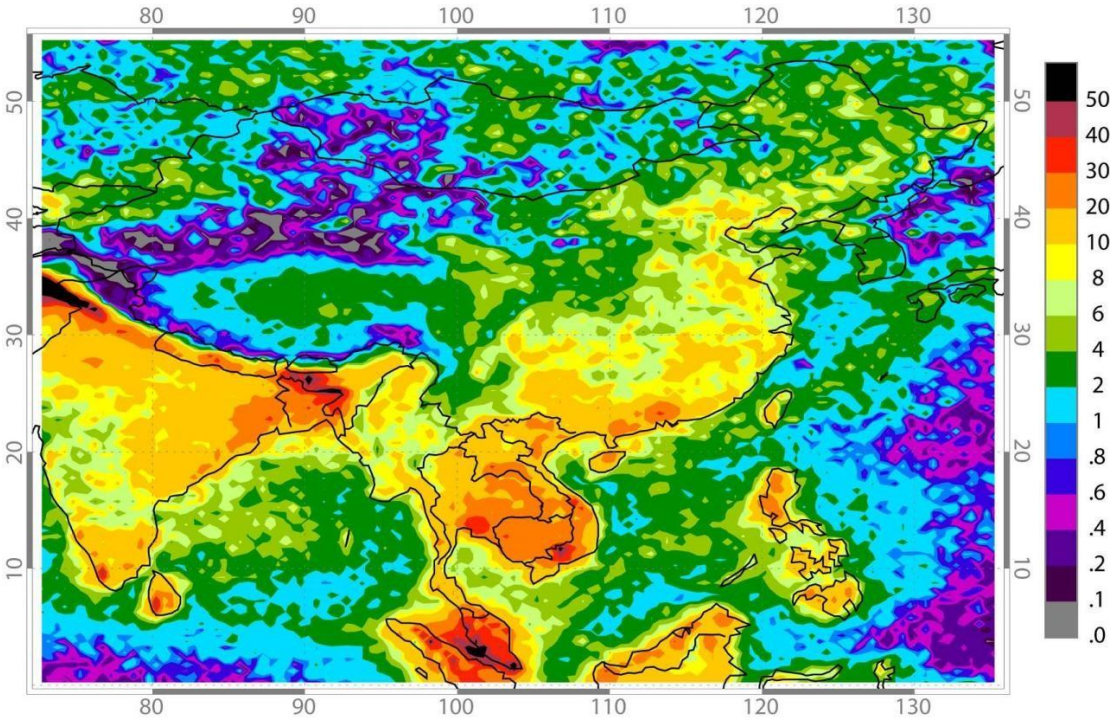
This observation aligns with Fig. 9, as the box plots depicted in Fig. 9 have not displayed the outlier values. Hence, there is no contradiction between these findings.

At lines 242, only 91 CG flashes above 6000 m: is it a problem of detection? A small area at this altitude? Usually mountains are favorable for lightning activity.

Response: In fact, according to the description provided in lines 115-116, CNLDN indeed has some blinds areas in the desert regions of Xinjiang and the uninhabited high-altitude areas of Tibet Minor comments, which will somehow lead to lower observed results. So,"91 CG flashes occurred above 6000 m" has been revised to "91 CG flashes were observed above 6000 m".

Although mountains are favorable for lightning activity, the extremely high-altitude regions above 6000m are typically covered by year-round ice and snow, resulting in a

minimal occurrence of lightning events. The aforementioned conclusion can be supported by satellite-based lightning observations below.



(Lightning observations from1994 to 2013 by LIS on TRMM)

At line 345, it is not true for the -CG flashes, it does not decrease with altitude (only true for +CG flashes). At line 350, it is not clear since the lightning activity is low in this plateau. More detailed explanation about "complexity" is necessary.

Response: Thanks for your remind. It has been revised to "The distribution of +CG peak current narrows with increasing altitude."

At line 350, it is not clear since the lightning activity is low in this plateau. More detailed explanation about "complexity" is necessary.

Response: The statement in the original text has been changed to "The Tibetan Plateau is primarily responsible for the intricate lightning activity versus altitude over China. As the "third pole" of the Earth, the charge structure of thunderstorm clouds on the Tibetan Plateau always has some special characteristics due to the high-altitude ground surface. Furthermore, its influence on the uplift and obstruction of water vapor can also affect the climatic characteristics of other regions.". See lines 392-397.

Minor comments:

- line 18: CNT is never defined in the paper. It is necessary to do it in both abstract once and in the text at the first use.

Response: Thank you for your reminder. This article has changed all the CNT in the text to CST (China Standard Time) and given the full name at the first appearance in the abstract and the main text.

- line 37: what is meso-small? Is it used in the literature?

Response: After consulting the literature, We found that this expression is indeed uncommon, so we changed it to "mesoscale or small scale" in the article.

- line 38: lightning is usually associated with cumulonimbus, stratus is not really associated.

- line 39: nuclear explosions are not frequent (hopefully!), is it necessary to indicate it?

- line 52: replace "could" by "can"

- line 154: "grid"

Response: Thank you for your reminder. The relevant descriptions have been revised according to the above four comments.

- line 202: "a larger spatial scale" it is not clear where the scale is considered, in the cloud?

Response: It has been deleted.

- line 208: space. Often the space has to be added.

Response: Thanks for the reminder, we have done a full-text index and added the missing spaces.

- line 252: "peak current"

- line 266: "The red lines represent" there are two red lines.

Response: Thank you for your reminder. The relevant descriptions have been revised according to the above two comments.

- line 268: the sentence has to be revised. In Fig. 5 the peak current is not plotted but the proportion of +CG.

Response: The sentence has been revised to "Fig.5 illustrates the hour-by-hour frequency and proportion variations of CG flashes throughout the day."

- line 291: "peak current". Rephrase with "The hourly distribution of the peak current value and its average are shown in Figure 6 for +CG and -CG flashes."

Response: This statement does make the description clearer and more reasonable, and it has been modified according to your comments.

- line 295: "at noon"

- line 303: "for each hour and not each month..

- line 312: space before % (in other parts also).

- line 321: grid (and other figure captions).

Response: Thank you for your reminder. The relevant descriptions have been revised

according to the above four comments.

- line 328: is it necessary to say “in terms of temporal and spatial scales”? If it corresponds it is enough.

Response: I think it's important to emphasize this, because this article is discussed separately in time and space, and we can all reach a consistent conclusion. Both in time and space scales, the two have good consistency.

- line 378: Rephrase “due to their different mechanisms” with due to different storm structures” if you agree?

Response: I agree that this change has a better effect.

- line 393: delete “midnight” after checking. “drops”.

Response: Modifications have been made accordingly.

- line 402: Rephrase “The +CG proportion exhibits significant spatial variability.”

Response: It has been revised to “The distribution of the +CG stroke proportion exhibits significant spatial variability.”

Reviewer #3:

In this manuscript the authors analyze the characteristics of cloud-to-ground lightning in China over a 6-year period as observed by the Chinese National Lightning Detection Network (CNLDN). The current manuscript has undergone previously already a round of peer-review. Before this manuscript could be accepted for publication the following points should be taken into account:

This article has three two changes. Firstly, based on the feedback from the first reviewer, the statistics on lightning flash have been modified to statistics on lightning strokes. Secondly, due to the long review period, new data for another year has been obtained, expanding the data collection period to seven years (2016-2022). As a result, the relevant statistical values have undergone slight fluctuations, and the figures have been adjusted accordingly. However, the main conclusions remain essentially unchanged. Additionally, several citations of relevant research progress have been added.

- Acronyms: CNLDN (it is common practice not to use acronyms in the title), CNT (in abstract, and later in the text), TRMM (introduction at L79) should be defined before the acronym is used.

Response: The title has replaced CNLDN with its full name, and other abbreviations in the text have also been marked with the full name at their first occurrence.

- Throughout the text 'current peak' is used. In stead, 'peak current' is what is commonly used in scientific journals.

Response: The phrase 'current peak' in the full text has been revised.

- Introduction L46: what do you mean with 'scientific protection (...)'?

Response: It has been revised to "Therefore, the timely and accurate monitoring of lightning serves as an effective approach for the development of lightning science and scientifically mitigating the hazards of lightning strikes."

- Introduction L51/52: only references to some LF networks are listed, without any reference to VLF networks. Some extra references to, e.g., GLD360 & WWLLN, should be included since the authors speak about the advantages of ionospheric reflections of the radiation emitted by discharges.

Response: The relevant content has been added to lines 58-62.

- Introduction L59-61: it would be good to include most recent references to the networks NLDN, LASA, and EUCLID.

Response: The relevant content has been added to lines 58-62.

- Introduction L79: rephrase 'was no longer updated'

Response: It has been revised to "discontinued updates"

- Introduction L80: 'detection rate'. Do you mean 'detection efficiency'?

Response: Thanks. The ‘‘detection rate” has been replaced by “detection efficiency”.

- Introduction L89-L91: rephrase last sentence of the introduction.

Response: The last sentence has been rephrased as “Furthermore, China's extensive geographical expanse, spanning a wide range of latitudes and longitudes, coupled with its intricate topography, provides a unique opportunity for investigating the correlation between lightning occurrences and geographic factors.”

- Sect. 2 L100–105: 1) what about the detection of IC pulses? The focus of this paper is not on IC, however, if IC pulses are detected, it would be good to mention it in the text.

Response: This study collected data spanning seven years; however, the detection capability for IC pulses was only added to CNLDN in half of 2021 and 2022. After conducting statistical analysis, it was found that the detection efficiency of IC was relatively lower. Therefore, this paper does not include any relevant descriptions regarding IC detection.

2) This manuscript discusses, amongst others, the spatial distribution of CG flashes. It is therefore a necessity to state the flash detection efficiency (DE) and location accuracy (LA) of CNLDN and add references to publications thereof. Otherwise, the reader has no idea about the quality of the network, and hence, the quality of the results in this study.

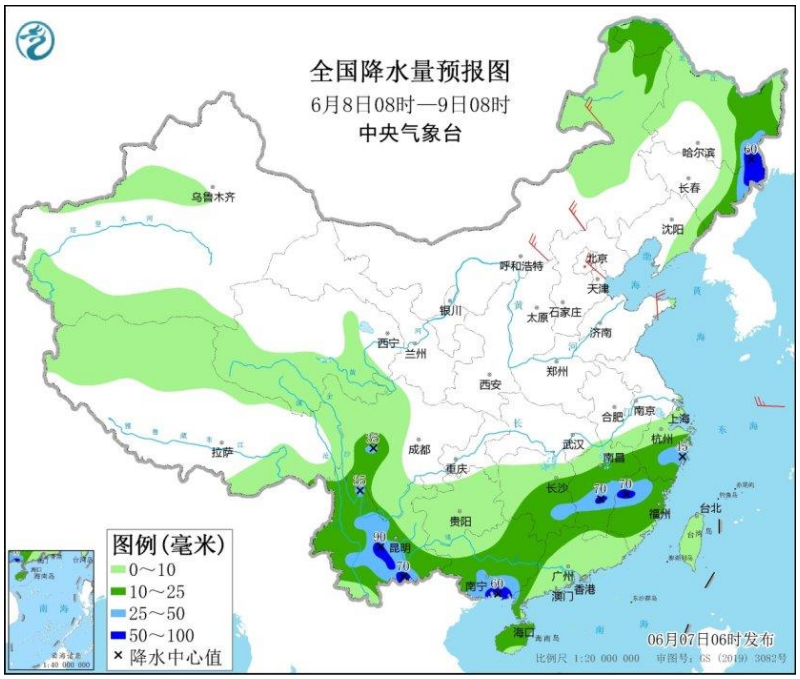
Response: Indeed there has been no research conducted to evaluate the detection efficiency across all regions covered by CNLDN. The current research progresses on the local assessment of CNLDN are added in the introduction at lines 87-100.

- Sect. 2 L109: ‘’triggered stations’. Do you mean ‘participating stations’? There is an important difference.

Response: According to the suggestions provided by the first reviewer, the " triggered stations " has been changed to " reporting sensors".

- Fig.1: what is the purpose of the inset Figure in the bottom right corner? At first glance, it does not add anything and could be removed.

Response: The inset map in the corner is a supplementary depiction of the nine-dash line to ensure the integrity of China's territorial boundaries. Generally, Chinese maps that comply with the verification of the Ministry of Natural Resources of China require the inclusion of the nine-dash line and the South China Sea region. As shown in the following officially released figure.



- Sect. 3.1.: I would advice to include mean/median values of the flash density per region. This is not included at the moment.

Response: Tab.1 has been added to the text including the annual average numbers of return strokes, stroke densities, and peak current values of the four regions.

- Sect. 3.1: it is better to use for the unit of flash densities 'fl km-2 yr-1', where 'fl' stands for flashes

Response: Your suggestion is good, but the manuscript has already been modified based on the first reviewer's recommendation to change the focus from statistics on lightning flash to statistics on lightning return strokes.

- Sect. 3.1, Fig. 2, L154: 1) 'gird' → 'grid' ,

Response: The above-mentioned error has been corrected.

2) why 0.25x0.25 degree grid is used? It would be good to justify this size. The authors could, e.g., refer to Diendorfer (2008, some comments on the achievable accuracy of local ground flashes density values, Proc. 29th Int. Conf. On Lightning Protection, Uppsala, Sweden), who demonstrated that in order to obtain an uncertainty of less than 20% at 90% confidence level, a grid size has to be chosen in such a way that the dimensions of each cell and the number of years considered both comply with the minimum requirements of the following equation, following the Poisson distribution of the law of rare events: Ng x Tobs x Acell >= 80. In your case the grid cell area Acell is about 25x25km2, Tobs=6 years. Hence, Ng >= 80 / (6x625) = 0.02 fl km-2 yr-1. It follows that your chosen grid size is ok to work with.

Response: Thank you for your suggestion. We have incorporated the reasoning for our choice of grid size based on the literature you provided at lines 156-161 of the text.

"According to the research of Diendorfer (2008), lightning is a highly stochastic phenomenon and if we require an uncertainty of less than ± 20 % there should be more than 80 events per grid cell. Therefore, we establish the grid size as 0.25° ×0.25°, ensuring that the results within the confidence interval for all regions, except part of areas in Xinjiang and Tibet."

- Text related to Fig. 4: it would be good to include mean/median values of the absolute peak current for -CG & +CG observed in the different regions.

Response: The mean peak current values have been added to Tab. 1 and relevant descriptions have been added at lines 284-288.

- What I miss in this manuscript, is some connections to observations in other parts of the world. For instance, how do the spatial densities and in particular the absolute peak currents compare to observations in other parts of the world? One could compare to, e.g., EUCLID (e.g., Poelman et al., 2016, https://nhess.copernicus.org/articles/16/607/2016/) or NLDN journal papers, since those networks are similar to CNLDN and above all are one of the best documented networks in terms of DE and LA.

Response: Thanks for your suggestions. The relative comparisons have been added to lines 254-266, 312-314

- Similar to previous point: the authors could include some comparison to observations made by other networks in China, e.g., Xia et al. (a 6yr cloud-to-ground lightning climatology and its relationship to rainfall over Central and Eastern China, https://doi.org/10.1175/JAMC-D-15-0029.1). How well do the current results overlap with those published in the past?

Response: Thanks for your suggestions. The relative comparisons have been added to lines 162-164,178-179.

- Text related to Fig. 5 L291-300: what could be the reason behind the fact that, e.g., in region I the peak current decreases 'in the noon and afternoon'?

Response: Throughout the analysis in this paper, a consistent finding has emerged: in periods or regions with high lightning frequency, the peak current of lightning discharges tends to weaken. In the noon and afternoon, where lightning frequency is high, the peak current values are comparatively lower. However, this paper merely objectively describes the observed phenomena, and it is difficult to provide a reasonable scientific explanation based on the existing observations.

- Sect. 3.2.2: maybe this section could be moved directly after Sect. 3.1, which deals with the spatial distribution of the CG flash density?

Response: Thank you for your valuable suggestion. However, Section 3.2 investigates the differences between +CG and -CG, while Section 3.1 focuses on the overall distribution characteristics and their relationship with topography and climate. We would like to maintain the original structure as it is.

- General comment: throughout the text the others mention names of places, e.g., Shanxi, Shaanxi, Guizhou, … Many, if not all, non-Chinese readers will not have a clue where those exactly are located. Maybe the others could include in some way in Fig. 1 the locations of the places mentioned in the text?

Response: The geographical abbreviations in Fig. 1 have been replaced with their full names, and the geographical names unfriendly for non-Chinese readers mentioned in the text have been labeled in Fig. 1 using the alphabetical labels (a, b, c, d, etc.).

- Fig. 8 L327-329: last sentence should be rephrased.

Response: It has been revised to "Therefore, it can be concluded that a high proportion of +CG stroke typically corresponds to larger current values in terms of temporal and spatial scales."

- Fig. 8; the authors could use a similar scale. Now, the scale for |-CG| is [0,200]kA, whereas for +CG it is [0,250] kA. I would use the same scale from [0,200] kA.

Response: Both figures have been modified to have the same current range of 0-250kA.

- Fig. 8: what is the cause of the much higher absolute peak current in the area around 28N, 95E?

Response: The exceptionally strong lightning current in Mêdog County may be because of its unique geographical location (at the gap of the Himalayas Mountains), leading to distinct charge distributions within thunderstorm clouds. However, due to a lack of relevant observations and research, it cannot be confirmed at this time.

- Fig. 9: is a similar trend also found in other parts of the world? Did the others check the literature carefully?

Response: As the "Roof of the World", the Qinghai-Tibet Plateau is unique to China and provides a valuable opportunity for investigating the correlation between lightning occurrences and geographic factors. Currently, we have not found other research regarding the relationship between lightning and altitude.