Dear Editor and Referee#3,

Thank you very much for your attention and the referee's evaluation and comments on this work. Those comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our research. Following are point-by-point responses to Referee #3's comments. All the line numbers mentioned in responses are referred to the manuscript with changes marked.

**(1)** The manuscript is in need of careful English language editing throughout, particularly the specific scientific term and the sentence structure. There are too many to spend time providing a full list of typos and language corrections.

**Reply**: Thank you for your comment. We are sorry for these language mistakes in this manuscript. We have revised most of the content in the article and carefully checked the language to reduce these errors.

**(2)** The data processing of polluted and clean subsets is not unambiguous (Lines 124-125). What the exact AOD range or value are used in this study? Please clarify.

**Reply**: Thank you for your comment. We have rewritten this part and added a figure to illustrate the distribution of samples' AOD value and the AOD range of clean and polluted subsets (Fig. 2-1). (Lines: 138-155)

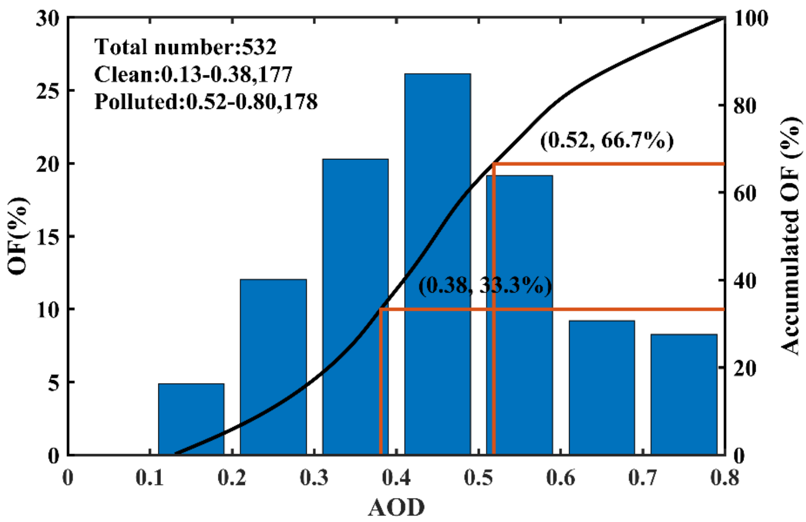


Figure 2-1. The probability density function of ranked AOD of 532 samples. Black solid lines denote accumulated occurrence frequencies for the AOD. Red lines show the top and bottom terciles.

**(3)** I still cannot understand how these two periods (Period 1 and Period2, lines 218-220) are chosen. However, these two time periods are the basis for the following analysis and discussion.

**Reply**: Thank you for your comments. In this manuscript, we aim to investigate the diurnal differences in the effect of aerosols on lightning in the Sichuan Basin. By comparing the diurnal variation of CG lighting flashes under clean and polluted subsets, we found that the difference in the response of CG lightning flashes to aerosols mainly occurred between the afternoon and other times (night and morning). Little difference between the CG lightning flashes was found between the clean and polluted subset, while at other times (especially around midnight), the CG lightning flashes in the polluted subset were markedly greater than that in the clean subset. Therefore, we selected two time periods in the afternoon and night respectively in the following content to investigate the relationship between CG lightning flashes and aerosols, thermodynamics-dynamics factors and cloud-related parameters.

**(4)** How do you define the different time periods in this study? The time periods used in this paper include "nighttime (1800-600BJT)" (line 139), "midnight (2400-0100 BJT)" (line 140), "night (2300-2400 BJT)" (line 188), "midnight (2400-0300 BJT)" (line 170), "midnight (2300-0200 BJT)" (line 171), …, which is very confusing.

**Reply**: Thank you for your comment. We are sorry for these unclear descriptions in the manuscript. We have revised these descriptions in the revised manuscript. We direct describe the different time periods using numbers like "1200-1800 BJT".

**(5)** Conclusions are based on assumptions, rather than on detailed analysis of the corresponding observation results. No statistics are presented to prove the points as follows:

(5.1) Lines 193-195: "We speculate that this may be one of the causes for the inconsistent response results of PPCG to aerosol loading in different periods."

(5.2) Lines 228-232: "Meanwhile, the relationship between aerosols and CG lightning flashes did not show a similar nonlinear relationship at night time. We speculate that this may be due to the lack of solar radiation at night, weakening aerosol radiative effects."

(5.3) Lines 253-255: "Thus, we may infer that the thunderstorm system in the period1 is different to that in period2."

(5.4) Lines 351-353: "Therefore, it can be inferred that aerosols have different effects on lightning at different times in the study region."

**Reply**: Thank you for your comment. Given these comments, we have revised the manuscript's content. The specific modifications are as follows:

**Reply to 5.1:** In the previous manuscript, we investigated the diurnal variation of PPCG under polluted and clean conditions. The results showed that there were some differences in PPCG's response to AOD at different times of the day, but they were not obvious. After we improved the sample processing method (as described in the reply to comment 9), the difference in PPCG response to AOD became less obvious (as shown in Fig. 5-1). Therefore, we decided to remove this part of the PPCG analysis in the revised version. We will mainly focus on investigating the difference between the daytime and nighttime effects of aerosols on lightning frequency in the study area, which is also the main purpose of this study at the beginning. Some studies have reported the relationship between aerosols and PPCG, but different results have been found in different regions (i.e., positive correlation: Tan et al. 2016; Murray et al. 2000; negative correlation: Kar et al. 2014; Naccarato et al. 2003). This is an interesting subject worthy of further study. In future research, we will adopt more appropriate methods to conduct a more comprehensive study about this.

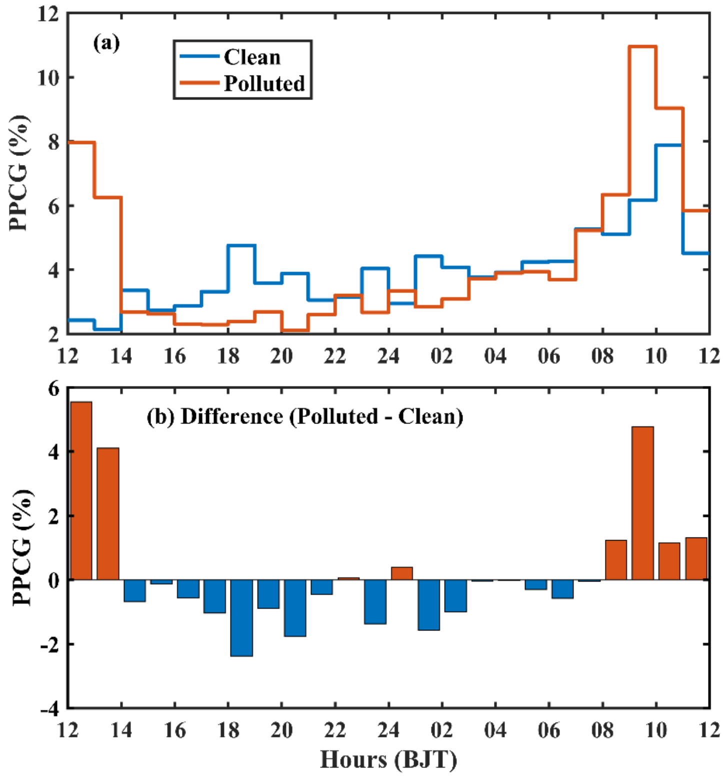


Figure 5-1. (a) The diurnal variation of the percentage of positive polarity CG lightning flashes (PPCG) in clean and polluted subsets. (b) The difference in the PPCG between polluted and clean subsets

**Reply to 5.2 and 5.4**: Firstly, in the previous manuscript, our analysis mainly compared the differences in the relationship between aerosols and lightning flashes in the afternoon and part of the night. The descriptions such as "Therefore, it can be inferred that aerosols have different effects on lightning at different times in the study region" in the article are not rigorous. We have revised these descriptions in the manuscript.

The reason why we chose these two time periods is that we found that the difference in the relationships between aerosols and lightning flashes in these two time periods was the most obvious. In the afternoon (1200-1800

BJT), the lightning flashes have little difference in polluted and clean subsets, while at night (2300-0500 BJT), the lightning flashes have the largest difference in polluted and clean subsets (as shown in Fig. 5-2).

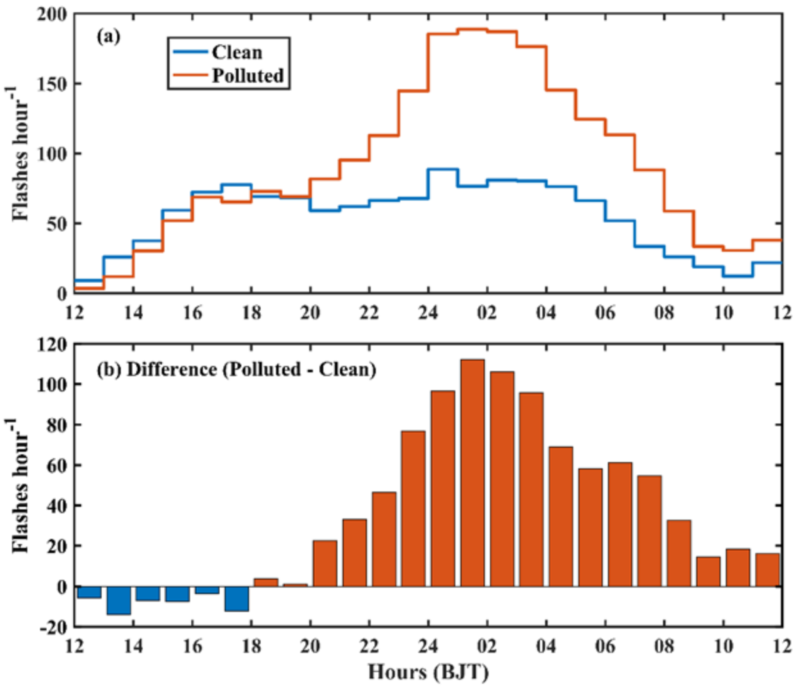


Figure 5-2. (a) The diurnal variations in CG lightning flashes under clean and polluted subsets over the study region during the summer (June, July, and August) season of 2010-2018. (b) The histogram of the difference in CG lightning flashes between the polluted and clean subsets

Further analysis shows that the relationships between AOD and lightning flashes in these two periods (afternoon: 1200-1800 BJT, night: 2300-0500 BJT) are apparent different (as shown in Fig. 5-3). The AOD and lightning flashes show different nonlinear relationships in the afternoon and night. The lightning flashes first increase with the increase of AOD and then decrease when AOD exceed about 0.3. At night, the lightning flashes also first increase with the increase of AOD but change little when AOD exceed about 0.3. Some studies also reported a similar nonlinear relationship between aerosol loading and lightning flashes and found a similar tipping point of AOD (Wang et al. 2018: ~0.3, Altaratz et al. 2010, Koren et al. 2008: ~0.25). The microphysical effect of aerosols increases with the increase of aerosols loading, but when the aerosol concentration exceeds a threshold value, the microphysical effect of aerosols will reach saturation. On the contrary, the direct effect of aerosols is weak when the aerosol concentration is relatively low, and will gradually become stronger with the increase of the aerosol concentration (Rosenfeld et al. 2008). The relative intensity of these two effects of aerosols changes with the aerosol concentration, which may result in the nonlinear relationship between aerosols and lightning frequency.

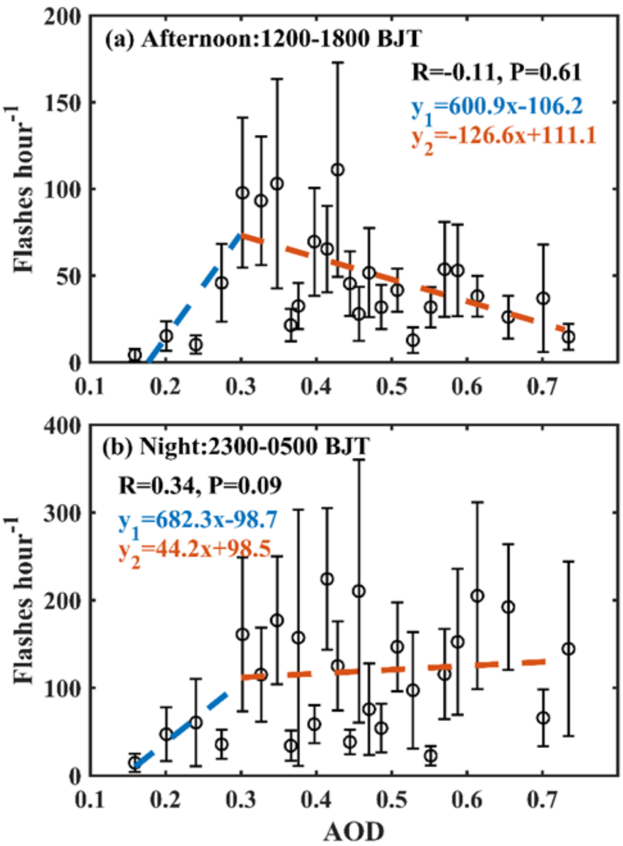


Figure 5-3. Relationships between lightning flashes and AOD in (a) afternoon (1200–1800 BJT) and (b) night (2300–0500 BJT). Note that samples are first sorted by AOD and then samples with similar AOD were averaged to create the presented scatter plot.

The max number of samples in each bin is equal to or less than 20. The difference between the maximum and minimum AOD values of samples in each bin is equal to or less than 0.05. An estimation of the error was calculated from the standard deviation of each bin divided by the square root of the number of data points in the bin. Linear-fit lines, Pearson correlation coefficients (r), and significant level (p) are also shown.

In this study, when the aerosol loading is relatively low (AOD<~0.3), the aerosols both positively correlated with the lightning flashes in the two time periods. The biggest difference in the influence of aerosols on lightning flashes in these two time periods occurs when the concentration of aerosols is relatively high (AOD>~0.3). We speculate that this may be caused by the different roles of solar radiation in the afternoon and at night in the study region, as well as special topographic and meteorological conditions. To prove this, we added the analysis of the relationship between 2m temperature and AOD, cloud-related factors (as shown in Fig. 5-4). When the aerosol loading is relatively high, the aerosol layer above the surface will reduce the solar radiation that reaches the surface by absorbing or scattering the solar radiation and thus reducing the surface temperature (Fig. 5-4a). This effect will disappear at night because of the absence of solar radiation during this time period. Therefore, no significant relationship can be found between AOD and T at night (Fig. 5-4e). The increase in cloud liquid water will lead to thicker and larger clouds and prevent solar radiation from reaching the ground. Meanwhile, too much cloud liquid water may promote the development of the warm-rain process and further reduce the T. On the other hand, the increase in T is also conducive to the rise of water vapour which is conducive to an increase in cloud liquid water. In the afternoon, when the TCLW is less than about 0.1 kg $m^{-2}$, the relationship between T and TCLW is unclear. However, at night, when the TCLW is less than about 0.1 kg $m^{-2}$, TLCW is positively correlated with T. This shows that when the TCLW is relatively small (<~0.1 kg $m^{-2}$) and the precipitation process has not yet formed, in the afternoon, the increase of cloud water content by T and the decrease of T by TCLW through blocking solar radiation cancel each other, resulting in an insignificant relationship between T and TCLW. At night, due to the absence of solar radiation, the effect of TCLW reducing T by blocking solar radiation disappears, and the effect of T on the increase of TCLW is dominant, resulting in a positive correlation between them. When the TCLW is relatively large (>~0.1 kg $m^{-2}$), no matter in the afternoon or at night, the warm-rain process is promoted, and the evaporation of precipitation on the surface reduces the T. In the afternoon, the relationship between TCIW and T is similar to that between TCLW and T (Fig. 5-4c). However, at night, no obvious relationship was found between TCIW and T (Fig. 5-4g). This may be due to the fact that the TCIW is more related to the strength of the updraft. The T at night is not the main factor affecting the convection intensity, but the conversion process from TCIW to precipitation is more complex, so the TCIW has a weaker effect on the reduction of the T. In addition, increase aerosol loading will produce more but smaller cloud droplets that inhibit the warm rain process and may lead to an increase in cloud liquid water (Fig. 5-4d and h). Therefore, the reason for the negative relationship between AOD and T in the afternoon may also include the effect of aerosol on cloud water content. In summary, in the afternoon, excessive aerosols will reduce the T through its direct radiative effects and microphysical effects. At night, such inhibit effects on T are reduced. The reduced T leads to the increase of atmospheric stability and thus inhibits lightning activity. This may explain the difference in the relationships between AOD and lightning flashes in the afternoon and night.

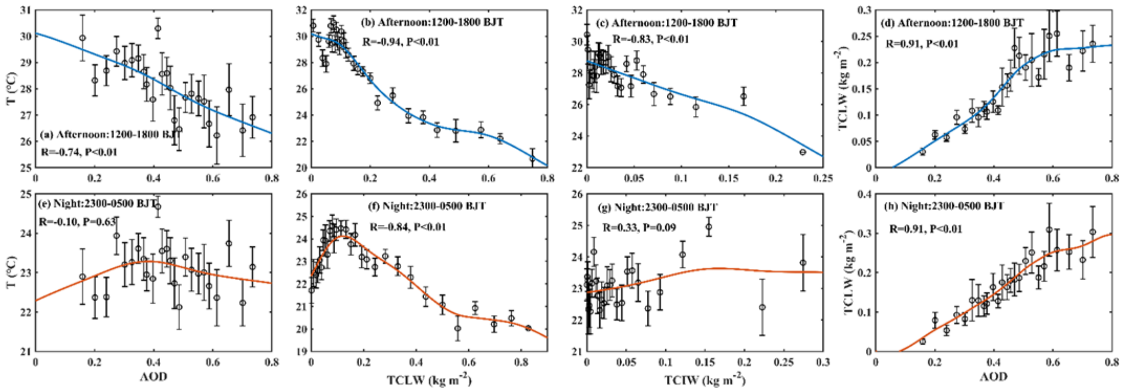


Figure 5-4. Relationships in (a and e) AOD-T, (b and f) TCLW-T, (c and g) TCIW and (d and h) AOD-TCLW in the afternoon (1200–1800 BJT) and night (2300–0500 BJT). Note that samples are first sorted by (a, e, d, and h) AOD, (b, f) TCLW, and (c, g) TCIW, and then samples with similar (a, e, d, and h) AOD, (b, f) TCLW, and (c, g) TCIW were averaged to create the presented scatter plot. The max number of samples in each bin is equal to or less than 20. The difference between the maximum and minimum AOD, TCLW, and TCIW values of samples in each bin is equal to or less than 0.05, 0.05 and 0.01. An estimation of the error was calculated from the standard deviation of each bin divided by the square root of the number of data points in the bin. Smoothing spline-fit curves, Pearson correlation coefficients (r), and significant level (p) are also shown in each panel.

**Reply to 5.3**: This inference is not rigorous. Based on the diurnal change of the spatial distribution of lightning flashes (as shown in Fig. 5-5), the spatial distribution of lightning has obvious differences in different time periods. Compared with the afternoon, nighttime lightning mainly occurred in the south and west part of the study region. This regional difference may also be the reason why the relationship between vertical wind shear and lightning flashes is different in the afternoon and at night. We have revised the relevant statements in the manuscript.

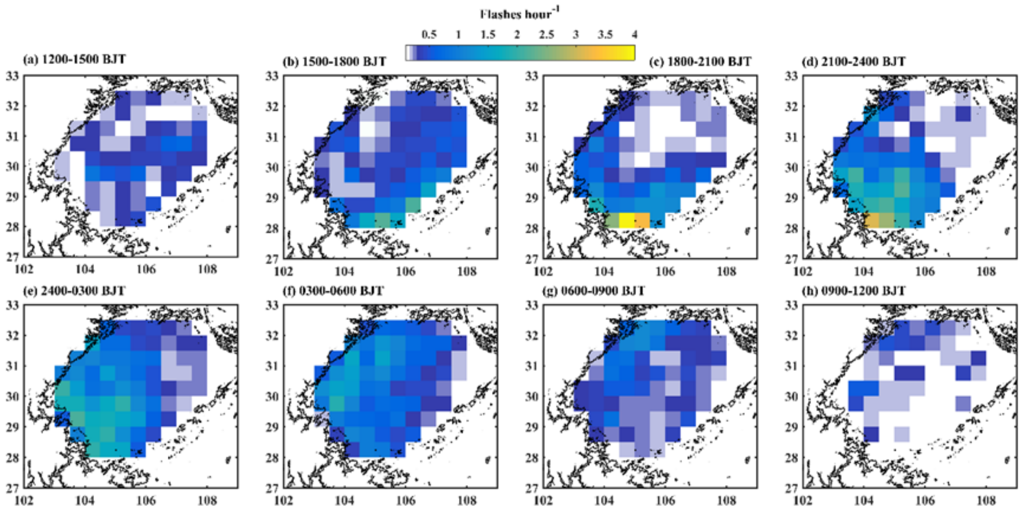


Figure 5-5. Diurnal cycle of total CG lightning flashes (unit: flashes hour$^{-1}$) on a 0.5°×0.5° grid with an interval of 3 hours (BJT) for 2010–2018 including the summer months (June, July, and August). The black lines represent the 1500m contour lines.

**(6)** The results show that there are differences in the spatial distribution of CG lightning between polluted and clean subsets (Fig.5). What is the reason of this distribution? Will this influence the following analysis? Before the authors discuss the relationships between CG and aerosols at different periods, a more comprehensive discussion, related to the differences in the spatial distribution of CG lightning between polluted and clean subsets is required.

**Reply**: Thank you for your comment. We have redrawn this figure and added more information (as shown in Fig. 6-1). Between 2100 BJT and

0900 BJT, the difference in lightning flashes under polluted and clean subsets is obvious, but it is not obvious for the rest of the time (the change of lightning flashes of most grid points is less than 1). During this period, the most obvious differences were concentrated in the south and northwest parts of the study region (Figure 6-1d, I, j, and k).

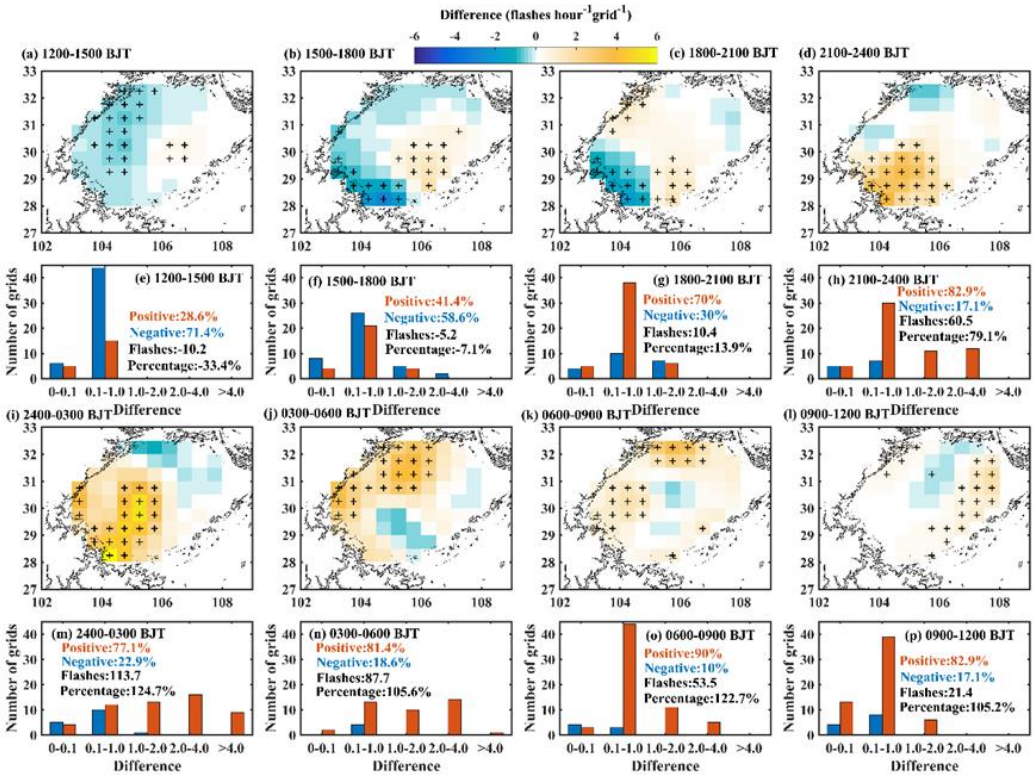


Figure 6-1. (a-d, i-l) Diurnal changes of total CG lightning flash differences (unit: flashes hour$^{-1}$) between polluted and clean subset (polluted−clean) during the study period with an interval of 3 hours (BJT). Black lines represent the 1500m contour lines. The spatial resolution is 0.5°×0.5°. The colour in a grid represents the value of lightning flashes change in the grid. Plus signs denote those grids with relatively large lightning flashes difference (the absolute value of lightning flashes difference ranks in the top third). (e-h, m-p) Histograms of the differences (red: positive, blue: negative) between lightning flashes in the polluted and clean subsets. The percentages of grids with the positive (negative) difference in the total grids, the total change of lightning flashes, and its percentage are also given.

Fig. 6-2 and 6-3 show the diurnal cycle of lightning flashes in polluted and clean subsets, respectively. In general, the spatial distribution of lightning flashes under polluted and clean subsets is similar, especially between 1800 and 0600 BJT. We speculate that the spatial distribution of lightning flashes in the study region is mainly controlled by terrain and meteorological conditions, and aerosol may have little impact on its spatial distribution. The difference brought by aerosols may be mainly reflected in the time difference. In addition, this difference in the spatial distribution of lightning flashes needs to be considered in the following analysis. This may be the reason for the difference in lightning flashes and other factors (such as vertical wind shear) between afternoon and night.

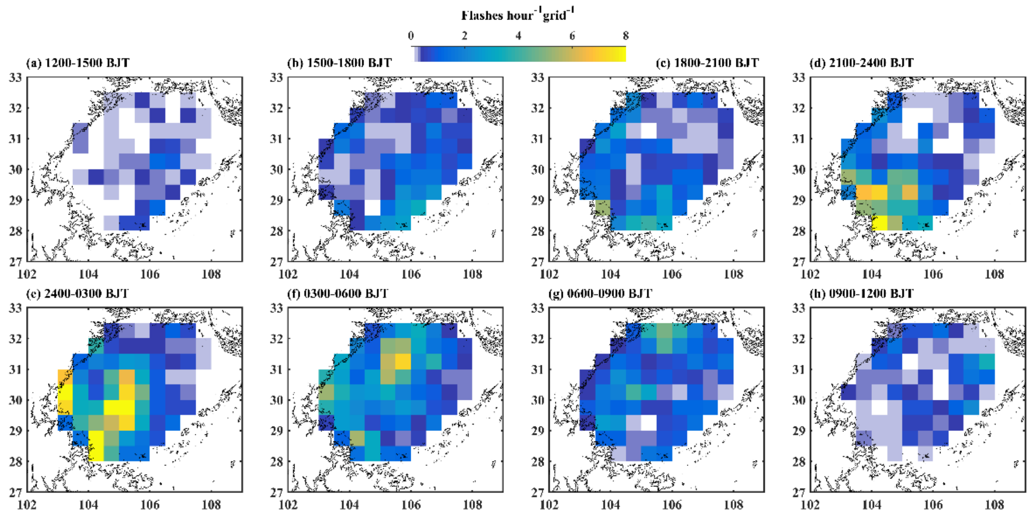


Figure 6-2. Diurnal cycle of lightning flashes in polluted subset on a 0.5°×0.5° grid with an interval of 3 hours (BJT) for 2010–2018 including the summer months (June, July, and August). The black lines represent the 1500m contour lines.

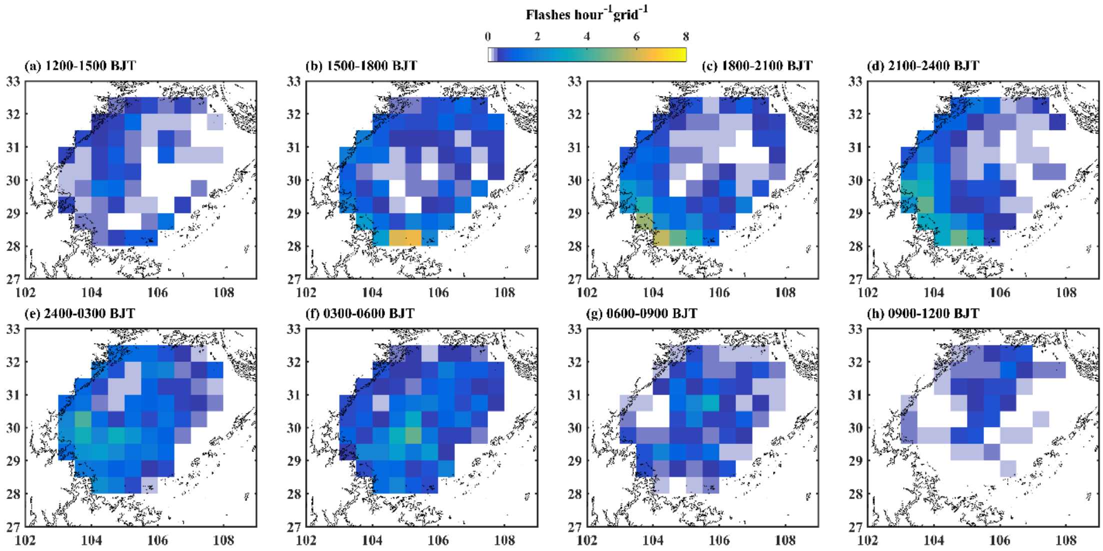


Figure 6-3. Same as in Fig. 6-2, but for lightning flashes in a clean subset.

**(7)** Lines 240-283, Figures 7-9: How did the samples be sorted? More information about the methods should be provided. Furthermore, your conclusion seems not reliable because of the large standard deviation of each bin.

**Reply**: Thank you for your comment. In the previous manuscript, when creating the scatter plot between lightning flashes and other factors (referred to as x), the lightning data were first sorted as a function of x and then every 20 points were averaged. This method does not control the range of x in each bin, resulting in a large standard deviation in some bins. We have improved this method in the revised manuscript. The samples were first sorted as a function of x and then samples with similar x were averaged. The max number of samples in each bin is equal to or less than 20. The difference between the maximum and minimum x of samples in each bin is limited to a fixed range. This information has been added to the figure title. With the improved method, the standard deviation in each figure is lower than the previous results.

**(8)** Lines 256-271: The analysis seems to be completely wrong. The authors claim that “A positive relationship (r = 0.94) between them is found in Period2” (line 261, Fig. 8b). However, a negative relationship between them is shown in Fig. 8b.

**Reply**: We are sorry for this mistake. We have checked and revised this wrong analysis in the revised manuscript.

**(9)** Figures 10-11: The authors got “564 samples” in total (line 123), however, the total number of samples in Figs. 10-11 is much larger than 564 samples, which cannot convince the reader of the validity of the conclusions.

**Reply**: Thank you for your comments. In the revised manuscript, we modified the sample processing method.

In the previous manuscript, the time of a sample includes 24 hours. It starts at 0600 BJT one day and ends at 0600 BJT the next day, as shown in Fig. 9-1.

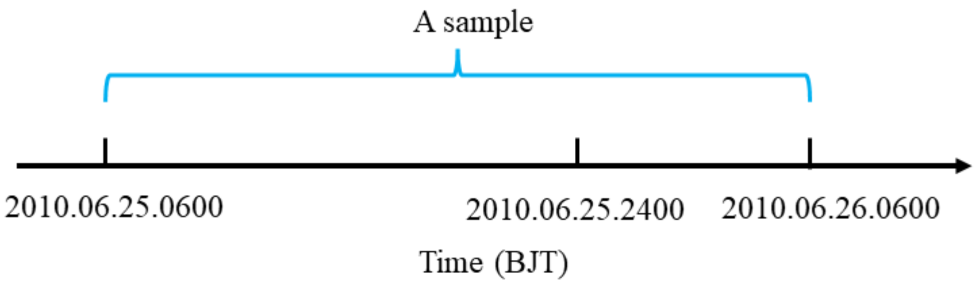


Figure 9-1. Schematic diagram of sample time selection.

Then, we only retain grids with CG flashes larger than ten during the period of a sample (the blue region shown in Fig. 9-2) to make sure there are relatively strong thunderstorms in those grids (hereinafter referred to as useful grids). Only samples with useful grids will be retained. Based on this rule, we finally got 564 samples during the whole study period.

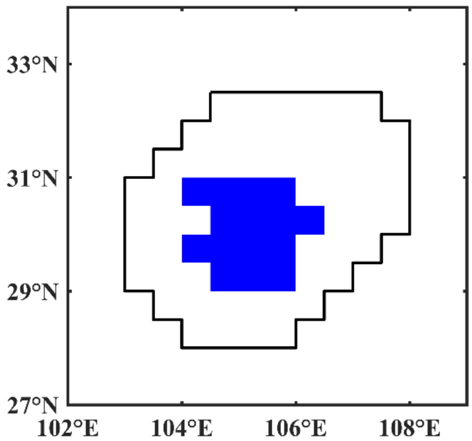


Figure 9-2. Black lines frame the study region. The blue region is grids with CG flashes larger than ten during the period of a sample. The spatial resolution of these grids is 0.5°×0.5°.

The AOD in a sample was calculated from the hourly averaged AOD of these grids as follows:

$$\mathrm{AOD_{Sample}} = \frac{\sum_{k=1}^{24} \mathrm{AOD_{Grid,k}}}{24 \times \mathrm{n_{Grid}}}$$

The $\mathrm{AOD_{Sample}}$ is the AOD value of a sample. The $\mathrm{AOD_{Grid,k}}$ is the AOD value in k hour of a useful grid. The $\mathrm{n_{Grid}}$ is the number of useful grids in a sample.

This method has some drawbacks. It did not take into account the wet deposition of aerosols by precipitation during thunderstorms. Therefore, the definition of clean and polluted subsets, as well as the analysis related to the value of AOD in the previous manuscript were not rigorous. In addition, we set a lightning threshold of ten to filter out many relatively weak lightning activities. However, these weak lightning activities should also be considered in the analysis. In the revised manuscript, we have improved the sample processing method in view of these drawbacks.

In the revised manuscript, a sample starts at 1200 BJT one day and ends at 1200 BJT the next day, as shown in Fig. 9-3 (b). In the study region, most thunderstorms from in the afternoon, at night, and the next morning (Fig. 9-3 (a)). The thunderstorms in the morning may be associated with intense thunderstorms at night. Therefore, noon is a relatively appropriate cut-off point for the sample period. The thunderstorm is weakest at noon, and the impact of precipitation on aerosols is relatively weak. Therefore, we selected the averaged AOD of the useful grids on the first hour (between 1200 BJT and 1300 BJT) of a sample period to represent the $AOD_{Sample}$. In addition, we limited the number of grids with CG lightning flashes to less than 10% of the total grids (7 grids) in each of the six hours before the start of a sample. This is to ensure that thunderstorm has been weak for a period of time before the start of a sample to reduce the possible impact of thunderstorm precipitation on aerosol loading.

(a)

(b)

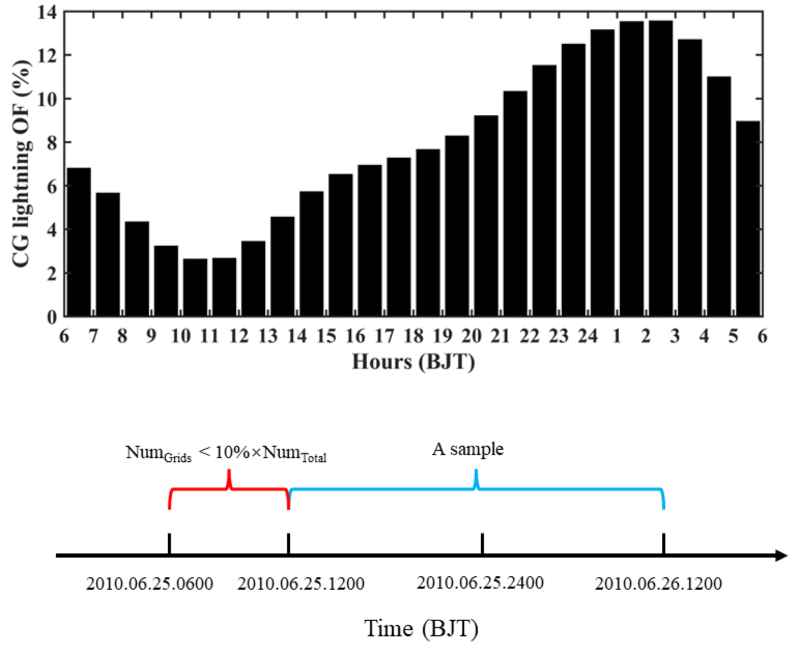


Figure 9-3. (a) The diurnal variation of CG lightning flashes during the study period. $Num_{Grids}$: number of grids with CG lightning flashes in each hour. $Num_{Total}$: number of grids (70) in the entire study region. (b) Schematic diagram of sample time selection.

It should be noted that the definition of useful grids has been changed to those grids with at least one CG lightning flash during a sample period. This change allowed some grids with relatively weak thunderstorms to include in the analysis. Finally, the AOD in a sample is calculated as follows:

$$\mathrm{AOD_{Sample}} = \frac{\sum_{k=1}^{n_{Grid}} \mathrm{AOD_k}}{\mathrm{n_{Grid}}}$$

The $AOD_{Sample}$ is the AOD value of a sample. The $AOD_k$ is the AOD value in the first hour of a useful grid. The $n_{Grid}$ is the number of useful grids in a sample. Finally, we got 532 samples. The definition of the clean and polluted subsets is the same as the method used in the previous manuscript. All samples are sorted according to $AOD_{Sample}$ and divided into three equal sample subsets where the top third of the AOD range is labelled as polluted, and the bottom third is labelled as clean. The distribution of samples' AOD and the AOD range of clean and polluted are shown in Fig. 9-4.

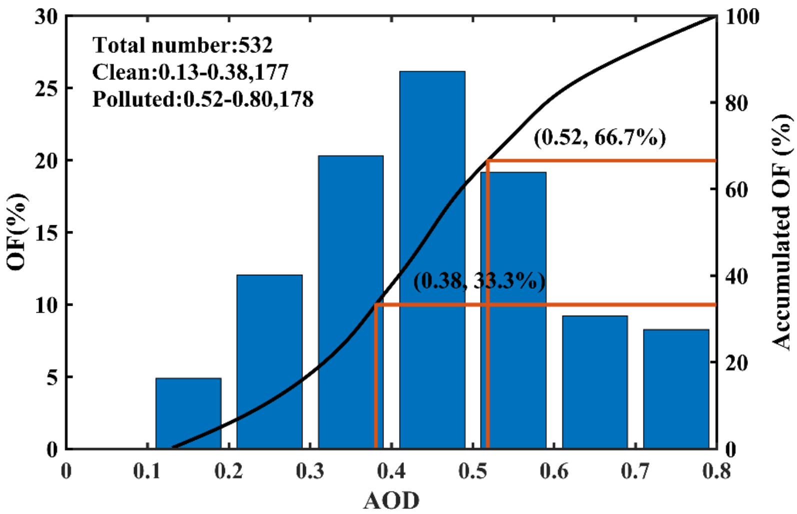


Figure 9-4. The probability density function of ranked AOD of 532 samples. Black solid lines denote accumulated occurrence frequencies for the AOD. Red lines show the top and bottom terciles.

In section 3.4 (in raw manuscript), we aim to discuss the joint effects of aerosols and dynamics-thermodynamics factors. The analysis method we used needs enough samples. Therefore, we take each useful grid in a sample as a new sample, thus obtaining 11408 new samples. However, this method is not rigorous, so we abandoned it in the revised manuscript. We adjust the content in section 3.4 and the analysis in section 3.4 is still based on the 532 samples used in the above content.

**Technical corrections:**

**Reply**: Thank you for your technical corrections. We have revised all these errors in the revised manuscript.

**References**:

Altaratz, O., Koren, I., Yair, Y.Y., and Price, C.G.: Lightning response to smoke from Amazonian fires, Geophys. Res. Lett., 37, L07801, https://doi.org/10.1029/2010GL042679, 2010.

Kar, S.K., and Liou, Y.: Enhancement of cloud-to-ground lightning activity over Taipei, Taiwan in relation to urbanization, Atmos. Res., 147, 111–120, https://doi.org/10.1016/J.ATMOSRES.2014.05.017, 2014.

Koren, I., Martins, J.V., Remer, L.A., and Afargan, H.: Smoke Invigoration Versus Inhibition of Clouds over the Amazon, Science, 321, 946–949, https://doi.org/10.1126/science.1159185, 2008.

Tan, Y., Peng, L.K., Shi, Z., and Haiqin, C.: Lightning flash density in relation to aerosol over Nanjing (China), Atmos. Res., 174, 1–8, https://doi.org/10.1016/J.ATMOSRES.2016.01.009, 2016.

Murray, N.D., Orville, R.E., and Huffines, G.R.: Effect of pollution from Central American fires on cloud-to-ground lightning in May 1998, Geophys. Res. Lett., 27, 2249–2252, https://doi.org/10.1029/2000GL011656, 2000.

Naccarato, K.P., Pinto, O., and Pinto, I.R.: Evidence of thermal and aerosol effects on the cloud-to-ground lightning density and polarity over large urban areas of Southeastern Brazil, Geophys. Res. Lett., 30, 1674, https://doi.org/10.1029/2003GL017496, 2003.

Rosenfeld, D., Lohmann, U., Raga, G.B., O'Dowd, C.D., Kulmala, M., Fuzzi, S., Reissell, A., and Andreae, M.O.: Flood or Drought: How Do Aerosols Affect Precipitation? Science, 321, 1309–1313, https://doi.org/10.1126/science.1160606, 2008.

Saunders, C.P.: Charge Separation Mechanisms in Clouds, Space. Sci. Rev., 137, 335–353, https://doi.org/10.1007/S11214-008-9345-0, 2008.

Wang, Q., Li, Z., Guo, J., Zhao, C., and Cribb, M.: The climate impact of aerosols on the lightning flash rate: is it detectable from long-term measurements? Atmos. Chem. Phys., 18, 12797–12816, https://doi.org/10.5194/ACP-18-12797-2018, 2018.