Dear Editor and Referee#2,

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 #2's comments. All the line numbers mentioned in responses are referred to the manuscript with changes marked.

(1) There is no outstanding innovation in this paper, including analysis methods and conclusions. The authors are requested to extract the innovative points of this paper in the introduction and emphasize the innovative points in the conclusion, on the premise of adjusting the research content.

Reply: Thank you for your comment. We have adjusted the content of the manuscript. The main purpose of this study is to investigate the difference between the effects of aerosols on lightning during the day and at night. Previous studies show that the relationship between aerosol and lightning is very complicated. Aerosols may promote or inhibit lightning activities, or have no obvious impact on lightning activities. One of the reasons for this phenomenon is that aerosol radiation inhibition and microphysical promotion are often combined, and environmental factors should also be considered. Some studies based on hourly data reveal that the aerosolinhibited effect on lightning weakens after sunset (Guo et al. 2016). The current study aims to investigate the difference in the effects of aerosols on lightning under conditions with and without solar radiation. We have emphasized these in the introduction and conclusion part in the revised manuscript. (Lines: 68-73, 314-350)

(2) Line 81. In this paper, the data with 0.5° spatial resolution are selected to discuss the relationship between aerosol and lightning activity in the Sichuan Basin. Is it statistically significant to analyze the data with such rough resolution in such a limited space?

Reply: Thank you for your comment. The minimum resolution of multi-data limits the data resolution used in the final analysis of this paper. But we have used the data of a long time series to obtain enough samples. For the topic to be analyzed in this paper, these data are relatively sufficient. Although the study region in this paper has a limited spatial scope, the lightning activity in this area is significantly larger than that in the surrounding areas at night (Xia et al. 2015). The aerosol value in this area is also significantly higher than that in the surrounding areas. However, the coarse resolution of these data will also bring some unavoidable problems. There will be some deficiencies in the interpretation of some phenomena. In future work, we will look for and use higher-quality data to further explore the possible impact of aerosols on lightning activities in the study region and its surrounding region.

(3) It is suggested to use the satellite lightning data to verify the ground-based lightning data used in this paper.

Reply: Thank you for your comment. We compared the data of ground-based CG lightning and satellite-based lightning density (from LIS), including spatial distribution and diurnal variation (Fig. 3-1). Overall, the lightning data from the ground and satellite were similar. This have been added to the supplementary materials.

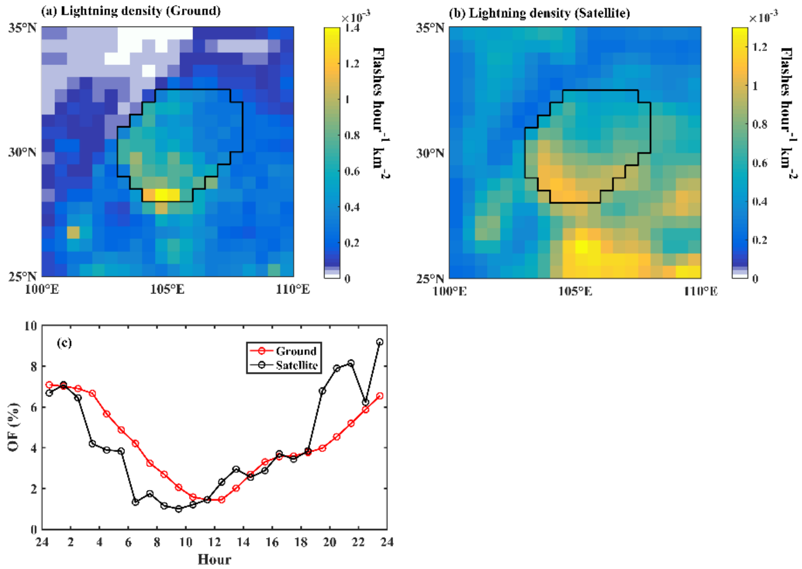

Figure 3-1. Spatial distribution of lightning density (flashes hour^{-1} km^{-2}) from (a) ground and (b) satellite at a spatial resolution of 0.5°×0.5°. (c) Diurnal variation of lightning occurrence frequency (OF).

(4) Line 95. First, there is an obvious error. The spatial resolution of the AOD data of MERRA-2 is not 0.5°×0.5°, please check and confirm. Since the resolution is not 0.5°, how to match and discuss with other data is a major problem. Secondly, the AOD data selected in this paper are reanalysis data. In the study area, the authors did not compare with the satellite observation and ground-based observation, so it is obviously unreasonable not to verify the availability of the data.

Reply: Thank you for your comment. Yes, the raw spatial resolution of the AOD data of MERRA-2 should be 0.5°×0.625°. We downloaded the AOD data from MERRA's official website, which provides tools to change the resolution (as shown in Fig. 4-1). Among them, we chose bilinear interpolation to process the spatial resolution of AOD to 0.5°×0.5° to match with other data. We have added this process in the revised manuscript.

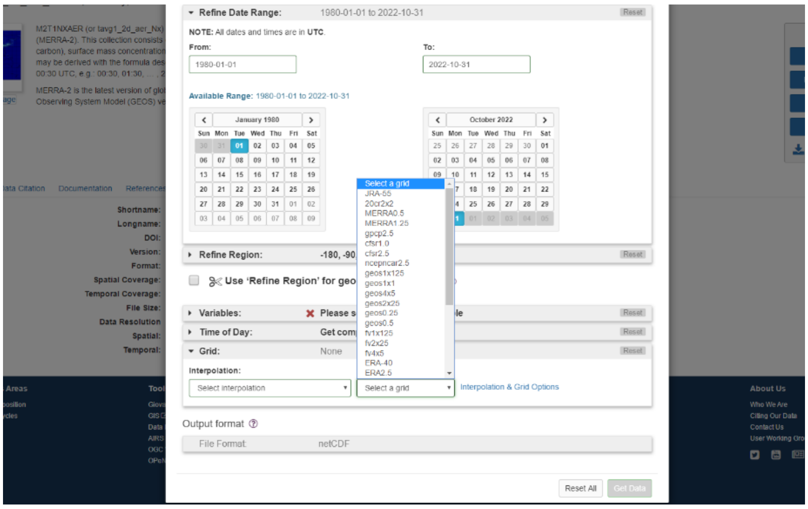

Figure 4-1

We compared the AOD data of MERRA and MODIS in the study area (as shown in Fig. 4-2). It can be found that the AOD data of MERRA is well correlated with the AOD data of MODIS in the study region. These have been added to the supplementary materials.

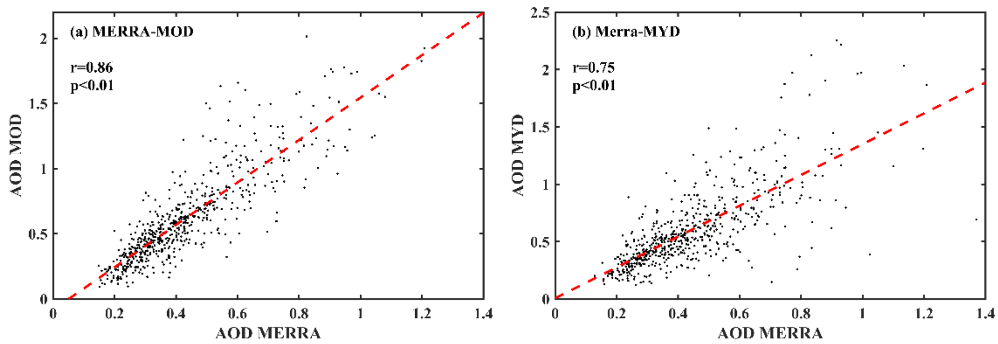

Figure 4-2

(5) Line 105. What is the time resolution of the thermodynamic and cloud-related data selected in this paper? Please clarify. TCIW and TCLW are reanalysis data. Currently, a variety of satellite products provide ice water path and cloud water path, please replace them with satellite observation data.

Reply: Thank you for your comment. The time resolution of the thermodynamic and cloud-related data selected in this paper is hourly. We have clarified this in the revised manuscript. Although a large number of satellite data can provide cloud ice and liquid water path data, there are still some deficiencies in the continuity of space and time, which cannot meet the needs of this study. Therefore, this paper selects the reanalysis data to analyse.

(6) The wind shear is calculated using 925 and 500 hPa latitude and longitude winds, which is approximately from the ground to 5km. What does this kind of wind shear mean for a thunderstorm cloud? Wind shear in the middle and lower troposphere might be considered.

Reply: Thank you for your comment. In the previous manuscript, the selection of wind shear was referred to Wang et al. (2018). It may not be suitable for the study region of this study because of the large latitude difference between the study region in this study and that of Wang et al. (2018).

In the revised manuscript, we selected wind shear in the low (850hPa to 700hPa, about 1.5km~3km) and middle (500hPa to 400hPa, about 5km~7km) troposphere, respectively. The relationship between the wind shear and CG lightning flashes is shown in Figs. 6-1 and 6-2. In period1, CG lightning flashes decrease with the increase of wind shear in the low and middle troposphere (Fig. 6-1a and Fig. 6-2a). In period2, a similar relationship was found between CG lightning flashes and wind shear in the middle troposphere (Fig. 6-2b) but a reversed relationship was found between CG lightning flashes and wind shear in the low troposphere (Fig. 6-2b).

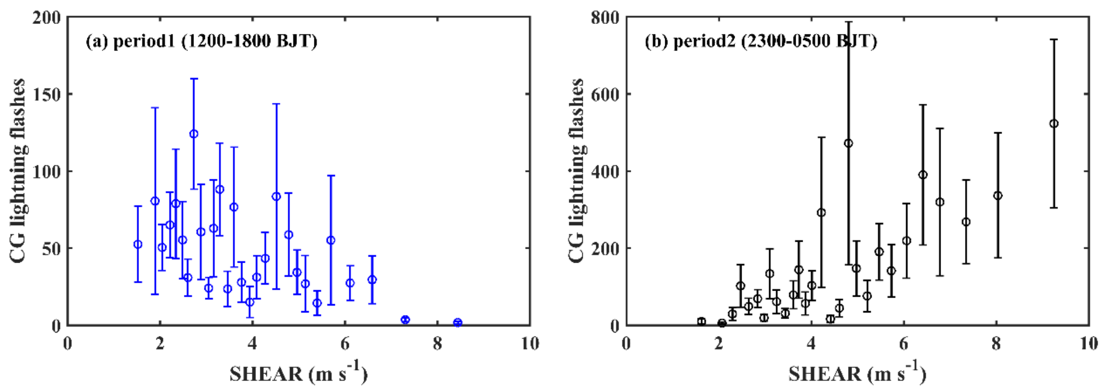

Figure 6-1. Relationship between wind shear (SHEAR) in the low troposphere and CG lightning flashes in (a) period1 and (2) period2.

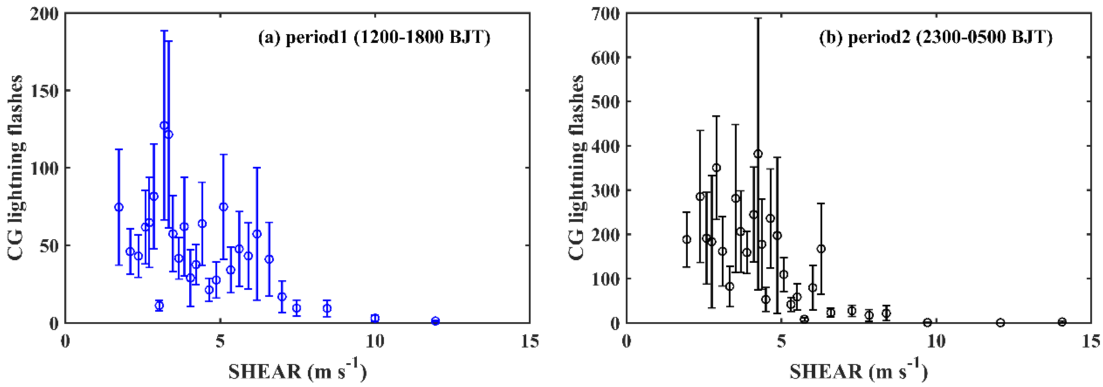

Figure 6-2. Same as in Fig. 6-1, but for wind shear (SHEAR) in the middle troposphere.

The relationships between CG lightning flashes and wind shear in the low troposphere during the two periods are similar to that found in the previous manuscript. However, when considering the wind shear in the middle troposphere, the wind shear plays a role in suppressing CG lightning flashes in both two periods. (Lines: 239-251)

(7) Line 134. How could a low-pressure system, which tends to bring rainy weather, cause heavy air pollution? This is very puzzling.

Reply: Thank you for your comments. Generally, due to the dynamic and thermodynamic effects of the Tibetan Plateau, low-pressure systems (such as southwest vortex and low trough) are often formed at 700 hPa. In summer and autumn, they are warm and moist and usually lead to local precipitation. However, in winter and spring, these low-pressure systems are dry and cold. As they pass over the Sichuan Basin, they may form a strong temperature inversion layer over the urban agglomeration in front of them. This makes the lower troposphere in these areas more stable, which is not conducive to the diffusion of air pollutants and leads to serious air pollution (Ning et al. 2018).

(8) In section 3.2, How are clean and polluted subsets defined? When defining the polluted subset, is AOD used on the day of lightning or before the thunderstorm when there is no precipitation? Because of the significant wet deposition of precipitation, it is not reasonable to choose the aerosol on the day of lightning to define the polluted and clean subset.

Reply: Thank you for your comment. 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. 8-1.

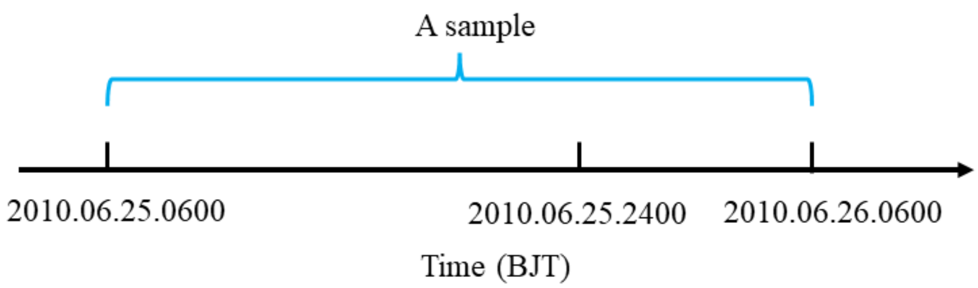

Figure 8-1. Schematic diagram of sample time selection.

Then, we only retain grids with CG flashes larger than ten during the period of a sample (the blue region shown in Fig. 8-2) 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.

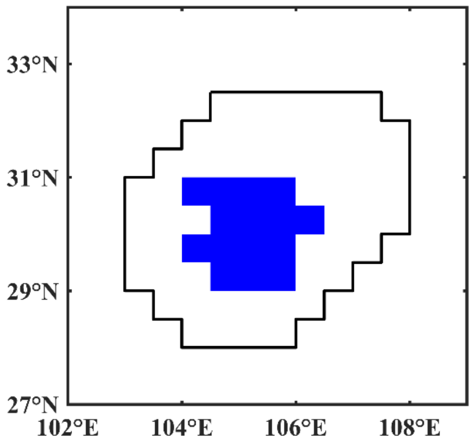

Figure 8-2. Black lines frame the study region. The blue region is grids with CG flashes larger than ten during the period of a sample. The spatial resolution of these grids is 0.5°×0.5°.

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.

In the previous manuscript, we defined the clean and polluted subsets according to the value of $\mathrm{AOD_{Sample}}$. All samples are sorted according to $\mathrm{AOD_{Sample}}$ 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.

This method 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 the revised manuscript, we have changed the selection method of AOD. A sample starts at 1200 BJT one day and ends at 1200 BJT the next day, as shown in Fig. 8-3 (b). In the study region, most thunderstorms from in the afternoon, at night, and the next morning (Fig. 8-3 (a)). The thunderstorms in the morning may be associated with intense thunderstorms in 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 impact of thunderstorm precipitation on AOD values.

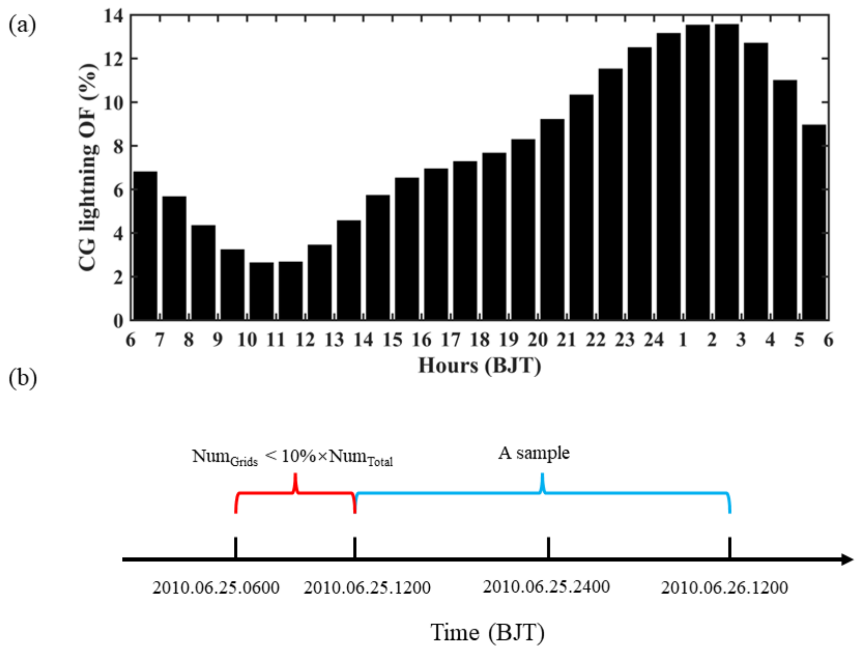

Figure 8-3. (a) The diurnal variation of CG lightning flashes during the study period. Num_{Grids}: number of grids with CG lightning flashes in each hour. Num_{Total}: number of grids (70) in the entire study region. (b) Schematic diagram of sample time selection.

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:

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

The $\mathrm{AOD_{Sample}}$ is the AOD value of a sample. The $\mathrm{AOD_k}$ is the AOD value in the first hour of a useful grid. The $\mathrm{n_{Grid}}$ is the number of useful grids in a sample. The definition of the clean and polluted subsets is the same as the method used in the previous manuscript. (Lines: 138-155)

(9) Line 593. the caption does not correspond to the figure, figure b and c.

Reply: Thank you for your comment. We are sorry for this mistake. We have redrawn this figure and revised its caption.

(10) In Figure 4, there is little difference in lightning between the polluted background and the clean background between 13:00 and 18:00, and there is more lightning in the polluted background in the rest of the time. However, it is not rigorous to describe the difference between day and night in the whole paper, because the difference is only seen from the figure between the afternoon and other times.

Reply: Thank you for your comment. We have revised the relevant description in the manuscript. We selected the time periods of the afternoon (1200-1800 BJT) and night (2300-0500) BJT as the main analysis time periods. In the revised manuscript, these two time periods are referred to as afternoon and night.

(11) Line 600, Which variable has a spatial resolution of 0.1°? The resolution described in the above data description is 0.5°.

Reply: We are sorry for this mistake. The correct resolution of this figure should be 0.5°×0.5°. We have redrawn this figure and rewritten its title. The redrawn figure is shown in the figure below:

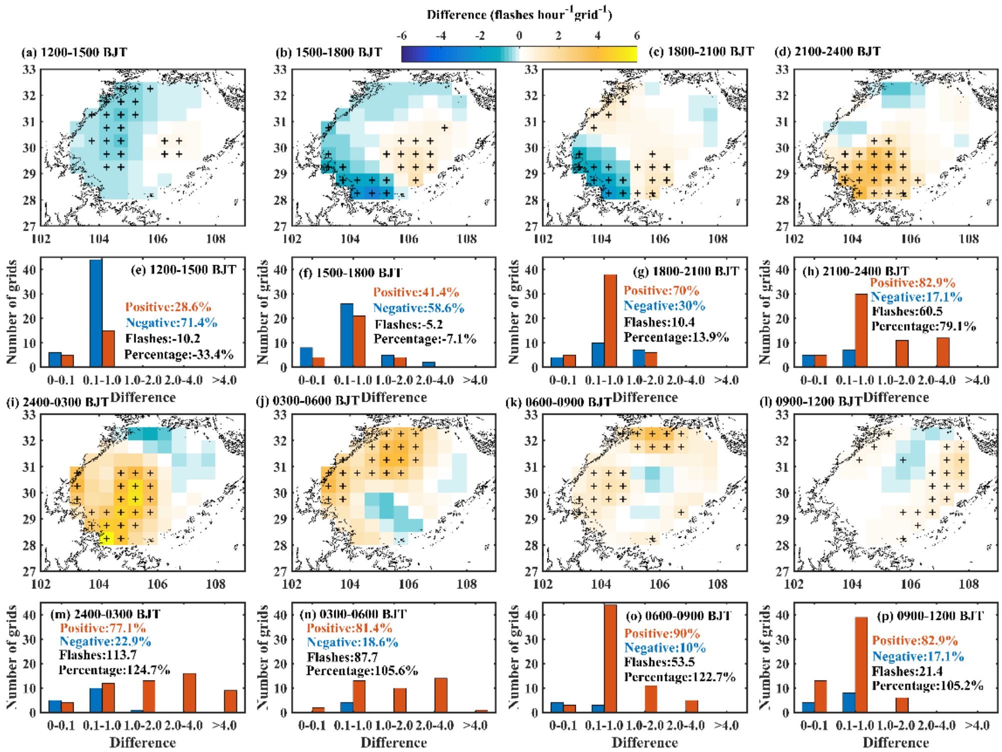
Figure 11-1. (a-d, i-l) Diurnal changes of total CG lightning flash differences (unit: flashes hour^{-1}) between polluted and clean subset (polluted−clean) during the study period with an interval of 3 hours (BJT). Black lines represent the 1500m contour lines. The spatial resolution is 0.5°×0.5°. The 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.

(12) In Figure 7b, in period 2 (in red), the fitting line between wind shear and lightning may not be suitable, as it should rise first and then fall. And why the apparent difference in the relationship between wind shear and lightning at the two different period (red and blue)?

Reply: Thank you for your comment. We have reselected the dada of SHEAR as described in the reply to comment 6. The relationship between lightning flashes and Low SHEAR is similar to that found in the previous manuscript. From the results found in the diurnal cycle of lightning flashes' spatial distribution, we can know that the spatial distribution of lightning flashes in the study area is significantly different at different times. The lightning distributions in the afternoon and at night are different, which may lead to differences in the structure of thunderstorm activities during the two periods. This may result in the different relationship between Low SHEAR and lightning in these two periods.

(13) Line 256, TCL?

Reply: We are sorry for this mistake. We have revised it in the revised manuscript.

(14) In Figure 8b, it is generally believed that ice particles directly determine the activity of lightning. In period 1 (blue), lightning has no obvious relationship with ice water. How to explain this?

Reply: Thank you for your comment. We have redrawn this figure using the data processed by the improved method. For TCIW, a nonlinear relationship (R=0.11) between lightning flashes and TCIW is also found in the afternoon. A positive relationship (r=0.85) between them is found at night. It should be noted that when the TCIW is less than about 0.05kg m-2, the positive relationship between TCIW and lightning flashes is robust (both in the afternoon and at night). When the TCIW is greater than 0.05kg m-2, the relationship between TCIW and lightning flashes becomes more dispersed and the uncertainties in each bin become larger. But in general, lightning flashes are more under conditions with more TCIW. We speculate that the reason why the relationship between ice water content and lightning is not obvious under the condition of high ice water content may be due to the selection of parameters. The TCIW may not directly reflect the content of ice water in thunderstorm clouds, but may also include the content of ice water in other types of clouds.

(15) In Figure 8, the authors analyze the relationship between lightning and TCLW and TCIW. But in Figure 9, only TCLW is analyzed, not TCIW. Does lightning depend more on liquid water than ice water? The connectivity and logic here need to be improved.

Reply: Thank you for your comment. In figure 9 (in the previous manuscript), we aim to analyze the effect of TCLW on surface temperature and CAPE. The effects of TCIW on the surface temperature and CAPE are relatively weaker than TCLW. Therefore, we did not analyse it in figure 9 (in the previous manuscript). In the revised manuscript, we have redrawn this figure and added the discussion of TCIW. The relevant content has been rewritten.

(16) Figure 9c is not well understood. Does it refer to the effect of TCLW on temperature? What is the physical mechanism by which TCLW affects surface temperature?

Reply: Thank you for your comment. The relationship between TCLW and surface temperature has been re analyzed (as shown in Fig. 16-1b and f). In general, TCLW was negatively (afternoon: R=-0.94, night: R=-0.84) correlated with T in the afternoon and at night (Fig. 10b and f). However, it is worth noting that when TCLW is less than about 0.1 kg m^{-2}, the relationship between TCLW and T is not significant in the afternoon, while at night, TCLW is positively correlated with T. An increase in the amount of liquid water in clouds means thicker and wider clouds. The thicker and wider clouds will block more solar radiation from reaching the ground, thus reducing the surface temperature. On the other hand, the increase in surface temperature will strengthen the updraft, so that more water vapour will be transmitted upward to form more cloud liquid water. In the afternoon, the relationship between TCLW and T may contain the above two mechanisms, which leads to an insignificant relationship between them. At night, the absence of solar radiation reduces the reduction of clouds to surface temperature, and the promotion of surface temperature to cloud liquid water content is dominant. Therefore, a positive correlation between TCLW and T at night. However, too much liquid water in the cloud may promote a warm-rain process. The precipitation falling to the ground will significantly reduce the surface temperature. Therefore, when the TCLW exceeds a certain value (>~0.1 kg m^{-2}), it has a negative correlation with the T.

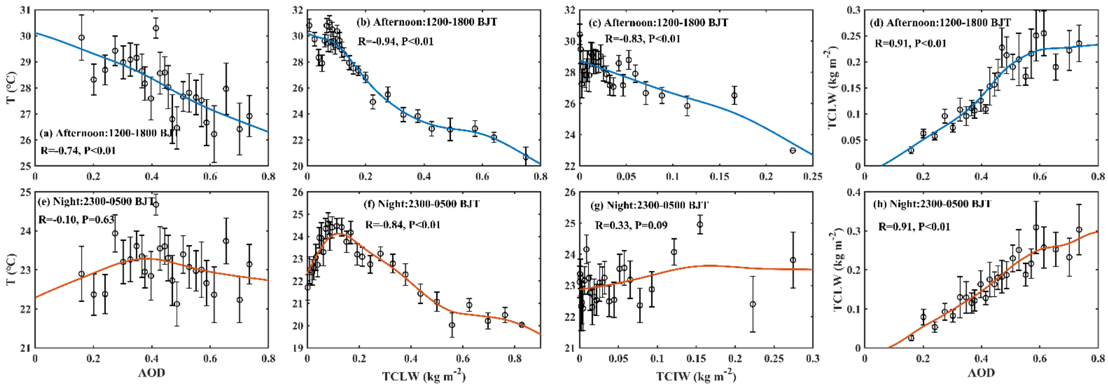

Figure 16-1. Relationships in (a and e) AOD-T, (b and f) TCLW-T, (c and g) TCIW and (d and h) AOD-TCLW in the afternoon (1200–1800 BJT) and night (2300–0500 BJT). Note that samples are first sorted by (a, e, d, and h) AOD, (b, f) TCLW, and (c, g) TCIW, and then samples with similar (a, e, d, and h) AOD, (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 uncertainty 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.

(17) In Figures 11 a and b, lower TCLW corresponds to more lightning in period 1, while this relationship is reversed in period 2. Why does liquid water have opposite effects on lightning in different periods?

Reply: Thank you for your comment. After we improved the method that processed the data, the relationship between lightning flashes and TCLW both show a nonlinear relationship in the afternoon and at night (as shown in Fig. 17-1a and c). The CG lightning flashes increase with the increase of TCLW when the TCLW is relatively low (<~0.1kg m-2), but decrease with the rise of TCLW when its value exceeds about 0.1kg m-2. With the updraft, increasing cloud liquid water can provide more liquid water to the mixed phase region of the cloud to form more supercooled water and ice particles which fuels lightning activity. However, too much cloud liquid water may promote warm cloud precipitation rather than from convection and lightning activities.

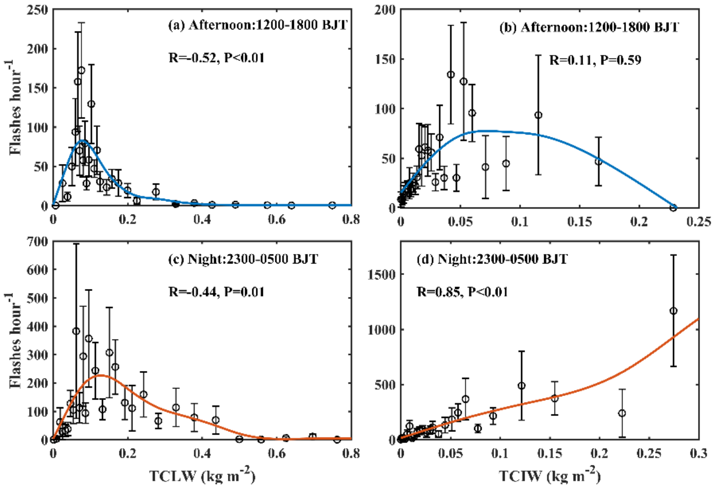

Figure 17-1. Relationships between lightning flashes and cloud-related factors: (a, c) TCLW and (b, d) TCIW in the afternoon (1200–1800 BJT) and night (2300–0500 BJT). Note that samples are first sorted by TCLW or TCIW and then samples with similar TCLW or TCIW were averaged to create the presented scatter plot. The max number of samples in each bin is equal to or less than 20. The difference between the maximum and minimum (a and c) TCLW and (b and d) TCIW values of samples in each bin is equal to or less than 0.05 and 0.01. An estimation of the uncertainty 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.

(18) In Figure 12, the authors suggest that aerosol inhibit convective activity during the day through ARIs, but in the absence of any evidence presented above, this speculation is unconvincing.

Reply: Thank you for your comment. We added analysis to prove this possible effect of aerosols. In the afternoon, AOD is negatively (R=-0.74) correlated with T (Fig. 18-1a). At night, no obvious relationship (R=-0.10) between them can be found (Fig. 18-1e). We speculate that high aerosol loading leads to strong aerosol direct radiative effects. Excessive aerosol loading reduces the solar radiation reaching the ground by absorbing and scattering solar radiation, thus reducing the temperature of the ground below the aerosol layer. At night, solar radiation is absent, and so does the direct radiation effect of aerosols, which has no significant impact on the surface temperature. In general, TCLW was negatively (afternoon: R=-0.94, night: R=-0.84) correlated with T in the afternoon and at night (Fig. 18-1b and f). However, it is worth noting that when TCLW is less than about 0.1 kg m^{-2}, the relationship between TCLW and T is not significant in the afternoon, while at night, TCLW is positively correlated with T. An increase in the amount of liquid water in clouds means thicker and wider clouds. The thicker and wider clouds will block more solar radiation from reaching the ground, thus reducing the surface temperature. On the other hand, the increase in surface temperature will strengthen the updraft, so that more water vapour will be transmitted upward to form more cloud liquid water. In the afternoon, the relationship between TCLW and T may contain the above two mechanisms, which leads to an insignificant relationship between them. At night, the absence of solar radiation reduces the reduction of clouds to surface temperature, and the promotion of surface temperature to cloud liquid water content is dominant. Therefore, a positive correlation between TCLW and T at night. However, too much liquid water in the cloud may promote a warm-rain process. The precipitation falling to the ground will significantly reduce the surface temperature. Therefore, when the TCLW exceeds a certain value (>~0.1 kg m^{-2}), it has a negative correlation with the T. In the afternoon, the relationship between TCIW and T is similar to that between TCLW and T (Fig. 18-1c). But at night, the TCIW has no obvious relationship (R=0.33) with T (Fig. 18-1g). This may be because the ice water content in clouds is related to more factors, and the conversion process from ice water content to precipitation is more complex, with a less direct impact of surface temperature. In the afternoon, the inhibition of TCIW on surface temperature is more reflected in reducing the solar radiation reaching the ground. At night, the absence of solar radiation, and the precipitation formed by the cloud ice water has no obvious influence on the surface temperature, resulting in no obvious relationship between TCIW and T. AOD is positively correlated (afternoon: R=0.91, night: R=0.91) with TCLW in the afternoon and at night (Fig. 18-1d and h). By acting as CCN, increasing aerosol concentration will produce more but smaller cloud droplets, thus delaying the warm-rain process, so that more liquid water can be retained in the cloud. Therefore, we can speculate that the inhibition of aerosols on the surface temperature in the afternoon is not only through the direct radiation inhibition of aerosols, but also through the increase of cloud water content. In addition, the decrease of the cloud droplet size will increase the albedo of clouds, further enhancing the scattering effect of clouds on solar radiation.

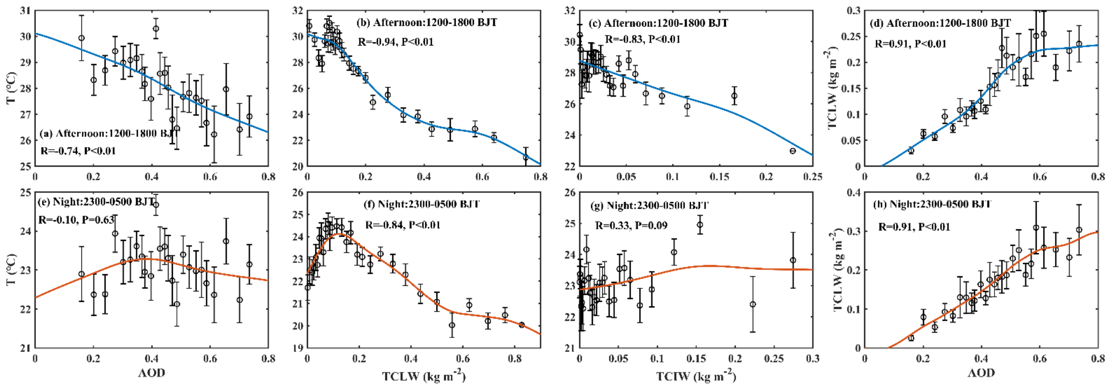

Figure 18-1. Relationships in (a and e) AOD-T, (b and f) TCLW-T, (c and g) TCIW and (d and h) AOD-TCLW in the afternoon (1200–1800 BJT) and night (2300–0500 BJT). Note that samples are first sorted by (a, e, d, and h) AOD, (b, f) TCLW, and (c, g) TCIW, and then samples with similar (a, e, d, and h) AOD, (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 uncertainty 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.

(19) The authors attempted to explain the difference between the effects of aerosols on lightning during the day and tnight, using a schematic diagram. The authors suggest that aerosol do not exhibit radiative effects at night. Previous study (Fan et al., 2015) have suggested that in the Sichuan Basin, aerosols make the boundary layer more stable through radiation effects in the daytime, which makes the convection more vigorous at night. The viewpoint that aerosols do not affect lightning through radiation effects at nighttime cannot be accepted.

Reply: Thank you for your comment. We have carefully read this paper.

Our description of aerosol radiation effects in the article is not rigorous. In this paper, we want to emphasize that the direct radiation effect of aerosols which directly inhibit convection is disappear at night. We have revised the schematic diagram.

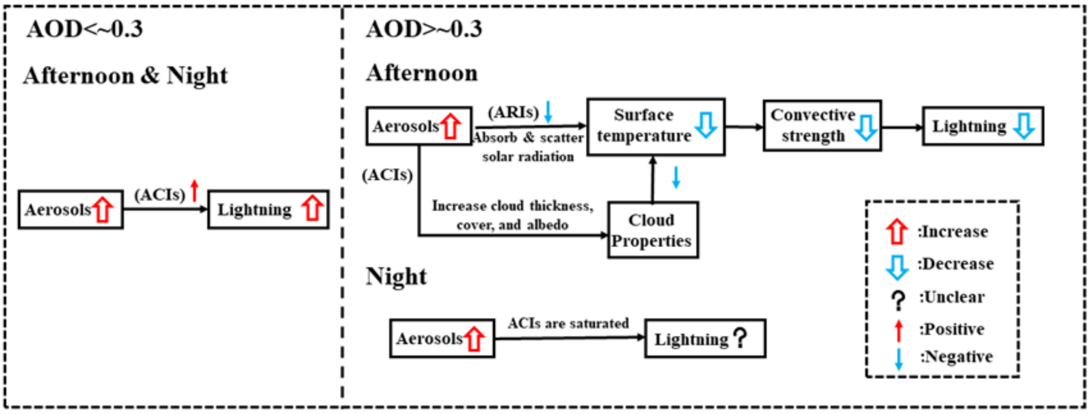

Figure. 19-1. Schematic diagram illustrating the effects of aerosols on lightning activity over the study region.

(20) The prominent nocturnal convective activity in the Sichuan Basin is mainly due to the relative thermal difference between the Sichuan basin and the Tibetan Plateau and the cold advection from the Tibetan Plateau to the east at night (Jin et al., 2013). The authors should consider these factors in studies to clarify the cause of the aerosol effect on nighttime lightning.

Reply: Thank you for your comment. We have carefully read this article and related research. We have added the influence mechanism of lightning diurnal variation in the Sichuan Basin mentioned in these articles to the revised manuscript. These factors lead to the relative stability of the atmosphere in the study region in the daytime, which is not conducive to the formation of large-scale convective activities. However, the weakening of too much aerosol to the solar radiation reaching the ground further increases the stability of the atmosphere. Therefore, in the afternoon, we found that under the condition of high aerosol loading, aerosol has a significant inhibition effect on lightning. At night, these factors lead to the instability of the atmosphere in the Sichuan Basin, which is more likely to form convective activities. The microphysical effects of aerosol may be dominant. The remote impact of aerosol radiation proposed by Fan et al. (2015) may only affect the mountainous region of the study region and mainly under extreme pollution conditions. In general, aerosols at night mainly affect convective activities through microphysical effects. However, the stimulation of aerosol microphysical effects on convective activities will be saturated when the aerosol concentration is high, resulting in the continued increase of aerosols when the aerosol loading is relatively high.

References:

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