# Reply to comments on “Satellite-based estimate of the variability of warm cloud properties associated with aerosol and meteorological conditions”

October 30, 2018

We thank the reviewer's thoughtful comments which are helpful not only for this manuscript but also for our future research. Our replies for all the comments are shown below.

**Major points**

**1. Comments: (1) The authors make use of a technique previously used to investigate possible links between aerosol and cloud fraction, extending it to look at the development of other cloud properties. A key part of this method involves making sure that the starting state similar as possible for high and low aerosol environments and then investigating the difference between them. If this method works as intended, the mean change in cloud properties over the timestep should be a function only of local meteorology and there should be no difference in the cloud properties between the high and low aerosol populations at the start time. I am therefore unclear what is being shown in section 4.1, where a difference apparently exists. Are the authors following the method of Gryspeerdt et al (2014), or have they created a new method? If the authors are just looking at the relationship between AOD and cloud properties, how have they accounted for the impact of local meteorology (e.g. Quaas et al, ACP, 2010)?**

**Answer**: Normalised histograms of cloud properties for the high and low AOD populations are made for the whole region (Section 3.1), because the data volume based on each 1° x 1° location is relatively small. However, the difference between the cloud properties for low and high AOD at the start time is based on each 1° x 1° location (Section 4.1). So the difference of the cloud properties between the low and high AOD at the start time still exist and is not zero. In order to make the reader understand, text was added as follows.

Page 5 lines 37-39 and page 6 lines 1-2, : Text was added as:’ Note that here and in the following sections, normalised histograms of cloud properties for the high and low AOD populations are made for the whole region (Section 3.1), because the data volume based on each 1° x 1° location is relatively small. However, the difference between the cloud properties for low and high AOD at the start time is based on each 1° x 1° location (Section 4.1). So the difference of the cloud properties between the low and high AOD at the start time is not zero.’

Page 9, line 14-16: Text was added as:’ Although normalized histograms of meteorological parameters are made for high and low AOD conditions at the start time, the normalization described in Sect. 3.1 is based on the whole region. Differences in meteorological conditions may still occur between each 1° x 1° grid cell.'

Meanwhile, in order to consider the effect of meteorological conditions on the relationship between aerosol and cloud further, we analyze the meteorology of the different regions in Section 4.2 (see page 9-10). This new Section 4.2 "The meteorology of the four target regions" reads:

**4.2 The meteorology of the four target regions**

The meteorological and aerosol effects on clouds are reported to be tightly connected, and this connection must be accounted for in any study of aerosol-cloud interactions (Stevens and Feingold, 2009; Koren et al., 2010). Although normalized histograms of meteorological parameters are made for high and low AOD conditions at the start time, the normalization described in Sect. 3.1 is based on the whole region. Differences in meteorological conditions may still occur between each 1° x 1° grid cell. In this study, we analyze the meteorology of the different regions, in support of the interpretation of the regional variation of the relationships between aerosols and clouds.

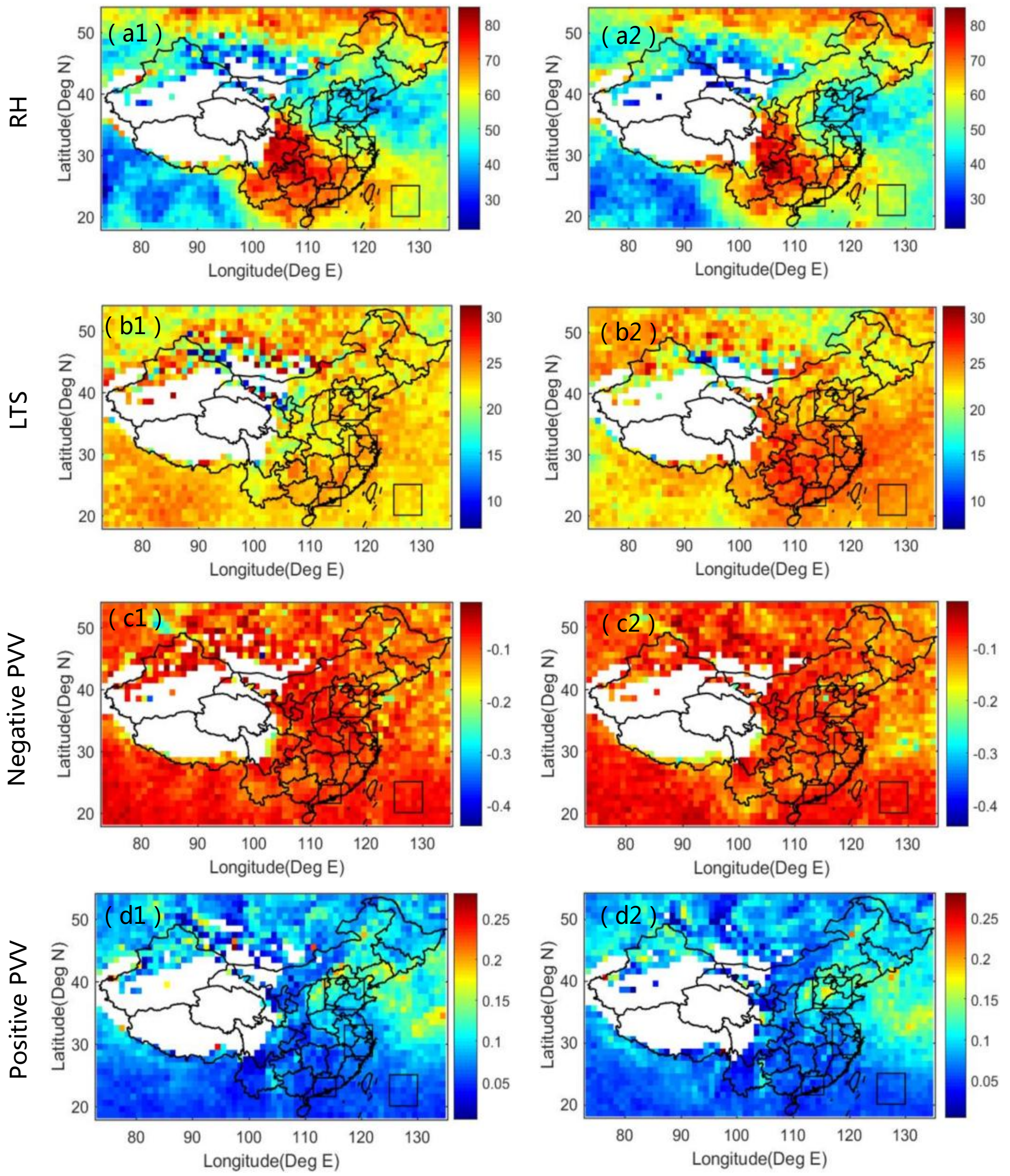


Figure 4 Spatial distributions of meteorological parameters (top to bottom: RH, LTS, positive PVV and negative PVV) at the start time of the timestep (MODIS/Terra) for low AOD conditions (left, a1-d1) and for high AOD conditions (right, a2-d2). All the data are averaged over all years between 2008 and 2017.

The spatial variations of the aerosol and cloud properties over the four regions, averaged over the years 2008-2017, are shown in Fig. 4. Over the urban clusters, we can see an increasing north–south pattern in RH and LTS, with the lowest values found in the PRD. For the negative PVV, the spatial distributions for the low and high AOD situations are remarkably similar, with the highest values over the BTH and decreasing toward the south to near zero over the PRD. In contrast, the positive PVV is smallest over the BTH, with little variation over the study area. Overall, the meteorological parameters over the YRD and PRD are similar to those over the ECS, irrespective of the AOD. Furthermore, the LTS is significant larger in the high AOD conditions for all the four regions. Zhao et al. (2006) proposed that the enhancement in the atmospheric stability tends to depress upward motion and precipitation, leading to an increase in aerosol particles. The spatial distributions of both positive and negative PVV in the low AOD conditions are similar to those in the high AOD conditions.

**2. Comments: (2) Similarly, it is not clear what section 4.2 is showing. While the title states that it is discussing the 'mean change', it is apparently also investigating the difference between high and low AOD. If this is the case, could it not be merged with section 4.3, which is explicitly about the difference in relation to the aerosol environment? I would expect that the difference in the development between the regions would be a function of local meteorology. If 4.2 is intended to be about the mean cloud development, perhaps it could be used to better describe the meteorology of the different regions, helping the interpretation of the regional variation of the results in section 4.3.**

**Answer:** Yes, we agree with your suggestions. Section 4.2 was merged with Section 4.3 (as new Section 4.3, see pages 10-15), explicitly examining the difference of cloud properties in relation to aerosol environment. Furthermore, new Section 4.2 was added (see response to question 1) to describe the meteorology of the four target regions, in support of the interpretation of the regional variation of relationship between aerosol and cloud (see page 9-10 in the revised manuscript).

**3. Comments: (3) While this work has the potential for producing interesting results if the method is properly clarified, the results that are currently within the paper are not set in the context of existing work, which makes them difficult to interpret. The results in section 4.3 and not compared to section 4.1 or previous work, meaning that potentially interesting results are missed. As some examples, P13L14 suggests that there is little change in the CDR development as a function of aerosol - this inability to detect the Twomey effect might mean that this method is not suitable for investigating aerosol cloud interactions, or it could mean that changes in CDR proceed via different pathways and timescales than the CF changes observed in Gryspeerdt et al. (2014). Although the difference in results over land and ocean was one of the key results of Gryspeerdt et al (2014), other result are different - this work finds exactly the opposite dCF response to relative humidity (section 4.4). This would again be an interesting result for discussion that is missed as it is not set in context.**

**Answer**: The variation of cloud properties to the aerosol environment has become more clear by reanalyzing all the MODIS C6.1 data for the whole acquisition period between 2008 and 2017, rather than MODIS C5.1 data from 2008 to 2011. This change is shown throughout the revised manuscript (all the figures were changed/modified in this respect). Following the reviewer's comments, the results in Section 4.3 have been linked to Section 4.1 and compared to previous work.

Part of text in Section 4.3 was shown in follows (see page 14-15 in the revised manuscript):

"Figure 7 shows that the values of d(CDR) over the three urban clusters are not mostly positive or negative, which indicates that in high AOD conditions over land the variation in CDR during the three hours between the MODIS/Terra and Aqua overpasses is similar. Over the ECS the values of d(CDR) is positive, which indicates that the CDR in high AOD conditions decreases much more than during low AOD conditions over ocean. Wang et al. (2014) also reported a negative correlation between CDR and AOD over the ECS, in accordance with the Twomey effect. Furthermore, CDR tends to be smallest in polluted and strong-inversion environments, an outcome in good agreement with the findings of Matsui et al. (2006). Most of the d(COT) values are negative over the four regions, especially for the YRD, PRD and ECS. This shows that the COT increases less in high AOD conditions than in low AOD conditions, over both land and ocean, which is contrast with the findings of Meskhidze et al. (2009). Likewise, the values of d(CWP) are almost all negative over the four regions although over the BTH urban cluster the values are not clear. This indicates that in high AOD conditions the CWP increases less during the timestep than in low AOD conditions, a result in accordance with the conclusion that higher LTS is linked with a slightly lower CWP (Matsui et al., 2006). We can conclude that the variation trend of COT and CWP after 3 hours depends little on the initial AOD, but the initial AOD conditions can affect the amplitude of variation of COT and CWP. Meanwhile, the values of d(CF) are smaller than zero over the ECS. This shows that the cloud fraction in high AOD conditions over ECS decreases less than that in low AOD conditions. However, Meskhidze et al. (2009) found that an increase of the aerosol concentration may lead to enhanced reduction of afternoon cloud coverage and optical thickness for marine stratocumulus regions off the coast of California, Peru, and southern Africa. Therefore, the connection between AOD and variation of cloud cover could be a response to regional-scale changes in aerosol covarying with meteorological conditions. The value of d(CF) is overall positive over the PRD, which indicates that over the PRD in high AOD conditions the cloud cover increases much more than the cloud cover decreases in low AOD conditions. Mauger and Norris (2007) have shown that scenes with large AOD and large cloud fraction experienced greater LTS. As regards CTP, we find that the values of d(CTP) are positive over the BTH and PRD urban cluster, but the values of d(CTP) over the other two regions are not significant. It indicates that in high AOD conditions over the PRD region the CTP increases much more than the CTP decreases in low AOD conditions. We can conclude that the variation in d(Cloud_X) is different for continental and oceanic clouds. This applies to CDR, cloud fraction (CF) and CTP, but not to COT and CWP. Table 2 summarizes the differences between the mean changes in cloud properties for low and high AOD over the timestep of 3 hours.

Based on the above findings, we conclude that over the ECS the values of CDR, CWP and CTP are smaller but the values of COT and CF are larger in high AOD conditions. After the 3 hours timestep, CDR, CF and CTP become smaller, irrespective of the AOD. Furthermore, CDR decreases much more in high AOD conditions but CF and CTP decreases much more in low AOD conditions. In contrast, COT and CWP become larger in both AOD conditions, more significantly in low AOD conditions. Over the urban clusters, COT and CWP also increase over the timestep in both AOD conditions, especially for the low AOD condition. For CF the values in low AOD conditions decrease over the timestep. The CTP change behaves differently among the three urban clusters during the 3 hours."

The sentence in P13L14 in old version manuscript is "Figure 6 shows that the values of d(CDR) vary around zero over the three urban clusters, which indicates that during high and low AOD over land the change in CDR during the three hours between the MODIS/Terra and Aqua overpasses is similar." The sentence means that there are changes (increase or decrease) of CDR in both AOD conditions after 3 hours timestep, but the variation quantity is similar. So, it doesn't indicate that this inability to detect the Twomey effect. As Figures 3(a1-a2) show, over the ECS, CDR is smaller at high AOD than at low AOD, which is consistent with Twomey's effect. In contrast, over the three urban clusters, CDR is larger at high AOD. This behavior has been observed before for warm clouds in conditions with high AOD (Liu et al., 2017) and may result from the intense competition for the available water vapour and the evaporation of smaller droplets as a consequence of the high aerosol abundance over these regions (Yuan et al., 2008; Wang et al., 2014; Tang et al., 2014; Liu et al., 2017).

The effects of initial cloud fraction and meteorological conditions on the change in CF under low and high AOD conditions after the 3 hours timestep over land are also explored. In our new version manuscript, there are two cases are considered: (1) when the cloud cover increases (ΔCloud_X>0); (2) when the cloud cover decreases (ΔCloud_X<0). The d(CF) (see Section 3.2) response to relative humidity is different for both cases (see Section 4.4 in the revised manuscript). However, the results of Gryspeerdt et al. (2014) are based on the combination of the two cases.

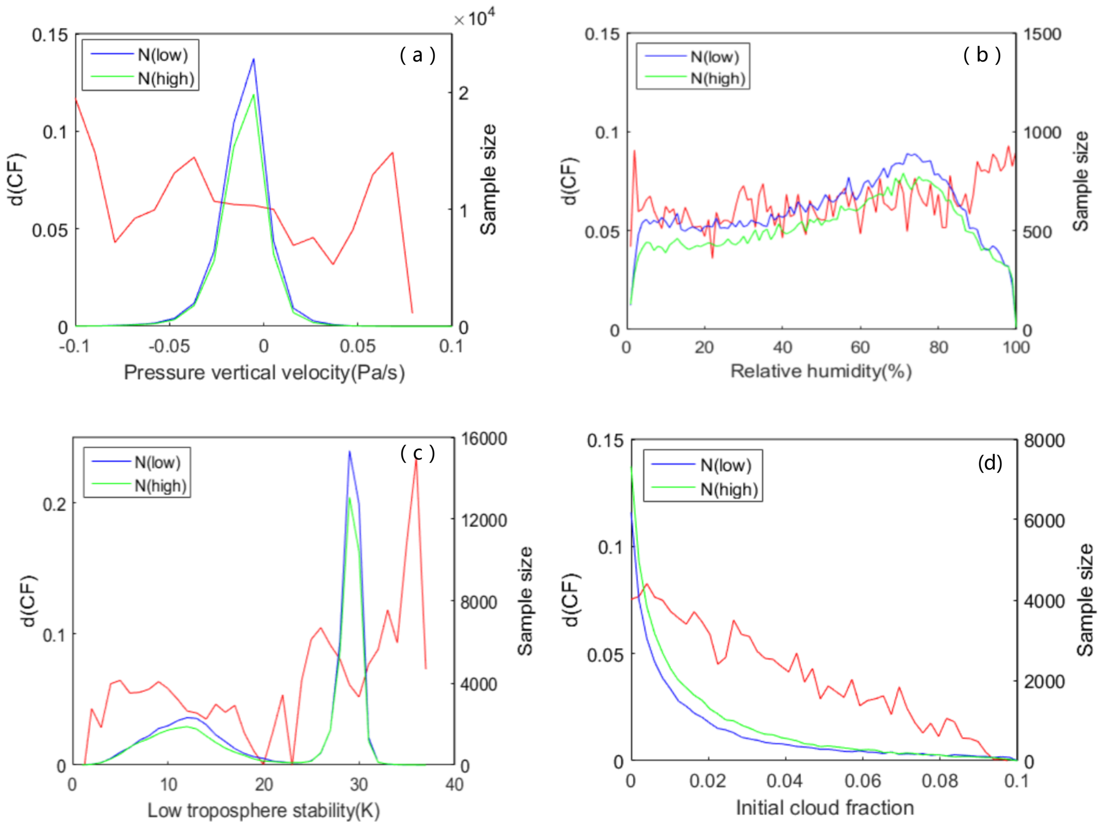

Figure 8. Variation of d(CF) (red) as function of initial meteorological parameters and cloud fraction for warm clouds when the cloud cover increases under both low and high AOD conditions after the 3 hours timestep over land. The distribution of points for low (blue) and high (green) AOD as a function of meteorological parameters is shown by the solid lines. This plot is composed from MODIS data (including Terra and Aqua) for all warm cloud points over the years 2008-2017. Meteorological parameters are plotted along the horizontal axis, the left vertical axis denotes d(CF) and the right vertical axis denotes the number of high and low AOD samples.

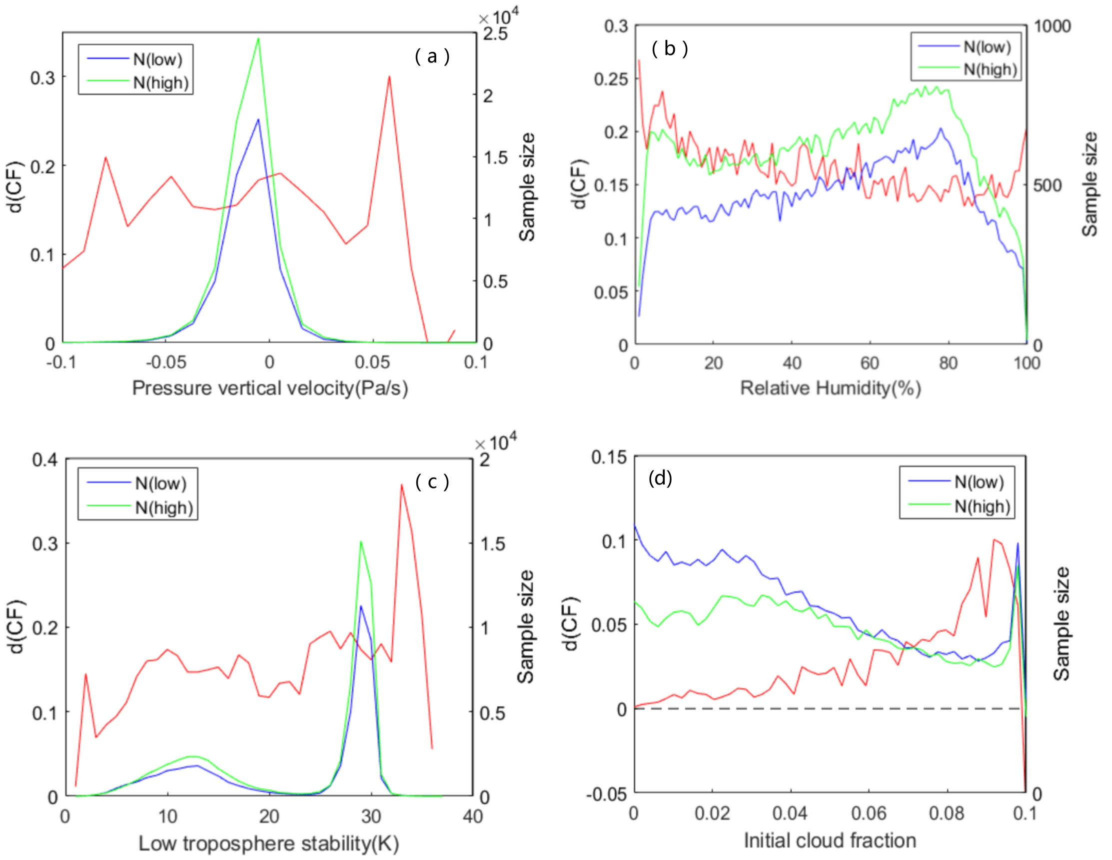


Figure 9 The same as Fig. 8 but for warm clouds when the cloud cover decreases under both low and high AOD conditions after the 3 hours timestep over land.

**4. Comments: (4) I am not clear of the purpose of choosing the different regions in this work. They are explained in section 2, but very little reference is made to these meteorological differences later in the paper. Other than noting that the aerosol-cloud relationships are different in these regions, there is little discussion of why there is a difference. As variations have previously been noted in the strength of aerosol-cloud relationships, it would be good to include some discussion as to why they are different. This would help this paper build on the previous literature in this area.**

**Answer:** Yes, following the reviewer's comments, we add the meteorology of the four target regions in new Section 4.2, in support of the interpretation of the regional variation of relationship between aerosol and cloud. Furthermore, we have discussions of those different aerosol-cloud relationships in different regions and gave possible reasons (see pg.11 lines 11-16 in the revised manuscript).

In order to include some discussion as to why they are different, text was added as: 'From the perspective of considering all urban clusters (BTH, YRD and PRD), both COT and CWP increase over land during the 3 hours timestep for both low and high AOD. Overall, the variation in cloud properties after the timestep over BTH is less significant than over the YRD and PRD for both low and high AOD conditions. This may result from less humid and more unstable atmospheric environments over the BTH than over the other two urban clusters (as shown in Section 4.2).' in the Page 11, line 11-16.

**Specific comments**

**1. Comments: (1) Page 1, Line 39: Twomey 1974/77?**

**Answer**: We made this change (see page 2, lines 3-4). "Due to interactions with aerosols, the climatic effects of clouds are further complicated (Rosenfeld, 2000; Twomey, 2007)" has been changed to "Due to interactions with aerosols, the climatic effects of clouds are further complicated (Rosenfeld, 2000; Twomey, 1974; Twomey, 1977)."

**2. Comments: (2) Page 2, Line 3: a smaller droplet radius does not always result in precipitation suppression, especially if the warm rain frequency is already low (e.g. Muelmenstaedt et al., GRL, 2015)**

**Answer**: "Thus, cloud albedo increases and the smaller cloud droplet effective radius results in the suppression of precipitation, which in turn results in a longer cloud lifetime, and maintaining a larger liquid water path (Albrecht, 1989; Feingold et al., 2001)" has been changed to "Thus, cloud albedo increases and the smaller cloud droplet effective radius in most cases results in the suppression of precipitation, which in turn results in a longer cloud lifetime, and maintaining a larger liquid water path (Albrecht, 1989; Feingold et al., 2001)" in the revised manuscript (see page2, line 8-10).

**3. Comments: (3) Page 4, Line 1: Why not use collection 6 data? There is also almost four times as much MODIS daily data available as it being used here. Why has this specific time period been chosen? A larger data record would improve the statistical significance of this work.**

**Answer:** Following the reviewer's comments, we use collection 6.1 data and reanalyze all the data for the whole acquisition period between 2008 and 2017, rather than C5.1 data from 2008 to 2011. Therefore, the variation of cloud properties to the aerosol environment has been changed and more clear. This issue is shown throughout the revised manuscript (all the figures were changed/modified in this respect).

**4. Comments: (4) Page 4, Line 24: Why is aerosol optical depth used? Many previous studies have that it had severe limitations proxy for CCN (e.g. Penner et al, PNAS, 2011)**

**Answer:** The average CCN concentrations show a remarkable correlation to the corresponding AOT values, it provides an easily measured proxy for CCN concentration (Andreae, 2009). Meanwhile, in the present study the use of AI would not be appropriate, because our study is conducted mostly over land areas. This has to do with the use of the Ångström exponent in the derivation of AI, namely, the Ångström exponent is not reliable over land areas. We quote a personal communication with L. Remer (20 June 2010), NASA GSFC: "Ångström over land is not reliable and we recommend strongly not to use it"; hence, AOD is used in our study (Kourtidis et al., 2015).

**5. Comments: (5) Page 5, Line 2: 'representative of typical thermodynamic conditions' it is not clear what this means.**
**Answer**: "…which is representative of typical thermodynamic conditions (Klein and Hartmann, 1993)." has been changed to "…which can be regarded as a measure of the strength of the inversion that caps the planetary boundary layer (Klein and Hartmann, 1993; Wood and Bretherton, 2006)" in the revised manuscript (see page 4, line 30-31).

**6. Comments: (6) Page 6, Lines 1: Are all parameters considered at the same time? Gryspeerdt et al, also used meteorological parameters normalization.**
**Answer:** Yes, normalized histograms of cloud properties and meteorological parameters are made for high and low AOD conditions following the method described by Gryspeerdt et al. (2014).

**7. Comments: (7) Page 6, Line 2: Normalisation by cloud fraction makes the biggest difference in what?**
**Answer:** We made this change (see page 5 lines 34-35). "…even though we find that the normalization for the cloud fraction made the biggest difference by far." has been changed to "Among those cloud properties, this process of normalization has the greatest effect on the cloud fraction and its dependence on aerosol-cloud interaction."

**8. Comments: (8) Page 6, Line 2: Does this mean this normalization method is applied throughout this work?**
**Answer:** Yes, the sentence means the normalization method is applied throughout the work. And "In the further analysis, we only take a subset of original data by removing random samples until the histograms are similar." has been changed to "Throughout the work, we only take a subset of original data by removing random samples until the histograms are similar." (see page 5, line 35-36 in the revised manuscript)

**9. Comments: (9) Page 6, Line 24: As mentioned earlier should the difference between the cloud properties at the start time not be zero?**
**Answer**: Normalised histograms of cloud properties for the high and low AOD populations are made for the whole region (Section 3.1), because the data volume based on each 1° x 1° location is relatively small. However, the difference between

the cloud properties for low and high AOD at the start time is based on each 1° x 1° location (Section 4.1). So the difference of the cloud properties between the low and high AOD at the start time is not zero (see response to question 1 in major points section).

**10. Comments: (10) Page 7, Line 7, Perhaps also Yuan et al, ACP, 2008 (Increase of cloud droplet size with aerosol optical depth: An observation and modeling study, 10.1029/2007JD008632)**

**Answer**: We made this change (see page 7, line 6-8). "…may result from the intense competition for the available water vapour and the evaporation of smaller droplets as a consequence of the high aerosol abundance over these regions (Wang et al., 2014; Liu et al., 2017)." has been changed to "…may result from the intense competition for the available water vapour and the evaporation of smaller droplets as a consequence of the high aerosol abundance over these regions (Yuan et al., 2008; Tang et al., 2014; Wang et al., 2014; Liu et al., 2017)."

**11. Comments: (11) Page 7, Line 22: Many previous studies have shown links between aerosol and cloud properties over China but it might be good to know why these relationships are different.**

**Answer**: We made this change (see page 8, line 11 and page 9 lines 1-7). Text are added as: "Some links between aerosol and cloud in the four regions are different from those of previous studies over China (Wang et al., 2014; Tang et al., 2014; Kourtidis et al., 2015; Liu et al., 2017), which might be due to the use of different data sets (MODIS C6.1 versus older versions), hypothesis and target areas characterized by complex aerosol compositions and varying meteorological conditions. Overall, the result implies that the interaction between aerosol particles and clouds is more complex and of greater uncertainty over land (BTH, YRD and PRD) than over ocean (ECS). Jin and Shepherd (2008) also noted that aerosol affect clouds more significantly over ocean than over land. They suggested that dynamic processes related to factors like urban land cover may play at least an equally critical role in cloud formation."

**12. Comments: (12) Figure3: What is this sample time series?**

**Answer**: Samples are collected from the pixels of the difference in cloud properties that covering the four regions and randomly as shown in the Figure3.

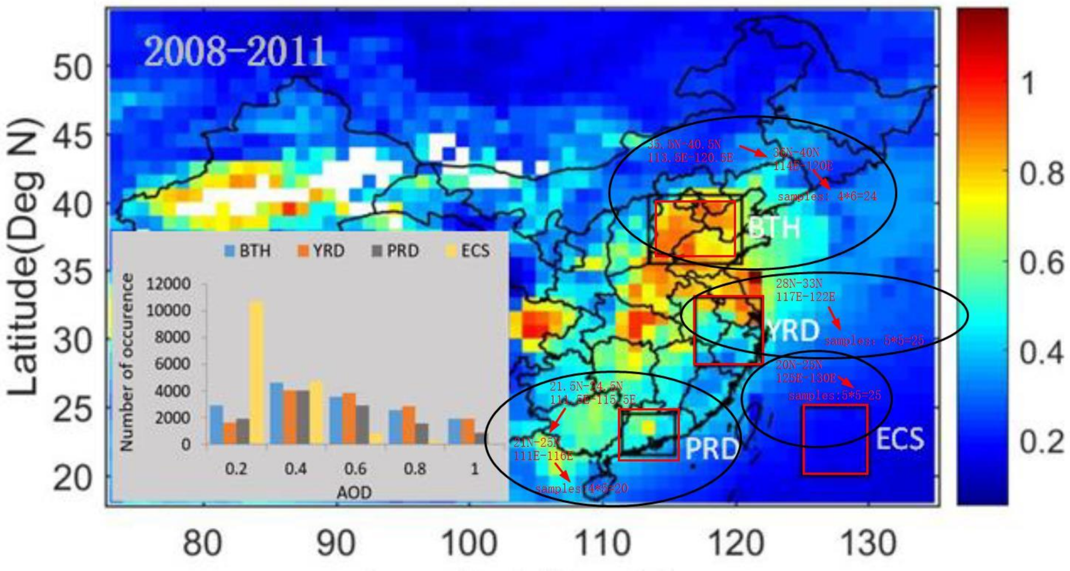


Figure A map of showing samples are collected in the four target regions.

**13. Comments: (13) Page 10, Line 4: If the variation of cloud properties depends little on the initial AOD, does that not mean that section 4.3 should show no results? This would be in contrast to previous studies.**

**Answer:** We made this change (see page 11, line 11-17 in the revised manuscript). The sentence "We can conclude that the variation of cloud properties after 3 hours depends little on the initial AOD over land, even though differences exist among the urban clusters" has been removed, which is not a correct conclusion. Further, the variation of cloud properties to the aerosol environment using different data sets (MODIS C6.1 versus older versions), we find that both COT and CWP increase over land during the 3 hours timestep for both low and high AOD. Overall, the variation in cloud properties after the timestep over BTH is less significant than over the YRD and PRD for both low and high AOD conditions. This may result from the less humid and most unstable atmospheric environments over the BTH than over the other two urban clusters (as shown in new Section 4.2). Over the ECS, in both low and high AOD conditions, CDR, CF and CTP decrease during the timestep while COT and CWP increase (see Figure 5 in the revised manuscript).

**14. Comments: (14) Page 13: As there have been several previous studies looking at aerosol and cloud relationships, it would be good to set these results in context of previous work.**

**Answer**: We made this change (see page 14 lines 8-37 and page 15 lines 1-8).

The variation of cloud properties to the aerosol environment has been more clear by reanalyzing all the MODIS C6.1 data for the whole acquisition period between 2008 and 2017, rather than MODIS C5.1 data from 2008 to 2011. This issue is shown throughout the revised manuscript (all the figures were changed/modified in this respect). Following the reviewer's comments, the results in Section 4.3 have been linked to Section 4.1 and compared to previous work.

Part of text in Section 4.3 was shown in follows (see page 14-15 in the revised manuscript): “Figure 7 shows that the values of d(CDR) over the three urban clusters are not mostly positive or negative, which indicates that in high AOD conditions over land the variation in CDR during the three hours between the MODIS/Terra and Aqua overpasses is similar. Over the ECS the values of d(CDR) is positive, which indicates that the CDR in high AOD conditions decreases much more than during low AOD conditions over ocean. Wang et al. (2014) also reported a negative correlation between CDR and AOD over the ECS, in accordance with the Twomey effect. Furthermore, CDR tends to be smallest in polluted and strong-inversion environments, an outcome in good agreement with the findings of Matsui et al. (2006). Most of the d(COT) values are negative over the four regions, especially for the YRD, PRD and ECS. This shows that the COT increases less in high AOD conditions than in low AOD conditions, over both land and ocean, which is contrast with the findings of Meskhidze et al. (2009). Likewise, the values of d(CWP) are almost all negative over the four regions although over the BTH urban cluster the values are not clear. This indicates that in high AOD conditions the CWP increases less during the timestep than in low AOD conditions, a result in accordance with the conclusion that higher LTS is linked with a slightly lower CWP (Matsui et al., 2006). We can conclude that the variation trend of COT and CWP after 3 hours depends little on the initial AOD, but the initial AOD conditions can affect the amplitude of variation of COT and CWP. Meanwhile, the values of d(CF) are smaller than zero over the ECS. This shows that the cloud fraction in high AOD conditions over ECS decreases less than that in low AOD conditions. However, Meskhidze et al. (2009) found that an increase of the aerosol concentration may lead to enhanced reduction of afternoon cloud coverage and optical thickness for marine stratocumulus regions off the coast of California, Peru, and southern Africa. Therefore, the connection between AOD and variation of cloud cover could be a response to regional-scale changes in aerosol covarying with meteorological conditions. The value of d(CF) is overall positive over the PRD, which indicates that over the PRD in high AOD conditions the cloud cover increases much more than the cloud cover decreases in low AOD conditions. Mauger and Norris (2007) have shown that scenes with large AOD and large cloud fraction experienced greater LTS. As regards CTP, we find that the values of d(CTP) are positive over the BTH and PRD urban cluster, but the values of d(CTP) over the other two regions are not significant. It indicates that in high AOD conditions over the PRD region the CTP increases much more than the CTP decreases in low AOD conditions. We can conclude that the variation in d(Cloud_X) is different for continental and oceanic clouds. This applies to CDR, cloud fraction (CF) and CTP, but not to COT and CWP. Table 2 summarizes the differences between the mean changes in cloud properties for low and high AOD over the timestep of 3 hours.

Based on the above findings, we conclude that over the ECS the values of CDR, CWP and CTP are smaller but the values of COT and CF are larger in high AOD conditions. After the 3 hours timestep, CDR, CF and CTP become smaller, irrespective of the AOD. Furthermore, CDR decreases much more in high AOD conditions but CF and CTP decreases much more in low AOD conditions. In contrast, COT and CWP become larger in both AOD conditions, more significantly in low AOD conditions. Over the urban clusters, COT and CWP also increase over the timestep in both AOD conditions, especially for the low AOD condition. For CF the values in low AOD conditions decrease over the timestep. The CTP change behaves differently among the three urban clusters during the 3 hours."

**15. Comments: (15) Page 15, Lines 7: presumably LTS**
**Answer**: Yes, we made this change (see pg.16 line 7).

**16. Comments: (16) Page 15, Line 12: I read exactly the opposite, it looks like there is a high impact of aerosol with descending air parcels.**
**Answer**: The effects of initial cloud fraction and meteorological conditions on the change in CF under low and high AOD conditions after the 3 hours timestep over land are also explored. In our new version manuscript, there are two cases are considered: (1) when the cloud cover increases (ΔCloud_X>0); (2) when the cloud cover decreases (ΔCloud_X<0). So, the results and discussions have been changed. We rephrased the sentence in the revised manuscript (see page 16 lines 13-28).

**17. Comments: (17) Page 15, Line 18: Is this change a very large relative humidity statistically significant or just noise?**
**Answer**: The effects of initial cloud fraction and meteorological conditions on the change in CF under low and high AOD conditions after the 3 hours timestep over land are also explored. In our new version manuscript, there are two cases are considered: (1) when the cloud cover increases (ΔCloud_X>0); (2) when the cloud cover decreases (ΔCloud_X<0). So, the results and discussions have been changed. We rephrased the sentence in the revised manuscript (see page 17 lines 2-9).

**18. Comments: (18) Page 15, Lines 23: LTS is almost always positive**
**Answer:** Yes, we made this change (see page 17 lines 12-13). "A positive LTS is associated with a stable atmosphere in which vertical mixing is prohibited; negative PVV indicates local upward motion of air parcels." has changed to "Low LTS represents an unstable atmosphere and high LTS represents a stable atmosphere."

**19. Comments: (19) Page 15, Line 25: 27K is a very high value for LTS and does not distinguish much between high and low values.**
**Answer**: The effects of initial cloud fraction and meteorological conditions on the change in CF under low and high AOD conditions after the 3 hours timestep over land are also explored. In our new version manuscript, there are two cases are considered: (1) when the cloud cover increases (ΔCloud_X>0); (2) when the cloud cover decreases (ΔCloud_X<0). So, the results and discussions have been changed. We rephrased the sentence in the revised manuscript (see page 17 lines 10-17).

**20. Comments: (20) Page 16, Line 4: Why is the initial cloud fraction included if its impact is not clear? Can we learn anything from it?**

**Answer:** The effects of initial cloud fraction and meteorological conditions on the change in CF under low and high AOD conditions after the 3 hours timestep over land are also explored. In our new version manuscript, there are two cases are considered: (1) when the cloud cover increases (ΔCloud_X>0); (2) when the cloud cover decreases (ΔCloud_X<0). So, the results and discussions have been changed. We rephrased the sentence in the revised manuscript (see page 17 lines 18-26).

**21. Comments: (21) Page 17, Line 28: This seems like something that could receive more discussion.**

**Answer:** We rephrased the sentence in the revised manuscript (see page 20 lines 7-13). Text was rephrased as follows.

Page 20 lines 7-13: The results show that scenes with large cloud fraction experience large AOD and stronger upward motion of air parcels. Meanwhile, scenes with large cloud fraction experience large AOD and larger RH when RH larger than 20%. Scenes with large cloud fraction change experience large AOD and larger LTS when LTS smaller than 10. Furthermore, scenes with smaller cloud fraction change experience large AOD and larger LTS when LTS larger than 10 and smaller than 20. We also find that smaller cloud fraction occurs when scenes experience larger AOD and larger initial cloud cover.

**22. Comments: (22) Page 17, Line 13: This relationship between initial cloud fraction and changing cloud fraction is mentioned again with very little explanation as to why.**

**Answer**: We made this change (see page 19 lines 27-29). Text was added as: 'Both COT and CWP increase over land and ocean after the timestep, irrespective of the AOD. The variation trend of COT and CWP after 3 hours depends little on the initial AOD, but the initial AOD conditions can affect the amplitude of variation of COT and CWP. '

**References**

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