Responses to the Comments of the Anonymous Referee #2

We very much appreciate the constructive comments and suggestions from this reviewer. Our point-by-point responses to the reviewer's comments are as follows (the reviewer's comments are marked in Italic font).

Comments:

This paper examines the impacts of biomass burning aerosols on convective systems over the northern Sumatra and the western Borneo in the Maritime Continent based on based on long-term WRF-Chem simulations. While the paper is well written and interesting, there are some concerns that need to be addressed before the paper being publishable.

(1) The resolution of inner domain at 5 km is still too coarse for simulating convective clouds.

We agree with the reviewer that 5 km is still not an ideally fine resolution for simulating convective clouds, although commonly previous studies have shown that WRF model with a similar resolution can still reflect many critical characteristics of deep convection without using convection parameterization (e.g., Wagner et al., 2018). Specifically, because of the purpose of this study and the availability of computational resource, we have decided to use a 5 km resolution with cumulus scheme off. Based on our model evaluation, especially the comparison of sounding profiles, the model under the current configuration can capture the major characters of the convective systems very well.

In the revised manuscript, we have added following sentences in Section 2.1, Lines 162-170:

"Owing to the main purpose of this study to reveal fire aerosol-convection interaction through modeling a large quantity of convective systems continually over a relatively long period, and the computational resource available to us as well, we have adopted a 5 km horizontal resolution which excluding cumulus parameterization scheme. Previous studies have shown that WRF model with a similar resolution without convection parameterization can still capture many critical characteristics of deep convection (Wagner et al., 2018). Our model evaluation, especially through the comparison of modeled results with sounding profiles, has demonstrated the same."

(2) The section of selected cases analysis looks vague and needs more detailed analysis. The impacts of aerosol on precipitation are very complicated (different mechanisms on different clouds under different conditions). It is too bold to get the conclusion just based on three cases even with cloud types unknown. There are so many convective cases that could be categorized them and analyzed in detail.

We have made our best effort to clarify the related discussions in the revised manuscript (see also our response to the Reviewer #1). First of all, we have made it clear that our simulations and analyses cover all the different cases, though we have chosen to identify different aspects of the impacts of fire aerosols through a different sets of analyses, ranging from deriving case-wise statistics to performing seasonal analysis.

The analyses based on selected three cases from each of the two study regions are just one of these. To avoid the impression that our conclusions were drawn from only three cases, we have made several revisions in the manuscript, One of the revised discussions in Lines 429-448 are: "In Sect. 3.2, we have discussed the significant rainfall increase occurred in the weak convective systems after adding fire aerosols due to aerosol invigoration effect. On one hand, regardless the strength of convection, the mean 3-hourly rainfall during the fire periods is 1.06±0.85 mm in FF and 1.09±0.86 mm in FFBB over the Sumatra region (r1), and statistically it does not change significantly in responding to fire aerosols. The rainfall difference in the Borneo region (r2) between FF and FFBB is also insignificant (1.32±1.20 mm $3hrs^{-1}$ in FF versus 1.35±1.14 mm $3hrs^{-1}$ in FFBB). On the other hand, we have found that the impacts of fire aerosols appear in several other rainfall patterns. For instance, the daily maximum and minimum rainfalls display clear differences between the FFBB and FF simulations, specifically in r2 rather than in r1 (Fig. 9). While for r1, the impacts of fire aerosol are reflected in event-wise statistics, e.g., higher event-wise maximum and minimum rainfall intensity in FFBB than in FF, identified in 30 out of 54 convective events in total. These are mostly weak convective events in r1. Interestingly, somewhat opposite to the rainfall statistics in r1, the intensity of event-wise maximum and minimum rainfall in r2 is higher in FF than in FFBB. The daily rainfall peak of 3-hr rainfall in r1 is mostly less than 3 mm; in comparison, one-third of convective events in r2 have daily maximum 3-hr rainfall exceeding 3 mm (Fig. 9c), suggesting that the convective systems in r2 tend to develop stronger than in r1 and the fire aerosols significantly suppress the maximum rainfall intensity of strong convections in r1. …"

We have specifically enhanced our discussion regarding mechanisms of fire aerosol-convection impacts. On example is the following added discussions in Line 333-341: "Our result is consistent with that of Lin et al. (2006), which suggested that biomass burning aerosols could invigorate convection and then increase precipitation based on satellite observations. The aerosol invigoration effect is referred to such a hypothetic process that increasing number of smaller cloud droplets due to higher aerosol concentration would reduce the efficiency of raindrop formation from self-collection among cloud droplets, and thus further slowdown the loss of these small droplets from being collected by larger raindrops and allow more of them reach high altitudes, where they would eventually collected by ice particles through riming, causing release of latent heat to enhance updraft."

Regarding defining a weak or strong convective system in the case study, 3 mm $3hr^{-1}$ of the averaged rainfall could be used as a threshold. We have clarified this in the revised manuscript.

(3) The heating effect of fire aerosols seems too weak to have significant influence on circulation.

The temperature increase from aerosol absorption is not necessarily too weak because our analysis did identify clear change of vertical velocity owing to the aerosol heating effect. This seems also consistent with the analysis of Zhang et al. (2019). Indeed, should the heat flux generated by fires be incorporated in the model, the warming effects from biomass burning would be much stronger and also persist in nocturnal timeframe.

We have added sentences in Lines 522-527 of the revised manuscript as: "Based on our analysis, the temperature increase is mainly associated with the thermodynamic perturbation from the absorption of sunlight by fire aerosols. This seems also consistent with the analysis of Zhang et al. (2019). Indeed, should the heat flux generated by fires be incorporated in the model, the warming effects from biomass burning would be much stronger and also persist in nocturnal timeframe."

Here are also some specific comments:
1. Line 153: What is the time frequency of nudging?

The time frequency of nudging is every 6 hours. We have added this information in the revised manuscript.

2. Line 183: needless parenthesis

Modified.

3. Line 205: How and why were these convective systems selected? Why only three?

The selected cases in Section 3.2 are chosen randomly from different fire periods of the two study regions. We did not set any criteria initially when we chose these cases. All these points have been clarified in the revised manuscript (Lines 221-224):
"The selected cases are chosen randomly from the different fire periods of the two study regions. We did not set any criteria initially when we chose these cases. After we analyzed all cases, 3 mm $3hr^{-1}$ was set as the threshold to distinguish weak and strong convections."
These cases were used to discuss modeled characteristics of individual cases and make comparison between cases from different regions without considering their weights in the overall case-wise statistics. We have actually made effort to avoid leaving any impression about whether they are representative in their corresponding case population. The ensemble characteristics of each case population are defined by their case-wise statistics.

4. Line 233: Were the model results interpolated to the resolution of TRMM before doing the comparison?

The modeled rainfall in FFBB has been interpolated to the resolution of TRMM for the comparison in Figure 3. Figure 2a is also made by following this procedure. However, we have just realized that the original Fig. 2b was not made after modeled data being remapped into TRMM grids; therefore, we have reprocessed data and replotted Fig. 2b in the revised manuscript to be consistent with other figures. We appreciate the reviewer for pointing out this.

5. Line 260: Why only this example sounding is shown? You may compare with many other cases and even show a statistical comparison.

We choose this example sounding in the main text because we have cloud vertical structure from CALIPSO for the same case. We have now added the sounding comparison of other 5 cases in the supplement.

6. Line 275: Only one case captured by CALIPSO?

We have compared more than 50 modeled convections during the fire season and within the simulation domains. Specifically, for the six selected cases in case study, only one case was captured by CALIPSO. The others captured by CALIPSO are not among the cases in the case study (some are even out of our analyzed domains). This is the reason why we only discussed this case in our case study discussion. We have mentioned this point in Lines 302-304 of the revised manuscript.

7. Line 311-314: It is confusing. Aerosol impact on ice-phase microphysical processes is still considered in Morrison through the CCN effect. It is the IN effect of aerosol that is missed.

We thank the reviewer for indicating this. We have added "In our model configuration, fire aerosol can still affect ice process, however, through CCN effect rather than serving directly as ice nuclei." into Lines 344-346 in the revised manuscript.

8. Line 315-321: More background information of these cases are necessary. You just simply saying that one case has weaker convective systems than other two. This is too ambiguous.

The reviewer's comment is well taken. We have added the sounding profiles of all six cases in the supplement to present the environmental condition of each of these convections. We have also added a sentence of: "After we analyzed all cases, 3 mm $3hr^{-1}$ was set as the threshold to distinguish weak and strong convections" into Lines 223-224 in the revised manuscript.

9. Line 454: The temperature increase seems too small. Is this significant? Maybe the difference is within the model simulating error range.

As we replied in the general comment (3), based on our analysis we believe this temperature increase is mainly associated with the thermodynamic perturbation from the absorption of sunlight by fire aerosols. It is also consistent with the analysis of Zhang et al. (2019). Again, should the heat flux generated by fires be incorporated in the model, the warming effects from biomass burning would be much stronger and also persist in nocturnal timeframe.

10. Line 455-457: No figure showing this conclusion. How much land breeze and surface convergence is weakened.

We have added Fig. 11 to demonstrate this conclusion in the revised manuscript.

Reference:

Lin, J.C., Matsui, T., Pielke Sr., R.A., Kummerow, C., Effects of biomass-burning-derived aerosols on precipitation and clouds in the Amazon Basin: a satellite-based empirical study, *Journal of Geophysical Research: Atmospheres* **111**(2006).

Wagner, A., Heinzeller, D., Wagner, S., Rummler, T., Kunstmann, H., Explicit Convection and Scale-Aware Cumulus Parameterizations: High-Resolution Simulations over Areas of Different Topography in Germany, *Monthly Weather Review* **146**(2018), pp. 1925-1944.

Zhang, Y., Fan, J., Logan, T., Li, Z., Homeyer, C.R., Wildfire impact on environmental thermodynamics and severe convective storms, *Geophysical Research Letters* **0**(2019).