Response to Referee #2

We thank Reviewer#2 for several constructive comments and recommendations. We have made a number of the suggested changes and have addressed the points raised. Below, we reproduce the referee's questions using italic font in quote, followed by our responses. All authors listed on the manuscript have concurred with the response and revisions.

"This climate modeling study examines the impact of biomass burning aerosols on pre-monsoon circulation and rainfall over Southeast Asia. A sensitivity approach is used to test the response of modeled atmospheric dynamics, thermodynamics, surface evaporation, cloud microphysical and macrophysical properties to the direct radiative forcing and/or indirect effects of the biomass burning aerosols by turning on or off the regional emissions, and by including or excluding aerosols globally in the radiative transfer calculations. The modeling tool used for this study is the state-of-the-art GEOS-5 general circulation model equipped with a double-moment cloud microphysics scheme that treats aerosol-cloud interactions for both stratiform and convective clouds. Some of the results are just a demonstration of the model's ability to represent aerosol effects, but some are quite new and of interest to the community. The paper is generally well written and the figures have very good quality. I recommend for publication in ACP only after the following comments are satisfactorily addressed and the manuscript is to be revised accordingly."

- Our responses to specific queries and points of clarification are as follows:

General comments:

"1) More comprehensive literature review on recent studies of South/Southeast Asian monsoon (rather than the classic papers on aerosol effects, IPCC report, textbook and the authors' own publications) is needed to put this work in the right context."

- This deficiency is identified by both reviewers. The revised version has a more comprehensive literature review.

"2) It is mentioned in the paper that QFED emission data are used for biomass burning inventory in the GOCART aerosol model in GEOS-5. What are the injection heights of fire emissions? This is important in determining the vertical distribution of BB aerosols."

- In GOCART, BB emissions are evenly distributed within the model's planetary boundary layer (Petrenko et al., 2012). The model subsequently transports horizontally and vertically all aerosols including the BB according to model's dynamics and moist physics.

"How about other emissions (besides the fire emissions) and the natural dust and sea salt aerosols? It's necessary to compare BB aerosols and the "background" aerosols (in the ZeroBoth) at least in the region of interest to give an idea of the respective contributions to total aerosols."

- The GOCART module simulates five aerosol species, sulfates, sea salt, dust, organic, and black carbon. 'High' experiments are the outcome of higher BB emission while 'Zero' assumes no BB emission in the selected region. The atmosphere carries naturally all the other aerosols generated by the GOCART module. The only difference between the 'High' and 'Zero' experiments is the BB emission within the selected SEA area are for high and zero BB emission scenarios, respectively. The following table provides regional mean AODs of each aerosol species from the experiments. We can see that carbonaceous aerosols are mostly from local BB emission. We also find 67% of sulfate in 'High' simulation experiments is due to sulfates in BB emissions. Dust and sea salt are not affected by BB emission and their differences between the two experiments are very small. The numbers of AOD table below were added in the revised manuscript.

Table R2.1 Regional mean AODs from the experiments in March where 'HighBoth' has high BB emission and 'ZeroBoth' have zero BB emission, from 90E to 110E and 12N to 30N.

	High	Zero	Difference
Organic Carbon	0.518	0.031	0.487
Black Carbon	0.063	0.013	0.050
Sulfate	0.192	0.129	0.063
Dust	0.0086	0.0085	0.0001
Sea Salt	0.0024	0.0024	0.0

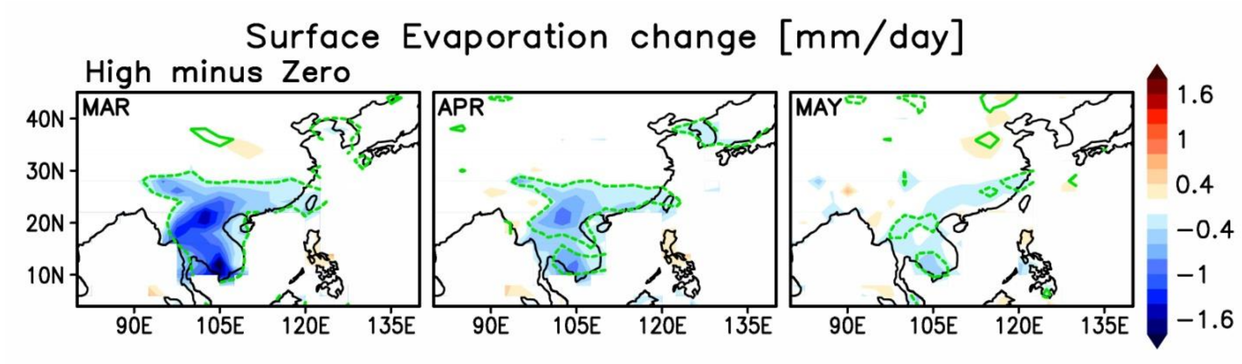
"3) It is not very clear how the GEOS-5 simulations were conducted and how the monthly or seasonal mean quantities were derived from the model simulations. How were the initial conditions for the ten ensemble members taken? It sounds that each simulation was run for a rather short time period. How is this justified for the comparison of three dimensional spatial distribution of aerosol and cloud properties?"

- The monthly and seasonal mean quantities were derived by averaging an ensemble of 10 runs. Each run started on January 1st, and ended on September 1st using climatological SST. The initial conditions for each of the ensemble's ten members were taken from restart files of previous model run (Sud et al., 2013) which circumvents the need to allow adjustment period to analyzed initial conditions. The climate sensitivity of the pre-monsoon season, from February to June, was evaluated. Ensemble runs were needed to distinguish responses of the climate system from internal model variability. In order to extract statistically significant differences between 'High' and 'Zero' BB runs, the Student's t-test was used and differences exceeding 95% confidence level were delineated as significant. The manuscript was revised to include the above discussion.

"4) It was assumed in the paper that the surface evaporation decreases in response to BB aerosol forcing, which was used to explain some of the critical model results. This can be easily examined from the model output and should be presented in the paper."

- It was not assumed, but rather diagnosed from the model runs and is now shown in the manuscript as Fig. 10. Please also refer to Fig. R2.1 below. Significant decreases in surface evaporation can be seen over the source region for March and April months. Also, there is a weak anomaly in May.

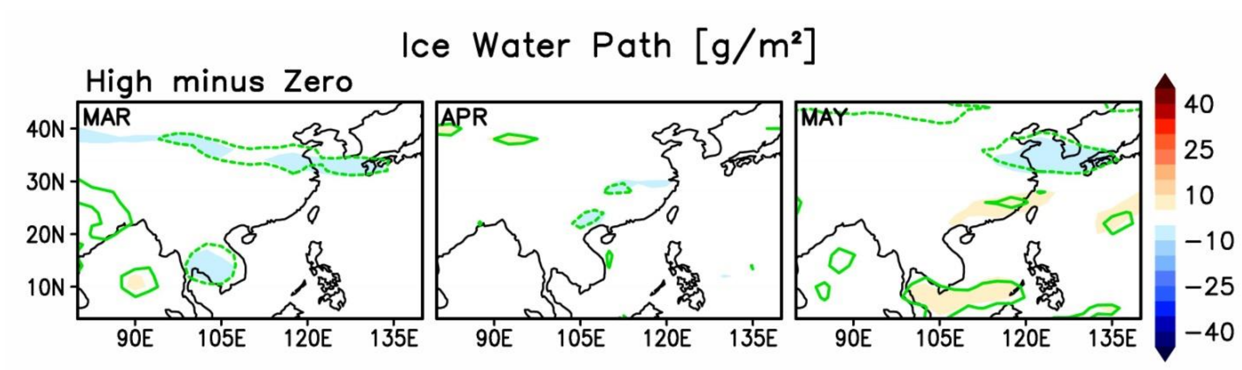
Fig. R2.1 HighBoth minus ZeroBoth for FMA simulations representing BBA effects on surface evaporation (mm/day) over land. Green contour mark regions of >95% significant in a student's t-test.



"5) The effect of BB aerosols on liquid clouds is the focus of this paper. However, ice cloud is relevant to the radiation budget and changes seen in temperature, moisture and circulation. Is BB aerosol connected to ice nucleation in GEOS-5? As mentioned in the summary and discussion section, aerosol-induced convective invigoration is not represented in the convective parameterization. How about the impact of additional freezing liquid droplets (due to precipitation suppression) on ice cloud microphysics?"

- Our model does include the ice cloud nucleation process (from Barahona and Nenes, 2009a, b) and the Bergeron–Findeisen process (from Rotstayn et al., 2000). As stated in the summary and discussion section and now discussed in more detail in Response to Reviewer#1, our convective parameterization ignores convective invigoration by cloud particle freezing. Moreover, in the spring season, the incidence of convection is comparatively much smaller than that in the summer season. In other words much fewer liquid cloud droplets are transported to the freezing level. Monthly mean ice water path plots, as expected, do not show a significant change in the ice-cloud related signal (Fig. R2.2, color bar corresponding Fig. 5c) compared to the liquid water path (Fig. 5c). We also conducted additional analysis by further decomposing CRE to SW and LW part following a recommendation by Referee #1. The outcome is pretty much as expected. Please refer to the response to Reviewer #1.

Fig. R2.2 Same layout as in Fig. R2.1, but for ice water path (g/m^2)



"6) Please make better use of acronyms in the paper. Some are inconsistent and redundant (e.g., BB vs. BBA; AIE vs. IE; ADE vs. DE; LCER vs. Reff; CDNC vs. Nc)"

- Those inconsistent and/or redundancies identified above are corrected in the revised manuscript. Now BBA, IE, DE, R_{eff}, N_c are used in the manuscript.

"7) The BB aerosol impact is amplified by using the high emission in 2007, so some of the conclusions are not applicable to the general climate in the Southeast Asia region. This should be noted in the abstract and summary. It is arguably more reasonable to use the climatological BB emissions instead."

- We agree, but our choices were deliberate and were driven by the weak signal, compared to interannual variability, that resulted when contrasting simulations of high and low BB years. We decided therefore to enhance the aerosol impact by comparing no BB versus high BB scenarios. This idealization amplifies the response whereby we can isolate the statistically significant changes and for examining the impact of BBA changes. We improve the discussion in the revised manuscript based on the reviewer guidance.

Specific comments and technical edits:

"1) P32887, L24-26: among the biomass burning aerosols, organic carbon should have much larger impact on CCN number than black carbon."

- The statement is revised as "Furthermore, many particles from BB emission are active cloud condensation nuclei (CCN) (Petters et al., 2009). Hence more BB emission leads to more CCN and ice nuclei (IN) and thereby more cloud particles."

"2) P32888, L25: GEOS-5 is spelled out later in section 2, but the model is mentioned here for the first time."

- Revised as suggested.

"3) P32891, L13-16: this sentence has grammar issue."

- Revised as suggested.

"4) P32891, L20-23: this sentence has grammar issue."

- Revised as suggested.

"5) P32894, L10: the purpose of using COSP MODIS simulator to process model output should be for a fair model-observation comparison rather than " to enhance similarity with observations".

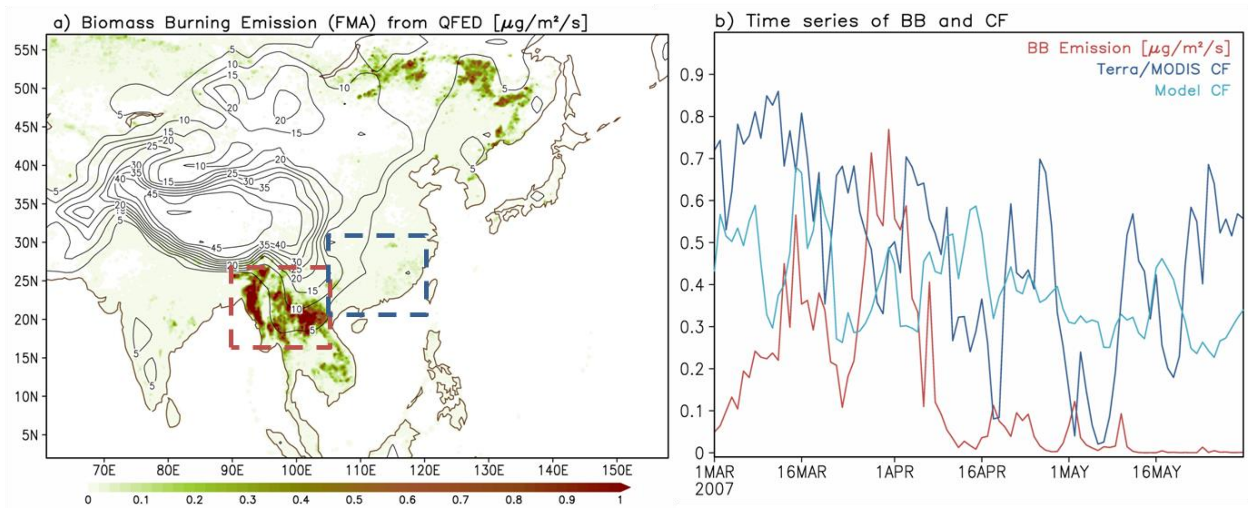
- We agree and have rephrased accordingly

"6) P32895, L6-9: first of all, I don't see the topography in the Fig. 4 is enough to lift the BB aerosols. Also, you are looking at the monthly or seasonal mean clouds and aerosols rather than snapshots. What is the "pre-existing clouds" statement based on?"

- Because Fig. 4 shows the zonal mean from 105 to 120E, the topography is not clearly displayed. Surface geopotential height is contoured in Fig. R2.3a.

Cloud fractions over the target area remain steady while BB activity affects them intermittently. So the scenario leads to BBA injection into "pre-existing clouds". Fig. R2.3b shows time series of area averaged BB emission and liquid cloud fractions from Terra/MODIS and the current model runs.

Fig. R2.3 a) FMA mean QFED BB emission (shaded, $\mu g/m^2/s$) and surface geopotential height (contour, 10^3m) b) averaged time series for dashed box area for BB emission (dark pink), liquid cloud fraction from Terra/MODIS (dark blue) from March to May 2007, and liquid cloud fraction from a member of 'HighBoth' run (light blue).



"7) P32895, second paragraph: it is more appropriate to place such model description into section 2. Some descriptions of how the five types aerosols are treated in GOCART are needed. For example, how many modes are there in the aerosol module? How are different species in the same mode mixed? Excluding BB aerosols might affect the way how "background" aerosols are represented in the model.

- As suggested, the description of GOCART is moved to Section 2 in the revised version. The GOCART module has five aerosol species with fifteen modes that span across different size distributions. There are five modes of dust size distribution, five modes of sea salt size, two modes of organic carbon separating hydrophilic and hydrophobic modes, two modes of black carbon also separating hydrophilic and hydrophobic, and one mode of sulfate. These modes are 'externally' mixed. Revisions have been made to show the amount of "background" aerosols.

"8) P32896, L10-16: The arguments of ": : : due to circulation changes induced by BB emission in the preceding months" and ": : :due to delayed precipitation in March and April" are questionable. Which kind of atmospheric response can last for a month in this region? How long can the clouds last in the model?"

- Indeed, it is a conjectural discussion that addresses the possibility of multiple quasi-static equilibrium modes linked to the large-scale circulation fields. We merely argue that if the pre-monsoon impact of aerosol is to push the circulation into a different equilibrium regime, then the effect of aerosol on the circulation can linger into the future month(s). We qualify the statement in the revised version.

"9) P32898, L14: change "cloudless" to "clear sky"."

- Changed as suggested.

"10) P32899 and Fig. 9: How were the temperature and tendency terms averaged temporally and spatially? It is not intuitive to derive the temperature change from the net change in heating rate shown in the figure. What causes the cooling below 900mb and the warning above 200mb?"

- The cooling below 900 hPa is from a cooling anomaly on the surface. The upper-level warming above is hard to understand because it cannot be directly linked to any heating rates of physical processes.

"11) P32901, second paragraph and Table 3: what does the indirect effect under clear sky mean?"

- "IE" defined in table 3 is the difference between HighInd and ZeroInd experiments. So the 'IE' includes not only aerosol indirect effect, but also associated feedbacks. We include the clear sky fluxes to calculate CRE changes in "IE"

"12) P32902, L1: this sentence needs revision."

- We have revisited the sentence and revised it for clarity.

"13) P32902, L17: "due to enhanced BBA activation" is inaccurate here. It's simply due to the presence of additional BB aerosols."

- Revised as suggested.

Reference

Petrenko, M., Kahn, R., Chin, M., Soja, A., Kucsera, T., and Harshvardhan: The use of satellite-measured aerosol optical depth to constrain biomass burning emissions source strength in the global model GOCART, Journal of Geophysical Research-Atmospheres, 117, doi:10.1029/2012JD017870, 2012.