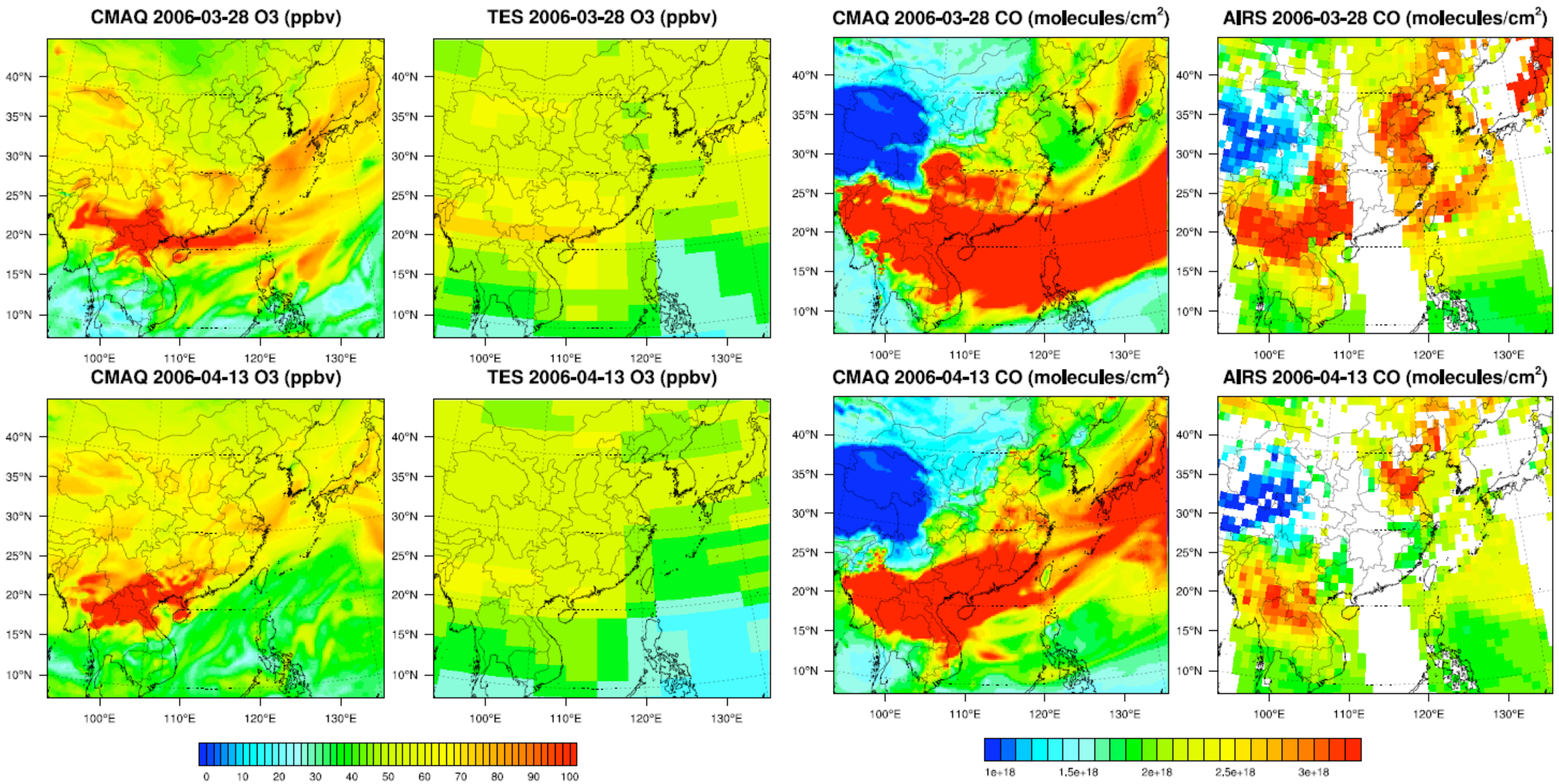
Response to the comment by Anonymous Referee #1

The authors studied the influence of biomass burning on regional air quality using CMAQ. I have mixed feelings about this paper. Although this paper has some interesting sections, such as the comparison of the FLAMBE and GFED emission inventory, this study needs extensive sensitivity studies and validation efforts (e.g., as suggested below) before the community can take the results of the study seriously.

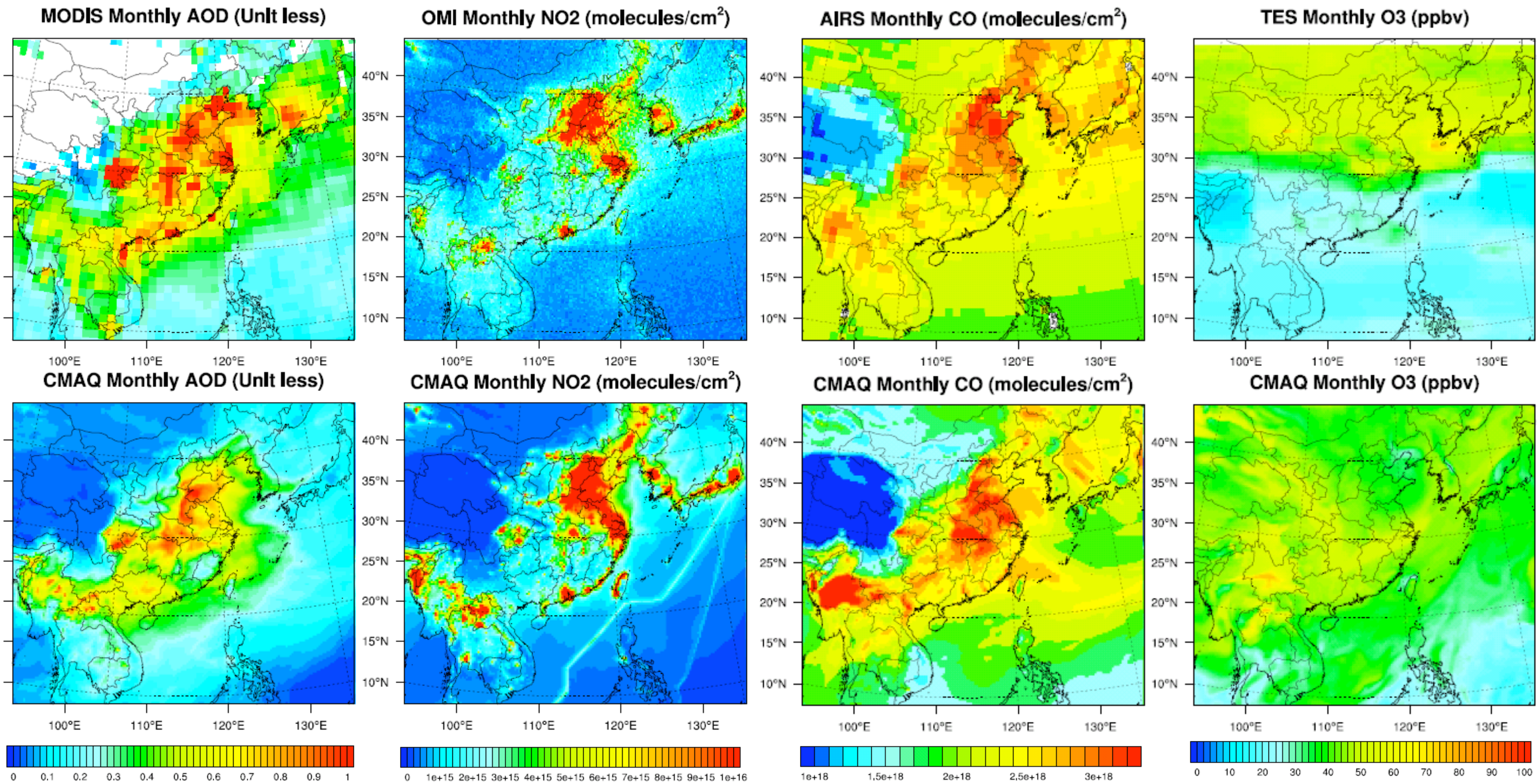
We thank the reviewer for a thorough comment on this manuscript. In the revised manuscript, we made those corresponding corrections and responses in the following the comments.

(1) The authors showed comparisons of modeled and satellite NO2 and AOD. Although satellite CO and O3 retrievals are also available, I wonder why the authors didn't include these data in their analysis. Comparisons of modeled and satellite CO and O3 need to be included in the analysis. Also monthly mean O3, CO, NO2, and AOD plots from both satellite and modeled data are needed as a part of the validation efforts.

We now added more comparison between the model results and satellite observation as the reviewer suggested. For the two intense episodes (i.e, March 28 and April 13), we added comparison between CMAQ modeled CO and AIRS (Atmospheric Infrared Sounder) measured CO, and also comparison between CMAQ modeled O_3 and TES (Tropospheric Emission Spectrometer) measured CO at around 820hPa. As shown in the figure below, satellite detected higher signals of O_3 and CO over the Southeast Asia region, especially over Burma, Northern Thailand, Vietnam and Southern China. Compared to observation, the model simulated stronger signals and overestimated around 20~50% over the most intense fire regions. In addition, the model predicted a more obvious transport pattern from the source region to over the Western Pacific, which is relatively weak from satellite. In other parts of the study domain, the model could relatively simulate well. The great uncertainty of biomass burning emission should be the major reason for the difficulty in modeling CO and O_3 over source fire regions.


CMAQ 2006-03-28 O3 (ppbv)
TES 2006-03-28 O3 (ppbv)
CMAQ 2006-03-28 CO (molecules/cm2)
AIRS 2006-03-28 CO (molecules/cm2)
CMAQ 2006-04-13 O3 (ppbv)
TES 2006-04-13 O3 (ppbv)
CMAQ 2006-04-13 CO (molecules/cm2)
AIRS 2006-04-13 CO (molecules/cm2)
0 10 20 30 40 50 60 70 80 90 100
1e+18 1.5e+18 2e+18 2.5e+18 3e+18

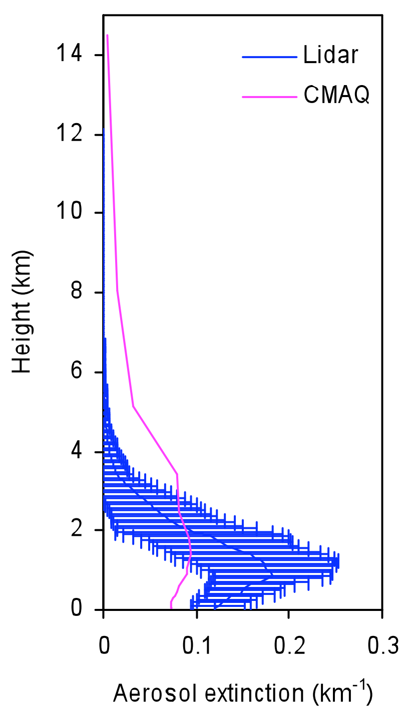
The monthly mean O_3, CO, NO_2, and AOD plots from both satellite and modeled data are presented as below. Generally, the model could well capture the spatial distribution of most species on the monthly basis. For AOD, the model slightly overestimated in the northern part of Southeast Asia, e.g, Burma, Laos, while underestimated in the southern part of Southeast Asia, mostly in Thailand. Correspondingly, the similar situation could be found in the monthly CO concentrations. In Burma, obvious overestimation was simulated. The model performance of NO_2 was the best among the four species simulated above. The model performed very well in mainland China and simulated very consistent spatial distribution to the hot spots in Northern, Eastern China, and the Pearl River Delta region. There were some overestimations of NO_2 over some limited regions in Southeast Asia. The relatively good model performance of NO_2 concentrations was probably due to that its emission factor from biomass burning was relatively low compared to the anthropogenic sources. The simulation of O_3 performed relatively well above 30N, however, it overestimated below it, especially in Southeast Asia and Southern China. The overestimation could reach about 10 ~ 20 ppbv. We suspected that the local biomass burning emission should be responsible for this.



MODIS Monthly AOD (Unit less)
OMI Monthly NO2 (molecules/cm2)
AIRS Monthly CO (molecules/cm2)
TES Monthly O3 (ppbv)
CMAQ Monthly AOD (Unit less)
CMAQ Monthly NO2 (molecules/cm2)
CMAQ Monthly CO (molecules/cm2)
CMAQ Monthly O3 (ppbv)
10°N 15°N 20°N 25°N 30°N 35°N 40°N
100°E 110°E 120°E 130°E
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
0 1e+15 2e+15 3e+15 4e+15 5e+15 6e+15 7e+15 8e+15 9e+15 1e+16
1e+18 1.5e+18 2e+18 2.5e+18 3e+18
0 10 20 30 40 50 60 70 80 90 100

(2) The authors showed vertical distributions of CO, O3 and PM2.5. However, without validating/comparing their results with observations, such study brings little value to the community. I would recommend that the authors at least show comparisons with CALIOP data.

Thanks for the suggestion of adding vertical comparison. During the BASE-Asia field campaign, NASA operated a Micro-Pulse Lidar (MPL) in Phimai, which provided vertical distribution of aerosol. The figure below shows the comparison between measured and modeled aerosol extinction coefficient (km^{-1}). The modeled aerosol extinctions were converted from the same IMPROVE algorithm as used in the other parts of this study at each layer (total 19 layers). As shown in the figure, the model could generally capture the aerosol vertical distribution. Both lidar and model presented a decreasing trend of aerosol extinction coefficient from the ground to the high altitudes. However, there was underestimation below the PBL (i.e, around 2km), which could be due to underestimation of local anthropogenic emission near the ground. Some overestimation was observed at higher altitudes, which could be due to the problem of the allocation method of biomass burning emission. Generally, the vertical distribution of aerosol was reasonably well simulated, implying that the modeled vertical results could be further utilized.



(3) In table 3, the authors showed the model evaluation of CO, O3, and PM2.5 using observations from Hong Kong and Taiwan. The authors need to include some kind of estimates of statistical significance or, at least, the authors should include the number of data samples used in the analysis.

We added the numbers of observational data available for model evaluation for each species and added more statistical analysis. The index of agreement (IOA) is calculated as below:

$$\text{IOA} = 1 - \frac{\sum_{i=1}^{N}(C_m - C_o)^2}{\sum_{i=1}^{N}(|C_m - \overline{C_o}| + |C_o - \overline{C_o}|)^2}$$

Where C_m, C_o, and $\overline{C_o}$ is the modeled, observed and average observed result, respectively. A value of 1.0 indicates perfect agreement between predicted and observed results.

Factor 2 analysis is used to check whether the air quality model results are acceptable. Factor 2 calculates the percentages of the ratios of model value to observational value that lie between 0.5 and 2.It is calculated as

R = $\frac{N_{[0.5,2]}}{N_t}$, where R is the percentage of the ratios between 0.5 and 2; $N_{[0.5,2]}$ is the number of the ratios between 0.5 and 2; and N_t is the total number of comparison points.

The table below summarizes the statistics for model performance. For CO, O_3, and $PM_{2.5}$, IOA are all higher than 0.6, indicating reliable model performance. Factor 2 analysis indicated that model values of CO and O_3 had over 60% fraction lie between 0.5 to 2.0 fold of the measurement data. For $PM_{2.5}$, the Factor 2 analysis shows lower values, indicating PM was more difficult to predict compared to gaseous species.

	Hong Kong				Taiwan				AERONET			
	CO	O_3_40[1]	O_3_60[2]	$PM_{2.5}$	CO	O_3_40[1]	O_3_60[2]	$PM_{2.5}$	Phimai	Mukdahan	HK_Poly	TW_ChengKung
No.[3]	6346	404	50	8733	2180	1268	179	2148	64	70	26	80
MNB	-0.18	0.02	-0.09	0.02	0.41	0.23	-0.03	-0.09	-0.39	-0.31	0.58	0.60
MNE	0.35	0.29	0.23	0.55	0.59	0.39	0.37	0.79	0.46	0.39	0.74	0.76
MFB	-0.28	-0.05	-0.15	-0.22	0.19	0.13	-0.14	-0.55	-0.61	-0.48	0.31	0.31
MFE	0.40	0.31	0.27	0.57	0.41	0.33	0.38	0.86	0.67	0.55	0.50	0.53
IOA[4]	0.63	0.89	0.84	0.73	0.70	0.76	0.86	0.66	0.64	0.48	0.60	0.58
F2[5]	0.69	0.83	0.64	0.59	0.82	0.98	0.91	0.43	0.56	0.61	0.69	0.70

[1] a cutoff value of 40 ppbv is set.

[2] a cutoff value of 60 ppbv is set.

[3] Number of the observation data available for model evaluation

[4] Index of aggrement, see **Apprendix A** for definition

[5] Factor 2, see **Apprendix A** for definition

(4) Besides emission inventory, how would other parameters affect the results? The authors should show a sensitivity study of various factors on their study, such as the wet/dry deposition. In fact, a comprehensive sensitivity study is necessary before the users can gain a better appreciation of their study.

Yes, we agree with the reviewer that more sensitivity studies should be conducted. However, the main scope of this study doesn't focus on the sensitivity runs about different scenarios. We still think that biomass burning emission is the most influential factor on air quality in Southeast Asia as biomass burning emission in this area is really uncertain. At this stage, there needs substantial computation time to conduct comprehensive sensitivity runs for the regional model. Also, we don't have enough observation data, especially the ground data. Thus it is difficult to find out which sensitivity run gives the best result. That's the reason that we don't conduct many sensitivity runs and we hope that the reviewer could understand this.

(5) The authors used an empirical method to convert CMAQ aerosol concentrations to AOD. What is the wavelength of their AOD estimates? I am surprised that fixed mass extinction efficiency values were used because such values vary with wavelength. Also, the authors need to do a literature review and use recent estimates of mass extinction efficiencies from publications.

The AOD values estimated from CMAQ by using the empirical method are calculated for the wavelength of 550 nm. We didn't use fixed mass extinction efficiency for all the wavelengths but only for 550 nm as the MODIS products used in this study are all at the wavelength of 550 nm. We agree with the reviewer that more recent mass extinction efficiencies should be better used. However, on the one hand, mass extinction efficiencies measured in Southeast Asia have never been reported to our best knowledge. On the other hand, the empirical method used in this study (i.e, cited from Malm et al., 1994) has been widely used and validated in estimating AOD by using CMAQ in (Daniela et al., 2009; Park et al., 2011; Roy et al., 2007). Thus, we tended to choose the method that has been validated to have reasonable consistence with various observational datasets.

References:

Daniela Viviana Vladutescu, Erika Garofalo, Barry Gross, Fred Moshary, Samir Ahmed, 2009. CMAQ validation of optical parameters and PM2.5 based on lidar and sky radiometers. A sensitivity study of optical parameters to hygroscopic aerosols. Lidar Remote Sensing for Environmental Monitoring X, edited by Upendra N. Singh, Proc. of SPIE Vol. 7460, 74600H. doi: 10.1117/12.826248.

R. S. Park, C. H. Song, K. M. Han, M. E. Park, S.-S. Lee, S.-B. Kim, and A. Shimizu, 2011. A study on the aerosol optical properties over East Asia using a combination of CMAQ-simulated aerosol optical properties and remote-sensing data via a data assimilation technique. Atmos. Chem. Phys., 11, 12275–12296, doi:10.5194/acp-11-12275-2011.

Roy, B., R. Mathur, A. B. Gilliland, and S. C. Howard, 2007. A comparison of CMAQ-based aerosol properties with IMPROVE, MODIS, and AERONET data, J. Geophys. Res., 112, D14301, doi:10.1029/2006JD008085.

(6) The authors compared modeled PM2.5 values with ground observations from Hong Kong and Taiwan. What about AOD? I believe there are several AERONET sites available within the study region.

We now have added the comparison between modeled AOD and AERONET measured AOD as the reviewer suggested. In this study period, four AERONET sites with enough data are used to compare with the modeled AOD. Two of them are located in Thailand (i.e, Phimai and Mukdahan), and the other two are located in Hong Kong (HK_Poly) and Taiwan (TW_ChengKung), respectively. We evaluated the model performance of AOD by using statistics of MNB, MNE, MFB, MFE, IOA and Factor 2. The results are shown in the table of Question (3). At the two sites of Thailand, AOD were underestimated. Lower local anthropogenic emissions or biomass burning emission were probably responsible for this. Model over-predicted AOD at downwind regions. IOA analysis shows moderate model performance at Mukdahan and relatively good performances at other sites. Factor 2 analysis shows that most of the simulated results lie in the vicinity of observational data.

Other comments:

(1) Page 32209, line 1, I could not find Zhang, 2008 in the reference list.

We have now added the missing reference: "Zhang, Y.: Online-coupled meteorology and chemistry models: history, current status, and outlook, Atmos. Chem. Phys., 8, 2895-2932, doi:10.5194/acp-8-2895-2008, 2008.". Thanks for pointing out this mistake.

(2) Page 32211, line 28, "ef" should be "EF".

Yes, we corrected this mistake in the revised manuscript.

(3) Page 32214, line 13-14. There are two MODIS AOD products available. Which product do the authors refer to here?

We used the Level 2 Collection 5 AOD product in this study. We have now made it more clear in the revised manuscript.

(4) Page 32239, line 3, "and at 550nm" should be "at 550 nm"

Thanks for pointing out this mistake. We have corrected it.