Response to Referee #1

General Comments:

This study diagnoses uncertainties in global biomass burning emission inventories and discusses the causes of large biases. In this study, the authors compared gas- and particulate-phase emissions from four biomass burning emission inventories established by bottom-up and top-down approaches. The authors quantified the contribution of different factors to the uncertainty in biomass burning emissions and proposed that dry matter was the main cause of regional bias in CO emission estimates. Vegetation classification methods and fire detection products led to the uncertainties in bottom fuel consumption and burned area calculations, resulted in biases in dry matter. They reported that the variability of particulate-phase emission was even higher than that of gas-phase emission. In addition, they compared the simulated results with satellite measurements, and given certain inventory recommendations based on different study areas and spatiotemporal scales. This study is well written and well organized, and could support improvements in biomass burning emission inventories in further studies. I recommend accepting it after minor revisions.

Response:

We thank the reviewer for the positive comments. We have revised the manuscript carefully according to the reviewer's suggestions.

Specific Comments:

1. The second paragraph beginning with “Recent studies” can be combined with the third paragraph beginning with “Previous studies”.

Response:

Thank you for your suggestion. We have revised the sentence as follows: “Previous studies often found that there is a significant deviation between the gaseous or particulate pollutants simulated by the model and the satellite retrieval value (Bian et al., 2007; Chen et al., 2009; Carter et al., 2020), one of the most important reasons comes from the uncertainties in emission inventories.” Please find in lines 62-65.

2. Section 2. The description of Biomass Burning emission inventories and Quantitative statistical methods can be shortening. Some details can be moved to supplementary information.

Response:

Thank you for your helpful suggestion. We have shortened section 2.1, which introduces the biomass burning emission inventories. Details have been relocated to the supplementary information. For specific changes, please refer to the tracked changes in section 2 of the manuscript.

3. Line 545-561. There is a little bit of confusion about this paragraph. The authors said, "The total QFED FRP is 1.5 times higher than VFEI0, but DM in QFED2.5 inventory is 30% lower than VFEI0", and also said: "Therefore, although the two top-down emission inventories use similar algorithms, significant bias occurs under high cloud fraction conditions, with QFED2.5 estimating DM much higher than VFEI0". So, does the low DM in the QFED2.5 mainly occur under low or medium cloud fraction? Could the authors give some specific values?

Response:

Apologies for the confusion. Upon reevaluation of the data, we observed that the DM in QFED2.5 inventory is consistently lower than that in VFEI0, with a significant bias occurring under high cloud fraction conditions. We have revised the paragraph for clarity as follows:

"The estimations of FRP and DM are strongly influenced by the horizontal resolution of satellite products. For example, in the BONA region during July (the month with the most intense burning at the position of 50°-70°N, 100°-130°W), the total QFED FRP (average FRP measured by MOD and MYD) is 1.5 times higher than VFEI0 (Fig. S7). Additionally, the differing α values between QFED2.5 and VFEI0 in BONA can potentially result in higher DM in QFED2.5 compared to VFEI0 by a factor of 1.3-3.8. However, the actual DM in the QFED2.5 inventory is 30% lower than in VFEI0. The relatively high FRP density used in VFEI0 (Fig. S8) results in a higher DM than in QFED2.5 due to its superior horizontal resolution, enabling the precise delineation of fire areas. It is important to note that while the empirical factor also influences the amount of DM, its impact should not be as significant as the difference caused by the horizontal resolution of satellite products (Kaiser et al., 2012; Darmenov et al., 2015; Ferrada et al. 2022)."

Please refer to lines 496-506 for the specific details.

4. Figure 2 showed that FINN1.5 estimated much larger CO emissions than other emission inventories in EQAS. The authors also selected the EQAS as one of the important biomass burning regions based on the fact that "(1) regional BB CO emissions above 20Tg/yr, (2) BB CO emissions account for more than 70% of the total". However, table 3 shows similar CO column averages across the four BB emission inventories. Could the authors also

explain why? Additionally, it is important to show simulated near-surface/different vertical layer CO concentrations.

Response:

Thank you for the comment. Various vertical layers of CO concentrations have been added to Table R1. While a substantial bias exists among BB emissions (~30%), influencing surface-layer CO concentrations, these differences decrease with altitude. For example, the ratio of maximum to minimum CO values at the 900 hPa level is 1.18, decreasing to 1.07 at the 200 hPa level. Our results are consistent with Bian et al (2007).

Table R1. Comparison of CESM-CAM6 simulated CO column averages and satellite retrieved CO mixing ratio averages (units:ppbv) in EQAS during the fire season

Layer	Satellite	CESM2-CAM6			
	MOPITT	FINN1.5	GFED4s	QFED2.5	VFEI0
100hPa	49.19	47.53	48.96	46.58	46.83
200hPa	66.20	68.22	72.09	67.07	67.58
300hPa	64.29	69.62	74.27	68.51	69.06
400hPa	65.65	70.76	76.58	69.56	70.18
500hPa	68.58	70.24	77.25	68.98	69.67
600hPa	74.14	67.54	75.00	66.56	67.23
700hPa	75.10	67.21	77.89	66.24	66.91
800hPa	75.44	70.91	85.49	69.62	70.51
900hPa	86.42	75.37	89.32	74.83	75.79

5. Line 660-665. Is there any reference to support the conclusion that the overestimation of SOA in South Hemispheric South America is due to biogenic sources?

Response:

Thank you for your important comment. He et al. (2015) used CESM/CAM5 and reported that 75% of secondary organic aerosol in South Asia originates from biogenic sources. Tilmes et al. (2019), using CESM2, further reported that biogenic emissions contribute to at least two-thirds of the total SOA burden. Additionally, Jo et al. (2023) suggest a higher SOA concentration than other aerosols in South America across all vertical levels. Thus, the overestimation of SOA in the South Hemisphere is attributed to biogenic sources.

We have included the related references in Line 613.

References:

Bian, H., Chin, M., Kawa, S., Duncan, B., Arellano, A., and Kasibhatla, P.: Sensitivity of global CO simulations to uncertainties in biomass burning sources, Journal of Geophysical Research: Atmospheres, 112, 2007.

Carter, T. S., Heald, C. L., Jimenez, J. L., Campuzano-Jost, P., Kondo, Y., Moteki, N., Schwarz, J. P., Wiedinmyer, C., Darmenov, A. S., and da Silva, A. M.: How emissions uncertainty influences the distribution and radiative impacts of smoke from fires in North America, Atmospheric Chemistry and Physics, 20, 2073-2097, 2020.

Chen, Y., Li, Q., Randerson, J., Lyons, E., Kahn, R., Nelson, D., and Diner, D.: The sensitivity of CO and aerosol transport to the temporal and vertical distribution of North American boreal fire emissions, Atmospheric Chemistry and Physics, 9, 6559-6580, 2009.

Darmenov, A., da Silvia, A., and Koster, R.: The Quick Fire Emissions Dataset (QFED): Documentation of Versions 2.1, 2.2 and 2.4. Volume 38; Technical Report Series on Global Modeling and Data Assimilation, 2015.

Ferrada, G. A., Zhou, M., Wang, J., Lyapustin, A., Wang, Y., Freitas, S. R., and Carmichael, G. R.: Introducing the VIIRS-based Fire Emission Inventory version 0 (VFEIv0), Geoscientific Model Development, 15, 8085-8109, 2022.

He, J., Zhang, Y., Tilmes, S., Emmons, L., Lamarque, J.-F., Glotfelty, T., Hodzic, A., and Vitt, F.: CESM/CAM5 improvement and application: comparison and evaluation of updated CB05_GE and MOZART-4 gas-phase mechanisms and associated impacts on global air quality and climate, Geoscientific Model Development, 8, 3999-4025, 2015.

Jo, D. S., Tilmes, S., Emmons, L. K., Wang, S., & Vitt, F. : A New Simplified Parameterization of Secondary Organic Aerosol in the Community Earth System Model Version 2 (CESM2; CAM6. 3), Geoscientific Model Development Discussions, 1-24, 2023.

Kaiser, J., Heil, A., Andreae, M., Benedetti, A., Chubarova, N., Jones, L., Morcrette, J.-J., Razinger, M., Schultz, M., and Suttie, M.: Biomass burning emissions estimated with a global fire assimilation system based on observed fire radiative power, Biogeosciences, 9, 527-554, 2012.

Tilmes, S., Hodzic, A., Emmons, L., Mills, M., Gettelman, A., Kinnison, D. E., Park, M., Lamarque, J. F., Vitt, F., and Shrivastava, M.: Climate forcing and trends of organic aerosols in the Community Earth System Model (CESM2), Journal of Advances in Modeling Earth Systems, 11, 4323-4351, 2019.

Response to Referee #2

General Comments:

This study mainly focused on investigating the differences among widely adopted emission inventories of biomass burning and revealing the main reasons. It is a necessary work for improving the emission inventories in the future. The manuscript can be accepted after the following questions addressed.

Response:

We thank the reviewer for the very helpful comments. We have revised the manuscript carefully according to the reviewer's suggestions.

Specific Comments:

1. The abstract should be shorted and refined.

Response:

Thanks for the helpful suggestion. We have shortened the abstract, which is now only 381 words.

2. Line 41: we give certain inventory recommendations based on different study areas and spatiotemporal scales. What are your certain recommendations for the global emission inventory? Please briefly describe in abstract, which is important to help readers find the key points of the paper.

Response:

Thanks for the helpful suggestion. We added following sentences in the abstract: "In the high latitudes of the Northern Hemisphere, using GFED4s and QFED2.5 can better capture the AOD magnitude and diurnal variation. In equatorial Asia, GFED4s outperform AErosol RObotic NETwork others in representing day-to-day changes, particularly during intense burning. In Southeast Asia, we recommend using the OC emission magnitude from FINN1.5 combined with daily variability from QFED2.5. In the Southern Hemisphere, the latest VFEI0 has performed relatively well."

For specific changes, please refer to the tracked changes in the manuscript.

3. The introduction should be re-written again. The authors listed so many literatures, while they do not better summarize them. At the end of each *paragraph, the main contents or research shortages should be given. Line 123-150 is not necessary to give these equations in the introduction. Line 181-190, wordy sentences.*

Response:

Thank you for your valuable feedback. We have thoroughly revised the introduction, addressing your suggestions, which include removing equations and shortening the section. For specific changes, please refer to the tracked changes in the manuscript.

4. The calculation of DM (Line 411-419), FC (Line 508-510), EF (567-569) may not be included in part 3. This is the introduction of methods, instead of the analysis of emission inventories.

Response:

Thank you for your kindly reminder. We have relocated these calculations to section 2.2. For specific changes, please refer to the tracked changes in the manuscript.

5. Line 550-553: How empirical factor affect the amount of DM? It is also an important factor with uncertainty.

Response:

In a top-down approach, the fire radiative powers are integrated over time to obtain fire radiative energy, which is then converted to dry matter (DM) using an empirical coefficient α. QFED2.5 uses MODIS Collection 6 MOD14/MYD14 level 2 products for estimating fire radiative power. The initial value of α in QFED2.5 is derived from Kaiser et al. (2009) and is adjusted monthly based on global emissions of GFED2 in 2003–2007, resulting in two sets of empirical coefficients: αMOD14 = 1.89 × 10-6 kg (DM) J^{-1} and αMYD14 = 0.644 × 10-6 kg (DM) J^{-1} (Kaiser et al., 2012; Darmenov et al., 2015). In contrast, the empirical coefficient used in VFEI0 is derived from the linear regression of GFED3.1DM and VIIRS FRP. In the Boreal North America (BONA) region, dominated by extratropical forest, the α value in VFEI0 is approximately 0.49×10-6 kg (DM) J^{-1} (Ferrada et al., 2022).

Therefore, the differing α values between QFED2.5 and VFEI0 in BONA can result in higher DM in QFED2.5 compared to VFEI0 by a factor of 1.3-3.8. However, Figure. S8 shows that the DM in VFEI0 is considerably higher than that in QFED2.5. According to our calculations, DM in the QFED2.5 inventory is 30% lower than in VFEI0. The FRP density used in VFEI0 leads to higher DM than in QFED2.5 due to its superior horizontal resolution, enabling more precise delineation fire areas. It's important to note that although the empirical factor also influences the amount of DM, but its impact should not be as significant as the difference caused by the horizontal resolution of satellite products.

We have revised this paragraph in Lines 496-506.

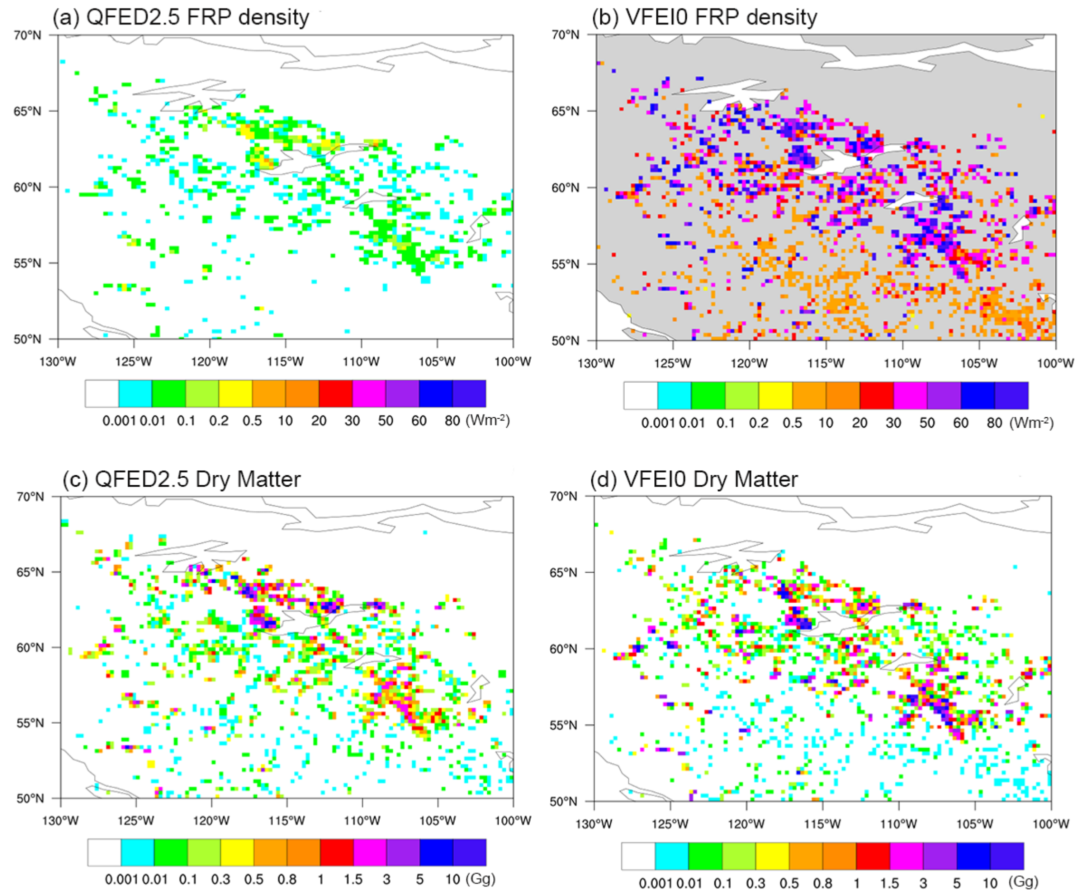

Figure S8. (a-b) Distribution of FRP density and (c-d) final DM in QFED2.5 and VFEI0 in the region shown in Figs. 5 during each July from 2013 to 2016.

6. The uncertainty of emission inventories was impacted by a combination of those factors (EF, DM). Monte Carlo simulations were usually performed in articles to evaluate the estimation uncertainty quantitatively for pollutant emissions. So those combined uncertainty results of the emission inventories in different regions can be compared, which may be associated to the regional applicability of BB emission inventories.

Response:

Thank you for the suggestion. Typically, Monte Carlo simulations are employed by researchers when creating an inventory and dealing with the distribution of EF and DM that initial possess uncertainty. These simulations use algorithms to generate stochastic values based on the Probability Density Function (PDF) of the data. Commonly, PDFs are represented as normal, lognormal, triangular, and uniform distributions.

However, in our study, the EFs used in the four emission inventories follow previous studies listed in Table 1. Additionally, for each biome, the EF values among the four inventories exhibit similarity. Furthermore, DM in this study is calculated by dividing the emissions of each species by the EF. Consequently, as we lack a reasonable PDF distribution for EF and DM with initial uncertainty, it becomes challenging to calculate the uncertainty in emission inventories using Monte Carlo simulations.

Our study aims to elucidate the variation in EF and DM across four emission inventories in each region. This includes examining how differences in vegetation classification affect EF and DM, and how DM is affected by the sensitivity of different satellite products to cloud obscuration.

Conclusion：wordy sentences. Line 715-720, we all know these, and they are not your conclusions or new findings.

Response:

Thank you for the suggestion. We have deleted these sentences.

From Figure.1 to Figure. 7, all the datasets are from the literatures or former studies. These should not be the main contents of this study. The modeling works, especially for the comparison between the modeling results, the bias and the reasons should be emphasized.

Response:

Thank you for this important comment. We have shortened the conclusion section that describes from Figure 1 to Figure 7. Please find the revised paragraph in Lines 663-693.

Table 1, all the emission factors adopted in the four emission inventories can not reflect the real emission situation. Can the author optimize the emission factors with your modeling works? I think it will contribute more to science, but not just compare the values.

Response:

Thank you for the important suggestions. Emission factors quantify the grams of trace gases and aerosols emitted per kilogram of biomass burned. We agree that the emission factors will significantly contribute to the BB emissions. Table 2 in our study displays the differences in EFs among these four emission inventories. However, actual emission factors also vary widely depending on the different state of combustion (Pokhrel et al., 2021). Pokhrel et al. (2021) reported a positive correlation between EF of a specific species and the modified combustion efficiency (which describes the combustion state of fires, with an MCE>0.92 indicating predominantly flaming combustion). We have another study focusing on the impact of combustion efficiency on the BB emission factors.

We have added following sentences in conclusion and discussion: "It is worth noting that emission factors (as listed in Table 2) significantly contribute to the differences in BB emissions. However, actual emission factors vary widely depending on the different state of combustion (Pokhrel et al., 2021). Further study is needed to understand the impact of combustion efficiency on the BB EFs and optimize them."

References:

Darmenov, A., da Silvia, A., and Koster, R.: The Quick Fire Emissions Dataset (QFED): Documentation of Versions 2.1, 2.2 and 2.4. Volume 38; Technical Report Series on Global Modeling and Data Assimilation, 2015.

Ferrada, G. A., Zhou, M., Wang, J., Lyapustin, A., Wang, Y., Freitas, S. R., and Carmichael, G. R.: Introducing the VIIRS-based Fire Emission Inventory version 0 (VFEIv0), Geoscientific Model Development, 15, 8085-8109, 2022.

Kaiser, J., Flemming, J., Schultz, M., Suttie, M., and Wooster, M.: The MACC global fire assimilation system: First emission products (GFASv0), Tech. Memo. 596, ECMWF, Reading, UK, 2009.

Kaiser, J., Heil, A., Andreae, M., Benedetti, A., Chubarova, N., Jones, L., Morcrette, J.-J., Razinger, M., Schultz, M., and Suttie, M.: Biomass burning emissions estimated with a global fire assimilation system based on observed fire radiative power, Biogeosciences, 9, 527-554, 2012.

Pokhrel, R. P., Gordon, J., Fiddler, M. N., Bililign, S.: Impact of combustion conditions on physical and morphological properties of biomass burning aerosol, Aerosol Science and Technology, 55(1), 80-91, 2021.