We sincerely appreciate the detailed feedback you provided on our manuscript, which greatly assisted us in our research endeavors. We have addressed the rationale for choosing March 2019 as the study period by adding additional information, including citations and the data in Figure 1, to better emphasize the importance of this choice. We have explained in detail that the BB emissions inventory provides aerosol types and how the model handles inorganic aerosols to satisfy your questions about aerosols. In addition, we add in the discussion section that insufficient inversion of the BB emissions inventory can lead to uncertainties. Regarding the comparison with satellite products, we clarified that the purpose of this comparison is to help evaluate the accuracy and performance of the model, especially under different BB emission inventories. At the same time, we emphasize our main focus on the differences in aerosol mass concentrations and their spatial and temporal distributions in the PSEA region for the different emission inventories, as well as the use of the WRF-Chem model with the same model configuration to assess aerosol optical properties and radiative forcing during BB in the PSEA region. A detailed line-by-line response is provided below.

<mark>Main comments</mark>

(1)To further emphasize why the month that was used for the simulations as it was one line in the introduction that may be lost, it would be good in Fig. 1 (or another figure), to show the total fire counts in Peninsular Southeast Asia.
Response:
1. We have accepted the reviewer's suggestions and added the spatial distribution characteristics of the MODIS inversion fire points in March 2019 to Figure 1(b), as well as a histogram showing the total number of fire points for each month in 2019 in Figure 1(c). This will help to further emphasize the importance of the period used in the simulation.
2. Regarding the reviewer's inquiry about the rationale for selecting March 2019 as the study period, we have incorporated pertinent information in the manuscript.
1)Lines 83-86. " Wiedinmyer et al. (2023) have shown that the seasonal cycle (averaged over 2012-2019) of CO emissions from BB in various regions of the world and the latest version of FINN v2.5 (MODIS+ VIIRS) has an emission peak in March, primarily driven by emissions from the PSEA. However, this peak is absent in GFED and is less pronounced in other emission inventories (FINN1.5, FEER, GFAS, QFED) " Therefore, it is imperative to determine the causes of emissions from different fire sources in mainland Southeast Asia in March.
2)Lines 95-103. "The World Meteorological Organization's report highlights that the early part of 2019 corresponds to the El Niño cycle (from April to May, the temperature of waters beneath the surface of the tropical Pacific has notably declined) (Organization, 2019), during which meteorological conditions are more favourable for the occurrence and propagation of BB (Cochrane, 2009). Additionally, Yin (2020) discovered that over the past 18 years (2001-2018), the PSEA region predominantly experienced the peak of BB activity in March each year. Fan et al. (2023) and Duc et al. (2021) confirmed that the PSEA suffered severe air quality impacts during the BB in March 2019. Therefore, centered on the period of March 2019, this study aims to analyze how emission uncertainties or differences from different BB inventories affect the spatial and temporal distribution of aerosols and their radiative effects in the PSEA region."

(2)How does the model treat the inorganic aerosol? E.g., it is not clear if the inorganic aerosol

is treated thermodynamically or not. This is important to better understand how the model may be treating aerosol liquid water, aerosol acidity, etc., which all impact the physicochemical properties of the aerosol and thus the aerosols' optical properties.

Response:

In this study, we use the WRF-Chem model to treat inorganic aerosols through the Model for Simulating Aerosol Interactions and Chemistry (MOSAIC) mechanism. The MOSAIC mechanism has been designed with a highly modular structure to facilitate seamless coupling between various chemical and microphysical processes. The current version of the model incorporates several key features and modules, including the treatment of inorganic aerosols. The following are the key aspects related to the treatment of inorganic aerosols in the model:

1. MOSAIC explicitly addresses various important inorganic aerosol species that are significant at urban, regional, and global scales (Zaveri et al., 2008). These species encompass sulfate, methanesulfonate, nitrate, chloride, carbonate, ammonium, sodium, calcium, black carbon (BC), primary organic mass (OC), and liquid water. Unspecified inorganic species such as silica, other inert minerals, and trace metals are grouped together as 'other inorganic mass' (OIN). The model also accounts for the gas-phase species that can partition to the particle phase, which includes H_2SO_4, HNO_3, HCl, NH_3, and MSA (methanesulfonic acid). Work is ongoing to include the treatment of secondary organic aerosols (SOA).

2. The MOSAIC model incorporates a thermodynamic module that enables the accurate prediction of particle deliquescence, water content, and solid-liquid phase equilibrium in multicomponent aerosols at specific relative humidity (RH) and temperature (T) conditions. This module is crucial for computing the mass transfer driving forces for dynamic gas-particle partitioning of various semivolatile species. The thermodynamic module is specially designed to be both accurate and computationally efficient for 3-D modeling applications.

In summary, the MOSAIC mechanism in the WRF-Chem model treats inorganic aerosols through a thermodynamic approach, explicitly considering several important inorganic species. It also accurately accounts for phase equilibria and deliquescence, which are crucial for understanding aerosol liquid water content, aerosol acidity, and their impact on aerosol physicochemical and optical properties. The comprehensive treatment of inorganic aerosols in the model ensures its reliability and applicability across various scales and applications. Many scholars have already used this mechanism to simulate aerosol optical properties (AOPs) during the BB period, and they have obtained reliable research results (Palacios-Peña et al., 2018; Archer-Nicholls et al., 2015; Wu et al., 2017). Therefore, modifications were made in the manuscript from line 127 to line 128 (<u>other inorganic aerosols through a thermodynamic approach, with high efficiency and accuracy for use in air quality and regional/global aerosol modeling (Zhang et al., 2018).</u>).

(3) As the results are presented, it is currently not clear what the purpose of the satellite products comparisons with the model results provides for the conclusions. E.g., the authors discuss how different emission inventories provide different agreement depending on the satellite product and/or land-based product, which indicates no emission inventory is superior. Further, the authors have not provided or discussed the following properties that would be

potentially of more interest/importance in understanding the aerosol from biomass burning to compare with observations and products:

Response:

1. This study aims to analyze the differences in mass concentration and spatial-temporal distribution of pollutants in different BB emission inventories, and how their incorporation into WRF-Chem affects regional air quality, the spatiotemporal distribution of aerosols, and aerosol radiative effects in the PSEA region. Our focus is not on analyzing the micro-level differences in BB emission inventories from the bottom up (such as classification of organic and inorganic aerosols, aerosol size, oxidation, etc.) and selecting aerosol mechanisms for models. Instead, we have compiled and analyzed eight BB emission inventories to provide the necessary scientific basis for other scholars to simulate AOPs and radiation forcing in the PSEA region based on BB emission inventories. Specifically, these emission inventories share identical model configurations, including meteorological initial and boundary conditions, gas-phase chemistry, and aerosol mechanisms, as well as the same geographical region and study period. Through this design, our research contributes to revealing differences and uncertainties among different BB emission inventories, particularly concerning the PSEA region. We aim to understand how different inventories capture BB emissions and their effects on aerosol and gas emissions. Additionally, the paper also focuses on AOPs, such as aerosol optical depth (AOD), absorbing aerosol optical depth (AAOD), and aerosol extinction coefficient (AEC). Furthermore, it analyzes the impact of different BB emission inventories on direct radiative forcing (DRF), aiming to assess their impact on atmospheric radiation balance and better understand the impact of aerosols on climate. Our results suggest that FINN1.5 and IS4FIRES are recommended for accurately assessing the impact of BB on air quality and climate in the PSEA region.

2. Satellite remote sensing products can provide reliable observational data over a large area compared to ground stations, which has advantages for studying the large-scale impact of BB. In addition, the products are not affected by human disturbances, making them more representative of the confirmed environment of atmospheric aerosols. Many scholars have used satellite remote sensing products to evaluate model simulations of aerosol optical characteristics during BB (Palacios-Peña et al., 2018; Reddington et al., 2016). This paper first validates satellite remote sensing products with ground stations before using them as evaluation data for models, so the data is reliable. By comparing the model-simulated aerosol optical characteristics with satellite products, researchers can evaluate the accuracy and performance of the model. This helps to determine the reliability and usability of the model, especially when simulating atmospheric aerosols. Such evaluation helps to identify the limitations and room for improvement of the model.

(a) What is the aerosol composition with each emission inventory? E.g., how much primary vs secondary organic carbon/aerosol? How much secondary inorganic aerosol vs organic aerosol? How much black carbon vs these other components? All these aspects impact the hygroscopicity of the aerosol, and thus how it would be retrieved by satellite and ground-based measurements.

Table 1 presents the different aerosol types in the emission inventories. Currently, the emission factors used in the calculation of BB emission inventories are derived based on smoke samples

collected at low altitudes (sampled after any rapid initial cooling but before most photochemical reactions). The aerosols retrieved from these samples only provide information on particulate matter concentrations and do not include classified products for different aerosol types (e.g., secondary inorganic aerosol). Andreae and Merlet (2001) indicate that obtaining aerosol concentrations from emission factors should be regarded as rather crude estimates. They are intended for application to lightly aged plumes (1-2 hours) to avoid significant temporal changes shortly after emissions. Results for different particle categories seem to be quite consistent internally, even when they originate from various sources. Therefore, the BB emission inventories selected in this study (except for IS4FIRES, which only provides $PM_{2.5}$ mass concentration) provide BC, OC, $PM_{2.5}$, or PM_{10} mass concentrations and do not include the classification of secondary organic aerosols and secondary inorganic aerosols.

Figure 4 illustrates the species distribution in each emission inventory, including BC. Although the varying proportions of aerosol types in BB emissions do not constitute the main focus of this paper regarding aerosol hygroscopicity, we have included this aspect in the discussion section (Lines 558-561: Furthermore, the representation of aerosols in the BB emission inventories is insufficient, including chemical components, size distribution of aerosols, aging processes, hygroscopic growth, vertical and horizontal transport (including the injection height of fire emissions), and oxidation state (Reddington et al., 2016), which can all lead to modeling biases in AOPs. Importantly, these attributes also have an impact on aerosols in cloud and radiative forcing.).

(b) How does the size distribution change amongst the different emission inventories? Similar to the chemical composition, the sizes would impact both water uptake, scattering, and how well the satellite and ground-based observations detect the aerosol.

The size distribution of BB aerosols ranges from tens of nanometers to millimeters in a continuous spectrum, with the majority of the mass existing in the mode of several hundred nanometers (Reid et al., 2005). Mass concentration measurements are typically reported as PM_1, $PM_{2.5}$, PM_{10}, or TPM, representing size ranges less than 1, 2.5, and 10 µm, as well as the total particulate matter mass. In this study, the construction of aerosol emission factors for the eight emission inventories is derived from Andreae (2019); Akagi et al. (2011); Andreae and Merlet (2001), with $PM_{2.5}$, PM_1–PM_5 categorized as $PM_{2.5}$, and PM_{10} representing the $PM_{10-2.5}$ fraction. Differences in aerosols within BB emission inventories can impact water absorption, scattering, and the ability of satellites and ground-based observations to detect aerosols. Therefore, we have included this aspect in the discussion section (Lines 558-562).

(c) What is the oxidation state, e.g., O/C and H/C ratio, of the primary and secondary aerosol? Similar to (a), the amount of oxidation of the organic aerosol/carbon will impact its physicochemical properties and how it would be retrieved.

As mentioned in the response in (a), the BB emission inventories studied in this paper only derive BC, OC, $PM_{2.5}$, or PM_{10} mass concentrations in an idealized manner, based on in-situ measurements of young fire plumes. They do not include information on primary aerosols and the oxidative state of secondary aerosols. We have incorporated this aspect into the discussion section of the article

(Lines 558-562).

(d) Besides retrieval, all these properties would impact the aerosols role in clouds and radiative forcing, making it important to understand how much these differences may impact the differences presented in the different figures.

1. In our model, only the influence of ARI was considered, and the impact of ACI was not taken into account. We have added a section in the Discussion (Lines 587-592: <u>Additionally, the inclusion of ARI and aerosol–cloud interactions (ACI) the inclusion of direct and indirect radiation feedback in the WRF-Chem model has been found to effectively improve the simulation of AOPs in European wildfire simulations (Palacios-Peña et al., 2019), whereas this study only incorporates ARI. ACI is concerned with aerosols altering the albedo and lifetime of clouds (Baró et al., 2016). Failure to account for ACI may result in models that do not accurately simulate cloud droplet numbers and sizes, lifetimes, and radiative balances, with implications for climate and atmospheric AOPs (Gao et al., 2022).</u>).

2. The primary focus of this paper is to investigate the differences in aerosol mass concentrations and their spatiotemporal distribution among various BB emission inventories, as well as to assess AOPs and radiative forcing during BB events in the PSEA region using the WRF-Chem model with identical configurations. The reviewer has rightly pointed out that the classification of chemical species (primary organic, secondary inorganic, etc.), size distribution, oxidative characteristics, hygroscopic growth of BB aerosols in the emission inventories can significantly impact the simulation of AOPs and aerosol-cloud-radiation interactions, which are indeed crucial research topics. However, these aspects are not the primary focus of this paper and were not extensively explored. We have included this discussion in the article's discussion section (Lines 558-562).

(3) Without the information provided in (2), the intercomparisons of the model and observed PM2.5 is hard to interpret, as the models may be getting PM2.5 correct for the incorrect reason. Also, it is unclear in the intercomparison of the model with observed PM2.5 for one fire emission inventory how to interpret the results as (a) it seems most of the PM2.5 was measured in urban areas, meaning the urban emissions may be driving the intercomparison more than fire emissions and (b) the emission inventory used for the intercomparison and validation of the model has mixed results (e.g., Table 2).
Response:
1. We have provided additional information regarding point (2) and elaborated on it in the discussion section (Lines 558-561). While these characteristics can impact the inversion of BB emission inventories and subsequently influence the simulation results, the primary focus of this paper is the investigation of differences in aerosol mass concentrations and their spatiotemporal distribution among different BB emission inventories. We aim to assess their impact on the simulation of AOPs and radiative forcing. Our modeling approach maintains identical meteorological initial and boundary conditions, gas-phase chemistry, aerosol mechanisms, and covers the same geographical region and study period. Hence, we are capable of exploring how differences in aerosol mass concentrations and their spatiotemporal distribution in BB emission inventories affect the simulation of $PM_{2.5}$.

2. Comparisons of our simulated $PM_{2.5}$ with data from 23 monitoring stations indicate that the model is capable of reasonably reproducing the spatiotemporal distribution characteristics of pollutants (Figure S2). Notably, several stations in high BB emission areas, such as Chiang Rai Mueang in northern Thailand and Jinghong in China, show better performance (Table S7, with R values of 0.64 and 0.75, respectively) compared to stations located farther away from high BB emission areas. Furthermore, the results of all our stations compared with observations show better simulation performance in this region during BB events, in contrast to previous studies by other scholars (Lines 355-359).

3. Table 2 shows the comparison of the AOD and AAOD simulated by the model with the addition of the eight BB emission inventories with the AOD from the MODIS inversion and the AAOD from the TROPOMI inversion in the BB high-emission areas. The aerosol concentration in the FINNs emission inventory is significantly higher than the other emissions, so the simulation results show an overestimation and the others an underestimation. The AAOD also shows this trend, which was also found in Zhang et al. (2014). In addition, the difference in aerosol concentrations among the eight emission inventories was 11 times, but the simulated AOD and AAOD differences were reduced. These smaller differences in modeled variables may reflect atmospheric dispersion and deposition effects.

(4) Due to (2) and (3), the paper may be presented better as a comparison against the emission inventories without comparison with satellite and ground based products as it is not clear that there is a better emission inventory to used currently for chemical transport models. More discussion could be placed into the description in the similarity and differences in the physicochemical properties due to differences in the emission inventory, which would be of extreme interest towards the community.

Response:

1. Although the current BB aerosol inventories inverted by remotely sensed satellites or ground-based observations are somewhat deterministic due to (2) and (3), BB emission inventories are still able to characterize the spatial and temporal distribution of pollutants in large-scale BB emissions, and a large number of scholars have also analyzed BB events through the use of these emission inventories in models (Reddington et al., 2016; Zhang et al., 2014).

2. With the increasing frequency of global fires due to global warming, more and more scholars have studied the characteristics of wildfires through numerical simulations, in which the necessary input data for the model is the BB emission inventory. A large number of scholars have evaluated the applicability of BB emission inventories by comparing the performance of multiple emission inventories in models, and have given the most applicable emission inventories for global simulations or regional simulations (Desservettaz et al., 2022; Pan et al., 2020). Our results show that in the PSEA region, FINN1.5 and IS4FIRES schemes are recommended.

3. We greatly appreciate your interest in the physicochemical properties of BB aerosols in retrieval and modeling. In the paper, we have included relevant discussions (Lines 558-572).

(1) For all figures, please label either which emission inventory is being used or what location the observations/model is for. It is currently difficult to interpret the figures without this key

information.

Response:

We have accepted the reviewer's comments and have carefully rechecked the figures throughout the paper, in particular adding the names of the emission inventories to Figures 3, 4, and 13 to facilitate the reader's understanding.

(2) Please check figures and tables. There are many instances of inconsistencies or typos in the labels (e.g., line 103 says red line around the study area, Fig. 4 has methanal which is formaldehyde and then an abbreviation for methylglyoxal (Mgly) and methyl vinyl ketone twice with MACR for one, etc).

Response:

Thank you for your critical feedback and attention to detail. We deeply appreciate your effort in identifying these inconsistencies and typos in the figures and tables. We have since duly revised Lines 111-116 to accurately reflect the study area demarcation in the referenced figure. Additionally, we have corrected the labeling errors in Figure 4 ("methylglyoxal (MGLY), glyoxal (GLY), methacrolein (MACR), and lumped monoterpenes, as α-pinenedecane ($C_{10}H_{16}$)").

(3) It is highly recommended to not use rainbow for color bars. Rainbow color bars can be difficult to interpret due to color blindness and the contrast between colors can be difficult to observe differences. Similarly, the color bar in Fig. 6c and Fig. 10c is extremely difficult to read and interpret any differences.

Response:

We have considered the issues raised by the reviewers, particularly those related to the rainbow color spectrum and the color bars in the figure. We have modified the colors in Figures 6c and 10c to improve the readability and interpretability of the figures.

(4) Table S4. Please include location for each met station.

Response:

We have accepted the reviewer's feedback and supplemented the latitude and longitude data in Table S6.

(5) Please introduce the supplemental figures and tables in numerical order. E.g., right now, one supplemental table with a higher numerical value is introduced prior to a lower numerical value table, making the reader jump between tables.

Response:

We sincerely appreciate the reviewer's suggestions. We have re-checked the order of figures and tables in the supplements as they appear in the manuscript and conducted the following analysis. We found that the current order of citation is correct.

Figures	The first occurrence of line number
Figure S1	314
Figure S2	351
Figure S3	365
Figure S4	486

Tables	The first occurrence of line number
Table S1	180
Table S2	197
Table S3	197
Table S4	205
Table S5	216
Table S6	270
Table S7	273
Table S8	298
Table S9	461

Reference

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