We would like to thank Reviewer 1 for their review. In response to the feedback from both reviewers, we have implemented significant revisions to the manuscript. I believe there might be some misunderstanding by the reviewer and much of the criticisms raised by the first reviewer do not provide valid grounds for rejection. The specific points mentioned in the review are addressed below.
Our answers are highlighted in red font, while the reviewers' comments are in black. As a general comment we found this reviewer comments overall to be somewhat vague with little to substantiate them.

The manuscript entitled "Towards an improved understanding of wildfires CO emissions: a satellite remote-sensing perspective" by Griffin et al aims to derive CO emission coefficients by correlating TROPOMI CO with MODIS FRP and produce a new global CO emission inventory using the emission coefficients and GFAS FRP. The authors first estimate CO emissions directly for forest fires in an hour near the overpass time of S5P and evaluate temporally redistributed fire emissions from a Canada emission model – CFFEPS. By correlating TROPOMI CO flux to MODIS FRP, biome-specific CO emission coefficients are derived over different numbers of fire events. The annual budget of CO emissions is estimated finally by applying the derived CO emission coefficients to GFAS FRP, and further compared with several other inventories.

Overall, the topic of this study fits the scope of ACP well and it has very meaningful goals. As S5P TROPOMI provides CO observations of global fires at the highest spatial resolution yet, it provides a good opportunity to explore CO emission coefficient for global fires, which potentially improves the estimation of biomass burning emissions. Unfortunately, I think the study fails to achieve these goals due to the seriously flawed method for deriving emission coefficients and the failure of assessing the accuracy of CO budgets. First, I acknowledge that using TROPOMI CO observations to directly estimate CO emissions from fires during a specific short period of time is sound, and direct CO estimates are valuable independent emission data for evaluating other emission estimates. Yet, both the idea and CO estimation method are not new as TROPOMI CO has been successfully applied to assess fire emissions in several recently published papers. Now, let me lay out reasons why I think the method to derive emission coefficients is flawed.

To the best of my knowledge, at the time of submission there was no other paper containing a comprehensive global dataset of TROPOMI-derived wildfire CO emissions. Just recently (at the end of August 2023) a paper was published by Goudar et al., 2023 on plume detection and CO fire emissions using the TROPOMI dataset. Our manuscript, however, provides different approach and insights into CO fire emissions and provides a global budget, which is not the same as Goudar et al., but adds to the scientific knowledge. Our manuscript includes a comprehensive global dataset of CO fire emission estimates using TROPOMI, including over 15000 fire emission points, which are made publicly available. The reviewer did not provide references to the claimed "several recently published papers." Another relevant publication I am aware of is the paper by Stockwell et al., 2022 (which I co-authored), where we focused on a limited number of fire emissions in North America during the FIREX-AQ campaign with the aim to validate the emission estimation method. Our study introduces an improved method that automates the emission estimate by determining the plume width for each fire plume. It also includes a comprehensive uncertainty analysis. Magro et al., 2021 published CO emissions from fires in Portugal which is not global and only includes a small sample of fires.

Other papers used MOPITT observations, which are sparse and utilize a very different approach compared to our study has been used, such as 1D-box model and has to be used (Liu et al., 2005), and Silva et al., 2017 looked into regional combustion using MOPITT.

We included the following changes to our manuscript (introduction):

"It has also been used to derive fire emissions in Portugal (Magro et al., 2021).Most recently, Goudar et al. (2023) published an automated plume detection and emission estimation algorithm utilizing TROPOMI CO, in our study, an alternative approach is explored. "

References:

Goudar, M., Anema, J. C. S., Kumar, R., Borsdorff, T., and Landgraf, J.: Plume detection and emission estimate for biomass burning plumes from TROPOMI carbon monoxide observations using APE v1.1, Geoscientific Model Development, 16, 4835–4852, https://doi.org/10.5194/gmd-16-4835-2023, 2023

Magro, C., Nunes, L., Gonçalves, O. C., Neng, N. R., Nogueira, J. M. F., Rego, F. C., and Vieira, P.: Atmospheric Trends of CO and CH4 from Extreme Wildfires in Portugal Using Sentinel-5P TROPOMI Level-2 Data, Fire, 4, https://doi.org/10.3390/fire4020025, 2021

Liu, J., Drummond, J. R., Li, Q., Gille, J. C., and Ziskin, D. C.: Satellite mapping of CO emission from forest fires in Northwest America using MOPITT measurements, Remote Sensing of Environment, 95, 502–516, https://doi.org/https://doi.org/10.1016/j.rse.2005.01.009, 2005.

Silva, S. J. and Arellano, A. F.: Characterizing Regional-Scale Combustion Using Satellite Retrievals of CO, NO_2 and CO_2, Remote Sensing, 9, https://doi.org/doi:10.3390/rs9070744, 2017

Theoretically, emission coefficient (g/J), which represents the mass of emissions per Joule radiative energy emitted from fire, can be derived if continuous, accurate rate of emission and FRP (or emission mass and FRE) are known. One MODIS instrument provides daily up to two observations of fires at the same location at low-mid latitudes. If only daytime Aqua MODIS FRP is used, it only provides one observation as with TROPOMI CO observation. In the method of deriving CO emission coefficient by correlating TROPOMI CO to Aqua MODIS FRP, the underline assumptions are that emission flux based TROPOMI CO and Aqua MODIS FRP are able to represent mean CO flux and mean FRP for a given fire sample during a specific period of time (±30min or several hours?). I would not think these simplified assumptions hold in most cases. For MODIS FRP, it has a strong dependency on MODIS scan angle. In other words, FRP value can be largely different if the instrument observes the same fire at nadir and in large scan angles. In that case, emission coefficient likely changes largely when the scan angle varies. Moreover, the observation gaps between S5P and Aqua can be up to about 60 minutes although they are thought to be in similar orbits. I think this explains the very scattering distribution of samples in Fig 6, not to mention the very pool correlations in evergreen needle leaf dominated by forest wildfires. It looks like the authors are not aware of the characteristics of MODIS FRP except for listing the incapability of detecting very small fires and cloud/smoke contamination. A scientifically sound way would be deriving coefficients based on TROPOMI CO and FRP from the new-generation geostationary satellites, which has been done in several published papers that are never mentioned as background in Introduction nor discussed in Discussion. The accuracy of CO flux also relies on wind directions and speed, which are also a concern.

The reviewer questions the assumption made in deriving the CO emission coefficient by correlating TROPOMI CO to Aqua MODIS FRP, stating that these simplified assumptions may not hold in most cases. While it is true that we assume the emission coefficient remains constant throughout the day, introducing uncertainty, this is a common practice in top-down emission inventories that use FRP, such as GFAS. The GFAS emission coefficients do not vary throughout the day. In contrast, our study presents emission coefficients for additional biomes compared to GFAS and provides a comparison of direct emission estimates with both bottom-up and top-down approaches, which, to my knowledge, has not been done before.

We found a study by Freeborn et al., 2014 discussing the MODIS FRP uncertainty. While the uncertainty can be large for single hotspots as mentioned by the reviewer. For aggregated hotspots the uncertainty is much lower. On average, depending on the size of the fire we aggregate approximately 30 fire hotspots detected by MODIS, based on Freeborn et al., 2014 (Fig. 3) these would have a 6% uncertainty, much lower compared to our CO emission estimates that come with a 42% uncertainty and the uncertainty of the slope between FRP and CO emissions. We included the following discussion on this in the manuscript (Sect. 2.4):

“Depending on the size of the fire, we aggregate on average 30 thermal anomalies, based on Freeborn et al. (2014) this is associated with a 6 % uncertainty of the FRP, much lower compared to the uncertainty of the CO emissions estimates (42 %).”

The reviewer suggests that a scientifically sound way to derive coefficients would be based on TROPOMI CO and FRP from new-generation geostationary satellites. It is important to note that deriving coefficients based on TROPOMI CO and FRP from geostationary satellites is not feasible for global emissions and a global emission inventory. For example, we found the following study by Zhang et al., 2012, some regions, including India are not covered. Mota et al., 2018 used geostationary FRP with the focus on emissions from South Africa. In contrast to our study, neither of these two studies combined the FR with other satellite datasets. While it may be possible to get a diurnal FRP regionally, for example, in North America with GOES-R, our aim was to present a global perspective in this study. Geostationary satellites have different characteristics, such as GOES-R in North America and SEVIRI in Africa and Europe, making their combination complex and challenging. Lastly, varying FRP is one thing, but to address the reviewer's point would one not also need diurnal emissions, making this even harder in a global sense. CO is currently not measured by geostationary satellites. Despite a second thorough literature search, we were unable to locate papers that have combined direct CO emission estimates with geostationary satellite FRP.

The reviewer mentions concerns about the accuracy of CO flux, which relies on wind directions and speed. I want to emphasize that this aspect is considered in the uncertainty estimate. Furthermore, it is essential to recognize that estimating emissions from satellite observations always involves some uncertainty from the wind speed and direction, and it is impossible to eliminate this uncertainty.

References:

Freeborn, P. H., Wooster, M. J., Roy, D. P., and Cochrane, M. A.: Quantification of MODIS fire radiative power (FRP) measurement uncertainty for use in satellite-based active fire characterization and biomass burning estimation, Geophysical Research Letters, 41, 1988–1994, https://doi.org/https://doi.org/10.1002/2013GL059086, 2014

Zhang, X., Kondragunta, S., Ram, J., Schmidt, C., and Huang, H.-C.: Near-real-time global biomass burning emissions product from geostationary satellite constellation, Journal of Geophysical Research: Atmospheres, 117, https://doi.org/https://doi.org/10.1029/2012JD017459, 2012

Mota, B. and Wooster, M. J.: A new top-down approach for directly estimating biomass burning emissions and fuel consumption rates and totals from geostationary satellite fire radiative power (FRP), Remote Sensing of Environment, 206, 45–62, https://doi.org/https://doi.org/10.1016/j.rse.2017.12.016, 2018

The accuracy of the new CO inventories depends on the accuracy of the derived CO emission coefficients and that of GFAS FRE. FRE calculation requires continuous FRP observations. Diurnal FRP varies very largely from day to day even for the same fire, especially large forest wildfires, which have been reported in several JGR and RSE papers. I would not expect reliable FRE to be calculated from daily mean GFAS FRP that is averaged using merely up to four daily MODIS FRP observations, although GFAS emissions are used in ECMWF forecast models. Furthermore, simply comparing it with a few other inventories doesn't tell any information about the accuracy of the new CO inventory. There are more than 10 BB emission inventories for different purposes, and they can differ from each other by a factor of up to 30 in individual fire events although the difference in their annual budget could be much smaller. I don't see any meaningful contributions of a new inventory to the BB community without knowing its accuracy.

The reviewer questions the reliability of calculating fire radiative power (FRP) from daily mean GFAS FRP, which is assimilated using four or more daily MODIS FRP observations (from AQUA and TERRA). While we did not publish GFAS FRP, it is a reputable dataset that has undergone quality control and, to our knowledge, is the best currently available for our study.

I believe that the reviewer has missed the main objective of the study. The aim of our paper is not solely to publish a "better" emission inventory. In their review, the first three quarters of the paper, which encompass important aspects, have been entirely neglected. These include:

- The global and automated fire CO emissions estimates using TROPOMI, which is a substantial dataset (currently of over 15000 fire emissions) that we hope will be valuable to the scientific community. The aim is to eventually automate it entirely and provide CO fire emissions in near-real time.
- A comprehensive comparison between direct estimates, top-down and bottom-up approaches, shedding light on the strengths and weaknesses of each method.
- A comparison of different emission inventories and the examination of their trends. This analysis provides insights into the variations between five inventories.

We have provided uncertainties to the best of our abilities for the CO emission estimate and the emission coefficients. However, it is important to note that GFAS FRE does not include uncertainties, making it impossible to estimate uncertainties for the annual emissions. Moreover, none of the emission inventories that we compare our results to provide uncertainties.

We included an uncertainty range based on the emission coefficients found in different years:

"To assess the uncertainty of the total annual emissions of our estimates (TROPOMI-FRE), we also used emission coefficients derived from fires of individual years (2019 to 2021). Using emission coefficients from 2019,2020, and 2019-2021 combined did not impact the total emissions (see Fig. C1), only for 2021 the total emissions reduced by approximately 20%, due to overall lower EC_{CO} (for biomes 1-3, see Table C3). This shows that the uncertainty of our approach is at least 20%, but since the individual TROPOMI derived CO emissions have an uncertainty of 40%, we would expect the overall TROPOMI-FRE annual emission to have similar uncertainties on the order of 40%."

Considering the substantial variability and uncertainty inherent in fire emission models and inventories, I believe that any contribution, especially one with a completely different approach, should be welcomed to the scientific community.

To highlight the aim of our paper and make its goal clearer we included the following changes in the abstract:

- "Specifically, we use the TROPOMI (Tropospheric Monitoring Instrument) high spatial-resolution satellite datasets to create an automated and global database of burning CO emissions between 2019 and 2021."
- "A comprehensive comparison between direct estimates, top-down and bottom-up approaches, provides insight into the strengths and weaknesses of each method."

And in the introduction:

- "This approach has been entirely automated and has the capability to determine CO fire emissions in quasi near real time (as soon as TROPOMI CO and MODIS FRP observations are available)."
- "These emission coefficients can provide insights into the efficiency of combustion, and help quantifying how emissions from a particular ecological region or biome are related to the heat energy generated by wildfires in that region. This information can be valuable for understanding the environmental impact of wildfires in different ecosystems and for developing strategies to manage and mitigate their effects. Furthermore, FRP is often and more easily measured from satellites compared to CO, and determining a biome specific CO-to-FRP ratio can help to determine the daily total emissions of fires."

In response to the feedback from both reviewers, we have implemented significant revisions to the manuscript. We reviewed the manuscript, revising sections to enhance its quality by eliminating repetitions, rectifying typographical errors, and refining the wording. Part of the changes include a compete revision of section 5.1 "CO emissions over the past two decade": We changed Figure 9 to include all inventories discussed in this paper (with the exception of GFFEPS that is currently only available for 2019). We included a figure, showing the change of emissions for different regions from all inventories discussed in this paper (GFAS, GFED, FINN 1.5, FINN2.5). Additionally, we provided a table with the trends and indicate whether or not the trend is significant (for all 5 inventories, including our own).

We provided a PDF document illustrating the differences between the previous and current versions.

To sum up, I don’t see sound contributions from this study, thus I would not recommend it for publication in ACP.