Black text: Community comments by Dr. Jian Liu

Blue text: Our replies

Red text: Modified parts of the manuscript

The authors have conducted a lot of analysis work in this paper, demonstrating a new way to help people understand the emissions over Arctic. There are some issues :

→We appreciate the comments by Dr. Jian Liu. All the comments were helpful in improving our manuscript. Please see our answers to the specific comments below.

1) There are several models mentioned in this paper, as we know, models are impacted from the model itself, parameters, and input, such as emissions, so how did you find a balance between the models and their uncertainties, any assumptions included? If yes, more details should be given in the supplement.

→ Thank you for pointing this out. Though we used Hysplit in the analysis where FRP was related to the air mass transport, the model we mainly used in this manuscript was FLEXPART-WRF. The model was well validated and used for the estimation of source-receptor analysis (Liu et al., 2015; Zhu et al., 2020; Raut et al., 2017). More detailed information for the FLEXPART-WRF calculation in this study is added as Table S1 in the supplement file. Although the errors associated with the model's transport and wet removal may become larger with long-range transport, the uncertainties with emissions would outweigh for the cases affected by biomass burning, which is the main subject of this manuscript. We have added a summary table of RMSEs when using 6 different types of biomass burning emission inventories in Table S2.

"Table S1. Main configuration parameters adopted for the FLEXPART-WRF simulations in this study.

WRF-ARW 4.2.1 configuration	
Initial and boundary conditions	ECMWF ERA5 (Pressure-levels), hourly
PBL parameterization	MYNN level 2.5
Shortwave and longwave radiation	RRTMG
Land surface	Noah-MP
Microphysicis	Morrison 2-moment
Convection	Grell 3D ensemble
Maximum height	10 hPa
Domain size (x,y and z)	399x399x44 grids (mass points)
Map projection	Polar Stereographic

	centered at the North Pole

FLEXPART-WRF 3.3 configuration	
LSUBGRID	1 (enables subgrid terrain effect)
TURB_OPTION	1 (PBL turbulent mixing is calculated in the same manner with FLEXPART)
CBL_OPTION	1 (skewed option for the convective PBL)
SFC_OPTION	1 (PBL height is taken from WRF)
WIND_OPTION	1 (mass-weighted, time-averaged wind U,V and W calculated in WRF)
Interval of input data	hourly
Density of BC	1400 kg m^{-3}
Mean diameter of BC	0.25 μm
Standard deviation of BC size distribution	1.25
Release height	100-200 m A.G.L.
Number of particles	40,000
Output grids (horizontal)	180°W-180°E, 20°-90°N, every 0.5°
Output grids (vertical)	11 layers (50, 100, 150, 200, 500, 1000, 1500, 2000, 2500, 3000, 20000 m A.G.L.)

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2) FRP has widely been utilized in the top-down emission inventories, but for bottom-up emission researchers, the burned area and emission factors are used to estimate the biomass burning emission. Of course, the FRP should have some correlations with wildfires and these are acknowledged as two different technique routes for emission researchers. So the question here is how to help these researchers use the FRP or help each other, the authors should give accurate details in this part. If not, the conclusion will be weak. The authors should also make it clear that this might be useful to the bottom-up emissions in the results section.

→ Given that the emission rate is estimated as a product of activity data (AD) and emission factor (EF), previous inventory studies used FRP for the estimation of AD, namely, fuel burned or burned area. On the other hand, our study suggested that FRP information is also essential in improving EF estimation, in that the EFs of BC and/or CO dynamically changes with FRP. Previous studies generally only crudely assume the BC emission factors are constant over different combustion conditions. Though needing a total carbon (or CO2, as its major fraction) emission information for a full parameterization, we here proposed a new principle that the BC emission factor expression can be improved by taking combustion conditions (related to FRP) into account. This is clearly different from previous studies.

In addition, BC emission estimation using satellites would be improved by using our results. CO emissions estimated by satellite observations are sometimes used to estimate other pollutant emissions from forest fires using emission ratios derived from in situ measurements (Zheng et al., 2023). As its extension, BC emissions could be estimated, regarding our quantified BC/ΔCO ratios and their evolutions with FRP directly as the emission ratio of BC to CO.

We will modify our manuscript accordingly after we receive other reviewer's comments.

3) Following Question 2), based on this recently published paper (https://doi.org/10.5194/acp-24-367-2024), why did the authors choose GFED only as the emission inventory in the FLEXPART-WRF, how about using an FRP-based emission inventory and checking if there was some relation between BC/△CO and the differences for two different routes' emission inventories?

→ Thank you for pointing out an important paper. As indicated by this comment, some inventories have already used FRP to estimate AD, but they have not used to modify EF. Although we compared the model calculation results using the footprint calculated by the FLEXPART-WRF and 6 different emission inventories (FINNv1.5 and v2.5, GFED, GFAS, QFED, and FEER), including those using FRP (GFAS, QFED, and FEER), we found that GFED showed better agreement with the concentration observed at PFRR comparing to other inventories. This model comparison will be presented in detail in a separate paper (in prep.). For this reason, we showed only the GFED result in this paper. It would be ideal that FRP is used for estimating both AD and EF, as this study suggested; however, development of such an emission inventory and simulations using it will require more work and is out of scope in this paper. This suggestion is important and will be considered in the future. We added a summary table (Table S2) for tested emission inventories and their performance in the supplement file.

"Table S2. Root Mean Square Error (RMSE) of the 6-hour averaged model calculated BC mass concentrations at PFRR. Model-calculated BC mass concentrations were estimated using the same footprint calculated by the FLEXPART-WRF model and different emission inventories.

Inventory	RMSE (ng m^{-3})
FINN v1.5 (Wiedinmyer et al., 2011))	35.8
FINN v2.5 (MODIS+VIIRS) (Wiedinmyer et al., 2023)	28.4
GFED v4.1s (Randerson et al., 2015)	**12.7**
GFAS v1.2 (Kaiser et al., 2012)	26.6
QFED v2.5r1 (https://portal.nccs.nasa.gov/datashare/iesa/aerosol/emissions/QFED/v2.5r1/)	21.9
FEER v1.0-G1.2 (Ichoku and Ellison, 2014)	31.0

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4) In Fig. S2, there are some very high values from ground-based observations but not shown by NOAA hourly-average observations, does that mean the authors has a different data curation method from NOAA, if yes, why?

→ Because the NOAA aircraft observations were done approximately every 3 weeks, short peaks in between the opportunities were easily missed. We added a sentence below to the caption of Figure S2 and modified Figure S2.

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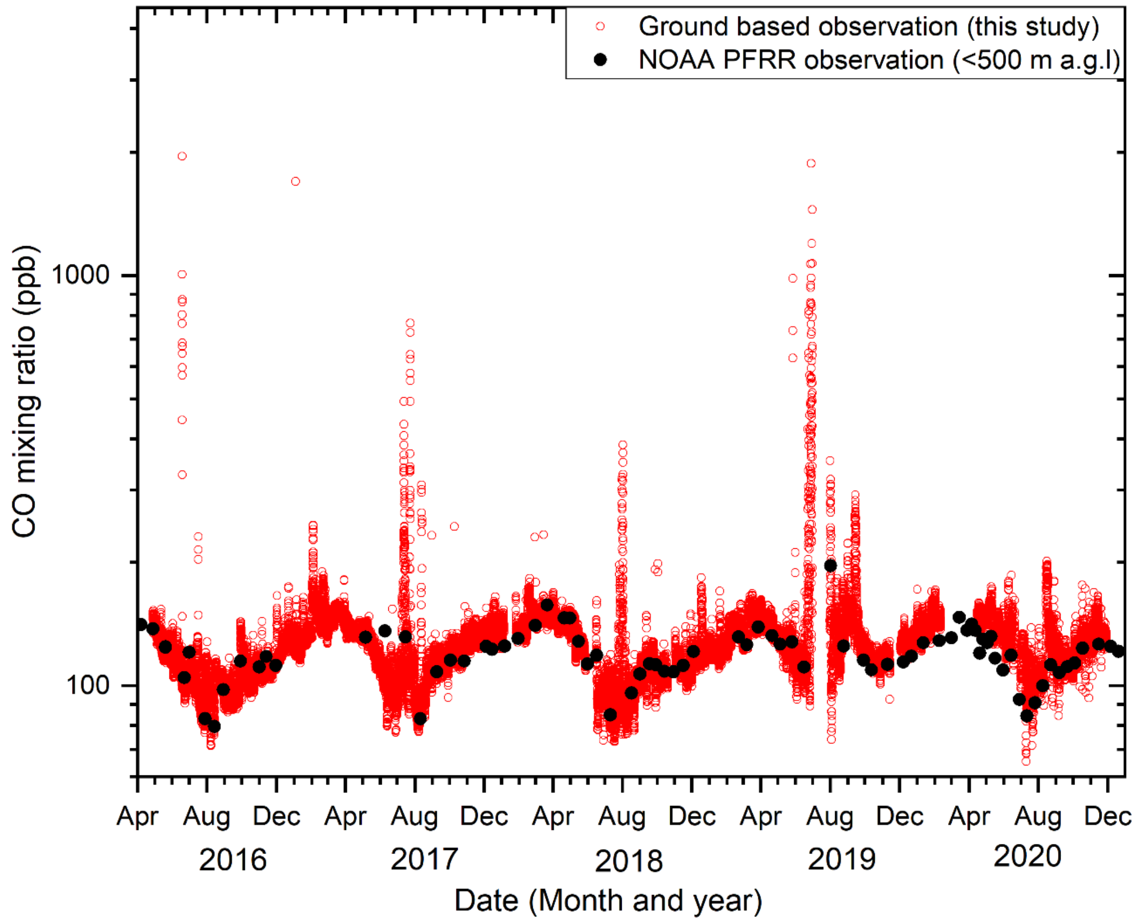

Figure S2. Time series of CO mixing ratios observed at PFRR. Red circles show the hourly ground-based observation (this study), and black points show the averages of individual aircraft observations (below 500 m a.g.l) made by NOAA Global Monitoring Laboratory approximately every 3 weeks. Because our observations were done continuously with a high-temporal resolution, several high-concentration peaks could be captured.

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5) Some minor revisions should be corrected, e.g. Line 81, "section 3.2" should be "Section 3.2" and so on. Lines 405, and 416, the references should include the DOI link, and other similar issues in the reference part.

→ Thank you for your kind indication. We corrected Line 81, Lines 405, 406, and other lines. In addition, related to the comment 2, we added three references (Akagi et al., 2011; Wiggins et al., 2021; Zheng et al., 2023).

[Modified and added references]

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