

Response to Reviewers

Thank you very much for taking the time to review our manuscript and provide helpful comments. Your feedback helped us improve the manuscript and make several parts clearer. We have carefully considered each comment and provided our responses below.

In addition to that, we would like to explain some additional changes, particularly changes related to how the emission factors (EF) were calculated and reported and how these changes affected the revised manuscript:

Formatting Guide:

1. *Reviewers' comments* are presented in black italic font.
2. *Responses to reviewers' comments* are presented in blue font.
3. **The revised text** is indented and quoted in dark orange font, with the corresponding **line numbers** highlighted in green.

Note: The overview paper cited as **Moraes et al. (2026)** has been submitted to the *Journal of Geophysical Research* and is currently under review. The updated version of the overview paper has been uploaded with the response to reviewers for reference. Please disregard the previously shared preprint version to avoid any confusion.

Additional corrections made during revision:

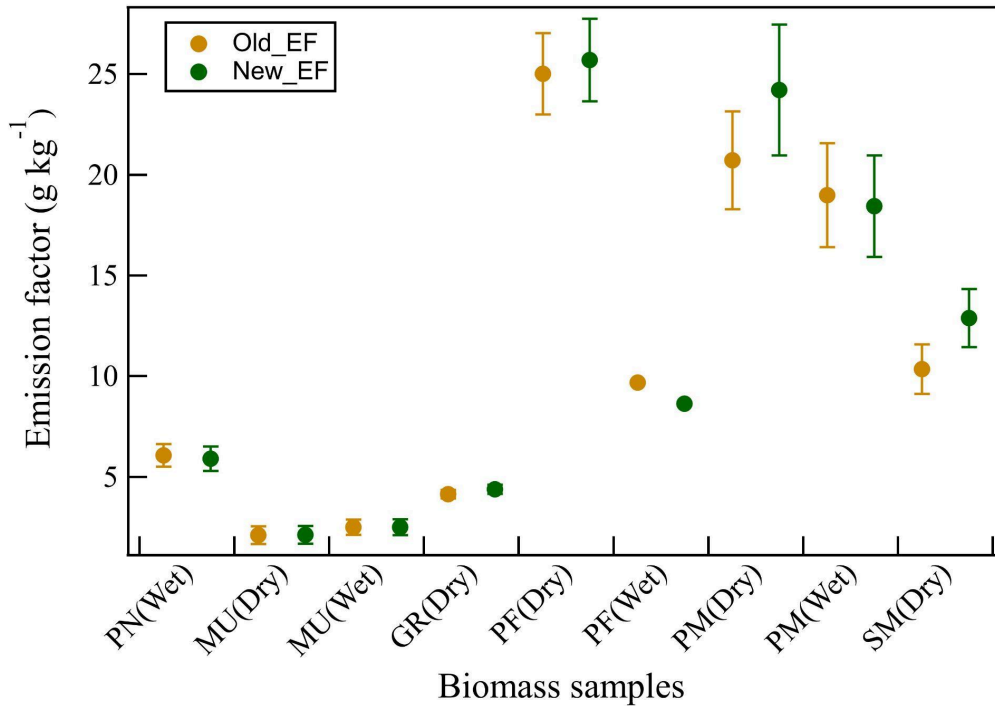
1. Correction to Fuel Consumption Calculations:

In the initial submission of this paper and the corresponding overview paper (Moraes et al., 7 May 2026), our calculations did not account for the fact that the heat of combustion evaporates moisture, meaning the remaining residue is effectively dry. To support this assumption, additional evidence was added to the Supplementary Information (Text S6) of the overview paper, including temperature data from different layers of the fuel bed, demonstrating that the fuel bed remained hot enough to drive off all moisture. The relevant text and equations were also modified in the overview paper. Consequently, we have revised our fuel consumption calculations and updated EF values (both manuscripts). Ultimately, the correction to the fuel mass consumption was relatively minor and only had a small impact on the magnitude of the EFs.

This is illustrated by the comparison of the original (Old_EF) and corrected (New_EF) Σ VOC EFs (entire burn period) for the entire burn in the figure below. Fire-integrated MCE values were also updated (negligible change). Therefore, this improvement to the fuel consumption calculation correction does not affect the observed trends, interpretation, or conclusions of the study.

Line 244 was updated as follows in the revised manuscript:

“TFC was calculated from real-time weight measurements for each burn, corrected for moisture content as detailed extensively in the overview paper (Moraes et al., 7 May 2026).



2. Dry peat CO₂ emission factors

When initially evaluating the direct measurements for the overview paper (Moraes et al., 7 May 2026), it was noted that the CO₂ values for the peat with moss (PF) and peat with mulch (PM) samples were low compared to observations in previous studies. The combustion process for these specific fuels was dominated by an extended smoldering phase, with the flaming phase lasting only a few minutes. Because of this prolonged smoldering, the emitted CO₂ concentrations frequently dropped very close to ambient background levels, which introduced significant uncertainty into the direct CO₂ measurements.

To resolve this uncertainty, it was decided to use a carbon mass balance (CMB) approach to calculate CO₂ values for the revised overview paper. The total volatilized carbon was determined based on the carbon percentage of the fuel and the total fuel mass burned, and then the measured carbon mass of the other emitted species (CO, CH₄, non-methane organic carbon (NMOC), EC, and OC) was subtracted to determine the balance of CO₂. This reverse-calculation method bypasses the signal-to-noise issues of the direct measurements and provides a much more reliable estimate of CO₂ emissions for fuels with long, low-intensity smoldering phases. This was

described in the overview manuscript by Moraes et al. (7 May 2026). The revised, CMB-based CO₂ EFs for dry peat with mulch (PM, dry) and peat with moss (PF, dry) from the overview paper were implemented in this study as well.

In Section 2.3, the following lines have been added after [line 202](#) in the revised manuscript:

“For peat with mulch, PM (dry) and peat with moss, PF (dry), direct CO₂ measurements were associated with greater uncertainty because combustion was dominated by prolonged smoldering, during which CO₂ concentrations frequently approached ambient background levels. Therefore, in Moraes et al. (2026), CO₂ EFs were calculated using a carbon mass balance (CMB) approach, in which the measured carbon in CO, CH₄, NMOC, elemental carbon (EC), and organic carbon (OC) was subtracted from the total fuel carbon. The CMB-based CO₂ EFs for PM (dry) and PF (dry) were also used in the present study.”

Consequence 1: Shift to higher average fire-integrated MCE for PM (dry) and PF (dry)

Fire-integrated MCE values for PM (dry) and PF (dry) were recalculated using the new CMB-based CO₂ EFs. This resulted in an increase in the average fire-integrated MCE from 0.76 to 0.85 for PM (dry) and from 0.77 to 0.83 for PF (dry). The previous values (0.76 and 0.77) were at the very low end of the reported literature range for peat fuels. The revised values are higher than the MCE used by Urbanski et al. (2014) for smoldering boreal duff (0.79) and observed for Canadian peat (0.80) by (Stockwell et al., 2015) but are still consistent with smoldering combustion. The shift in MCEs affects the EF vs. MCE relationships (Fig. 4, 5, 6b, 6c, S3, S4, S5, S8, and S9), although the interpretation remains unchanged. The linear relationships in Fig. 4, 6c, S3, S4, S8, S9, and relevant text have been updated accordingly.

The most significant change is that NMOC_G EFs from CFFEPS/Urbanski (2014) for “Boreal Forest Duff/Organic Soil” and from the Hayden et al. (2022) aircraft study are now in poorer agreement with the revised NMOC_G-MCE relationship from our study (Fig. S9). However, the relationship for the fuels investigated in this study remains robust, with R² increasing slightly from 0.82 to 0.84. The text in Section 3.6.1 has been revised accordingly.

Consequence 2: Removal of flaming- and smoldering-phase resolved EF–MCE relationships for Figure 4, S3 and S4

Previously, the relationships between NMOC and VOC EFs and MCE were evaluated for three combustion conditions: the entire burn, flaming phase, and smoldering phase. Because the time-resolved CO₂ measurements used to calculate phase-specific MCE were subject to uncertainty, particularly for PM (dry) and PF (dry), we decided not to report flaming- and smoldering-phase MCE values for any of the fuels in the revised manuscript. Accordingly, Figure 4 and Figs. S3 and S4 now present only EF–MCE relationships for the entire burn, and the corresponding discussion in Section 4.3 has been revised. The overall interpretation remains unchanged.

Consequence 3: Carbon budgets in Section 3.3 and Figure 3a

The revised CMB-based CO₂ EFs for PM (dry) and PF (dry) resulted in corresponding changes to their carbon budgets. Therefore, the total carbon EFs and the contribution of measured NMOC to the total measured carbon for these two fuels were recalculated, and Figure 3a and the corresponding discussion in Section 3.3 have been updated accordingly. By definition, the PM(dry) and PF(dry) fuels now show perfect carbon closure since the CO₂ EFs were calculated using a CMB approach. These changes do not alter the overall interpretation of the carbon budget (i.e., contributions of CH₄ and NMOC to the total remain very similar)

Anonymous Referee #1

In this manuscript, Afroz et al. fill the gap in the current understanding of Canadian wildfire boreal surface fuels and provide useful implications for evaluating current Canadian wildfire emission inventories, which underestimate the Canadian boreal peat EF. This manuscript also takes advantage of two Picarro measurements to quantify the total NMOC and provides promising insight by using fuel moisture to explain the variability in VOC emissions. However, several aspects require further clarification. In particular, the manuscript needs better justification for the duct-flow-based EF calculation method relative to the more commonly used carbon mass balance approach, and for missing low-molecular-weight VOCs and gas-particle partitioning. In addition, some comparisons between laboratory and aircraft-based measurements would benefit from a more cautious interpretation that accounts for differences in fuel type, combustion conditions, plume age, dilution, chemical processing, and sampling platform.

Response: We appreciate the reviewer's positive feedback. We have responded to the reviewer's comments and also made corrections to our manuscript. We believe the manuscript is much improved now.

Reviewers' major comments are below:

- 1. Many of the studies used for comparison (like Koss et al., 2018; Permar et al., 2021) use the carbon-mass balance method for calculating EF. The manuscript should clarify the advantages and limitations of this method relative to the carbon-mass balance method. Because this study directly relies on measured duct flow, it would also be useful to describe whether and how the hood/duct system was validated to ensure complete smoke capture.*

Response: Thank you for the comment. In this study, EFs were calculated by measuring the concentration of each species in the exhaust, combining it with the duct flow rate over the full burn, and dividing by the dry mass of fuel burned (Equation 2). This method is well suited to our controlled laboratory setup because both the amount of fuel burned and the exhaust flow were measured directly during each experiment. Although in this study we measured all carbon-containing species, this approach does not require this to be the case.

In comparison, the CMB method estimates EFs from measured carbon-containing emissions and the fuel's carbon content. This approach is especially useful for field, aircraft, or open-fire studies, where total exhaust flow and fuel consumption cannot be measured directly. CMB-based EFs depend on accurate fuel carbon content and adequate measurement of the major carbon-containing species, including CO₂, CO, CH₄, organic carbon compounds, and particulate carbon (e.g., black carbon). Therefore, unmeasured carbon-containing species can introduce uncertainty into CMB-derived EFs.

The experimental system included an overhead exhaust hood, controlled exhaust flow, a static mixer, and downstream sampling ports to collect well-mixed smoke. The direct-flow method depends on effective smoke capture by the hood–duct system and accurate measurement of the duct flow rate. As noted in [line 299](#), the uncertainty in duct flow was estimated as $\pm 12.2\%$. We acknowledge that incomplete smoke capture could lead to an underestimation of the absolute EFs. To check this, we compared the total carbon emissions from the ‘duct flow’ approach (i.e., CO, CO₂, CH₄ NMOC, EC, and OC) to the expected carbon emissions based on measured fuel carbon content (i.e., the ‘CMB’ approach). The ratio of these values provides the correction for converting the ‘duct-flow’ EFs to ‘CMB’ EFs. Excluding the dry peat fuels, the average ratio across burns ($N = 21$) is 1.07 ± 0.11 , indicating on average better than 10% agreement between the two approaches. Of the 21 burns, 12 were within 10%, 6 within 20% and 3 within 30% (the latter three were all surface material burns). This good agreement further validates the duct-flow approach. As mentioned above, the CMB approach was used to ‘correct’ CO₂ EFs for the dry peat fuels (PM, PF).

Finally, comparisons among fuels and repeated burns are expected to be less affected by the method since all experiments were conducted using the same hood–duct setup.

Extensive details on the hood–duct configuration and smoke-capture validation are provided in Moraes et al. (2026), and additional text has been added after [line 247](#) in the revised manuscript to point readers to the overview paper.

“This direct-flow approach is well suited to the controlled laboratory setup because both fuel consumption and exhaust flow were measured directly during each burn. The system used an overhead exhaust hood, controlled duct flow, a static mixer, and downstream sampling ports to promote complete smoke capture and well-mixed sampling; further details and validation of the hood–duct system are provided in Moraes et al. (2026). In comparison, the carbon mass balance (CMB) approach is useful when exhaust flow or fuel consumption cannot be measured directly, but depends on accurate fuel carbon content and adequate measurement of the major carbon-containing emissions.”

2. *The emission factor calculation equation is defined for mixing ratio (ppb); then it should be converted to 10^{-9} mol/mol. The authors should check the equation.*

Response: Thank you for identifying this error. We have corrected Equation (2).

3. *For the 46 VOC EFs, it would be helpful to compare the full set of reported VOCs with previous VOCs' full mass spectrum biomass-burning studies. This comparison would also help clarify the origin of the "missing VOC" percentage discussed for Figure 3(c) and Lines 345–350. Important low-molecular-weight compounds, such as methanol and formaldehyde, were not quantified in this study, although these species have been shown in previous laboratory and wildfire studies to contribute substantially to total VOC mass. The manuscript would benefit from a simple quantitative comparison or discussion of the expected contribution of these missing compounds to better place the reported VOC mass fraction in context.*

Response: Thank you for this helpful comment. We agree that the 46 quantified VOCs represent only a subset of the total emitted organic gases. The limitations of the measurement system, including the low-molecular-weight VOCs not quantified in this study (e.g., methanol, formaldehyde, ethene, ethane, and propane) and detected but unquantified compounds, are described in Section 2.2.

To address this comment, we revised the discussion associated with Fig. 3d (we believe the reviewer intended Fig. 3d rather than Fig. 3c). We clarify that the reported 13–34% value represents the fraction of measured NMOC carbon accounted for by the 46 quantified VOCs. We also added quantitative context from broad-spectrum biomass-burning measurements, which support our interpretation that the unquantified NMOC fraction likely includes contributions from low-molecular-weight VOCs, as well as I/SVOCs and other unmeasured organic gases.

Thus, the manuscript **lines 366–376** are revised as follows:

“The quantified Σ VOCs constituted 13–40% of total NMOC on a carbon basis, with the highest quantified contribution for the peat fuels (PM and PF) and PN, and the lowest for GR and MU. A substantial unquantified NMOC fraction is expected because only 46 species were quantified by the Vocus PTR-MS and I-CIMS. This fraction may include I/SVOCs, which can contribute from >5% to almost 40% depending on fuel type and the definition of I/SVOC (Yokelson et al., 2013; Hayden et al., 2022; Hatch et al., 2018). It is also expected to include low-molecular-weight VOCs and detected but unquantified compounds described in Section 2.2. For context, Simpson et al. (2011) reported that C1–C2 NMOC accounted for approximately 41% of measured NMOC carbon in fresh Canadian boreal wildfire plumes. Permar et al. (2021) also found that the top 10 most abundant VOCs were C1–C3 NMOC (acetic acid/glycoaldehyde, formaldehyde, acetaldehyde, ethane, methanol, formic acid, ethane, acetone/propanal, propene, hydroxyacetone), accounting for ~53% of total measured VOC mass emitted. Therefore, the quantified Σ VOCs should be interpreted as a subset of total NMOC rather than total VOC emissions.”

4. *For Figure S7(c). GR (dry) and MU (dry) correlation is poor ($R^2=0.31$). Additional explanation would be helpful. And are there any factors that affect it? Even for GR (dry, 20% moisture) and MU (dry, 4% moisture), they are considered “Dry”. Absolute fuel moisture can be a factor impacting the EF of VOCs beyond the fuel itself. It is helpful to clarify it.*

Response: Thank you for highlighting this point. We agree that fuel moisture may influence VOC EFs. However, the weak correlation between GR (dry) and MU (dry) likely reflects broader differences in fuel characteristics and burning behavior.

The two fuels had almost similar mean MCE values (0.93 and 0.94, for MU and GR, respectively), suggesting that overall combustion efficiency was not the main driver of the weak relationship. In contrast, their burn durations differed substantially: GR (dry) burned for 19 ± 12 min, whereas MU (dry) burned for 48 ± 16 min. Their thermal conditions also differed. The average flaming temperature for GR was approximately 600°C, whereas MU reached a surface temperature of approximately 800°C during flaming, followed by temperatures of around 200–300°C during the remaining burn period; the temperature at 4 cm depth was approximately 600°C. These differences suggest that the two fuels experienced different thermal histories and combustion dynamics.

Differences in fuel composition may also contribute to the distinct VOC emission profiles. In particular, GR and woody MU can differ in their relative biopolymer composition, including cellulose, hemicellulose, and lignin, which can generate different VOC products during thermal decomposition. GR and MU also had the largest difference in fuel nitrogen content (1.21% vs. 0.27% N). Fuel structure may also be important. Compared with MU, GR is generally less dense, less compact, and more porous, which can alter air penetration, heat transfer, flame spread, and local combustion conditions. Together, differences in moisture content, nitrogen content, biopolymer composition, burn temperature, physical structure, and burn dynamics may explain the weak correspondence between the VOC EFs of GR (dry) and MU (dry).

For better clarification, the following text was added to the supplementary information (Line 197), after the sentence: “An exception is GR (dry) and MU (dry), which are poorly correlated ($R^2 = 0.31$) despite both having high MCE and clustering on the PCA scores plot.”

“Although both fuels were classified as ‘dry,’ their measured moisture contents differed substantially, with $20 \pm 0.80\%$ for GR (dry) and 4.15% for MU (dry). Differences in fuel composition, including the relative abundance of major biopolymers such as cellulose, hemicellulose, and lignin, may also contribute to their distinct VOC emission profiles. In addition, differences in combustion temperature, physical structure, and burn duration may have influenced VOC formation and emission. GR and MU also differed strongly in nitrogen content and particle size characteristics, with their mean particle diameters

occurring at opposite ends of the observed range; these broader fuel-specific differences are discussed in the overview paper (Moraes et al., 2026). Thus, the weak GR (dry)–MU (dry) correlation likely reflects factors beyond combustion efficiency alone.”

5. *Regarding the “Mag-Mode” the manuscript described in the supplementary material, the manuscript should explain more clearly how this bias was corrected. Are there any high m/z species that are underestimated?*

Response: The “Mag-Mode” does not result in bias for the measurements reported here, as only calibrated species are reported. We mention it in the Supporting Information for three main reasons. First, because “Mag-Mode” causes non-unity transmission (above the BSQ cut-off), it was not possible to calculate sensitivities from PTR rate coefficients (Sekimoto et al., 2017; Jensen et al., 2023), as others have done (i.e., Koss et al., 2018; Hayden et al., 2022). This was unfortunate and only discovered after the experiments and precluded reporting on a larger number of VOCs. Second, we acknowledge that multiple isomers could potentially contribute to a signal at a given m/z (i.e., an isomer of the calibrated compound) and then indicate that these sensitivities for PTR across all species generally fall within a narrow range (varying by less than a factor of ~2-4) to put the potential uncertainty into perspective. However, because of “Mag-Mode” this was not the case for our study (i.e., there was a larger range of measured sensitivities across all calibrated compounds). Regardless, k_{PTR} theory shows that for VOCs with the same mass (i.e., experiencing the same transmission), the sensitivities will vary considerably less than a factor of 2 because of the dependence of PTR sensitivity on molecular properties, which include molecular weight, polarizability, and dipole moment (Sekimoto et al., 2017). So, we are trying to make the point that “Mag-Mode” does not introduce additional uncertainty for calibrated compounds. Finally, we mention the “Mag-Mode” so that the sensitivities (presented in Table S1) can be interpreted in the context of other reported sensitivities (i.e., Link et al., 2025; Pagonis et al., 2019). Therefore, there was no “correction of bias” and no high-m/z species were underestimated.

Lines 83 to 88 in the supplementary information are revised as follows:

“However, it is expected that VOCs with the same exact mass will have sensitivities that vary considerably less than a factor of 2, given the dependence of PTR sensitivity on the PTR rate coefficient (k_{PTR}), which depends on molecular properties, including molecular weight, polarizability, and dipole moment (Sekimoto et al., 2017). Since the main impact of “Mag-Mode” is to affect the m/z-dependent transmission of ions through Vocus PTR-MS, and we only report data for calibrated species, the “Mag-Mode” does not introduce a bias to our results”.

6. *Lines 270–275, gas and aerosol partitioning can play an important role in BB emission (May et al., 2013; Pagonis et al., 2023). This topic needs to be included in the discussion.*

Response: Thank you to the reviewers for making this important point. Gas-particle partitioning of organics (i.e., condensation of lower-volatility organics to particles or evaporation of lower-volatility organics from primary organic aerosol) is an important consideration for a) deriving biomass burning EFs and b) interpreting differences between studies (i.e., especially aircraft vs. laboratory) (May et al., 2013; Pagonis et al., 2023; Permar et al., 2021; Selimovic et al., 2019). These considerations are especially important for interpreting filter measurements, which may be susceptible to sampling artifacts from condensation of semi-volatile vapors. High concentrations of organic aerosol in lab experiments compared to ambient may also shift gas-particle partitioning to the particle phase, whereas heating and dilution of primary organic aerosol (POA) would be expected to lead to evaporation of semi-volatile vapors. In our experiments, emissions were rapidly diluted (duct flow ~ 400 L/s) (decreasing the concentration of POA, which could lead to evaporation), and the temperature would have decreased (which would have an opposite effect and lead to condensation of vapors to OA). We do note that these temperatures would still have been higher than many aircraft studies. These would have counteracting effects. Predominantly, we measured high-volatility species that would be in the gas phase under a range of conditions and were unlikely to be influenced by gas-particle partitioning. A few individual species with lower volatility (e.g., guaiacol, nitrophenol) as well as the total NMOC may be influenced by gas-particle partitioning. Particle number size distributions measured using a scanning mobility particle sizer (SMPS) are reported in the revised overview paper (Moraes et al., 2026). Shifts to smaller geometric mean diameters for denuded vs. undenuded particles were observed and indicate that smoke particles contain a non-volatile solid core coated with semi-volatile organics. The largest shifts were observed for the smoldering fuels (i.e., peat with moss and peat with mulch). A detailed analysis of gas-particle partitioning is beyond the scope of this paper. Laboratory studies of biomass burning VOC emissions (e.g., Koss et al., 2018; Stockwell et al., 2014, 2015) do not typically correct for gas-particle partitioning. To acknowledge the potential impacts, additional discussion has been added to [Lines 281-296](#).

“For instance, lower-volatility “sticky” VOCs may exhibit partitioning delays. Lower-volatility species are typically emitted during the low-temperature combustion associated with smoldering combustion (Sekimoto et al., 2018). However, if they are emitted during the flaming-phase, partitioning delays may lead to an apparent reduction in flaming-phase EFs and a corresponding enhancement of smoldering-phase EFs. These effects are unlikely to alter overall EF, but we acknowledge they may influence the relative magnitude of phase-resolved EFs for a small number of VOCs in this study (e.g., $C_7H_8O_2$). Gas-particle partitioning (i.e., condensation of organic vapors with decreasing temperature in the duct or evaporation of primary organic aerosol due to dilution in the duct) may also impact the observed EFs (May et al., 2013; Pagonis et al., 2023; Selimovic et al., 2019). Indeed, concurrent measurements of particle number size

distributions using a scanning mobility particle sizer (Moraes et al., 2026) show shifts to smaller geometric mean diameters for denuded vs. undenuded particles, suggesting that smoke particles contain a non-volatile solid core coated with semi-volatile organics. Nonetheless, the majority of species quantified in this paper are high-volatility organic compounds and therefore expected to be present in the gas-phase only. It is possible that the measured EFs for a small number of lower-volatility species quantified here (e.g., $C_7H_8O_2$, $C_6H_5NO_3$) or the total NMOC could be impacted by volatilization or condensation. However, a detailed analysis is beyond the scope of this paper. Gas-particle partitioning may also explain differences between our laboratory results and other studies, particularly aircraft studies, which sample at different temperatures and organic aerosol mass loadings (Permar et al., 2021; Semilovic et al., 2019)."

Detailed comments are:

1. Line 319, *acrylic acid should be $C_3H_4O_2$.*

Response: Thank you. It has now been corrected (line 340).

2. Line 330-334, *guaiacol is considered a low-temperature pyrolysis indicator in a PMF analysis. Even high- or low-temperature pyrolysis does not correspond exactly to the commonly used "flaming" or "smoldering", but it still can be helpful to add here.*

Response: Thank you, we agree and highlighted this concept in the section on Individual VOC (Lines 431 - 436). We have also revised this section to clarify this concept up front in line 334:

"High emissions of guaiacol are a result of low-temperature pyrolysis (Sekimoto et al., 2018), which is often associated with the smoldering phase, although the correspondence is not exact. - It should also be noted that the literature EF for guaiacol shown in Fig. 2 is limited to three studies (Koss et al., 2018; Hayden et al., 2022; Permar et al., 2021), none of which investigated laboratory combustion of peat or organic soils."

3. Line 372, *can you explain why MU has poor correlations?*

Response: Thank you for raising this point. We agree that the distinct behavior of MU deserves further clarification. While we cannot identify a single definitive reason for its poor correlations and relatively low NMOC, Σ VOC, and individual VOC emissions, several possible explanations are discussed in our response to Major Comment #4 above. We have also added a reference to the overview paper (Moraes et al., 2026), where other distinctive characteristics of MU are reported, including the lowest PM_{2.5} and PM₁₀ EFs, the smallest geometric mean particle diameter, and the highest combustion efficiency when all measured carbon emissions are considered. These observations further suggest that MU exhibited distinct combustion and emission behavior compared with the other fuels.

4. Line 391, *most of the quantified VOC. How many? Can you present XX out of 46 or as a percentage?*

Response: Since a) the 46 quantified VOCs are only a subset of the many VOCs emitted during biomass combustion and only represent a fraction of the total NMOC (and exclude important C1-C3 contributors); b) only 23 of these quantified VOCs are plotted in Figures 5 and S5 as a function of MCE and with literature studies (in part because some quantified VOCs had low EF and few literature-reported values); and c) the strength of the linear relationship is not quantified, we feel it does not make sense or add value to quantify this as a percentage. These figures are meant to highlight the strength (or weakness) of the EF-MCE relationship across the fuels in the study and across the literature in a more qualitative sense.

Line 415 has been edited to change “most” to “many”.

5. Line 560, *the higher EFs of HONO, NO, VOCs, and other species observed in lab studies compared with aircraft measurements cannot be explained simply by the difference between fresh and aged smoke. Other factors, such as differences in fuel type, peat contribution, fuel nitrogen content, combustion conditions, and sampling platform, can also affect this. For example, peat fuels can emit more N-containing species, while aircraft measurements of aged plumes may be affected by chemical processing, gas-particle partitioning, dilution, and possible loss or evaporation of SVOCs, IVOCs, etc.*

Response: The text has been revised to clarify that the higher EFs of inorganic nitrogen species may reflect not only differences between fresh and aged emissions but also peat contribution, fuel nitrogen content, combustion conditions, and sampling platform.

“EFs of inorganic nitrogen species (NO, HONO, and NH₃) from the peat-associated fuels were significantly higher. These differences may reflect variations in fuel composition, burning characteristics, and the comparison of fresh emissions in this study with aged aircraft-measured plumes reported by Hayden et al. (2022).”

Anonymous Referee #2

This manuscript presents a study investigating the trace gas emissions from controlled laboratory burning of Canadian boreal forest fuels. The topic of this study falls within the scope of the journal Atmospheric Chemistry and Physics. This manuscript is generally laid out well and shows its academic value. This manuscript is recommended to be published after making some minor technical changes.

Response: We appreciate the reviewer's positive feedback. We have responded to the reviewer's comments and also made corrections to our manuscript.

1. Line 134: Please provide the full form of PFA before using the acronym by itself.

Response: We have added the full form, perfluoroalkoxy alkane (PFA), to the manuscript (line 134).

2. Line 141: Please define m/z . The ratio might be common for people using mass spectrometers but should still be mentioned first.

Response: The term " m/z " is now introduced as the mass-to-charge ratio (line 142).

3. Line 162: Please provide the full form of UHP before using the acronym by itself. While it might be obvious for people using compressed gases in cylinders, it should still be provided first. Also please provide the percentage of purity for UHP in this case.

Response: Thank you. We have defined UHP as “ultra-high-purity” at its first occurrence and specified the gas purity as 99.999% (lines 163-164).

4. Line 179: Please provide the definition of E/N .

Response: The term E/N , defined as the “reduced electric field,” was already provided at its first occurrence on line 179.

5. Line 182: Please spell out what PEEK stands for first before using the acronym by itself, even though this type of tubing might be very common in the field.

Response: PEEK has now been defined as polyether ether ketone in the manuscript (line 183).

6. Line 537: What is the relation between NMOG and $NMOC_G$?

Response: Thank you for catching this. “NMOG” was a typographical error and has been corrected to “ $NMOC_G$ ” in the manuscript.

7. Figure 7: Please provide a version in the supplementary information with error bars.

Response: A figure has been added to the SI as Figure S10. The tags have been removed for clarity, and only positive vertical error bars are shown due to the log scale.

Reference

Hatch, L. E., Rivas-Ubach, A., Jen, C. N., Lipton, M., Goldstein, A. H., and Barsanti, K. C.: Measurements of I/SVOCs in biomass-burning smoke using solid-phase extraction disks and two-dimensional gas chromatography, *Atmospheric Chemistry and Physics*, 18, 17801–17817, <https://doi.org/10.5194/acp-18-17801-2018>, 2018.

Hayden, K. L., Li, S.-M., Liggio, J., Wheeler, M. J., Wentzell, J. J. B., Leithead, A., Brickell, P., Mittermeier, R. L., Oldham, Z., Mihele, C. M., Staebler, R. M., Moussa, S. G., Darlington, A., Wolde, M., Thompson, D., Chen, J., Griffin, D., Eckert, E., Ditto, J. C., He, M., and Gentner, D. R.: Reconciling the total carbon budget for boreal forest wildfire emissions using airborne observations, *Atmospheric Chemistry and Physics*, 22, 12493–12523, <https://doi.org/10.5194/acp-22-12493-2022>, 2022.

Jensen, A. R., Koss, A. R., Hales, R. B., and de Gouw, J. A.: Measurements of volatile organic compounds in ambient air by gas-chromatography and real-time Vocus PTR-TOF-MS: calibrations, instrument background corrections, and introducing a PTR Data Toolkit, *Atmospheric Measurement Techniques*, 16, 5261–5285, <https://doi.org/10.5194/amt-16-5261-2023>, 2023.

Koss, A. R., Sekimoto, K., Gilman, J. B., Selimovic, V., Coggon, M. M., Zarzana, K. J., Yuan, B., Lerner, B. M., Brown, S. S., Jimenez, J. L., Krechmer, J., Roberts, J. M., Warneke, C., Yokelson, R. J., and de Gouw, J.: Non-methane organic gas emissions from biomass burning: identification, quantification, and emission factors from PTR-ToF during the FIREX 2016 laboratory experiment, *Atmospheric Chemistry and Physics*, 18, 3299–3319, <https://doi.org/10.5194/acp-18-3299-2018>, 2018.

Link, M. F., Claflin, M. S., Cecelski, C. E., Akande, A. A., Kilgour, D., Heine, P. A., Coggon, M., Stockwell, C. E., Jensen, A., Yu, J., Huynh, H. N., Ditto, J. C., Warneke, C., Dresser, W., Gemmell, K., Jorga, S., Robertson, R. L., de Gouw, J., Bertram, T., Abbatt, J. P. D., Borduas-Dedekind, N., and Poppendieck, D.: Product ion distributions using H_3O^+ proton-transfer-reaction time-of-flight mass spectrometry (PTR-ToF-MS): mechanisms, transmission effects, and instrument-to-instrument variability, *Atmospheric Measurement Techniques*, 18, 1013–1038, <https://doi.org/10.5194/amt-18-1013-2025>, 2025.

Moraes, A. H., Talebian, S., Afroz, R., Al-Jabiri, M. H., Chan, A. W. H., Chang, R. Y.-W., Chen, K., Corbin, J. C., Drinovec, L., Isenor, B. H., Lee, A., Liggio, J., Liu-Kang, C., Marshall, G., Moallemi, A., Mocnik, G., Moussa, S. G., Olfert, O., Saleh, M., Sipkens, T. A., Shen, H., Wentzell, J. J., Wren, S. N., Yus-Diez, J., Hayes, P. L., Abbatt, J. P. D., Olfert, J., and Zhao, R.: Combustion Characteristics and Emission Factors of Trace Gases and Particulate Matter from Biomass Relevant to Canadian Wildfires: Overview of the 2024 BBCan Campaign, *American Geophysical Union*, 2026.

Pagonis, D., Krechmer, J. E., de Gouw, J., Jimenez, J. L., and Ziemann, P. J.: Effects of gas–wall partitioning in Teflon tubing and instrumentation on time-resolved measurements of gas-phase organic compounds, *Atmospheric Measurement Techniques*, 10, 4687–4696, <https://doi.org/10.5194/amt-10-4687-2017>, 2017.

Pagonis, D., Selimovic, V., Campuzano-Jost, P., Guo, H., Day, D. A., Schueneman, M. K., Nault, B. A., Coggon, M. M., DiGangi, J. P., Diskin, G. S., Fortner, E. C., Gargulinski, E. M., Gkatzelis, G. I., Hair, J. W., Herndon, S. C., Holmes, C. D., Katich, J. M., Nowak, J. B., Perring, A. E., Saide, P., Shingler, T. J., Soja, A. J., Thapa, L. H., Warneke, C., Wiggins, E. B., Wisthaler, A., Yacovitch, T. I., Yokelson, R. J., and Jimenez, J. L.: Impact of Biomass Burning Organic Aerosol Volatility on Smoke Concentrations Downwind of Fires, *Environ. Sci. Technol.*, 57, 17011–17021, <https://doi.org/10.1021/acs.est.3c05017>, 2023.

Permar, W., Wang, Q., Selimovic, V., Wielgasz, C., Yokelson, R. J., Hornbrook, R. S., Hills, A. J., Apel, E. C., Ku, I.-T., Zhou, Y., Sive, B. C., Sullivan, A. P., Collett Jr, J. L., Campos, T. L., Palm, B. B., Peng, Q., Thornton, J. A., Garofalo, L. A., Farmer, D. K., Kreidenweis, S. M., Levin, E. J. T., DeMott, P. J., Flocke, F., Fischer, E. V., and Hu, L.: Emissions of Trace Organic Gases From Western U.S. Wildfires Based on WE-CAN Aircraft Measurements, *Journal of Geophysical Research: Atmospheres*, 126, e2020JD033838, <https://doi.org/10.1029/2020JD033838>, 2021.

Sekimoto, K., Li, S.-M., Yuan, B., Koss, A., Coggon, M., Warneke, C., and de Gouw, J.: Calculation of the sensitivity of proton-transfer-reaction mass spectrometry (PTR-MS) for organic trace gases using molecular properties, *International Journal of Mass Spectrometry*, 421, 71–94, <https://doi.org/10.1016/j.ijms.2017.04.006>, 2017.

Sekimoto, K., Koss, A. R., Gilman, J. B., Selimovic, V., Coggon, M. M., Zarzana, K. J., Yuan, B., Lerner, B. M., Brown, S. S., Warneke, C., Yokelson, R. J., Roberts, J. M., and de Gouw, J.: High- and low-temperature pyrolysis profiles describe volatile organic compound emissions from western US wildfire fuels, *Atmospheric Chemistry and Physics*, 18, 9263–9281, <https://doi.org/10.5194/acp-18-9263-2018>, 2018.

Selimovic, V., Yokelson, R. J., McMeeking, G. R., and Coefield, S.: In situ measurements of trace gases, PM, and aerosol optical properties during the 2017 NW US wildfire smoke event, *Atmospheric Chemistry and Physics*, 19, 3905–3926, <https://doi.org/10.5194/acp-19-3905-2019>, 2019.

Simpson, I. J., Akagi, S. K., Barletta, B., Blake, N. J., Choi, Y., Diskin, G. S., Fried, A., Fuelberg, H. E., Meinardi, S., Rowland, F. S., Vay, S. A., Weinheimer, A. J., Wennberg, P. O., Wiebring, P., Wisthaler, A., Yang, M., Yokelson, R. J., and Blake, D. R.: Boreal forest fire emissions in fresh Canadian smoke plumes: C₁-C₁₀ volatile organic compounds (VOCs), CO₂, CO, NO₂, NO, HCN and CH₃CN, *Atmospheric Chemistry and Physics*, 11, 6445–6463, <https://doi.org/10.5194/acp-11-6445-2011>, 2011.

Stockwell, C. E., Yokelson, R. J., Kreidenweis, S. M., Robinson, A. L., DeMott, P. J., Sullivan, R. C., Reardon, J., Ryan, K. C., Griffith, D. W. T., and Stevens, L.: Trace gas emissions from combustion of peat, crop residue, domestic biofuels, grasses, and other fuels: configuration and Fourier transform infrared (FTIR) component of the fourth Fire Lab at Missoula Experiment (FLAME-4), *Atmospheric Chemistry and Physics*, 14, 9727–9754, <https://doi.org/10.5194/acp-14-9727-2014>, 2014.

Stockwell, C. E., Veres, P. R., Williams, J., and Yokelson, R. J.: Characterization of biomass burning emissions from cooking fires, peat, crop residue, and other fuels with high-resolution

proton-transfer-reaction time-of-flight mass spectrometry, *Atmospheric Chemistry and Physics*, 15, 845–865, <https://doi.org/10.5194/acp-15-845-2015>, 2015.

Urbanski, S.: *Wildland fire emissions, carbon, and climate: Emission factors*, *Forest Ecology and Management*, 317, 51–60, <https://doi.org/10.1016/j.foreco.2013.05.045>, 2014.

Yokelson, R. J., Burling, I. R., Gilman, J. B., Warneke, C., Stockwell, C. E., de Gouw, J., Akagi, S. K., Urbanski, S. P., Veres, P., Roberts, J. M., Kuster, W. C., Reardon, J., Griffith, D. W. T., Johnson, T. J., Hosseini, S., Miller, J. W., Cocker III, D. R., Jung, H., and Weise, D. R.: *Coupling field and laboratory measurements to estimate the emission factors of identified and unidentified trace gases for prescribed fires*, *Atmospheric Chemistry and Physics*, 13, 89–116, <https://doi.org/10.5194/acp-13-89-2013>, 2013.